

CSC 544

Data Visualization

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Lecture 08

Visual Encoding

Feb. 8, 2023

Today's Agenda

- Reminders:
 - P01, A02 questions?
- Goals for today:
 - Discuss visual encoding

Types of Visual Encoding

Marks

- Basic graphical elements / primitives
- Classified according to number of spatial dimensions required

→ Points



(0-dimensional)

→ Lines



(1-dimensional)

→ Areas



(2-dimensional)

Channels

- Parameters that control the appearance of marks

④ Position

→ Horizontal



→ Vertical



→ Both



④ Color



④ Shape



④ Tilt



④ Size

→ Length



→ Area

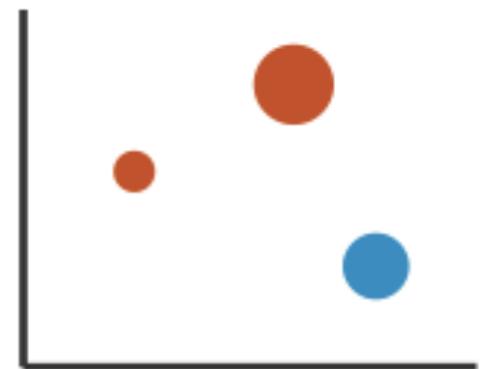
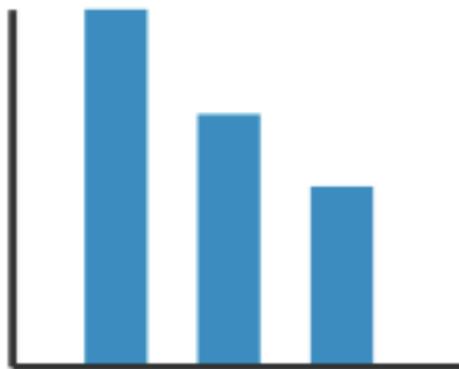


→ Volume



Visual Encoding

- Selection of a **combination of marks and channels** to show abstract data dimensions (try it out below)



What are the Marks and Channels?

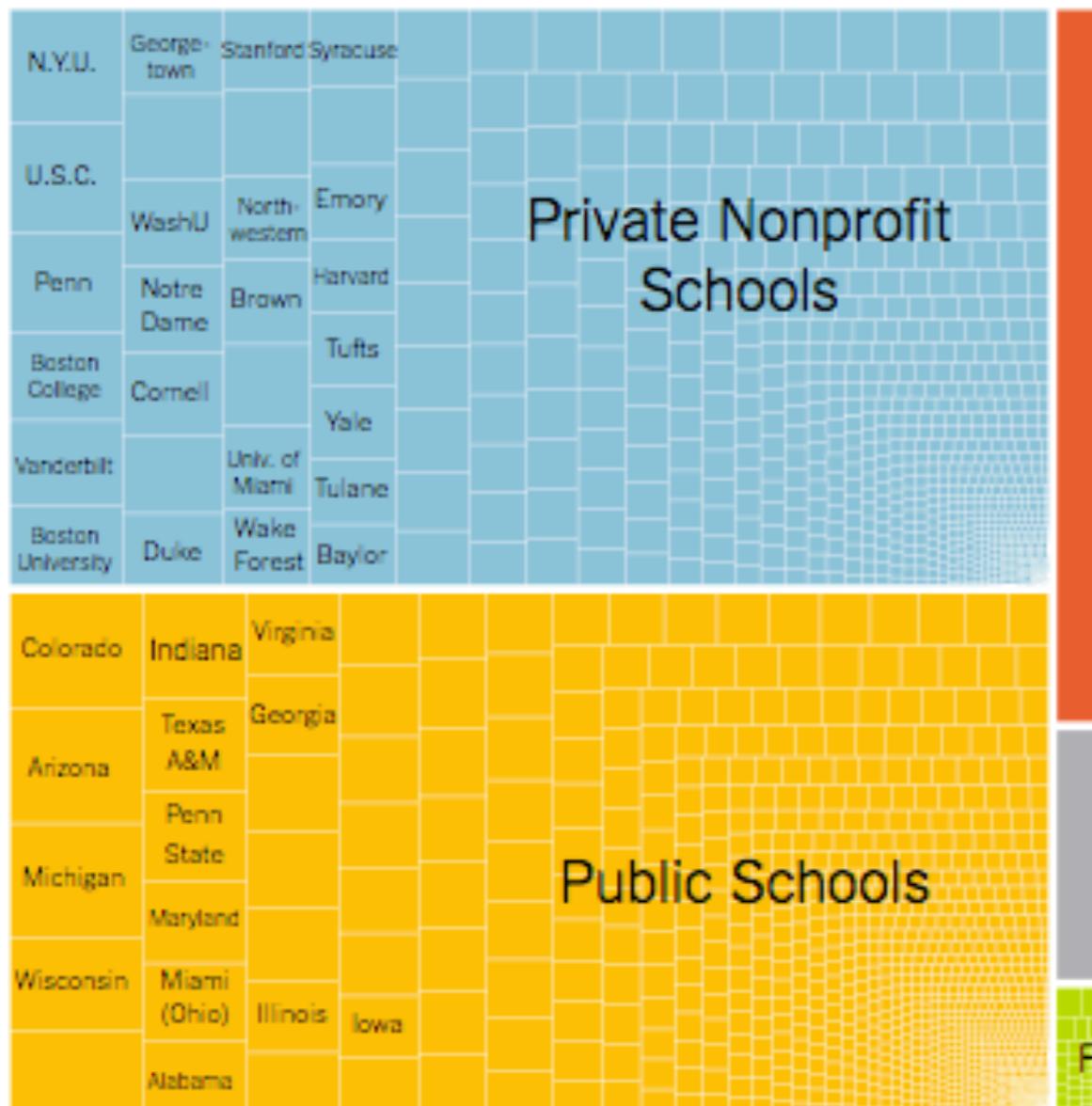
As early as 1500 CE, the Incans were using knotted cords, called khipus, as a form of data visualization.



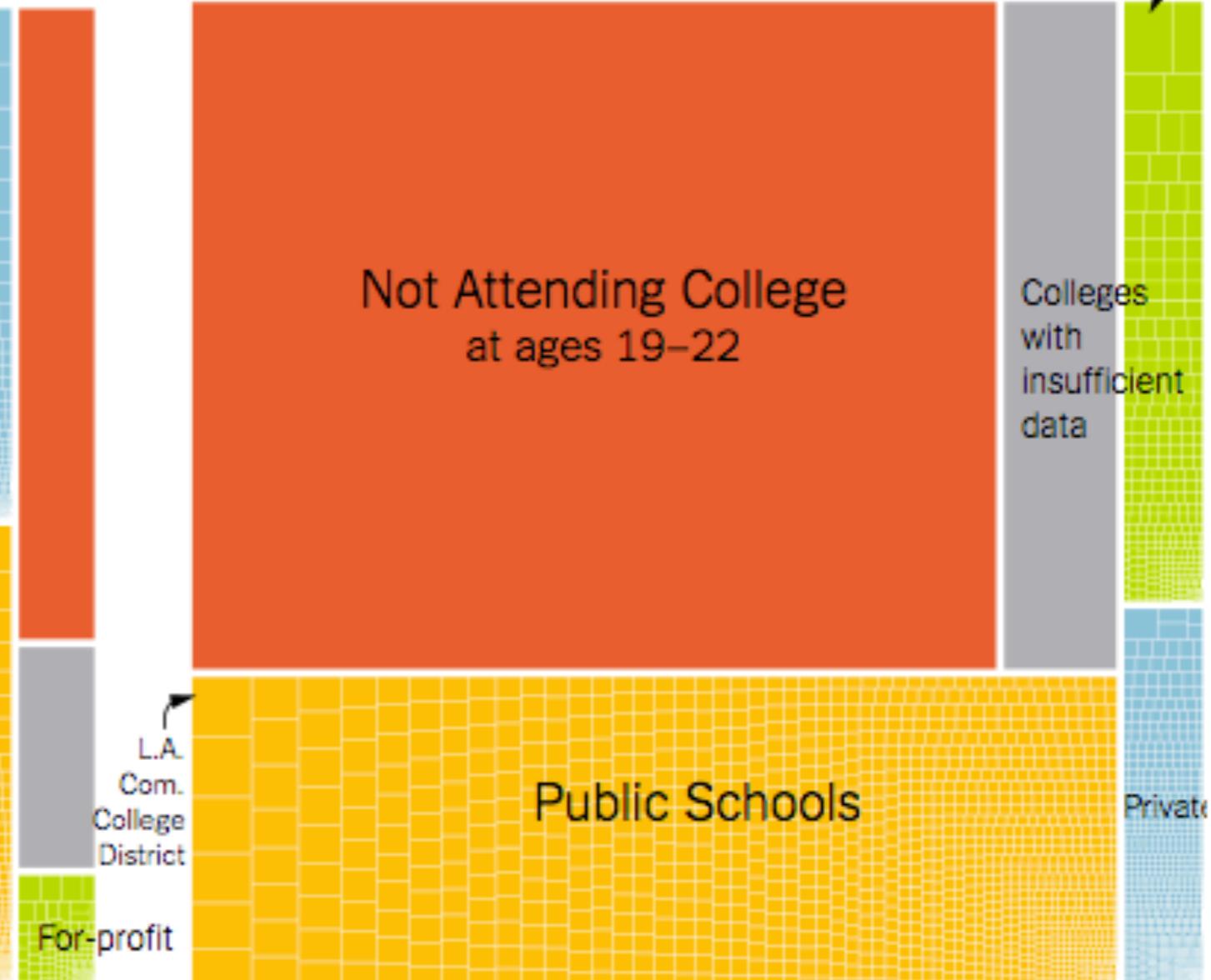
What are the Marks and Channels?

