Information Visualization: Visual and Perceptual Principles

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InfoVis

Computer Graphics

HCI

Human Perception

Color Theory

Psychoogy
Perceptual Principles

Human perception
- Important role in Visualization
- Understanding of perception can improve visualization

Information visualization uses *perception* to amplify cognition

Preattentive Processing

Gestalt Laws

Change Blindness

Use of Color
Perceptual Processing

Design visual information to be efficiently perceivable – quick, unambiguous

Need to understand how human visual perception and information processing works

Perception science related to:

- Physiology: study the physical, biochemical and information processing functions of living organisms
- Cognitive psychology: studying internal mental processes
  - how do people learn, understand, solve problems with regard to sensory information?
Model of Perceptual Processing 1

Numerous other models exist

Simplified 3-stage model: many subsystems involved in human vision

Stage 1 – rapid parallel processing to extract low level properties of a visual scene

- Detection of shape, spatial attributes, orientation, color, texture, movement
- Billions of Neurons work in parallel, extracting information simultaneously
- Occurs automatically, independent of focus
- Information is transitory (though briefly held in a short lived visual buffer)
- Often called “preattentive” processing
Model of Perceptual Processing 2

Stage 2 – pull out structures via pattern perception
- Visual field is divided in simple patterns: e.g. continuous contours, regions of the same color / texture
- Object recognition
- Slower serial processing

Stage 3 – sequential goal-directed processing
- Information is further reduced to a few objects held in visual working memory
- Used to answer and construct visual queries
- Attention-driven - forms the basis for visual thinking
- Interfaces to other subsystems:
  - Verbal linguistic: connection of words and images
  - Perception-for-action: motor system to control muscle movement
Preattentive Processing

Limited set of visual properties are detected rapidly

200 – 250 milliseconds

If a decision takes a fixed amount of time regardless of the number of distracters, it is considered to be preattentive.
Color

We can preattentively spot red circle.
Shape

We can preattentively spot blue square.
Conjunction Search

Looking for a red circle, not possible preattentively.

[Healey]
Color and Shape

It is easy to perceive color boundary,

It is not easy to perceive shape boundary!

[Healey]
Color and Shape
Few More Examples

Perception in Visualization,
Christopher G. Healey,
http://www.csc.ncsu.edu/faculty/healey/PP
Preattentive Processing Conclusions

Experiments used to identify following tasks as preattentive:

- Target detection
- Boundary detection
- Region Tracking
- Counting and Estimation

We can use those features to draw attention in visualization

Careful design necessary

Beware of interference and hierarchy (color and shape, e.g.)
Gestalt Laws

1912 – Gestalt school of psychology

Germany: M. Westheimer, K. Koffka, W. Kohler

Proximity, Similarity, Connectedness, Continuity

Principles of pattern recognition

Originally proposed theory – wrong

Rules are still useful!
Gestalt Laws

1912 – Gestalt school of psychology

Germany: M. Westheimer, K. Koffka, W. Kohler

Proximity, Similarity, Connectedness, Continuity, Area
Gestalt Laws

1912 – Gestalt school of psychology

Germany: M. Westheimer, K. Koffka, W. Kohler

Proximity, Similarity, Connectedness, Continuity Area
Gestalt Laws

1912 – Gestalt school of psychology

Germany: M. Westheimer, K. Koffka, W. Kohler

Proximity, Similarity, Connectedness, Continuity
Gestalt Laws Continuity

smooth not abrupt change overrules proximity

[ Hearst Washington ]
Gestalt Laws Area

Smaller components of a pattern tend to be perceived as an object

White propeller and black propeller

[Andreas Butz]
Change Blindness

videos

Cycle continues for 60 s or until observer responds

[Ron Rensink]
Selective Attention

Video Door

Video Cards
The use of color

Edward Tufte:

“...avoiding catastrophe becomes the first principle in bringing color to information: Above all, do no harm. “


Color selection can

- Enhance and clarify visualization
- Obscure and confuse
Contrast and Analogy

Contrast – attention (different colors)

Analogy – grouping (similar colors)
Hue, Chroma, Value
Hue, Value, Chroma
Hue, Value, Chroma

[Image of color samples: Hue, Tint, Tone, Shade, (Hue + White), (Hue + Black), (Hue + Black + White)]

[Maureen Stone]
Contrast 1
Contrast 2
Guidelines 1

Modesty! Less is more

Use just a few hue values

Use blue in large regions, not thin lines

Use red and green in the center of the field of view (edges of retina not sensitive to these)

Use black, white, yellow in periphery

Use adjacent colors that vary in hue & value

Use bright background

Do not use red and green together (color blind people)
Guidelines 1

Avoid red and green together

Here’s how it looks if you’re colorblind
Tufte Guidelines 1

Pure, bright or very strong colors have loud, unbearable effects when they stand unrelieved over large areas adjacent to each other, but extraordinary effects can be achieved when they are used sparingly on or between dull background tones.

The placing of light, bright colors mixed with white next to each other usually produces unpleasant results, especially if the colors are used for large areas.

