CS 519: Scientific Visualization

What is Information Visualization?

Eric Shaffer

Some (many!) slides adapted from work by
Professor Tamara Munzner
University of British Columbia

A visualization is a visual representation of abstract **data** to aid **human cognition**

- Must be based on data
- The results must be readable, recognizable and useful

How many R's are there?

GLNSAGGKLDSANGNASDGN
KLANSDGLKNASDGNDFVMD
GJERKJVERJVJKENJLVNEKVJEN
VJEAJVJNDJVNAAJBVRKLVLJKD

How many R's are there?

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VJEAJVJNDJVNAAJBVRKLVLJKD

How Much Data Is There?

What Will We Do When The World's Data Hits 163 Zettabytes In 2025?

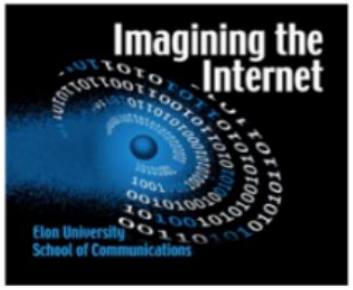
-Forbes.com

- A zettabyte is one trillion gigabytes
  - Zettabyte ~= 1, 000, 000, 000, 000, 000, 000, 000
  - 200x all words ever spoken by humans
- Current annual data creation rate is16.3ZB
- Most of that is not scientific data
  - It is not specifically associated with a physical domain

So…Maybe That Much Data is a Problem?

PewResearchCenter

Pew Internet
Pew Internet & American Life Project

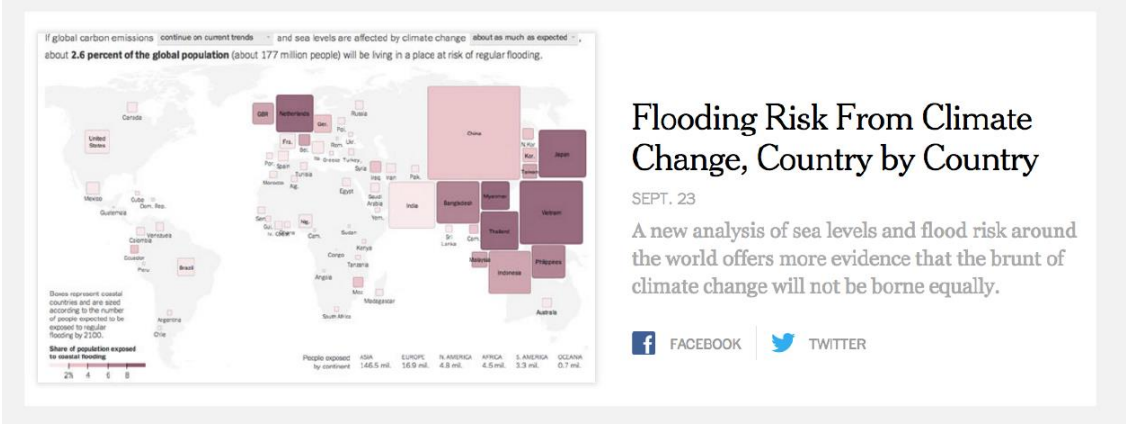


Big Data: Experts say new forms of information analysis will help people be more nimble and adaptive, but worry over humans' capacity to understand and use these new tools well

- Visualization is a proven technique to aid human comprehension of complex data
- It can aid in many analytical activities
  - Filtering, determining provenance, identifying critical events..,etc.

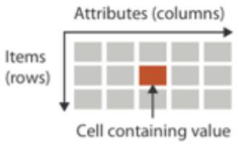
Benefits of Visualization

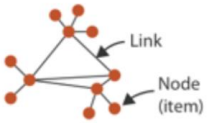
- Adapt data to a form better processed by people
  - Maximize the use of limited perception and cognition
- Ultimate goals
  - Explore the data
    - Find patterns
    - Fit a function
  - Tell a story
    - Convince others
    - Spread information



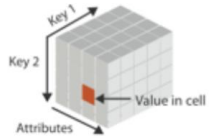
Dataset Types

Tables	Networks & Trees	Geometry	Clusters, Sets, Lists
Items	Items (nodes)	Items	Items
Attributes	Links	Positions	
	Attributes		





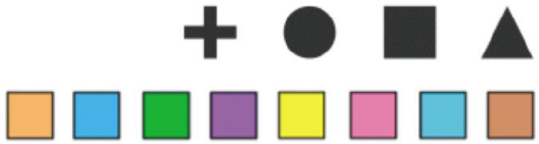
→ *Multidimensional Table*



→ *Trees*

Attribute Types

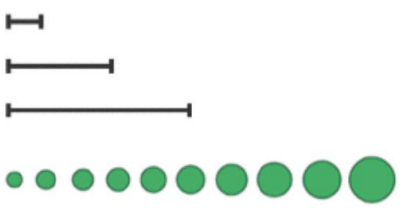
➔ Categorical
no implicit ordering



➔ Ordered

➔ *Ordinal*

➔ *Quantitative*
meaningful magnitude,
can do arithmetic

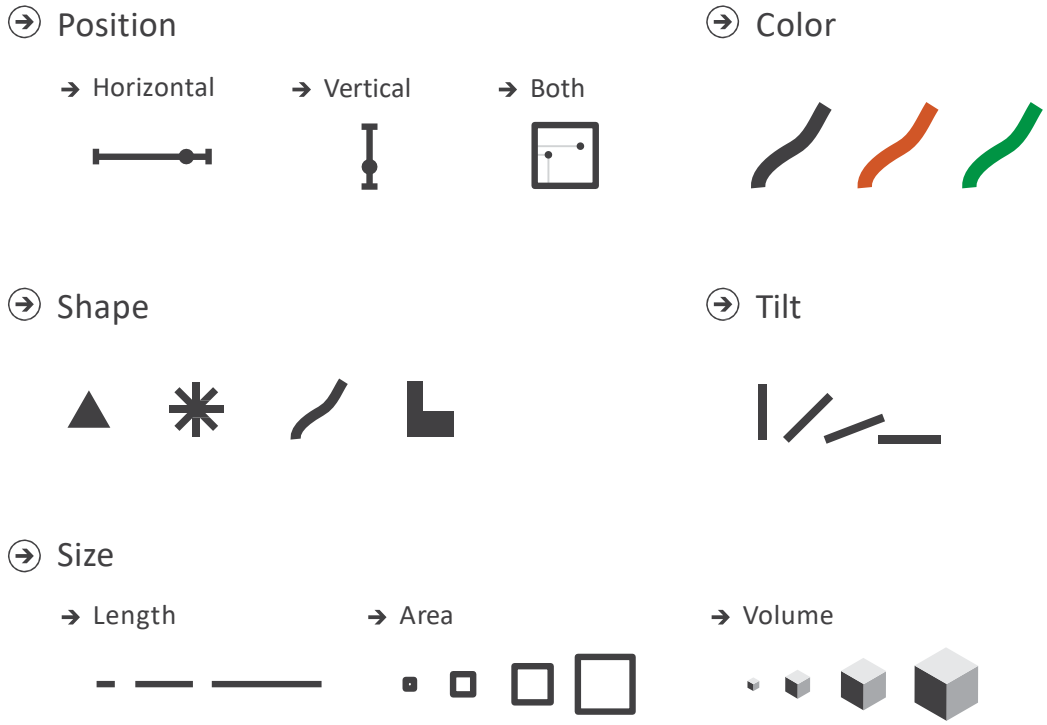


- Categorical also referred to as "nominal"
- What operations are possible for each type?

