

# 432 Class 12 Slides

[thomaseLove.github.io/432](https://thomaseLove.github.io/432)

2022-02-17

# Today's Agenda

Fitting logistic regressions using `tidymodels` packages

- Pre-processing activities
- Model building (with multiple fitting engines)
- Measuring model effectiveness
- Creating a model workflow

# Setup

```
library(here); library(knitr)
library(magrittr); library(janitor)
library(naniar); library(equationomatic)

library(tidymodels)
library(tidyverse)

theme_set(theme_bw())
```

# Today's Data (from Class 10)

```
fram_raw <- read_csv(here("data/framingham.csv")) %>%  
  type.convert(as.is = FALSE) %>%  
  clean_names()
```

Again, the variables describe  $n = 4238$  adults examined at baseline, then followed for 10 years to see if they developed incident coronary heart disease. Our outcome (below) has no missing values.

```
fram_raw %>% tabyl(ten_year_chd)
```

ten_year_chd	n	percent
0	3594	0.8480415
1	644	0.1519585

# Data Cleanup

```
fram_new <- fram_raw %>%
  rename(cigs = "cigs_per_day",
         stroke = "prevalent_stroke",
         hrate = "heart_rate",
         sbp = "sys_bp",
         chd10_n = "ten_year_chd") %>%
  mutate(educ = fct_recode(factor(education),
                            "Some HS" = "1",
                            "HS grad" = "2",
                            "Some Coll" = "3",
                            "Coll grad" = "4")) %>%
  mutate(chd10_f = fct_recode(factor(chd10_n),
                                   "chd" = "1", "chd_no" = "0")) %>%
  select(subj_id, chd10_n, chd10_f, age,
         cigs, educ, hrate, sbp, stroke)
```

# Data Descriptions (Main Variables Today)

The variables we'll use today are:

Variable	Description
subj_id	identifying code added by Dr. Love
chd10_n	(numeric) 1 = coronary heart disease in next 10 years
chd10_f	(factor) "chd_yes" or "chd_no" in next ten years
age	in years (range is 32 to 70)
cigs	number of cigarettes smoked per day
educ	4-level factor: educational attainment
hrate	heart rate in beats per minute
sbp	systolic blood pressure in mm Hg
stroke	1 = history of stroke, else 0

# Steps we'll describe today

- ➊ Prepare our (binary) outcome.
- ➋ Split the data into training and testing samples.
- ➌ Build a recipe for our model.
  - Specify roles for outcome and predictors.
  - Deal with missing data in a reasonable way.
  - Complete all necessary pre-processing so we can fit models.
- ➍ Specify a modeling engine for each fit we will create.
  - There are five available engines just for linear regression!
- ➎ Create a workflow for each engine and fit model to the training data.
- ➏ Compare coefficients graphically from two modeling approaches.
- ➐ Assess performance in the models we create in the training data.
- ➑ Compare multiple models based on their performance in test data.

Key Reference: Kuhn and Silge, *Tidy Modeling with R* or TMWR

# Stage 1. Prepare our outcome.

To do logistic regression using `tidymodels`, we'll want our binary outcome to be a factor variable.

```
fram_new %$% str(chd10_f)
```

```
Factor w/ 2 levels "chd_no","chd": 1 1 1 2 1 1 2 1 1 1 ...
```

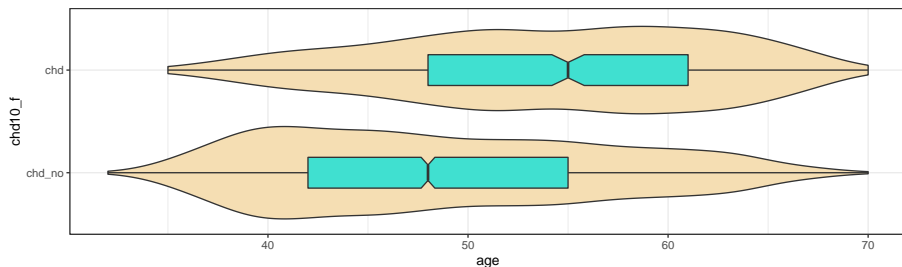
```
fram_new %>% tabyl(chd10_f, chd10_n)
```

chd10_f	0	1
chd_no	3594	0
chd	0	644



# Working with Binary Outcome Models

Does  $\Pr(\text{CHD in next ten years})$  look higher for *older* or *younger* people?



chd10_f	n	mean(age)	sd(age)	median(age)
chd_no	3594	48.77	8.41	48
chd	644	54.15	8.01	55

# So what do we expect in this model?

Pr(CHD in next ten years) looks higher for *older* people?

