The Lattice Plotting System in R

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The Lattice Plotting System

The lattice plotting system is implemented using the following packages:

- *lattice*: contains code for producing Trellis graphics, which are independent of the “base” graphics system; includes functions like `xyplot`, `bwplot`, `levelplot`
- *grid*: implements a different graphing system independent of the “base” system; the *lattice* package builds on top of *grid*
  - We seldom call functions from the *grid* package directly
- The lattice plotting system does not have a "two-phase" aspect with separate plotting and annotation like in base plotting
- All plotting/annotation is done at once with a single function call

Lattice Functions

- `xyplot`: this is the main function for creating scatterplots
- `bwplot`: box-and-whiskers plots (“boxplots”)
- `histogram`: histograms
- `stripplot`: like a boxplot but with actual points
- `dotplot`: plot dots on "violin strings"
- `splom`: scatterplot matrix; like `pairs` in base plotting system
- `levelplot`, `contourplot`: for plotting "image" data

Lattice Functions

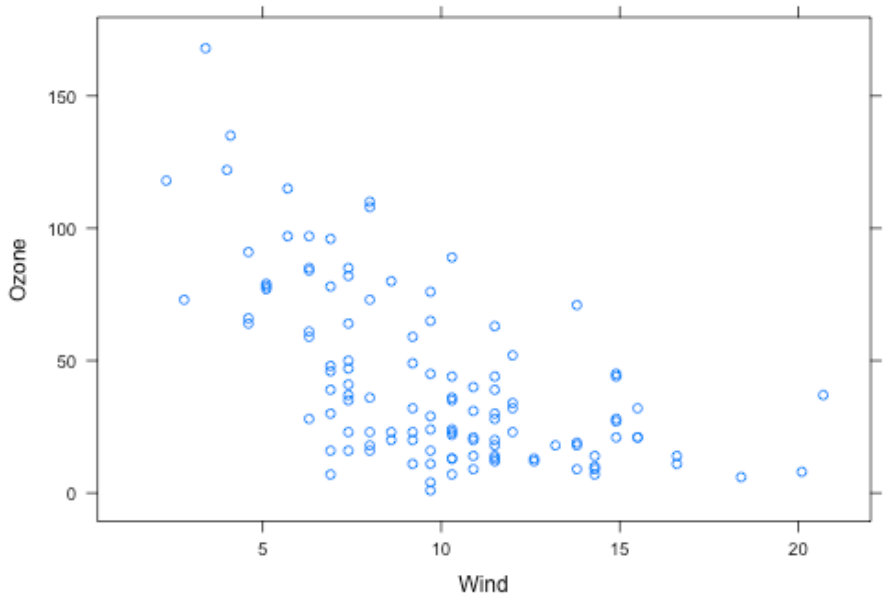
Lattice functions generally take a formula for their first argument, usually of the form

```
xyplot(y ~ x | f * g, data)
```

- We use the *formula notation* here, hence the ~.
- On the left of the ~ is the y-axis variable, on the right is the x-axis variable
- f and g are *conditioning variables* — they are optional
  - the * indicates an interaction between two variables
- The second argument is the data frame or list from which the variables in the formula should be looked up
  - If no data frame or list is passed, then the parent frame is used.
- If no other arguments are passed, there are defaults that can be used.

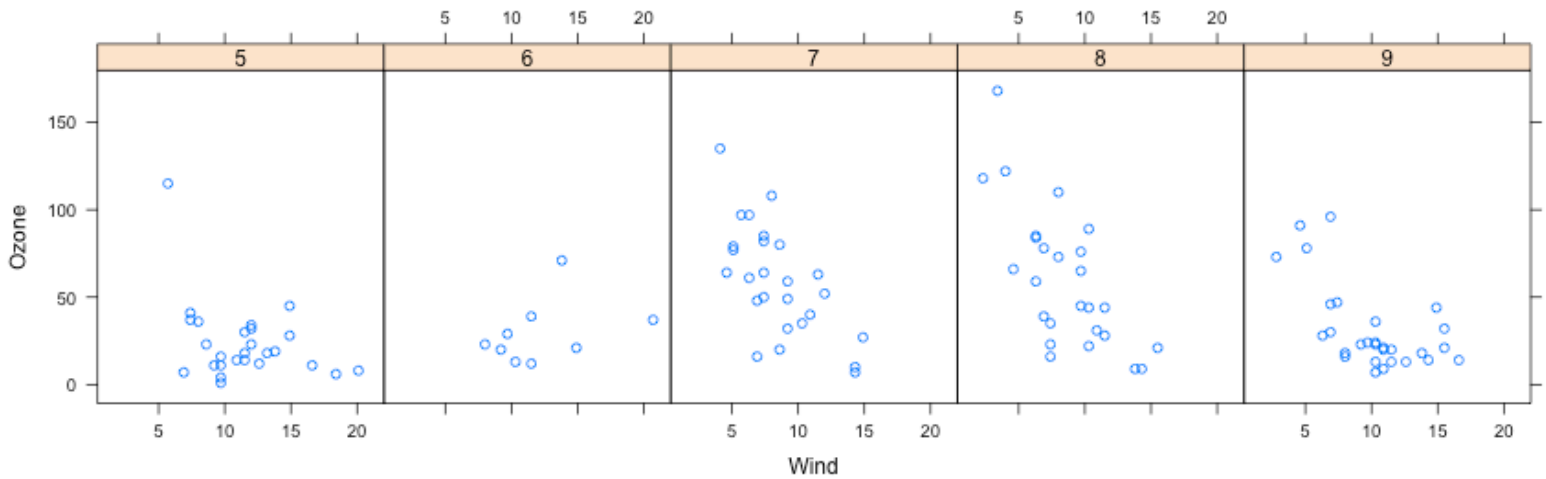
Simple Lattice Plot

```
library(lattice)
library(datasets)
## Simple scatterplot
xyplot(Ozone ~ Wind, data = airquality)
```



Simple Lattice Plot

```
library(datasets)
library(lattice)
## Convert 'Month' to a factor variable
airquality <- transform(airquality, Month = factor(Month))
xyplot(Ozone ~ Wind | Month, data = airquality, layout = c(5, 1))
```



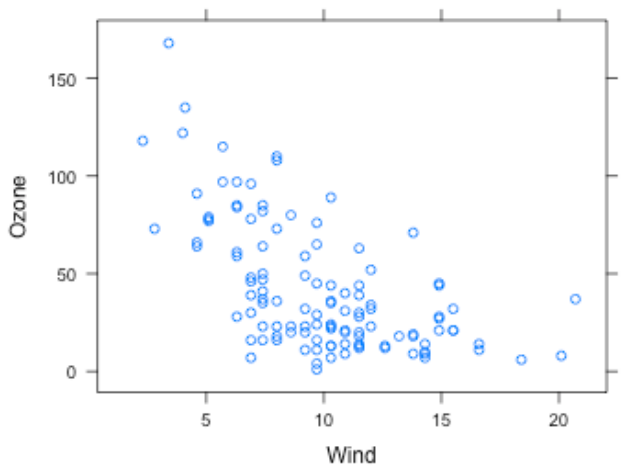
Lattice Behavior

Lattice functions behave differently from base graphics functions in one critical way.

- Base graphics functions plot data directly to the graphics device (screen, PDF file, etc.)
- Lattice graphics functions return an object of class **trellis**
- The print methods for lattice functions actually do the work of plotting the data on the graphics device.
- Lattice functions return "plot objects" that can, in principle, be stored (but it's usually better to just save the code + data).
- On the command line, trellis objects are *auto-printed* so that it appears the function is plotting the data

Lattice Behavior

```
p <- xyplot(Ozone ~ Wind, data = airquality)  ## Nothing happens!
print(p)  ## Plot appears
```



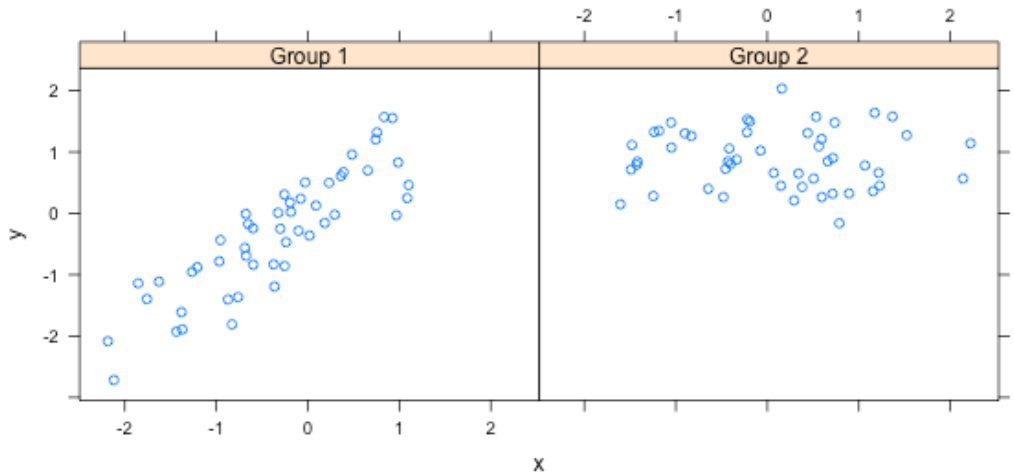

```
xyplot(Ozone ~ Wind, data = airquality)  ## Auto-printing
```

Lattice Panel Functions

- Lattice functions have a **panel function** which controls what happens inside each panel of the plot.
- The *lattice* package comes with default panel functions, but you can supply your own if you want to customize what happens in each panel
- Panel functions receive the x/y coordinates of the data points in their panel (along with any optional arguments)

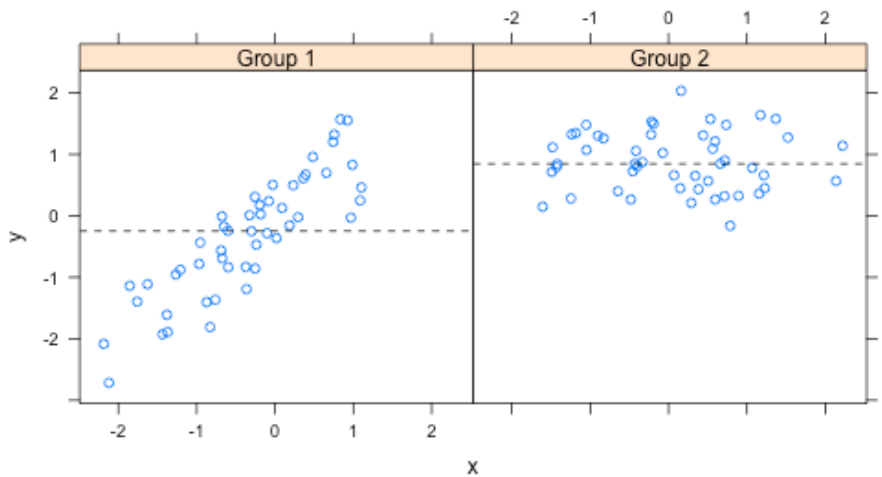
Lattice Panel Functions

```
set.seed(10)
x <- rnorm(100)
f <- rep(0:1, each = 50)
y <- x + f - f * x + rnorm(100, sd = 0.5)
f <- factor(f, labels = c("Group 1", "Group 2"))
xyplot(y ~ x | f, layout = c(2, 1))  ## Plot with 2 panels
```



