CS-E4840
Information Visualization
Lecture 8: Interaction

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FROM LAST LECTURE

Recap

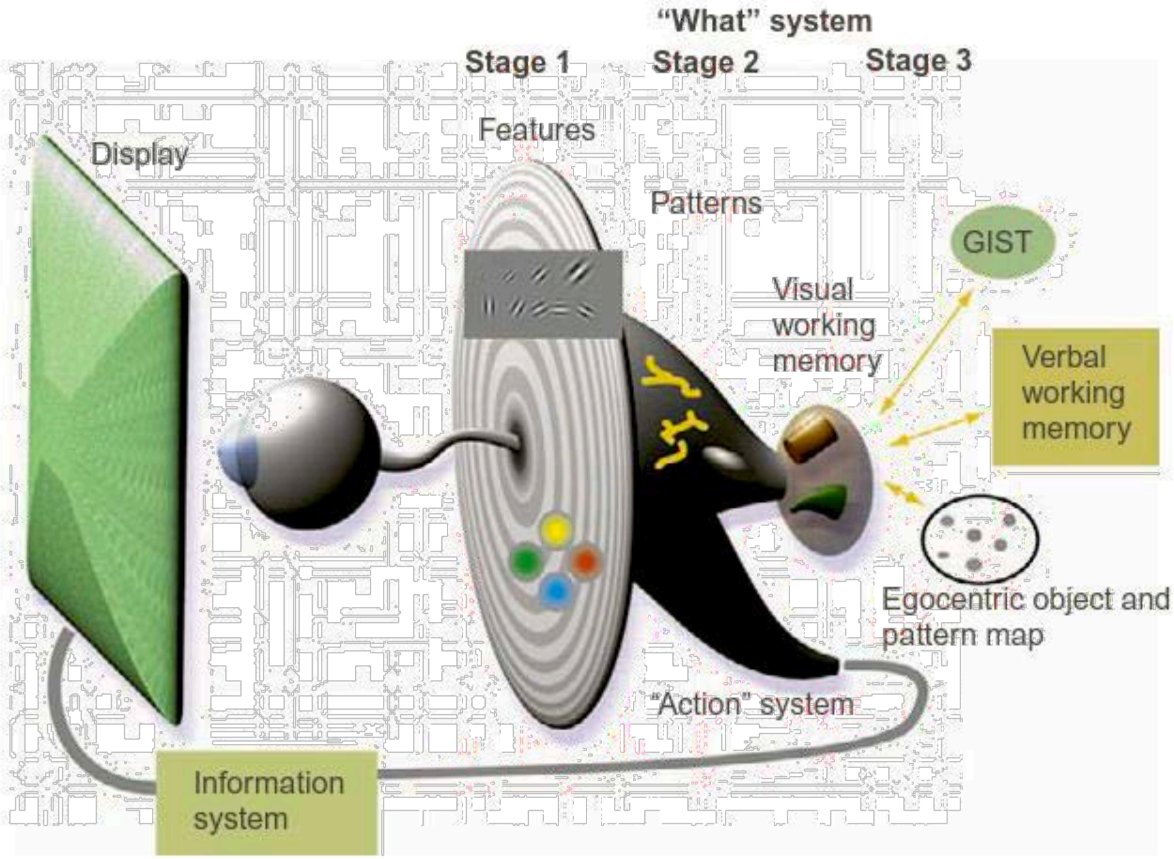
Visual patterns

Summary on glyph design

- Certain visual features “pop out” (pre-attentive features)
- Data variables should (usually) be mapped to pre-attentive features (they are processed fast)
- Restrictions (if you want pre-attentive design):
  - conjunction searches are usually not pre-attentive
  - one can effectively display only limited number of visual variables, with limited accuracy
  - integral visual dimensions interfere with each other: you should use separable dimensions instead

A model for perceptual processing

1. Parallel processing to extract low-level properties of the visual scene
    - rapid parallel processing
    - extraction of features, orientation, colour, texture and movement patterns
    - iconic store
    - bottom-up, data driven processing
2. **Pattern perception**
    - slow serial processing
    - involves both working memory and long-term memory
    - arbitrary symbols relevant
    - different pathways for object recognition and visually guided motion
3. Visual working memory



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Patterns in 2D data

- Exploratory visualization is based on finding patterns from data
- Oversimplification: the patterns are recognized between pre-attentive processing and higher level object perception
- Relevant questions:
  - How do we see groups?
  - How can 2D space be divided into perceptually distinct regions?
  - When are two patterns similar?
  - When do two different elements appear to be related?
- Patterns may be perceived even where there is only visual noise

Gestalt laws

- **Gestalt** is form in German
- The Gestalt School of Psychology (1912 onwards) investigated the way we perceive form
- They produced several Gestalt laws (laws of organisation) of pattern perception
- The Gestalt laws translate directly into design principles of visual displays
- Many of the rules seem obvious, but they are violated often

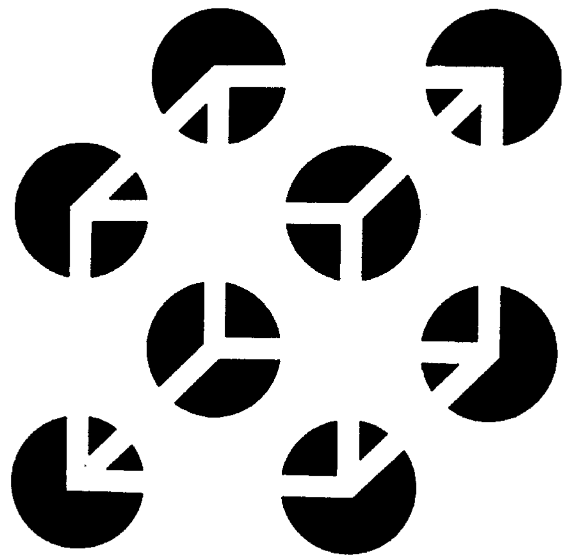


Figure 1. The subjective Necker cube. A phenomenally complete Necker cube can be seen overlying a white surface and eight black discs; so viewed, illusory contours corresponding to the bars of the cube can be seen extending between the discs. The illusory bars of the cube disappear when the discs are seen as 'holes' in an interposing surface, through which the corners of a partially occluded cube are viewed; curved subjective contours are then seen demarcating the interior edges of the 'holes'

Bradley and Petry 1977

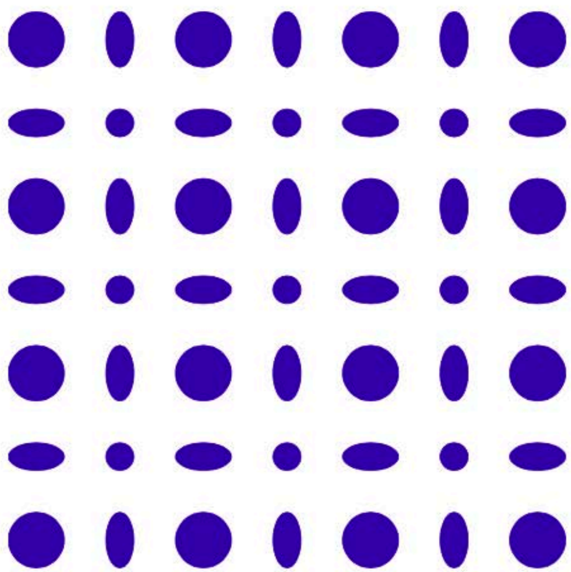
Gestalt laws

- Similarity
- Good continuation
- Proximity
- Symmetry
- Closure
- Relative size
- Common fate

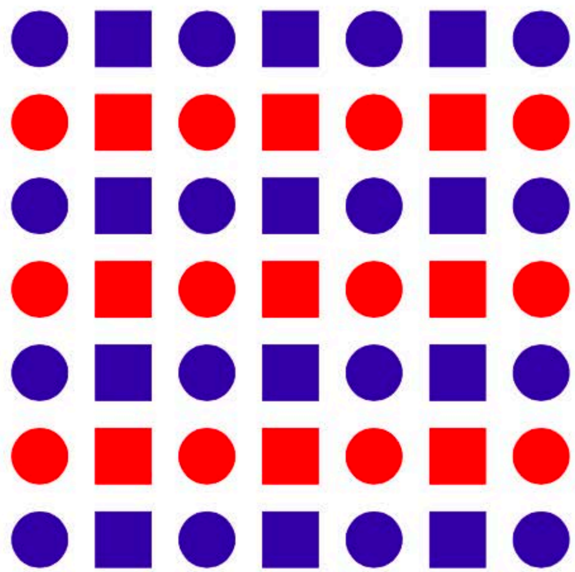
- some “new” motion-based Gestalt(-like) laws:
  - Patterns from motion
  - Animation and perception of shapes
  - Causality

Similarity

- Similar objects appear to be grouped together
- When designing a grid layout of a data set, code rows and/or columns using low-level visual channel properties, such as colour and texture



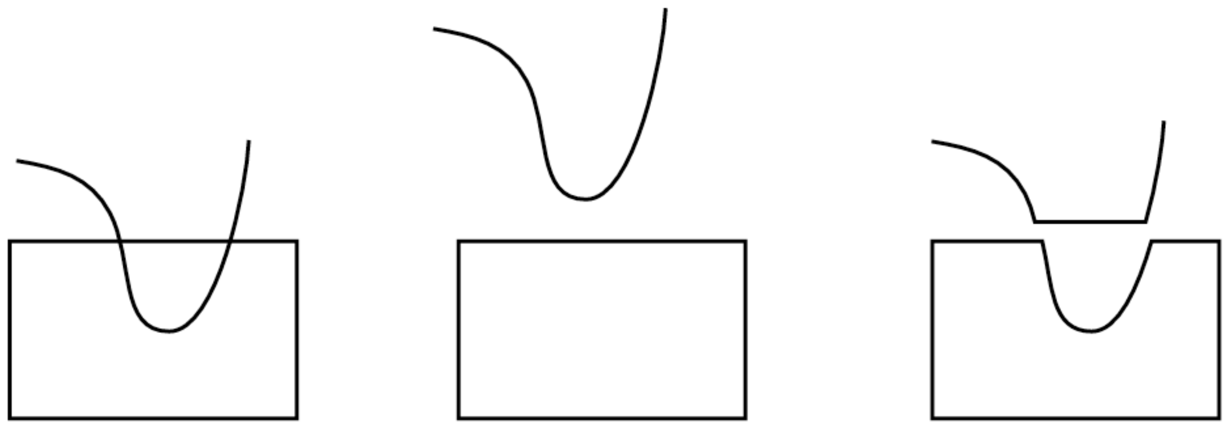
integral dimensions
emphasise overall pattern



separable dimensions
segment rows and columns

Good continuation

- Visual complete objects are more likely to be constructed from visual elements that are smooth and continuous, rather than ones that contain abrupt changes in direction
- In networks, lines connecting nodes should be smooth and continuous, so the nodes are easily identified



The pattern on the left is perceived as a curve overlapping a rectangle (centre) rather than 2 irregular shapes touching (right).

