# Interactive Information Visualization

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9 October 2003

## Outline

information visualization motivation

designing for humans

information visualization techniques

future directions



## Information visualization

interactive visual representation of abstract data
- help human perform some task more effectively



## Interactivity

static images
- 10,000 years
- art, graphic design

moving images
- 100 years
- cinematography

interactive graphics
- 20 years
- computer graphics, human-computer interaction



## Information visualization

interactive visual representation of abstract data
- help human perform some task more effectively

external representation
- reduces load on working memory

bridging many fields
- graphics: interacting in realtime
- cognitive psych: finding appropriate representation
- HCI: using task to guide design and evaluation



## Visualization Tasks

overview
zoom
filter
details-on-demand

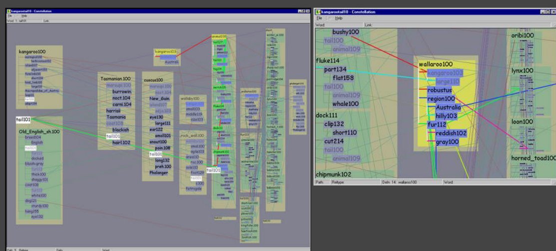
relate
history
extract

[The Eyes Have It: A Task by Data Type Taxonomy for Information Visualizations.
Ben Shneiderman
citeseer.nj.nec.com/shneiderman96eyes.html]

## Task-oriented design

custom design for checking semantic networks

- reading definition subgraph labels

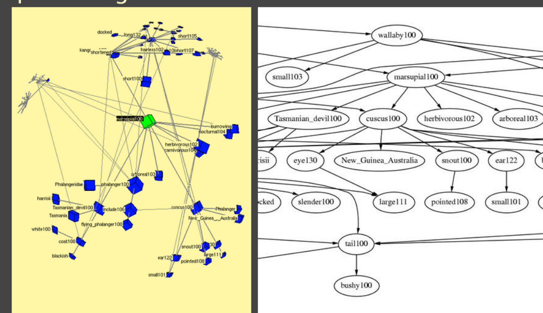


[graphics.stanford.edu/papers/munzner_thesis/html/node10.html#layoutefffig]



## Task-oriented design

previous general methods

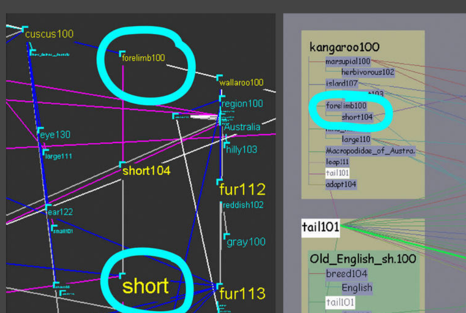



[graphics.stanford.edu/papers/munzner_thesis/html/node10.html#dotconstfig]



## Design tradeoffs

information density vs. visual salience




[graphics.stanford.edu/papers/munzner_thesis/html/node11.html#noncanonfig]



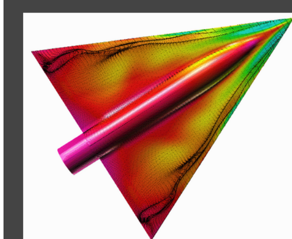
## Scientific vs. information visualization

scivis: inherently spatial data

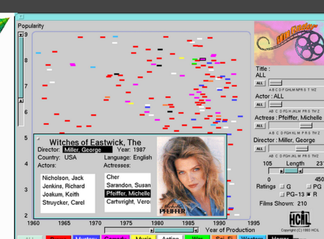
- fluid flow over airplane wing

infovis: abstract data, choice of spatialization

- FilmFinder



[www.nas.nasa.gov/NASnews/95/05/delta.html]



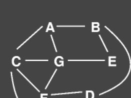
[Ahlberg and Shneiderman. CHI 94]



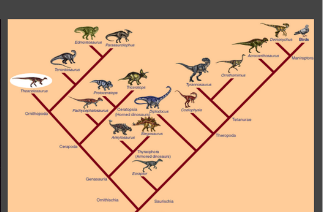
## Example: node-link graphs

powerful abstraction

common in many domains




[Cox and Patterson 92]



[www.dinoheart.org/images/cladogram.gif]



