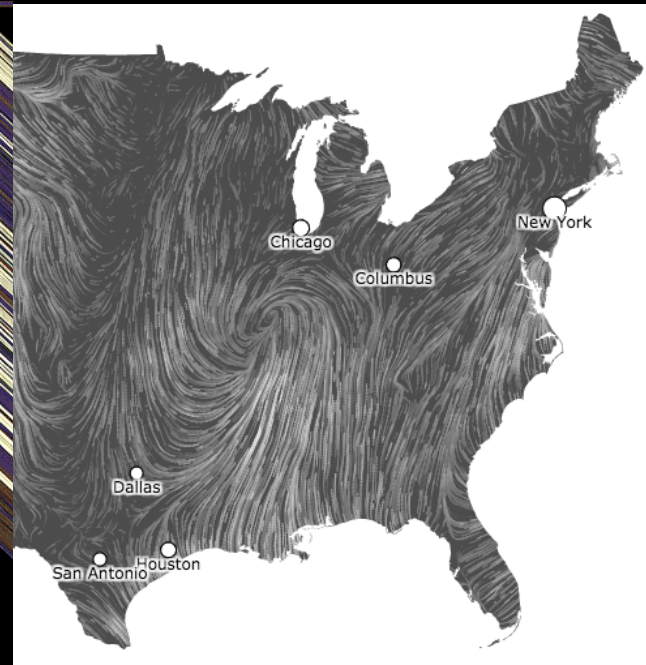
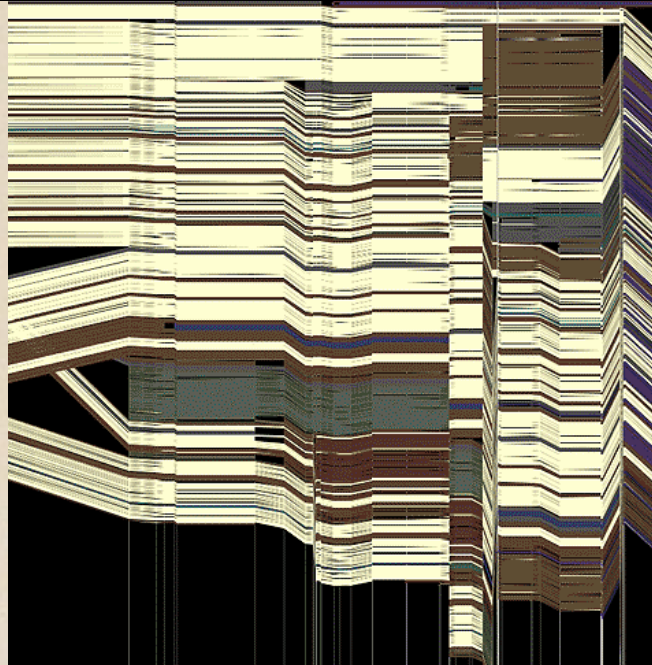
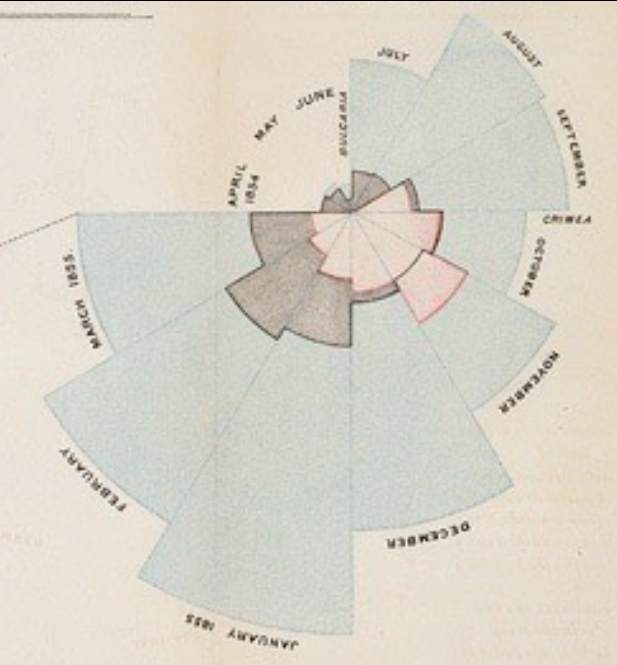


CSE 442 - Data Visualization

Uncertainty



Jeffrey Heer University of Washington

(with significant material from Michael Correll)

Questions To Answer

What Does Uncertainty Mean?

How Should I Visualize It?

What Can Go Wrong?

**What we talk about when we
talk about “uncertainty”...**

Things “Uncertainty” Can Mean

Doubt

Risk

Variability

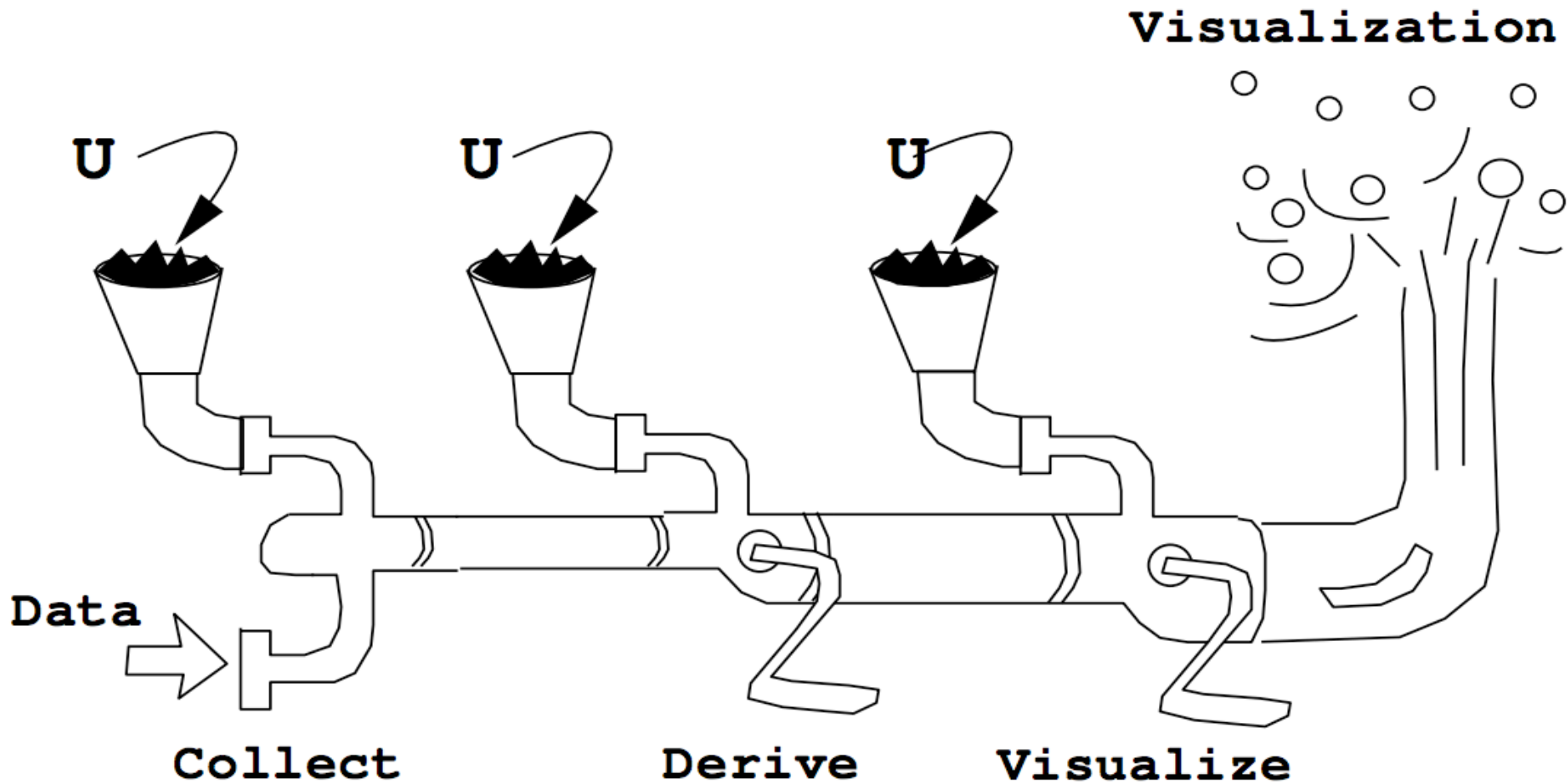
Error

Lack of Knowledge

Hedging

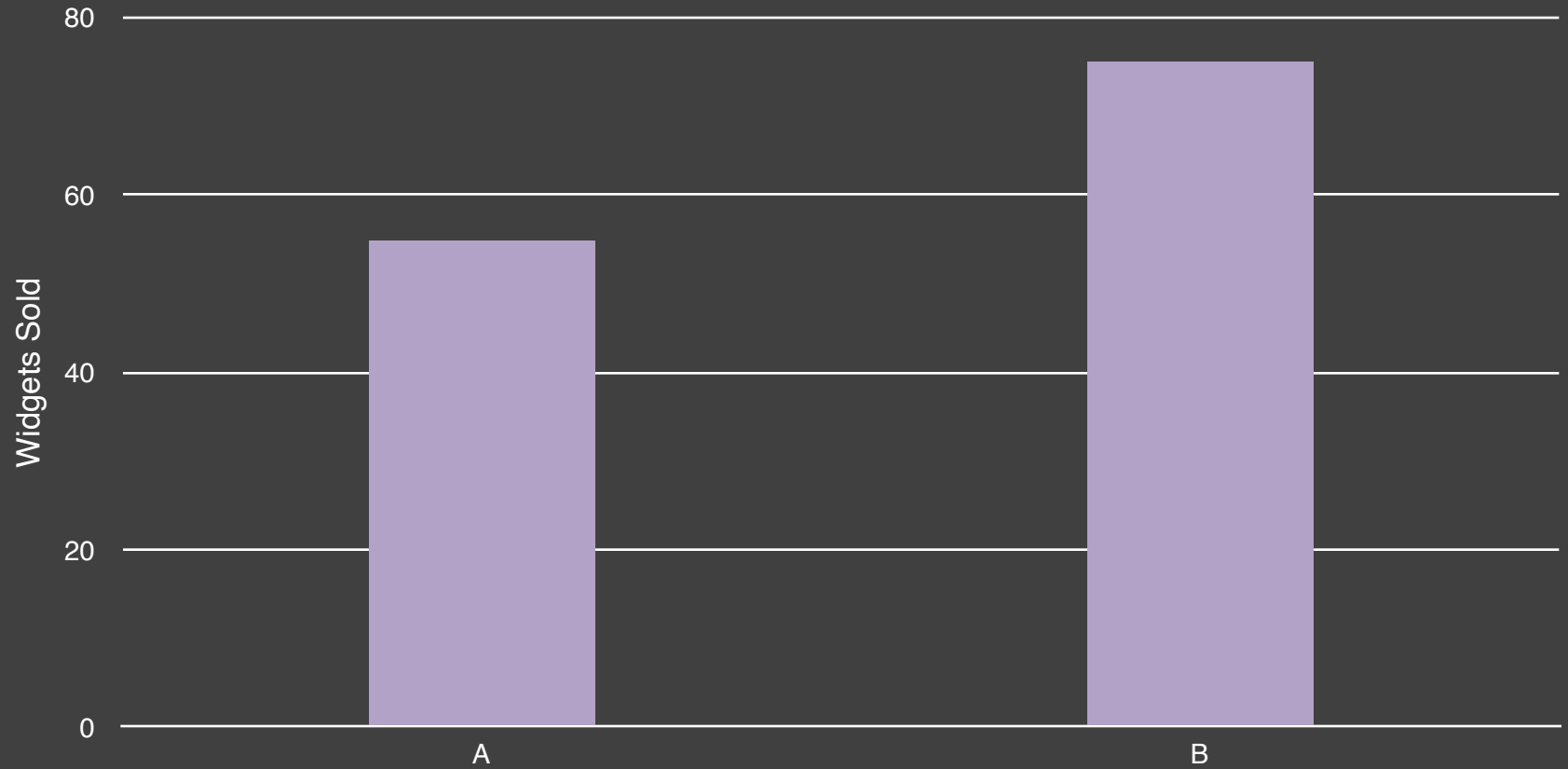
...

Uncertainty Vis Pipeline



A Bar Chart

Sales of Widgets for Stores A and B

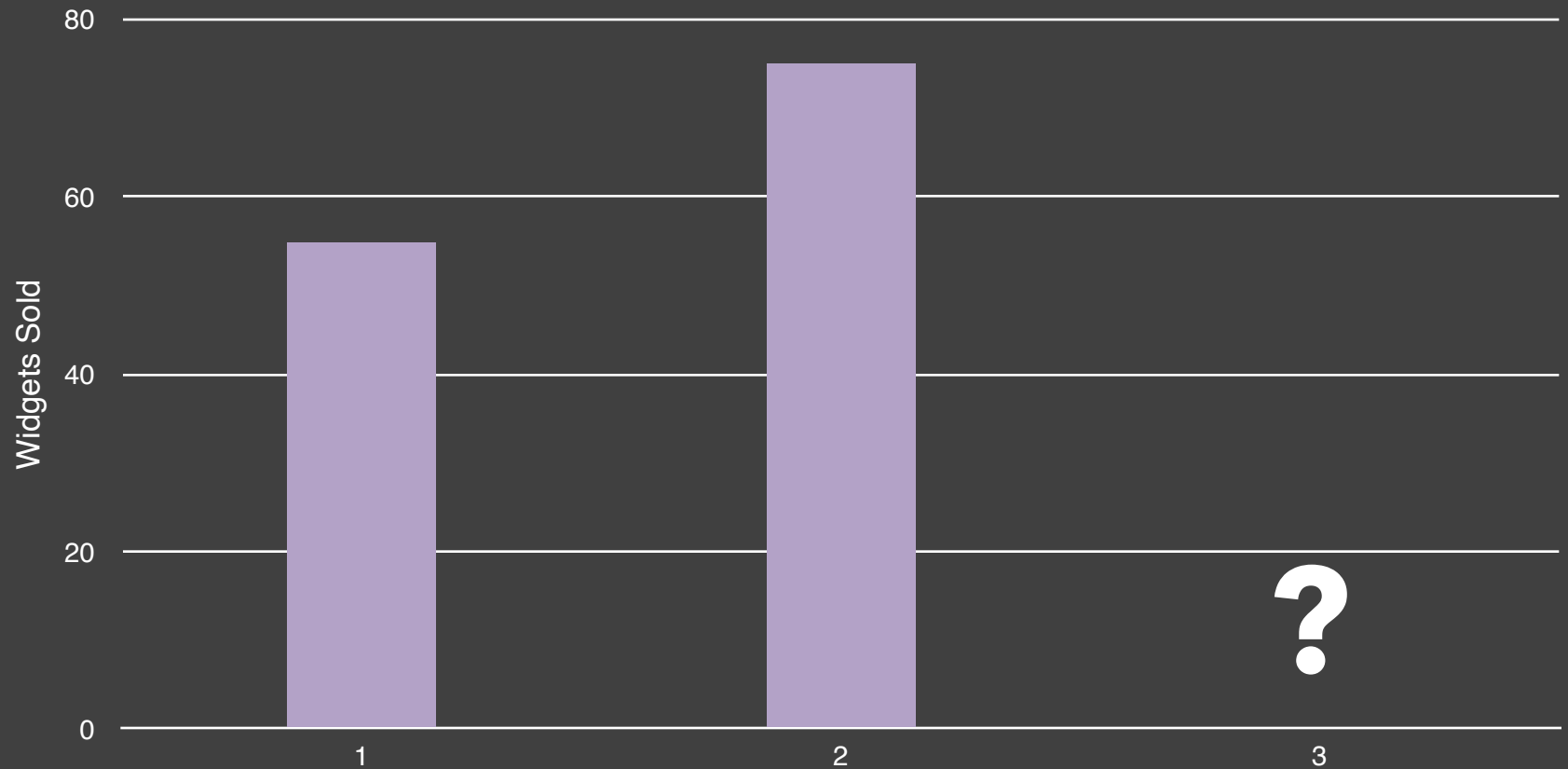


Measurement Uncertainty



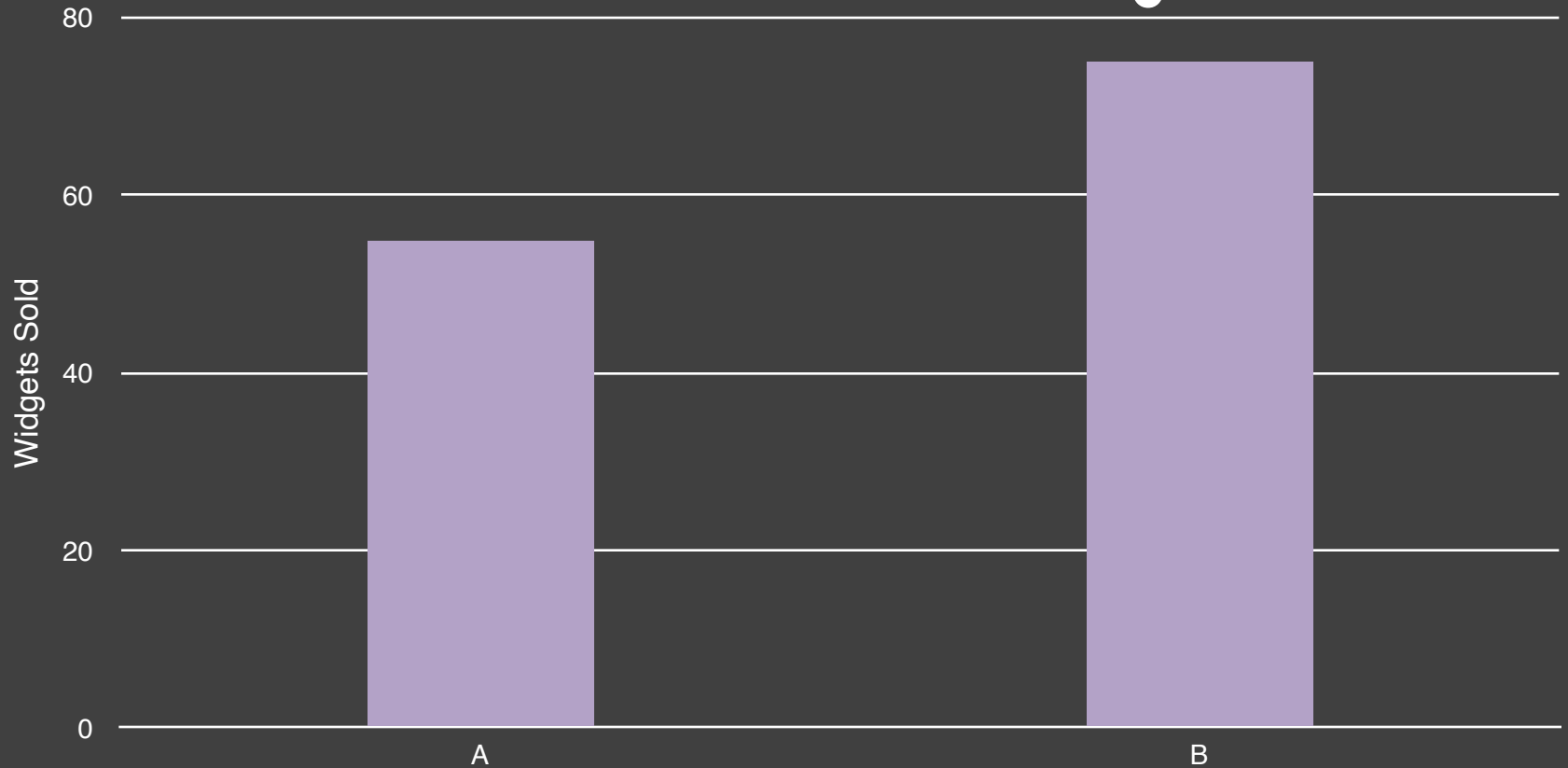
Forecast Uncertainty

Sales of Widgets for Quarters 1 and 2



Decision Uncertainty

We Should Close Store A ?



Uncertainty Sources

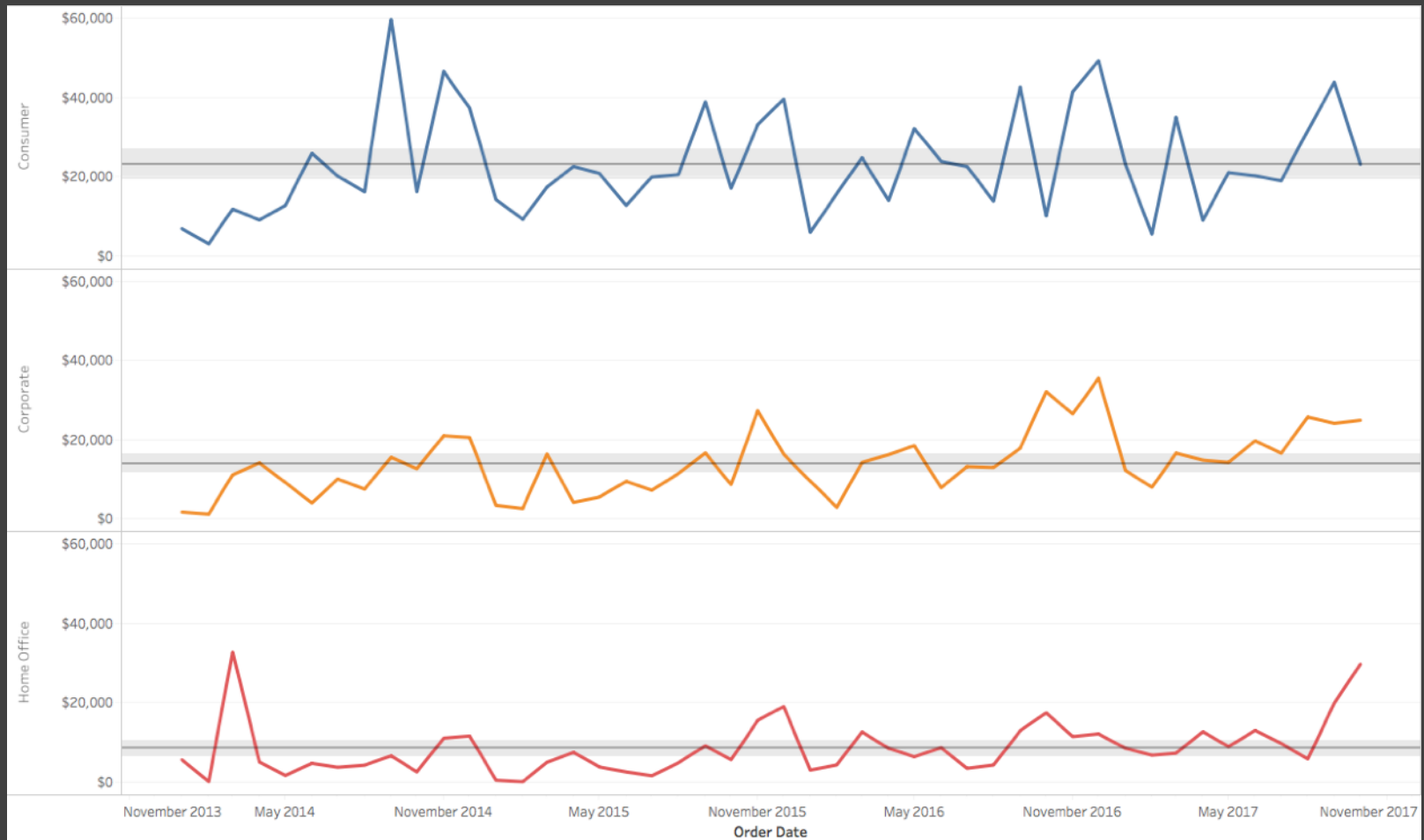
Measurement Uncertainty: "We're not sure what the data are"

Model Uncertainty: "We're not sure how the data fit together"

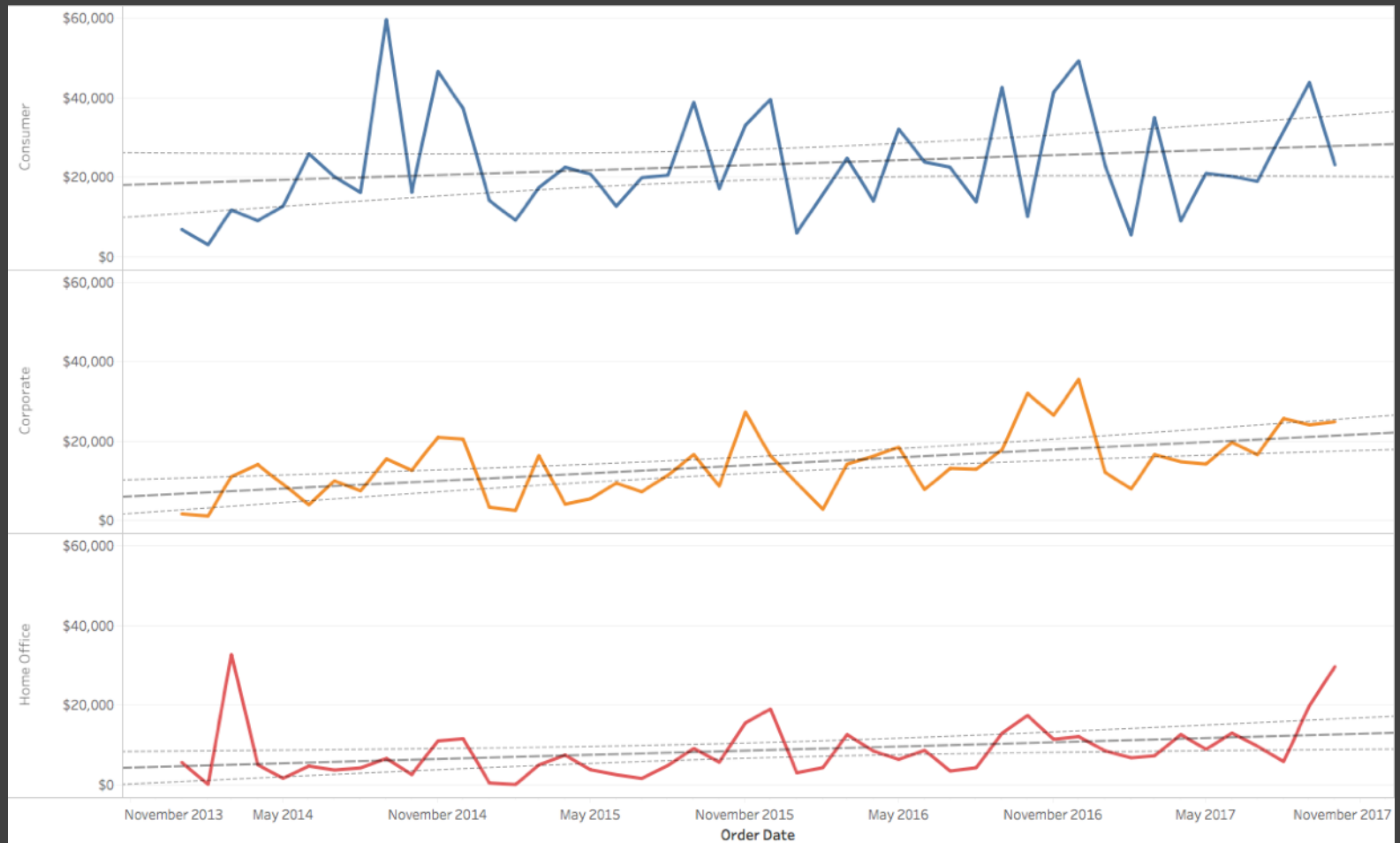
Forecast Uncertainty: "We're not sure what will happen to the data next"

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

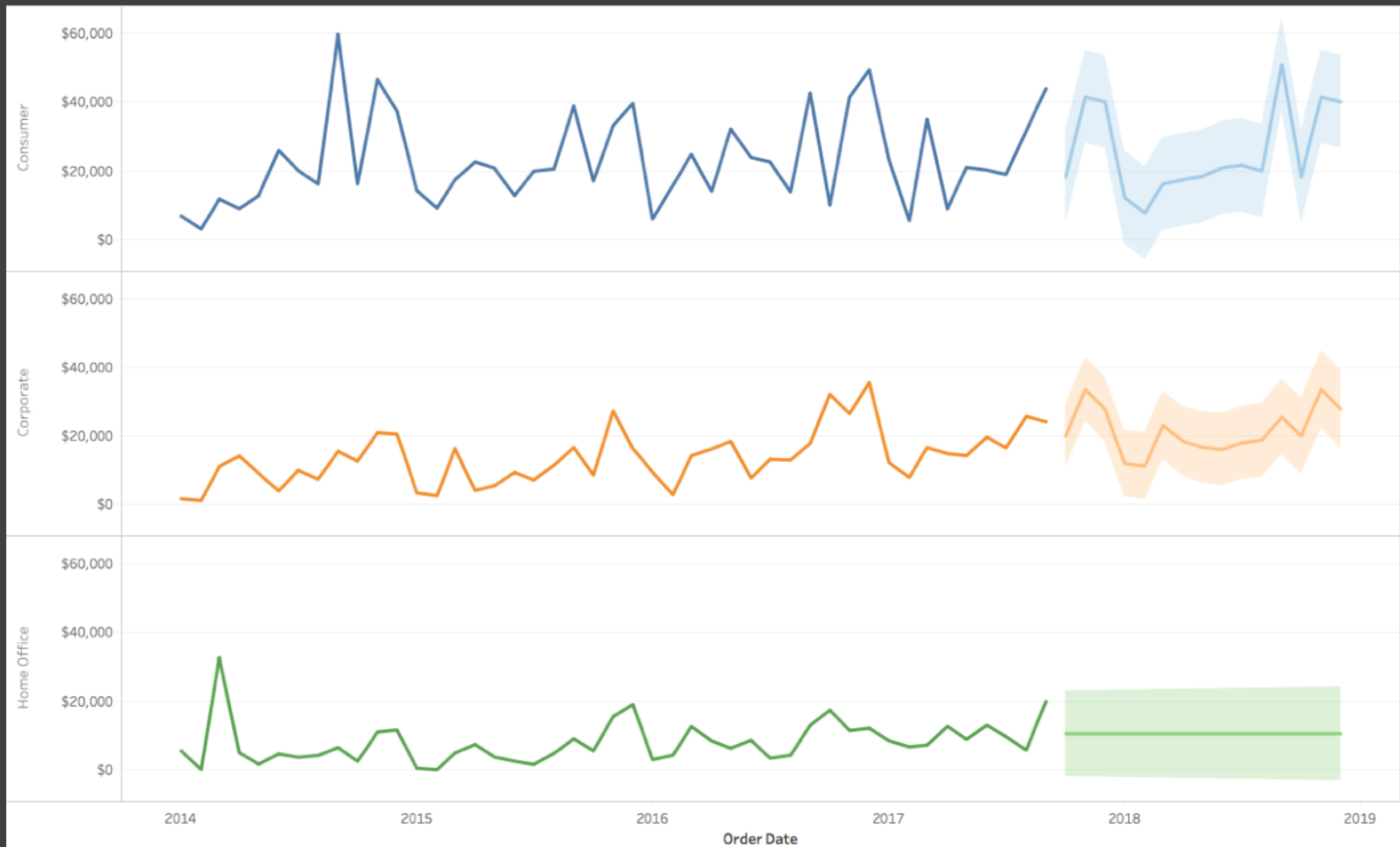
Measurement Uncertainty



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"



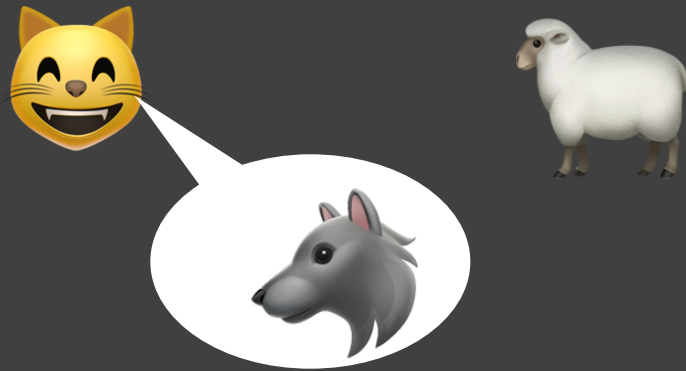
Types of Error



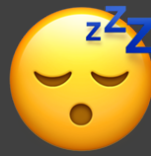
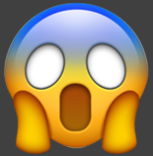
	 False Positive
 False Negative	

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

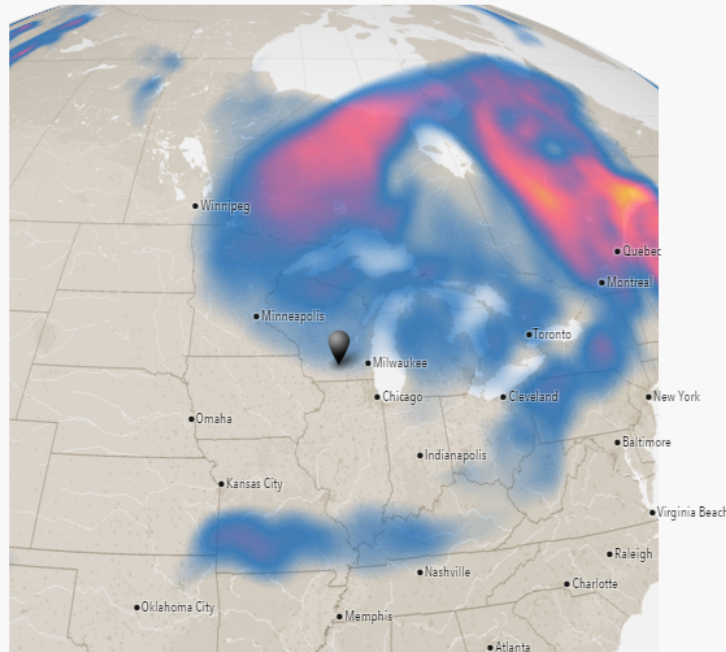
PRECIP MAP

Local

Regional

Global

TODAY 5PM



RIGHT NOW +

☁ 41°

Overcast · Feels like 32°

NEXT HOUR

Overcast for the hour.