If we predict  $\log(\text{odds}(\text{CHD in next ten years}))$ , we want to ensure that value will be **rising** with increased age.

So, for the `mage_1` model below, what sign do we expect for the slope of age?

```
mage_1 <- glm(chd10_f ~ age, family = binomial,  
              data = fram_new)
```

# Results for mage\_1

```
tidy(mage_1) %>% kable(digits = 3)
```

term	estimate	std.error	statistic	p.value
(Intercept)	-5.558	0.284	-19.585	0
age	0.075	0.005	14.166	0

```
tidy(mage_1, exponentiate = TRUE) %>% kable(digits = 3)
```

term	estimate	std.error	statistic	p.value
(Intercept)	0.004	0.284	-19.585	0
age	1.077	0.005	14.166	0

# Six ways to specify the outcome for this model

```
x1 <- glm(chd10_f ~ age,  
          family = binomial, data = fram_new)  
x2 <- glm(chd10_n ~ age,  
          family = binomial, data = fram_new)  
x3 <- glm((chd10_n == "1") ~ age,  
          family = binomial, data = fram_new)  
x4 <- glm((chd10_n == "0") ~ age,  
          family = binomial, data = fram_new)  
x5 <- glm((chd10_f == "chd") ~ age,  
          family = binomial, data = fram_new)  
x6 <- glm((chd10_f == "chd_no") ~ age,  
          family = binomial, data = fram_new)
```

What will happen to the age coefficient in these models?

# Age Models x1 and x2

```
x1 <- glm(chd10_f ~ age,  
          family = binomial, data = fram_new)  
extract_eq(x1, use_coefs = TRUE)
```

$$\log \left[ \frac{P(\widehat{\text{chd10\_f}} = \text{chd})}{1 - P(\widehat{\text{chd10\_f}} = \text{chd})} \right] = -5.56 + 0.07(\text{age}) \quad (1)$$

```
x2 <- glm(chd10_n ~ age,  
          family = binomial, data = fram_new)  
extract_eq(x2, use_coefs = TRUE)
```

$$\log \left[ \frac{P(\widehat{\text{chd10\_n}} = 1)}{1 - P(\widehat{\text{chd10\_n}} = 1)} \right] = -5.56 + 0.07(\text{age}) \quad (2)$$

# Age Models x3 and x4

```
x3 <- glm((chd10_n == "1") ~ age,  
          family = binomial, data = fram_new)  
extract_eq(x3, use_coefs = TRUE)
```

$$\log \left[ \frac{P(\widehat{\text{chd10\_n}} = 1)}{1 - P(\widehat{\text{chd10\_n}} = 1)} \right] = -5.56 + 0.07(\text{age}) \quad (3)$$

```
x4 <- glm((chd10_n == "0") ~ age,  
          family = binomial, data = fram_new)  
extract_eq(x4, use_coefs = TRUE)
```

$$\log \left[ \frac{P(\widehat{\text{chd10\_n}} = 0)}{1 - P(\widehat{\text{chd10\_n}} = 0)} \right] = 5.56 - 0.07(\text{age}) \quad (4)$$

# Age Models x5 and x6

```
x5 <- glm((chd10_f == "chd") ~ age,  
          family = binomial, data = fram_new)  
extract_eq(x5, use_coefs = TRUE)
```

$$\log \left[ \frac{P(\widehat{\text{chd10\_f}} = \text{chd})}{1 - P(\widehat{\text{chd10\_f}} = \text{chd})} \right] = -5.56 + 0.07(\text{age}) \quad (5)$$

```
x6 <- glm((chd10_f == "chd_no") ~ age,  
          family = binomial, data = fram_new)  
extract_eq(x6, use_coefs = TRUE)
```

$$\log \left[ \frac{P(\widehat{\text{chd10\_f}} = \text{chd\_no})}{1 - P(\widehat{\text{chd10\_f}} = \text{chd\_no})} \right] = 5.56 - 0.07(\text{age}) \quad (6)$$

## Stage 2. Split the data into training/test samples.

```
set.seed(20210311)

fram_splits <-
  initial_split(fram_new, prop = 3/4, strata = chd10_f)

fram_train <- training(fram_splits)
fram_test  <- testing(fram_splits)
```



