CSE 442 - Data Visualization

Interaction

Jeffrey Heer  University of Washington
[There is an] apparent challenge that computational artifacts pose to the longstanding distinction between the physical and the social, in the special sense of those things that one designs, builds, and uses, on the one hand, and those things with which one communicates, on the other.

“Interaction”– in a sense previously reserved for describing a uniquely interpersonal activity – seems appropriately to characterize what goes on between people and certain machines as well.

Lucy Suchman, *Plans and Situated Actions*
Interaction between people and machines requires mutual intelligibility or shared understanding.
Gulfs of Execution & Evaluation

Gulfs

Conceptual model
Evaluation
Execution
Real world

[Norman 1986]
Gulf of Execution

The difference between the user’s intentions and the allowable actions.

[Norman 1986]
Gulf of Execution
The difference between the user’s intentions and the allowable actions.

Gulf of Evaluation
The amount of effort that the person must exert to interpret the state of the system and to determine how well the expectations and intentions have been met.

[Norman 1986]
Gulf of Evaluation

Gulf

Evaluation

Conceptual model: x, y related?

Real world:

<table>
<thead>
<tr>
<th>X</th>
<th>Y</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.67</td>
<td>0.79</td>
</tr>
<tr>
<td>0.32</td>
<td>0.63</td>
</tr>
<tr>
<td>0.39</td>
<td>0.72</td>
</tr>
<tr>
<td>0.27</td>
<td>0.85</td>
</tr>
<tr>
<td>0.71</td>
<td>0.43</td>
</tr>
<tr>
<td>0.63</td>
<td>0.09</td>
</tr>
<tr>
<td>0.03</td>
<td>0.03</td>
</tr>
<tr>
<td>0.20</td>
<td>0.54</td>
</tr>
<tr>
<td>0.51</td>
<td>0.38</td>
</tr>
<tr>
<td>0.11</td>
<td>0.33</td>
</tr>
<tr>
<td>0.46</td>
<td>0.46</td>
</tr>
</tbody>
</table>
Gulf of Evaluation

Conceptual model: x, y related?

Real world:
Gulf of Evaluation

Conceptual model: $x, y$ correlated?

Evaluation

Real world:

$\rho = -0.29$
Gulf of Execution

Conceptual model: Draw a scatterplot

Real world:
- Move 90 30
- Rotate 35
- Pen down
- ...
Gulf of Execution

Conceptual model:
Draw a scatterplot

Real world
vl.markCircle()
.encode(
vl.x().fieldQ(...),
vl.y().fieldQ("")
)
Gulf of Execution

Conceptual model:
Draw a scatterplot

Execution
Gulf of Execution
The difference between the user’s intentions and the allowable actions.

Gulf of Evaluation
The amount of effort that the person must exert to interpret the state of the system and to determine how well the expectations and intentions have been met.

[Norman 1986]
Interactive Visualization
Interaction Techniques

Are there “essential” interactive operations for exploratory data visualization?
Taxonomy of Interactions
Taxonomy of Interactions

Data and View Specification
Visualize, Filter, Sort, Derive
Taxonomy of Interactions

Data and View Specification
Visualize, Filter, Sort, Derive
Taxonomy of Interactions

Data and View Specification
Visualize, Filter, Sort, Derive

View Manipulation
Select, Navigate, Coordinate, Organize
Taxonomy of Interactions

Data and View Specification
Visualize, Filter, Sort, Derive

View Manipulation
Select, Navigate, Coordinate, Organize
Taxonomy of Interactions

Data and View Specification
Visualize, Filter, Sort, Derive

View Manipulation
Select, Navigate, Coordinate, Organize

Process and Provenance
Record, Annotate, Share, Guide
Hours of footage lost each month due to dropped frames
Hours of footage lost each month due to dropped frames

- Framedrop problem discovered
- Issue announced publicly
- Upgrade causes glitch
Taxonomy of Interactions

