Multiple regression with R

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Agenda

- Introduce R
- Very basics of R (object assignment)
- R packages
- Running multiple regression models
- Visualizing multiple regression models

Who am I?

Daniel Anderson

- Research Associate: Behavioral Research and Teaching
- Dad (two daughters: 5 and 3)
- Quantitative educational researcher who **loves** R
- Primary areas of interest
    - R and computational educational research
    - Open data, open science, and reproducible workflows
    - Growth modeling (primarily through multilevel models)

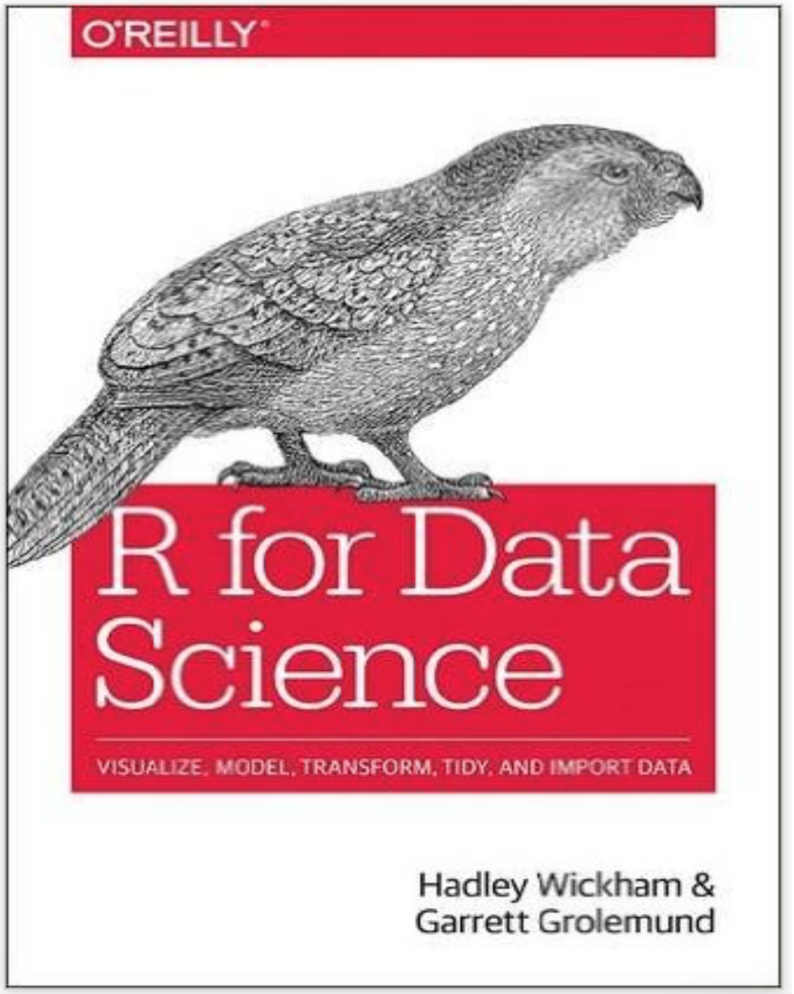
Part of why I love R

- Computer programming language = you can do ANYTHING!
- Develop websites: http://www.dandersondata.com
- Develop new algorithms/methods: https://github.com/DJAnderson07/esvis
- Create huge gains in efficiency: https://github.com/DJAnderson07/r2Winsteps
- Transparency and open and reproducible research
- The R community!

All of this great stuff and it just happens to also be free.

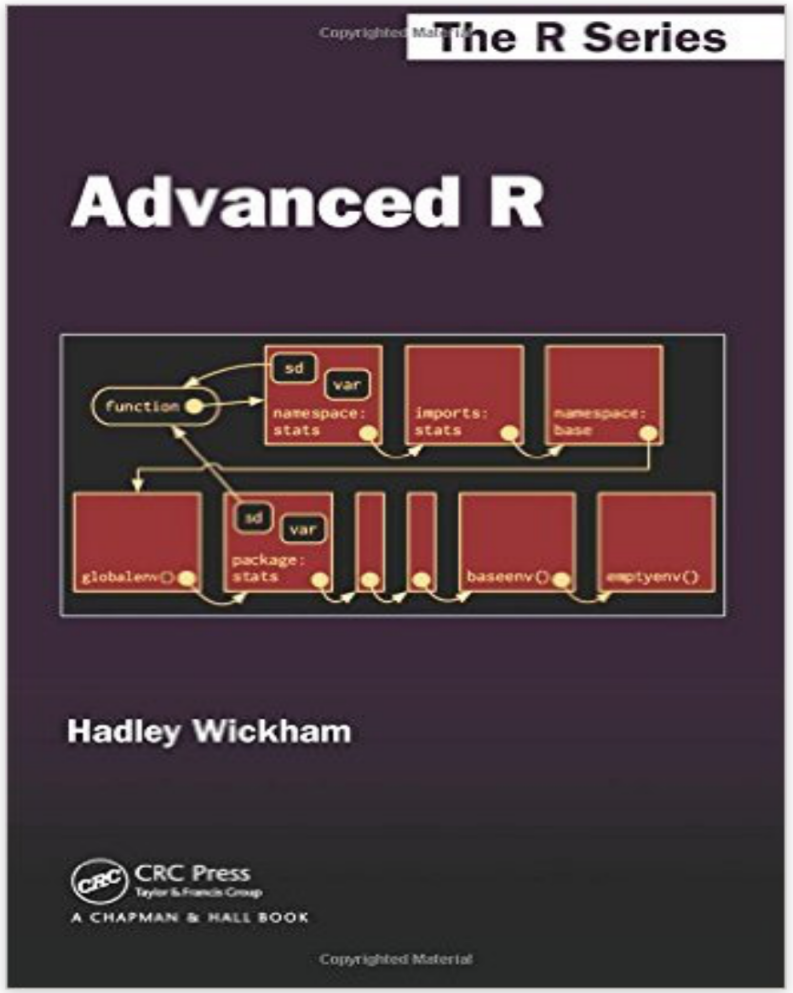
Free Books!

The book for the course I teach



R for Data Science

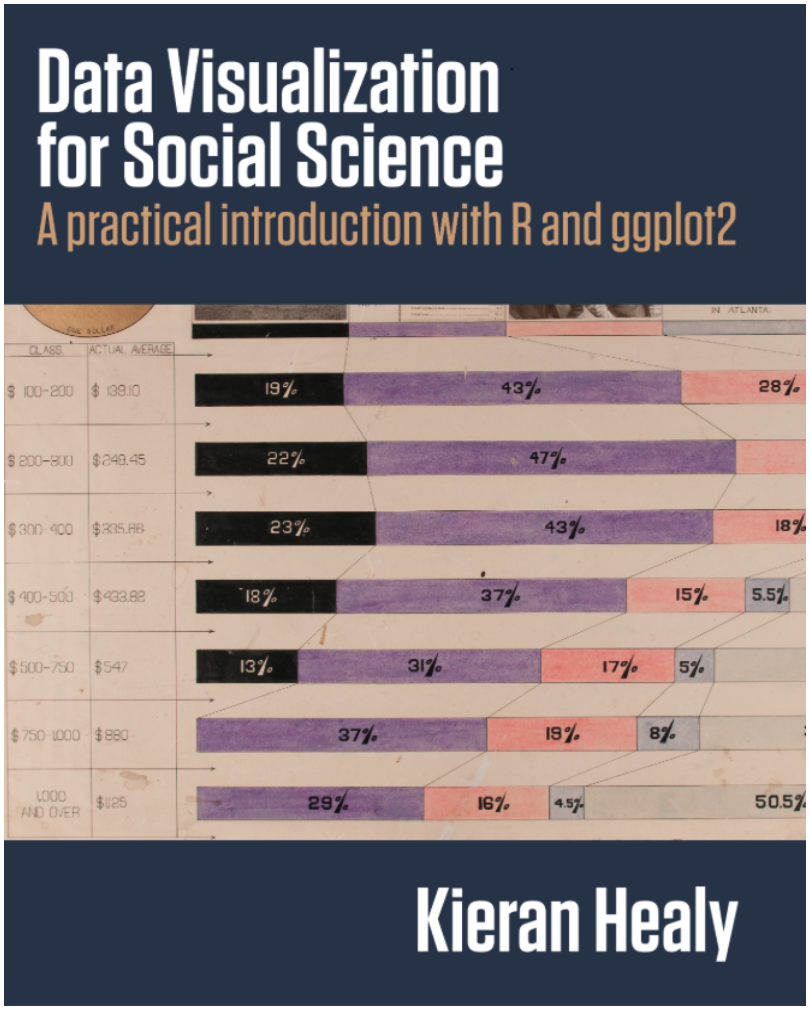
The book for the next course I would like to teach (if there is one)



Advanced R

Other books

Freely available at http://socviz.co



What is R?

