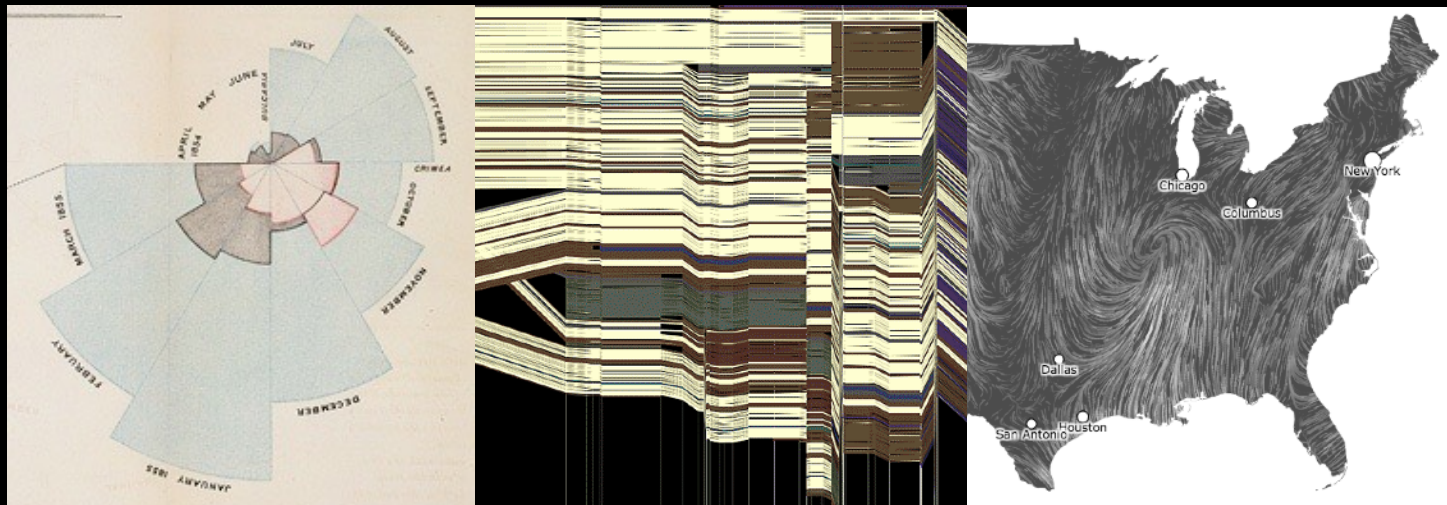


CSE 442 - Data Visualization

Uncertainty



Jeffrey Heer [University of Washington](#)

(with significant material from Michael Correll)

"I estimate that we catch 25% of our 100x errors, and 5% of our 5x errors."

Anonymous Data Science Team Manager

Topics

What Does Uncertainty Mean?

Uncertainty Visualization

Avoid Prematurely Suppressing Uncertainty

Visual Encodings of Uncertainty

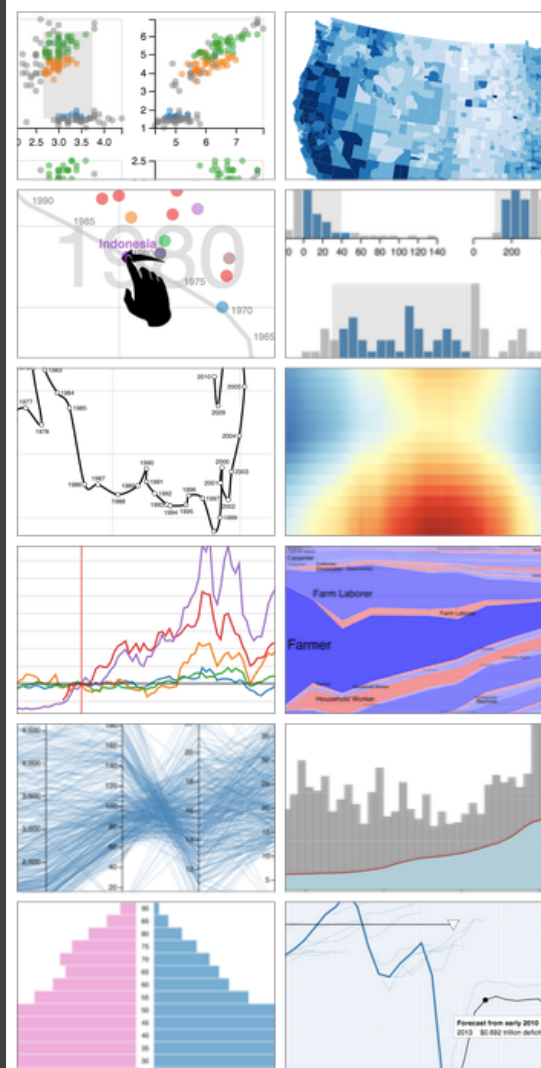
Frequency Framing & Hypothetical Outcomes

What Can Go Wrong?

Inferential Integrity

Graphical Inference & Model Checks

GOAL: Try not to fool yourself!



What Does Uncertainty Mean?

Things “Uncertainty” Can Mean

Doubt

Risk

Variability

Error

Lack of Knowledge

Hedging

...

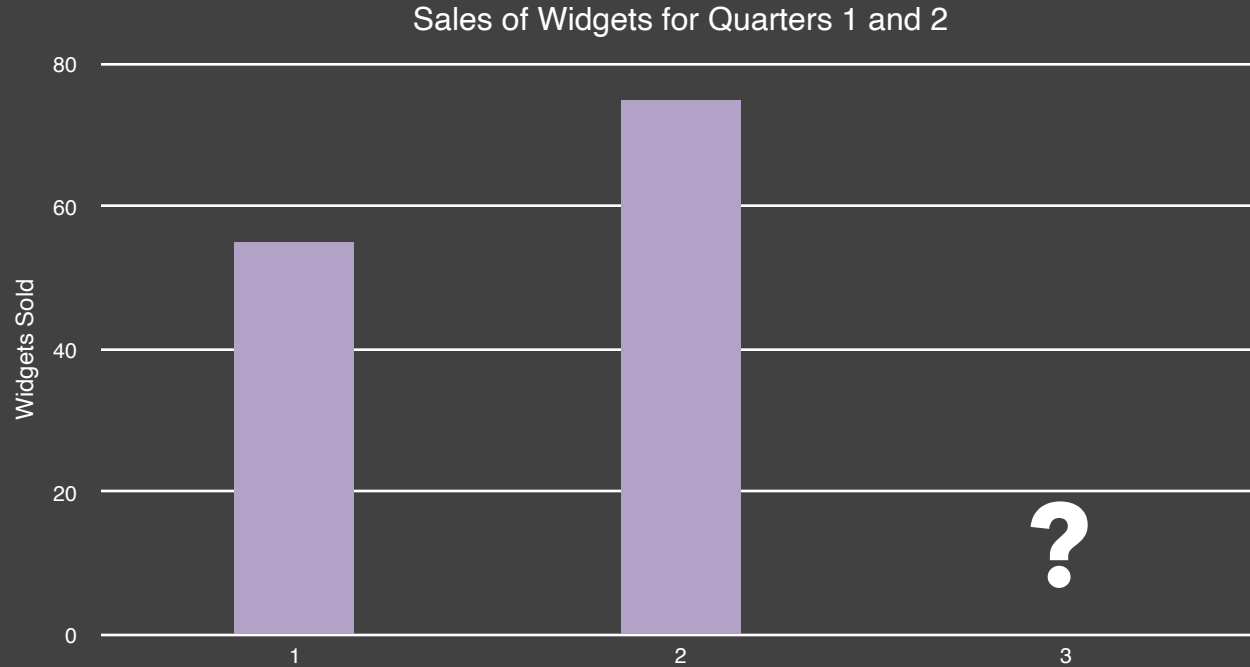
A Bar Chart



Measurement Uncertainty



Forecast Uncertainty



Decision Uncertainty



Uncertainty Sources

Measurement Uncertainty

"We're not sure what the data are"

Model Uncertainty

"We're not sure how the data fit together"

Forecast Uncertainty

"We're not sure what will happen to the data next"

Decision Uncertainty

"We're not sure what to do with the data"

Should I Bring an Umbrella?



Decision Uncertainty

"50% Chance of Rain"



Types of Error

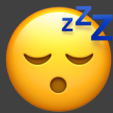
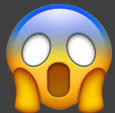


The Boy Who Cried Wolf

Type I: False Positive



Type II: False Negative





Sean J. Taylor @seanjtaylor

Here's my trick.

TYPE

FALSE POSITIVE

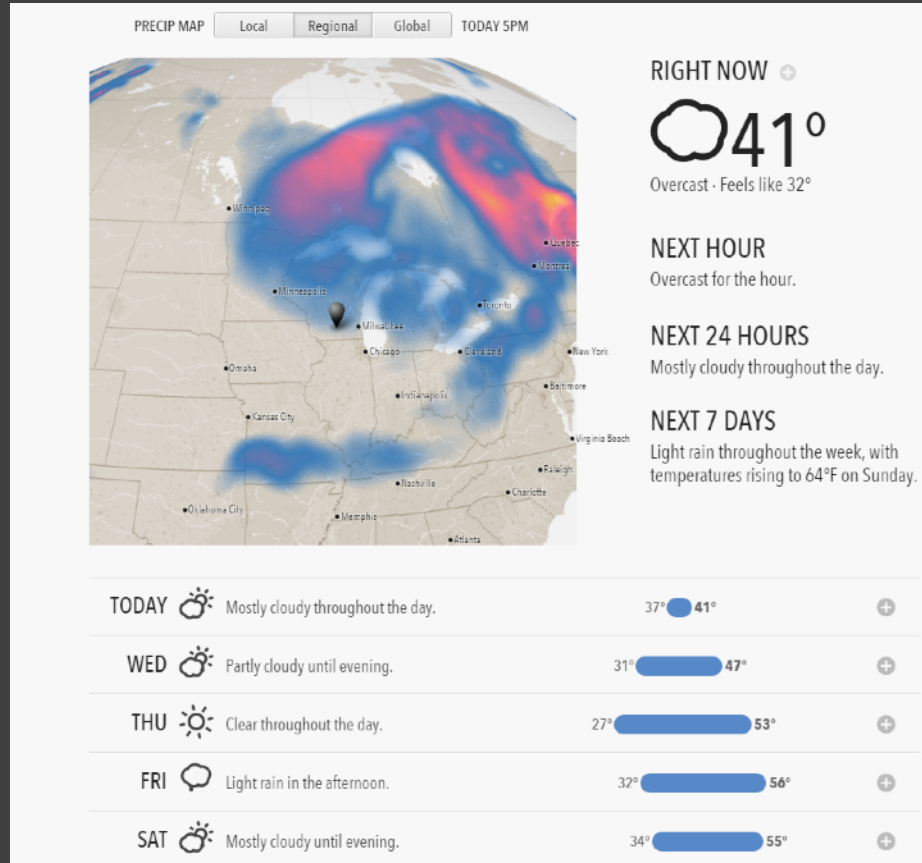
FALSE NEGATIVE

Model Uncertainty

"50% Chance of Rain"



Model Uncertainty



What Does Uncertainty Mean?

Any one of a number of potentially interconnected quantitative, qualitative, or factors that affect the quality, reliability, or utility of your data or data-driven decisions. Anything that can cause you to be unsure about your data or how to use it.

What Does Uncertainty Mean?

Any one of a number of potentially interconnected quantitative, qualitative, or factors that affect the quality, reliability, or utility of your data or data-driven decisions. Anything that can cause you to be unsure about your data or how to use it.

**LOTS OF
THINGS**

Uncertainty Visualization

Uncertainty Visualization

There are different **types** and **sources** of uncertainty.

We can **quantify** or **model** our uncertainty.

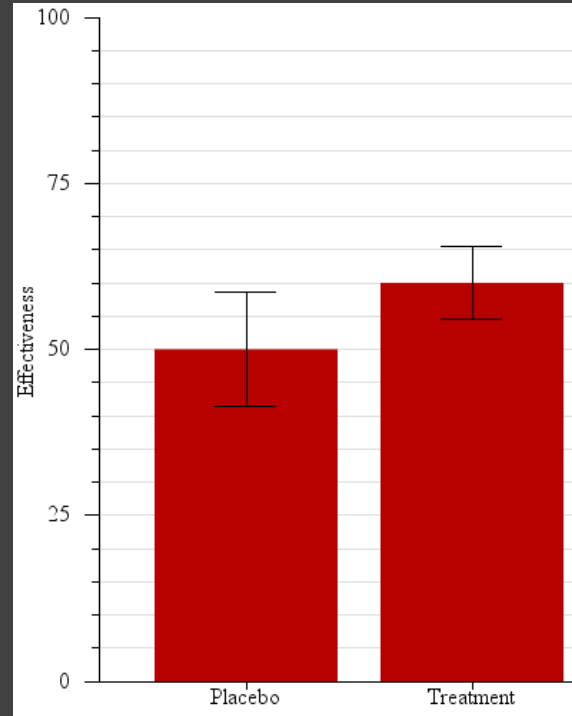
The visual presentation of uncertainty can **clash** with cognitive and perceptual biases.

**Avoid Prematurely
Suppressing Uncertainty**

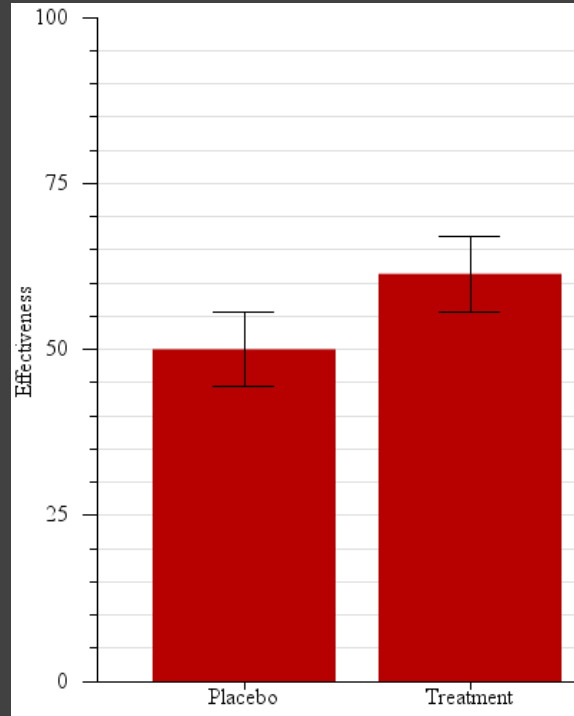
Error Bars

The mean treatment effect is higher than than the placebo.

Is this difference in means *statistically significant*?



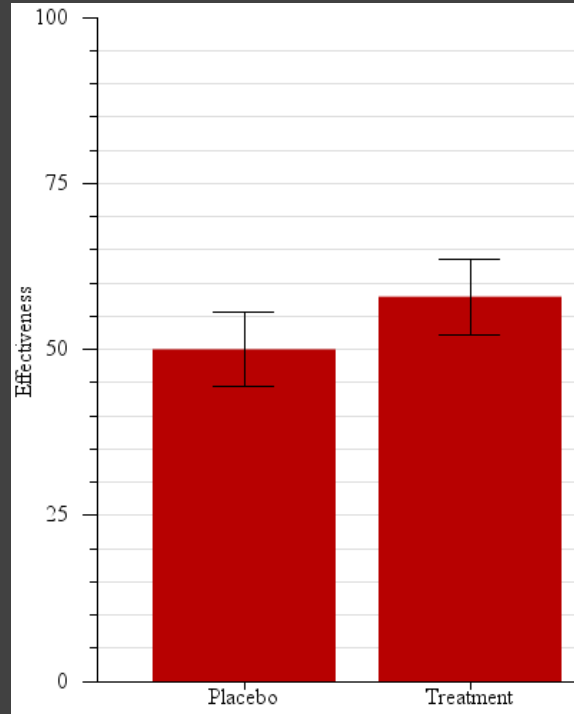
Guess the p-value...



Error bars depict
95% Conf. Interval

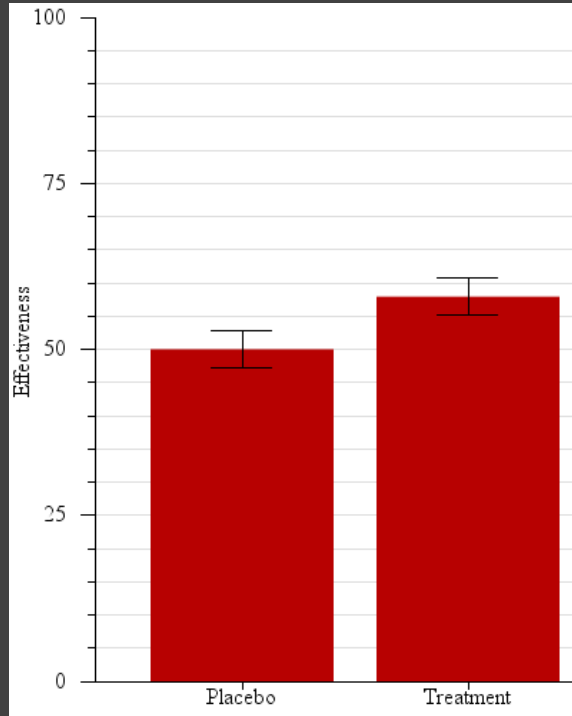
Guess the p-value...

Error bars depict
95% Conf. Interval

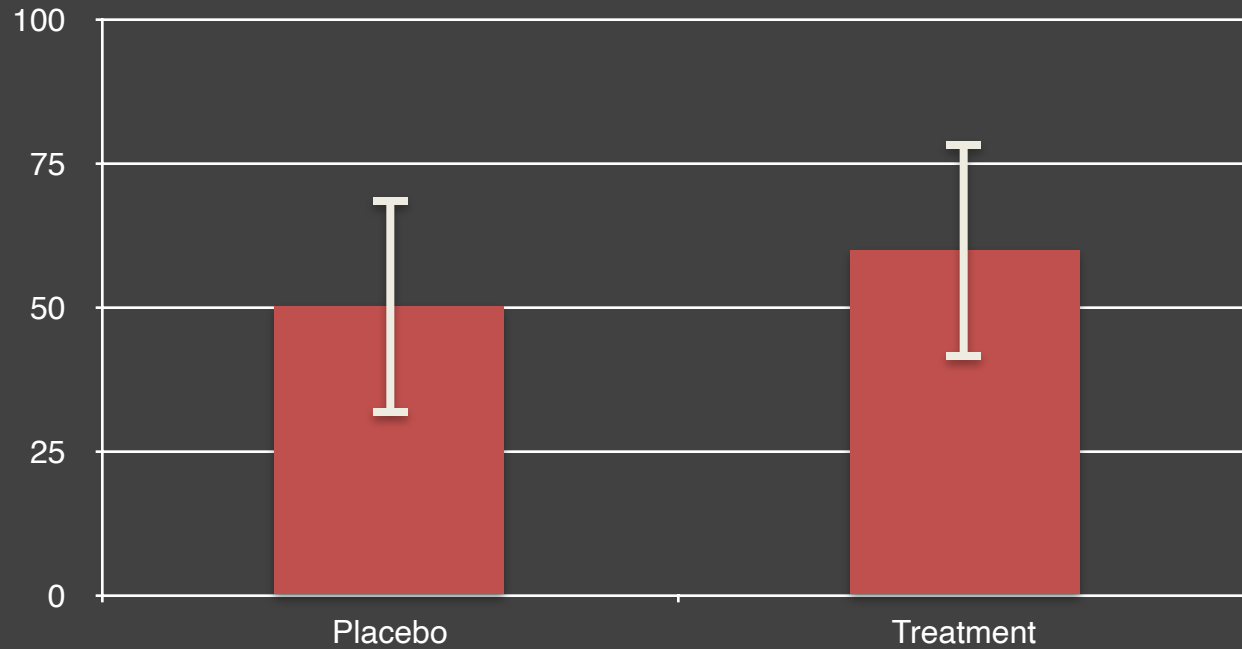


Guess the p-value...

