Perception and Design

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Based on slides from John Stasko, GTECH
Disclaimer

I am not a psychologist

A general understanding of these perceptual issues is still important for Information Visualization

For Information Visualization specific discussion, see Information Visualization, Perception for Design by Colin Ware

Relevant Courses: PSY 340, 442
Visual Encoding Principles

Visual encoding requires that we choose marks and the properties of those marks that we will drive with the data (sometimes those properties are called channels, retinal variables, visual variables, etc.)

Marks: points, lines, areas
Channels: Position, Color, Size, Orientation and Shape
Visual Perception

Sensation

Stimulus

Sensory Organ

Perceptual Organ

Rapid processing = Preattentive Processing
Fast than 10 ms per item

Iconic ( < 1 s)
Short Term (~3s)
Long Term
We study perception because we need to be aware of the strengths and limitations of the perceptual system and draw upon them when choosing our encodings.
Preattentive Processing or “Pop Out”

• A very limited set of visual properties are detected very rapidly and accurately by the low-level visual system

• Only certain things are processed preattentively!
  – Can we take advantage of these??
Preattentive Processing

How many 5’s do you see?

01993004768202084373593884790981123804998
98739847597893974983229384729134095093004
80387609901128048304994864509928293764529
90304784739902720384784576373890283899029
Preattentive Processing

How many 5’s do you see?

01993004768202084373593884790981123804998
98739847597893974983229384729134095093004
80387609901128048304994864509928293764529
90304784739902720384784576373890283899029
Color is Preattentively Processed

When a target is given a hue that is different from the distractors (non-targets), it can be preattentively located

Note: Preattentive processing typically requires that the target have only one distinct characteristic that is different
# Preattentive Attributes

<table>
<thead>
<tr>
<th>Form</th>
<th>Orientation</th>
<th>Line Colinearity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Line length</td>
<td>Spatial Grouping</td>
</tr>
<tr>
<td></td>
<td>Line Width</td>
<td>Blur</td>
</tr>
<tr>
<td></td>
<td>Size</td>
<td>Numerosity</td>
</tr>
<tr>
<td></td>
<td>Shape</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Curvature</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Added Marks</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Enclosure</td>
<td></td>
</tr>
<tr>
<td>Color</td>
<td>Hue</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Intensity</td>
<td></td>
</tr>
<tr>
<td>Spatial Position</td>
<td>2D Position</td>
<td>Stereoscopic Depth</td>
</tr>
<tr>
<td></td>
<td>Convex/concave</td>
<td>Shape from shading</td>
</tr>
<tr>
<td>Motion</td>
<td>Flicker</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Direction</td>
<td></td>
</tr>
</tbody>
</table>
Examples of Preattentive Attributes

Ware pg. 153

Not preattentive
What Kinds of Tasks Are Emenable to Preattentive Processing

Target detection
  Is something there?

Boundary detection
  Can the elements be grouped?

Region Tracking
  Track one or more elements with a unique visual feature

Counting
  How many elements of a certain type are present?
Example: Is there a red circle?

Images courtesy of Christopher Healey (http://www.csc.ncsu.edu/faculty/healey/PP/index.html)
Example: Is there a red circle?
Example: Is there a red circle?

Images courtesy of Christopher Healey
(http://www.csc.ncsu.edu/faculty/healey/PP/index.html)

Conjunctive targets normally not preattentively detected
Examples: Find the boundary
Find the Boundary

not preattentively processed
Preattentive Attribute Demos

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

All of the major channels commonly used in visual encoding do support popout individually, but not in combination with each other.

How can we take advantage of this information?