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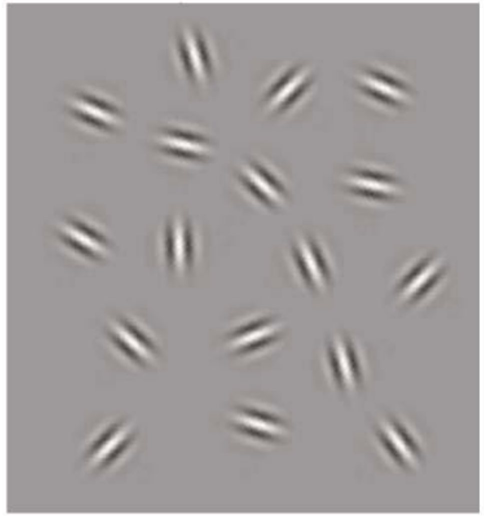
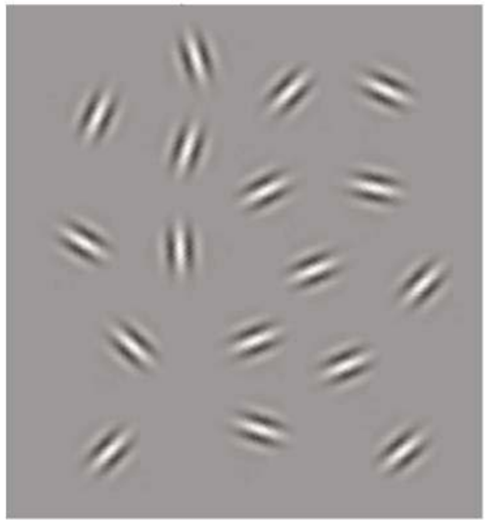
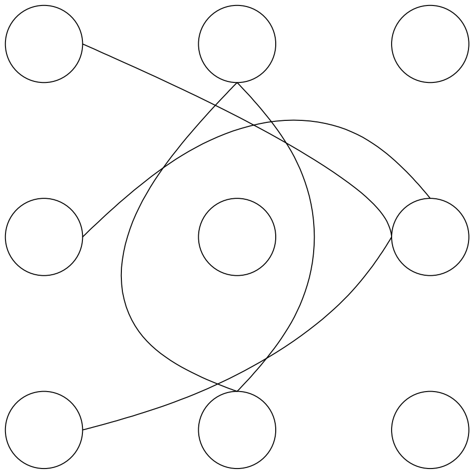
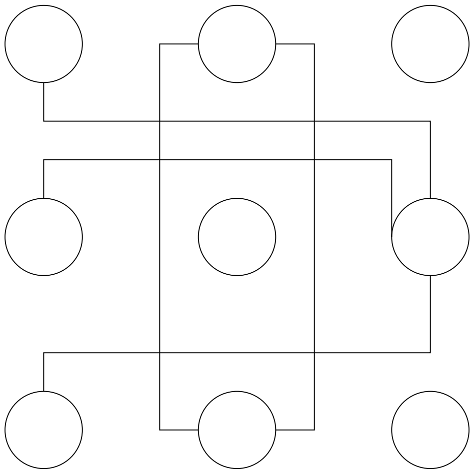
Good continuation

- Connectedness is one of the most powerful grouping principles
- It is easier to perceive connections when contours run smoothly









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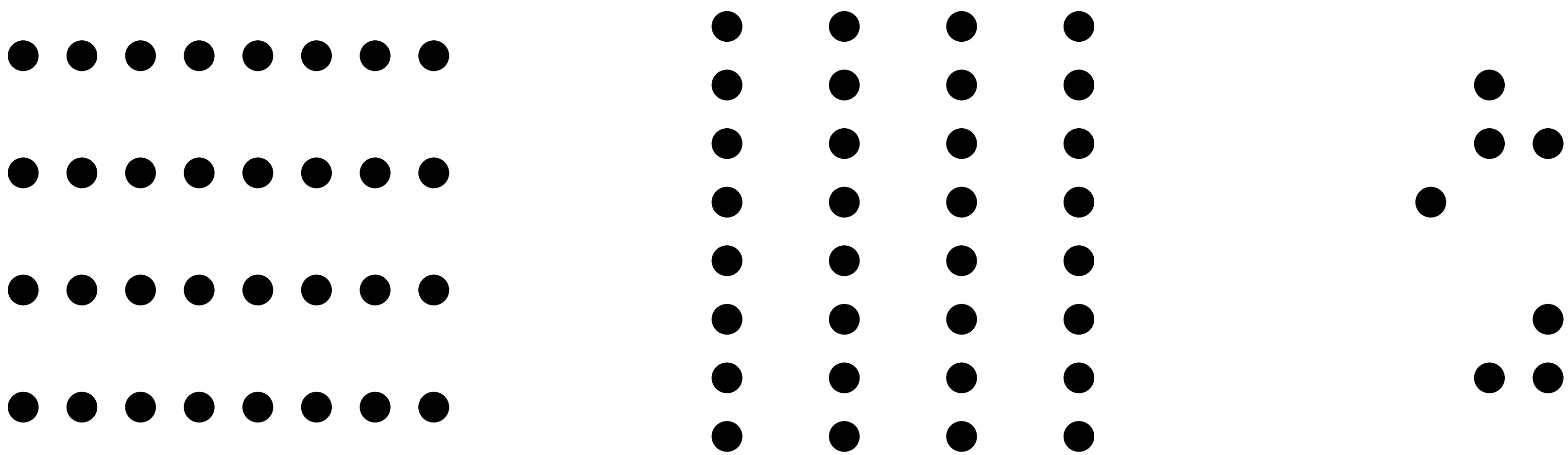
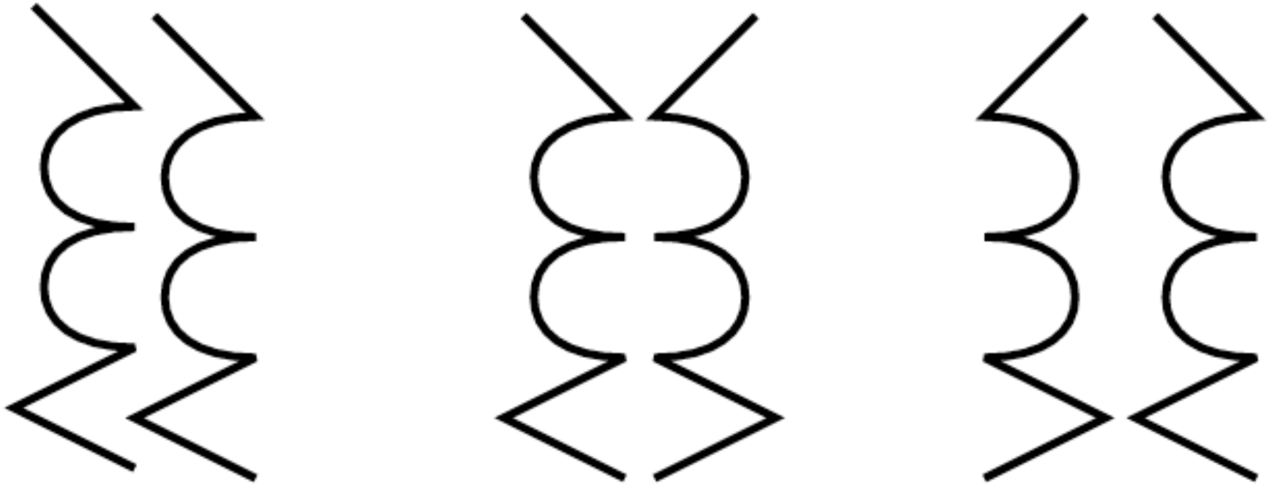
Proximity

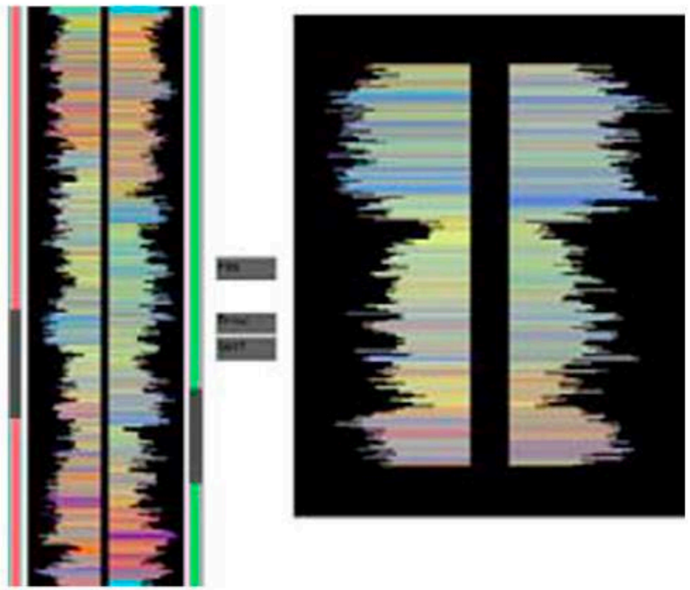
- Things that are near to each other appear to be grouped together
- Proximity is one of the most powerful gestalt laws
- Place the data elements into proximity to emphasise connections between them



Symmetry

- Symmetrically arranged pairs of lines are perceived together
- Use symmetry to make pattern comparisons easier
- Symmetrical relations should be arranged on horizontal or vertical axes (as symmetries are more easily perceived), unless a framing pattern is used





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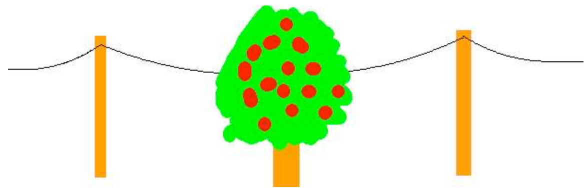
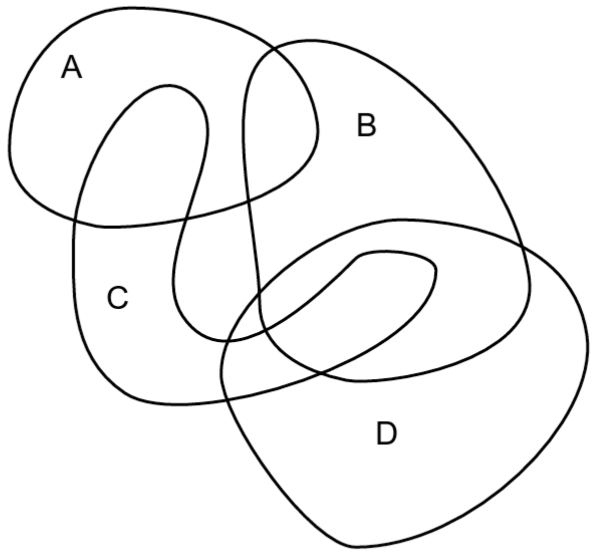
Closure

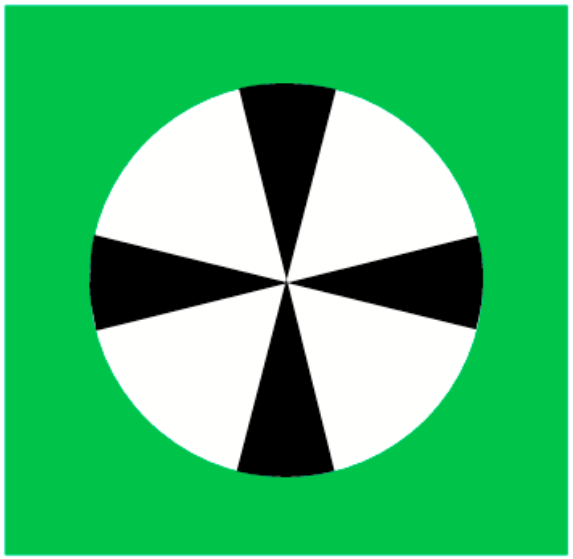
- A closed contour tends to be seen as an object
- There is a perceptual tendency to close contours that have gaps in them
- When a closed contour is seen, there is a very strong perceptual tendency of dividing space into a region enclosed by the contour (a common region) and a region outside the contour
- In window-based interface strong framing effects inhibit between window comparisons: related items should not be based in separate windows





Relative size

- Smaller components of a pattern tend to be perceived as an object



Rubin's reversible face-vase figure (multistability)

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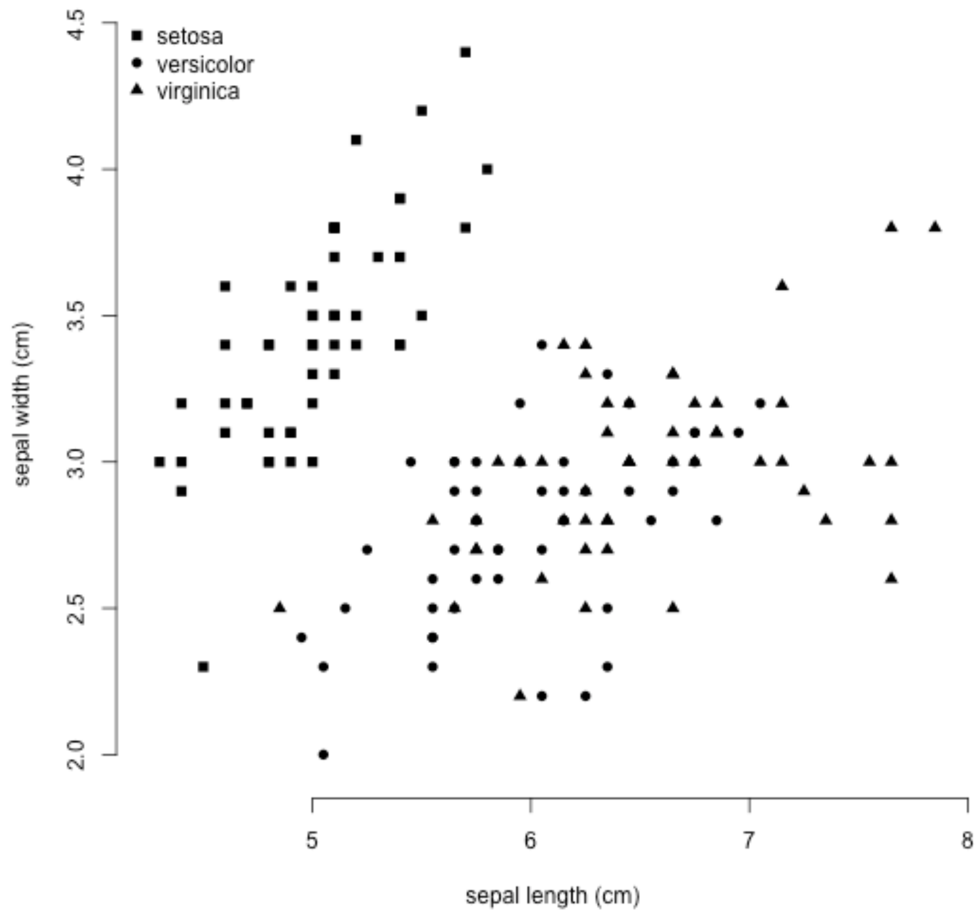
Common fate