Data and View Specification
Visualize, Filter, Sort, Derive

View Manipulation
Select, Navigate, Coordinate, Organize

Process and Provenance
Record, Annotate, Share, Guide
EXAMPEL:
Bertin’s Hotel Data
<table>
<thead>
<tr>
<th></th>
<th>J</th>
<th>F</th>
<th>M</th>
<th>A</th>
<th>M</th>
<th>J</th>
<th>J</th>
<th>A</th>
<th>S</th>
<th>O</th>
<th>N</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 %</td>
<td>26</td>
<td>21</td>
<td>26</td>
<td>28</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>20</td>
<td>40</td>
<td>15</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>2 %</td>
<td>69</td>
<td>70</td>
<td>77</td>
<td>71</td>
<td>37</td>
<td>36</td>
<td>39</td>
<td>39</td>
<td>55</td>
<td>60</td>
<td>68</td>
<td>72</td>
</tr>
<tr>
<td>3 %</td>
<td>7</td>
<td>6</td>
<td>3</td>
<td>6</td>
<td>23</td>
<td>14</td>
<td>19</td>
<td>14</td>
<td>9</td>
<td>6</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>4 %</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>8</td>
<td>6</td>
<td>6</td>
<td>4</td>
<td>2</td>
<td>12</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5 %</td>
<td>20</td>
<td>15</td>
<td>14</td>
<td>15</td>
<td>23</td>
<td>27</td>
<td>22</td>
<td>30</td>
<td>19</td>
<td>17</td>
<td>19</td>
<td>17</td>
</tr>
<tr>
<td>6 %</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>8</td>
<td>6</td>
<td>4</td>
<td>6</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>7 %</td>
<td>3</td>
<td>10</td>
<td>6</td>
<td>0</td>
<td>3</td>
<td>13</td>
<td>8</td>
<td>9</td>
<td>5</td>
<td>2</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>8 %</td>
<td>7</td>
<td>8</td>
<td>0</td>
<td>8</td>
<td>5</td>
<td>8</td>
<td>6</td>
<td>7</td>
<td>0</td>
<td>7</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>9 %</td>
<td>7</td>
<td>8</td>
<td>0</td>
<td>8</td>
<td>6</td>
<td>8</td>
<td>7</td>
<td>5</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>10 %</td>
<td>7</td>
<td>7</td>
<td>0</td>
<td>7</td>
<td>5</td>
<td>6</td>
<td>8</td>
<td>7</td>
<td>4</td>
<td>6</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>11 %</td>
<td>20</td>
<td>18</td>
<td>19</td>
<td>17</td>
<td>27</td>
<td>27</td>
<td>19</td>
<td>19</td>
<td>26</td>
<td>27</td>
<td>21</td>
<td>15</td>
</tr>
<tr>
<td>12 %</td>
<td>10</td>
<td>12</td>
<td>6</td>
<td>9</td>
<td>4</td>
<td>5</td>
<td>7</td>
<td>6</td>
<td>5</td>
<td>15</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>13 %</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>14 %</td>
<td>25</td>
<td>27</td>
<td>37</td>
<td>35</td>
<td>25</td>
<td>25</td>
<td>27</td>
<td>28</td>
<td>24</td>
<td>30</td>
<td>24</td>
<td>30</td>
</tr>
<tr>
<td>15 %</td>
<td>48</td>
<td>49</td>
<td>42</td>
<td>48</td>
<td>54</td>
<td>55</td>
<td>53</td>
<td>57</td>
<td>55</td>
<td>46</td>
<td>55</td>
<td>43</td>
</tr>
<tr>
<td>16 %</td>
<td>25</td>
<td>22</td>
<td>17</td>
<td>15</td>
<td>19</td>
<td>19</td>
<td>19</td>
<td>19</td>
<td>19</td>
<td>20</td>
<td>19</td>
<td>22</td>
</tr>
<tr>
<td>17 %</td>
<td>163</td>
<td>167</td>
<td>166</td>
<td>174</td>
<td>152</td>
<td>155</td>
<td>145</td>
<td>170</td>
<td>157</td>
<td>174</td>
<td>165</td>
<td>156</td>
</tr>
<tr>
<td>18 %</td>
<td>1.65</td>
<td>1.71</td>
<td>1.65</td>
<td>1.91</td>
<td>1.90</td>
<td>2.15</td>
<td>1.60</td>
<td>1.73</td>
<td>1.82</td>
<td>1.66</td>
<td>1.44</td>
<td></td>
</tr>
<tr>
<td>19 %</td>
<td>67</td>
<td>82</td>
<td>70</td>
<td>83</td>
<td>74</td>
<td>77</td>
<td>56</td>
<td>62</td>
<td>90</td>
<td>92</td>
<td>78</td>
<td>55</td>
</tr>
<tr>
<td>20 %</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1 % CLIENTELE FEMALE
2 % " LOCAL
3 % " U.S.A.
4 % " SOUTH AMERICA
5 % " EUROPE
6 % " M.EAST, AFRICA
7 % " ASIA
8 % BUSINESSMEN
9 % TOURISTS
10 % DIRECT RESERVATIONS
11 % AGENCY
12 % AIR CREWS
13 % CLIENTS UNDER 20 YEARS
14 % " 20-35 "
15 % " 35-55 "
16 % " MORE THAN 55 "
17 % PRICE OF ROOMS
18 % LENGTH OF STAY
19 % OCCUPANCY
20 % CONVENTIONS

