Uncertainty Visualization

Michael Correll Tableau Research

Questions To Answer

What Does Uncertainty Mean?

How Should I Visualize It?

What Can Go Wrong?

Definitions and Bookkeeping

WHAT DOES UNCERTAINTY MEAN, ANYWAY?

Things “Uncertainty” Can Mean

Doubt

Risk

Variability

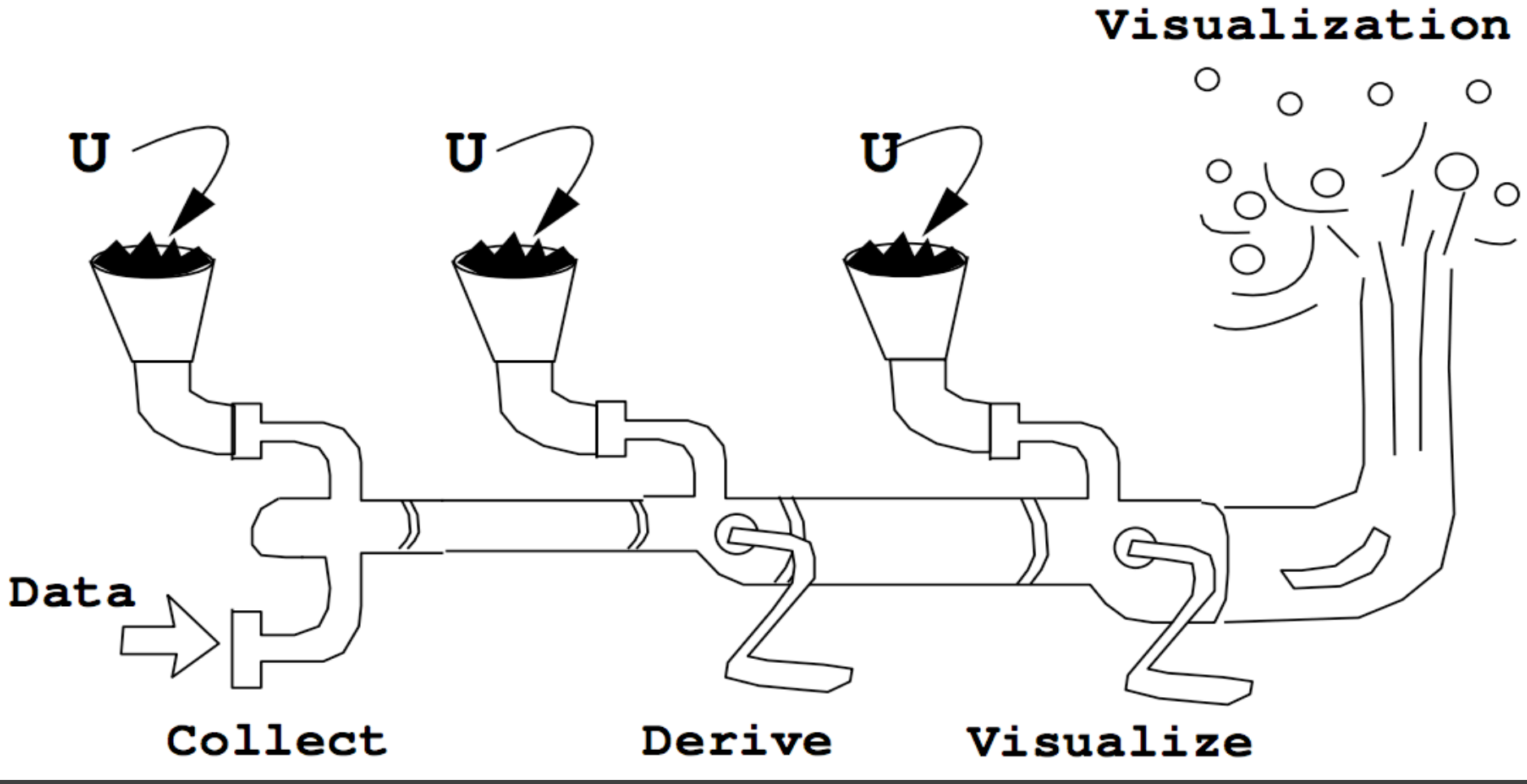
Error

Lack of Knowledge

Hedging

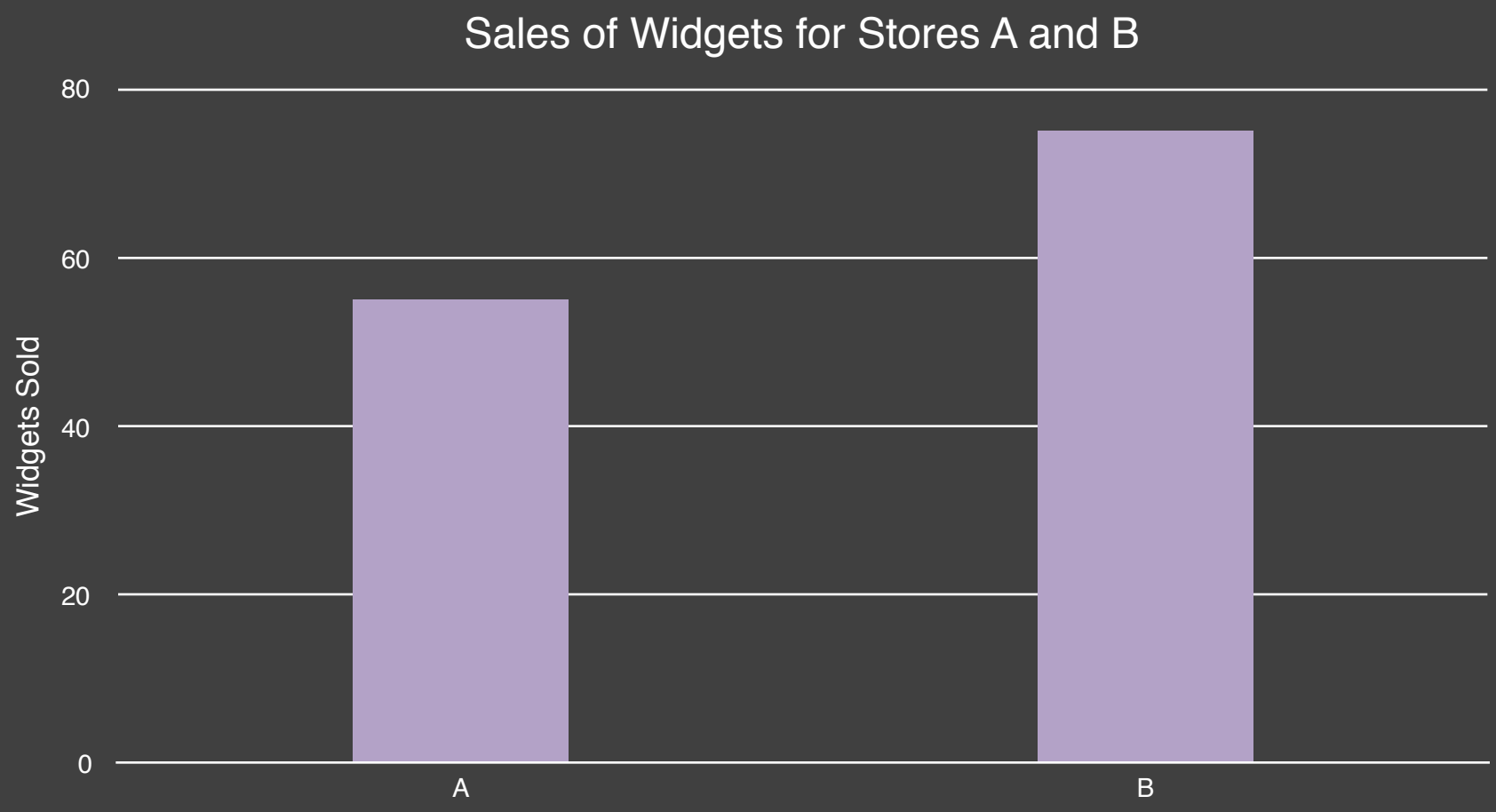
…

Uncertainty Vis Pipeline



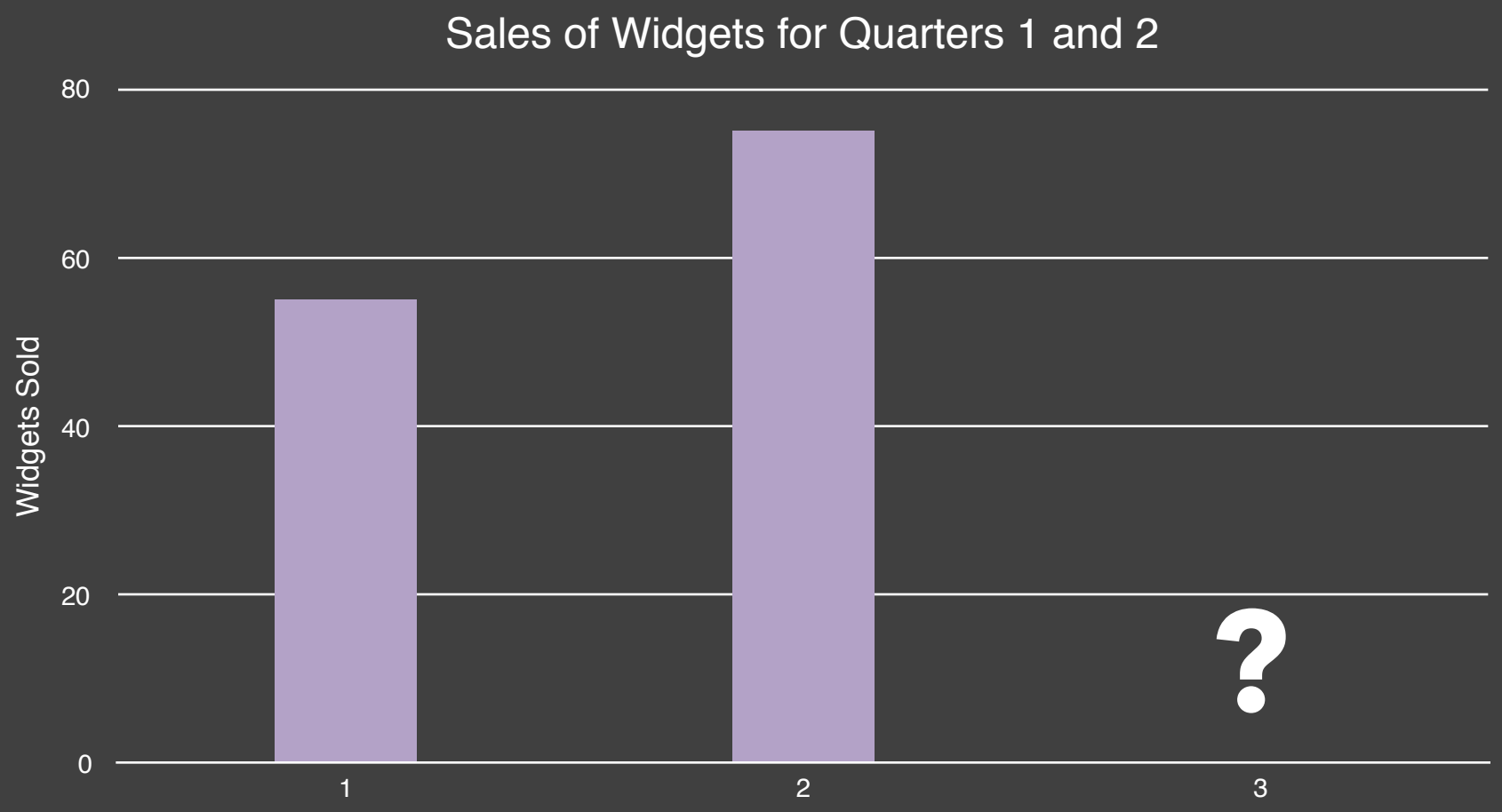
Pang et al. Approaches to Uncertainty Visualization. The Visual Computer, 1997.

A Bar Chart

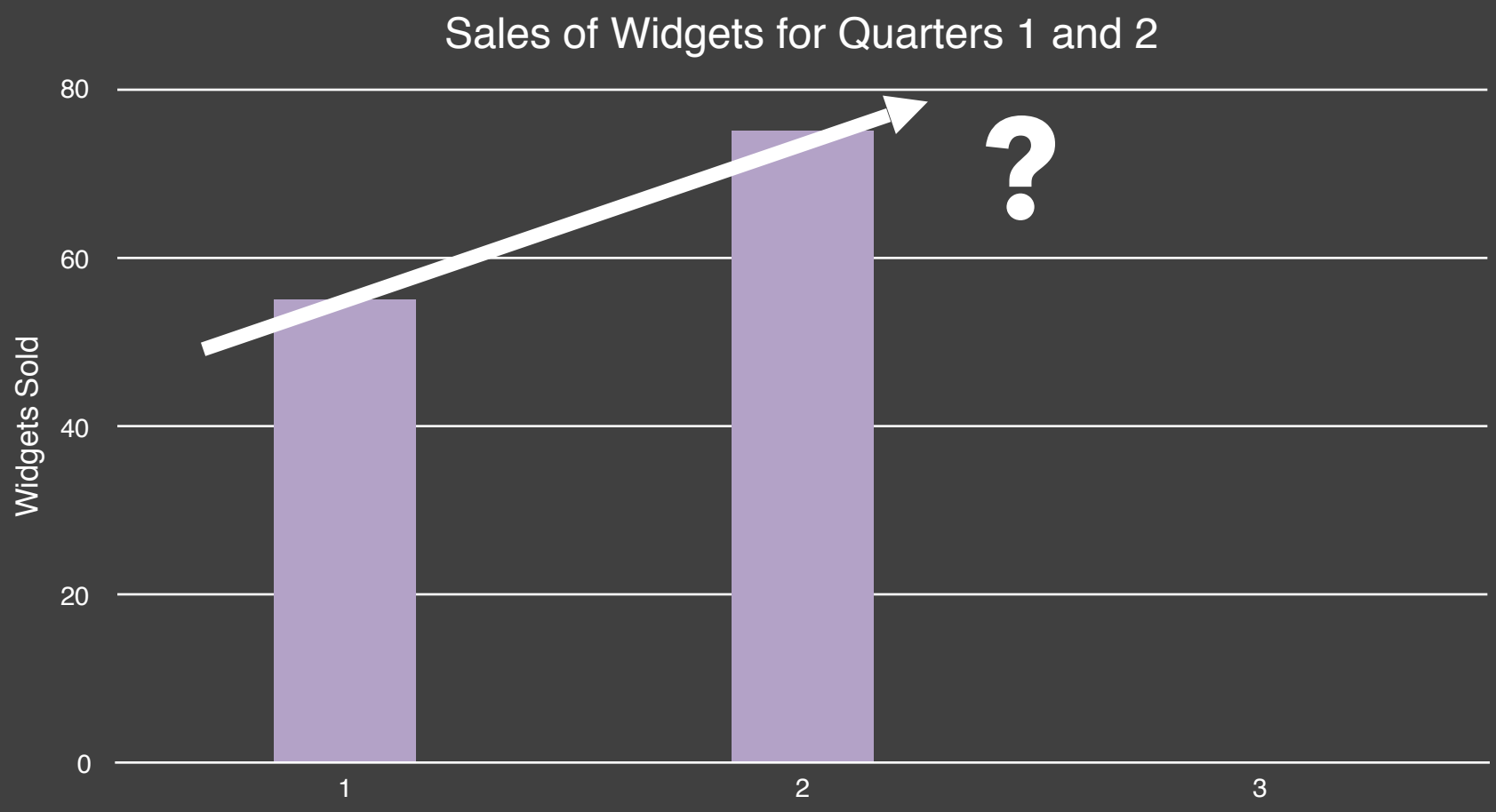

Sales of Widgets for Stores A and B
Widgets Sold
80
60
40
20
0
A
B

Measurement Uncertainty

Forecast Uncertainty



Model Uncertainty



Decision Uncertainty

Uncertainty Sources

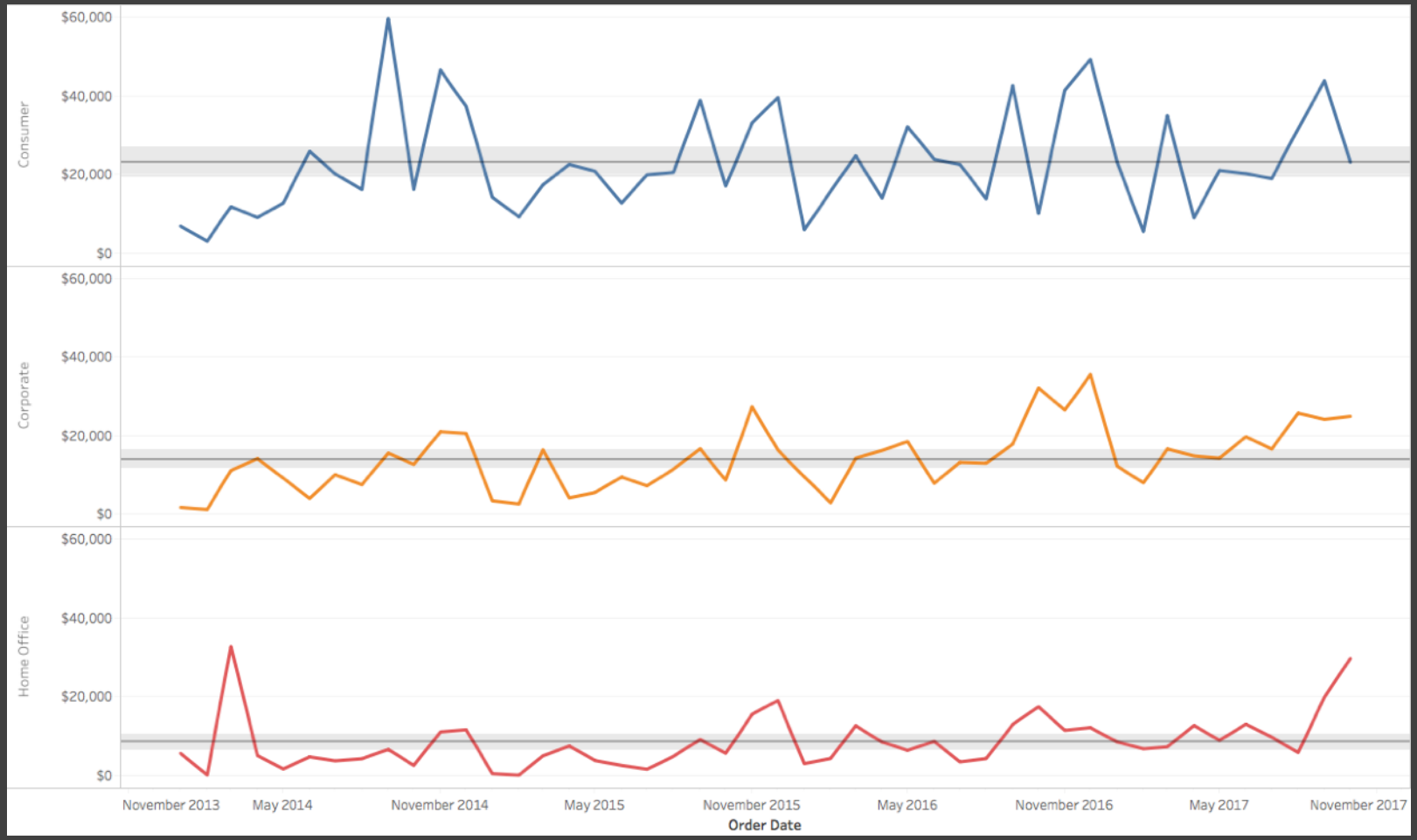
Measurement Uncertainty: “We’re not sure what the data are”

Forecast Uncertainty: “We’re not sure what will happen to the data next”

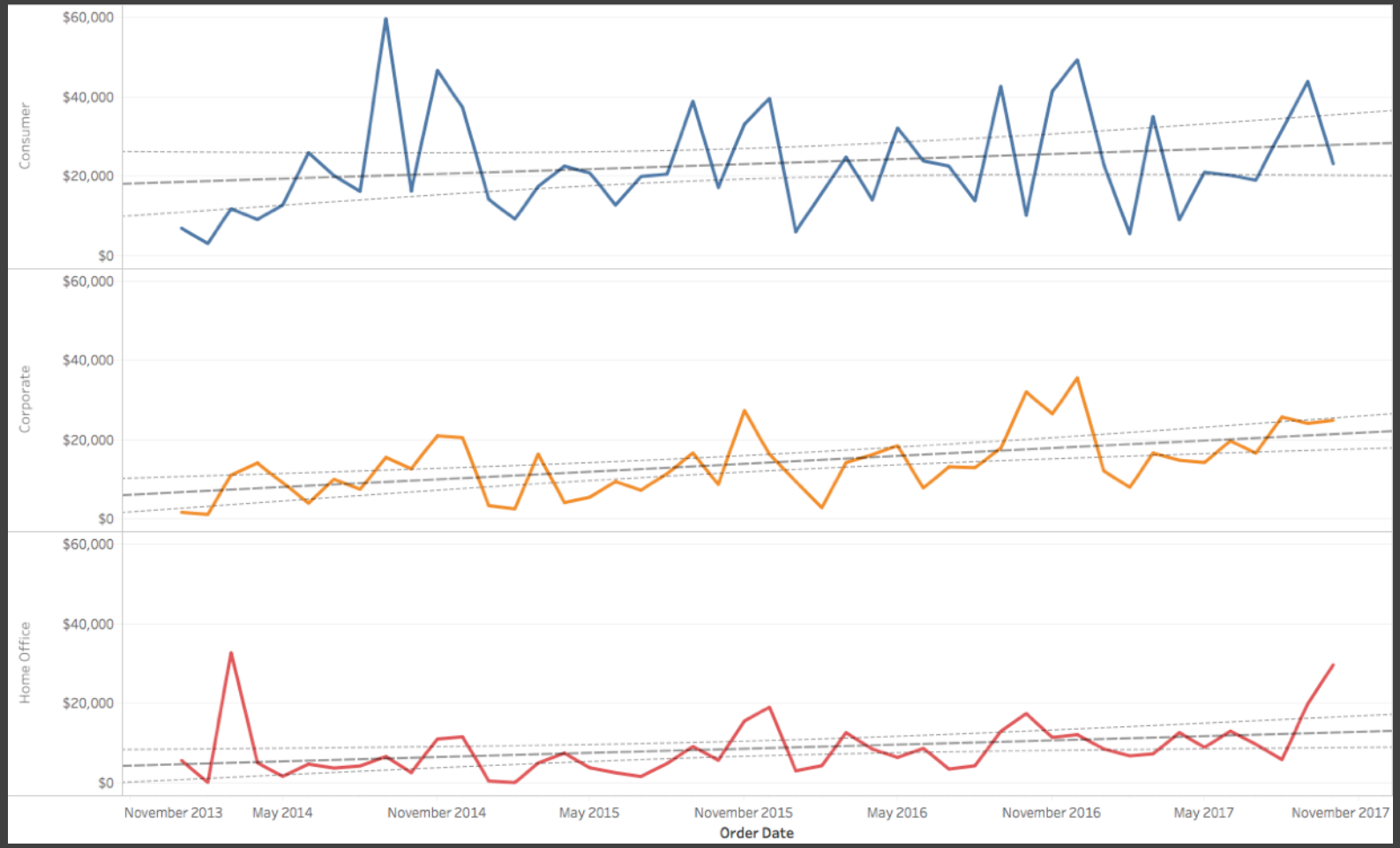
Model Uncertainty: “We’re not sure how the data fit together”

Decision Uncertainty: “We’re not sure what to do with the data”

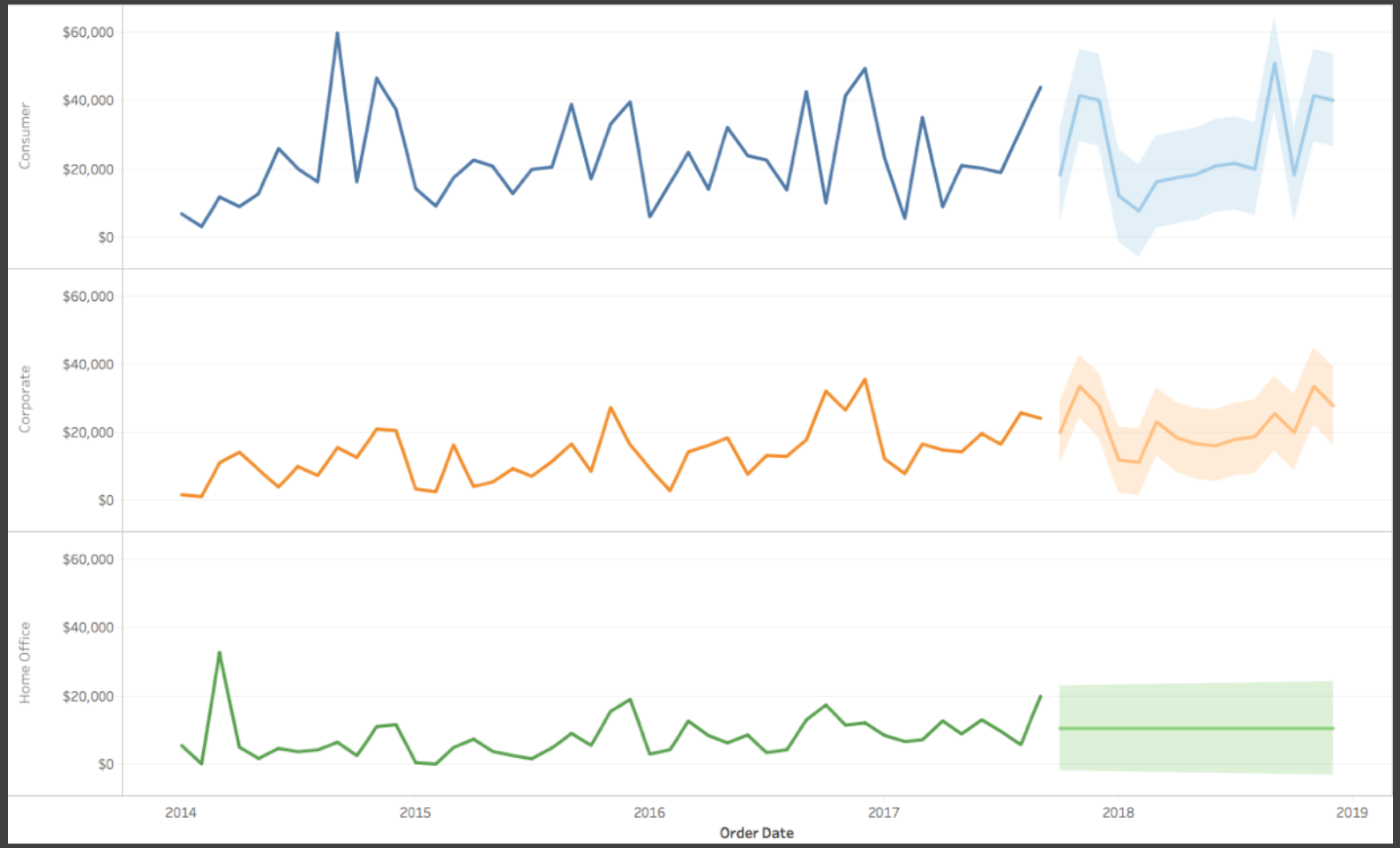
Measurement Uncertainty



Model Uncertainty



Forecast Uncertainty



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.

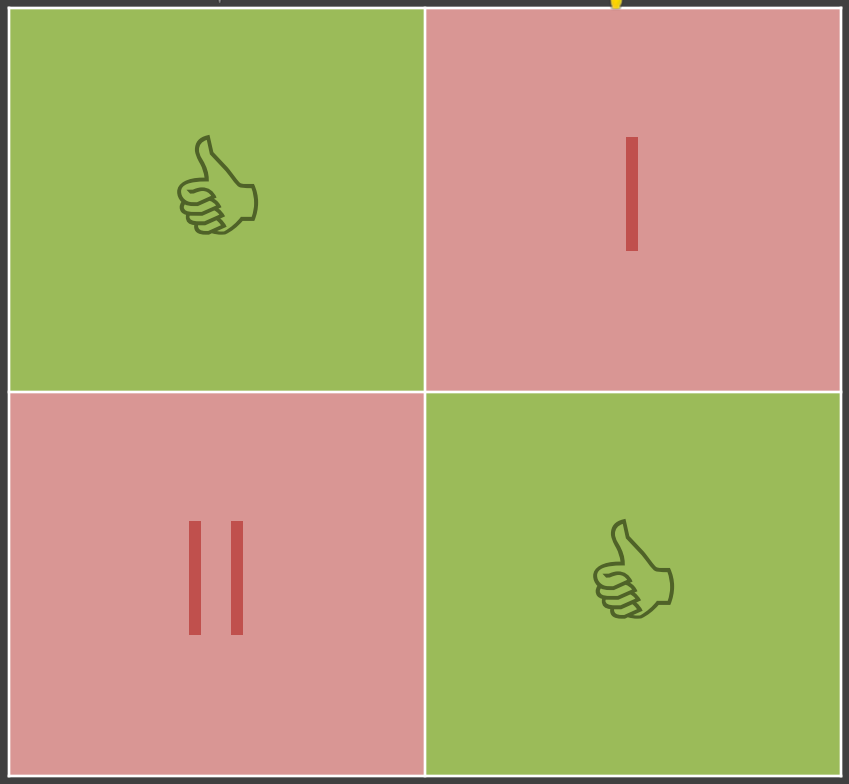
Should I Bring an Umbrella?

Decision Uncertainty

"50% Chance of Rain"

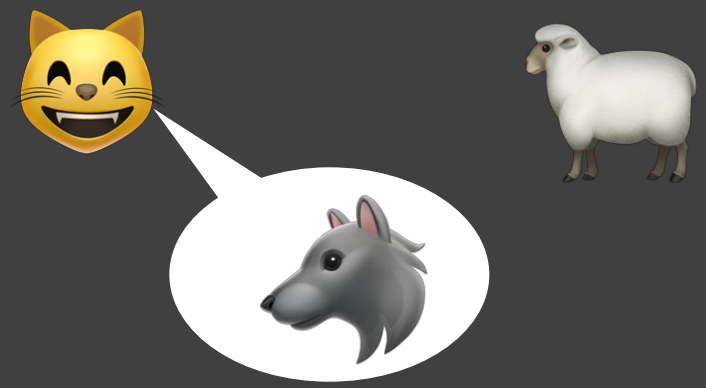
Error Types

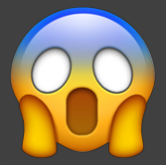
Error Types



The Boy Who Cried Wolf

Type I



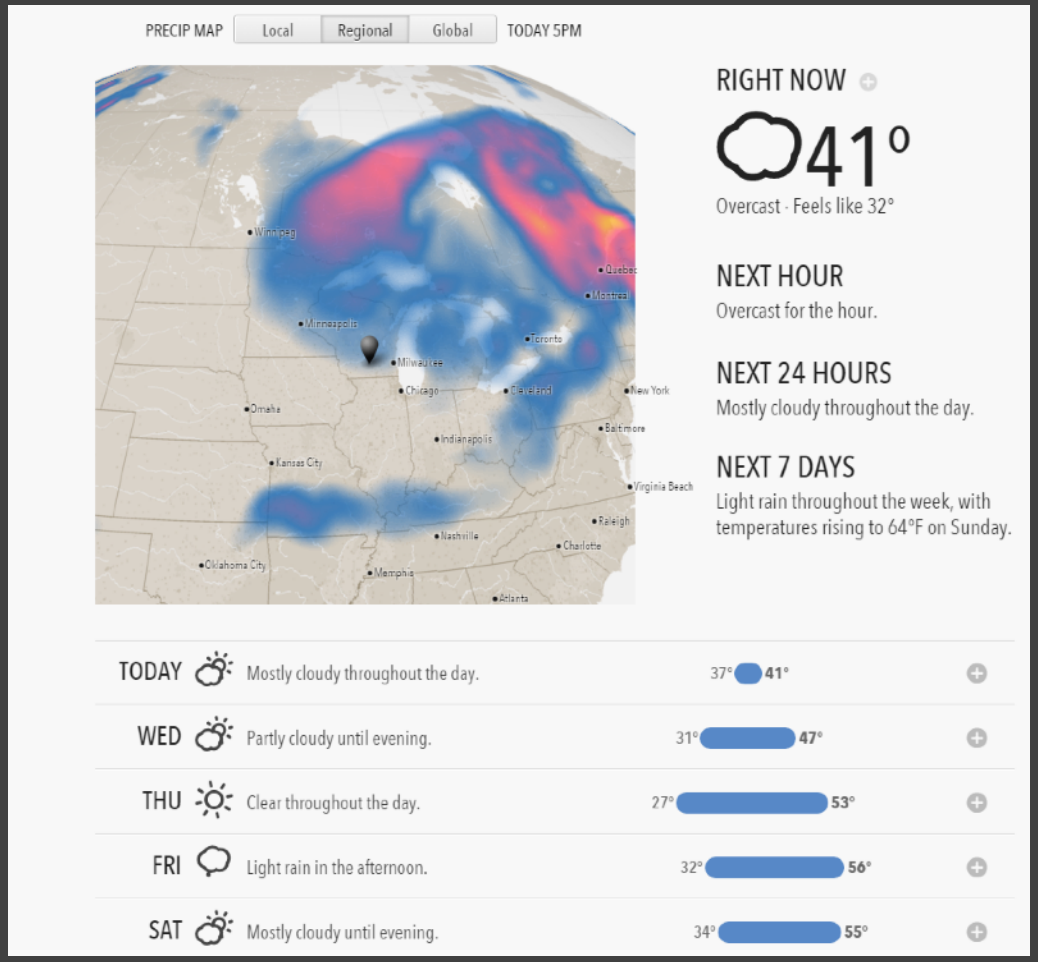


Type II

Model Uncertainty

"50% Chance of Rain"

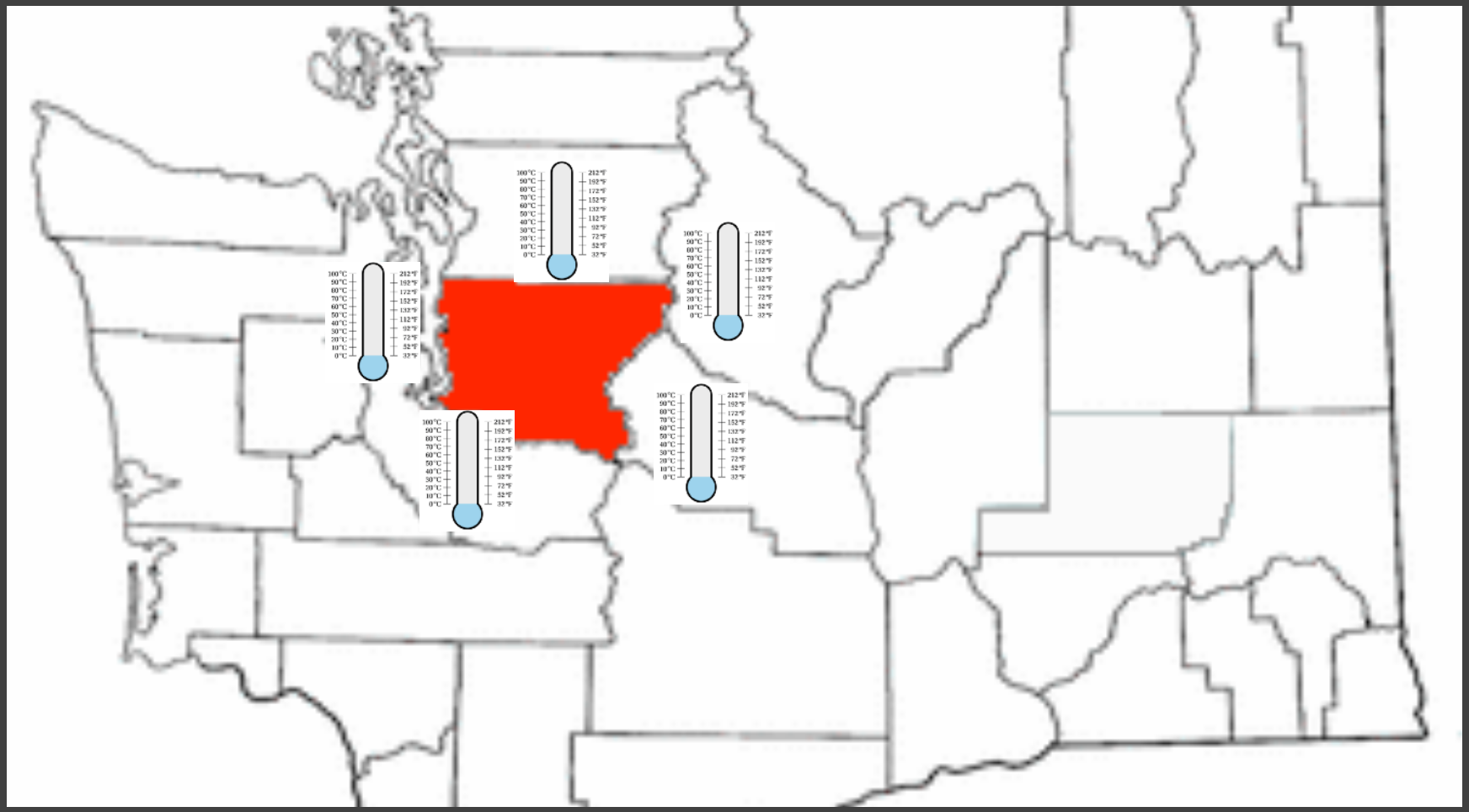
Model Uncertainty



Model Uncertainty

Measurement Uncertainty

Measurement Uncertainty



Measurement Uncertainty

Precision

Measurement Uncertainty

Precision

Measurement Uncertainty

Precision

Measurement Uncertainty

Precision

Accuracy

Measurement Uncertainty

Precision

Accuracy

Measurement Uncertainty

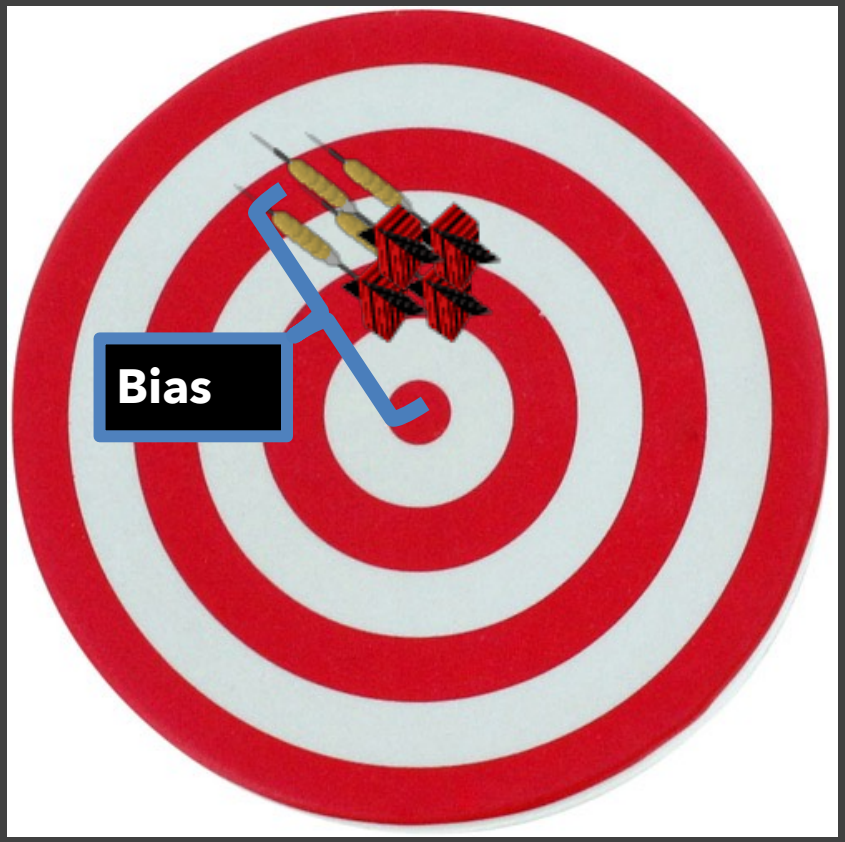
Precision

Accuracy

Measurement Uncertainty

Precision

Accuracy



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.

