

Work with Models

Data Visualization: Session 6

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Code Horizons, May 2022

Load our libraries

```
library(here)      # manage file paths  
library(socviz)    # data and some useful functions  
library(tidyverse) # your friend and mine  
library(gapminder) # Everyone's favorite dataset  
library(broom)     # Tidy model output  
library(marginaleffects) # Tidy marginal effects  
library(modelsummary) # Tidy summary tables and graphs  
library(scales)     # Format our axes and guides
```

We know `ggplot` can work with models

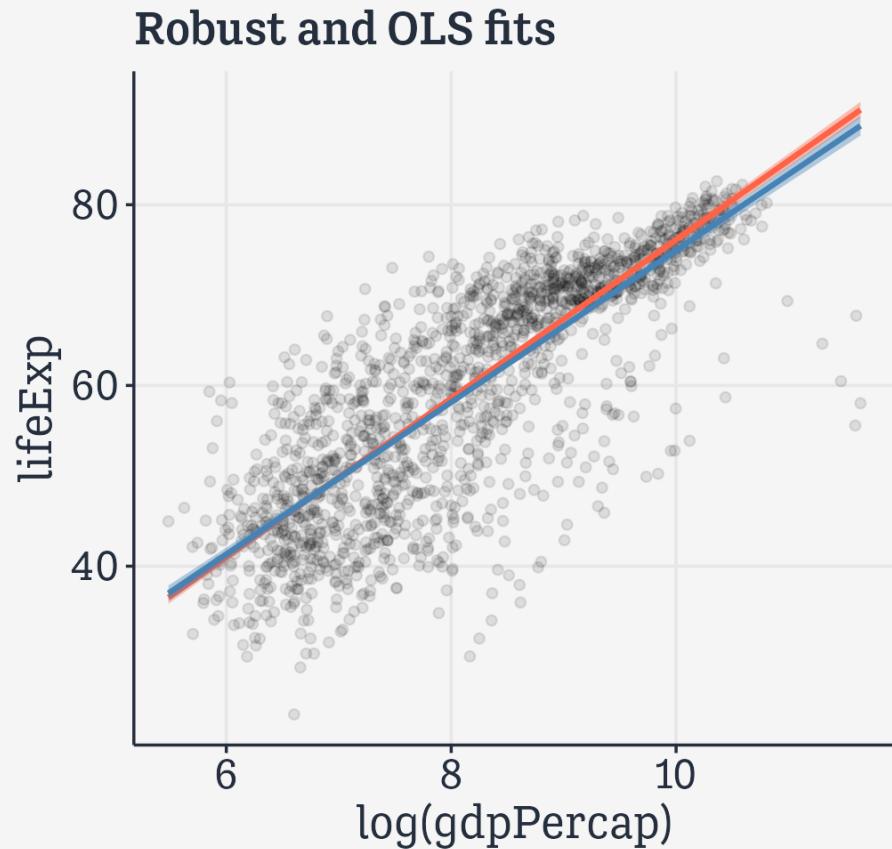
```
p <- gapminder |>  
  ggplot(mapping = aes(x = log(gdpPercap),  
                      y = lifeExp))  
  
p + geom_point(alpha=0.1) +  
  geom_smooth(color = "tomato",  
              fill="tomato",  
              method = MASS::rlm) +  
  geom_smooth(color = "steelblue",  
              fill="steelblue",  
              method = "lm") +  
  labs(title = "Robust and OLS fits")
```

We know because geoms often do calculations in the background, via their `stat` functions.

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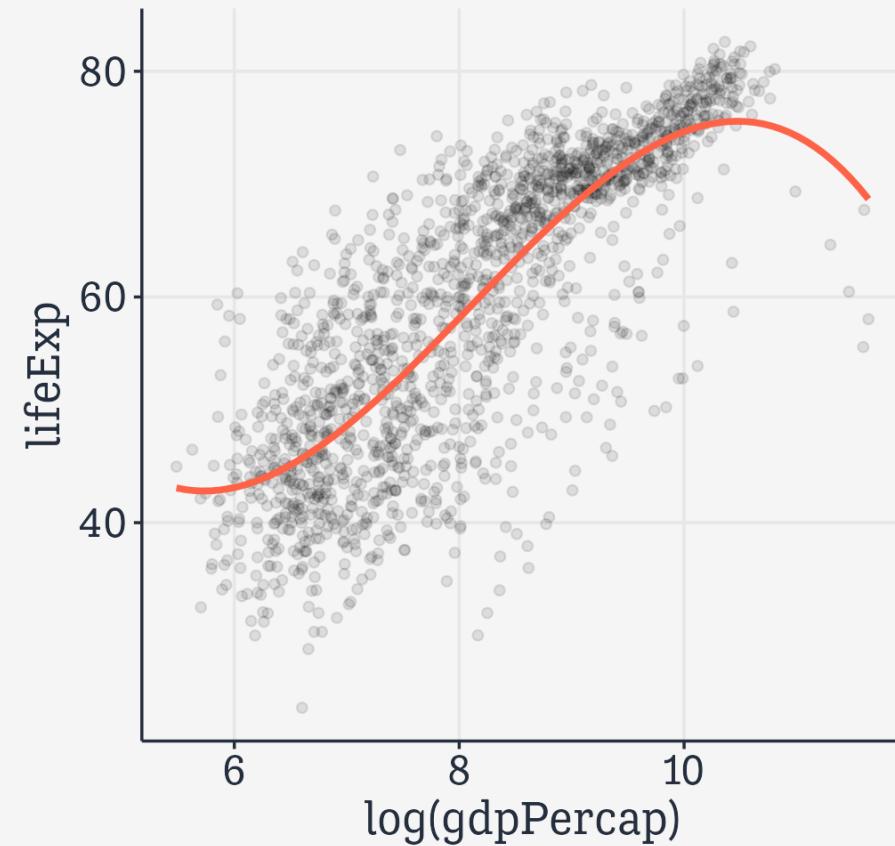


And these can be complex ...

```
p + geom_point(alpha=0.1) +  
  geom_smooth(color = "tomato",  
              method = "lm",  
              size = 1.2,  
              formula = y ~ splines::bs(x, 3),  
              se = FALSE)
```

And these can be complex ...

```
p + geom_point(alpha=0.1) +  
  geom_smooth(color = "tomato",  
              method = "lm",  
              size = 1.2,  
              formula = y ~ splines::bs(x, 3),  
              se = FALSE)
```

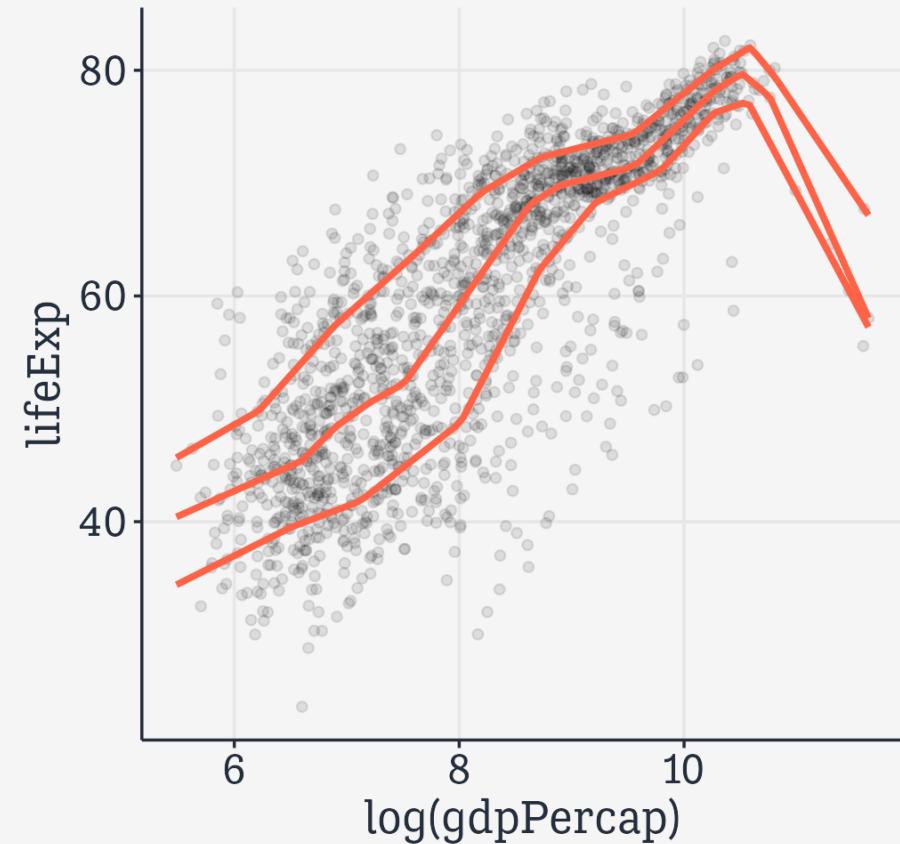


And these can be complex ... but ...

```
p + geom_point(alpha=0.1) +
  geom_quantile(color = "tomato",
    size = 1.2,
    method = "rqss",
    lambda = 1,
    quantiles = c(0.20, 0.5, 0.85))
```

And these can be complex ... but ...

```
p + geom_point(alpha=0.1) +  
  geom_quantile(color = "tomato",  
                size = 1.2,  
                method = "rqss",  
                lambda = 1,  
                quantiles = c(0.20, 0.5, 0.85))
```



**Transform and
summarize first.**

**Then send your clean
tables to ggplot.**

**Look inside
the box**

Again, objects are Bento Boxes of To-Do lists

gapminder

```
## # A tibble: 1,704 × 6
##   country   continent year lifeExp      pop gdpPercap
##   <fct>     <fct>    <int>  <dbl>    <int>    <dbl>
## 1 Afghanistan Asia     1952    28.8  8425333    779.
## 2 Afghanistan Asia     1957    30.3  9240934    821.
## 3 Afghanistan Asia     1962    32.0  10267083   853.
## 4 Afghanistan Asia     1967    34.0  11537966   836.
## 5 Afghanistan Asia     1972    36.1  13079460   740.
## 6 Afghanistan Asia     1977    38.4  14880372   786.
## 7 Afghanistan Asia     1982    39.9  12881816   978.
## 8 Afghanistan Asia     1987    40.8  13867957   852.
## 9 Afghanistan Asia     1992    41.7  16317921   649.
## 10 Afghanistan Asia    1997    41.8  22227415   635.
## # ... with 1,694 more rows
```

Fit a model

```
out <- lm(formula = lifeExp ~ gdpPercap + log(pop) + continent,
          data = gapminder)

summary(out)

##
## Call:
## lm(formula = lifeExp ~ gdpPercap + log(pop) + continent, data = gapminder)
##
## Residuals:
##     Min      1Q  Median      3Q     Max 
## -47.490  -4.614   0.250   5.293  26.094 
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)    
## (Intercept) 3.816e+01  2.050e+00 18.618 < 2e-16 ***
## gdpPercap   4.557e-04  2.345e-05 19.435 < 2e-16 ***
## log(pop)    6.394e-01  1.329e-01  4.810 1.64e-06 ***
## continentAmericas 1.308e+01  6.063e-01 21.579 < 2e-16 ***
## continentAsia    7.784e+00  5.810e-01 13.398 < 2e-16 ***
## continentEurope   1.695e+01  6.350e-01 26.691 < 2e-16 ***
## continentOceania  1.764e+01  1.779e+00  9.916 < 2e-16 ***  
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 8.336 on 1697 degrees of freedom
## Multiple R-squared:  0.585,    Adjusted R-squared:  0.5835 
## F-statistic: 398.7 on 6 and 1697 DF,  p-value: < 2.2e-16
```

Poke around inside

Use the Object Inspector to take a look

`out`

```
  └── coefficients
  └── residuals
  └── effects
  └── rank
  └── qr
      └── qr
      └── pivot
      └── qraux
      └── tol
      └── rank
  └── df.residual
  └── contrasts
  └── xlevels
  └── call
  └── terms
  └── model.frame
```

Predict from models: DIY method

Behind the curtain

predict() and its methods do a lot of work behind the scenes

We won't usually need to do this stuff manually. But the idea is that the generic **predict()** function has *methods* for specific sorts of models. Give it a model and some new data and it will produce predicted values for the new data. Here's an example/

The labor-intensive way

```
min_gdp <- min(gapminder$gdpPercap)
max_gdp <- max(gapminder$gdpPercap)
med_pop <- median(gapminder$pop)

# Make a grid of predictor values
pred_df <- expand_grid(gdpPercap = seq(from = min_gdp,
                                         to = max_gdp,
                                         length.out = 100)),
           pop = med_pop,
           continent = c("Africa", "Americas",
                         "Asia", "Europe", "Oceania"))

pred_df

## # A tibble: 500 × 3
##   gdpPercap     pop continent
##       <dbl>    <dbl> <chr>
## 1     241. 7023596. Africa
## 2     241. 7023596. Americas
## 3     241. 7023596. Asia
## 4     241. 7023596. Europe
## 5     241. 7023596. Oceania
## 6     1385. 7023596. Africa
## 7     1385. 7023596. Americas
## 8     1385. 7023596. Asia
## 9     1385. 7023596. Europe
## 10    1385. 7023596. Oceania
## # ... with 490 more rows
```

The labor-intensive way

```
# Get the predicted values
pred_out <- predict(object = out,
                      newdata = pred_df,
                      interval = "confidence")
head(pred_out)

##      fit     lwr     upr
## 1 48.35388 47.67735 49.03041
## 2 61.43646 60.43917 62.43375
## 3 56.13821 55.22045 57.05597
## 4 65.30361 64.21794 66.38927
## 5 65.99517 62.55277 69.43757
## 6 48.87530 48.20261 49.54799
```

