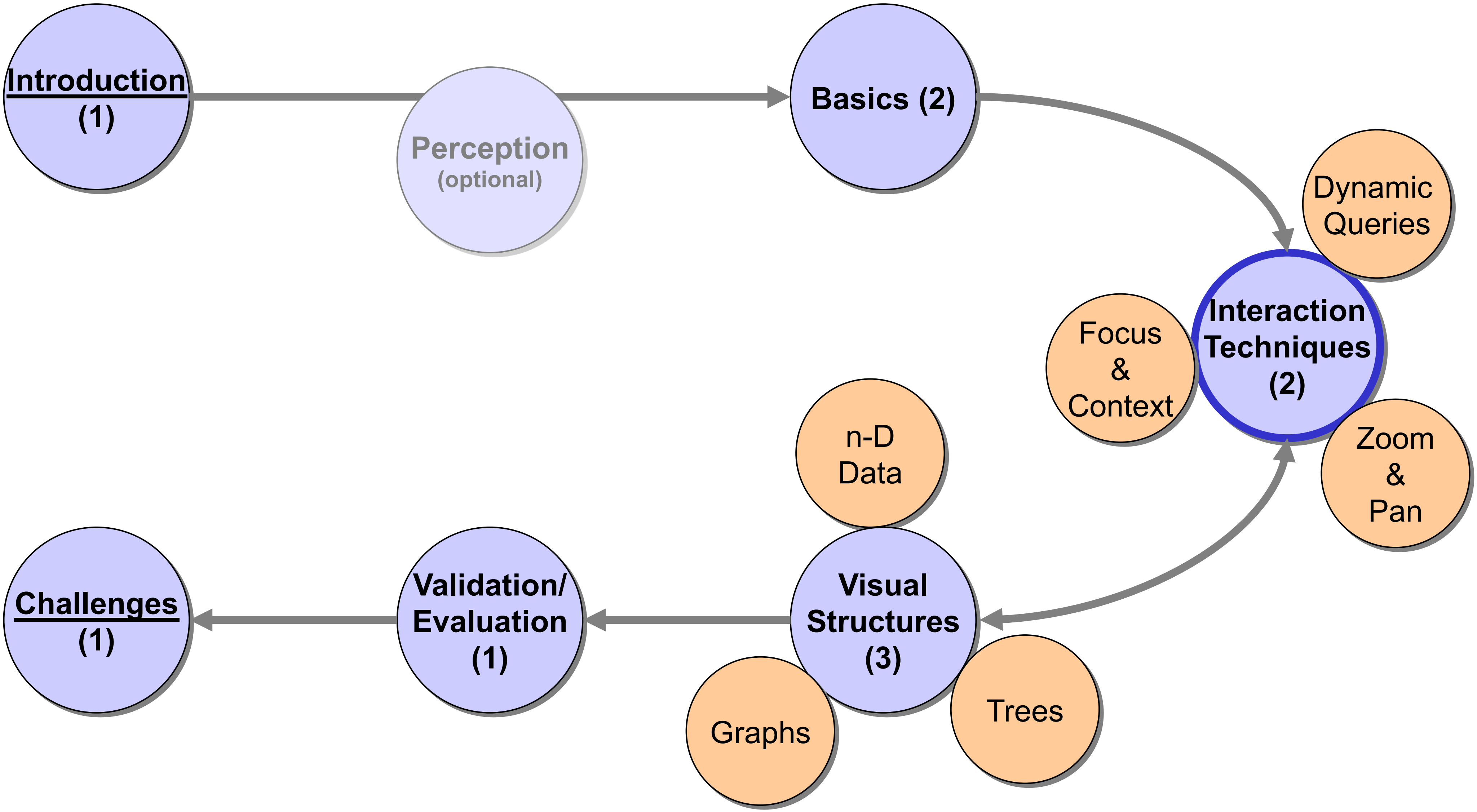
Information Visualization

3. Interaction Techniques

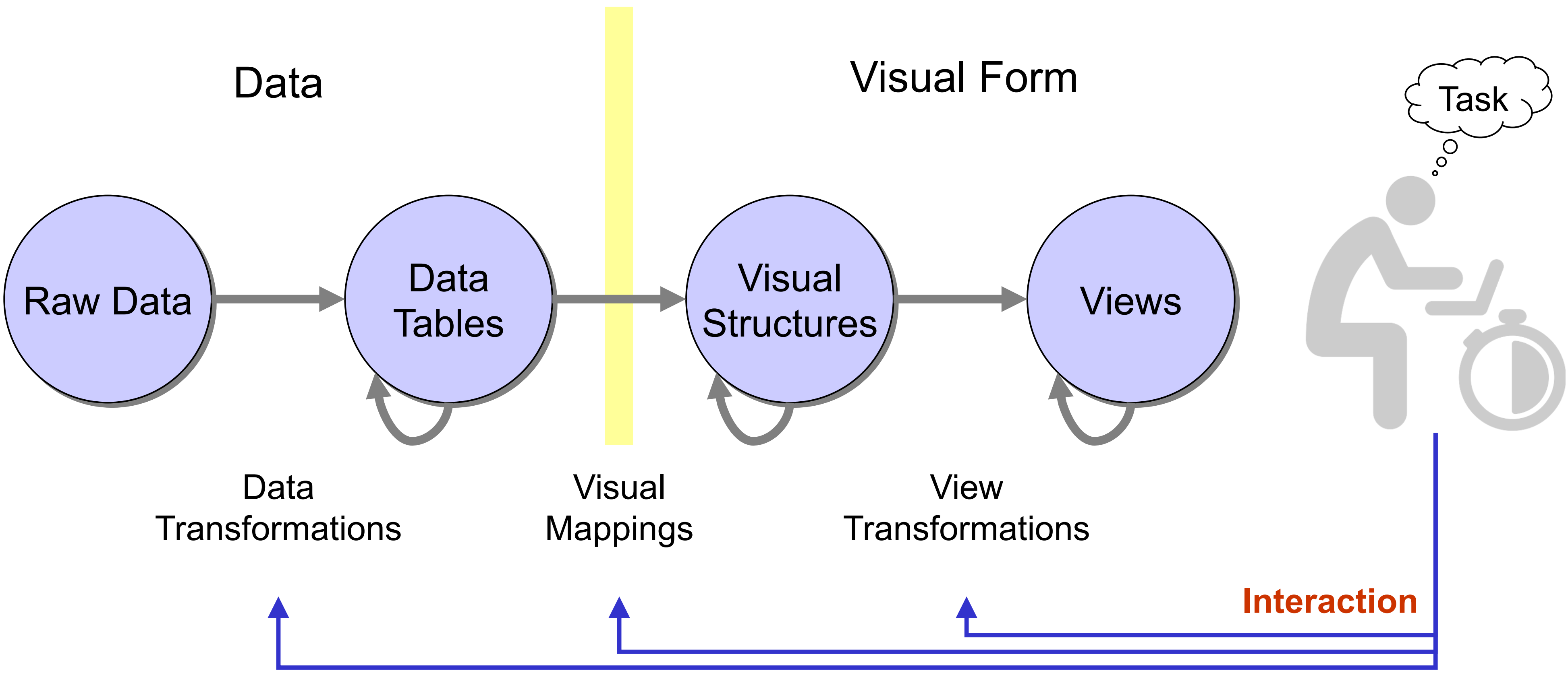
“Overview first, zoom and filter, then details-on-demand” [Shneiderman, 1996]

TNM111: 10 Lectures



3.1 Introduction

- Reminder (Reference Model from Chapter 2)



[CMS:17ff]

3.1 Introduction

- Interaction and Time
  - How fast must interaction be?
    - Interaction is a *real time process*, i.e., on the one hand, it must be fast enough to avoid frustration of the user. On the other hand, it should not be too fast to avoid overlooking important things
  - There are three levels:
    - 0.1 second – animations, sliders, sound, …
    - 1 second – system status messages, dialogs, …
    - 10 seconds – cognitive responses (editor, chess program, …)

[CMS:231]

3.1 Introduction

- Interaction taxonomies
  - Facilitate the better understanding of the entire design space of interaction
  - Interaction techniques are categorized
  - There are many taxonomy papers (not discussed here)
    - All of them focus on slightly different aspects and interaction levels
    - Yi et al. provide an overview of past taxonomies before 2007 in their paper “Toward a Deeper Understanding of the Role of Interaction in Information Visualization”
      - https://doi.org/10.1109/TVCG.2007.70515
    - A more comprehensive taxonomy, including also visual analytics aspects, has been proposed by Kerren and Schreiber in “Toward the Role of Interaction in Visual Analytics”
      - https://doi.org/10.1109/WSC.2012.6465208

3.1 Introduction

- Interaction Techniques
  - Interacting with data transformations (A) [→ Section 3.2]
    - Dynamic queries
    - Direct walk
    - Details-on-demand
    - Attribute walk
    - Brushing
    - Direct manipulation

[CMS:233ff]

3.1 Introduction

- Interaction Techniques (cont.)
  - Interacting with visual mappings (A) [→ Section 3.3]
    - Change the visual representations either *manually* or based on any *conditions* (dataflow, user background, etc.
  - Interacting with view transformations (B) [→ Sections 3.4 – 3.6]
    - Direct selection
    - Magic lenses
    - Camera movements (pan)
    - Zoom
    - Overview & Detail
    - Focus & Context

Direct selection, Magic lenses } Location Probes

Camera movements (pan), Zoom, Overview & Detail } Viewpoint Controls

Focus & Context } Distortions

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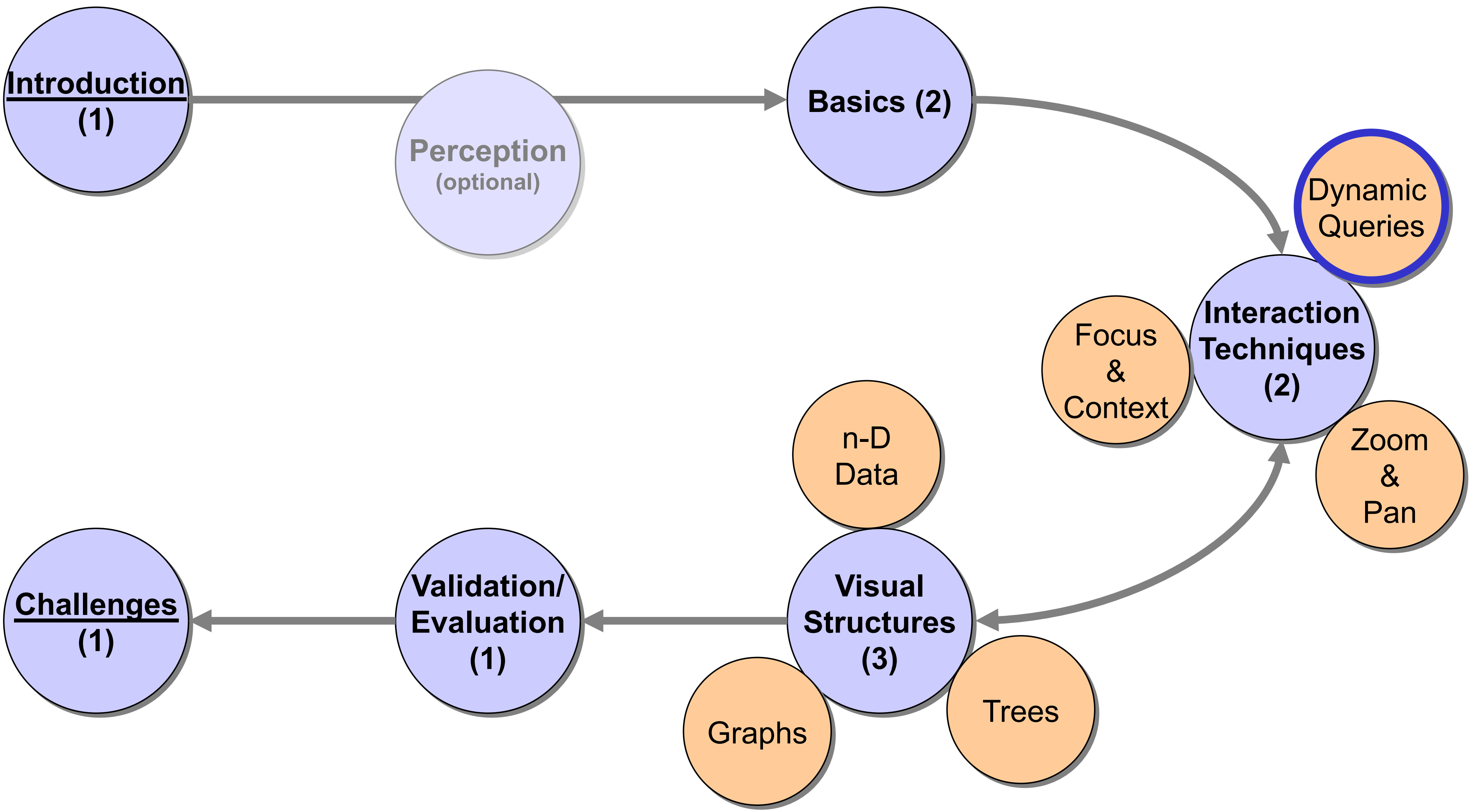
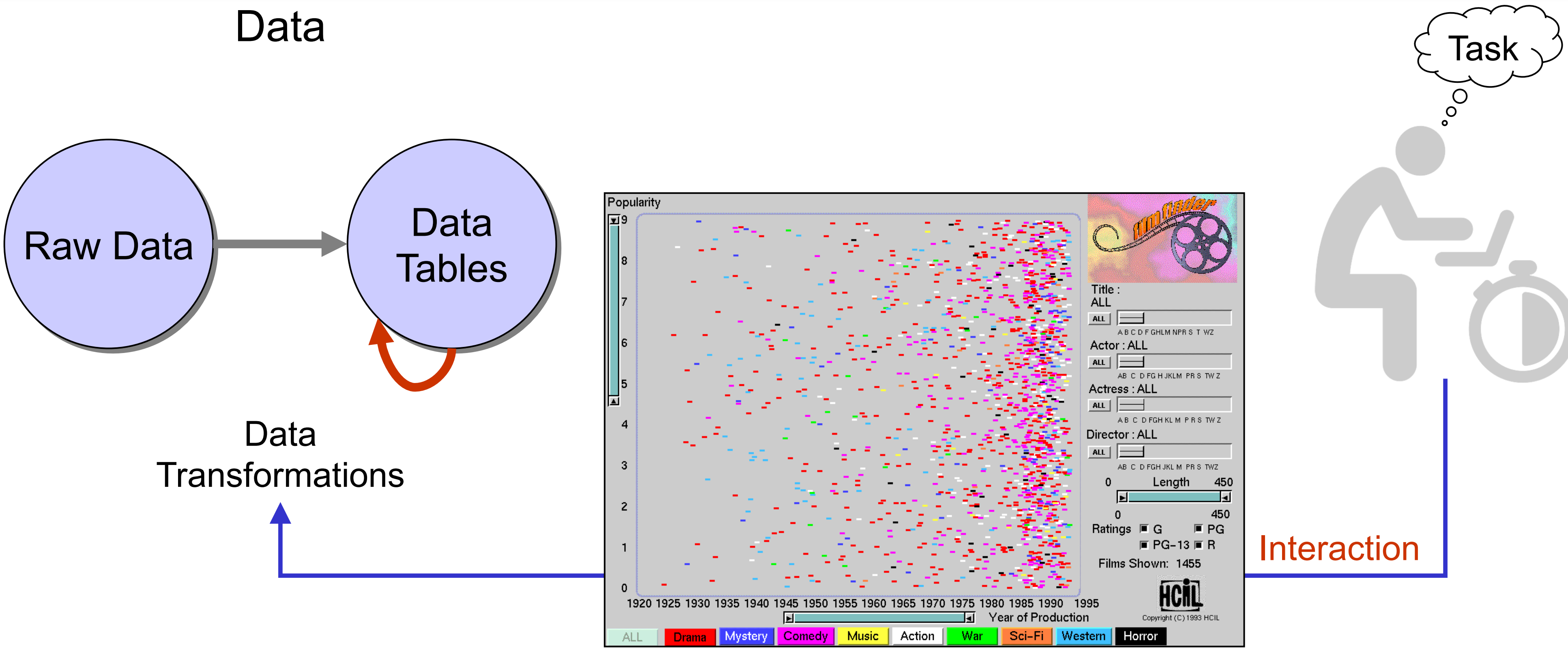


3.2 Data Transformations



- <u>Example:</u> FilmFinder
- Sliders filter the different cases. Only selected cases are shown in the scatter plot
  → **Dynamic Queries**

3.2.1 Dynamic Queries

- Motivation

  - Many problems cannot be described precisely. For instance, a family is searching a house for 1.5 Mio SEK with 3 sleeping rooms in the near of a good school and not too far away from their grandparents‘ house. Often, one noticed later that a garden or a short distance to public transportation plays an important role for the house prices

  - Visualization can help to support both aspects: the *formulation of the problem* AND *the problem solution* (and even a smooth transition between both aspects in the best case)

[Spe:70ff]

3.2.1 Dynamic Queries

- Classical search query for databases

  SELECT House address

  FROM Data base

  WHERE Price<=1,000,000 **AND** Bathrooms=2 **AND** Sleeping rooms>=3

- Typical Answer
  - 0 matches
  - 1,543 matches
    1. Norrköping, Storgatan 3, „Nice house with a beautiful garden …"
    2. Linköping, Kungsgatan 12231, „…"

- Often, one has no further hints how to restrict or extend the search query

3.2.1 Dynamic Queries

- Problems
  - You have to learn a special language (e.g., SQL)
  - Typos are not tolerated
  - Too much or too less matches
  - If this happens then you have no indicator how to change the query
  - Changing search queries can take a long time
  - No context
  - User has no idea about the inner structure of the data set

3.2.1 Dynamic Queries

- Dynamic queries are a widely-used concept in InfoVis
- Properties
  - Fast (visual) answer on the query, i.e., we get so-called „interactive answers“ (≤ 0.1 seconds)
  - Simultaneous display of query and result
  - Exploration
  - Dynamic exploration, i.e. activities take place according to the „What if...?“ principle

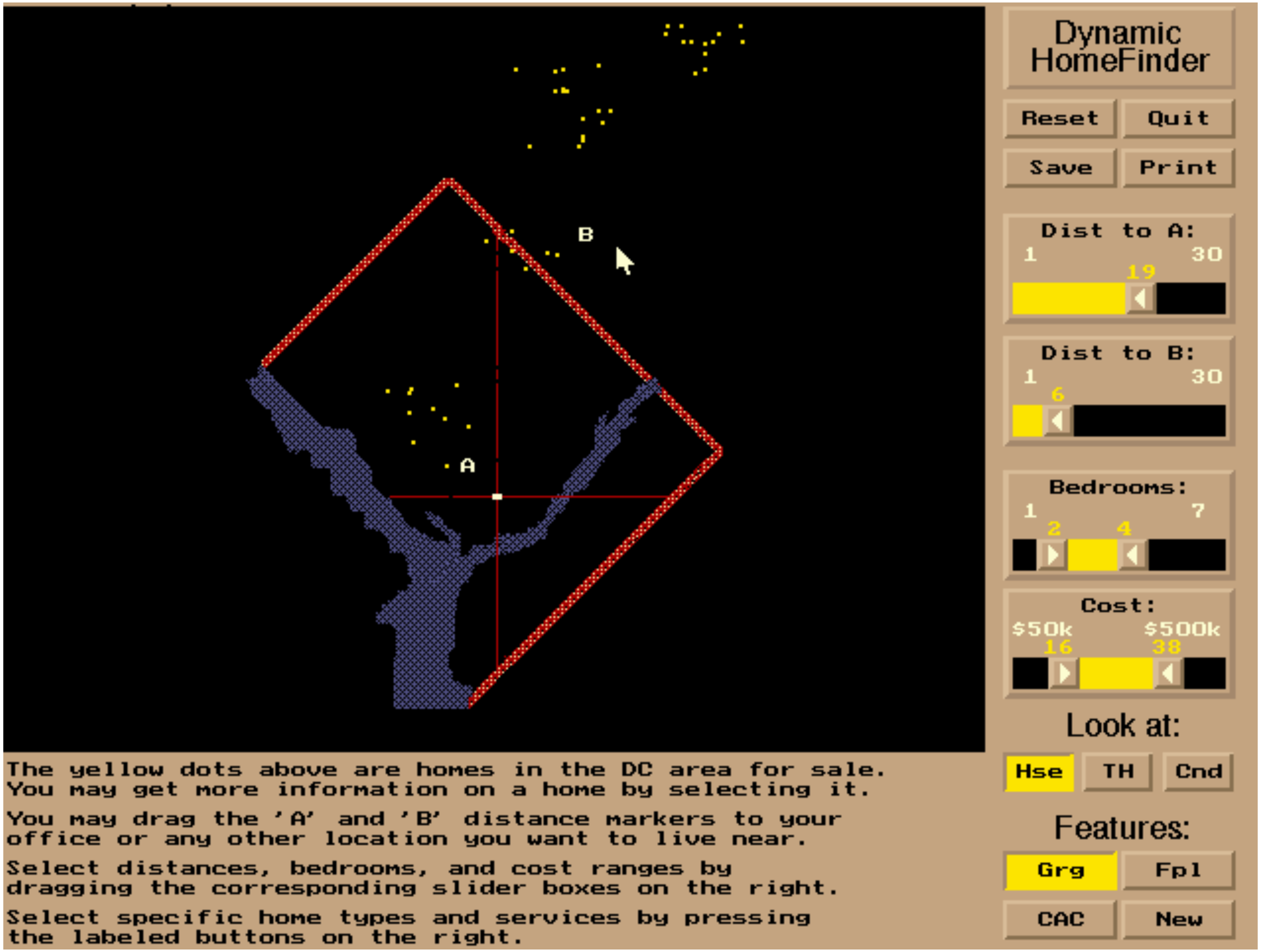
3.2.1 Dynamic Queries

- Example: Dynamic Homefinder

[Williamson, Shneiderman. The dynamic homefinder: evaluating dynamic queries in a real estate information exploration system. ACM, Proceedings SIGIR '92, 1992 339-346]

- Task (generic)
  - There is a set of objects with values for a set of attributes. Find the best object or a small number of objects that should be further analyzed

