Tutorial

Datenvisualisierung
und
Data Mining

Daniel A. Keim

Informatik & Informationswissenschaft

Universität Konstanz

Eine pdf Version des Tutorials ist verfügbar unter
“http://www.informatik.uni-halle.de/~keim”

Overview

1. Introduction 2
2. Data Preprocessing Techniques........................9
3. Visual Data Exploration Techniques 11
   - Geometric Techniques 11
   - Icon-based Techniques 21
   - Pixel-Oriented Techniques 31
   - Hierarchical Techniques 51
   - Graph-based Techniques 60
   - Hybrid Techniques 72
4. Distortion Techniques 73
5. Dynamic / Interaction Techniques 81
6. Comparison of the Techniques 96
7. Database Exploration and Visualization Systems 98
8. Summary and Conclusion 103

Bibliography..105

Goals of Visualization Techniques

- **Explorative Analysis**
  - starting point: data without hypotheses about the data
  - process: interactive, usually undirected search for structures, trends, etc.
  - result: visualization of the data, which provides hypotheses about the data
- Confirmative Analysis
  - starting point: hypotheses about the data
  - process: goal-oriented examination of the hypotheses
  - result: visualization of the data, which allows the confirmation or rejection of the hypotheses
- Presentation
  - starting point: facts to be presented are fixed a priori
  - process: choice of an appropriate presentation technique
  - result: high-quality visualization of the data presenting the facts

Data Exploration

Definition

Data Exploration is the process of searching and analyzing databases to find implicit but potentially useful information.

more formally:

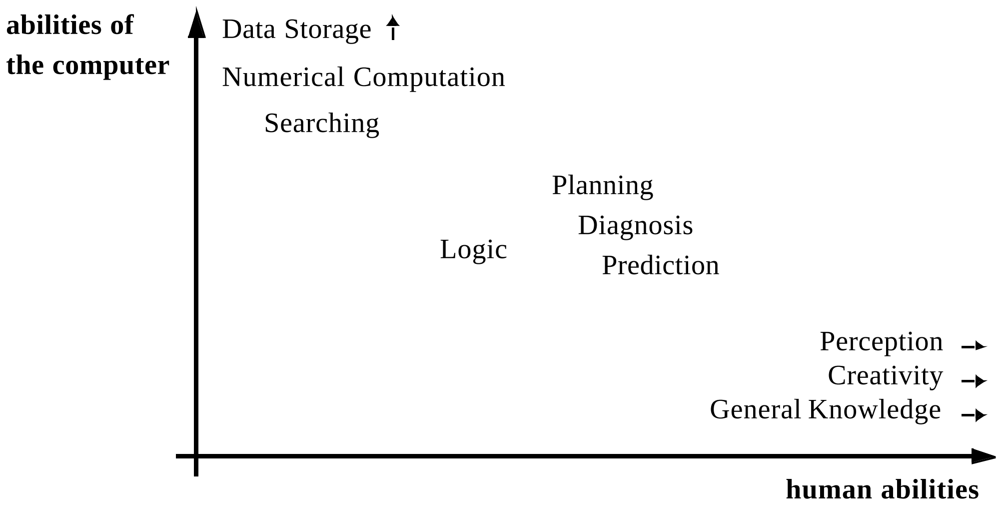
Data Exploration is the process of finding a

- subset D’ of the database D and
- hypotheses H_U(D’, C)

that a *user U* considers *useful* in an *application context C.*

Introduction

Comparison of the Abilities of Humans and Computers



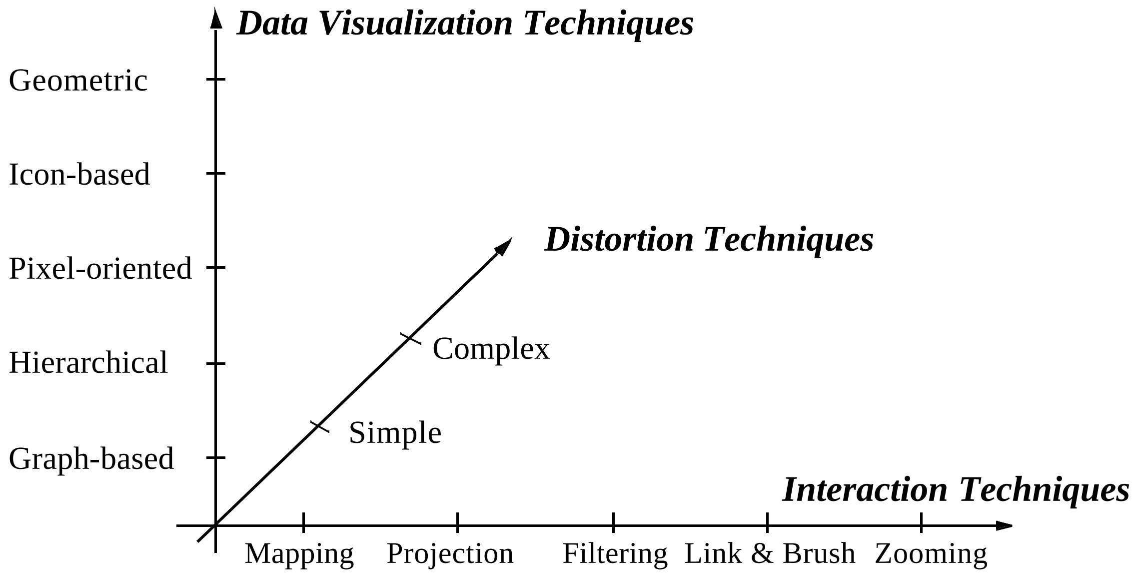
Introduction

Historical Overview of Exploratory Data Visualization Techniques (cf. [WB 95])

- pioneering work of Tufte [Tuf83, Tuf90] and Bertin [Ber81] focuses on
  - ⇨ visualization of data with inherent 2D-/3D-semantics
  - ⇨ general rules for layout, color composition, attribute mapping, etc.
- development of visualization techniques for different types of data with an underlying physical model
  - ⇨ geographic data, CAD data, flow data, image data, voxel data, etc.
- development of visualization techniques for arbitrary multidimensional data (without an underlying physical model)
  - ⇨ applicable to databases and other information resources

Introduction

Dimensions of Exploratory Data Visualizations



Introduction

Classification of Data Visualization Techniques

- Geometric Techniques: Scatterplots, Landscapes, Projection Pursuit, Prosection Views, Hyperslice, ***Parallel Coordinates***, ...
- Icon-based Techniques: Chernoff Faces, ***Stick Figures***, Shape-Coding, Color Icons, TileBars, ...
- Pixel-oriented Techniques: ***Recursive Pattern Technique*, *Circle Segments Technique*, Spiral- & Axes-Techniques,** ...
- Hierarchical Techniques: Dimensional Stacking, Worlds-within-Worlds, ***Treemap***, Cone Trees, InfoCube, ...
- Graph-Based Techniques: Basic Graphs (Straight-Line, Polyline, Curved-Line, ..)
  Specific Graphs (e.g., DAG, Symmetric, Cluster, ...)
  Systems (e.g., Tom Sawyer, Hy^+, *SeeNet*, *Narcissus*, ...)
- Hybrid Techniques: arbitrary combinations from above

Introduction

Distortion and Dynamic / Interaction Techniques

❑ **Distortion Techniques**

- Simple Distortion (e.g., ***Perspective Wall***, Bifocal Lenses, ***TableLens***, ***Graphical Fisheye Views***, ...)
- Complex Distortion (e.g., Hyperbolic Repr., ***Hyperbox***, ...)

❑ **Dynamic / Interaction Techniques**

- Data-to-Visualization Mapping (e.g., AutoVisual, S Plus, ***XGobi***, ***IVEE***, ...)
- Projections (e.g., GrandTour, S Plus, ***XGobi***, ...)
- Filtering (Selection, Querying) (e.g., ***MagicLens, Filter/Flow Queries, InfoCrystal***, ...)
- Linking & Brushing (e.g., ***Xmdv-Tool***, ***XGobi***, DataDesk, ...)
- Zooming (e.g., PAD++, ***IVEE***, DataSpace, ...)
- Detail on Demand (e.g., ***IVEE***, TableLens, ***MagicLens***, ***VisDB***, ...)

Data Preprocessing Techniques

❑ **Techniques for Dimension Reduction**
(Set of d-dim Data Items -> Set of k-dim. Data Items; k << d)

- Principal Component Analysis [DE82]
  Determines a minimal set of principal components (linear combinations of the original dimensions) which explain the main variations of the data.
- Factor Analysis [Har 67]
  Determines a set of unobservable common factors which explain the main variations of the data. The original dimensions are linear combinations of the common factors.
- Multidimensional Scaling [SRN72]
  Uses the similarity (or dissimilarity) matrix of the data as defining coordinate axes in multidimensional space. The Euclidean distance in that space is a measure of the similarity of the data items.
- Fastmap [FL95]
  Fastmap also operates on a given similarity matrix and iteratively reduces the number of dimensions while preserving the distances as much as possible.

Data Preprocessing Techniques

- **Subsetting Techniques**
  (Set of Data Items -> Subset of Data Items)
  - Sampling (determines a representative subset of the database)
  - Querying (determines a certain, usually a-priori fixed subset of the database)
- **Segmentation Techniques**
  (Set of Data Items -> Set of (Set of Data Items))
  - Segmentation based upon attribute values or attribute ranges
- **Aggregation Techniques**
  (Set of Data Items -> Set of Aggregate Values)
  - Aggregation (sum, count, min, max, ...) based upon
    - attribute values
    - topological properties, etc.
  - Visualizations of Aggregations:
    - Histograms
    - Pie Charts, Bar Charts, Line Graphs, etc.

Geometric Techniques

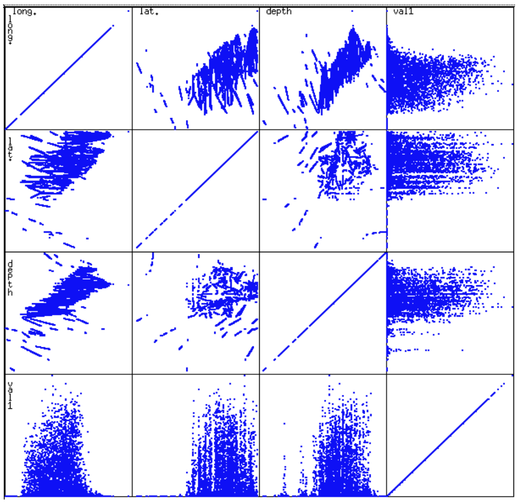
<u>Basic Idea</u>: Visualization of geometric transformations and projections of the data.

Overview

- **Scatterplot-Matrices [And 72, Cle 93]**
- **Landscapes [Wis95]**
- **Projection Pursuit Techniques [Hub85]**
  (⇨ techniques for finding meaningful projections of multidimensional data)
- **Prosection Views [FB94, STDS 95]**
- **Hyperslice [WL 93]**
- **Parallel Coordinates [Ins85, ID90]**

Geometric Techniques

Scatterplot-Matrices [Cle 93]



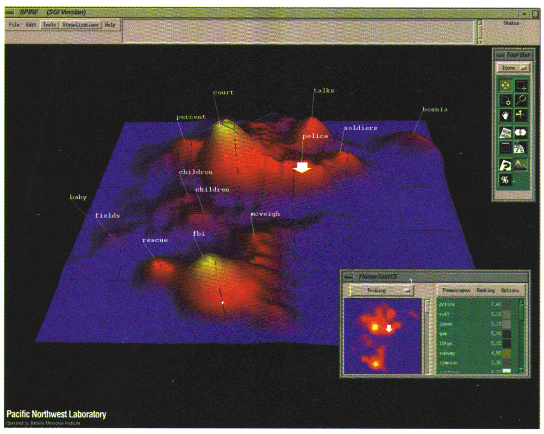
used by permission of M. Ward, Worcester Polytechnic Institute

➪ matrix of scatterplots (x-y-diagrams) of the k-dim. data [total of ($k^2/2$ - k) scatterplots]

Geometric Techniques

Landscapes [Wis 95]

used by permission of B. Wright, Visible Decisions Inc.



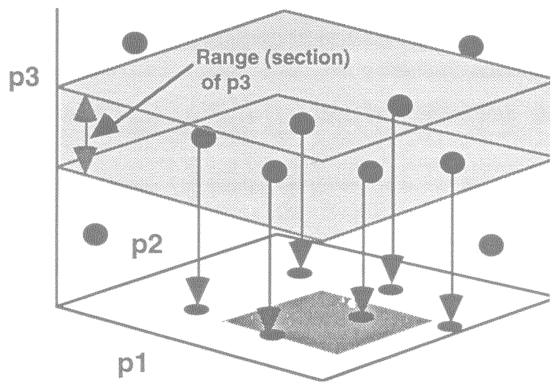
news articles visualized as a landscape

➪ visualization of the data as perspective landscape

➪ the data needs to be transformed into a (possibly artificial) 2D spatial representation which preserves the characteristics of the data

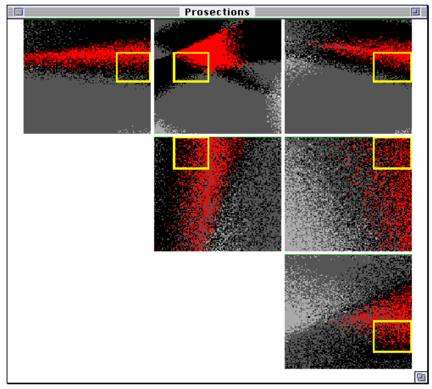
Geometric Techniques

Prosection Views [FB 94, STDS 95]



used by permission of R. Spence, Imperial College London

schematic representation



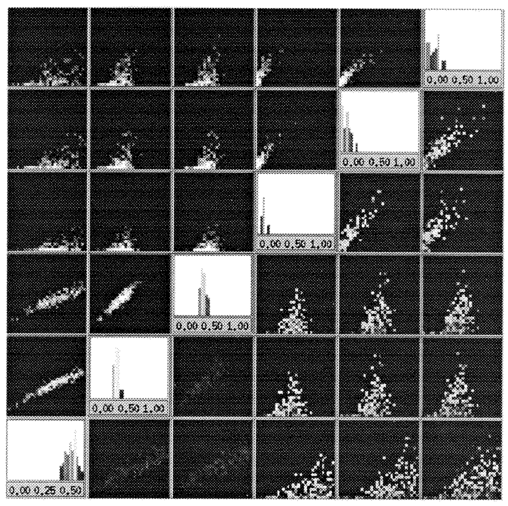
used by permission of R. Spence, Imperial College London

example

➪ matrix of all orthogonal projections where the result of the selected multidimensional range is colored differently (combination of selections and projections)

Geometric Techniques

Hyperslice [WL 93]



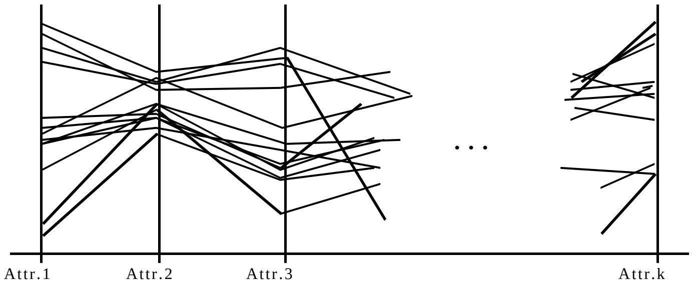
used by permission of J. J. van Wijk

➪ matrix of k^2 slices through the k-dim. data (the slices are determined interactively)

Geometric Techniques

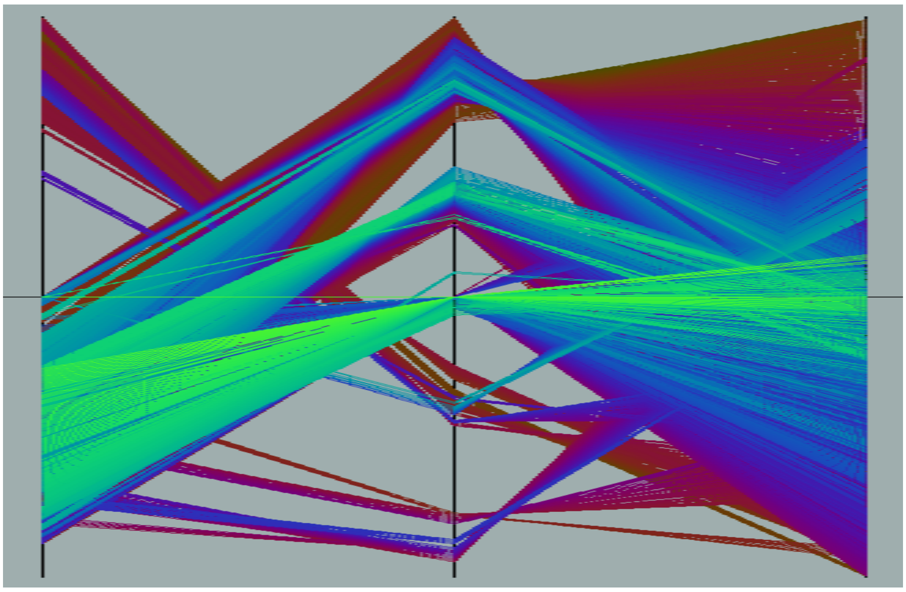
Parallel Coordinates [Ins 85, ID 90]

- n equidistant axes which are parallel to one of the screen axes and correspond to the attributes
- the axes are scaled to the [minimum, maximum] - range of the corresponding attribute
- every data item corresponds to a polygonal line which intersects each of the axes at the point which corresponds to the value for the attribute



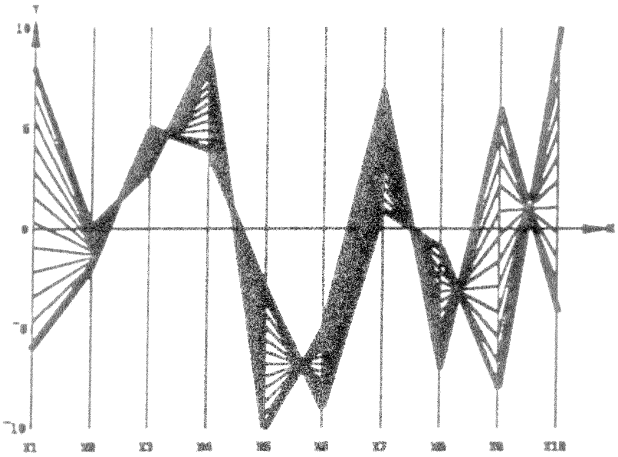
Geometric Techniques

Parallel Coordinates (cont’d)