Where the top 1% and the bottom 20% go to college

Top 1%



Bottom 20%



Channel Types

④ Position

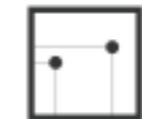
→ Horizontal



→ Vertical



→ Both



④ Color



④ Shape



④ Tilt

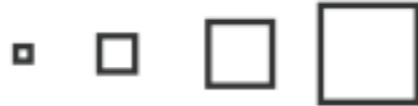


④ Size

→ Length



→ Area



→ Volume



Channel Types

identity (what or where)

magnitude (how much)

④ Position

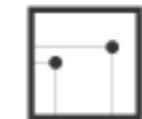
→ Horizontal



→ Vertical



→ Both



④ Color



④ Shape



④ Tilt



④ Size

→ Length



→ Area



→ Volume



Channel Types

identity (what or where)

magnitude (how much)

→ Position

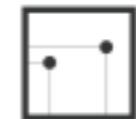
→ Horizontal



→ Vertical



→ Both



→ Color



→ Shape



→ Tilt



→ Size

→ Length



→ Area



→ Volume



Channel Types

identity (what or where)

magnitude (how much)

→ Position

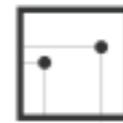
→ Horizontal



→ Vertical



→ Both



→ Color



→ Shape



→ Tilt



→ Size

→ Length



→ Area



→ Volume



Mark Types

Marks as Items/Nodes

→ Points



→ Lines



→ Areas



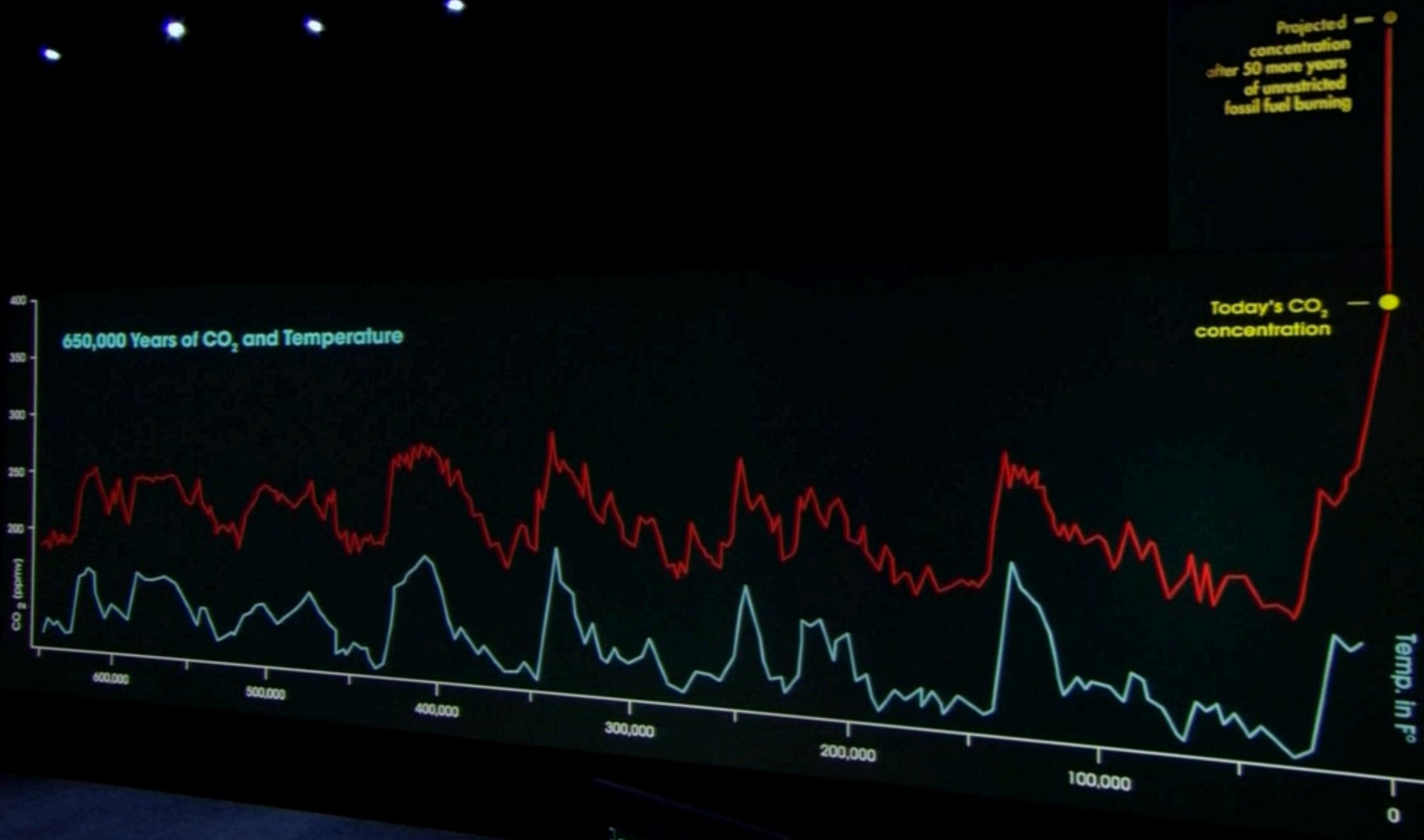
Marks as Links

→ Containment



→ Connection





Channel Effectiveness

Expressiveness vs. Effectiveness

- **Expressiveness principle:**
 - The visual encoding should express all of, and only, the information in the dataset attributes
- **Effectiveness principle:**
 - The most important attributes should be encoded with the most effective channels in order to be most noticeable

→ **Magnitude Channels: Ordered Attributes**

Position on common scale



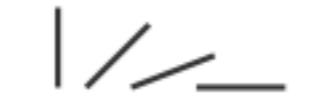
Position on unaligned scale



Length (1D size)



Tilt/angle



Area (2D size)



Depth (3D position)



Color luminance



Color saturation



Curvature



Volume (3D size)



→ **Identity Channels: Categorical Attributes**

Spatial region



Color hue



Motion



Shape

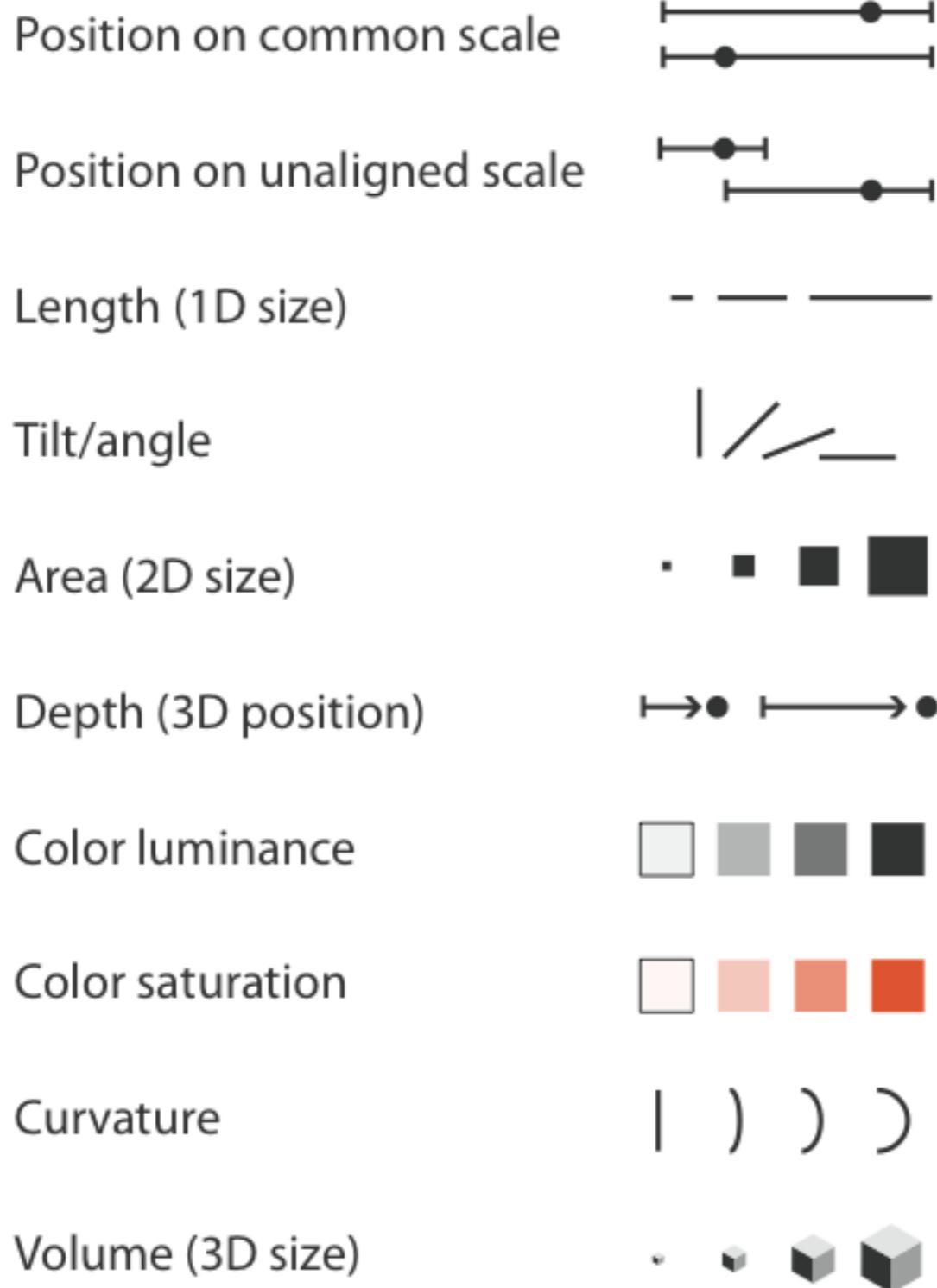


Expressiveness

(how much)