We know what pops out...BUT...what is good for conveying VALUES for various types of data?
Bertin’s Guidance 1967

The marks are perceived as PROPORTIONAL to each other

The marks can be perceived as SIMILAR

The marks are perceived as DIFFERENT, forming families

The marks are perceived as ORDERED

The marks are perceived as PROPORTIONAL to each other

Size

Value

Texture

Colour

Orientation

Shape

R.A. Metoyer
Cleveland and McGill 1984

Accuracy of judgement of quantity

- Position
- Length
- Angle
- Slope
- Area
- Volume
- Colour
- Density

Most accurate

Least accurate
Mackinlay’s Ranking 1986

Quantitative
- Position
- Length
- Angle
- Slope
- Area
- Volume
- Density
- Shape

Ordinal
- Position
- Density
- Colour saturation
- Colour hue
- Texture
- Connection
- Containment
- Length
- Angle
- Slope
- Area
- Volume

Categorical
- Position
- Colour hue
- Texture
- Connection
- Containment
- Density
- Colour saturation
- Shape
- Length
- Angle
- Slope
- Area
- Volume
Gestalt Principles - 1912

Gestalt theory describes how the mind organizes visual data

Original goal: how we perceive pattern, form, organization

6 Gestalt Principles

Visual attributes that incline us to \textit{group} the objects that we see in particular ways

<table>
<thead>
<tr>
<th>Proximity</th>
<th>Similarity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enclosure</td>
<td>Closure</td>
</tr>
<tr>
<td>Continuity</td>
<td>Connection</td>
</tr>
</tbody>
</table>
Gestalt Principles: Proximity
Gestalt Principles: Similarity

We group together objects similar in size, shape, color, and orientation
Gestalt Principles: Enclosure

Slide courtesy of John Stasko
Gestalt Principle: Closure
Gestalt Principle: Continuity

- blah A
- blah B
- blah C
- blah C
- blah C
- blah E
Gestalt Principle: Connection

- Connection refers to the way elements are linked together in a visual composition.
Channels and Marks: Types and Ranks

Ordered: Ordinal/Quantitative

- How much
  - position on common scale
  - position on unaligned scale
  - length (1D size)
  - tilt/angle
  - area (2D size)
  - curvature
  - volume (3D size)
  - lightness (black/white)
  - color saturation
  - stipple density

Categorical

- What
  - region
  - color hue
  - shape
  - stipple pattern

Marks as Items/Nodes

- points
- lines
- areas

Marks as Links

- containment (area)
- connection (line)
How Capacity Limits of Attention Influence Information Visualization Effectiveness

Steve Haroz and David Whitney

Fig. 1. These images each have one colored square that is unique within that image. How long does it take you to find each? How many color categories are there in each panel? Why does grouping make both tasks substantially easier?

Abstract—In this paper, we explore how the capacity limits of attention influence the effectiveness of information visualizations. We conducted a series of experiments to test how visual features (e.g., color vs. motion), layout, and variety of visual encodings impacted user performance. The experiments tested users’ abilities to (1) determine if a specified target is on the screen, (2) detect an odd-ball, distractor target, different from the other visible objects, and (3) gain a qualitative overview by judging the number of unique categories on the screen. Our results show that the severe capacity limits of attention strongly modulate the effectiveness of information visualizations, particularly the ability to detect unexpected information. Keeping in mind these capacity limits, we conclude with a set of design guidelines which depend on a visualization’s intended use.

Index Terms—Perception, attention, color, motion, user study, nominal axes, layout, goal-oriented design.

1 INTRODUCTION
An information visualization designer aims to present the maximum amount of data without overwhelming the user with complexity and information-overload. The components arranged to form a GUI or visualization are visual features—the properties of any image that the brain is capable of encoding and integrating into a coherent percept [1]. Examples that apply to visualization include position, color, size, orientation, texture [2], and motion [3–5]. The designer’s role is to effectively associate these visual features with corresponding dimensions or categories in the underlying data [6].

Unfortunately, the speed and capacity of human attention for these visual features are severely limited [7, 8] and these limits may influence the effectiveness of information visualizations. Exceeding the limits of visual attention markedly impacts both the accuracy and timing of one’s response to a visual scene (Fig. 1). This consequence may seem intuitive (e.g., the benefit of grouping in Fig. 1 might seem obvious), however visualizations often violate or ignore this intuition in part because it has not been formalized or empirically tested in visualization-related tasks. Characterizing and measuring these limitations in the context of data visualization is therefore fundamental and necessary to achieve the goal of conveying information via the human visual system.

