Fitting Linear Models

“The real voyage of discovery consists not in seeking new landscapes, but in having new eyes.”

Marcel Proust
Technology License Notices

- Scintilla - Copyright © 1998-2012 by Neil Hodgson <neilh@scintilla.org>. All Rights Reserved.

  Permission to use, copy, modify, and distribute this software and its documentation for any purpose and without fee is hereby granted, provided that the above copyright notice appear in all copies and that both that copyright notice and this permission notice appear in supporting documentation.

  NEIL HODGSON DISCLAIMS ALL WARRANTIES WITH REGARD TO THIS SOFTWARE, INCLUDING ALL IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS, IN NO EVENT SHALL NEIL HODGSON BE LIABLE FOR ANY SPECIAL, INDIRECT OR CONSEQUENTIAL DAMAGES OR ANY DAMAGES WHATSOEVER RESULTING FROM LOSS OF USE, DATA OR PROFITS, WHETHER IN AN ACTION OF CONTRACT, NEGLIGENCE OR OTHER TORTIOUS ACTION, ARISING OUT OF OR IN CONNECTION WITH THE USE OR PERFORMANCE OF THIS SOFTWARE.

- Telerik RadControls: Copyright © 2002-2012, Telerik. Usage of the included Telerik RadControls outside of JMP is not permitted.


- Made with Natural Earth. Free vector and raster map data @ naturalearthdata.com.

- Packages - Copyright © 2009-2010, Stéphane Sudre (s.sudre.free.fr). All rights reserved.
  Redistributions and use in source and binary forms, with or without modification, are permitted provided that the following conditions are met:
  Redistributions of source code must retain the above copyright notice, this list of conditions and the following disclaimer.
  Redistributions in binary form must reproduce the above copyright notice, this list of conditions and the following disclaimer in the documentation and/or other materials provided with the distribution.
  Neither the name of the WhiteBox nor the names of its contributors may be used to endorse or promote products derived from this software without specific prior written permission.

  THIS SOFTWARE IS PROVIDED BY THE COPYRIGHT HOLDERS AND CONTRIBUTORS “AS IS” AND ANY EXPRESS OR IMPLIED WARRANTIES, INCLUDING, BUT NOT LIMITED TO, THE IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE ARE DISCLAIMED. IN NO EVENT SHALL THE COPYRIGHT OWNER OR CONTRIBUTORS BE LIABLE FOR ANY DIRECT, INDIRECT, INCIDENTAL, SPECIAL, EXEMPLARY, OR CONSEQUENTIAL DAMAGES (INCLUDING, BUT NOT LIMITED TO, PROCUREMENT OF SUBSTITUTE GOODS OR SERVICES; LOSS
OF USE, DATA, OR PROFITS; OR BUSINESS INTERRUPTION) HOWEVER CAUSED AND ON ANY THEORY OF LIABILITY, WHETHER IN CONTRACT, STRICT LIABILITY, OR TORT (INCLUDING NEGLIGENCE OR OTHERWISE) ARISING IN ANY WAY OUT OF THE USE OF THIS SOFTWARE, EVEN IF ADVISED OF THE POSSIBILITY OF SUCH DAMAGE.

• iODBC software - Copyright © 1995-2006, OpenLink Software Inc and Ke Jin (www.iodbc.org). All rights reserved.
Redistribution and use in source and binary forms, with or without modification, are permitted provided that the following conditions are met:
  – Redistributions of source code must retain the above copyright notice, this list of conditions and the following disclaimer.
  – Redistributions in binary form must reproduce the above copyright notice, this list of conditions and the following disclaimer in the documentation and/or other materials provided with the distribution.
  – Neither the name of OpenLink Software Inc. nor the names of its contributors may be used to endorse or promote products derived from this software without specific prior written permission.

THIS SOFTWARE IS PROVIDED BY THE COPYRIGHT HOLDERS AND CONTRIBUTORS “AS IS” AND ANY EXPRESS OR IMPLIED WARRANTIES, INCLUDING, BUT NOT LIMITED TO, THE IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE ARE DISCLAIMED. IN NO EVENT SHALL OPENLINK OR CONTRIBUTORS BE LIABLE FOR ANY DIRECT, INDIRECT, INCIDENTAL, SPECIAL, EXEMPLARY, OR CONSEQUENTIAL DAMAGES (INCLUDING, BUT NOT LIMITED TO, PROCUREMENT OF SUBSTITUTE GOODS OR SERVICES; LOSS OF USE, DATA, OR PROFITS; OR BUSINESS INTERRUPTION) HOWEVER CAUSED AND ON ANY THEORY OF LIABILITY, WHETHER IN CONTRACT, STRICT LIABILITY, OR TORT (INCLUDING NEGLIGENCE OR OTHERWISE) ARISING IN ANY WAY OUT OF THE USE OF THIS SOFTWARE, EVEN IF ADVISED OF THE POSSIBILITY OF SUCH DAMAGE.

• bzip2, the associated library “libbzip2”, and all documentation, are Copyright © 1996-2010, Julian R Seward. All rights reserved.
Redistribution and use in source and binary forms, with or without modification, are permitted provided that the following conditions are met:
Redistributions of source code must retain the above copyright notice, this list of conditions and the following disclaimer.
The origin of this software must not be misrepresented; you must not claim that you wrote the original software. If you use this software in a product, an acknowledgment in the product documentation would be appreciated but is not required.
Altered source versions must be plainly marked as such, and must not be misrepresented as being the original software.

The name of the author may not be used to endorse or promote products derived from this software without specific prior written permission.

THIS SOFTWARE IS PROVIDED BY THE AUTHOR “AS IS” AND ANY EXPRESS OR IMPLIED WARRANTIES, INCLUDING, BUT NOT LIMITED TO, THE IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE ARE DISCLAIMED. IN NO EVENT SHALL THE AUTHOR BE LIABLE FOR ANY DIRECT, INDIRECT, INCIDENTAL, SPECIAL, EXEMPLARY, OR CONSEQUENTIAL DAMAGES (INCLUDING, BUT NOT LIMITED TO, PROCUREMENT OF SUBSTITUTE GOODS OR SERVICES; LOSS OF USE, DATA, OR PROFITS; OR BUSINESS INTERRUPTION) HOWEVER CAUSED AND ON ANY THEORY OF LIABILITY, WHETHER IN CONTRACT, STRICT LIABILITY, OR TORT (INCLUDING NEGLIGENCE OR OTHERWISE) ARISING IN ANY WAY OUT OF THE USE OF THIS SOFTWARE, EVEN IF ADVISED OF THE POSSIBILITY OF SUCH DAMAGE.

- MATLAB software is Copyright © 1984-2012, The MathWorks, Inc. Protected by U.S. and international patents. See www.mathworks.com/patents. MATLAB and Simulink are registered trademarks of The MathWorks, Inc. See www.mathworks.com/trademarks for a list of additional trademarks. Other product or brand names may be trademarks or registered trademarks of their respective holders.
Get the Most from JMP®

Whether you are a first-time or a long-time user, there is always something to learn about JMP.

Visit JMP.com to find the following:
• live and recorded webcasts about how to get started with JMP
• video demos and webcasts of new features and advanced techniques
• details on registering for JMP training
• schedules for seminars being held in your area
• success stories showing how others use JMP
• a blog with tips, tricks, and stories from JMP staff
• a forum to discuss JMP with other users

http://www.jmp.com/getstarted/
Contents
Fitting Linear Models

1 Learn about JMP
   Documentation and Additional Resources .............................................. 15
   Formatting Conventions ........................................................................ 17
   JMP Documentation ............................................................................. 17
      JMP Documentation Library ............................................................... 18
      JMP Help ......................................................................................... 22
   Additional Resources for Learning JMP ................................................. 22
      Tutorials ............................................................................................ 23
      Sample Data Tables ........................................................................... 23
      Learn about Statistical and JSL Terms .............................................. 23
      Learn JMP Tips and Tricks ................................................................. 24
      Tooltips .............................................................................................. 24
      JMP User Community ....................................................................... 24
      JPer Cable ......................................................................................... 24
      JMP Books by Users ......................................................................... 25
      The JMP Starter Window .................................................................... 25

2 Introduction to Fit Model
   Specify Linear Models ........................................................................... 27
   Overview of the Fit Model Platform ....................................................... 29
   Example of a Regression Analysis Using Fit Model .............................. 30
   Launch the Fit Model Platform .............................................................. 33
      Fitting Personalities .......................................................................... 33
      Fit Model Launch Window Elements .............................................. 36
   Construct Model Effects ....................................................................... 39
      Add .................................................................................................... 39
      Cross ................................................................................................. 39
      Nest .................................................................................................. 40
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Macros</td>
<td>41</td>
</tr>
<tr>
<td>Attributes</td>
<td>42</td>
</tr>
<tr>
<td>Transform</td>
<td>44</td>
</tr>
<tr>
<td>No Intercept</td>
<td>45</td>
</tr>
<tr>
<td>Construct Model Effects Tabs</td>
<td>45</td>
</tr>
<tr>
<td>Model Specification Options</td>
<td>46</td>
</tr>
<tr>
<td>Informative Missing</td>
<td>48</td>
</tr>
<tr>
<td>Validity Checks</td>
<td>50</td>
</tr>
<tr>
<td>Examples of Model Specifications and Their Model Fits</td>
<td>50</td>
</tr>
<tr>
<td>Statistical Details</td>
<td>69</td>
</tr>
<tr>
<td>3 Standard Least Squares Report and Options</td>
<td>71</td>
</tr>
<tr>
<td>Analyze Common Classes of Models</td>
<td></td>
</tr>
<tr>
<td>Example Using Standard Least Squares</td>
<td>73</td>
</tr>
<tr>
<td>Launch the Standard Least Squares Personality</td>
<td>76</td>
</tr>
<tr>
<td>Fit Least Squares Report</td>
<td>80</td>
</tr>
<tr>
<td>Response Options</td>
<td>84</td>
</tr>
<tr>
<td>Regression Reports</td>
<td>85</td>
</tr>
<tr>
<td>Estimates</td>
<td>108</td>
</tr>
<tr>
<td>Sorted Estimates</td>
<td>110</td>
</tr>
<tr>
<td>Expanded Estimates</td>
<td>114</td>
</tr>
<tr>
<td>Indicator Parameterization Estimates</td>
<td>116</td>
</tr>
<tr>
<td>Sequential Tests</td>
<td>117</td>
</tr>
<tr>
<td>Custom Test</td>
<td>118</td>
</tr>
<tr>
<td>Multiple Comparisons</td>
<td>120</td>
</tr>
<tr>
<td>Joint Factor Tests</td>
<td>133</td>
</tr>
<tr>
<td>Inverse Prediction</td>
<td>134</td>
</tr>
<tr>
<td>Cox Mixtures</td>
<td>138</td>
</tr>
<tr>
<td>Parameter Power</td>
<td>140</td>
</tr>
<tr>
<td>Correlation of Estimates</td>
<td>142</td>
</tr>
<tr>
<td>Effect Screening</td>
<td>144</td>
</tr>
<tr>
<td>Factor Profiling</td>
<td>155</td>
</tr>
<tr>
<td>Row Diagnostics</td>
<td>163</td>
</tr>
<tr>
<td>Save Columns</td>
<td>168</td>
</tr>
</tbody>
</table>
Mixed and Random Effect Model Reports and Options ................................................. 171
Mixed Models and Random Effect Models ......................................................... 172
Restricted Maximum Likelihood (REML) Method ..................................................... 176
EMS (Traditional) Model Fit Reports .............................................................. 181
Models with Linear Dependencies among Model Terms ........................................... 183
Statistical Details ................................................................................................. 188

4 Standard Least Squares Examples
Analyze Common Classes of Models .................................................................. 205
One-Way Analysis of Variance Example ............................................................. 207
Analysis of Covariance with Equal Slopes Example .............................................. 210
Analysis of Covariance with Unequal Slopes Example .......................................... 212
Response Surface Model Example ....................................................................... 214
Split Plot Design Example .................................................................................. 218
Estimation of Random Effect Parameters Example .............................................. 221
Knotted Spline Effect Example ........................................................................... 223
Bayes Plot for Active Factors Example ................................................................ 225

5 Stepwise Regression Models
Find a Model Using Variable Selection ................................................................ 227
Overview of Stepwise Regression ......................................................................... 229
Example Using Stepwise Regression ..................................................................... 229
The Stepwise Report ............................................................................................. 231
  Stepwise Platform Options .................................................................................. 231
  Stepwise Regression Control Panel .................................................................... 232
  Current Estimates Report .................................................................................... 237
  Step History Report ........................................................................................... 238
Models with Crossed, Interaction, or Polynomial Terms ........................................ 239
Models with Nominal and Ordinal Terms ............................................................. 240
Using the Make Model Command for Hierarchical Terms .................................... 242
Performing Logistic Stepwise Regression ............................................................. 243
The All Possible Models Option ............................................................................ 244
The Model Averaging Option ................................................................................. 246
Using Validation .................................................................................................... 247
6 Generalized Regression Models
   Build Models Using Regularization Techniques ................................................. 249
   Generalized Regression Overview ................................................................. 251
   Example of Generalized Regression ............................................................... 252
   Launch the Generalized Regression Personality ............................................. 254
      Model Launch Window .................................................................................. 258
   Model Fit Reports ............................................................................................ 260
      Model Summary ............................................................................................ 260
      Solution Path ............................................................................................... 261
      Parameter Estimates for Centered and Scaled Predictors ............................... 262
      Effect Tests ................................................................................................. 262
   Model Fit Options ............................................................................................ 263
   Generalized Regression Options ....................................................................... 264
   Additional Examples of the Generalized Regression Personality ...................... 264
      Poisson Generalized Regression ................................................................. 264
      Binomial Generalized Regression ............................................................... 266
      Zero-Inflated Poisson Regression .................................................................. 268
   Statistical Details ............................................................................................ 270
      Distributions ................................................................................................. 270

7 Mixed Models
   Jointly Model the Mean and Covariance ......................................................... 273
   Overview of the Mixed Model Personality ....................................................... 275
   Example Using Mixed Model ........................................................................... 276
   Launch the Mixed Model Personality .............................................................. 280
   The Fit Mixed Report ....................................................................................... 285
      Fit Statistics .................................................................................................. 287
      Random Effects Covariance Parameter Estimates ....................................... 289
      Fixed Effects Parameter Estimates .............................................................. 290
      Repeated Effects Covariance Parameter Estimates .................................... 290
      Random Coefficients .................................................................................... 291
      Random Effect Predictions ......................................................................... 291
      Fixed Effects Tests ....................................................................................... 291
      Multiple Comparisons .................................................................................. 292
## Fitting Linear Models

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marginal Model Diagnostic Plots</td>
<td>293</td>
</tr>
<tr>
<td>Marginal Model Profiling</td>
<td>294</td>
</tr>
<tr>
<td>Save Columns</td>
<td>294</td>
</tr>
<tr>
<td>Additional Examples</td>
<td>295</td>
</tr>
<tr>
<td>Repeated Measures Example</td>
<td>295</td>
</tr>
<tr>
<td>Covariance Structure: Unstructured Example</td>
<td>296</td>
</tr>
<tr>
<td>Covariance Structure: Residual Example</td>
<td>300</td>
</tr>
<tr>
<td>Covariance Structure: AR(1) Example</td>
<td>301</td>
</tr>
<tr>
<td>Split Plot Example</td>
<td>308</td>
</tr>
<tr>
<td>Spatial Example: Uniformity Trial</td>
<td>314</td>
</tr>
<tr>
<td>Correlated Response Example</td>
<td>321</td>
</tr>
<tr>
<td>Statistical Details</td>
<td>326</td>
</tr>
<tr>
<td>Convergence Score Test</td>
<td>326</td>
</tr>
<tr>
<td>Random Coefficient Model</td>
<td>327</td>
</tr>
<tr>
<td>Repeated Measures</td>
<td>328</td>
</tr>
<tr>
<td>Spatial Variability</td>
<td>331</td>
</tr>
<tr>
<td>The Kackar-Harville Correction</td>
<td>333</td>
</tr>
</tbody>
</table>

### Multivariate Response Models

#### Fit Relationships Using MANOVA

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Example of a Multiple Response Model</td>
<td>335</td>
</tr>
<tr>
<td>The Manova Report</td>
<td>337</td>
</tr>
<tr>
<td>The Manova Fit Options</td>
<td>339</td>
</tr>
<tr>
<td>Response Specification</td>
<td>340</td>
</tr>
<tr>
<td>Choose Response Options</td>
<td>341</td>
</tr>
<tr>
<td>Custom Test Option</td>
<td>342</td>
</tr>
<tr>
<td>Multivariate Tests</td>
<td>345</td>
</tr>
<tr>
<td>The Extended Multivariate Report</td>
<td>346</td>
</tr>
<tr>
<td>Comparison of Multivariate Tests</td>
<td>347</td>
</tr>
<tr>
<td>Univariate Tests and the Test for Sphericity</td>
<td>348</td>
</tr>
<tr>
<td>Multivariate Model with Repeated Measures</td>
<td>349</td>
</tr>
<tr>
<td>Example of a Compound Multivariate Model</td>
<td>352</td>
</tr>
<tr>
<td>Discriminant Analysis</td>
<td>354</td>
</tr>
</tbody>
</table>
9 Loglinear Variance Models
   Model the Variance and the Mean of the Response ............................................. 357
      Overview of the Loglinear Variance Model ................................................... 359
      Dispersion Effects ......................................................................................... 359
      Model Specification ....................................................................................... 359
      Notes ............................................................................................................. 360
      Example Using Loglinear Variance ............................................................... 360
      The Loglinear Report ..................................................................................... 362
      Loglinear Platform Options .......................................................................... 364
         Save Columns ............................................................................................. 364
         Row Diagnostics ....................................................................................... 365
      Examining the Residuals ................................................................................ 366
      Profiling the Fitted Model ............................................................................. 366
      Example of Profiling the Fitted Model .......................................................... 367

10 Logistic Regression with Nominal or Ordinal Responses
   Fit Models for Categorical Responses .............................................................. 369
      Introduction to Logistic Models .................................................................... 371
      The Logistic Fit Report .................................................................................. 372
         Logistic Plot ................................................................................................ 373
         Iteration History ......................................................................................... 373
         Whole Model Test ....................................................................................... 373
         Lack of Fit Test (Goodness of Fit) .............................................................. 376
         Parameter Estimates ................................................................................... 376
         Likelihood Ratio Tests ............................................................................... 377
      Logistic Fit Platform Options ....................................................................... 378
         Plot Options ................................................................................................ 378
         Likelihood Ratio Tests ............................................................................... 378
         Wald Tests for Effects ................................................................................ 378
         Confidence Intervals ................................................................................... 378
         Odds Ratios (Nominal Responses Only) ...................................................... 379
         Inverse Prediction ....................................................................................... 380
         Save Commands .......................................................................................... 383
         ROC Curve .................................................................................................. 384
         Lift Curve ................................................................................................... 385
### Fitting Linear Models

<table>
<thead>
<tr>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Confusion Matrix</td>
<td>386</td>
</tr>
<tr>
<td>Profiler</td>
<td>386</td>
</tr>
<tr>
<td>Validation</td>
<td>386</td>
</tr>
<tr>
<td>Example of a Nominal Logistic Model</td>
<td>387</td>
</tr>
<tr>
<td>Example of an Ordinal Logistic Model</td>
<td>392</td>
</tr>
<tr>
<td>Example of a Quadratic Ordinal Logistic Model</td>
<td>397</td>
</tr>
<tr>
<td>Stacking Counts in Multiple Columns</td>
<td>399</td>
</tr>
</tbody>
</table>

#### 11 Generalized Linear Models

**Fit Data with Nonnormal Response Distributions**

<table>
<thead>
<tr>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overview of Generalized Linear Models</td>
<td>401</td>
</tr>
<tr>
<td>The Generalized Linear Model Personality</td>
<td>403</td>
</tr>
<tr>
<td>Examples of Generalized Linear Models</td>
<td>404</td>
</tr>
<tr>
<td>Model Selection and Deviance</td>
<td>405</td>
</tr>
<tr>
<td>Examples</td>
<td>406</td>
</tr>
<tr>
<td>Poisson Regression</td>
<td>408</td>
</tr>
<tr>
<td>Poisson Regression with Offset</td>
<td>410</td>
</tr>
<tr>
<td>Normal Regression, Log Link</td>
<td>412</td>
</tr>
<tr>
<td>Platform Commands</td>
<td>416</td>
</tr>
</tbody>
</table>

#### A References

#### B Statistical Details

**Fitting Linear Models**

<table>
<thead>
<tr>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Response Models</td>
<td>427</td>
</tr>
<tr>
<td>Continuous Responses</td>
<td>429</td>
</tr>
<tr>
<td>Nominal Responses</td>
<td>429</td>
</tr>
<tr>
<td>Ordinal Responses</td>
<td>431</td>
</tr>
<tr>
<td>The Factor Models</td>
<td>432</td>
</tr>
<tr>
<td>Continuous Factors</td>
<td>433</td>
</tr>
<tr>
<td>Nominal Factors</td>
<td>433</td>
</tr>
<tr>
<td>Ordinal Factors</td>
<td>444</td>
</tr>
<tr>
<td>The Usual Assumptions</td>
<td>450</td>
</tr>
<tr>
<td>Assumed Model</td>
<td>450</td>
</tr>
<tr>
<td>Relative Significance</td>
<td>450</td>
</tr>
</tbody>
</table>
Multiple Inferences ...................................................... 451
Validity Assessment .................................................... 451
Alternative Methods ................................................... 452
Key Statistical Concepts .............................................. 452
Uncertainty, a Unifying Concept .................................... 452
The Two Basic Fitting Machines ................................. 453
Multivariate Details .................................................... 456
Multivariate Tests ....................................................... 456
Approximate $F$-Test .................................................... 457
Canonical Details ......................................................... 457
Discriminant Analysis .................................................. 458
Power Calculations ...................................................... 459
Computations for the LSN ............................................. 459
Computations for the LSV ............................................. 460
Computations for the Power ......................................... 461
Computations for the Adjusted Power .......................... 461
Inverse Prediction with Confidence Limits ..................... 462

Index

Fitting Linear Models .................................................. 465
Chapter 1
Learn about JMP
Documentation and Additional Resources

This chapter includes the following information:

- book conventions
- JMP documentation
- JMP Help
- additional resources, such as the following:
  - other JMP documentation
  - tutorials
  - indexes
  - Web resources

Figure 1.1 The JMP Help Home Window on Windows
Contents

Formatting Conventions ................................................................. 17
JMP Documentation ................................................................. 17
  JMP Documentation Library .................................................. 18
  JMP Help ............................................................. 22
Additional Resources for Learning JMP ........................................ 22
  Tutorials ............................................................... 23
  Sample Data Tables .......................................................... 23
  Learn about Statistical and JSL Terms ..................................... 23
  Learn JMP Tips and Tricks .................................................. 24
  Tooltips ................................................................. 24
  JMP User Community ....................................................... 24
  JMPer Cable .............................................................. 24
  JMP Books by Users .......................................................... 25
  The JMP Starter Window ..................................................... 25
Formatting Conventions

The following conventions help you relate written material to information that you see on your screen.

- Sample data table names, column names, pathnames, filenames, file extensions, and folders appear in *Helvetica* font.
- Code appears in *Lucida Sans Typewriter* font.
- Code output appears in *Lucida Sans Typewriter* italic font and is indented farther than the preceding code.
- **Helvetica bold** formatting indicates items that you select to complete a task:
  - buttons
  - check boxes
  - commands
  - list names that are selectable
  - menus
  - options
  - tab names
  - text boxes
- The following items appear in italics:
  - words or phrases that are important or have definitions specific to JMP
  - book titles
  - variables
- Features that are for JMP Pro only are noted with the JMP Pro icon. For an overview of JMP Pro features, visit [http://www.jmp.com/software/pro/](http://www.jmp.com/software/pro/).

**Note:** Special information and limitations appear within a Note.

**Tip:** Helpful information appears within a Tip.

JMP Documentation

JMP offers documentation in various formats, from print books and Portable Document Format (PDF) to electronic books (e-books).

- Open the PDF versions from the Help > Books menu or from the JMP online Help footers.
• All books are also combined into one PDF file, called *JMP Documentation Library*, for convenient searching. Open the *JMP Documentation Library* PDF file from the Help > Books menu.

• e-books are available at Amazon, Safari Books Online, and in the Apple iBookstore.

• You can also purchase printed documentation on the SAS website: http://support.sas.com/documentation/onlinedoc/jmp/index.html

**JMP Documentation Library**

The following table describes the purpose and content of each book in the JMP library.

<table>
<thead>
<tr>
<th>Document Title</th>
<th>Document Purpose</th>
<th>Document Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discovering JMP</td>
<td>If you are not familiar with JMP, start here.</td>
<td>Introduces you to JMP and gets you started creating and analyzing data.</td>
</tr>
<tr>
<td>Using JMP</td>
<td>Learn about JMP data tables and how to perform basic operations.</td>
<td>Covers general JMP concepts and features that span across all of JMP, including importing data, modifying columns properties, sorting data, and connecting to SAS.</td>
</tr>
<tr>
<td>Basic Analysis</td>
<td>Perform basic analysis using this document.</td>
<td>Describes these Analyze menu platforms:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Distribution</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Fit Y by X</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Matched Pairs</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Tabulate</td>
</tr>
<tr>
<td></td>
<td></td>
<td>How to approximate sampling distributions using bootstrapping is also included.</td>
</tr>
<tr>
<td>Document Title</td>
<td>Document Purpose</td>
<td>Document Content</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>----------------------------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td><em>Essential Graphing</em></td>
<td>Find the ideal graph for your data.</td>
<td>Describes these Graph menu platforms:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Graph Builder</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Overlay Plot</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Scatterplot 3D</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Contour Plot</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Bubble Plot</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Parallel Plot</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Cell Plot</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Treemap</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Scatterplot Matrix</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Ternary Plot</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Chart</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Also covers how to create background and custom maps.</td>
</tr>
<tr>
<td><em>Profilers</em></td>
<td>Learn how to use interactive profiling tools, which enable you to view cross-sections of any response surface.</td>
<td>Covers all profilers listed in the Graph menu. Analyzing noise factors is included along with running simulations using random inputs.</td>
</tr>
<tr>
<td><em>Design of Experiments Guide</em></td>
<td>Learn how to design experiments and determine appropriate sample sizes.</td>
<td>Covers all topics in the DOE menu.</td>
</tr>
<tr>
<td>Document Title</td>
<td>Document Purpose</td>
<td>Document Content</td>
</tr>
<tr>
<td>---------------------</td>
<td>----------------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Fitting Linear Models</td>
<td>Learn about Fit Model platform and many of its personalities.</td>
<td>Describes these personalities, all available within the Analyze menu Fit Model platform:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Standard Least Squares</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Stepwise</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Generalized Regression</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Mixed Model</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• MANOVA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Loglinear Variance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Nominal Logistic</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Ordinal Logistic</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Generalized Linear Model</td>
</tr>
<tr>
<td>Specialized Models</td>
<td>Learn about additional modeling techniques.</td>
<td>Describes these Analyze &gt; Modeling menu platforms:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Partition</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Neural</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Model Comparison</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Nonlinear</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Gaussian Process</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Time Series</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Response Screening</td>
</tr>
<tr>
<td></td>
<td></td>
<td>The Screening platform in the Analyze &gt; Modeling menu is described in Design of Experiments Guide.</td>
</tr>
<tr>
<td>Multivariate Methods</td>
<td>Read about techniques for analyzing several variables simultaneously.</td>
<td>Describes these Analyze &gt; Multivariate Methods menu platforms:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Multivariate</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Cluster</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Principal Components</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Discriminant</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Partial Least Squares</td>
</tr>
</tbody>
</table>

Document Title Document Purpose Document Content |
<table>
<thead>
<tr>
<th>Document Title</th>
<th>Document Purpose</th>
<th>Document Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quality and Process Methods</td>
<td>Read about tools for evaluating and improving processes.</td>
<td>Describes these Analyze &gt; Quality and Process menu platforms:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Control Chart Builder and individual control charts</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Measurement Systems Analysis</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Variability / Attribute Gauge Charts</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Capability</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Pareto Plot</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Diagram</td>
</tr>
<tr>
<td>Reliability and Survival Methods</td>
<td>Learn to evaluate and improve reliability in a product or system and analyze survival data for people and products.</td>
<td>Describes these Analyze &gt; Reliability and Survival menu platforms:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Life Distribution</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Fit Life by X</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Recurrence Analysis</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Degradation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Reliability Forecast</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Reliability Growth</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Reliability Block Diagram</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Survival</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Fit Parametric Survival</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Fit Proportional Hazards</td>
</tr>
<tr>
<td>Consumer Research</td>
<td>Learn about methods for studying consumer preferences and using that insight to create better products and services.</td>
<td>Describes these Analyze &gt; Consumer Research menu platforms:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Categorical</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Factor Analysis</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Choice</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Uplift</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Item Analysis</td>
</tr>
</tbody>
</table>
Learn about JMP

Chapter 1

Additional Resources for Learning JMP

<table>
<thead>
<tr>
<th>Document Title</th>
<th>Document Purpose</th>
<th>Document Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scripting Guide</td>
<td>Learn about taking advantage of the powerful JMP Scripting Language (JSL).</td>
<td>Covers a variety of topics, such as writing and debugging scripts, manipulating data tables, constructing display boxes, and creating JMP applications.</td>
</tr>
<tr>
<td>JSL Syntax Reference</td>
<td>Read about many JSL functions on functions and their arguments, and messages that you send to objects and display boxes.</td>
<td>Includes syntax, examples, and notes for JSL commands.</td>
</tr>
</tbody>
</table>

**Note:** The Books menu also contains two reference cards that can be printed: The Menu Card describes JMP menus, and the Quick Reference describes JMP keyboard shortcuts.

---

**JMP Help**

JMP Help is an abbreviated version of the documentation library that provides targeted information. You can open JMP Help in several ways:

- On Windows, press the F1 key to open the Help system window.
- Get help on a specific part of a data table or report window. Select the Help tool from the Tools menu and then click anywhere in a data table or report window to see the Help for that area.
- Within a JMP window, click the Help button.

---

**Additional Resources for Learning JMP**

In addition to JMP documentation and JMP Help, you can also learn about JMP using the following resources:

- Tutorials (see “Tutorials” on page 23)
- Sample data (see “Sample Data Tables” on page 23)
- Indexes (see “Learn about Statistical and JSL Terms” on page 23)
Learn about JMP

Additional Resources for Learning JMP

• Tip of the Day (see “Learn JMP Tips and Tricks” on page 24)
• Web resources (see “JMP User Community” on page 24)
• JMPer Cable technical publication (see “JMPer Cable” on page 24)
• Books about JMP (see “JMP Books by Users” on page 25)
• JMP Starter (see “The JMP Starter Window” on page 25)

Tutorials

You can access JMP tutorials by selecting Help > Tutorials. The first item on the Tutorials menu is Tutorials Directory. This opens a new window with all the tutorials grouped by category.

If you are not familiar with JMP, then start with the Beginners Tutorial. It steps you through the JMP interface and explains the basics of using JMP.

The rest of the tutorials help you with specific aspects of JMP, such as creating a pie chart, using Graph Builder, and so on.

Sample Data Tables

All of the examples in the JMP documentation suite use sample data. Select Help > Sample Data to do the following actions:

• Open the sample data directory.
• Open an alphabetized list of all sample data tables.
• Find a sample data table within a category.

Sample data tables are installed in the following directory:

On Windows: C:\Program Files\SAS\JMP<version_number>\Samples\Data
On Macintosh: \Library\Application Support\JMP<version_number>\Samples\Data

In JMP Pro, sample data is installed in the JMPRO (rather than JMP) directory.

Learn about Statistical and JSL Terms

The Help menu contains the following indexes:

Statistics Index Provides definitions of statistical terms.

Scripting Index Lets you search for information about JSL functions, objects, and display boxes. You can also edit and run sample scripts from the Scripting Index.
Learn JMP Tips and Tricks

When you first start JMP, you see the Tip of the Day window. This window provides tips for using JMP.

To turn off the Tip of the Day, clear the Show tips at startup check box. To view it again, select Help > Tip of the Day. Or, you can turn it off using the Preferences window. See the Using JMP book for details.

Tooltips

JMP provides descriptive tooltips when you place your cursor over items, such as the following:

- Menu or toolbar options
- Labels in graphs
- Text results in the report window (move your cursor in a circle to reveal)
- Files or windows in the Home Window
- Code in the Script Editor

Tip: You can hide tooltips in the JMP Preferences. Select File > Preferences > General (or JMP > Preferences > General on Macintosh) and then deselect Show menu tips.

JMP User Community

The JMP User Community provides a range of options to help you learn more about JMP and connect with other JMP users. The learning library of one-page guides, tutorials, and demos is a good place to start. And you can continue your education by registering for a variety of JMP training courses.

Other resources include a discussion forum, sample data and script file exchange, webcasts, and social networking groups.

To access JMP resources on the website, select Help > JMP User Community.

JMPer Cable

The JMPer Cable is a yearly technical publication targeted to users of JMP. The JMPer Cable is available on the JMP website:

http://www.jmp.com/about/newsletters/jmpercable/
JMP Books by Users

Additional books about using JMP that are written by JMP users are available on the JMP website:

http://www.jmp.com/support/books.shtml

The JMP Starter Window

The JMP Starter window is a good place to begin if you are not familiar with JMP or data analysis. Options are categorized and described, and you launch them by clicking a button. The JMP Starter window covers many of the options found in the Analyze, Graph, Tables, and File menus.

- To open the JMP Starter window, select View (Window on the Macintosh) > JMP Starter.
- To display the JMP Starter automatically when you open JMP on Windows, select File > Preferences > General, and then select JMP Starter from the Initial JMP Window list. On Macintosh, select JMP > Preferences > Initial JMP Starter Window.
About the Fit Model Platform

Using the Fit Model platform, you can specify complex models efficiently. Your task is simplified by Macros, Attributes, and transformations. Fit Model is your gateway to fitting a broad variety of models and effect structures.

These include:

• simple and multiple linear regression
• analysis of variance and covariance
• random effect, nested effect, mixed effect, repeated measures, and split plot models
• nominal and ordinal logistic regression
• multivariate analysis of variance (MANOVA)
• canonical correlation and discriminant analysis
• loglinear variance (to model the mean and the variance)
• generalized linear models (GLM)
• parametric survival and proportional hazards
• response screening, for studying a large number of responses

In JMP Pro, you can also fit the following:

• mixed models with a range of covariance structures
• generalized regression models including the elastic net, lasso, and ridge regression
• partial least squares
## Contents

- **Overview of the Fit Model Platform** .................................................. 29
- **Example of a Regression Analysis Using Fit Model** .......................... 30
- **Launch the Fit Model Platform** ......................................................... 33
  - Fitting Personalities ............................................................ 33
  - Fit Model Launch Window Elements ......................................... 36
- **Construct Model Effects** ................................................................. 39
  - Add .................................................................................... 39
  - Cross ............................................................................... 39
  - Nest ................................................................................. 40
  - Macros ............................................................................. 41
  - Attributes ....................................................................... 42
  - Transform ....................................................................... 44
  - No Intercept ................................................................... 45
- **Construct Model Effects Tabs** ......................................................... 45
- **Model Specification Options** ............................................................ 46
  - Informative Missing ............................................................ 48
- **Validity Checks** ........................................................................... 50
- **Examples of Model Specifications and Their Model Fits** ................. 50
- **Statistical Details** ......................................................................... 69
Overview of the Fit Model Platform

The Fit Model platform gives you an efficient way to specify models that have complex effect structures. These effect structures are linear in the predictor variables. Once you have specified your model, you can select the appropriate fitting technique from a number of fitting personalities. Once you choose a personality, the Fit Model window provides choices that are relevant for the chosen personality. This chapter focuses on the elements that are common to most personalities. For a description of all personalities, see “Fitting Personalities” on page 33.

Fit Model can be used to specify a wide variety of models that can be fit using various methods. Table 2.1 lists some typical models that can be defined using Fit Model. In the table, the effects X and Z represent columns with a continuous modeling type, while A, B, and C represent columns with a nominal or ordinal modeling type.

Refer to the section “Examples of Model Specifications and Their Model Fits” on page 50 to see the clicking sequences that produce these model effects, plots of the model fits, and some examples.

Table 2.1 Standard Model Types

<table>
<thead>
<tr>
<th>Type of Model</th>
<th>Model Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple Linear Regression</td>
<td>X</td>
</tr>
<tr>
<td>Polynomial in X to Degree k</td>
<td>X, X*X, ..., X^k</td>
</tr>
<tr>
<td>Polynomial in X and Z to Degree k</td>
<td>X, X<em>X, ..., X^k, Z, Z</em>Z, ..., Z^k</td>
</tr>
<tr>
<td>Multiple Linear Regression</td>
<td>X, Z, and other continuous columns</td>
</tr>
<tr>
<td>One-Way Analysis of Variance</td>
<td>A</td>
</tr>
<tr>
<td>Two-Way Analysis of Variance</td>
<td>A, B</td>
</tr>
<tr>
<td>Two-Way Analysis of Variance with Interaction</td>
<td>A, B, A*B</td>
</tr>
<tr>
<td>Analysis of Covariance, Equal Slopes</td>
<td>A, X</td>
</tr>
<tr>
<td>Analysis of Covariance, Unequal Slopes</td>
<td>A, X, A*X</td>
</tr>
<tr>
<td>Two-Factor Nested Random Effects Model</td>
<td>A, B[A]&amp;Random</td>
</tr>
<tr>
<td>Three-Factor Fully Nested Random Effects Model</td>
<td>A, B[A]&amp;Random, C[A,B]&amp;Random</td>
</tr>
</tbody>
</table>
Example of a Regression Analysis Using Fit Model

You have data resulting from an aerobic fitness study, and you want to predict the oxygen uptake from several continuous variables.

1. Open the Fitness.jmp sample data table.
2. Select Analyze > Fit Model. Note that the Personality box is empty.
3. Select Oxy and click Y.

   When you specify a continuous response, the Personality defaults to Standard Least Squares, but you are free to choose another personality. Also, the Emphasis defaults to Effect Leverage.

4. Press CTRL, and select Sex, Age, Weight, Runtime, RunPulse, RstPulse, and MaxPulse. Click Add to add these to the Construct Model Effects list. Note that you can select Keep dialog open if you want to have this window available later on. Your Model Specification window should appear as shown in Figure 2.1.

5. Click Run. Figure 2.2 gives a partial view of the report.
Figure 2.1 Model Specification Window for Fitness Regression Model
Figure 2.2  Partial View of Standard Least Squares Report for Fitness Data

The plot and reports for the whole model appear in the left-most report column. The columns to the right show leverage plots for each of the effects that you specified in the model. Due to space limitations, Figure 2.2 shows only the column for Sex, but the report shows columns for the other six effects as well. The red triangle menus contain additional options that add reports and plots to the report window. For details about the Standard Least Squares report window, see “Fit Least Squares Report” on page 80 in the “Standard Least Squares Report and Options” chapter.

Looking at the p-values in the Parameter Estimates report, you can see that Runtime, RunPulse, and MaxPulse appear to be significant predictors of oxygen uptake. The next step might be to reduce the model by removing insignificant predictors. See the “Stepwise Regression Models” chapter on page 227 for more information.
Launch the Fit Model Platform

You can launch the Fit Model platform by selecting Analyze > Fit Model. Figure 2.3 shows an example of the launch window for the Fitness.jmp sample data table.

Figure 2.3 Fit Model Launch Window

Note: When you select Analyze > Fit Model in a data table that has a script named Model (or model), the launch window is automatically filled in based on the script.

The Fit Model launch window lets you fit a large variety of types of models by selecting the desired Personality. Table 2.2 gives descriptions of the personalities and cross references to their chapters. This chapter focuses on the elements of Fit Model that are common to most personalities.

Fitting Personalities

In the Fit Model launch window, you select your fitting and analysis method by specifying a Personality. Based on the response (or responses) and the factors that you enter, JMP makes an initial context-based guess at the desired personality, but you can alter this selection in the Personality menu.

Table 2.2 briefly describes each personality and provides references to the chapters that describe each in detail.
# Introduction to Fit Model

## Launch the Fit Model Platform: Fitting Linear Models

### Table 2.2 Description of Fitting Personalities

<table>
<thead>
<tr>
<th>Personality</th>
<th>Description</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Standard Least Squares</strong></td>
<td>Fits models where the response is continuous. Techniques include regression, analysis of variance, analysis of covariance, mixed models, and analysis of designed experiments.</td>
<td>See the “Standard Least Squares Report and Options” chapter on page 71.</td>
</tr>
<tr>
<td><strong>Stepwise</strong></td>
<td>Facilitates variable selection for standard least squares and ordinal logistic analyses (or nominal with a binary response). For continuous responses, cross validation, p-value, BIC, and AICc criteria are provided. Also provided are options for fitting all possible models and for model averaging. For logistic fits, p-value, BIC, and AICc criteria are provided.</td>
<td>See the “Stepwise Regression Models” chapter on page 227.</td>
</tr>
<tr>
<td><strong>Generalized Regression</strong></td>
<td>Fits generalized linear models using regularized, also known as penalized, regression techniques. The regularization techniques include ridge regression, the lasso, the adaptive lasso, the elastic net, and the adaptive elastic net. The response distributions include the normal, binomial, Poisson, zero-inflated Poisson, negative binomial, zero-inflated negative binomial, and gamma.</td>
<td>See the “Generalized Regression Models” chapter on page 249.</td>
</tr>
<tr>
<td><strong>Mixed Model</strong></td>
<td>Fits a wide variety of linear models for continuous-responses with complex covariance structures. The situations addressed include:</td>
<td>See the “Mixed Models” chapter on page 273.</td>
</tr>
<tr>
<td></td>
<td>‒ Split plot experiments</td>
<td></td>
</tr>
<tr>
<td></td>
<td>‒ Random coefficients models</td>
<td></td>
</tr>
<tr>
<td></td>
<td>‒ Repeated measures designs</td>
<td></td>
</tr>
<tr>
<td></td>
<td>‒ Spatial data</td>
<td></td>
</tr>
<tr>
<td></td>
<td>‒ Correlated response data</td>
<td></td>
</tr>
</tbody>
</table>
### Table 2.2 Description of Fitting Personalities (Continued)

<table>
<thead>
<tr>
<th>Personality</th>
<th>Description</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Manova</strong></td>
<td>Fits models that involve multiple continuous Y variables. Techniques include multivariate analysis of variance, repeated measures, discriminant analysis, and canonical correlations.</td>
<td>See the “Multivariate Response Models” chapter on page 335.</td>
</tr>
<tr>
<td><strong>LogLinear Variance</strong></td>
<td>For a continuous Y variable, constructs models for both the mean and the variance. You can specify different sets of effects for the two models.</td>
<td>See the “Loglinear Variance Models” chapter on page 357.</td>
</tr>
<tr>
<td><strong>Nominal Logistic</strong></td>
<td>Fits a logistic regression model to a nominal response.</td>
<td>See the “Logistic Regression with Nominal or Ordinal Responses” chapter on page 369.</td>
</tr>
<tr>
<td><strong>Ordinal Logistic</strong></td>
<td>Fits a logistic regression model to an ordinal response.</td>
<td>See the “Logistic Regression with Nominal or Ordinal Responses” chapter on page 369.</td>
</tr>
<tr>
<td><strong>Proportional Hazard</strong></td>
<td>Fits a semi-parametric regression model (the Cox proportional hazards model) to assess the effect of explanatory variables on survival times, taking censoring into account. You can also launch this personality by selecting Analyze &gt; Reliability and Survival &gt; Fit Proportional Hazards.</td>
<td>See the Reliability and Survival Methods book.</td>
</tr>
<tr>
<td><strong>Parametric Survival</strong></td>
<td>Fits a general linear regression model to survival times. Use this option if you have survival times that can be expressed as a function of one or more explanatory variables. Takes into account various survival distributions and censoring. You can also launch this personality by selecting Analyze &gt; Reliability and Survival &gt; Fit Parametric Survival.</td>
<td>See the Reliability and Survival Methods book.</td>
</tr>
</tbody>
</table>
Table 2.2 Description of Fitting Personalities (Continued)

<table>
<thead>
<tr>
<th>Generalized Linear Model</th>
<th>Fits generalized linear models using various distribution and link functions. Techniques include logistic, Poisson, and exponential regression.</th>
<th>See the “Generalized Linear Models” chapter on page 401.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Partial Least Squares</td>
<td>Fits models to one or more $Y$s using latent factors. This permits models to be fit when explanatory variables ($X$s) are highly correlated, or when there are more $X$s than observations. You can also launch a partial least squares analysis by selecting Analyze &gt; Multivariate Methods &gt; Partial Least Squares.</td>
<td>See the Multivariate Methods book.</td>
</tr>
<tr>
<td>Response Screening</td>
<td>Automates the process of conducting tests for linear model effects across a large number of responses. Test results and summary statistics are presented in data tables and plots. A False-Discovery Rate (FDR) approach guards against incorrect declarations of significance. A robust estimation method reduces the sensitivity of tests to outliers. <strong>Note:</strong> This personality only allows continuous responses. Response Screening for individual factors is also available by selecting Analyze &gt; Modeling &gt; Response Screening. This platform supports categorical responses, and also provides equivalence tests and tests of practical significance.</td>
<td>See the Specialized Models book.</td>
</tr>
</tbody>
</table>

**Fit Model Launch Window Elements**

Table 2.3 describes the elements of the Fit Model launch window that are common to most personalities.
### Table 2.3 Elements Common to Most Personalities

<table>
<thead>
<tr>
<th><strong>Model Specification</strong></th>
<th>The red triangle menu next to Model Specification contains options that enable you to:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• Center effects when polynomials are included in the model</td>
</tr>
<tr>
<td></td>
<td>• Codes for missing values</td>
</tr>
<tr>
<td></td>
<td>• Set the alpha level for confidence intervals</td>
</tr>
<tr>
<td></td>
<td>• Save the model specifications to a script window or to a script attached to the data table</td>
</tr>
<tr>
<td></td>
<td>• Interact with SAS</td>
</tr>
<tr>
<td></td>
<td>• Set convergence criteria</td>
</tr>
<tr>
<td></td>
<td>See “Model Specification Options” on page 46.</td>
</tr>
<tr>
<td><strong>Select Columns</strong></td>
<td>Lists the unexcluded columns in the current data table.</td>
</tr>
<tr>
<td><strong>Y</strong></td>
<td>Identifies one or more response variables (the dependent variables) for the model.</td>
</tr>
<tr>
<td><strong>Weight</strong></td>
<td>Identifies a column whose values assign a weight to each row for the analysis. See “Weight” on page 39.</td>
</tr>
<tr>
<td><strong>Freq</strong></td>
<td>Identifies a column whose values assign a frequency to each row for the analysis. In general terms, the effect of a</td>
</tr>
<tr>
<td></td>
<td>frequency column is to expand the data table, so that any row with integer frequency $k$ is expanded to $k$ rows.</td>
</tr>
<tr>
<td></td>
<td>Row ordering is maintained. You are allowed to specify fractional frequencies. See “Frequency” on page 38.</td>
</tr>
<tr>
<td><strong>By</strong></td>
<td>Performs a separate analysis for each level of the variable.</td>
</tr>
<tr>
<td><strong>Add</strong></td>
<td>Adds effects to the model. See “Add” on page 39.</td>
</tr>
<tr>
<td><strong>Cross</strong></td>
<td>Creates interaction and polynomial effects by crossing two or more variables. See “Cross” on page 39.</td>
</tr>
<tr>
<td><strong>Nest</strong></td>
<td>Creates nested effects. See “Nest” on page 40.</td>
</tr>
<tr>
<td><strong>Macros</strong></td>
<td>Automatically generates effects for commonly used models. See “Macros” on page 41.</td>
</tr>
<tr>
<td><strong>Degree</strong></td>
<td>Applies the specified degree to models with factorial or polynomial effects generated using Macros. See <strong>Factorial</strong></td>
</tr>
<tr>
<td></td>
<td>to Degree and Polynomial to Degree in “Macros” on page 41.</td>
</tr>
</tbody>
</table>
Introduction to Fit Model

Chapter 2
Fitting Linear Models

Table 2.3 Elements Common to Most Personalities (Continued)

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attributes</td>
<td>Applies attributes to model effects. These attributes determine how the effects are treated. See “Attributes” on page 42.</td>
</tr>
<tr>
<td>Transform</td>
<td>Transforms selected continuous effects or Y columns. See “Transform” on page 44.</td>
</tr>
<tr>
<td>No Intercept</td>
<td>Excludes the intercept term from the model.</td>
</tr>
<tr>
<td>Personality</td>
<td>Specifies the fitting methodology. See “Construct Model Effects” on page 39.</td>
</tr>
<tr>
<td>Help</td>
<td>Takes you to Help topics for the Fit Model launch window.</td>
</tr>
<tr>
<td>Recall</td>
<td>Populates the launch window with the last model specification that you ran.</td>
</tr>
<tr>
<td>Remove</td>
<td>Removes the selected variable from the assigned role. Alternatively, double click the effect or select the effect and press the Backspace key.</td>
</tr>
<tr>
<td>Run</td>
<td>Generates the report window for the specified model and personality.</td>
</tr>
<tr>
<td>Keep dialog open</td>
<td>Keeps the launch window open after you run the analysis, enabling you to alter and re-run the analysis at any time.</td>
</tr>
</tbody>
</table>

Frequency

Frequency variables, entered in the Freq text box, are an option for most Fit Model personalities. In general, a frequency is interpreted as follows. Suppose that a row has a frequency \( f \). Then the computed results are identical to those for a data table containing \( f \) copies of that row, each having a frequency of one.

Rows with zero or missing frequency values are excluded from analyses. Rows with negative frequency values are permitted only for censored observations, otherwise they are excluded from analyses. When used with censored observations, negative frequency values can be used to fit truncated distributions.

Frequency values need not be integers. The technical details describing how frequency columns, including those with non-integer values, are handled are given in “Statistical Details” on page 69.
Weight

Weight variables are an option for those Fit Model personalities where estimation is performed using least squares or normal theory maximum likelihood. In these cases, the weight \( w \) for a given row scales that row's contribution to the loss function by \( w^{-1/2} \).

Weight variables can be useful in situations where there are observations with different variances. For example, this can happen when one performs regression modeling on data where each row consists of pre-summarized means. Here, rows involving a larger number of observations (smaller variance) should contribute more heavily to the loss function than rows involving a smaller number of observations (larger variance). You can ensure that this occurs by using appropriately defined weights.

Weight variables have an impact on estimates and standard errors. However, unlike frequency variables, they do not affect the degrees of freedom used in hypothesis tests.

Rows with negative or zero values for Weight are excluded from analyses.

Construct Model Effects

This section describes the options that you can use to facilitate entering effects into your model. Examples of how these options can be used to obtain specific types of models are given in “Examples of Model Specifications and Their Model Fits” on page 50.

Add

Adds effects to the model. These effects can either be added directly from the Select Columns list or they can be selected in that list and modified using Macros or Attributes. Effects can also be created and added, or modified, using Cross and Nest. The modeling types of the variables involved in the effect, as well as any Attribute assigned to the effect, determine how that effect is treated in the model.

Note: To remove an effect from the Construct Model Effects list, double-click the effect, or select it and click Remove or press the Backspace or Delete key.

Cross

Creates interaction or polynomial effects. Select two or more variables in the Select Columns list and click Cross. Or, select one or more variables in the Select Columns list and one or more effects in the Construct Model Effects list and click Cross.

See “Statistical Details” on page 427, for a discussion of how crossed effects are parameterized and coded.
Note: You can construct effects that combine up to ten columns as crossed and nested.

Example of Crossed Effects

Suppose that a product coating requires a dye to be applied. Both Dye pH and Dye Concentration are suspected to have an effect on the coating color. To understand their effects, you design an experiment where Dye pH and Dye Concentration are each set at a high and low level. It is possible that the effect of Dye pH on the color is more pronounced at the high level of Dye Concentration than at its low level. This is known as an interaction. To model this possible interaction, you include the crossed term, Dye pH * Dye Concentration, in the Construct Model Effects list. This enables JMP to test for an interaction.

Nest

Creates nested effects. If the levels of one effect (B) occur only within a single level of another effect (A), then B is said to be nested within A. The notation B[A], which is read as “B nested within A,” is typically used. Note that nesting defines a hierarchical relationship. A is called the outside effect and B is called the inside effect.

Note: The nesting terms must be specified in order from outer to inner. For example, if B is nested within A, and C is nested within B, then the model is specified as: A, B[A], C[B, A] (or, equivalently, A, B[A], C[A, B]). You can construct effects that combine up to ten columns as crossed and nested.

Example of Nested Effects

As an illustration of nesting, consider the math teachers in each of two schools. One school has three math teachers; the other school has two math teachers. Each teacher in each school teaches two or three classes consisting of non-overlapping groups of students. In this example, classes (C) are nested within teachers (B), and teachers (B) are nested within schools (A). Enter these effects in the Fit Model launch window as follows:

1. Add both A and B to the Construct Model Effects panel.
2. In the Construct Model Effects panel, click B.
3. In the Select Columns list, click A.
4. Click Nest. This converts B to the effect B[A].
5. Add C to the Construct Model Effects panel and click on it.
6. Select A and B in the Select Columns list.
7. Click Nest. The converts C to the effect C[A, B].
Macros

Provides options to automatically generate the effects for commonly used models and enter them into the Construct Model Effects list.

Table 2.4 Descriptions of the Macros Options

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Full Factorial</strong></td>
<td>Creates all main effects and interactions for the columns selected in the Select Columns list. These are entered in an order that is based on the order in which the main effects are listed in the Select Columns list. For an alternate ordering, see <strong>Factorial Sorted</strong>, in this table.</td>
</tr>
<tr>
<td><strong>Factorial to Degree</strong></td>
<td>Creates all main effects, but only interactions up to a specified degree (order). Specify the degree in the <strong>Degree</strong> box beneath the <strong>Macros</strong> button.</td>
</tr>
<tr>
<td><strong>Factorial Sorted</strong></td>
<td>Creates the same set of effects as the <strong>Full Factorial</strong> option but lists them in order of degree. All main effects are listed first, followed by all two-way interactions, then all three-way interactions, and so on.</td>
</tr>
<tr>
<td><strong>Response Surface</strong></td>
<td>Creates main effects, two-way interactions, and quadratic terms. The selected main effects are given the response surface attribute, denoted <strong>RS</strong>. When the RS attribute is applied to main effects and the Standard Least Squares personality is selected, a Response Surface report is provided. This report gives information about critical values and the shape of the response surface. See also Response Surface Effect in “Attributes” on page 42 and the Design of Experiments Guide.</td>
</tr>
<tr>
<td><strong>Mixture Response Surface</strong></td>
<td>Creates main effects and two-way interactions. Main effects have the response surface (<strong>RS</strong>) and mixture (<strong>Mixture</strong>) attributes. In the Standard Least Squares personality, the Mixture attribute causes a mixture model to be fit. The <strong>RS</strong> attribute creates a Response Surface report that is specific to mixture models. See also Mixture Effect in “Attributes” on page 42 and the Design of Experiments Guide.</td>
</tr>
<tr>
<td><strong>Polynomial to Degree</strong></td>
<td>Creates main effects and polynomial terms up to a specified degree. Specify the degree in the <strong>Degree</strong> box beneath the <strong>Macros</strong> button.</td>
</tr>
</tbody>
</table>
**Attributes**

Table 2.5 describes attributes that you can assign to an effect selected in the Construct Model Effects list.

<table>
<thead>
<tr>
<th><strong>Table 2.5 Descriptions of the Attributes Options</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Random Effect</strong></td>
</tr>
<tr>
<td><strong>Response Surface Effect</strong></td>
</tr>
</tbody>
</table>
Knotted Spline Effect

Knotted splines are used to fit a response $Y$ using a flexible function of a predictor. Consider the single predictor $X$. When the Knotted Spline Effect is assigned to $X$, and $k$ knots are specified, then $k-2$ additional effects are implicitly added to the set of predictors. Each of these effects is a piecewise cubic polynomial spline whose segments are defined by the knots. See Stone and Koo (1986).

The number of splines is determined by the number of knots, which you are asked to specify. The coefficients associated with the splines are estimated by maximum likelihood, conditional on the number of knots.

The placement of knots follows guidance given in the literature. In particular, if there are 100 or fewer points, the first and last knots are the fifth smallest and largest points, respectively. Otherwise, the first and last knots are placed at the 0.05 and 0.95 quantiles for 5 or fewer knots, or the 0.025 and 0.975 quantiles for more than 5 knots. The default number of knots is 5 for more than 30 observations, and 3 for fewer than 30 observations.

Note: Knotted splines are implemented only for main-effect continuous terms.

Table 2.5 Descriptions of the Attributes Options (Continued)

<table>
<thead>
<tr>
<th>Effect Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>LogVariance Effect</td>
<td>Assigns the LogVariance attribute to an effect. This attribute indicates that the effect is to be included in a model of the variance of the response. To include an effect in models for both the mean and variance of the response, you must specify the effect twice. In the tabbed interface, it must appear on both the Mean Effects and Variance Effects tabs. Otherwise, you can enter it twice on the Mean Effects tab, once without the LogVariance Effect attribute and once with the LogVariance Effect attribute.</td>
</tr>
<tr>
<td>Mixture Effect</td>
<td>Assigns the Mixture attribute to main effects. This is used to specify the main effects involved in the mixture. Note that the Mixture Response Surface option in the Macros list automatically assigns the mixture attribute to selected effects, and provides a Response Surface report when possible.</td>
</tr>
<tr>
<td>Excluded Effect</td>
<td>Assigns the Excluded attribute to an effect. This excludes the effect from the model fit, but, in the Standard Least Squares personality, provides least squares means for that effect.</td>
</tr>
<tr>
<td>Knotted Spline Effect</td>
<td>Assigns the Knotted attribute to a continuous main effect. This implicitly adds cubic splines for the effect to the model specification. See “Knotted Spline Effect” on page 43.</td>
</tr>
</tbody>
</table>
Transform

The Transform options transform selected Y columns or main effects that are selected in the Construct Model Effects text box.

**Note:** You can also transform a column by right-clicking it in the Select Columns list and selecting Transform. A reference to the transformed column appears in the Select Columns list. You can then use the column in the Fit Model window as you would any data table column. See the *Using JMP* book for details.

**Table 2.6 Descriptions of the Transform Options**

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>Removes any Transform options that have been applied.</td>
</tr>
<tr>
<td>Log</td>
<td>Applies the natural logarithm transformation to the selected variable.</td>
</tr>
<tr>
<td>Sqrt</td>
<td>Takes the square root of the values of the selected variable.</td>
</tr>
<tr>
<td>Square</td>
<td>Squares the values of the selected variable.</td>
</tr>
<tr>
<td>Reciprocal</td>
<td>Applies the transformation 1/X to the variable X.</td>
</tr>
<tr>
<td>Exp</td>
<td>Applies the exponential transformation to the selected variable.</td>
</tr>
<tr>
<td>Arrhenius</td>
<td>Applies the Arrhenius transformation to the variable T (temperature in degrees Centigrade):</td>
</tr>
<tr>
<td></td>
<td>[ X = \frac{11605}{T + 273.15} ]</td>
</tr>
<tr>
<td></td>
<td>This is the component of the Arrhenius relationship that is multiplied by the activation energy.</td>
</tr>
<tr>
<td>ArrheniusInv</td>
<td>Applies the inverse of the Arrhenius transformation to the variable X:</td>
</tr>
<tr>
<td></td>
<td>[ T = \frac{11605}{X} - 273.15 ]</td>
</tr>
<tr>
<td>Logit</td>
<td>Calculates the inverse of the logistic function for the selected column (where ( p ) is in the range of 0 to 1):</td>
</tr>
</tbody>
</table>
|            | \[ \text{Logit}(p) = \log\left(\frac{p}{1-p}\right) \] }
Chapter 2
Fitting Linear Models

Introduction to Fit Model

Construct Model Effects

Table 2.6 Descriptions of the Transform Options  (Continued)

<table>
<thead>
<tr>
<th>Transform</th>
<th>Description</th>
</tr>
</thead>
</table>
| Logistic  | Calculates the logistic (also known as Squish and Logist) function for the selected column (where the result is in the range of 0 to 1):  

\[
\text{Logistic}(x) = \frac{1}{1 + e^{-x}}
\]

| LogitPct  | Calculates the logit as a percent for the selected column (where \(pct\) is a percent in the range of 0 to 100):  

\[
\text{LogitPct}(pct) = \log\left( \frac{\frac{pct}{100}}{1 - \frac{pct}{100}} \right)
\]

| LogisticPct | Calculates the logistic (or logist) as a percent for the selected column (where the result is in the range of 0 to 100):  

\[
\text{LogisticPct}(x) = \frac{100}{1 + e^{-x}}
\]

No Intercept

Select No Intercept if you want to fit a model with no intercept term. Certain modeling structures require no intercept models. For these, the No Intercept box is checked by default.

Construct Model Effects Tabs

For certain personalities, described in Table 2.7, you can enter model effects using a tabbed interface.

Note: If you apply Attributes to effects on the first (main) tab, the attributes determine how the effects are treated in the model. If you run the model and then request Model Dialog from the report’s red triangle menu, you find that those effects appear on the appropriate tabs.
Table 2.7 Description of Personalities with Tabbed Construct Model Effects Input

<table>
<thead>
<tr>
<th>Model Specification Options</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Standard Least Squares</strong></td>
</tr>
<tr>
<td>Fixed Effects tab: Enter effects to be modeled as fixed effects. A fixed effect is one whose specific treatment levels are of interest. You want to compare the mean response across its treatment levels.</td>
</tr>
<tr>
<td>Random Effects tab: Enter effects to be modeled as random effects. A random effect is one whose levels are considered a random sample from a larger population. You want to estimate the variation in the response that is attributable to this effect.</td>
</tr>
<tr>
<td><strong>Mixed Model</strong></td>
</tr>
<tr>
<td>Fixed Effects tab: Enter effects to be modeled as fixed effects. See Standard Least Squares in this table.</td>
</tr>
<tr>
<td>Random Effects tab: Enter effects to be modeled as random effects. Use for variance component models and random coefficients models.</td>
</tr>
<tr>
<td>Repeated Structure tab: Use to select a covariance structure for repeated effects.</td>
</tr>
<tr>
<td><strong>LogLinear Variance</strong></td>
</tr>
<tr>
<td>Mean Effects tab: Enter effects for which you want to model expected values.</td>
</tr>
<tr>
<td>Variance Effects tab: Enter effects for which you want to model variance.</td>
</tr>
<tr>
<td>If you want to model both the expected value and variance of an effect, you must enter it on both tabs.</td>
</tr>
<tr>
<td><strong>Parametric Survival</strong></td>
</tr>
<tr>
<td>Location Effects tab: Enter effects that you want to use in modeling the location parameter, mu, or in the case of the Weibull distribution, the shape parameter.</td>
</tr>
<tr>
<td>Scale Effects tab: Enter effects that you want to use in modeling the scale parameter.</td>
</tr>
</tbody>
</table>

Table 2.8 describes the options in the red triangle menu next to Model Specification.
### Table 2.8 Descriptions of the Model Specification Options

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Center Polynomials</strong></td>
<td>Causes any continuous term involved in an effect with degree greater than one to be centered by its mean. This option is checked by default, except when a term involved in the effect is assigned the Mixture Effect attribute or has the Mixture column property. Terms with the Coding column property are centered midway between their specified High and Low values. Centering is useful in making regression coefficients more interpretable and in reducing collinearity between model effects.</td>
</tr>
<tr>
<td><strong>Informative Missing</strong></td>
<td>Selecting this option provides a coding system for missing values. This system allows estimation of a predictive model despite the presence of missing values. It is useful in situations where missing data are informative. See “Informative Missing” on page 48 for more details. This option is available for the following personalities: Standard Least Squares, Stepwise, Generalized Regression, MANOVA, Loglinear Variance, Nominal Logistic, Ordinal Logistic, Proportional Hazard, Parametric Survival, Generalized Linear Model, and Response Screening.</td>
</tr>
<tr>
<td><strong>Set Alpha Level</strong></td>
<td>Sets the alpha level for confidence intervals in the Fit Model analysis. The default alpha level is 0.05.</td>
</tr>
<tr>
<td><strong>Save to Data Table</strong></td>
<td>Saves your Fit Model launch window specifications as a script that is attached to the data table. The script is named Model. When a table contains a script called Model, this script automatically populates the launch window when you select <strong>Analyze &gt; Fit Model</strong>. (Simply rename the script if this is not desirable.) For details about JSL scripting, see the <strong>JMP Scripting Guide</strong>.</td>
</tr>
<tr>
<td><strong>Save to Script Window</strong></td>
<td>Copies your Fit Model launch window specifications to a script window. You can save the script window and re-create the model at any time by running the script.</td>
</tr>
</tbody>
</table>
**Informative Missing**

The Informative Missing option constructs a coding system that allows estimation of a predictive model despite the presence of missing values. It codes both continuous and categorical model effects.

---

**Table 2.8 Descriptions of the Model Specification Options (Continued)**

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Create SAS job</td>
<td>Creates a SAS program that can re-create the current analysis and data table in SAS in a script window. Once created, you have several options for submitting the code to SAS. 1. Copy and paste the code into the SAS Program Editor. This method is useful if you are running an older version of SAS (pre-version 8.2). 2. Select Edit &gt; Submit to SAS. 3. Save the file and double-click it to open it in a local copy of SAS. This method is useful if you would like to take advantage of SAS ODS options, such as generating HTML or PDF output from the SAS code. See the Using JMP book.</td>
</tr>
<tr>
<td>Submit to SAS</td>
<td>Submits code to SAS and displays the results in JMP. If you are not connected to a SAS server, prompts guide you through the connection process. See the Using JMP book.</td>
</tr>
<tr>
<td>Convergence Settings</td>
<td><strong>Note:</strong> This option appears only for certain personalities or if REML is selected as the method in the launch window. Depending on the model choice, the Convergence Settings menu includes the following options:  - <strong>Maximum Iterations</strong>  - <strong>Convergence Limit</strong>  Default values for the Maximum Iterations and Convergence Limit are 100 and 0.00000001, respectively. You can click on these values to enter new values for these limits. If you have a very large data set or a complicated model, you might want to limit the number of iterations. If your model does not readily converge, you might want to either increase the Maximum Iterations or increase the Convergence Limit.</td>
</tr>
</tbody>
</table>
Continuous Effects

When a continuous main effect has missing values, a new design matrix column is created. This column is an indicator variable, with values of one if the main effect column is missing and zero if it is not missing. In addition, missing values for the continuous main effect are replaced with the mean of the non-missing values. The mean is a neutral value that maintains the interpretability of parameter estimates.

The parameter associated with the indicator variable estimates the difference between the response predicted by the missing value grouping and the predicted response if the covariate is set at its mean.

For a higher-order effect, missing values in the covariates are replaced by the covariate means. This makes the higher-order effect zero for rows with missing values, assuming that Center Polynomials is checked (the default setting). This is because Center Polynomials centers the individual terms involved in a polynomial by their means.

In the Effect Tests report, each continuous main effect with missing values will have Nparm = 2. In the Parameter Estimates report, the parameter for a continuous main effect with missing values is labeled <colname> Or Mean if Missing and the indicator parameter is labeled <colname> Is Missing. Prediction formulas that you save to the data table are given in terms of expressions corresponding to these model parameters.

Categorical Effects

When a nominal or ordinal main effect has missing values, the missing values are coded as a separate level of that effect. As such, in the Effect Tests report, each categorical main effect with missing values will have one additional parameter.

In the Parameter Estimates report, the parameter for a nominal effect is labeled <colname>[].

For an ordinal effect, the parameter is labeled <colname>[-x], where x denotes the level with highest value ordering.

As with continuous effects, prediction formulas that you save to the data table are given in terms of expressions corresponding to the model parameters.

Coding Table

When you are using the Standard Least Squares personality, you can view the design matrix columns used in the Informative Missing model by selecting Save Columns > Save Coding Table.
Validity Checks

**Fit Model** checks your model for errors such as duplicate effects or missing effects in a hierarchy. If you receive an alert message, you can either click **Continue** to proceed with fitting, or click **Cancel** to stop the fitting process.

Examples of Model Specifications and Their Model Fits

This section gives templates for entering the effects for various model types that you can specify using the Construct Model Effects panel in the Fit Model platform.

- The model effects X and Z represent continuous columns.
- The model effects A, B, and C represent nominal or ordinal columns.

For most models, visual views of their model fits are also given.

**Simple Linear Regression**

Effects to be entered: X

1. In the Select Columns list, select X.
2. Click **Add**.

**Example of Simple Linear Regression Model**

Open Polycity.jmp. You are interested in the relationship between POP, the population in thousands of the given city, and Ozone. Ozone is the response of interest, and POP is the continuous model effect.

1. Select **Analyze > Fit Model**.
2. In the Select Columns list, select Ozone and click Y.
3. In the Select Columns list, select POP.
4. Click **Add**.

The Fit Model window appears as shown in Figure 2.4
Chapter 2
Introduction to Fit Model
Examples of Model Specifications and Their Model Fits

51

Chapter 2

Fitting Linear Models

Examples of Model Specifications and Their Model Fits

51

Chapter 2

Introduction to Fit Model

Examples of Model Specifications and Their Model Fits

51

Chapter 2

Introduction to Fit Model

Examples of Model Specifications and Their Model Fits

51

Chapter 2

Introduction to Fit Model

Examples of Model Specifications and Their Model Fits

51

Figure 2.4 Fit Model Window for Simple Linear Regression

When you click Run, the Fit Least Squares report appears, showing various results, including a Regression Plot. The Regression Plot shows the data and a simple linear regression model fit to the data (Figure 2.5).

Figure 2.5 Model Fit for Simple Linear Regression

When you click Run, the Fit Least Squares report appears, showing various results, including a Regression Plot. The Regression Plot shows the data and a simple linear regression model fit to the data (Figure 2.5).

Polynomial in X to Degree k

Effects to be entered: X, X*X, ..., X^k

1. Type k into the text box for Degree.
2. In the Select Columns list, select X.
3. Select Macros > Polynomial to Degree.
Figure 2.6 shows a plot of the data and a cubic polynomial model fit to the data for the Growth.jmp sample data table. This is one of the fits produced when you run the Bivariate data table script.

**Figure 2.6  Model Fit for a Degree-Three Polynomial in One Variable**

### Polynomial in X and Z to Degree k

Effects to be entered: $X, X^2, ..., X^k, Z, Z^2, ..., Z^k$

1. Type $k$ into the text box for **Degree**.
2. In the Select Columns list, select X and Z.
3. Select Macros > Polynomial to Degree.

For a plot of a degree-two fit for a polynomial two variables, see Figure 2.21.

### Multiple Linear Regression

Effects to be entered: Selected columns

1. In the Select Columns list, select the continuous effects of interest.
2. Click Add.

Figure 2.7 shows a surface profiler plot of the data and of the multiple linear regression fit to the data for the Grandfather Clocks.jmp sample data table. The model effects are Age and Bidders. The response is Price. You can obtain the plot by running the data table script Fit Model with Surface Profiler Plot.
Figure 2.7 Model Fit for a Multiple Linear Regression Model with Two Predictors

![Model Fit for a Multiple Linear Regression Model with Two Predictors](image)

Example of Multiple Linear Regression Model

See also “Example of a Regression Analysis Using Fit Model” on page 30 for an example with several predictors.

One-Way Analysis of Variance

Effects to be entered: A

1. In the Select Columns list, select one nominal or ordinal effect, A.
2. Click Add.

Consider the Golf Balls.jmp sample data table. You are interested in whether Durability varies by Brand. Figure 2.8 shows two plots.

The first is a plot, obtained using Fit Y by X, that shows the data by brand. Horizontal lines are plotted at the mean for each brand and line segments connect the means. To produce this plot, run the script OneWay: Durability by Brand in the Golf Balls.jmp sample data table.

The second plot is a profiler plot obtained using Fit Model. This second plot shows the predicted responses for each brand, connected by line segments. To produce this plot, run the script Fit Model: Durability by Brand in the Golf Balls.jmp sample data table. Drag the vertical dashed red line to the brand of interest. The horizontal dashed red line updates to intersect the vertical axis at the predicted response.
Two-Way Analysis of Variance

Effects to be entered: A, B

1. In the Select Columns list, select two nominal or ordinal effects, A and B.
2. Click Add.

Figure 2.9 shows two profiler plots of the fit to the data for the Analgesics.jmp sample data table. The model effects are gender and drug. The response is pain. To obtain this plot, run the data table script Fit Model. From the report’s red triangle menu, select Factor Profiling > Profiler.

The line segments in each plot connect the predicted values for the settings defined by the vertical dashed red lines. Move these to see predictions at other settings.

The top plot in Figure 2.9 shows predictions for females, while the bottom plot shows predictions for males. Note that the relative effects of the three drugs are consistent across the levels of gender. This is because there is no interaction term in the model. For an example with interaction, see Figure 2.11.
Two-Way Analysis of Variance with Interaction

Effects to be entered: A, B, A*B
1. In the Select Columns list, select two nominal or ordinal effects, A and B.
2. Select Macros > Full Factorial.
Or:
1. In the Select Columns list, select two nominal or ordinal effects, A and B.
2. Click Add.
3. In the Select Columns list, select A and B again and click Cross.

Example of Two-Way Analysis of Variance with Interaction
Open Popcorn.jmp. You are interested in whether popcorn and batch have an effect on yield.
1. Select Analyze > Fit Model.
2. In the Select Columns list, select yield and click Y.
3. In the Select Columns list, select popcorn and batch.
4. Select Macros > Full Factorial.
The Fit Model window appears as shown in Figure 2.10.

**Figure 2.10** Fit Model Window for Two-Way Analysis of Variance with Interaction

Figure 2.11 shows a profiler plot of the fit for this example. To obtain this plot, click Run in the Fit Model window shown in Figure 2.10. Then, from the red triangle menu for the Fit Least Squares report, select **Factor Profiling > Profiler**.

In the top plot, popcorn is set to gourmet, and in the bottom plot, it is set to plain. Note how the predicted values for the settings of batch depend on the type of popcorn. This is a consequence of the interaction between popcorn and batch.
Figure 2.11  Model Fit for a Two-Way Analysis of Variance with Interaction

![Model Fit for a Two-Way Analysis of Variance with Interaction](image)

**Three-Way Full Factorial**


1. In the Select Columns list, select three nominal or ordinal effects, A, B, and C.
2. Select Macros > Full Factorial.

**Example of Three-Way Full Factorial**

Open Tool Wear.jmp. You are interested in whether Speed, Angle, and Material, or their interactions, have an effect on the Wear of a cutting tool.

1. Select Analyze > Fit Model.
2. In the Select Columns list, select Wear and click Y.
3. In the Select Columns list, select Speed, Angle, and Material.
4. Select Macros > Full Factorial.

The Fit Model window appears as shown in Figure 2.12.
The Surface Profiler plots in Figure 2.13 show the predicted response for Wear in terms of the two continuous effects Speed and Angle. The plot on the left shows the predicted response when Material is A; the plot on the right shows the predicted response when Material is B. The points for which Material is A are colored red, while those for which Material is B are colored blue. The difference in the form of the response surfaces across the levels of Material is a consequence of the three-way interaction.

To obtain Surface Profiler plots, click Run in the Fit Model window shown in Figure 2.12. From the red triangle menu for the Fit Least Squares report, select Factor Profiling > Surface Profiler. To add points to the plot, open the Appearance panel and click Actual. If you want to make the points appear larger, right click in the plot, select Settings and adjust the Marker Size.

To show plots for both Materials A and B, use the slider marked Material in the Independent Variables panel, setting it at 0 for Material A and 1 for Material B. Note that the table contains two data table scripts that produce Surface Profiler plots: Prediction and Surface Profilers and Surface Profilers for Two Materials.
Figure 2.13 Model Fit for a Three-Way Full Factorial Design - Material A on Left, Material B on Right

Analysis of Covariance, Equal Slopes

Here you are interested in testing for the effect of A with X as a covariate. Suppose that you have reason to believe that the effect of X on the response does not depend on the level of A.

Effects to be entered: A, X

1. In the Select Columns list, select one nominal or ordinal effect, A, and one continuous effect, X.

2. Click Add.

Figure 2.14 shows the data from the Cleansing.jmp sample data table. You are interested in which Polymer removes the most Coal particles from a cleansing tank. However, you suspect that the pH of the tank also has an effect on removal. The plot shows an analysis of covariance fit. Here the slopes relating pH and Coal particles are assumed equal across the levels of Polymer.

The plot in Figure 2.14 is obtained as follows. In the Fit Model window, enter Coal particles as Y and both pH and Polymer in the Construct Model Effects text box. Click Run. The Regression Plot appears in the Fit Least Squares report. To color the points, select Rows > Color or Mark by Column, select Polymer from the Mark by Column list, and click OK.

However, a more complete analysis indicates that pH and Polymer do interact in their effect on Coal particles. The appropriate model fit is shown in “Analysis of Covariance, Unequal Slopes” on page 60.
Analysis of Covariance, Unequal Slopes

Here you are again interested in testing for the effect of A with X as a covariate. But you construct your model so as to admit the possibility that the effect of X on the response depends on the level of A.

Effects to be entered: A, X, A*X

1. In the Select Columns list, select one nominal or ordinal effect, A, and one continuous effect, X.
2. Select Macros > Full Factorial.

Or:

1. In the Select Columns list, select one nominal or ordinal effect, A, and one continuous effect, X.
2. Click Add.
3. In the Select Columns list, select A and X again and click Cross.

Example of Analysis of Covariance, Unequal Slopes

Open Cleansing.jmp. You are interested in whether any of the three polymers (Polymer) has an effect on coal particle removal (Coal particles). The tank pH is included as a covariate as it might affect a polymer’s ability to clean the tank. You allow for possibly different slopes when modeling the relationship between pH and Coal particles for the three Polymer types.

1. Select Analyze > Fit Model.
2. In the Select Columns list, select Coal particles and click Y.
3. In the Select Columns list, select pH and Polymer.
4. Select Macros > Full Factorial.

The Fit Model window appears as shown in Figure 2.15.

**Figure 2.15** Fit Model Window for Analysis of Covariance, Unequal Slopes

When you click **Run**, the Fit Least Squares report appears. The Effect Tests report indicates that the interaction between pH and Polymer is significant and should be included in the model.

The Regression Plot given in the report is shown in Figure 2.16. This plot shows the points and the model fit. The interaction allows the slopes of the lines that relate pH to Coal particles to depend on the Polymer. Note that, despite this interaction, over the range of interest, Polymer A consistently has the highest removal. If you want to color the points as shown in Figure 2.16, select **Rows > Color or Mark by Column**, select Polymer from the **Mark by Column** list, and click OK.
Two-Factor Nested Random Effects Model

Consider a model with two factors, A and B, but where B is nested within A. Although there are situations where a nested effect is treated as a fixed effect, in most situations a nested effect is treated as a random effect. For this reason, in the model described below, the nested effect is entered as a random effect.

Effects to be entered: A, B[A]&Random

1. In the Select Columns list, select two nominal or ordinal effects, A and B.
2. Click Add.
3. To nest B within A: In the Construct Model Effects list, select B. In the Select Columns list, select A. The two effects should be highlighted.
4. Click Nest.

Example of Two-Factor Nested Random Effects Model

Open the 2 Factors Nested.jmp sample data table located in the Variability Data subfolder. As part of a measurement systems analysis study, 24 randomly chosen parts are measured. These parts are evenly divided among the six operators who typically measure these parts. Each operator make three independent measurements of each of the four assigned parts.

