Information Visualization:
Introducing Research Need & Concepts

Vorlesung „Informationsvisualisierung”
Prof. Dr. Florian Alt, WS 2013/14

Konzept und Folien (4th revised edition):
Thorsten Büring, Andreas Butz, Michael Burch
Lecture Outline

1 Introduction
2 Perception
3 Multidimensional I
4 Multidimensional II
5 Interaction
6 Graphs & Networks
7 Hierarchies & Trees
8 Time-Based Data
9 Text & Document
10 Presentation I
11 Presentation II
12 AmbientInfoVis
Outline of today‘s lecture

• Motivation
• Visualization History (19th century - today)
  – Napoleon’s March to Moscow
  – Diagram of the Causes of Mortality
  – Death from Cholera
  – London Underground Map
• Definitions & InfoVis Goals and Challenges
• Bad vs. Good Design
  – The Lie Factor
  – Chart Junk
• Visualization Process
Good vs. Bad Design
Good vs. Bad Design - The Lie Factor

• Tufte 2001
  – “The representation of numbers, as physically measured on the surface of the graphic itself, should be directly proportional to the quantities represented.” [Tufte, 1983]
  – …defined as the ratio of the size of an effect shown in the graphic to the size of the effect in the data

\[
\text{Lie Factor} = \frac{\text{Size of effect in represented graphic}}{\text{Size of actual effect in data}}
\]
Good vs. Bad Design - The Lie Factor

- Magnitude of change mpg: 53%
- Magnitude of the change of line size: 783%
- Lie factor = 14.8
Good vs. Bad Design - The Lie Factor

• Lie by area: varying both dimensions simultaneously for change in 1D data (Tufte 2001)

Lie factor: 2.8

Lie factor: area of barrels: 9.4
Volume of barrels: 59.4
Good vs. Bad Design - Chart Junk

• Chart junk

  – “Chart junk refers to all visual elements in charts and graphs that are not necessary to comprehend the information represented on the graph, or that distract the viewer from this information.” [Tufte, 1983]

  – “The interior decoration of graphics generates a lot of ink that does not tell the viewer anything new. The purpose of decoration varies — to make the graphic appear more scientific and precise, to enliven the display, to give the designer an opportunity to exercise artistic skills. Regardless of its cause, it is all non-data-ink or redundant data-ink, and it is often chart junk.” [Tufte, 1983]
Visualization Process
InfoVis Reference Model

- Raw table to data table: filtering, data cleaning
- Data table to visual structures: pick mappings
- Visual structures to views: viewpoints, distortion etc.

Card et al. 1999

Diagram:

```
Data
  ^ Data Tables
    | Visual Structures
    v
Views
```

**Raw Data:** idiosyncratic formats
**Data Tables:** relations (cases by variables) + meta-data
**Visual Structures:** spatial substrates + marks + graphical properties
**Views:** graphical parameters (position, scaling, clipping, …)
Visualization Pipeline

1. **Data Analysis**: Data is prepared for visualization (e.g., by applying a smoothing filter, interpolating missing values, or correcting erroneous measurements). This is usually computer-centered, little or no user interaction.

2. **Filtering**: Selection of data portions to be visualized. This is usually user-centered.

3. **Mapping**: Focus data is mapped to geometric primitives (e.g., points, lines) and their attributes (e.g., color, position, size). This is the most critical step for achieving expressiveness and effectiveness.

4. **Rendering**: Geometric data are transformed to image data.
Visual Encoding

• The process of mapping data to visual variables is called visual mapping. Choosing different visual variables for representing different aspects of the same information can greatly influence the perception and understanding of the presented information. It is therefore important to know and appropriately use the characteristics of visual variables when creating any visual data representation.
Visual Encoding (more in next lecture)

• (used by Mackinlay, 1986, for quantitative data)

Figure 14: Accuracy Ranking of Quantitative Perceptual Tasks. Higher tasks are accomplished more accurately than lower tasks. Cleveland and McGill empirically verified the basic properties of this ranking.
Visual Encoding

- Visual Variables are a specified set of symbols that can be applied to data in order to translate information.
- Bertin defined seven different Visual Variables.

![Bertin's Original Visual Variables](http://www.infovis-wiki.net/images/8/89/VisualVariables.png)
Visualization Resource Limitations

• Technological and algorithmic limitations
  – Computational capacities
    • Is there an efficient algorithm?
  – Display capacities
    • How many objects can be rendered?

• Human limitations
  – Perceptual capacities
    • How many colors can be distinguished?
  – Cognitive capacities
    • How much can be remembered?
Commercial InfoVis Systems

- Tableau Software http://www.tableausoftware.com/
- Spotfire (Tibco): http://spotfire.tibco.com/index.cfm
- InfoZoom (Siemens): http://www.infozoom.com/deu/infozoom/video.htm
  - Applet: http://download.macrofocus.com/infoscope/
- Advizor Analyst: http://www.advizorsolutions.com/desktop.htm
- D3.js: http://d3js.org/
Visualcomplexity.com

- Webpage Visualcomplexity collects data visualizations
Chapter 2 - Visual Perception
Optimizing Information Visualization regarding the human visual system

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Outline

• Definition & Context
• Preattentive Processing
• Visual Memory
• Gestalt Theory
• Data encoding
  – glyphs
  – color
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.

