Visualization & Visual Variables

Chelsea Ambler      cq.ambler@ucalgary.ca
Learning Goals

• Visualization
  – What is it?
  – Why is it useful?

• Visual Variables
  – What are they?
  – Why do they matter?
  – What are their strengths/weaknesses?
What is Visualization?

A visualization can be applied to many datasets.

An infographic is created for a particular dataset.
What is Visualization?

- Visual representation of data
- “Transformation of the symbolic into the geometric” [McCormick et al, 1987]
- “… artificial memory that best supports our natural means of perception” [Bertin, 1967]
- “Use of computer-generated, interactive, visual representations of data to amplify cognition” [Card, Mackinlay, & Shneidermann, 1999]
- “The use of visual representations to explore, make sense of, and communicate data.” [Few, 2014]
What is Visualization?

1. Based on non-visual data
2. Produce an image
3. Result must be readable and recognizable

Robert Kosara
“The ability to take data –

to be able to understand it,
to visualize it,
to communicate it –

that’s going to be a hugely important skill in the next decades,

... because now we really do have essentially free and ubiquitous data.

So the complimentary **scarce factor is the ability to understand** the data and extract value from it.”

Hal Varian, Google’s Chief Economist
The McKinsey Quarterly, Jan 2009
Why do we Visualize?

• Visual bandwidth is enormous
Why do we Visualize?

- Visual bandwidth is enormous
- Human perceptual skills are remarkable
  - Trend, cluster, gap, outlier, pattern ...
  - Color, size, shape, proximity...
Perception

How many 3s?

1 8 4 7 9 5 3 2 1 2 4 6 7 8 9 5 6 4 3
4 8 0 6 4 8 0 3 2 8 8 7 9 6 2 3 1 0 6
9 9 6 3 4 4 2 6 8 1 5 6 8 7 9 0 3 2 1
1 5 6 8 7 9 6 5 1 2 3 5 9 9 7 8 9 6 5
4 3 2 1 3 2 1 5 4 9 8 3 4 2 5 8 4 8 9
2 2 1 5 6 7 8 6 5 6 3 1 4 5 1 3 4 5 1
## Perception

### How many 3s?

```
1 8 4 7 9 5 3 2 1 2 4 6 7 8 9 5 6 4 3
4 8 0 6 4 8 0 3 2 8 8 7 9 6 2 3 1 0 6
9 9 6 3 4 4 2 6 8 1 5 6 8 7 9 0 3 2 1
1 5 6 8 7 9 6 5 1 2 3 5 9 9 7 8 9 6 5
4 3 2 1 3 2 1 5 4 9 8 3 4 2 5 8 4 8 9
2 2 1 5 6 7 8 6 5 6 3 1 4 5 1 3 4 5 1
```
Perception

How many s?
Perception

How many ⬤s?
<table>
<thead>
<tr>
<th>Set A</th>
<th>Set B</th>
<th>Set C</th>
<th>Set D</th>
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<tbody>
<tr>
<td>X</td>
<td>Y</td>
<td>X</td>
<td>Y</td>
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<td>10</td>
<td>8.08</td>
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<td>6.95</td>
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<td>8.14</td>
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<td>13</td>
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<td>9</td>
<td>8.81</td>
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<td>8.77</td>
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<td>5</td>
<td>5.68</td>
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<td>4.74</td>
</tr>
</tbody>
</table>

**Summary Statistics**

$u_X = 9.0$, $\sigma_X = 3.317$

$u_Y = 7.5$, $\sigma_Y = 2.03$

Anscombe’s Quartet (Anscombe, Francis J., 1973)
Why do we Visualize?

• Visual bandwidth is enormous
• Human perceptual skills are remarkable
  – Trend, cluster, gap, outlier, pattern...
  – Color, size, shape, proximity...
• External representation
  – Reduces load on working memory
  – Offload cognition
<table>
<thead>
<tr>
<th>Paper</th>
<th>Mental Buffer</th>
</tr>
</thead>
<tbody>
<tr>
<td>57 X 48</td>
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</table>
## External Representation

<table>
<thead>
<tr>
<th>Paper</th>
<th>Mental Buffer</th>
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</thead>
<tbody>
<tr>
<td>5 57</td>
<td>7 * 8 = 56</td>
</tr>
<tr>
<td>X 48</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
</tr>
</tbody>
</table>
# External Representation