## Why visualize graphs?

Example: book topic relationships

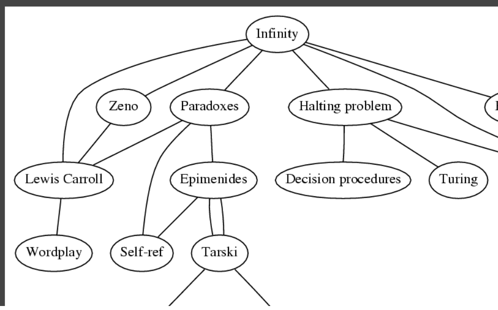
- [Godel, Escher, Bach. Hofstadter 1979]

Paradoxes – Lewis Carroll
Turing – Halting problem
Halting problem – Infinity
Paradoxes – Infinity
Infinity – Lewis Carroll
Infinity – Unpredictably long searches
Infinity – Recursion
Infinity – Zeno
Infinity – Paradoxes
Lewis Carroll – Zeno
Lewis Carroll – Wordplay

Halting problem – Decision procedures
BlooP and FlooP – AI
Halting problem – Unpredictably long searches
BlooP and FlooP – Unpredictably long searches
BlooP and FlooP – Recursion
Tarski – Truth vs. provability
Tarski – Epimenides
Tarski – Undecidability
Paradoxes – Self-ref
[...]

## Why visualize graphs?

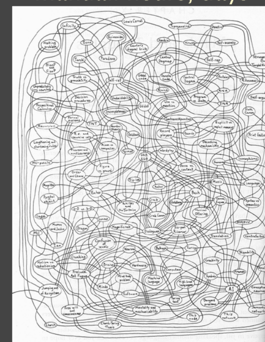
offload cognition to visual systems
minimal attention to read answer





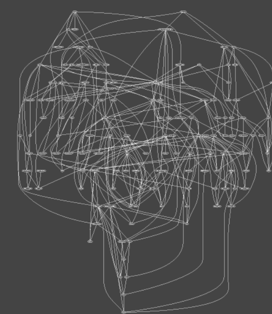

## Why draw graphs automatically?

manual: hours, days



[Godel, Escher, Bach. Hofstader 79]

automatic: seconds



dot, [Gansner et al 93]



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## Designing for Humans

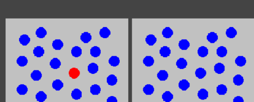
perception
visual dimensions
visual encoding



## Preattentive visual dimensions

color (hue) alone: preattentive

- attentional system not invoked
- search speed independent of distractor count



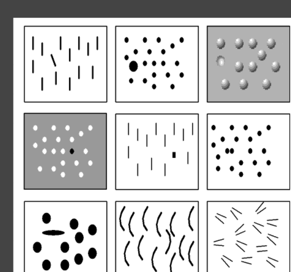
[Chris Healey, Preattentive Processing, www.csc.ncsu.edu/faculty/healey/PP/PP.html]



## Preattentive visual dimensions

many preattentive dimensions of visual modality

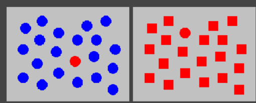
- hue
- shape
- texture
- length
- width
- size
- orientation
- curvature
- intersection
- intensity
- flicker
- direction of motion
- stereoscopic depth
- lighting direction



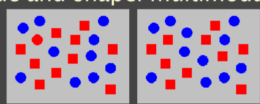
[Chris Healey, Preattentive Processing, www.csc.ncsu.edu/faculty/healey/PP/PP.html]

## Preattentive visual dimensions

color alone: preattentive
shape alone: preattentive



combined hue and shape: multimodal

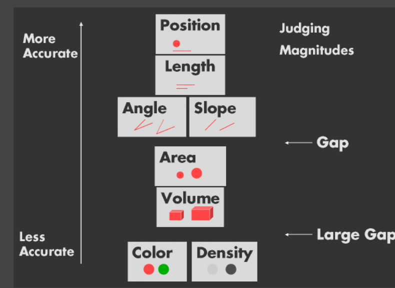


- requires attention
- search speed linear with distractor count

[Chris Healey, Preattentive Processing, www.csc.ncsu.edu/faculty/healey/PP/PP.html]



