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

- Conceptual model
- Real world

[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

Conceptual model: x, y related?

Evaluation

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?

Real world:

$\rho = -0.29$
Gulf of Execution

Conceptual model: Draw a scatterplot

Gulf

Real world

Move 90 30
Rotate 35
Pen down
...

Execution
Gulf of Execution

Conceptual model: Draw a scatterplot
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

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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
EXAMPLE:
Bertin’s Hotel Data
### Table of Clientele Analysis

<table>
<thead>
<tr>
<th></th>
<th>January</th>
<th>February</th>
<th>March</th>
<th>April</th>
<th>May</th>
<th>June</th>
<th>July</th>
<th>August</th>
<th>September</th>
<th>October</th>
<th>November</th>
<th>December</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</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>Female</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>Total</td>
<td>95</td>
<td>91</td>
<td>103</td>
<td>107</td>
<td>67</td>
<td>66</td>
<td>69</td>
<td>69</td>
<td>95</td>
<td>75</td>
<td>108</td>
<td>144</td>
</tr>
</tbody>
</table>

### Percentage Breakdown

- **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

### Price of Rooms

- $1.65
- $1.71
- $1.65
- $1.91
- $1.90
- $1.54
- $1.60
- $1.73
- $1.82
- $1.66
- $1.44

### Percentage Occupancy

- June: 67%
- July: 82%
- August: 70%
- September: 83%
- October: 74%
- November: 56%
- December: 62%
- January: 90%
- February: 78%
- March: 55%
- April: 52%

### Conventions

- January: X
- February: X
- March: X
- April: X
- May: X
- June: X
- July: X
- August: X
- September: X
- October: X
- November: X
- December: X
<table>
<thead>
<tr>
<th>% Occupancy</th>
<th>Active and Slow Periods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of Stay</td>
<td></td>
</tr>
<tr>
<td>Conventions</td>
<td>Discovery Factors</td>
</tr>
<tr>
<td>Businessmen</td>
<td></td>
</tr>
<tr>
<td>Agency Reservations</td>
<td>South America</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Air Crews</td>
<td>Recovery Factors Winter</td>
</tr>
<tr>
<td>Clients Under 20 Years</td>
<td></td>
</tr>
<tr>
<td>Clients More than 55 Years</td>
<td></td>
</tr>
<tr>
<td>Clients from 20-35 Years</td>
<td></td>
</tr>
<tr>
<td>Female Clientele</td>
<td></td>
</tr>
<tr>
<td>Local Clientele</td>
<td></td>
</tr>
<tr>
<td>Asia</td>
<td>Winter-Summer</td>
</tr>
<tr>
<td>Tourists</td>
<td></td>
</tr>
<tr>
<td>Direct Reservation</td>
<td></td>
</tr>
<tr>
<td>Price of Rooms</td>
<td>Summer</td>
</tr>
<tr>
<td>Middle East, Africa</td>
<td></td>
</tr>
<tr>
<td>U.S.A.</td>
<td></td>
</tr>
<tr>
<td>Europe</td>
<td></td>
</tr>
<tr>
<td>Clients from 35-55 Years</td>
<td></td>
</tr>
</tbody>
</table>

[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, Becker & Cleveland 1982
Brushing Scatterplots
Cross-Filtering

Arrival Delay (min)

Local Departure Time (hour)

Travel Distance (miles)
Baseball Statistics [Wills 95]
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

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

- How long in majors
- Avg assists vs avg putouts (fielding ability)
- Distribution of positions played
- Avg career HRs vs avg career hits (batting ability)
- Select high salaries
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
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, Veron

Title: ALL
Actor: ALL
Actress: Pfeiffer, Michelle
Director: Miller, George

Ratings: G, PG, PG-13, R
Films Shown: 210
• The Attribute Explorer
Attribute Explorer [Spence & Tweedie 96]

- Video Clip
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/
NameVoyager [Wattenberg 06]

http://www.babynamewizard.com/voyager
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?
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
Administrivia
A2: Exploratory Data Analysis

Use visualization software to form & answer questions

**First steps:** (Due Mon 4/10)
Step 1: Pick domain & data
Step 2: Pose questions
Step 3: Profile the data
Iterate as needed

Create visualizations
Interact with data
Refine your questions

Author a report
Screenshots of most insightful views (10+)
Include titles and captions for each view

Due by 5:00pm Friday, April 14
Tutorials!

