grid Graphics

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grid is a low-level graphics system which provides a great deal of control and flexibility in the appearance and arrangement of graphical output. grid does not provide high-level functions which create complete plots. What it does provide is a basis for developing such high-level functions (e.g., the lattice package), the facilities for customising and manipulating lattice output, the ability to produce high-level plots or non-statistical images from scratch, and the ability to add sophisticated annotations to the output from base graphics functions (see the gridBase package).

This document provides an introduction to the fundamental concepts underlying the grid package: **viewports**, **units**, and **graphical parameters**. There are also several examples to demonstrate what can be achieved and how to achieve it.

The description of the fundamental grid concepts is predicated on the following approach to constructing a statistical graphic (plot). You must be able to:

1. create and control different graphical regions and coordinate systems.
2. control which graphical region and coordinate system graphical output goes into.
3. produce graphical output (lines, points, text, ...) including controlling its appearance (colour, line type, line width, ...).

1 Creating and Controlling Graphics Regions and Coordinate Systems

In grid there can be any number of graphics regions. A graphics region is referred to as a *viewport* and is created using the viewport() function. A viewport can be positioned anywhere on a graphics device (page, window, ...), it can be rotated, and it can be clipped to. The following code describes a viewport which is centred within the page, and is half the width of the page, one quarter of the height of the page, and rotated 45°; Figure 1 shows a diagram of this viewport.

```
> viewport(x = 0.5, y = 0.5, width = 0.5, height = 0.25,
+     angle = 45)
```

The object returned by the `viewport()` function is only a *description* of a graphics region. A graphics region is only created on a graphics device when a viewport is "pushed" onto that device. This is achieved using the `pushViewport()` function. Each device has only one "current viewport" (by default this is the entire device), but it maintains a "tree" of viewports that have been pushed. The current viewport is a node on the viewport tree. The `pushViewport()` function adds a viewport as a leaf of the tree – the previous "current viewport" becomes the parent of this leaf and the new leaf becomes the current viewport. The `popViewport()` function prunes the current viewport (and all its children) from the tree – the parent of the pruned leaf becomes the current viewport. The function `upViewport()` acts like `popViewport()` in terms of setting the current viewport, but does not prune the previous "current viewport". The `downViewport()` function navigates down the tree to a viewport which has been specified by name (it adds no new viewports to the tree). This means that there is always only one graphics region to draw into, but it is possible to return to a previous graphics region through the appropriate set of push/pop/up/down operations.

As an example, the following code creates a graphics region in the top-left corner of the page using `pushViewport()`. This viewport is given the name `"vp1"`. It then does some drawing and calls `upViewport()` to return to the root of the viewport tree. Next, it creates another region in the bottom-right corner of the page (again using `pushViewport()`) and does some drawing there. Finally, it performs an `upViewport()` to the root of the tree and a `downViewport()` to return to the first graphics region and does some more drawing there (see Figure 2).

```
> grid.rect(gp = gpar(lty = "dashed"))
> vp1 <- viewport(x = 0, y = 0.5, w = 0.5, h = 0.5,
+     just = c("left", "bottom"), name = "vp1")
> vp2 <- viewport(x = 0.5, y = 0, w = 0.5, h = 0.5,
+     just = c("left", "bottom"))
> pushViewport(vp1)
> grid.rect(gp = gpar(col = "grey"))
> grid.text("Some drawing in graphics region 1",
+     y = 0.8)
> upViewport()
> pushViewport(vp2)
> grid.rect(gp = gpar(col = "grey"))
> grid.text("Some drawing in graphics region 2",
+     y = 0.8)
> upViewport()
> downViewport("vp1")
> grid.text("MORE drawing in graphics region 1",
+     y = 0.2)
> popViewport()
```

When several viewports are pushed onto the viewport tree, leaf viewports are located and sized within the context of their parent viewports. The following code gives an example; a viewport is defined which is one-quarter the size of its parent (half the width and half the height), and this viewport is pushed twice. The first time it gets pushed the parent is the root of the viewport tree (which is the entire device) so it is quarter of the size of the page. The second time the viewport is pushed, it is quarter of the size of *its parent viewport*. Figure 3 shows the output of these commands.