- A programming language
- Tremendously powerful and flexible statistical software that happens to be free
- No point-and-click interface
- Incredible array of external "packages" available for specialized analyses, data visualizations, or to automate much of the data "munging" process

Code-based interface

Moving to code/programming

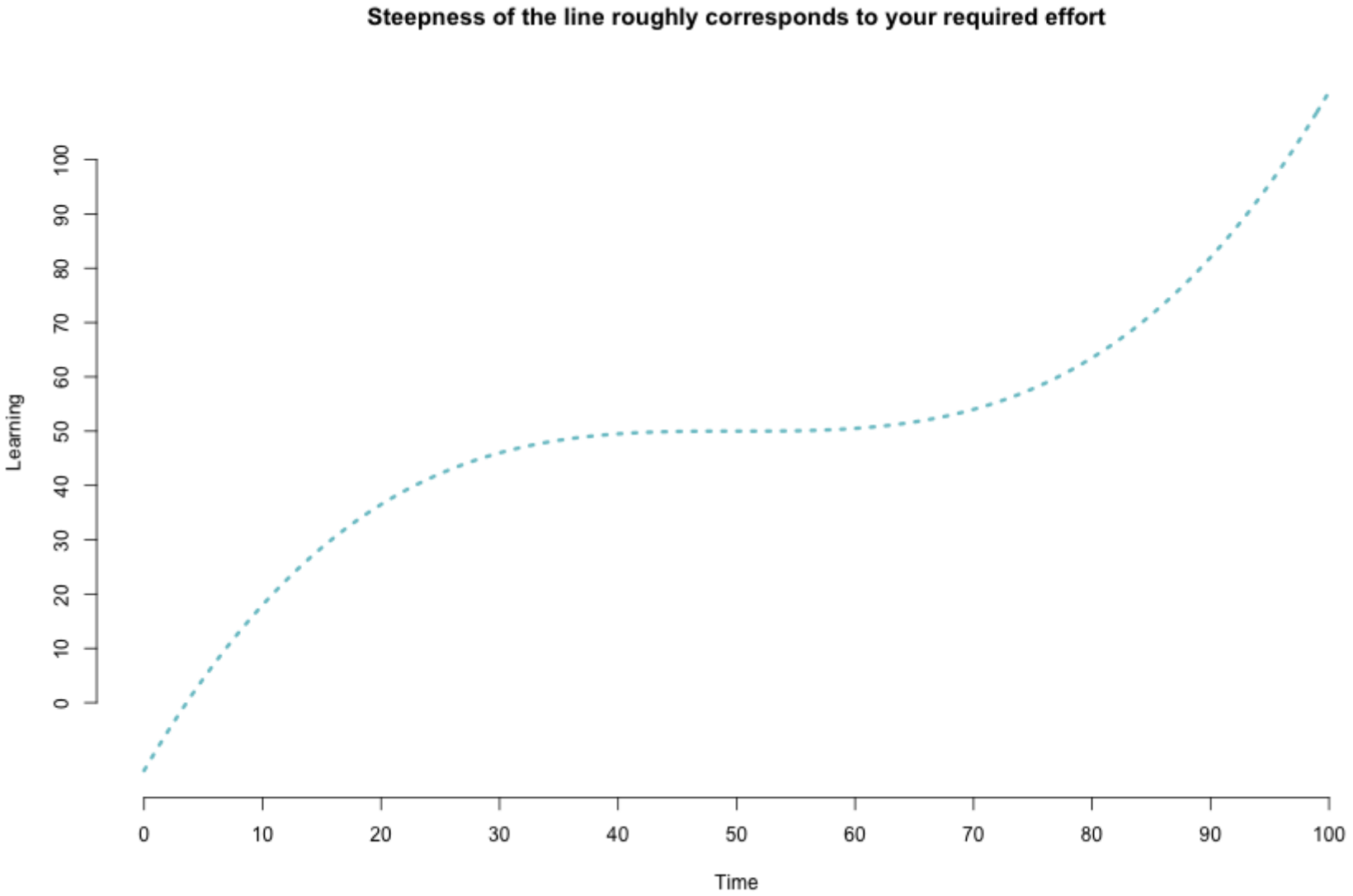
Advantages

- Flexibility
  - Only limited by your own creativity (and current level of programming skills, which are ever-evolving)
- Transparency
  - Documented record of every step taken in your data preparation and analysis
- Efficiency
  - Many (most?) tasks can be automated and/or applied to multiple datasets/variables simultaneously or essentially simultaneously

Disadvantages

- Steep learning curve
  - Absolutely requires a significant time investment, both to learn initially and build fluency
  - Equivalent to learning a new language
- You will lose patience with point-and-click interfaces
- Likely to become "one of the converted"

The R Learning Curve



How to learn R?

- Three most important ingredients: time, time, and more time
- A sprinkling of dedication and determination help.
- Be patient and forgiving with yourself. It will feel slow at first. Most people have not trained themselves to think in this way.

R as a big calculator

```
3 + 2
```

```
## [1] 5
```

```
(1/-(3/2)^2) / 2^-1/9
```

```
## [1] -0.09876543
```

Object Assignment

```
a <- 3
b <- 2
a + b
```

```
## [1] 5
```

```
a / (a + b)
```

```
## [1] 0.6
```

Object re-assignment

```
a <- 3
a
```

```
## [1] 3
```

```
a <- 7
a
```

```
## [1] 7
```

Object Assignment (continued)

Objects can be of a variety of types.

```
string <- "Hello world!"
logical <- TRUE
double <- 3.2587021
Integer <- 6L
```

In this case, we can't exactly do arithmetic with all of these. For example

```
string + double
```

```
## Error in string + double: non-numeric argume
```

But, these objects can be extremely useful in programming.

Functions and getting help

R functions

- Anything that carries out an operation in R is a function, even `+`.
- Functions (outside of primitive functions) are preceded by `()`
  - e.g., `sum()`, `lm()`

Getting help

- `?` can be helpful, but often too advanced early on
  - Helpful for understanding the formal arguments of a function
  - Scroll down to the examples first
- Google is your best friend
- Other good websites
  - http://stackoverflow.com
  - Mailing lists:
    - https://stat.ethz.ch/mailman/listinfo/r-help

R packages

R ships with considerable functionality. It also comes with a set of *pre-loaded* packages

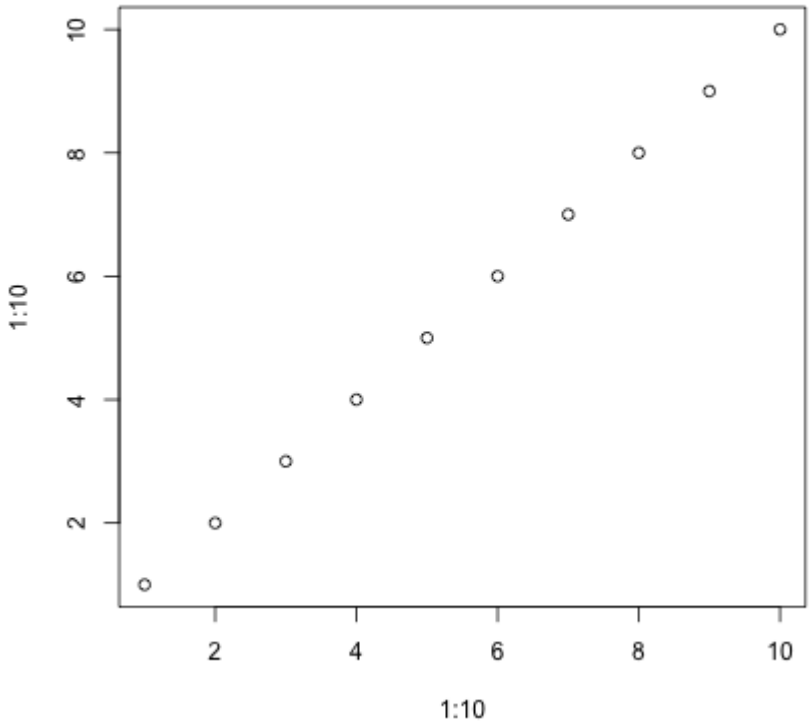
- e.g.
  - "base"
  - "graphics"
  - "stats"

R also comes with a set of packages installed, but not loaded on launch

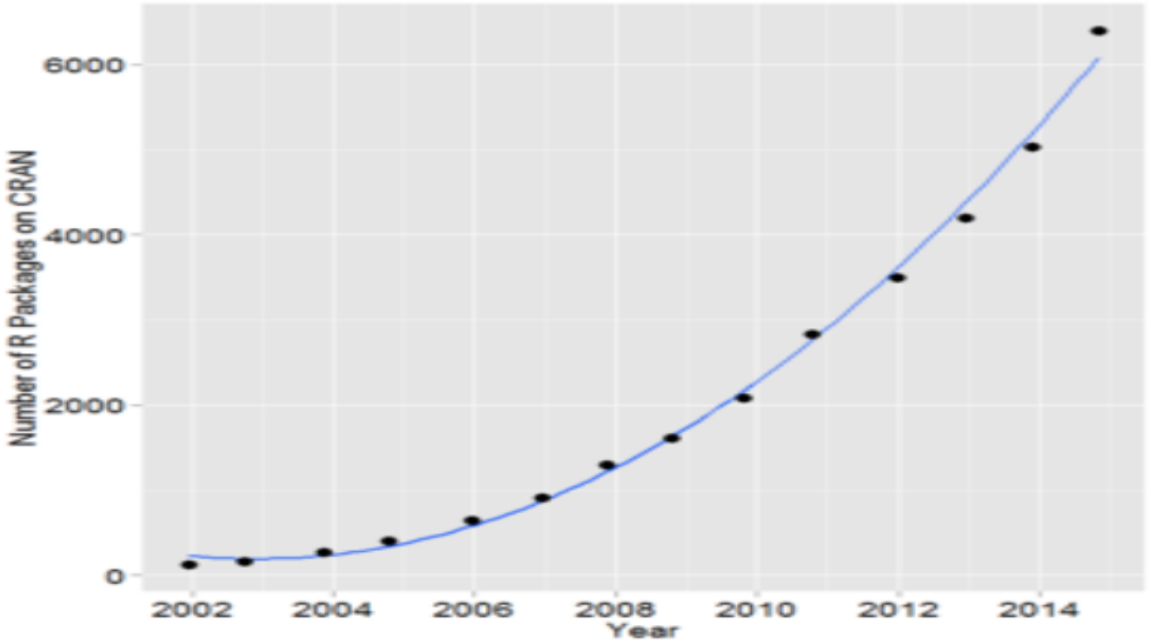
- e.g.
  - "boot"
  - "MASS"
  - "Matrix"