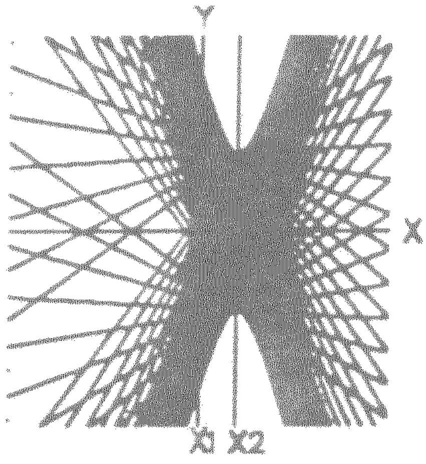
Geometric Techniques

Parallel Coordinates (cont'd)



used by permission of A. Inselberg, Tel Aviv University, Israel

points on a line in 10-dim. space

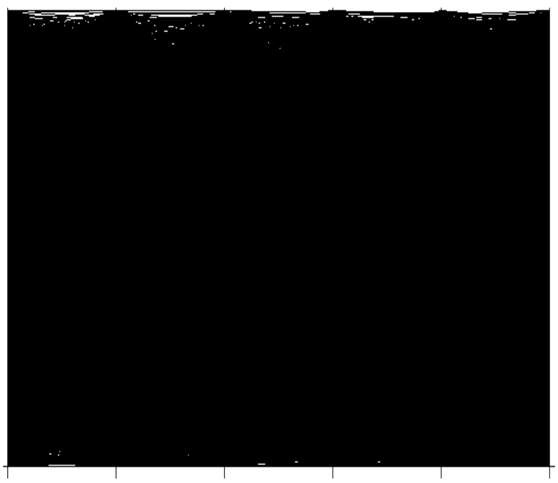


used by permission of A. Inselberg

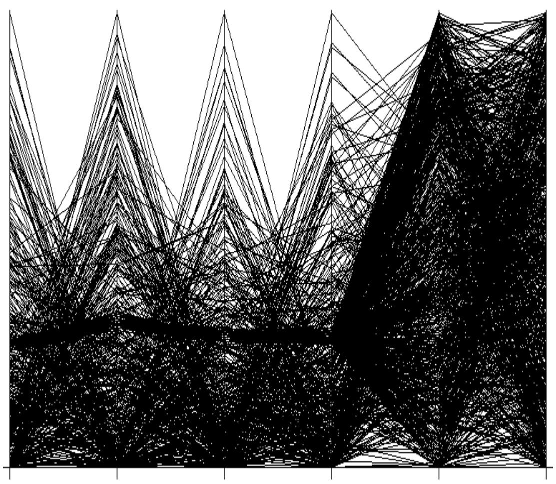
points on a circle in 2-dim. space

Geometric Techniques

Parallel Coordinates (cont'd)



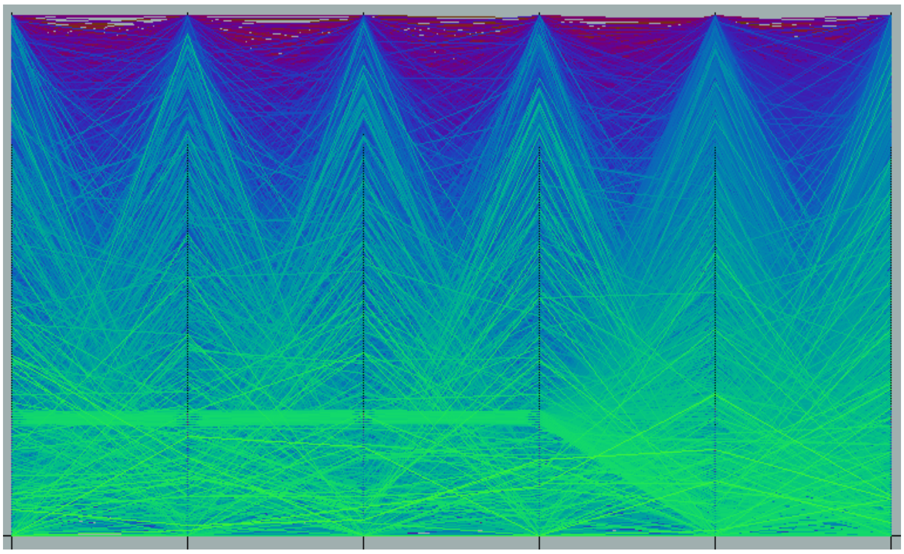
15.000 data items with noise



5% of the data (750 data items)

Geometric Techniques

Parallel Coordinates (cont'd)



15.000 data items with a query-dependent coloring

Icon-based Techniques

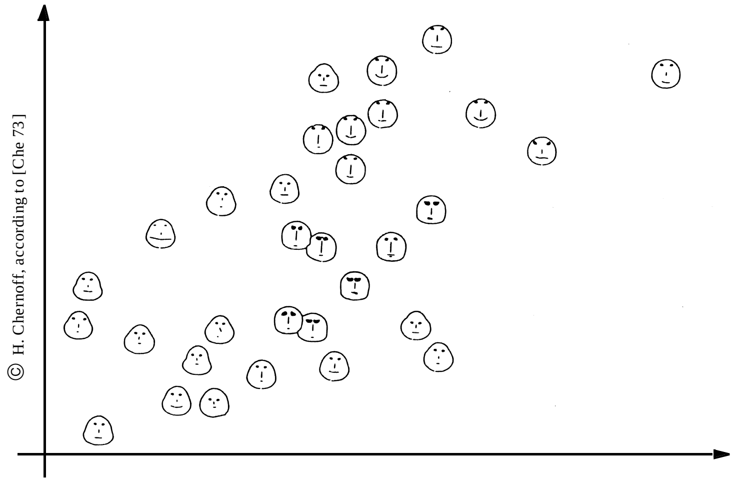
Basic Idea: Visualization of the data values as features of icons.

Overview

- **Chernoff-Faces [Che 73, Tuf83]**
- **Stick Figures [Pic70, PG88]**
- **Shape Coding [Bed 90]**
- **Color Icons [Lev 91, KK94]**
- **TileBars [Hea95]**
  (⇨ use of small icons representing the relevance feature vectors in document retrieval)

Icon-based Techniques

Chernoff-Faces [Che 73, Tuf 83]

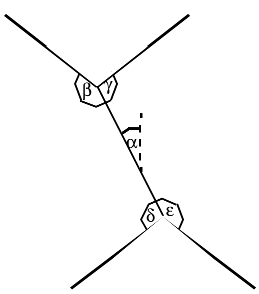


- visualization of the multidim. data using the properties of a face icon (shape of nose, mouth, eyes, and the shape of the face itself)

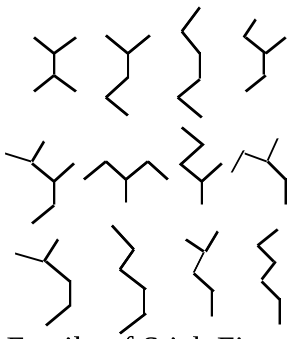
Icon-based Techniques

Stick Figures [Pic 70, PG 88]

- visualization of the multidimensional data using stick figure icons
- two attributes of the data are mapped to the display axes and the remaining attributes are mapped to the angle and/or length of the limbs
- texture patterns in the visualization show certain data characteristics



Stick Figure Icon

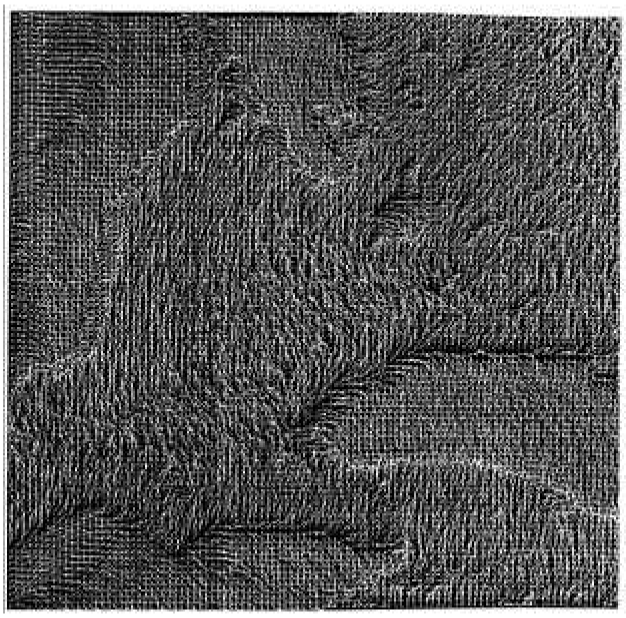


A Family of Stick Figures

Icon-based Techniques

Stick Figures (cont'd)

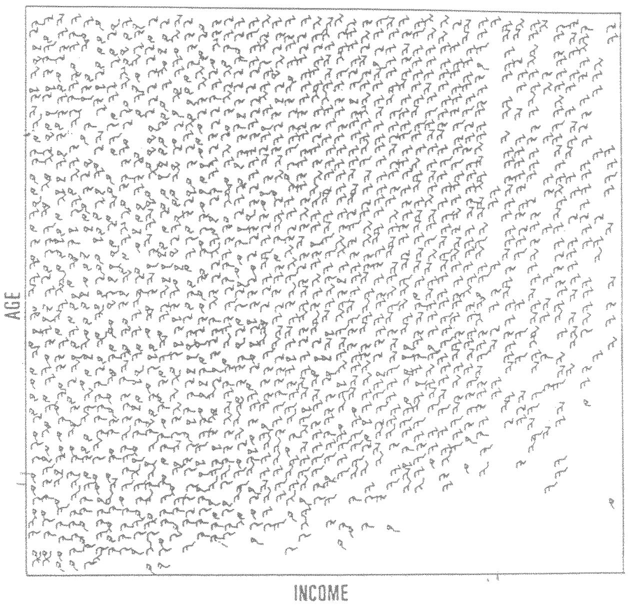
used by permission of G. Grinstein, University of Massachusetts at Lowell



5-dim. image data from the great lake region

Icon-based Techniques

Stick Figures (cont'd)

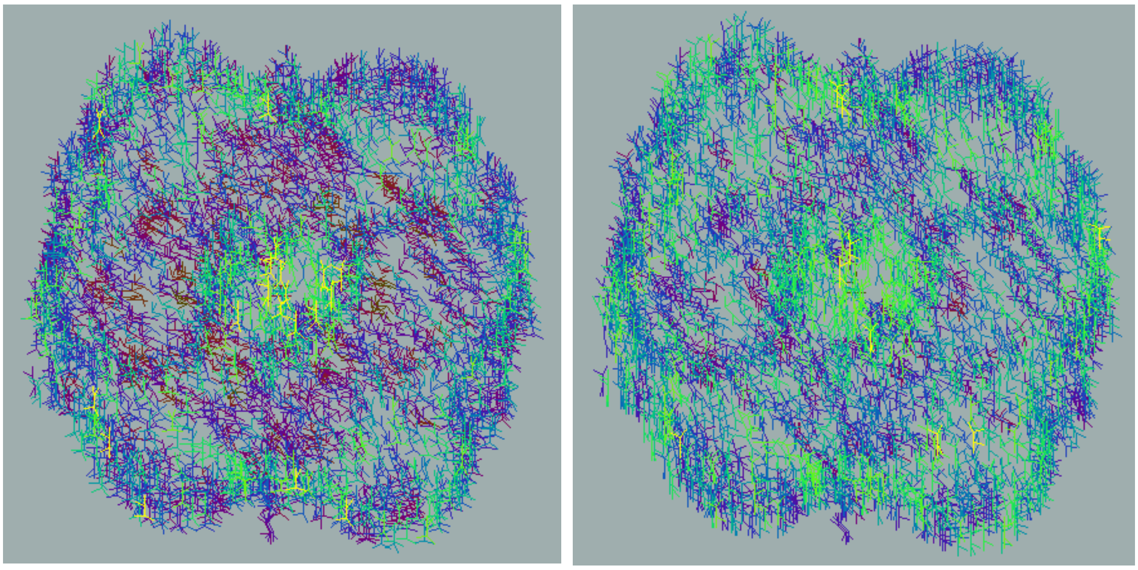


used by permission of G. Grinstein, University of Massachusetts at Lowell

census data showing age, income, sex, education, etc.

Icon-based Techniques

Stick Figures (cont'd)

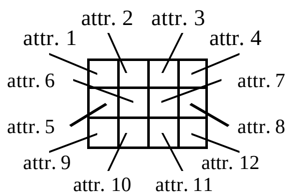


properties of the triangulation of molecule data

Icon-based Techniques

Shape Coding [Bed 90]

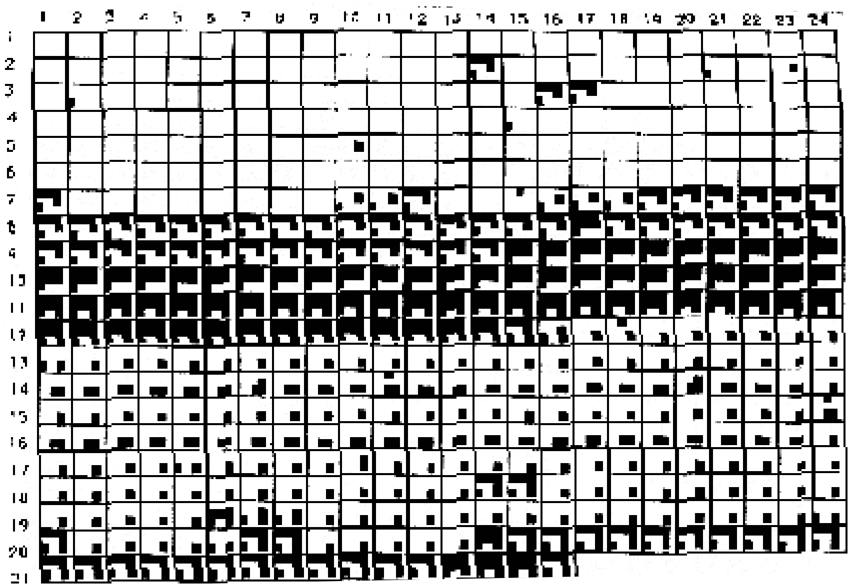
- ➪ the data are visualized using small arrays of fields
- ➪ each field represents one attribute value
- ➪ arrangement of attribute fields (e.g., 12-dimensional data):



- ➪ arrays are arranged line-by-line according to a given sorting (e.g., the time attribute for time-series data)

Icon-based Techniques

Shape Coding (cont'd)



time series of NASA earth observation data

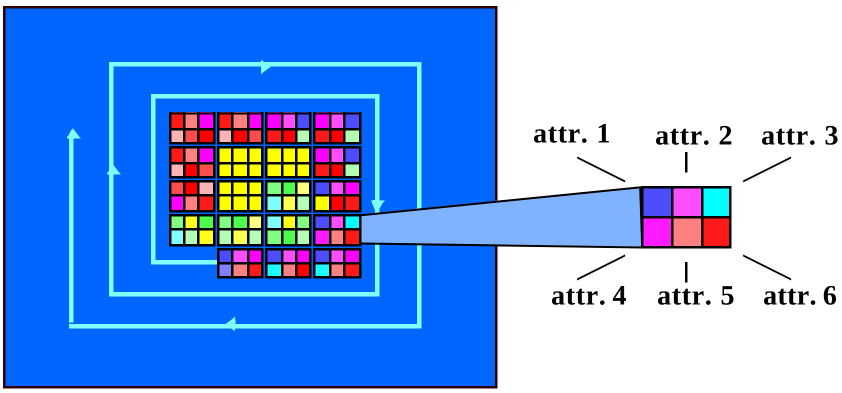
used by permission of J. Beddow

Icon-based Techniques

Color Icons [Lev 91, KK 94]

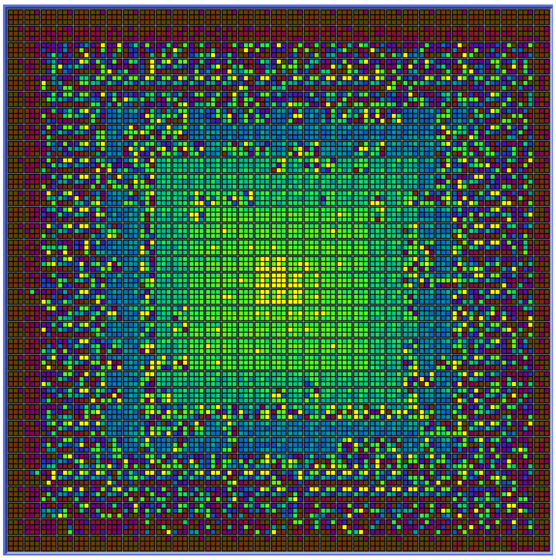
- visualization of the data using color icons
- color icons are arrays of color fields representing the attribute values
- arrangement is query-dependent (e.g., spiral)

schematic representation of 6-dim. data



Icon-based Techniques

Color Icons (cont'd)



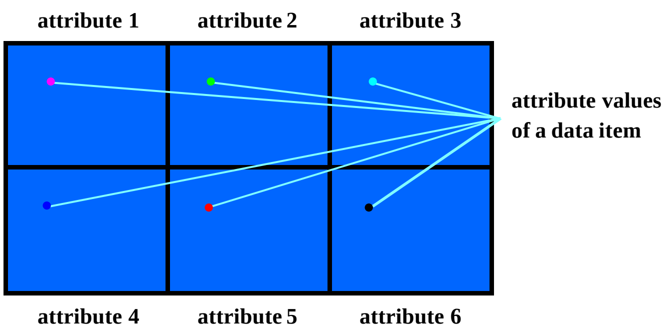
random data containing several clusters

Pixel-oriented Techniques

Basic Idea

- each attribute value is represented by one colored pixel
  (⇨ the value ranges of the attributes are mapped to a fixed colormap)
- the attribute values for each attribute are presented in separate subwindows
- example:

visualization of six-dim. data



Pixel-oriented Techniques

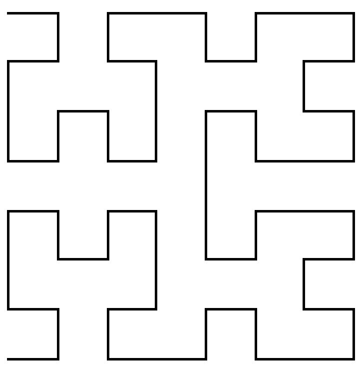
Overview [Kei 96]

- **Query-Independent Techniques**
  - **Simple Techniques**
  - **Space-Filling Curves**
  - **Recursive Pattern Technique**
- **Query-Dependent Techniques**
  - **Spiral Technique**
  - **Axes Technique**
  - **Circle Segments**