[Graphics and Graphic Information Processing, Bertin 81]
<table>
<thead>
<tr>
<th>% Occupancy</th>
<th>Active and Slow Periods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of Stay</td>
<td>Discovery Factors</td>
</tr>
<tr>
<td>Conventions</td>
<td></td>
</tr>
<tr>
<td>Businessmen</td>
<td></td>
</tr>
<tr>
<td>Agency Reservations</td>
<td></td>
</tr>
<tr>
<td>South America</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Air Crews</th>
<th>Recovery Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clients Under 20 Years</td>
<td>Winter</td>
</tr>
<tr>
<td>Clients More Than 55 Years</td>
<td></td>
</tr>
<tr>
<td>Clients From 20-35 Years</td>
<td>Winter-Summer</td>
</tr>
<tr>
<td>Female Clientele</td>
<td></td>
</tr>
<tr>
<td>Local Clientele</td>
<td></td>
</tr>
</tbody>
</table>

| Recovery Factors | |
|------------------||
| Asia | |
| Tourists | |
| Direct Reservation | |

| Price of Rooms | |
|----------------||
| Middle East, Africa | |
| U.S.A. | |
| Europe | |
| Clients From 35-55 Years | Summer |
[Graphics and Graphic Information Processing, Bertin 81]
EXAMPLE:
Tukey et al.'s PRIM-9
Selection
Basic Selection Methods

Point Selection
Mouse Hover / Click
Touch / Tap
Select Nearby Element (e.g., Bubble Cursor)
Basic Selection Methods

Point Selection
Mouse Hover / Click
Touch / Tap
Select Nearby Element (e.g., Bubble Cursor)

Region Selection
Rubber-band (rectangular) or Lasso (freehand)
Area cursors (“brushes”)
Brushing & Linking
Brushing

Direct attention to a subset of data [Wills 95]
Brushing & Linking

Select ("brush") a subset of data
See selected data in other views

The components must be *linked* by *tuple* (matching data points), or by *query* (matching range or values)
Brushing Scatterplots
Cross-Filtering

![Histograms of Arrival Delay (min), Local Departure Time (hour), and Travel Distance (miles)]
Baseball Statistics [Wills 95]

select high salaries
Baseball Statistics [Wills 95]

- Select high salaries
- Avg career HRs vs avg career hits (batting ability)
Baseball Statistics [Wills 95]

-how long in majors

-select high salaries

-avg career HRs vs avg career hits (batting ability)
Baseball Statistics [Wills 95]

- How long in majors
- Avg assists vs avg putouts (fielding ability)
- Select high salaries
- Avg career HRs vs avg career hits (batting ability)
Baseball Statistics [Wills 95]

- how long in majors
- select high salaries
- avg assists vs avg putouts (fielding ability)
- avg career HRs vs avg career hits (batting ability)
- distribution of positions played
Linking Assists to Positions
Dynamic Queries
SELECT house FROM seattle_homes
WHERE price < 1,000,000 AND bedrooms > 2
ORDER BY price
Issues with Textual Queries

1. For programmers
2. Rigid syntax
3. Only shows exact matches
4. Too few or too many hits
5. No hint on how to reformulate the query
6. Slow question-answer loop
7. Results returned as table
HomeFinder

The yellow dots above are homes in the DC area for sale. You may get more information on a home by selecting it.