Pre-loaded packages operate "out of the box". For example, `plot` is part of the *graphics* package, which ships with R.

```
plot(x = 1:10, y = 1:10)
```



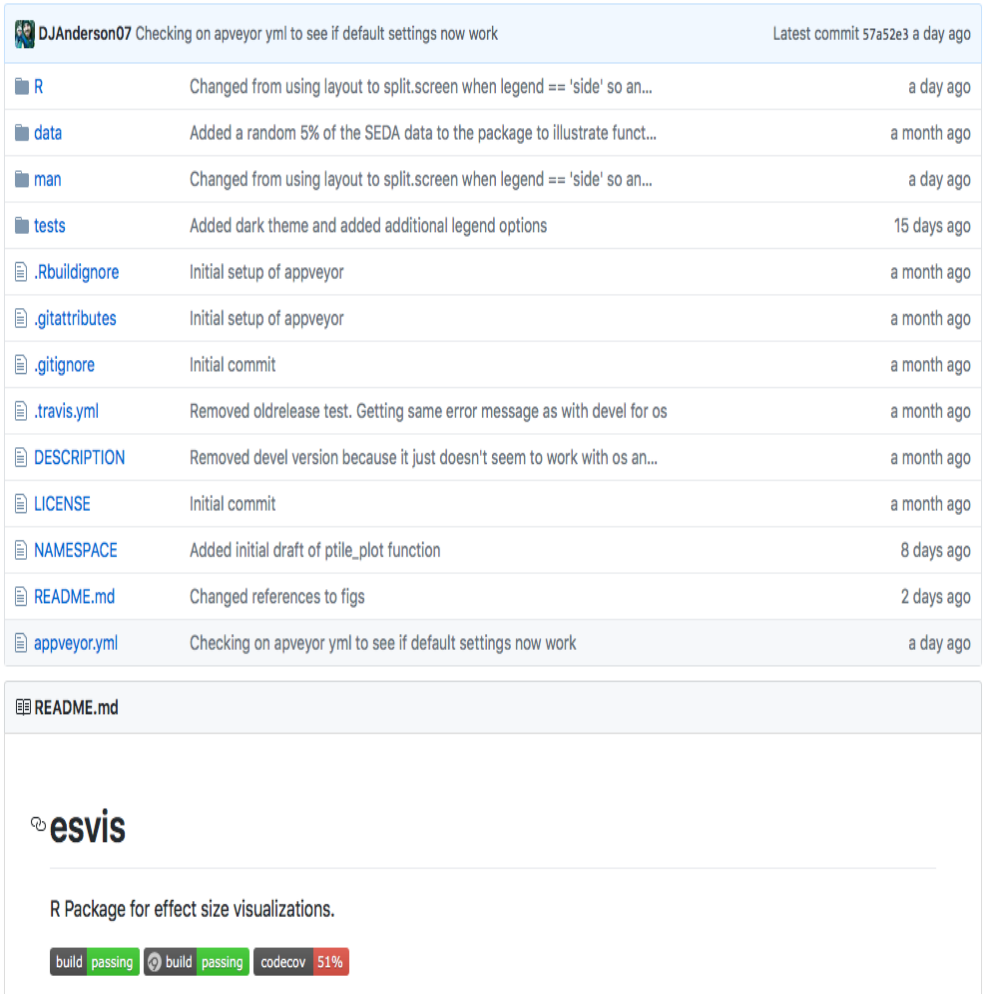
On CRAN



- Any of these can be installed with `install.packages("pkg_name")`. You will then have access to all the functionality of the package.
- Notice this plot only goes to mid-2014. As of this writing (11/22/17), there are 11,892 packages available on CRAN! See https://cran.r-project.org/web/packages/

Other packages

On github



DJAnderson07 Checking on apveyor yml to see if default settings now work — Latest commit 57a52e3 a day ago

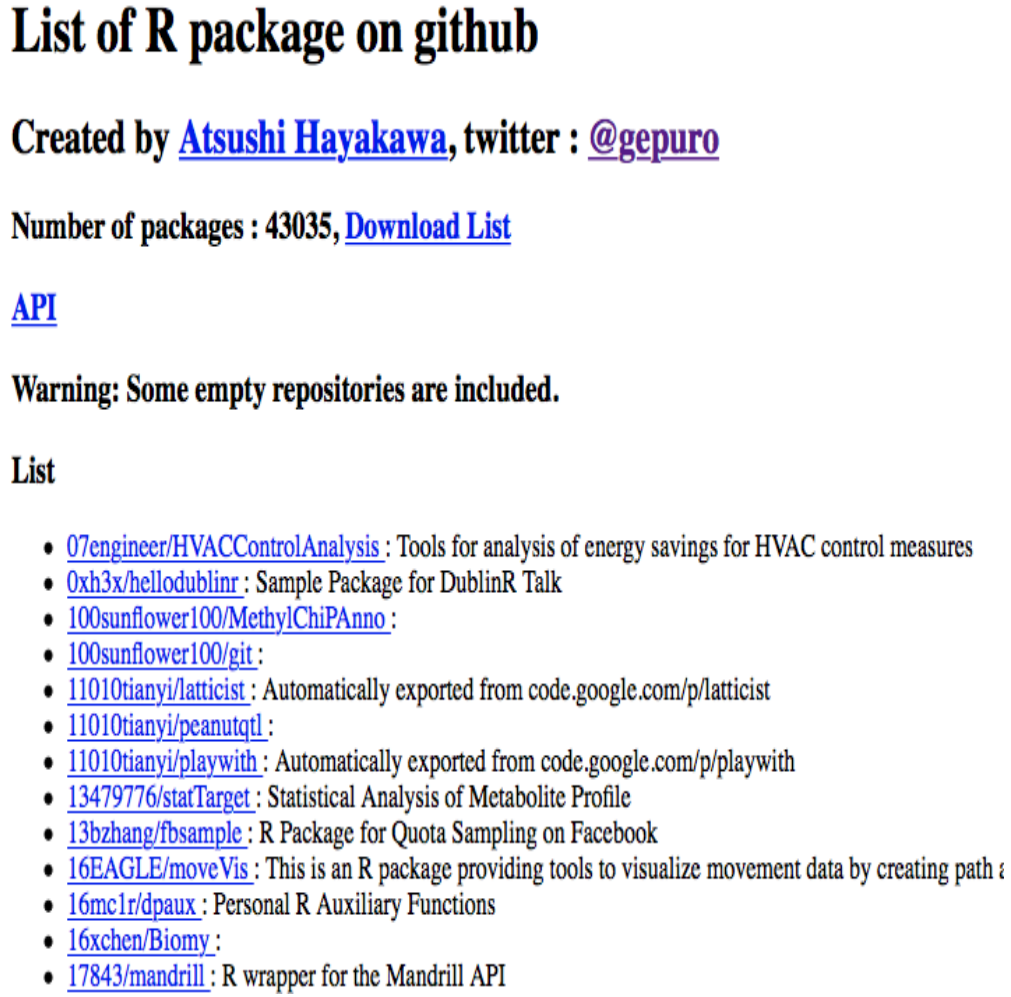
R	Changed from using layout to split.screen when legend == 'side' so an...	a day ago
data	Added a random 5% of the SEDA data to the package to illustrate funct...	a month ago
man	Changed from using layout to split.screen when legend == 'side' so an...	a day ago
tests	Added dark theme and added additional legend options	15 days ago
.Rbuildignore	Initial setup of appveyor	a month ago
.gitattributes	Initial setup of appveyor	a month ago
.gitignore	Initial commit	a month ago
.travis.yml	Removed oldrelease test. Getting same error message as with devel for os	a month ago
DESCRIPTION	Removed devel version because it just doesn't seem to work with os an...	a month ago
LICENSE	Initial commit	a month ago
NAMESPACE	Added initial draft of ptile_plot function	8 days ago
README.md	Changed references to figs	2 days ago
appveyor.yml	Checking on apveyor yml to see if default settings now work	a day ago

README.md

esvis

R Package for effect size visualizations.

build passing | build passing | codecov 51%



List of R package on github

Created by Atsushi Hayakawa, twitter : @gepuro

Number of packages : 43035, Download List

API

Warning: Some empty repositories are included.

List

- 07engineer/HVACControlAnalysis : Tools for analysis of energy savings for HVAC control measures
- 0xh3x/hellodublinr : Sample Package for DublinR Talk
- 100sunflower100/MethylChiPAnno :
- 100sunflower100/git :
- 11010tianyi/latticist : Automatically exported from code.google.com/p/latticist
- 11010tianyi/peanutqtl :
- 11010tianyi/playwith : Automatically exported from code.google.com/p/playwith
- 13479776/statTarget : Statistical Analysis of Metabolite Profile
- 13bzhang/fbsample : R Package for Quota Sampling on Facebook
- 16EAGLE/moveVis : This is an R package providing tools to visualize movement data by creating path a
- 16mc1r/dpaux : Personal R Auxiliary Functions
- 16xchen/Biomy :
- 17843/mandrill : R wrapper for the Mandrill API

Installing from github

First, install the *devtools* package from CRAN

```
install.packages("devtools")
```

Next, load the *devtools* library to access the `install_github` function. For example, to install my *esvis* package