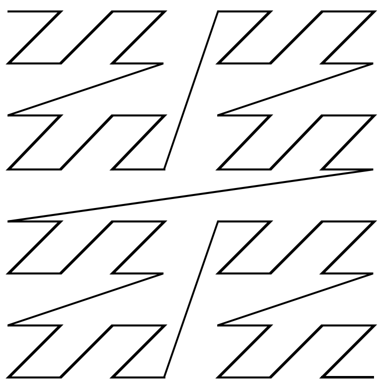
Pixel-oriented Techniques

Query-Independent Techniques:

Space-Filling Curve Arrangements



Peano-Hilbert

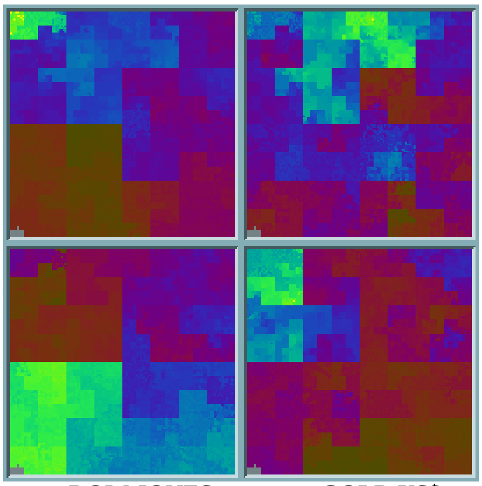


Morton (Z-Curve)

Pixel-oriented Techniques

Space-Filling Curve Arrangements

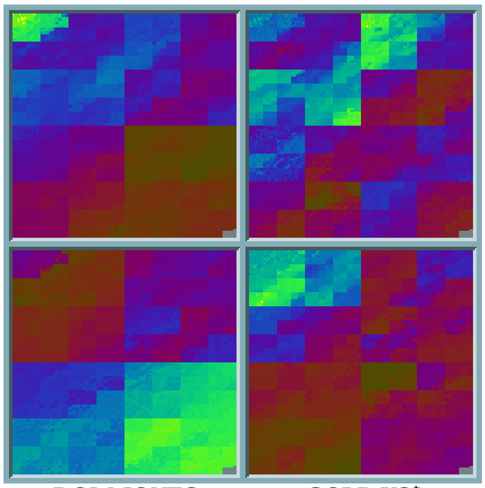
IBM DOLLAR



DOW JONES GOLD.US$

Peano-Hilbert

IBM DOLLAR



DOW JONES GOLD.US$

Morton (Z-Curve)

Pixel-oriented Techniques

Query-Independent Techniques:

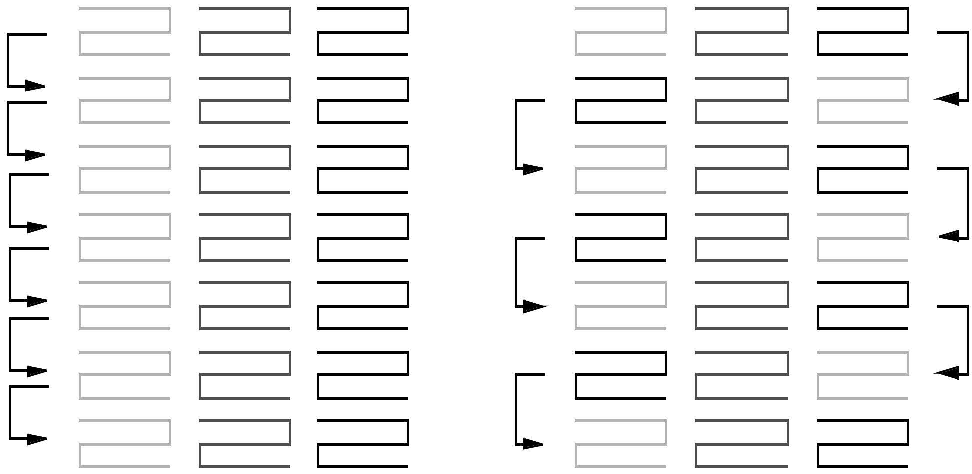
Recursive Pattern Technique [KKA 95]

- recursive generalization of iterated line- and column-based arrangements
- the user may specify the height h_i and width w_i for each recursion level
- on recursion level i, w_i patterns of recursion level $(i\text{-}1)$ are drawn in left-right direction and this is repeated h_i times in top-down direction

⇨ the pattern on recursion level i consists of $w_i \times h_i$ patterns of recursion level $(i\text{-}1)$

Pixel-oriented Techniques

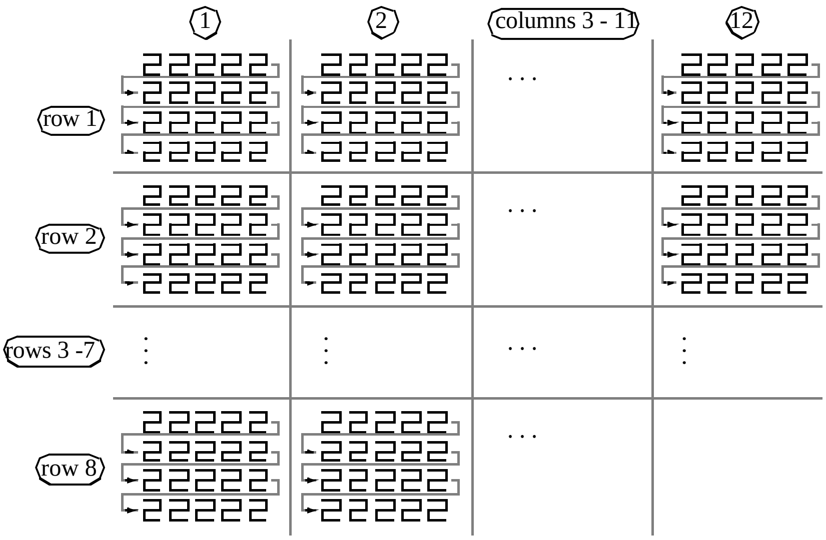
Recursive Pattern: Possible Arrangements



line-by-line loop   back-and-forth loop

Pixel-oriented Techniques

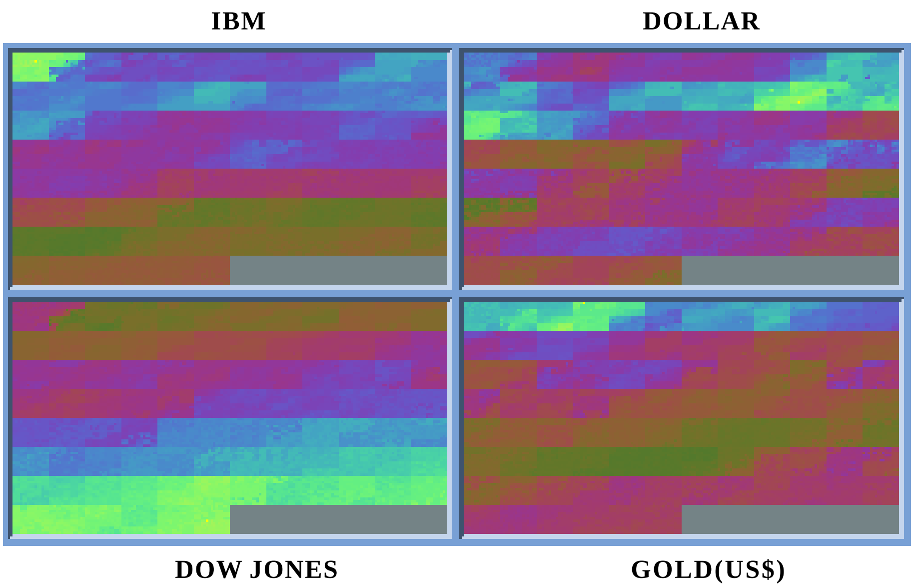
Recursive Pattern: Example of a Structured Arrangement



$(w_1, h_1) = (3,3)$, $(w_2, h_2) = (5,1)$, $(w_3, h_3) = (1, 4)$, $(w_4, h_4) = (12, 1)$, and $(w_5, h_5) = (1, 8)$

Pixel-oriented Techniques

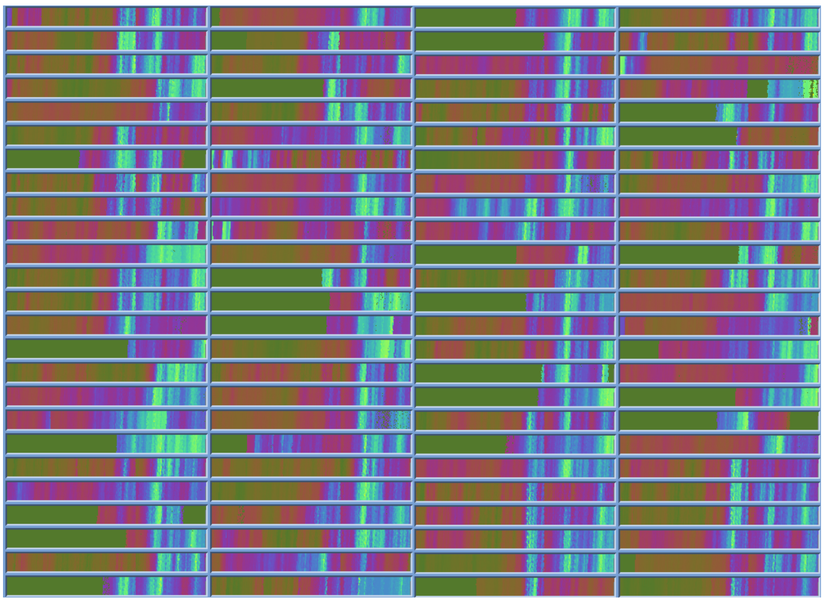
Recursive Pattern: Example of Financial Data



time series of financial data

Pixel-oriented Techniques

Recursive Pattern: FAZ-Index (Jan. ‘74 - Apr. ‘95)



time series of of the 100 stocks in the Frankfurt Stock Index

Pixel-oriented Techniques

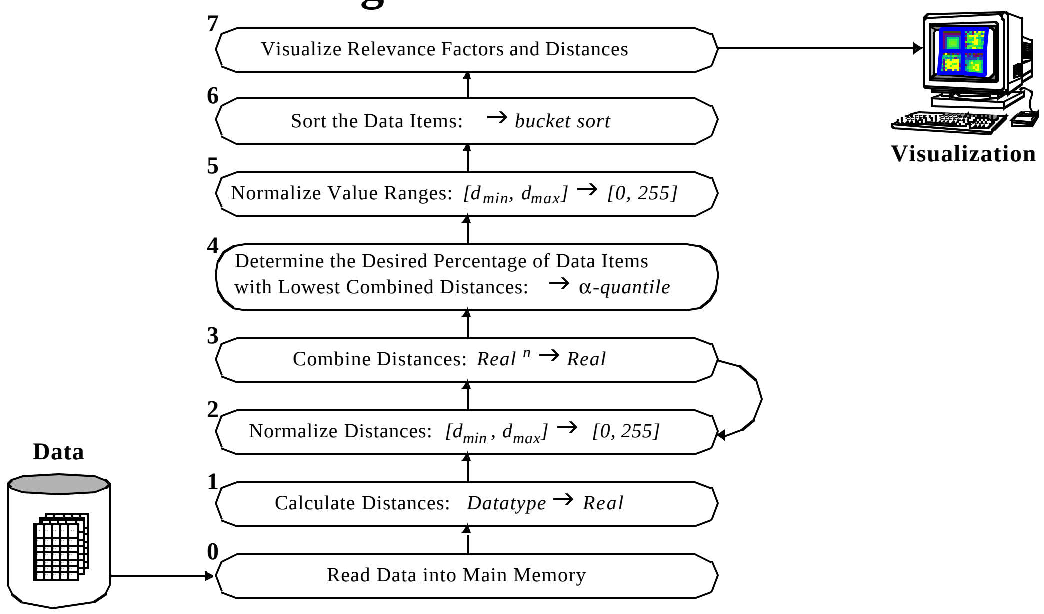
Query-Dependent Techniques: Basic Idea

- data items $(a_1, a_2, \ldots, a_m)$ & query $(q_1, q_2, \ldots, q_m)$

  ⇨ distances $(d_1, d_2, \ldots d_m)$
- extend distances by overall distance (d_{m+1})
- determine data items with lowest overall distances
- map distances to color (for each attribute)
- visualize each distance value d_i by one colored pixel

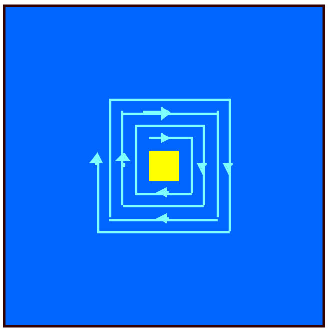
Pixel-oriented Techniques

Calculating the Visualizations

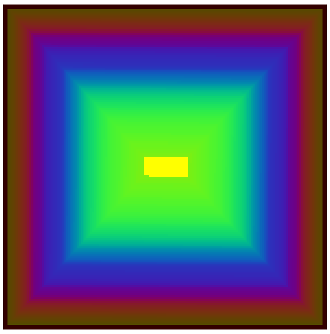


Pixel-oriented Techniques

Query-Dependent Techniques: Spiral Technique [KKS 93, KK 94]



arrangement in spiral form according to the overall distance

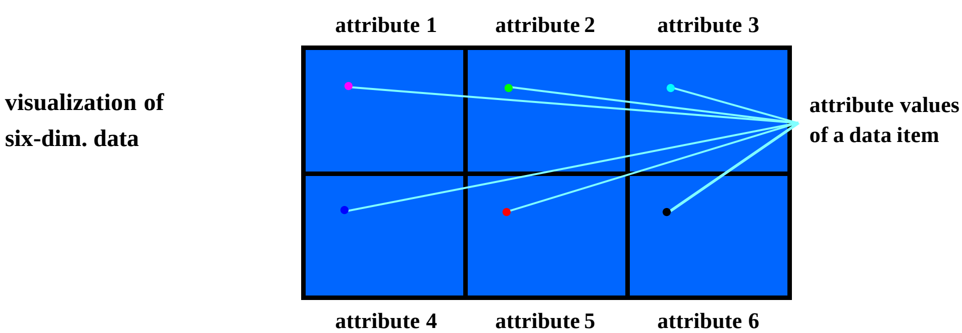


example of the overall distance

Pixel-oriented Techniques

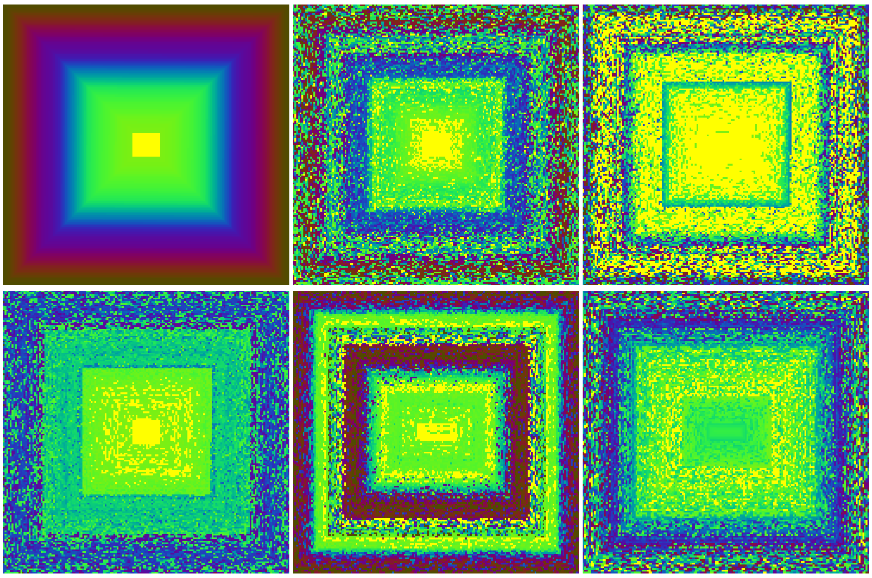
Spiral Technique (cont'd)

- the values for each of the attributes are presented in a separate subwindows
- the arrangement inside the subwindows is according to the overall distance
- example:



Pixel-oriented Techniques

Spiral Technique (cont'd)



result of a complex query

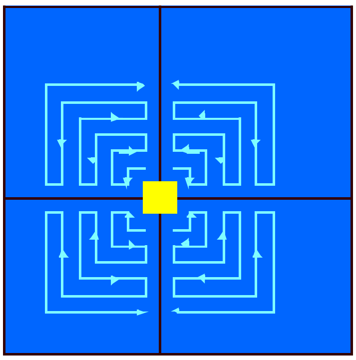
Pixel-oriented Techniques

Axes Technique [KK 94]

Attribute j

pos

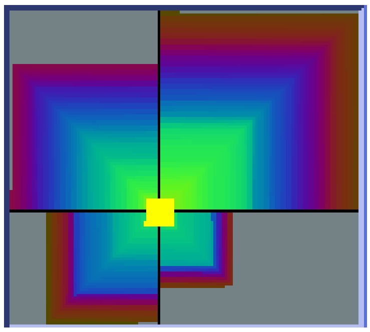
neg



neg pos

Attribute i

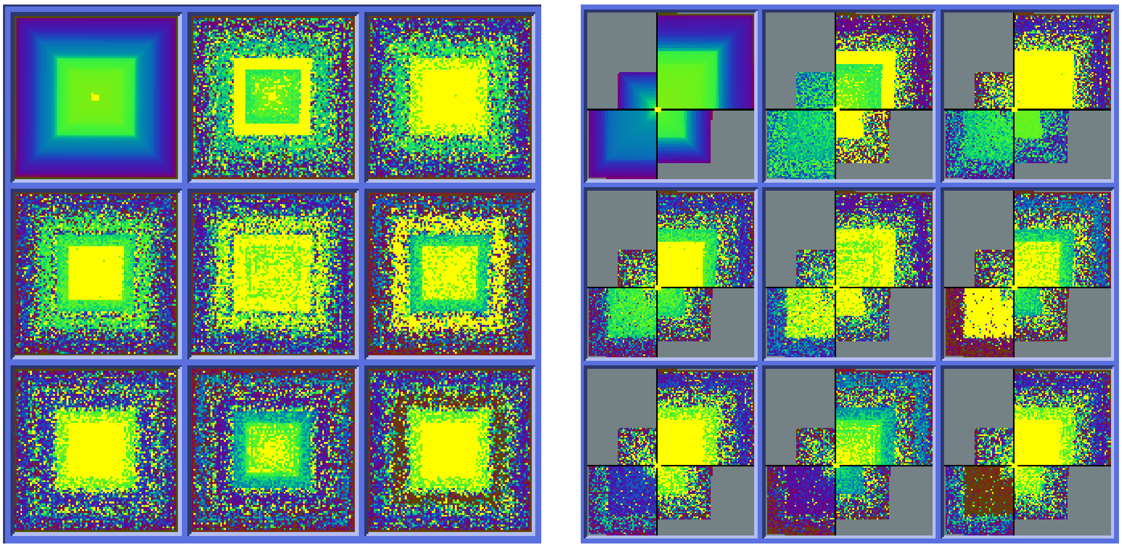
arrangement in partial spirals in each quadrant



example of the overall distance

Pixel-oriented Techniques

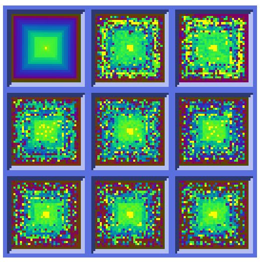
Spiral and Axes Techniques [KK 94]



