



Uncertainty in Data and Visualization

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Southern University of Science and Technology

Agenda

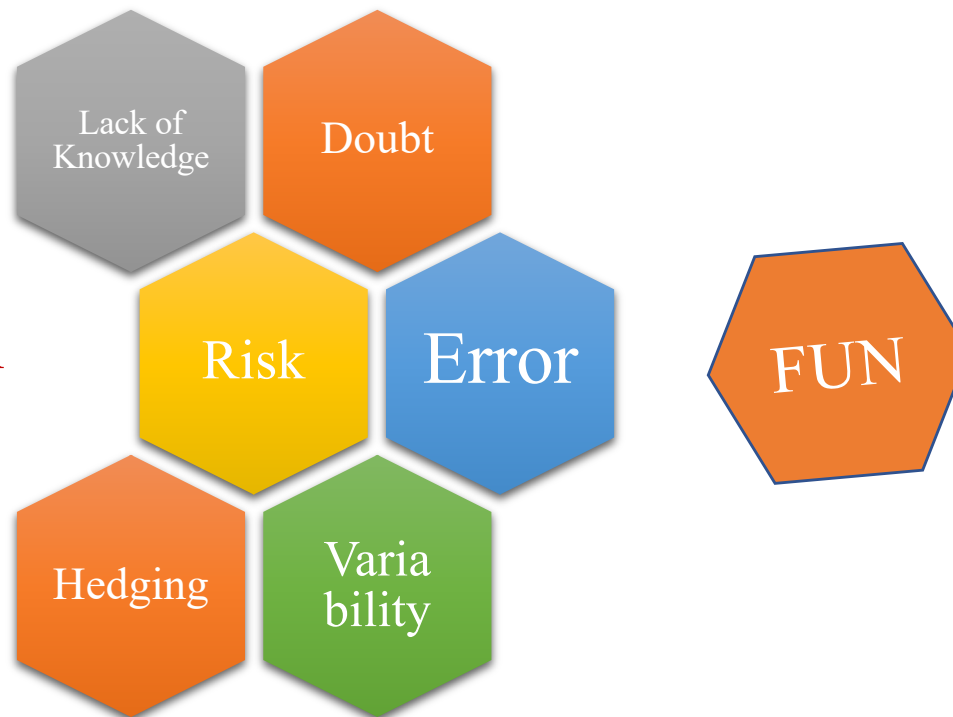
- What Does Uncertainty Mean?
- Uncertainty Visualization Pipeline
 1. Quantify Uncertainty
 2. Visual Encode Uncertainty
 3. Unify the Data Map and Uncertainty Map
- What Can Go Wrong

When we talk about “uncertainty”

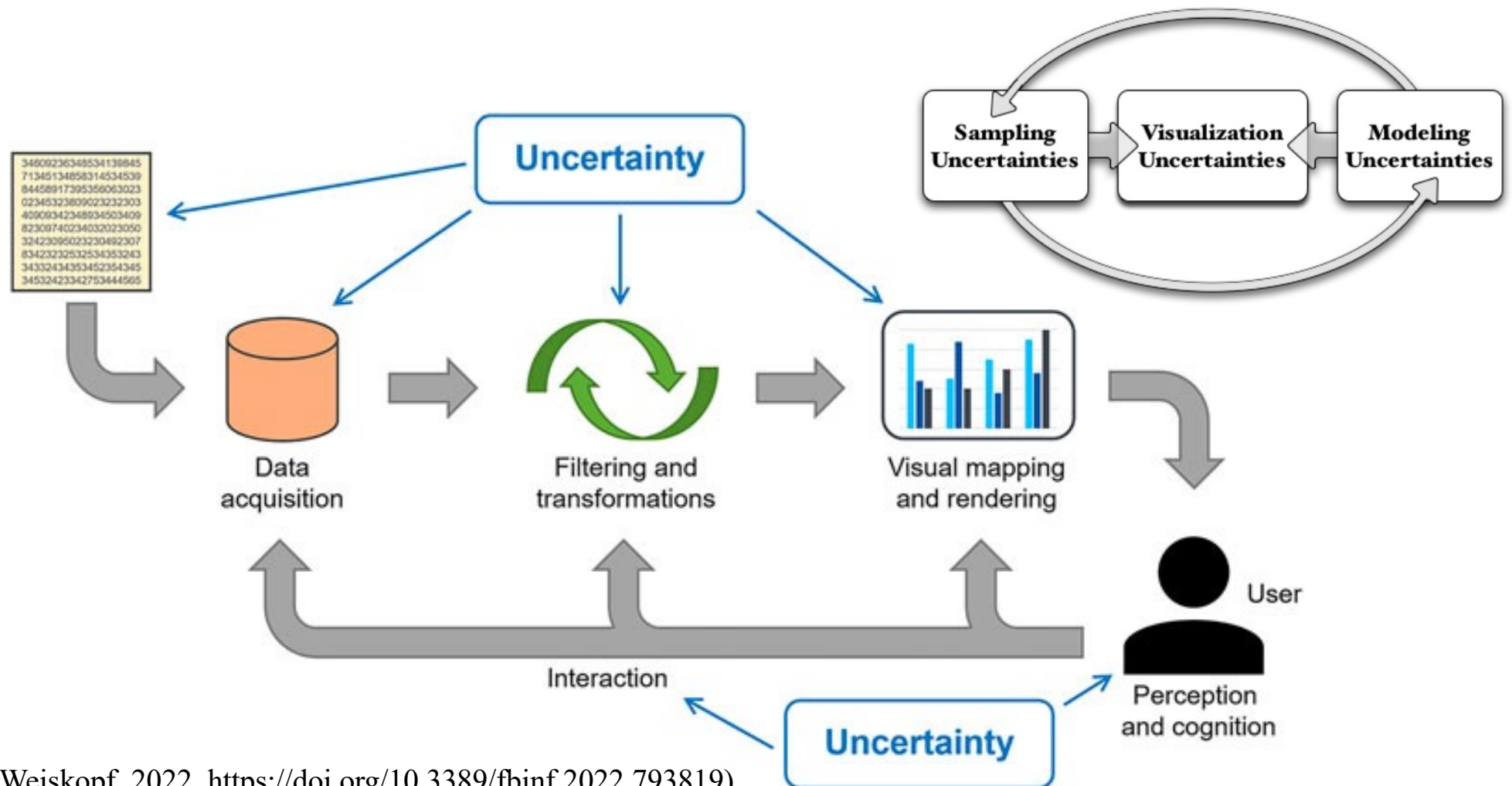
It can mean?

When we talk about “uncertainty”

