Information Visualization
An Overview

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What is Visualization?

- Visualize/Visualization:
  - To form a mental image or vision of [some thing]
  - To imagine or remember as if actually seeing
  - Constructing a visual image in the mind
  - Graphical representation of data or concepts
  - The use of computer supported, interactive, visual representations of data to amplify cognition

Information Visualization

The use of computer supported, interactive, visual representations of abstract data to amplify cognition [Card99]

Definitions

- *External Cognition* – Use of external world to accomplish cognition
- *Information Design* – The design of external representations to amplify cognition
- *Data Graphics* – Use of abstract, nonrepresentational visual representations of data to amplify cognition
- *Visualization* – Use of computer-based, interactive visual representations of data to amplify cognition
- *Scientific Visualization* – Use of interactive visual representations of scientific data, typically physically based, to amplify cognition
- *Information Visualization* – Use of interactive visual representations of abstract non-physically based data to amplify cognition

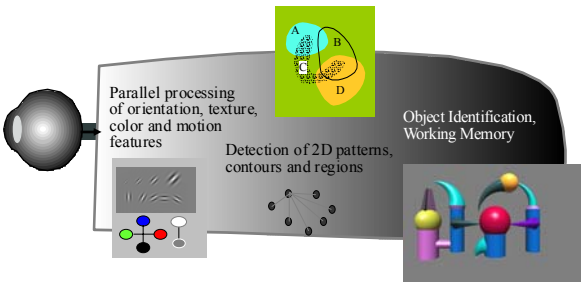
Issues

- Selection - From the data select what is relevant to the task at hand
- Representation - Must represent abstract concepts in some manner (e.g., slopes, color, shape, etc.)
- Presentation – Layout and placement
- Scale and Dimensionality – Scale & number of dimensions influences visualization

Issues (cont)

- Rearrangement, interaction, and exploration – must be able to interact
- Externalization – what the user sees on the display
- Mental Models – the human understanding and perception models
- Invention, Experience, and Skill – must creative in building visualization systems

Human Visual Processing



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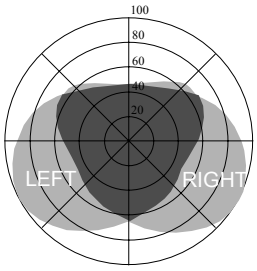
Human Visual Field



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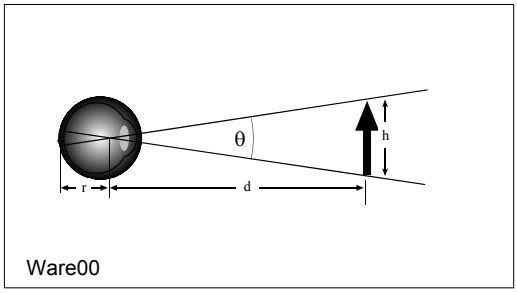
Visual Angle



Ware00

External Cognition

- The external world is important in thought and reasoning
- The use of cognitive artifacts or physical inventions to enhance cognition is common
- Multiplication aids, navigation charts, diagrams, etc

Amplifying Cognition

Increased Resources	
High-bandwidth hierarchical interaction	The human moving gaze system partitions limited channel capacity so that it combines high spatial resolution and wide aperture in sensing visual environments.
Parallel perceptual processing	Some attributes of visualizations can be processed in parallel compared to text, which is aerial.
Offload work from cognitive to perceptual system	Some cognitive inferences done symbolically can be recoded into inferences done with simple perceptual operations [Larkin'87].
Expanded working memory	Visualizations can expand the working memory available for solving a problem [Norman'93].
Expanded storage of information	Visualizations can be used to store massive amounts of information in a quickly accessible form (e.g., maps).
Reduced Search	
Locality of processing	Visualizations group information used together, reducing search [Larkin'87].
High data density	Visualizations can often represent a large amount of data in a small space [Tufte'83].
Spatially indexed addressing	By grouping data about an object, visualizations can avoid symbolic labels [Larkin'87].

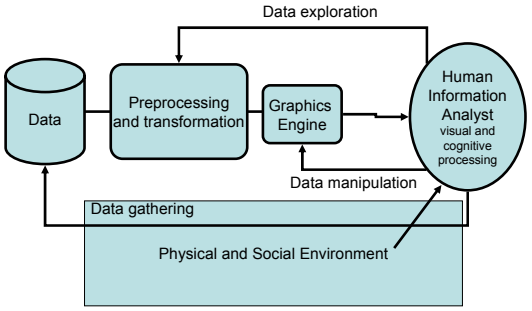
Amplifying Cognition

Enhanced Recognition of Patterns	
Recognition instead of recall	Recognizing information generated by a visualization is easier than recalling that information by the user.
Abstraction and aggregation	Visualizations simplify and organize information, supplying higher centers with aggregated forms of information through abstraction and selective omission [Card'91, Resnkioff'87]
Visual schemata for organization	Visually organizing data by structural relationships (e.g., by time) enhances patterns.
Value, relationship, trend	Visualizations can be constructed to enhance patterns at all three levels [Bertin'81].
Perceptual Inference	
Visual representations make some problems obvious	Visualization can support a large number of perceptual inferences that are extremely easy for humans [Larkin'87].
Graphical computations	Visualizations can enable complex specialized graphical computations [Hutchins'96].
Perceptual Monitoring	Visualizations can allow for the monitoring of a large number of potential events if the display is organized so that these stand out by appearance or motion.
Manipulability Medium	Unlike static diagrams, visualizations can allow exploration of a space of parameter values and can amplify user operations.