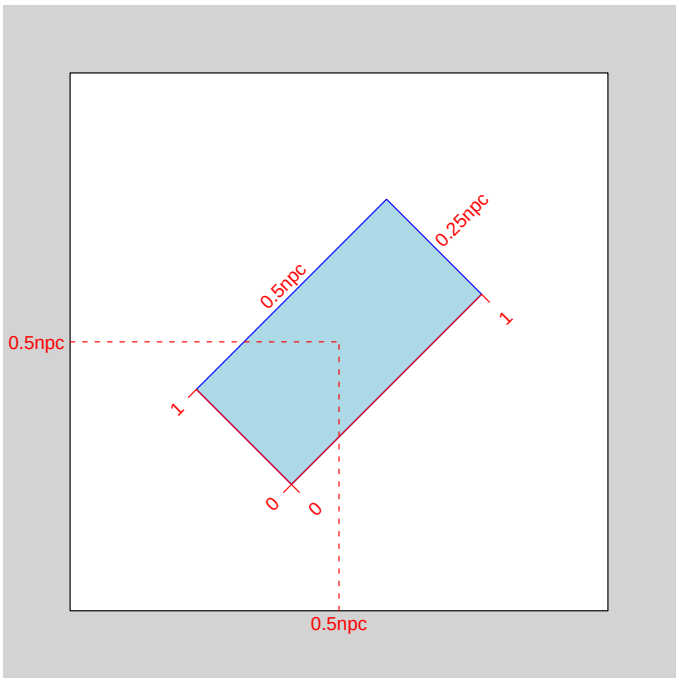

Figure 1: A diagram of a simple `grid` viewport (produced using the `grid.show.viewport()` function.

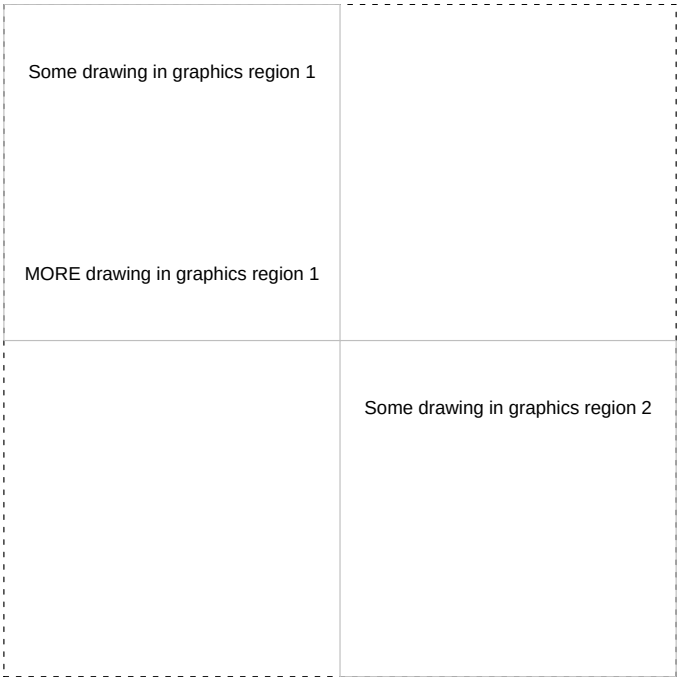

Figure 2: Defining and drawing in multiple graphics regions.

```
> grid.rect(gp = gpar(lty = "dashed"))
> vp <- viewport(width = 0.5, height = 0.5)
> pushViewport(vp)
> grid.rect(gp = gpar(col = "grey"))
> grid.text("quarter of the page", y = 0.85)
> pushViewport(vp)
> grid.rect()
> grid.text("quarter of the\nprevious viewport")
> popViewport(2)
```

Each viewport has a number of coordinate systems available. The full set is described in Table 1, but there are four main types: absolute coordinates (e.g., "inches", "cm") allow locations and sizes in terms of physical coordinates – there is no dependence on the size of the page; normalised coordinates (e.g., "npc") allow locations and sizes as a proportion of the page size (or the current viewport); relative coordinates (i.e., "native") allow locations and sizes relative to a user-defined set of x- and y-ranges; referential coordinates (e.g., "strwidth") where locations and sizes are based on the size of some other graphical object.

It is possible to specify the coordinate system for relative coordinates, but all other coordinate systems are implicitly defined based on the location and size of the viewport and/or the size of other graphical objects.

2 Directing Graphics Output into Different Graphics Regions and Coordinate Systems

Graphics output is always relative to the current viewport (on the current device). Selecting which region you want is a matter of push/pop/up/downing the appropriate viewports. However, that is not all; every viewport has a number of coordinate systems associated with it, so it is also necessary to select the coordinate system that you want to work with.

The selection of which coordinate system to use within the current viewport is made using the `unit()` function. The `unit()` function creates an object which is a combination of a value and a coordinate system (plus some extra information for certain coordinate systems). Here are some examples from the `help(unit)` page:

```
> unit(1, "npc")

[1] 1npc

> unit(1:3/4, "npc")

[1] 0.25npc 0.5npc  0.75npc

> unit(1:3/4, "npc")[2]

[1] 0.5npc
```