Definitions: Marks and Channels

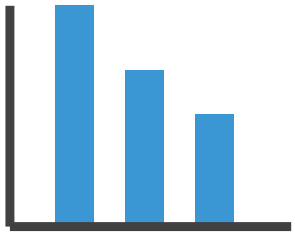
- marks
  - geometric primitives

- channels
  - control appearance of marks



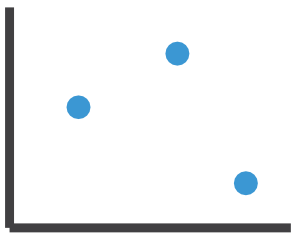
Encoding visually with marks and channels

- analyze idiom structure
  - as combination of marks and channels



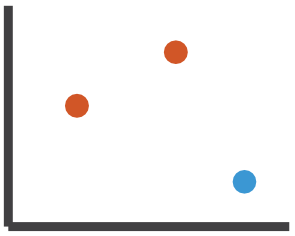
1:
vertical position

mark: line



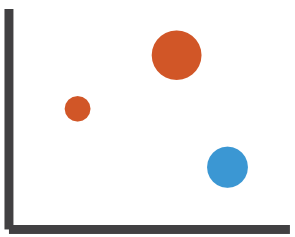
2:
vertical position
horizontal position

mark: point



3:
vertical position
horizontal position
color hue

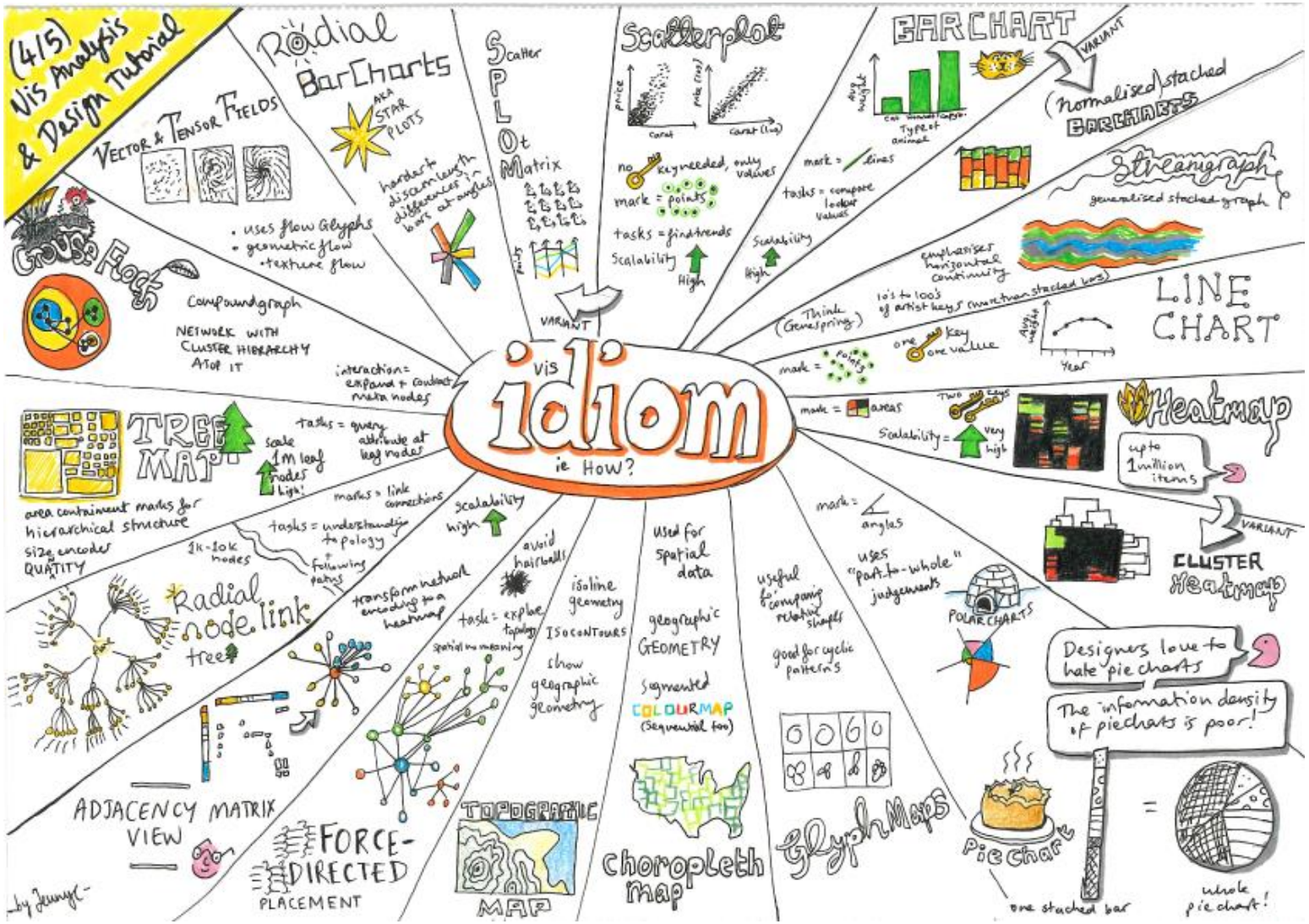
mark: point



4:
vertical position
horizontal position
color hue
size (area)

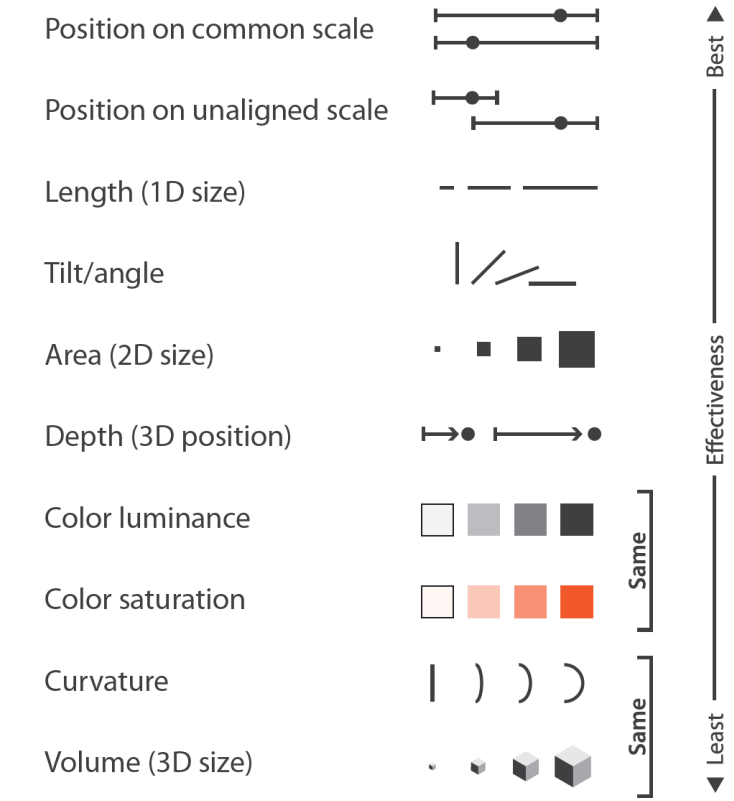
mark: point

What is an Idiom?

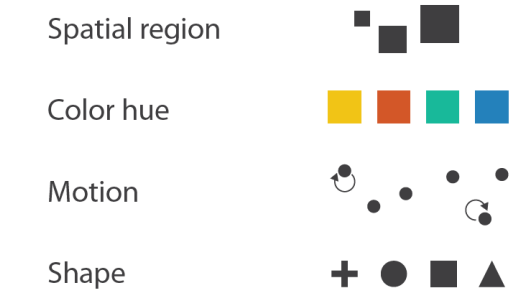


Channels: Rankings

Magnitude Channels: Ordered Attributes

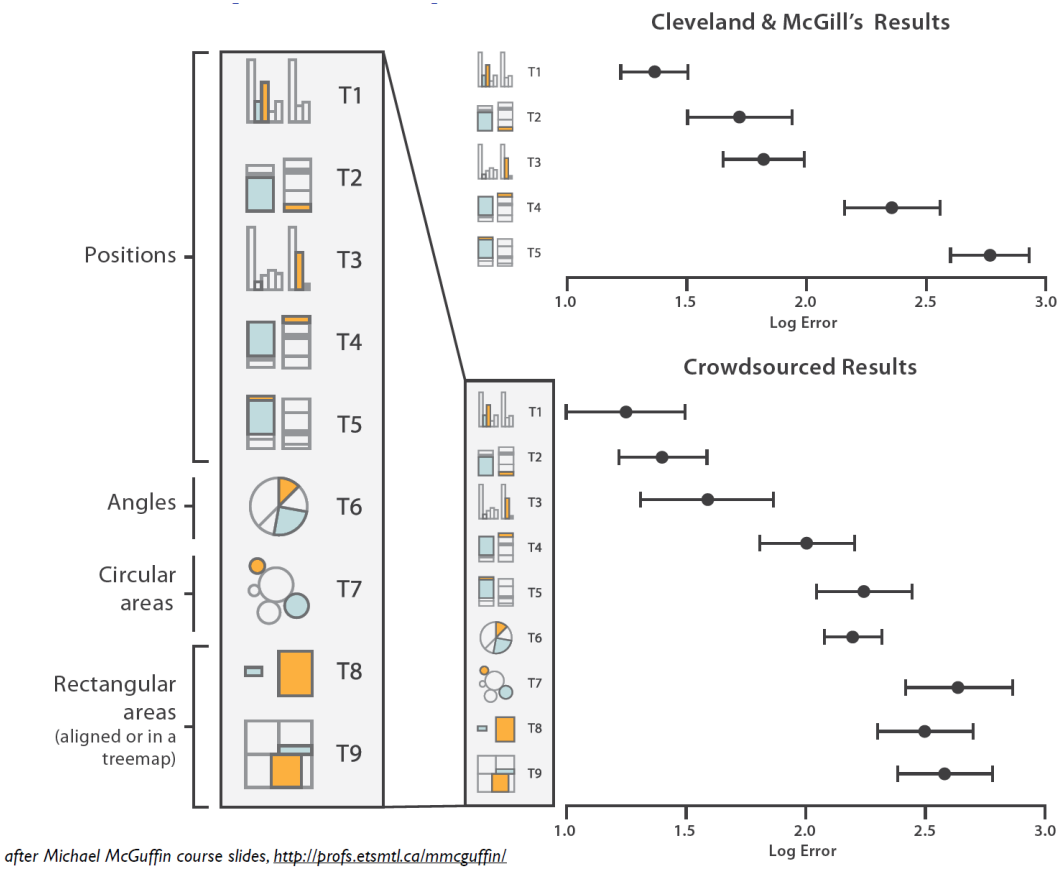


Identity Channels: Categorical Attributes



- effectiveness principle
  - encode most important attributes with highest ranked channels
- expressiveness principle
  - match channel and data characteristics

