Trellis Plots

Trellis Graphics

- Trellis Graphics is a family of techniques for viewing complex, multi-variable data sets.
- The ideas have been around for a while, but were formalized by researchers at Bell Laboratories during the 1990s.
- The techniques were given the name *Trellis* because they usually result in a rectangular array of plots, resembling a garden trellis.
- A number of statistical software systems provide multi-panel conditioning plots under the name *Trellis* plots or *Crossplots*.

Trellis Graphics in R

- The Trellis graphics system in R was written by Deepayan Sarkar of the University of Wisconsin, using the "Grid" graphics system written by Paul Murrell of Auckland.

- The system is a reimplementation of the the original Bell Labs Trellis system created by Bill Cleveland and Rick Becker.

- These class notes should show you all you need to know about producing simple Trellis displays.

- More extensive documentation is available on the class web site.

Using Trellis Graphics in R

- The trellis graphics system exists in parallel with the normal R graphics system.

- You cannot mix commands from the two systems, but Trellis provides equivalents to most of the normal graphics system commands.

- In order to produce Trellis plots you must load the “Lattice” library and start a “trellis aware” device.

```
> library(lattice)
> trellis.device()
```

Conditioning

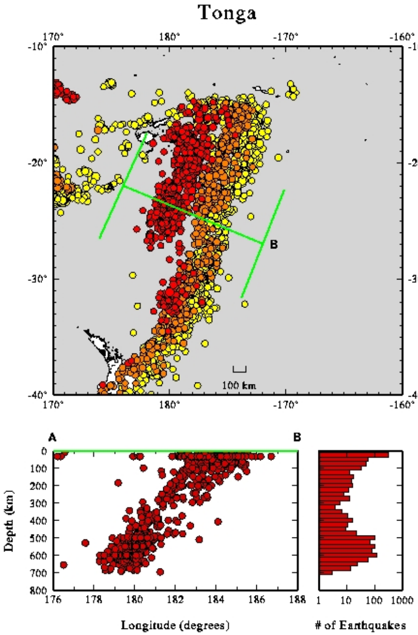
- Trellis plots are based on the idea of *conditioning* on the values taken on by one or more of the variables in a data set.

- In the case of a categorical variable, this means carrying out the same plot for the data subsets corresponding to each of the levels of that variable.

- In the case of a numeric variable, it means carrying out the same plots data subsets corresponding to intervals of that variable.

Example: Earthquake Locations

- R contains a data set called `quakes` which gives the location and magitude of earthquakes under the Tonga Trench, to the North of New Zealand.
- The spatial distribution of earthquakes in the area is of major interest, because this enables us to “see” the structure of the earthquake faults.
- Here is a plot from the Geology department at Berkeley, which tries to present the the spatial structure.



Tonga Trench Earthquakes

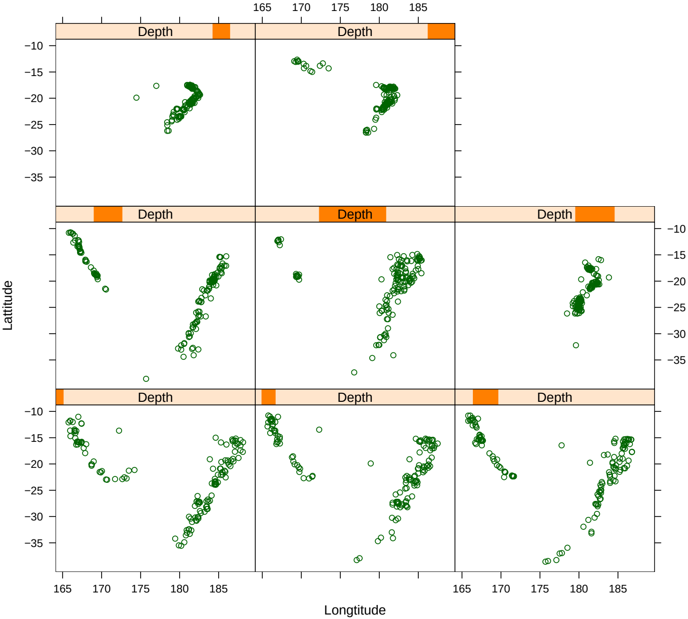
Yellow:	0 – 70 km
Orange:	71 – 300 km
Red:	300 – 800 km.

Problems with this Presentation

- There is a good deal of overplotting and this makes it hard to see all of the structure present in the data.
- The map makes it clear that we are looking down from above on the scene, but deeper quakes appear to be plotted on top of shallower ones.
- The division of depths into three intervals and presentation using colour is relatively crude.

A Trellis Plot

- We can overcome many of the problems of the previous plot by using a trellis display.
- We create the display by producing a sequence of graphs, each of which presents a different range of depths.
- In this case we will have a slight overlap of the intervals being plotted.


Depth
Depth
Depth
Depth
Depth
Depth
Depth
Depth
165
170
175
180
185
−10
−15
−20
−25
−30
−35
Lattitude
Longtitude

Explanation

- The plot is read left-to-right and bottom-to-top.
- Depth increases progressively through the plot.
- There are eight different depth intervals, each containing approximately the same number of earthquakes.
- Consecutive depth intervals overlap by a small amount.
- The range of depths covered by each interval is indicated in the bar above each plot.

Intepretation

- The shallower earthquakes are concentrated on two inclined fault planes.
- The most easterly of these fault planes is the one which bisects New Zealand.
- The Westerly fault plane has mainly shallow earthquakes, while the Easterly fault plane has both shallow and deep earthquakes.
- The deep earthquakes show distinct small angular fishhook structure which is not visible in the earlier plot.

Example: Barley Yields

- This example is concerned with the yields obtained from field trials of barley seed.

