Data Visualization (DSC 530/CIS 568)

Marks & Channels

Dr. David Koop
**D3.js** is a JavaScript library for manipulating documents based on data. **D3** helps you bring data to life using HTML, SVG, and CSS. D3’s emphasis on web standards gives you the full capabilities of modern browsers without tying yourself to a proprietary framework, combining powerful visualization...
D3 Introduction

• Ogievetsky has put together a nice set of interactive examples that show off the major features of D3
    - (Updated from original for D3 v5 with new joins)
  - https://beta.observablehq.com/@dakoop/d3-intro

• Other references:
  - Murrary’s book on Interactive Data Visualization for the Web
  - The D3 website: d3js.org
  - Ros's Slides on v4: https://iros.github.io/d3-v4-whats-new/
D3 Data Joins

- Two groups: data and visual elements
- Three parts of the join between them: enter, update, and exit
- enter: `s.enter()`, update: `s`, exit: `s.exit()`
Assignment 2

• Create a stacked bar chart using three different tools: Tableau, Vega-Lite, and D3

• Due Monday, Feb. 25
D3 Examples

- Bar Chart:
  - Start: http://codepen.io/dakoop/pen/dNxjYL
  - Simple Solution: http://codepen.io/dakoop/pen/aJoLBp
- With Axes and Scales: http://codepen.io/dakoop/pen/WpeZOV
- With Objects and Margin Convention: http://codepen.io/dakoop/pen/MJNGwZ
- More on Margin Convention:
  - https://bl.ocks.org/mbostock/3019563 (Note this is D3 v3!)
Visual Encoding

- How should we visualize this data?

<table>
<thead>
<tr>
<th>Name</th>
<th>Region</th>
<th>Population</th>
<th>Life Expectancy</th>
<th>Income</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>East Asia &amp; Pacific</td>
<td>1335029250</td>
<td>73.28</td>
<td>7226.07</td>
</tr>
<tr>
<td>India</td>
<td>South Asia</td>
<td>1140340245</td>
<td>64.01</td>
<td>2731</td>
</tr>
<tr>
<td>United States</td>
<td>America</td>
<td>306509345</td>
<td>79.43</td>
<td>41256.08</td>
</tr>
<tr>
<td>Indonesia</td>
<td>East Asia &amp; Pacific</td>
<td>228721000</td>
<td>71.17</td>
<td>3818.08</td>
</tr>
<tr>
<td>Brazil</td>
<td>America</td>
<td>193806549</td>
<td>72.68</td>
<td>9569.78</td>
</tr>
<tr>
<td>Pakistan</td>
<td>South Asia</td>
<td>176191165</td>
<td>66.84</td>
<td>2603</td>
</tr>
<tr>
<td>Bangladesh</td>
<td>South Asia</td>
<td>156645463</td>
<td>66.56</td>
<td>1492</td>
</tr>
<tr>
<td>Nigeria</td>
<td>Sub-Saharan Africa</td>
<td>141535316</td>
<td>48.17</td>
<td>2158.98</td>
</tr>
<tr>
<td>Japan</td>
<td>East Asia &amp; Pacific</td>
<td>127383472</td>
<td>82.98</td>
<td>29680.68</td>
</tr>
<tr>
<td>Mexico</td>
<td>America</td>
<td>111209909</td>
<td>76.47</td>
<td>11250.37</td>
</tr>
<tr>
<td>Philippines</td>
<td>East Asia &amp; Pacific</td>
<td>94285619</td>
<td>72.1</td>
<td>3203.97</td>
</tr>
<tr>
<td>Vietnam</td>
<td>East Asia &amp; Pacific</td>
<td>86970762</td>
<td>74.7</td>
<td>2679.34</td>
</tr>
<tr>
<td>Germany</td>
<td>Europe &amp; Central Asia</td>
<td>82338100</td>
<td>80.08</td>
<td>31191.15</td>
</tr>
<tr>
<td>Ethiopia</td>
<td>Sub-Saharan Africa</td>
<td>79996293</td>
<td>55.69</td>
<td>812.16</td>
</tr>
<tr>
<td>Turkey</td>
<td>Europe &amp; Central Asia</td>
<td>72626967</td>
<td>72.06</td>
<td>8040.78</td>
</tr>
</tbody>
</table>
Potential Solution