Accuracy: Visualization Experiments

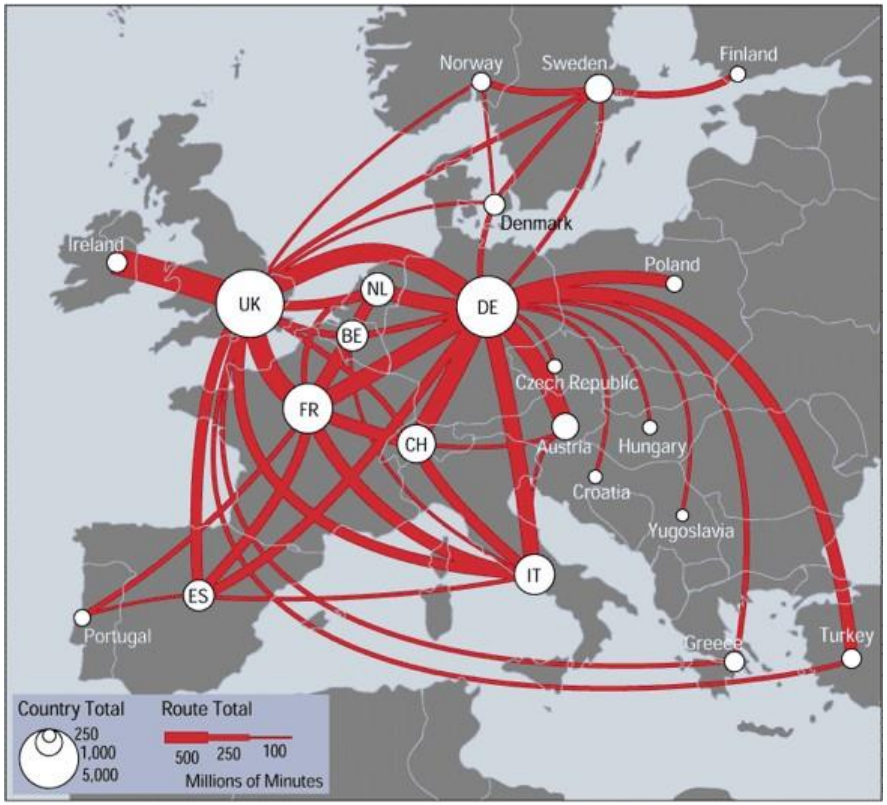


after Michael McGuffin course slides, http://profs.etsmtl.ca/mmcguffin/

[Crowdsourcing Graphical Perception: Using Mechanical Turk to Assess Visualization Design. Heer and Bostock. Proc ACM Conf. Human Factors in Computing Systems (CHI) 2010, p. 203–212.]

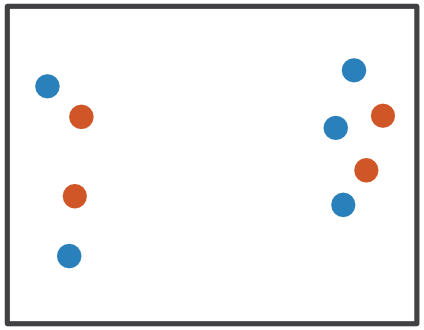
Discriminability: How many usable steps?

- must be sufficient for number of attribute levels to show
  - linewidth: few bins



Separability vs. Integrality

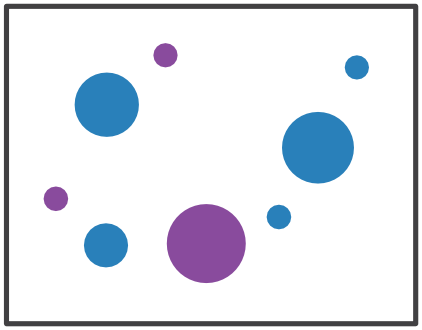
Position
✚ Hue (Color)



Fully separable

2 groups each

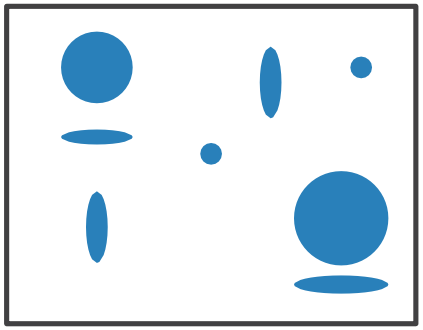
Size
✚ Hue (Color)