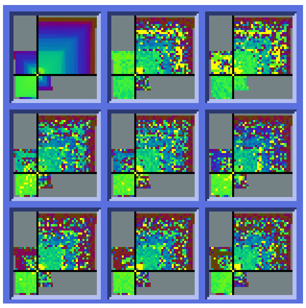
random data containing several clusters

Pixel-oriented Techniques

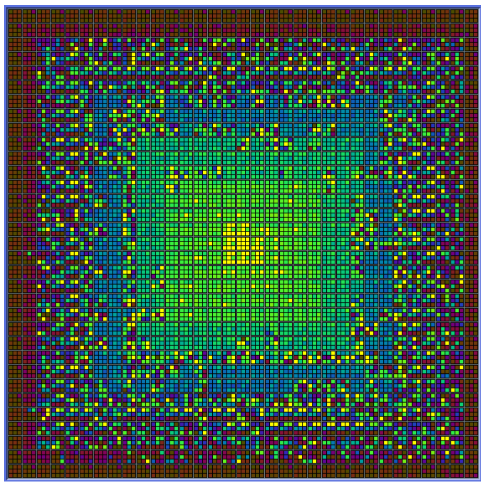
Spiral, Axes, and Color Icon Techniques [KK 94]



Spiral Technique



Axes Technique

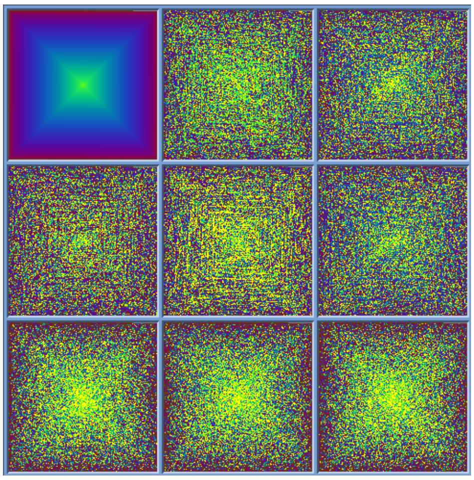


Color Icon Technique

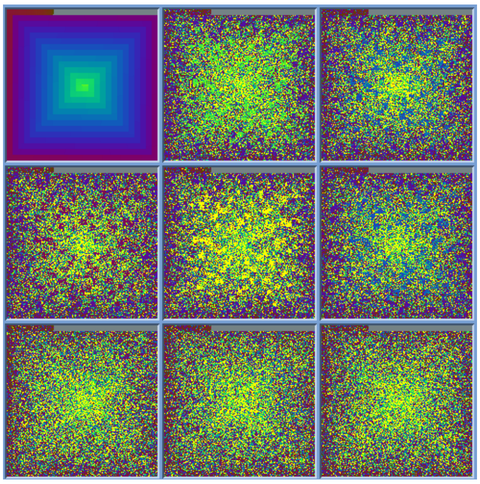
Pixel-oriented Techniques

Generalized Spiral Technique [Kei 95]

➪ Combination of Spiral Technique and Space-Filling Curves



Spiral Technique

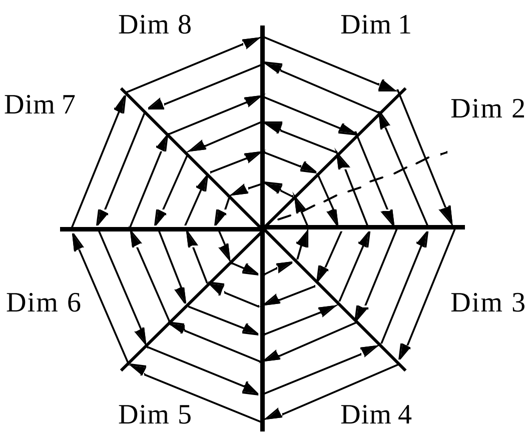


Snake-Spiral Technique

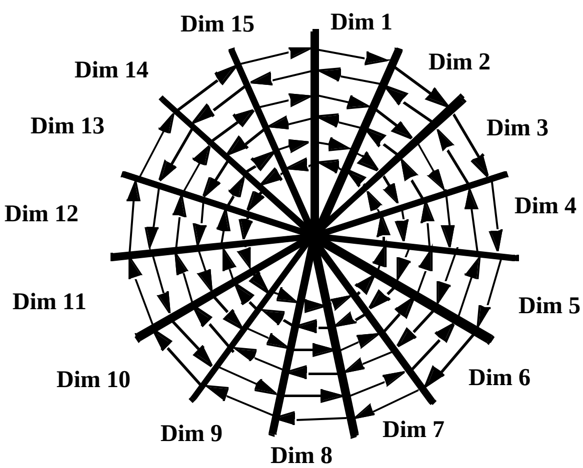
Pixel-oriented Techniques

Circle Segments Technique [AKK 96]

➪ Arrangement of Attributes on the Segments of a Circle



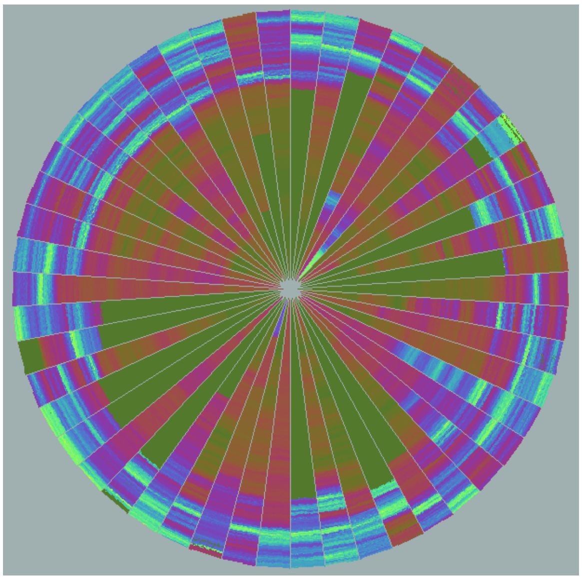
Arrangement of 8-dim. Data



Arrangement of 15-dim. Data

Pixel-oriented Techniques

Circle Segments Technique (cont'd)



time series of 50 stocks of the Frankfurt Stock Index

Hierarchical Techniques

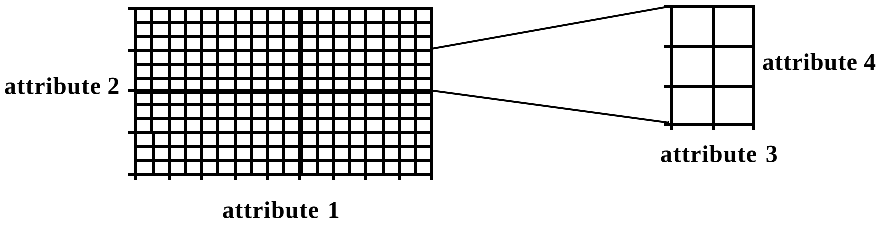
Basic Idea: Visualization of the data using a hierarchical partitioning into subspaces.

Overview

- **Dimensional Stacking [LWW 90]**
- **Worlds-within-Worlds [FB 90a/b]**
- **Treemap [Shn 92, Joh93]**
- **Cone Trees [RMC 91]**
- **InfoCube [RG 93]**

Hierarchical Techniques

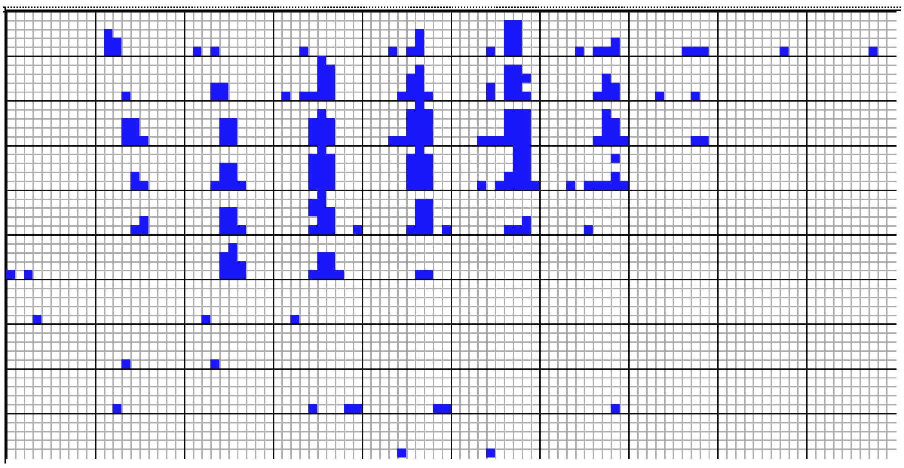
Dimensional Stacking [LWW 90]



- partitioning of the n-dimensional attribute space in 2-dimensional subspaces which are 'stacked' into each other
- partitioning of the attribute value ranges into classes
- the important attributes should be used on the outer levels
- adequate especially for data with ordinal attributes of low cardinality

Hierarchical Techniques

Dimensional Stacking (cont'd)

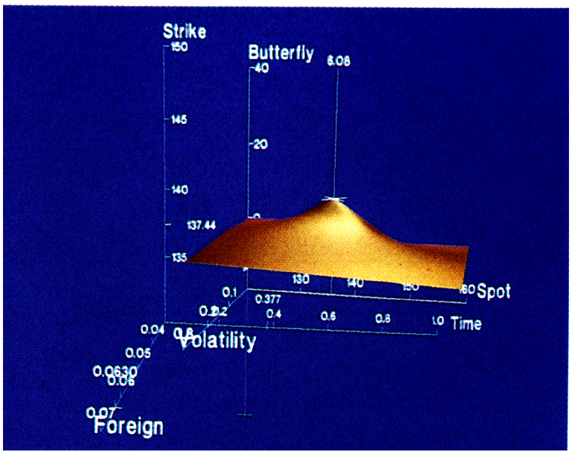


visualization of oil mining data with longitude and latitude mapped to the outer x-, y- axes and ore grade and depth mapped to the inner x-, y- axes

used by permission of M. Ward, Worcester Polytechnic Institute

Hierarchical Techniques

Worlds-within-Worlds [FB 90a/b]



used by permission of C. Beshers, S. Feiner, Columbia University

visualization of a six-dim. function

- partitioning of the n-dim. space into 3-dim. subspaces
  (e.g., a six-dim. object is displayed by having a new coordinate system for the last three dimensions sit inside the coordinate system for the first three)

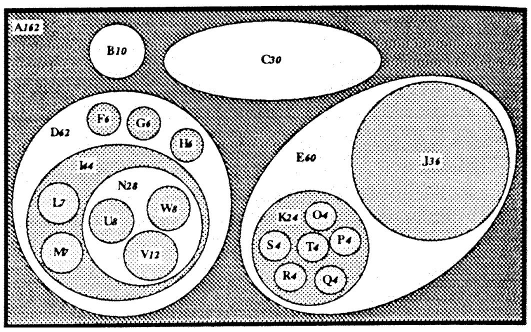
Hierarchical Techniques

Treemap [JS 91, Shn 92, Joh 93]

- screen-filling method which uses a hierarchical partitioning of the screen into regions depending on the attribute values
- the x- and y-dimension of the screen are partitioned alternately according to the attribute values (the attribute value ranges have to be partitioned into classes)
- the attributes used for the partitioning and their ordering are user-defined (the most important attributes should be used first)
- the color of the regions may correspond to an additional attribute
- suitable to get an overview over large amounts of hierarchical data (e.g., file system) and for data with multiple ordinal attributes (e.g., census data)

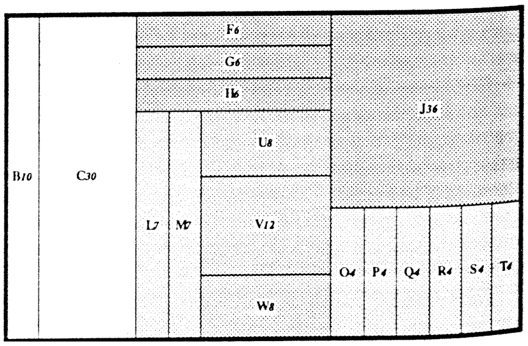
Hierarchical Techniques

Treemap (cont'd)



used by permission of B. Shneiderman, University of Maryland

Venn Diagram

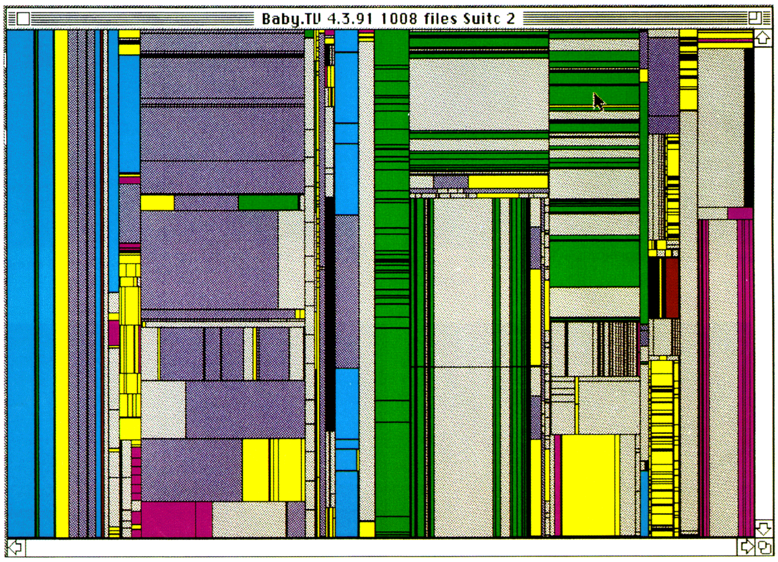


used by permission of B. Shneiderman, University of Maryland

Tree-Map

Hierarchical Techniques

Treemap (cont'd)



treemap of a file system containing about 1000 files

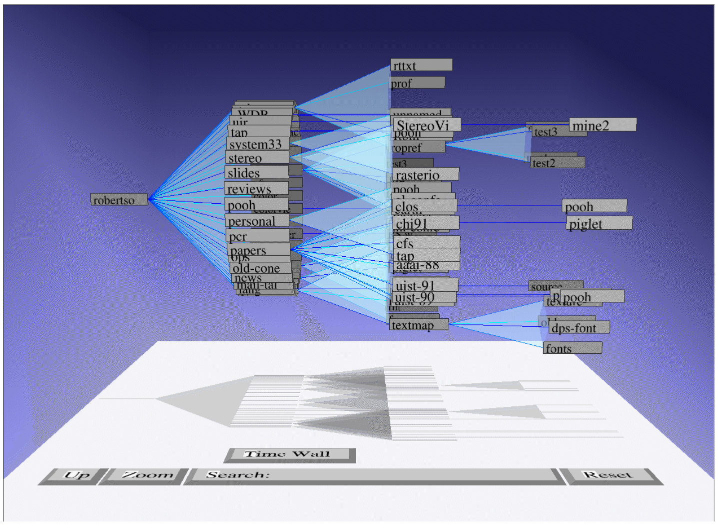
used by permission of B. Shneiderman, University of Maryland

Hierarchical Techniques

Cone Trees [RMC 91, CK 95]

➪ animated 3D visualizations of hierarchical data

used by permission of S. Card, Xerox PARC

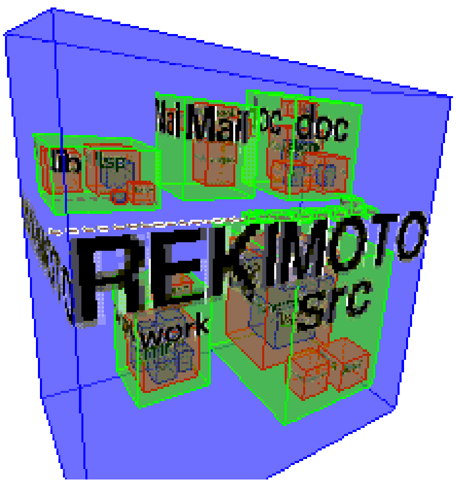


file system structure visualized as a cone tree

Hierarchical Techniques

InfoCube [RG 93]

used by permission of J. Rekimoto, Sony CS Lab Inc.



visualization of a file system structure

➪ 3D visualization of hierarchical data using transparent boxes

Graph-based Techniques

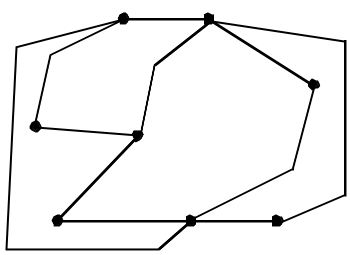
Basic Idea: Visualization of large graphs using techniques to convey the meaning of the graph clearly and quickly.

Overview [CT 94, BETT 94]

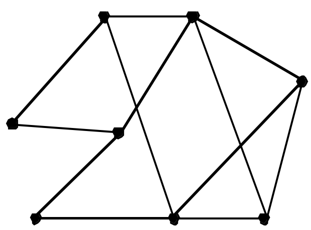
- **Basic Graphs** (e.g., Straight-Line, Polyline, Curved-Line, Orthogonal Graphs, ...)
- **Specific Graphs** (e.g., Directed Acyclic, Cluster-Optimized, Symmetry-Optimized Graphs, Hygraphs, ...)
- **Systems** (e.g., Tom Sawyer, Hy+ [CM93, Con94], SeeNet [EW 93, BEW95], Narcissus [HDWB95], ...)