The labor-intensive way

```
# Bind them into one data frame. We can do this safely
# here because we know the row order by construction.
# But this is not a safe approach in general.

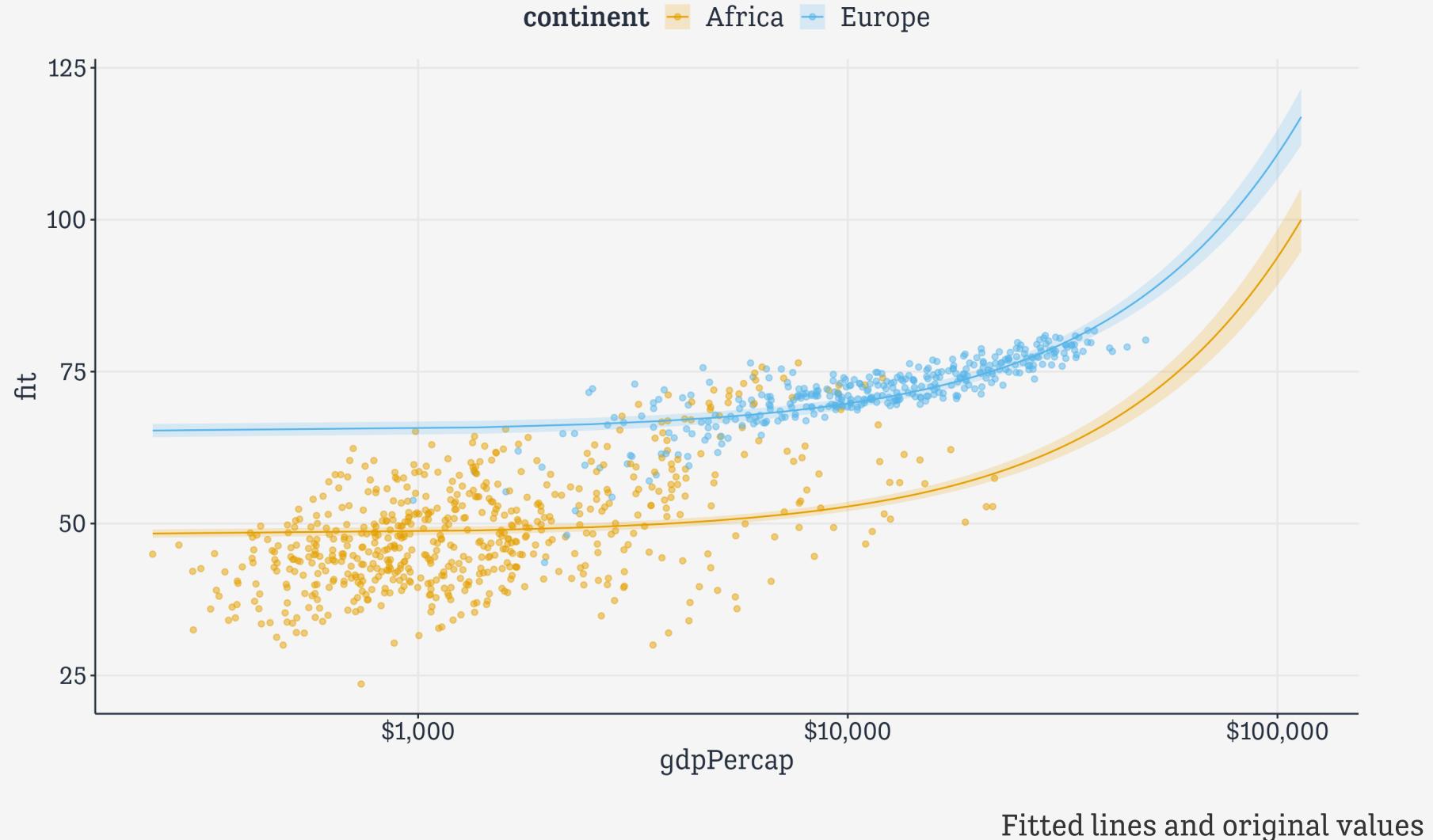
pred_df <- cbind(pred_df, pred_out)
head(pred_df)

##   gdpPercap     pop continent      fit      lwr      upr
## 1 241.1659 7023596    Africa 48.35388 47.67735 49.03041
## 2 241.1659 7023596   Americas 61.43646 60.43917 62.43375
## 3 241.1659 7023596      Asia 56.13821 55.22045 57.05597
## 4 241.1659 7023596   Europe 65.30361 64.21794 66.38927
## 5 241.1659 7023596  Oceania 65.99517 62.55277 69.43757
## 6 1385.4282 7023596    Africa 48.87530 48.20261 49.54799
```

The labor-intensive way

```
p <- ggplot(data = subset(pred_df, continent %in% c("Europe", "Africa")),
  aes(x = gdpPercap,
      y = fit,
      ymin = lwr,
      ymax = upr,
      color = continent,
      fill = continent,
      group = continent))

# Use the original data as the point layer
p_out <- p + geom_point(data = subset(gapminder,
  continent %in% c("Europe", "Africa")),
  mapping = aes(x = gdpPercap, y = lifeExp,
    color = continent),
  alpha = 0.5,
  inherit.aes = FALSE) +
# And the predicted values to draw the lines
  geom_line() +
  geom_ribbon(alpha = 0.2, color = FALSE) +
  scale_x_log10(labels = scales::dollar)
```



**Use broom to tidy
models**

We can't do anything with this

```
out <- lm(formula = lifeExp ~ gdpPercap + log(pop) + continent,
          data = gapminder)

summary(out)

##
## Call:
## lm(formula = lifeExp ~ gdpPercap + log(pop) + continent, data = gapminder)
##
## Residuals:
##     Min      1Q  Median      3Q     Max 
## -47.490  -4.614   0.250   5.293  26.094 
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)    
## (Intercept) 3.816e+01  2.050e+00 18.618 < 2e-16 ***
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## continentOceania  1.764e+01  1.779e+00  9.916 < 2e-16 ***  
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 8.336 on 1697 degrees of freedom
## Multiple R-squared:  0.585,    Adjusted R-squared:  0.5835 
## F-statistic: 398.7 on 6 and 1697 DF,  p-value: < 2.2e-16
```

Tidy regression output with **broom**

```
library(broom)

tidy(out)

## # A tibble: 7 × 5
##   term      estimate std.error statistic p.value
##   <chr>     <dbl>     <dbl>     <dbl>    <dbl>
## 1 (Intercept) 38.2      2.05     18.6  1.50e- 70
## 2 gdpPercap    0.000456  0.0000234 19.4  3.98e- 76
## 3 log(pop)     0.639     0.133     4.81  1.64e-  6
## 4 continentAmericas 13.1     0.606    21.6  1.85e- 91
## 5 continentAsia    7.78     0.581     13.4  5.52e- 39
## 6 continentEurope   16.9     0.635    26.7  2.43e-131
## 7 continentOceania  17.6     1.78     9.92  1.43e- 22
```

That's a *lot* nicer. Now it's just a tibble. We know those.

Tidy regression output with broom

```
out_conf <- tidy(out, conf.int = TRUE)
out_conf

## # A tibble: 7 × 7
##   term          estimate std.error statistic  p.value conf.low conf.high
##   <chr>        <dbl>     <dbl>      <dbl>    <dbl>    <dbl>     <dbl>
## 1 (Intercept) 38.2      2.05      18.6  1.50e- 70 34.1      42.2
## 2 gdpPercap    0.000456 0.0000234  19.4  3.98e- 76 0.000410  0.000502
## 3 log(pop)     0.639     0.133      4.81  1.64e- 6  0.379      0.900
## 4 continentAmericas 13.1     0.606      21.6  1.85e- 91 11.9      14.3
## 5 continentAsia  7.78      0.581      13.4  5.52e- 39 6.64      8.92
## 6 continentEurope 16.9      0.635      26.7  2.43e-131 15.7      18.2
## 7 continentOceania 17.6      1.78       9.92  1.43e- 22 14.2      21.1
```

Tidy regression output with broom

```
out_conf |>
  filter(term %nin% "(Intercept)") |>
  mutate(nicelabs = prefix_strip(term, "continent")) |>
  select(nicelabs, everything())

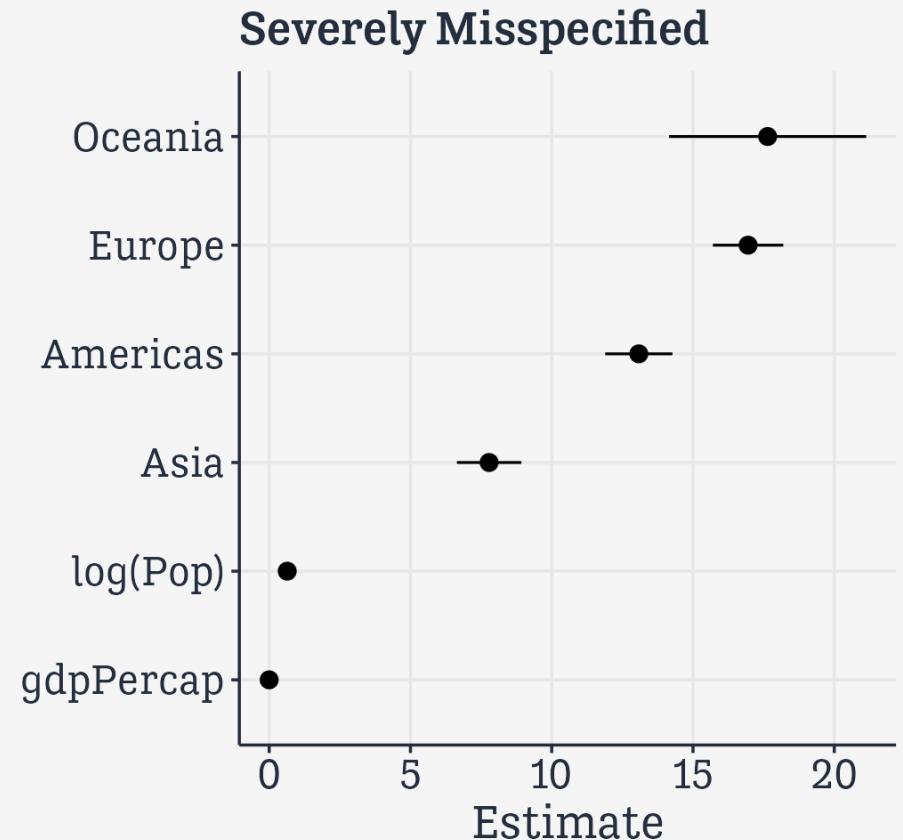
## # A tibble: 6 × 8
##   nicelabs term      estimate std.error statistic p.value conf.low conf.high
##   <chr>     <chr>      <dbl>     <dbl>      <dbl>     <dbl>     <dbl>     <dbl>
## 1 gdpPercap gdpPercap  0.000456  0.0000234    19.4  3.98e- 76  0.000410  0.000502
## 2 log(Pop)   log(pop)    0.639    0.133       4.81  1.64e- 6   0.379    0.900
## 3 Americas   continentAmericas 13.1     0.606      21.6  1.85e- 91  11.9     14.3
## 4 Asia       continentAsia    7.78     0.581      13.4  5.52e- 39  6.64     8.92
## 5 Europe     continentEurope  16.9     0.635      26.7  2.43e-131 15.7     18.2
## 6 Oceania    continentOceania 17.6     1.78       9.92  1.43e- 22  14.2     21.1
```

Tidy regression output with broom

```
out_conf |>
  filter(term %nin% "(Intercept)") |>
  mutate(nicelabs = prefix_strip(term, "continent")) |>
  ggplot(mapping = aes(x = estimate,
                        xmin = conf.low,
                        xmax = conf.high,
                        y = reorder(nicelabs,
                                    estimate))) +
  geom_pointrange() +
  labs(x = "Estimate",
       y = NULL,
       title = "Severely Misspecified")
```

Tidy regression output with **broom**

```
out_conf |>  
  filter(term %nin% "(Intercept)") |>  
  mutate(nicelabs = prefix_strip(term, "continent")) |>  
  ggplot(mapping = aes(x = estimate,  
                        xmin = conf.low,  
                        xmax = conf.high,  
                        y = reorder(nicelabs,  
                                    estimate))) +  
  
  geom_pointrange() +  
  labs(x = "Estimate",  
       y = NULL,  
       title = "Severely Misspecified")
```



Three ways to tidy

Component level: `tidy()`

Observation level: `augment()`

Model level: `glance()`

Component level

```
> summary(out)

Call:
lm(formula = lifeExp ~ gdpPercap + log(pop) + continent, data = gapminder)

Residuals:
    Min      1Q  Median      3Q     Max 
-47.490 -4.614  0.250  5.293 26.094 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)    
(Intercept) 3.816e+01 2.050e+00 18.618 < 2e-16 ***
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continentAsia   7.784e+00 5.810e-01 13.398 < 2e-16 ***
continentEurope  1.695e+01 6.350e-01 26.691 < 2e-16 ***
continentOceania 1.764e+01 1.779e+00  9.916 < 2e-16 ***  
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 8.336 on 1697 degrees of freedom
Multiple R-squared:  0.585,    Adjusted R-squared:  0.5835 
F-statistic: 398.7 on 6 and 1697 DF,  p-value: < 2.2e-16
```

Observation level

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continentOceania  1.764e+01 1.779e+00  9.916 < 2e-16 ***  
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Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

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```

Observation level

```
augment(out)
```

```
## # A tibble: 1,704 × 9
##   lifeExp gdpPercap `log(pop)` continent .fitted     .hat .sigma .cooksD .std.resid
##   <dbl>      <dbl>        <dbl> <fct>       <dbl>    <dbl>    <dbl>    <dbl>       <dbl>
## 1 28.8       779.       15.9 Asia       56.5 0.00302  8.31 0.00479 -3.33
## 2 30.3       821.       16.0 Asia       56.6 0.00299  8.31 0.00426 -3.15
## 3 32.0       853.       16.1 Asia       56.7 0.00296  8.32 0.00372 -2.96
## 4 34.0       836.       16.3 Asia       56.7 0.00294  8.32 0.00313 -2.73
## 5 36.1       740.       16.4 Asia       56.8 0.00294  8.32 0.00259 -2.48
## 6 38.4       786.       16.5 Asia       56.9 0.00292  8.33 0.00205 -2.21
## 7 39.9       978.       16.4 Asia       56.9 0.00291  8.33 0.00174 -2.04
## 8 40.8       852.       16.4 Asia       56.9 0.00292  8.33 0.00155 -1.93
## 9 41.7       649.       16.6 Asia       56.9 0.00294  8.33 0.00140 -1.82
## 10 41.8      635.       16.9 Asia       57.1 0.00297  8.33 0.00144 -1.84
## # ... with 1,694 more rows
```

Observation level

For OLS models:

`.fitted` – The fitted values of the model.