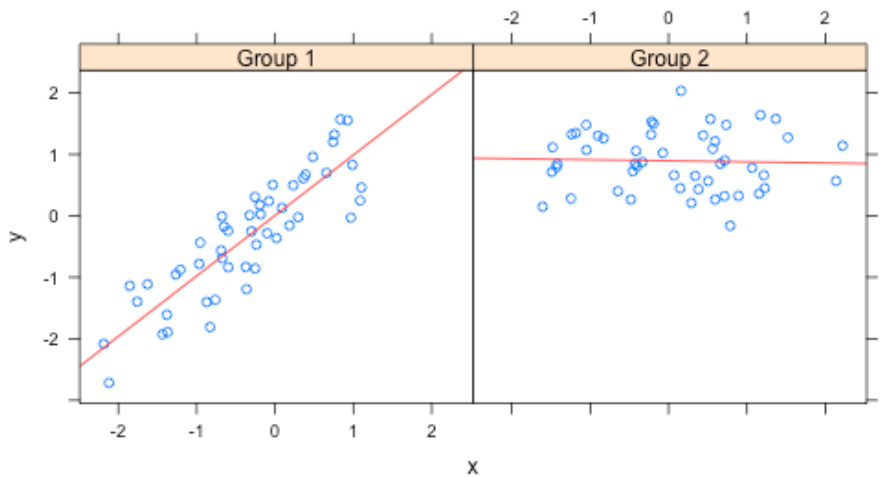
Lattice Panel Functions

```r
## Custom panel function
xyplot(y ~ x | f, panel = function(x, y, ...) {
    panel.xyplot(x, y, ...)  ## First call the default panel function for 'xyplot'
    panel.abline(h = median(y), lty = 2)  ## Add a horizontal line at the median
})
```



Lattice Panel Functions: Regression line

```
## Custom panel function
xyplot(y ~ x | f, panel = function(x, y, ...) {
    panel.xyplot(x, y, ...)  ## First call default panel function
    panel.lmline(x, y, col = 2)  ## Overlay a simple linear regression line
})
```

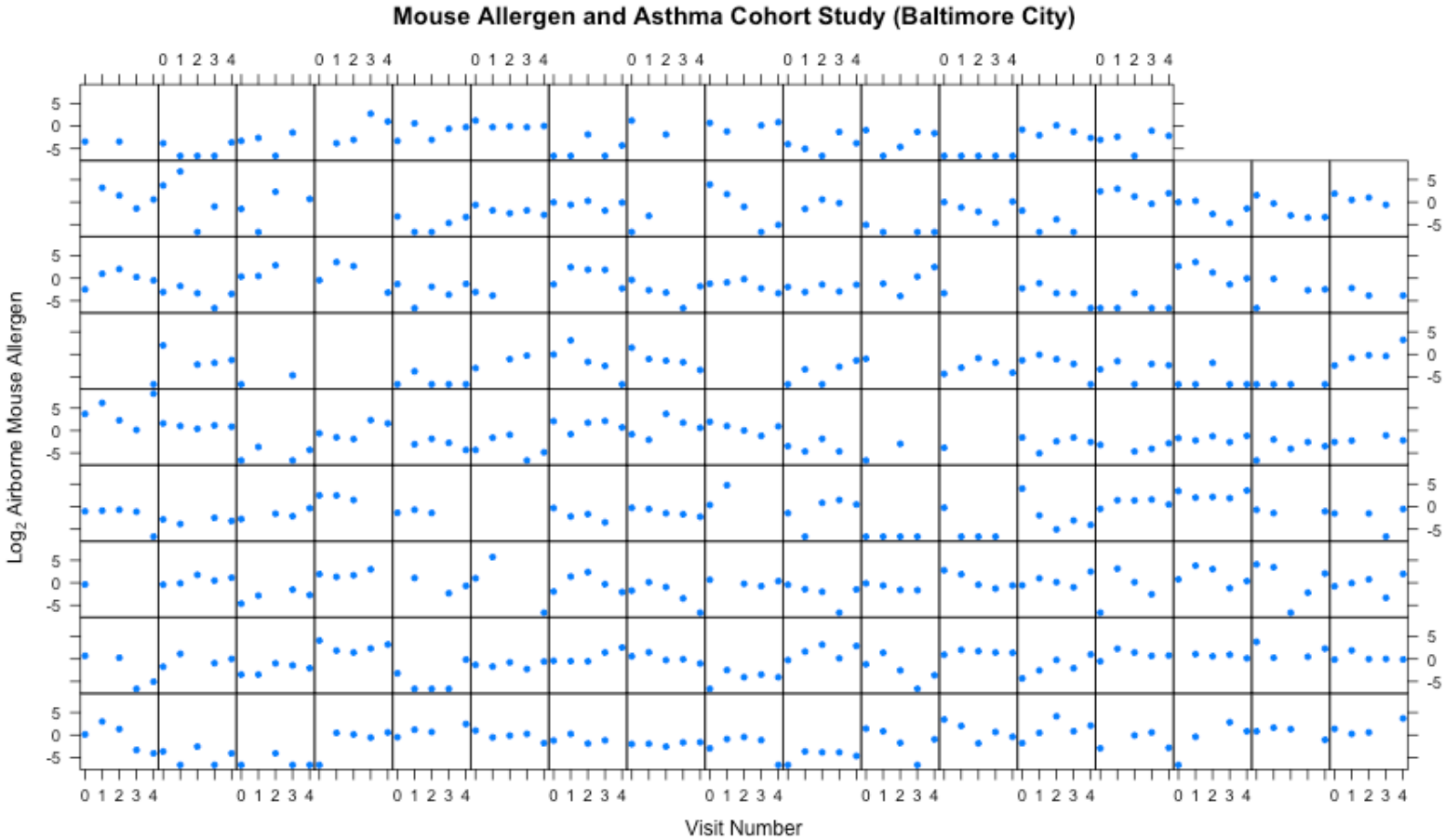


Many Panel Lattice Plot: Example from MAACS

- Study: Mouse Allergen and Asthma Cohort Study (MAACS)
- Study subjects: Children with asthma living in Baltimore City, many allergic to mouse allergen
- Design: Observational study, baseline home visit + every 3 months for a year.
- Question: How does indoor airborne mouse allergen vary over time and across subjects?

Ahluwalia et al., *Journal of Allergy and Clinical Immunology*, 2013

Many Panel Lattice Plot



Summary

- Lattice plots are constructed with a single function call to a core lattice function (e.g. `xyplot`)
- Aspects like margins and spacing are automatically handled and defaults are usually sufficient
- The lattice system is ideal for creating conditioning plots where you examine the same kind of plot under many different conditions
- Panel functions can be specified/customized to modify what is plotted in each of the plot panels

Plotting with ggplot2

Exploratory Data Analysis

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What is ggplot2?

- An implementation of the *Grammar of Graphics* by Leland Wilkinson
- Written by Hadley Wickham (while he was a graduate student at Iowa State)
- A "third" graphics system for R (along with **base** and **lattice**)
- Available from CRAN via `install.packages()`
- Web site: http://ggplot2.org (better documentation)

What is ggplot2?

- Grammar of graphics represents and abstraction of graphics ideas/objects
- Think “verb”, “noun”, “adjective” for graphics
- Allows for a “theory” of graphics on which to build new graphics and graphics objects
- “Shorten the distance from mind to page”

Grammar of Graphics

"In brief, the grammar tells us that a statistical graphic is a **mapping** from data to **aesthetic** attributes (colour, shape, size) of **geometric** objects (points, lines, bars). The plot may also contain statistical transformations of the data and is drawn on a specific coordinate system"

from *ggplot2* book

The Basics: `qplot()`

- Works much like the `plot` function in base graphics system
- Looks for data in a data frame, similar to lattice, or in the parent environment
- Plots are made up of *aesthetics* (size, shape, color) and *geoms* (points, lines)

The Basics: `qplot()`

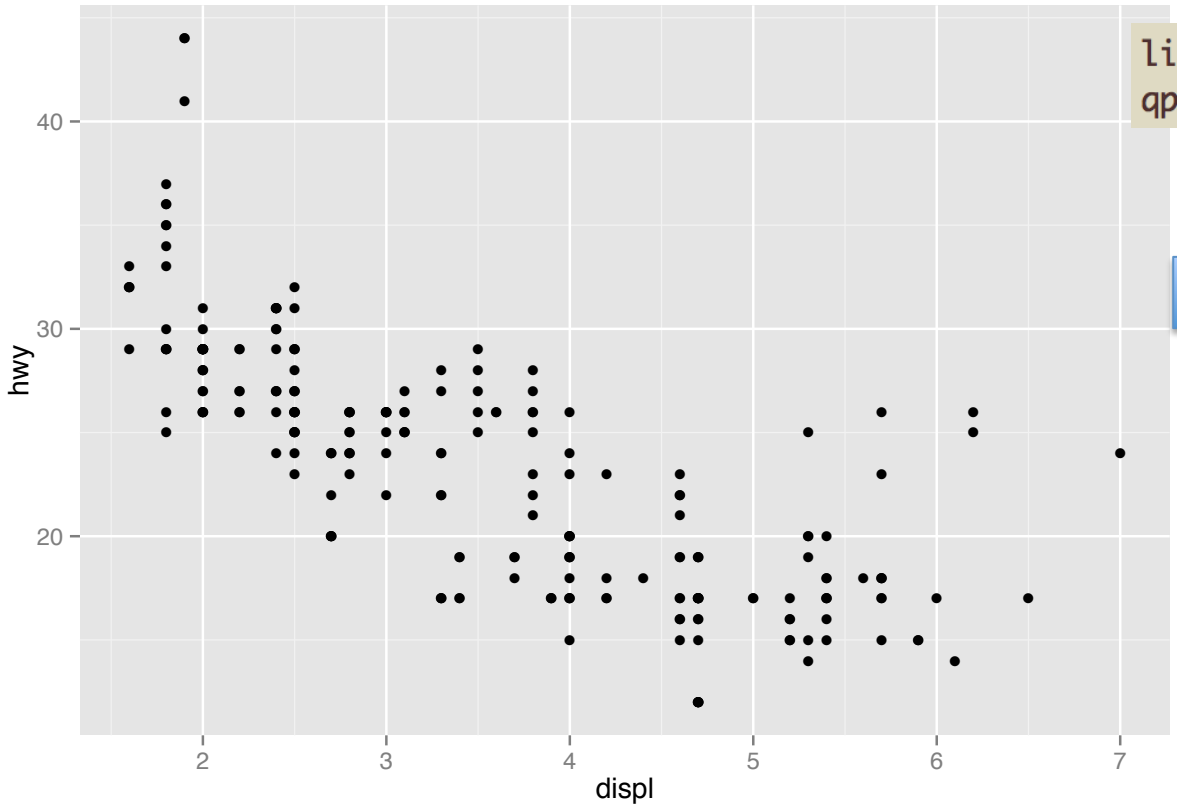
- Factors are important for indicating subsets of the data (if they are to have different properties); they should be **labeled**
- The qplot() hides what goes on underneath, which is okay for most operations
- ggplot() is the core function and very flexible for doing things qplot() cannot do

Example Dataset

```
> library(ggplot2)
> str(mpg)
'data.frame':   234 obs. of  11 variables:
 $ manufacturer: Factor w/ 15 levels "audi","chevrolet",..: 1 1 1 1 1 1 1 1 1 1 ...
 $ model       : Factor w/ 38 levels "4runner 4wd",..: 2 2 2 2 2 2 2 3 3 3 ...
 $ displ       : num  1.8 1.8 2 2 2.8 2.8 3.1 1.8 1.8 2 ...
 $ year        : int  1999 1999 2008 2008 1999 1999 2008 1999 1999 2008 ...
 $ cyl         : int  4 4 4 4 6 6 6 4 4 4 ...
 $ trans       : Factor w/ 10 levels "auto(av)","auto(l3)",..: 4 9 10 1 4 9 1 9 4 10
...
 $ drv         : Factor w/ 3 levels "4","f","r": 2 2 2 2 2 2 2 1 1 1 ...
 $ cty         : int  18 21 20 21 16 18 18 18 16 20 ...
 $ hwy         : int  29 29 31 30 26 26 27 26 25 28 ...
 $ fl          : Factor w/ 5 levels "c","d","e","p",..: 4 4 4 4 4 4 4 4 4 4 ...
 $ class       : Factor w/ 7 levels "2seater","compact",..: 2 2 2 2 2 2 2 2 2 2 ...
```

Factor label information important for annotation

ggplot2 “Hello, world!”