Graph-based Techniques

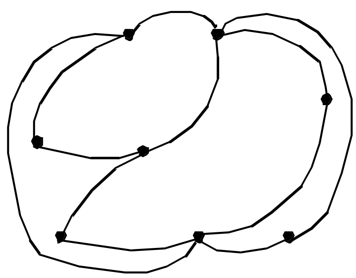
2D-Graph Drawings



Polyline Drawing



Straight-Line Drawing



Curved-Line Drawing

Graph-based Techniques

Properties of 2D-Graph Drawings

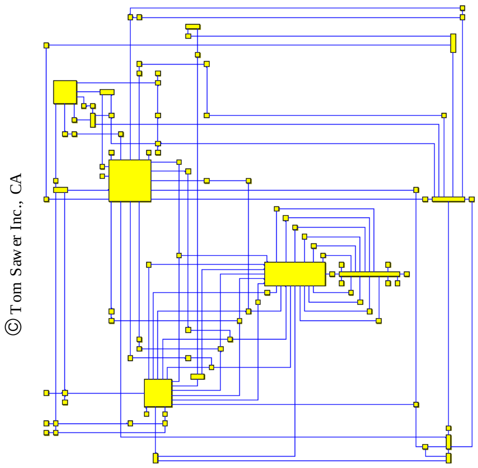
- planarity (no line crossings)
- orthogonality (only orthogonal lines)
- grid property (coordinates of vertices are integers)

Aesthetics Properties (Optimization Goals)

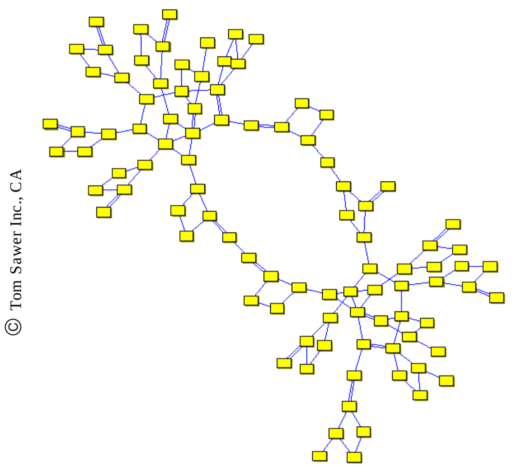
- minimal number of line crossings
- optimal display of symmetries
- optimal display of clusters
- minimal number of bends in polyline graphs
- uniform distribution of vertices
- uniform edge lengths

Graph-based Techniques

2D-Graph Drawings (Examples)



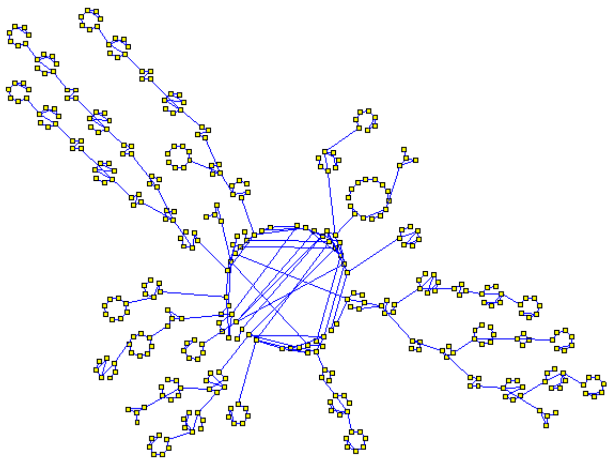
Orthogonal Graph



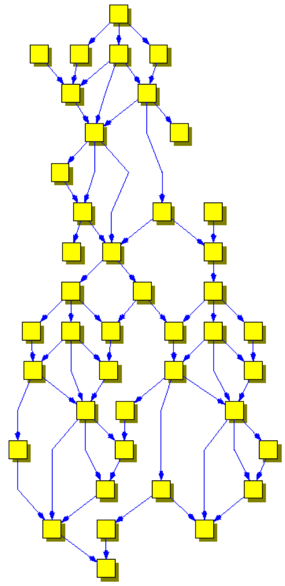
Symmetry-Optimized Graph

Graph-based Techniques

2D-Graph Drawings (Examples)



Cluster-Optimized Graph



Directed Acyclic Graph

Graph-based Techniques

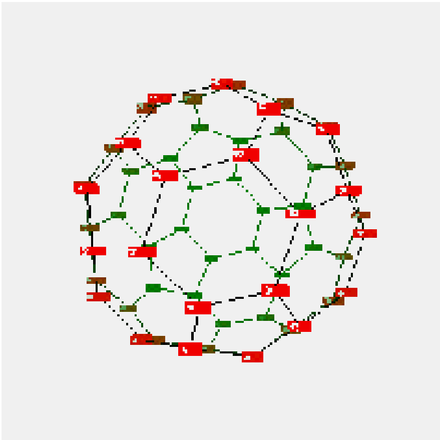
2D-Graph Drawings: Open Problems [BETT 94]

- Performance Bounds (e.g. for planarization, ...)
- Dynamic Algorithms
- Parallel Algorithms
- Complexity of Bend Minimization
- Angular Resolution Constraints
- Three-dimensional Graph Drawings

Graph-based Techniques

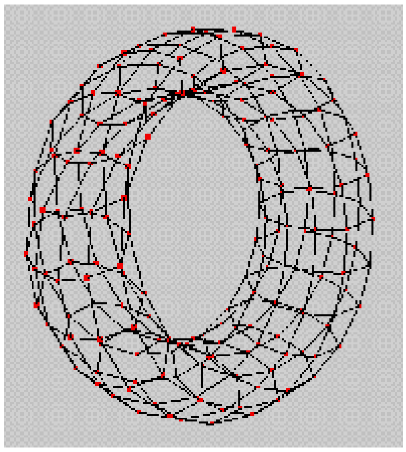
3D-Graph Drawings (cf. [CELR 94])

used by permission of A. Frick, University of Karlsruhe



Ball-like Graph

used by permission of A. Frick, University of Karlsruhe

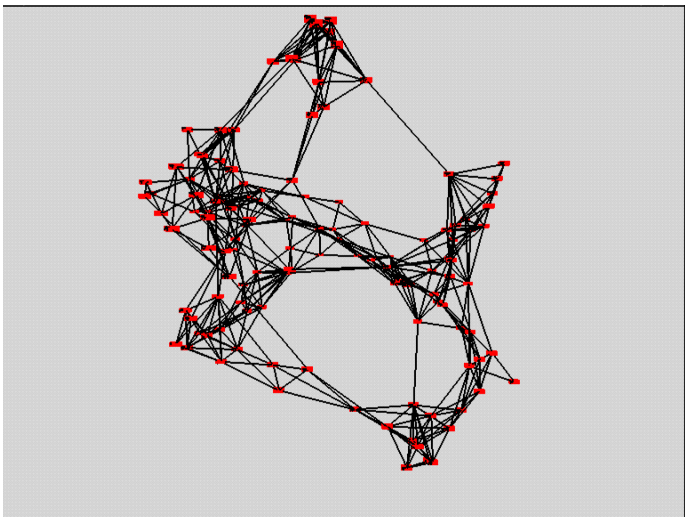


Torrus-like Graph

Graph-based Techniques

3D-Graph Drawings (cont'd)

used by permission of A. Frick, University of Karlsruhe

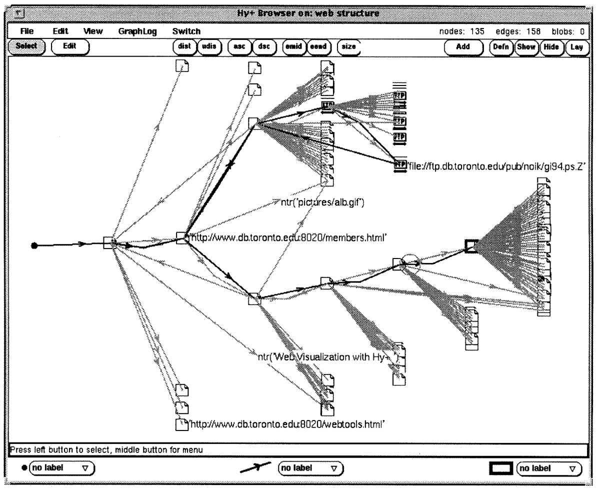


Cluster-Optimized 3D-Graph

Graph-based Techniques

Hygraphs (cont'd)

used by permission of A. Mendelzon, University of Toronto



visualization of a web browsing session

➪ multi-resolution visualization of hygraphs allowing an interactive manipulation using Graphlog

Graph-based Techniques

SeeNet [EW 93, BEW 95]

➪ visualization of hierarchical networks with weighted links

➪ special features of SeeNet:

- semantic node placement
  (minimizing the distance of nodes with high-weighted links)
- attributes are mapped to size and color of nodes and links
- interactivity for
  - changing the mappings
  - expanding or collapsing nodes within the hierarchy
  - getting additional information, etc.

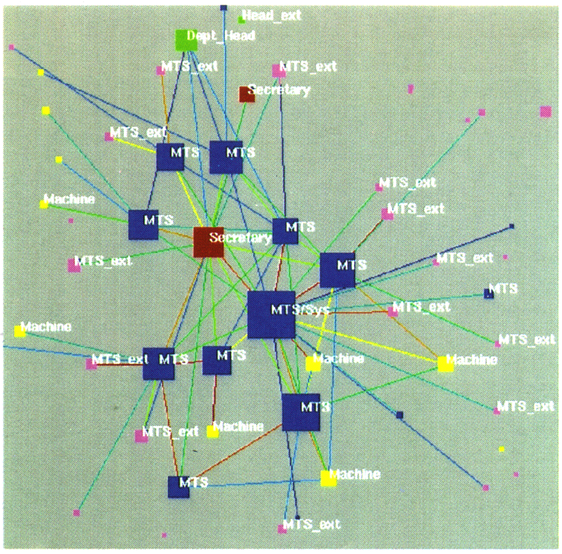
➪ mappings in the example:

- size of nodes: number of e-mail messages of a person
- color of nodes: function of staff members
- size of links: number of e-mail messages of the link
- color of links: blue for few through green and yellow to red for many messages

Graph-based Techniques

SeeNet (cont'd)

used by permission of S. Eick, Bell Labs

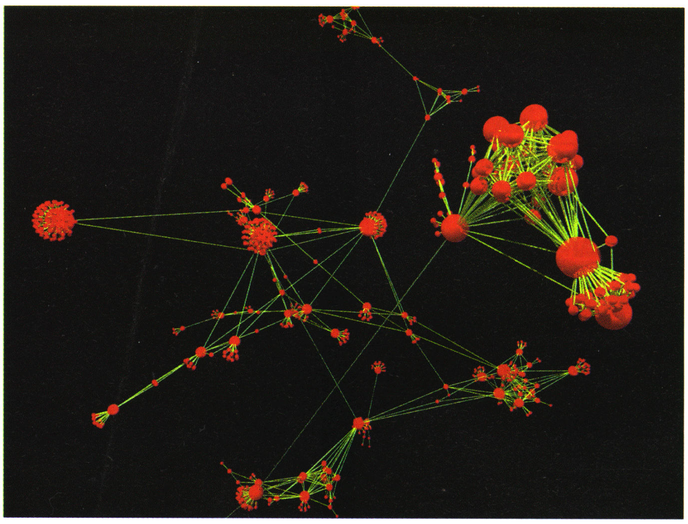


visualization of all e-mail connections in a department over a period of time

Graph-based Techniques

Narcissus [HDWB 95]

used by permission of B. Hendley, University of Birmingham



visualization of a large number of web pages

➪ visualization of complex highly interconnected data (e.g., graphs such as the web)

Hybrid Techniques

Basic Idea: Integrated use of multiple techniques in one or multiple windows to enhance the expressiveness of the visualizations.

- ➪ linking diverse visualization techniques may provide additional information
- ➪ virtually all visualization techniques are combined with dynamics & interactivity

Examples: IVEE [AW 95a/b] uses *Starfield Displays* [AS 94] which are scatter-plots of icons with dynamic zooming and mapping
(combination of geometric, icon-based, and dynamic techniques)

XmDv [War94] allows to dynamically link and brush scatterplot matrices, star icons, parallel coordinates, and dimensional stacking
(combination of geometric, icon-based, hierarchical and dynamic techniques)

Distortion Techniques

Basic Idea: Distortion of the image to allow a visualization of larger amounts of data

Overview [LA 94]

- **Simple:**
  - Perspective Wall [MRC 91]
  - Bifocal Displays [SA 82]
  - TableLens [RC 94]
  - Graph. Fisheye Views [Fur 86, SB 94]
  - Hyperbolic Repr. [LR 94, LRP 95]
- **Complex:**
  - Hyperbolic Repr. [LR 94, LRP 95]
  - 3D-Hyperbolic Repr. [MB95]
  - Hyperbox [AC91]

Distortion Techniques

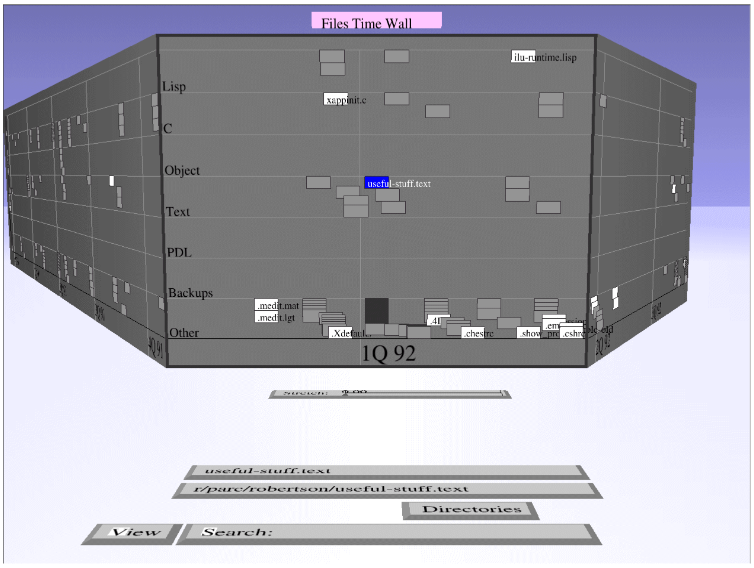
Perspective Wall [MRC 91]

- ➪ presentation of the data on a perspective wall
- ➪ the data outside the focal area are perspectively reduced in size
- ➪ the perspective wall is a variant of the bifocal lens display [SA82] which horizontally compresses the sides of the workspace by direct scaling

Distortion Techniques

Perspective Wall (cont'd)

used by permission of S. Card, Xerox PARC

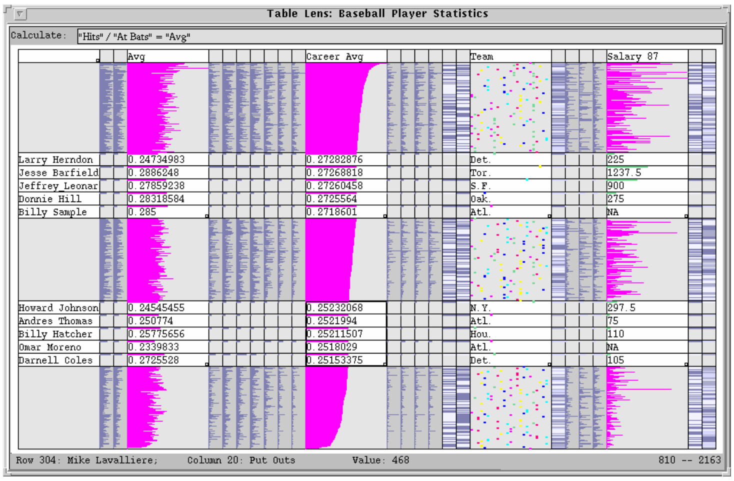


documents arranged on a perspective wall

Distortion Techniques

Table Lens [RC 94]

used by permission of R. Rao, Xerox PARC



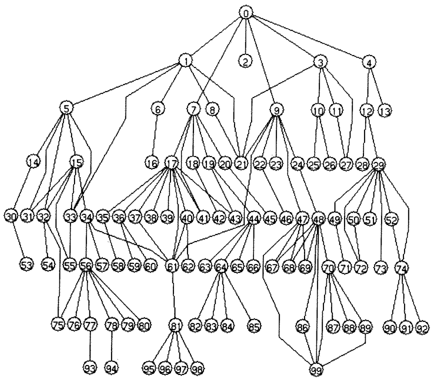
visualization of a baseball database with a few rows being selected in full detail

➪ compact visualization of a table (spreadsheet / database) with the possibility of viewing portions of the table in more detail

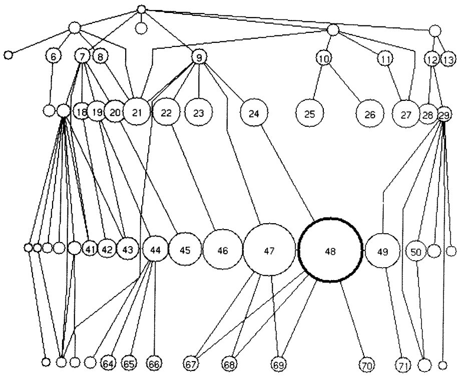
Distortion Techniques

Fisheye View [Fur 86, SB 94]

used by permission of G. Furnas, University of Michigan



original graph



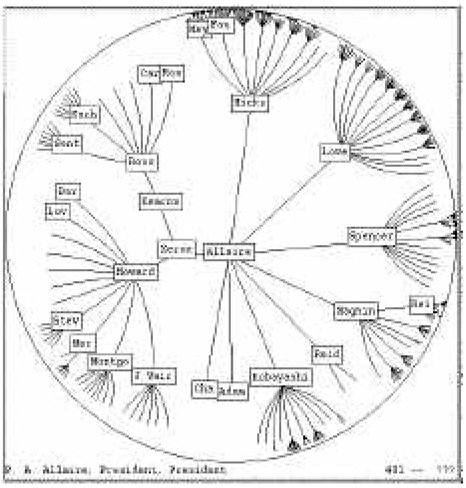
fisheye view of the graph

➪ graph visualization using a fisheye perspective

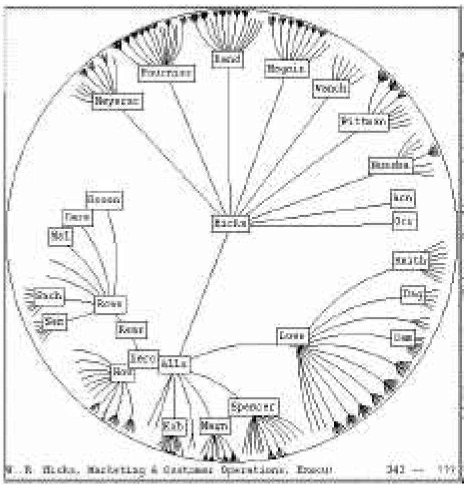
➪ shows an area of interest quite large and with detail and the other areas successively smaller and in less detail

Distortion Techniques

Hyperbolic Trees [LR 94, LRP 95]



used by permission of R. Rao, Xerox PARC



used by permission of R. Rao, Xerox PARC

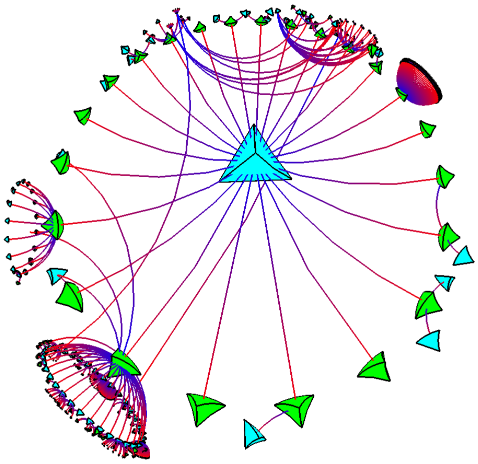
visualization of a large organizational hierarchy

➪ visualization of a tree structure in hyperbolic space with different foci

Distortion Techniques

3D-Hyperbolic Representation [MB 95, MHCF 96]

used by permission of T. Munzner, Stanford University

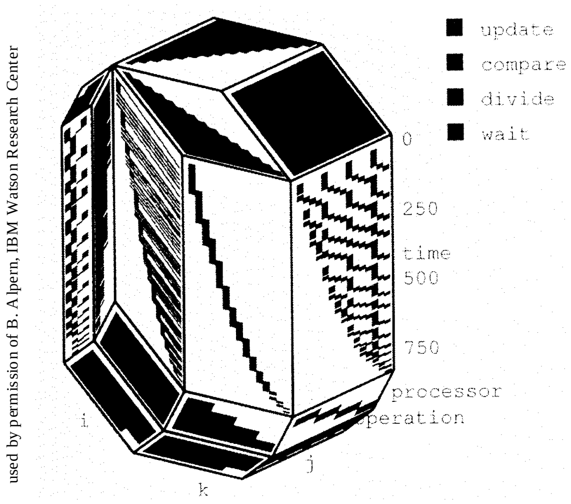


visualization of a large number of connected web-pages

➪ visualization of a graph in 3D hyperbolic conetree-like representation

Distortion Techniques

Hyperbox [AC 91]



parallel processing
performance data
visualized as a hyperbox

➪ mapping of scatterplots onto a hyperbox

Dynamic / Interaction Techniques

Basic Idea: Dynamic generation of the visualizations or interaction with the visualization for a more effective exploration of the data.

