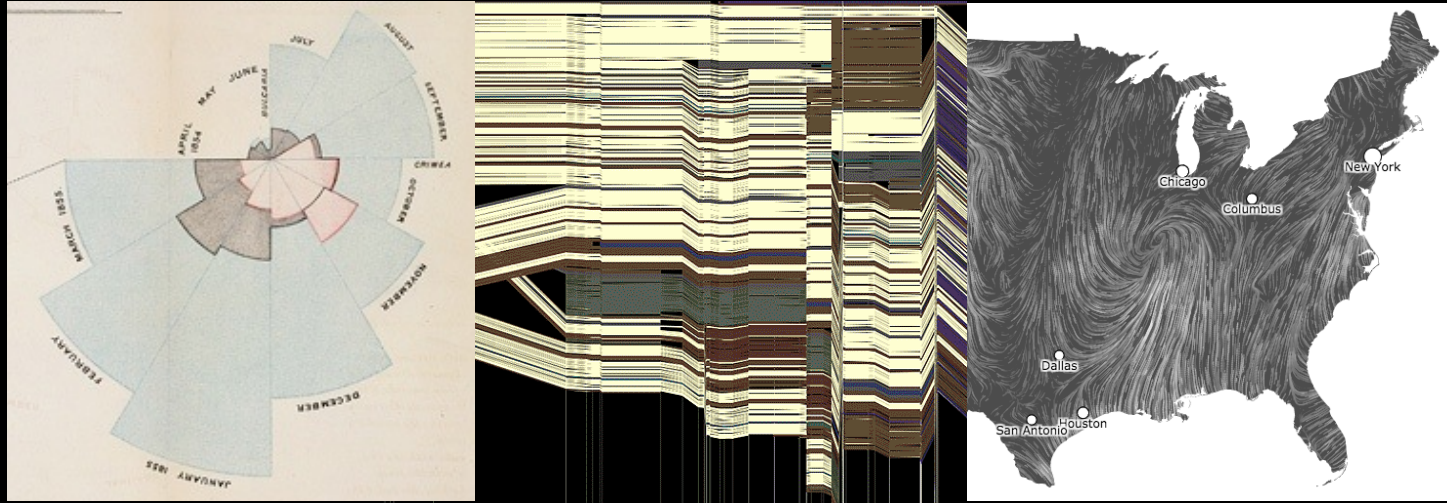


CSE 512 - Data Visualization

Uncertainty



Leilani Battle University of Washington

Session Outline

What Does Uncertainty Mean?

Uncertainty Visualization

Avoid Prematurely Suppressing Uncertainty

Visual Encodings of Uncertainty

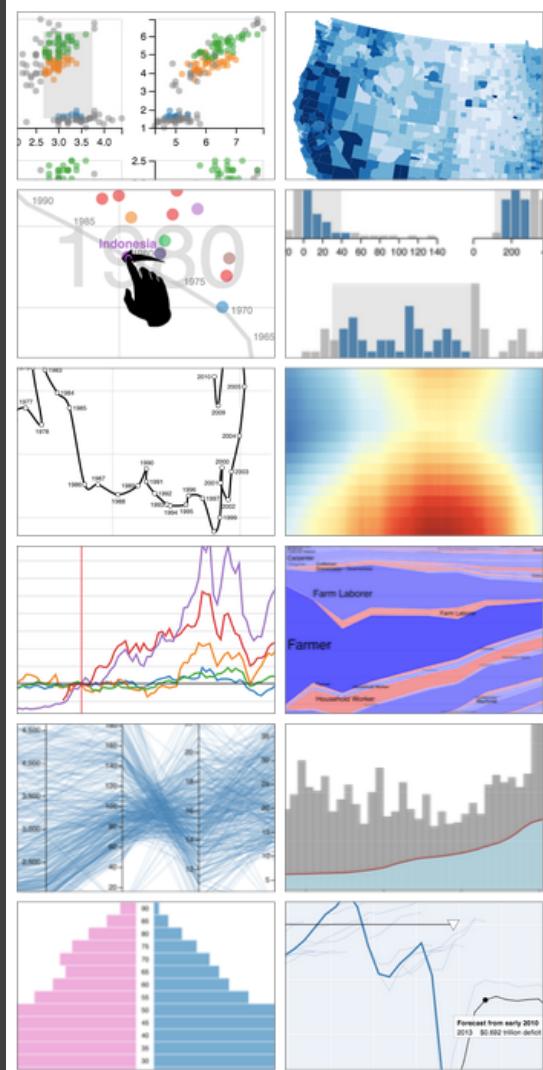
Frequency Framing & Hypothetical Outcomes

What Can Go Wrong?

Inferential Integrity

Graphical Inference & Model Checks

GOAL: Try not to fool yourself!



What Does Uncertainty Mean?

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.

A Bar Chart



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"

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

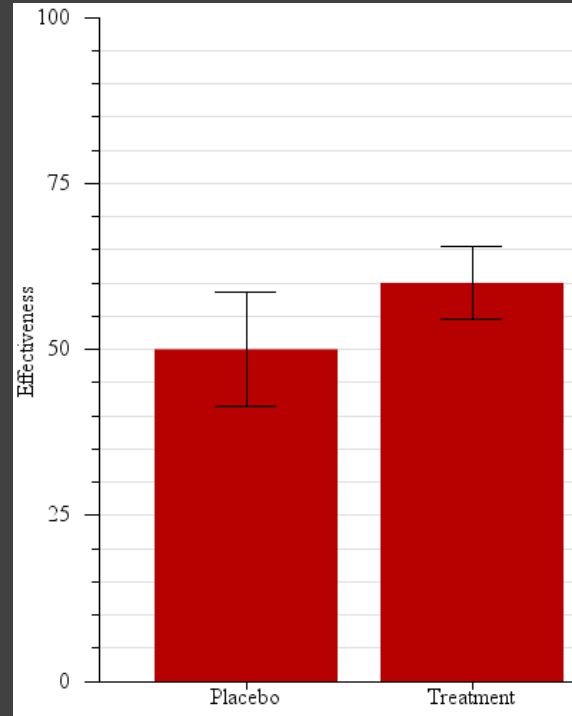
**Avoid Prematurely
Suppressing Uncertainty**

Error Bars

The mean treatment effect is higher than than the placebo.

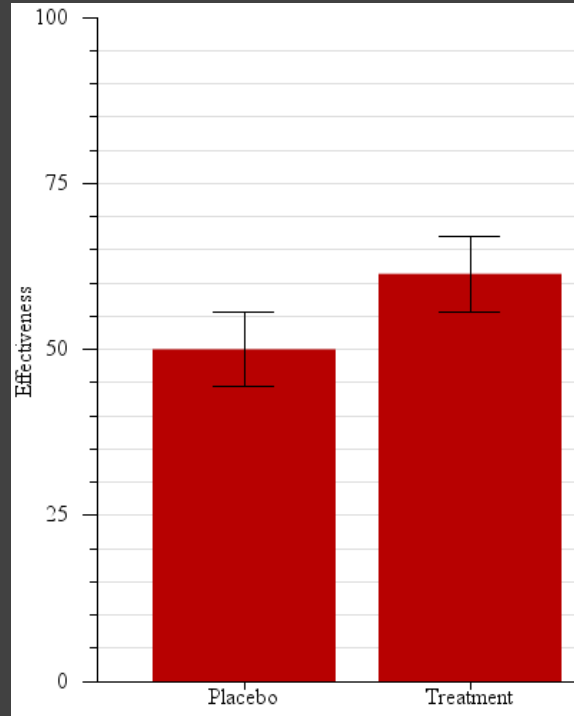
Is this difference in means *statistically significant*?

What do the error bars represent?

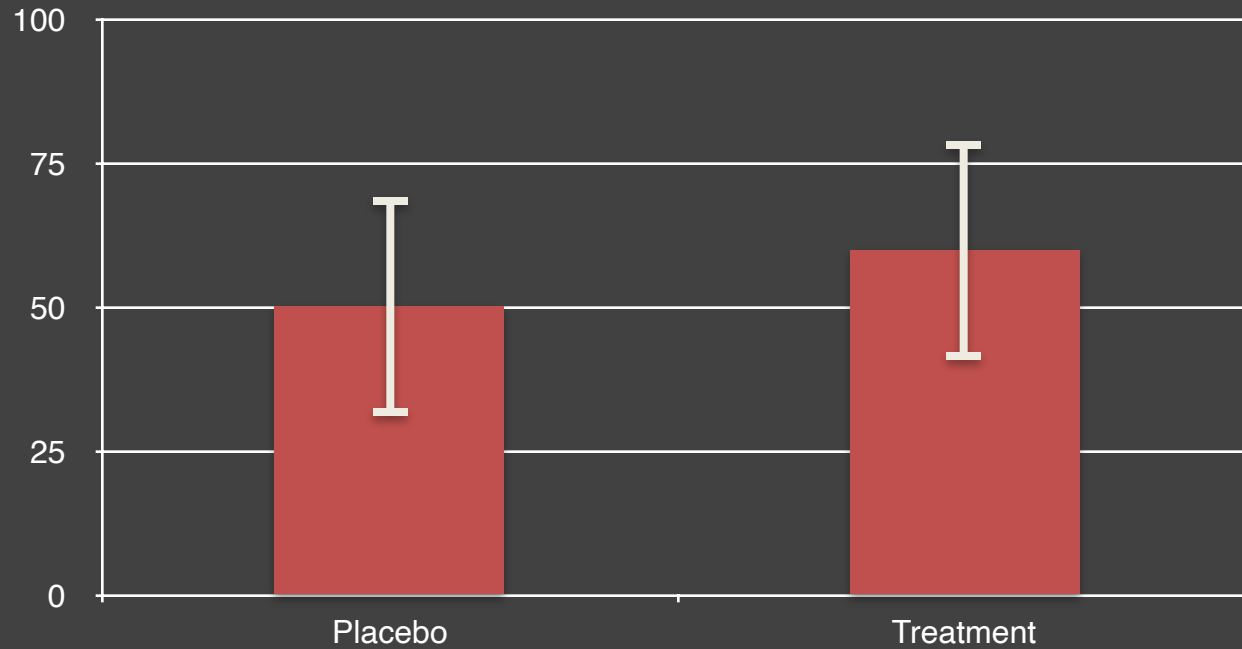


Guess the p-value...

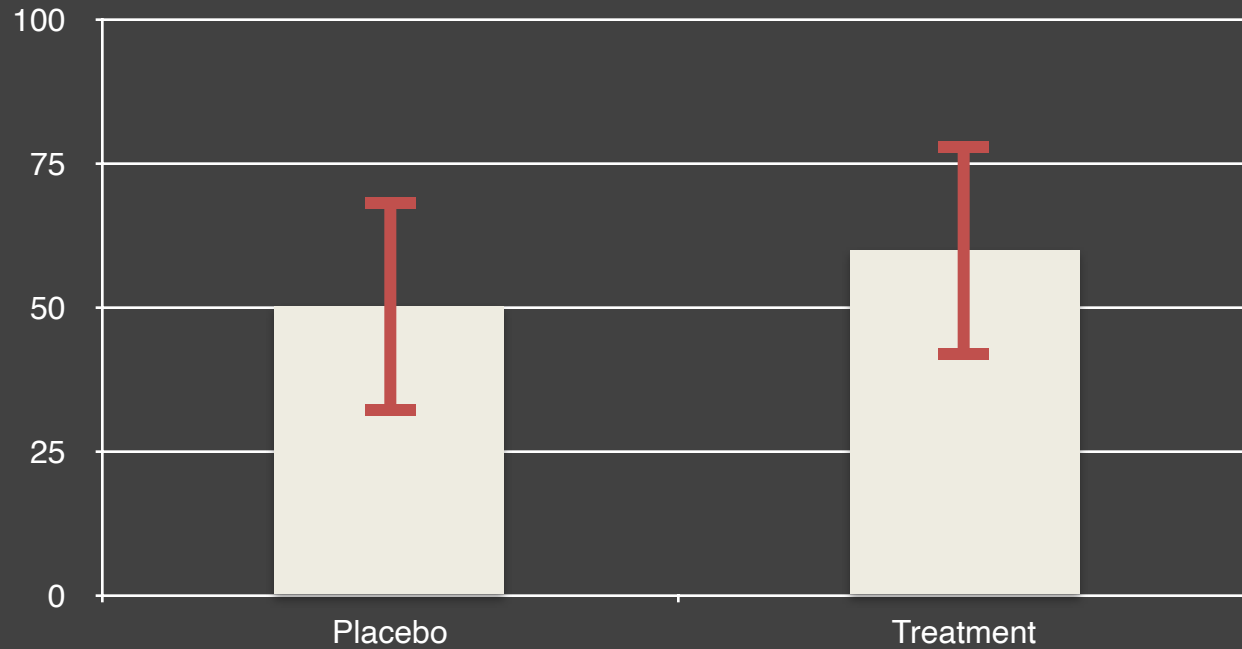
Error bars depict
95% Conf. Interval



Misplaced Emphasis?