Since the parts measured by one operator are measured only by that specific operator, Part is nested within Operator. Since the parts are a random sample of production, Part is considered a random effect. Since these specific six operators are of interest, Operator is treated as a fixed effect. The appropriate model is specified as follows.

1. Select Analyze > Fit Model.
2. In the Select Columns list, select Y and click Y.
3. In the Select Columns list, select Operator and Part.
4. Click Add.
5. To nest Part within Operator: In the Construct Model Effects list, select Part. In the Select Columns list, select Operator. The two effects should be highlighted.
6. Click Nest.

The Fit Model window appears as shown in Figure 2.17.

Figure 2.17 Fit Model Window for Two-Factor Nested Random Effects Model

8. Click Run to obtain the Fit Least Squares report.

Figure 2.18 shows two plots. The first is a Variability Chart showing the three measurements by each Operator on each of the four parts. Horizontal line segments show the mean measurement for each Operator.

To construct the Variability Chart in Figure 2.18, in the 2 Factors Nested.jmp sample data table, run the data table script Variability Chart - Nested. From the report’s red triangle menu, deselect Show Range Bars and select Show Group Means.

The second plot is the Fit Least Squares report Prediction Profiler plot for Operator. This plot shows the predicted response for each operator. The vertical dashed red line set at Jane indicates that Jane's predicted response is 0.997. You can see the correspondence between the model predictions given in the Prediction Profiler plot and the raw data in the Variability Chart.
Introduction to Fit Model
Examples of Model Specifications and Their Model Fits

Chapter 2
Fitting Linear Models

To obtain the Prediction Profiler plot, from the Fit Least Squares report red triangle menu, select Factor Profiling > Profiler.

These plots show how the predicted measurements for each Operator are modeled. However, keep in mind that you are not only interested in whether the operators differ in how they measure parts. You are also interested in the variability of the part measurements themselves, which requires estimation of the variance component associated with Part.

Figure 2.18  Model Fit for Two-Factor Nested Random Effects Model

Three-Factor Fully Nested Random Effects Model

Consider a model with three factors, A, B, and C, but where B is nested within A and C is nested within both A and B. Also consider B and C to be random effects.

Effects to be entered: A, B[A]&Random, C[A,B]&Random

1. In the Select Columns list, select three nominal or ordinal effects, A, B, and C.
2. Click Add.
3. To nest B within A: In the Construct Model Effects list, select B. In the Select Columns list, select A. The two effects should be highlighted.
4. Click Nest.
5. To nest C within A and B: In the Construct Model Effects list, select C. In the Select Columns list, select A and B. The three effects should be highlighted.

6. Click Nest.

7. With both B[A] and C[A,B] highlighted in the Construct Model Effects list, select Attributes > Random Effect.

Simple Split Plot or Repeated Measures Model

Here A is the whole plot variable, B[A] is the whole plot ID, and C is the split plot, or repeated measures, variable.

Effects to be entered: A, B[A]&Random, C, C*A

1. In the Select Columns list, select two nominal or ordinal effects, A and B.
2. Click Add.
3. To nest B within A: In the Construct Model Effects list, select B. In the Select Columns list, select A. The two effects should be highlighted.
4. Click Nest.
5. In the Construct Model Effects list, select B[A].
7. In the Select Columns list, select a third nominal or ordinal effect, C.
8. Click Add.
9. In the Construct Model Effects list, select C. In the Select Columns list, click A. Both effects should be highlighted.
10. Click Cross.

Example of a Simple Repeated Measures Model

Open the Animals.jmp sample data table. The column Miles gives the distance traveled by each of six animals in each of the four seasons. Note that there are two species and that subject, the animal identifier, is nested within species. Since these six animals are representatives of larger species populations, you decide to treat subject as a random effect. You want to model the response, miles, as a function of species and season, accounting for the fact that there are repeated measures for each animal.

1. Select Analyze > Fit Model.
2. In the Select Columns list, select miles and click Y.
3. In the Select Columns list, select species and subject.
4. Click Add.
5. To nest subject within species: In the Construct Model Effects list, select subject. In the Select Columns list, select species. The two effects should be highlighted.

6. Click Nest.

7. In the Construct Model Effects list, select subject[species].

8. Select Attributes > Random Effect.

9. In the Select Columns list, select season.

10. Click Add.

11. In the Construct Model Effects list, select season. In the Select Columns list, click species. Both effects should be highlighted.

12. Click Cross.

The Fit Model window appears as shown in Figure 2.19.

Figure 2.19  Fit Model Window for Simple Repeated Measures Model

---

**Two-Factor Response Surface Model**

Effects to be entered: X&RS, Z&RS, X*X, X*Z, Z*Z

1. In the Select Columns list, select two continuous effects, X and Z.

2. Select Macros > Response Surface.
Example of Two-Factor Response Surface Model

Open the Odor Control Original.jmp sample data table. You want to fit a response surface to model the response, odor, as a function of temp and gl ratio. (Although you could include ht, as shown in the data table script Response Surface, for this illustration do not.)

1. Select Analyze > Fit Model.
2. In the Select Columns list, select odor and click Y.
3. In the Select Columns list, select temp and gl ratio.
   
   The Fit Model window appears as shown in Figure 2.20.

Figure 2.20 Fit Model Window for Two-Factor Response Surface Model

5. Click Run.

Figure 2.21 shows a Surface Profiler plot of the data and a quadratic response surface fit to the data for the Odor Control Original.jmp sample data table. To obtain this plot, from the reporter's red triangle menu, select Factor Profiling > Surface Profiler. To show the points, click the disclosure icon to open the Appearance panel and click Actual. If you want to make the points appear larger, right click in the plot, select Settings and adjust the Marker Size.
Figure 2.21 Model Fit for a Degree-Two Polynomial in Two Variables

Knotted Spline Effect

Effects to be entered: X&Knotted

1. In the Select Columns list, select a continuous effect, X.
2. Click Add.
3. Select X in the Construct Model Effects list.
4. Select Attributes > Knotted Spline Effect.
5. In the menu that appears, specify the number of knots or accept the default number.
6. Click OK.

Figure 2.22 shows the Regression Plot for a model fit to the data in the XYZ Stock Averages (plots).jmp sample data table. Here Date is assigned the Knotted Spline Effect and five knots are specified. DJI Close is the response.
Figure 2.22 Model Fit for a Knotted Spline with Five Knots

Statistical Details

Frequencies

The impact of frequencies, including those with non-integer values, on an analysis is explained by their effect on the loss function. Suppose that you want to estimate the parameter $\theta$ using response values $y_i$ and predictors $x_{i1}, x_{i2}, \ldots, x_{in}$. Suppose that the loss function, assuming no frequency variable, is given by:

$$L(\theta | y) = \sum_{i=1}^{n} L(\theta | y_i, x_{i1}, x_{i2}, \ldots, x_{in})$$

If frequencies $f_i$ are defined, then the loss function is:

$$L(\theta | y, f) = \sum_{i=1}^{n} f_i L(\theta | y_i, x_{i1}, x_{i2}, \ldots, x_{in})$$

Calculations for all inference-base quantities, such as parameter estimates, standard errors, hypothesis tests, and confidence intervals, are based on this form of the loss function.
Standard Least Squares Report and Options
Analyze Common Classes of Models

About Standard Least Squares

The Standard Least Squares personality within the Fit Model platform fits a wide spectrum of standard models. These models include regression, analysis of variance, analysis of covariance, and mixed models, as well as the models typically used to analyze designed experiments. Use the Standard Least Squares personality to construct linear models for continuous-response data using least squares or, in the case of random effects, restricted maximum likelihood (REML).

Analytic results are supported by compelling dynamic visualization tools such as profilers, contour plots, and surface plots (see the book Profilers). These visual displays stimulate, complement, and support your understanding of the model. They enable to optimize several responses simultaneously and to explore the effect of noise.

Figure 3.1 Examples of Standard Least Squares Plots
## Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Example Using Standard Least Squares</td>
<td>73</td>
</tr>
<tr>
<td>Launch the Standard Least Squares Personality</td>
<td>76</td>
</tr>
<tr>
<td>Fit Least Squares Report</td>
<td>80</td>
</tr>
<tr>
<td>Response Options</td>
<td>84</td>
</tr>
<tr>
<td>Regression Reports</td>
<td>85</td>
</tr>
<tr>
<td>Estimates</td>
<td>108</td>
</tr>
<tr>
<td>Sorted Estimates</td>
<td>110</td>
</tr>
<tr>
<td>Expanded Estimates</td>
<td>114</td>
</tr>
<tr>
<td>Indicator Parameterization Estimates</td>
<td>116</td>
</tr>
<tr>
<td>Sequential Tests</td>
<td>117</td>
</tr>
<tr>
<td>Custom Test</td>
<td>118</td>
</tr>
<tr>
<td>Multiple Comparisons</td>
<td>120</td>
</tr>
<tr>
<td>Joint Factor Tests</td>
<td>133</td>
</tr>
<tr>
<td>Inverse Prediction</td>
<td>134</td>
</tr>
<tr>
<td>Cox Mixtures</td>
<td>138</td>
</tr>
<tr>
<td>Parameter Power</td>
<td>140</td>
</tr>
<tr>
<td>Correlation of Estimates</td>
<td>142</td>
</tr>
<tr>
<td>Effect Screening</td>
<td>144</td>
</tr>
<tr>
<td>Factor Profiling</td>
<td>155</td>
</tr>
<tr>
<td>Row Diagnostics</td>
<td>163</td>
</tr>
<tr>
<td>Save Columns</td>
<td>168</td>
</tr>
<tr>
<td>Mixed and Random Effect Model Reports and Options</td>
<td>171</td>
</tr>
<tr>
<td>Mixed Models and Random Effect Models</td>
<td>172</td>
</tr>
<tr>
<td>Restricted Maximum Likelihood (REML) Method</td>
<td>176</td>
</tr>
<tr>
<td>EMS (Traditional) Model Fit Reports</td>
<td>181</td>
</tr>
<tr>
<td>Models with Linear Dependencies among Model Terms</td>
<td>183</td>
</tr>
<tr>
<td>Statistical Details</td>
<td>188</td>
</tr>
</tbody>
</table>
Chapter 3

Fitting Linear Models

Example Using Standard Least Squares

In a study of the effect of drugs in treating a disease, thirty patients are randomly divided into three groups of ten. Two of these groups are administered drugs (Drug a and Drug d), while the third group is administered a placebo (Drug f). A pretreatment measure, x, is taken on each patient, as well as a posttreatment measure, y. The pretreatment score, x, is included as a covariate, to account for differences in the stage of the disease among patients. (This example is taken from Snedecor and Cochran, 1967, p. 422.)

You are interested in determining if there is a difference in the three Drug groups. You construct a model with response y and model effects Drug, x, and the interaction of Drug and x. The interaction might account for a situation where drugs have differential effects, based on the stage of the disease. (For background on the Fit Model window and the various personalities, see the “Introduction to Fit Model” chapter on page 27.)

1. Open the Drug.jmp sample data table.
2. Select Analyze > Fit Model.
3. Select y and click Y.
   When you add this column as Y, the fitting Personality becomes Standard Least Squares. An Emphasis option is added with a selection of Effect Leverage, which you can change if desired.
4. Select Drug and x. With these two effects highlighted in the Select Columns list, click Macros and select Full Factorial. The macro adds the two effects and their two-way interaction to the Construct Model Effects list (Figure 3.2).
5. Click Run.

The Fit Least Squares report is shown in Figure 3.3. Note that some of the constituent reports are closed because of space considerations. The Actual by Predicted, Residual by Predicted, and Leverage plots show no discrepancies in terms of model fit and underlying assumptions.
Since there are no apparent problems with the model fit, you can now interpret the statistical tests. Figure 3.4 shows the relevant reports. The overall model is significant, as shown in the Analysis of Variance report.

Although the Regression Plot suggests that Drug and the pretreatment measure, \( x \), interact, the Prob > F value in the Effect Tests report does not support that conclusion. The Effect Tests report also shows that \( x \) is significant in explaining \( y \), but Drug is not significant. The study does not detect a difference among the three groups. However, you cannot conclude that Drug has no effect. The drugs might have different effects, but the study size was not large enough to detect that difference.
Launch the Standard Least Squares Personality

Standard least squares is one of several analytic techniques that you can select in the Fit Model launch window.

This section describes how you select standard least squares as your fitting methodology in the Fit Model launch window. Options that are specific to this selection are also covered.

Fit Model Launch Window

You can specify models with both fixed and random effects in the Fit Model launch window. The options differ based on the nature of the model that you specify.

Fixed Effects Only

To fit models using the standard least squares personality, select Analyze > Fit Model and then select Standard Least Squares from the Personality list. When you enter one or more
continuous variables in the Y list, the Personality defaults to Standard Least Squares. Note, however, that other selections are available for continuous Y variables. When you specify only fixed effects for a Standard Least Squares fit, the Fit Model launch window appears as shown in Figure 3.5. This example illustrates the launch window using the Big Class.jmp sample data table.

**Figure 3.5 Fit Model Launch Window for a Fixed Effects Model**

When the Standard Least Squares personality is selected in the Personality list, an Emphasis option also appears. Emphasis options control the reports that are provided in the initial report window. Based on the model effects that are included, JMP infers which reports you are likely to want. However, any report not shown as part of the initial report can be shown by selecting the appropriate option from the default report’s red triangle menu.

For details about reports that are available for each Emphasis option, see “Emphasis Options for Standard Least Squares” on page 79.

**Random Effects**

If the specified model contains one or more random effects, then additional options become available in the Fit Model launch window. Consider the Machine.jmp sample data table. Each of six randomly chosen workers performs work at each of three machines and their output is rated. You are interested in estimating the variation in ratings across the workforce, rather than in determining whether these six specific workers’ ratings differ. You need to treat person and machine*person as random effects when you specify the model.

The Fit Model launch window for this model is shown in Figure 3.6. When the Random Effect attribute is applied to person, a Method option and two options relating to variance components appear in the Fit Model Launch window.
Standard Least Squares Options in the Fit Model Launch Window

Table 3.1 describes options appearing in the Fit Model launch window that are specific to the Standard Least Squares personality.

Table 3.1 Fit Model Launch Window Options for Standard Least Squares Personality

<table>
<thead>
<tr>
<th>Emphasis</th>
<th>Controls the types of reports and plots that appear in the initial report window. See Table 3.2.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Method</td>
<td>Only appears when random effects are specified. Estimates the model using one of these methods:</td>
</tr>
<tr>
<td></td>
<td>• REML. See “REML Variance Component Estimates” on page 178.</td>
</tr>
<tr>
<td></td>
<td>• EMS. Expected Mean Squares, also called the Method of Moments. See “EMS (Traditional) Model Fit Reports” on page 181.</td>
</tr>
<tr>
<td>Unbounded Variance Components</td>
<td>Selecting Unbounded Variance Components allows variance component estimates to be negative. This option is selected by default. This option should remain selected if you are interested in fixed effects, since bounding the variance estimates at zero leads to bias in the tests for fixed effects. See “Negative Variances” on page 175.</td>
</tr>
</tbody>
</table>

Note: Only appears when REML is selected as the Method.
Fitting Linear Models Example Using Standard Least Squares

Emphasis Options for Standard Least Squares

The three options in the Emphasis list control the types of plots and reports that you see as part of the initial report for the Standard Least Squares personality (Table 3.2). JMP chooses a default emphasis based on the number of rows in the data table and the number of effects entered in the Construct Model Effects list. You can change this choice of emphasis based on your needs. For details about how JMP chooses the emphasis, see “Emphasis Rules” on page 188.

After the initial report opens, you can add other reports and plots from the platform’s red triangle menu.

Table 3.2 Emphasis Options

<table>
<thead>
<tr>
<th>Emphasis Options</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Effect Leverage</td>
<td>Shows leverage and residual plots, as well as reports with details about the model fit. This option is useful when your main focus is model fitting.</td>
</tr>
<tr>
<td>Effect Screening</td>
<td>Displays a sorted or scaled parameter estimates report along with a graph (when appropriate), the Prediction Profiler, and reports with details about the model fit. This option is useful when you have many effects and your initial focus is to discover which effects are active, as in screening designs.</td>
</tr>
<tr>
<td>Minimal Report</td>
<td>Displays only the regression plot and reports with details about the model fit. This option is the least detailed and most concise. You can request reports of specific interest to you from the red triangle menus.</td>
</tr>
</tbody>
</table>
Missing Values

By default, rows that have missing values for Y or any model effects are excluded from the analysis.

Note: JMP Pro provides an Informative Missing option in the Fit Model window under Model Specification. Informative Missing enables you to fit models using rows where model effects are missing. See “Informative Missing” on page 48 in the “Introduction to Fit Model” chapter for details.

When your model contains a random effect, Y values are fit separately by default. The individual reports appear in the Fit Group report.

Suppose that your model contains only fixed effects. You enter more than one Y response, and some of these Y variables have missing values. JMP prompts you to select one of the following options:

- Fit Separately fits each Y using all rows that are nonmissing for that particular Y.
- Fit Together fits each Y uses only those rows that are nonmissing for all of the Y variables.

When you select Fit Separately, a Fit Group report organizes the individual reports for the Y variables. You can select profilers from the Fit Group red triangle menu to view all the Y variables in the same profiler. Alternatively, you can select a profiler from an individual Y variable report to view only that variable in the profiler.

When you select Fit Together, a Fit Least Squares report organizes the individual reports for each of the Y variables. However, all Y variables appear in the prediction, contour, and surface profilers.

Fit Least Squares Report

When you fit a model using the Standard Least Squares personality, you obtain a Fit Least Squares report. The content of the report is driven by the nature of the data and your selections in the Fit Model launch window.

Tip: To always see reports that do not appear by default, select them using File > Preferences > Platforms > Fit Least Squares.

Single versus Multiple Responses

When you fit a single response variable Y, the Fit Least Squares window organizes detailed reports in a report entitled “Response Y”. When you fit several responses, reports for individual responses are usually organized in a report entitled “Least Squares Fit”. However,
if there is missing response data, and you select the option to Fit Separately, reports for individual responses are organized in a report titled “Fit Group”.

**Report Structure Related to Emphasis**

When you select the Effect Leverage Emphasis in the Fit Model launch window, the report for a given response is arranged in columns. The left column consists of the Whole Model report, which contains additional reports that pertain to the model. Reports for each effect in the model are shown in the columns to the right of the Whole Model report.

When you select either the Effect Screening or Minimal Report Emphasis in the Fit Model launch window, all reports for each response are arranged in the left column.

**Special Reports**

This section describes the reports that are available based on the data structure or choices that you made regarding effect attributes.

**Singularity Details**

When there are linear dependencies among model effects, the Singularity Details report appears as the first report under the Response report title. It displays the linear functions that the model terms satisfy. These functions define the aliasing relationships among model terms. Figure 3.7 shows an example for the Singularity.jmp sample data table.

*Figure 3.7  Singularity Details Report*

When there are linear dependencies among effects, estimates of some model terms are not unique. See “Models with Linear Dependencies among Model Terms” on page 183.

**Response Surface Report**

When an effect in a model has the response surface (&RS) or mixture response surface (&RS&Mixture) attribute, a Response Surface report is provided. See Figure 3.8 for an example of a Response Surface report for the Tiretread.jmp sample data table.
Figure 3.8  Response Surface Report

Matrix of Second-Order Terms
The Coef table shows parameter estimates for the second-order model terms. The table provides you with a concise summary of the estimated model parameters.

Solution Report
The Solution report gives a critical value (maximum, minimum, or saddle point), if one exists, along with the predicted value at that point. It also alerts you if the solution falls outside the range of the data.

Canonical Curvature Report
The eigenvalues and eigenvectors of the matrix of second-order parameter estimates determine the type of curvature. The eigenvectors show the principal directions of the surface, including the directions of greatest and smallest curvature.

The eigenvalues are provided in the first row of the Canonical Curvature table.

- If the eigenvalues are negative, the response surface curves downward from a maximum.
- If the eigenvalues are positive, the surface shape curves upward from a minimum.
- If there are both positive and negative eigenvalues, the surface is saddle shaped, curving up in one direction and down in another direction. See Figure 3.9 for an example using the Tiretread.jmp sample data table.
Chapter 3
Fitting Linear Models

Chapter 3
Fitting Linear Models

Standard Least Squares Report and Options
Fit Least Squares Report

83

The eigenvectors listed below the eigenvalues show the orientation of the principal axes. The larger the absolute value of an eigenvalue, the greater the curvature of the response surface in its associated direction. Sometimes a zero eigenvalue occurs. This eigenvalue means that, along the direction described by the corresponding eigenvector, the fitted surface is flat.

Note: The response surface report is not shown for response surface models consisting of more than 20 factors. No error message or alert is given. For more information about response surface designs, see the Design of Experiments Guide book.

Mixed and Random Effect Model Reports

When you specify a random effect in the Fit Model launch window, the Method list appears. This list provides two fitting methods: REML (Recommended) and EMS (Traditional). Additional reports as well as Save Columns and Profiler options are shown, based on the model and the method that you select.

For details about the REML method reports, see “Restricted Maximum Likelihood (REML) Method” on page 176. For details about the EMS method reports, see “EMS (Traditional) Model Fit Reports” on page 181.

Least Squares Fit Options

You might have more than one Y and no missing response values, or more than one Y with missing values. When you select Fit Together, the responses are grouped in a report called Least Squares Fit. The red triangle menu includes the following options:

Profilers  Shows all responses in a single profiler. You can view the effects of model terms on all responses simultaneously and perform multiple optimization. See “Factor Profiling” on page 155.
Model Dialog  Shows the completed launch window for the current analysis.
Script  Contains options that are available to all platforms. See the Using JMP book.

Fit Group Options

When you have more than one Y and you select Fit Separately, the responses are grouped in a report called Fit Group. The red triangle menu includes the following options:

Profiler  Shows all responses in a single profiler. You can view the effects of model terms on all responses simultaneously and perform multiple optimization. See “Profiler” on page 156.
Contour Profiler  Shows all responses in a single contour profiler. You can explore the effects of model terms on all responses simultaneously.
Surface Profiler  Shows separate surface profiler reports for each response.
Arrange in Rows  Rearranges the reports for the platform analyses in a specified number of rows. This would be used mostly to arrange reports so that more reports fit in a window or on the page of output.
Order by Goodness of Fit  Sorts the reports by significance of fit (RSquare). This option is only available for platforms that surface the RSquare to the platform level. For example, if you have hundreds of Oneway analyses generated from one launch window, they will appear in a FitGroup and you can sort them so that the strongest relationships appear first.
Script  Contains options that are available to all platforms. See the Using JMP book.

For details about the JMP profilers, see Profilers.

Response Options

Red triangle menu options for the response give you the ability to customize reports according to your needs.

Table 3.3  Description of Response Options

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression Reports</td>
<td>Shows basic reports and report options. See “Regression Reports” on page 85.</td>
</tr>
<tr>
<td>Estimates</td>
<td>Provides options for further analyses relating to parameter estimates. See “Estimates” on page 108.</td>
</tr>
<tr>
<td>Effect Screening</td>
<td>Provides reports and plots for identifying significant effects. See “Effect Screening” on page 144.</td>
</tr>
</tbody>
</table>
Table 3.3 Description of Response Options (Continued)

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factor Profiling</td>
<td>Provides profilers, interaction, and cube plots to examine how the response is related to the model terms. Also provides a plot and report for fitting a Box-Cox transformation. See “Factor Profiling” on page 155.</td>
</tr>
<tr>
<td>Row Diagnostics</td>
<td>Provides plots and reports for examining residuals. Also reports the PRESS statistic and provides a Durbin-Watson test. See “Row Diagnostics” on page 163.</td>
</tr>
<tr>
<td>Save Columns</td>
<td>Saves model results as columns in the data table, except for Save Coding Table, which saves results in a separate data table. See “Save Columns” on page 168.</td>
</tr>
<tr>
<td>Model Dialog</td>
<td>Shows the completed Fit Model launch window for the current analysis.</td>
</tr>
<tr>
<td>Script</td>
<td>Contains options that are available to all platforms. See the Using JMP book.</td>
</tr>
</tbody>
</table>

Regression Reports

The Regression Reports menu provides summary information about model fit, effect significance, and model parameters.

Table 3.4 Description of Regression Reports and Options

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summary of Fit</td>
<td>Shows a summary of model fit. See “Summary of Fit” on page 86.</td>
</tr>
<tr>
<td>Analysis of Variance</td>
<td>Shows calculations for comparing the fitted model to a simple mean model. See “Analysis of Variance” on page 87.</td>
</tr>
<tr>
<td>Parameter Estimates</td>
<td>Shows a report containing the parameter estimates and t tests for the hypothesis that each parameter is zero. See “Parameter Estimates” on page 89.</td>
</tr>
<tr>
<td>Effect Tests</td>
<td>Shows tests for the fixed effects in the model. See “Effect Tests” on page 90.</td>
</tr>
</tbody>
</table>
Table 3.4 Description of Regression Reports and Options (Continued)

<table>
<thead>
<tr>
<th>Effect Details</th>
<th>Shows a report containing details, plots, and tests for individual effects. See “Effect Details” on page 92.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Note:</strong></td>
<td>When the Effect Leverage Emphasis option is selected, each effect has its own report at the top of the Fit Least Squares report window. This report includes effect details options as well as a leverage plot. See “Leverage Plots” on page 164.</td>
</tr>
<tr>
<td>Lack of Fit</td>
<td>Shows a test assessing if the model has the appropriate effects, when that test can be conducted. See “Lack of Fit” on page 106.</td>
</tr>
<tr>
<td>Show All Confidence Intervals</td>
<td>Shows confidence intervals for:</td>
</tr>
<tr>
<td></td>
<td>• Parameter estimates in the Parameter Estimates report</td>
</tr>
<tr>
<td></td>
<td>• Least squares means in the Least Squares Means Table</td>
</tr>
<tr>
<td>AICc</td>
<td>Shows AICc and BIC values in the Summary of Fit report. See Table 5.4 on page 234.</td>
</tr>
</tbody>
</table>

Summary of Fit

The Summary of Fit report provides details such as RSquare calculations and the AICc and BIC values.

Table 3.5 Description of the Summary of Fit Report

| RSquare | Estimates the proportion of variation in the response that can be attributed to the model rather than to random error. Using quantities from the corresponding Analysis of Variance table, RSquare (also called the coefficient of multiple determination) is calculated as:
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>[ \frac{\text{Sum of Squares(Model)}}{\text{Sum of Squares(C. Total)}} ]</td>
</tr>
<tr>
<td>An RSquare closer to 1 indicates a better fit to the data than does an RSquare closer to 0. An RSquare near 0 indicates that the model is not a much better predictor of the response than is the response mean.</td>
<td></td>
</tr>
</tbody>
</table>
Table 3.5 Description of the Summary of Fit Report (Continued)

| **Rsquare Adj** | Adjusts RSquare for the number of parameters in the model. Rsquare Adj facilitates comparisons among models with different numbers of parameters. The computation uses the degrees of freedom. Using quantities from the corresponding Analysis of Variance table, Rsquare Adj is calculated as:

\[
1 - \frac{\text{Mean Square(Error)}}{\text{Sum of Squares (C. Total)/DF(C. Total)}}
\]

| **Root Mean Square Error** | Estimates the standard deviation of the random error. This quantity is the square root of the Mean Square for Error in the Analysis of Variance report.

**Note:** Root Mean Square Error is commonly known as RMSE.

| **Mean of Response** | Shows the overall mean of the response values.

| **Observations (or Sum Wgts)** | Gives the number of observations used in the model.

- This value is the same as the number of rows in the data table under the following conditions: there are no missing values, no excluded rows, and no column assigned to the role of Weight or Freq.
- This value is the sum of the positive values in the Weight column if there is a column assigned to the role of Weight.
- This value is the sum of the positive values in the Freq column if there is a column assigned to the role of Freq.

| **AICc** | Shows or hides the corrected Akaike Information Criterion value (AICc) and the Bayesian Information Criterion value (BIC). Both of these are measures of model fit that are helpful when comparing models. Smaller values indicate a better fit. See Table 5.4 on page 234 for details.

**Note:** AICc and BIC appear only if you have selected the AICc option from the Regression Reports menu or if you have set AICc as a Fit Least Squares preference.

**Analysis of Variance**

The Analysis of Variance report provides the calculations for comparing the fitted model to a model where all predicted values equal the response mean.
Note: If either a Frequency or a Weight variable is entered in the Fit Model launch window, the entries in the Analysis of Variance report are adjusted in keeping with the descriptions in “Frequency” on page 38 and “Weight” on page 39.

### Table 3.6 Description of the Analysis of Variance Report

<table>
<thead>
<tr>
<th>Source</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>DF</td>
<td>Gives the associated <em>degrees of freedom</em> (DF) for each source of variation.</td>
</tr>
<tr>
<td></td>
<td>• The C. Total DF is always one less than the number of observations.</td>
</tr>
<tr>
<td></td>
<td>• The C. Total DF is partitioned into degrees of freedom for the Model and</td>
</tr>
<tr>
<td></td>
<td>Error:</td>
</tr>
<tr>
<td></td>
<td>‒ The Model degrees of freedom is the number of parameters (other than the</td>
</tr>
<tr>
<td></td>
<td>intercept) used to fit the model.</td>
</tr>
<tr>
<td></td>
<td>‒ The Error DF is the difference between the C. Total DF and the Model</td>
</tr>
<tr>
<td></td>
<td>DF.</td>
</tr>
<tr>
<td>Sum of Squares</td>
<td>Gives the associated Sum of Squares (SS) for each source of variation.</td>
</tr>
<tr>
<td></td>
<td>• The total (C. Total) SS is the sum of the squared differences between the</td>
</tr>
<tr>
<td></td>
<td>response values and the sample mean. It represents the total variation</td>
</tr>
<tr>
<td></td>
<td>in the response values.</td>
</tr>
<tr>
<td></td>
<td>• The Error SS is the sum of the squared differences between the fitted</td>
</tr>
<tr>
<td></td>
<td>values and the actual values. It represents the variability that remains</td>
</tr>
<tr>
<td></td>
<td>unexplained by the fitted model.</td>
</tr>
<tr>
<td></td>
<td>• The Model SS is the difference between C. Total SS and Error SS. It</td>
</tr>
<tr>
<td></td>
<td>represents the variability explained by the model.</td>
</tr>
<tr>
<td>Mean Square</td>
<td>Lists the mean squares. Each Mean Square is the sum of squares divided by</td>
</tr>
<tr>
<td></td>
<td>its corresponding DF.</td>
</tr>
<tr>
<td></td>
<td>Note: The square root of the Mean Square for Error is the same as RMSE in</td>
</tr>
<tr>
<td></td>
<td>the Summary of Fit report.</td>
</tr>
<tr>
<td>F Ratio</td>
<td>Shows the model mean square divided by the error mean square. The F</td>
</tr>
<tr>
<td></td>
<td>Ratio is the test statistic for a test of whether the model differs</td>
</tr>
<tr>
<td></td>
<td>significantly from a model where all predicted values are the response</td>
</tr>
<tr>
<td></td>
<td>mean.</td>
</tr>
</tbody>
</table>
Parameter Estimates

The Parameter Estimates report shows the estimates of the model parameters and, for each parameter, gives a $t$ test for the hypothesis that it equals zero.

**Note:** Estimates are obtained and tested, if possible, even when there are linear dependencies among the model terms. Such estimates are labeled Biased or Zeroed. For details, see “Mixed and Random Effect Model Reports and Options” on page 171.

<table>
<thead>
<tr>
<th>Table 3.6 Description of the Analysis of Variance Report (Continued)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Prob &gt; F</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 3.7 Description of the Parameter Estimates Report</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Term</strong></td>
</tr>
<tr>
<td><strong>Estimate</strong></td>
</tr>
<tr>
<td><strong>Std Error</strong></td>
</tr>
<tr>
<td><strong>$t$ Ratio</strong></td>
</tr>
<tr>
<td>**Prob&gt;</td>
</tr>
</tbody>
</table>
Table 3.7 Description of the Parameter Estimates Report (Continued)

<table>
<thead>
<tr>
<th>Description</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lower 95%</strong></td>
<td>Shows the lower 95% confidence limit for the parameter estimate.</td>
</tr>
<tr>
<td><strong>Upper 95%</strong></td>
<td>Shows the upper 95% confidence limit for the parameter estimate.</td>
</tr>
<tr>
<td><strong>Std Beta</strong></td>
<td>Shows parameter estimates for a regression model where all of the</td>
</tr>
<tr>
<td></td>
<td>terms have been standardized to a mean of 0 and a variance of 1.</td>
</tr>
<tr>
<td><strong>VIF</strong></td>
<td>Shows the variance inflation factor for each term in the model. High</td>
</tr>
<tr>
<td></td>
<td>VIFs indicate a collinearity issue among the terms in the model.</td>
</tr>
<tr>
<td></td>
<td>The VIF for the $i^{th}$ term, $x_i$, is defined as follows:</td>
</tr>
<tr>
<td></td>
<td>$VIF_i = \frac{1}{1 - R_i^2}$</td>
</tr>
<tr>
<td></td>
<td>where $R_i^2$ is the $R$-square, or coefficient of multiple</td>
</tr>
<tr>
<td></td>
<td>determination, for the regression of $x_i$ as a function of the</td>
</tr>
<tr>
<td></td>
<td>other explanatory variables.</td>
</tr>
<tr>
<td><strong>Design Std Error</strong></td>
<td>Shows the square roots of the relative variances of the parameter</td>
</tr>
<tr>
<td></td>
<td>estimates (Goos and Jones, 2011, p. 25):</td>
</tr>
<tr>
<td></td>
<td>$\sqrt{\text{diag}(X'X)^{-1}}$</td>
</tr>
<tr>
<td></td>
<td>These are the standard errors divided by RMSE.</td>
</tr>
</tbody>
</table>

**Effect Tests**

The Effect Tests report only appears when there are fixed effects in the model. The effect test for a given effect tests the null hypothesis that all parameters associated with that effect are zero. An effect might have only one parameter as for a single continuous explanatory variable.
In this case, the test is equivalent to the $t$ test for that term in the Parameter Estimates report. A nominal or ordinal effect can have several associated parameters, based on its number of levels. The effect test for such an effect tests whether all of the associated parameters are zero.

Note the following:

- Effect tests are conducted, when possible, for effects whose terms are involved in linear dependencies. For details, see “Models with Linear Dependencies among Model Terms” on page 183.

- Parameterization and handling of singularities differ from the SAS GLM procedure. For details about parameterization and handling of singularities, see the “The Factor Models” on page 432 in the “Statistical Details” appendix.

**Table 3.8** Description of the Effect Tests Report

<table>
<thead>
<tr>
<th>Source</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source</td>
<td>Lists the effects in the model.</td>
</tr>
<tr>
<td>Nparm</td>
<td>Shows the number of parameters associated with the effect. A continuous effect has one parameter. The number of parameters for a nominal or ordinal effect is one less than its number of levels. The number of parameters for a crossed effect is the product of the number of parameters for each individual effect.</td>
</tr>
<tr>
<td>DF</td>
<td>Shows the degrees of freedom for the effect test. Ordinarily, Nparm and DF are the same. They can differ if there are linear dependencies among the predictors. In such cases, DF might be less than Nparm, indicating that at least one parameter associated with the effect is not testable. Whenever DF is less than Nparm, the note LostDFs appears to the right of the line in the report. If there are degrees of freedom for error, the test is conducted. For details, see “Effect Tests Report” on page 185.</td>
</tr>
<tr>
<td>Sum of Squares</td>
<td>Gives the sum of squares for the hypothesis that the effect is zero.</td>
</tr>
<tr>
<td>F Ratio</td>
<td>Gives the F statistic for testing that the effect is zero. The $F$ Ratio is the ratio of the mean square for the effect divided by the mean square for error. The mean square for the effect is the sum of squares for the effect divided by its degrees of freedom.</td>
</tr>
<tr>
<td>Prob &gt; F</td>
<td>Gives the $p$-value for the effect test.</td>
</tr>
<tr>
<td>Mean Square</td>
<td>Shows the mean square for the effect, which is the sum of squares for the effect divided by its DF. <strong>Note:</strong> Only appears if you right-click in the report and select Columns &gt; Mean Square.</td>
</tr>
</tbody>
</table>
Effect Details

The Effect Details report provides details, plots, and tests for individual effects. It consists of separate reports based on the emphasis that you select in the Fit Model launch window.

- **Effect Leverage emphasis:** Each effect has its own report at the top of the Fit Least Squares report window to the right of the Whole Model report. In this case, the report includes a Leverage Plot for the effect.

- **Effect Screening or Minimal Report emphases:** The Effect Details report is provided but is initially closed. Click the disclosure icon to show the report.

The initial content of the report is the Table of Least Squares Means. Depending on the nature of the effect, this table might not be appropriate, and the default report might initially show no content. However, certain red triangle options are available.

Table of Effect Options

The red triangle options next to an effect name are described in Table 3.9. For certain modeling types, some of these options might not be appropriate and are therefore not available.

| Table 3.9  Description of Effect Options |
|-----------|------------------------------------------|
| **LSMeans Table** | Shows the statistics that are compared when effects are tested. See “LSMeans Table” on page 93. This option is not enabled for continuous effects. |
| **LSMeans Plot** | Plots least squares means for nominal and ordinal effects and their interactions. See “LSMeans Plot” on page 95. |
| **LSMeans Contrast** | Shows the Contrast Specification window, which enables you to specify and test contrasts to compare levels for nominal and ordinal effects and their interactions. See “LSMeans Contrast” on page 97. |
| **LSMeans Student’s t** | Gives tests and confidence intervals for pairwise comparisons of least squares means using Student’s t tests. See “LSMeans Student’s t and LSMeans Tukey HSD” on page 99. **Note:** The significance level applies to individual comparisons and not to all comparisons collectively. The error rate for the collection of comparisons is greater than the error rate for individual tests. |
Table 3.9 Description of Effect Options (Continued)

   | **Note:** The significance level applies to the collection of pairwise comparisons. The significance level is exact if the sample sizes are equal and conservative if the sample sizes differ (Hayter, 1984). |
| LSMeans Dunnett | Gives tests and confidence intervals for pairwise comparisons against a control level that you specify. Also provides a plot of test results. See “LSMeans Dunnett” on page 102. |
| Test Slices | For each level of each column in the interaction, jointly tests pairwise comparisons among all the levels of the other classification columns in the interaction. See “Test Slices” on page 103.  
   | **Note:** Only available for interactions involving nominal and ordinal effects. |
| Power Analysis | Shows the Power Details report, which enables you to analyze the power for the effect test. For details, see “Power Analysis” on page 104. |

### LSMeans Table

Least squares means are values predicted by the model for the levels of a categorical effect where the other model factors are set to *neutral* values. The neutral value for a continuous effect is defined to be its sample mean. The neutral value for a nominal effect that is not involved in the effect of interest is the average of the coefficients for that effect. The neutral value for an uninvolved ordinal effect is defined to be the first level of the effect in the value ordering.

Least squares means are also called *adjusted means* or *population marginal means*. Least squares means can differ from simple means when there are other effects in the model. In fact, it is common for the least squares means to be closer together than the sample means. This situation occurs because of the nature of the neutral values where these predictions are made.

Because least squares means are predictions at specific values of the other model factors, you can compare them. When effects are tested, comparisons are made using the least squares means. For further details about least squares means, see “Least Squares Means across Nominal Factors” on page 437 in the “Statistical Details” appendix and “Ordinal Least Squares Means” on page 447.
For main effects, the Least Squares Means Table also includes the sample mean (Figure 3.10).

**Example of a Least Squares Means Table**

1. Open the Big Class.jmp sample data table.
2. Select **Analyze > Fit Model**.
3. Select **weight** and click **Y**.
4. Select **age**, **sex**, and **height** and click **Add**.
5. From the **Emphasis** list, select **Effect Screening**.
6. Click Run.
7. The Effect Details report appears near the bottom of the Fit Least Squares report and is initially closed. Click the disclosure icon next to the Effect Details report title to show the report.

The Effect Details report, shown in Figure 3.10, shows reports for each of the three effects. Least Squares Means tables are given for **age** and **sex**, but not for the continuous effect **height**. Notice how the least squares means differ from the sample means.

**Figure 3.10** Least Squares Mean Table

<table>
<thead>
<tr>
<th>Level</th>
<th>Leastsq Mean</th>
<th>Std Error</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>119.38671</td>
<td>25.89922</td>
<td>99.000</td>
</tr>
<tr>
<td>13</td>
<td>105.70132</td>
<td>5.896543</td>
<td>94.714</td>
</tr>
<tr>
<td>14</td>
<td>93.53645</td>
<td>3.946891</td>
<td>100.833</td>
</tr>
<tr>
<td>15</td>
<td>90.61866</td>
<td>5.172035</td>
<td>108.286</td>
</tr>
<tr>
<td>16</td>
<td>100.20769</td>
<td>7.788838</td>
<td>118.333</td>
</tr>
<tr>
<td>17</td>
<td>121.93606</td>
<td>0.0768181</td>
<td>140.567</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Level</th>
<th>Leastsq Mean</th>
<th>Std Error</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>121.43502</td>
<td>6.1844278</td>
<td>100.944</td>
</tr>
<tr>
<td>M</td>
<td>117.33750</td>
<td>5.7895626</td>
<td>108.318</td>
</tr>
</tbody>
</table>

**Table 3.10** Description of the Least Squares Means Table Options

<table>
<thead>
<tr>
<th>Level</th>
<th>Lists the categorical levels or combination of levels.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Least Sq Mean</td>
<td>Gives an estimate of the least squares mean for each level.</td>
</tr>
<tr>
<td>Estimability</td>
<td>Displays a warning if a least squares mean is not estimable.</td>
</tr>
<tr>
<td>Note: This column only appears when a message has to be displayed.</td>
<td></td>
</tr>
<tr>
<td>Std Error</td>
<td>Gives the standard error of the least squares mean for each level.</td>
</tr>
</tbody>
</table>
### LSMeans Plot

This option constructs least squares means (LS Means) plots for nominal and ordinal main effects and their interactions. The Popcorn.jmp sample data table illustrates an interaction between two categorical effects. Figure 3.11 shows the Least Squares Means tables and the corresponding LS Means plots for two categorical effects in the Popcorn.jmp sample data table.

To transpose the factors in an LS Means Plot for a two-factor interaction:

- Deselect the LSMeans Plot option.
- Hold the SHIFT key and select the LSMeans Plot option again.

To revert to the original plot, deselect the LS Means Plot option and reselect the option without holding the SHIFT key.

---

### Table 3.10 Description of the Least Squares Means Table Options (Continued)

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower 95%</td>
<td>Shows the lower 95% confidence limit for the least squares mean.</td>
</tr>
<tr>
<td><strong>Note:</strong></td>
<td>Only appears if you have the Regression Reports &gt; Show All Confidence Intervals option selected or if you right-click in the report and select Columns &gt; Lower 95%.</td>
</tr>
<tr>
<td>Upper 95%</td>
<td>Shows the upper 95% confidence limit for the least squares mean.</td>
</tr>
<tr>
<td><strong>Note:</strong></td>
<td>Only appears if you have the Regression Reports &gt; Show All Confidence Intervals option selected or if you right-click in the report and select Columns &gt; Upper 95%.</td>
</tr>
<tr>
<td>Mean</td>
<td>Gives the response sample mean for the given level. This mean differs from the least squares mean if the values for other effects in the model do not balance out across this effect.</td>
</tr>
</tbody>
</table>
Figure 3.11  Least Squares Means Tables and Plots for Two Effects

Example of an LS Means Plot

To create the report in Figure 3.11, follow these steps:

1. Open the Popcorn.jmp sample data table.
2. Select Analyze > Fit Model.
3. Select yield and click Y.
4. Select popcorn, oil amt, and batch and click Macros > Full Factorial. Note that the Emphasis changes to Effect Screening.
5. Click Run.
6. Click the Effect Details disclosure icon to show the details for the seven model effects.
7. Hold down the CTRL key. From the red triangle menu for any one of the effects, select LSMeans Plot.

   All LS Means Plot reports are now open.

8. To transpose the factors in the plot for popcorn*batch, deselect the LSMeans plot option. Then hold the SHIFT key while you select the LSMeans Plot option again.

Figure 3.12 shows the popcorn*batch interaction plot with the factors transposed. Compare it with the plot in Figure 3.11. These plots depict the same information but, depending on your interest, one might be more intuitive than the other.
A contrast is a linear combination of parameter values. In the Contrast Specification window, you can specify multiple contrasts and jointly test whether they are zero (Figure 3.13).

JMP builds contrasts in terms of the least squares means of the effect. Each column of the contrast is normalized to have sum zero and so that the sum of the absolute values equals two. If a contrast involves a covariate, you can specify the value of the covariate at which to test the contrast.

The Contrast Specification box shows the name of the effect and the names of the levels in the effect. The contrast values, which are initially set to zero, appear next to cells containing + and - signs. Click these buttons to compare levels.

Each time you click the + or - button, the contrast coefficients are normalized to make their sum zero and their absolute sum equal to two, if possible. To compare additional levels, click the New Column button. A new column appears in which you define a new contrast. After you are finished, click Done. The Contrast report appears (Figure 3.14). The overall test is a joint $F$ test for all contrasts.

Note: If you attempt to specify more than the maximum number of contrasts possible, the test automatically evaluates.

The Contrast Report provides the following detail about the joint $F$ test:

- **SS**  sum of squares for the joint test
- **NumDF**  numerator degrees of freedom
- **DenDF**  denominator degrees of freedom
- **F Ratio**  ratio of SS divided by NumDF divided by the mean square error
- **Prob > F**  $p$-value for the significance test
Test Detail Report
The Test Detail report (Figure 3.14) shows a column for each contrast that you tested. For each contrast, the report gives its estimated value, its standard error, a $t$ ratio for a test of that single contrast, the corresponding $p$-value, and its sum of squares.

Parameter Function Report
The Parameter Function report (Figure 3.14) shows the contrasts that you specified expressed as linear combinations of the terms of the model.

Example of LSMeans Contrast
To illustrate the LSMeans Contrast option, form a contrast that compares the first two age levels with the next two levels.

Follow these steps to create the report shown in Figure 3.13.
1. Open the Big Class.jmp sample data table.
2. Select Analyze > Fit Model.
3. Select weight and click Y.
4. Select age, sex, and height, and click Add.
5. Select age in the Select Columns list, select height in the Construct Model Effects list, and click Cross.
6. Click Run.
   The Fit Least Squares report appears.
7. From the red triangle menu next to age, select LSMeans Contrast.
   The Contrast Specification report shown in Figure 3.13 appears.

**Figure 3.13** LSMeans Contrast Specification for age

8. Click “+” for the ages 12 and 13.
9. Click “−” for ages 14 and 15.

This contrast tests whether the mean weights differ for the two age groups, based on predicted values at a height of 62.55.

10. Note that there is a text box next to the continuous effect height. The default value is the mean of the continuous effect.

11. Click **Done**.

12. Open the **Test Detail** and **Parameter Function** reports.

The Contrast report is shown in Figure 3.14. The test for the contrast is significant at the 0.05 level. You conclude that the predicted weight for age 12 and 13 children differs statistically from the predicted weight for age 14 and 15 children at the mean height of 62.55.

**Figure 3.14 LSMeans Contrast Report**

**LSMeans Student’s t and LSMeans Tukey HSD**

The LSMeans Student’s t and LSMeans Tukey HSD (*honestly significant difference*) options test pairwise comparisons of model effects. Both options provide a matrix where each cell contains the difference in means, the standard error of the difference, and lower and upper confidence limits. The significance level and corresponding critical value are given above the matrix. The default significance level is 0.05, but recall that you can specify a significance level in the Fit Model launch window.
Figure 3.15 shows the LSMeans Tukey report for the effect age in the Big Class.jmp sample data table. (You can obtain this report by running the Fit Model data table script and selecting LS Means Tukey HSD from the red triangle menu for age.) The differences in means, standard error, and confidence limits are shown in the table. The cells with red results correspond to levels that differ at the stated 0.05 significance level.

A Connecting Letters Report appears by default below the table. Note that levels 17, 12, 16, 13, and 15 are connected by the letter A. The connection indicates that these levels do not differ at the 0.05 significance level. Also, levels 16, 13, 15, and 14 are connected by the letter B, indicating that they do not differ statistically. However, ages 17 and 14, and ages 12 and 14, are not connected by a common letter, indicating that these two pairs of levels are statistically different.
The LSMeans Student’s t option is based on the usual independent samples, equal variance $t$ test. Each comparison is based on the specified significance level. The overall error rate resulting from conducting multiple comparisons exceeds that specified significance level.

On the other hand, the LSMeans Tukey HSD option conducts Tukey HSD tests. For these comparisons, the significance level applies to the entire collection of pairwise comparisons. The significance level is exact if the sample sizes are equal and conservative if the sample sizes differ (Hayter, 1984). For this reason, confidence intervals for LS Means Tukey HSD are wider than those for LSMeans Student’s t.
The red triangle options that appear in each report window show or hide optional reports. All five options below are available for LSMeans Student's t. The first three options are available for LSMeans Tukey HSD. For both LSMeans Student's t and LSMeans Tukey HSD, the Crosstab Report and the Connecting Letters Report are provided by default.

**Crosstab Report**  Shows a two-way table that provides, for each pair of levels, the difference in means, the standard error of the difference, and confidence limits for the difference. The contents of cells containing significant differences are highlighted in red.

**Connecting Letters Report**  Illustrates significant and non-significant comparisons with connecting letters. Levels not connected by the same letter are significantly different. Levels connected by the same letter are not significantly different.

**Ordered Differences Report**  Ranks the differences from largest to smallest, giving standard errors, confidence limits, and \( p \)-values. Also plots the differences on a bar chart with overlaid confidence intervals.

**Detailed Comparisons**  Gives individual detailed reports for each comparison. For a given comparison, the report shows the estimated difference, standard error, confidence interval, \( t \) ratio, degrees of freedom, and \( p \)-values for one- and two-sided tests. Also shown is a plot of the \( t \) distribution, which illustrates the significance test for the comparison. The area of the shaded portion is the \( p \)-value for a two-sided test.

**Equivalence Test**  Uses the Two One-Sided Tests (TOST) method to test for a practical difference between the means (Schuirmann, 1987). You must select a threshold difference for which smaller differences are considered practically equivalent. Two one-sided \( t \) tests are constructed for the null hypotheses that the true difference exceeds the threshold values. If both tests reject, this indicates that the difference in the means does not exceed either threshold value. Therefore, the groups are considered practically equivalent.

**LSMeans Dunnett**

Dunnett's test (Dunnett, 1955) compares a set of means against the mean of a control group. The error rate applies to the collection of pairwise comparisons. The LSMeans Dunnett option conducts Dunnett's test for the levels of the given effect. Hsu's factor analytical approximation is used for the calculation of \( p \)-values and confidence intervals (Hsu, 1992).

When you select LSMeans Dunnett, you are prompted to enter a control level for the effect. The LS Means Differences Hsu-Dunnett report shows the significance level, the value of the test statistic (Q), and the control level.

A report for the LSMeans Dunnett option for effect treatment in the Cholesterol.jmp sample data table is shown in Figure 3.16. Here, the response is June PM and the level of treatment called Control is specified as the control level.
The report has two options:

**Control Differences Report**  The Control Differences report is shown by default. For each level of the effect, a table shows the following information: the level being compared to the control level, the estimated difference, the standard error of the difference, a confidence interval, and the \( p \)-value for the comparison.

**Control Differences Chart**  For each level other than the control, a point shows the difference between the LS Mean for that level and the LS Mean for the control level. Upper and lower decision limits (UDL, LDL) are plotted. The report has a Show Summary Report option and Display options. The Show Summary Report option gives the plot detail. The Display options enable you to modify the plot appearance.

**Test Slices**

The Test Slices option is enabled for interaction effects composed of nominal or ordinal columns. For each level of each nominal or ordinal column in the interaction, this option produces a report that jointly tests all pairwise comparisons of settings involving that level. The test is effectively a test of differences within the specified “slice” of the interaction.

Suppose that you are interested in an \( A^*B^*C \) interaction, where one of the levels of \( A \) is “Small”. The Test Slice report for the slice \( A = \text{Small} \) jointly tests all pairwise comparisons of the \( B^*C \) levels when \( A = \text{Small} \). It allows you to detect differences in levels within an interaction.
The Test Slice reports follow the same format as do the LSMeans Contrast reports. See “LSMeans Contrast” on page 97.

**Power Analysis**

Opens the Power Details window, where you can enter information to obtain retrospective or prospective details for the *F* test of a specific effect.

**Note:** To ensure that your study includes sufficiently many observations to detect the required differences, use information about power when you *design* your experiment. Such an analysis is called a **prospective** power analysis. Consider using the DOE platform to design your study. Both DOE > Sample Size and Power and DOE > Evaluate Design are useful for prospective power analysis. For an example of a prospective power analysis using standard least squares, see “Prospective Power Analysis” on page 199.

Figure 3.17 shows an example of the Power Details window for the Big Class.jmp sample data table. Using the Power Details window, you can explore power for values of alpha (α), sigma (σ), delta (δ), and Number (study size). Enter a single value (From only), two values (From and To), or the start (From), stop (To), and increment (By) for a sequence of values. Power calculations are reported for all possible combinations of the values that you specify.

**Figure 3.17  Power Details Window**

For details about the Power Details window, select the Fitting Linear Models PDF file from the Help > Books menu. See the section called Power Analysis in the Statistical Details appendix of the Fitting Standard Least Squares Models chapter.

For further details, see “Power Analysis” on page 193.
### Table 3.11 Description of the Power Details Window

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Alpha (α)</strong></td>
<td>The significance level of the test. This value is between 0 and 1, and is often 0.05, 0.01, or 0.10. The initial value for Alpha, shown in the first row, is 0.05, unless you have selected Set Alpha Level and set a different value in the Fit Model launch window.</td>
</tr>
<tr>
<td><strong>Sigma (σ)</strong></td>
<td>An estimate of the residual error in the model. The initial value shown in the first row, provided for guidance, is the RMSE (the square root of the mean square error).</td>
</tr>
<tr>
<td><strong>Delta (δ)</strong></td>
<td>The effect size of interest. See “Effect Size” on page 194 for details. The initial value, shown in the first row, is the square root of the sum of squares for the hypothesis divided by the number of observations in the study.</td>
</tr>
<tr>
<td><strong>Number (n)</strong></td>
<td>The sample size. The initial value, shown in the first row, is the number of observations in the current study.</td>
</tr>
<tr>
<td><strong>Solve for Power</strong></td>
<td>Solves for the power as a function of α, σ, δ, and n. The power is the probability of detecting a difference of size δ by seeing a test result that is significant at level α, for the specified σ and n. For more details, see “Computations for the Power” on page 461 in the “Statistical Details” appendix.</td>
</tr>
<tr>
<td><strong>Solve for Least Significant Number</strong></td>
<td>Solves for the smallest number of observations required to obtain a test result that is significant at level α, for the specified δ and σ. For more details, see “Computations for the LSN” on page 459 in the “Statistical Details” appendix.</td>
</tr>
<tr>
<td><strong>Solve for Least Significant Value</strong></td>
<td>Solves for the smallest positive value of a parameter or linear function of the parameters that produces a p-value of α. The least significant value is a function of α, σ, and n. This option is available only for one-degree-of-freedom tests. For more details, see “Computations for the LSV” on page 460 in the “Statistical Details” appendix.</td>
</tr>
</tbody>
</table>
Lack of Fit

The Lack of Fit report gives details for a test that assesses whether the model fits the data well. The Lack of Fit report only appears when it is possible to conduct this test. The test relies on the ability to estimate the variance of the response using an estimate that is independent of the model. Constructing this estimate requires that response values are available at replicated values of the model effects. The test involves computing an estimate of pure error, based on a sum of squares, using these replicated observations.

In the following situations, the Lack of Fit report does not appear because the test statistic cannot be computed:

- There are no replicated points with respect to the X variables, so it is impossible to calculate a pure error sum of squares.
- The model is saturated, meaning that there are as many estimated parameters as there are observations. Such a model fits perfectly, so it is impossible to assess lack of fit.

The difference between the error sum of squares from the model and the pure error sum of squares is called the lack of fit sum of squares. The lack of fit variation can be significantly greater than pure error variation if the model is not adequate. For example, you might have the wrong functional form for a predictor, or you might not have enough, or the correct, interaction effects in your model.

Table 3.12 Description of the Lack of Fit Report

| Source | Lists the three sources of variation: Lack of Fit, Pure Error, and Total Error. |
### Table 3.12 Description of the Lack of Fit Report (Continued)

<table>
<thead>
<tr>
<th>DF</th>
<th>Records the DF for each source of error:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• The DF for Total Error is the same as the DF value found on the Error line of the Analysis of Variance table. Based on the sum of squares decomposition, the Total Error DF is partitioned into degrees of freedom for Lack of Fit and for Pure Error.</td>
</tr>
<tr>
<td></td>
<td>• The Pure Error DF is pooled from each replicated group of observations. In general, if there are $g$ groups, each with identical settings for each effect, the pure error DF, denoted $DF_{PE}$, is given by:</td>
</tr>
<tr>
<td></td>
<td>[ DF_{PE} = \sum_{i=1}^{g} (n_i - 1) ]</td>
</tr>
<tr>
<td></td>
<td>where $n_i$ is the number of replicates in the $i^{th}$ group.</td>
</tr>
<tr>
<td></td>
<td>• The Lack of Fit DF is the difference between the Total Error and Pure Error DFs.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sum of Squares</th>
<th>Records an associated sum of squares (SS) for each source of error:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>• The Total Error SS is the sum of squares found on the Error line of the corresponding Analysis of Variance table.</td>
</tr>
<tr>
<td></td>
<td>• The Pure Error SS is the total of the sum of squares values for each replicated group of observations. The Pure Error SS divided by its DF estimates the variance of the response at a given predictor setting. This estimate is unaffected by the model. In general, if there are $g$ groups, each with identical settings for each effect, the Pure Error SS, denoted $SS_{PE}$, is given by:</td>
</tr>
<tr>
<td></td>
<td>[ SS_{PE} = \sum_{i=1}^{g} SS_i ]</td>
</tr>
<tr>
<td></td>
<td>where $SS_i$ is the sum of the squared differences between each observed response and the mean response for the $i^{th}$ group.</td>
</tr>
<tr>
<td></td>
<td>• The Lack of Fit SS is the difference between the Total Error and Pure Error sum of squares.</td>
</tr>
</tbody>
</table>

| Mean Square | Shows the mean square for the Source, which is the Sum of Squares divided by the DF. A Lack of Fit mean square that is large compared to the Pure Error mean square suggests that the model is not fitting well. The $F$ ratio provides a formal test. |
Estimates

The Estimates menu provides additional detail about model parameters. To better understand estimates, you might want to review JMP’s approach to coding nominal and ordinal effects. See “Details of Custom Test Example” on page 188, “Nominal Factors” on page 433 in the “Statistical Details” appendix, and “Ordinal Factors” on page 444 in the “Statistical Details” appendix.

If your model contains random effects, then only the options below that are appropriate are available from the Estimates menu.

Table 3.12 Description of the Lack of Fit Report (Continued)

<table>
<thead>
<tr>
<th>Table 3.12 Description of the Lack of Fit Report (Continued)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>F Ratio</strong></td>
</tr>
<tr>
<td><strong>Prob &gt; F</strong></td>
</tr>
<tr>
<td><strong>Max RSq</strong></td>
</tr>
</tbody>
</table>
|                              | \[
| \frac{SS(C. \text{ Total}) - SS(Pure Error)}{SS(C. \text{ Total})} = 1 - \frac{SS(Pure Error)}{SS(C. \text{ Total})}
|                              | This formula defines the Max RSq. |

Table 3.13 Description of Estimates Options

<table>
<thead>
<tr>
<th>Table 3.13 Description of Estimates Options</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Show Prediction Expression</strong></td>
</tr>
<tr>
<td><strong>Sorted Estimates</strong></td>
</tr>
</tbody>
</table>
### Table 3.13 Description of Estimates Options (Continued)

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expanded Estimates</td>
<td>Adds a report that expands the Parameter Estimates report by giving parameter estimates for all levels of nominal effects. See “Expanded Estimates” on page 114.</td>
</tr>
<tr>
<td>Indicator Parameterization</td>
<td>Adds a report called Indicator Function Parameterization, which gives parameter estimates when the model is parametrized using the classical indicator functions. See “Indicator Parameterization Estimates” on page 116.</td>
</tr>
<tr>
<td>Sequential Tests</td>
<td>Shows sums of squares as effects are added to the model sequentially. Conducts $F$ tests based on the sequential sums of squares. See “Sequential Tests” on page 117.</td>
</tr>
<tr>
<td>Custom Test</td>
<td>Enables you to test a custom hypothesis. See “Custom Test” on page 118.</td>
</tr>
<tr>
<td>Multiple Comparisons</td>
<td>Opens a window where you specify comparisons among effect levels. These can involve a single effect or you can define flexible custom comparisons. You can compare to the overall mean, to a control mean, or you can obtain all pairwise comparisons using Tukey HSD or Student’s $t$. You can also conduct equivalence tests. See “Multiple Comparisons” on page 120.</td>
</tr>
<tr>
<td>Joint Factor Tests</td>
<td>For each main effect in the model, JMP produces a joint test on all of the parameters involving that main effect. This option is available only when the model contains interactions. See “Joint Factor Tests” on page 133.</td>
</tr>
<tr>
<td>Inverse Prediction</td>
<td>For one or more values of the response, predicts values of explanatory variables. See “Inverse Prediction” on page 134.</td>
</tr>
<tr>
<td>Cox Mixtures</td>
<td>Produces parameter estimates for the Cox mixture model. Using these to derive factor effects and estimate the response surface shape relative to a reference point in the design space. See “Cox Mixtures” on page 138.</td>
</tr>
<tr>
<td></td>
<td><strong>Note:</strong> Appears only for models with mixture effects.</td>
</tr>
<tr>
<td>Parameter Power</td>
<td>Adds columns to the Parameter Estimates report that give power and other details relating to the corresponding hypothesis tests. See “Parameter Power” on page 140.</td>
</tr>
<tr>
<td>Correlation of Estimates</td>
<td>Produces a correlation matrix for all parameter estimates in the model. See “Correlation of Estimates” on page 142.</td>
</tr>
</tbody>
</table>
Show Prediction Expression

The Show Prediction Expression option shows the equation used to predict the response. Figure 3.18 shows an example for the Drug.jmp sample data table. This expression is given as a typical JMP formula. For example, to predict the response for someone on Drug a with $x = 10$, you would calculate, with some rounding: $-2.696 - 1.185 + 0.987(10) = 5.99$.

Example of a Prediction Expression
1. Open the Drug.jmp sample data table.
2. Select Analyze > Fit Model.
3. Select $y$ and click $Y$.
4. Select Drug and $x$, and then click Add.
5. Click Run.
6. From the red triangle menu next to Response $y$, select Estimates > Show Prediction Expression. The report in Figure 3.18 appears.

Sorted Estimates

The Sorted Estimates option produces a version of the Parameter Estimates report that is useful in screening situations. If the design is not saturated, the Sorted Estimates report gives the information found in the Parameter Estimates report, but with the terms, other than the Intercept, sorted in decreasing order of significance (second report in Figure 3.19). If the design is saturated, then Pseudo $t$ tests are provided. These are based on Lenth’s pseudo standard error (Lenth, 1989). See “Lenth’s PSE” on page 112.

Example of a Sorted Estimates Report
1. Open the Reactor.jmp sample data table.
2. Select Analyze > Fit Model.
3. Select $Y$ and click $Y$. 
4. Make sure that 2 appears in the Degree box near the bottom of the window.

5. Select F, Ct, A, T, and Cn and click Macros > Factorial to Degree.

6. Click Run.

**Figure 3.19** Sorted Parameter Estimates

The Sorted Parameter Estimates report also appears automatically if the Emphasis is set to Effect Screening and all of the effects have only one parameter.

Note the following differences between the Parameter Estimates report and the Sorted Parameter Estimates report (both shown in Figure 3.19):

- The Sorted Parameter Estimates report does not show the intercept.
- The effects are sorted by the absolute value of the t ratio, showing the most significant effects at the top.
- A bar chart shows the t ratio with vertical lines showing critical values for the 0.05 significance level.
Sorted Estimates Report for Saturated Models

Screening experiments often involve fully saturated models, where there are not enough degrees of freedom to estimate error. In these cases, the Sorted Estimates report (Figure 3.19) gives relative standard errors and constructs \( t \) ratios and \( p \)-values using Lenth’s pseudo standard error (PSE). These quantities are labeled with \textit{Pseudo} in their names. See “\textit{Lenth’s PSE}” on page 112 and “\textit{Pseudo t-Ratios}” on page 112.

A note explains the change and shows the PSE. The report provides the following information:

- **Term**: The model term whose coefficient is of interest.
- **Estimate**: The parameter estimates are presented in sorted order, with smallest \( p \)-values listed first.
- **Relative Standard Error**: If there are no degrees of freedom for residual error, the report gives relative standard errors. The relative standard error is computed by setting the root mean square error equal to 1.
- **Pseudo \( t \)-Ratio**: A \( t \) ratio for the estimate, computed using pseudo standard error. The value of Lenth PSE is shown in a note at the bottom of the report.
- **Pseudo \( p \)-Value**: A \( p \)-value computed using an error degrees of freedom value (DFE) of \( m/3 \), where \( m \) is the number of parameters other than the intercept. The value of DFE is shown in a note at the bottom of the report.

**Lenth’s PSE**

Lenth’s pseudo standard error (PSE) is an estimate of residual error due to Lenth (1989). It is based on the principle of effect sparsity: in a screening experiment, relatively few effects are active. The inactive effects represent random noise and form the basis for Lenth’s estimate.

The value is computed as follows:

1. Consider the absolute values of all non-intercept parameters.
2. Remove all parameter estimates whose absolute values exceed 3.75 times the median absolute estimate.
3. Multiply the median of the remaining absolute values of parameter estimates by 1.5.

**Pseudo \( t \)-Ratios**

When relative standard errors are equal, Lenth’s PSE is shown in a note at the bottom of the report. The Pseudo \( t \)-Ratio is calculated as follows:

\[
\text{Pseudo } t\text{-Ratio} = \frac{\text{Estimate}}{\text{PSE}}
\]
When relative standard errors are not equal, the TScale Lenth PSE is computed. This value is the PSE of the estimates divided by their relative standard errors. The Pseudo t-Ratio is calculated as follows:

\[
\text{Pseudo t-Ratio} = \frac{\text{Estimate}}{\text{TScale Lenth PSE} \times \text{Relative Std Error}}
\]

Note that, to estimate the standard error for a given estimate, TScale Lenth PSE is adjusted by multiplying it by the estimate’s relative standard error.

**Example of a Saturated Model**

1. Open the Reactor.jmp sample data table.
2. Select Analyze > Fit Model.
3. Select Y and click Y.
4. Select the following five columns: F, Ct, A, T, and Cn.
5. Click the Macros button and select Full Factorial.
6. Click Run.

The Sorted Parameter Estimates report appears (Figure 3.20). Note that Lenth’s PSE and the degrees of freedom used are given at the bottom of the report. The report indicates that, based on their Pseudo p-Values, the effects Ct, Ct*T, T*Cn, T, and Cn are highly significant.
In dealing with parameter estimates, you must understand how JMP codes nominal and ordinal columns. For details about how nominal columns are coded, see “Details of Custom Test Example” on page 188. For complete details about how ordinal columns are coded and modeled, see “Nominal Factors” on page 433 and “Ordinal Factors” on page 444.

Use the Expanded Estimates option when there are nominal terms in the model and you want to see details for the full set of estimates. The Expanded Estimates option provides the estimates, their standard errors, t ratios, and p-values.

**Example of an Expanded Estimates Report**

1. Open the Drug.jmp sample data table.
2. Select **Analyze > Fit Model**.
3. Select y and click Y.
4. Select Drug and x, and then click Add.
5. Click Run.
6. From the red triangle menu next to Response y, select **Estimates > Expanded Estimates**.
The Expanded Estimates report, along with the Parameter Estimates report, is shown in Figure 3.21. Note that an estimate for the term Drug[f] appears in the Expanded Estimates report. The null hypothesis for the test is that the mean for the Drug f group does not differ from the overall mean. The test for Drug[f] is significant at the 0.05 level, suggesting that the mean response for the Drug f group differs from the overall response. See “Interpretation of Tests for Expanded Estimates” on page 115 for more details.

**Figure 3.21** Comparison of Parameter Estimates and Expanded Estimates

| Term    | Estimate | Std Error | t Ratio | Prob>|t| |
|---------|----------|-----------|--------|------|
| Intercept | -0.095773 | 1.911083 | -0.14 | 0.892 |
| Drug[a] | -1.135077 | 1.096822 | -1.12 | 0.2742 |
| Drug[f] | -1.076965 | 1.041298 | -1.03 | 0.309 |
| x       | 0.0871688 | 0.164408 | 6.00 | <0.0001* |

| Term    | Estimate | Std Error | t Ratio | Prob>|t| |
|---------|----------|-----------|--------|------|
| Intercept | -0.095773 | 1.911083 | -0.14 | 0.892 |
| Drug[a] | -1.135077 | 1.096822 | -1.12 | 0.2742 |
| Drug[f] | -1.076965 | 1.041298 | -1.03 | 0.309 |
| x       | 0.0871688 | 0.164408 | 6.00 | <0.0001* |

**Interpretation of Tests for Expanded Estimates**

Suppose that your model consists of a single nominal factor that has \( n \) levels. That factor is represented by \( n-1 \) indicator variables, one for each of \( n-1 \) levels. The parameter estimate corresponding to any one of these \( n-1 \) indicator variables is the difference between the mean response for that level and the average response across all levels. This representation is due to the way that JMP codes nominal variables (see “Details of Custom Test Example” on page 188). The parameter estimate is often interpreted as the effect of that level.

For example, in the Cholesterol.jmp sample data table, consider the single factor treatment and the response June PM. The parameter estimate associated with the term, or indicator variable, treatment[A] is the difference between the mean of June PM for treatment A and the overall mean of June PM.

The effects across all levels of a nominal variable are constrained to sum to zero. Consider the effect of the last level in the level ordering, namely, the level that is coded with –1s. The effect of this level is the negative of the sum of the effects across the other \( n-1 \) levels. It follows that the effect of the last level is the negative of the sum of the parameter estimates across the other \( n-1 \) levels.
The Expanded Estimates option in the Estimates menu calculates missing estimates, tests for all effects that involve nominal columns, and shows them in a text report. You can verify that the mean (or sum) of the estimates across the levels of any such effect is zero. In particular, this relationship indicates that these estimates, and their associated tests, are not independent of each other.

In the Drug.jmp report shown in Figure 3.21, the estimates for the terms associated with Drug are based on a model that includes the covariate x.

**Notes:**

- The estimate for Drug[a] is the difference between the least squares mean for Drug a and the overall mean of y.
- The estimate for Drug[f], given in the Expanded Estimates report, is the negative of the sum of the estimates for Drug[a] and Drug[d].
- The test for Drug [f] presented in the Expanded Estimates report tests whether the response for the Drug f group differs from the overall mean response.
- If nominal factors are involved in high-degree interactions, the Expanded Estimates report can be lengthy. For example, a five-way interaction of two-level nominal factors produces only one parameter estimate but has $2^5 = 32$ expanded effects, which are all identical up to sign changes.

**Indicator Parameterization Estimates**

This option displays parameter estimates for the model where nominal and ordinal columns have been coded using the SAS GLM parameterization. The SAS GLM and JMP coding schemes are described in “The Factor Models” on page 432 in the “Statistical Details” appendix.

To create the report in Figure 3.22, follow the steps in “Example of an Expanded Estimates Report” on page 114. But instead of selecting Expanded Estimates, select Indicator Parameterization Estimates.

![Indicator Function Parameterization](image)

Note that there might be differences in models derived using the JMP versus the SAS GLM parameterization. Some models are equivalent. Other models (such as no-intercept models, models with missing cells, models with nominal or ordinal effects, and mixture models) will most likely show differences.
Sequential Tests

The Sequential Tests report shows sums of squares and tests as effects are added to the model sequentially. The order of entry is defined by the order of effects as they appear in the Fit Model launch window’s Construct Model Effects list. The report in Figure 3.23 is for the Drug.jmp sample data table.

**Figure 3.23** Sequential Tests Report

<table>
<thead>
<tr>
<th>Source</th>
<th>Nparm</th>
<th>DF</th>
<th>Seq SS</th>
<th>F Ratio</th>
<th>Prob &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drug</td>
<td>2</td>
<td>2</td>
<td>293.6000</td>
<td>9.1486</td>
<td>0.0013*</td>
</tr>
<tr>
<td>x</td>
<td>1</td>
<td>1</td>
<td>577.8974</td>
<td>36.045</td>
<td>&lt;.0001*</td>
</tr>
</tbody>
</table>

The sums of squares that form the basis for sequential tests are also called *Type I Sums of Squares*. They are computed by fitting models in steps following the specified entry order of effects. Consider a specific effect. Compute the model sum of squares for a model containing all effects entered prior to that effect. Then compute the model sum of squares for a model containing those effects and the specified effect. The sequential sum of squares for the specified effect is the increase in the model sum of squares.

Refer to Figure 3.23, showing sequential sums of squares for the Drug.jmp sample data table. In the Fit Model launch window, Drug was entered first, followed by x. A model consisting only of Drug has model sum of squares equal to 293.6. When x is added to the model, the model sum of squares becomes 871.4974. The increase of 577.8974 is the sequential sum of squares for x.

The tests shown in the Sequential (Type 1) Tests report are $F$ tests based on sequential sums of squares, also called *Type I Tests*. The $F$ Ratio tests the specified effect, where the model contains only that effect and the effects listed above it in the Source column.

The sequential sums of squares sum to the model sum of squares. Another nice feature is that, under the usual model assumptions, the values are statistically independent of each other. However, they do depend on the order of terms in the model and, as such, are not appropriate in many situations.

Sequential tests are considered appropriate in the following situations:

- balanced analysis of variance models specified in proper sequence (that is, two-way interactions follow main effects in the effects list, and so on)
- purely nested models specified in the proper sequence
- polynomial regression models specified in the proper sequence.

The tests given in the Parameter Estimates and Effect Tests reports are based on *Type III Sums of Squares*. Here the sum of squares for an effect is the extra sum of squares explained by the effect after all other effects have been entered in the model.
Custom Test

To test one or more custom hypotheses involving any model parameters, select Custom Test from the Estimates menu. In this window, you can specify one or more linear functions, or contrasts, of the model parameters.

The results include individual tests for each contrast and a joint test for all contrasts. See Figure 3.24. The report for the individual contrasts gives the estimated value of the specified linear function of the parameters and its standard error. A t ratio, its p-value, and the associated sum of squares are also provided. Below the individual contrast results, the joint test for all contrasts gives the sum of squares, the numerator degrees of freedom, the F ratio, and its p-value.

Caution: These tests are conducted using residual error. If you have random effects in your model and if you use EMS instead of REML, then these tests might not be appropriate.

Note: If you are testing for effects that are involved in higher-order effects, consider using a test for least squares means, rather than a custom test. Least squares means are adjusted for other model effects. You can test least squares means contrasts under Effect Details.

Custom Test Report Components

The Custom Test specification window has the following components:

- **Editable text box**  The space beneath the Custom Test title bar is an editable area for entering a test name.
- **Parameter**  Lists the model terms. To the right of the list of terms are columns of zeros corresponding to the corresponding parameters. Enter values in these cells to specify the linear functions for your tests.
- **The “=“ sign**  The last line in the Parameter list is labeled “=”. Enter a constant into this cell to complete the specification for each contrast.
- **Add Column**  Adds columns of zeros so that you can jointly test several linear functions of the parameters.
- **Done**  Click the Done button to perform the tests. The report changes to show the test statistic value, the standard error, and other statistics for each test column. The joint F test for all columns is given in a box at the bottom of the report.

Custom Test Report Options

The red triangle menu for the Custom Test report has two options:

- **Power Analysis**  Provides a power analysis for the joint test. This option is available only after the test has been conducted. For details, see “Parameter Power” on page 140.
Remove  Removes the Custom Test report.

Note: Select Estimates > Custom Test repeatedly to conduct several joint custom tests.

Figure 3.24 shows an example of the specification window with three contrasts, using the Cholesterol.jmp sample data table. Note that the constant is set to zero for all three tests. The report for these tests is shown in Figure 3.25.

Example of a Custom Test

The Cholesterol.jmp sample data table gives repeated measures on 20 patients at six time periods. Four treatment groups are studied. Typically, this data should be properly analyzed using all repeated measures as responses. This example considers only the response for June PM.

Suppose that you want to test three contrasts. You want to compare the mean responses for: treatment A to treatment B, treatments A and B to the control group, and treatments A and B to the control and placebo groups.

To test these contrasts using Custom Test:
1. Open the Cholesterol.jmp sample data table.
2. Select Analyze > Fit Model.
3. Select June PM and click Y.
4. Select treatment and click Add.
5. Click Run.
6. From the red triangle next to Response June PM, select Estimates > Custom Test.
7. In the Custom Test specification window, click Add Column twice to create three columns.
8. Fill in the editable area with a test name and enter values in the three columns as shown in Figure 3.24.

To see how to obtain these values, particularly those in the third column, see “Base Model for Nominal Responses” on page 430 in the “Statistical Details” appendix.
9. Click Done.

Figure 3.24  Custom Test Specification Window for Three Contrasts
The results shown in Figure 3.25 indicate that all three hypotheses are individually, as well as jointly, significant.

**Figure 3.25 Custom Test Report Showing Tests for Three Contrasts**

To see how to obtain these values, particularly those in the third column, see “Base Model for Nominal Responses” on page 430 in the “Statistical Details” appendix.

**Multiple Comparisons**

Use this option to obtain tests and confidence levels that compare means defined by levels of your model effects. The goal when making multiple comparisons is to determine if group means differ, while controlling the probability of reaching an incorrect conclusion. The Multiple Comparisons option lets you compare group means with an overall average mean (Analysis of Means) and with a control group mean. You can also conduct pairwise comparisons using either Tukey HSD or Student’s $t$. To identify pairwise differences that are of practical importance, you can perform equivalence tests.

The Student’s $t$ method only controls the error rate for an individual comparison. As such, it is not a true multiple comparison procedure. All other methods provided control the overall error rate for all comparisons of interest. Each of these methods uses a multiple comparison adjustment in calculating $p$-values and confidence limits.

If your model contains nominal and ordinal effects, you can conduct comparisons using Least Squares Means estimates, or you can define specific comparisons using User-Defined Estimates. If your model contains only continuous effects, you can compare means using User-Defined Estimates.

**Note:** The Mixed Model personality does not support User-Defined Estimates.
Note: Suppose that a continuous effect consists of relatively few levels. If you are interested in comparisons using Least Squares Means Estimates, consider assigning that effect an ordinal (or nominal) modeling type.

Launch the Option

An example of the control window for the Multiple Comparisons option is shown in Figure 3.26. This example is based on the Big Class.jmp data table, with weight as Y and age, sex, and height as model effects. Two classes of estimates are available for comparisons: Least Squares Means Estimates and User-Defined Estimates.

Least Squares Means Estimates

This option compares least squares means and is available only if there are nominal or ordinal effects in the model. Recall that least squares means are means computed at some neutral value of the other effects in the model. (For a definition of least squares means, see “LSMeans Table” on page 93.) You must select the effect of interest. In Figure 3.26, Least Squares Means Estimates for age are specified.