# Did the stratification work?

```
fram_train %>% tabyl(chd10_f)
```

chd10_f	n	percent
chd_no	2695	0.8480176
chd	483	0.1519824

```
fram_test %>% tabyl(chd10_f)
```

chd10_f	n	percent
chd_no	899	0.8481132
chd	161	0.1518868

## Stage 3. Build a recipe for our model.

```
fram_rec <-  
  recipe(chd10_f ~ age + cigs + educ + hrate +  
          sbp + stroke, data = fram_new) %>%  
  step_impute_bag(all_predictors()) %>%  
  step_dummy(all_nominal(), -all_outcomes()) %>%  
  step_normalize(all_predictors())
```

- 1 Specify the roles for the outcome and the predictors.
- 2 Use bagged trees to impute missing values in predictors.
- 3 Form dummy variables to represent all categorical variables.
  - Forgetting the `-all_outcomes()` wasted a half hour of my life, so learn from my mistake.
- 4 Normalize (subtract mean and divide by SD) all quantitative predictors.

## Stage 4. Specify engines for our fit(s).

```
fram_glm_model <-  
  logistic_reg() %>%  
  set_engine("glm")  
  
prior_dist <- rstanarm::normal(0, 3)  
  
fram_stan_model <- logistic_reg() %>%  
  set_engine("stan",  
    prior_intercept = prior_dist,  
    prior = prior_dist)
```

## Stage 5. Create a workflow and fit model(s).

```
fram_glm_wf <- workflow() %>%  
  add_model(fram_glm_model) %>%  
  add_recipe(fram_rec)  
  
fram_stan_wf <- workflow() %>%  
  add_model(fram_stan_model) %>%  
  add_recipe(fram_rec)
```

Ready to fit the models?

# Fit the glm and stan models

```
fit_A <- fit(fram_glm_wf, fram_train)

set.seed(432)

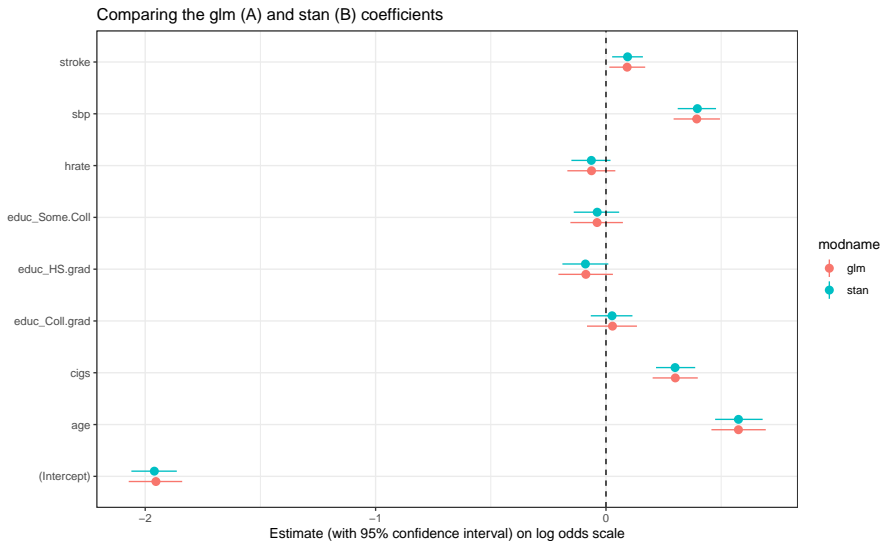
fit_B <- fit(fram_stan_wf, fram_train)
```

## Produce tidied coefficients (log odds scale)

```
A_tidy <- tidy(fit_A, conf.int = T) %>%  
  mutate(modname = "glm")  
  
B_tidy <- broom.mixed::tidy(fit_B, conf.int = T) %>%  
  mutate(modname = "stan")  
  
coefs_comp <- bind_rows(A_tidy, B_tidy)
```

That's set us up for some plotting.

