Visualization Principles

Tamara Munzner
Department of Computer Science
University of British Columbia

VIZBI 2011: Workshop on Visualizing Biological Data
16 Mar 2011

http://www.cs.ubc.ca/~tmm/talks.html#vizbi11

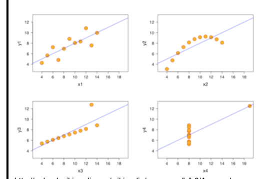
Defining visualization

computer-based visualization systems provide visual representations of datasets intended to help people carry out some task more effectively

Defining visualization

computer-based visualization systems provide visual representations of datasets intended to help people carry out some task more effectively

- human in the loop needs the details



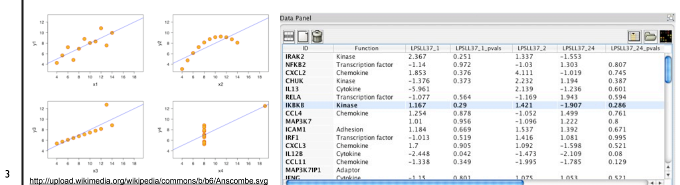
http://upload.wikimedia.org/wikipedia/commons/b/b6/Anscombe.svg

Identical statistics	
x mean	9.0
x variance	10.0
y mean	7.50
y variance	3.75
x/y correlation	0.816

Defining visualization

computer-based visualization systems provide visual representations of datasets intended to help people carry out some task more effectively

- human in the loop needs the details
- external representation: perception vs cognition

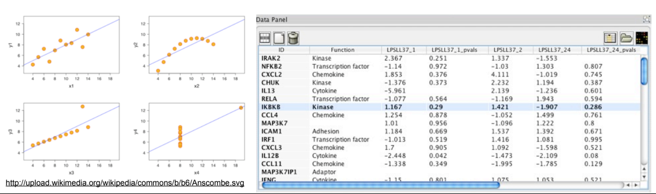


http://upload.wikimedia.org/wikipedia/commons/b/b6/Anscombe.svg

Defining visualization

computer-based visualization systems provide visual representations of datasets intended to help people carry out some task more effectively

- human in the loop needs the details
- external representation: perception vs cognition
- intended task

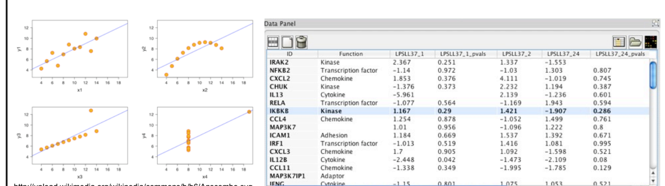


http://upload.wikimedia.org/wikipedia/commons/b/b6/Anscombe.svg

Defining visualization

computer-based visualization systems provide visual representations of datasets intended to help people carry out some task more effectively

- human in the loop needs the details
- external representation: perception vs cognition
- intended task
- measureable definitions of effectiveness



http://upload.wikimedia.org/wikipedia/commons/b/b6/Anscombe.svg

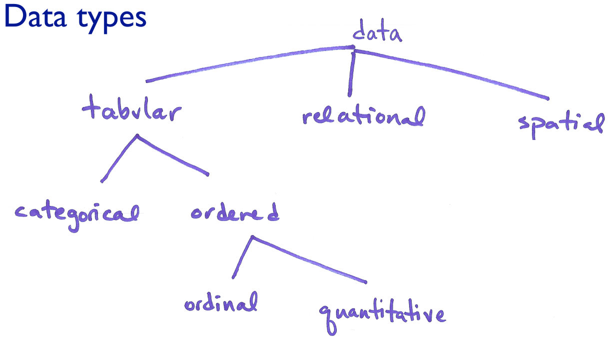
Visualization design space

- huge space of design alternatives
  - –tradeoffs abound
- many possibilities now known to be ineffective
  - avoid random walk through parameter space
  - avoid some of our past mistakes
  - extensive experimentation has already been done
- guidelines continue to evolve
  - –we reflect on lessons learned in design studies
  - –iterative refinement usually wise