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LOTS OF THINGS

Uncertainty Maps and Model Visualization

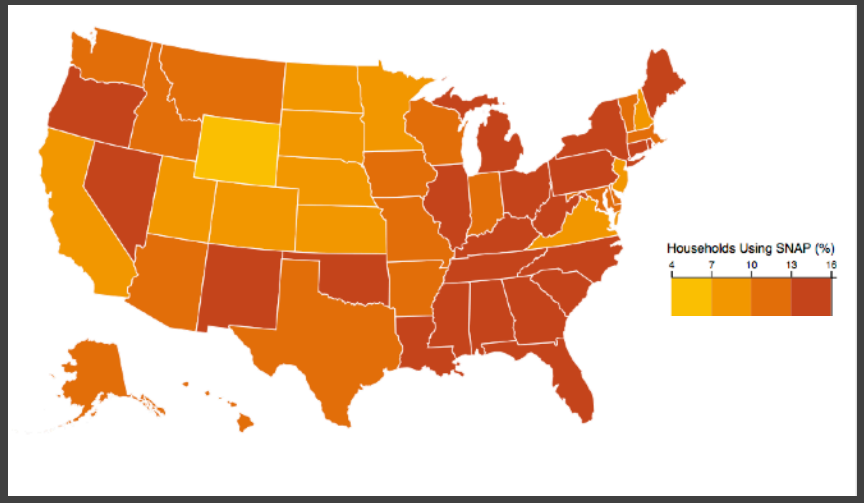
HOW SHOULD I VISUALIZE UNCERTAINTY?

Uncertainty Vis Pipeline

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

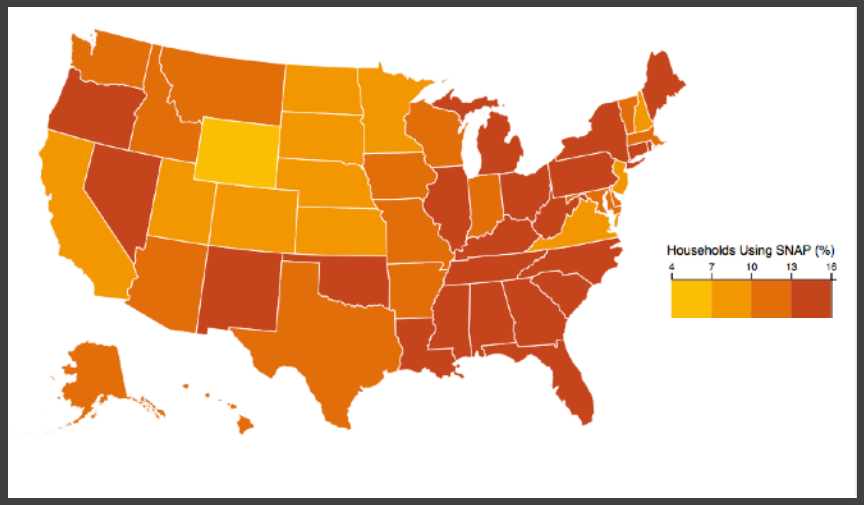
SNAP

Data Map

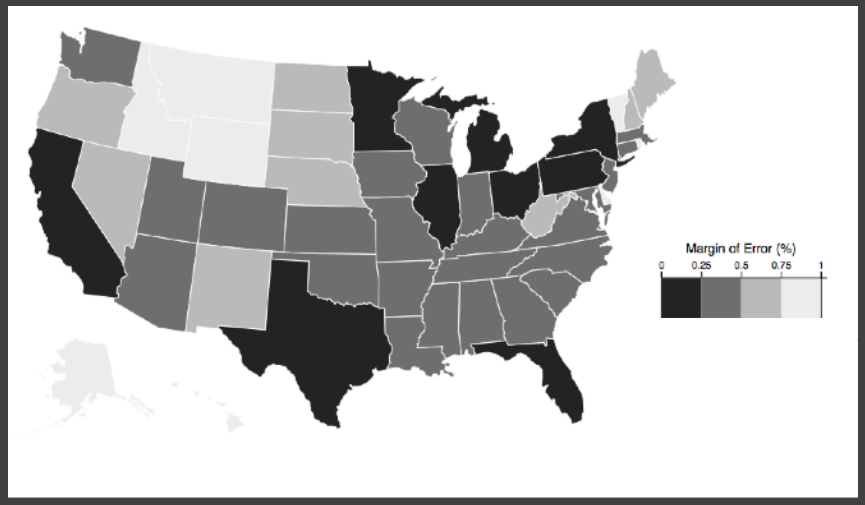


SNAP

Data Map



Uncertainty Map



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Uncertainty Vis Pipeline

1) Quantify Uncertainty
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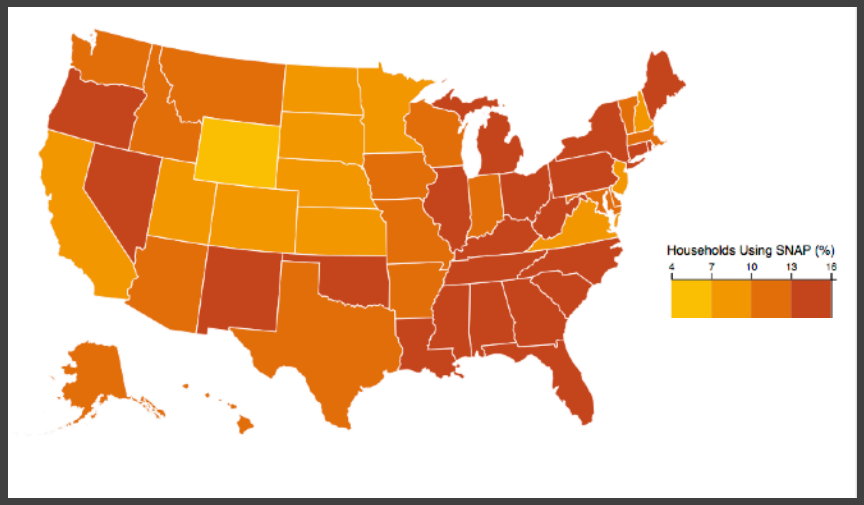
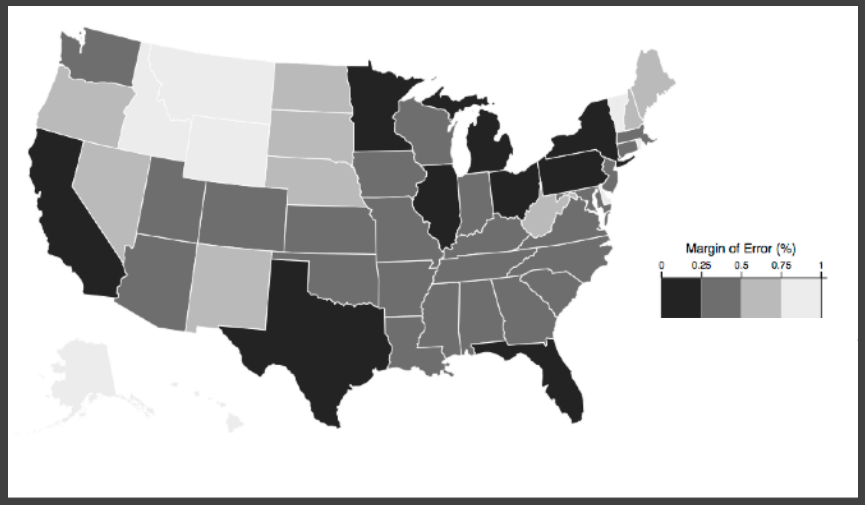
4) Unify the Data Map and Uncertainty Map

How to Unify?

Data Map

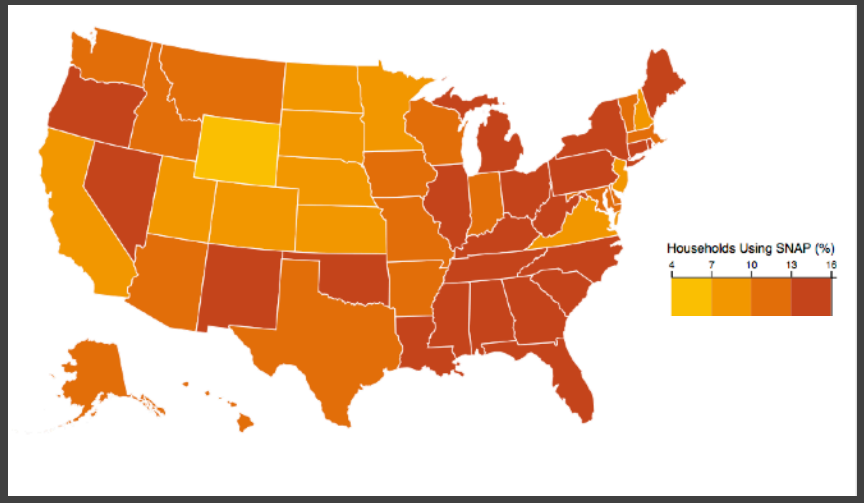


Uncertainty Map

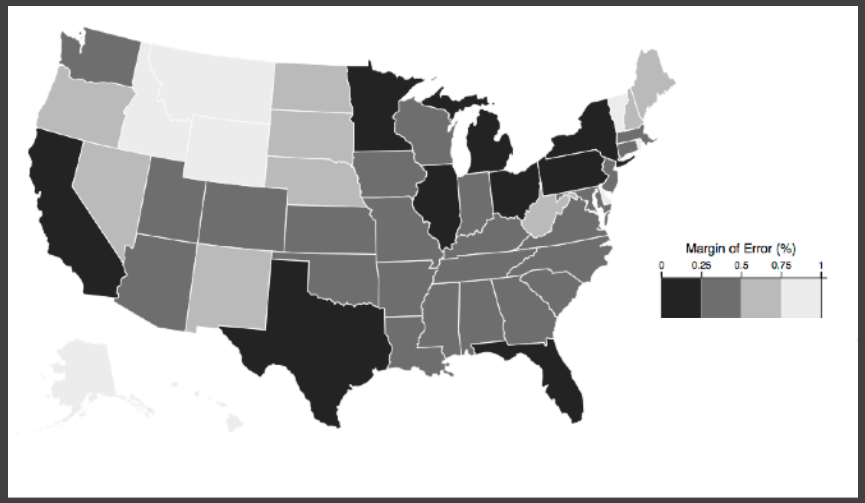


Juxtaposition

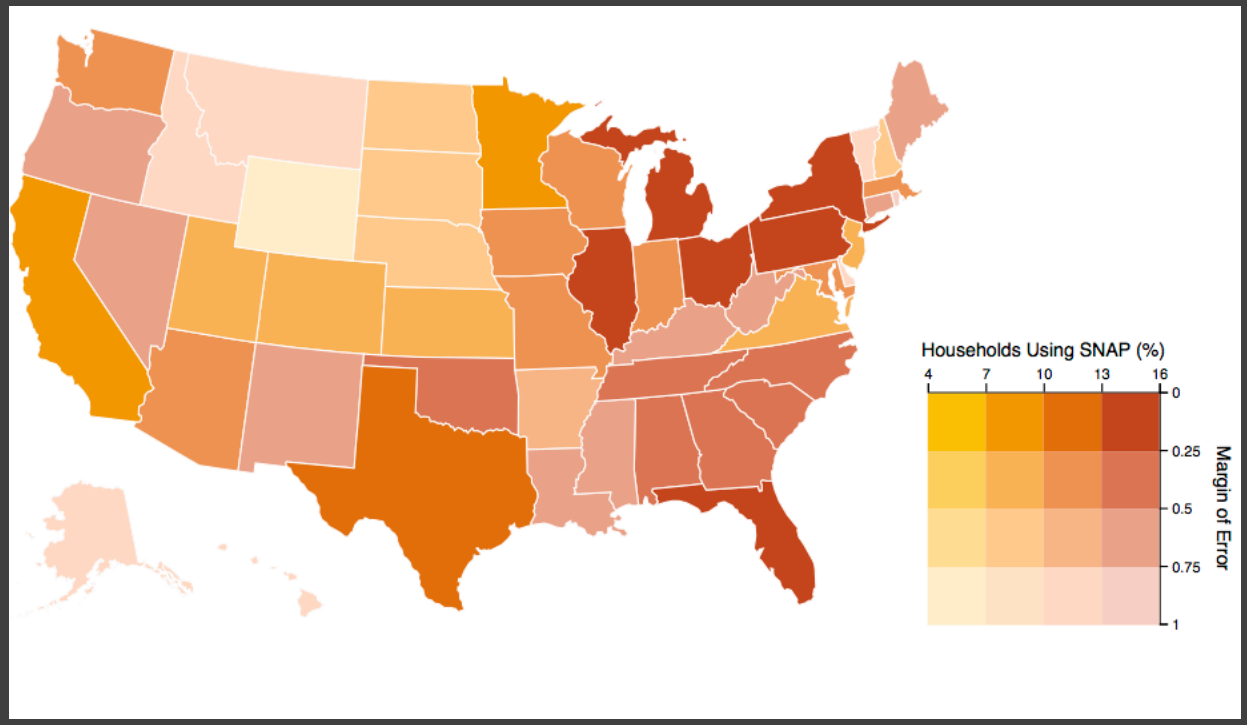
Data Map



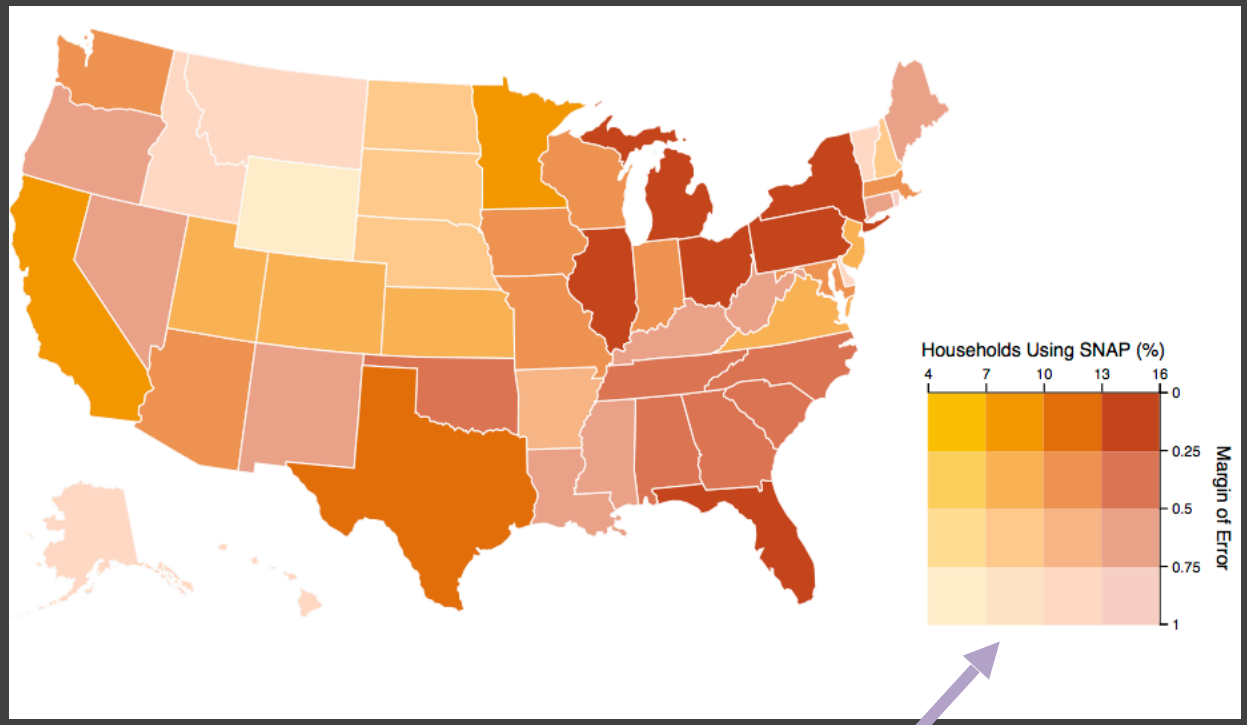
Uncertainty Map



Superposition

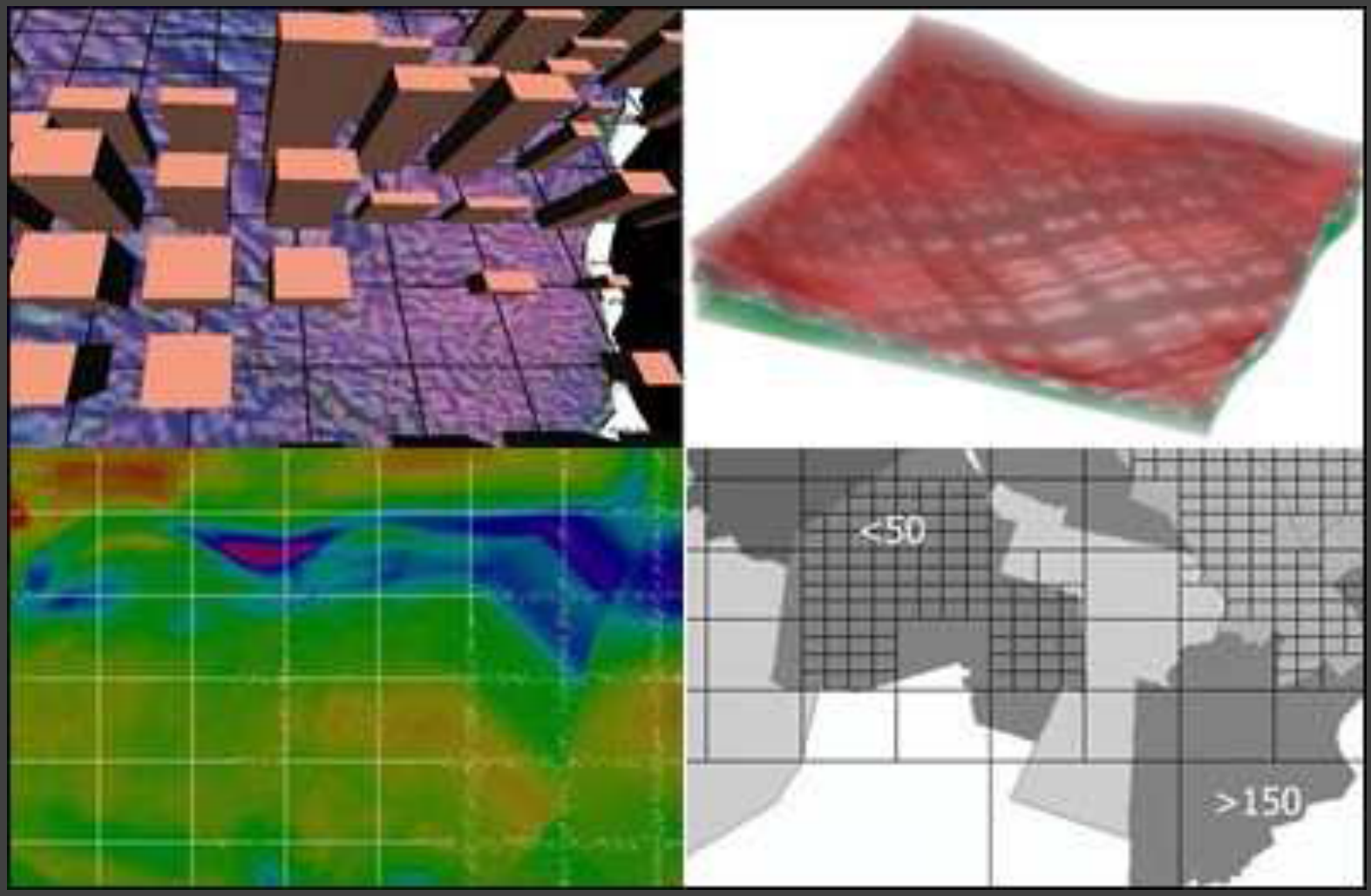


Superposition



Bivariate Map

Superposition



Griethe, Henning and Schumann, Heidrun. The Visualization of Uncertain Data: Methods and Problems. SimVis, 2006.

Uncertainty Vis Pipeline

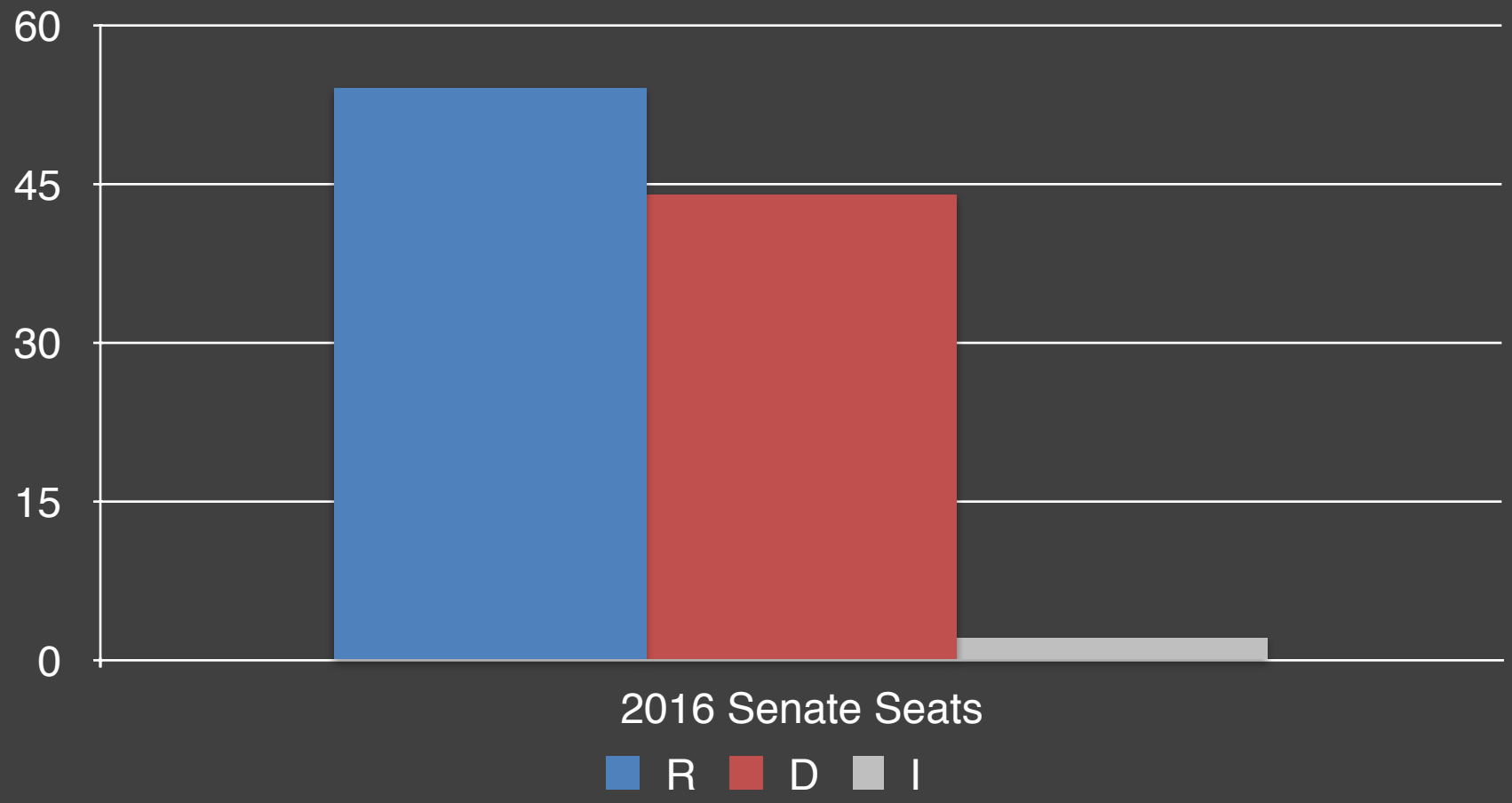
1) Quantify Uncertainty
2) Choose a free visual variable
3) Encode uncertainty with the variable
4) Unify the Data Map and Uncertainty Map

Uncertainty Vis Pipeline

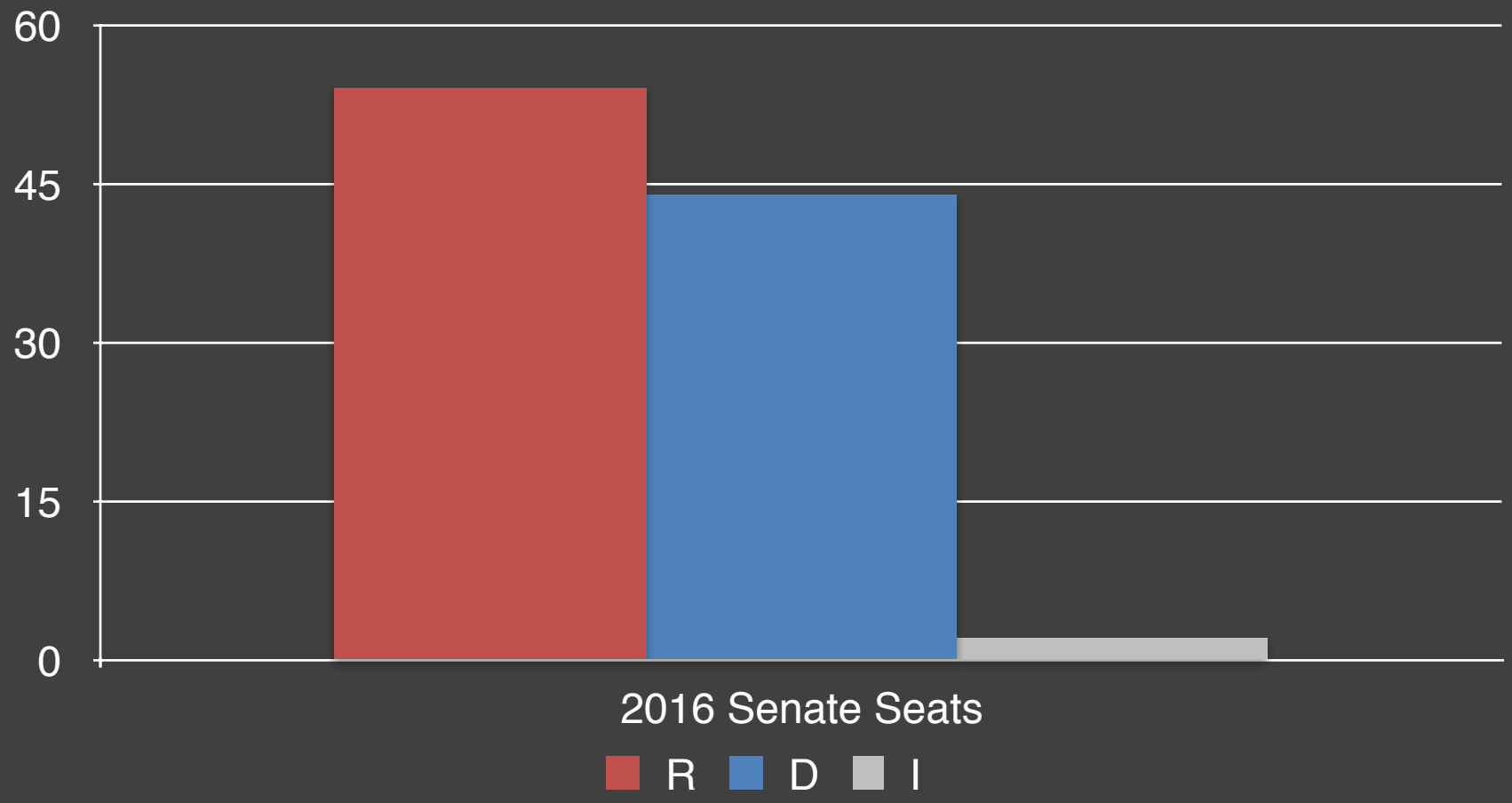
1) Quantify Uncertainty
2) Choose a free **visual variable**
3) Encode uncertainty with the variable
4) Unify the Data Map and Uncertainty Map

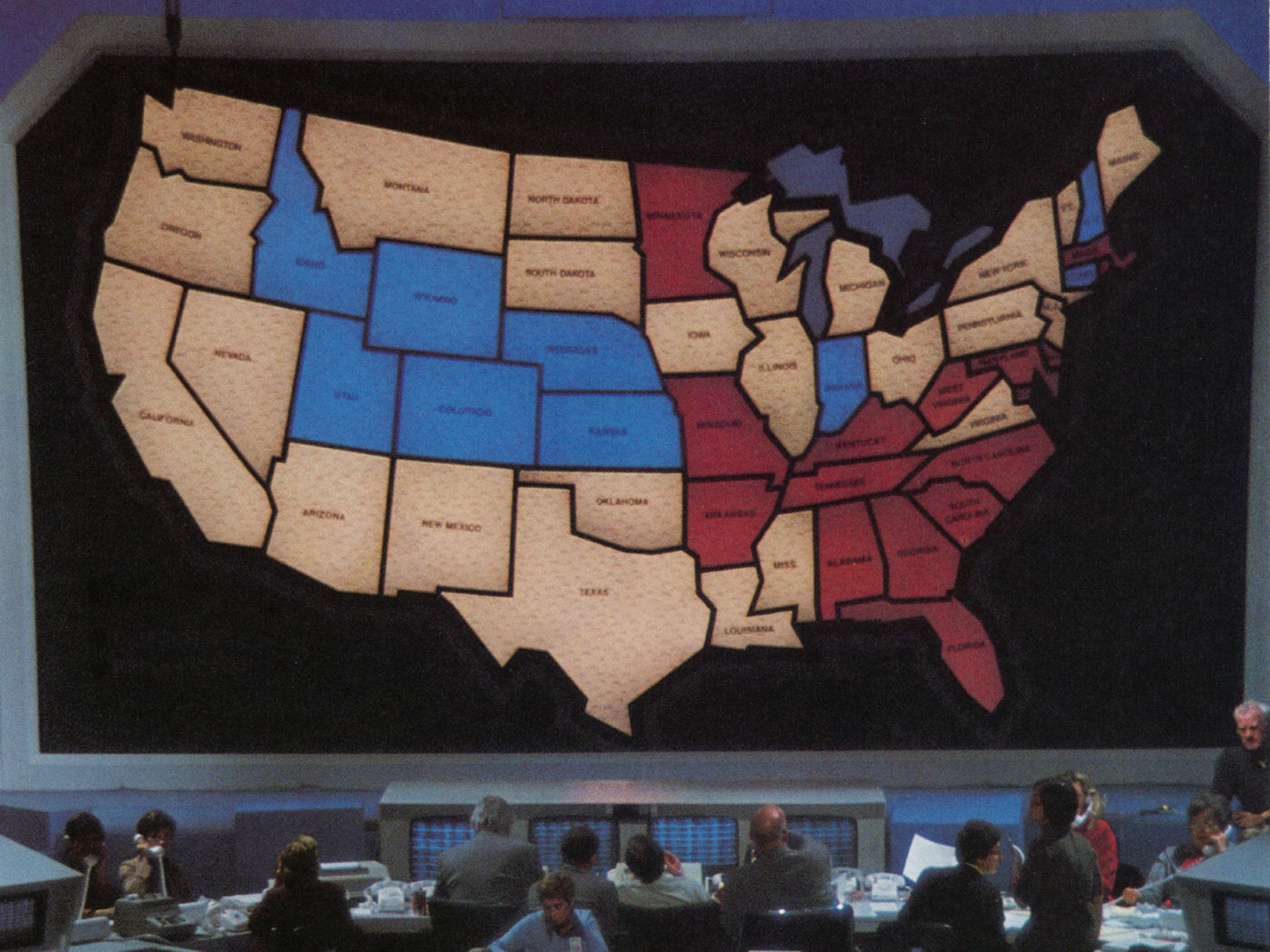
Semiotics of Uncertainty

The Variable Matters!

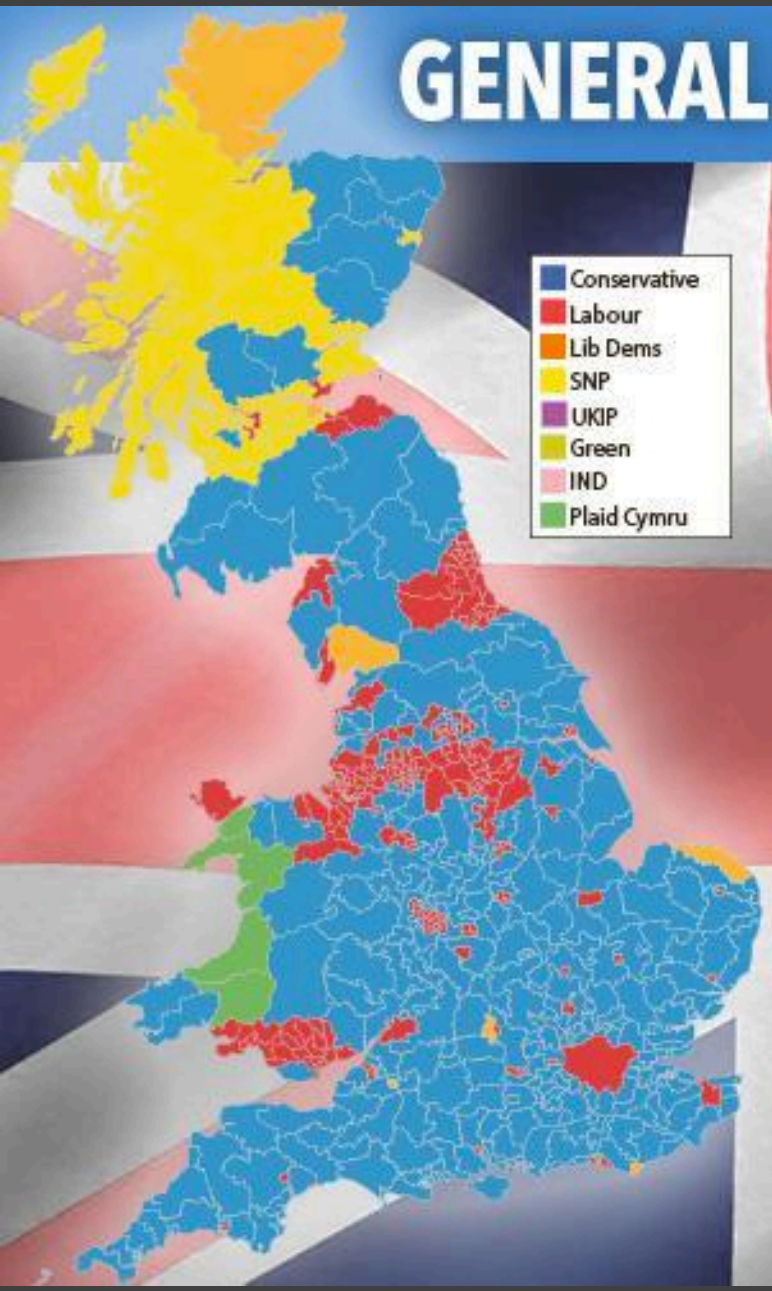


The Variable Matters!