- The data comes from the 1930s so there is no direct genetic modification going here.

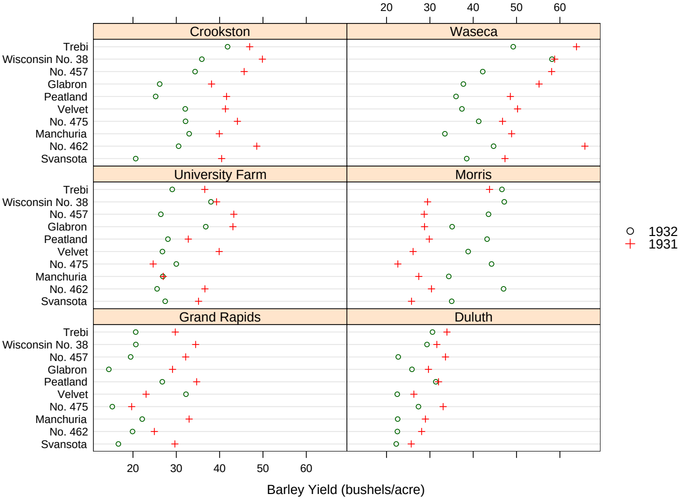
- The trials were conducted in 1931 and 1932, using:
  - 10 different strains of barley
  - 6 different growing sites

- There are $2 \times 10 \times 6 = 120$ observations.

- It was suspected for a long time that there was something odd about this data set.

The Trellis Plot

- The plot we will look at shows that barley yields for each of the 10 strains at the 6 sites and for each year.
- The results for each site are plotted on a separate graph – i.e. we are working conditional on the site.
- The yields from the two years are superimposed on each of the plots.


Crookston
Waseca
University Farm
Morris
Grand Rapids
Duluth
Trebi
Wisconsin No. 38
No. 457
Glabron
Peatland
Velvet
No. 475
Manchuria
No. 462
Svansota
20
30
40
50
60
○ 1932
+ 1931
Barley Yield (bushels/acre)

The Trellis Technology

- There are a variety of displays which can be produced by Trellis, including:
  - Bar Charts
  - Dot Charts
  - Box and Whisker Plots
  - Histograms
  - Density Traces
  - QQ Plots
  - Scatter Plots
- A common framework is used to produce all these plots.

Some Terminology

- Every Trellis display consists of a series of rectangular *panels*, laid out in a regular row-by-column array.
- The indexing of the array is left-to-right, bottom-to-top.
- The x axes of all the panels are identical. This is also true for the y axes.
- Each panel of the a display corresponds to conditioning, either on the levels of a factor, or on sub-intervals of the range of a numeric variable.

Shingles

- The conditioning carried out in the earthquake plot is described by a *shingle*.

- A shingle consists of a number of overlapping intervals (like the shingles on a roof of a house).

- Assuming that the earthquake depths are contained in the variable `depth`, the shingle is created as follows.

```
> depth = quakes$depth
> Depth = equal.count(depth, number=8,
                             overlap=.1)
```

- The shingle assigned to `Depth` has 8 intervals with adjacent intervals having 10% of their values in common.

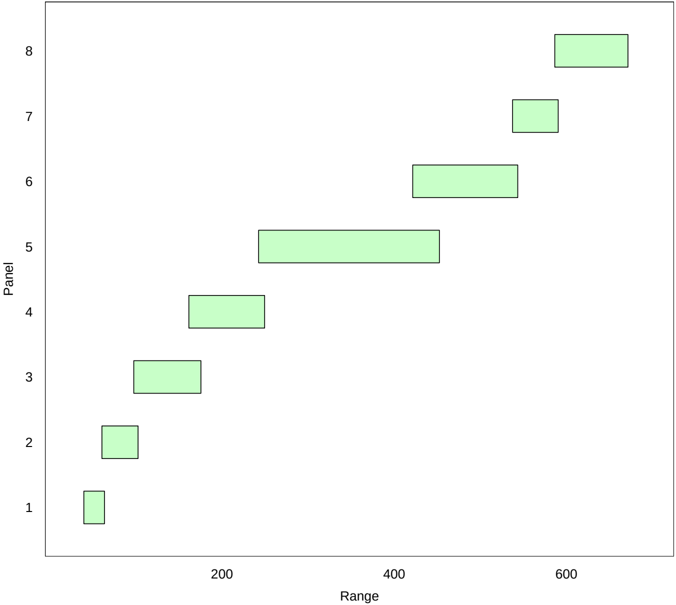
Shingles

- A shingle contains the numerical values it was created from and can be treated like a copy of that variable. For example:

  ```
  > range(Depth)
  [1]  40 680
  > range(depth)
  [1]  40 680
  ```

- A shingle also has the information attached to it. This can be displayed by printing or plotting the shingle.

  ```
  > plot(Depth)
  ```


8
7
6
5
4
3
2
1
Panel
200
400
600
Range

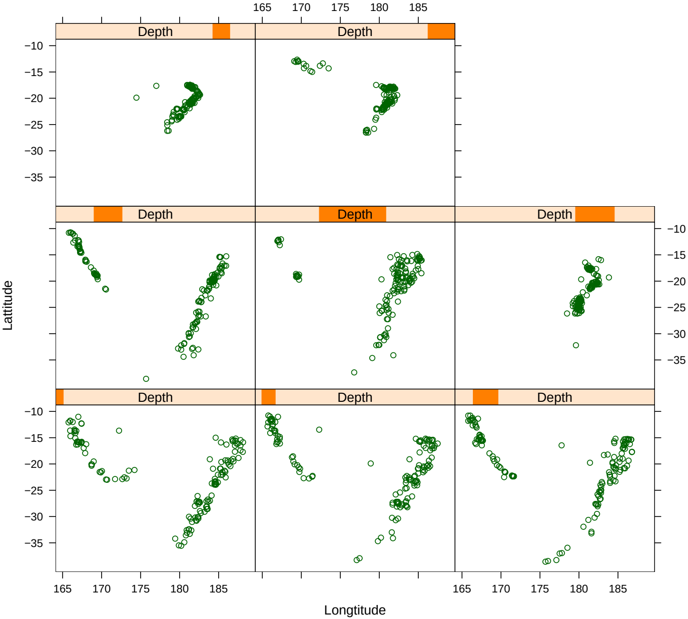
Producing the Plot

- The display of the earthquakes is produced by the function `xyplot`, which is the Trellis variant of a scatter plot function.