## Dimensional ranking

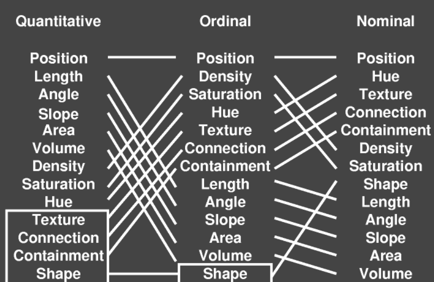



[graphics.stanford.edu/courses/cs448b-02-spring/lectures/encoding/walk015.html]



## Dimensional ranking varies by data type

spatial position best for all types

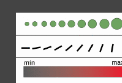



[Mackinlay, Automating the Design of Graphical Presentations of Relational Information, ACM TOG 5:2, 1986]



## Data types and marks

continuous (quantitative)
- 10 inches, 17 inches, 23 inches



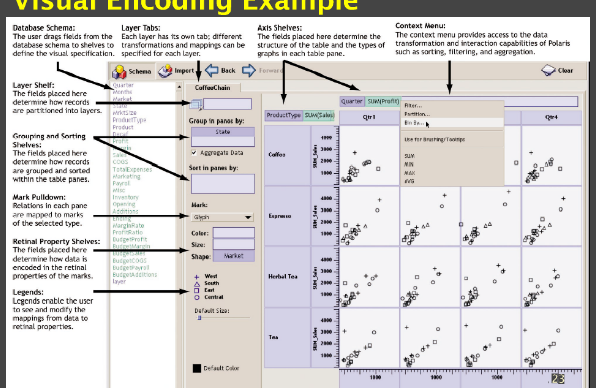

ordered (ordinal)
- small, medium, large

categorical (nominal)
- apples, oranges, bananas

[graphics.stanford.edu/papers/polaris]



## Visual Encoding Example




[Polaris: A System for Query, Analysis and Visualization of Multi-dimensional Relational Databases, Stolte, Tang and Hanrahan

## Human Perception

sensors/transducers
- psychophysics: determine characteristics

relative judgements: strong
absolute judgements: weak
- continuing theme

different optimizations than most machines
- eyes are not cameras
- perceptual dimensions not nD array
- (brains are not hard disks)

## Psychophysical Measurement

JND: just noticeable difference
- create "subjective" scale

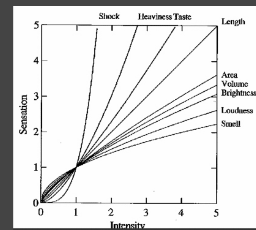
prothetic: how much
- JND constant
- loudness, brightness

metathetic: where
- JND increasing
- pitch, inclination



## Nonlinear perception of magnitudes

sensory modalities not equally discriminable
- Stevens power law



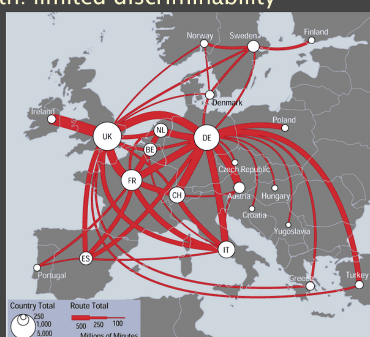

$S = I^p$

[Stevens, On the Theory of Scales of Measurement, Science 103:2684, 1946]



## Dimensional dynamic range

linewidth: limited discriminability




[mappa.mundi.net/maps/maps_014/telegeography.html]



## Integral vs. separable dimensions

| red-green yellow-blue | x-size y-size | size orientation | color shape | color motion | color location |
|---|---|---|---|---|---|

[Colin Ware, Information Visualization: Perception for Design. Morgan Kaufmann 1999.]



