CSE 512 - Data Visualization

Graphical Perception

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Design Principles  [Mackinlay 86]

Expressiveness
A set of facts is expressible in a visual language if the sentences (i.e. the visualizations) in the language express all the facts in the set of data, and only the facts in the data.

Effectiveness
A visualization is more effective than another visualization if the information conveyed by one visualization is more readily perceived than the information in the other visualization.
Design Principles Translated

Tell the truth and nothing but the truth (don’t lie, and don’t lie by omission)

Use encodings that people decode better (where better = faster and/or more accurate)
Effectiveness Rankings

**QUANTITATIVE**
- Position
- Length
- Angle
- Slope
- Area (Size)
- Volume
- Density (Value)
- Color Sat
- Color Hue
- Texture

**ORDINAL**
- Position
- Density (Value)
- Color Sat
- Color Hue
- Texture
- Connection
- Containment
- Length
- Angle
- Slope
- Area (Size)
- Volume

**NOMINAL**
- Position
- Color Hue
- Texture
- Connection
- Containment
- Density (Value)
- Color Sat
- Shape
- Length
- Angle
- Slope
- Area
- Volume

[Mackinlay 86]
Graphical Perception

The ability of viewers to interpret visual (graphical) encodings of information and thereby decode information in graphs.
Topics

Signal Detection
Magnitude Estimation
Using Multiple Visual Encodings
Pre-Attentive Processing
Gestalt Grouping
Change Blindness
A3 Submissions
Detection
Detecting Brightness

Which is brighter?
Detecting Brightness

Which is brighter?

(128, 128, 128)  (144, 144, 144)
Detecting Brightness

Which is brighter?
Detecting Brightness

(134, 134, 134)  
(128, 128, 128)  

Which is brighter?
Just Noticeable Difference (JND)

JND (Weber’s Law)

Perceived Change \[ \Delta S = k \frac{\Delta I}{I} \]

Scale Factor (Empirically Determined)

Ratios more important than magnitude

Change of Intensity

Physical Intensity

Most continuous variation in stimuli are perceived in discrete steps
Encoding Data with Color

Value is perceived as ordered
- Encode ordinal variables (O)

- Encode continuous variables (Q) [not as well]

Hue is normally perceived as unordered
- Encode nominal variables (N) using color
Steps in Font Size

Sizes standardized in 16\textsuperscript{th} century

\begin{center}
\begin{tabular}{cccccc}
6 & 7 & 8 & 9 & 10 & 11 \ 12 \ 14 \ 16 \ 18 \ 21 \ 24 \ 36 \ 48 \ 60 \ 72
\end{tabular}
\end{center}
Magnitude Estimation
A Quick Experiment...
Compare area of circles
Compare length of bars
Compare area of circles
Compare length of bars
Steven’s Power Law

Exponent (Empirically Determined)

\[ S = I^p \]

Perceived Sensation  Physical Intensity

Predicts bias, not necessarily accuracy!

[Graph from Wilkinson 99, based on Stevens 61]
## Exponents of Power Law

<table>
<thead>
<tr>
<th>Sensation</th>
<th>Exponent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loudness</td>
<td>0.6</td>
</tr>
<tr>
<td>Brightness</td>
<td>0.33</td>
</tr>
<tr>
<td>Smell (Coffee)</td>
<td>0.55</td>
</tr>
<tr>
<td>Smell (Heptane)</td>
<td>0.6</td>
</tr>
<tr>
<td>Temperature</td>
<td>1.0 (Cold) – 1.6 (Warm)</td>
</tr>
<tr>
<td>Taste (Saccharine)</td>
<td>0.6</td>
</tr>
<tr>
<td>Taste (Salt)</td>
<td>-1.3</td>
</tr>
<tr>
<td>Vibration</td>
<td>0.6 (250 Hz) – 0.95 (60 Hz)</td>
</tr>
<tr>
<td>Duration</td>
<td>1.1</td>
</tr>
<tr>
<td>Pressure</td>
<td>1.1</td>
</tr>
<tr>
<td>Heaviness</td>
<td>1.45</td>
</tr>
<tr>
<td>Electric Shock</td>
<td>3.5</td>
</tr>
</tbody>
</table>

[Psychophysics of Sensory Function, Stevens 61]
Apparent MagnitudeScaling

$S = 0.98A^{0.87}$ [from Flannery 71]
Graphical Perception  [Cleveland & McGill 84]
Figure 3. Graphs from position–angle experiment.
Figure 16. Log absolute error means and 95% confidence intervals for judgment types in position—length experiment (top) and position—angle experiment (bottom).
Graphical Perception Experiments
Empirical estimates of encoding effectiveness
Relative Magnitude Comparison