It can mean



The visualization pipeline including uncertainty

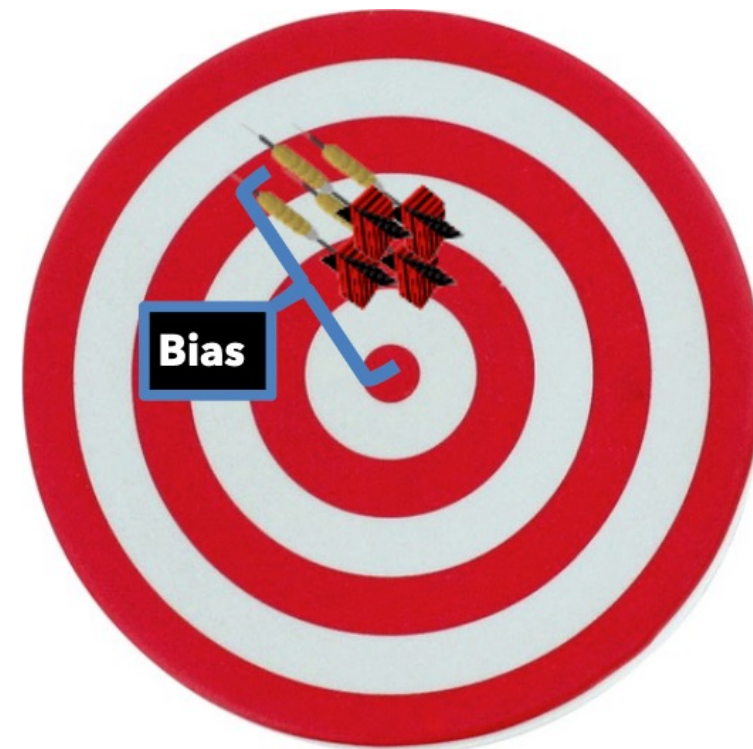


Measurement Uncertainty

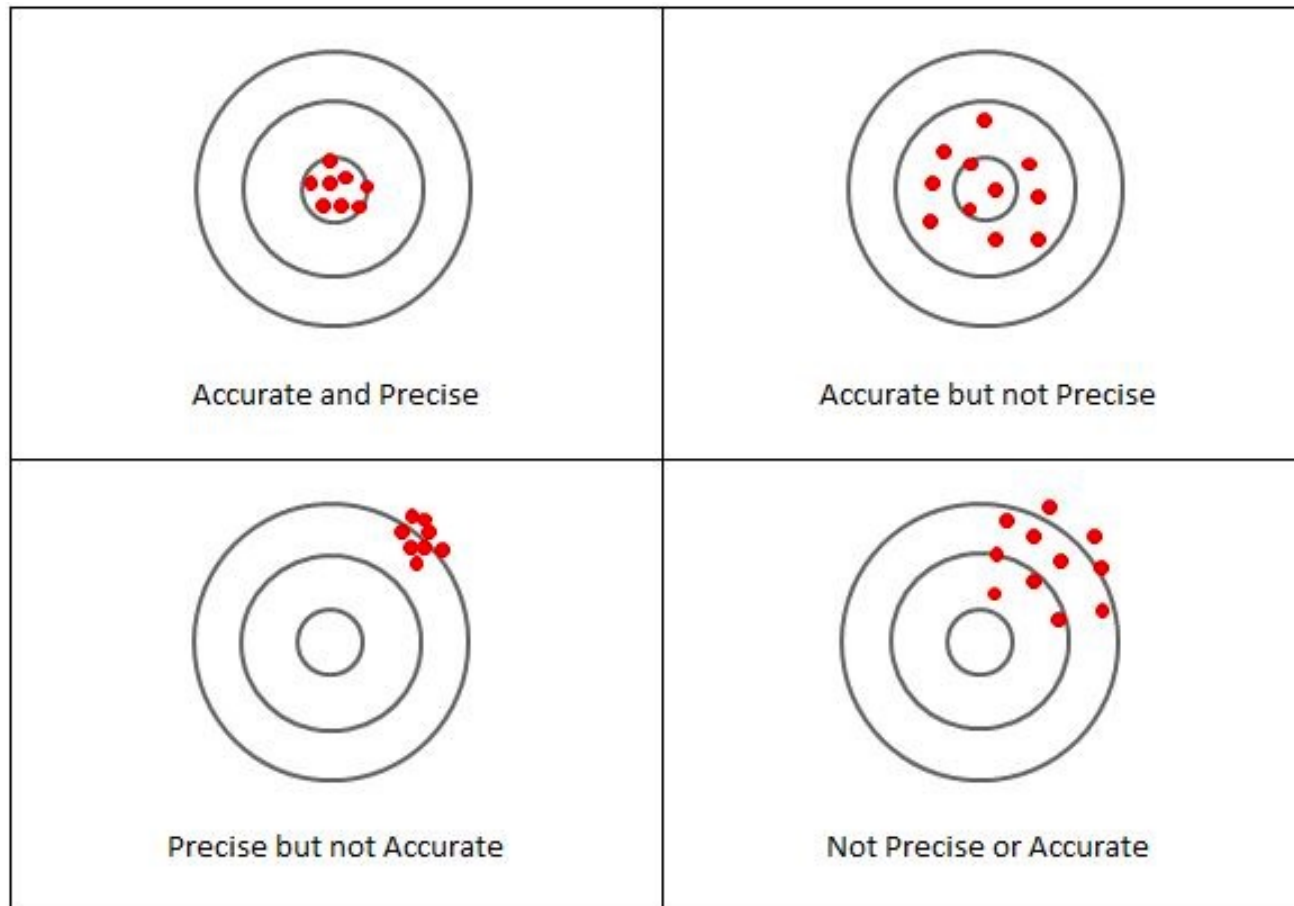
Accuracy



Precision



Measurement Uncertainty

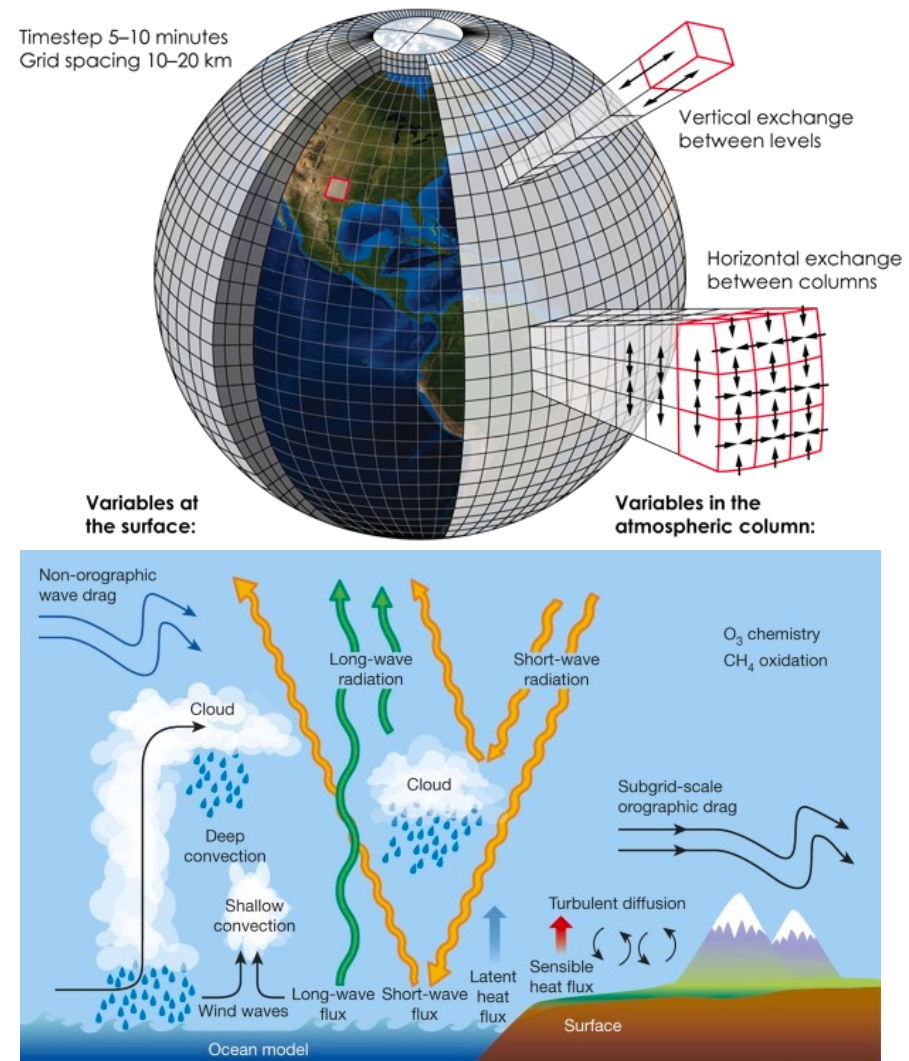


Model Uncertainty



Weather forecast modeling

Credit: K. Cantner, AGI.



<https://doi.org/10.1038/nature14956>

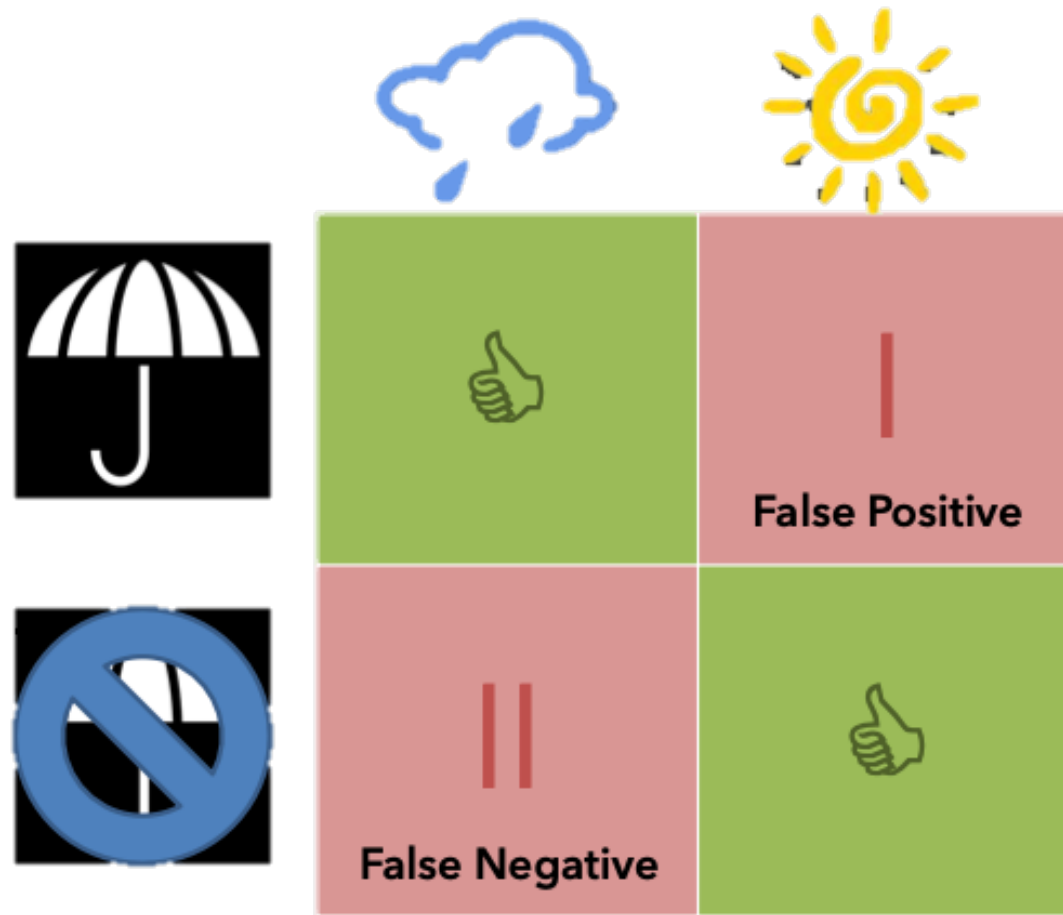
Decision Uncertainty

Should I Bring an Umbrella?

“50% Chance of Rain”



Types of Error



What Does Uncertainty Mean?

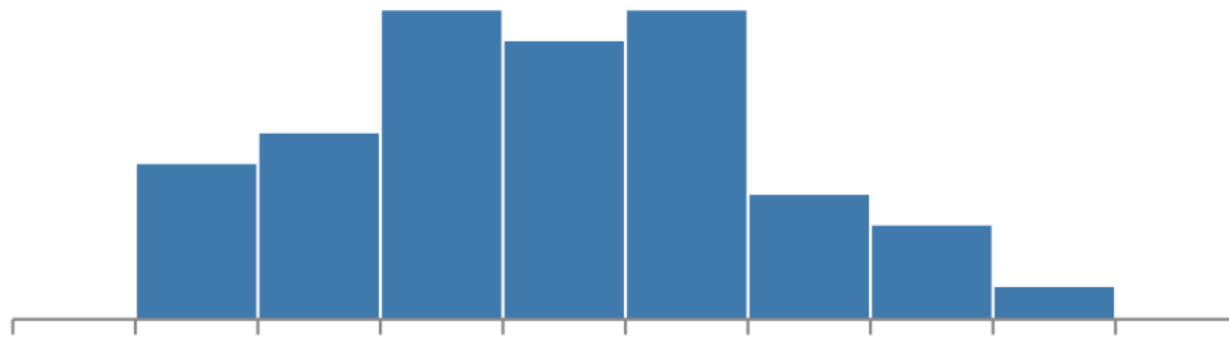
Any one of a number of potentially interconnected quantitative, qualitative, or factors that affect the quality, reliability, or utility of your data or data-driven decisions. Anything that can cause you to be unsure about your data or how to use it.

