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LECTURE 9

Data Sampling

How to sample effectively, and how to quantify the samples we collect.

Data 100/Data 200, Spring 2023 @ UC Berkeley

Narges Norouzi and Lisa Yan

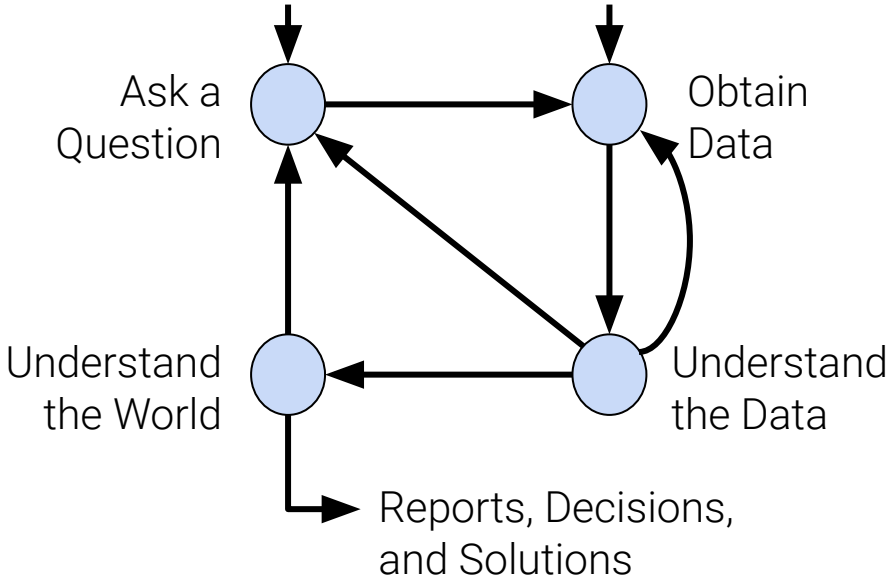
Content credit: Acknowledgments

Today's Roadmap

Lecture 09, Data 100 Spring 2023

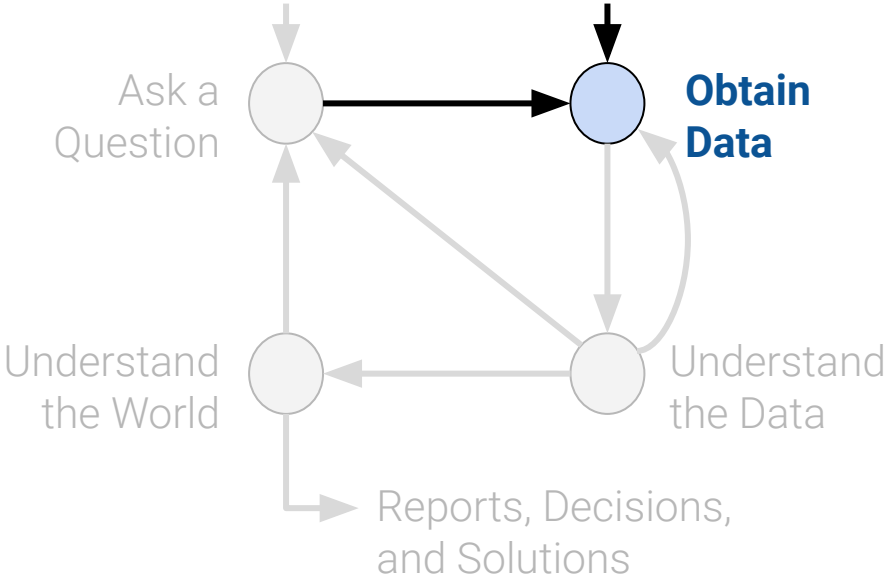
- **Review: Data Science Lifecycle**
- Censuses and Surveys
- Sampling: Definitions
- Bias: A Case Study
- Probability Samples
- Multinomial Probabilities

We call this the
Data Science Lifecycle.