Overview

- **Data-to-Visualization Mapping**
- **Projections**
- **Filtering (Selection, Querying)**
- **Linking & Brushing**
- **Zooming**
- **Detail on Demand**

Dynamic / Interaction Techniques

- **Dynamic / Interactive Data-to-Visualization Mapping**
  - dynamic or interactive mapping of the data attributes to the parameters of the visualization
  - parameters of the visualization are
    - x-, y-, and z-axes
    - color and size of icons, links, etc.
  - examples:
    - AutoVisual [BF 93]
    - S Plus [BCW88]
    - XGobi [SCB 92, BCS 96]
    - IVEE / Spotfire [AW 95a/b]
    - SDM [CRMK95], ...

Dynamic / Interaction Techniques

- **Dynamic / Interactive Projections**
  - dynamic or interactive variation of the projections
  - visualization of the remaining parameters in 2D or 3D
  - automatic variation results in an animation of the data
  - examples:
    - GrandTour [Asi 85]
    - S Plus [BCW88]
    - XGobi [SCB 92, BCS 96]
    - Influence & Attribute Explorer [STDS95, SDTS95]
    - ...

Dynamic / Interaction Techniques

❑ Dynamic / Interactive Filtering

➪ dynamic or interactive determination of subsets of the database

➪ distinction between
- ***selection:*** direct selection of the desired subset
- ***querying:*** specification of properties of the desired subset

➪ specific problem: specification of complex boolean conditions

➪ examples:
- Magic Lenses [Bie93] / Moveable Filter [FS 95]
- Filter-Flow Model [YS93]
- InfoCrystal [Spo 93]
- DEVise [Liv 97]
- Dynamic Queries [AS94, Eic 94, GR94]
- ...

Dynamic / Interaction Techniques

Magic Lenses / Moveable Filter [Bie 93, SFB 94, FS 95]

➪ interactive selection using lens-like tools which selectively filter the data in the considered areas

➪ multiple lenses / moveable filters can be used for a multi-level filtering (allowing complex conditions)

© Xerox PARC

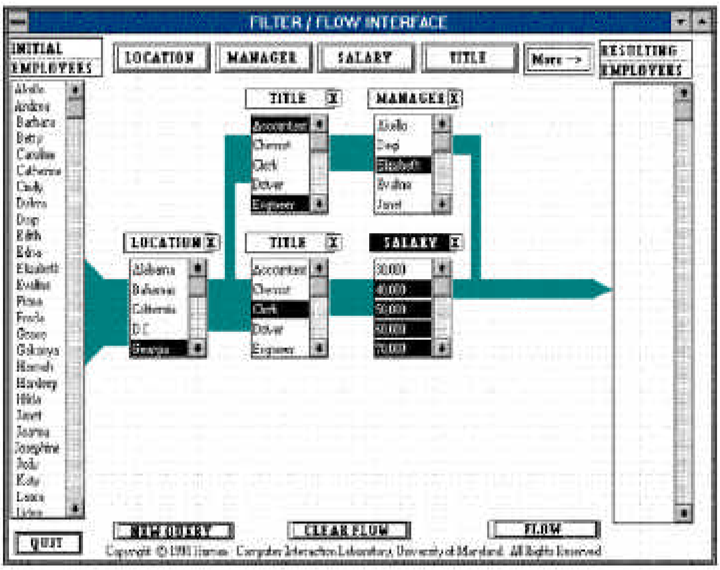
Dynamic / Interaction Techniques

Filter-Flow Model [YS 93]

- ➪ selection based on a dataflow-oriented model:
  the data flows through filter-units which reduce the flow
- ➪ especially useful for an intuitive specification of complex boolean queries:
  - AND-connected query portions may be specified using multiple filter units in a pipeline fashion
  - OR-connected query portions may be specified using multiple independent flows which reunite into a single bigger flow

Dynamic / Interaction Techniques

Filter-Flow Model (cont'd)



used by permission of B. Shneiderman, University of Maryland

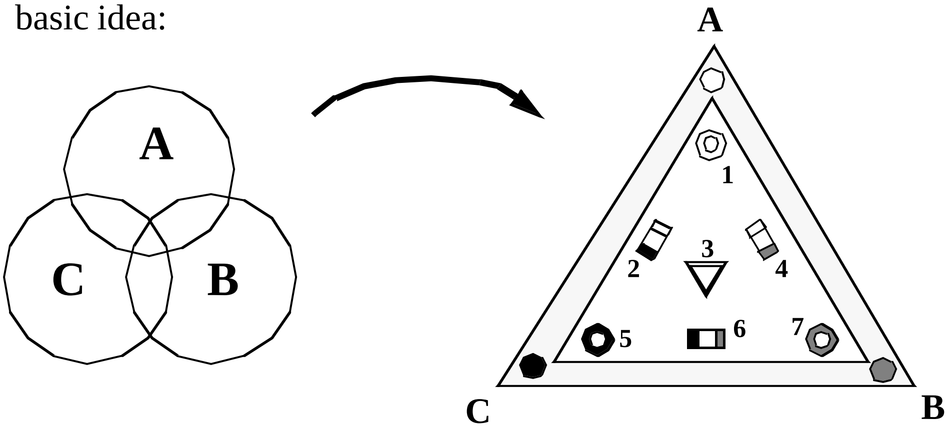
complex boolean query:

Find the accountants or engineers from Georgia who are managed by Elizabeth, or the clerks from Georgia who make more than 30.000!

Dynamic / Interaction Techniques

InfoCrystal [Spo 93]

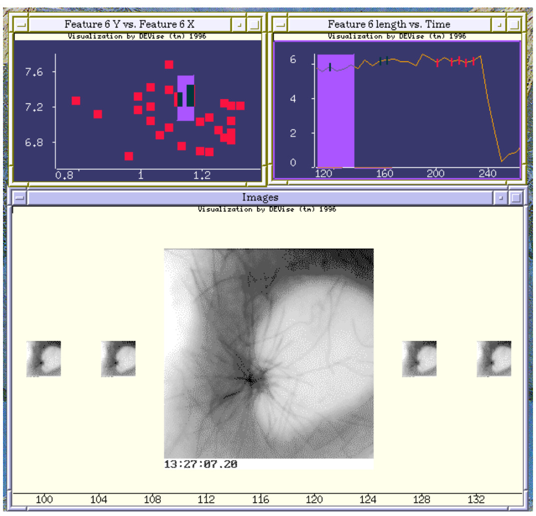
- specification of complex boolean queries using an intuitive model for specifying complex subsets
- basic idea:



Dynamic / Interaction Techniques

DEVise [Liv 97]

- tool set for the construction of interactive visualizations



interactive selection of data items in the upper two subwindows

Dynamic / Interaction Techniques

❑ Dynamic / Interactive Linking & Brushing

➪ prerequisite: multiple visualizations of the same data (e.g., visualizations of different projections)

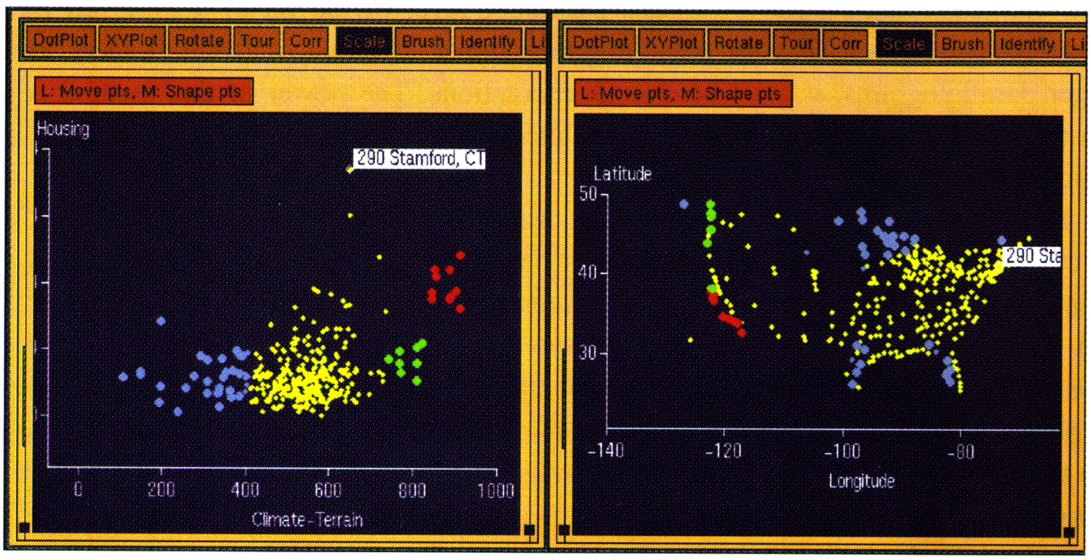
➪ interactive changes made in one visualization are automatically reflected in the other visualizations

➪ examples:
- Xmdv-Tool [War94]
- S Plus [BCW88]
- XGobi [SCB 92, BCS 96]
- DataDesk [Vel92, WUT95]
- ...

Dynamic / Interaction Techniques

XGobi [SCB 92, BSC 96]

used by permission of A. Buja, Bell Labs, © Am. Stat. Assoc.



climate and housing data of the US

taken from [BSC96]

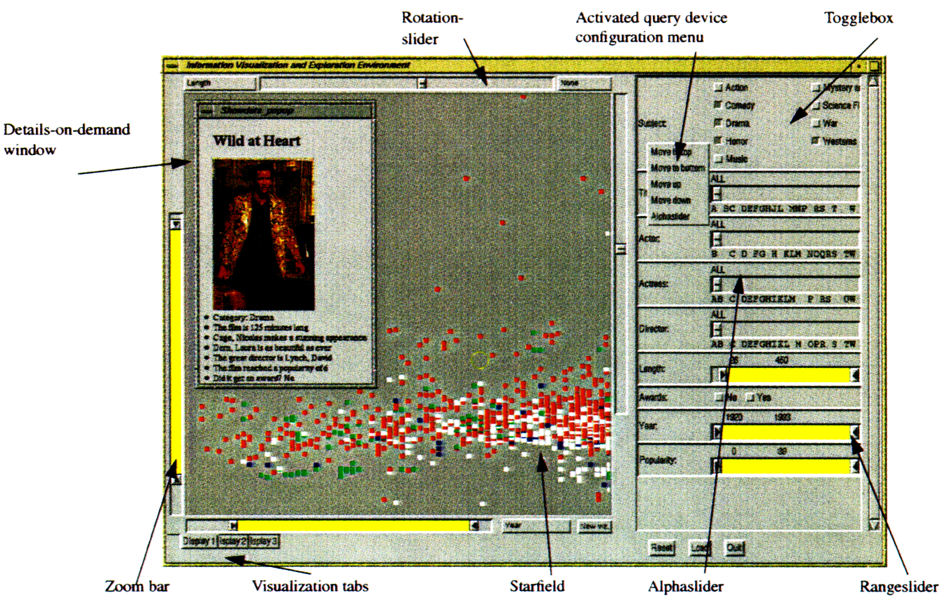
Dynamic / Interaction Techniques

❑ Dynamic / Interactive Zooming

- ➪ visualization of large amounts of data in reduced form to provide an overview of the data
- ➪ variable zooming of the data with automatic changes of the visualization modes to present more details
- ➪ examples:
  - PAD++ [PF 93, Bed 94, BH94]
  - IVEE [AW95a/b]
  - DataSpace [ADLP 95]
  - ...
- ➪ a comparison of fisheye and zooming techniques can be found in [Sch93]

Dynamic / Interaction Techniques

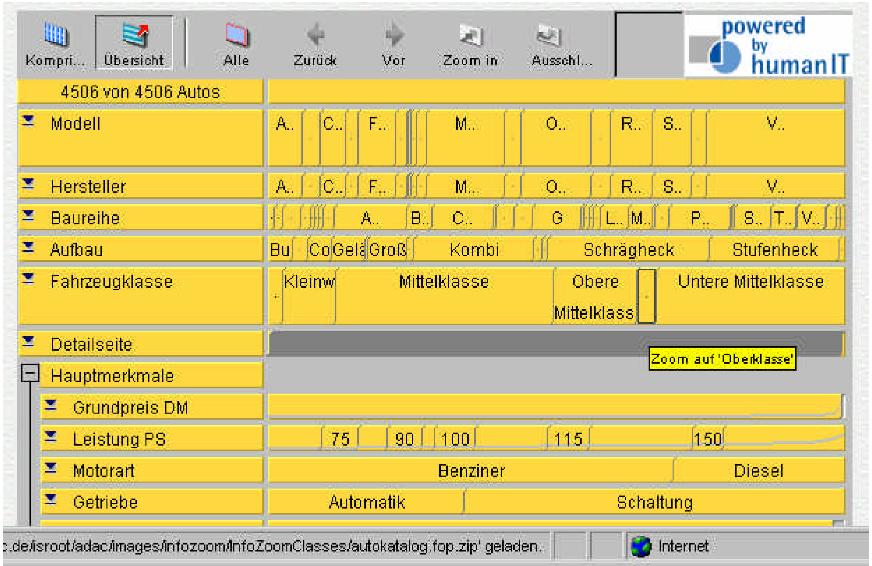
IVEE / Spotfire [AW 95a/b]



used by permission of C. Ahlberg, IVEE Development

Dynamic / Interaction Techniques

InfoZoom [Hum 01]



used by permission of H.-G. Lindner, HumanIT

web-pages of the German Automobile Association (ADAC)

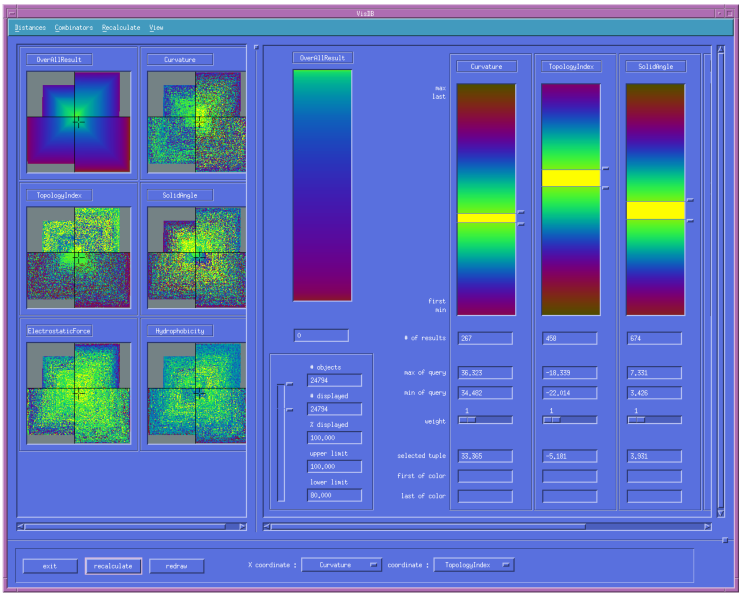
Dynamic / Interaction Techniques

❑ Interactive Details on Demand

- ➪ the possibility to interactively obtain more details of the visualized data
- ➪ details are, for example, the attribute values corresponding to an icon or additional attribute values of a data item
- ➪ examples:
  - IVEE / Spotfire [AW 95a/b]
  - Table Lens [RC 94]
  - Magic Lens [Bie 93]
  - VisDB [KK 94, KK 95]
  - ...

Dynamic / Interaction Techniques

VisDB [Kei 94]



Comparison of the Techniques

Criteria for Comparison [KK 96]

comparison of the described information visualization techniques based on their suitability for certain

- ➪ **data characteristics**
  (e.g., no. of variates, no. of data items, categorical data,...)
- ➪ **task characteristics**
  (e.g., clustering, multi variate hot spots,...)
- ➪ **visualization characteristics**
  (e.g., visual overlap, learning curve, ...)

<u>Disclaimer:</u> The following comparison table expresses my personal opinion obtained from reading the literature and experimenting with several of the described techniques. Many of the ratings are arguable and largely depend on the considered data, the exploration task, experience of the user, etc. In addition, implementations of the techniques in real systems usually avoid the drawbacks of a single technique by combining it with other techniques, which is also not reflected in the ratings.

