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Lattice

Multivariate Data Visualization with R

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To Pinaki Mitra

Preface

The lattice package is software that extends the R language and environment for statistical computing (R Development Core Team, 2007) by providing a coherent set of tools to produce statistical graphics with an emphasis on multivariate data. It is modeled on the Trellis suite in S and S-PLUS®. From the user's point of view, it is a self-contained system that is largely independent of other graphics facilities in R. This book is about lattice, and is primarily intended for (1) both long-time and new R users looking for a powerful system to produce conventional statistical graphics, (2) existing lattice users willing to learn a little bit of R programming to gain increased flexibility, and (3) developers who wish to implement new graphical displays building on the infrastructure already available in lattice.

Why lattice?

Graphics can effectively complement statistical data analysis in various ways. Successful graphics arise from a combination of good design and good implementation. In this day and age, implementation is almost exclusively driven by computers. There is no lack of software tools that allow their users to convert data into graphics; lattice is yet another candidate in this ever-widening pool.

What makes lattice stand out? A good general-purpose tool should not get in the way of the user, yet it should be flexible enough to enable most tasks (without undue difficulty), whether it be standard, slightly out of the ordinary, or entirely novel. lattice tries to meet this standard by being a high-level tool that produces structured graphics, while retaining flexibility by systematically decoupling the various elements of a display; the individual elements have well thought-out defaults, but these can be overridden for detailed control. The end-product is a system that allows the creation of common statistical graphics, often with fairly complex structure, with very simple code. At the same time, it allows various degrees of customization, without requiring undue effort.

What to expect from this book

It is easy to get started with lattice, but the transition from seemingly simple to more sophisticated use can be difficult without an appreciation of how the different components and their defaults interact with each other. This appreciation can only come from experience, but it is hoped that this book can ease the transition to some extent.

The book started out as a manual for lattice, and was not intended to offer qualitative guidelines about the effective design of statistical graphics. This plan was abandoned quite early on; a static book is not the ideal vehicle for documenting an evolving system, and it is hard to look at and change bits and pieces of a picture without discussing its merits and drawbacks. In the end, this book consists of some comments on graphical design, some interesting (one would hope) examples, and large doses of lattice code and wisdom. It is still a book that is primarily about software; the code in the book is at least as important as the pictures. No code is hidden in this book, and if there is one key message that the reader should expect to take away, it is that lattice allows the creation of complex displays using relatively little code. This economy may not be appealing to everyone, but it is what I liked most about the Trellis system, and what has driven much of the development of lattice beyond the original goal of compatibility with Trellis. The other key idea that is difficult to communicate in function documentation, and one that is addressed in this book, is that of interrelationships between the different components of lattice, and how they can be effectively exploited.

What not to expect from this book

This book is not an exhaustive manual for lattice. Most functions in lattice are described to some extent in this book, but it does not serve as the definitive reference. There are two reasons for this. First, there are many features in lattice that are obscure and of very limited use, and do not justify detailed discussion. Second, lattice is an evolving system, and any attempt to document it exhaustively is sure to get out of date quickly. All functions in lattice come with online documentation, which should be used as the definitive reference.

How to read this book

That depends to a large extent on the reader. Those new to lattice should start with Chapter 1 to get a feel for what lattice is all about. Chapter 2 gives a more thorough, and sometimes quite technical, overview of the lattice model. Intermediate to advanced readers should find this chapter instructive. Beginners are encouraged to go through it as well, but should be prepared to encounter parts they find difficult, and skip them without getting bogged down; things should become clearer after gaining some practical experience.

The rest of Part I describes the various high-level functions in lattice. These chapters can be read in any order. Not much is said about the design of these graphics as they are standard, and most of the focus is on the software implementation. The level is basic for the most part; however, a few examples do go into some detail for the sake of taking a discussion to its natural conclusion. Again, beginners should be prepared to skip these parts during a first reading. Part II is more of a reference, going into the nitty-gritty details of lattice. A basic understanding of all the chapters is important to get the most out of lattice, but is not essential for casual use. These chapters too can be read in any order, for the most part, and the reader should feel free to pick and choose. The final two chapters, in Part III, deal with extensions to lattice, and are primarily intended for future developers. Of course, they can still be useful to the casual reader for the examples they provide.

It is important to realize that lattice is a complicated piece of software, and it is unrealistic to expect full mastery of it after one reading. The key to "getting it" is practical experience, and the best way to gain that experience is to try out the code. All the code in this book, along with the figures they produce, is available from the supporting Web site

`http://lmdvr.r-forge.r-project.org/`

A critical aspect of graphics that is hard to communicate in a book is its iterative nature; graphics that are presented to an audience is rarely the result of a first attempt. This process is reflected in some of the examples in this book, but many others have silently omitted many intermediate steps. One can get a sense of these missing steps by asking: "What is the purpose of this particular argument?" In other words, trying out variations of the code should be an integral part of the learning process.

The final thing to remember is that all this is the means to an end, namely, producing effective visualizations of data. Software can help, but the ultimate decisions are still the responsibility of the user. For those looking for guidance on how to create effective graphs, the work of Edward R. Tufte, William S. Cleveland, and of course John W. Tukey, are invaluable resources.