(what or where)

④ **Magnitude Channels: Ordered Attributes**



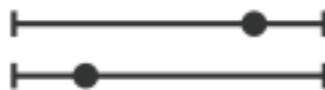
④ **Identity Channels: Categorical Attributes**



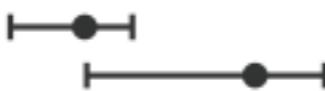
Expressiveness

→ Magnitude Channels: Ordered Attributes

Position on common scale



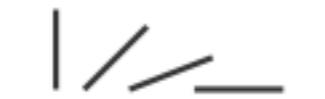
Position on unaligned scale



Length (1D size)



Tilt/angle



Area (2D size)



Depth (3D position)



Color luminance



Color saturation



Curvature



Volume (3D size)



→ Identity Channels: Categorical Attributes

Spatial region



Color hue



Motion



Shape



Effectiveness
↑ Most
↓ Least
Same

Effectiveness

**Where Do These
Rankings Come From?**

Jacques Bertin

- French cartographer
(1918-2011)
- Wrote Semiology of Graphics
(1967)
- Theoretical principles for
visual encoding



O = Ordinal, Q = Quantitative
≠ = Differences ≡ = Similarities

VARIABLES OF THE IMAGE

XY 2 DIMENSIONS OF THE PLANE

OQ	
-----------	--

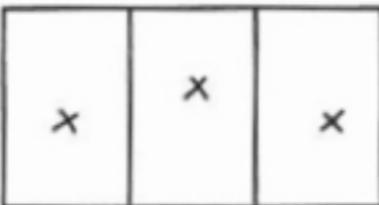
Z

SIZE

OQ	
O	

VALUE

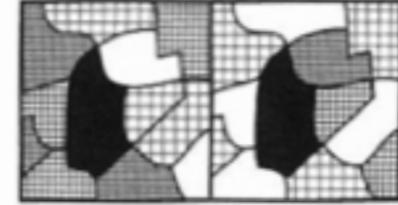
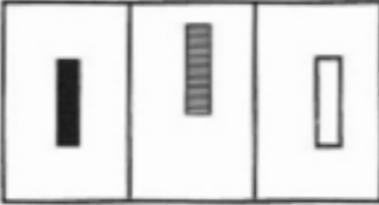
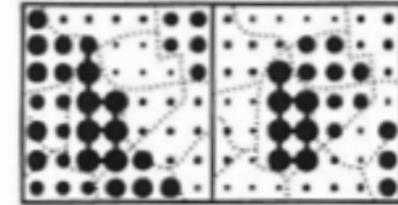
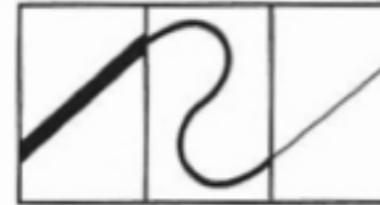
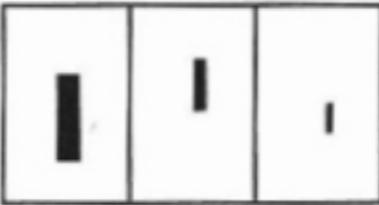
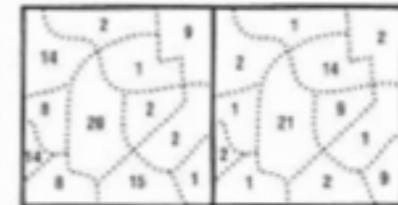
POINT



LINE



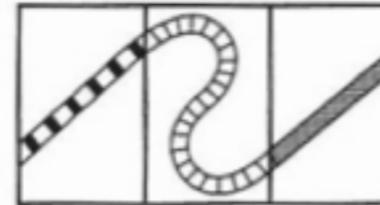
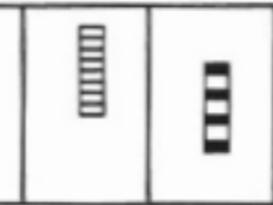
AREA (ZONE)



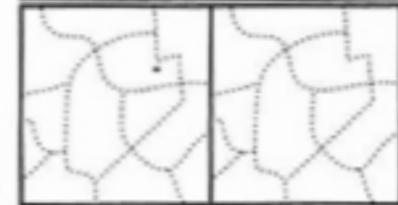
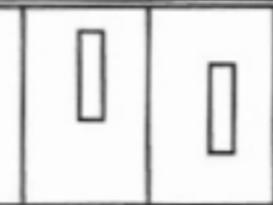
DIFFERENTIAL VARIABLES

TEXTURE

COLOR



ORIENTATION



SHAPE

Cleveland & McGill, 1984

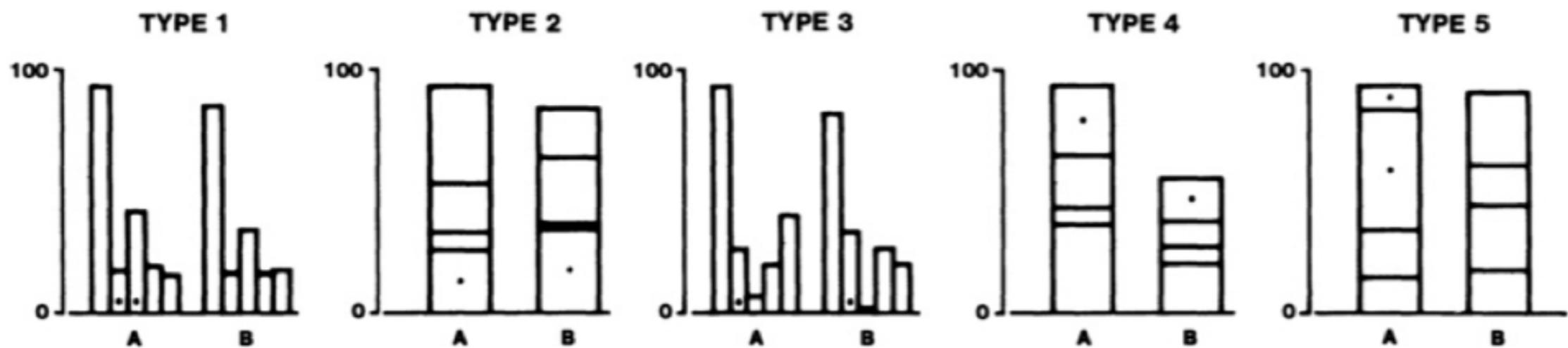


Figure 4. Graphs from position-length experiment.

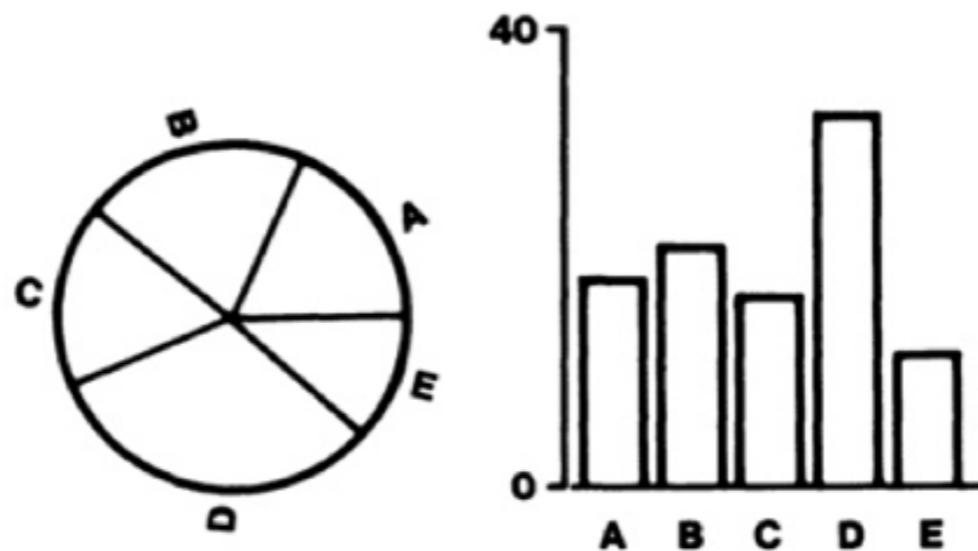
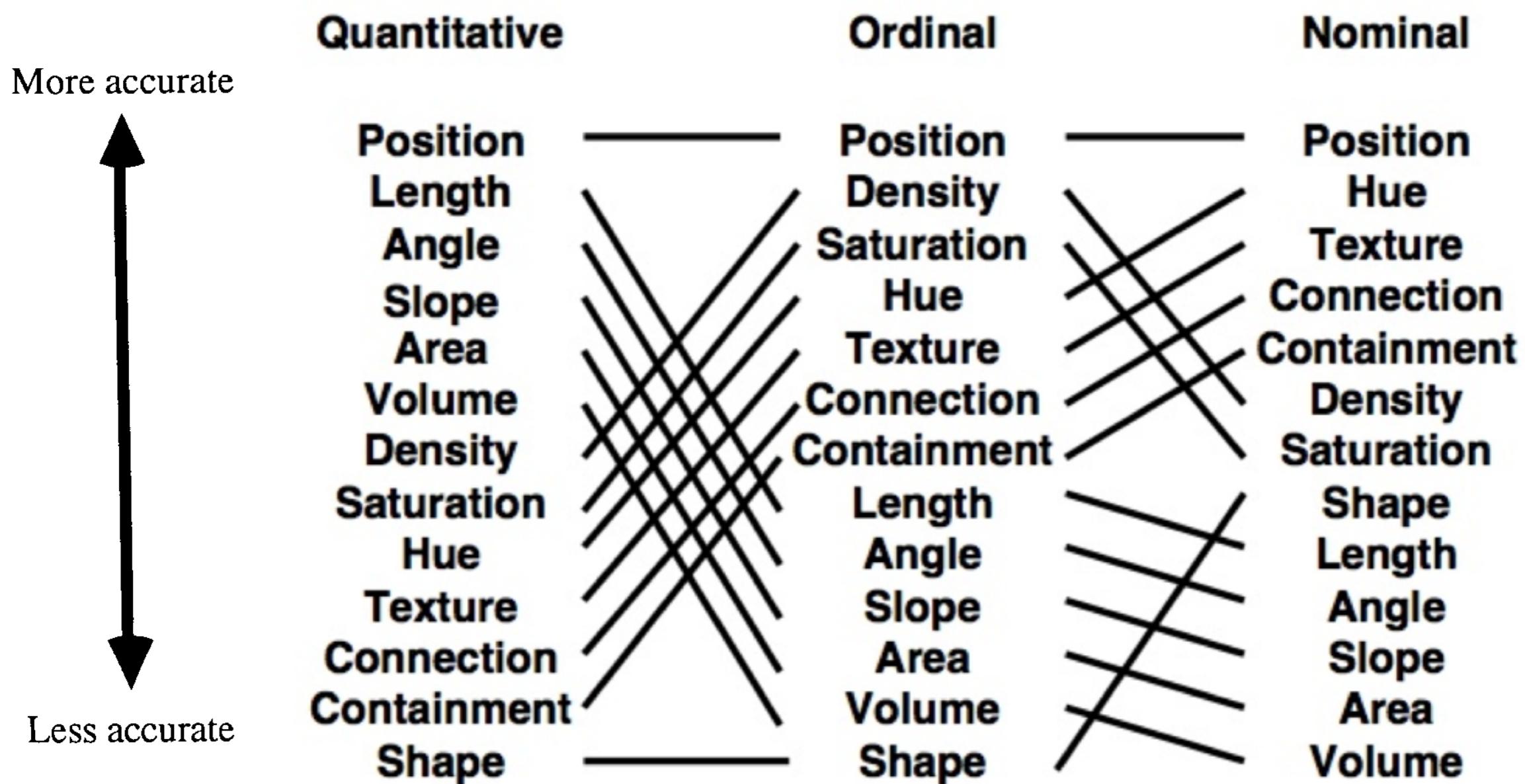