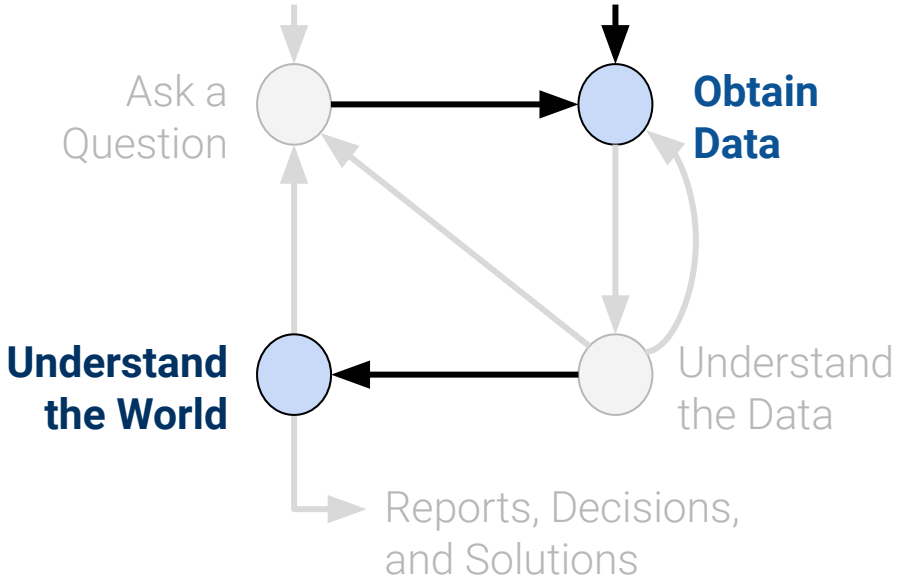
Today

How do we collect data?



Today

How does understanding data collection help us understand the world?



Censuses and Surveys

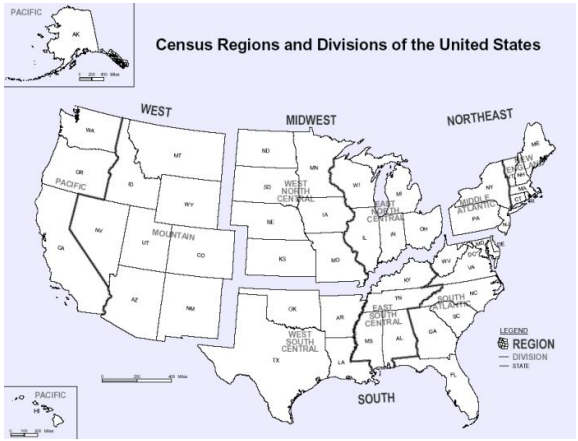
Lecture 09, Data 100 Spring 2023

- Review: Data Science Lifecycle
- **Censuses and Surveys**
- Sampling: Definitions
- Bias: A Case Study
- Probability Samples
- Application: The Gallup Poll today
- Extra: Permutations and Combinations

The US Decennial Census

- Was held in April 2020.
- Counts **every person** living in all 50 states, DC, and US territories. (Not just citizens.)
- Mandated by the Constitution. Participation is required by law.
- Important uses:
  - Allocation of Federal funds.
  - Congressional representation.
  - Drawing congressional and state legislative districts.

In general: a **census** is “an official count or survey of a **population**, typically recording various details of individuals.”



data.census.gov

Sampling from a finite population

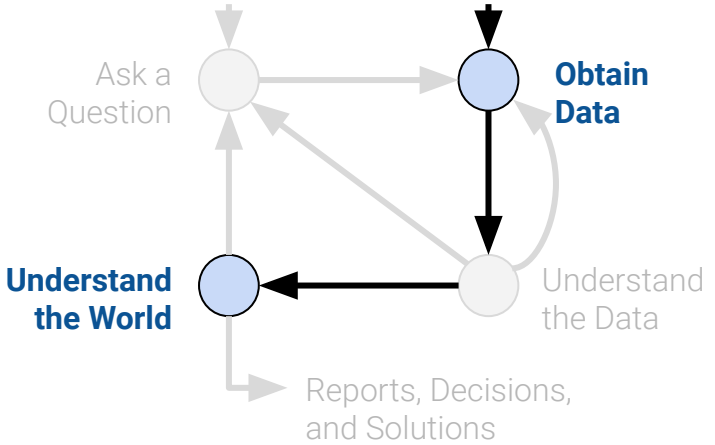
A census is great, but expensive and difficult to execute.

- Would **all** voters be willing to participate in a voting census prior to an actual election?

A **sample** is a subset of the population.

- Samples are often used to make **inferences about the population**.
- How you draw the sample will affect your accuracy.
- Two common sources of error:
  - **chance error**: random samples can vary from what is expected, in any direction.
  - **bias**: a systematic error in one direction.

Inference: quantifying degree of certainty in our models of the world.
Data 8 book



Survey

> In general: a **census** is "an official count or **survey** of a population, typically recording various details of individuals."

A **survey** is a set of questions.

- For instance: workers survey individuals and households.

What is asked, and how it is asked, can affect:

- How the respondent answers.
- **Whether** the respondent answers.

There are entire courses on surveying!
See Stat 152 at Berkeley (Sampling Surveys).