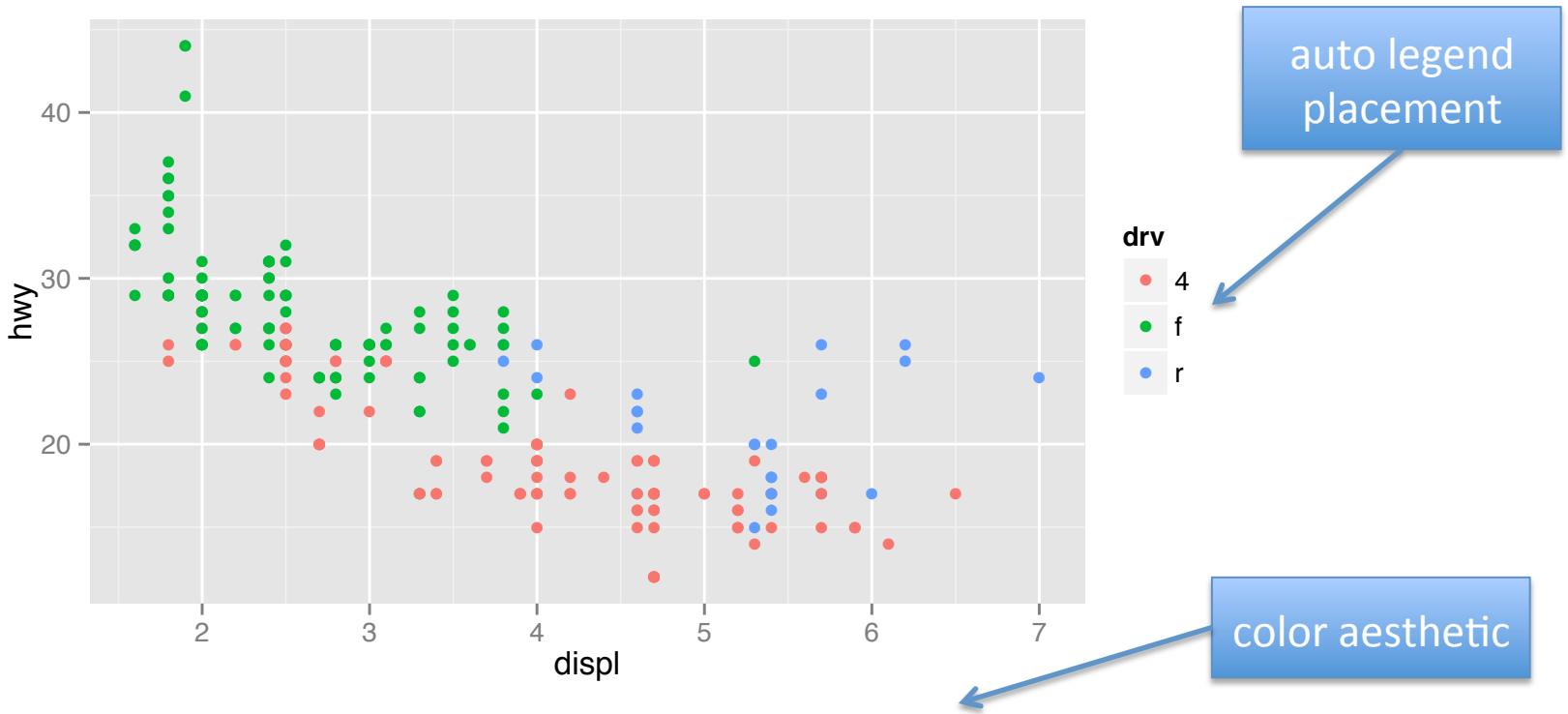

```
library(ggplot2)
qplot(displ, hwy, data = mpg)
```

x coord

y coord

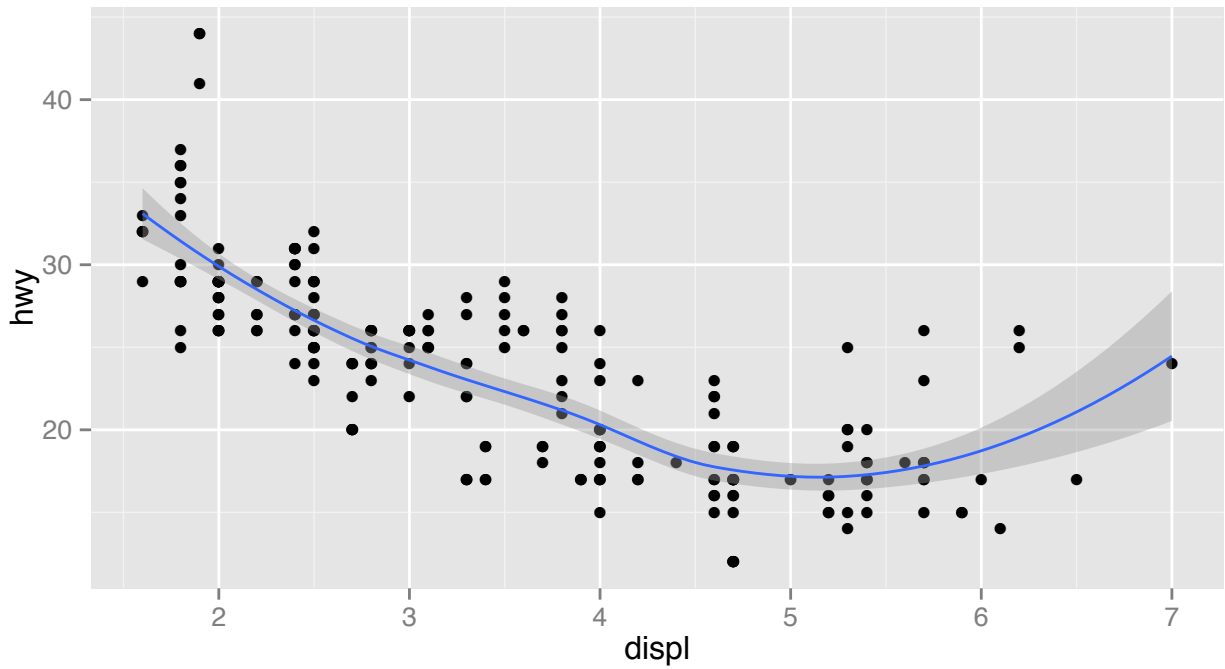
data frame

Modifying aesthetics



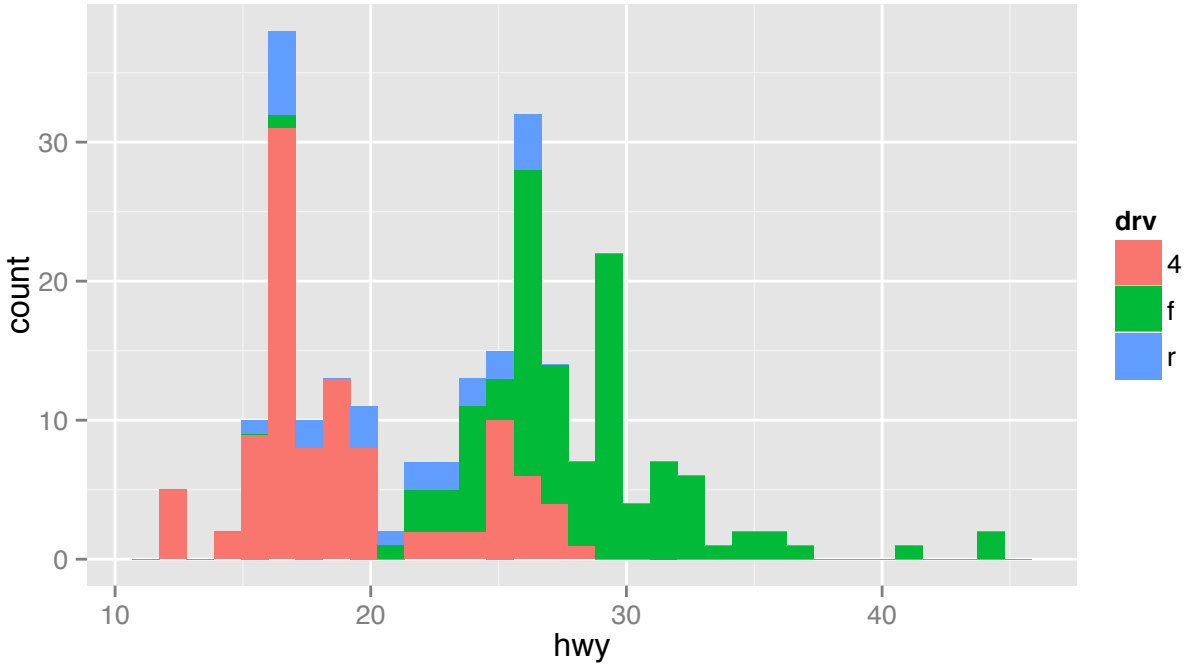
qplot(displ, hwy, data = mpg, color = drv)

Adding a geom



qplot(displ, hwy, data = mpg, geom = c("point", "smooth"))

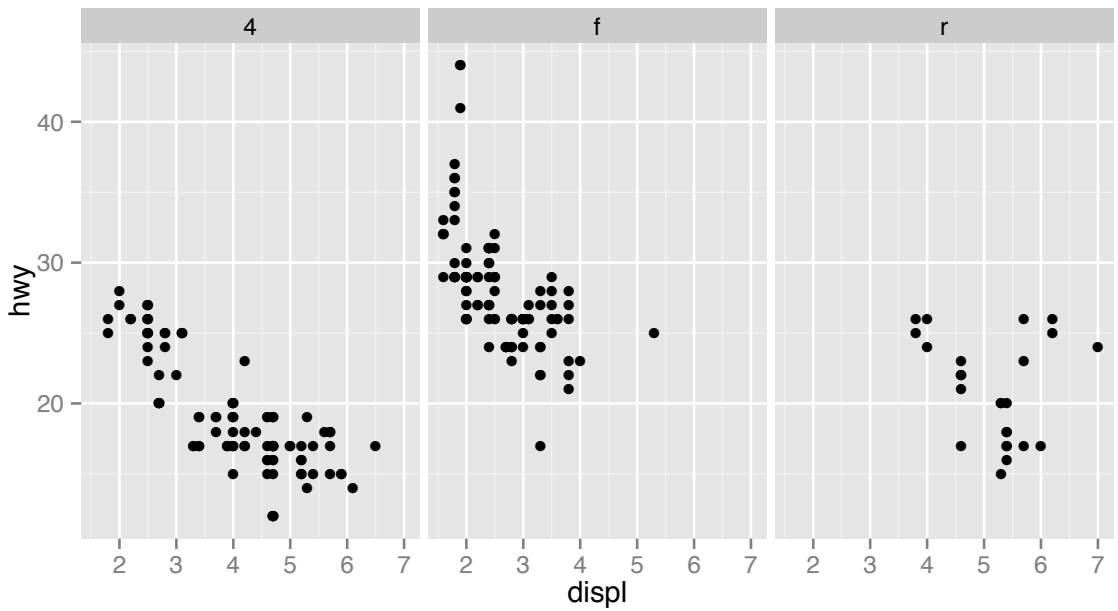
Histograms

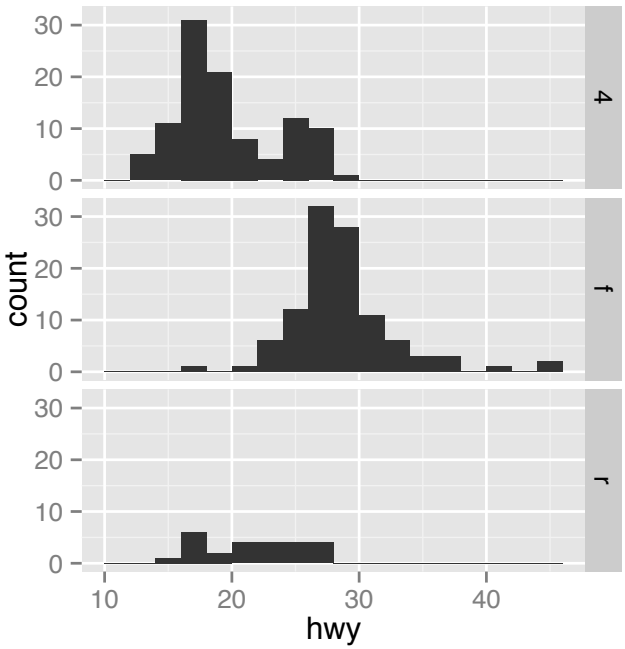


qplot(hwy, data = mpg, fill = drv)

