Chapter 2 - Visual Perception
Optimizing Information Visualization regarding the human visual system

Vorlesung „Informationsvisualisierung”
Prof. Dr. Florian Alt, WS 2016/17

Konzept und Folien (5th revised edition):
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Outline

• Definition & Context
• Preattentive Processing
• Gestalt Theory
• Data encoding
  – glyphs
  – color
• Visual Memory
• Summary
Definition and Context
Perceptual Processing

• Perception (from Latin perceptio, percipio)
• Process of attaining awareness or understanding of the environment by organizing and interpreting sensory information
• Involves signals in the nervous system, which result from physical stimulation of the sense organs
• Senses:
  – Vision involves light striking the retinas of the eyes
  – Smell is mediated by odor molecules
  – Hearing involves pressure waves
Perceptual Processing

• “Perception is our window to the world that enables us to experience what is out there in our environment. Thus, perception is the first step in the process that eventually results in all of our cognitions. Paying attention, forming and recalling memories, using language, and reasoning and solving problems all depend - right at the beginning - on perception. Without perception, these processes would be absent or greatly degraded. Therefore it is accurate to say that perception is the gateway to cognition.”

[Goldstein, 2005]
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

• 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 (cognitive) focus
  – Information is transitory (though briefly held in a short-lived visual buffer)
  – Often called “preattentive” processing
Model of Perceptual Processing

• **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
Model of Perceptual Processing

Image taken from Ware 2001
Example

• Route between the two letters?

• Stage 1:
  – automatic parallel extraction of colors, shapes, position etc.

• Stage 2:
  – Pattern finding of black contours (lines) between two symbols (letters)

• Stage 3:
  – Few objects are held in working memory at a time
  – Identify path sequentially (formulate new visual query)

• In this lecture we will focus on aspects related to stage 1 & 2 of the model
Another Example

2007 Sales Revenue
(U.S. dollars in thousands)

<table>
<thead>
<tr>
<th></th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
<th>Oct</th>
<th>Nov</th>
<th>Dec</th>
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<td>2,593</td>
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<td>2,838</td>
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<td>2,938</td>
<td>2,739</td>
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<td>International</td>
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<td>673</td>
<td>593</td>
<td>644</td>
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<td>$2,557</td>
<td>$2,979</td>
<td>$3,266</td>
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<td>$3,218</td>
<td>$3,517</td>
<td>$2,975</td>
<td>$2,773</td>
<td>$3,537</td>
<td>$3,322</td>
<td>$3,585</td>
<td>$4,183</td>
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</table>

2007 Sales Revenue

USD (thousands)
Another Example

- Domestic sales were much higher than international sales throughout the year.

- Domestic sales trended upward during the course of the year as a whole while international sales remained relatively flat.

- The month of August was an exception to otherwise relatively consistent sales in the international market. (Perhaps most of this company’s international customers are Europeans who were on vacation in August.)

- Domestic sales exhibited a monthly pattern of up, up, down, which repeated itself quarterly (“hockey stick”).
Pre-Attentive Processing
Preattentive Processing

• A limited set of basic visual properties are processed preattentively
• Information that “pops out”
• Parallel processing by the low-level visual system (Stage 1 in the model)
• Occurs prior to conscious attention
• Important for designing effective visualizations
  – What features can be perceived rapidly?
  – Which properties are good discriminators?
  – What can mislead viewers?
  – How to design information such that it pops out?
Example: Find the 3s
Example: Find the 3s
Feature Integration Theory

• Anne Treisman
  – Original researcher in the field of preattentive processing
  – Princeton University, Department of Psychology

• Treisman studied two major problems:
  – Determination of which visual properties are detected preattentively
  – Formulation of a hypothesis about how the visual system performs preattentive processing

• Experiments using target and boundary detection for preattentive feature classification
  – Measuring of preattentive task performance by
    • Response time
    • Accuracy
Feature Integration Theory

• Measurement of response time
  – Viewers asked to answer the task (target detection) as fast as possible by having a high level of accuracy
  – Number of distractors increased for the scenes

• If response time is relatively constant and below a given threshold, task is considered preattentive.
  – Otherwise viewers must apply search strategies to confirm or reject the presence or absence of a target.
  – Increased number of distractors would increase time taken to answer the task
Feature Integration Theory