[Gapminder, Wealth & Health of Nations]

D. Koop, DSC 530, Spring 2019
Another Solution

[Gapminder, Wealth & Health of Nations]
What about change over years?
Another Solution showing trends over time

Income per person (GDP/capita, PPP$ inflation-adjusted)

[Gapminder, Wealth & Health of Nations]
Visual Encoding

- How do we encode data visually?
  - **Marks** are the basic graphical elements in a visualization
  - **Channels** are ways to control the appearance of the marks

- Marks classified by dimensionality:
  - Points
  - Lines
  - Areas

- Also can have surfaces, volumes

- Think of marks as a mathematical definition, or if familiar with tools like Adobe Illustrator or Inkscape, the path & point definitions
### Bertin’s Original Visual Variables

<table>
<thead>
<tr>
<th>Position</th>
<th>changes in the x, y location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size</td>
<td>change in length, area or repetition</td>
</tr>
<tr>
<td>Shape</td>
<td>infinite number of shapes</td>
</tr>
<tr>
<td>Value</td>
<td>changes from light to dark</td>
</tr>
<tr>
<td>Colour</td>
<td>changes in hue at a given value</td>
</tr>
<tr>
<td>Orientation</td>
<td>changes in alignment</td>
</tr>
<tr>
<td>Texture</td>
<td>variation in ‘grain’</td>
</tr>
</tbody>
</table>
Visual Channels

- **Position**
  - Horizontal
  - Vertical
  - Both

- **Color**
  - Black
  - Red
  - Green

- **Shape**
  - Triangle
  - Star
  - Line
  - Letter L

- **Tilt**
  - 45°

- **Size**
  - Length
  - Area
  - Volume

[Munzner (ill. Maguire), 2014]
## Visual Attributes Survey

### Table of Visual Attributes

**Richard Brath v. Sept 2013**

<table>
<thead>
<tr>
<th>Transform</th>
<th>Information Visualization Researchers</th>
<th>Vision Rsch</th>
<th>Shape Rsch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Length</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Size (Area)</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Orientation</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Volume</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shape</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Angle</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Curvature</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Curvature</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mark</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Line Ending</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Closure</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Local Warp</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Edge Type</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corner Type</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Icon, glyph, etc</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Colour</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brightness</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Hue</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Saturation</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Texture</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Granularity</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pattern</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Orientation</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

[r. brath]
More Visual Attributes

Table of Visual Attributes
Richard Brath
v. Sept 2013

| Relation | Connection  | Containment |  |  |  |  |  |  |
|----------|-------------|-------------|  |  |  |  |  |  |
|          | X           | X           |  |  |  |  |  |  |

| Optics   | Blur        | Transparency | Stereo Depth | Concavity | Light Direction | Shadow | Partial occlusion |  |  |  |
|----------|-------------|--------------|--------------|-----------|-----------------|--------|-------------------|  |  |  |
|          | X           | X            | X            | X         | X               | X      |                   |  |  |  |

| Movement | Flicker     | Speed        | Direction    |  |  |  |  |  |  |
|----------|-------------|--------------|--------------|  |  |  |  |  |  |
|          | X           | X            | X            |  |  |  |  |  |  |

| Misc     | Numerosity  | Spatial Grouping | Arrangement | Resolution | Artistic Effects | Text Labels |  |  |  |
|----------|-------------|------------------|-------------|------------|------------------|-------------|  |  |  |
|          | X           |                  | X           | X          |                  | X           |  |  |  |

<table>
<thead>
<tr>
<th>Vision Rsch</th>
<th>Preattentive Perception</th>
<th>Shape Rsch</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Brath 2008/2011</td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>