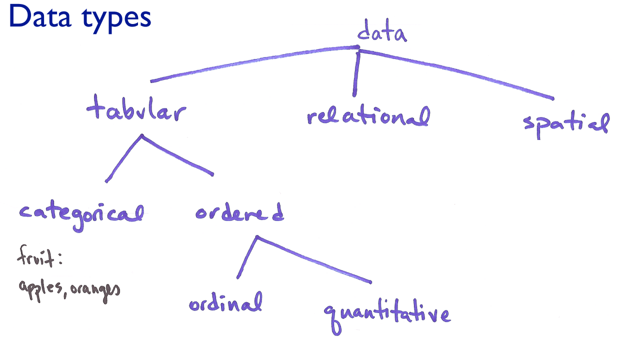
Principles

- know your visual channel types and ranks
- categorical color constraints
- power of the plane
- danger of depth
- resolution beats immersion
- eyes beat memory
- validate against the right threat

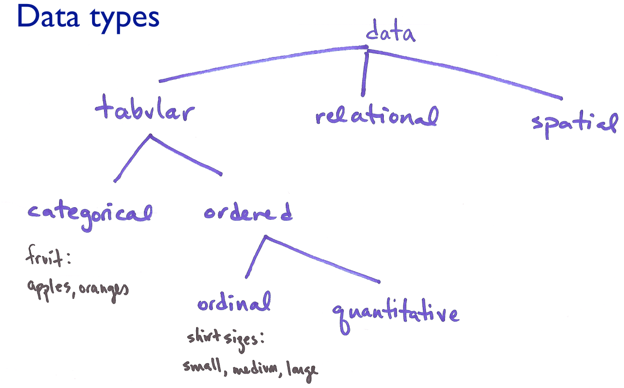
Data types



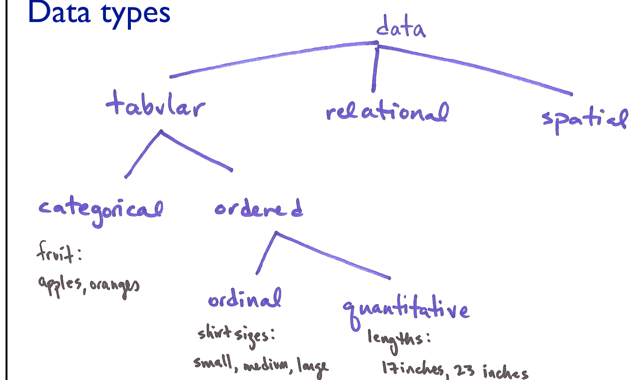
Data types



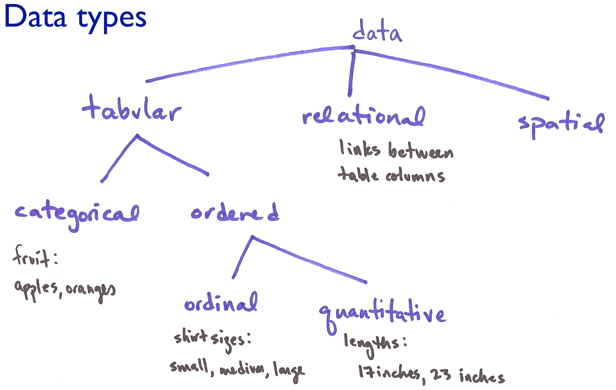
Data types



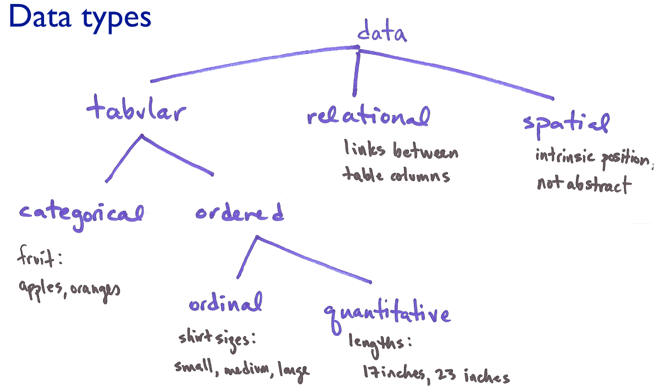
Data types



Data types



Data types



Visual encoding

Visual encoding

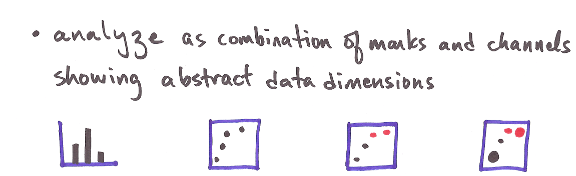


Image theory

- marks : geometric primitives
  - points
  - lines
  - areas
- visual channels : control appearance of marks
  - position
    - horizontal, vertical, both
  - color
  - shape
  - tilt
  - size

Visual encoding

- analyze as combination of marks and channels showing abstract data dimensions

Visual encoding

- analyze as combination of marks and channels showing abstract data dimensions

1: vertical position

mark: line

Visual encoding

- analyze as combination of marks and channels showing abstract data dimensions

1: vertical position

2: vertical position, horizontal position

mark: line / mark: point

Visual encoding

- analyze as combination of marks and channels showing abstract data dimensions

1: vertical position

2: vertical position, horizontal position

3: vertical position, horizontal position, color

mark: line / mark: point / mark: point

Visual encoding

- analyze as combination of marks and channels showing abstract data dimensions

1: vertical position

2: vertical position, horizontal position

3: vertical position, horizontal position, color

4: vertical position, horizontal position, color, size

mark: line / mark: point / mark: point / mark: point

Visual channel types and rankings

What / where

How much

Visual channel types and rankings

What / where
- planar position
- color hue
- shape
- stipple pattern

How much