Coordinate System Name	Description
`"npc"`	Normalised Parent Coordinates. Treats the bottom-left corner of the current viewport as the location $(0, 0)$ and the top-right corner as $(1, 1)$.
`"native"`	Locations and sizes are relative to the x- and y-scales for the current viewport.
`"inches"`	Locations and sizes are in terms of physical inches. For locations, $(0, 0)$ is at the bottom-left of the viewport.
`"cm"`	Same as `"inches"`, except in centimetres.
`"mm"`	Millimetres.
`"points"`	Points. There are 72.27 points per inch.
`"bigpts"`	Big points. There are 72 big points per inch.
`"picas"`	Picas. There are 12 points per pica.
`"dida"`	Dida. 1157 dida equals 1238 points.
`"cicero"`	Cicero. There are 12 dida per cicero.
`"scaledpts"`	Scaled points. There are 65536 scaled points per point.
`"char"`	Locations and sizes are specified in terms of multiples of the current nominal `fontheight`.
`"lines"`	Locations and sizes are specified in terms of multiples of the height of a line of text (dependent on both the current `fontsize` and the current `lineheight`).
`"snpc"`	Square Normalised Parent Coordinates. Locations and size are expressed as a proportion of the *smaller* of the width and height of the current viewport.
`"strwidth"`	Locations and sizes are expressed as multiples of the width of a given string (dependent on the string and the current `fontsize`).
`"strheight"`	Locations and sizes are expressed as multiples of the height of a given string (dependent on the string and the current `fontsize`).
`"grobwidth"`	Locations and sizes are expressed as multiples of the width of a given graphical object (dependent on the current state of the graphical object).
`"grobheight"`	Locations and sizes are expressed as multiples of the height of a given graphical object (dependent on the current state of the graphical object).

Table 1: The full set of coordinate systems available in `grid` viewports.

```
> unit(1:3/4, "npc") + unit(1, "inches")

[1] 0.25npc+1inches 0.5npc+1inches  0.75npc+1inches

> min(unit(0.5, "npc"), unit(1, "inches"))

[1] min(0.5npc, 1inches)

> unit.c(unit(0.5, "npc"), unit(2, "inches") + unit(1:3/4,
+     "npc"), unit(1, "strwidth", "hi there"))

[1] 0.5npc          2inches+0.25npc 2inches+0.5npc
[4] 2inches+0.75npc 1strwidth
```

Notice that unit objects are treated much like numeric vectors. You can index a unit object, it is possible to do simple arithmetic (including `min` and `max`), and there are several unit-versions of common functions (e.g., `unit.c`, `unit.rep`, and `unit.length`; `unit.pmin`, and `unit.pmax`)).

`grid` functions that have arguments specifying locations and sizes typically assume a default coordinate system is being used. Most often this default is "npc". In other words, if a raw numeric value, `x`, is specified this is implicitly taken to mean `unit(x, "npc")`. The `viewport()` function is one that assumes "npc" coordinates, so in all of the viewport examples to this point, we have only used "npc" coordinates to position viewports within the page or within each other. It is also possible to position viewports using any of the coordinate systems described in Table 1.

As an example, the following code makes use of `"npc"`, `"native"`, `"inches"`, and `"strwidth"` coordinates. It first pushes a viewport with a user-defined x-scale, then pushes another viewport which is centred at the x-value 60 and half-way up the first viewport, and is 3 inches high[1] and as wide as the text "coordinates for everyone". Figure 4 shows the resulting output.

```
> pushViewport(viewport(y = unit(3, "lines"), width = 0.9,
+     height = 0.8, just = "bottom", xscale = c(0,
+         100)))
> grid.rect(gp = gpar(col = "grey"))
> grid.xaxis()
> pushViewport(viewport(x = unit(60, "native"),
+     y = unit(0.5, "npc"), width = unit(1, "strwidth",
+         "coordinates for everyone"), height = unit(3,
+         "inches")))
> grid.rect()
> grid.text("coordinates for everyone")
> popViewport(2)
```

[1] If you want to check the figure, the scaling factor is 3.5/6 (i.e., the rectangle in the figure should be 1.75" or 3.94cm high).

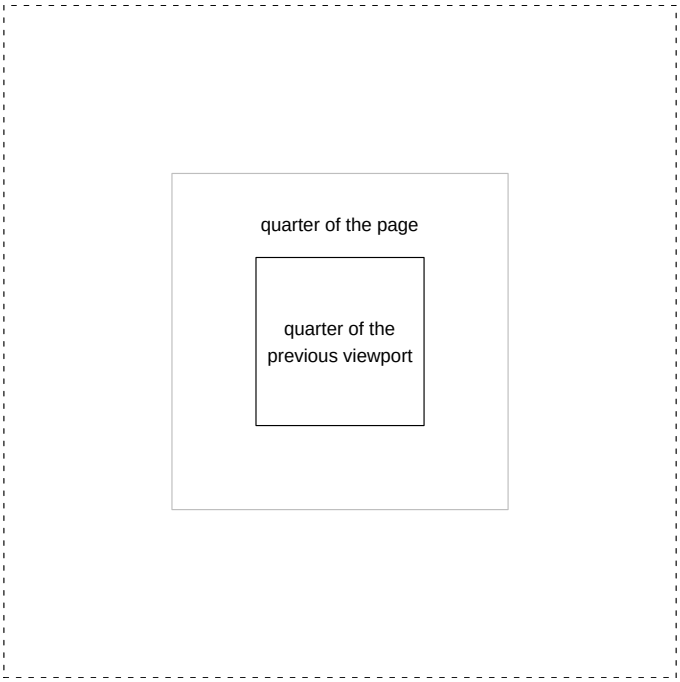

Figure 3: The result of pushing the same viewport onto the viewport stack twice.