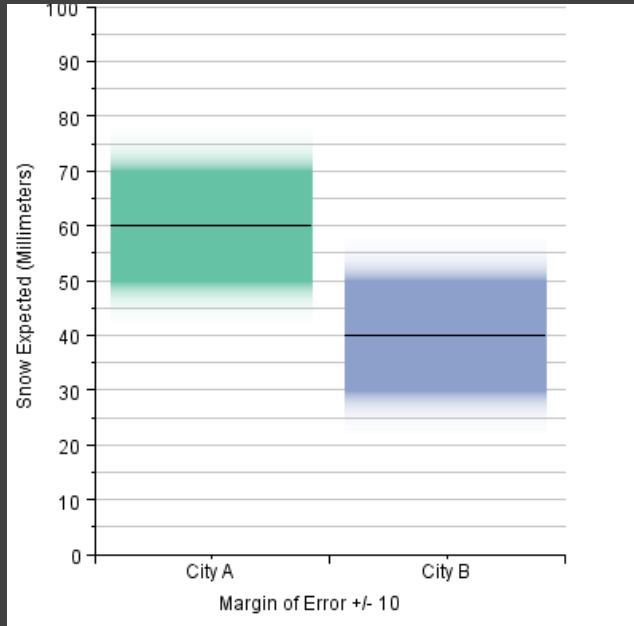
Misplaced Emphasis?



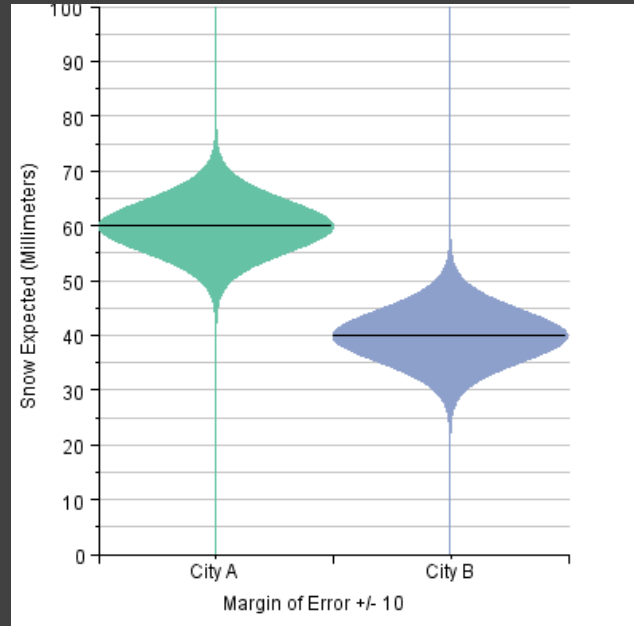
For inference tasks, focus
on the **uncertainty**, not
the point estimate!

Alternatives to Error Bars

Gradient Plot



Violin Plot



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.

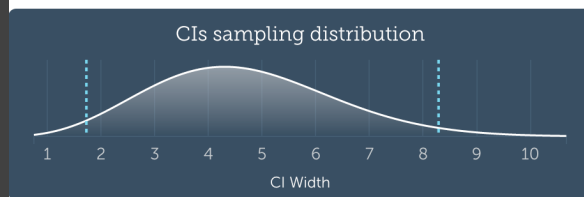
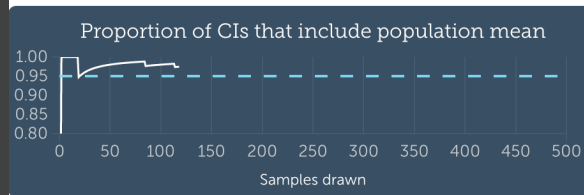
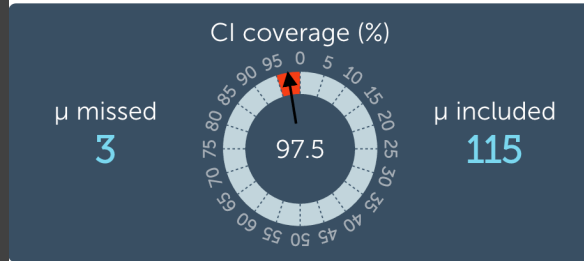
Wrong!

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

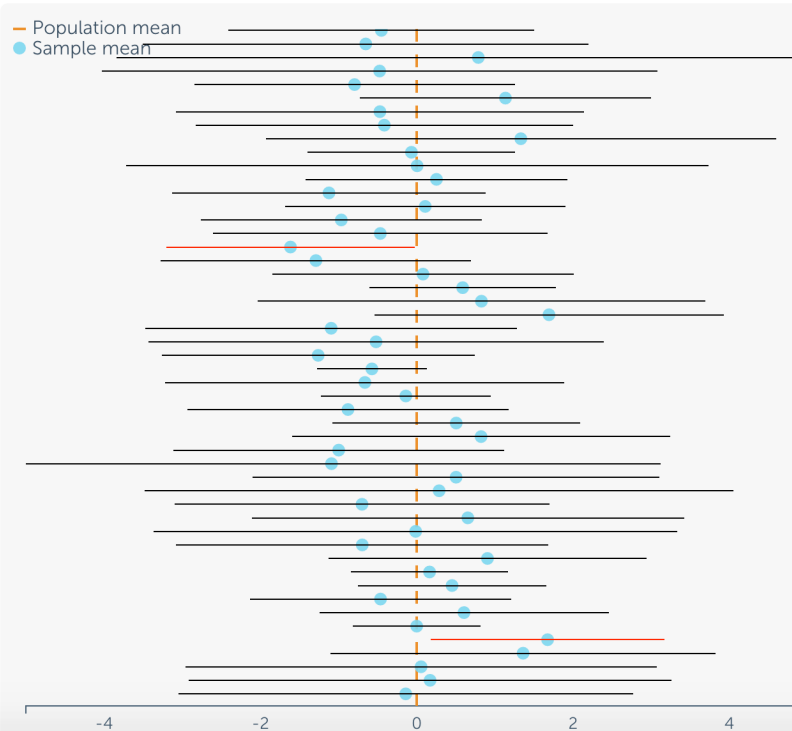
“Confidence” concerns the procedure, not the data. (Though see Bayesian *credible intervals*...)