Figure 3. Graphs from position-angle experiment.

Mackinlay, 1986



Heer & Bostock, 2010 (+ Mechanical Turk)

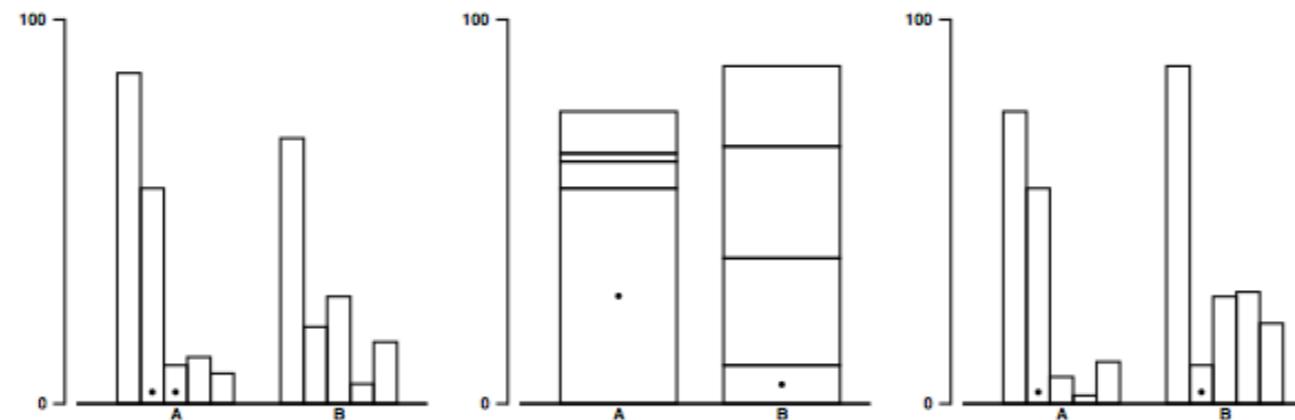


Figure 1: Stimuli for judgment tasks T1, T2 & T3. Subjects estimated percent differences between elements.

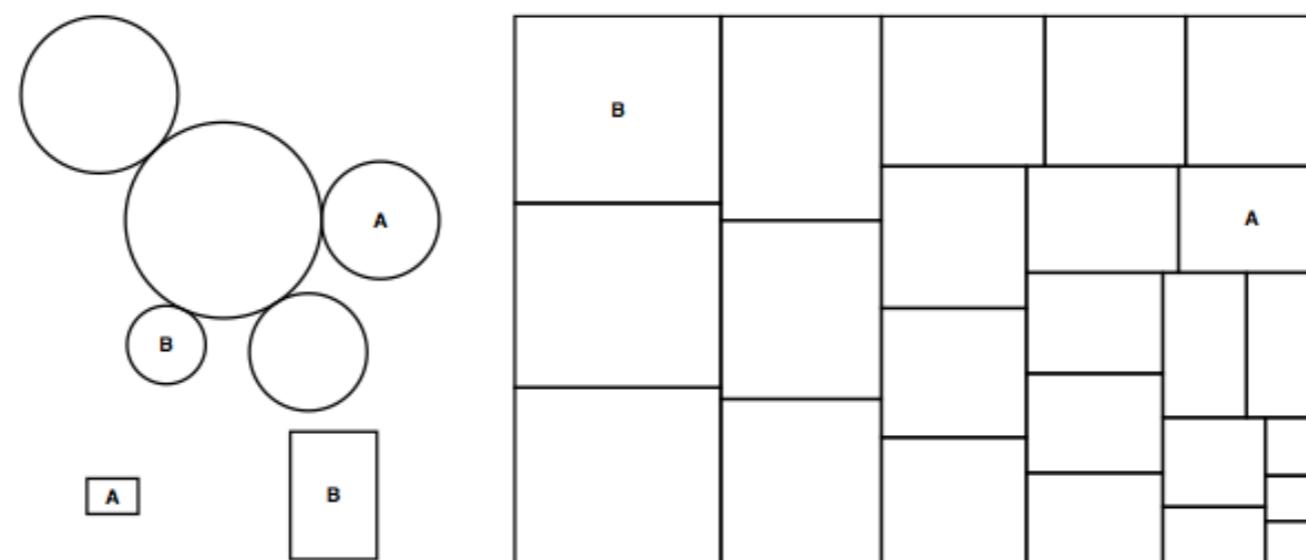


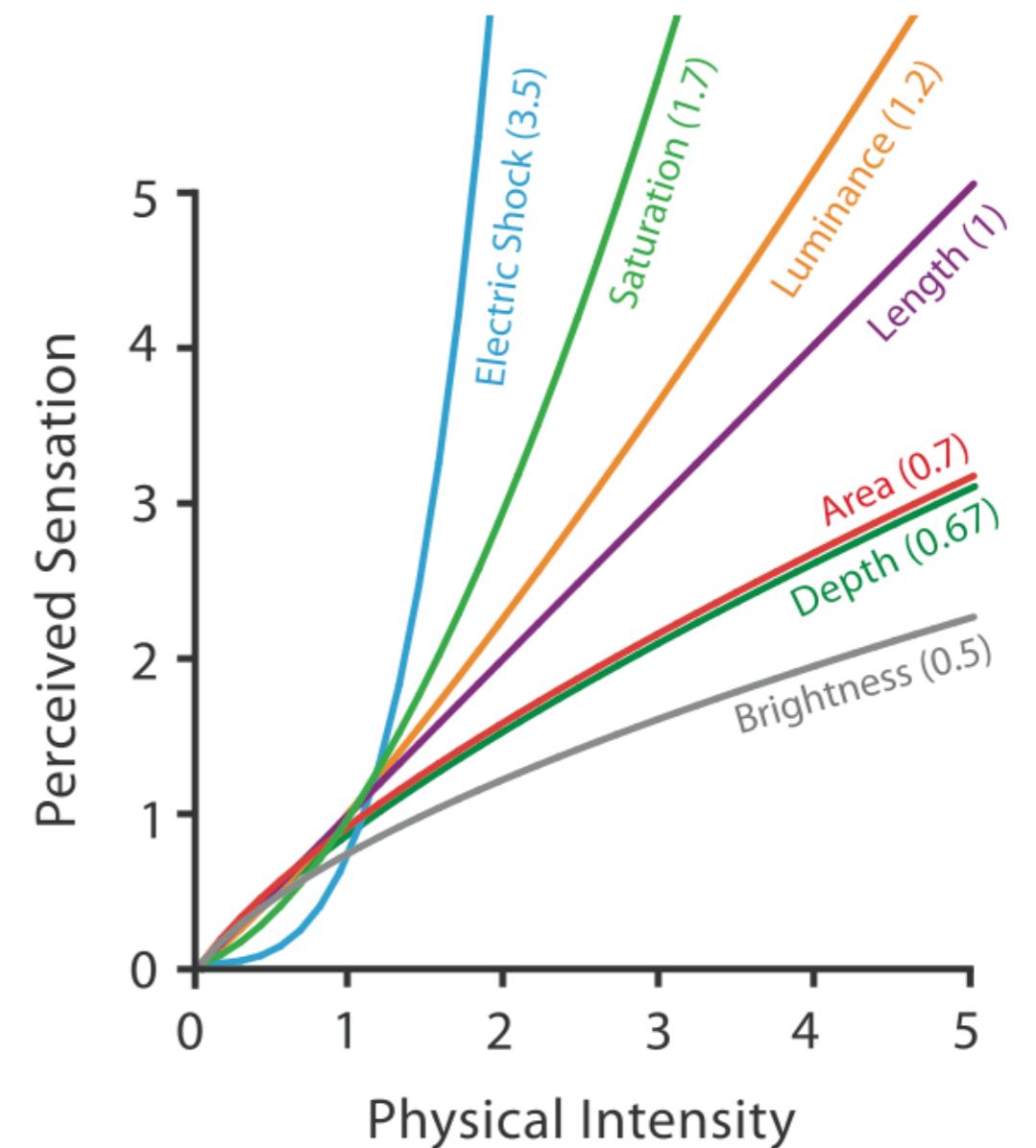
Figure 2: Area judgment stimuli. Top left: Bubble chart (T7), Bottom left: Center-aligned rectangles (T8), Right: Treemap (T9).