Quantify Uncertainty

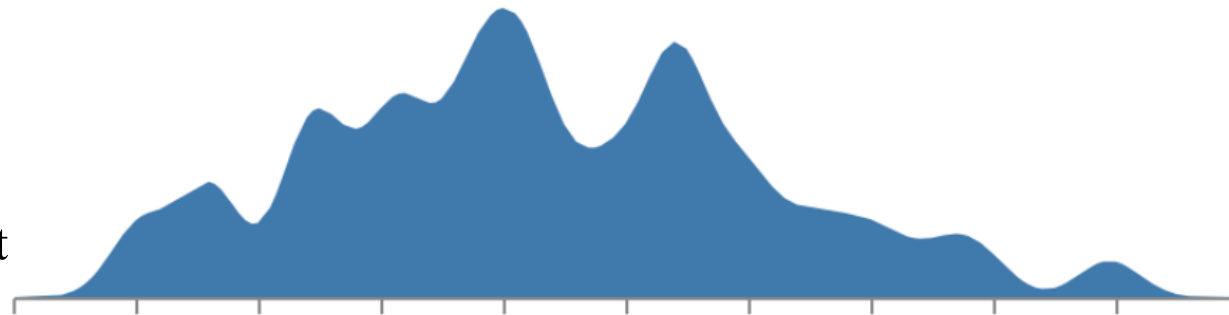
Distributions

probabilistic modeling of data uncertainty

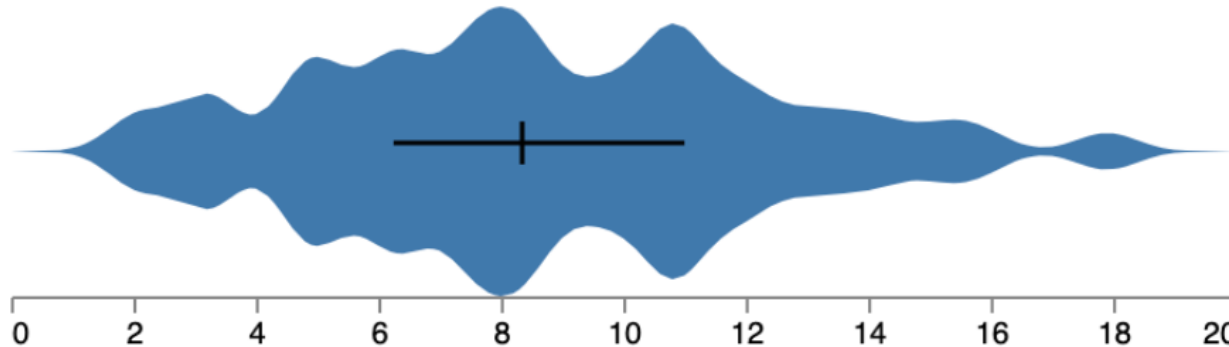
Histogram



Density Plot

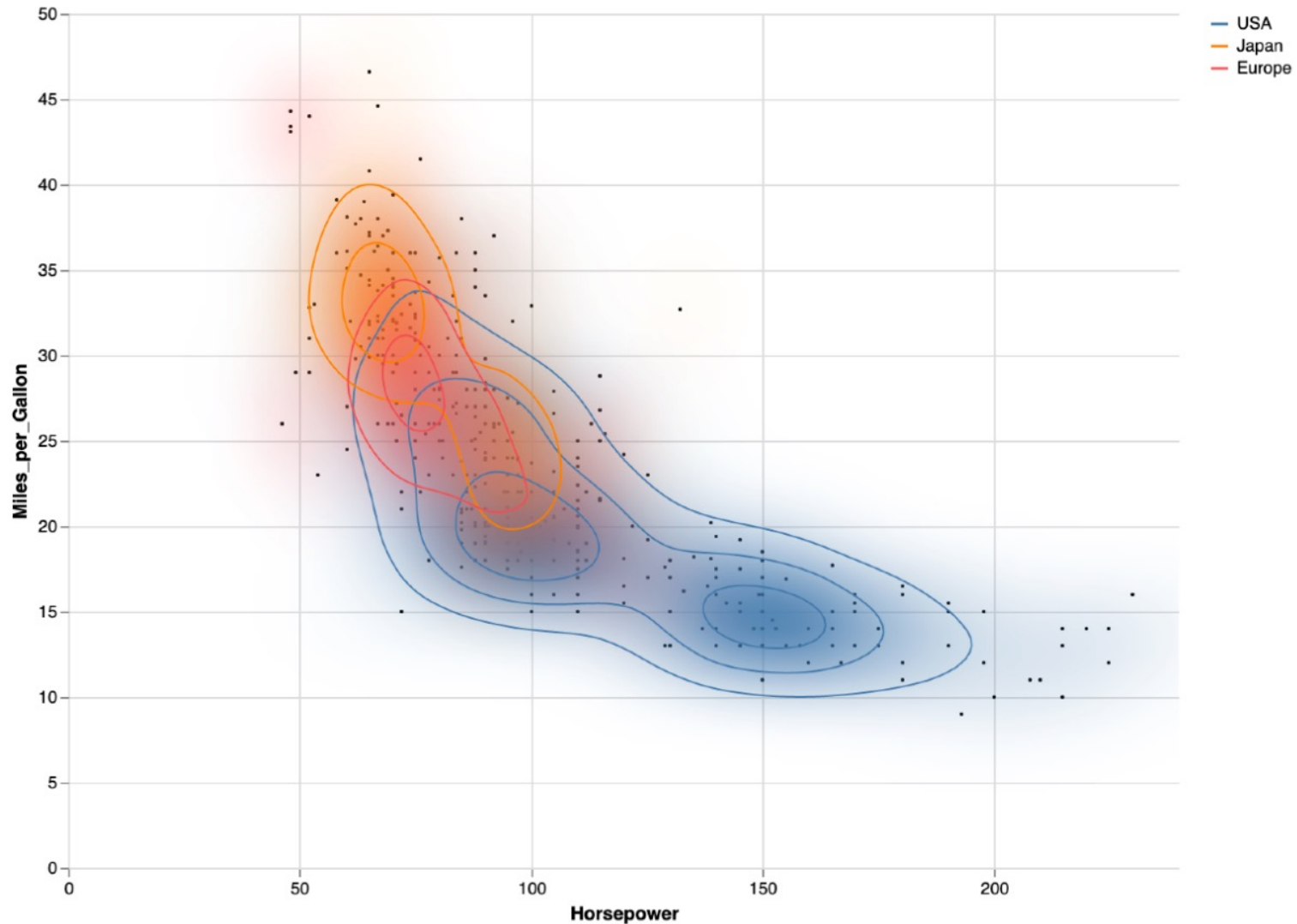


Violin Plot



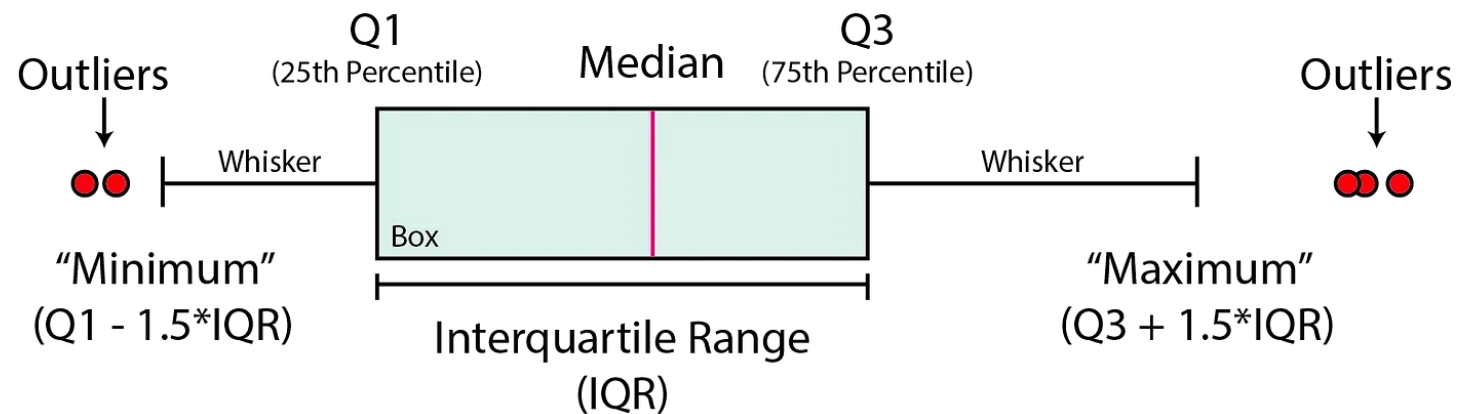
Distributions

probabilistic modeling of data uncertainty



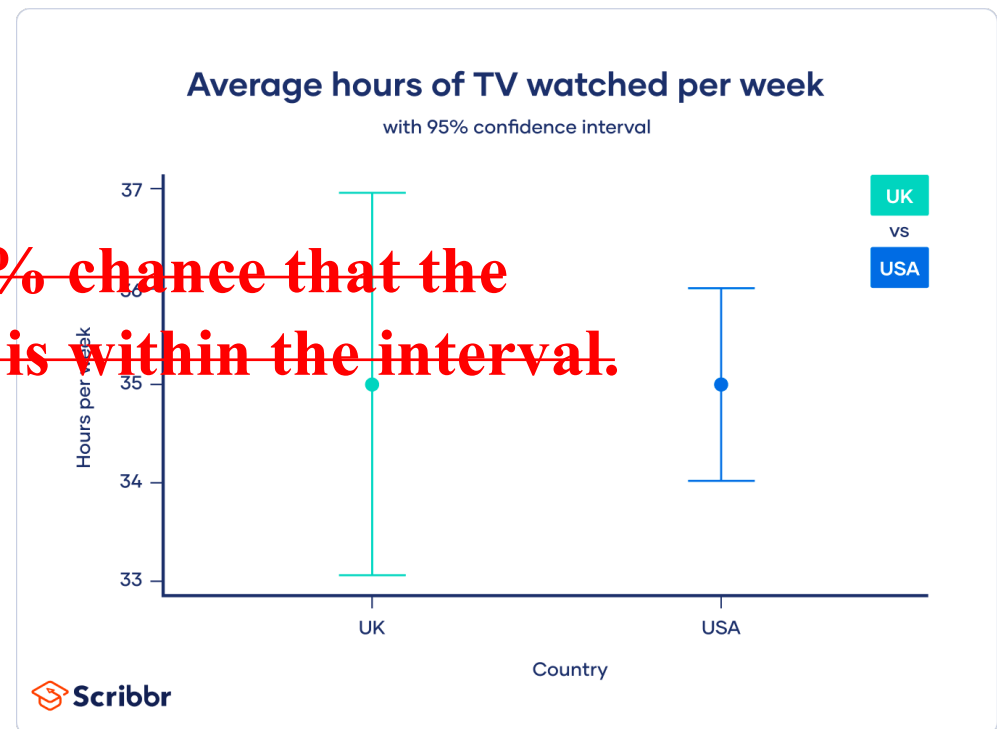
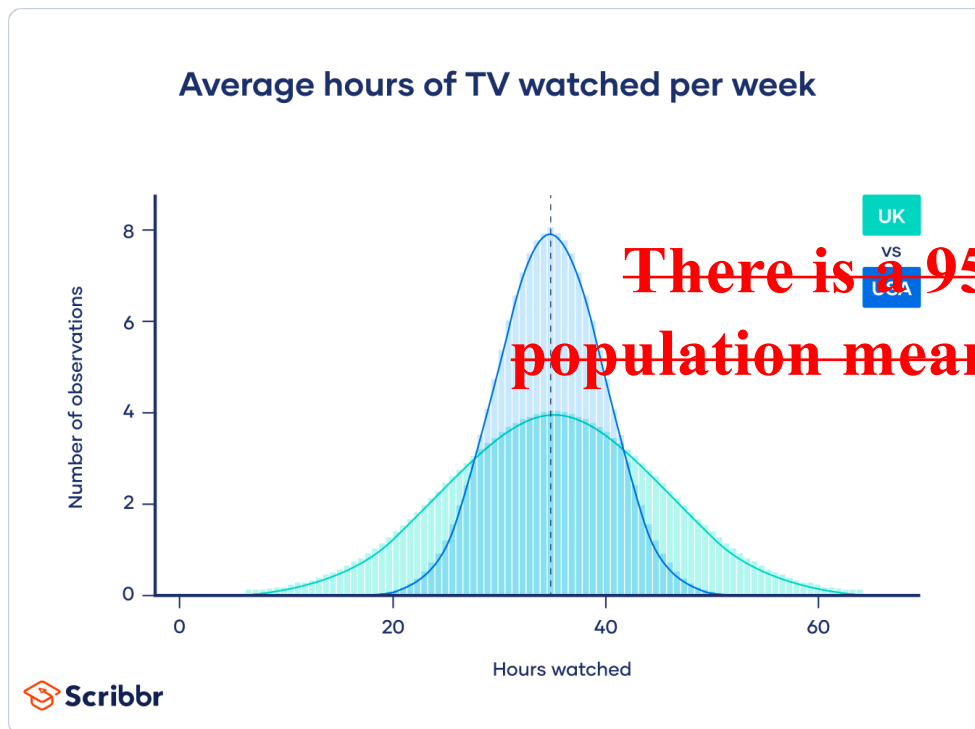
Error Bars

- Standard Deviation (σ) Standard Error ($\sigma / \sqrt{n}$)
- $1.5 * \text{IQR}$ (Interquartile Range)
- Confidence Intervals
- ... and so on



Confidence Intervals

- You survey 100 Brits and 100 Americans about their television-watching habits, and find that both groups watch an average of 35 hours of television per week.



$$CI = \bar{x} \pm z \frac{s}{\sqrt{n}}$$

CI = confidence interval

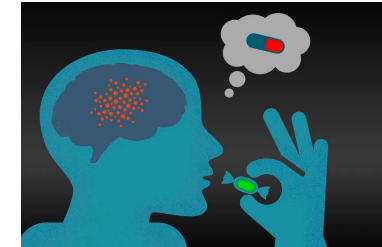
$\bar{x}$ = sample mean

z = confidence level value

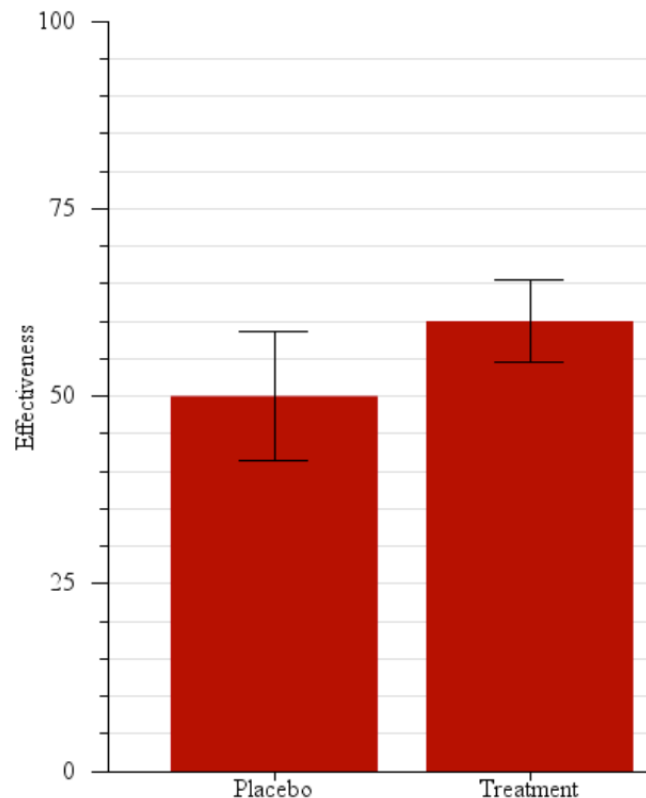
s = sample standard deviation

n = sample size

Error Bars

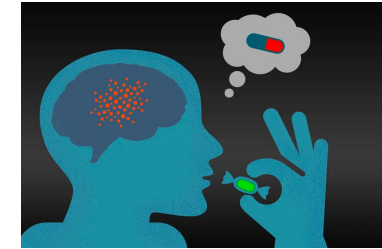


- Double-blind placebo control trials.
- Is this difference in means statistically significant?