- Relative motion is an extremely efficient method of showing patterns from data
- Data points oscillate around center point
- Variables: frequency, phase, amplitude of motion
- Phase is the most effective variable



Animation and perception of shape

- Gestalt laws also work for animated images: structures and patterns are seen from partial data (as with static images)
- Mystery lights in the dark:

No delay

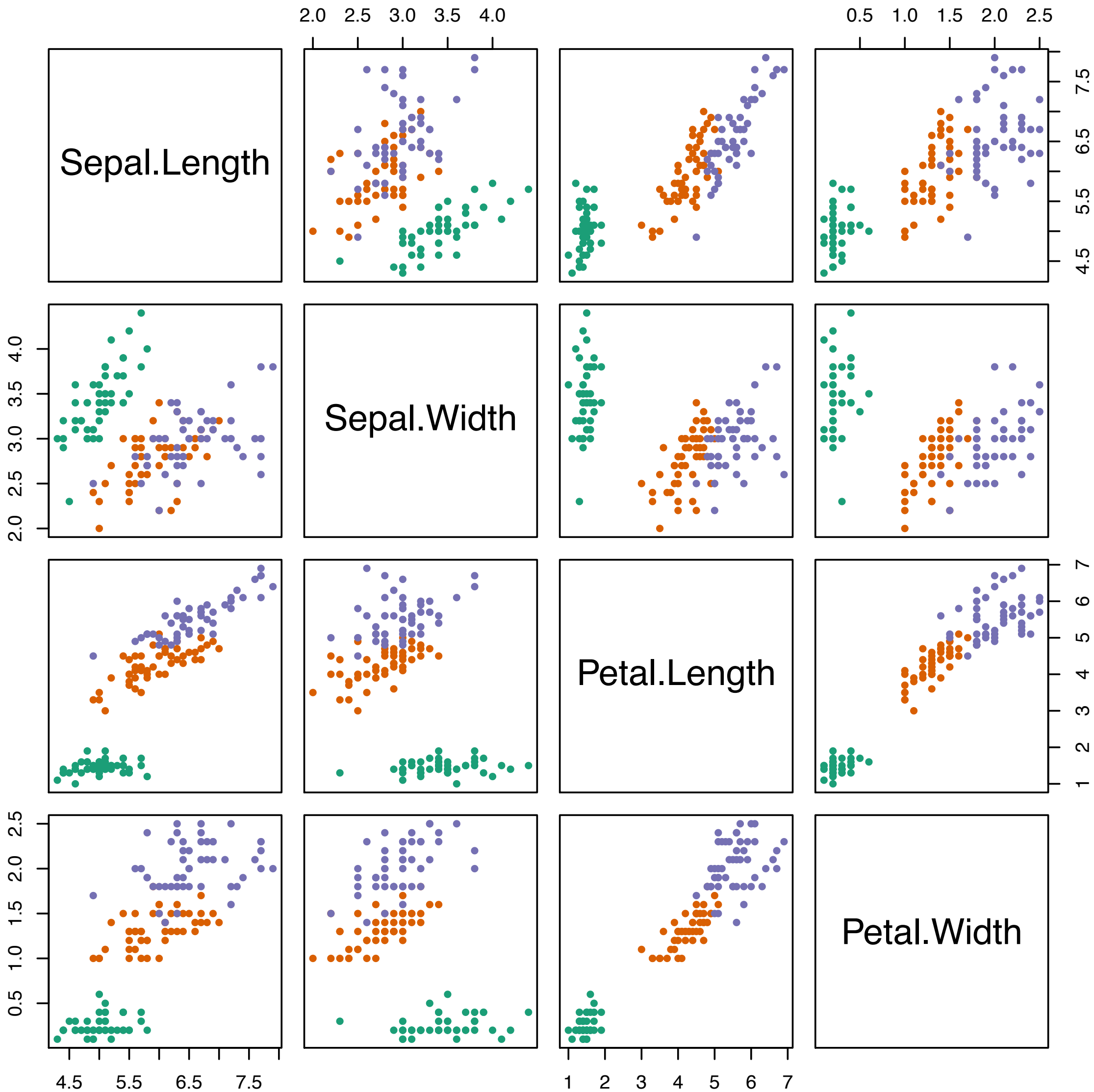
Causality

- *Launching:* an object is perceived to set another into motion
- Perception of launching requires precise timing (delays less than 0.07-0.16 s)
- Already infants can perceive causal relations, such as launching

Delay of 0.2 s

Gestalt laws in action:

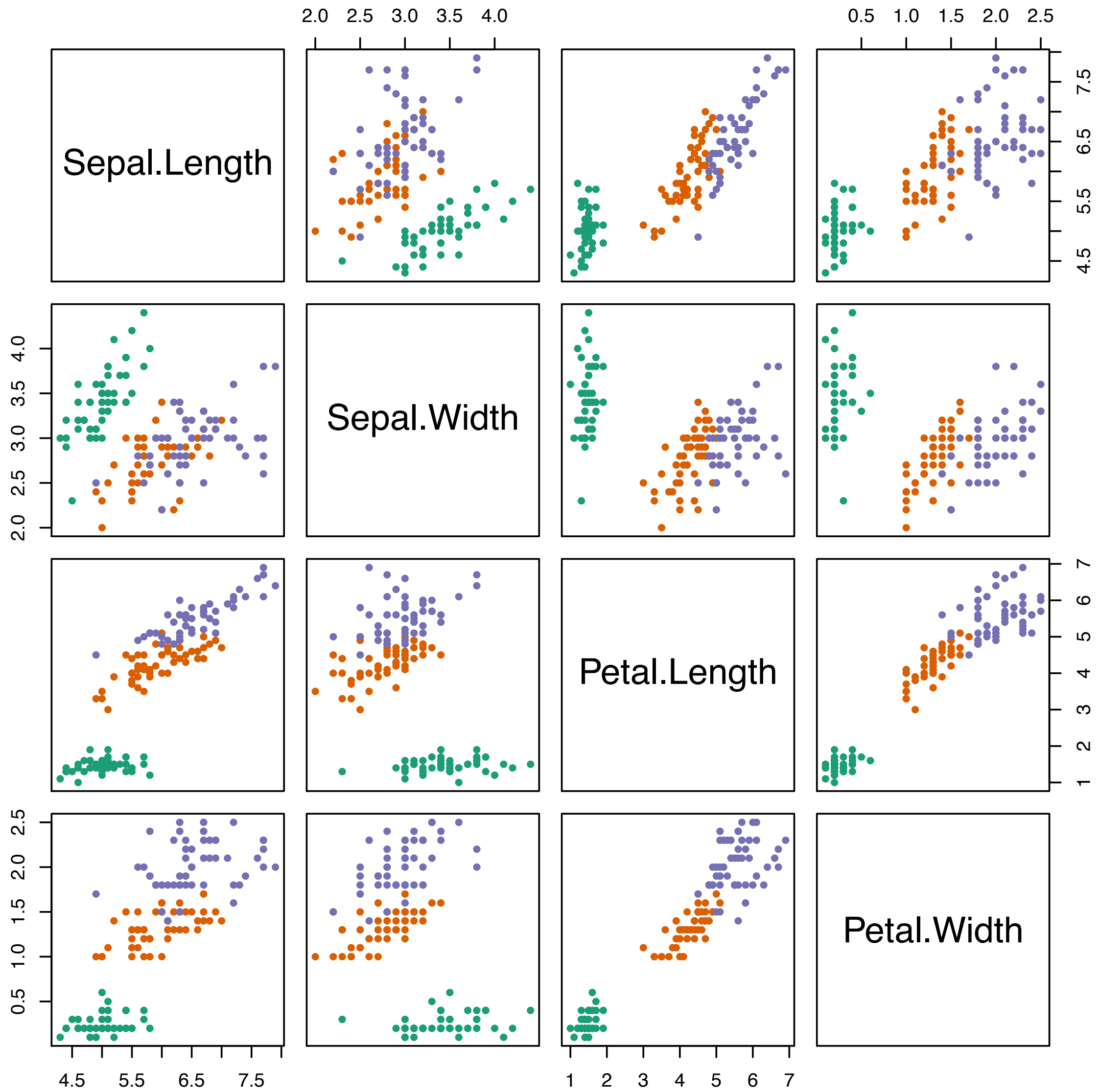
Small multiples (trellis)



Which laws apply here?

Gestalt laws in action:

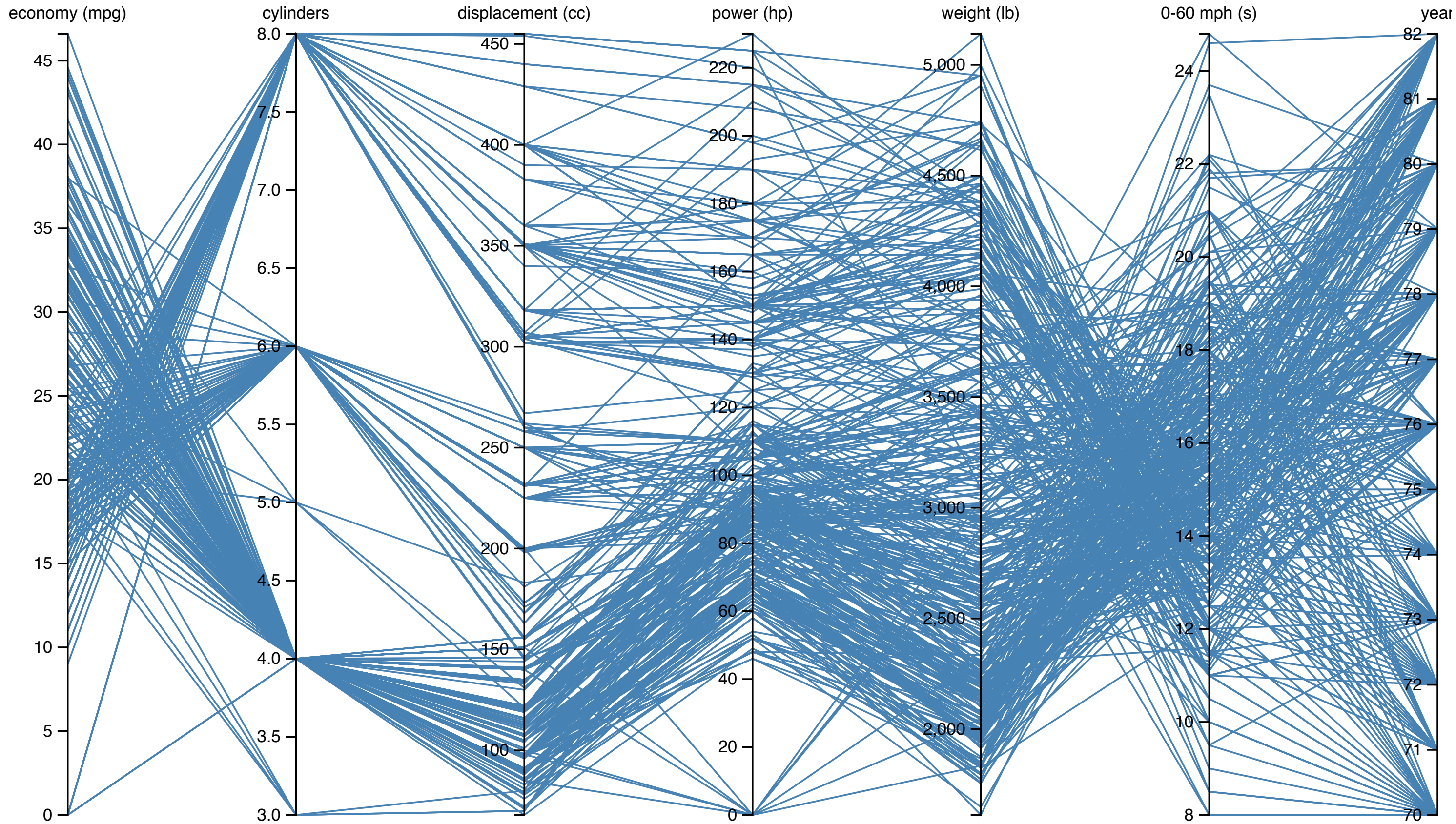
Small multiples (trellis)