**What criteria determine
channel ranks?**

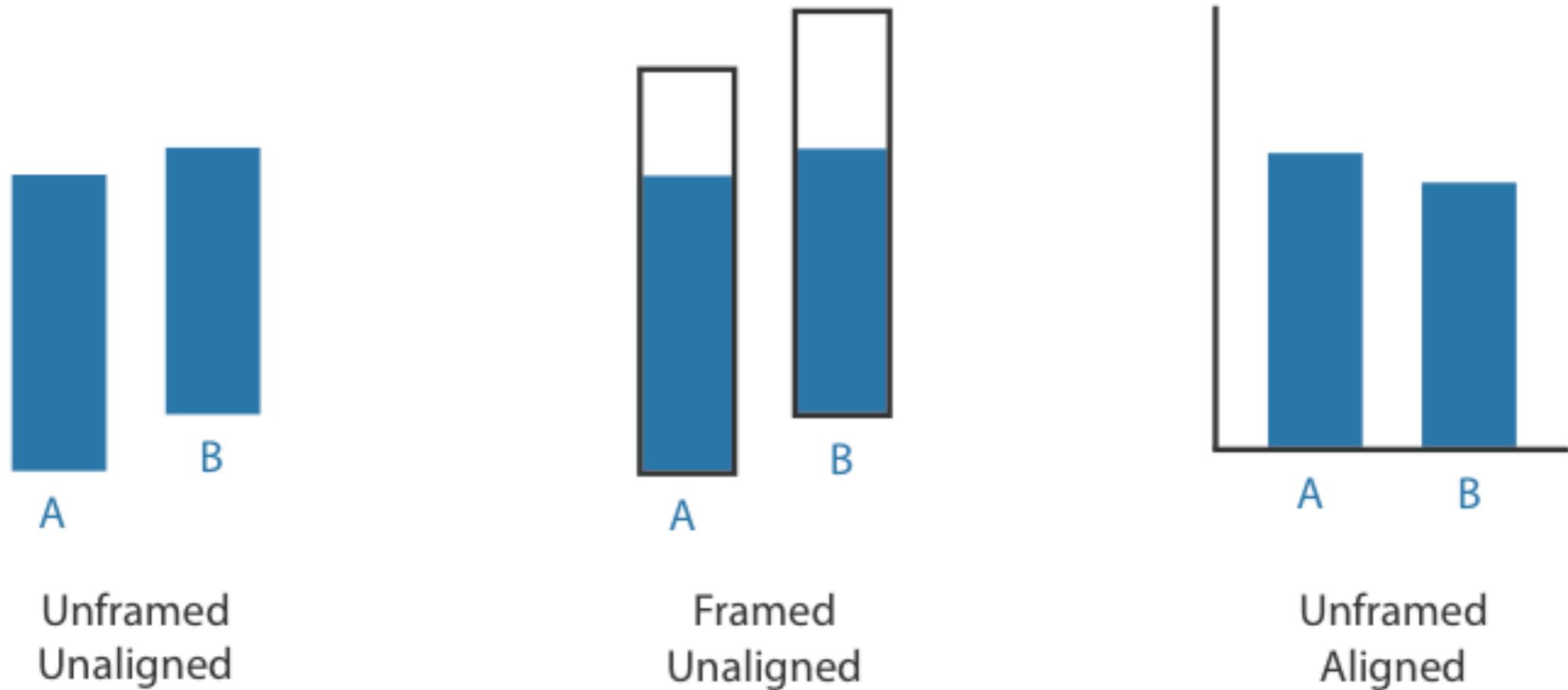
Accuracy

Steven's Psychophysical Power Law: $S = I^N$

- How close is human perceptual judgement to some objective measurement of the stimulus?
- Just noticeable difference depends on the signal type!
- Generalizes Weber's Law



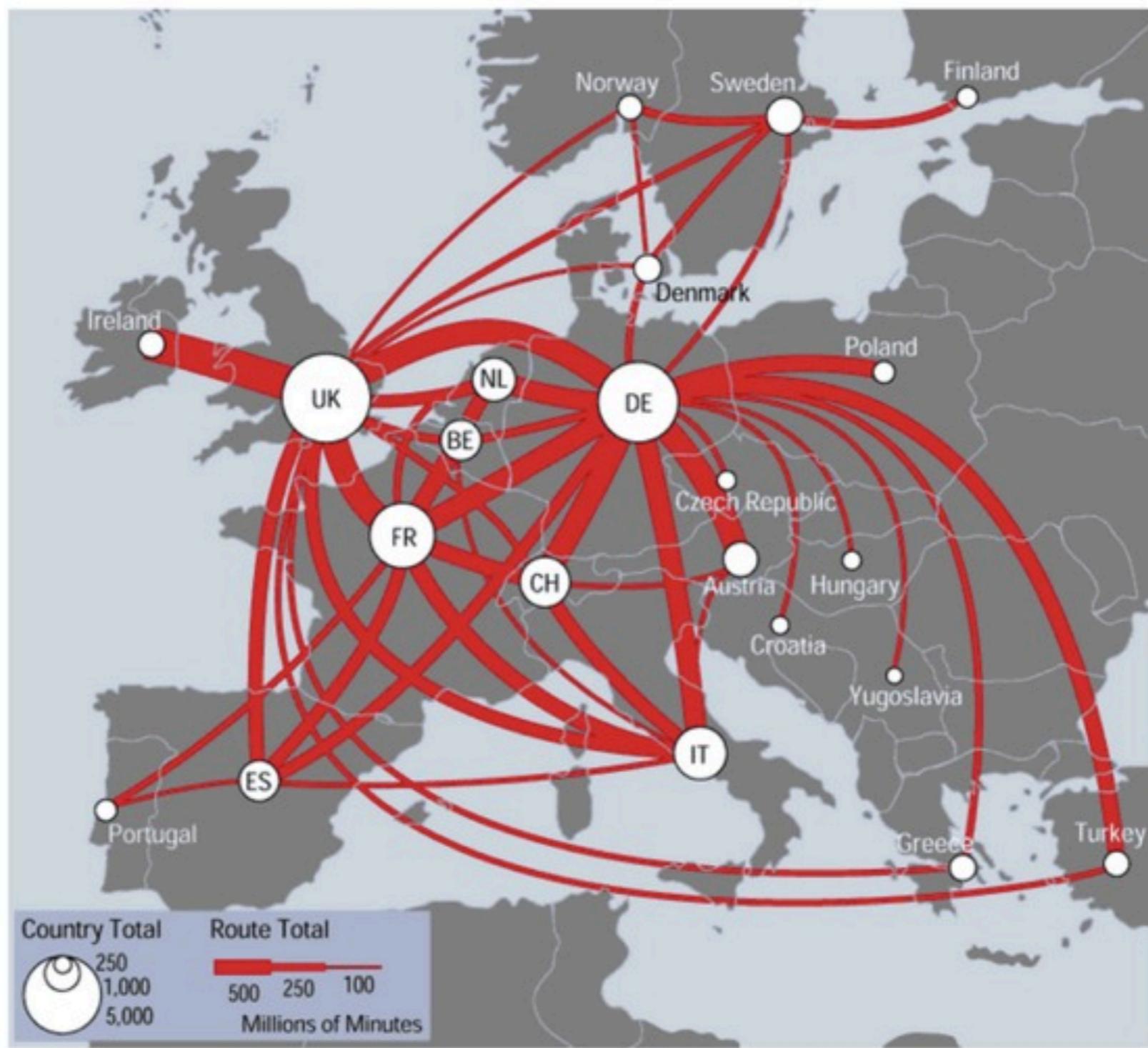
Recall: Weber's Law



- We judge on relative, not absolute, differences
- Specifically, ratio of intensity increment to background is constant.
- The perceived minimum increment is **just noticeable difference**
- Change the background, change the increment

Discriminability

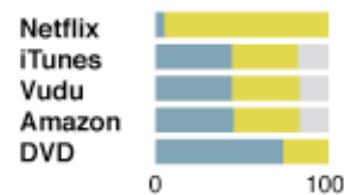
- Limitations on the range of discernible differences



Streaming the Box Office

Top 100 in 2011

■ AVAILABLE
■ NOT AVAILABLE
■ PURCHASE ONLY



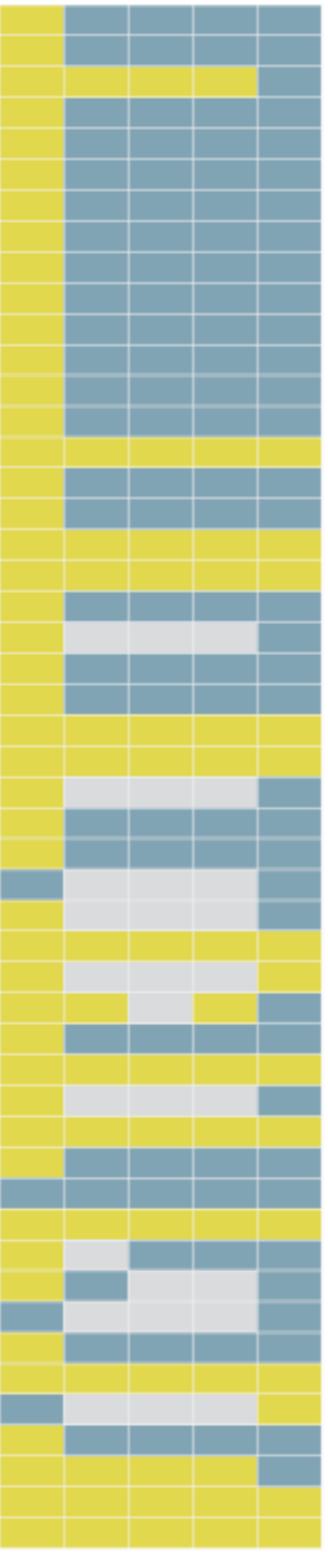
Tristan Louis compiled a list of the top 100 movies at the box office, according to Box Office Mojo, that were available streaming. This is a graphical version of that list.