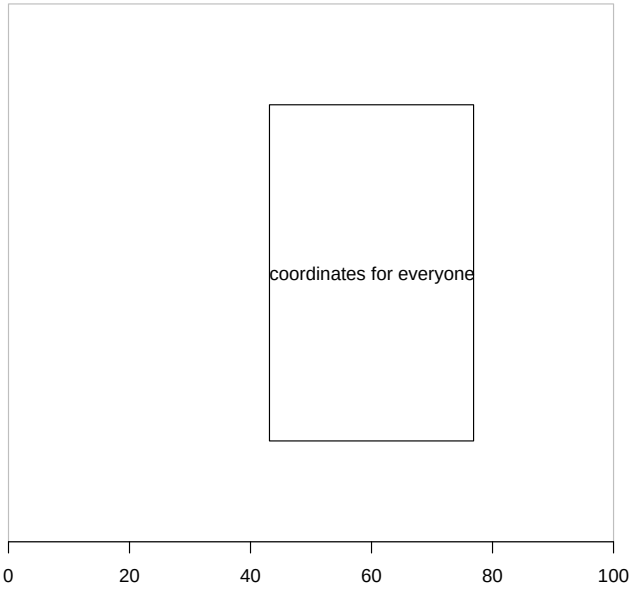

Figure 4: A viewport positioned using a variety of coordinate systems.

2.1 Layouts

grid provides an alternative method for positioning viewports within each other based on *layouts*[2]. A layout may be specified for any viewport. Any viewport pushed immediately after a viewport containing a layout may specify its location with respect to that layout. In the following simple example, a viewport is pushed with a layout with 4 rows and 5 columns, then another viewport is pushed which occupies the second and third columns of the third row of the layout.

```
> pushViewport(viewport(layout = grid.layout(4,
+     5)))
> grid.rect(gp = gpar(col = "grey"))
> grid.segments(c(1:4/5, rep(0, 3)), c(rep(0, 4),
+     1:3/4), c(1:4/5, rep(1, 3)), c(rep(1, 4),
+     1:3/4), gp = gpar(col = "grey"))
> pushViewport(viewport(layout.pos.col = 2:3, layout.pos.row = 3))
> grid.rect(gp = gpar(lwd = 3))
> popViewport(2)
```

Layouts introduce a special sort of unit called "null". These can be used in layouts to specify relative column-widths or row-heights. In the following, slightly more complex, example, the layout specifies something similar to a standard plot arrangement; there are bottom and left margins 3 lines of text wide, top and right margins 1cm wide, and two rows and columns within these margins where the bottom row is twice the height of the top row (see Figure 6).

```
> grid.show.layout(grid.layout(4, 4, widths = unit(c(3,
+     1, 1, 1), c("lines", "null", "null", "cm")),
+     heights = c(1, 1, 2, 3), c("cm", "null", "null",
+         "lines")))
```

3 Producing Graphics Output

grid provides a standard set of graphical primitives: lines, text, points, rectangles, polygons, and circles. There are also two higher level components: x- and y-axes. Table 2 lists the grid functions that produce these primitives.

NOTE: all of these graphical primitives are available in all graphical regions and coordinate systems.

3.1 Controlling the Appearance of Graphics Output

grid recognises a fixed set of graphical parameters for modifying the appearance of graphical output (see Table 3).

[2]The primary reference for layouts is [**?**]. Layouts in grid represent an extension of the idea to allow

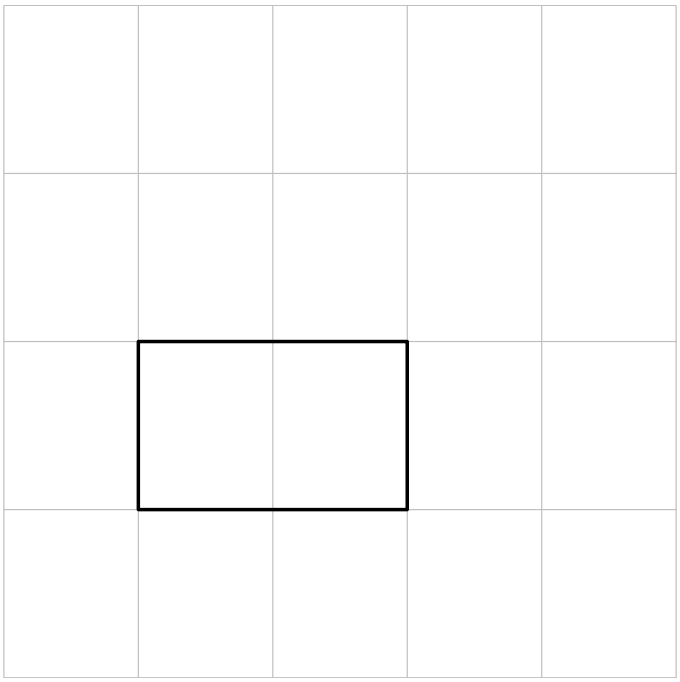

Figure 5: A viewport positioned using a layout.