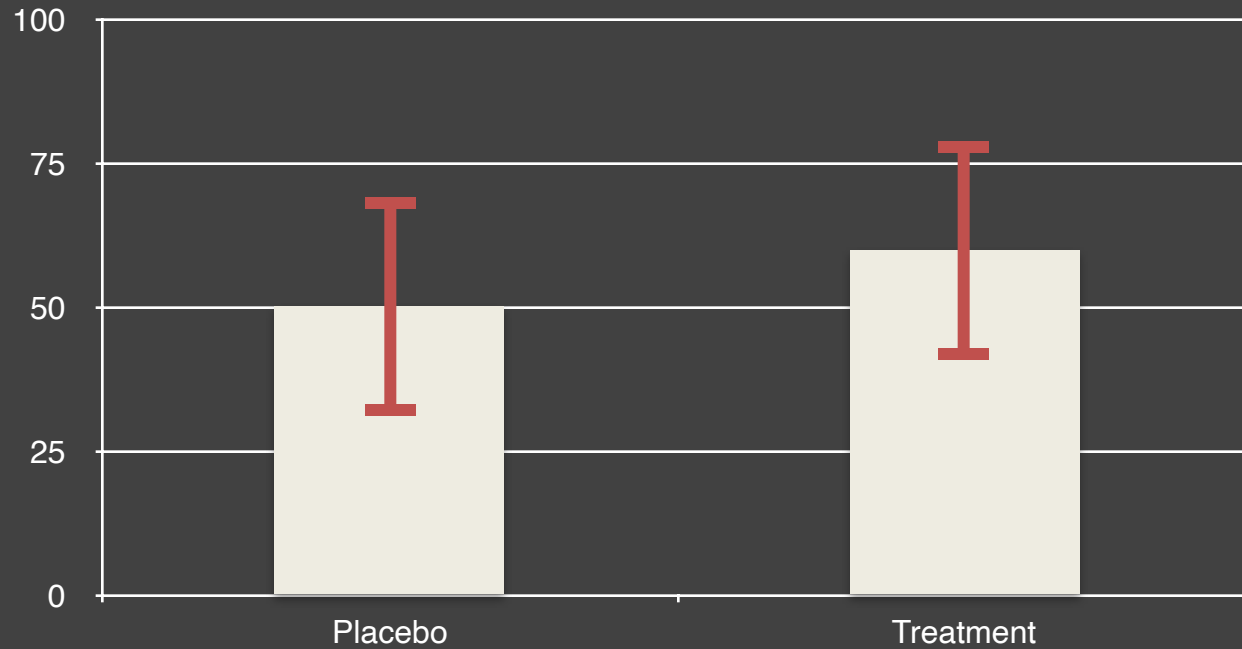
Error bars depict
standard error



Misplaced Emphasis?



Misplaced Emphasis?



For inference tasks, focus
on the **uncertainty**, not
the point estimate!

Confidence Intervals

What does a 95% confidence interval indicate?

One interpretation is: there is a 95% chance that the population mean is within the interval.

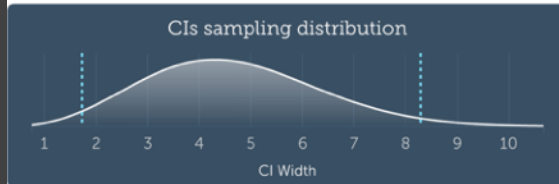
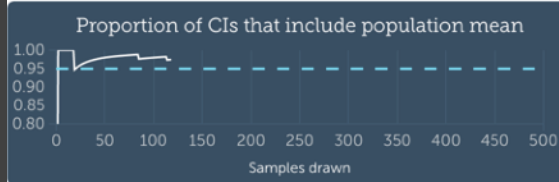
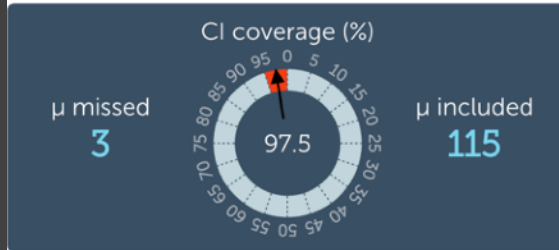
Wrong!

Rather, given an infinite number of independent experiments, 95% of the confidence intervals generated will contain the true population mean.

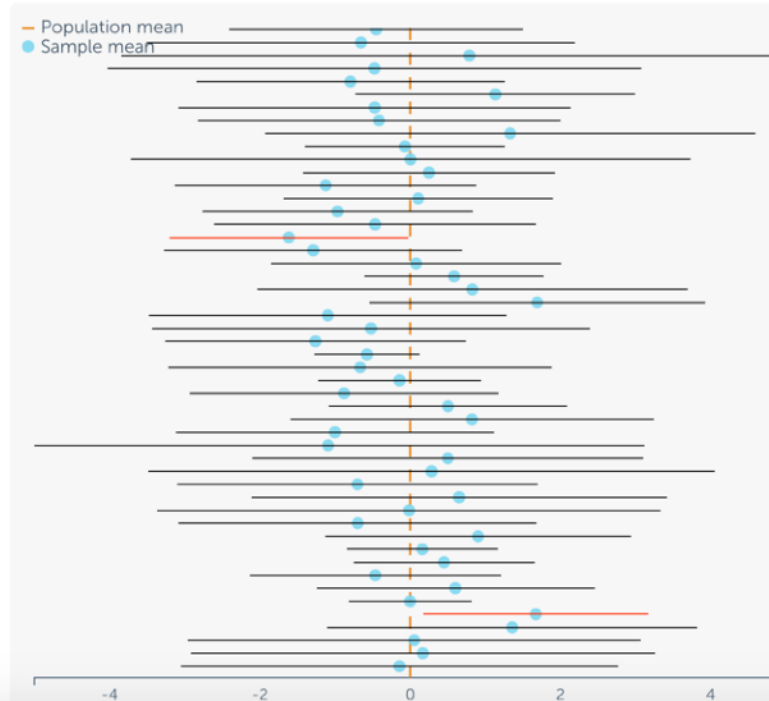
“Confidence” concerns the procedure, not the data. (Though see Bayesian *credible intervals*...)

Confidence Intervals

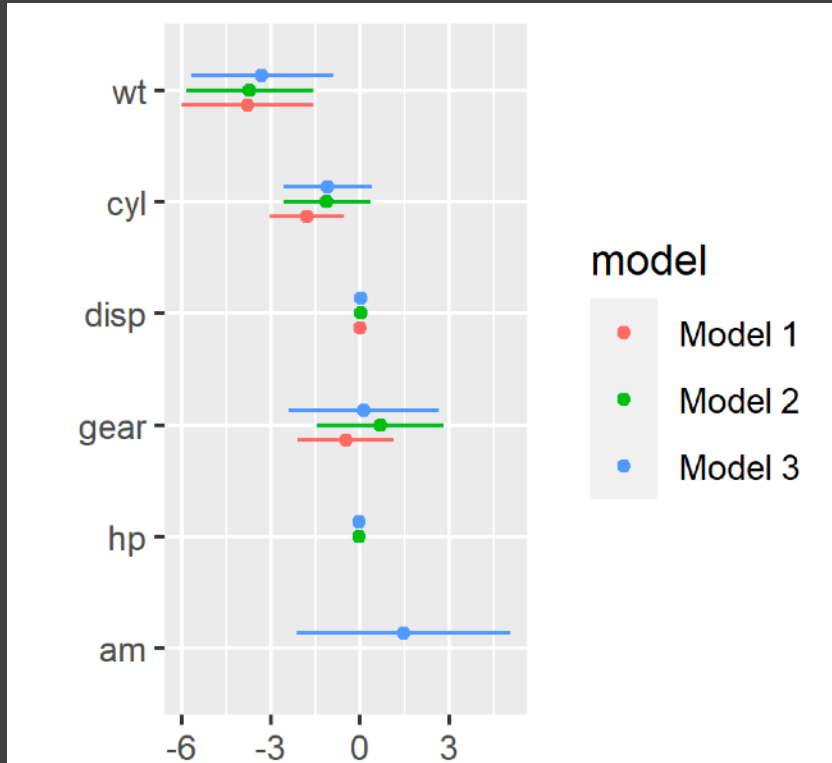
Simulation statistics



95% confidence intervals



Regression Coefficients



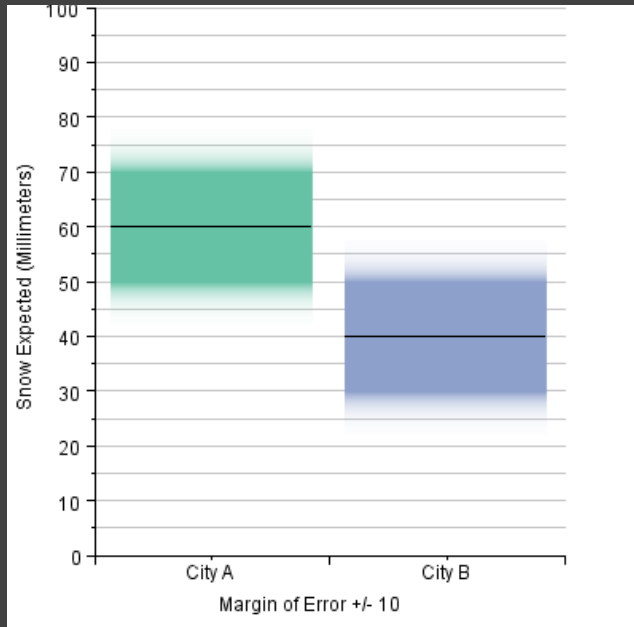
95% CIs for regression model parameters.

Here, we compare fitted parameters from 3 different models. Not all predictors are included in all models.

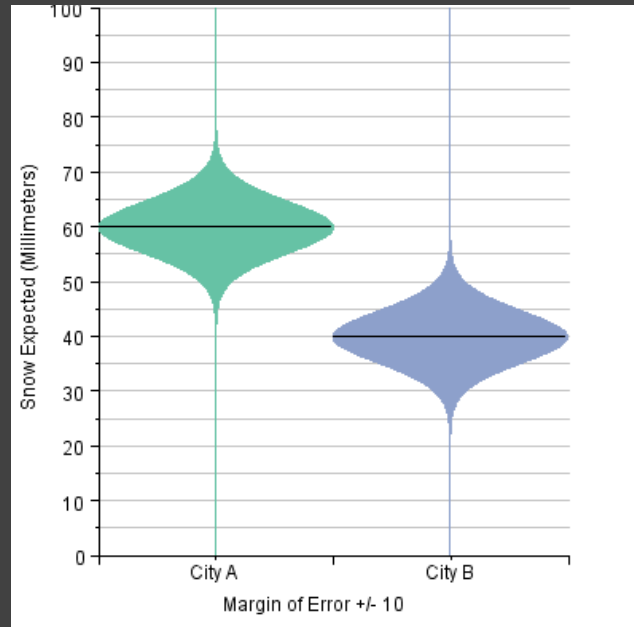
Visual comparison: does the CI overlap 0?

Alternatives to Error Bars

Gradient Plot

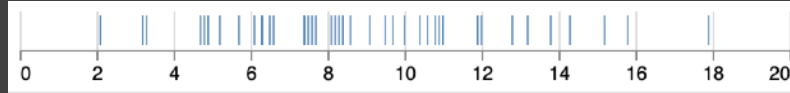


Violin Plot

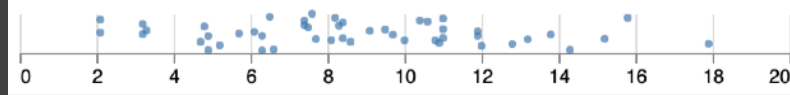


Distribution Visualizations

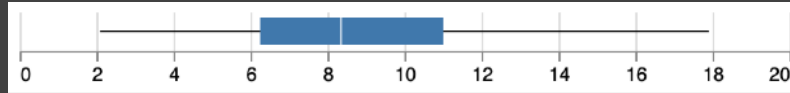
Strip Plot



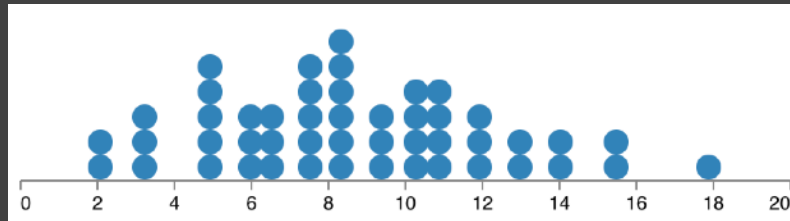
Jittered Plot



Box Plot



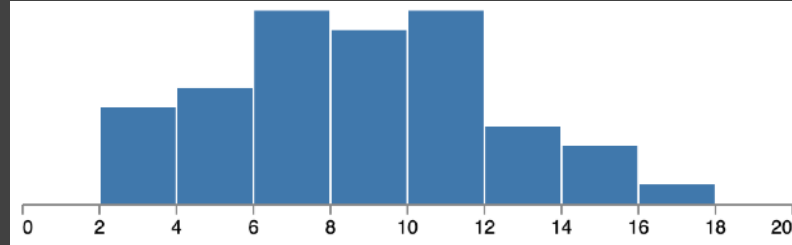
Dot Plot



Distribution Visualizations

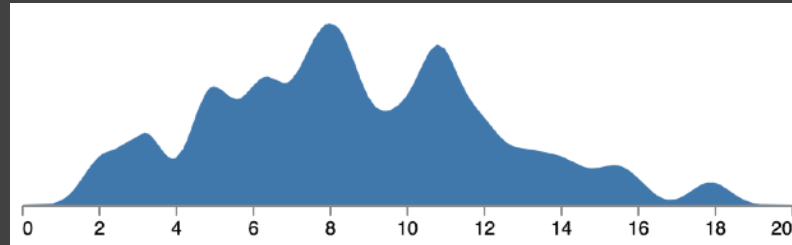
Histogram

bin size = 2



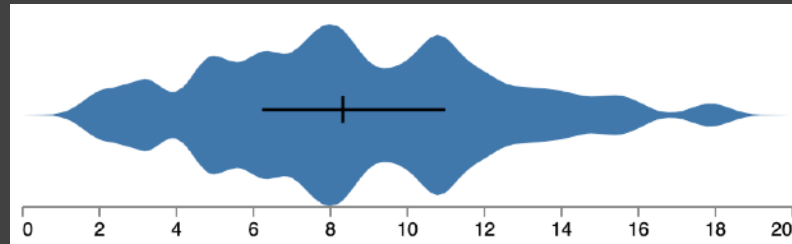
Density Plot

kde, $\sigma = 0.5$



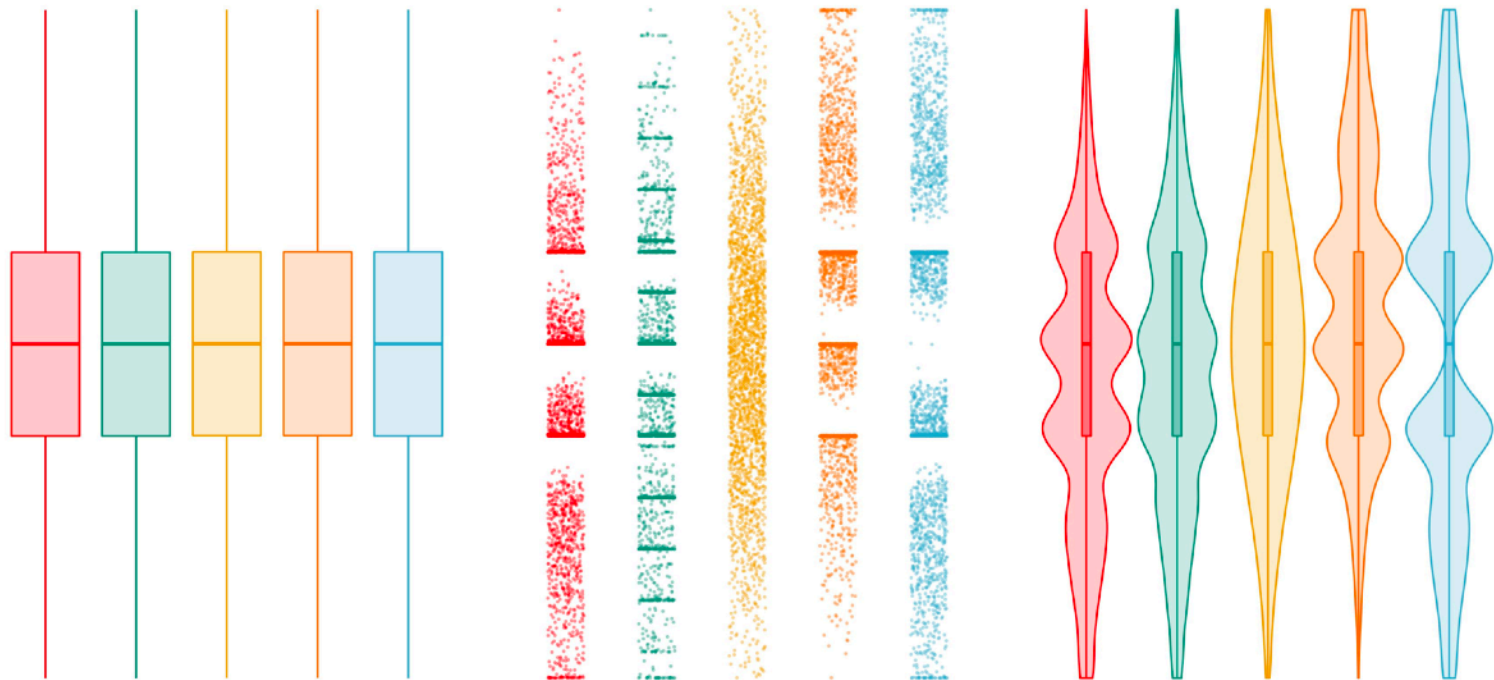
Violin Plot

kde, $\sigma = 0.5$

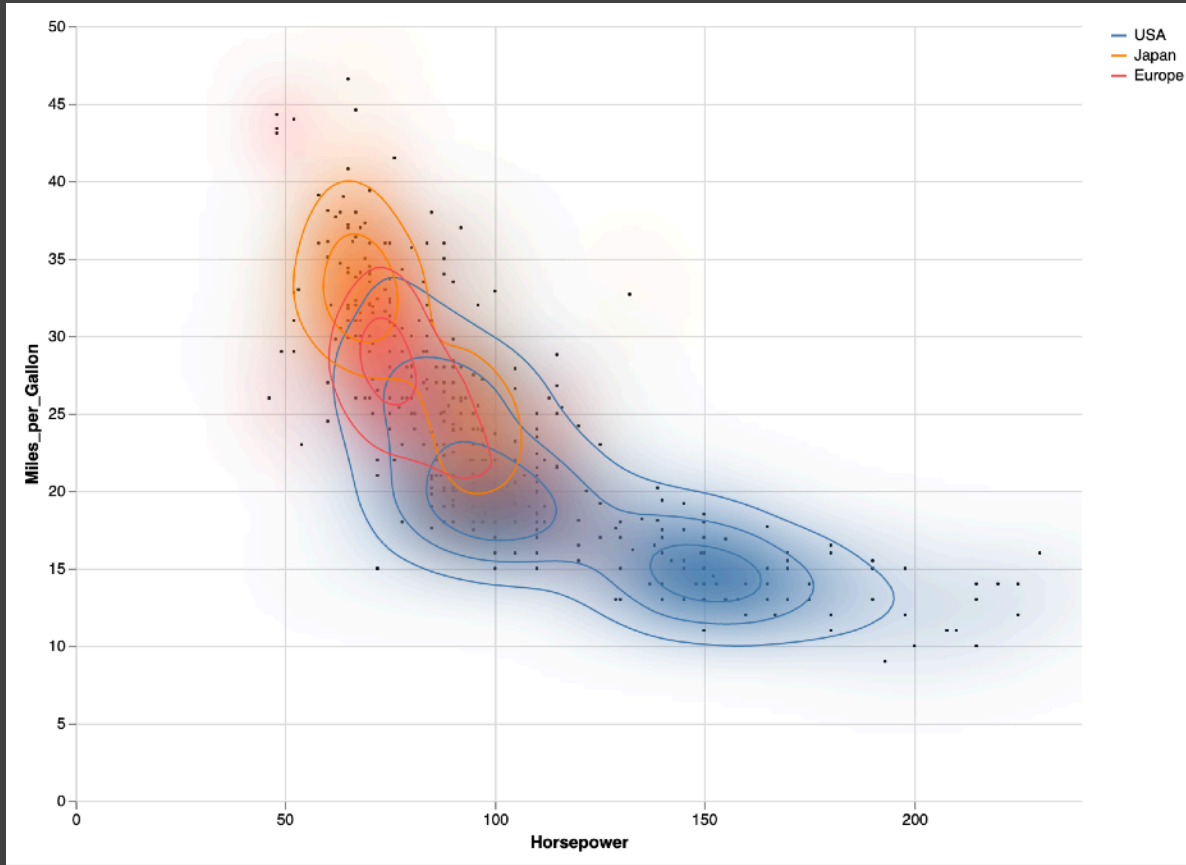


Identical boxplots, different distributions

Boxplots are great. They show medians and ranges and enable comparison of different groups. However, boxplots can be misleading. Different datasets can have the same descriptive statistics (left), but quite different underlying distributions (middle). Therefore, it is crucial to visualize the distribution in addition to descriptive statistics. Violin plots with integrated boxplots are great for this.