Some interference

2 groups each

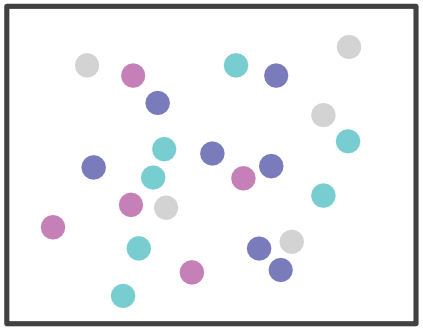
Width
✚ Height



Some/significant interference

3 groups total: integral area

Red
✚ Green

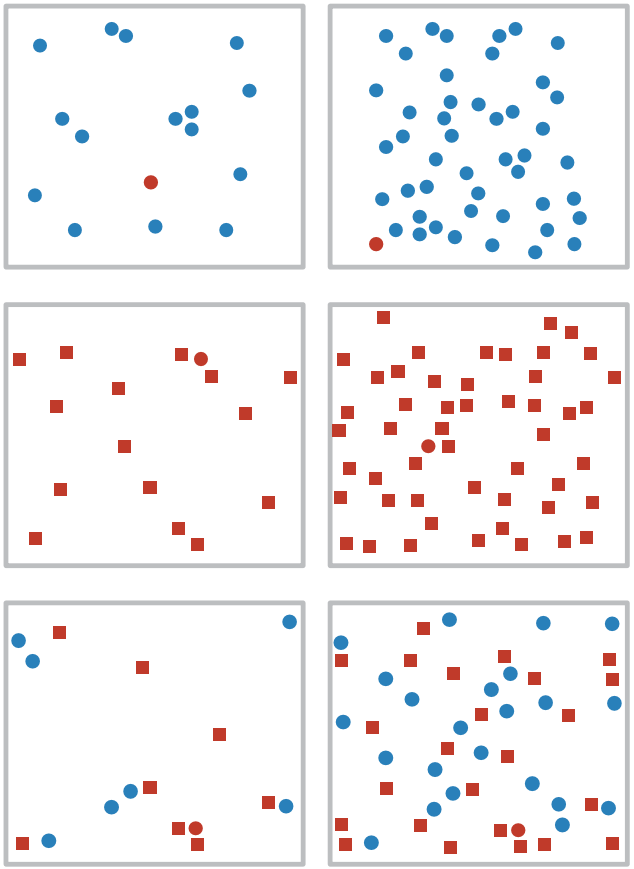


Major interference

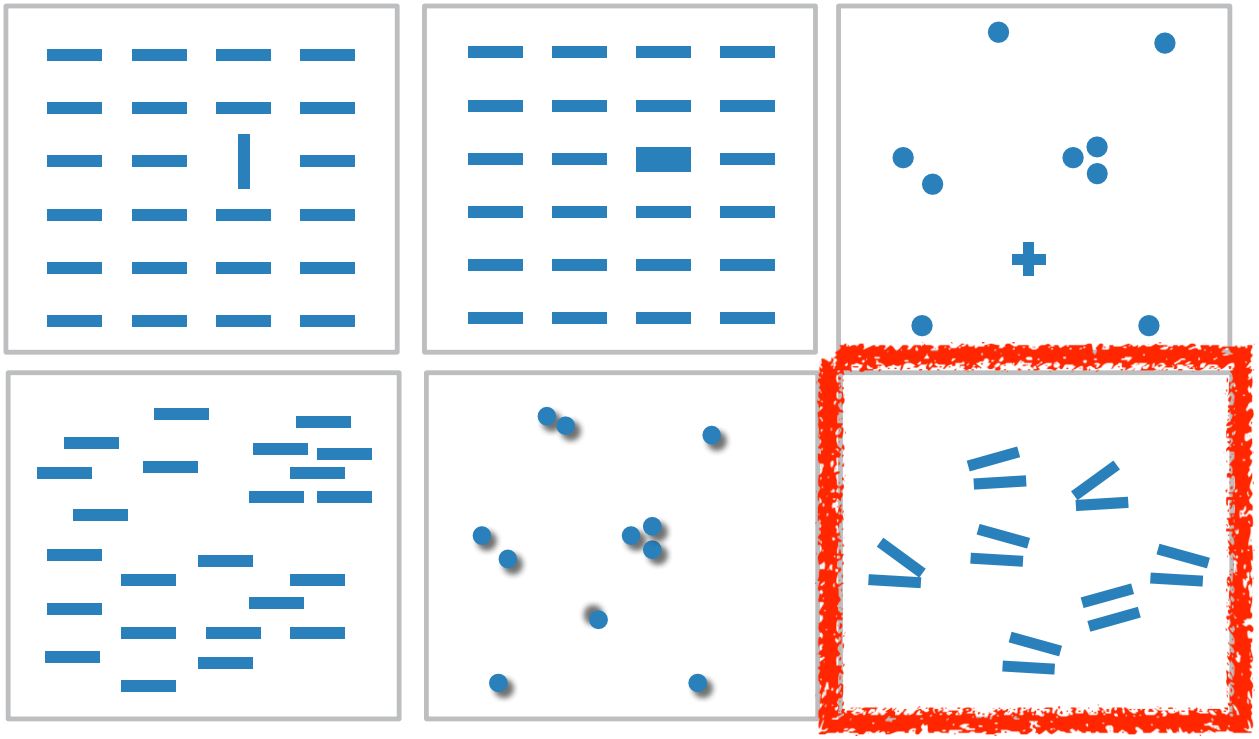
4 groups total: integral hue

Popout

- find the red dot
  - how long does it take?
- parallel processing on many individual channels
  - speed independent of distractor count
  - speed depends on channel and amount of difference from distractors
- serial search for (almost all) combinations
  - speed depends on number of distractors



Popout



- many channels: tilt, size, shape, proximity, shadow direction, ...
- but not all! parallel line pairs do not pop out from tilted pairs

Grouping

- containment
- connection

Marks as Links

Containment

Connection

- proximity
  - same spatial region
- similarity
  - same values as other categorical channels

Identity Channels: Categorical Attributes

Spatial region

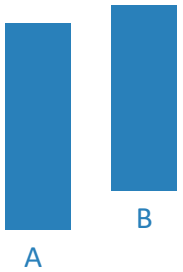
Color hue

Motion

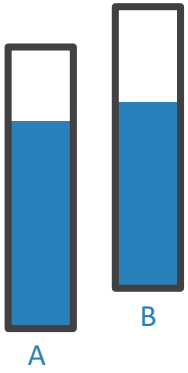
Shape

Relative vs. Absolute Judgements

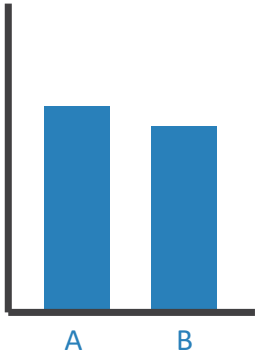
- perceptual system mostly operates with relative judgements, not absolute
  - that's why accuracy increases with common frame/scale and alignment
  - Weber's Law: ratio of increment to background is constant
    - filled rectangles differ in length by 1:9, difficult judgement
    - white rectangles differ in length by 1:2, easy judgement



length



position along unaligned common scale

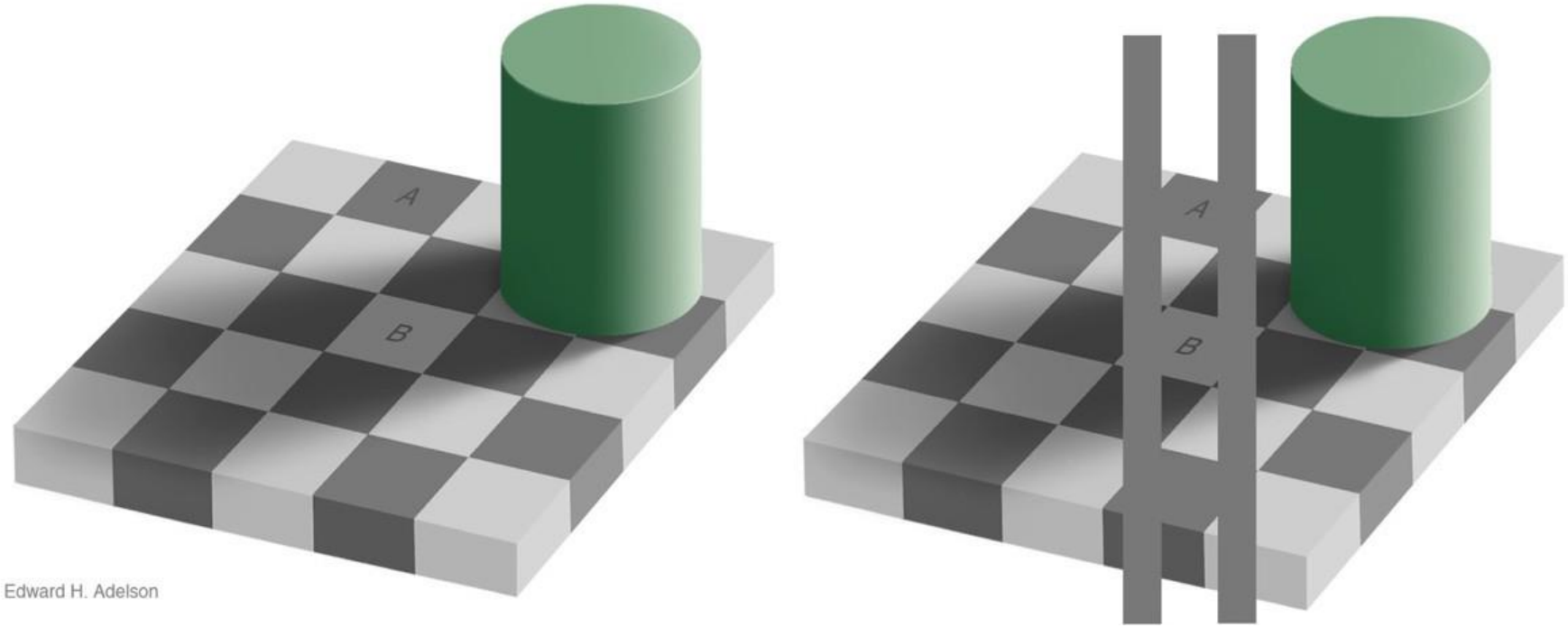


position along aligned scale

after [Graphical Perception: Theory, Experimentation, and Application to the Development of Graphical Methods. Cleveland and McGill. Journ. American Statistical Association 79:387 (1984), 531–554.]

Relative vs. Absolute Judgements

- perception of luminance is contextual based on contrast with surroundings



http://persci.mit.edu/gallery/checkershadow

Principles Based on Practice

- No unjustified 3D
  - Power of the plane, dangers of depth
  - Occlusion hides information
  - Perspective distortion loses information
  - Tilted text isn't legible
- No unjustified 2D
- Eyes beat memory
- Resolution over immersion
- Overview first, zoom and filter, details on demand
- Function first, form next

- (Get it right in black and white)

No Unjustified 3D

- high-ranked spatial position channels: **planar** spatial position
  - not depth!