WASHINGTON
OREGON
CALIFORNIA
NEVADA
IDAHO
MONTANA
WYOMING
UTAH
ARIZONA
COLORADO
NEW MEXICO
NORTH DAKOTA
SOUTH DAKOTA
NEBRASKA
KANSAS
OKLAHOMA
TEXAS
MINNESOTA
IOWA
MISSOURI
ARKANSAS
LOUISIANA
WISCONSIN
ILLINOIS
MICHIGAN
INDIANA
OHIO
KENTUCKY
TENNESSEE
MISS.
ALABAMA
GEORGIA
FLORIDA
SOUTH CAROLINA
NORTH CAROLINA
VIRGINIA
WEST VIRGINIA
PENNSYLVANIA
NEW YORK
MAINE

GENERAL ELECTION RESULTS 2017

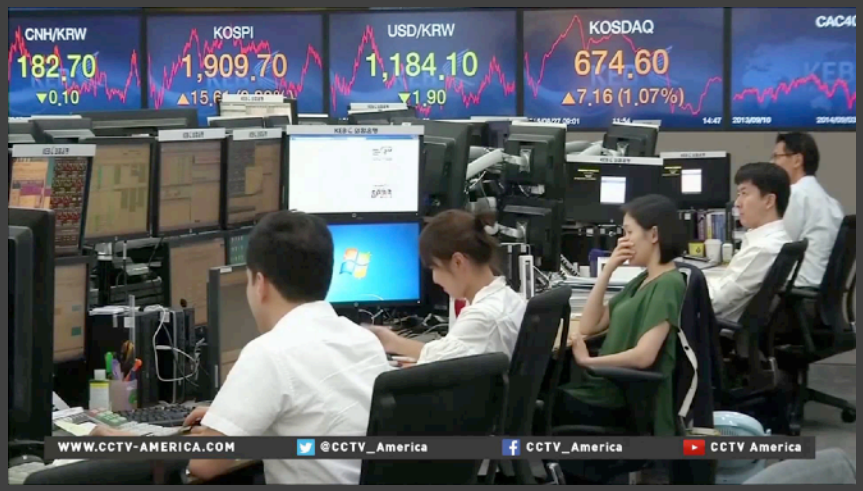


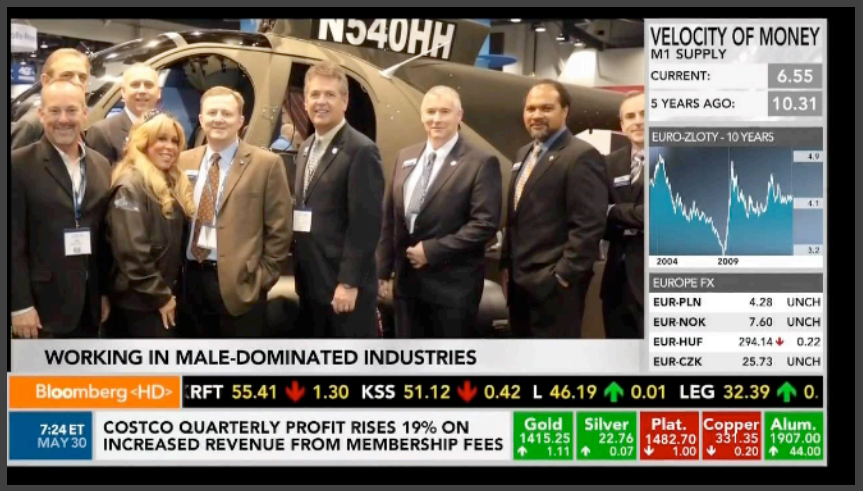
MAY

CORBYN

STURGEON

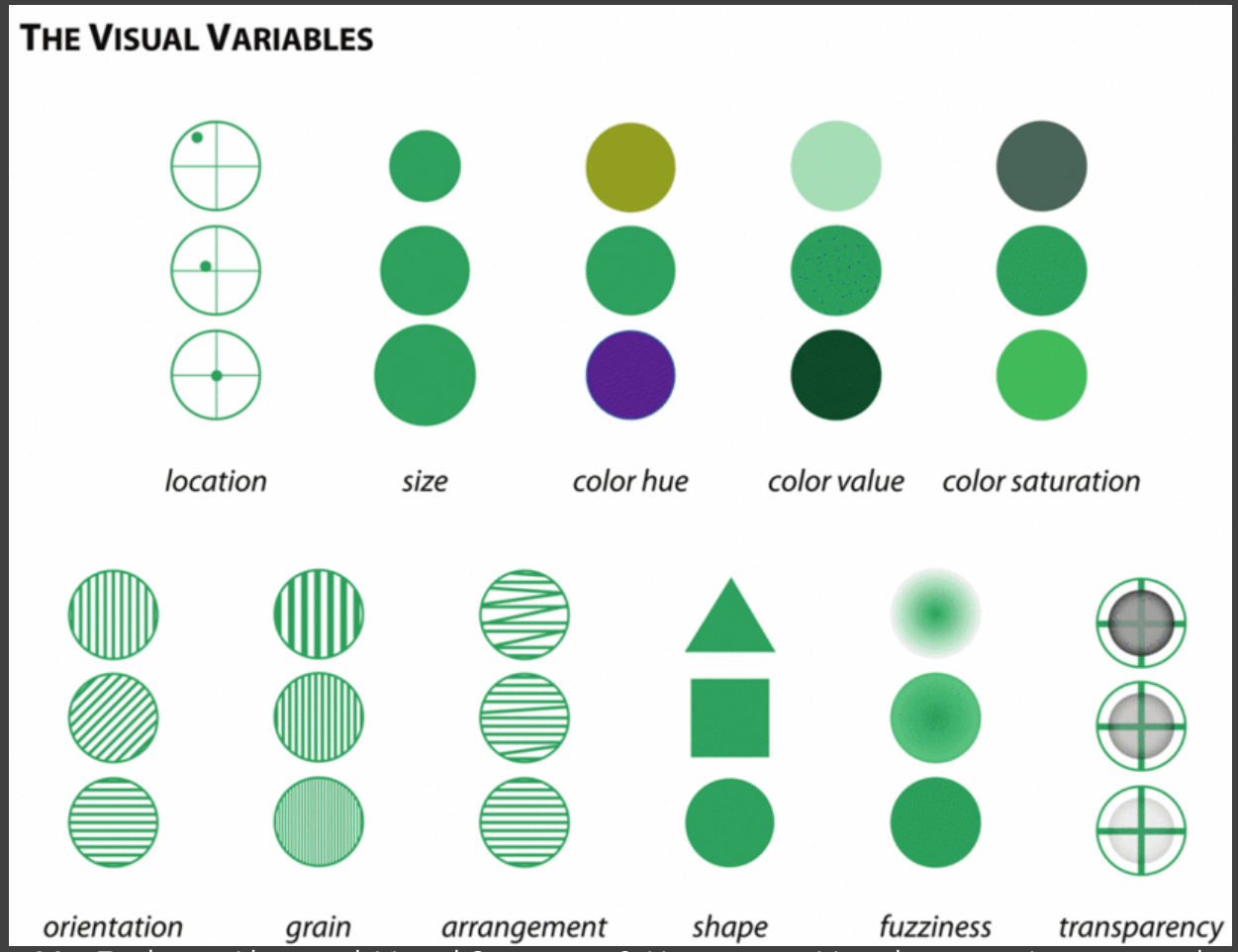
FARRON


CNH/KRW
182.70
▼0.10
KOSPI
1,909.70
USD/KRW
1,184.10
▼1.90
KOSDAQ
674.60
▲7.16 (1.07%)
WWW.CCTV-AMERICA.COM
@CCTV_America
CCTV_America
CCTV America

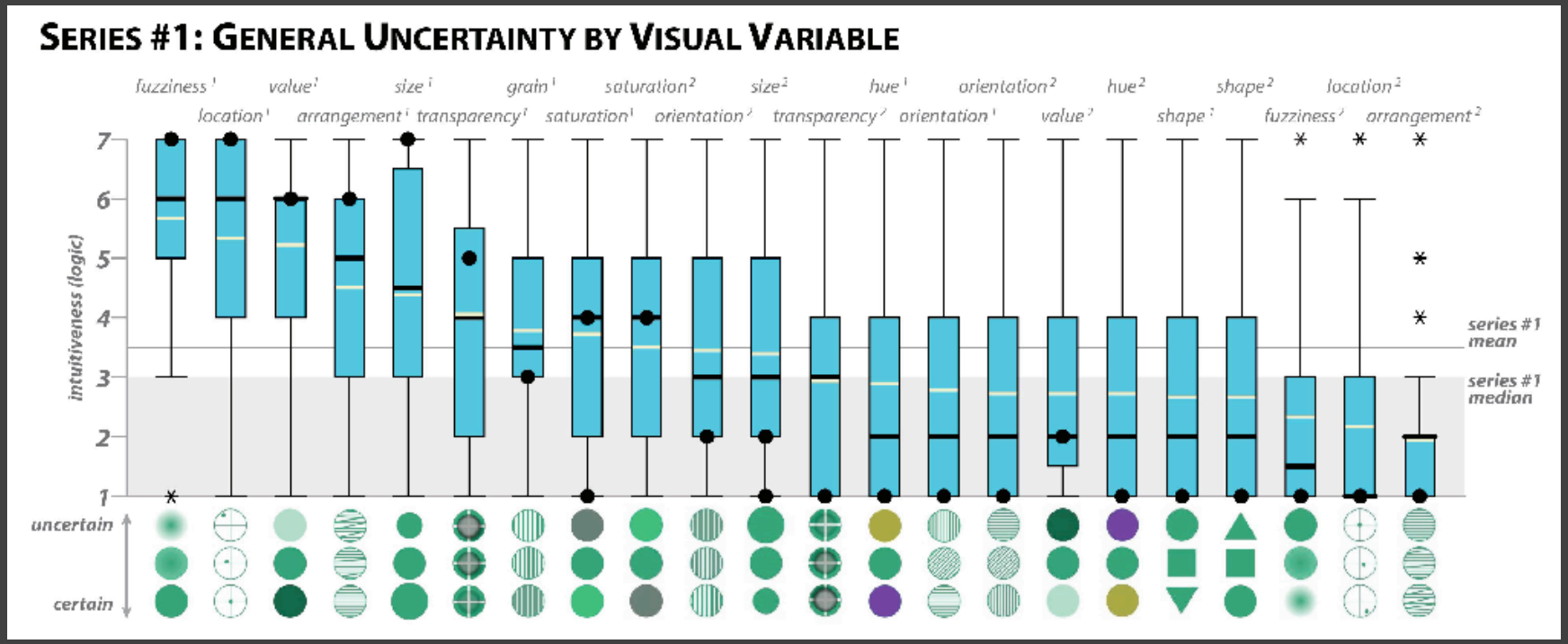

N540HH
VELOCITY OF MONEY
M1 SUPPLY
CURRENT: 6.55
5 YEARS AGO: 10.31
EURO-ZLOTY - 10 YEARS
2004
2009
EUROPE FX
EUR-PLN 4.28 UNCH
EUR-NOK 7.60 UNCH
EUR-HUF 294.14 0.22
EUR-CZK 25.73 UNCH
WORKING IN MALE-DOMINATED INDUSTRIES
Bloomberg HD
RFT 55.41 1.30 KSS 51.12 0.42 L 46.19 0.01 LEG 32.39
7:24 ET MAY 30
COSTCO QUARTERLY PROFIT RISES 19% ON INCREASED REVENUE FROM MEMBERSHIP FEES
Gold 1415.25 1.11
Silver 22.76 0.07
Plat. 1482.70 1.00
Copper 331.35 0.20
Alum. 1907.00 44.00

Semiotics of Uncertainty

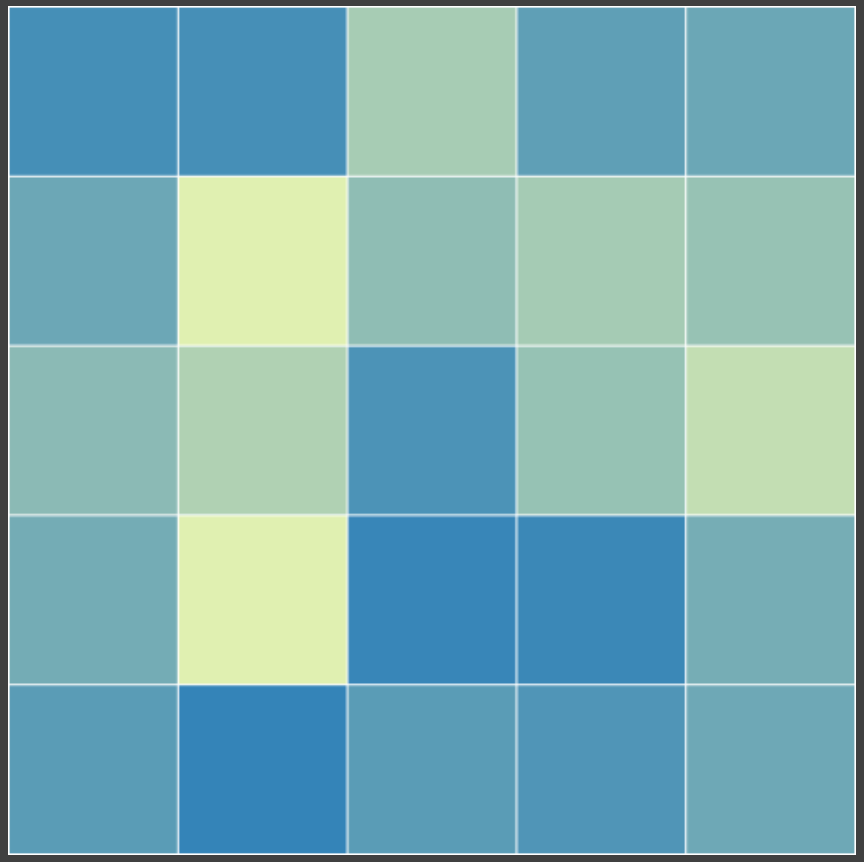
Semiotics of Uncertainty

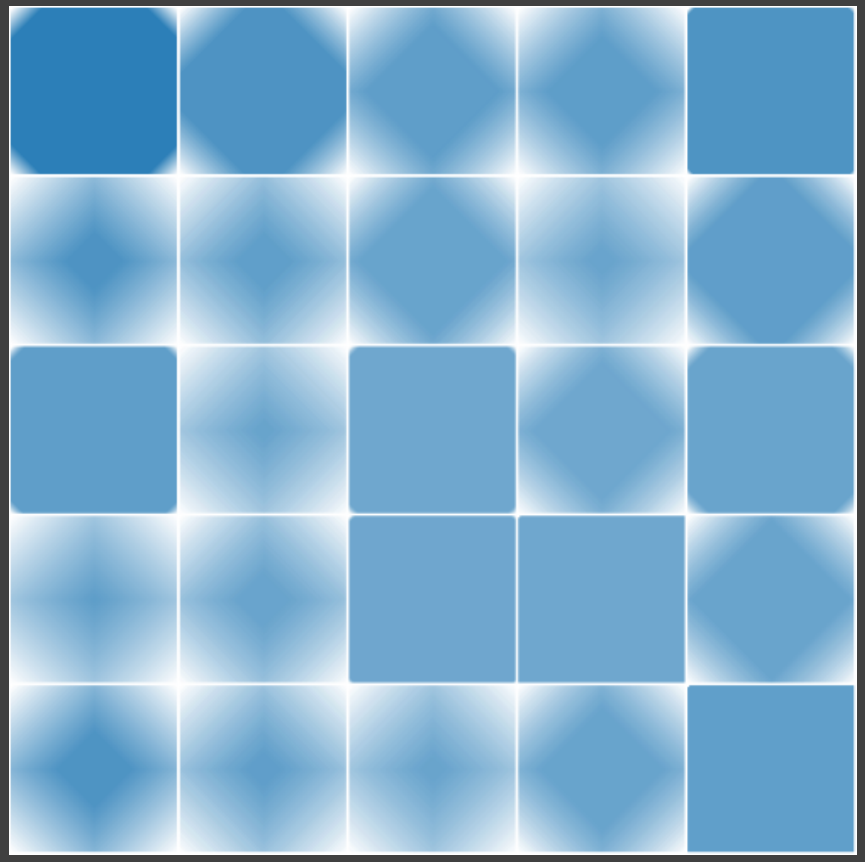


MacEachren, Alan et al. Visual Semiotics & Uncertainty Visualization: An empirical study. IEEE VIS, 2012.

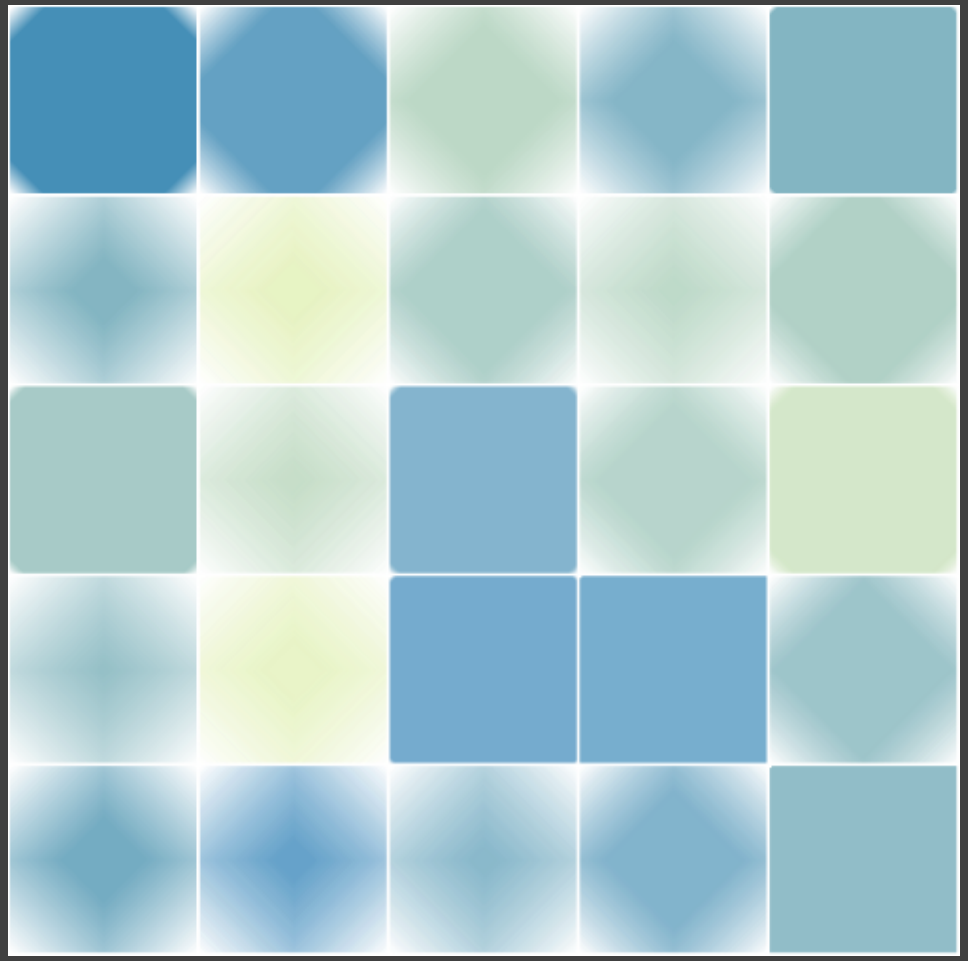

SERIES #1: GENERAL UNCERTAINTY BY VISUAL VARIABLE
fuzziness 1
location 1
value 1
arrangement 1
size 1
transparency 1
grain 1
saturation 1
saturation 2
orientation 2
size 2
transparency 2
hue 1
orientation 1
orientation 2
value 2
hue 2
shape 1
shape 2
fuzziness 2
location 2
arrangement 2
intuitiveness (logic)
7
6
5
4
3
2
1
series #1 mean
series #1 median
uncertain
certain

Fuzziness Juxtaposition

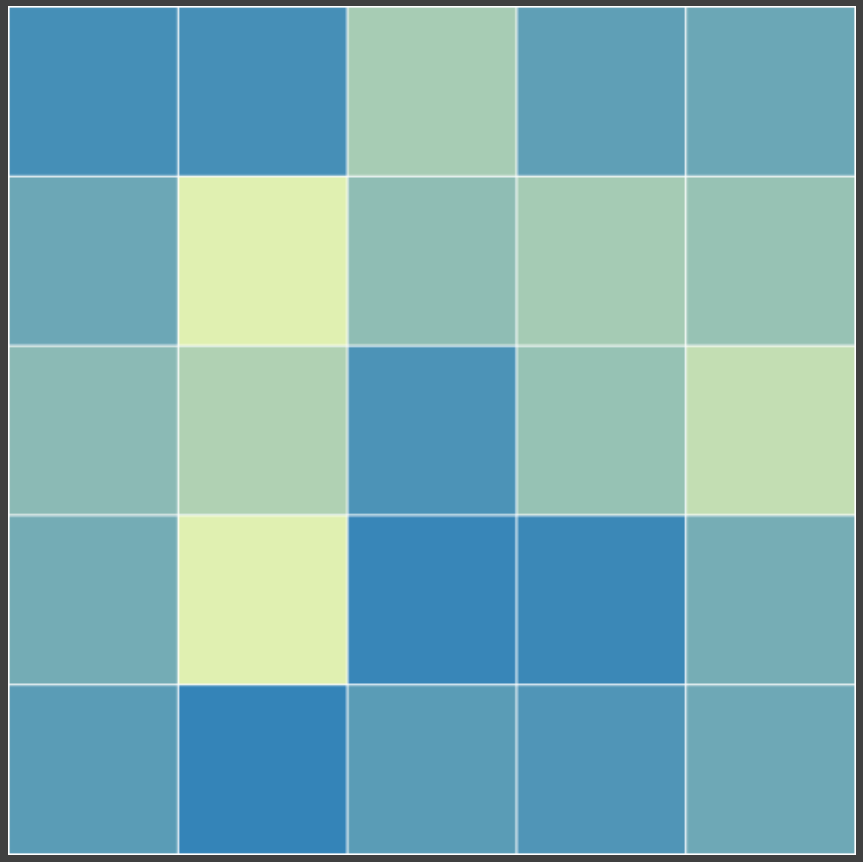


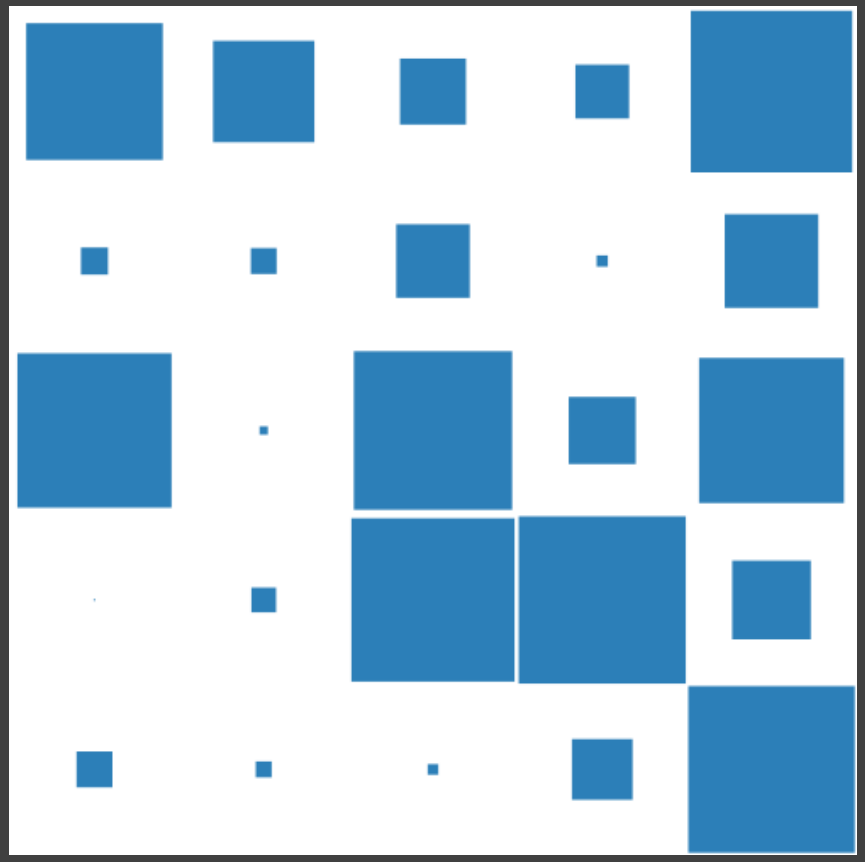


Fuzziness Superposition

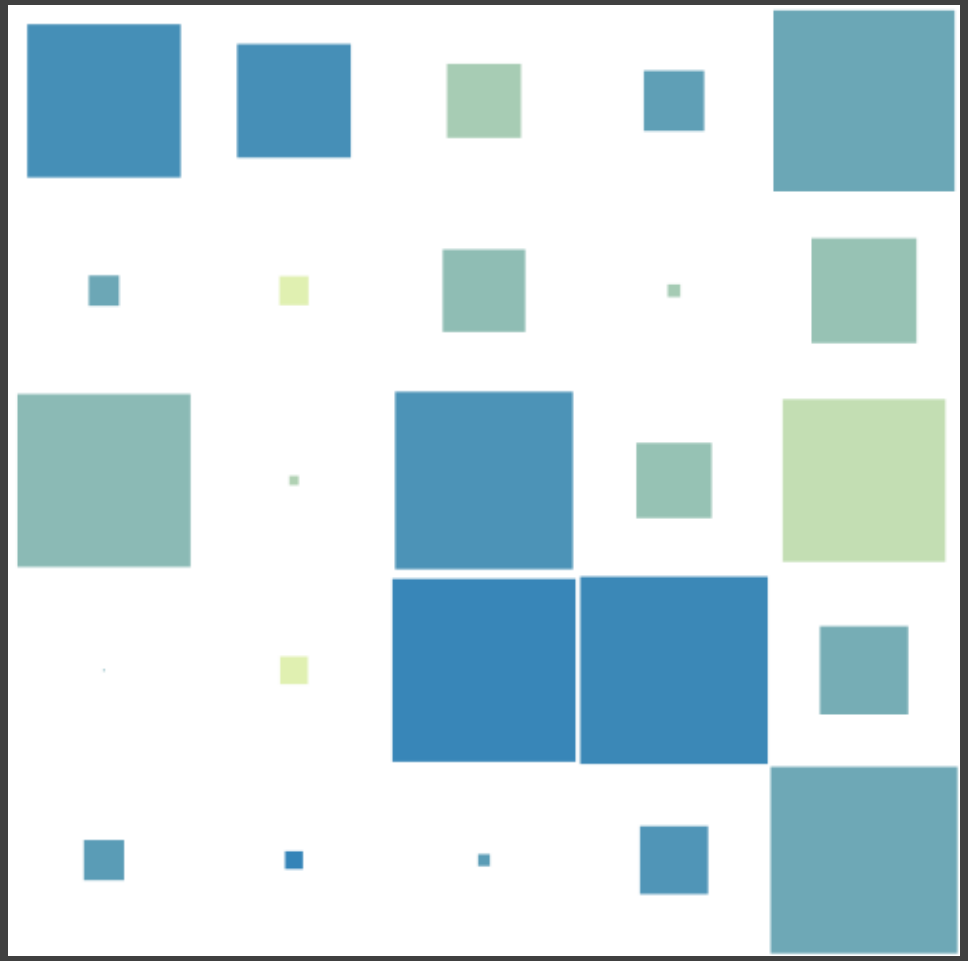


Size Juxtaposition

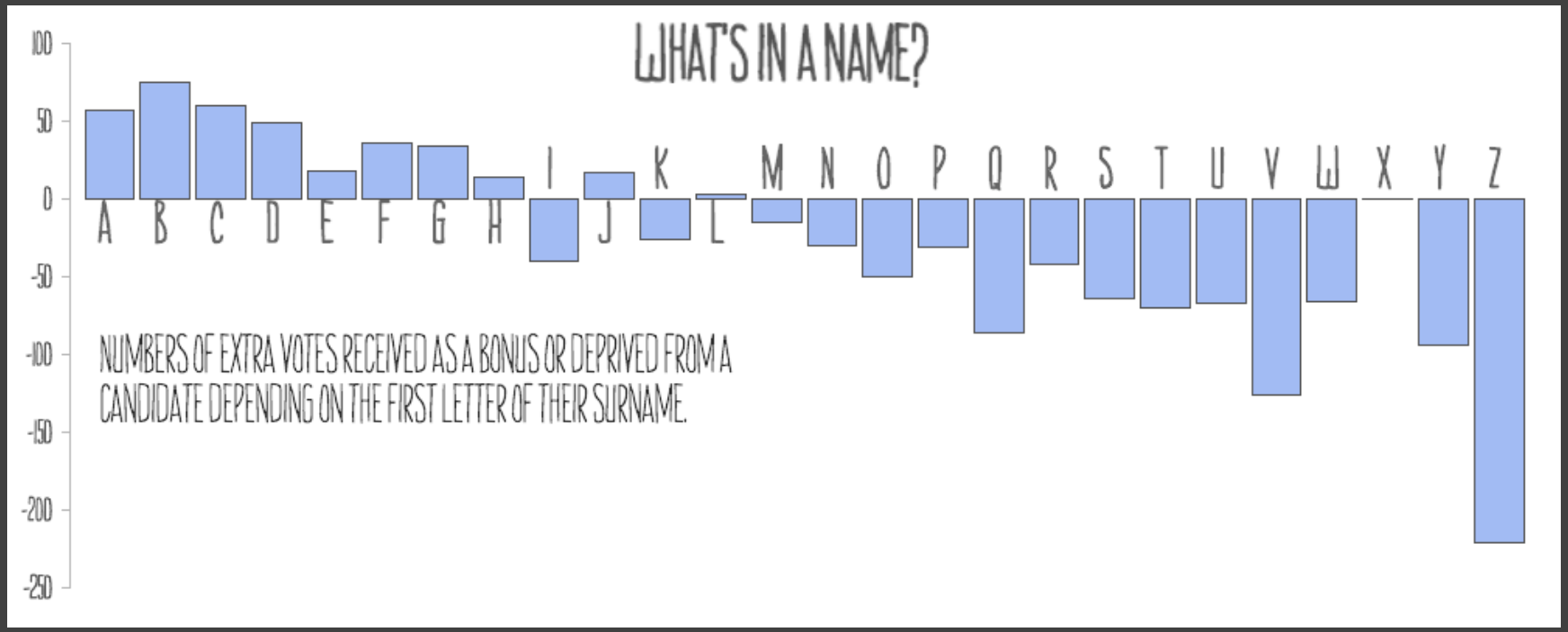




Size Superposition



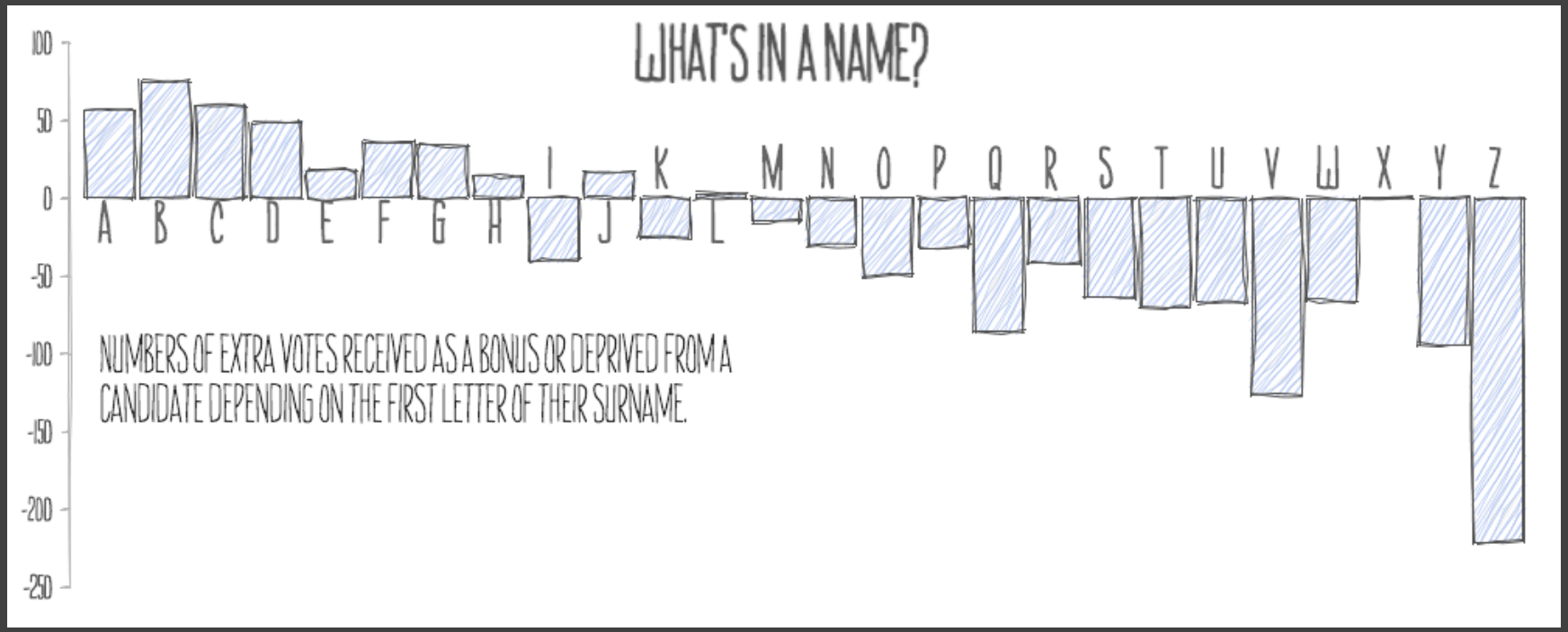
“Sketchiness”



Wood, Jo et al. Sketchy rendering for information visualization. IEEE VIS, 2012.

Boukhelifa, Nadia et al. Evaluating sketchiness as a visual variable for the depiction of qualitative uncertainty. IEEE VIS, 2012.

“Sketchiness”



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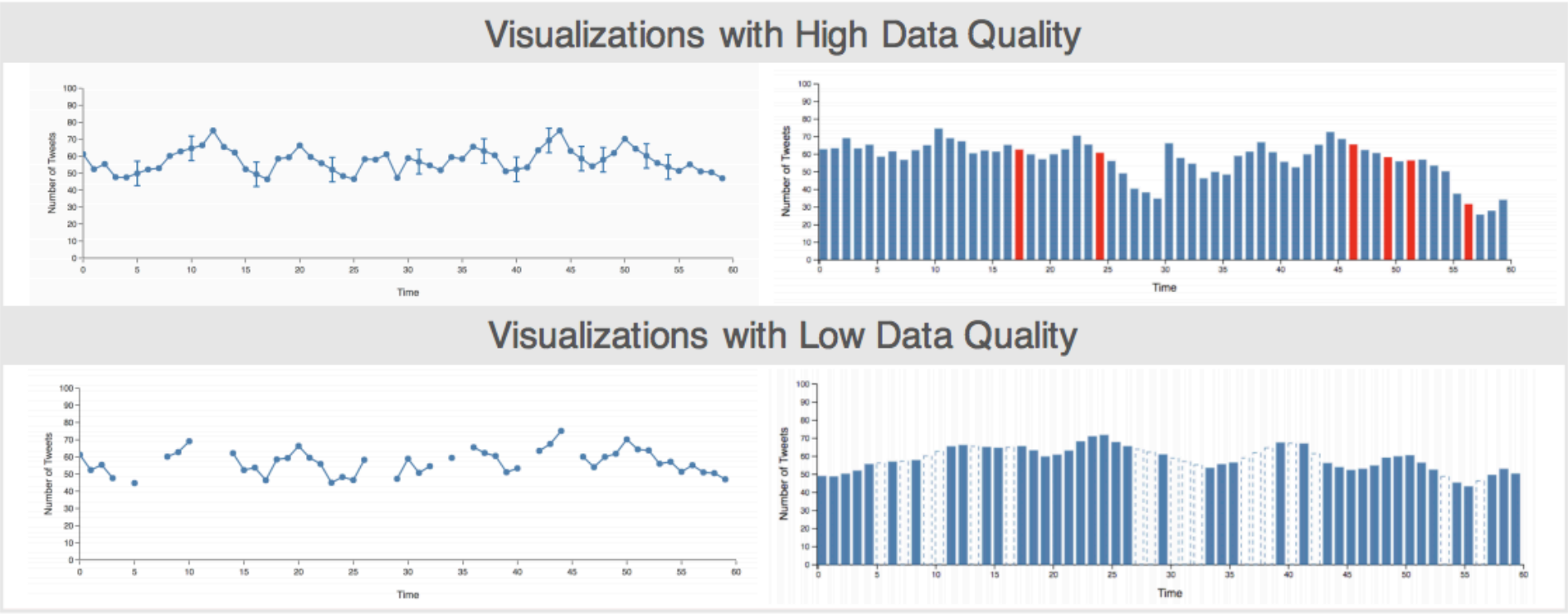
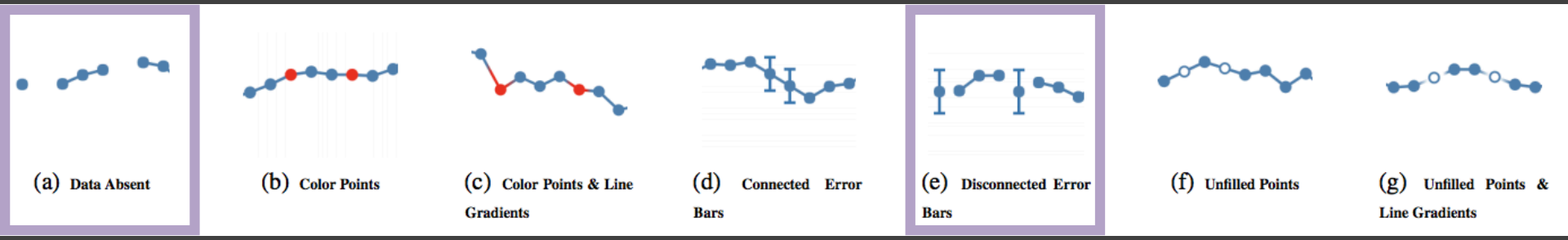
Perceived Data Quality



Song, Hayeon and Szafir, Danielle. Where's My Data? Evaluating Visualizations with Missing Data. IEEE VIS, 2018.

Perceived Data Quality



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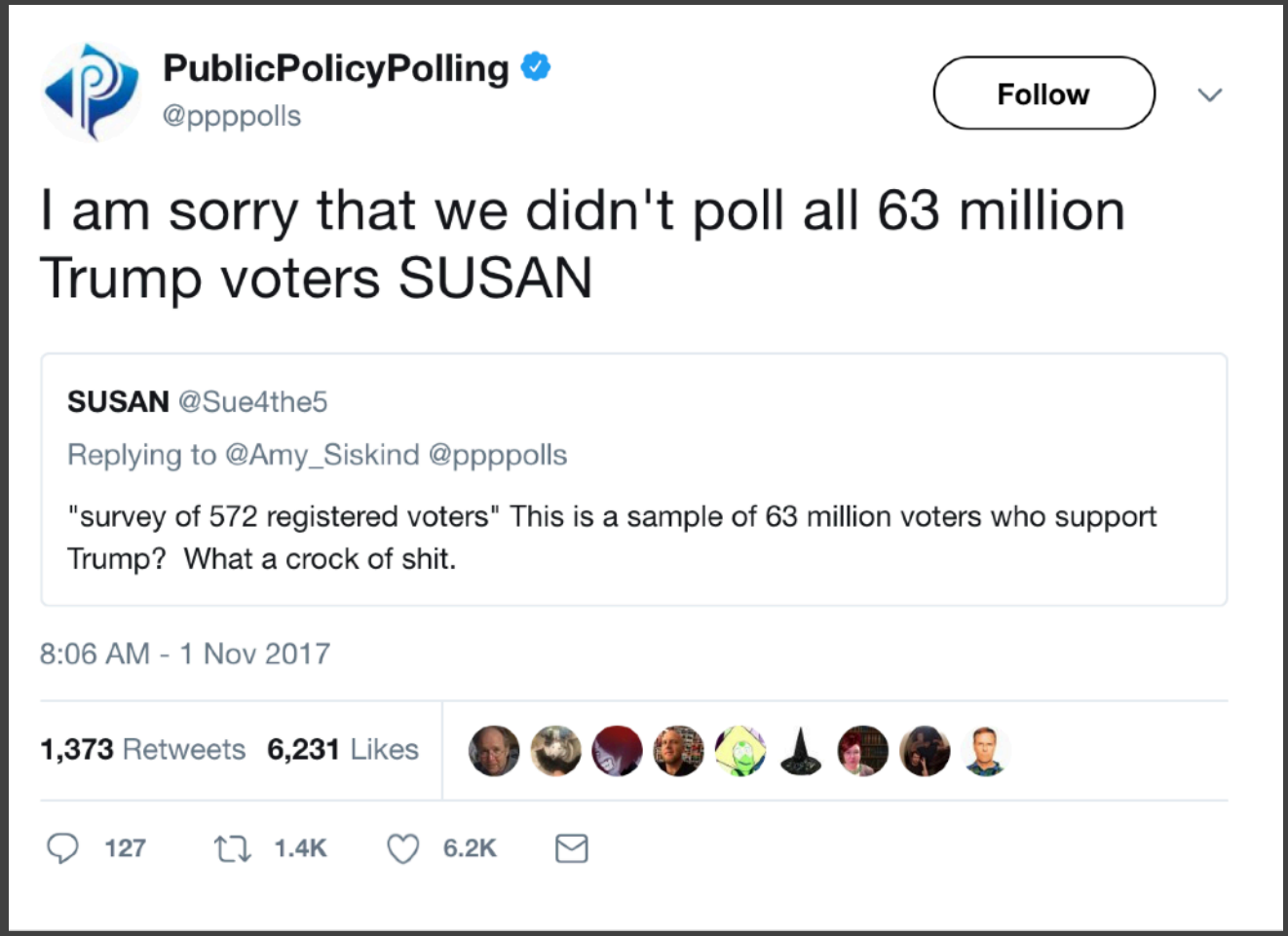
Encoding Uncertainty

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

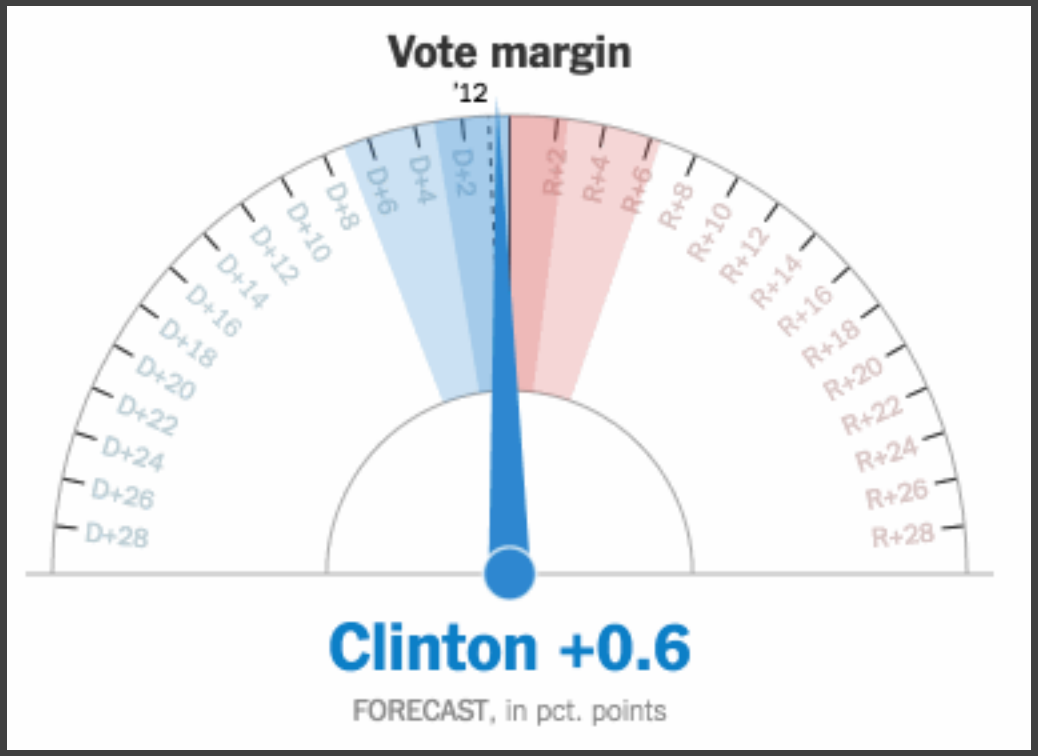
However, intuitive variables may not always be accurately interpreted!

