Research Analysis

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CS 376

Last time

- What is a statistical test?
- Chi-square
- t-test
- Paired t-test

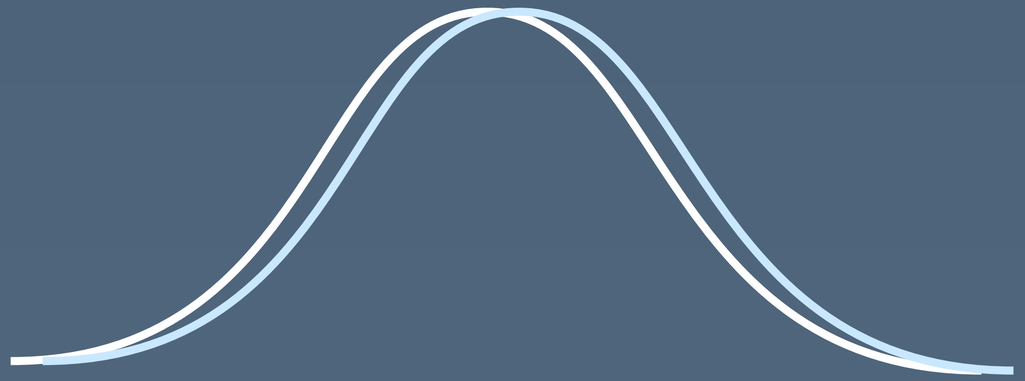
Today

- ANOVA
- Posthoc tests
- Two-way ANOVA
- Repeated measures ANOVA

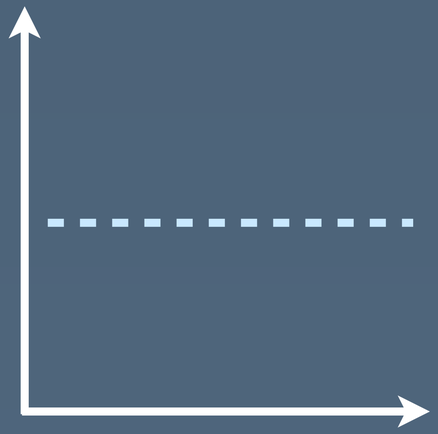
Recall: hypothesis testing

Anatomy of a statistical test

- If your change had no effect, what would the world look like?



No difference in means

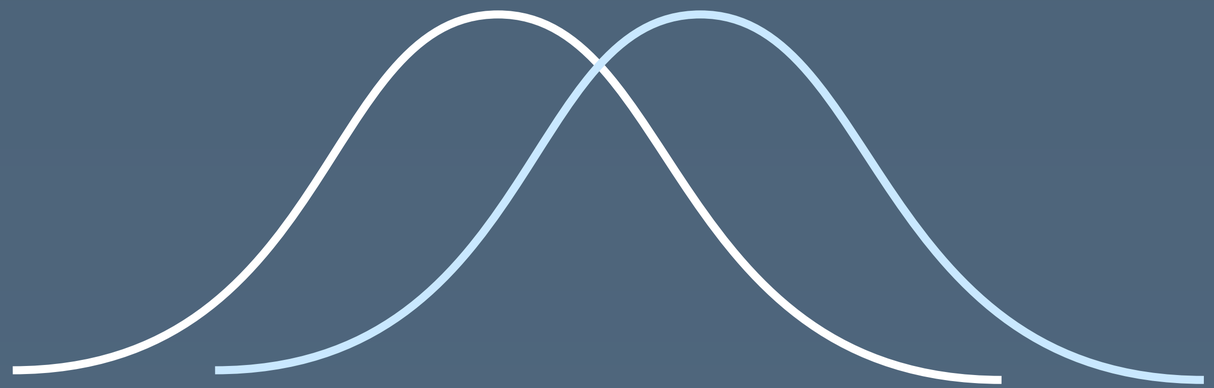


No slope in relationship

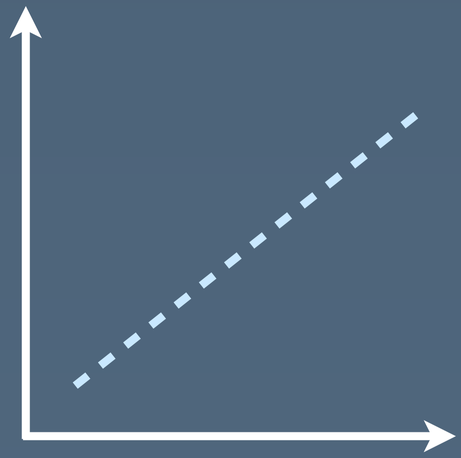
- This is known as the **null hypothesis**

Anatomy of a statistical test

- Given the difference you observed, how likely is it to have occurred by chance?