NEXT 24 HOURS

Mostly cloudy throughout the day.

NEXT 7 DAYS

Light rain throughout the week, with temperatures rising to 64°F on Sunday.

TODAY ☁ Mostly cloudy throughout the day.

37° 41°



WED ☁ Partly cloudy until evening.

31° 47°



THU ☀ Clear throughout the day.

27° 53°



FRI ☁ Light rain in the afternoon.

32° 56°



SAT ☁ Mostly cloudy until evening.

34° 55°



Measurement Uncertainty

Precision



Measurement Uncertainty

Precision



Measurement Uncertainty

Precision



Measurement Uncertainty

Precision



Accuracy



Measurement Uncertainty

Precision



Accuracy



Measurement Uncertainty

Precision



Accuracy

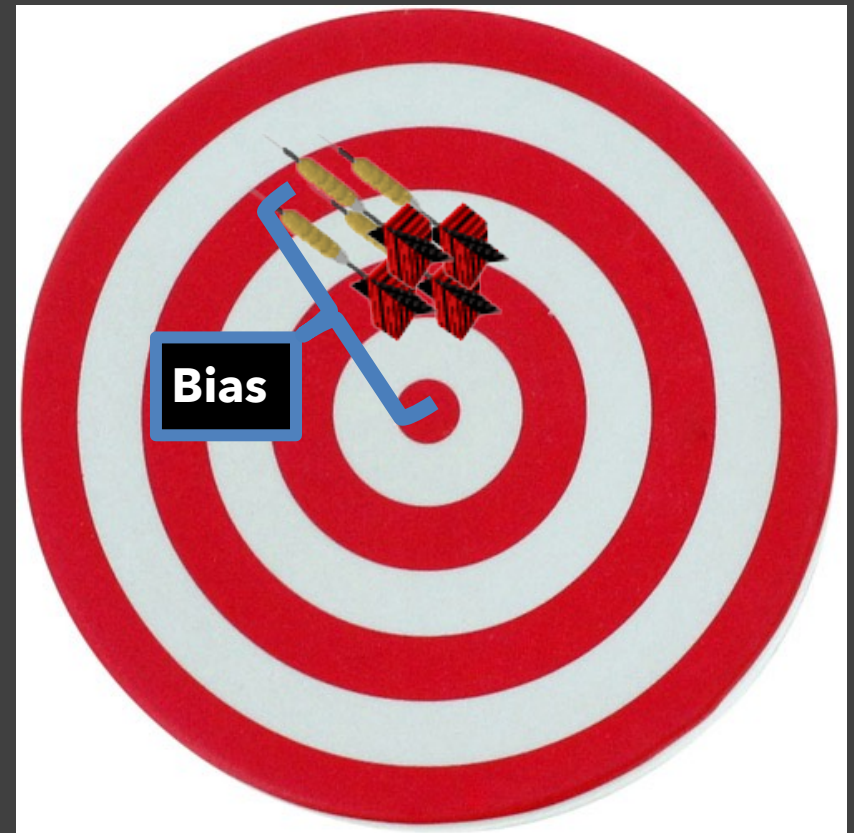


Measurement Uncertainty

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.

What Does Uncertainty Mean?

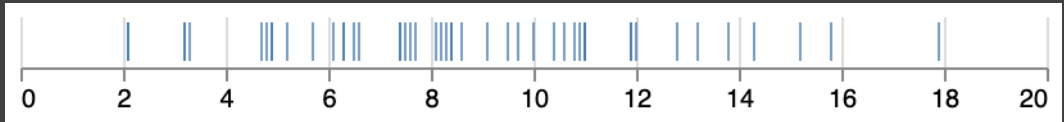
Any one of a number of potentially interconnected quantitative, qualitative, or factors that affect the quality, reliability, or utility of your data or data-driven decisions. Anything that can cause you to be unsure about your data or how to use it.

**LOTS OF
THINGS**

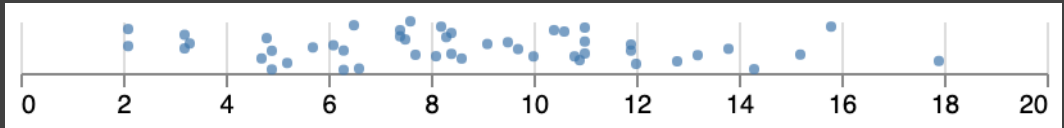
Visualizing Distributions

Distribution Visualizations

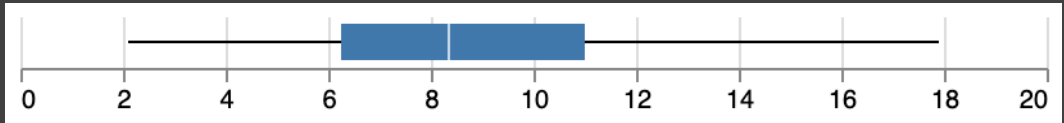
Strip Plot



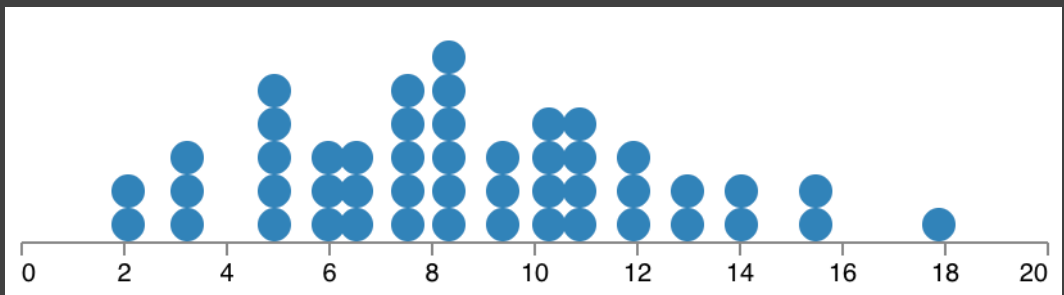
Jittered Plot



Box Plot



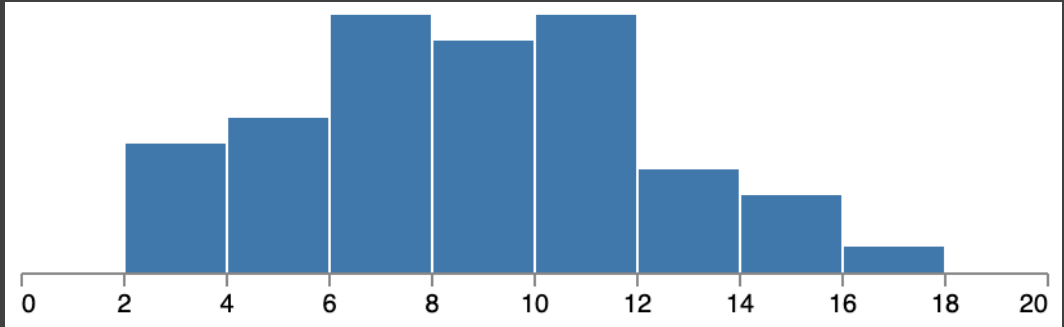
Dot Plot



Distribution Visualizations

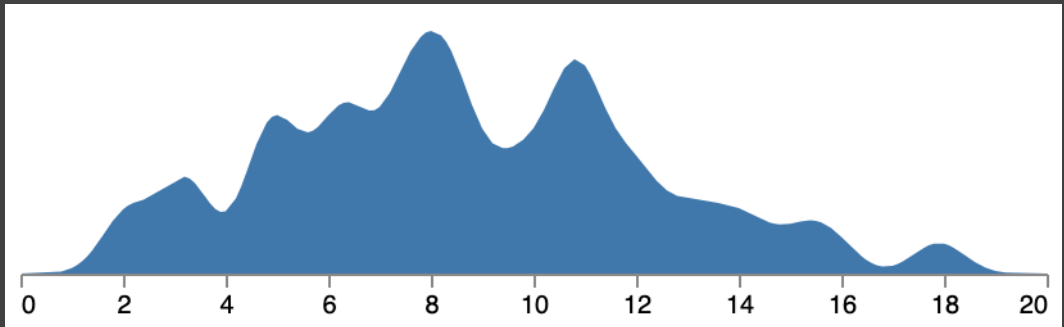
Histogram

bin size = 2



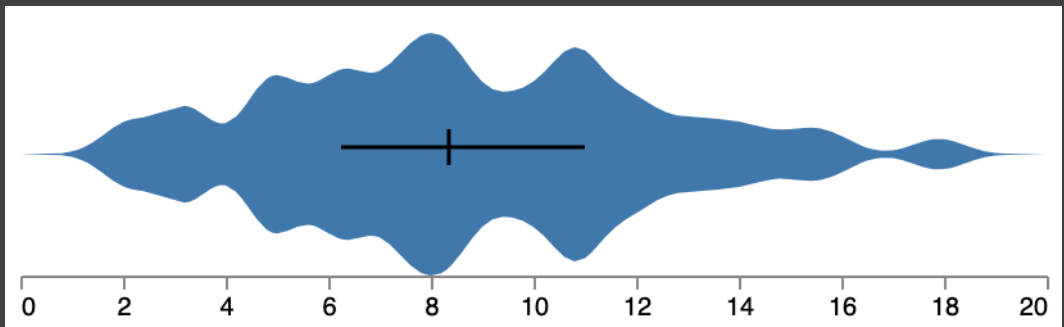
Density Plot

kde, $\sigma = 0.5$



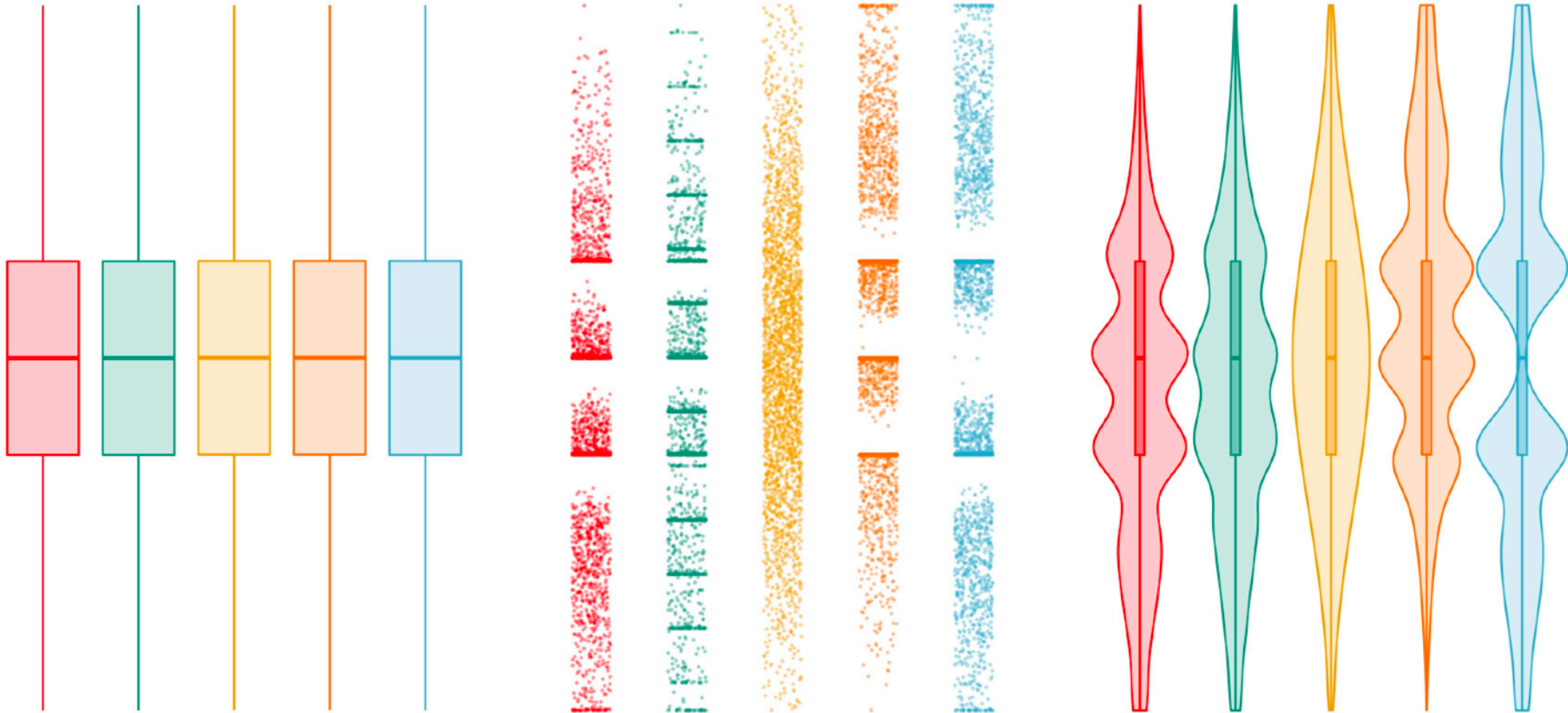
Violin Plot

kde, $\sigma = 0.5$

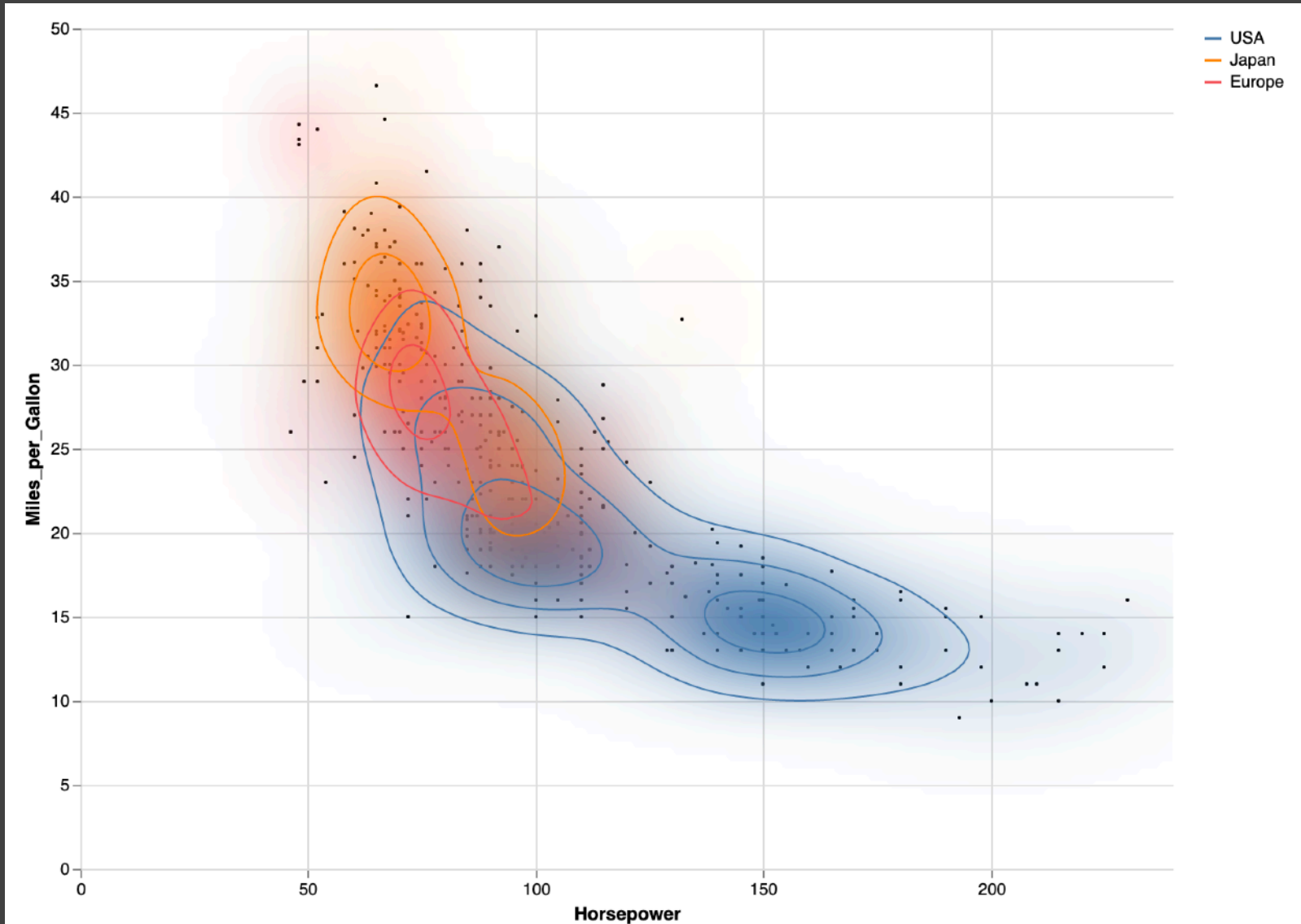


Identical boxplots, different distributions

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



Quantified Uncertainty

Error Bars

Standard Deviation (σ)

Standard Error (σ / \sqrt{n})

1.5 * IQR (Interquartile Range)

Confidence Intervals

... *and so on*

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.

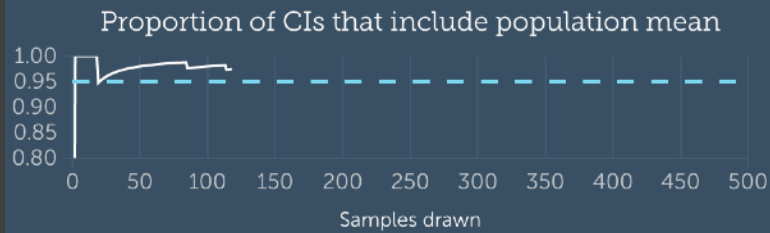
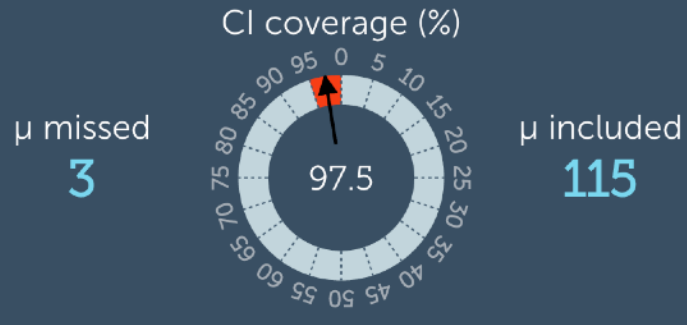
Wrong!

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

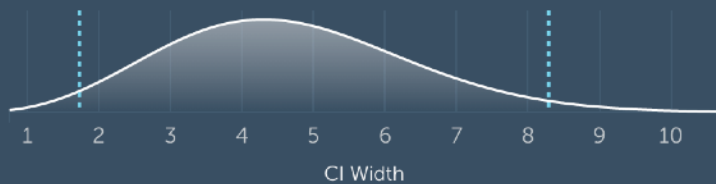
“Confidence” concerns the procedure, not the data. (Though see Bayesian *credible intervals*...)

Confidence Intervals

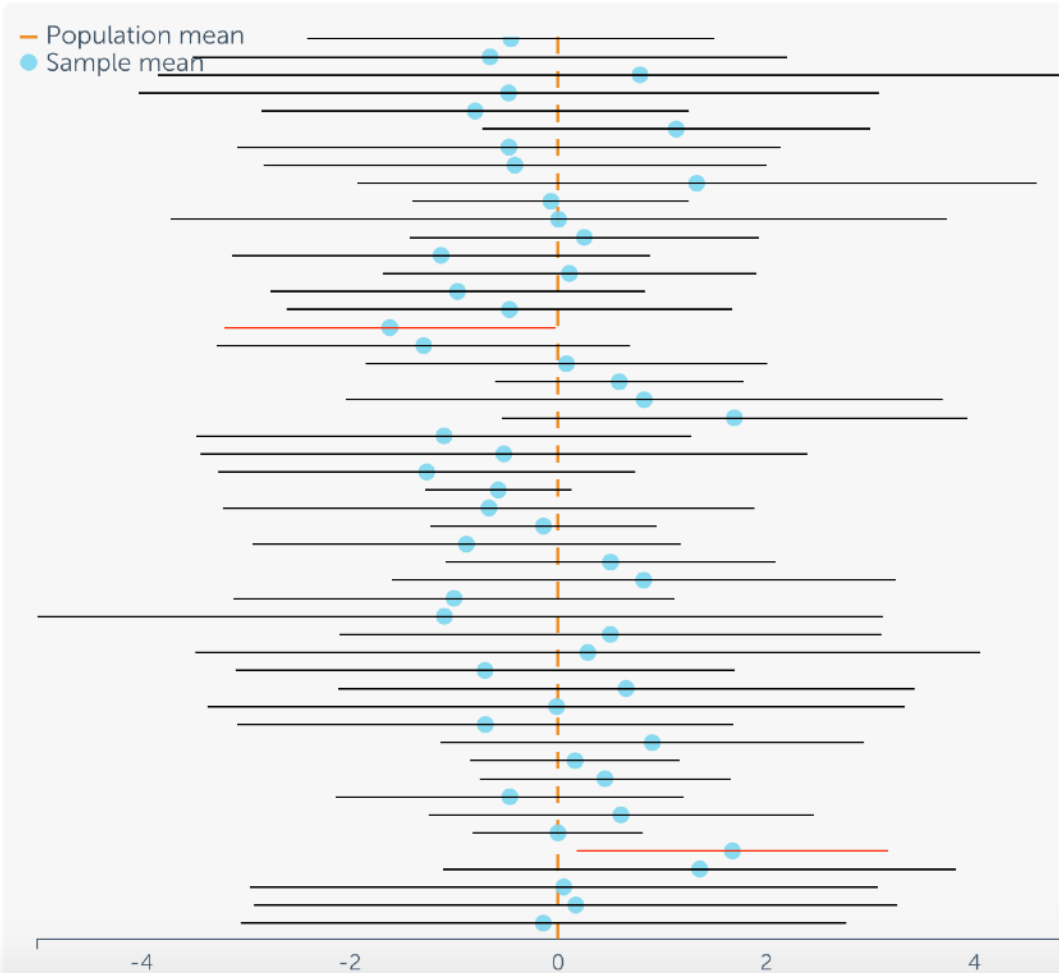
Simulation statistics



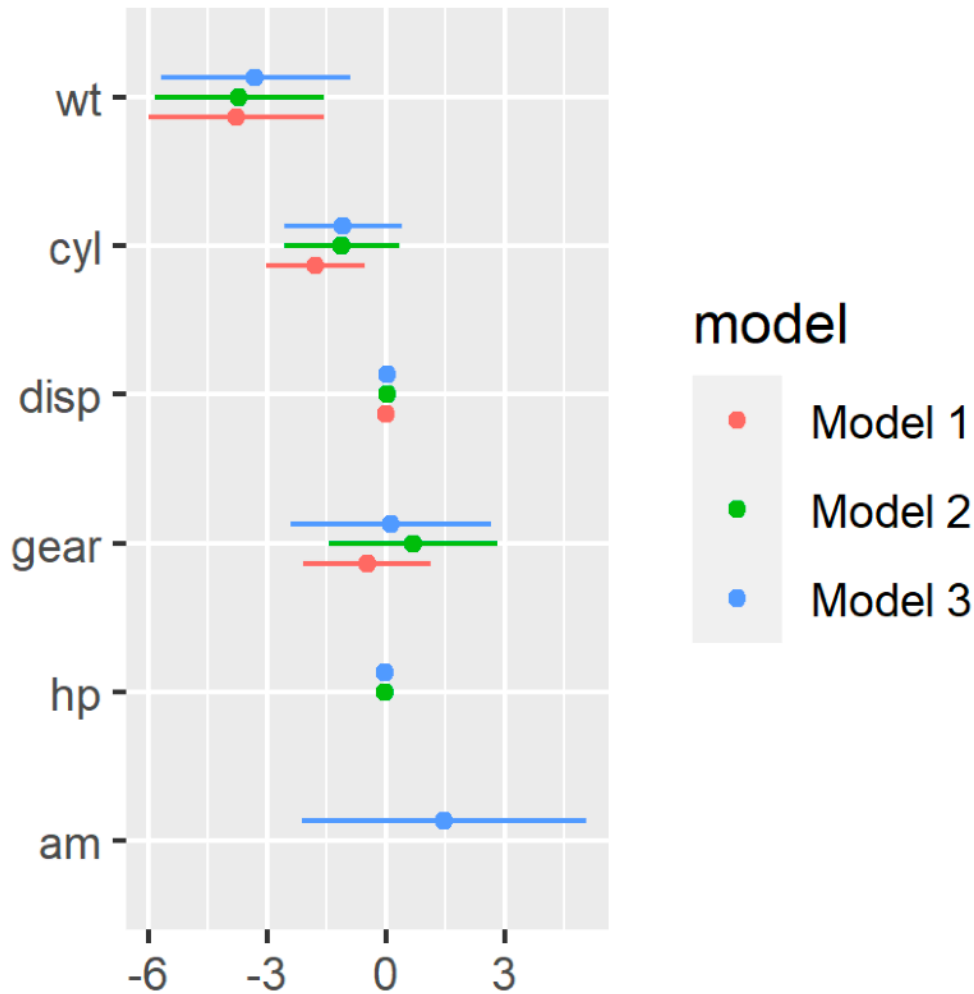
CIs sampling distribution



95% confidence intervals



Regression Coefficients



95% CIs for regression model parameters.

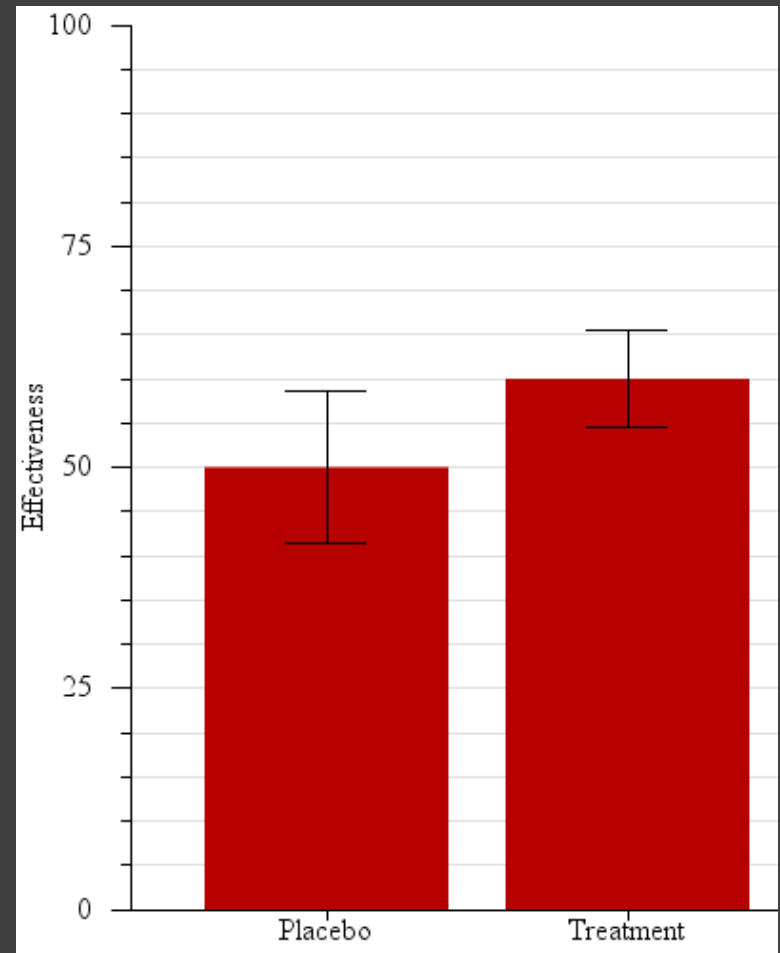
Here, we compare fitted parameters from 3 different models. Not all predictors are included in all models.