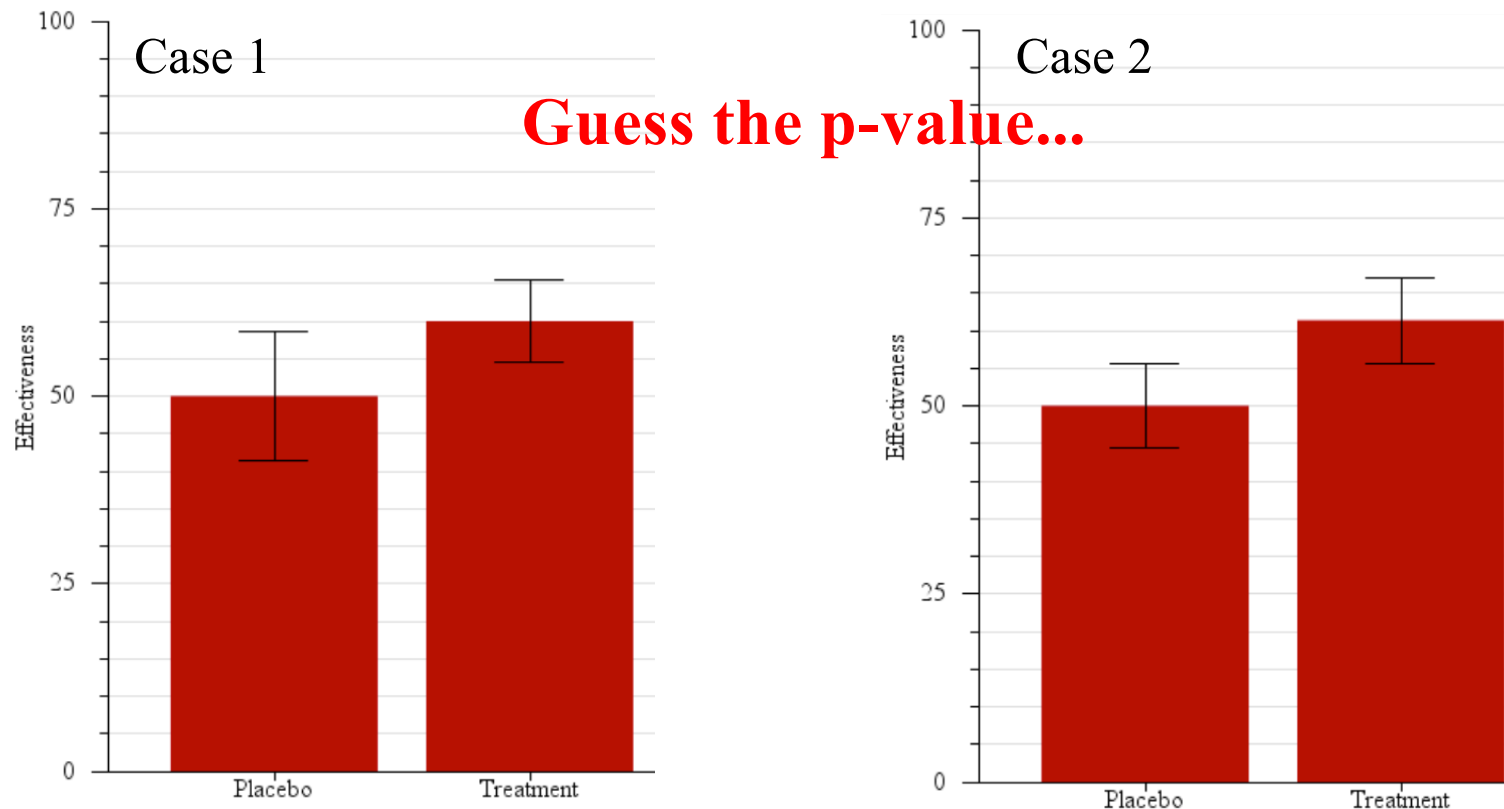


Error bars depict 95% Confidence Interval

Error Bars

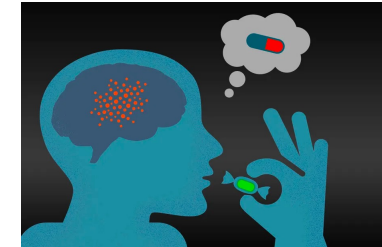


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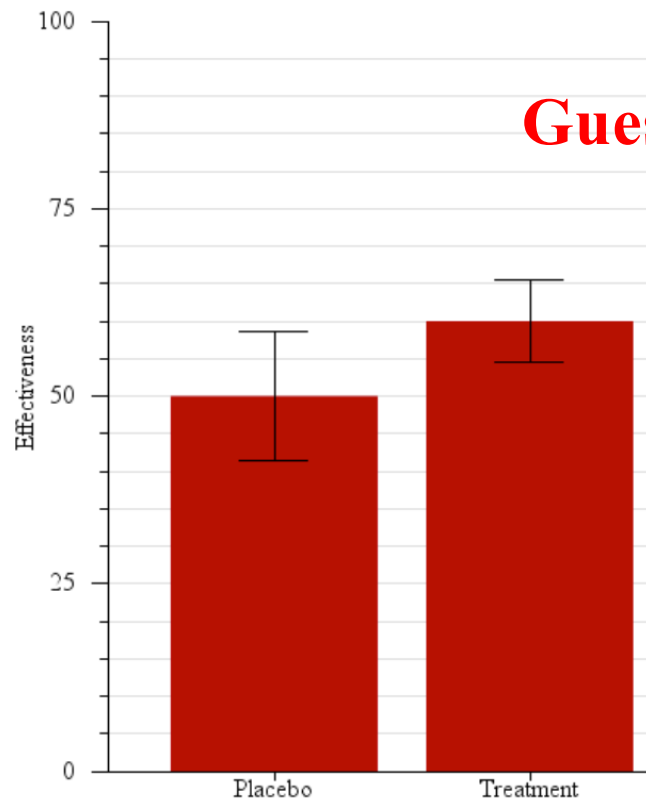


Error bars depict 95% Confidence Interval

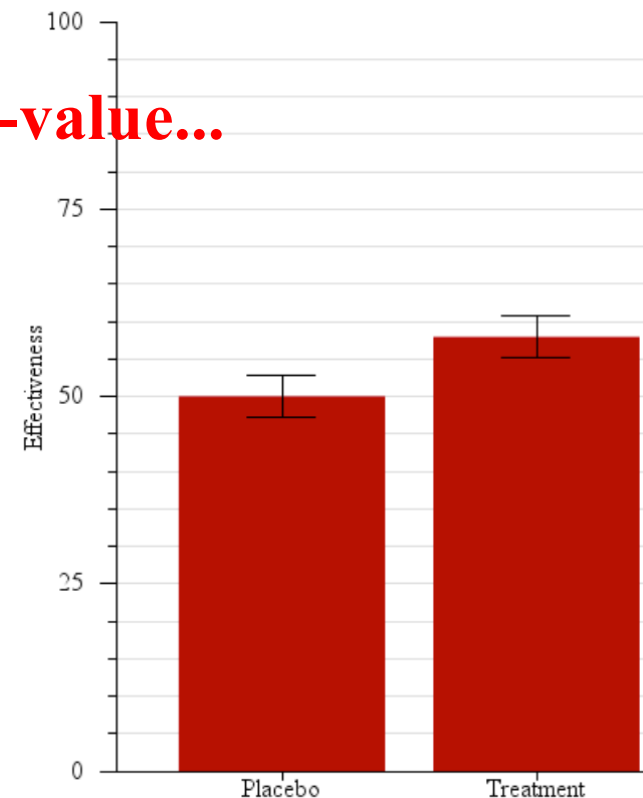
Error Bars



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Error bars depict 95% Confidence Interval

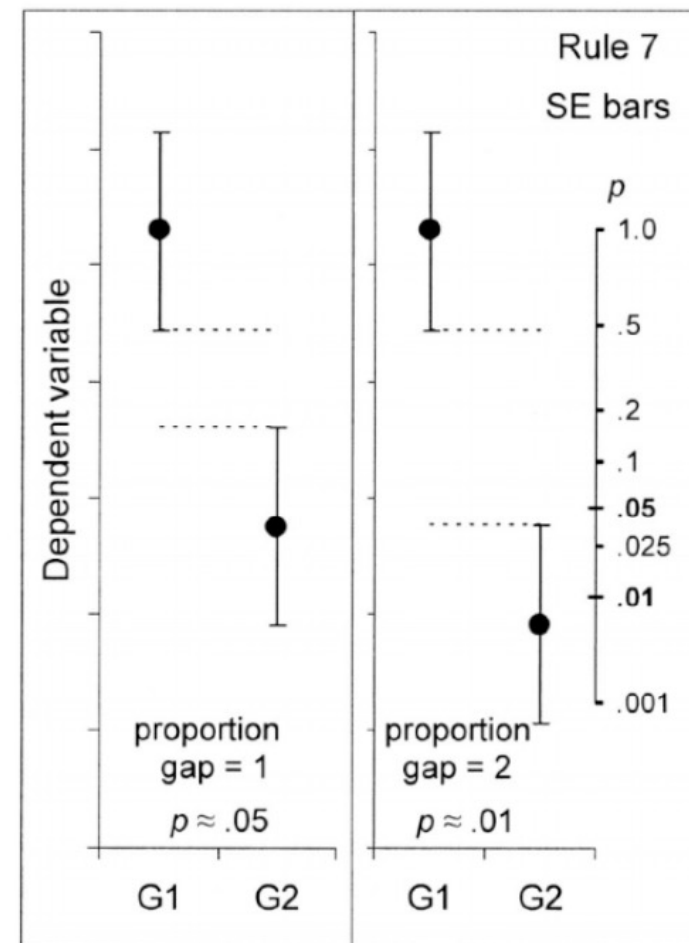
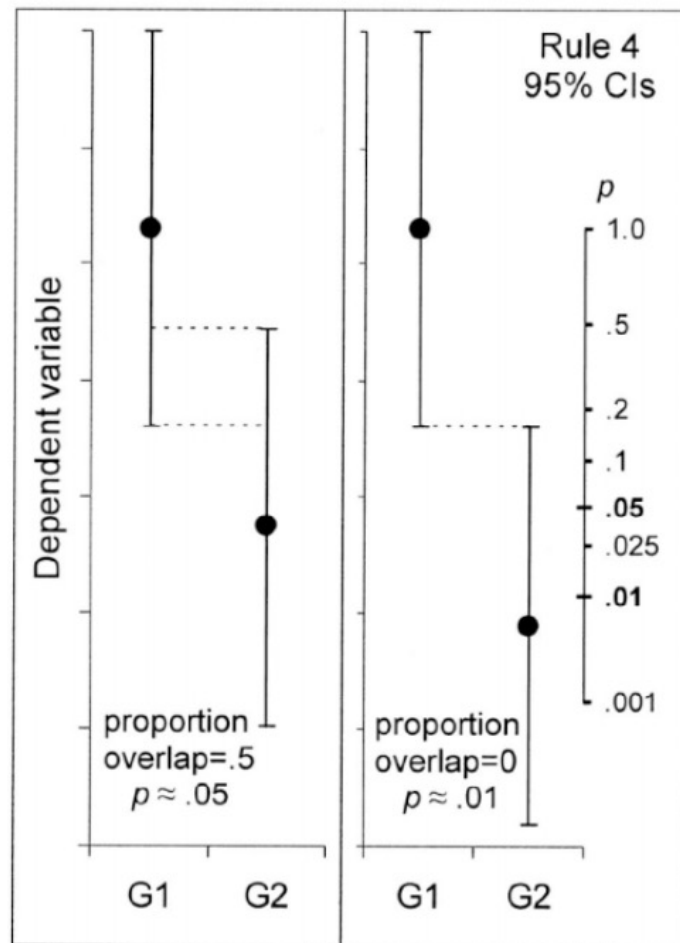


Error bars depict standard error

Guess the p-value...

