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

Widgets Sold

A
B

Widgets Sold
0 20 40 60 80

A Bar Chart

Sales of Widgets for Stores A and B

Widgets Sold

A
B

Widgets Sold
0 20 40 60 80
Measurement Uncertainty

Sales of Widgets for Stores A and B

Widgets Sold

A

B
Sales of Widgets for Quarters 1 and 2

Forecast Uncertainty
Decision Uncertainty

We Should Close Store A?

Widgets Sold

A

B
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”
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
Model Uncertainty

“50% Chance of Rain”
Model Uncertainty

**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**
- Variance

**Accuracy**
- Bias
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
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 ($\sigma$)
Standard Error ($\sigma / \sqrt{n}$)
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

- CI coverage (%): 97.5%
  - $\mu$ missed: 3
  - $\mu$ included: 115

Proportion of CIs that include population mean

- Samples drawn: 0 to 500
  - Proportion: 0.80 to 1.00

CIs sampling distribution

- CI Width: 1 to 10
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 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

- Rule 4
- 95% CIs

Standard Error

Rule 7
- SE bars

Misplaced Emphasis?
Misplaced Emphasis?
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
Uncertainty Vis Pipeline

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

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

Data Map

Uncertainty Map
Juxtaposition

Data Map

Uncertainty Map
Superposition
Superposition

Uncertainty Vis Pipeline

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

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

Series #1: General Uncertainty by Visual Variable
Fuzziness Juxtaposition
Fuzziness Superposition
Size Juxtaposition
Size Superposition
“Sketchiness”


“Sketchiness”


Perceived Data Quality

Visualizations with High Data Quality

Visualizations with Low Data Quality

Perceived Data Quality

Error & perceived quality decrease with more missing data
Highlighting missing data increased perceived quality
Linear interpolation led to highest perceived quality
Absent data led to lower perceived quality, credibility, confidence
Limited evidence for accuracy bias from imputation methods

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

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
The NYT Needle

Vote margin

Clintoon +0.6
FORECAST, in pct. points
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 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 ubiquitous bulletin service which The Times will also maintain. To display the flashed bulletins so that the crowds, and those sitting and standing comfortably, can see them easily and comfortably, a special 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 Marlium office of The Times, 135 West 51st Street.

The electric signal from the tower of the Times Building will be flashed from a point 300 feet above the street level. A steady light in the north will show that delegation has been elected; a steady light to the south will indicate the election of the candidate and a steady light to the north will indicate the election of the candidate.

Jerome's election will be indicated by a steady light in the west. A light in the north, moving from east to west, will indicate the election of the candidate. A light to the south, moving from east to west, will indicate the election of the candidate.
Election Results by Searchlight.

The Times Election Searchlight Code.

Jerome West
McMullan North
Irvins East

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 have been elected.

This will be entirely separate and distinct from the telegraphic bulletin service which The Times will also maintain. We display the detailed bulletin so that the crowd, one can see them easily and comfortably. A stepladder scaffold 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, 136 West 135th Street.

The electric device from the tower of the Times Building will be flashed from a point 260 feet above the street level. A steady light in the north will indicate McKinley's election; a steady light in the south will indicate Bryan's election. A light moving from east to west will indicate the returns in Cook County; if red, favorable to Bryan. A light moving from west to east will indicate the returns from Illinois favor McKinley; if red, Bryan.

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

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, and 1 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.
Value-Suppressing Uncertainty Palette
Bivariate Map
Value-Suppressing Uncertainty Palette

Value-Suppressing Uncertainty Palette

Model Visualization

Model Visualization

Model Visualization
Model Visualization

Predicted Bus Arrival Times

Make uncertainty concrete via *hypothetical outcomes*.

[Kay et al. 2016]
Predicted Bus Arrival Times

Support decision making relative to risk tolerance.

18/20 = 90% chance the bus comes at ~8 min or later

[Kay et al. 2016]
Predicted Bus Arrival Times

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

[Kay et al. 2016]
Hypothetical Outcome Plots
I am male and currently 29 years old.
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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Administrivia
## Final Project Schedule

<table>
<thead>
<tr>
<th>Category</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proposal</td>
<td>Wed, May 18</td>
</tr>
<tr>
<td>Milestone</td>
<td>Fri, May 27</td>
</tr>
<tr>
<td>Poster</td>
<td>Wed, June 1</td>
</tr>
<tr>
<td>Deliverables</td>
<td>Tue, June 7</td>
</tr>
</tbody>
</table>

### Logistics
- **Final project description posted online**
- Groups of up to 4 people
- Select topics and form groups now!
- Potential project ideas shared on edstem!
Reminders!

Virtual Guest Lecture This Thursday 5/19!

Final Project Proposal Due Wed 5/18, 11:59pm
https://courses.cs.washington.edu/courses/cse512/22sp/fp.html

Three Peer Evaluations Due Tue 5/17, 11:59pm
https://courses.cs.washington.edu/courses/cse512/22sp/a3-peereval.html
What Can Go Wrong?
Which Stock To Buy?

**Company A**

**Company B**
Neither!

Company A

Company B

A1

=RAND()
Pareidolia
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.
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.

Choropleth maps of cancer deaths in Texas. One plot shows a real data set. 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.
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

\[ P(A|B) = \frac{P(B|A)P(A)}{P(B)} \]
Bayes’ Law

\[ P(A|B) = \frac{P(B|A)P(A)}{P(B)} \]

\[ P(\text{Cancer} \mid +\text{Test}) = \frac{P(+\text{Test}|\text{Cancer})P(\text{Cancer})}{P(+\text{Test})} \]
Bayes’ Law

\[ P(A|B) = \frac{P(B|A)P(A)}{P(B)} \]

\[ P(Cancer \mid +Test) = \frac{P(+Test|Cancer)P(Cancer)}{P(+Test)} \]

\[ P(+) = P(+ \land C)P(C) + P(+ \land \neg C)P(\neg C) \]
Bayes’ Law

\[ P(A|B) = \frac{P(B|A)P(A)}{P(B)} \]

\[ P(\text{Cancer} \mid +\text{Test}) = \frac{P(+\text{Test}\mid\text{Cancer})P(\text{Cancer})}{P(+\text{Test})} \]

\[ P(+) = P(+ \land \text{C})P(\text{C}) + P(+ \land \sim\text{C})P(\sim\text{C}) \]

\[ P(+) = 0.01 \times 0.8 + 0.99 \times 0.1 \]

\[ P(+) = 0.107 \]

\[ P(\text{C} \mid +) = \frac{0.8 \times 0.01}{0.107} \approx 0.075 \]
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.
Base Rate Fallacy

How To Present Probabilities

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

Less Intuitive  More Intuitive

Quantile Dot Plots

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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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.