Hypothesis Testing

February 28, 2019

Data Science CSCI 1951A

Brown University

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HTAs: Wennie Zhang, Maulik Dang, Gurnaaz Kaur

Announcements

- Nothing…
- Do *you* have any announcements?

Follow up from last time

- That expected value question…
  - Was going for: $0 = 0.1(100 - \text{cost}) - 0.9(\text{cost})$
- Question: Continuous pdfs! Does it make sense to talk about these (as opposed to just the cdf)?
  - Yes!

Today

- Hypothesis Testing and Pvalues
- Law of Large Numbers/Central Limit Theorem
- Z-tests and T-tests
- Chi-Squared Tests

I will not talk about biased coins. I will not talk about biased coins. I will not talk about biased coins. I will not talk about biased coins. I will not talk about biased coins. I will not talk about biased coins. I will not talk about biased coins. I will not talk about biased coins. I will not talk about biased coins. I will not talk about biased coins. I will not talk about biased coins.

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"I swear literally like 80% of the answers are just (b)"

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Probability of this?

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The bigger picture

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- Start with real world phenomenon/observations

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The bigger picture

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Now

- Chose parameters of the model based on theories, do analysis to see if its a good fit

AND/OR

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The bigger picture

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- Chose parameters of the model based on theories, do analysis to see if its a good fit

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Later

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$$\langle \Omega, F, P \rangle$$

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Ω = {b, not b}

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{b, not b}

p(B) = 0.8
p(not B) = 0.2

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Assumption under investigation

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(almost like a…biased coin…? no wait what who said that ew stop.)

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Idiot!
There is literally only like a 0.000105% chance you are right!

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???

Clicker Question!

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"I swear literally like 80% of the answers are just (b)"

What is the probability of this event?

b	b	b	d
b	a	b	b
b	b	b	b

a) 1.0
b) 0.4
c) 0.04
d) 0.004

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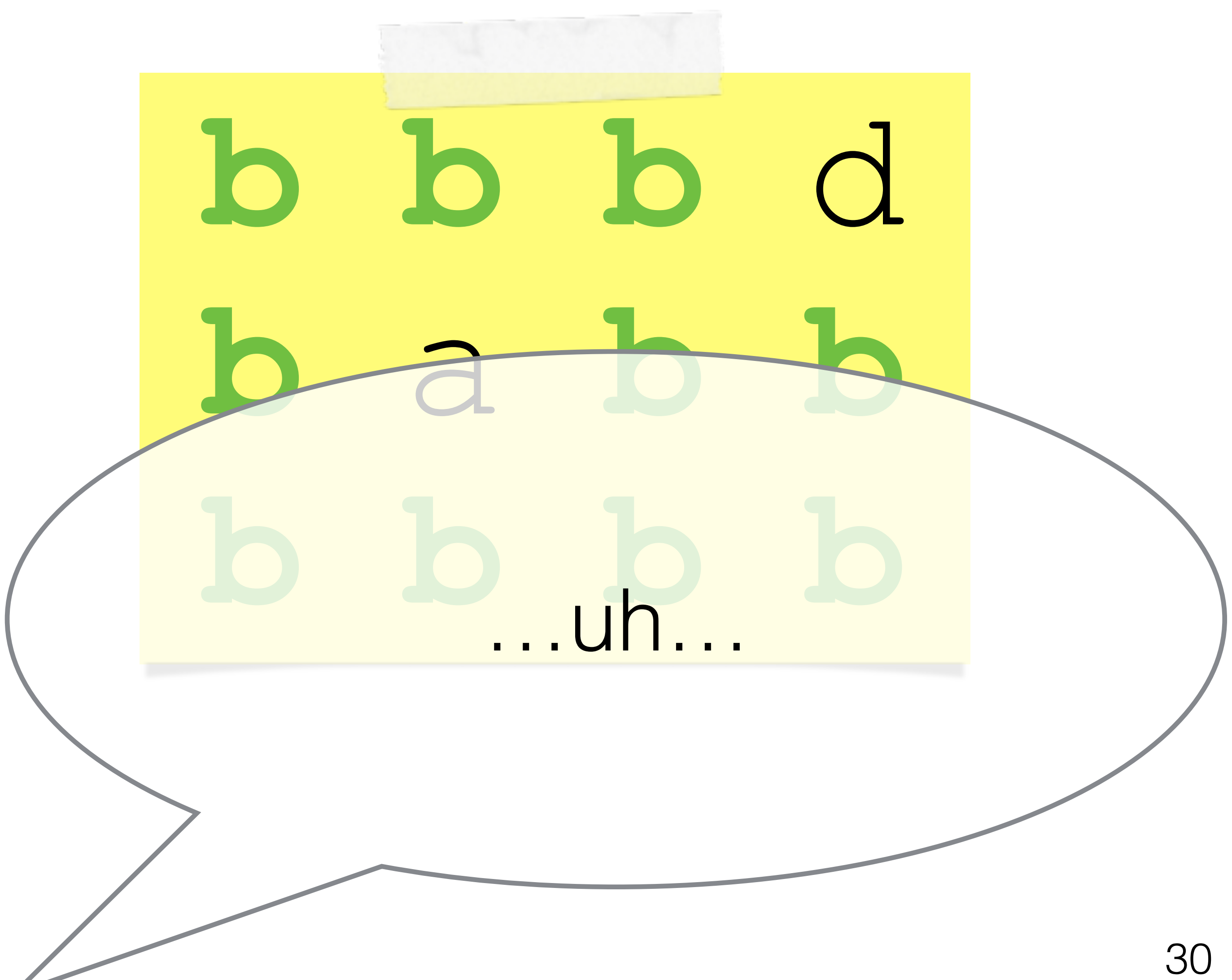

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~~Probability of this?~~

Probability of anything as surprising as this

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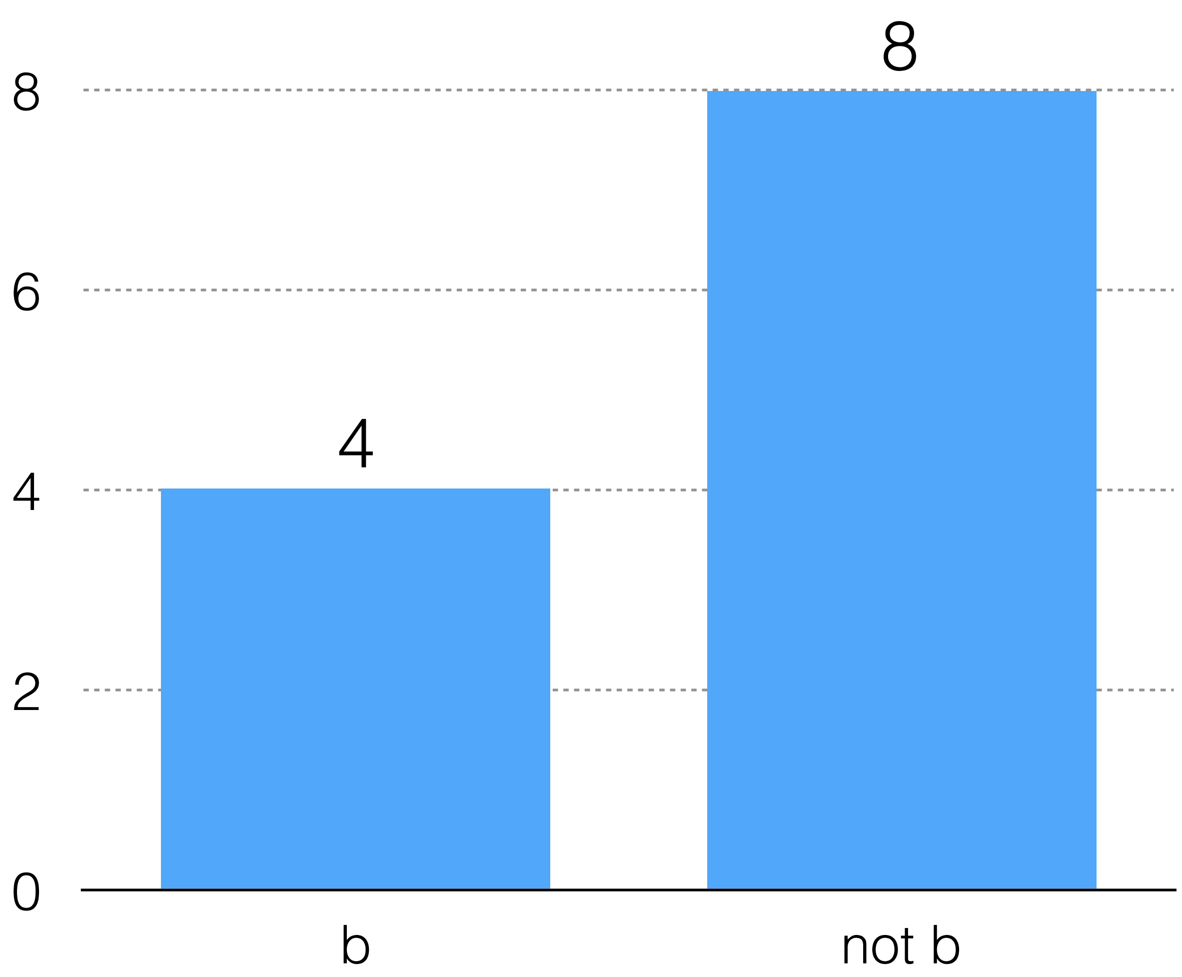

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X = number of (b)s

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$$f(k) = \binom{n}{k} p^k (1-p)^{n-k}$$

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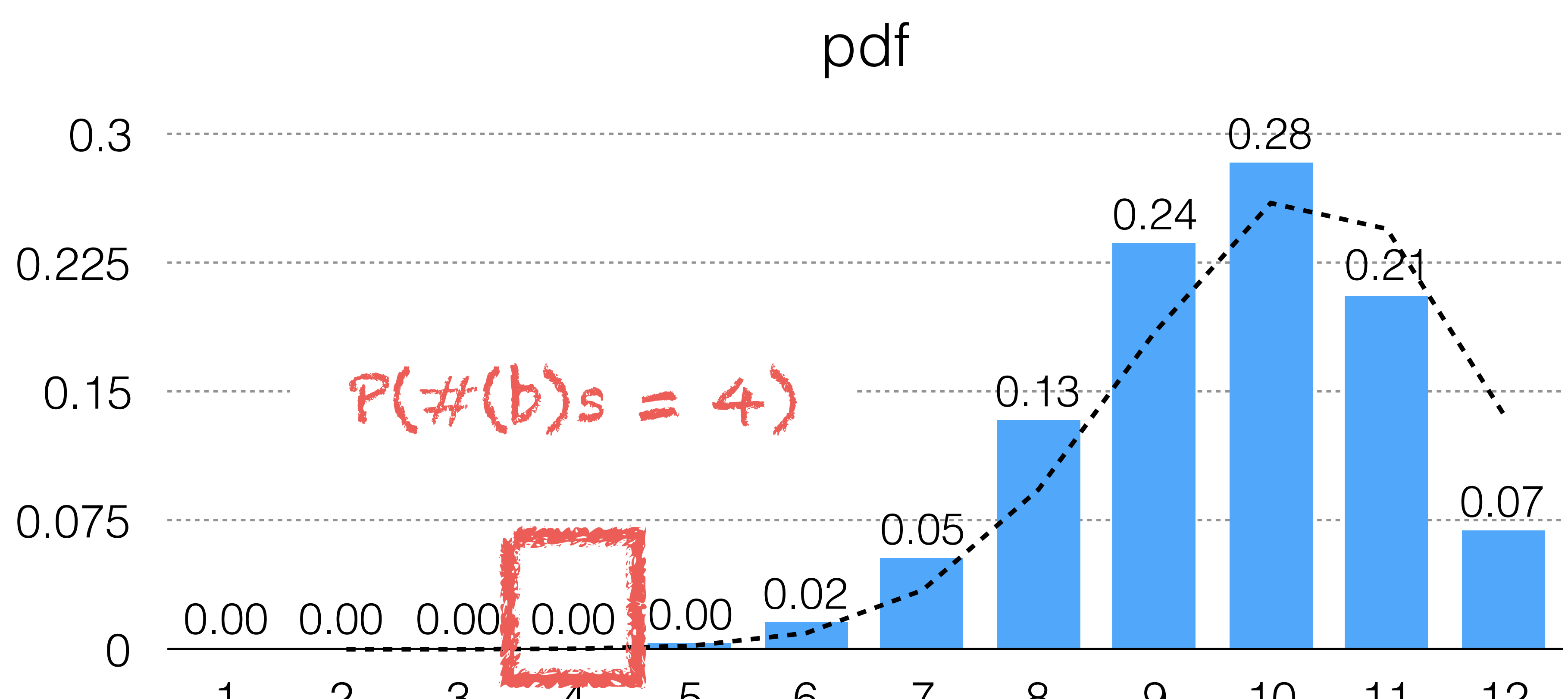

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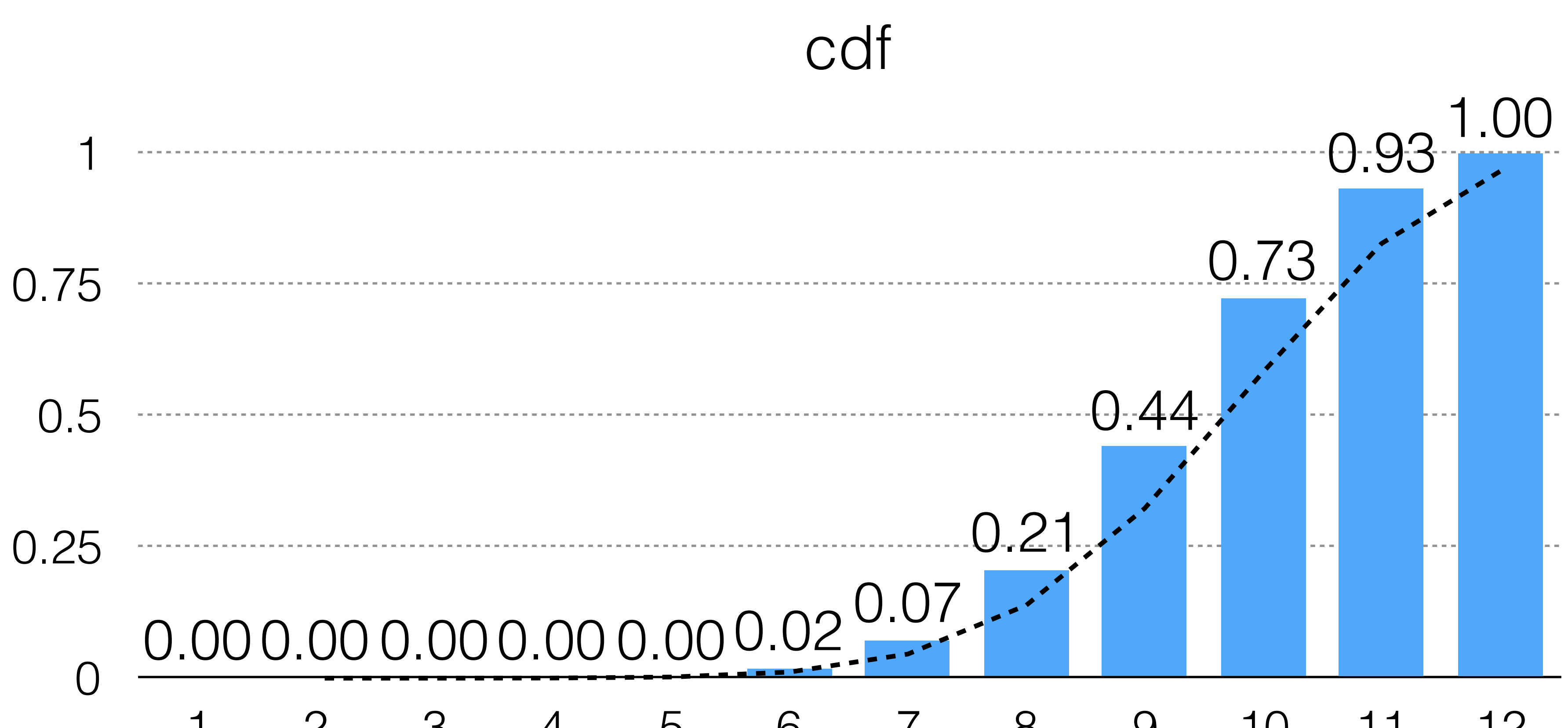

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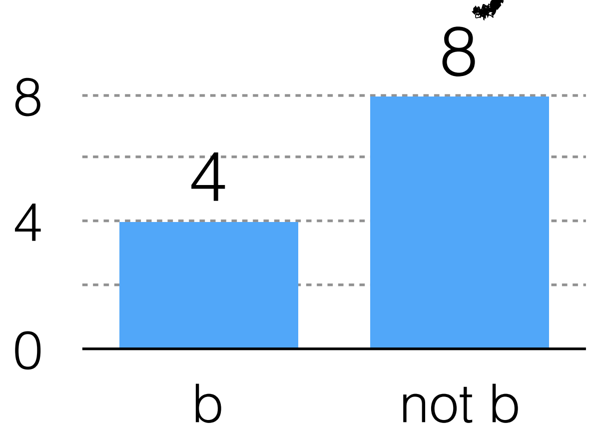
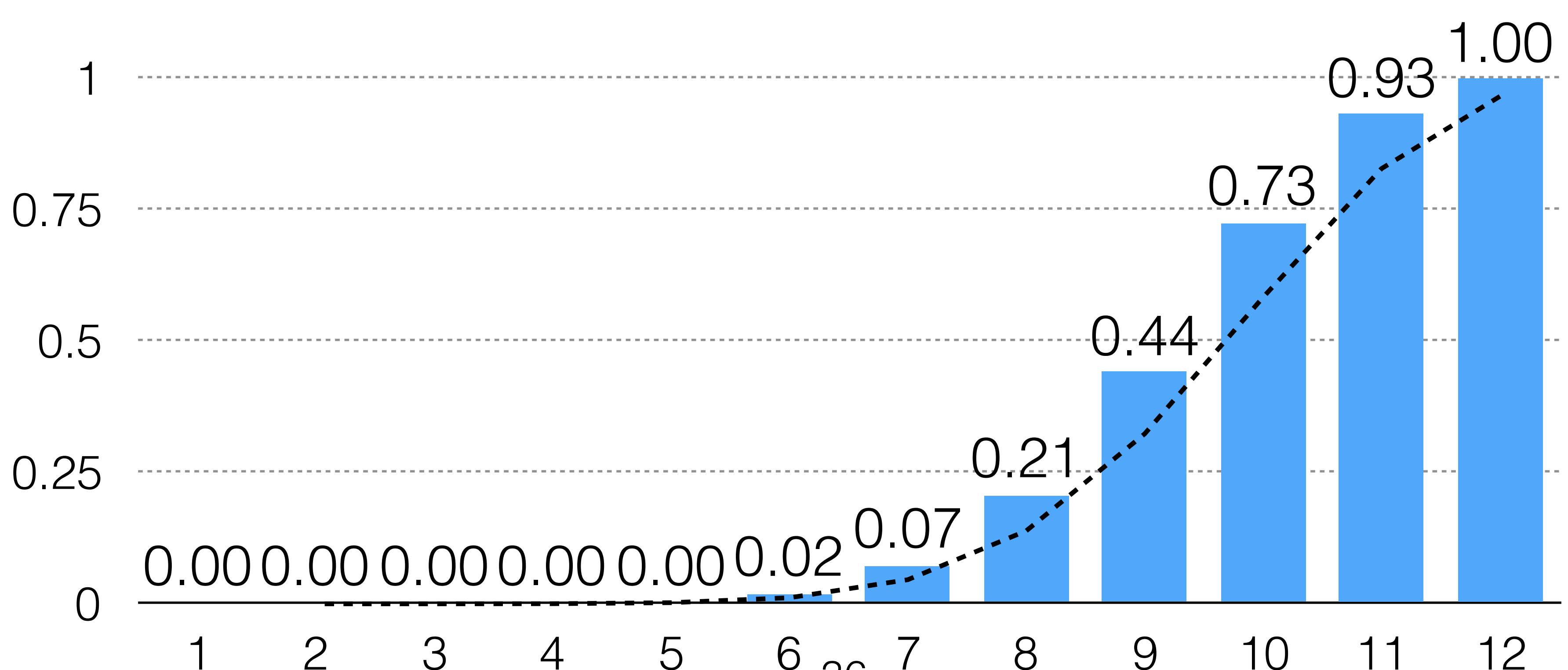


Is the 4 (b)s we observed significantly lower than what we would expect by chance, assuming that in fact 90% of answers are (b)?

cdf



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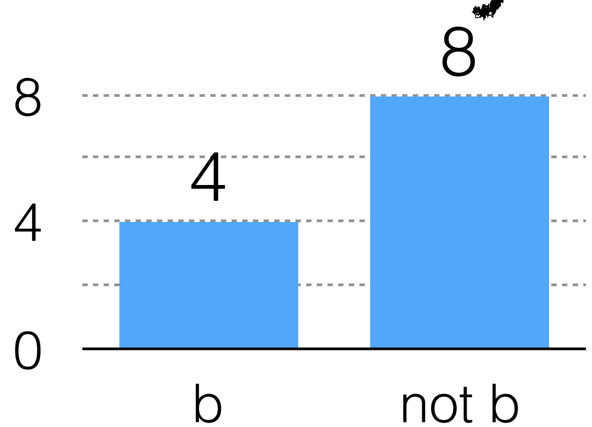

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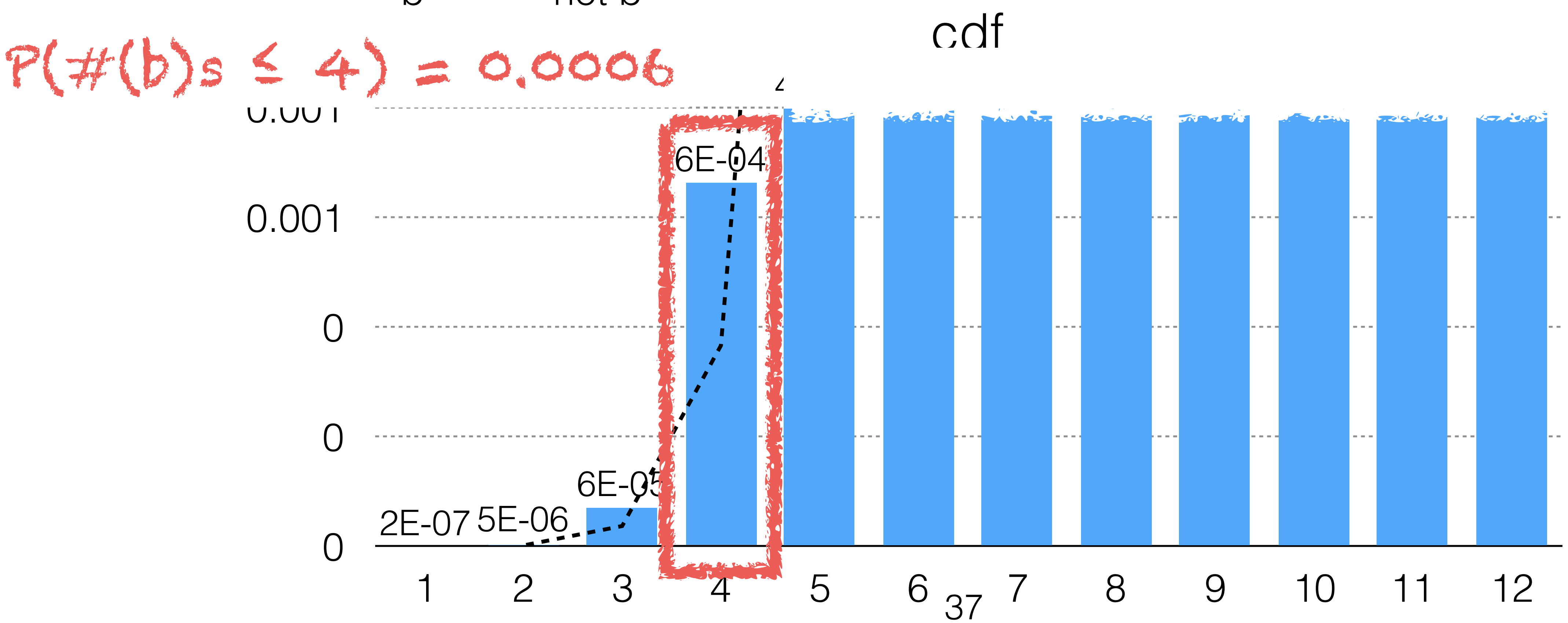

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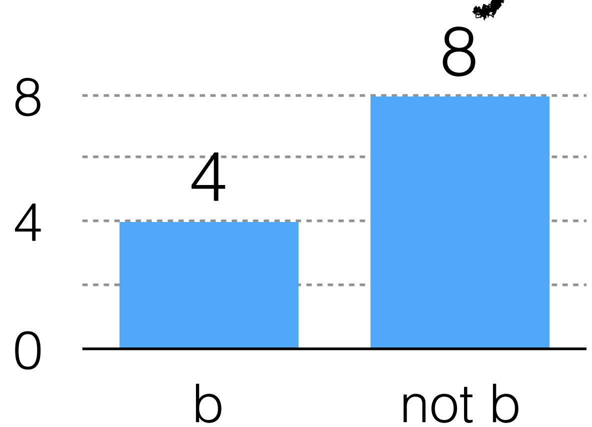
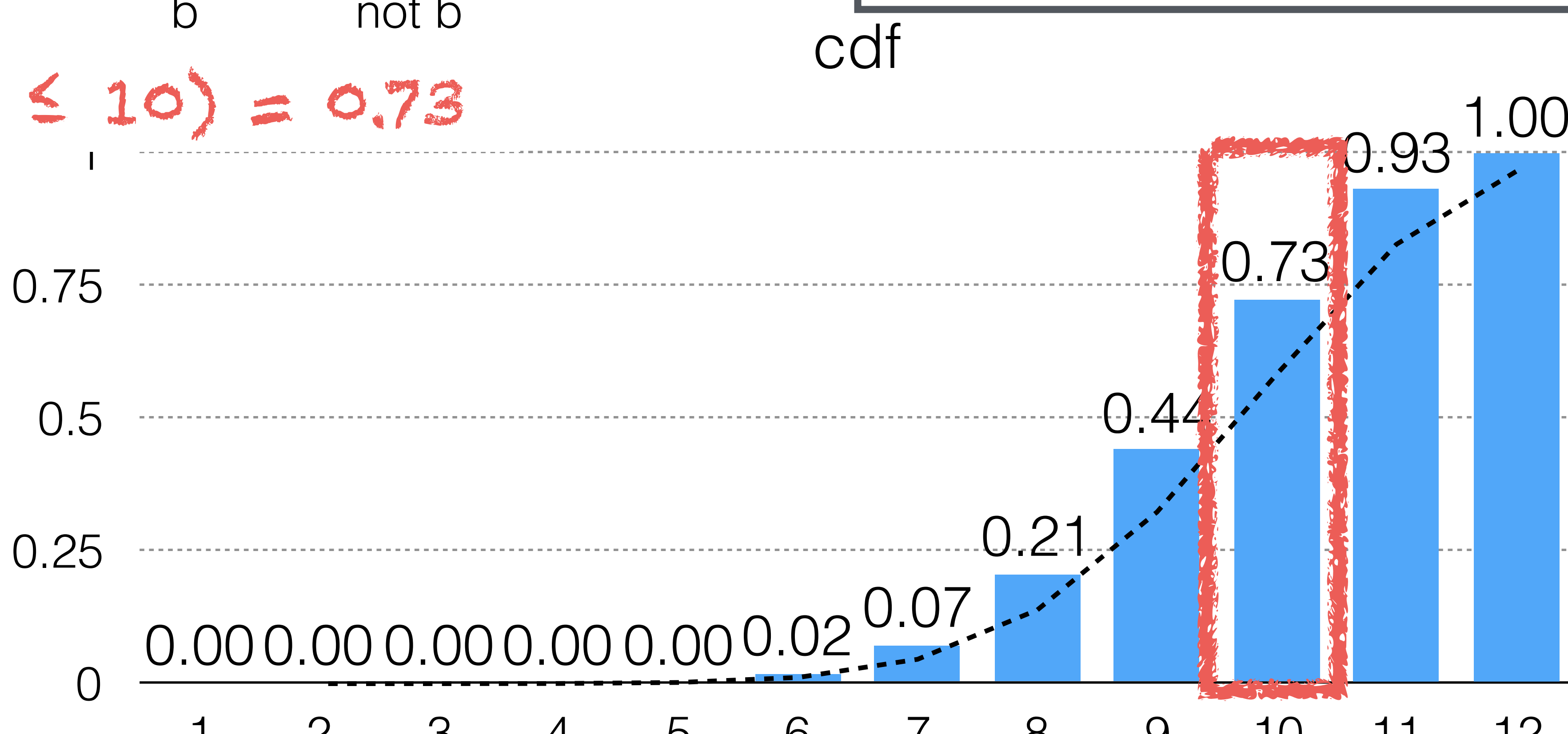


Is the 4 (b)s we observed significantly lower than what we would expect by chance, assuming that in fact 90% of answers are (b)?

