Uncertainty

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(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

Widgets Sold

A
B

0
20
40
60
80

A
B
Measurement Uncertainty

Sales of Widgets for Stores A and B

Widgets Sold

A

B

0 20 40 60 80
Forecast Uncertainty

Sales of Widgets for Quarters 1 and 2

<table>
<thead>
<tr>
<th>Quarter</th>
<th>Widgets Sold</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>60</td>
</tr>
<tr>
<td>2</td>
<td>80</td>
</tr>
<tr>
<td>3</td>
<td>?</td>
</tr>
</tbody>
</table>
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”
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
Type
FALSE POSITIVE
FALSE NEGATIVE
Model Uncertainty

“50% Chance of Rain”
Model Uncertainty

**Right Now**
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.

**Wed**
Partly cloudy until evening.

**Thu**
Clear throughout the day.

**Fri**
Light rain in the afternoon.

**Sat**
Mostly cloudy until evening.
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

- μ missed: 3
- μ included: 115

95% confidence intervals

- Proportion of CIs that include population mean
- CIs sampling distribution
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

Rule 4
95% CIs

Dependent variable

proportion overlap = .5
p ≈ .05

G1 G2

proportion overlap = 0
p ≈ .01

G1 G2

Standard Error

Rule 7
SE bars

Dependent variable

proportion gap = 1
p ≈ .05

G1 G2

proportion gap = 2
p ≈ .01

G1 G2

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
SNAP

Data Map

Uncertainty 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

Bivariate Map
Superposition

Uncertainty Vis Pipeline

1) Quantify uncertainty
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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
Semiotics of Uncertainty

Leci n’est pas une pipe.
The Variable Matters!

2016 Senate Seats

- Blue: R
- Red: D
- Gray: I
The Variable Matters!

2016 Senate Seats

- R
- D
- I
Semiotics of Uncertainty
Semiotics of Uncertainty

SERIES #1: GENERAL UNCERTAINTY BY VISUAL VARIABLE

- fuzziness
- value
- size
- grain
- saturation
- size
- hue
- orientation
- hue
- shape
- fuzziness
- arrangement

Intuitiveness (log)

Uncertain

Certain

Series #1

Mean

Median
Fuzziness Juxtaposition
Fuzziness Superposition
Size Juxtaposition
Size Superposition
“Sketchiness”


"Sketchiness"


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

'12

D+28
D+26
D+24
D+22
D+20
D+18
D+16
D+14
D+12
D+10
D+8
D+6
D+4
D+2

R+28
R+26
R+24
R+22
R+20
R+18
R+16
R+14
R+12
R+10
R+8
R+6
R+4
R+2

Clinton +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 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 ordinary bulletins which The Times will also maintain. To display the flashed bulletin so that the crowds can see them easily and comfortably, a special electric motor will be set up in the triangle north of the Times Building and the bulletin displayed on canvases stretched from the north side of the building. There will be a similar service at the Harlem office of The Times, 120 West 135th Street.

The electric signals from the tower of the Times Building will be flashed from a point 300 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 Irving's election, and a steady light to the south will indicate Jerome'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.
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

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

[Kay et al. 2016]
Predicted Bus Arrival Times

Support decision making relative to risk tolerance.

Cumulative distribution function

18/20 = 90% chance the bus comes at ~8 min or later
Hypothetical Outcome Plots
Life Expectancy

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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IT DEPENDS
What Can Go Wrong?
Which Stock To Buy?

Company A

Company B
Neither!

Company A

Company B

A1 = RND()}
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 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.

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.
How To Present Probabilities

<table>
<thead>
<tr>
<th>Less Intuitive</th>
<th>Probability</th>
<th>P(A) = 0.6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage</td>
<td>60% chance of A</td>
<td></td>
</tr>
<tr>
<td>Natural Frequency</td>
<td>3 out of 5 times, A happens.</td>
<td></td>
</tr>
</tbody>
</table>

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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IT DEPENDS

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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.