Color

Color can be an important factor in the visual impact of a graphic. Most figures in this book are black and white, but a few color plates are also included. Of these, some have the corresponding black and white versions as well, and have been chosen to highlight the impact of color. Others are solely available in color, as their black and white versions are of little or no use. Color versions of all figures are available on the book's Web site.

Prerequisites

No prior experience with lattice is required to read this book, but basic familiarity with R, and in particular the ability to use its online help system, is

assumed. The first chapter of Dalgaard (2002) should suffice for the most part. Relatively advanced concepts such as generic functions and method dispatch are relevant, but can be ignored for casual use (these concepts are briefly introduced where relevant, but not at any deep level). No familiarity with traditional R graphics is presumed. Knowledge of the grid package can be beneficial, but is not essential.

Several R packages are used in this book. lattice itself should come with all recent installations of R, and it should be sufficient to type

```
> library("lattice")
```

at the R prompt to start using it. Other packages used explicitly (not counting further dependencies) are grid, latticeExtra, copula, ellipse, gridBase, flowViz, flowCore, hexbin, locfit, logspline, mapproj, maps, MASS, MEMSS, mlmRev, and RColorBrewer. All of these may not be of interest (some are required just for one or two examples); type

```
> help("install.packages")
```

to learn how to install the packages you need from CRAN.[1] flowCore, flowViz, and hexbin are Bioconductor packages, and may be installed by typing

```
> source("http://bioconductor.org/biocLite.R")
> biocLite(c("flowCore", "flowViz", "hexbin"))
```

A bit of history

The design of S graphics has been heavily influenced by the principles of graph construction laid out in *The Elements of Graphing Data* (Cleveland, 1985). This influence carries over to Trellis graphics, which incorporates further ideas (notably multipanel conditioning and banking) presented in *Visualizing Data* (Cleveland, 1993). Trellis graphics was first implemented in the S system, and has been available in S-PLUS for several years.

The name Trellis refers both to the general ideas underlying the system, as well as the specific implementation in S. The lattice package is an independent implementation of Trellis graphics (in the first sense), with an API closely modeled on the one in S. Unlike the S version, which is implemented using traditional graphics, lattice uses Paul Murrell's grid package, which provides more flexible low-level tools.

Although modeled on it, the lattice API is not identical to that of the Trellis suite in S. Some of the differences are due to the choice of grid as the underlying engine, but many are intentional. Still, where possible, effort has been made to allow Trellis code written in S to run with minimal modification. Consequently, writings about the original Trellis suite mostly apply to lattice as well. This includes the wealth of resources at the Trellis Web site at Bell Labs:

[1] The Comprehensive R Archive Network, `http://cran.r-project.org`

`http://netlib.bell-labs.com/cm/ms/departments/sia/project/trellis/`

However, the converse is not true. lattice has been extended beyond the original API in various ways, and is now at a point where it is difficult to partition its feature set into S-compatible ones and additional enhancements. For this reason, this book makes no attempt to distinguish between these, and presents Trellis graphics solely as implemented in the lattice package.

Caveats and alternatives

No system is perfect for all uses, and lattice is no exception. Trellis is a "high-level" paradigm by design, and lattice imposes considerable structure on the displays it creates. lattice allows a lot of wiggle room within these constraints while retaining its stylistic consistency and simple user interface, but this is not always enough. Fortunately, R provides excellent facilities for creating new displays from scratch, especially using the grid package. lattice itself is implemented using grid, and can benefit from the use of low-level facilities provided by it. Even for high-level graphics, R provides various alternatives. The traditional graphics system includes many high-level tools, which although not as proficient in dealing with multivariate data, often provide a richer set of options. Murrell (2005) gives a comprehensive overview of both traditional R graphics and grid graphics (as well as a brief introduction to lattice). The vcd package, inspired by Friendly (2000), provides many useful tools for categorical data, often with Trellis-style conditioning. Another high-level alternative is Hadley Wickham's ggplot2 (formerly ggplot) package, modeled on the approach of Wilkinson (1999), which is philosophically rather different from the Trellis approach. Like lattice, vcd and ggplot are also implemented using grid.

One thing R currently has virtually no support for is interactive graphics. Fortunately, some R packages provide interfaces to external systems that are better, notably rgl (OpenGL) and rggobi (GGobi). The playwith package written by Felix Andrews provides a modicum of interactivity within the R graphics framework, and works well with displays produced by lattice.

Acknowledgements

Ross Ihaka and Paul Murrell are the primary architects of the graphics infrastructure in R that lattice builds upon; lattice would have been particularly difficult to write without Paul's grid package. The lattice API is modeled on the original implementation of Trellis graphics in S. Implementing software is nowhere near as difficult as designing it, and the success of lattice owes much to the insight of the original designers. R is the wonderful platform that it is due to the efforts of its developer team and its vibrant user community, whose feedback has also driven much of the development of lattice beyond its

original goals. My own introduction to R was eased by encouragement and guidance from Doug Bates and Saikat DebRoy.

Thanks to John Kimmel and Doug Bates for convincing me to start writing this book, and to Robert Gentleman for providing a wonderful environment in which to finish it. Several friends and colleagues commented on drafts of the book and the supporting Web site. Feedback from Springer's anonymous reviewers, and in particular John Maindonald, has been extremely valuable. On a technical note, this book was written on a number of different computers running Debian® GNU/Linux®, using the combination of Sweave and LaTeX as a document preparation system. The use of Emacs+ESS as the editing environment has improved productivity considerably.

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