3.2.1 Dynamic Queries



[Video]

http://www.cs.umd.edu/hcil/pubs/screenshots/

3.2.1 Dynamic Queries

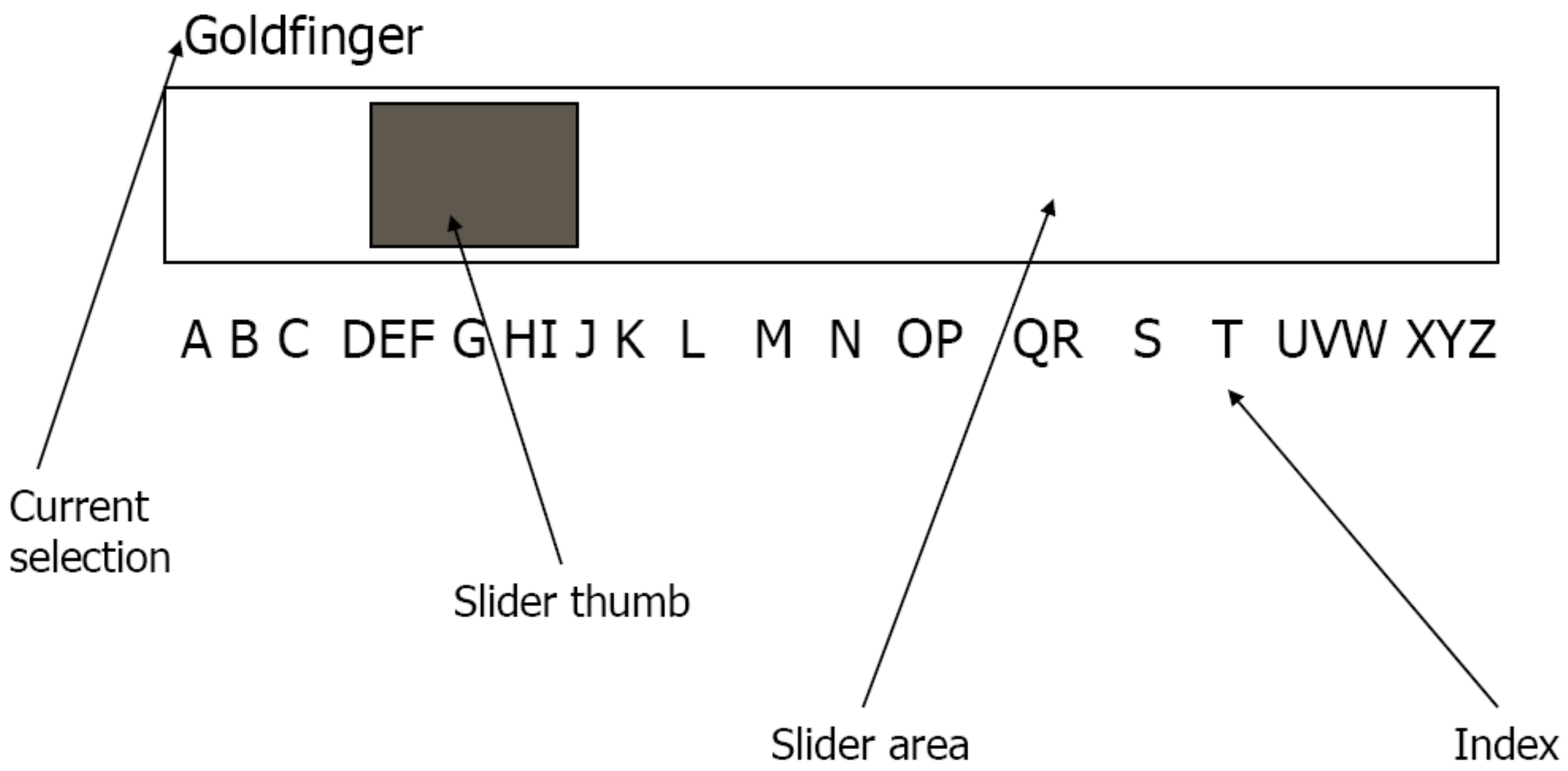
- We have different interfaces
  - Buttons
    - Used for nominal and ordinal (radio buttons) attribute values
  - Sliders
    - Used for ordinal and quantitative attribute values

- Especially in the area of sliders, some people have developed new solutions how the data selection can be improved …

[Inspired by J. Stasko's course]

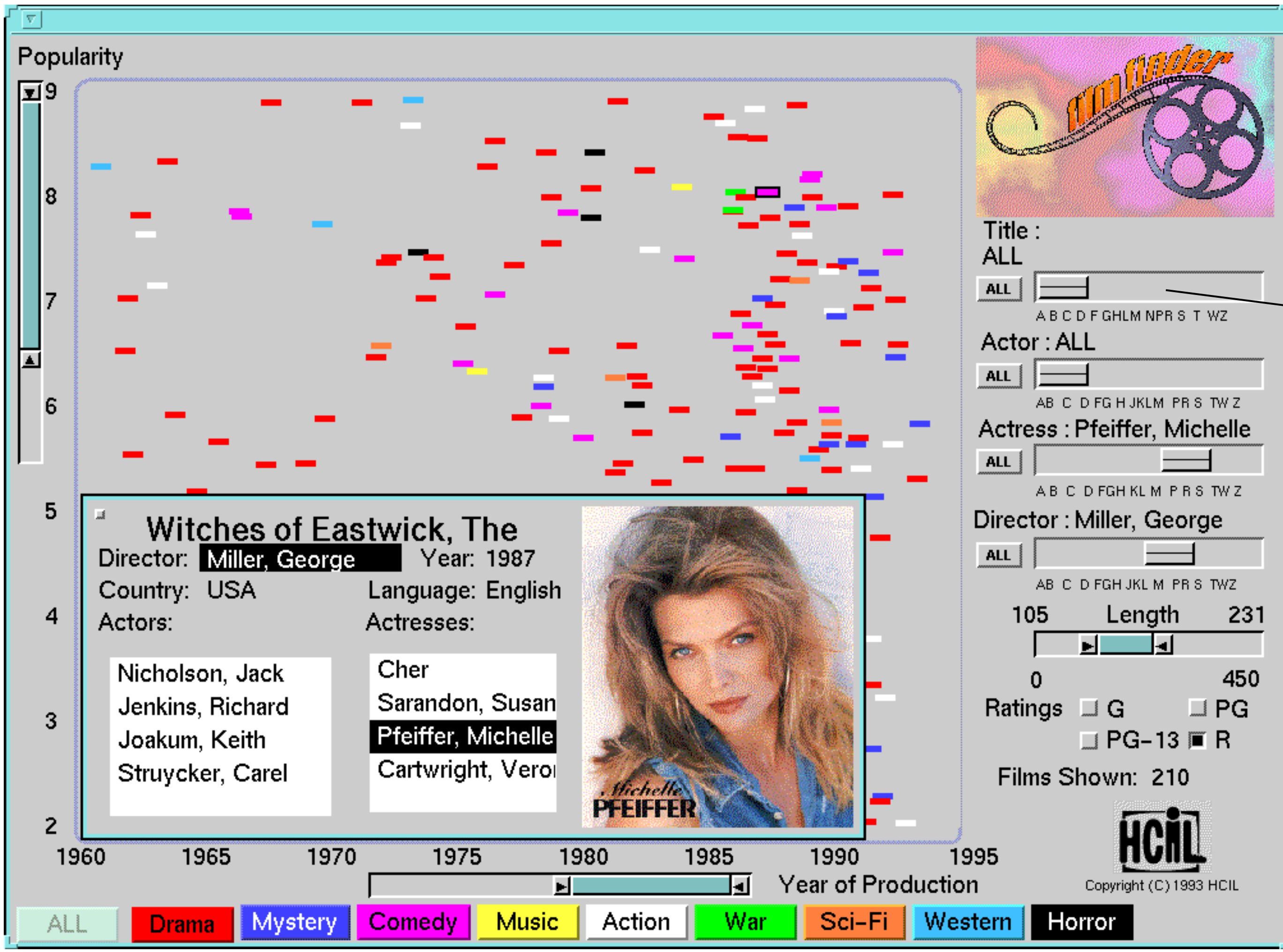
3.2.1 Dynamic Queries

- The dynamic selection of words can be performed with the help of the **Alphaslider**



3.2.1 Dynamic Queries

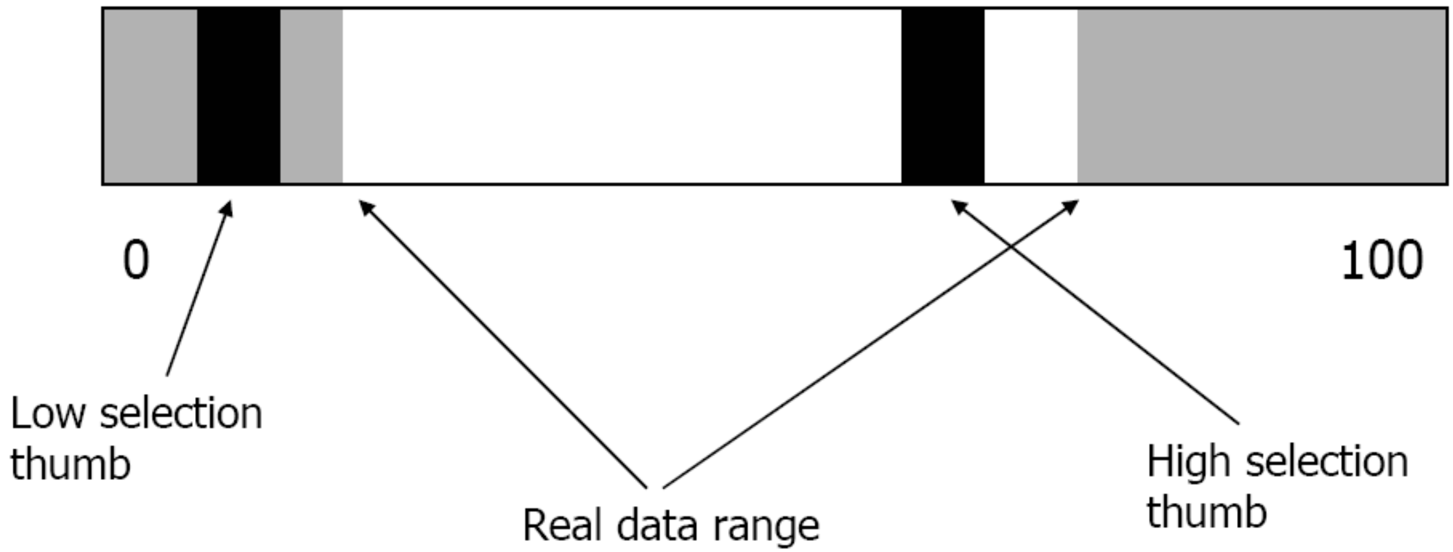
- <u>Example:</u> FilmFinder



Alphaslider

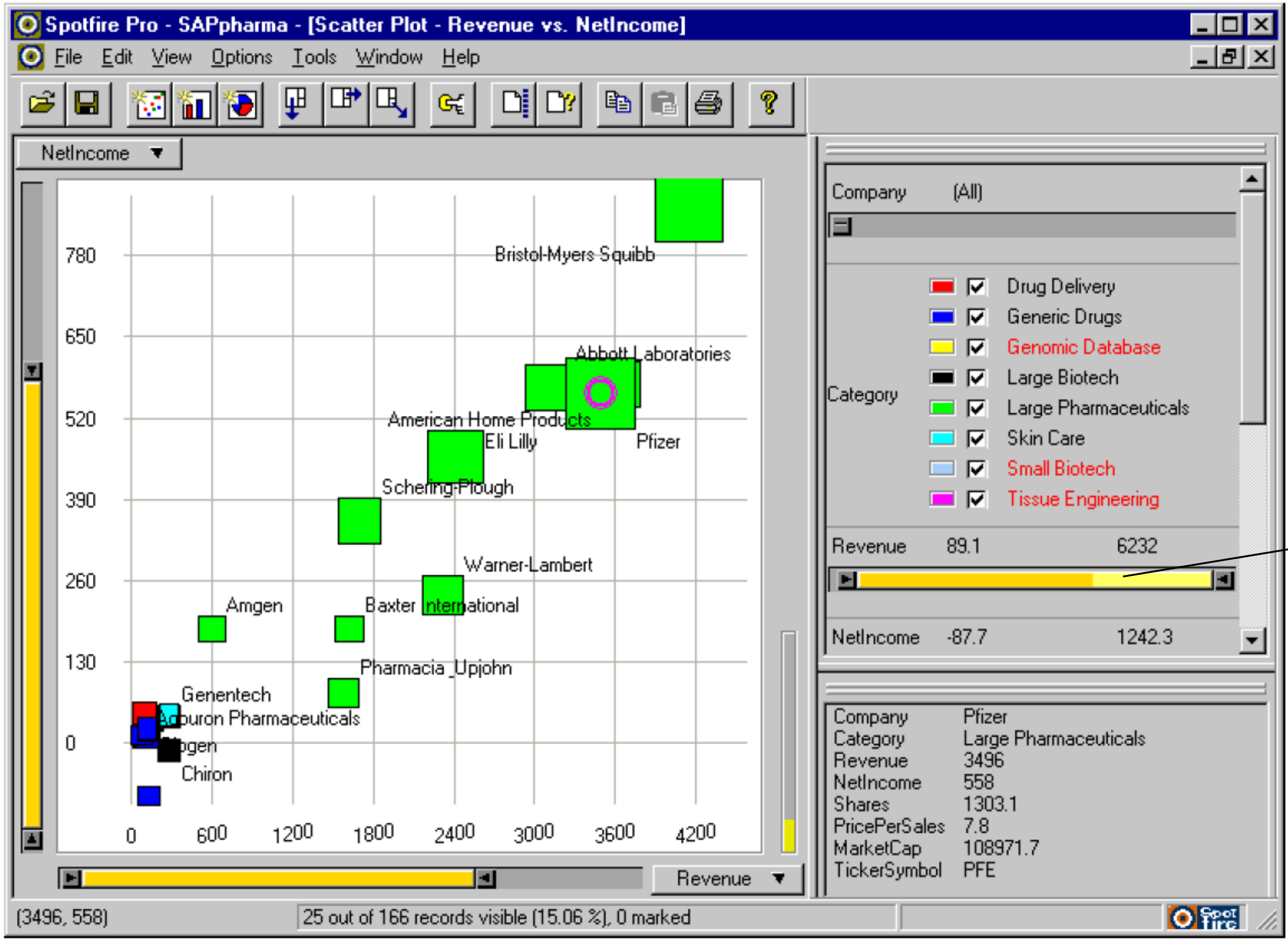
3.2.1 Dynamic Queries

- Hints on dataless areas can be given by the **Rangeslider**



3.2.1 Dynamic Queries

- Example: Spotfire



Rangeslider

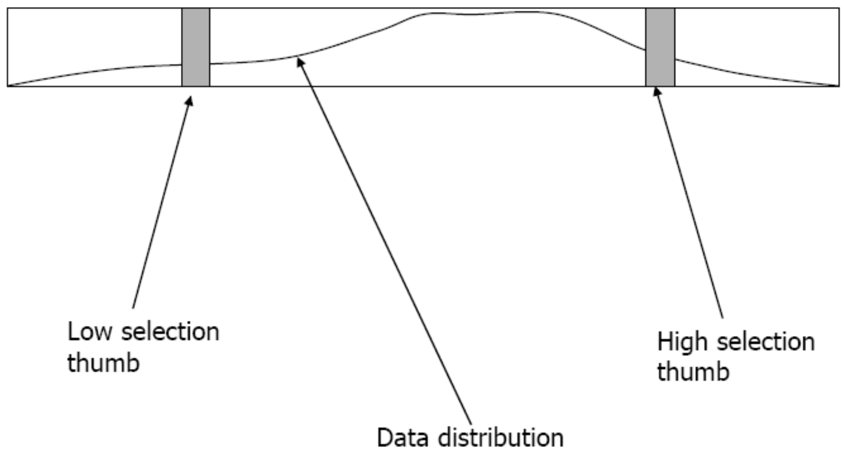
[Video]

3.2.1 Dynamic Queries

- Advantages of dynamic queries
  - One can work much more faster
  - Exploration, Undo, …
  - „Natural“ kind of interaction
- Disadvantages
  - Is it possible to specify Boolean expressions in this way?
    - Probably not, but how often do you need this?
  - Interfaces need space on the screen
    - Solution: show data *within* control interfaces!

3.2.1 Dynamic Queries

- Data Visualization Sliders



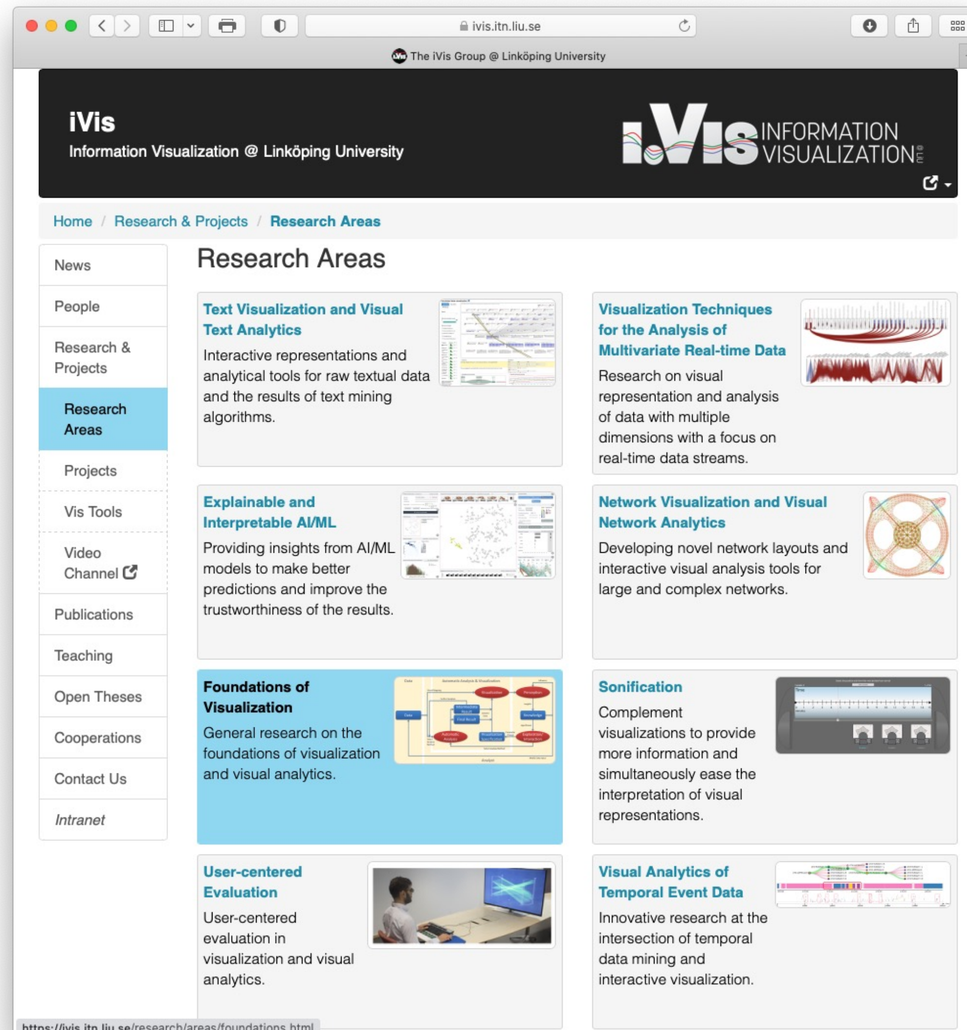
[Eick et al., UIST ´94]

- Scented Widgets

[Willett et al., InfoVis ´07]

3.2.2 Direct Walk

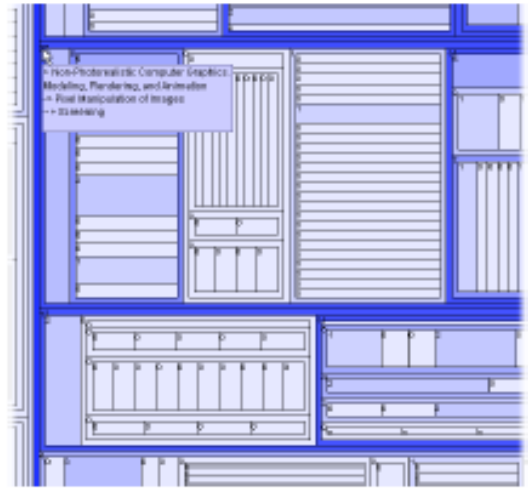
- Direct links between different cases of the data table
- One jumps from case to case, i.e., from information to information. This can be done via mouse-clicks or similar
- <u>Examples:</u> HTML pages in a web browser via links



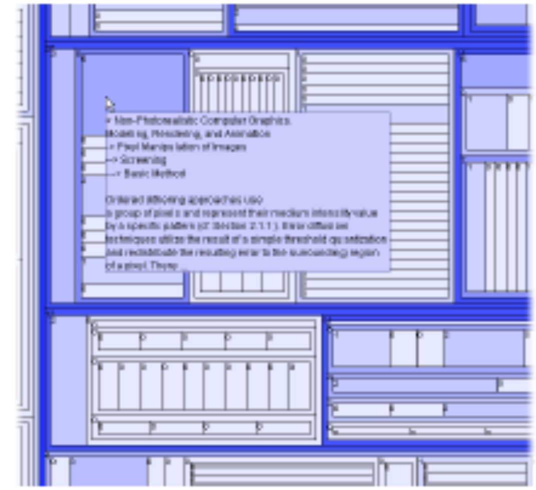
http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.24.2797

3.2.3 Details-on-demand

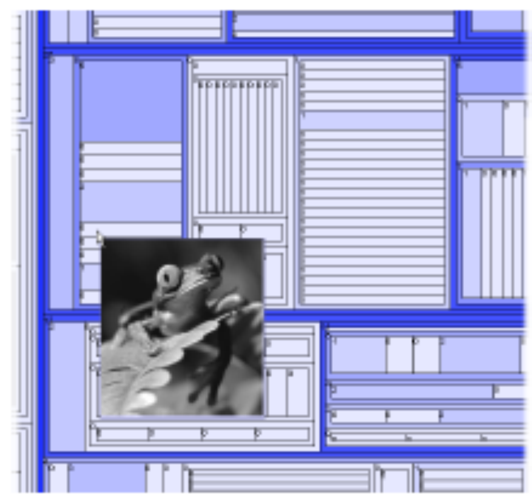
- The tool only shows few data cases in order to display a richer amount of attributes!
  - for example by displaying groups of elements
- Thus, we have more space on the screen, and we can add more information for each data object using the same space



(a) Section node



(b) Paragraph node



(c) Image node

https://doi.org/10.2312/VisSym/VisSym04/121-128

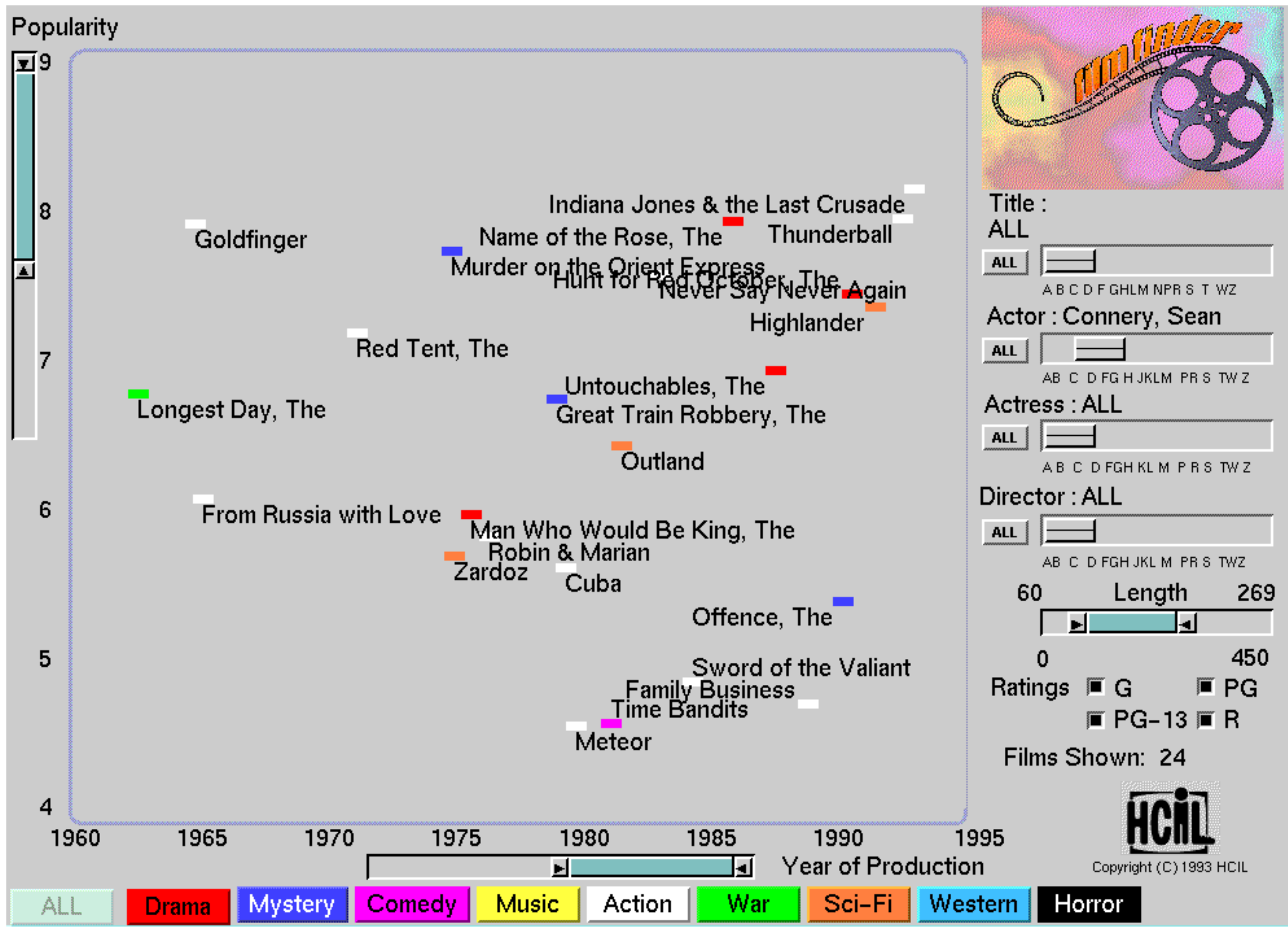
3.2.4 Attribute Walk

- The user selects some cases/data objects and looks for further cases with similar attributes

FilmFinder

Select cases with similar attributes (for example, movies with actor „Sean Connery“).