## Gestalt Laws

principles of pattern perception
- "gestalt": German for "pattern"
- original proposed mechanisms wrong
- rules themselves still useful

Pragnatz
- simplest possibility wins

subsequent examples from
- Information Visualization: Perception for Design
- Colin Ware
- Morgan Kaufmann, 2000



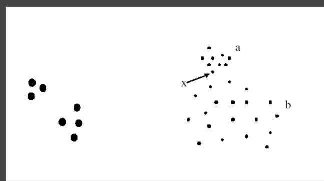
## Gestalt Principles

proximity, similarity,
continuity/connectedness/good continuation
closure, symmetry
common fate (things moving together)

[psychlab1.hanover.edu/classes/Sensation/sld013.htm]

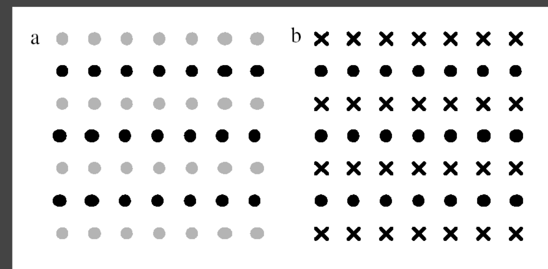
figure/ground, relative sizes

## Proximity





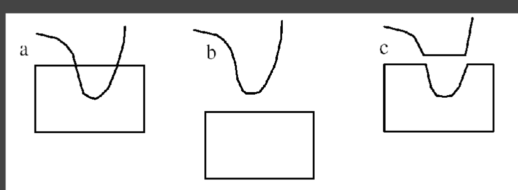

## Similarity






## Continuity

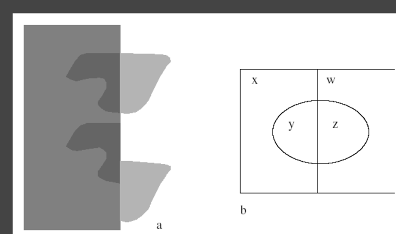
smooth not abrupt change
overrules proximity






## Transparency

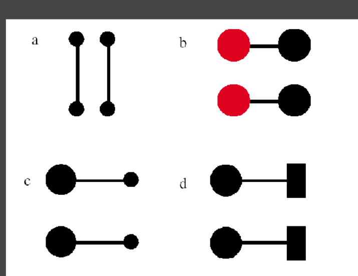
needed for perception
- continuity
- color correspondence






## Connectedness

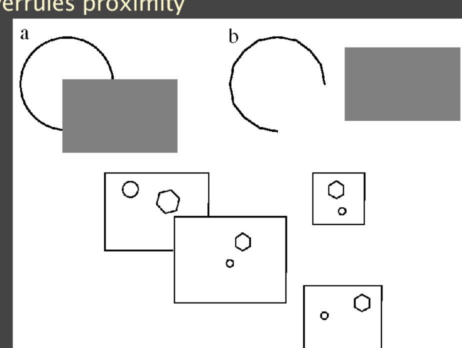
can overrule size, shape





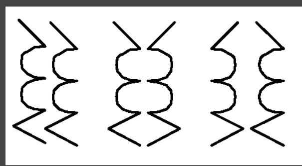

## Closure

overrules proximity



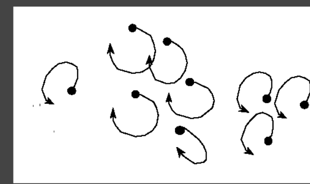
## Symmetry

emphasizes relationships





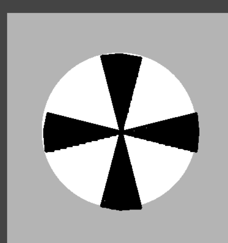
## Common Fate





## Relative Size

smaller components perceived as objects





## Figure/Ground

determined by combination of previous laws



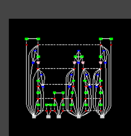
## Graph Drawing Tension

node placement

close
- proximity

far
- visual popout of long edge

either
- connectedness



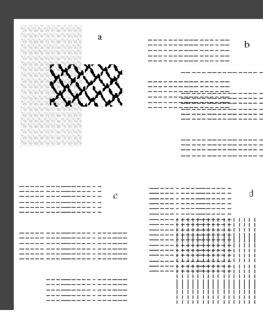
[www.research.att.com/sw/tools/graphviz]

tradeoffs abound in infovis!