Facets

qplot(displ, hwy, data = mpg, facets = . ~ drv)





qplot(hwy, data = mpg, facets = drv ~ ., binwidth = 2)

MAACS Cohort

- Mouse Allergen and Asthma Cohort Study
- Baltimore children (aged 5—17)
- Persistent asthma, exacerbation in past year
- Study indoor environment and its relationship with asthma morbidity
- Recent publication: http://goo.gl/WqE9j8

Example: MAACS

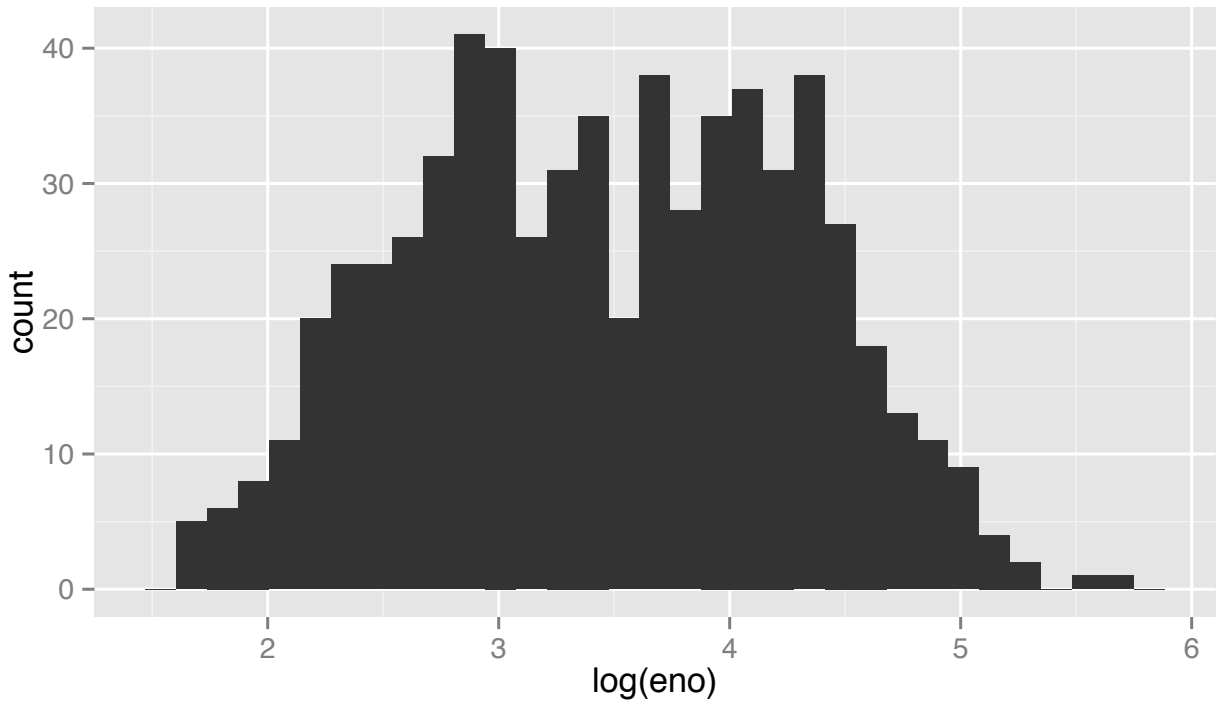
Exhaled nitric oxide

```
> str(maacs)
'data.frame':   750 obs. of  5 variables:
 $ id       : int  1 2 3 4 5 6 7 8 9 10 ...
 $ eno      : num  141 124 126 164 99 68 41 50 12 30 ...
 $ duBedMusM: num  2423 2793 3055 775 1634 ...
 $ pm25     : num  15.6 34.4 39 33.2 27.1 ...
 $ mopos    : Factor w/ 2 levels "no","yes": 2 2 2 2 2 2 2 2 2 2 ...
```

Fine particulate matter

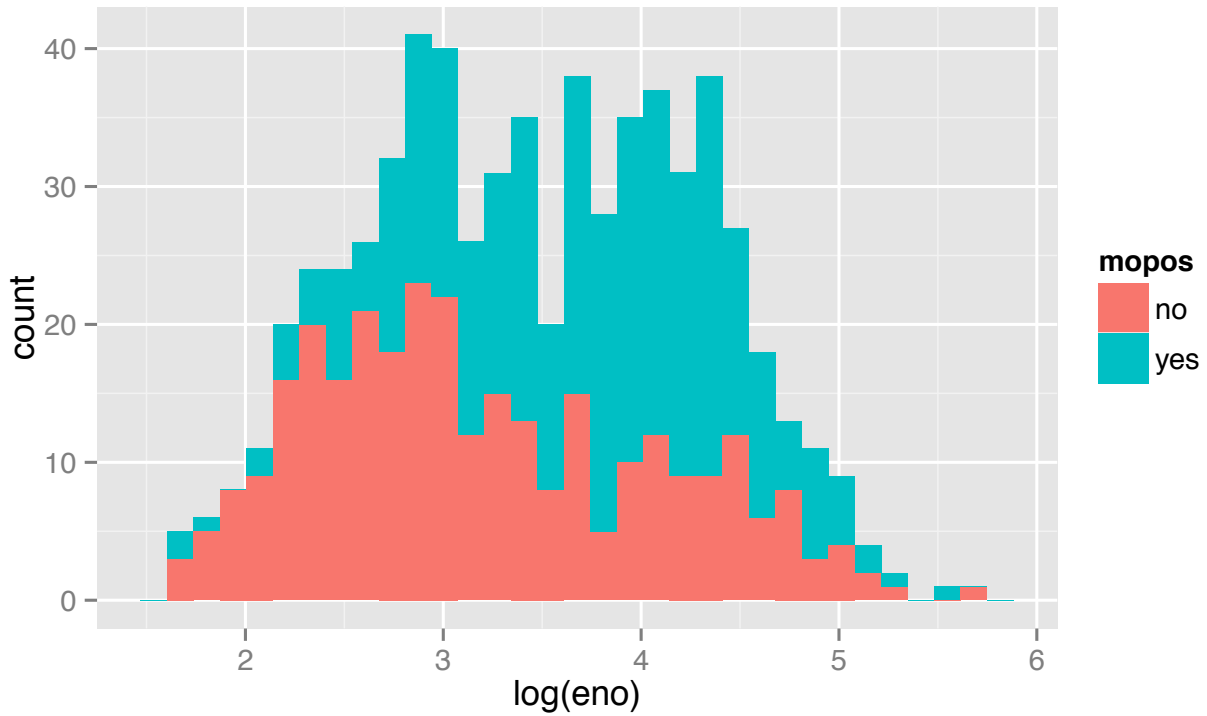
Sensitized to mouse allergen

Histogram of eNO



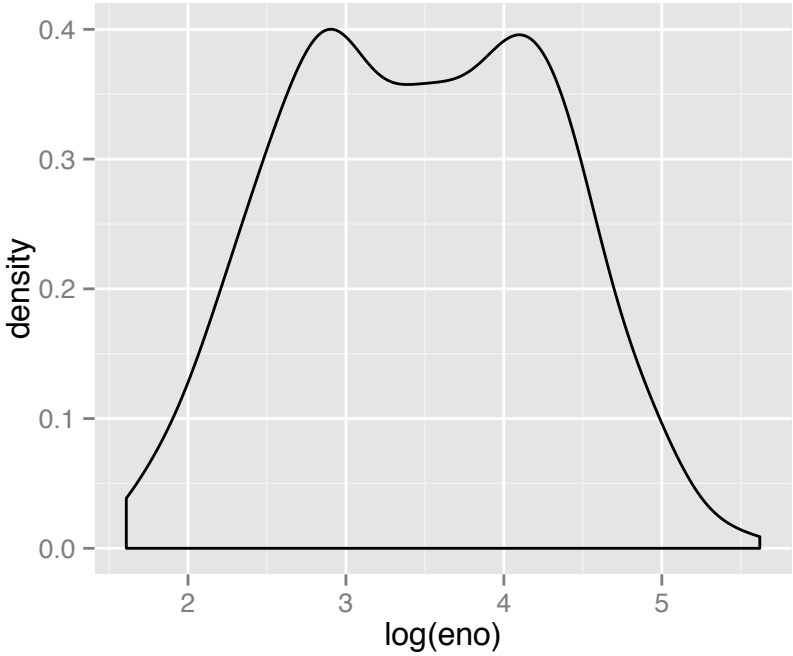
qplot(log(eno), data = maacs)

Histogram by Group

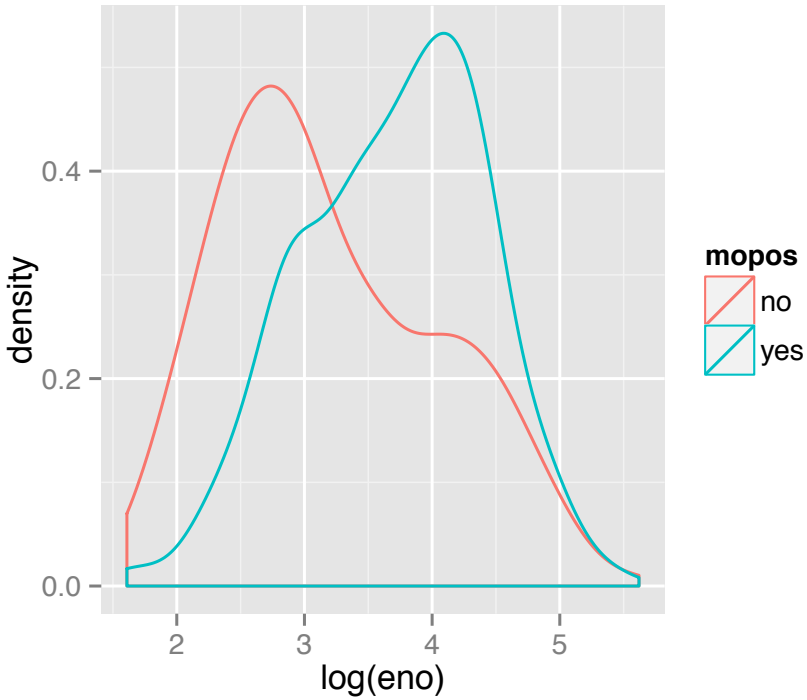


qplot(log(eno), data = maacs, fill = mopos)

Density Smooth

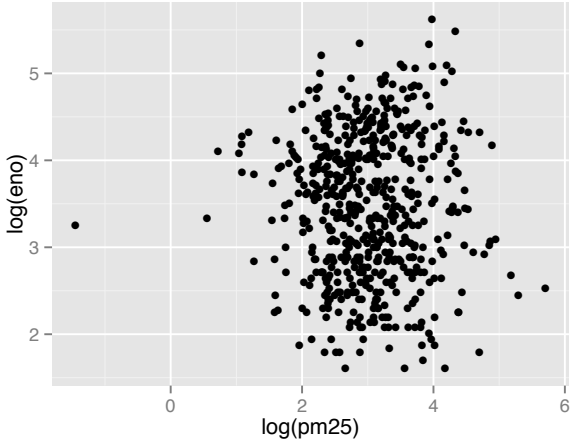


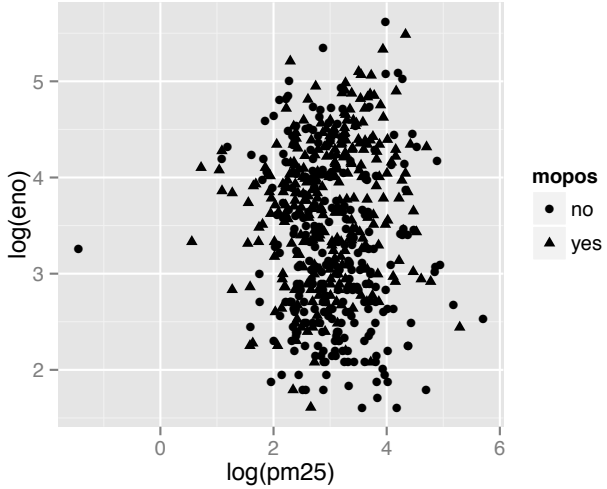
qplot(log(eno), data = maacs, geom = "density")