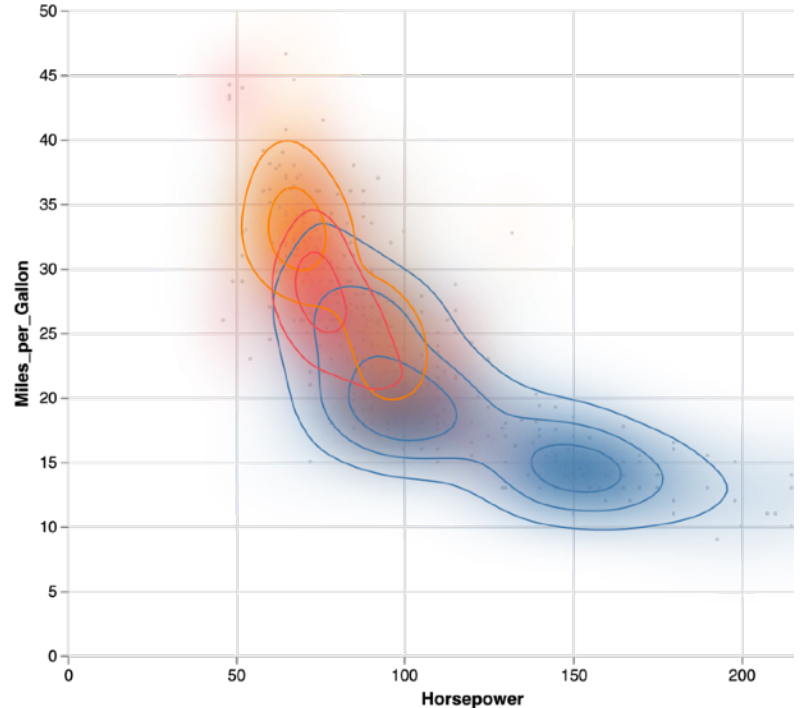
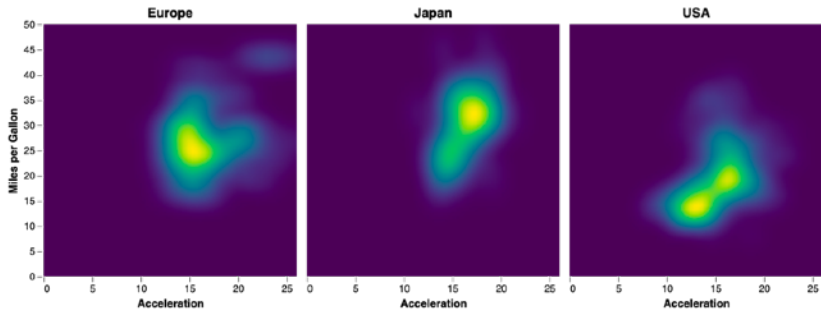
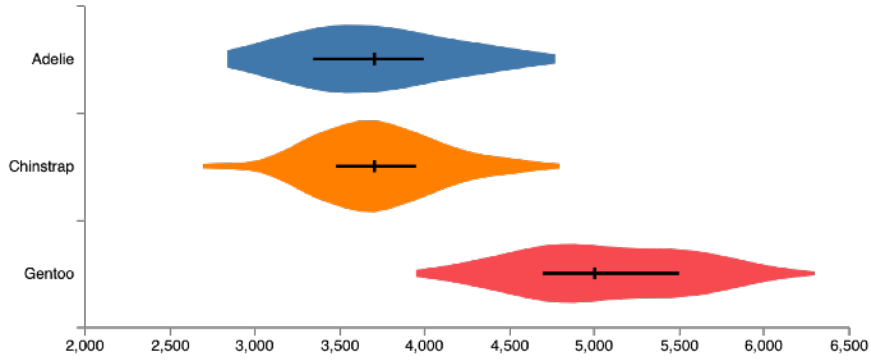


Now in 2D! Heatmaps, Contours



Kernel Density Estimation (KDE)

Enables violin plots, heat maps, contour plots...



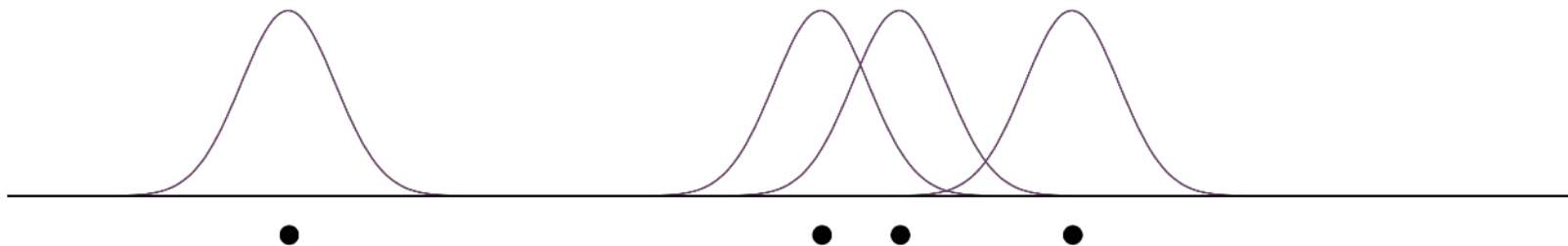
Kernel Density Estimation

For a set of input data points...



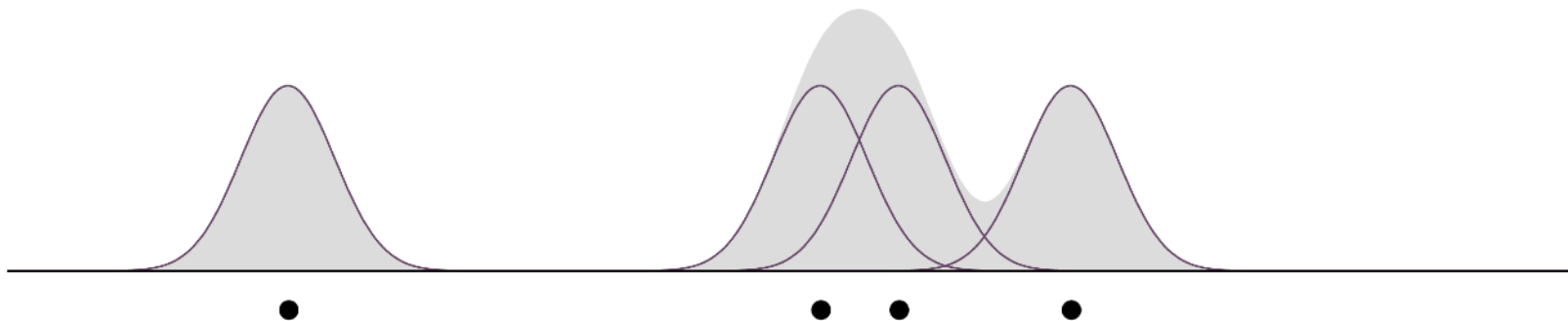
Kernel Density Estimation

Represent each point with a "kernel" distribution



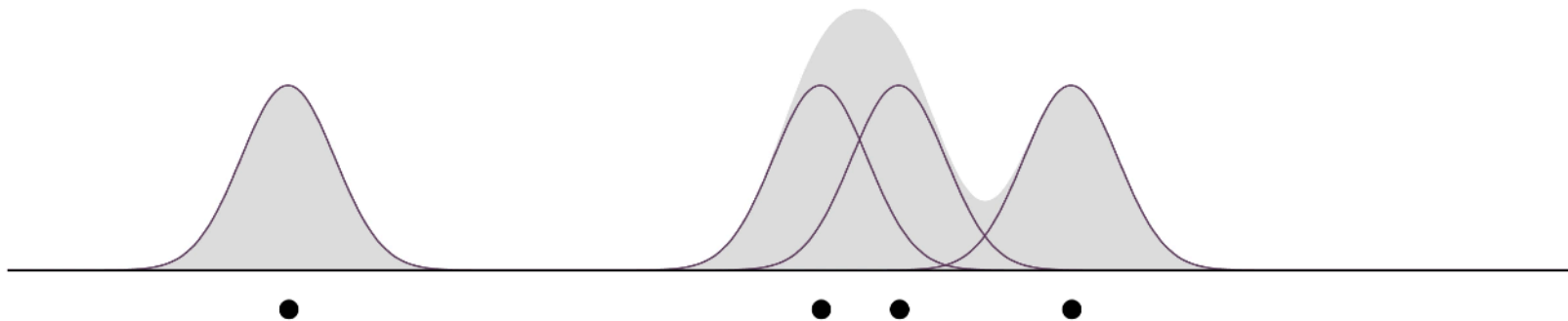
Kernel Density Estimation

Sum the kernels to form a density estimate



Kernel Density Estimation

Sized by bandwidth (standard deviation)



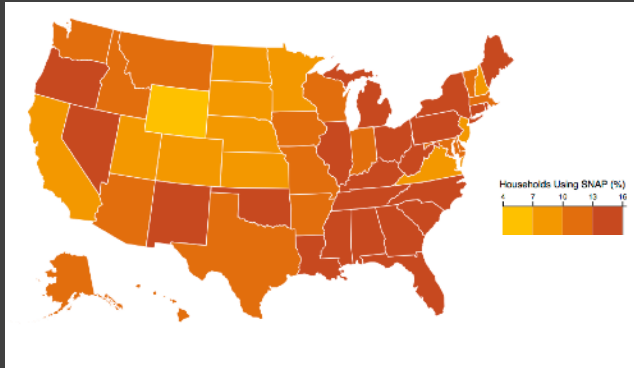
Visual Encodings of Uncertainty

Uncertainty Vis Pipeline

- 1) Quantify uncertainty
- 2) Choose a free visual variable
- 3) Encode uncertainty with the variable

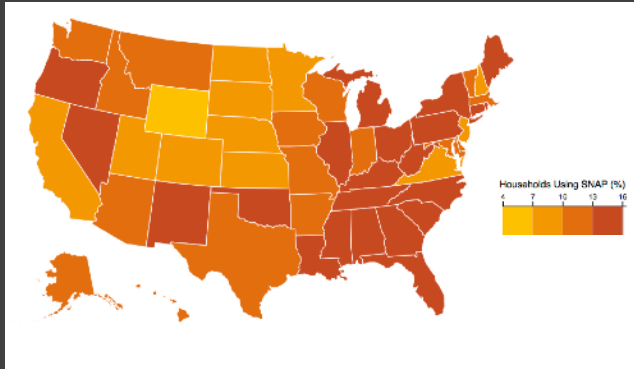
SNAP

Data Map

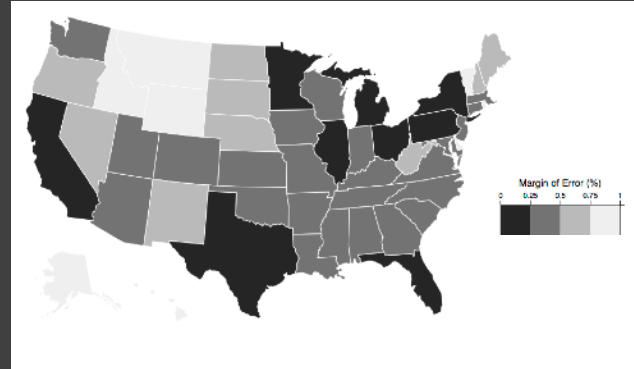


SNAP

Data Map



Uncertainty Map



Uncertainty Vis Pipeline

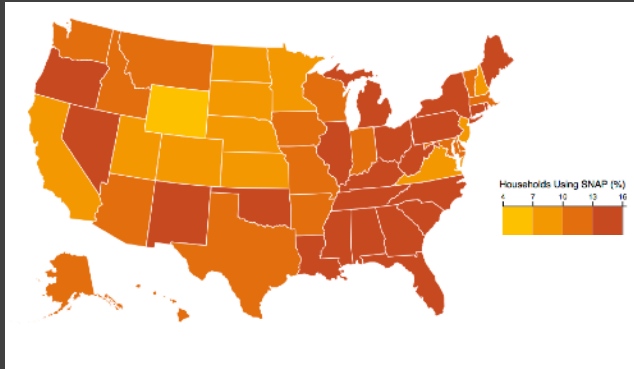
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Uncertainty Vis Pipeline

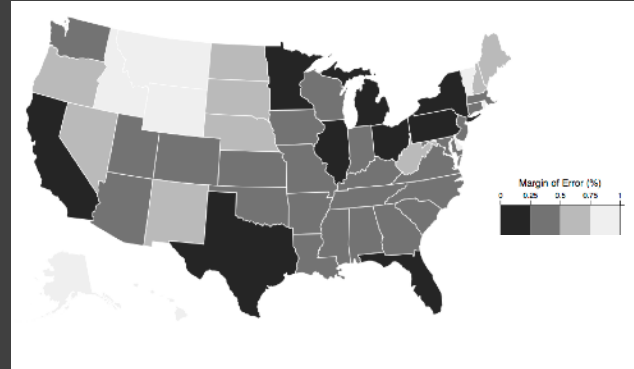
- 1) Quantify uncertainty
- 2) Choose a free visual variable
- 3) Encode uncertainty with the variable
- 4) Unify the Data Map and Uncertainty Map

How to Unify?

Data Map

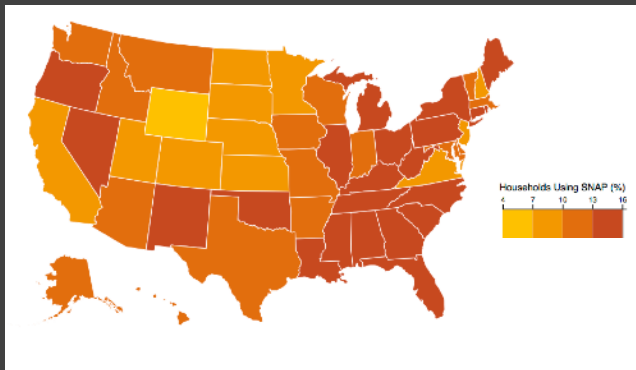


Uncertainty Map

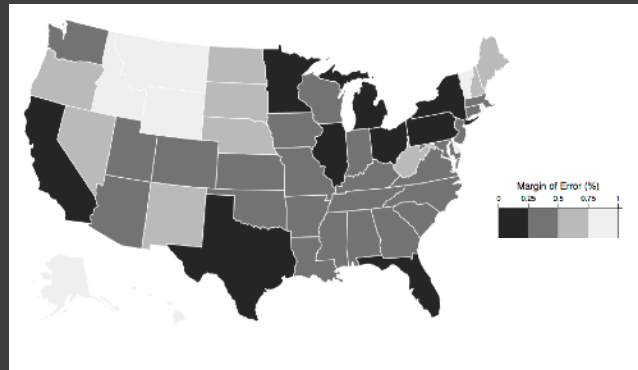


Juxtaposition

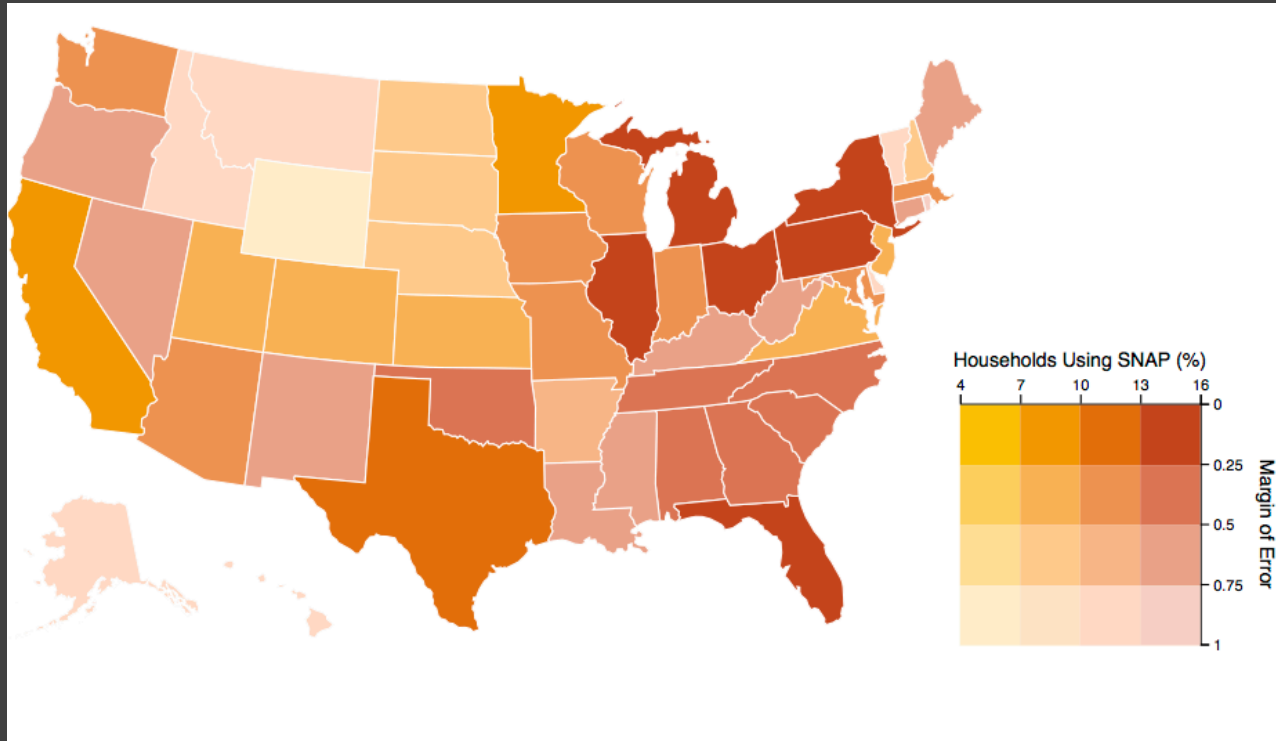
Data Map



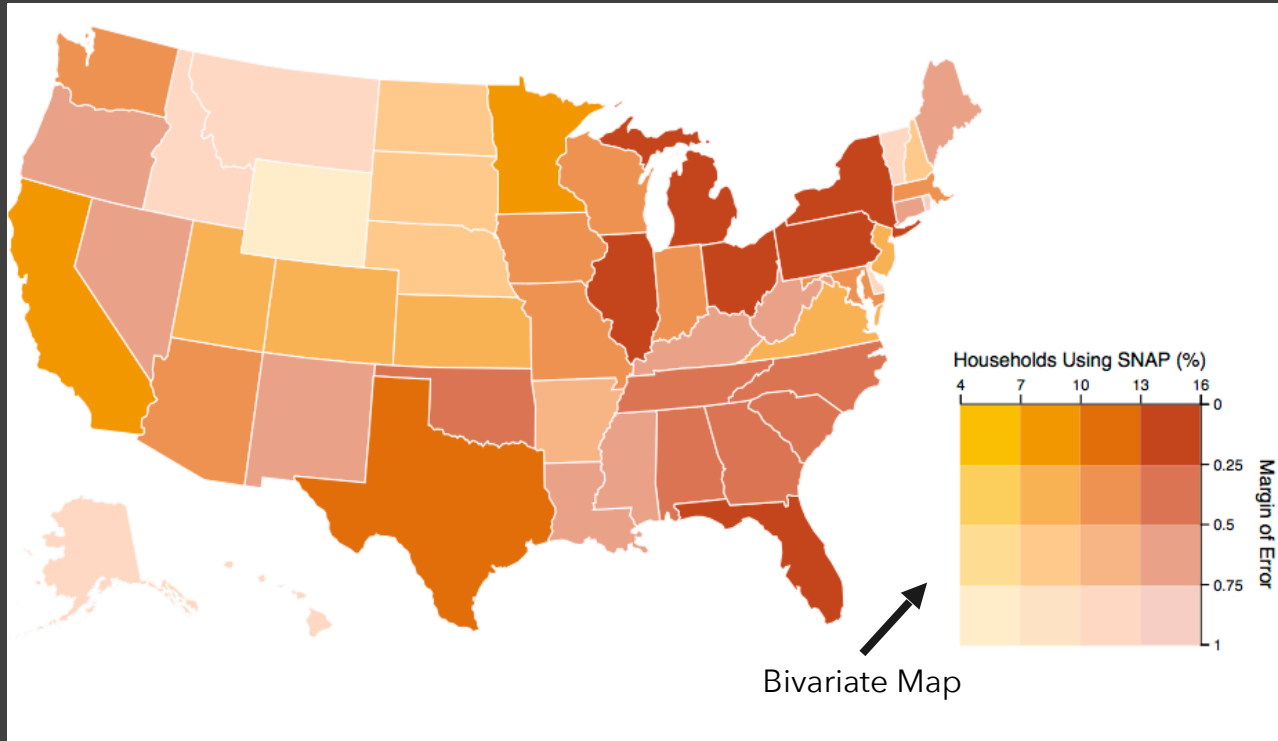
Uncertainty Map



Superposition



Superposition



Uncertainty Vis Pipeline

- 1) Quantify uncertainty
- 2) Choose a free visual variable
- 3) Encode uncertainty with the variable
- 4) Unify the Data Map and Uncertainty Map