Then, the tool searches for other movies with similar attributes.

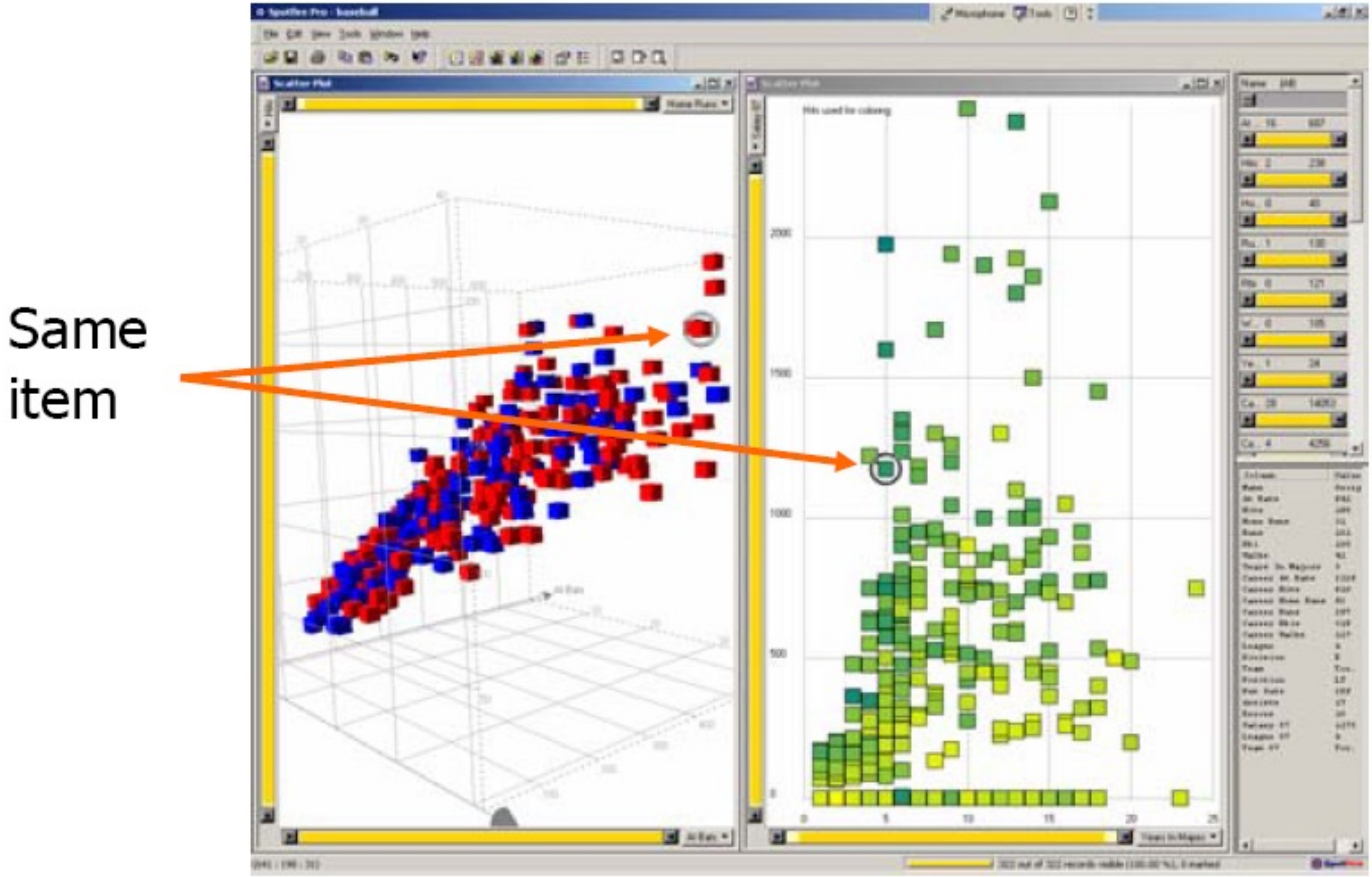


https://hcil.umd.edu/research-histories/

3.2.5 Brushing & Linking

- *Brushing & Linking* is used if several views on the same data object are needed
- Selecting or highlighting of a data object in a specific view (brushing) leads to a highlight/selection in another view (linking)
  - Consistent display
  - Facilitates the search
- Widely-used technique in InfoVis!
- Example: Spotfire

3.2.5 Brushing & Linking



http://www.cs.umd.edu/hcil/pubs/

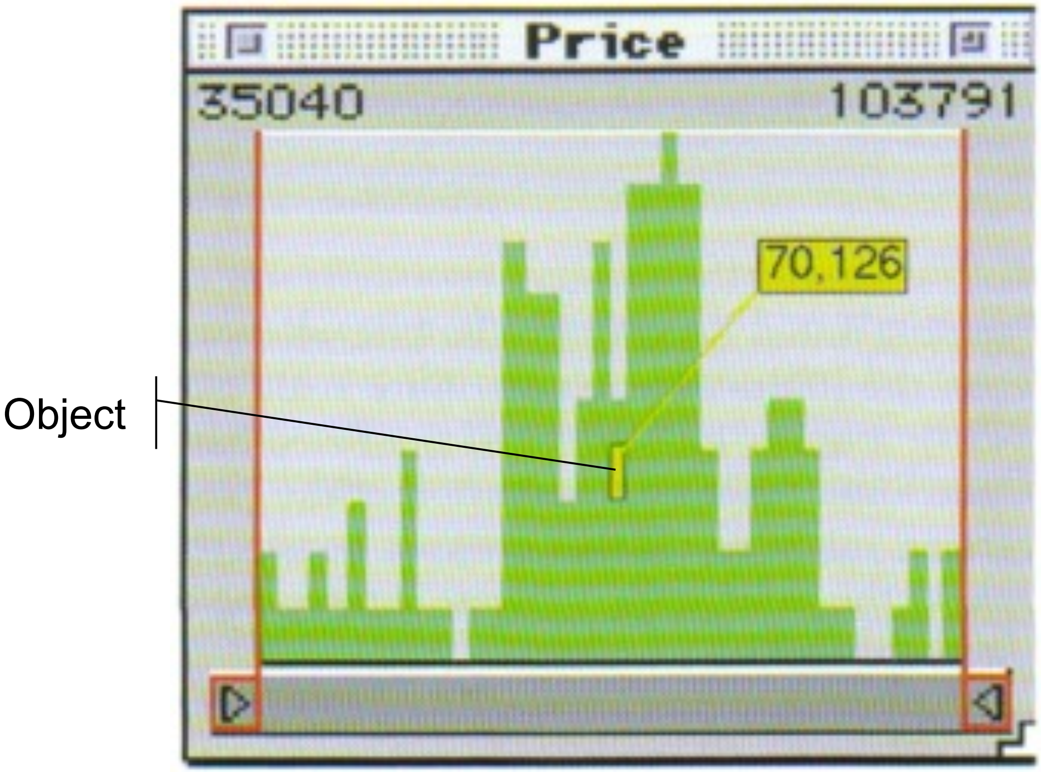
[Inspired by J. Stasko's course]

3.2.5 Brushing & Linking

- Histogram Brushing
  - Special case of the general brushing idea
  - Attributes of data objects can be represented very well with histograms
  - Values and domains can be clicked and selected
    - Selected elements are highlighted in other views as in general brushing
    - Very good to show correlations, comparisons and trends!
  - Example: Attribute Explorer
    - All cases (here houses) are displayed, and an own view is used for each attribute

3.2.5 Brushing & Linking

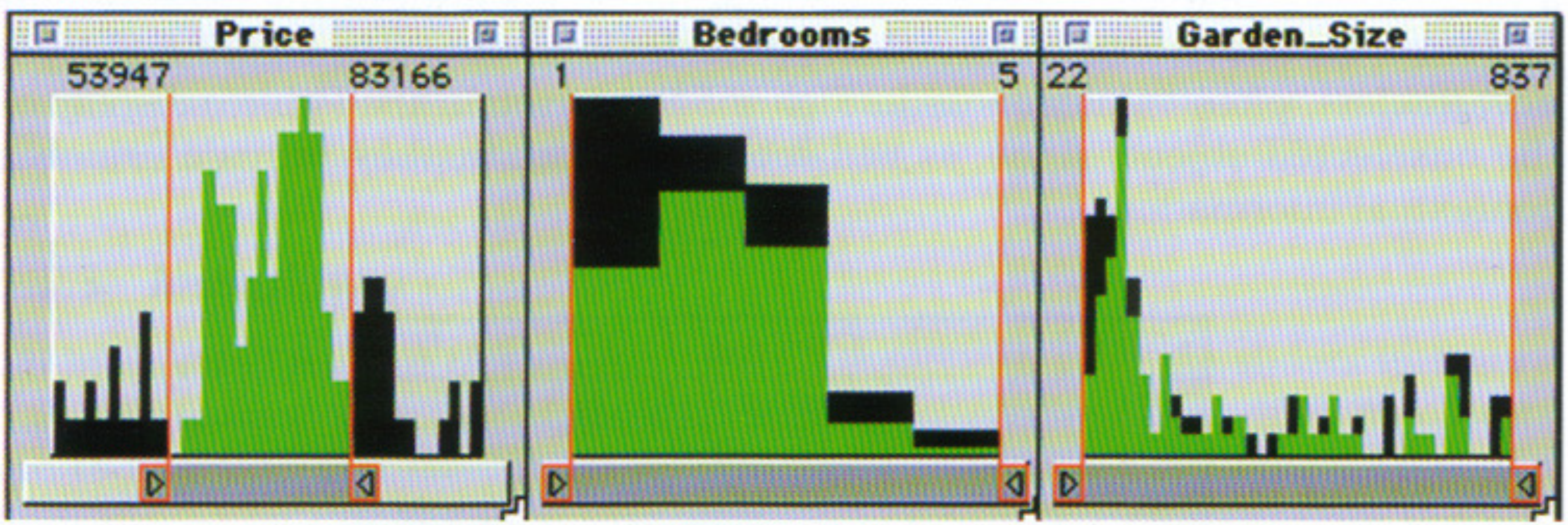
- Selection in the Attribute Explorer
  - Attribute: price



3.2.5 Brushing & Linking

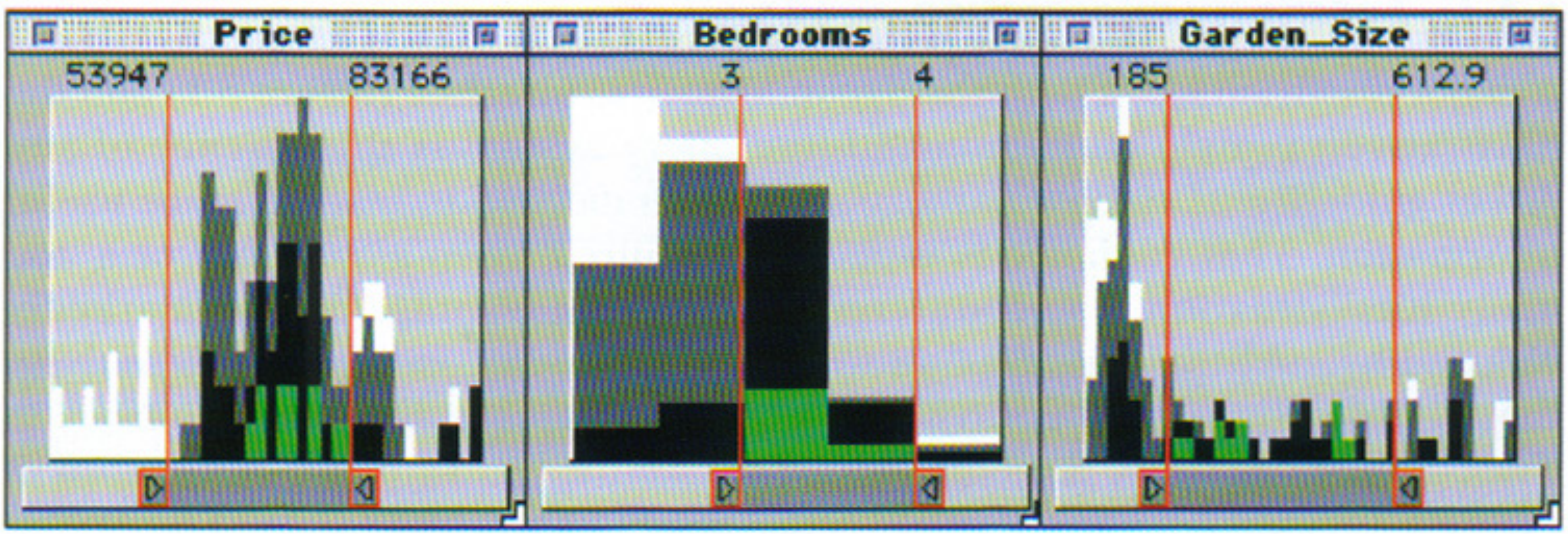
- Brushing in the Attribute Explorer
  - Attributes: prices, bedrooms, garden size

A selected Price range is brushed over the Bedrooms and Garden Size histograms



3.2.5 Brushing & Linking

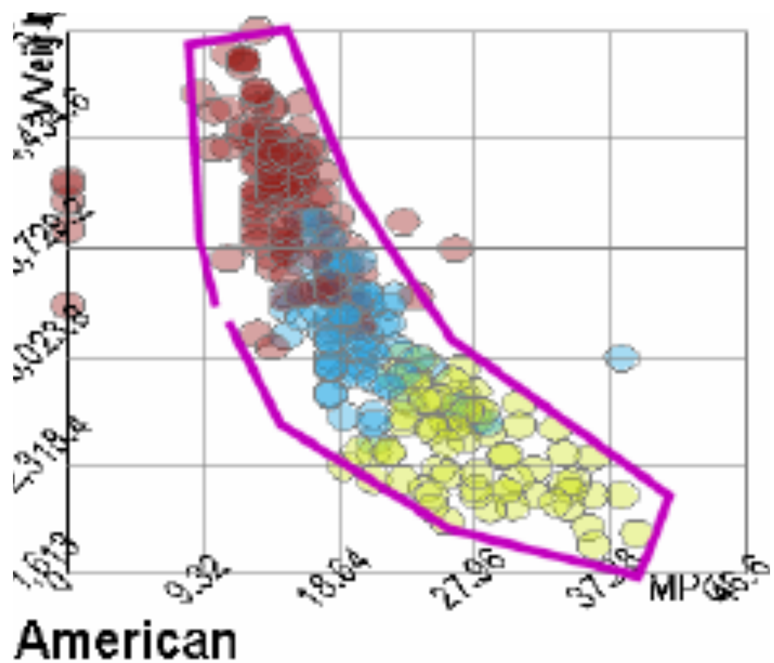
- Brushing in the Attribute Explorer (cont.)
  - Attributes: price, bedrooms, garden size
  - Limits (constraints through other histograms) are considered



In the Attribute Explorer separate limits on three attributes combine to identify houses that satisfy all limits

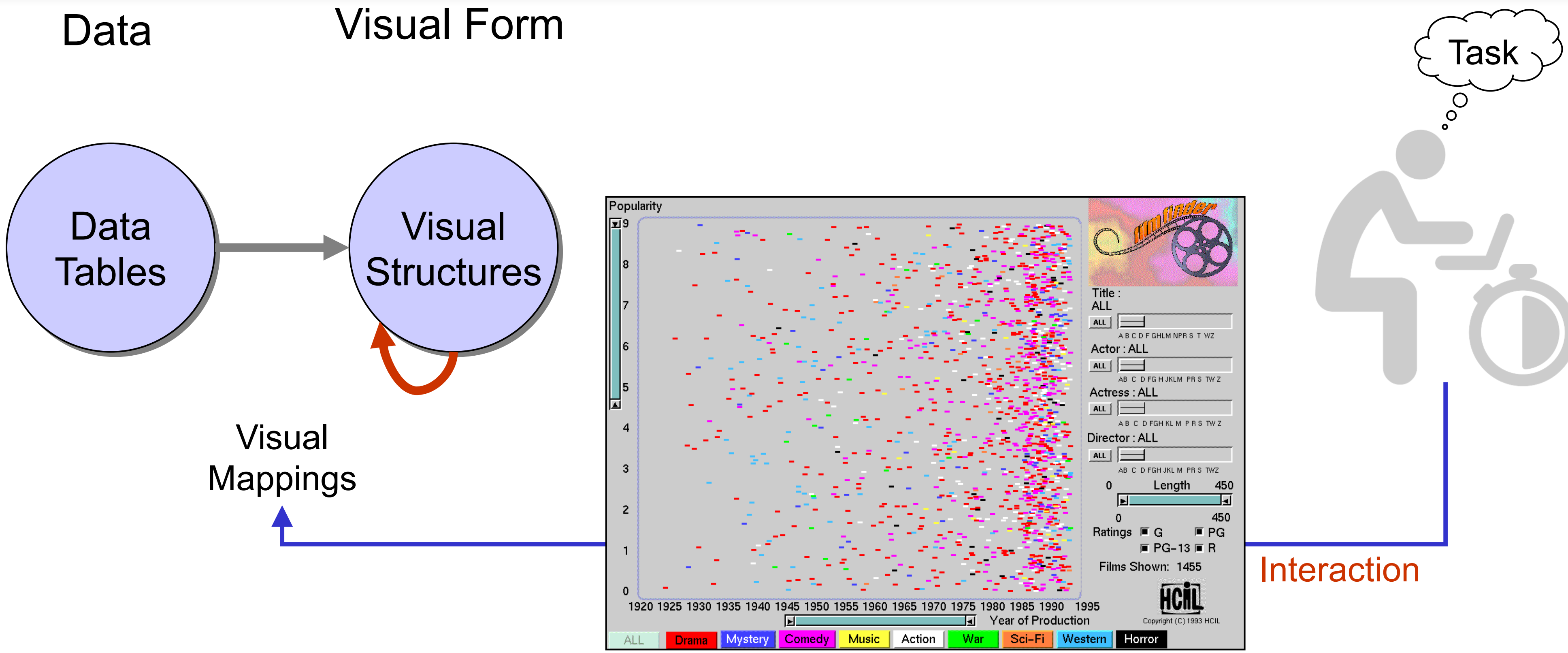
3.2.6 Direct Manipulation

- The user can move, modify, etc. visual objects on the screen with the help of a device (e.g., a mouse)
- Direct manipulation can be used for data transformation modifications, for example, by embedding widgets (like a lasso tool) in a visualization and using them to control specific parameters, filter, …



http://dl.acm.org/citation.cfm?id=1166265

3.3 Visual Mapping



- Example: FilmFinder
- By clicking on the y-axis. The user can change the label and the scatter plot from *Popularity* to *Rating*

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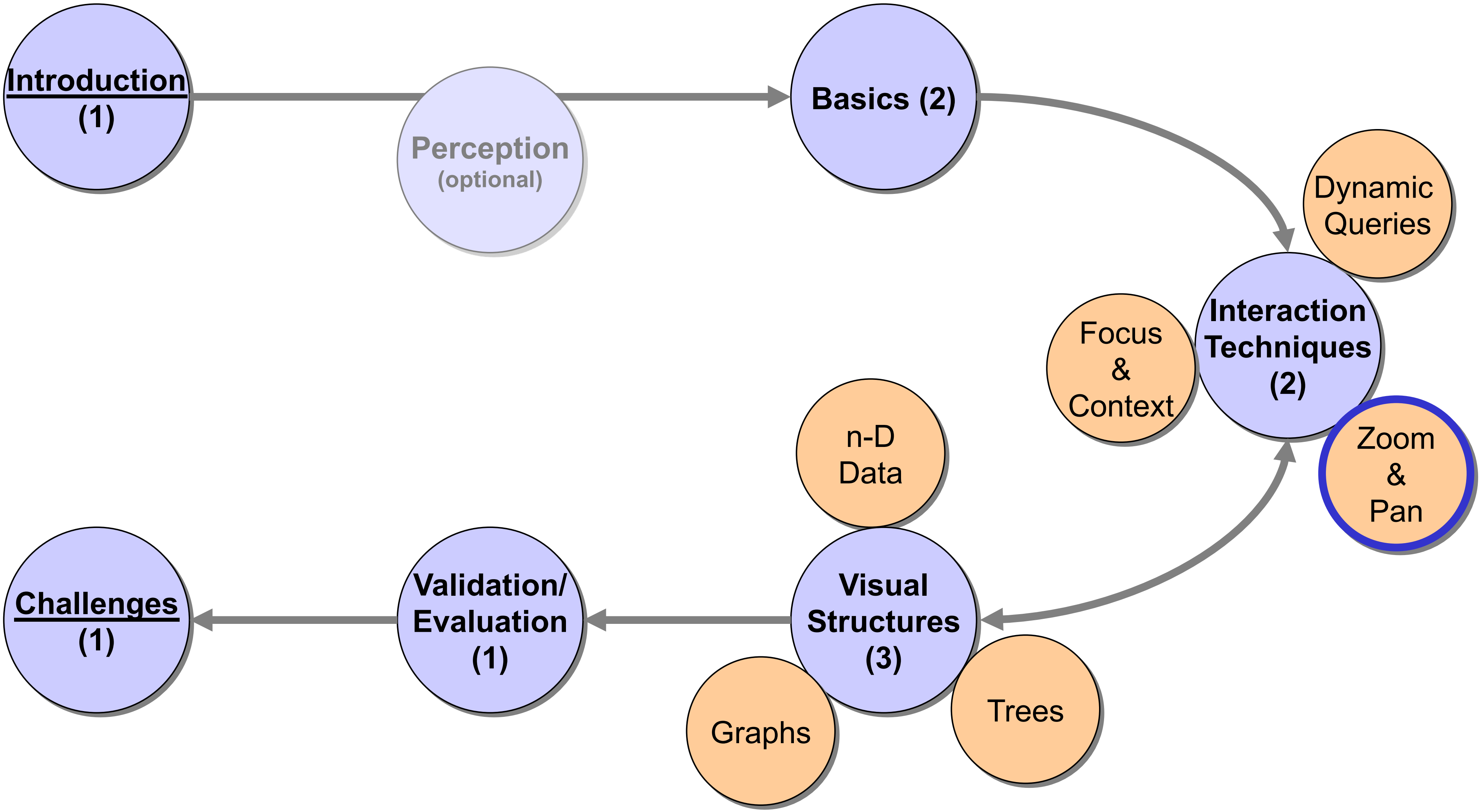
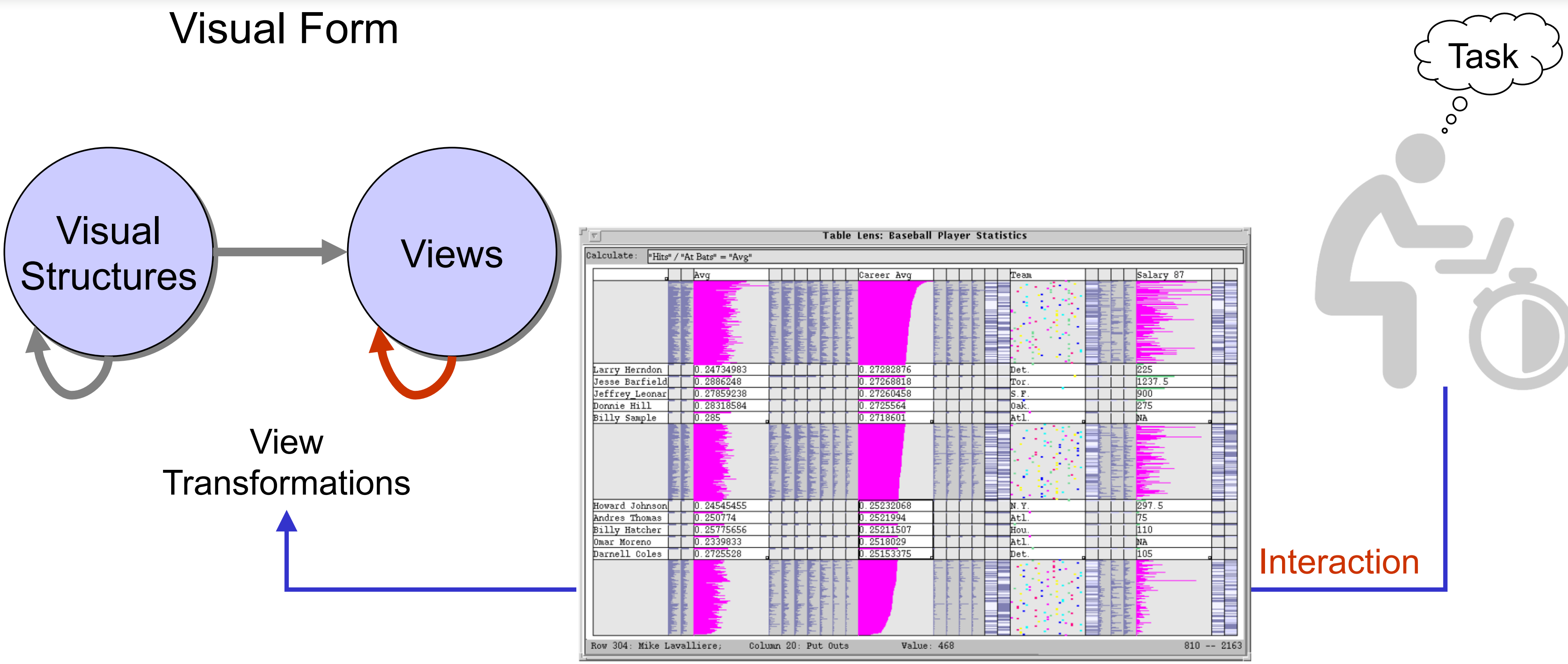