`.se.fit` – The standard errors of the fitted values.

`.resid` – The residuals.

`.hat` – The diagonal of the hat matrix.

`.sigma` – An estimate of the residual standard deviation when the corresponding observation is dropped from the model.

`.cooksdist` – Cook's distance, a common regression diagnostic.

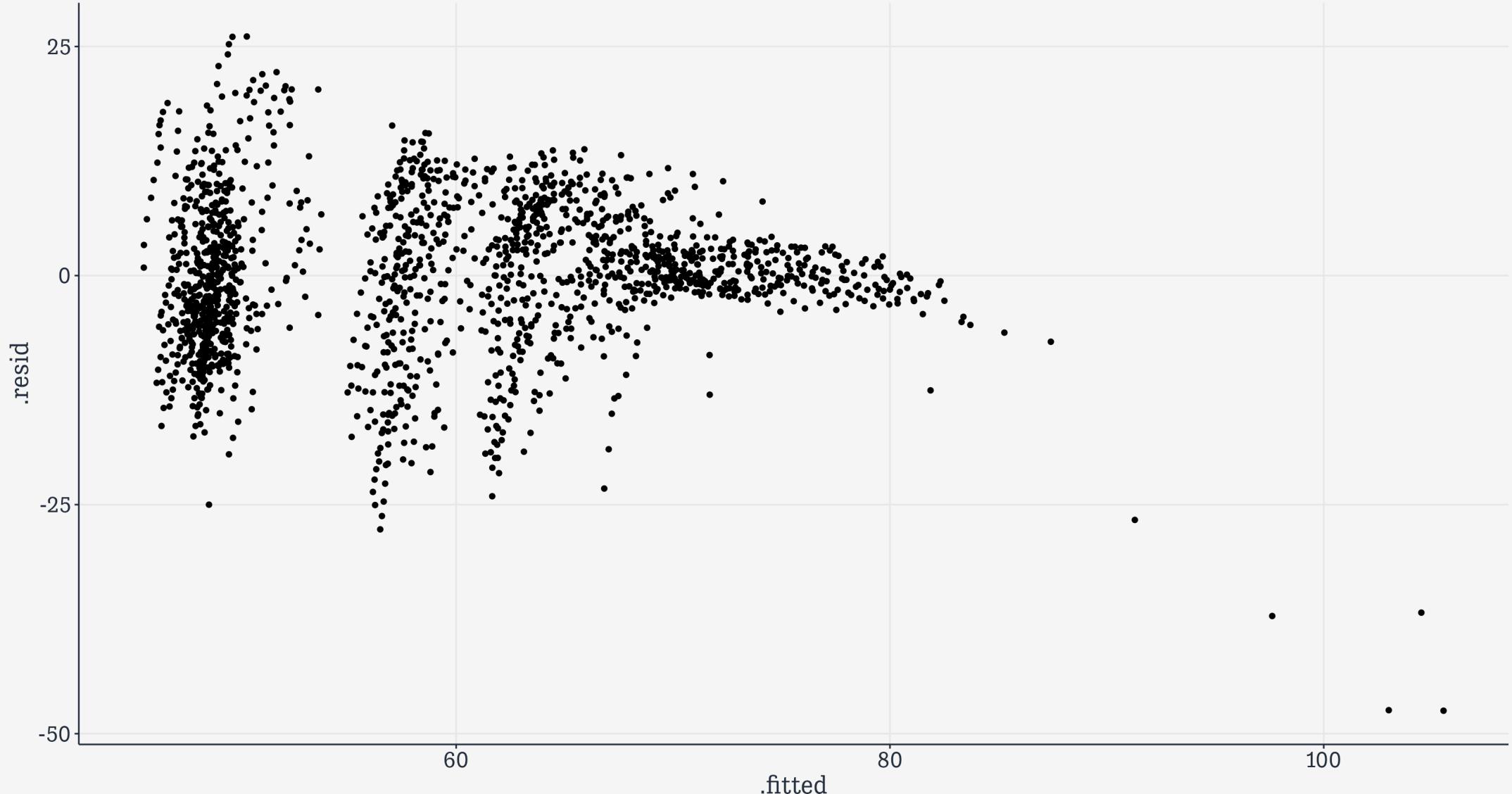
`.std.resid` – The standardized residuals.

Observation level

```
# Adding the data argument puts back any additional columns from the original
# tibble
out_aug <- augment(out, data = gapminder)
head(out_aug)

## # A tibble: 6 × 12
##   country    continent  year lifeExp      pop gdpPercap .fitted .resid     .hat .sigma .cooksD .std.resid
##   <fct>      <fct>    <int>  <dbl>     <int>     <dbl>    <dbl>    <dbl>    <dbl>    <dbl>    <dbl>      <dbl>
## 1 Afghanistan Asia      1952    28.8    8425333    779.    56.5   -27.7  0.00302    8.31  0.00479   -3.33
## 2 Afghanistan Asia      1957    30.3    9240934    821.    56.6   -26.2  0.00299    8.31  0.00426   -3.15
## 3 Afghanistan Asia      1962    32.0   10267083    853.    56.7   -24.7  0.00296    8.32  0.00372   -2.96
## 4 Afghanistan Asia      1967    34.0   11537966    836.    56.7   -22.7  0.00294    8.32  0.00313   -2.73
## 5 Afghanistan Asia      1972    36.1   13079460    740.    56.8   -20.7  0.00294    8.32  0.00259   -2.48
## 6 Afghanistan Asia      1977    38.4   14880372    786.    56.9   -18.4  0.00292    8.33  0.00205   -2.21

## Residuals vs Fitted Values
p <- ggplot(data = out_aug,
             mapping = aes(x = .fitted, y = .resid))
p_out <- p + geom_point()
```



I told you it was misspecified

Component level

```
> summary(out)

Call:
lm(formula = lifeExp ~ gdpPercap + log(pop) + continent, data = gapminder)

Residuals:
    Min      1Q  Median      3Q     Max 
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Coefficients:
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continentEurope   1.695e+01 6.350e-01 26.691 < 2e-16 ***
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Multiple R-squared:  0.585,    Adjusted R-squared:  0.5835 
F-statistic: 398.7 on 6 and 1697 DF,  p-value: < 2.2e-16
```

Component level

```
glance(out)

## # A tibble: 1 × 12
##   r.squared adj.r.squared sigma statistic  p.value      df logLik     AIC     BIC deviance df.residual  nobs
##   <dbl>        <dbl> <dbl>      <dbl> <dbl> <dbl> <dbl> <dbl> <dbl>       <int> <int>
## 1    0.585      0.584  8.34     399. 1.01e-319     6 -6028. 12072. 12115. 117921.      1697  1704
```

The usefulness of `glance()` becomes clearer when dealing with ensembles of models.

Another example

A Kaplan-Meier Curve

```
library(survival)
```

```
head(lung)
```

```
##   inst time status age sex ph.ecog ph.karno pat.karno meal.cal wt.loss
## 1    3  306     2  74    1      1     90     100    1175     NA
## 2    3  455     2  68    1      0     90      90    1225     15
## 3    3 1010     1  56    1      0     90      90     NA     15
## 4    5  210     2  57    1      1     90      60    1150     11
## 5    1  883     2  60    1      0    100      90     NA      0
## 6   12 1022     1  74    1      1     50      80    513      0
```

```
tail(lung)
```

```
##   inst time status age sex ph.ecog ph.karno pat.karno meal.cal wt.loss
## 223    1  116     2  76    1      1     80      80     NA      0
## 224    1  188     1  77    1      1     80      60     NA      3
## 225   13  191     1  39    1      0     90      90    2350     -5
## 226   32  105     1  75    2      2     60      70    1025      5
## 227    6  174     1  66    1      1     90    100    1075      1
## 228   22  177     1  58    2      1     80      90    1060      0
```

A Kaplan-Meier Curve

First we fit the model:

```
## Hazard model
out_cph <- coxph(Surv(time, status) ~ age + sex, data = lung)

summary(out_cph)

## Call:
## coxph(formula = Surv(time, status) ~ age + sex, data = lung)
##
## n= 228, number of events= 165
##
##          coef exp(coef)    se(coef)      z Pr(>|z|)
## age   0.017045  1.017191  0.009223  1.848  0.06459 .
## sex  -0.513219  0.598566  0.167458 -3.065  0.00218 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
##          exp(coef) exp(-coef) lower .95 upper .95
## age     1.0172     0.9831    0.9990    1.0357
## sex     0.5986     1.6707    0.4311    0.8311
##
## Concordance= 0.603  (se = 0.025 )
## Likelihood ratio test= 14.12  on 2 df,    p=9e-04
## Wald test            = 13.47  on 2 df,    p=0.001
## Score (logrank) test = 13.72  on 2 df,    p=0.001
```

A Kaplan-Meier Curve

Then we create the survival curve, which is *nearly* tidy out of the box:

```
## Hazard model
out_surv <- survfit(out_cph)

## See how this is just a print method,
## not a tibble, or even a data frame.
## So it just runs off the end of the slide.
summary(out_surv)

## Call: survfit(formula = out_cph)
##
##   time n.risk n.event survival std.err lower 95% CI upper 95% CI
##      5    228      1 0.9958 0.00417    0.9877 1.000
##     11    227      3 0.9833 0.00831    0.9671 1.000
##     12    224      1 0.9791 0.00928    0.9611 0.997
##     13    223      2 0.9706 0.01096    0.9494 0.992
##     15    221      1 0.9664 0.01170    0.9438 0.990
##     26    220      1 0.9622 0.01240    0.9382 0.987
##     30    219      1 0.9579 0.01305    0.9327 0.984
##     31    218      1 0.9537 0.01368    0.9273 0.981
##     53    217      2 0.9452 0.01484    0.9165 0.975
##     54    215      1 0.9409 0.01538    0.9112 0.972
##     59    214      1 0.9366 0.01590    0.9060 0.968
##     60    213      2 0.9280 0.01689    0.8955 0.962
##     61    211      1 0.9237 0.01735    0.8903 0.958
##     62    210      1 0.9194 0.01780    0.8852 0.955
##     65    209      2 0.9109 0.01865    0.8751 0.948
##     71    207      1 0.9066 0.01906    0.8700 0.945
##     79    206      1 0.9023 0.01945    0.8650 0.941
```

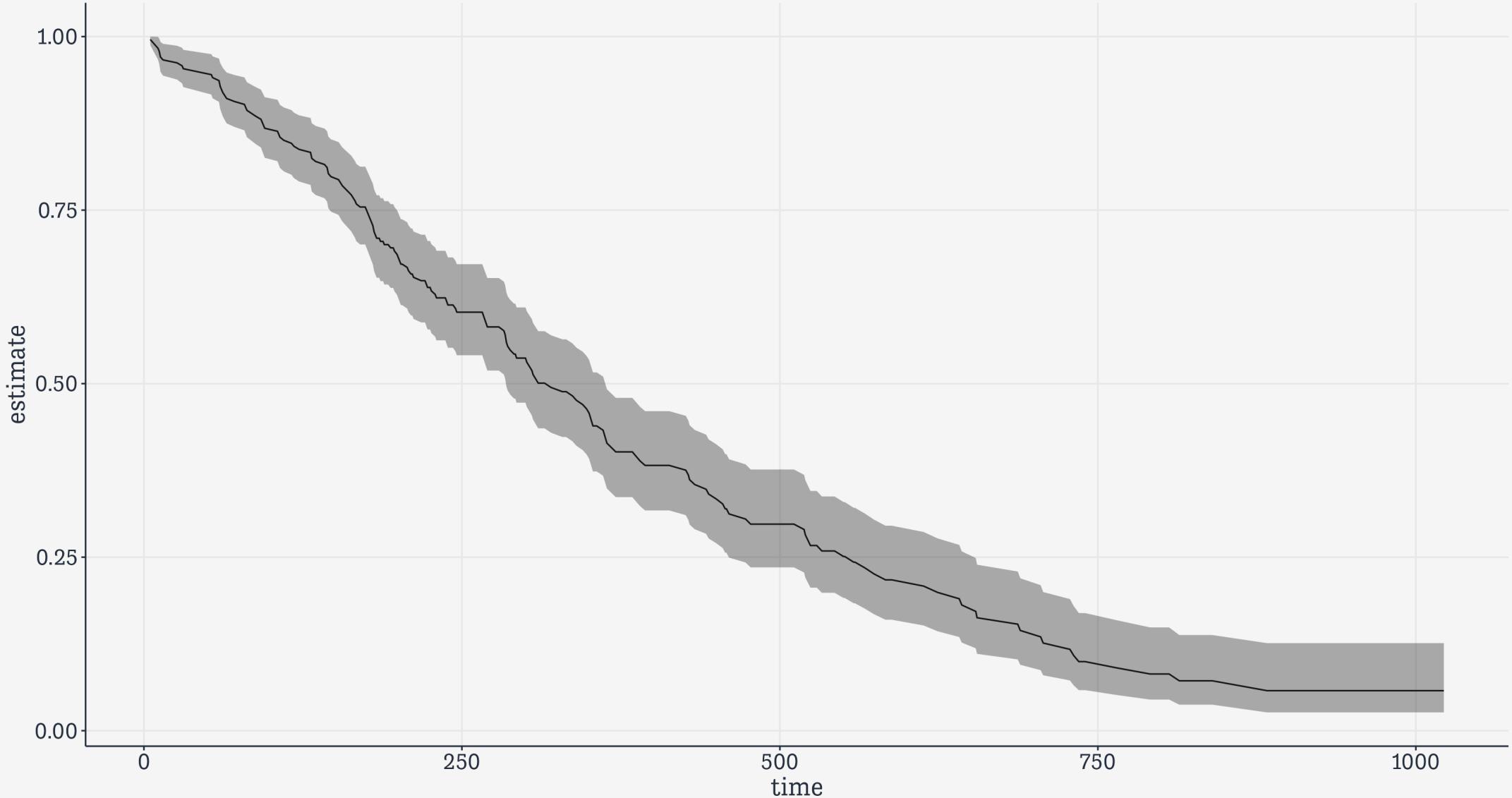
A Kaplan-Meier Curve

Then we tidy it and draw the plot.

```
## Much nicer. (See how the column headers have been regularized, too.)
out_tidy <- tidy(out_surv)
out_tidy

## # A tibble: 186 × 8
##   time n.risk n.event n.censor estimate std.error conf.high conf.low
##   <dbl>   <dbl>   <dbl>   <dbl>     <dbl>     <dbl>      <dbl>     <dbl>
## 1     5     228     1     0    0.996  0.00419     1    0.988
## 2    11     227     3     0    0.983  0.00845     1.00  0.967
## 3    12     224     1     0    0.979  0.00947     0.997  0.961
## 4    13     223     2     0    0.971  0.0113     0.992  0.949
## 5    15     221     1     0    0.966  0.0121     0.990  0.944
## 6    26     220     1     0    0.962  0.0129     0.987  0.938
## 7    30     219     1     0    0.958  0.0136     0.984  0.933
## 8    31     218     1     0    0.954  0.0143     0.981  0.927
## 9    53     217     2     0    0.945  0.0157     0.975  0.917
## 10   54     215     1     0    0.941  0.0163     0.972  0.911
## # ... with 176 more rows

p_out <- out_tidy |>
  ggplot(mapping = aes(x = time, y = estimate)) +
  geom_line() +
  geom_ribbon(mapping = aes(ymin = conf.low, ymax = conf.high),
              alpha = 0.4)
```



Kaplan-Meier Plot

Grouped Analysis with broom

Pipelines show
their real power
when used
iteratively

Iteration without tears (or explicit loops)

You might be familiar with code that looks like this:

```
x <- 10

for (i in 1:5) {
  print(x + i)
}

## [1] 11
## [1] 12
## [1] 13
## [1] 14
## [1] 15
```

This is one way to do something repeatedly.