Probability of seeing a mean difference at least this large, by chance, is 0.012



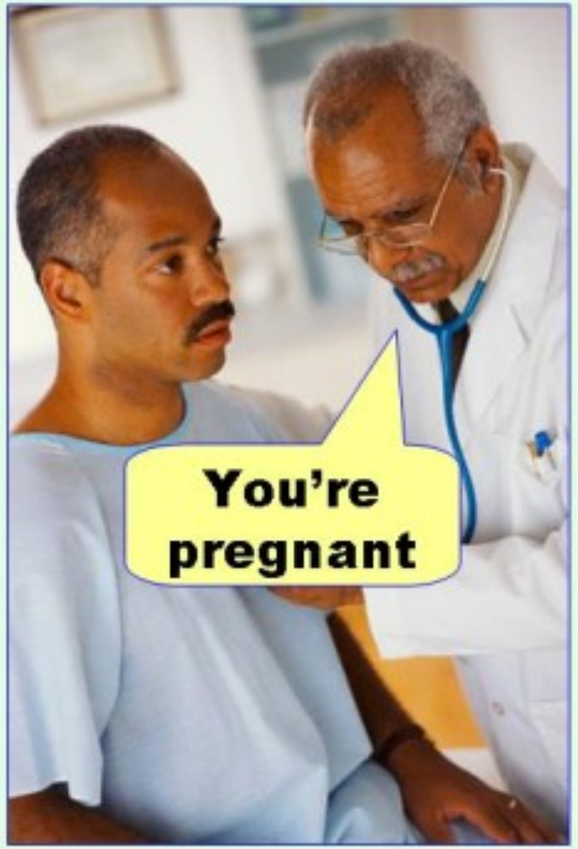
Probability of seeing a slope at least this large, by chance, is 0.012

Errors

Difference detected?	Difference exists? Y	Difference exists? N
Y	True positive	Type 1 error publish false findings
N	Type 2 error get more data?	True negative

Errors

Type I error
(false positive)



Type II error
(false negative)