Uncertainty Vis Pipeline

- 1) Quantify uncertainty
- 2) Choose a free **visual variable**
- 3) Encode uncertainty with the variable
- 4) Unify the Data Map and Uncertainty Map

Semiotics of Uncertainty

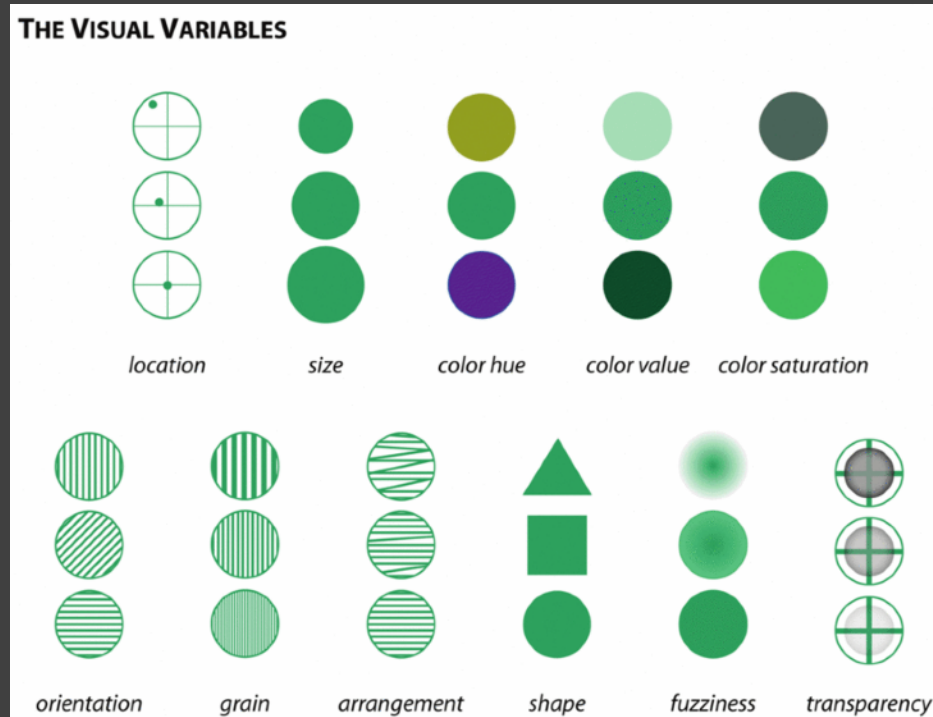


Ceci n'est pas une pipe.

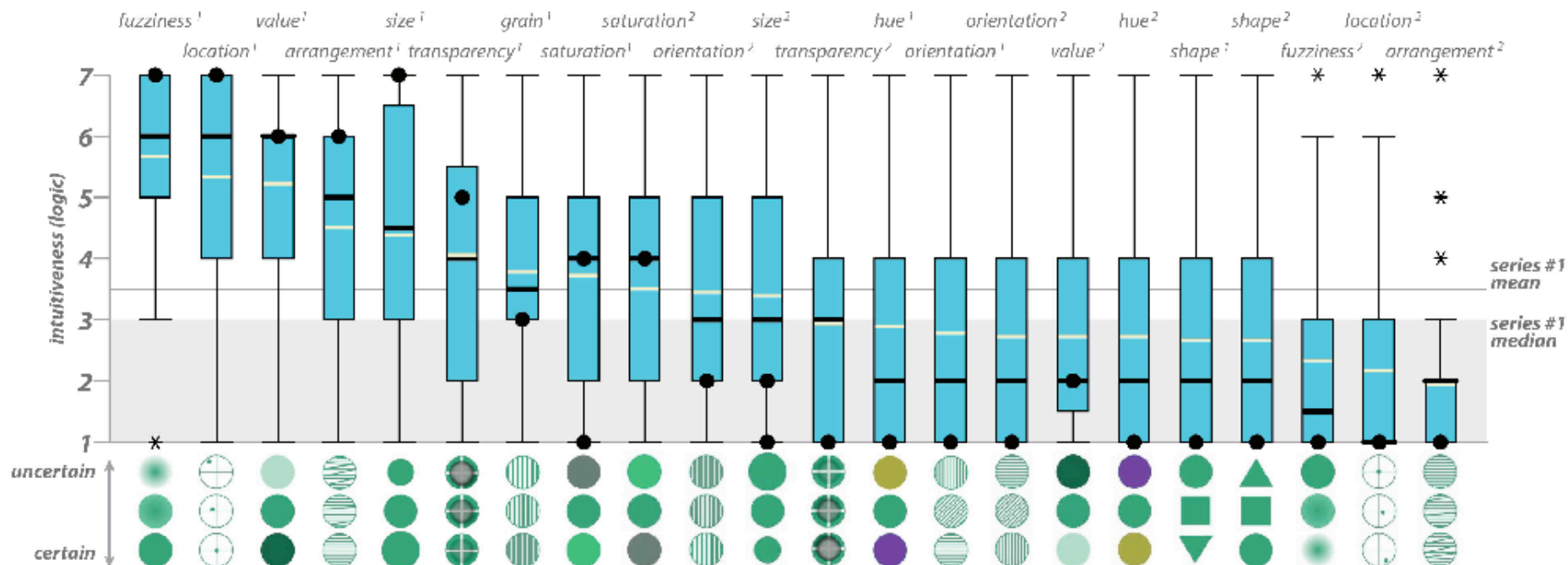
Semiotics of Uncertainty



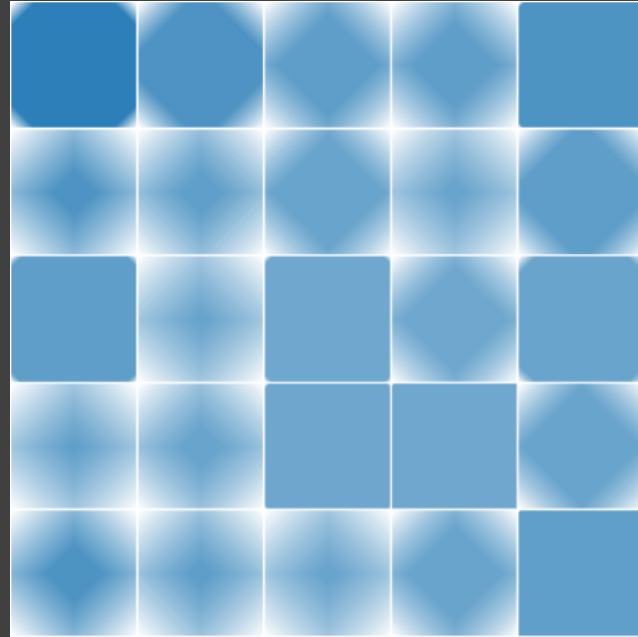
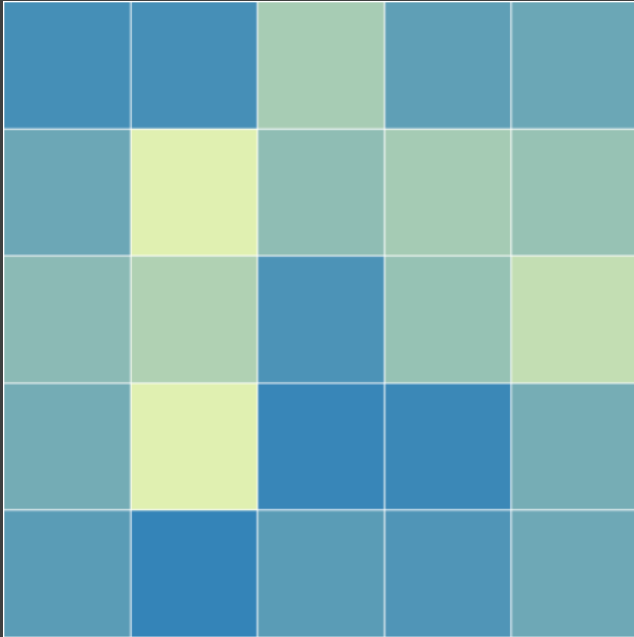
Semiotics of Uncertainty



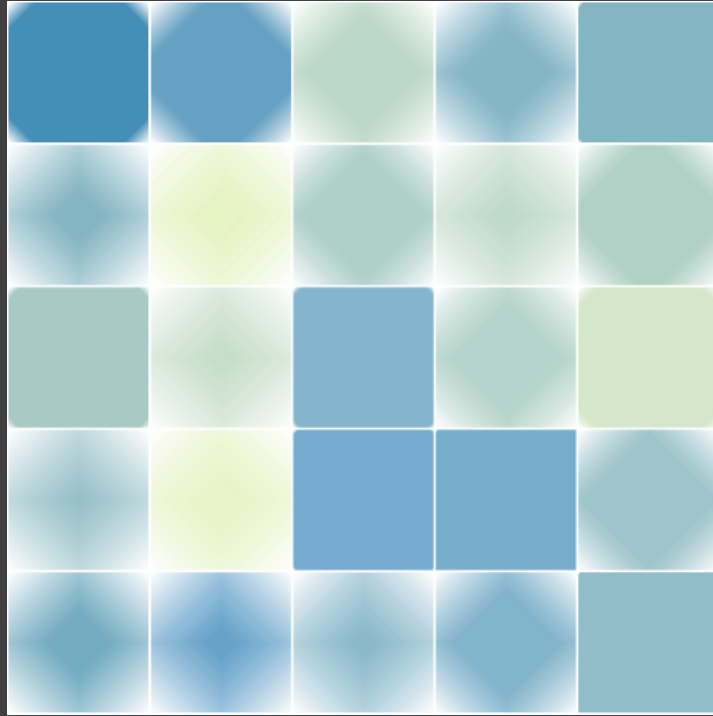
SERIES #1: GENERAL UNCERTAINTY BY VISUAL VARIABLE



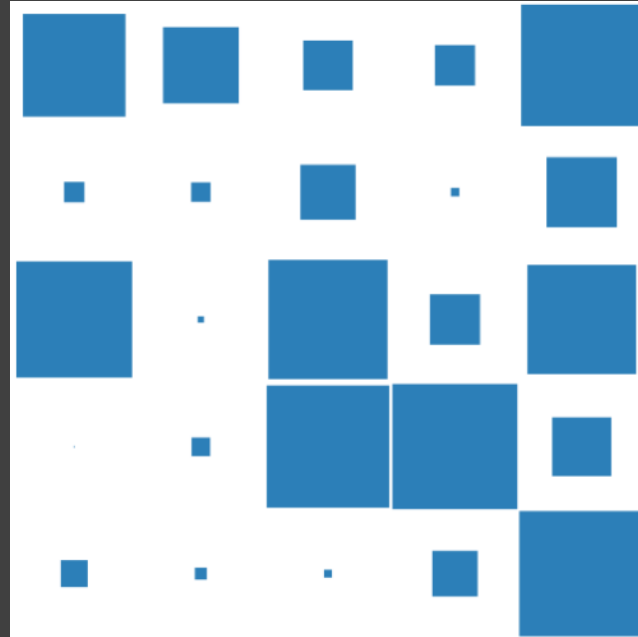
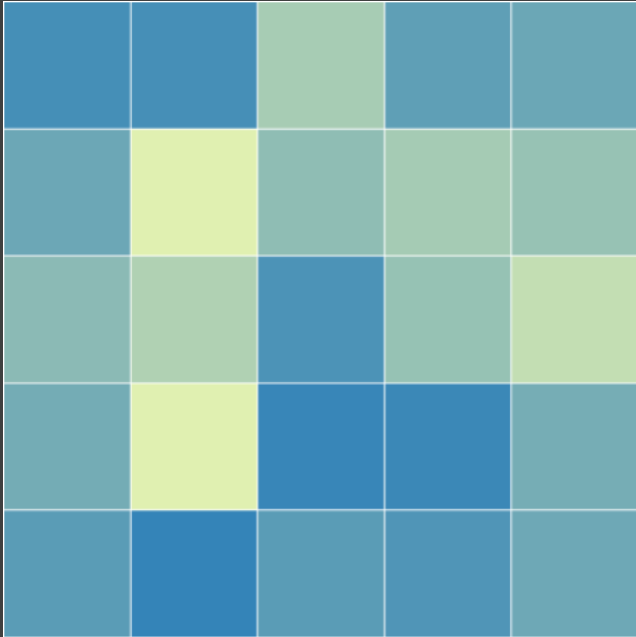
Fuzziness Juxtaposition