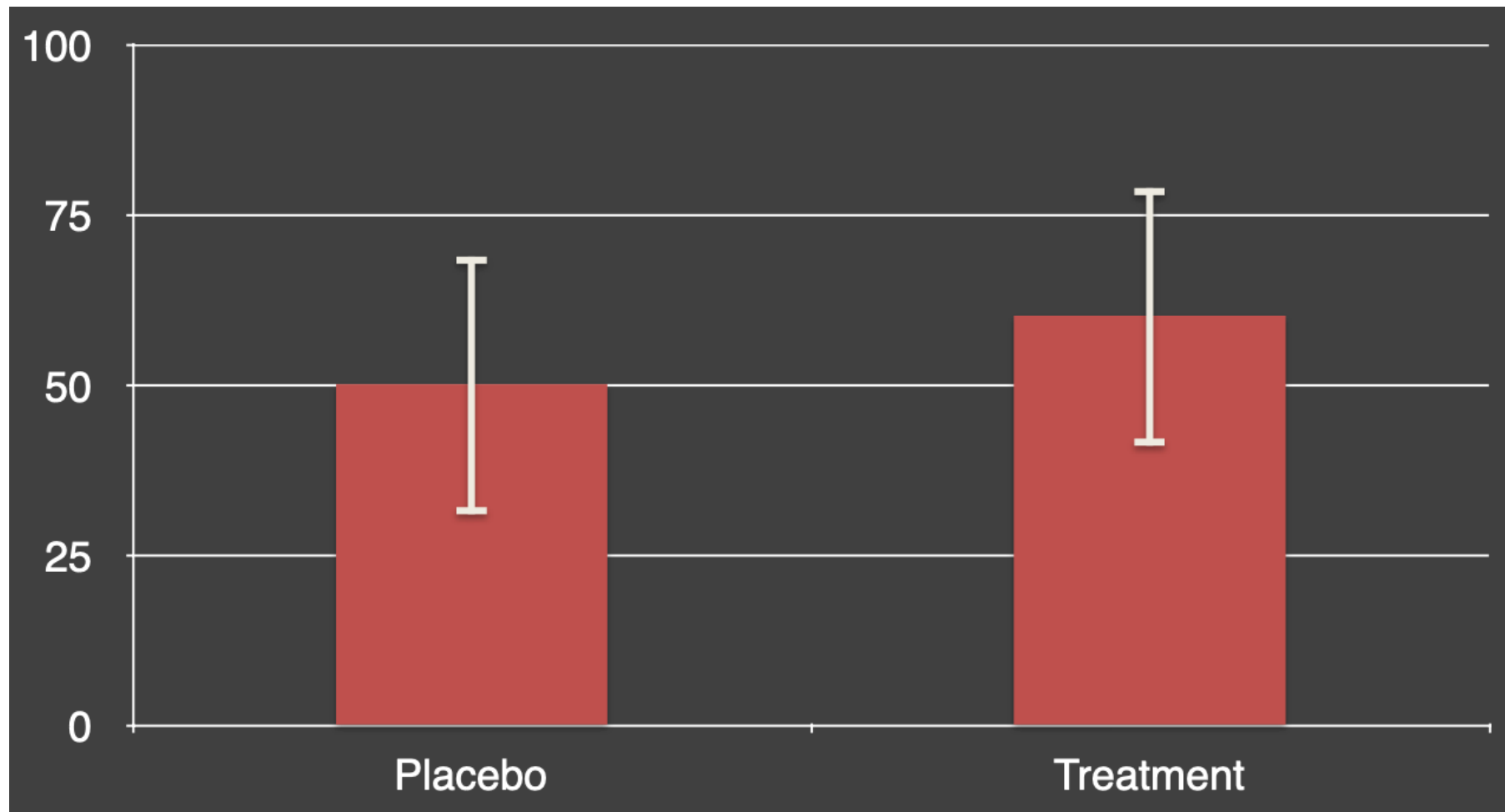
Inference by Eye

95% CIs

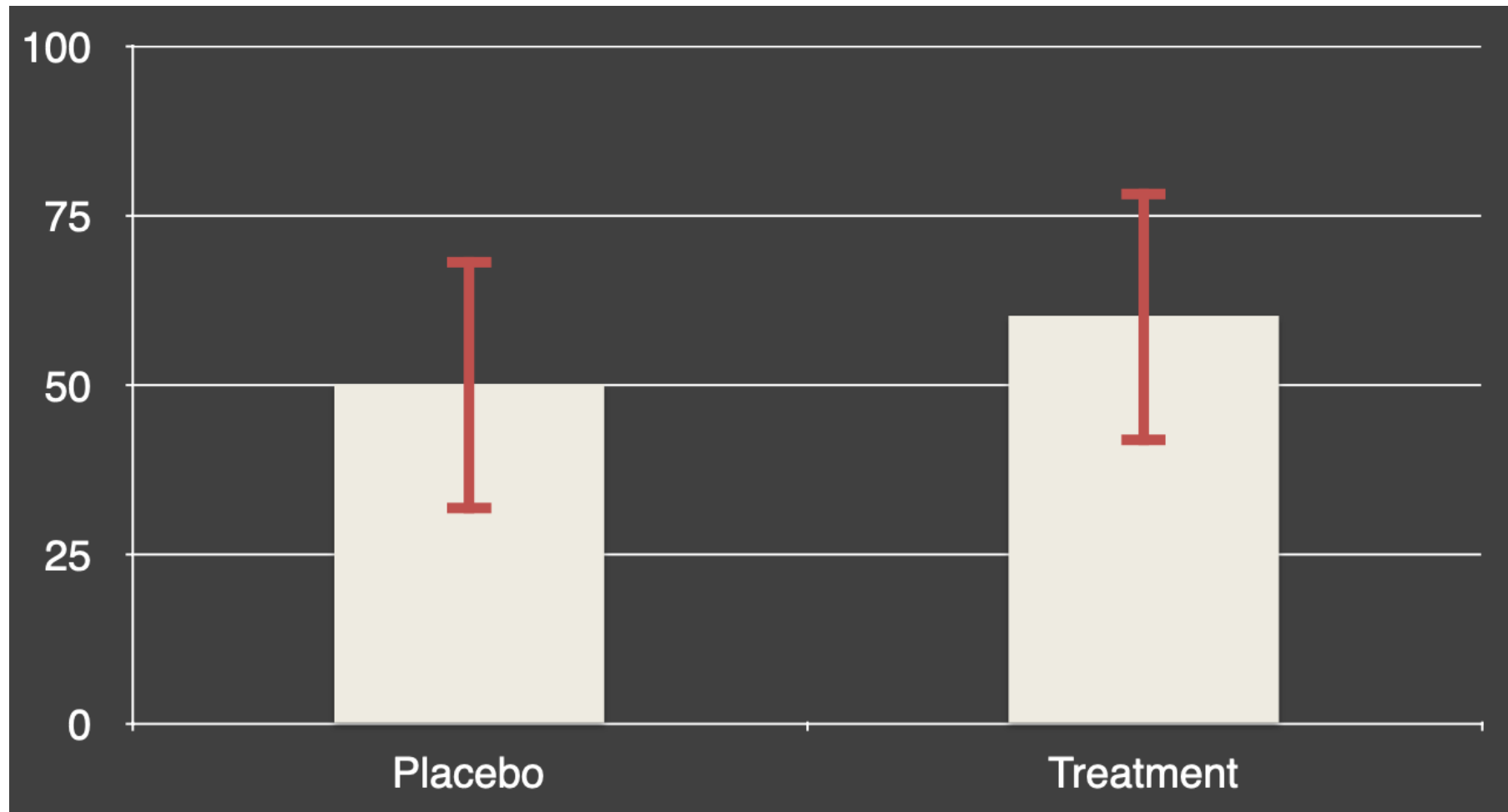


Cumming, Geoff and Finch, Sue. Inference by eye: confidence intervals and how to read pictures of data. American Psychologist, 2005.

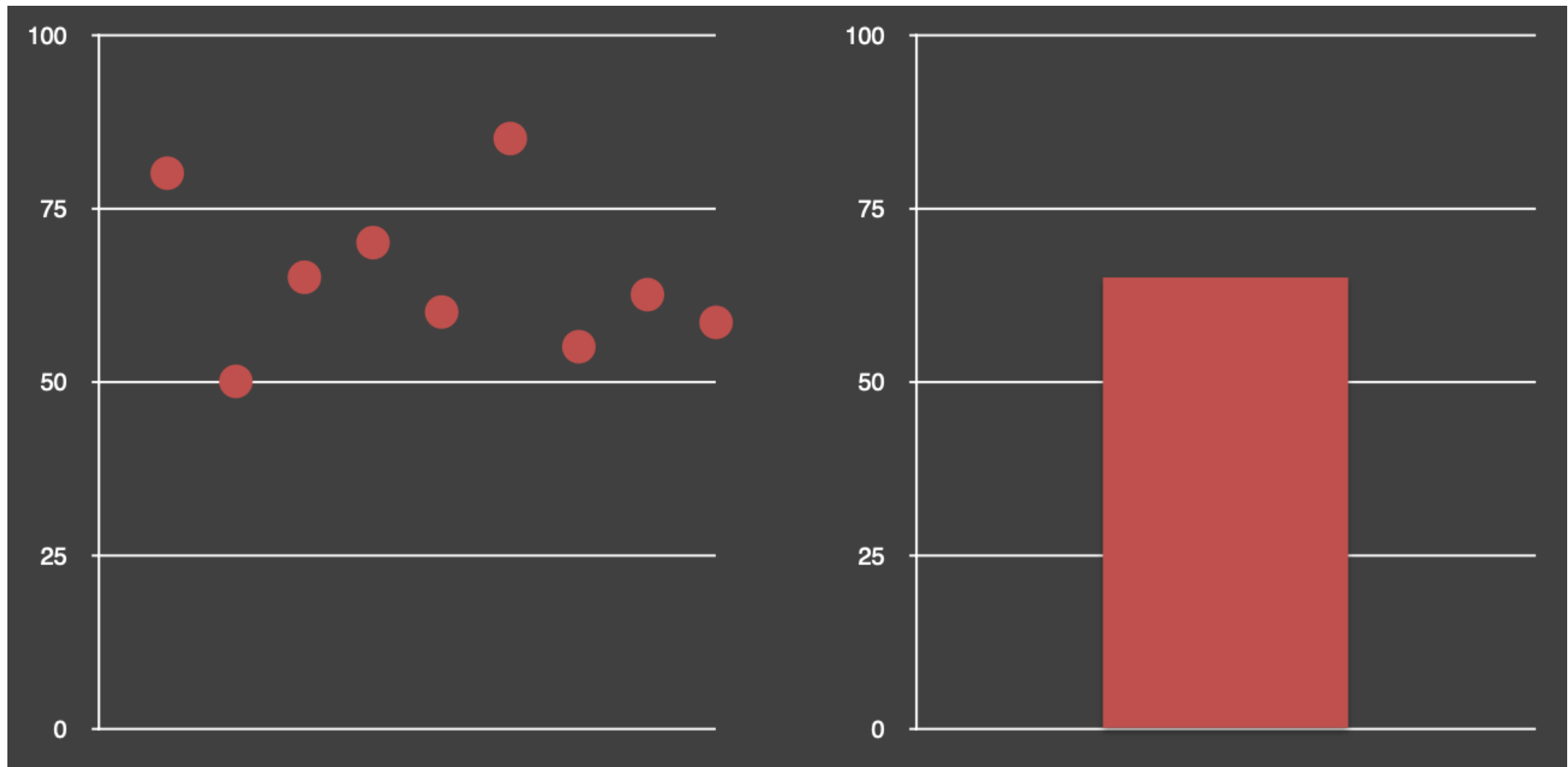
Misplaced Emphasis?



Misplaced Emphasis?