- The plot was produced as follows:

```
> Depth = equal.count(quakes$depth,
                      number = 8,
                      overlap = .1)
> xyplot(lat ~ long | Depth, data = quakes,
         xlab = "Longtitude",
         ylab = "Lattitude")
```

- There are two steps here (i) creating the shingle and (ii) producing the display.


Depth
Depth
Depth
Depth
Depth
Depth
Depth
Depth
165
170
175
180
185
−10
−15
−20
−25
−30
−35
Lattitude
Longtitude

The Plot Formula

- The first argument to `xyplot` is a symbolic formula describing the plot.

- In this case the formula is:

  ```
  lat ~ long | Depth
  ```

  which is an instruction to plot `lat` on the y axis against `long` on the x axis with conditioning intervals as described in `Depth`.

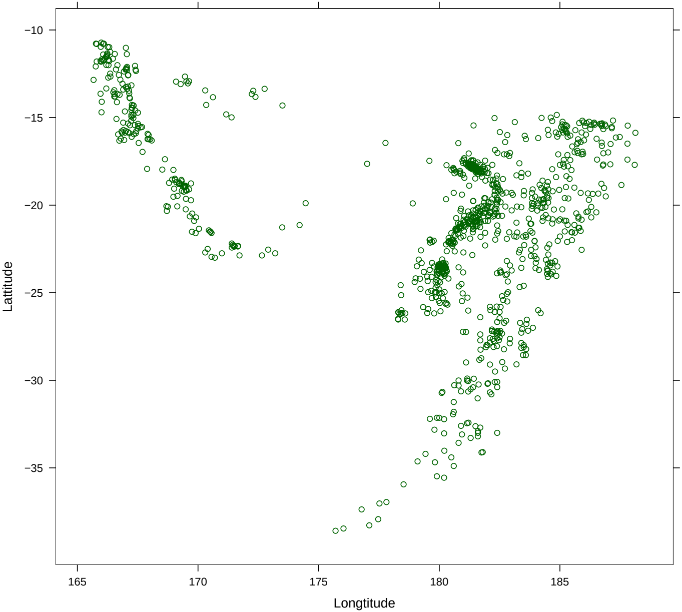
- The second argument to `xyplot` specifies which data frame the data for the plot should be obtained from.

- Additional arguments control other aspects of the plot.

Unconditional Plots

- The `xyplot` function can be used to produced an unconditional plot by omitting the conditioning specification from the plot formula.

```
> xyplot(lat ~ long, data = quakes,
         xlab = "Longtitude",
         ylab = "Lattitude")
```


−10
−15
−20
−25
−30
−35
165
170
175
180
185
Lattitude
Longtitude

The Barley Yield Plot

- The barley yield plot is produced by the function `dotchart` which can be used to numeric values against a categorical variable.

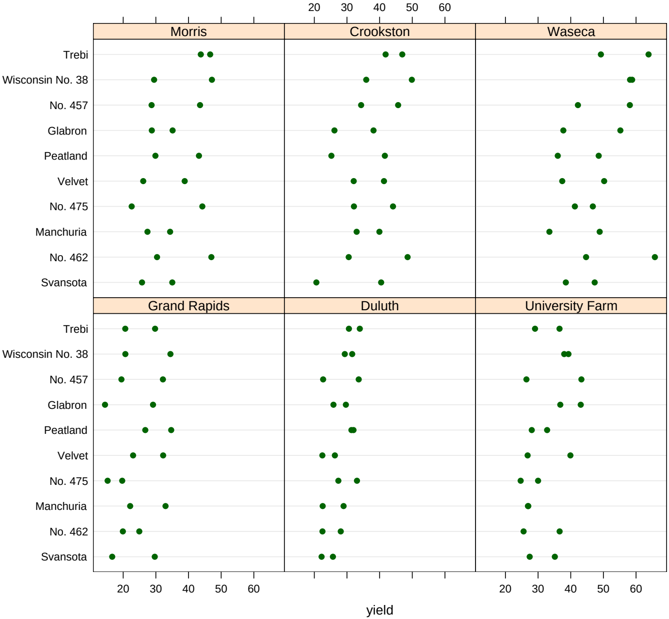
- In this case, the numeric variable is the barley yield and the categorical variable is the seed strain.

- We also condition on the value of another variable, the growing site.

A First Attempt

- The following code is a simple attempt at creating a dot chart using similar code to that for the earthquakes.