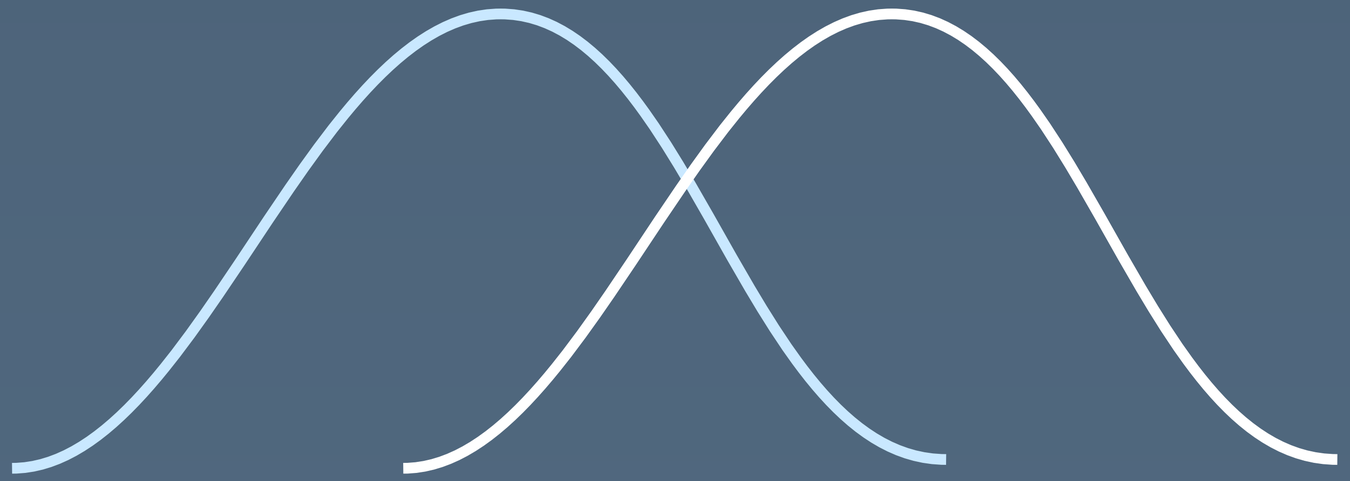
p-value

- The probability of seeing the observed difference by chance
  - In other words, P(Type I error)
- Typically accepted levels: 0.05, 0.01, 0.001

ANOVA

t-test: compare two means

- “Do people fix more bugs with our IDE bug suggestion callouts?”

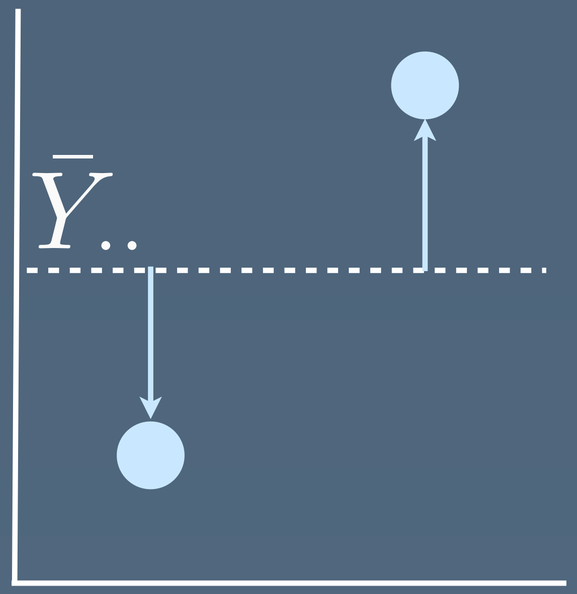


ANOVA: compare N means

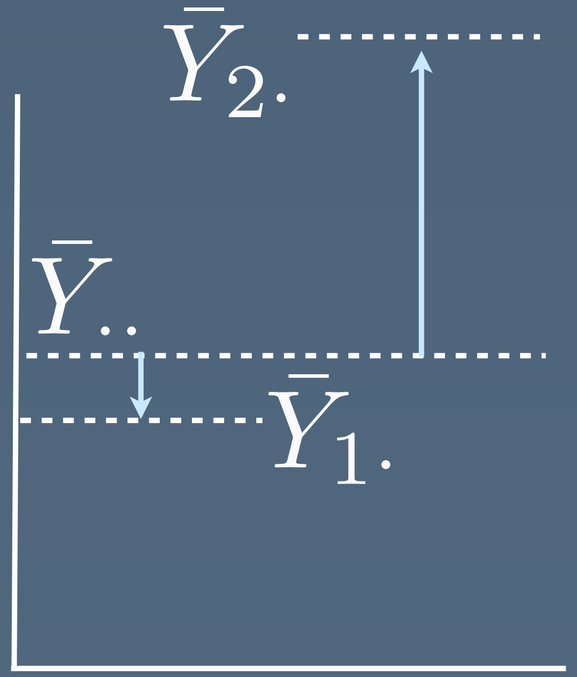
- “Do people fix more bugs with our IDE bug suggestion callouts, with warnings, or with nothing?”

Rough intuition for ANOVA test

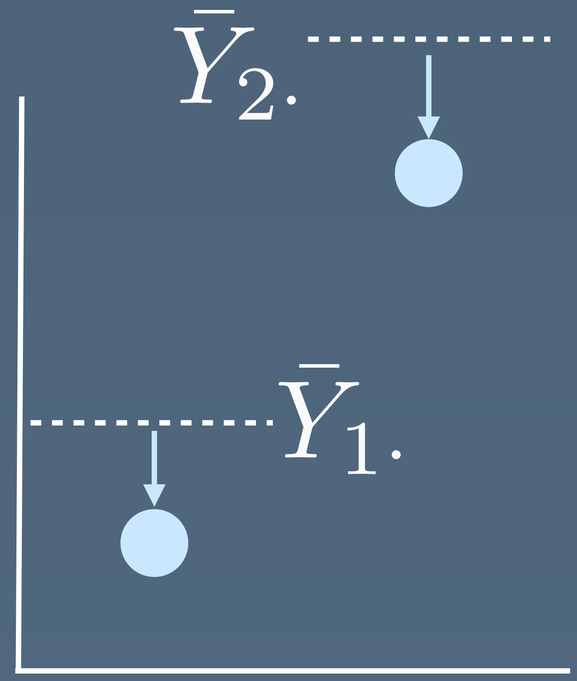
How much of the total variation can be accounted for by looking at the means of each condition?