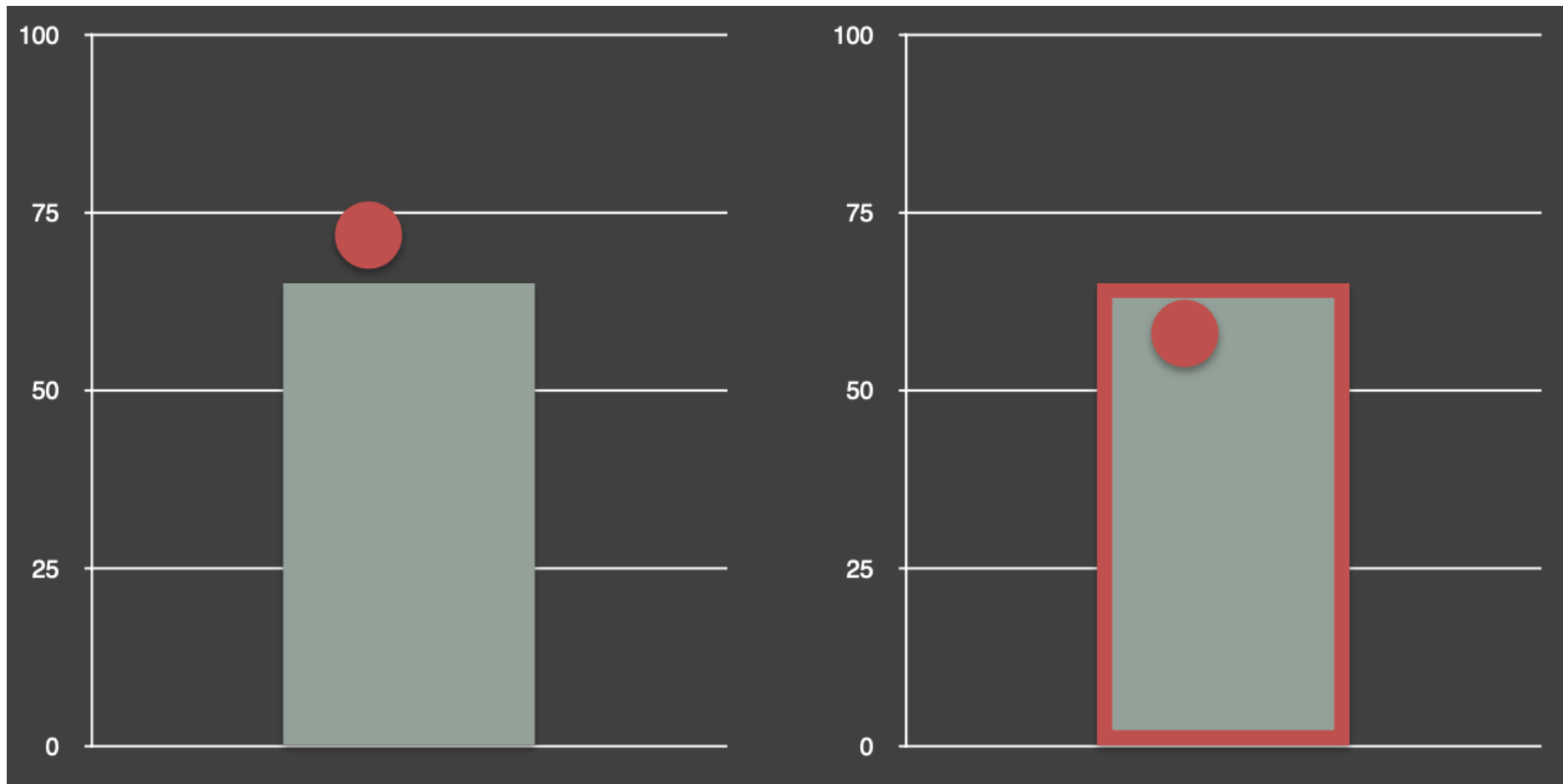


Within-the-Bar Bias



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

Within-the-Bar Bias



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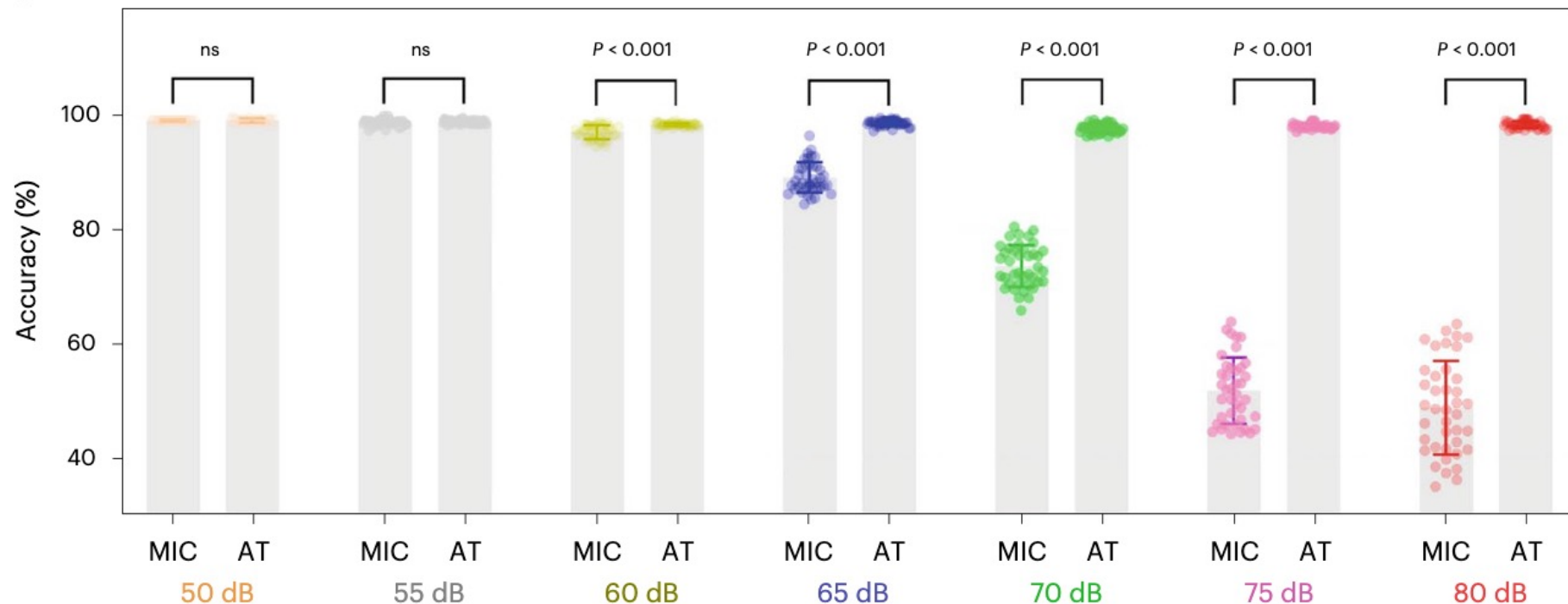
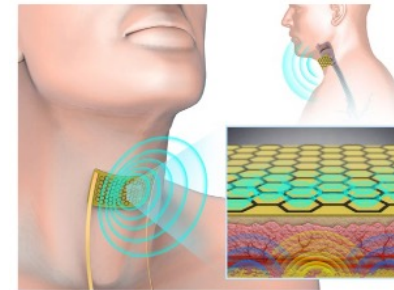
Alternatives to Error Bars

nature machine intelligence

Article

<https://doi.org/10.1038/s42256-023-00616-6>

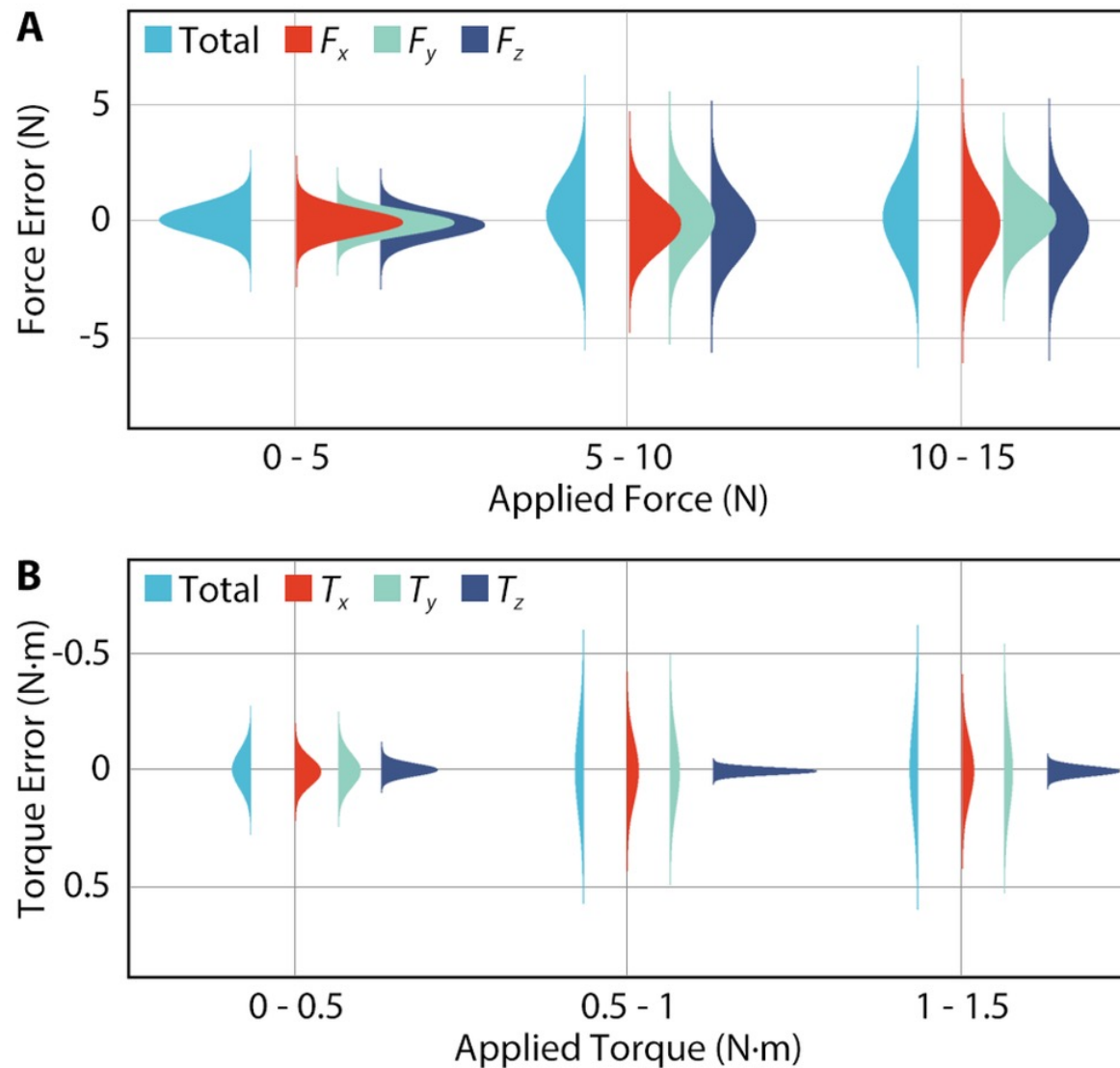
Mixed-modality speech recognition and interaction using a wearable artificial throat



Comparisons of vowel recognition accuracy between the AT and a commercial microphone under different noise levels ($n = 40$ independent experiments; error bars indicate s.d.).