3.4 View Transformations



- <u>Example:</u> Table Lens
  - Location Probes, Viewpoint Controls and distortion techniques are integrated in the GUI mostly. In the screenshot, two areas (bundles of rows) are focused

3.4 View Transformations

- <u>Fundamental Problem:</u> **Scale**
  - Many data sets are too big and too complex in order to display them on a screen
  - Reasons
    - Too many different cases/objects
    - Too many attributes/variables for each case
  - Users want to highlight specific cases or attributes (active) or get them highlighted (passive). However, the focus on important things permanently changes in normal cases

[Inspired by J. Stasko‘s course]

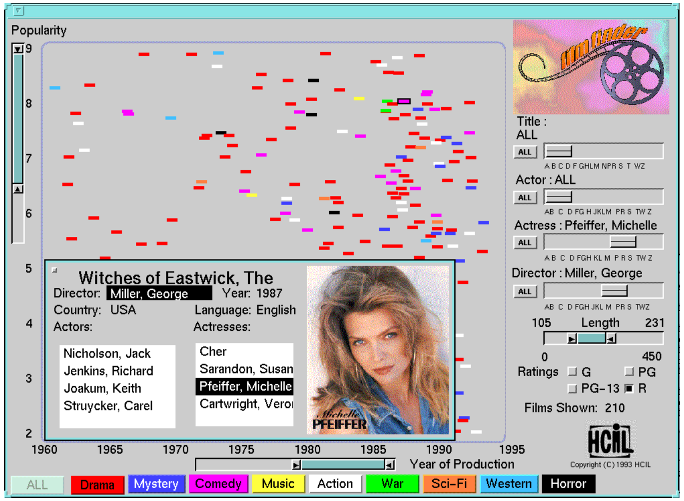
3.4 View Transformations

- Trivial solution: **Scrolling**
  - Mostly-used approach
  - Scrollbars shall give orientation and a possibility to quickly move through the document
- Problems
  - Where am I? The largest part of the document is hidden!
  - → No *Context* !

[Spe:113ff]

3.4.1 Direct Selection

- *Direct Selection* is a simple method to modify views
  - One selects objects or groups of objects in any way (e.g., with the mouse)
  - Selected objects are highlighted, manipulated, and/or additional information of these objects are displayed
  - Examples
    - Brushing and Linking
    - Pop-up windows
    - …

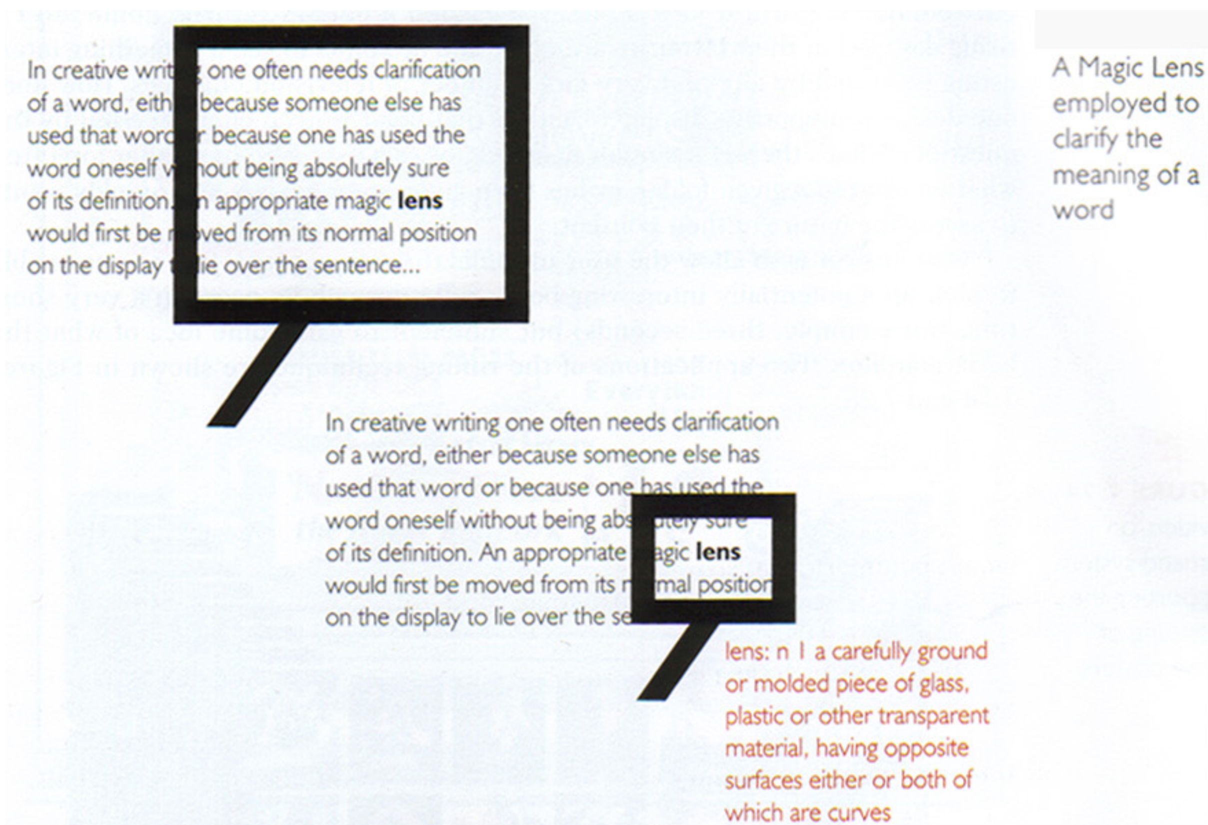


http://www.cs.umd.edu/hcil/spotfire/

[Inspired by J. Stasko's course]

3.4.2 Magic Lenses

- The *Magic Lens* approach uses a magnifying glass metaphor in order to select an element from its context and to fade in additional information



[Spe:124ff]

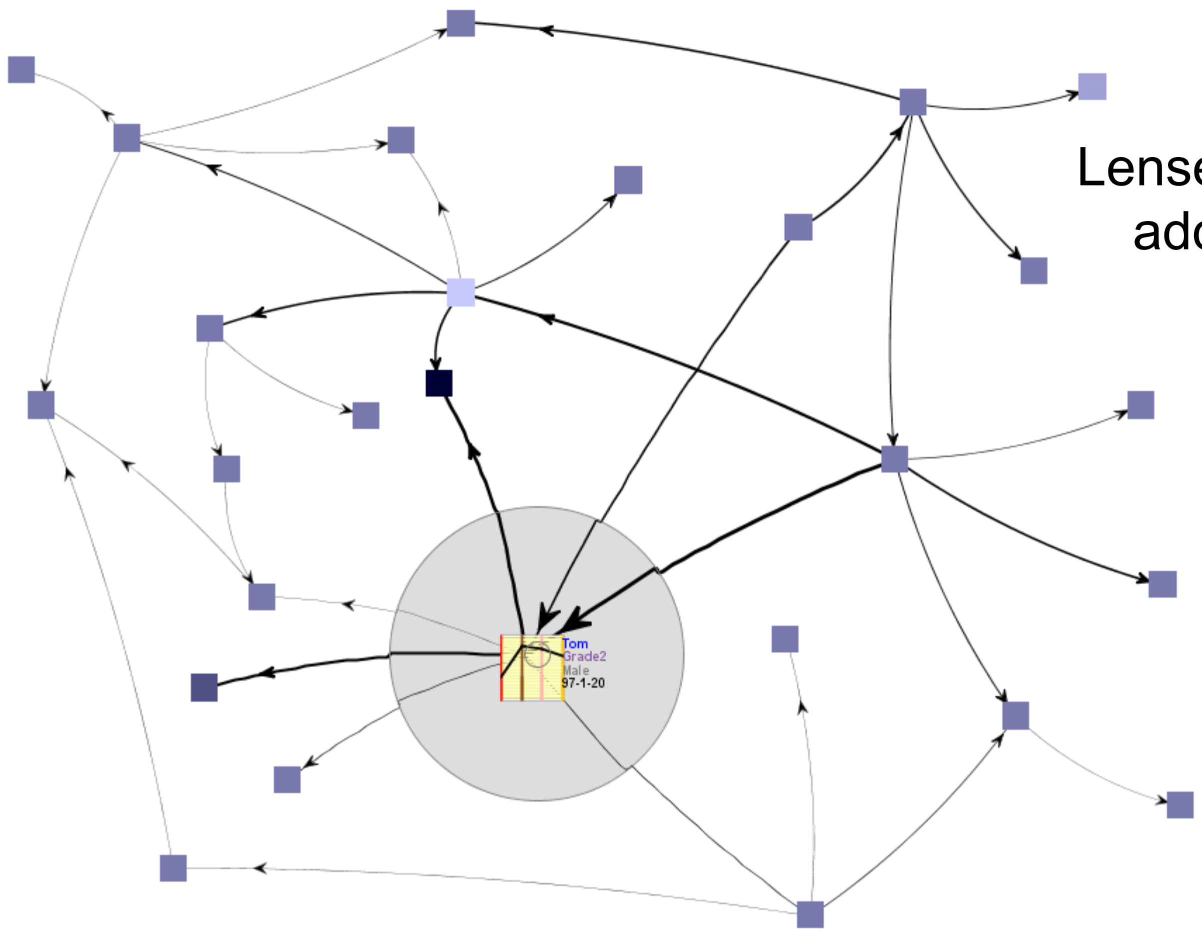
3.4.2 Magic Lenses

- Advantages
  - Intuitive metaphor
  - Less space consuming
  - Preserves the context
- Can be often used
  - Different kinds of lenses show different information (lens can be parameterized), depending of the application area
  - Examples

[Bier, E., et al., "Toolglass and Magic Lenses: The Seethrough Interface," Proc. ACM SIGGRAPH 1993, Anaheim, Calif., Aug. 1993, pp. 73-80.]

3.4.2 Magic Lenses

- Examples



Lenses for showing additional data

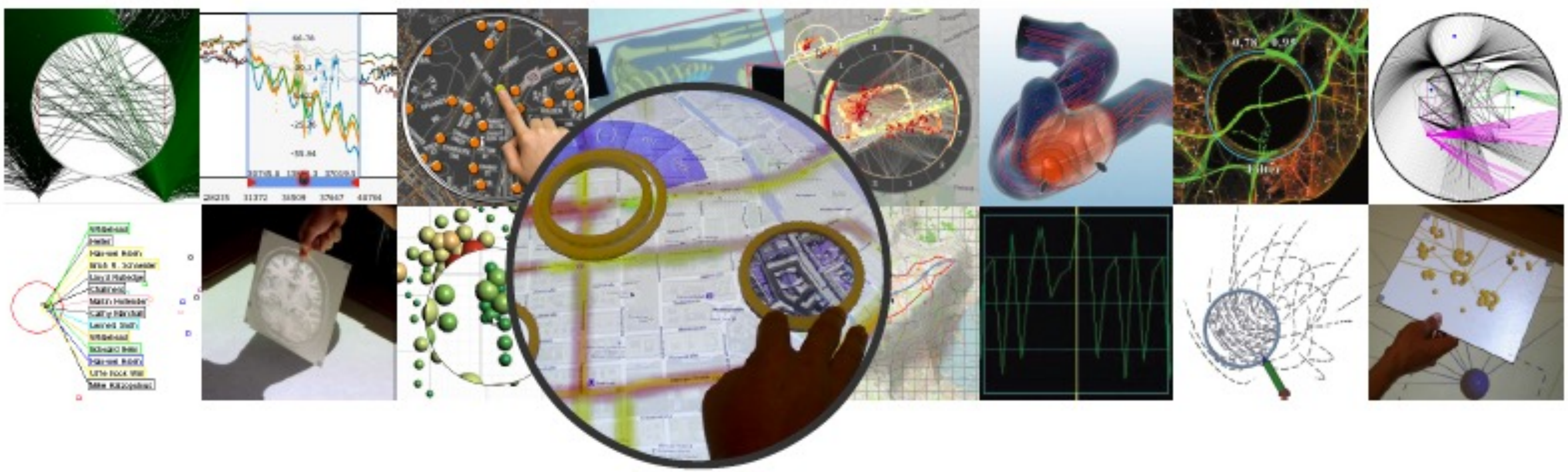
[Video]

[I. Jusufi, Y. Dingjie, A. Kerren. The Network Lens: Interactive Exploration of Multivariate Networks Using Visual Filtering. pp. 35-42, International Conference Information Visualisation, 2010]

3.4.2 Magic Lenses

- Examples

Survey for interactive lenses in information visualization

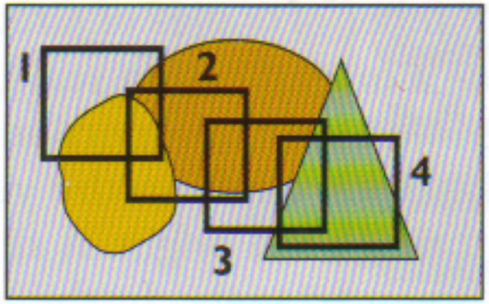


[Video]

[C. Tominski, S. Gladisch, U. Kister, R. Dachselt, H. Schumann. A Survey on Interactive Lenses in Visualization. STAR – State of The Art Report, Eurographics Conference on Visualization (EuroVis), 2014]

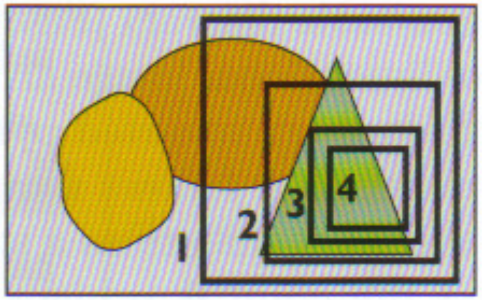
3.4.3 Zoom & Pan

- Panning
  - is the smooth movement of a viewing frame over a 2D image



Panning is the smooth movement of a viewing frame over a 2D image

- Zooming
  - is the increasing magnification of a decreasing fraction of an image (or vice versa)

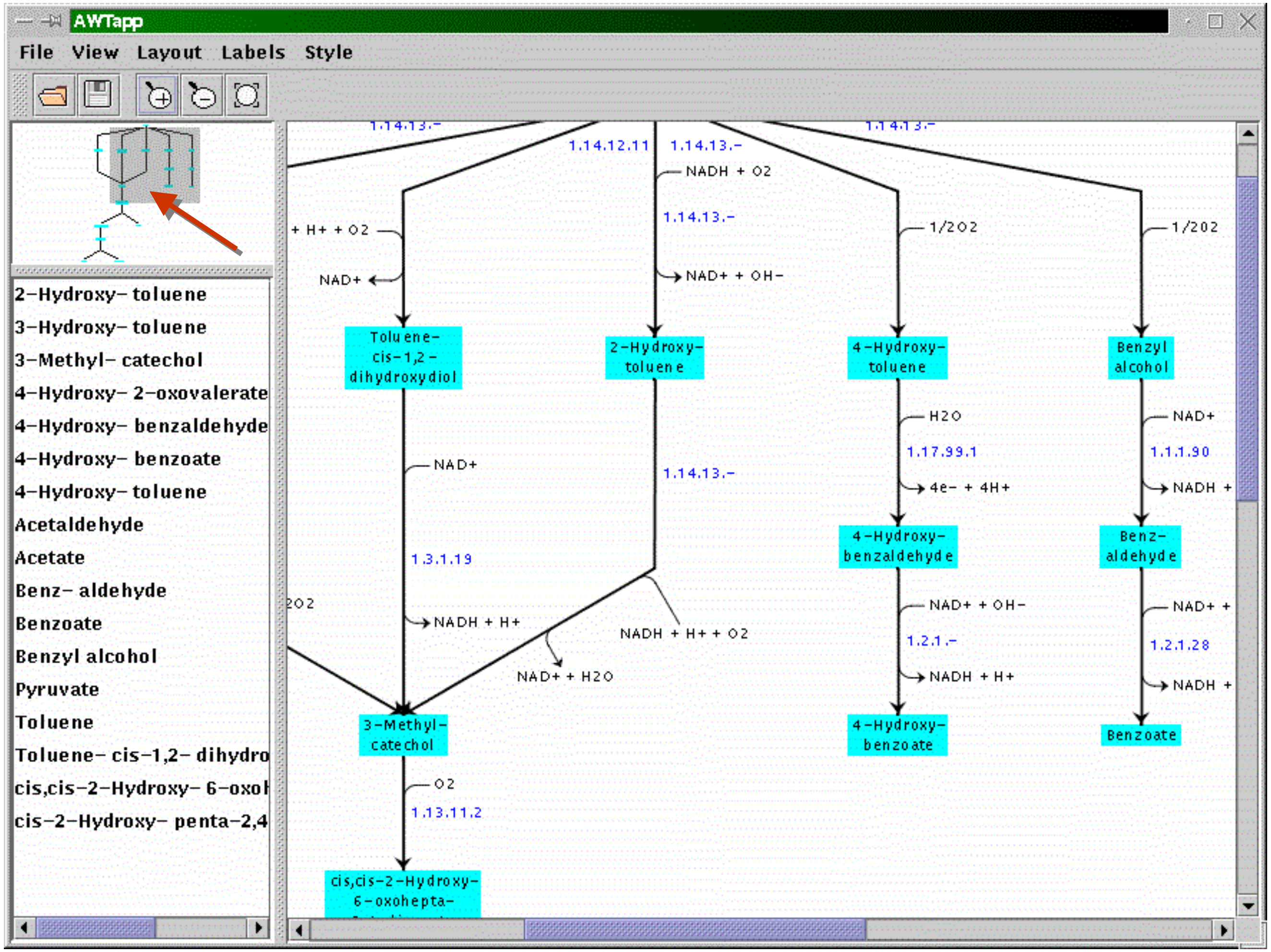


Zooming is the increasing magnification of a decreasing fraction of an image (or vice versa)

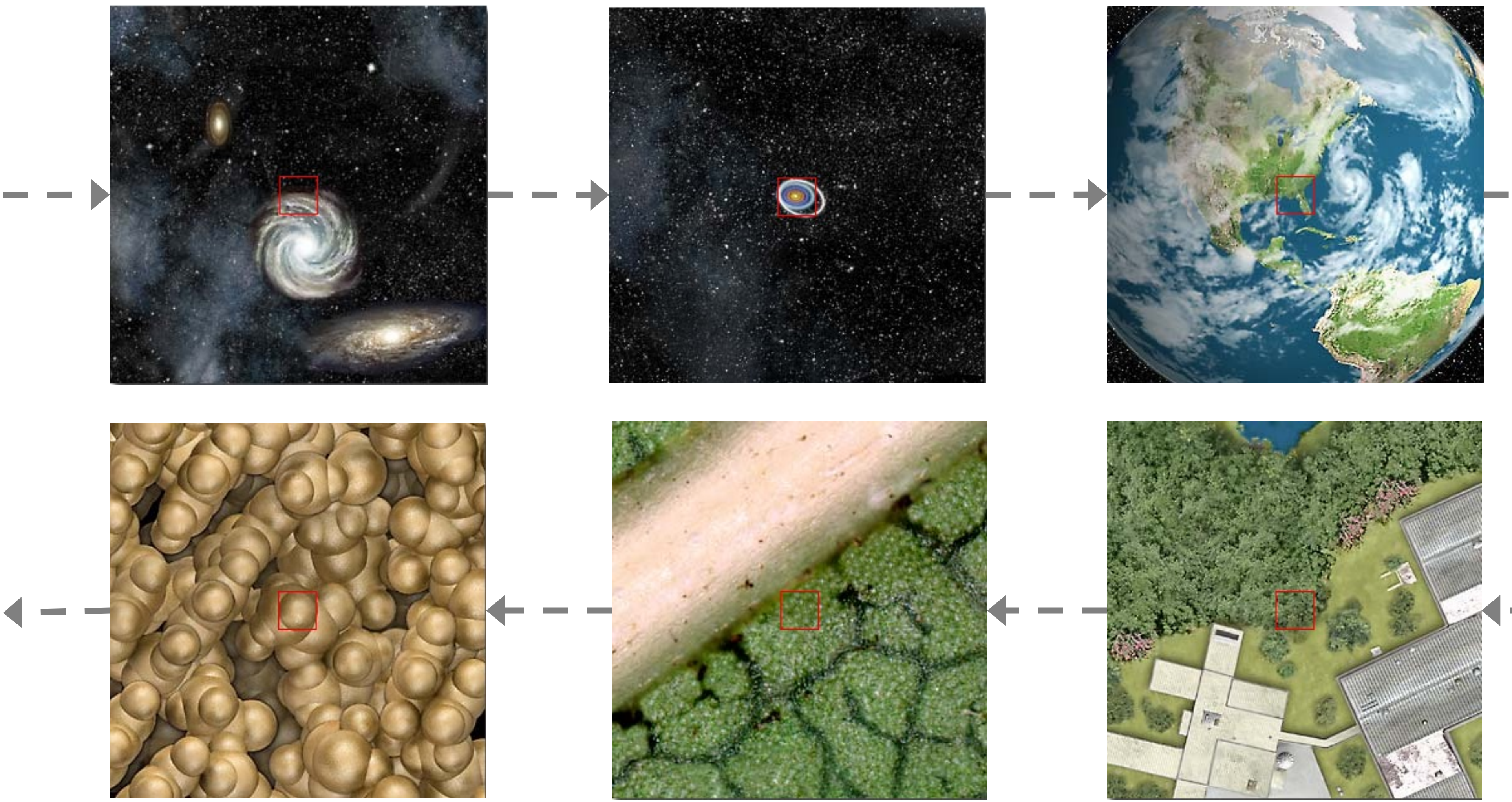
[Spe:130ff]

3.4.3 Zoom & Pan

- Example: Panning



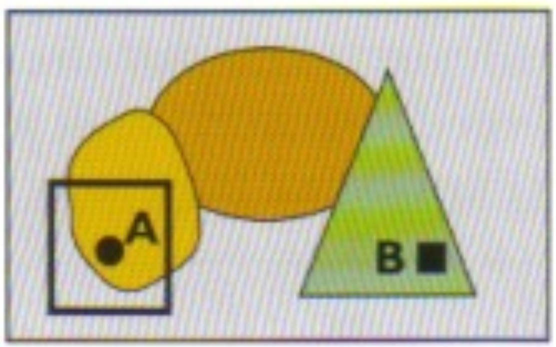
- Example: Zooming



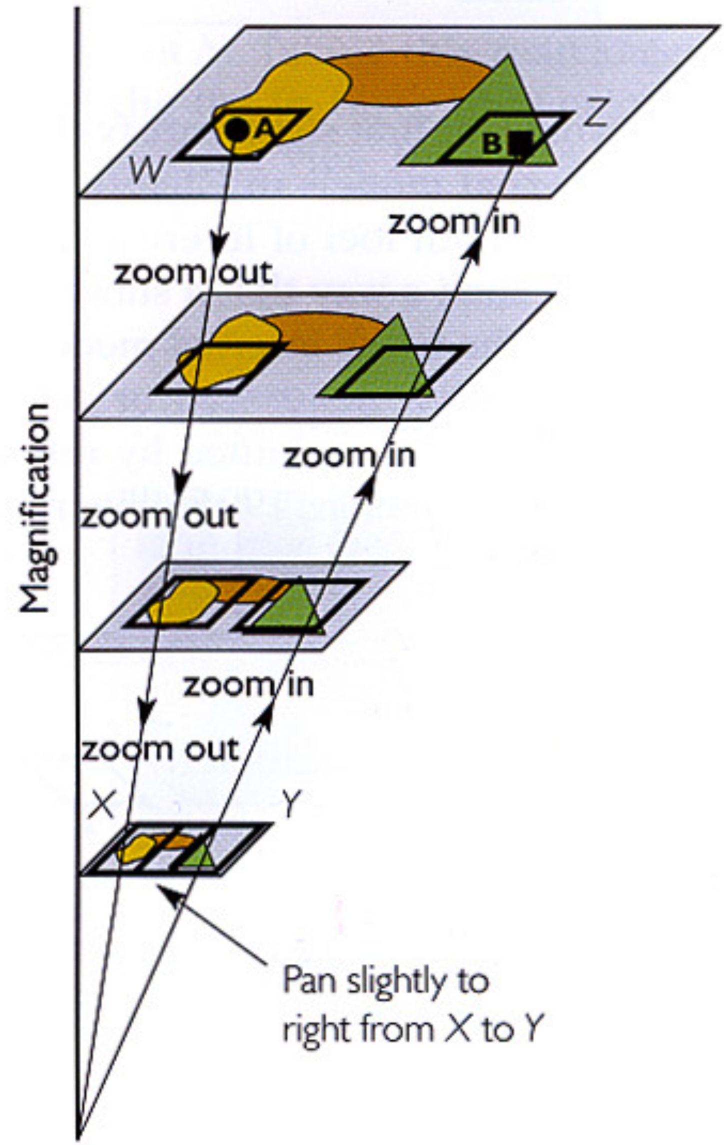
http://micro.magnet.fsu.edu/primer/java/scienceopticsu/powersof10/

3.4.3 Zoom & Pan

- Scenario: A user analyzes the focus point A, then he/she wishes to analyze point B.