Visual channel types and rankings

What / where
- planar position
- color hue
- shape
- stipple pattern

How much
- position on common scale
- position on unaligned scale
- length (1D size)
- tilt, angle
- area (2D size)
- curvature
- volume (3D size)
- lightness black/white
- color saturation
- stipple density

Visual channel types and rankings

Categorical
What / where
- planar position
- color hue
- shape
- stipple pattern

How much
- position on common scale
- position on unaligned scale
- length (1D size)
- tilt, angle
- area (2D size)
- curvature
- volume (3D size)
- lightness black/white
- color saturation
- stipple density

Visual channel types and rankings

Categorical
What / where
- planar position
- color hue
- shape
- stipple pattern

Ordered : ordinal/quantitative
How much
- position on common scale
- position on unaligned scale
- length (1D size)
- tilt, angle
- area (2D size)
- curvature
- volume (3D size)
- lightness black/white
- color saturation
- stipple density

Visual channel types and rankings

Categorical
What / where
- planar position
- color hue
- shape
- stipple pattern

Grouping
- Containment (2D)
- Connection (1D)
- Similarity (other channels)
- Proximity (position)

Ordered : ordinal/quantitative
How much
- position on common scale
- position on unaligned scale
- length (1D size)
- tilt, angle
- area (2D size)
- curvature
- volume (3D size)
- lightness black/white
- color saturation
- stipple density

Visual channel types and rankings

Categorical
What / where
- planar position
- color hue
- shape
- stipple pattern

Relational, Same Category
Grouping
- Containment (2D)
- Connection (1D)
- Similarity (other channels)
- Proximity (position)

Ordered : ordinal/quantitative
How much
- position on common scale
- position on unaligned scale
- length (1D size)
- tilt, angle
- area (2D size)
- curvature
- volume (3D size)
- lightness black/white
- color saturation
- stipple density

Power of the plane: only position works for all!