Figure 3.26  Launch Window for Least Squares Means Estimates

User-Defined Estimates

The specification of User-Defined Estimates is illustrated in Figure 3.27. Three levels of age and both levels of sex have been selected. Also, two values of height have been manually entered. The Add Estimates button has been clicked, resulting in the listing of all possible combinations of the specified levels. At this point, you can specify more estimates and click the Estimates button again to add them to the list of Estimates for Comparison.
When you use User-Defined Estimates, effects with no specified levels are set as follows:

- Continuous effects are set to the mean of the effect.
- Nominal and ordinal effects are set to the first level in the value ordering.

**Note:** In this section, we will use the term *mean* to refer to either estimates of least squares means or user-defined estimates.

### Choose Initial Comparisons

Once you have specified estimates, you can choose the types of comparisons that you would like to see in your initial report by making selections under Choose Initial Comparisons. Or click OK without making any selections.

The potential selections for your initial reports are:

- Comparisons with Overall Average
- Comparisons with Control
- All Pairwise Comparisons - Tukey HSD
• All Pairwise Comparisons - Student’s t

Each of these selections opens a report with an area at the top that shows details specific to the report. This information includes the quantile, or critical value. For the true multiple comparisons procedures, the method used for the multiple comparison adjustment is shown. If you have specified User-Defined Estimates, the report displays a list of effects that do not vary relative to the specified estimates and the levels at which these effects are set. Unless you have specified otherwise, any continuous effect is set to its mean. Any nominal or ordinal effect is set to the first level in its value ordering.

If you click OK without selecting from the Choose Initial Comparisons list, the Multiple Comparisons report opens, showing the Estimates table. From the Multiple Comparison’s red triangle menu, all of the options listed above are available. The available reports and options are described below.

Estimates Report

By default, the Multiple Comparisons option displays an Estimates report, even when no initial comparison type has been specified. For each combination of levels of interest, this table gives an estimate of the mean, as well as a test and confidence interval. Specifically, this table gives the following:

- **Levels of the Categorical Effects** The first columns in the report identify the effect or effects of interest. The values in the columns specify the groups being analyzed.
- **Estimate** Gives an estimate of the mean for each group.
- **Std Error** Gives the standard error of the mean for each group.
- **DF** Shows the degrees of freedom for a test of whether the mean is 0.
- **t Ratio** Shows the t ratio for the significance test.
- **Prob>|t|** Gives the p-value for the significance test.
- **Lower 95%** Shows the lower confidence limit for the mean. You can change the confidence level by selecting Set Alpha Level in the Fit Model window.
- **Upper 95%** Shows the upper confidence limit for the mean.

Comparisons with Overall Average

This option compares the means for the specified levels specified to the overall mean for these levels. It displays a table showing confidence intervals for differences from the overall mean and a chart showing decision limits. The method used to make the comparisons is called analysis of means (ANOM) (Nelson, et al., 2005). ANOM is a multiple comparison procedure that controls the joint error rate for all pairwise comparisons to the overall mean. See Figure 3.28 for a report based on the Movies.jmp sample data table.
ANOM might appear similar to analysis of variance. However, it is fundamentally different in that it identifies levels with means that differ from the overall mean for all levels. In contrast, analysis of variance tests for differences in the means themselves.

At the top of the Comparisons with Overall Average report you find:

**Quantile**  The value of Nelson’s $h$ statistic used in constructing the decision limits.

**Avg**  The average mean. For least squares estimates, the average mean is a weighted average of the group least squares means that represents the overall mean at the neutral settings where the group least squares means are calculated.

Specifically, the average least squares mean is a weighted average with weights inversely proportional to the diagonal entries of the matrix $L(X'X)^{-1}L'$. Here $L$ is the matrix of coefficients used to compute the group least squares means. For a technical definition of least squares means and the average least squares mean, see the GLM Procedure section in the *SAS/STAT 9.3 User’s Guide*. Search for “Construction of Least Squares Means”.

For user-defined estimates, the average mean is defined similarly. However, in this case, $L$ is the matrix of coefficients used to define the estimates.

**Adjustment**  Describes the method used to obtain the critical value:

- Nelson: Provides exact critical values and $p$-values. Used whenever possible, in particular, when the estimates are uncorrelated.

- Nelson-Hsu: Provides approximate critical values and $p$-values based on Hsu’s factor analytical approximation is used (Hsu, 1992). Used when exact values can not be obtained.

- Sidak: Used when both Nelson and Nelson-Hsu fail.

For technical details, see the GLM Procedure section in the *SAS/STAT 9.3 User’s Guide*. Search for “Approximate and Simulation-Based Methods”.

Three options are available from the Comparisons with Overall Average report menu:

**Differences from Overall Average**  

For each comparison of a group’s mean to the overall mean, this report provides the following details:

- **Difference** - the estimated difference

- **Std Error** - the standard error of the difference

- **DF** - the degrees of freedom used in constructing the confidence interval

- **Lower and Upper limits** for the confidence interval
Comparisons with Overall Average Decision Chart

This decision chart plots a point at the mean for each group. A horizontal line is plotted at the average mean. Upper and lower decision limits are plotted. Suppose that a point corresponding to a group mean falls outside these limits. This occurrence indicates that the group mean differs from the overall mean, based on the analysis of means test at the specified significance level. The significance level is shown below the chart.

The Comparisons with Overall Average Decision Chart report menu has these options:

- **Show Summary Report**  Produces a table showing the estimate, decision limits, and the limit exceeded for each group
- **Display Options**  Gives several options for controlling the display of the chart.
- **Calculate P-Values**  Adds columns giving t ratios (t Ratio) and p-values (Prob>|t|) to the Comparisons with Overall Average report. Note that computing exact critical values and p-values for unbalanced designs requires complex integration and can be computationally challenging. When calculations for such a quantile fail, the Sidak quantile is computed but p-values are not available.

Example of Comparisons with Overall Average

Consider the Movies.jmp sample data table. You are interested in whether any of the four Rating categories are unusual in that their mean Domestic $ revenues differ from the overall average revenue. You specify a model with Domestic $ as the response and Type, Rating, and Year as model effects.

1. Open the Movies.jmp sample data table.
2. Select Analyze > Fit Model.
3. Select Domestic $ and click Y.
4. Select Type, Rating, and Year, and click Add
5. Click Run.
6. From the red triangle next to Response Domestic $, select Estimates > Multiple Comparisons.
7. From the Choose an Effect list, select Rating.
8. In the Choose Initial Comparisons list, select Comparisons with Overall Average.
9. Click OK.
10. From the Comparisons with Overall Average red triangle menu, select Calculate P-Values.

The results shown in Figure 3.28 indicate that the least squares means for movies with a Rating of PG-13 and R differ significantly from the overall average in terms of Domestic $.
Comparisons with Control

If you select Comparisons with Control, a window opens, asking you to specify a control setting. When you click OK, the Comparisons with Control report appears in your Fit Least Squares report.

This option compares the means for the levels specified to the control level. It displays a table showing confidence intervals for differences from the control level and a chart showing decision limits. Dunnett’s method is used to make the comparisons. Dunnett’s method is a multiple comparison procedure that controls the error rate over all comparisons (Hsu, 1996 and Westfall et al., 2011).

When exact calculation of p-values and confidence intervals is not possible, Hsu’s factor analytical approximation is used (Hsu, 1992). Note that computing exact critical values and p-values for unbalanced designs requires complex integration and can be computationally intensive. When calculations for such a quantile fail, the Sidak quantile is computed.

In addition to the list of effects that do not vary for the specified estimates, at the top of the Comparisons with Control report you also find:

**Quantile**  The critical value for Dunnett’s test.

**Control**  The control level or levels.

**Adjustment**  Describes the method used to obtain the critical value:
- Dunnett: Provides exact critical values and $p$-values. Used whenever possible, in particular, when the estimates are uncorrelated.
- Dunnett-Hsu: Provides approximate critical values and $p$-values based on Hsu’s factor analytical approximation (Hsu, 1992). Used when exact values can not be obtained.
- Sidak: Used when both Dunnett and Dunnett-Hsu fail.

For technical details, see the GLM Procedure section in the SAS/STAT 9.3 User’s Guide. Search for “Approximate and Simulation-Based Methods”.

Three options are available from the Comparisons with Control report menu:

**Differences from Control**

For each comparison of a group mean to the control mean, this report provides the following details:

- **Difference** - the estimated difference
- **Std Error** - the standard error of the difference
- **DF** - the degrees of freedom used in constructing the confidence interval
- **Lower and Upper limits for the confidence interval**

**Comparisons with Control Decision Chart**

This decision chart plots a point at the mean for each group being compared to the control group. A horizontal line shows the mean for the control group. Upper and lower decision limits are plotted. When a point falls outside these limits, it corresponds to a group whose mean differs from the control group mean based on Dunnett’s test at the specified significance level. That level is shown beneath the chart.

The Comparisons with Control Decision Chart report menu has these options:

- **Show Summary Report** Produces a table showing the estimate, decision limits, and the limit exceeded for each group
- **Display Options** Gives several options for controlling the display of the chart.

**Calculate P-Values**

Adds columns giving $t$ ratios ($t$ Ratio) and $p$-values ($\text{Prob}>|t|$) to the Comparisons with Control report. Note that computing exact critical values and $p$-values for unbalanced designs requires complex integration and can be computationally challenging. When calculations for such a quantile fail, the Sidak quantile is computed but $p$-values are not available.
All Pairwise Comparisons

The All Pairwise Comparisons option shows either a Tukey HSD All Pairwise Comparisons or Student’s t All Pairwise Comparisons report (Hsu, 1996 and Westfall et al., 2011). Tukey HSD comparisons are constructed so that the significance level applies jointly to all pairwise comparisons. In contrast, for Student’s t comparisons, the significance level applies to each individual comparison. When making several pairwise comparisons using Student’s t tests, the risk that one of the comparisons incorrectly signals a difference can well exceed the stated significance level.

At the top of the Tukey HSD All Pairwise Comparisons report you find:

**Quantile**  The critical value for the test. Note that, for Tukey HSD, the quantile is $q / (\sqrt{n})$, where $q$ is the appropriate percentage point of the studentized range statistic.

**Adjustment**  Describes the method used to obtain the critical value:

- Tukey: Provides exact critical values and $p$-values. Used when the means are uncorrelated and have equal variances, or when the design is variance-balanced.
- Tukey-Kramer: Provides approximate critical values and $p$-values. Used when exact values can not be obtained.

For technical details, see the GLM Procedure section in the SAS/STAT 9.3 User’s Guide. Search for “Approximate and Simulation-Based Methods”.

At the top of the Student’s t All Pairwise Comparisons report you find the Quantile, or critical value, for the $t$ test.

All Pairwise Differences Report

Both Tukey HSD and Student’s $t$ compare all pairs of levels. For each pairwise comparison, the All Pairwise Differences report shows:

- The levels being compared
- Difference - the estimated difference between the means
- Std Error - the standard error of the difference
- DF - the degrees of freedom used in constructing the confidence interval
- $t$ Ratio - the $t$ ratio for the test of whether the difference is zero
- Prob > |t| - the $p$-value for the test
- Lower and Upper limits for a confidence interval for the difference in means

All Pairwise Comparisons Scatterplot

This plot, sometimes called a diffogram or a mean-mean scatterplot, displays the confidence intervals for all means pairwise differences. (See Figure 3.30 for an example.) Colors indicate which differences are significant.
The plot shows a reference line as an upwardly sloping line on the diagonal. This line represents points where the two means are equal. Each line segment corresponds to a confidence interval for a pairwise comparison. The coordinates of the point displayed on the line segment are the means for the corresponding groups. Clicking on one of these points displays a tooltip identifying the groups being compared and showing the estimated difference. If a line segment crosses the line on the diagonal, then the means can be equal and the comparison is not significant.

**Equivalence Tests**

Use this option to conduct one or more equivalence tests. Equivalence tests are useful when you want to detect differences that are of *practical* interest. You are asked to specify a threshold difference for group means for which smaller differences are considered practically equivalent. In other words, if two group means differ by this amount or less, you are willing to consider them equivalent.

Once you have specified this value, the Equivalence Tests report appears. The bounds that you have specified are given at the top of the report. The report consists of a table giving the equivalence tests and a scatterplot that displays them. The equivalence tests and confidence intervals are based on Tukey HSD or Student's *t* critical values, corresponding to the option that you selected.

**Equivalence TOST Tests**

The Two One-Sided Tests (TOST) method is used to test for a practical difference between the means (Schuirmann, 1987). Two one-sided *t* tests are constructed for the null hypotheses that the true difference exceeds the threshold values. If both tests reject, the difference in the means does not statistically exceed either threshold value. Therefore, the groups are considered practically equivalent. If only one or neither test rejects, then the groups might not be practically equivalent.

For each comparison, the Equivalence TOST Tests report gives:

- Difference - the estimated difference in the means
- Lower Bound *t* Ratio, Upper Bound *t* Ratio - the lower and upper bound *t* ratios for the two one-sided significance tests
- Lower Bound p-Value, Upper Bound p-value - *p*-values corresponding to the lower and upper bound *t* ratios
- Maximum *p*-Value - the maximum of the lower and upper bound *p*-values
- Lower and Upper limits for a $1 - 2\alpha$ confidence interval for the difference in the means.
Equivalence Tests Scatterplot

Using colors, this scatterplot indicates which means are practically equivalent and which are not as determined by the equivalence test. (See Figure 3.31.)

The plot shows a solid reference line on the diagonal as well as a shaded reference band. The width of the band is twice the practical difference. Each line segment corresponds to a $1 - 2\alpha$ confidence interval for a pairwise comparison. The coordinates of the point on the line segment are the means for the corresponding groups. Clicking on one of these points displays a tooltip indicating the groups being compared and the estimated difference. When a line segment is entirely contained within the diagonal band, it follows that the means are practically equivalent.

Remove

This option removes the Equivalence Tests report.

Example of Tukey HSD All Pairwise Comparisons

Consider the Movies.jmp sample data table. You are interested in Domestic $ differences for action and drama movies across two Rating categories, PG-13 and R, in the year 1998.

1. Open the Movies.jmp sample data table.
2. Select Analyze > Fit Model.
3. Select Domestic $ and click Y.
4. Select Type, Rating, and Year, and click Add.
5. Click Run.
6. From the red triangle next to Response Domestic $, select Estimates > Multiple Comparisons.
7. From the Type of Estimates list, click User-Defined Estimates.
8. From the Choose Type levels list, select Action (Action should already be selected by default) and Drama.
9. From the Choose Rating levels list, select PG-13 and R.
10. In the list entitled Year, enter the year 1998.
11. Click Add Estimates. Note that all possible combinations of the levels you specified are now displayed beneath the Add Estimates button.
12. In the Choose Initial Comparisons list, select All Pairwise Comparisons - Tukey HSD.

Check that your window is populated as shown in Figure 3.29.
13. Click OK.

The All Pairwise Differences report indicates that three of the six pairwise comparisons are significant. The All Pairwise Comparisons Scatterplot, shown in Figure 3.30, shows the confidence intervals for these comparisons in red. Also shown is the tooltip for one of these intervals, indicating that the interval compares Action, Rating R movies to Drama, Rating PG-13 movies, and that the mean difference in Domestic $ is -53.58.

Figure 3.29  Populated Used-Defined Estimates Window
14. From the Tukey HSD All Pairwise Comparisons report’s red triangle menu, select **Equivalence Tests**.

15. In the text box that appears, enter 50.

16. Click OK.

TOST tests are conducted to determine which movie categories differ, given that you consider categories that differ by less than 50 to be equivalent. The Equivalence Tests Scatterplot (Figure 3.31) indicates that four pairs of movie categories can be considered not equivalent.
Joint Factor Tests

The Joint Factor Test option appears when interaction effects are present. For each main effect in the model, JMP produces a joint test of whether all the coefficients for terms involving that main effect are zero. This test is conditional on all other effects being in the model. Specifically, the joint test is a general linear hypothesis test of a restricted model. In that model, all parameters that correspond to the specified effect and the interactions that contain it are set to zero.

Example of a Joint Factor Tests Report

1. Open the Big Class.jmp sample data table.
2. Select Analyze > Fit Model.
3. Select weight and click Y.
4. Select age, sex, and height and click Macros > Factorial to degree.
5. Verify that 2 appears in the Degree box.
6. Click Run.
7. From the red triangle next to Response weight, select Estimates > Joint Factor Tests.

The report shown in Figure 3.32 appears.

Note that the test for age has 15 degrees of freedom. This test involves the five parameters for age, the five parameters for age*sex, and the five parameters for height*age. The null hypothesis for this test is that all 15 parameters are zero.
Inverse Prediction

*Inverse prediction* occurs when you use a statistical model to infer the value of an explanatory variable, given a value of the response variable. Inverse prediction is sometimes referred to as *calibration*.

By selecting Inverse Prediction on the Estimates menu, you can estimate values of an independent variable, \(X\), that correspond to specified values of the response (Figure 8 and Figure 3.36). In addition, you can specify values for other explanatory variables in the model (Figure 3.36). The inverse prediction computation provides confidence limits for values of \(X\) that correspond to the specified response value. You can specify the response value to be the mean response or simply an individual response. For an example, see “Example of Inverse Prediction” on page 135.

Analyzing Multiple Explanatory Variables

When the model includes multiple explanatory variables, you can predict the value of \(X\) for the specified values of the other variables. You might want to predict the amount of running time that results in an oxygen uptake of 50 when one’s resting pulse rate is 60. You might want separate inverse predictions for both males and females. Specify these requirements using the inverse prediction option.

The inverse prediction window shows the list of explanatory variables to the left. (See Figure 3.36 for an example.) Each continuous variable is initially set to its mean. Each nominal or ordinal variable is set to its lowest level (in terms of value ordering). You must remove the value for the variable that you want to predict, setting it to missing. Also, you must specify the values of the other variables for which you want your inverse prediction to hold (if these differ from the default settings). In the list to the right in the window, you can supply one or more response values of interest. For an example, see “Example of Predicting a Single X Value with Multiple Model Effects” on page 137.

**Note:** The confidence limits for inverse prediction can sometimes result in a one-sided or even an infinite interval. For technical details, see “Inverse Prediction with Confidence Limits” on page 462 in the “Statistical Details” appendix.
Example of Inverse Prediction

In this example, you fit a regression model that predicts oxygen uptake from Runtime. Then you estimate the Runtime values that result in specified oxygen uptake values. There is only a single X, Runtime, so you start by using the Fit Y by X platform to obtain a visual approximation of the inverse prediction values.

1. Open the Fitness.jmp sample data table.
2. Select Analyze > Fit Y by X.
4. Select Runtime and click X, Factor.
5. Click OK.
6. From the red triangle menu, select Fit Line.

Use the crosshair tool as described below to approximate the Runtime value that results in a mean Oxy value of 50.

7. Select Tools > Crosshairs.
8. Click the Oxy axis at about 50 and then drag the cursor so that the crosshairs intersect with the prediction line.

Figure 3.33 shows that a Runtime of about 9.779 gives an inverse prediction of about 50 (49.97) for Oxy.

Figure 3.33  Bivariate Fit for Fitness.jmp
To obtain an exact prediction for Runtime, along with a confidence interval, use the Fit Model launch window as follows:

1. From the Fitness.jmp sample data table, select Analyze > Fit Model.
2. Select Oxy and click Y.
3. Select Runtime and then click Add.
4. Click Run.
5. From the red triangle menu next to Response Oxy, select Estimates > Inverse Prediction.
6. Enter four values for Oxy as shown in Figure 3.34.
7. Click OK.

**Figure 3.34  Completed Inverse Prediction Specification Window**

The Inverse Prediction report (Figure 3.35) gives predicted Runtime values that correspond to each specified Oxy value. The report also shows upper and lower 95% confidence limits for these Runtime values, relative to obtaining the mean response.
Figure 3.35 Inverse Prediction Report

The exact predicted Runtime resulting in an Oxy value of 50 is 9.7935. This value is close to the approximate Runtime value of 9.779 found in the Bivariate Fit report shown in Figure 3.33. The Inverse Prediction report also gives a plot showing the linear relationship between Oxy and Runtime and the confidence intervals.

Example of Predicting a Single X Value with Multiple Model Effects

This example predicts the Runtime that results in oxygen uptake of 50 when RstPulse is 60. The Runtime is predicted for both males and females.

1. From the Fitness.jmp sample data table, select Analyze > Fit Model.
2. Select Oxy and click Y.
3. Select Sex, Runtime, and RstPulse and then select Add.
4. Click Run.
5. From the red triangle menu next to Response Oxy, select Estimates > Inverse Prediction.
6. Delete the value for Runtime, because you want to predict that value.
7. Select the All box next to Sex to estimate Runtime for all levels of Sex.
8. Replace the mean for RstPulse with 60.
9. Enter the value 50 for Oxy as shown in Figure 3.36.
10. Click OK.
The report, shown in Figure 3.37, gives the predicted values of Runtime for both females and males. The report also includes 95% confidence intervals for Runtime values that give a mean response of 50.

The plot shows the linear fits for females and males, given that RstPulse is 60. The two confidence intervals are shown in red and blue, respectively. Note that the intervals overlap, indicating that the true values of Runtime leading to an Oxy value of 50 might be identical for both males and females. Stated differently, you cannot conclude that the values of Runtime that lead to an Oxy value of 50 differ for males and females, at the given confidence level.

Cox Mixtures

Note: This option is available only for mixture models.
Standard least squares fits mixture models using the parameterization suggested in Scheffé (1958). The parameters for this model cannot easily be used to judge the effects of the mixture components. The Cox Mixture model is a reparameterized and constrained version of the Scheffé model. Using its parameter estimates, you can derive factor effects and the response surface shape relative to a reference point in the design space. See Cornell (1990) for a complete discussion.

The Cox Mixture option opens a window where you enter the reference mixture. If you enter components for the reference mixture that do not sum to one, then the components are proportionately scaled so that they do sum to one. The rescaled mixture is shown in the report as the Reference Mixture.

**Example of Cox Mixtures**

1. Open the Five Factor Mixture.jmp sample data table.
2. Select **Analyze > Fit Model**.
3. Select Y1 and click Y.
4. Select X1, X2, X3, X4, and X5.
5. Select **Macros > Mixture Response Surface**.
6. Click **Run**.
7. From the red triangle menu next to Response Y1, select **Estimates > Cox Mixtures**.

![Cox Reference Mixture Window](image)

8. Type the reference mixture points shown in Figure 3.38.
9. Click **OK**.

The report (Figure 3.39) shows the parameter estimates for the Cox mixture model, along with standard errors, and hypothesis tests. The reference mixture is displayed on the right.
Parameter Power

The power of a statistical test is the probability that the test will be significant, if a difference actually exists. The power of the test indicates how likely your study is to declare a true effect to be significant. The Parameter Power option addresses retrospective power analysis.

Note: To ensure that your study includes sufficiently many observations to detect the required differences, use information about power when you design your experiment. This type of analysis is called prospective power analysis. Consider using the DOE platform to design your study. Both DOE > Sample Size and Power and DOE > Evaluate Design are useful for prospective power analysis. For an example of a prospective power analysis using standard least squares, see “Prospective Power Analysis” on page 199.

The power of a test to detect a difference is determined by the following factors:

- the unknown parameter values tested
- the sample size
- the unknown residual error variance
- the significance level of the test
- the size of the effect to be detected

Suppose that you have already conducted your study, analyzed your data, and found that an effect of interest is not significant. You might be interested in the size of the difference that you might have been likely to detect or the power of the test that you conducted. Or you might want to know the number of observations that you would have needed to detect a difference of a given size with high probability.
The Parameter Power option inserts three columns of values relating to retrospective power analysis in the Parameter Estimates report. The least significant value (LSV0.05), the least significant number (LSN0.05), and a power calculation (AdjPower0.05) are provided.

The Parameter Power calculations apply to a new sample that has the same variability profile as the observed sample.

Caution: The results provided by the LSV0.05, LSN, and AdjPower0.05 should not be used in prospective power analysis. They do not reflect the uncertainty inherent in a future study.

- **LSV0.05** is the least significant value. This number is the smallest absolute value of the estimate that would make this test significant at significance level 0.05. To be more specific, suppose that the number of observations, the mean square error and that the sum of squares and cross-products matrix for the design remain unchanged. Then, if the absolute value of the estimate had been less than LSV0.05, the Prob>|t| value would have exceeded 0.05. (For more details, see “The Least Significant Value (LSV)” on page 196.)

- **LSN** is the least significant number. This number is the number of observations that would make this test significant at significance level 0.05. Specifically, suppose that the estimate of the parameter, the mean square error, and the sum of squares and cross-products matrix for the design remain unchanged. Then, if the number of observations had been less than the LSN, the Prob>|t| value would have exceeded 0.05. (For more details, see “The Least Significant Number (LSN)” on page 196.)

- **AdjPower0.05** is the adjusted power value. This number is an estimate of the probability that this test will be significant. Sample values from the current study are substituted for the parameter values typically used in a power calculation. The adjusted power calculation adjusts for bias that results from direct substitution of sample estimates into the formula for the non-centrality parameter (Wright and O’Brien, 1988). (For more details, see “The Adjusted Power and Confidence Intervals” on page 197.)

The LSV, LSN, and adjusted power are useful in assessing a test's sensitivity. These retrospective calculations also provide an enlightening instructional tool. However, you must be cautious in interpreting these values (Hoenig and Heisey, 2001).

For further details about LSV, LSN, and adjusted power, see “Power Analysis” on page 193. For an example of a retrospective analysis, see “Example of Retrospective Power Analysis” on page 198.

For details about LSV, LSN, and adjusted power, select the Fitting Linear Models PDF file from the Help > Books menu. See the section called Power Analysis in the Statistical Details appendix of the Fitting Standard Least Squares Models chapter.
Correlation of Estimates

The Correlation of Estimates command on the Estimates menu computes the correlation matrix for the parameter estimates. These correlations indicate whether collinearity is present.

For insight on the construction of this matrix, consider the typical least squares regression formulation. Here, the response \( (Y) \) is a linear function of predictors \( (x's) \) plus error \( (\varepsilon) \):

\[
Y = \beta_0 + \beta_1 x_1 + \ldots + \beta_p x_p + \varepsilon
\]

Each row of the data table contains a response value and values for the \( p \) predictors. For each observation, the predictor values are considered fixed. However, the response value is considered to be a realization of a random variable.

Considering the values of the predictors fixed, for any set of \( Y \) values, the coefficients, \( \beta_0, \beta_1, \ldots, \beta_p \), can be estimated. In general, different sets of \( Y \) values lead to different estimates of the coefficients. The Correlation of Estimates option calculates the theoretical correlation of these parameter estimates. (For technical details, see “Details of Custom Test Example” on page 188.)

The correlations of the parameter estimates depend solely on the predictor values and a term representing the intercept. The correlation between two parameter estimates is not affected by the values of the response.

A high positive correlation between two estimates suggests that a collinear relationship might exist between the two corresponding predictors. Note, though, that you need to interpret these correlations with caution (Belsley, D. A., Kuh, E., and Welsch, R. E., 1980, p. 185 and pp. 92-94). Also, a rescaling of a predictor that shifts its mean changes the correlation of its parameter estimate with the intercept’s value.

Example of Correlation of Estimates

1. Open the Socioeconomic.jmp sample data table.
2. Select Analyze > Fit Model.
3. Select Median House Value and click Y.
4. Select Total Population, Median School Years, Total Employment, and Professional Services and click Add.
5. In the Emphasis list, select Minimal Report.
6. Click Run.
7. From the Response red triangle menu, select Estimates > Correlation of Estimates.
The report (Figure 3.40) shows high negative correlations between the parameter estimates for the Intercept and Median School Years (–0.9818). High negative correlations also exist between Total Population and Total Employment (–0.9746).

**Coding for Nominal Effects**

When you enter a column with a nominal modeling type into your model, JMP represents it internally as a set of continuous indicator variables. Each variable assumes only the values –1, 0, and 1. (Note that this coding is one of many ways to use indicator variables to code nominal variables.) If your nominal column has \( n \) levels, then \( n-1 \) of these indicator variables are needed to represent it. (The need for \( n-1 \) indicator variables relates directly to the fact that the main effect associated with the nominal column has \( n-1 \) degrees of freedom.) Full details are covered in “Nominal Factors” on page 433 in the “Statistical Details” appendix.

Suppose that you have a nominal column with four levels. Take, as an example, the `treatment` column in the `Cholesterol.jmp` sample data table. The `treatment` column has four levels: A, B, Control, and Placebo. Each of the first three levels is represented by an indicator variable. These indicator variables are named `treatment[A]`, `treatment[B]`, and `treatment[Control]`.

The indicator variable for a given level assigns the values 1 to that level, –1 to the last level, and 0 to the remaining levels. Table 3.14 shows the definitions of the `treatment[A]`, `treatment[B]`, and `treatment[Control]` indicator variables for this example. For example, consider the indicator variable `treatment[A]`. As shown in Table 3.14, this variable assigns values as follows:

- The value 1 is assigned to rows that have `treatment` = A
- The value 0 is assigned to rows that have `treatment` = B or Control
- The value –1 is assigned to rows that have `treatment` = Placebo
The order of the levels is determined either by the Value Ordering column property, if you have assigned one, or by the default ordering assigned by JMP. The default ordering is typically the numeric sorting order for numbers and the alphanumeric sorting order for character data. However, certain categorical values, such as the names of months, are sorted appropriately by default. For details about value ordering, see the Using JMP book.

These variables are used to parametrize the model. They do not typically appear in the data table, but the estimated coefficients for these variables are given in the Parameter Estimates and other reports. Although many other codings are possible, this coding has proven to be practical and interpretable.

For information about the coding of ordinal effects, see “Ordinal Factors” on page 444 in the “Statistical Details” appendix.

**Effect Screening**

A screening design often provides no degrees of freedom for error. So classical tests for effects are not available. In such cases, Effect Screening is particularly useful.

For these designs, most inferences about effect sizes assume that the estimates for non-intercept parameters are uncorrelated and have equal variances. These assumptions hold for the models associated with many classical experimental designs. However, there are situations where these assumptions do not hold. In both of these situations, the Effect Screening platform guides you in determining which effects are significant.

The Effect Screening platform uses the principle of effect sparsity (Box and Meyer, 1986). This principle asserts that relatively few of the effects that you study in a screening design are active. Most are inactive, meaning that their true effects are zero and that their estimates are random error.

The following Effect Screening options are available:

**Scaled Estimates**  Gives parameter estimates corresponding to factors that are scaled to have a mean of zero and a range of two. See “Scaled Estimates and the Coding of Continuous...”
Terms” on page 145.

**Normal Plot**  Identifies parameter estimates that deviate from normality, helping you determine which effects are active. See “Normal Plot Report” on page 151.

**Bayes Plot**  Computes posterior probabilities for all model terms using a Bayesian approach. See “Bayes Plot Report” on page 152.

**Pareto Plot**  Plots the absolute values of the orthogonalized and standardized parameter estimates, relating these to the sum of their absolute values. See “Pareto Plot Report” on page 154.

### Scaled Estimates and the Coding of Continuous Terms

A parameter estimate is highly dependent on the scale of its corresponding factor. When you convert a factor from grams to kilograms, its parameter estimate changes by a multiple of a thousand. When you apply the same change to a squared (quadratic) term, its parameter estimate changes by a multiple of a million.

To better understand and compare effect sizes, you should examine parameter estimates in a scale-invariant fashion. It makes sense to use a scale that relates the size of a parameter estimate to the size of the effect of its corresponding term on the response. There are many approaches to doing this.

The Effect Screening > Scaled Estimates command on the report’s red triangle menu gives coefficients corresponding to scaled factors. The factors are scaled to have a mean of zero and a range of two.

If the sample values for the factor are such that the maximum and minimum values are equidistant from the sample mean, then the scaled factor ranges from –1 to 1. This scaling corresponds to the traditional coding used in the design of experiments. In the case of regression with a single factor, the scaled parameter estimate is half of the predicted response change as the factor travels its whole range.

Scaled estimates are important in assessing the impact of model terms when the data involve uncoded values. For orthogonal designs, the scaled estimates are identical to the estimates for the uncoded data.

**Note:** The Coding column property scales factor values linearly so that their coded values range from –1 to 1. Parameter estimates are given in terms of these coded values, so that scaled estimates are not required in this situation. (Unlike the transformation used to obtain scaled estimates, the coded values might not have mean zero.)

### Example of Scaled Estimates

1. Open the Drug jmp sample data table.
2. Select Analyze > Fit Model.
3. Select y and click Y.
4. Select Drug and x and add these to the Construct Model Effects list.
6. Click Run.
7. From the red triangle menu next to Response y, select Effect Screening > Scaled Estimates.

The report (Figure 3.41) indicates that the continuous factor, x, is centered by its mean and scaled by its half-range.

**Figure 3.41** Scaled Estimates Report

The model fits three parallel lines, one for each Drug group. The x values range from 3 to 21.
The Scaled Estimate for x, 8.8846543, is half the difference between the predicted value for x = 21 and the predicted value for x = 3 for any one of the Drug groups. You can verify this fact by selecting Save Columns > Prediction Formula from the report's red triangle menu. Then add rows to obtain predicted values for each of the Drug groups at x = 21 and x = 3.

So, over the range of x values in this particular data set, the impact of x is to vary the response over a range of about 17.8 units. Note that the parameter estimate for x based on the raw data is 0.9871838; it does not permit direct interpretation in terms of the response.

**Plot Options**

The Normal, Bayes, and Pareto Plot options provide reports that appear as part of the Effect Screening report. These reports can be constructed so that they correct for unequal variances and correlations among the estimates.

**Note:** The Normal, Bayes, and Pareto Plot options require that your model involves at least four parameters, one of which can be the intercept.

**Transformations**

When you select any of the plot options, the following information appears directly beneath the Effect Screening report title:
• If the estimates have equal variances and are uncorrelated, these two notes appear:
  – The parameter estimates have equal variances.
  – The parameter estimates are not correlated.

• If the estimates have unequal variances or are correlated, then an option list replaces the relevant note. The list items selected by default show that JMP has transformed the estimates. If you want to undo either or both transformations, select the appropriate list items.

Lenth PSE Values

A Lenth PSE (pseudo standard error) table appears directly beneath the notes or option lists. (For a description of the PSE, see “Lenth’s PSE” on page 112.)

The Lenth table provides one or two of the following statistics:

Lenth PSE The Lenth pseudo standard error for the estimates. Lenth PSE is provided when the parameter estimates have equal variances and are uncorrelated.

t-Test Scale Lenth PSE The Lenth pseudo standard error computed for the transformed parameter estimates divided by their standard errors in the transformed scale. It is provided when the parameter estimates have unequal variances or are uncorrelated or both.

Coded Scale Lenth PSE The Lenth pseudo standard error for the transformed parameter estimates. It is provided when the parameter estimates have unequal variances or are uncorrelated or both.

Parameter Estimate Population Report

The Parameter Estimate Population report gives tests for the parameter estimates. The tests are based on transformations as specified in the option lists.

• The option Using estimates standardized to have equal variances applies a normalizing transformation to standardize the variances. This option is selected by default when the variances are unequal.

• The option Using estimates orthogonalized to be uncorrelated applies a transformation to remove correlation. This option is selected by default when the estimates are correlated. The transformation that is applied is identical to the transformation that is used to calculate sequential sums of squares. The estimates measure the additional contribution of the variable after all previous variables have been entered into the model.

• If the notes indicate that the estimates have equal variances and are not correlated, no transformation is applied.

The columns that appear in the table depend on the selections initially described in the notes or option lists. The report highlights any row corresponding to an estimate with a \(p\)-value of
0.15 or less. All versions of the report give Term, Estimate, and either $t$-Ratio and Prob>|t| or Pseudo $t$-Ratio and Pseudo $p$-Value.

**Term**  Gives the model term whose parameter estimate is of interest.

**Estimate**  Gives the estimate for the parameter. Estimate sizes can be compared only when the model effects have identical scaling.

**$t$-Ratio**  Appears if there are degrees of freedom for error. This value is the parameter estimate divided by its standard error.

**Prob>|t|**  Gives the $p$-value for the test. If a transformation is applied, this option gives the $p$-value for a test using the transformed data.

**Pseudo $t$-Ratio**  Appears when there are no degrees of freedom for error. If the relative standard errors of the parameters are equal, Pseudo $t$-Ratio is the parameter estimate divided by Lenth's PSE. If the relative standard errors vary, it is calculated as shown in “Pseudo $t$-Ratios” on page 112.

**Pseudo $p$-Value**  Appears when there are no degrees of freedom for error. The $p$-value is derived using a $t$ distribution. The degrees of freedom are $m/3$, rounded down to the nearest integer, where $m$ is the number of parameters.

If Using estimates standardized to have equal variances is selected and the note indicating that the parameter estimates are not correlated appears, the report shows a column called Standardized Estimate. This column provides estimates of the parameters resulting from the transformation used to transform the estimates to have equal variances.

If both Using estimates standardized to have equal variances and Using estimates orthogonalized to be uncorrelated are selected, the report gives a column called Orthog Coded. The following information is provided:

**Orthog Coded**  Gives the estimate of the parameter resulting from the transformation that is used to orthogonalize the estimates.

**Orthog $t$-Ratio**  Appears if there are degrees of freedom for error. Gives the $t$ ratio for the transformed estimates.

**Pseudo Orthog $t$-Ratio**  Appears if there are no degrees of freedom for error. It is a $t$ ratio computed by dividing the orthogonalized estimate, Orthog Coded, by Coded Scale Lenth PSE.

**Effect Screening Report**

Figure 3.42 shows the Effect Screening report that you create by running the Fit Model script in the Bicycle.jmp sample data table. Note that you would select Effect Screening > Normal Plot in order to obtain this form of the report. The notes directly beneath the report title indicate that no transformation is required. Consequently, the Lenth PSE is displayed. Because there are no degrees of freedom for error, no estimate of residual error can be constructed. For this reason, Lenth's PSE is used as an estimate of residual error to obtain pseudo $t$ ratios.
Pseudo $p$-values are given for these $t$ ratios. Rows corresponding to the three estimates with $p$-values of 0.15 or less are highlighted.

**Figure 3.42** Effect Screening Report for Equal Variance and Uncorrelated Estimates

<table>
<thead>
<tr>
<th>Term</th>
<th>Estimate</th>
<th>Pseudo $t$-Ratio</th>
<th>Pseudo $p$-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>65.5300</td>
<td>88.0007</td>
<td>0.0001*</td>
</tr>
<tr>
<td>HRiard(down)</td>
<td>0.5000</td>
<td>0.0007</td>
<td>0.5736</td>
</tr>
<tr>
<td>Distan(set)</td>
<td>-4.9900</td>
<td>-0.2000</td>
<td>0.1014</td>
</tr>
<tr>
<td>Soft(set)</td>
<td>1.5900</td>
<td>0.5900</td>
<td>0.4644</td>
</tr>
<tr>
<td>Tresp[hrad]</td>
<td>-1.2500</td>
<td>-1.6667</td>
<td>0.2275</td>
</tr>
<tr>
<td>Rest[low]</td>
<td>0.2500</td>
<td>0.3333</td>
<td>0.7086</td>
</tr>
<tr>
<td>Rtes[om]</td>
<td>0.3000</td>
<td>0.3333</td>
<td>0.7086</td>
</tr>
</tbody>
</table>

Effect Screening Report for Unequal Variances and Correlated Estimates

In the Odor.jmp sample data table, run the Model script and click Run. To create the report shown in Figure 3.43, select **Effect Screening > Normal Plot** from the Response Y red triangle menu. You can also create the report by selecting the Bayes Plot or Pareto Plot options in the Response Y red triangle menu.

The notes directly beneath the report title indicate that transformations were required both to standardize and orthogonalize the estimates. The correlation matrix is shown in the Correlation of Estimates report.

The report shows the $t$-Test Scale and Coded Scale Lenth PSEs. But, because there are degrees of freedom for error, the tests in the Parameter Estimate Population report do not use the Lenth PSEs. Rows corresponding to the three estimates with $p$-values of 0.15 or less are highlighted. A note at the bottom of the Parameter Estimate Population report indicates that orthogonalized estimates depend on their order of entry into the model.
Correlations of Estimates Report

The Correlations of Estimates report appears only if the estimates are correlated (Figure 3.43). The report provides the correlation matrix for the parameter estimates. This matrix is similar to the one that you obtain by selecting the Estimates > Correlation of Estimates red triangle option. However, to provide a more compact representation, the report does not show column headings. See “Correlation of Estimates” on page 142 for details.

“Transformation to make uncorrelated” Report

The “Transformation to make uncorrelated” report appears only if the estimates are correlated. The report gives the matrix used to transform the design matrix to produce uncorrelated parameter estimates. The transformed, or orthogonally coded, estimates are obtained by pre-multiplying the original estimates with this matrix and dividing the result by 2.

The transformation matrix can be obtained using the Cholesky decomposition. Express $X'X$ as $LL'$, where $L$ is the lower triangular matrix in the Cholesky decomposition. Then the transformation matrix is given by $L'$. 
This transformation orthonormalizes each regressor with respect to the regressors that precede it in the ordering of model terms. The transformation produces a diagonal covariance matrix with equal diagonal elements. The coded estimates are a result of this iterative process.

**Note:** The orthogonally coded estimates depend on the order of terms in the model. Each effect’s contribution is estimated only after it is made orthogonal to previously entered effects. Consider entering main effects first, followed by two-way interactions, then three-way interactions, and so on.

### Normal Plot Report

Below the Normal Plot report title, select either a normal plot or a half-normal plot (Daniel 1959). Both plots are predicated on the principle of effect sparsity, namely, the idea that relatively few effects are active. Those effects that are inactive represent random noise. Their estimates can be assumed to have a normal distribution with mean 0 and variance $\sigma^2$, where $\sigma^2$ represents the residual error variance. It follows that, on a normal probability plot, estimates representing inactive effects fall close to a line with slope $\sigma$.

**Normal Plot**

If no transformation is required, the vertical coordinate of the normal plot represents the value of the estimate and the horizontal coordinate represents its normal quantile. Points that represent inactive effects should follow a line with slope of $\sigma$. Lenth’s PSE is used to estimate $\sigma$ and a blue line with this slope is shown on the plot.

If a transformation to orthogonality has been applied, the vertical axis represents the Normalized Estimates. These are the Orthog $t$-Ratio values found in the Parameter Estimate Population report. (The Orthog $t$-Ratio values are the Orthog Coded estimates divided by the Coded Scale Lenth PSE.)

Because the estimates are normalized by an estimate of $\sigma$, the points corresponding to inactive effects should fall along a line of slope 1. A red line with slope 1 is shown on the plot, as well as a blue line with slope equal to the t-Test Scale Lenth PSE.

In all cases, estimates that deviate from normality at the 0.15 level, based on the $p$-values in the Parameter Estimate Population report, are labeled on the plot.

**Half-Normal Plot**

The half normal plot shows the absolute values of effects. The construction of the axes and the lines displayed mirror those aspects of normal plot.

Figure 3.44 shows the Normal Plot report for the Bicycle.jmp sample data table. No transformation is needed for this model, so the plot shows the raw estimates plotted against their normal quantiles. A line with slope equal to Lenth’s PSE is shown on the plot. The plot suggests that Gear, Dynamo, and Seat are active factors.
Example of a Normal Plot

1. Open the Bicycle.jmp sample data table.
2. Select Analyze > Fit Model.
3. Select Y and click Y.
4. Select HBars through Brkfast and click Add.
5. Click Run.
6. From the red triangle menu next to Response Y, select Effect Screening > Normal Plot.

The following Normal Plot appears.

![Normal Plot](image)

Bayes Plot Report

The Bayes Plot report gives another approach to determining which effects are active. This report helps you compute posterior probabilities using a Bayesian approach. This method, due to Box and Meyer (1986), assumes that the estimates are a mixture from two distributions. The majority of the estimates, corresponding to inactive effects, are assumed to be pure random normal noise with variance $\sigma^2$. The remaining estimates, the active ones, are assumed to come from a contaminating distribution that has a variance $K$ times larger than $\sigma^2$.

- **Term**: Gives the model term corresponding to the parameter estimate.
- **Estimate**: Gives the parameter estimate. The Bayes plot is constructed with respect to estimates that have estimated standard deviation equal to 1. If the estimates are not correlated, the $t$-Ratio is used. If the estimates are correlated, the Orthog $t$-Ratio is used.
- **Prior Prob**: Enables you to specify a probability that the estimate is nonzero (equivalently, that the estimate is in the contaminating distribution). Prior probabilities for estimates are
usually set to equal values. The commonly recommended value of 0.2 appears initially, though you can change it.

**K Contam**  The value of the contamination coefficient, representing the ratio of the contaminating distribution variance to the error variance. $K$ is commonly set to 10, which is the default value.

**Std Err Scale**  If there are degrees of freedom for an estimate of standard error, this value is set to 1. JMP uses this value because the estimates used in the report are transformed and scaled to unit variance. The value is set to 0 for a saturated model with no estimate of error. If you specify a different value, think of it in terms of a scale factor of the RMSE estimate.

**DFE**  Gives the error degrees of freedom.

The specifications window, showing default settings for a Bayes Plot for the Bicycle.jmp sample data table, is shown in Figure 3.45. Clicking Go in this window updates the report to show Posterior probabilities for each of the terms and a bar chart (Figure 3.46).

**Example of a Bayes Plot**

1. Open the Bicycle.jmp sample data table.
2. Select Analyze > Fit Model.
3. Select Y and click Y.
4. Select HBars through Brkfast and click Add.
5. Click Run.
6. From the red triangle menu next to Response Y, select Effect Screening > Bayes Plot.

**Figure 3.45 Bayes Plot Specifications**

7. Click Go to calculate the posterior probabilities.
Figure 3.46 Bayes Plot Report

The note beneath the plot in the Bayes Plot report gives the Posterior Prob that the sample is uncontaminated. Posterior Prob is the probability, based on the priors and the data, that there are no active effects whatsoever. The probability is small, 0.0144, indicating that it is likely that there are active effects. The Posterior probability column suggests that at least Dynamo and Gear are active effects.

Pareto Plot Report

The Pareto Plot report presents a Pareto chart of the absolute values of the estimates. Figure 3.47 shows a Pareto Plot report for the Bicycle.jmp sample data table.

- If the original estimates have equal variances and are not correlated, the original estimates are plotted.
- If the original estimates have unequal variances and are not correlated, the t ratios are plotted.
- If the original estimate have unequal variances and are correlated, the Orthog Coded estimates are plotted.

The cumulative sum line in the plot sums the absolute values of the estimates. Keep in mind that the orthogonal estimates depend on the order of entry of terms into the model.

Note: The estimates that appear in the plot are standardized to have equal variances and are transformed to be orthogonal. You have the option of undoing these transformations. See “Transformations” on page 147.

Figure 3.47 Pareto Plot
Factor Profiling

The Factor Profiling menu helps you explore and visualize your estimated model. You can explore the shape of the response surface, find optimum settings, simulate response data based on your specified noise assumptions, and transform the response if needed. The Profiler, Contour Profiler, Mixture Profiler, and Surface Profiler are extremely versatile tools whose use extends beyond standard least squares models. Details on their interpretation and use are found in the Profilers book.

Table 3.15 Description of Factor Profiling Options

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Profiler</td>
<td>Shows prediction traces for each X variable. Enables you to find optimum settings for one or more responses and to explore response distributions using simulation. See “Profiler” on page 156 and the Profilers book.</td>
</tr>
<tr>
<td>Interaction Plots</td>
<td>Shows a matrix of interaction plots, when there are interaction effects in the model. See “Interaction Plots” on page 156.</td>
</tr>
<tr>
<td>Contour Profiler</td>
<td>Provides an interactive contour profiler, which is useful for optimizing response surfaces graphically. See “Contour Profiler” on page 158 and the Profilers book.</td>
</tr>
</tbody>
</table>
| Mixture Profiler      | Shows response contours of mixture experiment models on a ternary plot. See “Mixture Profiler” on page 159 and the Profilers book.  
                           **Note:** This option appears only if you apply the Mixture Effect attribute to three or more effects or the Mixture property to three or more columns. |
| Cube Plots            | Shows predicted values for the extremes of the factor ranges laid out on the vertices of cubes. See “Contour Profiler” on page 158. |
| Box Cox Y Transformation | Finds a Box-Cox power transformation of the response that is best in terms of satisfying the normality and homogeneity of variance assumptions. See “Box Cox Y Transformation” on page 160. |
| Surface Profiler      | Shows a three-dimensional surface plot of the response surface. See “Surface Profiler” on page 162 and the Profilers book. |
**Profiler**

**Note:** For complete details see the Profiler chapter of the Profilers book.

The **Profiler** (or Prediction Profiler) shows prediction traces for each X variable.

Figure 3.48 illustrates part of the profiler for the Reactor.jmp sample data table. The vertical dotted line for each X variable shows its current value or current setting. Use the Profiler to change one variable at a time in order to examine the effect on the predicted response.

**Figure 3.48 Illustration of Prediction Traces**

The factors F and Ct in Figure 3.48 are continuous. If the factor is nominal, the x-axis displays the levels.

For each X variable, the value above the factor name is its current value. You change the current value by clicking in the graph or by dragging the dotted line where you want the new current value to be.

- The horizontal dotted line shows the current predicted value of each Y variable for the current values of the X variables.
- The black lines within the plots show how the predicted value changes when you change the current value of an individual X variable. The 95% confidence interval for the predicted values is shown by a dotted curve surrounding the prediction trace (for continuous variables) or an error bar (for categorical variables).

**Interaction Plots**

When there are interaction effects in the model, the Interaction Plots option shows a matrix of interaction plots. Each cell of the matrix contains a plot whose horizontal axis is scaled for the effect displayed in the column in which the plot appears. Line segments are plotted for the interaction of that effect with the effect displayed in the corresponding row. So, an interaction plot shows the interaction of the row effect with the column effect.
A line segment is plotted for each level of the row effect. Response values predicted by the model are joined by line segments. Non-parallel line segments give visual evidence of possible interactions. However, the p-value for such a suggested interaction should be checked before concluding that it exists. Figure 3.49 gives an interaction plot matrix for the Reactor.jmp sample data table.

**Example of Interaction Plots**

1. Open the Reactor.jmp sample data table.
2. Select **Analyze > Fit Model**.
3. Select **Y** and click **Y**.
4. Make sure that the **Degree** box has a 2 in it.
5. Select **Ct**, **A**, **T**, and **Cn** and click **Macros > Factorial to Degree**.
6. Click **Run**.
7. From the red triangle menu next to Response Y, select **Factor Profiling > Interaction Plots**.

**Figure 3.49 Interaction Plots**

The plot corresponding to the T*Cn interaction is the third plot in the bottom row of plots or equivalently, the third plot in the last column of plots. Either plot shows that the effect of Cn on Y is fairly constant at the low level of T, whether Cn is set at a high or low level. However, at the high level of T, the effect of Cn on Y differs based on its level. Cn at –1 leads to a higher predicted Y than Cn at 1. Note that this interaction is significant with a p-value < 0.0001.

In certain designs, two-way interactions are aliased with other two-way interactions. When this aliasing occurs, cells in the Interaction Profiles plot corresponding to these interactions are dimmed.
Contour Profiler

Note: For complete details see the Contour Profiler chapter of the Profilers book.

Use the interactive Contour Profiler for optimizing response surfaces graphically. The Contour Profiler shows contours for the fitted model for two factors at a time. The report also includes a surface plot.

Figure 3.50 shows a contour profiler view for the Tiretread.jmp sample data table. Run the data table script RSM for 4 Responses and select Profilers > Contour Profiler from the Least Squares Fit report menu.

Figure 3.50 Contour Profiler

Choose the axes for the contour plot. Slide or edit to move the cross hairs and change the current factor values.

Slide or edit to change the desired response contour. Shades the area outside the limits.
Mixture Profiler

**Note:** This option appears only if you specify the **Macros > Mixture Response Surface** option for an effect. For complete details see the Mixture Profiler chapter of the *Profilers* book.

The Mixture Profiler shows response contours of mixture experiment models on a ternary plot. Use the Mixture Profiler when three or more factors in your experiment are components in a mixture. The Mixture Profiler helps you visualize and optimize the response surfaces of your experiment.

Figure 3.51 shows the Mixture Profiler for the model in the Plasticizer.jmp sample data table. Run the **Model** data table script and then select **Factor Profiling > Mixture Profiler** from the report's red triangle menu. You modify plot axes for the factors by selecting different radio buttons at the top left of the plot. The Lo and Hi Limit columns at the upper right of the plot let you enter constraints for both the factors and the response.

**Figure 3.51  Mixture Profiler**
Cube Plots

The Cube Plots option displays predicted values for the extremes of the factor ranges. These values appear on the vertices of cubes (Figure 3.52). The vertices are defined by the smallest and largest observed values of the factor. When you have multiple responses, the multiple responses are shown stacked at each vertex.

Example of Cube Plots

1. Open the Reactor.jmp sample data table.
2. Select Analyze > Fit Model.
3. Select Y and click Y.
4. Make sure that the Degree box has a 2 in it.
5. Select Ct, A, T, and Cn and click Macros > Factorial to Degree.
6. Click Run.
7. From the Response Y red triangle menu, select Factor Profiling > Cube Plots.

Figure 3.52 Cube Plots

Note that there is one cube for Cn = –1 and one for Cn = 1. To change the layout so that the factors are mapped to different cube coordinates, click a factor name in the first cube. Drag it to cover the factor name for the desired axis. For example, in Figure 3.52, if you click T and drag it over Ct, then T and Ct (and their corresponding coordinates) exchange places. To see the levels of Cn in a single cube, exchange it with another factor in the first cube by dragging it over that factor.

Box Cox Y Transformation

A Box-Cox power transformation is used to transform the response so that the usual regression assumptions of normality and homogeneity of variance are more closely satisfied. The transformed response can then be fit using a regression model. However, you can also use
the Box-Cox power transformation to transform a variable for other reasons. This transformation is appropriate only when the response, $Y$, is strictly positive.

A commonly used transformation raises the response to some power. Box and Cox (1964) formalized and described this family of power transformations. The formula for the transformation is constructed to provide a continuous definition in terms of the parameter $\lambda$, and so that the error sums of squares are comparable. Specifically, the following equation provides the family of transformations:

$$Y_{\lambda} = \begin{cases} \frac{y^\lambda - 1}{\lambda y^{\lambda-1}} & \text{if } \lambda \neq 0 \\ y \ln(y) & \text{if } \lambda = 0 \end{cases}$$

Here, $\bar{y}$ denotes the geometric mean.

The Box Cox Y Transformation option fits transformations from $\lambda = -2$ to 2 in increments of 0.2. To choose a proper value of $\lambda$, the likelihood function for each of these transformations is computed. They are computed under the assumption that the errors are independent and normal with mean zero and variance $\sigma^2$. The value of $\lambda$ that maximizes the likelihood is selected. This value also minimizes the SSE over the selected values of $\lambda$.

The Box-Cox Transformations report displays a plot showing the sum of squares error (SSE) against the values of $\lambda$.

The Box Cox Y Transformation Options report provides the following options:

**Save Best Transformation**  Creates a new column in the data table and saves the formula for the best transformation.

**Save Specific Transformation**  Shows the best value for $\lambda$ but enables you to enter a value of $\lambda$ of your choice. Selecting this option also creates a column in the data table with the formula for your specified transformation.

**Table of Estimates**  Creates a new data table containing parameter estimates and SSE values for all $\lambda$ from –2 to 2, in increments of 0.2.

**Example of Box-Cox Y Transformation**

1. Open the Reactor.jmp sample data table.
2. Select Analyze > Fit Model.
3. Select Y and click Y.
4. Make sure that the Degree box has a 2 in it.
5. Select F, Ct, A, T, and Cn and click Macros > Factorial to Degree.
6. Click Run.
7. From the red triangle menu next to Response Y, select **Factor Profiling > Box Cox Y Transformation**.

The plot in Figure 3.53 shows that the best values of $\lambda$ are approximately between 1.0 and 1.5. The value that JMP selects, using its 0.2 unit grid of $\lambda$ values, is 1.2.

8. To see the 1.2 value, select **Save Best Transformation** and look at the formula or select **Save Specific Transformation** and look at the value presented.

9. To see the SSE values used to construct the graph, select **Table of Estimates**.

**Figure 3.53** Box Cox Y Transformation

---

**Surface Profiler**

*Note:* For complete details see the Surface Plot chapter of the *Profilers* book.

The Surface Profiler shows a three-dimensional surface plot of the response surface.

Figure 3.54 shows the Surface Profiler for the model in the Odor.jmp sample data table. Run the **Model** data table script and then select **Factor Profiling > Surface Profiler** from the report's red triangle menu. You can change the variables on the axes using the radio buttons under **Independent Variables**. Also, you can plot points by clicking **Actual** under **Appearance**.
Row Diagnostics

The row diagnostics menu addresses issues specific to rows, or observations.

Table 3.16 Description of Row Diagnostics Options

<table>
<thead>
<tr>
<th>Plot Regression</th>
<th>Shows a Regression Plot report, displaying a scatterplot of the data and regression lines for each level of the categorical effect.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Note:</strong> This option only appears if there is exactly one continuous effect and no more than one categorical effect in the model. In that case, the Regression Plot report is provided by default.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Plot Actual by Predicted</th>
<th>Shows an Actual by Predicted plot, which plots the observed values of Y against the predicted values of Y. This plot is the leverage plot for the whole model. See “Leverage Plots” on page 164.</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Plot Effect Leverage</th>
<th>Shows a Leverage Plot report for each effect in the model. The plot shows how observations influence the test for that effect and gives insight on multicollinearity. See “Leverage Plots” on page 164.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Note:</strong> Effect Leverage Plots are shown by default when Effect Leverage is selected as the Emphasis in the Fit Model launch window. They appear to the right of the Whole Model report. When another Emphasis is selected, the Effect Leverage Plots appear in the Effect Details report. In all cases, the option Regression Reports &gt; Effect Details must be selected in order for Effect Leverage plots to display.</td>
<td></td>
</tr>
</tbody>
</table>
The response $Y$ is regressed on all the predictors except $X$, and the residuals are obtained. Call these residuals the $Y$-residuals. Then $X$ is regressed on all the other predictors in the model and the residuals are computed. Call these residuals the $X$-residuals. The $X$-residuals might...
contain information beyond what is present in the Y-residuals, which were obtained without X in the model.

The effect leverage plot for X is essentially a scatterplot of the X-residuals against the Y-residuals (Figure 3.57). To help interpretation and comparison with other plots that you might construct, JMP adds the mean of Y to the Y-residuals and the mean of X to the X-residuals. The translated Y-residuals are called the Y Leverage Residuals and the translated X-residuals are called X Leverage values. The points on the Effect Leverage plots are these X Leverage and Y Leverage Residual pairs.

JMP fits a least squares line to these points as well as confidence bands for the mean; the line of fit is solid red and the confidence bands are shown as dashed red curves. The slope of the least squares line is precisely the estimate of the coefficient on X in the model where Y is regressed on X and the other predictors. The dashed horizontal blue line is set at the mean of the Y Leverage Residuals. This line describes a situation where the X residuals are not linearly related to the Y residuals. If the line of fit has nonzero slope, then adding X to the model can be useful in terms of explaining variation.

Figure 3.55 shows how residuals are depicted in the leverage plot. The distance from a point to the line of fit is the residual for a model that includes the effect. The distance from the point to the horizontal line is what the residual error would be without the effect in the model. In other words, the mean line in the leverage plot represents the model where the hypothesized value of the parameter (effect) is constrained to zero.

**Figure 3.55 Illustration of a Generic Leverage Plot**

Confidence curves for the line of fit are shown on leverage plots. These curves provide a visual indication of whether the test of interest is significant at the 5% level (or at the Set Alpha Level that you specified in the Fit Model launch window). If the confidence region between the curves contains the horizontal line representing the hypothesis, then the effect is not significant. If the curves cross the line, the effect is significant. See the examples in Figure 3.56.
If the modeling type of a predictor X is continuous, then the x-axis is scaled in terms of the units of the X. The x-axis range mirrors the range of X values. The slope of the line of fit in the leverage plot is the parameter estimate for X. See the left illustration in Figure 3.57.

If the effect is nominal or ordinal, or if the effect is a complex effect such as an interaction, then the x-axis cannot represent the values of the effect directly. In this case the x-axis is scaled in units of the response, and the line of fit is a diagonal with a slope of 1. The Whole Model leverage plot, where the hypothesis of interest is that all parameter values are zero, uses this scaling. (See “Leverage Plot Details” on page 189.) For this plot, the x-axis is scaled in terms of predicted response values for the whole model, as illustrated by the right-hand plot in Figure 3.57.

The leverage plot for the linear effect in a simple regression is the same as the traditional plot of actual response values against the predictor.

**Leverage**

The term leverage is used because these plots help you visualize the influence of points on the test for including the effect in the model. A point that is horizontally distant from the center of the plot exerts more influence on the effect test than does a point that is close to the center. Recall that the test for an effect involves comparing the sum of squared residuals to the sum of squared residuals of the model with that effect removed. At the extremes, the differences of the residuals before and after being constrained by the hypothesis tend to be comparatively larger. Therefore, these residuals tend to have larger contributions to the sums of squares for that effect’s hypothesis test.

**Multicollinearity**

Multicollinearity is a condition where two or more predictors are highly related, or more technically, involved in a nearly linear dependent relationship. When multicollinearity is present, standard errors can be inflated and parameters estimates can be unstable. If an effect
is collinear with other predictors, the $y$-axis values are very close to the horizontal line at the mean, because the effect brings no new information. Because of the dependency, the $x$-axis values also tend to cluster toward the middle of the plot. This situation indicates that the slope of the line of fit is unstable.

**The Whole Model Actual by Predicted Plot**

The Plot Effect Leverage option produces a leverage plot for each effect in the model. In addition, the Actual by Predicted plot can be considered to be a leverage plot. This plot lets you visualize the test that all the parameters in the model (except the intercept) are zero. The same test is conducted analytically in the Analysis of Variance report. (See “Leverage Plot Details” on page 189 for details about this plot.)

**Example of a Leverage Plot for a Linear Effect**

1. Open the Big Class.jmp sample data table.
2. Select Analyze > Fit Model.
3. Select weight and click Y.
4. Select height, age, and sex, and click Add.
5. Click Run.

The Whole Model Actual by Predicted Plot and the effect Leverage Plot for height are shown in Figure 3.57. The Whole Model plot, on the left, tests for all effects. You can infer that the model is significant because the confidence curves cross the horizontal line at the mean of the response, weight. The Leverage Plot for height, on the right, also shows that height is significant, even with age and sex in the model. Neither plot suggests concerns relative to influential points or multicollinearity.

**Figure 3.57 Whole Model and Effect Leverage Plots**
Press

The Press, or prediction error sum of squares, statistic is an estimate of prediction error computed using leave-one-out cross validation. In leave-one-out cross validation, each observation, in turn, is removed. Consider a specific observation. The model is fit with that observation withheld and then a predicted value is obtained for that observation. The residual for that observation is computed. This procedure is applied to all observations and the residuals are squared and summed to give the Press value.

Specifically, the Press statistic is given by

$$\text{Press} = \frac{1}{n} \sum_{i=1}^{n} (\hat{y}_{(i)} - y_i)^2$$

where $n$ is the number of observations, $y_i$ is the observed response value for the $i^{th}$ observation, and $\hat{y}_{(i)}$ is the predicted response value for the $i^{th}$ observation. These values are based on a model fit without including that observation.

The Press RMSE is defined as $\sqrt{\text{Press}/n}$.

Save Columns

Each Save Columns option adds one or more new columns to the current data table. Additional Save Columns options appear when the fitting method is REML. These are detailed in “REML Save Columns Options” on page 180.

Note the following:

- When formulas are created, they are entered as Formula column properties.
- For many of the new columns, a Notes column property is added describing the column and indicating that Fit Least Squares created it.
- For the Predicted Formula and Predicted Values options, a Predicting column property is added. This property is used internally by JMP in conducting model comparisons (Analyze > Modeling > Model Comparison). When you fit many models, it is also useful to you because it documents the origin of the column.
### Table 3.17 Description of the Save Columns Options

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
</tr>
</thead>
</table>
| **Prediction Formula** | Creates a new column called Pred Formula <colname> that contains both the formula and the predicted values. A Predicting column property is added, noting the source of the prediction.  
  **Note:** Pred Formula <colname> inherits certain properties from <colname>. These include Response Limits, Spec Limits, and Control Limits. If you change these properties for <colname> after saving Pred Formula <colname>, they will not update in Pred Formula <colname>.  
  See “Prediction Formula” on page 171 for more details. |
| **Predicted Values**  | Creates a new column called Predicted <colname> that contains the predicted values computed by the specified model. Both a Notes and a Predicting column property are added, noting the source of the prediction.  
  **Note:** Predicted <colname> inherits certain properties from <colname>. These include Response Limits, Spec Limits, and Control Limits. If you change these properties for <colname> after saving Predicted <colname>, they will not update in Predicted <colname>. |
| **Residuals**        | Creates a new column called Residual <colname> that contains the observed response values minus their predicted values.                                                                                       |
| **Mean Confidence Interval** | Creates two new columns called Lower 95% Mean <colname> and Upper 95% Mean <colname>. These columns contain the lower and upper 95% confidence limits for the mean response.  
  **Note:** If you hold the SHIFT key while selecting the option, you are prompted to enter an $\alpha$ level for the computations. |
| **Indiv Confidence Interval** | Creates two new columns called Lower 95% Indiv <colname> and Upper 95% Indiv <colname>. These columns contain lower and upper 95% confidence limits for individual response values.  
  **Note:** If you hold the SHIFT key while selecting the option, you are prompted to enter an $\alpha$ level for the computations. |
<p>| <strong>Studentized Residuals</strong> | Creates a new column called Studentized Resid &lt;colname&gt;, which contains the residuals divided by their standard errors.                                                                                   |
| <strong>Hats</strong>             | Creates a new column called h &lt;colname&gt;. The column values are the diagonal values of the matrix $X(X'X)^{-1}X'$, sometimes called hat values.                                                                  |</p>
<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Std Error of Predicted</td>
<td>Creates a new column called StdErr Pred &lt;colname&gt; that contains the standard errors of the predicted mean response.</td>
</tr>
<tr>
<td>Std Error of Residual</td>
<td>Creates a new column called StdErr Resid &lt;colname&gt; that contains the standard errors of the residual values.</td>
</tr>
<tr>
<td>Std Error of Individual</td>
<td>Creates a new column called StdErr Indiv &lt;colname&gt; that contains the standard errors of the individual predicted response values.</td>
</tr>
</tbody>
</table>
| Effect Leverage Pairs          | Creates a set of new columns that contain the X Leverage values and Y Leverage Residuals for each leverage plot. For each effect in the model, two columns are added. If the response column name is R and the effect is X, the new column names are:  

  X Leverage of X for R  
  Y Leverage of X for R  

  In the columns panel, these columns are organized in a columns group called Leverage. |
| Cook's D Influence             | Creates a new column called Cook's D Influence <colname>, which contains values of the Cook's D influence statistic. |
| StdErr Pred Formula            | Creates a new column called PredSE <colname> that contains both the formula and the values for the standard error of the predicted values.  

  Note: The saved formula can be large. If you do not need the formula, use the Std Error of Predicted option. |
| Mean Confidence Limit Formula  | Creates two new columns called Lower 95% Mean <colname> and Upper 95% Mean <colname>. These columns contain both the formulas and the values for lower and upper 95% confidence limits for the mean response.  

  Note: If you hold the SHIFT key while selecting the option, you are prompted to enter an α level for the computations. |
| Indiv Confidence Limit Formula | Creates two new columns called Lower 95% Indiv <colname> and Upper 95% Indiv <colname>. These columns contain both the formulas and the values for lower and upper 95% confidence limits for individual response values.  

  Note: If you hold the SHIFT key while selecting the option, you are prompted to enter an α level for the computations. |
**Prediction Formula**

Pred Formula <colname> differs from Predicted <colname> in that it contains the prediction formula. Right-click in the Pred Formula <colname> column heading and select Formula to see the prediction formula. The prediction formula can require considerable space if the model is large. If you do not need the formula with the column of predicted values, use the Save Columns > Predicted Values option. For information about formulas, see the Using JMP book.

The Prediction Formula option is useful for predicting values in new rows or for use with the profilers. The profilers are available in the Fit Least Squares report (Factor Profiling). However, when your data table includes formula columns, you can also use the profilers provided in the Graph menu. When you are analyzing multiple responses, accessing the profilers from the Graph menu can be useful.

**Note:** If you select Graph > Profiler to access the profilers, first save the formula columns to the data table using Prediction Formula and StdErr Pred Formula. Then place both of these formulas into the Y, Prediction Formula role in the Profiler window. After you click OK, specify whether you want to use PredSE <colname> to construct confidence intervals for Pred Formula <colname>. Otherwise, JMP creates a separate profiler plot for PredSE <colname>.

**Mixed and Random Effect Model Reports and Options**

Mixed and random effect models can be specified in the Fit Model launch window. The Standard Least Squares personality fits the variance component covariance structure. Two methods, REML and EMS, are provided for fitting such models.

**Note:** JMP Pro users are encouraged to use the Mixed Model personality in the Fit Model window. The Mixed Model personality offers a broader set of covariance structures than does Standard Least Squares.
Mixed Models and Random Effect Models

A random effect model is a model all of whose factors represent random effects. (See “Random Effects” on page 172.) Such models are also called variance component models. Random effect models are often hierarchical models. A model that contains both fixed and random effects is called a mixed model. Repeated measures and split-plot models are special cases of mixed models. Often the term mixed model is used to subsume random effect models.

To fit a mixed model, you must specify the random effects in the Fit Model launch window. However, if all of your model effects are random, you can also fit your model in the Variability / Attribute Gauge Chart platform. Only certain models can be fit in this platform. Note that the fitting methods used in the Variability / Attribute Gauge Chart platform do not allow variance component estimates to be negative. For details about how the Variability / Attribute Gauge Chart platform fits variance components models, see the documentation in the Quality and Process Methods book.

Random Effects

A random effect is a factor whose levels are considered a random sample from some population. Often, the precise levels of the random effect are not of interest, rather it is the variation reflected by the levels that is of interest (the variance components). However, there are also situations where you want to predict the response for a given level of the random effect. Technically, a random effect is considered to have a normal distribution with mean zero and nonzero variance.

Suppose that you are interested in whether two specific ovens differ in their effect on mold shrinkage. An oven can process only one batch of 50 molds at a time. You design a study where three randomly selected batches of 50 molds are consecutively placed in each of the two ovens. Once the batches are processed, shrinkage is measured for five parts randomly selected from each batch.

Note that Batch is a factor with six levels, once for each batch. So, in your model, you include two factors, Oven and Batch. Because you are specifically interested in comparing the effect of each oven on shrinkage, Oven is a fixed effect. But you are not interested in the effect of these specific six batches on the mean shrinkage. These batches are representative of a whole population of batches that could have been chosen for this experiment and to which the results of the analysis must generalize. Batch is considered a random effect. In this experiment, the Batch factor is of interest in terms of the variation in shrinkage among all possible batches. Your interest is in estimating the amount of variation in shrinkage that it explains. (Note that Batch is also nested within Oven, because only one batch can be processed once in one oven.)

Now suppose that you are interested in the weight of eggs for hens subjected to two feed regimes. Ten hens are randomly assigned to feed regimes: Five are given Feed regime A and five are given Feed regime B. However, these ten hens have some genetic differences that are
not accounted for in the design of the study. In this case, you are interested in the predicted weight of the eggs from certain specific hens as well as in the variance of the weights of eggs among hens.

The Classical Linear Mixed Model

JMP fits the classical linear mixed effects model:

\[
Y = X\beta + Z\gamma + \epsilon
\]

\[
\gamma \sim N(0, G)
\]

\[
\epsilon \sim N(0, \sigma^2 I_n)
\]

Here,

- \(Y\) is an \(n \times 1\) vector of responses
- \(X\) is the \(n \times p\) design matrix for the fixed effects
- \(\beta\) is a \(p \times 1\) vector of unknown fixed effects with design matrix \(X\)
- \(Z\) is the \(n \times s\) design matrix for the random effects
- \(\gamma\) is an \(s \times 1\) vector of unknown random effects with design matrix \(Z\)
- \(\epsilon\) is an \(n \times 1\) vector of unknown random errors
- \(G\) is an \(s \times s\) diagonal matrix with identical entries for each fixed effect
- \(I_n\) is an \(n \times n\) identity matrix
- \(\gamma\) and \(\epsilon\) are independent

The diagonal elements of \(G\), as well as \(\sigma^2\), are called variance components. These variance components, together with the vector of fixed effects \(\beta\) and the vector of random effects \(\gamma\), are the model parameters that must be estimated.

The covariance structure for this model is sometimes called the variance component structure (SAS/STAT 9.2 User’s Guide, 2008, p. 3955). This covariance structure is the only one available in the Standard Least Squares personality.

The Mixed Model personality fits a variety of covariance structures, including Residual, First-order Autogressive (or \(AR(1)\)), Unstructured, and Spatial. See “Repeated Structure Tab” on page 284 in the “Mixed Models” chapter for more information.
REML versus EMS for Fitting Models with Random Effects

JMP provides two methods for fitting models with random effects:

- **REML**, which stands for *restricted maximum likelihood* (always the recommended method)
- **EMS**, which stands for *expected mean squares* (use only for teaching from old textbooks)

The REML method is now the mainstream fitting methodology, replacing the traditional EMS method. REML is considerably more general in terms of applicability than the EMS method. The REML approach was pioneered by Patterson and Thompson (1974). See also Wolfinger, Tobias, and Sall (1994) and Searle, Casella, and McCulloch (1992).

The EMS method, also called the *method of moments*, was developed before the availability of powerful computers. Researchers restricted themselves to balanced situations and used the EMS methodology, which provided computational shortcuts to compute estimates for random effect and mixed models. Because many textbooks still in use today use the EMS method to introduce models containing random effects, JMP provides an option for EMS. (See, for example, McCulloch, Searle, and Neuhaus, 2008, Poduri, 1997, and Searle, Casella, and McCulloch, 1992.)

The REML methodology performs maximum likelihood estimation of a restricted likelihood function that does not depend on the fixed-effect parameters. This yields estimates of the variance components that are then used to obtain estimates of the fixed effects. Estimates of precision are based on estimates of the covariance matrix for the parameters. Even when the data are unbalanced, REML provides useful estimates, tests, and confidence intervals.

The EMS methodology solves for estimates of the variance components by equating observed mean squares to expected mean squares. For balanced designs, a complex set of rules specifies how estimates are obtained. There are problems in applying this technique to unbalanced data.

For balanced data, REML estimates are identical to EMS estimates. But, unlike EMS, REML performs well with unbalanced data.

Specifying Random Effects and Fitting Method

Models with random effects are specified in the Fit Model launch window. To specify a random effect, highlight it in the Construct Model Effects list and select **Attributes > Random Effect**. This appends &Random to the effect name in the model effect list. (For a definition of random effects, see “Random Effects” on page 172.) Random effects can also be specified in a separate effects tab. (See “Construct Model Effects Tabs” on page 45 in the “Introduction to Fit Model” chapter.)

In the Fit Model launch window, once the &Random attribute has been appended to an effect, you are given a choice of fitting Method: REML (Recommended) or EMS (Traditional).
Caution: You must declare crossed and nested relationships explicitly. For example, a subject ID might also identify the group that contains the subject, as when each subject is in only one group. In such a situation, subject ID must still be declared as nested within group. Take care to be explicit in defining the design structure.

Unrestricted Parameterization for Variance Components

There are two different approaches to parameterizing the variance components: the unrestricted and the restricted approaches. The issue arises when there are mixed effects in the model, such as the interaction of a fixed effect with a random effect. Such an interaction term is considered to be a random effect.

In the restricted approach, for each level of the random effect, the sum of the interaction effects across the levels of the fixed effect is assumed to be zero. In the unrestricted approach, the mixed terms are simply assumed to be independent random realizations of a normal distribution with mean 0 and common variance. (This assumption is analogous to the assumption typically applied to residual error.)

JMP and SAS use the unrestricted approach. This distinction is important because many statistics textbooks use the restricted approach. Both approaches have been widely taught for 60 years. (For a discussion of both approaches, see Cobb, 1998, Section 13.3).

Negative Variances

Though variances are always positive, it is possible to have a situation where the unbiased estimate of the variance is negative. Negative estimates can occur in experiments when an effect is very weak or when there are very few levels corresponding to a variance component. By chance, the observed data can result in an estimate that is negative.

Unbounded Variance Components

JMP can produce negative estimates for both REML and EMS. For REML, there are two options in the Fit Model launch window: Unbounded Variance Components and Estimate Only Variance Components. The Unbounded Variance Components option is selected by default. Deselecting this option constrains variance component estimates to be nonnegative.

You should leave the Unbounded Variance Components option selected if you are interested in fixed effects. Constraining the variance estimates to be nonnegative leads to bias in the tests for the fixed effects.
Estimate Only Variance Components

Select this option if you want to see only the REML Variance Component Estimates report. If you are interested only in variance components, you might want to constrain variance components to be nonnegative. Deselecting the Unbounded Variance Components option and selecting the Estimate Only Variance Components option might be appropriate.

Restricted Maximum Likelihood (REML) Method

Based on the fitting method selected, the Fit Least Squares report provides different analysis results and provide additional menu options for Save Columns and Profiler. In particular, the analysis of variance report is not shown because variances and degrees of freedom do not partition in the usual way. You can obtain the residual variance estimate from the REML Variance Component Estimates report. (See “REML Variance Component Estimates” on page 178.) The Effect Tests report is replaced by the Fixed Effect Tests report where fixed effects are tested. Additional reports give predicted values for the random effects and details about the variance components.

Figure 3.58 shows the report obtained for a fit to the Investment Castings.jmp sample data using the REML method. Run the script Model - REML, and then fit the model. Note that Casting is a random effect and is nested within Temperature.

Figure 3.58  Fit Least Squares Report for REML Method
Random Effect Predictions

For each term in the model, this report gives an empirical estimate of its *best linear unbiased predictor* (BLUP) and a test for whether the corresponding coefficient is zero.

**Note:** The Regression Reports > Parameter Estimates option must be selected for the Random Effect Predictions report to appear.

<table>
<thead>
<tr>
<th>Table 3.18 Description of Random Effect Predictions Report</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Term</strong></td>
</tr>
<tr>
<td><strong>BLUP</strong></td>
</tr>
<tr>
<td><strong>Std Error</strong></td>
</tr>
<tr>
<td><strong>DFDen</strong></td>
</tr>
<tr>
<td><strong>t Ratio</strong></td>
</tr>
<tr>
<td>**Prob&gt;</td>
</tr>
<tr>
<td><strong>Lower 95%</strong></td>
</tr>
<tr>
<td><strong>Upper 95%</strong></td>
</tr>
</tbody>
</table>

**Best Linear Unbiased Predictors**

The term *best linear unbiased predictor* (BLUP) refers to an estimator of a random effect. Specifically, it is an estimator that, among all unbiased estimators, minimizes mean square prediction error. The Random Effect Predictions report gives estimates of the BLUPs, or *empirical* BLUPs. These are empirical because the BLUPs depend on the values of the variance components, which are unknown. The estimated values of the variance components are substituted into the formulas for the BLUPs, resulting in the estimates shown in the report.
REML Variance Component Estimates

When REML is selected as the fitting method in the Fit Model launch window, the REML Variance Component Estimates report is provided.