FiveThirtyEight

Politics Sports Science & Health Economics Culture

JUN. 27, 2019, AT 12:42 PM

The Supreme Court Stopped The Census Citizenship Question — For Now

By Amelia Thomson-DeVeaux

NATIONAL

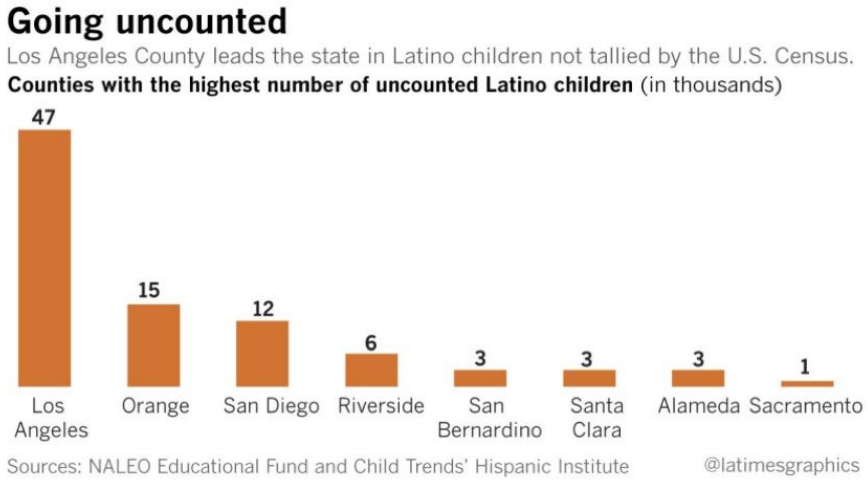
Citizenship Question To Be Removed From 2020 Census In U.S. Territories

August 9, 2019 · 3:23 PM ET

FiveThirtyEight, NPR

Undercounting in the US Decennial Census

LA Times 2010 Census



How do we know these numbers?
Other surveys

WaPo 2000 Census

High Court Rejects Sampling In Census
Ruling Has Political, Economic Impacts

Sampling methods would estimate Americans who missed the survey.
— Most often minorities/poor who vote Dem.
— "The better way is to improve the methods for contacting and questioning every household"

NY Times 2020 Census

In 2020 Census, Big Efforts in Some States. In Others, Not So Much.

California is spending $187 million to try to ensure an accurate count of its population. The Texas Legislature decided not to devote any money to the job. Why?

Sampling: Definitions

Lecture 09, Data 100 Spring 2023

- Review: Data Science Lifecycle
- Censuses and Surveys
- **Sampling: Definitions**
- Bias: A Case Study
- Probability Samples
- Multinomial Probabilities

Population, sample, and sampling frame

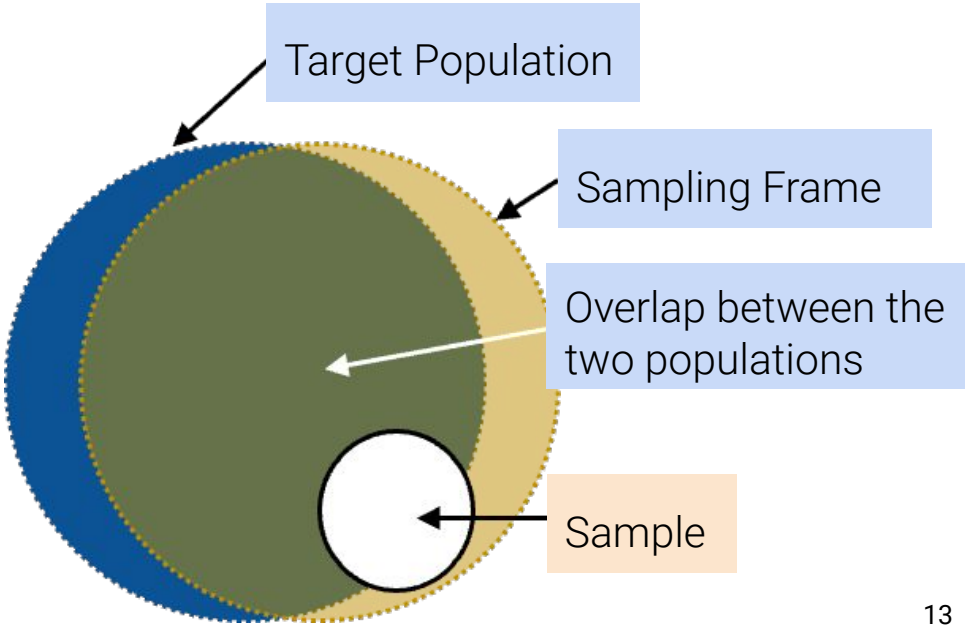
Population: The group that you want to learn something about.

Sampling Frame: The list from which the sample is drawn.

- If you're sampling people, the sampling frame is the set of all people that could possibly end up in your sample.

Sample: Who you actually end up sampling.

- A subset of your sampling frame.



There may be individuals in your **sampling frame** (and hence, your sample) that are **not** in your population!

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How are you engaging with today's lecture?

ⓘ Start presenting to display the poll results on this slide.