➔ **Magnitude Channels: Ordered Attributes**

Position on common scale

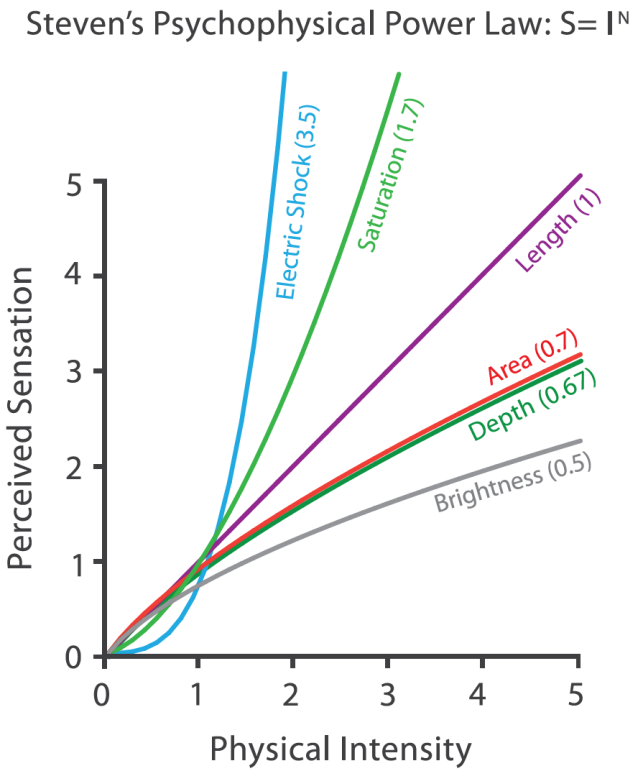
Position on unaligned scale

Length (1D size)

Tilt/angle

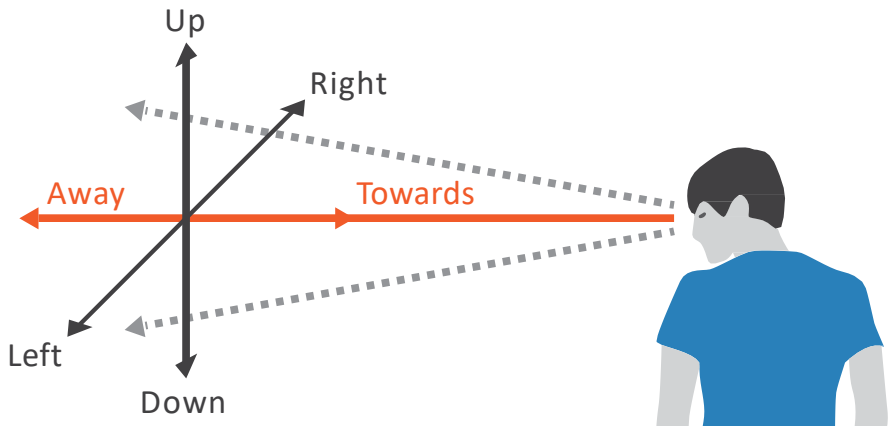
Area (2D size)

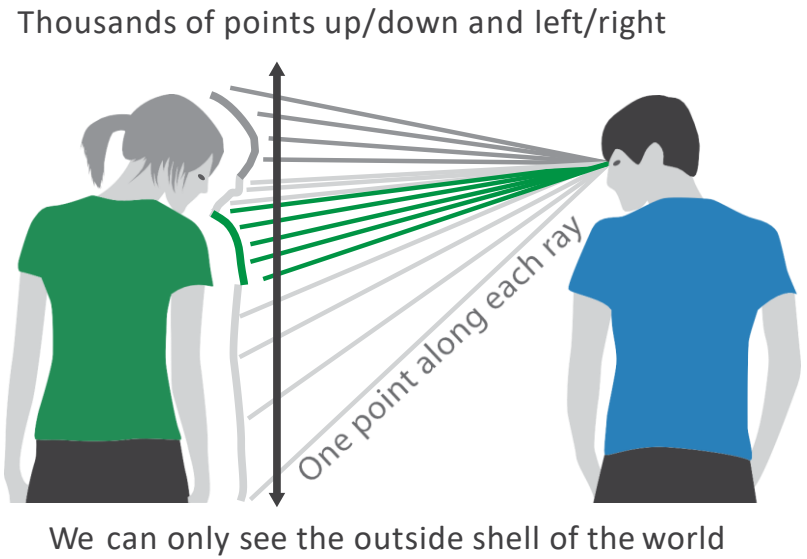
Depth (3D position)



Danger of Depth

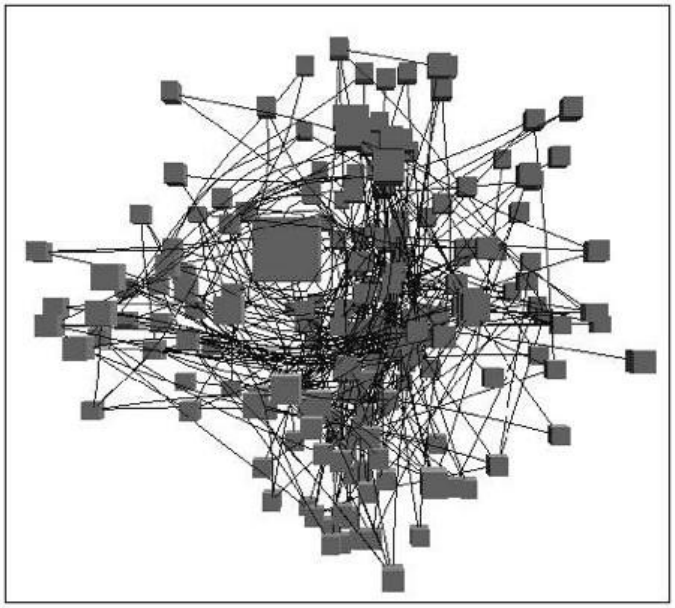
- we don't really live in 3D: we ***see*** in 2.05D
  - acquire more info on image plane quickly from eye movements
  - acquire more info for depth slower, from head/body motion





Occlusion Hides Information

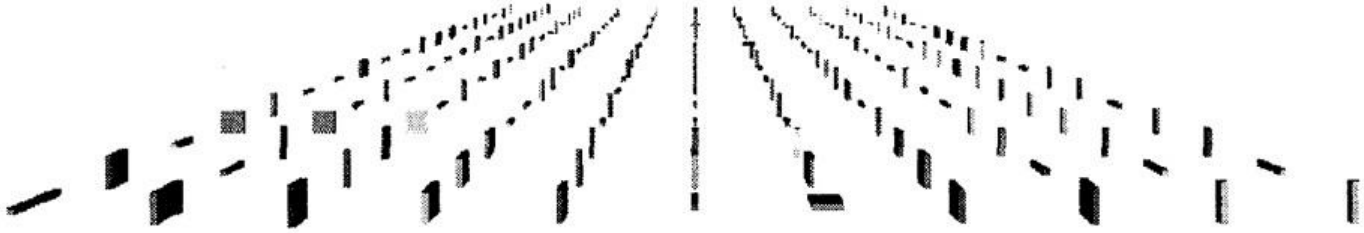
- occlusion
- interaction complexity



[DistortionViewingTechniques for 3D Data. Carpendale et al. InfoVis 1996.]

Perspective Projection Loses Information

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

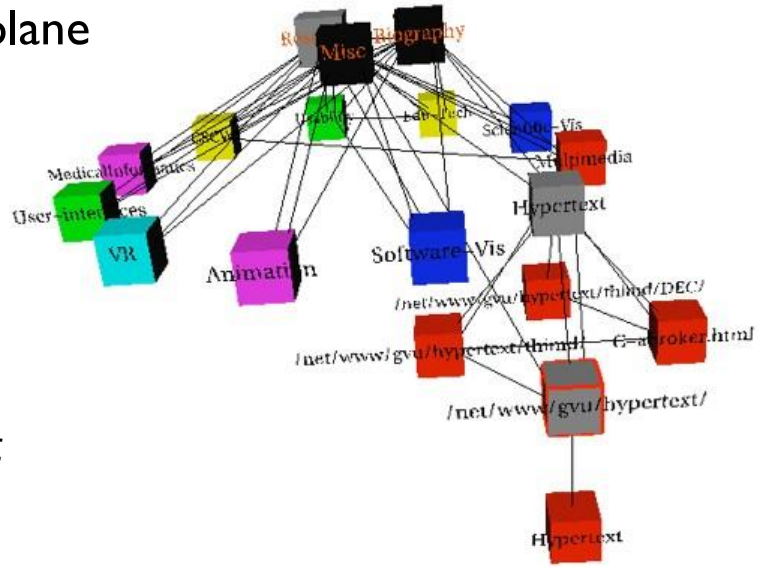


[Visualizing the Results of Multimedia Web Search Engines. Mukherjea, Hirata, and Hara. InfoVis 96]

Tilted Text Is Not Legible

- 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.]