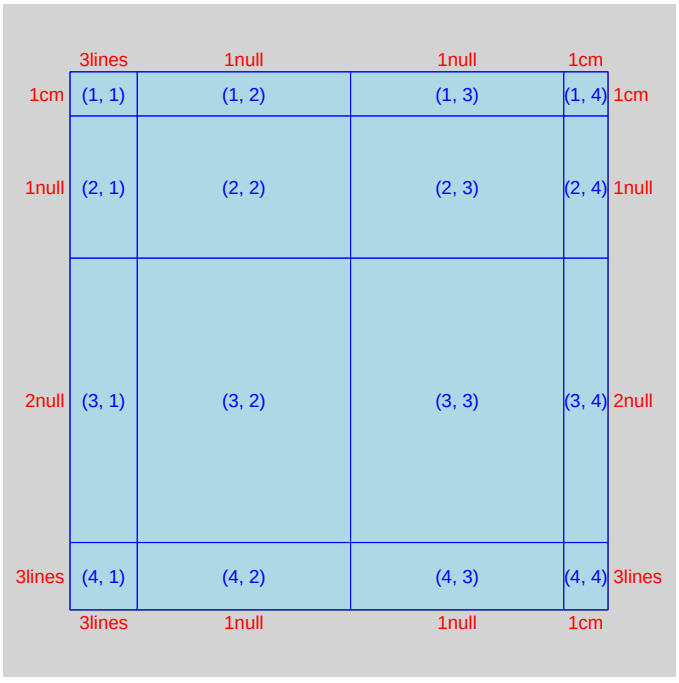

Figure 6: A more complex layout.

grid.text	Can specify angle of rotation.
grid.rect	
grid.circle	
grid.polygon	
grid.points	Can specify type of plotting symbol.
grid.lines	
grid.segments	
grid.arrows	Can add these to lines, segments, and line.to's
grid.grill	Convenience function for drawing grid lines
grid.move.to	
grid.line.to	
grid.xaxis	Top or bottom axis
grid.yaxis	Left or right axis

Table 2: grid graphical primitives.

col	colour of lines, text, ...
fill	colour for filling rectangles, circles, polygons, ...
lwd	line width
lty	line type
fontsize	The size of text (in points)
fontface	The font face (bold, italic, ...)
fontfamily	The font family

Table 3: grid graphical parameters.

Graphical parameter settings may be specified for both viewports and graphical objects. A graphical parameter setting for a viewport will hold for all graphical output within that viewport *and* for all viewports subsequently pushed onto the viewport stack, *unless* the graphical object or viewport specifies a different parameter setting.

A description of graphical parameter settings is created using the gpar() function, and this description is associated with a viewport or a graphical object via the gp argument. The following code demonstrates the effect of graphical parameter settings (see Figure 7).

```
> pushViewport(viewport(gp = gpar(fill = "grey",
+     fontface = "italic")))
> grid.rect()
> grid.rect(width = 0.8, height = 0.6, gp = gpar(fill = "white"))
> grid.text(paste("This text and the inner rectangle",
+     "have specified their own gpar settings",
+     sep = "\n"), y = 0.75, gp = gpar(fontface = "plain"))
> grid.text(paste("This text and the outer rectangle",
+     "accept the gpar settings of the viewport",
```

a greater range of units for specifying row heights and column widths. grid also differs in the way that children of the layout specify their location within the layout.

```
+     sep = "\n"), y = 0.25)
> popViewport()
```

Examples

The remaining sections provide some code examples of the use of `grid`.

The first example constructs a simple scatterplot from first principles. Just like in base graphics, it is quite straightforward to create a simple plot by hand. The following code produces the equivalent of a standard `plot(1:10)` (see Figure 8).

```
> grid.rect(gp = gpar(lty = "dashed"))
> x <- y <- 1:10
> pushViewport(plotViewport(c(5.1, 4.1, 4.1, 2.1)))
> pushViewport(dataViewport(x, y))
> grid.rect()
> grid.xaxis()
> grid.yaxis()
> grid.points(x, y)
> grid.text("1:10", x = unit(-3, "lines"), rot = 90)
> popViewport(2)
```

Now consider a more complex example, where we create a barplot with a legend (see Figure 9). There are two main parts to this because grid has no predefined barplot function; the construction of the barplot will itself be instructive, so we will start with just that.