total deviation
from grand mean



deviation of factor mean
from grand mean



deviation of response
from factor mean

ANalysis Of VAriance (ANOVA)

- Degrees of freedom: how many values can vary? (Using n and r)

  Degrees of freedom in individual data points: n - 1
  Degrees of freedom in factor level averages: r - 1
  Combined: n - r

Finally: run the test!

- How large is the value we constructed from the F distribution?
- Test if

$$F^* > F(1-\alpha; r-1, n-r)$$

```
> aov <- aov(value ~ group, data)
> summary(aov)
             Df Sum Sq Mean Sq F value  Pr(>F)
group         2  22.75   11.38    12.1 0.00032 ***
Residuals    21  19.75    0.94
```

factor

error ("what's left")

3 factor levels
24 observations

hopefully
top >> bottom

F(2,21)

p < .001

Reporting an ANOVA

- “A one-way ANOVA revealed a significant difference in the effect of news feed source on number of likes ($F(2, 21)=12.1$, $p<.001$).”

```
> aov <- aov(value ~ group, data)
> summary(aov)
             Df Sum Sq Mean Sq F value  Pr(>F)
group         2  22.75   11.38    12.1 0.00032 ***
Residuals    21  19.75    0.94
```

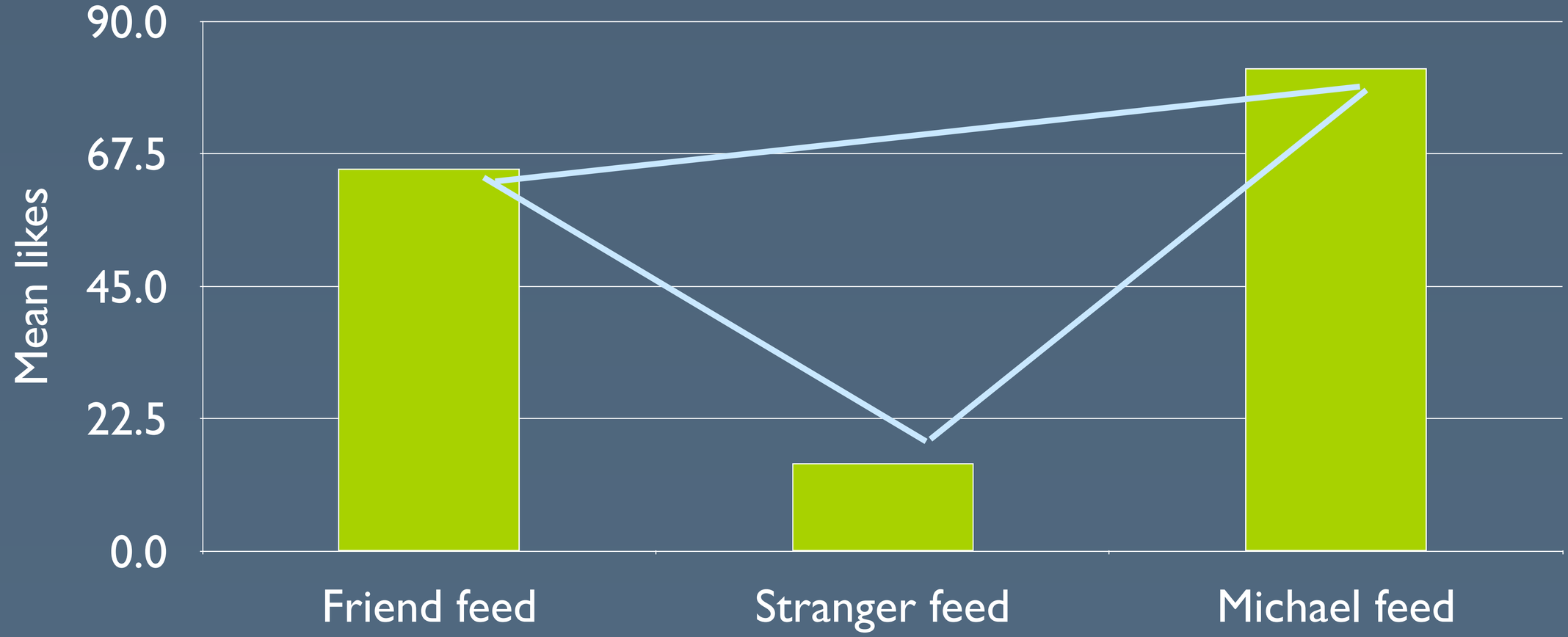
Posthoc tests

ANOVA! Are we done no

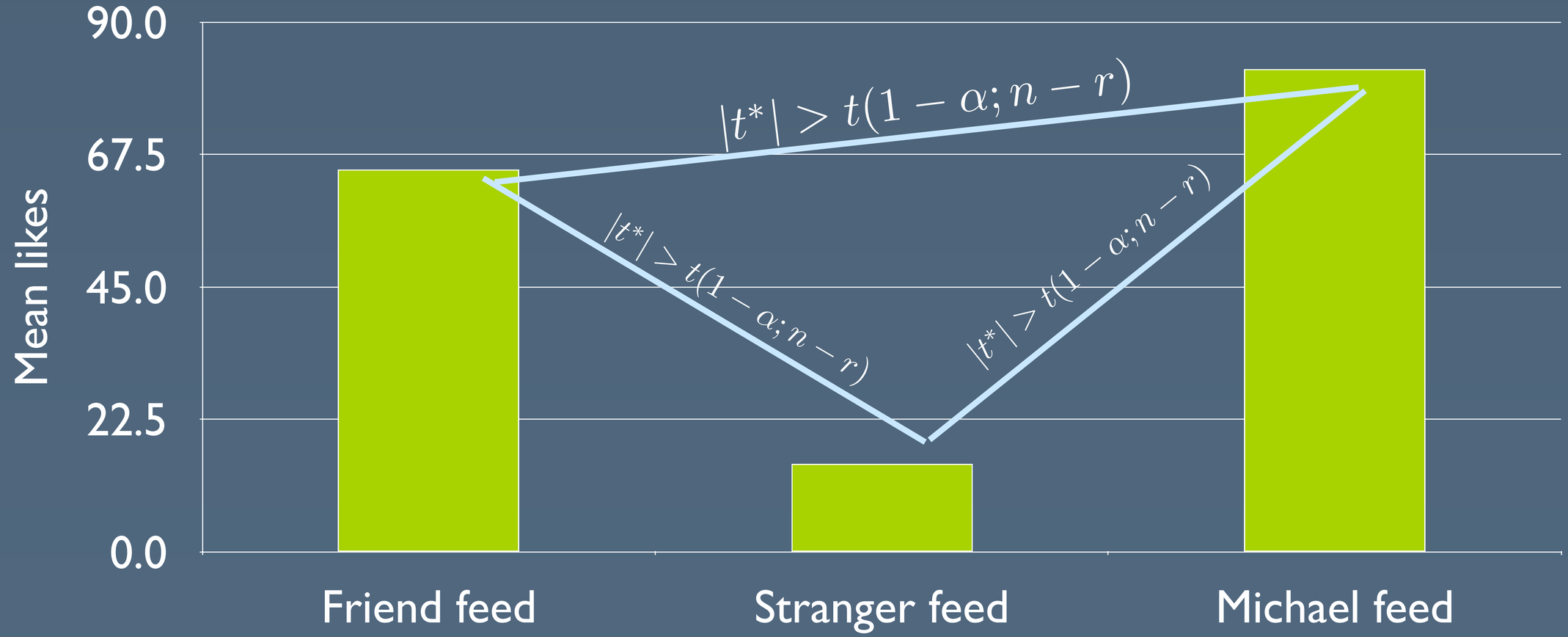
- Significant means "One of the μ_i are different."
- That's not very helpful: "There is some difference between populating the Facebook news feed with friends vs. strangers vs. only Michael's status updates"

Estimating pairwise differences

- Which pairs of factor levels are different from each other?