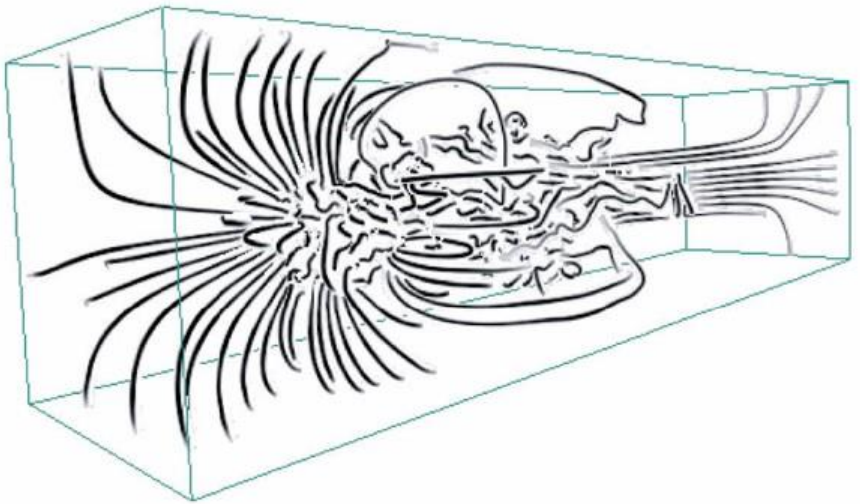
Justified 3D: Shape Perception

- benefits outweigh costs when task is shape perception for 3D spatial data
  - interactive navigation supports synthesis across many viewpoints

Targets

Spatial Data

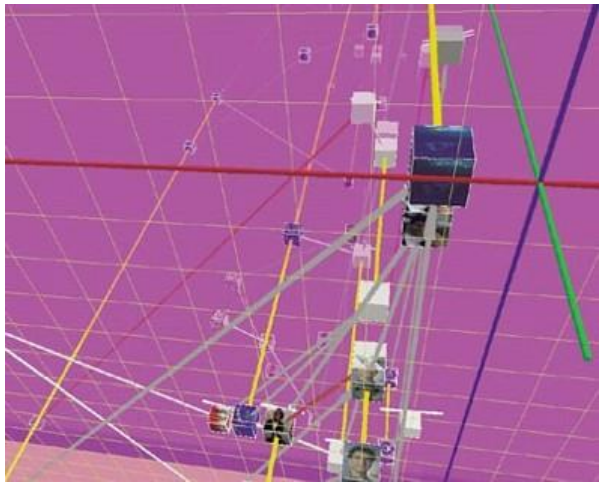
→ Shape



[Image-Based Streamline Generation and Rendering. Li and Shen. IEEE Trans. Visualization and Computer Graphics (TVCG) 13:3 (2007), 630–640.]

No Unjustified 3D

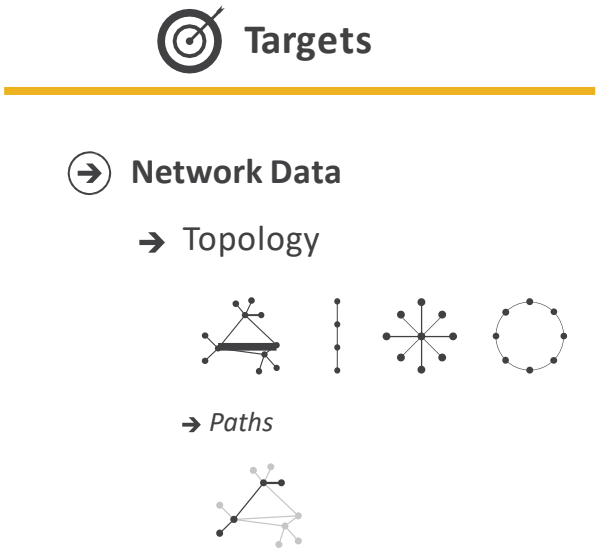
- 3D legitimate for true 3D spatial data
- 3D needs very careful justification for abstract data
  - enthusiasm in 1990s, but now skepticism
  - be especially careful with 3D for point clouds or networks



[WEBPATH-a three dimensionalWeb history. Frecon and Smith. Proc. InfoVis 1999]

No Unjustified 2D

- consider whether network data requires 2D spatial layout
  - especially if reading text is central to task!
  - arranging as network means lower information density and harder label lookup compared to text lists
- benefits outweigh costs when topological structure/context important for task
  - be especially careful for search results, document collections, ontologies

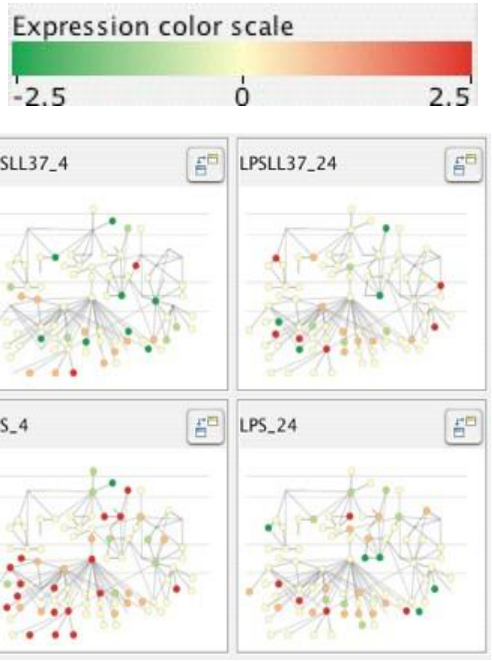


Eyes Beat Memory

- 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

Eyes Beat Memory Example

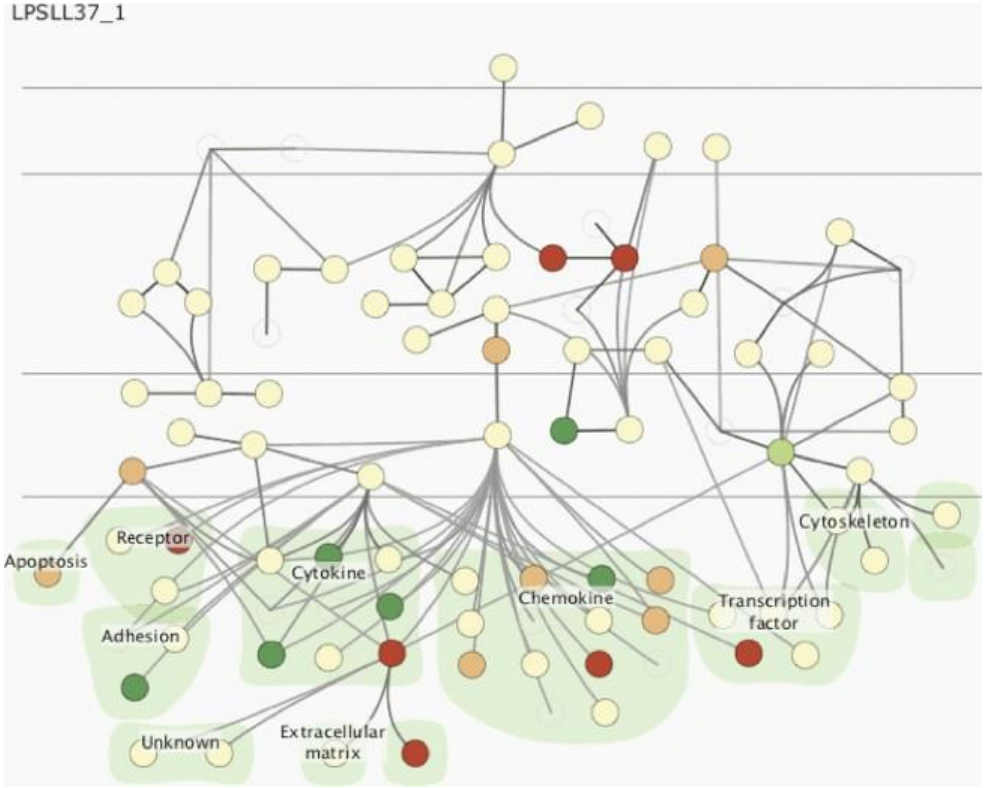
- small multiples: one graph instance per experimental condition
  - same spatial layout
  - color differently, by condition



[Cerebral: Visualizing Multiple Experimental Conditions on a Graph with Biological Context. Barsky, Munzner, Gardy, and Kincaid. IEEE Trans. Visualization and Computer Graphics (Proc. InfoVis 2008) 14:6 (2008), 1253–1260.]