Confidence Intervals

Simulation statistics



95% confidence intervals



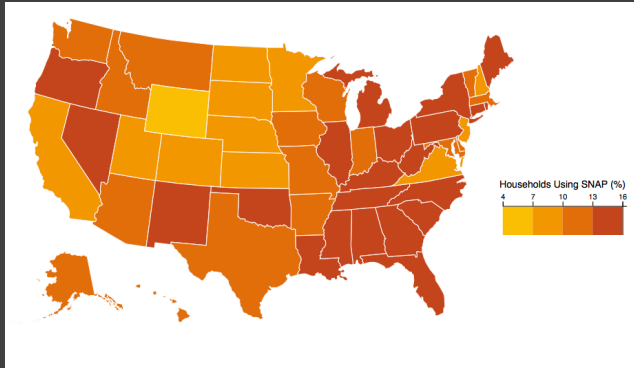
Visual Encodings of Uncertainty

Uncertainty Vis Pipeline

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

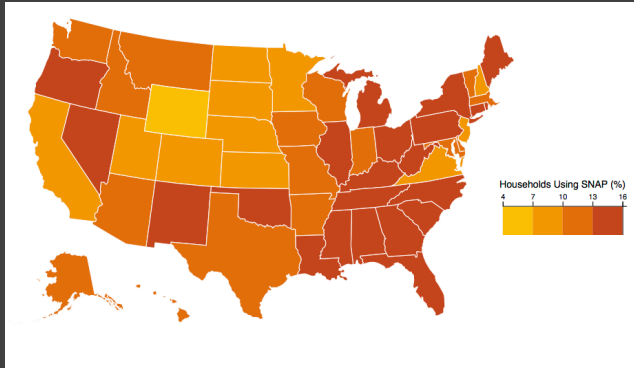
SNAP

Data Map

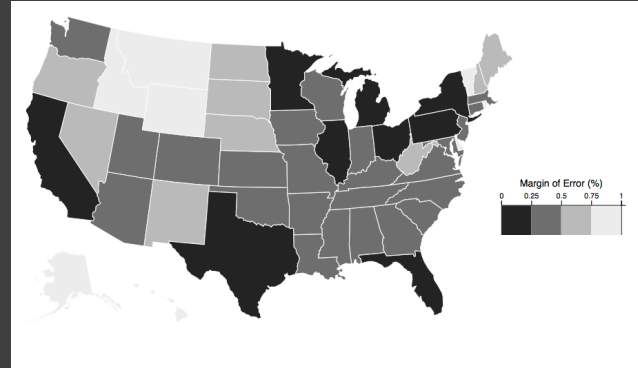


SNAP

Data Map

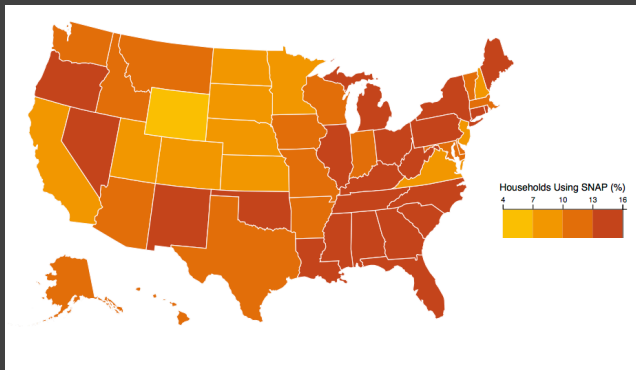


Uncertainty Map

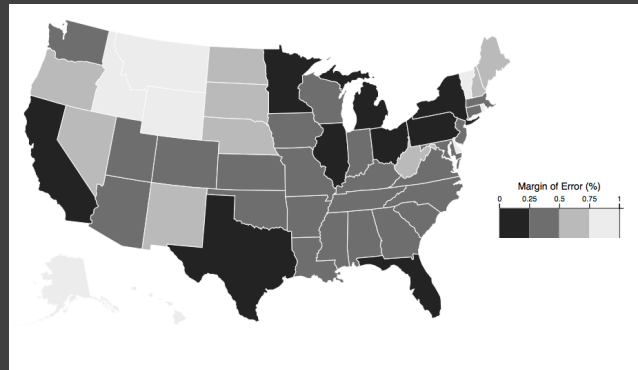


Juxtaposition

Data Map



Uncertainty Map



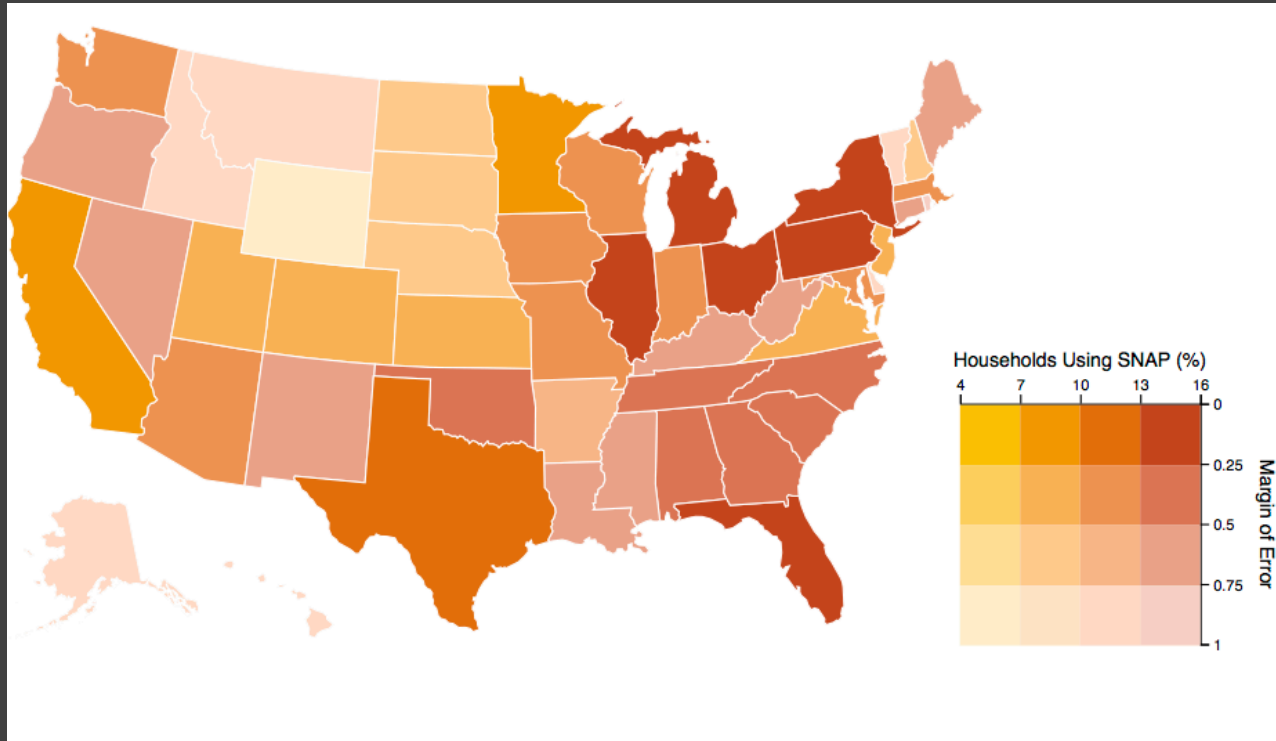
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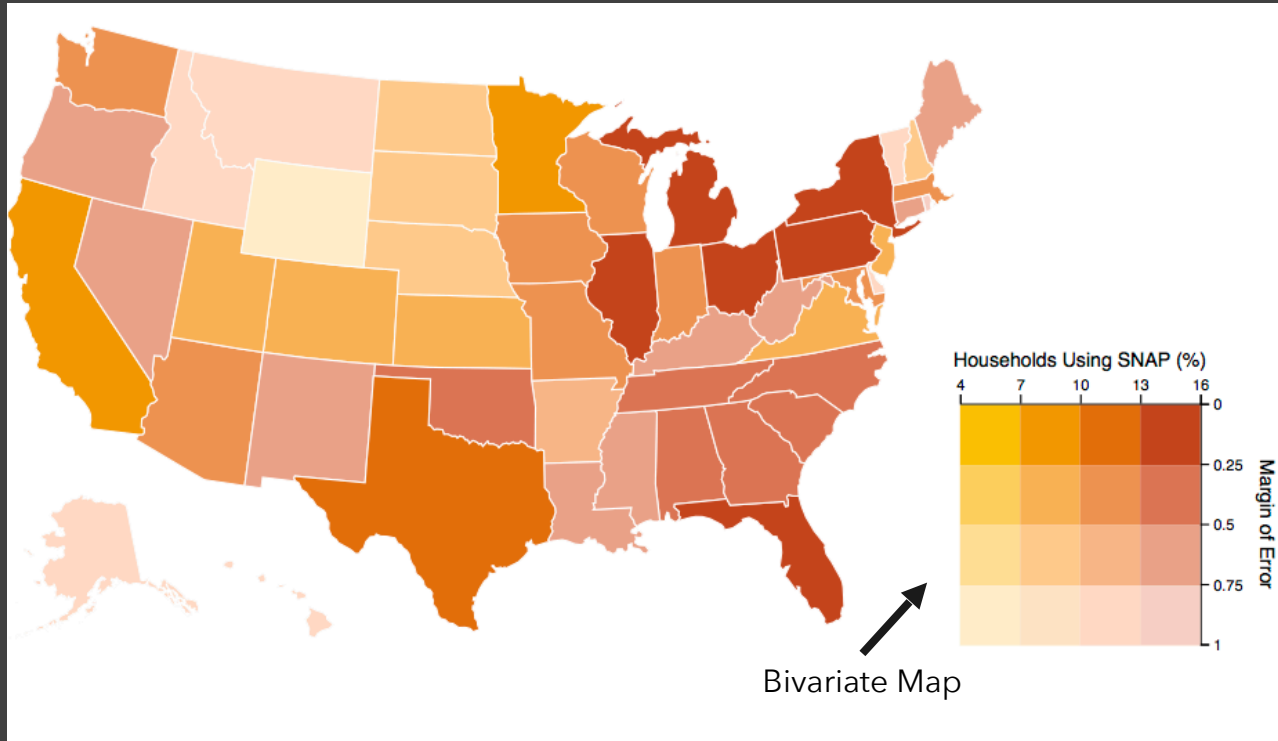
Uncertainty Vis Pipeline

- 1) Quantify uncertainty
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- 3) Encode uncertainty with the variable
- 4) Unify the Data Map and Uncertainty Map

Superposition



Superposition



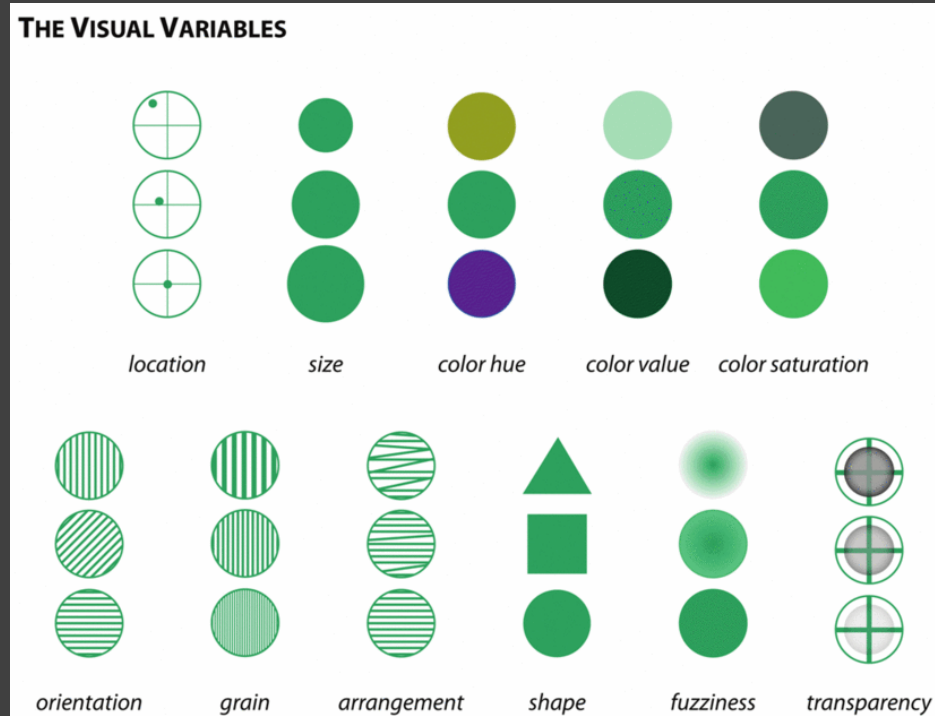
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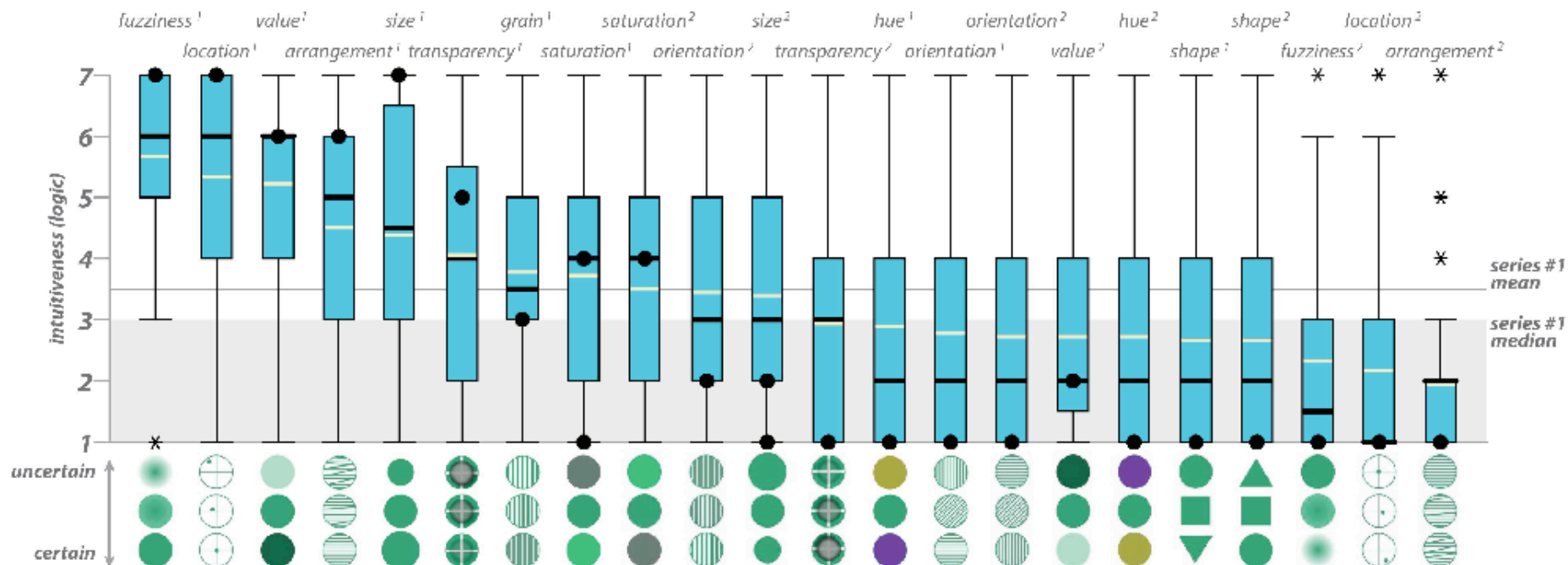
Uncertainty Vis Pipeline

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- 3) Encode uncertainty with the variable
- 4) Unify the Data Map and Uncertainty Map