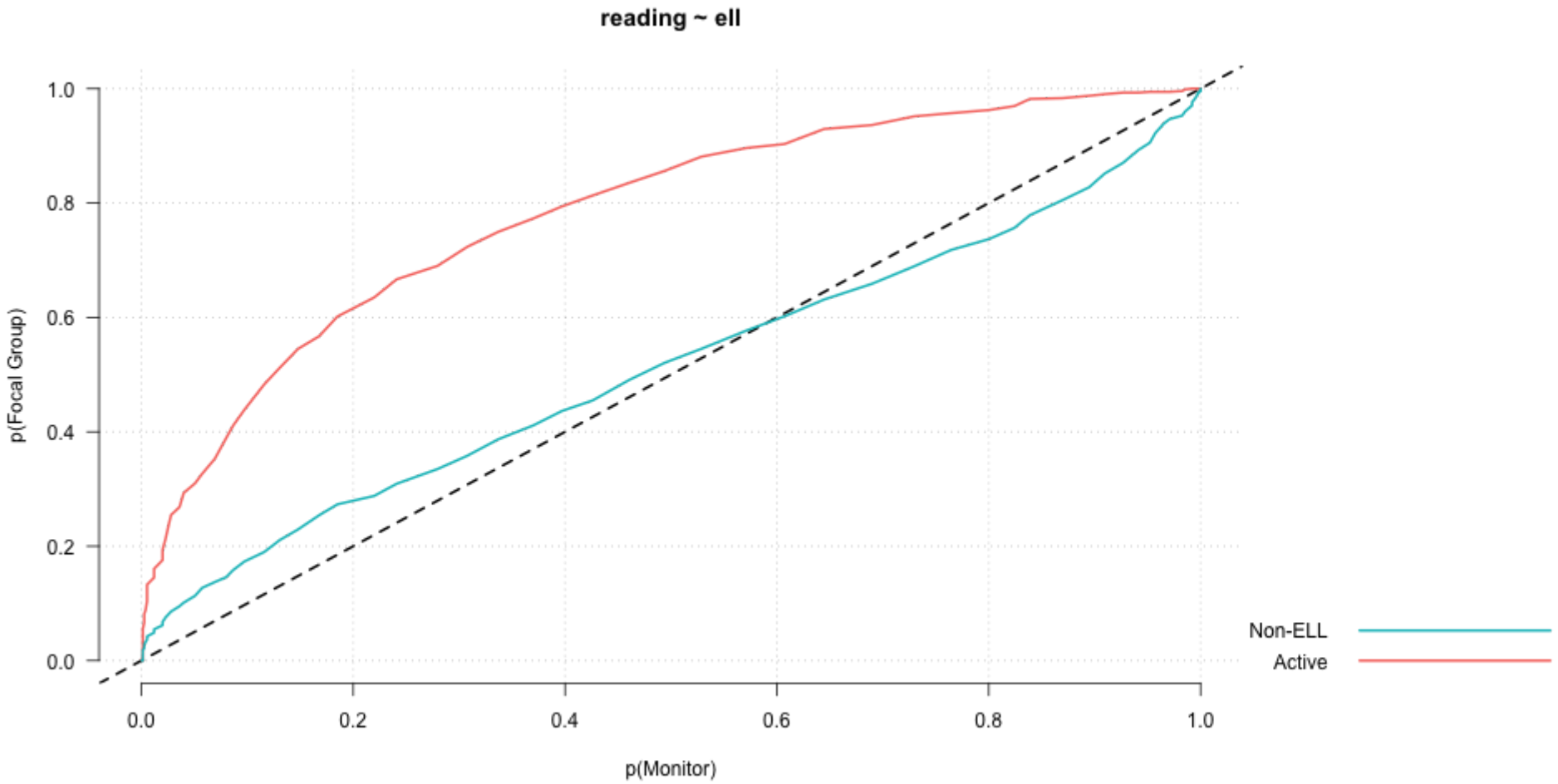
```
library(devtools)
install_github("DJAnderson07/esvis")
```

You then have access to all the functionality of that package once you load it. Let's look at these data:

SID	COHORT	SPED	ETHNICITY	FRL	ELL	SEASON	READING	MATH
332347	1	Non-Sped	Native Am.	Non-FRL	Non-ELL	Winter	208	205
400047	1	Non-Sped	Native Am.	FRL	Non-ELL	Spring	212	218
402107	1	Non-Sped	White	Non-FRL	Non-ELL	Winter	201	212
402547	1	Non-Sped	White	Non-FRL	Non-ELL	Fall	185	177
403047	1	Sped	Hispanic	FRL	Active	Winter	179	192
403307	1	Sped	Hispanic	Non-FRL	Non-ELL	Winter	189	188

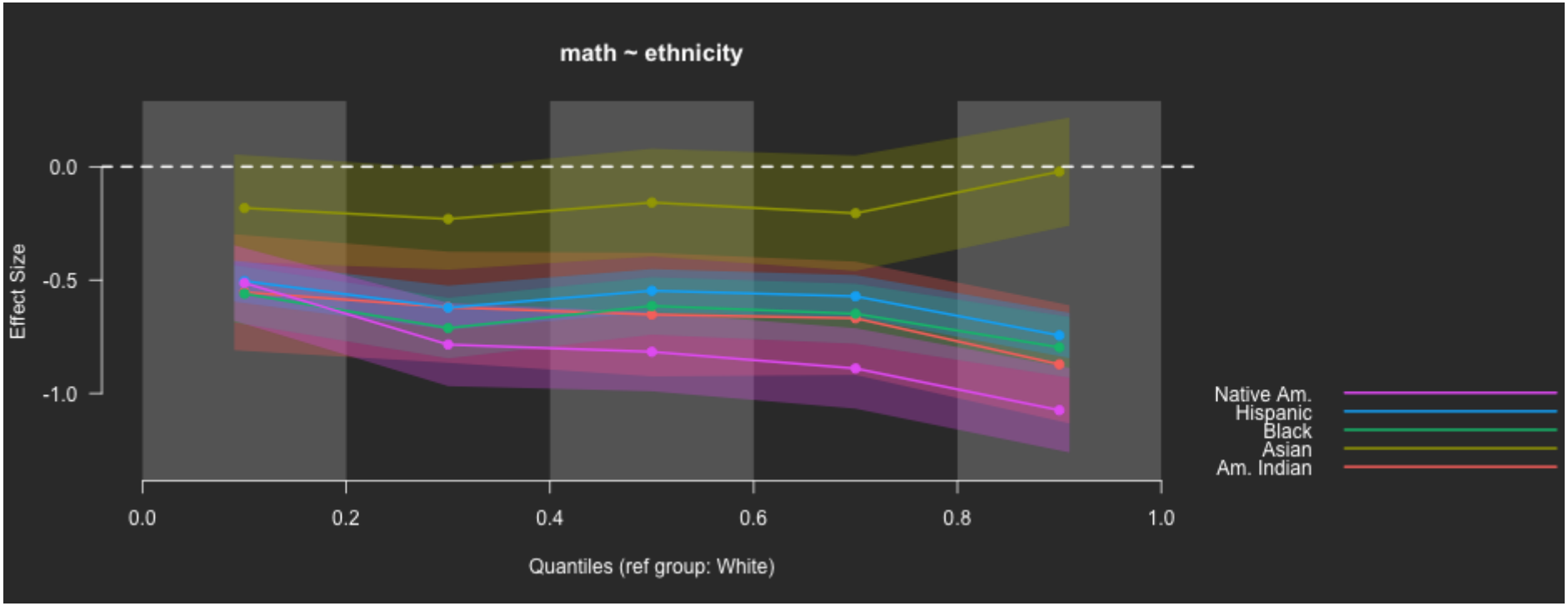
PP-Plot

```
library(esvis)
pp_plot(reading ~ ell, benchmarks)
```



Binned quantile effect sizes

```
binned_plot(math ~ ethnicity, benchmarks,
            qtiles = seq(0, 1, .2),
            theme = "dark")
```



ES Calculation

```
hedg_g(math ~ ethnicity, benchmarks, ref_group = "White")
```

```
##   ref_group  foc_group   estimate
## 1     White      Asian -0.1811177
## 2     White   Hispanic -0.6226720
## 3     White      Black -0.6547893
## 4     White Am. Indian -0.6685548
## 5     White Native Am. -0.8248879
```

```
auc(math ~ ethnicity, benchmarks)
```

```
##     ref_group  foc_group  estimate
## 1       White      Asian 0.5623478
## 2       White   Hispanic 0.6689338
## 3       White      Black 0.6805925
## 4       White Am. Indian 0.6888028
## 5       White Native Am. 0.7352343
## 6       Asian   Hispanic 0.6030755
## 7       Asian      Black 0.6155365
## 8       Asian Am. Indian 0.6231116
```

Is this exciting!?! YES!!!

Why is this such a big deal?

- With just a basic knowledge of R you have access to literally thousands of packages
  - Expanding on a daily basis
  - Provides access to cutting edge and specialized functionality for analysis, data visualization, and data munging
  - Some of the most modern thinking on data analysis topics are often represented in these packages

Fitting multiple regression models

Want to follow along?

- Copy and paste the following code in your R console

```
install.packages(c("tidyverse", "rio", "devtools", "arm", "lm.beta", "visreg", "lme4"))
```

Step 0

- Before fitting model, you'll generally need to import some data, let's do so now
- Make sure your data file is stored in the same place that your script is
- The `setclass` argument above is actually not required, but makes it a bit easier to work with.

```
library(rio)
d <- import("synthetic_data.csv", setclass = "tbl_df")
d
```

```
## # A tibble: 11,218 x 6
##         SID grade clock cohort  LD33    SS
##       <int> <int> <int>  <int> <chr> <int>
##  1  1243667     7     1      5 Never   238
##  2 12961647     6     0      7 Never   221
##  3  5477581     7     1      5 Never   224
##  4  4177568     8     2      5 Never   248
##  5  9368752     7     1      6 Never   239
##  6  7736290     7     1      7 Never   239
##  7  9486143     6     0      5 Never   220
##  8  6181953     7     1      5 Never   237
```

Research Questions

1. What is the average growth from Grades 6-8 in math (`SS`)
2. Does the averge initial achievement or rate of growth depend upon `cohort`?
3. Does the averge initial achievement or rate of growth depend upon `LD33`, the students' pattern of SLD classification?
    - I don't remember why the variable has the name it does

NOTE: Multiple regression is NOT the best way to approach this. A multilevel model would be preferable. But, at the end, I'll show you how simple it is to extend what we do here to the multilevel modeling approach.