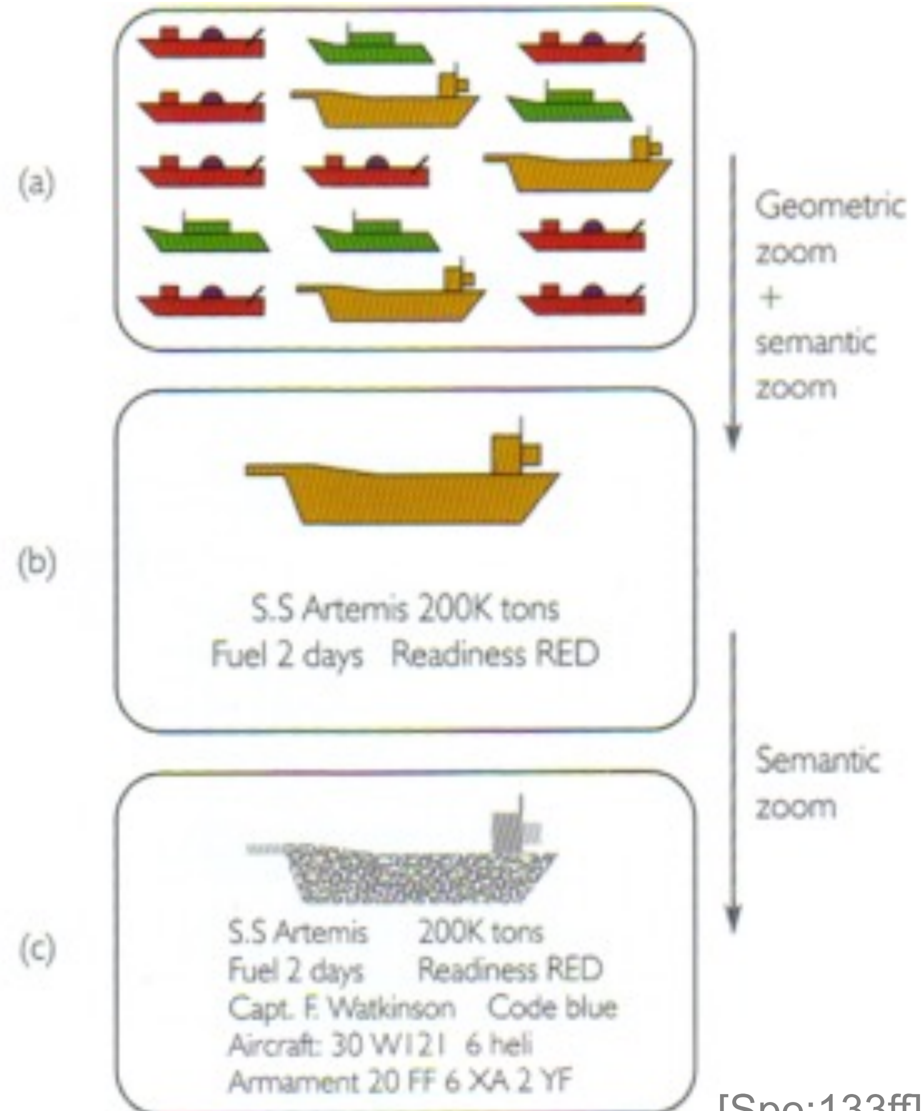
- To preserve the good overview, he/she zooms out in order to see both points. Then, he/she zooms in to point B
- → Space-*Scale-Diagram*



[Furnas, Bederson, Space-Scale Diagrams: Understanding Multi-Scale Interfaces, CHI'95 Proceedings, ACM, 1995, 234-241]

3.4.4 Semantic Zooming

- Semantic Zooming includes a stepwise fading in of more information
- This can happen during „normal“ Zooming or independent from any geometric zoom function



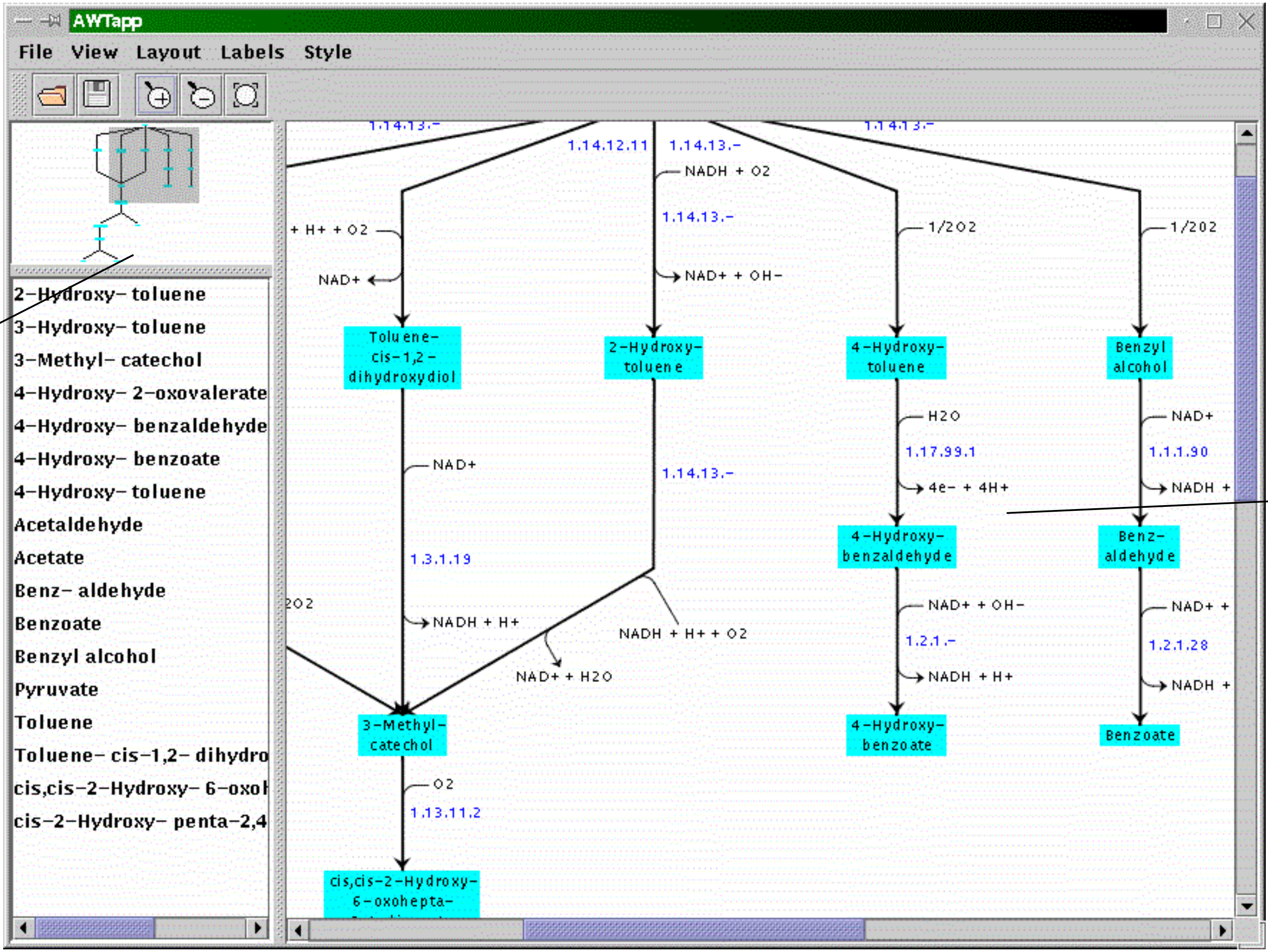
[Spe:133ff]

3.5 Overview & Detail

- Ideally, a tool should offer both overview *and* detail
- Of course, this concept is also a view transformation
- There are two different ways to combine both aspects
  - *Time* – Change between overview and detail; use the same space for display
  - *Space* – Use different areas on the screen at the same time
- Both ideas have disadvantages and advantages
  - Especially important for mobile devices with relatively small screens

3.5.1 Introduction

Overview

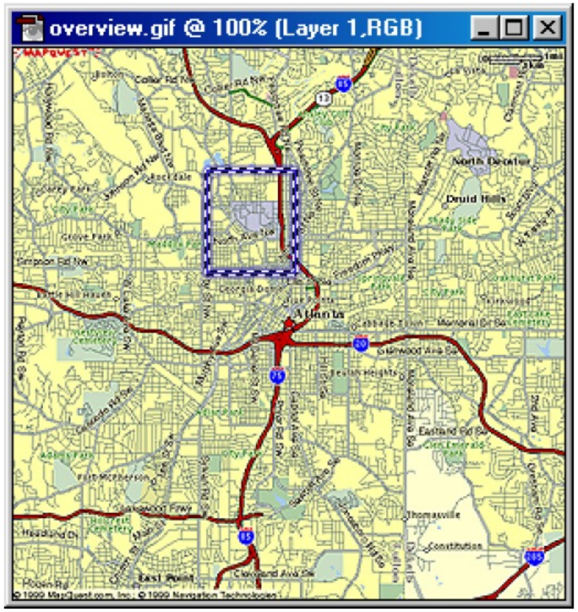


Detail

3.5.2 Solutions

1) Only detail
   - Scrolling or Panning

2) One window with zoom and replacement function
   - Zooming area will replace the „old“ view in a second step
   - Context switches might be confusing



3.5.2 Solutions

3) Coordinated pair of views

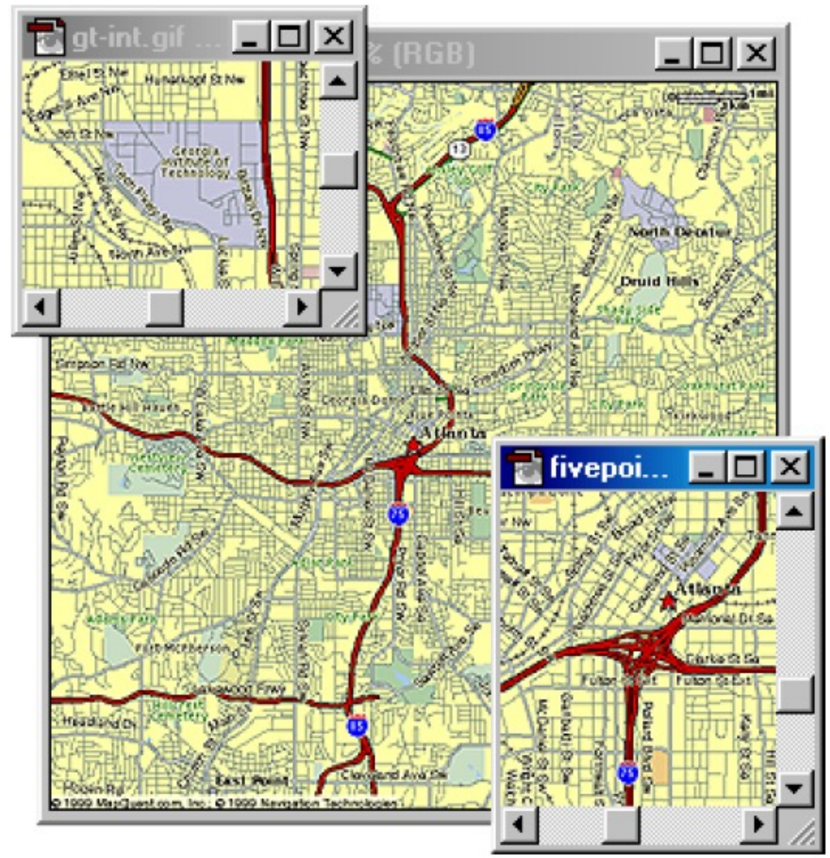
- How large should the different views be and where should they be positioned?

4) Multilevel-Browser

- Views do not overlap

3.5.2 Solutions

5) Free zooming and multiple overlaps
   - Very flexible, but manual window management by the user



Focus & Context techniques try to solve some of the problems of *Overview & Detail*, see Section 4.6

3.5.3 Design Concepts

- What is the „best“ solution? It depends on the application
  - Analysis
    - High level of detail, complete view on the data, …
  - Navigation
    - Global view is important; pan and zoom is not so important
  - …
- The key aspect is the use of several views
  - Baldonado et al. present a model for using several views, i.e., they discuss views regarding
    - choice
    - presentation
    - interaction

[M. Baldonado, A. Woodruff, and A. Kuchinsky. Guidelines for using multiple views in information visualization. In Advanced Visual Interfaces, pages 110--119, 2000.]

3.5.4 Application Example

Information Mural

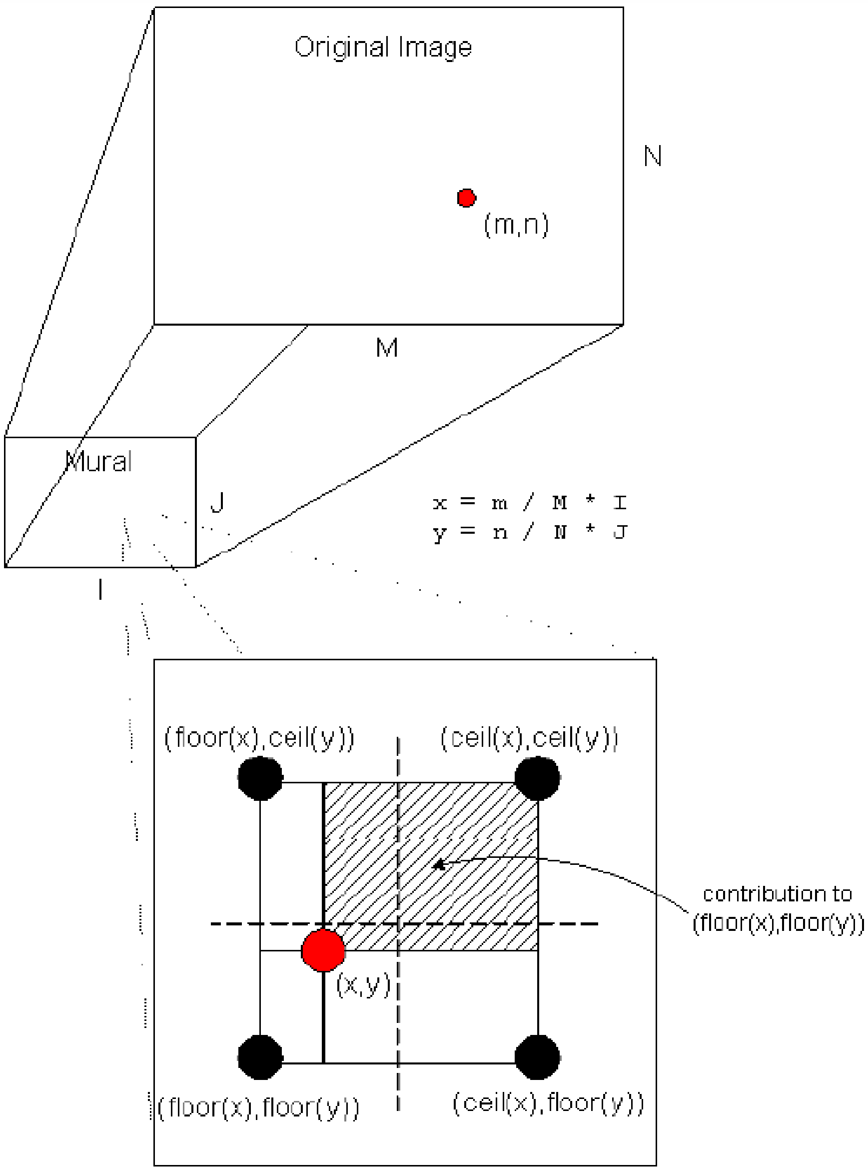
- [Jerding, Dean and Stasko, John, "The Information Mural: A Technique for Displaying and Navigating Large Information Spaces,“ IEEE Transactions on Visualization and Computer Graphics, Vol. 4, No. 3, July-Sept. 1998, pp 257-271.]

- Motivation
  - What should we do if the data are too big for an overview window?
    - We have more data points than pixel
    - We want *not* scroll (because of the disadvantages of scrolling)
  - Solution
    - Use shadowing, antialiasing, etc. in order to design a clever, alternative overview

3.5.4 Application Example

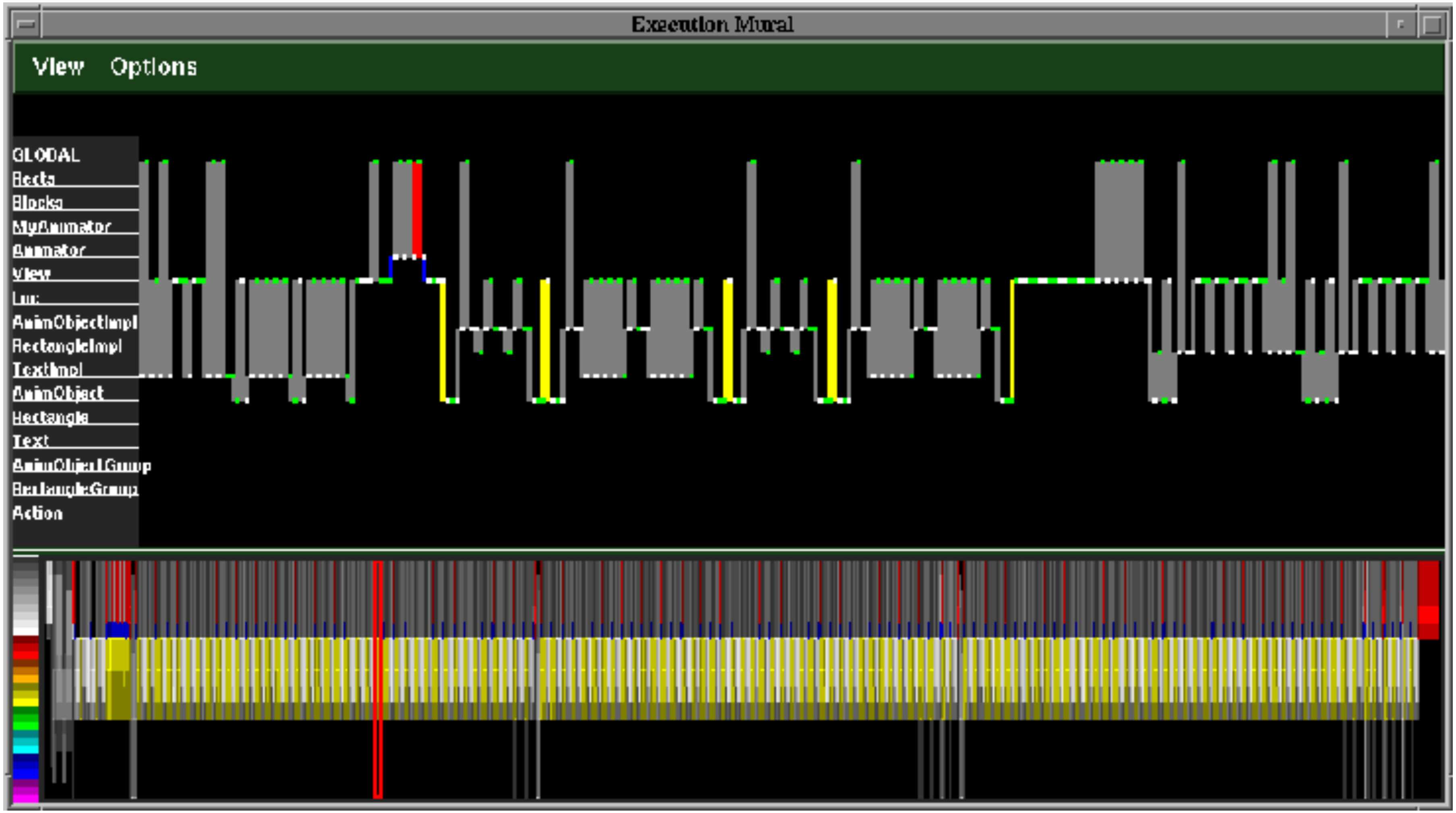
Idea

- We imagine that each data case is a ink spot and each pixel is a container
  - The data objects (ink) do not fit into a container → ink drains into other, adjacent containers
  - Use color- and/or grayscales