Visual comparison: does the CI overlap 0?

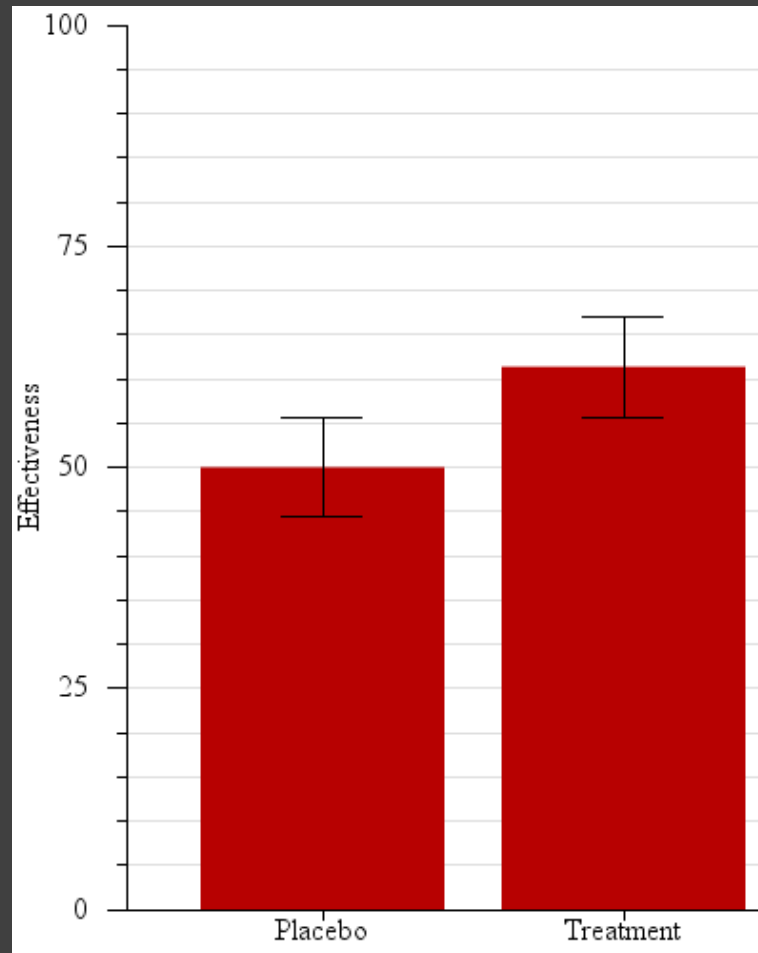
Error Bars

The mean treatment effect is higher than than the placebo.

Is this difference in means *statistically significant*?

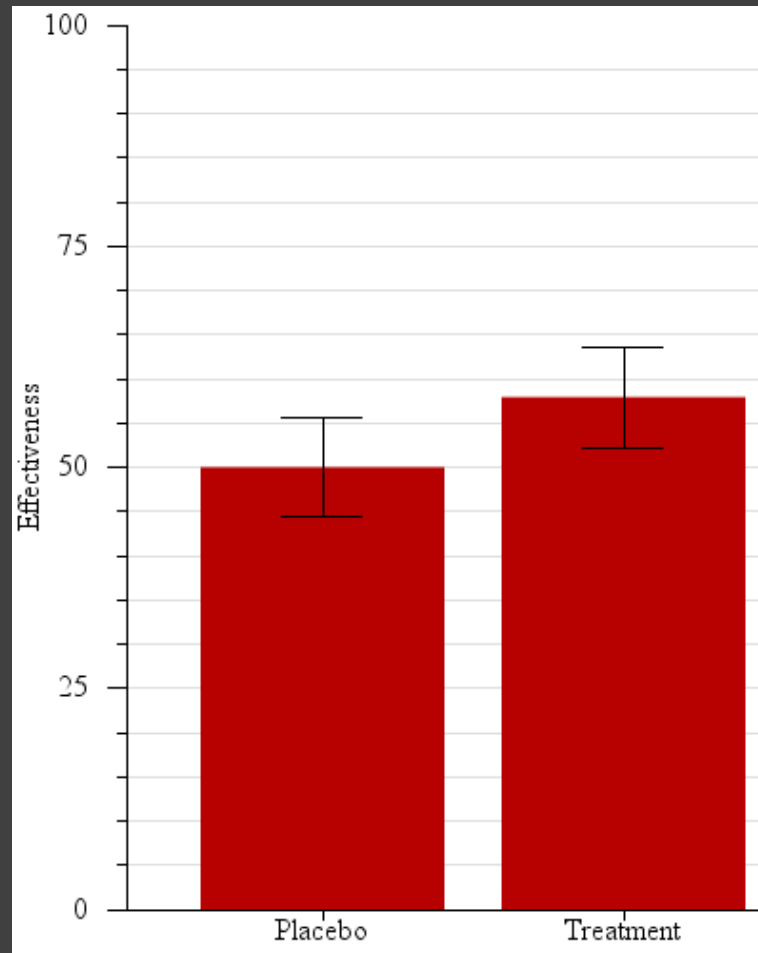


Guess the p-value...



Error bars depict
95% Conf. Interval

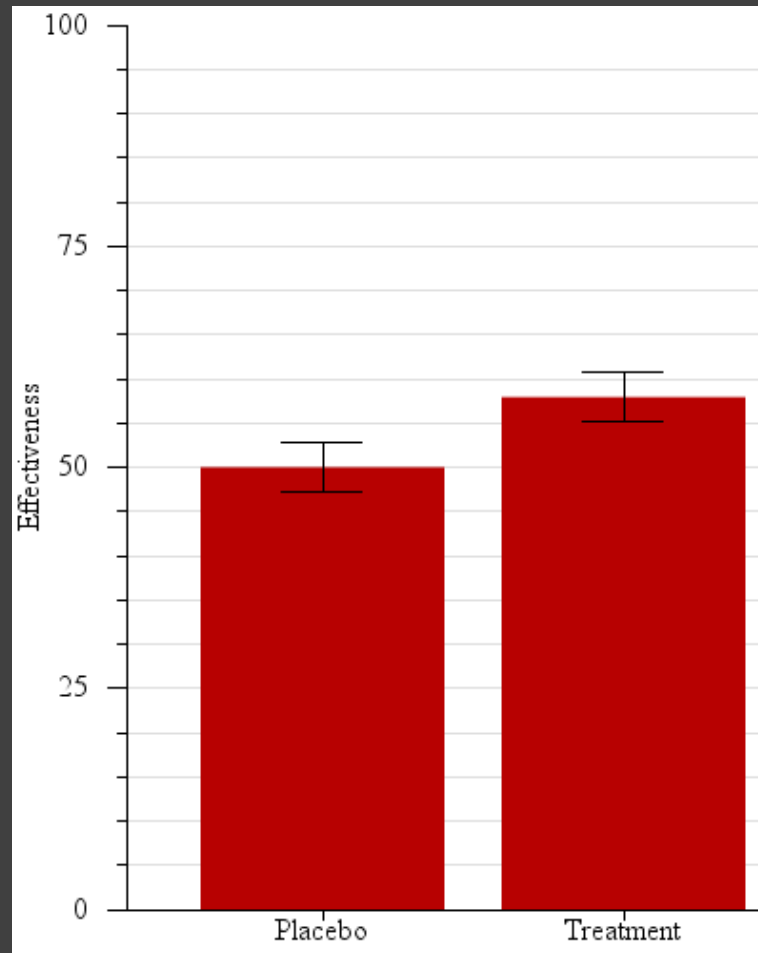
Guess the p-value...



Error bars depict
95% Conf. Interval

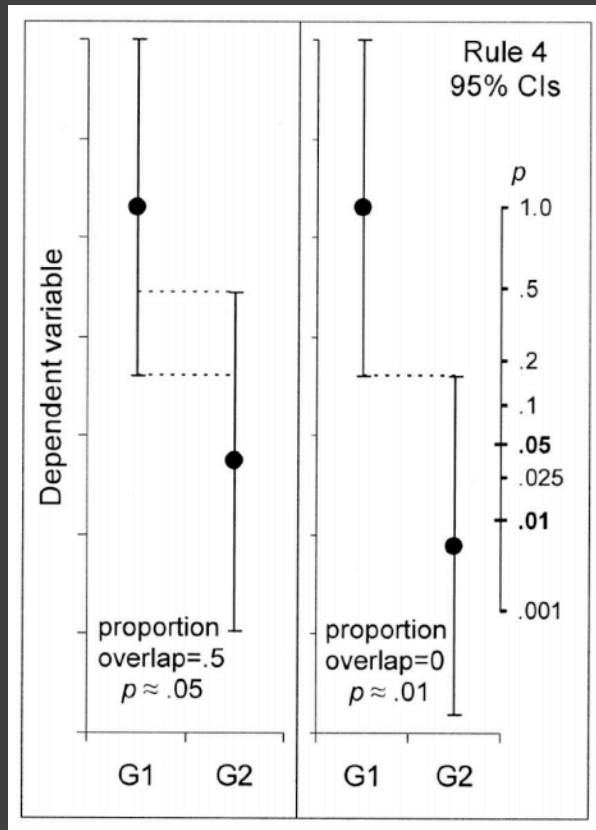
Guess the p-value...

Error bars depict
standard error

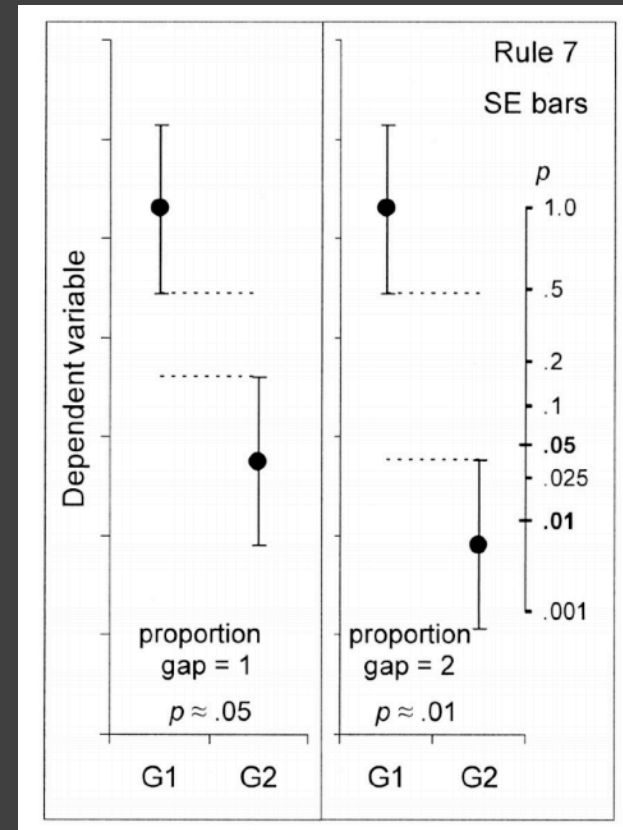


Inference by Eye

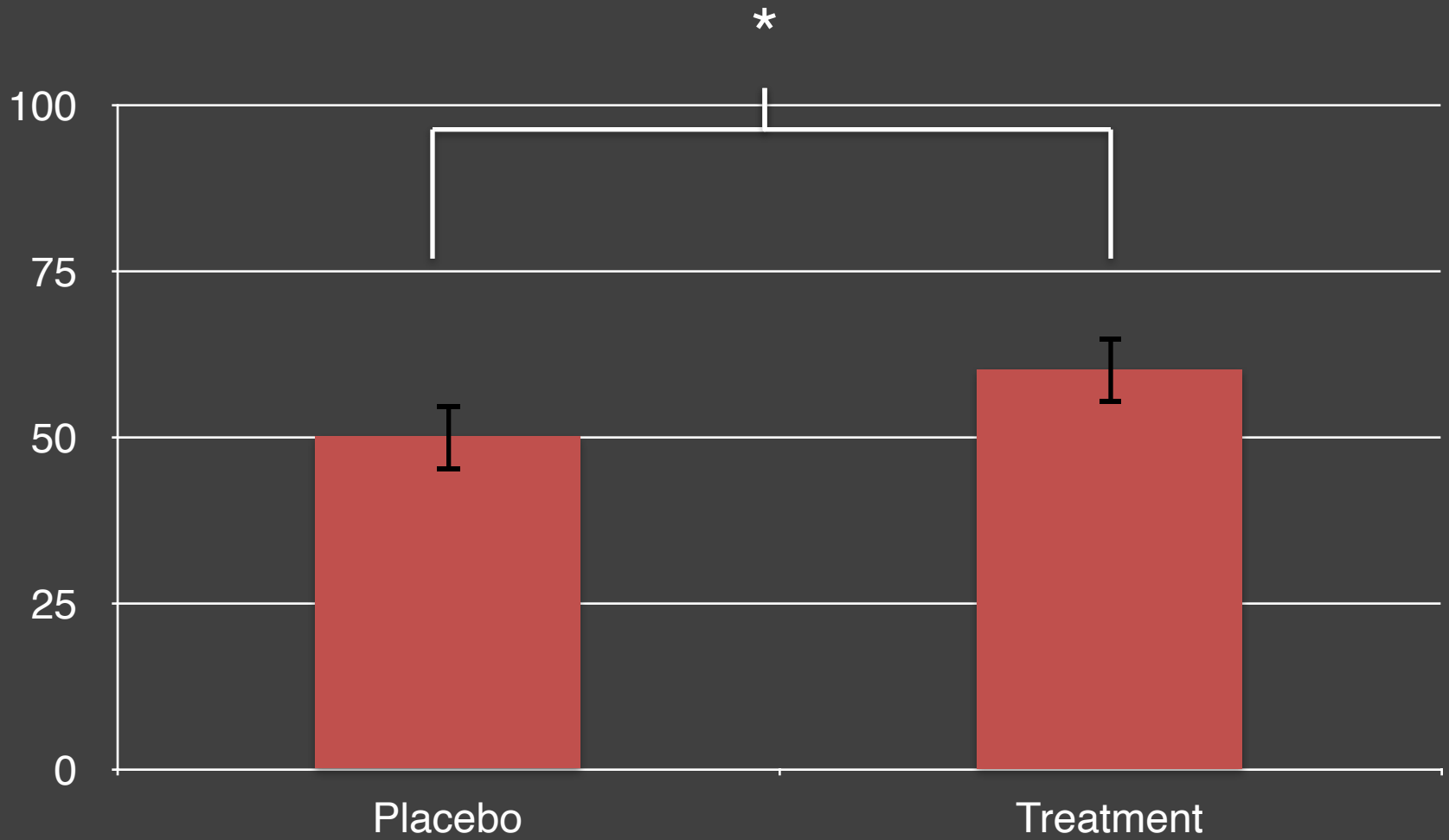
95% CIs



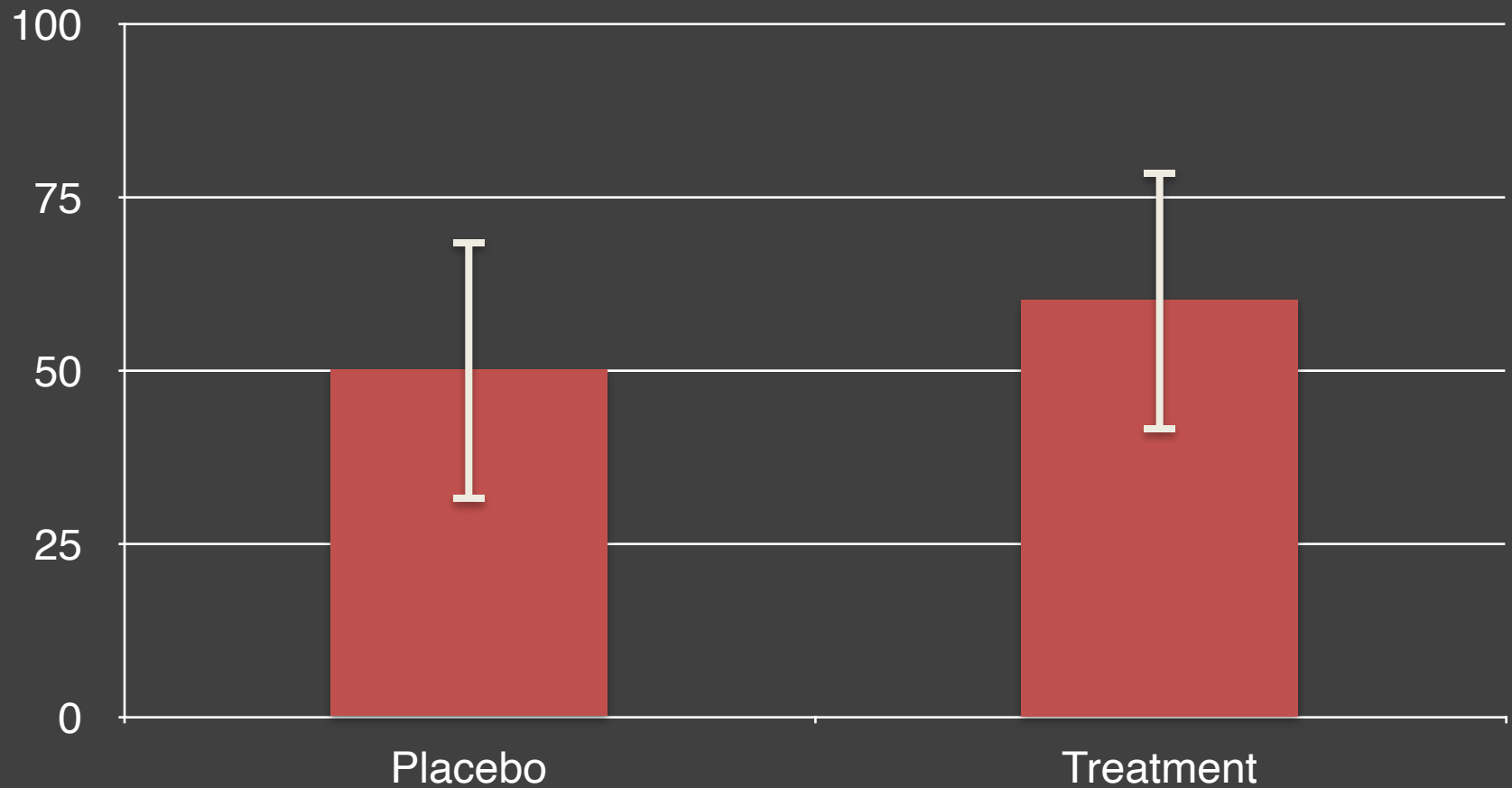
Standard Error



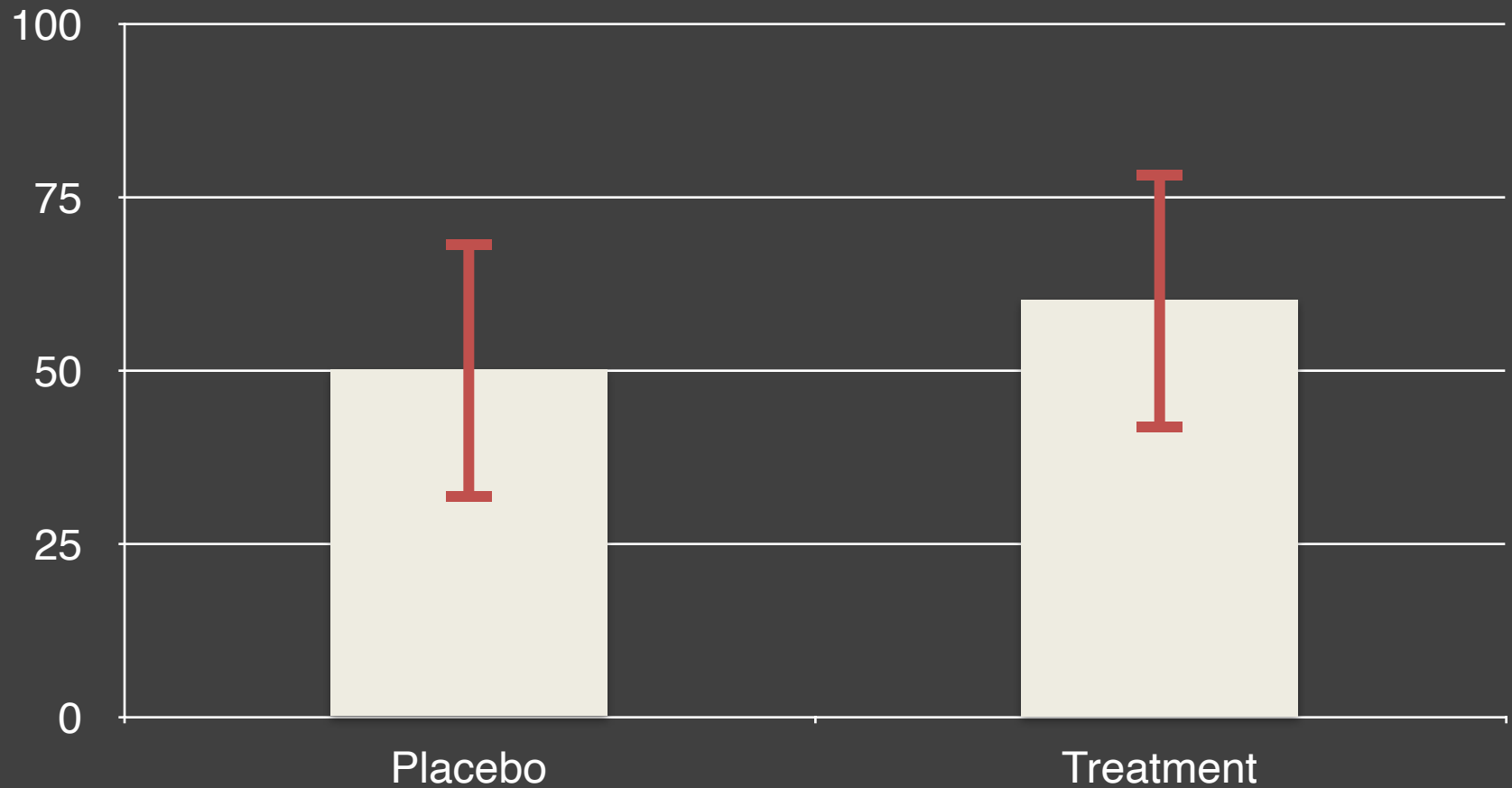
Cumming, Geoff and Finch, Sue. Inference by eye: confidence intervals and how to read pictures of data. American Psychologist, 2005.



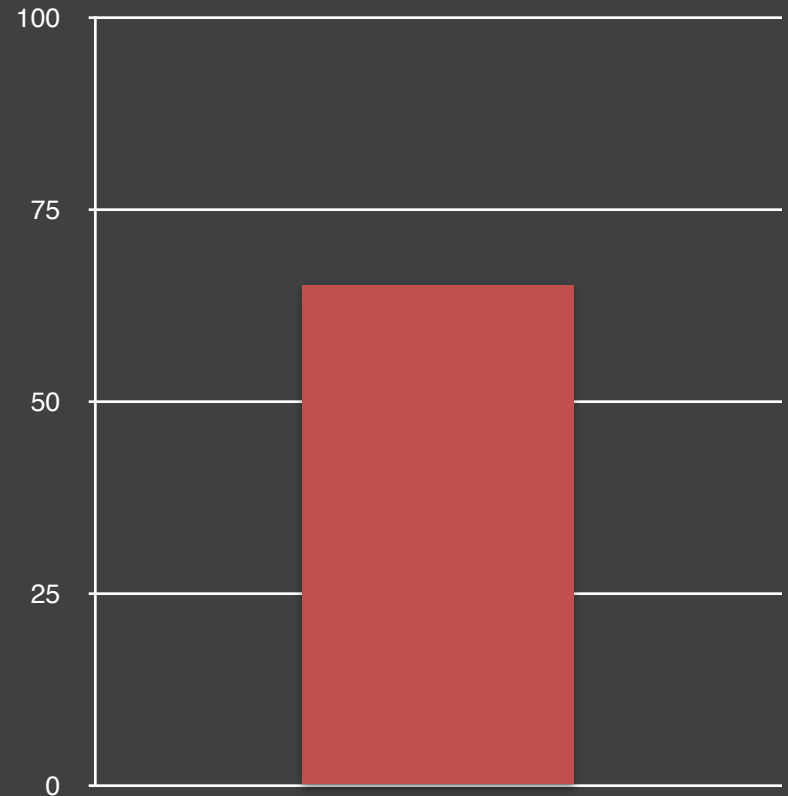
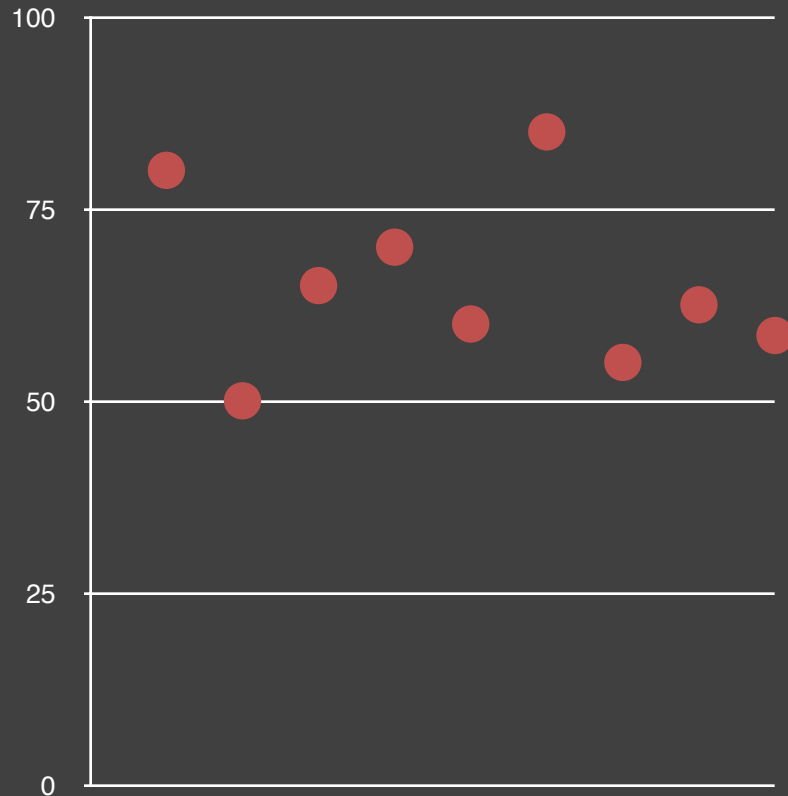
Misplaced Emphasis?



Misplaced Emphasis?

