Perception

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CS 294-10: Visualization
Spring 2010

Assignment 2: Visualization Design

Due before class on Feb 8, 2010

Data and Image Models

Nominal, ordinal and quantitative

N - Nominal (labels)
- Operations: =, ≠

O - Ordered
- Operations: =, ≠, <, >, ≥, ≤

Q - Interval (Location of zero arbitrary)
- Operations: =, ≠, <, >, ≤, ≥
- Can measure distances or spans

Q - Ratio (zero fixed)
- Operations: =, ≠, <, >, ≤, ≥, ÷, –
- Can measure ratios or proportions

S. S. Stevens. On the theory of scales of measurements. 1946
Visual variables

- Position
- Size
- Length
- Area
- Volume
- Value
- Texture
- Color
- Orientation
- Shape

Note: Bertin does not consider 3D or time
Note: Card and Mackinlay extend the number of vars.

Automated Design
Jock Mackinlay’s APT 86

Combinatorics of encodings

Challenge:
Pick the best encoding from the exponential number of possibilities \((n+1)^3\)

Principle of Consistency:
The properties of the image (visual variables) should match the properties of the data

Principle of Importance Ordering:
Encode the most important information in the most effective way
Mackinlay’s criteria

**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.

Subject of perception lecture

Mackinlay’s ranking

<table>
<thead>
<tr>
<th>Quantitative</th>
<th>Ordinal</th>
<th>Nominal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position</td>
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Conjectured effectiveness of the encoding

Mackinlay’s design algorithm

- User formally specifies data model and type
- APT searches over design space
  - Tests expressiveness of each visual encoding
  - Generates image for encodings that pass test
  - Tests perceptual effectiveness of resulting image
- Outputs most effective visualization

[Mackinlay, APT, 1986]
Perception

Mackinlay's ranking of encodings

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<th>QUANTITATIVE</th>
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Detection

Detecting brightness

Which is brighter?
Detecting brightness

Which is brighter?

(128, 128, 128)  
(144, 144, 144)

Just noticeable difference

JND (Weber’s Law)

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

- Ratios more important than magnitude
- Most continuous variations in stimuli are perceived in discrete steps

Steps in font size

Sizes standardized in 16th century

Steps in line width

[based on slide from Munzner]
Estimating Magnitude

Steven’s power law

\[ S = I^p \]

- \( p < 1 \): underestimate
- \( p > 1 \): overestimate

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>Taste</td>
<td>0.6 (Saccharine)</td>
</tr>
<tr>
<td>Taste</td>
<td>1.3 (Salt)</td>
</tr>
<tr>
<td>Temperature</td>
<td>1.0 (Cold) – 1.6 (Warm)</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>
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[Psychophysics of Sensory Function, Stevens 61]

[graph from Wilkinson 99, based on Stevens 61]
Apparent magnitude scaling

\[ S = 0.98A^{0.87} \]  
(from Flannery 71)

Proportional symbol map

Newspaper Circulation

[Cartography: Thematic Map Design, Figure 8.8, p. 172, Dent, 96]

Graduated sphere map

Cleveland and McGill
Relative magnitude estimation

<table>
<thead>
<tr>
<th>Most accurate</th>
<th>Position (common) scale</th>
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| Least accurate | Color hue-saturation-density |
Mackinlay’s ranking of encodings

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Conjectured effectiveness of visual encodings

Pre-attentive vs. Attentive

How many 3’s

1281768756138976546984506985604982826762
980989458224509856459945098450980943585
9091030209905959595772564675050678904567
8845789809821677654876364908560912949686

[based on slide from Stasko]
Visual pop-out: Color

[Image: http://www.csc.ncsu.edu/faculty/healey/PP/index.html]

Visual pop-out: Shape

[Image: http://www.csc.ncsu.edu/faculty/healey/PP/index.html]

Feature conjunctions

[Image: http://www.csc.ncsu.edu/faculty/healey/PP/index.html]

Preattentive features

[Image: Information Visualization. Figure 5. 5 Ware 04]
More preattentive features

- Line (blob) orientation: Julesz & Bergen (1983), Wolfe et al. (1992)
- Length: Triesman & Gormican (1988)
- Width: Julesz (1985)
- Size: Triesman & Gelade (1980)
- Curvature: Triesman & Gormican (1988)
- Number: Julesz (1985), Triesman & Pypylsyn (1994)
- Terminators: Julesz & Bergen (1983)
- Intersection: Julesz & Bergen (1983)
- Flicker: Julesz (1970)
- Binocular lustre: Wolfe & Franzel (1988)
- Stereoscopic depth: Nakayama & Silverman (1986)
- 3-D depth cues: Enns (1990)
- Lighting direction: Enns (1990)

Preattentive conjunctions

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

Most conjunctions are not preattentive

Feature-integration theory

Treisman’s feature integration model [Healey04]

Multiple Attributes
One-dimensional: Lightness

White  Black  White  Black
White  Black  White  White

One-dimensional: Shape

Square  Circle  Circle  Square
Circle  Circle  Circle  Circle

Correlated dims: Shape or lightness

Circle  Square  Square  Circle
Square  Square  Square  Circle

Orthogonal dims: Shape & lightness

Circle  Square  Square  Circle
**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

**Types of dimensions**

- **Integral**
  - Filtering interference and redundancy gain

- **Separable**
  - No interference or gain

- **Configural**
  - Only interference, but no redundancy gain

- **Asymmetrical**
  - One dimension separable from other, not vice versa
    - Stroop effect – Color naming influenced by word identity, but word naming not influenced by color

**Correlated dims: Size and value**

W. S. Dobson, Visual information processing and cartographic communication: The role of redundant stimulus dimensions, 1983 (reprinted in MacEachren, 1995)
Othogonal dims: Aspect ratio

Summary of Integral-Separable

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.

Adrien Treuille’s applet

http://www.cs.washington.edu/homes/treuille/resc/set