[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

[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

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>
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<tr>
<td>0.39</td>
<td>0.72</td>
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<td>0.27</td>
<td>0.85</td>
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<tr>
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<td>0.63</td>
<td>0.09</td>
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<tr>
<td>0.03</td>
<td>0.03</td>
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<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**

Evaluation

Conceptual model: are x and y correlated?

Real world:

\[ \rho = -0.29 \]
Gulf of Execution

Conceptual model: Draw a scatterplot

Real world
Move 90 30
Rotate 35
Pen down
...

Gulf
Gulf of Execution

Conceptual model:
Draw a scatterplot

```javascript
vl.markCircle().encode(
  vl.x().fieldQ(...),
  vl.y().fieldQ(...)
)
```

Real world
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
<table>
<thead>
<tr>
<th>Region</th>
<th>Segment</th>
<th>Technology</th>
<th>Office Supplies</th>
<th>Furniture</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central</td>
<td>Consumer</td>
<td>[Graph]</td>
<td>[Graph]</td>
<td>[Graph]</td>
</tr>
<tr>
<td></td>
<td>Corporate</td>
<td>[Graph]</td>
<td>[Graph]</td>
<td>[Graph]</td>
</tr>
<tr>
<td></td>
<td>Home Office</td>
<td>[Graph]</td>
<td>[Graph]</td>
<td>[Graph]</td>
</tr>
<tr>
<td>East</td>
<td>Consumer</td>
<td>[Graph]</td>
<td>[Graph]</td>
<td>[Graph]</td>
</tr>
<tr>
<td></td>
<td>Corporate</td>
<td>[Graph]</td>
<td>[Graph]</td>
<td>[Graph]</td>
</tr>
<tr>
<td></td>
<td>Home Office</td>
<td>[Graph]</td>
<td>[Graph]</td>
<td>[Graph]</td>
</tr>
<tr>
<td>South</td>
<td>Consumer</td>
<td>[Graph]</td>
<td>[Graph]</td>
<td>[Graph]</td>
</tr>
<tr>
<td></td>
<td>Corporate</td>
<td>[Graph]</td>
<td>[Graph]</td>
<td>[Graph]</td>
</tr>
<tr>
<td></td>
<td>Home Office</td>
<td>[Graph]</td>
<td>[Graph]</td>
<td>[Graph]</td>
</tr>
<tr>
<td>West</td>
<td>Consumer</td>
<td>[Graph]</td>
<td>[Graph]</td>
<td>[Graph]</td>
</tr>
<tr>
<td></td>
<td>Corporate</td>
<td>[Graph]</td>
<td>[Graph]</td>
<td>[Graph]</td>
</tr>
<tr>
<td></td>
<td>Home Office</td>
<td>[Graph]</td>
<td>[Graph]</td>
<td>[Graph]</td>
</tr>
</tbody>
</table>
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
EXAMPLE:
Bertin’s Hotel Data
<table>
<thead>
<tr>
<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>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<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>
<td>1% CLIENTELE FEMALE</td>
</tr>
<tr>
<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>
<td>2% LOCAL</td>
</tr>
<tr>
<td>7</td>
<td>6</td>
<td>3</td>
<td>6</td>
<td>14</td>
<td>19</td>
<td>14</td>
<td>9</td>
<td>6</td>
<td>8</td>
<td>8</td>
<td></td>
<td>3% U.S.A.</td>
</tr>
<tr>
<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>
<td></td>
<td>4% SOUTH AMERICA</td>
</tr>
<tr>
<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>19</td>
<td>17</td>
<td></td>
<td>5% EUROPE</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>8</td>
<td>6</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td></td>
<td>6% M. EAST, AFRICA</td>
<td></td>
</tr>
<tr>
<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>
<td>7% ASIA</td>
</tr>
<tr>
<td>78</td>
<td>80</td>
<td>85</td>
<td>86</td>
<td>85</td>
<td>87</td>
<td>70</td>
<td>76</td>
<td>87</td>
<td>85</td>
<td>87</td>
<td>80</td>
<td>8% BUSINESSMEN</td>
</tr>
<tr>
<td>22</td>
<td>20</td>
<td>15</td>
<td>14</td>
<td>15</td>
<td>13</td>
<td>30</td>
<td>24</td>
<td>13</td>
<td>15</td>
<td>13</td>
<td>20</td>
<td>9% TOURISTS</td>
</tr>
<tr>
<td>70</td>
<td>70</td>
<td>75</td>
<td>74</td>
<td>69</td>
<td>68</td>
<td>74</td>
<td>75</td>
<td>68</td>
<td>68</td>
<td>64</td>
<td>75</td>
<td>10% DIRECT RESERVATIONS</td>
</tr>
<tr>
<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>
<td>11% AGENCY</td>
</tr>
<tr>
<td>10</td>
<td>12</td>
<td>9</td>
<td>4</td>
<td>5</td>
<td>7</td>
<td>6</td>
<td>6</td>
<td>5</td>
<td>15</td>
<td>10</td>
<td></td>
<td>12% AIR CREWS</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>4</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>
<td></td>
<td>13% CLIENTS UNDER 20 YEARS</td>
</tr>
<tr>
<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>
<td>15% 35-55</td>
</tr>
<tr>
<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>20</td>
<td>19</td>
<td>22</td>
<td></td>
<td>16% MORE THAN 55</td>
</tr>
<tr>
<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>
<td>17% PRICE OF ROOMS</td>
</tr>
<tr>
<td>1.65</td>
<td>1.71</td>
<td>1.65</td>
<td>1.91</td>
<td>1.90</td>
<td>2.</td>
<td>1.54</td>
<td>1.60</td>
<td>1.73</td>
<td>1.82</td>
<td>1.66</td>
<td>1.44</td>
<td>18% LENGTH OF STAY</td>
</tr>
<tr>
<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>
<td>19% OCCUPANCY</td>
</tr>
<tr>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>CONVENTIONS</td>
</tr>
</tbody>
</table>