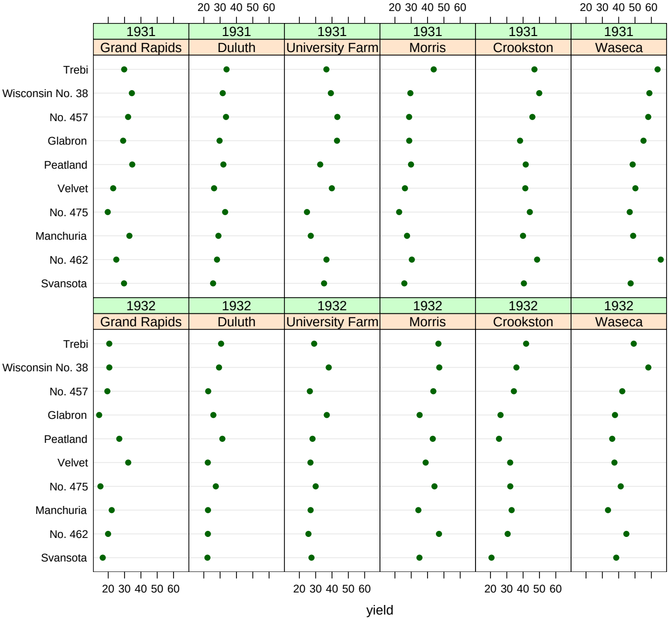
```
> dotplot(variety ~ yield | site,
          data = barley)
```


Morris
Crookston
Waseca
Grand Rapids
Duluth
University Farm
Trebi
Wisconsin No. 38
No. 457
Glabron
Peatland
Velvet
No. 475
Manchuria
No. 462
Svansota
20
30
40
50
60
yield

A Second Attempt

- We could also try conditioning on both site and year.

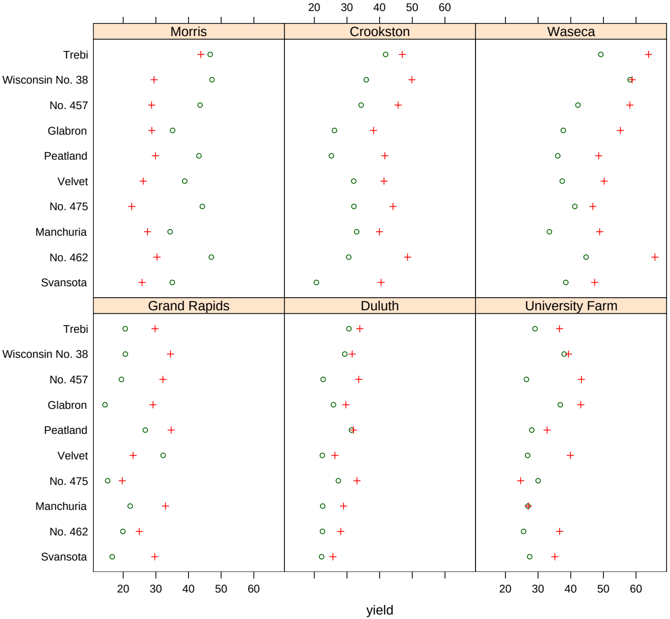
```
> dotplot(variety ~ yield | site * year,
          data = barley)
```


20 30 40 50 60
1931
Grand Rapids
Duluth
University Farm
Morris
Crookston
Waseca
1932
Trebi
Wisconsin No. 38
No. 457
Glabron
Peatland
Velvet
No. 475
Manchuria
No. 462
Svansota
yield

A Third Attempt

- What we need is to superimpose the two years for each site on a single panel.

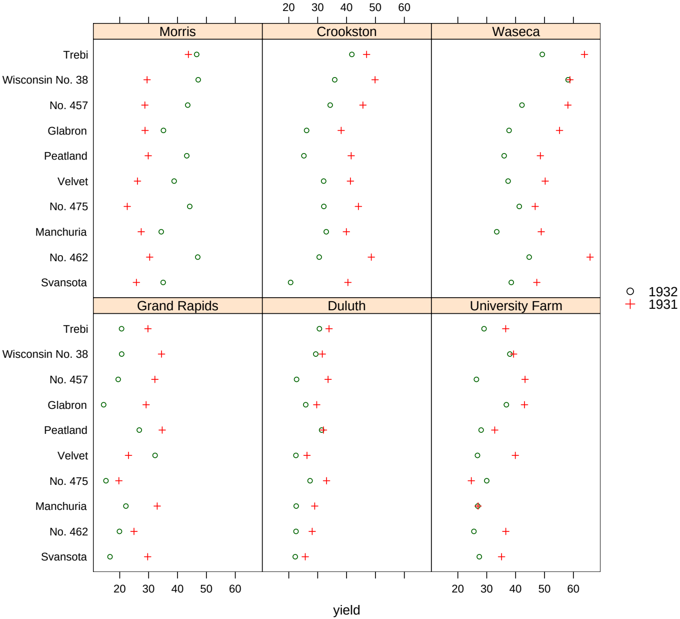
```
> dotplot(variety ~ yield | site,
          data = barley,
          panel = panel.superpose,
          group = year,
          pch = c(1, 3))
```


Morris
Crookston
Waseca
Grand Rapids
Duluth
University Farm
Trebi
Wisconsin No. 38
No. 457
Glabron
Peatland
Velvet
No. 475
Manchuria
No. 462
Svansota
20
30
40
50
60
yield

A Fourth Attempt

- The last plot is quite close.
- We need to add a legend which indicates which year is which.

```
> dotplot(variety ~ yield | site,
          data = barley,
          panel = panel.superpose,
          group = year, pch = c(1, 3),
          key = list(space = "right",
            transparent = TRUE,
            points = list(pch = c(1, 3),
              col = 1:2),
            text = list(c("1932", "1931"))))
```


Morris
Crookston
Waseca
Grand Rapids
Duluth
University Farm
Trebi
Wisconsin No. 38
No. 457
Glabron
Peatland
Velvet
No. 475
Manchuria
No. 462
Svansota
20
30
40
50
60
yield
○ 1932
+ 1931