Table 3.19 Description of REML Variance Component Estimates Report

<table>
<thead>
<tr>
<th>Random Effect</th>
<th>Lists all random effects in the model.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Var Ratio</td>
<td>Gives the ratio of the variance component for the effect to the variance component for the residual. It compares the effect’s estimated variance to the model’s estimated error variance.</td>
</tr>
<tr>
<td>Var Component</td>
<td>Gives the estimated variance component for the effect. Note that the variance component for the Total is the sum of the positive variance components only. The sum of all variance components is given beneath the table.</td>
</tr>
<tr>
<td>Std Error</td>
<td>Gives the standard error for the variance component estimate.</td>
</tr>
<tr>
<td>95% Lower</td>
<td>Gives the lower 95% confidence limit for the variance component. (For details, see “Confidence Intervals for Variance Components” on page 178.)</td>
</tr>
<tr>
<td>95% Upper</td>
<td>Gives the upper 95% confidence limit for the variance component. (For details, see “Confidence Intervals for Variance Components” on page 178.)</td>
</tr>
<tr>
<td>Pct of Total</td>
<td>Gives the ratio of the variance component for the effect to the variance component for the total as a percentage.</td>
</tr>
<tr>
<td>Sqrt Variance Component</td>
<td>Gives the square root of the corresponding variance component. It is an estimate of the standard deviation for the effect.</td>
</tr>
<tr>
<td>Norm KHC</td>
<td>Gives the Kackar-Harville correction. (For details, see “Kackar-Harville Correction” on page 179.)</td>
</tr>
</tbody>
</table>

Note: Only appears if you right-click in the report and select Sqrt Variance Component.

Confidence Intervals for Variance Components

The method used to calculate the confidence limits depends on whether you have selected Unbounded Variance Components in the Fit Model launch window. Note that Unbounded Variance Components is selected by default.
• If Unbounded Variance Components is selected, Wald-based confidence intervals are computed. These are valid asymptotically but note that they can be unreliable with small samples.

• If Unbounded Variance Components is not selected, meaning that parameters have a lower boundary constraint of zero, a Satterthwaite approximation is used (Satterthwaite, 1946).

Kackar-Harville Correction

In the REML method, the standard errors of the fixed effects are estimated using estimates of the variance components. However, if variability in these estimates is not taken into account, the standard error is underestimated. To account for the increased variability, the covariance matrix of the fixed effects is adjusted using the Kackar-Harville correction (Kackar and Harville, 1984 and Kenward and Roger, 1997). All calculations that involve the covariance matrix of the fixed effects use this correction. These include least squares means, fixed effect tests, confidence intervals, and prediction variances. For statistical details, see “The Kackar-Harville Correction” on page 192.

Norm KHC is the Frobenius (matrix) norm of the Kackar-Harville correction. In cases where the design is fairly well balanced, Norm KHC tends to be small.

Covariance Matrix of Variance Components Estimates

This report gives an estimate of the asymptotic covariance matrix for the variance components. It is the inverse of the observed Fisher information matrix.

Iterations

The estimates of \( \sigma^2 \) and the variance components in \( G \) are obtained by maximizing a residual log-likelihood function that depends on only these parameters. An iterative procedure attempts to maximize the residual log-likelihood function, or equivalently, to minimize \( -2 \) times the residual log likelihood \( (-2 \text{LogLike}) \). The Iterations report provides details about this procedure.

**Iter**  Iteration number.

**-2LogLike**  Twice the negative log likelihood. It is the objective function.

**Norm Gradient**  The norm of the gradient (first derivative) of the objective function.
Parameters  The column labeled Parameters and the remaining columns each correspond to a random effect. The order of the columns follows the order in which random effects are listed in the REML Variance Component Estimates report. At each iteration, the value in the column is the estimate of the variance component at that point.

The convergence criterion is based on the gradient, with a default tolerance of $10^{-8}$. You can change the criterion in the Fit Model launch window by selecting the option Convergence Settings > Convergence Limit and specifying the desired tolerance.

Fixed Effect Tests

When REML is used, the Effect Tests report provides tests for the fixed effects.

Table 3.20 Description of Effect Tests Report

<table>
<thead>
<tr>
<th>Source</th>
<th>Lists the fixed effects in the model.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nparm</td>
<td>Gives the number of parameters associated with the effect.</td>
</tr>
<tr>
<td>DF</td>
<td>Gives the degrees of freedom associated with the effect.</td>
</tr>
<tr>
<td>DFDen</td>
<td>Gives the denominator degrees of freedom. These are based on an approximation to the distribution of the statistic obtained when the covariance matrix is adjusted using the Kenward-Roger correction. (See “Kackar-Harville Correction” on page 179 and “Random Effects” on page 77.)</td>
</tr>
<tr>
<td>FRatio</td>
<td>Gives the computed $F$ ratio.</td>
</tr>
<tr>
<td>Prob &gt; F</td>
<td>Gives the $p$-value for the effect test.</td>
</tr>
</tbody>
</table>

REML Save Columns Options

When you use the REML method, five additional options appear in the Save Columns menu. These option names start with the adjective Conditional. This prefix indicates that the calculations for these columns use the predicted values for the terms associated with the random effects, rather than their expected values of zero.

Table 3.21 Description of REML Save Columns Options

<table>
<thead>
<tr>
<th>Conditional Pred Formula</th>
<th>Saves the prediction formula to a new column in the data table.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conditional Pred Values</td>
<td>Saves the predicted values to a new column in the data table.</td>
</tr>
<tr>
<td>Conditional Residuals</td>
<td>Saves the residuals to a new column in the data table.</td>
</tr>
<tr>
<td>Conditional Mean CI</td>
<td>Saves the confidence interval for the mean.</td>
</tr>
</tbody>
</table>
REML Profiler Option

When you use the REML method and select Factor Profiling > Profiler, a new option, Conditional Predictions, appears on the red triangle menu next to Prediction Profiler. Note that the conditional values use the predicted values for the random effects, rather than their zero expected values.

Note: The profiler displays conditional predicted values and conditional mean confidence intervals for all combinations of factors levels, some of which might not be meaningful due to nesting.

EMS (Traditional) Model Fit Reports

Caution: The use of EMS is not recommended. REML is the recommended method.

When EMS is selected as the fitting method, four new reports are displayed. The Effect Tests report is not shown, as tests for both fixed and random effects are conducted in the Tests wrt Random Effects report.

Expected Mean Squares

The expected mean square for a model effect is a linear combination of variance components and fixed effect values, including the residual error variance. This table gives the coefficients that define each model effect’s expected mean square. The rows of the matrix correspond to the effects, listed to the left. The columns correspond to the variance components, identified across the top. Each expected mean square includes the residual variance with a coefficient of one. This information is given beneath the table.

Figure 3.59 shows the Expected Mean Squares report for the Investment Castings.jmp sample data table. Run the Model - EMS script and then run the model.

Figure 3.59 Expected Mean Squares Report
As indicated by the table, the expected mean square for Treatment is

$$16\theta^2_{Treatment} + 4\sigma^2_{Wafer[Treatment]} + \sigma^2_{Error}$$

where $\theta^2_{Treatment}$ is the sum of the squares of the effects for Treatment divided by the number of levels of Treatment minus one.

**Variance Component Estimates**

Estimates of the variance components are obtained by equating the expected mean squares to the corresponding observed mean squares and solving. The Variance Component Estimates report gives the estimated variance components.

- **Component**  Lists the random effects
- **Var Comp Est**  Gives the estimate of the variance component
- **Percent of Total**  Gives the ratio of the variance component to the sum of the variance components.
- **CV**  Gives the coefficient of variation for the variance component. It is 100 times the square root of the variance component, divided by the mean response. CV only appears if you right-click in the report and select Columns > CV. On Macintosh, press CONTROL and select Columns > CV.

**Test Denominator Synthesis**

For each effect to be tested, an F statistic is constructed. The denominator for this statistic is the mean square whose expectation is that of the numerator mean square under the null hypothesis. This denominator is constructed, or synthesized, from variance components and values associated with fixed effects.

- **Source**  Shows the effect to be tested
- **MS Den**  Gives the estimated mean square for the denominator of the $F$ test
- **DF Den**  Gives the degrees of freedom for the synthesized denominator. These are constructed using Satterthwaite’s method (Satterthwaite, 1946).
- **Denom MS Synthesis**  Gives the variance components used in the denominator synthesis. The residual error variance is always part of this synthesis.

**Tests wrt Random Effects**

Tests for fixed and random effects are presented in this report.

<table>
<thead>
<tr>
<th>Source</th>
<th>Lists the effects to be tested. These include fixed and random effects.</th>
</tr>
</thead>
<tbody>
<tr>
<td>SS</td>
<td>Gives the sum of squares for the effect.</td>
</tr>
</tbody>
</table>
Fitting Linear Models: Models with Linear Dependencies among Model Terms

Caution: Standard errors for least squares means and denominators for contrast F tests use the synthesized denominator. In certain situations, such as tests involving crossed effects compared at common levels, these tests might not be appropriate. Custom tests are conducted using residual error, and leverage plots are constructed using the residual error, so these also might not be appropriate.

EMS Profiler

When you use the EMS method and select Factor Profiling > Profiler, the profiler gives conditional predictions and conditional mean confidence intervals. (See “REML Save Columns Options” on page 180.) These conditional values use the predicted values for the random effects, rather than their zero expected values.

Note: The profiler displays conditional predicted values and conditional mean confidence intervals for all combinations of factors levels, some of which might not be meaningful due to nesting.

Models with Linear Dependencies among Model Terms

When there are linear dependencies among the columns of the matrix of predictors, several standard least squares reports are affected.

Singularity Details

The linear regression model is formulated as $Y = X\beta + \epsilon$. Here $X$ is a matrix whose first column consists of 1s, and whose remaining columns are the values of the non-intercept terms in the model. If the model consists of $p$ terms, including the intercept, then $X$ is an $n \times p$ matrix, where $n$ is the number of observations. The parameter estimates, denoted by the vector $b$, are typically given by the formula:

$$b = (X'X)^{-1}X'Y$$
However, this formula presumes that \( X'X^{-1} \) exists, in other words, that the \( p \times p \) matrix \( X'X \) is invertible, or equivalently, of full rank. Situations often arise when \( X'X \) is not invertible because there are linear dependencies among the columns of \( X \).

In such cases, the matrix \( X'X \) is singular, and the Fit Least Squares report displays a report entitled Singularity Details immediately below the main title bar (Figure 3.60). This report gives expressions that describe the linear dependencies. The terms involved in these linear dependencies are aliased (confounded).

Figure 3.60 shows reports for the Reactor 8 Runs.jmp sample data table. To obtain these reports, fit a model with Percent Reacted as Y. Enter Feed Rate, Catalyst, Stir Rate, Temperature, Concentration, Catalyst*Stir Rate, Catalyst*Concentration, and Feed Rate*Catalyst as model effects.

### Parameter Estimates Report

When \( X'X \) is singular, a generalized inverse is used to obtain estimates. This approach permits some, but not all, of the parameters involved in a linear dependency to be estimated. Parameters are estimated based on the order of entry of their associated terms into the model, so that the last terms entered are the ones whose parameters are not estimated. Estimates are given in the Parameter Estimates report, and parameters that cannot be estimated are given estimates of 0.

However, estimates of parameters for terms involved in linear dependencies are not unique. Because the associated terms are aliased, there are infinitely many vectors of estimates that satisfy the least squares criterion. In these cases, “Biased” appears to the left of these estimates in the Parameter Estimates report. “Zeroed” appears to the left of the estimates of 0 in the Parameter Estimates report for terms involved in a linear dependency whose parameters
cannot be estimated. For an example, see Figure 3.60.

If there are degrees of freedom available for an estimate of error, $t$ tests for parameters estimated using biased estimates are conducted. These tests should be interpreted with caution, though, given that the estimates are not unique.

**Effect Tests Report**

In a standard least squares fit, only as many parameters are estimable as there are model degrees of freedom. In conducting the tests in the Effect Tests report, each effect is considered to be the last effect entered into the model.

- If all the Model degrees of freedom are used by the other effects, an effect shows DF equal to 0. When DF equals 0, no sum of squares can be computed. Therefore, the effect cannot be tested.
- If not all Model degrees of freedom are used by the other effects, then that effect has nonzero DF. However, its DF might be less than its number of parameters (Nparm), indicating that only some of its associated parameters are testable.

An $F$ test is conducted if the degrees of freedom for an effect are nonzero, assuming that there are degrees of freedom for error. Whenever DF is less than Nparm, the description LostDFs is displayed to the far right in the row corresponding to the effect (Figure 3.60). These effects have the opportunity to explain only model sums of squares that have not been attributed to the aliased effects that have absorbed their lost degrees of freedom. It follows that the sum of squares given in the Effect Tests report most likely underrepresents the “true” sum of squares associated with the effect. If the test is significant, its significance is meaningful. But lack of significance should be interpreted with caution.


**Examples**

Open the Singularity.jmp sample data table. There is a response $Y$, four predictors $X_1, X_2, X_3,$ and $A$, and five observations. The predictors are continuous except for $A$, which is nominal with four levels. Also note that there is a linear dependency among the continuous effects, namely, $X_3 = X_1 + X_2$. 
Non-Uniqueness of Estimates

To see that estimates are not unique when there are linear dependencies:

1. Open the Singularity.jmp sample data table.
2. Run the script Model 1. The script opens a Fit Model launch window where the effects are entered in the order \( X_1, X_2, X_3 \).
3. Click Run and leave the report window open.
4. Run the script Model 2. The script opens a Fit Model launch window where the effects are entered in the order \( X_1, X_3, X_2 \).
5. Click Run and leave the report window open.

Compare the two reports (Figure 3.61). The Singularity Details report at the top of both reports displays the linear dependency, indicating that \( X_1 = X_3 - X_2 \).

Now compare the Parameter Estimates reports for both models. Note, for example, that the estimate for \( X_1 \) for Model 1 is –1.25 while for Model 2 it is 2.75. In both models, only two of the terms associated with effects are estimated, because there are only two model degrees of freedom. See the Analysis of Variance report. The estimates of the two terms that are estimated are labeled Biased while the remaining estimate is set to 0 and labeled Zeroed.

The Effect Tests report shows that no tests are conducted. Each row is labeled LostDFs. The reason this happens is as follows. The effect test for any one of these effects requires it to be entered into the model last. However, the other two effects entirely account for the model sum of squares associated with the two model degrees of freedom. So there are no degrees of freedom or associated sum of squares left for the effect of interest.

Figure 3.61  Fit Least Squares Reports for Model 1 (on left) and Model 2 (on right)
LostDFs

To gain more insight on LostDFs, follow the steps below or run the data table script Fit Model Report:

1. Open the Singularity.jmp sample data table.
2. Click Analyze > Fit Model.
3. Select Y and click Y.
4. Select X1 and A and click Add.
5. Set the Emphasis to Minimal.
6. Click Run.

Portions of the report are shown in (Figure 3.62). The Singularity Details report shows that there is a linear dependency involving X1 and the three terms associated with the effect A. (For details about how a nominal effect is coded, see “Details of Custom Test Example” on page 188). The Analysis of Variance report shows that there are three model degrees of freedom. The Parameter Estimates report shows Biased estimates for the three terms X1, A[a], and A[b] and a Zeroed estimate for the fourth, A[c].

The Effect Tests report shows that X1 cannot be tested, because A must be entered first and A accounts for the three model degrees of freedom. However, A can be tested, but with only two degrees of freedom. (X1 must be entered first and it accounts for one of the model degrees of freedom.) The test for A is partial, so it must be interpreted with care.

**Figure 3.62** Fit Least Squares Report for Model with X1 and A
**Statistical Details**

This chapter appendix contains further detail on topics related to material in this chapter.

**Emphasis Rules**

The default emphasis in the Fit Model launch window is based on the number of rows, \( n \), and the number of effects (\( k \)) entered in the Construct Model Effects list.

- If \( n > 1000 \), the Emphasis is set to Minimal Report.
- If \( n \leq 1000 \) and \( k \leq 4 \), the Emphasis is set at Effect Leverage.
- If \( n \leq 1000 \) and \( k \geq 10 \), the Emphasis is set at Effect Screening.
- If \( n \leq 1000 \) and \( 4 < k < 10 \) and \( n - k > 20 \), the Emphasis is set at Effect Leverage.
- If none of these conditions hold, the Emphasis is set at Effect Screening.

**Details of Custom Test Example**

In “Example of a Custom Test” on page 119, you are interested in testing three contrasts using the Cholesterol.jmp sample data table. Specifically, you want to compare:

- the mean responses for treatments A and B,
- the mean response for treatments A and B combined to the mean response for the control group,
- the mean response for treatments A and B combined to the mean response for the combined control and placebo groups.

To derive the contrast coefficients that you enter into the Custom Test columns, do the following. Denote the theoretical effects for the four treatment groups as: \( \alpha_A \), \( \alpha_B \), \( \alpha_{\text{Control}} \) and \( \alpha_{\text{Placebo}} \). These are the treatment effects, so they are constrained to sum to 0. Because the parameters associated with the indicator variables represent only the first three effects, you need to formulate your contrasts in terms of these first three effects. See “Details of Custom Test Example” on page 188 and “Interpretation of Parameters” on page 434 in the “Statistical Details” appendix for more information.

The hypotheses that you want to test can be written in terms of model effects as follows:

- Compare treatment A to treatment B: \( \alpha_A - \alpha_B = 0 \)
- Compare treatments A and B to the control group: \( 0.5(\alpha_A + \alpha_B) - \alpha_{\text{Control}} = 0 \)
- Compare treatments A and B to the control and placebo groups:
  \[
  0.5(\alpha_A + \alpha_B) - 0.5(\alpha_{\text{Control}} + \alpha_{\text{Placebo}}) = \alpha_A + \alpha_B = 0
  \]
To obtain contrast coefficients for this contrast, you need to write the placebo effect in terms of the model effects. Specifically, use the fact that \( \alpha_A + \alpha_B + \alpha_{Control} + \alpha_{Placebo} = 0 \). Then \( \alpha_{Placebo} = -\alpha_A - \alpha_B - \alpha_{Control} \). It follows that:

\[
0.5(\alpha_A + \alpha_B) - 0.5(\alpha_{Control} + \alpha_{Placebo}) = 0.5(\alpha_A + \alpha_B) - 0.5(\alpha_{Control} - \alpha_A - \alpha_B - \alpha_{Control})
\]

\[
= 0.5(\alpha_A + \alpha_B) - 0.5\alpha_{Control} + 0.5(\alpha_A + \alpha_B + \alpha_{Control})
\]

\[
= \alpha_A + \alpha_B
\]

\[
= 0
\]

**Correlation of Estimates**

Consider a data set with \( n \) observations and \( p - 1 \) predictors. Define the matrix \( X \) to be the design matrix. That is, \( X \) is the \( n \times p \) matrix whose first column consists of 1s and whose remaining \( p - 1 \) columns consist of the \( p - 1 \) predictor values. (Nominal columns are coded in terms of indicator predictors. Each of these is a column in the matrix \( X \).)

The estimate of the vector of regression coefficients is

\[
\hat{\beta} = (X'X)^{-1}X'Y
\]

where \( Y \) represents the vector of response values.

Under the usual regression assumptions, the covariance matrix of \( \hat{\beta} \) is

\[
Cov(\hat{\beta}) = \sigma^2(X'X)^{-1}
\]

where \( \sigma^2 \) represents the variance of the response.

The correlation matrix for the estimates is obtained by dividing each entry in the covariance matrix by the product of the square roots of the diagonal entries. Define \( V \) to be the diagonal matrix whose entries are the square roots of the diagonal entries of the covariance matrix:

\[
V = \text{Sqrt(Diag(Cov(\hat{\beta})))}
\]

Then the correlation matrix for the parameter estimates is given by:

\[
\text{Corr}(\hat{\beta}) = V^{-1}(X'X)^{-1}V
\]

**Leverage Plot Details**

Effect leverage plots are also referred to as partial-regression residual leverage plots (Belsley, Kuh, and Welsch, 1980) or added variable plots (Cook and Weisberg, 1982). Sall (1990) generalized these plots to apply to any linear hypothesis.
JMP provides two types of leverage plots:
- Effect Leverage plots show observations relative to the hypothesis that the effect is not in the model, given that all other effects are in the model.
- The Whole Model leverage plot, given in the Actual by Predicted Plot report, shows the observations relative to the hypothesis of no factor effects.

In the Effect leverage plot, only one effect is hypothesized to be zero. However, in the Whole Model Actual by Predicted plot, all effects are hypothesized to be zero. The paper by Sall (1990) generalizes the idea of a leverage plot to arbitrary linear hypotheses, of which the Whole Model leverage plot is an example. The details from that paper, summarized in this section, specialize to the two types of plots found in JMP.

### Construction

Suppose that the estimable hypothesis of interest is

\[ L\beta = 0 \]

The leverage plot characterizes this test by plotting points so that the distance of each point to the sloped regression line displays the unconstrained residual. The distance to the horizontal line at 0 displays the residual when the fit is constrained by the hypothesis. The difference between the sums of squares of these two sets of residuals is the sum of squares due to the hypothesis. This value becomes the main component of the \( F \) test.

The parameter estimates constrained by the hypothesis can be written

\[ b_0 = b - (X'X)^{-1}L\lambda \]

Here \( b \) is the least squares estimate

\[ b = (X'X)^{-1}X'y \]

and lambda is the Lagrangian multiplier for the hypothesis constraint, calculated by

\[ \lambda = (L(X'X)^{-1}L')^{-1}Lb \]

The unconstrained and hypothesis-constrained residuals are, respectively,

\[ r = y - Xb \]
\[ r_0 = r + X(X'X)^{-1}L\lambda \]

For each observation, consider the point with x-axis value \( v_x \) and y-axis value \( v_y \) where:
- \( v_x \) is the unconstrained residual minus the constrained residual, \( r - r_0 \), reflecting information left over once the constraint is applied
- \( v_y \) is the x-axis value plus the unconstrained residual
Thus, these points have x and y coordinates

\[ v_x = X(X'X)^{-1}L'\lambda \quad \text{and} \quad v_y = r + v_x \]

These points form the basis for the leverage plot. You can scale the axes to make the plots more meaningful. This construction is illustrated in Figure 3.63, where the solid line has slope 1.

**Figure 3.63** Construction of Leverage Plot

Superimposing a Test on the Leverage Plot

In simple linear regression, you can plot the confidence limits for the expected value of the response as a smooth function of the predictor variable \( x \)

\[
\begin{align*}
\text{Upper (x)} &= \mathbf{xb} + t_{\alpha/2}s\sqrt{x(X'X)^{-1}x'} \\
\text{Lower (x)} &= \mathbf{xb} - t_{\alpha/2}s\sqrt{x(X'X)^{-1}x'}
\end{align*}
\]

where \( x = [1 \ x] \) is the 2-vector of predictors.

These confidence curves give a visual assessment of the significance of the corresponding hypothesis test, illustrated in Figure 3.56:

- **Significant**: If the slope parameter is significantly different from zero, the confidence curves cross the horizontal line at the response mean.
- **Borderline**: If the t test for the slope parameter is sitting right on the margin of significance, the confidence curve is asymptotic to the horizontal line at the response mean.
- **Not Significant**: If the slope parameter is not significantly different from zero, the confidence curve does not cross the horizontal line at the response mean.
Leverage plots mirror this thinking by displaying confidence curves. These are adjusted so that the plots are suitably centered. Denote a point on the $x$-axis by $z$. Define the functions

$$\text{Upper}(z) = z + \sqrt{\frac{n-2}{n} s^2 \frac{1}{\alpha/2} \frac{\hat{h}}{\hat{h}} + \frac{(F_{\alpha}/F)z^2}{2}}$$

and

$$\text{Lower}(z) = z - \sqrt{\frac{n-2}{n} s^2 \frac{1}{\alpha/2} \frac{\hat{h}}{\hat{h}} + \frac{(F_{\alpha}/F)z^2}{2}}$$

where $F$ is the $F$ statistic for the hypothesis and $F_{\alpha}$ is the reference value for significance $\alpha$.

And $\hat{h} = \bar{x}(XX)^{-1}\bar{x}'$, where $\bar{x}$ is a row vector consisting of suitable middle values for the predictors, such as their means.

These functions behave in the same fashion as do the confidence curves for simple linear regression:

- If the $F$ statistic is greater than the reference value, the confidence functions cross the $x$-axis.
- If the $F$ statistic is equal to the reference value, the confidence functions have the $x$-axis as an asymptote.
- If the $F$ statistic is less than the reference value, the confidence functions do not cross.

Also, it's important that Upper($z$) - Lower($z$) is a valid confidence interval for the predicted value at $z$.

**The Kackar-Harville Correction**

The variance matrix of the fixed effects is always modified to include a Kackar-Harville correction. The variance matrix of the BLUPs, and the covariances between the BLUPs and the fixed effects, are not Kackar-Harville corrected. The rationale for this approach is that corrections for BLUPs can be computationally and memory intensive when the random effects have many levels.

In SAS, the Kackar-Harville correction is done for both fixed effects and BLUPs only when the DDFM=KENWARDROGER is set.

- Standard errors for linear combinations involving only fixed effects parameters match PROC MIXED DDFM=KENWARDROGER. This case assumes that one has taken care to transform between the different parameterizations used by PROC MIXED and JMP.
- Standard errors for linear combinations involving only BLUP parameters match PROC MIXED DDFM=SATTERTHWAITE.
- Standard errors for linear combinations involving both fixed effects and BLUPS do not match PROC MIXED for any DDFM option if the data are unbalanced. However, these standard errors are between what you get with the DDFM=SATTERTHWAITE and
Degrees of Freedom

The degrees of freedom for tests involving only linear combinations of fixed effect parameters are calculated using the Kenward and Roger correction. So JMP’s results for these tests match PROC MIXED using the DDFM=KENWARDROGER option. If there are BLUPs in the linear combination, JMP uses a Satterthwaite approximation to get the degrees of freedom. The results then follow a pattern similar to what is described for standard errors in the preceding paragraph.


Power Analysis

Options relating to power calculations are available only for continuous-response models.

These are the contexts in which power and related test details are available:

Parameter Estimate

To obtain retrospective test details for each parameter estimate, select Estimates > Parameter Power from the report’s red triangle menu. This option displays the least significant value, the least significant number, and the adjusted power for the 0.05 significance level test for each parameter based on current study data.

Effect or Effect Details

To obtain either prospective or retrospective details for the F test of a specific effect, select Power Analysis from the effect’s red triangle menu. Keep in mind that, for the Effect Screening and Minimal Report personalities, the report for each effect is found under Effect Details. For the Effect Leverage personality, the report for an effect is found to the right of the first (Whole Model) column in the report.

LS Means Contrast

To obtain either prospective or retrospective details for a test of one or more contrasts, select LSMeans Contrast from the effect’s red triangle menu. Define the contrasts of interest and click Done. From the Contrast red triangle menu, select Power Analysis.
Custom Test

To obtain either prospective or retrospective details for a custom test, select Estimates > Custom Test from the response’s red triangle menu. Define the contrasts of interest and click Done. From the Custom Test red triangle menu, select Power Analysis.

In all cases except the first, selecting Power Analysis opens the Power Details window. You then enter information in the Power Details window to modify the calculations according to your needs.

Effect Size

The effect size, denoted by $\delta$, is a measure of the difference between the null hypothesis and the true values of the parameters involved. The null hypothesis might be formulated in terms of a single linear contrast that is set equal to zero, or of several such contrasts. The value of $\delta$ reflects the difference between the true values of the contrasts and their hypothesized values of 0.

In general terms, the effect size is given by:

$$\delta = \sqrt{\frac{SS_{\text{Hyp(Pop)}}}{n}}$$

where $SS_{\text{Hyp(Pop)}}$ is the sum of squares for the hypothesis being tested given in terms of population parameters and $n$ is the total number of observations.

When observations are available, the estimated effect size is calculated by substituting the calculated sum of squares for the hypothesis into the formula for $\delta$.

Balanced One-Way Layout

For example, in the special case of a balanced one-way layout with $k$ levels where the $i^{th}$ group has mean response $\alpha_i$,

$$\delta^2 = \frac{\sum (\alpha_i - \bar{\alpha})^2}{k}$$

Recall that JMP codes parameters so that, for $i = 1, 2, ..., k-1$

$$\beta_i = (\alpha_i - \bar{\alpha})$$

and

$$\beta_k = - \sum_{m=1}^{k-1} \alpha_m$$

So, in terms of these parameters, $\delta$ for a two-level balanced layout is given by:
or $\delta = |\beta_1|$

**Unbalanced One-Way Layout**

In the case of an unbalanced one-way layout with $k$ levels, and where the $i^{th}$ group has mean response $\alpha_i$ and $n_i$ observations, and where:

$$\delta^2 = \frac{1}{k} \sum_{i=1}^{k} \left( \frac{n_i}{n} \right) \left( \alpha_i - \bar{\alpha} \right)^2$$

**Effect Size and Power**

The power is the probability that the $F$ test of a hypothesis is significant at the $\alpha$ significance level, when the true effect size is a specified value. If the true effect size equals $\delta$, then the test statistic has a noncentral $F$ distribution with noncentrality parameter

$$\lambda = \frac{n \delta^2}{\sigma^2}$$

When the null hypothesis is true (that is, when the effect size is zero), the noncentrality parameter is zero and the test statistic has a central $F$ distribution.

The power of the test increases with $\lambda$. In particular, the power increases with sample size $n$ and effect size $\delta$, and decreases with error variance $\sigma^2$.

Some books (for example, Cohen, 1977) use a standardized effect size, $\Delta = \delta / \sigma$, rather than the raw effect size used by JMP. For the standardized effect size, the noncentrality parameter equals $\lambda = n \Delta^2$.

In the Power Details window, $\delta$ is initially set to $\sqrt{\frac{SS_{Hyp}}{n}}$. $SS_{Hyp}$ is the sum of squares for the hypothesis, and $n$ is the number of observations in the current study. $SS_{Hyp}$ is an estimate of $\delta$ computed from the data, but such estimates are biased (Wright and O’Brien, 1988). To calculate power using a sample estimate for $\delta$, you might want to use the Adjusted Power and Confidence Interval calculation rather than the Solve for Power calculation. The adjusted power calculation uses an estimate of $\delta$ that is partially corrected for bias. See “Computations for the Adjusted Power” on page 461 in the “Statistical Details” appendix.

**Plot of Power by Sample Size**

To see a plot of power by sample size, select the Power Plot option from the red triangle menu at the bottom of the Power report. JMP plots the Power and Number columns from the Power table. The plot shown in Figure 3.64 results from plotting the Power table obtained in “Example of Retrospective Power Analysis” on page 198.
The Least Significant Number (LSN)

The least significant number (LSN) is the smallest number of observations that leads to a significant test result, given the specified values of delta, sigma, and alpha. Recall that delta, sigma, and alpha represent, respectively, the effect size, the error standard deviation, and the significance level.

Note: LSN is not a recommendation of how large a sample to take because it does not take into account the probability of significance. It is computed based on specified values of delta and sigma.

The LSN has these characteristics:

- If the LSN is less than the actual sample size \( n \), then the effect is significant.
- If the LSN is greater than \( n \), the effect is not significant. If you believe that more data will show essentially the same structural results as does the current sample, the LSN suggests how much data you would need to achieve significance.
- If the LSN is equal to \( n \), then the \( p \)-value is equal to the significance level alpha. The test is on the border of significance.
- The power of the test for the effect size, calculated when \( n = \text{LSN} \), is always greater than or equal to 0.5. Note, however, that the power can be close to 0.5, which is considered low for planning purposes.

The Least Significant Value (LSV)

The LSV, or least significant value, is computed for single-degree-of-freedom hypothesis tests. These include tests for the significance of individual model parameters, as well as more general linear contrasts. The LSV is the smallest effect size, in absolute value, that would be
significant at level alpha. The LSV gives a measure of the sensitivity of the test on the scale of the parameter, rather than on a probability scale.

The LSV has these characteristics:

- If the absolute value of the parameter estimate or contrast is greater than or equal to the LSV, then the \( p \)-value of the significance test is less than or equal to alpha.
- The absolute value of the parameter estimate or contrast is equal to the LSV if and only if its significance test has \( p \)-value equal to alpha.
- The LSV is the radius of a \( 1 - \alpha \) confidence interval for the parameter or linear combination of parameters. The \( 1 - \alpha \) confidence interval is centered at the estimate of the parameter or contrast.

**Power**

The power of a test is the probability that the test gives a significant result. The power is a function of the effect size \( \delta \), the significance level \( \alpha \), the error standard deviation \( \sigma \), and the sample size \( n \). The power is the probability that you will detect a specified effect size at a given significance level. In general, you would like to design studies that have high power of detecting differences that are of practical or scientific importance.

Power has these characteristics:

- If the true value of the parameter is in fact the hypothesized value, the power equals the significance level of the test. The significance level is usually a small value, such as 0.05. The small value is appropriate, because you want a low probability of seeing a significant result when the postulated hypothesis is true.
- If the true value of the parameter is not the hypothesized value, in general, you want the power to be as large as possible.
- Power increases as: sample size increases; error variance decreases; the difference between the true parameter value and the hypothesized value increases.

**The Adjusted Power and Confidence Intervals**

In retrospective power analysis, you typically substitute sample estimates for the population parameters involved in power calculations. This substitution causes the noncentrality parameter estimate to have a positive bias (Wright and O'Brien, 1988). The adjusted power calculation is based on a form of the estimated noncentrality parameter that is partially corrected for this bias.

You can also construct a confidence interval for the adjusted power. Such confidence intervals tend to be wide. See Wright and O'Brien, 1988, end of section 2.
Note that the adjusted power and confidence interval calculations are relevant only for the value of $\delta$ estimated from the data (the value provided by default). For other values of delta, the adjusted power and confidence interval are not provided.

For more details, see “Computations for the Adjusted Power” on page 461 in the “Statistical Details” appendix.

Example of Retrospective Power Analysis

This example illustrates a retrospective power analysis using the Big Class.jmp sample data table. The Power Details window (Figure 3.65) permits exploration of various quantities over ranges of values for $\alpha$, $\sigma$, $\delta$, and Number, or study size. Clicking Done replaces the window with the results of the calculations.

1. Open the Big Class.jmp sample data table.
2. Select Analyze > Fit Model.
3. Select weight and click Y.
4. Add age, sex, and height as the effects.
5. Click Run.
6. From the red triangle next to age, select Power Analysis.

![Power Details Window for Age](image)

7. Replace the $\delta$ value in the From box with 3, and enter 6 and 1 in the To and By boxes as shown in Figure 3.65.
8. Replace the Number value in the From box with 20, and enter 60 and 10 in the To and By boxes as shown in Figure 3.65.
9. Select Solve for Power and Solve for Least Significant Number.
10. Click Done.
11. The Power Details window is replaced by the Power Details report shown in Figure 3.66
This analysis is a retrospective power analysis because the calculations assume a study with a structure identical to that of the Big Class.jmp sample data table. For example, the calculation of power in this example depends on the effects entered into the model and the number of subjects in each age and sex grouping. Also, the value of $\sigma$ was derived from the current study, though you could have replaced it with a value that would be representative of a future study.

For details about the power results shown in Figure 3.66, see “Power” on page 197. For details about the least significant number (LSN), see “The Least Significant Number (LSN)” on page 196.

**Prospective Power Analysis**

Prospective analysis helps you answer the question, “If differences of a specified size exist, will I detect them given my proposed sample size, alpha level, and estimate of error variance?” In a prospective power analysis, you must provide estimates of the group means and sample sizes in a data table. You must also provide an estimate of the error standard deviation $\sigma$ in the Power Details window.
Equal Group Sizes

Consider a situation where you are comparing the means of three independent groups. To obtain sample sizes to achieve a given power, select **DOE > Sample Size and Power** and then select **k Sample Means**. Here, you enter your estimate of the error standard deviation. In the Prospective Means list, you enter means that reflect the smallest differences that you want to detect. If, for example, you want to detect a difference of 8 units between any two means, enter the extreme values of the means, say, 40, 40, and 48. Because the power is based on deviations from the grand mean, you can enter only values that reflect the desired differences (for example 0, 0, and 8).

If you click **Continue**, you obtain a graph of power versus sample size. If you specify either power or sample size in the Sample Size window, the other quantity is computed. In particular, if you specify power, the sample size that is provided is the total required sample size. The k Sample Means calculation assumes equal group sizes. For three groups, you would divide the sample size by 3 to obtain the individual group sizes. For more information about k Sample Means, see the Design of Experiments Guide book.

Unequal Group Sizes

Suppose that you want to design a study that uses groups of different sizes. You need to plan an experiment to study two treatments that reportedly reduce bacterial counts. You want to compare the effect of these treatments with results from a control group that receives no treatment. You also want to detect a difference of at least 8 units between the means of either treatment group and the control group. But the control group must be twice as large as either treatment group. The two treatment groups also must be equal in size. Previous studies suggest that the error standard deviation is on the order of 5 or 6.

To obtain a prospective power analysis for this situation, create a data table containing some basic information, as shown in the Bacteria.jmp sample data table (Figure 3.67).

**Figure 3.67 Bacteria.jmp Data Table**

<table>
<thead>
<tr>
<th></th>
<th>Group</th>
<th>Group Means</th>
<th>Relative Sizes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Control</td>
<td>40</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>Treatment A</td>
<td>40</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>Treatment B</td>
<td>40</td>
<td>1</td>
</tr>
</tbody>
</table>

- The Group column identifies the groups.
- The Means column reflects the smallest difference among the columns that it is important to detect. Here, it is assumed that the control group has a mean of about 40. You want the test to be significant if either treatment group has a mean that is at least 8 units higher than the mean of the control group. For this reason, you assign a mean of 48 to one of the two treatment groups. Set the mean of the other treatment group equal to that of the control group. (Alternatively, you could assign the control group and one of the treatment groups
means of 0 and the remaining treatment group a mean of 8.) Note that the differences in the group means are population values.

- The Relative Sizes column shows the desired relative sizes of the treatment groups. This column indicates that the control group needs to be twice as large as each of the treatment groups. (Alternatively, you could start out with an initial guess for the treatment sizes that respects the relative size criterion.)

**Note:** The Relative Sizes column must be assigned the role of a Freq (frequency). See the symbol to the right of the column name in the Columns panel.

Next, use Fit Model to fit a one-way analysis of variance model (Figure 3.68). Note that Relative Sizes is declared as Freq in the launch window. Also, the Minimal Report emphasis option is selected.

![Figure 3.68 Fit Model Launch Window for Bacteria Study](image)

Click Run to obtain the Fit Least Squares report. The report shows Root Mean Square Error and Sum of Squares for Error as 0.0, because you specified a data table with no error variation within the groups. You must enter a proposed range of values for the error variation to obtain the power analysis. Specifically, you have information that the error variation will be about 5 but might be as large as 6.

1. Click the disclosure icon next to Effect Details to open this report.
2. From the red triangle menu next to Group Means, select Power Analysis.
3. To explore the range of error variation suspected by the scientist, under $\sigma$, enter 5 in the first box and 6 in the second box (Figure 3.69).
4. Note that $\delta$ is entered as 3.464102. This is the effect size that corresponds to the specified difference in the group means. The data table contains three hidden columns that illustrate
the calculation of the effect size. (See “Unbalanced One-Way Layout” on page 195.)

5. To explore power over a range of study sizes, under **Number**, enter 16 in the first box, 64 in the second box, and an increment of 4 in the third box (Figure 3.69).

6. Select **Solve for Power**.

7. Click **Done**.

**Figure 3.69** Power Details Window for Bacteria Study

The Power Details report, shown in Figure 3.70, replaces the Power Details window. This report gives power calculations for $\alpha = 0.05$, for all combinations of $\sigma = 5$ and 6, and sample sizes of 16 to 64 in increments of size 4. When $\sigma$ is 5, to obtain about 90% power, you need a total sample size of about 32. You need 16 subjects in the control group and 8 in each of the treatment groups. On the other hand, if $\sigma$ is 6, then a total of 44 subjects is required.
Click the arrow at the bottom of the table in the Power Details report to obtain a plot of power versus sample size for the two values of $\sigma$, shown in Figure 3.71. Here, the red markers correspond to $\sigma = 5$ and the green correspond to $\sigma = 6$. 

**Figure 3.71**  Power Plot for Bacteria Study
About Standard Least Squares Examples

This chapter provides examples with instructional material for several standard least squares topics. These include analysis of variance, analysis of covariance, a response surface model, a split plot design, estimation of random effect parameters, a knotted spline fit, and the identification of active factors using a script that provides a Bayesian approach.
Contents

One-Way Analysis of Variance Example .................................................. 207
Analysis of Covariance with Equal Slopes Example ............................... 210
Analysis of Covariance with Unequal Slopes Example ............................. 212
Response Surface Model Example .......................................................... 214
Split Plot Design Example .................................................................. 218
Estimation of Random Effect Parameters Example .................................. 221
Knotted Spline Effect Example ............................................................... 223
Bayes Plot for Active Factors Example .................................................. 225
One-Way Analysis of Variance Example

In a one-way analysis of variance, a different mean is fit to each of the different groups, as identified by a nominal variable. To specify the model in JMP, select a continuous response column and a nominal effect column. This example uses the data in Drug.jmp.

1. Open the Drug.jmp sample data table.
2. Select Analyze > Fit Model.
3. Select y and click Y.
4. Select Drug and click Add.
5. Click Run.

In this example, Drug has three levels, a, d, and f. The standard least squares fitting method translates this specification into a linear model as follows: The nominal variables define a sequence of indicator variables, which only assume the values 1, 0, and –1. The linear model is written as follows:

\[
y_i = \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} + \epsilon_i
\]

where:
- \( y_i \) is the observed response for the \( i^{th} \) observation
- \( x_{1i} \) is the value of the first indicator variable for the \( i^{th} \) observation
- \( x_{2i} \) is the value of the second indicator variable for the \( i^{th} \) observation
- \( \beta_0, \beta_1, \) and \( \beta_2 \) are parameters for the intercept, the first indicator variable, and the second indicator variable, respectively
- \( \epsilon_i \) are the independent and normally distributed error terms

The first indicator variable, \( x_{1i} \), is defined as follows. Note that Drug=a contributes a value 1, Drug=d contributes a value 0, and Drug=f contributes a value –1 to the indicator variable:

\[
x_{1i} = \begin{cases} 
1, & \text{if Drug} = a \\
0, & \text{if Drug} = d \\
-1, & \text{if Drug} = f 
\end{cases}
\]

The second indicator variable, \( x_{2i} \), is given the following values:

\[
x_{2i} = \begin{cases} 
0, & \text{if Drug} = a \\
1, & \text{if Drug} = d \\
-1, & \text{if Drug} = f 
\end{cases}
\]
The estimates of the means for the three levels in terms of this parameterization are as follows:

\[ \mu_a = \beta_0 + \beta_1 \]
\[ \mu_d = \beta_0 + \beta_2 \]
\[ \mu_f = \beta_0 - \beta_1 - \beta_2 \]

Solving for \( \beta \) yields the following:

\[ \beta_0 = \frac{(\mu_a + \mu_d + \mu_f)}{3} = \mu \text{ (the average over levels)} \]
\[ \beta_1 = \mu_a - \mu \]
\[ \beta_2 = \mu_d - \mu \]

Therefore, if regressor variables are coded as indicators for each level minus the indicator for the last level, then the parameter for a level is interpreted as the difference between that level’s response and the average response across all levels. See the appendix “Statistical Details” on page 427 for additional information about the interpretation of the parameters for nominal factors.

Figure 4.1 shows the Leverage Plot and the LS Means Table for the Drug effect. Figure 4.2 shows the Parameter Estimates and the Effect Tests reports for the one-way analysis of the drug data.

**Figure 4.1** Leverage Plot and LS Means Table for Drug
Figure 4.2 Parameter Estimates and Effect Tests for Drug.jmp

<table>
<thead>
<tr>
<th>Term</th>
<th>Estimate</th>
<th>Std Error</th>
<th>t Ratio</th>
<th>Prob&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>7.9</td>
<td>1.109186</td>
<td>7.13</td>
<td>0.0001*</td>
</tr>
<tr>
<td>Drug[a]</td>
<td>-2.6</td>
<td>1.557494</td>
<td>-1.68</td>
<td>0.1006</td>
</tr>
<tr>
<td>Drug[d]</td>
<td>-1.8</td>
<td>1.557494</td>
<td>-1.15</td>
<td>0.2650</td>
</tr>
</tbody>
</table>

The Drug effect can be studied in more detail by using a contrast of the least squares means, as follows:

1. From the red triangle menu next to Drug, select LSMeans Contrast.
2. Click the + boxes for drugs a and d, and the - box for drug f to define the contrast that compares the average of drugs a and d to f (shown in Figure 4.3).
3. Click Done.

Figure 4.3 Contrast Example for the Drug Experiment

The Contrast report shows that the LSMean for drug f is significantly different from the average of the LSMeans of the other two drugs.
Analysis of Covariance with Equal Slopes Example

An analysis of variance model with a continuous regressor term is called an analysis of covariance. In the Drug.jmp sample data table, the column x is a covariate.

The covariate adds an additional term, \( x_{3i} \), to the model equation. The model analysis of covariance model is written this way:

\[
y_i = \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} + \beta_3 x_{3i} + \epsilon_i
\]

There are two model effects: one is a nominal main effect involving two parameters, and the other is continuous covariate associated with one parameter.

1. Open the Drug.jmp sample data table.
2. Select Analyze > Fit Model.
3. Select y and click Y.
4. Select both Drug and x and click Add.
5. Click Run.

The Regression Plot in the report shows that you have fit a model with equal slopes (Figure 4.4). Compared to the main effects model (Drug effect only), R\( \text{Square} \) increases from 22.8\% to 67.6\%. The Root Mean Square Error decreases from 6.07 to 4.0. As shown in Figure 4.4, the \( F \)-test significance probability for the whole model decreases from 0.03 to less than 0.0001.
The drug data table contains replicated observations. For example, rows 1 and 11 both have Drug = a and x = 11. In modeling fitting, replicated observations can be used to construct a pure error estimate of variation. Another estimate of error can be constructed for unspecified functional forms of covariates, or interactions of nominal effects. These estimates form the basis for a lack of fit test. If the lack of fit error is significant, this indicates that there is some effect in your data not explained by your model.

The Lack of Fit report shows the results of this test for the drug data. The lack of fit error is not significant, as seen by the Prob > F value of 0.7507.

The covariate, x, accounts for much of the variation in the response previously accounted for by the Drug variable. Thus, even though the model is fit with much less error, the Drug effect is no longer significant. The significance of Drug observed in the main effects model appears to be explained by the covariate.
The least squares means in the covariance model differ from the ordinary means. This is because they are adjusted for the effect of \( x \), the covariate, on the response, \( y \). The least squares means are values predicted for each of the three levels of Drug, when the covariate, \( x \), is held at some neutral value. The neutral value is chosen to be the mean of the covariate, which is 10.7333.

The least squares means are calculated as follows, using the parameter estimates given in the Parameter Estimates report:

**Prediction Expression:**  
\[-2.696 - 1.185*\text{Drug}[a] - 1.0761*\text{Drug}[d] + 0.98718*\text{x}\]

**For a:**  
\[-2.696 - 1.185*(1) - 1.0761*(0) + 0.98718*(10.7333) = 6.71\]

**For d:**  
\[-2.696 - 1.185*(0) - 1.0761*(1) + 0.98718*(10.7333) = 6.82\]

**For f:**  
\[-2.696 - 1.185*(-1) - 1.0761*(-1) + 0.98718*(10.7333) = 10.16\]

Figure 4.5 shows a leverage plot for each effect. Because the covariate is significant, the leverage values for Drug are dispersed somewhat from their least squares means.

**Figure 4.5** Comparison of Leverage Plots for Drug Test Data

---

**Analysis of Covariance with Unequal Slopes Example**

Continuing with the Drug.jmp sample data table, this example fits a model where the slope for the covariate depends on the level of Drug.

1. Open the Drug.jmp sample data table.
2. Select Analyze > Fit Model.
3. Select \( y \) and click Y.
4. Select both Drug and \( x \) and click Macros > Factorial to Degree.

   This adds terms up to the degree specified in the **Degree** box to the model. The default value for **Degree** is 2. Thus the main effects of Drug and \( x \), and their interaction, Drug*\( x \), are added to the model effects list.
5. Click **Run**.

This specification adds two columns to the linear model (call them $x_4i$ and $x_5i$) that allow the slopes for the covariate to differ by Drug level. The new variables are formed by multiplying the indicator variables for Drug by the covariate values, giving the following formula:

$$y_i = \beta_0 + \beta_1 x_{1i} + \beta_2 x_{2i} + \beta_3 x_{3i} + \beta_4 x_{4i} + \beta_5 x_{5i} + \epsilon_i$$

Table 4.1 shows the coding for this model. The mean of $X$, which is 10.7333, is used in centering continuous terms.

<table>
<thead>
<tr>
<th>Regressor</th>
<th>Effect</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>$X_1$</td>
<td>Drug[a]</td>
<td>+1 if a, 0 if d, −1 if f</td>
</tr>
<tr>
<td>$X_2$</td>
<td>Drug[d]</td>
<td>0 if a, +1 if d, −1 if f</td>
</tr>
<tr>
<td>$X_3$</td>
<td>$X$</td>
<td>the values of $X$</td>
</tr>
<tr>
<td>$X_4$</td>
<td>Drug[a] * ($X - 10.733$)</td>
<td>$X - 10.733$ if a, 0 if d, −($X - 10.733$) if f</td>
</tr>
<tr>
<td>$X_5$</td>
<td>Drug[d] * ($X - 10.733$)</td>
<td>0 if a, $X - 10.733$ if d, −($X - 10.733$) if f</td>
</tr>
</tbody>
</table>

A portion of the report is shown in Figure 4.6. The Regression Plot shows fitted lines with different slopes. The Effect Tests report gives a $p$-value for the interaction of 0.56. This is not significant, indicating the model does not need to include different slopes.

**Figure 4.6** Plot with Interaction
Response Surface Model Example

This example constructs a response surface model using the Odor Control Original.jmp file in the Sample Data folder. The objective is to find the range of temperature (temp), gas-liquid ratio (gl ratio), and height (ht) values that minimize the odor of a chemical production process.

1. Open the Odor Control Original.jmp sample data table.
2. Select Analyze > Fit Model.
3. Select odor and click Y.
4. Select temp, gl ratio, and ht, and click Macros > Response Surface.
   This Macro adds terms up to degree two to the model (Figure 4.7). The main effects appear in the Construct Model Effects list with a &RS suffix. As a result, the analysis results will include a Response Surface report.
5. Click Run.

Parameter Estimates

The Parameter Estimates table shows estimates of the model parameters (Figure 4.8). Two of the quadratic effects, gl ratio*gl ratio and temp*temp, as well as the main effect of ht, are significant at the 0.05 level.
6. From the report's red triangle menu, select **Save Columns > Prediction Formula**. This inserts a column into the data table called **Pred Formula odor**. This column contains the prediction formula defined by the coefficients shown in the Parameter Estimates table.

**Response Surface Report**

A response surface report is provided (Figure 4.9). This report shows a table showing the second-order model coefficients in matrix form. The Solution report shows the critical values for the main effects. These are the values where a maximum, a minimum, or a saddle point occur. The Solution report indicates which of these occurs at the critical point. In this example, the response surface achieves a minimum at the critical value.

**Figure 4.9  Response Surface Report**

<table>
<thead>
<tr>
<th>Coef</th>
<th>temp</th>
<th>gl ratio</th>
<th>ht</th>
<th>odor</th>
</tr>
</thead>
<tbody>
<tr>
<td>temp</td>
<td>32.083333</td>
<td>8.25</td>
<td>1.3</td>
<td>1.3</td>
</tr>
<tr>
<td>gl ratio</td>
<td>67.833333</td>
<td>1.33</td>
<td>3.3</td>
<td>3.3</td>
</tr>
<tr>
<td>ht</td>
<td>6.083333</td>
<td>2.33</td>
<td>2.33</td>
<td>2.33</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Variable</th>
<th>Critical Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>temp</td>
<td>0.1216125</td>
</tr>
<tr>
<td>gl ratio</td>
<td>0.1995706</td>
</tr>
<tr>
<td>ht</td>
<td>1.770348</td>
</tr>
</tbody>
</table>

Solution is a Minimum
Critical values outside data range
Predicted Value at Solution: -52.33461
Canonical Curvature Report

The Response Surface report also contains the Canonical Curvature subreport (Figure 4.10). This report shows the eigenstructure of the matrix of second-order parameter estimates. The eigenstructure is useful for identifying the shape and orientation of the curvature. The eigenvalues, given in the first row of the Canonical Curvature table, are negative if the response surface curves down from a maximum. The eigenvalues are positive if the surface curves up from a minimum. If the eigenvalues are mixed, the surface is saddle shaped, curving up in one direction and down in another direction.

The eigenvectors listed beneath the eigenvalues show the orientations of the principal axes. In this example the eigenvalues are positive, which indicates that the surface achieves a minimum. The direction of greatest curvature corresponds to the largest eigenvalue (48.8588). That direction is defined by the corresponding eigenvector components. For the first direction, gl ratio, with an eigenvector value of 0.97112, has the greatest influence. The direction defined by the eigenvalue of 31.1035 is determined more by temp (0.97070), than by gl ratio or ht.

Sometimes a zero eigenvalue occurs. This means that, in the direction described by the corresponding eigenvector, the fitted surface is flat.

Figure 4.10 Basic Reports for Response Surface Model

Using the Prediction Profiler for Optimization

The Solution report indicates that the surface is minimized at a point that falls outside the range of the data. Suppose that you want to minimize the response within the range of the design values.

The Prediction Profiler report, at the bottom of the results window, shows the quadratic behavior of the response surface along traces for temp and gl ratio (Figure 4.11).
7. From the Prediction Profiler’s red triangle menu, select **Desirability Functions**.

In the top row for odor, to the far right, a cell that plots the desirability function is added. A row of cells showing desirability traces is added beneath the row for odor.

8. In the upper right cell, hold the Control key and click.

9. In the drop-down list, select **Minimize**.

10. Click **OK**.

11. From the Prediction Profiler’s red triangle menu, select **Maximize Desirability**.

Settings within the design region that minimize odor are shown beneath the profiler (Figure 4.12).

---

**Figure 4.11 Prediction Profiler**

![Prediction Profiler](image)

---

**Figure 4.12 Prediction Profiler with Desirability Function Optimized**

![Prediction Profiler](image)
Split Plot Design Example

Levels of random effects are randomly selected from a larger population of levels. For the purpose of inference, the distribution of a random effect is assumed to be normal, with mean zero and some variance (called a variance component).

In a sense, every model has at least one random effect, which is the effect that makes up the residual error. The individual observations are assumed to be randomly selected from a much larger population, and the error term is assumed to have a mean of zero and variance $\sigma^2$.

The most common random effects model is the repeated measures or split plot model. Table 4.2 lists the types of effects in a split plot model. In these models, the experiment has two layers. Some effects are applied on the whole plots or subjects of the experiment. Then these plots are divided or the subjects are measured at different times and other effects are applied within those subunits. The effects describing the whole plots or subjects are whole plot effects, and the subplots or repeated measures are subplot effects. Usually the subunit effect is omitted from the model and absorbed as residual error.

<table>
<thead>
<tr>
<th>Split Plot Model</th>
<th>Type of Effect</th>
<th>Repeated Measures Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>whole plot treatment</td>
<td>fixed effect</td>
<td>across subjects treatment</td>
</tr>
<tr>
<td>whole plot ID</td>
<td>random effect</td>
<td>subject ID</td>
</tr>
<tr>
<td>subplot treatment</td>
<td>fixed effect</td>
<td>within subject treatment</td>
</tr>
<tr>
<td>subplot ID</td>
<td>random effect</td>
<td>repeated measures ID</td>
</tr>
</tbody>
</table>

Each of these cases can be treated as a layered model, and there are several traditional ways to fit them in a fair way. The situation is treated as two different experiments:

1. The whole plot experiment has whole plot or subjects as the experimental unit to form its error term.
2. Subplot treatment has individual measurements for the experimental units to form its error term (left as residual error).

The older, traditional way to test whole plots is to do any one of the following:

- Take means across the measurements and fit these means to the whole plot effects.
- Form an $F$-ratio by dividing the whole plot mean squares by the whole plot ID mean squares.
- Organize the data so that the split or repeated measures form different columns. Fit a MANOVA model, and use the univariate statistics.
These approaches work if the structure is simple and the data are complete and balanced. However, there is a more general model that works for any structure of random effects. This more generalized model is called the *mixed model*, because it has both fixed and random effects.

The most common type of layered design is a balanced split plot, often in the form of repeated measures across time. One experimental unit for some of the effects is subdivided (sometimes by time period) and other effects are applied to these subunits.

Consider the data in the Animals.jmp sample data table (the data are fictional). The study collected information about differences in the seasonal hunting habits of foxes and coyotes. Each season for one year, three foxes and three coyotes were marked and observed periodically. The average number of miles that they wandered from their dens during different seasons of the year was recorded (rounded to the nearest mile). The model is defined by the following aspects:

- The continuous response variable called *miles*
- The *species* effect with values fox or coyote
- The *season* effect with values fall, winter, spring, and summer
- An animal identification code called *subject*, with nominal values 1, 2, and 3 for both foxes and coyotes

There are two layers to the model:

1. The top layer is the between-subject layer, in which the effect of being a fox or coyote (*species* effect) is tested with respect to the variation from subject to subject.
2. The bottom layer is the within-subject layer, in which the repeated-measures factor for the four seasons (*season* effect) is tested with respect to the variation from season to season within a subject. The within-subject variability is reflected in the residual error.

The *season* effect can use the residual error for the denominator of its $F$-statistics. However, the between-subject variability is not measured by residual error and must be captured with the subject within species (*subject[species]*) effect in the model. The $F$-statistic for the between-subject effect *species* uses this nested effect instead of residual error for its $F$-ratio denominator.

*Note:* JMP Pro users can construct this model using the Mixed Model personality.

To specify the split plot model for this data, follow these steps:

1. Open the Animals.jmp sample data table.
2. Select Analyze > Fit Model.
3. Select miles and click Y.
4. Select species and subject and click Add.
5. In the Select Columns list, select species.

6. In the Construct Model Effects list, select subject.

7. Click Nest.
   
   This adds the subject within species (subject[species]) effect to the model.

8. Select the nested effect subject[species].

9. Select Attributes > Random Effect.
   
   This nested effect is now identified as an error term for the species effect and appears as subject[species]&Random.

10. In the Select Columns list, select season and click Add.

    When you define an effect as random using the Attributes menu, the Method options (REML and EMS) appear at the top right of the dialog, with REML selected as the default. The populated launch window is shown in Figure 4.13.

Figure 4.13 Fit Model Dialog

11. Click Run.

    The report is shown in Figure 4.14. Both fixed effects, species and season, are significant. The REML Variance Component Estimates report gives estimates of the subject within species and residual variances.
Random effects have a dual character. In one characterization, they represent residual error, such as the error associated with a whole-plot experimental unit. In another characterization, they are like fixed effects, associating a parameter to each level of the random effect. As parameters, you have extra information about them—they are derived from a normal distribution with mean zero and the variance estimated by the variance component. The effect of this extra information is that the estimates of the parameters are shrunken toward zero.

The parameter estimates associated with random effects are called BLUPs (Best Linear Unbiased Predictors). Some researchers consider these BLUPs as parameters of interest, and others consider them uninteresting by-products of the methodology.
BLUP parameter estimates are used to estimate random-effect least squares means, which are therefore also shrunken toward the grand mean. The degree of shrinkage depends on the variance of the effect and the number of observations per level in the effect. With large variance estimates, there is little shrinkage. If the variance component is small, then more shrinkage takes place. If the variance component is zero, the effect levels are shrunk to exactly zero. It is even possible to obtain highly negative variance components where the shrinkage is reversed. You can consider fixed effects as a special case of random effects where the variance component is very large.

The REML method balances the information about each individual level with the information about the variances across levels. If the number of observations per level is large, the estimates shrink less. If there are very few observations per level, the estimates shrink more. If there are infinitely many observations, there is no shrinkage and the estimates are identical to fixed effects.

Suppose that you have batting averages for different baseball players. The variance component for the batting performance across players describes how much variation is typical between players in their batting averages. Suppose that the player only plays a few times and that the batting average is unusually small or large. Then you tend not to trust that estimate, because it is based on only a few at-bats. But if you mix that estimate with the grand mean, that is, shrink the estimate toward the grand mean, you would trust the estimate more. For players who have a long batting record, you would shrink much less than those with a short record.

You can explore this behavior yourself.

1. Open the Baseball.jmp sample data table.
2. Select Analyze > Fit Model.
3. Select Batting and click Y, Response.
4. Select Player and click X, Factor.
5. Select Player in the Construct Model Effects box, and select Random Effect from the Attributes list.
6. Click Run.

Table 4.3 shows the Least Squares Means from the Player report for a REML (Recommended) fit. Also shown are the Method of Moment estimates, obtained using the EMS Method. The Method of Moment estimates are the ordinary Player means. Note that the REML estimate for Suarez, who has only three at-bats, is shrunken more towards the grand mean than estimates for other players with more at-bats.
Chapter 4
Fitting Linear Models

Standard Least Squares Examples

Knotted Spline Effect Example

Table 4.3 Comparison of Estimates between Method of Moments and REML

<table>
<thead>
<tr>
<th></th>
<th>Method of Moments</th>
<th>REML</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variance Component</td>
<td>0.01765</td>
<td>0.019648</td>
<td></td>
</tr>
<tr>
<td>Anderson</td>
<td>0.29500000</td>
<td>0.29640407</td>
<td>6</td>
</tr>
<tr>
<td>Jones</td>
<td>0.20227273</td>
<td>0.20389793</td>
<td>11</td>
</tr>
<tr>
<td>Mitchell</td>
<td>0.32333333</td>
<td>0.32426295</td>
<td>6</td>
</tr>
<tr>
<td>Rodriguez</td>
<td>0.55000000</td>
<td>0.54713393</td>
<td>6</td>
</tr>
<tr>
<td>Smith</td>
<td>0.35681818</td>
<td>0.35702094</td>
<td>11</td>
</tr>
<tr>
<td>Suarez</td>
<td>0.55000000</td>
<td>0.54436227</td>
<td>3</td>
</tr>
</tbody>
</table>

| Least Squares Means     | same as ordinary means | shrunken from means |

Knotted Spline Effect Example

Use the Knotted Spline Effect option to have JMP fit a segmentation of smooth polynomials to a specified effect. When you select this attribute, a window appears, enabling you to specify the number of knot points. (Knotted splines are only implemented for main-effect continuous terms.)

JMP follows the advice in the literature in positioning the points. The knotted spline is also referred to as a Stone spline or a Stone-Koo spline. See Stone and Koo (1986). If there are 100 or fewer points, the first and last knots are the fifth point inside the minimum and maximum, respectively. Otherwise, the first and last knots are placed at the 0.05 and 0.95 quantiles if there are 5 or fewer knots, or the 0.025 and 0.975 quantiles for more than 5 knots. The default number of knots is 5 unless there are 30 or fewer points. In that case, the default is 3 knots.

Knotted splines have the following properties in contrast to smoothing splines:

- Knotted splines work inside of general models with many terms, whereas smoothing splines are for bivariate regressions.
- The regression basis is not a function of the response.
- Knotted splines are parsimonious, adding only $k - 2$ terms for curvature for $k$ knot points.
- Knotted splines are conservative compared to pure polynomials in the sense that the extrapolation outside the range of the data is a straight line, rather than a polynomial.
- There is an easy test for curvature.
Example Using the Knotted Spline Effect to Test for Curvature

To test for curvature, follow these steps:

1. Open the Growth.jmp sample data table.
2. Select Analyze > Fit Model.
   The Fit Model Launch Window appears.

3. Select the ratio column and click Y.
4. Select the age column and click Add.
5. Select age in the Effects pane and select Attributes > Knotted Spline Effect.
6. For the number of knots, type 5 and click OK.
7. Click Run.
8. From the report’s red triangle menu, select Estimates > Custom Test.
   Notice that there is only one column. You want three columns.
9. Click the Add Column button twice to produce a total of three columns.
10. In the first column, type 1 for age&Knotted@4.5.
11. In the second column, type 1 for age&Knotted@20.5.
12. In the third column, type 1 for age&Knotted@36.
Fitting Linear Models

Bayes Plot for Active Factors Example

Suppose that you conduct an experimental design and want to determine which factors are active. You can address this in several ways using JMP. This example illustrates a script that can be used to identify active factors using a Bayesian approach.

1. Open the Reactor.jmp sample data table.
2. Open the BayesPlotforFactors.jsl sample script.
4. Select Y and click Y, Response.

The report in Figure 4.17 appears. The small Prob > F value indicates that there is curvature.

Figure 4.16 Values for the Custom Test for Curvature

<table>
<thead>
<tr>
<th>Parameter</th>
<th>0</th>
<th>0</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>ageKnotted</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>ageKnotted@4.5</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>ageKnotted@10.25</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>ageKnotted@18</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

Click and type above to form hypothesis test.

13. Click Done.

Figure 4.17 Curvature Report
6. Click OK.

**Figure 4.18 Bayes Plot for Factor Activity**

<table>
<thead>
<tr>
<th>Factor</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>0.00006</td>
</tr>
<tr>
<td>C_t</td>
<td>1</td>
</tr>
<tr>
<td>A</td>
<td>0.00182</td>
</tr>
<tr>
<td>T</td>
<td>1</td>
</tr>
<tr>
<td>C_n</td>
<td>1</td>
</tr>
</tbody>
</table>

The Model Complexity indicates that the highest order interaction to consider is two. Therefore, all possible models that include up to second-order interactions are constructed. Based on the value assigned to Prior Probability, a posterior probability is computed for each of the possible models. The probability for a factor is the sum of the probabilities for each of the models where it was involved.

This approach identifies C_t, T, and C_n as active factors, and A and F as inactive.

If the ridge parameter were zero (not allowed), all the models would be fit by least squares. As the ridge parameter increases, the parameter estimates for any model shrink toward zero. Details on the ridge parameter, and why it cannot be zero, are given in Box and Meyer (1993).
Chapter 5

Stepwise Regression Models
Find a Model Using Variable Selection

About Stepwise Regression

Stepwise regression is an approach to selecting a subset of effects for a regression model. Use stepwise regression when there is little theory to guide the selection of terms for a model, and the modeler wants to use whatever seems to provide a good fit. The Stepwise Fit also includes features for looking at all possible models (including heredity factors) and model averaging.
Contents

Overview of Stepwise Regression ........................................ 229
Example Using Stepwise Regression ................................... 229
The Stepwise Report ...................................................... 231
  Stepwise Platform Options ............................................ 231
  Stepwise Regression Control Panel .................................. 232
  Current Estimates Report ............................................... 237
  Step History Report ................................................... 238
Models with Crossed, Interaction, or Polynomial Terms ............. 239
Models with Nominal and Ordinal Terms ............................... 240
Using the Make Model Command for Hierarchical Terms ........... 242
Performing Logistic Stepwise Regression .............................. 243
The All Possible Models Option .......................................... 244
The Model Averaging Option ............................................. 246
Using Validation .......................................................... 247
Overview of Stepwise Regression

In JMP, stepwise regression is a personality of the Fit Model platform. The Stepwise feature computes estimates that are the same as those of other least squares platforms, but it facilitates searching and selecting among many models.

The approach is somewhat controversial. The significance levels on the statistics for selected models violate the standard statistical assumptions because the model has been selected rather than tested within a fixed model. On the positive side, the approach has been helpful for 30 years in reducing the number of terms. The book Subset Selection in Regression, by A. J. Miller (1990), brings statistical sense to model selection statistics.

This chapter uses the term significance probability in a mechanical way to represent that the calculation would be valid in a fixed model, recognizing that the true significance probability could be nowhere near the reported one.

Example Using Stepwise Regression

The Fitness.jmp (SAS Institute Inc. 1987) data table contains the results of an aerobic fitness study. Aerobic fitness can be evaluated using a special test that measures the oxygen uptake of a person running on a treadmill for a prescribed distance. However, it would be more economical to find a formula that uses simpler measurements that evaluate fitness and predict oxygen uptake. To identify such an equation, measurements of age, weight, run time, and pulse were taken for 31 participants who ran 1.5 miles.

Note: For purposes of illustration, certain values of MaxPulse and RunPulse have been changed from data reported by Rawlings (1988, p.105).

1. Open the Fitness.jmp sample data table.
2. Select Analyze > Fit Model.
3. Select Oxy and click Y.
4. Select Weight, Runtime, RunPulse, RstPulse, MaxPulse, and click Add.
5. For Personality, select Stepwise.
Validation is available only in JMP Pro.

6. Click Run.

To find a good oxygen uptake prediction equation, you need to compare many different regression models. Use the options in the Stepwise report window to search through models with combinations of effects and choose the model that you want.
Chapter 5  
Fitting Linear Models

The Stepwise Report

The Stepwise report window contains platform options, a regression control panel, current estimates, and step history.

Table 5.1 Description of the Stepwise Report Window

<table>
<thead>
<tr>
<th>Platform options</th>
<th>The red triangle menu next to Stepwise Fit contains options that affect all of the variables. See “Stepwise Platform Options” on page 231.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stepwise Regression</td>
<td>Limits regressor effect probabilities, determines the method of selecting effects, starts or stops the selection process, and creates a model. See “Stepwise Regression Control Panel” on page 232.</td>
</tr>
<tr>
<td>Control</td>
<td></td>
</tr>
<tr>
<td>Step History</td>
<td>Records the effect of adding a term to the model. See “Step History Report” on page 238.</td>
</tr>
</tbody>
</table>

Stepwise Platform Options

The red triangle menu next to Stepwise Fit contains the following platform options.

Table 5.2 Descriptions of Stepwise Platform Options

<table>
<thead>
<tr>
<th>K-Fold Crossvalidation</th>
<th>Performs K-Fold cross validation in the selection process. When selected, this option enables the Max K-Fold RSquare stopping rule (“Stepwise Regression Control Panel” on page 232). Available only for continuous responses. For more information about validation, see “Using Validation” on page 247.</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Possible Models</td>
<td>Enter values for the maximum number of terms to fit in any one model. Also enter values for the maximum number of best model results to show for each number of terms in the model. You can restrict the models to those that imply a parent-child relationship (or heredity). See “The All Possible Models Option” on page 244. Available only for continuous responses.</td>
</tr>
</tbody>
</table>
Stepwise Regression Models
The Stepwise Report

Chapter 5
Fitting Linear Models

Table 5.2 Descriptions of Stepwise Platform Options (Continued)

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model Averaging</td>
<td>Enables you to average the fits for a number of models, instead of picking a single best model.</td>
</tr>
<tr>
<td></td>
<td>See “The Model Averaging Option” on page 246.</td>
</tr>
<tr>
<td></td>
<td>Available only for continuous responses.</td>
</tr>
<tr>
<td>Plot Criterion History</td>
<td>Creates a plot of AICc and BIC versus the number of parameters.</td>
</tr>
<tr>
<td>Plot RSquare History</td>
<td>Creates a plot of training and validation R-square versus the number of parameters.</td>
</tr>
<tr>
<td></td>
<td>Available only for continuous responses.</td>
</tr>
<tr>
<td>Clear History</td>
<td>Clears and resets the step history.</td>
</tr>
<tr>
<td>Model Dialog</td>
<td>Shows the completed launch window for the current analysis.</td>
</tr>
</tbody>
</table>

Stepwise Regression Control Panel

Use the Stepwise Regression Control panel to limit regressor effect probabilities, determine the method of selecting effects, begin or stop the selection process, and create a model.

Figure 5.3 Stepwise Regression Control Panel
### Table 5.3 Description of the Stepwise Regression Control Panel

<table>
<thead>
<tr>
<th>Stopping Rule</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>P-value Threshold</strong></td>
<td>uses p-values (significance levels) to enter and remove effects from the model. Two other options appear when P-value Threshold is chosen: <strong>Prob to Enter</strong> is the maximum p-value that an effect must have to be entered into the model during a forward step. <strong>Prob to Leave</strong> is the minimum p-value that an effect must have to be removed from the model during a backward step.</td>
</tr>
<tr>
<td><strong>Minimum AICc</strong></td>
<td>uses the minimum corrected Akaike Information Criterion to choose the best model.</td>
</tr>
<tr>
<td><strong>Minimum BIC</strong></td>
<td>uses the minimum Bayesian Information Criterion to choose the best model.</td>
</tr>
<tr>
<td><strong>Max Validation RSquare</strong></td>
<td>uses the maximum R-square from the validation set to choose the best model. This is available only when a validation column is used, and the validation column has two or three distinct values. For more information about validation, see “Using Validation” on page 247.</td>
</tr>
<tr>
<td><strong>Max K-Fold RSquare</strong></td>
<td>uses the maximum R-square from K-fold cross validation to choose the best model. This is available only when K-Fold cross validation is used. For more information about validation, see “Using Validation” on page 247.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Direction</th>
<th>Choose how effects enter and leave the model:</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Forward</strong></td>
<td>brings in the regressor that most improves the fit, given that term is significant at the level specified by <strong>Prob to Enter</strong>. See “Forward Selection Example” on page 236.</td>
</tr>
<tr>
<td><strong>Backward</strong></td>
<td>removes the regressor that affects the fit the least, given that term is not significant at the level specified in <strong>Prob to Leave</strong>. See “Backward Selection Example” on page 236.</td>
</tr>
<tr>
<td><strong>Mixed</strong></td>
<td>alternates the forward and backward steps. It includes the most significant term that satisfies <strong>Prob to Enter</strong> and removes the least significant term satisfying <strong>Prob to Leave</strong>. It continues removing terms until the remaining terms are significant and then it changes to the forward direction.</td>
</tr>
</tbody>
</table>
Table 5.3 Description of the Stepwise Regression Control Panel (Continued)

<table>
<thead>
<tr>
<th>Rules</th>
<th>Note: Appears only if your model contains related terms.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Change the rules that are applied when there is a hierarchy of terms in the model. Select one of the following options:</td>
</tr>
<tr>
<td>Combine</td>
<td>groups a term with its precedent terms and calculates the group’s significance probability for entry as a joint F test. Combine is the default rule.</td>
</tr>
<tr>
<td>Restrict</td>
<td>restricts the terms that have precedents so that they cannot be entered until their precedents are entered.</td>
</tr>
<tr>
<td>No Rules</td>
<td>gives the selection routine complete freedom to choose terms, regardless of whether the routine breaks a hierarchy or not.</td>
</tr>
<tr>
<td>Whole Effects</td>
<td>enters only whole effects, when terms involving that effect are significant. This rule applies only when categorical variables with more than two levels are entered as possible model effects.</td>
</tr>
<tr>
<td>Go</td>
<td>Automates the selection process to completion.</td>
</tr>
<tr>
<td>Stop</td>
<td>Stops the selection process.</td>
</tr>
<tr>
<td>Step</td>
<td>Increments the selection process one step at a time.</td>
</tr>
<tr>
<td>Arrow buttons</td>
<td>Step forward and backward one step in the selection process.</td>
</tr>
<tr>
<td>Enter All</td>
<td>Enters all unlocked terms into the model.</td>
</tr>
<tr>
<td>Remove All</td>
<td>Removes all unlocked terms from the model.</td>
</tr>
<tr>
<td>Make Model</td>
<td>Creates a model for the Fit Model window from the model currently showing in the Current Estimates table. In cases where there are nominal or ordinal terms, Make Model can create new data table columns to contain terms that are needed for the model.</td>
</tr>
<tr>
<td>Run Model</td>
<td>Runs the model currently showing in the Current Estimates table.</td>
</tr>
</tbody>
</table>

Table 5.4 describes the statistics for the current model, which appear below the Stepwise Regression Control panel.

Table 5.4 Description of Current Model Statistics

| SSE            | Sum of squares for the current model. |
Table 5.4 Description of Current Model Statistics (Continued)

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>DFE</td>
<td>Degrees of freedom for the current model.</td>
</tr>
<tr>
<td>RMSE</td>
<td>Root mean square error (residual) for the current model.</td>
</tr>
<tr>
<td>RSquare</td>
<td>Proportion of the variation in the response that can be attributed to terms in the model rather than to random error.</td>
</tr>
<tr>
<td>RSquare Adj</td>
<td>Adjusts $R^2$ to make it more comparable over models with different numbers of parameters by using the degrees of freedom in its computation. The adjusted $R^2$ is useful in stepwise procedure because you are looking at many different models and want to adjust for the number of terms in the model.</td>
</tr>
</tbody>
</table>
| Cp        | Mallow’s $C_p$ criterion for selecting a model. It is an alternative measure of total squared error and can be defined as follows: 

$$C_p = \left( \frac{\text{SSE}}{\hat{s}^2} \right) - (N - 2p)$$

where $\hat{s}^2$ is the MSE for the full model and $\text{SSE}_p$ is the sum-of-squares error for a model with $p$ variables, including the intercept. Note that $p$ is the number of $x$-variables+1. If $C_p$ is graphed with $p$, Mallows (1973) recommends choosing the model where $C_p$ first approaches $p$. |
| p         | Number of parameters in the model, including the intercept. |
| AICc      | Corrected Akaike’s Information Criterion, defined as follows: 

$$\text{AICc} = -2\text{loglikelihood} + k + \frac{2k(k+1)}{n-k-1}$$

where $k$ is the number of estimated parameters, including intercept and error terms in the model, and $n$ is the number of observations in the data set. Burnham and Anderson (2004) discuss using AICc for model selection. The best model has the smallest value, as discussed in Akaike (1974). |
| BIC       | Bayesian Information Criterion defined as 

$$-2\text{loglikelihood} + k \ln(n)$$

where $k$ is the number of parameters, and $n$ is the sample size. |
Stepwise Regression Models
The Stepwise Report

Chapter 5
Fitting Linear Models

Forward Selection Example

In forward selection, terms are entered into the model and most significant terms are added until all of the terms are significant.

1. Complete the steps in “Example Using Stepwise Regression” on page 229.
   Notice that the default selection for Direction is Forward.

2. Click Step.
   From the top figure in Figure 5.4, you can see that after one step, the most significant term, Runtime, is entered into the model.

3. Click Go.
   The bottom figure in Figure 5.4 shows that all of the terms have been added, except RstPulse and Weight.

Figure 5.4 Current Estimates Table for Forward Selection

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimate</th>
<th>df</th>
<th>SS</th>
<th>&quot;F-Ratio&quot;</th>
<th>&quot;Prob&gt;F&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>after one step</td>
<td>Intercept</td>
<td>0.4217727</td>
<td>1</td>
<td>0</td>
<td>0.000</td>
</tr>
<tr>
<td>Runtime</td>
<td>0.3195554</td>
<td>1</td>
<td>832.961</td>
<td>94.099</td>
<td>4.8e-10</td>
</tr>
<tr>
<td>Weight</td>
<td>0.139138</td>
<td>1</td>
<td>0.017</td>
<td>0.0014</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimate</th>
<th>df</th>
<th>SS</th>
<th>&quot;F-Ratio&quot;</th>
<th>&quot;Prob&gt;F&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>after all steps</td>
<td>Intercept</td>
<td>0.9607998</td>
<td>1</td>
<td>0</td>
<td>0.000</td>
</tr>
<tr>
<td>Weight</td>
<td>0.998591</td>
<td>1</td>
<td>4.09256</td>
<td>0.027</td>
<td>0.27137</td>
</tr>
<tr>
<td>Runtime</td>
<td>-2.9701865</td>
<td>1</td>
<td>443.203</td>
<td>73.071</td>
<td>3.25e-9</td>
</tr>
<tr>
<td>RstPulse</td>
<td>-0.375142</td>
<td>1</td>
<td>0.14117</td>
<td>8.393</td>
<td>0.01928</td>
</tr>
<tr>
<td>MaxPulse</td>
<td>0.3942161</td>
<td>1</td>
<td>41.3476</td>
<td>8.001</td>
<td>0.01403</td>
</tr>
</tbody>
</table>

Backward Selection Example

In backward selection, terms are entered into the model and least significant terms are removed until all of the remaining terms are significant.