# Stage 6. Compare coefficients of the fits.



# Can we compare coefficients as odds ratios?

```
A_odds <- A_tidy %>%  
  mutate(odds = exp(estimate),  
         odds_low = exp(conf.low),  
         odds_high = exp(conf.high)) %>%  
  filter(term != "(Intercept)") %>%  
  select(modname, term, odds, odds_low, odds_high)  
  
head(A_odds, 2)
```

```
# A tibble: 2 x 5  
  modname term    odds odds_low odds_high  
  <chr>   <chr> <dbl>    <dbl>    <dbl>  
1 glm    age    1.78     1.58     2.00  
2 glm    cigs    1.35     1.22     1.49
```

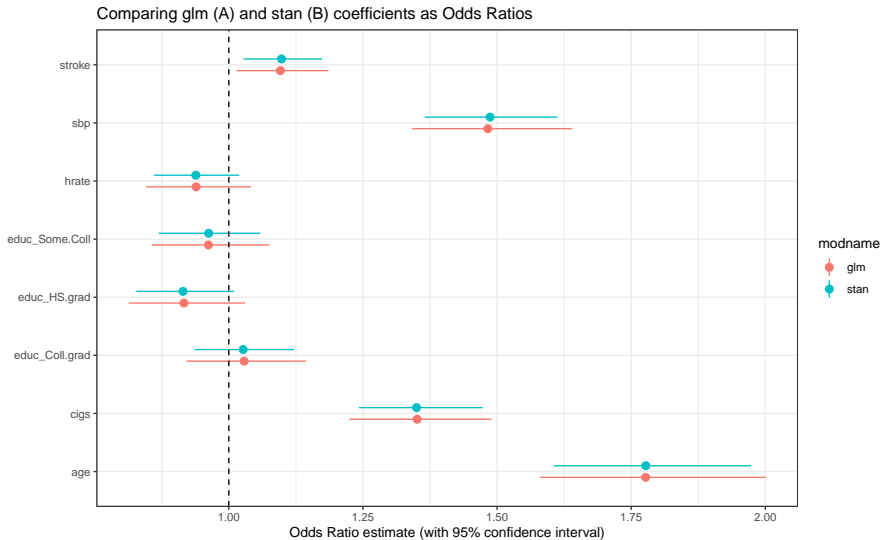
Then repeat to create B\_odds (see next slide)



# Creating B\_odds

```
B_odds <- B_tidy %>%  
  mutate(odds = exp(estimate),  
         odds_low = exp(conf.low),  
         odds_high = exp(conf.high)) %>%  
  filter(term != "(Intercept)") %>%  
  select(modname, term, odds, odds_low, odds_high)
```

# Combined Results Plotted on Odds Ratio scale



## Stage 7. Assess training sample performance.

- 1 We'll make predictions for the training sample using each model, and use them to find the C statistic and plot the ROC curve.
- 2 We'll show some other summaries of performance in the training sample.

# Make Predictions with fit\_A

We'll start by using the glm model fit\_A to make predictions.

```
glm_probs <-  
  predict(fit_A, fram_train, type = "prob") %>%  
  bind_cols(fram_train %>% select(chd10_f))  
  
head(glm_probs, 4)
```

```
# A tibble: 4 x 3  
  .pred_chd_no .pred_chd chd10_f  
    <dbl>      <dbl> <fct>  
1      0.739      0.261 chd  
2      0.898      0.102 chd  
3      0.651      0.349 chd  
4      0.778      0.222 chd
```

## Obtain C statistic for fit\_A

Next, we'll use `roc_auc` from `yardstick`. This assumes that the first level of `chd10_f` is the thing we're trying to predict. Is that true in our case?

```
fram_train %>% tabyl(chd10_f)
```

```
chd10_f    n    percent
chd_no 2695 0.8480176
chd    483 0.1519824
```

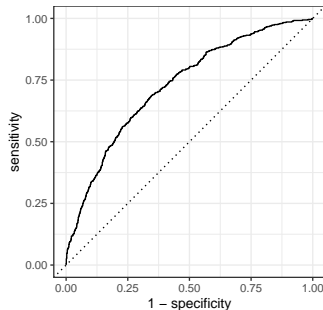
No. We want to predict the second level: `chd`. So we need to switch the `event_level` to “second”, like this.

```
glm_probs %>% roc_auc(chd10_f, .pred_chd,
                      event_level = "second") %>%
  kable(dig = 5)
```

.metric	.estimator	.estimate
roc_auc	binary	0.72722

# Can we plot the ROC curve for fit\_A?

```
glm_roc <- glm_probs %>%  
  roc_curve(chd10_f, .pred_chd, event_level = "second")  
autoplot(glm_roc)
```



- Again, our C statistic for the glm fit is 0.717.