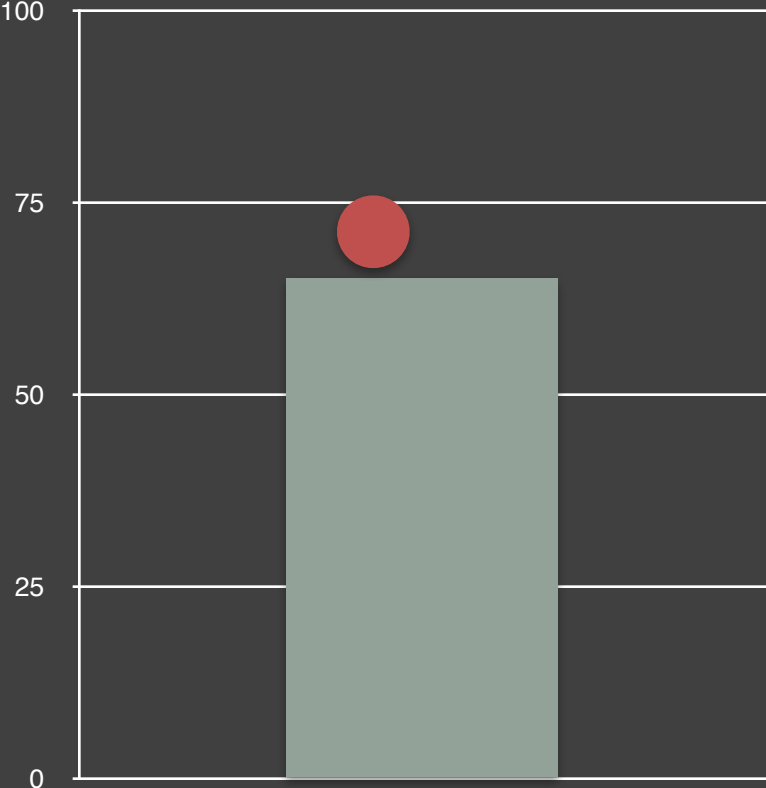
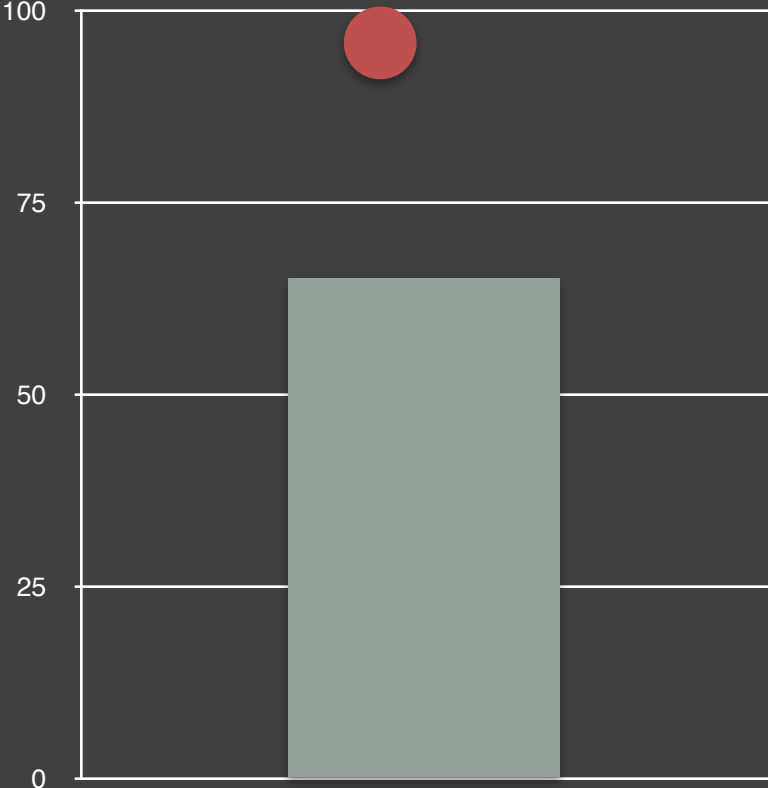


Within-the-Bar Bias

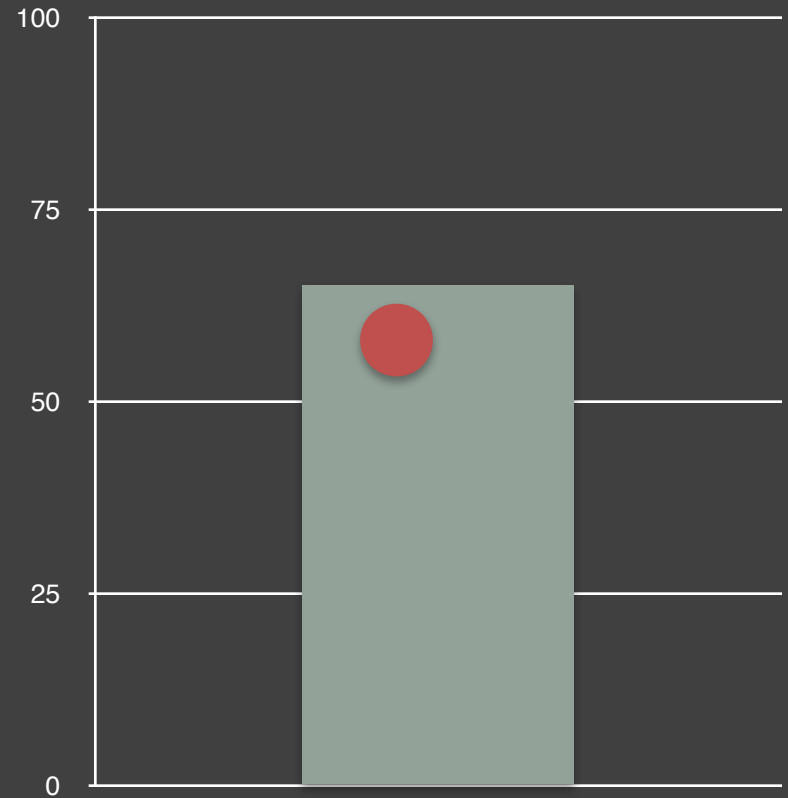
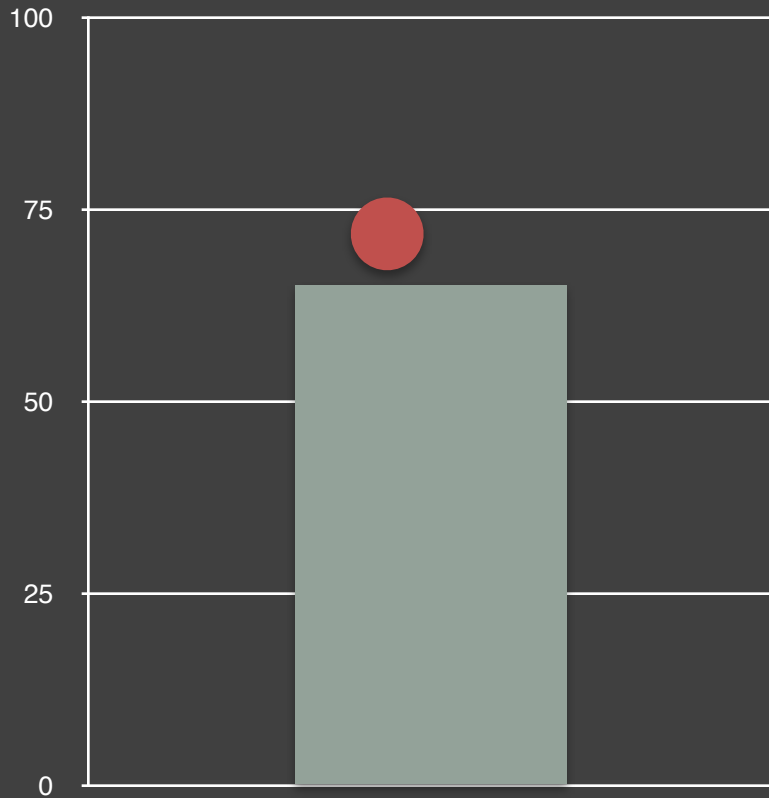


Newman & Scholl. (2012) "Bar graphs depicting averages are perceptually misinterpreted: the within-the-bar bias."

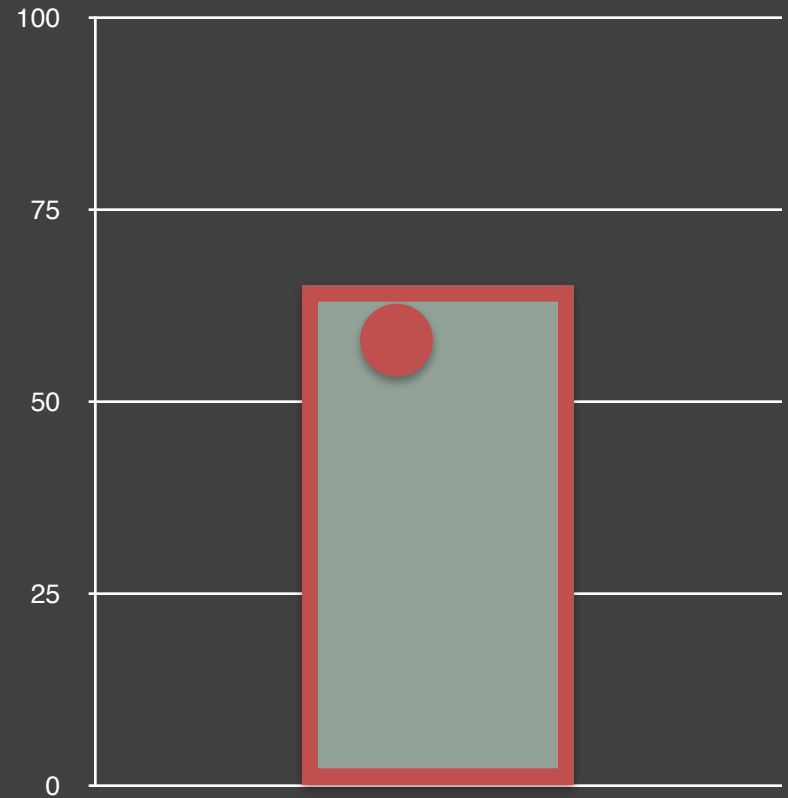
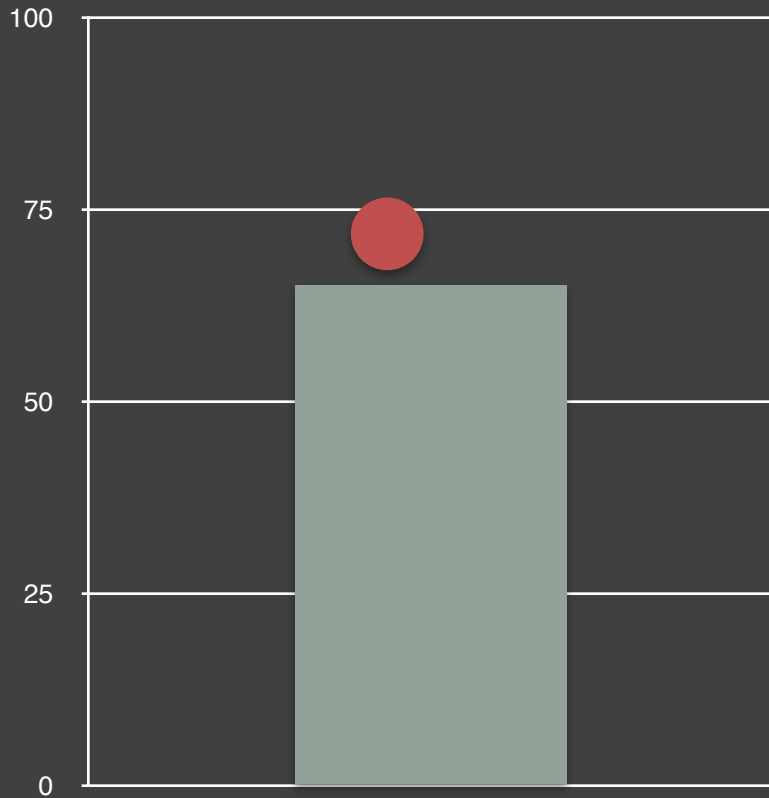
Within-the-Bar Bias



Within-the-Bar Bias

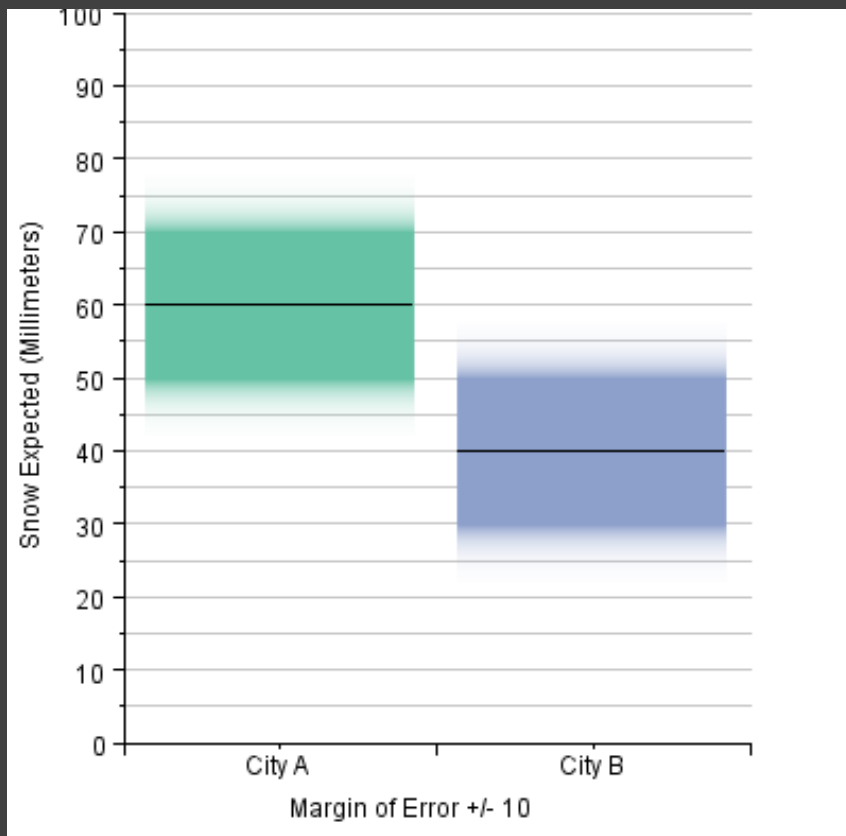


Within-the-Bar Bias

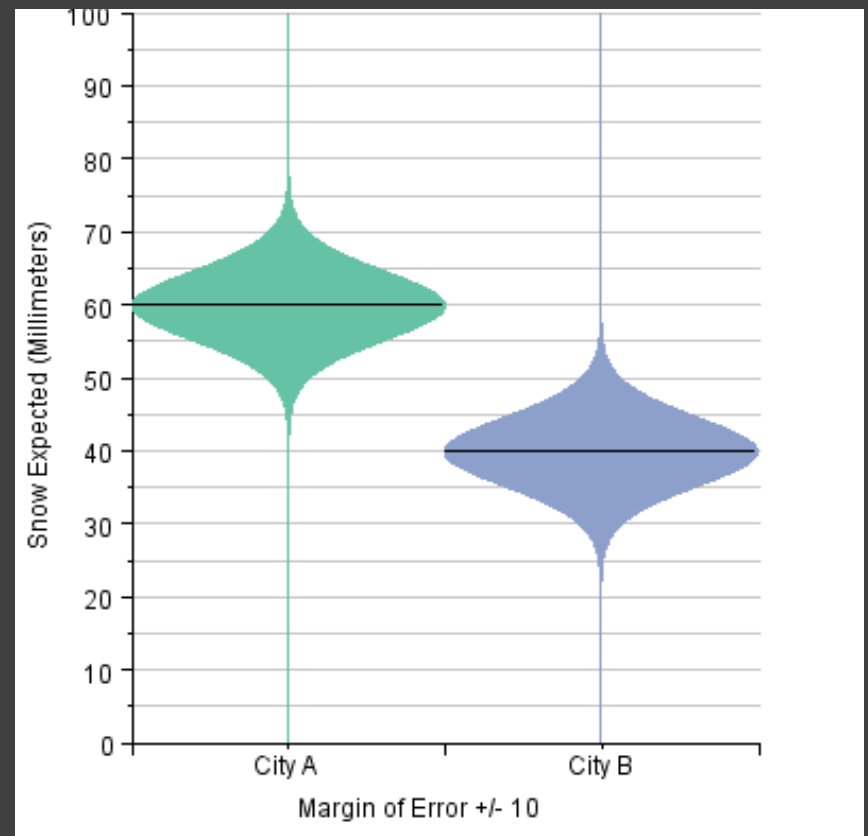


Alternatives to Error Bars

Gradient Plot



Violin Plot



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

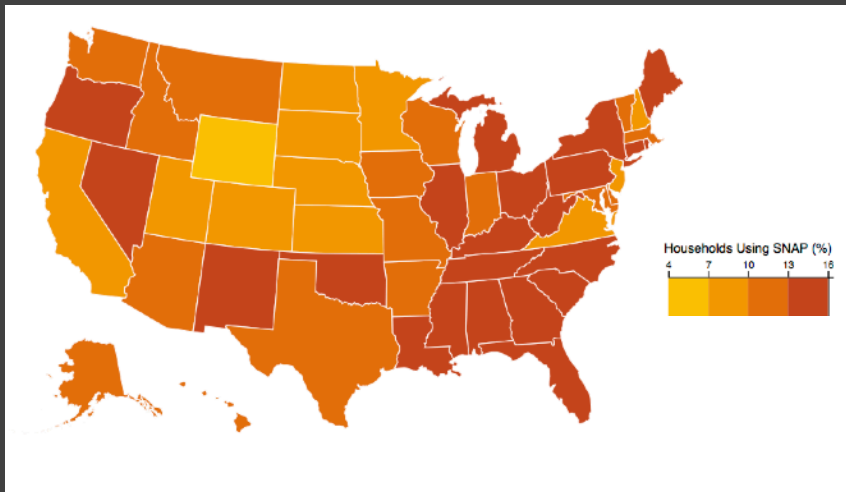
Encoding Uncertainty

Uncertainty Vis Pipeline

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

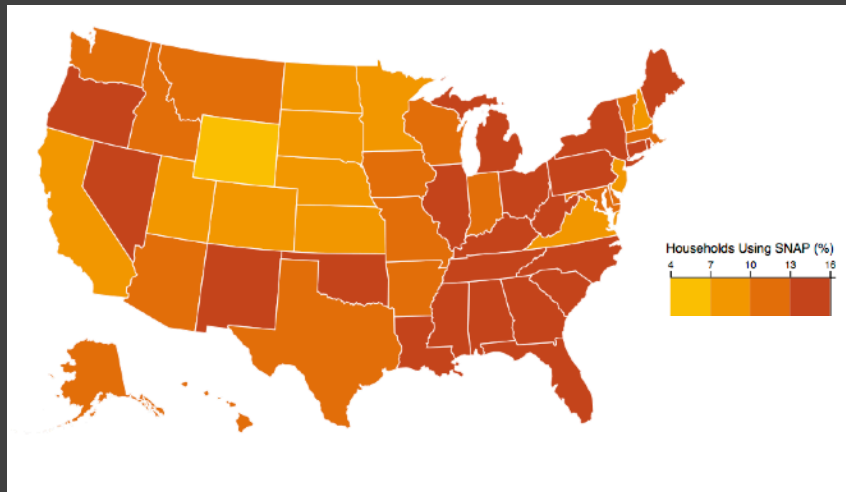
SNAP

Data Map

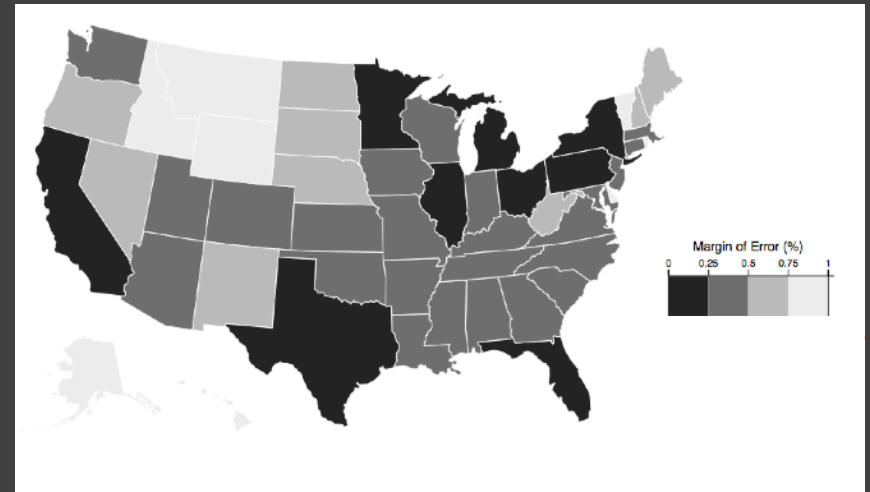


SNAP

Data Map



Uncertainty Map



Uncertainty Vis Pipeline

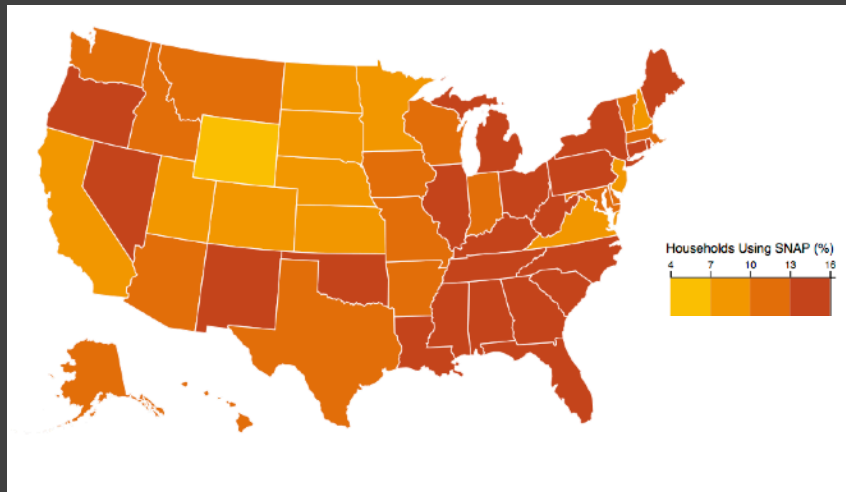
- 1) Quantify uncertainty
- 2) Choose a free visual variable
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Uncertainty Vis Pipeline

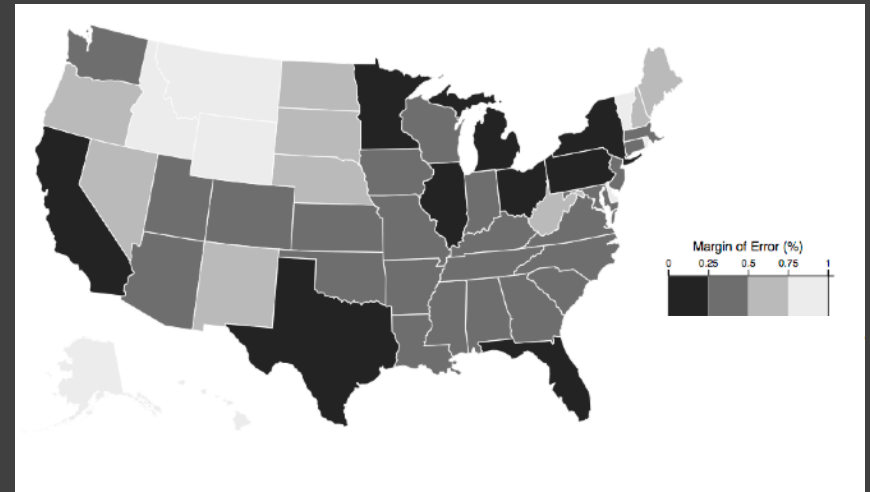
- 1) Quantify uncertainty
- 2) Choose a free visual variable
- 3) Encode uncertainty with the variable
- 4) Unify the Data Map and Uncertainty Map

How to Unify?