Most accurate:
- Position (common) scale
- Position (non-aligned) scale

Least accurate:
- Color hue-saturation-density
<table>
<thead>
<tr>
<th>QUANTITATIVE</th>
<th>ORDINAL</th>
<th>NOMINAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position</td>
<td>Position</td>
<td>Position</td>
</tr>
<tr>
<td>Length</td>
<td>Density (Value)</td>
<td>Color Hue</td>
</tr>
<tr>
<td>Angle</td>
<td>Color Sat</td>
<td>Texture</td>
</tr>
<tr>
<td>Slope</td>
<td>Color Hue</td>
<td>Connection</td>
</tr>
<tr>
<td>Area (Size)</td>
<td>Texture</td>
<td>Containment</td>
</tr>
<tr>
<td>Volume</td>
<td>Connection</td>
<td>Density (Value)</td>
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<tr>
<td>Density (Value)</td>
<td>Containment</td>
<td>Color Sat</td>
</tr>
<tr>
<td>Color Sat</td>
<td>Length</td>
<td>Shape</td>
</tr>
<tr>
<td>Color Hue</td>
<td>Angle</td>
<td>Length</td>
</tr>
<tr>
<td>Texture</td>
<td>Slope</td>
<td>Angle</td>
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<tr>
<td>Connection</td>
<td>Area (Size)</td>
<td>Slope</td>
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<tr>
<td>Containment</td>
<td>Volume</td>
<td>Area</td>
</tr>
<tr>
<td>Shape</td>
<td>Shape</td>
<td>Volume</td>
</tr>
</tbody>
</table>
Multiple Attributes
One-Dimensional: Lightness

White
White
Black
White
Black
White
White
Black
White
White
One-Dimensional: Shape

- Square
- Circle
- Circle
- Square
- Circle

- Square
- Circle
- Circle
- Square
- Circle

- Circle
- Circle
- Circle
- Circle
- Circle
Redundant: Shape & Lightness

Circle  Square  Circle  Square
Circle  Square  Circle  Square
Orthogonal: Shape & Lightness

Circle
Square
Square
Circle
Square
Speeded Classification

Redundancy Gain
Facilitation in reading one dimension when the other provides redundant information

Filtering Interference
Difficulty in ignoring one dimension while attending to the other
Speeded Classification

Response Time

Dimension Classified

Lightness

R 1 O

Shape

R 1 O

Interference

Gain
Types of Perceptual Dimensions

**Integral**
Filtering interference and redundancy gain

**Separable**
No interference or gain

**Asymmetric**
One dim separable from other, not vice versa

*Example*: The Stroop effect - color naming is influenced by word identity, but word naming is not influenced by color
Stroop Effect: What word?

blue
yellow
red
orange
green
purple
Stroop Effect: What color?

blue
yellow
red
orange
green
purple
Size and Value

W. S. Dobson, Visual information processing and cartographic communication: The role of redundant stimulus dimensions, 1983 (reprinted in MacEachren, 1995)
Orientation & Size

FIGURE 3.36. A map of temperature and precipitation using symbol size and orientation to represent data values on the two variables.

How well can you see temperature or precipitation? Is there a correlation between the two?

[MacEachren 95]
LENGTH & LENGTH

**FIGURE 3.38.** An example of the use of an ellipse as a map symbol in which the horizontal and vertical axes represent different (but presumably related) variables.

[MacEachren 95]
FIGURE 3.39. Bivariate map of NO$_3$ and SO$_4$ trends. The original Carr et al. version of this map used a wheel with eight spokes, rather than a simple dot, as the center of each glyph. When large enough, this added feature facilitates judgment of specific values. After Carr et al. (1992, Fig. 7a, p. 234). Adapted by permission of the American Congress on Surveying and Mapping.

[MacEachren 95]
Summary of Integral & Separable

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Integral</th>
<th>Separable</th>
</tr>
</thead>
<tbody>
<tr>
<td>red-green</td>
<td></td>
<td></td>
</tr>
<tr>
<td>yellow-blue</td>
<td></td>
<td></td>
</tr>
<tr>
<td>x-size</td>
<td></td>
<td></td>
</tr>
<tr>
<td>y-size</td>
<td></td>
<td></td>
</tr>
<tr>
<td>size</td>
<td></td>
<td></td>
</tr>
<tr>
<td>orientation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>color</td>
<td></td>
<td></td>
</tr>
<tr>
<td>shape</td>
<td></td>
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</tr>
<tr>
<td>color</td>
<td></td>
<td></td>
</tr>
<tr>
<td>motion</td>
<td></td>
<td></td>
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<tr>
<td>location</td>
<td></td>
<td></td>
</tr>
<tr>
<td>color</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

[Figure 5.25, Color Plate 10, Ware 2000]
**Set**

Each card has **4 features**:
- Color
- Symbol
- Number
- Shading/Texture

A set consists of 3 cards in which each feature is the SAME or DIFFERENT on each card.
Pre-Attentive Processing
How Many 3’s?

1281768756138976546984506985604982826762
9809858458224509856458945098450980943585
9091030209905959595772564675050678904567
8845789809821677654876364908560912949686

[based on a slide from J. Stasko]
How Many 3’s?