Iteration without tears (or explicit loops)

We can also write, e.g.,

```
x <- c(10, 20, 30, 40)

for (i in 1:length(x)) {
  # Add 5 to the ith element of x
  print(x[i] + 5)
}

## [1] 15
## [1] 25
## [1] 35
## [1] 45
```

This way we can refer to each element of x in turn, and do the same thing to it.

Iteration without tears (or explicit loops)

The more complicated the thing we want to do, the more likely we are to use functions to help us out.

```
x <- 10

for (i in 1:5) {
  print(sqrt(x + i))
}

## [1] 3.316625
## [1] 3.464102
## [1] 3.605551
## [1] 3.741657
## [1] 3.872983
```

Isn't this like ... Vectorized arithmetic?

The simplest cases are not that different from the vectorized arithmetic we saw before.

```
a <- c(1:10)  
b <- 1  
  
# You know what R will do here  
a + b  
  
## [1] 2 3 4 5 6 7 8 9 10 11
```

Isn't this like ... Vectorized arithmetic?

The simplest cases are not that different from the vectorized arithmetic we saw before.

```
a <- c(1:10)  
b <- 1  
  
# You know what R will do here  
a + b  
  
## [1] 2 3 4 5 6 7 8 9 10 11
```

R's vectorized rules add b to every element of a. In a sense, the **+** operation can be thought of as a function that takes each element of a and does something with it. In this case "add b".

Repeatedly applying a function

We can make this explicit by writing a function:

```
a <- c(1:10)

add_b <- function(x) {
  b <- 1
  x + b # for any x
}
```

Now:

```
add_b(x = a)

## [1]  2  3  4  5  6  7  8  9 10 11
```

In effect we take the vector **a** and feed it to the **add_b()** function one element at a time.

Repeatedly applying a function

Again, R's vectorized approach means it automatically applies `add_b()` to every element of the `x` we give it.

```
add_b(x = 10)
## [1] 11

add_b(x = c(1, 99, 1000))
## [1]    2 100 1001
```

Iterating in a pipeline

Some operations can't directly be vectorized in this way, most often because the function we want to apply only knows what to do if it is handed, say, a vector. It doesn't understand what to do if it's handed a list of vectors or a tibble of them, etc. This is when we might find ourselves manually iterating---writing out every single step explicitly.

```
library(gapminder)
gapminder |>
  summarize(country_n = n_distinct(country),
            continent_n = n_distinct(continent),
            year_n = n_distinct(year),
            lifeExp_n = n_distinct(lifeExp),
            population_n = n_distinct(population))

## # A tibble: 1 × 5
##   country_n continent_n year_n lifeExp_n population_n
##       <int>      <int>    <int>      <int>
## 1        142          5     12       1626        4060
```

That's tedious to write! Computers are supposed to allow us to avoid that sort of thing.

Iterating in a pipeline

So how would we iterate this? What we want is to apply the `n_distinct()` function to each column of `gapminder`. But we can't easily write a loop inside a pipeline. We want a way to iterate that lets us repeatedly apply a function without explicitly writing a loop.

```
library(gapminder)
gapminder |>
  summarize(n_distinct(country),
            n_distinct(continent),
            n_distinct(year),
            n_distinct(lifeExp),
            n_distinct(population))

## # A tibble: 1 × 5
##   `n_distinct(country)` `n_distinct(continent)` `n_distinct(year)` `n_distinct(lifeExp)` `n_distinct(population)`
##             <int>                <int>              <int>                  <int>                <int>
## 1               142                   5                  12                 1626                 4060
```

Using `n_distinct()` in this context is an idea I got from Rebecca Barter's discussion of purrr.

Iterating in a pipeline

In real life, you'd use **across()**, like this:

```
gapminder |>  
  summarize(across(everything(), n_distinct))  
  
## # A tibble: 1 × 6  
##   country continent year lifeExp   pop gdpPercap  
##   <int>     <int> <int>    <int> <int>      <int>  
## 1     142         5    12     1626  1704       1704
```

Iterating in a pipeline

But you could also say "Feed each column of `gapminder` in turn to the `n_distinct()` function".

This is what the `map()` function is for.

```
map(gapminder, n_distinct)

## $country
## [1] 142
##
## $continent
## [1] 5
##
## $year
## [1] 12
##
## $lifeExp
## [1] 1626
##
## $pop
## [1] 1704
##
## $gdpPercap
## [1] 1704
```

Read it as "Feed each column of `gapminder` to the `n_distinct()` function.

(This is pretty much what `across()` is doing more nicely.)

Iterating in a pipeline

Or, in pipeline form:

```
gapminder |>  
  map(n_distinct)
```

```
## $country  
## [1] 142  
##  
## $continent  
## [1] 5  
##  
## $year  
## [1] 12  
##  
## $lifeExp  
## [1] 1626  
##  
## $pop  
## [1] 1704  
##  
## $gdpPercap  
## [1] 1704
```

You can see we are getting a *list* back.

Iterating in a pipeline

Or, in pipeline form:

```
result <- gapminder |>  
  map(n_distinct)  
  
class(result)  
## [1] "list"  
  
result$continent  
## [1] 5  
  
result[[2]]  
## [1] 5
```

Iterating in a pipeline

But we know `n_distinct()` should always return an integer. So we use `map_int()` instead of the generic `map()`.

```
gapminder |>  
  map_int(n_distinct)  
  
## # A tibble: 142 x 5  
##   country continent year lifeExp pop gdpPercap  
##   <dbl>     <dbl> <dbl>    <dbl> <dbl>      <dbl>  
## 1       1        5     12     1626    1704      1704
```

The thing about the `map()` family is that it can deal with all kinds of input types and output types.

**So what's the use
of all that stuff?**

Grouped analysis and **list columns**

Let's say I want to fit a simple model to data for all countries in Europe in 1977.

```
eu77 <- gapminder |>
  filter(continent == "Europe", year == 1977)

fit <- lm(lifeExp ~ log(gdpPercap), data = eu77)

summary(fit)

##
## Call:
## lm(formula = lifeExp ~ log(gdpPercap), data = eu77)
##
## Residuals:
##     Min      1Q      Median      3Q      Max 
## -7.4956 -1.0306  0.0935  1.1755  3.7125 
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)    
## (Intercept) 29.489     7.161   4.118 0.000306 ***
## log(gdpPercap) 4.488     0.756   5.936 2.17e-06 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 2.114 on 28 degrees of freedom
## Multiple R-squared:  0.5572,    Adjusted R-squared:  0.5414 
## F-statistic: 35.24 on 1 and 28 DF,  p-value: 2.173e-06
```

Grouped analysis and **list columns**

What if I want to do that for all Continent-Year combinations? I'm not going to write a loop!

```
out_le <- gapminder |>
  group_by(continent, year) |>
  nest()

out_le

## # A tibble: 60 × 3
## # Groups:   continent, year [60]
##   continent   year    data
##   <fct>     <int> <list>
## 1 Asia        1952 <tibble [33 × 4]>
## 2 Asia        1957 <tibble [33 × 4]>
## 3 Asia        1962 <tibble [33 × 4]>
## 4 Asia        1967 <tibble [33 × 4]>
## 5 Asia        1972 <tibble [33 × 4]>
## 6 Asia        1977 <tibble [33 × 4]>
## 7 Asia        1982 <tibble [33 × 4]>
## 8 Asia        1987 <tibble [33 × 4]>
## 9 Asia        1992 <tibble [33 × 4]>
## 10 Asia       1997 <tibble [33 × 4]>
## # ... with 50 more rows
```

Think of nesting as a kind of "super-grouping". Look in the object inspector.

Grouped analysis and **list columns**

Europe '77 is still in there.

```
out_le |>
  filter(continent == "Europe" & year == 1977) |>
  unnest(cols = c(data))

## # A tibble: 30 × 6
## # Groups: continent, year [1]
##   continent year country      lifeExp     pop gdpPercap
##   <fct>     <int> <fct>      <dbl>     <int>     <dbl>
## 1 Europe     1977 Albania     68.9    2509048     3533.
## 2 Europe     1977 Austria     72.2    7568430     19749.
## 3 Europe     1977 Belgium     72.8    9821800     19118.
## 4 Europe     1977 Bosnia and Herzegovina 69.9    4086000     3528.
## 5 Europe     1977 Bulgaria     70.8    8797022     7612.
## 6 Europe     1977 Croatia     70.6    4318673     11305.
## 7 Europe     1977 Czech Republic 70.7    10161915    14800.
## 8 Europe     1977 Denmark     74.7    5088419     20423.
## 9 Europe     1977 Finland     72.5    4738902     15605.
## 10 Europe    1977 France      73.8    53165019    18293.
## # ... with 20 more rows
```

Grouped analysis and **list columns**

Here we write a tiny, very specific function and **map()** it to every row in the data column.

```
fit_ols <- function(df) {  
  lm(lifeExp ~ log(gdpPerCap), data = df)  
}  
  
out_le <- gapminder |>  
  group_by(continent, year) |>  
  nest() |>  
  mutate(model = map(data, fit_ols))
```

Grouped analysis and **list** columns

Now we have a new column. Each row of the `model` column contains a full regression for that continent-year.

```
out_le

## # A tibble: 60 × 4
## # Groups: continent, year [60]
##   continent year data           model
##   <fct>     <int> <list>        <list>
## 1 Asia      1952 <tibble [33 × 4]> <lm>
## 2 Asia      1957 <tibble [33 × 4]> <lm>
## 3 Asia      1962 <tibble [33 × 4]> <lm>
## 4 Asia      1967 <tibble [33 × 4]> <lm>
## 5 Asia      1972 <tibble [33 × 4]> <lm>
## 6 Asia      1977 <tibble [33 × 4]> <lm>
## 7 Asia      1982 <tibble [33 × 4]> <lm>
## 8 Asia      1987 <tibble [33 × 4]> <lm>
## 9 Asia      1992 <tibble [33 × 4]> <lm>
## 10 Asia     1997 <tibble [33 × 4]> <lm>
## # ... with 50 more rows
```

Grouped analysis and *list* columns

We can tidy the nested models, too.

```
fit_ols <- function(df) {  
  lm(lifeExp ~ log(gdpPerCap), data = df)  
}  
  
out_tidy <- gapminder |>  
  group_by(continent, year) |>  
  nest() |>  
  mutate(model = map(data, fit_ols),  
         tidied = map(model, tidy))  
  
out_tidy  
  
## # A tibble: 60 × 5  
## # Groups: continent, year [60]  
##   continent year data           model  tidied  
##   <fct>     <int> <list>        <list> <list>  
## 1 Asia       1952 <tibble [33 × 4]> <lm>    <tibble [2 × 5]>  
## 2 Asia       1957 <tibble [33 × 4]> <lm>    <tibble [2 × 5]>  
## 3 Asia       1962 <tibble [33 × 4]> <lm>    <tibble [2 × 5]>  
## 4 Asia       1967 <tibble [33 × 4]> <lm>    <tibble [2 × 5]>  
## 5 Asia       1972 <tibble [33 × 4]> <lm>    <tibble [2 × 5]>  
## 6 Asia       1977 <tibble [33 × 4]> <lm>    <tibble [2 × 5]>  
## 7 Asia       1982 <tibble [33 × 4]> <lm>    <tibble [2 × 5]>  
## 8 Asia       1987 <tibble [33 × 4]> <lm>    <tibble [2 × 5]>  
## 9 Asia       1992 <tibble [33 × 4]> <lm>    <tibble [2 × 5]>  
## 10 Asia      1997 <tibble [33 × 4]> <lm>    <tibble [2 × 5]>  
## # ... with 50 more rows
```