Comparison of the Techniques

Comparison: An Attempt

		clustering	multi-variate hot spot	no. of variates	no. of data items	categorical data	visual overlap	learning curve
Geometric Techniques	Scatterplot Matrices	++	++	+	+	-	o	++
	Landscapes	+	+	-	o	o	+	+
	Prosection Views	++	++	+	+	-	o	+
	Hyperslice	+	+	+	+	-	o	o
	Parallel Coordinates	o	++	++	-	o	--	o
Icon-based Techniques	Stick Figure	o	o	+	-	-	-	o
	Shape Coding	o	-	++	+	-	+	-
	Color Icon	o	-	++	+	-	+	-
Pixel-oriented Techniques	Query-Independent	+	+	++	++	-	++	+
	Query-Dependent	+	+	++	++	-	++	-
Hierarchical Techniques	Dimensional Stacking	+	+	o	o	++	o	o
	Worlds-within-Worlds	o	o	o	+	o	o	o
	Treemap	+	o	+	o	++	+	o
	Cone Trees	+	+	o	+	o	+	+
	InfoCube	o	o	-	-	o	o	+

Database Visualization Systems

Overview

- **Statistics-oriented Systems**
- **Visualization-oriented Systems**
- **Database-oriented Systems**
- **Special Purpose Visualization Systems**

Database Visualization Systems

- **Statistics-oriented Systems**
  - SPlus [BCW 88] / Trellis [BCS 96]
    (→ generic system for statistical analysis and visualization)
  - XGobi [XGobi, SCB 92, BSC96]
    (→ extensible lisp-based system for statistical analysis and visualization)
  - Data Desk [Vel92, WUT95]
    (→ commercial system for statistical analysis and visualization; features: dyn. linking & brushing of scatterplots and histograms)
  - Diamond (SPSS)
    (→ commercial system for statistical analysis and visualization; features: dyn. linking & brushing of scatterplots, parallel coordinates, etc.)
  - DataSpace [ADLP 95]
    (→ 3D-arrangement of a large number of arbitrary visualizations)

Database Visualization Systems

- **Visualization-oriented Systems**
  - ExVis [GPW 89]
    (→ features: stick figure and other icon-based techniques)
  - Parallel Visual Explorer (IBM)
    (→ features: parallel coordinate technique with query-based coloring, etc.)
  - XmDv [War94, MW95]
    (→ features: scatterplot matrices, star icons, parallel coordinates, dimensional stacking, dynamic linking and brushing)
  - Influence & Attribute Explorer [STDS95, SDTS 95]
    (→ features: scatterplot and prosection matrices, histograms, dynamic linking and brushing)
  - Information Visualizer (Xerox) [HC86, CRY96]
    (→ features: diverse information visualization techniques including perspective wall, table lens, cone trees)

Database Visualization Systems

❑ **Database-oriented Systems**

- ➪ Hy+ [CM 93]
  (→ features: query and visualizations of hygraphs)
- ➪ TreeViz [Joh 93]
  (→ features: treemap technique)
- ➪ VisDB [KK94, KK95]
  (→ system for interactive slider-based exploration of very large databases
  features: stick figure, parallel coordinate, and pixel-oriented techniques)
- ➪ IVEE [AW 95a/b] / Spotfire
  (→ commercial system for database exploration;
  features: generic interactive slider-based visualization environment)
- ➪ DEVise [Liv 97]
  (→ system for the generation of interactive special purpose database visualizations)

Database Visualization Systems

❑ **Special Purpose Visualization Systems**

- ➪ Software & Algorithm Visualization
  (e.g., SeeSoft [ESS92, BE96] - a listing of Software & Algorithm Interfaces can be found under "http://wwwbroy.informatik.tu-muenchen.de/~trilk/sv.html"
  for an overview paper see [SP92])
- ➪ Web Visualization
  (e.g., Narcissus [HDWB95], WebBook and WebForager [CRY96]
  - a listing of Web Visualization Interfaces can be found under
  "http://www.geog.ucl.ac.uk/casa/martin/geography_of_cyberspace.html")
- ➪ Visualization in Information Retrieval
  (e.g., Vibe [Ols93] - a bibliography of Information Retrieval Interfaces can be found under "http://www.pitt.edu/~korfhage/viri_bib.htm";
  for an overview paper see [Car 96])

Summary and Conclusions

Summary

- there are a number of recently developed visualization techniques which are applicable to database exploration
- there are different techniques for different types of data (relational tables, hierarchies, graphs, etc.)
- many of the techniques are applicable to traditional relational information sources
- there are a number of research prototypes and commercial systems available

Summary and Conclusions

Research Issues

- development of integrated information visualization and exploration systems
  (integration with techniques from statistics, machine learning, databases, ...)
- in-depth evaluation and comparison of visualization techniques for database exploration (-> possibilities for improvement)
- using more dynamics & interaction to steer the mining process
- case studies in a variety of application areas

Bibliography

[AC91] Alpern B., Carter L.: *'Hyperbox'*, Proc. Visualization '91, San Diego, CA, 1991, pp.133-139.

[ADLP95] Anupam V., Dar S., Leibfried T., Petajan E.: *'DataSpace: 3-D Visualization of Large Databases'*, Proc. Int. Symp. on Information Visualization, Atlanta, GA, 1995, pp.82-88.

[AKK96] M. Ankerst, D. A. Keim, H.-P. Kriegel: *'Circle Segments: A Technique for Visually Exploring Large Multidimensional Data Sets'*, VISUALIZATION '96, HOT TOPIC SESSION, San Francisco, CA, 1996.

[And72] Andrews D. F.: *'Plots of High-Dimensional Data'*, in: Biometrics, Vol.29, 1972, pp.125-136.

[And95] Andrews K.: *'Visualizing Cyberspace: Information Visualization in the Harmony Internet Browser'*, Proc. Int. Symp. on Information Visualization, Atlanta, GA, 1995, pp.97-104.

[AS94] Ahlberg C., Shneiderman B.: *'Visual Information Seeking: Tight Coupling of Dynamic Query Filters with Starfield Displays'*, Proc. Human Factors in Computing Systems CHI '94 Conf., Boston, MA, 1994, pp. 313-317.

[AS95] Ayers E. Z., Stasko J. T.: *'Using Graphic History in Browsing the World Wide Web'*, Proc. 4th Int. World Wide Web Conf., Boston, MA, 1995.

[Asi85] Asimov D.: *'The Grand Tour: A Tool For Viewing Multidimensional Data'*, SIAM Journal of Science & Stat. Comp., Vol. 6, 1985, pp.128-143.

[AW95a] Ahlberg C., Wistrand E.: *'IVEE: An Environment for Automatic Creation of Dynamic Queries Applications'*, Proc. Human Factors in Computing Systems CHI '95 Conf., Demo Program, Denver, CO, 1995.

Bibliography

[AW95b] Ahlberg C., Wistrand E.: *'IVEE: An Information Visualization and Exploration Environment'*, Proc. Int. Symp. on Information Visualization, Atlanta, GA, 1995, pp.66-73.

[BCS 96] Becker R. A., Cleveland W. S., Shyu M.-J.: *'The Visual Design and Control of Trellis Display'*, Journal of Computational and Graphical Statistics, Vol. 5, No. 2, 1996, pp.123-155.

[BSC96] Buja A., Swayne D. F., Cook D.: *'Interactive High-Dimensional Data Visualization'*, Journal of Computational and Graphical Statistics, Vol.5, No.1, 1996, pp.78-99.

[BCW88] Becker R., Chambers J. M., Wilks A. R.: *'The New S Language'*, Wadsworth & Brooks/Cole Advanced Books and Software, Pacific Grove, CA, 1988.

[BE96] Ball T., Eick S.: *'Software Visualization in the Large'*, Computer, Vol. 29, No. 4, 1996, pp.33-43.

[Bed90] Beddow J.: *'Shape Coding of Multidimensional Data on a Mircocomputer Display'*, Visualization'90, San Francisco, CA, 1990, pp.238-246.

[Bed94] Bederson B.: *'Pad++: Advances in Multiscale Interfaces'*, Proc. Human Factors in Computing Systems CHI '94 Conf., Boston, MA, 1994, p. 315.

[BEMW 90] Becker R. A., Eick S. G., Miller E. O., Wilks A. R.: *'Dynamic Graphics for Network Visualization'*, Proc. Visualization '90, San Francisco, CA, 1990, pp.93-95.

[Ben 95] Benford S., Snowdon D., Greenhaigh C., Ingram R., Knox I., Brown C.: *'Vr-vibe: A Virtual Environment for Co-operative Information Retrieval'*, Proc. Eurographics '95, Maastricht, The Netherlands, 1995, pp. 349-360.

Bibliography

[Ber81] Bertin J.: *'Graphics and Graphic Information Processing'*, Berlin, 1981.

[BETT 94] Battista G. D., Eades P., Tamassia R., Tollis I.: *'Annotated Bibliography on Graph Drawing Algorithms'*, Computational Geometry: Theory and Applications, Vol. 4, 1994, pp.235-282.

[BEW 95] Becker R. A., Eick S. G., Wilks A. R.: *'Visualizing Network Data'*, Transactions on Visualization and Computer Graphics, Vol. 1, No. 1, 1995, pp.16-28.

[BF93] Beshers C., Feiner S.: *'AutoVisual: Rule-Based Design of Interactive Multivariate Visualizations'*, IEEE Computer Graphics and Applications, Vol.13, No. 4, 1993, pp.41-49.

[BFN 86] Boecker H.-D., Fischer G., Nieper H.: *'The Enhancement of Unterstanding through Visual Representations'*, Proc. Human Factors in Computing Systems CHI '86 Conf., Boston, MA, 1986, pp.44-58.

[BH86] Bryce D., Hull R.: *'SNAP: A Graphics Based Schema Manager'*, Proc. 2ndInt. Conf. on Data Engineering, Los Angeles, CA, 1986, pp.151-164.

[BH 91] Brown M. H., Hershberger J.: *'Color and Sound in Algorithm Animation'*, Proc. IEEE Symp. on Visual Languages, 1991, pp.10-17.

[BH 94] Bederson B. B., Hollan J. D.: *'Pad++: A Zooming Graphical Interface for Exploring Alternate Interface Physics'*, Proc. UIST, 1994, pp.17-26.

Bibliography

[Bie 93] Bier E. A., Stone M. C., Pier K., Buxton W., DeRose T.: *'Toolglass and Magic Lenses: The see-through Interface'*, Proc. SIGGRAPH '93, Anaheim, CA, 1993, pp.73-80.

[BMMS91] Buja A., McDonald J.A., Michalak J., Stuetzle W.: *'Interactive Data Visualization Using Focusing and Linking'*, Visualization'91, San Diego, CA, 1991, pp.156-163.

[BN 93] Brown M. H., Najork M. A.: *'Algorithm Animation Using 3D Interactive Graphics'*, Proc. UIST, 1993, pp.93-100.

[Bro 91] Brown M. H.: *'Zeus: A System for Algorithm Animation and Multi-View Editing'*, Proc. IEEE Symp. on Visual Languages, 1991, pp.4-9.

[Car 96] Card S. K.: *'Visualizing Retrieved Information: A Survey'*, IEEE CG&A, 1996, pp. 63-67.

[CE95] Cox K. C., Eick S. G.: *'3D Displays of Internet Traffic'*, Proc. Symp. on Information Visualization, Atlanta, GA, 1995, pp.129-131.

[CELR94] Cohen R. F., Eades P., Lin T., Ruskey F.: *'Three-dimensional Graph Drawing'*, Proc. Graph Drawing, 1994, in: Lecture Notes in Computer Science, Vol. 894, Springer, 1994, pp.1-11.

[Che73] Chernoff H.: *'The Use of Faces to Represent Points in k-Dimensional Space Graphically'*, Journal Amer. Statistical Association, Vol. 68, pp.361-368.

[CK 95] Carrière J., Kazman R.: *'Interacting with Huge Hierarchies: Beyond Cone Trees'*, Proc. Symp. on Information Visualization, Atlanta, GA, 1995, pp.90-96.

Bibliography

[Cle93] Cleveland W. S.: *'Visualizing Data'*, AT&T Bell Laboratories, Murray Hill, NJ, Hobart Press, Summit NJ, 1993.

[Cle94] Cleveland W. S.: *'The Elements of Graphing Data'*, Hobart Press, Summit, NJ, revised edition.

[CM93] Consens M. P., Mendelzon A. O.: *'Hy+: A Hygraph-based Query and Visualization System'*, Proc. ACM SIGMOD Int. Conf. on Management of Data, Washington, DC, 1993, pp.511-516.

[Con94] Consens M. P., Eigler F. Ch., Hasan M. Z., Mendelzon A. O., Noik E. G., Ryman A. G., Vista D.: *'Architecture and Applications of the Hy+ Visualization System'*, IBM Systems Journal, Vol.33, No.3, 1994, pp.458-476.

[CPS 95] Chan M. C., Pacifici G., Stadler R.: *'Managing Real-Time Services in Multimedia Networks Using Dynamic Visualization and high-level Controls'*, Proc. Multimedia '95, San Francisco, CA, 1995.

[CR92] Cox K. C., Roman G.-C.: *'Abstraction in Algorithm Animation'*,Proc. Symp. on Visual Languages, 1992, pp.18-23.

[CRMK 95] Chuah M. C., Roth S. F., Mattis J., Kolojejchick J.: *'SDM: Malleable Information Graphics'*, Proc. Symp. on Information Visualization '95, Atlanta, GA, 1995, pp.36-42.

[CRY 96] Card S. K., Robertson G. G., York W.: *'The WebBook and the WebForager: An Information Workspace for the World Wide Web'*, Proc. Human Factors in Computing Systems CHI '96 Conf., 1996.

[CT 94] Cruz I. F., Tamassia R.: *'How to Visualize a Graph: Specification and Algorithms'*, 1994.

Bibliography

[DE82] Dunn G., Everitt B.: *'An Introduction to Mathematical Taxonomy'*,Cambridge University Press, Cambridge, MA, 1982.

[DH 95] Drew N. S., Hendley R. J.: *'Visualizing Complex Interacting Systems'*, Proc. Human Factors in Computing Systems CHI'95 Conf., Denver, CO, 1995, pp.204-205.

[Doe94] Doemel P.: *'Webmap - A Graphical Hypertext Navigation Tool'*, Proc. 2nd Int. World Wide Web Conf., Chicago, IL, 1994.

[Eic94] Eick S. G.: *'Data Visualization Sliders'*, Proc. ACM UIST, 1994, pp.119-120.

[Eic96] Eick S. G.: *'Aspects of Network Visualization'*, Proc. IEEE CG&A, 1996, pp.69-72.

[ES92] Eick S. G., Steffen J. L.: *'Visualizing Code Profiling Line Oriented Statistics'*, Proc. Visualization '92, Boston, MA, 1992, pp.210-217.

[ESS92] Eick S.G., Steffen J.L., Sumner E.E.: *'SeeSoft - A Tool for Visualizing Software'*, IEEE Transactions on Software Engineering, Vol.18, No.11, 1992, pp. 957-968.

[EW93] Eick S. G., Wills G. J.: *'Navigating Large Networks with Hierarchies'*, Visualization'93, San Jose, CA, 1993, pp.204-210.

[FB90a] Feiner S., Beshers C.: *'Visualizing n-Dimensional Virtual Worlds with n-Vision'*, Computer Graphics, Vol. 24, No. 2, 1990, pp.37-38.

Bibliography

[FB90b] Feiner S., Beshers C.: *'World within World: Metaphors for Exploring n-dimensional Virtual Worlds'*, Proc. UIST, 1990, pp.76-83.

[FB94] Furnas G. W., BujaA.: *'Prosections Views: Dimensional Inference through Sections and Projections'*, Journal of Computational and Graphical Statistics, Vol.3, No.4, 1994, pp.323-353.

[FB95] Furnas G. W., Bederson B. B.: *'Space-Scale Diagrams: Unterstanding Multiscale Interfaces'*, Proc. Human Factors in Computing Systems CHI '95 Conf., Denver, CO, 1995.

[FL95] Faloutsos C., Lin K.: *'Fastmap: A fast Algorithm for Indexing, Data-Mining and Visualization of Traditional and Multimedia Datasets'*, Proc. ACM SIGMOD Int. Conf. on Management of Data, San Jose, CA, 1995, pp.163-174.

[FPF 88] Fairchild K., Poltrok S., Furnas G.: *'SemNet: Three Dimensional Graphic Representations of Large Knowledge Bases'* , Lawrence Erlbaum (ed.), 1988, pp.201-233.

[FS95] Fishkin K., Stone M. C.: *'Enhanced Dynamic Queries via Movable Filters'*, Proc. Human Factors in Computing Systems CHI '95 Conf., Denver, CO, 1995, pp.415-420.

[Fur86] Furnas G.: *'Generalized Fisheye Views'*, Proc. Human Factors in Computing Systems CHI'86 Conf., Boston, MA, 1986, pp.18-23.

[FW94] Frolich M., Werner M.: *'Demonstration of the Interactive Graph Visualization System da vinci'*, Proc. Graph Drawing, 1994, in: Lecture Notes in Computer Science, Vol. 894, Springer, 1994, pp.266-269.

Bibliography

[FZ94] Furnas G. W., Zacks J.: *'Multitrees: Enriching and Reusing Hierarchical Structures'*, Proc. Human Factors in Computing Systems CHI '94 Conf., Boston, MA, 1994, pp.330-336.

[Ger95] Gershon N., LeVasseur J., Winstead J., Croall J., Pernick A., Ruh W.: *'Visualizing Internet Resources'*, Proc. Symp on Information Visualization '95, Atlanta, GA, 1995, pp.122-128.

[Ger96] Gershon N.: *'Moving Happily Through the World Wide Web'*, Proc. IEEE CG&A, 1996, pp.72-74.

[GKNV93] Gansner E. R., Koutsofois E., North S. C., Vo K.-P.: *'A Technique for Drawing Directed Graphs'*, IEEE Transactions on Software Engineering, Vol. 19, No. 3, 1993, pp.214-229.

[GPW89] Grinstein G, Pickett R., Williams M. G.: *'EXVIS: An Exploratory Visualization Environment'*, Proc. Graphics Interface '89, London, Ontario, Canada, 1989.

[GR94] Goldstein J., Roth S. F.: *'Using Aggregation and Dynamic Queries for Exploring Large Data Sets'*, Proc. Human Factors in Computing Systems CHI '94 Conf., Boston, MA, 1994, pp.23-29.

[GT96] Garg A., Tamassia R.: *'Giotto3d: A System for Visualizing Hierarchical Structures in 3d'*, Proc. Graph Drawing,'96, in: Lecture Notes in Computer Science, Springer, 1996.

[Har67] Harman H. H.: *'Modern Factor Analysis'*, University of Chicago Press, 1967.

[HC86] J.D.A. Henderson and S.K. Card: 'Rooms: The Use of Multiple Virtual Workspaces to Reduce Space Contention in Window-based Graphical User Interfaces', ACM Trans. on Graphics, Vol. 5, No. 3, July 1986, pp. 211-241.