Other kinds of populations

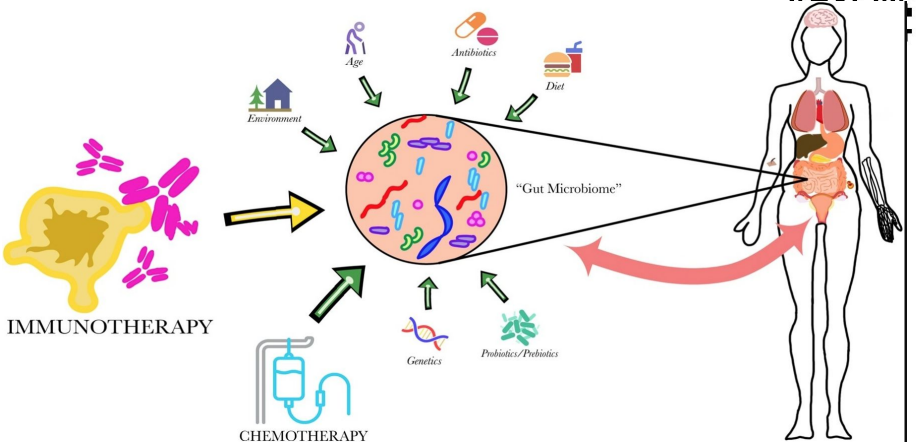
The individuals in a population are not always people!

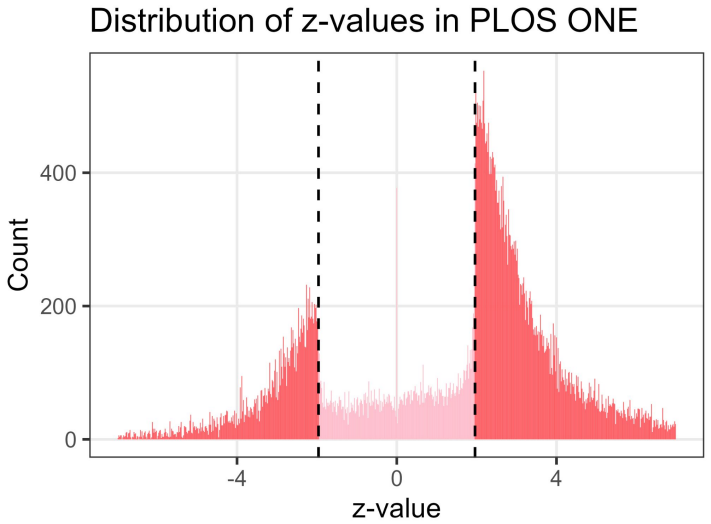
Could be

- **Bacteria** in your gut (sampled using DNA sequencing)
- **Trees** of a certain species
- **Small businesses** receiving a microloan
- **Published results** in a journal / field (example)

In any of these cases we might examine a sample and try to draw an inference about the population it came from.

- Simplest example: what % have some binary property (like voting intention)?





Bias: A Case Study

Lecture 09, Data 100 Spring 2023

- Review: Data Science Lifecycle
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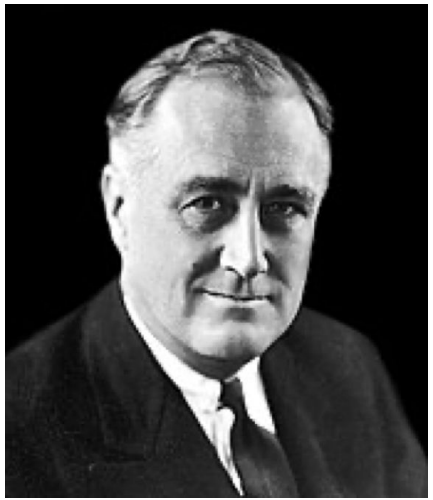
Case study: 1936 Presidential Election



Roosevelt (D)

Landon (R)

In 1936, President Franklin D. Roosevelt (left) went up for re-election against Alf Landon (right). As is usual, **polls** were conducted in the months leading up to the election to try and predict the outcome.

(Election result spoiler: Landon was not a U.S. President)

The Literary Digest: Election Prediction

The *Literary Digest* was a magazine. They had successfully predicted the outcome of 5 general elections coming into 1936.

They sent out their survey to **10,000,000** individuals, who they found from:

- Phone books.
- Lists of magazine subscribers.
- Lists of country club members.

	% Roosevelt	**# surveyed**
Actual election	**61%**	**All voters** (~45,000,000)
The Literary Digest poll	43%	10,000,000

How could this have happened?
They surveyed 10 million people!

The Literary Digest: What happened?