Grouped analysis and **list** columns

We can get the tidied results out into the main table if we like.

```
out_tidy <- out_tidy |>
  unnest(cols = c(tidied)) |>
  filter(term %nin% "(Intercept)" &
        continent %nin% "Oceania")

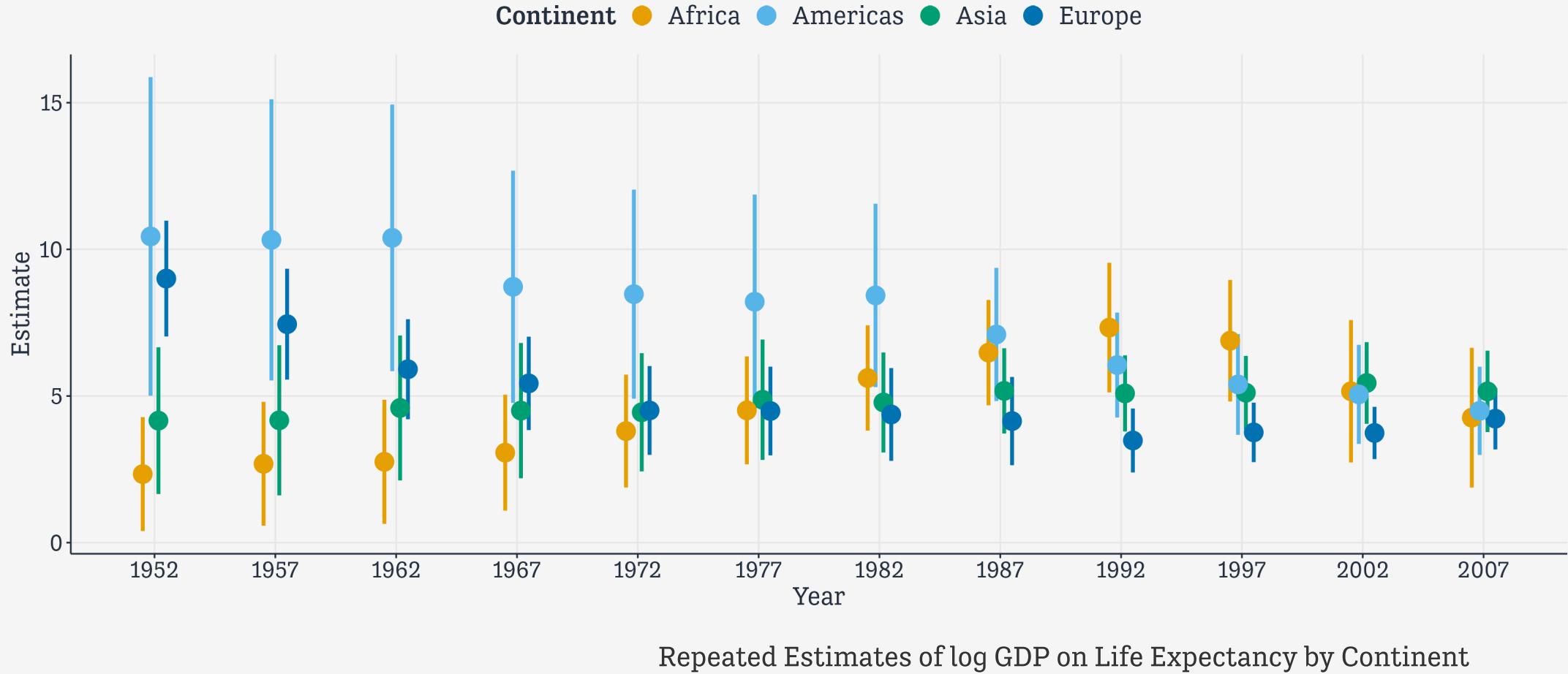
out_tidy

## # A tibble: 48 × 9
## # Groups: continent, year [48]
##   continent year data           model term      estimate std.error statistic    p.value
##   <fct>     <int> <list>         <list> <chr>       <dbl>     <dbl>      <dbl>      <dbl>
## 1 Asia       1952 <tibble [33 × 4]> <lm> log(gdpPercap) 4.16      1.25      3.33 0.00228
## 2 Asia       1957 <tibble [33 × 4]> <lm> log(gdpPercap) 4.17      1.28      3.26 0.00271
## 3 Asia       1962 <tibble [33 × 4]> <lm> log(gdpPercap) 4.59      1.24      3.72 0.000794
## 4 Asia       1967 <tibble [33 × 4]> <lm> log(gdpPercap) 4.50      1.15      3.90 0.000477
## 5 Asia       1972 <tibble [33 × 4]> <lm> log(gdpPercap) 4.44      1.01      4.41 0.000116
## 6 Asia       1977 <tibble [33 × 4]> <lm> log(gdpPercap) 4.87      1.03      4.75 0.0000442
## 7 Asia       1982 <tibble [33 × 4]> <lm> log(gdpPercap) 4.78      0.852     5.61 0.00000377
## 8 Asia       1987 <tibble [33 × 4]> <lm> log(gdpPercap) 5.17      0.727     7.12 0.000000531
## 9 Asia       1992 <tibble [33 × 4]> <lm> log(gdpPercap) 5.09      0.649     7.84 0.0000000760
## 10 Asia      1997 <tibble [33 × 4]> <lm> log(gdpPercap) 5.11      0.628     8.15 0.0000000335
## # ... with 38 more rows
```

Plot what we have

```
p <- ggplot(data = out_tidy,
             mapping = aes(x = year, y = estimate,
                           ymin = estimate - 2*std.error,
                           ymax = estimate + 2*std.error,
                           group = continent,
                           color = continent))

p_out <- p +
  geom_pointrange(size = rel(1.25),
                  position = position_dodge(width = rel(1.3))) +
  scale_x_continuous(breaks = unique(gapminder$year)) +
  labs(x = "Year",
       y = "Estimate",
       color = "Continent")
```



And there's more ...

Let's go back to this stage:

```
# New model
fit_ols2 <- function(df) {
  lm(lifeExp ~ log(gdpPercap) + log(pop), data = df)
}

out_tidy <- gapminder |>
  group_by(continent, year) |>
  nest() |>
  mutate(model = map(data, fit_ols2),
         tidied = map(model, tidy))

out_tidy

## # A tibble: 60 × 5
## # Groups: continent, year [60]
##   continent    year data          model  tidied
##   <fct>      <int> <list>        <list> <list>
## 1 Asia        1952 <tibble [33 × 4]> <lm>   <tibble [3 × 5]>
## 2 Asia        1957 <tibble [33 × 4]> <lm>   <tibble [3 × 5]>
## 3 Asia        1962 <tibble [33 × 4]> <lm>   <tibble [3 × 5]>
## 4 Asia        1967 <tibble [33 × 4]> <lm>   <tibble [3 × 5]>
## 5 Asia        1972 <tibble [33 × 4]> <lm>   <tibble [3 × 5]>
## 6 Asia        1977 <tibble [33 × 4]> <lm>   <tibble [3 × 5]>
## 7 Asia        1982 <tibble [33 × 4]> <lm>   <tibble [3 × 5]>
## 8 Asia        1987 <tibble [33 × 4]> <lm>   <tibble [3 × 5]>
## 9 Asia        1992 <tibble [33 × 4]> <lm>   <tibble [3 × 5]>
## 10 Asia       1997 <tibble [33 × 4]> <lm>   <tibble [3 × 5]>
## # ... with 50 more rows
```

A function to draw a coef plot

```
# Plot the output from our model
mod_plot <- function(data,
                      title){
  data |>
    filter(term %nin% "(Intercept)") |>
    ggplot(mapping = aes(x = estimate,
                          xmin = estimate - std.error,
                          xmax = estimate + std.error,
                          y = reorder(term, estimate))) +
    geom_pointrange() +
    labs(title = title,
         y = NULL)
}
```

Add it using `map2()` or `pmap()`

When we have two arguments to feed a function we can used `map2()`. The general case is `pmap()`, for passing along any number of arguments in a list.

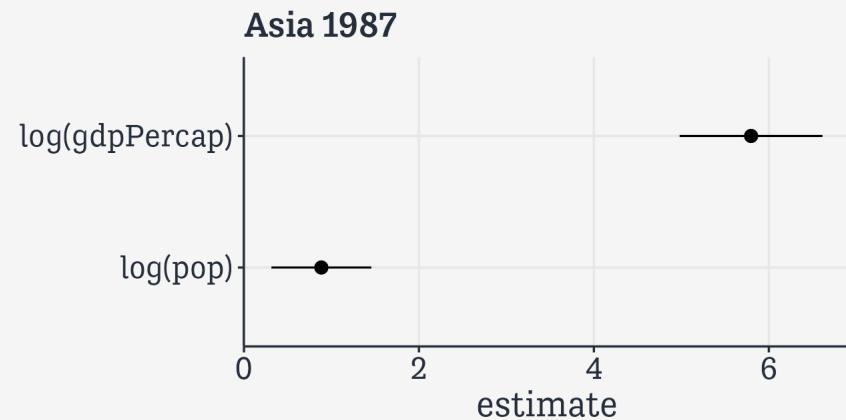
```
out_tidy <- gapminder |>
  group_by(continent, year) |>
  nest() |>
  mutate(title = paste(continent, year),
    model = map(data, fit_ols2),
    tidied = map(model, tidy),
    ggout = pmap(list(tidied,
                      title),
                 mod_plot))
```

out_tidy

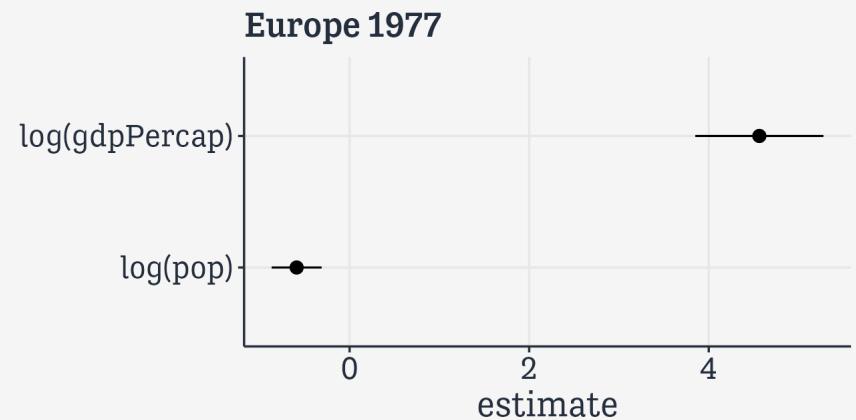
```
## # A tibble: 60 × 7
## # Groups:   continent, year [60]
##   continent   year data           title   model   tidied      ggout
##   <fct>     <int> <list>         <chr>   <list> <list>       <list>
## 1 Asia        1952 <tibble [33 × 4]> Asia 1952 <lm>   <tibble [3 × 5]> <gg>
## 2 Asia        1957 <tibble [33 × 4]> Asia 1957 <lm>   <tibble [3 × 5]> <gg>
## 3 Asia        1962 <tibble [33 × 4]> Asia 1962 <lm>   <tibble [3 × 5]> <gg>
## 4 Asia        1967 <tibble [33 × 4]> Asia 1967 <lm>   <tibble [3 × 5]> <gg>
## 5 Asia        1972 <tibble [33 × 4]> Asia 1972 <lm>   <tibble [3 × 5]> <gg>
## 6 Asia        1977 <tibble [33 × 4]> Asia 1977 <lm>   <tibble [3 × 5]> <gg>
## 7 Asia        1982 <tibble [33 × 4]> Asia 1982 <lm>   <tibble [3 × 5]> <gg>
## 8 Asia        1987 <tibble [33 × 4]> Asia 1987 <lm>   <tibble [3 × 5]> <gg>
## 9 Asia        1992 <tibble [33 × 4]> Asia 1992 <lm>   <tibble [3 × 5]> <gg>
```

A plot!

out_tidy\$ggout[[8]]



out_tidy\$ggout[[18]]



We don't just put them in there for fun

We can e.g. `walk` the plots out to disk

`walk()` is `map()` for when you just want a "side-effect" such as printed output. There is also `walk2()` and `pwalk()`

```
pwalk(  
  list(  
    filename = paste0(out_tidy$title, ".png"),  
    plot = out_tidy$ggout,  
    path = here("figures"),  
    height = 3, width = 4,  
    dpi = 300  
)  
,  
ggsave  
)
```

Peek in the figures/ folder

```
fs::dir_ls(here("figures")) |>  
  basename()  
  
## [1] "Africa 1952.png"    "Africa 1957.png"    "Africa 1962.png"    "Africa 1967.png"    "Africa 1972.png"    "Africa 1977.png"    "Af  
## [8] "Africa 1987.png"    "Africa 1992.png"    "Africa 1997.png"    "Africa 2002.png"    "Africa 2007.png"    "Americas 1952.png"  "Am  
## [15] "Americas 1962.png"  "Americas 1967.png"  "Americas 1972.png"  "Americas 1977.png"  "Americas 1982.png"  "Americas 1987.png"  "Am  
## [22] "Americas 1997.png"  "Americas 2002.png"  "Americas 2007.png"  "Asia 1952.png"     "Asia 1957.png"     "Asia 1962.png"     "As  
## [29] "Asia 1972.png"      "Asia 1977.png"      "Asia 1982.png"      "Asia 1987.png"      "Asia 1992.png"      "Asia 1997.png"      "As  
## [36] "Asia 2007.png"       "Europe 1952.png"   "Europe 1957.png"   "Europe 1962.png"   "Europe 1967.png"   "Europe 1972.png"   "Eu  
## [43] "Europe 1982.png"     "Europe 1987.png"   "Europe 1992.png"   "Europe 1997.png"   "Europe 2002.png"   "Europe 2007.png"   "Occ  
## [50] "Oceania 1957.png"    "Oceania 1962.png"  "Oceania 1967.png"  "Oceania 1972.png"  "Oceania 1977.png"  "Oceania 1982.png"  "Oce  
## [57] "Oceania 1992.png"    "Oceania 1997.png"  "Oceania 2002.png"  "Oceania 2007.png"
```

**Get model-based
graphics right**

Present findings in substantive terms

Present findings in substantive terms

Show degrees of confidence or uncertainty

Present findings in substantive terms

Show degrees of confidence or uncertainty

Show the data when you can

These points apply just
as well to presenting
data in *any* format:
tables, models, text,
whatever. Graphs are
not special here!

