Graphical Perception

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

Which best encodes quantities?

Position
Length
Area
Volume
Value (Brightness)
Color Hue
Orientation (Angle)
Shape
Mackinlay’s ranking of encodings

<table>
<thead>
<tr>
<th>QUANTITATIVE</th>
<th>ORDINAL</th>
<th>NOMINAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position</td>
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<tr>
<td>Length</td>
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Topics

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

Detecting Brightness

Which is brighter?
Detecting Brightness

Which is brighter?

Detecting Brightness

Which is brighter?
**Just Noticeable Difference**

JND (Weber’s Law)
\[ \Delta S = k \frac{\Delta I}{I} \]

Ratios more important than magnitude
Most continuous variation in stimuli perceived in discrete steps

**Information in color and value**

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

Hue is normally perceived as unordered
∴ Encode nominal variables (N) using color

**Steps in font size**

Sizes standardized in 16th century

```
6 7 8 9 10 11 12 14 16 18 21 24 36 48 60 72
```

**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>
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<tbody>
<tr>
<td>Loudness</td>
<td>0.6</td>
</tr>
<tr>
<td>Brightness</td>
<td>0.33</td>
</tr>
<tr>
<td>Smell</td>
<td>0.55 (Coffee) - 0.6 (Heptane)</td>
</tr>
<tr>
<td>Taste</td>
<td>0.6 (Saccharine) - 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>
</tr>
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</table>

[Psychophysics of Sensory Function, Stevens 61]

**Apparent magnitude scaling**

\[ S = 0.98A^{1.07} \]

[Cartography: Thematic Map Design, Figure 8.6, p. 170, Dent, 96]

[graph from Wilkinson 99, based on Stevens 61]
Proportional symbol map

Newspaper Circulation

Graduated sphere map

Cleveland and McGill

Figure 4. Graphs from position—length experiment.

[Cleveland and McGill 84]
Relative magnitude estimation

Mackinlay’s ranking of encodings

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Administrivia

Assignment 1
Scores and comments will be returned shortly

Assignment 2: Visual Data Analysis
Use visualization software (Tableau) to form & answer questions
First steps:
- Step 1: Pick a domain
- Step 2: Pose questions
- Step 3: Find Data
- Iterate
Create visualizations
- Interact with data
- Refine your questions
Make wiki notebook
- Keep record of your analysis
- Prepare a final graphic and caption
Due by end of day on Monday, October 12
**Protovis Tutorial**

Creating interactive visualizations in JavaScript using the Protovis framework (protovis.org)

**Friday October 9, 4-5:30pm**
**104 Gates**
Led by Mike Bostock

**Next Week (10/12 & 10/14)**

Jeff and Mike will be attending VisWeek.

**Mon 10/12:** Color
Guest lecturer: Jason Chuang, Stanford CS

**Wed 10/14:** Flash/Flare Tutorial
Tutorial leader: Jason Chuang, Stanford CS

**Pre-attentive vs. Attentive Visual Processing**

**How many 3’s**

1281768756138976546984506985604982826762
9809858458224509856458945098450980943585
9091030209905959595772564675050678904567
8845789809821677654876364908560912949686

[based on slide from Stasko]
How many 3’s

128176875613976546984506985604982826762980985845822450985645894509845098094398590910320990595955772564675050678045678845789809821677654876364908560912949686

[based on slide from 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

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

Most conjunctions are not pre-attentive

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>Triesman &amp; Gormican (1988)</td>
</tr>
<tr>
<td>Flicker</td>
<td>Julesz (1971)</td>
</tr>
<tr>
<td>Direction of motion</td>
<td>Nakayama &amp; Silverman (1986), Driver &amp; McLeod (1992)</td>
</tr>
<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>

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

Feature-integration theory

Treisman’s feature integration model [Healey 04]
Multiple Attributes

One-dimensional: Lightness

- White
- Black

One-dimensional: Shape

- Circle
- Square

Correlated dims: Shape or lightness

- Circle
- Square

Orthogonal dims: Shape & lightness

- 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

Types of Dimensions

- Integral: Filtering interference and redundancy gain
- Separable: No interference or gain
- Configural: Interference, “condensation”, no redundancy gain
- Asymmetrical: 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
Size and Value

Orientation and Size (Single Mark)

Shape and Size (Single Mark)

Length and Length (Single Mark)
**Angle and Angle** (Composed Marks)

![Image](https://example.com/angle_angle_composed_marks.png)

*MacEachren 95*

---

**Summary of Integral-Separable**

![Image](https://example.com/integral_separable.png)

*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.

![Image](https://example.com/set_cards.png)

Adrien Treuille’s applet

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

---

**Gestalt Grouping**

![Image](https://example.com/gestalt_grouping.png)
Principles

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

Figure/Ground

Principle of surroundedness

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

Figure/Ground

Ambiguous
Unambiguous (?)

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**

- 

**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

[http://coe.sdsu.edu/eet/articles/visualperc1/start.htm](http://coe.sdsu.edu/eet/articles/visualperc1/start.htm)

**Transparency**

- Requires continuity and proper color correspondence [from Ware 04]
Layering and Small Multiples

Layering: Gridlines

Signal and background compete above, as an electrocardiogram trace-line becomes caught up in a thick grid. Below, the screened-down grid stays behind traces from each of 12 monitoring leads.

Electrocardiogram tracelines [from Tufte 90]

Layering: Gridlines

Stravinsky score [from Tufte 90]

Layering: color and line width

IBM Series III Copier [from Tufte 90]
Small Multiples

Change Blindness

[Figure 2.11, p. 38, MacEachren 95]

Change Blindness

[Example from Palmer 99, originally due to Rock]

Change detection
Change detection

Demonstrations

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

Summary

Choosing effective visual encodings requires knowledge of visual perception

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

Gestalt principles provide high-level guidelines
We don’t always see everything that is there