Using a visualization should provide information or more broadly compared with serially inspecting the raw data in the form of a table or database [9]. A perceptual hindrance that restricts a user to serially inspecting each visualized element rather than enabling a rapid summary perception of the whole scene would make the visualization function better than a simple table. It is therefore critical to understand how the capacity limits of attention impact various visualization tasks.

To study the effect of these limits, we tested the effect of two types of arrangements or layouts on user performance in visual search and subtituting (or rapid counting [10]) experiments. We also examined how performance in these experiments is influenced by user goals and the variety of a visualization’s visual features. To measure maximum performance, the experiments all had subjects fully attending to one task as opposed to dividing attention with a peripheral display [11].

We conducted three experiments with the similar stimuli that used either colored or moving features. Each experiment’s task, however, corresponded to a different, commonly performed visualization task:
- Detect a unique target with a known appearance (e.g., find the red object)
- Detect a unique target with an unknown appearance (e.g., find a unique or oddball target)
- Determine and compare the number of visual categories (e.g., determine extent of heterogeneity or consistency)

The latter two tasks are of particular interest, as performing them by browsing a table or running a database query is difficult. For example, finding the hour of the day that you receive the most or
How Capacity Limits of Attention Influence Information Visualization Effectiveness

Specific goal: understanding how the capacity limits of attention impact various tasks

InfoVis Guidelines based on experimental results
Experimental Design: The Tasks

Visual Search: Find a Known Target
Visual Search: Find the Oddball
Subitizing: Counting

Encodings: Color and Motion

The target has the property (color), the distractors may have many different values
InfoVis Guidelines

6.1 Grouping greatly helps for some tasks
   For Known target, grouping doesn’t help
   For Oddball, it helped for colors and motion
   For Subitizing, it helped for colors

6.2 If you can’t group, change the task

6.3 When there are too many categories, “less is more”

6.4 Assigning visual features to data dimensions
   Different features have different capacities
   (e.g. may not work on ‘angle’)

Oregon State University
Interaction & Perception

Human perception and cognition also has implications for how we design interaction – i.e. the dynamic aspects of a visualization.
Change Blindness

An interruption in what is being seen (eye blink, saccade, blank screen, etc.) renders us blind to a change in the scene.
Change Blindness Effect

- The **inability** to detect changes to an object or scene
- [http://www.csc.ncsu.edu/faculty/healey/PP/movies/Airplane.gif](http://www.csc.ncsu.edu/faculty/healey/PP/movies/Airplane.gif)

[slides 35 – 53 courtesy of Mei-Ching Lien]
Why Is It Difficult to Notice The Change?

Under normal conditions...

- if something changes, our visual system picks up this signal (transient detection signal)
Why Is It Difficult to Notice The Change?

Under normal conditions...

- if something changes, our visual system picks up this signal (transient detection signal)

Without the transient detection signal, it’s very difficult to detect the change
Another Example
What has changed in the next slide?
What has changed?
Normal Condition
Transient Detection
Side-By-Side
Why Is It Difficult to Notice The Change?

Under normal conditions...

- if something changes, our visual system picks up this signal (transient detection signal)

Without the transient detection signal, it’s very difficult to detect the change

The brain makes the assumption that objects do not change unexpectedly
Design Implications

Don’t mask changes (ie. a *view* change in conjunction with a mark change)
Give them duration – won’t be missed by a blink (physical masking!)
Important: pay close attention to task and do not make any noise!

One more…
How many passes did you count?

How many of you saw the gorilla?
Selective Attention

- Many observers failed to detect the unexpected event (selective looking)
Implication

Don’t divert attention from important aspects of the visualization

Make one change at a time

Bring attention to changes
Blindness Summary

Making changes (change blindness)
  Give it duration
  Don’t mask it

Don’t distract (inattentinal blindness)
Bring attention to the change