Plot Marginal Effects

The marginaleffects package

An example from the GSS

gss_sm

```
## # A tibble: 2,867 x 32
##   year   id ballot    age childs sibs degree race sex   region income16 relig marital padeg madeg partyid polviews happy
##   <dbl> <dbl> <labelle> <dbl> <dbl> <lab> <fct> <fct>
## 1 2016     1 1           47      3 2  Bach... White Male  New E... $170000... None Married Grad... High... Indepe... Moderate Pret...
## 2 2016     2 2           61      0 3  High ... White Male  New E... $50000 ... None Never ... Lt H... High... Ind,ne... Liberal Pret...
## 3 2016     3 3           72      2 3  Bach... White Male  New E... $75000 ... Cath... Married High... Lt H... Not St... Conserv... Very...
## 4 2016     4 1           43      4 3  High ... White Fema... New E... $170000... Cath... Married <NA>  High... Not St... Moderate Pret...
## 5 2016     5 3           55      2 2  Gradu... White Fema... New E... $170000... None Married Bach... High... Not St... Slightl... Very...
## 6 2016     6 2           53      2 2  Junio... White Fema... New E... $60000 ... None Married <NA>  High... Not St... Slightl... Very...
## 7 2016     7 1           50      2 2  High ... White Male  New E... $170000... None Married High... High... Not St... Slightl... Pret...
## 8 2016     8 3           23      3 6  High ... Other Fema... Middl... $30000 ... Cath... Married Lt H... Lt H... Ind,ne... Slightl... Very...
## 9 2016     9 1           45      3 5  High ... Black Male  Middl... $60000 ... Prot... Married Lt H... Lt H... Strong... <NA>  Pret...
## 10 2016    10 3          71      4 1  Junio... White Male  Middl... $60000 ... None Divorc... High... High... Strong... Conserv... Pret...
## # ... with 2,857 more rows, and 11 more variables: pres12 <labelled>, wtssall <dbl>, income_rc <fct>, agegrp <fct>, ageq <fct>, si
## #   kids <fct>, religion <fct>, bigregion <fct>, partners_rc <fct>, obama <dbl>
```

Set up our model

```
gss_sm$polviews_m <- relevel(gss_sm$polviews,
                               ref = "Moderate")

out_bo <- glm(obama ~ polviews_m + sex*race,
              family = "binomial",
              data = gss_sm)

tidy(out_bo)

## # A tibble: 12 × 5
##   term                estimate std.error statistic p.value
##   <chr>               <dbl>     <dbl>      <dbl>    <dbl>
## 1 (Intercept)        0.296     0.134      2.21    2.70e- 2
## 2 polviews_mExtremely Liberal  2.37      0.525      4.52    6.20e- 6
## 3 polviews_mLiberal       2.60      0.357      7.29    3.10e-13
## 4 polviews_msSlightly Liberal  1.29      0.248      5.21    1.94e- 7
## 5 polviews_msSlightly Conservative -1.36     0.181     -7.48    7.68e-14
## 6 polviews_mConservative      -2.35     0.200     -11.7    1.07e-31
## 7 polviews_mExtremely Conservative -2.73     0.387     -7.04    1.87e-12
## 8 sexFemale            0.255     0.145      1.75    7.96e- 2
## 9 raceBlack             3.85      0.501      7.68    1.61e-14
## 10 raceOther            -0.00214   0.436     -0.00492  9.96e- 1
## 11 sexFemale:raceBlack      -0.198     0.660     -0.299   7.65e- 1
## 12 sexFemale:raceOther       1.57      0.588      2.68    7.37e- 3
```

Calculate the Marginal Effects

```
library(marginaleffects)

bo_mfx <- marginaleffects(out_bo)

## This gives us the marginal effects at the unit level
as_tibble(bo_mfx)

## # A tibble: 15,282 × 14
##   rowid type   term   contrast      dydx std.error statistic p.value conf.low conf.high obama polviews_m
##   <int> <chr>  <chr>    <chr>     <dbl>    <dbl>     <dbl>    <dbl>    <dbl>    <dbl>    <dbl> <dbl> <fct>
## 1     1 response polviews_m Extremely Liberal - Moderate  0.362    0.0433     8.35 6.76e-17  0.277    0.446    0 Moderate
## 2     2 response polviews_m Extremely Liberal - Moderate  0.362    0.0433     8.35 6.76e-17  0.277    0.446    1 Liberal
## 3     3 response polviews_m Extremely Liberal - Moderate  0.362    0.0433     8.35 6.76e-17  0.277    0.446    0 Conservat
## 4     4 response polviews_m Extremely Liberal - Moderate  0.315    0.0361     8.72 2.90e-18  0.244    0.385    0 Moderate
## 5     5 response polviews_m Extremely Liberal - Moderate  0.315    0.0361     8.72 2.90e-18  0.244    0.385    1 Slightly
## 6     6 response polviews_m Extremely Liberal - Moderate  0.315    0.0361     8.72 2.90e-18  0.244    0.385    1 Slightly
## 7     7 response polviews_m Extremely Liberal - Moderate  0.362    0.0433     8.35 6.76e-17  0.277    0.446    0 Conservat
## 8     8 response polviews_m Extremely Liberal - Moderate  0.0141   0.00701    2.01 4.43e- 2  0.000360   0.0279   1 Slightly
## 9     9 response polviews_m Extremely Liberal - Moderate  0.0133   0.00595    2.24 2.50e- 2  0.00168   0.0250   1 Liberal
## 10   10 response polviews_m Extremely Liberal - Moderate  0.362    0.0433     8.35 6.76e-17  0.277    0.446    0 Moderate
## # ... with 15,272 more rows
```

Calculate the AMEs

And this gives us the Average Marginal Effects

```
summary(bo_mfx) |>
  as_tibble()

## # A tibble: 9 × 9
##   type    term    contrast      estimate std.error statistic  p.value conf.low conf.high
##   <chr>   <chr>   <chr>        <dbl>     <dbl>     <dbl>     <dbl>     <dbl>     <dbl>
## 1 response polviews_m Extremely Liberal - Moderate  0.268     0.0295    9.10 0     0.210     0.326
## 2 response polviews_m Liberal - Moderate            0.277     0.0229   12.1 0     0.232     0.322
## 3 response polviews_m Slightly Liberal - Moderate  0.193     0.0302    6.39 1.66e-10  0.134     0.253
## 4 response polviews_m Slightly Conservative - Moderate -0.266     0.0330   -8.06 6.66e-16 -0.330     -0.201
## 5 response polviews_m Conservative - Moderate       -0.412     0.0283   -14.5 0     -0.467     -0.356
## 6 response polviews_m Extremely Conservative - Moderate -0.454     0.0420   -10.8 0     -0.536     -0.371
## 7 response sex      Female - Male                  0.0443    0.0177    2.51 1.22e- 2  0.00967    0.0789
## 8 response race    Black - White                 0.403     0.0173   23.4 0     0.369     0.437
## 9 response race    Other - White                 0.125     0.0386    3.23 1.24e- 3  0.0490     0.200
```

Alternatively, do it with broom

```
tidy(bo_mfx)
```

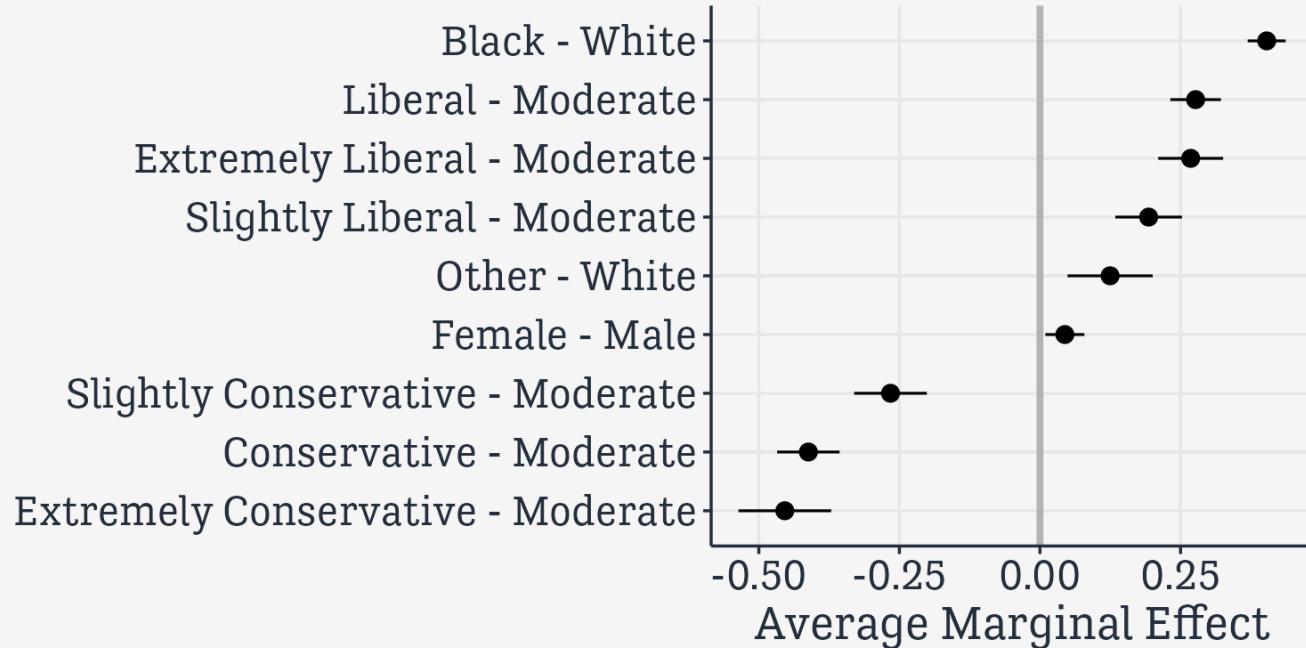
```
##      type     term          contrast estimate std.error statistic p.value conf.low conf.high
## 1 response polviews_m Extremely Liberal - Moderate  0.2681   0.0295     9.10 0.00e+00  0.21032  0.3258
## 2 response polviews_m           Liberal - Moderate  0.2768   0.0229    12.07 0.00e+00  0.23190  0.3218
## 3 response polviews_m Slightly Liberal - Moderate  0.1933   0.0302     6.39 1.66e-10  0.13400  0.2526
## 4 response polviews_m Slightly Conservative - Moderate -0.2658   0.0330    -8.06 6.66e-16 -0.33042 -0.2011
## 5 response polviews_m           Conservative - Moderate -0.4119   0.0283    -14.54 0.00e+00 -0.46741 -0.3564
## 6 response polviews_m Extremely Conservative - Moderate -0.4538   0.0420    -10.80 0.00e+00 -0.53614 -0.3714
## 7 response     sex            Female - Male    0.0443   0.0177     2.51 1.22e-02  0.00967  0.0789
## 8 response     race           Black - White   0.4032   0.0173    23.36 0.00e+00  0.36939  0.4371
## 9 response     race           Other - White   0.1247   0.0386     3.23 1.24e-03  0.04905  0.2005
```

Which gets us back to familiar territory

```
tidy(bo_mfx) |>  
  ggplot(mapping = aes(x = estimate,  
                        xmin = conf.low,  
                        xmax = conf.high,  
                        y = reorder(contrast,  
                                    estimate))) +  
  geom_vline(xintercept = 0, color = "gray70",  
             size = rel(1.2)) +  
  geom_pointrange() +  
  labs(x = "Average Marginal Effect",  
       y = NULL)
```

Which gets us back to familiar territory

```
tidy(bo_mfx) |>  
  ggplot(mapping = aes(x = estimate,  
                        xmin = conf.low,  
                        xmax = conf.high,  
                        y = reorder(contrast,  
                                    estimate))) +  
  geom_vline(xintercept = 0, color = "gray70",  
             size = rel(1.2)) +  
  geom_pointrange() +  
  labs(x = "Average Marginal Effect",  
       y = NULL)
```



marginaleffects can do a lot more

marginaleffects 0.4.1.9000 [Adjusted predictions](#) [Marginal effects](#) [Contrasts](#) [Marginal means](#) [Functions](#) [Changelog](#)

The marginaleffects package for R



marginaleffects is an R package to compute and plot adjusted predictions, marginal effects, contrasts, and marginal means for a *wide* variety of models.

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Links

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Citation

[Citing marginaleffects](#)

Developers

Vincent Arel-Bundock
Author, maintainer, copyright holder 

Dev status

 codecov 90%
 R-CMD-check passing
CRAN 0.4.1
dependencies 3/4

`marginalEffects` can do a lot more

It includes a range of plotting methods, to produce graphics directly.

These are built on `ggplot`. Similarly integration with `broom` means that you can use the package-specific plotting functions take the tidy output and adapt it to your own needs.

Also check out `modelsummary`, by the same author, for quick and flexible summaries of models and datasets. Again, this sort of package is very convenient to use directly. But with just a little facility with R and tidyverse-style idioms and patterns, you'll get even more out of it. You'll better understand how to adapt it and why its functions work as they do.

Complex Surveys

Using the `survey` and `srvyr` packages

Working with complex surveys

As always, our question is "What's the smoothest way for me to get the **tidy table of results** I need to hand off to **ggplot**?"