$P(\#(b)s \leq 10) = 0.73$



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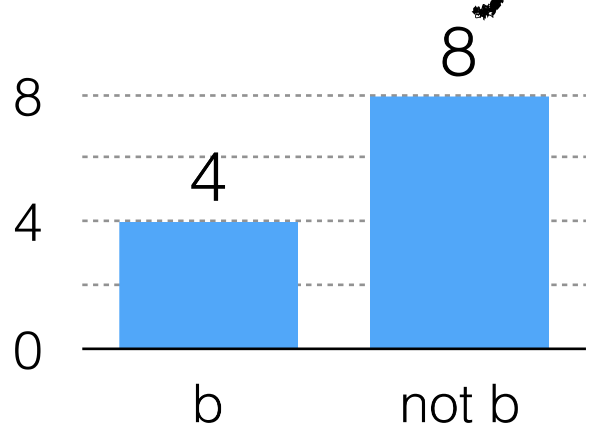
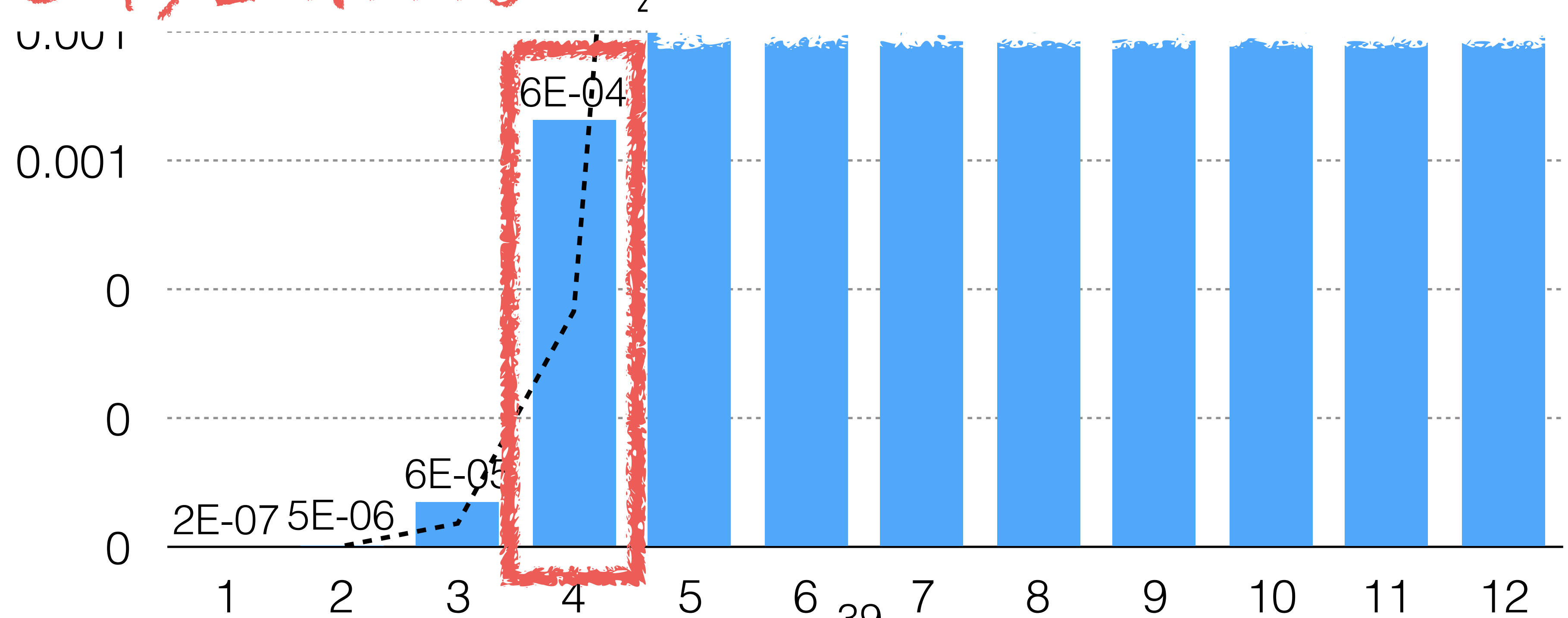


Is the 4 (b)s we observed significantly lower than what we would expect by chance, assuming that in fact 90% of answers are (b)?

P(#(b)s ≤ 4) = 0.0006



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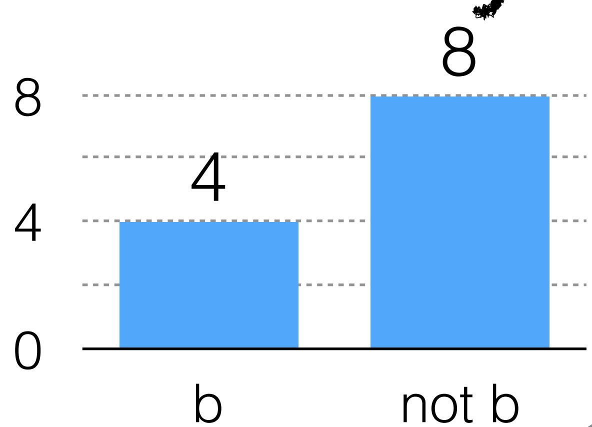
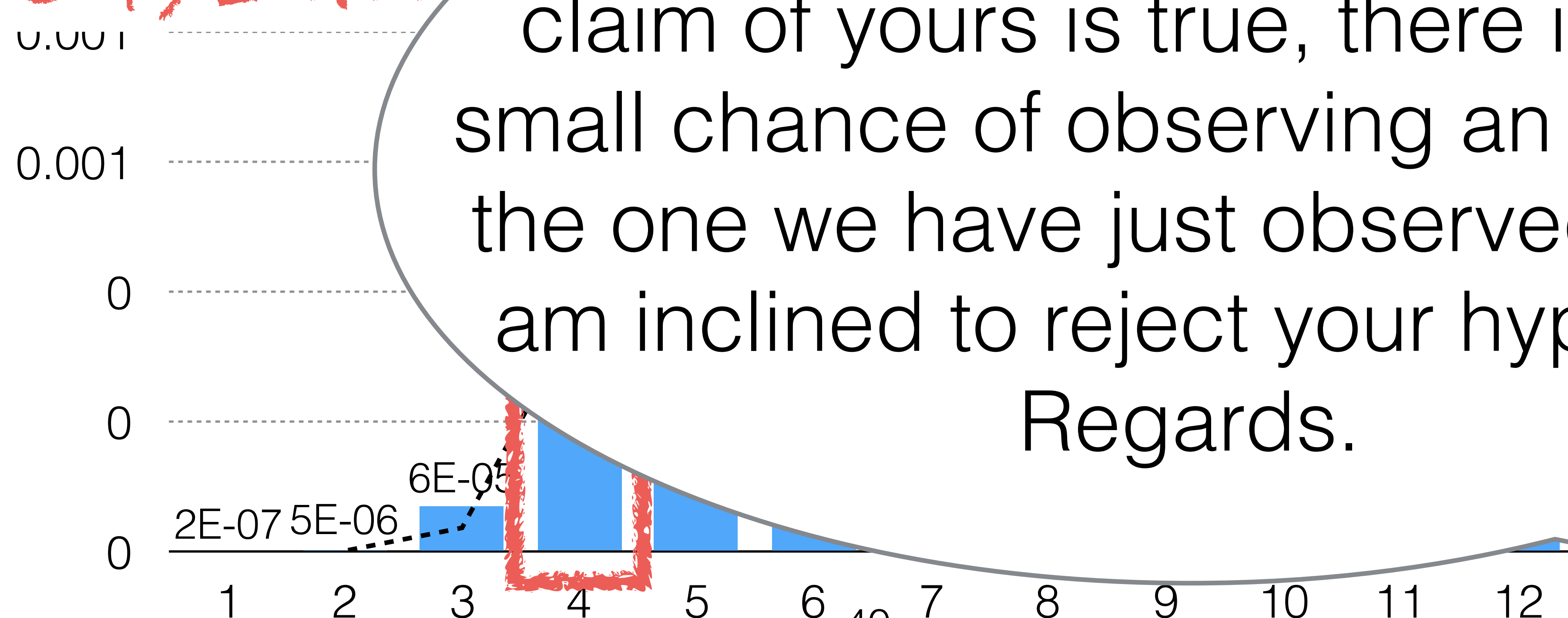


Is the 4 (b)s we observed significantly lower than what we would … chance, assuming … (b)?

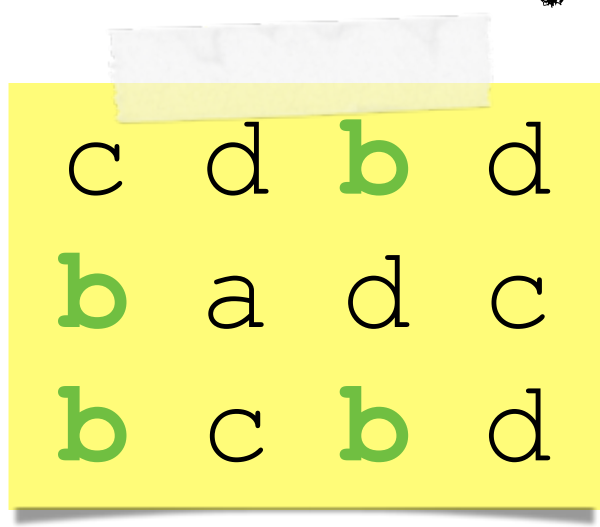
$P(\#(b)s \leq 4) = 0.000$…



Dear friend, assuming this claim of yours is true, there is a very small chance of observing an event like the one we have just observed. Thus, I am inclined to reject your hypothesis. Regards.

Hypothesis Testing

"I swear literally like 80% of the answers are just (b)"

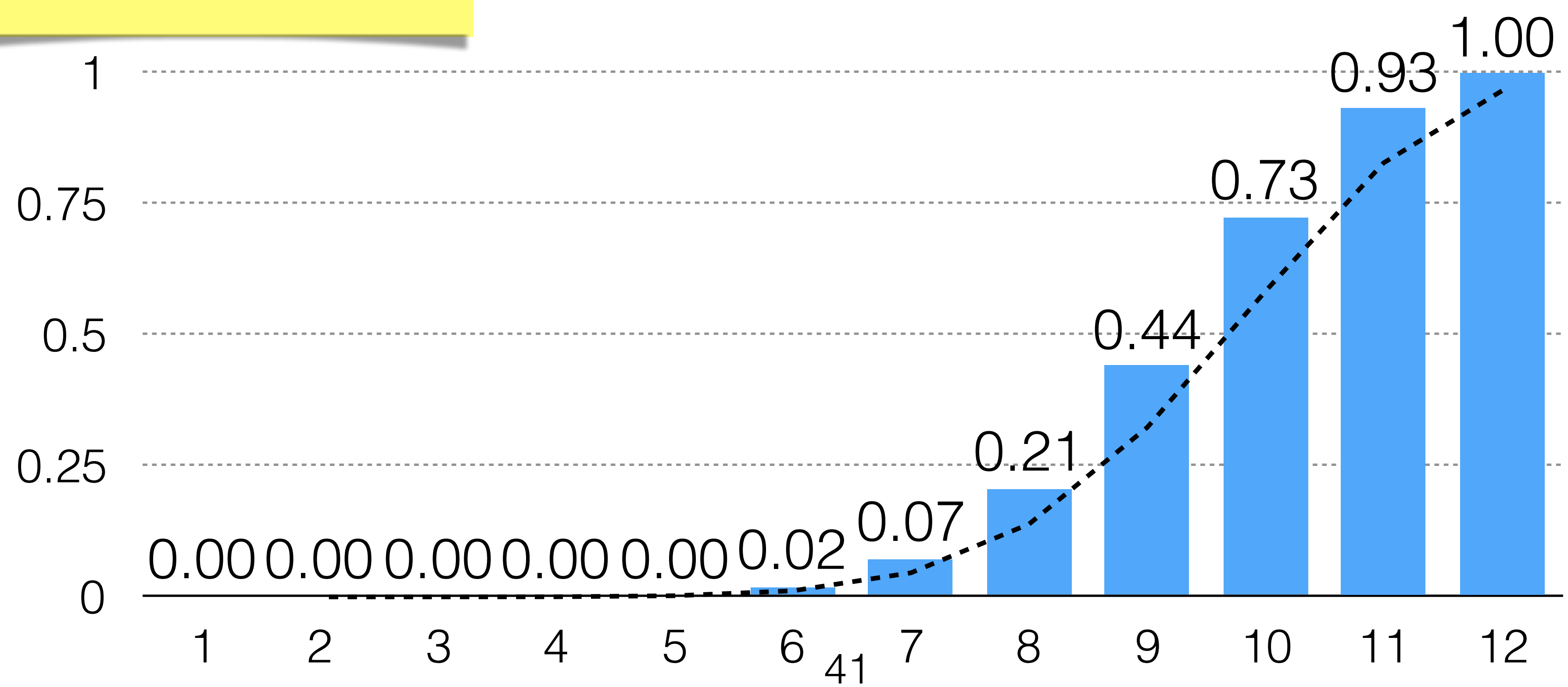


$\longrightarrow$ 4

$$\langle \Omega, F, P \rangle$$

{b, not b} p(B) = 0.8

cdf



Hypothesis Testing

Null Hypothesis

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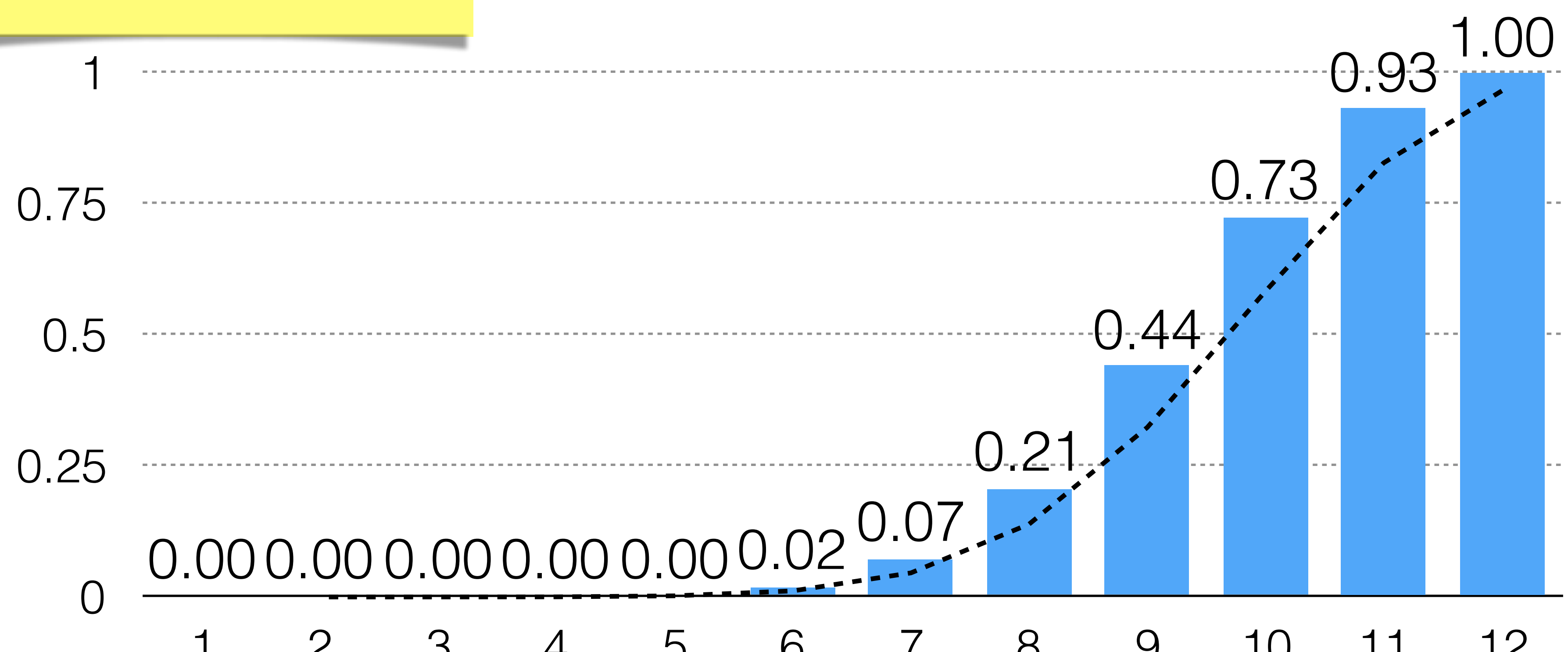

Hypothesis Testing

Observation/Sample

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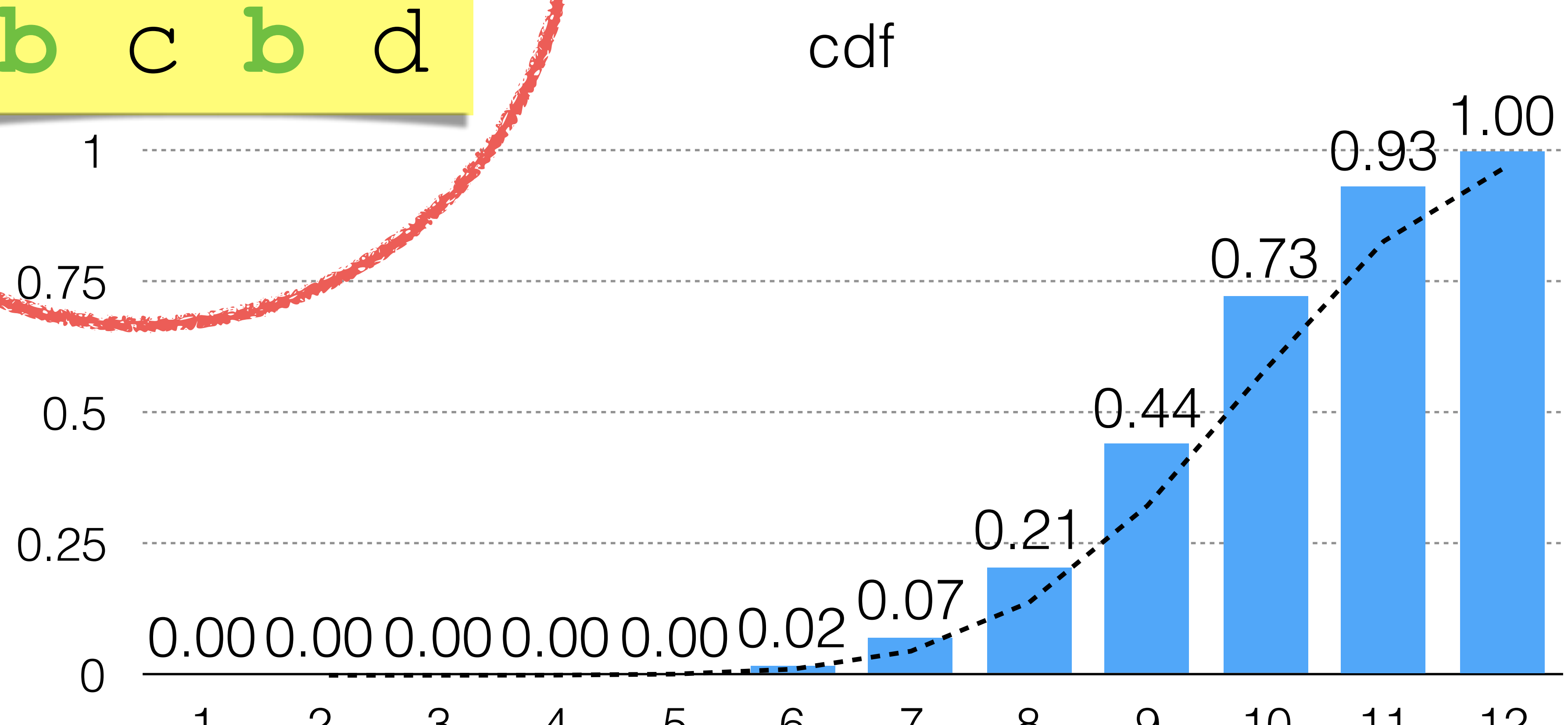

Hypothesis Testing

Test Statistic

"I swear literally like 80% of the answers are just (b)"

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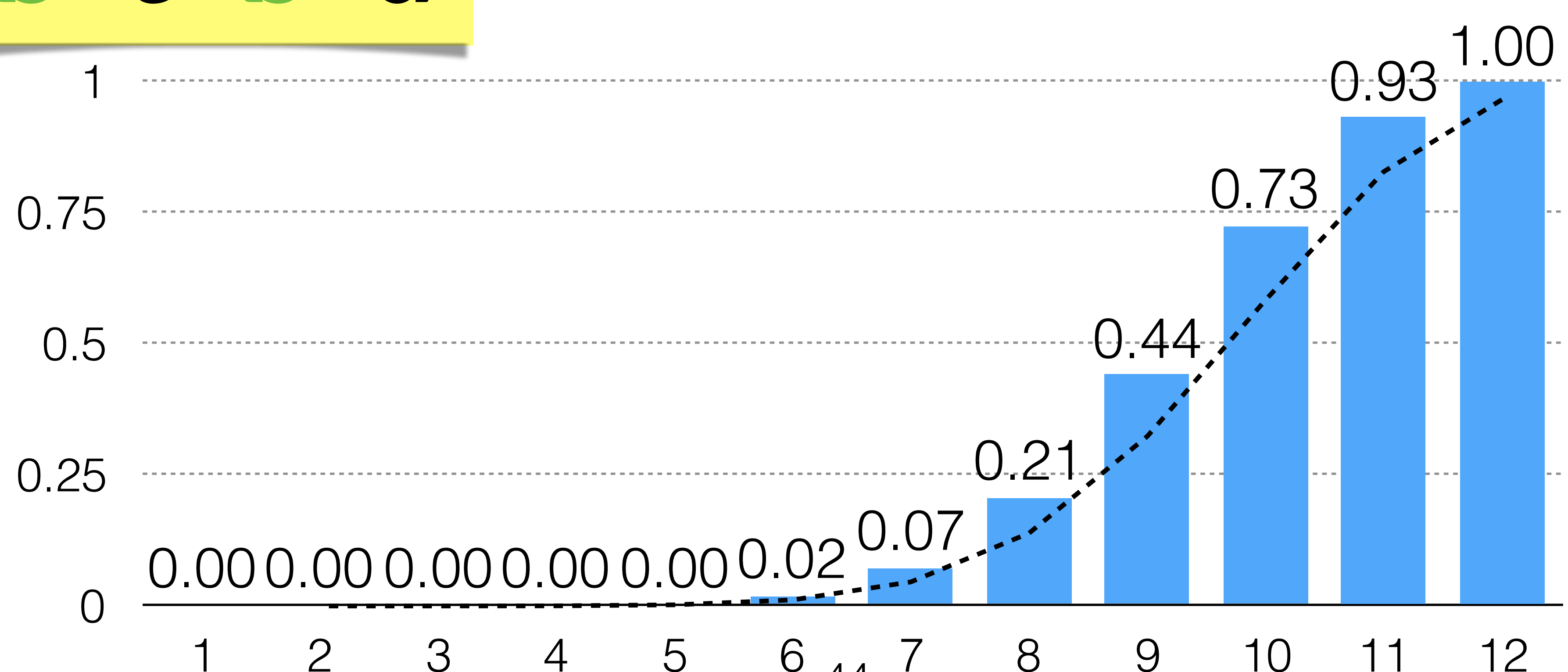

Hypothesis Testing

Theoretical Distribution

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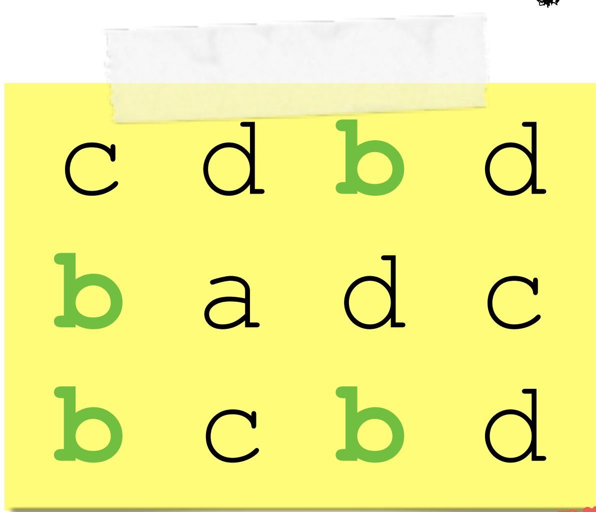

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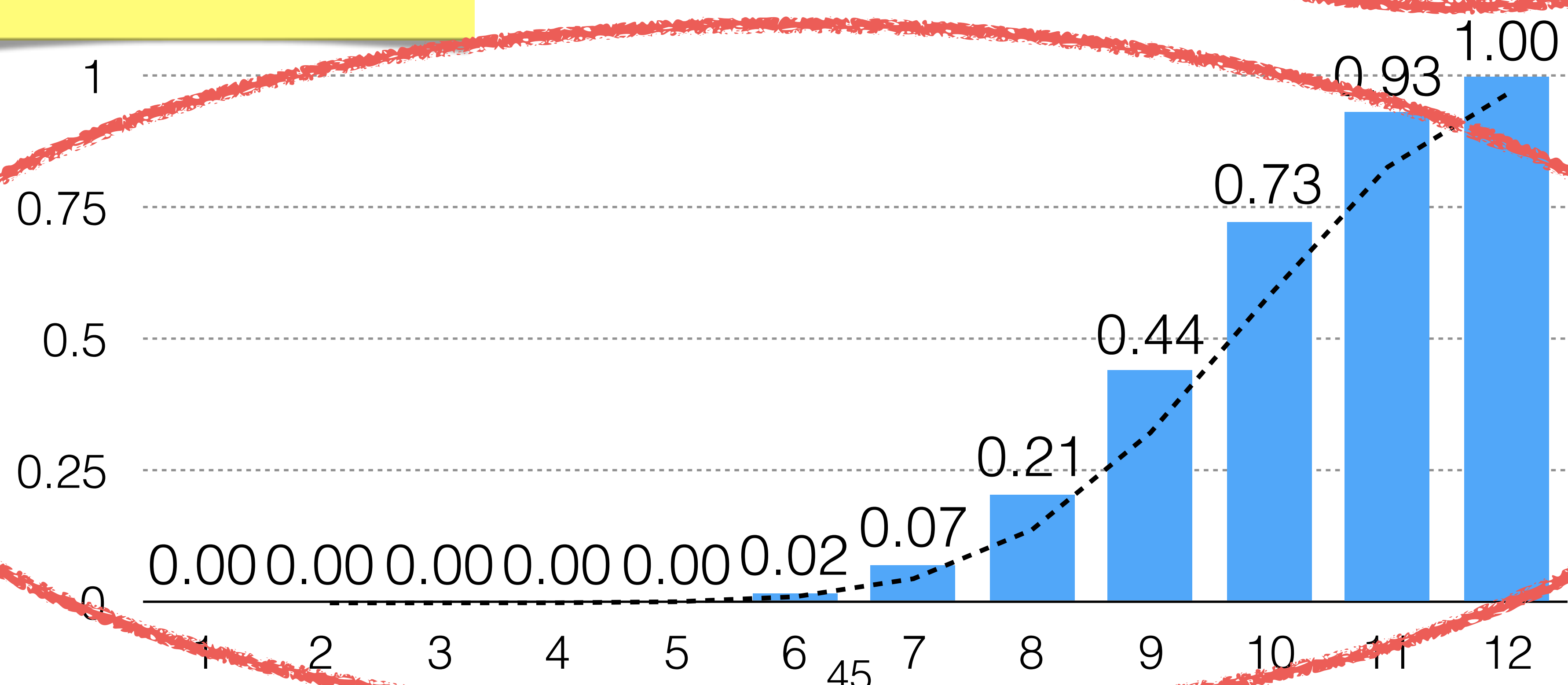

Hypothesis Testing

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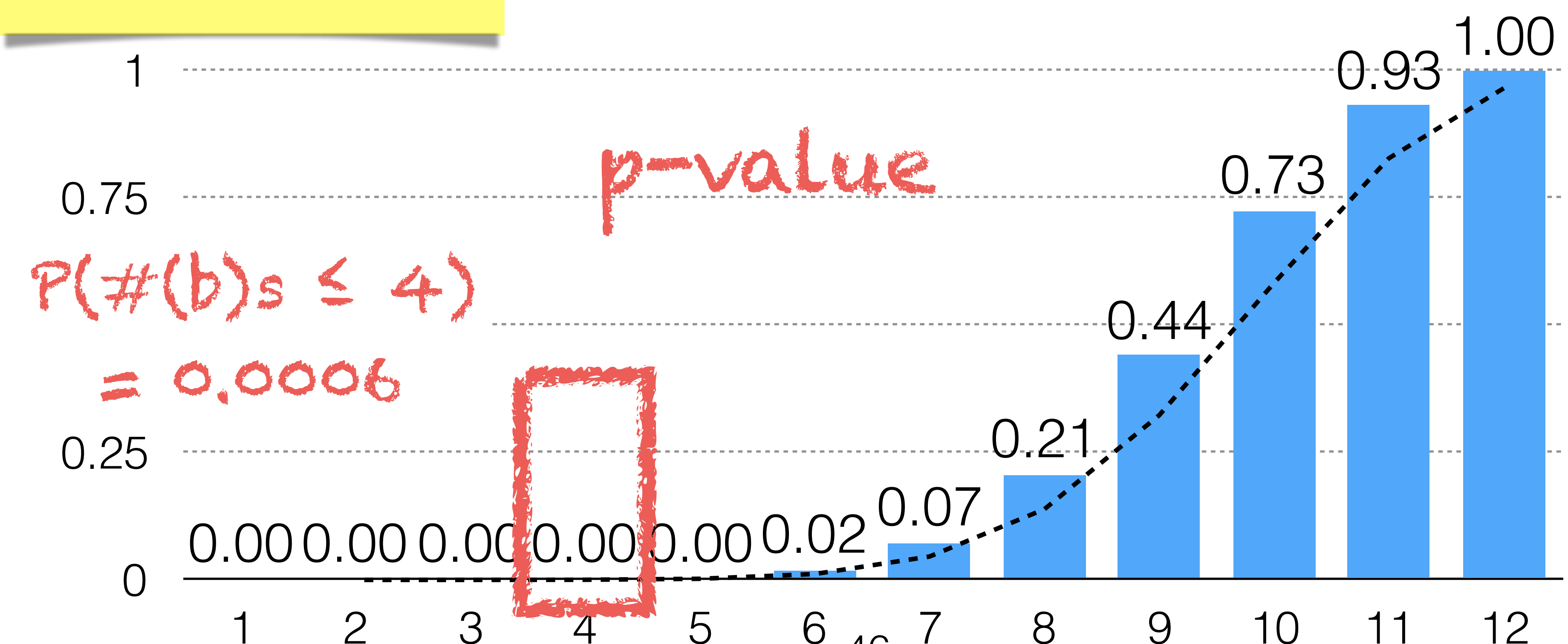

Clicker Question!

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Given all of this, is your friend wrong?

a) Yes!
b) No...