• Measurement of accuracy
  – Represented for a small, fixed exposure duration, then removed
  – Number of distractors is varied for each stimulus
  – If viewer answers task correctly, feature used to define the target is called preattentive
  – Exposure duration threshold 200-250 msec, because viewers can only have „one look“ at the stimulus

• Treisman collected a list of visual features that are detected preattentively
  – Some features are asymmetric
    • Sloped line between many vertical lines detected preattentively
    • Vertical line between many sloped lines NOT detected preattentively

• Effect of types of background distractors
Color: Hue

- Is there a red circle present in the image?

Color is preattentively processed!

Images taken from http://www.csc.ncsu.edu/faculty/healey/PP/index.html
Form: Shape

• Is there a red circle present in the image?

Shape is preattentively processed!

Images taken from http://www.csc.ncsu.edu/faculty/healey/PP/index.html
Color & Form

• Is there a red circle present in the image?

Conjunction of 2 properties is usually not preattentive!

Images taken from http://www.csc.ncsu.edu/faculty/healey/PP/index.html
Conjunction Search

• A target with a **unique** visual property (e.g., shape OR color) “pops out”

• **Conjunction** target is made up of non-unique features
  – Requires a time-consuming serial search, e.g.
    – For every red colored item: is it a circle?
    – For every circular item: is it red?

• Many studies showed that most conjunction targets cannot be detected preattentively
Color & Form

• Exploiting low-level visual processes in a visualization
• Attention can be drawn to areas of potential interest in a display.
• Data-feature mapping must take advantage of visual system strengths
  – Well-designed to the viewer’s analysis and tasks at hand
  – No visual interference effects that consequently hide information or make them hard to locate by conjunction search
Boundary Detection

• Do items form a boundary? If yes, based on which attribute(s)?

Preattentive: grouping by hue

Conjunction search: grouping by hue and shape

Images taken from http://www.csc.ncsu.edu/faculty/healey/PP/index.html
Preattentive Processing

• Form: Orientation

Images taken from http://www.csc.ncsu.edu/faculty/healey/PP/index.html
Preattentive Processing

- Form: Length / Width

Images taken from http://www.csc.ncsu.edu/faculty/healey/PP/index.html
Preattentive Processing

• Form: Closure

Images taken from http://www.csc.ncsu.edu/faculty/healey/PP/index.html
Preattentive Processing

- Form: Curvature

Images taken from http://www.csc.ncsu.edu/faculty/healey/PP/index.html
Preattentive Processing

• Form: Spatial Grouping

Images taken from http://www.csc.ncsu.edu/faculty/healey/PP/index.html
Preattentive Processing

• Spatial Position: 3D Depth

Images taken from http://www.csc.ncsu.edu/faculty/healey/PP/index.html
Preattentive Processing

- Color: Luminance / Intensity

Images taken from http://www.csc.ncsu.edu/faculty/healey/PP/index.html
Common Pre-attentive Properties

<table>
<thead>
<tr>
<th>Group</th>
<th>Attribute</th>
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<tr>
<td>Form</td>
<td>Length</td>
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<tr>
<td></td>
<td>Width</td>
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<tr>
<td></td>
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<tr>
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<tr>
<td>Shape</td>
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<tr>
<td>Curvature</td>
<td></td>
</tr>
<tr>
<td>Enclosure</td>
<td></td>
</tr>
<tr>
<td>Spatial Grouping</td>
<td></td>
</tr>
<tr>
<td>Blur</td>
<td></td>
</tr>
<tr>
<td>Color</td>
<td>Hue</td>
</tr>
<tr>
<td></td>
<td>Intensity</td>
</tr>
<tr>
<td>Spatial Position</td>
<td>2-D Position</td>
</tr>
<tr>
<td>Motion</td>
<td>Direction</td>
</tr>
</tbody>
</table>
Examples
Examples

• Visualization encodes product sales and marketing expense
• What if we need to see the relationship of profits to both sales revenues and marketing expenses?