For complex surveys, we use **survey**, the standard package for survey analysis in R, and **srvyr**, a helper package designed to integrate what **survey** can do with the Tidyverse framework.

```
## Load the packages
library(survey)
library(srvyr)
```

Example: The GSS again

This time, a small piece of the full GSS from the early 1970s to 2018.

```
gss_lon
```

```
## # A tibble: 62,466 × 25
##   year   id ballot age degree race sex   siblings kids bigregion income16 religion marital padeg madeg partyid polvi
##   <dbl> <dbl> <labelled> <labe...> <fct> <fct>
## 1 1972     1 NA      23    Bache... White Fema... 3       0   Midwest <NA> Jewish  Never ... Lt H... <NA> Ind,ne... <NA>
## 2 1972     2 NA      70    Lt Hi... White Male  4      4+   Midwest <NA> Catholic Married Lt H... Lt H... Not St... <NA>
## 3 1972     3 NA      48    High ... White Fema... 5      4+   Midwest <NA> Protest... Married Lt H... Lt H... Indepe... <NA>
## 4 1972     4 NA      27    Bache... White Fema... 5       0   Midwest <NA> Other   Married Bach... High... Not St... <NA>
## 5 1972     5 NA      61    High ... White Fema... 2       2   Midwest <NA> Protest... Married Lt H... Lt H... Strong... <NA>
## 6 1972     6 NA      26    High ... White Male  1       0   Midwest <NA> Protest... Never ... Bach... Grad... Ind,ne... <NA>
## 7 1972     7 NA      28    High ... White Male  6+      2   Midwest <NA> Catholic Divorc... Bach... High... Ind,ne... <NA>
## 8 1972     8 NA      27    Bache... White Male  1       0   Midwest <NA> Jewish   Never ... Bach... High... Ind,ne... <NA>
## 9 1972     9 NA      21    High ... Black Fema... 2       2   South   <NA> Protest... Never ... High... High... Strong... <NA>
## 10 1972    10 NA     30    High ... Black Fema... 6+      4+   South   <NA> Protest... Married Lt H... Lt H... Strong... <NA>
## # ... with 62,456 more rows, and 6 more variables: grass <fct>, zodiac <fct>, pres12 <labelled>, wtssall <dbl>, vpsu <dbl>, vstrat
```

Add the weighting information

```
# These details are dependent on the kind of survey you're working with
options(survey.lonely.psu = "adjust")
options(na.action="na.pass")

gss_svy <- gss_lon |>
  filter(year > 1974) |>
  mutate(stratvar = interaction(year, vstrat)) |>
  as_survey_design(ids = vpsu,
                    strata = stratvar,
                    weights = wtssall,
                    nest = TRUE)

gss_svy # Now it's no longer simply a tibble

## Stratified 1 - level Cluster Sampling design (with replacement)
## With (4399) clusters.
## Called via srvyr
## Sampling variables:
##   - ids: vpsu
##   - strata: stratvar
##   - weights: wtssall
## Data variables: year (dbl), id (dbl), ballot (labelled), age (labelled), degree (fct), race (fct), sex (fct), siblings (fct),
##   (fct), income16 (fct), religion (fct), marital (fct), padeg (fct), madeg (fct), partyid (fct), polviews (fct), happy (fct),
##   grass (fct), zodiac (fct), pres12 (labelled), wtssall (dbl), vpsu (dbl), vstrat (dbl), stratvar (fct)
```

Trends in the happy measure

```
out_hap <- gss_svy |>
  group_by(year, sex, happy) |>
  summarize(prop = survey_mean(na.rm = TRUE, vartype = "ci"))

out_hap

## # A tibble: 221 × 6
## # Groups:   year, sex [56]
##   year   sex   happy       prop   prop_low prop_upp
##   <dbl> <fct> <fct>     <dbl>     <dbl>     <dbl>
## 1 1975 Male  Very Happy  0.319    0.279    0.358
## 2 1975 Male  Pretty Happy 0.555    0.514    0.597
## 3 1975 Male  Not Too Happy 0.119    0.0934   0.145
## 4 1975 Male  <NA>        0.00670 -0.0000539 0.0134
## 5 1975 Female Very Happy  0.345    0.310    0.380
## 6 1975 Female Pretty Happy 0.516    0.472    0.560
## 7 1975 Female Not Too Happy 0.138    0.108    0.167
## 8 1975 Female <NA>        0.00117 -0.00113  0.00347
## 9 1976 Male  Very Happy  0.328    0.289    0.367
## 10 1976 Male  Pretty Happy 0.543    0.505    0.580
## # ... with 211 more rows
```

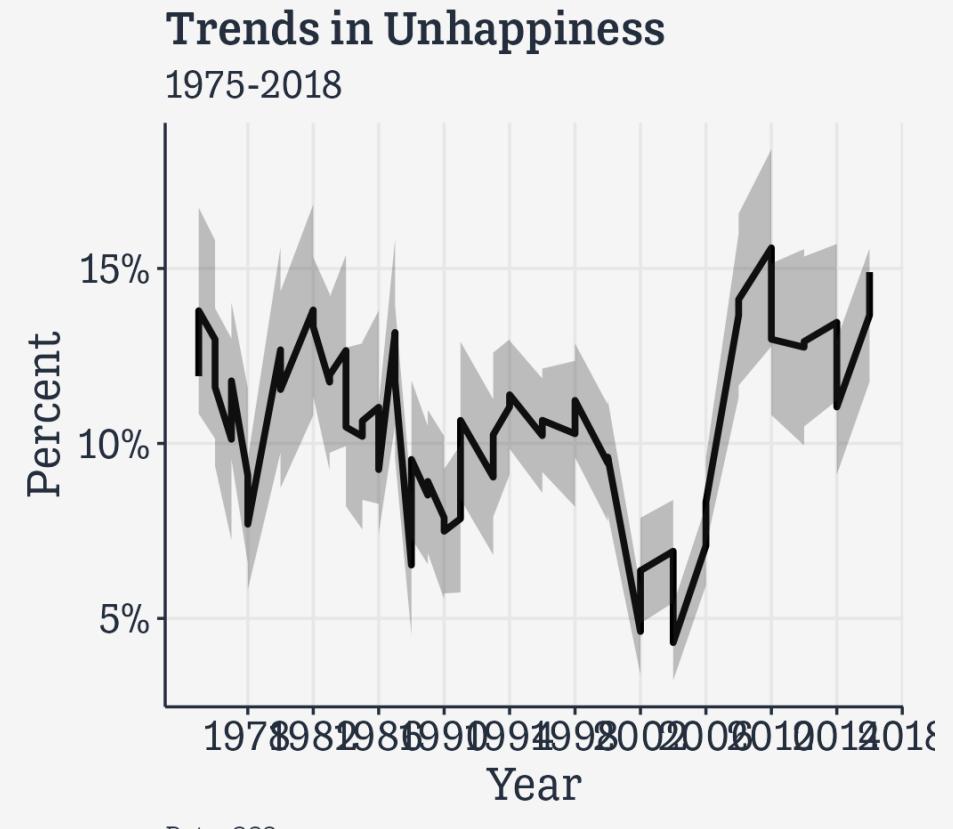
Once again, it's now a tidy tibble, and we know what to do with those.

```
out_hap |>
  filter(happy == "Not Too Happy") |>
  ggplot(mapping = aes(x = year,
                        y = prop,
                        ymin = prop_low,
                        ymax = prop_upp)) +
  geom_line(size = 1.2) +
  geom_ribbon(alpha = 0.3) +
  scale_x_continuous(breaks =
    seq(1978, 2018, 4)) +
  scale_y_continuous(labels =
    label_percent(accuracy = 1)) +
  labs(x = "Year",
       y = "Percent",
       title = "Trends in Unhappiness",
       subtitle = "1975-2018",
       caption = "Data: GSS.")
```

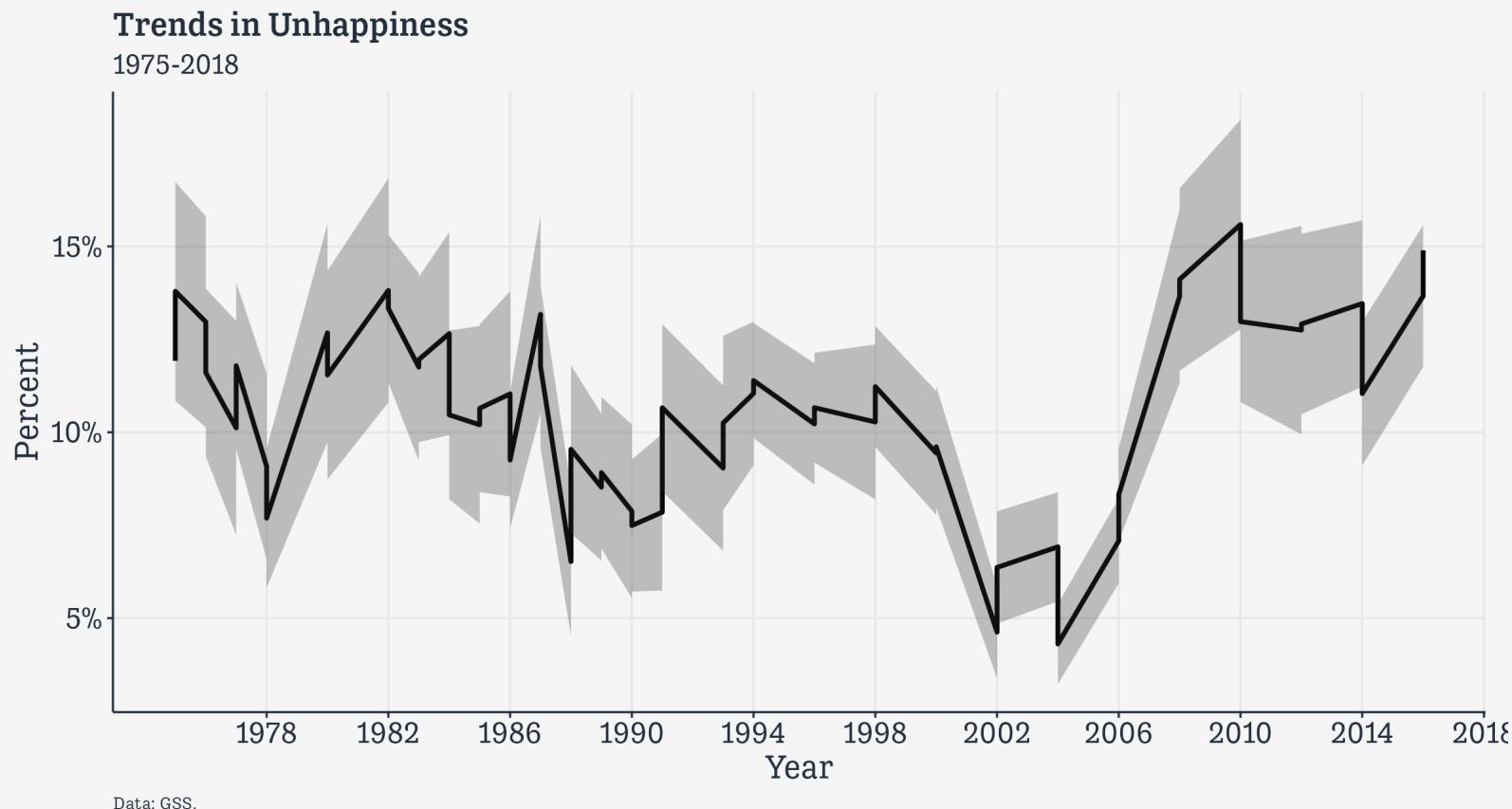
```

out_hap |>
  filter(happy == "Not Too Happy") |>
  ggplot(mapping = aes(x = year,
                        y = prop,
                        ymin = prop_low,
                        ymax = prop_upp)) +
  geom_line(size = 1.2) +
  geom_ribbon(alpha = 0.3) +
  scale_x_continuous(breaks =
    seq(1978, 2018, 4)) +
  scale_y_continuous(labels =
    label_percent(accuracy = 1)) +
  labs(x = "Year",
       y = "Percent",
       title = "Trends in Unhappiness",
       subtitle = "1975-2018",
       caption = "Data: GSS.")

```



With a proper aspect ratio



A more complex example

```
gss_svy |>
  filter(year %in% seq(1976, 2016, by = 4)) |>
  group_by(year, race, degree) |>
  summarize(prop = survey_mean(na.rm = TRUE))

## # A tibble: 162 × 5
## # Groups:   year, race [30]
##   year race   degree      prop    prop_se
##   <dbl> <fct> <fct>      <dbl>    <dbl>
## 1 1976 White Lt High School 0.327    0.0160
## 2 1976 White High School   0.517    0.0161
## 3 1976 White Junior College 0.0128   0.00298
## 4 1976 White Bachelor     0.101    0.00955
## 5 1976 White Graduate     0.0392   0.00642
## 6 1976 White <NA>         0.00285  0.00151
## 7 1976 Black Lt High School 0.558    0.0603
## 8 1976 Black High School   0.335    0.0476
## 9 1976 Black Junior College 0.0423   0.0192
## 10 1976 Black Bachelor    0.0577   0.0238
## # ... with 152 more rows
```

Let's put that in an object

```
out_yrd <- gss_svy |>  
  filter(year %in% seq(1976, 2016, by = 4)) |>  
  group_by(year, race, degree) |>  
  summarize(prop = survey_mean(na.rm = TRUE))
```

Check the sums

```
out_yrd |>  
  group_by(year, race) |>  
  summarize(tot = sum(prop))  
  
## # A tibble: 30 × 3  
## # Groups:   year [10]  
##       year race   tot  
##   <dbl> <fct> <dbl>  
## 1 1976 White 1.00  
## 2 1976 Black 1.00  
## 3 1976 Other 1  
## 4 1980 White 1.00  
## 5 1980 Black 1  
## 6 1980 Other 1  
## 7 1984 White 1.00  
## 8 1984 Black 1.00  
## 9 1984 Other 1  
## 10 1988 White 1.00  
## # ... with 20 more rows
```

Set up the plot

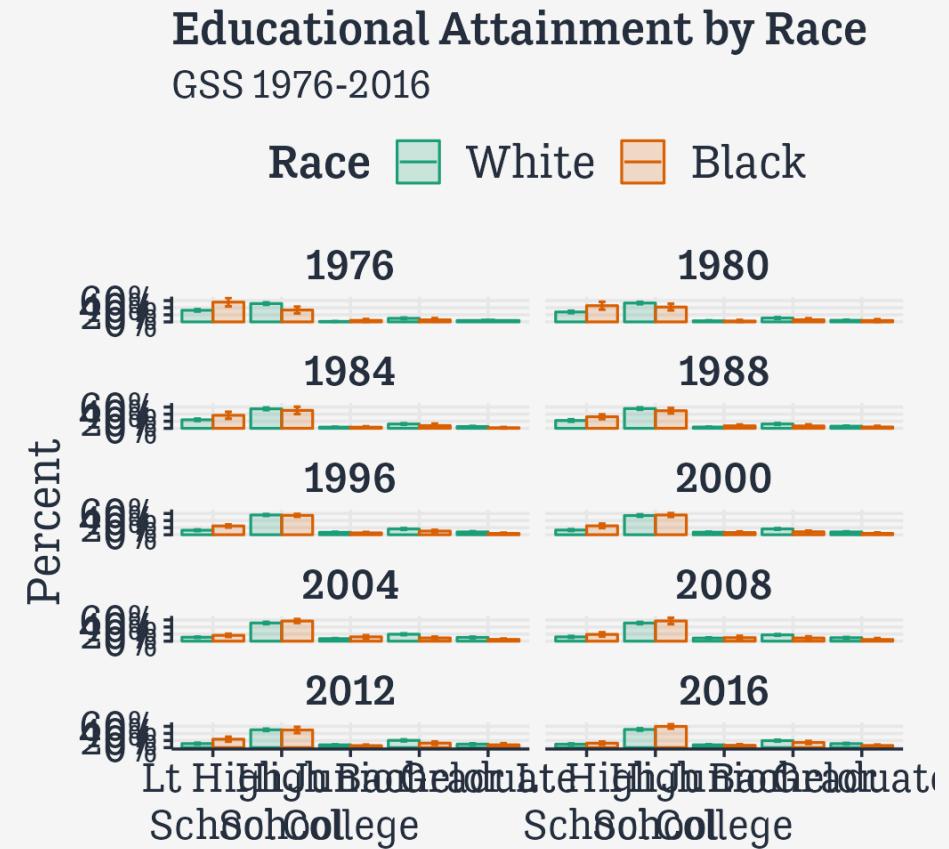
```
p <- out_yrd |>  
  drop_na() |>  
  filter(race %nin% "Other") |>  
  ggplot(mapping = aes(x = degree,  
                        y = prop,  
                        ymin = prop - 2*prop_se,  
                        ymax = prop + 2*prop_se,  
                        fill = race,  
                        color = race,  
                        group = race))  
  
dodge_w <- position_dodge(width = 0.9)
```