A grand strategy is to use colors found in nature, especially those on the lighter side, such as blues, yellows, and grays of sky and shadow.

[Tufte: ENVISIONING INFORMATION]
Large area background or base-colors should do their work most quietly, allowing the smaller, bright areas to stand out most vividly, if the former are muted, grayish or neutral.

If a picture is composed of two or more large, enclosed areas in different colors, then the picture falls apart. Unity will be maintained, however, if the colors of one area are repeatedly intermingled in the other, if the colors are interwoven carpet-fashion throughout the other.
Guidelines 2

Use existing pallets, e.g.:

Colorbrewer
- http://colorbrewer2.org/

Tableau
Guidelines:

Use existing pallets, Colorbrewer (http://colorbrewer2.org/), e.g.
Guidelines 2

Tableau 10 Variations

<table>
<thead>
<tr>
<th>Tableau 10</th>
<th>Tableau 10 Light</th>
<th>Tableau 10 Medium</th>
</tr>
</thead>
<tbody>
<tr>
<td>31.119 180</td>
<td>174.199 232</td>
<td>114.158 206</td>
</tr>
<tr>
<td>255.127 14</td>
<td>255.187 120</td>
<td>255.150 74</td>
</tr>
<tr>
<td>44.160 44</td>
<td>152.223 138</td>
<td>103.191 92</td>
</tr>
<tr>
<td>214.39 40</td>
<td>255.152 150</td>
<td>237.102 93</td>
</tr>
<tr>
<td>148.103 189</td>
<td>197.176 213</td>
<td>173.139 201</td>
</tr>
</tbody>
</table>

These are the colors from the palette, without decoration.

Tableau 10 Bordered

<table>
<thead>
<tr>
<th>Tableau 10 Bordered</th>
<th>Tableau 10 Light bordered</th>
<th>Tableau 10 Medium border</th>
</tr>
</thead>
<tbody>
<tr>
<td>31.119 180</td>
<td>174.199 232</td>
<td>114.158 206</td>
</tr>
<tr>
<td>255.127 14</td>
<td>255.187 120</td>
<td>255.150 74</td>
</tr>
<tr>
<td>44.160 44</td>
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<td>103.191 92</td>
</tr>
<tr>
<td>214.39 40</td>
<td>255.152 150</td>
<td>237.102 93</td>
</tr>
<tr>
<td>148.103 189</td>
<td>197.176 213</td>
<td>173.139 201</td>
</tr>
</tbody>
</table>

The colors above have borders, making them visually more like the palette.
Selecting Semantically-Resonant Colors for Data Visualization

S. Lin, J. Fortuna, C. Kulkarni, M. Stoney, J. Heer – EuroVis 2013
Selecting Semantically-Resonant Colors for Data Visualization

S. Lin, J. Fortuna, C. Kulkarni, M. Stoney, J. Heer – EuroVis
Data and InfoVis

Data

Raw Data ➔ Data Tables

Data Transformations
Raw Data

Documents → Words → Word Vectors

Other units:
- Sentence
- Paragraph
- Section
- Chapter
- Characters
- Pictures

Meaning

Jock Mackinlay’s Slide
Raw Data Issues

Errors

Variable formats

Missing data

Variable types

Table Structure

| Document | D1 | D2 | D3 | ...
|----------|----|----|----|-----
| TUWIEN   | 1  | 0  | 0  |     |
| UNIWIEN  | 0  | 1  | 0  |     |
| about    | 1  | 0  | 1  |     |
| ...      | ...| ...| ...|     |

| TUWIEN | D1, ...
|--------|--------
| UNIWIEN| D2, ...
| about  | D1, D3,
| ...    | ...

[ Jock Mackinlay]
Data Transformations

Process of converting Raw Data into Data Tables.

Used to build and improve Data Tables
Data Tables

Data Tables:
- Cases/Items
- Variables
  - Nominal
  - Quantitative
  - Ordinal
- Values
- Metadata

<table>
<thead>
<tr>
<th>Name</th>
<th>N</th>
<th>Anna</th>
<th>Hans</th>
<th>Peter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>Q</td>
<td>17</td>
<td>46</td>
<td>15</td>
</tr>
<tr>
<td>ID</td>
<td>O</td>
<td>11111</td>
<td>22222</td>
<td>33333</td>
</tr>
</tbody>
</table>
Data Tables

INPUT

Row data: movements and check-ins, more than 25 millions of entries:

2014-6-06 08:00:59, 903769, check-in, 99, 77
2014-6-06 08:00:59, 1696241, check-in, 99, 77
2014-6-06 08:01:03, 531348, movement, 64, 97
2014-6-06 08:01:04, 179386, movement, 64, 97
...
Data Tables

**PROCESS**

Semi-automatic
Data processing:

1. Match coordinates to the facilities using the map
2. Create a record for each unique ID containing:
   a. events and trajectories
   b. basic scalars: rides count, moves count, ...
   c. time series: distance travelled, ...
Data Tables

**FINAL DATA**

Final data (2 out of 11 374 rows):