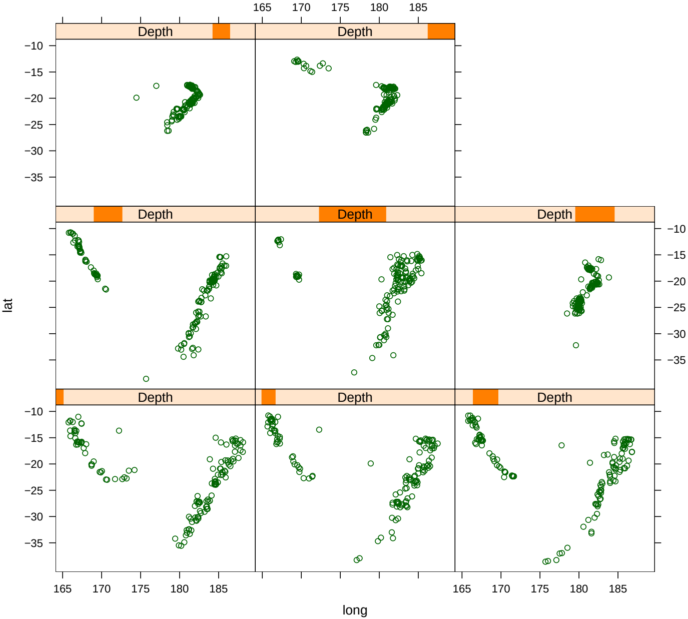
Choice of Colour Scheme

- The default colour scheme used by Trellis uses light colours on a medium-gray background.

- This is a bad choice of colour scheme because there is less contrast between foreground colours and the background than there might be.

- It is a good idea to use an alternative colour scheme which uses a dark colours on a white background.

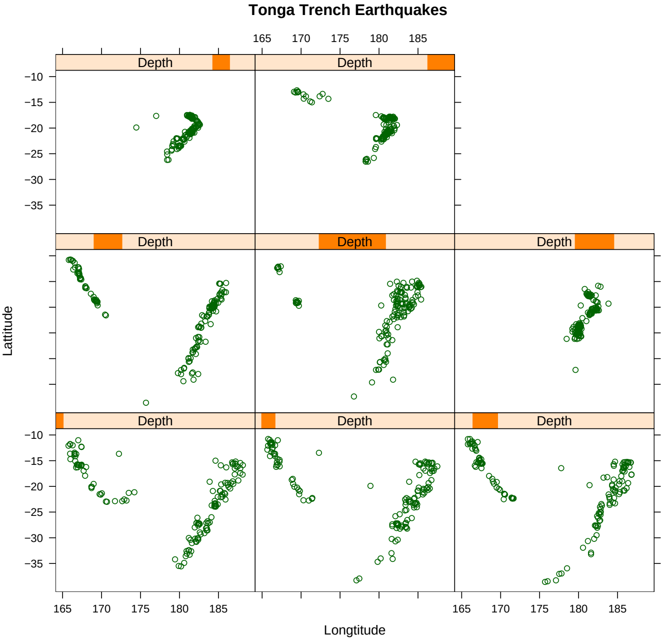
```
> trellis.par.set(theme = col.whitebg())

> xyplot(lat ~ long | Depth, data = quakes)
```


Depth
Depth
Depth
Depth
Depth
Depth
Depth
Depth
lat
long
165
170
175
180
185
−10
−15
−20
−25
−30
−35

Titles and Axis Annotation

- As with all graphics it is possible to add a title and axis annotation using `main=`, `lab=` and `ylab=` arguments.

```
> xyplot(lat ~ long | Depth, data = quakes,
         main = "Tonga Trench Earthquakes",
         xlab = "Longtitude",
         ylab = "Lattitude")
```


Tonga Trench Earthquakes
Depth
Depth
Depth
Depth
Depth
Depth
Depth
Depth
165
170
175
180
185
−10
−15
−20
−25
−30
−35
Lattitude
Longtitude

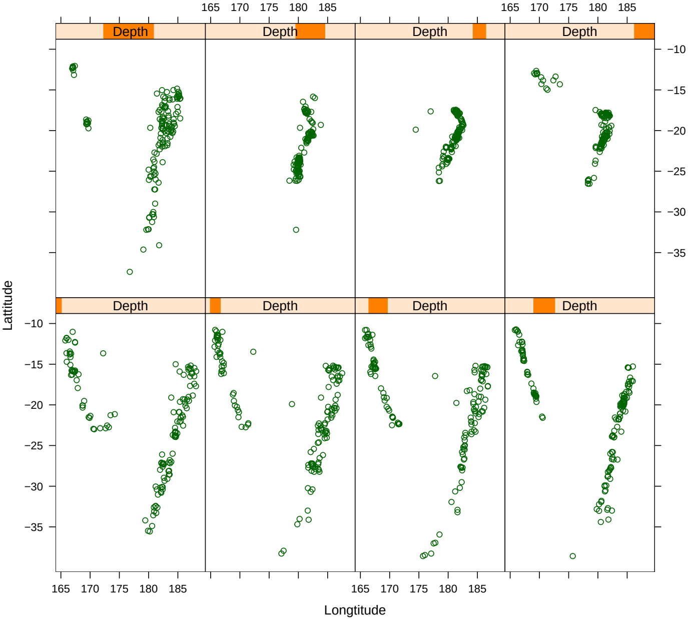
Layout Control

- By default, Trellis usually chooses a good plot layout, but sometimes it is useful to override the choice using the `layout` argument.

- The `layout` argument should be a vector of three values giving the number of rows, number of columns and number of pages desired for the display.