Data Map

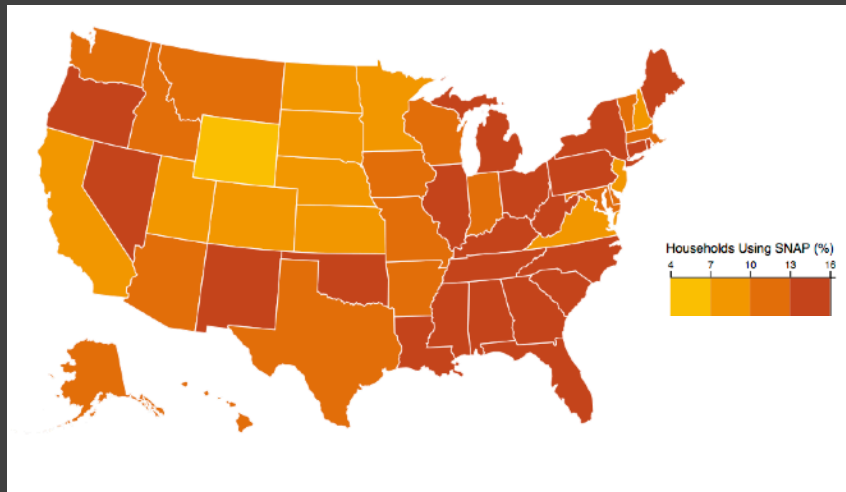


Uncertainty Map

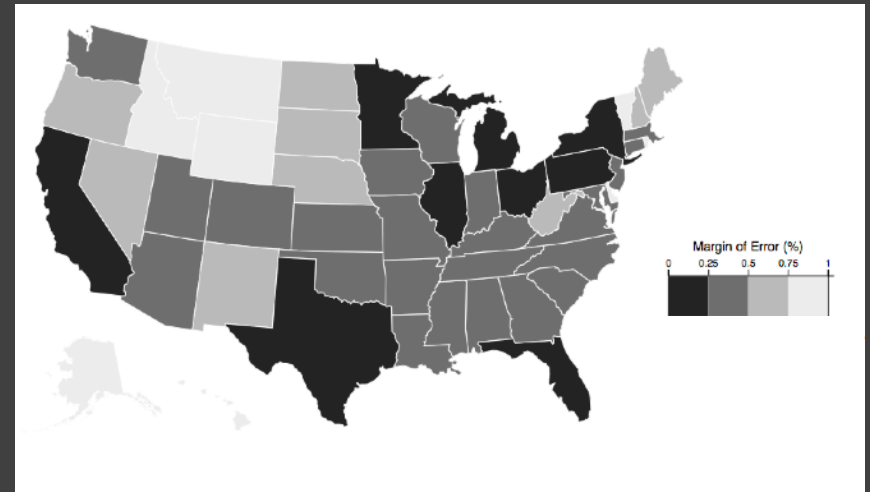


Juxtaposition

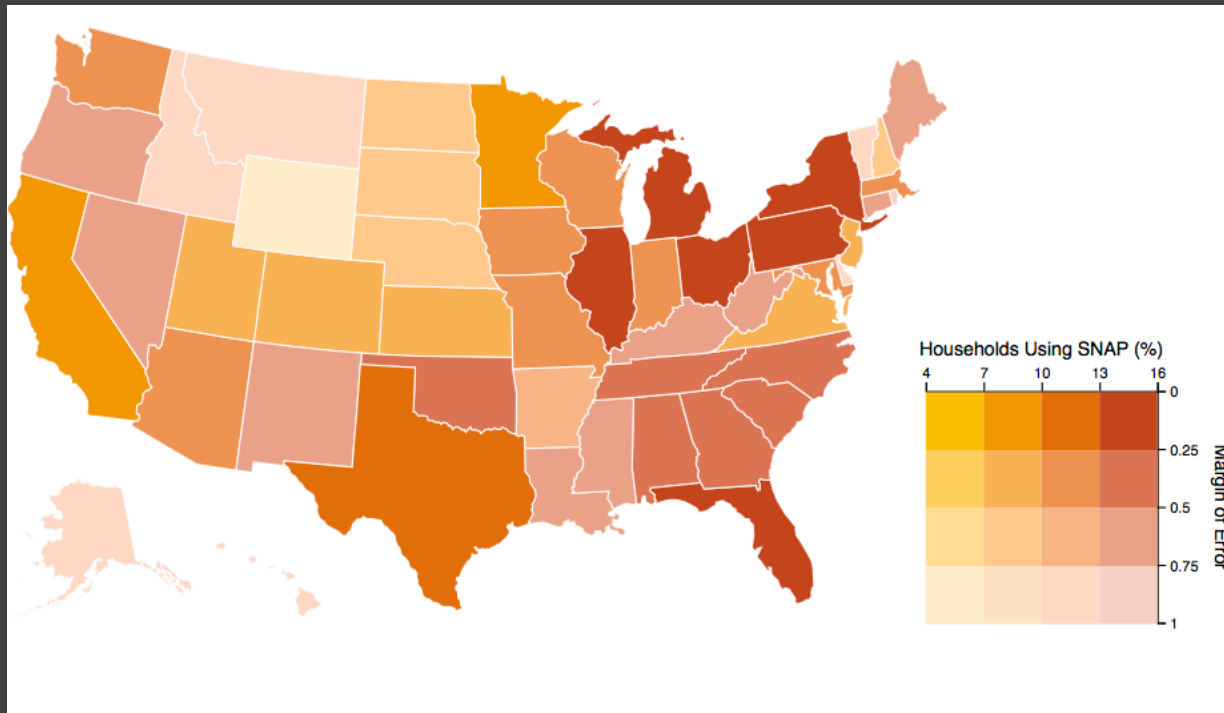
Data Map



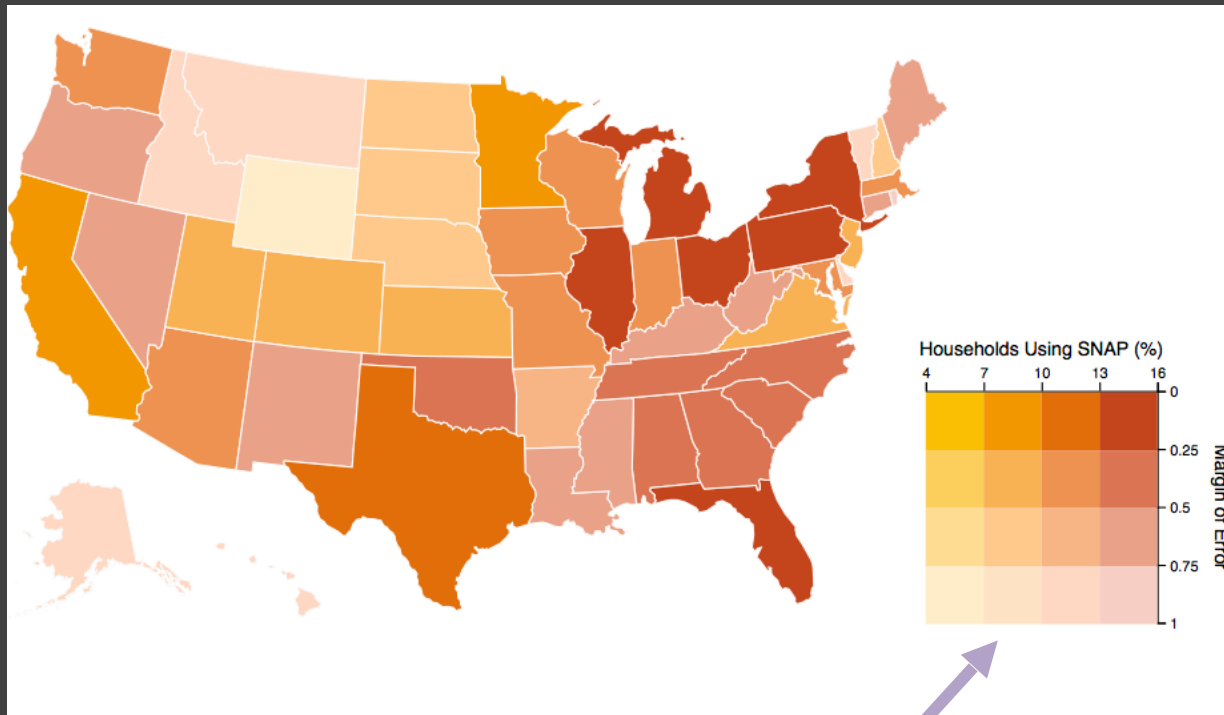
Uncertainty Map



Superposition

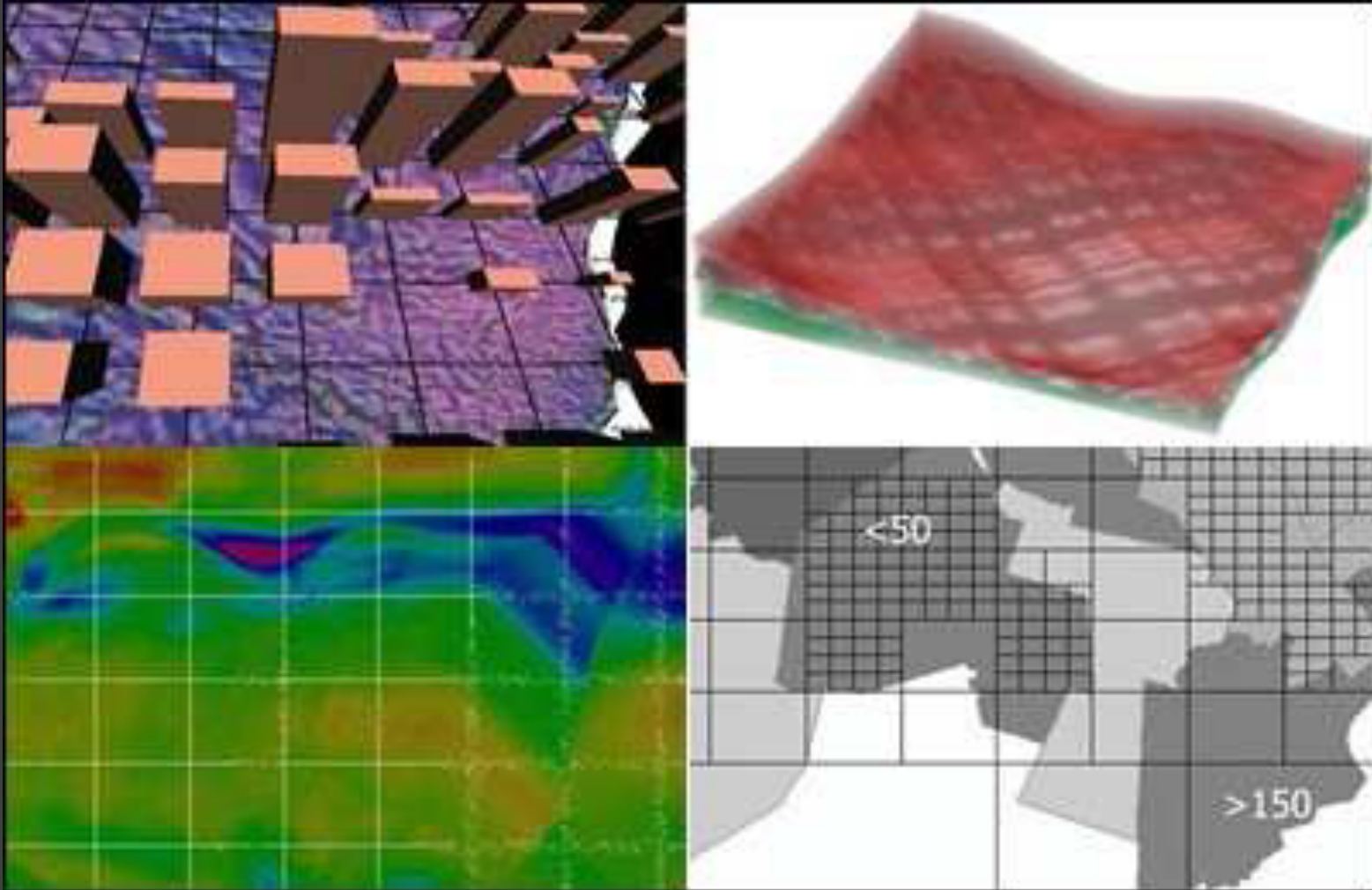


Superposition



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

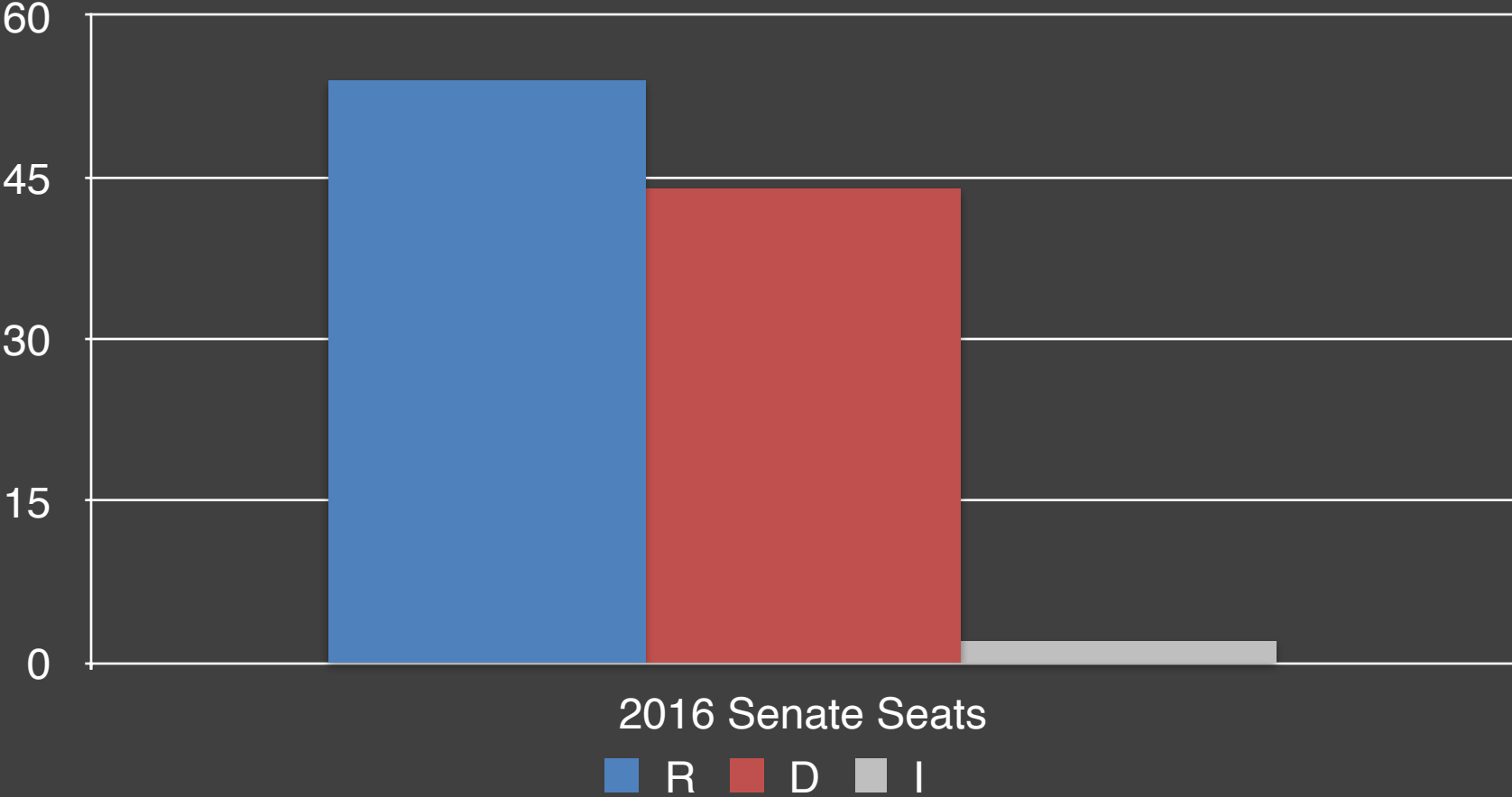
- 1) Quantify uncertainty
- 2) Choose a free **visual variable**
- 3) Encode uncertainty with the variable
- 4) Unify the Data Map and Uncertainty Map

Semiotics of Uncertainty

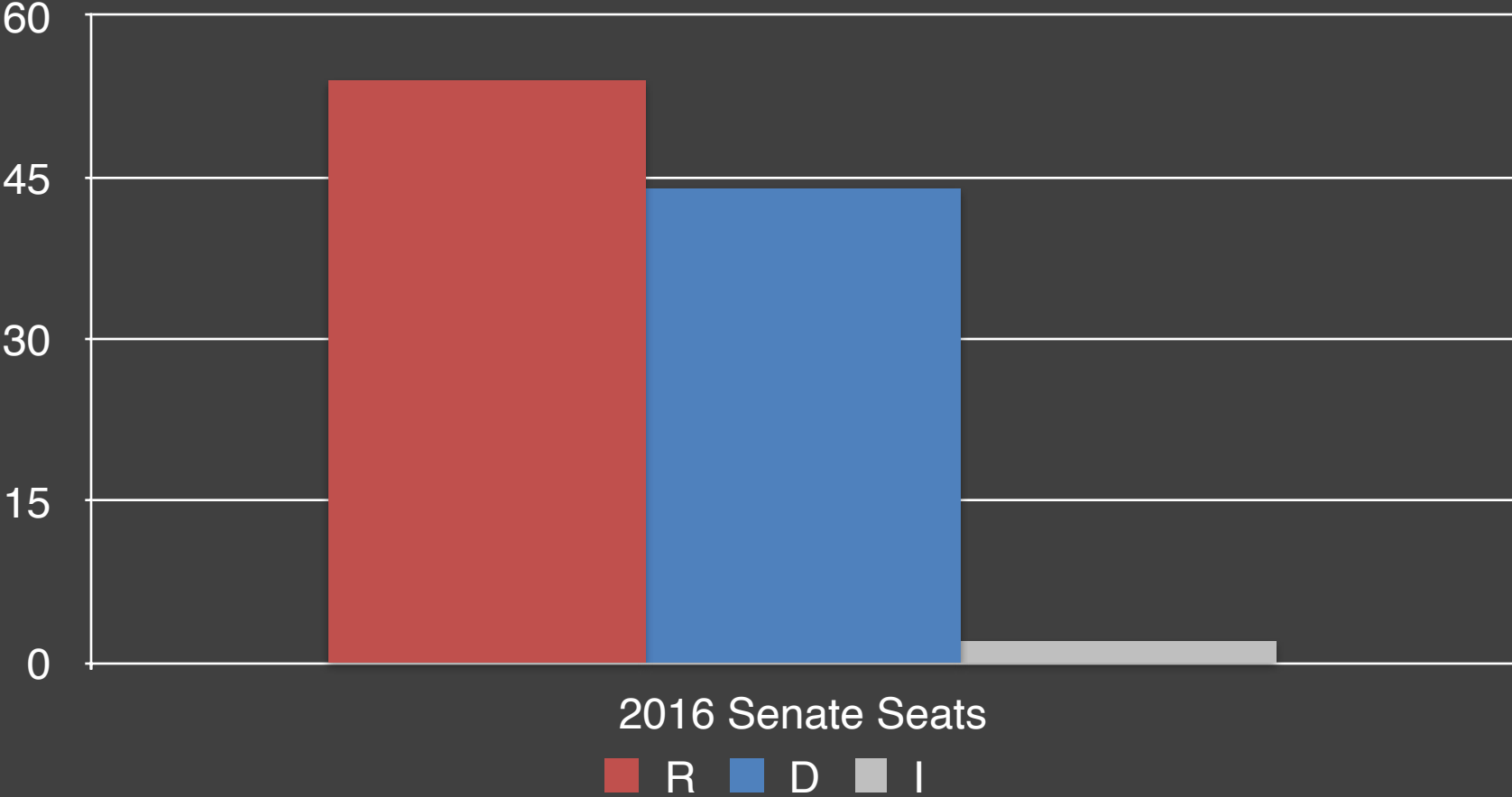


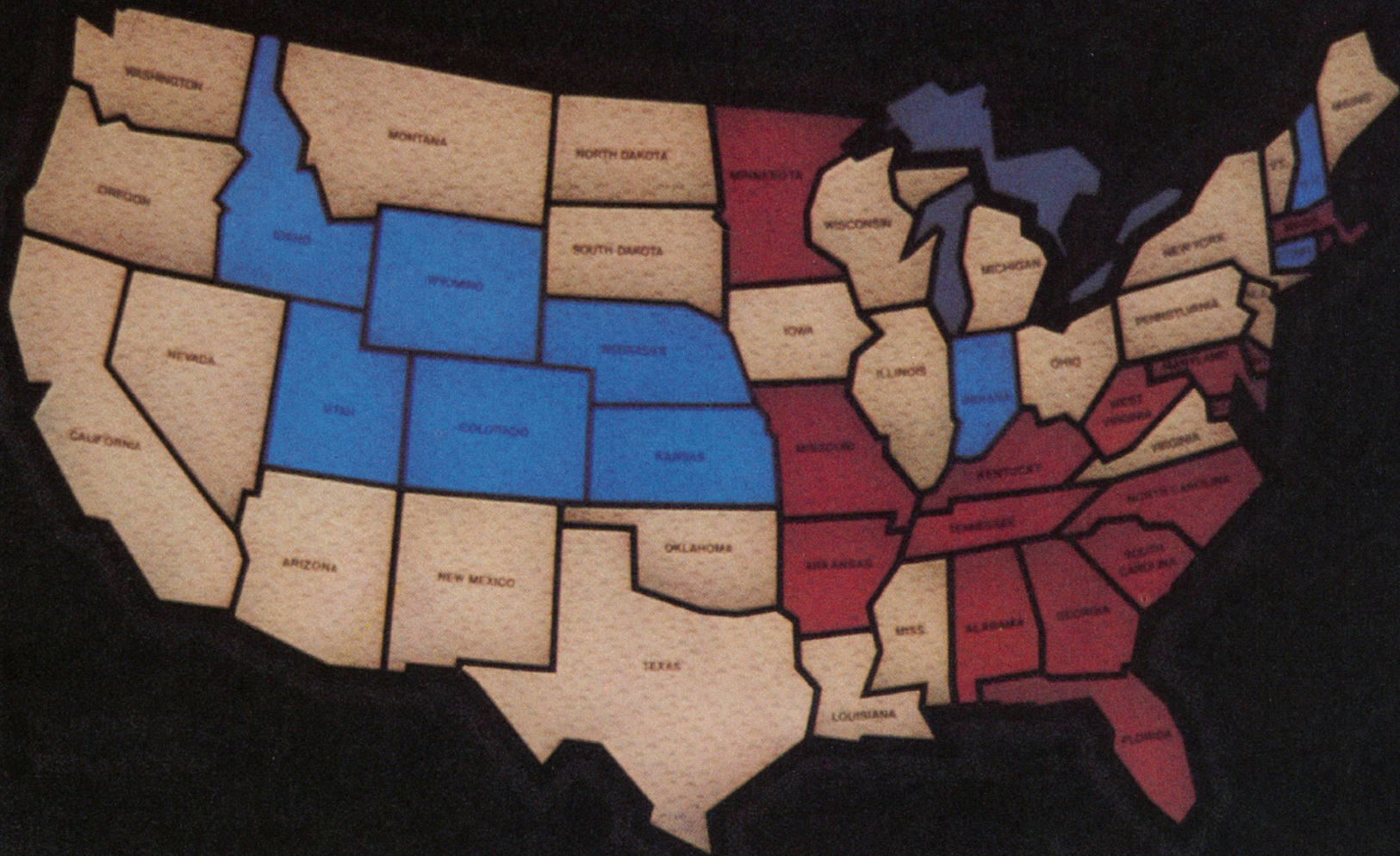
Ceci n'est pas une pipe.

The Variable Matters!



The Variable Matters!







VELOCITY OF MONEY
M1 SUPPLY
CURRENT: 6.55
5 YEARS AGO: 10.31

EURO-ZLOTY - 10 YEARS

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 ▲ 0.

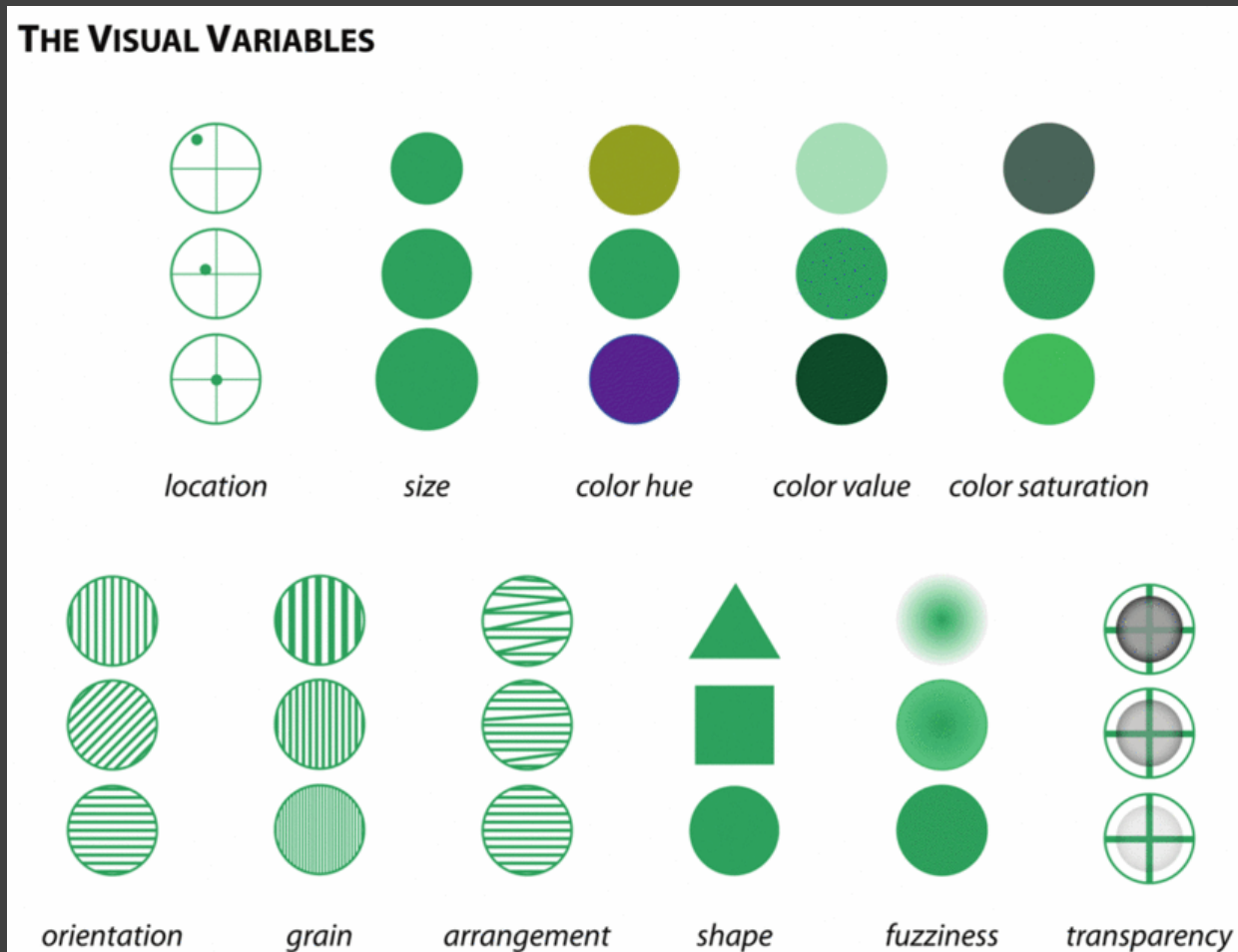
7:24 ET MAY 30 **COSTCO QUARTERLY PROFIT RISES 19% ON INCREASED REVENUE FROM MEMBERSHIP FEES**

Gold	1415.25	▲ 1.11
Silver	22.76	▲ 0.07
Plat.	1482.70	▼ 1.00
Copper	351.35	▼ 0.20
Alum.	1907.00	▲ 44.00

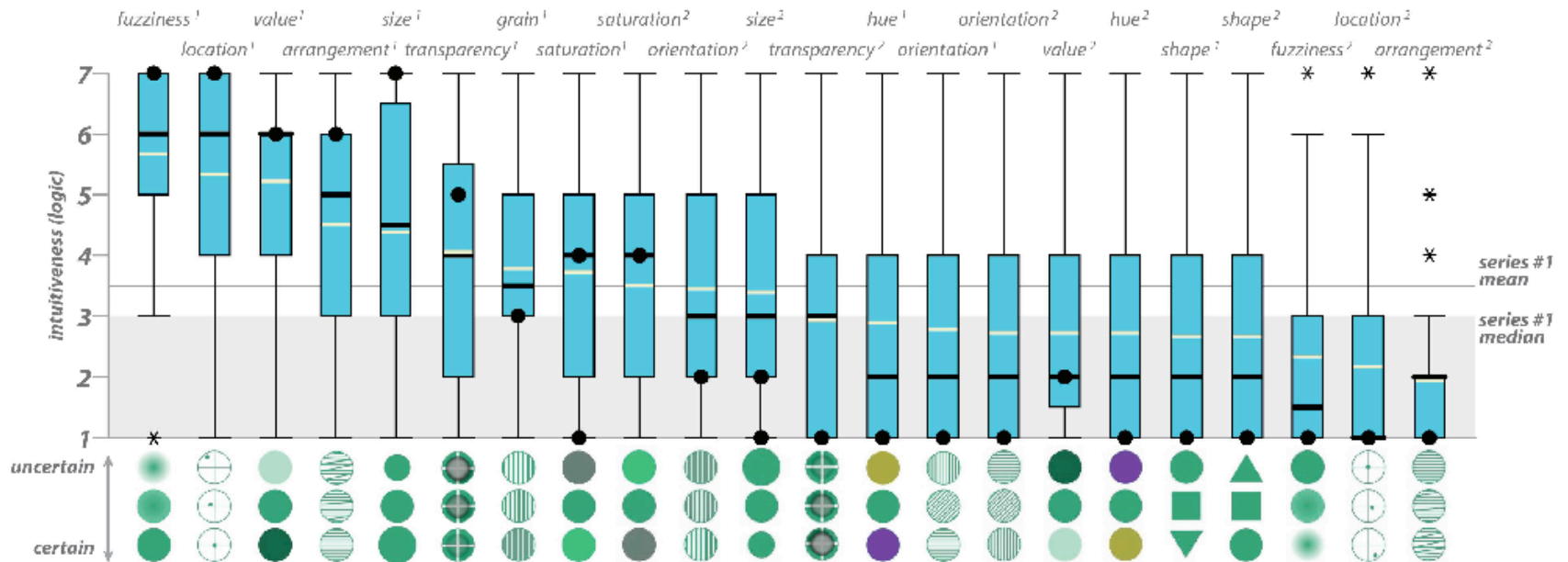
Semiotics of Uncertainty



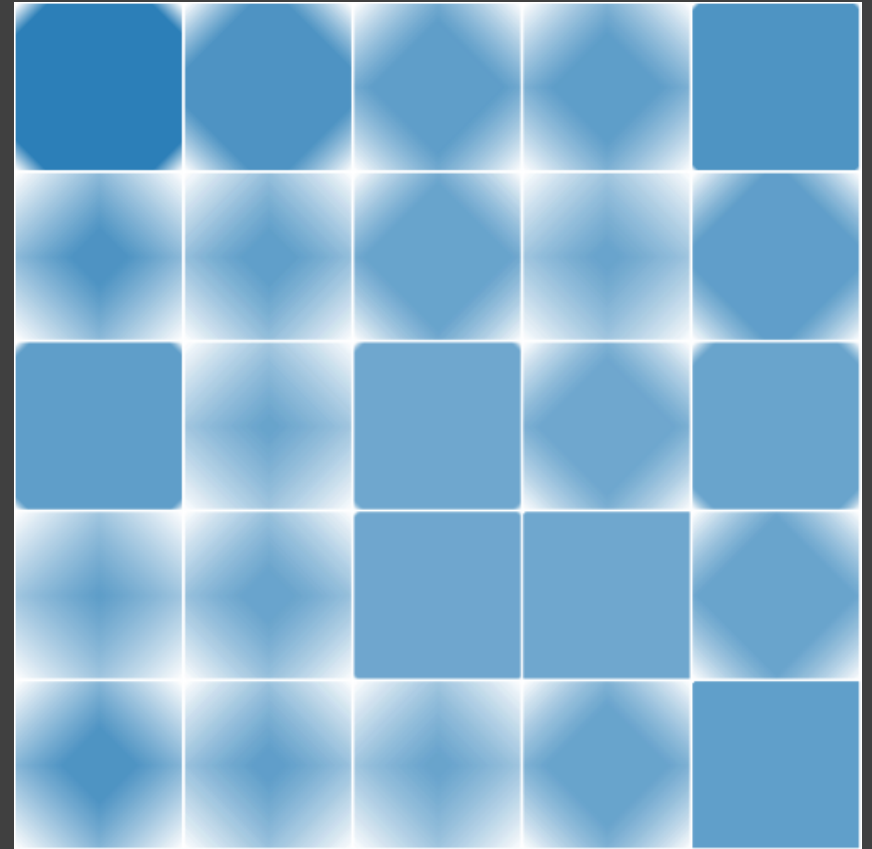
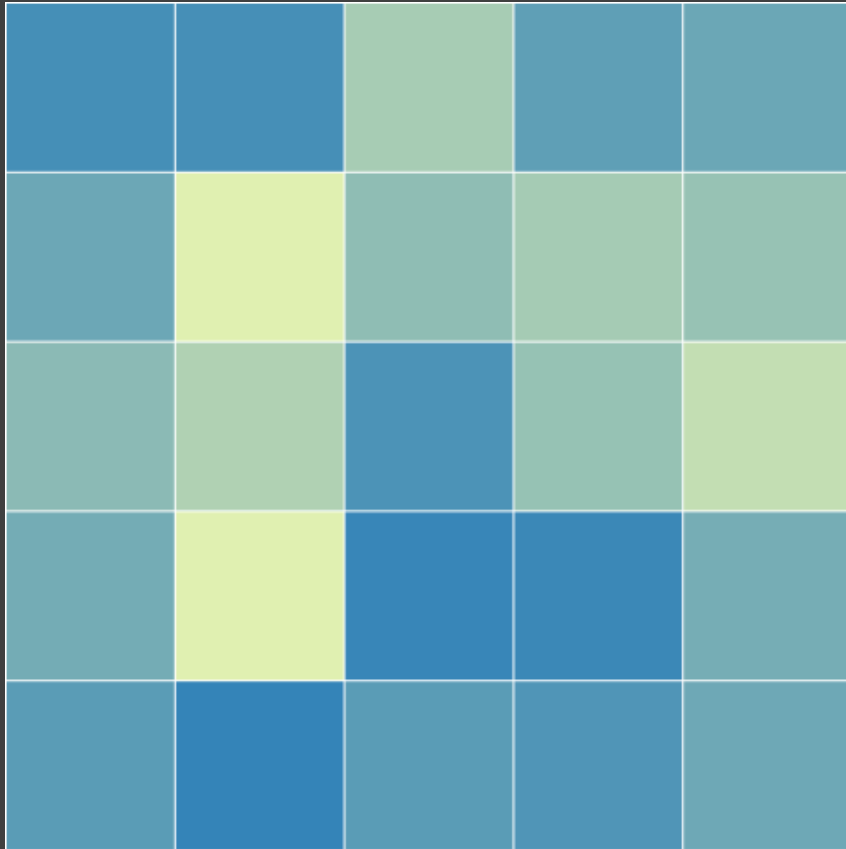
Semiotics of Uncertainty



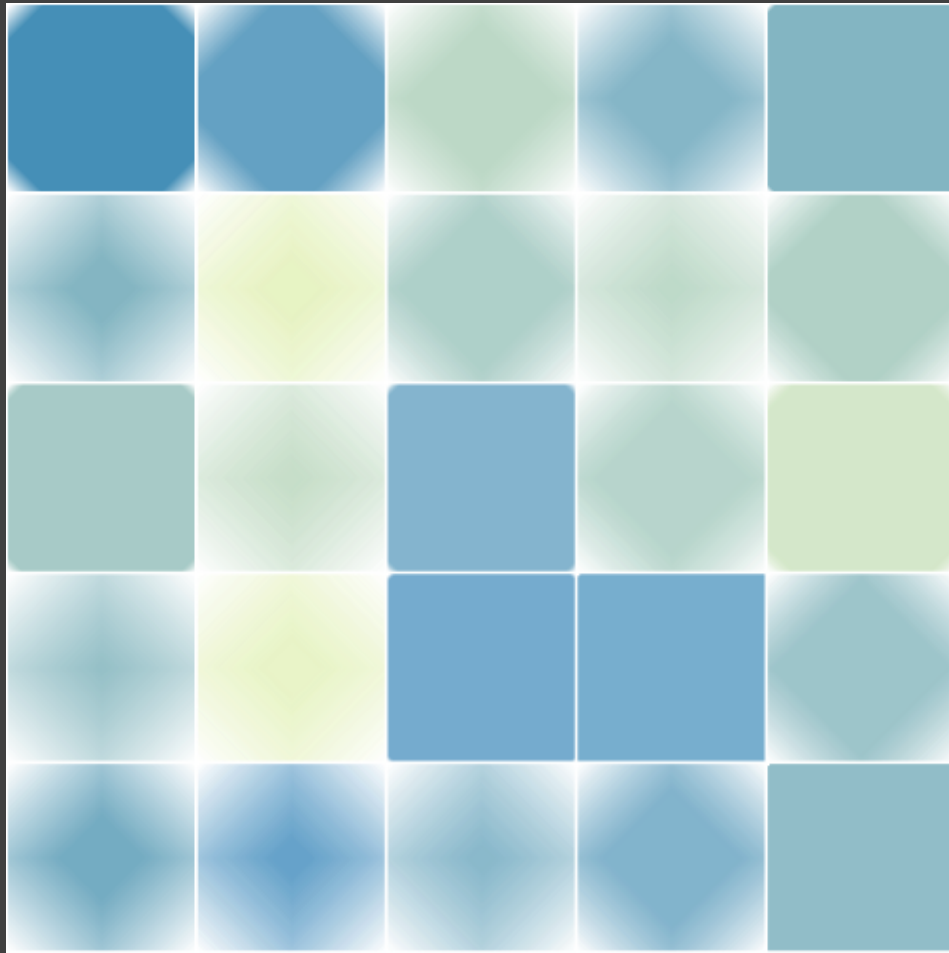
SERIES #1: GENERAL UNCERTAINTY BY VISUAL VARIABLE