"I swear literally like 80% of the answers are just (b)"

c	d	b	d
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$\longrightarrow$ 4

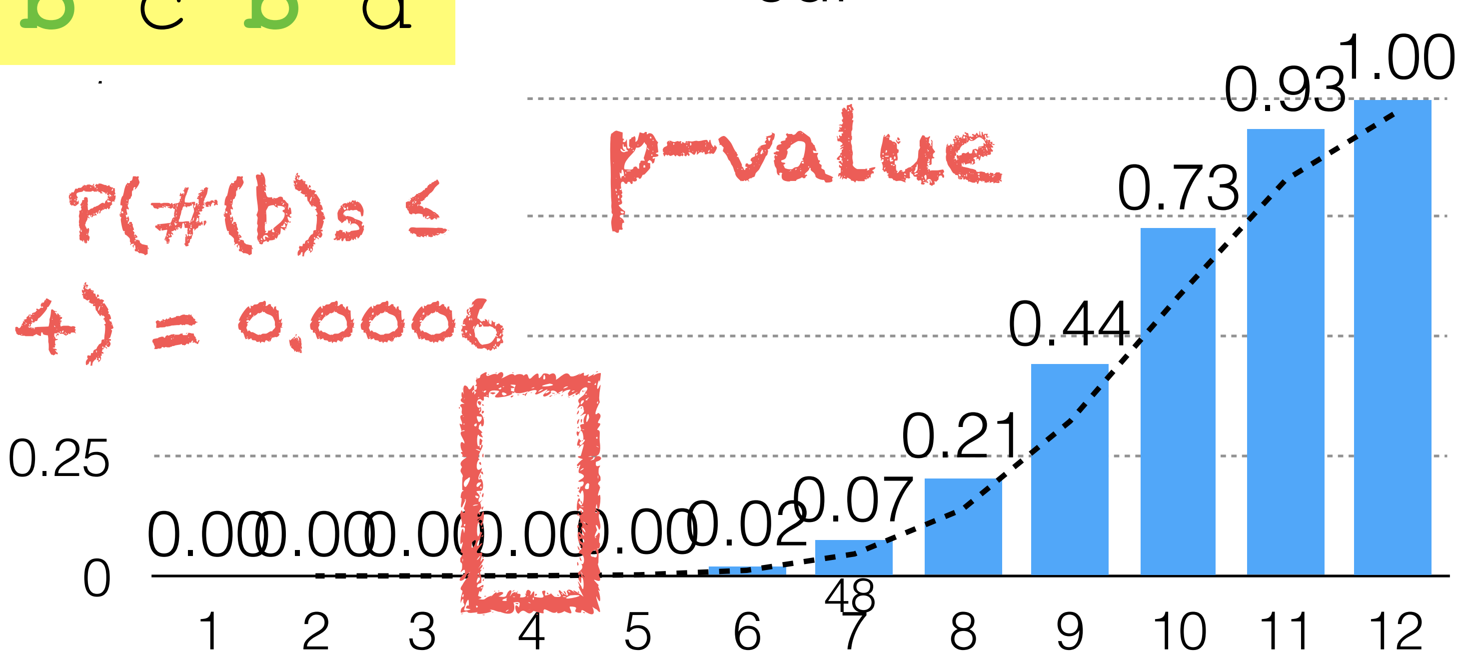
cdf

$\langle \Omega, F, P \rangle$

{b, not b}   p(B) = 0.8

p-value

P(#(b)s ≤ 4) = 0.0006



Discussion Question!

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a) Yes!
b) No...

"I swear literally like 80% of the answers are just (b)"

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$\longrightarrow$ 4 cdf

$\langle \Omega, F, P \rangle$

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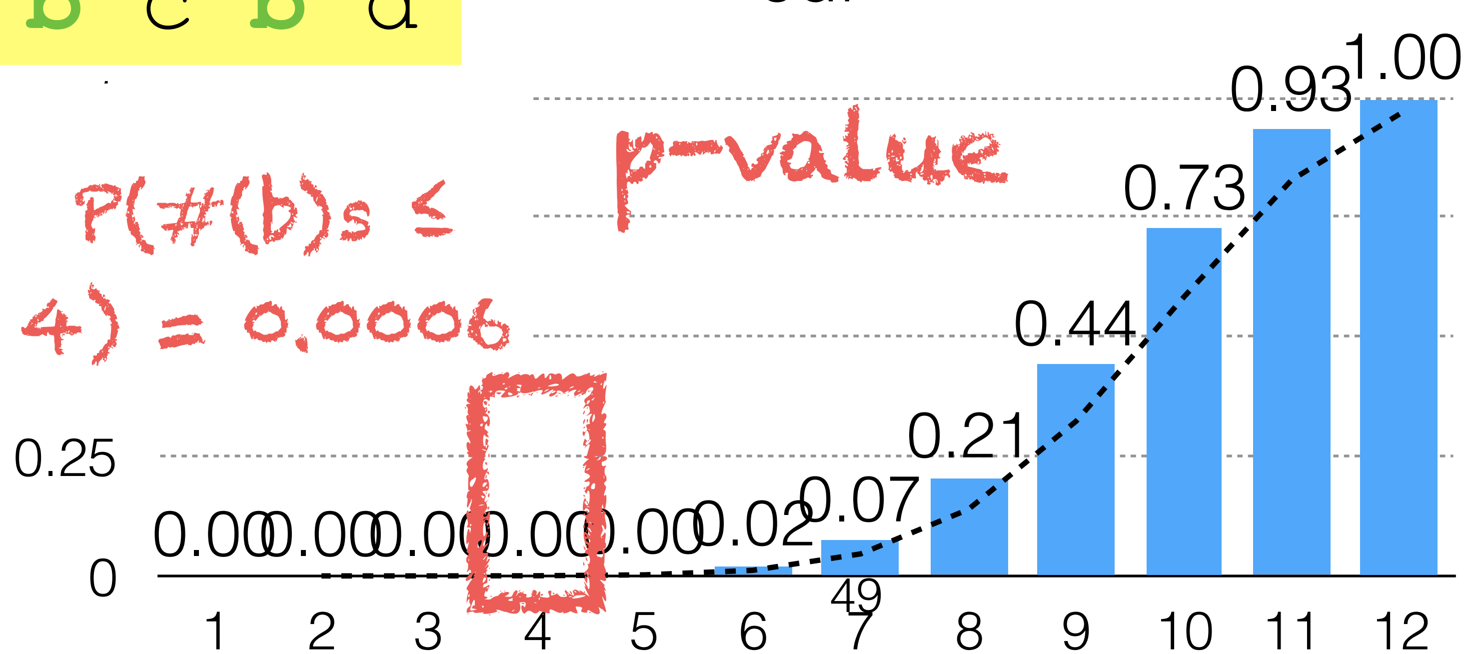
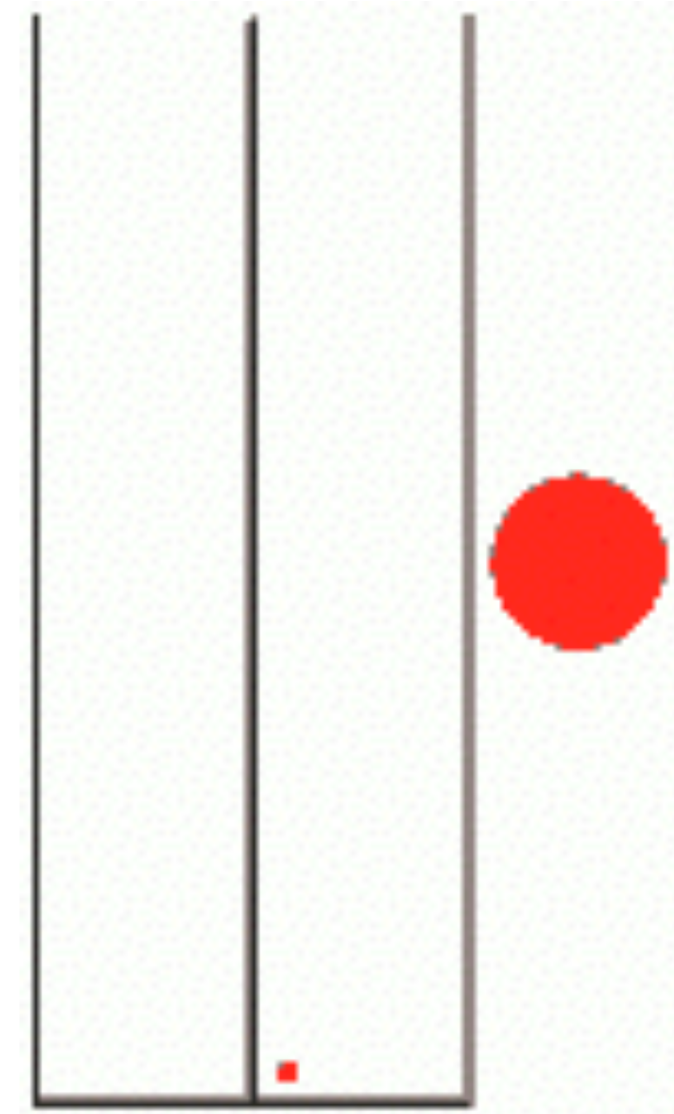


Law of Large Numbers

- If you perform the same experiment a large number times, the *average* will converge to the expected value
- Assumes that errors are "random" and uncorrelated, so will balance out over time

$$\bar{X}_n = \frac{1}{n}(X_1 + \cdots + X_n)$$

$$\bar{X}_n \to \mu \text{ as } n \to \infty$$



https://en.wikipedia.org/wiki/Law_of_large_numbers

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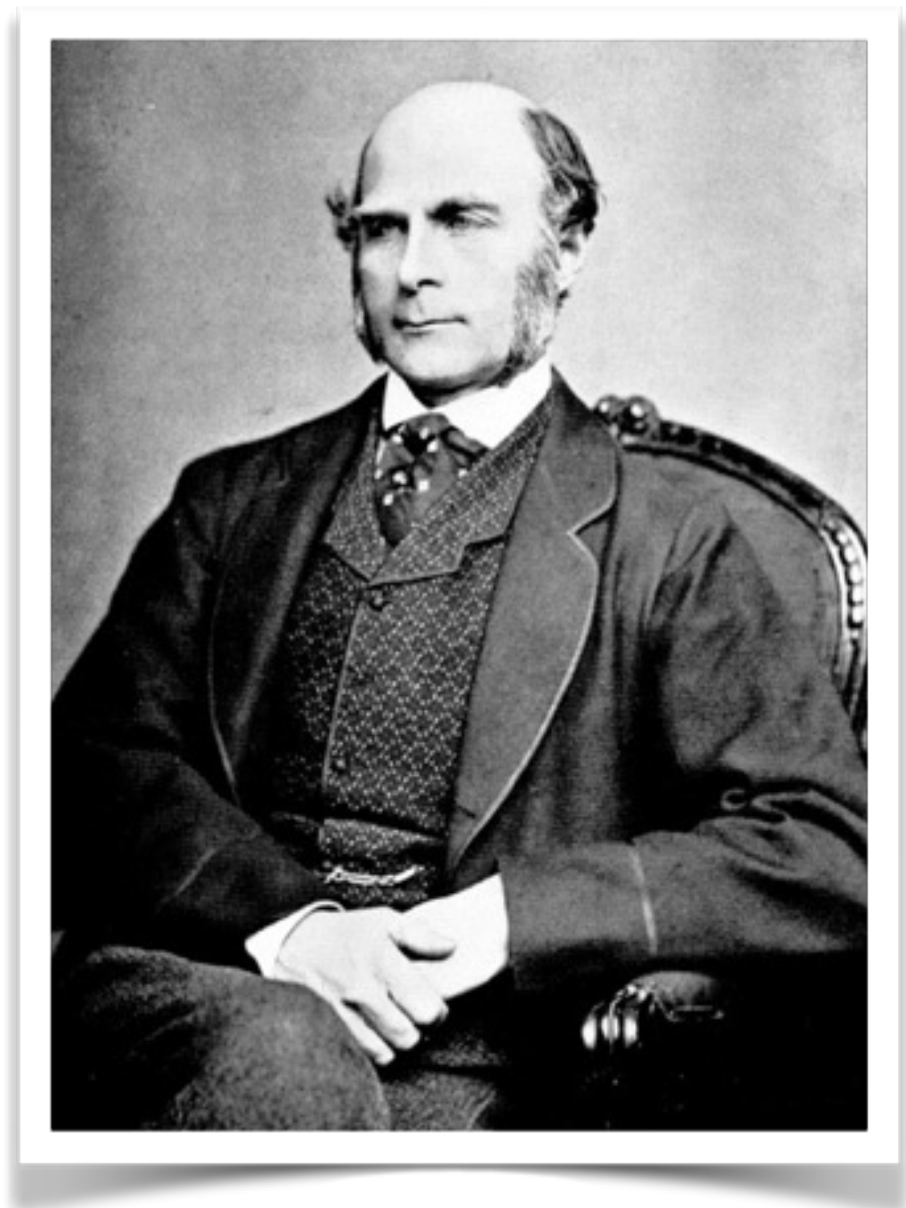
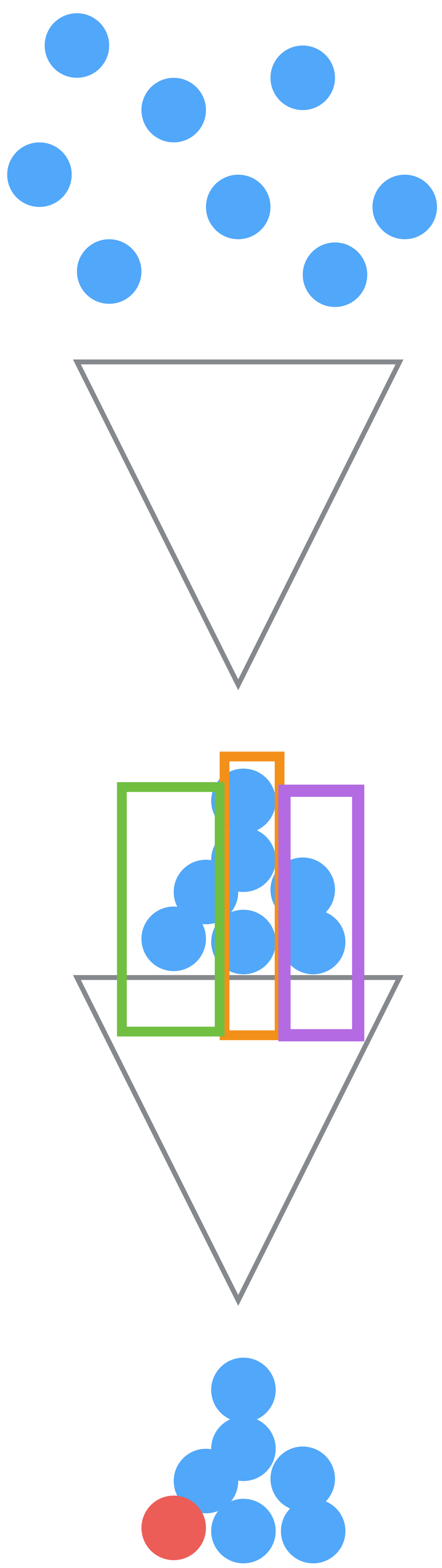


Clicker Question!

Where is the red ball most likely to have come from?

a) Green Region
b) Orange Region
c) Purple Region



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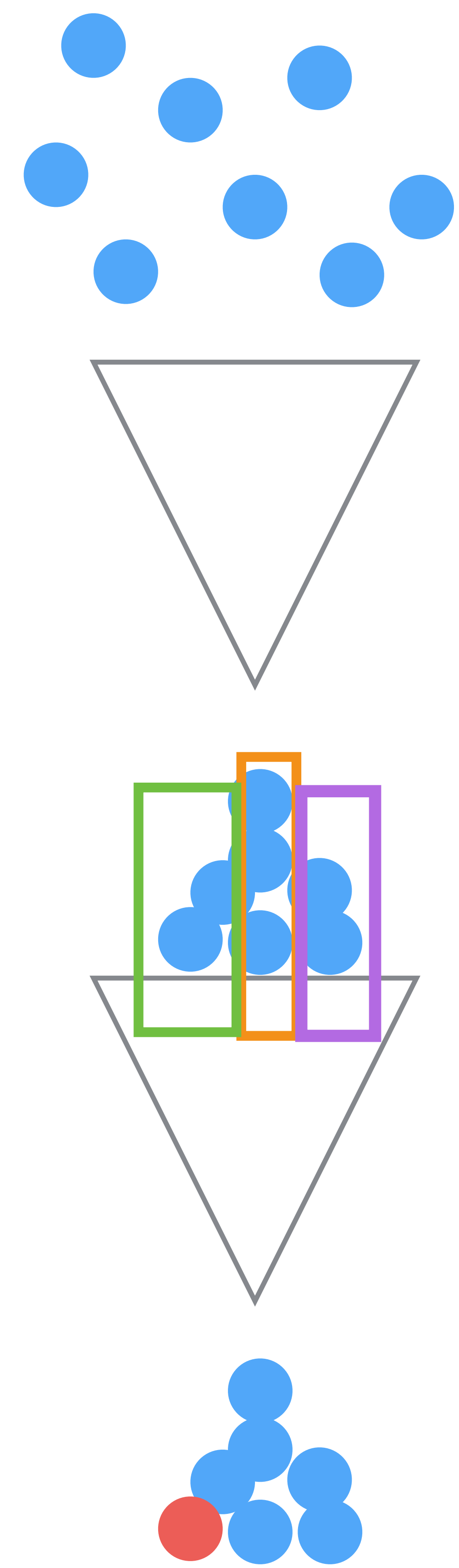

Regression to the Mean

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- On repeated measurement, extreme values are likely to become closer to the mean

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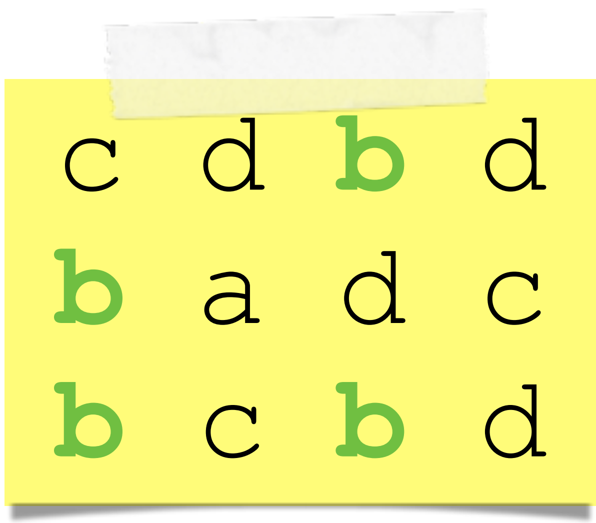
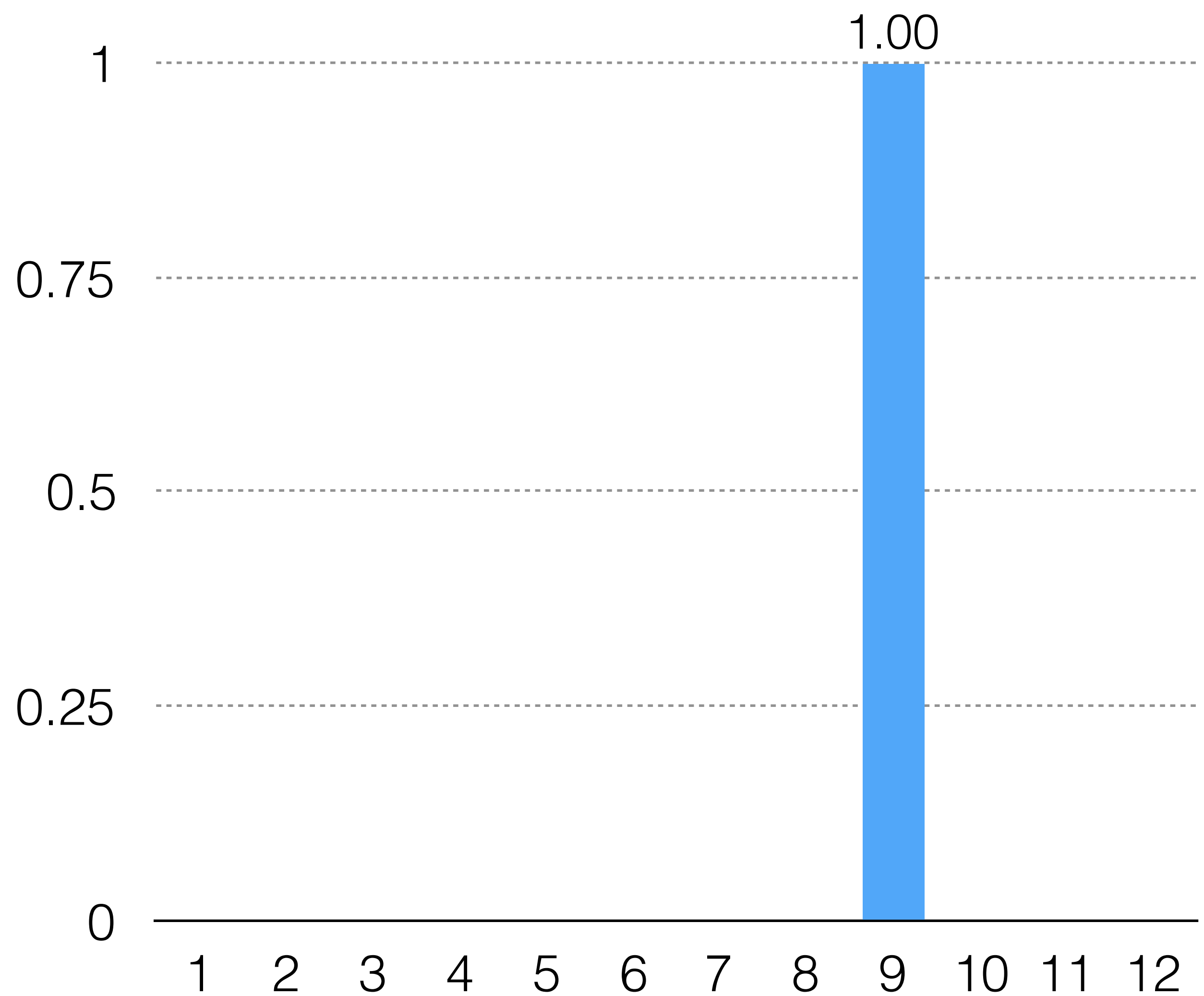
- On repeated measurement, extreme values are likely to become closer to the mean
- Usually applied to repeated measurements of random variables
- Historical observations related to population genetics

Central Limit Theorem

- Given $X_1 \ldots X_n$
- Not only does a $\bar{X}_n \to \mu \text{ as } n \to \infty$
- But the distribution approaches a normal distribution

Central Limit Theorem





Central Limit Theorem

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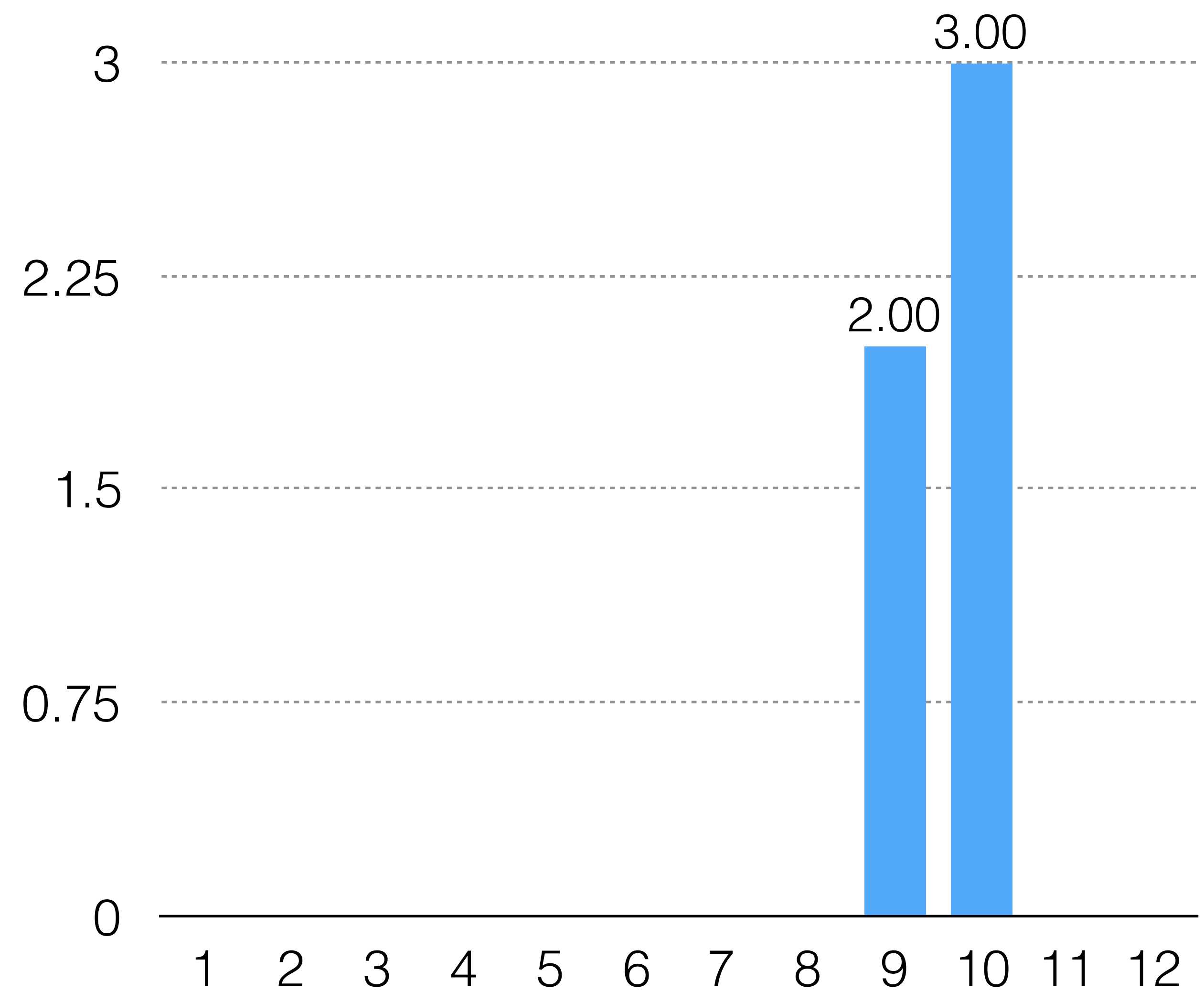

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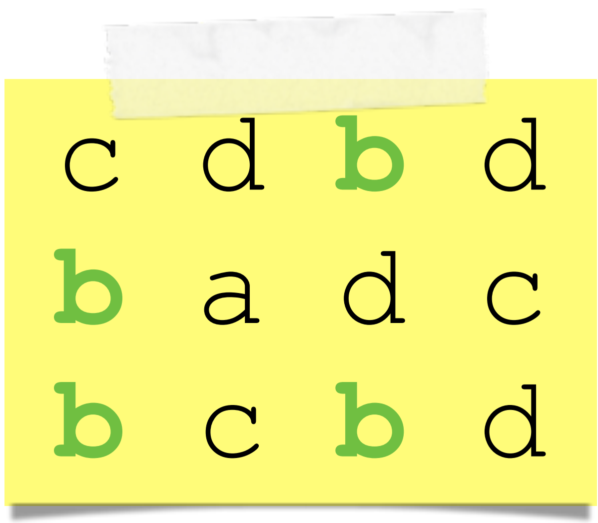