Source: Tristan Louis
By: Nathan Yau

1-50

- 1 Harry Potter and the Deathly Hallows Part 2
- 2 Transformers: Dark of the Moon
- 3 The Twilight Saga: Breaking Dawn Part 1
- 4 The Hangover Part II
- 5 Pirates of the Caribbean: On Stranger Tides
- 6 Fast Five
- 7 Cars 2
- 8 Thor
- 9 Rise of the Planet of the Apes
- 10 Captain America: The First Avenger
- 11 The Help
- 12 Bridesmaids
- 13 Kung Fu Panda 2
- 14 X-Men: First Class
- 15 Puss in Boots
- 16 Rio
- 17 The Smurfs
- 18 Mission: Impossible — Ghost Protocol
- 19 Sherlock Holmes: A Game of Shadows
- 20 Super 8
- 21 Rango
- 22 Horrible Bosses
- 23 Green Lantern
- 24 Hop
- 25 Paranormal Activity 3
- 26 Just Go With It
- 27 Bad Teacher
- 28 Cowboys & Aliens
- 29 Gnomeo and Juliet
- 30 The Green Hornet
- 31 Alvin and the Chipmunks: Chipwrecked
- 32 The Lion King (in 3D)
- 33 Real Steel
- 34 Crazy, Stupid, Love.
- 35 The Muppets
- 36 Battle: Los Angeles
- 37 Immortals
- 38 Zookeeper
- 39 Limitless
- 40 Tower Heist
- 41 Contagion
- 42 Moneyball
- 43 Justin Bieber: Never Say Never
- 44 Dolphin Tale
- 45 Jack and Jill
- 46 No Strings Attached
- 47 Mr. Popper's Penguins
- 48 Unknown
- 49 The Adjustment Bureau
- 50 Happy Feet Two

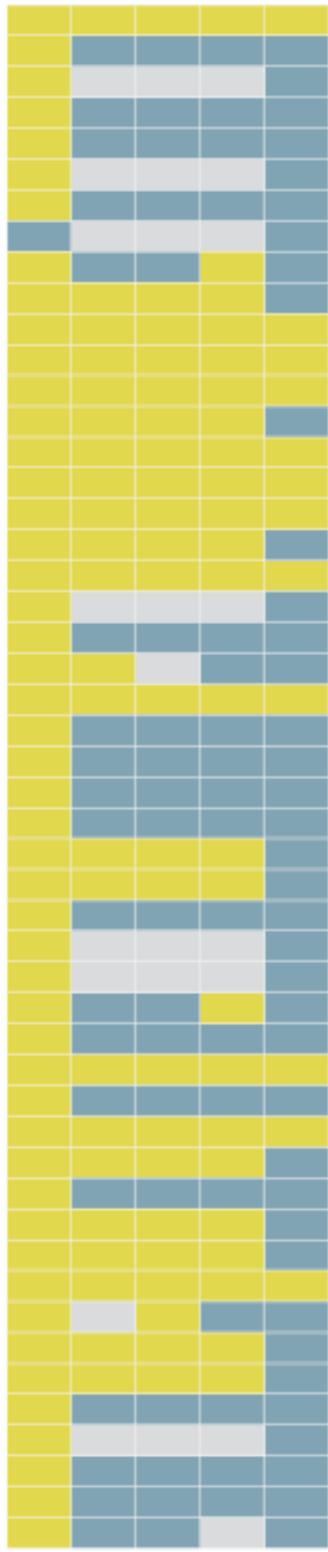
Netflix
Amazon
iTunes
Vudu
DVD



51-100

- 51 The Girl with the Dragon Tattoo (2011)
- 52 Water for Elephants
- 53 The Lincoln Lawyer
- 54 Midnight in Paris
- 55 Friends with Benefits
- 56 I Am Number Four
- 57 Source Code
- 58 Insidious
- 59 Tyler Perry's Madea's Big Happy Family
- 60 Diary of a Wimpy Kid: Rodrick Rules
- 61 Footloose (2011)
- 62 The Adventures of Tintin
- 63 Hugo
- 64 The Dilemma
- 65 New Year's Eve
- 66 Arthur Christmas
- 67 War Horse
- 68 Hall Pass
- 69 We Bought a Zoo
- 70 Soul Surfer
- 71 Final Destination 5
- 72 The Ides of March
- 73 The Descendants
- 74 Hanna
- 75 Something Borrowed
- 76 Spy Kids: All the Time in the World
- 77 Scream 4
- 78 Big Mommas: Like Father, Like Son
- 79 Red Riding Hood
- 80 Paul
- 81 The Roommate
- 82 Jumping the Broom
- 83 The Change-Up
- 84 30 Minutes or Less
- 85 In Time
- 86 Colombiana
- 87 J. Edgar
- 88 Sucker Punch
- 89 Larry Crowne
- 90 50/50
- 91 Drive (2011)
- 92 A Very Harold & Kumar 3D Christmas
- 93 Courageous
- 94 The Rite
- 95 Arthur (2011)
- 96 The Debt
- 97 Priest
- 98 The Mechanic
- 99 Abduction
- 100 Beastly

Netflix
Amazon
iTunes
Vudu
DVD



Separability vs Integrality

- **Separable:** can judge each channel individually
- **Integral:** two channels viewed holistically