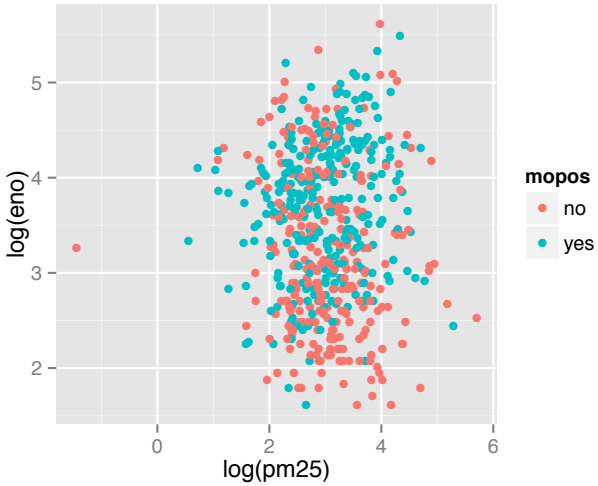


qplot(log(eno), data = maacs, geom = "density", color = mopos)

Scatterplots: eNO vs. $PM_{2.5}$





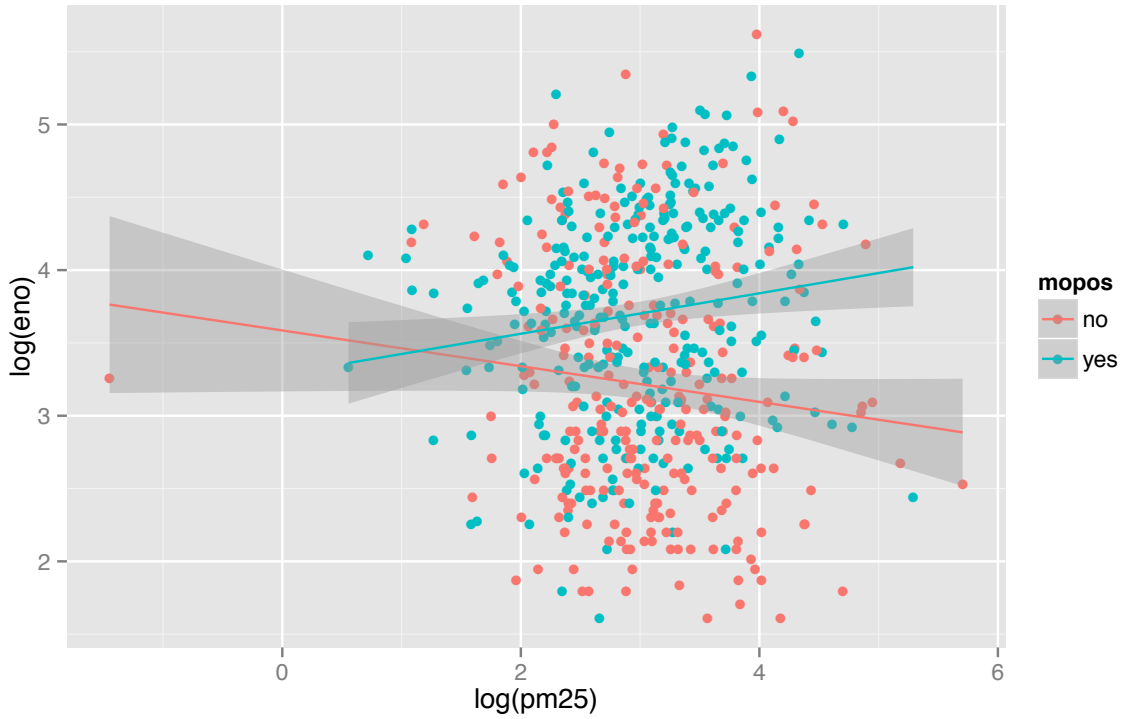



```
qplot(log(pm25), log(eno), data =
maacs)
```

```
qplot(log(pm25), log(eno), data =
maacs, shape = mopos)
```

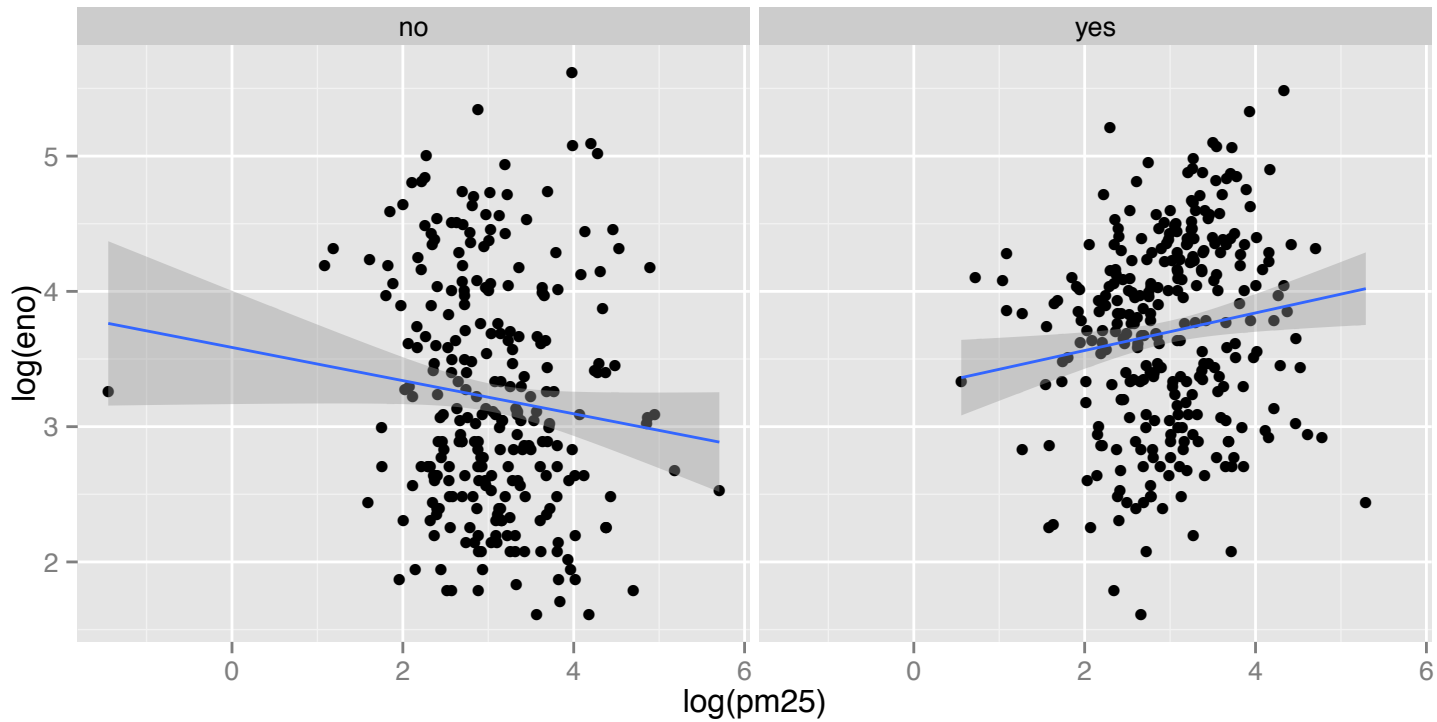
```
qplot(log(pm25), log(eno), data =
maacs, color = mopos)
```

Scatterplots: eNO vs. $PM_{2.5}$



qplot(log(pm25), log(eno), data = maacs, color = mopos, geom = c("point", "smooth"), method = "lm")

Scatterplots: eNO vs. $PM_{2.5}$



qplot(log(pm25), log(eno), data = maacs, geom = c("point", "smooth"), method = "lm", facets = . ~ mopos)

Summary of qplot()

- The qplot() function is the analog to plot() but with many built-in features
- Syntax somewhere in between base/lattice
- Produces very nice graphics, essentially publication ready (if you like the design)
- Difficult to go against the grain/customize (don't bother; use full ggplot2 power in that case)

Resources

- The *ggplot2* book by Hadley Wickham
- The *R Graphics Cookbook* by Winston Chang (examples in base plots and in ggplot2)
- ggplot2 web site (http://ggplot2.org)
- ggplot2 mailing list (http://goo.gl/OdW3uB), primarily for developers

What is ggplot2?

- An implementation of the *Grammar of Graphics* by Leland Wilkinson
- Grammar of graphics represents and abstraction of graphics ideas/objects
- Think “verb”, “noun”, “adjective” for graphics
- Allows for a “theory” of graphics on which to build new graphics and graphics objects

Basic Components of a ggplot2 Plot

- A **data frame**
- **aesthetic mappings**: how data are mapped to color, size
- **geoms**: geometric objects like points, lines, shapes.
- **facets**: for conditional plots.
- **stats**: statistical transformations like binning, quantiles, smoothing.
- **scales**: what scale an aesthetic map uses (example: male = red, female = blue).
- **coordinate system**

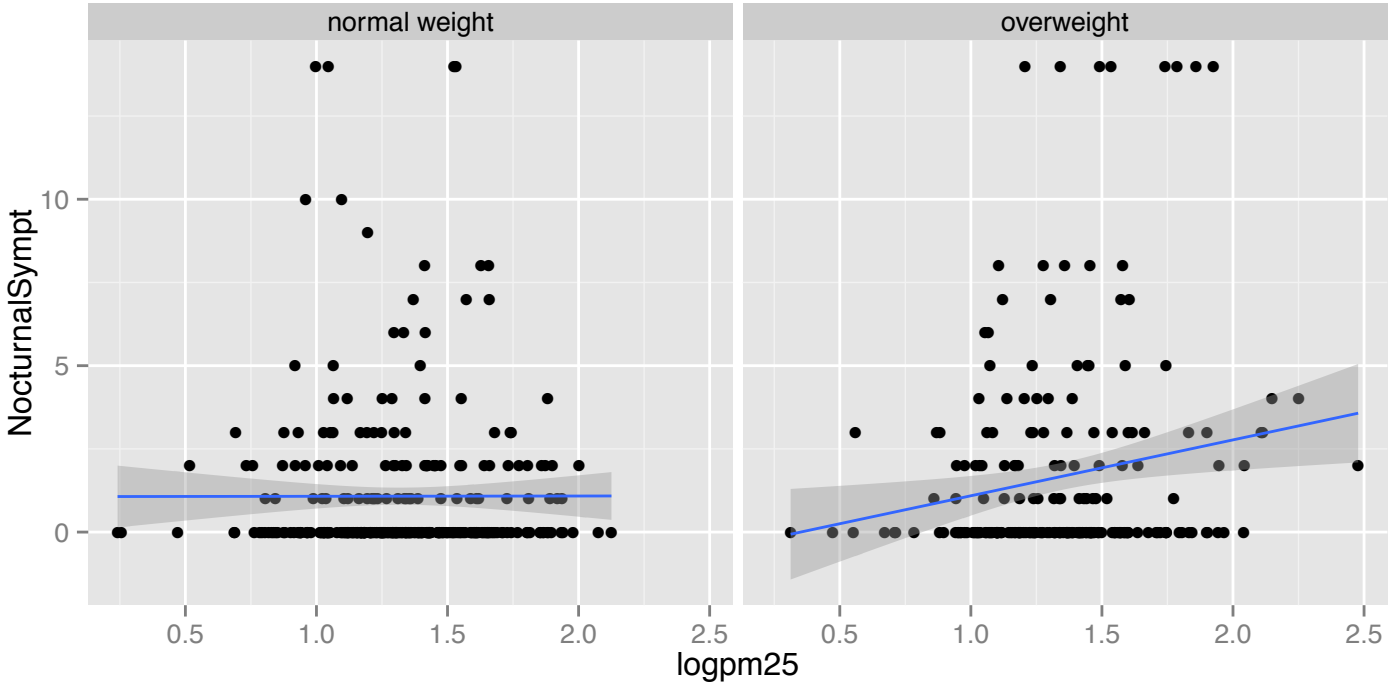
Building Plots with ggplot2

- When building plots in ggplot2 (rather than using qplot) the “artist’s palette” model may be the closest analogy
- Plots are built up in layers
  - Plot the data
  - Overlay a summary
  - Metadata and annotation

Example: BMI, $PM_{2.5}$, Asthma

- Mouse Allergen and Asthma Cohort Study
- Baltimore children (age 5-17)
- Persistent asthma, exacerbation in past year
- Does BMI (normal vs. overweight) modify the relationship between $PM_{2.5}$ and asthma symptoms?