1. Complete the steps in “Example Using Stepwise Regression” on page 229.

2. Click Enter All.
Chapter 5
Fitting Linear Models

Stepwise Regression Models

237

Figure 5.5 All Effects Entered Into the Model

3. For Direction, select Backward.
4. Click Step two times.

The first backward step removes RstPulse and the second backward step removes Weight.

Figure 5.6 Current Estimates with Terms Removed and Step History Table

The Current Estimates and Step History tables shown in Figure 5.6 summarize the backwards stepwise selection process.

Current Estimates Report

Use the Current Estimates report to enter, remove, and lock in model effects. (The intercept is permanently locked into the model.)

Figure 5.7 Current Estimates Table
Step History Report

As each step is taken, the Step History report records the effect of adding a term to the model. For example, the Step History report for the Fitness.jmp example shows the order in which the terms entered the model and shows the statistics for each model. See “Example Using Stepwise Regression” on page 229.

Use the radio buttons on the right to choose a model.

### Table 5.5 Description of the Current Estimates Report

<table>
<thead>
<tr>
<th>Lock</th>
<th>Locks a term in or out of the model. A checked term cannot be entered or removed from the model.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entered</td>
<td>Indicates whether a term is currently in the model. You can click a term’s check box to manually bring an effect in or out of the model.</td>
</tr>
<tr>
<td>Parameter</td>
<td>Lists effect names.</td>
</tr>
<tr>
<td>Estimate</td>
<td>Current parameter estimate (zero if the effect is not currently in the model).</td>
</tr>
<tr>
<td>nDF</td>
<td>Number of degrees of freedom for a term. A term has more than one degree of freedom if its entry into a model also forces other terms into the model.</td>
</tr>
<tr>
<td>SS</td>
<td>Reduction in the error (residual) sum of squares (SS) if the term is entered into the model or the increase in the error SS if the term is removed from the model. If a term is restricted in some fashion, it could have a reported SS of zero.</td>
</tr>
<tr>
<td>“F Ratio”</td>
<td>Traditional test statistic to test that the term effect is zero. It is the square of a $t$-ratio. It is in quotation marks because it does not have an $F$-distribution for testing the term because the model was selected as it was fit.</td>
</tr>
<tr>
<td>“Prob&gt;F”</td>
<td>Significance level associated with the $F$ statistic. Like the “F Ratio,” it is in quotation marks because it is not to be trusted as a real significance probability.</td>
</tr>
<tr>
<td>R</td>
<td><strong>Note:</strong> Appears only if you right-click in the report and select Columns &gt; R. Multiple correlation with the other effects in the model.</td>
</tr>
</tbody>
</table>
Models with Crossed, Interaction, or Polynomial Terms

Often with models from experimental designs, you have cross-product or interaction terms. For continuous factors, these are simple multiplications. For nominal and ordinal factors, the interactions are outer products of many columns. When there are crossed terms, you usually want to impose rules on the model selection process so that a crossed term cannot be entered unless all its subterms (terms that contain it) are in the model.

Example Using Interaction Terms

1. Open the Reactor.jmp sample data table (Box, Hunter, and Hunter 1978).
2. Select Analyze > Fit Model.
3. Select Y and click Y.
4. In the Degree box, type 2.
5. Select F, Ct, A, T, and Cn and click Macros > Factorial to Degree.
6. For Personality, select Stepwise.
7. Click Run.

Figure 5.9 Initial Current Estimates Report
The model in Figure 5.9 contains all factorial terms up to two-factor interactions for the five continuous factors. Note that some terms have more than one degree of freedom (nDF) due to the restrictions placed on some of the terms. Under the model selection rules described above, a crossed term cannot be entered into the model until all its subterms are also in the model. For example, if the stepwise process enters F*Ct, then it must also enter F and Ct, which gives F*Ct an nDF of 3.

Figure 5.10  Current Estimates Report, Step 1

<table>
<thead>
<tr>
<th>Entered Parameter</th>
<th>Estimate</th>
<th>SS</th>
<th><em>F Ratio</em></th>
<th><em>Prob&gt;F</em></th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>96.6</td>
<td>1</td>
<td>0.000</td>
<td>1</td>
</tr>
<tr>
<td>F</td>
<td>0</td>
<td>1</td>
<td>15.125</td>
<td>0.283</td>
</tr>
<tr>
<td>Ct</td>
<td>9.76</td>
<td>2</td>
<td>446.5</td>
<td>39.676</td>
</tr>
<tr>
<td>A</td>
<td>3.125</td>
<td>1</td>
<td>0.054</td>
<td>0.81919</td>
</tr>
<tr>
<td>T</td>
<td>5375</td>
<td>2</td>
<td>2572</td>
<td>2.936</td>
</tr>
<tr>
<td>Ct</td>
<td>0</td>
<td>1</td>
<td>3125</td>
<td>0.710</td>
</tr>
<tr>
<td>F*Ct</td>
<td>0</td>
<td>2</td>
<td>30.25</td>
<td>0.256</td>
</tr>
<tr>
<td>F*M</td>
<td>0</td>
<td>3</td>
<td>22.75</td>
<td>0.123</td>
</tr>
<tr>
<td>F*T</td>
<td>0</td>
<td>2</td>
<td>21.25</td>
<td>0.170</td>
</tr>
<tr>
<td>F*Cn</td>
<td>0</td>
<td>3</td>
<td>327.75</td>
<td>2.200</td>
</tr>
<tr>
<td>Ct*M</td>
<td>0</td>
<td>2</td>
<td>8.25</td>
<td>0.097</td>
</tr>
<tr>
<td>Ct*T</td>
<td>6.025</td>
<td>1</td>
<td>1406.5</td>
<td>25.084</td>
</tr>
<tr>
<td>Ct*Cn</td>
<td>0</td>
<td>2</td>
<td>344.5</td>
<td>3.957</td>
</tr>
<tr>
<td>F*Cm</td>
<td>0</td>
<td>2</td>
<td>36.25</td>
<td>0.334</td>
</tr>
<tr>
<td>F*Cn</td>
<td>0</td>
<td>2</td>
<td>321.75</td>
<td>2.150</td>
</tr>
<tr>
<td>T*Cn</td>
<td>0</td>
<td>2</td>
<td>1289.5</td>
<td>57.700</td>
</tr>
</tbody>
</table>

The progress of multiterm inclusion is a balance between numerator degrees of freedom and opportunities to improve the fit. When there are significant interaction terms, often several terms enter at the same step. If the Step button is clicked once, Ct*T is entered along with its two contained effects Ct and T. However, a step back is not symmetric because a crossed term can be removed without removing its two component terms. Note that Ct now has 2 degrees of freedom because if Stepwise removes Ct, it also removes Ct*T.

Models with Nominal and Ordinal Terms

Traditionally, stepwise regression has not addressed the situation when there are categorical terms in the model. When nominal or ordinal terms are in regression models, they are carried as sets of dummy or indicator columns. When there are only two levels, there is no problem because they generate only a single column. However, for more than two levels, multiple columns must be handled. The convention in JMP for nominal variables in standard platforms is to model these terms so that the parameter estimates average out to zero across all the levels.

In the stepwise platform, categorical variables (nominal and ordinal) are coded in a hierarchical fashion, which is different from the other least squares fitting platforms. In hierarchical coding, the levels of the categorical variable are considered in some order and a split is made to make the two groups of levels that most separate the means of the response.
Then, each group is further subdivided into its most separated subgroups, and so on, until all
the levels are distinguished into \( k - 1 \) terms for \( k \) levels.

For nominal terms, the order of levels is determined by the means of the Ys. For ordinal terms,
the order is fixed.

**Example of a Model with a Nominal Term**

1. Open the Football.jmp sample data table.
2. Select Analyze > Fit Model.
3. Select Speed and click Y.
4. Select Weight and Position2 and click Add.
   Notice that Position2 is a nominal variable with values representing football positions.
5. For Personality, select Stepwise.
6. Click Run.

**Figure 5.11 Position Hierarchy**

<table>
<thead>
<tr>
<th>Current Estimates</th>
<th>Estimate</th>
<th>df</th>
<th>SS</th>
<th>&quot;F Ratio&quot;</th>
<th>&quot;Prob&gt;F&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>101.0822</td>
<td>1</td>
<td>1</td>
<td></td>
<td>0.005</td>
</tr>
<tr>
<td>Weight</td>
<td>91.0659</td>
<td>1</td>
<td>0</td>
<td>22.09</td>
<td>0.14</td>
</tr>
<tr>
<td>Position2{wr&amp;db&amp;o&amp;lb&amp;te–ki&amp;l}</td>
<td>732.2850</td>
<td>1</td>
<td>0</td>
<td>102.98</td>
<td>0.01</td>
</tr>
<tr>
<td>Position2{wr&amp;db&amp;o–lb&amp;te}</td>
<td>91.9623</td>
<td>1</td>
<td>0</td>
<td>22.09</td>
<td>0.14</td>
</tr>
<tr>
<td>Position2{ki-l}</td>
<td>74.6293</td>
<td>1</td>
<td>0</td>
<td>102.98</td>
<td>0.01</td>
</tr>
<tr>
<td>Position2{wr&amp;db}</td>
<td>824.5263</td>
<td>4</td>
<td>0</td>
<td>33.99</td>
<td>0.40</td>
</tr>
<tr>
<td>Position2{wr-db}</td>
<td>91.9623</td>
<td>1</td>
<td>0</td>
<td>22.09</td>
<td>0.14</td>
</tr>
<tr>
<td>Position2{lb–te}</td>
<td>74.6293</td>
<td>1</td>
<td>0</td>
<td>102.98</td>
<td>0.01</td>
</tr>
<tr>
<td>Position2{wr–db}</td>
<td>74.6293</td>
<td>1</td>
<td>0</td>
<td>102.98</td>
<td>0.01</td>
</tr>
</tbody>
</table>

- The method first splits Position into two groups with the term Position2{wr&db&o&lb&te–ki&l}. One group (the slower group) consists of the wide receivers (wr), defensive backs (db), offensive backs (o), linebackers (lb), and tight ends (te). The other group (the faster group) is the kickers (ki), and linemen (l), which ultimately split as Position2{ki-l}.
- The next split subdivides the slower group into wide receivers (wr), defensive backs (db), and offensive backs(o) versus linebackers (lb) and tight ends (te), shown as Position2{wr&db&o–lb&te}. The linebackers (lb) and tight ends split (te) to form Position2{lb–te}.
- The slower group divides again giving Position2{wr&db–o}, wide receivers (wr) and defensive backs (db) versus offensive backs (o).
- The last subdivision is the wide receivers (wr) and defensive backs (db), Position2{wr–db}.

These terms can be illustrated by the tree hierarchy shown at the top in Figure 5.12.
Using the Make Model Command for Hierarchical Terms

If you have a model with nominal or ordinal terms, when you click Make Model or Run Model, the Fit Model platform creates a new set of columns in the data table. The model appears in a new Fit Model window for the response variable. The next example uses the Hotdogs2 sample data to illustrate how Stepwise constructs a model with hierarchical effects.

Example Using the Make Model Command for Hierarchical Terms

A simple model examines the cost per ounce ($/oz) of hot dogs as a function of the Type of hot dog (Meat, Beef, Poultry) and the Size of the hot dog (Jumbo, Regular, Hors d’oeuvre).

1. Open the Hot Dogs2.jmp sample data table.
2. Select Analyze > Fit Model.
3. Select $/oz and click Y.
4. Select Type and Size and click Add.
5. For Personality, select Stepwise.
6. Click Run.
7. For Stopping Rule, select P-value Threshold.
8. For Rules, select Restrict.
9. Click Go.

**Figure 5.13** Current Estimates Report for a Model with Hierarchical Effects

<table>
<thead>
<tr>
<th>Current Estimates</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LockEnteredParameter</strong></td>
</tr>
<tr>
<td>Intercept</td>
</tr>
<tr>
<td>Type</td>
</tr>
<tr>
<td>Size</td>
</tr>
<tr>
<td>Size(Regular,Jumbo)</td>
</tr>
<tr>
<td>Size(Regular,Jumbo)</td>
</tr>
</tbody>
</table>

10. Click **Make Model**.

The following actions occur:

- Indicator variables are created in the data table for those checked rows in the Current Estimates table that are partial levels of a main effect. In this example, two columns are created for Type and one column is created for Size.
- A new Fit Model launch window appears. The effects are those that were selected in the stepwise process. Run the Fit Model window.

**Performing Logistic Stepwise Regression**

JMP performs logistic stepwise regression in a similar way to standard least squares logistic regression. To run a logistic stepwise regression, simply add terms to the model as usual and choose Stepwise from the personality drop-down menu.

The difference in the report when the response is categorical is in the **Current Estimates** section of the report. Wald/Score chi-square statistics appear, and the overall fit of the model is shown as -LogLikelihood.

**Example Using Logistic Stepwise Regression**

1. Open the Fitness.jmp sample data table.
2. Select **Analyze > Fit Model**.
3. Select Sex and click **Y**.
4. Select Weight, Runtime, RunPulse, RstPulse, and MaxPulse and click **Add**.
5. For **Personality**, select **Stepwise**.
6. Click **Run**.
7. For **Rules**, select Restrict.
8. Click **Go**.
Stepwise Regression Models

Chapter 5

The All Possible Models Option

The enter and remove statistics are calculated using cheap Score or Wald chi-square tests respectively, but the regression estimates and log-likelihood values are based on the full iterative maximum likelihood fit. If you want to compare the Wald/Score values, look at the Step History report.

The All Possible Models Option

For continuous responses, the Stepwise platform includes the All Possible Models option. It is accessible from the red-triangle menu on the Stepwise control panel. Enter values for the maximum number of terms to fit in any one model and for the maximum number of best model results to show for each number of terms in the model.

Example Using the All Possible Models Option

1. Open the Fitness jmp sample data table.
2. Select Analyze > Fit Model.
3. Select Oxy and click Y.
4. Select Runtime, RunPulse, RstPulse, and MaxPulse and click Add.
5. For Personality, select Stepwise.
6. Click Run.
7. From the red triangle menu next to Stepwise, select All Possible Models.
8. Enter 3 for the maximum number of terms, and enter 5 for the number of best models.
9. Click OK.

All possible models (up to three terms in a model) are fitted.

The models are listed in increasing order of the number of parameters that they contain. The model with the highest $R^2$ for each number of parameters is highlighted. The radio button column at the right of the table enables you to select one model at a time and check the results.
The recommended criterion for selecting a model is to choose the one corresponding to the smallest BIC or AICc value. Some analysts also want to see the $C_p$ statistic. Mallow’s $C_p$ statistic is computed, but initially hidden in the table. To make it visible, Right-click (Control-click on the Macintosh) in the table and select Columns > $C_p$ from the menu that appears.

The Model Averaging Option

The model averaging technique enables you to average the fits for a number of models, instead of picking a single best model. The result is a model with excellent prediction capability. This feature is particularly useful for new and unfamiliar models that you do not want to overfit. When many terms are selected into a model, the fit tends to inflate the estimates. Model averaging tends to shrink the estimates on the weaker terms, yielding better predictions. The models are averaged with respect to the AICc weight, calculated as follows:

$$\text{AICcWeight} = \exp[-0.5(\text{AICc} - \text{AICcBest})]$$

$\text{AICcBest}$ is the smallest AICc value among the fitted models. The AICc Weights are then sorted in decreasing order. The AICc weights cumulating to less than one minus the cutoff of the total AICc weight are set to zero, allowing the very weak terms to have true zero coefficients instead of extremely small coefficient estimates.

Example Using the Model Averaging Option

1. Open the Fitness.jmp sample data table.
2. Select Analyze > Fit Model.
3. Select Oxy and click Y.
4. Select Runtime, RunPulse, RstPulse, and MaxPulse and click Add.
5. For Personality, select Stepwise.
6. Click Run.
7. From the red triangle menu next to Stepwise, select Model Averaging.
8. Enter 3 for the maximum number of terms, and keep 0.95 for the weight cutoff.

Figure 5.17  Model Averaging Window

9. Click OK.
In the Model Averaging report, average estimates and standard errors appear for each parameter. The standard errors shown reflect the bias of the estimates toward zero.

10. Click **Save Prediction Formula** to save the prediction formula in the original data table.

**Using Validation**

Validation is the process of using part of a data set to estimate model parameters, and using the other part to assess the predictive ability of the model.

- The *training* set is the part that estimates model parameters.
- The *validation* set is the part that assesses or validates the predictive ability of the model.
- The *test* set is a final, independent assessment of the model’s predictive ability. The test set is available only when using a validation column.

The training, validation, and test sets are created by subsetting the original data into parts. Subsetting is done through the use of a validation column on the Fit Model launch window. The validation column’s values determine how the data is split, and what method is used for validation:

- If the column has two distinct values, then training and validation sets are created.
- If the column has three distinct values, then training, validation, and test sets are created.
- If the column has four or more distinct values, K-Fold cross validation is performed.

When you use validation, model fit statistics appear for the training, validation, and test sets.

**K-Fold Cross Validation**

K-Fold cross validation divides the original data into K subsets. In turn, each of the K sets is used to validate the model fit on the rest of the data, fitting a total of K models. The model giving the best validation statistic is chosen as the final model. This method is best for small data sets, because it makes efficient use of limited amounts of data.
To use K-Fold cross validation, do one of the following:

- Use a validation column with four or more distinct values.
- From the red triangle menu for Stepwise Fit, select **K-Fold Crossvalidation**.
Generalized Regression Models
Build Models Using Regularization Techniques

About Generalized Regression

In JMP Pro, the Fit Model platform’s Generalized Regression personality provides shrinkage techniques that specifically address modeling correlated and high-dimensional data. Two of these techniques, the Lasso and the Elastic Net, perform variable selection as part of the modeling procedure.

Large data sets that contain many variables typically evidence multicollinearity issues. Modern data sets often include more variables than observations, requiring variable selection if traditional modeling techniques are to be used. The presence of multicollinearity and a profusion of predictors exposes the shortcomings of classical techniques.

Even for small data sets with little or no correlation, including designed experiments, the Lasso and Elastic Net are useful. They can be used to obtain better predictive models or to select variables for model reduction or for future study.

The Generalized Regression personality is useful for many modeling situations. This personality enables you to specify a variety of distributions for your response variable. Use it when your response is continuous, binomial, a count, or a zero-inflated count. Use it when you are interested in variable selection or when you suspect collinearity in your predictors. More generally, use it to fit models that you compare to models obtained using other techniques.

Figure 6.1 The Solution Path for an Elastic Net Fit
# Contents

- Generalized Regression Overview ................................................. 251
- Example of Generalized Regression .............................................. 252
- Launch the Generalized Regression Personality ............................... 254
  - Model Launch Window .............................................................. 258
- Model Fit Reports ................................................................. 260
  - Model Summary ................................................................. 260
  - Solution Path ........................................................................ 261
  - Parameter Estimates for Centered and Scaled Predictors .................. 262
  - Effect Tests ........................................................................... 262
- Model Fit Options ........................................................................ 263
- Generalized Regression Options .................................................... 264
- Additional Examples of the Generalized Regression Personality ........... 264
  - Poisson Generalized Regression ................................................ 264
  - Binomial Generalized Regression .............................................. 266
  - Zero-Inflated Poisson Regression .............................................. 268
- Statistical Details ........................................................................ 270
  - Distributions .......................................................................... 270
Generalized Regression Overview

The Generalized Regression personality features regularized, or penalized, regression techniques. Such techniques attempt to fit better models by shrinking the model coefficients toward zero. The resulting estimates are biased. This increase in bias can result in decreased prediction variance, thus lowering overall prediction error. Two of these techniques, the Lasso and the Elastic Net, include variable selection as part of the modeling procedure.

Modeling techniques such as the Elastic Net and the Lasso are particularly promising for large data sets, where collinearity is typically a problem. In fact, modern data sets often include more variables than observations. This situation is sometimes referred to as the \( p > n \) problem, where \( n \) is the number of observations and \( p \) is the number of predictors. Such data sets require variable selection if traditional modeling techniques are to be used.

The Elastic Net and Lasso are also useful for small data sets with little correlation, including designed experiments. They can be used to obtain better predictive models or to select variables for model reduction or for future study.

The personality provides four classes of modeling techniques.

- Maximum Likelihood
- Lasso
- Elastic Net
- Ridge Regression

The Lasso and Elastic Net are relatively recent techniques (Tibshirani, 1996, Zou and Hastie, 2005). Both techniques penalize the size of the model coefficients, resulting in a continuous shrinkage. An optimal level of shrinkage is determined by one of several validation methods. Both techniques have the ability to shrink coefficients to zero. In this way, variable selection is built into the modeling procedure. The Elastic Net model subsumes both the Lasso and ridge regression as special cases.

The Lasso has two shortcomings. When several variables are highly correlated, it tends to select only one variable from that group. When the number of variables, \( p \), exceeds the number of observations, \( n \), the Lasso selects at most \( n \) predictors.

The Elastic Net, on the other hand, tends to select all variables from a correlated group, fitting appropriate coefficients. It can also select more than \( n \) predictors when \( p > n \). The Elastic Net fit generally takes more processing time than the Lasso.

Ridge regression was among the first of the penalized regression methods proposed (Hoerl, 1962, Hoerl and Kennard, 1970). Ridge regression does not shrink coefficients to zero, so it does not perform variable selection.

The Maximum Likelihood method is a classical approach. It provides a baseline to which you can compare the other techniques.
The Generalized Regression personality also fits an adaptive version of the Lasso and the Elastic Net. These adaptive versions attempt to penalize active variables less than inactive variables. The adaptive versions were developed to ensure that the oracle property holds. The oracle property guarantees the following: Asymptotically, your estimates are what they would have been had you known in advance which predictors were active contributors to the model. More specifically:

- Your model correctly identifies the predictors that should have zero coefficients.
- Your estimates converge to those that would have been obtained had you started with only the active predictors.

The Generalized Regression personality enables you to specify a variety of distributions for your response variable. The distributions fit include normal, binomial, Poisson, zero-inflated Poisson, negative binomial, zero-inflated negative binomial, and gamma. This flexibility enables you to fit categorical and count responses, as well as continuous responses, and specifically, right-skewed continuous responses. The personality also provides a variety of validation criteria for model selection.

**Example of Generalized Regression**

The data in the Diabetes.jmp sample data table consist of measurements on 442 diabetics. The response of interest is Y, disease progression measured one year after a baseline measure was taken. Ten variables thought to be related to disease progression are also measured at baseline. This example shows how to develop a predictive model using generalized regression techniques.

1. Open the Diabetes.jmp sample data table.
2. Select Analyze > Fit Model.
3. Select Y from the Select Columns list and click Y.
4. Select Age through Glucose and click Macros > Factorial to degree.
   
   This adds all terms up to degree 2 (the default in the Degree box) to the model.
5. Select Validation from the Select Columns list and click Validation.
6. From the Personality list, select Generalized Regression.
7. Click Run.
   
   The Generalized Regression Model Launch control panel appears. Note that the default fit is an Adaptive Elastic Net.
   
   Because you specified a validation column in the Fit Model window, the Validation Method is set to Validation Column.
8. From the Estimation Method list, select Lasso.
9. Click Go.
The Solution Path report (Figure 6.2) shows a plot of the parameter estimates. The shrinkage increases as the Magnitude of Scaled Parameter Estimates decreases. The estimates at the far right of the plot are the maximum likelihood estimates. A vertical red line indicates those parameter values selected by the validation criterion, in this case, the holdback sample defined by the column Validation.

**Figure 6.2 Solution Path Plot**

10. Select the option **Select Nonzero Terms** from the Adaptive Lasso with Validation Column Validation report’s red triangle menu.

This option highlights the nonzero terms in the Parameter Estimates for Centered and Scaled Data report (Figure 6.3) and their paths in the Solution Path plot. Note that only 11 of the 55 parameter estimates are nonzero. Also note that the scale parameter for the normal distribution (sigma) is estimated and shown in the last line of the Parameter Estimates for Centered and Scaled Data report.
To save the prediction formula, select **Save Columns > Save Prediction Formula** from the red triangle menu for the Adaptive Lasso with Validation Column Validation report.

**Launch the Generalized Regression Personality**

Launch the Generalized Regression personality by selecting **Analyze > Fit Model**, entering one or more columns for **Y**, and selecting **Generalized Regression** from the **Personality** menu (Figure 6.4).
Figure 6.4 Fit Model Launch Window with Generalized Regression Selected

For details about aspects of the Fit Model window that are common to all personalities, see the “Introduction to Fit Model” chapter on page 27. Details specific to the Generalized Regression personality are presented here.

If your model effects have missing values, you can treat these missing values as informative categories. Select the Informative Missing option from the Model Specification window’s red triangle menu.

When you select Generalized Regression from the Personality menu, the Distribution option appears. Here you can specify a distribution for Y. The abbreviation ZI means zero-inflated. The options are described below.

**Normal**  
Y has a normal distribution with mean μ and standard deviation σ. The link function for μ is the identity. That is, the mean of Y is expressed as a linear model. In estimating the model parameters, the scale parameter σ is profiled out. It is then replaced by its maximum likelihood estimate (MLE). (Note that the MLE is not the typical unbiased estimator for σ.)
Binomial  Y has a binomial distribution with parameters $p$ and $n$. The link function for $p$ is the logit. When you select Binomial as the Distribution, the response variable must be specified in one of the following ways.

- Unsummarized: If your data are not summarized as frequencies of events, specify a single binary column as the response.
- Summarized with Freq column: If your data are summarized as frequencies of successes and failures, specify a single binary column as the response. This column can have any modeling type. Assign the frequency column to the Freq role.
- Summarized with count column entered as second Y: If your data are summarized as frequencies of events (successes) and trials, specify two continuous columns as Y in this order: the count of the number of successes, and the count of the number of trials.

Poisson  Y has a Poisson distribution with mean $\lambda$. The link function for $\lambda$ is the logarithm. Poisson regression is permitted even if Y assumes non-integer values.

ZI Poisson  Y has a zero-inflated Poisson distribution with parameters $\lambda$ and zero-inflation parameter $\pi$. The parameter $\lambda$ is the conditional mean based on the observations coming from the Poisson distribution and not the inflating zeros. The link function for $\lambda$ is the logarithm. ZI Poisson regression is permitted even if Y assumes no observed zeros or non-integer values See “Distributions” on page 270.

Negative Binomial  Y has a negative binomial distribution with mean $\mu$ and dispersion parameter $\sigma$. The link function for $\mu$ is the logarithm. Negative binomial regression is permitted even if Y assumes non-integer values See “Distributions” on page 270.

ZI Negative Binomial  Y has a zero-inflated negative binomial with location parameter $\mu$, dispersion parameter $\sigma$, and zero-inflation parameter $\pi$. The parameter $\mu$ is the conditional mean based on the observations coming from the negative binomial distribution and not the inflating zeros. The link function for $\mu$ is the logarithm. Zero-inflated negative binomial regression is permitted even if Y assumes no observed zeros or non-integer values See “Distributions” on page 270.

Gamma  Y has a gamma distribution with parameters $\mu$ and $\sigma$. The link function for $\mu$ is the logarithm See “Distributions” on page 270.

Table 6.1 gives the Data Types, Modeling Types, and other requirements for Y variables assigned the various distributions.

<table>
<thead>
<tr>
<th>Distribution</th>
<th>Data Type</th>
<th>Modeling Type</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>Numeric</td>
<td>Continuous</td>
<td></td>
</tr>
<tr>
<td>Binomial, unsummarized</td>
<td>Any</td>
<td>Any</td>
<td>Binary</td>
</tr>
</tbody>
</table>
Table 6.1 Requirements for Y for Distributions (Continued)

<table>
<thead>
<tr>
<th>Distribution</th>
<th>Data Type</th>
<th>Modeling Type</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Binomial, summarized with Freq column</td>
<td>Any</td>
<td>Any</td>
<td>Binary</td>
</tr>
<tr>
<td>Binomial, summarized with count column entered as second Y</td>
<td>Numeric</td>
<td>Continuous</td>
<td>Nonnegative</td>
</tr>
<tr>
<td>Poisson</td>
<td>Numeric</td>
<td>Any</td>
<td>Nonnegative</td>
</tr>
<tr>
<td>Zero-Inflated Poisson</td>
<td>Numeric</td>
<td>Any</td>
<td>Nonnegative</td>
</tr>
<tr>
<td>Negative Binomial</td>
<td>Numeric</td>
<td>Any</td>
<td>Nonnegative</td>
</tr>
<tr>
<td>Zero-Inflated Negative Binomial</td>
<td>Numeric</td>
<td>Any</td>
<td>Nonnegative</td>
</tr>
<tr>
<td>Gamma</td>
<td>Numeric</td>
<td>Continuous</td>
<td>Positive</td>
</tr>
</tbody>
</table>

Details on how these distributions are parameterized are given in “Distributions” on page 270. Table 6.2 summarizes the details.

Table 6.2 Distributions, Parameters, and Link Functions

<table>
<thead>
<tr>
<th>Distribution</th>
<th>Parameters</th>
<th>Mean Model Link Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>$\mu, \sigma$</td>
<td>Identity($\mu$)</td>
</tr>
<tr>
<td>Binomial</td>
<td>$p$</td>
<td>Logit($p$)</td>
</tr>
<tr>
<td>Poisson</td>
<td>$\lambda$</td>
<td>Log($\lambda$)</td>
</tr>
<tr>
<td>Zero-Inflated Poisson</td>
<td>$\lambda, \pi$ (zero-inflation)</td>
<td>Log($\lambda$)</td>
</tr>
<tr>
<td>Negative Binomial</td>
<td>$\mu, \sigma$</td>
<td>Log($\mu$)</td>
</tr>
<tr>
<td>Zero-Inflated Negative Binomial</td>
<td>$\mu, \sigma, \pi$ (zero-inflation)</td>
<td>Log($\mu$)</td>
</tr>
<tr>
<td>Gamma</td>
<td>$\mu, \sigma$</td>
<td>Log($\mu$)</td>
</tr>
</tbody>
</table>

After selecting an appropriate Distribution, click Run. The Generalized Regression Model Launch panel opens.
Model Launch Window

In the Model Launch window, select options for the Estimation Method and the Validation Method. Then click Go to run the specified analysis.

Estimation Method Options

Ridge, the Lasso, and the Elastic Net are penalized regression techniques. They shrink the size of regression coefficients, thus biasing them, in order to improve predictive ability. Two types of penalties are used in these techniques:

- the $l_1$ penalty, which penalizes the sum of the absolute values of the regression coefficients
- the $l_2$ penalty, which penalizes the sum of the squares of the regression coefficients

The following methods are available for model fitting:

**Maximum Likelihood**  Computes maximum likelihood estimates for model parameters. No penalty is imposed.

**Ridge**  Computes parameter estimates using ridge regression. This technique applies an $l_2$ penalty.

**Lasso**  Computes parameter estimates by applying an $l_1$ penalty. Due to the $l_1$ penalty, some coefficients can be estimated as zero. Thus, variable selection is performed as part of the fitting procedure. In the ordinary Lasso, all coefficients are equally penalized.

**Adaptive Lasso**  Computes parameter estimates by penalizing a weighted sum of the absolute values of the regression coefficients. The weights in the $l_1$ penalty are determined by the data in such a way as to guarantee the oracle property (Zou, 2006). This option is not available if MLEs for the regression parameters cannot be computed. MLEs cannot be computed when the number of predictors exceeds the number of observations or when there are strict linear dependencies among the predictors.

**Elastic Net**  Computes parameter estimates by applying both an $l_1$ penalty and an $l_2$ penalty. The $l_1$ penalty ensures that variable selection is performed. The $l_2$ penalty improves predictive ability by shrinking the coefficients as ridge does.

**Adaptive Elastic Net**  Computes parameter estimates using an adaptive $l_1$ penalty as well as an $l_2$ penalty. This option is not available if MLEs for the regression parameters cannot be computed. MLEs cannot be computed when the number of predictors exceeds the number of observations or when there are strict linear dependencies among the predictors.

**Note:** When you select an Elastic Net fit, the algorithm computes the Lasso, Elastic Net, and ridge fits, in that order. The progress bar for the Elastic Net indicates when the algorithm is fitting Lasso, Elastic Net, and ridge. If a fit is time consuming, this allows you to determine which fits have been completed should you click Accept the Current Estimates. For example, you might wait until the Lasso fits are complete before accepting the current estimates.
Discussion of Estimation Methods

The Maximum Likelihood option gives you a way to construct classical models for the response distributions supported by the Generalized Regression personality. In addition, a model based on maximum likelihood can serve as a baseline for model comparison.

Ridge regression is a biased regression technique that does not result in zero parameter estimates. It is useful when you want to retain all predictors in your model.

The Lasso and the adaptive Lasso can evidence poor performance when predictors are highly correlated. These techniques tend to select only one of a group of correlated predictors. High-dimensional data tend to have highly correlated predictors. For this type of data, the Elastic Net might be a better choice than the Lasso.

The Elastic Net tends to provide better prediction accuracy than the Lasso when predictors are highly correlated. (In fact, both ridge and the Lasso are special cases of the Elastic Net.) In terms of predictive ability, the adaptive Elastic Net often outperforms both the Elastic Net and the adaptive Lasso. The Elastic Net has the ability to select groups of correlated predictors and to assign appropriate parameter estimates to the predictors involved.

Validation Method Options

**KFold**  Partitions the data into $K$ subsets, or *folds*. In turn, each fold is used to validate the model that is fit to the rest of the data, fitting a total of $K$ models. This method is best for small data sets, because it makes efficient use of limited amounts of data.

**Holdback**  Randomly selects the specified proportion of the data for a validation set, and uses the other portion of the data to fit the model. This method is useful for large data sets.

**Leave-One-Out**  Performs leave-one-out cross validation. This is equivalent to KFold, with the number of folds equal to the number of rows. This option should not be used on moderate or large data sets. It can require long processing time for even a moderate number of observations.

**BIC**  Minimizes the Bayesian Information Criterion (BIC) over the solution path. If $k$ is the number of parameters and $n$ is the sample size, the BIC is defined as:

$$BIC = -2 \log \text{Likelihood} + k \ln(n)$$

**AIC**  Minimizes the Akaike Information Criterion (AIC) over the solution path. If $k$ is the number of parameters and $n$ is the sample size, the AIC is defined as:

$$AIC = -2 \log \text{Likelihood} + 2k$$

Note that AIC, and not the corrected AIC, is used. This is because of complications introduced when the number of parameters approaches or exceeds the sample size.

**None**  Does not use validation. Only available for the Maximum Likelihood Estimation Method.
Validation Column  Uses the column specified in the Fit Model window as having the Validation role.

When you click Go, a report opens. The title of the report specifies the fitting and validation methods that you selected. You can return to the Model Launch window to perform additional analyses and choose other estimation and validation methods.

Model Fit Reports

For each Estimation Method and Validation Method that you specify in the Model Launch panel, a report is produced. The report specifies your selected Estimation and Validation methods in its title.

The following reports are presented by default.

• Model Summary
• Solution Path (shown for all but the Maximum Likelihood Estimation Method)
• Parameter Estimates for Centered and Scaled Predictors
• Effect Tests

Model Summary

The Model Summary report describes the model that you have fit, and provides summary information about the fit itself.

Model Description Detail

The first part of the Model Summary report gives information that describes the model that you have fit.

Response  The column assigned to the Y role in the Fit Model window.

Distribution  The Distribution selected in the Fit Model window.

Estimation Method  The Estimation Method selected in the Model Launch panel.

Validation Method  The Validation Method selected in the Model Launch panel.

Mean Model Link  The link function for the model for the mean, based on the Distribution selected in the Fit Model window.

Scale Model Link  The link function for the model for the scale parameter, based on the Distribution selected in the Fit Model window.

Probability Model Link  The link function for the model for the probability, shown when Binomial is selected as the Distribution in the Fit Model window.
**Dispersion Model Link**  The link function for the model for the dispersion parameter, based on the Distribution selected in the Fit Model window.

**Zero Inflation Model Link**  The link function for the model for the zero inflation parameter, based on the Distribution selected in the Fit Model window.

**Model Fit Detail**

This part of the Model Summary report gives statistics related to the model fit. If any of KFold, Holdback, Leave-One-Out, or Validation Column is selected as the Validation Method, these statistics are computed separately for the training and validation sets. If KFold or Leave-One-Out is the Validation Method, the statistics given correspond to the validation fold with the smallest prediction error, and its associated training set.

**Number of rows**  The number of rows.

**Sum of Frequencies**  The sum of the values of a column assigned to the Freq or Weight role in the Fit Model window.

**-LogLikelihood**  The negative of the natural logarithm of the likelihood function for the specified model. Smaller is better.

**BIC**  The Bayesian Information Criterion: \( \text{BIC} = -2 \text{LogLikelihood} + k \ln(n) \). Smaller is better.

**AIC**  The Akaike Information Criterion: \( \text{AIC} = -2 \text{LogLikelihood} + 2k \). Smaller is better.

**Solution Path**

The Solution Path report plots the estimated parameters against the magnitude of the scaled parameter estimates. This report appears for all Estimation Methods except Maximum Likelihood.

The Parameter Estimates are plotted using the vertical axis. These are the scaled parameter estimates. They are derived for a model expressed in terms of centered and scaled predictors (see “Parameter Estimates for Centered and Scaled Predictors” on page 262).

The horizontal scaling for the plot is given in terms of the Magnitude of Scaled Parameter Estimates. This is the \( l_1 \) norm, defined as the sum of the absolute values of the scaled parameter estimates for the model for the mean. (Estimates corresponding to the intercept, dispersion parameters, and zero-inflation parameters are excluded from the calculation of the \( l_1 \) norm.) A vertical red line is placed at the value of the \( l_1 \) norm for the solution displayed in the Parameter Estimates for Centered and Scaled Predictors report.

When the number of predictors is less than the number of observations, the plot shows the entire range of estimates from zero to the unpenalized fit given by the MLE. Otherwise, the plot extends to a magnitude that is close to the unpenalized solution. To view the path associated with a given model term, click on the row corresponding to that term in the Parameter Estimates for Centered and Scaled Predictors report.
Parameter Estimates for Centered andScaled Predictors

For all fits in the Generalized Regression personality, all predictors are centered to have mean
zero and scaled to have standard deviation one. This puts all predictors on an equal footing
relative to the penalties applied.

The Parameter Estimates for Centered and Scaled Predictors report gives parameter estimates
for the model expressed in terms of the centered and scaled predictors. The estimates are
determined by the Validation Method that you specified. The estimates are depicted in the
Solution Path plot by a vertical red line.

Note: To see the parameter estimates in terms of the unstandardized predictor values, select
Save Columns > Save Prediction Formula from the report’s red triangle menu.

Tip: Clicking on a row in the report selects the associated column (or columns) in the data
table. This column selection is useful in terms of running further analyses.

The report provides the following information:

Term A list of the model terms.

Estimate The parameter estimate corresponding to the centered and scaled model term.

Std Error The standard error of the estimate. This is obtained using M-estimation and a
sandwich formula (Zou, 2006, and Huber and Ronchetti, 2009).

Wald ChiSquare The ChiSquare value for a Wald test of whether the parameter is zero.

Prob > ChiSquare The p-value for the Wald test.

Lower 95% The lower bound for a 95% confidence interval for the parameter. Note that you
can change the alpha level in the Fit Model window by selecting Set Alpha Level from the
red triangle menu.

Upper 95% The upper bound for a 95% confidence interval for the parameter. Note that you
can change the alpha level in the Fit Model window by selecting Set Alpha Level from the
red triangle menu.

Effect Tests

Source A list of the effects in the model.

DF The degrees of freedom for the Wald ChiSquare test.

Wald ChiSquare The ChiSquare value for a Wald test of whether all parameters associated
with the effect are zero.

Prob > ChiSquare The p-value for the Wald ChiSquare test.
Model Fit Options

Each model fit report has a red triangle menu with these options:

Select Nonzero Terms  Highlights terms with nonzero coefficients in the report. Also selects all associated columns in the data table.

Select Zeroed Terms  Highlights terms with zero coefficients in the report. Also selects all associated columns in the data table.

Profiler  Displays the Prediction Profiler. For details, see the Profilers book.

Covariance of Estimates  Displays a matrix showing the covariances of the parameter estimates. These are calculated using M-estimation and a sandwich formula (Zou, 2006, and Huber and Ronchetti, 2009).

Correlation of Estimates  Displays a matrix showing the correlations of the parameter estimates. These are calculated using M-estimation and a sandwich formula (Zou, 2006, and Huber and Ronchetti, 2009).

Diagnostic Plots  Provides two options: Plot Actual by Predicted and Plot Residual by Predicted. If a Validation column is specified or if KFold, Holdback, or Leave-One-Out is selected as the Validation Method, then plots are constructed for both the training and validation sets. If KFold or Leave-One-Out is selected, then the plots correspond to the validation set that optimizes prediction error, and its corresponding training set.

-  Plot Actual by Predicted plots actual Y values on the vertical axis and predicted Y values on the horizontal axis.
-  Plot Residual by Predicted plots the residuals on the vertical axis and the predicted Y values on the horizontal axis.

Save Columns  Enables you to save the following columns to the data table:

-  Save Prediction Formula: Saves the prediction formula, given in terms of the observed (unstandardized) data values. See “Distributions” on page 270 for mean formulas.
-  Save Residual Formula: Save a formula for the residuals, given in the form Y minus the prediction formula. Not available if Binomial is selected as the Distribution.
-  Save Variance Formula: Saves a formula for the variance of the prediction. The variance of the prediction is calculated using the formula for the variance of the selected Distribution. The value of the parameter involved in the link function is estimated by applying the inverse of the link function to the estimated linear component. Other parameters are replaced by their estimates. See “Distributions” on page 270 for variance formulas. Not available if Binomial is selected as the Distribution.
Save Validation Column: Only available if you choose KFold, Holdback, Leave-One-Out, or Validation Column as a Validation Method. Saves a column that describes the assignment of rows to folds. For KFold, the column lists the fold to which the row was assigned. For Holdback and Validation Column, each row is identified as belonging to the Training or Validation set. For Leave-One-Out, the row’s value indicates its order in being left out.

Remove Fit  Removes the report for the fit.

---

**Poisson Generalized Regression**

The Liver Cancer.jmp sample data table contains liver cancer Node Count values for 136 patients. It also includes measurements on six potentially related variables: BMI, Age, Time, Markers, Hepatitis, and Jaundice. These columns are described in Column Notes in the data table.

This example develops a prediction model for Node Count using the six predictors. Node Count is modeled using a Poisson distribution.

1. Open the Liver Cancer.jmp sample data table.
2. Select Analyze > Fit Model.
3. Select Node Count from the Select Columns list and click Y.
4. Select BMI through Jaundice and click Macros > Factorial to degree. This adds all terms up to degree 2 (the default in the Degree box) to the model.
5. Select Validation from the Select Columns list and click Validation.
6. From the Personality list, select Generalized Regression.
7. From the Distribution list, select Poisson.
8. Click Run.
   The Generalized Regression Model Launch control panel appears. Note that the default Estimation Method is an adaptive Elastic Net.
9. Select Lasso from the Estimation Method list.
10. Click **Go**.

11. From the report’s red triangle menu, select **Select Nonzero Terms**.

The Solution Path is shown in Figure 6.5. The paths for terms that have nonzero coefficients are highlighted. Think of the solution paths as moving from right to left across the plot, as the solutions shrink farther from the MLE. A number of terms have paths that shrink them to zero fairly early.

The vertical axis in the Solution Path plot represents the values of the parameter estimates for the standardized predictors. The vertical red line indicates their values at the optimal shrinkage, as determined by cross validation. At this point, eleven terms have nonzero coefficients.

**Figure 6.5** Solution Path for Lasso Fit with Nonzero Terms Highlighted

![Solution Path](image)

The Parameter Estimates Report for Centered and Scaled Predictors (Figure 6.6) shows the parameter estimates. The eleven terms with nonzero parameter estimates are highlighted. These include interaction effects. In the data table, all six predictor columns are selected because every predictor column appears in a term that has a nonzero coefficient.

The Effect Tests report indicates that only one effect is significant at the 0.05 level: the **Age** \(^*\) **Markers** interaction.

12. Click on the row for (Age - 56.3994)\(\times\)Markers[0] in the Parameter Estimates for Centered and Scaled Predictors report.

This action highlights that effect's path in the Solution Path plot.
13. From the Adaptive Lasso with Validation Column Validation report's red triangle menu, select **Save Columns > Save Prediction Formula** and **Save Columns > Save Variance Formula**.

Two columns are added to the data table: Node Count Prediction Formula and Node Count Variance.

14. Right-click either column header and select **Formula** to view the formula. Alternatively, click on the plus sign to the right of the column name in the Columns panel.

The prediction formula in the **Save Prediction Formula** column applies the exponential function to the estimated linear part of the model. The prediction variance formula in **Node Count Variance** is given by the identical formula, because the variance of a Poisson distribution equals its mean.

### Binomial Generalized Regression

This example shows how to develop a prediction model for the binomial response, **Severity**, in the Liver Cancer.jmp sample data table.

1. Open the Liver Cancer.jmp sample data table.
2. Select **Analyze > Fit Model**.
3. Select Severity from the Select Columns list and click **Y**.
4. Select BMI through Jaundice and click **Macros > Factorial to degree**.

All terms up to degree 2 (the default in the **Degree** box) are added to the model.
5. Select Validation from the Select Columns list and click **Validation**.

6. From the Personality list, select **Generalized Regression**.

7. From the Distribution list, select **Binomial**.

8. Click **Run**.
   
The Generalized Regression Model Launch control panel appears.

9. **Elastic Net** is selected as the Estimation Method. Click **Go**.
   
The Solution Path is shown in Figure 6.7. The paths for terms that have nonzero coefficients are shown in blue. The optimal parameter values are substantially shrunken away from the MLE.

**Figure 6.7 Solution Path Plot**

10. Select the Select Zeroed Terms option from the Adaptive Lasso with Validation Column Validation report’s red triangle menu.

    The twelve terms that have coefficient estimates of zero are highlighted in the Parameter Estimates Report for Centered and Scaled Predictors. The Effect Tests report shows that only one term, **Time**, is significant at the 0.05 level. However, the **Time*Markers** interaction has a small p-value of 0.0665.

11. To see how **Time** and the **Time*Markers** interaction affect **Severity**, select Profiler from the Adaptive Elastic Net report’s red triangle menu.

    The Prediction Profiler is shown in Figure 6.8.
Figure 6.8 Profiler for Probability That Severity = High, Time Low

12. Move the red dashed line for Time from left to right to see its interaction with Markers (Figure 6.8 and Figure 6.9). For patients who enter the study with small values of Time since diagnosis, Markers have little impact on Severity. But for patients who enter the study having been diagnosed for a longer time, Markers are important. For those patients, normal markers suggest a lower probability of high Severity.

Figure 6.9 Profiler for Probability That Severity = High, Time High

Zero-Inflated Poisson Regression

The Fishing.jmp sample data table contains fictional data for a study of various factors that affect the number of fish caught by groups visiting a park. The data table contains 250 responses from families or groups of traveling companions. This example models the number of Fish Caught as a function of Live Bait, Fishing Poles, Camper, People, and Children. These columns are described in Column Notes in the data table.

The data table contains a hidden column called Fished. During data collection, it was never determined whether anyone in the group had actually fished. However, the Fished column is included in the table to emphasize the point that catching zero fish can happen in one of two ways: Either no one in the group fished, or everyone who fished in the group was unlucky.

Therefore, zero responses can come from two sources. To address this issue, you can fit a zero-inflated distribution. Because a Poisson distribution is appropriate for the count data resulting from people who fished, you fit a zero-inflated Poisson distribution.

1. Open the Fishing.jmp sample data table.
2. Select Analyze > Fit Model.
3. Select Fish Caught from the Select Columns list and click **Y**.
4. Select Live Bait through Children and click **Macros > Factorial to degree**. Terms up to degree 2 (the default in the **Degree** box) are added to the model.
5. Select Validation from the Select Columns list and click **Validation**.
6. From the Personality list, select **Generalized Regression**.
7. From the Distribution list, select **ZI Poisson**.
8. Click **Run**. The Model Launch control panel appears, with Adaptive Elastic Net selected as the estimation method.
9. Click **Go**. The Solution Path and Parameter Estimates for Centered and Scaled Predictor reports indicate that a fair number of terms are zeroed. The Zero Inflation parameter, whose estimate is shown on the last line of the report, is highly significant. This indicates that some of the variation in the response, Fish Caught, may be due to the fact that some groups did not fish.

**Figure 6.10** Parameter Estimates for Centered and Scaled Predictors Report

![](image)

The Effect Tests report indicates that four terms are significant at the 0.05 level: Live Bait, Fishing Poles, Fishing Poles*Camper, and Fishing Poles*Children.

10. Select **Profiler** from the red triangle menu for the Adaptive Elastic Net with Validation Column Validation report.
11. From the Profiler report’s red triangle menu, select **Desirability Functions**. A function is imposed on the response, which indicates that maximizing the number of Fish Caught is desirable. (See the Profilers book for more information about desirability functions.)
12. From the Profiler report’s red triangle menu, select **Maximize Desirability**.

The Profiler, with settings that maximize the number of fish caught, is shown in Figure 6.11. You can vary the settings to see the impact of the significant effects: Live Bait, Fishing Poles, Fishing Poles*Camper, and Fishing Poles*Children. For example, live bait is associated with more fish; campers tend to bring more fishing poles than non-campers and, therefore, catch more fish.

![Prediction Profiler with Fish Caught Maximized](image)

13. From the Adaptive Elastic Net with Validation Column Validation report’s red triangle menu, select **Save Columns > Save Prediction Formula** and **Save Columns > Save Variance Formula**.

Two columns are added to the data table: Fish Caught Prediction Formula and Fish Caught Variance.

14. Right-click either column header and select **Formula** to view the formula. Alternatively, click the plus sign to the right of the column name in the Columns panel. Note the appearance of the estimated zero-inflation parameter, 0.7864579, in both of these formulas.

---

**Statistical Details**

**Distributions**

The distributions fit by the Generalized Regression personality are given below in terms of the parameters used in model fitting. Although it is not specifically stated as part of their descriptions, the Generalized Regression personality enables you to input non-integer values for the discrete distributions.
Normal Distribution
\[ f(y | \mu, \sigma) = \frac{1}{\sigma \sqrt{2\pi}} \exp\left\{-\frac{(y - \mu)^2}{2\sigma^2}\right\}, -\infty < y < \infty \]
\[ E(Y) = \mu \]
\[ Var(Y) = \sigma^2 \]

Binomial Distribution
\[ f(y | n, p) = \binom{n}{y} p^y (1 - p)^{n-y}, \quad y = 0, 1, 2, \ldots, n \]
\[ E(Y) = np \]
\[ Var(Y) = np(1 - p) \]

Poisson Distribution
\[ f(y | \lambda) = \frac{\lambda^y}{y!} \exp(-\lambda), \quad y = 0, 1, 2, \ldots \]
\[ E(Y) = \lambda \]
\[ Var(Y) = \lambda \]

Zero-Inflated Poisson Distribution
\[ f(y | \lambda, \pi) = \begin{cases} 
\pi + (1 - \pi) \exp(-\lambda), & \text{for } y = 0 \\
(1 - \pi) \frac{\lambda^y}{y!} \exp(-\lambda), & \text{for } y = 1, 2, \ldots 
\end{cases} \]
\[ E(Y) = (1 - \pi) \lambda \]
\[ Var(Y) = \lambda(1 - \pi)(1 + \pi \lambda) \]

Negative Binomial Distribution
\[ f(y | \mu, \sigma) = \frac{\Gamma(y + (1/\sigma))}{\Gamma(y + 1) \Gamma(1/\sigma)} \frac{(\mu \sigma)^y}{(1 + \mu \sigma)^{y + (1/\sigma)}}, \quad y = 0, 1, 2, \ldots \]
\[ E(Y) = \mu \]
\[ Var(Y) = \mu + \sigma \mu^2 \]
Zero-Inflated Negative Binomial Distribution

\[ f(y | \mu, \sigma, \pi) = \begin{cases} 
\pi + (1 - \pi)(1 + \mu \sigma)^{-1/\sigma}, & \text{for } y = 0 \\
(1 - \pi) \frac{\Gamma(y + 1/\sigma)}{\Gamma(y + 1) \Gamma(1/\sigma)} \left( \frac{(\mu \sigma)^y}{y + 1/\sigma} \right), & \text{for } y = 1, 2, \ldots
\end{cases} \]

\[ E(Y) = (1 - \pi) \mu \]
\[ Var(Y) = \mu (1 - \pi) [1 + \mu (\sigma + \pi)] \]

Gamma Distribution

\[ f(y | \mu, \sigma) = \frac{y^{(\mu/\sigma) - 1} \exp(-y/\sigma)}{\Gamma(\mu/\sigma) \sigma^{\mu/\sigma}}, \quad y > 0 \]

\[ E(Y) = \mu \]
\[ Var(Y) = \mu \sigma \]
Chapter 7

Mixed Models

Jointly Model the Mean and Covariance

About Mixed Models

In JMP Pro, the Fit Model platform’s Mixed Model personality fits a wide variety of linear models for continuous responses with complex covariance structures. These models include random coefficients, repeated measures, spatial data, and data with multiple correlated responses. Use the Mixed Model personality to specify linear mixed models and their covariance structures conveniently using an intuitive interface, and to fit these models using maximum likelihood methods.

Analytic results are supported by compelling dynamic visualization tools such as profilers, surface plots, and contour plots. These visual displays stimulate, complement, and support your understanding of the model. See the Profilers book for more information.

Figure 7.1 Surface Profiler for a Repeated Measures Experiment
## Contents

Overview of the Mixed Model Personality .................................................. 275  
Example Using Mixed Model .................................................................. 276  
Launch the Mixed Model Personality ..................................................... 280  
The Fit Mixed Report .......................................................................... 285  
  Fit Statistics ...................................................................................... 287  
  Random Effects Covariance Parameter Estimates ............................ 289  
  Fixed Effects Parameter Estimates .................................................. 290  
  Repeated Effects Covariance Parameter Estimates ....................... 290  
  Random Coefficients ....................................................................... 291  
  Random Effect Predictions .............................................................. 291  
  Fixed Effects Tests .......................................................................... 291  
  Multiple Comparisons ..................................................................... 292  
  Marginal Model Diagnostic Plots ..................................................... 293  
  Marginal Model Profiling ................................................................. 294  
  Save Columns ................................................................................... 294  
Additional Examples ............................................................................ 295  
  Repeated Measures Example .......................................................... 295  
  Covariance Structure: Unstructured Example ............................... 296  
  Covariance Structure: Residual Example ....................................... 300  
  Covariance Structure: AR(1) Example ........................................... 301  
  Split Plot Example ........................................................................... 308  
  Spatial Example: Uniformity Trial ................................................. 314  
  Correlated Response Example ......................................................... 321  
Statistical Details .................................................................................... 326  
  Convergence Score Test .................................................................... 326  
  Random Coefficient Model ............................................................... 327  
  Repeated Measures ......................................................................... 328  
  Spatial Variability ............................................................................. 331  
The Kackar-Harville Correction ............................................................. 333
Overview of the Mixed Model Personality

In JMP Pro, the Mixed Model personality lets you analyze models with complex covariance structures. The situations that can be analyzed include:

- Split plot experiments
- Random coefficients models
- Repeated measures designs
- Spatial data
- Correlated response data

Split plot experiments are experiments with two or more levels, or sizes, of experimental units resulting in multiple error terms. Such designs are often necessary when some factors are easy to vary and others are more difficult to vary. (See the Custom Design chapter in Design of Experiments Guide.)

Random coefficients models are also known as hierarchical or multilevel models (Singer 1998; Sullivan, Dukes, and Losina 1999). These models are used when batches or subjects are thought to differ randomly in intercept and slope. Drug stability trials in the pharmaceutical industry and individual growth studies in educational research often require random coefficient models.

Repeated measures designs, spatial data, and correlated response data share the property that observations are not independent, requiring that you model their correlation structure.

- Repeated measures designs, also known as within-subject designs, model changes in a response over time or space while allowing errors to be correlated.
- Spatial data are measurements made in two or more dimensions, typically latitude and longitude. Spatial measurements are often correlated as a function of their spatial proximity. Upton and Fingelton (1985) observe that the many varieties of spatial data preclude a classification system that is “simultaneously exclusive, exhaustive, imaginative, and satisfying.”
- Correlated response data result from making several measurements on the same experimental unit. For example, height, weight, and blood pressure readings taken on individuals in a medical study, or hardness, strength, and elasticity measured on a manufactured item, are likely to be correlated. Although these measurements can be studied individually, treating them as correlated responses can lead to useful insights.

Failure to account for correlation between observations can result in incorrect conclusions about treatment effects. However, estimating covariance structure parameters uses information in the data. The number of parameters being estimated impacts power and the Type I error rate. For this reason, you must choose covariance models judiciously. For more information, see “Repeated Measures Example” on page 295.
Example Using Mixed Model

In a study of wheat yield, ten varieties of wheat are randomly selected from the population of varieties of hard red winter wheat adapted to dry climate conditions. These are randomly assigned to six one-acre plots of land. The preplanting moisture content of the plots could influence the germination rate and hence the eventual yield of the plots. Thus, the amount of preplanting moisture in the top 36 inches of soil is determined for each plot. You are interested in determining if the moisture content affects yield.

Because the varieties are randomly selected, the regression model for each variety is a random model selected from the population of variety models. The intercept and slope are random for each variety and might be correlated. The random coefficients are centered at the fixed effects. The fixed effects are the population intercept and the slope, which are the expected values of the population of the intercepts and slopes of the varieties. (This example is taken from SAS for Mixed Models, 2nd Edition, 2006, pp. 320.)

Fitting the model using REML in the Standard Least Squares personality lets you view the variation in intercepts and slopes (Figure 7.2). Note that the slopes do not have much variability, but the intercepts have quite a bit. The intercept and slope might be negatively correlated; varieties with lower intercepts seem to have higher slopes.

**Figure 7.2** Standard Least Squares Regression
To model the correlation between the intercept and the slope, use the Mixed Models personality. You are interested in determining the population regression equation as well as variety-specific equations.

1. Open the Wheat.jmp sample data table.
2. Select Analyze > Fit Model.
3. Select Yield and click Y.
4. Select Mixed Model from the Personality list. Alternatively, you can select the Mixed Model personality first, and then click Y to add Yield.
5. Select Moisture and click Add on the Fixed Effects tab.

Figure 7.3 Completed Fit Model Launch Window Showing Fixed Effects

1. Select the Random Effects tab.
2. Select Moisture and click Add.
3. Select Moisture in the random effects area, select Variety, and then click Nest Random Coefficients.
Random effects are grouped by variety, and the intercept is included as a random component.

4. Click **Run**.

The Fit Mixed report is shown in Figure 7.5. Note that some of the constituent reports are closed because of space considerations. The Actual by Predicted plot shows no discrepancy in terms of model fit and underlying assumptions.

Because there are no apparent problems with the model fit, you can now interpret the statistical tests and obtain the regression equation. The effect of moisture upon yield is significant, as shown in the Fixed Effects Tests report. The estimates given in the Fixed Effects Parameter Estimates indicate that the estimated population regression equation is as follows:

\[ \text{Yield} = 33.43 + 0.66 \times \text{Moisture} \]

The Random Effects Covariance Parameter Estimates report gives estimates of the variance of the varieties' intercepts, Var(Intercept), and slopes, Var(Moisture), and their covariance, Cov(Moisture, Intercept). In this case, the intercept and slope are not significantly correlated, because the confidence interval for the estimate includes zero. The report also gives an estimate of the residual variance.
Figure 7.5 Fit Mixed Report
Although you have an estimate of the population regression equation, you are also interested in variety 2's estimated yield.

5. Open the Random Coefficients report to see the estimates of the variety effects for Intercept and Moisture. These coefficients estimate how each variety differs from the population.

For variety 2, you obtain the following prediction equation:

\[
Yield = 33.43 - 2.28 + 0.66 \times Moisture - 0.07 \times Moisture = 31.15 + 0.59 \times Moisture
\]

Here you see that variety 2 starts with a lower yield than the population average and increases with Moisture at a slower rate than the population average.

**Figure 7.6** Random Coefficients Report

---

**Launch the Mixed Model Personality**

Mixed Model is one of several personalities that you can select in the Fit Model launch window. This section describes how you select Mixed Model as your fitting methodology in the Fit Model launch window. Options that are specific to this selection are also covered.

**Fit Model Launch Window**

You can specify models with fixed effects, random effects, a repeated structure or a combination of those. The options differ based on the nature of the model that you specify.
To fit models using the mixed model personality, select **Analyze > Fit Model** and then select **Mixed Model** from the Personality list. Note that when you enter a continuous variable in the Y list before selecting a Personality, the Personality defaults to Standard Least Squares.

When fitting models using the Mixed Model personality, you can allow unbounded variance components. This means that variance components that have negative estimates are not reported as zero. This option is selected by default. It should remain selected if you are interested in fixed effects, because bounding the variance estimates at zero leads to bias in the tests for fixed effects. See “**Negative Variances**” on page 175 in the “Standard Least Squares Report and Options” chapter for details about the Unbounded Variance Components option.

**Fixed Effects Tab**

Add all fixed effects on the Fixed Effects tab. Use the Add, Cross, Nest, Macros, and Attributes options as needed. For details about using these options, see the “**Introduction to Fit Model**” chapter on page 27.

The fixed effects for analysis of the Split Plot.jmp sample data table appear in Figure 7.7. Note that it is possible to have no fixed effects in the model. For an example, see “**Spatial Example: Uniformity Trial**” on page 314.

**Figure 7.7** Fit Model Launch Window Showing Completed Fixed Effects
Random Effects Tab

Specify traditional variance component models and random coefficients models using the Random Effects tab.

Variance Components

For a traditional variance component model, specify terms such as random blocks, whole plot error terms, and subplot error terms using the Add, Cross, or Nest options. For details about using these options, see the “Introduction to Fit Model” chapter on page 27.

Figure 7.8 shows the random effects specification for the Split Plot.jmp sample data where Carcass is a random block. “Split Plot Example” on page 308 describes the example in detail.

Figure 7.8 Fit Model Launch Window Showing Completed Random Effects Tab

Random Coefficients

To construct random coefficients models, use the Nest Random Coefficients button to create groups of random coefficients.

1. Select the continuous columns from the Select Columns list that are predictors.
2. Select the Random Effects tab and then Add.
3. Select these effects in the Random Effects tab. Also select the column that contains the random effect whose levels define the individual regression models. This column is essentially the subject in a random statement in SAS PROC MIXED.

4. Click the **Nest Random Coefficients** button.

This last step creates random intercept and random slope effects that are correlated within the levels of the random effect. The subject is nested within the other effects due to the variability among subjects. If you believed that the intercept might be fixed for all groups, you would select `Intercept[<group>]|&Random Coefficients(1)` and then click **Remove**.

You can define multiple groups of random coefficients in this fashion, as in hierarchical linear models. This might be necessary when you have both a random batch effect and a random batch by treatment effect on the slope and intercept coefficients. This might also be necessary in a hierarchical linear model: when you have a random student effect and random school effect on achievement scores and students are nested within school.

Random coefficients are modeled using an unstructured covariance structure. Figure 7.9 shows the random coefficients specification for the `Wheat.jmp` sample data. (See also “Example Using Mixed Model” on page 276.)

**Figure 7.9** Completed Fit Model Launch Window Showing Random Coefficients
Repeated Structure Tab

Use the Repeated Structure tab to select a covariance structure for repeated effects in the model. The repeated structure is set to Residual by default. The Residual structure specifies that there is no covariance between observations, namely, the errors are independent. All other covariance structures model covariance between observations. For details about the structures, see “Repeated Measures” on page 328 and “Spatial Variability” on page 331 in the Statistical Details section.

Table 7.1 lists the covariance structures available and the requirements for using each structure.

Table 7.1 Repeated Covariance Structure Requirements

<table>
<thead>
<tr>
<th>Structure</th>
<th>Repeated Column Type</th>
<th>Required Number of Repeated Columns</th>
<th>Subject</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residual</td>
<td>not applicable</td>
<td>0</td>
<td>not applicable</td>
</tr>
<tr>
<td>AR(1)</td>
<td>continuous</td>
<td>1</td>
<td>optional</td>
</tr>
<tr>
<td>Unstructured</td>
<td>categorical</td>
<td>1</td>
<td>required</td>
</tr>
<tr>
<td>Spatial</td>
<td>continuous</td>
<td>2+</td>
<td>optional</td>
</tr>
<tr>
<td>Spatial Anisotropic</td>
<td>continuous</td>
<td>2+</td>
<td>optional</td>
</tr>
<tr>
<td>Spatial with Nugget</td>
<td>continuous</td>
<td>2+</td>
<td>optional</td>
</tr>
<tr>
<td>Spatial Anisotropic with Nugget</td>
<td>continuous</td>
<td>2+</td>
<td>optional</td>
</tr>
</tbody>
</table>
The Fit Mixed Report

The Fit Model red triangle menu options give you the ability to customize reports according to your needs.

Table 7.2  Fit Mixed Options

<table>
<thead>
<tr>
<th>Report Option</th>
<th>Description</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fit Statistics</td>
<td>Shows report for model fit statistics. This report appears by default.</td>
<td>“Fit Statistics” on page 287</td>
</tr>
</tbody>
</table>
### Table 7.2  Fit Mixed Options  (Continued)

<table>
<thead>
<tr>
<th>Report Option</th>
<th>Description</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed Effects Parameter Estimates</td>
<td>Shows report of fixed effects parameter estimates. This report appears by default.</td>
<td>“Fixed Effects Parameter Estimates” on page 290</td>
</tr>
<tr>
<td>Repeated Effects Covariance Parameter Estimates</td>
<td>Shows report of repeated effects covariance parameter estimates. This report appears when you specify repeated effects in the launch window.</td>
<td>“Repeated Effects Covariance Parameter Estimates” on page 290</td>
</tr>
<tr>
<td>Random Coefficients</td>
<td>Shows report of random coefficients. This report appears when you specify random effects in the launch window.</td>
<td>“Random Coefficients” on page 291</td>
</tr>
<tr>
<td>Random Effects Predictions</td>
<td>Shows report of random effect predictions. This report appears when you specify random effects in the launch window.</td>
<td>“Random Effect Predictions” on page 291</td>
</tr>
<tr>
<td>Fixed Effects Test</td>
<td>Shows test of fixed effects. This report appears by default.</td>
<td>“Fixed Effects Tests” on page 291</td>
</tr>
<tr>
<td>Multiple Comparisons</td>
<td>Opens Multiple Comparisons dialog window to select one or more effects and initial comparisons. This report is optional for categorical fixed effects.</td>
<td>“Multiple Comparisons” on page 292</td>
</tr>
<tr>
<td>Marginal Model Diagnostic Plots</td>
<td>Provides plots to assess model fit. The Actual by Predicted Plot appears by default.</td>
<td>“Marginal Model Diagnostic Plots” on page 293</td>
</tr>
<tr>
<td>Marginal Model Profiling</td>
<td>Provides profilers to examine the relationship between the response and the model terms. This report is optional.</td>
<td>“Marginal Model Profiling” on page 294</td>
</tr>
<tr>
<td>Save Columns</td>
<td>Saves model results as columns in the data table.</td>
<td>“Save Columns” on page 294</td>
</tr>
</tbody>
</table>
Table 7.2  Fit Mixed Options  (Continued)

<table>
<thead>
<tr>
<th>Report Option</th>
<th>Description</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model Dialog</td>
<td>Shows the completed Fit Model launch window for the current analysis.</td>
<td>“Fit Model Launch Window” on page 280</td>
</tr>
<tr>
<td>Script</td>
<td>Contains options that are available to all platforms.</td>
<td>See the Using JMP book.</td>
</tr>
</tbody>
</table>

**Fit Statistics**

The Fit Statistics report gives statistics used for model comparison. For all fit statistics, smaller is better. A likelihood ratio test between two models can be performed if one model is contained within the other. If not, a cautious comparison of likelihoods can be informative.

Table 7.3  Description of Fit Statistics Report

<table>
<thead>
<tr>
<th>-2 Residual Log Likelihood</th>
<th>The final evaluation of twice the negative residual log likelihood, the objective function.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$-2\log\text{likelihood}_{R}(G, R) = \log</td>
</tr>
<tr>
<td></td>
<td>where $r = y - X(X'V^{-1}X) - X'V^{-1}y$</td>
</tr>
<tr>
<td></td>
<td>and $p$ is the rank of $X$. Use the residual likelihood only for model comparisons where the fixed effects portion of the model is identical.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>-2 Log Likelihood</th>
<th>The evaluation of twice the negative log likelihood function. Unlike the -2 residual log likelihood, the -2 log likelihood is invariant to parameterization.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$-2\log\text{likelihood}(G, R) = \log</td>
</tr>
<tr>
<td></td>
<td>Use the log likelihood for model comparisons in which the fixed, random, and repeated effects differ in any of the models.</td>
</tr>
</tbody>
</table>
The Fit Mixed Report

Fitting Linear Models

If there are problems with model convergence, a warning message is displayed below the fit statistics. Figure 7.11 shows the warning that suggests the cause and possible solutions to the convergence issue. It also includes a test of the relative gradient at the final iteration. If this test is non-significant, the model might be correct but not fully reaching the convergence criteria. In this case, consider using the model and results with caution. For details, see “Convergence Score Test” on page 326.

**Figure 7.11 Convergence Score Test**

<table>
<thead>
<tr>
<th>Fit Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>-2 Residual Log Likelihood</td>
</tr>
<tr>
<td>-2 Log Likelihood</td>
</tr>
<tr>
<td>AICc</td>
</tr>
<tr>
<td>BIC</td>
</tr>
</tbody>
</table>

**Warning:** Parameter estimation algorithm did not converge.

Relative Gradient Criteria: 5352

**Convergence Score Test**

<table>
<thead>
<tr>
<th>ChiSquare</th>
<th>DF</th>
<th>Prob ChiSq</th>
</tr>
</thead>
<tbody>
<tr>
<td>5352</td>
<td>2</td>
<td>&lt;.0001</td>
</tr>
</tbody>
</table>

Possible causes:
- Model not appropriate. Fixed effects, random effects, or repeated components may be incorrect.
- Model too complex for the size of the dataset.
- Data may have problematic outliers.
- Data may be highly unbalanced.
- Linear or near-linear dependencies exist among the input columns.
- Response is skewed, highly discrete, or not approximately normally distributed.

Possible solutions:
- If the convergence score test p-value > .05 consider using the model and results with caution.
- Consider an alternative model, possibly a simpler one.
- Remove outliers and rare levels of categorical factors.
- Transform response so that it is more nearly normally distributed.
- Increase the maximum iterations.

### Table 7.3 Description of Fit Statistics Report (Continued)

<table>
<thead>
<tr>
<th>AICc</th>
<th>Corrected Akaike’s Information Criterion, defined as</th>
</tr>
</thead>
</table>
|      | \[
|      | AICc = -2\text{loglikelihood} + 2k + \frac{2k(k + 1)}{n - k - 1} \] |

where \( k \) is the number of estimated parameters (including intercept and variance and covariance terms in the model) and \( n \) is the number of observations in the data set. See Burnham and Anderson (2004) and Akaike (1974).

<table>
<thead>
<tr>
<th>BIC</th>
<th>Bayesian Information Criterion, defined as</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>[-2\text{loglikelihood} + k \ln(n)]</td>
</tr>
</tbody>
</table>

where \( k \) is the number of parameters and \( n \) is the sample size.
Random Effects Covariance Parameter Estimates

The Random Effects Covariance Parameter Estimates report provides details of the covariance parameters of the random effects that you specified in the model.

**Table 7.4 Description of the Random Effects Covariance Parameter Estimates Report**

<table>
<thead>
<tr>
<th>Covariance Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lists all covariance parameters of the random effects you specified in the model.</td>
<td></td>
</tr>
<tr>
<td>Subject</td>
<td>Lists the subject from which the block diagonal covariance matrix was formed.</td>
</tr>
<tr>
<td>Estimate</td>
<td>Gives the estimated variance or covariance component for the effect.</td>
</tr>
<tr>
<td>Std Error</td>
<td>Gives the standard error for the covariance component estimate.</td>
</tr>
<tr>
<td>95% Lower</td>
<td>Gives the lower 95% confidence limit for the covariance component. For details, see “Confidence Intervals for Variance Components” on page 289.</td>
</tr>
<tr>
<td>95% Upper</td>
<td>Gives the upper 95% confidence limit for the covariance component. For details, see “Confidence Intervals for Variance Components” on page 289.</td>
</tr>
</tbody>
</table>

**Confidence Intervals for Variance Components**

The method used to calculate the confidence limits depends on whether you have selected Unbounded Variance Components in the Fit Model launch window. Note that the Unbounded Variance Components is selected by default.

- If Unbounded Variance Components is selected, Wald-based confidence intervals are computed. These intervals are valid asymptotically, but note that they can be unreliable with small samples. The intervals are wider, which might lead you to mistakenly believe that an estimate is not significantly different from zero.

- If Unbounded Variance Components is not selected, meaning that the parameters have a lower boundary constraint of zero, a Satterthwaite approximation is used (Satterthwaite 1946). The confidence intervals are also bounded at zero.
Fixed Effects Parameter Estimates

The Fixed Effects Parameter Estimates report provides details for the fixed effect parameters specified in the model. For each parameter, the report provides the following details:

- the Estimate
- the standard error (Std Error)
- a t test for the hypothesis that the estimate equals zero
- a 95% confidence interval on the estimate.

Table 7.5 Description of the Fixed Effects Parameter Estimates Report

<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gives the model term corresponding to the estimated parameter. The first term is always the intercept, unless you selected the No Intercept option in the Fit Model launch window. Continuous columns that are part of higher order terms are centered by default. Nominal or ordinal effects appear with values of levels in brackets. See “Statistical Details” on page 326 for information about the coding of nominal and ordinal terms.</td>
<td></td>
</tr>
<tr>
<td>Estimate</td>
<td>Gives the parameter estimate for each term. This is the estimate of the term’s coefficient in the model.</td>
</tr>
<tr>
<td>Std Error</td>
<td>Gives an estimate of the standard error for the parameter estimate.</td>
</tr>
<tr>
<td>DFDen</td>
<td>Gives the denominator degrees of freedom, that is, the degrees of freedom for error, for the effect test. DFDen is calculated using the Kenward-Roger first order approximation. For details, see “The Kackar-Harville Correction” on page 333.</td>
</tr>
<tr>
<td>t Ratio</td>
<td>Tests whether the true value of the parameter is zero. The t Ratio is the ratio of the estimate to its standard error. Given the usual assumptions about the model, the t Ratio has a Student’s t distribution under the null hypothesis.</td>
</tr>
<tr>
<td>Prob&gt;</td>
<td>t</td>
</tr>
<tr>
<td>95% Lower</td>
<td>Shows the lower 95% confidence limit for the parameter.</td>
</tr>
<tr>
<td>95% Upper</td>
<td>Shows the upper 95% confidence limit for the parameter.</td>
</tr>
</tbody>
</table>

Repeated Effects Covariance Parameter Estimates

The Repeated Effects Covariance Parameter Estimates report provides details for the covariance parameters of the repeated effects that you specified in the model. It includes the Estimate, Standard Error, and 95% confidence bounds for each parameter.
**Note:** Variances are covariances of effects with themselves.

<table>
<thead>
<tr>
<th>Table 7.6  Description of the Random Effects Covariance Parameter Estimates Report</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Covariance Parameter</strong></td>
</tr>
<tr>
<td><strong>Estimate</strong></td>
</tr>
<tr>
<td><strong>Std Error</strong></td>
</tr>
<tr>
<td><strong>95% Lower</strong></td>
</tr>
<tr>
<td><strong>95% Upper</strong></td>
</tr>
</tbody>
</table>

**Random Coefficients**

For each random effect, provides a report showing estimated coefficients and a report showing the matrix of covariance estimates. Each row of the coefficients report corresponds to one level of the random effect. The row shows all coefficient estimates associated with that level of the random effect. The random coefficient estimates are used in conjunction with fixed effect estimates to create predictions for any specific level of the random effect.

**Random Effect Predictions**

For each random effect in the model, this report gives an estimate known as the *best linear unbiased predictor* (BLUP) and its standard error.

**Fixed Effects Tests**

Shows a significance test for each fixed effect in the model. The test for a given effect tests the null hypothesis that all parameters associated with that effect are zero. An effect might have only one parameter as for a single continuous explanatory variable. In this case, the test is equivalent to the *t* test for that term in the Fixed Effects Parameter Estimates report. A nominal or ordinal effect can have several associated parameters, based on its number of levels. The effect test for such an effect tests whether all of the associated parameters are zero.
The Fit Mixed Report

Chapter 7
Fitting Linear Models

Mixed Models

Chapter 7
The Fit Mixed Report

The Fit Mixed Report Fitting Linear Models

Multiple Comparisons

The Multiple Comparisons option provides various methods for comparing least squares means of main effects and interaction effects. Only the fixed effect portion of the model is used in the multiple comparisons. The Multiple Comparisons report shows estimates of the least squares means, standard error, a $t$ test of no effect, and a 95% confidence interval. This report is followed by the multiple comparisons test that you select. The All Pairwise Comparisons report provides equivalence tests.

For details about the multiple comparisons options see “Multiple Comparisons” on page 120 in the “Standard Least Squares Report and Options” chapter. Note that the Mixed Model personality supports only Least Squares Means Estimates, so that only ordinal or nominal effects are addressed. Figure 7.12 shows the multiple comparisons window for the Split Plot.jmp sample data table. Table 7.8 describes Multiple Comparisons options.

Table 7.7  Description of the Fixed Effects Tests Report

<table>
<thead>
<tr>
<th>Source</th>
<th>Lists the fixed effects in the model.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nparm</td>
<td>Shows the number of parameters associated with the effect. A continuous effect has one parameter. The number of parameters for a nominal or ordinal effect is one less than its number of levels. The number of parameters for a crossed effect is the product of the number of parameters for each individual effect.</td>
</tr>
<tr>
<td>DFNum</td>
<td>Shows the numerator degrees of freedom for the effect test.</td>
</tr>
<tr>
<td>DFDen</td>
<td>Shows the denominator degrees of freedom for the effect test (the degrees of freedom for error). DFDen is calculated using the Kenward-Roger first order approximation. For details, see “The Kackar-Harville Correction” on page 333.</td>
</tr>
<tr>
<td>F Ratio</td>
<td>Gives the computed $F$ ratio for testing that the effect is zero.</td>
</tr>
<tr>
<td>Prob &gt; F</td>
<td>Gives the $p$-value for the effect test.</td>
</tr>
</tbody>
</table>

Multiple Comparisons

The Multiple Comparisons option provides various methods for comparing least squares means of main effects and interaction effects. Only the fixed effect portion of the model is used in the multiple comparisons. The Multiple Comparisons report shows estimates of the least squares means, standard error, a $t$ test of no effect, and a 95% confidence interval. This report is followed by the multiple comparisons test that you select. The All Pairwise Comparisons report provides equivalence tests.