Model Visualization

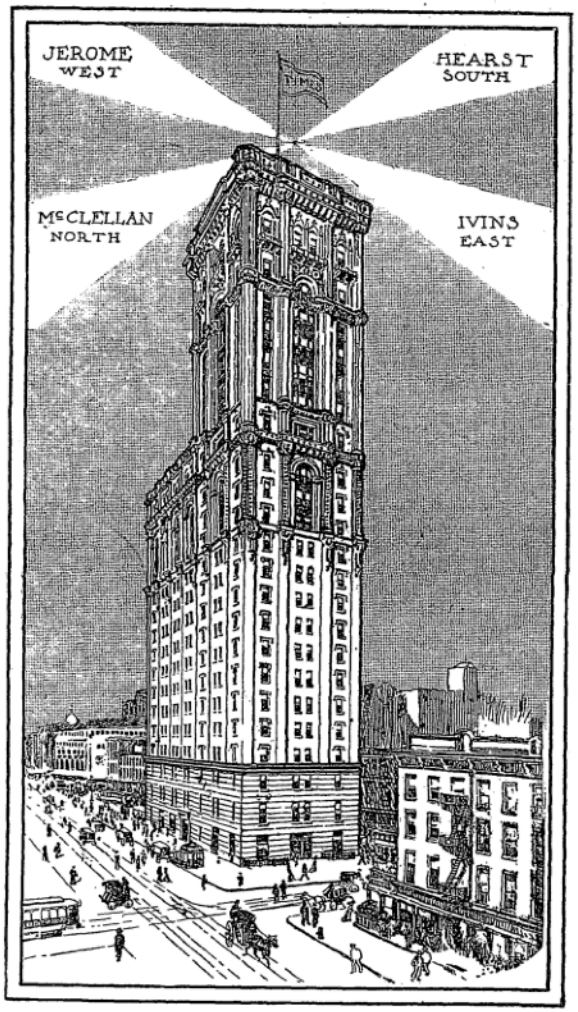
Polling Data



The NYT Needle



ELECTION RESULTS BY SEARCHLIGHT.



The Times Election Searchlight Code.

News Will Be Flashed from the Tower of The Times Building on Tuesday Night.

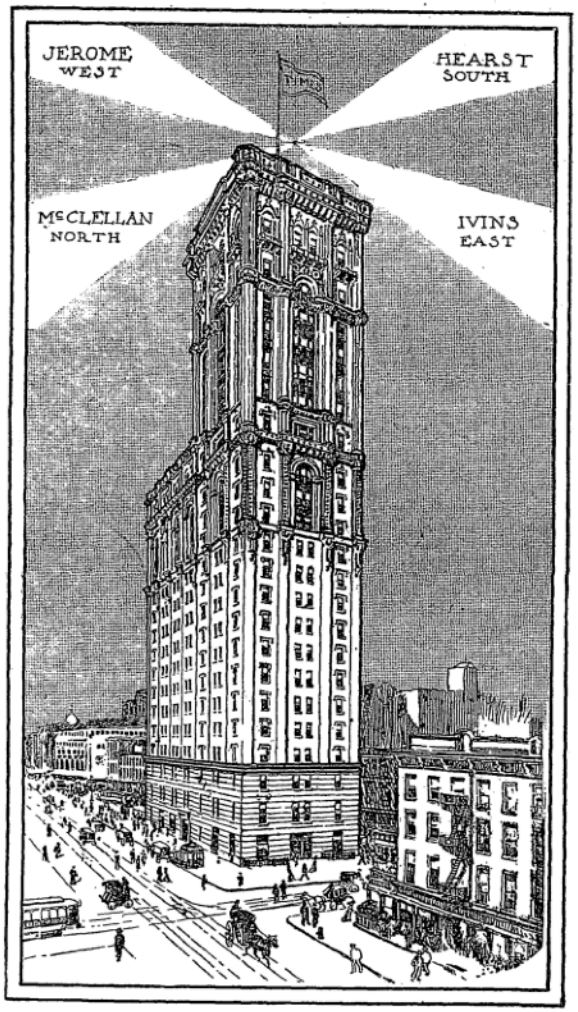
The results of the election next Tuesday night will be flashed by electric light from the tower of the Times Building, so that for miles around people will be able to tell which of the candidates has won.

This will be entirely separate and distinct from the elaborate bulletin service which THE TIMES will also maintain. To display the detailed bulletins so that the crowds can see them easily and comfortably, a stereopticon machine will be set up in the triangle north of the Times Building and the bulletins displayed on canvas stretched from the north side of the building. There will be a similar service at the Harlem office of THE TIMES, 129 West 125th Street.

The electric signals from the tower of the Times Building will be flashed from a point 365 feet above the street level. A steady light to the north will show that McClellan has been elected; a steady light to the east will indicate Ivins's election, and a steady light to the south will indicate that Hearst has won.

Jerome's election will be indicated by a steady light to the west. A light to the north, waving from east to west, will indicate Osborne's election. A light to the south, waving from east to west, will indicate Shearn's election.

ELECTION RESULTS BY SEARCHLIGHT.



The Times Election Searchlight Code.

News Will Be Flashed from the Tower of The Times Building on Tuesday Night.

The results of the election next Tuesday night will be flashed by electric light from the tower of the Times Building, so that for miles around people will be able to tell which of the candidates has won.

This will be entirely separate and distinct from the elaborate bulletin service which THE TIMES will also maintain. To display the detailed bulletins so that the crowds can see them easily and comfortably, a stereopticon machine will be set up in the triangle north of the Times Building and the bulletins displayed on canvas stretched from the north side of the building. There will be a similar service at the Harlem office of THE TIMES, 129 West 125th Street.

The electric signals from the tower of the Times Building will be flashed from a point 365 feet above the street level. A steady light to the north will show that McClellan has been elected; a steady light to the east will indicate Ivins's election, and a steady light to the south will indicate that Hearst has won.

Jerome's election will be indicated by a steady light to the west. A light to the north, waving from east to west, will indicate Osborne's election. A light to the south, waving from east to west, will indicate Shearn's election.

Election Bulletins
BY BOMBS.

TUESDAY NIGHT
THE TRIBUNE
will send up from the roof of the
GREAT NORTHERN HOTEL

hourly, shells containing blue and red stars—exactly on the hour—at 7, 8, 9, 10, 11 p. m. 12 midnight, 1 and 2 a. m. Wednesday morning, unless election is decided earlier, in which case twelve bombs will be sent up in rapid succession. Blue to indicate McKinley's election. Red to indicate Bryan's election.

SIX BOMBS EVERY HOUR.

The first bomb sent up, if blue, indicates the returns in **COOK COUNTY** at that hour are favorable to McKinley; if red, favorable to Bryan.

After sixty seconds two bombs will be sent up in rapid succession, and will indicate, if blue, that returns from **ILLINOIS** favor McKinley; if red, Bryan.

After sixty seconds more three bombs will be sent up in rapid succession, and if blue will indicate that at that hour returns from the **entire country** favor McKinley; if red, Bryan. Each bomb bursts high in the air, scattering a shower of stars.

Polling Data

Candidate A is ahead of Candidate B in the polls, with 55% of the likely voters*

Polling Data

Candidate A is ahead of Candidate B in the polls, with 55% of the likely voters*

*poll of 100 people, margin of error +/-5

Monte Carlo Approach

Candidate A is ahead of
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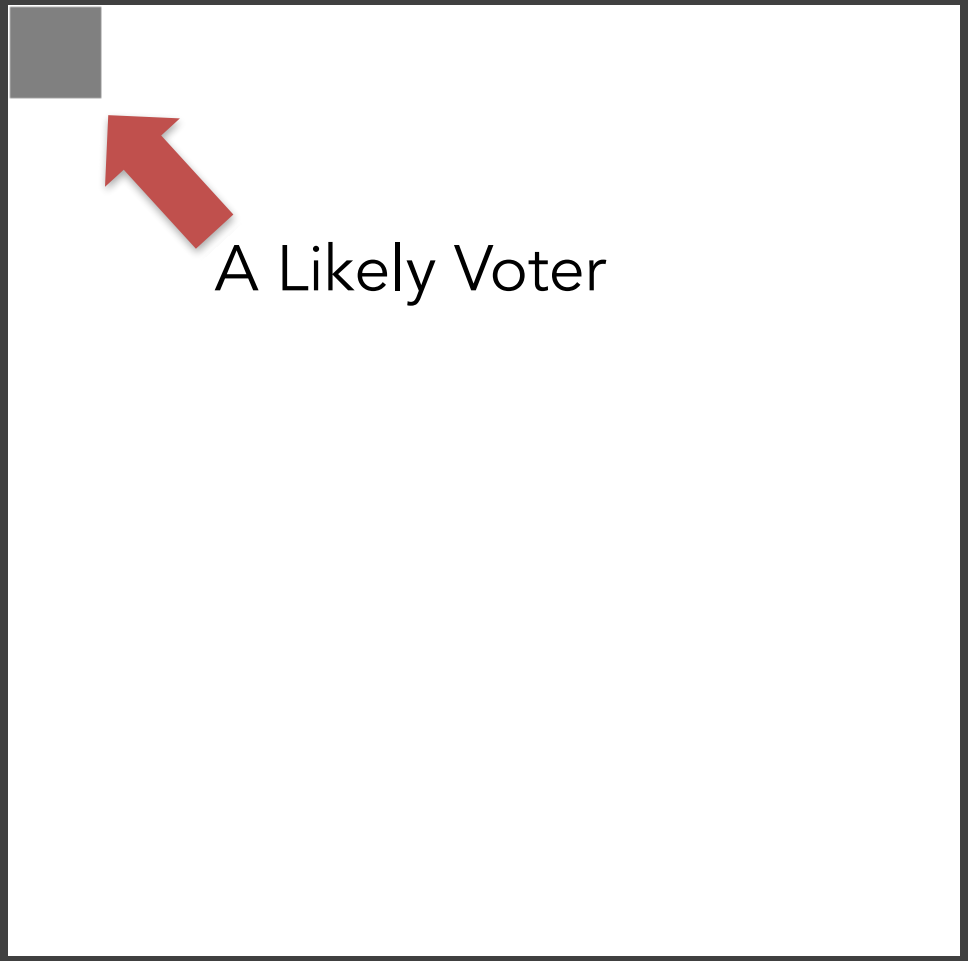
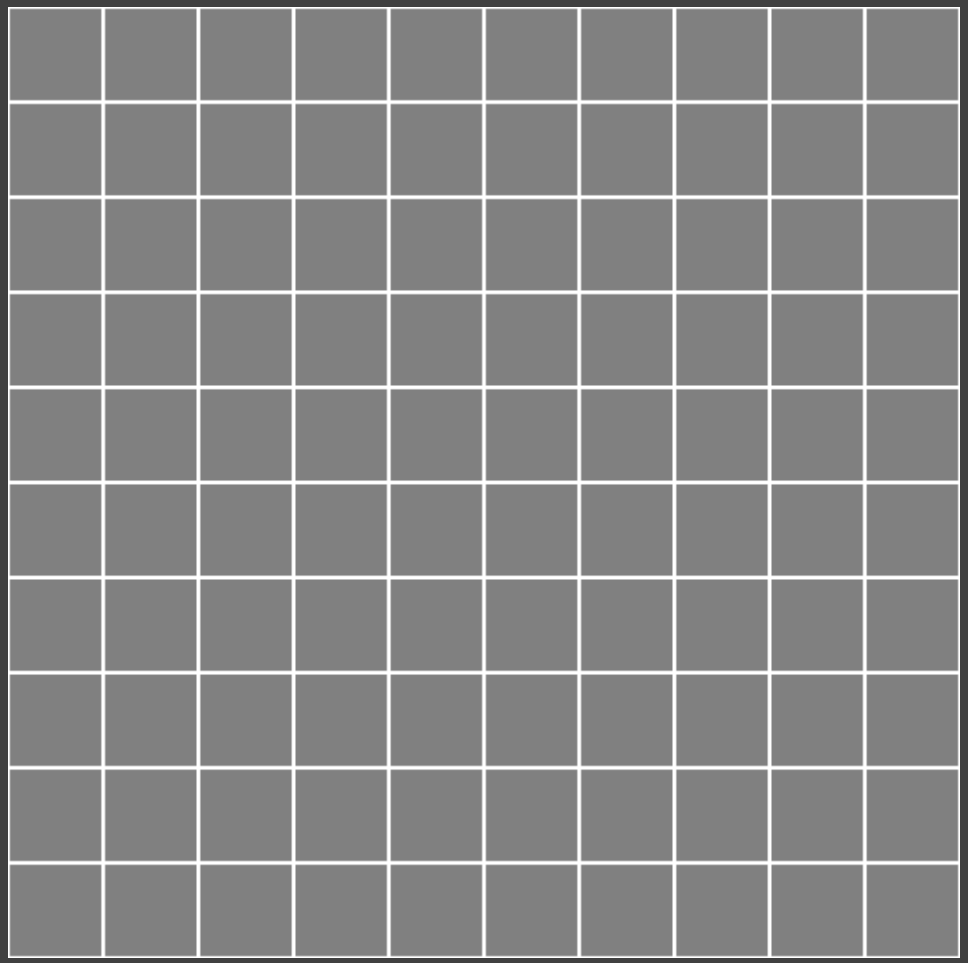
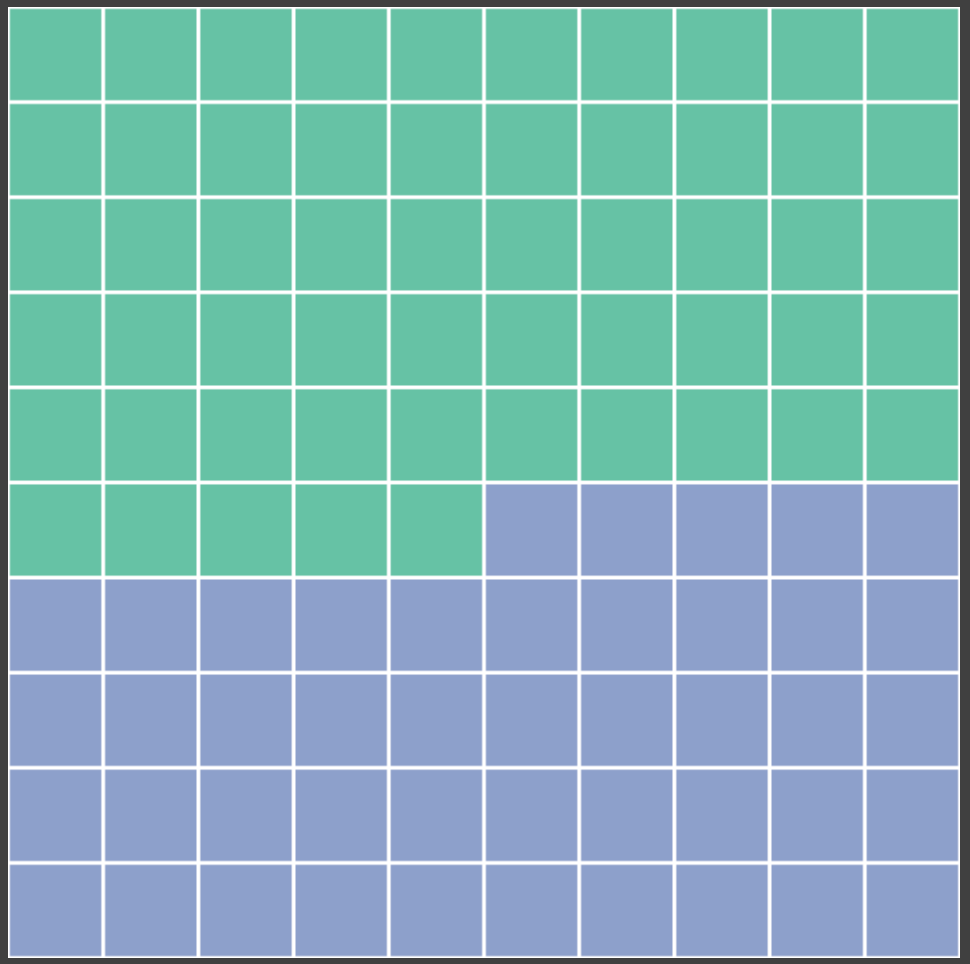
with 55% of the likely
voters*

*poll of 100 people,
margin of error +/-5

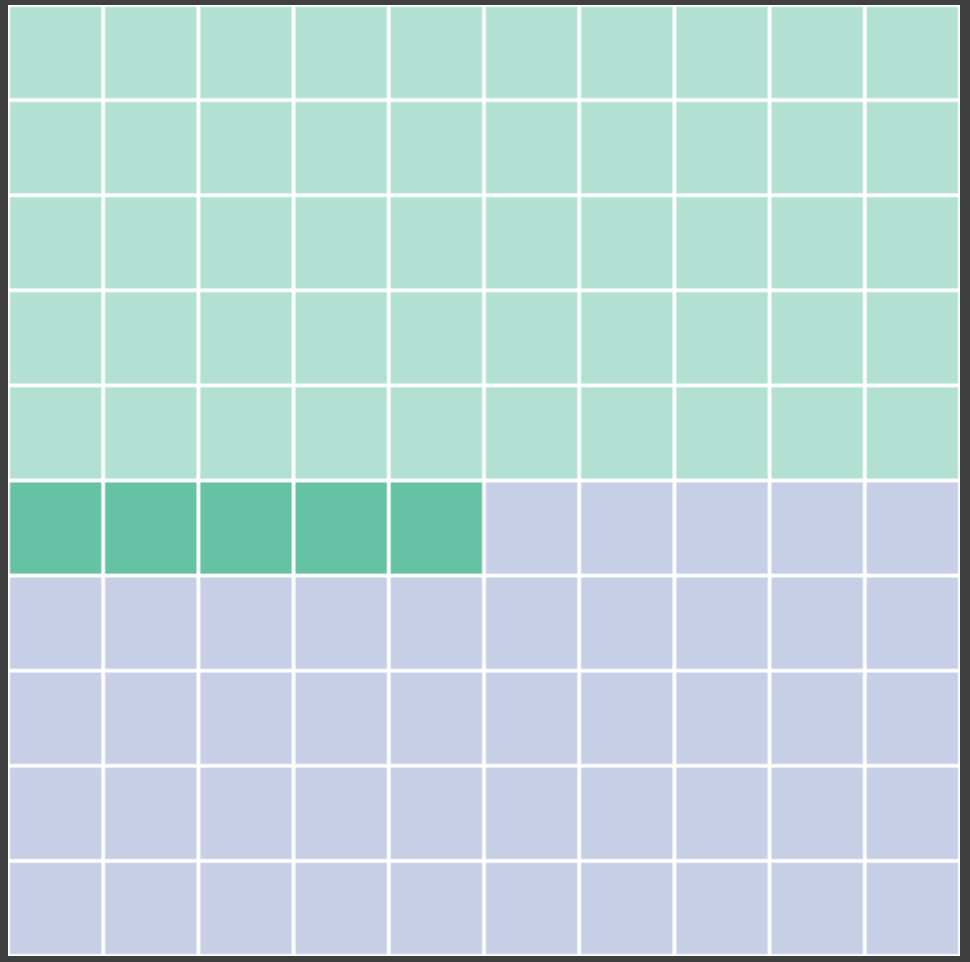

A Likely Voter



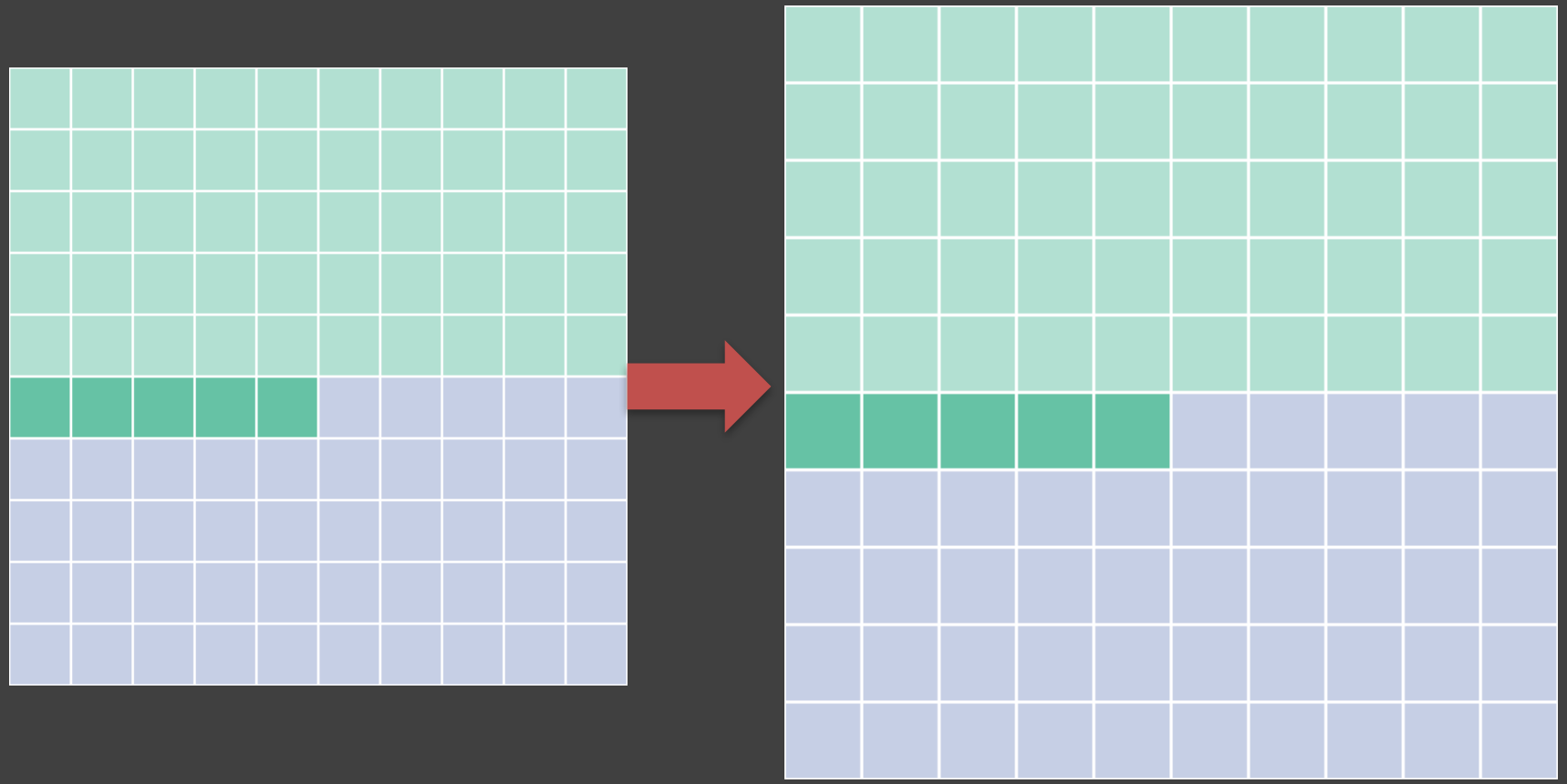
Poll



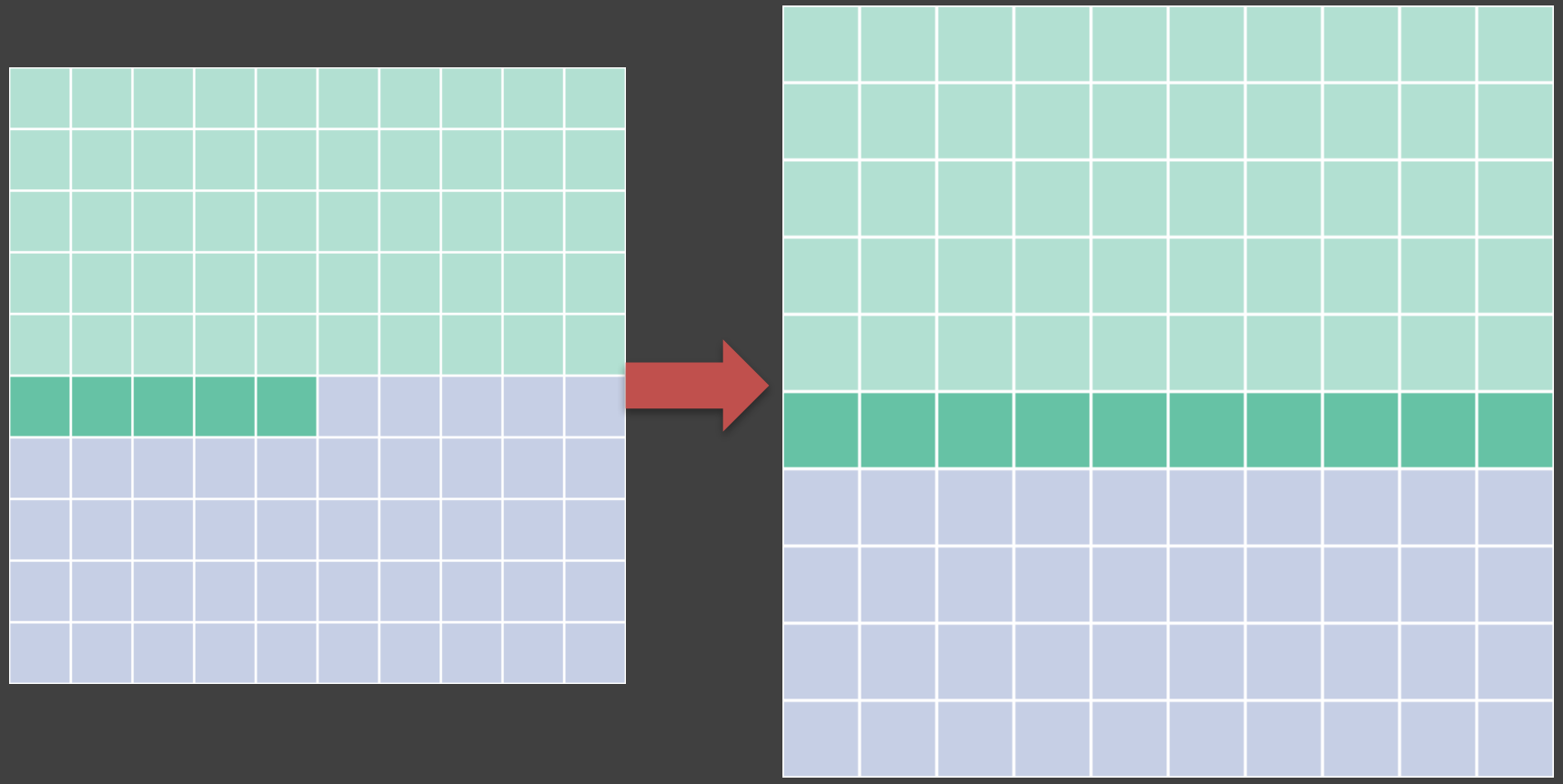
Poll



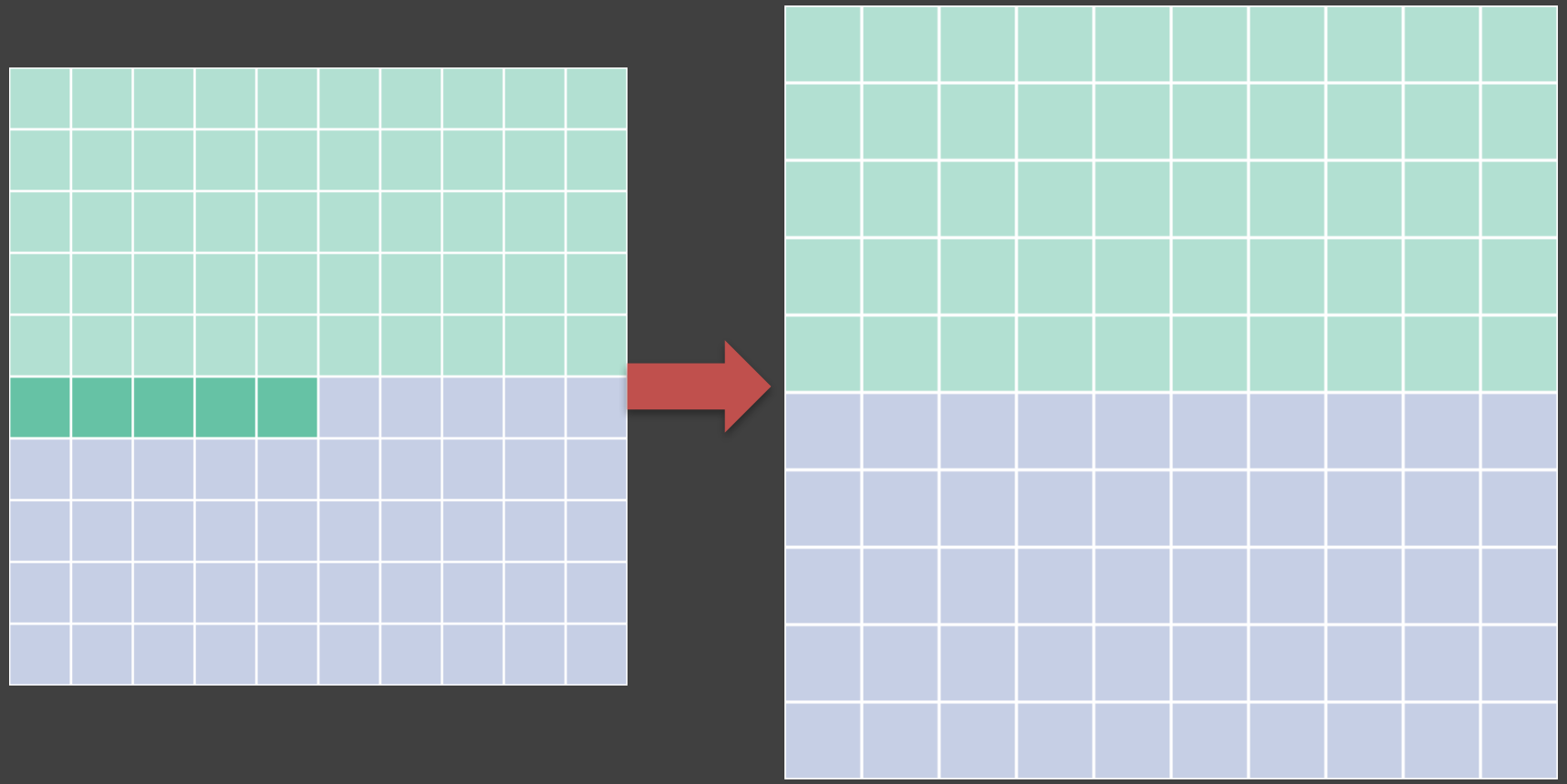
Actual Election?



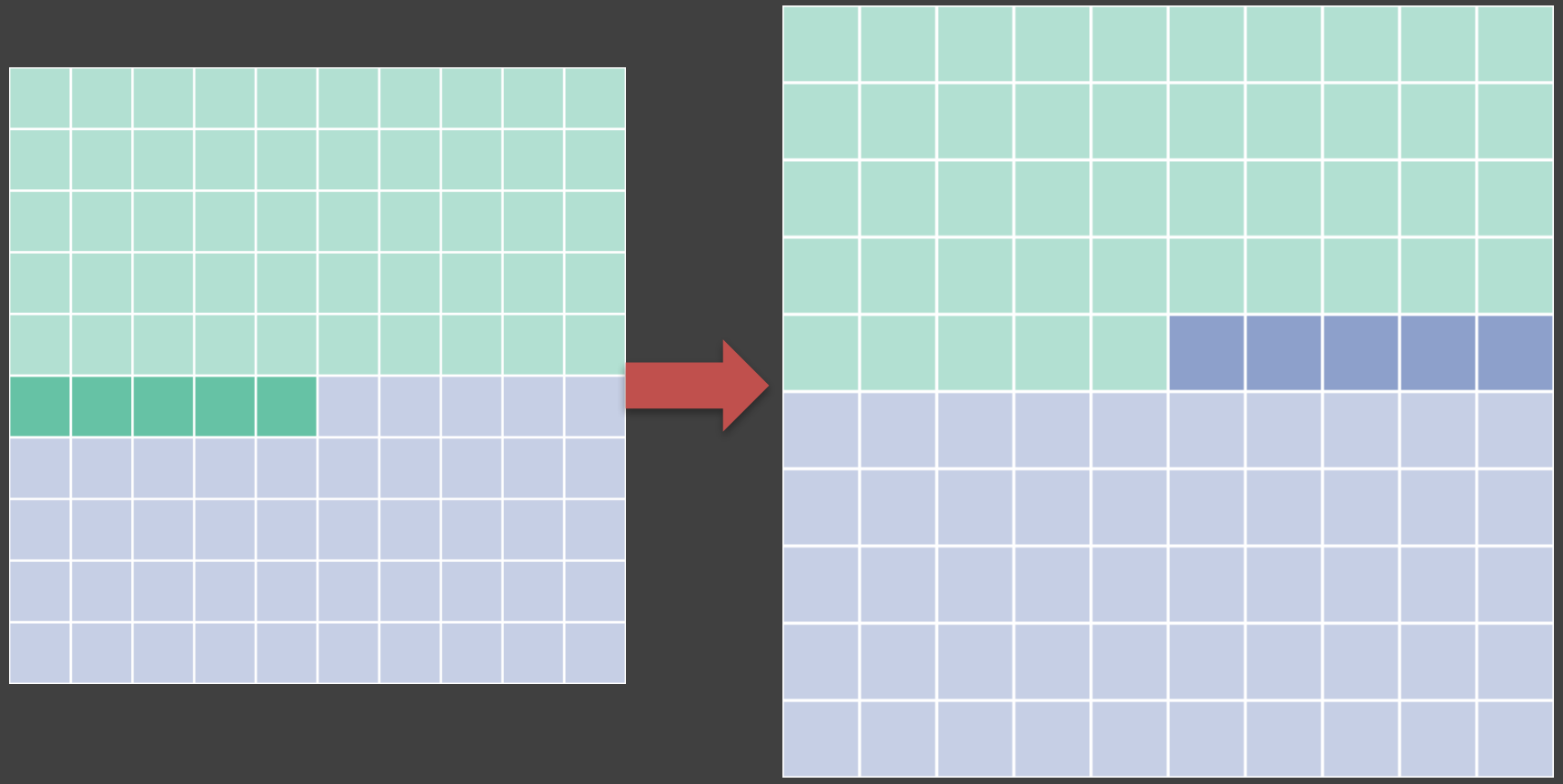
Actual Election?