Basic Plot




```
qplot(logpm25, NocturnalSympt, data = maacs, facets = . ~ bmicat, geom =
c("point", "smooth"), method = "lm”)
```

Building Up in Layers

```
> head(maacs)
    logpm25        bmicat NocturnalSympt
2 1.5361795 normal weight              1
3 1.5905409 normal weight              0
4 1.5217786 normal weight              0
5 1.4323277 normal weight              0
6 1.2762320    overweight              8
8 0.7139103    overweight              0

> g <- ggplot(maacs, aes(logpm25, NocturnalSympt))

> summary(g)
data: logpm25, bmicat, NocturnalSympt [554x3]
mapping:  x = logpm25, y = NocturnalSympt
faceting: facet_null()
```

Data Frame

Aesthetics

Initial call to ggplot

Summary of ggplot object

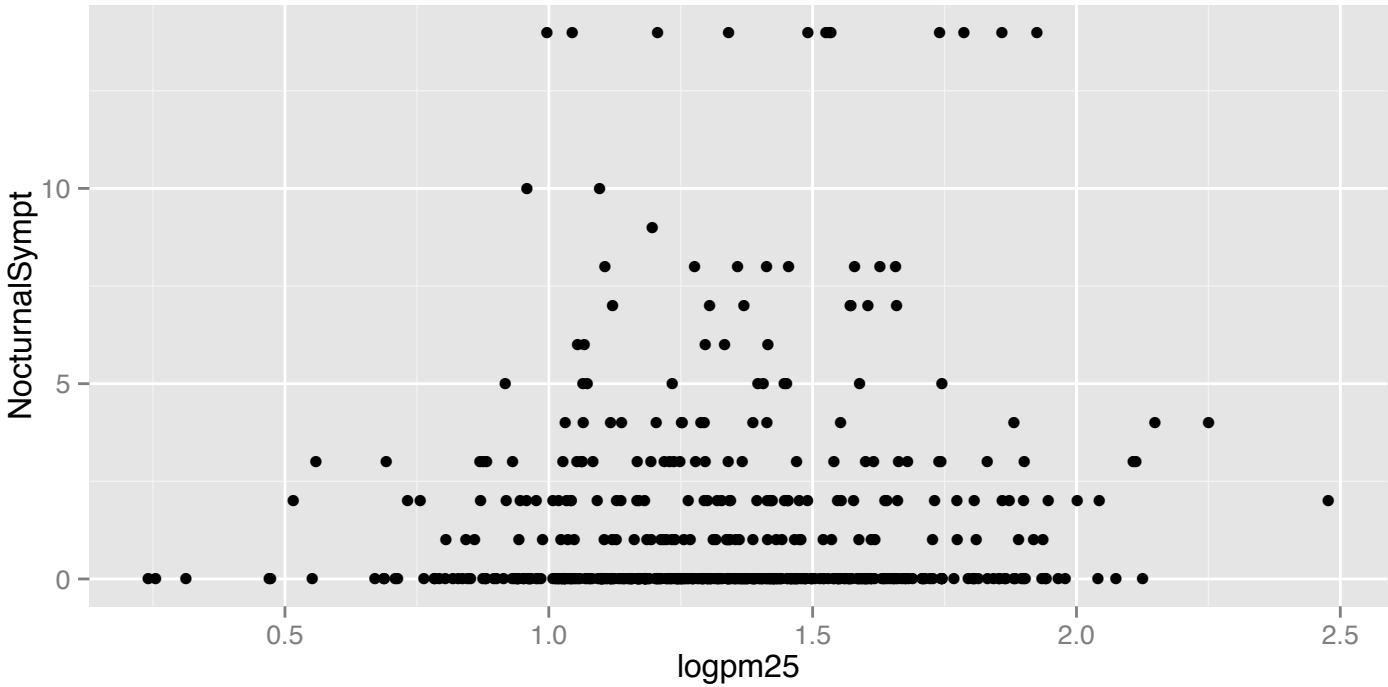
No Plot Yet!

```
> g <- ggplot(maacs, aes(logpm25, NocturnalSympt))
> print(g)
Error: No layers in plot

> p <- g + geom_point()
> print(p)

> g + geom_point()
```

Explicitly save and print ggplot object

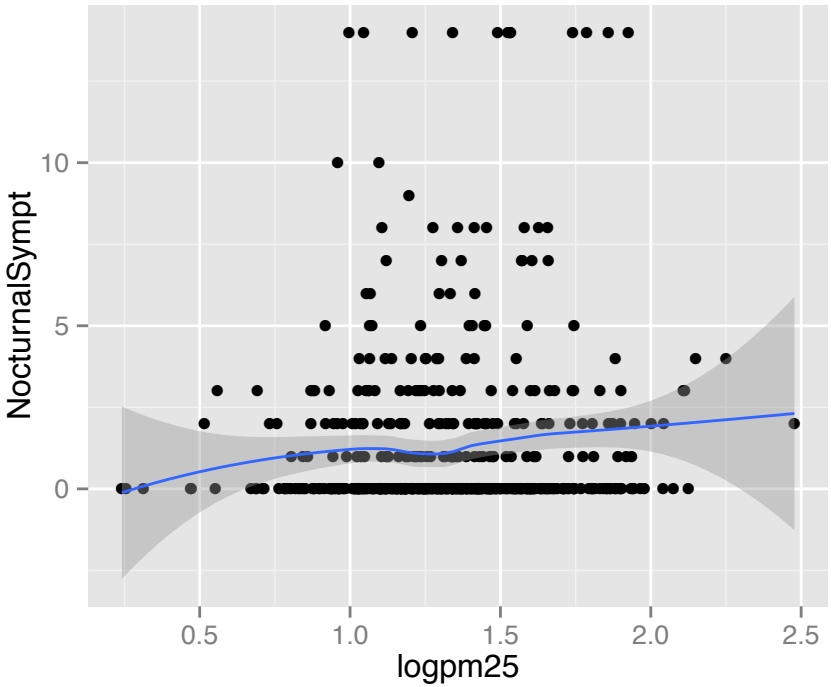
Auto-print plot object without saving

First Plot with Point Layer

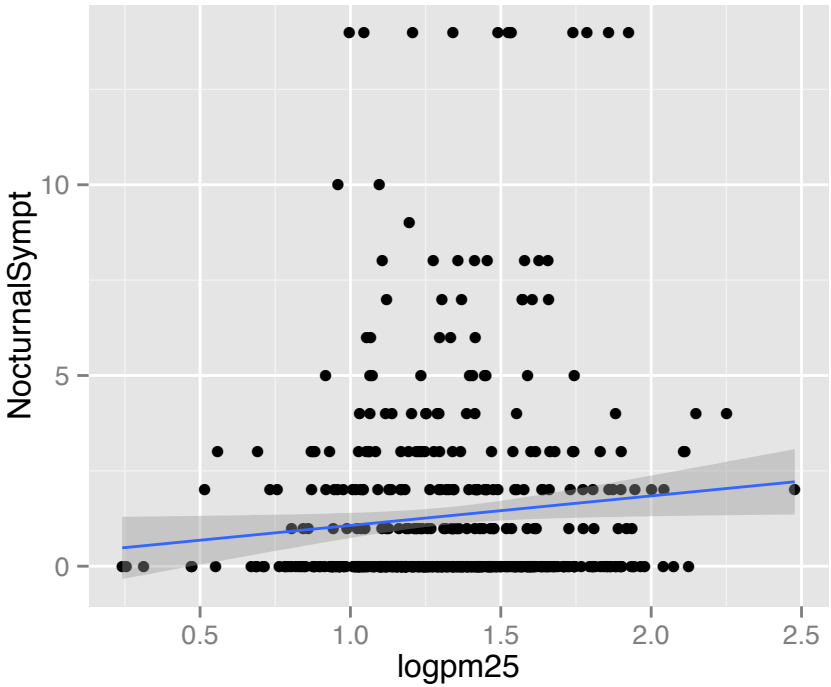



```
g <- ggplot(maacs, aes(logpm25, NocturnalSympt))
g + geom_point()
```

Adding More Layers: Smooth



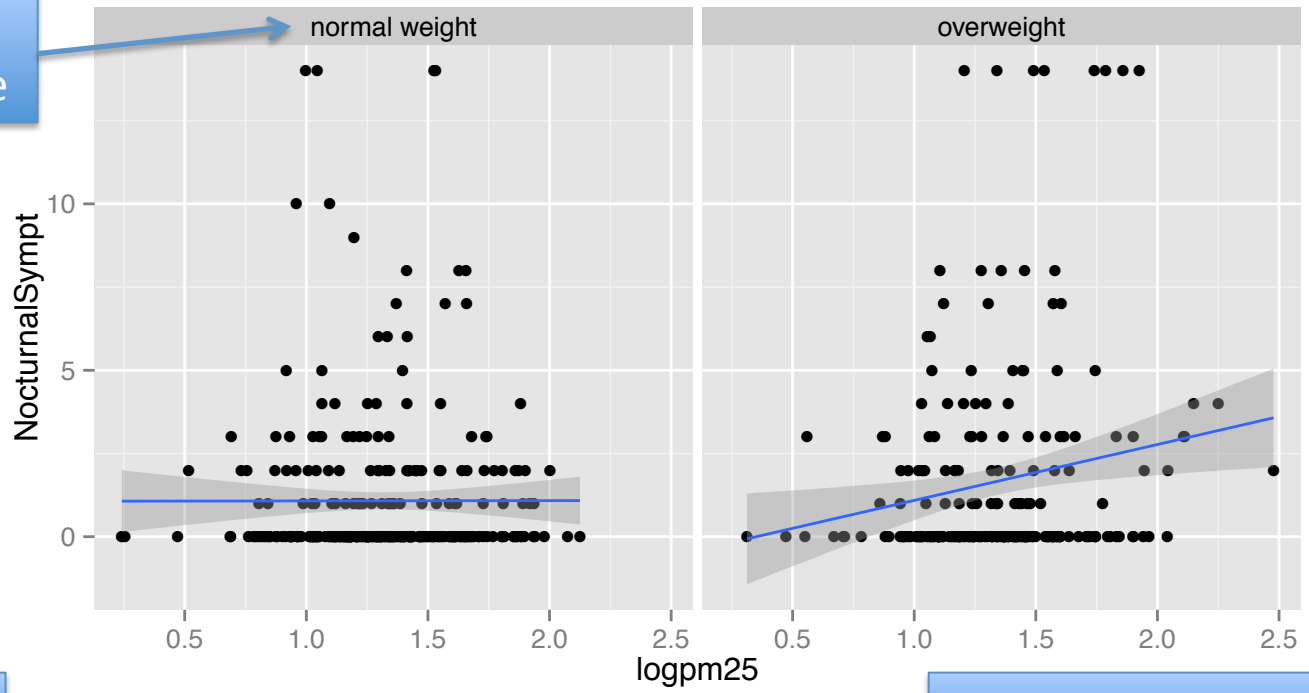

```
g + geom_point() + geom_smooth()
```




```
g + geom_point() + geom_smooth(method = "lm”)
```

Adding More Layers: Facets

Labels from facet variable



Add facets

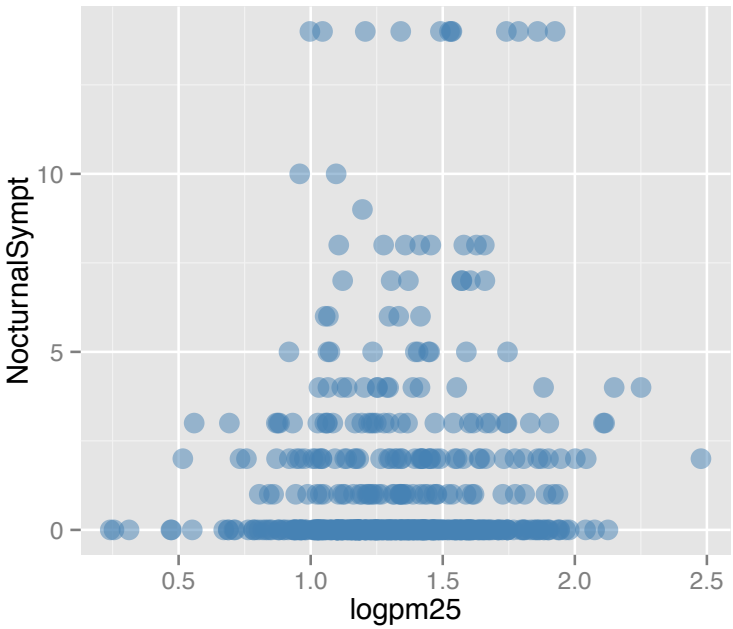
Faceting (factor) variable

```
g + geom_point() + facet_grid(. ~ bmicat) + geom_smooth(method = "lm")
```