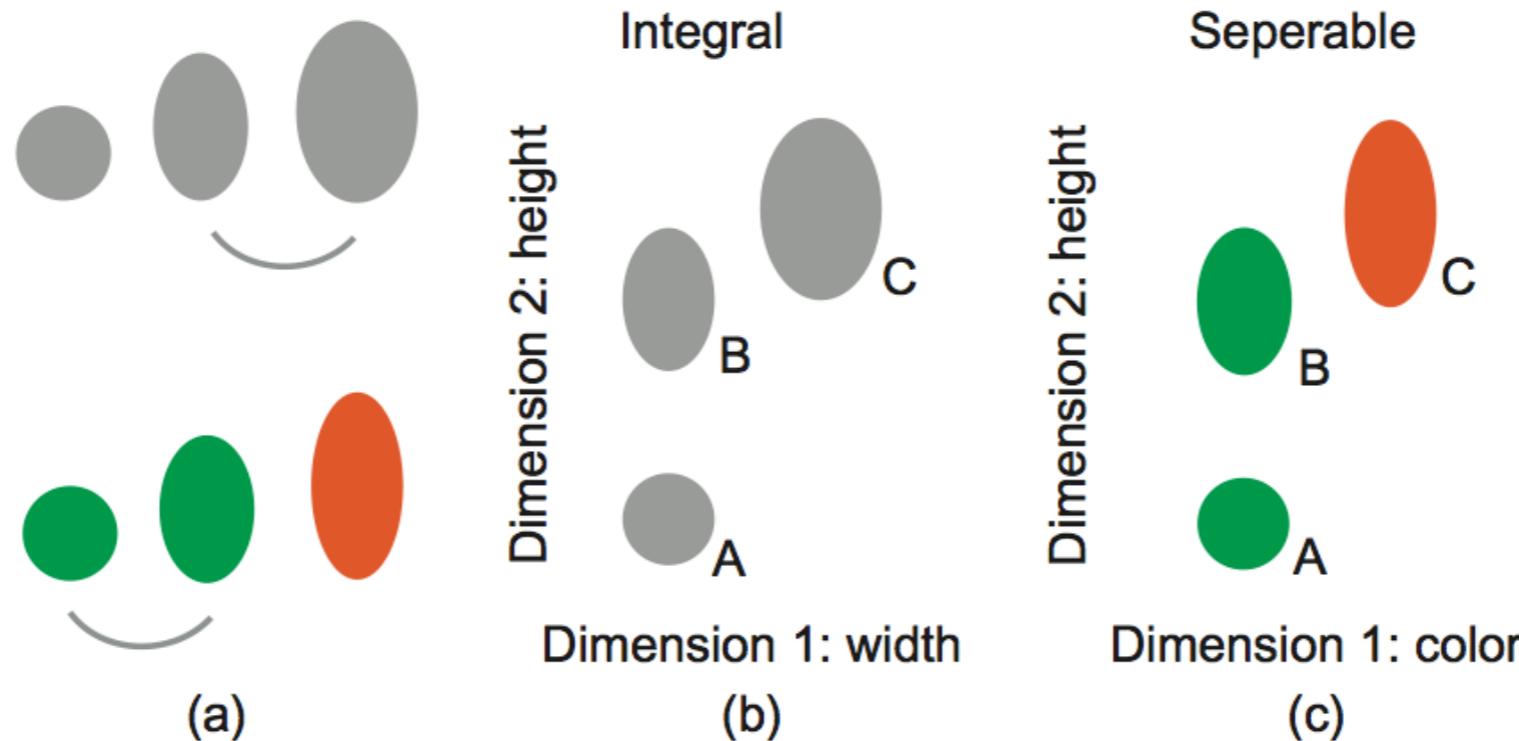
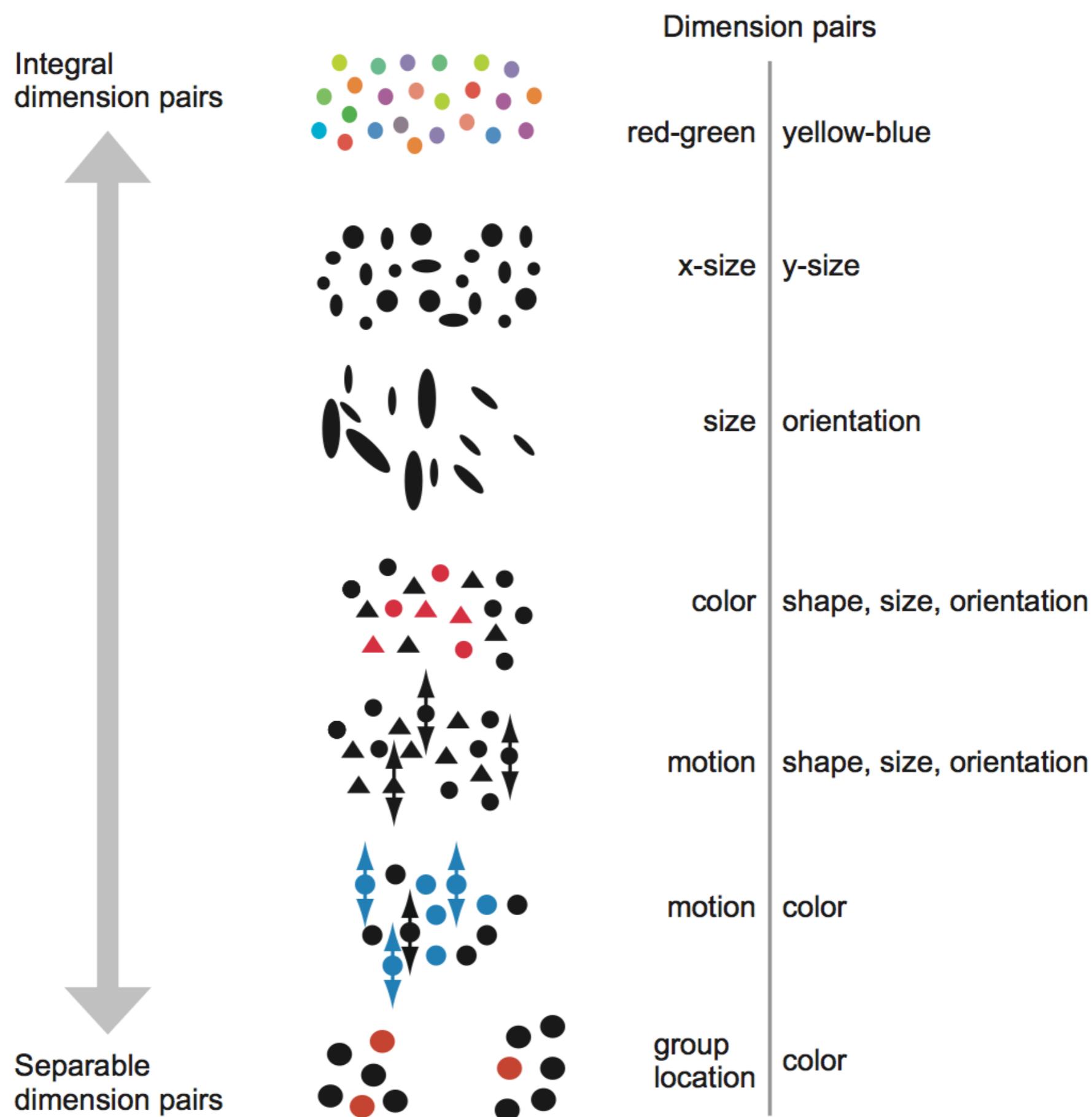


Figure 5.19 (a) The width and height of an ellipse are perceived integrally, so the ellipses are seen as more similar to each other (because they have the same shape) than the pair having the same width. The color and height of a shape are perceived separably, so the two green shapes are seen as most similar. (b, c) Space plots of the two examples.



READING, WRITING, AND EARNING MONEY

The latest data from the U.S. Census's American Community Survey paints a fascinating picture of the United States at the county level. We've looked at the educational achievement and the median income of the entire nation, to see where people are going to school, where they're earning money, and if there is any correlation.



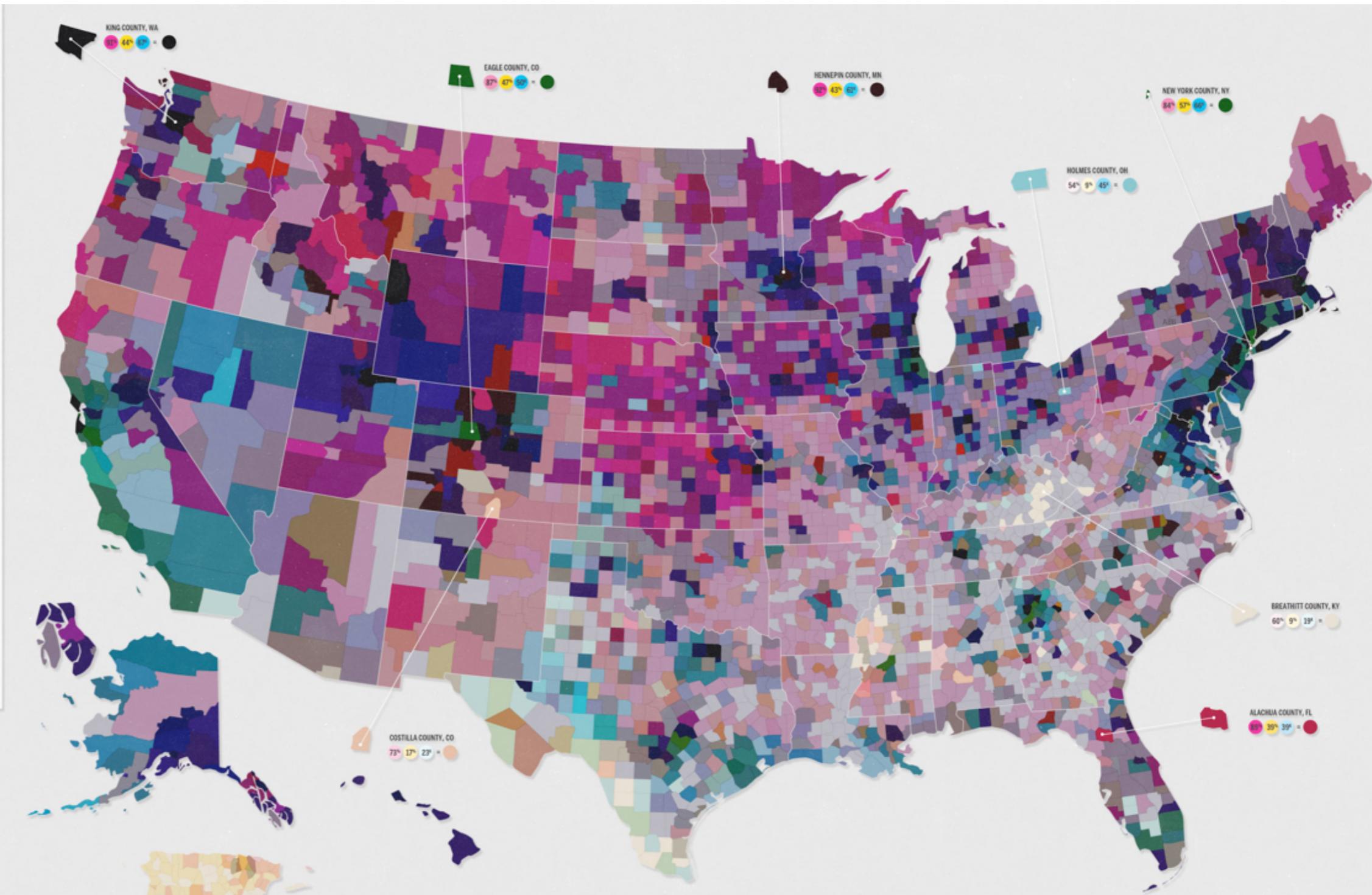
(A) HIGH SCHOOL GRADUATES



(B) COLLEGE GRADUATES



(C) MEDIAN HOUSEHOLD INCOME



The map at right is a product of overlaying the three sets of data. The variation in hue and value has been produced from the data shown above. In general, darker counties represent a more educated, better paid population while lighter areas represent communities with fewer graduates and lower incomes.