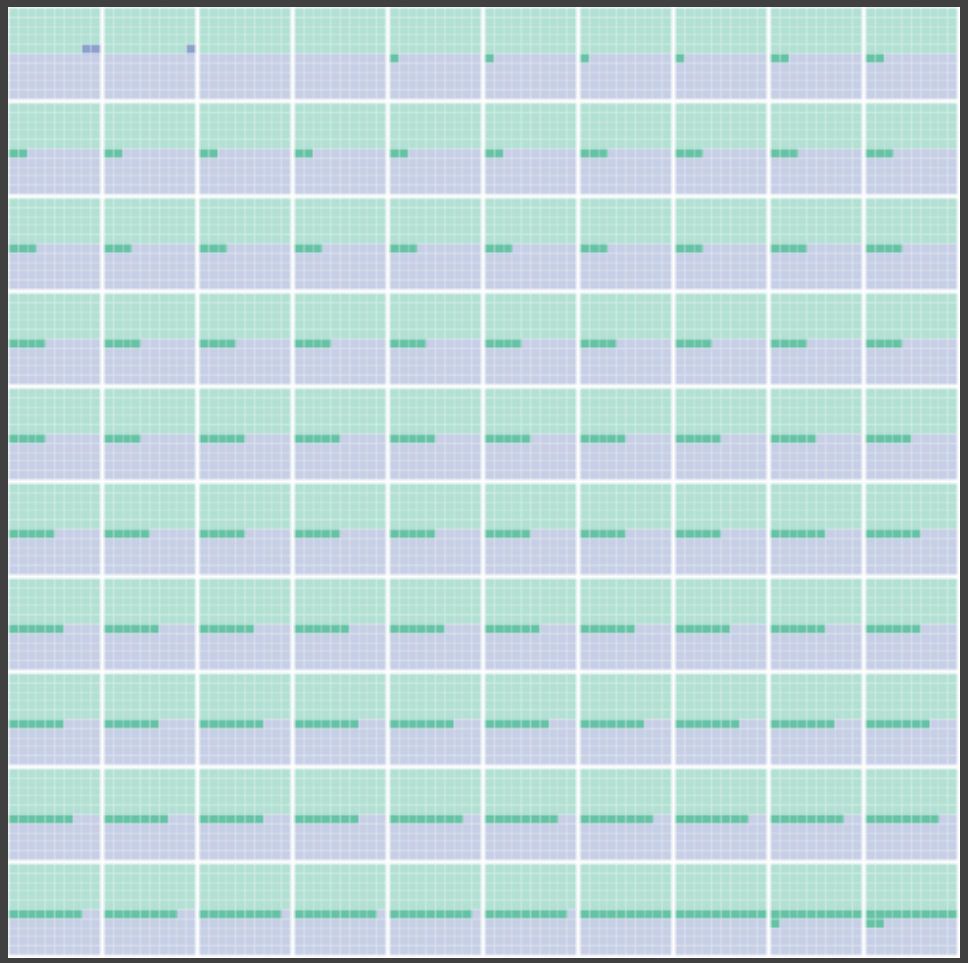


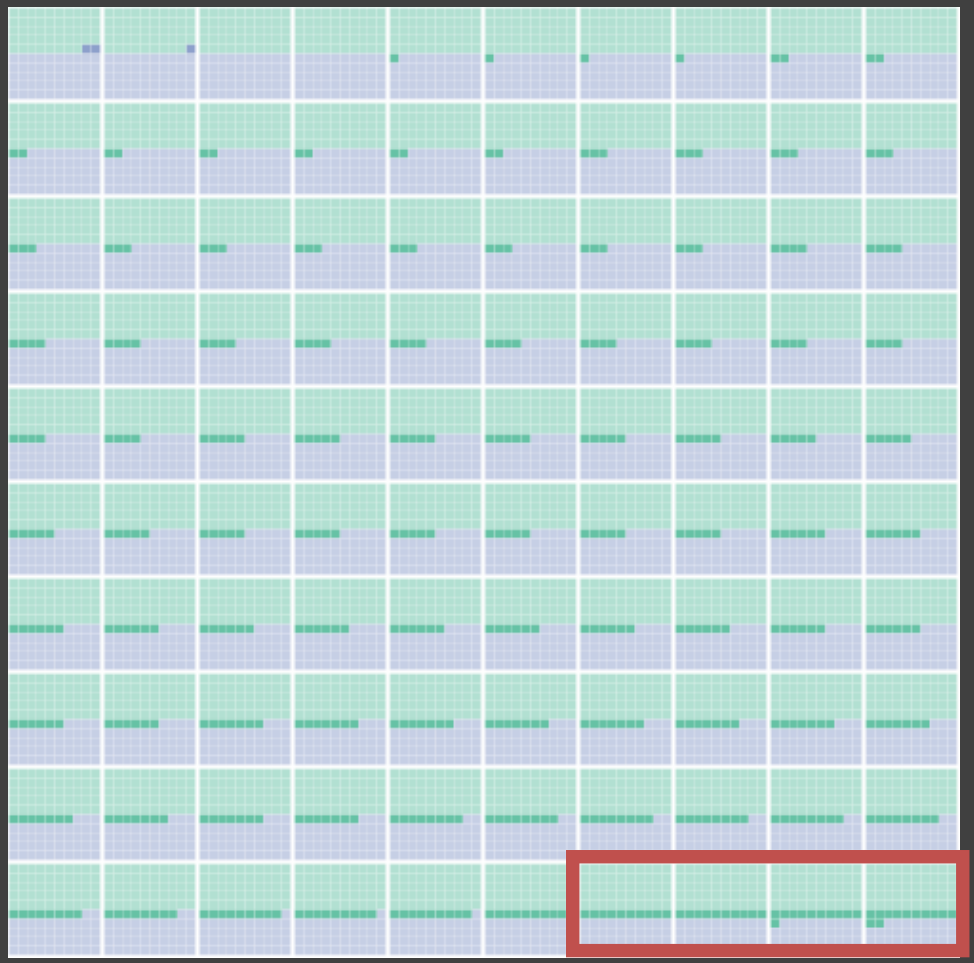
Actual Election?

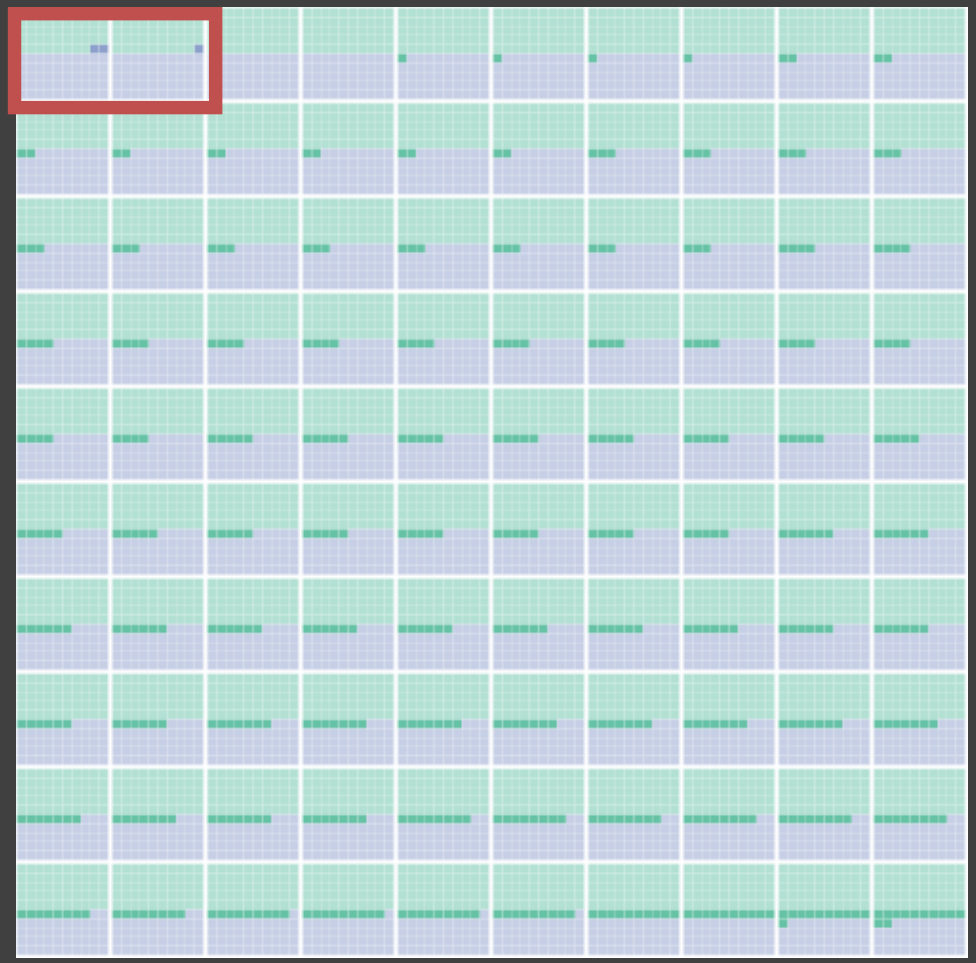


Actual Election?



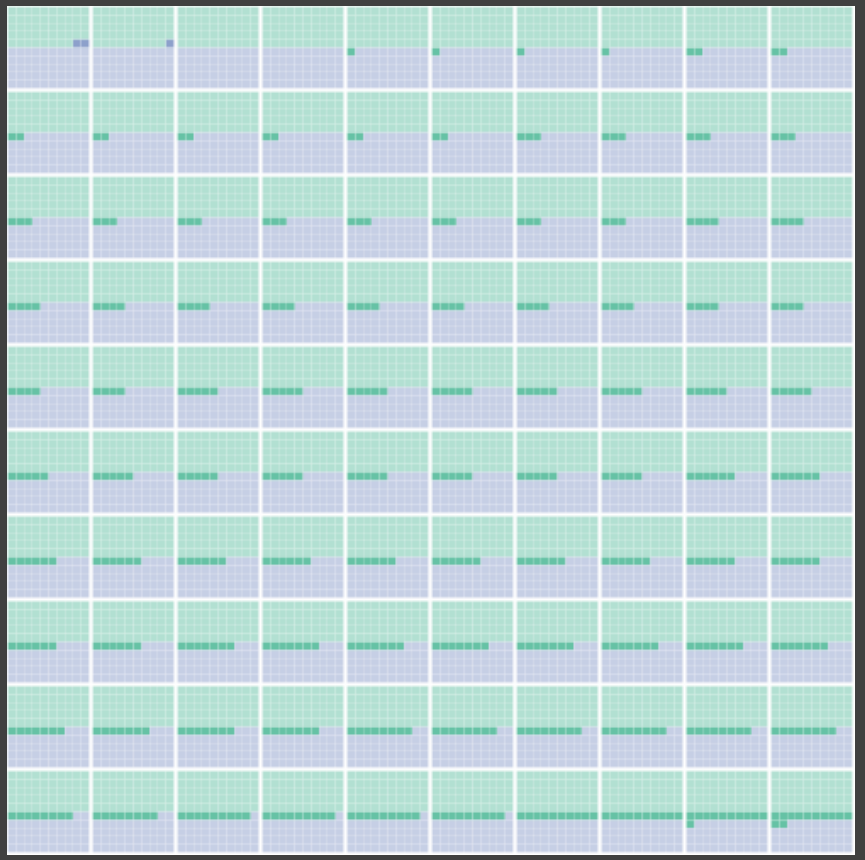






Pangloss Plot

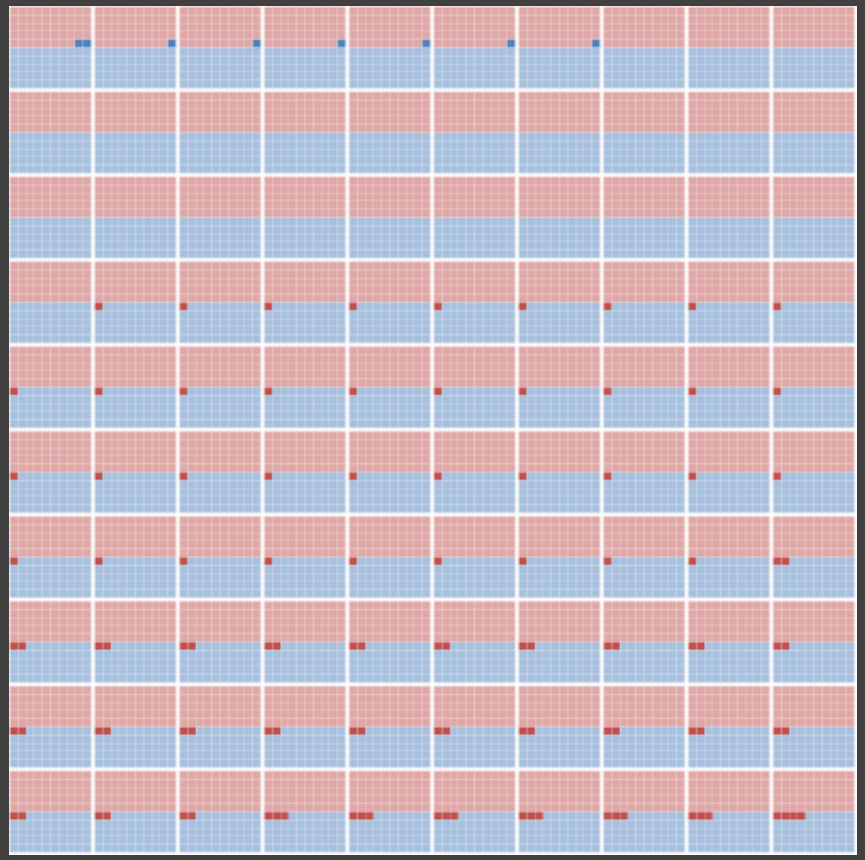
Candidate A is ahead of Candidate B in the polls, with 55% of the likely voters*



*poll of 100 people, margin of error +/-5

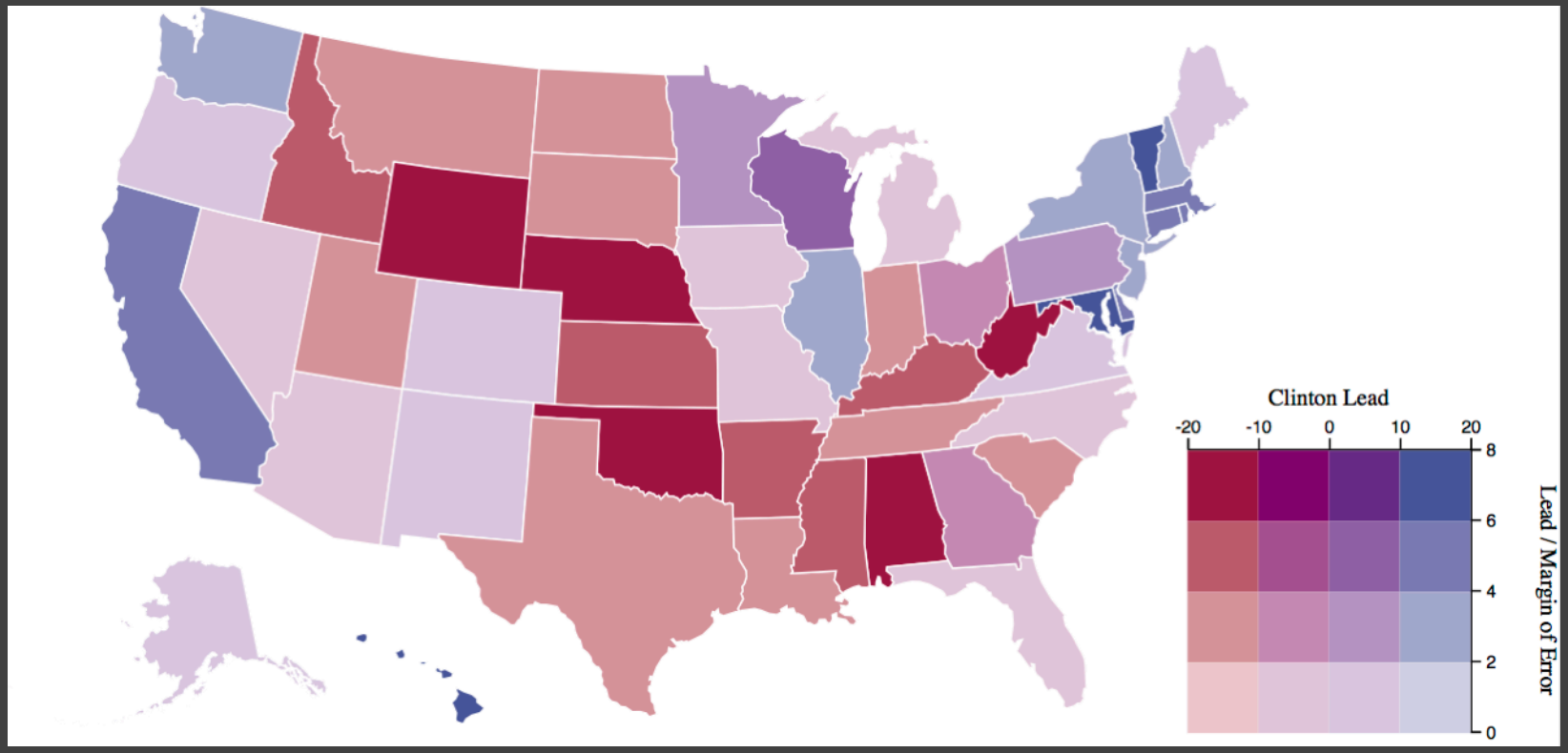
Pangloss Plot

Romney is ahead of Obama in the polls, with 51% of the likely voters*

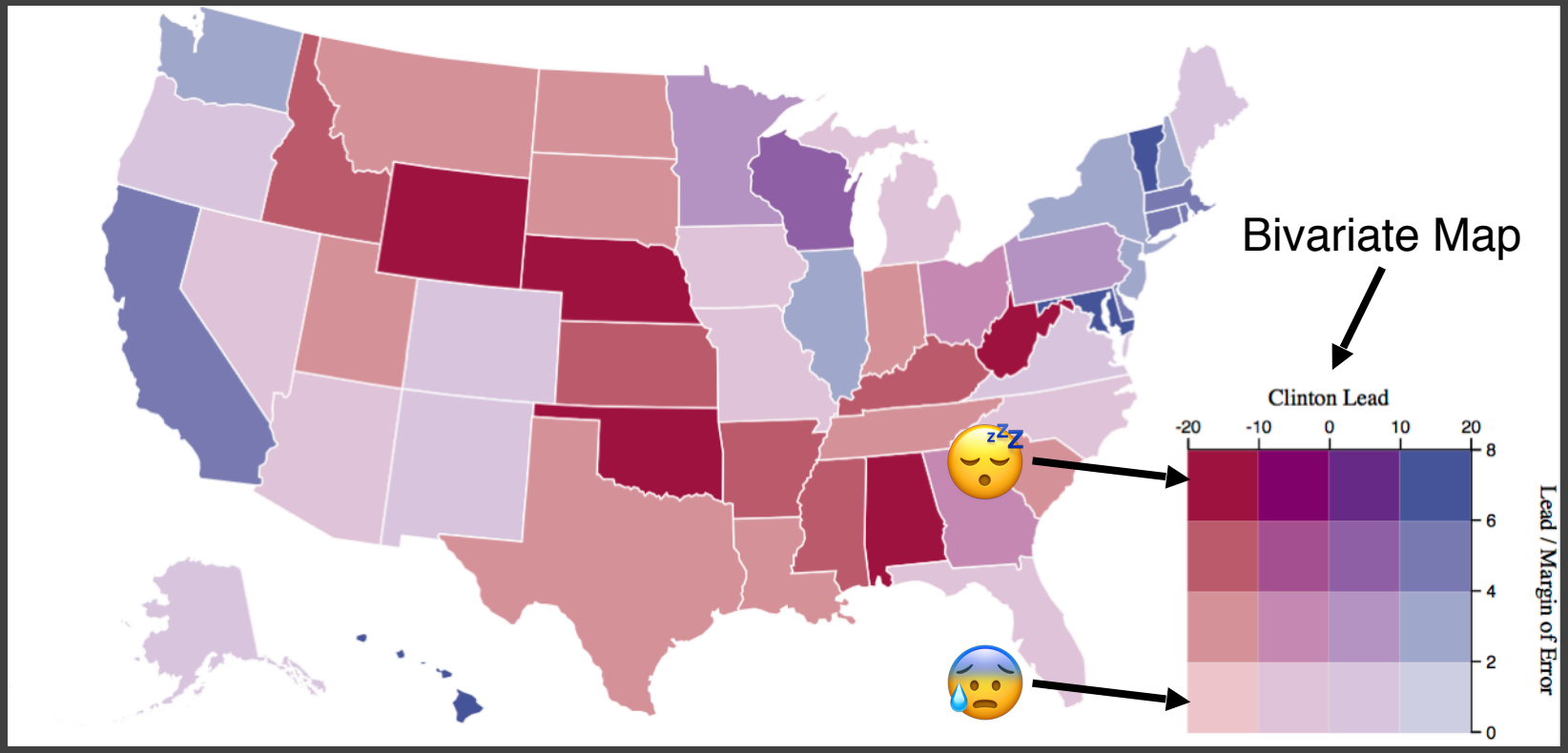


*poll of 3,117 people, margin of error +/-2

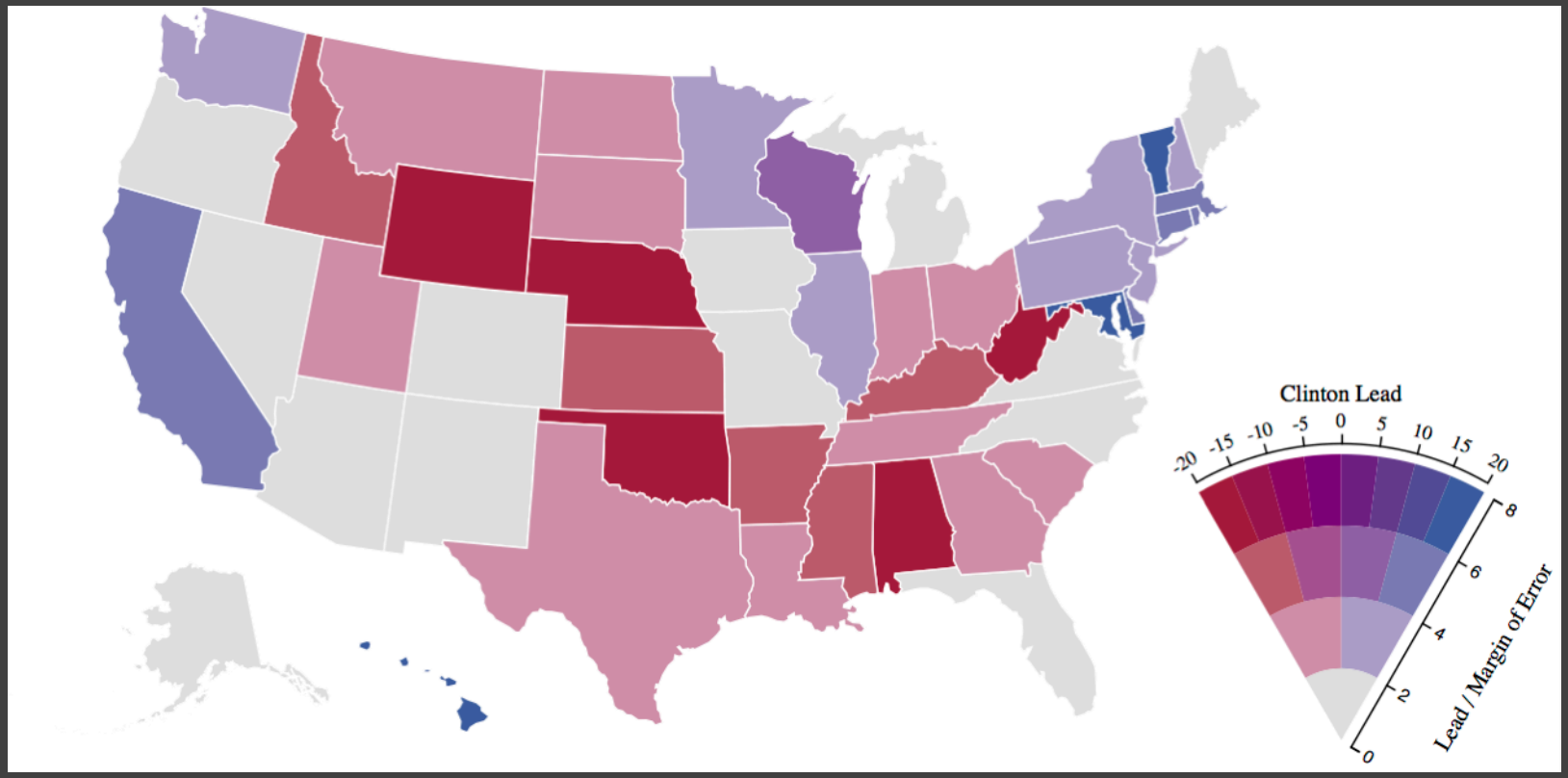
Value-Suppressing Uncertainty Palette



Bivariate Map

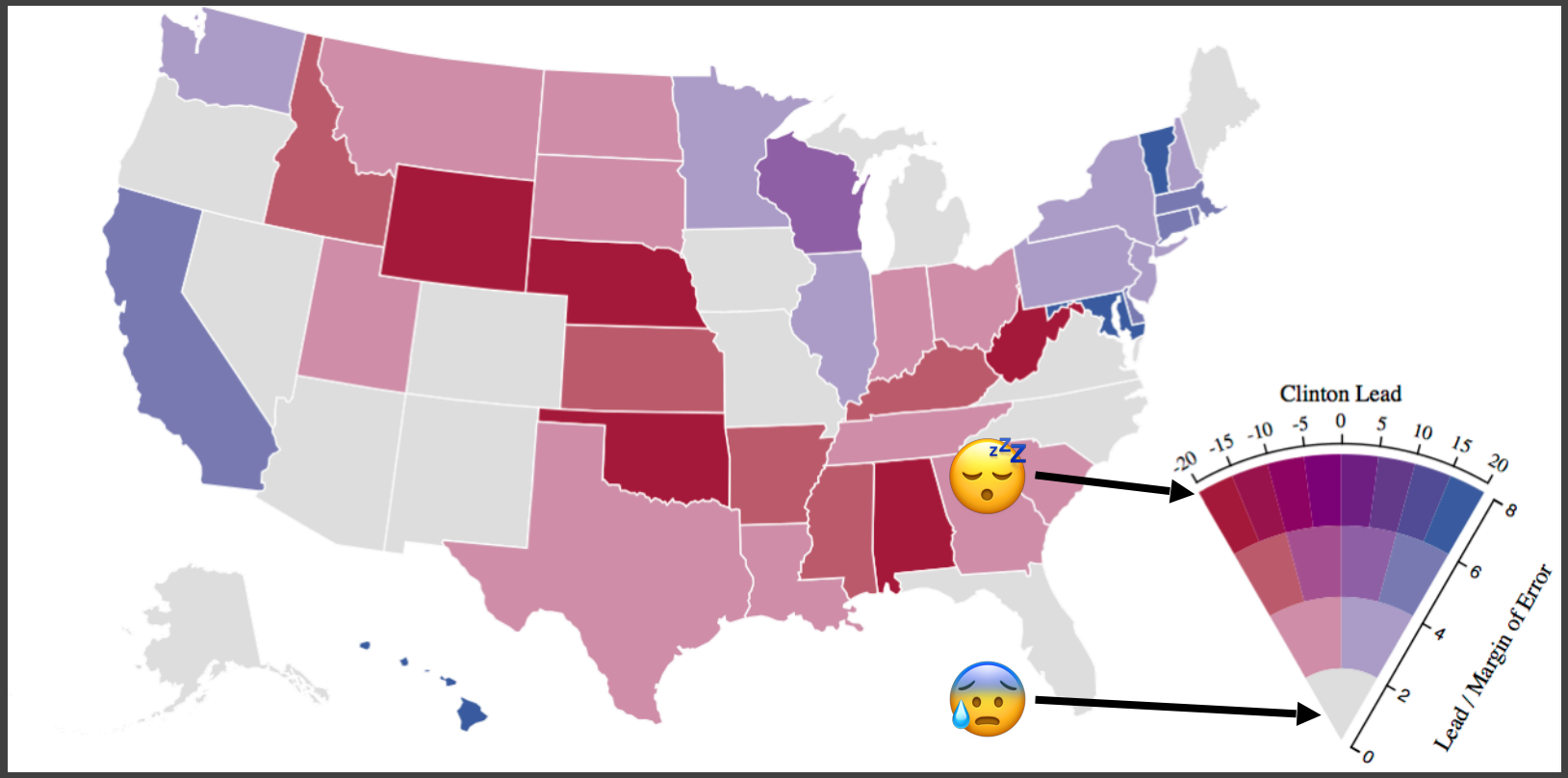


Value-Suppressing Uncertainty Palette



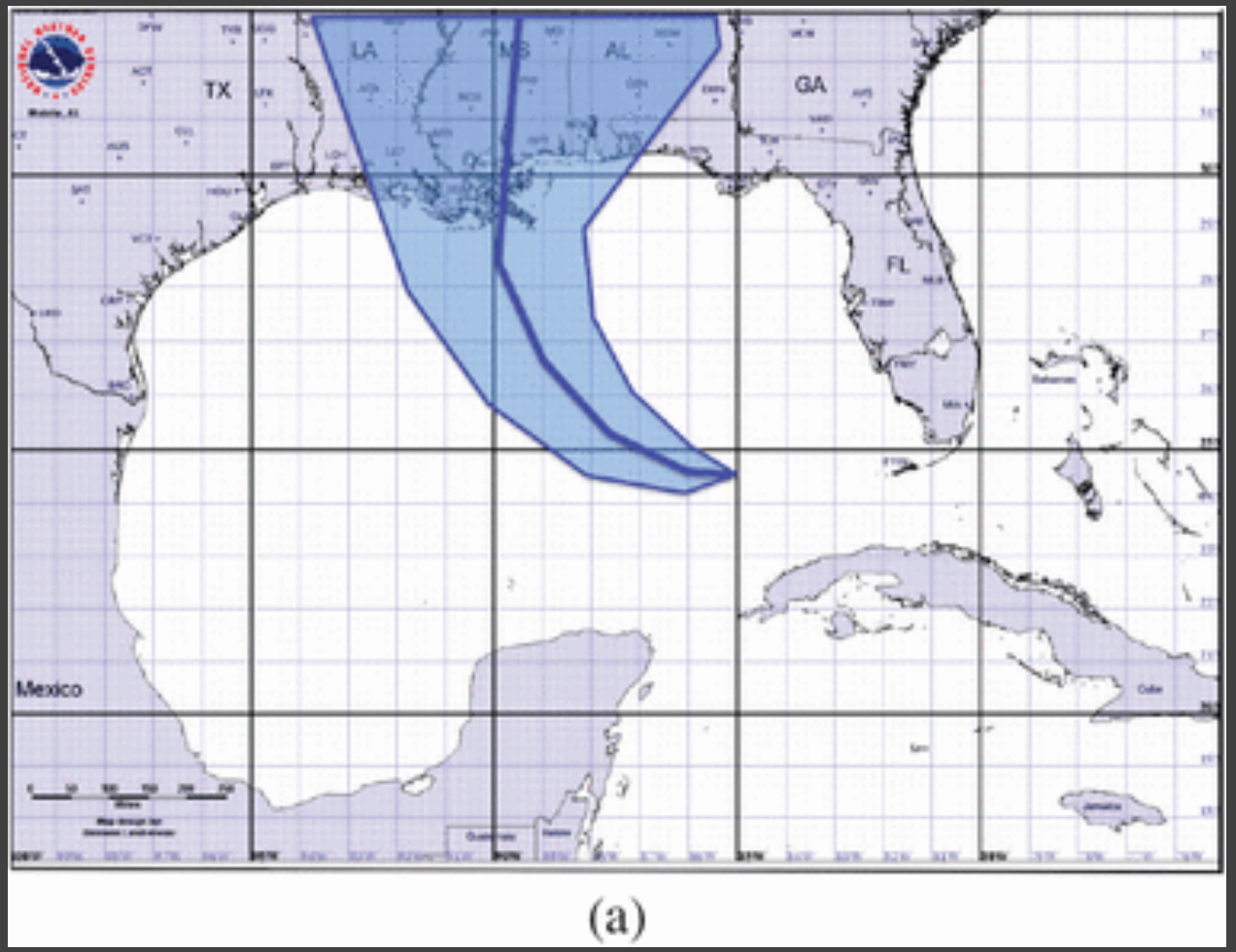
Correll et al. “Value-Suppressing Uncertainty Palettes.” CHI 2018.

Value-Suppressing Uncertainty Palette



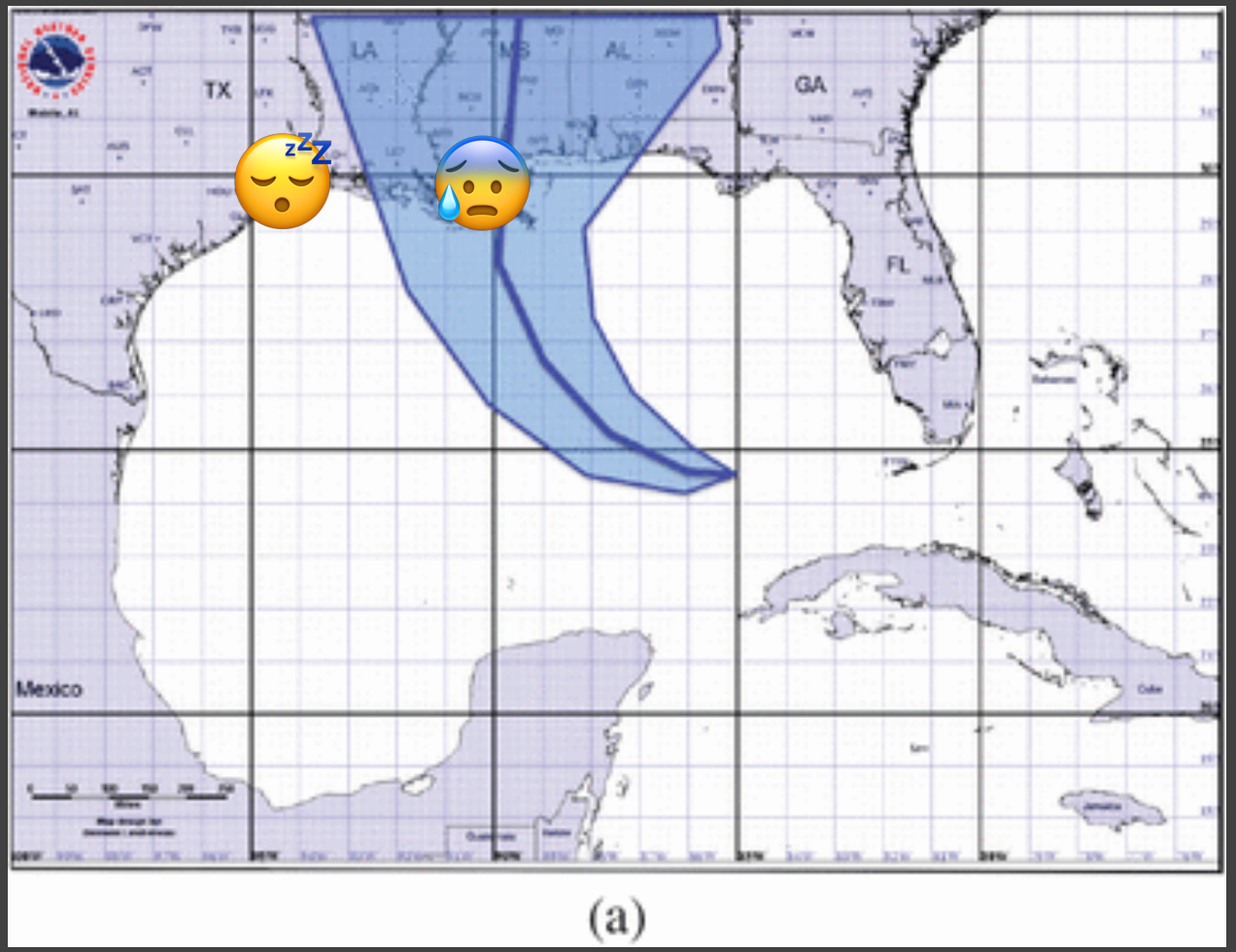
Correll et al. “Value-Suppressing Uncertainty Palettes.” CHI 2018.

Model Visualization



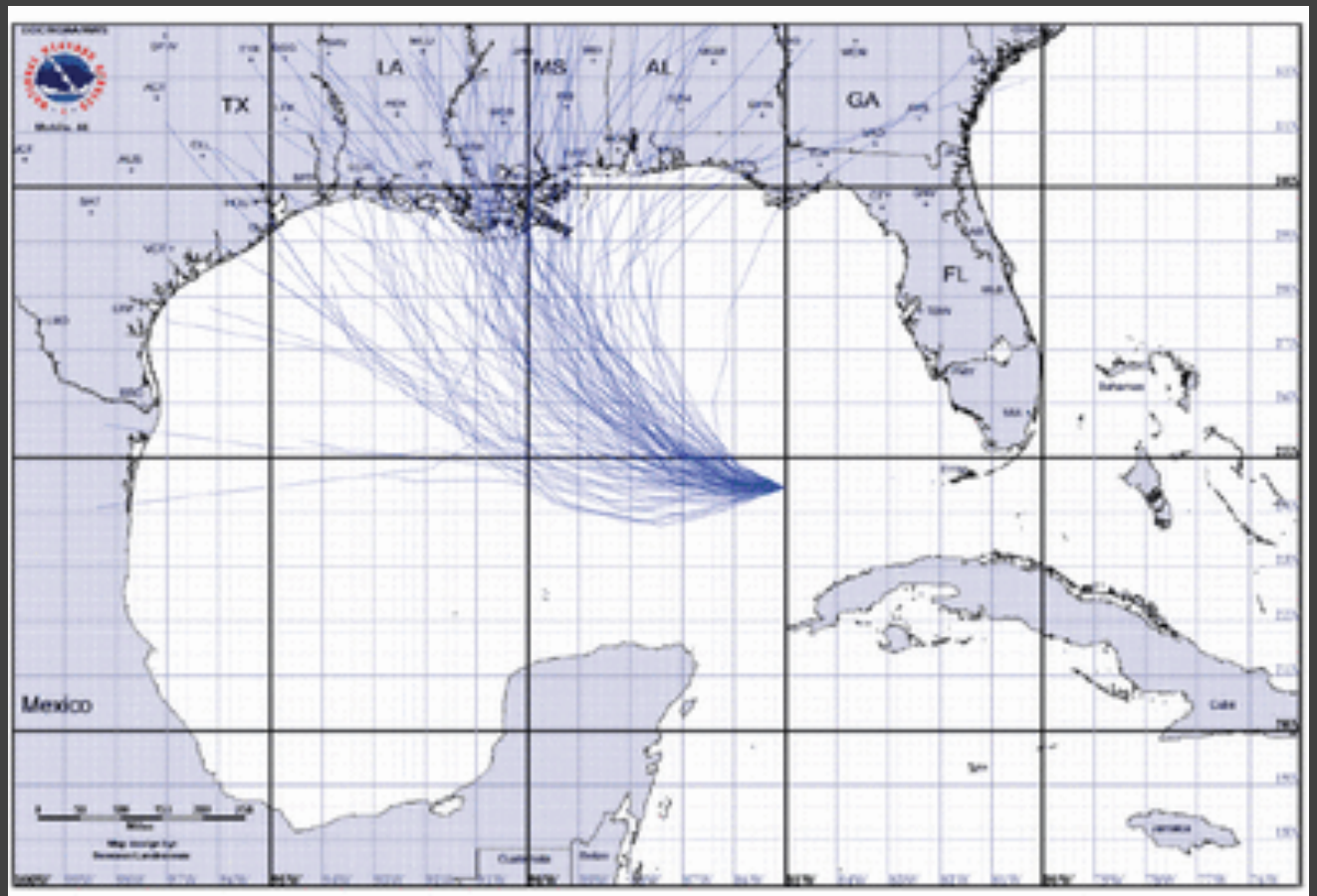
Cox, Jonathan and House, Donald and Lindell, Michael. Visuazlising uncertainty in predicted hurricane tracks. International Journal for Uncertainty Quantification, 2013.