[Graphics and Graphic Information Processing, Bertin 81]
[Graphics and Graphic Information Processing, Bertin 81]
<table>
<thead>
<tr>
<th></th>
<th>Active and Slow Periods</th>
<th>Discovery Factors</th>
</tr>
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<tbody>
<tr>
<td>JFMAMJASONDJFMAMJASONDJFMAMJASOND</td>
<td>18% Occupancy</td>
<td></td>
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<tr>
<td>18 Length of Stay</td>
<td></td>
<td></td>
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<tr>
<td>20 Conventions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8 Businessmen</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11 Agency Reservations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 South America</td>
<td></td>
<td></td>
</tr>
</tbody>
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<table>
<thead>
<tr>
<th></th>
<th>Recovery Factors</th>
<th></th>
</tr>
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<tbody>
<tr>
<td>JFMAMJASONDJFMAMJASONDJFMAMJASOND</td>
<td>18 Air Crews</td>
<td></td>
</tr>
<tr>
<td>18 Clients Under 20 Years</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18 Clients More Than 55 Years</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14 Clients From 20-35 Years</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Female Clientele</td>
<td>Recovery Factors</td>
<td>Winter</td>
</tr>
<tr>
<td>2 Local Clientele</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7 Asia</td>
<td>Winter-Summer</td>
<td></td>
</tr>
<tr>
<td>9 Tourists</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 Direct Reservation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17 Price of Rooms</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 Middle East, Africa</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 U.S.A.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 Europe</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15 Clients From 35-55 Years</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Winter</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 Summer</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

[Graphics and Graphic Information Processing, Bertin 81]
[Graphics and Graphic Information Processing, Bertin 81]
[Graphics and Graphic Information Processing, Bertin 81]
[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]

- Years
- Log(1+Salary)
- Assists - PutO
- CHits/Years - C
- Position

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**
- **select high salaries**
- **avg assists vs avg putouts (fielding ability)**
- **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)
- Distribution of positions played
- Avg career HRs vs avg career hits (batting ability)
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

[All] [ ]

A B C D F G H L M N P R S T W Z

[Ahlberg and Shneiderman 94]
### Witches of Eastwick, The

**Director:** Miller, George  
**Year:** 1987

**Country:** USA  
**Language:** English

**Actors:**  
- Nicholson, Jack  
- Jenkins, Richard  
- Joakum, Keith  
- Struycker, Carel

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

---

**Year of Production:**

- **1960**  
- **1965**  
- **1970**  
- **1975**  
- **1980**  
- **1985**  
- **1990**  
- **1995**

**Length:** 231 minutes

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

**Films Shown:** 210

---

[Copyright (C) 1993 HCIL]

[Ahlberg and Shneiderman 94]
• The Attribute Explorer
NameVoyager [Wattenberg 06]

http://www.babynamewizard.com/voyager
DimpVis [Kondo 14]
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:
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 (8+)
Include titles and captions for each view

Due by 11:59pm Friday, Apr 23
Break Time!
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

Scatter Plot Matrix

Concat & Layered Views

Faceted Views
Indexed Chart

Focus + Context

Cross-Filtering

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

```javascript
markBar().encode(
  x().fieldQ('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