- For example, vision involves light striking the retinas of the eyes, smell is mediated by odor molecules and 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

Image taken from Ware 2001
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
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
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

142416496357598475921765968474891728482
285958819829450968504850695847612124044
074674898985171495969124567659608020860
608365416496457590643980479248576960781
285960799918712845268101495969124567781
874241649645757659608149596912456701285
960799164964575127879918712845298496912
223591649645759588198250963576596080596
Example: Find the 3s
Preattentive Processing

• How does the human visual system analyze images?
• Important result: Discovery of a limited set of visual properties that are detected very rapidly by low-level and fast-acting visual processes.
• Initially called „Preattentive“
• We do not need focused attention.
• BUT: Attention plays a critical role even at this early stage of vision.
• Term „Preattentive“ also used today
Theories of Preattentive Processing

• Feature integration theory
• Guided search theory
• Similarity theory
• Textons theory
• Boolean maps theory
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
Preattentive Processing

- Performing tasks on large multi-element displays in less than 200-250 msec considered preattentive
- Eye movements take at least 200 msec to initiate
- Certain information on the display seen in parallel by low-level visual processes
Color

• Is there a red circle present in the image?

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

• 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
Shape

• Is there a red circle present in the image?

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

• Is there a red circle present in the image?

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

- 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?
Color & Shape

• Visual system has no unique visual property to search for the target location
• Search for red elements sees red squares
• Search for circular elements sees blue circles
• Many studies showed that most conjunction targets cannot be detected preattentively
• Time-consuming serial search must be performed to confirm display or absence
Color & Shape

• 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)?

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

• Line orientation

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

- Length / Width

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

• Closure

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

• Curvature

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

- Density / Contrast

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

• Luminance

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

- Intersection

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

• Terminators

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

- 3D Depth

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

- Form
  - Line orientation
  - Line length
  - Line width
  - Size
  - Curvature
  - Shape
  - Spatial grouping

- Color
  - Hue
  - Intensity
  - Motion
  - Flicker
  - Direction of motion
  - Spatial Position
  - 2D position
  - Stereoscopic depth
  - Convexity / Concavity

Images taken from http://www.csc.ncsu.edu/faculty/healey/PP/index.html
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 greater 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
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.
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 (Slocum1983)
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
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://tepserver.ucsd.edu/~jlevin/gp/time-example-common-fate/](http://tepserver.ucsd.edu/~jlevin/gp/time-example-common-fate/)
Visual Memory
Visual Memory

• Preattentive Processing asks: „What visual elements pop out from the display and put our focus of attention to a special region on screen?“

• Also important question: „What is remembered about a visual element when we look at a different region on screen?“
Visual Memory

• Example: old style aircraft altimeter
  – Thinnest hand indicates number of tens of thousands of feet
  – Next larger hand number of thousands of feet
  – Quick glance after interruption results in misinterpretation if the change in the display is not noticed
  – Difference of ten thousand feet

• Phenomenon: inability to detect changes in visual scenes
  – mid-eye movement
  – mid-blink
  – Flicker (short blanking of screen)
  – Gradual change
Visual Memory

• Postattentive amnesia
• Change blindness
• Inattentional blindness
• Memory-guided search
• Attentional blink

• Finding out what we remember when we inspect a visualization is important when designing effective diagrams.
Postattentive Amnesia

- Study by Jeremy Wolfe
  - Telling a viewer the target before showing him the scene

- Showing a viewer the scene then telling him the target
Postattentive Amnesia

• Which experiment performs better?
  – Assumption: Seeing the scene first then the description helps for detecting the target and performs better.
  – Wolfe‘s study results: Assumption not true!
  – No additional information is „saved“ in the visual system after focus of attention is put to new visual elements
Change Blindness

- Defined as "the difficulty in detecting changes in scenes."
- Signification of attention (or lack thereof) is very crucial in determining change in a picture, scene, or environment.
- Study by Ronald Rensink
  - Results: pictures must be alternated from one to the other several times until participants were able to detect the difference.
  - When a cue was added indicating where particular changes are in the picture, participants performed faster.
- Psychophysics research
  - A short interruption in a scene may make a viewer blind to significant differences in the scene during the interruption.
CB: Flicker Example 1

http://www.csc.ncsu.edu/faculty/healey/PP/index.html
CB: Flicker Example 2

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

• Related to change blindness
  – Viewers can totally fail to perceive visual elements or activities
  – Caused by an absence of attention to the unseen object
  – Clear evidence of the importance of attention for perceiving.

• Important experiments
  – Invisible gorilla test (Daniel Simons and Christopher Chabris)
  – Workmen with door (Daniel Simons and Daniel Levin)
  – Color changing card trick
Curious Psychology #1
Inattentional Blindness

• Participants of a study were found unable to detect a change from one person to another in mid-conversation (Simson & Levin 1998)

• Sample principle: insensitivity to changes of objects in movie scenes interrupted by a cut (Levin & Simons 1997)

• Various examples: http://viscog.beckman.uiuc.edu/djs_lab/demos.html

• Problem related to the short-lived visual buffer and the very limited capacity of our visual working memory

• Need to emphasize changes

• In some applications changes may be distracting, e.g. ambient information visualization -> utilize CB
Inattentional Blindness

Recognition is primed by expectation

- http://www.youtube.com/watch?v=kjtSfTCrMm4&feature=related
Summary

• It is not enough to simply show something.
• We need to pay attention when and how it is shown.
• Otherwise people might miss it or take forever to find it.

• Apply your knowledge about perception to check whether your visualizations are effective!
Data Encoding
Characteristics of Visual Properties

• Some properties possess intrinsic meaning
  – Density with Grayscale: the darker the more
  – Size / Length / Area: the larger the more
  – Position: depending on culture, in Europe the leftmost / topmost are first
  – Color: depending on culture, e.g. white associated with death in Japan

• Accuracy of representations for quantitative measures (empirically verified by Cleveland & McGill, 1985)