Model Visualization



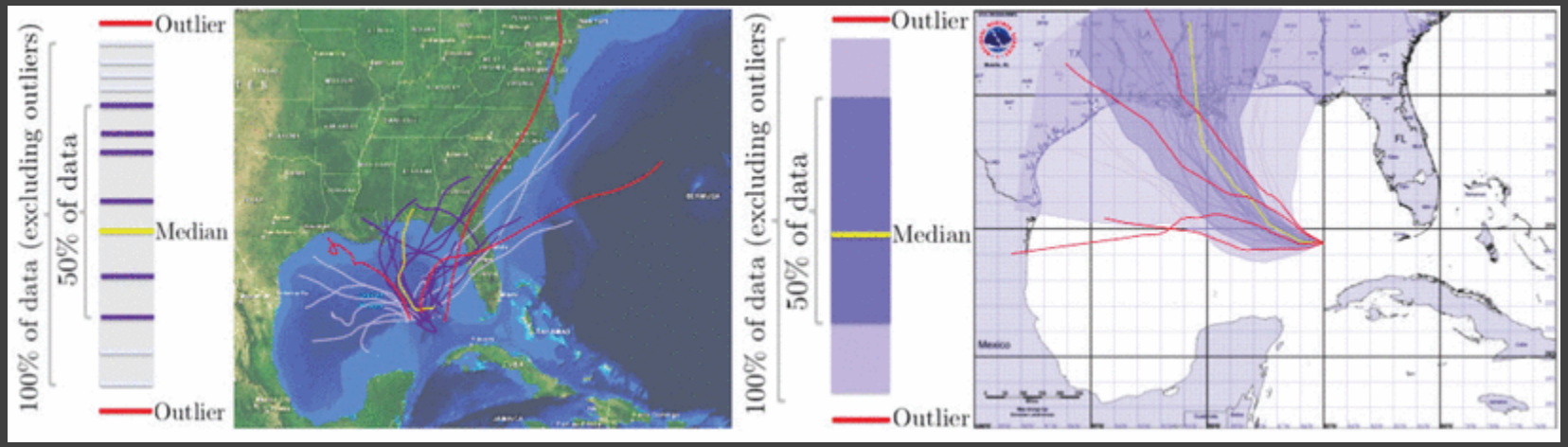
Cox, Jonathan and House, Donald and Lindell, Michael. Visuazlising uncertainty in predicted hurricane tracks. International Journal for Uncertainty Quantification, 2013.

Model Visualization



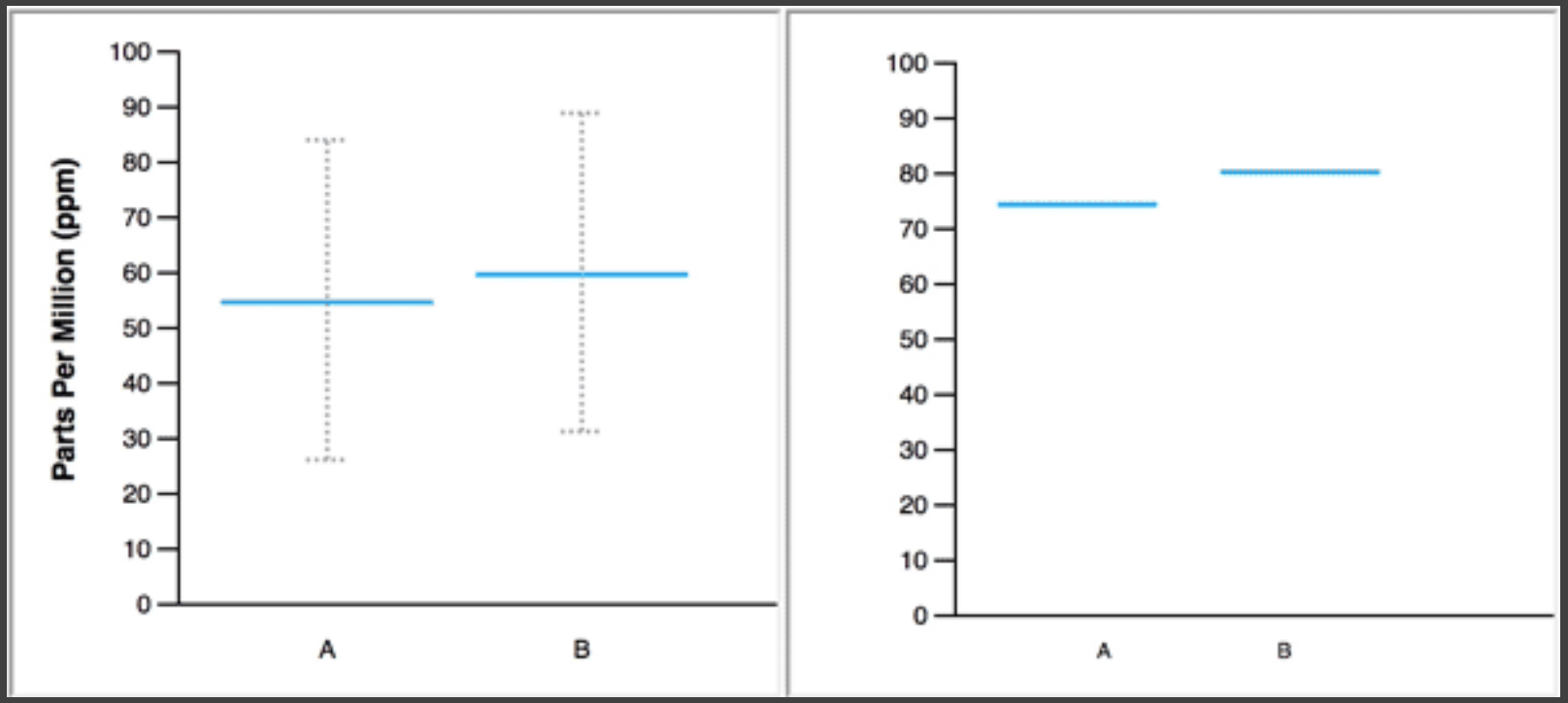
(b)

Model Visualization

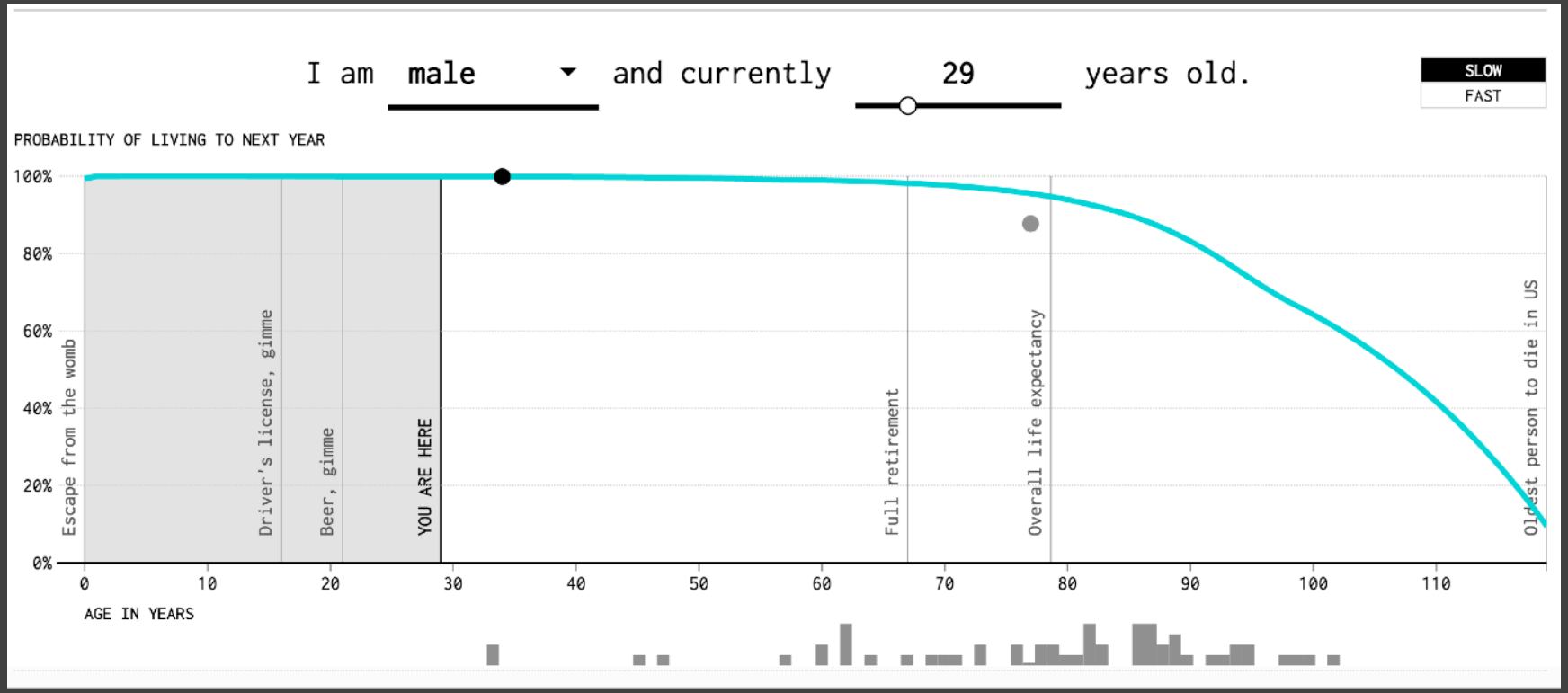


M. Mirzargar, R. Whitaker and R. Kirby. Curve Boxplot: Generalization of Boxplot for Ensembles of Curves. IEEE VIS 2014.

Hypothetical Outcome Plots



Life Expectancy



Model Visualization

Building models is necessary to quantify uncertainty

It is important to communicate the variability in model outcomes

Dynamic or ensemble displays can help communicate complex models

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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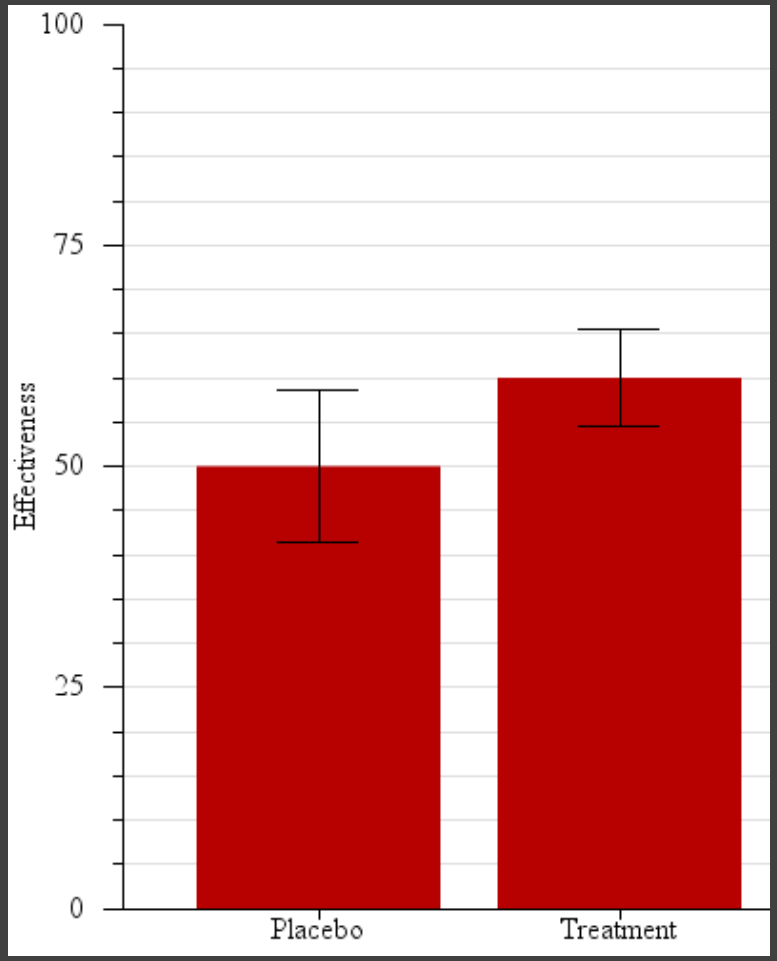
IT DEPENDS

Cognitive and Perceptual Biases and Disfluencies

WHAT CAN GO WRONG WHEN VISUALIZING UNCERTAINTY?

Error Bars

Is the treatment *statistically significantly* better than the placebo?



What's a 95% t-Confidence Interval?

An algorithm for constructing intervals given an unbiased sample. Assuming a t-distribution of sampling error,

95% of such intervals will contain the population mean.

Error Bars

Standard Deviation?

Standard Error ($\sigma/\sqrt{n}$)

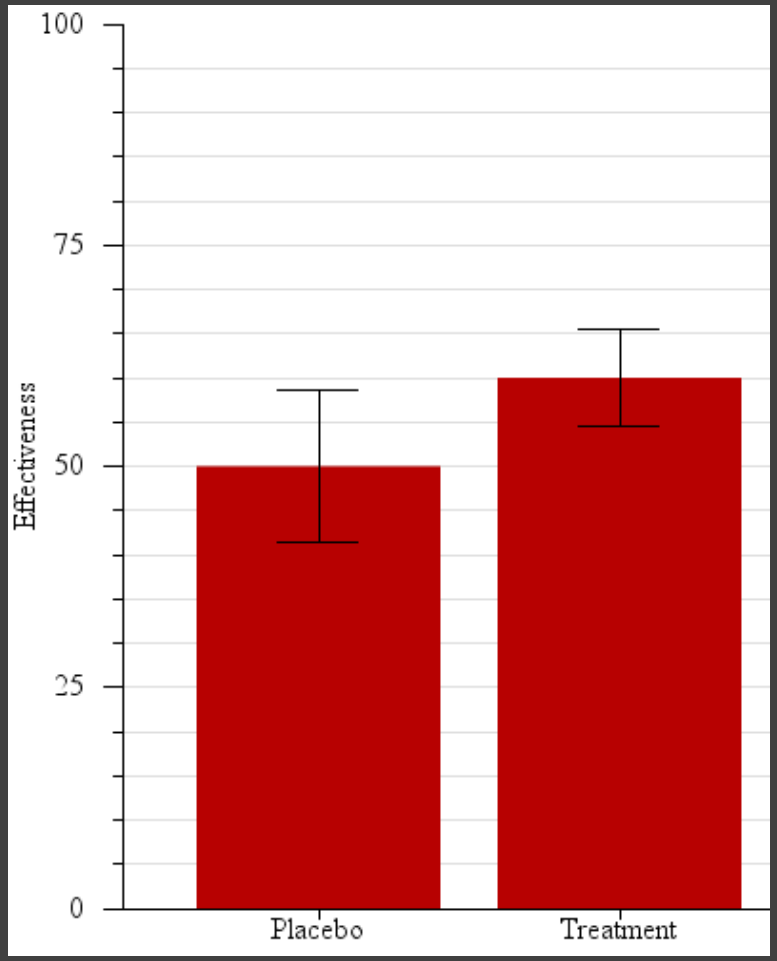
T-Confidence Interval?

Z-Confidence Interval?

Bootstrapped Interval?

Min/Max?

1.5*IQR (Q3-Q1)?



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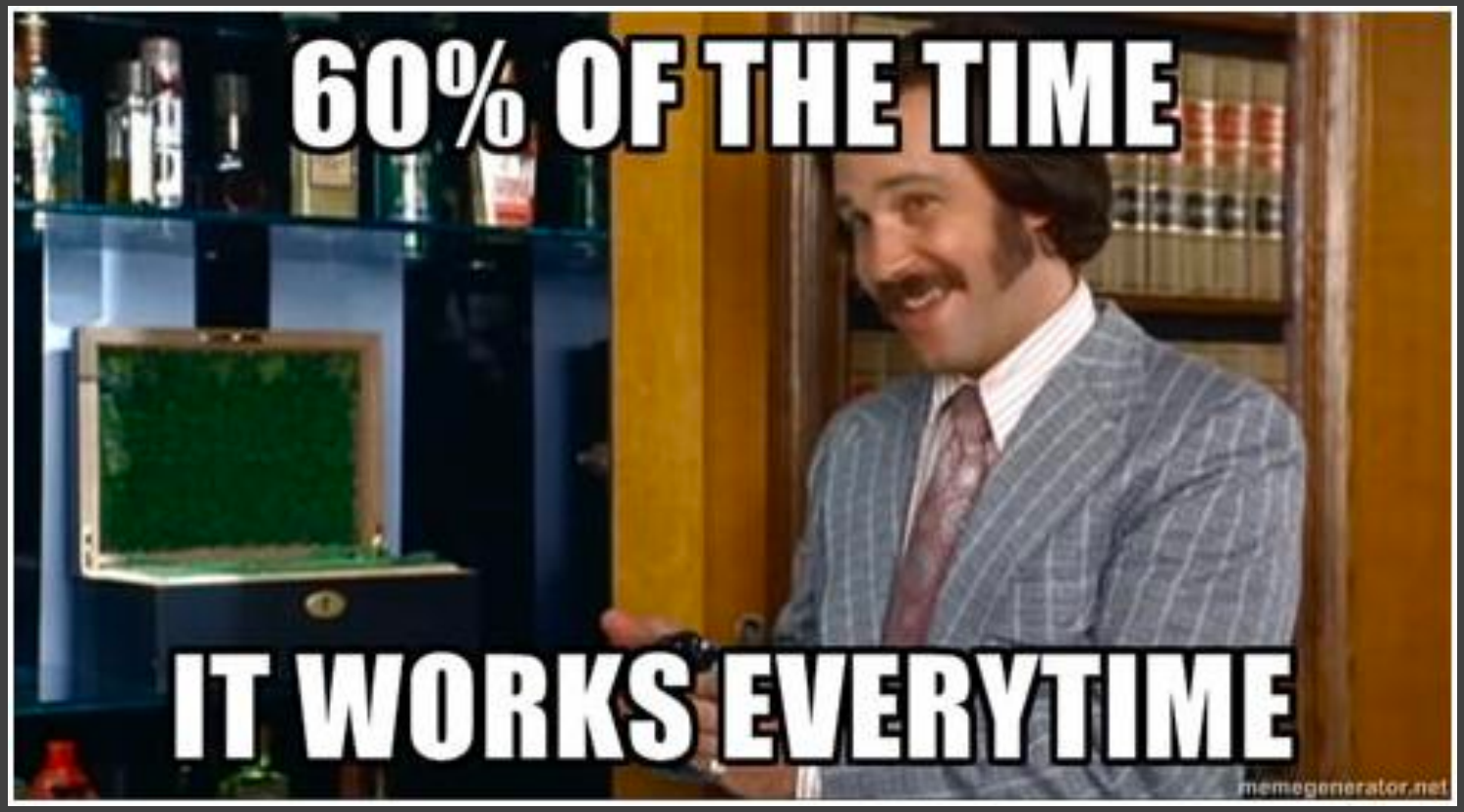

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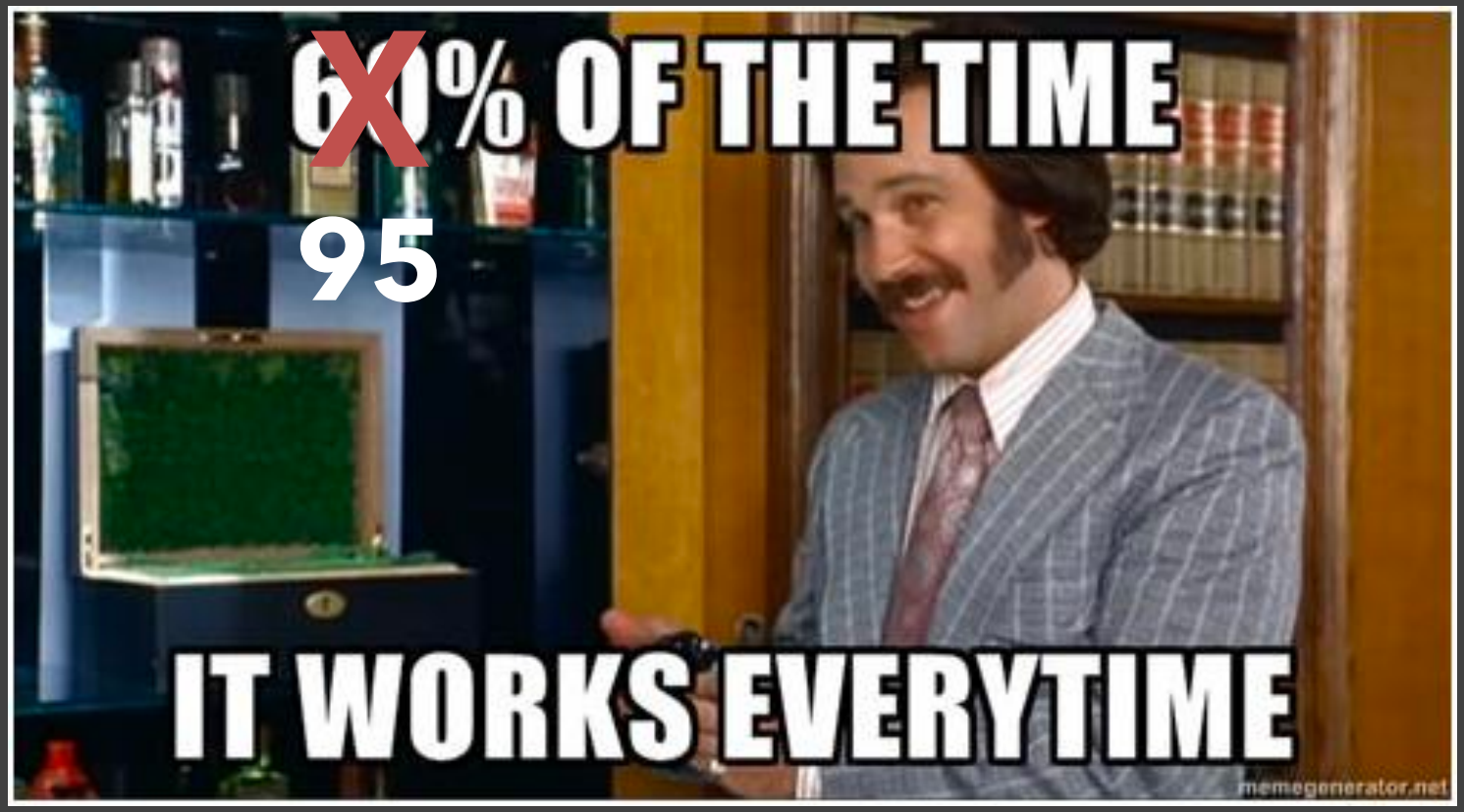
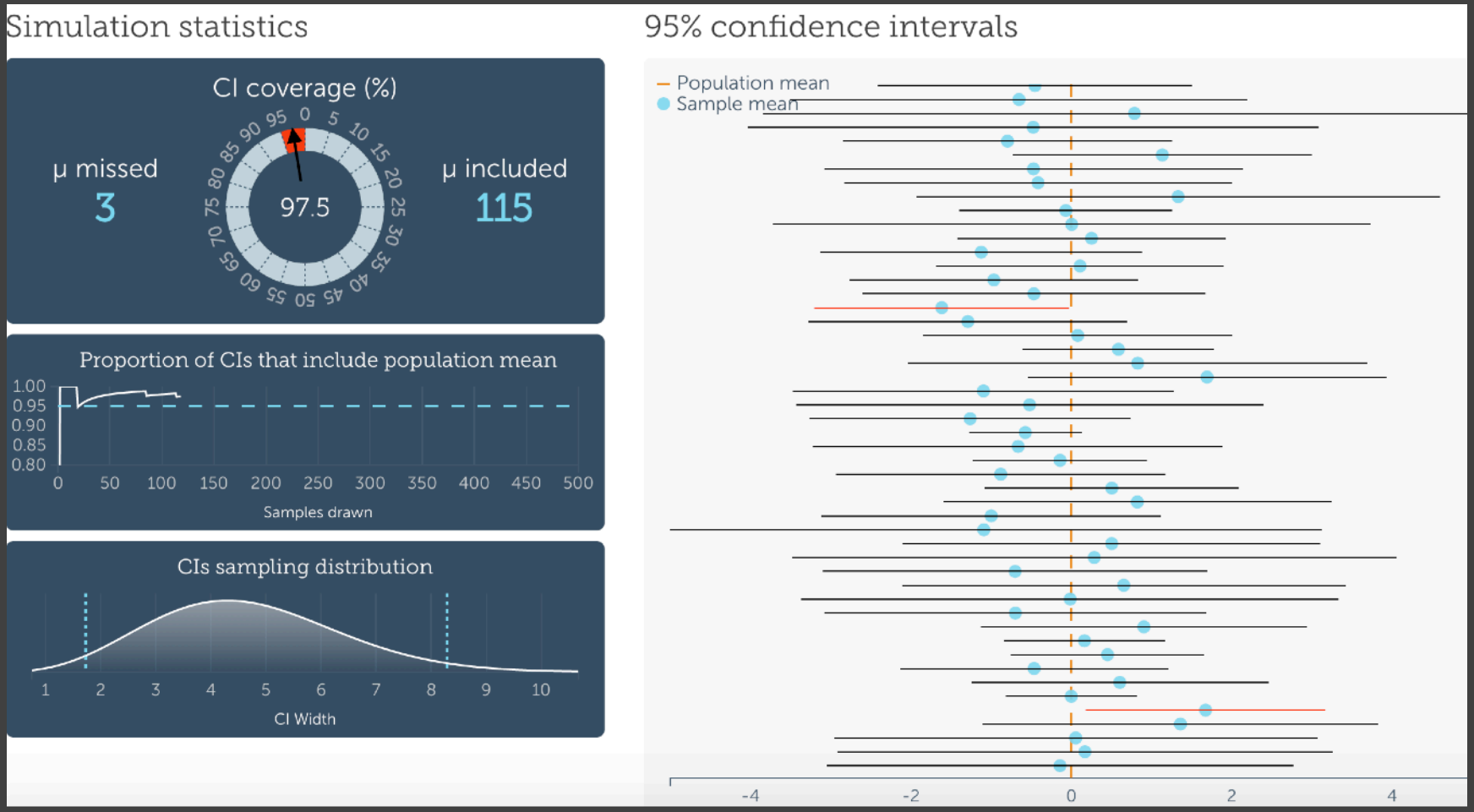
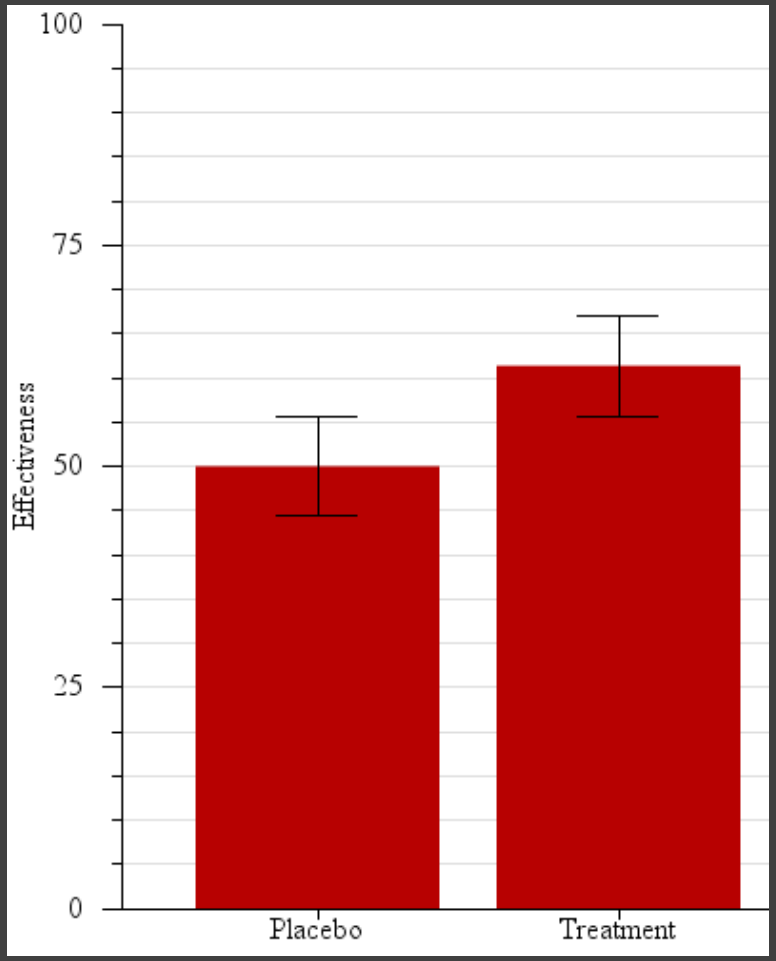


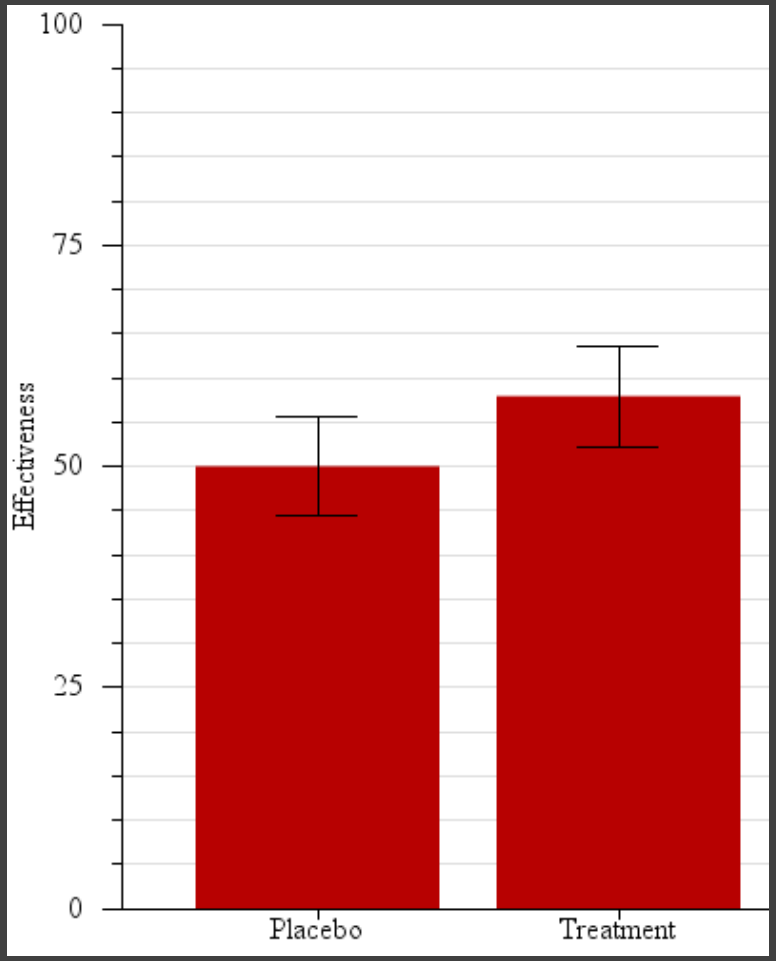
Confidence Intervals



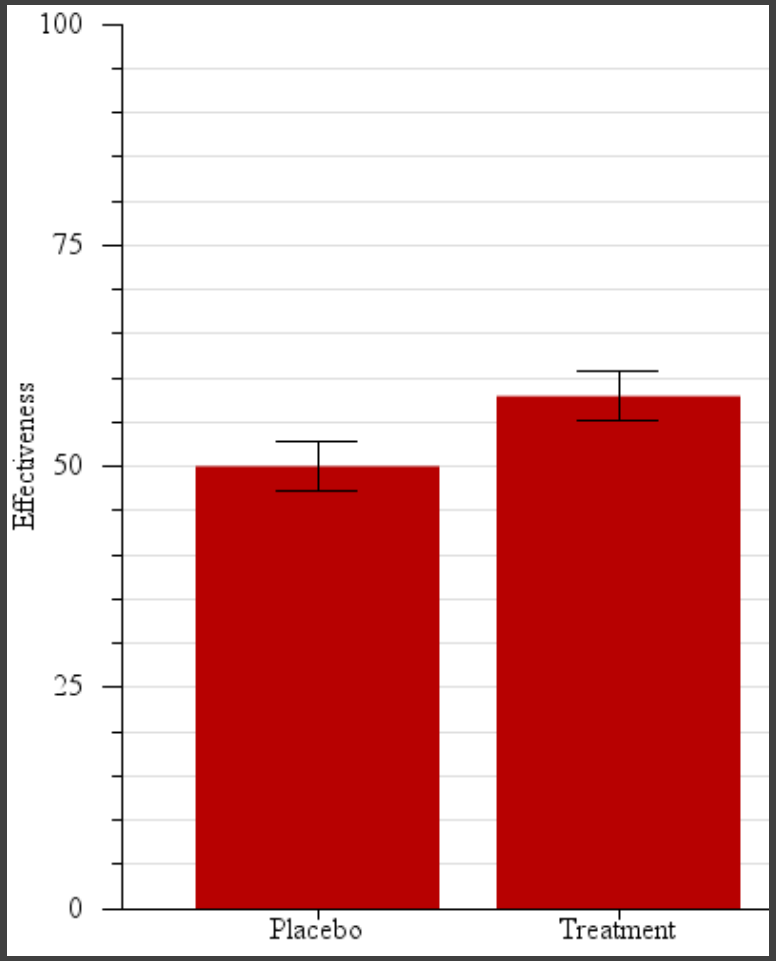
Guess the p-value



Guess the p-value

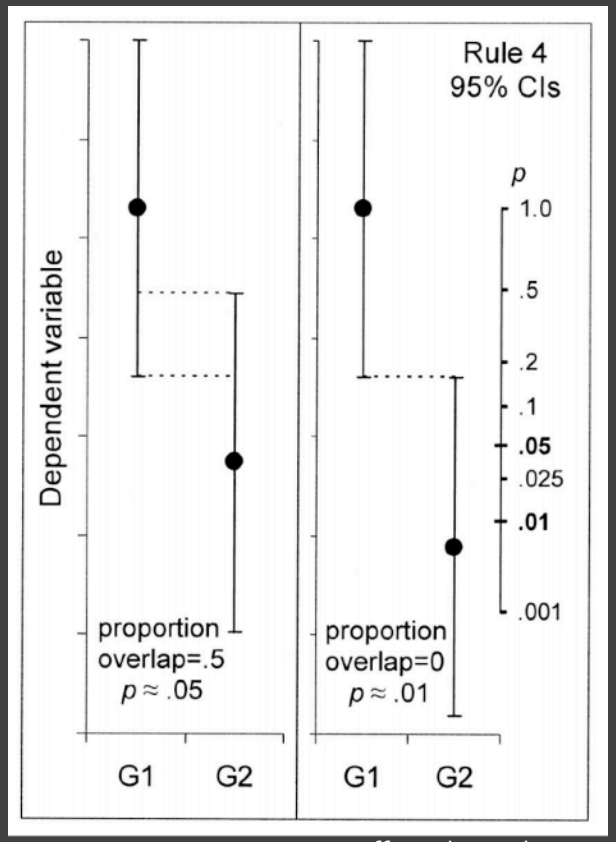


Guess the p-value

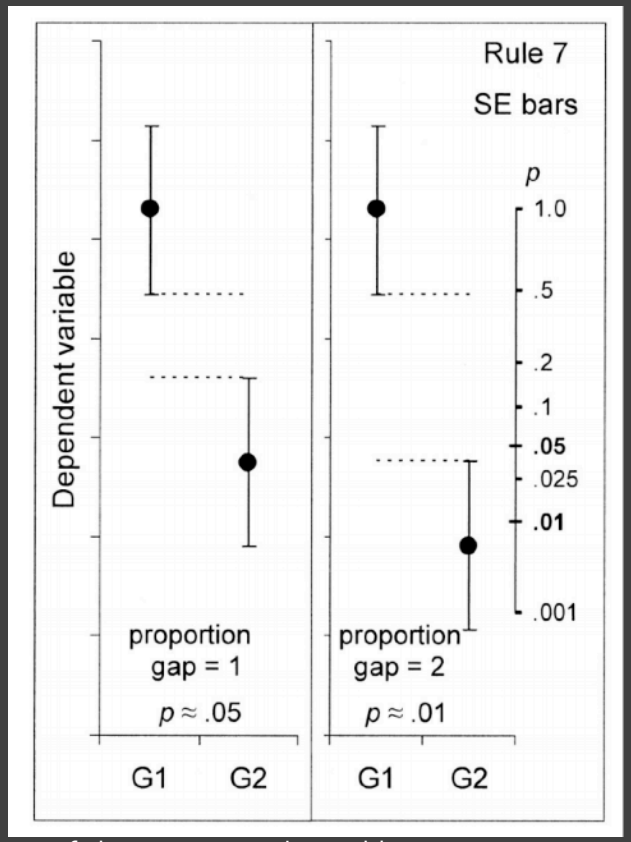


Inference by Eye

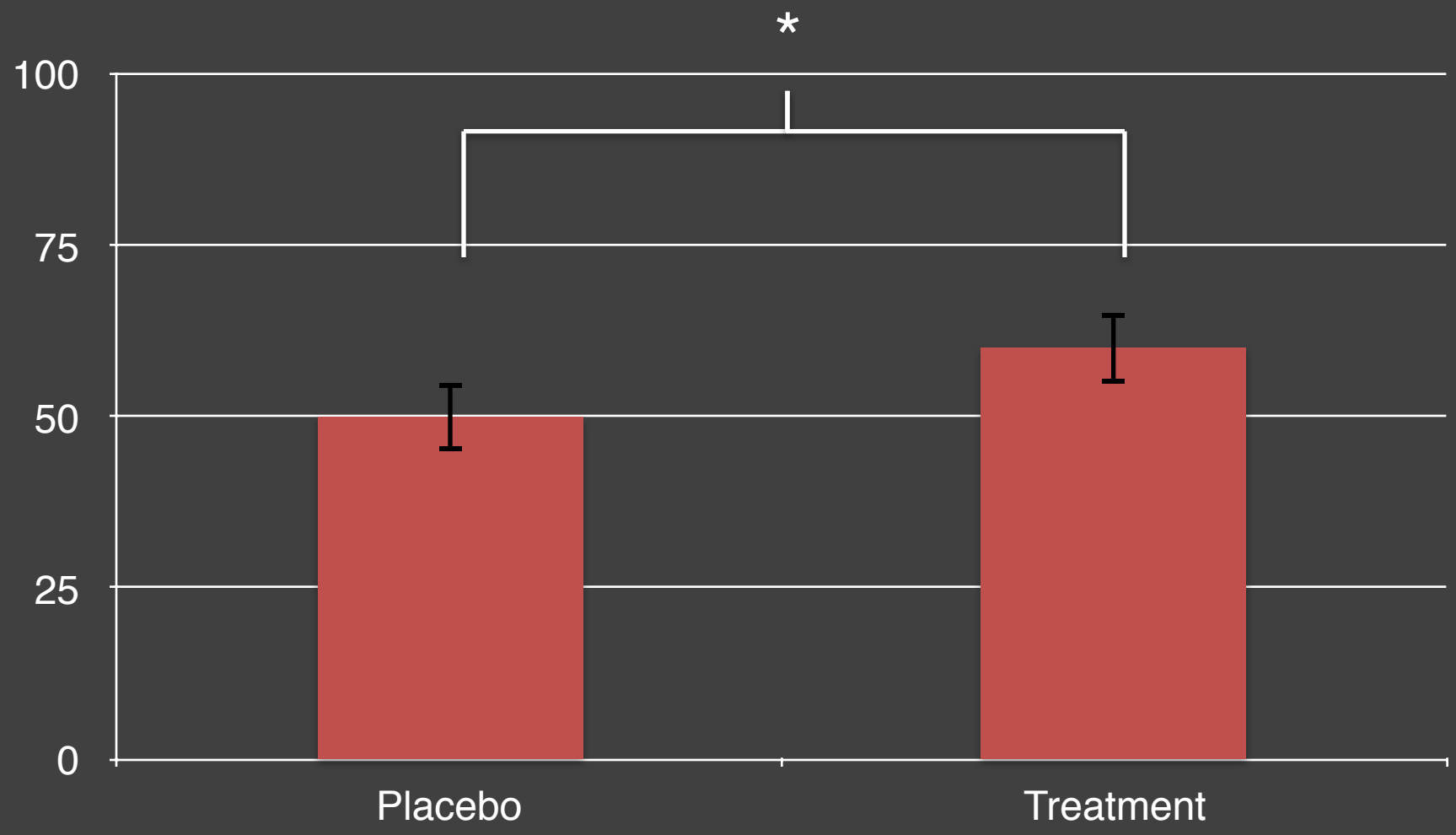
95% CIs

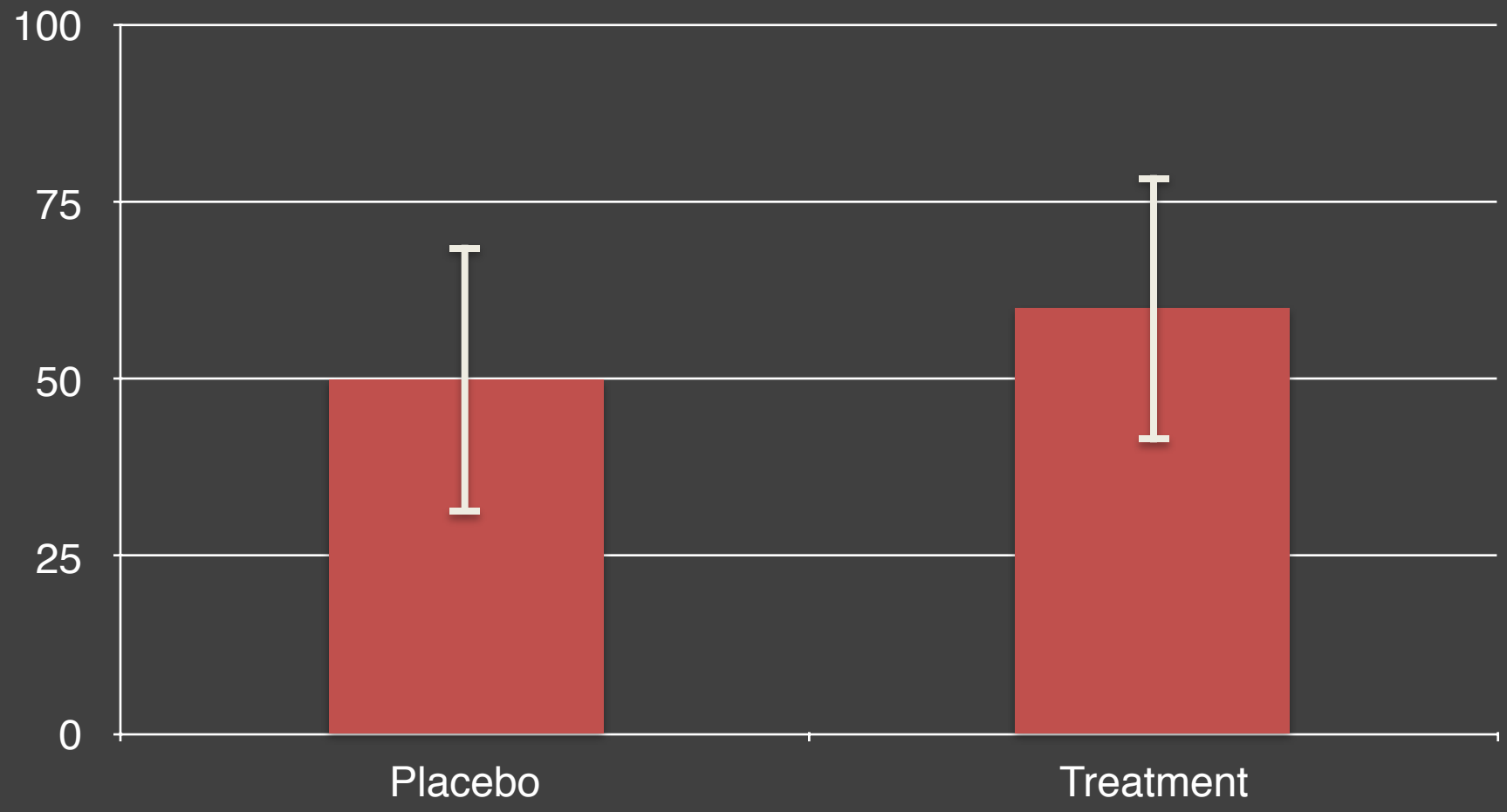


Standard Error



Cumming, Geoff and Finch, Sue. Inference by eye: confidence intervals and how to read pictures of data. American Psychologist, 2005.