- Symmetry
- Proximity
- Closure

Gestalt laws in action:

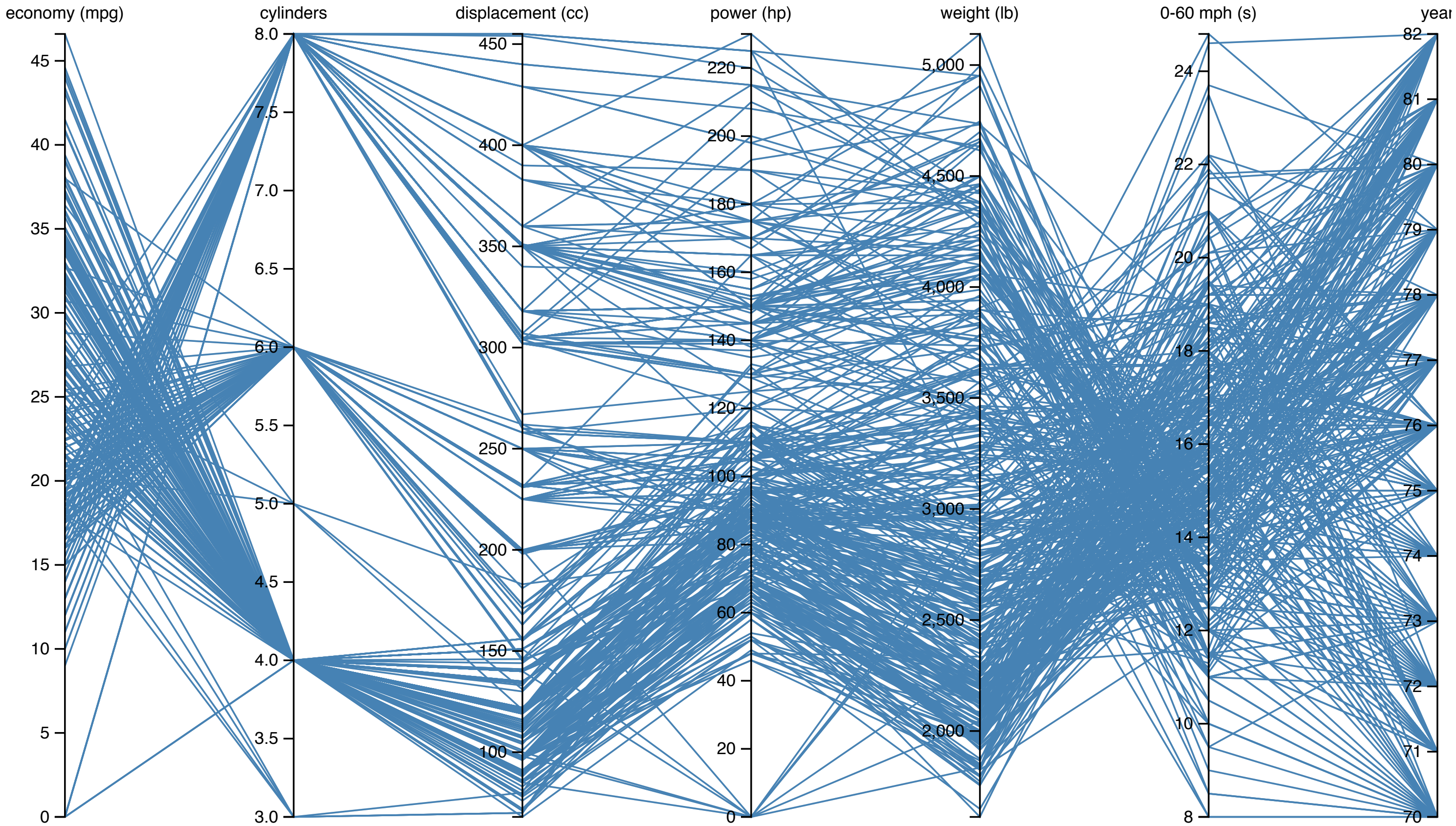
Parallel coordinates



Which laws apply here?

https://bl.ocks.org/jasondavies/1341281

Parallel coordinates



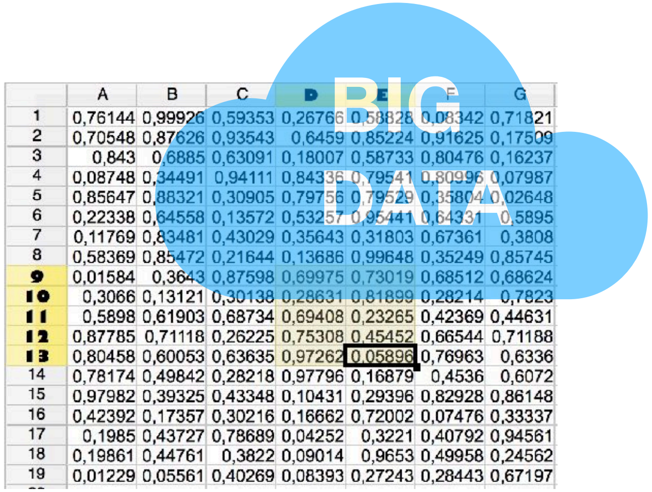
- Proximity
- Good continuation
- Closure?

https://bl.ocks.org/jasondavies/1341281

NEW IN THIS LECTURE

PART III
Big Data

Course topics

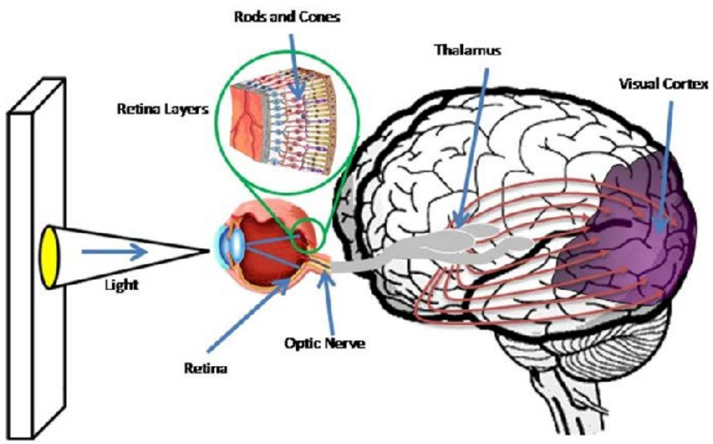


	A	B	C	D	E	F	G
1	0,76144	0,99926	0,59353	0,26766	0,58828	0,08342	0,71821
2	0,70548	0,87626	0,93543	0,6459	0,85224	0,91625	0,17509
3	0,843	0,6885	0,63091	0,18007	0,58733	0,80476	0,16237
4	0,08748	0,34491	0,94111	0,84336	0,79541	0,80996	0,07987
5	0,85647	0,88321	0,30905	0,79756	0,79529	0,35804	0,02648
6	0,22338	0,64558	0,13572	0,53257	0,95441	0,64331	0,5895
7	0,11769	0,83481	0,43029	0,35643	0,31803	0,67361	0,3808
8	0,58369	0,85472	0,21644	0,13686	0,99648	0,35249	0,85745
9	0,01584	0,3643	0,87598	0,69975	0,73019	0,68512	0,68624
10	0,3066	0,13121	0,30138	0,28631	0,81899	0,28214	0,7823
11	0,5898	0,61903	0,68734	0,69408	0,23265	0,42369	0,44631
12	0,87785	0,71118	0,26225	0,75308	0,45452	0,66544	0,71188
13	0,80458	0,60053	0,63635	0,97262	0,05896	0,76963	0,6336
14	0,78174	0,49842	0,28218	0,97796	0,16879	0,4536	0,6072
15	0,97982	0,39325	0,43348	0,10431	0,29396	0,82928	0,86148
16	0,42392	0,17357	0,30216	0,16662	0,72002	0,07476	0,33337
17	0,1985	0,43727	0,78689	0,04252	0,3221	0,40792	0,94561
18	0,19861	0,44761	0,3822	0,09014	0,9653	0,49958	0,24562
19	0,01229	0,05561	0,40269	0,08393	0,27243	0,28443	0,67197

Part 3. how to show the right data?

Part 1. how to design a presentation?

Human Visual System



Part 2. how we see it?

NEW IN THIS LECTURE

Big data: too much for one view?

- Dynamic visualization
  - interactive navigation in information space
  - show only a selection of data at a time
- Algorithmic data mining
  - clustering and aggregation
  - dimensionality reduction

Interactive visualisations

- Interactive visualisations can be characterised by *feedback loops*

- Three levels of feedback:
  1. visual-manual control loop (data manipulation)
  2. **view refinement and navigation control loop (exploration and navigation)** [discussed here]
  3. problem solving loop

- Relevant time scales:
  1. ~0.1 s (psychological moment)
  2. ~1 s (unprepared response)
  3. ~10 s (unit task)

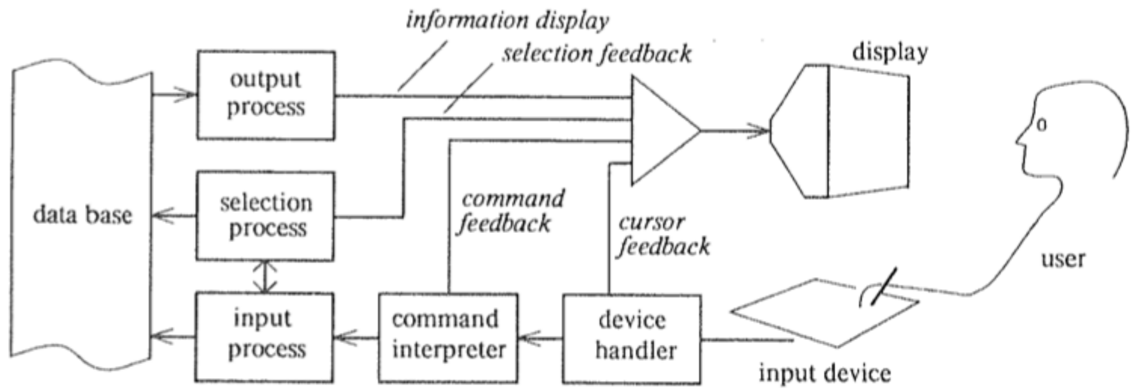


Figure 28-10 Expanded model of the interactive process showing feedback paths.

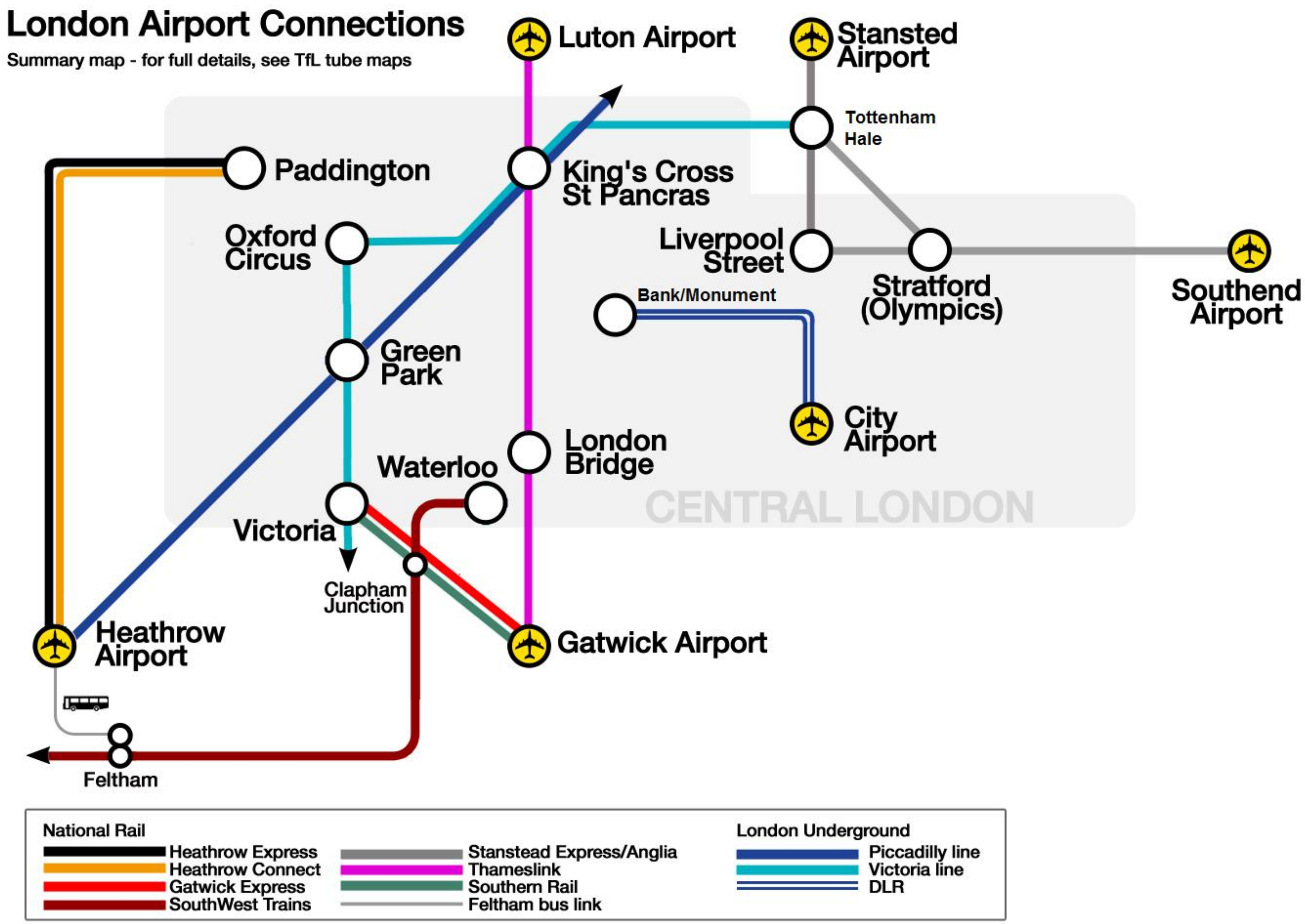
Way-finding in real spaces

- Seigel and White (1975):
    1. Key landmarks (e.g., post office, church) are learned with no spatial understanding (*declarative knowledge*)
    2. Procedural knowledge about routes from a location to another is learned, landmarks act as decision points (e.g., turn left at church; *procedural knowledge*)
    3. Cognitive map is formed (e.g., the church is about 1 kilometre north from train station; *cognitive spatial maps*)