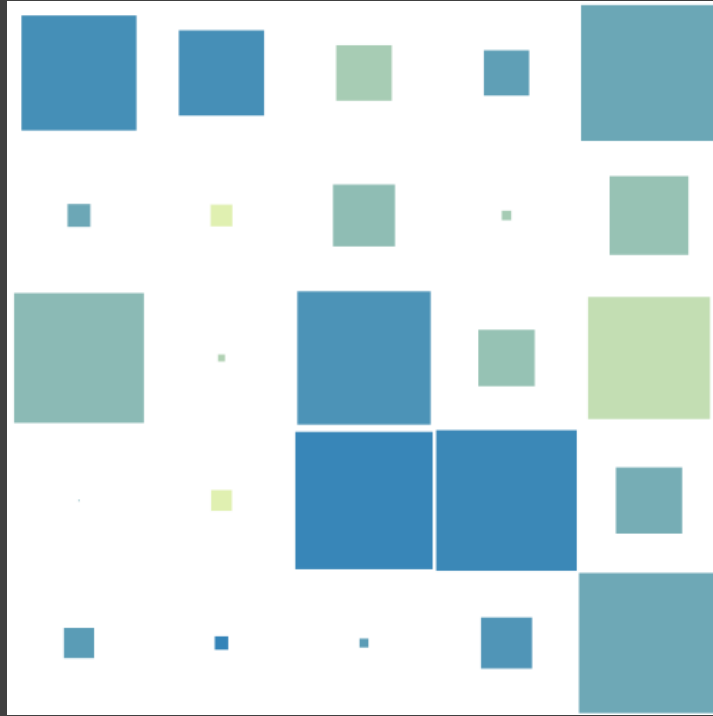
Fuzziness Superposition



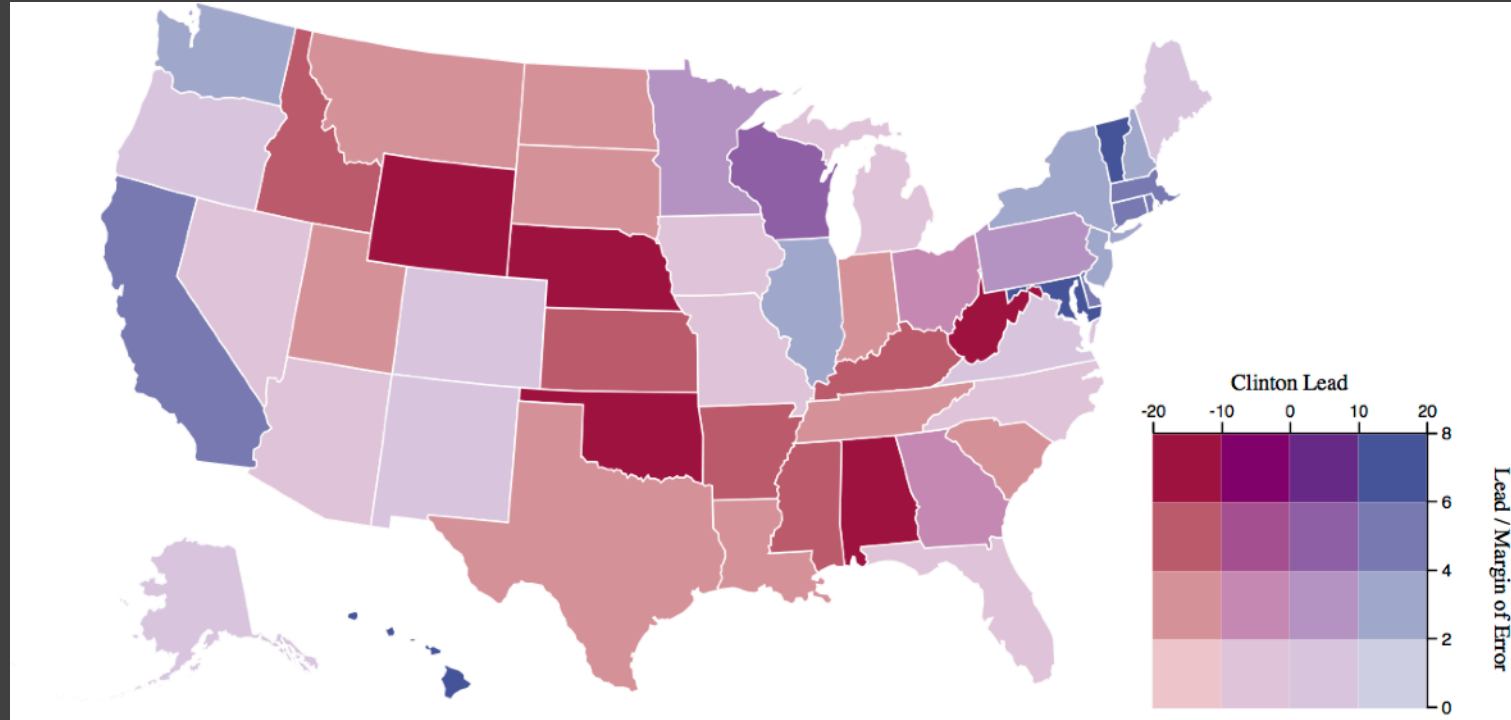
Size Juxtaposition



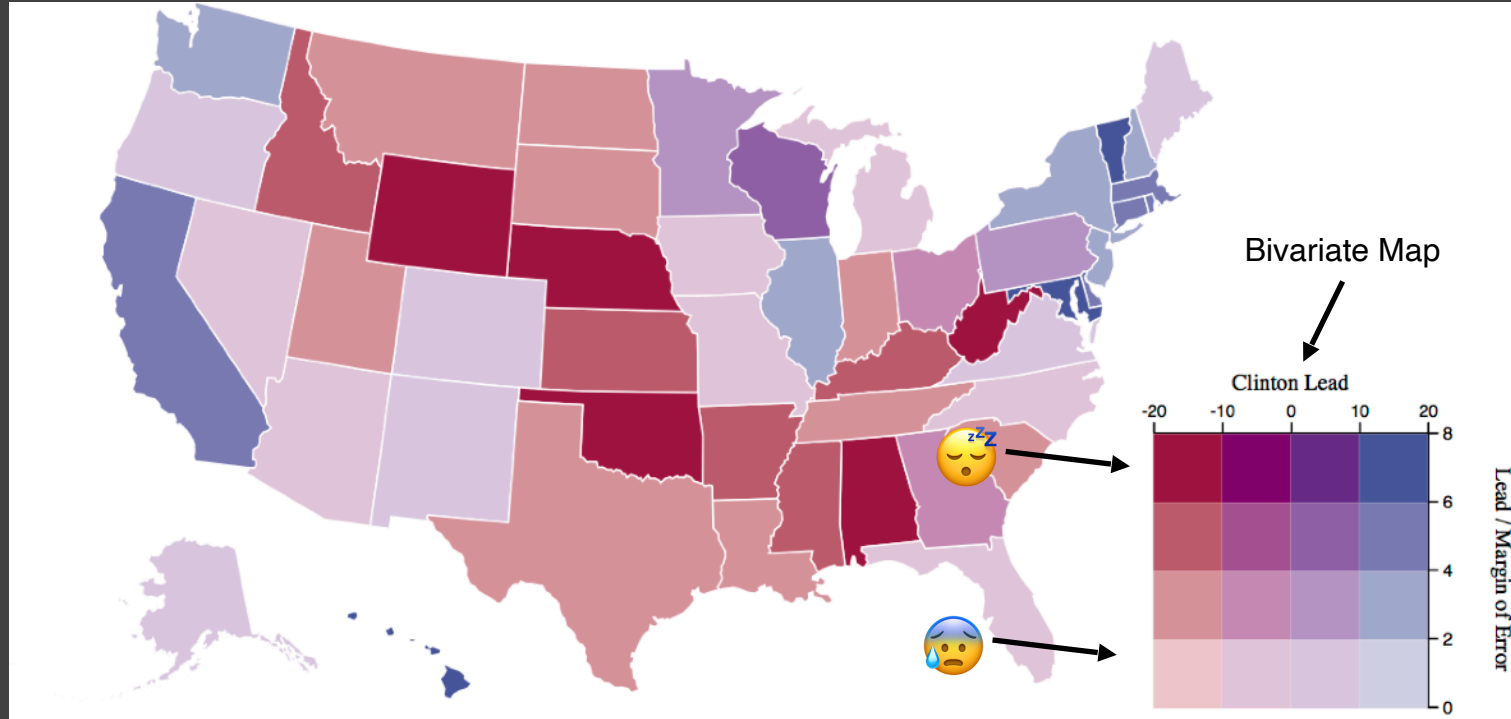
Size Superposition



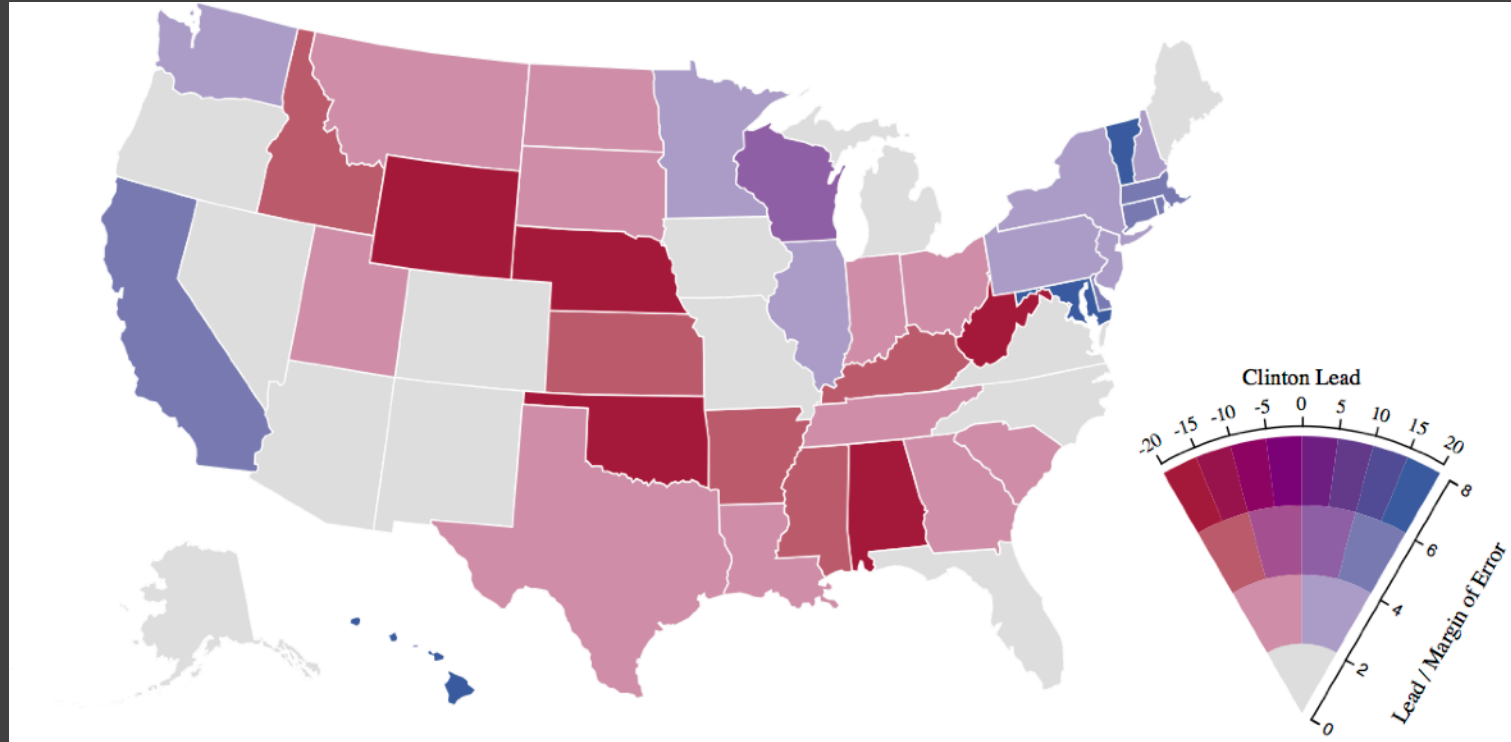
Value Suppressing Uncertainty Palettes



Bivariate Map

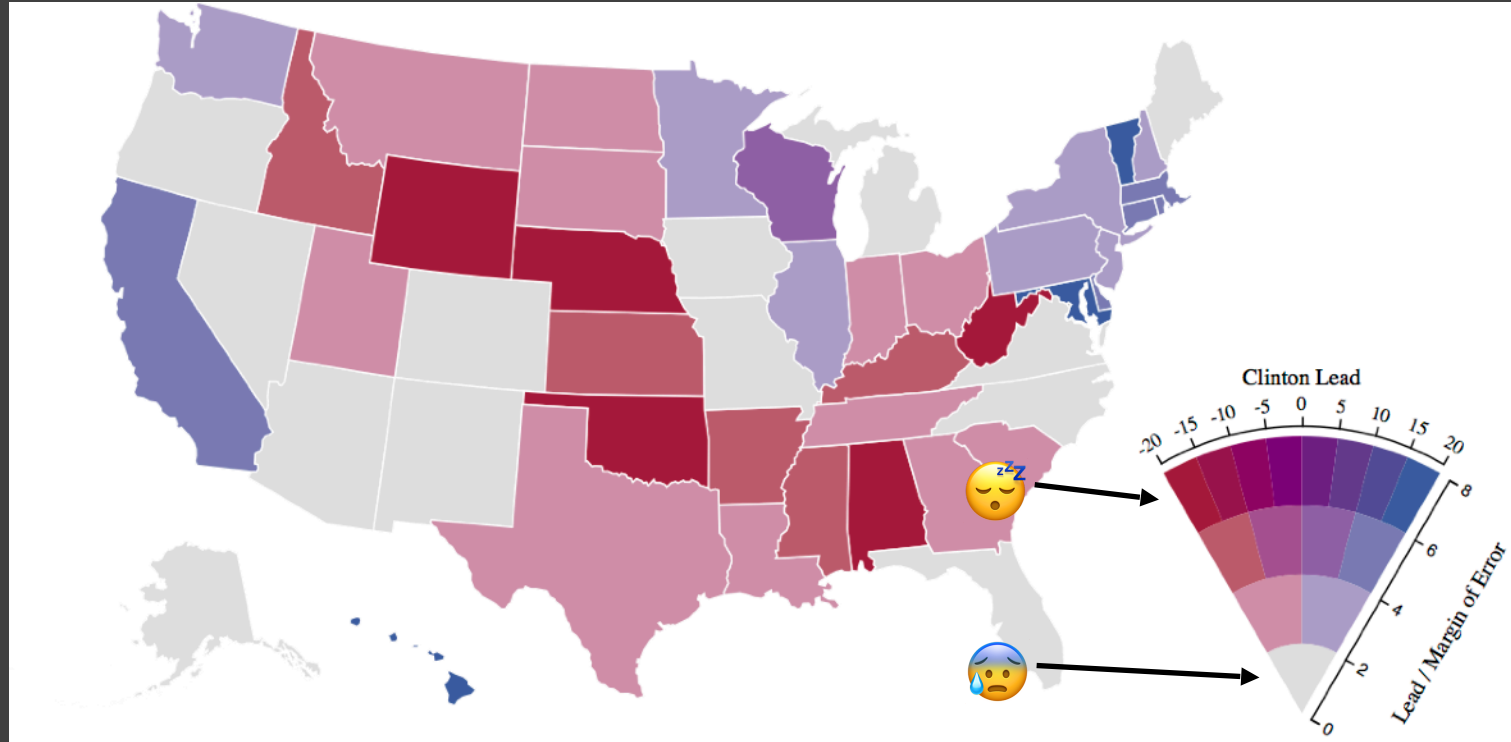


Value Suppressing Uncertainty Palettes



Correll, Moritz & Heer. "Value-Suppressing Uncertainty Palettes." CHI 2018.

Value Suppressing Uncertainty Palettes

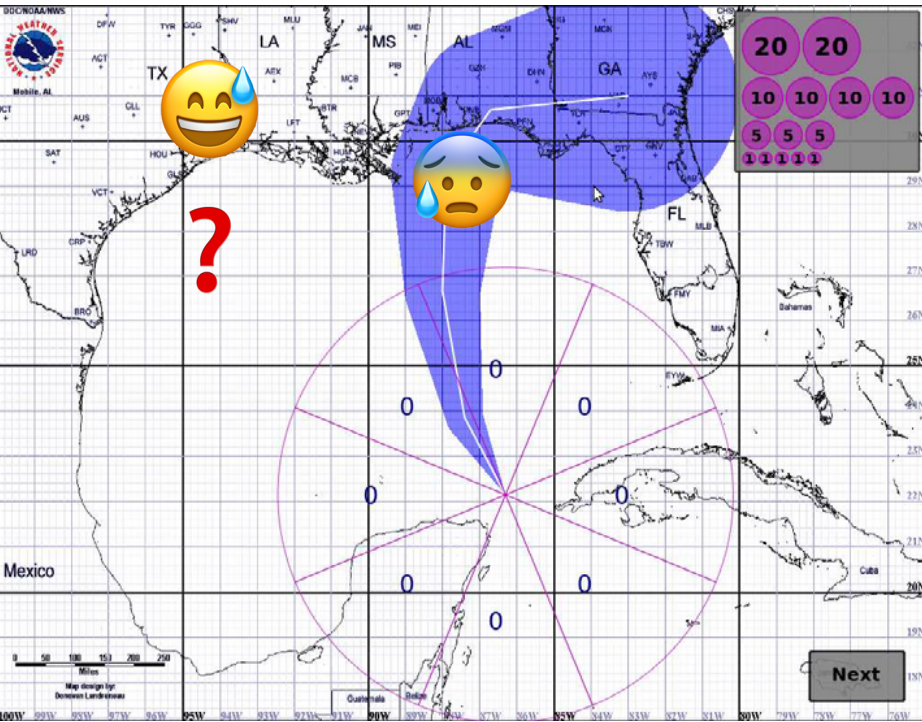


Encoding Uncertainty

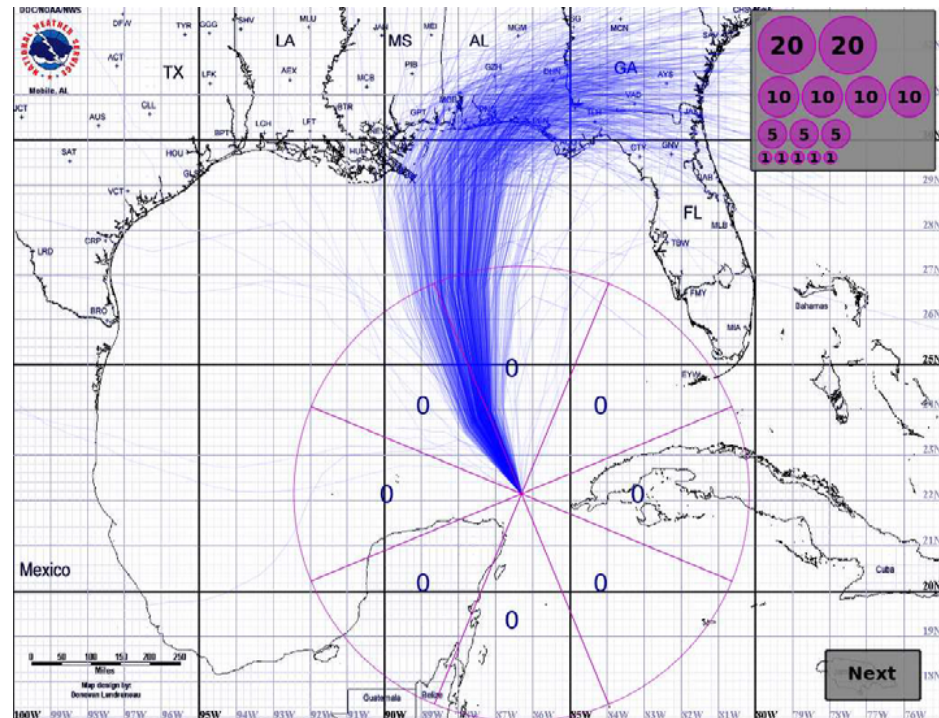
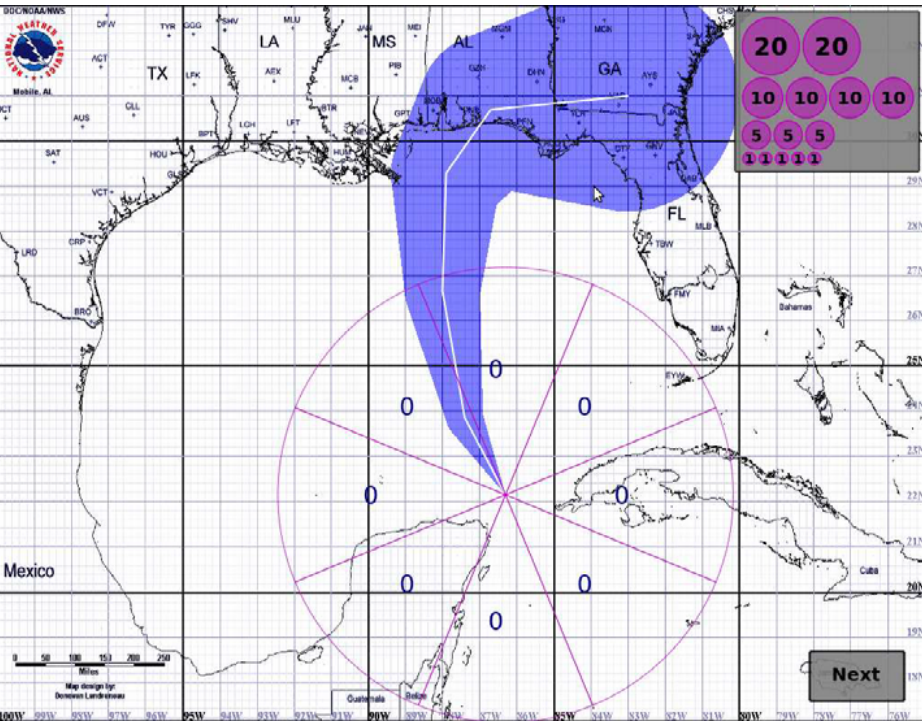
Some visual variables (like fuzziness and value) have a **semiotic connection** to uncertainty.

However, intuitive variables may not always be accurately interpreted!

Frequency Framing & Hypothetical Outcomes



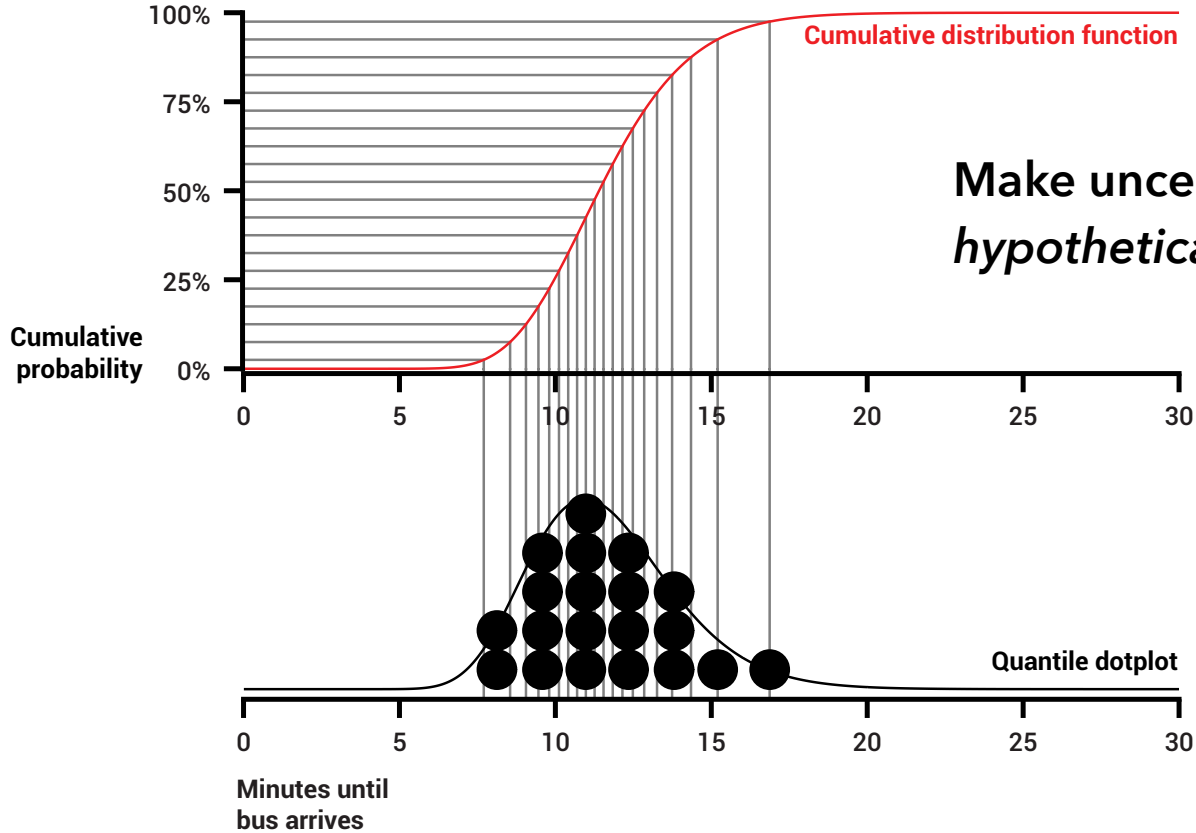
Size or likelihood of hurricane?
 Is New Orleans safe?



Size or likelihood of hurricane?
Is New Orleans safe?