Mapping Data to Visual Form

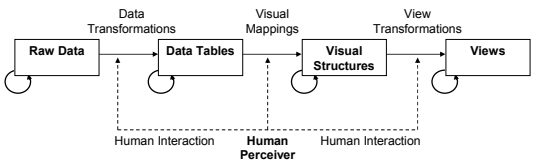
- Visualizations are adjustable mappings from data to visual form to the perceiver

Visualization Process



Four stages consisting of: 1) Data collection/storage, 2) Transform data into something understandable, 3) Display hardware/Software, 4) Perceiver. [Ware'00]

Reference Model for Visualization



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, etc.)

Visualization can be described as a mapping of data to visual form that supports human interaction for making visual sense [Card '99].

Data Tables

- Raw data comes in many forms – flat file, spread sheet, source code, execution trace
- Need to transform raw data into a (set of) relations that are structured to facilitate mapping to visual form
- Meta data is included (labels, semantics, etc)
- Organize multi-dimensional data
- Transformations incur a loss or gain of information and raw data may have errors/noise

Visual Structures

- Augment a spatial substrate with marks and graphical properties to encode information
- Good visual structures have mappings that preserve the data
- Mapping is expressive if all and only the data in the Data table are represented
- Mapping is effective if it is faster to interpret, conveys more distinctions, or leads to fewer errors than some other mapping

Spatial Substrate

- There are limits to the perceptual system
- There are also representational limits to graphics as a general medium
- There are a limited number of components that visual structures are composed [Bertin 77, 81, Mackinlay 86, Card 97]
- Most fundamental aspect of visual structures is the use of space

Describing Space

- Unstructured Axis - no axis
- Nominal Axis - a region is divided into sub-regions
- Ordinal Axis - the ordering of these sub-regions is meaningful
- Quantitative Axis - a region has a metric

Working with Space

- Composition – the orthogonal placement of axes to create a 2D (3D) metrics space. (e.g., scatter plot)
- Alignment – the repetition of an axis at a different position in the space. (e.g., multiple variables on same graph)
- Folding – the continuation of an axis in an orthogonal dimension. (e.g., wrap around)
- Recursion – the repeated subdivision of space (e.g., interactive zooming)
- Overloading – the reuse of the same space for the same data table.

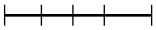
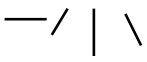
Marks, Connections, Enclosure

- Marks – points 0D, lines 1D, areas 2D, volumes 3D – graphical features
- Points and lines can be used to signify graphs and trees
- This allows relations among objects to be shown without the geometric constraints implicit in mapping variables onto spatial axes (links imply connections)
- Enclosures can also be used to encode information (e.g., hierarchies, clusters)

Retinal Properties

- Bertin's [67, 83] six retinal variables.
- Spatial properties and object properties
- Cross separated according to how good they are to express
  - Extent (has a natural zero point)
  - Differentiating (comparison between marks)

Retinal Variables

	Spatial	Object
Extent	Position  Size 	Gray scale 
Differential	Orientation 	Color  Texture  Shape

Processing Visual Features

- Visual features that can be automatically processed by humans
- Could utilize these for visual encoding of data

- number, line orientation, length, width, size curvature, terminators, intersection, closure, color, intensity, flicker, direction of motion, binocular luster, stereoscopic depth, 3D depth cues, lighting direction

Temporal Encoding

- Visual structures can also encode information temporally
- Humans perceptions is very sensitive to change in mark position
- Time as animation is a good example

View Transformations

- Interactively modify and augment visual structures to turn static presentations into visualizations
- Visualizations exist in time-space
- Three common view transformations
  - Location probes – use location to reveal additional information
  - Viewpoint control – zooming, panning, etc
  - Distortion – focus + context views

User Tasks

- Primary tasks that an information visualization system should support [Shneiderman, Wiss, Carr, Jonsson]
  - Overview
  - Zoom
  - Filter
  - Details on Demand
  - Relate
  - History
  - Extract

Overview

- Gain an overview of the entire collection of data
- Abstraction mechanism may be necessary
- Loss of details often necessary
- Allows for point of reference – seeing the whole map and were you are

Zoom

- Allows zooming in on items of interest (from an overview)
- Drill down
- From the abstract view to the detail view
- Navigational control

Filter

- Allows filtering out uninteresting details or features
- Filtering may disturb the global context
- Can be supported by retinal properties

Details-on-demand

- Selection of an item or group and retrieve additional detailed information as needed
- Via pop up windows or drill down
- May need to support various abstractions or views of the data and mapping between them

Relate

- View relationships among items
- For graph and tree organizations must support parent child and other relationships
- Could be supported via a query mechanism

History

- Keep a history of actions to support undo, replay, and progressive refinement
- A visitation path should be supported
- Points of reference or trail markers may be needed

Extract

- Allows extraction of sub-collections and query parameters
- Query language may be used to support exploration and extraction of interesting information