- For example, we can rearrange the earthquake plot as follows:

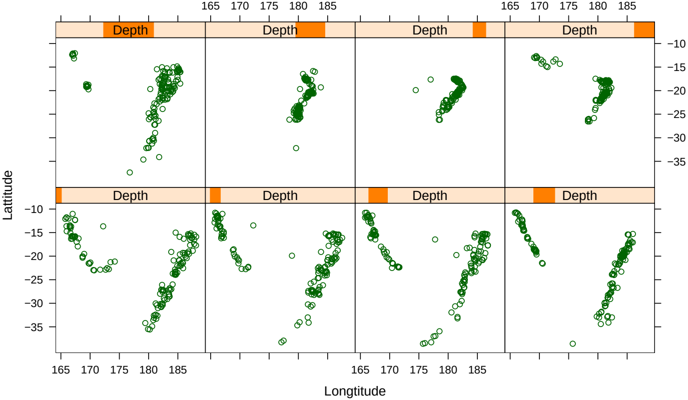
```
> xyplot(lat ~ long | Depth, data = quakes,
         layout = c(4, 2, 1),
         xlab = "Longtitude",
         ylab = "Lattitude")
```


Depth
165
170
175
180
185
−10
−15
−20
−25
−30
−35
Lattitude
Longtitude

Aspect Ratio Control

- The panels in the previous plot are rather too tall relative to their widths.
- By default, plots are sized so that they they occupy the full surface of the output window.
- This can changed by specifying the aspect ratio for the plots.

```
> xyplot(lat ~ long | Depth, data = quakes,
         aspect = 1,
         layout = c(4, 2, 1),
         xlab = "Longtitude",
         ylab = "Lattitude")
```


Depth
Depth
Depth
Depth
Depth
Depth
Depth
Depth
165
170
175
180
185
−10
−15
−20
−25
−30
−35
Lattitude
Longtitude

Trellis Examples

- For the rest of the lecture we will look at a variety of examples of Trellis plots.
- This is really just scratching the surface of what can be done with trellis.

Death Rates by Gender and Location

- In this example we'll look at the Virginia death rate data.

- The data values are death rates per 1000 of population cross-classified by age and population group.

- We are intested in how death rate changes with age and how the death rates in the different population groups compare.

Data Manipulation

- The data values are stored by R as a matrix.

- We first have to turn the death rates into a vector and create the cross-classifying factors.

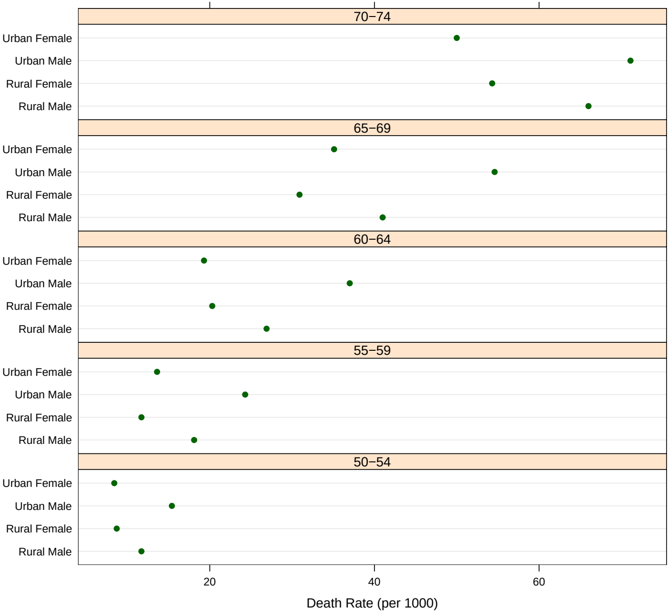
```
> rate = as.vector(VADeaths)
> age = row(VADeaths, as.factor = TRUE)
> group = col(VADeaths, as.factor = TRUE)
```

Dotchart 1

- We start by displaying deaths against age, conditional on population group.

- The command below uses `layout` to force the panels to be stacked above each other to make comparisons easy.

```
> dotplot(group ~ rate | age,
          xlab = "Death Rate (per 1000)",
          layout = c(1, 5, 1))
```


70−74
65−69
60−64
55−59
50−54
Urban Female
Urban Male
Rural Female
Rural Male
20
40
60
Death Rate (per 1000)

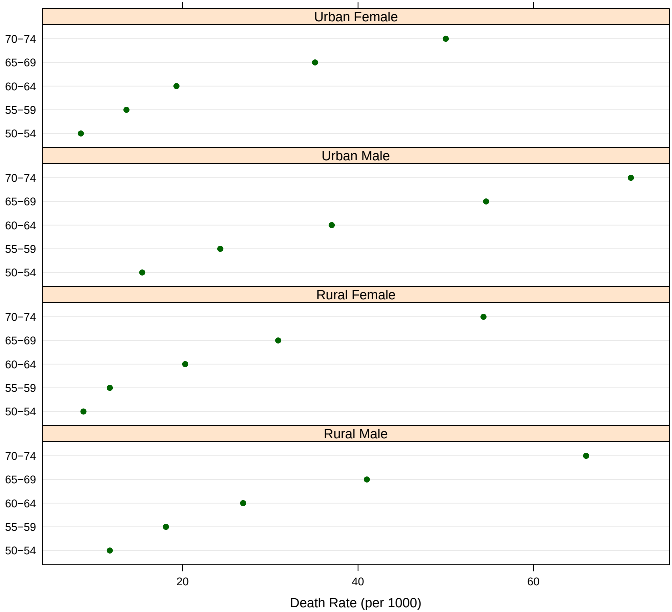
Dotchart 2

- The first display is hard to read because the variantion within each age group is “noisy.”

- We could try to get around this by ordering the population categories differently.

- Alternatively we can interchange the roles of the cross-classifying variables.