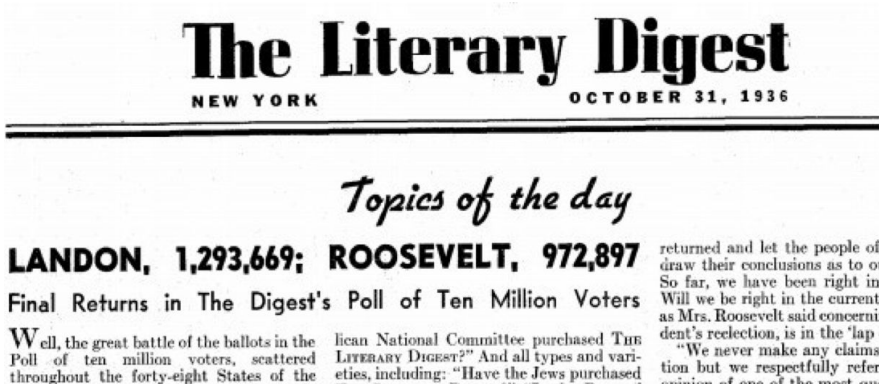
(1) The Literary Digest sample was **not representative** of the population.

- The Digest's **sampling frame**: people in the phonebook, subscribed to magazines, and went to country clubs.
- These people were more affluent and tended to vote Republican (Landon).

	% Roosevelt	# surveyed
Actual election	**61%**	**All voters** (~45,000,000)
The Literary Digest poll	43%	10,000,000

(2) Only 2.4 million people **actually filled out the survey!**

- 24% response rate (low).
- Who knows how the 76% **non-respondents** would have polled?



The Literary Digest

NEW YORK — OCTOBER 31, 1936

Topics of the day

LANDON, 1,293,669; ROOSEVELT, 972,897

Final Returns in The Digest's Poll of Ten Million Voters

Well, the great battle of the ballots in the Poll of ten million voters, scattered throughout the forty-eight States of the

lican National Committee purchased THE LITERARY DIGEST?" And all types and varieties, including: "Have the Jews purchased

returned and let the people of draw their conclusions as to o So far, we have been right in Will we be right in the current as Mrs. Roosevelt said concerni dent's reelection, is in the 'lap "We never make any claims tion but we respectfully refer

Gallup's Poll: Election Prediction

George Gallup, a rising statistician, also made predictions about the 1936 elections.

His estimate was **much** closer despite having a smaller **sample size** of "only" 50,000

(Also more than necessary!)

	% Roosevelt	# surveyed
Actual election	**61%**	**All voters** (~45,000,000)
The Literary Digest poll	43%	10,000,000
George Gallup's poll	56%	50,000
George Gallup's prediction of Digest's prediction	44%	3,000

George Gallup also predicted what The Literary Digest was going to predict, within 1%, with a **sample size of only 3000 people**.

- He predicted the Literary Digest's **sampling frame** (phonebook, magazine subscribers, country clubs).
- So he sampled those same individuals!

Samples, while convenient, are subject to chance error and **bias**.

Adapted from *Statistics* by Freedman, Pisani, and Purves, W.W. Norton NY

The Gallup Poll today

https://media.gallup.com/PDF/FAQ/HowArePolls.pdf

> The actual number of people that need to be interviewed for a given sample is to some degree less important than the soundness of the **fundamental equal probability of selection principle**…

Gallup U.S. Election polls:

- **Sampling Frame**: "civilian, non-institutionalized population" of adults in telephone households in continental US
- **Random Digit Dialing** to include both listed/unlisted phone numbers (avoid **selection bias**)
- **Within household selection process** to randomly select if ≥1 adult in household
  - If no answer, recall multiple times (avoids **non-response bias**)

→ **Simple Random Sample?**

According to Gallup's report:

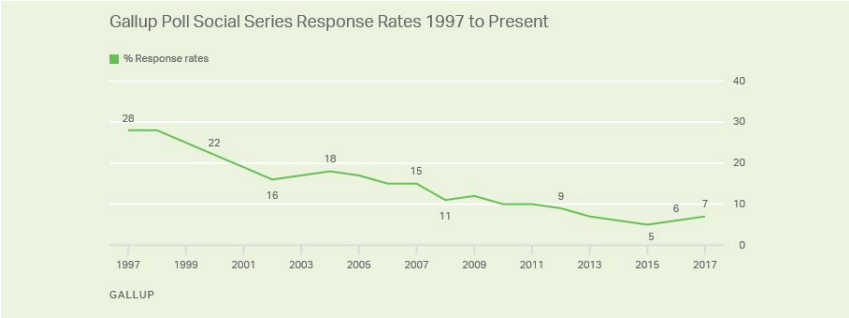
> …**question wording** is probably the **greatest source of bias and error** in the data, followed by question order.

Election polling is hard!