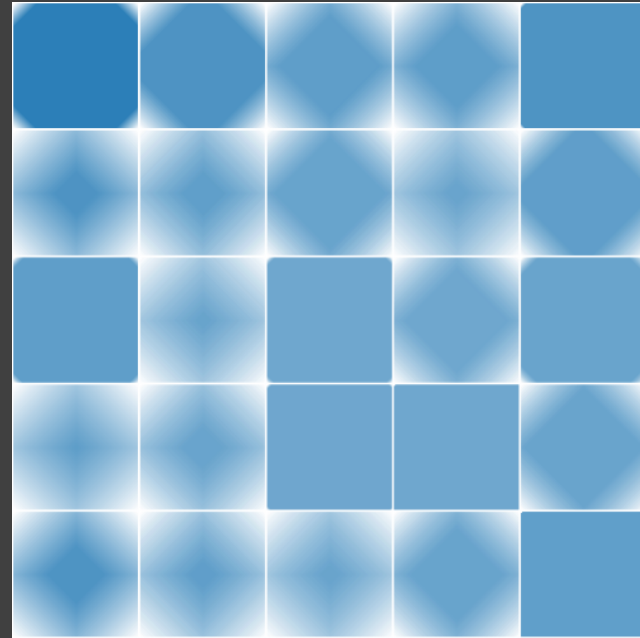
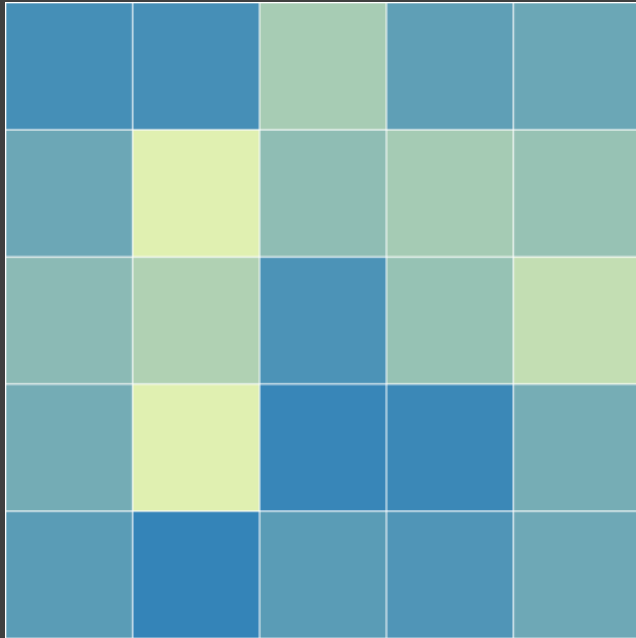
Semiotics of Uncertainty



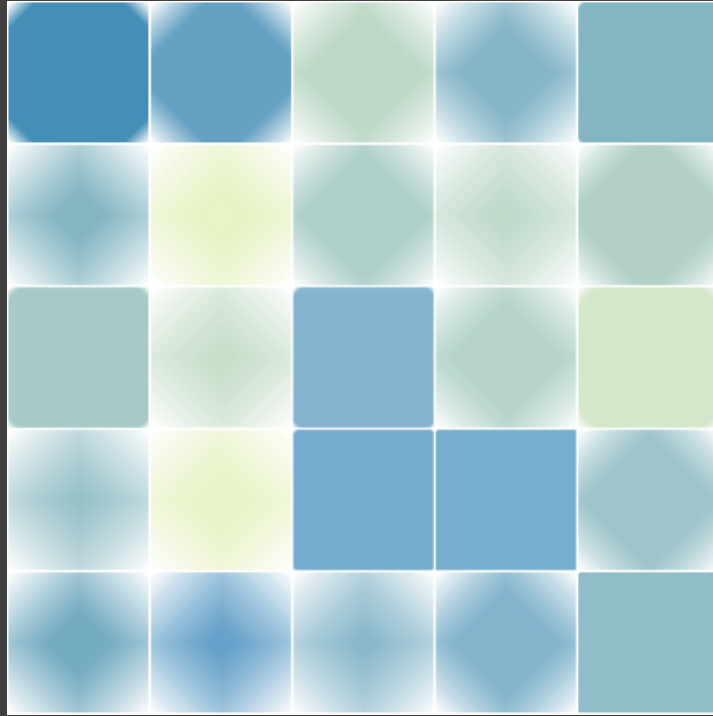
SERIES #1: GENERAL UNCERTAINTY BY VISUAL VARIABLE



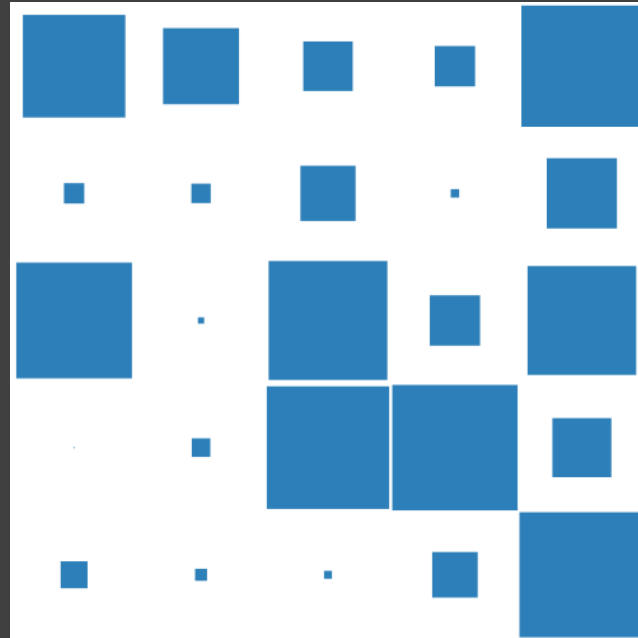
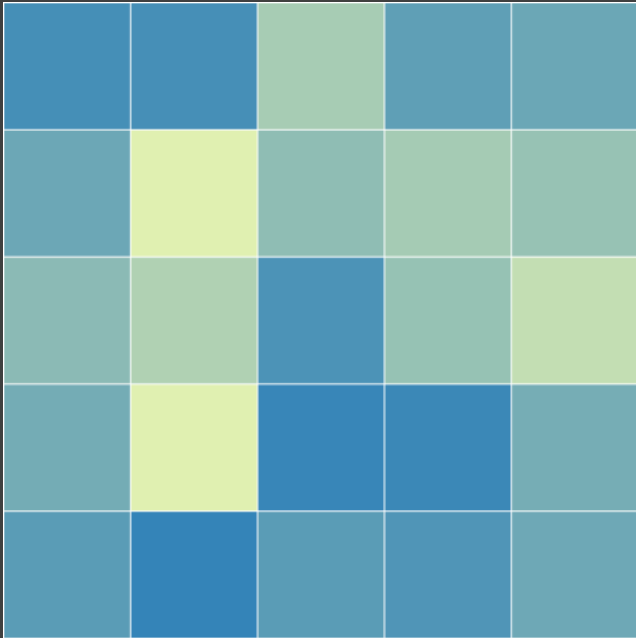
Fuzziness Juxtaposition