<table>
<thead>
<tr>
<th>Paper</th>
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</thead>
<tbody>
<tr>
<td>( \frac{5}{57} \times \frac{48}{48} )</td>
<td>( 7 \times 8 = 56 )</td>
</tr>
<tr>
<td></td>
<td>( 5 \times 8 = 40 + 5 = 45 )</td>
</tr>
</tbody>
</table>
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<td>[25] 57</td>
<td>[7 \times 8 = 56]</td>
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<tr>
<td>X 48</td>
<td>[5 \times 8 = 40 + 5 = 45]</td>
</tr>
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<td>[4 \times 7 = 28]</td>
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</tr>
<tr>
<td>456</td>
<td>4 * 7 = 28</td>
</tr>
<tr>
<td>228</td>
<td>4 * 5 = 20 + 2 = 22</td>
</tr>
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<td>228</td>
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<tr>
<td>2736</td>
<td>6 + 0 = 6</td>
</tr>
<tr>
<td></td>
<td>5 + 8 = 13</td>
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<tr>
<td></td>
<td>2 + 4 = 6 + 1 = 7</td>
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<td>2 + 4 = 6 + 1 = 7</td>
</tr>
<tr>
<td></td>
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</tr>
</tbody>
</table>

![Bar chart showing comparison between Mental and Paper & Pencil methods.](chart.png)
External Representation

- Paradoxes – Lewis Carroll
- Paradoxes – Epimenides
- Paradoxes – Self-ref
- Paradoxes – Infinity
- Epimenides – Self-ref
- Epimenides – Tarski
- Halting Problem – Decision Procedure
- Halting Problem - Turing
- Infinity – Halting problem
- Infinity – Recursion
- Infinity – Zeno
- Infinity – Lewis Carroll
- Zeno – Lewis Carroll
- Lewis Carroll – Wordplay
- Tarski – Epimenides
- Tarski – Truth vs Provability
- Tarski - Undecidability
External Representation

- Infinity
  - Zeno
  - Paradoxes
    - Lewis Carroll
      - Wordplay
    - Epimenides
    - Self-ref
    - Tarski
      - Truth vs. provability
      - Undecidability
  - Halting problem
    - Decision procedures
    - Turing
Why do we Visualize?

• Visual bandwidth is enormous
• Human perceptual skills are remarkable
  – Trend, cluster, gap, outlier, pattern...
  – Color, size, shape, proximity...
• External representation
  – Reduces load on working memory
  – Offload cognition
• Fewer coded symbols to decode
Decoding

Compare:

2947 vs 6621 vs 95.12
Decoding

Compare:

2947 vs 6621 vs 95.12
Why we Visualize

Myths:

• To target visual learners
• To help those who are bad with numbers
• To grab attention with eye-catching displays

Stephen Few http://www.perceptualedge.com/blog/?p=1897
Why we Visualize

• See the big picture
  – Don’t have read & interpret each datum on its own
• Easily & rapidly compare values
  – Line graph
• See patterns among values
• Compare patterns

http://www.perceptualedge.com/blog/?p=1897
How do we Visualize?

• Know the Data
  – Number of attributes, data type, quality

• Know your purpose (& audience)
  – What do you/they want to see or focus on?

• Select visual variables to encode the data
  – Be aware of:
    • Human perceptual system
    • Display capacity
    • Characteristics of data (size, type)
    • Task
Visual Encoding

Data Types:

• Categorical

• Ordered
  – Ordinal
  – Quantitative

<table>
<thead>
<tr>
<th>Small</th>
<th>Medium</th>
<th>Large</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>5.29</td>
</tr>
<tr>
<td>42</td>
<td>101</td>
<td></td>
</tr>
</tbody>
</table>
Visual Encoding

Marks

• what attributes can we change?
Visual Encoding

Visual Channels:

- Position
- Angle/Slope

- Lightness
- Saturation
- Hue

Size

- Length
- Area/Volume

- Texture
- Connection
- Containment

- Shape
Visual Encoding

- Can we judge magnitude?
- Can we perceive differences?
  - How many bins (differences) can we apply/perceive?
- Are channels independent?
  - interference with some channels
Visual Variable Properties

- **Selective** - can we pick it out of the crowd?
- **Associative** - can we identify groups?
- **Quantitative** - can we tell if one is 3X another?
- **Order** - can we tell order (smallest to largest)?
- **Length (bins/slices)** - how many differences can we see?
Is Size Selective?

find the big & small Muppets

Is Size Associative?
find all the small Muppets

Is Size Quantitative?

compare Kermit and Fozzie
Is Size Quantitative?

compare Kermit and Fozzie

Is Size Quantitative?

What value is Kermit compared to?
Is Size Ordered?

put the Muppets in order

Does Size Have Length?

how many different sizes can we use/perceive?