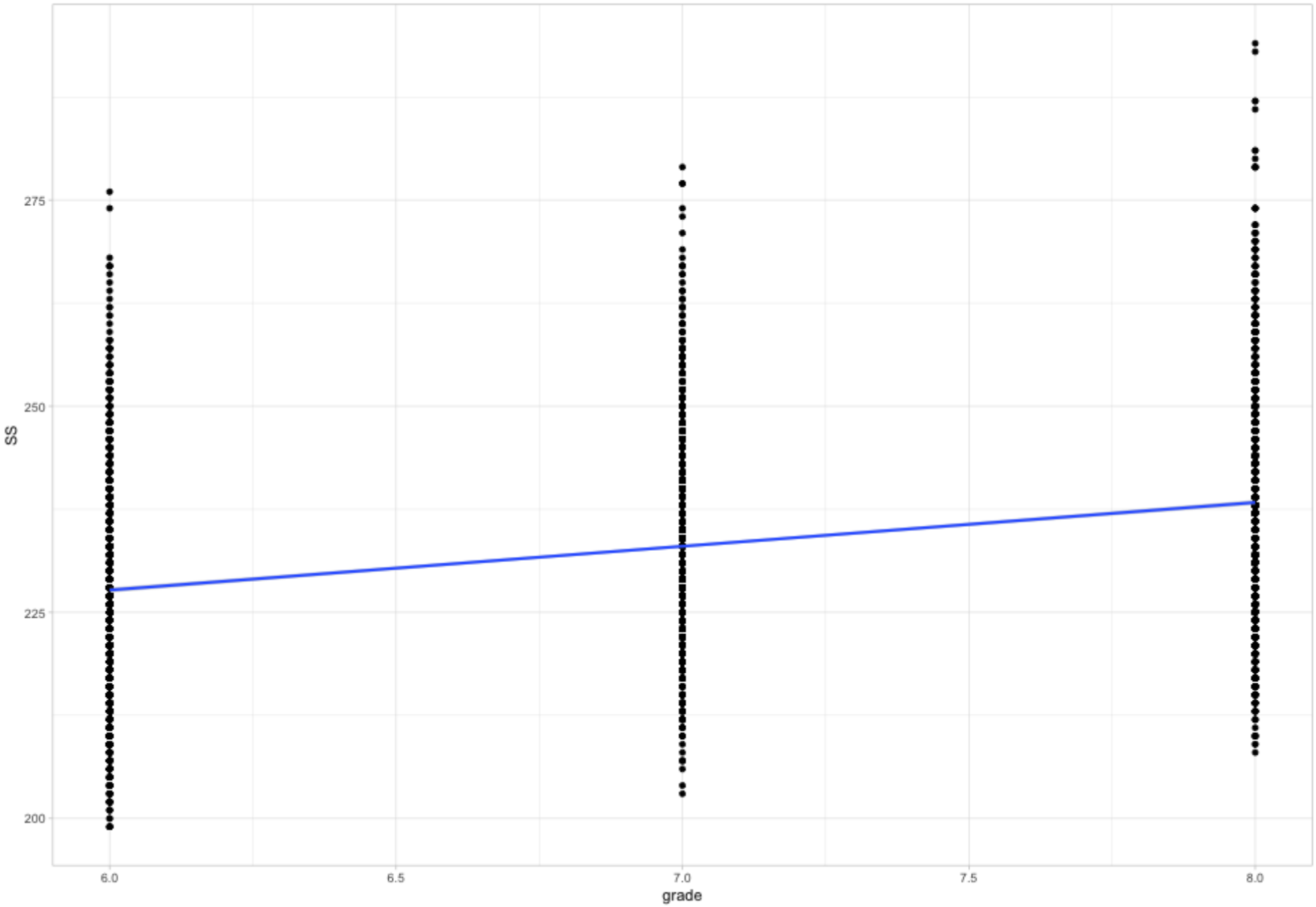
Step 1: Look at your data!

Always best to visualize your data first. Let's produce plots addressing each of our research questions.

1) What does the average growth look like? (plot on next slide)

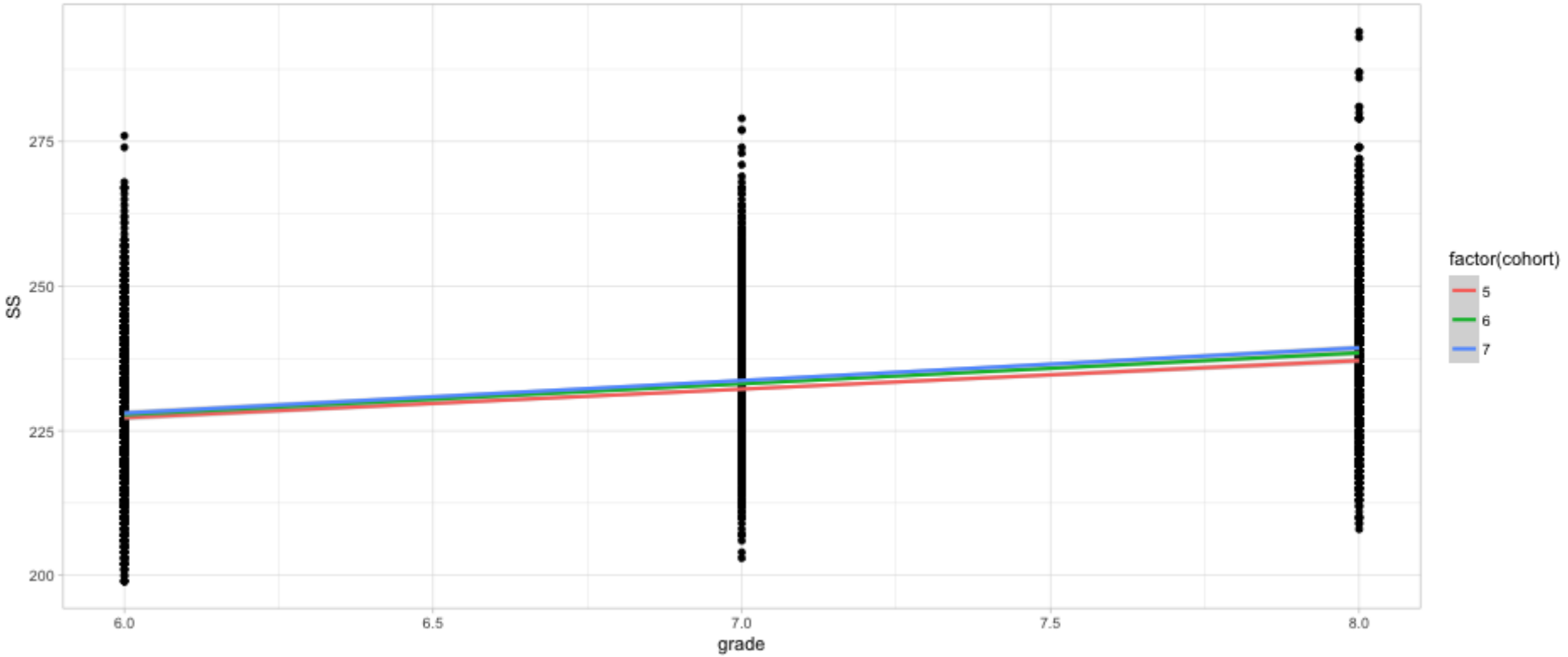
```
library(tidyverse)
theme_set(theme_light()) # Not neccessary, but I like it

ggplot(d, aes(x = grade, y = SS)) +
  geom_point() +
  geom_smooth(method = "lm")
```


275
250
225
200
SS
6.0
6.5
7.0
7.5
8.0
grade

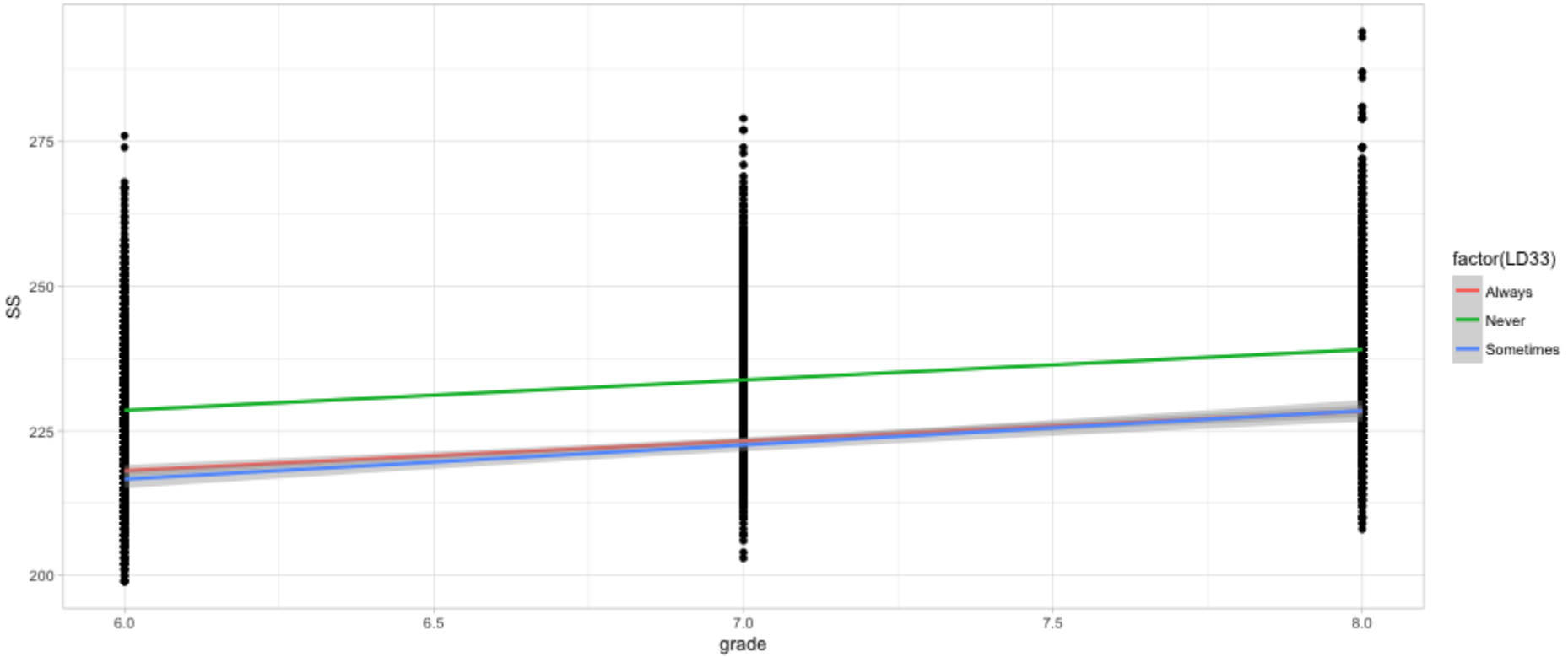
Does initial achievement or average growth depend upon cohort?

```
ggplot(d, aes(grade, SS)) +
  geom_point() +
  geom_smooth(method = "lm",
              aes(color = factor(cohort)))
```