Fuzziness Superposition



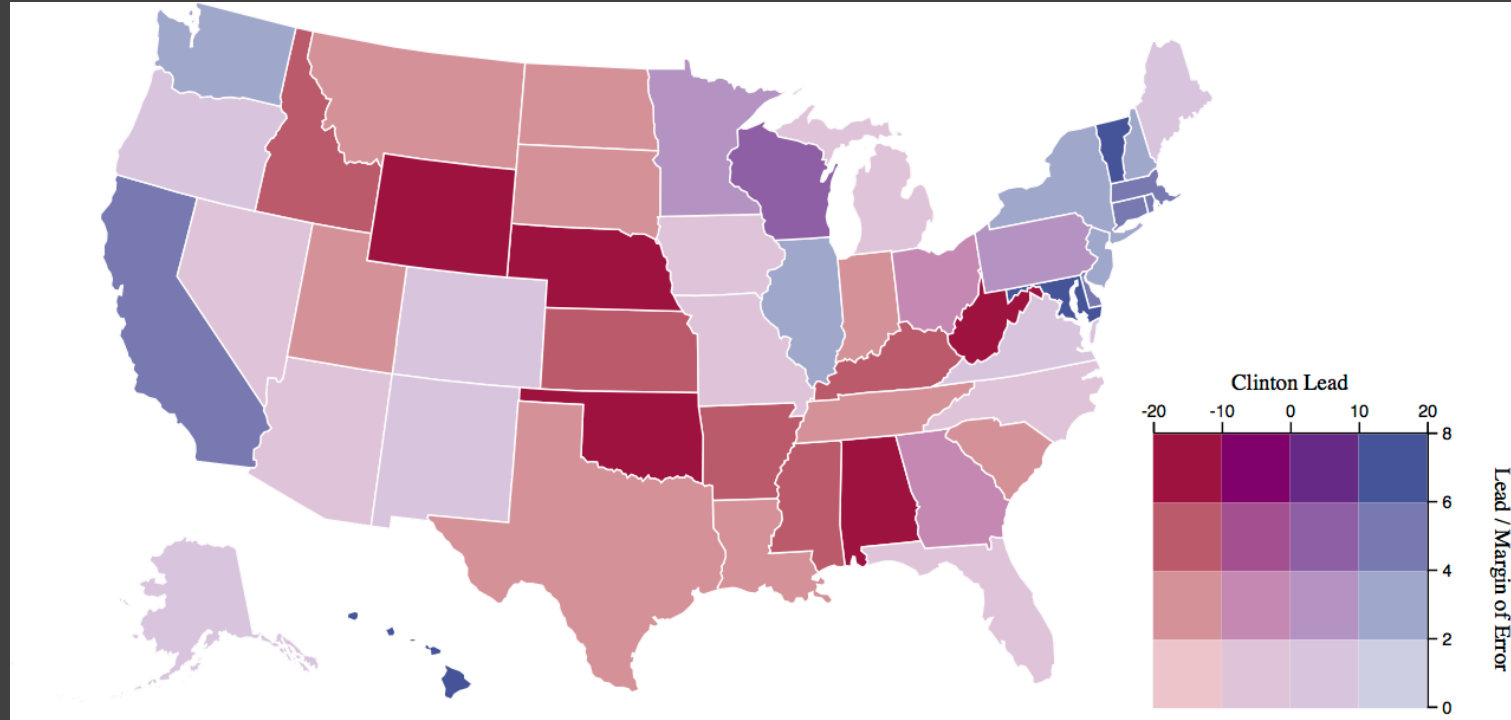
Size Juxtaposition



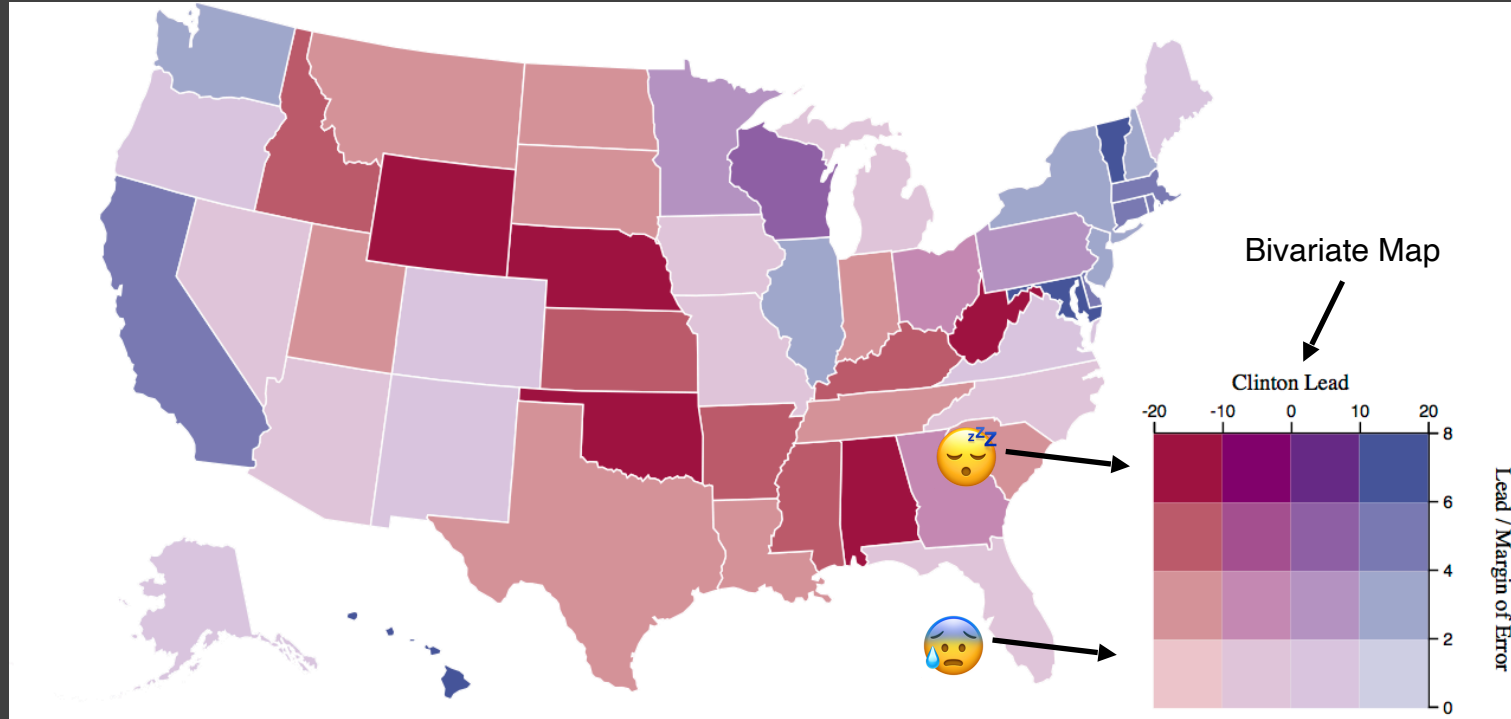
Size Superposition



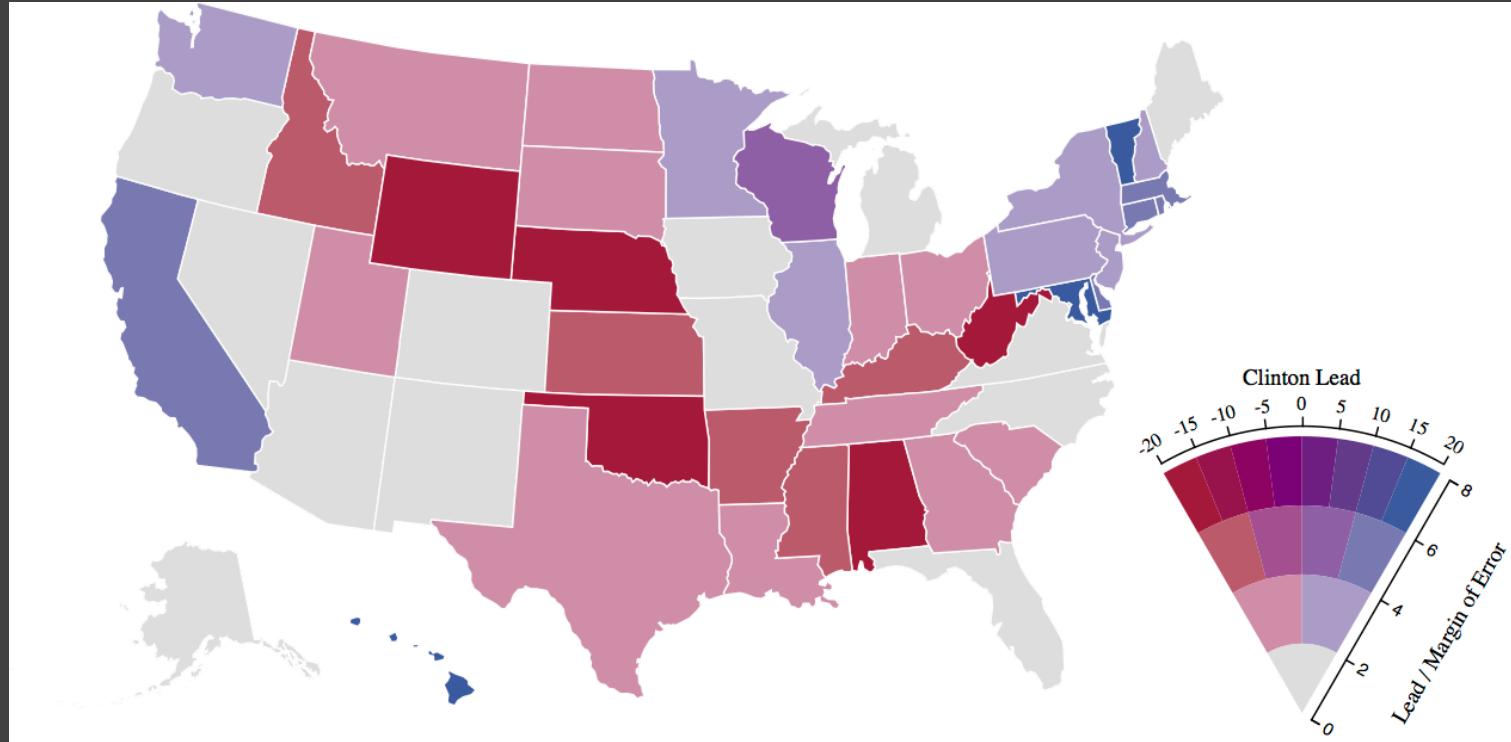
Value Suppressing Uncertainty Palettes



Bivariate Map



Value Suppressing Uncertainty Palettes



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

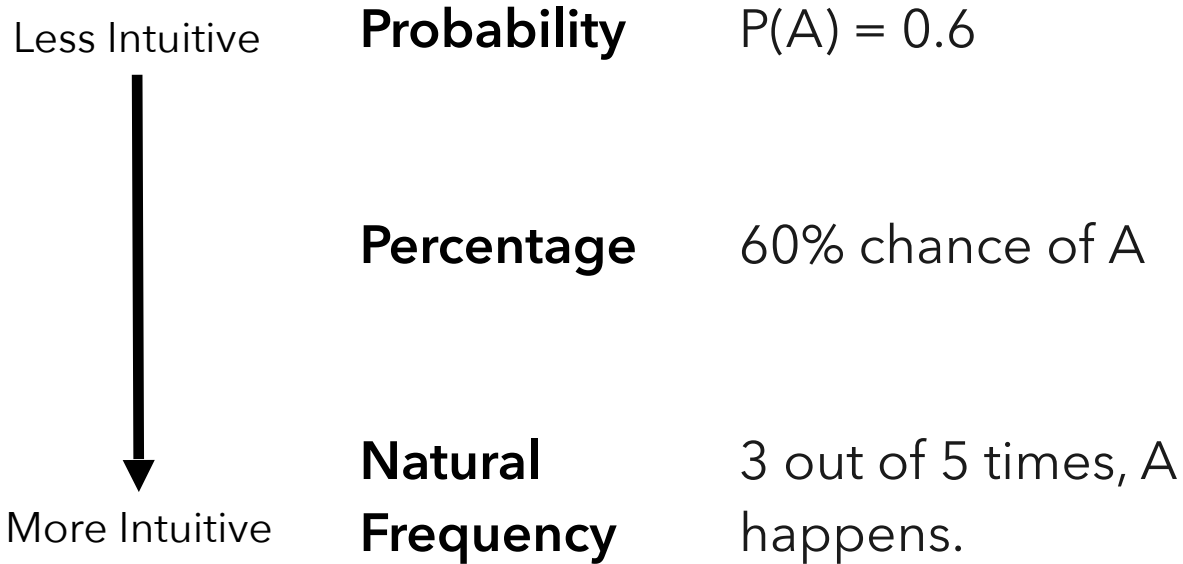
Encoding Uncertainty

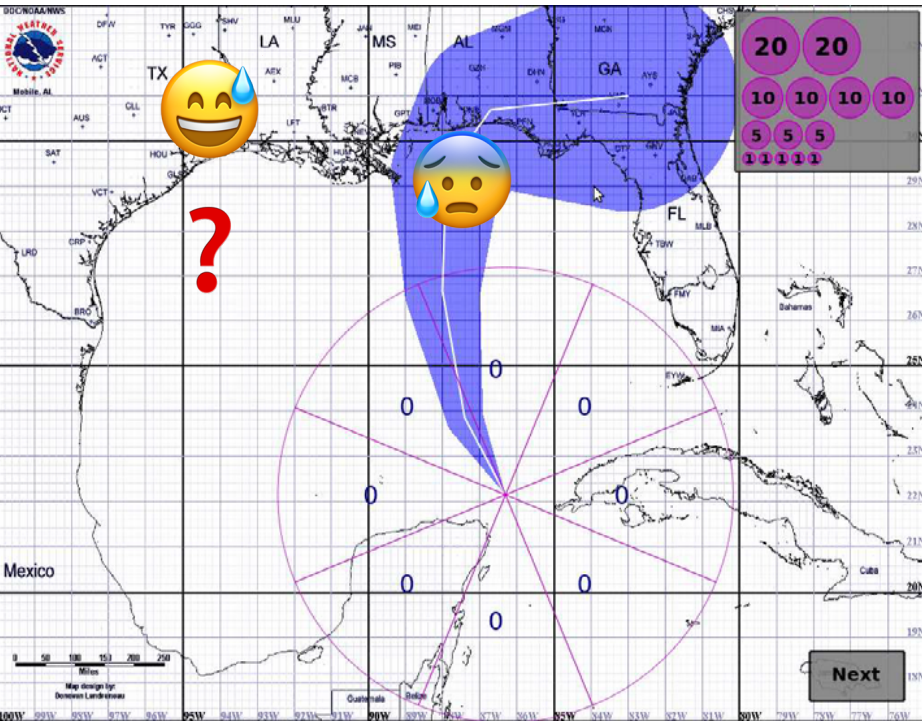
Some visual variables (like fuzziness and value) have a **semiotic connection** to uncertainty.

However, intuitive variables may not always be accurately interpreted!

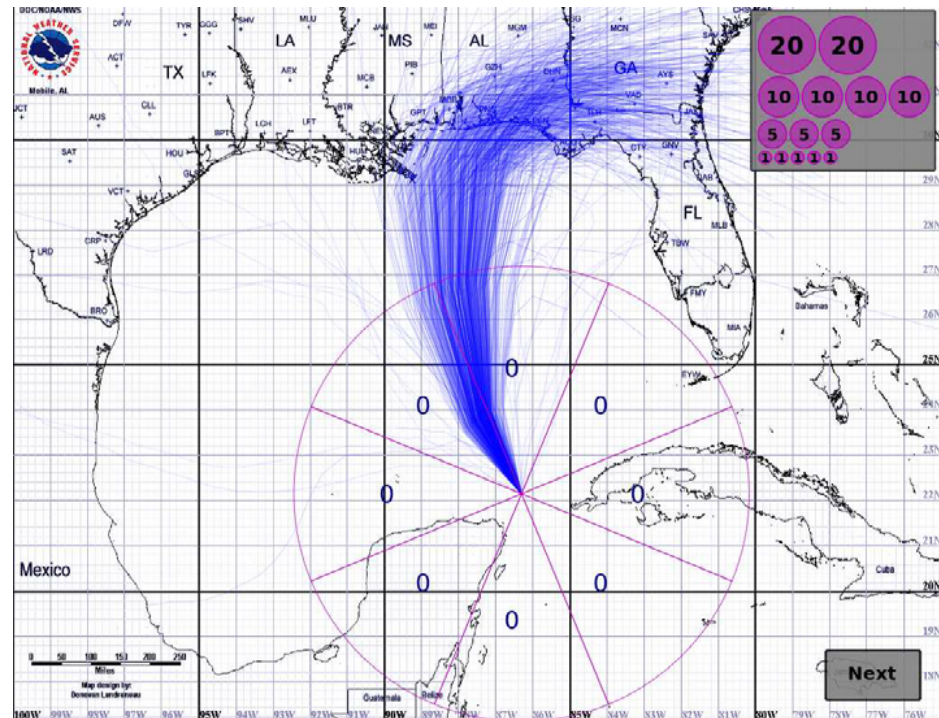
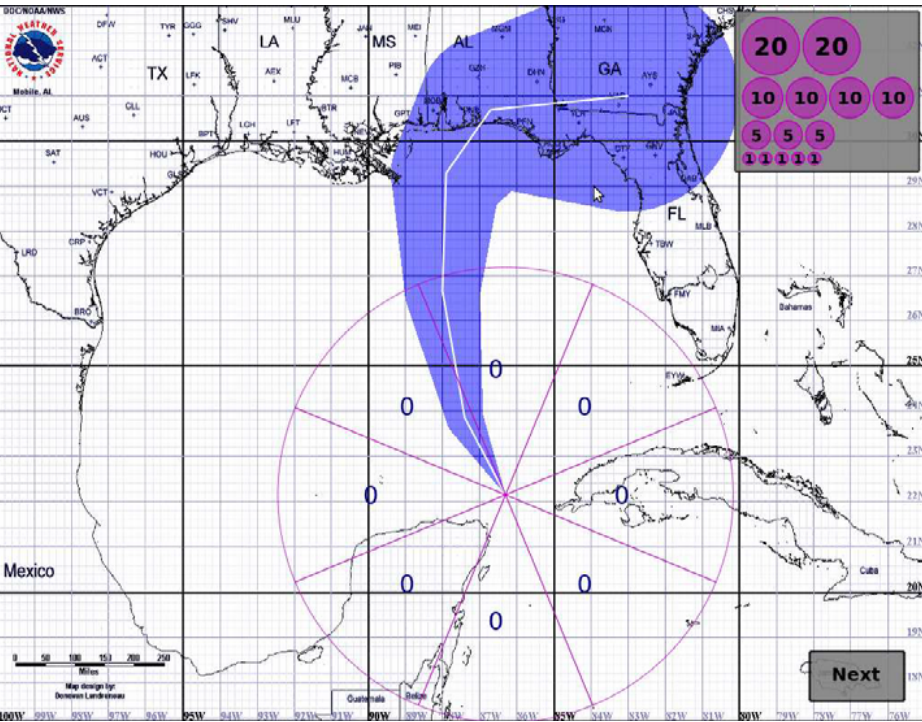
Frequency Framing & Hypothetical Outcomes

How to Present Probabilities





Size or likelihood of hurricane?
 Is New Orleans safe?