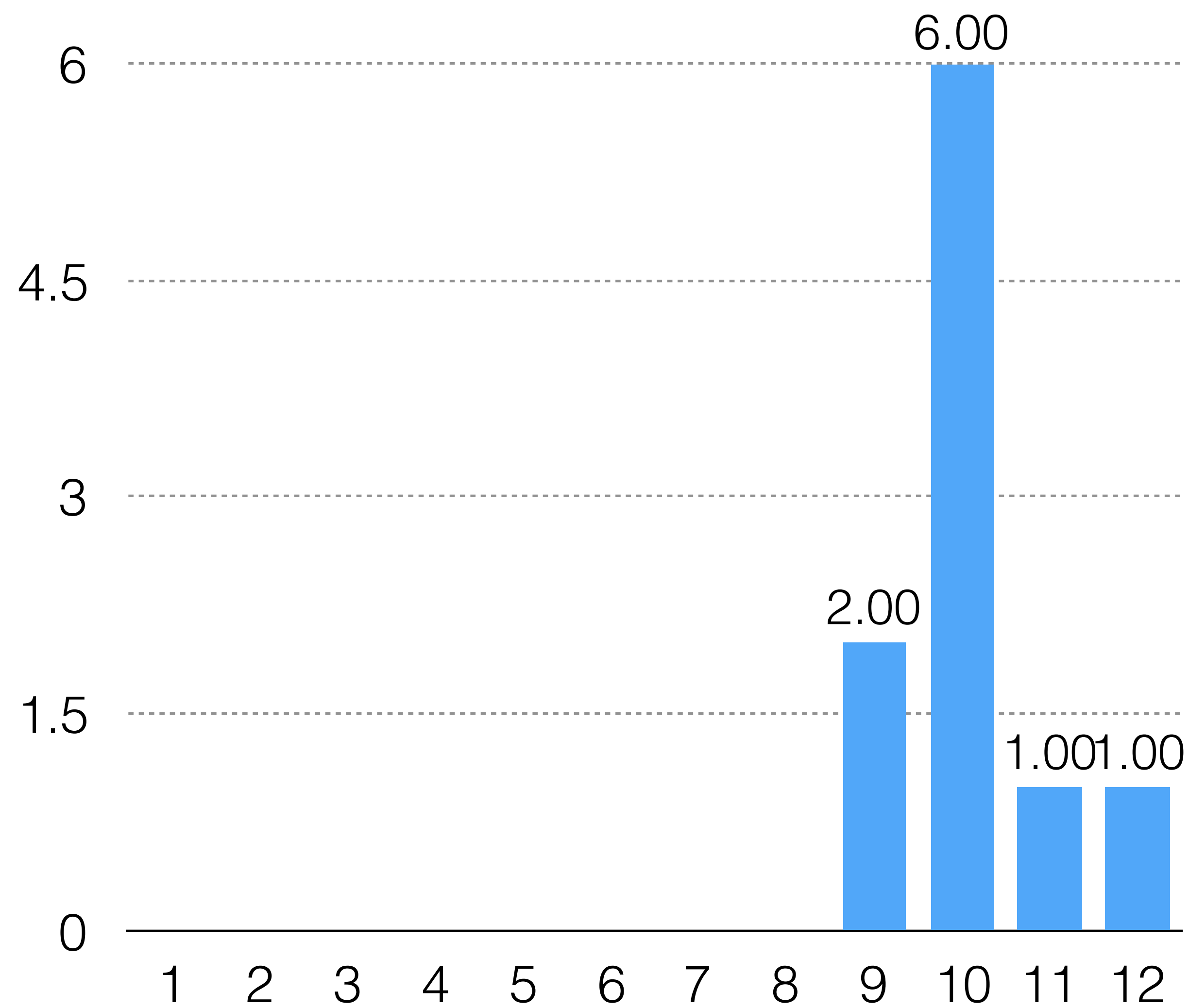

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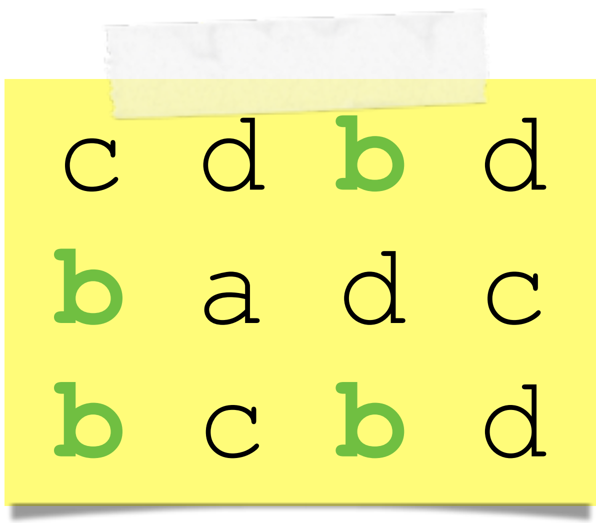
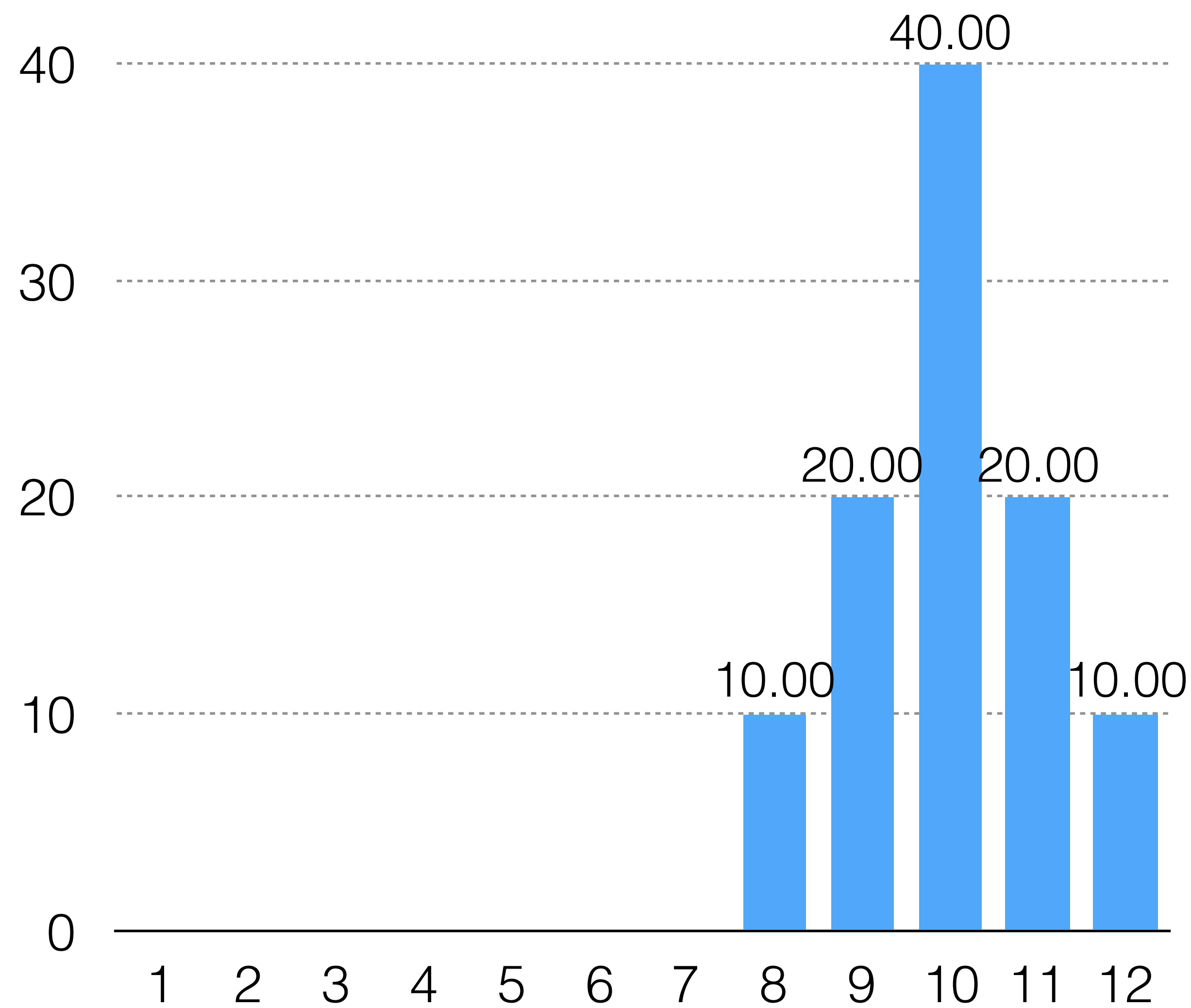
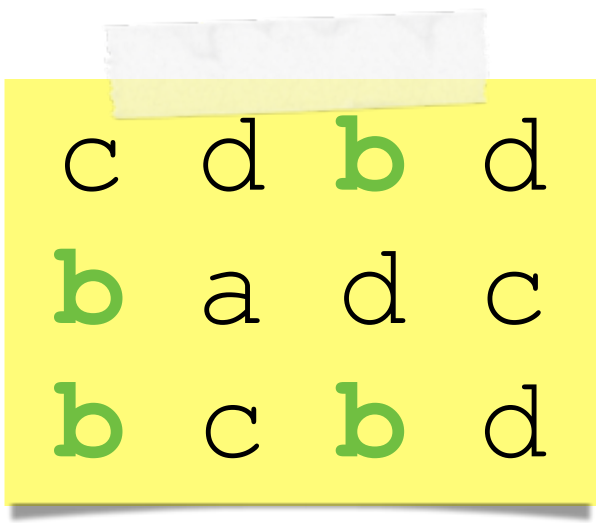
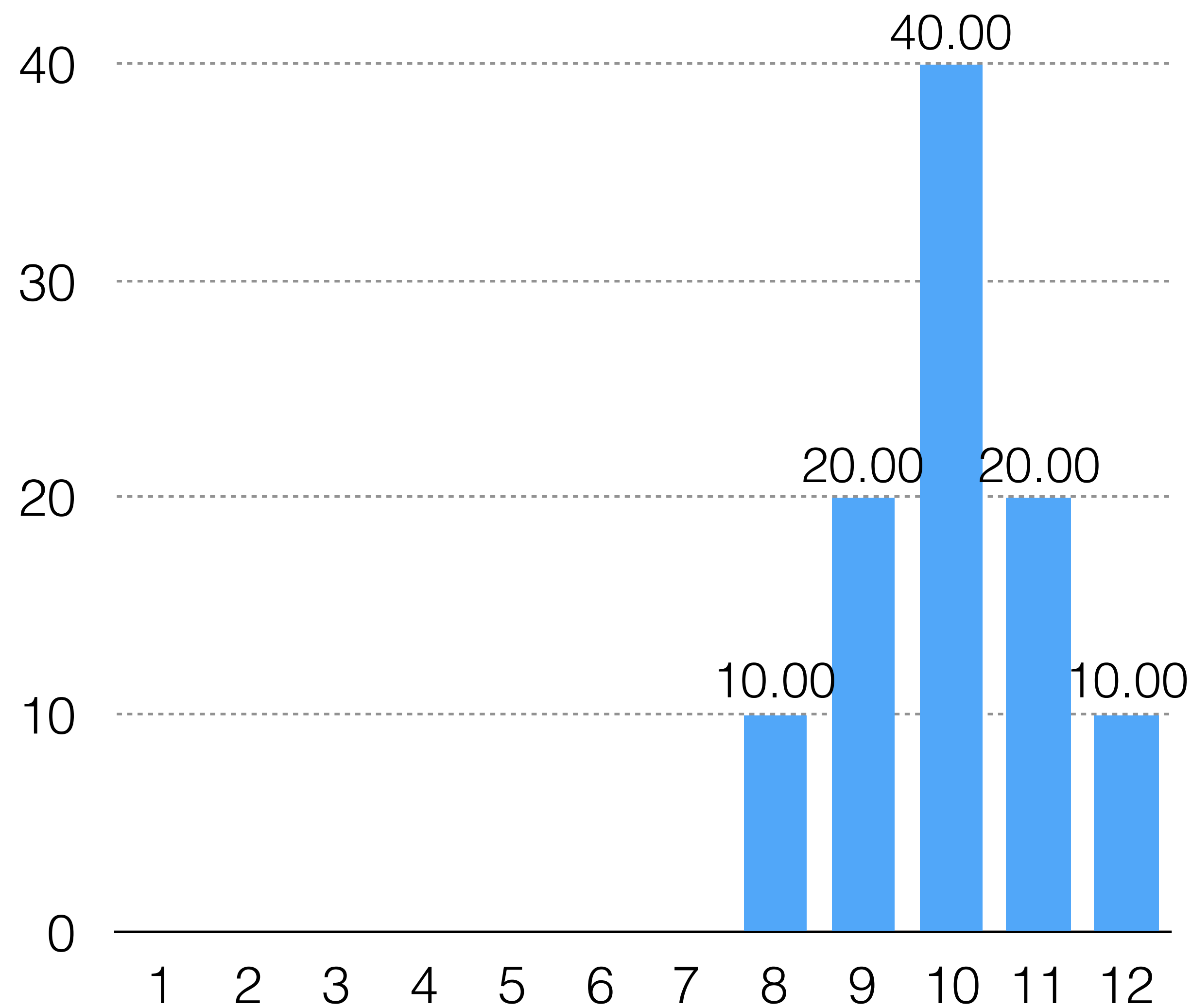




Central Limit Theorem



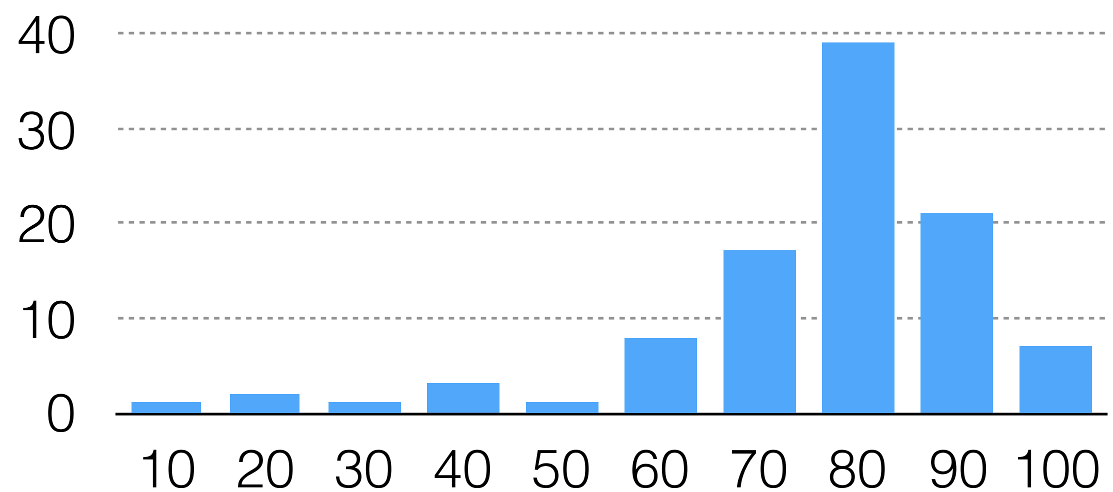


Can apply statistical methods designed for normal distributions even when underlying distribution is not normal

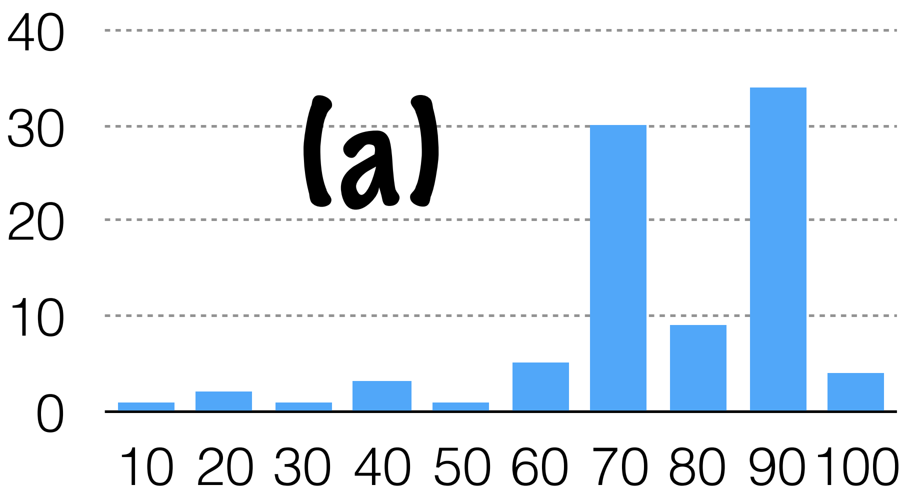
Clicker Question!

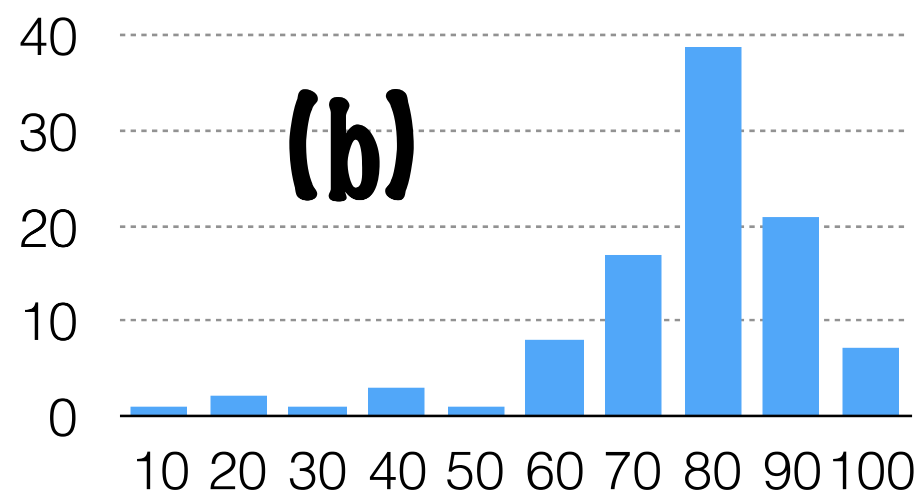
Clicker Question!

Every year, I compute the mean grade in my class. I never change the material or my methods for evaluating because, lazy. Over the 439 years that I have been teaching this class, this has resulted in the below distribution.



Which of these is mostly like the typical distribution on any given year?





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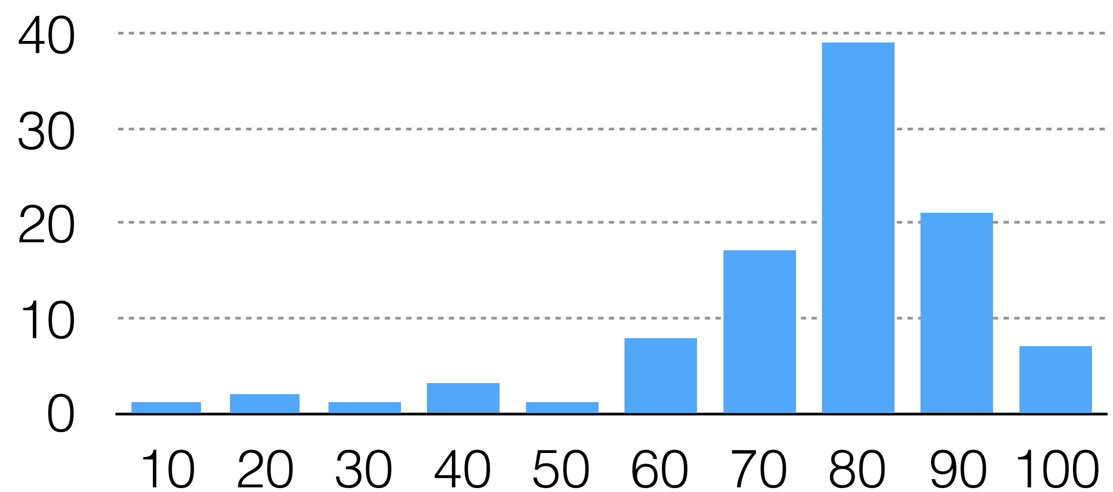

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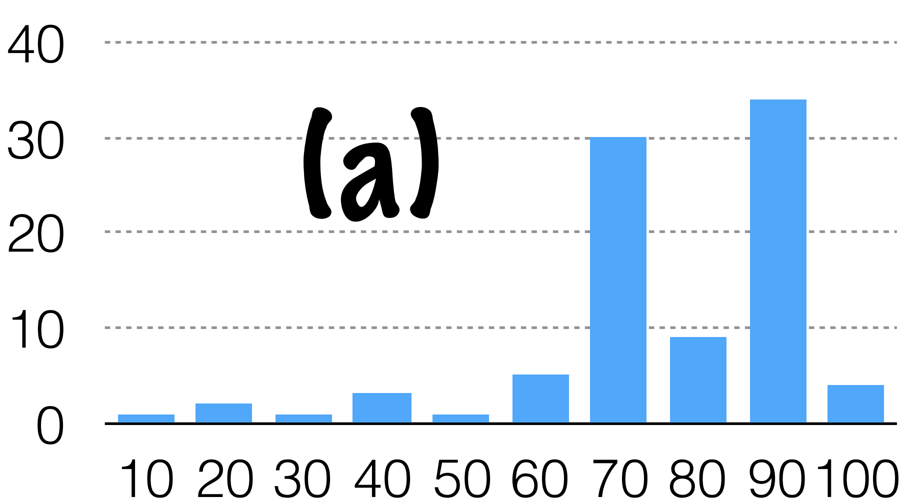

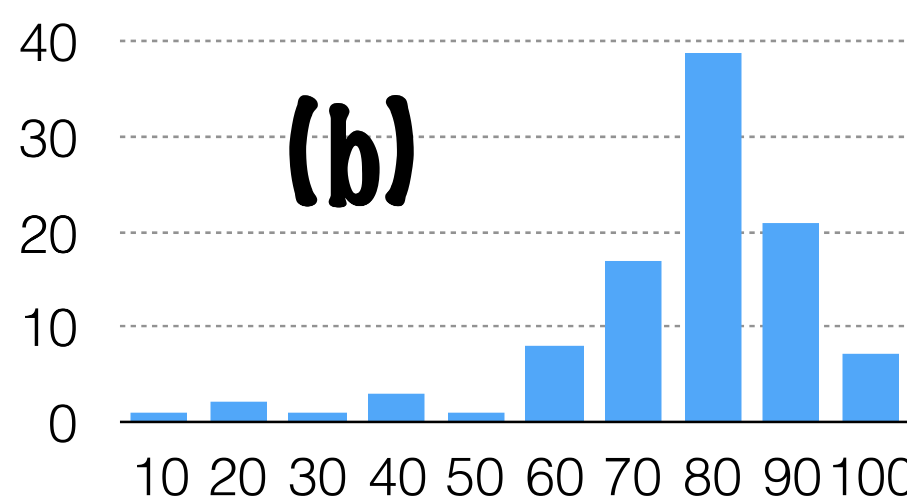

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Central Limit Theorem: repeated measures of mean will be normally distributed, doesn't assume the population over which you are taking the mean is normally distributed.

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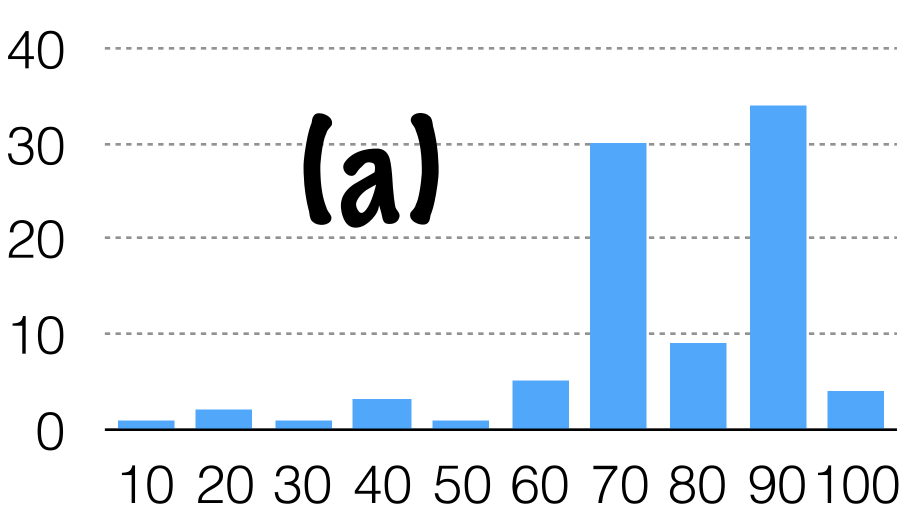

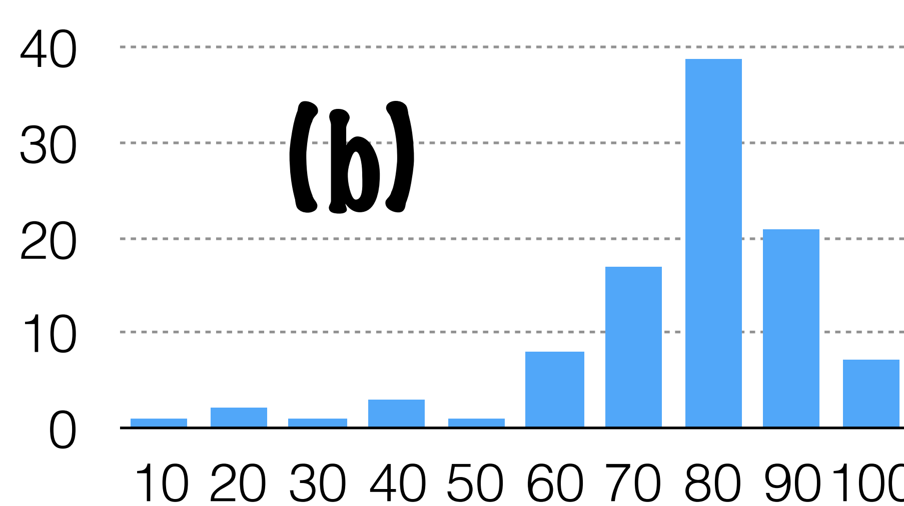

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Are the answers to my clicker questions random?

c	d	b	d
b	a	d	c
b	c	b	d

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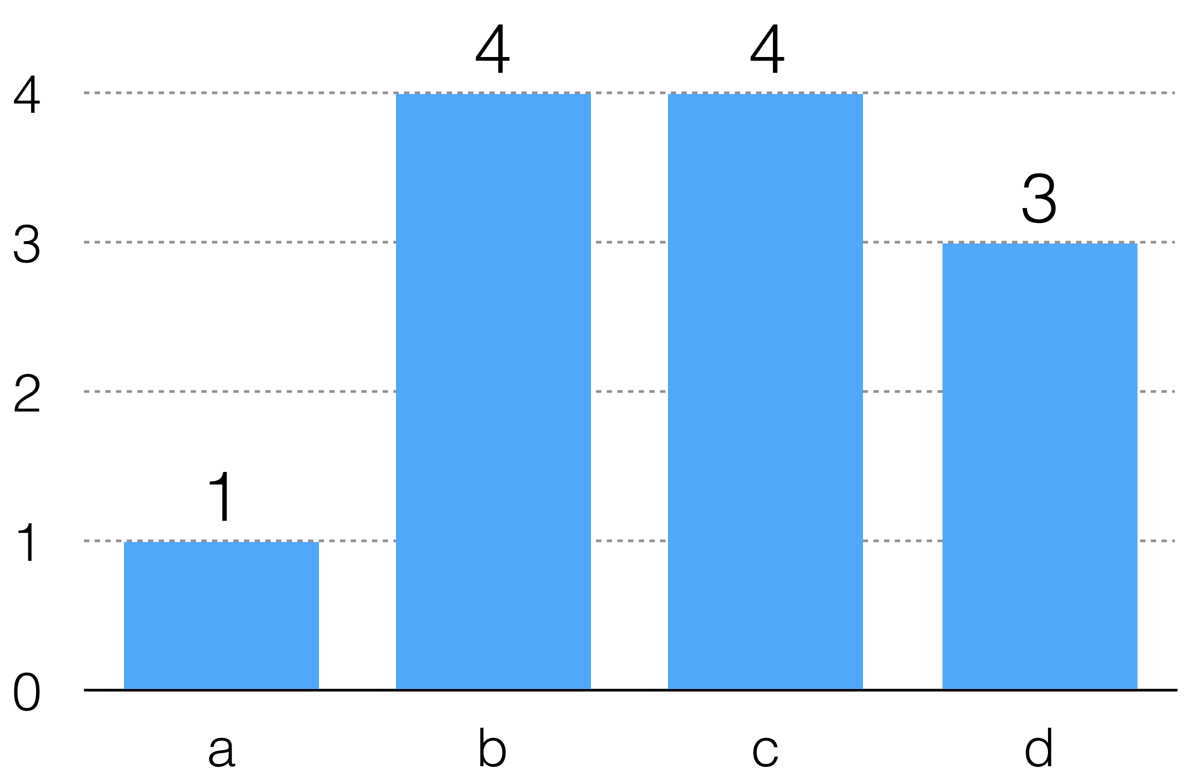

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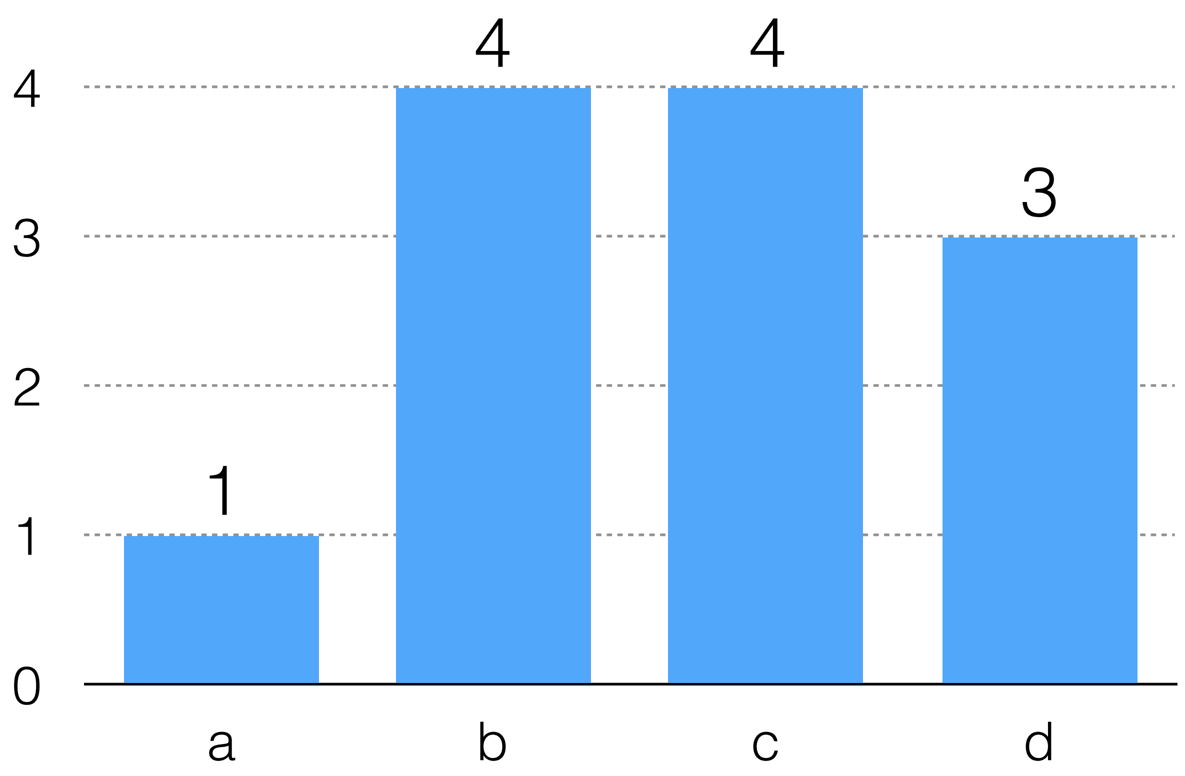

Xi = count of answer i

p(a) = p(b) = p(c) = p(d) = 0.25

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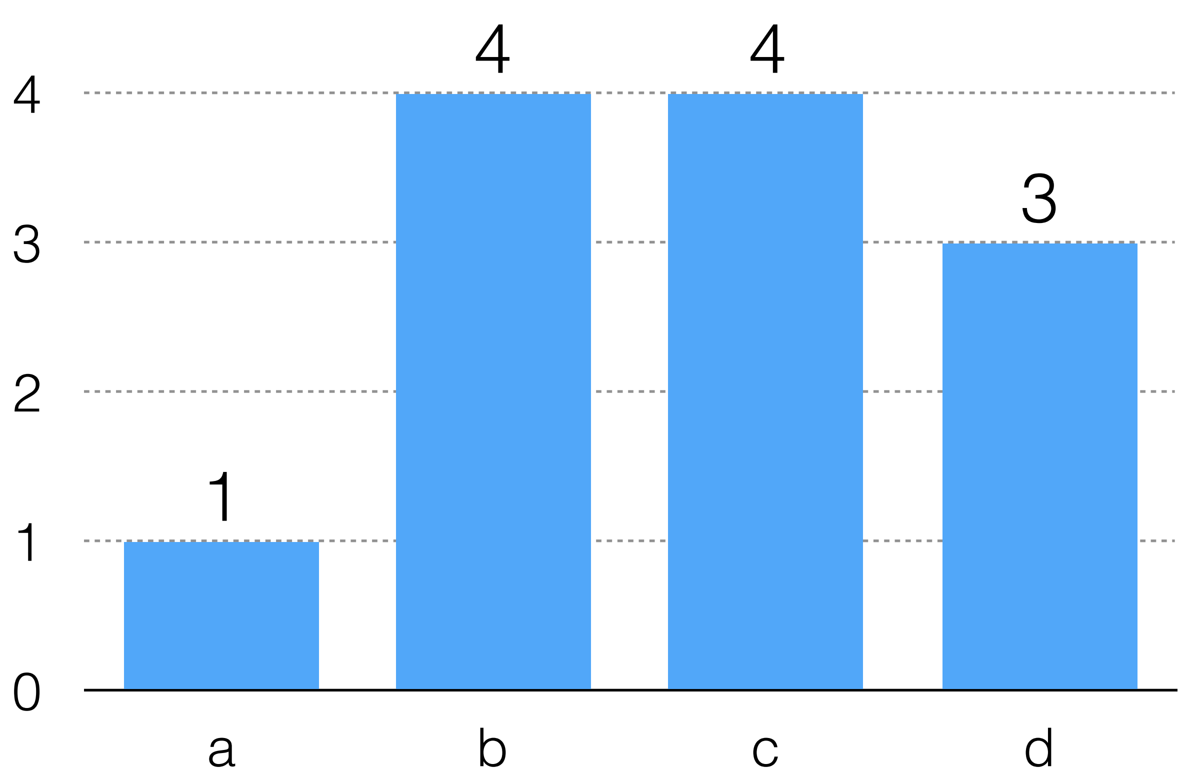

Is this distribution significantly different than what we would expect by chance, assuming that in fact all answers are equally likely?