The data to be plotted are as follows: we have four measures to represent at four levels; the data are in a matrix with the measures for each level in a column.

```
> barData <- matrix(sample(1:4, 16, replace = T),
+     ncol = 4)
```

We will use colours to differentiate the measures.

```
> boxColours <- 1:4
```

We create the barplot within a function so that we can easily reproduce it when we combine it with the legend.

```
> bp <- function(barData) {
+     nbars <- dim(barData)[2]
+     nmeasures <- dim(barData)[1]
+     barTotals <- rbind(rep(0, nbars), apply(barData,
+         2, cumsum))
+     barYscale <- c(0, max(barTotals) * 1.05)
```

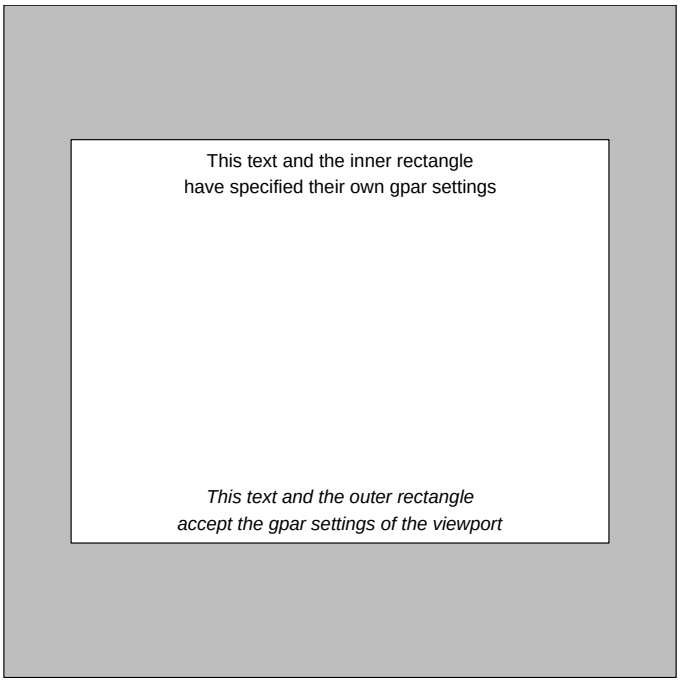

Figure 7: The effect of different graphical parameter settings.

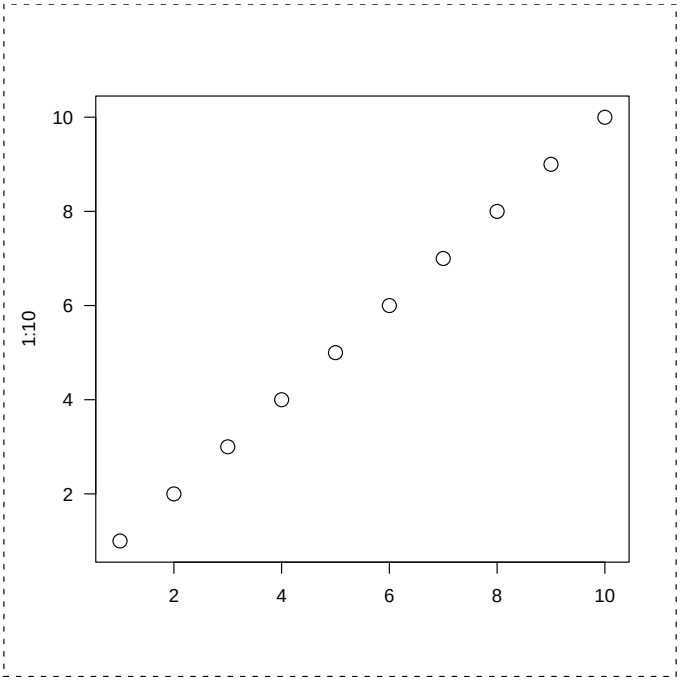

Figure 8: The grid equivalent of `plot(1:10)`.

```
+     pushViewport(plotViewport(c(5, 4, 4, 1), yscale = barYscale,
+         layout = grid.layout(1, nbars)))
+     grid.rect()
+     grid.yaxis()
+     for (i in 1:nbars) {
+         pushViewport(viewport(layout.pos.col = i,
+             yscale = barYscale))
+         grid.rect(x = rep(0.5, nmeasures), y = unit(barTotals[1:nmeasures,
+             i], "native"), height = unit(diff(barTotals[,
+             i]), "native"), width = 0.8, just = "bottom",
+             gp = gpar(fill = boxColours))
+         popViewport()
+     }
+     popViewport()
+ }
```

Now we turn our attention to the legend. We need some labels and we will enforce the constraint that the boxes in the legend should be 0.5" square:

```
> legLabels <- c("Group A", "Group B", "Group C",
+     "Something Longer")
> boxSize <- unit(0.5, "inches")
```

The following draws the legend elements in a column, with each element consisting of a box with a label beneath.

```
> leg <- function(legLabels) {
+     nlabels <- length(legLabels)
+     pushViewport(viewport(layout = grid.layout(nlabels,
+         1)))
+     for (i in 1:nlabels) {
+         pushViewport(viewport(layout.pos.row = i))
+         grid.rect(width = boxSize, height = boxSize,
+             just = "bottom", gp = gpar(fill = boxColours[i]))
+         grid.text(legLabels[i], y = unit(0.5,
+             "npc") - unit(1, "lines"))
+         popViewport()
+     }
+     popViewport()
+ }
```