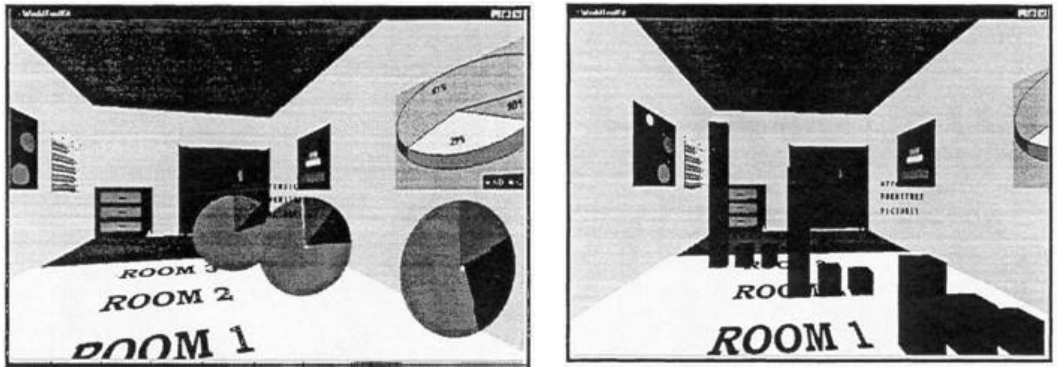
Why Not Animation

- disparate frames and regions: comparison difficult
  - vs contiguous frames
  - vs small region
  - vs coherent motion of group
- change blindness
  - even major changes difficult to notice if mental buffer wiped
- safe special case
  - animated transitions



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



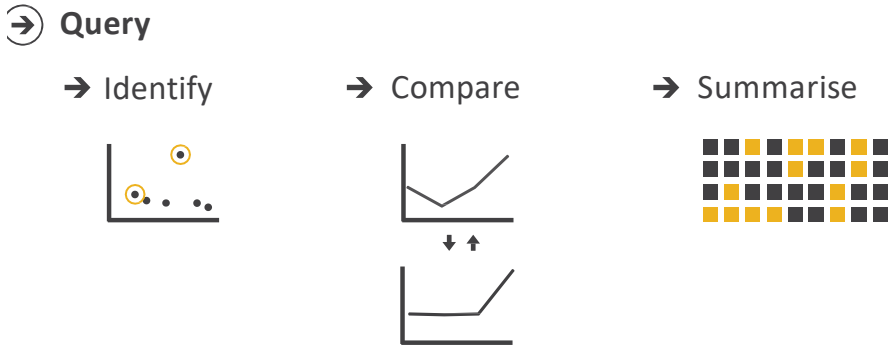
[Development of an information visualization tool using virtual reality. Kirner and Martins. Proc. Symp Applied Computing 2000]

Overview First, Zoom and Filter, Details on Demand

- influential mantra from Shneiderman

[The Eyes Have It: A Task by Data Type Taxonomy for Information Visualizations. Shneiderman. Proc. IEEE Visual Languages, pp. 336–343, 1996.]

- overview = summary
  - microcosm of full vis design problem



- nuances
  - beyond just two levels: multi-scale structure
  - difficult when scale huge: give up on overview and browse local neighborhoods?

[Search, Show Context, Expand on Demand: Supporting Large Graph Exploration with Degree-of-Interest. van Ham and Perer. IEEE Trans. Visualization and Computer Graphics (Proc. InfoVis 2009) 15:6 (2009), 953–960.]

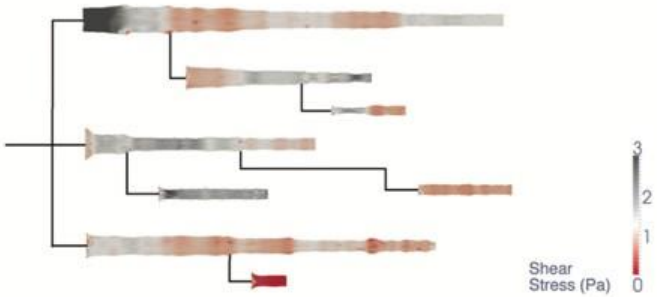
Function First, Form Next

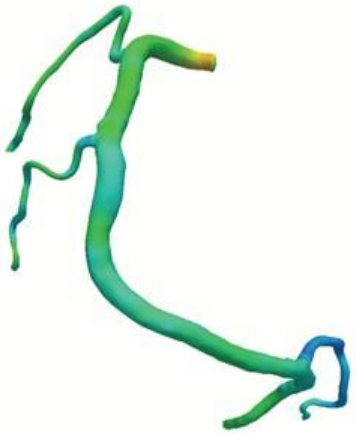
- start with focus on functionality
  - straightforward to improve aesthetics later on, as refinement
  - if no expertise in-house, find good graphic designer to work with

- dangerous to start with aesthetics
  - usually impossible to add function retroactively

HemoViz Design Study

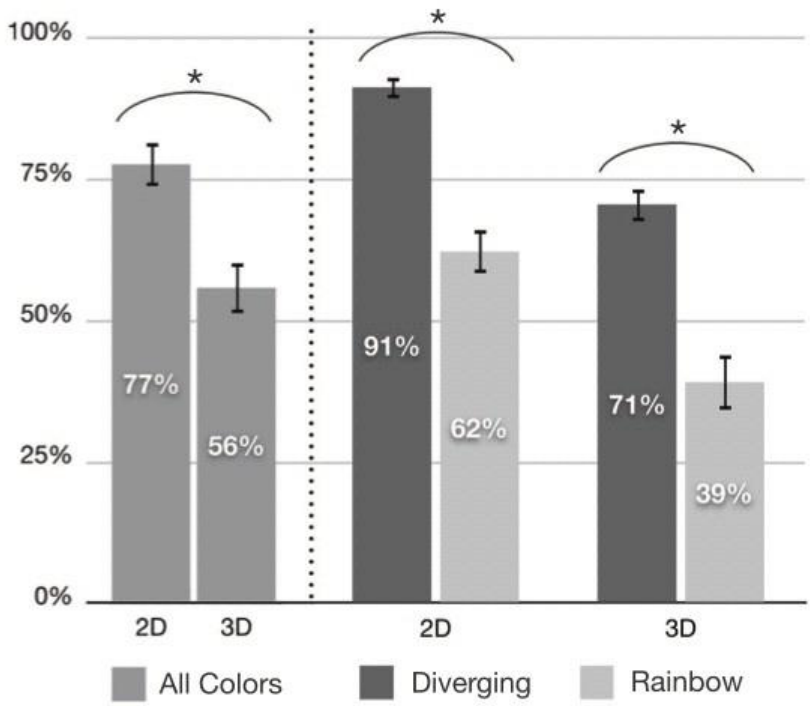
- formative study with experts
  - –task taxonomy
- HemoViz design
- deploy attempt fails
  - –experts balk: demand 3D and rainbows
- quantitative user study
  - –med students, real data
  - – 91% with 2D/divergingvs 39% with 3D/rainbows
  - –experts willing to use

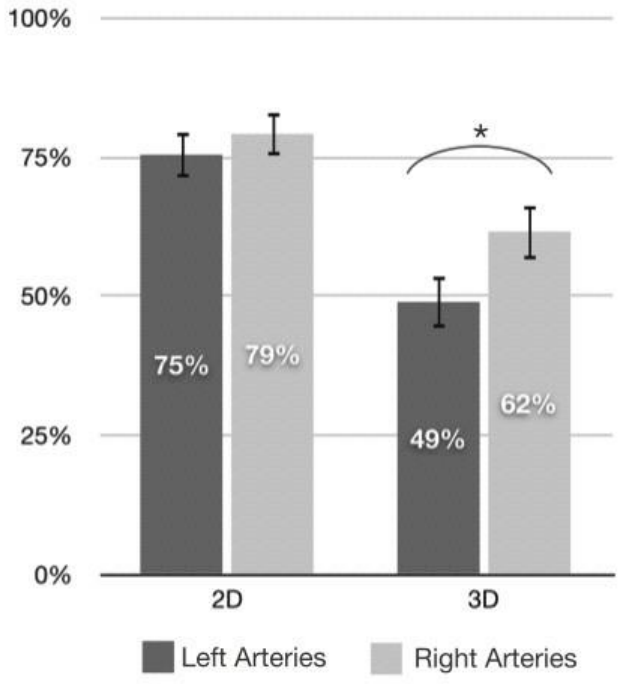




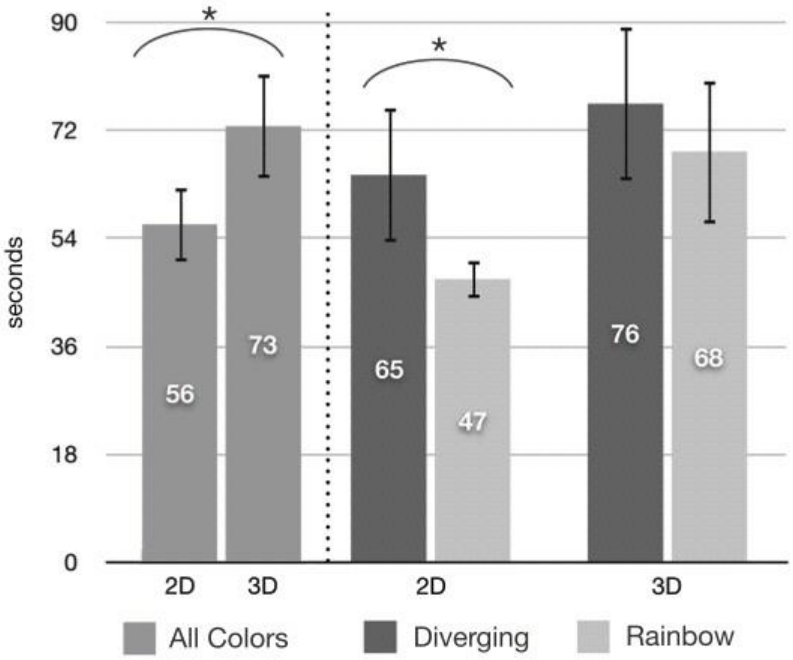
[Fig 1. Borkin et al. Artery Visualizations for Heart Disease Diagnosis. Proc InfoVis 2011.]]