Categorical
What / where
- planar position
- color hue
- shape
- stipple pattern

Relational, Same Category
Grouping
- Containment (2D)
- Connection (1D)
- Similarity (other channels)
- Proximity (position)

Ordered : ordinal/quantitative
How much
- position on common scale
- position on unaligned scale
- length (1D size)
- tilt, angle
- area (2D size)
- curvature
- volume (3D size)
- lightness black/white
- color saturation
- stipple density

Ranking differs for all other channels

Categorical
What / where
- planar position
- color hue
- shape
- stipple pattern

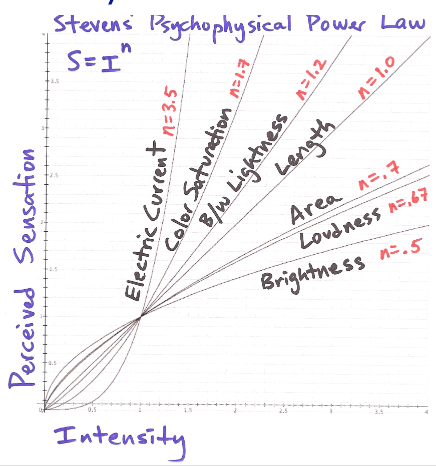
Relational, Same Category
Grouping
- Containment (2D)
- Connection (1D)
- Similarity (other channels)
- Proximity (position)

Ordered : ordinal/quantitative
How much
- position on common scale
- position on unaligned scale
- length (1D size)
- tilt, angle
- area (2D size)
- curvature
- volume (3D size)
- lightness black/white
- color saturation
- stipple density

Channel rankings

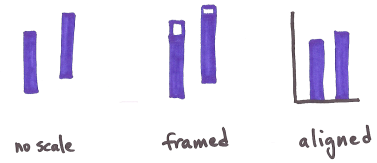
- effectiveness principle: encode most important attributes with highest ranked channels [Mackinlay 86]
- where do rankings come from?
  - accuracy, discriminability, separability, popout

Accuracy



Accuracy

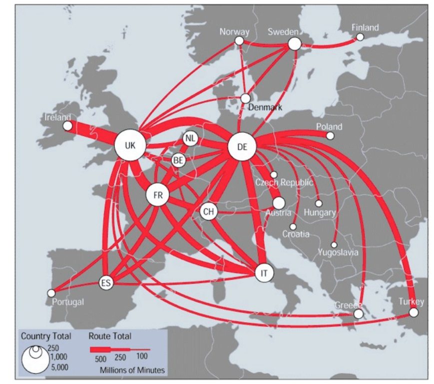
- position along common scale



- frame increases accuracy [Cleveland 84]
- Weber's Law: relative judgements
  - filled rectangles differ by 1:9
  - white rectangles differ by 1:2

Discriminability: How many usable steps?

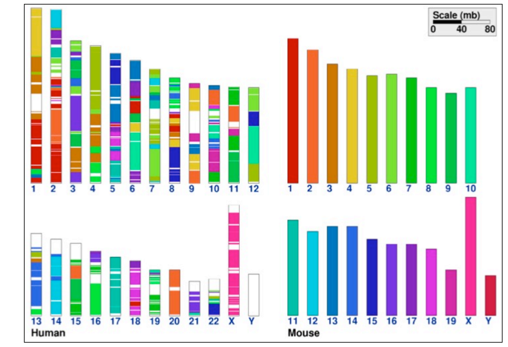
- linewidth: only a few



[mappa.mundi.net/maps/maps 014/telegeography.html]

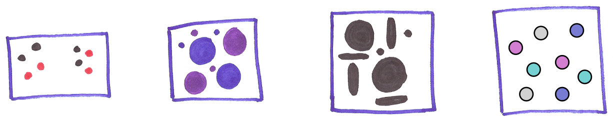
Discriminability: Categorical color constraints

- noncontiguous small regions of color: only 6-12 bins

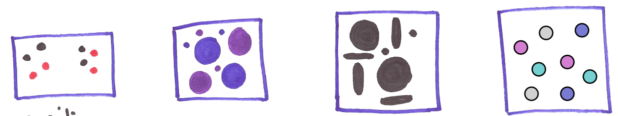


Cinteny: flexible analysis and visualization of synteny and genome rearrangements in multiple organisms. Sinha and Meller. Bioinformatics 2007