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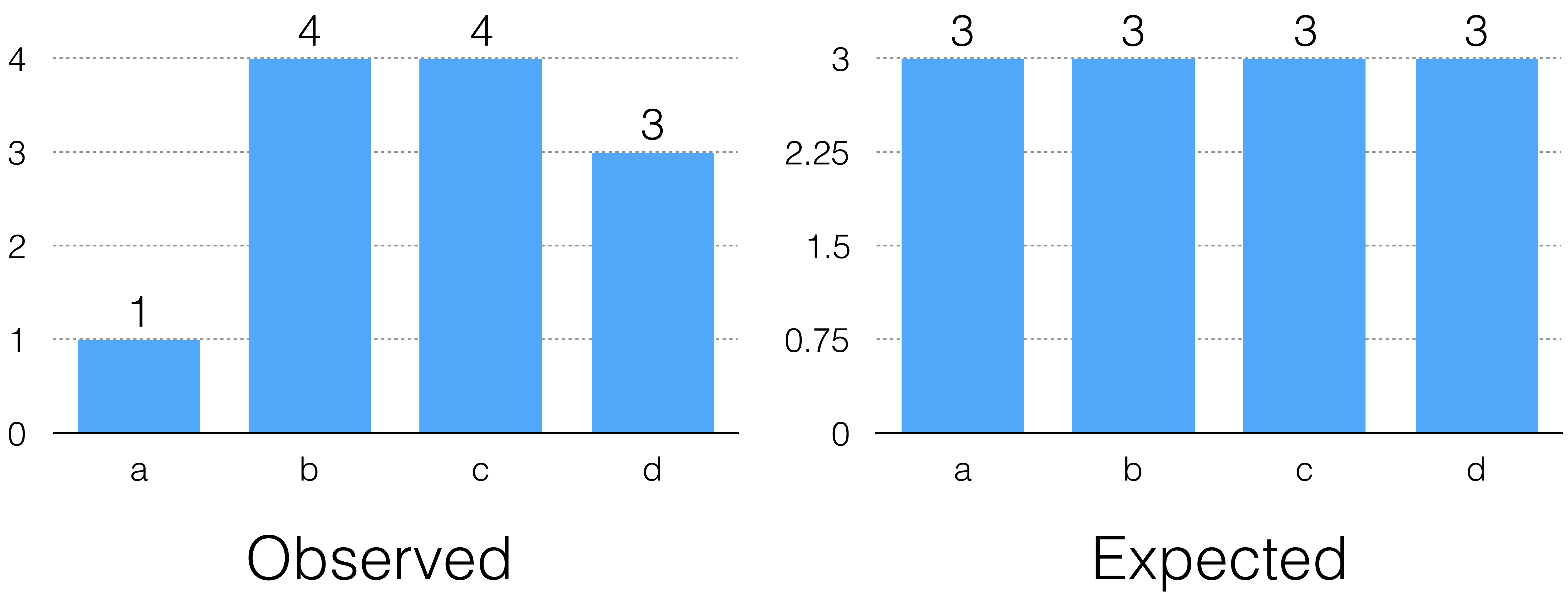

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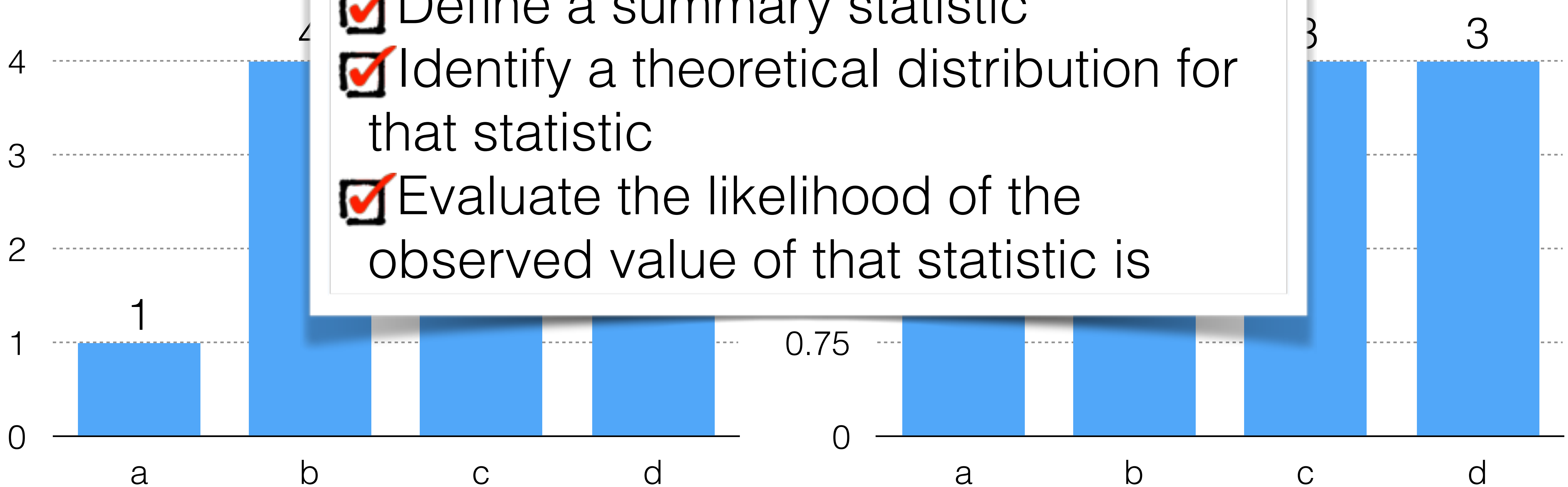

- ☑ Define a summary statistic
- ☑ Identify a theoretical distribution for that statistic
- ☑ Evaluate the likelihood of the observed value of that statistic is

Observed

Expected

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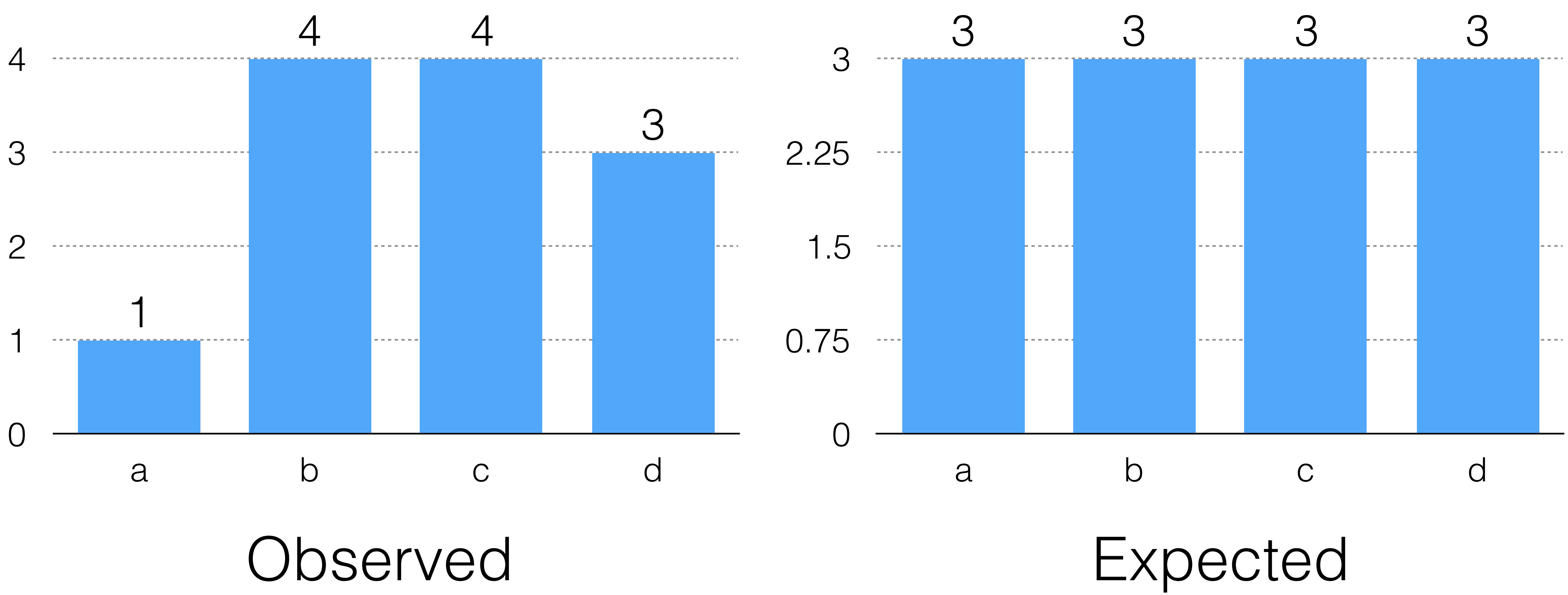

Want to model the difference between these

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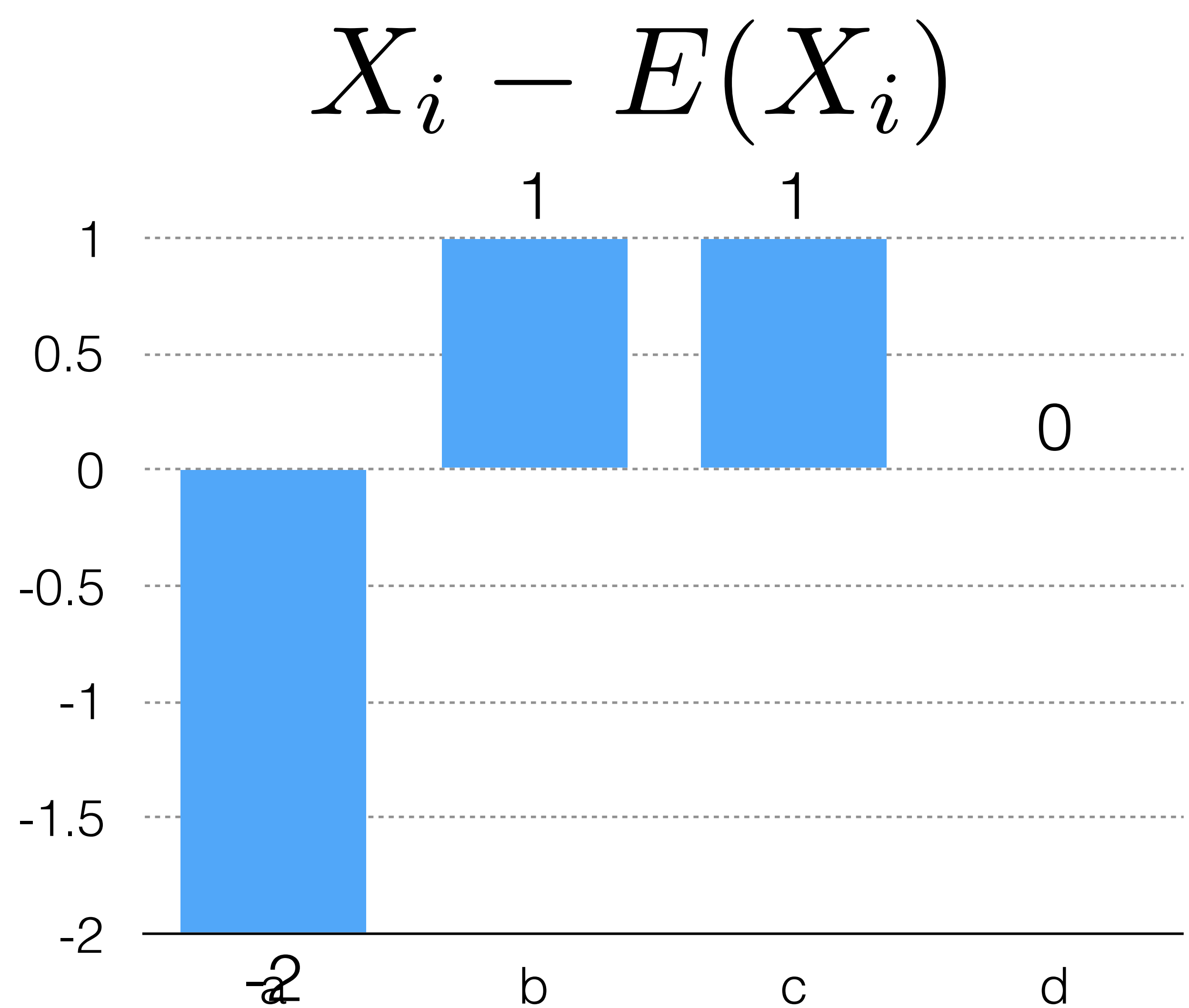

Clicker Question!

Should I use the total difference between observed and expected as my summary statistic? I.e.

$$\sum_i (X_i - E(X_i))$$

a) Yes! That sounds good.
b) No! I have qualms...

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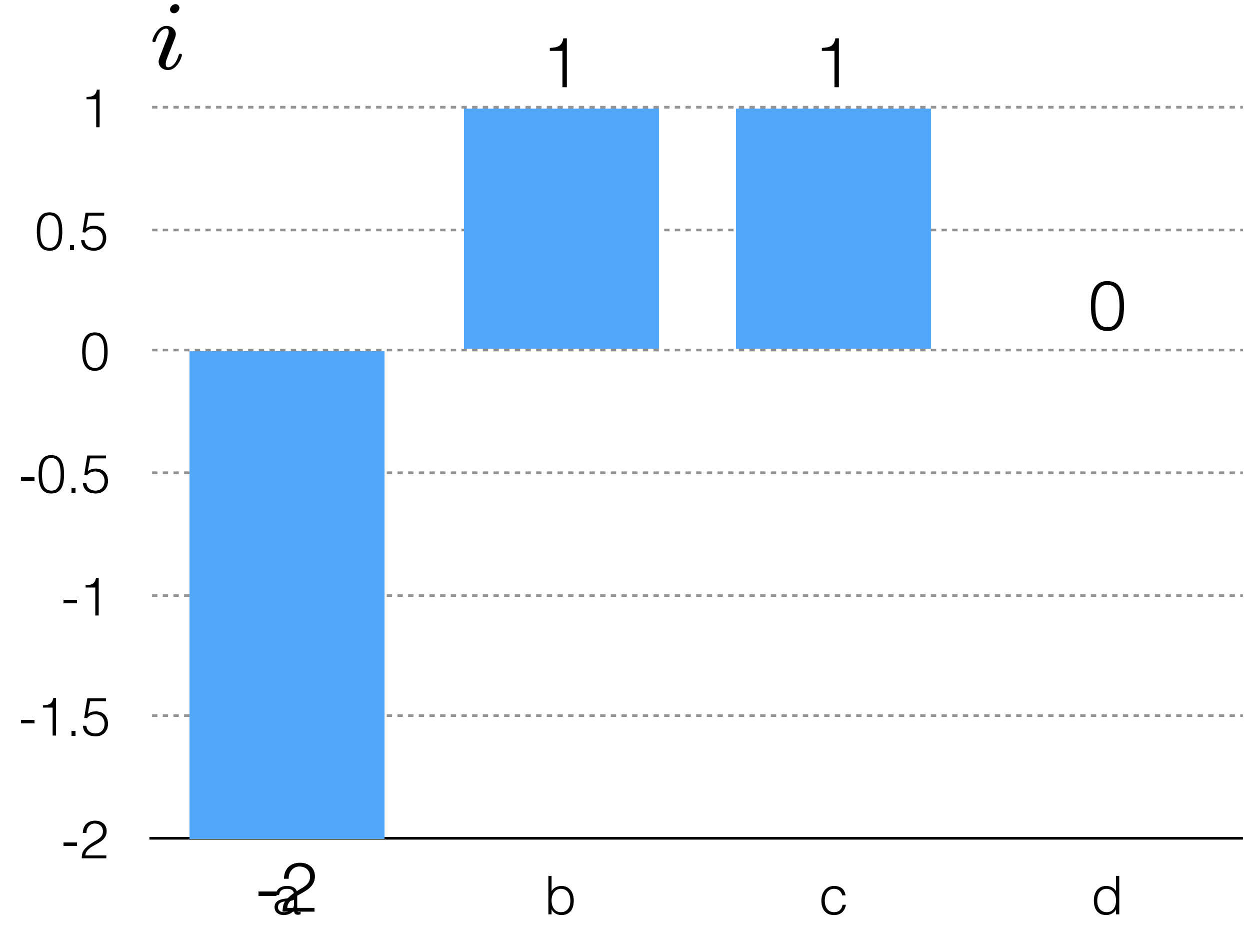
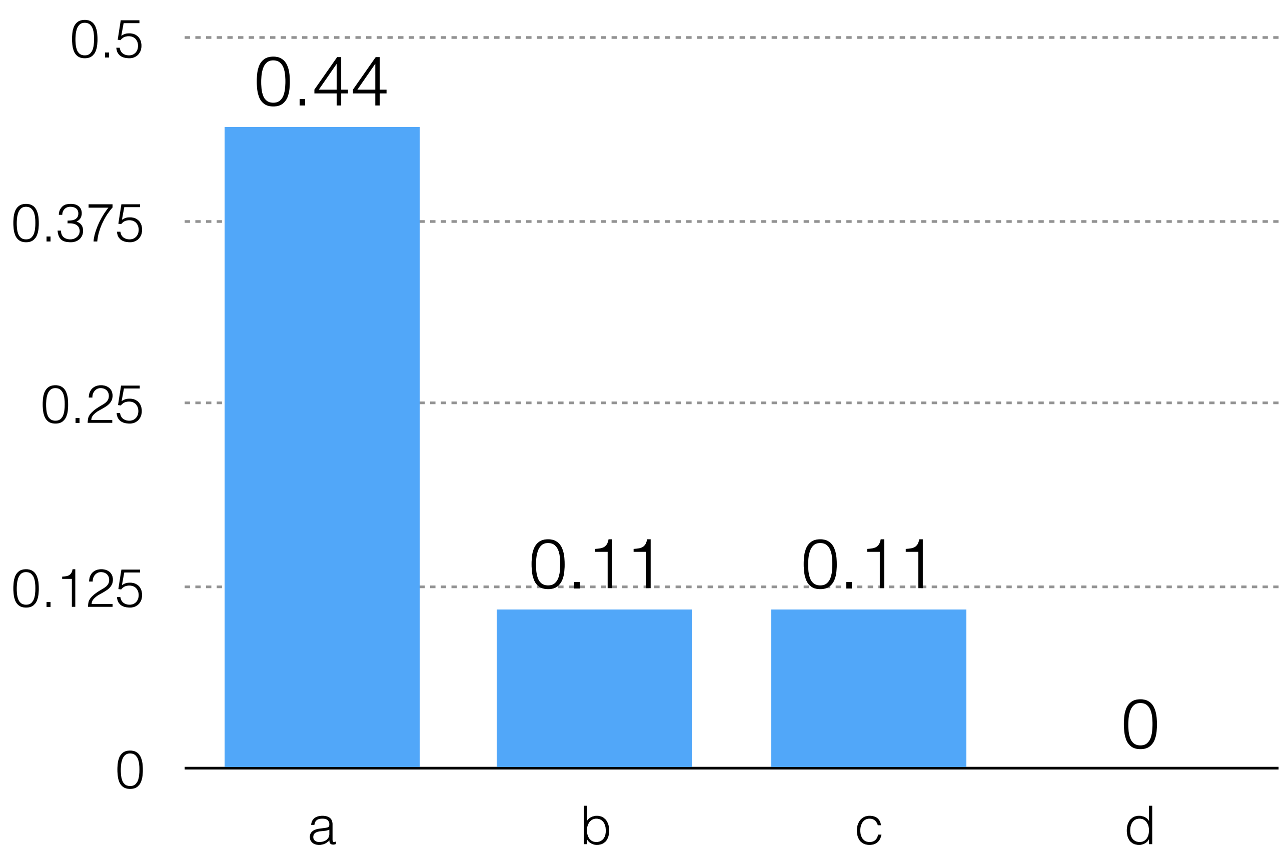
$$\sum_i (X_i - E(X_i)) = 0$$



Are the answers to my clicker questions random?

$$\sum_i (X_i - E(X_i))^2$$



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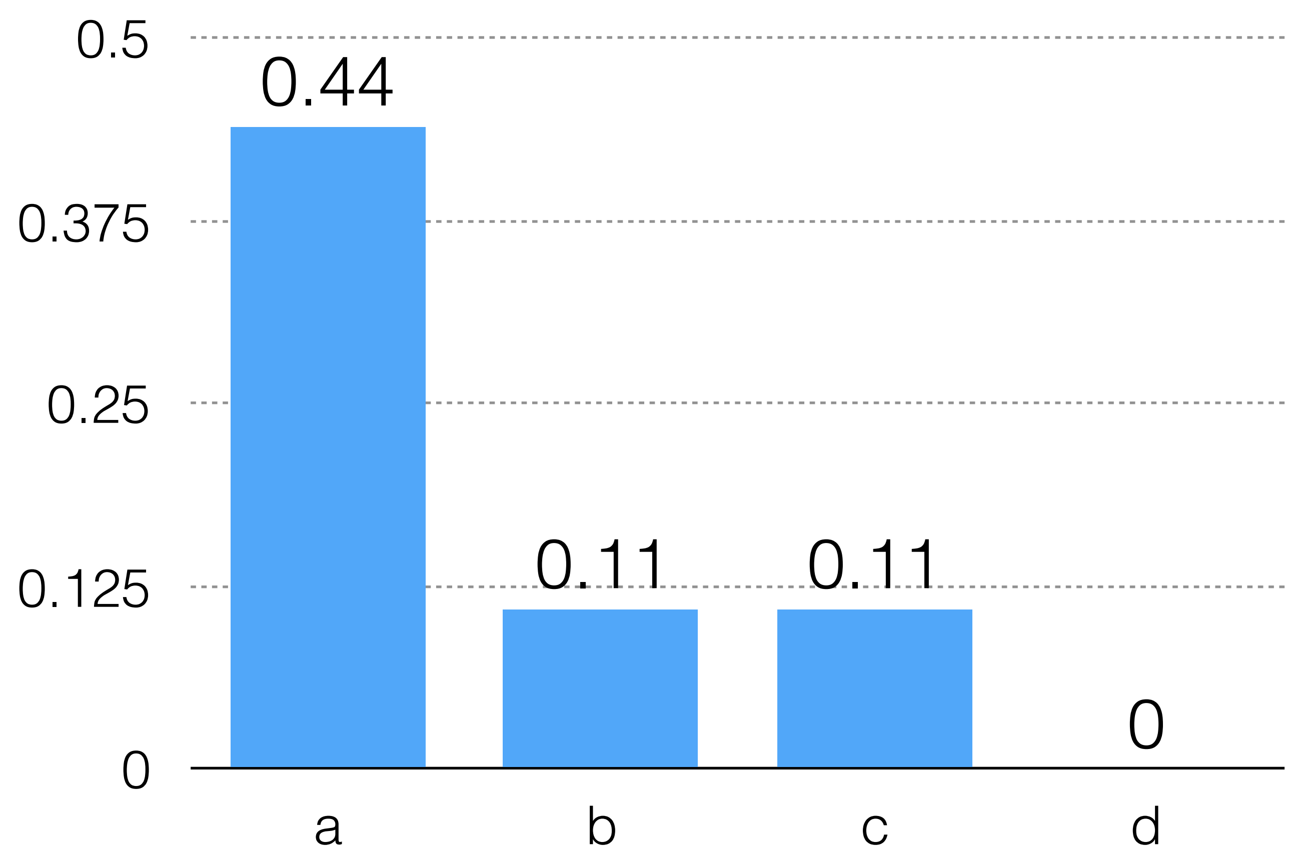
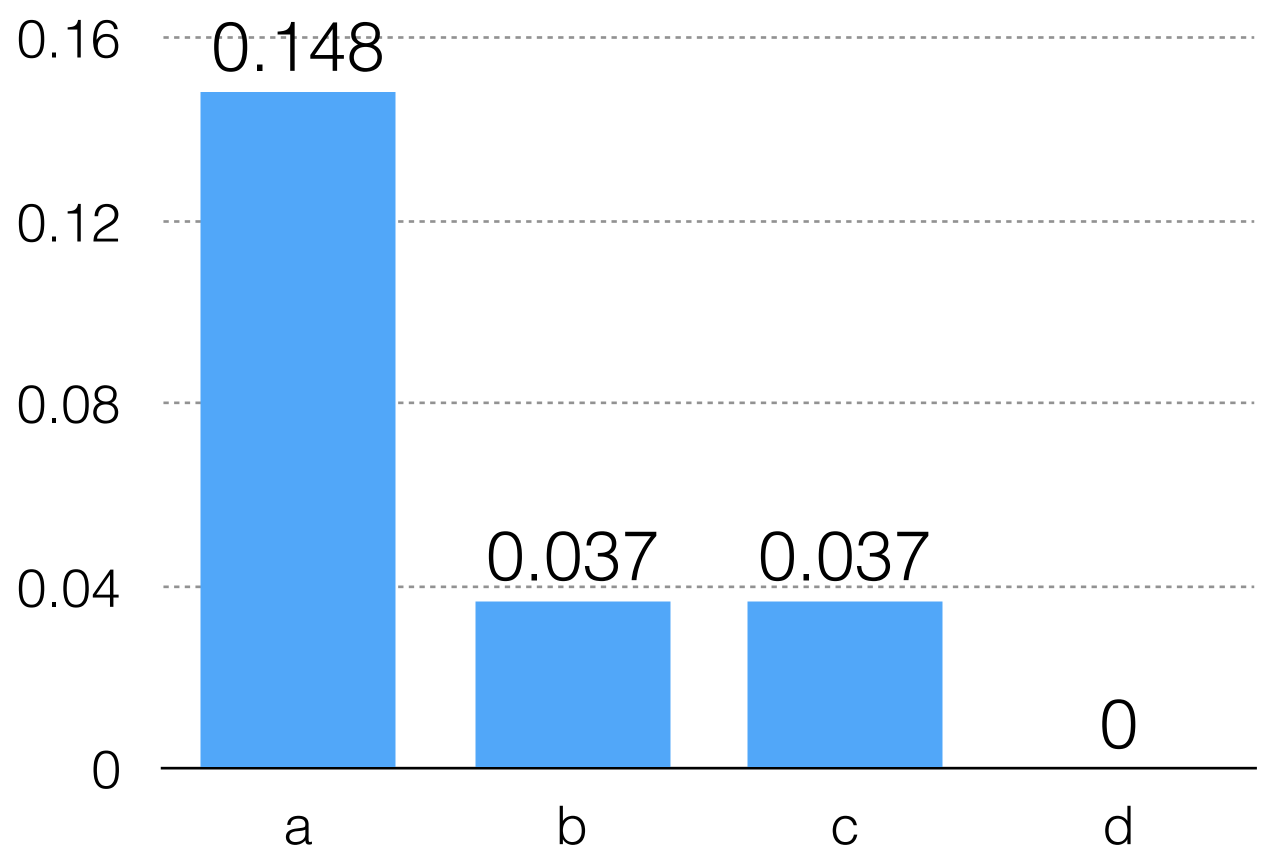


Thoughts?

Are the answers to my clicker questions random?

$$\sum_i \frac{(X_i - E(X_i))^2}{E(X_i)}$$



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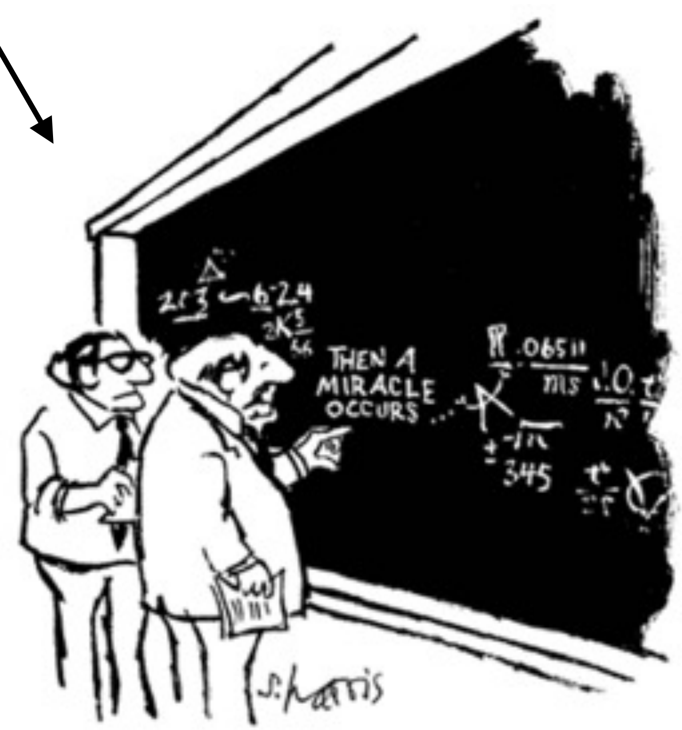

"I think you should be more explicit here in step two."