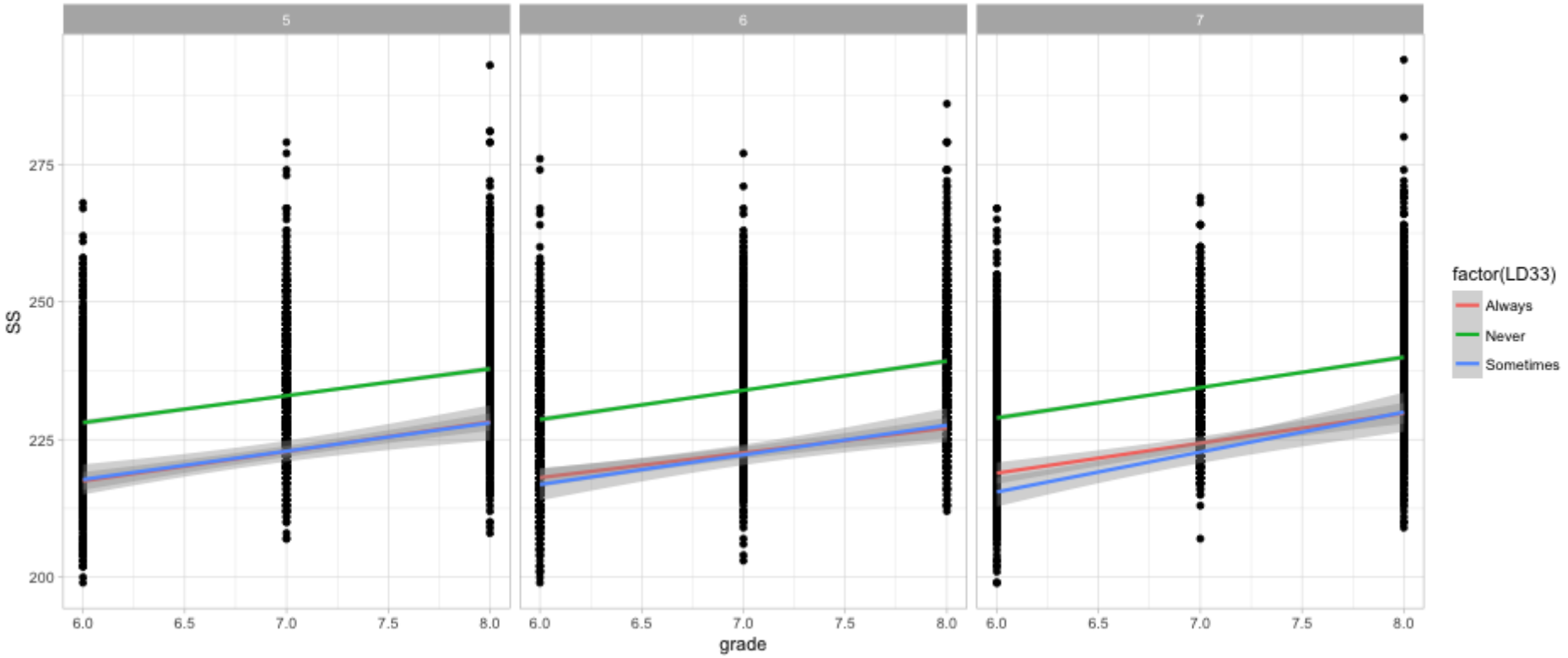
Does initial achievement or average growth depend upon LD status?

```
ggplot(d, aes(grade, SS)) +
  geom_point() +
  geom_smooth(method = "lm",
              aes(color = factor(LD33)))
```



What about both?

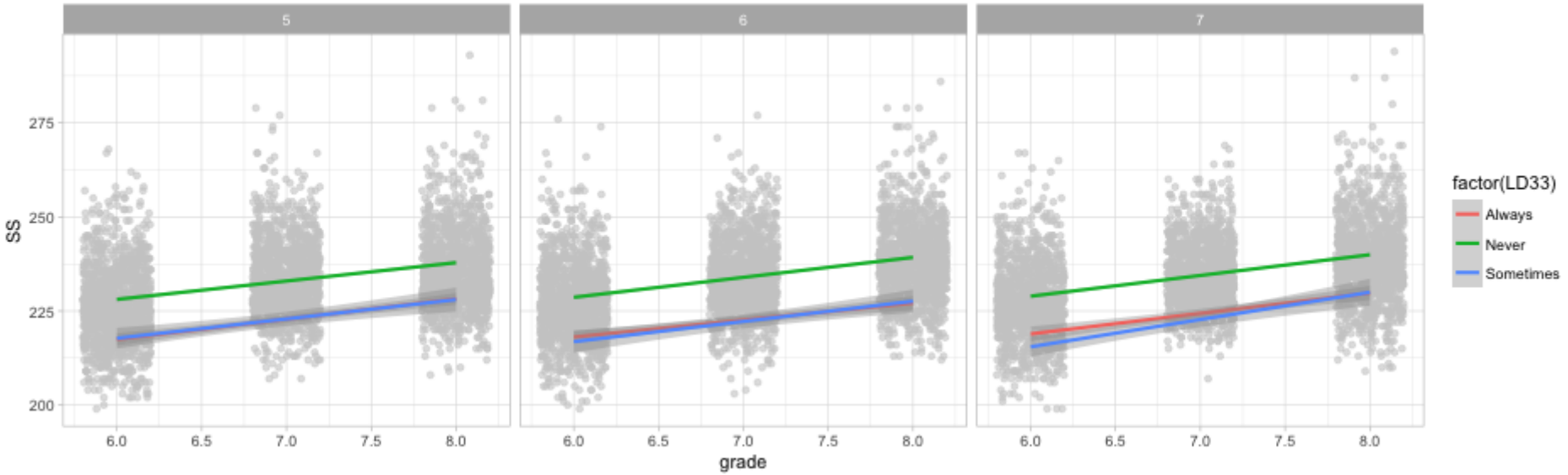
```
ggplot(d, aes(grade, SS)) +
  geom_point() +
  geom_smooth(method = "lm",
              aes(color = factor(LD33))) +
  facet_wrap(~cohort)
```



Quick aside

- `geom_jitter` might be slightly better in this case

```
ggplot(d, aes(grade, SS)) +
  geom_jitter(height = 0, width = 0.2, color = "gray80", alpha = 0.6) +
  geom_smooth(method = "lm",
              aes(color = factor(LD33))) +
  facet_wrap(~cohort)
```



Step 2: Fit the model

- Use the `lm` function
  - Part of base R
  - Takes the following general form

```
mod <- lm(outcome ~ predictor1 + predictor2 + predictorN,
          data = d)
```

Fit simple linear regression model first

```
library(arm)
time_mod <- lm(SS ~ clock, data = d)
display(time_mod, detail = TRUE)
```

```
## lm(formula = SS ~ clock, data = d)
##             coef.est coef.se t value Pr(>|t|)
## (Intercept)  227.70     0.15 1485.71    0.00
## clock          5.31     0.12   44.85    0.00
## ---
## n = 11218, k = 2
## residual sd = 10.24, R-Squared = 0.15
```

Include a categorical predictor

- In R, categorical predictors need to be defined as factors
- Factors can have any underlying contrast matrix, but by default dummy-coding is used, with the reference level being the first level

Change *cohort* to be a factor

```
d$cohort <- as.factor(d$cohort)
```

Inspect the contrast matrix with

```
contrasts(d$cohort)
```

```
##   6 7
## 5 0 0
## 6 1 0
## 7 0 1
```

Change the reference level with

```
d$cohort <- relevel(d$cohort, ref = "7")
contrasts(d$cohort)
```

```
##   5 6
## 7 0 0
## 5 1 0
## 6 0 1
```

Fit a second model

```
cohort_mod <- lm(SS ~ clock + cohort, data = d)
display(cohort_mod, detail = TRUE)
```

```
## lm(formula = SS ~ clock + cohort, data = d)
##             coef.est coef.se t value Pr(>|t|)
## (Intercept)  228.40     0.21 1104.77    0.00
## clock          5.31     0.12   44.87    0.00
## cohort5       -1.50     0.24   -6.33    0.00
## cohort6       -0.57     0.24   -2.43    0.02
## ---
## n = 11218, k = 4
## residual sd = 10.22, R-Squared = 0.16
```

Compare models

```
anova(time_mod, cohort_mod)
```

```
## Analysis of Variance Table
##
## Model 1: SS ~ clock
## Model 2: SS ~ clock + cohort
##   Res.Df     RSS Df Sum of Sq      F    Pr(>F)
## 1  11216 1175695
## 2  11214 1171426  2    4269.3 20.435 1.385e-09 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Add cohort as predictor of the slope

```
cohort_mod2 <- lm(SS ~ clock + cohort + clock:cohort, data = d)
display(cohort_mod2, detail = TRUE)
```

```
## lm(formula = SS ~ clock + cohort + clock:cohort, data = d)
##                coef.est coef.se t value Pr(>|t|)
## (Intercept)    228.06     0.27  847.84    0.00
## clock            5.64     0.21   27.34    0.00
## cohort5         -0.79     0.38   -2.09    0.04
## cohort6         -0.27     0.38   -0.72    0.47
## clock:cohort5   -0.71     0.29   -2.44    0.01
## clock:cohort6   -0.30     0.29   -1.02    0.31
## ---
## n = 11218, k = 6
## residual sd = 10.22, R-Squared = 0.16
```

Quick note on syntax

The following two lines of code are equivalent

```
cohort_mod2 <- lm(SS ~ clock + cohort + clock:cohort, data = d)
cohort_mod2 <- lm(SS ~ clock*cohort, data = d)
```

Need standardized coefficients?