Many sources of bias:

- **Who responds** to polls?
- Do voters **tell the truth?**
- How can we **predict turnout?**

Single-digit response rates are the norm



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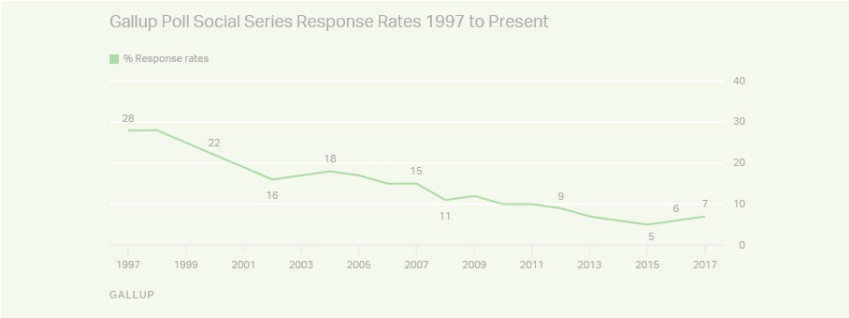

Poll numbers we see in the news are filtered through **proprietary statistical algorithms** that re-weight respondents
→ **"house effects"** of different pollsters

2022 ELECTION

Will The Polls Overestimate Democrats Again?

By Nate Silver
SEP. 16, 2022, AT 6:00 AM

FiveThirtyEight (source)

Polling bias isn't consistent

Weighted-average statistical bias in polls in final 21 days of the campaign

	PRES.	STATE LEVEL			
CYCLE	GENERAL	GOVERNOR	U.S. SENATE	U.S. HOUSE	COMBINED
1998	–	R+5.8	R+4.5	R+0.9	R+3.8
1999-2000	R+2.4	R+0.2	R+2.8	D+1.2	R+1.8
2001-02	–	D+3.5	D+2.0	D+1.4	D+2.6
2003-04	D+1.1	D+1.9	D+0.8	D+2.1	D+1.4
2005-06	–	D+0.4	R+2.1	D+1.1	D+0.1
2007-08	D+1.0	R+0.1	D+0.1	D+1.4	D+0.9
2009-10	–	R+0.2	R+0.8	D+1.3	D+0.4
2011-12	R+2.5	R+1.6	R+3.1	R+3.2	R+2.8
2013-14	–	D+2.3	D+2.7	D+3.9	D+2.8
2015-16	D+3.3	D+3.1	D+2.8	D+3.4	D+3.0
2017-18	–	R+0.9	EVEN	R+0.8	R+0.5
2019-20	D+4.2	D+5.6	D+5.0	D+6.1	D+4.8
All years	D+1.3	D+0.9	D+0.7	D+1.2	D+1.1

Common Biases

Selection Bias

- Systematically excluding (or favoring) particular groups.
- How to avoid: Examine the sampling frame and the method of sampling.

Response Bias

- People don't always respond truthfully.
- How to avoid: Examine the nature of questions and the method of surveying.

Non-response Bias

- People don't always respond.
- How to avoid: Keep your surveys short, and be persistent.
- People who don't respond aren't like the people who do!

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How satisfied are you with the 50-minute discussion sections?

ⓘ Start presenting to display the poll results on this slide.

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We perceive office hour wait times to be very long. How long do you spend in office hours?

ⓘ Start presenting to display the poll results on this slide.

Multinomial Probabilities (1/3)

https://numpy.org/doc/stable/reference/random/generated/numpy.random.multinomial.html

Demo

Interlude

Announcements

Reminder: Check Weekly Ed post announcement.
This week's:
https://edstem.org/us/courses/33744/discussion/2581425

On-Time deadline is the expected deadline.

- Extenuating circumstances are **not**: forgetting to tag pages, submitting to wrong portal, not saving before exporting PDF, not checking autograder.
- **The grace period is intended to cushion logistical errors**. We will not accommodate such requests going forward.

Alternate in-person midterm request form:
(March 9, 5:00-7:00pm)
https://edstem.org/us/courses/33744/discussion/2586326

Probability Samples

Lecture 09, Data 100 Spring 2023

- Review: Data Science Lifecycle
- Censuses and Surveys
- Sampling: Definitions
- Bias: A Case Study
- **Probability Samples**
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Quality, not quantity!

A **huge sample size** does not fix a **bad sampling method**!

We want the sample to be **representative** of the population.

Think about **tasting soup**: if it's **well-stirred**, a spoonful is all you need!

Easiest way to to get a representative sample is by using **randomness**.

Convenience Samples

(source)

A **convenience sample** is whatever you can get ahold of.

Example: Scientists in New South Wales (AUS) collect specimens from eucalyptus trees to keep in museums, recording **where they came from** in latitude / longitude.

*Can we use this data to map the **geographic distribution** of eucalyptus trees?*

Warning:

- Haphazard ≠ **random**.
- Many potential sources of bias!

Like polls, we can try to correct bias by statistical modeling. But better if we don't have to!

Probability Sample (aka Random Sample)

Why sample at random? **Not** just to eliminate bias!