Roughly: we do pairwise t-tests



But…familywise error!

- $\alpha = .05$ implies a .95 probability of being correct
- If we do m tests, the actual probability of being correct is now:

$$\alpha^m = .95 \cdot .95 \cdot .95 \cdot \ldots$$

$$< .95$$

Bonferroni correction

- Avoid familywise error by adjusting α to be more conservative
- Divide α by the number of comparisons you make
  - 4 tests at $\alpha = .05$ implies using $\alpha = .0125$
- Conservative but accurate method of compensating for multiple tests

Bonferroni correction

```
> pairwise.t.test(value, group, p.adj='bonferroni')

   Pairwise comparisons using t tests with pooled SD

data:  value and group

  A       B
B 0.02971 -
C 0.00023 0.15530

P value adjustment method: bonferroni
```

Tukey test

- Less conservative than Bonferroni
- Compares all pairs of factor level means

```
> TukeyHSD(aov)
  Tukey multiple comparisons of means
    95% family-wise confidence level

Fit: aov(formula = value ~ group, data = data)

$group
     diff         lwr      upr     p adj
B-A 1.375  0.1527988 2.597201 0.0257122
C-A 2.375  1.1527988 3.597201 0.0002167
C-B 1.000 -0.2222012 2.222201 0.1222307
```

Reporting

- “Posthoc tests using Bonferroni correction revealed that friend feed and Michael feed were significantly better than a stranger feed ($p<.05$), but the two were not significantly different from each other ($p=.32$).”

Two-way ANOVA

Crossed study designs

- Suppose you wanted to measure the impact of two factors on total likes on Facebook:
  - Strong ties vs. weak ties in your news feed
  - Presence of a reminder of the last time you liked each friend's content (e.g., "You last liked a story from John Hennessy in January")
- This is a 2 x 2 study: two factor levels for each factor {tie strength, reminder}

Interaction effects

- Sometimes the basic model doesn't capture subtle interactions between factors
  - Data: People who see strong ties and have a reminder are especially active
  - Result: Grand mean 8, strong tie mean 11, reminder mean 7, but mean in this cell is 20

Two-factor ANOVA test

- Test for main effects and interaction

```
> anova(lm(time ~ device * technique))
Analysis of Variance Table

Response: time
                 Df Sum Sq Mean Sq  F value    Pr(>F)
device            1  981.0  981.02  94.5291 2.581e-12 ***
technique         2 3423.8 1711.90 164.9547 < 2.2e-16 ***
device:technique  2   75.3   37.65   3.6275   0.03522 *
Residuals        42  435.9   10.38
```

factor or interaction SS MS F p

- Main effects are significant, but interaction effect is also significant

Significant interaction?

- Significant interactions mean that you can't just report the main effects — the story is more complicated
- Inspect to figure it out:

	Pen	Touch
Technique A	15.3	21.1
Technique B	23.9	33.1
Technique C	32.9	44.9

The slower techniques (B, C) harm Touch more than Pen

Repeated measures ANOVA

Within-subjects studies

- Control for individual variation using the mean response for each participant
- Before: we found the mean effect of each treatment
- Now: we find the mean effect of each participant

Repeated measures in R

repeated measures error term

effect of subtracting out the participant means

remaining main effects

```
> aov <- aov(value ~ factor(group) +
+ Error(factor(participant)/factor(group)), repeatframe)
> summary(aov)

Error: factor(participant)
          Df Sum Sq Mean Sq F value Pr(>F)
Residuals  7  5.167  0.7381

Error: factor(participant):factor(group)
              Df Sum Sq Mean Sq F value  Pr(>F)
factor(group)  2  22.75  11.375   10.92 0.00139 **
Residuals     14  14.58   1.042
```

All together now

Always follow every step!

1. Visualize the data
2. Compute descriptive statistics (e.g., mean)
3. Remove outliers >2 standard deviations from the mean
4. Check for heteroskedasticity and non-normal data
   - Try log, square root, or reciprocal transform
   - ANOVA is robust against non-normal data, but not against heteroskedasticity
5. Run statistical test
6. Run any posthoc tests if necessary