```
# install.packages("lm.beta")
library(lm.beta)
lm.beta(cohort_mod2)
```

```
##
## Call:
## lm(formula = SS ~ clock + cohort + clock:cohort, data = d)
##
## Standardized Coefficients::
##   (Intercept)         clock       cohort5       cohort6 clock:cohort5
##    0.00000000    0.41424809   -0.03344220   -0.01152243   -0.04243530
## clock:cohort6
##   -0.01779824
```

Let's skip ahead and fit the full model

- We want *clock*, *cohort*, and *ld status* all entered in the model, as well as the interaction between *clock* and *cohort*, and *clock* and *ld status*

Try to write the code on your own

Model

```
full_mod <- lm(SS ~ clock + cohort + LD33 +
                  clock:cohort + clock:LD33,
                data = d)
display(full_mod, detail = TRUE)
```

```
## lm(formula = SS ~ clock + cohort + LD33 + clock:cohort + clock:LD33,
##     data = d)
##                     coef.est coef.se t value Pr(>|t|)
## (Intercept)         218.47     0.69  318.29    0.00
## clock                 5.47     0.54   10.20    0.00
## cohort5              -0.79     0.36   -2.19    0.03
## cohort6              -0.27     0.36   -0.75    0.45
## LD33Never            10.44     0.67   15.64    0.00
## LD33Sometimes        -1.48     1.14   -1.30    0.19
## clock:cohort5        -0.64     0.28   -2.30    0.02
## clock:cohort6        -0.28     0.28   -0.99    0.32
## clock:LD33Never       0.07     0.52    0.14    0.89
## clock:LD33Sometimes   0.78     0.94    0.84    0.40
## ---
## n = 11218, k = 10
## residual sd = 9.83, R-Squared = 0.22
```

Compare our last model to prior models

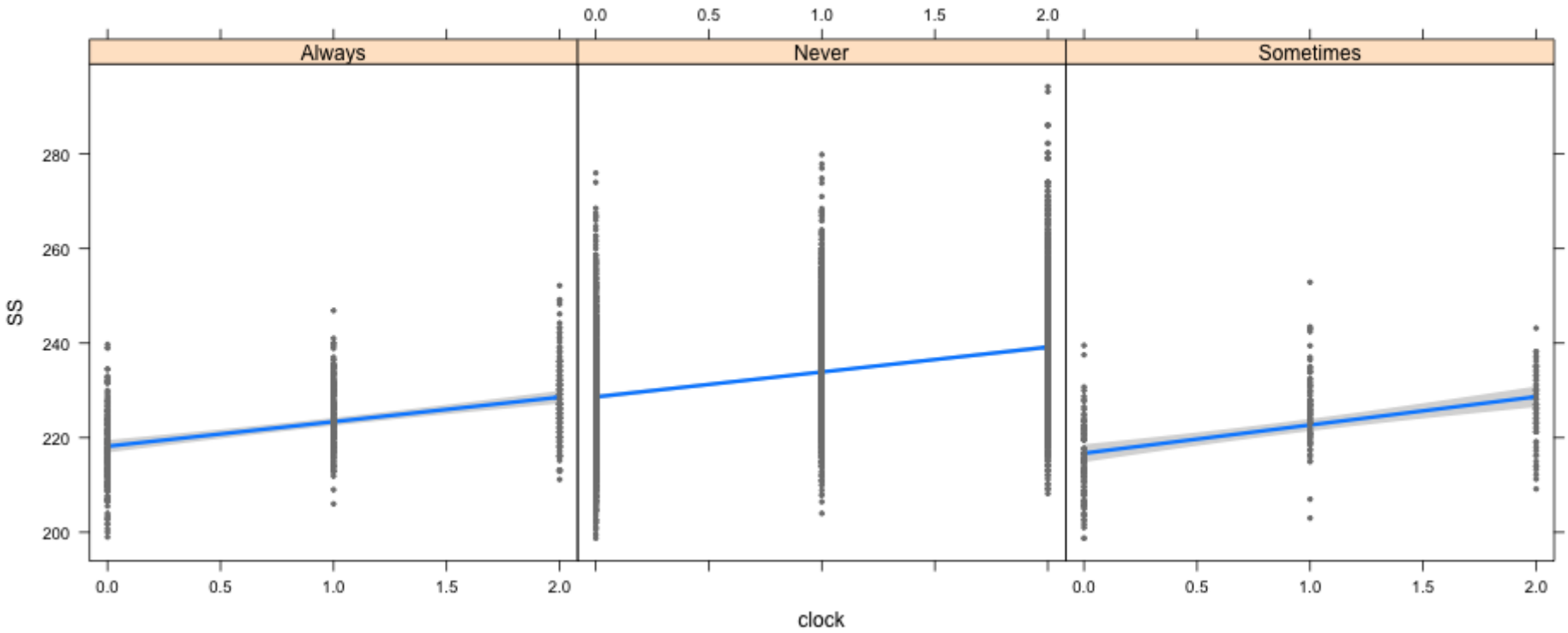
```
anova(cohort_mod2, full_mod)
```

```
## Analysis of Variance Table
##
## Model 1: SS ~ clock + cohort + clock:cohort
## Model 2: SS ~ clock + cohort + LD33 + clock:cohort + clock:LD33
##   Res.Df     RSS Df Sum of Sq      F    Pr(>F)
## 1  11212 1170801
## 2  11208 1084086  4     86714 224.13 < 2.2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

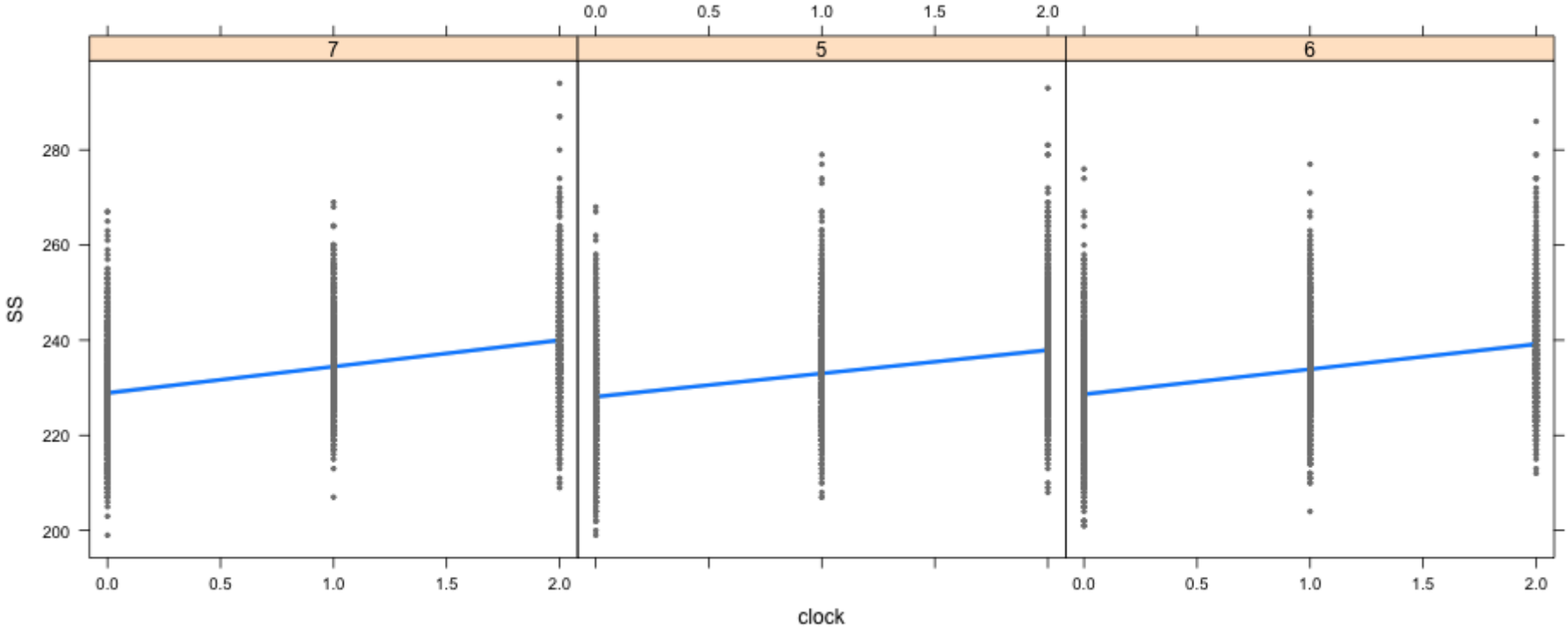
Visualizing the fitted models

(I'm guessing I'm almost out of time, but quickly...) The *visreg* package is amazing, and I highly recommend it