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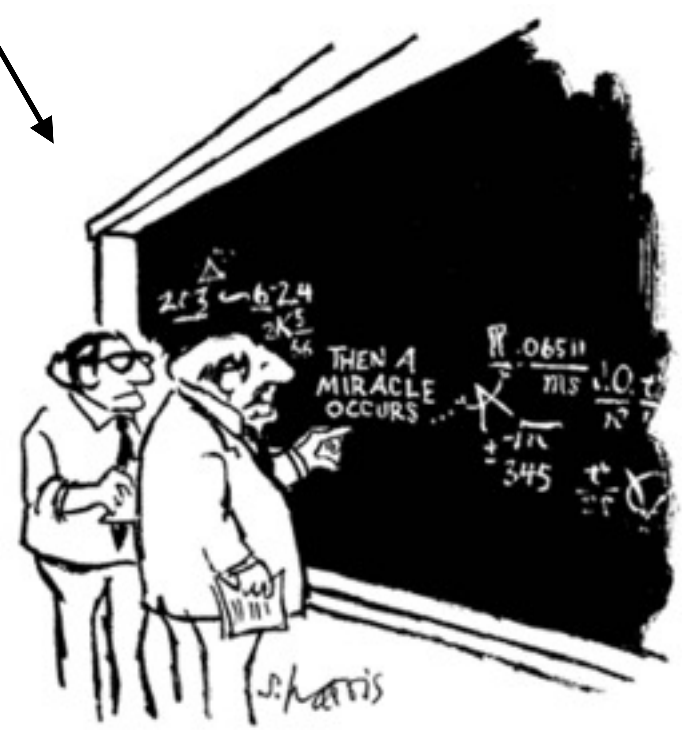

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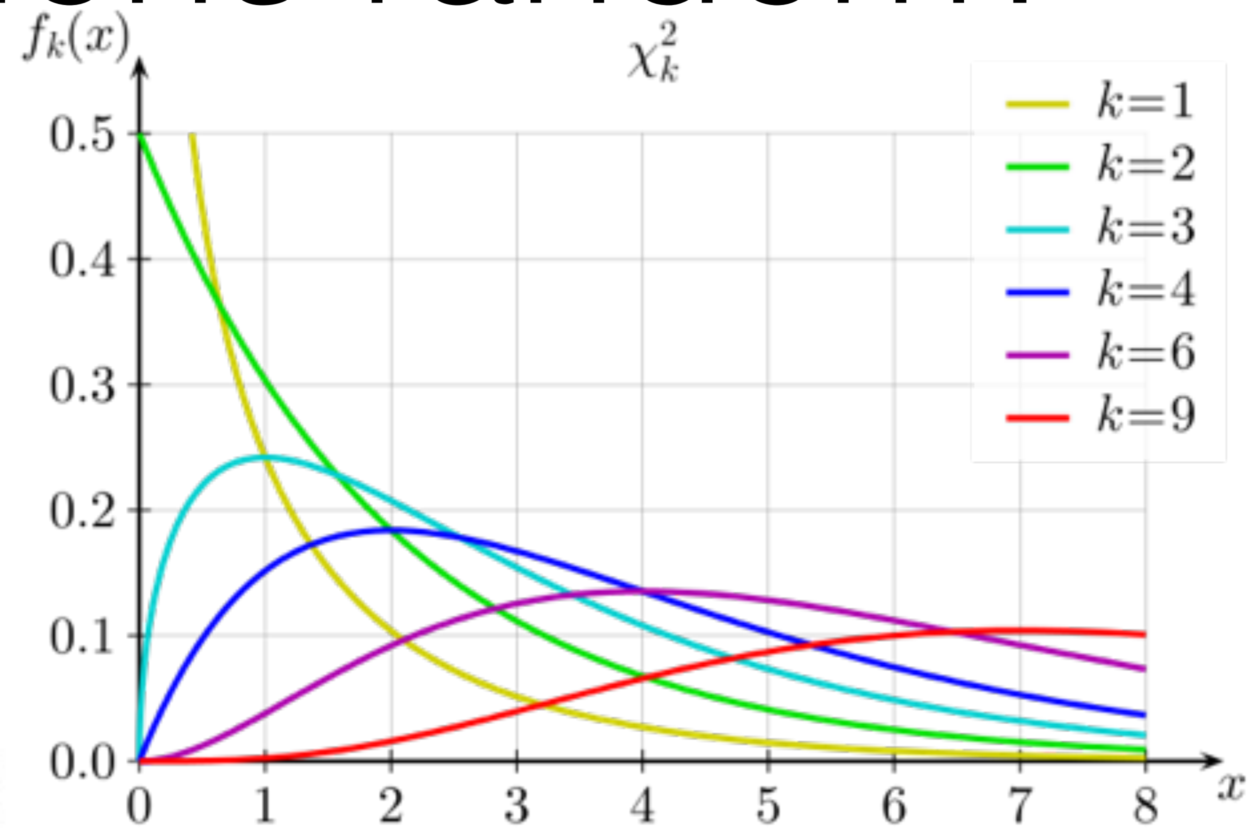
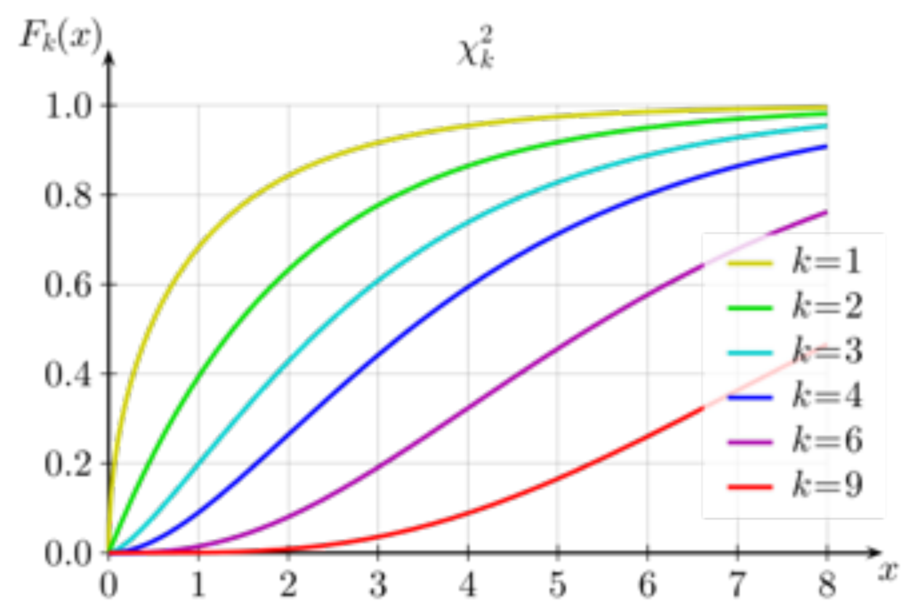


Chi Squared Test

$$\sum_i \frac{(X_i - E(X_i))^2}{E(X_i)}$$



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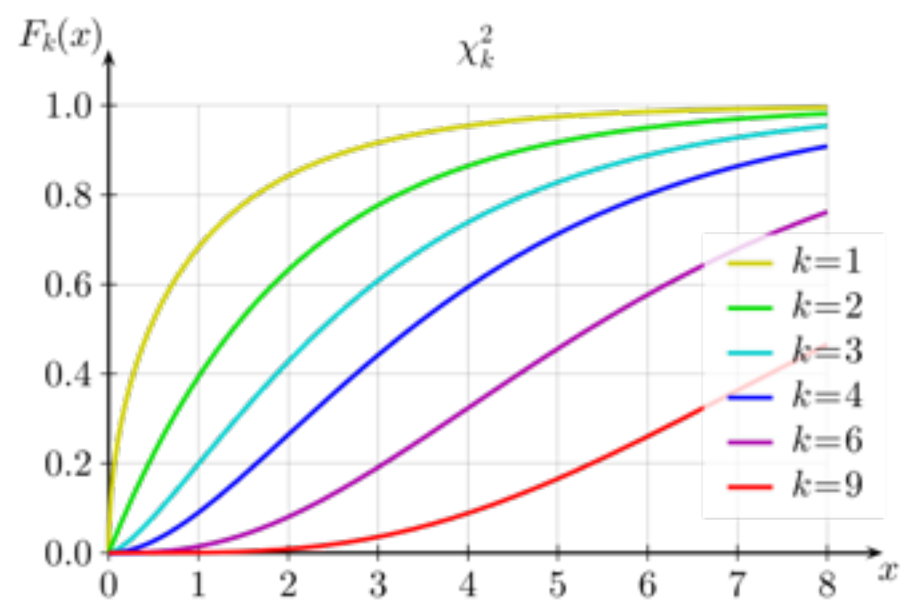
cdf that we can compute explicitly



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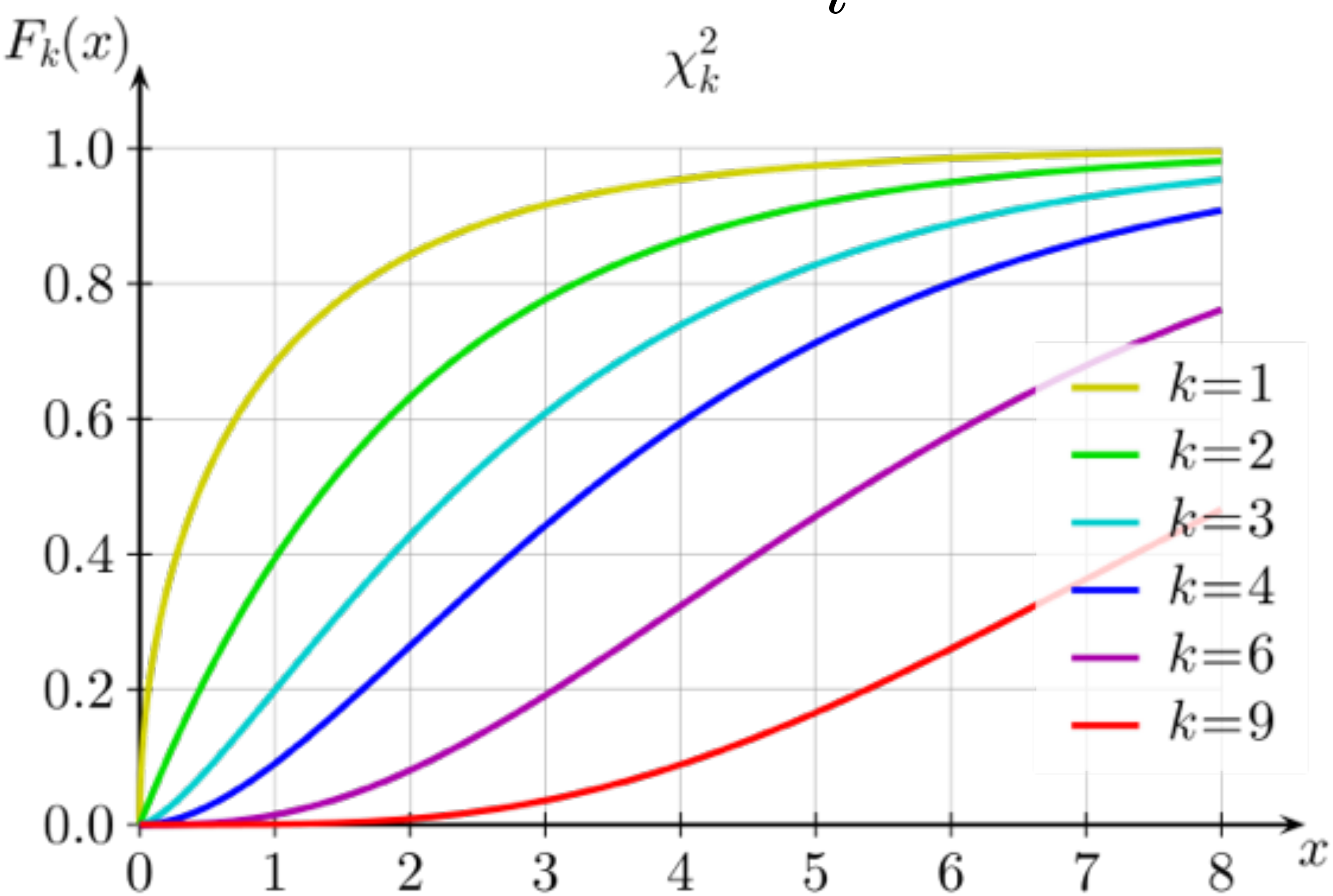

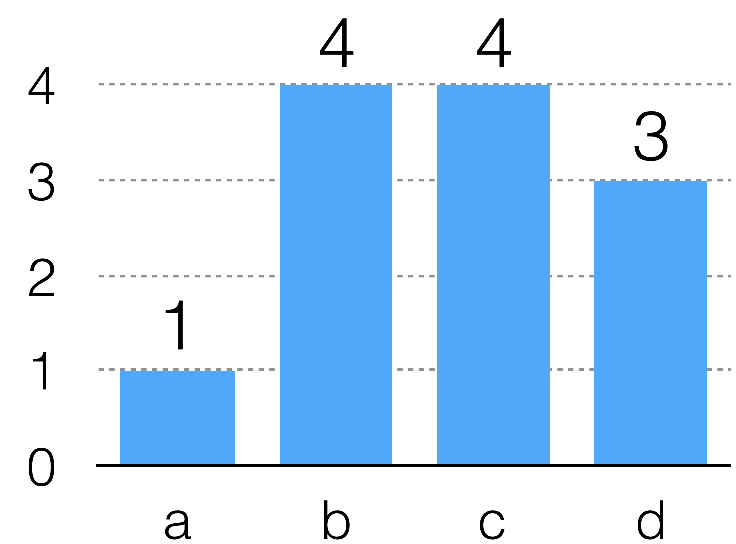

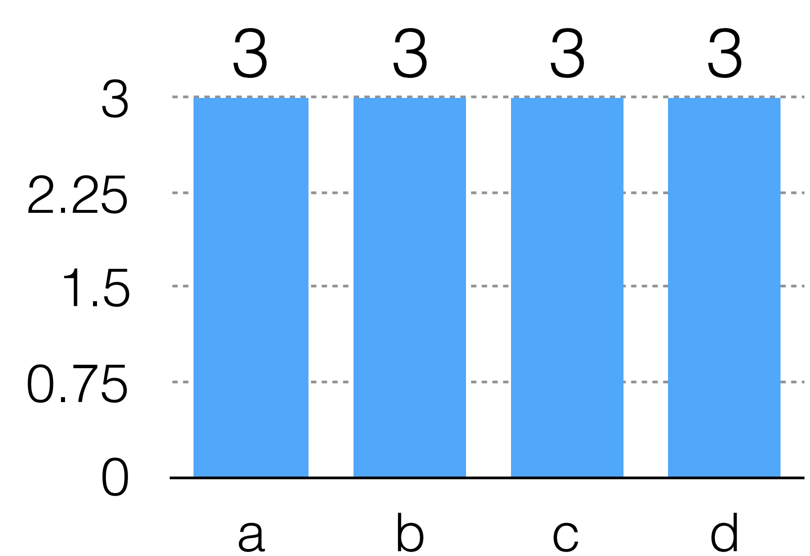

Chi Squared Test

not really remarkable

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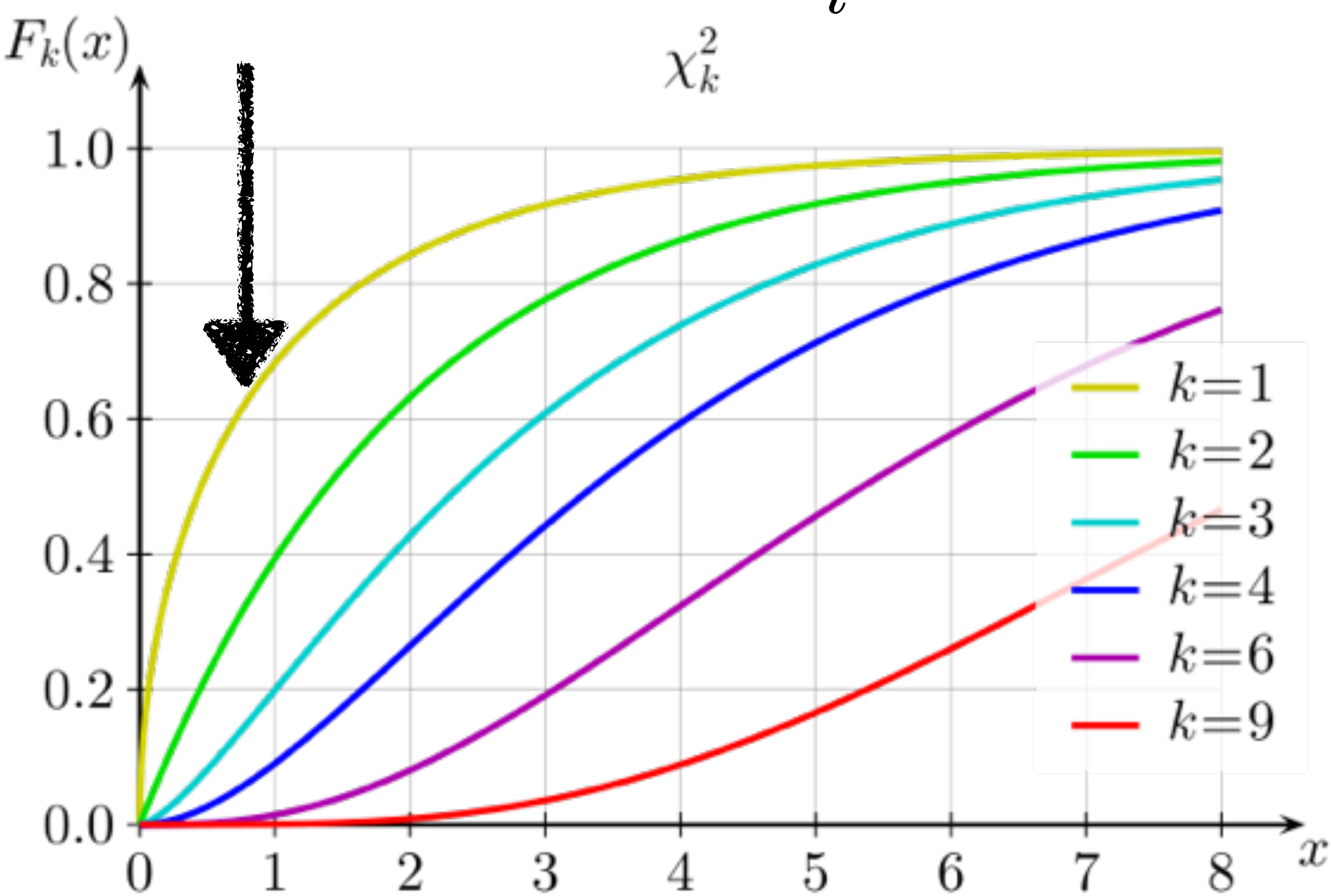

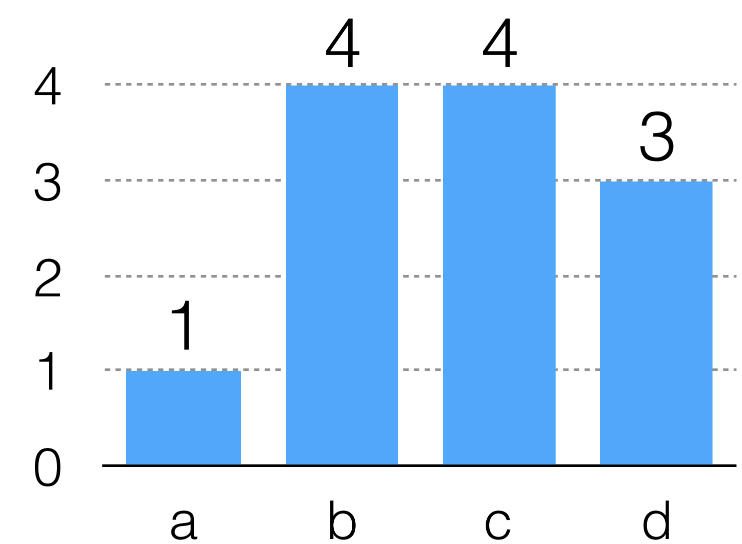

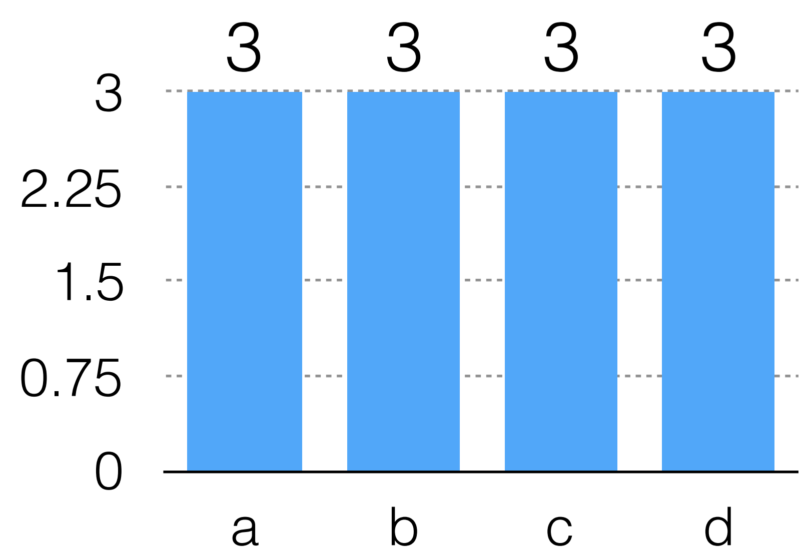

Hypothesis Testing in General

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Hypothesis Testing in General

Thing you can model

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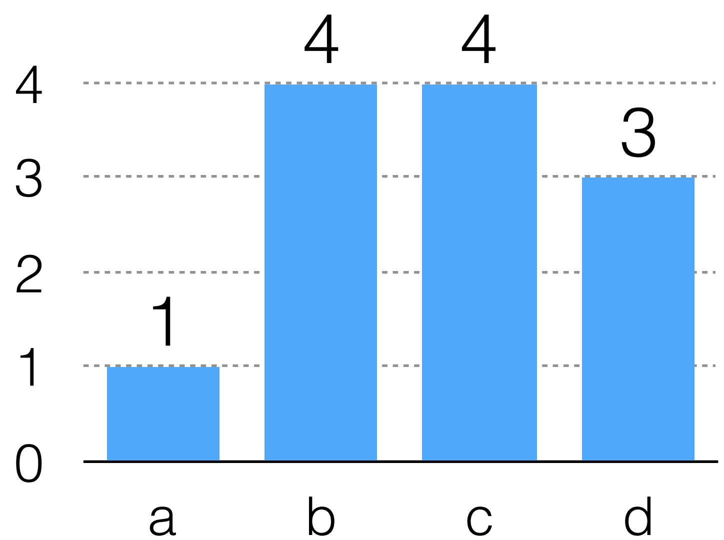

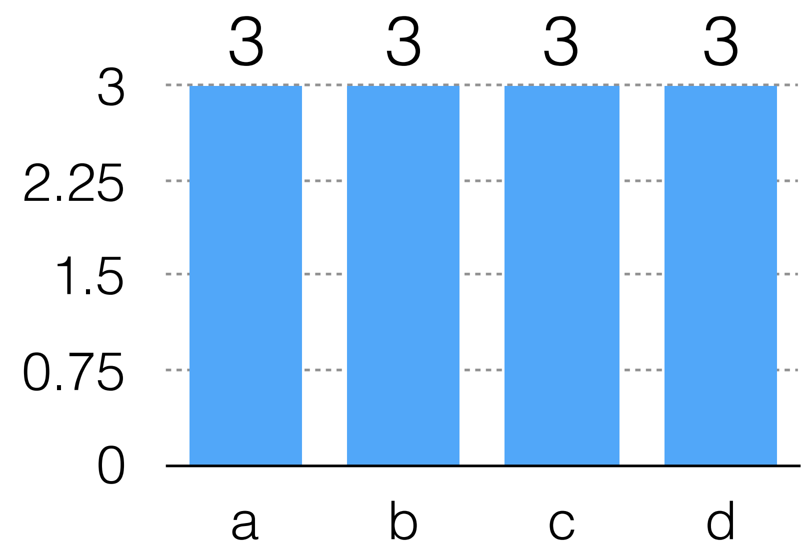

a) The number of (a)s is the same as the number of (b)s
b) The distribution observed is different from what is expected
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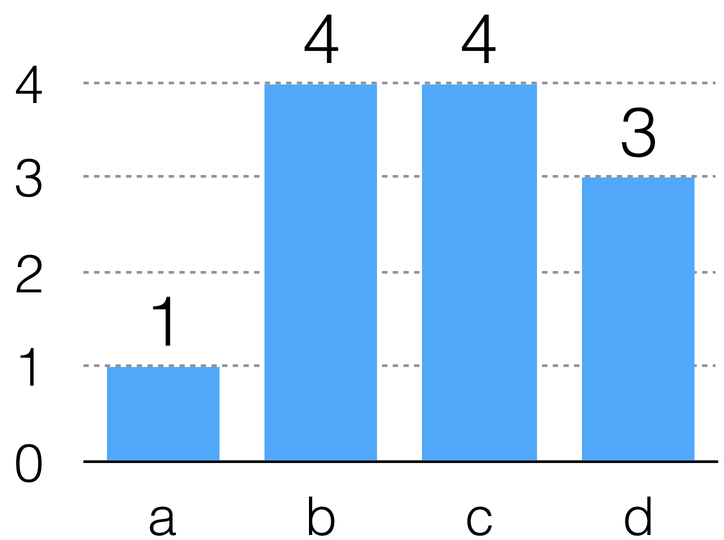

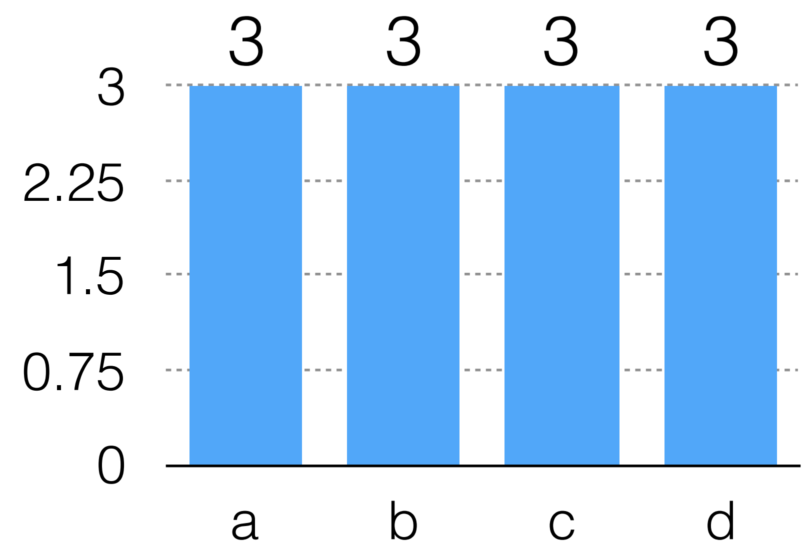

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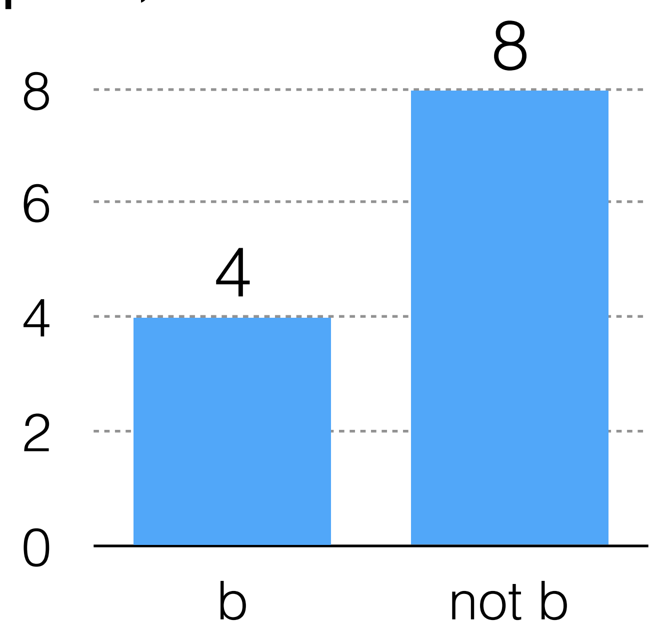

a) 80% of the answers are (b)
b) The answers are evenly distributed
c) The number of (b)s is abnormally low
d) The number of (b)s is expected

Clicker Question!