Separability vs. integrality



Separability vs. integrality

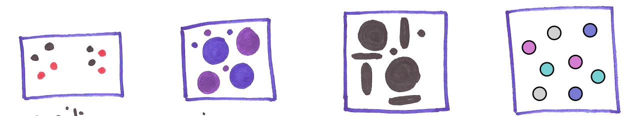


position
hue (color)

fully separable

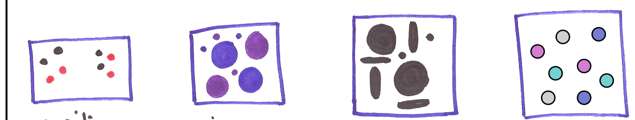
2 groups each

Separability vs. integrality



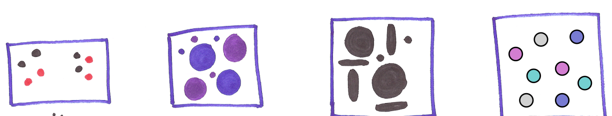
position hue (color)	size hue (color)
fully separable	some interference
	difficult to discriminate small items
2 groups each	(2 groups each)

Separability vs. integrality



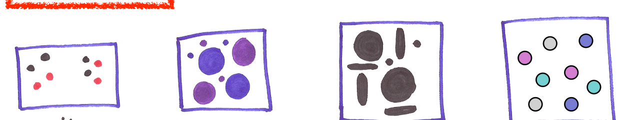
position hue (color)	size hue (color)	size: width size: height
fully separable	some interference	some/significant interference
	difficult to discriminate small items	integral percept: area (planar size)
2 groups each	(2 groups each)	3 groups

Separability vs. integrality



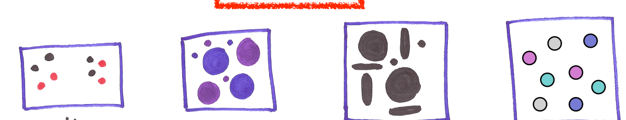
position hue (color)	size hue (color)	size: width size: height	red green
fully separable	some interference	some/significant interference	major interference
	difficult to discriminate small items	integral percept: area (planar size)	integral percept: color/hue
2 groups each	(2 groups each)	3 groups	4 groups

Separability vs. integrality



position hue (color)	size hue (color)	size: width size: height	red green
fully separable	some interference	some/significant interference	major interference
	difficult to discriminate small items	integral percept: area (planar size)	integral percept: color/hue
2 groups each	(2 groups each)	3 groups	4 groups

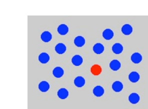
Separability vs. integrality

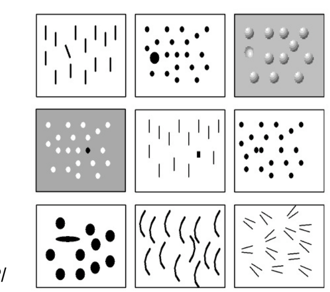


position hue (color)	size hue (color)	size: width size: height	red green
fully separable	some interference	some/significant interference	major interference
	difficult to discriminate small items	integral percept: area (planar size)	integral percept: color/hue
2 groups each	(2 groups each)	3 groups	4 groups

Popout: Most channels

- parallel processing on most channels
  - sufficiently different item noticed immediately, independent of distractor count
- some channels have no popout: serial search required

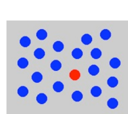


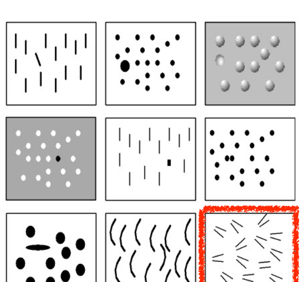


Healey. Perception in Visualization
http://www.csc.ncsu.edu/faculty/healey/PP/

Popout: Most channels

- parallel processing on most channels
  - sufficiently different item noticed immediately, independent of distractor count
- some channels have no popout: serial search required

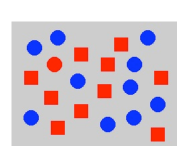




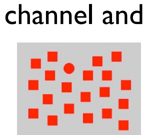
Healey. Perception in Visualization
http://www.csc.ncsu.edu/faculty/healey/PP/

Popout limits

- only one channel at a time
  - combination searches are serial
    - most channel pairs
    - all channel triplets, etc



- within channel, speed depends on which channel and how different item is from surroundings
  - 'sufficiently different': context dependent