For details about the multiple comparisons options see “Multiple Comparisons” on page 120 in the “Standard Least Squares Report and Options” chapter. Note that the Mixed Model personality supports only Least Squares Means Estimates, so that only ordinal or nominal effects are addressed. Figure 7.12 shows the multiple comparisons window for the Split Plot.jmp sample data table. Table 7.8 describes Multiple Comparisons options.
Marginal Model Diagnostic Plots

The diagnostic plots are based on marginal residuals. Denote the linear mixed model by $E[Y|\gamma] = X\beta + Z\gamma$. Here $\beta$ is the vector of fixed effects, and $\gamma$ is the vector of random effects. The marginal residuals are the residuals from the fixed effects part of the predictive model:

$$r = Y - X\hat{\beta}$$

The Actual by Predicted plot is displayed by default. It plots the observed values of $Y$ against the predicted values of $Y$. It provides a visual assessment of model fit.
The Residual Plots option provides three visual methods to assess model fit.

**Residual by Predicted Plot**  Shows the residuals plotted against the predicted values of $Y$. You typically want to see the residual values scattered randomly about zero.

**Residual Quantile Plot**  Shows the quantiles of the residuals plotted against the quantiles of a standard normal distribution. Also shown is a bar chart of the residuals. If the residuals are normally distributed, the points on the normal quantile plot should approximately fall along the red diagonal line. This type of plot is also called a quantile-quantile plot, or Q-Q plot. The normal quantile plot also shows Lilliefors confidence bounds (Conover 1980).

**Residual by Row Plot**  shows residuals plotted against row numbers. This plot can help you detect patterns that result from the row ordering of the observations.

### Marginal Model Profiling

The profiler plots are based on marginal predicted values. Denote the linear mixed model by $E[Y|\gamma] = X\beta + Zy$. Here $\beta$ is the vector of fixed effects, and $\gamma$ is the vector of random effects. The marginal predictions are the predictions from the fixed effects part of the predictive model, given by $X\hat{\beta}$.

Four types of profilers are provided:

- Profiler
- Contour Profiler
- Mixture Profiler
- Surface Profiler

Options that are appropriate for the model that you are fitting are enabled. See Figure 7.20 for an example of a Profiler. See Figure 7.39 for an example of a Surface Profiler. For details about the profiler, see the Profilers book.

### Save Columns

Each Save Columns option adds a new column to the data table. Only the fixed effect portion of the model is used when saving columns.

**Table 7.9**  Saved Columns

<table>
<thead>
<tr>
<th>Prediction Formula</th>
<th>Creates a new column called Pred Formula <code>&lt;colname&gt;</code> that contains both the formula and the marginal mean predicted values. A Predicting column property is added, noting the source of the prediction.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard Error of Predicted</td>
<td>Creates a new column called StdErr Pred <code>&lt;colname&gt;</code> that contains standard errors for the predicted marginal mean responses.</td>
</tr>
</tbody>
</table>
Repeated Measures Example

Consider the Cholesterol Stacked.jmp sample data table. A study was performed to test two new cholesterol drugs against a control drug. Five patients with high cholesterol were randomly assigned to each of four treatments (the two experimental drugs, the control, and a placebo). Each patient's total cholesterol was measured at six times during the study: the first day in April, May, and June in the morning and afternoon. You are interested in whether either of the new drugs is effective at lowering cholesterol and in whether time and treatment interact.

Two methods have historically been used to analyze such a design: Multivariate Analysis of Variance (MANOVA) or a split-plot in time univariate analysis of variance (ANOVA) with either the Huynh-Feldt (1976) or Greenhouse-Geisser (1959) correction. Both of these options are available using the MANOVA personality in Fit Model. These two options are the two extremes for modeling the covariance structure. The MANOVA analysis assumes an unstructured covariance structure where all variances and covariances are estimated individually. The independent split-plot in time analysis assumes that all errors are independent. In the Gaussian data case this is equivalent to assuming a compound symmetry covariance structure.

These two models can result in vastly different conclusions about the treatment effects. When you assume a complex covariance structure, information in the data is used to estimate the covariance parameters. Therefore, it is important to find a model appropriate for the data. If you fit too many covariance parameters, you run the risk of over fitting your model.

- When the model is over fit, the power to detect differences is smaller than if you were to assume a less complex covariance structure.
- When the model is under fit, Type I error control is lost. In some cases, this leads to inflated rejection rates. In other cases, decreased rejection rates occur due to inflated variance.

When you model repeated measures data, be careful to find the appropriate covariance structure to balance these issues.
Mixed Models
Additional Examples

Chapter 7
Fitting Linear Models

The Mixed Model personality fits a variety of covariance structures. For repeated measures in time, the first-order autoregressive (AR(1)) covariance structure often provides an appropriate correlation structure. This structure allows for correlated observations but without over fitting the model.

Suppose that your model has \( J \) observation times. Then the number of covariance parameters in the covariance matrices for the three structures available are as follows:

- Unstructured, \( J(J+1)/2 \)
- AR(1), 2
- Independent Split Plot, 2

See “Repeated Measures” on page 328 for more information.

Open Cholesterol.jmp to see a format that is typically used for recording repeated measures data. For Mixed Model analysis of this data, each cholesterol measurement needs to be in its own row, as in Cholesterol Stacked.jmp. To construct Cholesterol Stacked.jmp, the data in Cholesterol.jmp was stacked using Tables > Stack.

The Days column in the stacked table was constructed using a formula. The Days column gives the number days of into the study when the cholesterol measurement was taken. Its modeling type is continuous. This is necessary because the AR(1) covariance structure requires the repeated effect be continuous.

The first step is to choose the appropriate covariance structure for these data. You fit the three covariance structures:

- Unstructured: This model fits all covariance parameters.
- Residual: This model is equivalent to the usual variance components structure. In this case, the model fits two variances.
- AR(1): This model fits two covariance parameters, one of which determines how the covariance changes with time.

You evaluate the model fits using AICc. The BIC criterion can also be used. In this case, the same model is chosen by both criteria.

Tip: This section walks you through many aspects of fitting repeated measures (from fitting the model to deciding on the best covariance structure). Leave the Fit Model launch window open as you work through each example.

Covariance Structure: Unstructured Example

Begin by fitting a model using an Unstructured covariance structure.

1. Open Cholesterol Stacked.jmp.
2. Select Analyze > Fit Model.
3. Select **Keep dialog open** so that you can return to the launch window in the next example.
4. Select **Y** and click **Y**.
5. Select **Mixed Model** from the Personality list.
6. Select **Treatment**, **Month**, and **AM/PM**, and then select **Macros > Full Factorial**.

**Figure 7.13** Fit Model Launch Window Showing Completed Fixed Effects Tab

7. Select the **Repeated Structure** tab.
8. Select **Unstructured** from the Structure list.
9. Select **Time** and click **Repeated**. The **Repeated** column defines the repeated measures within a subject.
10. Select **Patient** and click **Subject**.

**Note:** The Unstructured covariance model does not allow duplicate values on the repeated structure variables. Suppose that, in this example, the subject was nested within treatment, and that the patients had been numbered using the values 1, 2, 3, 4, and 5 within each treatment. A warning would be given when you run this analysis. You would need to renumber the patients to have different identifiers for each value of the Repeated variable. Or you would need to create a column in the data table that represents nesting within treatment and enter this effect as Subject.
11. Click **Run**.

The Fit Mixed report is shown in Figure 7.15. Because you want to compare your three models using AICc or BIC, you are interested in the Fit Statistics report. The AICc for the unstructured model is 703.84.

The Repeated Effects Covariance Parameter Estimates report shows estimates of all 21 covariance parameters. As you would expect, observations taken closer in time have higher covariance than those farther apart. Also, variance increases with time.
Chapter 7
Fitting Linear Models

Mixed Models
Additional Examples

Figure 7.15  Fit Mixed Report - Unstructured Covariance Structure

![Fit Mixed Report - Unstructured Covariance Structure](image)
Covariance Structure: Residual Example

The Residual covariance structure is appropriate when you fit a split-plot model.


2. On the Repeated Structure tab, select Residual from the Structure list.

3. If you are continuing from the previous example, remove Time and Patient. Otherwise, a warning appears: “Repeated columns and subject columns are ignored when the Residual covariance structure is selected.” You are given the option to click OK to continue the analysis.

4. Select the Random Effects tab.

5. Select Patient and click Add.

6. Select Patient in the Random Effects area, select the Treatment column, and then click Nest.

Figure 7.16 Fit Model Launch Window Showing Completed Random Effects Tab

7. Click Run.

The Fit Mixed report is shown in Figure 7.17. The Fit Statistics report shows that the AICc for the Residual model is 832.55, as compared to 703.84 for the Unstructured model.
The estimates of the two covariance parameters are shown in the Random Effects Covariance Parameter Estimates report. These are estimates of the variance of Patient within Treatment, and of the Residual variance.

Figure 7.17 Fit Mixed Report - Residual Error Covariance Structure

Covariance Structure: AR(1) Example

Finally, fit the AR(1) structure.

2. If you are continuing from the previous example, select Patient[Treatment] on the Random Effects tab and then click Remove.
   If you include both random effects and repeated effects, there is often insufficient data to estimate both effects.
3. Select theRepeated Structure tab.
4. Select AR(1) from the Structure list.
5. Select Days and click **Repeated**.
6. Select Patient and click **Subject**.

**Figure 7.18** Fit Model Launch Window Showing Completed Repeated Effects Tab

7. Click **Run**.

The Fit Mixed report is shown in Figure 7.19. The Fit Statistics report shows that the **AICc** for the AR(1) model is 652.63, compared with 832.55 for the Residual model and 703.84 for the Unstructured model. Based on the AICc criterion, the AR(1) model is the best of the three models.

The AR(1) structure requires the estimation of two covariance parameters. These estimates are shown in the Repeated Effects Covariance Parameter Estimates report. The AR(1) Days parameter estimate is an estimate of $\rho$, the correlation parameter in the AR(1) structure.
Because the AR(1) model gives the best fit, you adopt it as your model and proceed with your analysis. The Fixed Effects Tests report indicates that there is a significant interaction between Treatment and Month as well as a main effect of AM/PM.

To explore these significant effects, select Marginal Model Profiling > Profiler from the Fit Mixed report’s red triangle menu. The Marginal Model Profiler report (Figure 7.20) shows that, for Treatments A and B, cholesterol levels (Y) decrease steadily over the three months. However, when you set Treatment to Control or Placebo, you see virtually no change over the three months (Figure 7.21).

Note that Treatment A seems to result in lower cholesterol readings in May than Treatment B does. If this effect is significant, it might indicate that Treatment A acts more quickly than B. The next section, “Compare Treatment A and Treatment B” on page 304, shows you how to evaluate the treatments.

The profiler also shows the main effect of AM/PM. By setting Treatment and Month to all 12 combinations of their levels, you see that the predicted cholesterol level is consistently higher in the afternoon than in the morning.
Comparing Treatment A and Treatment B

At this point, you want to determine whether Treatment A results in lower readings in May than does Treatment B.

1. Select Multiple Comparisons from the Fit Mixed red triangle menu.
2. Select Treatment*Month from the Choose an Effect list.
3. Select All Pairwise Comparisons - Tukey HSD from the Choose Initial Comparisons list.
4. Click OK.

In the All Pairwise Differences report (Figure 7.22), find the row that corresponds to Treatment A in Month May and -Treatment B in -Month May. The $p$-value for the test of equal means is <.0001. The confidence interval for the difference is -39.62 to -11.38. You conclude that Treatment A reduces cholesterol levels by at least 11 points more than Treatment B in the first month of treatment.
In the All Pairwise Differences report, you also see that both Treatments A and B result in significantly lower cholesterol levels than the control Treatment in May and June. The confidence intervals indicate that both Treatments are highly effective.

**Figure 7.22** Portion of All Pairwise Differences Report for Treatment*Month Interaction Effect

Conduct an Equivalence Test

In connection with the main effect of AM/PM, suppose that the physician with whom you are working only considers a change that exceeds three points to have practical significance. Conduct an equivalence test to see whether the effect of AM/PM is of practical interest.

1. Select *Multiple Comparisons* from the Fit Mixed red triangle menu.
2. Select *AM/PM* from the Choose an Effect list.
3. Select *All Pairwise Comparisons - Tukey HSD* from the Choose Initial Comparisons list.
4. Click *OK*.
   
   The report shows that the estimated difference between the afternoon and morning observations is about 4.0. Though this is statistically significant, is it sufficiently larger than 3.0 to be considered not equivalent to 3.0?
5. Select *Equivalence Tests* from the Tukey HSD All Pairwise Comparisons red triangle menu.
6. Type 3 in the field for Difference considered practically zero.
7. Click *OK*. 
The Equivalence TOST Tests report and Equivalence Test Scatterplot shows that the 4 point difference is of practical significance (Figure 7.23).

Figure 7.23 Equivalent TOST Test and Equivalence Test Scatterplot for AM/PM Effect

Regression Model for AR(1) Model Example

Using the Month and AM/PM categorical effects, you have compared three covariance structures for the cholesterol data. (Note that a categorical effect was required for the Unstructured fit.) You have decided to use an AR(1) covariance structure.

Suppose now that you want to model the effect of treatment in terms of the continuous effect Days instead of the categorical effects. You can then predict cholesterol levels at arbitrary time during treatment.

1. After following steps in “Covariance Structure: AR(1) Example” on page 301, return to the Fit Model launch window.
2. On the Fixed Effects tab, select the existing fixed effects and click Remove.
3. Select Treatment and Days then select Macros > Full Factorial.
Figure 7.24 Fit Model Launch Window Showing Fixed Effects Tab

4. Click **Run**.

   The Fit Mixed report is shown in Figure 7.25. You see that the interaction of Treatment and Days is highly significant indicating different regressions for the drugs.

**Note:** To predict outcomes for the drugs at different days, use the profiler. See the *Profilers* book for more information.
Split Plot Example

The Mixed Model personality offers a straightforward approach to specifying and analyzing split-plot experiments. Mixed Model provides tabs for specifying effects. The resulting analysis is targeted to random effects. Note, however, that split-plot experiments can also be analyzed using the Standard Least Squares personality.

The data in the Split Plot.jmp sample data table come from a study of the effects of tenderizer and length of cooking time on meat. Six beef carcasses were randomly selected from carcasses at a meat packaging plant. From the right rib-eye muscle of each carcass, three rolled roasts were prepared under uniform conditions. Each of these three roasts was assigned a tenderizing treatment at random. After treatment, a coring device was used to mark four cores of meat near the center of each.
The three roasts from the same carcass were placed together in a preheated oven and allowed to cook. After 30 minutes, one of the cores was taken at random from each roast. Cores were removed in this fashion again after 36 minutes, 42 minutes, and 48 minutes. As each set cooled to serving temperature, the cores were measured for tenderness using the Warner-Bratzler device. Larger measurements indicate tougher meat.

Your interest centers on the effects of tenderizer, roasting time, and especially whether there is an interaction between tenderizer and roasting time. This design addresses that goal.

1. Open the Split Plot.jmp sample data table.
2. Select Analyze > Fit Model.
3. Select Y and click Y.
4. Select Mixed Model from the Personality list.
5. Select Tenderizer and Roasting Time, and then select Macros > Full Factorial.

**Figure 7.26** Fit Model Launch Window Showing Completed Fixed Effects Tab

7. Select Carcass and click Add to create the random carcass effect.
8. Select Carcass and Tenderizer and click Cross.

The Carcass*Tenderizer interaction is the error term for the whole plot factor, Tenderizer. This is equivalent to the Carcass*Tenderizer&Random term in Standard Least Squares.

**Figure 7.27** Fit Model Launch Window Showing Completed Random Effects Tab

9. Click Run.

The Fit Mixed report is shown in Figure 7.29.

The Actual by Predicted Plot shows no issues with model fit, so you can proceed to interpret the results. The Fixed Effects Tests report indicates that there is a significant interaction between tenderizer and roasting time.
Figure 7.28 Fit Mixed Report
Explore the Interaction between Tenderizer and Roasting Time

1. Select **Marginal Model Profiling > Profiler** from the Fit Mixed report’s red triangle menu.

**Figure 7.29** Marginal Model Profiler with Roasting Time Set to 30 Minutes

2. Move the red dashed vertical line in the Roasting Time panel to 36, 42, and 48.
   In Figure 7.30, notice that both the papain and vinegar tenderizers result in significantly lower tenderness scores than the control when roasting time is either 30 or 36 minutes. However, at 42 minutes, there are no significant differences. At 48 minutes, papain gives a value lower than the control, but vinegar does not. Papain gives lower tenderness scores than does vinegar at all times except 42 minutes.

3. Select **Multiple Comparisons** from the Fit Mixed red triangle menu.

4. Select **Tenderizer*Roasting Time**.

5. Select **All Pairwise Comparisons - Tukey HSD** and then click **OK**.
   Figure 7.30 shows a partial list of all pairwise comparisons. Most of the differences between papain and vinegar that you observed in the profiler are statistically significant. Therefore, it appears that papain is the better tenderizer.
Chapter 7
Fitting Linear Models

Figure 7.30 Truncated Multiple Comparisons

Mixed Models
Additional Examples

313


Spatial Example: Uniformity Trial

Consider the Uniformity Trial.jmp sample data table. An agronomic uniformity trial was conducted on an 8x8 grid of plots. In a uniformity trial, a test crop is grown on a field with no experimental treatments applied. The response variable, often yield, is measured. The idea is to characterize variability in the field as background for planning a designed experiment to be conducted on that field. (See SAS for Mixed Models, 2nd Edition, 2006, pp. 447.)

Your objective is to use the information from these data to design a yield trial with 16 treatments. Specifically, you want to decide whether to conduct future experiments on the field as:

- a complete block design with 4 blocks (denoted Quarter in the data)
- an incomplete block design with 16 blocks (denoted Subquarter in the data)
- a completely randomized design with spatially correlated errors

With this objective, spatial data can be treated as repeated measures with two or more dimensions as repeated effects. So, you can compare and choose an appropriate model using the values in the Fit Statistics report. You start by determining if there is significant spatial variability, then you determine whether there is a nugget effect.

Once you have established whether there is a nugget effect, you determine the best fitting spatial covariance structure. Finally, you fit the blocking models and compare these to the best spatial structure. In this example, both AICc and BIC are used to select a best model. “Spatial Variability” on page 331 provides more information about nugget effects and other spatial terminology.

Tip: This section walks you through many aspects of fitting spatial data (from fitting the model to deciding on the best covariance structure). Leave the Fit Model launch window open as you work through each example.

Fit a Spatial Structure Model

To determine whether there is significant spatial variability, you can fit a model that accounts for spatial variability. Then you can compare the likelihood for this spatial model to the likelihood for a model that does not account for spatial variability. You can do this because the independent errors model is nested within the spatial model family: The independent errors model is a spatial model with spatial correlation, $\rho$, equal to 0. This means that you can perform a formal likelihood ratio test of the two models.

First, fit the model that accounts for spatial structure.

1. Open the Uniformity Trial.jmp sample data table.
2. Select Analyze > Fit Model.
3. Select Keep dialog open so that you can return to the launch window in the next example.
4. Select Yield and click Y.
5. Select Mixed Model from the Personality list.
7. ChooseSpatial from the list next to Structure.
8. Choose Spherical from the list next to Type.
9. Select Row and Column and click Repeated.

**Figure 7.31** Completed Fit Model Launch Window Showing Repeated Structure Tab

10. Click Run.

The Fit Mixed report is shown in Figure 7.32. The Actual by Predicted Plot shows that the predicted yield is a single value. This is because only spatial covariance was fit. The Fit Statistics report shows that -2 Log Likelihood is 227.68, and the AICc is 234.08.
Next, fit the independent errors model.

1. Return to the Fit Model Launch Window.
2. Select **Repeated Structure** tab.
3. Select **Residual** from the Structure list.
4. Remove **Row** and **Column** from the Repeated effects list. Otherwise, a warning appears: “Repeated columns and subject columns are ignored when the Residual covariance structure is selected.”
5. Click Run.
The fit statistics for the independent errors model are: -2 Log Likelihood = 254.22, and AICc = 258.41. Each of these exceeds the corresponding value for the spatial correlation model, where -2 Log Likelihood is 227.68 and the AICc is 234.08. Because smaller values of these statistics indicate a better fit, the spatial model might provide a better fit.

**Conduct a Likelihood Ratio Test (Optional)**

A formal likelihood ratio test shows whether the spatial correlation model explains significant variation. One model must be nested in another model to create valid likelihood ratio tests. Typically, spatial models are compared using AICc or BIC rather than through formal likelihood ratio testing. Evaluating the AICc or BIC is faster, and many spatial models are not nested.

You can conduct a likelihood ratio test in this example, because the independent errors model is nested within the spatial model family. The independent errors model is a spatial model with spatial correlation, $\rho$, equal to 0. This means that you can perform a formal likelihood ratio test of the two models.

In this example, the likelihood ratio test statistic is $254.22 - 227.68 = 26.54$. Comparing this to a Chi-square distribution on one degree of freedom, the null hypothesis of no spatial correlation is rejected with a $p$-value < 0.0001. You can conclude that these data contain significant spatial variability.

**Select the Type of Spatial Covariance**

Next, you determine which spatial covariance structure best fits the data:

- with or without a nugget effect (variation over relatively small distances)
- isotropic (spatial correlation is equal in all directions) or anisotropic (spatial correlation differs in the two directions)
- type of structure, spherical, Gaussian, exponential, or power.

1. Return to the Fit Model launch window.
2. Select the **Repeated Structure** tab.
3. Select Row and Column and click **Repeated**.
4. Select **Spatial with Nugget** from the Structure list.
5. Select **Spherical** from the Type list.
6. Click **Run**.

The Fit Mixed report is shown in Figure 7.33. Notice that the log likelihoods are essentially equal to those of the spherical with no nugget model, and the AICc is slightly higher (236.36 compared to 234.08). The Repeated Effects Covariance Parameter Estimates report shows that the Nugget covariance parameter has an estimate of zero. There does not appear to be any evidence for a nugget effect.
7. Return to the Fit Model launch window.
8. Select Repeated Structure tab.
9. To test anisotropy, select Spatial Anisotropic from the Structure list.
10. Select Spherical from the Type list.
11. Click Run.

The Fit Mixed report is shown in Figure 7.34. The fit statistics indicate not as good a fit as the isotropic (spatial structure) spherical model (AICc 262.62 compared to 234.08). The Repeated Effects Covariance Parameter Estimates report shows that the estimates for the Row (Spatial Spherical Row) and Column (Spatial Spherical Column) covariances are very close. There is no evidence to suggest that spatial correlations within rows and columns of the grid differ.
**Figure 7.34** Fit Mixed Report - Spatial Anisotropic Spherical

Determine the Type of the Spatial Structure

An isotropic spatial structure with no nugget is appropriate. To determine the Type of the spatial structure, you can compare the available types.

Repeat step 1 through step 4 in “Select the Type of Spatial Covariance” on page 317. Change Spatial with Nugget to Spatial and then change Spherical to the other available types: Power, Exponential, Gaussian. The observed AICc values for these types and the other fits that you performed are summarized in Table 7.10.

**Table 7.10** Fit Statistics for Spatial Models Fit

<table>
<thead>
<tr>
<th>Structure</th>
<th>Type</th>
<th>AICc</th>
<th>BIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spatial</td>
<td>Spherical</td>
<td>234.08</td>
<td>240.16</td>
</tr>
<tr>
<td>Residual</td>
<td></td>
<td>258.41</td>
<td>262.53</td>
</tr>
<tr>
<td>Spatial with Nugget</td>
<td>Spherical</td>
<td>236.36</td>
<td>244.31</td>
</tr>
<tr>
<td>Spatial Anisotropic</td>
<td>Spherical</td>
<td>262.62</td>
<td>270.58</td>
</tr>
<tr>
<td>Spatial</td>
<td>Power</td>
<td>240.24</td>
<td>246.32</td>
</tr>
<tr>
<td>Spatial</td>
<td>Exponential</td>
<td>240.24</td>
<td>246.32</td>
</tr>
<tr>
<td>Spatial</td>
<td>Gaussian</td>
<td>238.37</td>
<td>244.44</td>
</tr>
</tbody>
</table>
The best fitting spatial model is the Spherical covariance structure. Now you must compare this model to the complete and incomplete block models to complete the objectives of the uniformity trial.

**Compare the Model to Block Designs**

Run the Graph Builder script from the Uniformity Trial.jmp sample data table. Figure 7.35 shows the plot of the proposed complete and incomplete block designs for the field. The color indicates the quarter fields that would serve as complete blocks. The numbered points represent the subquarter fields that would serve as incomplete blocks.

**Figure 7.35 Graph Builder Plot of Proposed Complete and Incomplete Block Designs**

To fit the complete block model, follow these steps.

1. Return to the Fit Model launch window.
2. Select **Repeated Structure** tab.
3. Select **Residual** from the Structure list.
4. Remove Row and Col from the effect. Otherwise, a pop-up dialog appear stating, “Repeated columns and subject columns are ignored when the Residual covariance structure is selected.”

5. Select the Random Effects tab.

6. Select Quarter and click Add.

7. Click Run.

8. Run the incomplete block model by replacing Quarter in step 6 with Subquarter.

Both AICc’s and BICs for the competing models are shown in Table 7.11. The spherical covariance structure results in the best model fit. This indicates that, for future studies using this field, a completely randomized design with spatially correlated errors is preferred.

<table>
<thead>
<tr>
<th>Table 7.11 Fit Statistics for Spatial and Block Models</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
</tr>
<tr>
<td>----------------------</td>
</tr>
<tr>
<td>Spherical</td>
</tr>
<tr>
<td>RCBD</td>
</tr>
<tr>
<td>Incomplete block</td>
</tr>
</tbody>
</table>

**Correlated Response Example**

Consider the Tiretread Stacked.jmp sample data table. The effect of three factors (Silica, Silane, and Sulfur) is studied for four responses (Abrasion, Modulus, Elong, and Hardness).

Open Tiretread.jmp to see a format that is typically used for recording repeated measures data. For Mixed Model analysis of this data, each repeated measurement needs to be in its own row, as in Tiretread Stacked.jmp. To construct Tiretread Stacked.jmp, the data in Tiretread.jmp was stacked using Tables > Stack.

One way to analyze this data is to fit separate response surfaces for each of the four responses. This modeling approach assumes that the responses are independent. However, all four measurements are taken on each tire, so it is possible that there is within-tire correlation. Failure to account for this correlation could result in poor decisions and predictions. You can use the Mixed Model personality to account for and model the possible correlation.

You want to fit separate response surfaces for the four responses while simultaneously accounting for possible correlation among the responses.

1. Open the Tiretread Stacked.jmp sample data table.
2. Select Analyze > Fit Model.
3. Select Y and click Y.
4. Select Mixed Model from the Personality list.
5. Select Characteristic and click Add. Characteristic creates a separate effect for each type of response measurement. This allows different intercepts for the four response surfaces.
6. Select Silica, Silane, and Sulfur, and select Response Surface from the Macros list.
7. Select the nine response surface effects in the Fixed Effects tab.
8. Select Characteristic from the Select Columns list.
9. Click Cross. This adds effects that allow individual fits for the four response surfaces. Figure 7.36 shows the completed fixed effects tab.

**Figure 7.36** Fit Model Launch Window Showing Completed Fixed Effects Tab
10. Select the **Repeated Structure** tab.

11. Select **Unstructured** from the Structure list.

12. Select **Characteristic** and click **Repeated**.

13. Select **Tire** and click **Subject**.

**Figure 7.37** Fit Model Launch Window Showing Repeated Structure Tab

14. Click **Run**.

The Fit Mixed report is shown in Figure 7.38. The Repeated Effects Covariance Parameter Estimates report gives the estimated variances and covariances for the four responses. All of the confidence intervals for the covariance estimates include zero. This suggests that the analysis of the responses that treats them as independent is not necessarily incorrect. Although, there might not be enough data to detect nonzero covariances.

In any case, using the repeated measures approach, the model that is fit acknowledges any potential covariance among responses. More importantly, it provides additional information about effects.

The Fixed Effects Test report indicates that **Characteristic** is significant. This is expected. However, note that the Silane*Sulfur*Characteristic and Silica*Characteristic interactions are significant. This information is not available from the usual univariate analysis.
Explore the Silane*Sulfur*Characteristic Interaction Using the Surface Profiler

1. Select Marginal Model Profiling > Surface Profiler from the Fit Mixed red triangle menu.

2. In the Independent Variables panel, select Silane and Sulfur.

   The values of the Characteristic column are represented by 0 (ABRASION), 1 (ELONG), 2 (HARDNESS), and 3 (MODULUS). (These values are determined by the column's value ordering.)
3. Change the Characteristic value to 3 for MODULUS (Figure 7.39).
   Note that Figure 7.39 shows a cross-section of the response surface for the Silica value 1.2.

**Figure 7.39** Surface Profiler Showing the Response Surface for MODULUS and Silica = 1.2

---

**Explore Interactions Using the Profiler**

1. Select Marginal Model Profiling > Profiler from the Fit Mixed red triangle menu.
2. Move the red dashed vertical line in the Characteristic panel through all four Characteristics as you view the other factors.
   The predicted values shown in the profiler match those obtained using the univariate analysis. However, the model includes effects that involve Characteristic. This makes it easier for you to identify the impact of the operational factors. Figure 7.40 shows the profiler for ABRASION. The Y scale is changed to display the effects of Silica, Silane, and Sulfur more effectively.
Convergence Score Test

The convergence failure warning shows the score test for the following hypothesis: that the unknown maximum likelihood estimate (MLE) is consistent with the parameter given in the final iteration of the model-fitting algorithm. This hypothesis test is possible because the relative gradient criterion is algebraically equivalent to the score test statistic. Remarkably, the score test does not require knowledge of the true MLE.

Score Test

Consider first the case of a single parameter, \( \theta \). Let \( l \) be the log-likelihood function for \( \theta \) and let \( x \) be the data. The score is the derivative of the likelihood function with respect to \( \theta \):

\[
U(\theta) = \frac{\partial l(\theta|x)}{\partial \theta}
\]

The observed information is:

\[
I(\theta) = -\frac{\partial^2 l(\theta|x)}{\partial \theta^2}
\]

The statistic for the score test of \( H_0: \theta = \theta_0 \) is:

\[
S(\theta_0) = \frac{U(\theta_0)^2}{I(\theta_0)}
\]

This statistic has an asymptotic Chi-square distribution with 1 degree of freedom under the null hypothesis.
The score test can be generalized to multiple parameters. Consider the vector of parameters $\theta$. Then the test statistic for the score test of $H_0: \theta = \theta_0$ is:

$$S(\theta_0) = U'(\theta_0)I^{-1}(\theta_0)U(\theta_0)$$

where

$$U(\theta) = \frac{\partial l(\theta|\mathbf{x})}{\partial \theta}$$

and

$$I(\theta) = -\frac{\partial^2 l(\theta|\mathbf{x})}{\partial \theta \partial \theta'}$$

and $U'$ denotes the transpose of the matrix $U$.

The test statistic is asymptotically Chi-square distribution with $k$ degrees of freedom. Here $k$ is the number of unbounded parameters.

**Relative Gradient**

The convergence criterion for the Mixed Model fitting procedure is based on the relative gradient $g^\top H^{-1} g$. Here, $g(\theta) = U(\theta)$ is the gradient of the likelihood function and $H(\theta) = I(\theta)$ is its Hessian.

Let $\theta_0$ be the value of $\theta$ where the algorithm terminates. Note that the relative gradient evaluated at $\theta_0$ is the score test statistic. A $p$-value is calculated using a Chi-square distribution with $k$ degrees of freedom. This $p$-value gives an indication of whether the value of the unknown MLE is consistent with $\theta_0$. The number of unbounded parameters listed in the Random Effects Covariance Parameter Estimates report equals $k$.

**Random Coefficient Model**

The standard random coefficient model specifies a random intercept and slope for each subject. Let $y_{ij}$ denote the measurement of the $j^{th}$ observation on the $i^{th}$ subject. Then the random coefficient model can be written as:

$$y_{ij} = a_i + b_i x_{ij} + e_{ij}$$

where

$i = 1, 2, \ldots, t$

$j = 1, 2, \ldots, n_i$
You can reformulate the model to reflect the fixed and random components that are estimated by JMP as follows.

\[ y_{ij} = (\alpha + a_i^*) + (\beta + b_i^*)x_{ij} + e_{ij} \]

where

\[ a_i^* = \alpha_i - \alpha \]
\[ b_i^* = \beta_i - \beta \]

and

\[ \begin{bmatrix} a_i^* \\ b_i^* \end{bmatrix} \sim iid N\left(0, \Sigma_G\right) \]

with \( G \) and \( e_{ij} \) defined as above.

**Repeated Measures**

The form of the repeated measures model is \( y_{ijk} = \alpha_{ij} + s_{ik} + e_{ijk} \) where

- \( \alpha_{ij} \) can be written as a treatment and time factorial
- \( s_{ik} \) is the random effect of the \( k^{th} \) subject assigned to the \( i^{th} \) treatment
- \( j = 1, \ldots, m \) denotes the repeated measurements over time.

Assume that the \( s_{ik} \) are independent and identically distributed \( N(0, \sigma_s^2) \) variables. Denote the number of treatment factors by \( t \) and the number of subjects by \( s \). Then the distribution of \( e_{ijk} \) is \( N(0, \Sigma) \), where

\[ \Sigma = I_s \otimes \text{Var}(y_{ik}|s_{ik}) \]

and
Denote the block diagonal component of the covariance matrix $\Sigma$ corresponding to the $i_k$th subject within treatment by $\Sigma_{ik}$. In other words, $\Sigma_{ik} = \text{Var}(y_{ijk} | s_{ik})$. Because observations over time within a subject are not typically independent, it is necessary to estimate the variance of $y_{ijk} | s_{ik}$. Failure to account for the correlation leads to distorted inference. The following sections describe the structures available for $\Sigma_{ik}$.

**Unstructured Covariance Structure**

\[
\Sigma = \begin{bmatrix}
\sigma_1^2 & \sigma_{12} & \sigma_{13} & \ldots & \sigma_{1(m-1)} & \sigma_{1m} \\
\sigma_{12} & \sigma_2^2 & \sigma_{12} & \ldots & \sigma_{2(m-1)} & \sigma_{2m} \\
\sigma_{13} & \sigma_{12} & \sigma_3^2 & \ldots & \sigma_{3(m-1)} & \sigma_{3m} \\
\vdots & \vdots & \vdots & \ddots & \vdots & \vdots \\
\sigma_{(m-1)^2} & \sigma_{(m-1)^2} & \sigma_{(m-1)^2} & \ldots & \sigma_{(m-1)m} & \sigma_{(m-1)m} \\
\sigma_{m1} & \sigma_{m2} & \sigma_{m3} & \ldots & \sigma_{mm} \\
\end{bmatrix}
\]

Here, the variance among observations taken at time $j$ is:

\[
\sigma_j^2 = \text{Var}(y_{ijk} | s_{ik})
\]

The covariance between observations taken at times $j$ and $j'$ is:

\[
\sigma_{jj'} = \text{Cov}(y_{ijk}, y_{ij'k} | s_{ik})
\]

Observations at every time have a unique variance and observations within the same subject at every pair of distinct times have a unique covariance.
AR(1) Covariance Structure

Here \( t_j \) is the time of observation \( j \). In this structure, observations taken at any given time have the same variance, \( \sigma^2 \). The parameter \( \rho \), where \(-1 < \rho < 1\), is the correlation between two observations that are one unit of time apart. As the time difference between observations increases, their covariance decreases because \( \rho \) is raised to a higher power. In many applications, AR(1) provides an adequate model of the within-subject correlation, providing more power without sacrificing Type I error control.

Compound Symmetry Covariance Structure

In JMP, a compound symmetry covariance structure is implemented using the independent errors, mixed-model approach. Random effects are classified into two categories: G-side or R-side. See Searle, Casella, and McCulloch (1992) for additional details.

The G-side random effects are associated with the design matrix for random effects. The R-side random effects are associated with residual error. Within-subject variance is part of the design structure and is modeled on the G-side. Between-subject variance falls into the residual structure and is modeled R-side. In the independent structure:

- The random effects G-side variance is modeled by \( s_{ik} \sim \text{iid } N(0, \sigma_s^2) \).
- The R-side variance is modeled by \( e_{ijk} \sim \text{iid } N(0, \sigma^2) \).

It follows that the covariance matrix is given by:

\[
\Sigma_{ik} = \sigma_s^2 J + \sigma^2 I = \\
\begin{bmatrix}
\sigma_s^2 + \sigma^2 & \sigma_s^2 & \cdots & \sigma_s^2 \\
\sigma_s^2 & \sigma_s^2 + \sigma^2 & \cdots & \sigma_s^2 \\
\vdots & \vdots & \ddots & \vdots \\
\sigma_s^2 & \sigma_s^2 & \cdots & \sigma_s^2 + \sigma^2 
\end{bmatrix}
\]

where \( J \) is a matrix consisting of 1s and \( I \) is an identity matrix.
Alternatively, all variance could be modeled R-side. Under the Gaussian assumption, this compound-symmetry covariance structure is equivalent to the independence model (Type=CS in SAS). This structure is not available in JMP and is listed here for informational purposes only.

\[
\Sigma_{ik} = \sigma_e^2 \begin{bmatrix}
1 & \rho & \cdots & \rho \\
1 & \rho & & \\
\vdots & & \ddots & \\
1 & & & 1
\end{bmatrix}
\]

where

\[
\sigma_e^2 = \sigma_s^2 + \sigma^2
\]

and

\[
\rho = \frac{\sigma_s^2}{\sigma_s^2 + \sigma^2}.
\]

### Spatial Variability

Here, the primary objective is to estimate spatial correlation. Consider the simple model \( y_i = \mu + e_i \). The spatial structure is modeled through the error term, \( e_i \). In general, the spatial correlation model can be defined as \( \text{Var}(e_i) = \sigma_e^2 \) and \( \text{Cov}(e_i, e_j) = \sigma_{ij} \).

Let \( s_i \) denote the location of \( y_i \) where \( s_i \) is specified by two coordinates. The coordinates could be latitude and longitude, row and column, indices of north-south and east-west, and so on.

The spatial structure is typically restricted by assuming that the covariance is a function of the Euclidean distance, \( d_{ij} \) between the locations \( s_i \) and \( s_j \).

The covariance can be written as \( \text{Cov}(e_i, e_j) = \sigma^2[f(d_{ij})] \).

If \( f(d_{ij}) \) does not depend on the direction, then the covariance structure is isotropic. If it does, then the structure is anisotropic. The spatial model functions available in JMP are shown below.

The following formulas for isotropic structures are provided:

- **Spherical**

\[
f(d_{ij}) = [1 - 1.5(d_{ij}/\rho) + 0.5(d_{ij}/\rho)^3] \times \mathbf{1}_{\{d_{ij} < \rho\}}
\]

where \( \mathbf{1}_{\{d_{ij} < \rho\}} = \begin{cases} 
1, & \text{if } d_{ij} < \rho \\
0, & \text{if } d_{ij} \geq \rho
\end{cases} \)
Mixed Models
Statistical Details

Chapter 7
Fitting Linear Models

- Exponential
  \[ f(d_{ij}) = \exp(-d_{ij}/\rho) \]
- Gaussian
  \[ f(d_{ij}) = \exp(-d_{ij}^2/\rho^2) \]
- Power
  \[ f(d_{ij}) = \rho^{d_{ij}} \]

For anisotropic models, the formulas are products of the isotropic formula with distance measured separately in each of the directions. Specifically, if \( c \) is the number of coordinates, then \( d_{ij} \) in the isotropic formulas is replaced by \( d_{ijk} \). \( d_{ijk} \) is the absolute distance between the \( k \)th coordinate, \( k = 1, 2, \ldots, c \), of the \( i \)th and \( j \)th observations in data table.

In some cases, the models above do not account for measurement error or abrupt changes over relatively small distances or measurement error. To address these cases, use an additional parameter, \( \sigma_1^2 \):

\[
\text{Var}(e_i) = \sigma^2 + \sigma_1^2
\]

and

\[
\text{Cov}(e_i, e_j) = \sigma^2[f(d_{ij})]
\]

Relationship to a Semivariogram

When the spatial process is second-order stationary, these parameters define a semivariogram. Borrowed from geostatistics, the semivariogram is the standard tool for describing and estimating spatial variability. It measures spatial variability as a function of the distance, \( d_{ij} \), between observations. Its key features are:

- **Nugget** Defined as the intercept. The variability between observations where \( d_{ij} = 0 \). It corresponds to \( \sigma_1^2 \).

- **Sill** Defined as the value of the semivariogram at the plateau reached for larger distances. It corresponds to the variance of an observation. In models with no nugget effect, the sill corresponds to \( \sigma^2 \). In models with a nugget effect, the sill is \( \sigma^2 + \sigma_1^2 \), and the partial sill corresponds to \( \sigma_1^2 \).

- **Range** Defined as the distance at which the semivariogram reaches the sill. At distances less than the range, observations are spatially correlated. For distances greater than or equal to the range, spatial correlation is effectively zero. In spherical models, \( \rho \) is the range. In exponential models, \( 3\rho \) is the practical range. In Gaussian models, \( \rho \sqrt{3} \) is the practical range. The practical range is defined as the distance where covariance is reduced to 95% of the sill.
In Figure 7.33 “Fit Mixed Report - Spatial Spherical with Nugget” on page 318, the repeated effects covariance parameter estimates represent the various semivariogram features:

**Spatial Spherical**  An estimate of the range, \( \rho \).

**Nugget**  A scaled estimate of \( \sigma_1^2 \). The Residual times the Nugget is \( \sigma_1^2 \).

**Residual**  The partial sill (or the sill in no nugget models).

### The Kackar-Harville Correction

The variance matrix of the fixed effects is always modified to include a Kackar-Harville correction. The variance matrix of the BLUPs, and the covariances between the BLUPs and the fixed effects, are not Kackar-Harville corrected. The rationale for this approach is that corrections for BLUPs can be computationally and memory intensive when the random effects have many levels. In SAS, the Kackar-Harville correction is done for both fixed effects and BLUPs only when the DDFM=KENWARDROGER is set.

For covariance structures that have nonzero second derivatives with respect to the covariance parameters, the Kenward-Roger covariance matrix adjustment includes a second-order term. This term can result in standard error shrinkage. Also, the resulting adjusted covariance matrix can then be indefinite and is not invariant under reparameterization. The first-order Kenward-Roger covariance matrix adjustment eliminates the second derivatives from the calculation. All spatial structures and the AR(1) structure are covariance structures that generally lead to nonzero second derivatives.

Because JMP implements the Kenward-Roger first-order adjustment

- Standard errors for linear combinations involving only fixed effects parameters match PROC MIXED DDFM=KENWARDROGER(FIRSTORDER). This presumes that one has taken care to transform between the different parameterizations used by PROC MIXED and JMP.
- Standard errors for linear combinations involving only BLUP parameters match PROC MIXED DDFM=SATTERTHWAIT.
- Standard errors for linear combinations involving both fixed effects and BLUPS do not match PROC MIXED for any DDFM option if the data are unbalanced. However, these standard errors are between those obtained using the DDFM=SATTERTHWAIT and DDFM=KENWARDROGER options. If the data are balanced, JMP matches SAS regardless of the DDFM option, because the Kackar-Harville correction is null.
Degrees of Freedom

The degrees of freedom for tests involving only linear combinations of fixed effect parameters are calculated using the first-order Kenward and Roger correction. So JMP’s results for these tests match PROC MIXED using the DDFM=KENWARDROGER(FIRSTORDER) option. If there are BLUPs in the linear combination, JMP uses a Satterthwaite approximation to get the degrees of freedom. The results then follow a pattern similar to what is described for standard errors in the preceding paragraph.

About Multivariate Models

Multivariate models fit several responses (Y variables) to a set of effects. The functions across the Y variables can be tested with appropriate response designs.

In addition to creating standard MANOVA (Multivariate Analysis of Variance) models, you can use the following techniques:

- Repeated measures analysis when repeated measurements are taken on each subject and you want to analyze effects both between subjects and within subjects across the measurements. This multivariate approach is especially important when the correlation structure across the measurements is arbitrary.

- Canonical correlation to find the linear combination of the X and Y variables that has the highest correlation.

- Discriminant analysis to find distance formulas between points and the multivariate means of various groups so that points can be classified into the groups that they are most likely to be in. A more complete implementation of discriminant analysis is in the Discriminant platform.

The multivariate fit begins with a rudimentary preliminary analysis that shows parameter estimates and least squares means. You can then specify a response design across the Y variables and multivariate tests are performed.
## Contents

<table>
<thead>
<tr>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Example of a Multiple Response Model</td>
<td>337</td>
</tr>
<tr>
<td>The Manova Report</td>
<td>339</td>
</tr>
<tr>
<td>The Manova Fit Options</td>
<td>340</td>
</tr>
<tr>
<td>Response Specification</td>
<td>340</td>
</tr>
<tr>
<td>Choose Response Options</td>
<td>341</td>
</tr>
<tr>
<td>Custom Test Option</td>
<td>342</td>
</tr>
<tr>
<td>Multivariate Tests</td>
<td>345</td>
</tr>
<tr>
<td>The Extended Multivariate Report</td>
<td>346</td>
</tr>
<tr>
<td>Comparison of Multivariate Tests</td>
<td>347</td>
</tr>
<tr>
<td>Univariate Tests and the Test for Sphericity</td>
<td>348</td>
</tr>
<tr>
<td>Multivariate Model with Repeated Measures</td>
<td>349</td>
</tr>
<tr>
<td>Example of a Compound Multivariate Model</td>
<td>352</td>
</tr>
<tr>
<td>Discriminant Analysis</td>
<td>354</td>
</tr>
</tbody>
</table>
Example of a Multiple Response Model

This example uses the Golf Balls.jmp sample data table (McClave and Dietrich, 1988). The data are a comparison of distances traveled and a measure of durability for three brands of golf balls. A robotic golfer hit a random sample of ten balls for each brand in a random sequence. The hypothesis to test is that distance and durability are the same for the three golf ball brands.

1. Open the Golf Balls.jmp sample data table.
2. Select Analyze > Fit Model.
3. Select Distance and Durability and click Y.
4. Select Brand and click Add.
5. For Personality, select Manova.

Figure 8.1 Manova Setup

6. Click Run.
The initial results might not be very interesting in themselves, because no response design has been specified yet. After you specify a response design, the multivariate platform displays tables of multivariate estimates and tests. For details about specifying a response design, see “Response Specification” on page 340.
The Manova Report

The Manova report window contains the following elements:

Table 8.1  Description of the Manova Report Window

<table>
<thead>
<tr>
<th>Element</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manova Fit red triangle menu</td>
<td>Contains save options. See “The Manova Fit Options” on page 340.</td>
</tr>
<tr>
<td>Parameter Estimates</td>
<td>Contains the parameter estimates for each response variable (without details like standard errors or $t$-tests). There is a column for each response variable.</td>
</tr>
<tr>
<td>Least Squares Means</td>
<td>Reports the overall least squares means of all of the response columns, least squares means of each nominal level, and least squares means plots of the means.</td>
</tr>
<tr>
<td>Partial Correlation</td>
<td>Shows the covariance matrix and the partial correlation matrix of residuals from the initial fit, adjusted for the $X$ effects.</td>
</tr>
<tr>
<td>Overall E&amp;H Matrices</td>
<td>Shows the E and H matrices:</td>
</tr>
<tr>
<td></td>
<td>• The elements of the $E$ matrix are the cross products of the residuals.</td>
</tr>
<tr>
<td></td>
<td>• The $H$ matrices correspond to hypothesis sums of squares and cross products.</td>
</tr>
<tr>
<td></td>
<td>There is an $H$ matrix for the whole model and for each effect in the model. Diagonal elements of the $E$ and $H$ matrices correspond to the hypothesis (numerator) and error (denominator) sum of squares for the univariate $F$ tests. New $E$ and $H$ matrices for any given response design are formed from these initial matrices, and the multivariate test statistics are computed from them.</td>
</tr>
</tbody>
</table>
The Manova Fit Options

Table 8.2 describes the options in the red triangle menu next to Manova Fit.

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Save Discrim</td>
<td>Performs a discriminant analysis and saves the results to the data table. For more details, see “Discriminant Analysis” on page 354.</td>
</tr>
<tr>
<td>Save Predicted</td>
<td>Saves the predicted responses to the data table.</td>
</tr>
<tr>
<td>Save Residuals</td>
<td>Saves the residuals to the data table.</td>
</tr>
<tr>
<td>Model Dialog</td>
<td>Shows the completed launch window for the current analysis.</td>
</tr>
<tr>
<td>Script</td>
<td>Contains options that are available to all platforms. See Using JMP.</td>
</tr>
</tbody>
</table>

Response Specification

Specify the response designs for various tests using the Response Specification panel.

Figure 8.3  Response Specification Panel

Table 8.3 Description of the Response Specification Panel

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Choose Response</td>
<td>Provides choices for the M matrix. See “Choose Response Options” on page 341.</td>
</tr>
<tr>
<td>Univariate Tests Also</td>
<td>Obtains adjusted and unadjusted univariate repeated measures tests and multivariate tests. Use in repeated measures models.</td>
</tr>
<tr>
<td>Test Each Column</td>
<td>Obtains univariate ANOVA tests and multivariate tests on each response.</td>
</tr>
</tbody>
</table>

The following buttons only appear once you have chosen a response option:

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run</td>
<td>Performs the analysis and shows the multivariate estimates and tests. See “Multivariate Tests” on page 345.</td>
</tr>
<tr>
<td>Help</td>
<td>Takes you to the help for the Response Specification panel.</td>
</tr>
</tbody>
</table>
Chapter 8
Fitting Linear Models

Multivariate Response Models
Response Specification

Table 8.3 Description of the Response Specification Panel (Continued)

| Orthogonalize | Orthonormalizes the matrix. Orthonormalization is done after the column contrasts (sum to zero) for all response types except Sum. |
| Delete Last Column | Reduces the dimensionality of the transformation. |

Choose Response Options

The response design forms the M matrix. The columns of an M matrix define a set of transformation variables for the multivariate analysis. The Choose Response button contains the options for the M matrix.

Table 8.4 Descriptions of the Choose Response Options

| Repeated Measures | Constructs and runs both Sum and Contrast responses. |
| Sum | Sum of the responses that gives a single value. |
| Identity | Uses each separate response, the identity matrix. |
| Contrast | Compares each response and the first response. |
| Polynomial | Constructs a matrix of orthogonal polynomials. |
| Helmert | Compares each response with the combined responses listed below it. |
| Profile | Compares each response with the following response. |
| Mean | Compares each response with the mean of the others. |
| Compound | Creates and runs several response functions that are appropriate if the responses are compounded from two effects. |
| Custom | Uses any custom M matrix that you enter. |

The most typical response designs are Repeated Measures and Identity for multivariate regression. There is little difference in the tests given by the Contrast, Helmert, Profile, and Mean options, since they span the same space. However, the tests and details in the Least Squares means and Parameter Estimates tables for them show correspondingly different highlights.

The Repeated Measures and the Compound options display dialogs to specify response effect names. They then fit several response functions without waiting for further user input. Otherwise, selections expand the control panel and give you more opportunities to refine the specification.
Custom Test Option

Set up custom tests of effect levels using the Custom Test option.

**Note:** For instructions on how to create custom tests, see “Custom Test” on page 118 in the “Standard Least Squares Report and Options” chapter.

The menu icon beside each effect name gives you the commands shown here, to request additional information about the multivariate fit:

<table>
<thead>
<tr>
<th>Table 8.5 Description of the Custom Test Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test Details</td>
</tr>
<tr>
<td>Centroid Plot</td>
</tr>
<tr>
<td>Save Canonical Scores</td>
</tr>
<tr>
<td>Contrast</td>
</tr>
</tbody>
</table>

**Note:** The Contrast command is the same as for regression with a single response. See the “LSMeans Contrast” on page 97 in the “Standard Least Squares Report and Options” chapter, for a description and examples of the LSMeans Contrast commands.

Example of Test Details (Canonical Details)

1. Open the Iris.jmp sample data table.
   - The Iris data (Mardia, Kent, and Bibby 1979) have three levels of Species named Virginica, Setosa, and Versicolor. There are four measures (Petal length, Petal width, Sepal length, and Sepal width) taken on each sample.
2. Select Analyze > Fit Model.
3. Select Petal length, Petal width, Sepal length, and Sepal width and click Y.
4. Select Species and click Add.
5. For Personality, select Manova.
6. Click Run.
7. Click on the Choose Response button and select Identity.
8. Click Run.
9. From the red triangle menu next to Species, select **Test Details**.

The eigenvalues, eigenvectors, and canonical correlations appear. See Figure 8.4.

**Figure 8.4** Test Details

<table>
<thead>
<tr>
<th>Test</th>
<th>Value</th>
<th>Approx F</th>
<th>NumDF</th>
<th>DenDF</th>
<th>ProbF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wilks' Lambda</td>
<td>0.9234308</td>
<td>199.1453</td>
<td>8</td>
<td>200</td>
<td>&lt;.0001*</td>
</tr>
<tr>
<td>Pillai's Trace</td>
<td>1.1819868</td>
<td>53.4865</td>
<td>8</td>
<td>200</td>
<td>&lt;.0001*</td>
</tr>
<tr>
<td>Hotelling-Lawley</td>
<td>0.477507</td>
<td>583.1970</td>
<td>8</td>
<td>200</td>
<td>&lt;.0001*</td>
</tr>
<tr>
<td>Roy's Max Root</td>
<td>22.151620</td>
<td>1185.9974</td>
<td>4</td>
<td>146</td>
<td>&lt;.0001*</td>
</tr>
</tbody>
</table>

**Table 8.6** Description of Test Details

<table>
<thead>
<tr>
<th>Description</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eigenvalue</td>
<td>Lists the eigenvalues of the $E^{-1}H$ matrix used in computing the multivariate test statistics.</td>
</tr>
<tr>
<td>Canonical Corr</td>
<td>Lists the canonical correlations associated with each eigenvalue. This is the canonical correlation of the transformed responses with the effects, corrected for all other effects in the model.</td>
</tr>
<tr>
<td>Eigvec</td>
<td>Lists the eigenvectors of the $E^{-1}H$ matrix, or equivalently of $(E + H)^{-1}H$.</td>
</tr>
</tbody>
</table>

**The Centroid Plot**

The **Centroid Plot** command (accessed from the red triangle next to Species) plots the centroids (multivariate least squares means) on the first two canonical variables formed from the test space, as in Figure 8.5. The first canonical axis is the vertical axis so that if the test space is only one dimensional the centroids align on a vertical axis. The centroid points appear with a circle corresponding to the 95% confidence region (Mardia, Kent, and Bibby, 1979). When centroid plots are created under effect tests, circles corresponding to the effect being tested appear in red. Other circles appear blue. Biplot rays show the directions of the original response variables in the test space.

Click the **Centroid Val** disclosure icon to show additional information, shown in Figure 8.5.
The first canonical axis with an eigenvalue accounts for much more separation than does the second axis. The means are well separated (discriminated), with the first group farther apart than the other two. The first canonical variable seems to load the petal length variables against the petal width variables. Relationships among groups of variables can be verified with Biplot Rays and the associated eigenvectors.

**Figure 8.5** Centroid Plot and Centroid Values

| CentroidVal | 2.10510845 | 6.68417254 | 0 | 0 |
| Sepal length | 1.25222877 | 6.69629758 | 0 | 0 |
| Sepal width | 3.51736259 | 8.11458779 | 0 | 0 |
| Petal length | 5.58320969 | 6.19744241 | 0 | 0 |
| Petal width | 3.83264424 | 6.98789104 | 0 | 0 |
| versicolor | -5.52948955 | 6.67689655 | 0 | 0 |
| virginica | 3.83915694 | 6.93057391 | 0 | 0 |
| virginica | 7.88785869 | 7.17429614 | 0 | 0 |

**Save Canonical Scores (Canonical Correlation)**

Canonical correlation analysis is not a specific command, but it can be done by a sequence of commands in the multivariate fitting platform, as follows:

1. Follow steps 1-8 in “Example of Test Details (Canonical Details)” on page 342.
2. From the red triangle menu next to Whole Model, select **Test Details**.
3. From the red triangle menu next to Whole Model, select **Save Canonical Scores**.

The details list the canonical correlations (Canonical Corr) next to the eigenvalues. The saved variables are called Canon[1],Canon[2], and so on. These columns contain both the values and their formulas.

To obtain the canonical variables for the X side, repeat the same steps, but interchange the X and Y variables. If you already have the columns Canon[n] appended to the data table, the new columns are called Canon[n] 2 (or another number) that makes the name unique.

For another example, proceed as follows:
1. Open the Exercise.jmp sample data table.
2. Select Analyze > Fit Model.
3. Select chins, situps, and jumps and click Y.
4. Select weight, waist, and pulse and click Add.
5. For Personality, select Manova.
6. Click Run.
7. Click on the Choose Response button and select Identity.
8. Click Run.
9. From the red triangle menu next to Whole Model, select Test Details.
10. From the red triangle menu next to Whole Model, select Save Canonical Scores.

Figure 8.6  Canonical Correlations

<table>
<thead>
<tr>
<th>Test</th>
<th>Value</th>
<th>Approx. F</th>
<th>NumDF</th>
<th>DenDF</th>
<th>ProbF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wilks' Lambda</td>
<td>0.3605996</td>
<td>2.0462</td>
<td>9</td>
<td>34.229</td>
<td>0.0005</td>
</tr>
<tr>
<td>Pillai's Trace</td>
<td>0.6794015</td>
<td>1.5597</td>
<td>9</td>
<td>18.756</td>
<td>0.1951</td>
</tr>
<tr>
<td>Hotelling-Lawley</td>
<td>1.7778416</td>
<td>2.0397</td>
<td>9</td>
<td>19.033</td>
<td>0.0007*</td>
</tr>
<tr>
<td>Roy's Max Root</td>
<td>1.7247387</td>
<td>9.1568</td>
<td>3</td>
<td>18.09</td>
<td>0.0009*</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Eigenvalue</th>
<th>Cor</th>
<th>1.72473874</th>
<th>0.79559985</th>
<th>0.0419084</th>
<th>0.20655684</th>
<th>0.00025629</th>
</tr>
</thead>
<tbody>
<tr>
<td>chins</td>
<td>0.0250806</td>
<td>-0.016026</td>
<td>0.05944187</td>
<td>0.06383903</td>
<td>-0.0052909</td>
<td></td>
</tr>
<tr>
<td>situps</td>
<td>0.0637953</td>
<td>0.004022</td>
<td>-0.005447</td>
<td>0.0002399</td>
<td>0.0014087</td>
<td></td>
</tr>
<tr>
<td>jumps</td>
<td>-0.002399</td>
<td>0.004022</td>
<td>0.0014087</td>
<td>0.0002399</td>
<td>0.0014087</td>
<td></td>
</tr>
</tbody>
</table>

The output canonical variables use the eigenvectors shown as the linear combination of the Y variables. For example, the formula for canon[1] is as follows:

\[ 0.02503681\times \text{chins} + 0.00637953\times \text{situps} + -0.0052909\times \text{jumps} \]

This canonical analysis does not produce a standardized variable with mean 0 and standard deviation 1, but it is easy to define a new standardized variable with the calculator that has these features.

---

**Multivariate Tests**

**Example Choosing a Response**

1. Complete the steps in “Example of a Multiple Response Model” on page 337.
2. Click on the Choose Response button and select Identity.
3. Click Run.
The **M Matrix** report gives the response design that you specified. The **M-transformed Parameter Estimates** report gives the original parameter estimates matrix multiplied by the transpose of the M matrix.

**Note:** Initially in this chapter, the matrix names $E$ and $H$ refer to the error and hypothesis cross products. After specification of a response design, $E$ and $H$ refer to those matrices transformed by the response design, which are actually $M^T EM$ and $M^T HM$.

### The Extended Multivariate Report

In multivariate fits, the sums of squares due to hypothesis and error are matrices of squares and cross products instead of single numbers. And there are lots of ways to measure how large a value the matrix for the hypothesis sums of squares and cross products (called $H$ or $SSCP$) is compared to that matrix for the residual (called $E$). JMP reports the four multivariate tests that are commonly described in the literature. If you are looking for a test at an exact significance level, you may need to go hunting for tables in reference books. Fortunately, all four tests can be transformed into an approximate $F$ test. If the response design yields a single value, or if the hypothesis is a single degree of freedom, the multivariate tests are equivalent and yield the same exact $F$ test. JMP labels the test **Exact F**; otherwise, JMP labels it **Approx. F**.

In the golf balls example, there is only one effect so the Whole Model test and the test for **Brand** are the same, which show the four multivariate tests with approximate $F$ tests. There is only a single intercept with two DF (one for each response), so the $F$ test for it is exact and is labeled **Exact F**.
The red triangle menus on the Whole Model, Intercept, and Brand reports contain options to generate additional information, which includes eigenvalues, canonical correlations, a list of centroid values, a centroid plot, and a **Save** command that lets you save canonical variates.

The effect (**Brand** in this example) popup menu also includes the option to specify contrasts.

The custom test and contrast features are the same as those for regression with a single response. See the “Standard Least Squares Report and Options” chapter on page 71.

“**Multivariate Details**” on page 456 in the appendix “Statistical Details” on page 427, shows formulas for the MANOVA table tests.

Table 8.7 describes each Multivariate report (except the Sphericity Test table; see “**Univariate Tests and the Test for Sphericity**” on page 348).

**Table 8.7 Descriptions of Multivariate Reports**

| Test | Labels each statistical test in the table. If the number of response function values (columns specified in the M matrix) is 1 or if an effect has only one degree of freedom per response function, the exact F test is presented. Otherwise, the standard four multivariate test statistics are given with approximate F tests: Wilks’ Lambda (Λ), Pillai’s Trace, the Hotelling-Lawley Trace, and Roy’s Maximum Root. |
| Value | Value of each multivariate statistical test in the report. |
| Approx. F (or Exact F) | F-values corresponding to the multivariate tests. If the response design yields a single value or if the test is one degree of freedom, this is an exact F test. |
| NumDF | Numerator degrees of freedom. |
| DenDF | Denominator degrees of freedom. |
| Prob>F | Significance probability corresponding to the F-value. |

**Comparison of Multivariate Tests**

Although the four standard multivariate tests often give similar results, there are situations where they differ, and one might have advantages over another. Unfortunately, there is no clear winner. In general, here is the order of preference in terms of power:

1. Pillai’s Trace
2. Wilks’ Lambda
3. Hotelling-Lawley Trace
4. Roy’s Maximum Root
When there is a large deviation from the null hypothesis and the eigenvalues differ widely, the order of preference is the reverse (Seber 1984).

**Univariate Tests and the Test for Sphericity**

There are cases, such as a repeated measures model, that allow transformation of a multivariate problem into a univariate problem (Huynh and Feldt 1970). Using univariate tests in a multivariate context is valid in the following situations:

- If the response design matrix $M$ is orthonormal ($M'M = \text{Identity}$).
- If $M$ yields more than one response the coefficients of each transformation sum to zero.
- If the *sphericity* condition is met. The sphericity condition means that the $M$-transformed responses are uncorrelated and have the same variance. $M\Sigma M$ is proportional to an identity matrix, where $\Sigma$ is the covariance of the $Y$s.

If these conditions hold, the diagonal elements of the $E$ and $H$ test matrices sum to make a univariate sums of squares for the denominator and numerator of an $F$ test. Note that if the above conditions do not hold, then an error message appears. In the case of Golf Balls.jmp, an identity matrix is specified as the $M$-matrix. Identity matrices cannot be transformed to a full rank matrix after centralization of column vectors and orthonormalization. So the univariate request is ignored.

**Example of Univariate and Sphericity Test**

1. Open the Dogs.jmp sample data table.
2. Select Analyze > Fit Model.
3. Select LogHist0, LogHist1, LogHist3, and LogHist5 and click Y.
4. Select drug and dep1 and click Add.
5. In the Construct Model Effects panel, select drug. In the Select Columns panel, select dep1. Click Cross.
6. For Personality, select Manova.
7. Click Run.
8. Select the check box next to Univariate Tests Also.
9. In the Choose Response menu, select Repeated Measures.
   
   Time should be entered for YName, and Univariate Tests Also should be selected.
10. Click OK.
The sphericity test checks the appropriateness of an unadjusted univariate $F$ test for the within-subject effects using the Mauchly criterion to test the sphericity assumption (Anderson 1958). The sphericity test and the univariate tests are always done using an orthonormalized $M$ matrix. You interpret the sphericity test as follows:

- If the sphericity Chi-square test is not significant, you can use the unadjusted univariate $F$-tests.
- If the sphericity test is significant, use the multivariate or the adjusted univariate tests.

The univariate $F$ statistic has an approximate $F$-distribution even without sphericity, but the degrees of freedom for numerator and denominator are reduced by some fraction epsilon ($\varepsilon$). Box (1954), Greenhouse and Geisser (1959), and Huynh-Feldt (1976) offer techniques for estimating the epsilon degrees-of-freedom adjustment. Muller and Barton (1989) recommend the Greenhouse-Geisser version, based on a study of power.

The epsilon adjusted tests in the multivariate report are labeled G-G (Greenhouse-Geisser) or H-F (Huynh-Feldt), with the epsilon adjustment shown in the value column.

**Multivariate Model with Repeated Measures**

One common use of multivariate fitting is to analyze data with repeated measures, also called *longitudinal data*. A subject is measured repeatedly across time, and the data are arranged so that each of the time measurements form a variable. Because of correlation between the measurements, data should not be stacked into a single column and analyzed as a univariate model unless the correlations form a pattern termed *sphericity*. See the previous section, “Univariate Tests and the Test for Sphericity” on page 348, for more details about this topic.

With repeated measures, the analysis is divided into two layers:

- Between-subject (or across-subject) effects are modeled by fitting the sum of the repeated measures columns to the model effects. This corresponds to using the `Sum` response function, which is an $M$-matrix that is a single vector of 1s.
• Within-subjects effects (repeated effects, or time effects) are modeled with a response function that fits differences in the repeated measures columns. This analysis can be done using the Contrast response function or any of the other similar differencing functions: Polynomial, Helmert, Profile, or Mean. When you model differences across the repeated measures, think of the differences as being a new within-subjects effect, usually time. When you fit effects in the model, interpret them as the interaction with the within-subjects effect. For example, the effect for Intercept becomes the Time (within-subject) effect, showing overall differences across the repeated measures. If you have an effect A, the within-subjects tests are interpreted to be the tests for the A*Time interaction, which model how the differences across repeated measures vary across the A effect.

Table 8.8 on page 351 shows the relationship between the response function and the model effects compared with what a univariate model specification would be. Using both the Sum (between-subjects) and Contrast (within-subjects) models, you should be able to reconstruct the tests that would have resulted from stacking the responses into a single column and obtaining a standard univariate fit.

There is a direct and an indirect way to perform the repeated measures analyses:

• The direct way is to use the popup menu item Repeated Measures. This prompts you to name the effect that represents the within-subject effect across the repeated measures. Then it fits both the Contrast and the Sum response functions. An advantage of this way is that the effects are labeled appropriately with the within-subjects effect name.

• The indirect way is to specify the two response functions individually. First, do the Sum response function and second, do either Contrast or one of the other functions that model differences. You need to remember to associate the within-subjects effect with the model effects in the contrast fit.

Repeated Measures Example

For example, consider a study by Cole and Grizzle (1966). The results are in the Dogs.jmp table in the sample data folder. Sixteen dogs are assigned to four groups defined by variables drug and dep1, each having two levels. The dependent variable is the blood concentration of histamine at 0, 1, 3, and 5 minutes after injection of the drug. The log of the concentration is used to minimize the correlation between the mean and variance of the data.

1. Open the Dogs.jmp sample data table.
2. Select Analyze > Fit Model.
3. Select LogHist0, LogHist1, LogHist3, and LogHist5 and click Y.
4. Select drug and dep1 and select Full Factorial from the Macros menu.
5. For Personality, select Manova.
6. Click Run.
7. In the *Choose Response* menu, select *Repeated Measures*. Time should be entered for YName. If you check the *Univariate Tests Also* check box, the report includes univariate tests, which are calculated as if the responses were stacked into a single column.

8. Click **OK**.

**Figure 8.9** Repeated Measures Window

Table 8.8 shows how the multivariate tests for a *Sum* and *Contrast* response designs correspond to how univariate tests would be labeled if the data for columns *LogHist0*, *LogHist1*, *LogHist3*, and *LogHist5* were stacked into a single Y column, with the new rows identified with a nominal grouping variable, *Time*.

**Table 8.8** Corresponding Multivariate and Univariate Tests

<table>
<thead>
<tr>
<th>Sum M-Matrix Between Subjects</th>
<th>Contrast M-Matrix Within Subjects</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Multivariate Test</strong></td>
<td><strong>Univariate Test</strong></td>
</tr>
<tr>
<td><strong>Multivariate Test</strong></td>
<td><strong>Univariate Test</strong></td>
</tr>
<tr>
<td><strong>Intercept</strong></td>
<td><strong>Intercept</strong></td>
</tr>
<tr>
<td><strong>Drug</strong></td>
<td><strong>Drug</strong></td>
</tr>
<tr>
<td><strong>Depl</strong></td>
<td><strong>Depl</strong></td>
</tr>
<tr>
<td><strong>Time</strong></td>
<td><strong>Time</strong></td>
</tr>
<tr>
<td><strong>Time*Drug</strong></td>
<td><strong>Time*Depl</strong></td>
</tr>
</tbody>
</table>

The between-subjects analysis is produced first. This analysis is the same (except titling) as it would have been if *Sum* had been selected on the popup menu.

The within-subjects analysis is produced next. This analysis is the same (except titling) as it would have been if *Contrast* had been selected on the popup menu, though the within-subject effect name (*Time*) has been added to the effect names in the report. Note that the position formerly occupied by Intercept is *Time*, because the intercept term is estimating overall differences across the repeated measurements.
Example of a Compound Multivariate Model

JMP can handle data with layers of repeated measures. For example, see the Cholesterol.jmp data table. Groups of five subjects belong to one of four treatment groups called A, B, Control, and Placebo. Cholesterol was measured in the morning and again in the afternoon once a month for three months (the data are fictional). In this example, the response columns are arranged chronologically with time of day within month.

1. Open the Cholesterol.jmp sample data table.
2. Select Analyze > Fit Model.
3. Select April AM, April PM, May AM, May PM, June AM, and June PM and click Y.
4. Select treatment and click Add.
5. Next to Personality, select Manova.
6. Click Run.

**Figure 8.10** Treatment Graph

In the treatment graph, you can see that the four treatment groups began the study with very similar mean cholesterol values. The A and B treatment groups appear to have lower cholesterol values at the end of the trial period. The control and placebo groups remain unchanged.

7. Click on the Choose Response menu and select Compound.

Complete this window to tell JMP how the responses are arranged in the data table and the number of levels of each response. In the cholesterol example, the time of day columns are arranged within month. Therefore, you name time of day as one factor and the month effect as the other factor. Testing the interaction effect is optional.

8. Use the options in Figure 8.11 to complete the window.
9. **Click OK.**

The tests for each effect appear. Parts of the report are shown in Figure 8.12. Note the following:

- With a p-value of 0.6038, the interaction between Time and treatment is not significant. This means that there is no difference in treatment between AM and PM. Since Time has two levels (AM and PM) the exact f-test appears.

- With p-values of <0.0001, the interaction between Month and treatment is significant. This suggests that the differences between treatment groups change depending on the month. The treatment graph in Figure 8.10 indicates no difference among the groups in April, but the difference between treatment types (A, B, Control, and Placebo) becomes large in May and even larger in June.

- The interaction effect between Month, Time, and treatment is not statistically significant.
Discriminant analysis is a method of predicting some level of a one-way classification based on known values of the responses. The technique is based on how close a set of measurement variables are to the multivariate means of the levels being predicted. Discriminant analysis is more fully implemented using the Discriminant Platform (see the *Multivariate Methods* book).

In JMP you specify the measurement variables as Y effects and the classification variable as a single X effect. The multivariate fitting platform gives estimates of the means and the covariance matrix for the data, assuming that the covariances are the same for each group. You obtain discriminant information with the **Save Discrim** option in the popup menu next to the MANOVA platform name. This command saves distances and probabilities as columns in the current data table using the initial E and H matrices.
For a classification variable with $k$ levels, JMP adds $k$ distance columns, $k$ classification probability columns, the predicted classification column, and two columns of other computational information to the current data table.

**Example of the Save Discrim Option**

Examine Fisher’s Iris data as found in Mardia, Kent, and Bibby (1979). There are $k = 3$ levels of species and four measures on each sample.

1. Open the Iris.jmp sample data table.
2. Select **Analyze > Fit Model**.
3. Select Sepal length, Sepal width, Petal length, and Petal width and click **Y**.
4. Select Species and click **Add**.
5. Next to Personality, select **Manova**.
6. Click **Run**.
7. From the red triangle menu next to Manova Fit, select **Save Discrim**.

The following columns are added to the Iris.jmp sample data table:

<table>
<thead>
<tr>
<th>Column</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>SqDist[0]</td>
<td>Quadratic form needed in the Mahalanobis distance calculations.</td>
</tr>
<tr>
<td>SqDist[setosa]</td>
<td>Mahalanobis distance of the observation from the Setosa centroid.</td>
</tr>
<tr>
<td>SqDist[versicolor]</td>
<td>Mahalanobis distance of the observation from the Versicolor centroid.</td>
</tr>
<tr>
<td>SqDist[virginica]</td>
<td>Mahalanobis distance of the observation from the Virginica centroid.</td>
</tr>
<tr>
<td>Prob[0]</td>
<td>Sum of the negative exponentials of the Mahalanobis distances, used below.</td>
</tr>
<tr>
<td>Prob[setosa]</td>
<td>Probability of being in the Setosa category.</td>
</tr>
<tr>
<td>Prob[versicolor]</td>
<td>Probability of being in the Versicolor category.</td>
</tr>
<tr>
<td>Prob[virginica]</td>
<td>Probability of being in the Virginica category.</td>
</tr>
<tr>
<td>Pred Species</td>
<td>Species that is most likely from the probabilities.</td>
</tr>
</tbody>
</table>
Now you can use the new columns in the data table with other JMP platforms to summarize the discriminant analysis with reports and graphs. For example:

1. From the updated Iris.jmp data table (that contains the new columns) select **Analyze > Fit Y by X**.
2. Select Species and click **Y, Response**.
3. Select Pred Species and click **X, Factor**.
4. Click **OK**.

The Contingency Table summarizes the discriminant classifications. Three misclassifications are identified.

**Figure 8.13** Contingency Table of Predicted and Actual Species
About Loglinear Variance Models

The Loglinear Variance personality of the Fit Model platform enables you to model both the expected value and the variance of a response using regression models. The log of the variance is fit to one linear model and the expected response is fit to a different linear model simultaneously.

**Note:** The estimates are demanding in their need for a lot of well-designed, well-fitting data. You need more data to fit variances than you do means.

For many engineers, the goal of an experiment is not to maximize or minimize the response itself, but to aim at a target response and achieve minimum variability. The loglinear variance model provides a very general and effective way to model variances, and can be used for unreplicated data, as well as data with replications.
## Contents

- Overview of the Loglinear Variance Model .............................................. 359
- Model Specification .................................................................................. 359
- Notes ........................................................................................................... 360
- Example Using Loglinear Variance ............................................................ 360
- The Loglinear Report .................................................................................. 362
- Loglinear Platform Options ....................................................................... 364
  - Save Columns ......................................................................................... 364
  - Row Diagnostics .................................................................................... 365
- Examining the Residuals ............................................................................ 366
- Profiling the Fitted Model .......................................................................... 366
  - Example of Profiling the Fitted Model ..................................................... 367
Overview of the Loglinear Variance Model

The loglinear-variance model (Harvey 1976, Cook and Weisberg 1983, Aitken 1987, Carroll and Ruppert 1988) provides a way to model the variance simply through a linear model. In addition to having regressor terms to model the mean response, there are regressor terms in a linear model to model the log of the variance:

- mean model: \( E(y) = X\beta \)
- variance model: \( \log(\text{Variance}(y)) = Z\lambda \),

or equivalently

\[
\text{Variance}(y) = \exp(Z\lambda)
\]

where the columns of \( X \) are the regressors for the mean of the response, and the columns of \( Z \) are the regressors for the variance of the response. The regular linear model parameters are represented by \( \beta \), and \( \lambda \) represents the parameters of the variance model.

Log-linear variance models are estimated using REML.

A dispersion or log-variance effect can model changes in the variance of the response. This is implemented in the Fit Model platform by a fitting personality called the Loglinear Variance personality.

Dispersion Effects

Modeling dispersion effects is not very widely covered in textbooks, with the exception of the Taguchi framework. In a Taguchi-style experiment, this is handled by taking multiple measurements across settings of an outer array, constructing a new response which measures the variability off-target across this outer array, and then fitting the model to find out the factors that produce minimum variability. This kind of modeling requires a specialized design that is a complete cartesian product of two designs. The method of this chapter models variances in a more flexible, model-based approach. The particular performance statistic that Taguchi recommends for variability modeling is \( STD = -\log(s) \). In JMP’s methodology, the \( \log(s^2) \) is modeled and combined with a model that has a mean. The two are basically equivalent, since \( \log(s^2) = 2 \log(s) \).

Model Specification

Log-linear variance effects are specified in the Fit Model dialog by highlighting them and selecting LogVariance Effect from the Attributes drop-down menu. &LogVariance appears at the end of the effect. When you use this attribute, it also changes the fitting Personality at the top to LogLinear Variance. If you want an effect to be used for both the mean and variance of the response, then you must specify it twice, once with the LogVariance option.
Example Using Loglinear Variance

The data table InjectionMolding.jmp contains the experimental results from a 7-factor $2^7 \cdot 3^3$ fractional factorial design with four added centerpoints [from Myers and Montgomery, 1995, page 519, originally Montgomery, 1991]. Preliminary investigation determined that the mean response only seemed to vary with the first two factors, Mold Temperature, and Screw Speed, and the variance seemed to be affected by Holding Time.

Figure 9.1 Injection Molding Data

1. Open the InjectionMolding.jmp sample data table.
2. Select Analyze > Fit Model.
Since the variables in the data table have preselected roles assigned to them, the launch window is already filled out.

Figure 9.2 Fit Model Dialog

3. Click Run.
The Mean Model for Shrinkage report gives the parameters for the mean model, and the Variance Model for Shrinkage report gives the parameters for the variance model.

The Loglinear Report

The top portion of the resulting report shows the fitting of the Expected response, with reports similar to standard least squares, though actually derived from restricted maximum likelihood (REML).
The second portion of the report shows the fit of the variance model. The **Variance Parameter Estimates** report shows the estimates and relevant statistics. Two hidden columns are provided:

- The hidden column $\exp(\text{Estimate})$ is the exponential of the estimate. So, if the factors are coded to have $+1$ and $-1$ values, then the $+1$ level for a factor would have the variance multiplied by the $\exp(\text{Estimate})$ value and the $-1$ level would have the variance multiplied by the reciprocal of this column. To see a hidden column, right-click on the report and select the name of the column from the **Columns** menu that appears.

- The hidden column labeled $\exp(2|\text{Estimate}|)$ is the ratio of the higher to the lower variance if the regressor has the range $-1$ to $+1$.