- Cognitive maps form more rapidly if they have access to maps

- Lessons to accelerate formation of cognitive maps: provide **distinctive landmarks** (focus) and **overview maps** (context)

Topological map



https://de.maps-london.com

Landmarks (focus) and overview map (context)

https://de.maps-london.com

Exploring information space: navigation + focus&context

- **Focus+context problem**: how to find details from a larger context in information space. Or, how to *navigate efficiently* in abstract spaces.

- There are several visual techniques to help this (providing user overview, position and landmarks):

  - **Elision techniques.** Part of the structure are hidden until they are needed.
  - **Distortion techniques.** Magnify regions of interest, decrease space of irrelevant regions.
  - **Rapid zooming techniques.** User zooms in and out of regions of interest.
  - **Multiple windows.** Some windows show overview and others content.
  - **Micro-macro readings.** A high-resolution static visualisation supports focus+context.

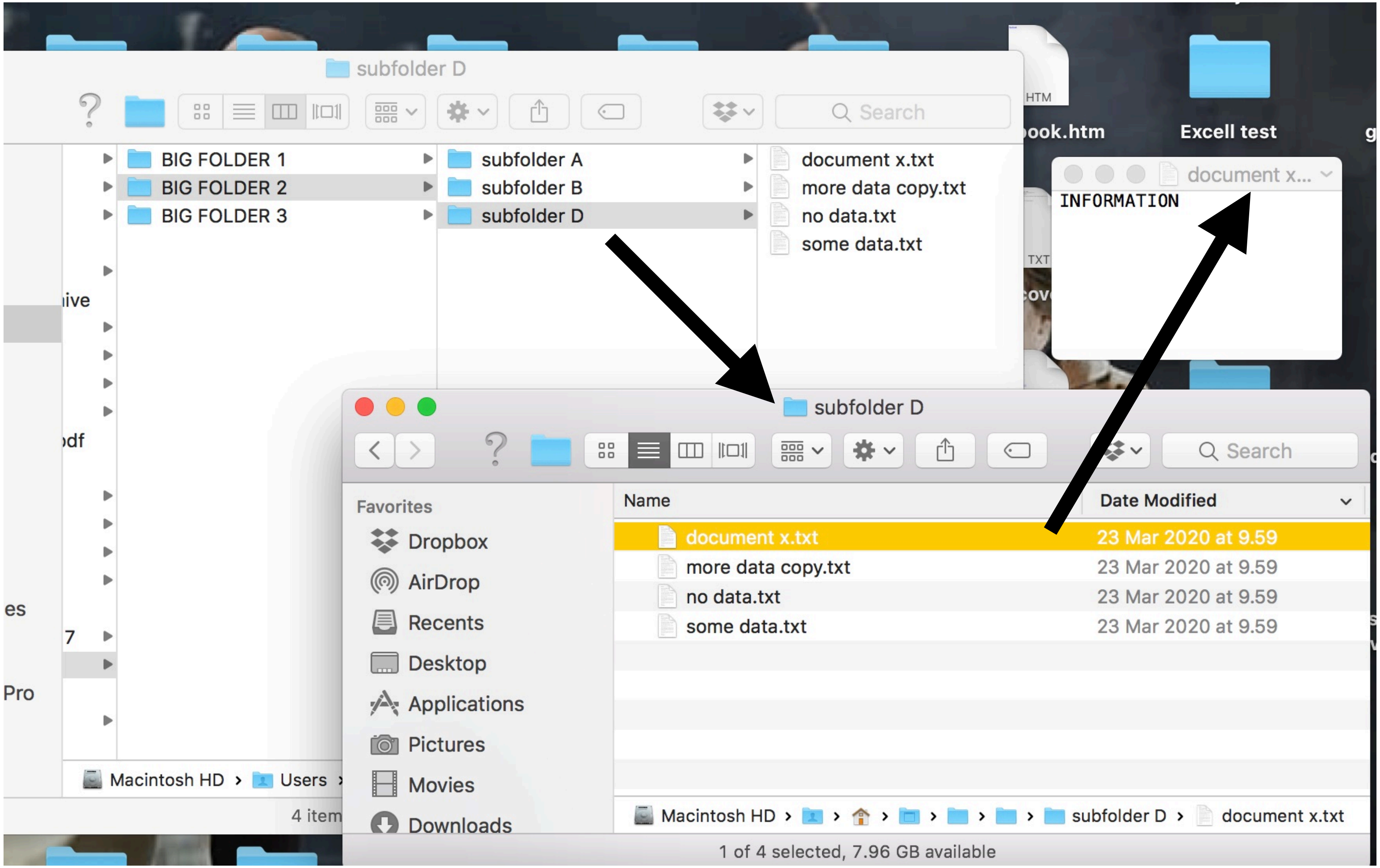
  - Often used in combinations

Elision:
Magic lenses and toolglasses

E.Bier (1993) https://dl.acm.org/doi/pdf/10.1145/166117.166126

- *purpose*: show selected hidden information interactively
- **features**
  - **magic lens** = movable area on the screen acting as filter, through which additional things or a modified view can be seen
  - **toolglass** modifies the effect of a manipulation tool
  - especially for two-handed interaction
  - also studied in 3D
- applications
  - multi-purpose maps
  - scientific visualization of dense data
  - annotations in technical documents
  - maintenance information in drawings
- *demo:*
  - https://www.youtube.com/watch?v=v7M3yw4Y71I

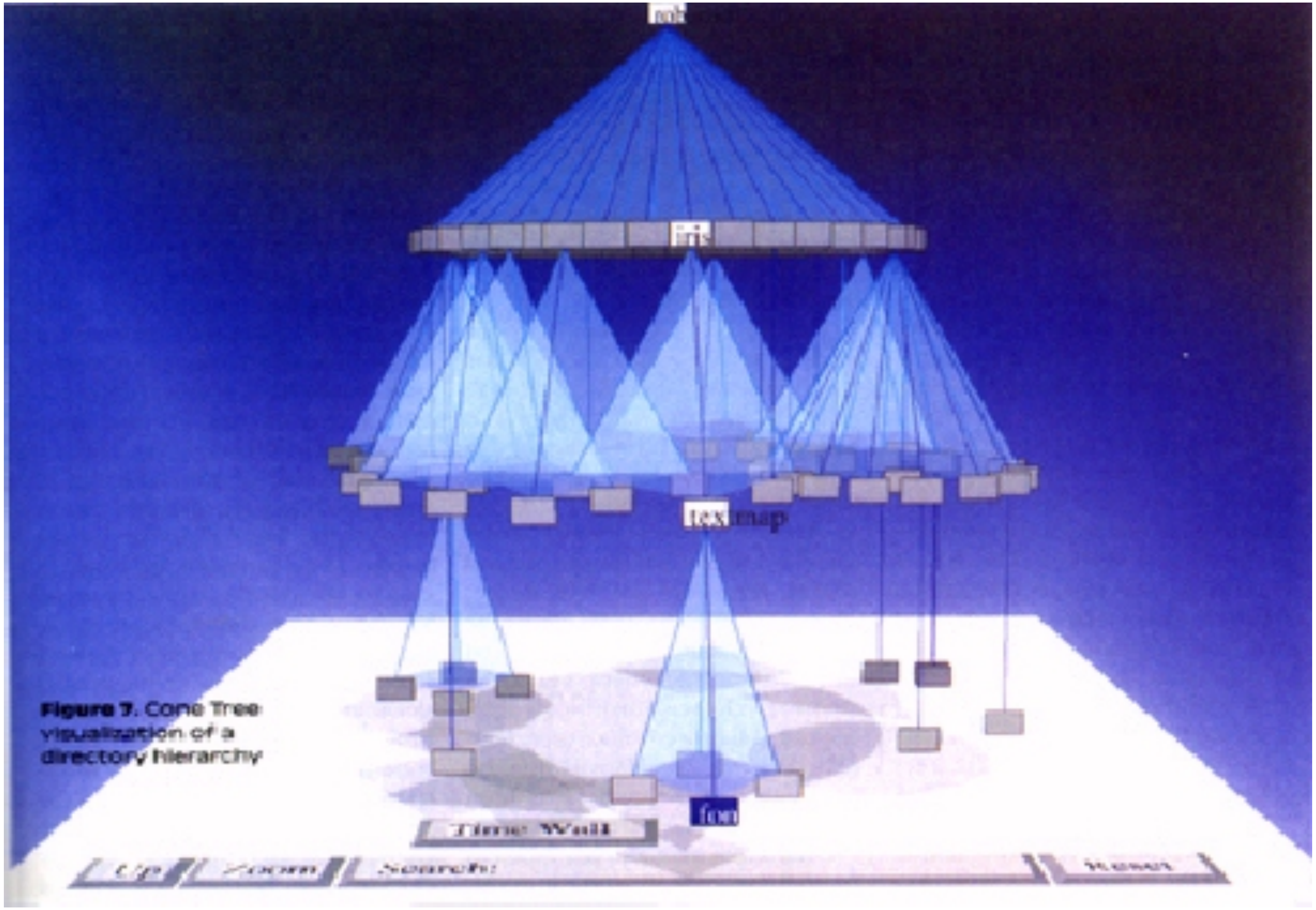
Elision:
Aggregation of data into folders



- cf. outline view of hierarchical structured documents, e.g. Word

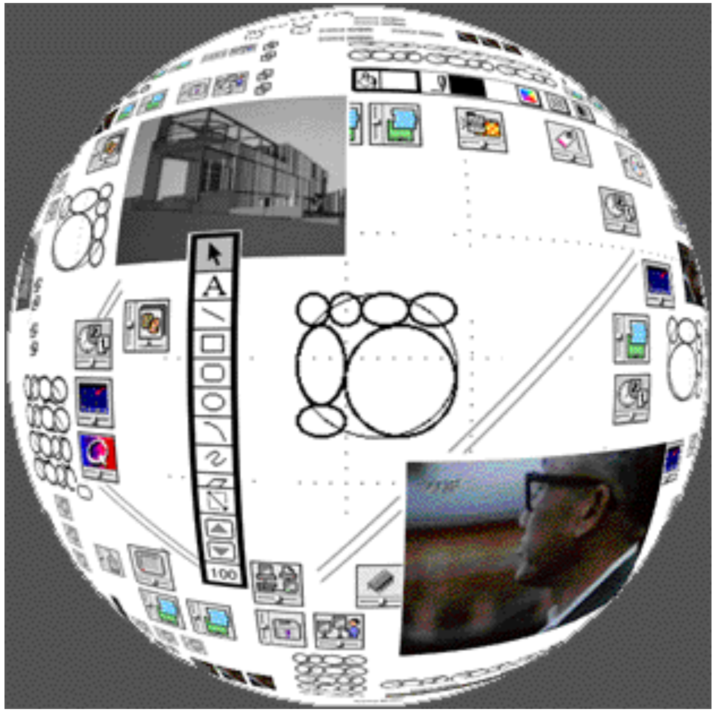
Elision and transparency: Folders in 3D

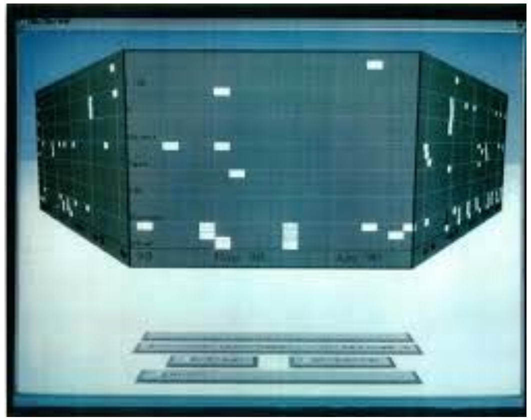
https://infovis-wiki.net/wiki/Cone_Trees