[based on a slide from J. Stasko]
Visual Pop-Out: Color

http://www.csc.ncsu.edu/faculty/healey/PP/index.html
Visual Pop-Out: Shape

http://www.csc.ncsu.edu/faculty/healey/PP/index.html
Feature Conjunctions

http://www.csc.ncsu.edu/faculty/healey/PP/index.html
Pre-Attentive Features

[Information Visualization. Figure 5. 5 Ware 04]
## More Pre-Attentive Features

<table>
<thead>
<tr>
<th>Feature</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line (blob) orientation</td>
<td>Julesz &amp; Bergen [1983]; Wolfe et al. [1992]</td>
</tr>
<tr>
<td>Length</td>
<td>Triesman &amp; Gormican [1988]</td>
</tr>
<tr>
<td>Width</td>
<td>Julesz [1985]</td>
</tr>
<tr>
<td>Size</td>
<td>Triesman &amp; Gelade [1980]</td>
</tr>
<tr>
<td>Curvature</td>
<td>Triesman &amp; Gormican [1988]</td>
</tr>
<tr>
<td>Number</td>
<td>Julesz [1985]; Trick &amp; Pylyshyn [1994]</td>
</tr>
<tr>
<td>Terminators</td>
<td>Julesz &amp; Bergen [1983]</td>
</tr>
<tr>
<td>Intersection</td>
<td>Julesz &amp; Bergen [1983]</td>
</tr>
<tr>
<td>Closure</td>
<td>Enns [1986]; Triesman &amp; Souther [1985]</td>
</tr>
<tr>
<td>Intensity</td>
<td>Beck et al. [1983]; Triesman &amp; Gormican [1988]</td>
</tr>
<tr>
<td>Flicker</td>
<td>Julesz [1971]</td>
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<tr>
<td>Direction of motion</td>
<td>Nakayama &amp; Silverman [1986]; Driver &amp; McLeod [1992]</td>
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<tr>
<td>Binocular lustre</td>
<td>Wolfe &amp; Franzel [1988]</td>
</tr>
<tr>
<td>Stereoscopic depth</td>
<td>Nakayama &amp; Silverman [1986]</td>
</tr>
<tr>
<td>3-D depth cues</td>
<td>Enns [1990]</td>
</tr>
<tr>
<td>Lighting direction</td>
<td>Enns [1990]</td>
</tr>
</tbody>
</table>
Pre-Attentive Conjunctions

Spatial conjunctions are often pre-attentive
- Motion and 3D disparity
- Motion and color
- Motion and shape
- 3D disparity and color
- 3D disparity and shape

But most conjunctions are NOT pre-attentive
Feature Integration Theory

Treisman’s feature integration model [Healey 04]

Feature maps for orientation & color [Green]
Gestalt Grouping
Gestalt Principles

Figure/Ground
Proximity
Similarity
Symmetry
Connectedness
Continuity
Closure
Common Fate
Transparency
Figure/Ground

Ambiguous

Principle of surroundedness

Principle of relative size

http://www.aber.ac.uk/media/Modules/MC10220/visper07.html
Figure/Ground

http://www.aber.ac.uk/media/Modules/MC10220/visper07.html
Proximity

[Ware 00]
Similarity

Rows dominate due to similarity [from Ware 04]
Symmetry

Bilateral symmetry gives strong sense of figure [from Ware 04]
Connectedness

Connectedness overrules proximity, size, color shape [from Ware 04]
Continuity

We prefer smooth not abrupt changes [from Ware 04]

Connections are clearer with smooth contours [from Ware 04]
Continuity: Vector Fields

Prefer field that shows smooth continuous contours [from Ware 04]
Continuity: Vector Fields

 Prefer field that shows smooth continuous contours [from Ware 04]
Closure

We see a circle behind a rectangle, not a broken circle [from Ware 04]

Illusory contours [from Durand 02]
Common Fate

Dots moving together are grouped
Transparency

Requires continuity and proper color correspondence [from Ware 04]
Change Blindness
Change Blindness
Change Blindness
Change Blindness
Change Blindness
Change Blindness

[Example from Palmer 99, originally due to Rock]
Demonstrations

http://www.psych.ubc.ca/~rensink/flicker/download/

http://www.youtube.com/watch?v=Ahg6qcgoay4
Summary

Choosing effective visual encodings requires knowledge of visual perception.

**Visual features/attributes**
Individual attributes often pre-attentive
Multiple attributes may be separable or integral

**Gestalt principles** provide high-level guidelines

We don’t always see everything that is there!
A3 Peer Evals - due Mon 5/13

Visualization Design
Choice of visual encodings (expressive, effective?)
Is the appropriate information visible by default?

Interaction Design
Choice of interaction techniques
Do they enhance understanding of the data?
Usability, discoverability, performance

Overall Design Quality
Organization, legibility, fitness for chosen goals