The report also shows the standard error, chi-square, $p$-value, and profile likelihood confidence limits of each estimate. The residual parameter is the overall estimate of the variance, given all other regressors are zero.
Does the variance model fit significantly better than the original model? The likelihood ratio test for this question compares the fitted model with the model where all parameters are zero except the intercept, the model of equal-variance. In this case the $p$-value is highly significant. Changes in Hold Time change the variance.

The **Variance Effect Likelihood Ratio Tests** refit the model without each term in turn to create the likelihood ratio tests. These are generally more trusted than Wald tests.

---

**Loglinear Platform Options**

The red triangle menu next to Loglinear Variance Fit contains the following options.

**Table 9.1** Descriptions of Loglinear Platform Options

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Save Columns</strong></td>
<td>Creates one or more columns in the data table. See “Save Columns” on page 364.</td>
</tr>
<tr>
<td><strong>Row Diagnostics</strong></td>
<td>Plots row diagnostics. See “Row Diagnostics” on page 365.</td>
</tr>
<tr>
<td><strong>Profiler</strong></td>
<td>Opens the <strong>Profiler</strong>, <strong>Contour Profiler</strong>, or <strong>Surface Profiler</strong>. See “Factor Profiling” on page 155 in the “Standard Least Squares Report and Options” chapter.</td>
</tr>
<tr>
<td><strong>Model Dialog</strong></td>
<td>Shows the completed launch window for the current analysis.</td>
</tr>
<tr>
<td><strong>Script</strong></td>
<td>Contains options that are available to all platforms. See <strong>Using JMP</strong>.</td>
</tr>
</tbody>
</table>

**Save Columns**

**Table 9.2** Descriptions of Save Columns Options

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Prediction Formula</strong></td>
<td>Creates a new column called <strong>Mean</strong>. The new column contains the predicted values for the mean, as computed by the specified model.</td>
</tr>
<tr>
<td><strong>Variance Formula</strong></td>
<td>Creates a new column called <strong>Variance</strong>. The new column contains the predicted values for the variance, as computed by the specified model.</td>
</tr>
<tr>
<td><strong>Std Dev Formula</strong></td>
<td>Creates a new column called <strong>Std Dev</strong>. The new column contains the predicted values for the standard deviation, as computed by the specified model.</td>
</tr>
</tbody>
</table>
Table 9.2 Descriptions of Save Columns Options (Continued)

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residuals</td>
<td>Creates a new column called Residual that contains the residuals, which are the observed response values minus predicted values. See “Examining the Residuals” on page 366.</td>
</tr>
<tr>
<td>Studentized Residuals</td>
<td>Creates a new column called Studentized Resid. The new column values are the residuals divided by their standard error.</td>
</tr>
<tr>
<td>Std Error of Predicted</td>
<td>Creates a new column called Std Err Pred. The new column contains the standard errors of the predicted values.</td>
</tr>
<tr>
<td>Std Error of Individual</td>
<td>Creates a new column called Std Err Indiv. The new column contains the standard errors of the individual predicted values.</td>
</tr>
<tr>
<td>Mean Confidence Interval</td>
<td>Creates two new columns, Lower 95% Mean and Upper 95% Mean. The new columns contain the bounds for a confidence interval for the prediction mean.</td>
</tr>
<tr>
<td>Indiv Confidence Interval</td>
<td>Creates two new columns, Lower 95% Indiv and Upper 95% Indiv. The new columns contain confidence limits for individual response values.</td>
</tr>
</tbody>
</table>

Row Diagnostics

Table 9.3 Descriptions of Row Diagnostics Options

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plot Actual by Predicted</td>
<td>Plots the observed values by the predicted values of Y. This is the leverage plot for the whole model.</td>
</tr>
<tr>
<td>Plot Studentized Residual by Predicted</td>
<td>Plots the Studentized residuals by the predicted values of Y.</td>
</tr>
<tr>
<td>Plot Studentized Residual by Row</td>
<td>Plots the Studentized residuals by row.</td>
</tr>
</tbody>
</table>
Examining the Residuals

To see the dispersion effect, follow these steps:

1. Open the InjectionMolding.jmp sample data table.
2. Select Analyze > Fit Model.
   Since the variables in the data table have preselected roles assigned to them, the launch window is already filled out.
3. Click Run.
4. From the red triangle menu next to Loglinear Variance Fit, select Save Columns > Residuals.
5. In the InjectionMolding.jmp sample data table, right-click on the continuous icon next to Hold Time in the Columns panel, and select Nominal.
6. Select Analyze > Fit Y by X.
7. Select Shrinkage Residual and click Y, Response.
8. Select Hold Time and click X, Factor.
9. Click OK.

Figure 9.6 Residual by Dispersion Effect

In this plot it is easy to see the variance go up as the Hold Time increases. This is done by treating Hold Time as a nominal factor.

Profiling the Fitted Model

Use the Profiler, Contour Profiler, or Surface Profiler to gain further insight into the fitted model. To select a profiler option, click on the red triangle menu next to Loglinear Variance Fit and select one of the options under the Profilers menu.
Example of Profiling the Fitted Model

For example, suppose that the goal was to find the factor settings that achieved a target of 31 for the response, but at the smallest variance. Fit the models and choose Profiler from the report menu. For example, Figure 9.7 shows the Profiler set up to match a target value for a mean and to minimize variance.

1. Open the InjectionMolding.jmp sample data table.
2. Select Analyze > Fit Model.

Since the variables in the data table have preselected roles assigned to them, the launch window is already filled out.
3. Click Run.
4. From the red triangle menu next to Loglinear Variance Fit, select Profilers > Profiler.
5. From the red triangle menu next to Prediction Profiler, select Prediction Intervals.

**Figure 9.7** Prediction Intervals

6. Change the following values:
   - MoldTemp to 0.2
   - Screw Speed to 0.1
   - Hold Time to -1
One of the best ways to see the relationship between the mean and the variance (both modeled with the LogVariance personality) is through looking at the individual prediction confidence intervals about the mean. Regular confidence intervals (those shown by default in the Profiler) do not show information about the variance model as well as individual prediction confidence intervals do. Prediction intervals show both the mean and variance model in one graph.

If \( Y \) is the modeled response, and you want a prediction interval for a new observation at \( x_n \), then:

\[
s^2|x_n = s^2 Y|x_n + s^2 Y\hat{x}_n
\]

where:

- \( s^2|x_n \) is the variance for the individual prediction at \( x_n \)
- \( s^2 Y|x_n \) is the variance of the distribution of \( Y \) at \( x_n \)
- \( s^2 Y\hat{x}_n \) is the variance of the sampling distribution of \( \hat{Y} \), and is also the variance for the mean.

Because the variance of the individual prediction contains the variance of the distribution of \( Y \), the effects of the changing variance for \( Y \) can be seen. Not only are the individual prediction intervals wider, but they can change shape with a change in the variance effects.
About Logistic Regression

For nominal response variables, the Fit Model platform fits a linear model to a multi-level logistic response function using maximum likelihood. Likelihood-ratio statistics and Lack of Fit tests are computed for the whole model. Likelihood-ratio tests and Wald tests can be computed for each effect in the model. When the response is binary, odds ratios (with confidence intervals) are available.

For ordinal response variables, the Fit Model platform fits the cumulative response probabilities to the logistic distribution function of a linear model using maximum likelihood. Likelihood-ratio test statistics are provided for the whole model and lack of fit.

For simple main effects, you can use the Fit Y by X platform to see a cumulative logistic probability plot for each effect. See the Basic Analysis book.
## Contents

- Introduction to Logistic Models ................................................................. 371
- The Logistic Fit Report ............................................................................. 372
  - Logistic Plot ......................................................................................... 373
  - Iteration History ................................................................................. 373
  - Whole Model Test ................................................................................ 373
  - Lack of Fit Test (Goodness of Fit) ..................................................... 376
  - Parameter Estimates .......................................................................... 376
  - Likelihood Ratio Tests ...................................................................... 377
- Logistic Fit Platform Options .................................................................... 378
  - Plot Options ...................................................................................... 378
  - Likelihood Ratio Tests ...................................................................... 378
  - Wald Tests for Effects ...................................................................... 378
  - Confidence Intervals ......................................................................... 378
  - Odds Ratios (Nominal Responses Only) ........................................... 379
  - Inverse Prediction ............................................................................. 380
  - Save Commands ................................................................................. 383
  - ROC Curve ......................................................................................... 384
  - Lift Curve .......................................................................................... 385
  - Confusion Matrix ............................................................................... 386
  - Profiler .............................................................................................. 386
- Validation ................................................................................................... 386
- Example of a Nominal Logistic Model ..................................................... 387
- Example of an Ordinal Logistic Model .................................................... 392
- Example of a Quadratic Ordinal Logistic Model .................................... 397
- Stacking Counts in Multiple Columns ..................................................... 399
Introduction to Logistic Models

Logistic regression fits nominal Y responses to a linear model of X terms. To be more precise, it fits probabilities for the response levels using a logistic function. For two response levels, the function is:

\[
P(Y = r_1) = \left(1 + e^{-Xb}\right)^{-1} \quad \text{where } r_1 \text{ is the first response}
\]

or equivalently:

\[
\log \left(\frac{P(Y = r_1)}{P(Y = r_2)}\right) = Xb \quad \text{where } r_1 \text{ and } r_2 \text{ are the two responses}
\]

For r nominal responses, where \( r > 2 \), it fits \( r - 1 \) sets of linear model parameters of the following form:

\[
\log \left(\frac{P(Y = i)}{P(Y = r)}\right) = Xb_i
\]

The fitting principal of maximum likelihood means that the \( \beta \)s are chosen to maximize the joint probability attributed by the model to the responses that did occur. This fitting principal is equivalent to minimizing the negative log-likelihood (–LogLikelihood) as attributed by the model:

\[
\text{Loss } = -\text{logLikelihood} = \sum_{i=1}^{n} \text{–log(Prob(i\text{th row has the } y_j\text{ th response}))}
\]

For example, consider an experiment that was performed on metal ingots prepared with different heating and soaking times. The ingots were then tested for readiness to roll. See Cox (1970). The Ingots.jmp data table in the sample data folder has the experimental results. The categorical variable called ready has values 1 and 0 for readiness and not readiness to roll, respectively.

The Fit Model platform fits the probability of the not readiness (0) response to a logistic cumulative distribution function applied to the linear model with regressors heat and soak:

\[
\text{Probability (not ready to roll)} = \frac{1}{1 + e^{-(\beta_0 + \beta_1 \text{heat} + \beta_2 \text{soak})}}
\]

The parameters are estimated by minimizing the sum of the negative logs of the probabilities attributed to the observations by the model (maximum likelihood).
To analyze this model, select **Analyze > Fit Model**. The *ready* variable is *Y*, the response, and *heat* and *soak* are the model effects. The count column is the *Freq* variable. When you click **Run**, iterative calculations take place. When the fitting process converges, the nominal or ordinal regression report appears. The following sections discuss the report layout and statistical tables, and show examples.

**The Logistic Fit Report**

Initially, the Logistic platform produces the following reports:

- Iterations
- Whole Model Test
- Lack of Fit (only if applicable)
- Parameter Estimates
- Effect Likelihood Ratio Tests

You can also request Wald Tests. All tests compare the fit of the specified model with subset or superset models, as illustrated in Figure 10.1. If a test shows significance, then the higher order model is justified.

- Whole model tests: if the specified model is significantly better than a reduced model without any effects except the intercepts.
- Lack of Fit tests: if a saturated model is significantly better than the specified model.
- Effect tests: if the specified model is significantly better than a model without a given effect.

**Figure 10.1 Relationship of Statistical Tables**

Tests are a comparison of model fits

- **Reduced model** (with only intercepts)
- **Specified model**
- **Saturated model** (a parameter for each unique combination of *x* values)
- **Whole Model Test** (optional)
- **Lack-of-Fit Test** (Goodness of Fit $G^2$)
- **Wald Effect Tests**
- **Likelihood-ratio Effect Tests** (default)
- **Model without $i$th effect**
Logistic Plot

If your model contains a single continuous effect, then a logistic report similar to the one in Fit Y By X appears. See the Basic Analysis book for an interpretation of these plots.

Iteration History

After launching Fit Model, an iterative estimation process begins and is reported iteration by iteration. After the fitting process completes, you can open the Iteration History report and see the iteration steps.

Figure 10.2 Iteration History

```
<table>
<thead>
<tr>
<th>Iter</th>
<th>Objective</th>
<th>Gradient</th>
<th>Norm Gradient</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>263.24786589</td>
<td>18.501466591</td>
<td>3500.4890148</td>
</tr>
<tr>
<td>1</td>
<td>76.2940807072</td>
<td>6.140769087</td>
<td>727.00273343</td>
</tr>
<tr>
<td>2</td>
<td>53.30029197</td>
<td>2.9100640839</td>
<td>197.00411238</td>
</tr>
<tr>
<td>3</td>
<td>48.346065628</td>
<td>1.0882544501</td>
<td>51.063641722</td>
</tr>
<tr>
<td>4</td>
<td>47.69131265</td>
<td>0.1931790967</td>
<td>8.903232493</td>
</tr>
<tr>
<td>5</td>
<td>47.67282965</td>
<td>0.0007825247</td>
<td>3218.031712</td>
</tr>
<tr>
<td>6</td>
<td>47.67280683</td>
<td>0.0004112622</td>
<td>6.610795e-10</td>
</tr>
<tr>
<td>7</td>
<td>47.67280683</td>
<td>1.33811e-11</td>
<td>6.610795e-10</td>
</tr>
</tbody>
</table>
```

The Iterations history is available only for Nominal Logistic reports.

Whole Model Test

The Whole Model table shows tests that compare the whole-model fit to the model that omits all the regressor effects except the intercept parameters. The test is analogous to the Analysis of Variance table for continuous responses. The negative log-likelihood corresponds to the sums of squares, and the Chi-square test corresponds to the $F$ test.
Figure 10.3 Whole Model Test

The Whole Model table shows these quantities:

- **Model** lists the model labels called Difference (difference between the Full model and the Reduced model), Full (model that includes the intercepts and all effects), and Reduced (the model that includes only the intercepts).

- **–LogLikelihood** records an associated negative log-likelihood for each of the models.

- **Difference** is the difference between the Reduced and Full models. It measures the significance of the regressors as a whole to the fit.

- **Full** describes the negative log-likelihood for the complete model.

- **Reduced** describes the negative log-likelihood that results from a model with only intercept parameters. For the ingot experiment, the –LogLikelihood for the reduced model that includes only the intercepts is 53.49.

- **DF** records an associated degrees of freedom (DF) for the Difference between the Full and Reduced model. For the ingots experiment, there are two parameters that represent different heating and soaking times, so there are 2 degrees of freedom.

- **Chi-Square** is the Likelihood-ratio Chi-square test for the hypothesis that all regression parameters are zero. It is computed by taking twice the difference in negative log-likelihoods between the fitted model and the reduced model that has only intercepts.
Prob>ChiSq is the probability of obtaining a greater Chi-square value by chance alone if the specified model fits no better than the model that includes only intercepts.

RSquare (U) shows the $R^2$, which is the ratio of the Difference to the Reduced negative log-likelihood values. It is sometimes referred to as $U$, the uncertainty coefficient. RSquare ranges from zero for no improvement to 1 for a perfect fit. A Nominal model rarely has a high Rsquare, and it has a Rsquare of 1 only when all the probabilities of the events that occur are 1.

AICc is the corrected Akaike Information Criterion.

BIC is the Bayesian Information Criterion

Observations (or Sum Wgts) is the total number of observations in the sample.

Measure gives several measures of fit to assess model accuracy.

Entropy RSquare is the same as R-Square (U) explained above.

Generalized RSquare is a generalization of the Rsquare measure that simplifies to the regular Rsquare for continuous normal responses. It is similar to the Entropy RSquare, but instead of using the log-likelihood, it uses the $2/n$ root of the likelihood.

Mean -Log p is the average of -log(p), where p is the fitted probability associated with the event that occurred.

RMSE is the root mean square error, where the differences are between the response and p (the fitted probability for the event that actually occurred).

Mean Abs Dev is the average of the absolute values of the differences between the response and p (the fitted probability for the event that actually occurred).

Misclassification Rate is the rate for which the response category with the highest fitted probability is not the observed category.

For Entropy RSquare and Generalized RSquare, values closer to 1 indicate a better fit. For Mean -Log p, RMSE, Mean Abs Dev, and Misclassification Rate, smaller values indicate a better fit.

After fitting the full model with two regressors in the ingots example, the –LogLikelihood on the Difference line shows a reduction to 5.82 from the Reduced –LogLikelihood of 53.49. The ratio of Difference to Reduced (the proportion of the uncertainty attributed to the fit) is 10.9% and is reported as the Rsquare (U).

To test that the regressors as a whole are significant (the Whole Model test), a Chi-square statistic is computed by taking twice the difference in negative log-likelihoods between the fitted model and the reduced model that has only intercepts. In the ingots example, this Chi-square value is $2 \times 5.82 = 11.64$, and is significant at 0.003.
**Logistic Regression with Nominal or Ordinal Responses**

**Chapter 10**

The Logistic Fit Report

**Fitting Linear Models**

---

**Lack of Fit Test (Goodness of Fit)**

The next questions that JMP addresses are whether there is enough information using the variables in the current model or whether more complex terms need to be added. The Lack of Fit test, sometimes called a Goodness of Fit test, provides this information. It calculates a pure-error negative log-likelihood by constructing categories for every combination of the regressor values in the data (Saturated line in the Lack Of Fit table), and it tests whether this log-likelihood is significantly better than the Fitted model.

**Figure 10.4 Lack of Fit Test**

The Saturated degrees of freedom is \( m - 1 \), where \( m \) is the number of unique populations. The Fitted degrees of freedom is the number of parameters not including the intercept. For the Ingots example, these are 18 and 2 DF, respectively. The Lack of Fit DF is the difference between the Saturated and Fitted models, in this case \( 18 - 2 = 16 \).

The Lack of Fit table lists the negative log-likelihood for error due to Lack of Fit, error in a Saturated model (pure error), and the total error in the Fitted model. Chi-square statistics test for lack of fit.

In this example, the lack of fit Chi-square is not significant (Prob>ChiSq = 0.617) and supports the conclusion that there is little to be gained by introducing additional variables, such as using polynomials or crossed terms.

**Parameter Estimates**

The Parameter Estimates report gives the parameter estimates, standard errors, and associated hypothesis test. The Covariance of Estimates report gives the variances and covariances of the parameter estimates.
Fitting Linear Models

The Logistic Fit Report

Figure 10.5 Parameter Estimates Report

<table>
<thead>
<tr>
<th>Term</th>
<th>Estimate</th>
<th>Std Error</th>
<th>ChiSquare</th>
<th>Prob&gt;ChiSq</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>5.55916846</td>
<td>1.1199947</td>
<td>24.66</td>
<td>&lt;.0001*</td>
</tr>
<tr>
<td>heat</td>
<td>-0.0820308</td>
<td>0.037345</td>
<td>11.95</td>
<td>0.0005*</td>
</tr>
<tr>
<td>soak</td>
<td>-0.0567713</td>
<td>0.3312131</td>
<td>0.03</td>
<td>0.8639</td>
</tr>
</tbody>
</table>

For log odds of 0/1

<table>
<thead>
<tr>
<th>Covariance of Estimates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept  heat  soak</td>
</tr>
<tr>
<td>Intercept  1.2537 -0.022 -0.282</td>
</tr>
<tr>
<td>heat       -0.022  0.0026  0.026</td>
</tr>
<tr>
<td>soak       -0.282  0.0026  0.1997</td>
</tr>
</tbody>
</table>

Likelihood Ratio Tests

The Likelihood Ratio Tests command produces a table like the one shown here. The Likelihood-ratio Chi-square tests are calculated as twice the difference of the log-likelihoods between the full model and the model constrained by the hypothesis to be tested (the model without the effect). These tests can take time to do because each test requires a separate set of iterations.

This is the default test if the fit took less than ten seconds to complete.

Figure 10.6 Effect Likelihood Ratio Tests

<table>
<thead>
<tr>
<th>LR Source</th>
<th>Nparm</th>
<th>DF</th>
<th>ChiSquare</th>
<th>Prob&gt;ChiSq</th>
</tr>
</thead>
<tbody>
<tr>
<td>heat</td>
<td>1</td>
<td>1</td>
<td>11.048822</td>
<td>0.0005*</td>
</tr>
<tr>
<td>soak</td>
<td>1</td>
<td>1</td>
<td>0.0204484</td>
<td>0.8849</td>
</tr>
</tbody>
</table>
Logistic Fit Platform Options

The red triangle menu next to the analysis name gives you the additional options that are described next.

Plot Options

These options are described in the Basic Analysis book.

Likelihood Ratio Tests


Wald Tests for Effects

One downside to likelihood ratio tests is that they involve refitting the whole model, which uses another series of iterations. Therefore, they could take a long time for big problems. The logistic fitting platform gives an optional test, which is more straightforward, serving the same function. The Wald Chi-square is a quadratic approximation to the likelihood-ratio test, and it is a by-product of the calculations. Though Wald tests are considered less trustworthy, they do provide an adequate significance indicator for screening effects. Each parameter estimate and effect is shown with a Wald test. This is the default test if the fit takes more than ten seconds to complete.

Figure 10.7 Effect Wald Tests

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>ChiSquare</th>
<th>Prob&gt;ChiSq</th>
</tr>
</thead>
<tbody>
<tr>
<td>heat</td>
<td>1</td>
<td>11.945228</td>
<td>0.0005*</td>
</tr>
<tr>
<td>soak</td>
<td>1</td>
<td>0.0237929</td>
<td>0.8839</td>
</tr>
</tbody>
</table>

Likelihood-ratio tests are the platform default and are discussed under “Likelihood Ratio Tests” on page 377. It is highly recommended to use this default option.

Confidence Intervals

You can also request profile likelihood confidence intervals for the model parameters. When you select the Confidence Intervals command, a dialog prompts you to enter \( \alpha \) to compute the \( 1 - \alpha \) confidence intervals, or you can use the default of \( \alpha = 0.05 \). Each confidence limit requires a set of iterations in the model fit and can be expensive. Furthermore, the effort does not always succeed in finding limits.
Odds Ratios (Nominal Responses Only)

When you select Odds Ratios, a report appears showing Unit Odds Ratios and Range Odds Ratios, as shown in Figure 10.9.

From the introduction (for two response levels), we had

\[
\log \left( \frac{\text{Prob}(Y = r_1)}{\text{Prob}(Y = r_2)} \right) = X \beta \quad \text{where } r_1 \text{ and } r_2 \text{ are the two response levels}
\]

so the odds ratio

\[
\frac{\text{Prob}(Y = r_1)}{\text{Prob}(Y = r_2)} = \exp(X \beta) = \exp(\beta_0) \cdot \exp(\beta_1 X_1) \cdots \exp(\beta_i X_i)
\]

Note that \(\exp(\beta_i(X_i + 1)) = \exp(\beta_i) \cdot \exp(\beta_i)\). This shows that if \(X_i\) changes by a unit amount, the odds is multiplied by \(\exp(\beta_i)\), which we label the unit odds ratio. As \(X_i\) changes over its whole range, the odds are multiplied by \(\exp((X_{\text{high}} - X_{\text{low}})\beta_i)\) which we label the range odds ratio. For binary responses, the log odds ratio for flipped response levels involves only changing the sign of the parameter, so you might want the reciprocal of the reported value to focus on the last response level instead of the first.
Two-level nominal effects are coded 1 and -1 for the first and second levels, so range odds ratios or their reciprocals would be of interest.

**Dose Response Example**

In the Dose Response.jmp sample data table, the dose varies between 1 and 12.

1. Open the Dose Response.jmp sample data table.
2. Select **Analyze > Fit Model**.
3. Select **response** and click **Y**.
4. Select **dose** and click **Add**.
5. Click **Run**.
6. From the red triangle next to **Nominal Logistic Fit**, select **Odds Ratio**.

**Figure 10.10 Odds Ratios**

![Odds Ratios Table](image)

The unit odds ratio for dose is 1.606 (which is \( \exp(0.474) \)) and indicates that the odds of getting a \( Y = 0 \) rather than \( Y = 1 \) improves by a factor of 1.606 for each increase of one unit of dose. The range odds ratio for dose is 183.8 (\( \exp((12-1)*0.474) \)) and indicates that the odds improve by a factor of 183.8 as dose is varied between 1 and 12.

**Inverse Prediction**

For a two-level response, the **Inverse Prediction** command finds the \( x \) value that results in a specified probability.

To see an example of inverse prediction:

1. Open the Ingots.jmp sample data table.
2. Select **Analyze > Fit Y by X**.
3. Select **ready** and click **Y, Response**.
4. Select **heat** and click **X, Factor**.
5. Select count and click **Freq**.

6. Click **OK**.

The cumulative logistic probability plot shows the result.

**Figure 10.11** Logistic Probability Plot

![Logistic Fit of ready By heat](image)

Note that the fitted curve crosses the 0.9 probability level at a heat level of about 39.5, which is the inverse prediction. To be more precise and to get a fiducial confidence interval:

7. From the red triangle menu next to Logistic Fit, select **Inverse Prediction**.

8. For **Probability**, type 0.9.

9. Click **OK**.

The predicted value (inverse prediction) for heat is 39.8775, as shown in Figure 10.12.
However, if you have another regressor variable (Soak), you must use the Fit Model platform, as follows:

1. From the Ingots.jmp sample data table, select Analyze > Fit Model.
2. Select ready and click Y.
3. Select heat and soak and click Add.
4. Select count and click Freq.
5. Click Run.
6. From the red triangle next to Nominal Logistic Fit, select Inverse Prediction.

Then the Inverse Prediction command displays the Inverse Prediction window shown in Figure 10.13, for requesting the probability of obtaining a given value for one independent variable. To complete the dialog, click and type values in the editable X and Probability columns. Enter a value for a single X (heat or soak) and the probabilities that you want for the prediction. Set the remaining independent variable to missing by clicking in its X field and deleting. The missing regressor is the value that it will predict.
Logistic Regression with Nominal or Ordinal Responses

Chapter 10
Fitting Linear Models

Figure 10.13 The Inverse Prediction Window and Table

See the appendix “Statistical Details” on page 427 for more details about inverse prediction.

Save Commands

If you have ordinal or nominal response models, the Save Probability Formula command creates new data table columns.

If the response is numeric and has the ordinal modeling type, the Save Quantiles and Save Expected Values commands are also available.

The Save commands create the following new columns:

**Save Probability Formula**  
creates columns in the current data table that save formulas for linear combinations of the response levels, prediction formulas for the response levels, and a prediction formula giving the most likely response.

For a nominal response model with \( r \) levels, JMP creates

- columns called Lin\([j]\) that contain a linear combination of the regressors for response levels \( j = 1, 2, \ldots, r - 1 \)
- a column called Prob\([r]\), with a formula for the fit to the last level, \( r \)
• columns called Prob\[j\] for \( j < r \) with a formula for the fit to level \( j \)

• a column called Most Likely responsename that picks the most likely level of each row based on the computed probabilities.

For an ordinal response model with \( r \) levels, JMP creates

• a column called Linear that contains the formula for a linear combination of the regressors without an intercept term

• columns called Cum\[j\], each with a formula for the cumulative probability that the response is less than or equal to level \( j \), for levels \( j = 1, 2, ... r - 1 \). There is no Cum\[j\] that is 1 for all rows

• columns called Prob\[j\], for \( 1 < j < r \), each with the formula for the probability that the response is level \( j \). Prob\[1\] is the difference between Cum\[1\] and Cum\[0\]. Prob\[r\] is 1–Cum\[r–1\].

• a column called Most Likely responsename that picks the most likely level of each row based on the computed probabilities.

**Save Quantiles** creates columns in the current data table named OrdQ.05, OrdQ.50, and OrdQ.95 that fit the quantiles for these three probabilities.

**Save Expected Value** creates a column in the current data table called Ord Expected that is the linear combination of the response values with the fitted response probabilities for each row and gives the expected value.

**ROC Curve**

Receiver Operating Characteristic (ROC) curves measure the sorting efficiency of the model's fitted probabilities to sort the response levels. ROC curves can also aid in setting criterion points in diagnostic tests. The higher the curve from the diagonal, the better the fit. An introduction to ROC curves is found in the Basic Analysis book. If the logistic fit has more than two response levels, it produces a generalized ROC curve (identical to the one in the Partition platform). In such a plot, there is a curve for each response level, which is the ROC curve of that level versus all other levels. Details on these ROC curves are found in Partition chapter of the Specialized Models book.

**Example of an ROC Curve**

1. Open the Ingots.jmp sample data table.
2. Select Analyze > Fit Model.
3. Select ready and click Y.
4. Select heat and soak and click Add.
5. Select count and click Freq.
6. Click Run.
7. From the red triangle next to Nominal Logistic Fit, select **ROC Curve**.

8. Select 1 as the positive level and click **OK**.

**Figure 10.14** ROC Curve

![ROC Curve](image)

**Lift Curve**

Produces a lift curve for the model. A lift curve shows the same information as an ROC curve, but in a way to dramatize the richness of the ordering at the beginning. The Y-axis shows the ratio of how rich that portion of the population is in the chosen response level compared to the rate of that response level as a whole. See the Partition chapter of the *Specialized Models* book for more details about lift curves. See the *Specialized Models* book for details about lift curves.

Figure 10.15 shows the lift curve for the same model specified for the ROC curve (Figure 10.14).
**Confusion Matrix**

A confusion matrix is a two-way classification of the actual response levels and the predicted response levels. For a good model, predicted response levels should be the same as the actual response levels. The confusion matrix gives a way of assessing how the predicted responses align with the actual responses.

**Profiler**

Brings up the prediction profiler, showing the fitted values for a specified response probability as the values of the factors in the model are changed. This feature is available for both nominal and ordinal responses. For detailed information about profiling features, refer to the *Profiler* book.

**Validation**

Validation is the process of using part of a data set to estimate model parameters, and using the other part to assess the predictive ability of the model.

- The *training* set is the part that estimates model parameters.
- The *validation* set is the part that assesses or validates the predictive ability of the model.
- The *test* set is a final, independent assessment of the model’s predictive ability. The test set is available only when using a validation column.

The training, validation, and test sets are created by subsetting the original data into parts. This is done through the use of a validation column in the Fit Model launch window.
The validation column’s values determine how the data is split, and what method is used for validation:

- If the column has two distinct values, then training and validation sets are created.
- If the column has three distinct values, then training, validation, and test sets are created.
- If the column has more than three distinct values, or only one, then no validation is performed.

When validation is used, model fit statistics are given for the training, validation, and test sets.

**Example of a Nominal Logistic Model**

A market research study was undertaken to evaluate preference for a brand of detergent (Ries and Smith 1963). The results are in the Detergent.jmp sample data table. The model is defined by the following:

- the response variable, brand with values m and x
- an effect called softness (water softness) with values soft, medium, and hard
- an effect called previous use with values yes and no
- an effect called temperature with values high and low
- a count variable, count, which gives the frequency counts for each combination of effect categories.

The study begins by specifying the full three-factor factorial model as shown by the Fit Model dialog in Figure 10.16. To specify a factorial model, highlight the three main effects in the column selector list. Then select Full Factorial from the Macros popup menu.
Validation is available only in JMP Pro.

The tables in Figure 10.17 show the three-factor model as a whole to be significant (Prob>ChiSq = 0.0006) in the Whole Model table. The Effect Likelihood Ratio Tests table shows that the effects that include softness do not contribute significantly to the model fit.
Figure 10.17 Tables for Nominal Response Three-Factor Factorial

<table>
<thead>
<tr>
<th>Model</th>
<th>LogLikelihood</th>
<th>DF</th>
<th>ChiSquare</th>
<th>Prob&gt;ChiSq</th>
</tr>
</thead>
<tbody>
<tr>
<td>Difference</td>
<td>18.41201</td>
<td>11</td>
<td>32.29562</td>
<td>0.0000*</td>
</tr>
<tr>
<td>Full</td>
<td>0.02200</td>
<td>0.0080</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduced</td>
<td>0.0980861</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- $R^2$ (U): 0.9736
- AICc: 1580.91
- DIC: 1474.48
- Observations (or Sum Wgts): 1608

Next, use the Fit Model Dialog again to remove the softness factor and its interactions because they do not appear to be significant. You can do this easily by double-clicking the softness factor in the Fit Model dialog. A dialog appears, asking if you want to remove the other factors that involve softness (click Yes). This leaves the two-factor factorial model in Figure 10.18.
Figure 10.18 A Two-factor Factorial Model with Nominal Response

The Whole Model Test table shows that the two-factor model fits as well as the three-factor model. In fact, the three-factor Whole Model table in Figure 10.19 shows a larger Chi-square value (32.83) than the Chi-square value for the two-factor model (27.17). This results from the change in degrees of freedom used to compute the Chi-square values and their probabilities.
The report shown in Figure 10.19 supports the conclusion that previous use of a detergent brand, and water temperature, have an effect on detergent preference, and the interaction between temperature and previous use is not statistically significant (the effect of temperature does not depend on previous use).
Example of an Ordinal Logistic Model

If the response variable has an ordinal modeling type, the platform fits the cumulative response probabilities to the logistic function of a linear model using maximum likelihood. Likelihood-ratio test statistics are provided for the whole model and lack of fit. Wald test statistics are provided for each effect.

If there is an ordinal response and a single continuous numeric effect, the ordinal logistic platform in Fit Y by X displays a cumulative logistic probability plot.

Details of modeling types are discussed in the Basic Analysis book. The details of fitting appear in the appendix “Statistical Details” on page 427. The method is discussed in Walker and Duncan (1967), Nelson (1976), Harrell (1986), and McCullagh and Nelder (1983).

Note: If there are many response levels, the ordinal model is much faster to fit and uses less memory than the nominal model.

As an example of ordinal logistic model fitting, McCullagh and Nelder (1983) report an experiment by Newell to test whether various cheese additives (A to D) had an effect on taste. Taste was measured by a tasting panel and recorded on an ordinal scale from 1 (strong dislike) to 9 (excellent taste). The data are in the Cheese.jmp sample data table.

1. Open the Cheese.jmp sample data table.
2. Select Analyze > Fit Model.
3. Select Response and click Y.
4. Select Cheese and click Add.
5. Select Count and click Freq.
6. Click Run.
7. From the red triangle next to Ordinal Logistic Fit, select Wald Tests.
The model in this example reduces the $-\text{LogLikelihood}$ of 429.9 to 355.67. This reduction yields a likelihood-ratio Chi-square for the whole model of 148.45 with 3 degrees of freedom, showing the difference in perceived cheese taste to be highly significant.

The Lack of Fit test happens to be testing the ordinal response model compared to the nominal model. This is because the model is saturated if the response is treated as nominal rather than ordinal, giving 21 additional parameters, which is the Lack of Fit degrees of freedom. The nonsignificance of Lack of Fit leads one to believe that the ordinal model is reasonable.

There are eight intercept parameters because there are nine response categories. There are only three structural parameters. As a nominal problem, there are $8 \times 3 = 24$ structural parameters.

When there is only one effect, its test is equivalent to the Likelihood-ratio test for the whole model. The Likelihood-ratio Chi-square is 148.45, different from the Wald Chi-square of 115.15, which illustrates the point that Wald tests are to be regarded with some skepticism.
To see whether a cheese additive is preferred, look for the most negative values of the parameters (Cheese D's effect is the negative sum of the others, shown in Figure 10.1.).

Table 10.1  Parameter Estimates and Preferences for Cheese Additives in Cheese.jmp

<table>
<thead>
<tr>
<th>Cheese</th>
<th>Estimate</th>
<th>Preference</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>-0.8622</td>
<td>2nd place</td>
</tr>
<tr>
<td>B</td>
<td>2.4896</td>
<td>least liked</td>
</tr>
<tr>
<td>C</td>
<td>0.8477</td>
<td>3rd place</td>
</tr>
<tr>
<td>D</td>
<td>-2.4750</td>
<td>most liked</td>
</tr>
</tbody>
</table>

You can also use the Fit Y by X platform for this model, which treats ordinal responses like nominal and shows a contingency table analysis. See Figure 10.21. The Fit Model platform can also be used, but you must change the ordinal response, Response, to nominal. See Figure 10.22. Nominal Fit Model results are shown in Figure 10.22. Note that the negative log-likelihood values (84.381) and the likelihood chi-square values (168.76) are the same.

Figure 10.21  Fit Y by X Platform Results for Cheese.jmp
### Figure 10.22  Fit Model Platform Results Setting Response to Nominal for Cheese.jmp

<table>
<thead>
<tr>
<th>Model</th>
<th>LogLikelihood</th>
<th>DF</th>
<th>ChiSquare</th>
<th>Prob&gt;ChiSq</th>
</tr>
</thead>
<tbody>
<tr>
<td>Difference</td>
<td>84.38105</td>
<td>24</td>
<td>166.7821</td>
<td>&lt;0.001*</td>
</tr>
<tr>
<td>Full</td>
<td>245.61986</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduced</td>
<td>125.60980</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- RSquare (U): 0.1983
- AICc: 767.100
- BIC: 86.841
- Observations (or Sum Wgt): 208

### Parameter Estimates

<table>
<thead>
<tr>
<th>Measure</th>
<th>Training Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entropy/RSquare</td>
<td>0.1363 -LogLik(model)/LogLik(0)</td>
</tr>
<tr>
<td>Generalized R-Square</td>
<td>0.5845 (1-L(0)/L(model))(2m)/(1-L(0)/(2m))</td>
</tr>
<tr>
<td>Mean-Log p</td>
<td>1.6012 [\sum \psi_i / n]</td>
</tr>
<tr>
<td>RMSE</td>
<td>0.7655 [\sqrt{\psi_i^2 / n}]</td>
</tr>
<tr>
<td>Mean Abs Dev</td>
<td>0.7772 [\sum \psi_i / n]</td>
</tr>
<tr>
<td>Misclassification Rate</td>
<td>0.6535 [\hat{p}<em>i / \hat{p}</em>{Max}/n]</td>
</tr>
<tr>
<td>N</td>
<td>208 n</td>
</tr>
</tbody>
</table>

### Effect Likelihood Ratio Tests

<table>
<thead>
<tr>
<th>Source</th>
<th>Df</th>
<th>ChiSquare</th>
<th>Prob&gt;ChiSq</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cheese</td>
<td>24</td>
<td>166.7821</td>
<td>&lt;0.001*</td>
</tr>
</tbody>
</table>

If you want to see a graph of the response probabilities as a function of the parameter estimates for the four cheeses, add the Score variable as a response surface effect to the Fit Model dialog as shown. To create the model in Figure 10.23, select Score in the column selector list, and then select **Response Surface** from the Macros popup menu on the Fit Model dialog.
Validation is available only in JMP Pro.

Click **Run** to see the analysis report and the cumulative logistic probability plot in Figure 10.24. The distance between each curve is the fitted response probability for the levels in the order for the levels on the right axis of the plot.

**Figure 10.24** Cumulative Probability Plot for Ordinal Logistic Regression
Example of a Quadratic Ordinal Logistic Model

The Ordinal Response Model can fit a quadratic surface to optimize the probabilities of the higher or lower responses. The arithmetic in terms of the structural parameters is the same as that for continuous responses. Up to five factors can be used, but this example has only one factor, for which there is a probability plot.

Consider the case of a microwave popcorn manufacturer who wants to find out how much salt consumers like in their popcorn. To do this, the manufacturer looks for the maximum probability of a favorable response as a function of how much salt is added to the popcorn package. An experiment controls salt amount at 0, 1, 2, and 3 teaspoons, and the respondents rate the taste on a scale of 1=low to 5=high. The optimum amount of salt is the amount that maximizes the probability of more favorable responses. The ten observations for each of the salt levels are shown in Table 10.2.

<table>
<thead>
<tr>
<th>Salt Amount</th>
<th>Salt Rating Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>no salt</td>
<td>1 3 2 4 2 2 1 4 3 4</td>
</tr>
<tr>
<td>1 tsp.</td>
<td>4 5 3 4 5 4 5 4 5 5</td>
</tr>
<tr>
<td>2 tsp.</td>
<td>4 3 5 1 4 2 5 4 3 2</td>
</tr>
<tr>
<td>3 tsp.</td>
<td>3 1 2 3 1 2 1 2 1 2</td>
</tr>
</tbody>
</table>

Use Fit Model with the Salt in Popcorn.jmp sample data to fit the ordinal taste test to the surface effect of salt. Use Taste Test as Y. Highlight Salt in the Select Columns box, and then select Macros > Response Surface.

The report shows how the quadratic model fits the response probabilities. The curves, instead of being shifted logistic curves, become a folded pile of curves where each curve achieves its optimum at the same point. The critical value is at Mean(X)–0.5 *b1/b2 where b1 is the linear coefficient and b2 is the quadratic coefficient. This formula is for centered X. From the Parameter Estimates table, you can compute the optimum as 1.5 - 0.5 * (0.5637/1.3499) = 1.29 teaspoons of salt.
The distance between each curve measures the probability of each of the five response levels. The probability for the highest response level is the distance from the top curve to the top of the plot rectangle. This distance reaches a maximum when the amount of salt is about 1.3 teaspoons. All curves share the same critical point.

The parameter estimates for Salt and Salt*Salt become the coefficients used to find the critical value. Although it appears as a minimum, it is only a minimum with respect to the probability curves. It is really a maximum in the sense of maximizing the probability of the highest response. The Solution portion of the report is shown under Response Surface in Figure 10.25, where 1.29 is shown under Critical Value.
Stacking Counts in Multiple Columns

Data that are frequencies (counts) listed in several columns of your data table are not the form that you need for logistic regression. For example, the Ingots2.jmp data table in the data folder (see Figure 10.26) has columns Nready and NNotReady that give the number of ready and number of not ready ingots for each combination of Heat and Soak values. To do a logistic regression, you need the data organized like the table in Figure 10.27.

To make a new table, suitable for logistic regression, select the Stack command from the Tables menu. Complete the Stack dialog by choosing Nready and NNotReady as the columns to stack, and then click OK in the Stack dialog. This creates the new table in Figure 10.27. If you use the default column names, Label is the response (Y) column and Data is the frequency column.

The example in the section “Introduction to Logistic Models” on page 371, shows a logistic regression using a sample data table Ingots.jmp. It has a frequency column called count (equivalent to the Data column in the table below) and a response variable called Ready, with values 1 to represent ingots that are ready and 0 for not ready.

**Figure 10.26 Original Data Table**

<table>
<thead>
<tr>
<th></th>
<th>Heat</th>
<th>Soak</th>
<th>NNotReady</th>
<th>Nready</th>
<th>NTotal</th>
<th>P</th>
<th>Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7</td>
<td>1</td>
<td>10</td>
<td>0</td>
<td>10</td>
<td>0.500</td>
<td>8.9315</td>
</tr>
<tr>
<td>2</td>
<td>7</td>
<td>1.7</td>
<td>17</td>
<td>0</td>
<td>17</td>
<td>0.500</td>
<td>11.7035</td>
</tr>
<tr>
<td>3</td>
<td>7</td>
<td>2.2</td>
<td>7</td>
<td>0</td>
<td>7</td>
<td>0.500</td>
<td>4.9220</td>
</tr>
<tr>
<td>4</td>
<td>7</td>
<td>2.8</td>
<td>12</td>
<td>0</td>
<td>12</td>
<td>0.500</td>
<td>6.3170</td>
</tr>
<tr>
<td>5</td>
<td>7</td>
<td>4</td>
<td>9</td>
<td>0</td>
<td>9</td>
<td>0.500</td>
<td>6.2933</td>
</tr>
<tr>
<td>6</td>
<td>14</td>
<td>1</td>
<td>31</td>
<td>0</td>
<td>31</td>
<td>0.500</td>
<td>21.4876</td>
</tr>
<tr>
<td>7</td>
<td>14</td>
<td>1.7</td>
<td>43</td>
<td>0</td>
<td>43</td>
<td>0.500</td>
<td>20.8053</td>
</tr>
<tr>
<td>8</td>
<td>14</td>
<td>2.2</td>
<td>31</td>
<td>2</td>
<td>33</td>
<td>0.500</td>
<td>22.8739</td>
</tr>
<tr>
<td>9</td>
<td>14</td>
<td>2.8</td>
<td>91</td>
<td>0</td>
<td>91</td>
<td>0.500</td>
<td>21.4876</td>
</tr>
<tr>
<td>10</td>
<td>14</td>
<td>4</td>
<td>19</td>
<td>0</td>
<td>19</td>
<td>0.500</td>
<td>13.1608</td>
</tr>
<tr>
<td>11</td>
<td>27</td>
<td>1</td>
<td>55</td>
<td>1</td>
<td>56</td>
<td>0.500</td>
<td>30.8162</td>
</tr>
<tr>
<td>12</td>
<td>27</td>
<td>1.7</td>
<td>43</td>
<td>4</td>
<td>44</td>
<td>0.500</td>
<td>20.4805</td>
</tr>
<tr>
<td>13</td>
<td>27</td>
<td>2.2</td>
<td>21</td>
<td>0</td>
<td>21</td>
<td>0.500</td>
<td>14.5551</td>
</tr>
</tbody>
</table>
### Figure 10.27  Stacked Data Table

<table>
<thead>
<tr>
<th>Heat</th>
<th>Seek</th>
<th>Total</th>
<th>P</th>
<th>Loss</th>
<th>Label</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>7</td>
<td>19</td>
<td>0.5090</td>
<td>6.9315</td>
<td>Notready</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>7</td>
<td>19</td>
<td>0.5090</td>
<td>6.9315</td>
<td>Notready</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>7</td>
<td>17</td>
<td>0.5090</td>
<td>11.7035</td>
<td>Notready</td>
<td>17</td>
</tr>
<tr>
<td>4</td>
<td>7</td>
<td>17</td>
<td>0.5090</td>
<td>11.7035</td>
<td>Notready</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>7</td>
<td>22</td>
<td>0.5090</td>
<td>4.0520</td>
<td>Notready</td>
<td>7</td>
</tr>
<tr>
<td>6</td>
<td>7</td>
<td>22</td>
<td>0.5090</td>
<td>4.0520</td>
<td>Notready</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>7</td>
<td>26</td>
<td>0.5090</td>
<td>0.2170</td>
<td>Ready</td>
<td>12</td>
</tr>
<tr>
<td>8</td>
<td>7</td>
<td>26</td>
<td>0.5090</td>
<td>0.2170</td>
<td>Ready</td>
<td>0</td>
</tr>
<tr>
<td>9</td>
<td>7</td>
<td>4</td>
<td>0.5090</td>
<td>6.2383</td>
<td>Notready</td>
<td>8</td>
</tr>
<tr>
<td>10</td>
<td>7</td>
<td>4</td>
<td>0.5090</td>
<td>6.2383</td>
<td>Notready</td>
<td>0</td>
</tr>
<tr>
<td>11</td>
<td>14</td>
<td>31</td>
<td>0.5090</td>
<td>21.4870</td>
<td>Notready</td>
<td>31</td>
</tr>
<tr>
<td>12</td>
<td>14</td>
<td>31</td>
<td>0.5090</td>
<td>21.4870</td>
<td>Ready</td>
<td>0</td>
</tr>
<tr>
<td>13</td>
<td>14</td>
<td>17</td>
<td>0.5090</td>
<td>26.9059</td>
<td>Notready</td>
<td>43</td>
</tr>
<tr>
<td>14</td>
<td>14</td>
<td>17</td>
<td>0.5090</td>
<td>26.9059</td>
<td>Notready</td>
<td>0</td>
</tr>
</tbody>
</table>
About Generalized Linear Models

Generalized Linear Models provide a unified way to fit responses that do not fit the usual requirements of least-squares fits. In particular, frequency counts, which are characterized as having a Poisson distribution indexed by a model, are easily fit by a Generalized Linear Model.

The technique, pioneered by Nelder and Wedderburn (1972), involves a set of iteratively reweighted least-squares fits of a transformed response.

Additional features of JMP’s Generalized Linear Model personality include the following:

- likelihood ratio statistics for user-defined contrasts, that is, linear functions of the parameters, and $p$-values based on their asymptotic chi-square distributions
- estimated values, standard errors, and confidence limits for user-defined contrasts and least-squares means
- graphical profilers for examining the model
- confidence intervals for model parameters based on the profile likelihood function
- optional bias-corrected maximum likelihood estimator discussed by Firth (1993)
## Contents

- Overview of Generalized Linear Models .................................................. 403
- The Generalized Linear Model Personality ............................................... 404
- Examples of Generalized Linear Models .................................................. 405
  - Model Selection and Deviance ............................................................... 406
- Examples ............................................. 408
  - Poisson Regression ............................... 408
  - Poisson Regression with Offset ......................................................... 410
  - Normal Regression, Log Link ............................................................. 412
- Platform Commands ................................................................. 416
Overview of Generalized Linear Models

While traditional linear models are used extensively in statistical data analysis, there are types of problems for which they are not appropriate.

- It may not be reasonable to assume that data are normally distributed. For example, the normal distribution (which is continuous) may not be adequate for modeling counts or measured proportions.

- If the mean of the data is naturally restricted to a range of values, the traditional linear model may not be appropriate, since the linear predictor can take on any value. For example, the mean of a measured proportion is between 0 and 1, but the linear predictor of the mean in a traditional linear model is not restricted to this range.

- It may not be realistic to assume that the variance of the data is constant for all observations. For example, it is not unusual to observe data where the variance increases with the mean of the data.

A generalized linear model extends the traditional linear model and is, therefore, applicable to a wider range of data analysis problems. See the section “Examples of Generalized Linear Models” on page 405 for the form of a probability distribution from the exponential family of distributions.

As in the case of traditional linear models, fitted generalized linear models can be summarized through statistics such as parameter estimates, their standard errors, and goodness-of-fit statistics. You can also make statistical inference about the parameters using confidence intervals and hypothesis tests. However, specific inference procedures are usually based on asymptotic considerations, since exact distribution theory is not available or is not practical for all generalized linear models.
The Generalized Linear Model Personality

Generalized linear models are fit as a personality of the Fit Model Dialog. After selecting **Analyze > Fit Model**, select **Generalized Linear Model** from the drop-down menu before or after assigning the effects to the model.

**Figure 11.1** Generalized Linear Model Launch Dialog

When you specify that you are fitting a generalized linear model, the Fit Model dialog changes to allow you to select a Distribution and a Link Function. Options for Overdispersion Tests and Intervals and for Firth Bias-adjusted Estimates also appear. In addition, an Offset button is added to the Fit Model window.

**Table 11.1** Description of Fit Model options for Generalized Linear Models

<table>
<thead>
<tr>
<th>Distribution</th>
<th>Assigns the appropriate response probability distribution to the model. See “Examples of Generalized Linear Models” on page 405.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Link Function</td>
<td>A link function relates the linear model to the response variable. See “Examples of Generalized Linear Models” on page 405.</td>
</tr>
<tr>
<td>Overdispersion Tests and Intervals</td>
<td>Fits a model that includes an overdispersion parameter.</td>
</tr>
</tbody>
</table>
### Table 11.2 Examples of Generalized Linear Models

<table>
<thead>
<tr>
<th>Model</th>
<th>Response Variable</th>
<th>Distribution</th>
<th>Canonical Link Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional Linear Model</td>
<td>continuous</td>
<td>Normal</td>
<td>identity, $g(\mu) = \mu$</td>
</tr>
<tr>
<td>Logistic Regression</td>
<td>a count or a binary random variable</td>
<td>Binomial</td>
<td>logit, $g(\mu) = \log\left(\frac{\mu}{1-\mu}\right)$</td>
</tr>
<tr>
<td>Poisson Regression in Log Linear Model</td>
<td>a count</td>
<td>Poisson</td>
<td>log, $g(\mu) = \log(\mu)$</td>
</tr>
<tr>
<td>Exponential Regression</td>
<td>positive continuous</td>
<td>Exponential</td>
<td>$\frac{1}{\mu}$</td>
</tr>
</tbody>
</table>

JMP fits a generalized linear model to the data by maximum likelihood estimation of the parameter vector. There is, in general, no closed form solution for the maximum likelihood estimates of the parameters. JMP estimates the parameters of the model numerically through an iterative fitting process. The dispersion parameter $\phi$ is also estimated by dividing the Pearson goodness-of-fit statistic by its degrees of freedom. Covariances, standard errors, and confidence limits are computed for the estimated parameters based on the asymptotic normality of maximum likelihood estimators.
A number of link functions and probability distributions are available in JMP. The built-in link functions are

- **Identity**: \( g(\mu) = \mu \)
- **Logit**: \( g(\mu) = \log\left(\frac{\mu}{1-\mu}\right) \)
- **Probit**: \( g(\mu) = \Phi^{-1}(\mu) \), where \( \Phi \) is the standard normal cumulative distribution function
- **Log**: \( g(\mu) = \log(\mu) \)
- **Reciprocal**: \( g(\mu) = \frac{1}{\mu} \)
- **Power**: \( g(\mu) = \begin{cases} 
  \mu^\lambda & \text{if } \lambda \neq 0 \\
  \log(\mu) & \text{if } \lambda = 0 
\end{cases} \)
- **Complementary Log-Log**: \( g(m) = \log(-\log(1 - \mu)) \)

When you select the Power link function, a number box appears enabling you to enter the desired power.

The available distributions and associated variance functions are

- **Normal**: \( V(\mu) = 1 \)
- **Binomial (proportion)**: \( V(\mu) = \mu(1-\mu) \)
- **Poisson**: \( V(\mu) = \mu \)
- **Exponential**: \( V(\mu) = \mu^2 \)

When you select **Binomial** as the distribution, the response variable must be specified in one of the following ways:

- If your data is not summarized as frequencies of events, specify a single binary column as the response. The response column must be nominal. If your data is summarized as frequencies of events, specify a single binary column as the response, along with a frequency variable in the Freq role. The response column must be nominal, and the frequency variable gives the count of each response level.
- If your data is summarized as frequencies of events and trials, specify two continuous columns in this order: a count of the number of successes, and a count of the number of trials. Alternatively, you can specify the number of failures instead of successes.

## Model Selection and Deviance

An important aspect of generalized linear modeling is the selection of explanatory variables in the model. Changes in goodness-of-fit statistics are often used to evaluate the contribution of subsets of explanatory variables to a particular model. The **deviance**, defined to be twice the difference between the maximum attainable log likelihood and the log likelihood at the
maximum likelihood estimates of the regression parameters, is often used as a measure of
goodness of fit. The maximum attainable log likelihood is achieved with a model that has a
parameter for every observation. The following table displays the deviance for each of the
probability distributions available in JMP.

**Table 11.3 Deviance Functions**

<table>
<thead>
<tr>
<th>Distribution</th>
<th>Deviance</th>
</tr>
</thead>
<tbody>
<tr>
<td>normal</td>
<td>$\sum w_i (y_i - \mu_i)^2$</td>
</tr>
<tr>
<td>Poisson</td>
<td>$2 \sum w_i \left[ y_i \log \left( \frac{y_i}{\mu_i} \right) - (y_i - \mu_i) \right]$</td>
</tr>
<tr>
<td>binomial$^a$</td>
<td>$2 \sum w_i m_i \left[ y_i \log \left( \frac{y_i}{\mu_i} \right) + (1 - y_i) \log \left( \frac{1 - y_i}{1 - \mu_i} \right) \right]$</td>
</tr>
<tr>
<td>exponential</td>
<td>$2 \sum w_i \left[ - \log \left( \frac{y_i}{\mu_i} \right) + \left( \frac{y_i - \mu_i}{\mu_i} \right) \right]$</td>
</tr>
</tbody>
</table>

$^a$ In the binomial case, $y_i = r_i/m_i$, where $r_i$ is a binomial count and $m_i$ is the binomial number of trials parameter.

The Pearson chi-square statistic is defined as

$$X^2 = \sum \frac{w_i (y_i - \mu_i)^2}{V(\mu_i)}$$

where $y_i$ is the $i^{th}$ response, $\mu_i$ is the corresponding predicted mean, $V(\mu_i)$ is the variance function, and $w_i$ is a known weight for the $i^{th}$ observation. If no weight is known, $w_i = 1$ for all observations.

One strategy for variable selection is to fit a sequence of models, beginning with a simple
model with only an intercept term, and then include one additional explanatory variable in
each successive model. You can measure the importance of the additional explanatory
variable by the difference in deviances or fitted log likelihoods between successive models.
Asymptotic tests computed by JMP enable you to assess the statistical significance of the
additional term.

Whenever the distribution is non-normal, a normal critical value is used instead of a $t$ in
inverse prediction.
Examples

The following examples illustrate how to use JMP's generalized linear models platform.

Poisson Regression

This example uses data from a study of nesting horseshoe crabs. Each female crab had a male crab resident in her nest. This study investigated whether there were other males, called satellites, residing nearby. The data set CrabSatellites.jmp contains a response variable listing the number of satellites, as well as variables describing the female crab's color, spine condition, weight, and carapace width. The data are shown in Figure 11.2.

Figure 11.2 Crab Satellite Data

<table>
<thead>
<tr>
<th>satell</th>
<th>color</th>
<th>spine</th>
<th>width</th>
<th>weight</th>
<th>weightstd</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Medium</td>
<td>28.3</td>
<td>3950</td>
<td>1.96201468</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Dark</td>
<td>22.5</td>
<td>1560</td>
<td>-1.6376251</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Light</td>
<td>28.0</td>
<td>2380</td>
<td>-0.2297702</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Dark</td>
<td>24.8</td>
<td>2160</td>
<td>-0.6840905</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Dark</td>
<td>26.0</td>
<td>2860</td>
<td>0.26215375</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Medium</td>
<td>23.2</td>
<td>2160</td>
<td>-0.5543505</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Light</td>
<td>29.5</td>
<td>2350</td>
<td>-0.1511020</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Dark</td>
<td>24.7</td>
<td>1960</td>
<td>-0.9389555</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Medium</td>
<td>23.7</td>
<td>1960</td>
<td>-0.8443145</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Dark</td>
<td>25.6</td>
<td>2160</td>
<td>-0.4972092</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Dark</td>
<td>24.3</td>
<td>2160</td>
<td>-0.4972092</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Medium</td>
<td>25.0</td>
<td>2850</td>
<td>0.66808407</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Medium</td>
<td>29.2</td>
<td>2360</td>
<td>1.9201460</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Dark</td>
<td>21.3</td>
<td>1960</td>
<td>-1.6176171</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Medium</td>
<td>26.0</td>
<td>2300</td>
<td>-0.2377552</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Light</td>
<td>27.1</td>
<td>2300</td>
<td>0.9681203</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Medium</td>
<td>25.2</td>
<td>2180</td>
<td>-0.7570953</td>
<td></td>
</tr>
</tbody>
</table>

To fit the Poisson loglinear model:

- Select Analyze > Fit Model
- Assign satell as Y
- Assign color, spine, width, and weight as Effects
- Choose the Generalized Linear Model Personality
- Choose the Poisson Distribution

The Log Link function should be selected for you automatically.

- Click Run.

The results are shown in Figure 11.3.
Figure 11.3 Crab Satellite Results

<table>
<thead>
<tr>
<th>Whole Model Test</th>
<th>L-R</th>
<th></th>
<th>DF</th>
<th>Prob&gt;Chisq</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>LogLikelihood</td>
<td>ChiSquare</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Difference</td>
<td>41.803657</td>
<td>83.2961</td>
<td>7</td>
<td>&lt;.0001*</td>
</tr>
<tr>
<td>Full</td>
<td>452.44192</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reduced</td>
<td>494.04666</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Goodness Of Fit</th>
<th>L-R</th>
<th></th>
<th>DF</th>
<th>Prob&gt;Chisq</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fit Statistic</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pseudo</td>
<td>523.8165</td>
<td>186</td>
<td></td>
<td>&lt;.0001*</td>
</tr>
<tr>
<td>Deviance</td>
<td>549.9555</td>
<td>196</td>
<td></td>
<td>&lt;.0001*</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Effect Tests</th>
<th>L-R</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Source</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>color</td>
<td>3</td>
<td>0.2405455</td>
<td></td>
<td>0.0333*</td>
</tr>
<tr>
<td>space</td>
<td>2</td>
<td>1.794222</td>
<td></td>
<td>0.4078</td>
</tr>
<tr>
<td>width</td>
<td>1</td>
<td>0.1166818</td>
<td></td>
<td>0.7324</td>
</tr>
<tr>
<td>weight</td>
<td>1</td>
<td>0.9438942</td>
<td></td>
<td>0.0626*</td>
</tr>
</tbody>
</table>

The Whole Model Test table gives information to compare the whole-model fit to the model that contains only the intercept parameter. The Reduced model is the model containing only an intercept. The Full model contains all of the effects as well as the intercept. The Difference is the difference of the log likelihoods of the full and reduced models. The Prob>Chisq is analogous to a whole-model F-test.
Second, goodness-of-fit statistics are presented. Analogous to lack-of-fit tests, they test for adequacy of the model. Low p-values for the ChiSquare goodness-of-fit statistics indicate that you may need to add higher-order terms to the model, add more covariates, change the distribution, or (in Poisson and binomial cases especially) consider adding an overdispersion parameter. AICc is also included and is the corrected Akaike's Information Criterion, where

\[
AICc = -2\text{loglikelihood} + \frac{2k(k + 1)}{n - k - 1}
\]

and k is the number of estimated parameters in the model and n is the number of observations in the data set. This value may be compared with other models to determine the best-fitting model for the data. The model having the smallest value, as discussed in Akaike (1974), is usually the preferred model.

The Effect Tests table shows joint tests that all the parameters for an individual effect are zero. If an effect has only one parameter, as with simple regressors, then the tests are no different from the tests in the Parameter Estimates table.

The Parameter Estimates table shows the estimates of the parameters in the model and a test for the hypothesis that each parameter is zero. Simple continuous regressors have only one parameter. Models with complex classification effects have a parameter for each anticipated degree of freedom. Confidence limits are also displayed.

**Poisson Regression with Offset**

The sample data table Ship Damage.JMP is adapted from one found in McCullagh and Nelder (1983). It contains information on a certain type of damage caused by waves to the forward section of the hull. Hull construction engineers are interested in the risk of damage associated with three variables: ship Type, the year the ship was constructed (Yr Made) and the block of years the ship saw service (Yr Used).

In this analysis we use the variable Service, the log of the aggregate months of service, as an offset variable. An offset variable is one that is treated like a regression covariate whose parameter is fixed to be 1.0.

These are most often used to scale the modeling of the mean in Poisson regression situations with log link. In this example, we use log(months of service) since one would expect that the number of repairs be proportional to the number of months in service. To see how this works, assume the linear component of the GLM is called eta. Then with a log link function, the model of the mean with the offset included is:

\[
\exp[\text{Log(months of service)} + \text{eta}] = [(\text{months of service}) \cdot \exp(\text{eta})].
\]

To run this example, assign

- **Generalized Linear Model** as the Personality
- **Poisson** as the Distribution, which automatically selects the Log link function
• N to Y
• Service to Offset
• Type, Yr Made, Yr Used as effects in the model
• Overdispersion Tests and Intervals with a check mark

The Fit Model dialog should appear like the one shown in Figure 11.4.

**Figure 11.4 Ship Damage Fit Model Dialog**

![Ship Damage Fit Model Dialog](image)

When you click Run, you see the report shown in Figure 11.5. Notice that all three effects (Type, Yr Made, Yr Used) are significant.
Normal Regression, Log Link

Consider the following data set, where \( x \) is an explanatory variable and \( y \) is the response variable.
Using Fit Y By X, you can easily see that y varies nonlinearly with x and that the variance is approximately constant (see Figure 11.7). A normal distribution with a log link function is chosen to model these data; that is, log(μᵢ) = xᵢ'β so that μᵢ = exp(xᵢ'β). The completed Fit Model dialog is shown in Figure 11.8.
Figure 11.8 Nor Fit Model Dialog

After clicking Run, you get the following report.
Because the distribution is normal, the Studentized Deviance residuals and the Deviance residuals are the same. To see this, select Diagnostic Plots > Deviance Residuals by Predicted from the platform drop-down menu.
Platform Commands

The following commands are available in the Generalized Linear Model report.

**Custom Test** allows you to test a custom hypothesis. Refer to “Custom Test” on page 118 in the “Standard Least Squares Report and Options” chapter for details on custom tests.

**Contrast** allows you to test for differences in levels within a variable. If a contrast involves a covariate, you can specify the value of the covariate at which to test the contrast.

In the Crab Satellite example, suppose you want to test whether the dark-colored crabs attracted a different number of satellites than the medium-colored crabs. Selecting **Contrast** brings up the following dialog.

Here you choose **color**, the variable of interest. When you click **Go**, you are presented with a Contrast Specification dialog.
To compare the dark-colored to the medium-colored, click the + button beside Dark and Dark Med, and the - button beside Medium and Light Medium.

Click Done to get the Contrast report shown here.
Since the Prob>ChiSq is less than 0.05, we have evidence that there is a difference in satellite attraction based on color.

**Inverse Prediction** is used to predict an X value, given specific values for Y and the other X variables. This can be used to predict continuous variables only. For more details about Inverse Prediction, see “Inverse Prediction” on page 134 in the “Standard Least Squares Report and Options” chapter.

**Covariance of Estimates** produces a covariance matrix for all the effects in a model. The estimated covariance matrix of the parameter estimator is given by

$$
\Sigma = -H^{-1}
$$

where H is the Hessian (or second derivative) matrix evaluated using the parameter estimates on the last iteration. Note that the dispersion parameter, whether estimated or specified, is incorporated into H. Rows and columns corresponding to aliased parameters are not included in \( \Sigma \).

**Correlation of Estimates** produces a correlation matrix for all the effects in a model. The correlation matrix is the normalized covariance matrix. That is, if \( \sigma_{ij} \) is an element of \( \Sigma \), then the corresponding element of the correlation matrix is \( \frac{\sigma_{ij}}{\sigma_i \sigma_j} \), where \( \sigma_i = \sqrt{\sigma_{ii}} \).

**Profiler** brings up the Profiler for examining prediction traces for each X variable. Details on the profiler are found in “Profiler” on page 156 in the “Standard Least Squares Report and Options” chapter.
Contour Profiler brings up an interactive contour profiler. Details are found in the Profilers book.

Surface Profiler brings up a 3-D surface profiler. Details of Surface Plots are found in the Profilers book.

Diagnostic Plots is a submenu containing commands that allow you to plot combinations of residuals, predicted values, and actual values to search for outliers and determine the adequacy of your model. Deviance is discussed above in “Model Selection and Deviance” on page 406. The following plots are available:

- Studentized Deviance Residuals by Predicted
- Studentized Pearson Residuals by Predicted
- Deviance Residuals by Predicted
- Pearson Residuals By Predicted
- Actual by Predicted
- Regression Plot is available only when there is one continuous predictor and no more than one categorical predictor.
- Linear Predictor Plot is a plot of responses transformed by the inverse link function. This plot is available only when there is one continuous predictor and no more than one categorical predictor.

Save Columns is a submenu that lets you save certain quantities as new columns in the data table. Formulas for residuals are shown in Table 11.4.

<table>
<thead>
<tr>
<th></th>
<th>Saves the formula that predicts the current model.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prediction Formula</td>
<td>Saves the values predicted by the current model.</td>
</tr>
<tr>
<td>Predicted Values</td>
<td>Saves the 95% confidence limits for the prediction equation. The confidence limits reflect variation in the parameter estimates.</td>
</tr>
<tr>
<td>Mean Confidence Interval</td>
<td>Saves the confidence limits for a given individual value. The confidence limits reflect variation in the error and variation in the parameter estimates.</td>
</tr>
<tr>
<td>Save Indiv Confid Limits</td>
<td>Saves the deviance residuals.</td>
</tr>
<tr>
<td>Deviance Residuals</td>
<td>Saves the Pearson residuals.</td>
</tr>
<tr>
<td>Pearson Residuals</td>
<td>Saves the studentized deviance residuals.</td>
</tr>
<tr>
<td>Studentized Deviance Residuals</td>
<td>Saves the studentized Pearson residuals.</td>
</tr>
<tr>
<td>Studentized Pearson Residuals</td>
<td></td>
</tr>
</tbody>
</table>
(JSL only) Parametric
Formula

Saves the parametric formula using JSL:

\[
\text{fit model object} \llowerrightarrow \text{Parametric Formula( );}
\]

See the Object Scripting Index for an example.

Table 11.4 Residual Formulas

<table>
<thead>
<tr>
<th>Residual Type</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deviance</td>
<td>( r_{Di} = \sqrt{d_i \text{sign}(y_i - \mu_i)} )</td>
</tr>
<tr>
<td>Studentized Deviance</td>
<td>( r_{Di} = \frac{\text{sign}(y_i - \mu_i) \sqrt{d_i}}{\sqrt{\phi(1 - h_i)}} )</td>
</tr>
<tr>
<td>Pearson</td>
<td>( r_{Pi} = \frac{(y_i - \mu_i)}{\sqrt{V(\mu_i)}} )</td>
</tr>
<tr>
<td>Studentized Pearson</td>
<td>( r_{Pi} = \frac{y_i - \mu_i}{\sqrt{V(\mu_i)(1 - h_i)}} )</td>
</tr>
</tbody>
</table>

where \((y_i - \mu)\) is the raw residual, \(\text{sign}(y_i - \mu)\) is 1 if \((y_i - \mu)\) is positive and -1 if \((y_i - \mu)\) is negative, \(d_i\) is the contribution to the total deviance from observation \(i\), \(\phi\) is the dispersion parameter, \(V(\mu)\) is the variance function, and \(h_i\) is the \(i^{th}\) diagonal element of the matrix \(W_e^{1/2}X(X'W_eX)^{-1}XW_e^{1/2}\), where \(W_e\) is the weight matrix used in computing the expected information matrix. For additional information regarding residuals and generalized linear models, see “The GENMOD Procedure” in the SAS/STAT User Guide documentation.


Appendix A
Fitting Linear Models

References


This appendix discusses the different types of response models, their factors, their design coding, and parameterization. It also includes many other details of methods described in the main text.

The JMP system fits linear models to three different types of response models that are labeled continuous, ordinal, and nominal. Many details on the factor side are the same between the different response models, but JMP only supports graphics and marginal profiles on continuous responses—not on ordinal and nominal.

Different computer programs use different design-matrix codings, and thus parameterizations, to fit effects and construct hypothesis tests. JMP uses a different coding than the GLM procedure in the SAS system, although in most cases JMP and SAS GLM procedure produce the same results. The following sections describe the details of JMP coding and highlight those cases when it differs from that of the SAS GLM procedure, which is frequently cited as the industry standard.
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Response Models</td>
<td>429</td>
</tr>
<tr>
<td>Continuous Responses</td>
<td>429</td>
</tr>
<tr>
<td>Nominal Responses</td>
<td>429</td>
</tr>
<tr>
<td>Ordinal Responses</td>
<td>431</td>
</tr>
<tr>
<td>The Factor Models</td>
<td>432</td>
</tr>
<tr>
<td>Continuous Factors</td>
<td>433</td>
</tr>
<tr>
<td>Nominal Factors</td>
<td>433</td>
</tr>
<tr>
<td>Ordinal Factors</td>
<td>444</td>
</tr>
<tr>
<td>The Usual Assumptions</td>
<td>450</td>
</tr>
<tr>
<td>Assumed Model</td>
<td>450</td>
</tr>
<tr>
<td>Relative Significance</td>
<td>450</td>
</tr>
<tr>
<td>Multiple Inferences</td>
<td>451</td>
</tr>
<tr>
<td>Validity Assessment</td>
<td>451</td>
</tr>
<tr>
<td>Alternative Methods</td>
<td>452</td>
</tr>
<tr>
<td>Key Statistical Concepts</td>
<td>452</td>
</tr>
<tr>
<td>Uncertainty, a Unifying Concept</td>
<td>452</td>
</tr>
<tr>
<td>The Two Basic Fitting Machines</td>
<td>453</td>
</tr>
<tr>
<td>Multivariate Details</td>
<td>456</td>
</tr>
<tr>
<td>Multivariate Tests</td>
<td>456</td>
</tr>
<tr>
<td>Approximate F-Test</td>
<td>457</td>
</tr>
<tr>
<td>Canonical Details</td>
<td>457</td>
</tr>
<tr>
<td>Discriminant Analysis</td>
<td>458</td>
</tr>
<tr>
<td>Power Calculations</td>
<td>459</td>
</tr>
<tr>
<td>Computations for the LSN</td>
<td>459</td>
</tr>
<tr>
<td>Computations for the LSV</td>
<td>460</td>
</tr>
<tr>
<td>Computations for the Power</td>
<td>461</td>
</tr>
<tr>
<td>Computations for the Adjusted Power</td>
<td>461</td>
</tr>
<tr>
<td>Inverse Prediction with Confidence Limits</td>
<td>462</td>
</tr>
</tbody>
</table>
The Response Models

JMP fits linear models to three different kinds of responses: continuous, nominal, and ordinal. The models and methods available in JMP are practical, are widely used, and suit the need for a general approach in a statistical software tool. As with all statistical software, you are responsible for learning the assumptions of the models you choose to use, and the consequences if the assumptions are not met. For more information see “The Usual Assumptions” on page 450 in this chapter.

Continuous Responses

When the response column (column assigned the Y role) is continuous, JMP fits the value of the response directly. The basic model is that for each observation,

\[ Y = (\text{some function of the } X\text{'s and parameters}) + \text{error} \]

Statistical tests are based on the assumption that the error term in the model is normally distributed.

Fitting Principle for Continuous Response

The Fitting principle is called least squares. The least squares method estimates the parameters in the model to minimize the sum of squared errors. The errors in the fitted model, called residuals, are the difference between the actual value of each observation and the value predicted by the fitted model.

The least squares method is equivalent to the maximum likelihood method of estimation if the errors have a normal distribution. This means that the analysis estimates the model that gives the most likely residuals. The log-likelihood is a scale multiple of the sum of squared errors for the normal distribution.

Base Model for Continuous Responses

The simplest model for continuous measurement fits just one value to predict all the response values. This value is the estimate of the mean. The mean is just the arithmetic average of the response values. All other models are compared to this base model.

Nominal Responses

Nominal responses are analyzed with a straightforward extension of the logit model. For a binary (two-level) response, a logit response model is

\[ \log \left( \frac{P(y = 1)}{P(y = 2)} \right) = X\beta \]
which can be written
\[ P(y = 1) = F(X\beta) \]
where \( F(x) \) is the cumulative distribution function of the standard logistic distribution
\[ F(x) = \frac{1}{1 + e^{-x}} = \frac{e^x}{1 + e^x} \]

For \( r \) response levels, JMP fits the probabilities that the response is one of \( r \) different response levels given by the data values. The probability estimates must all be positive. For a given configuration of \( X \)'s, the probability estimates must sum to 1 over the response levels. The function that JMP uses to predict probabilities is a composition of a linear model and a multi-response logistic function. This is sometimes called a log-linear model because the logs of ratios of probabilities are linear models. JMP relates each response probability to the \( r \)th probability and fit a separate set of design parameters to these \( r - 1 \) models.

\[ \log\left(\frac{P(y = j)}{P(y = r)}\right) = X\beta(j) \quad \text{for } j = 1, ..., r - 1 \]

### Fitting Principle For Nominal Response

The fitting principle is called maximum likelihood. It estimates the parameters such that the joint probability for all the responses given by the data is the greatest obtainable by the model. Rather than reporting the joint probability (likelihood) directly, it is more manageable to report the total of the negative logs of the likelihood.

The uncertainty (–log-likelihood) is the sum of the negative logs of the probabilities attributed by the model to the responses that actually occurred in the sample data. For a sample of size \( n \), it is often denoted as \( H \) and written
\[ H = \sum_{i=1}^{n} -\log(P(y = y_i)) \]

If you attribute a probability of 1 to each event that did occur, then the sum of the negative logs is zero for a perfect fit.

The nominal model can take a lot of time and memory to fit, especially if there are many response levels. JMP tracks the progress of its calculations with an iteration history, which shows the –log-likelihood values becoming smaller as they converge to the estimates.

### Base Model for Nominal Responses

The simplest model for a nominal response is a set of constant response probabilities fitted as the occurrence rates for each response level across the whole data table. In other words, the
probability that \( y \) is response level \( j \) is estimated by dividing the total sample count \( n \) into the total of each response level \( n_j \), and is written

\[
p_j = \frac{n_j}{n}
\]

All other models are compared to this base model. The base model serves the same role for a nominal response as the sample mean does for continuous models.

The \( R^2 \) statistic measures the portion of the uncertainty accounted for by the model, which is

\[
1 - \frac{H(\text{full model})}{H(\text{base model})}
\]

However, it is rare in practice to get an \( R^2 \) near 1 for categorical models.

**Ordinal Responses**

With an ordinal response (\( Y \)), as with nominal responses, JMP fits probabilities that the response is one of \( r \) different response levels given by the data.

Ordinal data have an order like continuous data. The order is used in the analysis but the spacing or distance between the ordered levels is not used. If you have a numeric response but want your model to ignore the spacing of the values, you can assign the ordinal level to that response column. If you have a classification variable and the levels are in some natural order such as low, medium, and high, you can use the ordinal modeling type.

Ordinal responses are modeled by fitting a series of parallel logistic curves to the cumulative probabilities. Each curve has the same design parameters but a different intercept and is written

\[
P(y \leq j) = F(\alpha_j + X\beta) \text{ for } j = 1, \ldots, r - 1
\]

where \( r \) response levels are present and \( F(x) \) is the standard logistic cumulative distribution function

\[
F(x) = \frac{1}{1 + e^{-x}} = \frac{e^x}{1 + e^x}
\]

Another way to write this is in terms of an unobserved continuous variable, \( z \), that causes the ordinal response to change as it crosses various thresholds

\[
y = \begin{cases} 
  r & \alpha_{r-1} \leq z \\
  j & \alpha_{j-1} \leq z < \alpha_j \\
  1 & z \leq \alpha_1
\end{cases}
\]
where $z$ is an unobservable function of the linear model and error

$$z = X\beta + \varepsilon$$

and $\varepsilon$ has the logistic distribution.

These models are attractive in that they recognize the ordinal character of the response, they need far fewer parameters than nominal models, and the computations are fast even though they involve iterative maximum likelihood calculation.

A different but mathematically equivalent way to envision an ordinal model is to think of a nominal model where, instead of modeling the odds, you model the cumulative probability. Instead of fitting functions for all but the last level, you fit only one function and slide it to fit each cumulative response probability.

**Fitting Principle For Ordinal Response**

The maximum likelihood fitting principle for an ordinal response model is the same as for a nominal response model. It estimates the parameters such that the joint probability for all the responses that occur is the greatest obtainable by the model. It uses an iterative method that is faster and uses less memory than nominal fitting.

**Base Model**

The simplest model for an ordinal response, like a nominal response, is a set of response probabilities fitted as the occurrence rates of the response in the whole data table.

**The Factor Models**

The way the $x$-variables (factors) are modeled to predict an expected value or probability is the subject of the factor side of the model.

The factors enter the prediction equation as a linear combination of $x$ values and the parameters to be estimated. For a continuous response model, where $i$ indexes the observations and $j$ indexes the parameters, the assumed model for a typical observation, $y_i$, is written

$$y_i = \beta_0 + \beta_1 x_{1i} + \ldots + \beta_k x_{ki} + \varepsilon_i$$

where

- $y_i$ is the response
- $x_{ij}$ are functions of the data
- $\varepsilon_i$ is an unobservable realization of the random error
- $\beta_j$ are unknown parameters to be estimated.
The way the $x$’s in the linear model are formed from the factor terms is different for each modeling type. The linear model $x$’s can also be complex effects such as interactions or nested effects. Complex effects are discussed in detail later.