<table>
<thead>
<tr>
<th>USER ID</th>
<th>TRAJECTORY</th>
<th>RIDES COUNT</th>
<th>MOVE COUNT</th>
<th>DISTANCE (T)</th>
</tr>
</thead>
<tbody>
<tr>
<td>scalar</td>
<td>complex</td>
<td>scalar</td>
<td>scalar</td>
<td>complex</td>
</tr>
<tr>
<td>903769</td>
<td><img src="image1.png" alt="Image" /></td>
<td>30</td>
<td>1345</td>
<td><img src="graph1.png" alt="Graph" /></td>
</tr>
<tr>
<td>1696241</td>
<td><img src="image2.png" alt="Image" /></td>
<td>42</td>
<td>1987</td>
<td><img src="graph2.png" alt="Graph" /></td>
</tr>
</tbody>
</table>
Data Transformations

Values $\rightarrow$ Derived Values

Structure $\rightarrow$ Derived Structure

Values $\rightarrow$ Derived Structure

Structure $\rightarrow$ Derived Values

<table>
<thead>
<tr>
<th>Derived value</th>
<th>Derived structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>Sort</td>
</tr>
<tr>
<td>Class</td>
<td>Class</td>
</tr>
<tr>
<td>Promote</td>
<td>Promote</td>
</tr>
<tr>
<td>Demote</td>
<td>X,Y,Z$\rightarrow$P</td>
</tr>
<tr>
<td></td>
<td>xzy</td>
</tr>
</tbody>
</table>
Visual Mappings

Expressiveness

Effectiveness
Visual Mappings

Spatial Substrate (Type of Axes)
- Nominal (categorical)
- Ordinal (categorical)
- Quantitative (numerical)

Marks
- Type: Point, Line, Area, Volume
- Connection and Enclosure

Axes Location
- Composition
- Overloading
- Folding
- Recursion
Axes Location

Composition

Overloading

Folding

Recursion
## Use of Color, Size, and Value

<table>
<thead>
<tr>
<th></th>
<th>Size</th>
<th>Color</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal</td>
<td>in some cases</td>
<td><img src="#" alt="Color" /></td>
<td><img src="#" alt="Value" /></td>
</tr>
<tr>
<td>Ordinal</td>
<td><img src="#" alt="Size" /></td>
<td><img src="#" alt="Color" /></td>
<td><img src="#" alt="Value" /></td>
</tr>
<tr>
<td>Quantitative</td>
<td><img src="#" alt="Size" /></td>
<td><img src="#" alt="Color" /></td>
<td><img src="#" alt="Value" /></td>
</tr>
</tbody>
</table>
Wrong choice 1
Wrong choice 2
Accuracy Ranking

Accuracy Ranking of Quantitative Perceptual Tasks
Estimated; only pairwise comparisons have been validated
(Mackinlay 88 from Cleveland & McGill)
Visual Structures

Classification by use of space:

- **1D, 2D, 3D**
  - Refers to visualizations that encode information by positioning marks on **orthogonal axes**

- **Multivariable >3D**
  - Data Tables have so many variables that orthogonal Visual Structures are not sufficient
  - Multiple Axes, Complex Axes

- **Trees**
- **Networks**
1D Visual Structures

Linear data types
- text documents, program source code, alphabetical lists, etc.

Typically used for documents and timelines, particularly as part of a larger Visual Structure

Example:
- TileBars
1D Visual Structures – pie chart

Very often used

Very often criticized in visualization

Should be used very carefully and only if:

- Parts make up a meaningful whole
- Parts are mutually exclusive
- Parts are compared to the whole, not to each other
- There are just a few parts (not more than ~7)
1D Visual Structures – pie chart
1D Visual Structures – pie chart
1D Visual Structures – histogram, box plot

Each dimension (column in the table) can be visualized as 1D data

Histogram, Bar Chart, Box-Plot
2D Visual Structures

Chart, geographic data

Document collections

Example:
- 2D scattered plot
1D - 2D Visual Structures - Scaling

Dangerous use of 2D (3D) structures for 1D data

Scaling an area by two sides at the same time leads to a quadratic effect for a linear change.

Beware of area/volume

Florence Nightingale 1858 coxcomb chart the numbers of soldiers corresponds to the area, not the radius, of the circle segments.
Banks: Market Cap

- Market Value as of January 20\textsuperscript{th} 2009, $Bn
- Market Value as of Q2 2007, $Bn

From: http://www.perceptualedge.com/

While JPMorgan considers this information to be reliable, we cannot guarantee its accuracy or completeness.

Source: Bloomberg, Jan 20\textsuperscript{th} 2009
Declines in Bank Market Values Since the Financial Crisis Began

Loss from Qtr 2, 2007 to Jan 20, 2009

From: http://www.perceptualedge.com/

Among major banks, J.P. Morgan had the second least percentage decline in market value.
3D Visual Structures

Usually represent real world objects

3D Physical Data
- E.g., VoxelMan

3D Abstract Data
- E.g., Themescapes
Thank you!

Special thanks for used materials to M. E. Gröller
H. Hauser, S. Miksch, and colleagues from VRVis!