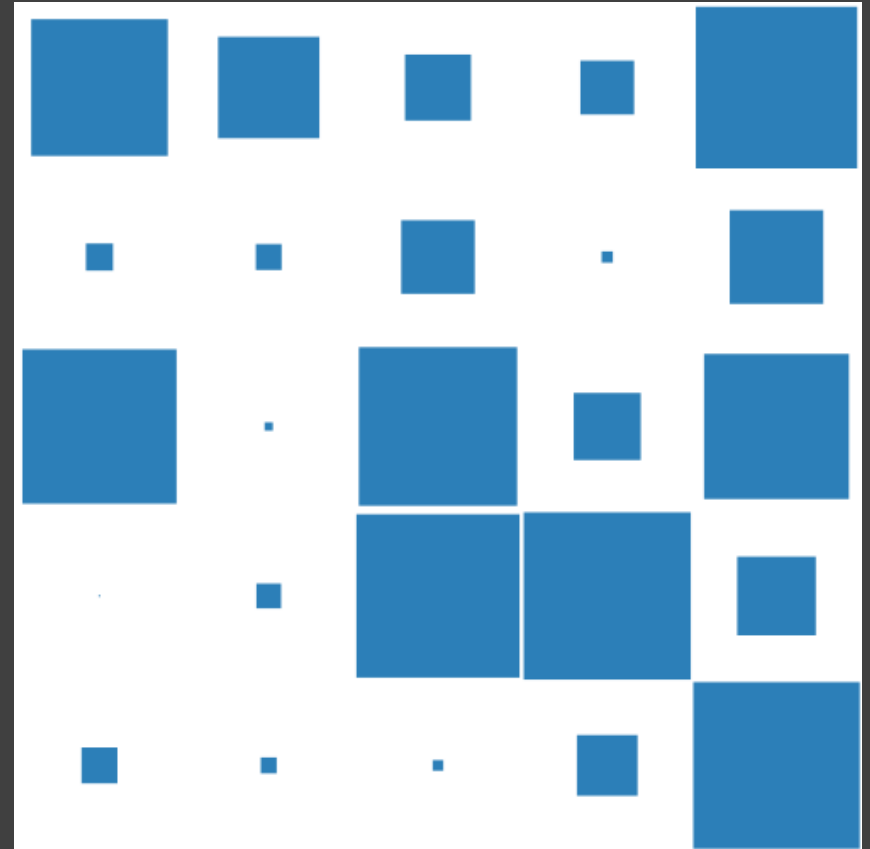
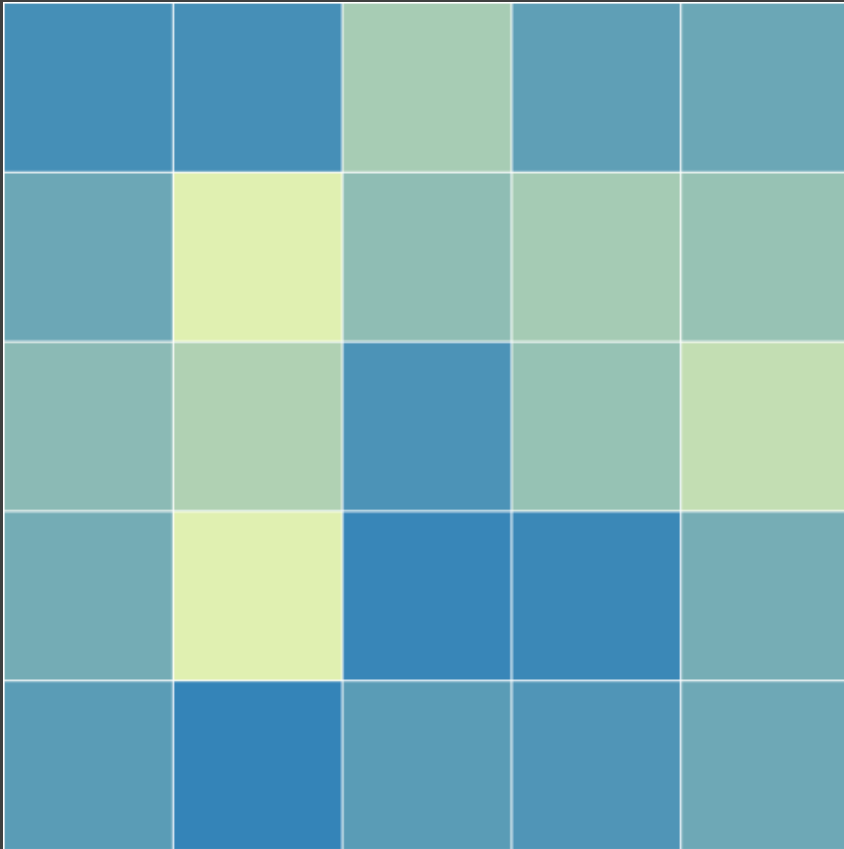
Fuzziness Juxtaposition



Fuzziness Superposition



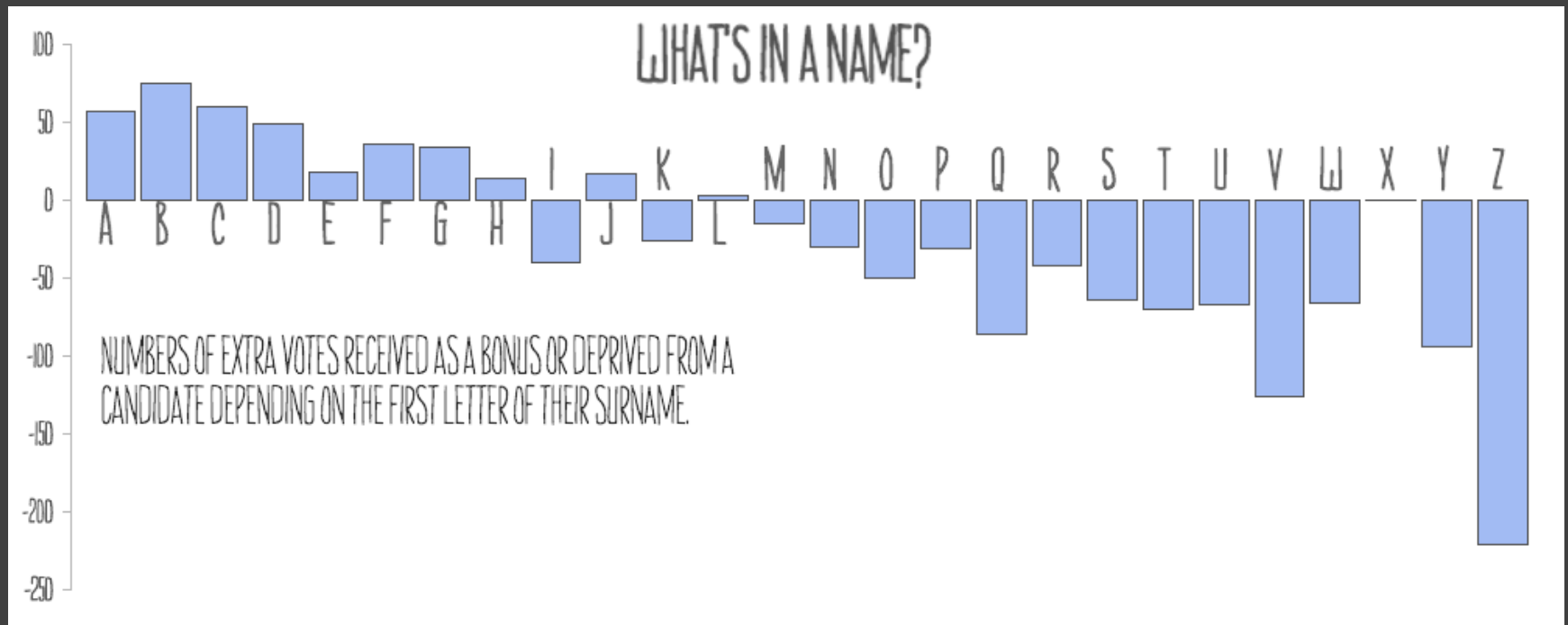
Size Juxtaposition



Size Superposition



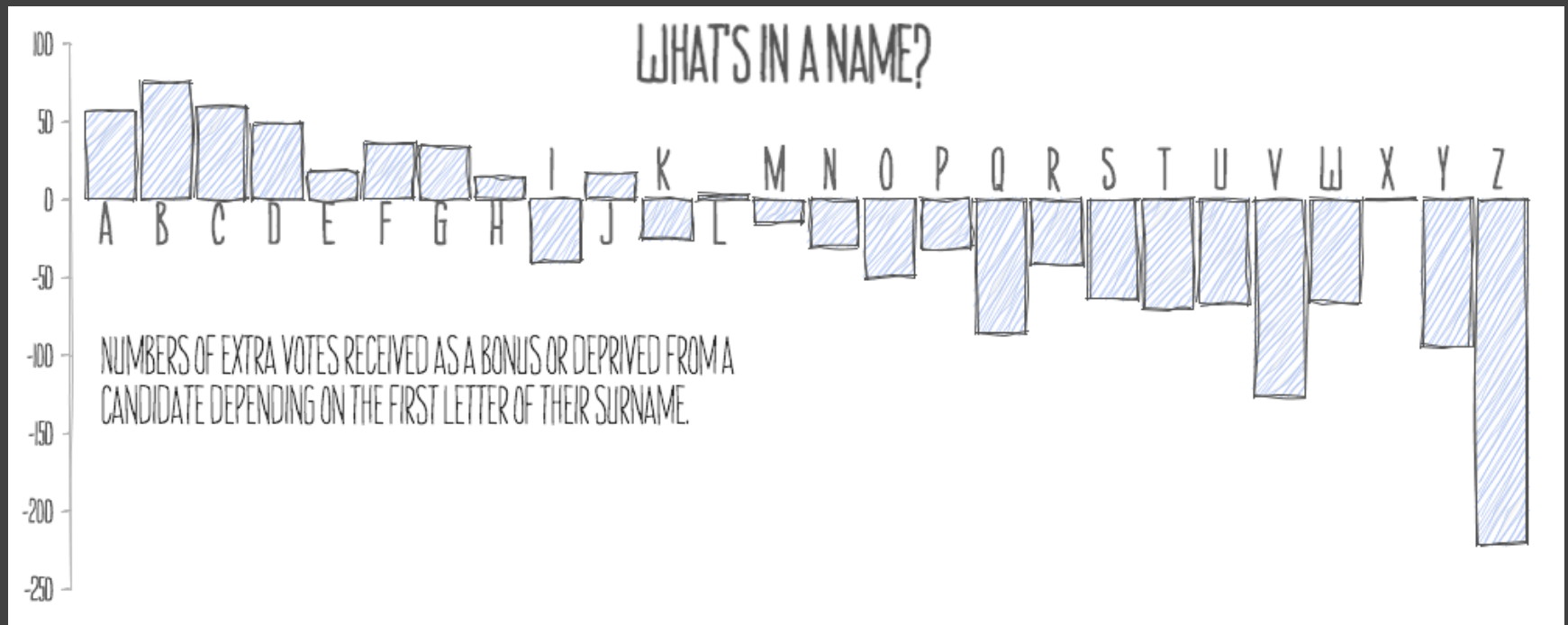
"Sketchiness"



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"



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.

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

KRAFTWEAK



THE MODEL

Polling Data



PublicPolicyPolling ✓

@ppppolls

Follow



I am sorry that we didn't poll all 63 million Trump voters SUSAN

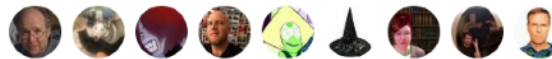
SUSAN @Sue4the5

Replying to @Amy_Siskind @ppppolls

"survey of 572 registered voters" This is a sample of 63 million voters who support Trump? What a crock of shit.

8:06 AM - 1 Nov 2017

1,373 Retweets 6,231 Likes



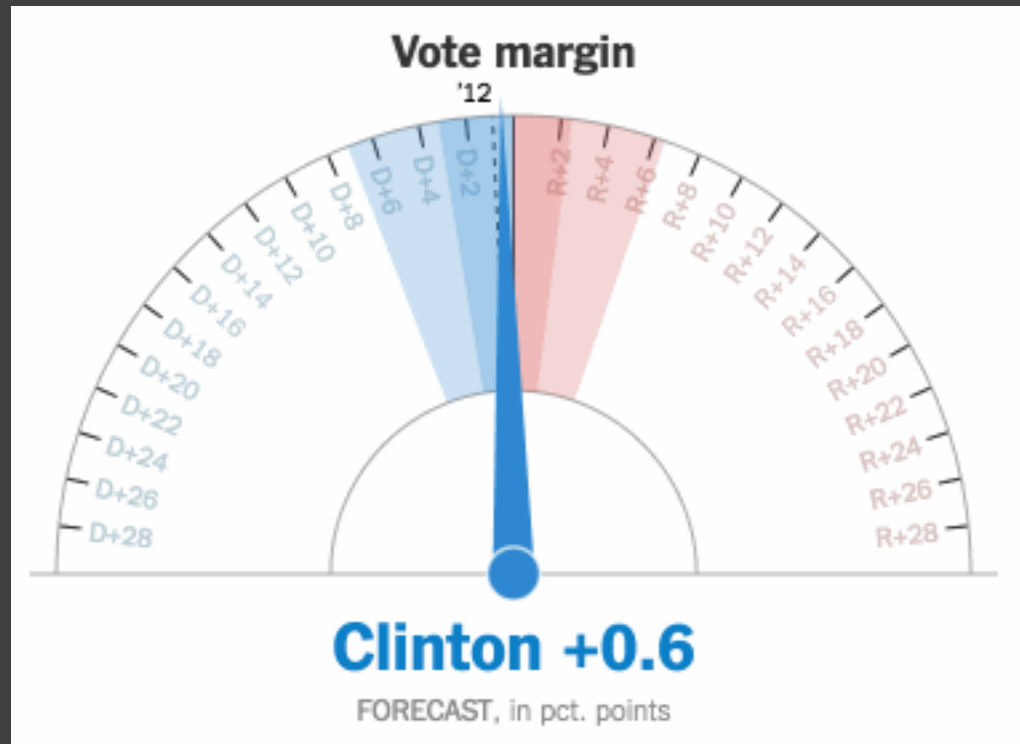
127

1.4K

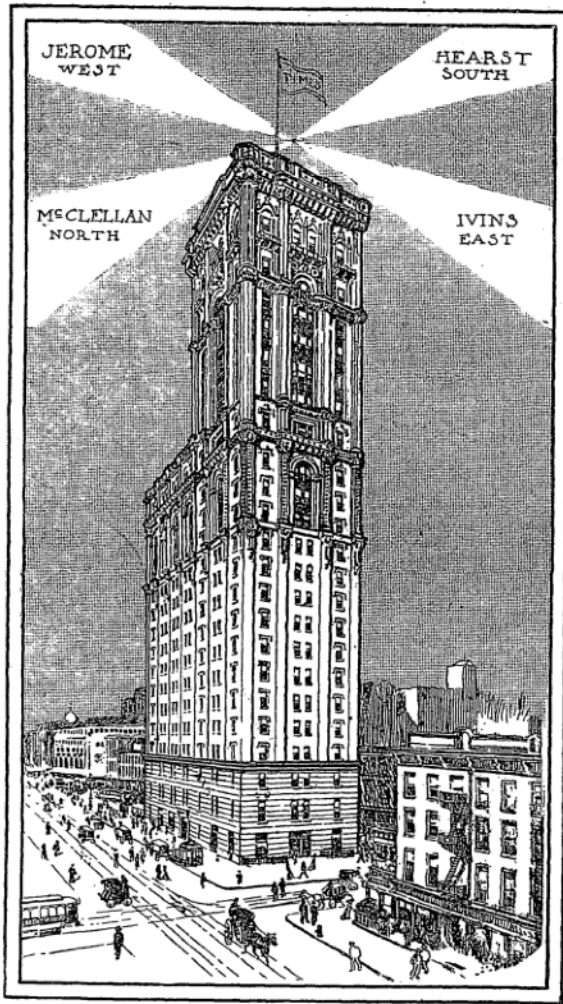
6.2K



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.

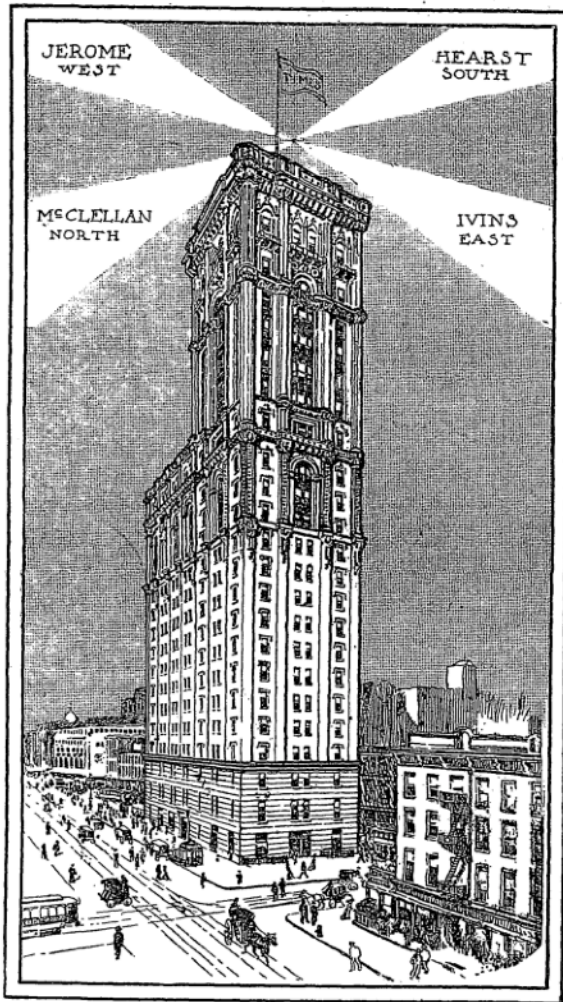
This will be entirely separate and distinct from the elaborate bulletin service which THE TIMES will also maintain. To display the detailed bulletins so that the crowds can see them easily and comfortably, a stereopticon machine will be set up in the triangle north of the Times Building and the bulletins 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.

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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.

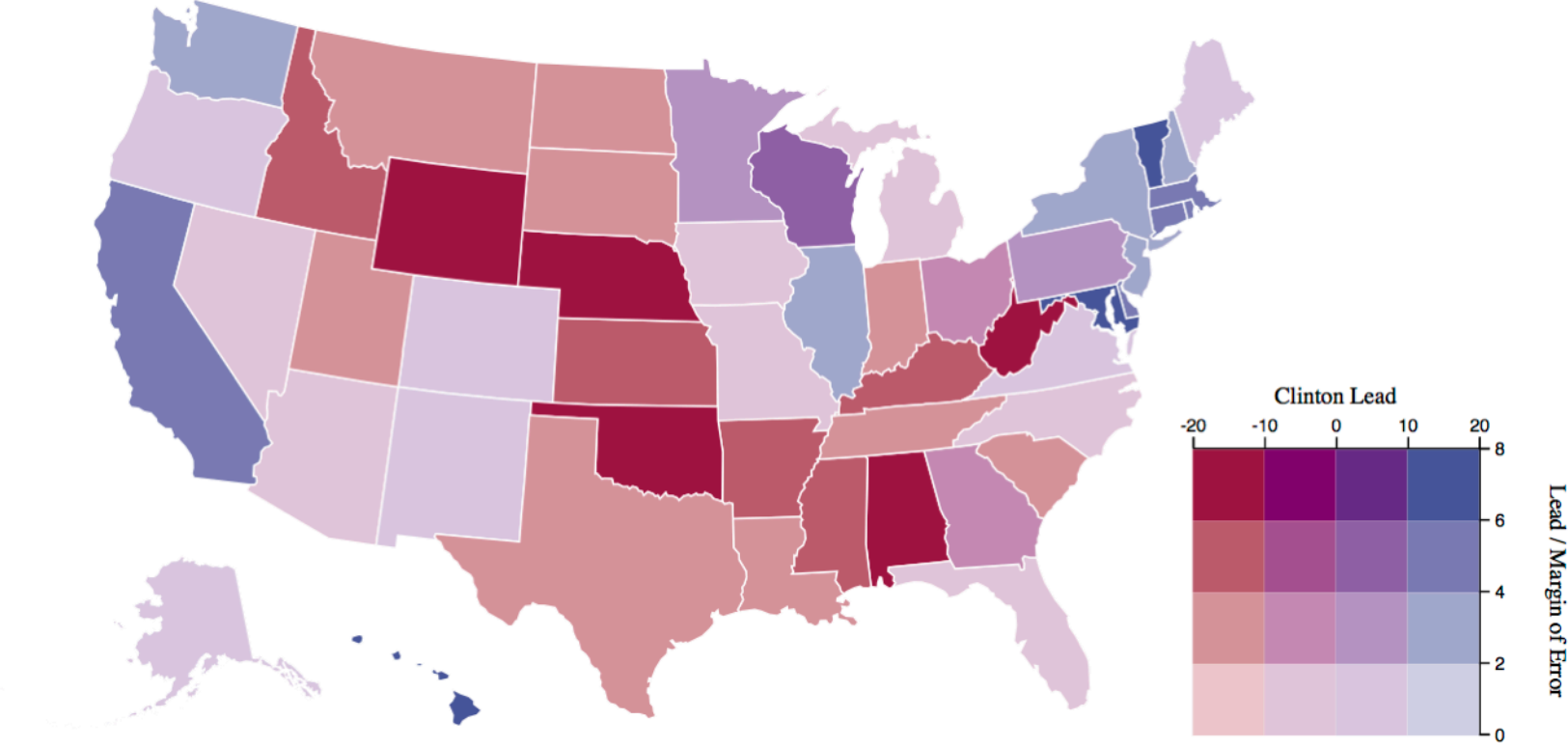
SIX BOMBS EVERY HOUR.

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.

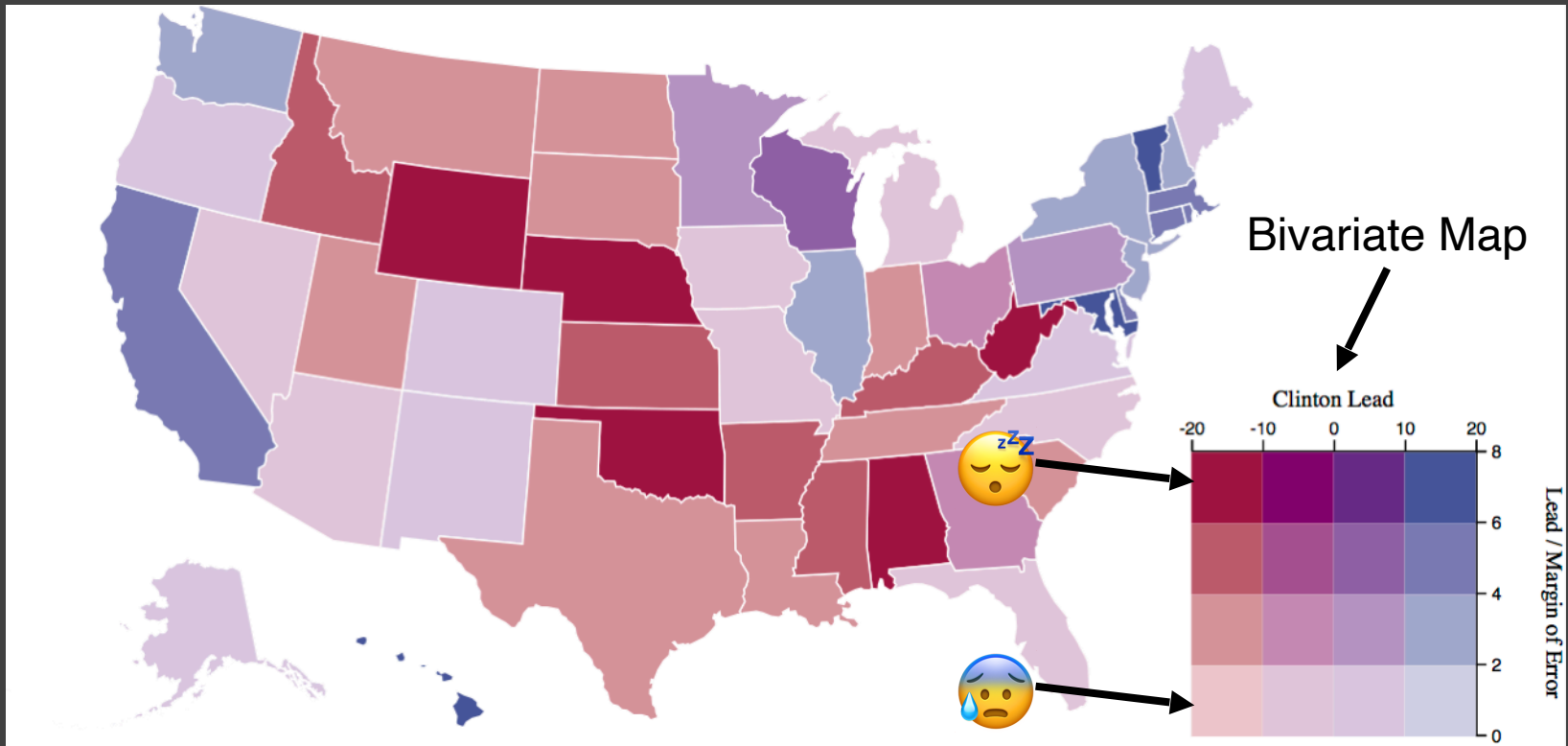
After sixty seconds two bombs will be sent up in rapid succession, and will indicate, if blue, that returns from **ILLINOIS** favor McKinley; if red, Bryan.

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.