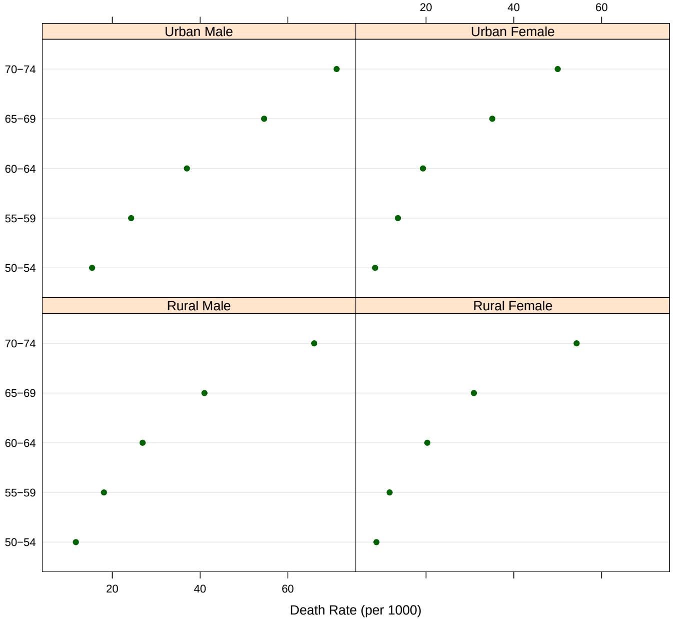
```
> dotplot(age ~ rate | group,
          xlab = "Death Rate (per 1000)",
          layout = c(1, 4, 1))
```


Urban Female
Urban Male
Rural Female
Rural Male
70−74
65−69
60−64
55−59
50−54
20
40
60
Death Rate (per 1000)

Dotchart 3

- The second display is better than the first, but can improve it with a different ordering of the panels.
- We'll arange the panels in a 2 × 2 array.
- This will allow us to make direct male/female and urban/rural comparisons.

```
> dotplot(age ~ rate | group,
          xlab = "Death Rate (per 1000)",
          layout = c(2, 2, 1))
```

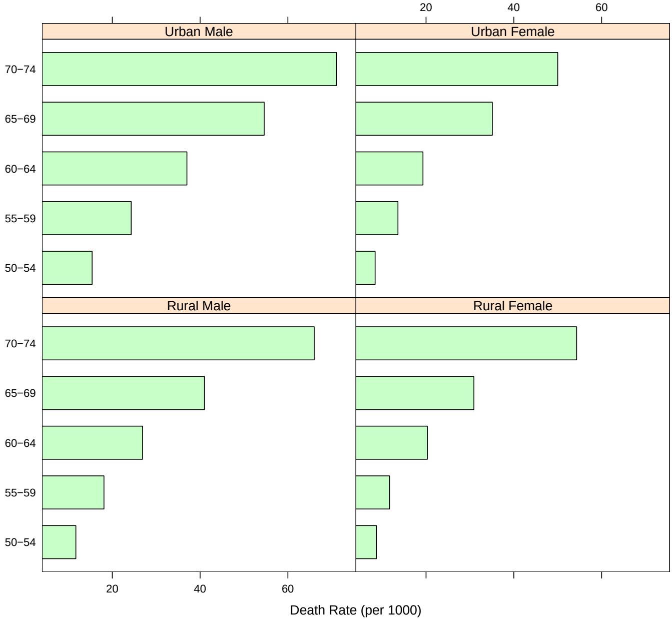

20
40
60
Urban Male
Urban Female
Rural Male
Rural Female
70−74
65−69
60−64
55−59
50−54
20
40
60
Death Rate (per 1000)

Alternative Displays

- The previous displays presented the data in “dotchart” displays.

- There are other alternatives, barcharts for example.

```
> barchart(age ~ rate | group,
           xlab = "Death Rate (per 1000)",
           layout = c(2, 2, 1))
```


Urban Male
Urban Female
Rural Male
Rural Female
70−74
65−69
60−64
55−59
50−54
20
40
60
Death Rate (per 1000)

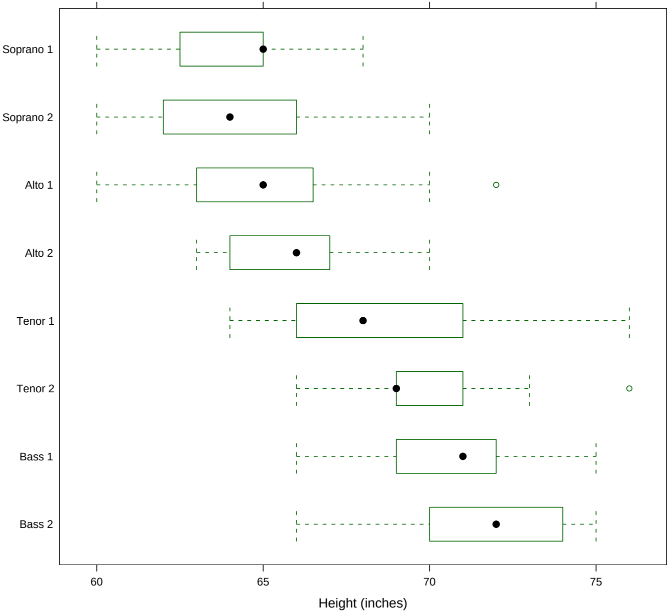
Heights of Singers

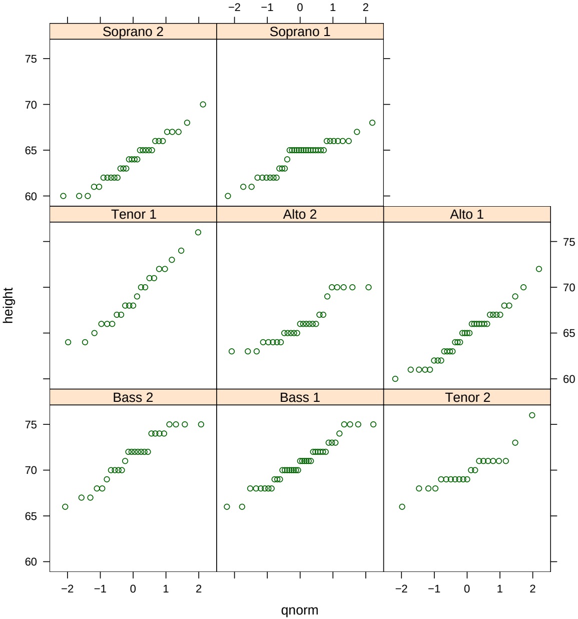
- In this example we'll examine the heights of the members of a large choral society.