*
100
75
50
25
0
Placebo
Treatment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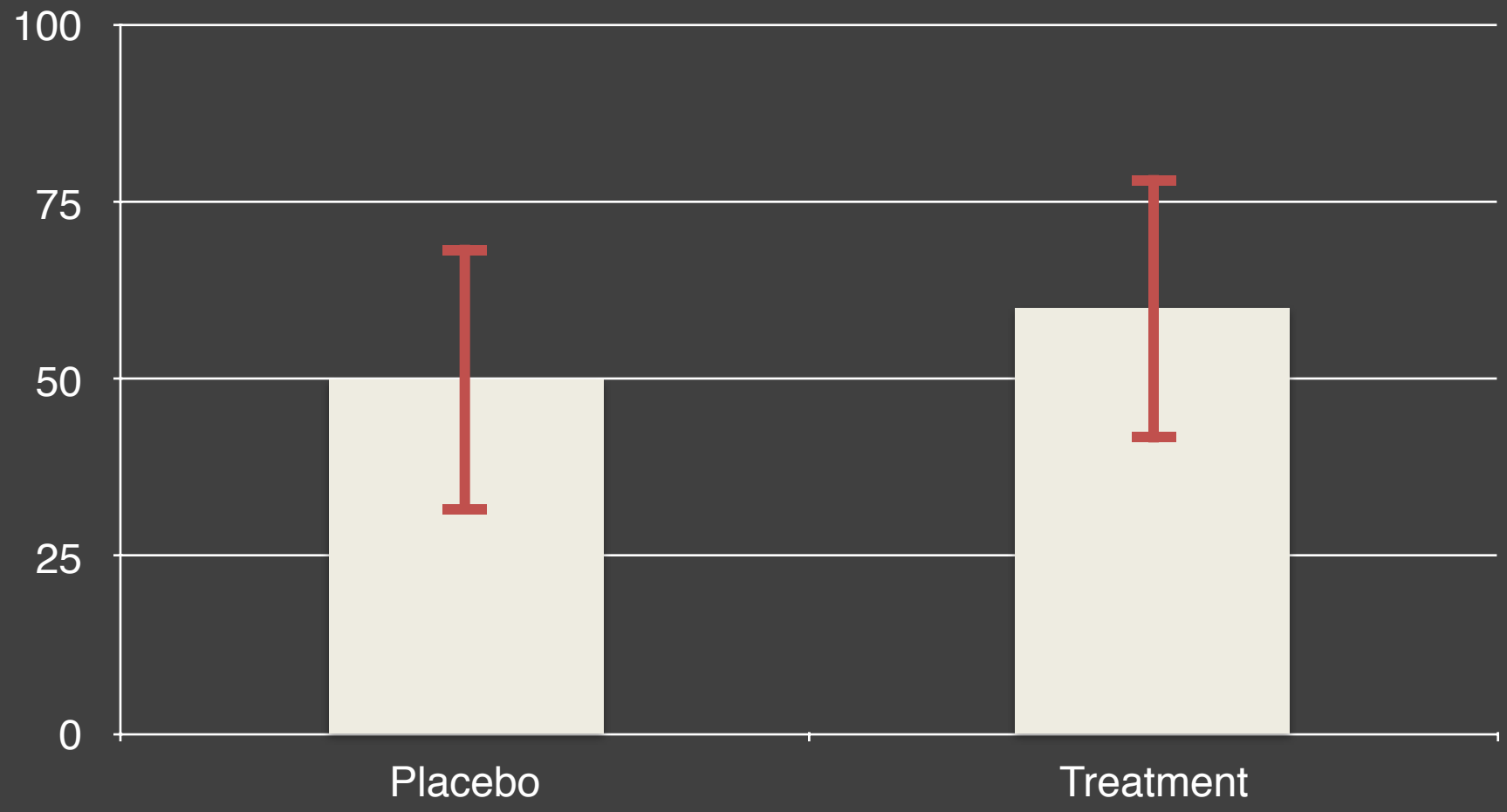
100
75
50
25
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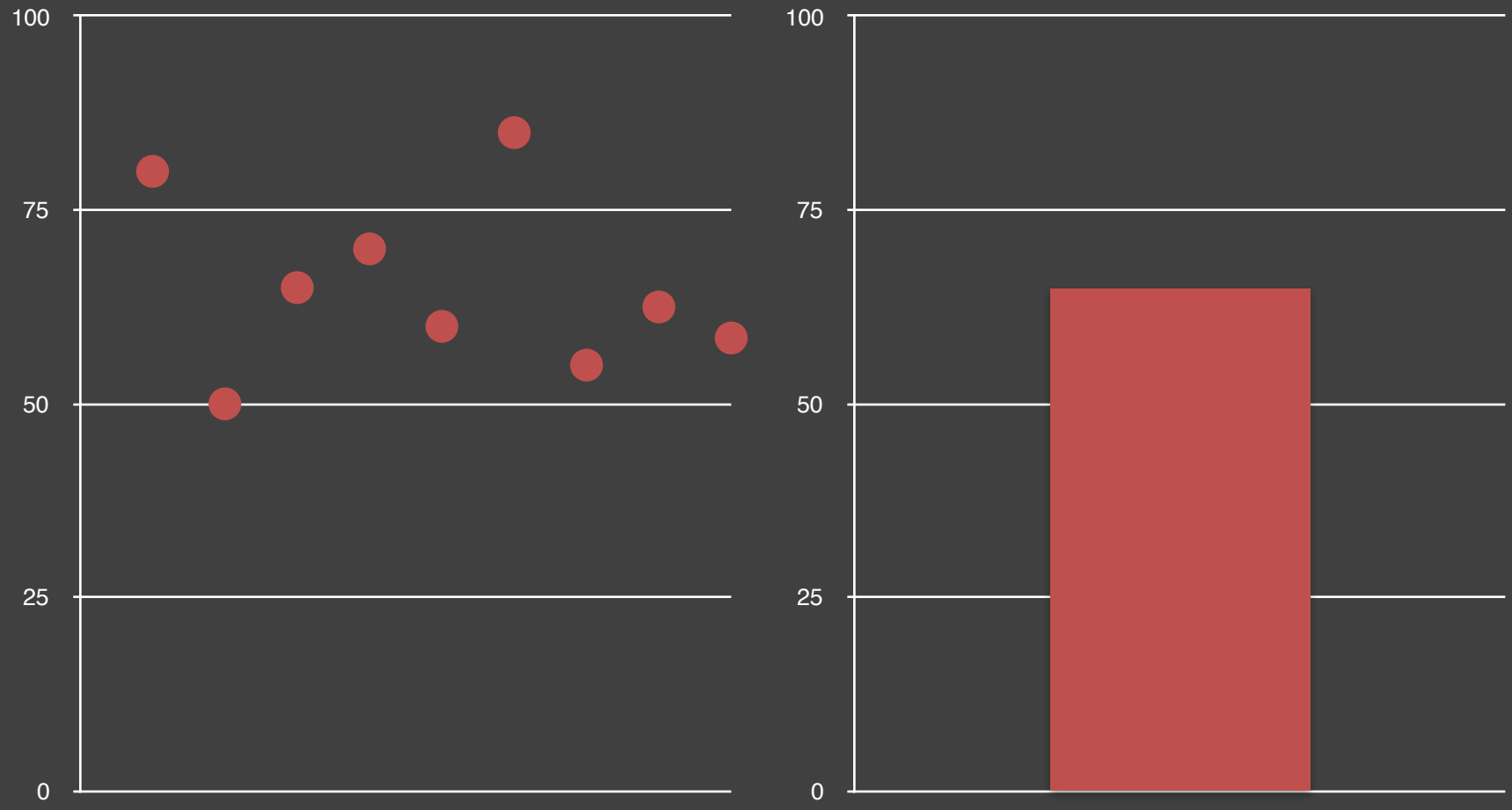
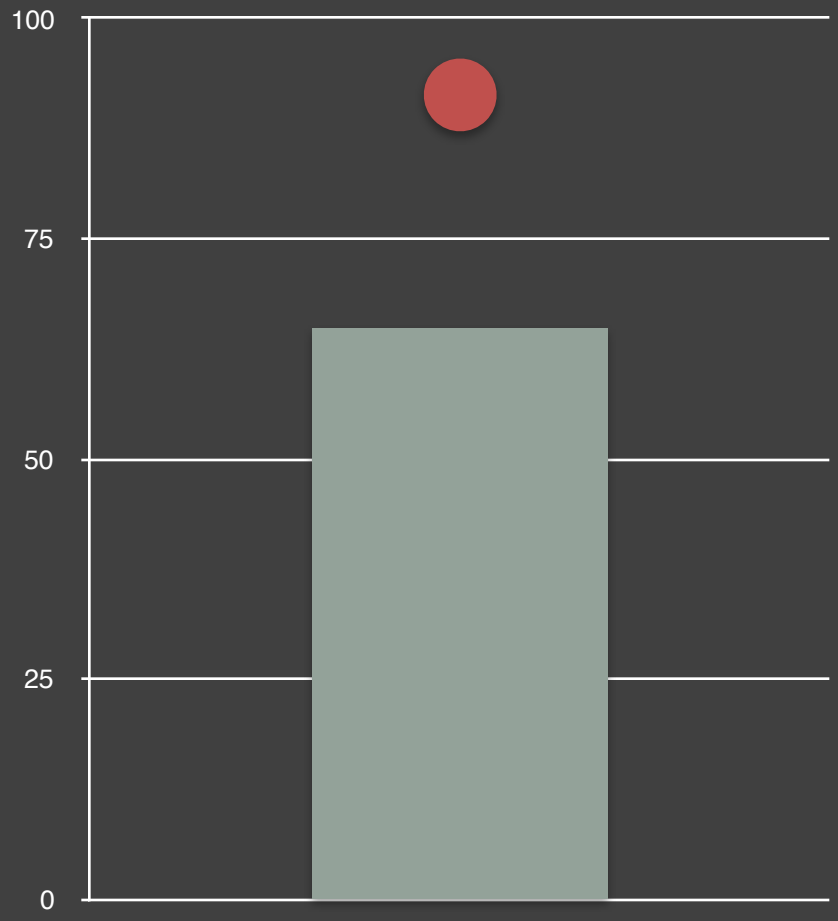
Placebo
Treatment

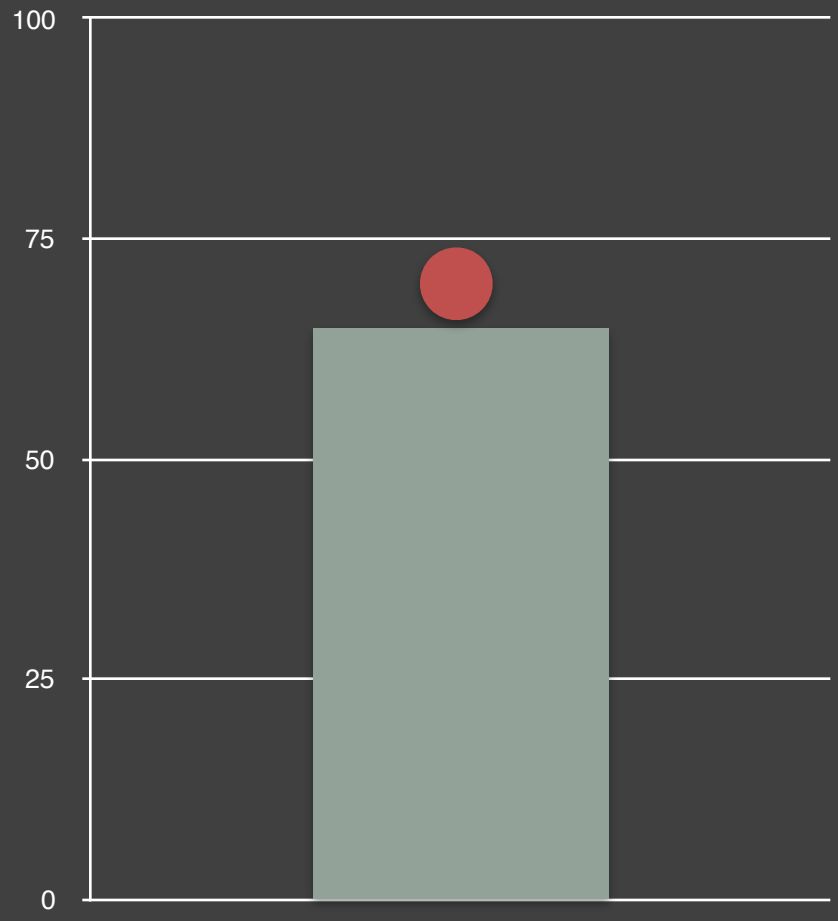
Within-the-bar bias



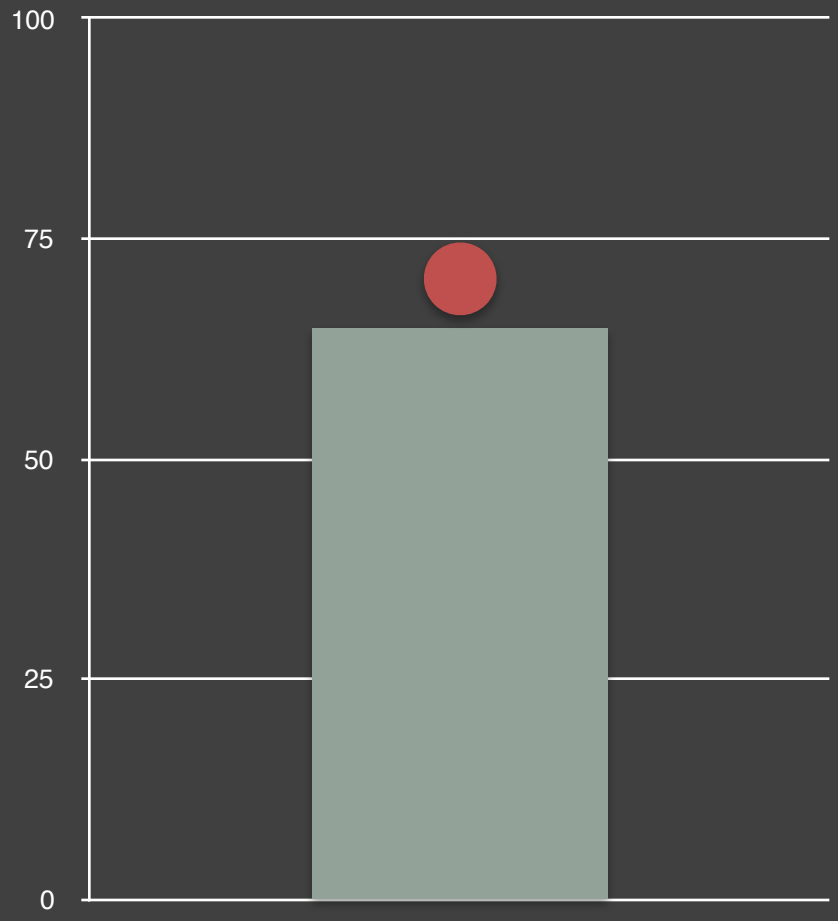
Newman, George E, and Brian J Scholl. “Bar graphs depicting averages are perceptually misinterpreted: the within-the-bar bias.” Psychonomic bulletin & review 19.4 (2012): 601–7.

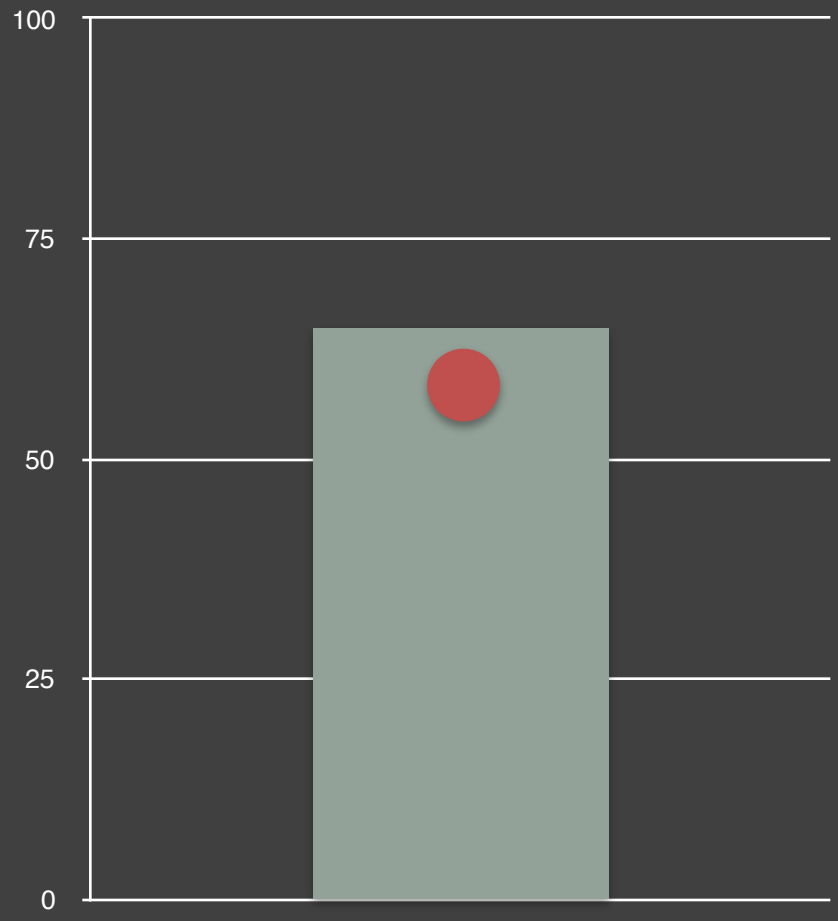
Within-the-bar bias



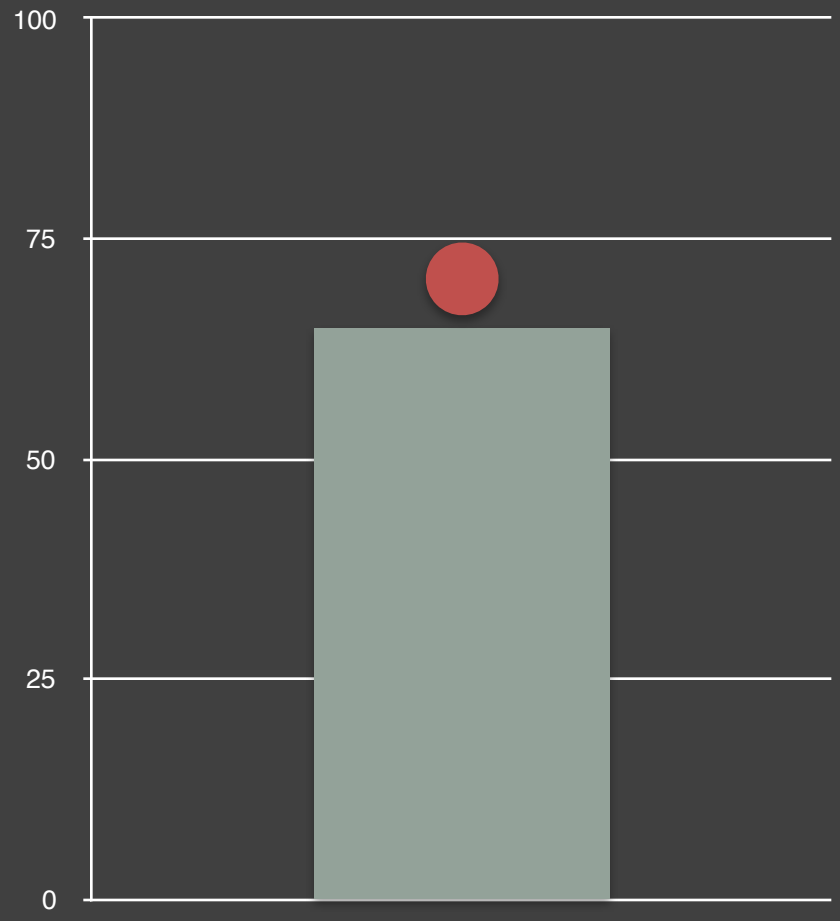


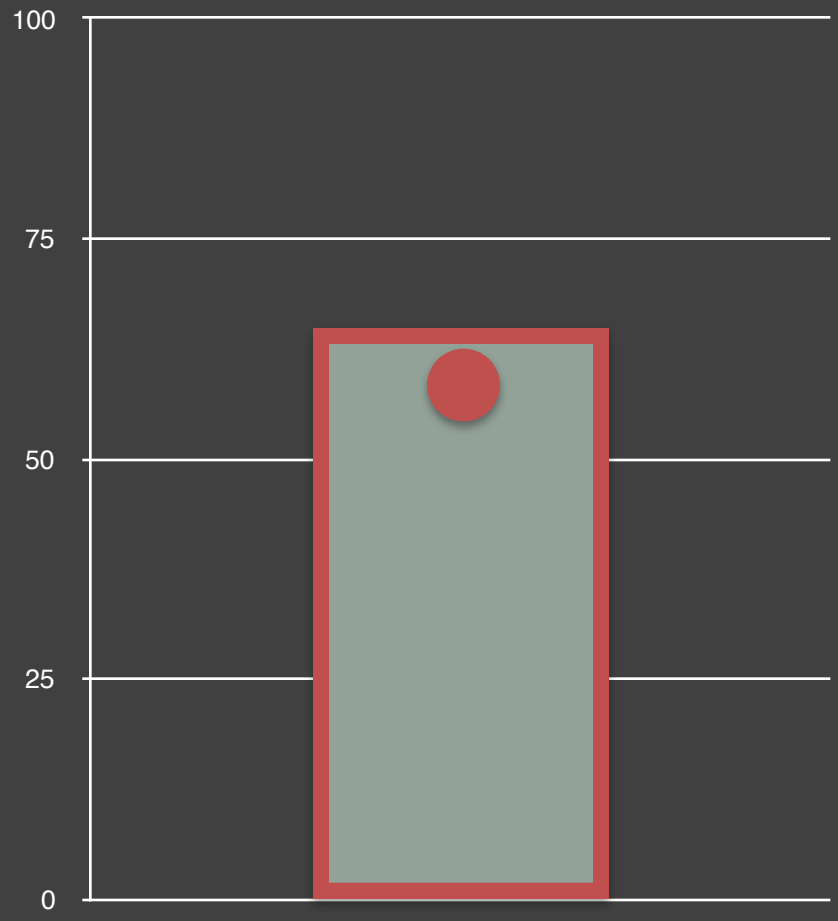
Within-the-bar bias



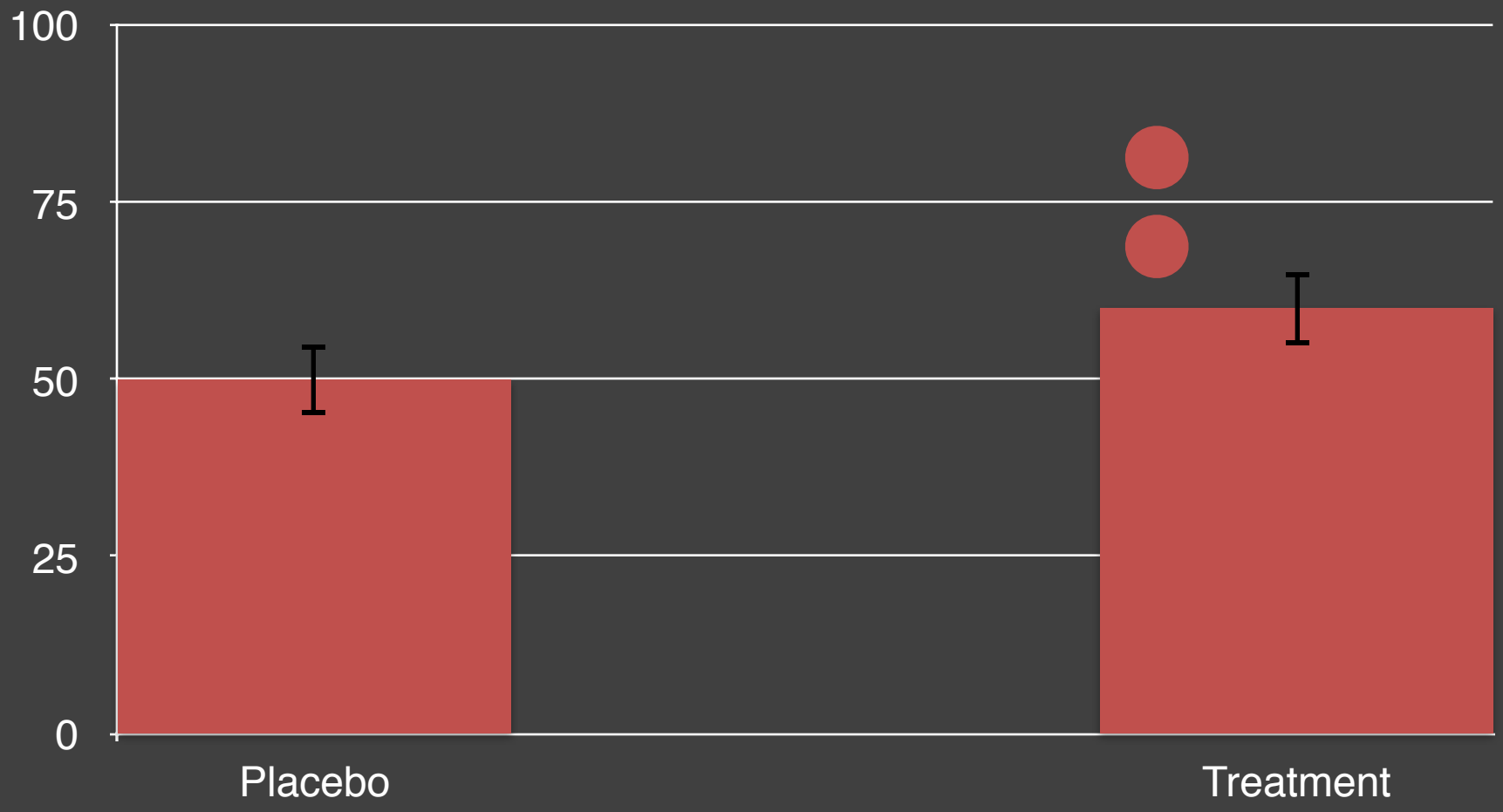


Within-the-bar bias



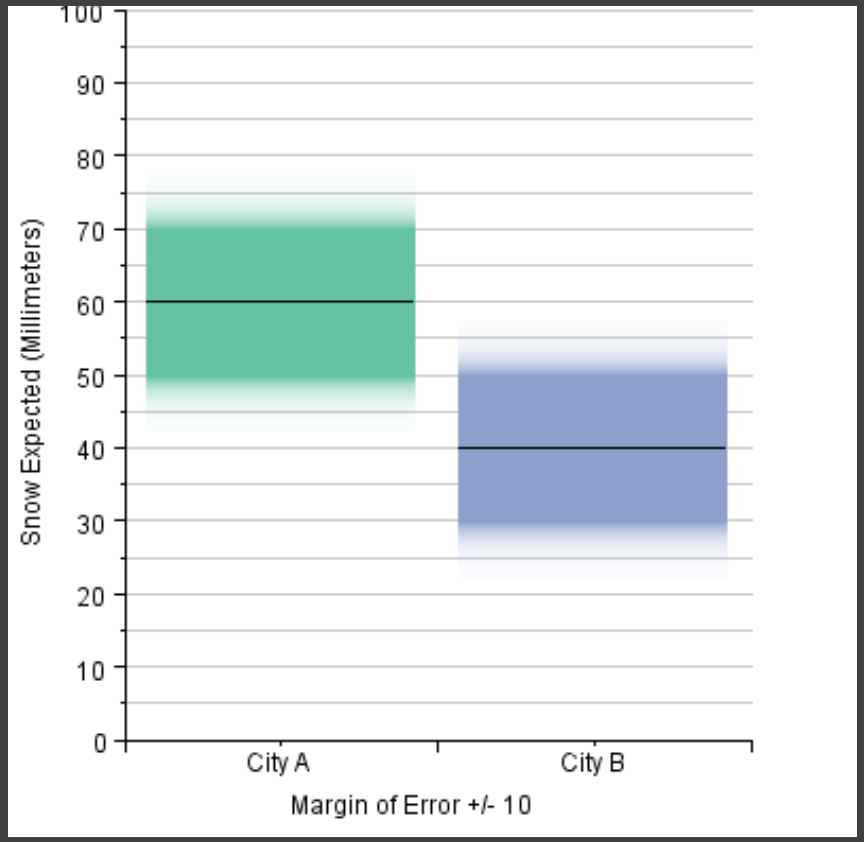


Binary Bias

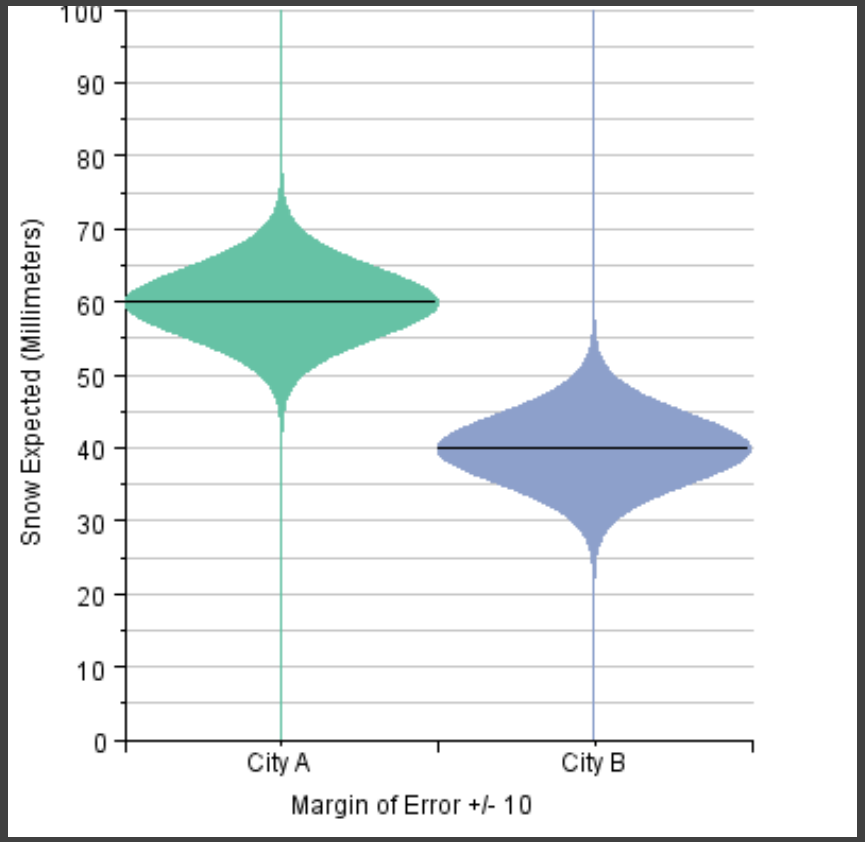


Alternatives

Gradient Plot

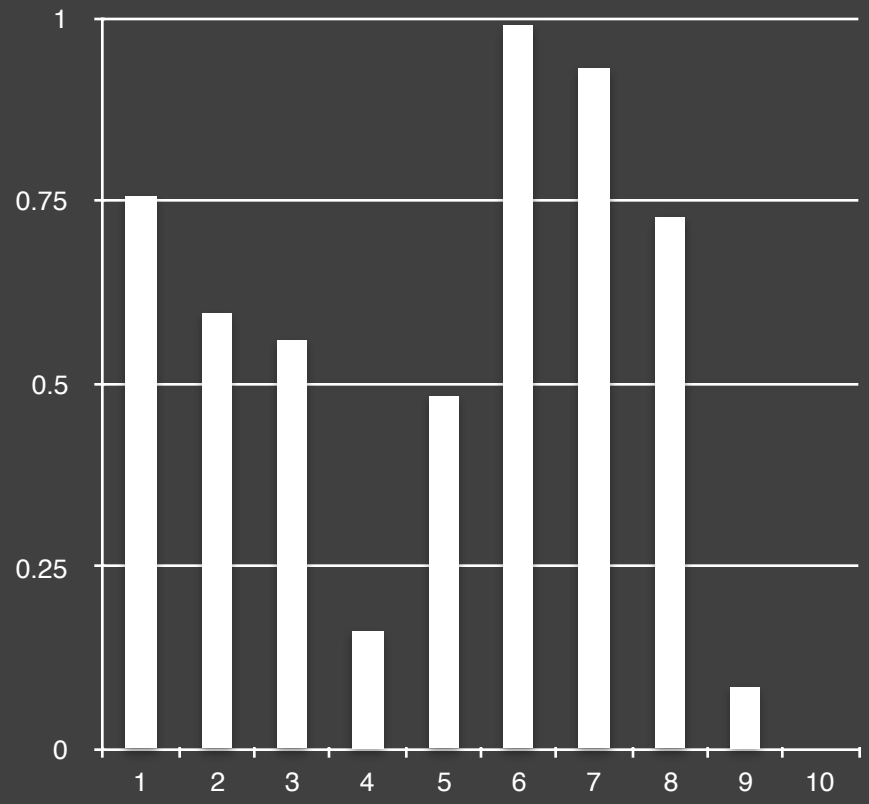


Violin Plot

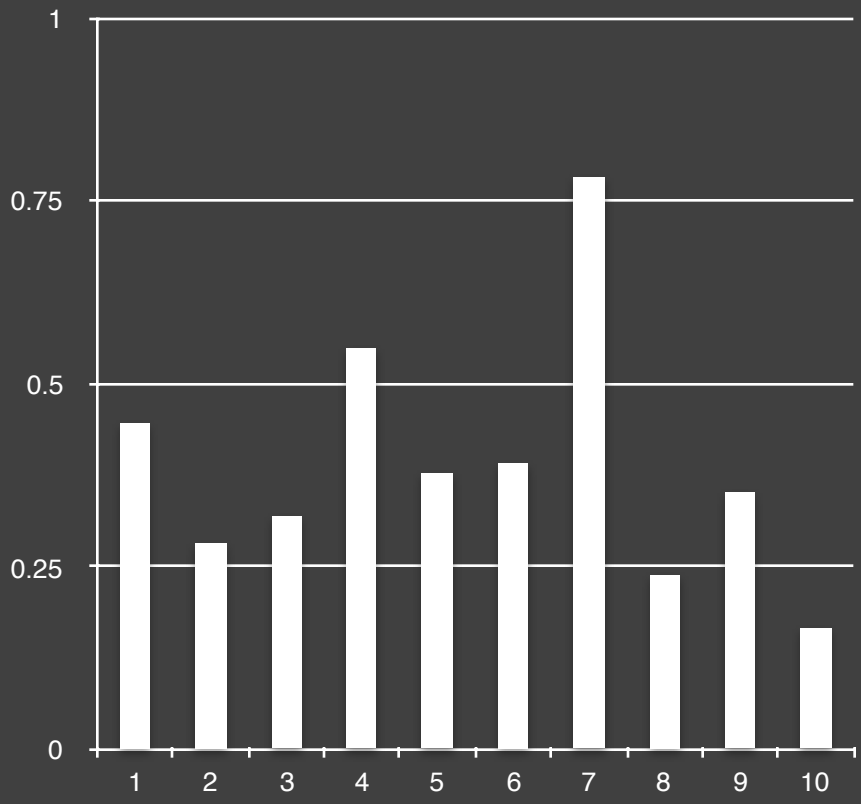


Which Stock To Buy?