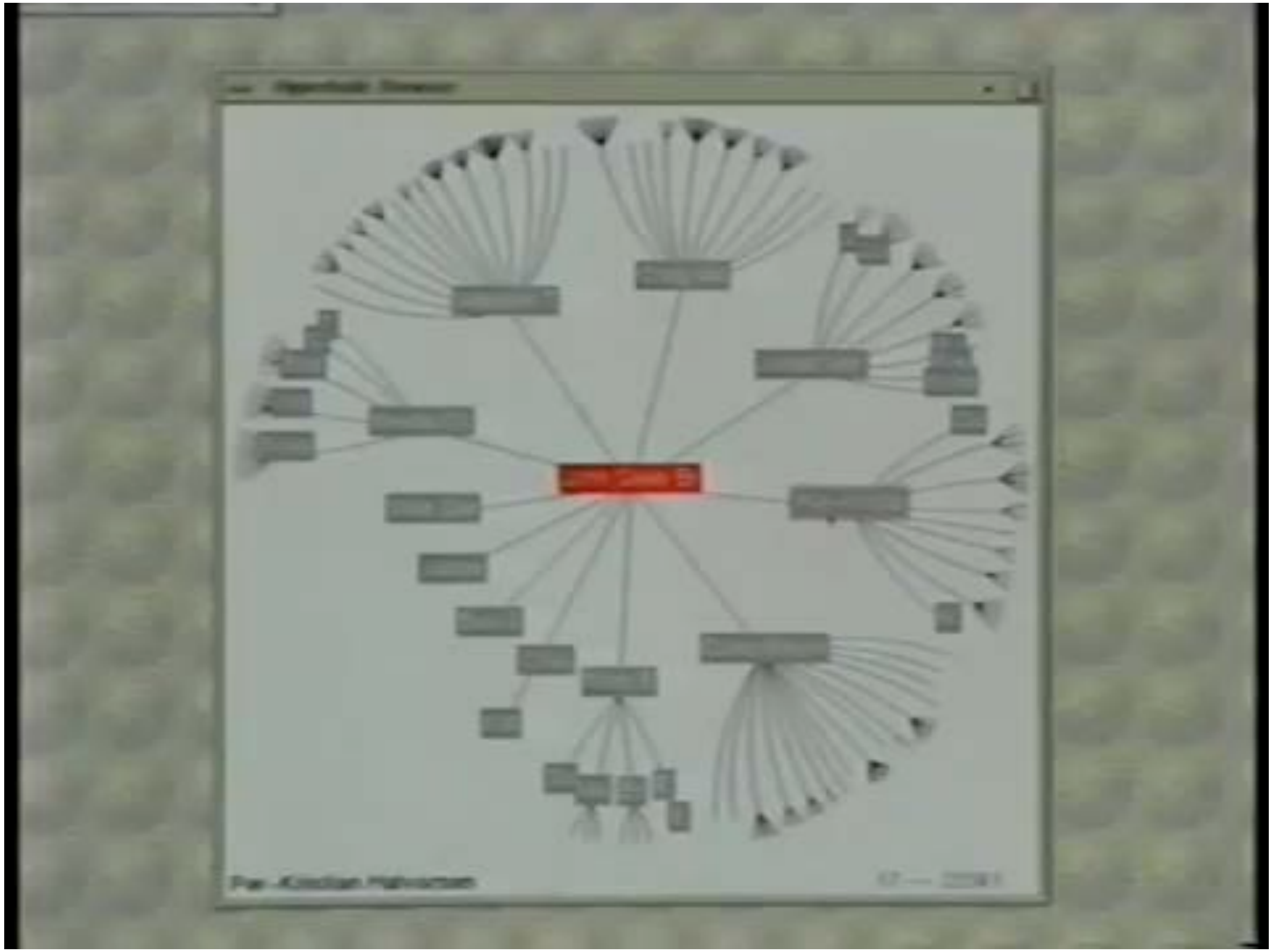
Distortion:
Multifocal / hyperbolic display

- *purpose*: see more data within limited display area
- **features**
  - shows important information larger on display, while keeping the surrounding space still visible
  - acts like multifocal goggles, or magnifying glass moving on the display
  - smooth animated transitions are essential to avoid distraction
- *pioneering work:*
  - *Office of the professional (SIGCHI'83)*
- *related work: perspective wall*
  (Mackinlay, Robertson and Card 1991)





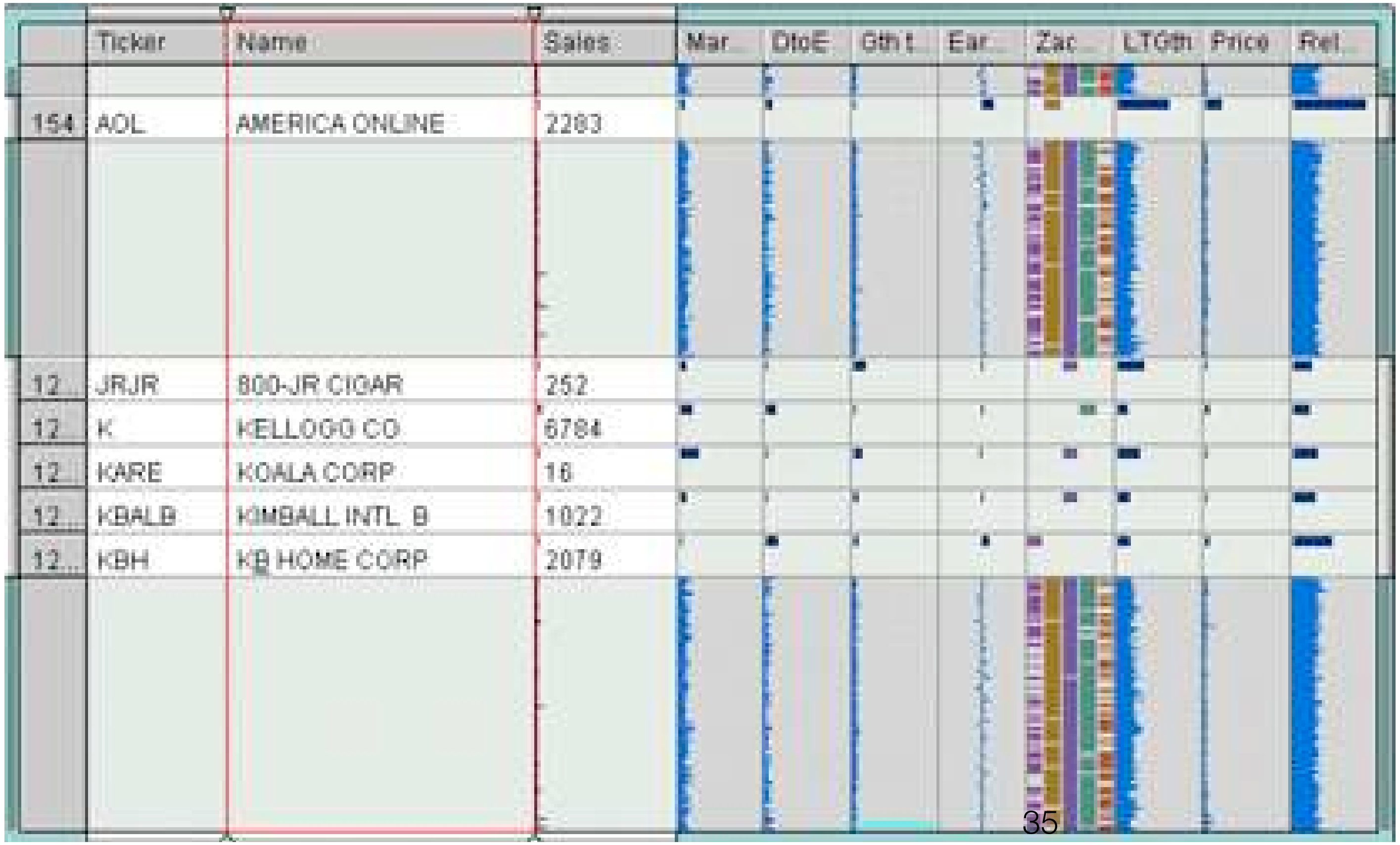
Distortion:
Hyperbolic tree browser



Lamping et al. CHI 1995. https://doi.org/10.1145/223904.223956
Demo: https://www.youtube.com/watch?v=8bhq08BQLDs

Elision and distortion: Table lens

- Table lens is a visualization tool for searching patterns and outliers in multivariate datasets (https://doi.org/10.1145/948449.948460)
- Time-cost function for different tasks (e.g., “find shape of the Nth column in the table lens”) can be calculated and verified experimentally (see the article)
- Demo at https://www.youtube.com/watch?v=qWqTrRAC52U



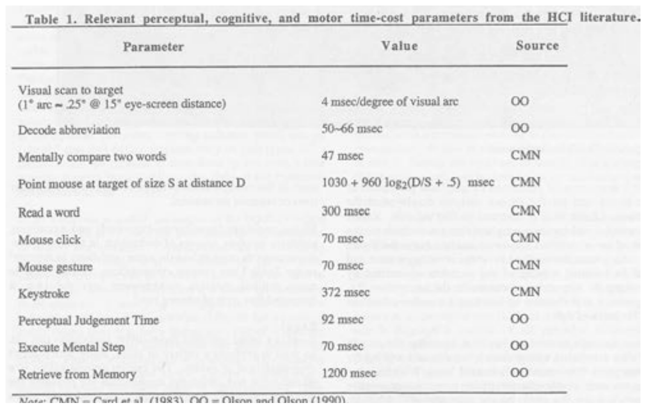


Table 1. Relevant perceptual, cognitive, and motor time-cost parameters from the HCI literature.

Parameter	Value	Source
Visual scan to target (1° arc ~ .25" @ 15" eye-screen distance)	4 msec/degree of visual arc	OO
Decode abbreviation	50–66 msec	OO
Mentally compare two words	47 msec	CMN
Point mouse at target of size S at distance D	$1030 + 960 \log_2(D/S + .5)$ msec	CMN
Read a word	300 msec	CMN
Mouse click	70 msec	CMN
Mouse gesture	70 msec	CMN
Keystroke	372 msec	CMN
Perceptual Judgement Time	92 msec	OO
Execute Mental Step	70 msec	OO
Retrieve from Memory	1200 msec	OO

Note: CMN = Card et al. (1983), OO = Olson and Olson (1990).

