3 Information Visualization

3.1 Motivation and Examples
3.2 Basics of Human Perception
3.3 Principles and Concepts
3.4 Standard Techniques for Visualization
3.5 Further Examples

Literature:
• Marti Hearst
  – http://bailando.sims.berkeley.edu/talks/chi03-tutorial.ppt
• Margret-Anne Storey
Visualization Reference Model

- Raw Data → Data Table filtering
- Data Table → Visual Structure pick mappings
- Visual Structure → Views probes, viewpoints, distortions

Raw Data: idiosyncratic formats
Data Tables: relations (cases by variables) + metadata
Visual Structures: spatial substrates + marks + graphical properties
Views: graphical parameters (position, scaling, clipping,...)

(Storey, 2004)
Types of Data

• Entities
  – Objects of interest

• Relationships
  – Form structures that relate entities
  – Many kinds of relationships exist
    » Is-part-of, is-kind-of, is-xyx-to, …

• Attributes of entities or relationships
  – Attribute vs. Independent information (entity)
  – Attribute is variable of a certain value type

• Operations
  – Actions can also be considered as data

• Metadata
  – Data about data
Basic Attribute Value Types

• Nominal (qualitative)
  – No inherent order (but can be tested for equality =)
  – Examples: City names, types of diseases, kind of fruit, ...

• Ordinal (qualitative)
  – Ordered (can be tested for <, >), but not at measurable intervals
  – Sequencing things, ranking
  – Examples: first, second, third, …; cold, warm, hot

• Nominal/Interval (quantitative)
  – Integer or real numbers
  – Ordered (can be tested for <, >)
  – Arithmetical operations, ratios are possible
  – Interval data: Derivation of gaps (e.g. time between departure and arrival)
  – Examples: Size and population of countries, schedule times, numeric grades

Hearst, 2003
Attribute Dimensions

- All kinds of tensors may appear as attribute values
- Tensor rank 0: Scalar
  - E.g. mass, temperature, length, price
- Tensor rank 1: Vector
  - E.g. force, momentum, location, direction
- Tensor rank 2: Matrix
  - E.g. linear transformation
- …
Mapping to Visual Structures

- Mapping from data tables to visual structures is
  - *expressive*
    if all data in the table (and only this information) are presented in the structure
  - *efficient*
    if the visual representation is easier to interpret for humans, can convey more distinctions or leads to fewer errors

(Storey, 2004)
Visual Structure

• Spatial substrate
  – Fixed number of dimensions
  – Inherently perceptual

• Axes
  – Unstructured axis
  – Nominal axis (division into subregions)
  – Ordinal axis (order has meaning)
  – Quantitative axis (metric associated with region)

• Graphical marks
  – Visible things that occur in space

(based on Storey, 2004)
Graphical Marks

• Four elementary types:
  – Points (0D)
  – Lines (1D)
  – Areas (2D)
  – Volumes (3D)

• In practice, marks need more dimensions than in theory
  – E.g. Points can be seen only if painted as areas

(based on Storey, 2004)
Mapping Examples

(assume 2-dimensional representations)

• Two scalars:
  – Price vs. top speed of cars

• Ordinal and scalar:
  – Max. price vs. brand of cars

• Ordinal and vector:
  – Price range vs. brand of cars

• Vector and scalar:
  – Location vs. average temperature

• Vector and vector:
  – Location vs. temperature range
Example: FilmFinder

- Witches of Eastwick, The
  - Director: Miller, George
  - Year: 1987
  - Country: USA
  - Language: English
  - Actors:
    - Nicholson, Jack
    - Jenkins, Richard
    - Joakim, Keith
    - Struyker, Carel
  - Actresses:
    - Cher
    - Sarandon, Susan
    - Pfeiffer, Michelle
    - Cartwright, Veronica

- Film Finder Interface
  - Title:
    - ALL
  - Actor:
    - ALL
  - Actress:
    - Pfeiffer, Michelle
  - Director:
    - Miller, George
  - Year of Production:
    - 1960-1995
  - Length:
    - 231 minutes
  - Ratings:
    - G
    - PG
    - PG-13
    - R
  - Films Shown:
    - 210
**View Transformations**

- Ability to interactively modify and augment visual Structures
  - Turning static presentations into visualizations
- Time is exploited to display more information
  - Dynamic Visualizations exist in space time
- Three common view transformations:
  1. Location probes: use location to reveal additional info
  2. Viewpoint controls: zoom, pan, clip the viewpoint
  3. Distortion: focus + context view
Example: View Transformations in Google Maps
Example: Interactive Graphs

http://www.cs.cmu.edu/~sage
Accuracy Ranking of Perceptual Tasks

Fig. 15. Ranking of perceptual tasks. The tasks shown in the gray boxes are not relevant to these types of data.