Annotation

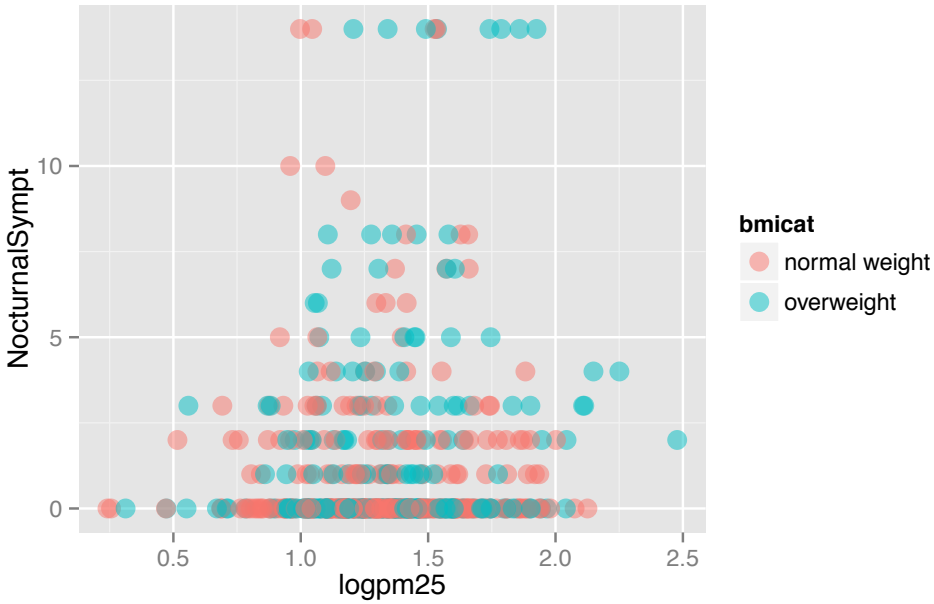
- Labels: xlab(), ylab(), labs(), ggtitle()
- Each of the “geom” functions has options to modify
- For things that only make sense globally, use theme()
  - Example: theme(legend.position = "none")
- Two standard appearance themes are included
  - theme_gray(): The default theme (gray background)
  - theme_bw(): More stark/plain

Modifying Aesthetics




```
g + geom_point(color = "steelblue",
size = 4, alpha = 1/2)
```

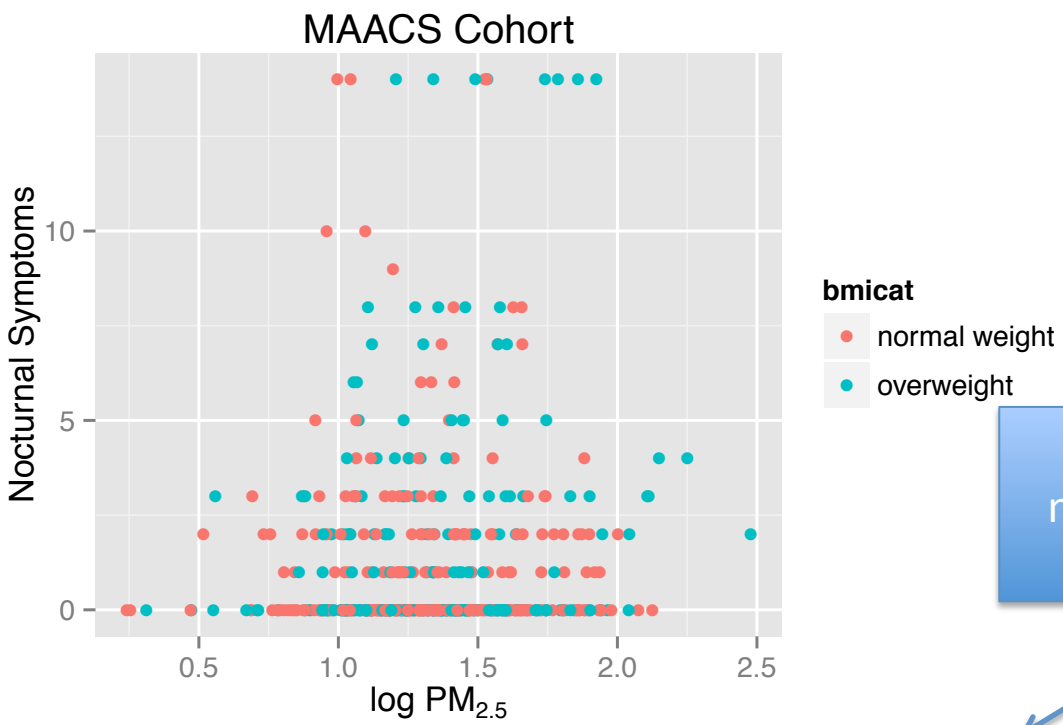
Constant values




```
g + geom_point(aes(color = bmicat),
size = 4, alpha = 1/2)
```

Data variable

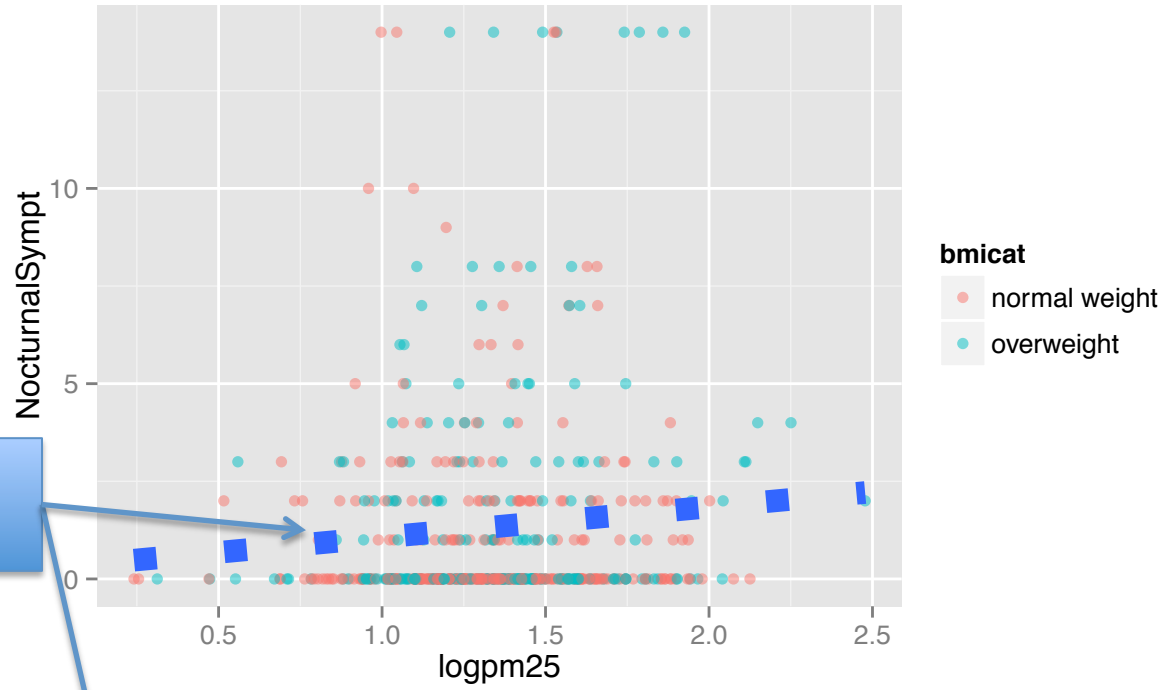
Modifying Labels



labs() function for modifying titles and x-, y-axis labels

```
g + geom_point(aes(color = bmicat)) + labs(title = "MAACS Cohort") + labs(x = expression("log "
* PM[2.5]), y = "Nocturnal Symptoms")
```

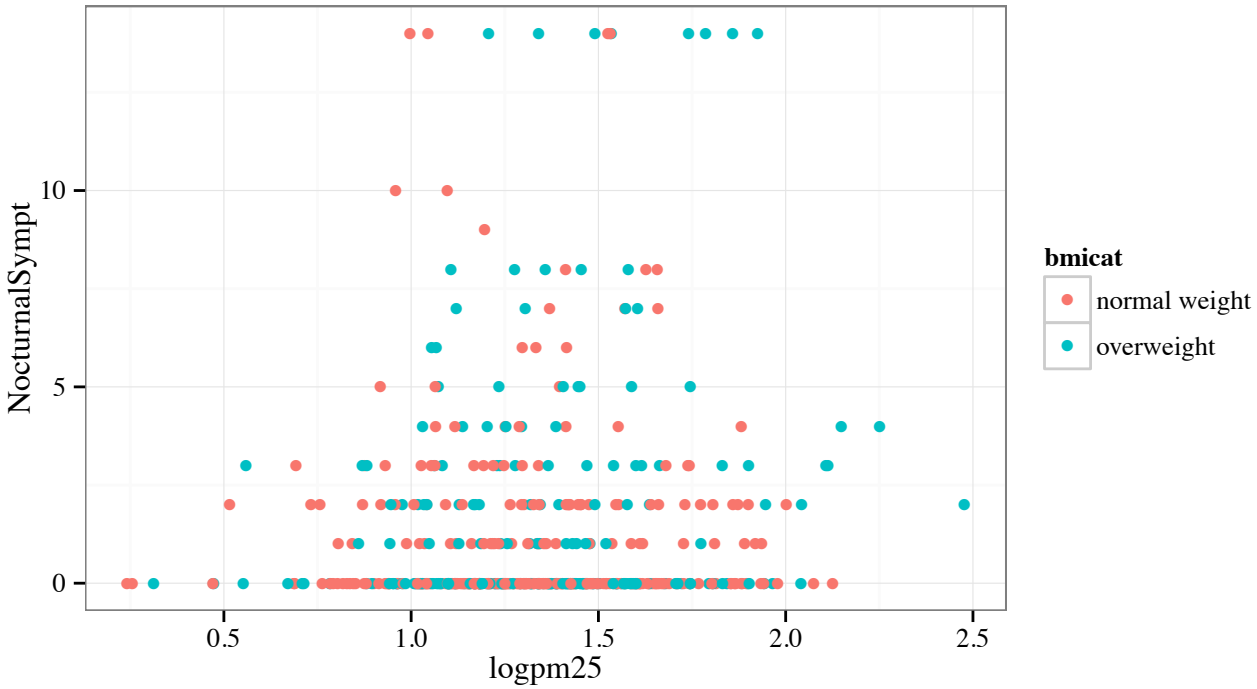
Customizing the Smooth



Modified smoother

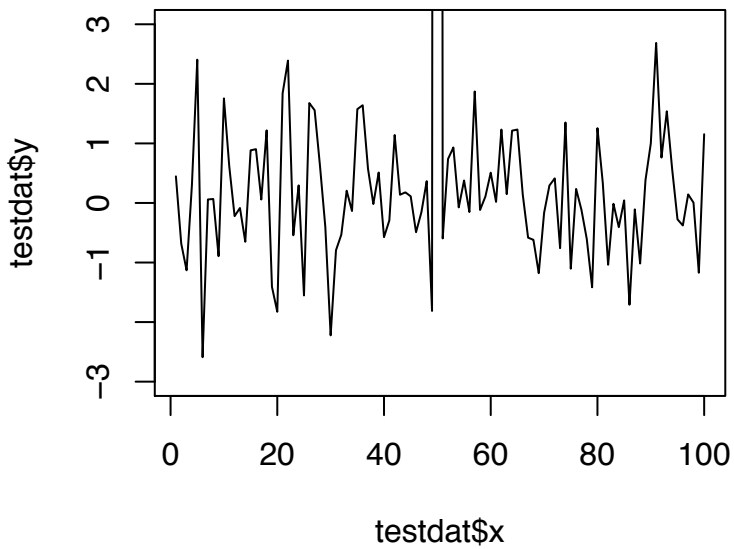
```
g + geom_point(aes(color = bmicat), size = 2, alpha = 1/2) +
geom_smooth(size = 4, linetype = 3, method = "lm", se = FALSE)
```