Alternatives to Error Bars

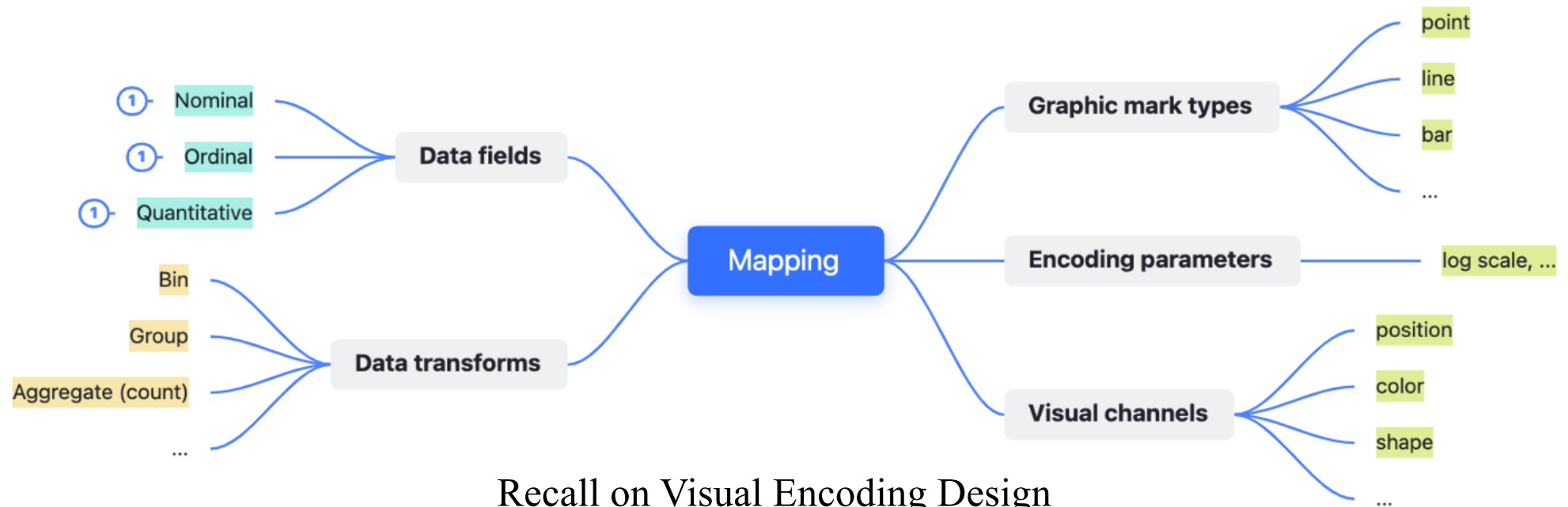
Violin Plot



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

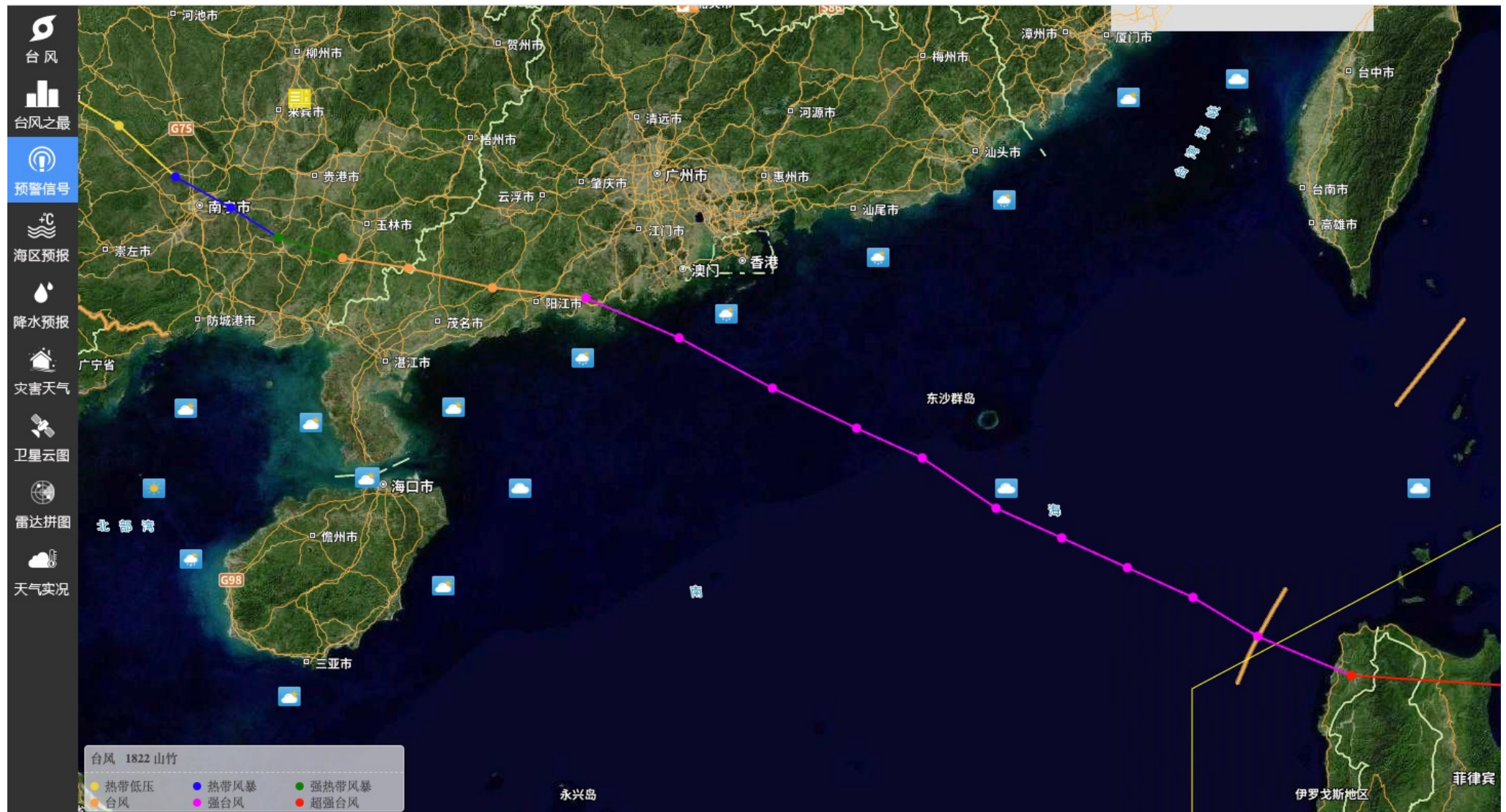
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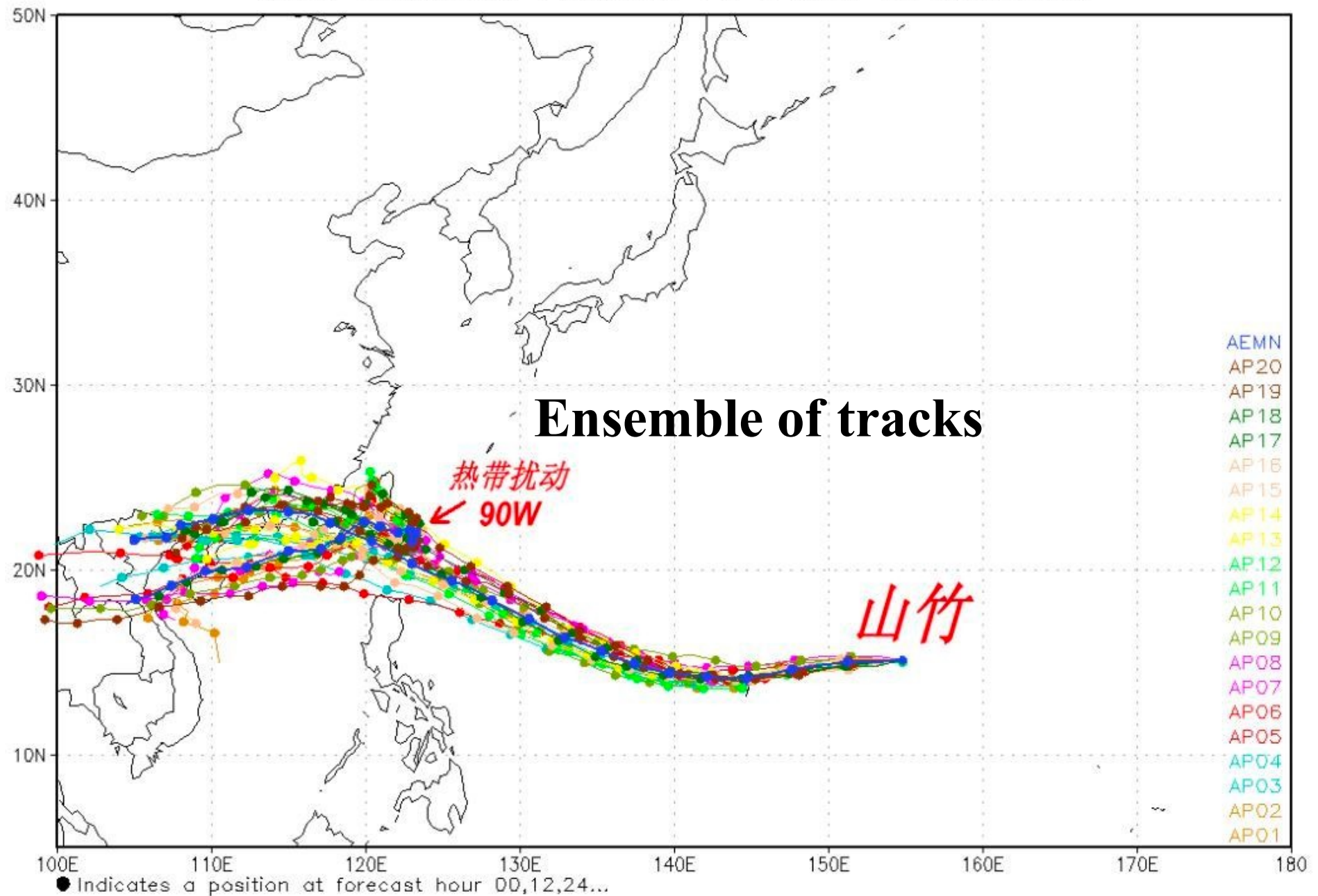


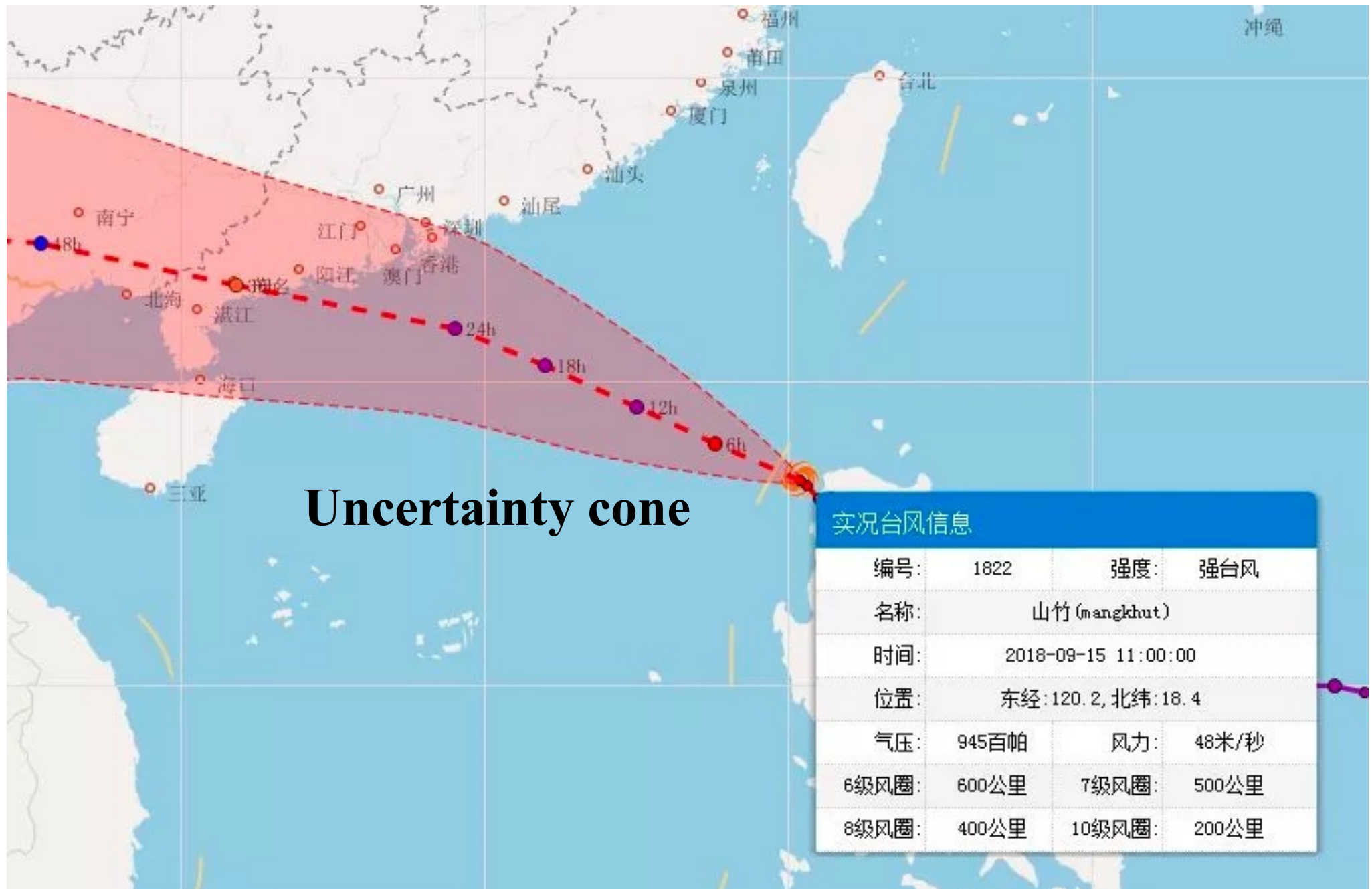
Super Typhoon Mangkhut (山竹)