- The values are in a data set called `singer` which is in the Lattice data library. They can be loaded with the `data` command once the Lattice library is loaded.

- The variables are named `height` (inches) and `voice.part`.

```
> bwplot(voice.part ~ height, data=singer,
         xlab="Height (inches)")

> qqmath(~ height | voice.part,
         aspect = 1, data = singer)
```


Soprano 1
Soprano 2
Alto 1
Alto 2
Tenor 1
Tenor 2
Bass 1
Bass 2
60
65
70
75
Height (inches)


Soprano 2
Soprano 1
Tenor 1
Alto 2
Alto 1
Bass 2
Bass 1
Tenor 2
height
qnorm
−2
−1
0
1
2
60
65
70
75

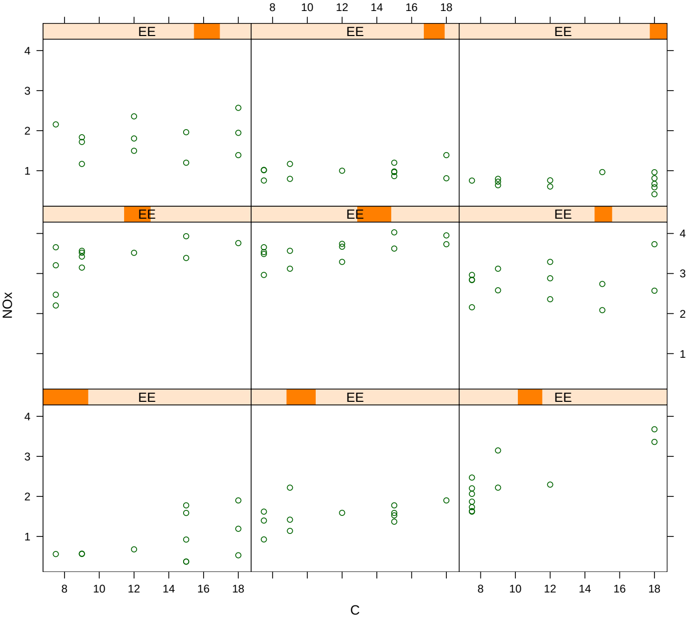
Measurement of Exhaust from Burning Ethanol

- The ethanol data frame records 88 measurements (rows) for three variables (columns) NOx , C , and E from an experiment in which ethanol was burned in a single cylinder automobile test engine.
- NOx gives the concentration of nitric oxide (NO) and nitrogen dioxide (NO2) in engine exhaust, normalised by the work done by the engine.
- C gives the compression ratio of the engine.
- E gives the equivalence ratio at which the engine was run – a measure of the richness of the air/ethanol mix.

Exploring the Relationship

- We can get a basic idea of the form of the relatioship between the variables using a simple conditioning plot.

```
> EE = equal.count(ethanol$E, number = 9,
                   overlap = 1/4)
> xyplot(NOx ~ C | EE, data = ethanol)
```

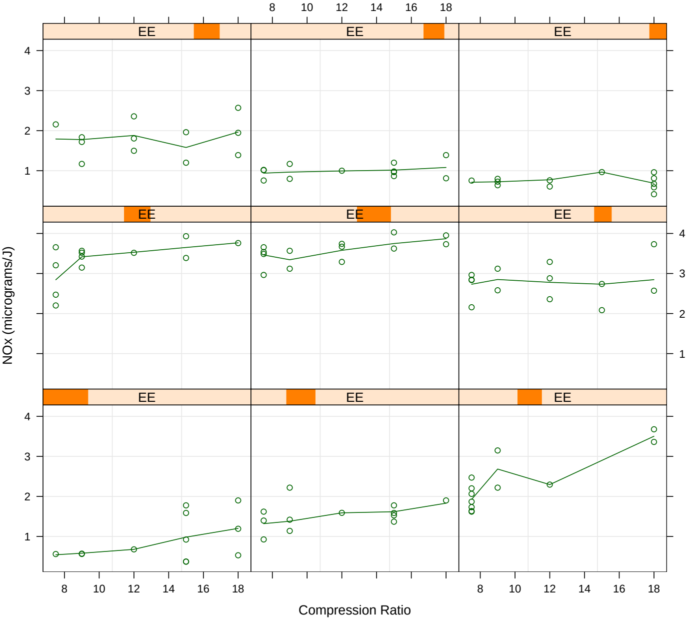

EE
NOx
C
8
10
12
14
16
18
1
2
3
4

A More Complex Plot

- We can enhance the previous plot by adding a smooth line through the points in each panel.

- This is done using the lowess smoother.

```
> xyplot(NOx ~ C | EE, data = ethanol,
         xlab = "Compression Ratio",
         ylab = "NOx (micrograms/J)",
         panel = function(x, y) {
             panel.grid(h = -1, v = 2)
             panel.xyplot(x, y)
             llines(lowess(x, y))
         })
```


EE
EE
EE
EE
EE
EE
EE
EE
EE
NOx (micrograms/J)
Compression Ratio
8
10
12
14
16
18
1
2
3
4