Size or likelihood of hurricane?
Is New Orleans safe?

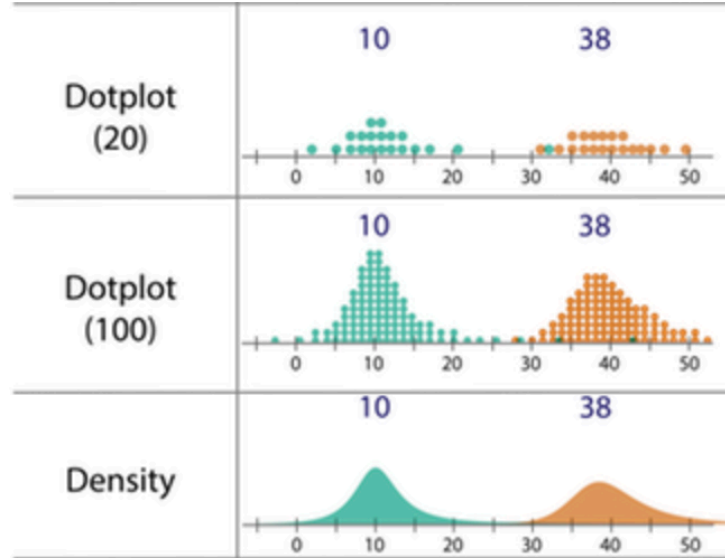
Make uncertainty more concrete
via *hypothetical outcomes*.

Quantile Dot Plots

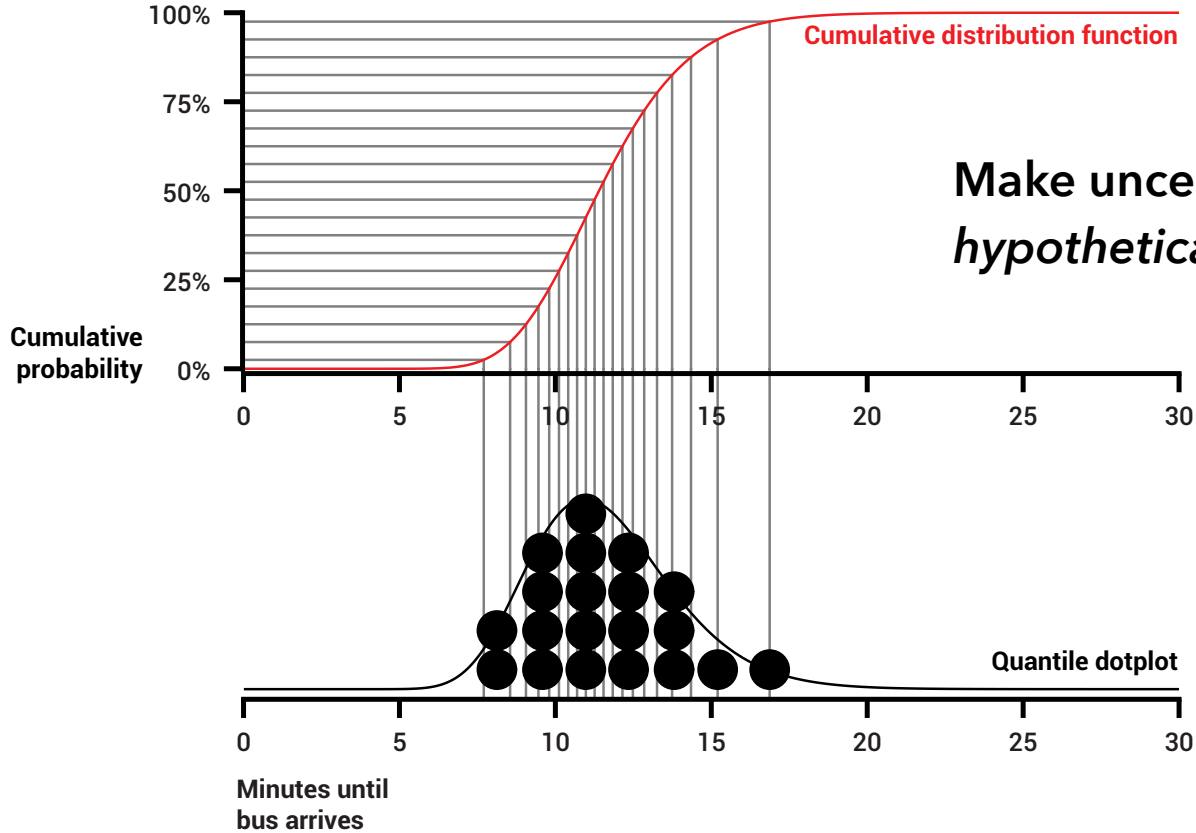
Less Error



More Error

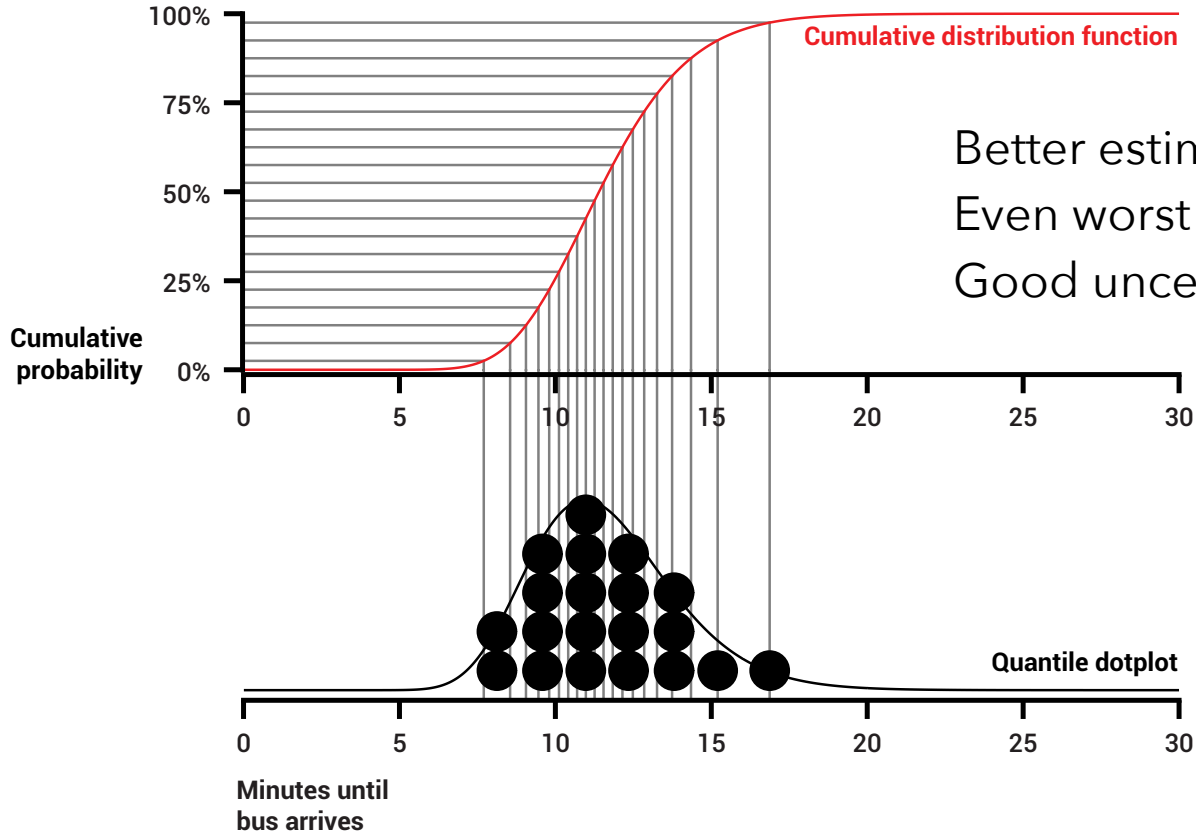


Predicted Bus Arrival Times



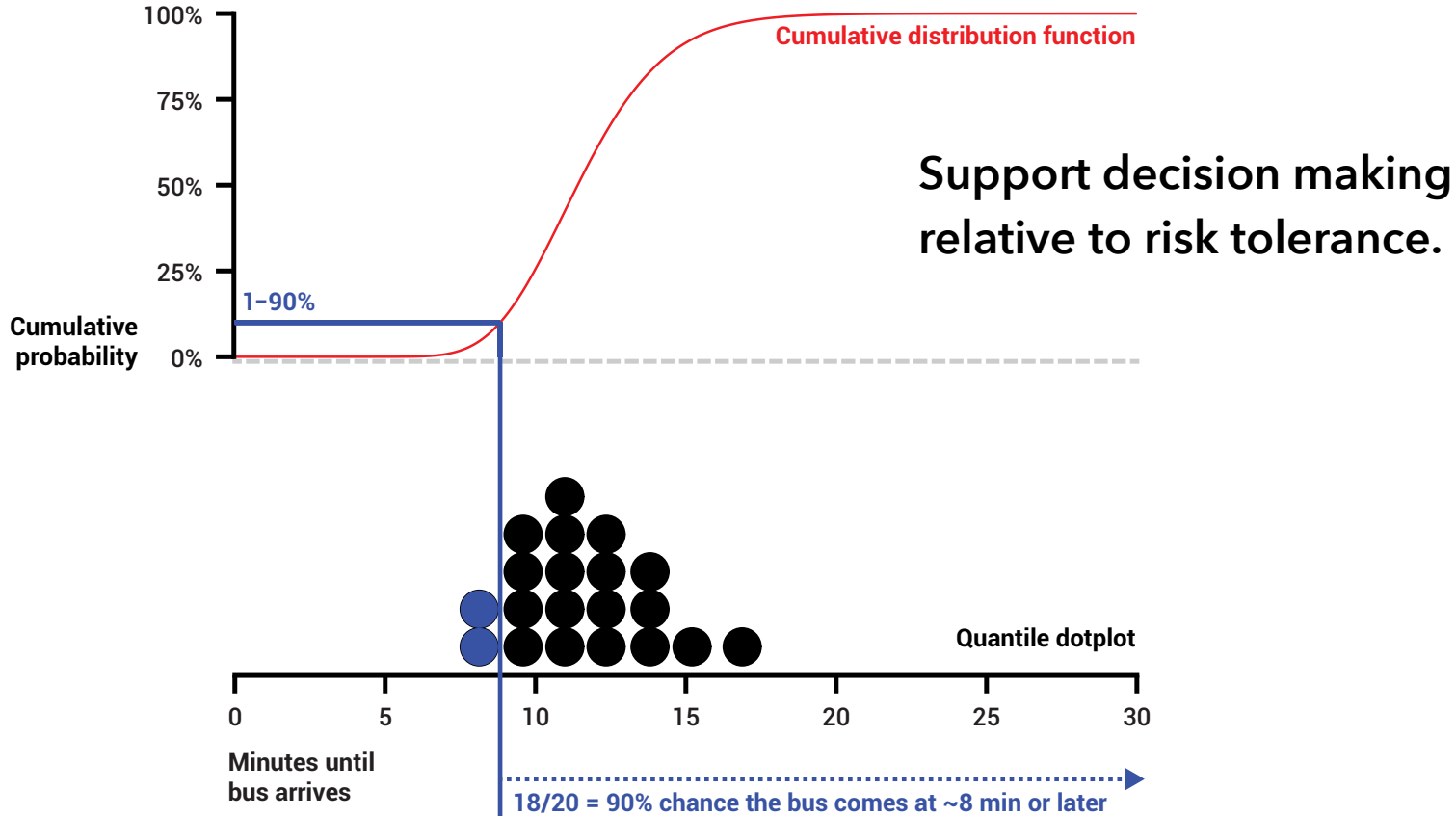
Make uncertainty concrete via
hypothetical outcomes.