Bibliography

[HDWB95] Hendley R. J., Drew N. S., Wood A. M., Beale R.: *'Narcissus: Visualizing Information'*, Proc. Int. Symp. on Information Visualization, Atlanta, GA, 1995, pp.90-94.

[Hea 95] Hearst M.: *'TileBars: Visualization of Term Distribution Information in Full Text Information Access'*, Proc. of ACM Human Factors in Computing Systems Conf. (CHI'95), 1995, pp. 59-66.

[Him94] Himsolt M. : *'Graphed: A Graphical Platform for the Implementation of Graph Algorithms'*, Proc. Graph Drawing'94, in: Lecture Notes in Computer Science, Vol. 894, Springer, pp.182-193.

[Hub85] Huber P. J.: *'Projection Pursuit'*, The Annals of Statistics, Vol. 13, No.2, 1985, pp.435-474.

[Hum 01] HumanIT Web Page: „http://www.humanit.de/infozoom", Feb. 2001.

[Ins85] Inselberg A.: *'The Plane with Parallel Coordinates, Special Issue on Computational Geometry'*, The Visual Computer, Vol. 1, 1985, pp.69-97.

[ID90] Inselberg A., Dimsdale B.: *'Parallel Coordinates: A Tool for Visualizing Multi-Dimensional Geometry'*, Visualization '90, San Francisco, CA, 1990, pp.361-370.

[JJ94] Jeron T., Jard C.: *'3D Layout of Reachability Graphics of Communicating Processes'*, Proc. Graph Drawing '94, in: Lecture Notes in Computer Science, Vol. 894, 1994, pp.25-32.

[Joh93] Johnson B.: *'Visualizing Hierarchical and Categorical Data'*, Ph.D. Thesis, Department of Computer Science, University of Maryland, 1993.

Bibliography

[JS91] Johnson B., Shneiderman B.: *'Treemaps: A Space-filling Approach to the Visualization of Hierarchical Information'*, Proc. Visualization '91 Conf., 1991, pp.284-291.

[JS95] Jerding D. F., Stasko J. T.: *'The Information Mural: A Technique for Displaying and Navigating Large Information Spaces'*, Proc. Symp. on Information Visualization '95, Atlanta, GA, 1995, pp.43-50.

[Kei 94] D. A. Keim: *'Visual Support for Query Specification and Data Mining'*, Shaker-Verlag, 1994, ISBN 3-8265-0594-8.

[Kei 95] D. A. Keim: *'Enhancing the Visual Clustering of Query-dependent Database Visualization Techniques using Screen-Filling Curves'*, Proc. Workshop on Database Issues for Data Visualization, Atlanta, GA, 1995, Springer, in: Lecture Notes in Computer Science, No. 1183, Springer, pp. 101-110.

[Kei96] Keim D. A.: *'Pixel-oriented Visualization Techniques for Exploring Very Large Databases'*, Journal of Computational and Graphical Statistics, Vol. 5, No. 1, 1996, pp. 58-77.

[KK94] Keim D. A., Kriegel H.-P.: *'VisDB: Database Exploration using Multidimensional Visualization'*, Computer Graphics & Applications, Sept.1994, pp.40-49.

[KK95] Keim D. A., Kriegel H.-P. : *'VisDB: A System for Visualizing Large Databases'*, System Demonstration, Proc. ACM SIGMOD Int. Conf. on Management of Data, San Jose, CA, 1995, p.482.

[KKA95] Keim D. A., Kriegel H.-P., Ankerst M.: *'Recursive Pattern: A Technique for Visualizing Very Large Amounts of Data'*, Proc. Visualization '95, Atlanta, GA, 1995, pp.279-286.

Bibliography

[KKS 93] D. A. Keim, H.-P. Kriegel, T. Seidl: *'Visual Feedback in Querying Large Databases'*, PROC. VISUALIZATION '93, San Jose, CA, 1993, pp.158-165.

[KKS94] Keim D. A., Kriegel H.-P., SeidlT.: *'Supporting Data Mining of Large Databases by Visual Feedback Queries'*, Proc. 10th Int. Conf. on Data Engineering, Houston, TX, 1994, pp.302-313.

[KK 96] Keim D. A., Kriegel H.-P.: 'Visualization Techniques for Mining Large Databases: A Comparison', Transactions on Knowledge and Data Engineering, Vol. 8, No. 6, Dec. 1996, pp. 923-938.

[KL93] Keim D. A., Lum V.: *'GRADI: A Graphical Database Interface for a Multimedia DBMS'*, Proc. Int. Workshop on Interfaces to Databases, Glasgow, England, 1992, in: Workshops in Computing, Springer, 1993, pp.95-112.

[KRB94] Kaugars K., Reinfelds J., Brazma A.: *'A Simple Algorithm for Drawing Large Graphs on Small Screens'*, Proc. Graph Drawing '94, in: Lecture Notes in Computer Science, Vol. 894, Springer, 1994, pp.278-281.

[LA94] Leung Y., Apperley M.: *'A Review and Taxonomy of Distortion-oriented Presentation Techniques'*, Proc. Human Factors in Computing Systems CHI '94 Conf., Boston, MA, 1994, pp. 126-160.

[Lev91] Levkowitz H.: *'Color icons: Merging color and texture perception for integrated visualization of multiple parameters'*, In Visualization '91, San Diego, CA, October 22-25 1991.

Bibliography

[Liv 97] M. Livny, R. Ramakrishnan, K. Beyer, G. Chen, D. Donjerkovic, S. Lawande, J. Myllymaki, and K. Wenger: 'DEVise: Integrated Querying and Visual Exploration of Large Datasets', Proc. of ACM SIGMOD, May, 1997.

[LR94] Lamping J., Rao R.: *'Laying out and Visualizing Large Trees Using a Hyperbolic Space'*, Proc. UIST, 1994, pp.13-14.

[LRP95] Lamping J., Rao R., Pirolli P.: *'A Focus + Context Technique Based on Hyperbolic Geometry for Visualizing Large Hierarchies'*, Proc. Human Factors in Computing Systems CHI '95 Conf., Denver, CO, 1995, pp. 401-408.

[LSR96] Lamm S. E., Scullin W. H., Reed D. A.: *'Real-time Geographic Visualization of World Wide Web Traffic'*, Proc. WWW, 1996.

[LWW90] LeBlanc J., Ward M. O., Wittels N.: *'Exploring N-Dimensional Databases'*, Visualization '90, San Francisco, CA, 1990, pp.230-239.

[MB95] Munzner T., Burchard P.: *'Visualizing the Structure of the World Wide Web in 3D Hyperbolic Space'*, Proc. VRML '95 Symp, San Diego, CA, 1995, pp.33-38.

[MF95] Mukherjea S., Foley J. D.: *'Showing the Context of Nodes in the World-Wide Web'*, Proc. ACM SIGCHI, Denver, CO, 1995.

Bibliography

[MF95] Mukherjea S., Foley J. D.: *'Visualizing Complex Hypermedia Networks through Multiple Hierarchical Views'*, Proc. ACM SIGCHI, Denver, CO, 1995.

[MF95] Mukherjea S., Foley J. D.: *'Visualizing the World-Wide Web with the Navigational View Builder'*, Proc. 3rd Int. World Wide Web Conf., Darmstadt, Germany, 1995.

[MGTS90] Mihalisin T., Gawlinski E., Timlin J., Schwendler J.: *'Visualizing A Scalar Field on an N-dimensional Lattice'*, Visualization '90, San Francisco, CA, 1990, pp.255-262.

[MHCF96] Munzner T., Hoffman E., Claffy K., Fenner B.: *'Visualizing the Global Topology of the mbone'*, Proc. Symp. on Information Visualization, 1996.

[MMIK95] Masui T., Minakuchi M., IV G. R., Kashiwagi K.: *'Multiple-View Approach for Smooth Information Retrieval'*, Proc. UIST, 1995, pp.199-206.

[MRC91] Mackinlay J. D., Robertson G. G., Card S. K.: *'The Perspective Wall: Detail and Context Smoothly Integrated'*, Proc. Human Factors in Computing Systems CHI '91 Conf., New Orleans, LA, 1991, pp.173-179.

[MSG 94] McCreary C., Shieh F.-S., Gill H.: *'Cg: A Graph Drawing System Using Graph-Grammar Parsing'*, Proc. Graph Drawing '94, in: Lecture Notes in Computer Science, Vol. 894, Springer, 1994, pp.270-273.

[MW95] Martin A.R., Ward M. O.: *'High Dimensional Brushing for Interactive Exploration of Multivariate Data'*, Visualization '95, Atlanta, GA, 1995, pp.271-278.

Bibliography

[Mye94] Myers B. A.: *'Visual Programming, Programming by Example and Program Visualization: A Taxonomy'*, Proc. Human Factors in Computing Systems CHI '94 Conf., Boston, MA, 1994, pp.59-66.

[NK94] North S. C., Koutsofois E.: *'Applications of Graph Visualization'*, Proc. Graphics Interface, 1994, pp. 235-245.

[Noi93] Noik E. G.: *'Layout-independent Fisheye Views of Nested Graphs'*, Proc. Symp. on Visual Languages, 1993, pp.336-341.

[Noi94] Noik E. G.: *'Encoding Presentation Emphasis Algorithms for Graphs'*, Proc. Graph Drawing '94, in: Lecture Notes in Computer Science, Vol. 894, Springer, 1994, pp.428-235.

[Noi94] Noik E. G.: *'A Space of Presentation Emphasis Techniques for Visualizing Graphs'*, Proc. Graphics Interface, 1994, pp.225-233.

[Ols93] Olsen K.A. et al.: *'Visualization of a Document Collection: The VIBE System'*, Information Processing and Management, Vol.29, No.1, 1993, pp.69-81.

[OW93] Ozoyoglu G., Wang H.: *'Example-Based Graphical Database Query Languages'*, Computer, Vol.26, No.5, 1993, pp.25-38.

[PB 94] Pitkow J., Bharat K.: *'Webviz: A Tool for World-Wide Web Access Log Visualization'*, Proc. 1st Int. World Wide Web Conf., Geneva, Switzerland, 1994.

Bibliography

[PF93] Perlin K., Fox D.: *'Pad: An Alternative Approach to the Computer Interface'*, Proc. SIGGRAPH, Anaheim, CA, 1993, pp.57-64.

[PG88] Pickett R. M., Grinstein G. G.: *'Iconographic Displays for Visualizing Multidimensional Data'*, Proc. IEEE Conf. on Systems, Man and Cybernetics, IEEE Press, Piscataway, NJ, 1988, pp.514-519.

[Pic70] Pickett R. M.: *'Visual Analyses of Texture in the Detection and Recognition of Objects'*, in: Picture Processing and Psycho-Pictorics, Lipkin B. S., Rosenfeld A. (eds.), Academic Press, New York, 1970.

[Rao 92] Rao R., Card S. K., Jellinek H. D., Mackinlay J. D., Robertson G. G.: *'The Information Grid: A Framework for Information Retrieval and Retrieval-centered Applications'*, Proc. UIST, 1992, pp.23-32.

[RC94] Rao R., Card S. K.: *'The Table Lens: Merging Graphical and Symbolic Representation in an Interactive Focus+Context Visualization for Tabular Information'*, Proc. Human Factors in Computing Systems CHI '94 Conf., Boston, MA, 1994, pp. 318-322.

[RCM93] Robertson G. G., Card S. K., Mackinlay J. D.: *'Information Visualization Using 3D Interactive Animation'*, Communications of the ACM, Vol. 36, No. 4, 1993, pp.57-71.

[Reg93] Regan B.: *'Two Algorithms for Drawing Trees in Three Dimensions'*, Proc. Graph Drawing, 1993.

[Rei 93] Reiss S. P.: *'A Framework for Abstract 3D Visualization'*, Proc. Symp. on Visual Languages, 1993, pp.108-115.

Bibliography

[Rei 94] Reiss S. P.: *'3-D Visualization of Program Information'*, Proc. Graph Drawing, 1994, in: Lecture Notes in Computer Science, Vol. 894, Springer, 1994, pp.12-24.

[Ren 94] Rennison E.: *'Galaxy of News: An Approach to Visualizing and Understanding Expansive News Landscapes'*, Proc. UIST, 1994, pp.3-12.

[RG 93] Rekimoto J., Green M.: *'The Information Cube: Using Transparency in 3d Information Visualization'*, Proc. 3rd Annual Workshop on Information Technologies & Systems (WITS '93), 1993, pp.125-132.

[RM93] Robertson G. G., Mackinlay J. D.: *'The Document Lens'*, Proc. UIST, 1993, pp.101-108.

[RMC91] Robertson G. G., Mackinlay J. D., Card S. K.: *'Cone Trees: Animated 3D Visualizations of Hierarchical Information'*, Proc. Human Factors in Computing Systems CHI '91 Conf., New Orleans, LA, 1991, pp. 189-194.

[SA82] Spence R., Apperley M.: *'Data Base Navigation: An Office Environment for the Professional'*, Behaviour and Information Technology, Vol.1, No.1, pp. 43-54.

[San94] Sander G.: *'Graph Layout through the VCG Tool'*, Proc. Graph Drawing, 1994, in: Lecture Notes in Computer Science, Springer, Vol. 894, Springer, 1994, pp. 194-205.

[SB94] Sarkar M., Brown M.: *'Graphical Fisheye Views'*, Communications of the ACM, Vol. 37, No. 12, 1994, pp.73-84.

Bibliography

[SCB92] Swayne D. F., Cook D., Buja A.: *'User's Manual for XGobi: A Dynamic Graphics Program for Data Analysis'*, Bellcore Technical Memorandum, 1992.

[Sch93] Schaffer, Doug, Zuo, Zhengping, Bartram, Lyn, Dill, John, Dubs, Shelli, Greenberg, Saul, Roseman, Mark: *'Comparing Fisheye and Full-Zoom Techniques for Navigation of Hierarchically Clustered Networks'*, Proc. Graphics Interface (GI '93), Toronto, Ontario, 1993, in: Canadian Information Processing Soc., Toronto, Ontario, Graphics Press, Cheshire, CT, 1993, pp. 87-96.

[SDTS95] Su H., Dawkes H., Tweedie L., Spence R.: *'An Interactive Visualization Tool for Tolerance Design'*, Technical Report, Imperial College, London, 1995.

[SFB94] Stone M. C., Fishkin K., Bier E. A.: *'The Movable Filter as a User Interface Tool'*, Proc. Human Factors in Computing Systems CHI '94 Conf., Boston, MA, 1994, pp. 306-312.

[Shn92] Shneiderman B.: *'Tree Visualization with Treemaps: A 2D Space-Filling Approach'*, ACM Transactions on Graphics, Vol. 11, No.1, pp.92-99, 1992.

[SM94] Sugiyama K., Misue K.: *'A Simple and Unified Method for Drawing Graphs: Magnetic-spring Algorithm'*, Proc. Graph Drawing, 1994, in: Lecture Notes in Computer Science, Vol. 894, Springer, 1994, pp.364-375.

[SP92] Stasko, John T. and Patterson, Charles, "Understanding and Characterizing Software Visualization Systems", Proc. of the 1992 IEEE Workshop on Visual Languages, Seattle, WA, September 1992, pp. 3-10.

Bibliography

[Spo93] Spoerri A.: *'InfoCrystal: A Visual Tool for Information Retrieval'*, Visualization '93, San Jose, CA, 1993, pp.150-157.

[STDS95] Spence R., Tweedie L., Dawkes H., Su H.: *'Visualization for Functional Design'*, Proc. Int. Symp. on Information Visualization (InfoVis '95), Atlanta, GA, 1995, pp.4-10.

[SRN72] Shepard R. N., Romney A. K., Nerlove S. B.: *'Multidimensional Scaling'*, Seminar Press, New York, 1972.

[SW93] Stasko J. T., Wehrli J. F.: *'Three-dimensional Computation Visualization'*, Proc. Symp. on Visual Languages, Bergen, Norway, 1993, pp.100-107.

[TD95] Tal A., Dobkin D.: *'Visualization of Geometric Algorithms'*, Transactions on Visualization and Computer Graphics, Vol. 1, No. 2, 1995, pp.194-204.

[Tuf83] Tufte E. R.: *'The Visual Display of Quantitative Information'*, Graphics Press, Cheshire, CT, 1983.

[Tuf90] Tufte E. R.: *'Envisioning Information'*, Graphics Press, Cheshire, CT, 1990.

[Vas94] Vasudevan V.: *'Supporting High Bandwidth Navigation in Object-Bases'*, Proc. 10th Int. Conf. on Data Engineering, Houston, TX, 1994, pp.294-301.

[Vel92] Velleman P. F: *'Data Desk 4.2: Data Description'*, Ithaca, NY, 1992.

Bibliography

[War94] Ward M. O.: *'XmdvTool: Integrating Multiple Methods for Visualizing Multivariate Data'*, Visualization'94, Washington, DC, 1994, pp.326-336.

[Wis 95] Wise J. A., Thomas J. J., Pennock K., Lantrip D., Pottier M., Schur A., Crow V.: *'Visualizing the Non-Visual: Spatial Analysis and Interaction with Information from Text Documents',* Proc. Symp. on Information Visualization, Atlanta, GA, 1995, pp.51-58.

[WB95] Wong P.C., Bergeron R. D.: *'30 Years of Multidimensional Multivariate Visualization'*, Proc. Workshop on Scientific Visualization, IEEE Computer Society Press, 1995.

[WDBH95] Wood A., Drew N., Beale R., Hendley B.: *'Hyperspace: Web Browsing with Visualisation'*, Proc. 3rd Int. World-Wide Web Conf., Poster, 1995, Darmstadt, Germany.

[WL93] van Wijk J. J., van Liere R.. D.: *'Hyperslice'*, Proc. Visualization '93, San Jose, CA, 1993, pp.119-125.

[Wri95] Wright W.: *'Information Animation Applications in the Capital Markets'*, Proc. Int. Symp. on Information Visualization, Atlanta, GA, 1995, pp.19-25.

[WUT95] Wilhelm A., Unwin A.R., Theus M.: *'Software for Interactive Statistical Graphics - A Review'*, Proc. Int. Softstat'95 Conf., Heidelberg, Germany, 1995.

[XGobi] XGobi Web-Page including pointers to publications and the most recent release of the XGobi software: "http://www.research.att.com/~andreas/xgobi/".

Bibliography

[YS 93] Young D. and Shneiderman B.: *'A graphical filter/flow model for boolean queries: An implementation and experiment'*, Journal of the American Society for Information Science Vol. 44,No. 6, 1993, pp. 327-339.

[Zlo77] Zloof M. M.: *'Query-By-Example: A Data Base Language'*, IBM Systems Journal, Vol. 4, 1977, pp.324-343.