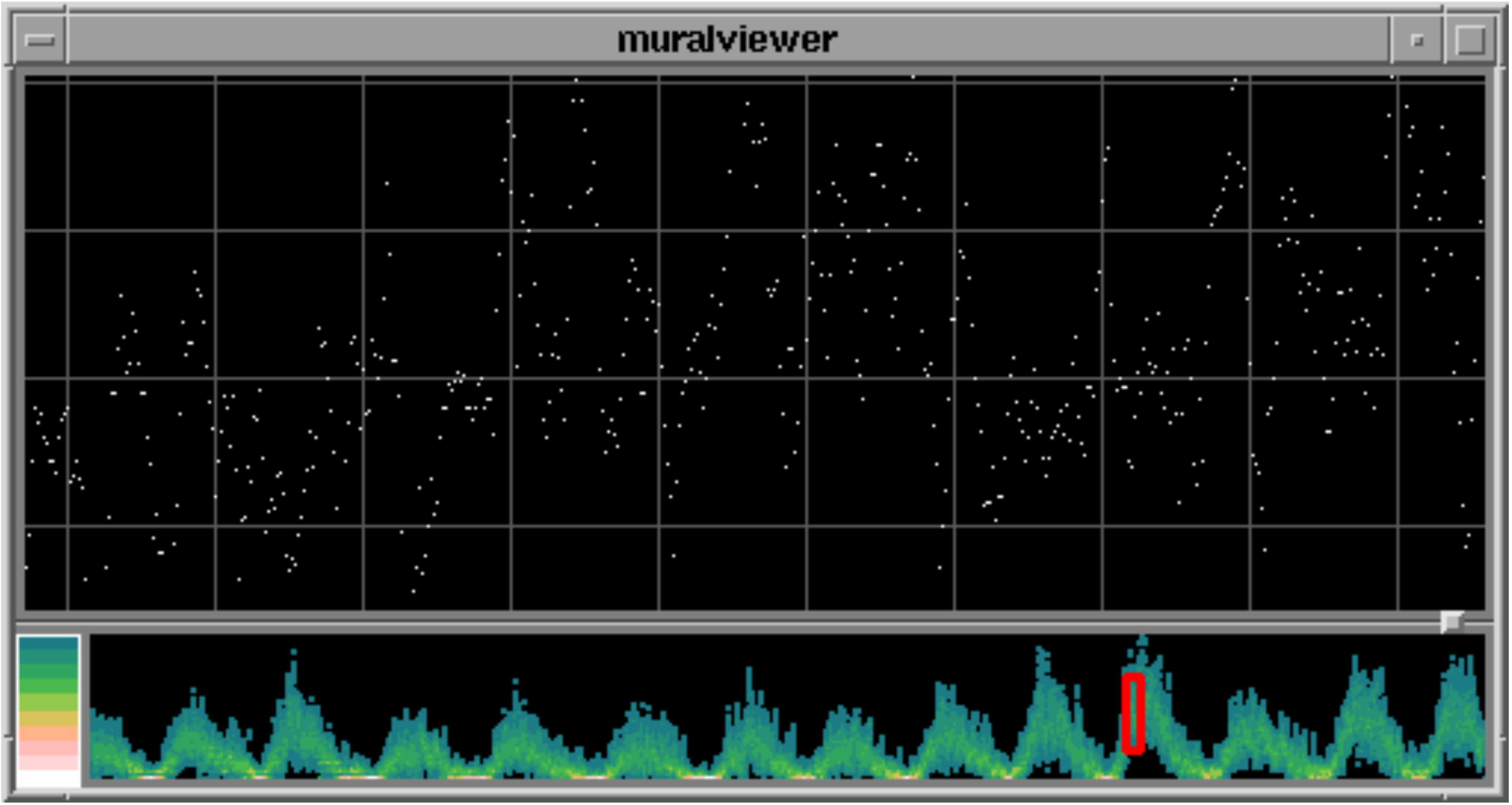
3.5.4 Application Example

- Example: Execution of object-oriented code

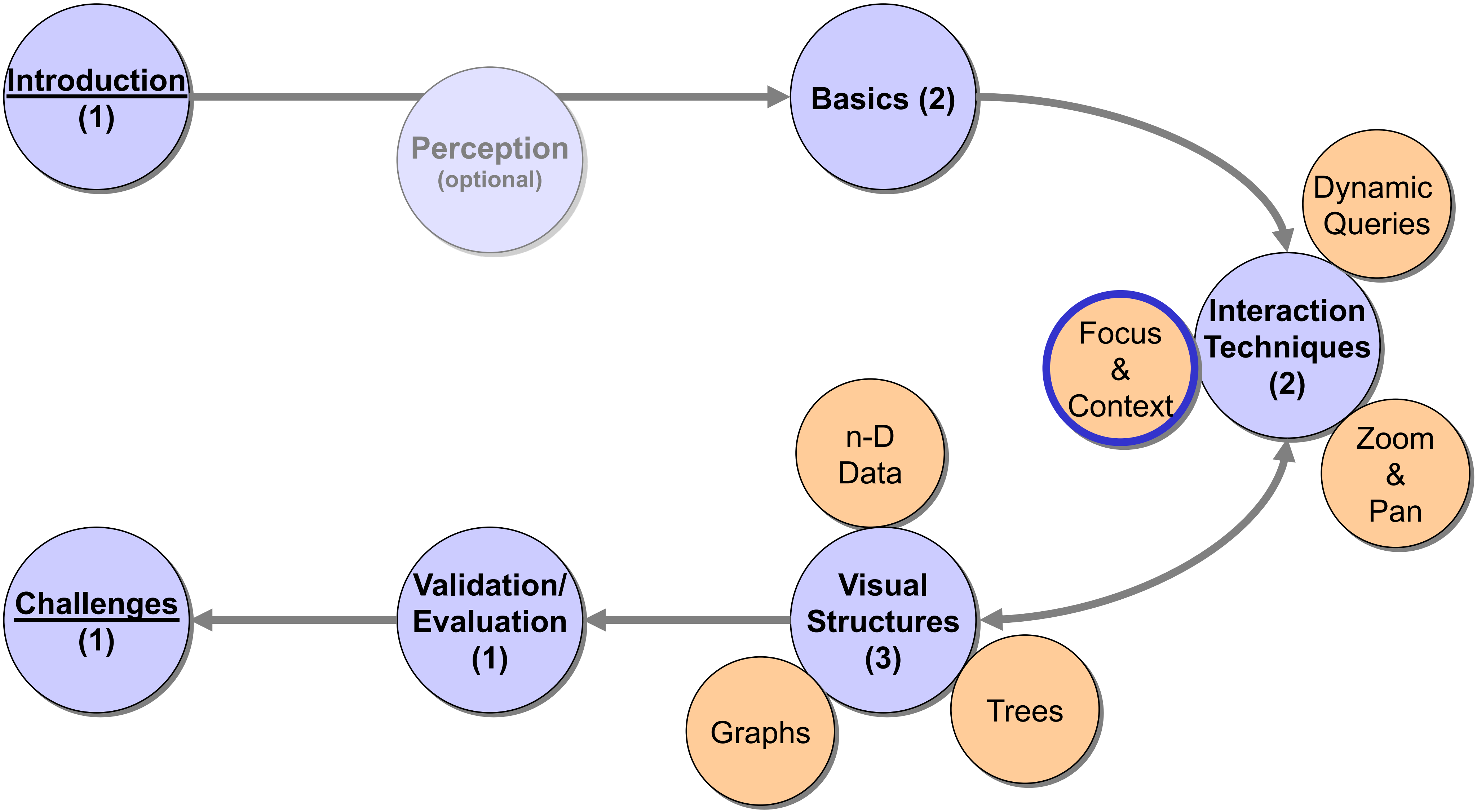


3.5.4 Application Example

- Example: Activity of sun spots over a 150 year period



TNM111: 10 Lectures

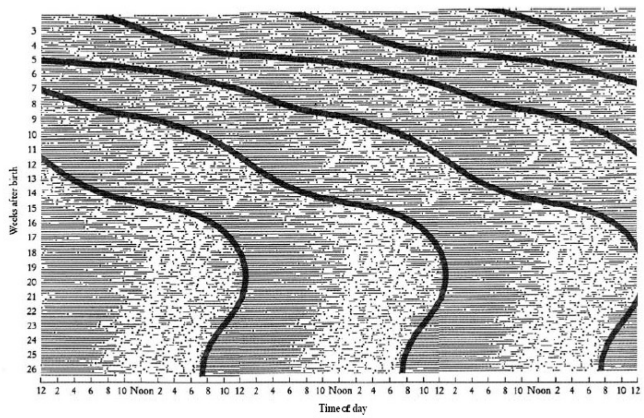


3.6 Focus & Context

- Challenge
  - Seamless and smooth coexistence of context/overview and focus/detail
  - In contrast to *Overview & Detail,* both aspects are embedded in <u>one</u> display/window
- What is that good for?
  - Harmonic coexistence of both aspects
  - Easy to switch between both aspects
  - Updates can be discovered better

3.6.1 Introduction

- Methods to selectively reduce information for the peripheral, contextual area
  - Filtering
    - Active/passive selection of cases
  - Selective Aggregation
    - Creates new cases that are aggregates of other cases (abstracting)
  - Micro-/Macro Readings
    - Graphics in which detail cumulates into larger coherent structures



3.6.1 Introduction

- Methods to selectively reduce information for the peripheral, contextual area (cont.)
  - Highlighting
    - Individual items are made visually distinctive in some way (color, frames, etc.)
  - Distortions
    - Cone Trees (3D)
    - Fisheye Views (1D, 2D, 3D)
    - Bifocal Displays (2D, 3D)
      - Perspective Wall (3D)
      - Document Lens (3D)
    - …

Most F&C techniques are concerned with distortion

3.6.2 Distortions

- 1D vs. 2D distortions

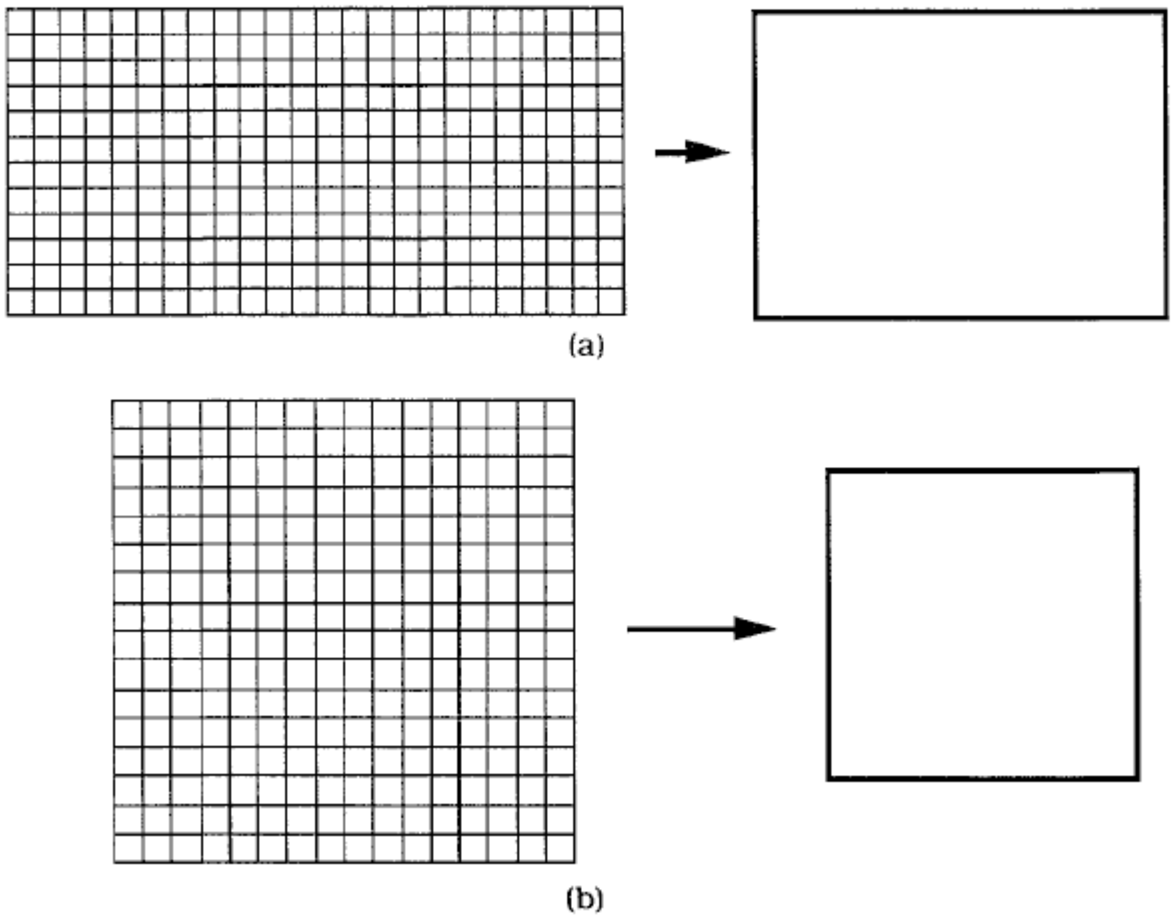
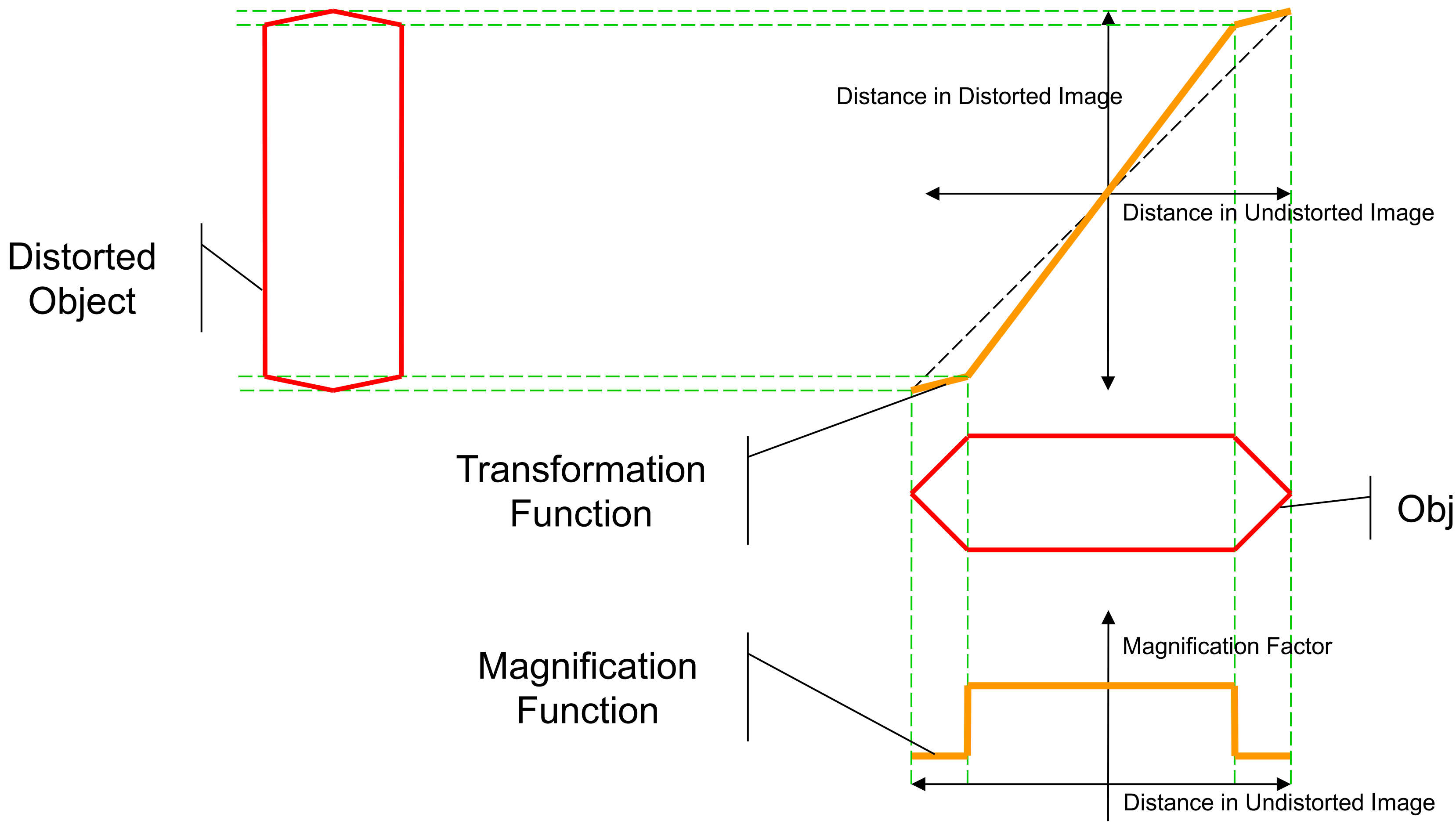


Fig. 4. A rectangular grid is to be mapped onto a confined space by applying a distortion-oriented technique; (a) in one dimension; (b) in two dimensions.

[Y.K. Leung and M.D. Apperley. A Review and Taxonomy of Distorsion-Oriented Presentation Techniques. ToCHI `94]

3.6.2 Distortions

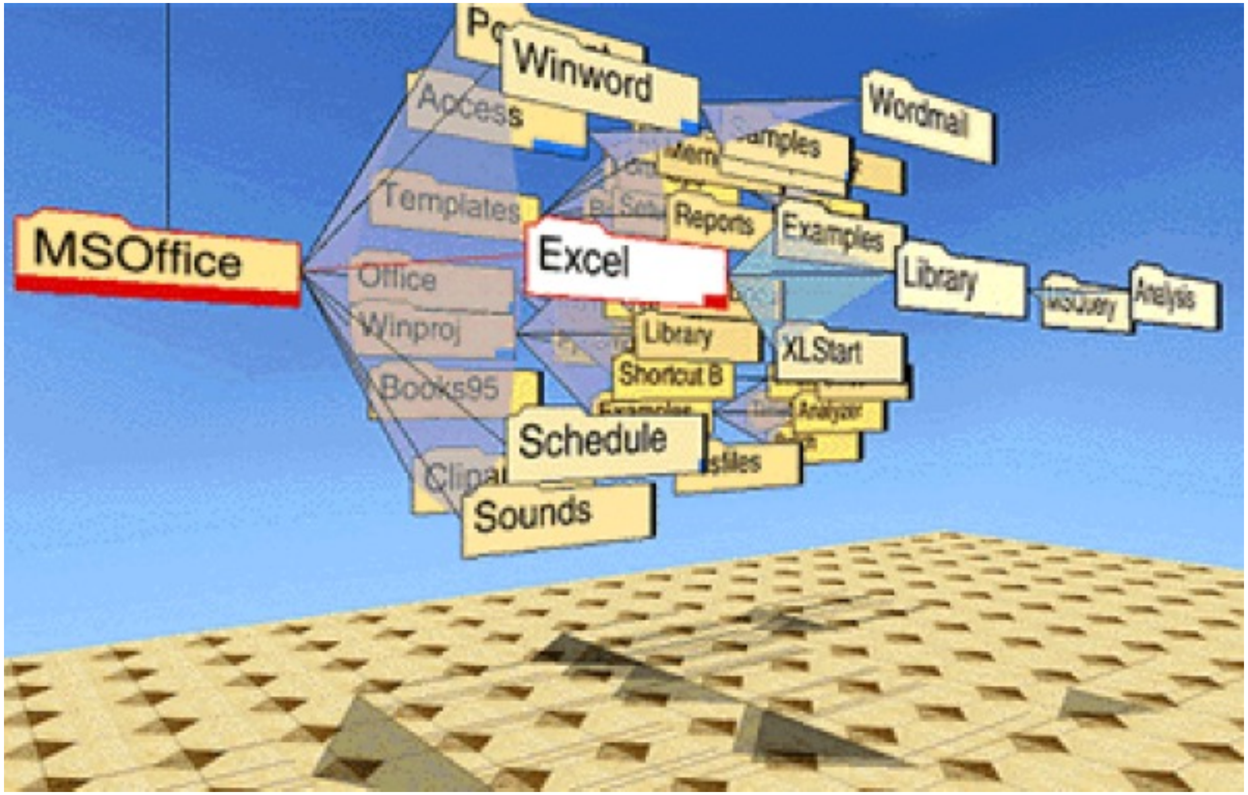
- Leung and Apperley compare distortion techniques with the help of transformation and magnification functions



[Y.K. Leung and M.D. Apperley. A Review and Taxonomy of Distorsion-Oriented Presentation Techniques. ToCHI `94]

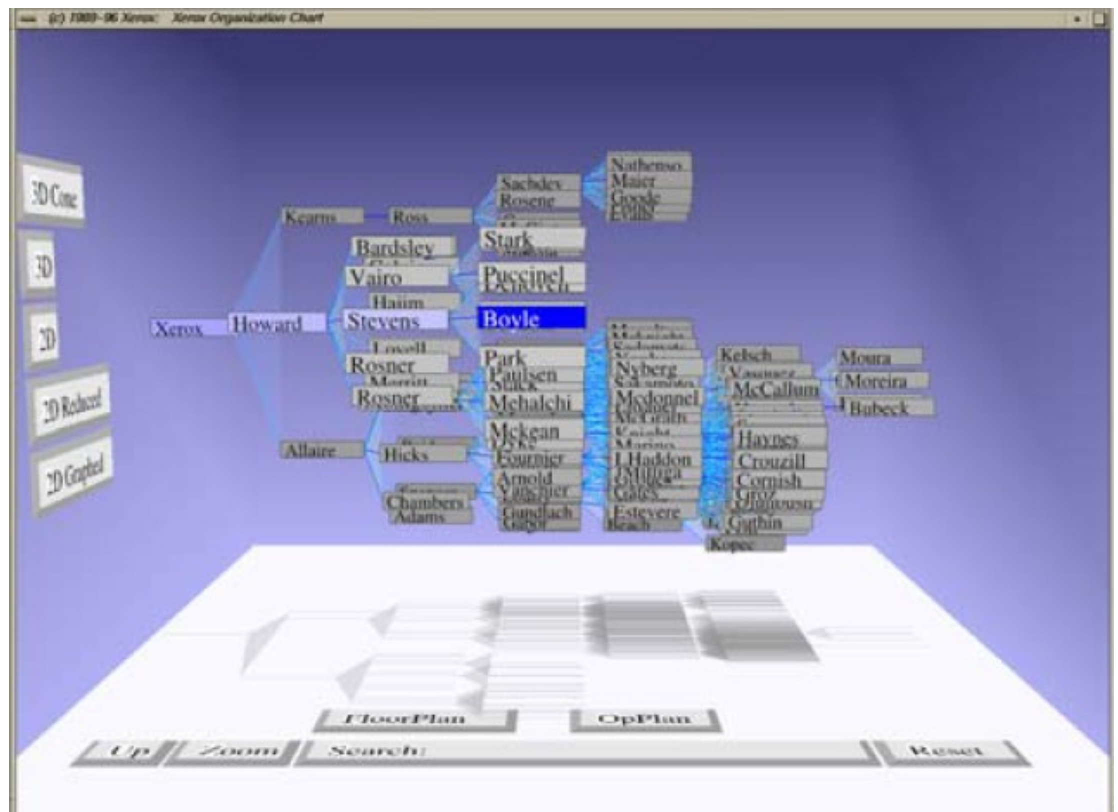
3.6.3 Cone Trees

- **Cone Trees:** 3D extension of traditional trees
- Tree levels are circularly positioned on discs



3.6.3 Cone Trees

- Perspective itself produces the distortion
  - Elements in foreground are in the focus
  - Elements in background form the context
- User can rotate or hide parts of the tree