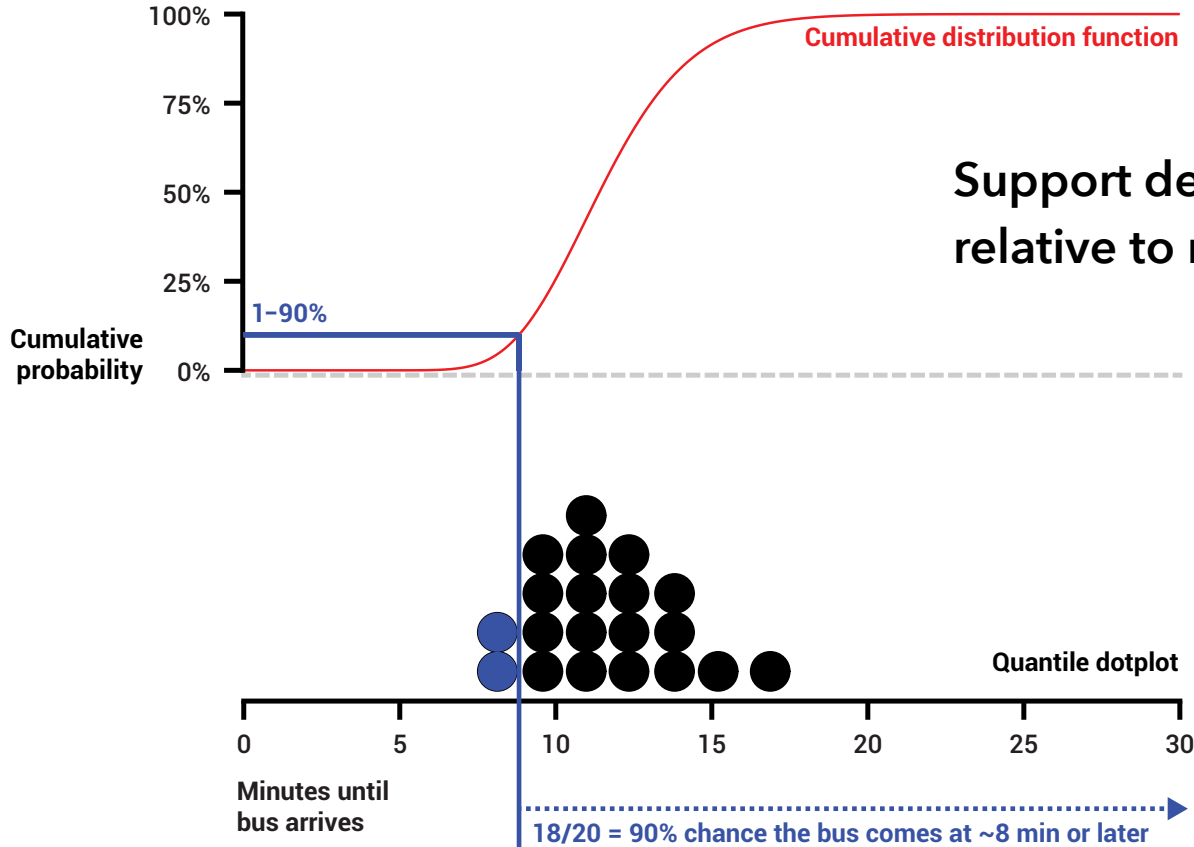
Make uncertainty more concrete
via *hypothetical outcomes*.

Predicted Bus Arrival Times



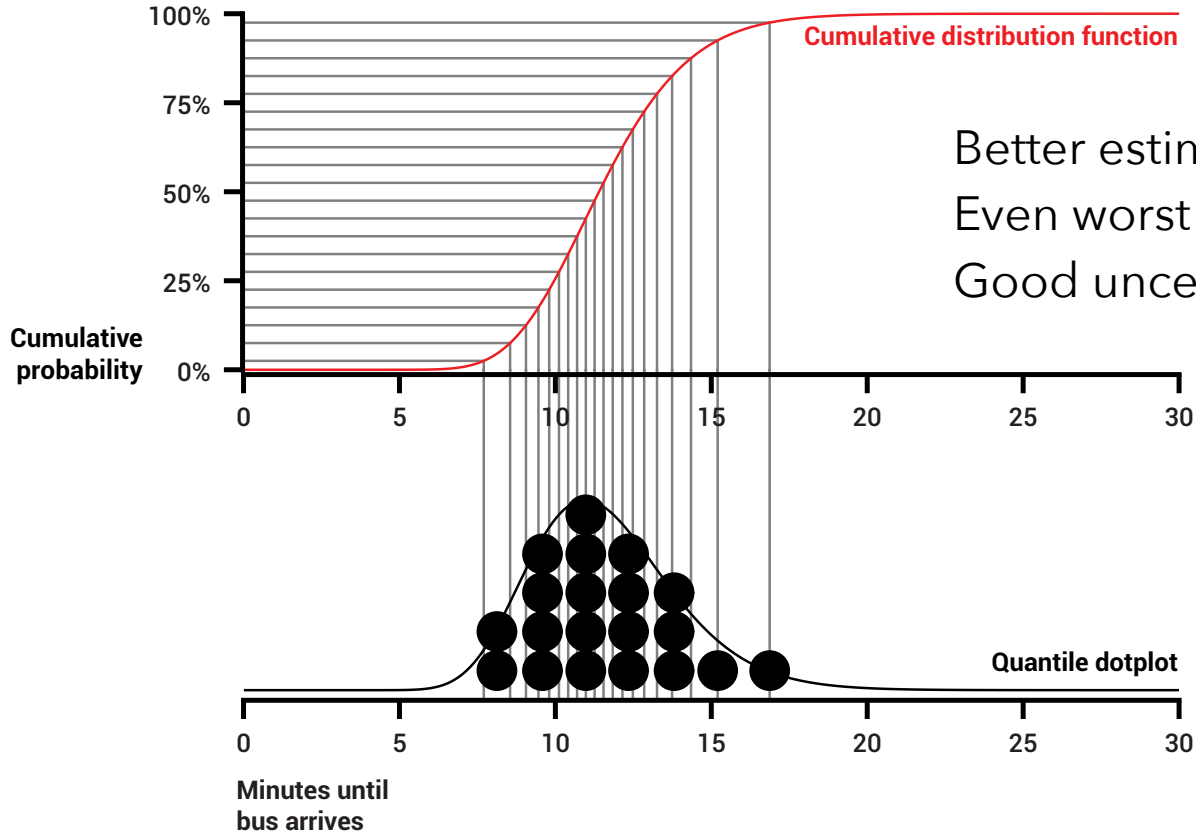
Make uncertainty concrete via
hypothetical outcomes.

Predicted Bus Arrival Times



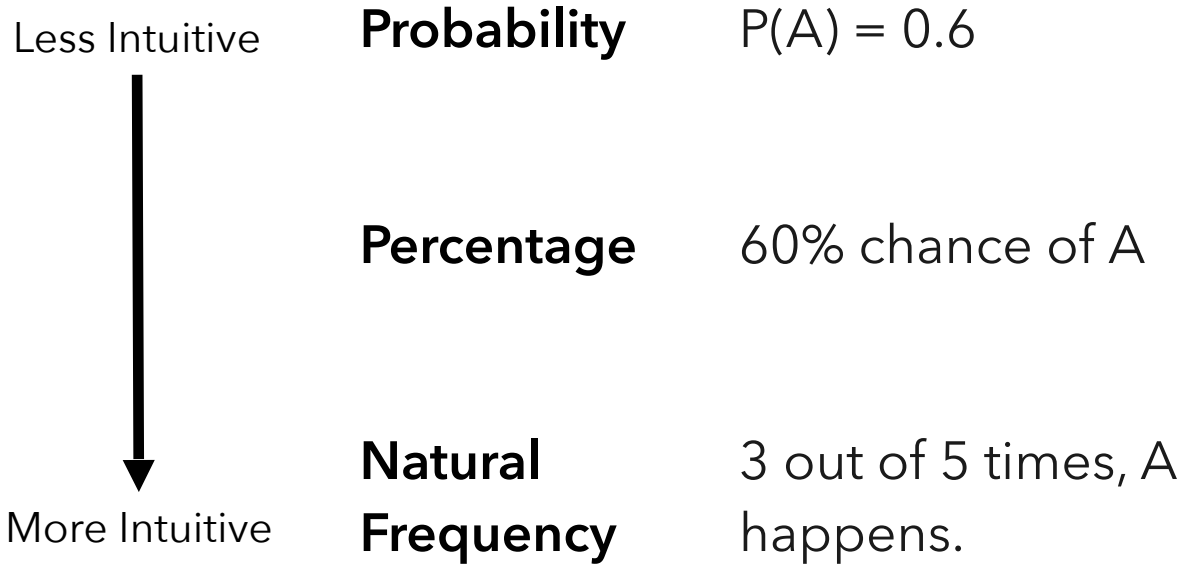
Support decision making
relative to risk tolerance.

Predicted Bus Arrival Times



Better estimates, decisions with time.
Even worst performers improve.
Good uncertainty displays possible!

How to Present Probabilities

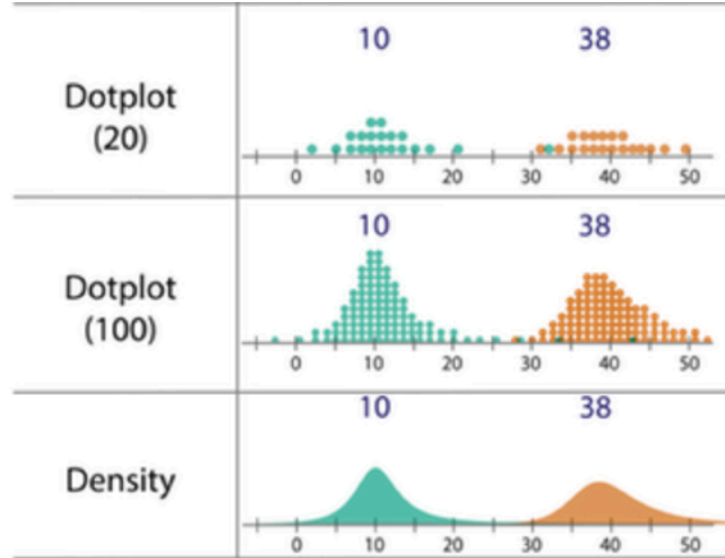


Quantile Dot Plots

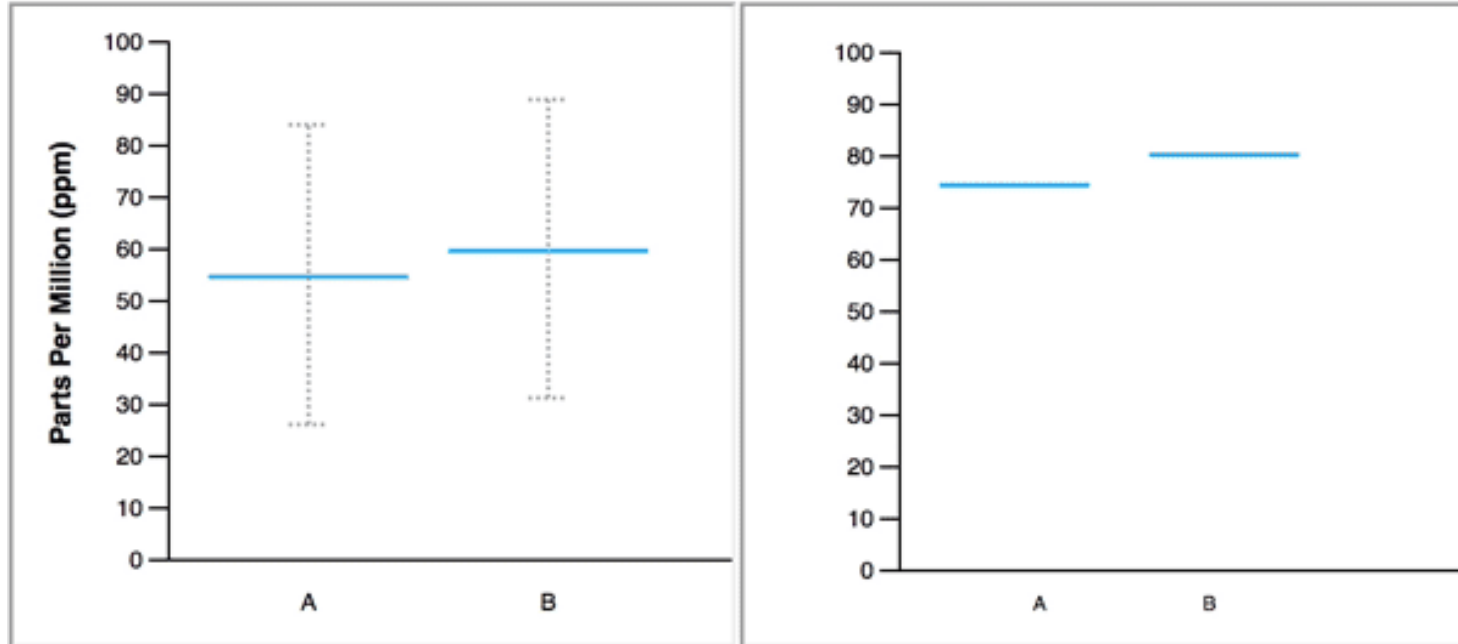
Less Error



More Error

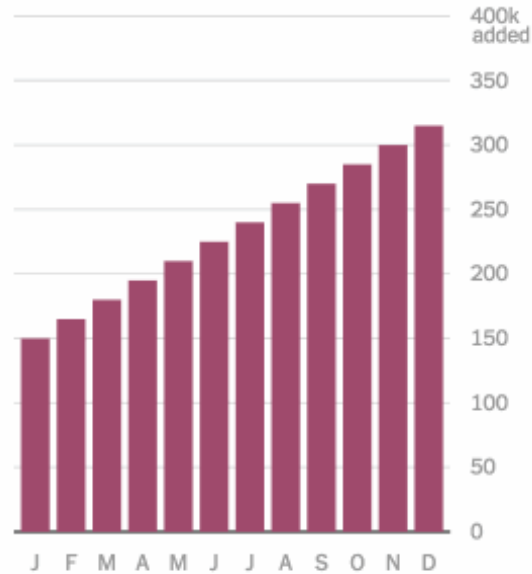


Hypothetical Outcome Plots



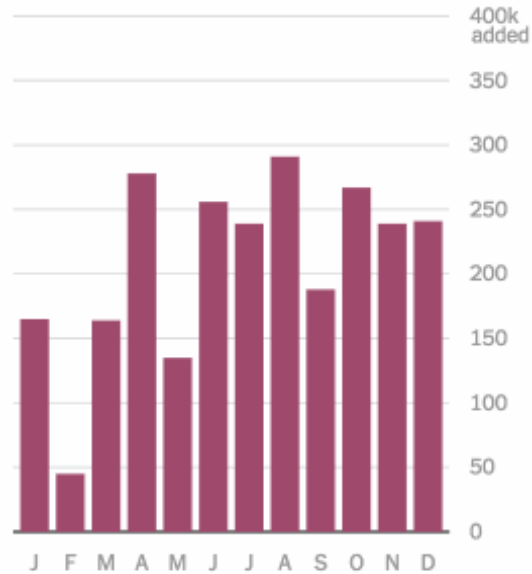
Hypothetical Outcome Plots

If job growth **had**
been accelerating...



...the jobs report
could look like this:

Pause



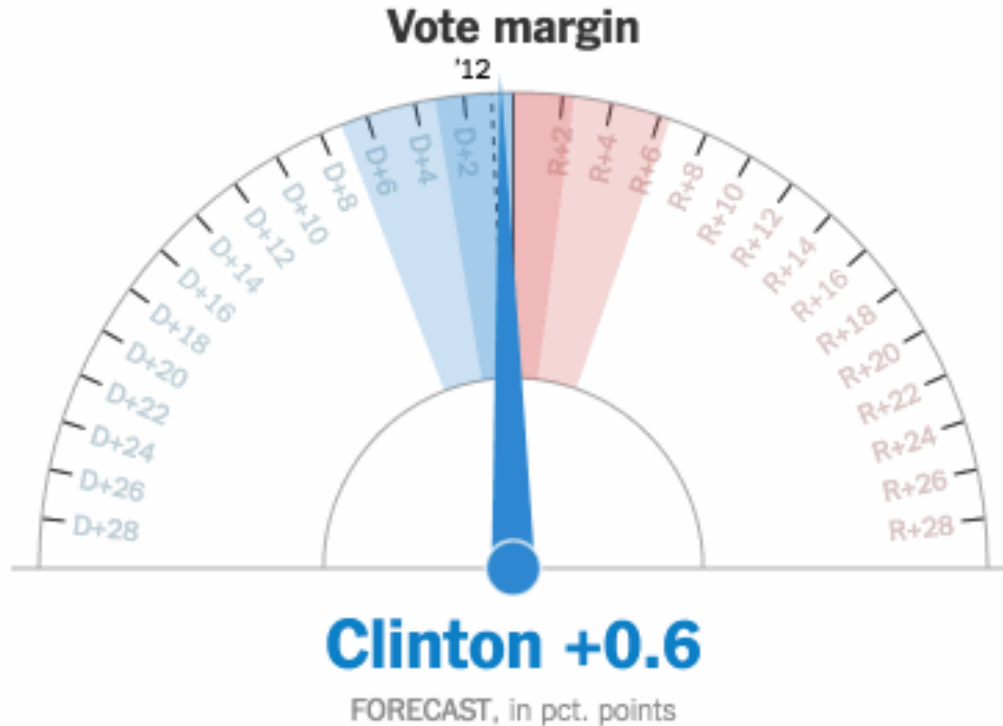
Hypothetical Outcomes

If the economy actually added 150,000 jobs last month, it would be possible to see any of these headlines:

The jobs number is just an estimate, and it comes with uncertainty.



The NY Times Needle



How Should I Visualize Uncertainty?

Choose an appropriate visual variable based on the domain, literacy, and expertise of your audience. Be mindful that any display of uncertainty inherently increases the complexity of your visualization, and that there is a preference/performance gap.

How Should I Visualize Uncertainty?

Choose an appropriate visual variable based on the domain, literacy, and expertise of your audience. Be mindful that any display of uncertainty inherently increases the complexity of your visualization, and that there is a preference/performance gap.

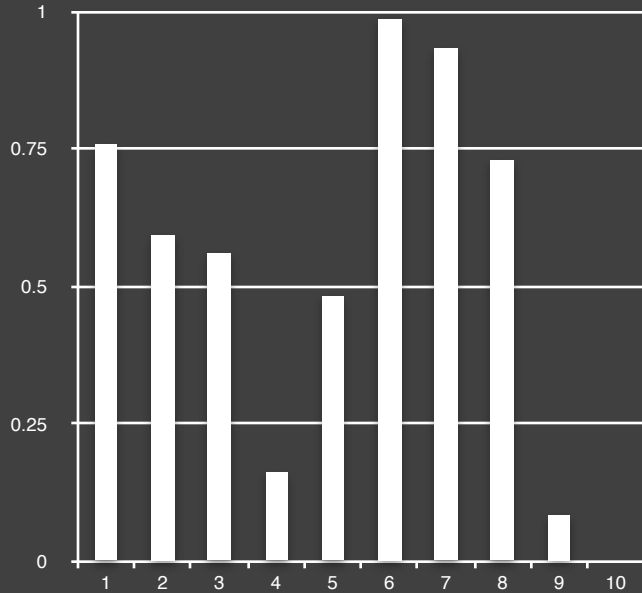
IT DEPENDS

What Can Go Wrong?

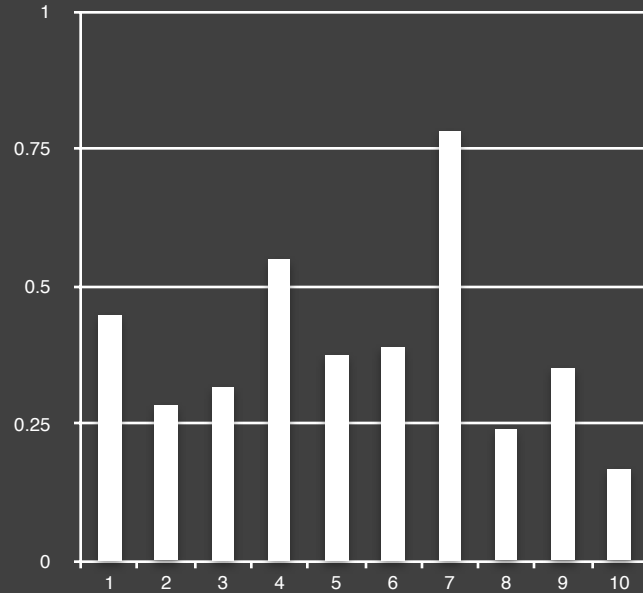
Inferential Integrity

Which Stock To Buy?