1. Random samples **do not** always produce **unbiased estimates** of population quantities.
   - Sometimes **close** to unbiased (e.g. **sample median** for **population median**)
2. With random samples we can **estimate** the **bias** and **chance error** → **quantify uncertainty**

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2. With random samples we can **estimate** the **bias** and **chance error** → **quantify uncertainty**

In a **probability sample** we know the chance any given **set** of individuals will be in the sample.

- All individuals in the population **need not** have the same chance of being selected.

The real world is usually more complicated!

- When Gallup calls, most people don't answer.
- We don't know the probability a given bacterium will get into a microbiome sample.
- We don't know journals' publication process.

If the sampling / measurement process isn't fully under our control, we try to **model it**.

Common random sampling schemes

A **random sample with replacement** is a sample drawn **uniformly** at random **with** replacement.

- Random doesn't always mean "uniformly at random," but in this specific context, it does.
- Some individuals in the population might get picked more than once

A **simple random sample (SRS)** is a sample drawn **uniformly** at random **without** replacement.

- **Every individual (and subset of individuals) has the same chance of being selected.**
- Every pair has the same chance as every other pair.
- Every triple has the same chance as every other triple.
- And so on.

A raffle could use either sampling scheme, depending on if winners are eligible for multiple prizes.

Imaginary Berkeley Pollster

The imaginary Bay Area city, **Bearkeley**, has an upcoming mayoral election.

Suppose we took a sample to predict the election outcome.

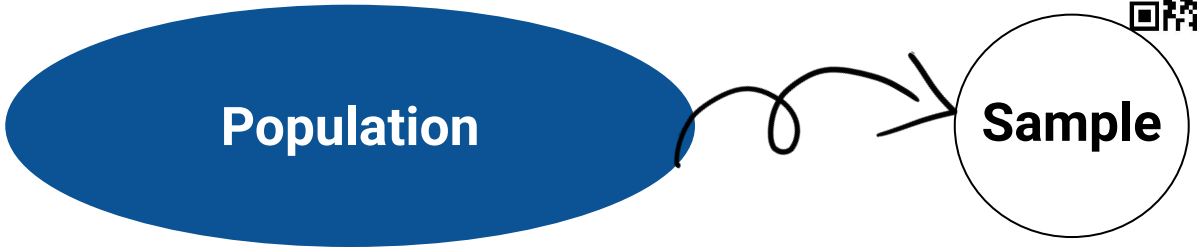
- We poll all retirees for their vote.
- Even if they answer truthfully, this is a **convenience sample**.

Then, suppose the election happens.

- How “off” is our poll from the actual election?
- How would a random sample with replacement have fared?

Demo

So far:



If a sample was **randomly sampled with replacement** from the population:

- It is a probability sample.
- We can quantify error and bias (to be covered later).
- **Given the population distribution**, we can compute the probability of us getting a **particular sample**.

Demo

Note: We almost **never** know the population distribution, so we can almost never do the analysis we did here!

But this is a good start.

Example Scheme 1: Stratified random sample

In Gotham City, about 50% of the population is male, want to choose 100 voters for my survey

- I choose exactly 50 from the males in Gotham, uniformly at random among the males (SRS)
- Other 50 from non-males, also uniformly at random (SRS)

This is a **probability sample** (Why might we want to do this?)

For any group of 100 people:

- If there are not exactly 50 males, the group cannot be chosen
- Any other group: chance is of choosing it is 1 / # of such groups

We'll learn more about quantifying error/bias later in a few weeks.

Replace 50/50 with 80/20 (80 males, 20 non-males)

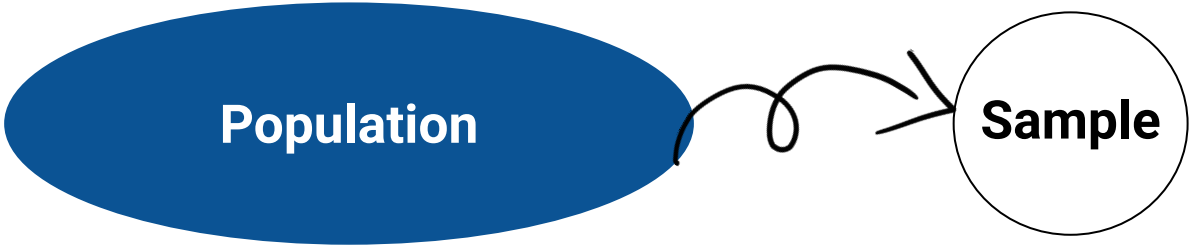
- Would it still be a probability sample?
- Would the % Dem in the sample be unbiased?
- **Challenge:** how could we make it unbiased?