• What pre-attentive visual attribute could we assign to each data point to encode profit?
Examples

• Visualization encodes product sales and marketing expense
• What if we need to see the relationship of profits to both sales revenues and marketing expenses?
Gestalt Theory
Cognition and Gestalt Laws

• See „Digitale Medien“, Chapter 3a (typography)
• Recap: step 2 of the visual information processing model – pattern and object recognition using the raw data collected in step 1
• Based on which visual properties do we structure the data?
• Gestalt school of psychology, founded in 1912, formulated Gestalt laws
• “The whole is other than the sum of parts.” (Koffka 1935)
• Laws still useful today, but not the neural mechanisms proposed
Cognition and Gestalt Laws

• Key principles of Gestalt theory
  – Emergence (Hervortreten)
  – Reification (Verdinglichung)
  – Multistability (Multistabilität)
  – Invariance (Beständigkeit)
  – Grouping (Gruppierung)
Emergence
Emergence

• The process of complex pattern formation from simpler rules

• Demonstrated by the perception of the black and white picture of a Dalmatian dog sniffing the ground in the shade of overhanging trees

• The dog is not recognized by first identifying its parts (feet, ears, nose, tail, etc.), and then inferring the dog from those component parts.

• Instead, the dog is perceived as a whole, all at once.
Emergence - Another Example
Reification

• Constructive or generative aspect of perception, by which the experienced percept contains more explicit spatial information than the sensory stimulus on which it is based.

• Triangle perceived in picture A, although no triangle has actually been drawn. In B and D the eye will recognize disparate shapes as "belonging" to a single shape, in C a complete three-dimensional shape is seen, where in actuality no such thing is drawn.

• Reification explained by progress in the study of illusory contours, which are treated by the visual system as "real" contours.
Multistability

• Multistability (or multistable perception) is the tendency of ambiguous perceptual experiences to pop back and forth unstably between two or more alternative interpretations.

• Examples are the Necker cube, Rubin's Vase illusion, the three-legged blivet, and artist M. C. Escher's artwork and the appearance of flashing marquee lights moving first one direction and then suddenly the other.

• Gestalt does not explain how images appear multistable, only that they do.
Invariance

• Property of perception whereby simple geometrical objects are recognized independent of rotation, translation, and scale

• Also other variations such as elastic deformations, different lighting, and different component features.

• Example: Captchas
Principles of Grouping

• Law of Proximity
• Law of Similarity
• Law of Closure
• Law of Good Continuation
• Law of Common Fate
• Law of Good Form
Law of Proximity

• Columns or rows?
• Small difference in spacing causes change in perception
• Use proximity to emphasize between display items
• To which group (top / bottom) does the x dot belong? Spacing is equal for both groups!
• Spatial concentration principle: we group regions of similar element density (Slocum 1983)
Law of Similarity

- Rows or columns?
- Similar elements tend to be grouped together
- Perception lends itself to seeing stimuli that physically resemble each other as part of the same object, and stimuli that are different as part of a different object.
- Allows for people to distinguish between adjacent and overlapping objects based on their visual texture and resemblance.
- Other stimuli that have different features are generally not perceived as part of the object.
- Our brain uses similarity to distinguish between objects who may lay adjacent to or overlap with each other based upon their visual texture.
Law of Closure

• Mind’s tendency to see complete figures or forms even if a picture is incomplete, partially hidden by other objects, or if part of the information needed to make a complete picture in our minds is missing.

• For example, if part of a shape’s border is missing people still tend to see the shape as completely enclosed by the border and ignore the gaps.

• This reaction stems from our mind’s natural tendency to recognize patterns that are familiar to us and thus fill in any information that may be missing.

• Closure is also thought to have evolved from ancestral survival instincts in that if one was to partially see a predator their mind would automatically complete the picture and know that it was a time to react to potential danger even if not all the necessary information was readily available.
Law of Good Continuation

- Palmer & Rock 1994
- Potentially more powerful organizing principle than proximity, color, size, shape

Example: node-link diagram
Law of Common Fate

• Visual elements moving in the same direction at the same velocity perceived as one large object
• Visual system very sensible to moving objects even when other details are obscured.
• Law of common fate is used in user-interface design (movement of a physical mouse synchronised with the movement of mouse cursor)
• Example taken from: http://tepsserver.ucsd.edu/~jlevin/gp/time-example-common-fate/