中央气象台·台风网 v3 <http://typhoon.nmc.cn/web.html>



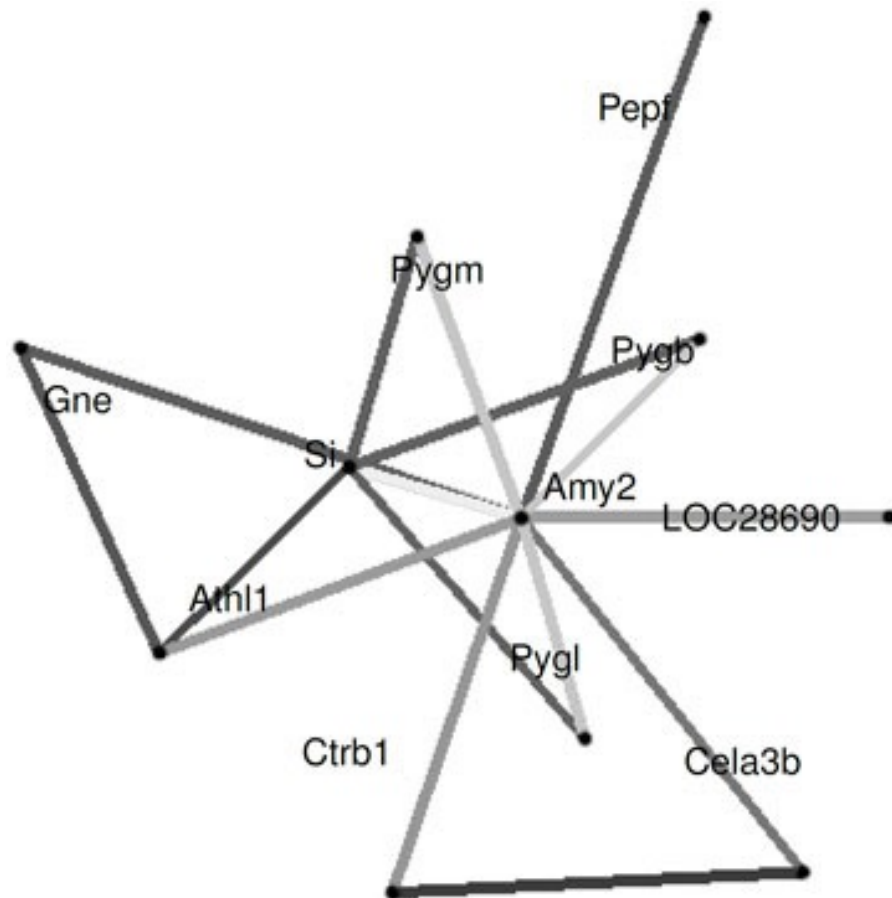
NCEP Ensemble Forecast TC Tracks 2018090900



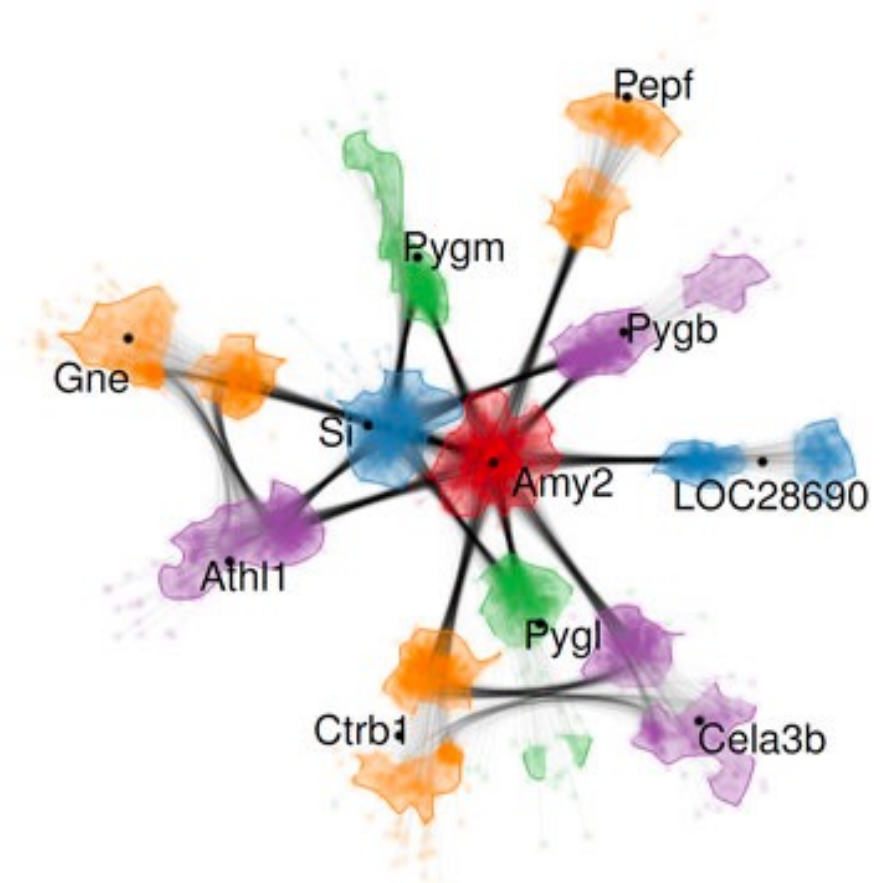


Visualizing protein–protein interactions

Traditional non-uncertainty visualization

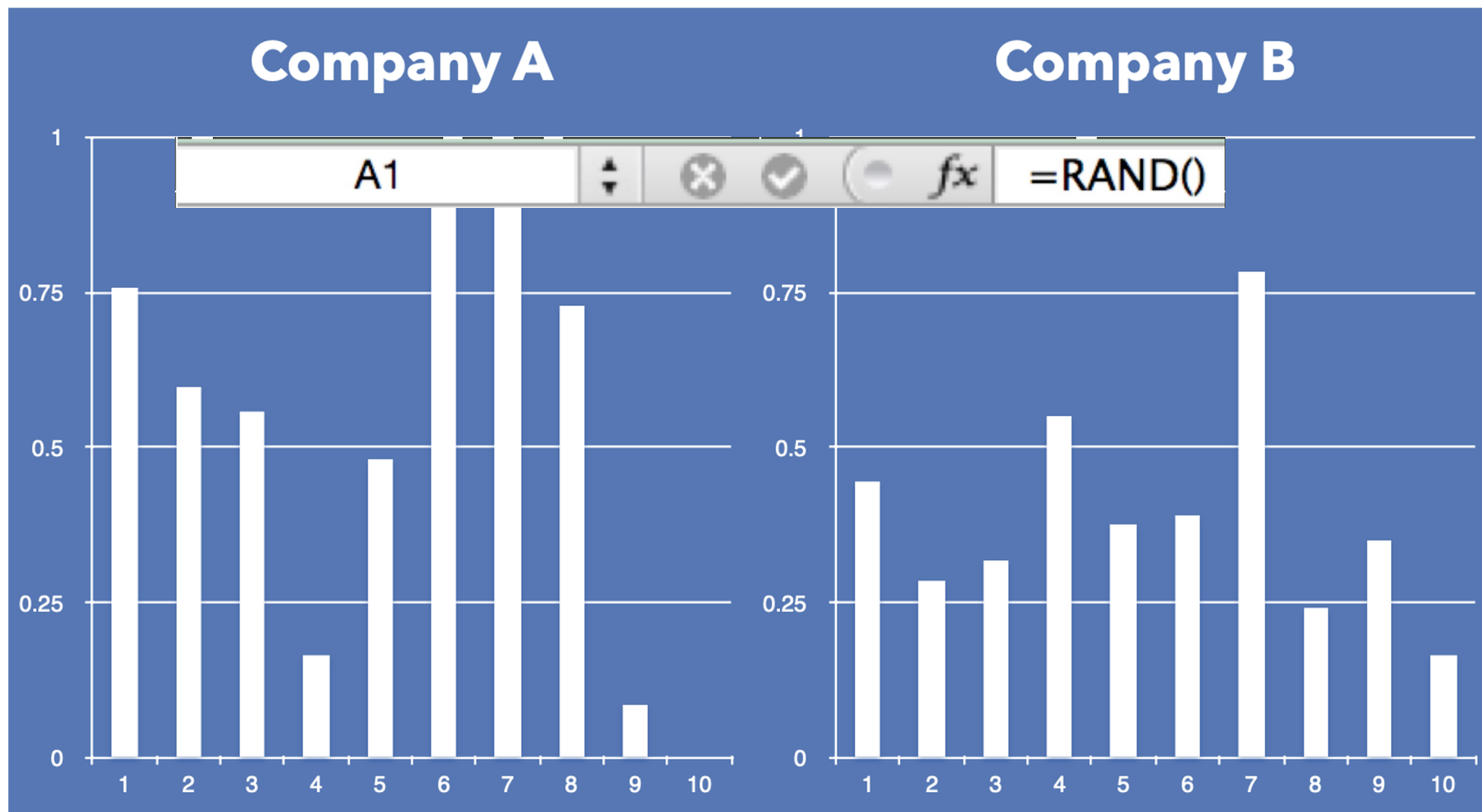


Uncertainty visualization



What Can Go Wrong?

- Which Stock To Buy? **Neither**

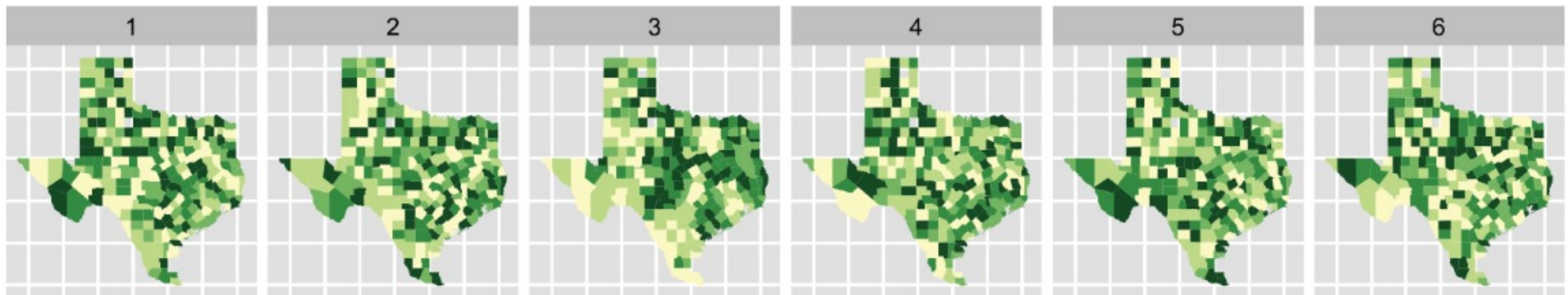


Pareidolia (幻想性视错觉)



The tendency to perceive a specific, often meaningful image in a random or ambiguous visual pattern

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.

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.

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.

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.



DS363: Design and Learning with Data

<https://ds363.ancorasir.com/>

Thank you~

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