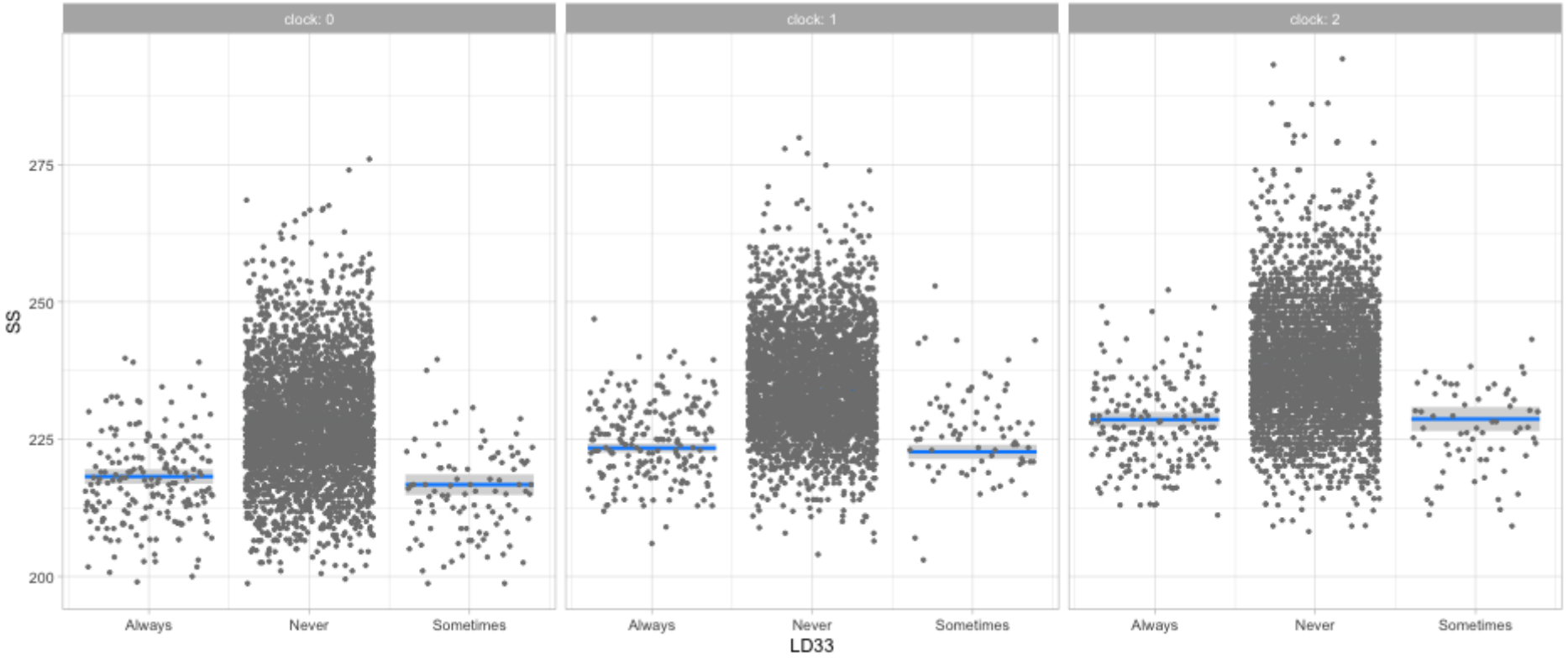
```
library(visreg)
visreg(full_mod, "clock", by = "LD33")
```



```
visreg(full_mod, "clock", by = "cohort")
```

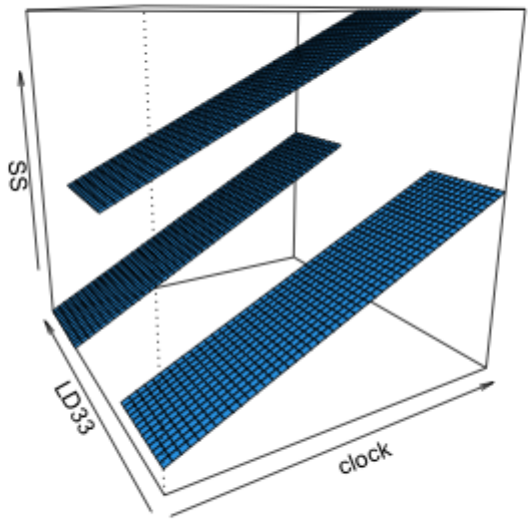


```
visreg(full_mod, "LD33", by = "clock", gg = TRUE)
```



Kinda hard but maybe helpful

```
visreg2d(full_mod, "clock", "LD33", plot.type = "persp")
```



See the following links for more info on the *visreg* package

- http://pbreheny.github.io/visreg
- http://myweb.uiowa.edu/pbreheny/publications/visreg.pdf

Last note - fitting the right model!

- The model we've fit should be multilevel. So let's do it!

```
#install.package("lme4")
library(lme4)
mlm <- lmer(SS ~ clock + cohort + LD33 +
                  clock:cohort + clock:LD33 +
              (1 + clock|SID),
                 data = d)
```

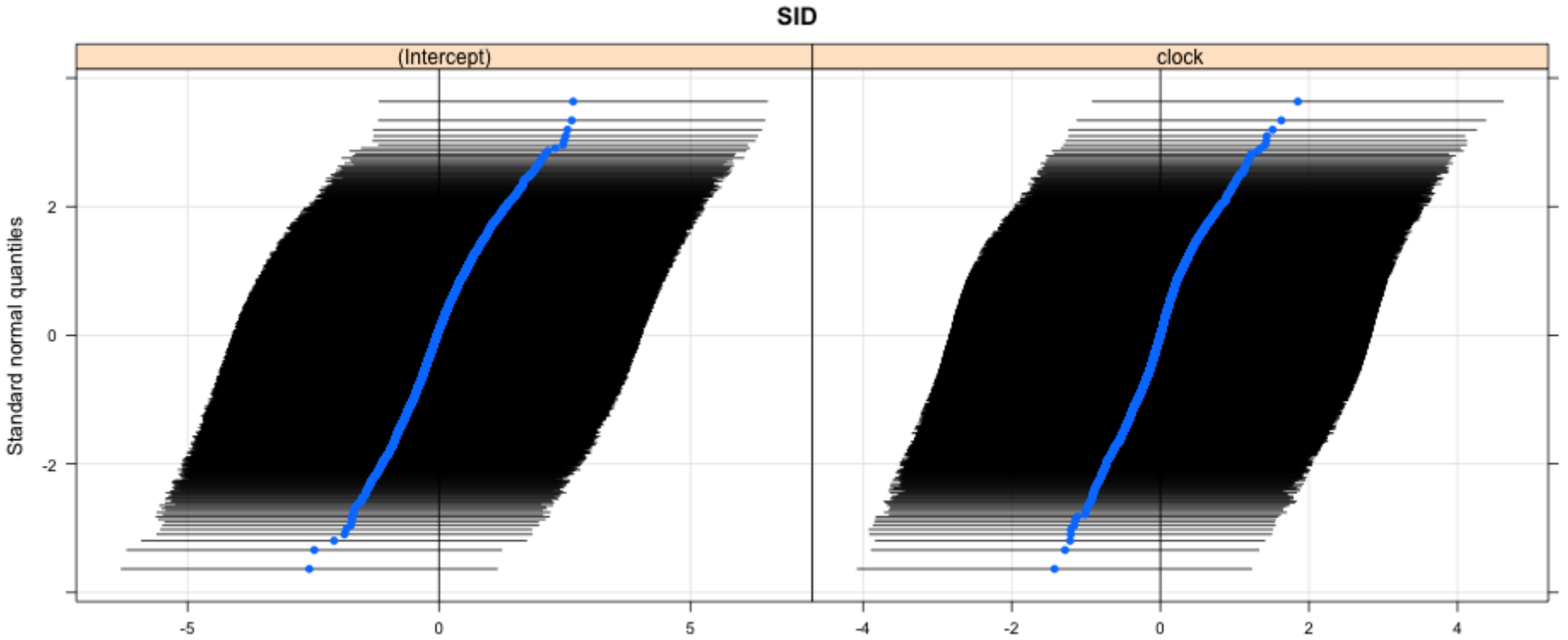
```
display(mlm, detail = TRUE)
```

```
## lmer(formula = SS ~ clock + cohort + LD33 + clock:cohort + clock:LD33 +
##     (1 + clock | SID), data = d)
##                     coef.est coef.se t value
## (Intercept)         218.45     0.68  319.73
## clock                 5.44     0.54   10.12
## cohort5              -0.76     0.37   -2.08
## cohort6              -0.27     0.36   -0.75
## LD33Never            10.44     0.66   15.74
## LD33Sometimes        -1.48     1.13   -1.31
## clock:cohort5        -0.61     0.28   -2.17
## clock:cohort6        -0.26     0.28   -0.92
## clock:LD33Never       0.10     0.52    0.20
## clock:LD33Sometimes   0.76     0.94    0.81
##
## Error terms:
##  Groups   Name        Std.Dev. Corr
##  SID      (Intercept) 2.08
##           clock       1.45     -0.35
##  Residual             9.54
## ---
## number of obs: 11218, groups: SID, 3580
```

How much variability?

```
library(lattice)
qqmath(ranef(mlm, condVar = TRUE))
```

```
## $SID
```



Parting thoughts

Today's lecture is mostly about exposure. R takes a lot of time and effort to learn, but it is really worth it.

Questions?

Thanks!

This is
my
thank you
dance!