3.6.4 Fisheye Views

- Real Fisheye Lenses

3.6.4 Fisheye Views

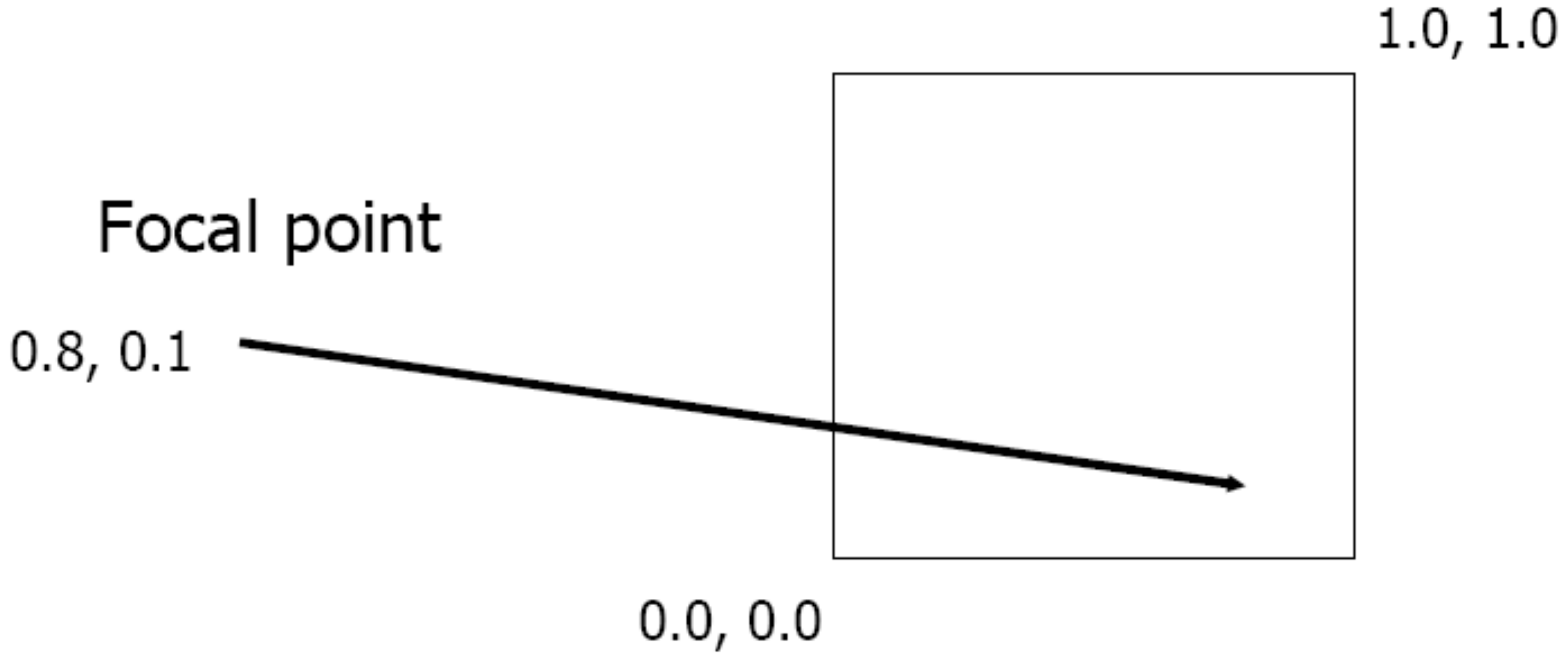
- Fisheye Views were introduced by Georges Furnas (Bell Laboratories) in 1981

  [Furnas, The FISHEYE View: A New Look at Structured Files, AT&T Laboratories, Murray Hill, NJ, 1981.]
  [Furnas, Generalized Fisheye Views: Visualizing Complex Information Spaces, CHI '86 Proceedings, ACM, 1986, 16-23]

- Furnas has defined several terms and metrics for a better understanding of Fisheye Views:
  - Focal Point
  - „Level of Detail"
    - Abbr.: LOD
  - Distance from Focus
  - „Degree Of Interest" function
    - Abbr.: DOI Function

3.6.4 Fisheye Views

- Focal Point
  - User looks at a specific object, at a specific coordinate, …
  - *f* = Focal point



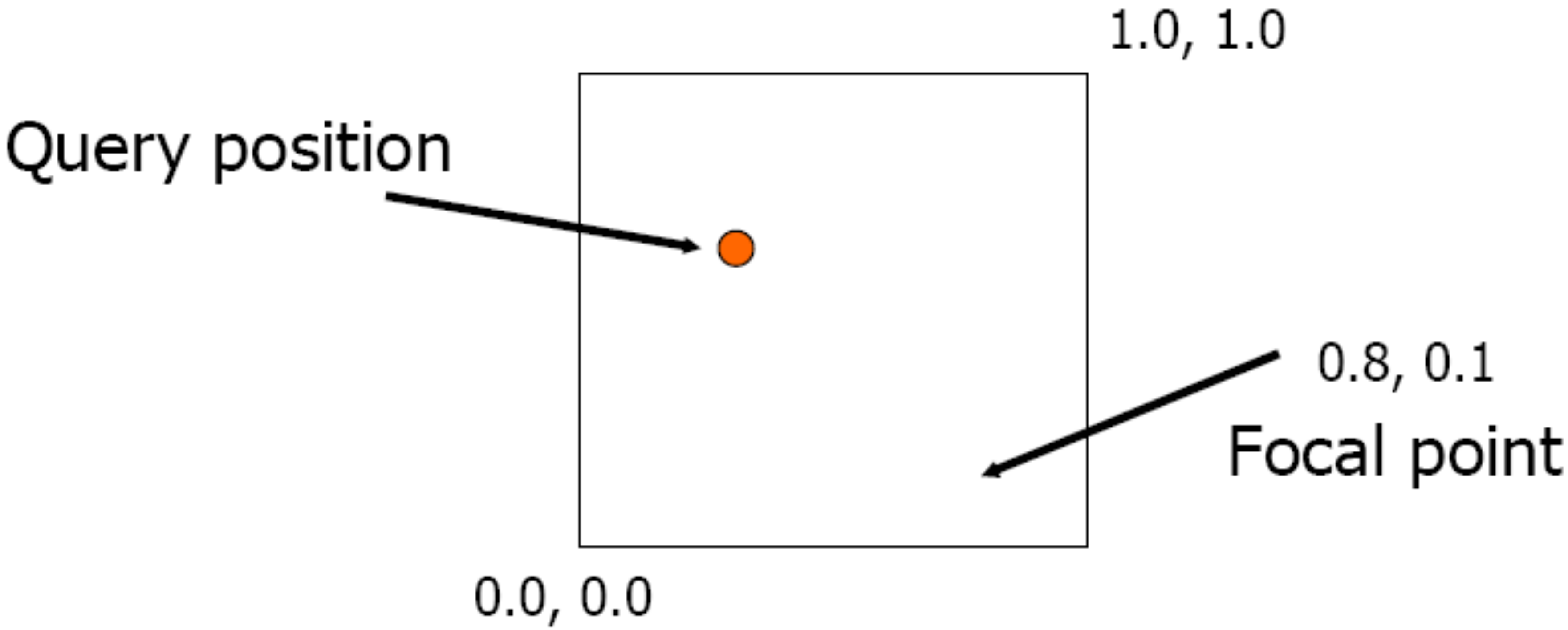
[Inspired by J. Stasko's course]

3.6.4 Fisheye Views

- LOD
  - This is some measure of a point‘s intrinsic importance, particularly to the global structure
  - A notion of high versus low resolution, degree of detail, etc.
  - → LOD(x)
  - Example
    - LOD(x_1) = -4 → lowest level with few details
    - LOD(x_2) = -3 → second-lowest level with a little more details
    - …
    - LOD(x_n) = 0 → highest level with many details

3.6.4 Fisheye Views

- Distance from Focus
  - Computation of the distance from the focal point *f* to each other data object at position *x*
  - → D(*x*,*f*)



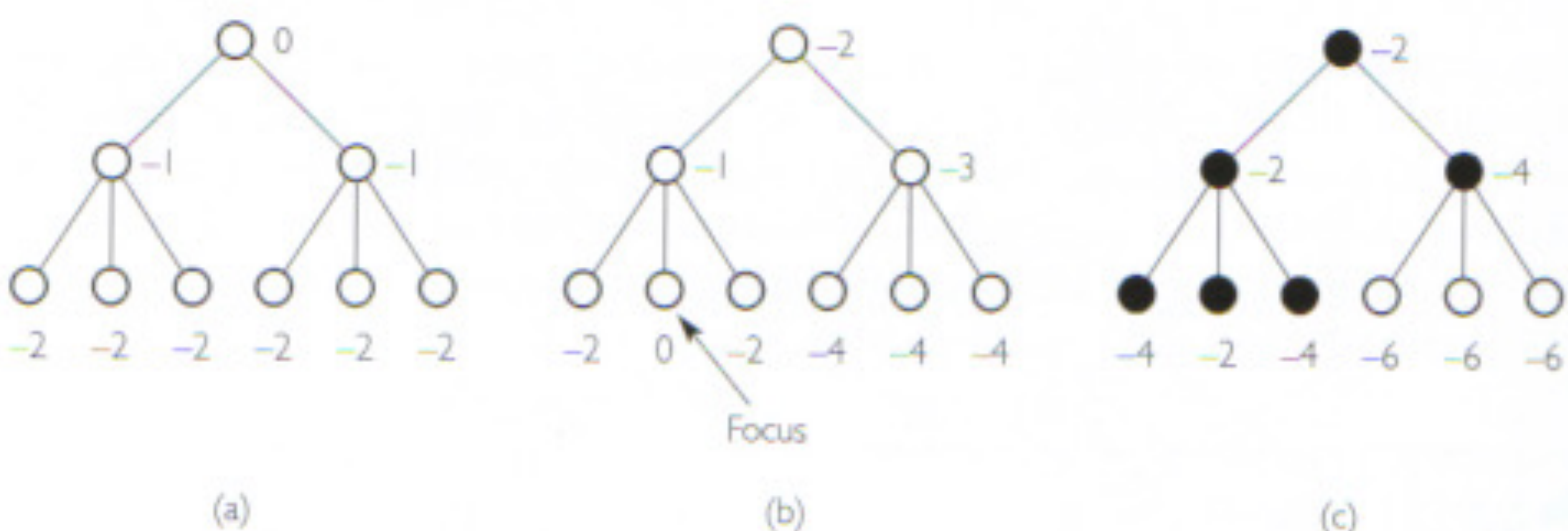
[Inspired by J. Stasko's course]

3.6.4 Fisheye Views

- DOI Function
  - This function determines how objects are drawn in the drawing area (≅ transf./magnif. functions)
  - DOI(x,f) = F(LOD(x), D(x,f))
    - F is monotone increasing in LOD
    - F is monotone decreasing in D
  - Typically, an object is only drawn if its DOI value is above a specific threshold. Thus, we can filter out some objects
  - With the help of this technique, we get a smooth interpolation between graphical objects on the screen dependent on their relative position to the focal point

3.6.4 Fisheye Views

- DOI Function (cont.)
  - Originally, Furnas took his cue from a tree



LOD(*x*) D(x,*f*) DOI(x,*f*)

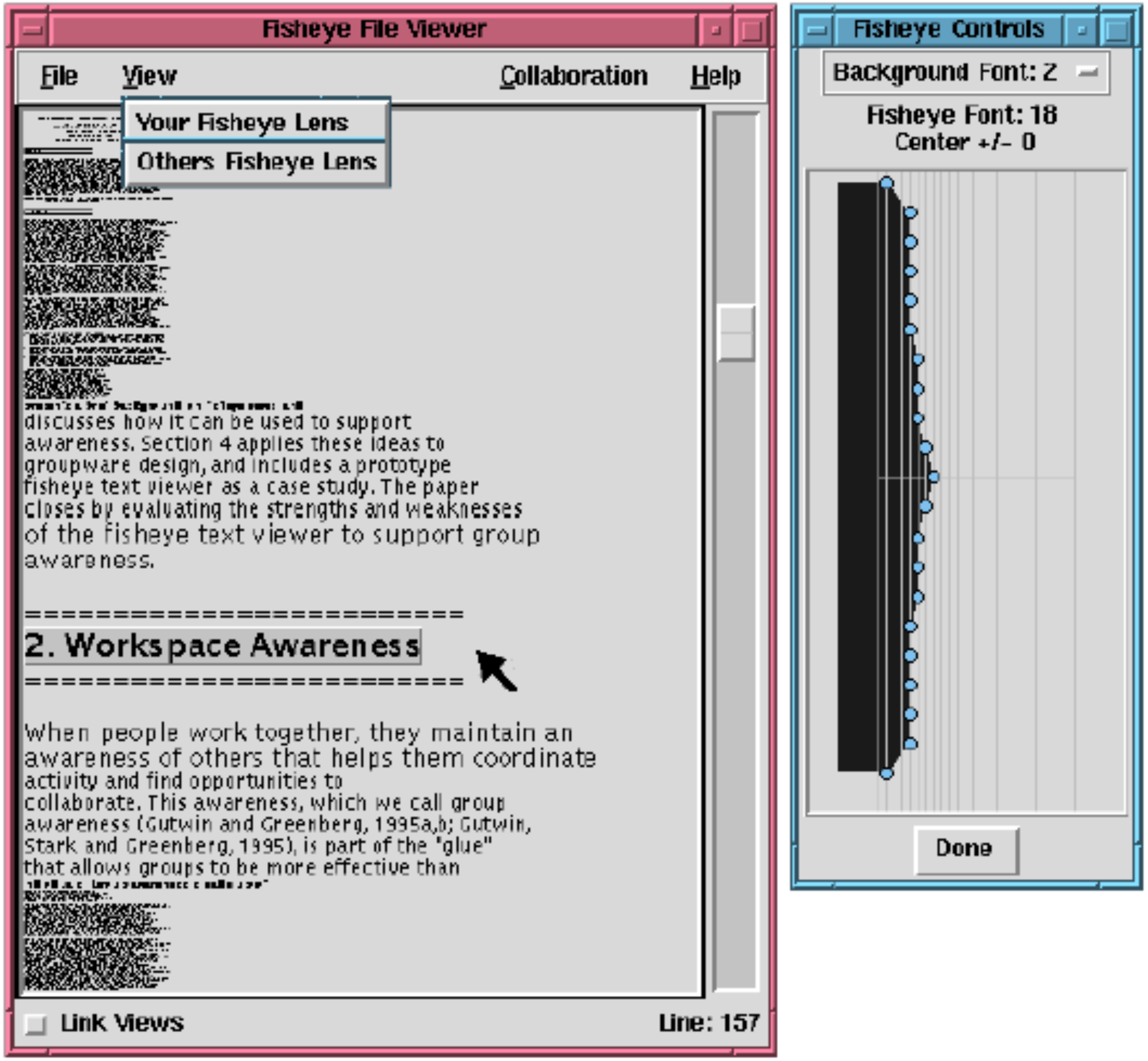
3.6.4 Fisheye Views

- Now, we can see that the original approach of Furnas was *not* meant spatially, but *logically*
- Later in 1992, Sarkar and Brown introduced so-called *Graphic Fisheye Views* that work with spatial distortions
- Thus, there are 2 different fisheye types which could also be combined with each other
  - Logic Fisheye Views
  - Graphic Fisheye Views (Distortions)

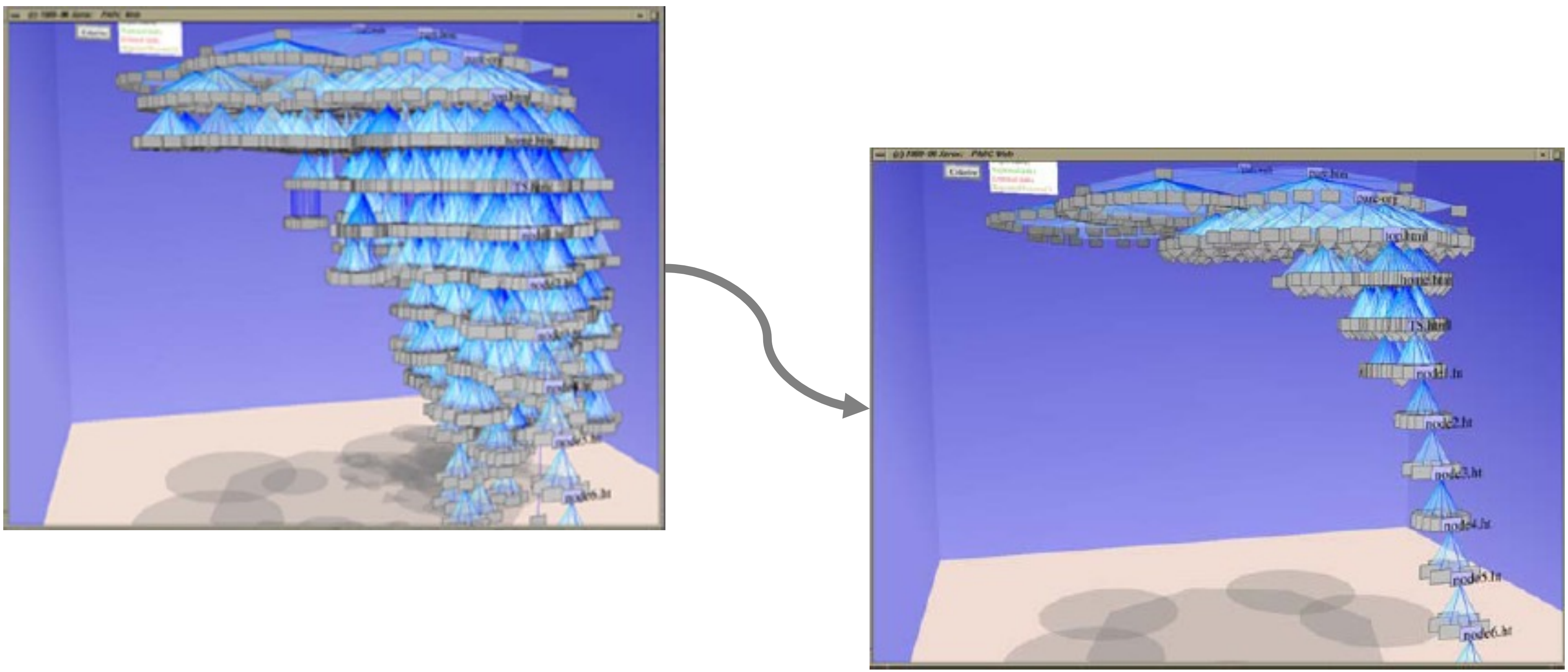
Logic Fisheye Views

Text (1D)

- Gutwin und Greenberg, HCI `96



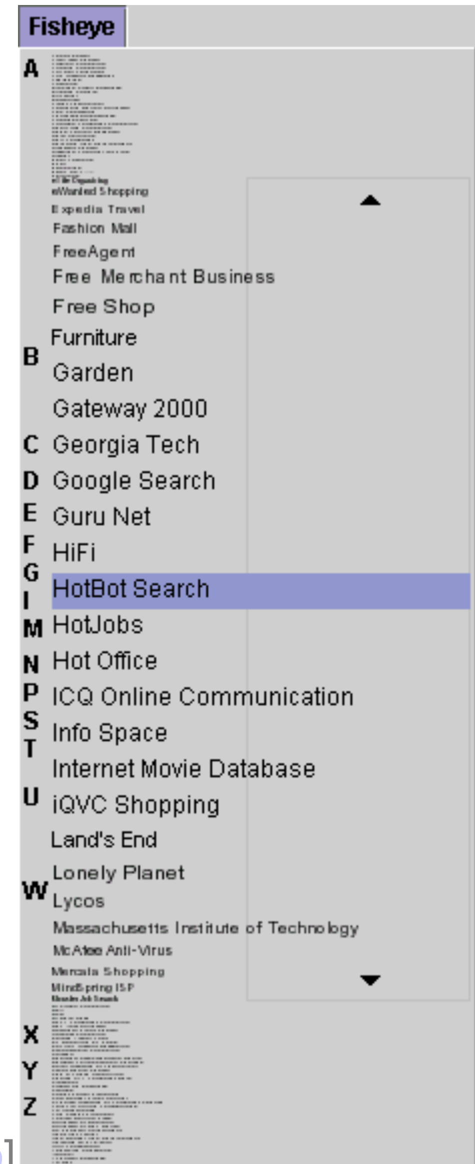
Cone Trees (3D)



Fisheye-Menus (2D)

- [Bederson, B. B. Fisheye Menus. Proceedings of ACM Conference on User Interface Software and Technology (UIST 2000), pp. 217-226, ACM Press]

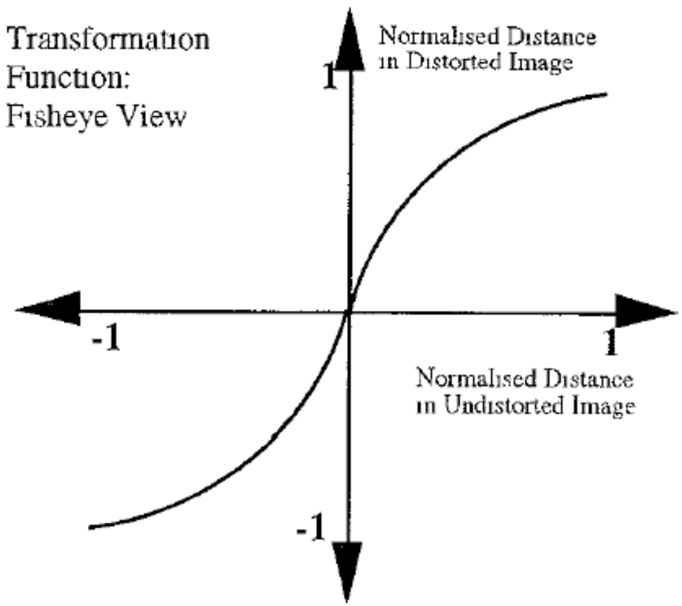
[Video]



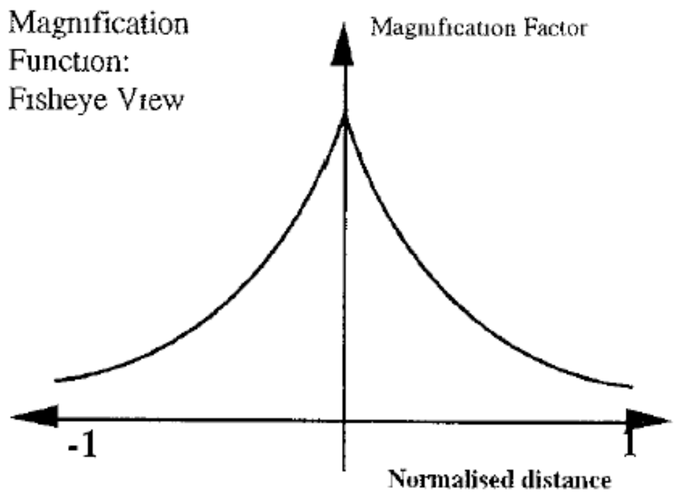
http://www.cs.umd.edu/hcil/fisheyemenu/

Graphic Fisheye Views

- Introduced by Sarkar and Brown in 1992 and mostly applied on 2D graphs
- Extension of the original Furnas approach with mathematical distortion methods



Transformation function



Magnification function

3.6.4 Fisheye Views [Graphic]

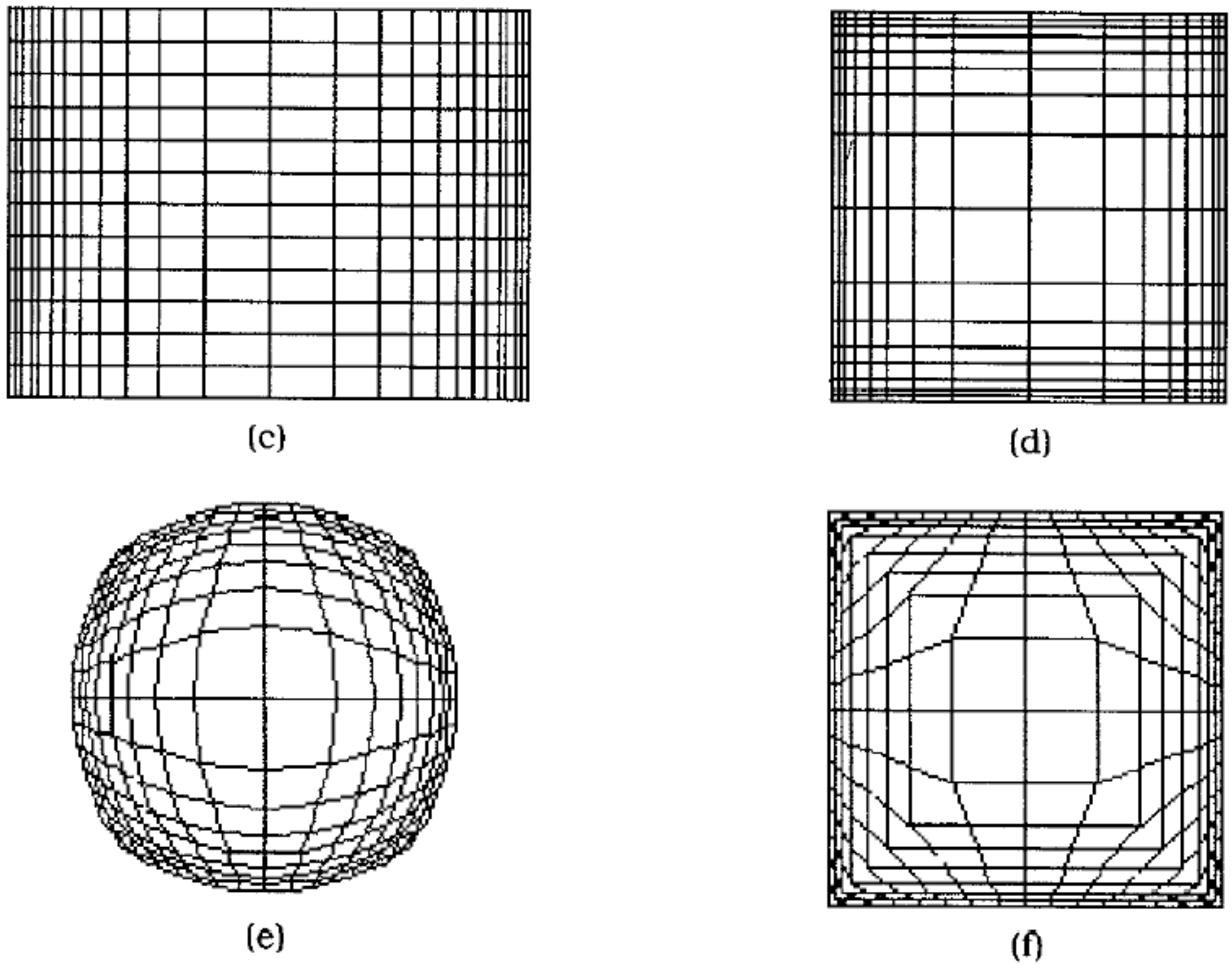


Fig. 11. The Fisheye View: (a) a typical transformation function; (b) the corresponding magnification function; (c) the application of the Fisheye View in one dimension; (d) a Cartesian Fisheye View in two dimensions; (e) a polar Fisheye View; (f) a normalized polar Fisheye View.