Predicted Bus Arrival Times

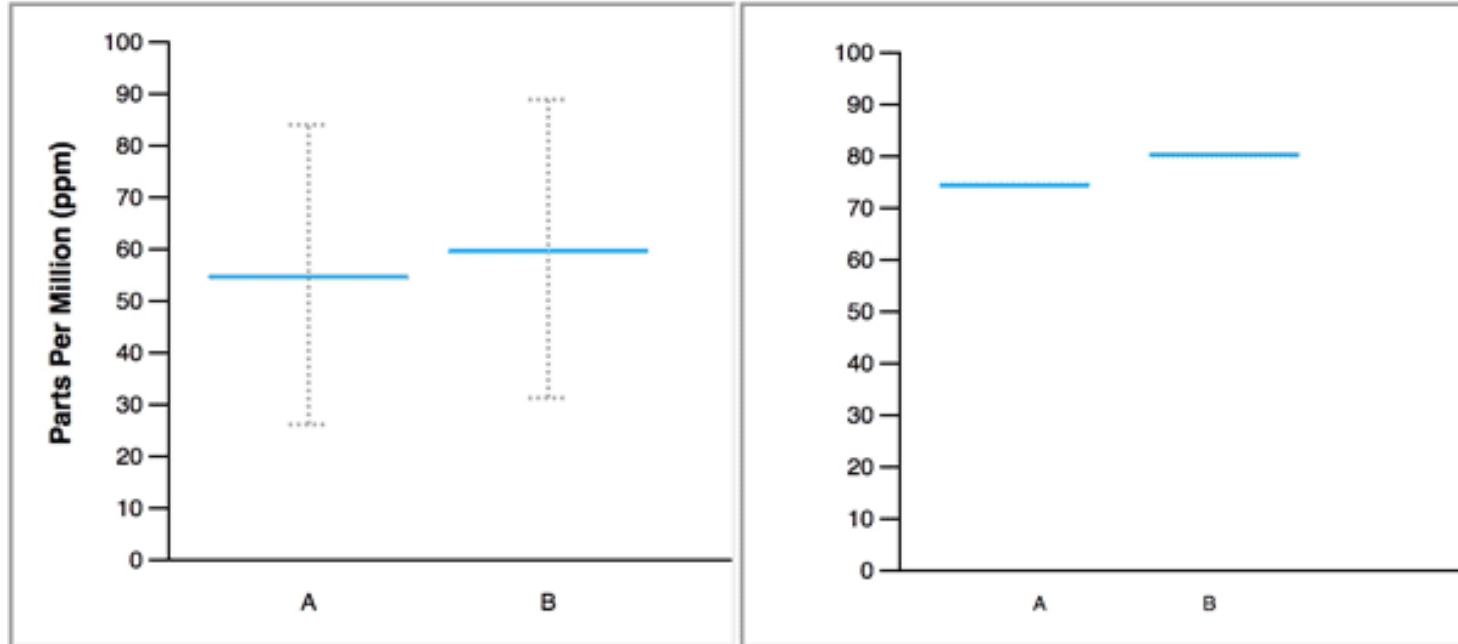


Better estimates, decisions with time.
Even worst performers improve.
Good uncertainty displays possible!

Predicted Bus Arrival Times



Hypothetical Outcome Plots



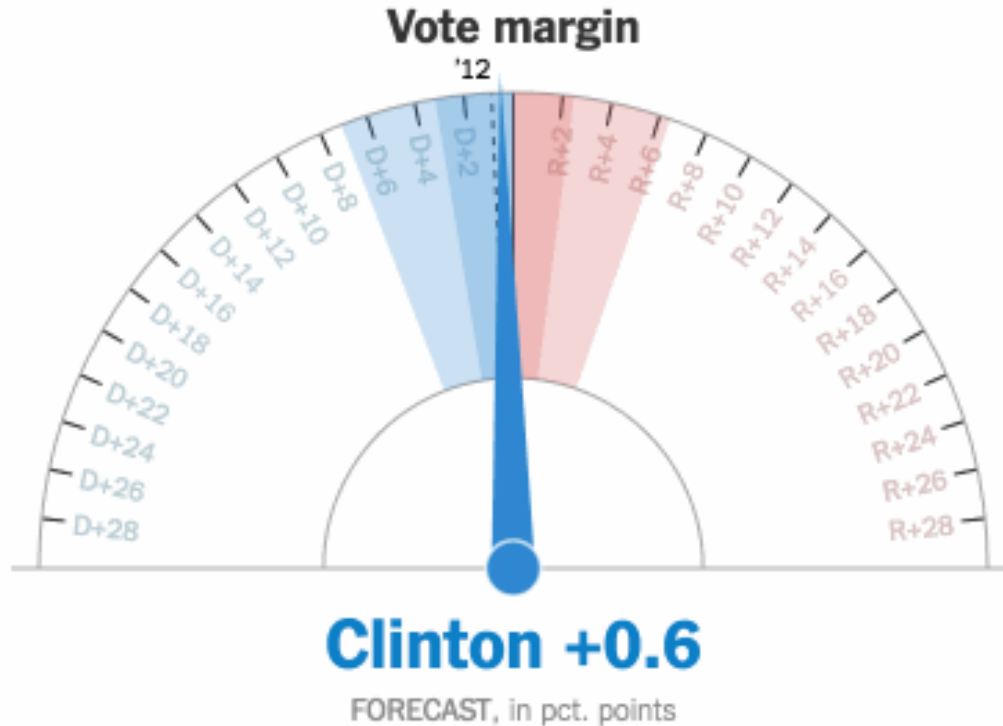
Hypothetical Outcomes

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.

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IT DEPENDS

What Can Go Wrong?

Inferential Integrity

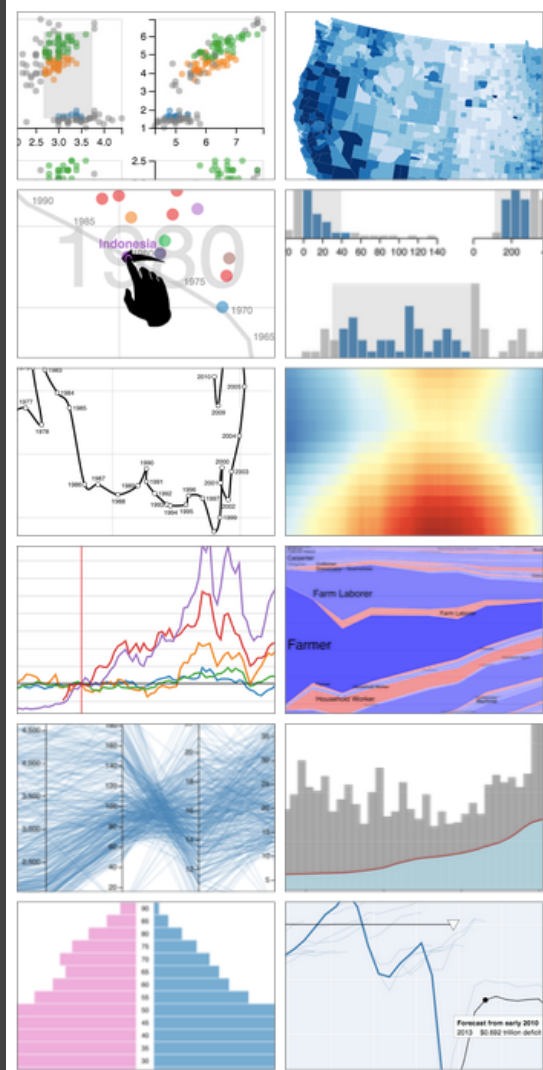
Some Causes of Inferential Failure

Premature Suppression of Uncertainty

False Discovery due to Random Fluctuation

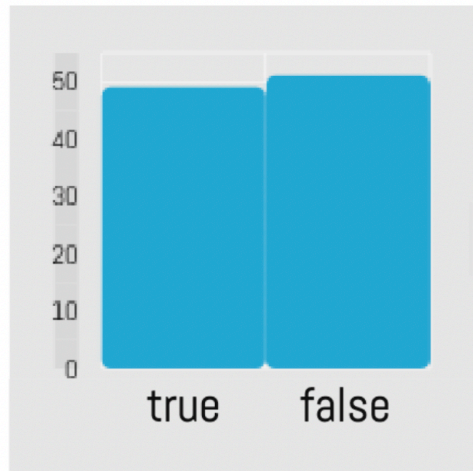
Incomplete or Biased Data

Confounding Variables

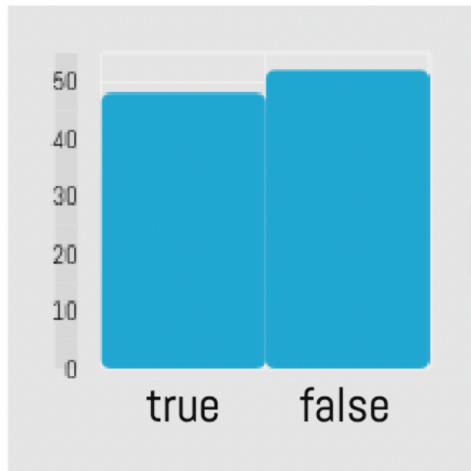


What Swag Should We Send? [Zgraggen et al. '18]

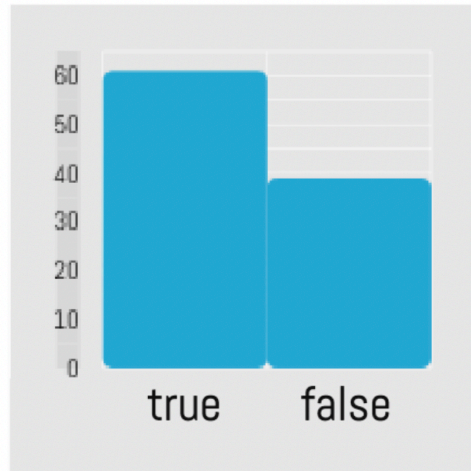
(a) 2006: pen (\$4)



(b) 2007 key chain (\$2)



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

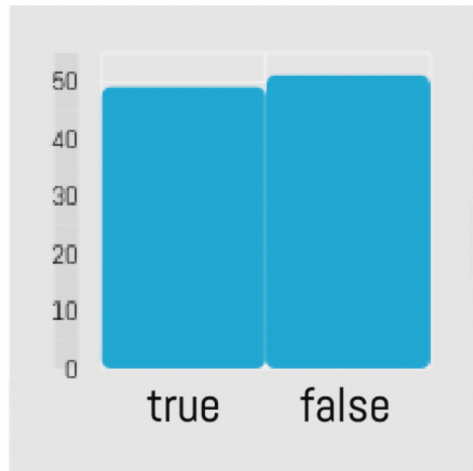


...