# Make Predictions with fit\_B

We'll use the stan model fit\_B to make predictions.

```
stan_probs <-  
  predict(fit_B, fram_train, type = "prob") %>%  
  bind_cols(fram_train %>% select(chd10_f))
```

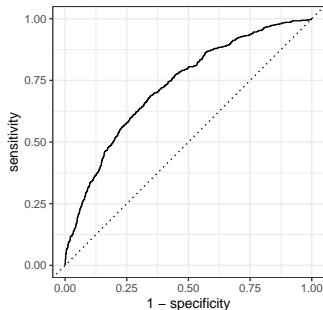
Now, we'll obtain the C statistic for fit\_B

```
stan_probs %>%  
  roc_auc(chd10_f, .pred_chd,  
          event_level = "second") %>%  
  kable(dig = 5)
```

.metric	.estimator	.estimate
roc_auc	binary	0.72717

# Plotting the ROC curve for fit\_B?

```
stan_roc <- stan_probs %>%  
  roc_curve(chd10_f, .pred_chd, event_level = "second")  
autoplot(stan_roc)
```



- Again, our C statistic for the stan fit is also 0.717.



## Other available summaries from `yardstick`

For a logistic regression where we're willing to specify a decision rule, we can consider:

- `Conf_mat` which produces a confusion matrix if we specify a decision rule.
  - There is a way to tidy a confusion matrix, summarize it with `summary()` and autoplot it with either a mosaic or a heatmap.
- `accuracy` = proportion of the data that are predicted correctly
- `kap` is very similar to `accuracy` but is normalized by the accuracy that would be expected by chance alone and is most useful when one or more classes dominate the distribution - attributed to Cohen (1960)
- `sens` = sensitivity and `spec` specificity
- `ppv` positive predictive value and `npv` negative predictive value

# Establishing a decision rule for the glm fit

Let's use `.pred_chd > 0.2` for now to indicate a prediction of chd.

```
glm_probs <-  
  predict(fit_A, fram_train, type = "prob") %>%  
  bind_cols(fram_train %>% select(chd10_f)) %>%  
  mutate(chd10_pre =  
    ifelse(.pred_chd > 0.2, "chd", "chd_no")) %>%  
  mutate(chd10_pre = fct_relevel(factor(chd10_pre),  
    "chd_no"))
```

# What can we run now?

```
conf_mat(glm_probs, truth = chd10_f, estimate = chd10_pre)
```

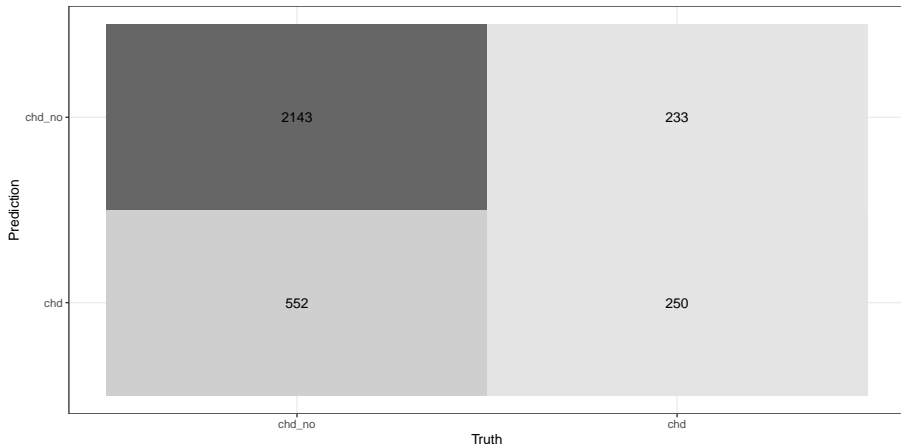
	Truth	
Prediction	chd_no	chd
chd_no	2143	233
chd	552	250

```
metrics(glm_probs, truth = chd10_f, estimate = chd10_pre)
```

```
# A tibble: 2 x 3
  .metric .estimator .estimate
  <chr>    <chr>         <dbl>
1 accuracy binary         0.753
2 kap      binary         0.246
```

# Plot a confusion matrix for the glm fit?

```
conf_mat(glm_probs,  
          truth = chd10_f, estimate = chd10_pre) %>%  
          autoplot(type = "heatmap")
```



# More Confusion Matrix Summaries?

Other available metrics include:

- sensitivity, specificity, positive predictive value, negative predictive value, and the statistics below.

```
conf_mat(glm_probs, truth = chd10_f, estimate = chd10_pre) %>%  
  summary() %>% slice(7:13)
```

```
# A tibble: 7 x 3
```