[R. Brath]
Channels

• Usually map an attribute to a single channel
  - Could use multiple channels but…
  - **Limited** number of channels

• Restrictions on size and shape
  - Points are nothing but location so size and shape are ok
  - Lines have a length, cannot easily encode attribute as length
  - Maps with boundaries have area, changing size can be problematic
Cartograms

[Election Results by Population, M. Newman, 2012]
Channel Types

- Identity => what or where, Magnitude => how much

**Magnitude Channels: Ordered Attributes**
- Position on common scale
- Position on unaligned scale
- Length (1D size)
- Tilt/angle
- Area (2D size)
- Depth (3D position)
- Color luminance
- Color saturation
- Curvature
- Volume (3D size)

**Identity Channels: Categorical Attributes**
- Spatial region
- Color hue
- Motion
- Shape

[Munzner (ill. Maguire), 2014]
Mark Types

- Can have marks for items and **links**
  - Connection => pairwise relationship
  - Containment => hierarchical relationship

**Marks as Items/Nodes**

- Points
- Lines
- Areas

**Marks as Links**

- Containment
- Connection

[Maguire (ill. Munzner), 2014]
Expressiveness and Effectiveness

- **Expressiveness Principle**: all data from the dataset and nothing more should be shown
  - Do encode ordered data in an ordered fashion
  - Don’t encode categorical data in a way that implies an ordering

- **Effectiveness Principle**: the most important attributes should be the most salient
  - Saliency: how noticeable something is
  - How do the channels we have discussed measure up?
Mackinlay's Ranking of Perceptual Tasks

 Quantitative
 Position
 Length
 Angle
 Slope
 Area
 Volume
 Density
 Color Saturation
 Color Hue
 Texture
 Connection
 Containment
 Shape

 Ordinal
 Position
 Density
 Color Saturation
 Color Hue
 Texture
 Connection
 Containment
 Length
 Angle
 Slope
 Area
 Volume

 Nominal
 Position
 Color Hue
 Texture
 Connection
 Containment
 Density
 Color Saturation
 Shape
 Length
 Angle
 Slope
 Area
 Volume

[Mackinlay, 1986]
# Properties and Best Uses of Visual Encodings

<table>
<thead>
<tr>
<th>Example</th>
<th>Encoding</th>
<th>Ordered</th>
<th>Useful values</th>
<th>Quantitative</th>
<th>Ordinal</th>
<th>Categorical</th>
<th>Relational</th>
</tr>
</thead>
<tbody>
<tr>
<td>position, placement</td>
<td>yes</td>
<td>infinite</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td></td>
</tr>
<tr>
<td>text labels</td>
<td>optional (alphabetical or numbered)</td>
<td>infinite</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td></td>
</tr>
<tr>
<td>length</td>
<td>yes</td>
<td>many</td>
<td>Good</td>
<td>Good</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>size, area</td>
<td>yes</td>
<td>many</td>
<td>Good</td>
<td>Good</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>angle</td>
<td>yes</td>
<td>medium/few</td>
<td>Good</td>
<td>Good</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pattern density</td>
<td>yes</td>
<td>few</td>
<td>Good</td>
<td>Good</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>weight, boldness</td>
<td>yes</td>
<td>few</td>
<td>Good</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>saturation, brightness</td>
<td>yes</td>
<td>few</td>
<td>Good</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>color</td>
<td>no</td>
<td>few (&lt; 20)</td>
<td>Good</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>shape, icon</td>
<td>no</td>
<td>medium</td>
<td>Good</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pattern texture</td>
<td>no</td>
<td>medium</td>
<td>Good</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>enclosure, connection</td>
<td>no</td>
<td>infinite</td>
<td>Good</td>
<td>Good</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>line pattern</td>
<td>no</td>
<td>few</td>
<td>Good</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>line endings</td>
<td>no</td>
<td>few</td>
<td>Good</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>line weight</td>
<td>yes</td>
<td>few</td>
<td>Good</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Noah Iliinsky • ComplexDiagrams.com/properties • 2012-06
How do we get these rankings?
Test % difference in length between elements