**Continuous Factors**

Continuous factors are placed directly into the design matrix as regressors. If a column is a linear function of other columns, then the parameter for this column is marked zeroed or nonestimable. Continuous factors are centered by their mean when they are crossed with other factors (interactions and polynomial terms). Centering is suppressed if the factor has a Column Property of Mixture or Coding, or if the centered polynomials option is turned off when specifying the model. If there is a coding column property, the factor is coded before fitting.

**Nominal Factors**

Nominal factors are transformed into indicator variables for the design matrix. SAS GLM constructs an indicator column for each nominal level. JMP constructs the same indicator columns for each nominal level except the last level. When the last nominal level occurs, a one is subtracted from all the other columns of the factor. For example, consider a nominal factor A with three levels coded for GLM and for JMP as shown below.

<table>
<thead>
<tr>
<th>A</th>
<th>A1</th>
<th>A2</th>
<th>A3</th>
<th>A13</th>
<th>A23</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>A2</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>A3</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>-1</td>
<td>-1</td>
</tr>
</tbody>
</table>

In GLM, the linear model design matrix has linear dependencies among the columns, and the least squares solution employs a generalized inverse. The solution chosen happens to be such that the A3 parameter is set to zero.

In JMP, the linear model design matrix is coded so that it achieves full rank unless there are missing cells or other incidental collinearity. The parameter for the A effect for the last level is the negative sum of the other levels, which makes the parameters sum to zero over all the effect levels.
Interpretation of Parameters

**Note:** The parameter for a nominal level is interpreted as the differences in the predicted response for that level from the average predicted response over all levels.

The design column for a factor level is constructed as the zero-one indicator of that factor level minus the indicator of the last level. This is the coding that leads to the parameter interpretation above.

Table B.2 Interpreting Parameters

<table>
<thead>
<tr>
<th>JMP Parameter Report</th>
<th>How to Interpret</th>
<th>Design Column Coding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>mean over all levels</td>
<td>1'</td>
</tr>
<tr>
<td>A[1]</td>
<td>$\alpha_1 - 1/3(\alpha_1 + \alpha_2 + \alpha_3)$</td>
<td>(A==1) – (A==3)</td>
</tr>
<tr>
<td>A[2]</td>
<td>$\alpha_2 - 1/3(\alpha_1 + \alpha_2 + \alpha_3)$</td>
<td>(A==2) – (A==3)</td>
</tr>
</tbody>
</table>

Interactions and Crossed Effects

Interaction effects with both GLM and JMP are constructed by taking a direct product over the rows of the design columns of the factors being crossed. For example, the GLM code

```plaintext
ieller'
;
CLASS A B;
MODEL A B A*B;
```

yields this design matrix:

Table B.3 Design Matrix

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>AB</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>B</td>
<td>1 2 3</td>
</tr>
<tr>
<td>A1 B1</td>
<td>1 0 0</td>
<td>1 0 0</td>
</tr>
<tr>
<td>A1 B2</td>
<td>1 0 0</td>
<td>0 1 0</td>
</tr>
<tr>
<td>A1 B2</td>
<td>1 0 0</td>
<td>0 0 1</td>
</tr>
<tr>
<td>A2 B1</td>
<td>0 1 0</td>
<td>1 0 0</td>
</tr>
<tr>
<td>A2 B2</td>
<td>0 1 0</td>
<td>0 1 0</td>
</tr>
<tr>
<td>A2 B2</td>
<td>0 1 0</td>
<td>0 0 1</td>
</tr>
<tr>
<td>A3 B1</td>
<td>0 0 1</td>
<td>1 0 0</td>
</tr>
</tbody>
</table>
Fitting Linear Models

The Factor Models

Using the JMP Fit Model command and requesting a factorial model for columns A and B produces the following design matrix. Note that A13 in this matrix is A1–A3 in the previous matrix. However, A13B13 is A13*B13 in the current matrix.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>B1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>A1</td>
<td>B2</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>A1</td>
<td>B3</td>
<td>1</td>
<td>0</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>A2</td>
<td>B1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>A2</td>
<td>B2</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>A2</td>
<td>B3</td>
<td>0</td>
<td>1</td>
<td>-1</td>
<td>-1</td>
<td>0</td>
<td>0</td>
<td>-1</td>
<td>-1</td>
</tr>
<tr>
<td>A3</td>
<td>B1</td>
<td>-1</td>
<td>-1</td>
<td>1</td>
<td>0</td>
<td>-1</td>
<td>0</td>
<td>-1</td>
<td>0</td>
</tr>
<tr>
<td>A3</td>
<td>B2</td>
<td>-1</td>
<td>-1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>-1</td>
<td>0</td>
<td>-1</td>
</tr>
<tr>
<td>A3</td>
<td>B3</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

The expected values of the cells in terms of the parameters for a three-by-three crossed model are:

The JMP coding saves memory and some computing time for problems with interactions of factors with few levels.
Nested Effects

Nested effects in GLM are coded the same as interaction effects because GLM determines the right test by what isn’t in the model. Any effect not included in the model can have its effect soaked up by a containing interaction (or, equivalently, nested) effect.

Nested effects in JMP are coded differently. JMP uses the terms inside the parentheses as grouping terms for each group. For each combination of levels of the nesting terms, JMP constructs the effect on the outside of the parentheses. The levels of the outside term need not line up across the levels of the nesting terms. Each level of nest is considered separately with regard to the construction of design columns and parameters.

Table B.6 Nested Effects

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>B(A)</th>
<th>A1</th>
<th>A1</th>
<th>A2</th>
<th>A2</th>
<th>A3</th>
<th>A3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>B13</td>
<td>B23</td>
<td>B13</td>
<td>B23</td>
<td>B13</td>
<td>B23</td>
</tr>
<tr>
<td>A1</td>
<td>B1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>A1</td>
<td>B2</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>A1</td>
<td>B3</td>
<td>1</td>
<td>0</td>
<td>−1</td>
<td>−1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>A2</td>
<td>B1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>A2</td>
<td>B2</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>A2</td>
<td>B3</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>−1</td>
<td>−1</td>
<td>0</td>
</tr>
<tr>
<td>A3</td>
<td>B1</td>
<td>−1</td>
<td>−1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>A3</td>
<td>B2</td>
<td>−1</td>
<td>−1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>A3</td>
<td>B3</td>
<td>−1</td>
<td>−1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>−1</td>
<td>−1</td>
</tr>
</tbody>
</table>
Fitting Linear Models

The Factor Models

Least Squares Means across Nominal Factors

Least squares means are the predicted values corresponding to some combination of levels, after setting all the other factors to some neutral value. The neutral value for direct continuous regressors is defined as the sample mean. The neutral value for an effect with uninvolved nominal factors is defined as the average effect taken over the levels (which happens to result in all zeroes in our coding). Ordinal factors use a different neutral value in “Ordinal Least Squares Means” on page 447. The least squares means might not be estimable, and if not, they are marked nonestimable. JMP's least squares means agree with GLM's (Goodnight and Harvey 1978) in all cases except when a weight is used, where JMP uses a weighted mean and GLM uses an unweighted mean for its neutral values.

Effective Hypothesis Tests

Generally, the hypothesis tests produced by JMP agree with the hypothesis tests of most other trusted programs, such as SAS PROC GLM (Hypothesis types III and IV). The following two sections describe where there are differences.

In the SAS GLM procedure, the hypothesis tests for Types III and IV are constructed by looking at the general form of estimable functions and finding functions that involve only the effects of interest and effects contained by the effects of interest (Goodnight 1978).

In JMP, the same tests are constructed, but because there is a different parameterization, an effect can be tested (assuming full rank for now) by doing a joint test on all the parameters for that effect. The tests do not involve containing interaction parameters because the coding has made them uninvolved with the tests on their contained effects.

If there are missing cells or other singularities, the JMP tests are different than GLM tests. There are several ways to describe them:

- JMP tests are equivalent to testing that the least squares means are different, at least for main effects. If the least squares means are nonestimable, then the test cannot include some comparisons and, therefore, loses degrees of freedom. For interactions, JMP is testing that the least squares means differ by more than just the marginal pattern described by the containing effects in the model.

- JMP tests an effect by comparing the SSE for the model with that effect with the SSE for the model without that effect (at least if there are no nested terms, which complicate the logic slightly). JMP parameterizes so that this method makes sense.

- JMP implements the effective hypothesis tests described by Hocking (1985, 80–89, 163–166), although JMP uses structural rather than cell-means parameterization. Effective hypothesis tests start with the hypothesis desired for the effect and include “as much as possible” of that test. Of course, if there are containing effects with missing cells, then this test will have to drop part of the hypothesis because the complete hypothesis would not be estimable. The effective hypothesis drops as little of the complete hypothesis as possible.
The differences among hypothesis tests in JMP and GLM (and other programs) that relate to the presence of missing cells are not considered interesting tests anyway. If an interaction is significant, the test for the contained main effects are not interesting. If the interaction is not significant, then it can always be dropped from the model. Some tests are not even unique. If you relabel the levels in a missing cell design, then the GLM Type IV tests can change.

The following section continues this topic in finer detail.

**Singularities and Missing Cells in Nominal Effects**

Consider the case of linear dependencies among the design columns. With JMP coding, this does not occur unless there is insufficient data to fill out the combinations that need estimating, or unless there is some kind of confounding or collinearity of the effects.

With linear dependencies, a least squares solution for the parameters might not be unique and some tests of hypotheses cannot be tested. The strategy chosen for JMP is to set parameter estimates to zero in sequence as their design columns are found to be linearly dependent on previous effects in the model. A special column in the report shows what parameter estimates are zeroed and which parameter estimates are estimable. A separate *singularities* report shows what the linear dependencies are.

In cases of singularities the hypotheses tested by JMP can differ from those selected by GLM. Generally, JMP finds fewer degrees of freedom to test than GLM because it holds its tests to a higher standard of marginality. In other words, JMP tests always correspond to tests across least squares means for that effect, but GLM tests do not always have this property.

For example, consider a two-way model with interaction and one missing cell where A has three levels, B has two levels, and the A3B2 cell is missing.

**Table B.7  Two-Way Model with Interaction**

<table>
<thead>
<tr>
<th>A B</th>
<th>A1</th>
<th>A2</th>
<th>B1</th>
<th>A1B1</th>
<th>A2B1</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1 B1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>A2 B1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>A3 B1</td>
<td>−1</td>
<td>−1</td>
<td>1</td>
<td>−1</td>
<td>−1</td>
</tr>
<tr>
<td>A1 B2</td>
<td>1</td>
<td>0</td>
<td>−1</td>
<td>−1</td>
<td>0</td>
</tr>
<tr>
<td>A2 B2</td>
<td>0</td>
<td>1</td>
<td>−1</td>
<td>0</td>
<td>−1</td>
</tr>
<tr>
<td>A3 B2</td>
<td>−1</td>
<td>−1</td>
<td>−1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Suppose this interaction is missing.

The expected values for each cell are:
Fitting Linear Models

The Factor Models

Obviously, any cell with data has an expectation that is estimable. The cell that is missing has an expectation that is nonestimable. In fact, its expectation is precisely that linear combination of the design columns that is in the singularity report.

Suppose that you want to construct a test that compares the least squares means of B1 and B2. In this example, the average of the rows in the above table give these least squares means.

$$\text{LSM(B1)} = \frac{1}{3}(\mu + \alpha_1 + \beta_1 + \alpha\beta_{11} + \mu + \alpha_2 + \beta_1 + \alpha\beta_{21} + \mu - \alpha_1 - \alpha_2 + \beta_1 - \alpha\beta_{11} - \alpha\beta_{21}) = \mu + \beta_1$$

$$\text{LSM(B2)} = \frac{1}{3}(\mu + \alpha_1 - \beta_1 - \alpha\beta_{11} + \mu + \alpha_2 - \beta_1 - \alpha\beta_{21} + \mu - \alpha_1 - \alpha_2 - \beta_1 + \alpha\beta_{11} + \alpha\beta_{21}) = \mu - \beta_1$$

$$\text{LSM(B1)} - \text{LSM(B2)} = 2\beta_1$$

Note that this shows that a test on the $\beta_1$ parameter is equivalent to testing that the least squares means are the same. But because $\beta_1$ is not estimable, the test is not testable, meaning there are no degrees of freedom for it.

Now, construct the test for the least squares means across the A levels.

$$\text{LSM(A1)} = \frac{1}{2}(\mu + \alpha_1 + \beta_1 + \alpha\beta_{11} + \mu + \alpha_1 - \beta_1 - \alpha\beta_{11}) = \mu + \alpha_1$$

$$\text{LSM(A2)} = \frac{1}{2}(\mu + \alpha_2 + \beta_1 + \alpha\beta_{21} + \mu + \alpha_2 - \beta_1 - \alpha\beta_{21}) = \mu + \alpha_2$$

$$\text{LSM(A3)} = \frac{1}{2}(\mu - \alpha_1 - \alpha_2 + \beta_1 - \alpha\beta_{11} - \alpha\beta_{21} + \mu - \alpha_1 - \alpha_2 - \beta_1 + \alpha\beta_{11} + \alpha\beta_{21}) = \mu - \alpha_1 - \alpha_2$$

<table>
<thead>
<tr>
<th>Table B.8 Expected Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
</tr>
<tr>
<td>A1</td>
</tr>
<tr>
<td>A2</td>
</tr>
<tr>
<td>A3</td>
</tr>
</tbody>
</table>
The Factor Models

Fitting Linear Models

\[
\text{LSM}(A1) - \text{LSM}(A3) = 2\alpha_1 + \alpha_2
\]

\[
\text{LSM}(A2) - \text{LSM}(A3) = 2\alpha_2 + \alpha_1
\]

Neither of these turn out to be estimable, but there is another comparison that is estimable; namely comparing the two A columns that have no missing cells.

\[
\text{LSM}(A1) - \text{LSM}(A2) = \alpha_1 - \alpha_2
\]

This combination is indeed tested by JMP using a test with 1 degree of freedom, although there are two parameters in the effect.

The estimability can be verified by taking its inner product with the singularity combination, and checking that it is zero:

<table>
<thead>
<tr>
<th>Table B.9 Verification</th>
</tr>
</thead>
<tbody>
<tr>
<td>parameters</td>
</tr>
<tr>
<td>m</td>
</tr>
<tr>
<td>a_1</td>
</tr>
<tr>
<td>a_2</td>
</tr>
<tr>
<td>b_1</td>
</tr>
<tr>
<td>ab_{11}</td>
</tr>
<tr>
<td>ab_{21}</td>
</tr>
</tbody>
</table>

It turns out that the design columns for missing cells for any interaction will always knock out degrees of freedom for the main effect (for nominal factors). Thus, there is a direct relation between the nonestimability of least squares means and the loss of degrees of freedom for testing the effect corresponding to these least squares means.

How does this compare with what GLM does? GLM and JMP do the same test when there are no missing cells. That is, they effectively test that the least squares means are equal. But when GLM encounters singularities, it focuses out these cells in different ways, depending on whether they are Type III or Type IV. For Type IV, it looks for estimable combinations that it can find. These might not be unique, and if you reorder the levels, you might get a different result. For Type III, it does some orthogonalization of the estimable functions to obtain a unique test. But the test might not be very interpretable in terms of the cell means.

The JMP approach has several points in its favor, although at first it might seem distressing that you might lose more degrees of freedom than with GLM:

1. The tests are philosophically linked to LSMeans.
2. The tests are easy computationally, using reduction sum of squares for reparameterized models.

3. The tests agree with Hocking’s “Effective Hypothesis Tests”.

4. The tests are whole marginal tests, meaning they always go completely across other effects in interactions.

The last point needs some elaboration: Consider a graph of the expected values of the cell means in the previous example with a missing cell for A3B2.

![Graph showing expected cell means with a missing cell]

The graph shows expected cell means with a missing cell. The means of the A1 and A2 cells are profiled across the B levels. The JMP approach says you can't test the B main effect with a missing A3B2 cell, because the mean of the missing cell could be anything, as allowed by the interaction term. If the mean of the missing cell were the higher value shown, the B effect would likely test significant. If it were the lower, it would likely test nonsignificant. The point is that you don’t know. That is what the least squares means are saying when they are declared nonestimable. That is what the hypotheses for the effects should be saying too—that you don’t know.

If you want to test hypotheses involving margins for subsets of cells, then that is what GLM Type IV does. In JMP you would have to construct these tests yourself by partitioning the effects with a lot of calculations or by using contrasts.

**JMP and GLM Hypotheses**

GLM works differently than JMP and produces different hypothesis tests in situations where there are missing cells. In particular, GLM does not recognize any difference between a nesting and a crossing in an effect, but JMP does. Suppose that you have a three-layer nesting of A, B(A), and C(A B) with different numbers of levels as you go down the nested design.
The Factor Models Fitting Linear Models

Table B.10 on page 442, shows the test of the main effect A in terms of the GLM parameters. The first set of columns is the test done by JMP. The second set of columns is the test done by GLM Type IV. The third set of columns is the test equivalent to that by JMP; it is the first two columns that have been multiplied by a matrix:

\[
\begin{bmatrix}
2 & 1 \\
1 & 2 \\
\end{bmatrix}
\]

to be comparable to the GLM test. The last set of columns is the GLM Type III test. The difference is in how the test distributes across the containing effects. In JMP, it seems more top-down hierarchical. In GLM Type IV, the test seems more bottom-up. In practice, the test statistics are often similar.

Table B.10 Comparison of GLM and JMP Hypotheses

<table>
<thead>
<tr>
<th>Parameter</th>
<th>JMP Test for A</th>
<th>GLM-IV Test for A</th>
<th>JMP Rotated Test</th>
<th>GLM-III Test for A</th>
</tr>
</thead>
<tbody>
<tr>
<td>u</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>a1</td>
<td>0.6667</td>
<td>-0.3333</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>a2</td>
<td>-0.3333</td>
<td>0.6667</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>a3</td>
<td>-0.3333</td>
<td>-0.3333</td>
<td>-1</td>
<td>-1</td>
</tr>
<tr>
<td>a1b1</td>
<td>0.1667</td>
<td>-0.0833</td>
<td>0.2222</td>
<td>0.25</td>
</tr>
<tr>
<td>a1b2</td>
<td>0.1667</td>
<td>-0.0833</td>
<td>0.3333</td>
<td>0.25</td>
</tr>
<tr>
<td>a1b3</td>
<td>0.1667</td>
<td>-0.0833</td>
<td>0.2222</td>
<td>0.25</td>
</tr>
<tr>
<td>a1b4</td>
<td>0.1667</td>
<td>-0.0833</td>
<td>0.2222</td>
<td>0.25</td>
</tr>
<tr>
<td>a2b1</td>
<td>-0.1667</td>
<td>0.3333</td>
<td>0</td>
<td>0.5</td>
</tr>
<tr>
<td>a2b2</td>
<td>-0.1667</td>
<td>0.3333</td>
<td>0</td>
<td>0.5</td>
</tr>
<tr>
<td>a3b1</td>
<td>-0.1111</td>
<td>-0.1111</td>
<td>-0.3333</td>
<td>-0.3333</td>
</tr>
<tr>
<td>a3b2</td>
<td>-0.1111</td>
<td>-0.1111</td>
<td>-0.3333</td>
<td>-0.3333</td>
</tr>
<tr>
<td>a3b3</td>
<td>-0.1111</td>
<td>-0.1111</td>
<td>-0.3333</td>
<td>-0.3333</td>
</tr>
<tr>
<td>a1b1c1</td>
<td>0.0833</td>
<td>-0.0417</td>
<td>0.1111</td>
<td>0.125</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Table B.10  Comparison of GLM and JMP Hypotheses  (Continued)

<table>
<thead>
<tr>
<th></th>
<th>0.0833</th>
<th>-0.0417</th>
<th>0.1111</th>
<th>0</th>
<th>0.125</th>
<th>0</th>
<th>0.1212</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>a1b1c2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a1b2c1</td>
<td>0.0556</td>
<td>-0.0278</td>
<td>0.1111</td>
<td>0</td>
<td>0.0833</td>
<td>0</td>
<td>0.0909</td>
<td>0</td>
</tr>
<tr>
<td>a1b2c2</td>
<td>0.0556</td>
<td>-0.0278</td>
<td>0.1111</td>
<td>0</td>
<td>0.0833</td>
<td>0</td>
<td>0.0909</td>
<td>0</td>
</tr>
<tr>
<td>a1b2c3</td>
<td>0.0556</td>
<td>-0.0278</td>
<td>0.1111</td>
<td>0</td>
<td>0.0833</td>
<td>0</td>
<td>0.0909</td>
<td>0</td>
</tr>
<tr>
<td>a1b3c1</td>
<td>0.0833</td>
<td>-0.0417</td>
<td>0.1111</td>
<td>0</td>
<td>0.125</td>
<td>0</td>
<td>0.1212</td>
<td>0</td>
</tr>
<tr>
<td>a1b3c2</td>
<td>0.0833</td>
<td>-0.0417</td>
<td>0.1111</td>
<td>0</td>
<td>0.125</td>
<td>0</td>
<td>0.1212</td>
<td>0</td>
</tr>
<tr>
<td>a1b4c1</td>
<td>0.0833</td>
<td>-0.0417</td>
<td>0.1111</td>
<td>0</td>
<td>0.125</td>
<td>0</td>
<td>0.1212</td>
<td>0</td>
</tr>
<tr>
<td>a1b4c2</td>
<td>0.0833</td>
<td>-0.0417</td>
<td>0.1111</td>
<td>0</td>
<td>0.125</td>
<td>0</td>
<td>0.1212</td>
<td>0</td>
</tr>
<tr>
<td>a2b1c1</td>
<td>-0.0833</td>
<td>0.1667</td>
<td>0</td>
<td>0</td>
<td>0.25</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>a2b1c2</td>
<td>-0.0833</td>
<td>0.1667</td>
<td>0</td>
<td>0</td>
<td>0.25</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>a2b2c1</td>
<td>-0.0833</td>
<td>0.1667</td>
<td>0</td>
<td>0</td>
<td>0.25</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>a2b2c2</td>
<td>-0.0833</td>
<td>0.1667</td>
<td>0</td>
<td>0</td>
<td>0.25</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>a3b1c1</td>
<td>-0.0556</td>
<td>-0.0556</td>
<td>-0.1667</td>
<td>-0.1667</td>
<td>-0.1667</td>
<td>-0.1667</td>
<td>-0.1667</td>
<td>-0.1667</td>
</tr>
<tr>
<td>a3b1c2</td>
<td>-0.0556</td>
<td>-0.0556</td>
<td>-0.1667</td>
<td>-0.1667</td>
<td>-0.1667</td>
<td>-0.1667</td>
<td>-0.1667</td>
<td>-0.1667</td>
</tr>
<tr>
<td>a3b2c1</td>
<td>-0.0556</td>
<td>-0.0556</td>
<td>-0.1667</td>
<td>-0.1667</td>
<td>-0.1667</td>
<td>-0.1667</td>
<td>-0.1667</td>
<td>-0.1667</td>
</tr>
<tr>
<td>a3b2c2</td>
<td>-0.0556</td>
<td>-0.0556</td>
<td>-0.1667</td>
<td>-0.1667</td>
<td>-0.1667</td>
<td>-0.1667</td>
<td>-0.1667</td>
<td>-0.1667</td>
</tr>
<tr>
<td>a3b3c1</td>
<td>-0.0556</td>
<td>-0.0556</td>
<td>-0.1667</td>
<td>-0.1667</td>
<td>-0.1667</td>
<td>-0.1667</td>
<td>-0.1667</td>
<td>-0.1667</td>
</tr>
<tr>
<td>a3b3c2</td>
<td>-0.0556</td>
<td>-0.0556</td>
<td>-0.1667</td>
<td>-0.1667</td>
<td>-0.1667</td>
<td>-0.1667</td>
<td>-0.1667</td>
<td>-0.1667</td>
</tr>
</tbody>
</table>
Ordinal Factors

Factors marked with the ordinal modeling type are coded differently than nominal factors. The parameters estimates are interpreted differently, the tests are different, and the least squares means are different.

The theme for ordinal factors is that the first level of the factor is a control or baseline level, and the parameters measure the effect on the response as the ordinal factor is set to each succeeding level. The coding is appropriate for factors with levels representing various doses, where the first dose is zero:

Table B.11 Ordinal Factors

<table>
<thead>
<tr>
<th>Term</th>
<th>Coded Column</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>a2</td>
</tr>
<tr>
<td>A1</td>
<td>0</td>
</tr>
<tr>
<td>A2</td>
<td>1</td>
</tr>
<tr>
<td>A3</td>
<td>1</td>
</tr>
</tbody>
</table>

From the perspective of the JMP parameterization, the tests for A are:

Table B.12 Tests for A

<table>
<thead>
<tr>
<th>parameter</th>
<th>GLM–IV test</th>
<th>JMP test</th>
</tr>
</thead>
<tbody>
<tr>
<td>m</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>a13</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>a23</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>a1:b14</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>a1:b24</td>
<td>0.11111</td>
<td>0</td>
</tr>
<tr>
<td>a1:b34</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>a2:b12</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>a3:b13</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>a3:b23</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>a1b1:c12</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>a1b2:c13</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Appendix B
Fitting Linear Models

So from JMP’s perspective, the GLM test looks a little strange, putting a coefficient on the a1b24 parameter.

The pattern for the design is such that the lower triangle is ones with zeros elsewhere.

For a simple main-effects model, this can be written

\[ y = \mu + \alpha_2 X_{(a \leq 2)} + \alpha_3 X_{(a \leq 3)} + \epsilon \]

noting that \( \mu \) is the expected response at \( A = 1 \), \( \mu + \alpha_2 \) is the expected response at \( A = 2 \), and \( \mu + \alpha_2 + \alpha_3 \) is the expected response at \( A = 3 \). Thus, \( \alpha_2 \) estimates the effect moving from \( A = 1 \) to \( A = 2 \) and \( \alpha_3 \) estimates the effect moving from \( A = 2 \) to \( A = 3 \).

If all the parameters for an ordinal main effect have the same sign, then the response effect is monotonic across the ordinal levels.

**Ordinal Interactions**

The ordinal interactions, as with nominal effects, are produced with a horizontal direct product of the columns of the factors. Consider an example with two ordinal factors A and B, each with three levels. JMP’s ordinal coding produces the design matrix shown next. The pattern for the interaction is a block lower-triangular matrix of lower-triangular matrices of ones.

### Table B.12 Tests for A (Continued)

<table>
<thead>
<tr>
<th>Interaction</th>
<th>Design Matrix</th>
</tr>
</thead>
<tbody>
<tr>
<td>a1b2:c23</td>
<td>0 0 0 0</td>
</tr>
<tr>
<td>a1b3:c12</td>
<td>0 0 0 0</td>
</tr>
<tr>
<td>a1b4:c12</td>
<td>0 0 0 0</td>
</tr>
<tr>
<td>a2b1:c13</td>
<td>0 0 0 0</td>
</tr>
<tr>
<td>a2b2:c12</td>
<td>0 0 0 0</td>
</tr>
<tr>
<td>a3b1:c12</td>
<td>0 0 0 0</td>
</tr>
<tr>
<td>a3b2:c12</td>
<td>0 0 0 0</td>
</tr>
<tr>
<td>a3b3:c12</td>
<td>0 0 0 0</td>
</tr>
</tbody>
</table>
Table B.13 Ordinal Interactions

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>A2</th>
<th>A3</th>
<th>B2</th>
<th>B3</th>
<th>A2</th>
<th>A3</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>B1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>A1</td>
<td>B2</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>A1</td>
<td>B3</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>A2</td>
<td>B1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>A2</td>
<td>B2</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>A2</td>
<td>B3</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>A3</td>
<td>B1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>A3</td>
<td>B2</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>A3</td>
<td>B3</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Note: When you test to see if there is no effect, there is not much difference between nominal and ordinal factors for simple models. However, there are major differences when interactions are specified. We recommend that you use nominal rather than ordinal factors for most models.

Hypothesis Tests for Ordinal Crossed Models

To see what the parameters mean, examine this table of the expected cell means in terms of the parameters, where $\mu$ is the intercept, $\alpha_2$ is the parameter for level A2, and so forth.

Table B.14 Expected Cell Means

<table>
<thead>
<tr>
<th>B1</th>
<th>B2</th>
<th>B3</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>$\mu$</td>
<td>$\mu + \alpha_2 + \beta_{12}$</td>
</tr>
<tr>
<td>A2</td>
<td>$\mu + \alpha_2$</td>
<td>$\mu + \alpha_2 + \beta_2 + \alpha_2\beta_2$</td>
</tr>
<tr>
<td>A3</td>
<td>$\mu + \alpha_2 + \alpha_3$</td>
<td>$\mu + \alpha_2 + \alpha_3 + \beta_2 + \alpha_2\beta_2 + \alpha_3\beta_{32} + \alpha_2\beta_{32} + \alpha_3\beta_{33}$</td>
</tr>
</tbody>
</table>
Note that the main effect test for A is really testing the A levels holding B at the first level. Similarly, the main effect test for B is testing across the top row for the various levels of B holding A at the first level. This is the appropriate test for an experiment where the two factors are both doses of different treatments. The main question is the efficacy of each treatment by itself, with fewer points devoted to looking for drug interactions when doses of both drugs are applied. In some cases it may even be dangerous to apply large doses of each drug.

Note that each cell’s expectation can be obtained by adding all the parameters associated with each cell that is to the left and above it, inclusive of the current row and column. The expected value for the last cell is the sum of all the parameters.

Though the hypothesis tests for effects contained by other effects differs with ordinal and nominal codings, the test of effects not contained by other effects is the same. In the crossed design above, the test for the interaction would be the same no matter whether A and B were fit nominally or ordinally.

**Ordinal Least Squares Means**

As stated previously, least squares means are the predicted values corresponding to some combination of levels, after setting all the other factors to some neutral value. JMP defines the neutral value for an effect with uninvolved ordinal factors as the effect at the first level, meaning the control or baseline level.

This definition of least squares means for ordinal factors maintains the idea that the hypothesis tests for contained effects are equivalent to tests that the least squares means are equal.

**Singularities and Missing Cells in Ordinal Effects**

With the ordinal coding, you are saying that the first level of the ordinal effect is the baseline. It is thus possible to get good tests on the main effects even when there are missing cells in the interactions—even if you have no data for the interaction.

**Example with Missing Cell**

The example is the same as above, with two observations per cell except that the A3B2 cell has no data. You can now compare the results when the factors are coded nominally with results when they are coded ordinally. The model as a whole fits the same as seen in tables shown in Figure B.1.
The parameter estimates are very different because of the different coding. Note that the missing cell affects estimability for some nominal parameters but for none of the ordinal parameters.
The singularity details show the linear dependencies (and also identify the missing cell by examining the values).

**Figure B.3** Comparison of Singularity Details for Nominal and Ordinal Fits

<table>
<thead>
<tr>
<th>Source</th>
<th>Kparm</th>
<th>EF</th>
<th>Sum of Squares</th>
<th>F Ratio</th>
<th>Prob &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2</td>
<td>2</td>
<td>81.333333</td>
<td>18.4848</td>
<td>0.0049*</td>
</tr>
<tr>
<td>B</td>
<td>1</td>
<td>0</td>
<td>0.000000</td>
<td>0.0000</td>
<td>LostDFs</td>
</tr>
<tr>
<td>A*B</td>
<td>2</td>
<td>1</td>
<td>0.000000</td>
<td>0.0000</td>
<td>LostDFs</td>
</tr>
</tbody>
</table>

The effect tests lose degrees of freedom for nominal. In the case of B, there is no test. For ordinal, there is no loss because there is no missing cell for the base first level.

**Figure B.4** Comparison of Effects Tests for Nominal and Ordinal Fits

<table>
<thead>
<tr>
<th>Source</th>
<th>Kparm</th>
<th>EF</th>
<th>Sum of Squares</th>
<th>F Ratio</th>
<th>Prob &gt; F</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2</td>
<td>2</td>
<td>91.333333</td>
<td>18.4848</td>
<td>0.0049*</td>
</tr>
<tr>
<td>B</td>
<td>1</td>
<td>1</td>
<td>6.250000</td>
<td>2.8400</td>
<td>0.1127</td>
</tr>
<tr>
<td>A*B</td>
<td>2</td>
<td>1</td>
<td>0.000000</td>
<td>0.0000</td>
<td>LostDFs</td>
</tr>
</tbody>
</table>

The least squares means are also different. The nominal LSMs are not all estimable, but the ordinal LSMs are. You can verify the values by looking at the cell means. Note that the A*B LSMs are the same for the two. Figure B.5 shows least squares means for an nominal and ordinal fits.
The Usual Assumptions

Before you put your faith in statistics, reassure yourself that you know both the value and the limitations of the techniques you use. Statistical methods are just tools—they cannot guard you from incorrect science (invalid statistical assumptions) or bad data.

Assumed Model

Most statistics are based on the assumption that the model is correct. To the extent that your model may not be correct, you must attenuate your credibility in the statistical reports that result from the model.

Relative Significance

Many statistical tests do not evaluate the model in an absolute sense. Significant test statistics might only be saying that the model fits better than some reduced model, such as the mean. The model can appear to fit the data but might not describe the underlying physical model well at all.
Multiple Inferences

Often the value of the statistical results is not that you believe in them directly, but rather that they provide a key to some discovery. To confirm the discovery, you may need to conduct further studies. Otherwise, you might just be sifting through the data.

For instance, if you conduct enough analyses you can find 5% significant effects in five percent of your studies by chance alone, even if the factors have no predictive value. Similarly, to the extent that you use your data to shape your model (instead of testing the correct model for the data), you are corrupting the significance levels in your report. The random error then influences your model selection and leads you to believe that your model is better than it really is.

Validity Assessment

Some of the various techniques and patterns to look for in assessing the validity of the model are as follows:

- Model validity can be checked against a saturated version of the factors with Lack of Fit tests. The Fit Model platform presents these tests automatically if you have replicated x data in a nonsaturated model.

- You can check the distribution assumptions for a continuous response by looking at plots of residuals and studentized residuals from the Fit Model platform. Or, use the Save commands in the platform popup menu to save the residuals in data table columns. Then use the Analyze > Distribution on these columns to look at a histogram with its normal curve and the normal quantile plot. The residuals are not quite independent, but you can informally identify severely non-normal distributions.

- The best all-around diagnostic tool for continuous responses is the leverage plot because it shows the influence of each point on each hypothesis test. If you suspect that there is a mistaken value in your data, this plot helps determine if a statistical test is heavily influenced by a single point.

- It is a good idea to scan your data for outlying values and examine them to see if they are valid observations. You can spot univariate outliers in the Distribution platform reports and plots. Bivariate outliers appear in Fit Y by X scatterplots and in the Multivariate scatterplot matrix. You can see trivariate outliers in a three-dimensional plot produced by the Graph > Scatterplot 3D. Higher dimensional outliers can be found with Principal Components or Scatterplot 3D, and with Mahalanobis and jack-knifed distances computed and plotted in the Multivariate platform.
Alternative Methods

The statistical literature describes special nonparametric and robust methods, but JMP implements only a few of them at this time. These methods require fewer distributional assumptions (nonparametric), and then are more resistant to contamination (robust). However, they are less conducive to a general methodological approach, and the small sample probabilities on the test statistics can be time consuming to compute.

If you are interested in linear rank tests and need only normal large sample significance approximations, you can analyze the ranks of your data to perform the equivalent of a Wilcoxon rank-sum or Kruskal-Wallis one-way test.

If you are uncertain that a continuous response adequately meets normal assumptions, you can change the modeling type from continuous to ordinal and then analyze safely, even though this approach sacrifices some richness in the presentations and some statistical power as well.

Key Statistical Concepts

There are two key concepts that unify classical statistics and encapsulate statistical properties and fitting principles into forms you can visualize:

- a unifying concept of uncertainty
- two basic fitting machines.

These two ideas help unlock the understanding of statistics with intuitive concepts that are based on the foundation laid by mathematical statistics.

Statistics is to science what accounting is to business. It is the craft of weighing and balancing observational evidence. Statistical tests are like credibility audits. But statistical tools can do more than that. They are instruments of discovery that can show unexpected things about data and lead to interesting new ideas. Before using these powerful tools, you need to understand a bit about how they work.

Uncertainty, a Unifying Concept

When you do accounting, you total money amounts to get summaries. When you look at scientific observations in the presence of uncertainty or noise, you need some statistical measurement to summarize the data. Just as money is additive, uncertainty is additive if you choose the right measure for it.

The best measure is not the direct probability because to get a joint probability you have to assume that the observations are independent and then multiply probabilities rather than add them. It is easier to take the log of each probability because then you can sum them and the total is the log of the joint probability.
However, the log of a probability is negative because it is the log of a number between 0 and 1. In order to keep the numbers positive, JMP uses the negative log of the probability. As the probability becomes smaller, its negative log becomes larger. This measure is called uncertainty, and it is measured in reverse fashion from probability.

In business, you want to maximize revenues and minimize costs. In science you want to minimize uncertainty. Uncertainty in science plays the same role as cost plays in business. All statistical methods fit models such that uncertainty is minimized.

It is not difficult to visualize uncertainty. Just think of flipping a series of coins where each toss is independent. The probability of tossing a head is 0.5, and \(-\log(0.5)\) is 1 for base 2 logarithms. The probability of tossing \(h\) heads in a row is simply

\[
p = \left(\frac{1}{2}\right)^h
\]

Solving for \(h\) produces

\[
h = -\log_2 p
\]

You can think of the uncertainty of some event as the number of consecutive “head” tosses you have to flip to get an equally rare event.

Almost everything we do statistically has uncertainty, \(-\log p\), at the core. Statistical literature refers to uncertainty as negative log-likelihood.

The Two Basic Fitting Machines

An amazing fact about statistical fitting is that most of the classical methods reduce to using two simple machines, the spring and the pressure cylinder.

Springs

First, springs are the machine of fit for a continuous response model (Farebrother, 1987). Suppose that you have \(n\) points and that you want to know the expected value (mean) of the points. Envision what happens when you lay the points out on a scale and connect them to a common junction with springs (see Figure B.6). When you let go, the springs wiggle the junction point up and down and then bring it to rest at the mean. This is what must happen according to physics.

If the data are normally distributed with a mean at the junction point where springs are attached, then the physical energy in each point’s spring is proportional to the uncertainty of the data point. All you have to do to calculate the energy in the springs (the uncertainty) is to compute the sum of squared distances of each point to the mean.
To choose an estimate that attributes the least uncertainty to the observed data, the spring settling point is chosen as the estimate of the mean. That is the point that requires the least energy to stretch the springs and is equivalent to the least squares fit.

**Figure B.6** Connect Springs to Data Points

That is how you fit one mean or fit several means. That is how you fit a line, or a plane, or a hyperplane. That is how you fit almost any model to continuous data. You measure the energy or uncertainty by the sum of squares of the distances you must stretch the springs.

Statisticians put faith in the normal distribution because it is the one that requires the least faith. It is, in a sense, the most random. It has the most non-informative shape for a distribution. It is the one distribution that has the most expected uncertainty for a given variance. It is the distribution whose uncertainty is measured in squared distance. In many cases it is the limiting distribution when you have a mixture of distributions or a sum of independent quantities. It is the distribution that leads to test statistics that can be measured fairly easily.

When the fit is constrained by hypotheses, you test the hypotheses by measuring this same spring energy. Suppose you have responses from four different treatments in an experiment, and you want to test if the means are significantly different. First, envision your data plotted in groups as shown here, but with springs connected to a separate mean for each treatment. Then exert pressure against the spring force to move the individual means to the common mean. Presto! The amount of energy that constrains the means to be the same is the test statistic you need. That energy is the main ingredient in the $F$-test for the hypothesis that tests whether the means are the same.
Pressure Cylinders

What if your response is categorical instead of continuous? For example, suppose that the response is the country of origin for a sample of cars. For your sample, there are probabilities for the three response levels, American, European, and Japanese. You can set these probabilities for country of origin to some estimate and then evaluate the uncertainty in your data. This uncertainty is found by summing the negative logs of the probabilities of the responses given by the data. It is written

\[ H = \sum h_y(i) = -\sum \log p_y(i) \]

The idea of springs illustrates how a mean is fit to continuous data. When the response is categorical, statistical methods estimate the response probabilities directly and choose the estimates that minimize the total uncertainty of the data. The probability estimates must be nonnegative and sum to 1. You can picture the response probabilities as the composition along a scale whose total length is 1. For each response observation, load into its response area a gas pressure cylinder, for example, a tire pump. Let the partitions between the response levels vary until an equilibrium of lowest potential energy is reached. The sizes of the partitions that result then estimate the response probabilities.

Figure B.7 shows what the situation looks like for a single category such as the medium size cars (see the mosaic column from Carpoll.jmp labeled medium in Figure B.8). Suppose there are thirteen responses (cars). The first level (American) has six responses, the next has two, and the last has five responses. The response probabilities become \( \frac{6}{13}, \frac{2}{13}, \) and \( \frac{5}{13} \), respectively, as the pressure against the response partitions balances out to minimize the total energy.

**Figure B.7 Effect of Pressure Cylinders in Partitions**

As with springs for continuous data, you can divide your sample by some factor and fit separate sets of partitions. Then test that the response rates are the same across the groups by measuring how much additional energy you need to push the partitions to be equal. Imagine the pressure cylinders for car origin probabilities grouped by the size of the car. The energy required to force the partitions in each group to align horizontally tests whether the variables have the same probabilities. Figure B.8 shows these partitions.
Multivariate Details

The following sections show computations used for multivariate tests and related, exact and approximate F-statistics, canonical details, and discriminant functions. In the following sections, \( E \) is the residual cross product matrix and \( \frac{E}{n-1} \) estimates the residual covariance matrix. Diagonal elements of \( E \) are the sum of squares for each variable. In discriminant analysis literature, this is often called \( W \), where \( W \) stands for within.

Multivariate Tests

Test statistics in the multivariate results tables are functions of the eigenvalues \( \lambda \) of \( E^{-1}H \). The following list describes the computation of each test statistic.

**Note:** After specification of a response design, the initial \( E \) and \( H \) matrices are premultiplied by \( M' \) and postmultiplied by \( M \).

**Table B.16** Computations for Multivariate Tests

<table>
<thead>
<tr>
<th>Test Statistic</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wilks’ Lambda</td>
<td>[ \Lambda = \frac{\text{det}(E)}{\text{det}(H+E)} = \prod_{i=1}^{n} \frac{1}{1 + \lambda_i' \lambda_i} ]</td>
</tr>
<tr>
<td>Pillai’s Trace</td>
<td>[ V = \text{Trace}[H(H+E)^{-1}] = \sum_{i=1}^{n} \frac{\lambda_i}{1 + \lambda_i} ]</td>
</tr>
<tr>
<td>Hotelling-Lawley</td>
<td>[ U = \text{Trace}(E^{-1}H) = \sum_{i=1}^{n} \lambda_i ]</td>
</tr>
<tr>
<td>Roy’s Max Root</td>
<td>[ \Theta = \lambda_1 ], the maximum eigenvalue of ( E^{-1}H ).</td>
</tr>
</tbody>
</table>
The whole model $L$ is a column of zeros (for the intercept) concatenated with an identity matrix having the number of rows and columns equal to the number of parameters in the model. $L$ matrices for effects are subsets of rows from the whole model $L$ matrix.

**Approximate $F$-Test**

To compute $F$-values and degrees of freedom, let $p$ be the rank of $H + E$. Let $q$ be the rank of $L(XX)^{-1}L'$, where the $L$ matrix identifies elements of $XX'$ associated with the effect being tested. Let $v$ be the error degrees of freedom and $s$ be the minimum of $p$ and $q$. Also let $m = 0.5(p-q-1)$ and $n = 0.5(v-p-1)$.

Table B.17 on page 457, gives the computation of each approximate $F$ from the corresponding test statistic.

**Table B.17** Approximate $F$-statistics

<table>
<thead>
<tr>
<th>Test</th>
<th>Approximate $F$</th>
<th>Numerator DF</th>
<th>Denominator DF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wilks' Lambda</td>
<td>$F = \frac{1}{\Lambda^{1/t}} \left( \frac{rt - 2u}{pq} \right)$</td>
<td>$pq$</td>
<td>$rt - 2u$</td>
</tr>
<tr>
<td>Pillai's Trace</td>
<td>$F = \frac{V}{s - V} \left( \frac{2n + s + 1}{2m + s + 1} \right)$</td>
<td>$s(2m + s + 1)$</td>
<td>$s(2n + s + 1)$</td>
</tr>
<tr>
<td>Hotelling-Lawley</td>
<td>$F = \frac{2(sn + 1)(n)}{s^2(2m + s + 1)}$</td>
<td>$s(2m + s + 1)$</td>
<td>$2(sn + 1)$</td>
</tr>
<tr>
<td>Roy's Max Root</td>
<td>$F = \frac{9(v - \max(p, q) + q)}{\max(p, q)}$</td>
<td>$\max(p, q)$</td>
<td>$v - \max(p, q) + q$</td>
</tr>
</tbody>
</table>

**Canonical Details**

The canonical correlations are computed as

$$\rho_i = \sqrt{\frac{\lambda_i}{1 + \lambda_i}}$$

The canonical Y's are calculated as

$$\hat{Y} = YMV$$

where $Y$ is the matrix of response variables, $M$ is the response design matrix, and $V$ is the matrix of eigenvectors of $E^{-1}H$. Canonical Y's are saved for eigenvectors corresponding to eigenvalues larger than zero.
The total sample centroid is computed as

\[ \text{Grand} = \bar{y} MV \]

where \( V \) is the matrix of eigenvectors of \( E^{-1}H \).

The centroid values for effects are calculated as

\[ m = (c_1'\bar{x}_j, c_2'\bar{x}_j, \ldots, c_g'\bar{x}_j) \quad \text{where} \quad c_i = \left(v_i'\left(\frac{E}{N - r}\right)v_i\right)^{-1/2} v_i \]

and the \( v \)'s are columns of \( V \), the eigenvector matrix of \( E^{-1}H \). \( \bar{x}_j \) refers to the multivariate least squares mean for the \( j \)th effect, \( g \) is the number of eigenvalues of \( E^{-1}H \) greater than 0, and \( r \) is the rank of the \( X \) matrix.

The centroid radii for effects are calculated as

\[ d = \sqrt{\frac{\chi^2_{g}(0.95)}{\left| L(X'X)^{-1}L' \right|}} \]

where \( g \) is the number of eigenvalues of \( E^{-1}H \) greater than 0 and the denominator \( L \)'s are from the multivariate least squares means calculations.

### Discriminant Analysis

The distance from an observation to the multivariate mean of the \( i \)th group is the Mahalanobis distance, \( D^2 \), and computed as

\[ D^2 = (y - \bar{y}_i)'S^{-1}(y - \bar{y}_i) = y'S^{-1}y - 2y'S^{-1}\bar{y}_i + \bar{y}_i'S^{-1}\bar{y}_i \]

where

\[ S = \frac{E}{N - 1} \]

In saving discriminant columns, \( N \) is the number of observations and \( M \) is the identity matrix.

The **Save Discrim** command in the popup menu on the platform title bar saves discriminant scores with their formulas as columns in the current data table. \( \text{Sqdist}[0] \) is a quadratic form needed in all the distance calculations. It is the portion of the Mahalanobis distance formula that does not vary across groups. \( \text{Sqdist}[i] \) is the Mahalanobis distance of an observation from the \( i \)th centroid. \( \text{Sqdist}[0] \) and \( \text{Sqdist}[i] \) are calculated as

\[ \text{Sqdist}[0] = y'S^{-1}y \]

and

\[ \text{Sqdist}[i] = \text{Sqdist}[0] - 2y_i'S^{-1}\bar{y}_i + \bar{y}_i'S^{-1}\bar{y}_i \]
Assuming that each group has a multivariate normal distribution, the posterior probability that an observation belongs to the $i$th group is

$$\text{Prob}[i] = \frac{\exp(\text{Dist}[i])}{\text{Prob}[0]}$$

where

$$\text{Prob}[0] = \sum e^{-0.5\text{Dist}[i]}$$

**Power Calculations**

The next sections give formulas for computing the least significant number (LSN), least significant value (LSV), power, and adjusted power. With the exception of LSV, these computations are provided for each effect, and for a collection of user-specified contrasts (under Custom Test and LS Means Contrast. LSV is only computed for a single linear contrast. In the details below, the hypothesis refers to the collection of contrasts of interest.

**Computations for the LSN**

The LSN solves for $N$ in the equation:

$$\alpha = 1 - \text{FDist} \left[ \frac{N\delta^2}{df_{Hyp} \sigma^2} \cdot \frac{df_{Hyp} N - df_{Hyp} - 1}{N - df_{Hyp} - 1} \right]$$

where

- $\text{FDist}$ is the cumulative distribution function of the central $F$ distribution
- $df_{Hyp}$ represents the degrees of freedom for the hypothesis
- $\sigma^2$ is the error variance
- $\delta^2$ is the squared effect size

For retrospective analyses, $\delta^2$ is estimated by the sum of squares for the hypothesis divided by $n$, the size of the current sample. If the test is for an effect, then $\delta^2$ is estimated by the sum of squares for that effect divided by the number of observations in the current study. For retrospective studies, the error variance $\sigma^2$ is estimated by the mean square error. These estimates, along with an $\alpha$ value of 0.05, are entered into the Power Details window as default values.
When you are conducting a prospective analysis to plan a future study, consider determining the sample size that will achieve a specified power (see “Computations for the Power” on page 461.)

### Computations for the LSV

The LSV is only computed for a single linear contrast.

#### Test of a Single Linear Contrast

Consider the one-degree-of-freedom test $L\beta = 0$, where $L$ is a row vector of constants. The test statistic for a $t$-test for this hypothesis is:

$$\frac{Lb}{s\sqrt{L(X'X)^{-1}L'}}$$

where $s$ is the root mean square error. We reject the hypothesis at significance level $\alpha$ if the absolute value of the test statistic exceeds the $1 - \alpha/2$ quantile of the $t$ distribution, $t_{1-\alpha/2}$, with degrees of freedom equal to those for error.

To find the least significant value, denoted $(Lb)^{LSV}$, we solve for $Lb$:

$$(Lb)^{LSV} = t_{1-\alpha/2}s\sqrt{L(X'X)^{-1}L'}$$

#### Test of a Single Parameter

In the special case where the linear contrast tests a hypothesis setting a single $\beta_i$ equal to 0, this reduces to:

$$b_i^{LSV} = t_{1-\alpha/2}s\sqrt{(X'X)^{-1}}_{ii} = t_{1-\alpha/2}\text{StdError}(b_i)$$

#### Test of a Difference in Means

In a situation where the test of interest is a comparison of two group means, the literature talks about the least significant difference (LSD). In the special case where the model contains only one nominal variable, the formula for testing a single linear contrast reduces to the formula for the LSD:

$$\text{LSD} = t_{1-\alpha/2}s\sqrt{\frac{1}{n_1} + \frac{1}{n_2}}$$

However, in JMP, the parameter associated with a level for a nominal effect measures the difference between the mean of that level and the mean for all levels. So, the LSV for such a comparison is half the LSD for the differences of the means.
Note: If you are testing a contrast across the levels of a nominal effect, keep in mind how JMP codes nominal effects. Namely, the parameter associated with a given level measures the difference to the average for all levels.

Computations for the Power

Suppose that you are interested in computing the power of a test of a linear hypothesis, based on significance level $\alpha$ and a sample size of $N$. You want to detect an effect of size $\delta$. To calculate the power, begin by finding the critical value for an $\alpha$-level F-test of the linear hypothesis. This is given by solving for $F_C$ in the equation

$$\alpha = 1 - FDist\left[F_C, df_{Hyp}N - df_{Model} - 1\right]$$

Here, $df_{Hyp}$ represents the degrees of freedom for the hypothesis, $df_{Model}$ represents the degrees of freedom for the model, and $N$ is the proposed (or actual) sample size.

Then calculate the noncentrality parameter associated with the desired effect size. The noncentrality parameter is given by:

$$\lambda = \left(\frac{N\delta^2}{\sigma^2}\right),$$

where $\sigma^2$ is a proposed (or estimated) value of the error variance.

Given an effect of size $\delta$, the test statistic has a noncentral F distribution, with distribution function denoted $FDist$ below, with noncentrality parameter $\lambda$. To obtain the power of your test, calculate the probability that the test statistic exceeds the critical value:

$$\text{Power} = 1 - FDist\left[F_C, df_{Hyp}N - df_{Model} - 1, \frac{N\delta^2}{\sigma^2}\right]$$

In obtaining retrospective power for a study with $n$ observations, JMP estimates the noncentrality parameter $\lambda = (n\delta^2)/\sigma^2$ by $\lambda = \frac{SS_{Hyp}}{\sigma^2}$, where $SS_{Hyp}$ represents the sum of squares due to the hypothesis.

Computations for the Adjusted Power

The adjusted power calculation (Wright and O’Brien, 1988) is only relevant for retrospective power analysis. Adjusted power calculates power using a noncentrality parameter estimate that has been adjusted to remove the positive bias that occurs when parameters are simply replaced by their sample estimates.
The estimate of the noncentrality parameter, $\lambda$, obtained by estimating $\delta$ and $\sigma$ by their sample estimates is

$$\hat{\lambda} = \frac{SS_{Hyp}}{MSE}$$

Wright and O’Brien (1988) explain that an unbiased estimate of the noncentrality parameter is given by

$$[\hat{\lambda}(df_{Error} - 2)/df_{Error}] - df_{Hyp} = \frac{\hat{\lambda}(N - df_{Model} - 1 - 2)}{N - df_{Model} - 1} - df_{Hyp}$$

The expression on the right illustrates the calculation of the unbiased noncentrality parameter when a sample size $N$, different from the study size $n$, is proposed for a retrospective power analysis. Here, $df_{Hyp}$ represents the degrees of freedom for the hypothesis and $df_{Model}$ represents the degrees of freedom for the whole model.

Unfortunately, this adjustment to the noncentrality estimate can lead to negative values. Negative values are set to zero, reintroducing some slight bias. The adjusted noncentrality estimate is

$$\hat{\lambda}_{adj} = \text{Max}[0, \frac{\hat{\lambda}(N - df_{Model} - 1 - 2)}{N - df_{Model} - 1} - df_{Hyp}]$$

The adjusted power is

$$\text{Power}_{adj} = 1 - \text{FDist}[F_C, df_{Hyp}, N - df_{Model} - 1, \hat{\lambda}_{adj}]$$

Confidence limits for the noncentrality parameter are constructed as described in Dwass (1955):

Lower CL for $\lambda = \text{Max}[0, \left(\sqrt{SS_{Hyp}/MSE} - \frac{df_{Hyp} F_C}{\sqrt{df_{Hyp} F_C}}\right)^2]$

Upper CL for $\lambda = \left(\sqrt{SS_{Hyp}/MSE} - \frac{df_{Hyp} F_C}{\sqrt{df_{Hyp} F_C}}\right)^2$

Confidence limits for the power are obtained by substituting these confidence limits for $\lambda$ into

$$\text{Power} = 1 - \text{FDist}[F_C, df_{Hyp}, N - df_{Model} - 1, \lambda]$$

**Inverse Prediction with Confidence Limits**

Inverse prediction estimates a value of an independent variable from a response value. In bioassay problems, inverse prediction with confidence limits is especially useful. In JMP, you can request inverse prediction estimates for continuous and binary response models. If the
response is continuous, you can request confidence limits for an individual response or an expected response.

The confidence limits are computed using Fieller’s theorem (Fieller, 1954), which is based on the following logic. The goal is predicting the value of a single regressor and its confidence limits given the values of the other regressors and the response.

- Let $b$ estimate the parameters $\beta$ so that we have $b$ distributed as $N(\beta, V)$.
- Let $x$ be the regressor values of interest, with the $i^{th}$ value to be estimated.
- Let $y$ be the response value.

We desire a confidence region on the value of $x[i]$ such that $\beta'x = y$ with all other values of $x$ given.

The inverse prediction is

$$x[i] = \frac{y - \beta'(i)x(i)}{\beta[i]}$$

where the parenthesized subscript $(i)$ indicates that the $i^{th}$ component is omitted. A confidence interval can be formed from the relation

$$(y - b'x)^2 < t^2 x'Vx$$

where $t$ is the $t$ value for the specified confidence level.

The equation

$$(y - b'x)^2 - t^2 x'Vx = 0$$

can be written as a quadratic in terms of $z = x[i]$: $g z^2 + h z + f = 0$

where

$$g = b[i]^2 - t^2 V[i, i]$$
$$h = -2y b[i] + 2b[i] b'_{(i)} x_{(i)} - 2t^2 V[i, (i)] x_{(i)}$$
$$f = y^2 - 2y b'_{(i)} x_{(i)} + (b'_{(i)} x_{(i)})^2 - t^2 x_{(i)} V_{(i)} x_{(i)}$$
Depending on the values of $g$, $h$, and $f$, the set of values satisfying the inequality, and hence the confidence interval for the inverse prediction, can have a number of forms:

- an interval of the form $(\phi_1, \phi_2)$, where $\phi_1 < \phi_2$
- two disjoint intervals of the form $(-\infty, \phi_1) \cup (\phi_2, \infty)$, where $\phi_1 < \phi_2$
- the entire real line, $(-\infty, \infty)$
- only one of $(-\infty, \phi)$ or $(\phi, \infty)$

In the case where the Fieller confidence interval is the entire real line, Wald intervals are presented.

**Note:** The Fit Y by X logistic platform and the Fit Model Nominal Logistic personalities use $t$ values when computing confidence intervals for inverse prediction. The Fit Model Generalized Linear Model personality, as well as PROC PROBIT in SAS/STAT, use $z$ values, which give different results.
Index
Fitting Linear Models

Symbols
&LogVariance 359

A
Actual by Predicted 419
Adaptive Elastic Net 258
Adaptive Lasso 258
Add 39
added variable plot 189
Adjusted Power 141
Adjusted Power and Confidence Interval 106, 197, 459
AIC 235
algorithms 427
Alpha 105
alternative methods 452
analysis of covariance
   equal slopes, example of specification 59
   unequal slopes, example of specification 60
analysis of covariance example 210
Analysis of Means 123
analysis of means 123
analysis of variance
   one-way, example of specification 53
   two-way, example of specification 54
analysis of variance example 207
Analysis of Variance report 87
Analysis of Variance table 373
ANOM 123, 125
ANOM Graph 125
Approx. F 347
approximate F test 457
Arrhenius transformation 44
ArrheniusInv transformation 44
assess validity 451
assumptions 450–452
Attributes 42

B
Backward 233
Baseball.jmp 222
Bayes Plot 152–226
best linear unbiased predictor 177
between-subject 219, 351
Biased parameter estimate 89, 184
bibliographic references 218
BLUP 177
Box Cox Transformation 160

C
C. Total 88
calculation details 427
calibration 134
canonical axis 344
Canonical Corr 343
canonical correlation 335, 344–345, 457
Canonical Curvature report 82, 216
canonical variables 342
center Polynomials 47
centrroid 458
Centroid Plot 342–343
Centroid Val 343
Cheese.jmp 392
Chi Square 375
Chi-Square 374
Cholesterol.jmp 352
citations 218
classification variable 354
closing JMP Starter window 25
Coding column property 145
column property
   Coding 145
Combine 234, 242
Comparison with Overall Average 123
Compound 341
compound multivariate example 352–354
computational details 427
Conditional Confidence CI 181
Conditional Mean CI 180
Conditional Pred Formula 180
Conditional Pred Values 180
Conditional Residuals 180
confidence interval for least squares mean 95
Confidence Intervals 378
Connecting Letters report 102
Construct Model Effects 39–46
contaminating distribution 152
continuous response model 429
Contour Profiler 364, 366, 419
Contrast 341–342, 350–351, 416
contrast 97
contrast M matrix 341, 351, 456
Contrast Specification window 97
Convergence Score Test 288
Convergence Settings 48
Cook’s D Influence 170
Correlated Response example in Mixed Model 321
Correlation of Estimates 142, 418
Cos Mixtures 138
count data 399
Covariance of Estimates 418
covariance structure 171
Covariance Structure Residual example 300
Covariance Structure, Unstructured example 296
Cp 235
Cp 235
CrabSattelites.jmp 408
Create SAS job 48
Cross 39
cross-product term 239
Crosstab Report 102
Cube Plots
changing layout 160
Cube Plots 160
cumulative logistic probability plot 381
Current Estimates table 237
current predicted value 156
current value 156
Custom 341

Custom Test 118, 342, 416

D
data table of frequencies 399
degrees of freedom 88
Delta 105
DenDF 347
design code 427
design matrix 445
desirability confidence curve 156
Detailed Comparisons Report 102
Detergent.jmp 387
deviance 406
Deviance Residuals by Predicted 419
DF 88, 91, 107, 374
DFE 235
Diabetes.jmp 252
Difference 374
discriminant analysis 335, 354, 458
Dispersion Effects 357–368
distance column 355
Distribution platform 451
Dogs.jmp 350
Dose Response.jmp 380
drag 156
Drug.jmp 212
dummy coding 213, 433
Durbin-Watson Test 164

E
effect 433–450
Effect Leverage
Whole Model reports 79
Effect Leverage 79
Effect Leverage Pairs 170
Effect Screening 144
Standardized Estimate 148
Effect Screening 79
effect size
and Power 195
Effect Tests
LostDFs 91, 185
effective hypothesis tests 437
EigenValue 343
Fitting Linear Models

eigenvalue decomposition 457
Eigvec 343
Elastic Net 258
Emphasis 79
EMS method 118
Enter All 234
Entered 238
epsilon adjustment 349
Equivalence Test 102
Equivalence Test in Mxed Model 305
Equivalence Tests 120, 129
Error 88
error matrix 346
Estimability 94
Estimate 89, 238
estimation methods, Generalized
Regression 258
Exact F 347
Excluded Effect 43
excluded rows 87
Exercise.jmp 345
Exp transformation 44
Expanded Estimates
interpretation 115
Expanded Estimates 114

F

F Ratio 88, 91, 108
F Ratio
in quotes 238
F test, joint 118
factor model 432–450
Factorial Sorted 41
Factorial to Degree 41
Fishing.jmp 268
Fit Group 80
Fit Least Squares
row diagnostics 163
Fit Model 27–68
Add 39
Attributes 42
By 37
Construct Model Effects 39
Cross 39
data table script 33
Degree 37
Emphasis 79
example 30–32
examples of model specifications 50–68
Frequency 38
Keep dialog open 38
launch window 33–39
Macros 41
missing values 48
model effects 39–46
Model Specification options 46
Nest 40
No Intercept 45
Personality 33
Recall 38
Remove 38
Select Columns 37
tabs 45
Transform 44
Transformations 44
validity check 50
Weight 39
Y 37
Fit Model platform 242, 397, 435
analysis of covariance 210
analysis of variance 207
example 158, 214–216, 222–223
expanded estimates 114
logistic regression 369
power analysis 140
stepwise regression
categorical terms 240–242
Fit Statistics report in Mixed Model 287
Fit Y by X platform 369, 394
Fitness.jmp 229
fitting machines 452
fitting principles 429–432
Fixed Effects
tab in Standard Least Squares 46
Football.jmp 241
formulas used in JMP calculations 427
Forward 233
Freq role 372
Frequency
Analysis of Variance report 88
Fit Model 38
frequency data table 399
Fitting Linear Models

Full 374
Full Factorial
   Fit Model Macro 41
Full Factorial 387

G
Gamma 256
Generalized Linear Model
   Personality 36
Generalized Regression
   Ridge Regression 258
   Adaptive Elastic Net 258
   Adaptive Lasso 258
   Distributions 255
   Elastic Net 258
   estimation methods 258
   Maximum Likelihood 258
   Personality 34
   validation methods 259
G-G 349
Go 234, 236
Golf Balls.jmp 337
Goodness of Fit test 376
Greenhouse-Geisser 349

H
H matrix 339, 346, 354, 456
Hats 169
Helmert 341, 350
heredity restriction, stepwise 231
H-F 349
hidden column 363
hierarchical effects 242
Holdback validation, Generalized Regression 259
Hotelling-Lawley Trace 347
Huynh-Feldt 349
hypothesis 454
hypothesis SSCP matrix 346
hypothesis test 437–443, 446

I
Identity 341

Indiv Confidence Interval 365
Individ Confidence Interval 169
Informative Missing, Fit Model 48
Ingots.jmp 371, 380, 399
Ingots2.jmp 399
InjectionMolding.jmp 360
interaction effect 239, 434
Interaction Plots 156
Inverse Prediction 134, 380
inverse prediction 462
Iris.jmp 342
Iteration History report 373, 430

J
JMP Starter 25
JMP tutorials 23
joint F test 118

K
key concepts 452
KFold validation, Generalized Regression 259
Knotted Spline Effect
description 43
   example of specification 68
Knotted Spline Effect 223
Knotted Splines
test for curvature 224
Kruskal-Wallis 452

L
L matrix 456
l1 penalty 258
l2 penalty 258
Lack of Fit
   saturated model 106
   lack of fit error 211
   lack of fit sum of squares 106
   Lack of Fit table 106, 376, 393
   Lasso 258
   layered design 218
   least significant difference 460
   and LSV 460
   least significant number 141, 196, 459
   least significant value 141, 459
Fitting Linear Models

Least Sq Mean 94
least squares fit
   introduction 429
Least Squares Meand plot 95
Least Squares Means 93
Least squares means 93
least squares means 437, 447
Leave-One-Out validation 259
Lenth’s method 112
Lenth’s pseudo standard error 112
Level 94
Leverage Plot 212
   X axis scaling 166
Leverage Plots 164
Likelihood Ratio test 377, 393
Likelihood Ratio Tests 377
limitations of techniques 450–452
linear dependence 438–441
linear models 29
linear rank tests 452
Liver Cancer.jmp 264
Location Effects
   tab in Fit Model 46
Lock 238
Log transformation 44
Logist function 45
Logistic 45
Logistic Percent 45
Logistic platform 369
   example 387–398
   response function 369
Logistic Stepwise Regression 243
LogisticPct 45
Logit Percent 45
LogitPct 45
–LogLikelihood 374
Log-Linear Variance 357
LogLinear Variance
   Personality 35
   tabs in Fit Model 46
Loglinear Variance 359
LogLinear Variance Model 357, 359–368
LogVariance Effect 43
log-variance effect 359
longitudinal data 349
LostDFs 91, 185

LS Means Constrast
   example 98
LS Means Student’s t 99
LS Means Tukey HSD 99
LSMeans Contrast 209
LSN 141, 196, 459
LSV 141, 459

M
M matrix 341, 346, 351, 456
machines of fit 452
Macros 41
Macros 387
Make Model 234, 242–243
MANOVA 218, 347
Manova
   Personality 35
manova 218
Manova test tables 347
Marginal Model Diagnostic Plots 293
Marginal Model Profiling 294
Mauchly criterion 349
Max RSq 108
maximum likelihood 371, 430
Mean 95, 341, 350
mean 429
Mean Confidence Interval 169, 365
Mean Effects
   tab in Fit Model 46
mean model 359–360
Mean of Response 87
Mean Square 88, 107
menu tips 24
Minimal Report 79
missing cells 438–441, 447
   nominal vs. ordinal factor 447–450
missing values
   Fit Model 48
   Standard Least Squares 80
missing values (Fit Model) 80
missing values, Generalized Regression 255
Mixed 233
mixed effects model example 62
mixed effects model, example of
   specification 64
Mixed Model
  calculate confidence limits 289
  Equivalence Test 305
  example 276
  Fixed Effects 281
  Multiple Comparisons 304
  Personality 34
  Random Effects 282
  Repeated Structure 284
  Split Plot example 308
  tabs in Fit Model 46
mixed model 219
  example of specification 65
Mixed Model personality 171
mixed model reports 171
mixed models 171
  BLUP 177
mixed models, DFDen 177
mixed models, Prob > |t| 177
mixed models, standard error 177
mixed models, t Ratio 177
Mixture Effect 43
Mixture Response Surface 41
Model 88
Model 374
Model Dialog 33–39
model effects 39–46
Model Script 33
model specification
  examples 50–68
Model Specification options 46
MSE 235
Multiple Comparison
  Adjustment 120
Multiple Comparisons
  Adjustment 123
  Analysis of Means 123
  ANOM 123
  Quantile 123
Multiple Comparisons in Mixed Model 304
multiple inference 451
multiple linear regression
  example of specification 52
multiple regression example 229
multivariate analysis of variance 35
multivariate least-squares means 342
multivariate mean 335
Multivariate platform 456–459

N
nDF 238
negative log-likelihood 373, 453
Negative Binomial 256
Nest
  example of model specification 40
  Fit Model 40
nested effect 175, 220, 436, 441
nested model
  two levels, example of specification 64
nested random effects model
  single level example 62
No Rules 234
Nominal 375
nominal factor 433, 437–441
Nominal Logistic
  Personality 35
nominal response model 429–431
nonestimable 433
normal distribution 454
Normal Plot 151
Nparm 91
Number 105

O
Observations 87, 375
Odds Ratio 380
Odds Ratio Example 380
Odor Control Original.jmp 214
Offset 411
offset variable 410
one-way analysis of variance
  example of specification 53
opening
  JMP Starter window 25
Ordered Differences Report 102
ordinal crossed model 446
ordinal factor 447
ordinal interaction 445
ordinal least squares means 447
Ordinal Logistic
  Personality 35
Fitting Linear Models

<table>
<thead>
<tr>
<th>Term</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>ordinal logistic regression</td>
<td>392</td>
</tr>
<tr>
<td>ordinal response model</td>
<td>429, 431–432</td>
</tr>
<tr>
<td>Orthog t-Ratio</td>
<td>152</td>
</tr>
<tr>
<td>orthonormal response design matrix</td>
<td>348</td>
</tr>
</tbody>
</table>

**P**

<table>
<thead>
<tr>
<th>Term</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameter</td>
<td>238</td>
</tr>
<tr>
<td>Parameter Estimates</td>
<td>89, 184</td>
</tr>
<tr>
<td>Parameter Estimates table</td>
<td>89, 214, 410</td>
</tr>
<tr>
<td>parameter interpretation</td>
<td>434</td>
</tr>
<tr>
<td>Parameter Power</td>
<td>140</td>
</tr>
<tr>
<td>Parametric Survival</td>
<td>35</td>
</tr>
<tr>
<td>Personality</td>
<td>34, 36</td>
</tr>
<tr>
<td>Pareto Plot</td>
<td>154</td>
</tr>
<tr>
<td>Partial Least Squares</td>
<td>33</td>
</tr>
<tr>
<td>Personality</td>
<td>229</td>
</tr>
<tr>
<td>Pillai’s Trace</td>
<td>347</td>
</tr>
<tr>
<td>Pearson Residuals By Predicted</td>
<td>419</td>
</tr>
<tr>
<td>Plot Actual by Predicted</td>
<td>163, 365</td>
</tr>
<tr>
<td>Plot Effect Leverage</td>
<td>163</td>
</tr>
<tr>
<td>Plot Regression</td>
<td>163</td>
</tr>
<tr>
<td>Plot Residual By Predicted</td>
<td>164</td>
</tr>
<tr>
<td>Plot Residual By Row</td>
<td>164</td>
</tr>
<tr>
<td>Plot Studentized Residual by Predicted</td>
<td>365</td>
</tr>
<tr>
<td>Plot Studentized Residual by Row</td>
<td>365</td>
</tr>
<tr>
<td>Poisson</td>
<td>256</td>
</tr>
<tr>
<td>Polynomial</td>
<td>341, 350</td>
</tr>
<tr>
<td>Polynomial regression model</td>
<td>51</td>
</tr>
<tr>
<td>one variable, example of model specification</td>
<td>51</td>
</tr>
<tr>
<td>two variables, example of model specification</td>
<td>52</td>
</tr>
<tr>
<td>Polynomial to Degree</td>
<td>41</td>
</tr>
<tr>
<td>FitModel Macro</td>
<td>41</td>
</tr>
<tr>
<td>one variable, example of model specification</td>
<td>51</td>
</tr>
<tr>
<td>two variables, example of model specification</td>
<td>52</td>
</tr>
<tr>
<td>Power</td>
<td>197</td>
</tr>
<tr>
<td>Power Analysis</td>
<td>140, 199, 459</td>
</tr>
<tr>
<td>Predicted Values</td>
<td>169</td>
</tr>
<tr>
<td>Prediction Formula</td>
<td>169, 364</td>
</tr>
<tr>
<td>prediction formula</td>
<td>383, 432–446</td>
</tr>
<tr>
<td>Prediction Profiler</td>
<td>156</td>
</tr>
<tr>
<td>Press</td>
<td>164</td>
</tr>
<tr>
<td>pressure cylinders fitting machine</td>
<td>455</td>
</tr>
<tr>
<td>Prob to Enter</td>
<td>233</td>
</tr>
<tr>
<td>Prob to Leave</td>
<td>233</td>
</tr>
<tr>
<td>Prob&gt;</td>
<td>t</td>
</tr>
<tr>
<td>Prob&gt;ChiSq</td>
<td>375</td>
</tr>
<tr>
<td>Prob&gt;F</td>
<td>89, 91, 108, 347</td>
</tr>
<tr>
<td>Prob&gt;F in quotes</td>
<td>238</td>
</tr>
<tr>
<td>Profile</td>
<td>341, 350</td>
</tr>
<tr>
<td>Proportion</td>
<td>35</td>
</tr>
<tr>
<td>Proportional Hazards</td>
<td>36</td>
</tr>
<tr>
<td>Personality</td>
<td>35</td>
</tr>
<tr>
<td>Prospective power analysis</td>
<td>199</td>
</tr>
<tr>
<td>PSE</td>
<td>112</td>
</tr>
<tr>
<td>pure error sum of squares</td>
<td>106</td>
</tr>
</tbody>
</table>

**Q**

<table>
<thead>
<tr>
<th>Term</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>quadratic ordinal logistic regression</td>
<td>397</td>
</tr>
</tbody>
</table>

**R**

<table>
<thead>
<tr>
<th>Term</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radial smoother</td>
<td>42</td>
</tr>
<tr>
<td>Random Effect</td>
<td>42</td>
</tr>
<tr>
<td>Random Effect</td>
<td>229</td>
</tr>
<tr>
<td>random effect model reports</td>
<td>171</td>
</tr>
<tr>
<td>random effect models</td>
<td>171</td>
</tr>
<tr>
<td>Random Effects</td>
<td>118</td>
</tr>
<tr>
<td>random effects</td>
<td>218</td>
</tr>
<tr>
<td>random effects model</td>
<td>172</td>
</tr>
<tr>
<td>Range Odds Ratios</td>
<td>379</td>
</tr>
<tr>
<td>Reactor.jmp</td>
<td>239</td>
</tr>
<tr>
<td>Reciprocal transformation</td>
<td>44</td>
</tr>
<tr>
<td>Reduced</td>
<td>374</td>
</tr>
</tbody>
</table>
references 218
Regression Model for AR(1) Model  
example 306
Regression Plot 163
relative significance 450
REML (Recommended) 222
REML method 118
Remove All 234
Repeated Measures 341
repeated measures  
example of specification 65
repeated measures design 335
example 349, 352–354
example of specification 65
Repeated Measures example 295
residual matrix 346
Residuals 169, 365
residuals 218, 429
response models 429–432
Response Specification dialog 340
Response Surface  
Fit Model Macro 41
Response Surface 395
response surface 215–216
Response Surface Effect 42
response surface model  
example of specification 66
Restrict 234, 242
restricted vs. unrestricted  
parameterization 175
retrospective power analysis 140
Ridge regression 258
RMSE 105
ROC 384
Root Mean Square Error 87
row diagnostics 163
Roy’s Maximum Root 347
RSquare 86, 235
RSquare (U) 375
RSquare Adj 87, 235
Rules 234
Run Model 372, 396

S
Salt in Popcorn.jmp 397
SAS GLM procedure 427, 429–443

Save 383, 451
Save Best Transformation 161
Save Canonical Scores 342
Save Coding Table 171
Save Columns 419
Save Discrim 354, 458
Save Expected Values 383–384
Save Probability Formula 383
Save Quantiles 383–384
Save Std Error of Predicted 170
Save to Data Table 47
Save to Script Window 47
Scale Effects  
tab in Fit Model 46
Scheffé Cubic 42
Sequential Tests 117
Set Alpha Level 47
Ship 410
Ship Damage.JMP 410
Show Prediction Expression 110
Sigma 105
significance probability  
stepwise regression 229
simple linear regression  
example of specification 50
singularity 438–441, 447
Singularity Details 183
Solution Path report 253, 261
Solution table 215
Solve for Least Significant Number 105
Solve for Least Significant Value 105
Solve for Power 105
Source 88, 91, 106
sources 218
Spatial Example, Mixed Model 314
sphericity 348–349
split plot  
example of specification 65
split plot design  
example 219
Split-plot example in Mixed Model 308
spring fitting machine 453–454
Sqrt transformation 44
Square transformation 44
Squish function 45
SS 238
Fitting Linear Models

SSE 234
Stack 399
Standard Least Squares
  Personality 34
tabs in Fit Model 46
standardized beta 90
Standardized Estimate 148
statistical details 427
Std 177
Std Dev Formula 364
Std Error 89, 94
Std Error of Individual 365
Std Error of Predicted 170, 365
Std Error of Residual 170
StdErr Pred Formula 170
Step 234
Stepwise
  Personality 34
stepwise
  heredity 231
stepwise regression 229, 242
categorical terms 240–242
  example 229, 236–237, 240
Logistic 243
Stop 234
Studentized Deviance Residuals by Predicted 419
Studentized Pearson Residuals by Predicted 419
Studentized Residuals 169, 365
Submit to SAS 48
subunit effect 218
Sum 341, 349–351
sum M matrix 351
Sum of Squares 88, 91, 107
Sum of Weights 87
Sum Wgts 375
Summary of Fit report 86
Surface Profiler 364, 366, 419

Test Each Column Separately Also 340
Test Slices 103
three-way full factorial model
  example of specification 57
tooltips 24
Transform
  Fit Model 44
tutorial examples
  analysis of covariance 210
  compound multivariate model 352–354
  contour profiler 158
  logistic regression 387–398
  multiple regression 229
  one-way Anova 207
  random effects 222–223
  repeated measures 349, 352–354
  response surface 214–216
  split plot design 219
  stepwise regression 229, 236–237, 240
tutorials 23
two-way analysis of variance
  example of specification 54
  with interaction, example of specification 55
Type I sums of squares 117
Type I tests 117
Types III and IV hypotheses 437

U
Unbounded Variance Components in Mixed Model 289
uncertainty 452
Unit Odds Ratios 379
Univariate Tests Also 340, 351
unrestricted vs. restricted parameterization 175
usual assumptions 450–452

V
validation methods, Generalized
  Regression 259
validity 451
Value 347
variance component model 172
variance components 175, 218

T
  t Ratio 89
  Taguchi 359
  Term 89
  Test 347
  Test Details 342–343
Variance Effect Likelihood Ratio Tests 364
Variance Effects
  tab in Fit Model 46
Variance Formula 364
Variance Parameter Estimates 363
VIF 90

W-Z
Wald test 377, 393
Weight
  Analysis of Variance report 88
  Fit Model 39
Whole Effects 234
Whole Model reports 79
Whole Model table 346, 373
Wilcoxon rank-sum 452
Wilks' Lambda 347
within-subject 219, 349, 351
zero eigenvalue 83, 216
zeroed 433
Zeroed parameter estimate 89, 184
Zero-Inflated Negative Binomial 256
Zero-Inflated Poisson 256