You may drag the 'A' and 'B' distance markers to your office or any other location you want to live near.

Select distances, bedrooms, and cost ranges by dragging the corresponding slider boxes on the right.

Select specific home types and services by pressing the labeled buttons on the right.

[Williamson and Shneiderman 92]
Direct Manipulation

1. Visual representation of objects and actions
2. Rapid, incremental and reversible actions
3. Selection by pointing (not typing)
4. Immediate and continuous display of results
FilmFinder

Popularity

Title: ALL

Actor: Connery, Sean

Director: ALL

Year of Production: 1960-1995

Ratings: G, PG, PG-13, R

Films Shown: 24

[Copyright (C) 1993 HCIL]

[Ahlberg and Shneiderman 94]
Alphaslider (?)

Title:
Moonstruck

[Alhberg and Shneiderman 94]
Details-on-Demand

Witches of Eastwick, The

Director: Miller, George
Year: 1987

Country: USA
Language: English

Actors:
- Nicholson, Jack
- Jenkins, Richard
- Joakum, Keith
- Struyker, Carel

Actresses:
- Cher
- Sarandon, Susan
- Pfeiffer, Michelle
- Cartwright, Veronica

Title:
- ALL

Actor:
- ALL

Actress:
- Pfeiffer, Michelle

Director:
- Miller, George

Year of Production:
- 1960 to 1995

Length: 231 minutes

Ratings:
- G
- PG
- PG-13
- R

Films Shown: 210

Copyright (C) 1993 HCIL
• The Attribute Explorer
Zipdecode [Fry 04]

Hit the letter z, or click the word zoom to enable or disable zooming.
Hold down shift while typing a number to replace the previous number (U.S. keyboards only).

http://benfry.com/zipdecode/
DimpVis [Kondo 14]
Parallel Coordinates [Inselberg]
Builds on Wattenberg’s [2001] idea for sketch-based queries of time-series data.
Query by Slope!
3D Dynamic Queries [Akers 04]
3D Dynamic Queries [Akers 04]
Pros & Cons

Pros
Controls useful for both novices and experts
Quick way to explore data
Pros & Cons

Pros
Controls useful for both novices and experts
Quick way to explore data

Cons
Simple queries
Lots of controls
Amount of data shown limited by screen space

Who would use these kinds of tools?
Prompting Reflection
You Draw It [Aisch et al. '15]

Draw your line on the chart below

Percent of children who attended college

Free tip: Your line should go through this point.
Summary

Most visualizations are interactive
Even passive media elicit interactions

Good visualizations are task dependent
Pick the right interaction technique
Consider the semantics of the data domain

Fundamental interaction techniques
Selection / Annotation, Sorting, Navigation, Brushing & Linking, Dynamic Queries
A2: Deceptive Visualization

Design two static visualizations for a dataset:
1. An earnest visualization that faithfully conveys the data
2. A deceptive visualization that tries to mislead viewers

Your two visualizations may address different questions. Try to design a deceptive visualization that appears to be earnest: *can you trick your classmates and course staff?*

You are free to choose your own dataset, but we have also provided some preselected datasets for you.

Submit two images and a brief write-up on Canvas.

Due by **Wed 10/20 11:59pm**.
A2 Peer Reviews

On Thursday 10/21 you will be assigned two peer A2 submissions to review. For each:

• Try to determine which is earnest and which is deceptive
• Share a rationale for how you made this determination
• Share feedback using the “I Like / I Wish / What If” rubric

Assigned reviews will be posted on the A2 Peer Review page on Canvas, along with a link to a Google Form. You should submit two forms: one for each A2 peer review.