Visual Variable Properties

- **Selective** - can we pick it out of the crowd?
- **Associative** - can we identify groups?
- **Quantitative** - can we tell if one is 3X another?
- **Order** - can we tell order (smallest to largest)?
- **Length** - how many differences can we see?
<table>
<thead>
<tr>
<th>Size</th>
</tr>
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<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Select</td>
</tr>
<tr>
<td>✓</td>
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</table>
Position

Select  Associate  Quantify  Order  Length
Position

Select  Associate  Quantify  Order  Length

✓
Position

Select  Associate  Quantify  Order  Length

✓
Position

Select  Associate  Quantify  Order  Length

✅  ✅  ✅
Position

<table>
<thead>
<tr>
<th>Select</th>
<th>Associate</th>
<th>Quantify</th>
<th>Order</th>
<th>Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>✓</td>
<td>✓</td>
<td></td>
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</tbody>
</table>

Graph with characters positioned on a coordinate plane.
Position

<table>
<thead>
<tr>
<th>Select</th>
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<th>Quantify</th>
<th>Order</th>
<th>Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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</tbody>
</table>
Position

<table>
<thead>
<tr>
<th>Select</th>
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<tr>
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<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

- Select
- Associate
- Quantify
- Order
- Length
Position

<table>
<thead>
<tr>
<th>Select</th>
<th>Associate</th>
<th>Quantify</th>
<th>Order</th>
<th>Length</th>
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<tbody>
<tr>
<td>✓</td>
<td>✓</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Image 1</th>
<th>Image 2</th>
<th>Image 3</th>
<th>Image 4</th>
<th>Image 5</th>
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<tbody>
<tr>
<td>![Image]</td>
<td>![Image]</td>
<td>![Image]</td>
<td>![Image]</td>
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</tbody>
</table>
Position

<table>
<thead>
<tr>
<th>Select</th>
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<th>Quantify</th>
<th>Order</th>
<th>Length</th>
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</thead>
<tbody>
<tr>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
</tr>
</tbody>
</table>

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The diagram shows a selection of characters from the Muppets, indicating their positions based on the criteria listed.
Position

<table>
<thead>
<tr>
<th>Select</th>
<th>Associate</th>
<th>Quantify</th>
<th>Order</th>
<th>Length</th>
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<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>
Shape

Select  Associate  Quantify  Order  Length

○ □ △
Shape

Select   Associate   Quantify   Order   Length

○ □ △    < 5
Shape

Select  Associate  Quantify  Order  Length

○ □ △  < 5  < 5
Shape

Select  Associate  Quantify  Order  Length

•  ■  △  < 5  < 5  X  X

| / __  

●  ○  □  △  < 5  < 5  X  X

△  ○  □  △  < 5  < 5  X  X

△  ○  □  △  < 5  < 5  X  X

△  ○  □  △  < 5  < 5  X  X

△  ○  □  △  < 5  < 5  X  X

△  ○  □  △  < 5  < 5  X  X
Shape

Select  Associate  Quantify  Order  Length

○  □  △  < 5  < 5  X  X  5/∞
Saturation/Lightness

Select  Associate  Quantify  Order  Length
Saturation/Lightness

Select  Associate  Quantify  Order  Length

[Checkmarks]
Saturation/Lightness

Select  Associate  Quantify  Order  Length

-  -  -  -  

-  -  

-  -  

Select, Associate, and Quantify are marked as valid.
Weber’s Law: human perception is fundamentally based on relative judgments, not absolute values.
Saturation/Lightness

Select   Associate   Quantify   Order   Length

☑   ☑   ☒   ☐
Saturation/Lightness

Select  Associate  Quantify  Order  Length

☑️  ☑️  ☒️

| /  | /  | /  | /  | ☒️  |

|  |  |  |  |  | ☒️  |
Saturation/Lightness

Select  Associate  Quantify  Order  Length

- ✓ ✓ X ✓
Saturation/Lightness

Select   Associate   Quantify   Order   Length

✓       ✓           X           ✓
Saturation/Lightness

Select  Associate  Quantify  Order  Length

[ ]  [ ]  [x]  [ ]  [v]  7 / 10
Hue

Select  Associate  Quantify  Order  Length
Hue

Select  Associate  Quantify  Order  Length

Select

✓
Hue

Select  Associate  Quantify  Order  Length

[Images of different colored circles and faces]
Hue

Select  Associate  Quantify  Order  Length

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<table>
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Select  Associate  Quantify  Order  Length

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Select  Associate  Quantify  Order  Length

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Rainbow Scale Considerations

Map 1

Map 3
Rainbow Scale Considerations

Map 1

Map 2

Map 3

Map 4
Destroys Detail
<table>
<thead>
<tr>
<th>Rainbow</th>
<th>Gray</th>
<th>Black-Body Radiation</th>
<th>Red-Green</th>
</tr>
</thead>
</table>

