Designs to Support Better Visual Data Communication

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Design choices can lead to powerful and intuitive insights, or leave important patterns obscured and misunderstood.

Data Visualization & Human Cognition & Perception

Design choices can lead to powerful and intuitive insights, or leave important patterns obscured and misunderstood.

Notice which day had the most/least # of cases.

Design choices can lead to powerful and intuitive insights, or leave important patterns obscured and misunderstood.

Notice the change in # of cases as time passes.

Design choices can lead to powerful and intuitive insights, or leave important patterns obscured and misunderstood.

Interpretation 1

Interpretation 2

Interpretation 3

Data → Visualization → Interpretation

Visualization 1

Visualization 2

Visualization 3
Designing a visualization involves a series of decisions, and each design decision can afford different interpretations.

Vehicle A
Vehicle B
Vehicle Component

Vehicle A's component 2 is more durable than that of B, but the other two are less durable.

Xiong, Setlur, Bach, Koh, Franconeri, 2021

Vehicle A and B are about equally durable.

Xiong, Setlur, Bach, Koh, Franconeri, 2021
Vehicle A's component 2 is more durable than that of B, but the other two are less durable. Vehicle A and B are about equally durable.

Vehicle Component

Durability

Xiong, Setlur, Bach, Koh, Franconeri, 2021

Matlen, Gentner & Franconeri, 2020

Your viewers are probably confused … Ajani, Lee, Xiong, Knaflic, Kemper, Franconeri, 2021
Your viewers are probably confused …

"People mostly get their news from TV and Radio. Least likely from their friends."

Ajani, Lee, Xiong, Knaflic, Kemper, Franconeri, 2021

Can you build a visualization to help viewers see that "people are increasingly relying on the internet to get their news."?

Compare the user rating of Looking for Alaska and Gone Girl

Challenge #1: What patterns people perceive in a visualization is hard to predict.

Challenge #2: Language can be ambiguous, making interpretation difficult.

Who will win in Year 4, Blue or Green?
Challenge #1: What patterns people perceive in a visualization is hard to predict.

Who will win in Year 4, Blue or Green?

Visual features matter, but people might draw different conclusions due to their motivation, experience or background knowledge.

What do you think the outcome of the election is in Year 4?

Blue Likely Wins

Year 1

Year 2

Year 3

Year 4

Tie

Blue Likely Wins

Green Likely Wins

Blue Likely Wins

Let's look at an example.

Challenge #2: Language can be ambiguous, making interpretation difficult.

Blue Likely Wins

Year 2

Year 3

Year 4

Tie

Blue Likely Wins

Green Likely Wins

Blue Likely Wins

Xiong, van Weelden, Waytz, & Franconeri, 2020
To what extent does this happen in visual analysis?
I believe that as the number of people whose names begin with “T” in a neighborhood increases, the number of trees in the same neighborhood increases.

1 Strongly Disagree
7 Strongly Agree

How much do you agree with...

I believe that as the number of environmental regulations increases, air quality increases.

1 Strongly Disagree
7 Strongly Agree

I believe that as the number of households with guns increases, the number of violent crimes increases.

1 Strongly Disagree
7 Strongly Agree

I believe that as the total rainfall in the US increases, the number of US lawyers increases.

1 Strongly Disagree
7 Strongly Agree
Real-world variable labels make people underestimate the correlation.

I believe that as the number of people whose names begin with "T" in a neighborhood increases, the number of trees in the same neighborhood increases.

I believe that as the number of people whose names begin with "T" in a neighborhood increases, the number of trees in the same neighborhood increases.

The stronger the belief, the more likely people will overestimate the correlation.

The stronger the belief, the more likely people will underestimate the correlation.

The stronger the belief, the more likely people will overestimate the correlation.
People's correlation estimation is associated with their beliefs. The stronger the belief, the more likely people will overestimate the correlation. (and vice versa)

Xiong, Stokes, Kim, Franconeri, 2022

Those must be outliers. Let me pretend that they don't exist.

Xiong, Stokes, Kim, Franconeri, 2022
Challenge #1: What patterns people perceive in a visualization is hard to predict.

Visual features matter, but people might draw different conclusions due to their motivation, experience or background knowledge.

$r = 0.5$

Challenge #2: Language can be ambiguous, making interpretation difficult.

Visual features matter, but people might draw different conclusions due to their motivation, experience or background knowledge.

$r = 0.5$

Since it’s not plausible, let’s err on the low side. Could be 0.5 – 0.8.