Draw the plot

```
p + geom_col(position = dodge_w, alpha = 0.2) +  
  geom_errorbar(position = dodge_w, width = 0.2) +  
  scale_x_discrete(labels = wrap_format(10)) +  
  scale_y_continuous(labels = label_percent()) +  
  scale_color_brewer(type = "qual",  
                     palette = "Dark2") +  
  scale_fill_brewer(type = "qual",  
                     palette = "Dark2") +  
  labs(title = "Educational Attainment by Race",  
       subtitle = "GSS 1976-2016",  
       fill = "Race",  
       color = "Race",  
       x = NULL, y = "Percent") +  
  facet_wrap(~ year, ncol = 2)
```

Draw the plot

```
p + geom_col(position = dodge_w, alpha = 0.2) +  
  geom_errorbar(position = dodge_w, width = 0.2) +  
  scale_x_discrete(labels = wrap_format(10)) +  
  scale_y_continuous(labels = label_percent()) +  
  scale_color_brewer(type = "qual",  
                     palette = "Dark2") +  
  scale_fill_brewer(type = "qual",  
                     palette = "Dark2") +  
  labs(title = "Educational Attainment by Race",  
       subtitle = "GSS 1976-2016",  
       fill = "Race",  
       color = "Race",  
       x = NULL, y = "Percent") +  
  facet_wrap(~ year, ncol = 2)
```



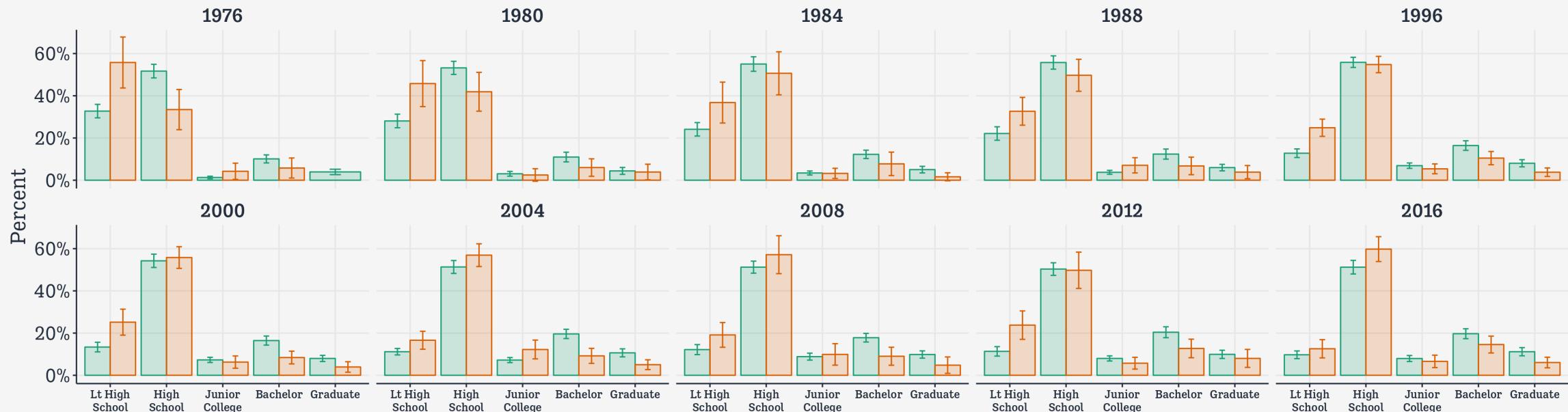
In full (but switch to rows)

```
p_out <- p +
  geom_col(position = dodge_w, alpha = 0.2) +
  geom_errorbar(position = dodge_w, width = 0.2) +
  scale_x_discrete(labels = wrap_format(10)) +
  scale_y_continuous(labels = label_percent()) +
  scale_color_brewer(type = "qual",
                      palette = "Dark2") +
  scale_fill_brewer(type = "qual",
                     palette = "Dark2") +
  labs(title = "Educational Attainment by Race",
       subtitle = "GSS 1976-2016",
       fill = "Race",
       color = "Race",
       x = NULL, y = "Percent") +
  facet_wrap(~ year, nrow = 2) +
  theme(axis.text.x =
        element_text(size = rel(0.6),
                     face = "bold"))
```

Educational Attainment by Race

GSS 1976-2016

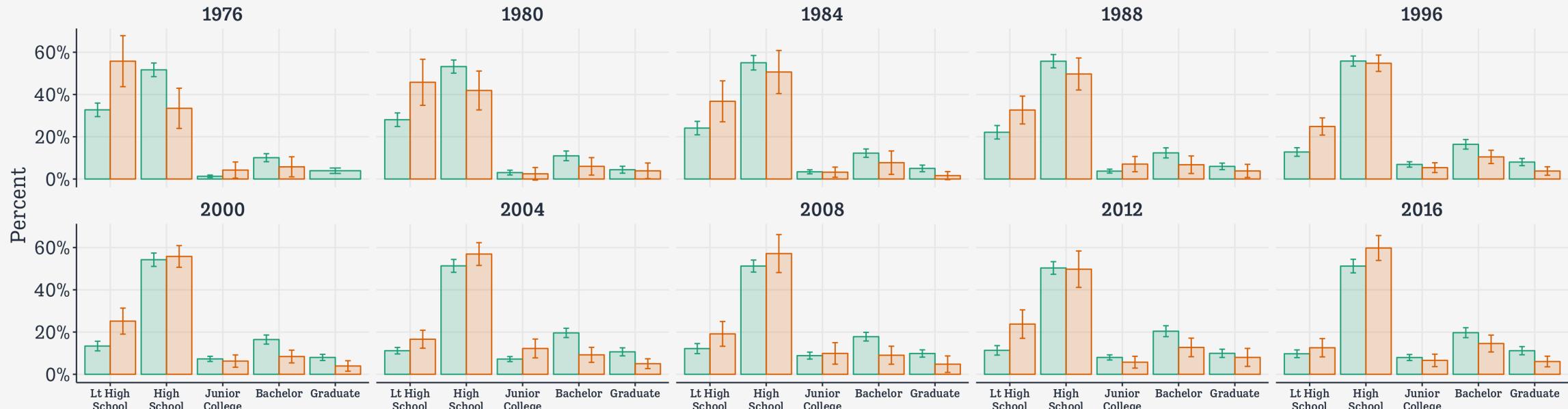
Race █ White █ Black



Educational Attainment by Race

GSS 1976-2016

Race ■ White ■ Black



Is this figure effective? Not really!

Let's try a different view

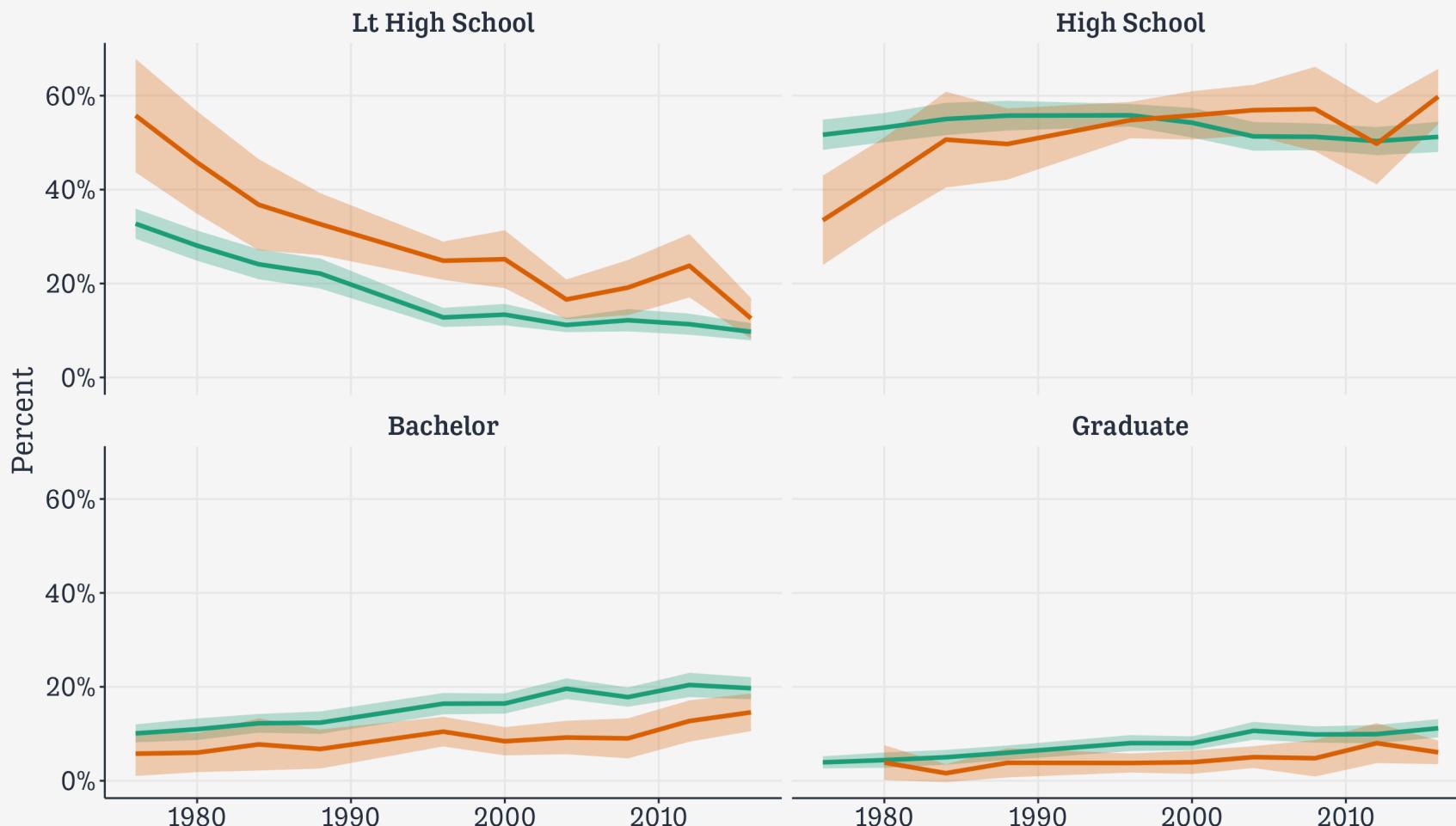
```
p <- out_yrd |>
  drop_na() |>
  filter(race %nin% "Other",
         degree %nin% "Junior College") |>
  ggplot(mapping = aes(x = year, y = prop,
                        ymin = prop - 2*prop_se,
                        ymax = prop + 2*prop_se,
                        fill = race, color = race,
                        group = race))

p_out <- p +
  geom_ribbon(mapping = aes(color = NULL),
               alpha = 0.3) +
  geom_line(size = rel(1.25)) +
  scale_y_continuous(labels = label_percent()) +
  scale_color_brewer(type = "qual", palette = "Dark2") +
  scale_fill_brewer(type = "qual", palette = "Dark2") +
  facet_wrap(~ degree, ncol = 2) +
  labs(title = "Educational Attainment by Race",
       subtitle = "GSS 1976-2016", fill = "Race",
       color = "Race", x = NULL, y = "Percent")
```

Educational Attainment by Race

GSS 1976-2016

Race ■ White ■ Black



Two other good packages: ggeffects

ggeffects 1.1.2.1  News Reference Introductions ▾ Plotting ▾ Practical Examples ▾ Technical Details ▾ 

ggeffects - Estimated Marginal Means and Adjusted Predictions from Regression Models

Lüdecke D (2018). *ggeffects: Tidy Data Frames of Marginal Effects from Regression Models*. Journal of Open Source Software, 3(26), 772. doi: [10.21105/joss.00772](https://doi.org/10.21105/joss.00772)



Why do we need (marginal/conditional) effects or (adjusted) predicted values?

Results of regression models are typically presented as tables that are easy to understand. For more complex models that include interaction or quadratic / spline terms, tables with numbers are less helpful and difficult to interpret. In such cases, *marginal effects* or *adjusted predictions* are far easier to understand. In particular, the visualization of such effects or predictions allows to intuitively get the idea of how predictors and outcome are associated, even for complex models.

Aim of this package

ggeffects is a light-weight package that aims at easily calculating marginal effects and adjusted predictions (or: *estimated marginal means*) at the mean or at representative values of covariates ([see definitions here](#)) from statistical models, i.e. **predictions generated by a model when one holds the non-focal variables constant and varies the focal variable(s)**. This is achieved by three core ideas that describe the philosophy of the function design:

1. Functions are type-safe and always return a data frame with the same, consistent structure;

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Developers

[Daniel Lüdecke](#)

Author, maintainer 

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Dev status

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Two other good packages: interactions

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**Look for packages
that work tidily**