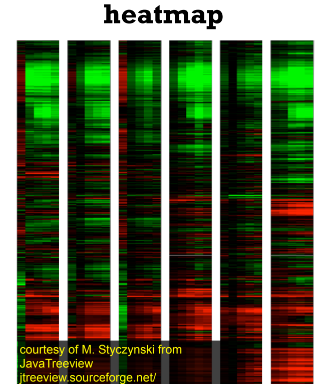


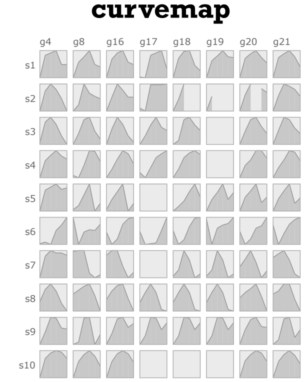
Healey. Perception in Visualization
http://www.csc.ncsu.edu/faculty/healey/PP/

Encoding example: Heatmaps vs. curvemaps

- color traditional, but spatial position outranks it

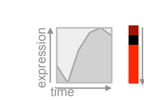
heatmap **curvemap**





Curvemap

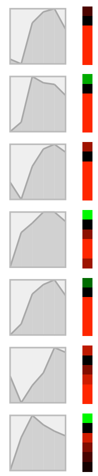
- shape perception easier for filled framed line charts than colored boxes



Pathline: A Tool for Comparative Functional Genomics. Meyer, Wong, Styczynski, Munzner, Pfister. EuroVis 2010.

Curvemap

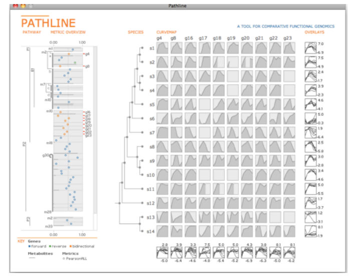
- shape perception easier for filled framed line charts than colored boxes

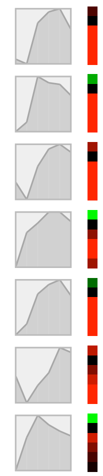


Pathline: A Tool for Comparative Functional Genomics. Meyer, Wong, Styczynski, Munzner, Pfister. EuroVis 2010.

Curvemap

- shape perception easier for filled framed line charts than colored boxes

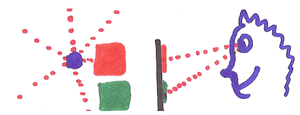




Pathline: A Tool for Comparative Functional Genomics. Meyer, Wong, Styczynski, Munzner, Pfister. EuroVis 2010.

Dangers of depth

- rankings for **planar** spatial position, not depth!
- we don't really live in 3D: we **see** in 2.05D
  - up/down and sideways: image plane
    - acquire more info quickly from eye movements
  - away: depth into scene
    - only acquire more info from head/body motion

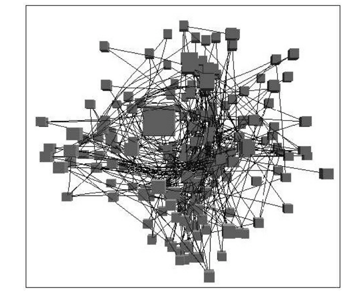


- further reading

Visual Thinking for Design (Chap 5). Colin Ware. 2008

Dangers of depth: difficulties of 3D

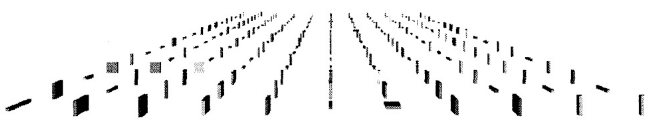
- occlusion
- interaction complexity



Distortion Viewing Techniques for 3D Data. Carpendale et al. InfoVis1996.

Dangers of depth: difficulties of 3D

- perspective distortion
  - interferes with all size channel encodings
  - power of the plane is lost!