Now that we have the two components, we can arrange them together to form a complete image. Notice that we can perform some calculations to make sure that we leave enough room for the legend, including 1 line of text as left and right margins. We also impose top and bottom margins on the legend to match the plot margins.

```
> grid.rect(gp = gpar(lty = "dashed"))
> legend.width <- max(unit(rep(1, length(legLabels)),
```

```
+     "strwidth", as.list(legLabels)) + unit(2,
+     "lines"), unit(0.5, "inches") + unit(2, "lines"))
> pushViewport(viewport(layout = grid.layout(1,
+     2, widths = unit.c(unit(1, "null"), legend.width))))
> pushViewport(viewport(layout.pos.col = 1))
> bp(barData)
> popViewport()
> pushViewport(viewport(layout.pos.col = 2))
> pushViewport(plotViewport(c(5, 0, 4, 0)))
> leg(legLabels)
> popViewport(3)
```

grid and lattice

The lattice package is built on top of grid and provides a quite sophisticated example of writing high-level plotting functions using grid. Because lattice consists of grid calls, it is possible to both add grid output to lattice output, and lattice output to grid output.

Adding grid to lattice

Panel functions in lattice can include grid calls. The following example adds a horizontal line at 0 to a standard xyplot (see Figure 10):

```
> if ("lattice" %in% .packages()) {
+     xyplot(y ~ x | g, panel = function(x, y) {
+         panel.xyplot(x, y)
+         grid.lines(unit(c(0, 1), "npc"), unit(0,
+             "native"), gp = gpar(col = "grey"))
+     })
+ }
```

The following example writes a left-justified label in each strip (see Figure 11):

```
> if ("lattice" %in% .packages()) {
+     xyplot(y ~ x | g, strip = function(which.given,
+         which.panel, var.name, factor.levels,
+         shingle.intervals, strip.names = "", style,
+         bg, fg, par.strip.text) {
+         grid.text(paste("Variable ", which.given,
+             ": Level ", which.panel[which.given],
+             sep = ""), unit(1, "mm"), 0.5, just = "left")
+     })
+ }
```

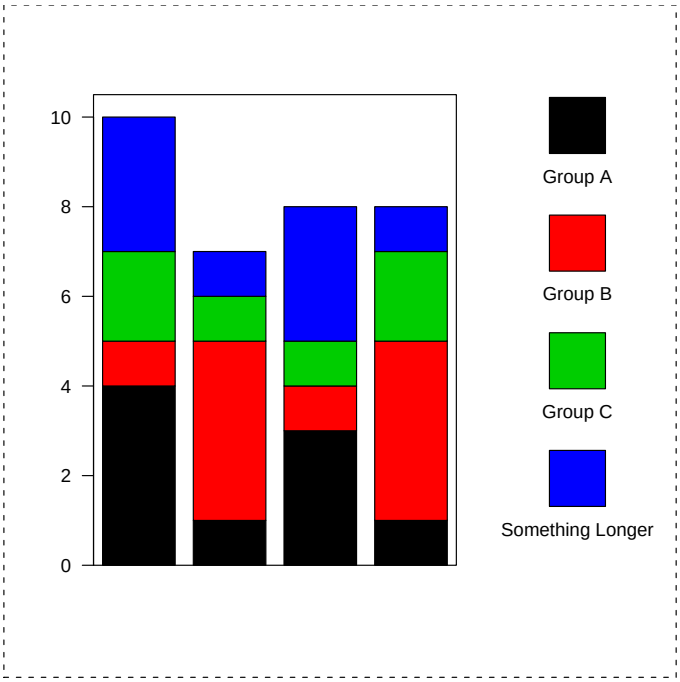

Figure 9: A barplot plus legend from first principles using `grid`.

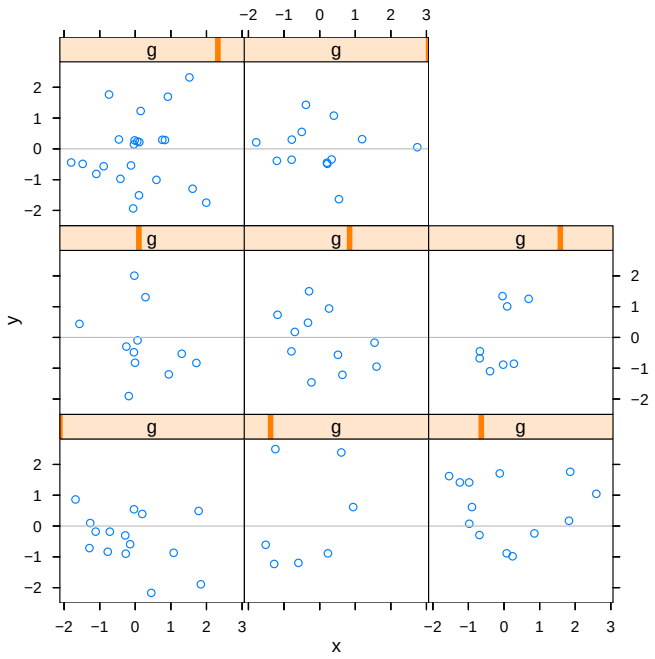

Figure 10: A `lattice` panel function using `grid`.