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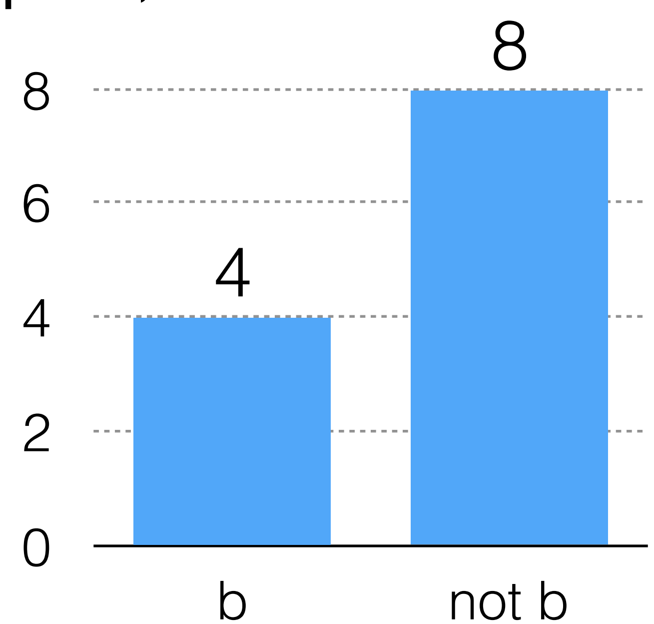

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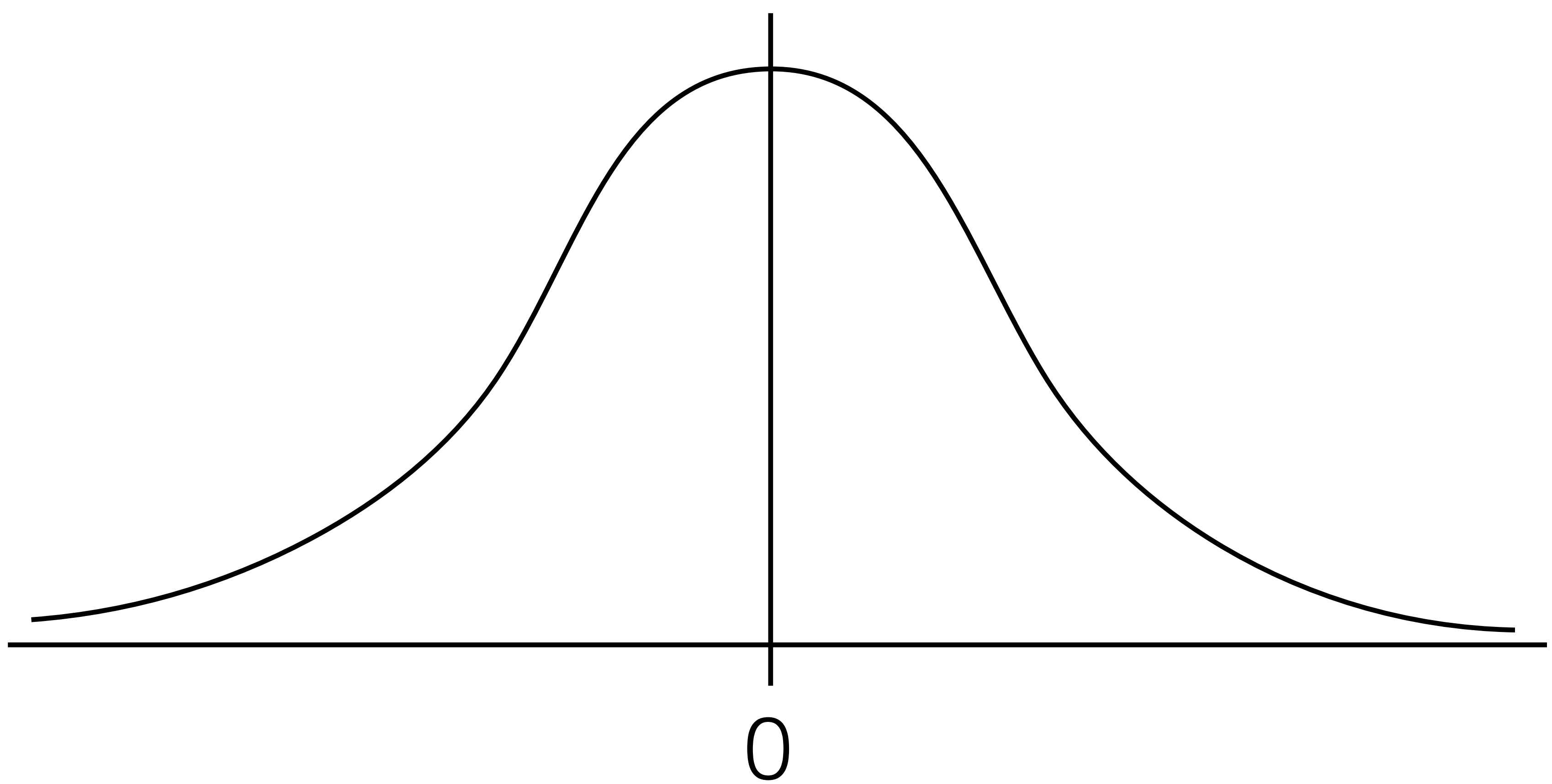
- We don't "accept" or "prove" H_0 or H_a

Standard Normal Distr.

$$\varphi(x) = \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}x^2}$$



z = distance from mean in std units

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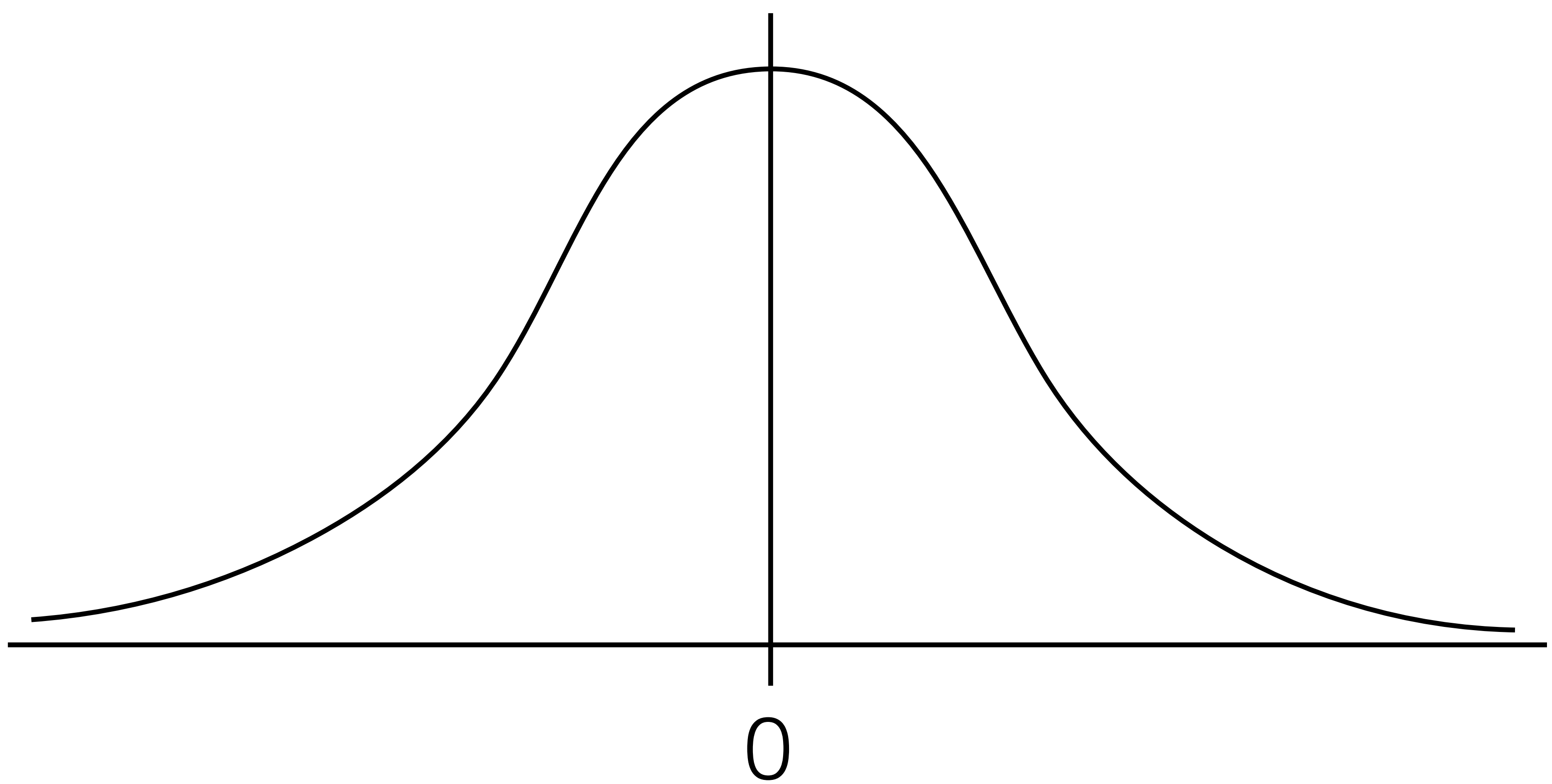

z = (observed - expected) / standard deviation

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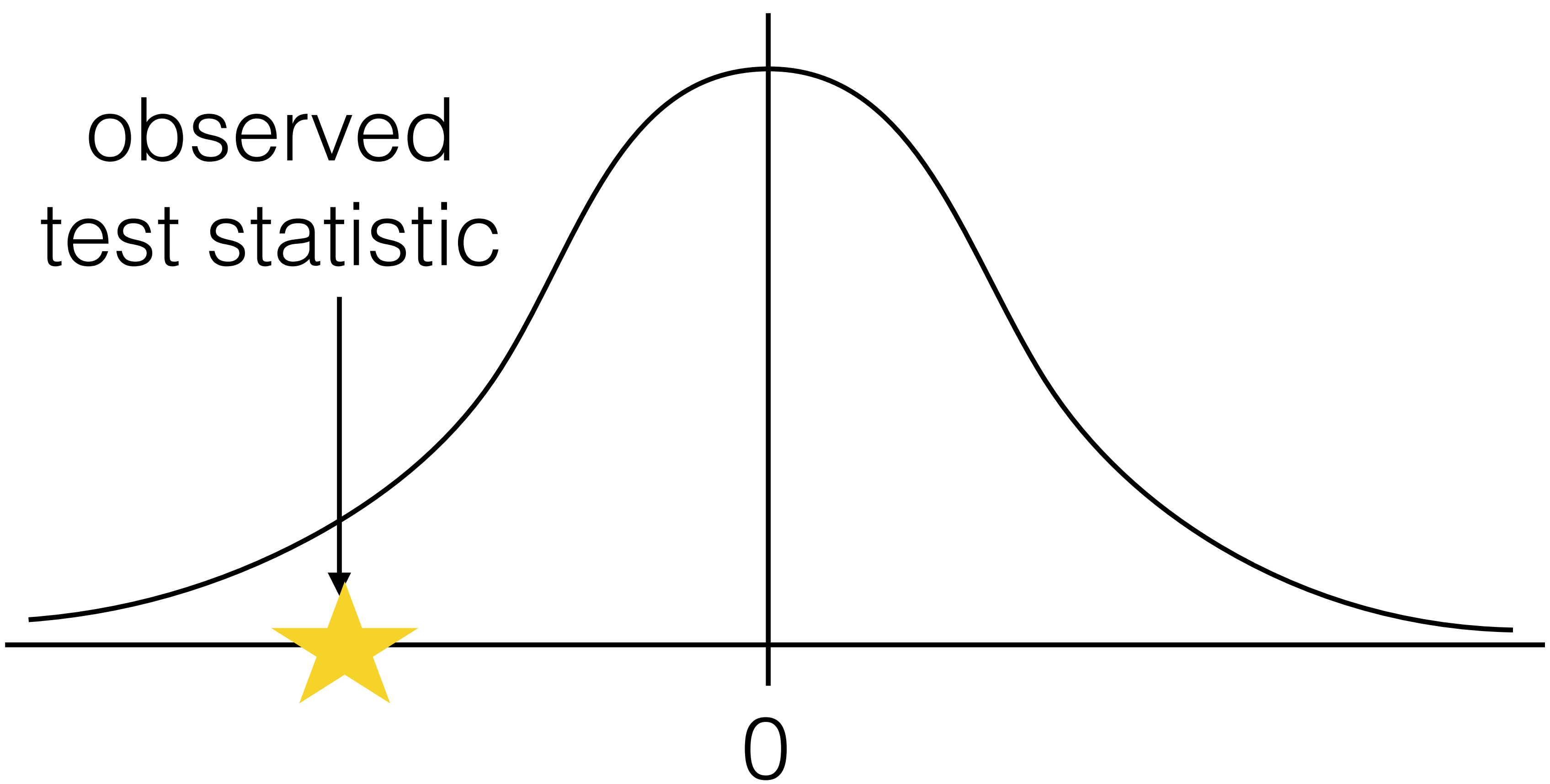

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cumulative
density =
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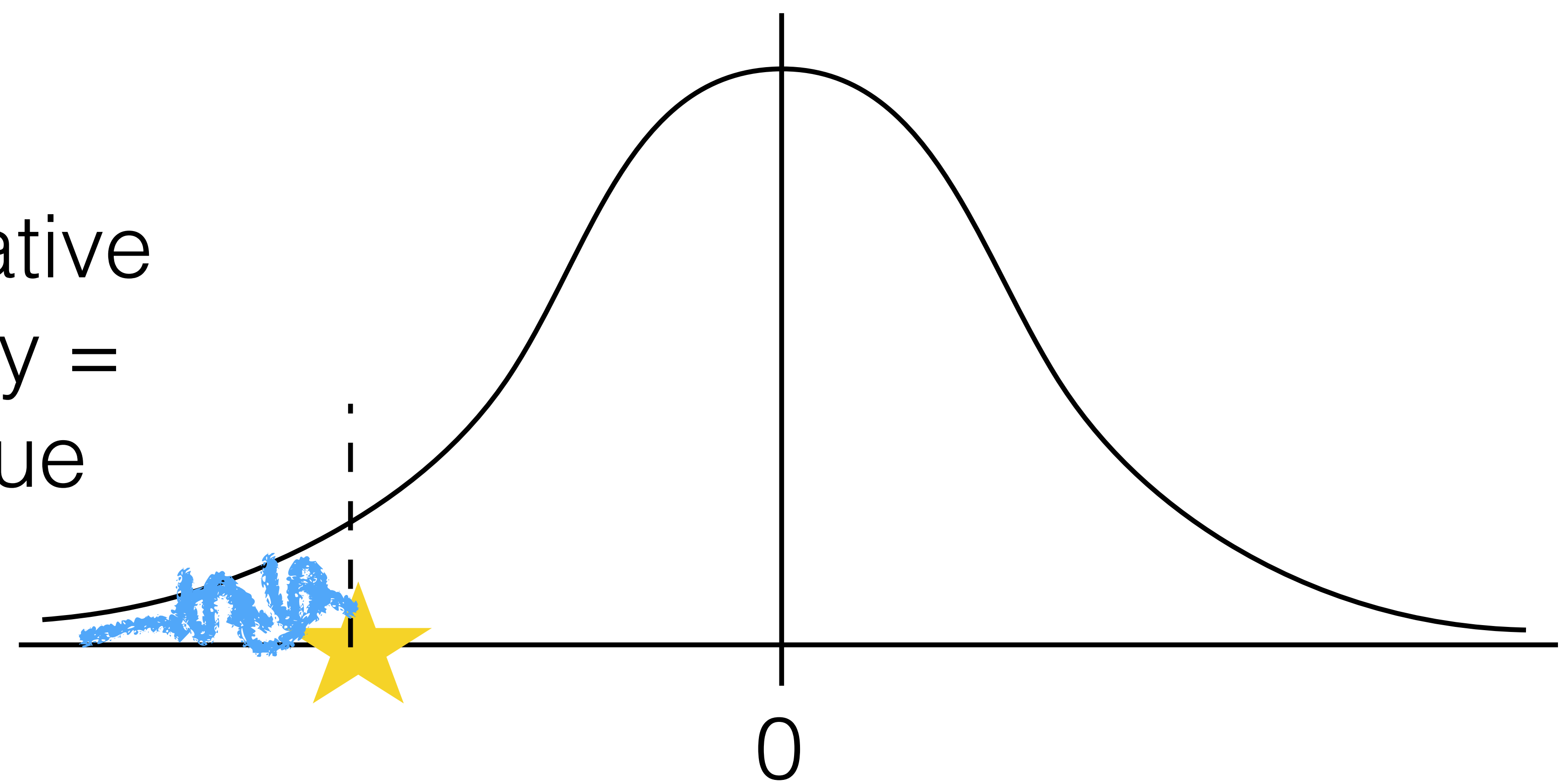

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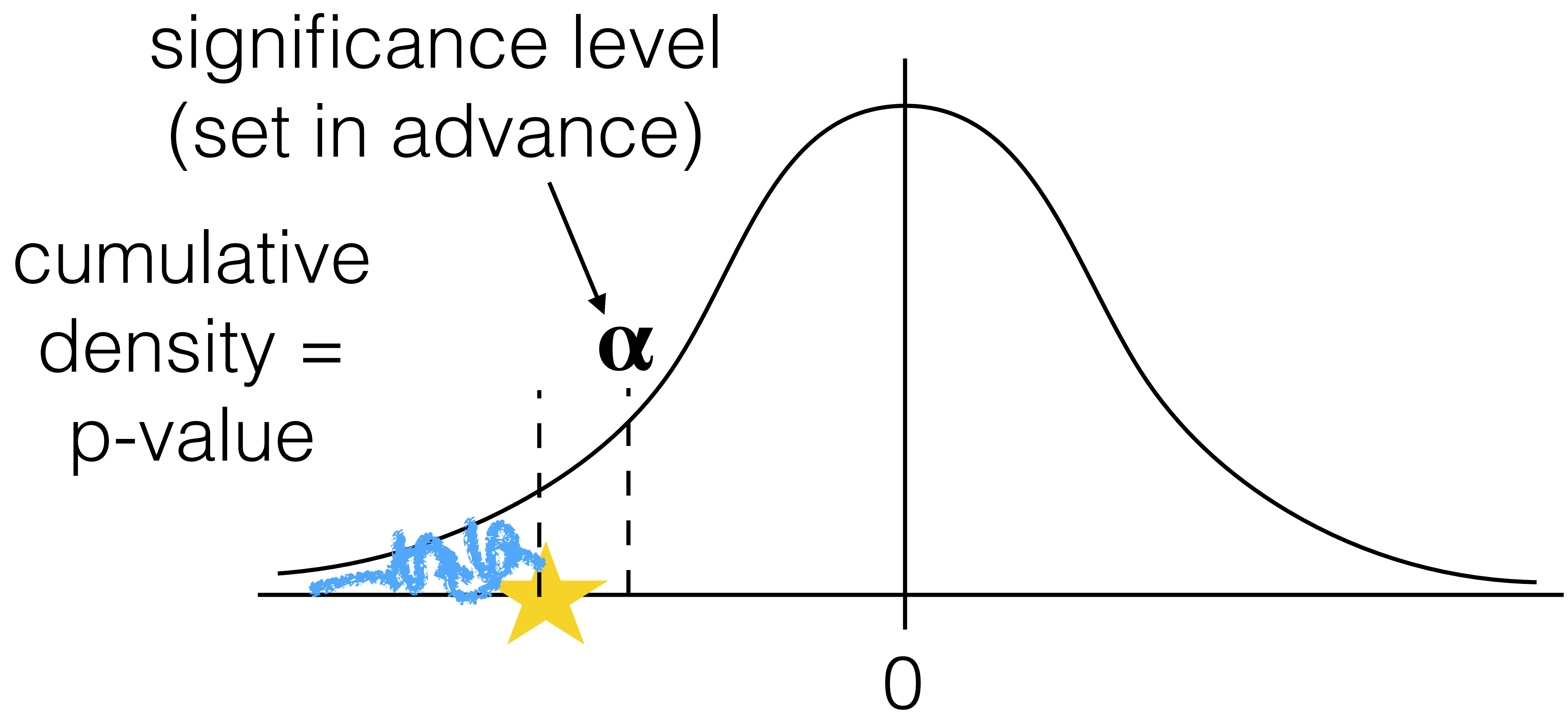

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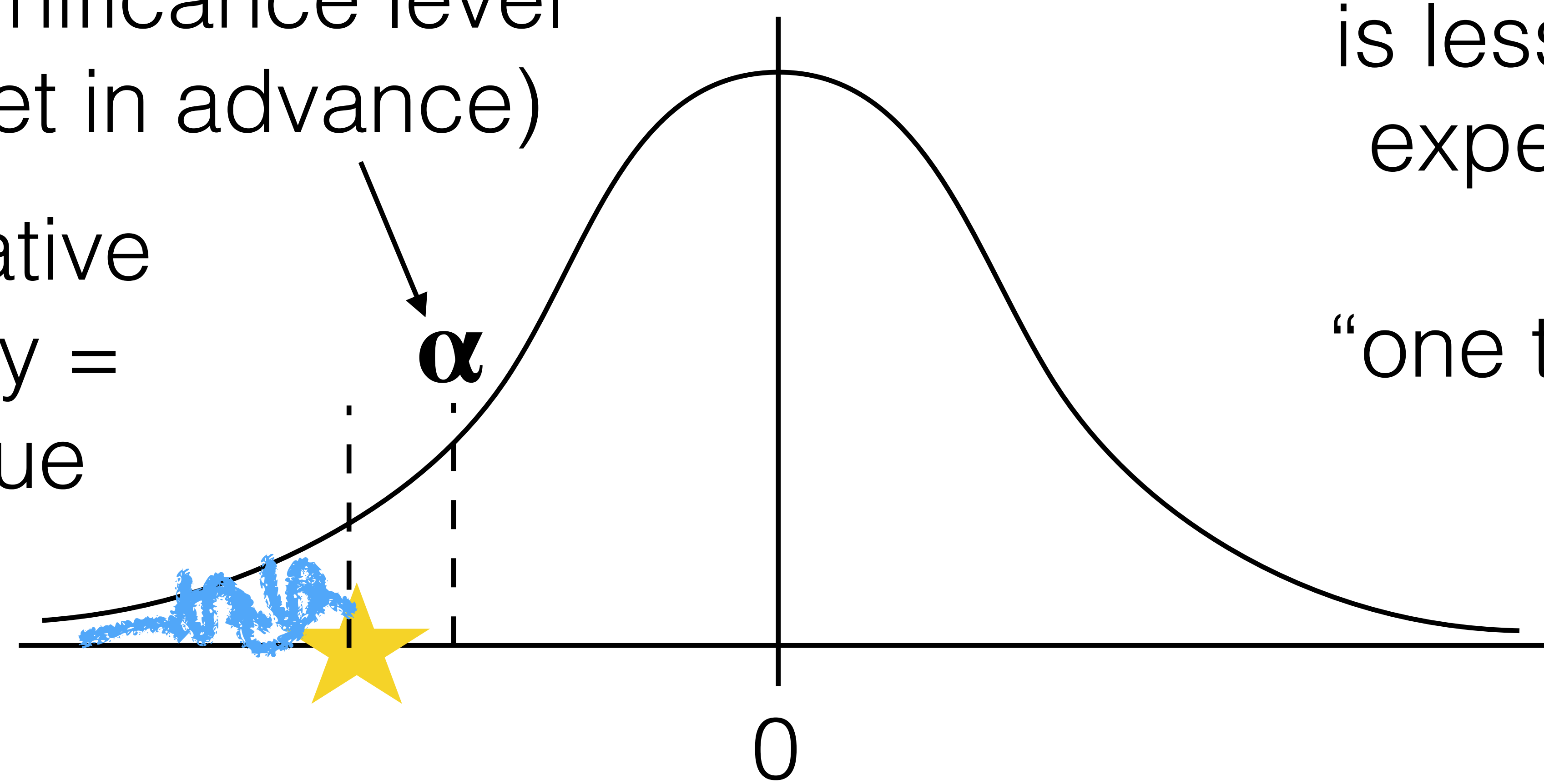
H_0 = test stat is less than expected

"one tailed"

significance level (set in advance)

cumulative density = p-value



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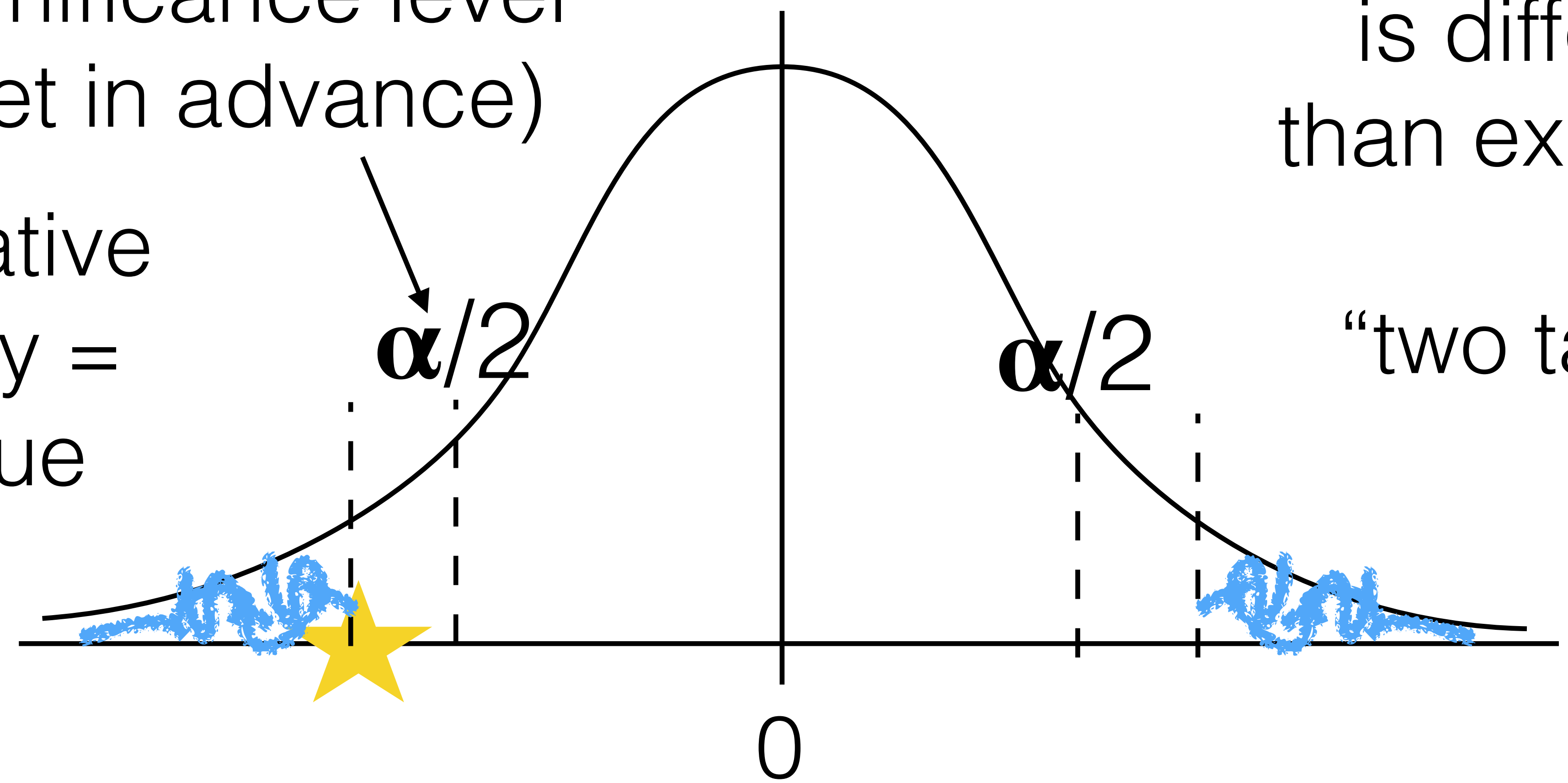


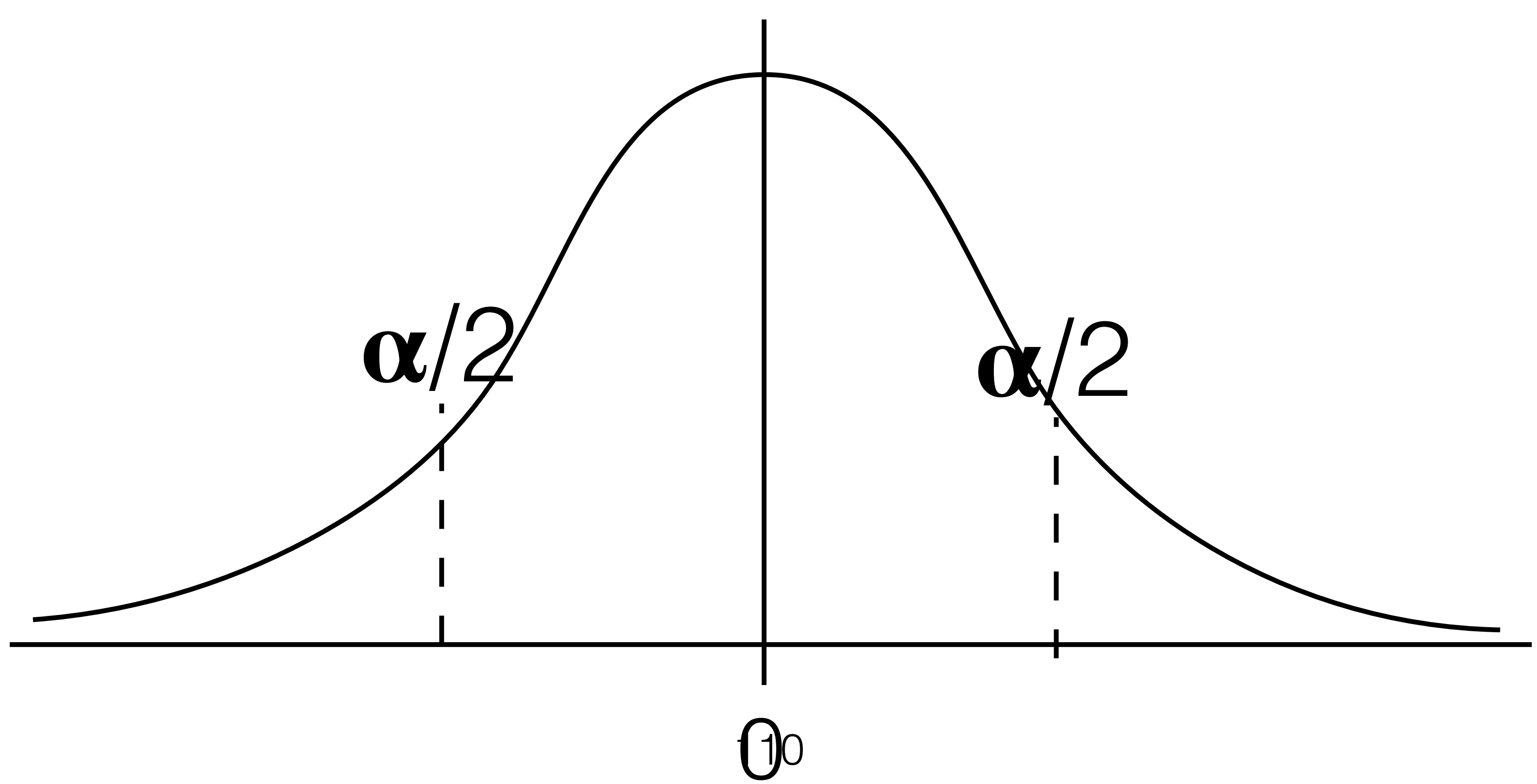
z = (observed - expected) / standard deviation

Test for population proportion

$$z = \frac{\hat{p} - p_0}{\sqrt{\frac{p_0(1-p_0)}{n}}}$$

H_0 = proportion of (b) is 80%

H_a = proportion of (b) is not 80%



Clicker Question!

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Why can we use a normally-distributed test statistic to evaluate a binomial distribution like this?

a) Because its a random variable
b) Because of regression to the mean
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e) The limit does not exist!