I’ll pretend I don’t see the actual data. I’ll pretend that they don’t exist.

Those must be outliers.

How people perceive data can also be subjected to psychophysical and cognitive biases.

Challenge #2: Language can be ambiguous, making interpretation difficult.

Visual features matter, but people might draw different conclusions due to their motivation, experience or background knowledge.

$r = 0.4$

$r = 0.6$

Psychophysics experiments to model how people perceive visualizations.

How people perceive data can also be subjected to psychophysical and cognitive biases.
Challenge #2: Language can be ambiguous, making interpretation difficult.

Cindy Data Visualization Human Cognition & Perception

Green Likely Wins
Tie
Blue Likely Wins

0
5
10
15
Number of People

Year 1
Year 2
Year 3
Year 4
Party
Blue
Green
Blue
Green
Blue
Green

% 47 32.5 44 38 51 47

Challenge #1: What patterns people perceive in a visualization is hard to predict. Visual features matter, but people might draw different conclusions due to their motivation, experience or background knowledge. How people perceive data can also be subjected perceptual + cognitive biases. Psychophysics experiments to model how people perceive visualizations.

Overestimation

Underestimation

Wide Aspect Ratio
Square Aspect Ratio
Tall Aspect Ratio

Ceja, McColeman, Xiong, Franconeri, IEEE VIS 2020

Thinking about Causation

"Using the Safety GPS system causes people to get in fewer accidents!"

Thinking about Correlation

"People who use the Safety GPS system tend to get in fewer accidents – not necessarily causal"

"Using the Safety GPS system causes people to get in fewer accidents!"

Xiong, Shapiro, Hullman, Franconeri 2020

Thinking about Causation

"Using the Safety GPS system causes people to get in fewer accidents!"

"People who use the Safety GPS system tend to get in fewer accidents – not necessarily causal"

Xiong, Shapiro, Hullman, Franconeri 2020

Thinking about Correlation
Challenge #2: Language can be ambiguous, making interpretation difficult.

Visual features matter, but people might draw different conclusions due to their motivation, experience, or background knowledge.

Psychophysics experiments to model how people perceive visualizations.

Challenges:

1. What patterns people perceive in a visualization is hard to predict.
2. Language can be ambiguous, making interpretation difficult.

To build a model that predicts what people perceive in a visualization, we have to figure out what people see first.
How people perceive data can also be influenced by perceptual and cognitive biases. Visual features matter, but people might draw different conclusions due to their motivation, experience or background knowledge. Language can be ambiguous, making interpretation difficult. Most participants made multiple comparisons that contained the entire set.
What if we ask them to indicate which bars they compared?

Vehicle A Component 1
Vehicle A Component 2
Vehicle A Component 3
Vehicle B Component 1
Vehicle B Component 2
Vehicle B Component 3

Vertical Comparison 1

Conclusions

Most participants made multiple comparisons that contained the entire set

What if we ask them to write expressions?

A > B
(not ambiguous)

A > B & B < C && A > C

(what?)

Some conclusions are just difficult to translate into mathematical expressions

Part 3 of Vehicle A is less durable than Part 2, but more than Part 1.

A3 < A2
A3 > A1

The durabilities are the same for both vehicles, but for different parts.

A1 = B2 & A1 != B1
A2 = B1 & A2 != B2
A3 = B3

Part 3 of Vehicle A is less durable than Part 2, but more than Part 1.

A3 < A2
A3 > A1

(A1 + A2 + A3) = (B1 + B2 + B3)

A1 = B2 & A1 != B1
A2 = B1 & A2 != B2
A3 = B3
Challenge #1: What patterns people perceive in a visualization is hard to predict.

- Visual features matter, but people might draw different conclusions due to their motivation, experience or background knowledge.

Challenge #2: Language can be ambiguous, making interpretation difficult.

- Visual features matter, but people might draw different conclusions due to their motivation, experience or background knowledge.

Number of People

<table>
<thead>
<tr>
<th>Party</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green</td>
<td>38%</td>
</tr>
<tr>
<td>Blue</td>
<td>51%</td>
</tr>
</tbody>
</table>

Year 1

- Green Likely Wins with 44% of the votes.

Year 2

- Tie with 47% for both Green and Blue.

Year 3

- Green Likely Wins with 38%.

Year 4

- Blue Likely Wins with 47%.

Human Cognition & Perception

- How people perceive data can also be influenced by their interpretation.

Scores

- Paper A received a higher score from Reviewer 1 and 2.