[Y.K. Leung and M.D. Apperley. A Review and Taxonomy of Distorsion-Oriented Presentation Techniques. ToCHI `94]

3.6.4 Fisheye Views [Graphic]

- Example with 2D graphs

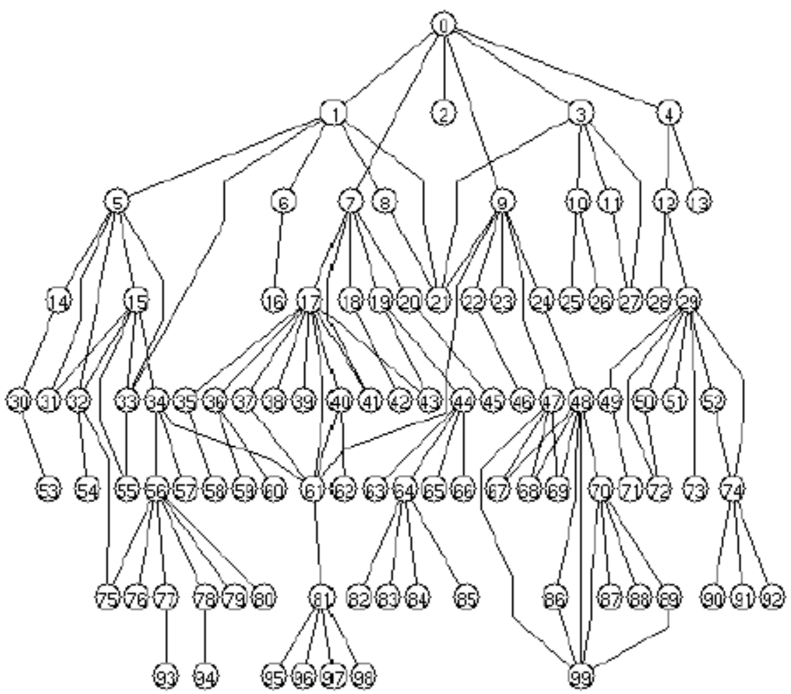


Figure 14: A graph with 100 vertices and 124 edges. All edges point downwards. The API of each vertex is related to its display level (e.g., the root has the highest API of 8, node 33 has an API of 4, and node 86 has an API of 2).

[Demo]

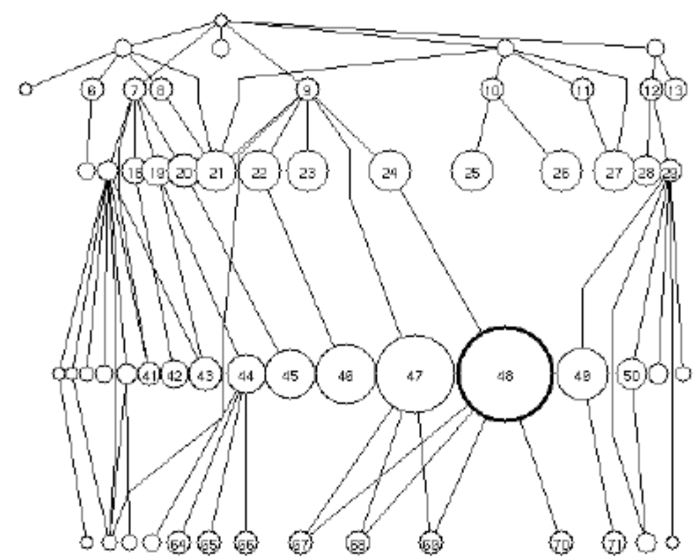
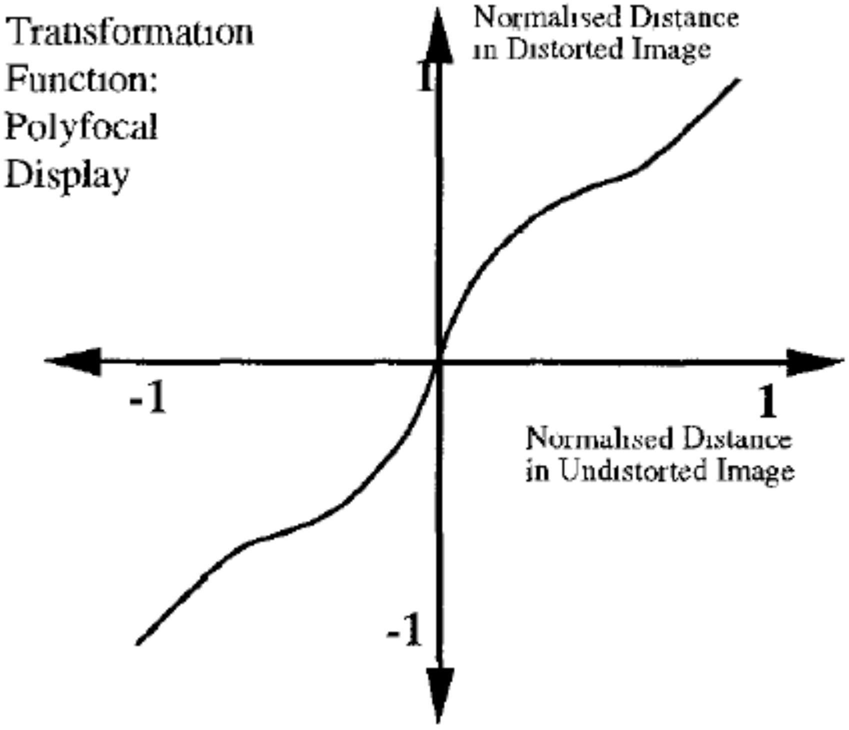


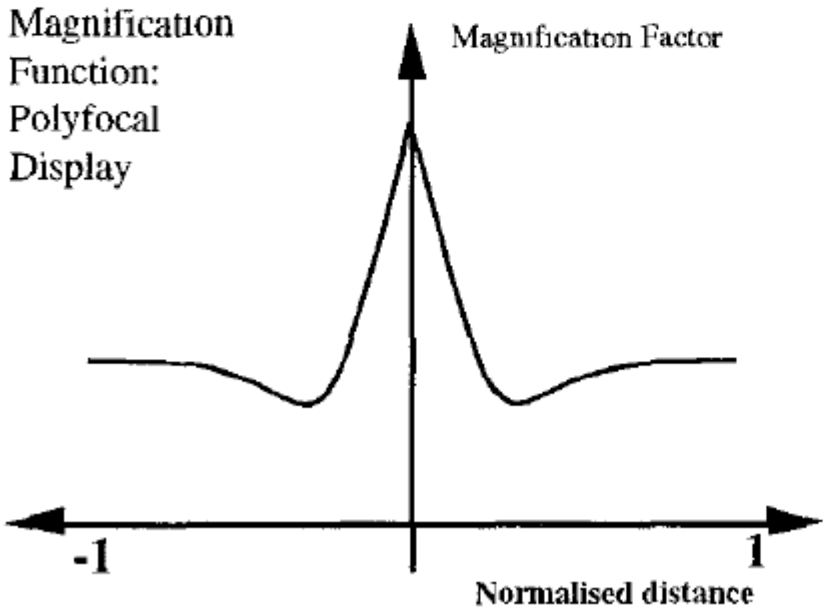
Figure 15: A graphical fisheye view of Figure 14. The focus is the vertex labeled 48.

[M. Sarkar and M.H. Brown, "Graphical Fisheye Views of Graphs." In Human Factors in Computing Systems: Proceedings of the CHI '92 Conference. New York: ACM, 1992.]

3.6.4 Fisheye Views [Graphic]

- By a clever choice of the functions, it is possible to set several foci at the same time (*Polyfocal Display*)





[Y.K. Leung and M.D. Apperley. A Review and Taxonomy of Distorsion-Oriented Presentation Techniques. ToCHI `94]

3.6.4 Fisheye Views [Graphic]

- Application on a grid

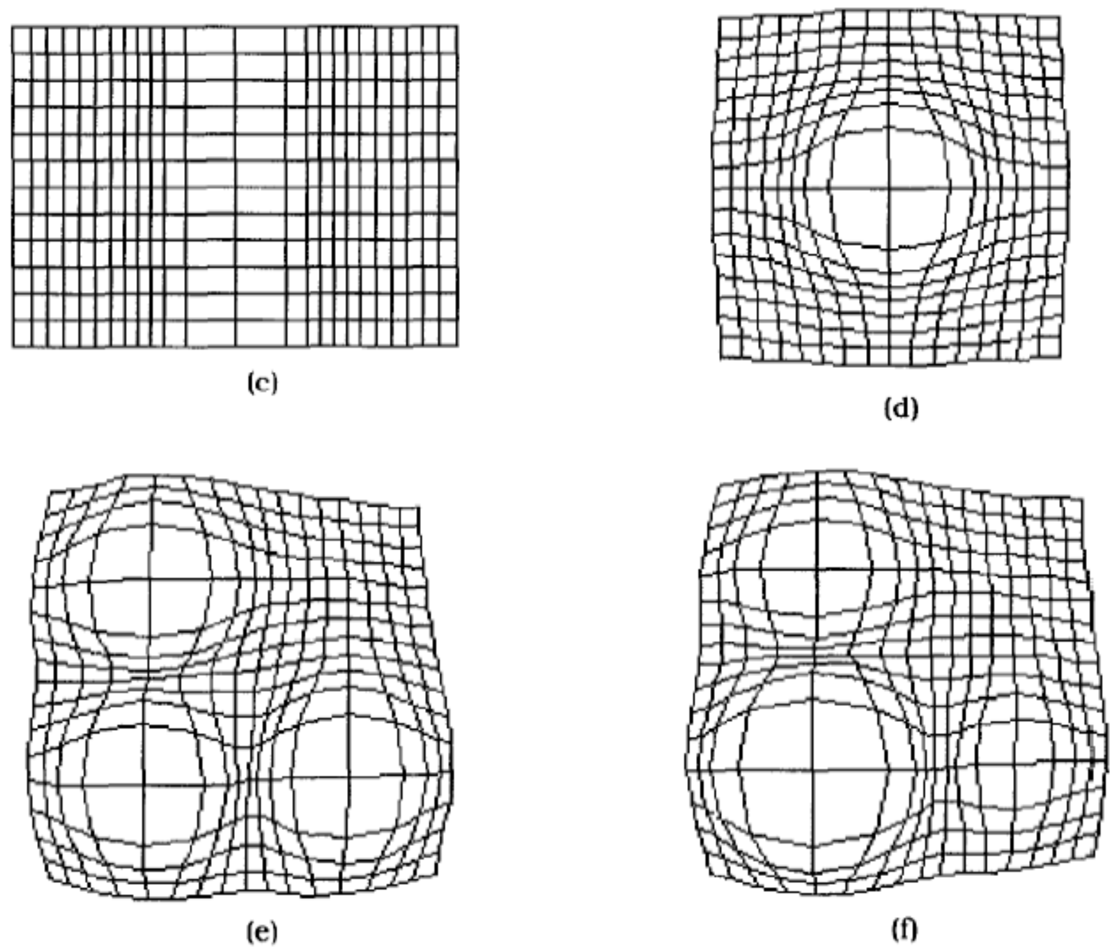


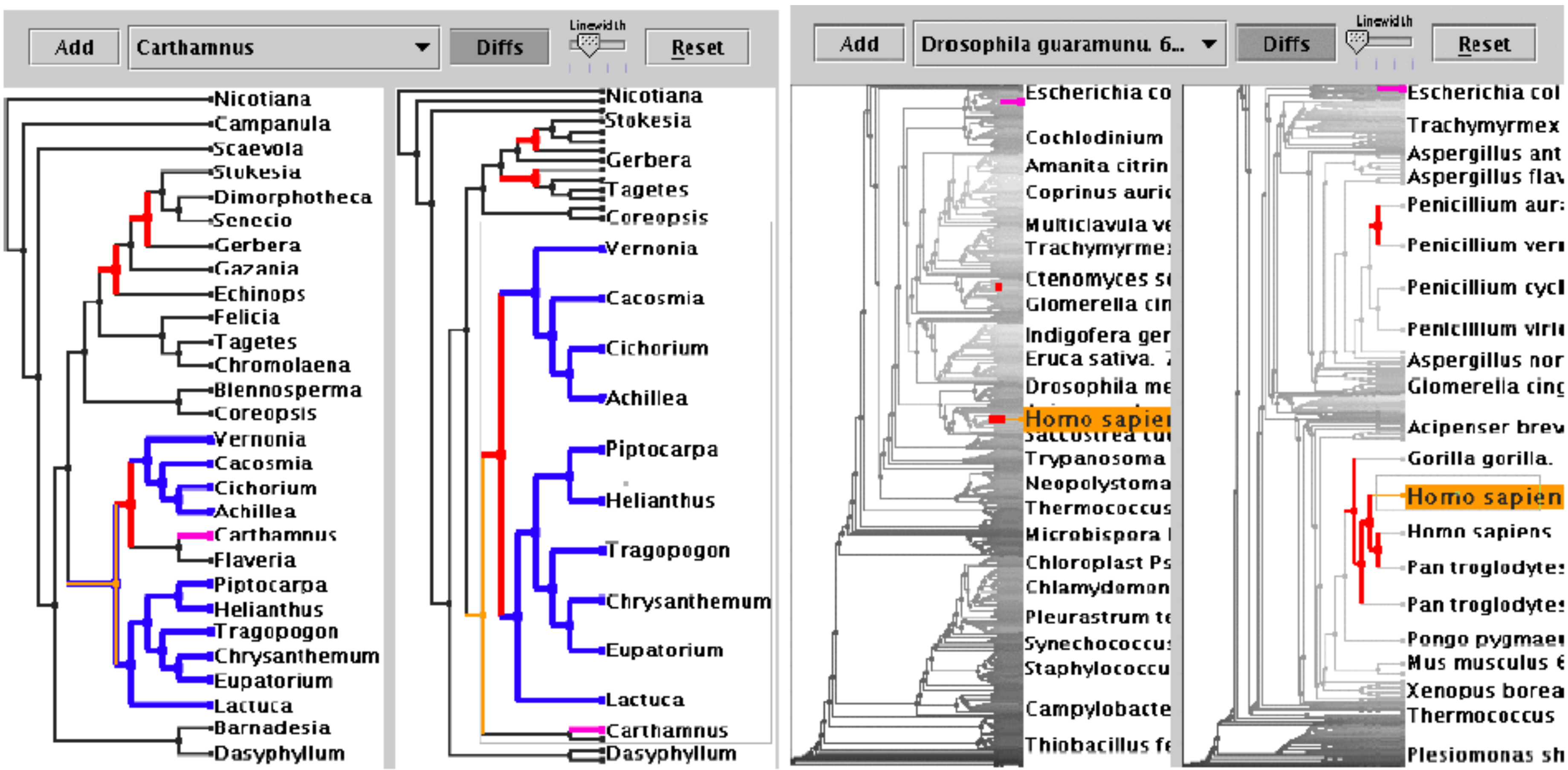
Fig. 5. The polyfocal projection: (a) a typical transformation function of a polyfocal projection; (b) the corresponding magnification function; (c) the application of the projection in one dimension; (d) the application of the projection in two dimensions; (e) a multiple-foci view of the projection using the same parameters for each focus point; (f) a multiple-foci view using different parameters.

[Y.K. Leung and M.D. Apperley. A Review and Taxonomy of Distorsion-Oriented Presentation Techniques. ToCHI `94]

3.6.4 Fisheye Views [Graphic]

- Polyfocal 1D distortions of 2D trees

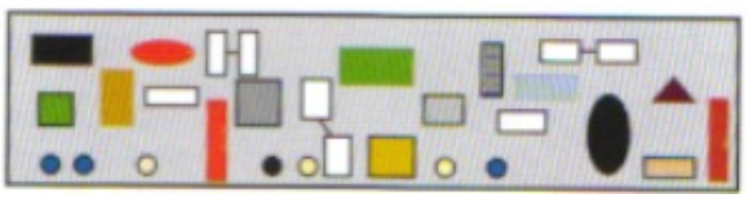
TreeJuxtaposer



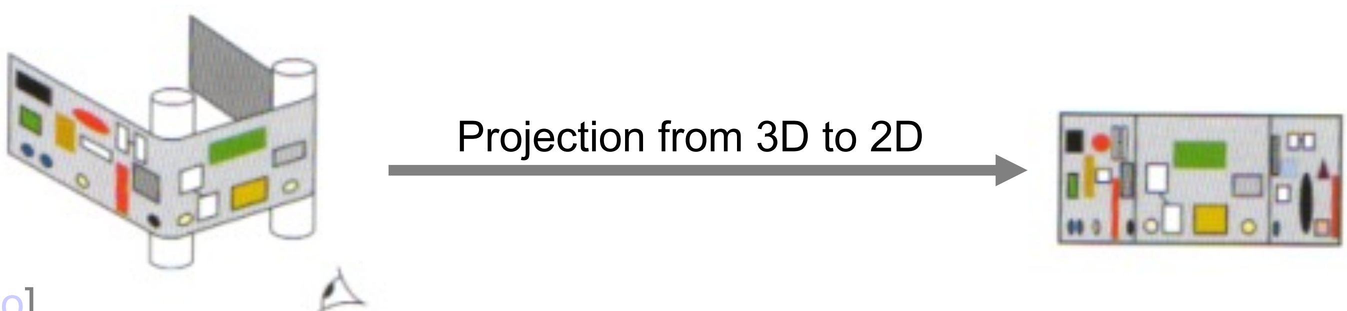
[TreeJuxtaposer: Scalable Tree Comparison using Focus+Context with Guaranteed Visibility. T. Munzner, F. Guimbretiere, S. Tasiran, L. Zhang, and Y. Zhou. SIGGRAPH 2003, published as ACM Transactions on Graphics 22(3), pages 453--462]

3.6.4 Fisheye Views [Graphic]

- Interesting application of the Fisheye View approach
  - → **Bifocal Displays**
- Idea
  - Information is placed on a long band



  - Elements in context are back folded in 3D space (→ Distortion)



[Video]

[R. Spence and M. Apperley. Data base navigation: An office environment for the professional. Behaviour and Information Technology, 1(1):43–54, 1982.]

3.6.4 Fisheye Views [Graphic]

Bifocal Display

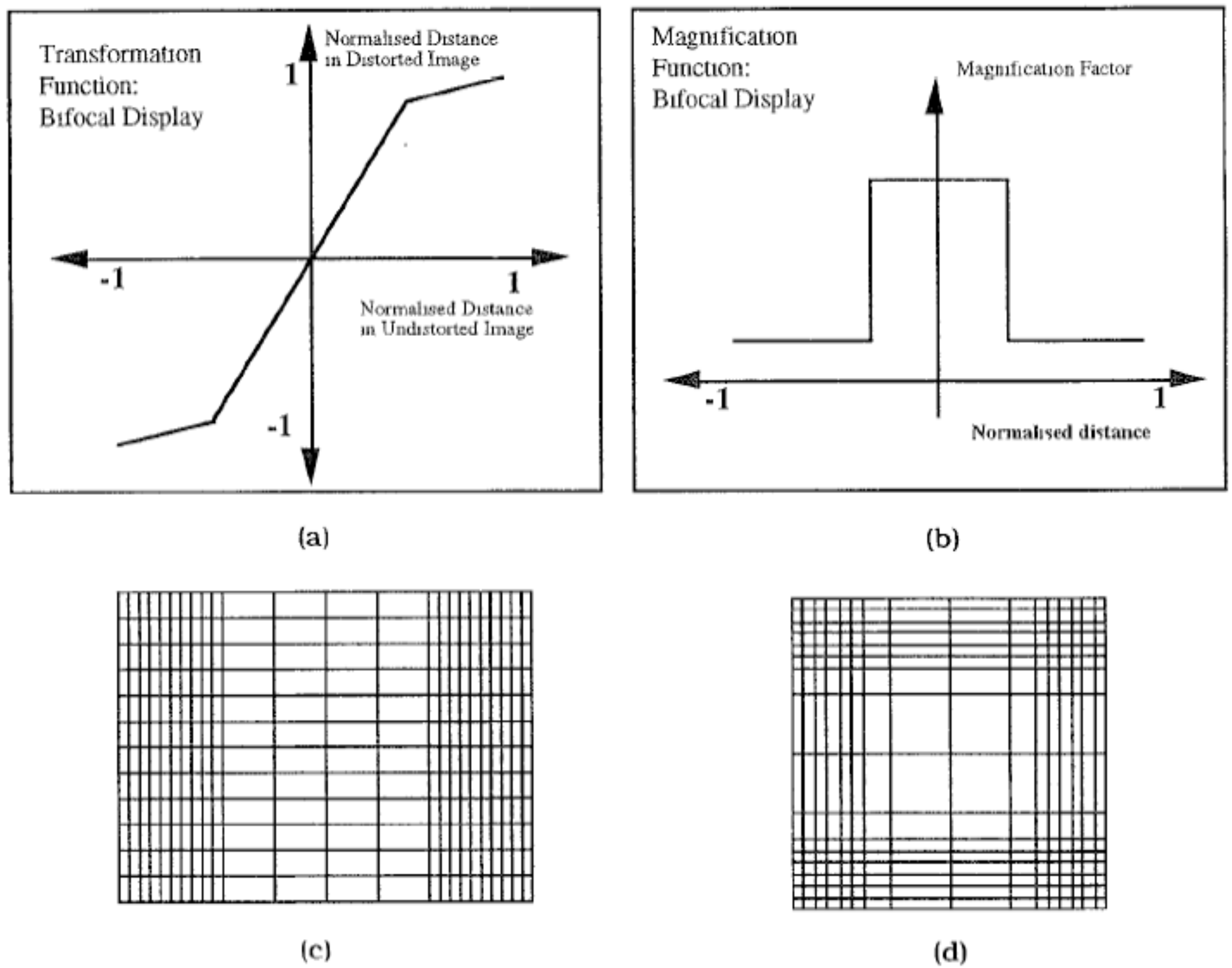


Fig. 6. The Bifocal Display: (a) a typical transformation function; (b) the corresponding magnification function; (c) the application of the display in one dimension; (d) the application of the display in two dimensions.

3.6.5 Discussion

- Advantages
  - F&C reflects the design of the human retina in the eye
  - Supports good navigation and exploration
  - Can be combined with other techniques (for example with Panning and Zooming, etc.)
- Disadvantages
  - Distortion can irritate
  - Sometimes hard to implement
  - Changing the focus point eventually requires a very complex and expensive recalculation of the graphical objects