	.metric <chr>	.estimator <chr>	.estimate <dbl>
1	mcc	binary	0.259
2	j_index	binary	0.313
3	bal_accuracy	binary	0.656
4	detection_prevalence	binary	0.748
5	precision	binary	0.902
6	recall	binary	0.795
7	f_meas	binary	0.845

# Establishing a decision rule for the stan fit

Let's also use `.pred_chd > 0.2` to indicate a prediction of chd.

```
stan_probs <-  
  predict(fit_B, fram_train, type = "prob") %>%  
  bind_cols(fram_train %>% select(chd10_f)) %>%  
  mutate(chd10_pre =  
    ifelse(.pred_chd > 0.2, "chd", "chd_no")) %>%  
  mutate(chd10_pre = fct_relevel(factor(chd10_pre),  
    "chd_no"))
```

# Confusion Matrix and Basic Metrics

```
conf_mat(stan_probs, truth = chd10_f, estimate = chd10_pre)
```

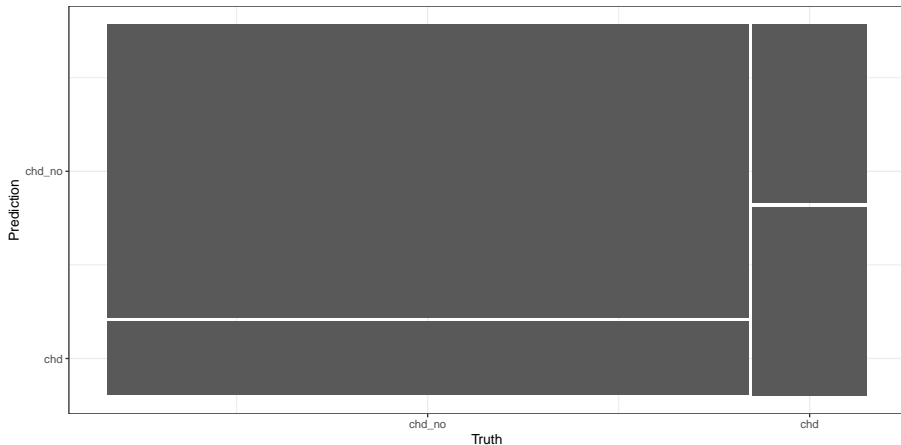
	Truth	
Prediction	chd_no	chd
chd_no	2154	235
chd	541	248

```
metrics(stan_probs, truth = chd10_f, estimate = chd10_pre)
```

```
# A tibble: 2 x 3
  .metric .estimator .estimate
  <chr>    <chr>         <dbl>
1 accuracy binary        0.756
2 kap      binary        0.248
```

# Plot a confusion matrix?

```
conf_mat(stan_probs,  
         truth = chd10_f, estimate = chd10_pre) %>%  
autoplot(type = "mosaic")
```





# More Confusion Matrix Summaries?

```
conf_mat(stan_probs,  
          truth = chd10_f, estimate = chd10_pre) %>%  
  summary()
```

# A tibble: 13 x 3

	.metric <chr>	.estimator <chr>	.estimate <dbl>
1	accuracy	binary	0.756
2	kap	binary	0.248
3	sens	binary	0.799
4	spec	binary	0.513
5	ppv	binary	0.902
6	npv	binary	0.314
7	mcc	binary	0.260
8	j_index	binary	0.313
9	bal_accuracy	binary	0.656
10	detection_prevalence	binary	0.752

## Stage 8. Assess test sample performance.

```
glm_test <-  
  predict(fit_A, fram_test, type = "prob") %>%  
  bind_cols(fram_test %>% select(chd10_f))  
  
stan_test <-  
  predict(fit_B, fram_test, type = "prob") %>%  
  bind_cols(fram_test %>% select(chd10_f))
```

# Test Sample C statistic comparison?

```
glm_test %>% roc_auc(chd10_f, .pred_chd,  
                    event_level = "second") %>%  
  kable(dig = 4)
```

.metric	.estimator	.estimate
roc_auc	binary	0.6947

```
stan_test %>% roc_auc(chd10_f, .pred_chd,  
                    event_level = "second") %>%  
  kable(dig = 4)
```

.metric	.estimator	.estimate
roc_auc	binary	0.6946

# Next Time

- Regression on Count Outcomes
- Quiz 1 will be made available today at 5 PM.