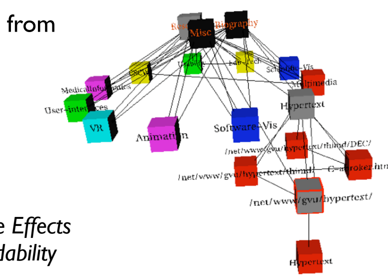


Visualizing the Results of Multimedia Web Search Engines. Mukherjea, Hirata, and Hara. InfoVis 96

Dangers of depth: difficulties of 3D

- text legibility
  - far worse when tilted from image plane
- further reading

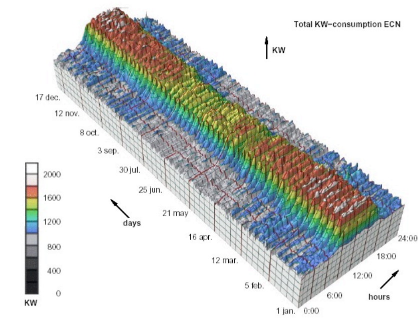
Exploring and Reducing the Effects of Orientation on Text Readability in Volumetric Displays. Grossman et al. CHI 2007



Visualizing the World-Wide Web with the Navigational View Builder. Mukherjea and Foley. Computer Networks and ISDN Systems, 1995.

Dangers of depth example

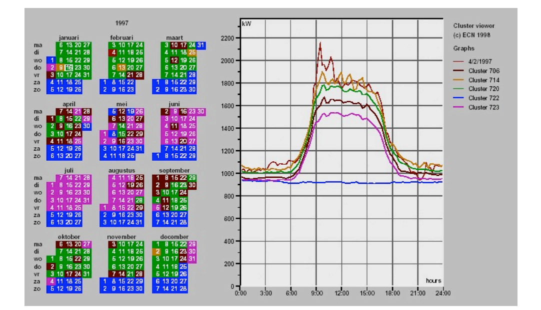
- extruded curves: detailed comparisons impossible



Cluster and Calendar based Visualization of Time Series Data. van Wijk and van Selow, Proc InfoVis 99.

Transformation to suitable abstraction

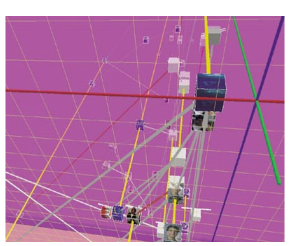
- derived data: clusters
- multiple views: calendar, superimposed 2D curves



Cluster and Calendar based Visualization of Time Series Data. van Wijk and van Selow, Proc InfoVis 99.

Dangers of depth: must justify

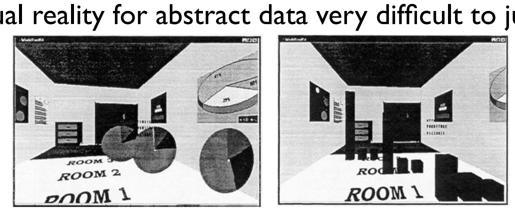
- 3D legitimate for true 3D spatial data
- 3D needs very careful justification for abstract data
  - enthusiasm in 1990s, but now skepticism
  - be especially careful with 3D for point clouds or networks



WEBPATH-a three dimensional Web history. Frecon and Smith. InfoVis 1999

Resolution beats immersion

- immersion typically not helpful for abstract data
  - do not need sense of presence or stereoscopic 3D
- resolution much more important
  - pixels are the scarcest resource
  - desktop also better for workflow integration
- virtual reality for abstract data very difficult to justify



Development of an information visualization tool using virtual reality. Kirner and Martins. Symp Applied Computing 2000

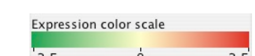
Eyes beat memory

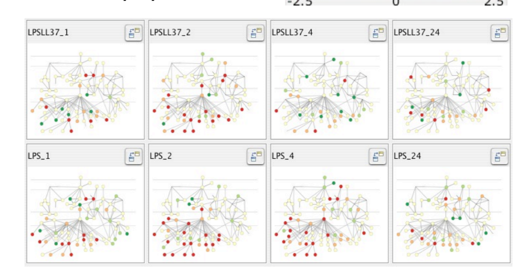
- principle: external cognition vs. internal memory
  - easy to compare by moving eyes between side-by-side views
  - harder to compare visible item to memory of what you saw
- implications for animation
  - great for choreographed storytelling
  - great for transitions between two states
  - poor for many states with changes everywhere
    - consider small multiples instead

literal	abstract
animation	small multiples
show time with time	show time with space