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Test for population means

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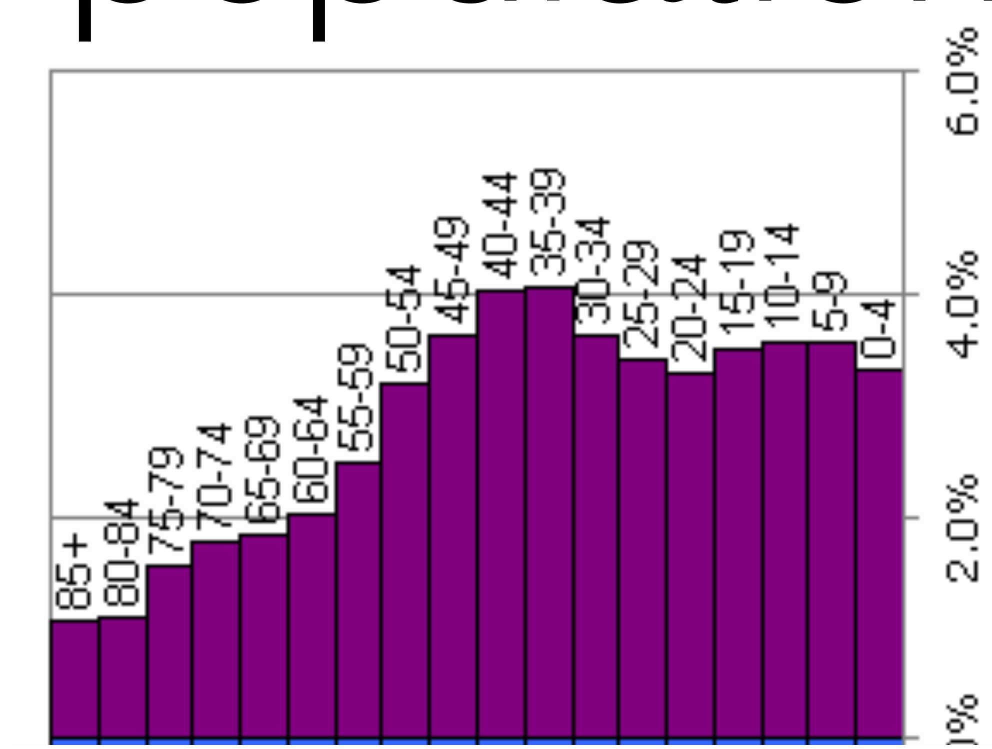
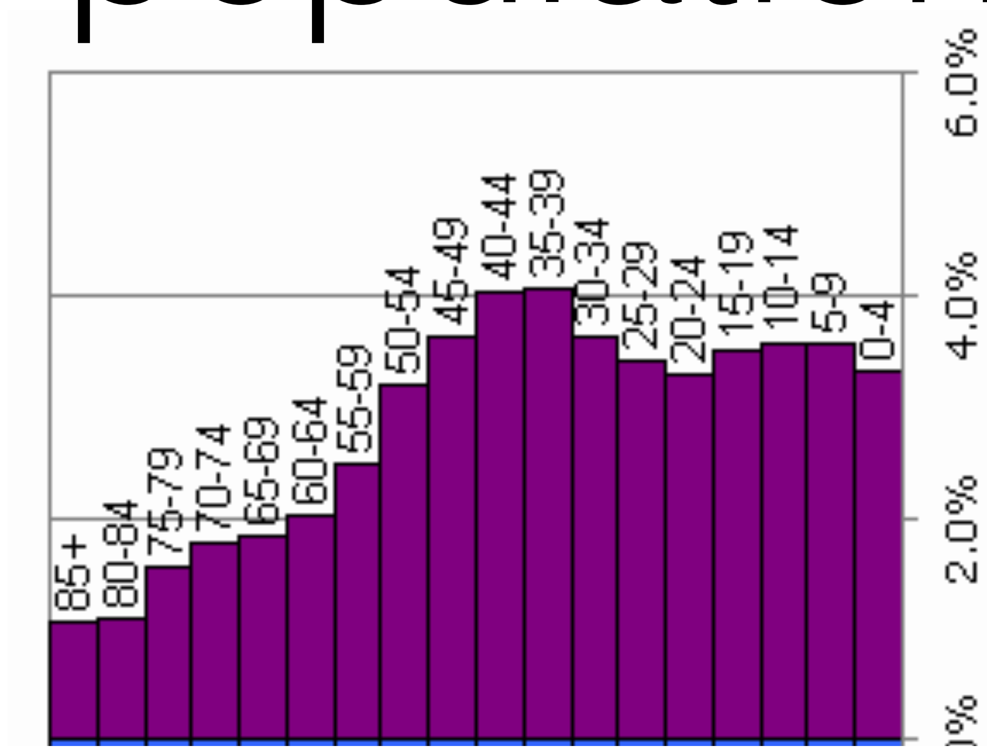


Distribution of ages in the US

http://www.censusscope.org/us/chart_age.html

Test for population means



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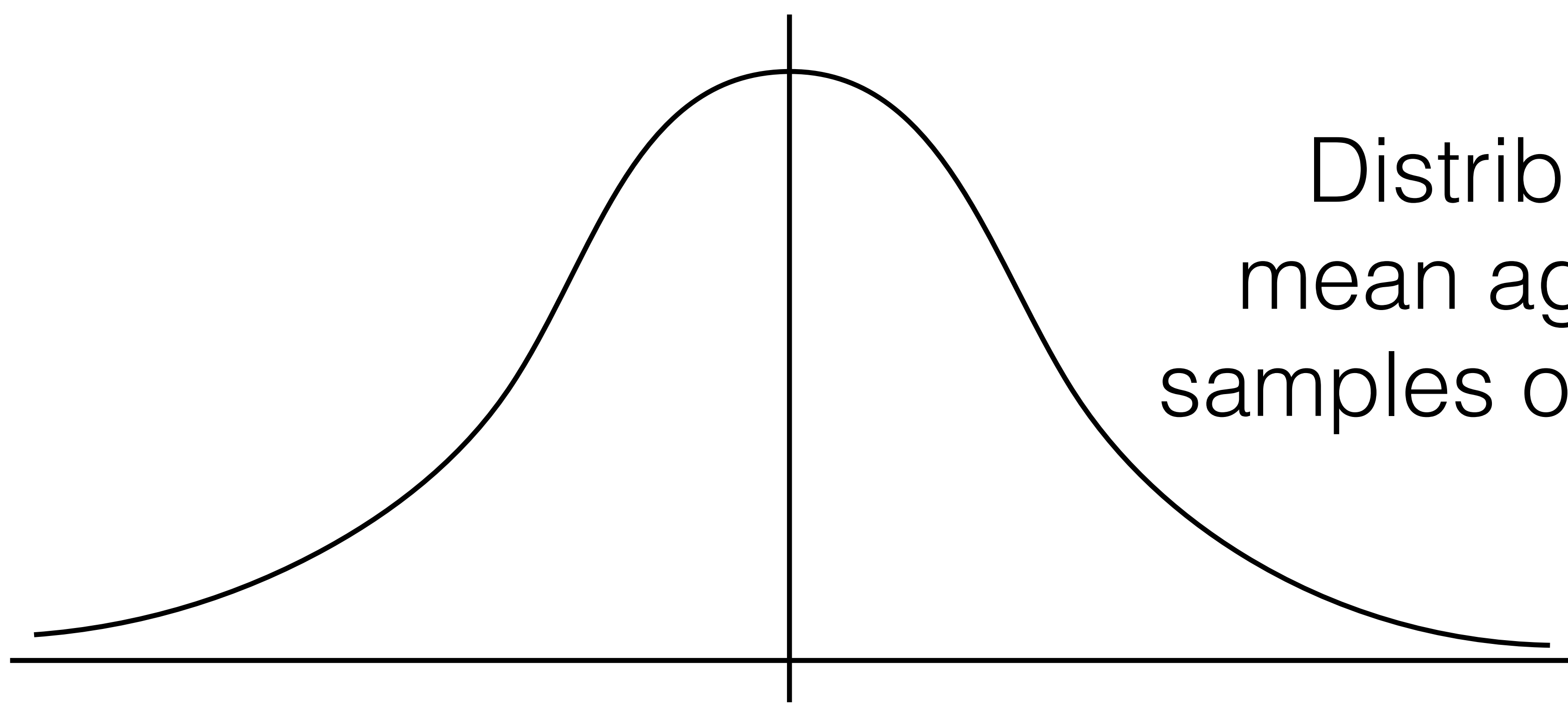

Distribution of mean ages given samples of US adults

0

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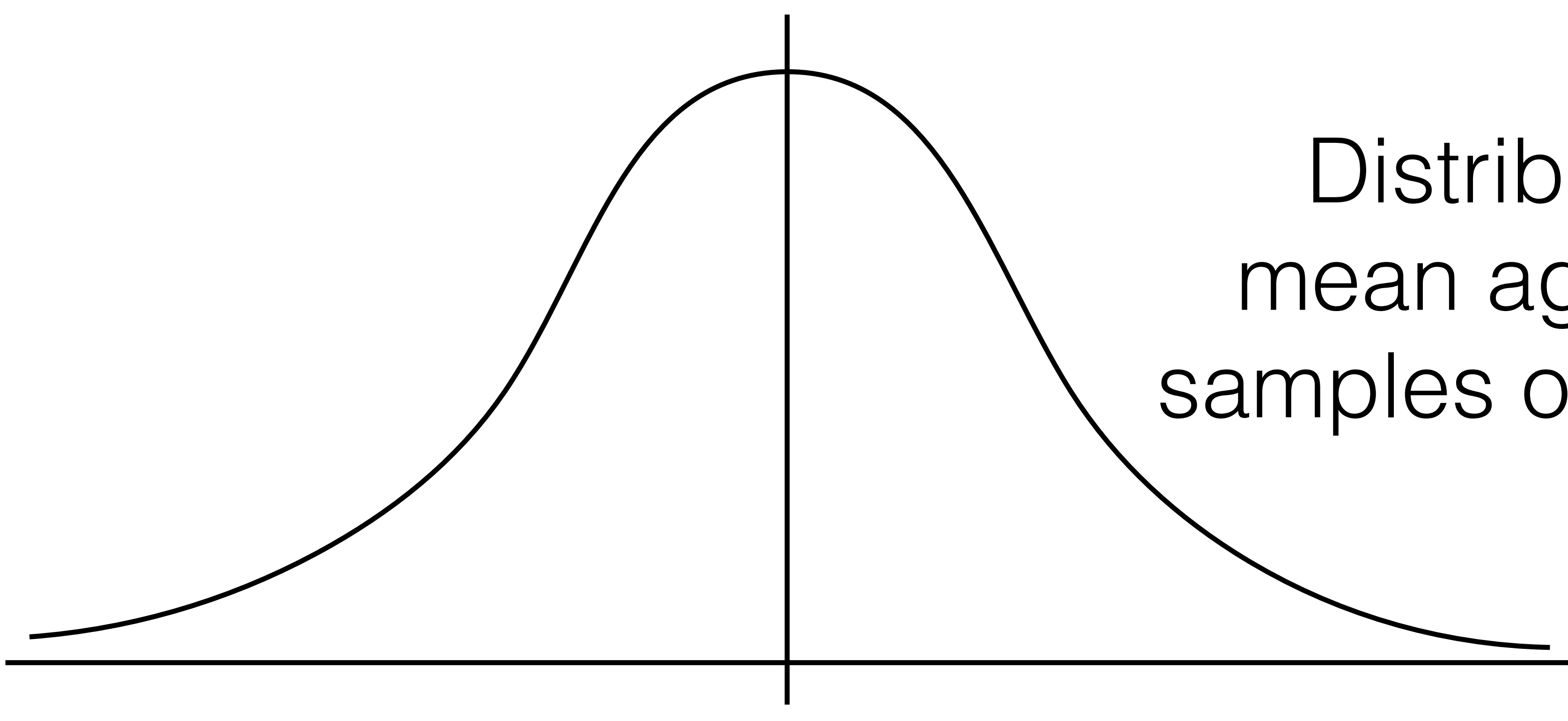
Test for population means

$$z = \frac{\bar{x} - \mu_0}{\sqrt{\frac{\sigma^2}{n}}}$$



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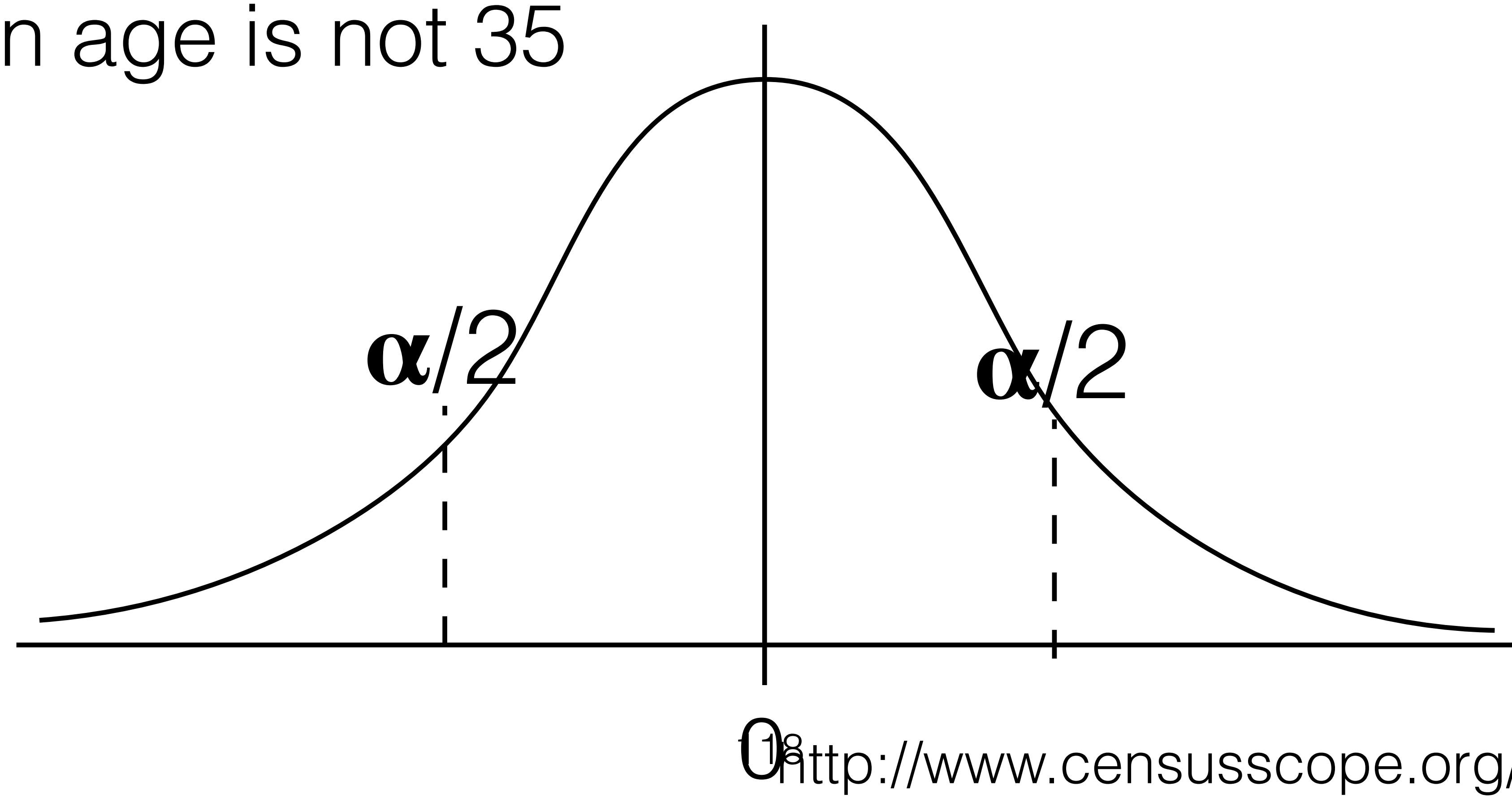
H_0 = mean age is 35

H_a = mean age is not 35



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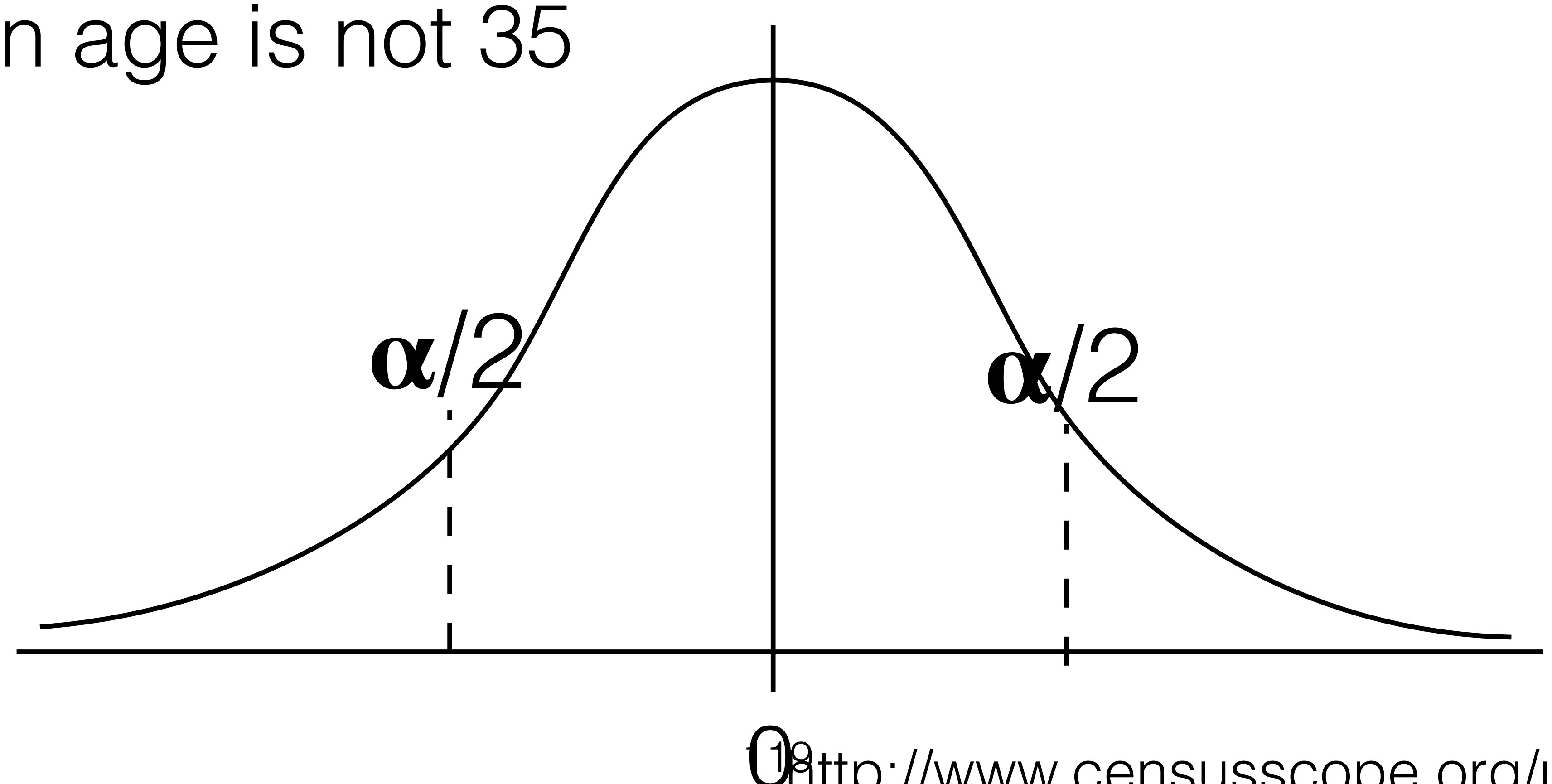

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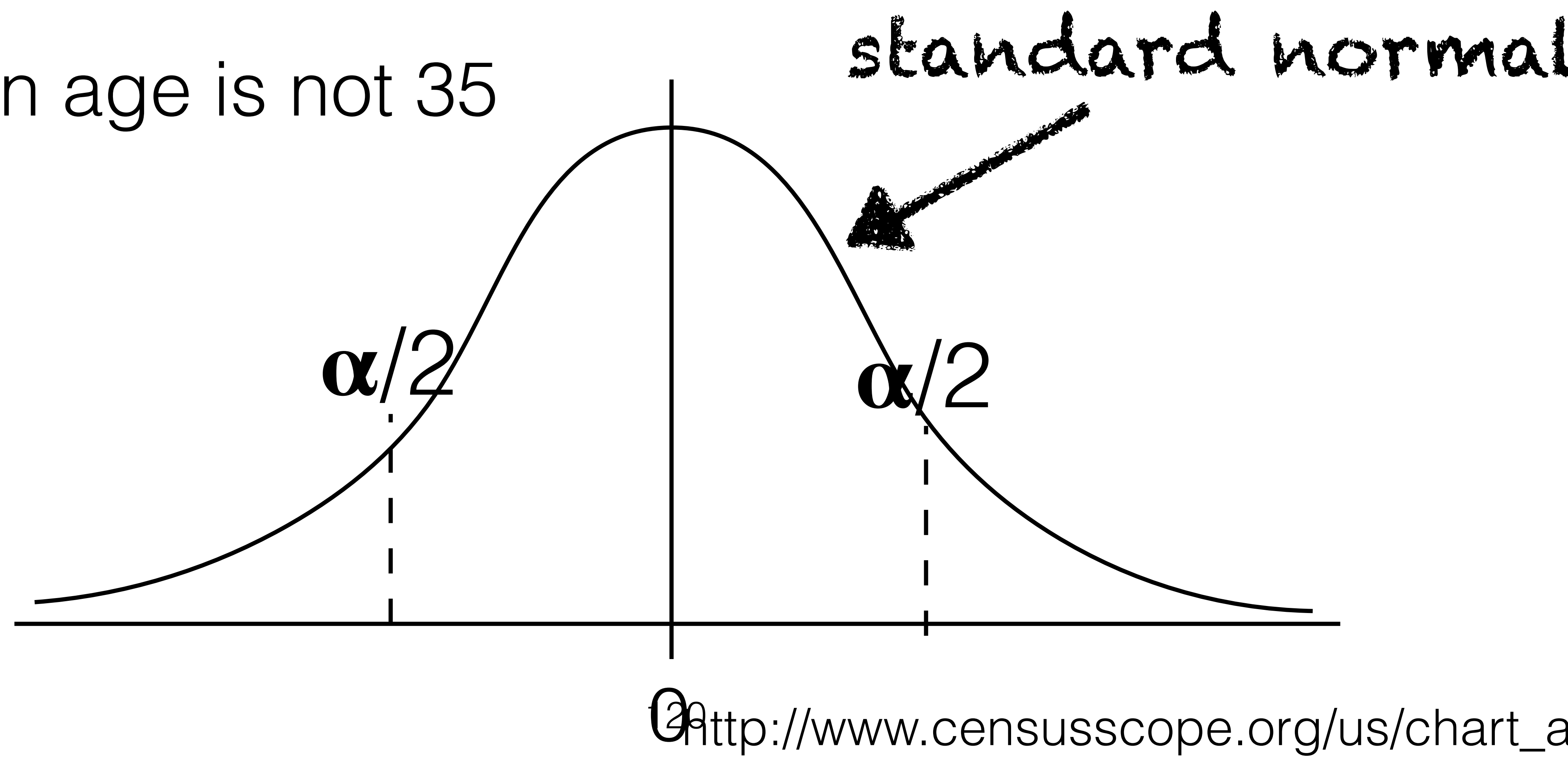
H_0 = mean age is 35

H_a = mean age is not 35



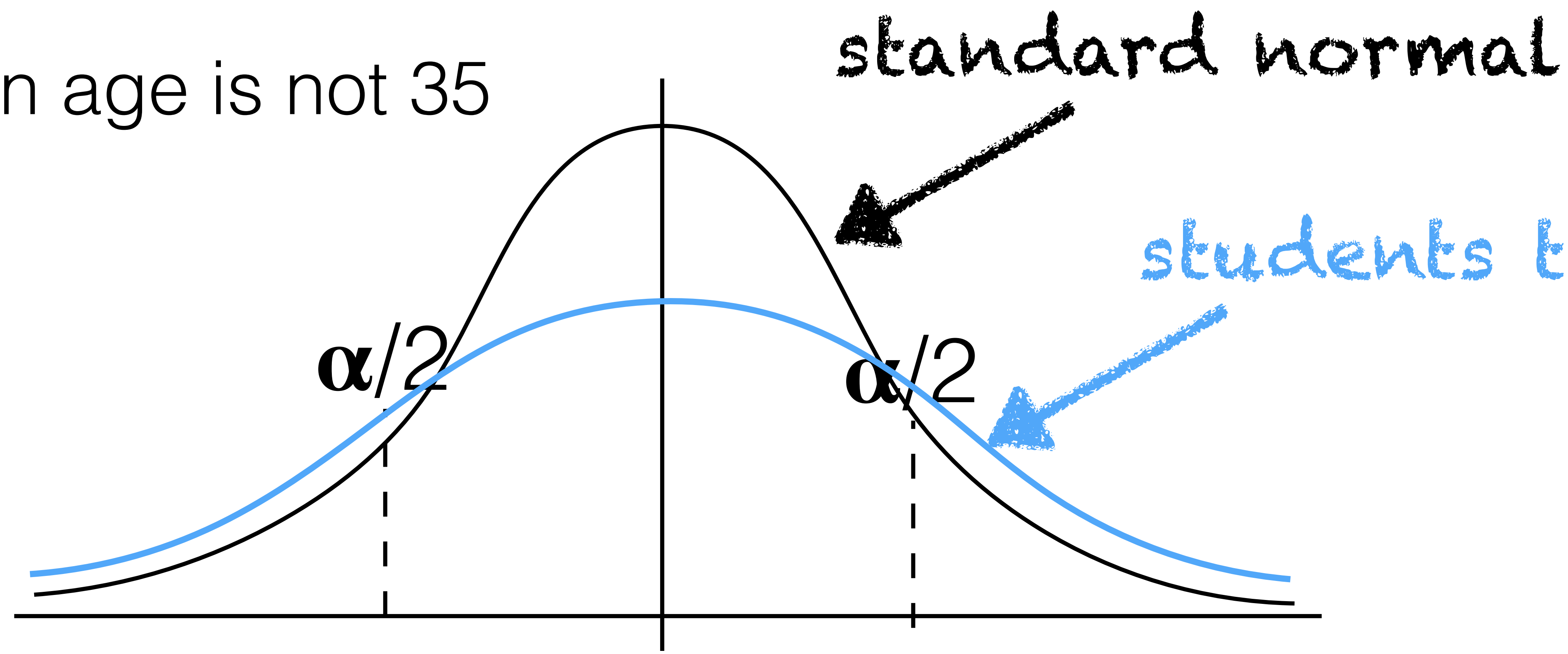
http://www.censusscope.org/us/chart_age.html

Test for population means

$$z = \frac{\bar{x} - \mu_0}{\frac{s}{\sqrt{n}}}$$

H_0 = mean age is 35

H_a = mean age is not 35



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Test for population means

$$z = \frac{\bar{x} - \mu_0}{\frac{s}{\sqrt{n}}}$$

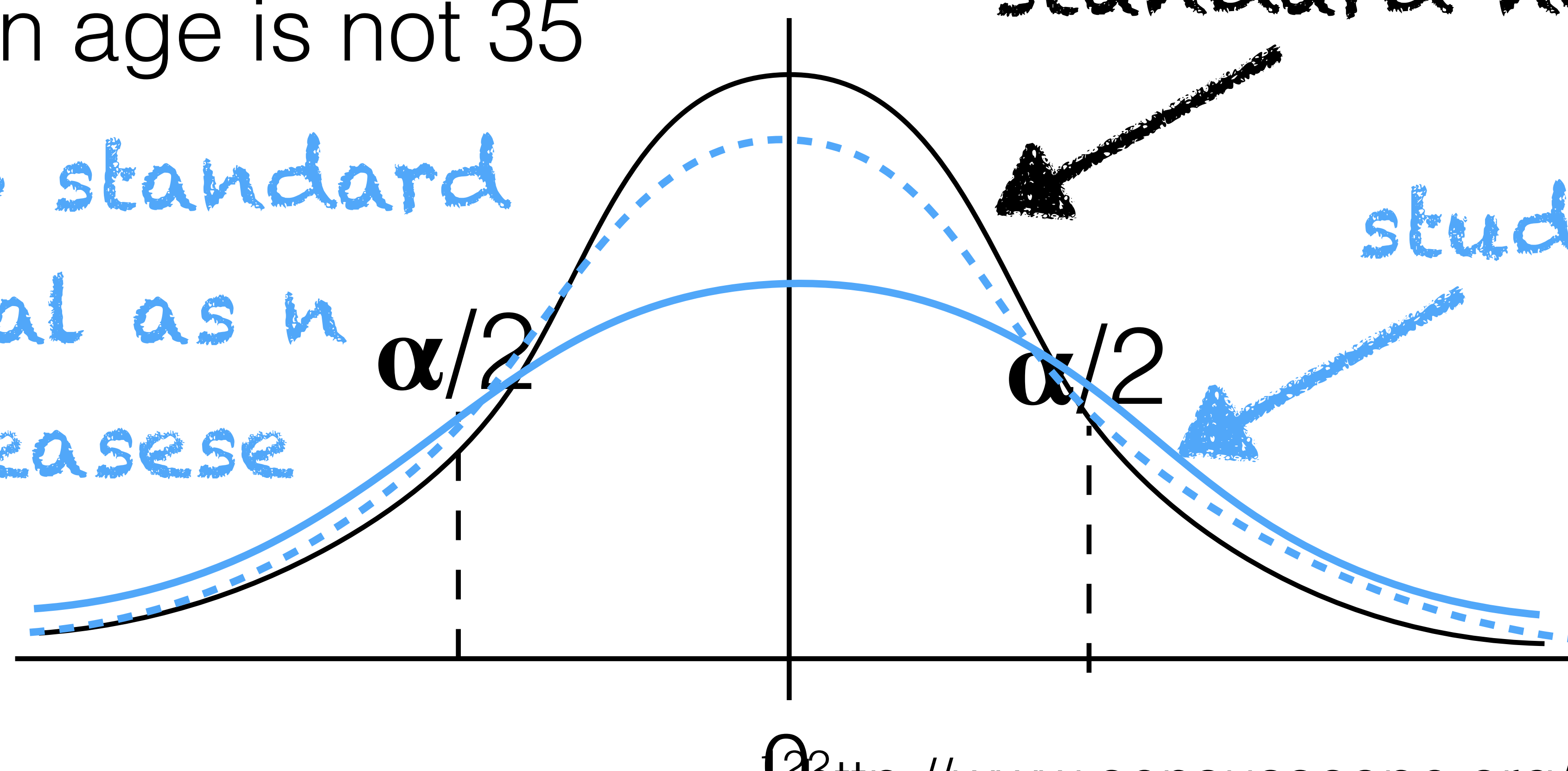
H_0 = mean age is 35

H_a = mean age is not 35

standard normal

closer to standard normal as n increasese

students t



http://www.censusscope.org/us/chart_age.html

okie done now