Mackinlay 88
Interpretations of Visual Properties

• Some properties have intrinsic meaning
  (Senay & Ingatious 97, Kosslyn, others)
  – Density (Greyscale)
    Darker -> More
  – Size / Length / Area
    Larger -> More
  – Position
    Leftmost -> first, Topmost -> first

• Some properties do not have intrinsic meaning, even some perceived quite accurately
  – Hue
    ??? no intrinsic meaning
  – Slope
    ??? no intrinsic meaning

Hearst, 2003
Color Schemes (1)

Order these (low->hi)

Hearst, 2003
Color Schemes (2)

- Gray scale
- Full spectral scale
- Single sequence part spectral scale
- Single sequence single hue scale
- Double-ended multiple hue scale

Hearst, 2003
Using Color

• Call attention to specific items
• Distinguish between classes of items
  – Increases the number of dimensions for encoding
• Increase the appeal of the visualization
• Proceed with caution
  – Less is more
  – Representing magnitude is tricky
• Examples
  – **Red**-orange-yellow-white
    » Works for cost
  – **Green**-light green-light brown-dark brown-grey-white works for atlases
  – **Grayscale** is unambiguous but has limited range

Hearst, 2003
Continuity

- Experience tells that visual elements are more likely to be continuous
- Implied connection
- Connections are used to show relations
Symmetry

- Symmetrical to emphasize relationship
Figure, Background, Transparency, Overlap

- What is foreground and what is background?
- Transparency is perceived only when good continuity and color correspondence exists.
- Visual interference in overlapping textures
Principles of Graphical Excellence (E. Tufte)

• Graphical excellence
  – The well-designed presentation of interesting data – a matter of substance, of statistics, and of design
    » consists of complex ideas communicated with clarity, precision and efficiency
    » is that which gives to the viewer the greatest number of ideas in the shortest time with the least ink in the smallest space
    » requires telling the truth about the data.

Hearst, 2003
Tufte Principle

Data ink = ink used for representing data
Chart ink = ink used for extra elements different from data
Avoid “chart junk”! Maximize the data-ink ratio:

Data-ink ratio = \frac{\text{data ink}}{\text{total ink used in graphic}}

Hearst, 2003
Tufte’s Graphical Integrity

- Some lapses intentional, some not

\[
\text{Lie Factor} = \frac{\text{size of effect in graph}}{\text{size of effect in data}}
\]

- Misleading uses of area
- Misleading uses of perspective
- Leaving out important context
- Lack of taste and aesthetics

Hearst, 2003
Lie factor

\[ \text{lie factor} = \frac{\text{size of effect shown in graph}}{\text{size of effect in data}} \]

where

\[ \text{size of effect} = \frac{|\text{second value} - \text{first value}|}{\text{first value}} \]

A lie factor that is either much higher or much lower than one is bad. A high lie factor \textit{exaggerates} differences between values. A low lie factor \textit{obscures} differences between values.

A common example of a high lie factor occurs when both dimensions of a two-dimensional figure are made proportional to the same data, so that the size of the figure is proportional to the square of the data; for instance,

<table>
<thead>
<tr>
<th>Year</th>
<th>Books circulated</th>
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<tbody>
<tr>
<td>2001</td>
<td>100</td>
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<tr>
<td>2002</td>
<td>141</td>
</tr>
<tr>
<td>2003</td>
<td>200</td>
</tr>
</tbody>
</table>

where the lie factor is about 2.4.

\[
\text{http://instruct.uwo.ca/fim-lis/504/504gra.htm}
\]
An example of a **low** lie factor can be seen in the "Cones" custom chart format in Microsoft Excel.

The heights of the (truncated) cones are proportional to the data, but their areas on the screen and their apparent volumes make the larger data values seem relatively small.