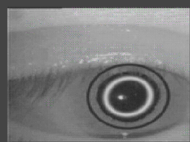
## Overlap

perception of overlapping textures depends on visual interference between patterns



## Eyes

saccades [video]
- high-resolution samples
- brain makes collage
- vision perceived as entire simultaneous field
- fixation points: dwell 200-600ms
- moving: 20-100ms



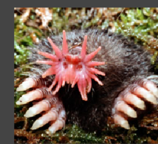
[vision.arc.nasa.gov/personnel/jbm/home/projects/osa98/osa98.html/

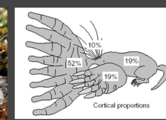


## Fovea

foveal vision
- high resolution
- thumbnail at arm's length

(foveal touch: star-nosed mole)






[www.nature.com/nsu/010329/010329-6.html
brain.nips.ac.jp/event/work131030/Catania_and_Kaas,_1997.pdf]



## Ears

perceived as temporal stream
- but also samples over time
- hard to filter out when not important
  - visual vs auditory attention

implications
- harder to create overview?
- hard to use as separable dimension?

'sonification' still very niche area
- alternative: supporting sound enhances immersion



## Affordances

visible/apparent function

- The Design of Everyday Things, Don Norman

- doors: push/pull

implications for infovis

- pixels, not tangible objects



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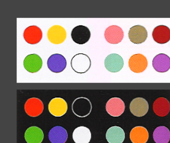
## Color rules of thumb



[Colin Ware, Information Visualization: Perception for Design. Morgan Kaufmann 1999.]

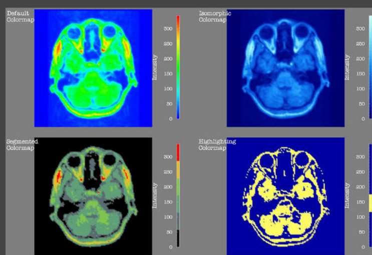
nominal
- bad: > 12 hues
- good: use <= ~12 hues

ordinal
- bad: using hue
- good: saturation/brightness

quantitative
- bad: rainbow colormaps
- good: interpolate between two hues

## Colormaps

rainbow colormaps usually bad idea
- hue is mediocre for showing order
- not perceptually linear!

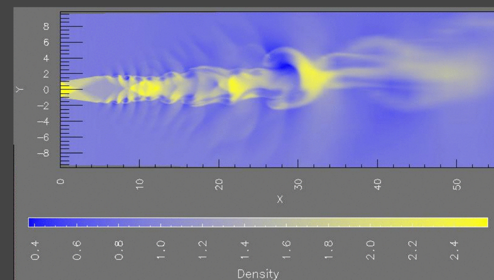


[Rogowitz and Treinish, How NOT to Lie with Visualization, www.research.ibm.com/dx/proceedings/pravda/truevis.htm



## Colormaps

interpolating between two hues usually safe



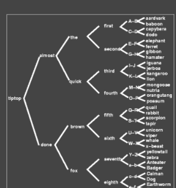

[Rogowitz and Treinish, How NOT to Lie with Visualization, www.research.ibm.com/dx/proceedings/pravda/truevis.htm



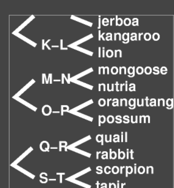
## Overview+detail

problem
- avoid user disorientation when inspecting detail
- hard for big datasets

bad: one window, must remember position



global overview

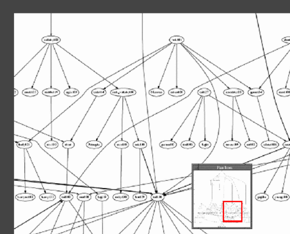



local detail



## Overview and detail

better: add linked overview window(s)



how to create overview?



## Overview and detail

SeeSoft: software maintenance
- (colormaps: segmented vs. continuous)

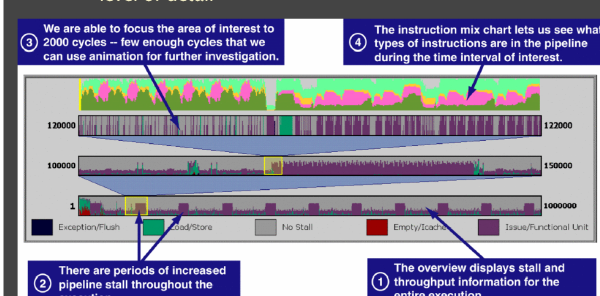
code age | platform dependencies

[Ball and Eick, Software Visualization in the Large, Computer 29:4, 1996 citeseer.nj.nec.com/ball96software.html]