Company A

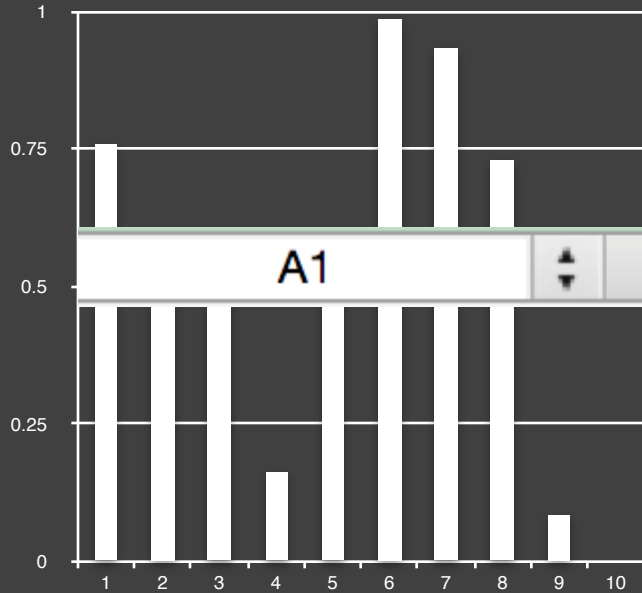


Company B

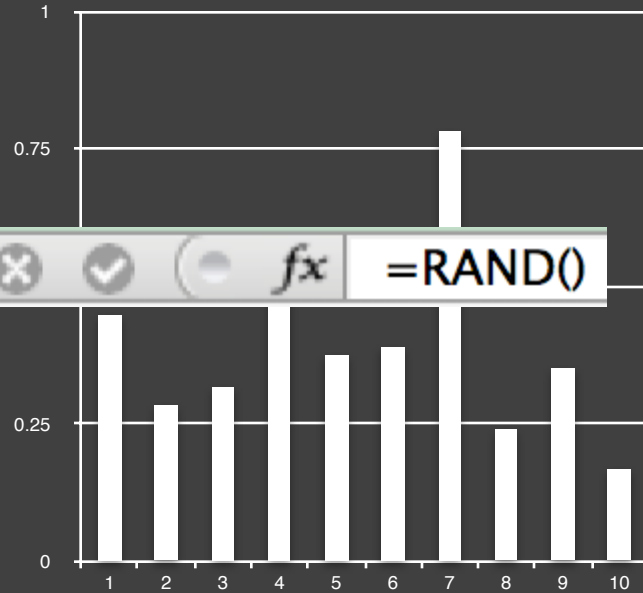


Neither!

Company A



Company B



A1

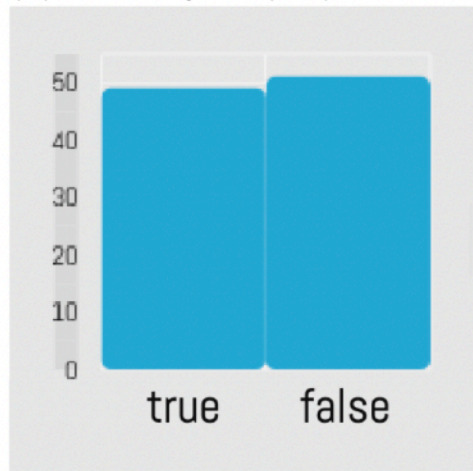


fx

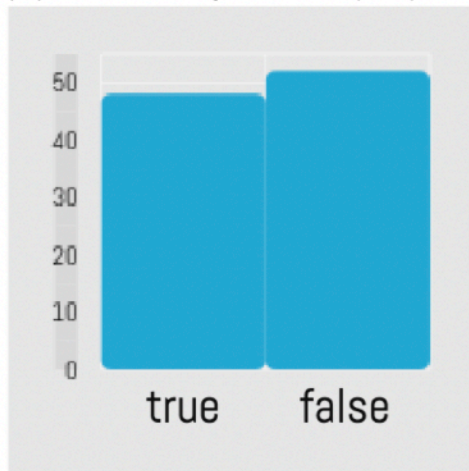
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What Swag Should We Send? [Zgraggen et al. '18]

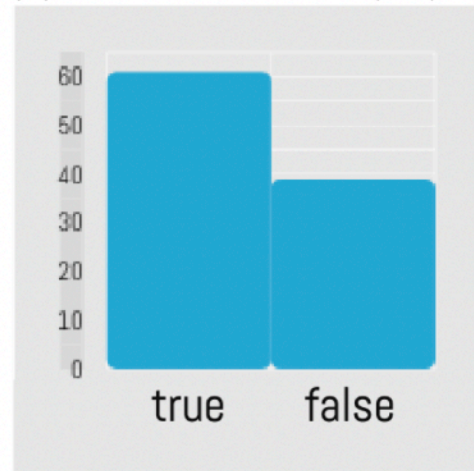
(a) 2006: pen (\$4)



(b) 2007 key chain (\$2)



(c) 2016: USB drive (\$4)

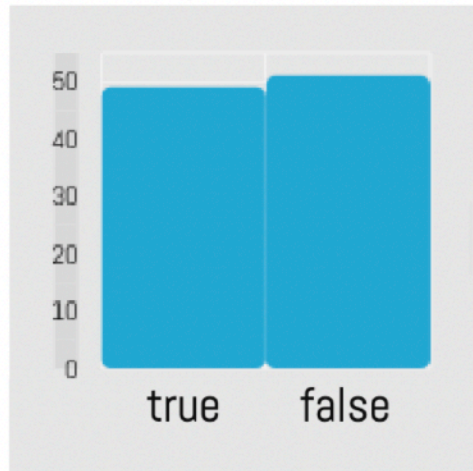


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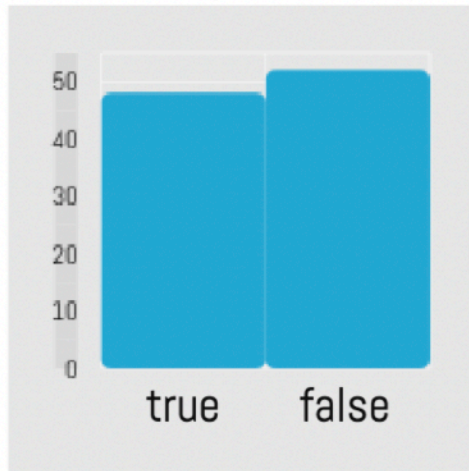
Recurring
Donor?

What Swag Should We Send? [Zgraggen et al. '18]

(a) 2006: pen (\$4)



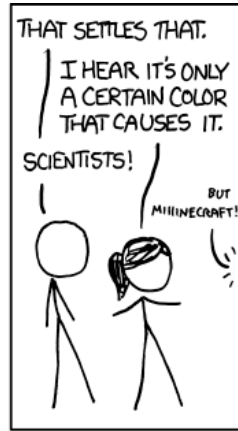
(b) 2007 key chain (\$2)

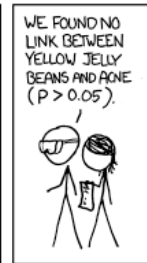
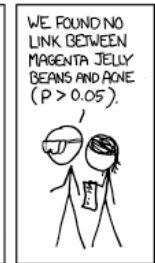
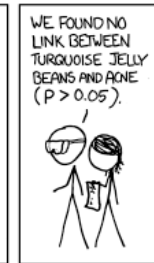
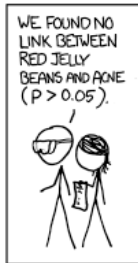
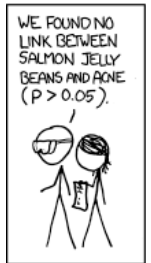
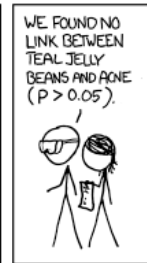
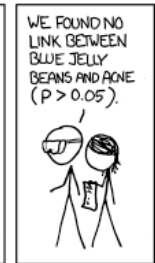
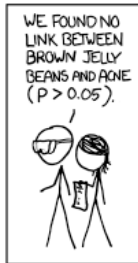
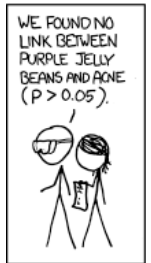
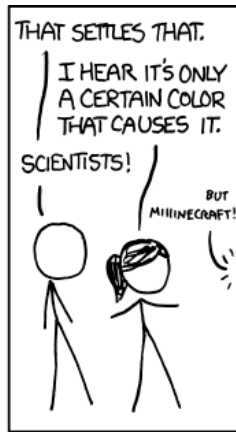


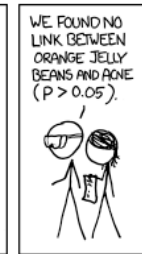
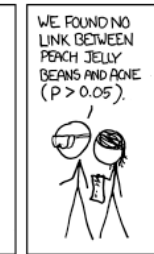
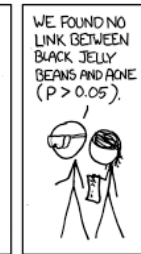
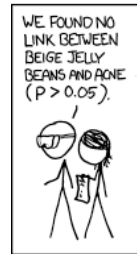
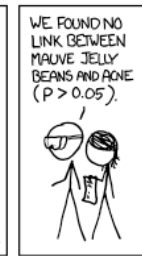
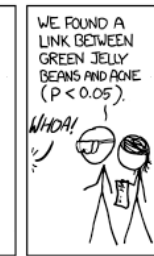
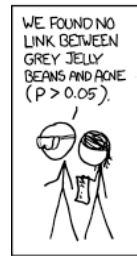
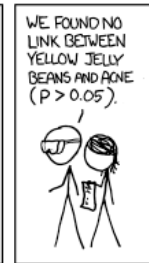
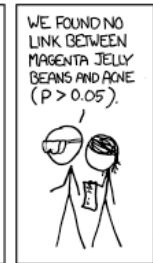
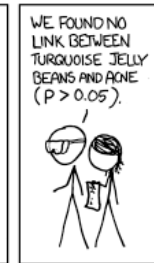
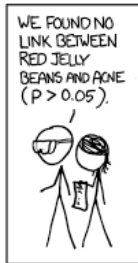
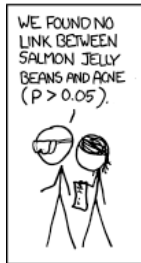
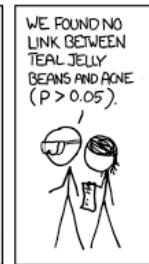
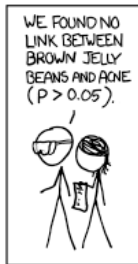
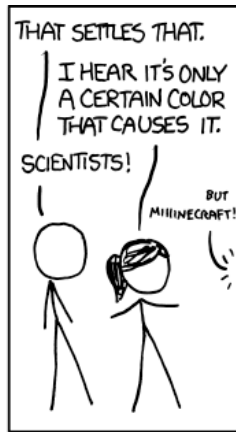
(c) 2016: USB drive (\$4)

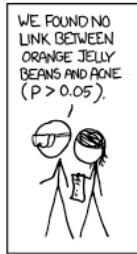
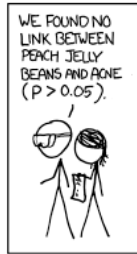
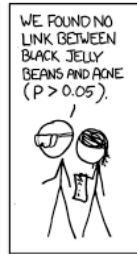
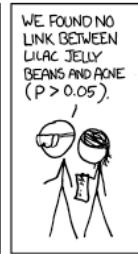
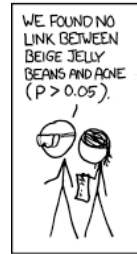
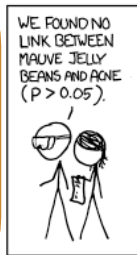
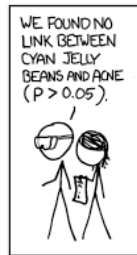
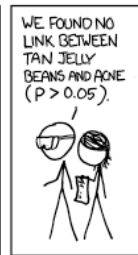
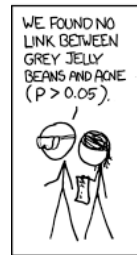
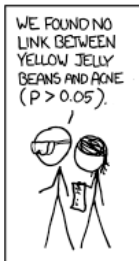
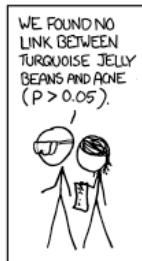
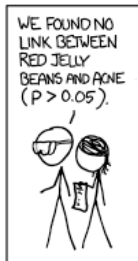
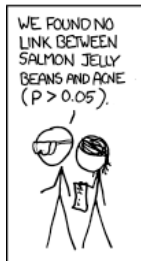
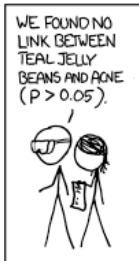
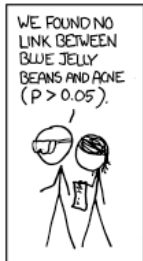
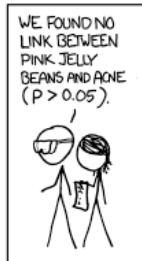
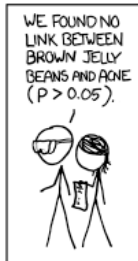
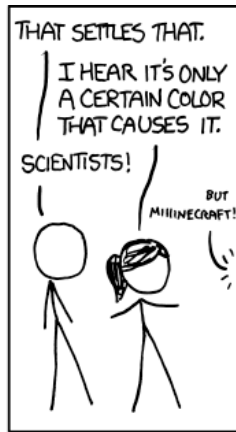


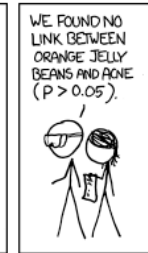
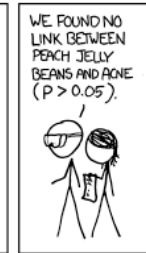
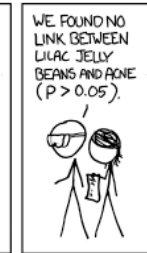
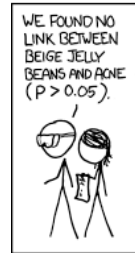
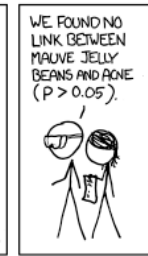
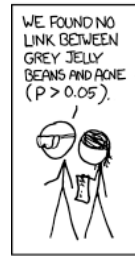
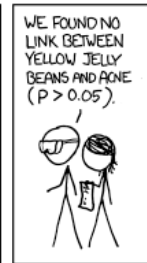
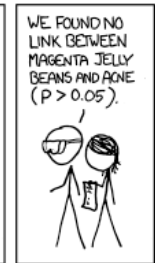
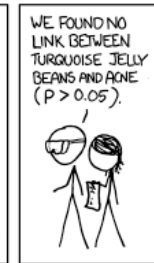
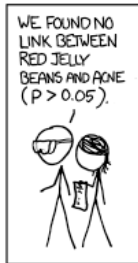
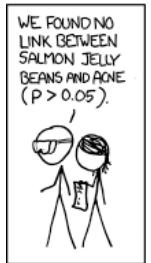
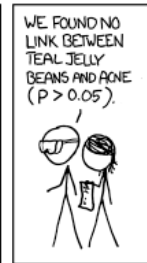
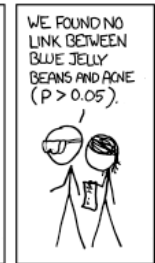
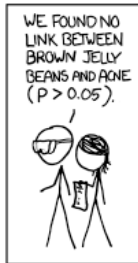
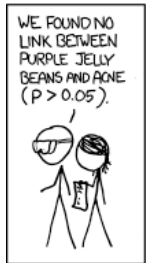
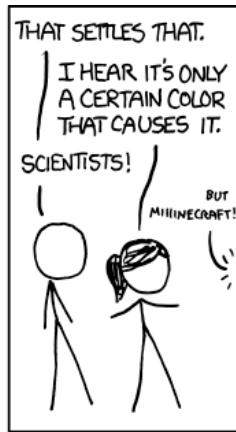
Figure 1. A user inspects several graphs and wrongly flags (c) as an insight because it looks different than (a) and (b). All were generated from the same uniform distribution and are the “same”. By viewing lots of visualizations, the chances increase of seeing an apparent insight that is actually the product of random noise.











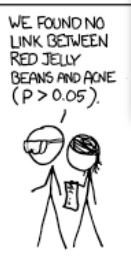
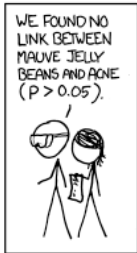
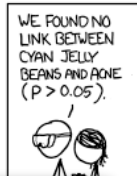
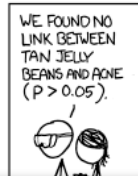
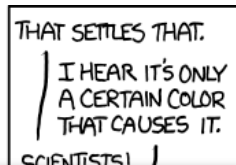
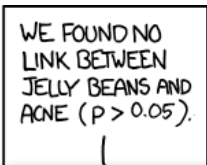
News

GREEN JELLY BEANS LINKED TO ACNE!

95% CONFIDENCE

ONLY 5% CHANCE OF COINCIDENCE!

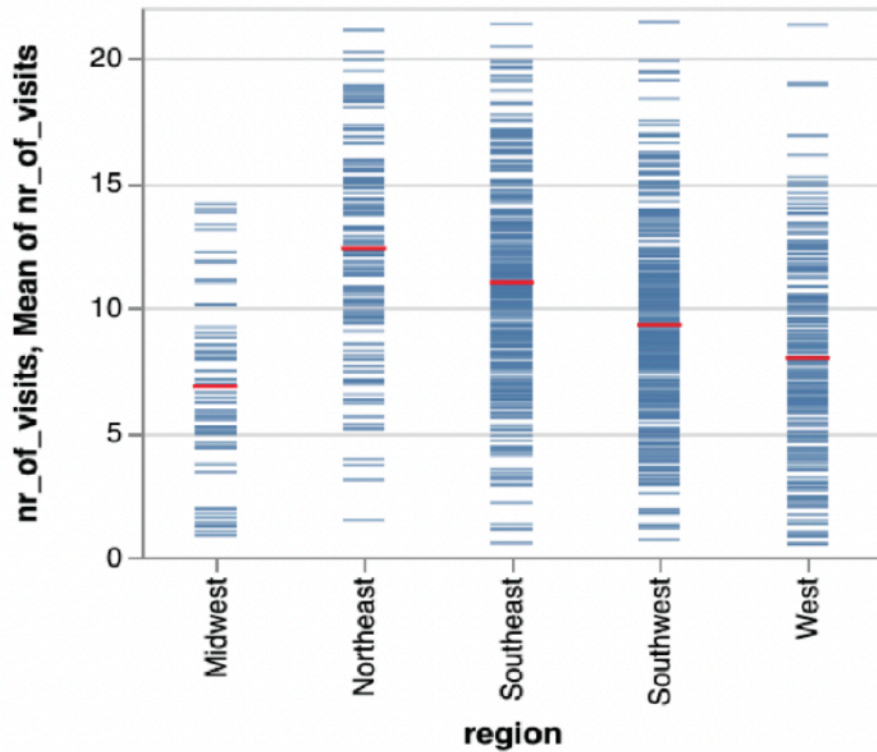
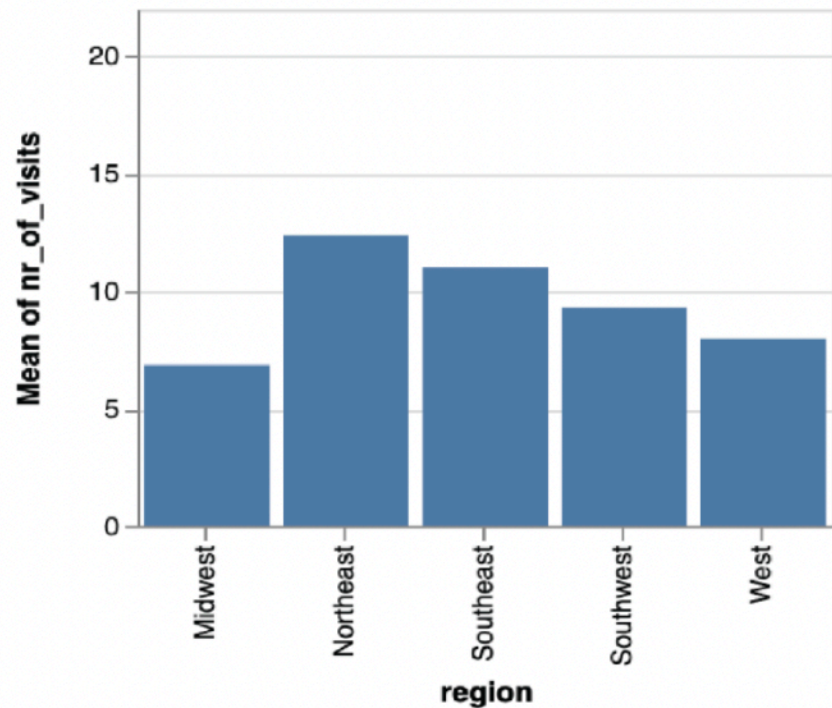
SCIENTISTS...