Hue

Select  Associate  Quantify  Order  Length

-  -  -

5/20

< 5 < 5

X X

7/10

| / __

4/8

Hue
Hue

Select  Associate  Quantify  Order  Length

✓  ✓  ✓  ✓  ✓  7 / 10
Angle
Angle

Select  Associate  Quantify  Order  Length

✓  ✓  X  X  4 / 8
Texture

Select  Associate  Quantify  Order  Length

Texture images
Texture

<table>
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<tr>
<td>✔️</td>
<td>✔️</td>
<td>X</td>
<td>X</td>
<td>✔️</td>
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| ![Texture Images]({}) | ![Texture Images]({}) | ![Texture Images]({}) | ![Texture Images]({}) | ![Texture Images]({}) | ![Texture Images]({}) | ![Texture Images]({}) | ![Texture Images]({}) | ![Texture Images]({}) | ![Texture Images]({}) |
### Visual Variable Properties

<table>
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<th>Quantify</th>
<th>Order</th>
<th>Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>![Circle]</td>
<td>✓</td>
<td>✓</td>
<td>✓ ~ ✓</td>
<td>✓</td>
<td>5/20</td>
</tr>
<tr>
<td>![Circle]</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>![Circle, Square, Triangle]</td>
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<td>✓</td>
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<td>X</td>
<td>✓</td>
<td>5 / ✓</td>
</tr>
<tr>
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<td>✓</td>
<td>✓</td>
<td>7 / 10</td>
<td></td>
</tr>
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<td></td>
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<td>✓</td>
<td>X</td>
<td>X</td>
<td>4 / 8</td>
</tr>
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<td>✓</td>
<td>X</td>
<td>X</td>
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Visualization Resources

Books

- **Semiology of Graphics** by Jacques Bertin
  - *The book on visual variables*

- **Visual Display of Quantitative Information, Beautiful Evidence, Visual Explanations, or Envisioning Information** by Edward Tufte
  - *Beautiful examples of historic visualizations*

- **Visualizing Data** by Ben Fry
  - *Current overarching text book*

- **Visual Thinking for Design** by Colin Ware
  - Ties perception theory and design processes to visualization practices.

- **Beautiful Visualization** by Steele & Iliinsky
  - Combines techniques from artists, designers, scientists, and others.
Visualization Resources

Web Sites

• New York Times
  – Dedicated team producing exceptional work.

• Information aesthetics
  – Creative design applied to visualization. Gorgeous.

• Eagereyes
  – Vis Researcher with criticism as well as overview from assorted research conferences.

• Gapminder
  – Hans Rosling’s stat software & data.

• Visual Business Intelligence
  – Analytics blog, frequently discussing big data and dashboard design.

• Tableau Viz of the Day
  – Daily example of a visualization created with Tableau software.

Sketching Exercise

- Create a visualization
- Anything you want
  - What interests you in the data?
  - What questions do you have?
- **Challenge**: Try to encode as many properties as possible in your visualization.
How Do We Visualize?

• Know the Data
  – Number of attributes
  – Date types: ordinal vs ordered (ordinal or quantitative)
  – Trustworthiness: bad fields, inaccuracies, missing values

• Know your purpose (& audience)
  – What do you/they want to see?
  – What might you/they want to focus on?

• Decide how to use the visual variables to encode the data
  – Requires awareness of:
    • Human perceptual system
    • Display capacity
    • Characteristics of data (size, type)
    • Task
Banff Trail
Varsity
Brentwood

△ Bath 2 Half Bath
● Bedroom

- 2593
- 2000
- 1500
- 1044
- 399,900
- 990,999

Price

- 2500
- 2000
- 1500
- 1000
- 500
- 200

Price

- 300k
- 400k
- 500k
- 600k
- 700k
- 800k
- 900k

Price

- 3 Bathrooms
- 2 Bathrooms
- Full
- Half

Bathrooms

- Banff Trail
- Varsity
- Brentwood
NW (14)

SW (3)

Room

- X 90
- X 2
- X 1
- X 1

- N/A
- Unfurnished
- Private entrance
- Utilities

- Downtown
- LRT / 60min
- Private bath

- Glamour - Bus / no private
<table>
<thead>
<tr>
<th>Variable</th>
<th>Select</th>
<th>Associate</th>
<th>Quantify</th>
<th>Order</th>
<th>Length</th>
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<td>✓</td>
<td>Yes (1D), Some (2D), Not advisable (3D)</td>
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</tbody>
</table>
Visualization & Visual Variables

Comments, questions, want more info?

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