Due by **Mon 10/25 11:59pm**.
I Like… / I Wish… / What If?

I LIKE…
Praise for design ideas and/or well-executed implementation details. Example: "I like the navigation through time via the slider; the patterns observed as one moves forward are compelling!"

I WISH…
Constructive statements on how the design might be improved or further refined. Example: "I wish moving the slider caused the visualization to update immediately, rather than the current lag."

WHAT IF?
Suggest alternative design directions, or even wacky half-baked ideas. Example: "What if we got rid of the slider and enabled direct manipulation navigation by dragging data points directly?"
An Interaction Grammar (Vega-Lite Selections)
Satyanarayan, Moritz, Wongsuphasawat, Heer. TVCG’17
Vega-Lite: A Grammar of Graphics
Vega-Lite: A Grammar of Multi-View Graphics
Vega-Lite: A Grammar of Interactive Graphics
Cross-Filtering in Vega-Lite
Cross-Filtering in Vega-Lite
Cross-Filtering in Vega-Lite

markBar().encode(
  x().fieldQ('delay').bin(true),
  y().count()
).data('data/flights.json')
Cross-Filtering in Vega-Lite

markBar().encode(
    x().field('delay').bin(true),
    y().count(),
    color().value('lightgrey')
).data('data/flights.json')
Cross-Filtering in Vega-Lite

markBar().encode(
  x().fieldQ(repeat('row').bin(true),
  y().count(),
  color().value('lightgrey'))
).repeat({
  row: ['delay', 'distance', 'hour']
}).data('data/flights.json')
Cross-Filtering in Vega-Lite

```javascript
layer(
    markBar().encode(
        x().fieldQ(repeat('row')).bin(true),
        y().count(),
        color().value('lightgrey')
    ),
    markBar().encode(
        x().fieldQ(repeat('row')).bin(true),
        y().count()
    )
)
.repeat(
    row: ['delay', 'distance', 'hour']
)
data('data/flights.json')
```
Cross-Filtering in Vega-Lite

```javascript
brush = selectInterval().encodings('x')

layer(
    markBar().encode(
        x().fieldQ(repeat('row')).bin(true),
        y().count(),
        color().value('lightgrey')
    ).params(brush),
    markBar().encode(
        x().fieldQ(repeat('row')).bin(true),
        y().count()
    )
).repeat({
    row: ['delay', 'distance', 'hour']
})
.data('data/flights.json')
```
Cross-Filtering in Vega-Lite

```javascript
brush = selectInterval.encodings('x')

layer(
    markBar().encode(
        x().fieldQ(repeat('row')).bin(true),
        y().count(),
        color().value('lightgrey')
    ).params(brush),
    markBar().encode(
        x().fieldQ(repeat('row')).bin(true),
        y().count()
    ).transform(filter(brush))
).repeat(
    row: ['delay', 'distance', 'hour']
)
.data('data/flights.json')
```
Cross-Filtering in Vega-Lite

brush = selectInterval.encodings('x')

layer(
    markBar().encode(
        x().fieldQ(repeat('row')).bin(true),
        y().count(),
        color().value('lightgrey')
    ).params(brush),
    markBar().encode(
        x().fieldQ(repeat('row')).bin(true),
        y().count()
    ).transform(filter(brush))
).repeat(
    row: ['delay', 'distance', 'hour']
)
.data('data/flights.json')

Multi-view interactive graphics in ~10 lines of code
What constitutes a selection?

**Input handlers**: click, shift-click, drag, zoom, ...

**Bindings**
- **Inputs**: interactive brush, query widgets
- **Axis scales**: pan / zoom a scale domain
- **Legends**: interactive selection

**Scale inversion**: visual space $\rightarrow$ data space

**Predicate**: test if a data record is selected

A selection can then *parameterize* data transformations and visual encodings.
Selections

Selections *invert* scales and *parameterize* graphics

Bind selection to scale domains: *Synchronized Pan & Zoom!*

Parameterized Transformations