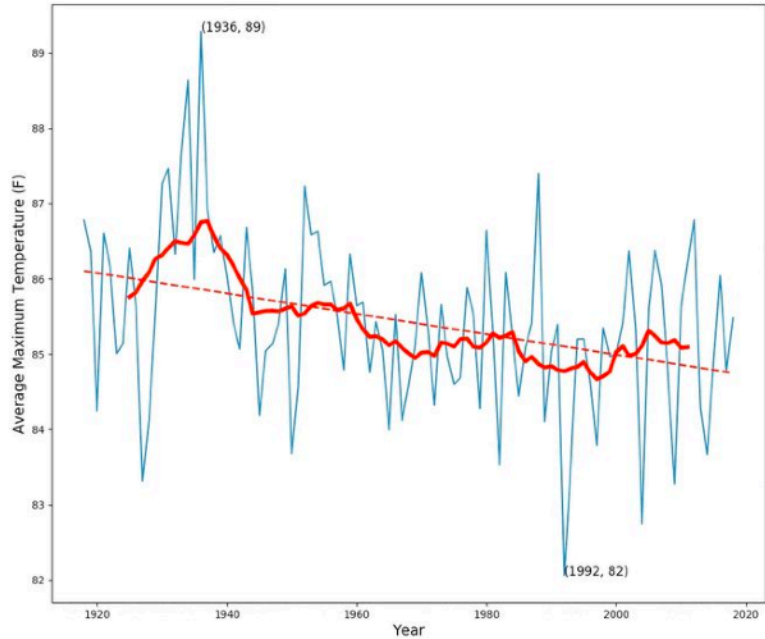
Multiple Comparisons Problem



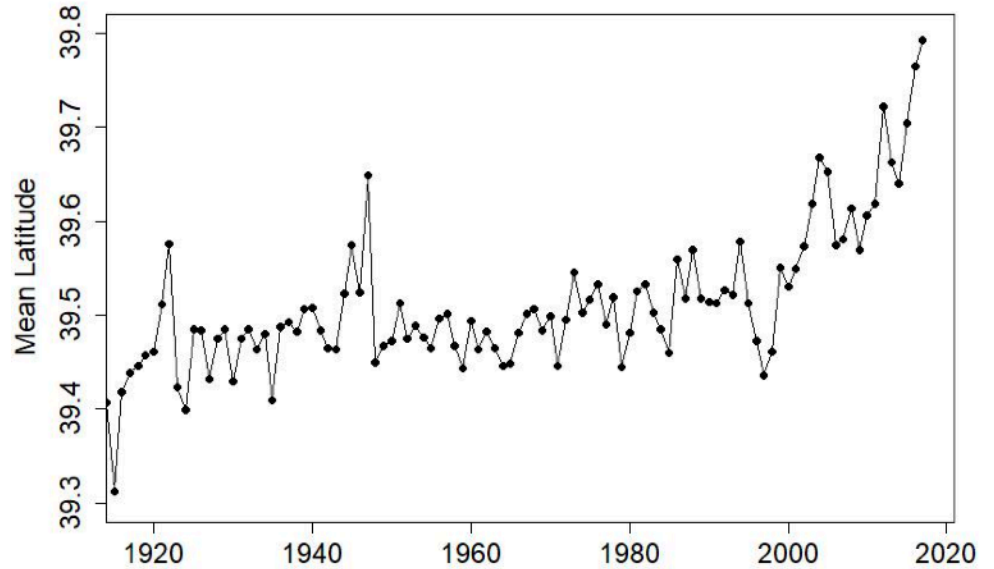
Aggregated vs. Disaggregated Views [Nguyen et al. '20]



Example: Is the U.S. cooling?

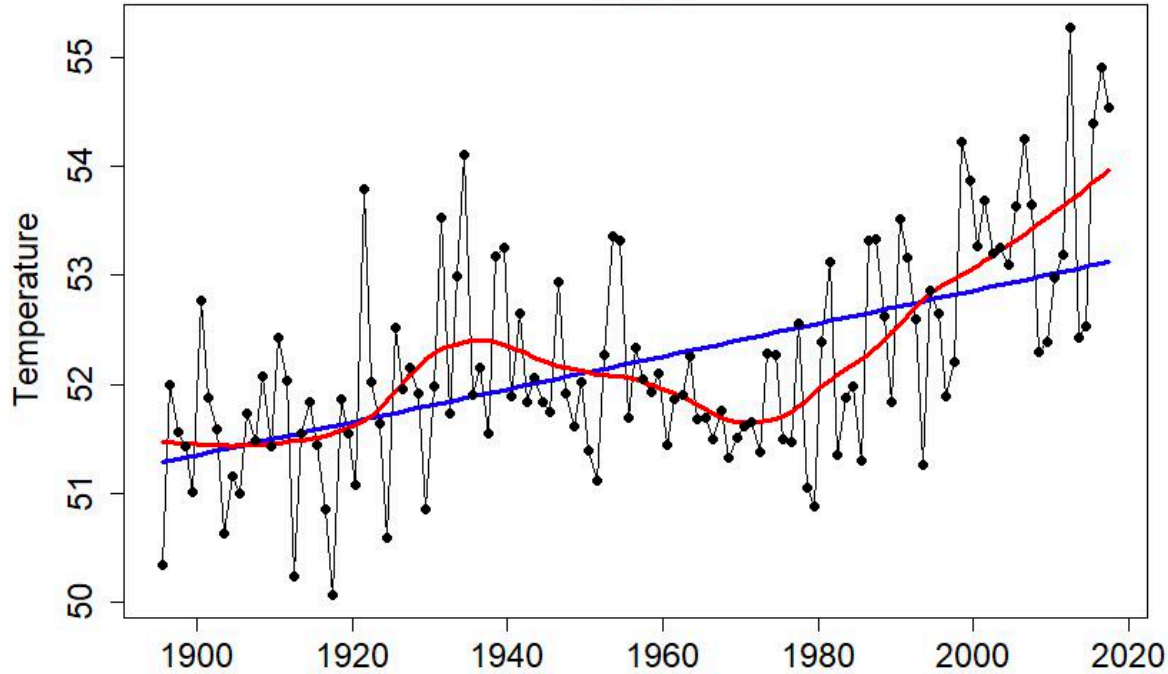


Starts at 1918. Summer temps only.
Raw average over weather stations.



But here is the mean latitude of
US weather stations, per year...

Example: Is the U.S. cooling? (No.)

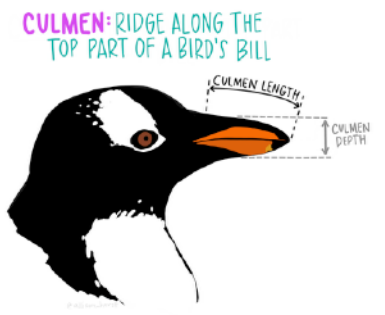
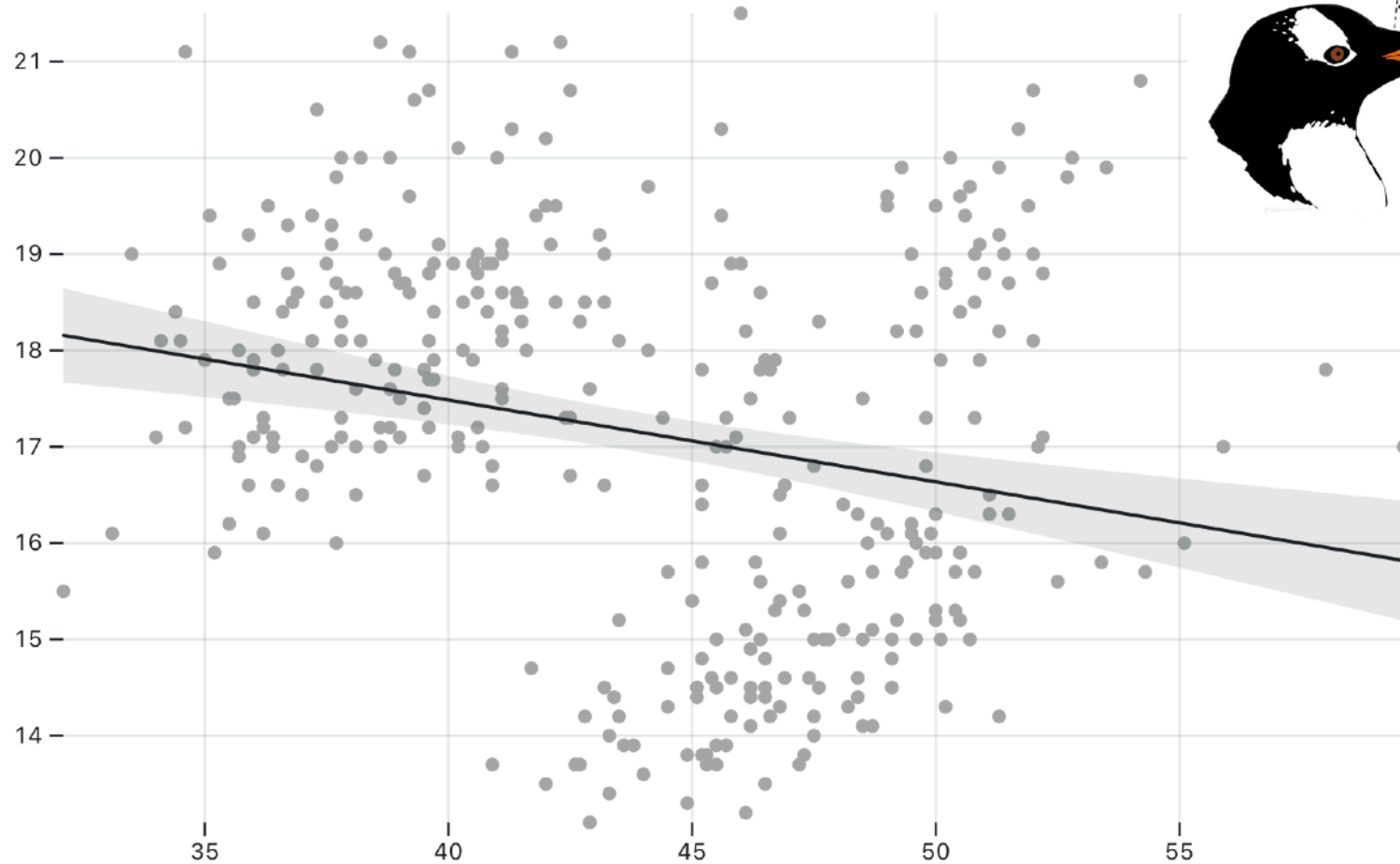


Include more historical data.

Include all four seasons.

Correct spatial averages to account for changes in weather station locations.

↑ culmen_depth_mm

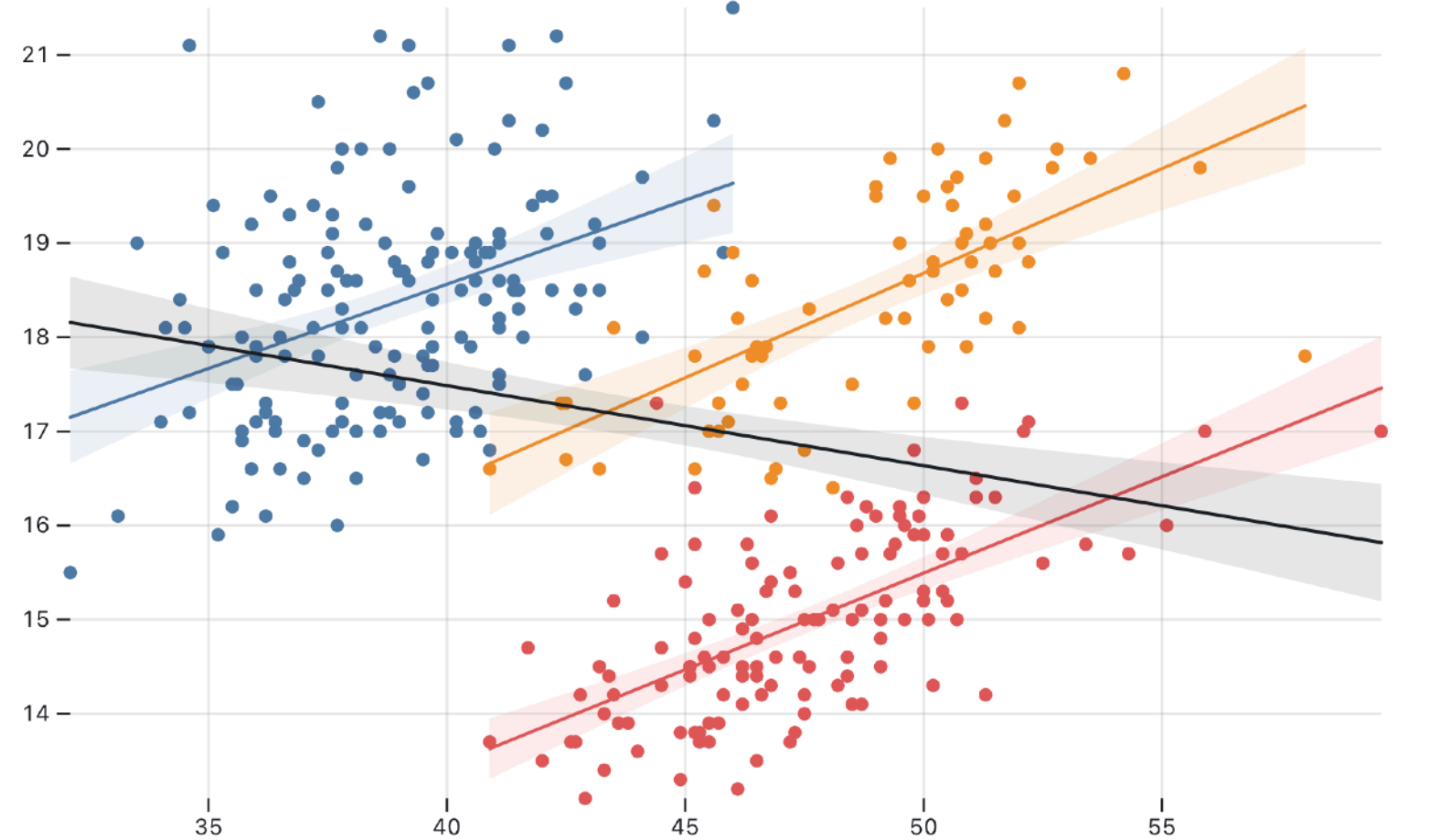


culmen_length_mm →

Simpson's Paradox!

Adelie Chinstrap Gentoo

↑ culmen_depth_mm



culmen_length_mm →

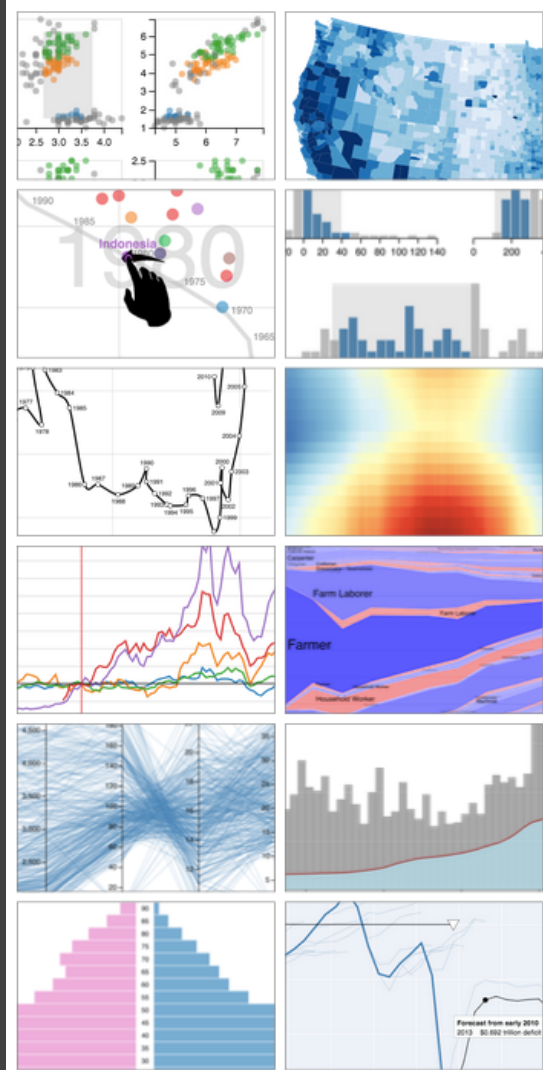
Some Causes of Inferential Failure

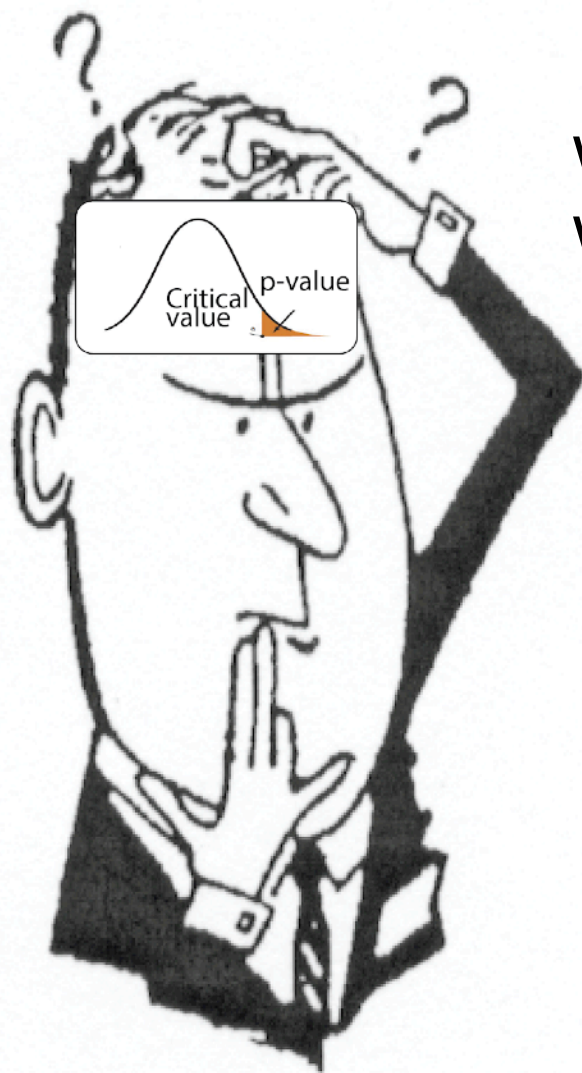
Premature Suppression of Uncertainty

False Discovery due to Random Fluctuation

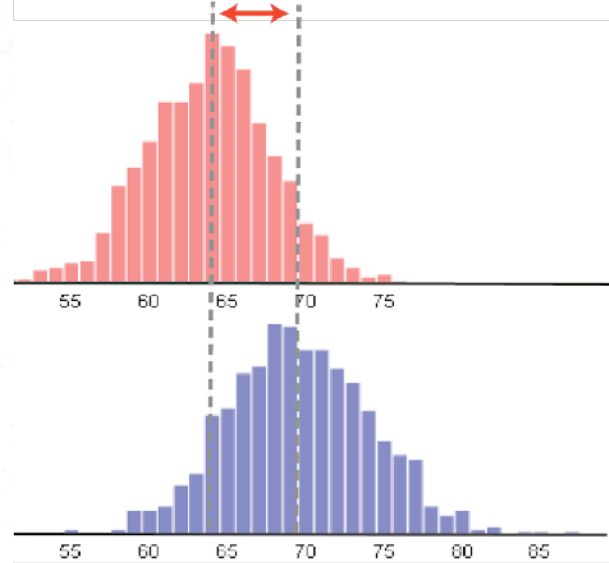
Incomplete or Biased Data

Confounding Variables





What might "random" look like?
What process generated the data?



What Can Go Wrong?

Uncertainty can be difficult to understand, and require a statistical background and high numeracy. Additionally, cognitive and perceptual biases can result in people making poor or error-prone decisions from uncertain data.

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A LOT

Summary

What Does Uncertainty Mean?

LOTS OF THINGS

How Should I Visualize It?

IT DEPENDS

What Can Go Wrong?

A LOT