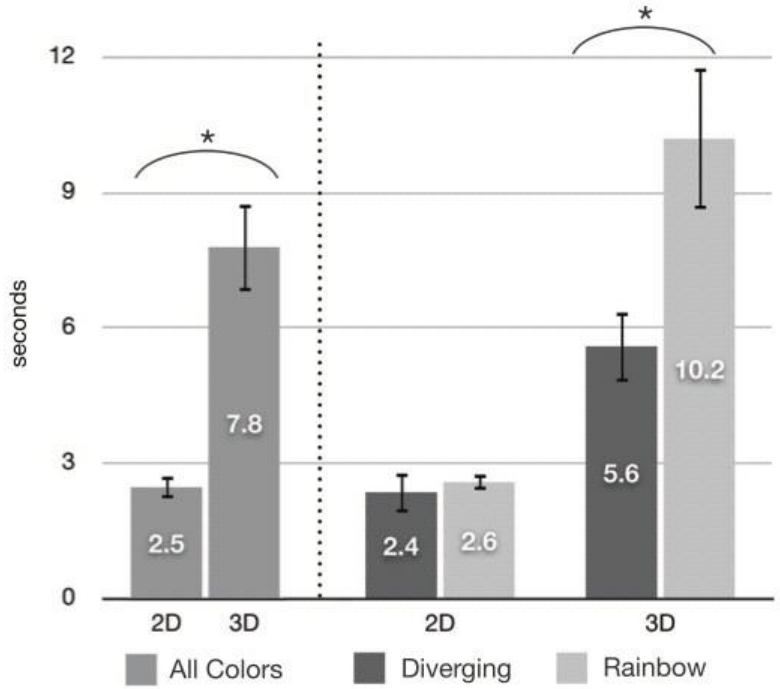
Study Results: Error





Study Results: Time





Critique

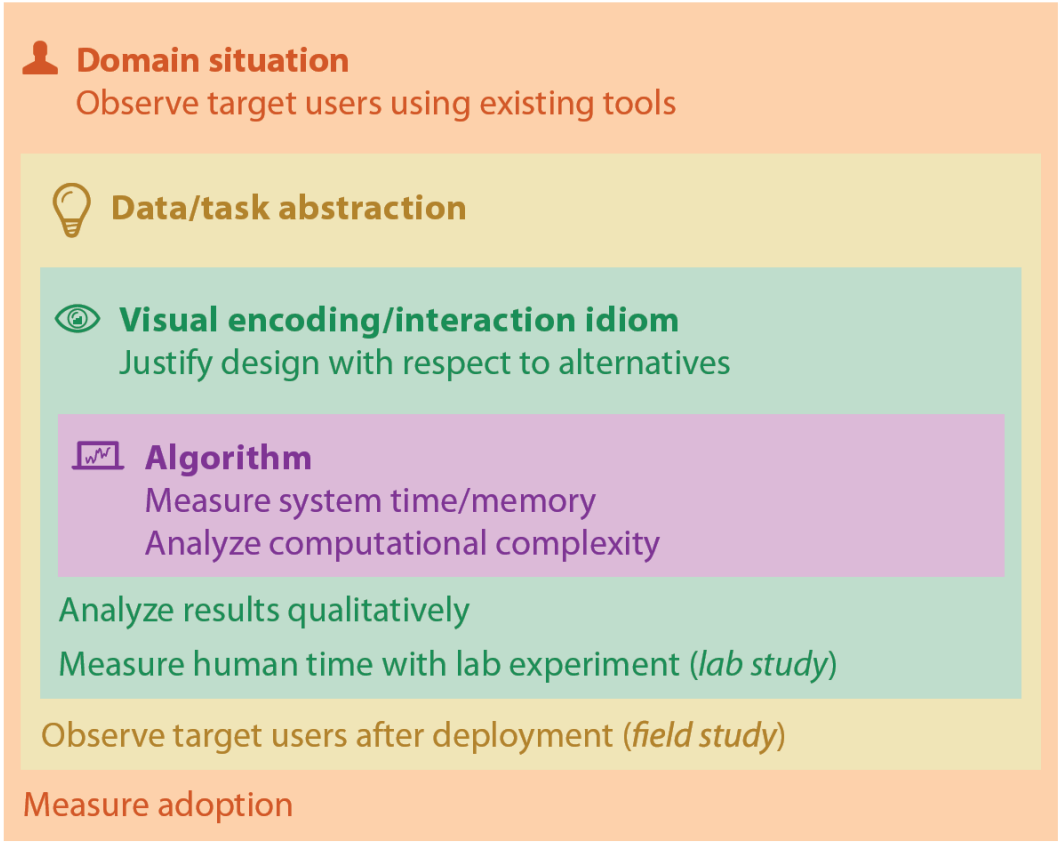
- many strengths
  - careful and well justified design, convincing human-subjects experiment
    - bringing visualization best practices to medical domain
- limitation
  - paper does not clearly communicate why colormap is diverging not sequential
    - answer by email
    - doctors care about extremely high and extremely low ESS (scalar) values
      - high values (top of scale, dark grey): extreme blood flow patterns may relate to heart malfunctions - but not imminently life threatening and don't indicate plaque locations
      - low values (bottom of scale, dark red): very diseased regions with lots of plaque, docs care a lot!
      - much debate from doctors on where is boundary between "normal" and "low" ESS values
        - » most think below 3 Pa are indicative of disease but many argue other values in the 2-4 range.
        - » all docs agree that values below 2 Pa are increasingly dangerous disease levels.
        - » thus map has transition at 3 Pa for the diverging point and truly red below 2 Pa
    - why continuous not segmented?
      - doctors gain tremendous insight by seeing the subtle patterning of the ESS values
      - particularly varying values in red region - patterns help them understand disease progression and severity
        - » especially useful for deciding what types of interventions to prescribe for the patient

Is Your Visualization Effective?

Four levels of design problems

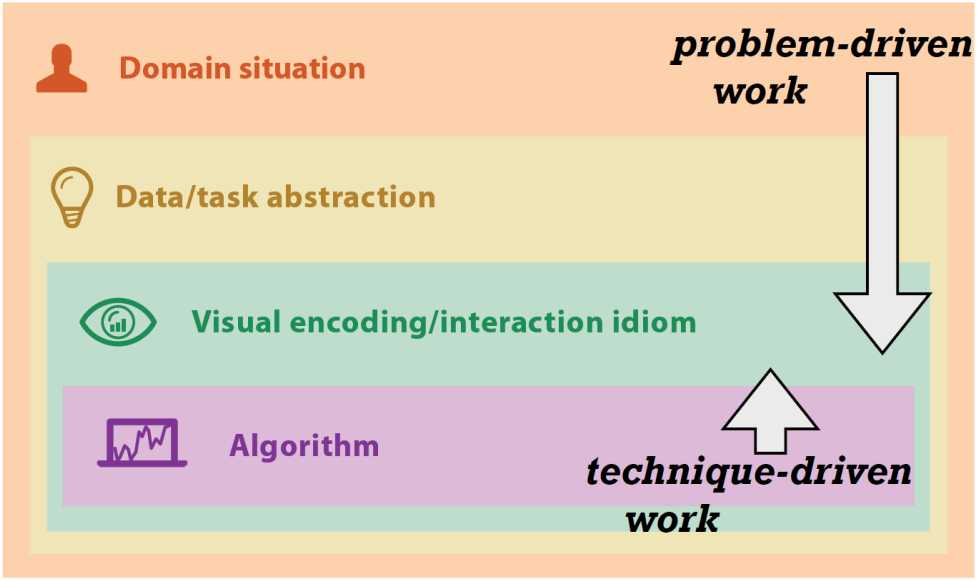
– different threats to validity at each level

Validation



mismatch: cannot show idiom good with system timings
mismatch: cannot show abstraction good with lab study

Visualization Research and Development



- In either case, visualization research benefits from a scientific approach
  - Scientific? Maybe "systematic" or "engineering" would be more apt
- Create a taxonomy of visual elements
  - Understand which elements are appropriate for a given problem