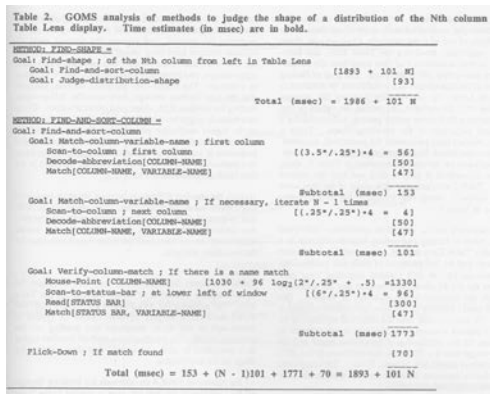
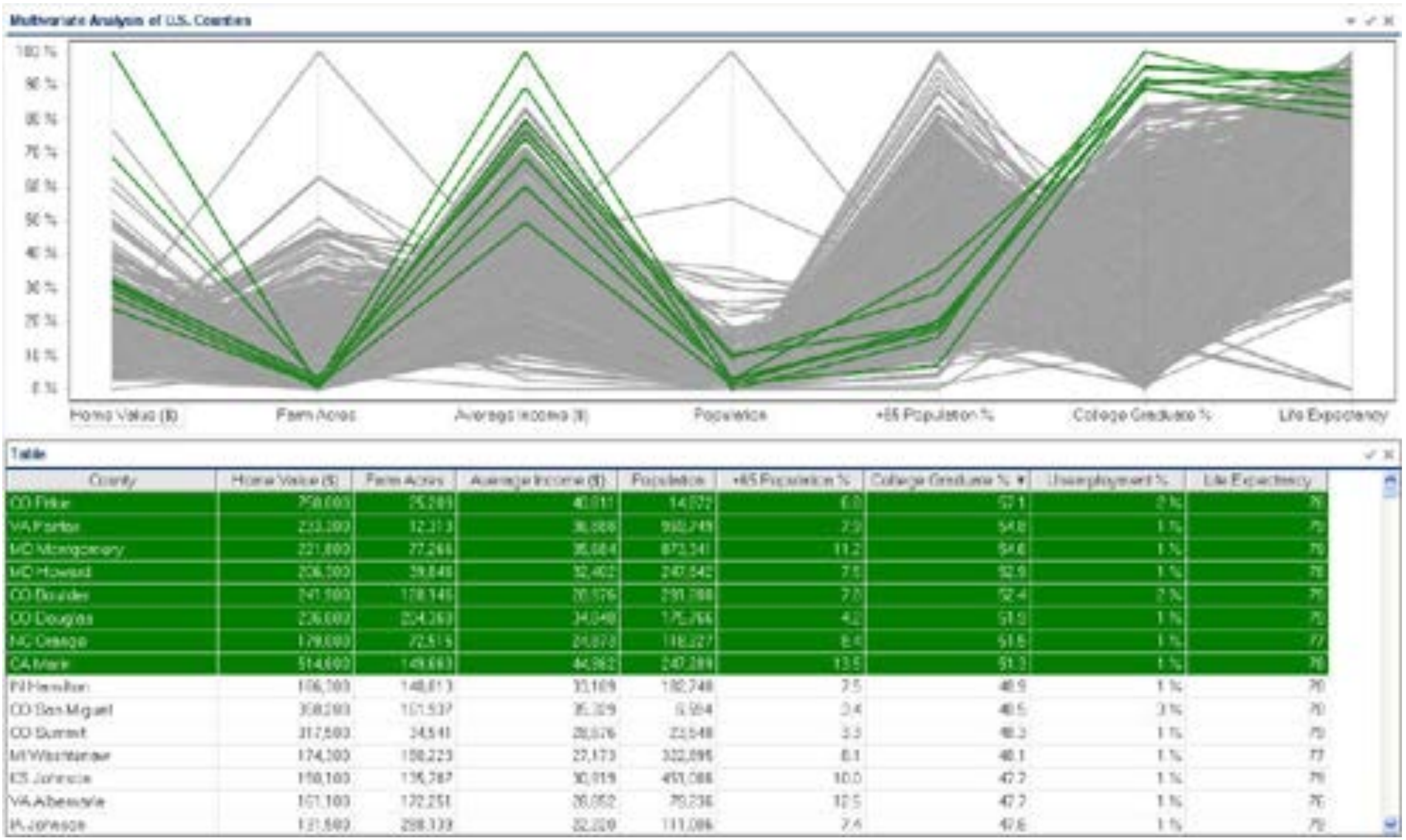


Table 2. GOMS analysis of methods to judge the shape of a distribution of the Nth column Table Lens display. Time estimates (in msec) are in bold.

```
METHOD: FIND-SHAPE =
Goal: Find-shape ; of the Nth column from left in Table Lens
   Goal: Find-and-sort-column                                  [1893 + 101 N]
   Goal: Judge-distribution-shape                                        [93]
                                                    ----------
                                          Total (msec) = 1986 + 101 N

METHOD: FIND-AND-SORT-COLUMN =
Goal: Find-and-sort-column
   Goal: Match-column-variable-name ; first column
      Scan-to-column ; first column                     [(3.5°/.25°)*4 = 56]
      Decode-abbreviation[COLUMN-NAME]                                 [50]
      Match[COLUMN-NAME, VARIABLE-NAME]                                [47]
                                                                ----
                                                  Subtotal (msec) 153
   Goal: Match-column-variable-name ; If necessary, iterate N - 1 times
      Scan-to-column ; next column                     [(.25°/.25°)*4 =  4]
      Decode-abbreviation[COLUMN-NAME]                                 [50]
      Match[COLUMN-NAME, VARIABLE-NAME]                                [47]
                                                                ----
                                                  Subtotal (msec) 101

   Goal: Verify-column-match ; If there is a name match
      Mouse-Point [COLUMN-NAME]      [1030 + 96 log2(2°/.25° + .5) =1330]
      Scan-to-status-bar ; at lower left of window     [(6°/.25°)*4 = 96]
      Read[STATUS BAR]                                                [300]
      Match[STATUS BAR, VARIABLE-NAME]                                 [47]
                                                                ----
                                                  Subtotal (msec) 1773

   Flick-Down ; If match found                                         [70]
                                                                ----
        Total (msec) = 153 + (N - 1)101 + 1771 + 70 = 1893 + 101 N
```

Elision and Multiple windows: Parallel coordinates view

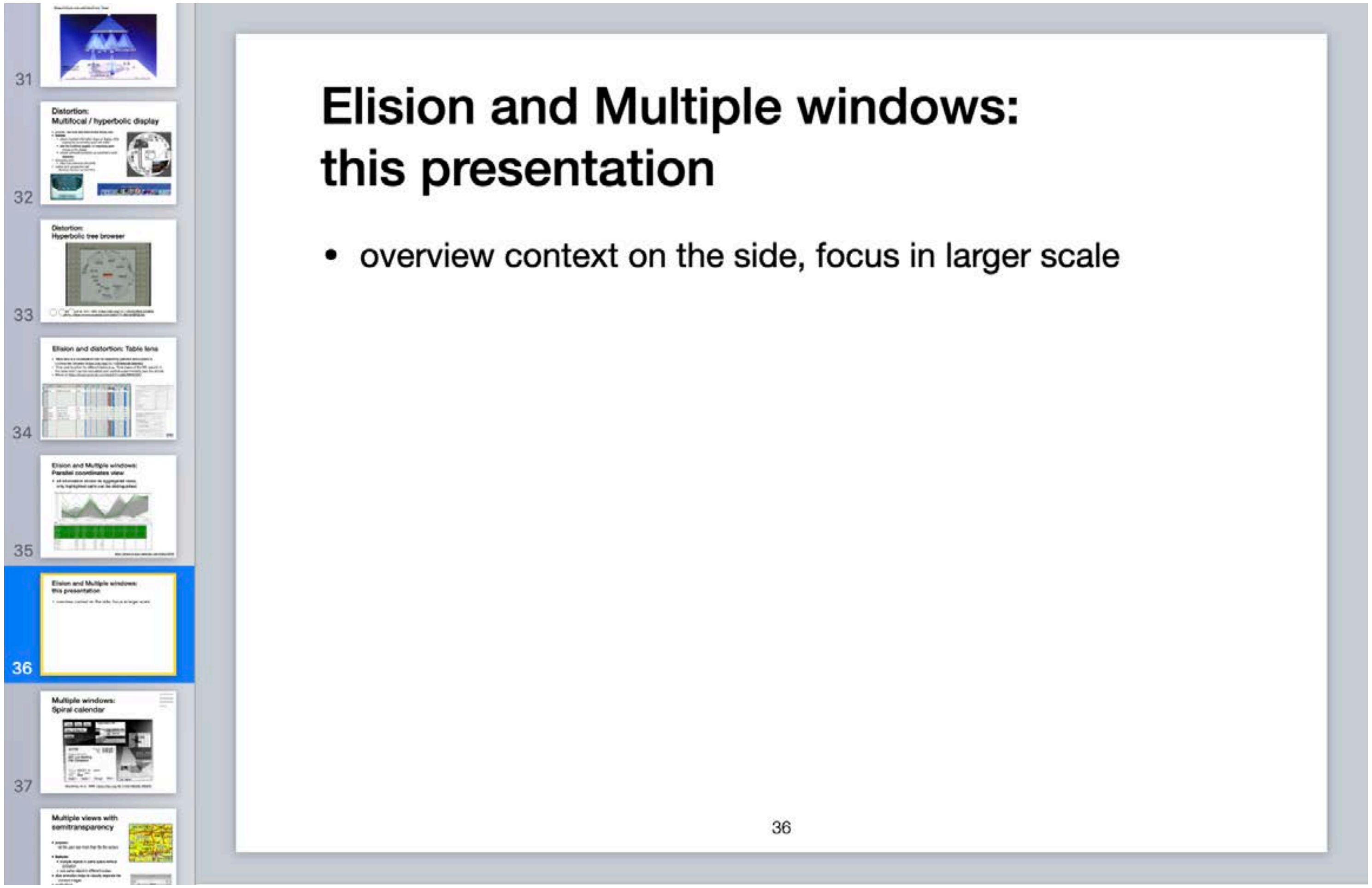
- all information shown as aggregated mass; only highlighted parts can be distinguished



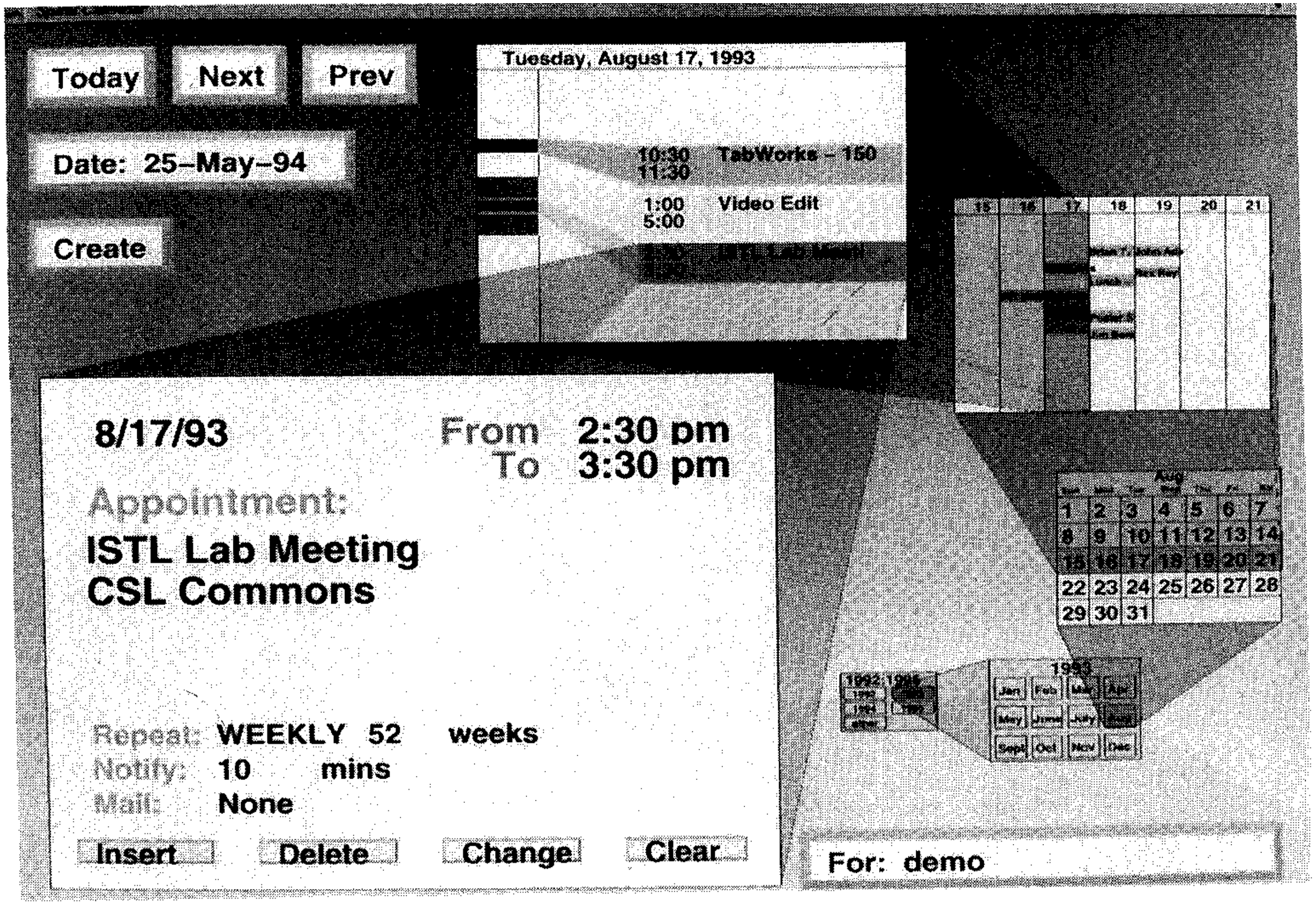
https://www.perceptualedge.com/articles/b-eye/parallel_coordinates.pdf