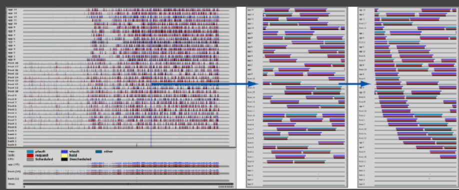
## Overview+detail

Rivet: performance tuning
- level of detail




[Stolte et al, Visualizing Application Behavior on Superscalar Processors, InfoVis 99, graphics.stanford.edu/papers/rivet_pipeline]

## Overview to detail to sorting



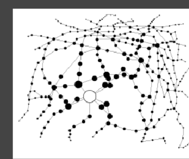
[Bosch, Performance Analysis and Visualization of Parallel Systems Using SimOS and Rivet: A Case Study, HPCA6, 2000. graphics.stanford.edu/papers/rivet_argus]



## Focus+context

- linked windows
  - still have cognitive load to correlate
- good solution:
  - merge overview, detail into single window

fisheye views [Furnas 86], [Sarkar et al 94]

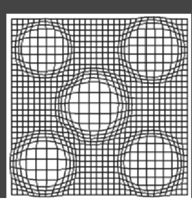




## Focus+context

- linked windows
  - still have cognitive load to correlate
- good solution:
  - merge overview, detail into single window

fisheye views [Furnas 86], [Sarkar et al 94]
nonlinear magnification [Keahey 96]





## TableLens

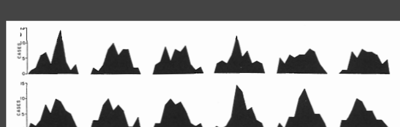
focus+context
power of sorting

www.tablelens.com



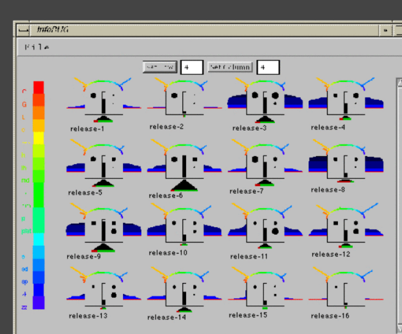
## Comparison

- bad: temporal, if many items
  - intermediate ones "overload mental buffer"
  - good: temporal blinking if two items
- good: side by side
  - array of small multiples
  - creates overview





## Glyph small multiples: InfoBug




[Chuah et al, Information Rich Glyphs for Software Management, IEEE CG&A 18:4 1998,www.cs.cmu.edu/~sage/Papers/CGAglyph/CGAglyph.pdf]

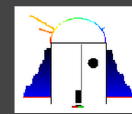
## Glyphs

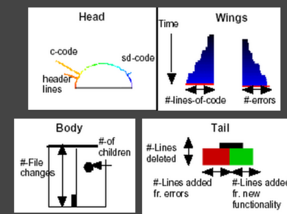
single graphical object that represents a multivariate data object



## Glyphs: InfoBug

software management



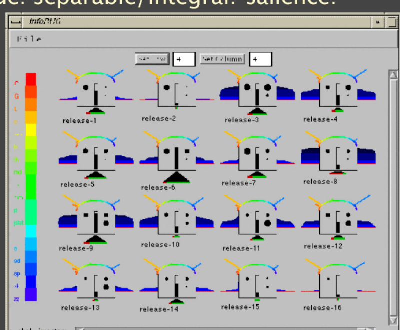





[Chuah et al, Information Rich Glyphs for Software Management, IEEE CG&A 18:4 1998,www.cs.cmu.edu/~sage/Papers/CGAglyph/CGAglyph.pdf]

## Glyph small multiples: InfoBug

critique: separable/integral? salience?