Charting on a **logarithmic** scale can also produce a low lie factor.

http://instruct.uwo.ca/fim-lis/504/504gra.htm
How to Exaggerate with Graphs
from Tufte '83

THE SHRINKING FAMILY DOCTOR
In California
Percentage of Doctors Devoted Solely to Family Practice

<table>
<thead>
<tr>
<th>Year</th>
<th>1964</th>
<th>1975</th>
<th>1990</th>
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<tbody>
<tr>
<td></td>
<td>27%</td>
<td>16.0%</td>
<td>12.0%</td>
</tr>
</tbody>
</table>

"Lie factor" = 2.8

Martí Hearst
How to Exaggerate with Graphs
from Tufte ’83

Error:
Shrinking along both dimensions

Marti Hearst
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Basic Types of Symbolic Displays
(Kosslyn 89)

• Graphs
• Charts
• Maps
• Diagrams

From Hearst, 2003
Graphs

- At least two scales required
- values associated by a symmetric “paired with” relation
  - Examples: scatter-plot, bar-chart, line graph
Common Graph Types

URL

length of access

length of page

# of accesses

length of access

length of access

days

# of accesses

Hearst, 2003
Scatter Plots

• Qualitatively determine if variables
  – are highly correlated
    » linear mapping between horizontal & vertical axes
  – have low correlation
    » spherical, rectangular, or irregular distributions
  – have a nonlinear relationship
    » a curvature in the pattern of plotted points

• Place points of interest in context
  – Color representing special entities

Hearst, 2003
When to use which type?

• Line graph
  – x-axis requires quantitative variable
  – Variables have contiguous values
  – Familiar/conventional ordering among ordinals

• Bar graph
  – Comparison of relative point values

• Scatter plot
  – Convey overall impression of relationship between two variables

• Pie Chart?
  – Emphasizing differences in proportion among a few numbers

Hearst, 2003
Charts

- Discrete relations among discrete entities
- Structure relates entities to one another
- Lines and relative position serve as links
- Examples: Family tree, flow chart

Hearst, 2003
Maps

- Internal relations determined (in part) by the spatial relations of what is pictured
- Labels paired with locations

www.thehighsierra.com

Hearst, 2003
Diagrams

- Schematic pictures of objects or entities
- Parts are symbolic (unlike photographs)
  - How-to illustrations
  - Figures in a manual


Hearst, 2003
Alternative Tree Visualizations (1)

Organization Chart

Tree Ring
Alternative Tree Visualizations (2)

Icicle Plot

Tree Map
Comparing Tree Visualizations
Typical Tasks for Viewing Trees

• Determine the type of tree, e.g.
  – Binary
  – N-ary
  – Balanced
  – Unbalanced

• Find relations, e.g.
  – Deepest common ancestor

• Size of the tree, e.g.
  – How many levels
  – How many leaves

• Details about leaves, e.g.
  – Largest leaf

• Different representation may be better for a given task, e.g.
  – To find out if a tree is balanced or how many levels exist, the Icicle Plot is good

For more details see:
Barlow et al. “A Comparison of 2-D Visualizations of Hierarchies” INFOVIS’01
http://www.sims.berkeley.edu/courses/is247/s02/readings/barlow.pdf
Information Visualization Tasks

Tasks in interactive workflow using visualized information:

• **Overview**  
  Gain an overview of the entire collection

• **Zoom**  
  Zoom in on items of interest

• **Filter**  
  Filter out uninteresting items

• **Details-on-demand**  
  Select an item or group and get details when needed

• **Relate**  
  View relationships among items

• **History**  
  Keep a history of actions to support undo, replay, and progressive refinement

• **Extract**  
  Allow extraction of sub-collections and of the query parameters

Shneiderman, 2003
Information Visualization
Mantra

…
Overview, zoom & filter, details-on-demand
Overview, zoom & filter, details-on-demand
Overview, zoom & filter, details-on-demand
Overview, zoom & filter, details-on-demand
Overview, zoom & filter, details-on-demand
Overview, zoom & filter, details-on-demand
Overview, zoom & filter, details-on-demand
…

Shneiderman, 2003
Example: PhotoMesa
Visualization Techniques for View Transformations

• Focus & Context
• Zoom & Pan
Focus & Context: Background

• Useful Field of View (UFOV)
  – Expands searchlight metaphor
  – Size of region from which we can rapidly take information
  – Maintains constant number of targets