Small multiples example: Cerebral

- small multiples: one graph instance per experimental condition
  - same spatial layout
  - color differently, by condition

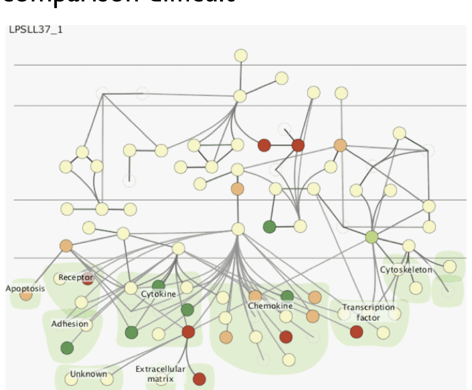




Cerebral: Visualizing Multiple Experimental Conditions on a Graph with Biological Context. Barsky, Munzner, Gardy, Kincaid. IEEE InfoVis 2008.

Why not animation?

- global comparison difficult



Why not animation?

- further reading

Animation: can it facilitate? Tversky et al. Intl Journ Human-Computer Studies, 57(4):247-262, 2002.

Beyond encoding and interaction

- three more levels of design questions
  - different threats to validity at each level
- validate against the right threat

problem: you misunderstood their needs

abstraction: you're showing them the wrong thing

encoding: the way you show it doesn't work

algorithm: your code is too slow

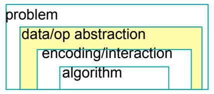
A Nested Model for Visualization Design and Validation. Munzner. IEEE InfoVis 2009.

Characterizing problems of real-world users

problem
data/op abstraction
encoding/interaction
algorithm

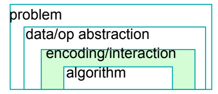
- identify a problem amenable to vis
  - provide novel capabilities
  - speed up existing workflow
- validation
  - immediate: interview and observe target users
  - downstream: notice adoption rates

Abstracting into operations on data types



- abstract from domain-specific to generic
- operations
  – sorting, filtering, browsing, comparing, finding trend/outlier, characterizing distributions, finding correlation...
- data types
  – tables of numbers, relational networks, spatial
  – transform into useful configuration: derived data
- validation
  –deploy in the field and observe usage

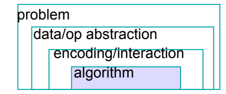
Designing visual encoding, interaction techniques



- visual encoding: drawings they are shown
- interaction: how they manipulate drawings
- validation
  –immediate: careful justification wrt known principles
  –downstream: qualitative or quantitative analysis of results
  –downstream: lab study measuring time/error on given task

- focus of this talk

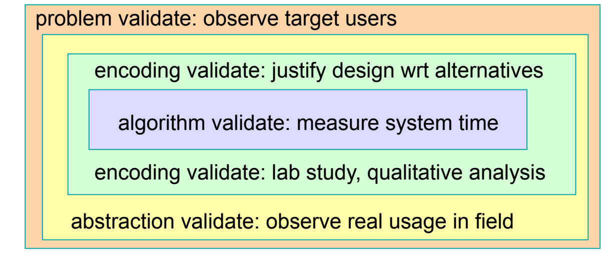
Creating algorithms to execute techniques



- automatically carry out specification
- validation
  –immediate: complexity analysis
  –downstream: benchmarks for system time, memory

Danger of validation mismatch

- cannot show encoding good with system timings
- cannot show abstraction good with lab study



Principles recap

- know your visual channel types and ranks
- categorical color constraints
- power of the plane
- danger of depth
- resolution beats immersion
- eyes beat memory

- validate against the right threat

More information

- vis intro book chapter
  –principles in more depth
  –also, techniques!

  http://www.cs.ubc.ca/~tmm/papers.html#akpchapter

- papers, videos, software, talks, courses
  http://www.cs.ubc.ca/~tmm

- this talk
  http://www.cs.ubc.ca/~tmm/talks.html#vizbi11