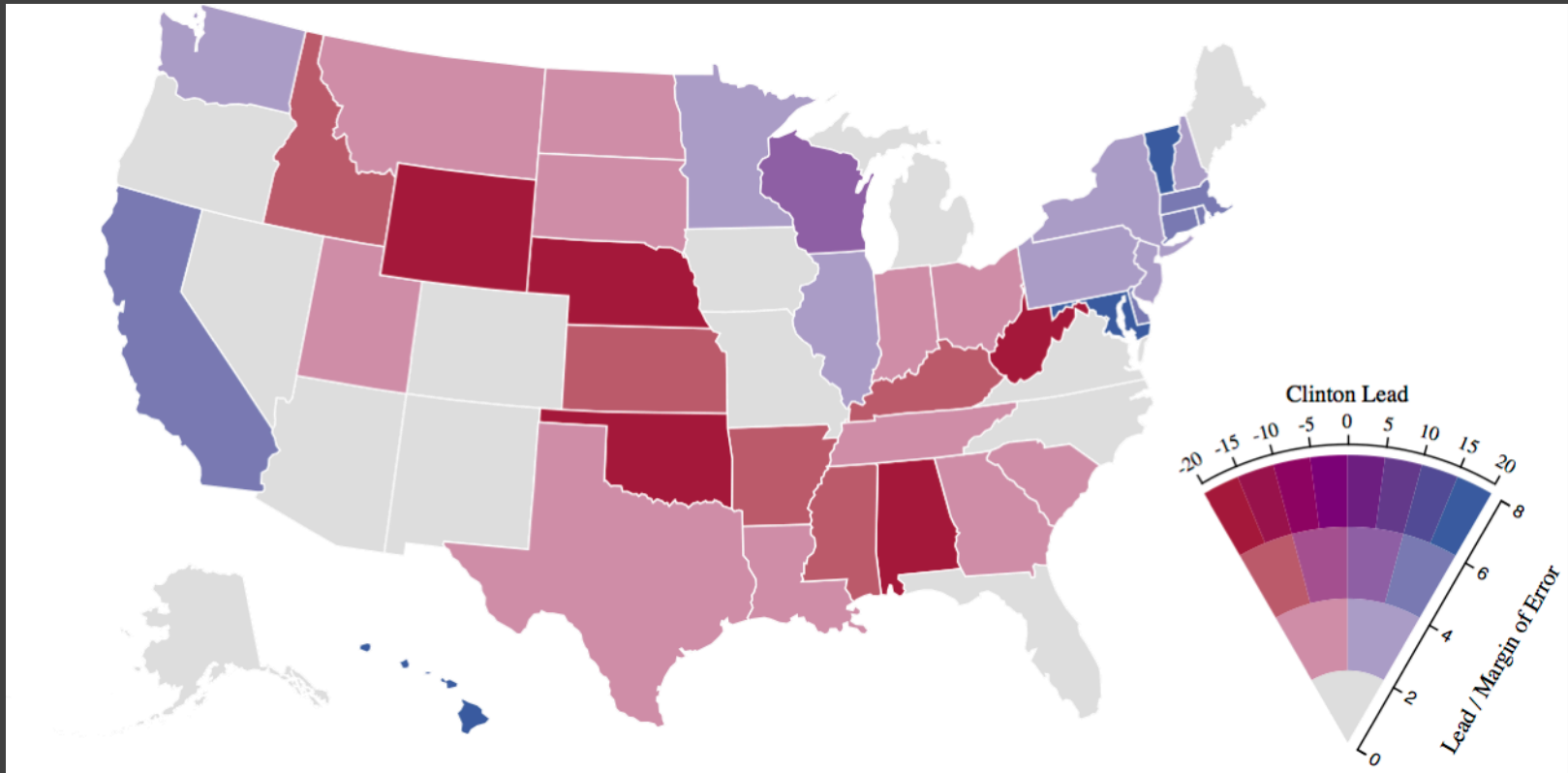
Value-Suppressing Uncertainty Palette



Bivariate Map

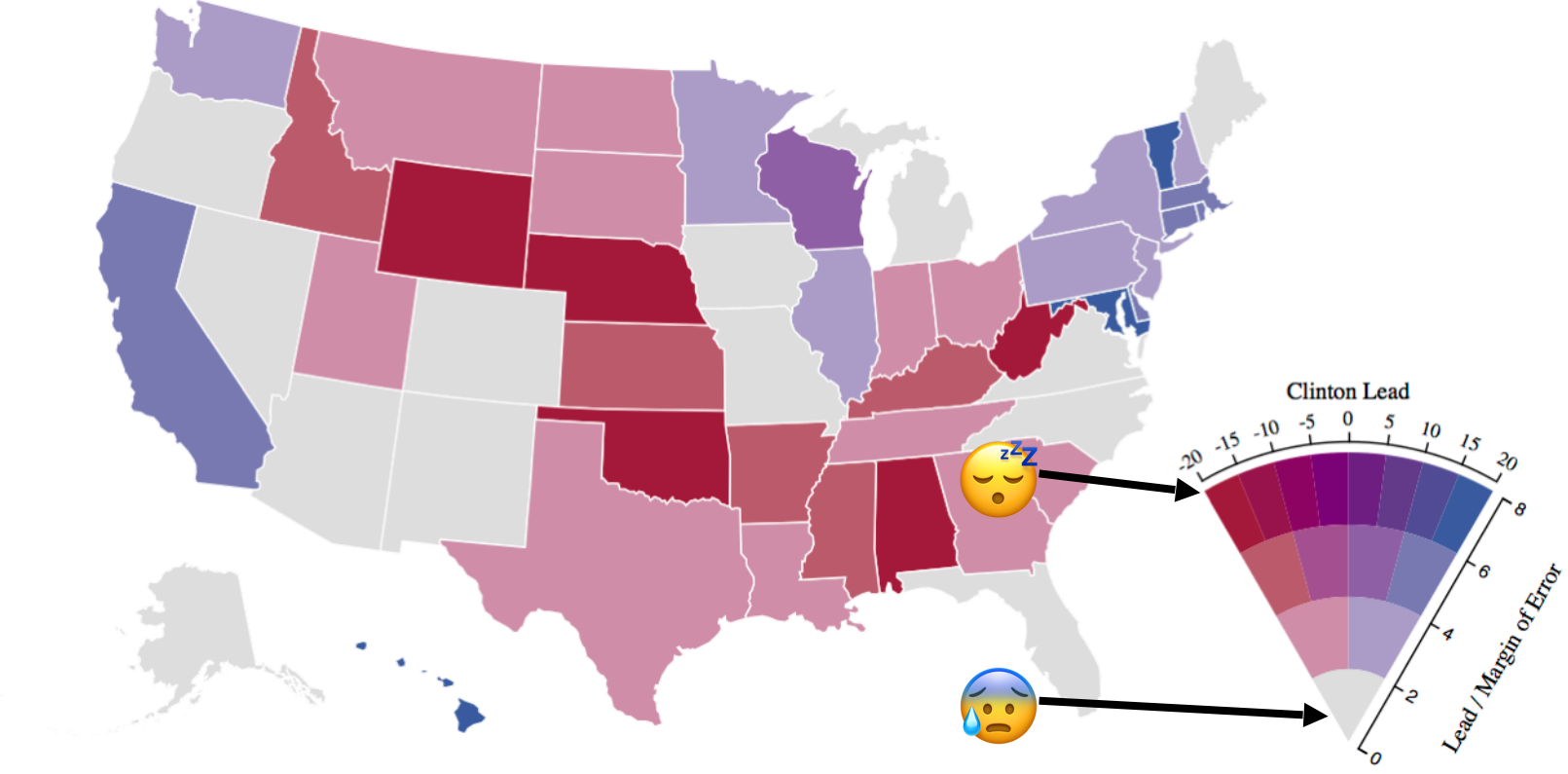


Value-Suppressing Uncertainty Palette



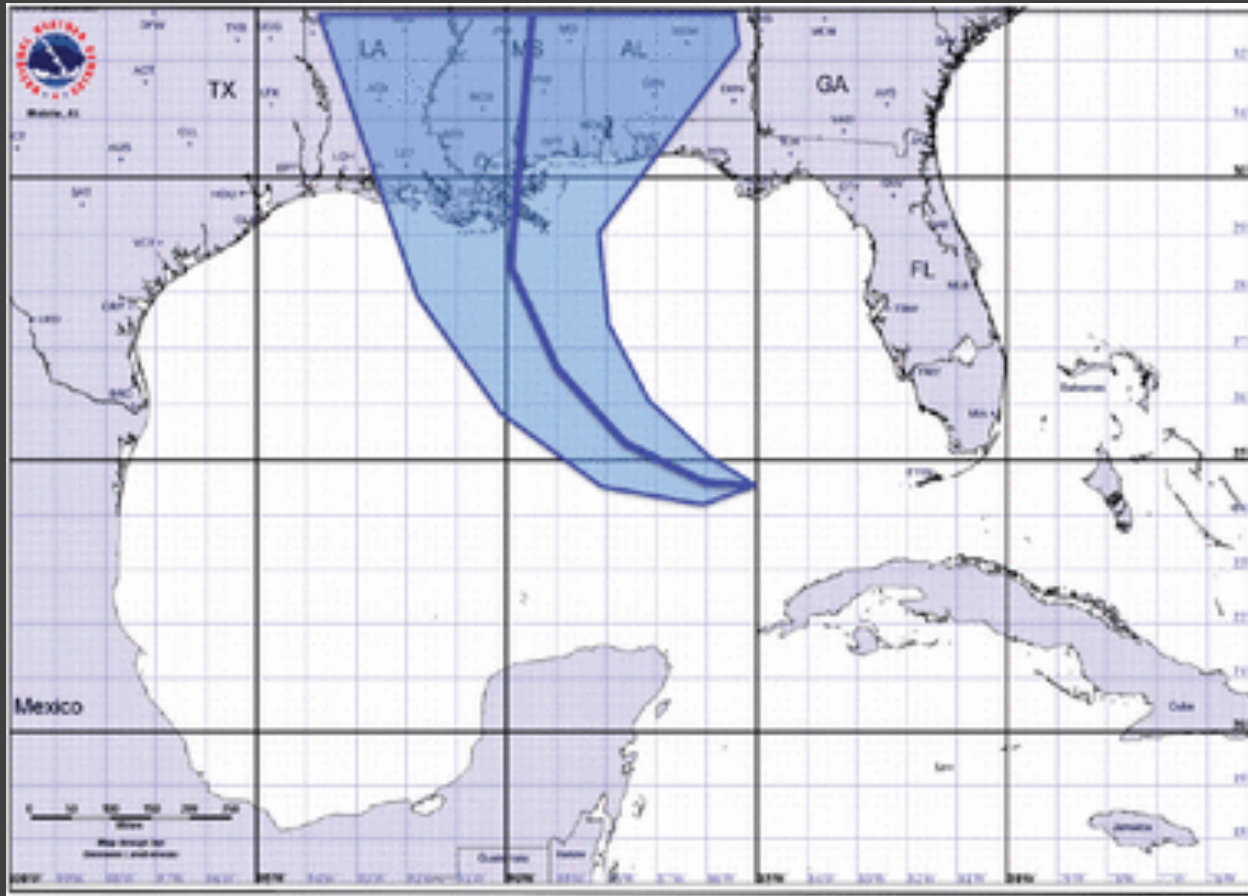
Correll, Moritz & Heer. "Value-Suppressing Uncertainty Palettes." CHI 2018.

Value-Suppressing Uncertainty Palette



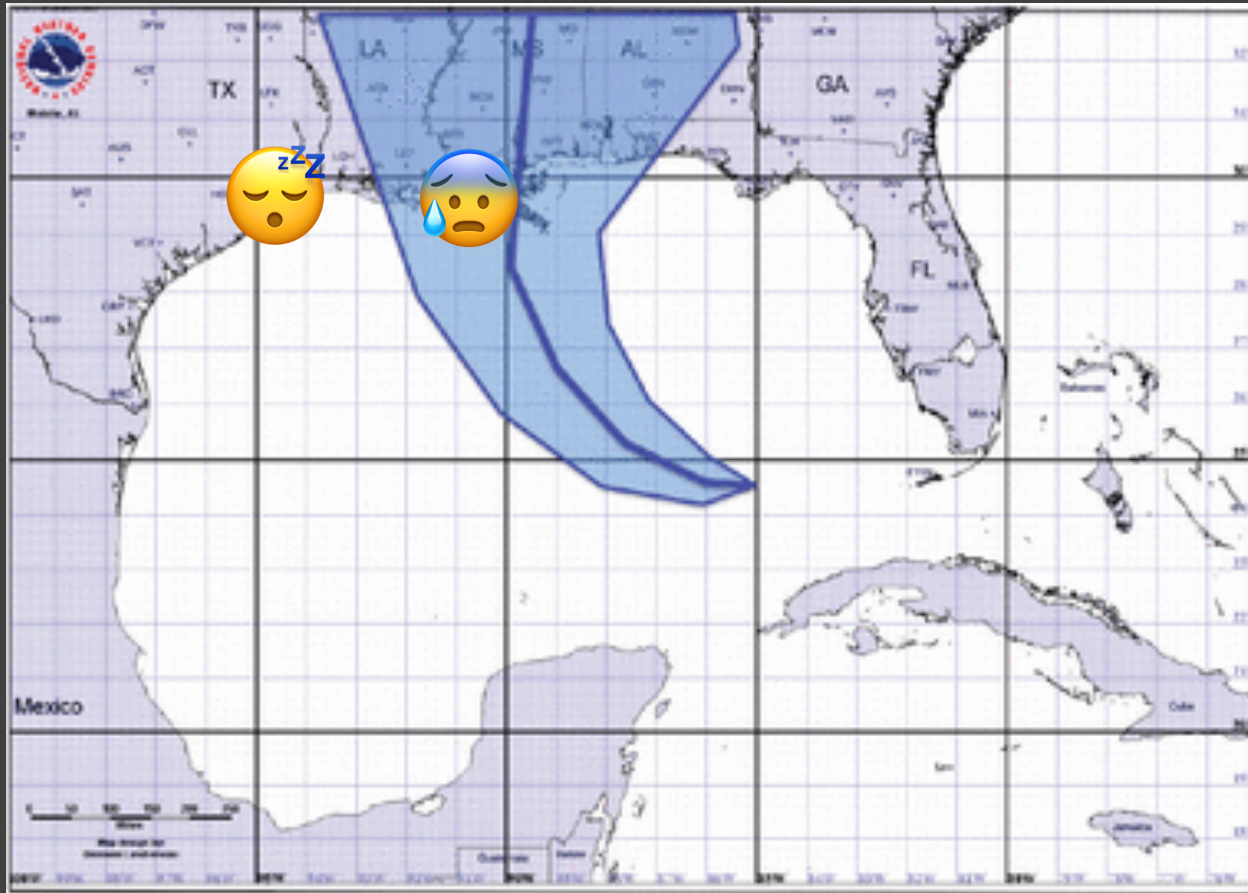
Correll, Moritz & Heer. "Value-Suppressing Uncertainty Palettes." CHI 2018.

Model Visualization



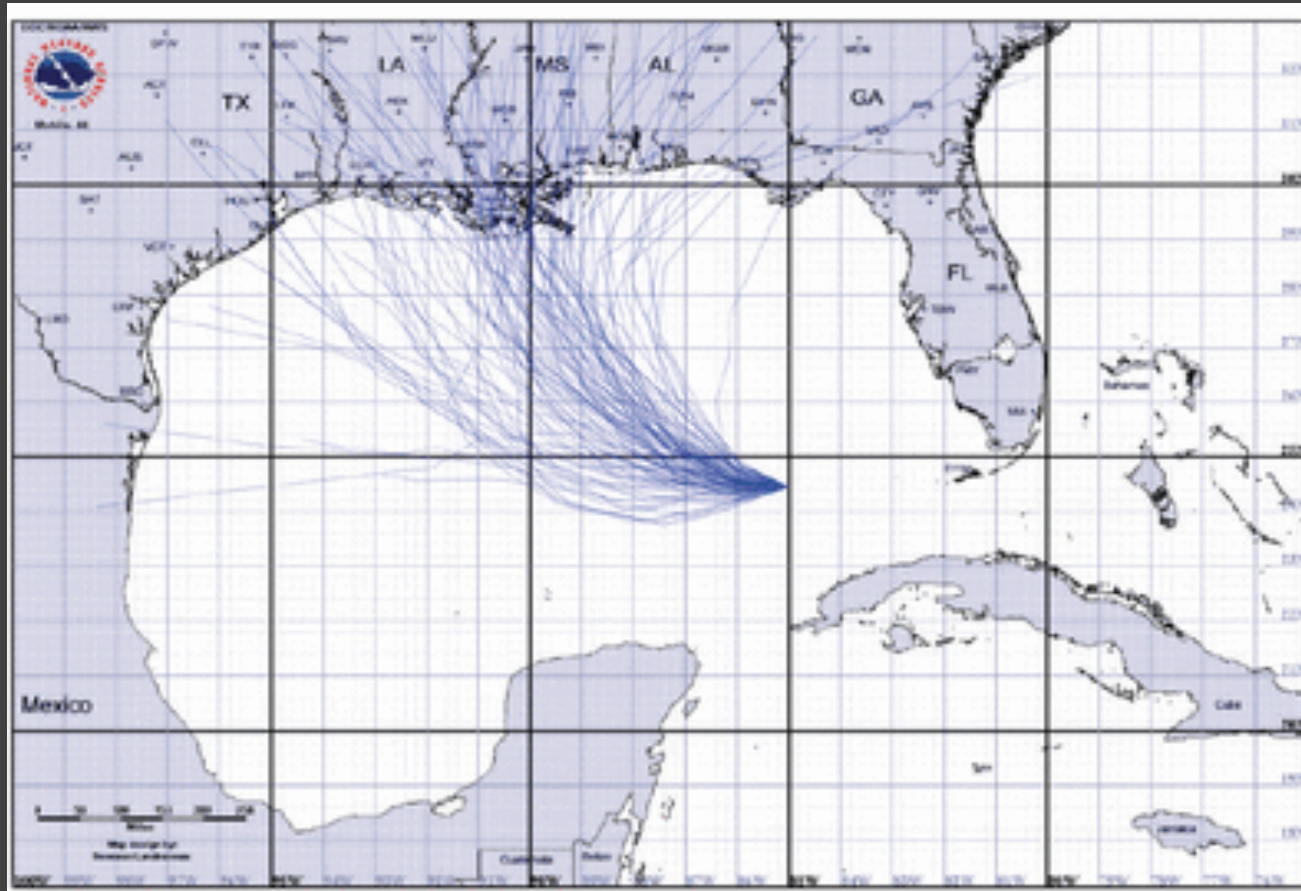
Cox, Jonathan and House, Donald and Lindell, Michael. Visualising uncertainty in predicted hurricane tracks. *International Journal for Uncertainty Quantification*, 2013.

Model Visualization

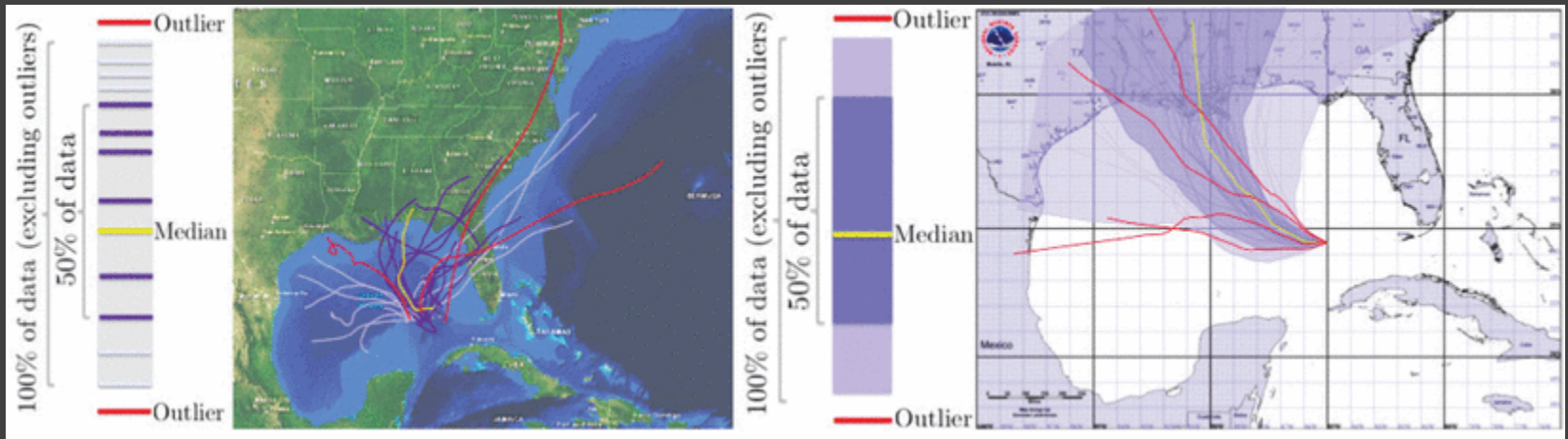


Cox, Jonathan and House, Donald and Lindell, Michael. Visualising uncertainty in predicted hurricane tracks. International Journal for Uncertainty Quantification, 2013.

Model Visualization

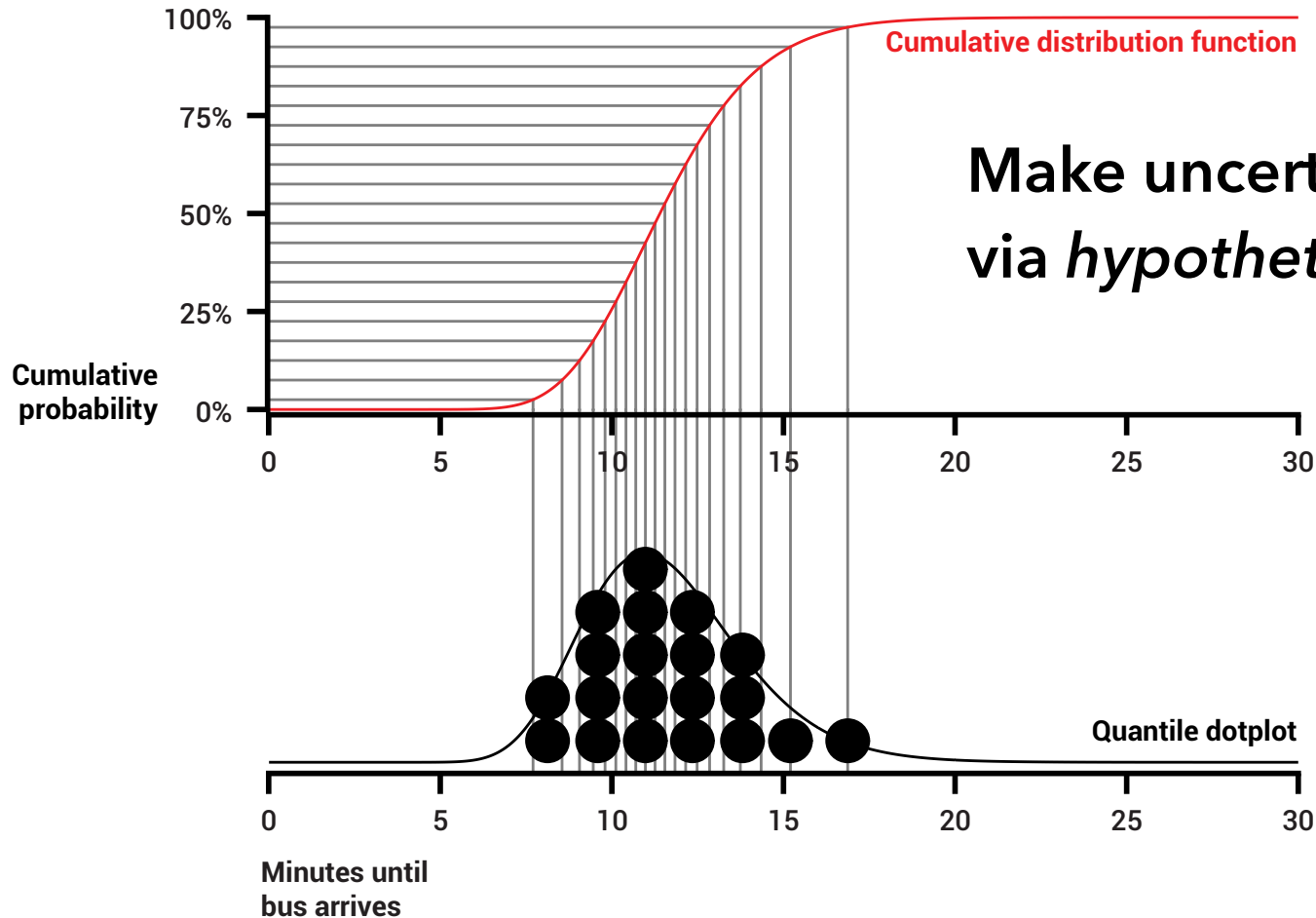


Model Visualization



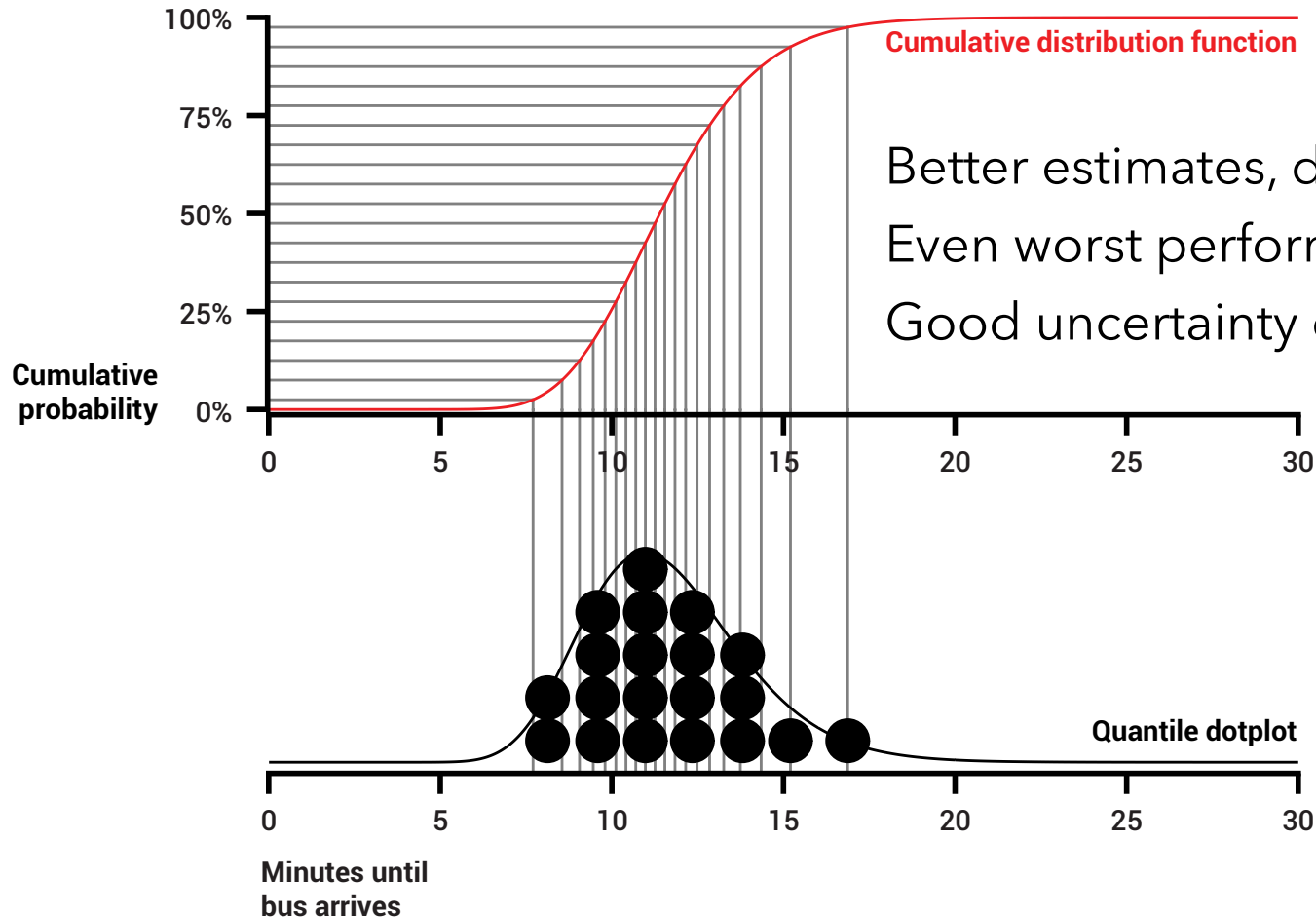
M. Mirzargar, R. Whitaker and R. Kirby. Curve Boxplot:
Generalization of Boxplot for Ensembles of Curves. IEEE VIS 2014.

Predicted Bus Arrival Times

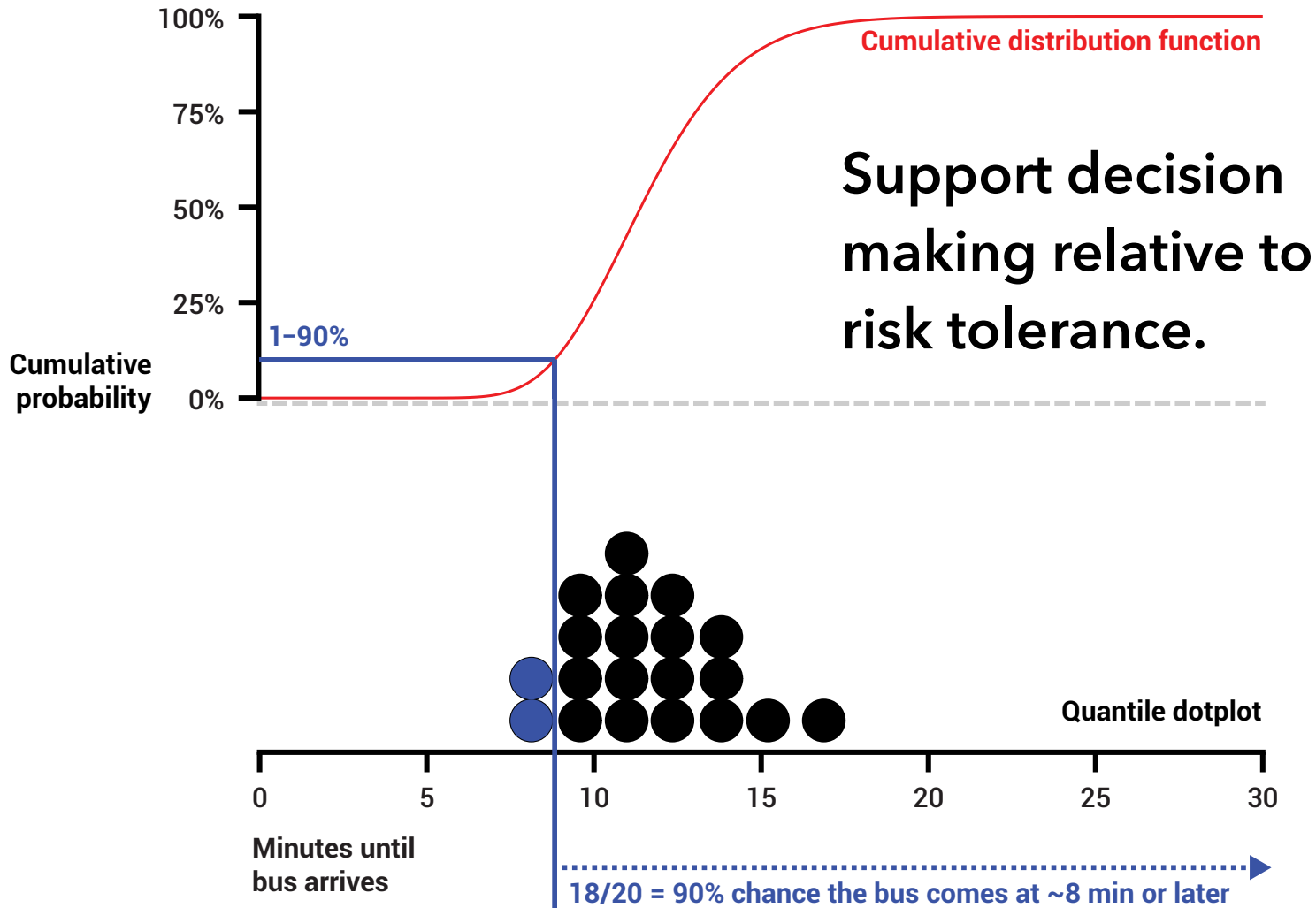


Make uncertainty concrete
via *hypothetical outcomes*.

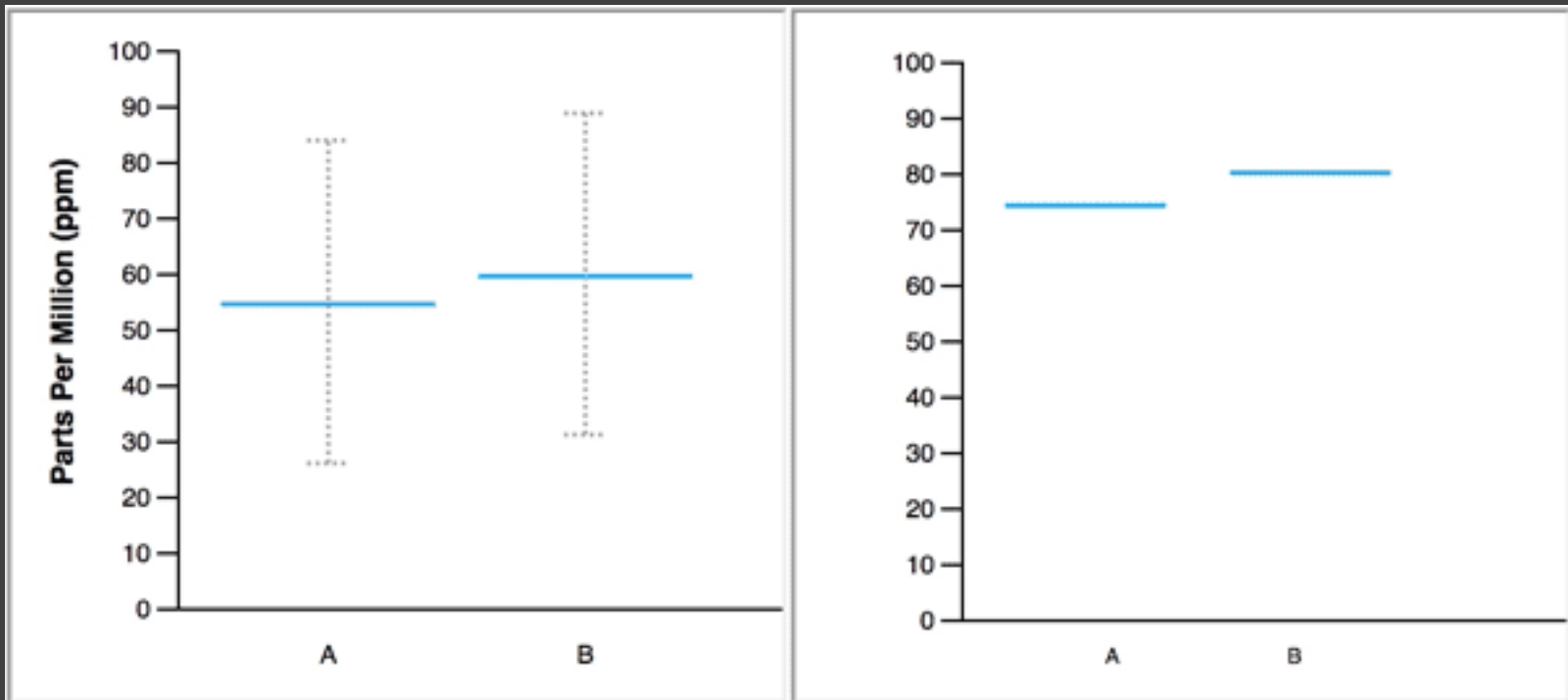
Predicted Bus Arrival Times



Predicted Bus Arrival Times



Hypothetical Outcome Plots



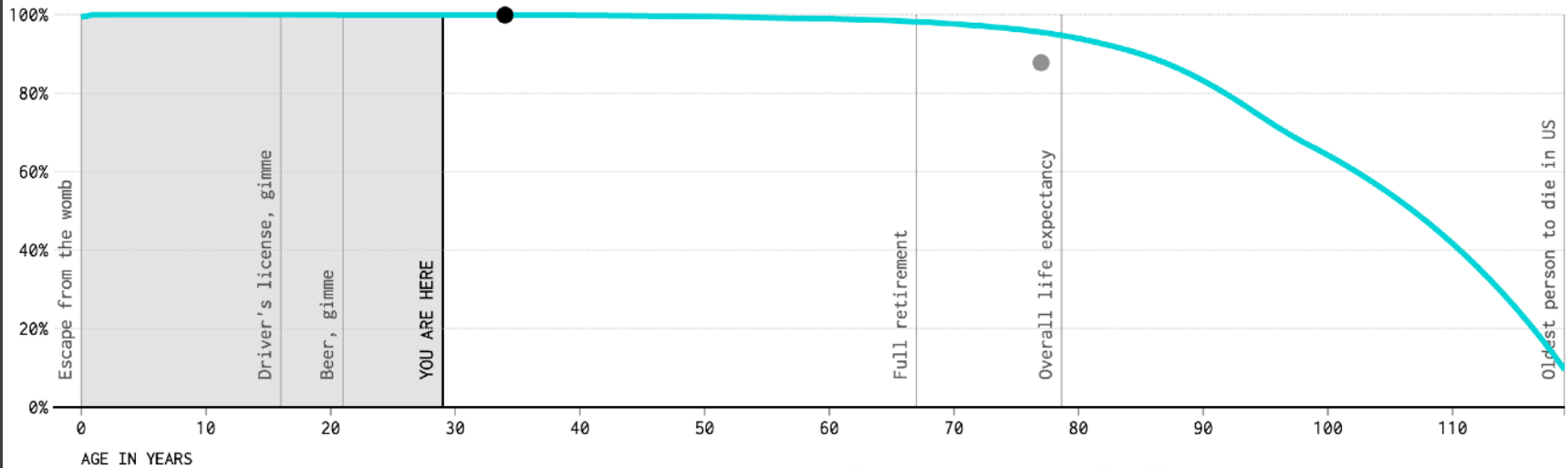
Life Expectancy

I am **male** and currently **29** years old.