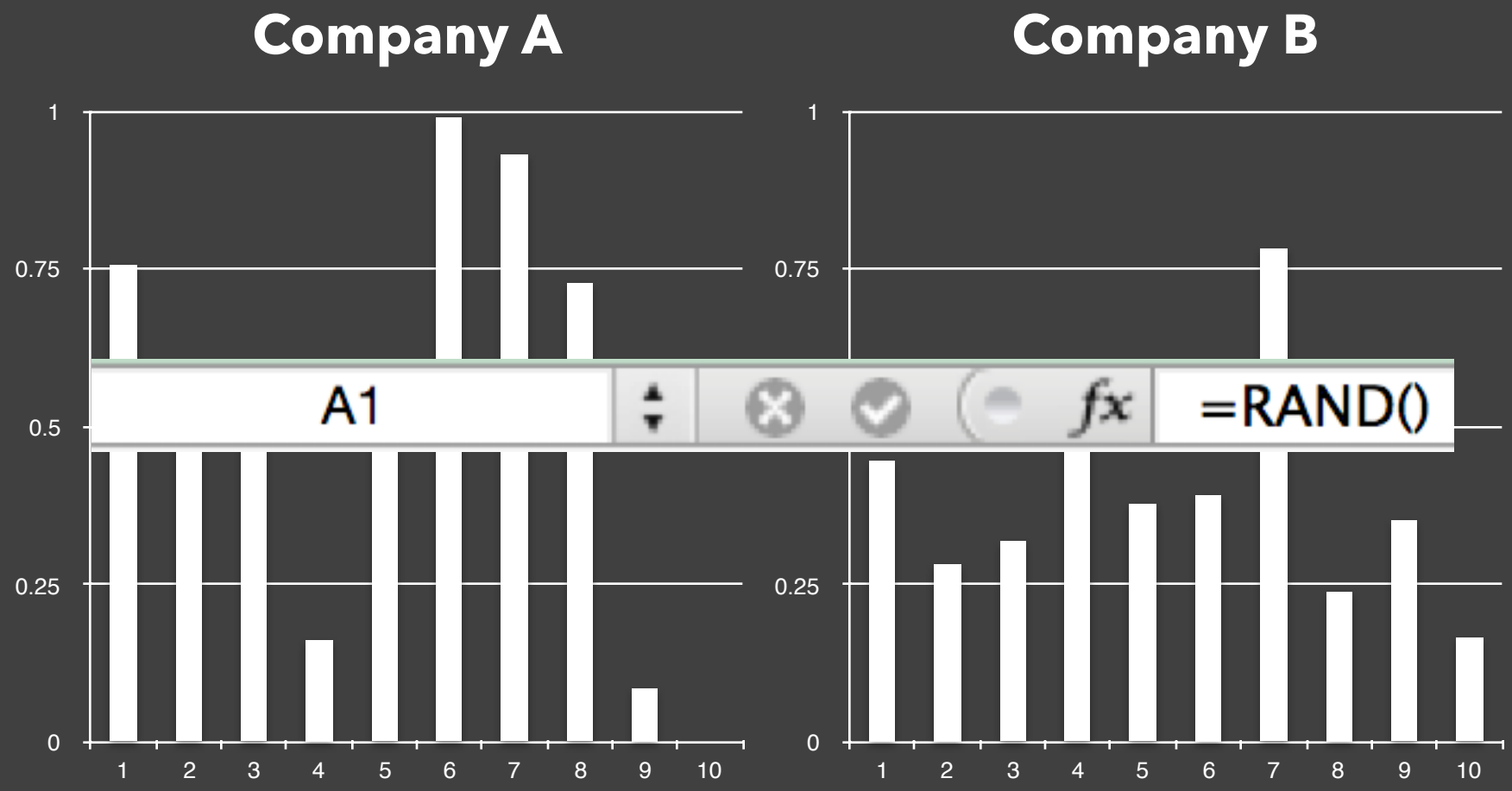
Company A



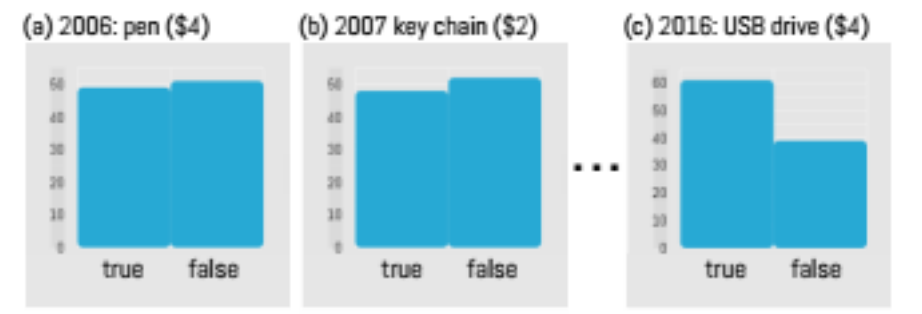
Company B



Neither!



What Swag Should We Send?



Zgraggen et al. “Investigating the Effect of the Multiple. Comparisons Problem in Visual Analysis. CHI 2018, to appear.

Fake Insights

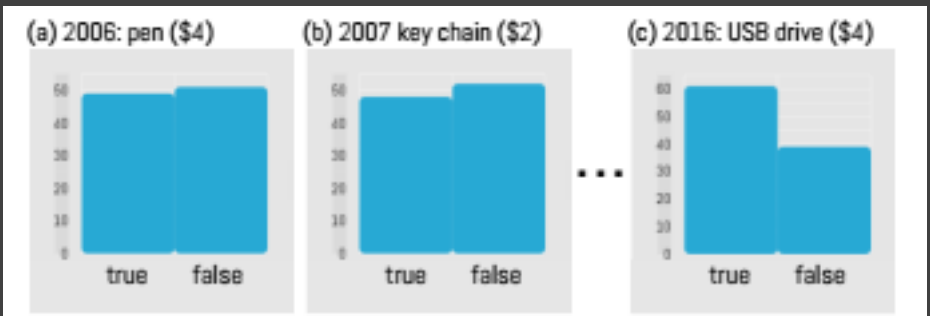


Figure 1. A user inspects several graphs and wrongly flags (c) as an insight because it looks different than (a) and (b). All were generated from the same uniform distribution and are the "same". By viewing lots of visualizations, the chances increase of seeing an apparent insight that is actually the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

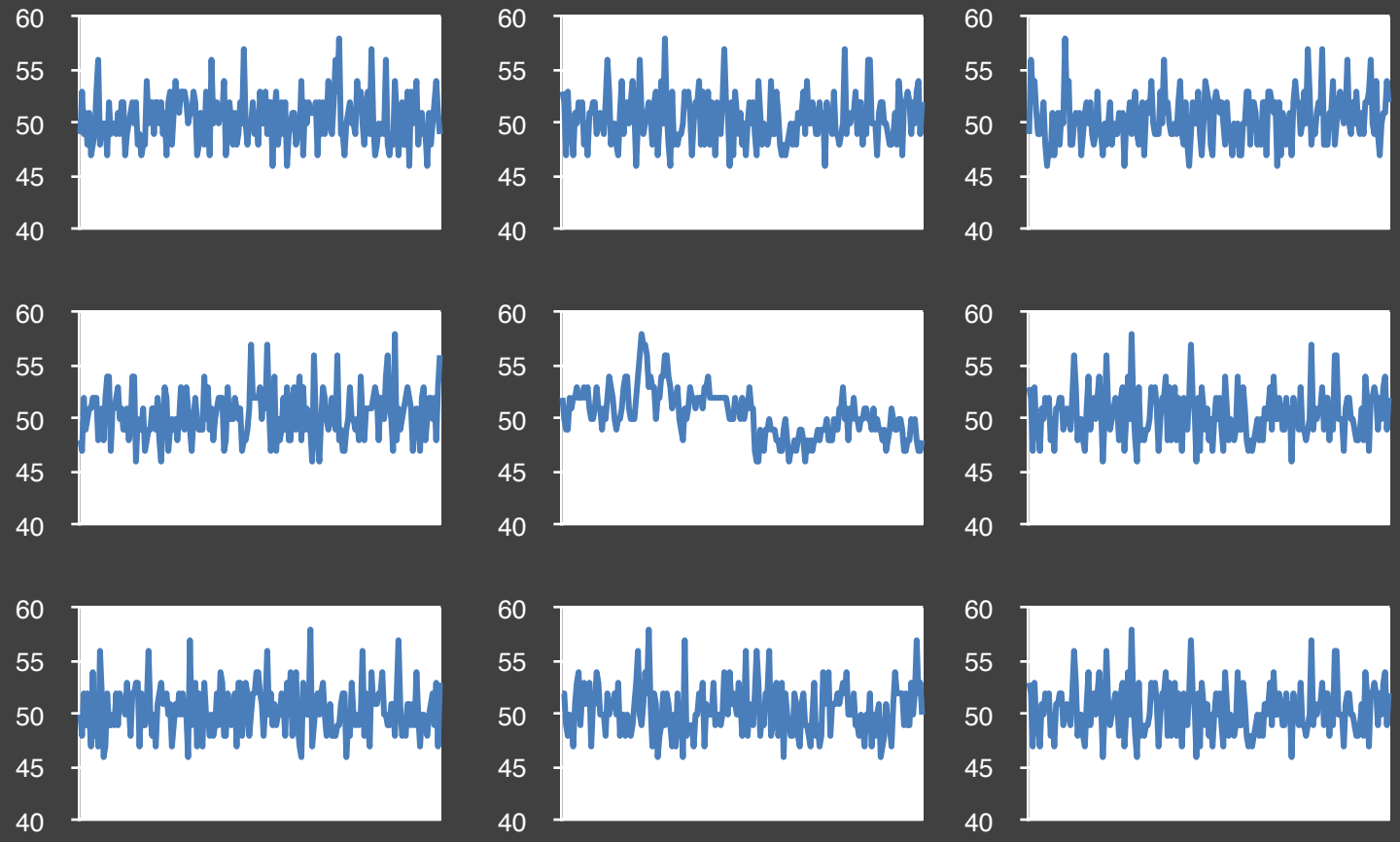
Zgraggen et al. "Investigating the Effect of the Multiple. Comparisons Problem in Visual Analysis. CHI 2018, to appear.

Wu Wei

Pareidolia

Jobs Reports

Have People Made Up Their Mind About Obama?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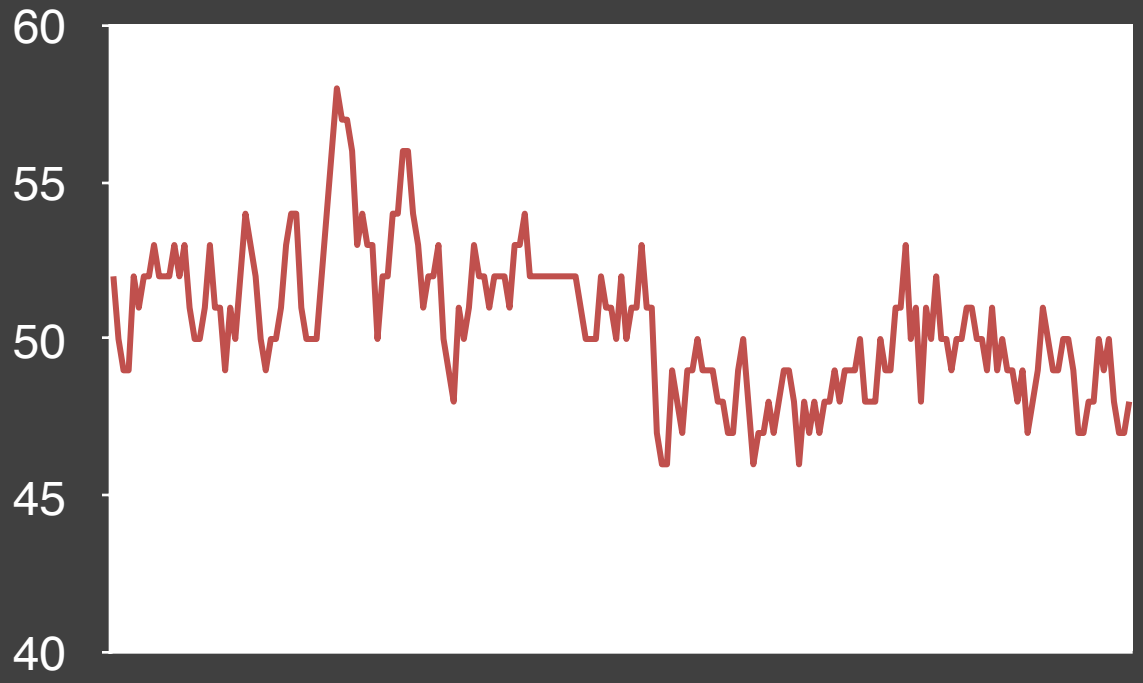
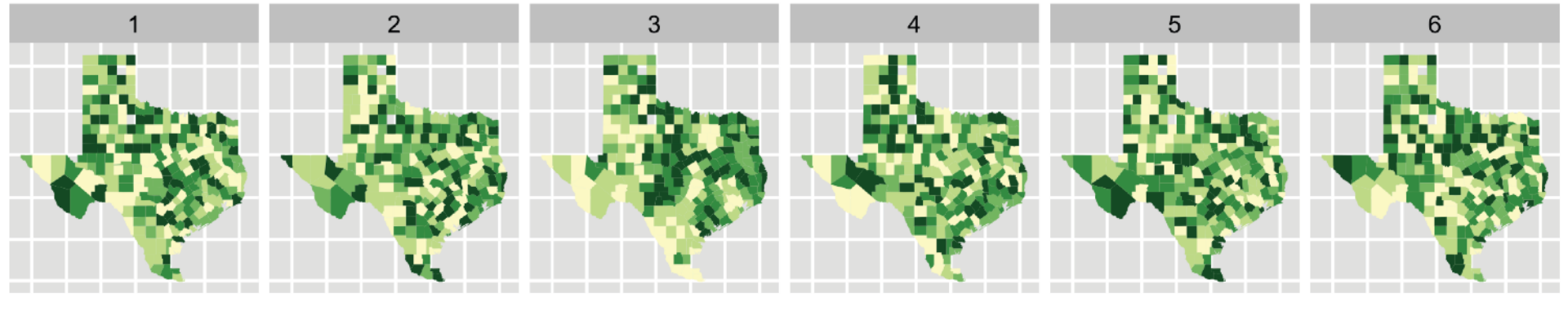
Visual Lineups



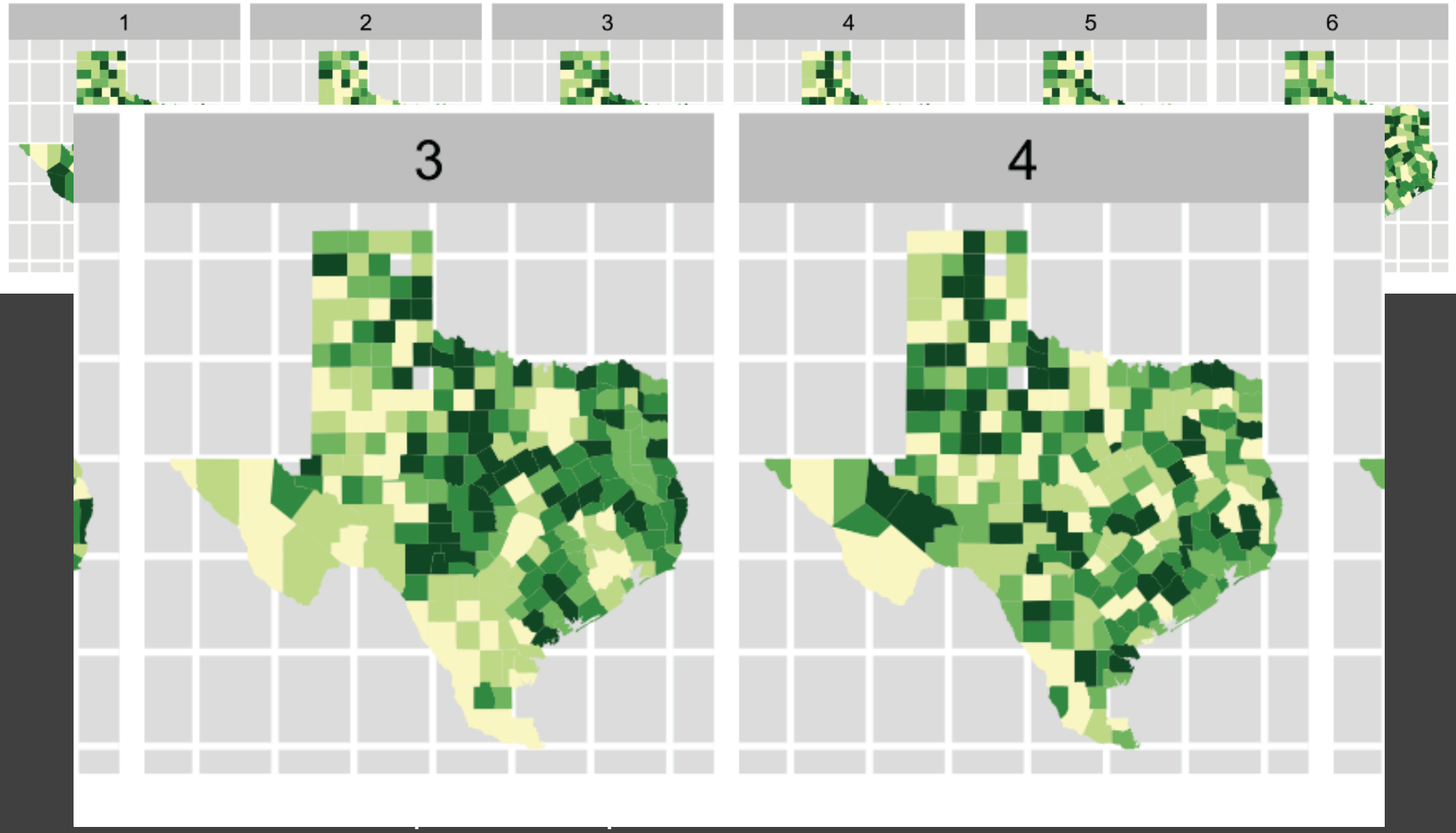


Choropleth maps of cancer deaths in Texas.

One plot shows a real data sets. The others are simulated under the null hypothesis of spatial independence.

Can you spot the real data? If so, you have some evidence of spatial dependence in the data.

Hadley Wickham et al. “Graphical inference for Infovis.” IEEE transactions on visualization and computer graphics 16.6 (2010): 973–9.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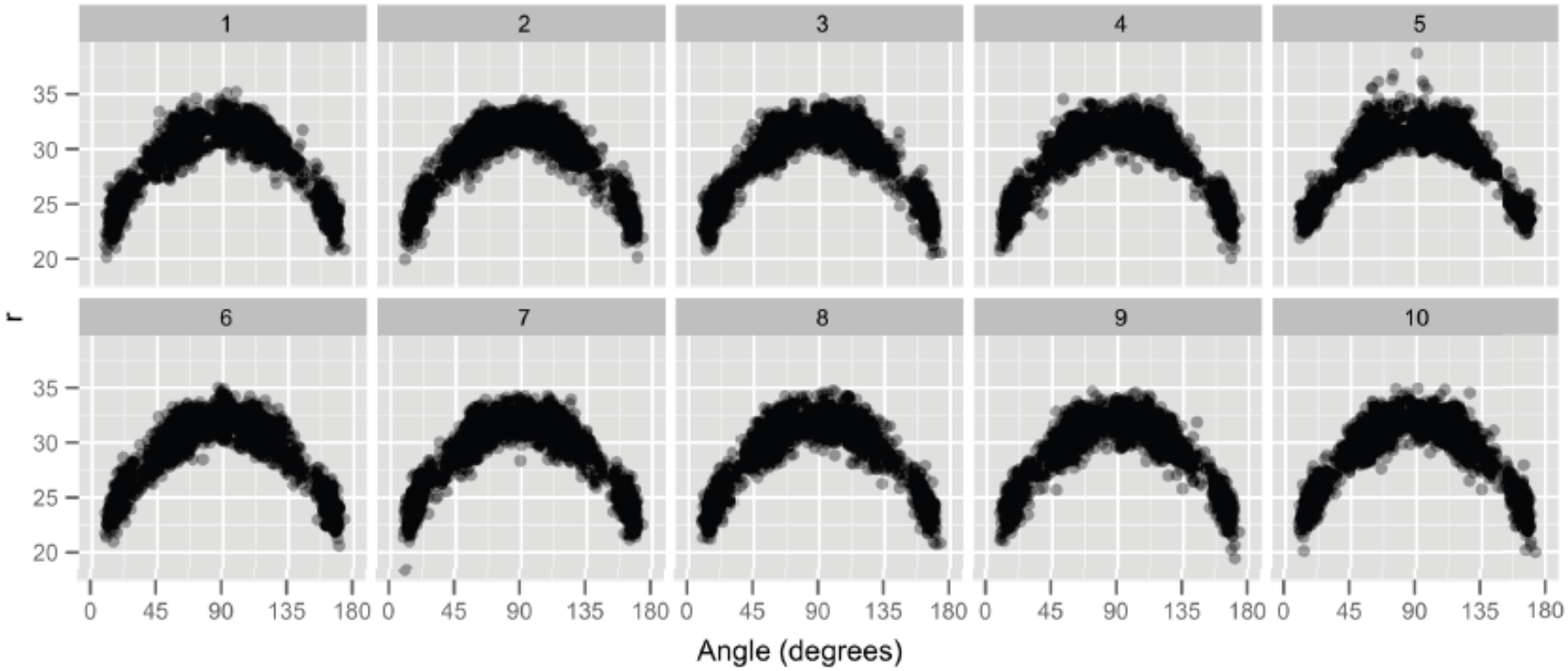

Distance vs. angle for 3 point shots by the LA Lakers.

One plot is the real data. The others are generated according to a null hypothesis of quadratic relationship.

Negative Results

People tend to analyze patterns and make decisions, even if there is “nothing to see.”

Negative or null results can correspond to weak and non-robust visual patterns across a model space.

Base Rate Fallacy

1% of 40 year old women have breast cancer

The probability a mammogram will detect breast cancer is 80%

The probability of a false positive is 10%.

If a 40 year old woman gets a positive result, what is the probability she has breast cancer?

Bayes' Law

$$P(A|B) = P(B|A)P(A) / P(B)$$

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$$P(\text{Cancer} \mid +\text{Test}) = P(+\text{Test}|\text{Cancer})P(\text{Cancer})/P(+\text{Test})$$

Bayes' Law

$$P(A|B) = P(B|A)P(A) / P(B)$$

$$P(\text{Cancer} \mid +\text{Test}) = P(+\text{Test}|\text{Cancer})P(\text{Cancer})/P(+\text{Test})$$

$$P(+) = P(+ \wedge C)P(C) + P(+ \wedge \sim C)P(\sim C)$$

Bayes' Law

$P(A|B) = P(B|A)P(A) / P(B)$

$P(Cancer \mid +Test) = P(+Test|Cancer)P(Cancer)/P(+Test)$

$P(+) = P(+ \wedge C)P(C) + P(+ \wedge \sim C)P(\sim C)$

$P(+) = 0.01*0.8 + 0.99*0.1$

$P(+) = 0.107$

$P(C \mid +) = 0.8 * 0.01 / 0.107 \approx \mathbf{0.075}$

Problems

People are bad at this.

People who should be good at this are bad at it.

How you present the problem affects how bad people are at it.

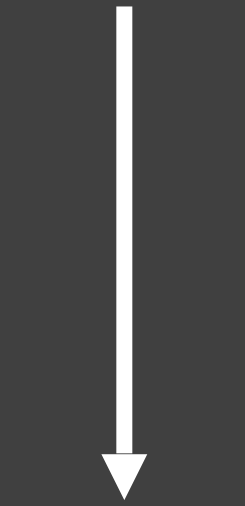
How To Present Probabilities

Probability	P(A) = 0.6
Percentage	60% chance of A
Natural Frequency	3 out of 5 times, A happens.

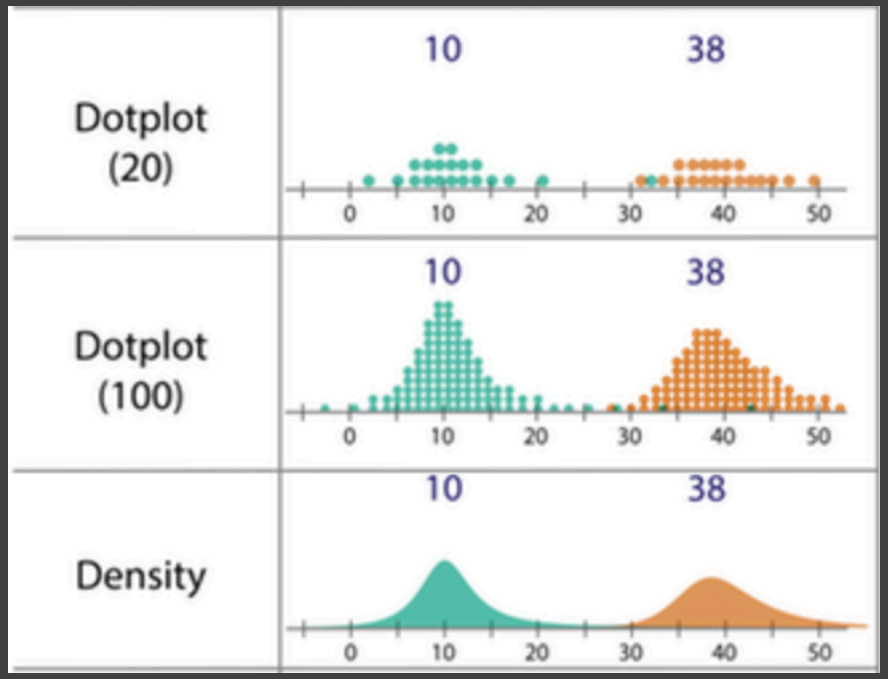
Alvitta Ottley, et al. “Improving Bayesian reasoning: the effects of phrasing, visualization, and spatial ability.” VIS 2016.

Quantile Dot Plots

Less Error

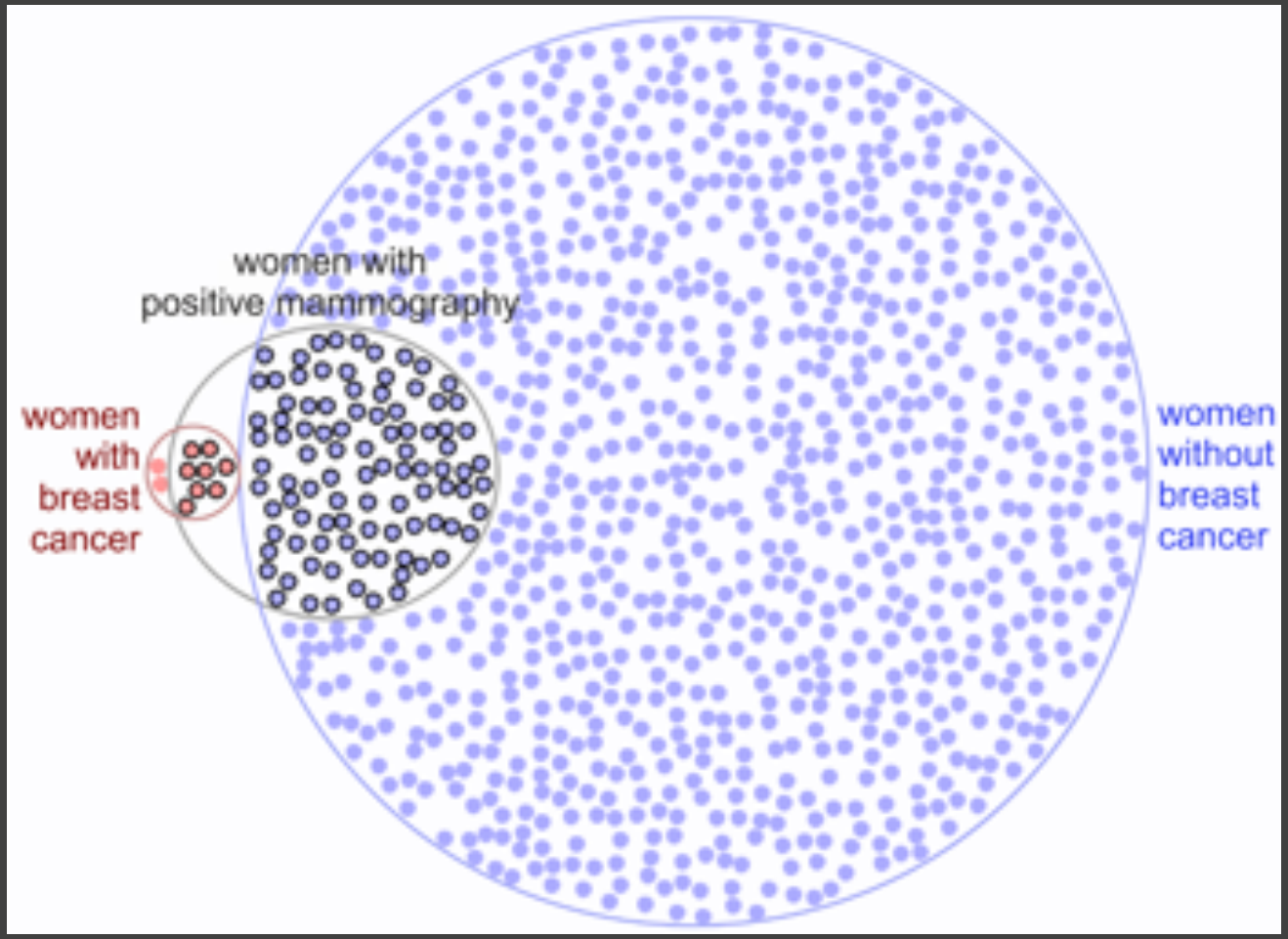


More Error



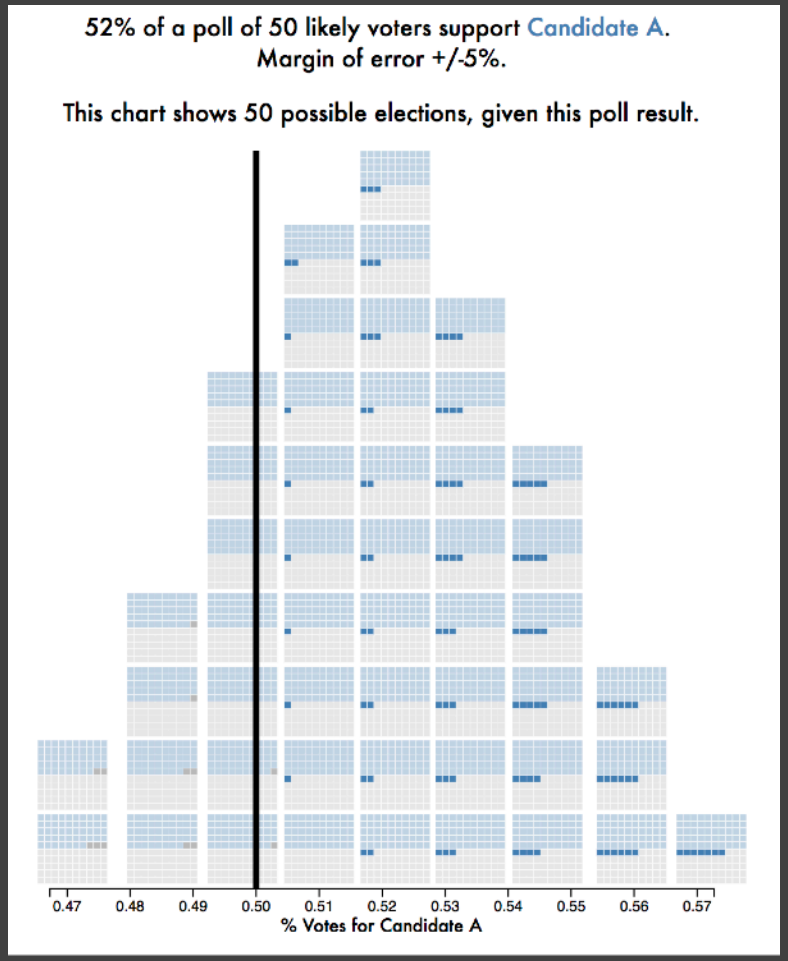
Matthew Kay, Tara Kola, Jessica Hullman, Sean Munson. "When(ish) is My Bus? User-centered Visualizations of Uncertainty in Everyday, Mobile Predictive Systems." CHI 2016.

Base Rate Fallacy



Luana Micallef, Pierre Dragicevic, and Jean-Daniel Fekete. "Assessing the Effect of Visualizations on Bayesian Reasoning Through Crowdsourcing." VIS 2012.

Pangloss Dot Plot?



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.

What Can Go Wrong?

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A LOT

Questions To Answer

What Does Uncertainty Mean?

How Should I Visualize It?

What Can Go Wrong?

Questions To Answer

What Does Uncertainty Mean?

LOTS OF
THINGS
IT DEPENDS

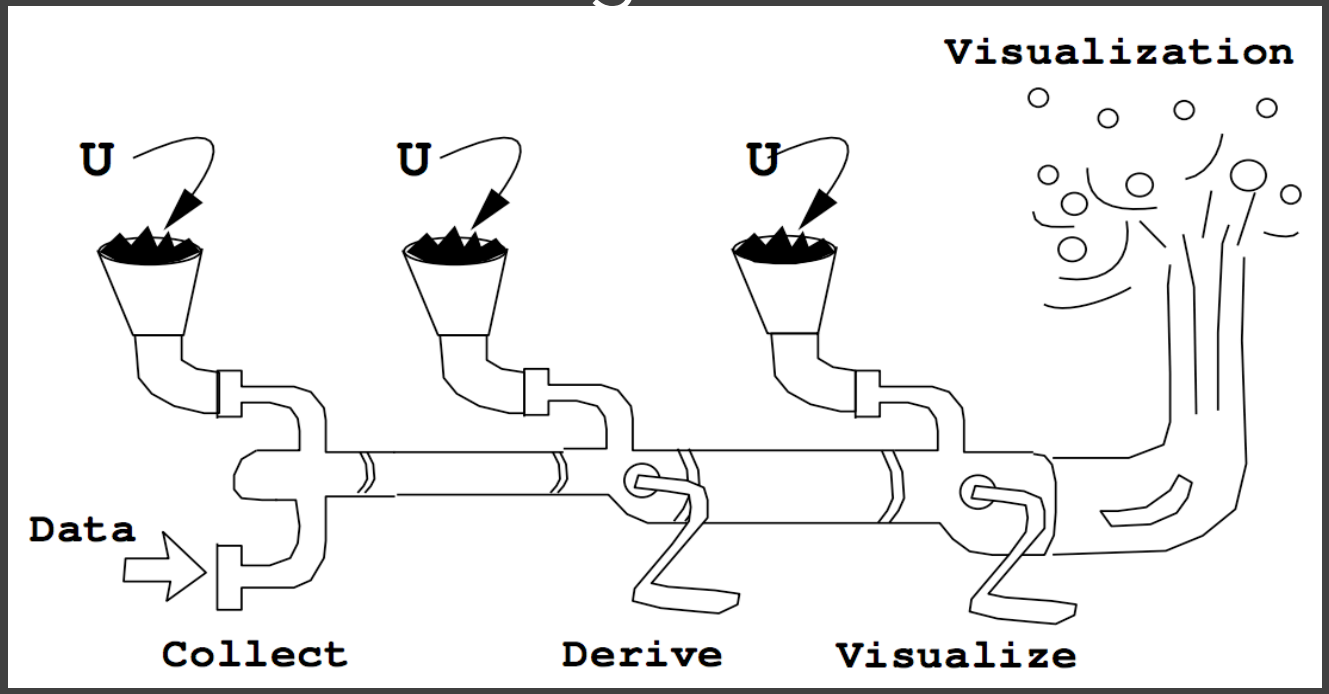
How Sho

What Ca

A LOT

Wrap Up

Uncertainty can happen at all stages of the analysis process, from data collection to final decision-making



Wrap Up

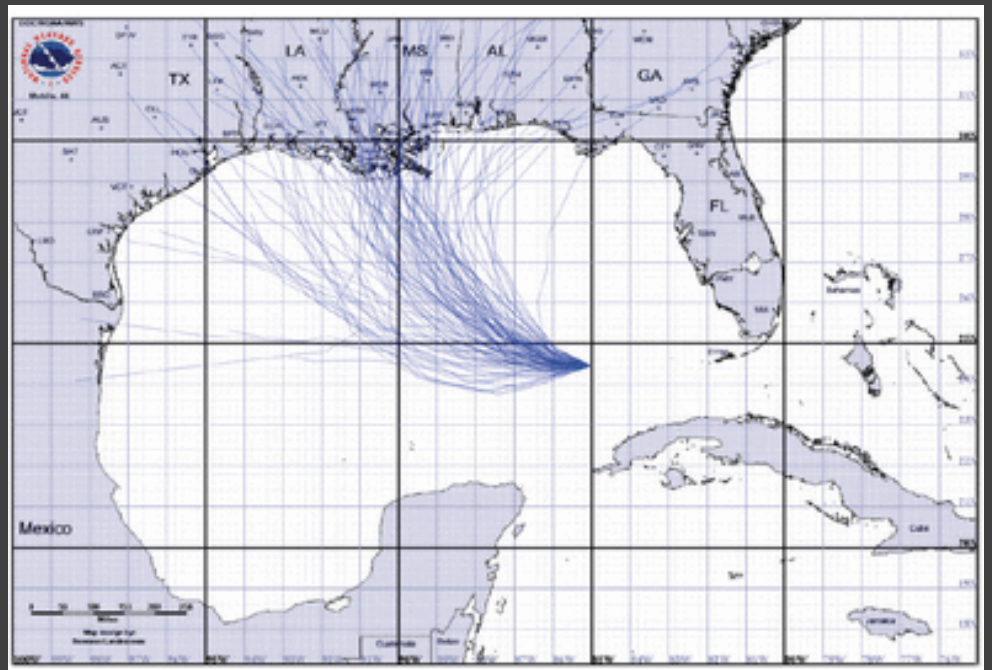
Variables like blur and transparency can be intuitive for showing uncertainty, but hard to decode.

Wrap Up

Consider when uncertainty is high enough that doing *nothing* is the right thing to do.

Wrap Up

Consider using discrete samples to show variation and uncertainty in a model



Stuff I Showed You

http://flowingdata.com/2015/09/23/years-you-have-left-to-live-probably/

http://rpsychologist.com/d3/CI/

https://www.nytimes.com/2014/05/02/upshot/how-not-to-be-misled-by-the-jobs-report.html?_r=0