Multinomial Probabilities

Lecture 02, Data 100 Spring 2022

- Review of last lecture
- Censuses and Surveys
- Sampling: Definitions
- Bias: A Case Study
- Probability Samples
- **Multinomial Probabilities**

So far



If we have a probability sample:

- We can quantify error and bias (to be covered later).
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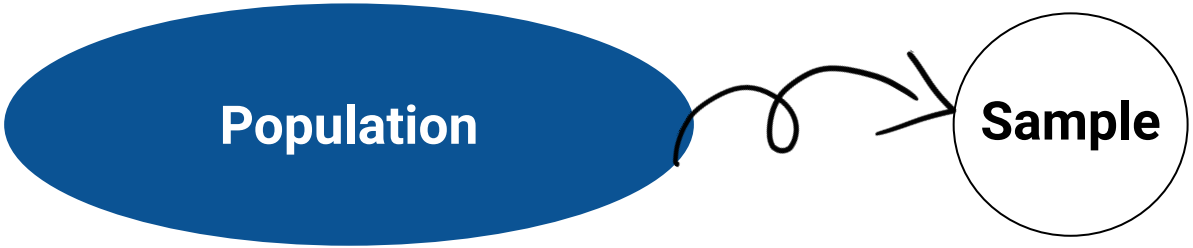
So far



If we have a probability sample:

- We can quantify error and bias (to be covered later).
- **Given the population distribution**, we can compute the probability of us getting a **particular sample**.

Note: We almost **never** know the population distribution! But this is a good start.

Special case: Random sampling with replacement of a **Categorical population distribution** produces **Multinomial Probabilities**.

A very common approximation for sampling

A common situation in data science:

- We have an enormous population.
- We can only afford to sample a relatively small number of individuals.

If the **population is huge** compared to the sample, then
random sampling with and without replacement are pretty much the same.

Example: Suppose there are 10,000 people in a population.
Exactly 7,500 of them like Snack 1; the other 2,500 like Snack 2.

What is the probability that in a random sample of 20, **all people like Snack 1**?

SRS (Random Sample Without Replacement)

$$\overbrace{\left(\frac{7500}{10000}\right)}^{0.75}\overbrace{\left(\frac{7499}{9999}\right)}^{0.74997}\cdots\overbrace{\left(\frac{7482}{9982}\right)}^{0.7495}\overbrace{\left(\frac{7481}{9981}\right)}^{0.7495} \approx .003151$$

Random Sample With Replacement

$$(0.75)^{20} \approx 0.003171$$

Probabilities of sampling with replacement are much easier to compute!

Multinomial Probabilities (1/3): The scenario

Multinomial probabilities arise when we:

- Sample at random, **with replacement**.
- Sample a fixed number (n) times.
- Sample from a **categorical distribution**.
  - If ≥2 categories, **Multinomial**:

Bag of marbles: 60% blue 30% green 10% red

Goal: **Count the number of each category** that end up in our sample.

- `np.random.multinomial` returns these counts.

Multinomial Probabilities (2/3): The formula (which you need not memorize)

If we are drawing at random with replacement **n** times, from a population broken into three separate categories (where $p_1 + p_2 + p_3 = 1$):

- Category 1, with proportion $\mathbf{p_1}$ of the individuals.
- Category 2, with proportion $\mathbf{p_2}$ of the individuals.
- Category 3, with proportion $\mathbf{p_3}$ of the individuals.

Then, the **multinomial probability** of drawing $\mathbf{k_1}$ individuals from Category 1, $\mathbf{k_2}$ individuals from Category 2, and $\mathbf{k_3}$ individuals from Category 3 (where $k_1 + k_2 + k_3 = n$) is

$$\frac{n!}{k_1!k_2!k_3!}p_1^{k_1}p_2^{k_2}p_3^{k_3}$$

At no point in this class will you be forced to memorize this! This is just for your own understanding. In practice (as you will see in homework), we use `np.random.multinomial` to compute these quantities.

Multinomial Probabilities (3/3): The intuition

Suppose we sample at random with replacement 7 times from a bag of marbles:

60% **blue** marbles 30% are **green** 10% are **red**.

Q1. What is P(**bgbbbgr**)?

Use product rule to determine probability for a particular **order**:

$$P(\text{bgbbbgr}) = 0.6 \times 0.3 \times 0.6 \times 0.6 \times 0.6 \times 0.3 \times 0.1 = (0.6)^4(0.3)^2(0.1)^1$$

Q2. What is P(4 **blue**, 2 **green**, 1 **red**) ?

$$\frac{7!}{4!\,2!\,1!}(0.6)^4(0.3)^2(0.1)^1$$

multinomial probability

Like before, use **addition rule** and **multiplication rule**:

# of ways to choose 4 of 7 places to write **b**, then choose 2 places to write **g** , (other 1 get filled with **r**)

For a particular outcome (say, Q1), probability of this **ordered series** of **b**'s, **g** 's, and **r**'s

Summary

Understanding the sampling process is what lets us go from **describing the data** to **understanding the world**

Without knowing / assuming something about how the data were collected:

- There is no connection between the **sample** and the **population**
- The **data set** doesn't tell us about the **world behind the data**