SLOW

FAST

PROBABILITY OF LIVING TO NEXT YEAR



AGE IN YEARS

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.

How Should I Visualize Uncertainty?

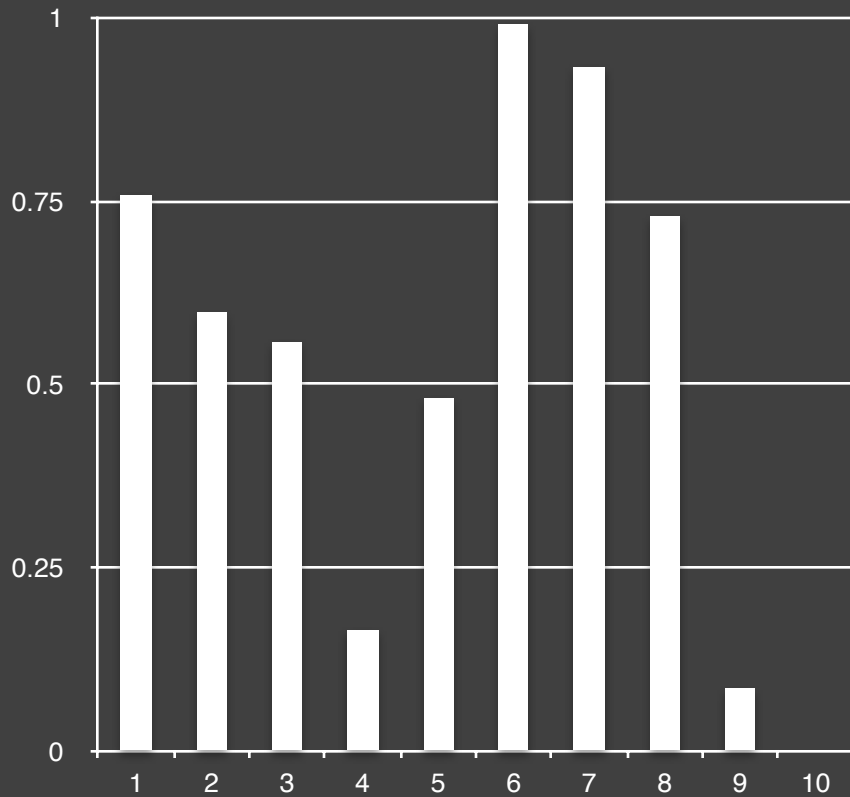
Choose an appropriate visual variable based on the domain, literacy, and expertise of your audience. Be mindful that any display of uncertainty inherently increases the complexity of your visualization, and that there is a preference/performance gap.

IT DEPENDS

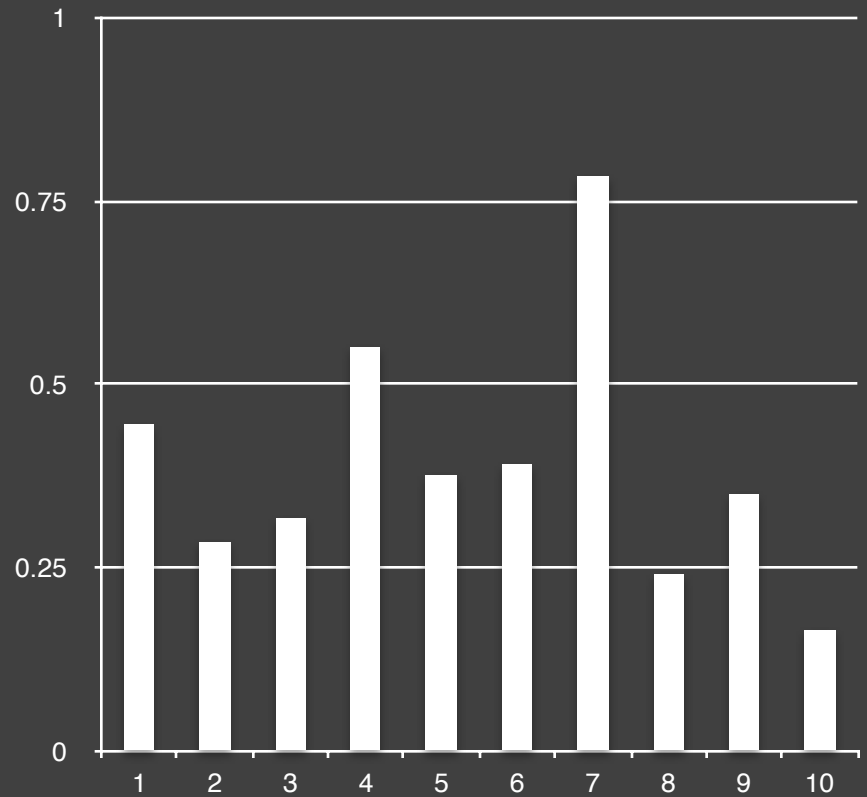
What Can Go Wrong?

Which Stock To Buy?

Company A

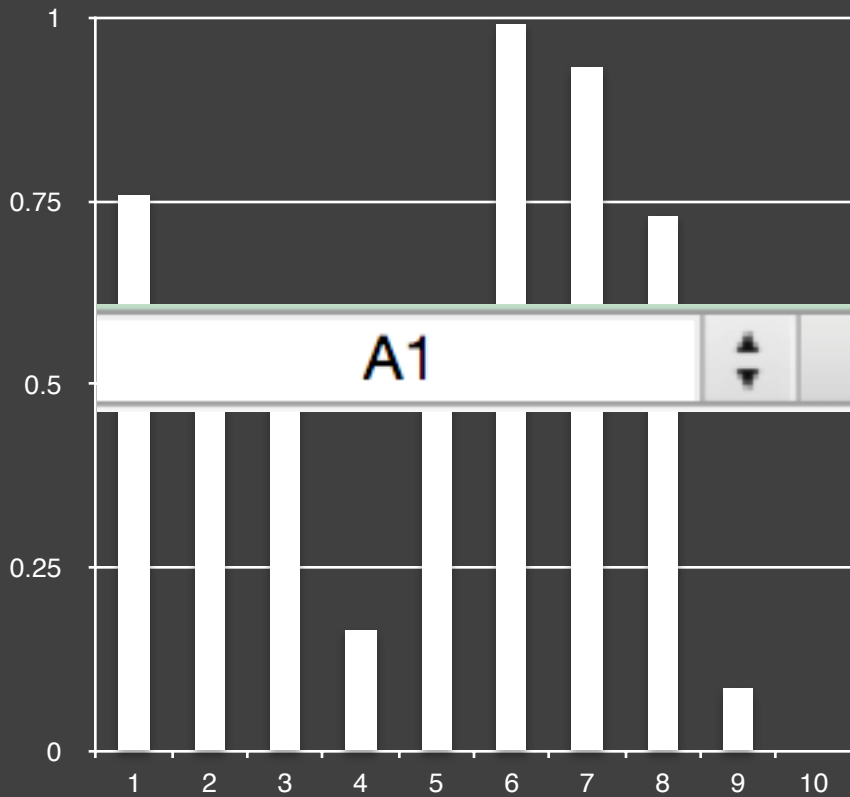


Company B

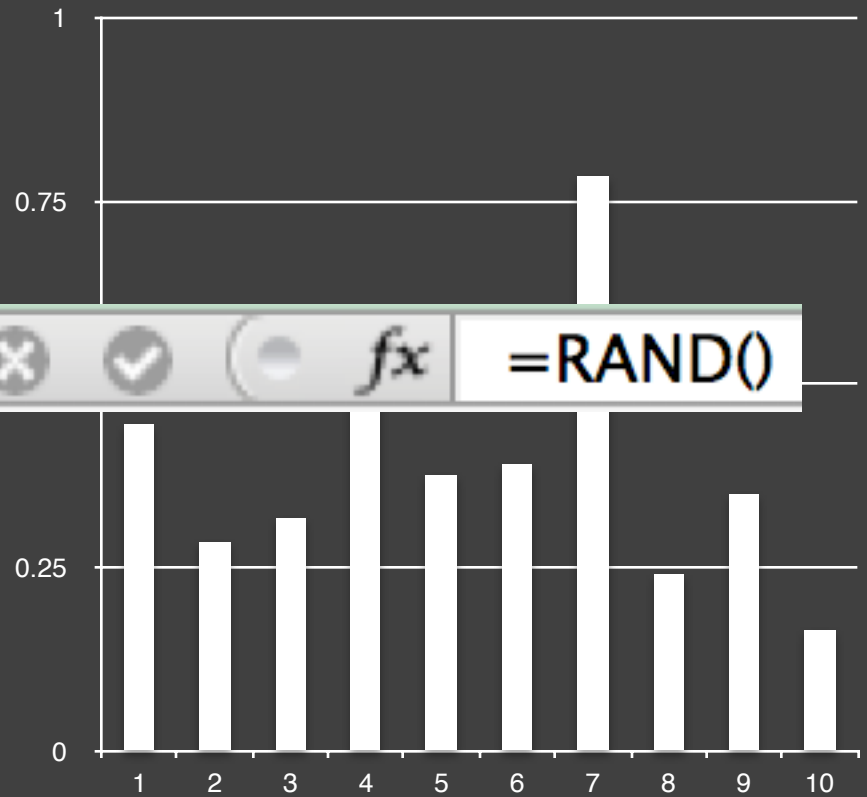


Neither!

Company A



Company B



A1



fx

=RAND()

Pareidolia



Jobs Reports

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.

*Job Growth
Plummets Amid
Prospect Of
New Slump*

Under 55,000 jobs
4% chance

*Disappointing
Jobs Report
Raises
Economic
Worries*

55,000 to 110,000
19% chance

*Slower Job
Creation
Disappoints
Economists*

110,000 to 140,000
19% chance

*Job Growth
Steady, New
Report Says*

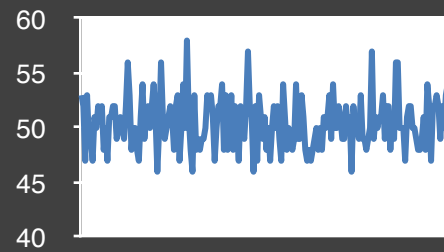
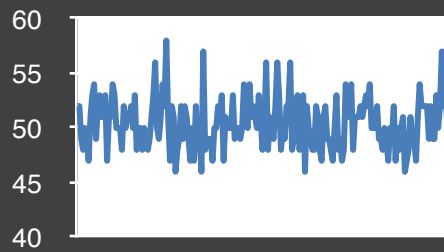
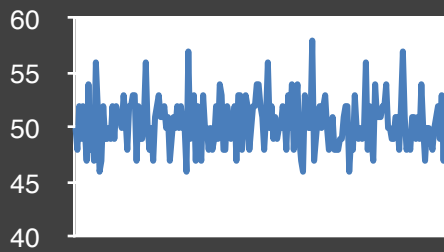
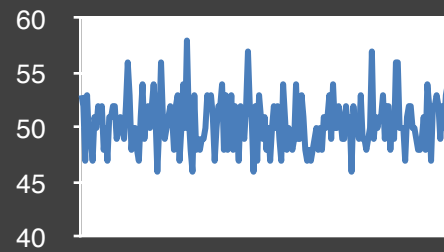
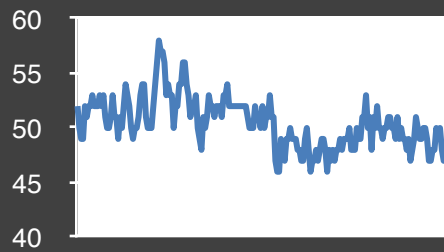
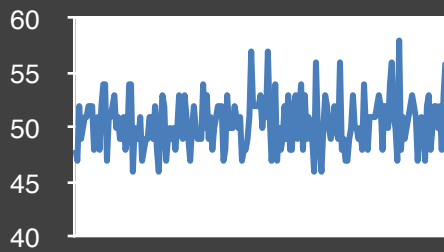
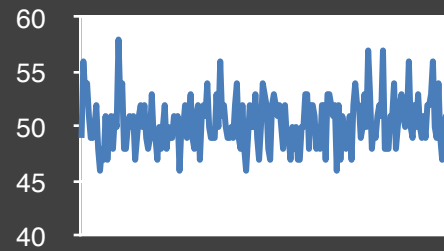
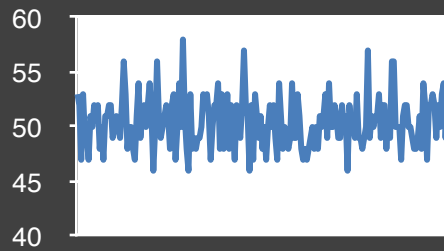
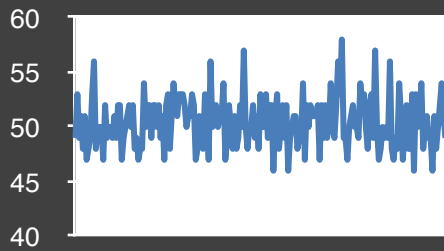
160,000 to 190,000
19% chance

*Job Creation
Accelerates In
Sign Of
Economy
Improving*

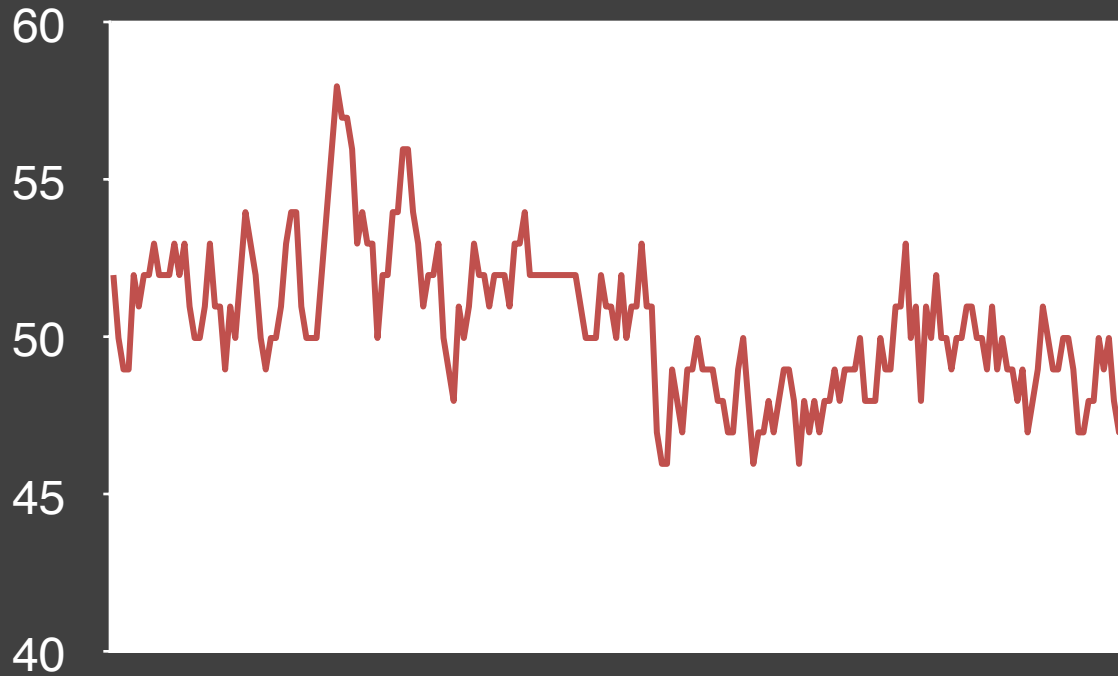
190,000 to 245,000
19% chance

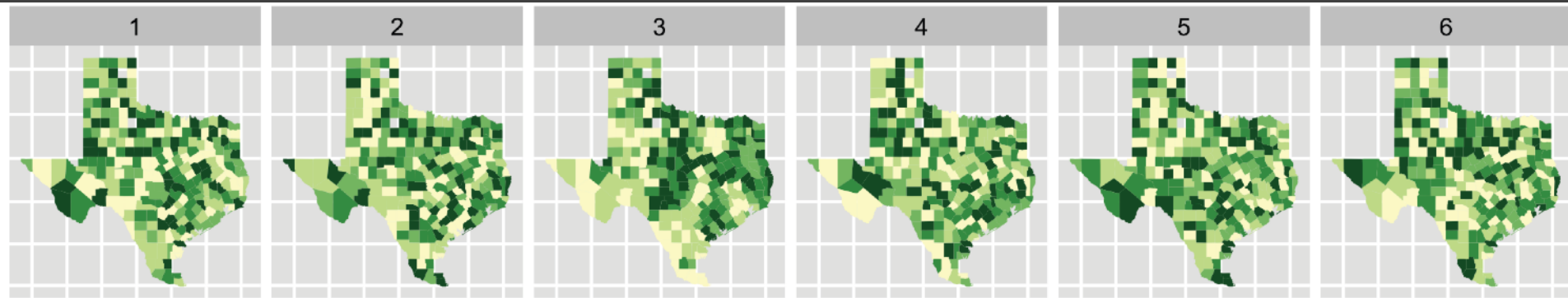
*Job Growth
Robust,
Pointing To
Economy
Surging*

245,000+
4% chance



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.

1

2

3

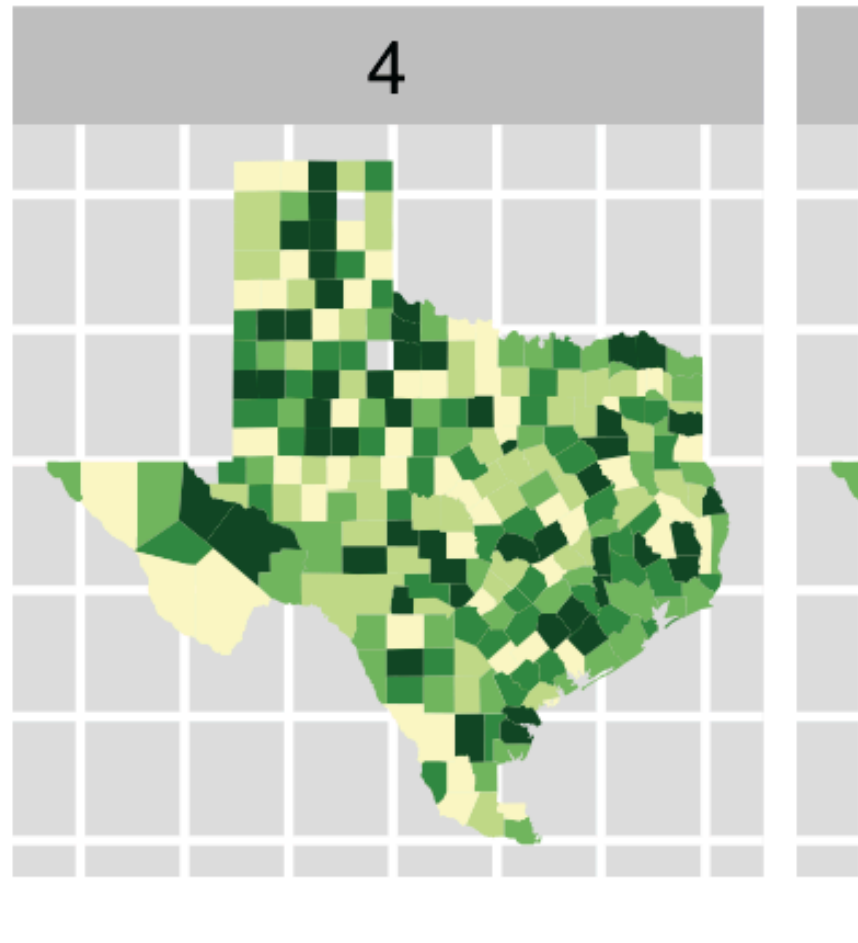
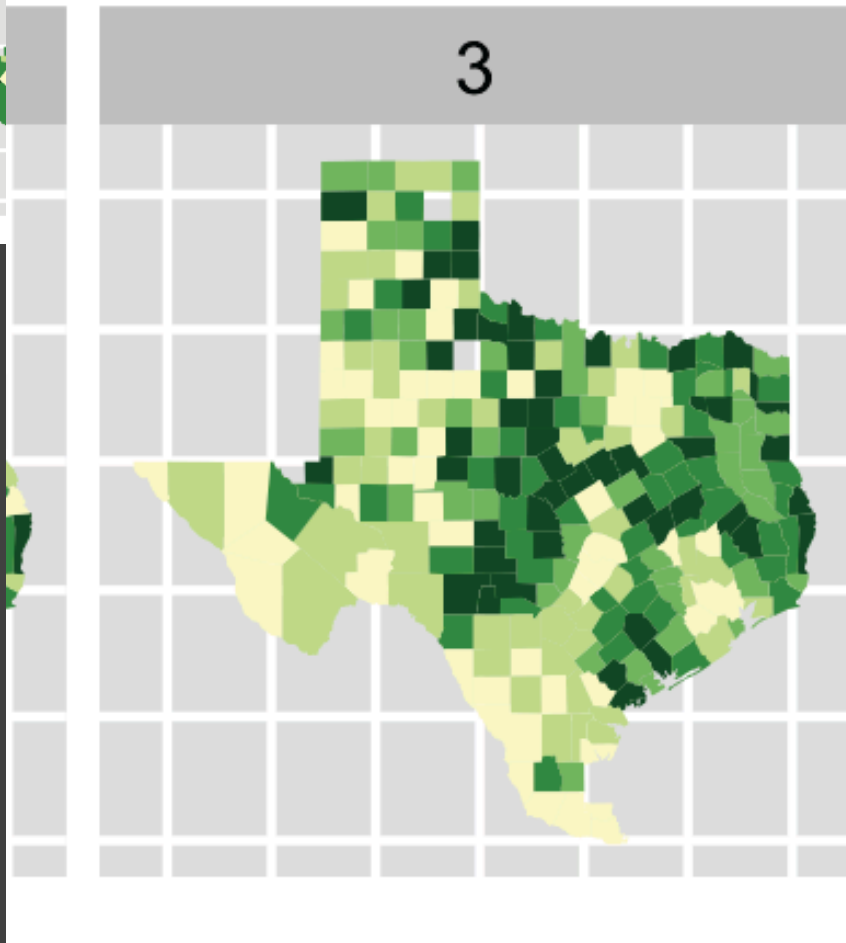
4

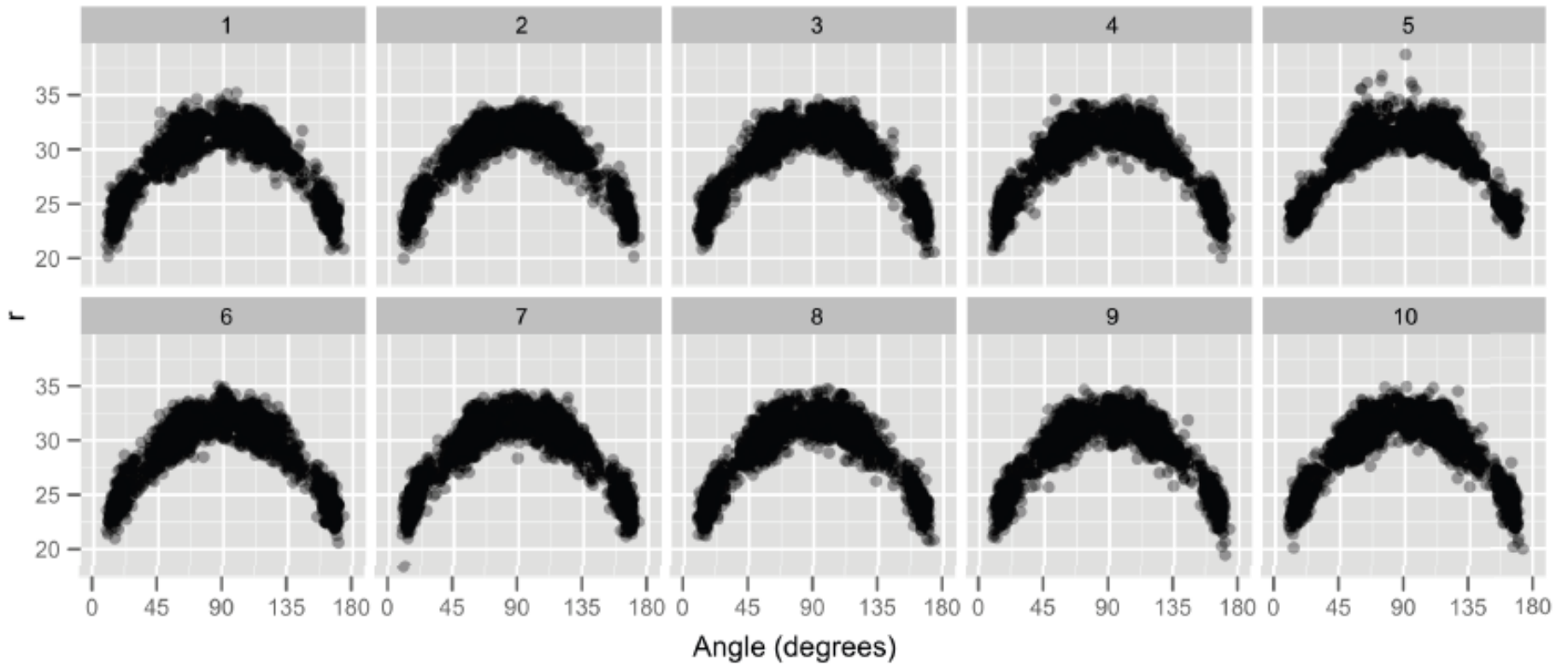
5

6

3

4





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.

How To Present Probabilities

Less Intuitive

Probability

$P(A) = 0.6$



Percentage

60% chance of A

More Intuitive

Natural
Frequency

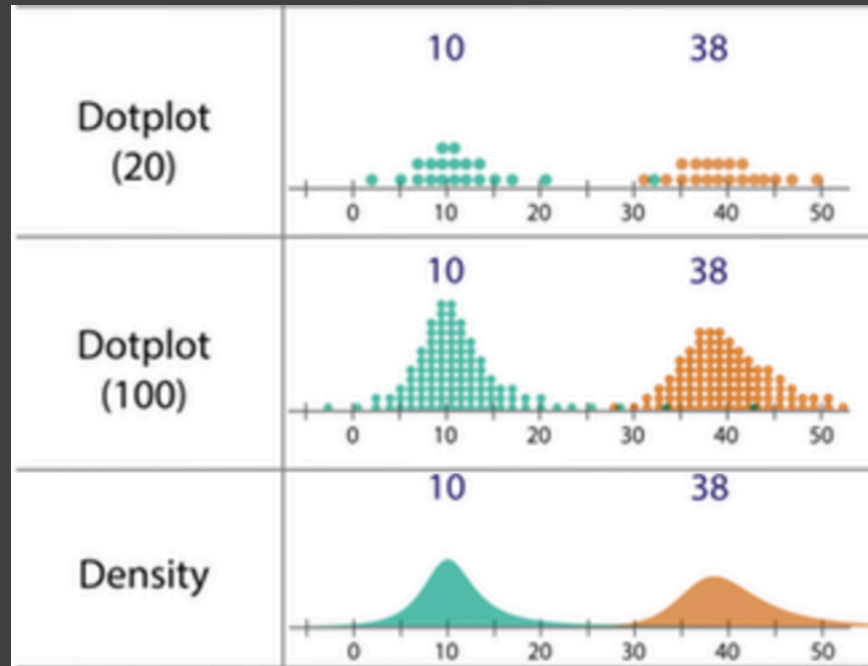
3 out of 5 times,
A happens.

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.

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

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

How Should I Visualize It?

IT DEPENDS

What Can Go Wrong?

A LOT

Conclusion

There are different **types** and **sources** of uncertainty associated with data.

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

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