Adding `lattice` to `grid`

It is also possible to use a `lattice` plot as an element of a `grid` image. The following example splits up the page so that there is an `xyplot` beside a panel of text (see Figure 12). First of all, the lattice plot is created, but not drawn. `grid` is used to create some regions and the lattice plot is drawn into one of those regions.

```
> if ("lattice" %in% .packages()) {
+     someText <- paste("A panel of text", "produced using",
+         "raw grid code", "that could be used",
+         "to describe", "the plot", "to the right.",
+         sep = "\n")
+     latticePlot <- xyplot(y ~ x | g, layout = c(2,
+         4))
+     grid.rect(gp = gpar(lty = "dashed"))
+     pushViewport(viewport(layout = grid.layout(1,
+         2, widths = unit.c(unit(1, "strwidth",
+             someText) + unit(2, "cm"), unit(1,
+             "null")))))
+     pushViewport(viewport(layout.pos.col = 1))
+     grid.rect(gp = gpar(fill = "light grey"))
+     grid.text(someText, x = unit(1, "cm"), y = unit(1,
+         "npc") - unit(1, "inches"), just = c("left",
+         "top"))
+     popViewport()
+     pushViewport(viewport(layout.pos.col = 2))
+     print(latticePlot, newpage = FALSE)
+     popViewport(2)
+ }
```

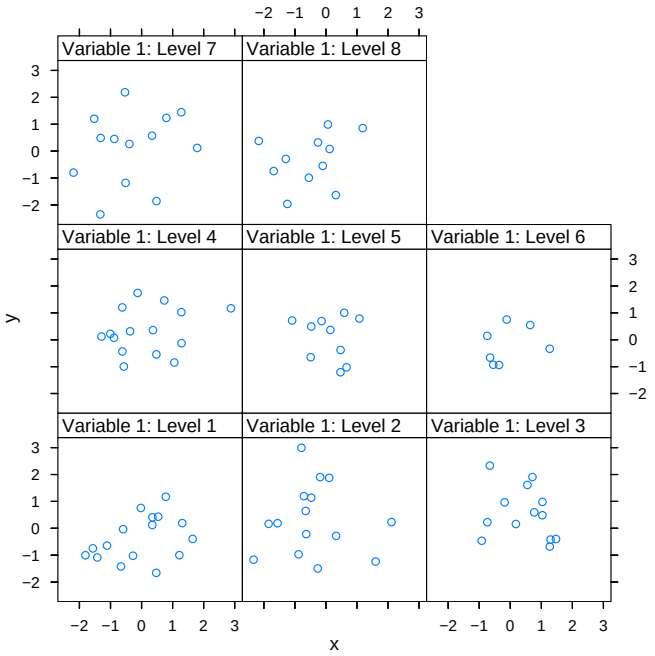

Figure 11: A `lattice` strip function using `grid`.

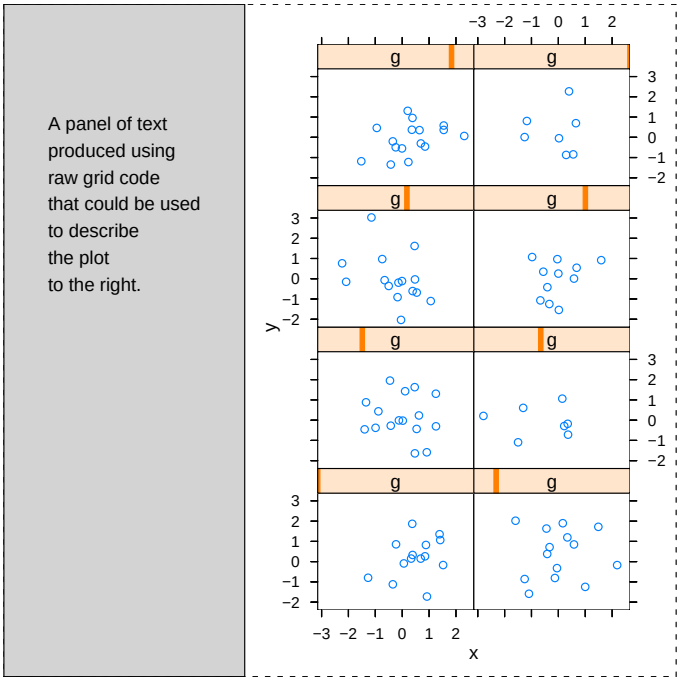

Figure 12: A `lattice` plot used as a component of a larger `grid` image.