Elision and Multiple windows: this presentation

- contextual overview on the side, slide focus in larger scale

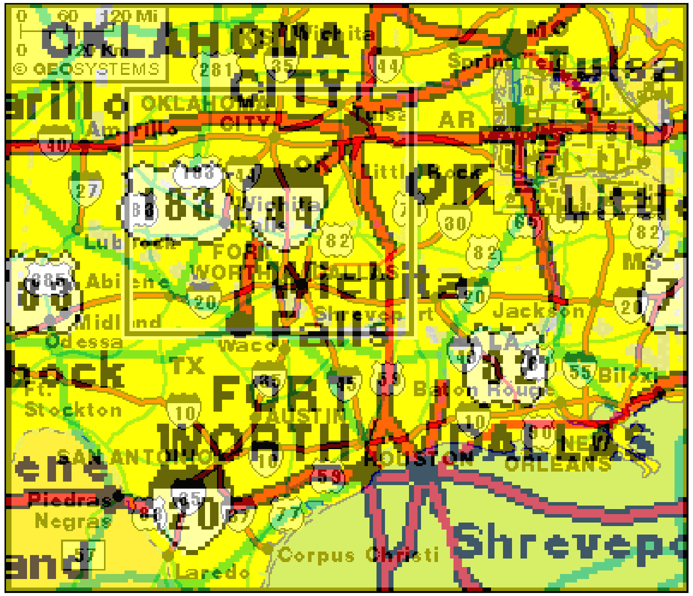


Multiple windows: Spiral calendar



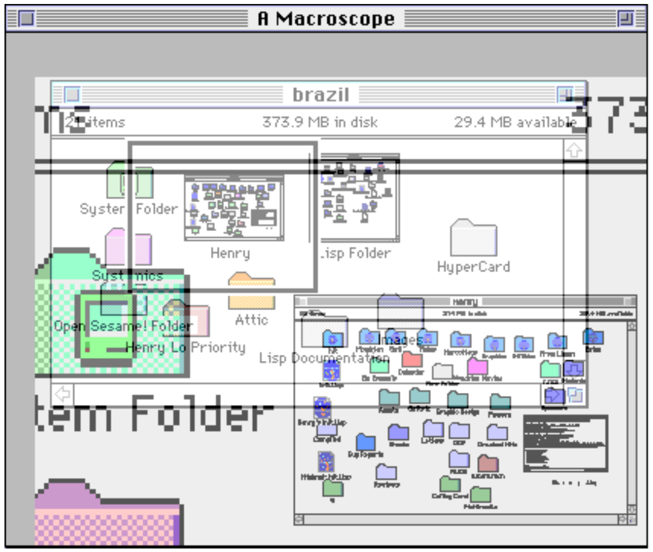
Mackinlay et al. 1995. https://doi.org/10.1145/192426.192470

Multiple views with semitransparency



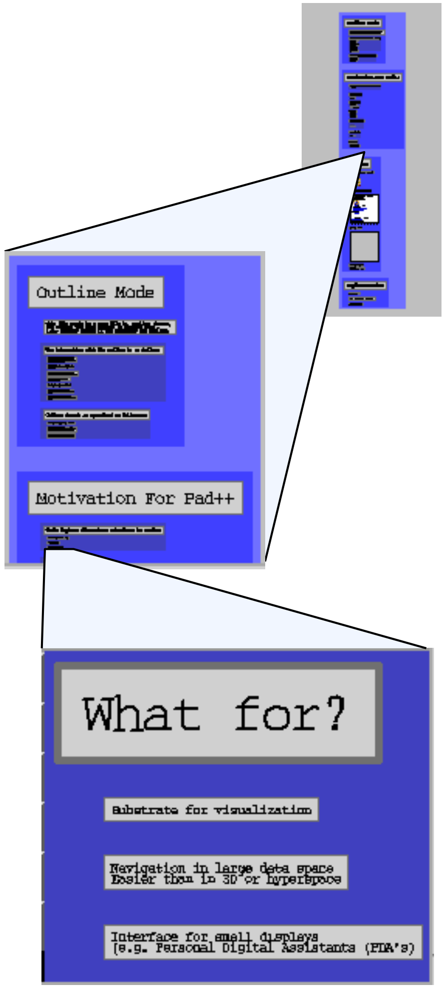
- *purpose*:
  let the user see more than fits the screen

- **features**
  - multiple objects in same space without occlusion
  - see same object in different scales
- slow animation helps to visually separate the overlaid images
- applications
  - map reading
  - desktop crowd (Windows 2000 / Mac Aqua)



Live demo

Rapid zooming



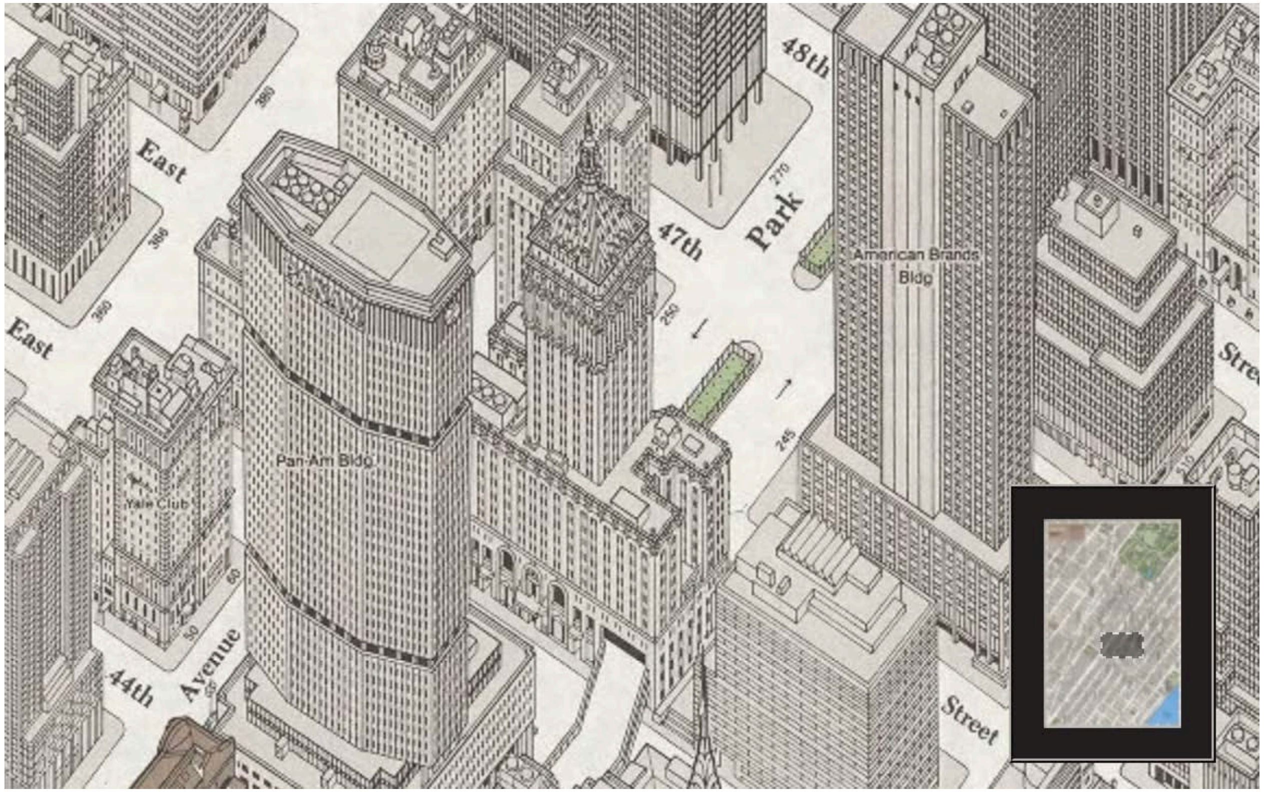
User zooms in and out of regions of interest.

- *purpose*:
  manage unlimited data within limited display area
- **features**
  - shows important information larger by zooming in
  - avoids the non-linear distortion of hyperbolic display
    - cheaper to implement
  - smooth transitions are essential
  - no inherent limitation of the resolution of displayed data
    - works best with dynamically regenerated or multiresolution images
- applications
  - *historical: Pad++* <u>*http://www.cs.umd.edu/hcil/pad++/*</u>
  - map visualization, e.g. GoogleMaps
  - presentation software, e.g. Prezi

Micro-macro reading

- Focus+context in static visualization
- Maximum utilization of the medium's resolution (e.g. printed paper)

- Map of Midtown Manhattan in Detailed Axonometric Projection:



https://www.davidrumsey.com/luna/servlet/detail/RUMSEY~8~1~272437~90046235:Map-of-Midtown-Manhattan-in-Detaile?qvq=w4s:/who%2FAnderson%25252C%2BConstantine%2FTopika%2BBusiness%2BMachines%2BSales%2BCorp.%2F;lc:RUMSEY~8~1&mi=3&trs=4

Effective View Navigation in abstract information space

- **Theoretical view** by Furnas (1997) https://doi.org/10.1145/258549.258800

- The information landscape can be thought as a tree or network G

- Effective View Navigation in G, EVN(G): how to organise information with links so that we have

EVT efficient traversal

- small views: number of outgoing links from a view (maximal *out-degree*, MOD) is small;

- short paths: the expected cost of traversal (number of steps, defined by *network diameter*, DIA) is minimised;

and

VN view navigable

- all targets have a good *residue* ('scent' of target) in each node, and *outlink-info* is small
  - requires good semantic classification of nodes

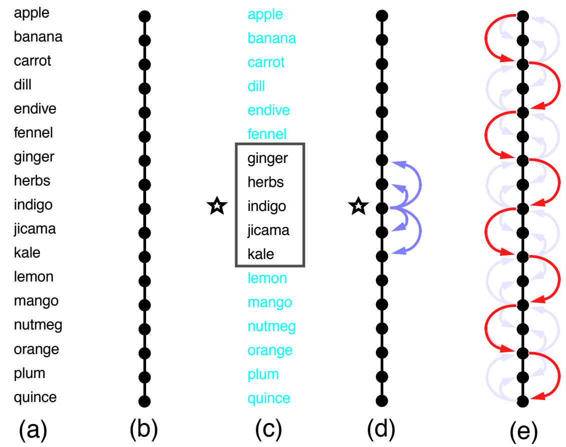


Figure 1. *(a) Schematic of an ordered list, (b) logical graph of the list, (c) local window view of the list, (d) associated part of viewing graph, showing that out degree is constant, (e) sequence of traversal steps showing the diameter of viewing graph is O(n).*

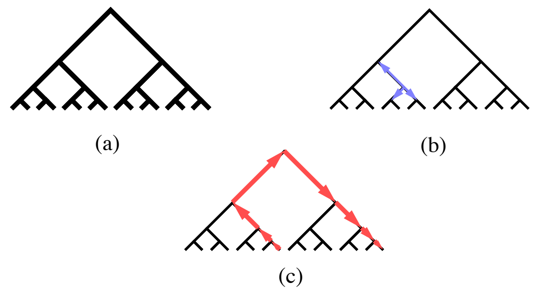


Figure 2. *An example of an Efficiently View Traversable Structure (a) logical graph of a balanced tree, (b) in gray, part of the viewing graph for giving local views of the tree showing the outdegree is constant, (c) a path showing the diameter to be O(log(n)).*

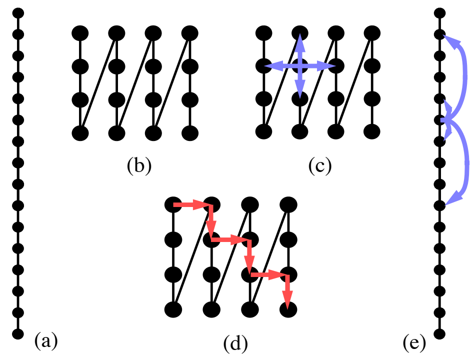


Figure 3. *Fixing the list viewer. (a) logical graph of the ordered list again, (b) the list is folded up in 2-D (c) part of the viewing graph showing the 2-D view-neighbors of Node6 in the list: out degree is O(1), (d) diameter of viewing graph is now reduced to O(sqrt(n)). (e) Unfolding the list, some view-neighbors of Node6 are far away, causing a decrease in diameter.*

Notes on Furnas' EVN paper

- Theoretical view $\Rightarrow$ can be applied in very different cases
- Written in 1997, when WWW was relatively new
  - now search engines are often more effective than navigation with explicit links
  - further development: semantic web
  - (in both, search is based on auxiliary metadata)
- Example of EVN in the web: Wikipedia
  - organized (partly) with hierarchical categories
  - rich additional cross linking

Summary

- **Focus+context problem**: how to find details from a larger context in information space. Or, how to *navigate efficiently* in abstract spaces.

- Several techniques, often in combination:
  - **Elision techniques**
  - **Distortion techniques**
  - **Rapid zooming techniques**
  - **Multiple windows**
  - **Micro-macro readings**

- Furnas' theory of effective view navigation

Next lecture

- Dimensionality reduction techniques