Web Programming: JavaScript, SVG, CSS
Thursday, April 6 - 4:30-5:50pm - PAA A118

Introduction to D3.js
Thursday, April 13 - 4:30-5:50pm - PAA A118
Final Project Proposal

Project topic, goals, datasets & team members.

You should work in **teams of 3-4**.

Submit proposal form by **Tuesday 4/18, 5pm**.

*If you do not have team mates, you should:*
- Use the facilities on Canvas
- Stay after class/tutorial to meet potential partners
Create an interactive visualization. Choose a driving question in your topic area and develop an appropriate visualization + interaction techniques, then deploy your visualization on the web.

Due by 5pm on Wednesday, May 3.

We will discuss in greater detail next week!
An Interaction Grammar (Vega-Lite Selections)

Satyanarayan et al. InfoVis’17 Best Paper
Specifying Interactions

Typically interactive behaviors are programmed using *imperative* event handler callbacks. When events occur, you must process the event, update the application state, re-draw, etc.

For a variety of visual analysis operations, what if you could *declaratively* specify the *semantics* of an interaction and have the event handling logic automatically *synthesized*?
{  
  "data": {"url": "data/flights.json"},  
  "mark": "bar",  
  "encoding": {  
    "x": {"field": "hour", "bin": true, "type": "Q"},  
    "y": {"field": "*", "aggregate": "count", "type": "Q"}  
  }  
}
{
  "data": {"url": "data/flights.json"},
  "mark": "bar",
  "encoding": {
    "x": {"field": "hour", "bin": true, "type": "Q"},
    "y": {"field": "*", "aggregate": "count", "type": "Q"}
  }
}
A bar chart can be initialized with a data source and encoding settings. The data is fetched from "data/flights.json" and the mark is set to "bar". The encoding includes binning the hour field with "type" set to "Q".

```json
{
  "data": {
    "url": "data/flights.json"
  },
  "mark": "bar",
  "encoding": {
    "x": {
      "field": "hour",
      "bin": true,
      "type": "Q"
    },
    "y": {
      "field": "*",
      "aggregate": "count",
      "type": "Q"
    }
  }
}
```
```json
{
  "data": {
    "url": "data/flights.json"},
  "mark": "bar",
  "encoding": {
    "x": {
      "field": "hour",
      "bin": true,
      "type": "Q"},
    "y": {
      "field": "*",
      "aggregate": "count",
      "type": "Q"}
  }
}
```

**Data**

**Mark**

**Transforms**

![Histogram of flight data]
```json
{
    "data": {
        "url": "data/flights.json"},
    "mark": "bar",
    "encoding": {
        "x": {
            "field": "hour",
            "bin": true,
            "type": "Q"},
        "y": {
            "field": ".",
            "aggregate": "count",
            "type": "Q"}
    }
}
```

**Data**

**Mark**

**Transforms** + Scales & Guides (not shown)
```json
{
  "repeat": {"column": ["hour", "delay", "distance"]},
  "spec": {
    "data": {"url": "data/flights.json"},
    "mark": "bar",
    "encoding": {
      "x": {"field": {"repeat": "column"}, "bin": true, "type": "Q"},
      "y": {"field": "+", "aggregate": "count", "type": "Q"}
    }
  }
}
```
{
  "repeat": {"column": ["hour", "delay", "distance"]},
  "spec": {
    "data": {"url": "data/flights.json"},
    "mark": "bar",
    "encoding": {
      "x": {
        "field": {"repeat": "column"},
        "bin": true,
        "type": "Q"
      },
      "y": {
        "field": "*",
        "aggregate": "count",
        "type": "Q"
      }
    }
  }
}
{
  "repeat": {{"column": ["hour", "delay", "distance"]},
  "spec": {
    "layers": [
      {
        "data": {{"url": "data/flights.json"},
        "mark": "bar",
        "encoding": {
          "x": {{"field": {{"repeat": "column"}, "bin": true, "type": "Q"},
          "y": {{"field": "*", "aggregate": "count", "type": "Q"}}
        }
      }
    ],
    "color": {"value": "goldenrod"}
  }
}
}
can be initialized
can be initialized
```json
{
  "repeat": {
    "column": ["hour", "delay", "distance"]
  },
  "spec": {
    "layers": [{
      "select": {
        "region": {
          "type": "interval",
          "project": {
            "channels": ["x"]
          }
        }
      }
    }, {
      "transform": {
        "filterWith": "region"
      }
    }]
  }
}
```
Panning & Zooming

Interactive Transformation

Overview + Detail