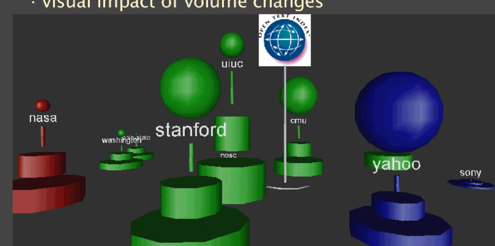


[Chuah et al, Information Rich Glyphs for Software Management, IEEE CG&A 18:4 1998,www.cs.cmu.edu/~sage/Papers/CGAglyph/CGAglyph.pdf]

## Glyphs: Web sites

Web sites circa 1996 [Bray 1996]
- # pages: base diameter, # outlinks: globe diameter
- # inlinks: height, domain: hue

critique
- visual impact of volume changes

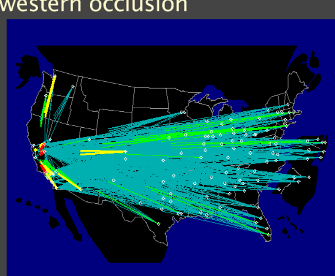





[Bray, Measuring the Web, WWW5, www5conf.inria.fr/fich_html/papers/P9/Overview.html]

## Minimizing occlusion

bad: Midwestern occlusion

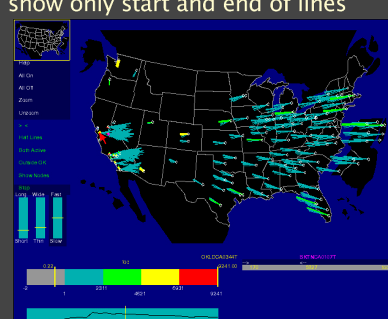


[citeseer.nj.nec.com/becker95visualizing.html]
[Becker, Eick, and Wilks. Visualizing Network Data, IEEE TVCG 1995]



## Minimizing occlusion

good: show only start and end of lines

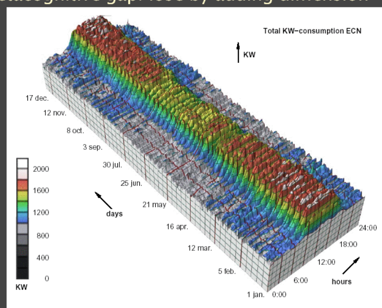


[citeseer.nj.nec.com/becker95visualizing.html]
[Becker, Eick, and Wilks. Visualizing Network Data, IEEE TVCG 1995]

# Minimizing occlusion: 3D vs. 2D

bad: 3D pretty but not useful

- metacognitive gap: lose by adding dimension

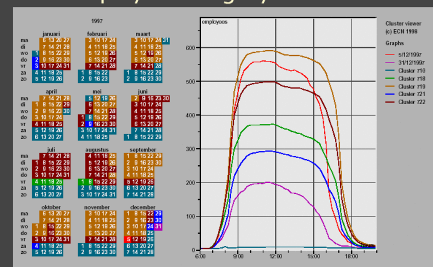



[van Wijk and van Selow, Cluster and Calender based Visualization of Time Series Data, InfoVis99, citeseer.nj.nec.com/vanwijk99cluster.html]



# Minimizing occlusion: 3D vs. 2D

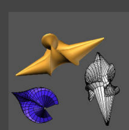
good: 2D display of category clusters



[van Wijk and van Selow, Cluster and Calender based Visualization of Time Series Data, InfoVis99, citeseer.nj.nec.com/vanwijk99cluster.html]

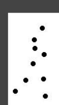


# Motion: clarify structure



navigation

- rotate/translate/zoom



[www.psy.vanderbilt.edu/faculty/blake/biowalker.gif]

object recognition

- moving lights at joints
  - Johannson 1973

animated transitions

- avoid change blindness
  - jump increases cognitive load
- smooth transition from one state to next
  - maintain object constancy



# Outline

information visualization motivation

designing for humans

information visualization techniques

future directions



# Future: scaling to huge datasets

data explosion

- sensors
  - Human Genome Project
  - Sloan Digital Sky Survey
- simulation
  - Accelerated Strategic Computing Initiative
  - microprocessor design
- logging
  - long-distance telephony backbone
  - Web traffic



# Future: dynamic data

static

- hyperlink structure of entire Web

dynamic

- entire Web changing through time (Internet Archive)

open problem: incremental/online layout

- minimal visual changes: maintain user's mental model
- faithfully represent current state

## Future: scaling display resolution

always pixel-bound in past

high-res displays now available

- 4K x 2K: 9Mpixels vs 1 Mpixel
- pixel rich

interactivity + resolution of paper

- add physical navigation (walk closer) to virtual navigation



## More Information

UBC Term 2 course: 533C Visualization

http://www.cs.ubc.ca/~tmm