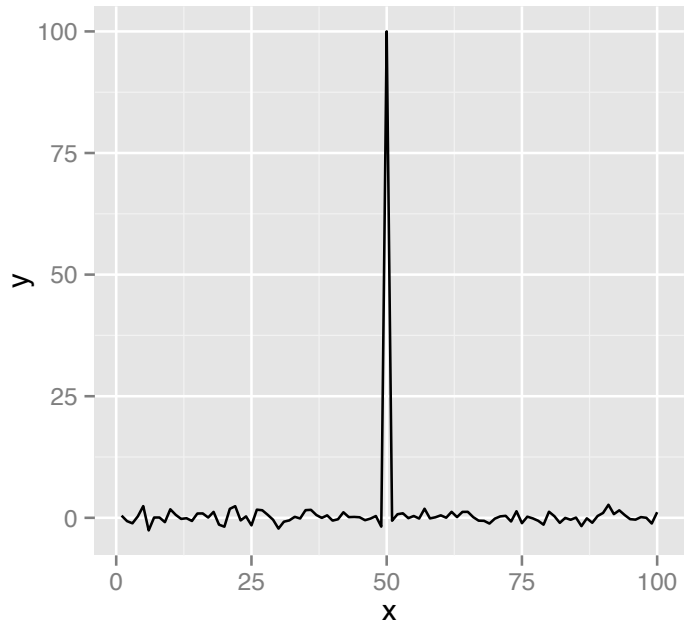
Changing the Theme




```
g + geom_point(aes(color = bmicat)) + theme_bw(base_family = "Times”)
```

A Notes about Axis Limits



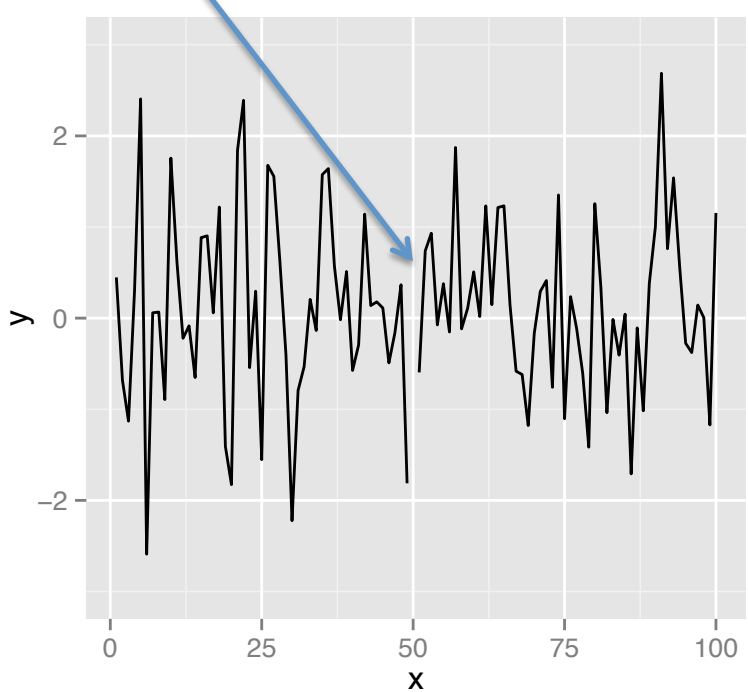



```
testdat <- data.frame(x = 1:100, y = rnorm(100))
testdat[50,2] <- 100  ## Outlier!
plot(testdat$x, testdat$y, type = "l", ylim = c(-3,3))
```

```
g <- ggplot(testdat, aes(x = x, y = y))
g + geom_line()
```

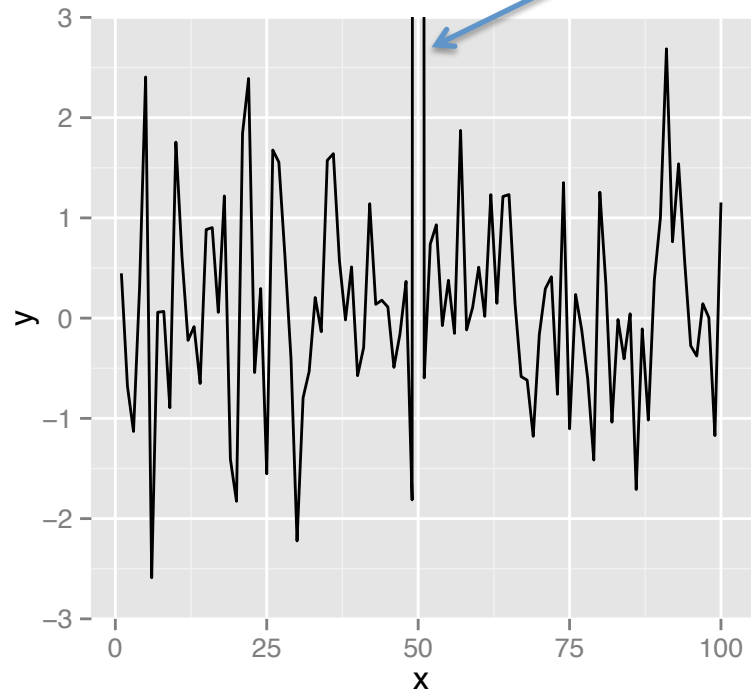
Axis Limits

Outlier missing




```
g + geom_line() + ylim(-3, 3)
```

Outlier included




```
g + geom_line() + coord_cartesian(ylim = c(-3, 3))
```

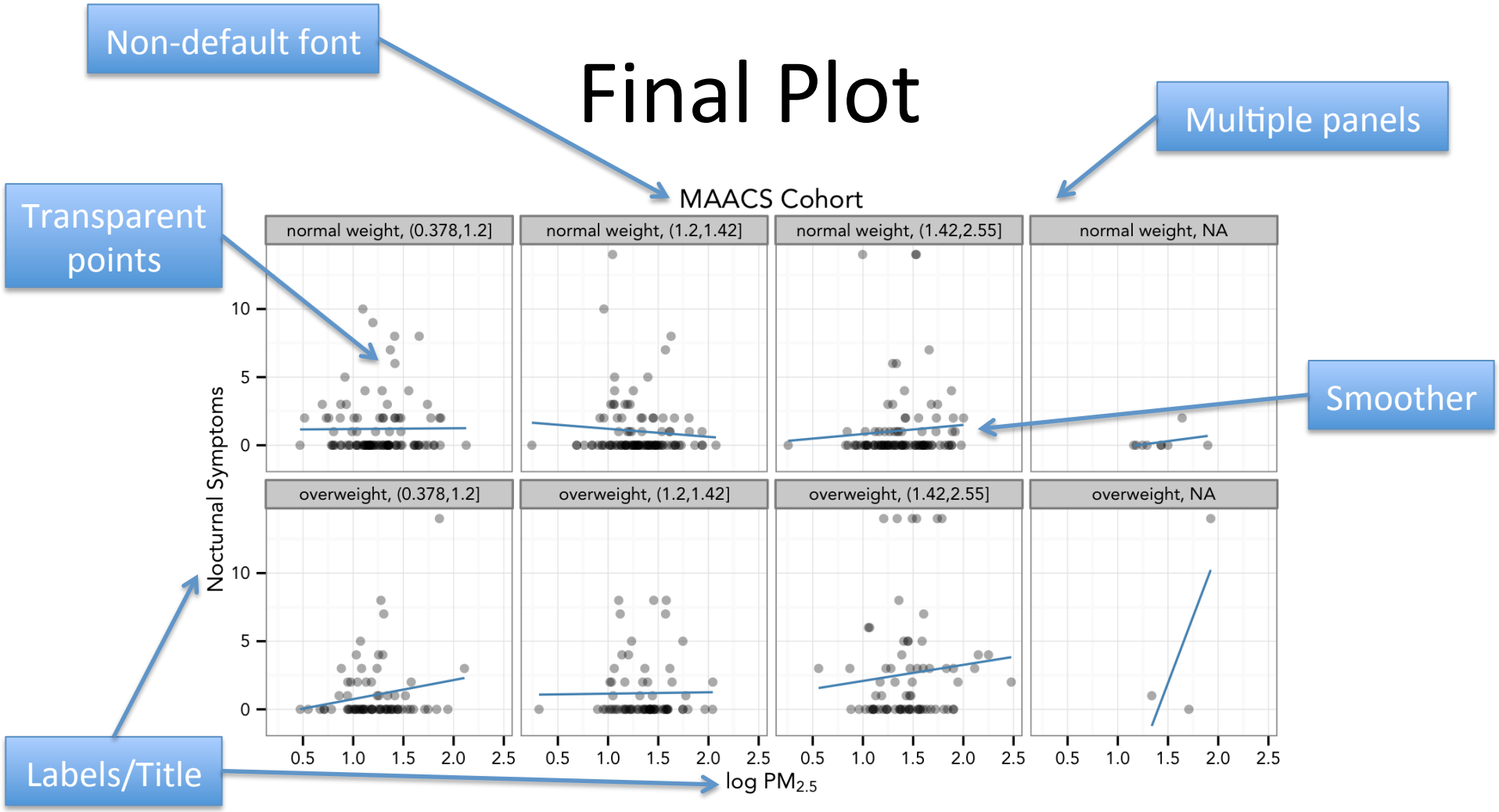
More Complex Example

- How does the relationship between $PM_{2.5}$ and nocturnal symptoms vary by BMI and NO_2?
- Unlike our previous BMI variable, NO_2 is continuous
- We need to make NO2 categorical so we can condition on it in the plotting
  - Use the cut() function for this

Making NO_2 Deciles

```
## Calculate the deciles of the data
> cutpoints <- quantile(maacs$logno2_new, seq(0, 1, length = 11), na.rm = TRUE)

## Cut the data at the deciles and create a new factor variable
> maacs$no2dec <- cut(maacs$logno2_new, cutpoints)

## See the levels of the newly created factor variable
> levels(maacs$no2dec)
 [1] "(0.378,0.969]" "(0.969,1.1]"   "(1.1,1.17]"    "(1.17,1.26]"
 [5] "(1.26,1.32]"   "(1.32,1.38]"   "(1.38,1.44]"   "(1.44,1.54]"
 [9] "(1.54,1.69]"   "(1.69,2.55]"
```

Final Plot


Non-default font
Multiple panels
Transparent points
Smoother
Labels/Title
MAACS Cohort
normal weight, (0.378,1.2]
normal weight, (1.2,1.42]
normal weight, (1.42,2.55]
normal weight, NA
overweight, (0.378,1.2]
overweight, (1.2,1.42]
overweight, (1.42,2.55]
overweight, NA
Nocturnal Symptoms
0
5
10
0.5
1.0
1.5
2.0
2.5
log PM2.5

Code for Final Plot

```
## Setup ggplot with data frame
g <- ggplot(maacs, aes(logpm25, NocturnalSympt))

## Add layers
g + geom_point(alpha = 1/3)
  + facet_wrap(bmicat ~ no2dec, nrow = 2, ncol = 4)
  + geom_smooth(method="lm", se=FALSE, col="steelblue")
  + theme_bw(base_family = "Avenir", base_size = 10)
  + labs(x = expression("log " * PM[2.5])
  + labs(y = "Nocturnal Symptoms”)
  + labs(title = "MAACS Cohort”)
```

Add points

Make panels

Add smoother

Change theme

Add labels

Summary

- ggplot2 is very powerful and flexible if you learn the “grammar” and the various elements that can be tuned/modified
- Many more types of plots can be made; explore and mess around with the package (references mentioned in Part 1 are useful)