• Tunnel Vision and Stress
  – UFOV narrows as cognitive load/stress goes up

• Role of Motion in Attracting Attention
  – UFOV larger for movement detection
Depth of Field

• Guiding user attention by blurring less relevant parts of an image
• Keeping the context

• Semantic Depth of field = blurring objects based on their relevance
Semantic Depth of Field - Example

The Psychology Division has been targeted for resourced expansion at Northumbria University. We are seeking to appoint up to three Lecturers/Senior Lecturers in Psychology (replacement/additional posts), starting September 2004. We are looking for ambitious, enthusiastic psychologists who wish to help build upon the considerable success of the Division of Psychology and teach in a lively, friendly department. The Division has a growing international reputation for research, particularly in the areas of human cognitive neurosciences and cognition & communication. Applications are welcome from new and experienced academics able to make a genuine contribution to our developing portfolio of research in these or other areas. Expertise in teaching language would be particularly welcome for one of the posts.

DIS2004 will take place in Kendall Square, Cambridge, Massachusetts, 1-4 August 2004.

The theme of DIS2004 is 'Across the Spectrum'. We seek to encompass the diverse and simultaneously inclusive nature of the discipline of interaction design. We are addressing the themes of: inter-disciplinarity, the relationships between social and work processes, the nature of information, aesthetics and emotion, as well as presenting new paradigms of interaction. With this approach we hope to create an arena for debate and
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Magnifying Glass

• Magnifying glass hides context!

• This is not focus +context

Menu

Menu graphical
Focus + Context

• Basic Idea:
  – Show selected regions of interest in greater detail (focus)
  – Preserve global view at reduced detail (context)
  – NO occlusion - All information is visible simultaneously

• Techniques
  – Fisheye views
  – Fisheye lens
  – Continuously variable zoom
  – Nonlinear magnification
  – Hyperbolic views
  – Distortion viewing
  – Rubber sheet views
Alternate Geometry

• Euclidean geometry – we use it since primary school…
  – 3 angles of a triangle add up to?
  – Shortest distance between two points?

• Spherical geometry
  – Geographical view of the world
    » What is the shortest way from Moscow to San Francisco?
    » Sum of angles of a triangle between Paris, NY, and Cape Town?
  – http://math.rice.edu/~pcmi/sphere/

• Hyperbolic Geometry / Space
  – Theory of Relativity
  – The “fifth” dimension
  – Can be projected into 2-D as a pseudosphere
  – Key: As a point moves away from the center towards the boundary circle, its distance approaches infinity
  – http://cs.unm.edu/~joel/NonEuclid/NonEuclid.html (Applet)
Distorted vs. Non-distorted

• Non-distorted
  – Display only a selection at a time
  – Scrolling
  – Paging access
  – Hierarchical structure
  – Structure-specific presentation

• Distorted
  – See the following slides
Basic Idea – Perspective Wall

From http://www.cs.ubc.ca/~tmm/courses/cpsc533c-03-spr/0324.fengdongdu.ppt
Fisheye View

<table>
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<th>Problems</th>
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Example: Fisheye Menu

- Applies fisheye graphical visualization techniques to linear menus
- For very long menus as alternative to
  - Hierarchies
  - Scrolling
  - Arrow-bars

- Benjamin B. Bederson. Fisheye Menus. UIST’00
- Demo
Fisheye View - Networks

![Figures showing networks with different perspectives.](image)

**Figure 1:** A graph with 134 vertices and 338 edges. The vertices represent major cities in the United States. The edges represent connections between cities.

**Figure 2:** A fisheye view of the graph in Figure 1. The focus is on St. Louis. The view is expanded to show more detailed connections.

**Figure 3:** A fisheye view of the graph in Figure 1. The focus is on Denver. The view is expanded to show more detailed connections.

**Figure 4:** A fisheye view of the graph in Figure 1, with the focus on Salt Lake City. The view is expanded to show more detailed connections.

*From Sarkar and Brown*
Panning and Zooming

• Panning
  – Smooth movement of camera across scene (or scene moves and camera stays still)

• Zooming
  – Increasing or decreasing the magnification of the objects in a scene

• Useful for changing focal point
• Also used in creating moving pictures from still pictures
  – “Ken Burns effect”, see Mac OS X photo screensaver
Example: LaunchTile Visual Design

- Three (pure) zoom levels