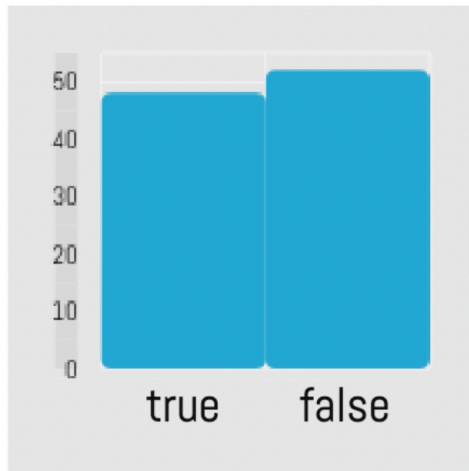
Recurring Donor?

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.

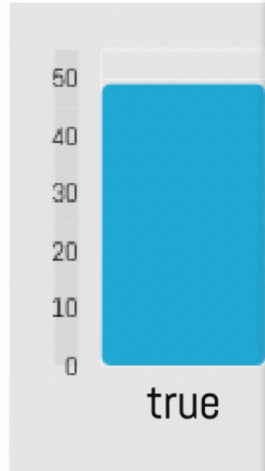
What Swag Should We Send? [Zgraggen et al. '18]

(a) 2006: pen (\$4)

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Recurring Donor?



Multiple Comparisons Problem

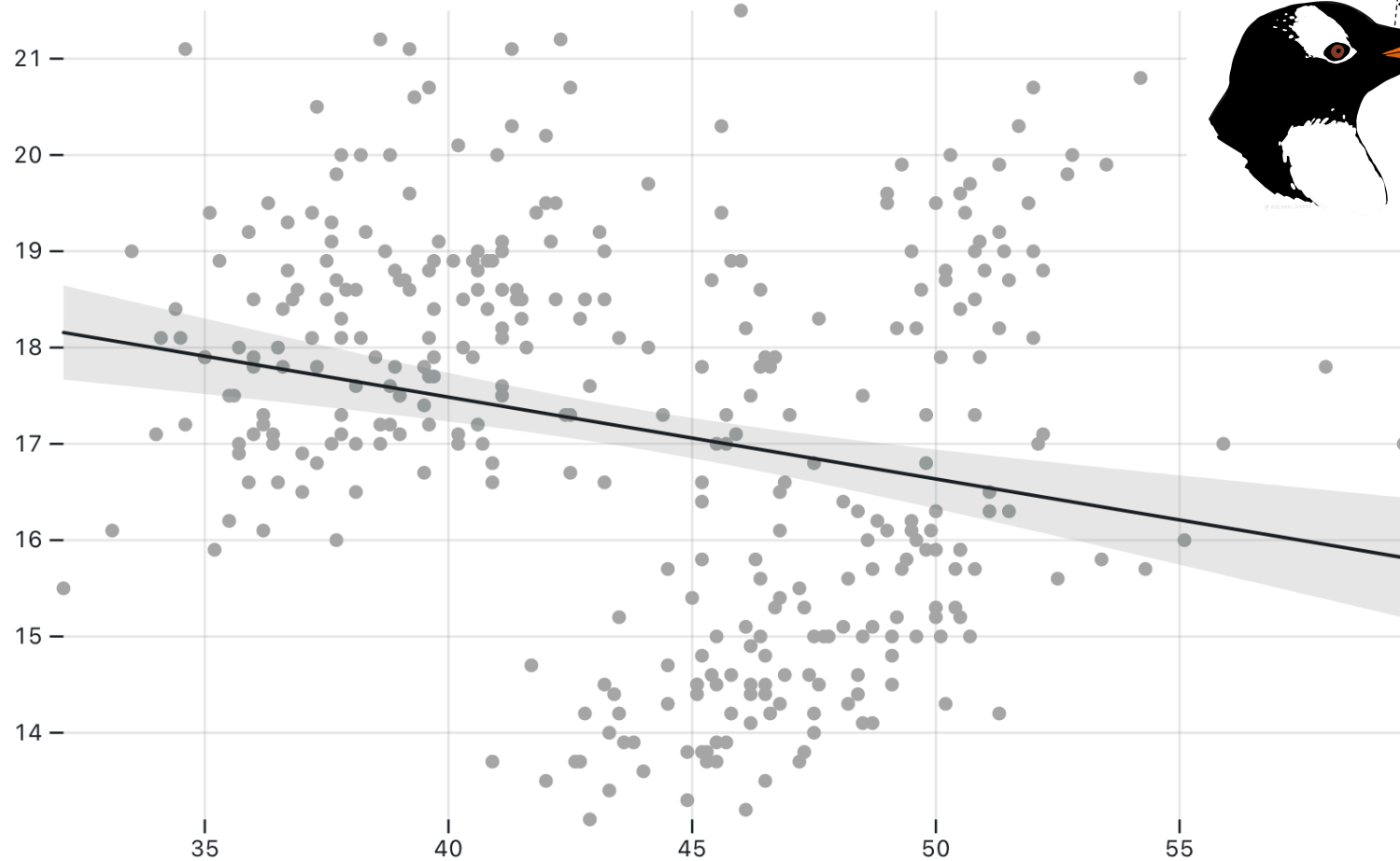


Figure 1. An apparent insight became apparent from the same

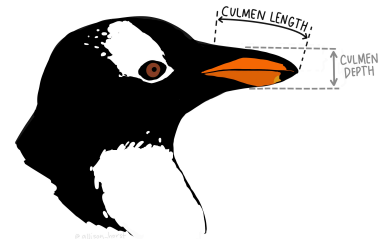
flags (c) as an insight were generated. By viewing lots

of visualizations, the chances increase of seeing an apparent insight that is actually the product of random noise.

↑ culmen_depth_mm



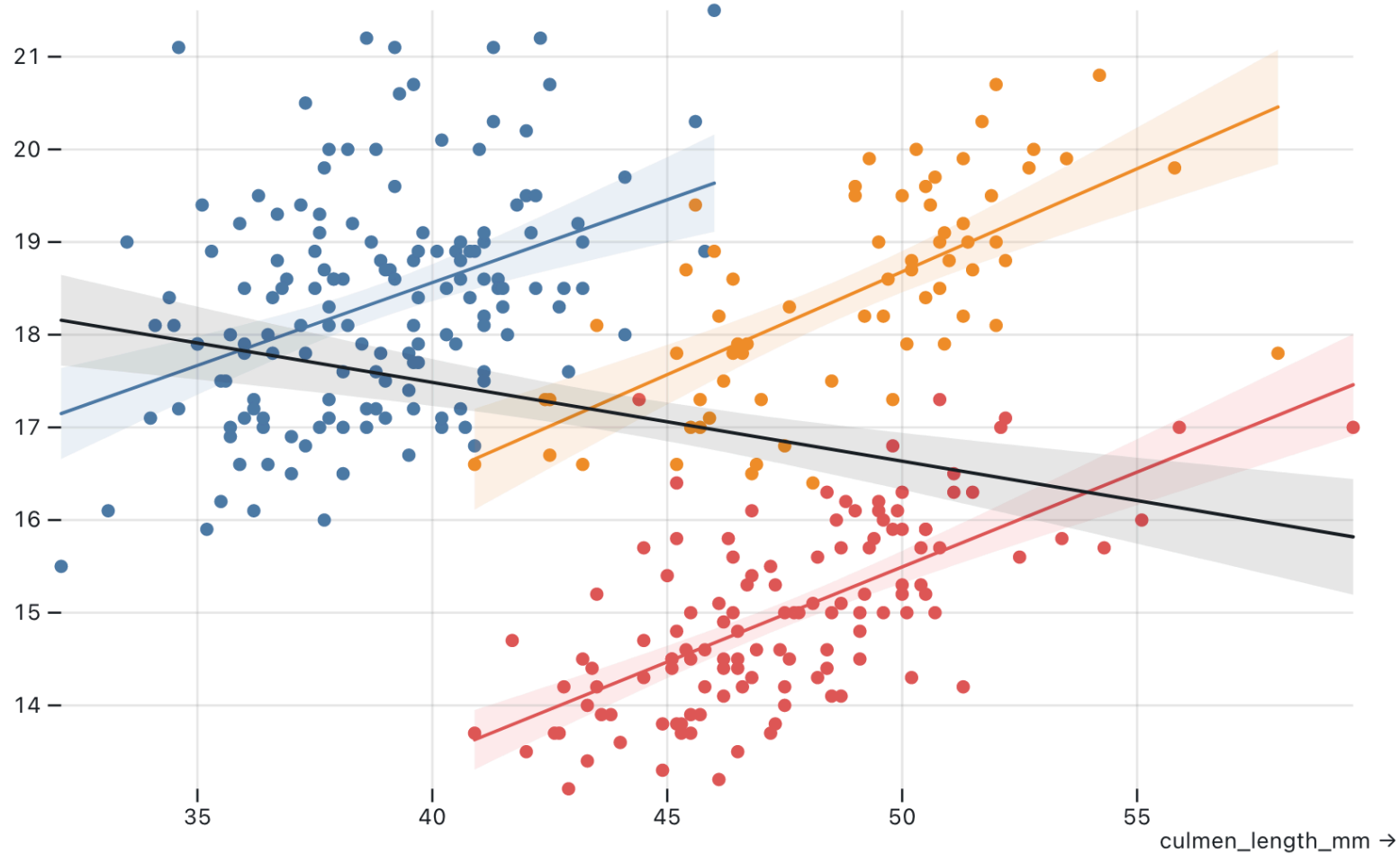
CULMEN: RIDGE ALONG THE TOP PART OF A BIRD'S BILL



Simpson's Paradox!

Adelie Chinstrap Gentoo

↑ culmen_depth_mm



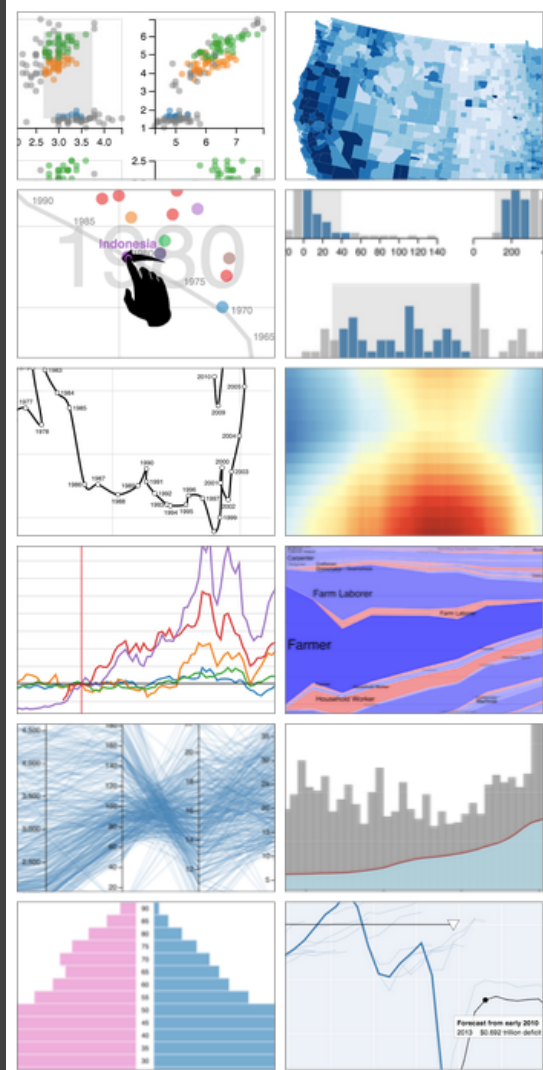
Summary

Recognize deceptive visualizations

Don't prematurely suppress uncertainty

Frequency framing & hypothetical outcomes

Bridging exploration and confirmation



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