When we implement a Natural Language Interface that allows the user to input natural language queries, these inputs can still be ambiguous and interpretable.
### Movie Names

<table>
<thead>
<tr>
<th>Movie Names</th>
<th>Box Office</th>
<th>User Ratings</th>
<th>Movie Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gaba, Setlur, Srinivasan, Hoffswell, Xiong 2022</td>
<td>66</td>
<td>319</td>
<td>160</td>
</tr>
</tbody>
</table>

#### Compare the popularity of Movies A and B

What do they mean by popularity? Do they mean box office? Maybe a combination between box office and user rating? But combination how?

#### Compare the box office numbers for squid game vs midnight mass

What do they mean by box office? Higher than average in the dataset? Top 10 percentile in length? Anything over an hour?

### Compare the performance of squid game and midnight mass

Compare the box office numbers for all highly-rated movies. Compare the silver medals won by tall athletes to short athletes.

### Resolve ambiguity by showing them a visualization!

(That best answers their queries)

### Compare a highly-rated book with similar highly-rated books with respect to price

Compare the price of squid game vs midnight mass. Compare the price of the silver medals won by tall athletes to short athletes.
Compare a highly-rated book with similar highly-rated books with respect to price.

Gaba, Setlur, Srinivasan, Hoffswell, Xiong 2022

Please rank the following visualization with regards to how easy a viewer can use them to make that comparison.
The US criminal legal system is very complex.

Trust and Data Visualization in Criminal Legal Reform

Trust

Growing demands for change.

District Attorney’s (DA) offices and prosecutors play a major role.

Progressive Prosecution through data transparency and dissemination.
Online data dashboards.

Progressive Prosecution through data transparency and dissemination.

How does sharing criminal legal data via dashboards impact public understanding + trust in the legal system?

Design of visualization dashboards seem to matter!

*This is correlational data*
Visualization design can change how people understand data and make decisions.

To Solve #1: Creating descriptive models of how people actually understand visualizations.

To Solve #2: Effectively mapping natural language descriptions of user intents to patterns they see in data.

Many thanks to my students... and collaborators...

You have a lot of power as a visualization designer. Design your visualizations thoughtfully.
Real-world variable labels make people underestimate the correlation on average.

Elicited Belief: Real-world variable labels make people underestimate the correlation on average. People who use the Safety GPS system tend to get in fewer accidents.
People who use the Safety GPS system tend to get in fewer accidents.

If people were to use the Safety GPS system,
they would get in fewer accidents.

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If people were to use the Safety GPS system,
they would get in fewer accidents.

# Bins (Aggregation)

2 bins

Continuous
Bar charts appear more causal because they group data into two bins.

Consider disaggregating data to reduce misguided causal conclusions.

Categorical Prototype Effects

Actual Stimulus Value    Category Prototype

Bias Toward the Prototype

Categorical Prototype Effects

Overestimation  Underestimation

Bias Toward the Prototype
Does the aspect ratio of a mark bias position estimates?

Wide Aspect Ratio
Square Aspect Ratio
Tall Aspect Ratio

Trial Display

Visual Noise Mask

Response

Response

Aspect ratio of a mark can bias position estimates

Overestimation
Underestimation

Signed Error (pixels)

Wide Ratio
Square Ratio
Tall Ratio

Absolute Error (pixels)

Wide Ratio
Square Ratio
Tall Ratio
Deficit Framing suggests...

"Average outcomes for Group A are better than Group B."
"...because people in Group A are better than people in Group B..."
"...therefore people in Group A must be better than Group B."

Superlatives

Component 2 is the most durable component in vehicle A.

Comparison

1 - 2 - 3 comparison e.g., 1 < 3

Component 1 is more durable than Component 2.

Component 1 is more durable than Component 3.

Component 2 is more durable than Component 3.

Component 3 is more durable than Component 2.

Comparison

Vehicle A's component 3 is less durable than vehicle B's component 3.

Pair comparison e.g., A3 < B3

Experimental Stimuli: 3 designs, 6 topics

Cluttered

Decluttered

Focused

Experimental Procedure

Redraw Graphs: Focused designs led to the most relevant information redrawn.
Recalled Conclusions: Focused designs led to more relevant conclusions.

Quantitative Ratings: Focused designs are rated as more aesthetically appealing, clear, and professional.

Qualitative Ratings

"The middle graph was by far the most appealing because it clearly conveyed the information, ignoring extraneous details and highlighting the key conclusion. The left graph suffered from overcrowding, and the right graph’s lack of color made it difficult to differentiate overlapping lines." [P15]