[Heer & Bostock, 2010]
Test % difference in **length** between elements

Answer: Left is \(~5.6x\) longer than Right

![Graph showing percentage difference in length between elements A and B.](image-url)
Test % difference in length between elements

[Heer & Bostock, 2010]
Test % difference in length between elements

[Heer & Bostock, 2010]
Test % difference in **length** between elements

![Diagram](modified-from-heer-bostock-2010)
Test % difference in **length** between elements

Answer: Right is 4x larger than Left

[Modified from Heer & Bostock, 2010]
Test % difference in area between elements

[Heer & Bostock, 2010]
Test % difference in area between elements

Answer: A is ~2.25x larger (in area) than B

[Heer & Bostock, 2010]
Test % difference in area between elements

[Heer & Bostock, 2010]
Test % difference in area between elements

Answer: B is ~6.1x larger (in area) than A
Test % difference in area between elements

[Heer & Bostock, 2010]
Test % difference in area between elements

Answer: B is ~2.5 larger (in area) than A

[Heer & Bostock, 2010]
Cleveland & McGill Experiments

Figure 4. Graphs from position–length experiment.

Figure 3. Graphs from position–angle experiment.

[Cleveland & McGill, 1984]
Heer & Bostock Experiments

- Rerun Cleveland & McGill’s experiment using Mechanical Turk
- … with more tests

Figure 2: Area judgment stimuli. Top left: Bubble chart (T7), Bottom left: Center-aligned rectangles (T8), Right: Treemap (T9).

[Heer & Bostock, 2010]
Results Summary

Cleveland & McGill’s Results

Crowdsourced Results

Positions
Rectangular areas (aligned or in a treemap)
Circular areas
Angles

[1.0 1.5 2.0 2.5 3.0]

Log Error

Log Error

1.0 1.5 2.0 2.5 3.0

1.0 1.5 2.0 2.5 3.0

1.0 1.5 2.0 2.5 3.0

[Munzner (ill. Maguire) based on Heer & Bostock, 2014]

D. Koop, DSC 530, Spring 2019
Psychophysics

• How do we perceive changes in stimuli
• The Psychophysical Power Law [Stevens, 1975]: All sensory channels follow a power function based on stimulus intensity ($S = I^n$)
• Length is fairly accurate
• Magnified vs. compressed sensations

Steven’s Psychophysical Power Law: $S = I^n$

[Munzner (ill. Maguire), 2014]
Ranking Channels by Effectiveness

**Magnitude Channels: Ordered Attributes**
- Position on common scale
- Position on unaligned scale
- Length (1D size)
- Tilt/angle
- Area (2D size)
- Depth (3D position)
- Color luminance
- Color saturation
- Curvature
- Volume (3D size)

**Identity Channels: Categorical Attributes**
- Spatial region
- Color hue
- Motion
- Shape

[Maguire, 2014]
Discriminability

What is problematic here?
Discriminability

• Can someone tell the difference?
• How many values (bins) can be used so that a person can tell the difference?
• Example: Line width
  - Matching a particular width with a legend
  - Comparing two widths
Separability

• Cannot treat all channels as independent!
• **Separable** means each individual channel can be distinguished
• **Integral** means the channels are perceived together

![Separability Diagram]

[Munzner (ill. Maguire) based on Ware, 2014]
Separable or Integral?
Separable or Integral?

The map at right is a product of overlaying the three sets of data. The variation in hue and value has been produced from the data shown above. In general, darker counties represent a more educated, better paid population while lighter areas represent communities with fewer graduates and lower incomes.
Visual Popout: Parallel Lines Require Search…

[Munzner (ill. Maguire), 2014]
Relative vs. Absolute Judgments

- Weber’s Law:
  - We judge based on relative not absolute differences
  - The amount of perceived difference depends on the object’s magnitude!
Luminance Perception

Edward H. Adelson

[E. H. Adelson, 1995]
Luminance Perception

[Edward H. Adelson, 1995]