A collaboration between GOOD and Gregory Hubacek.
SOURCE: US Census

Other Perceptual Phenomena Impact Effectiveness/Expressiveness

- In addition to Steven's power law and Weber's Law (relative judgements), also consider:
 - Popout
 - Gestalt Principles (grouping)

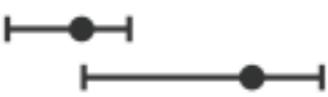
Planar Position

→ Magnitude Channels: Ordered Attributes

Position on common scale



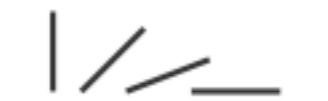
Position on unaligned scale



Length (1D size)



Tilt/angle



Area (2D size)



Depth (3D position)



Color luminance



Color saturation



Curvature



Volume (3D size)



→ Identity Channels: Categorical Attributes

Spatial region



Color hue



Motion



Shape



Most ▲

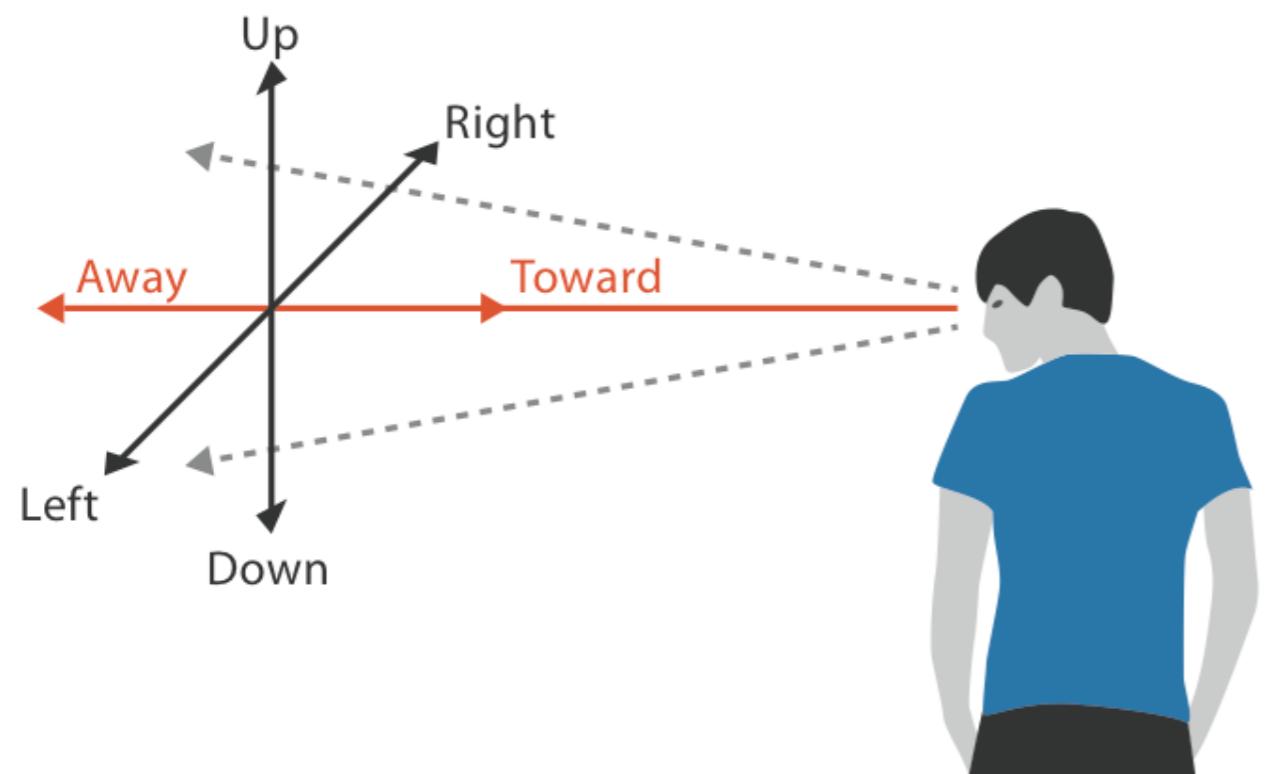
Effectiveness

Least ▼

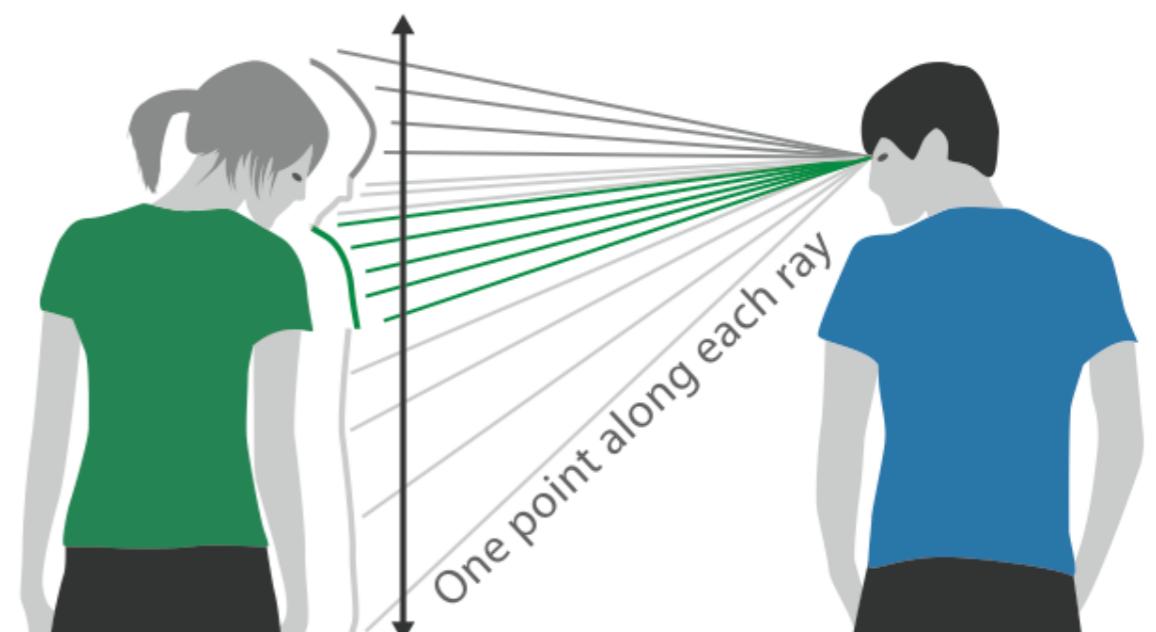
Same] [Same

We do not really see in 3D, or even 2.5D.
“It would be more accurate to say that visual space has 2.05D”

We do not really see in 3D, or even 2.5D.
“It would be more accurate to say that visual space has 2.05D”



Thousands of points up/down and left/right



We can only see the outside shell of the world

Effectiveness of Planar Position Does Not Extend to 3D

- Perspective cues
 - Interference with color and size channels
- Occlusion of data
- Text legibility

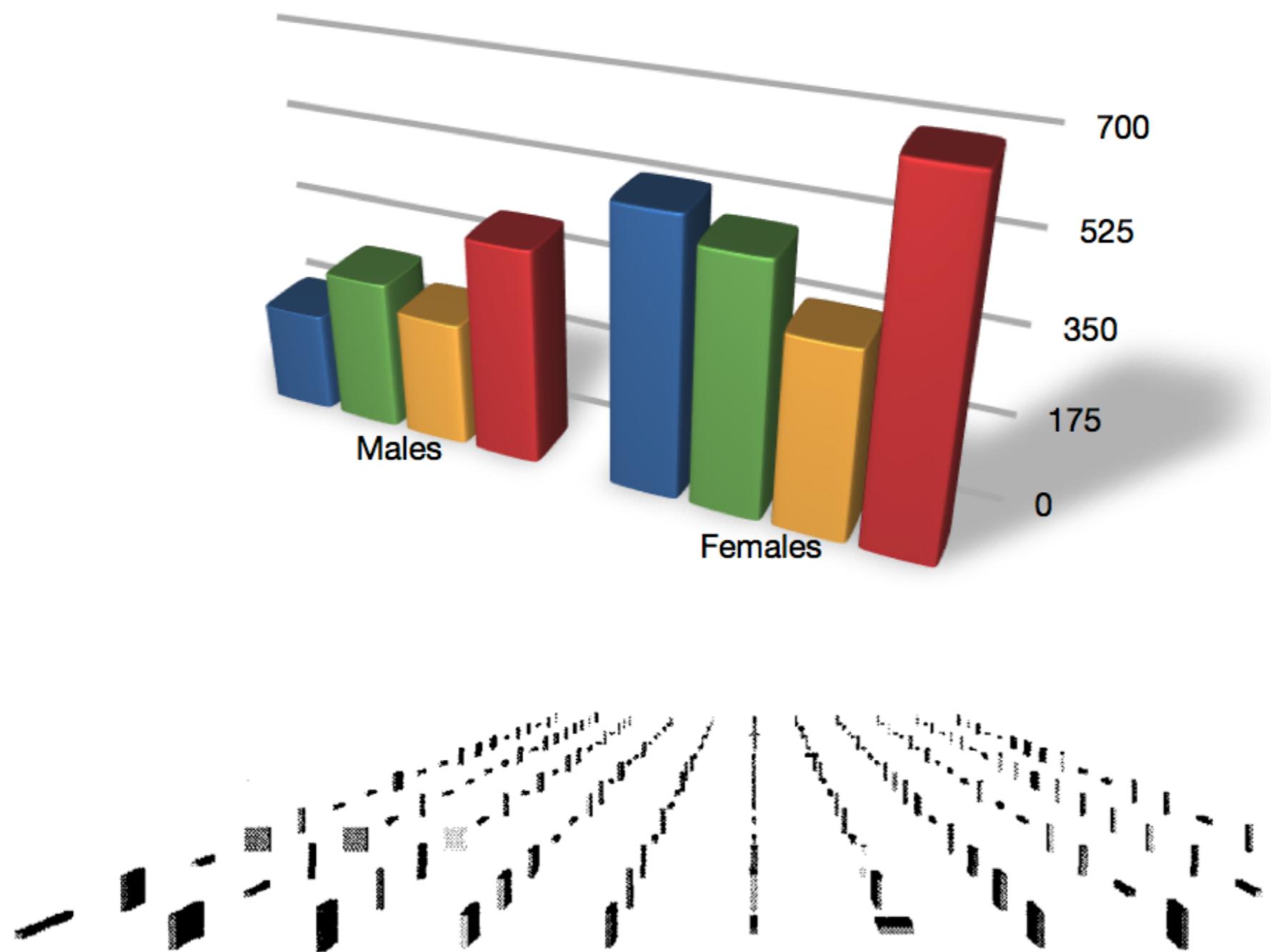


Figure 6.4. With perspective distortion, the power of the planar spatial position channel is lost, as is the size channel. From [Mukherjea et al. 96, Figure 1].

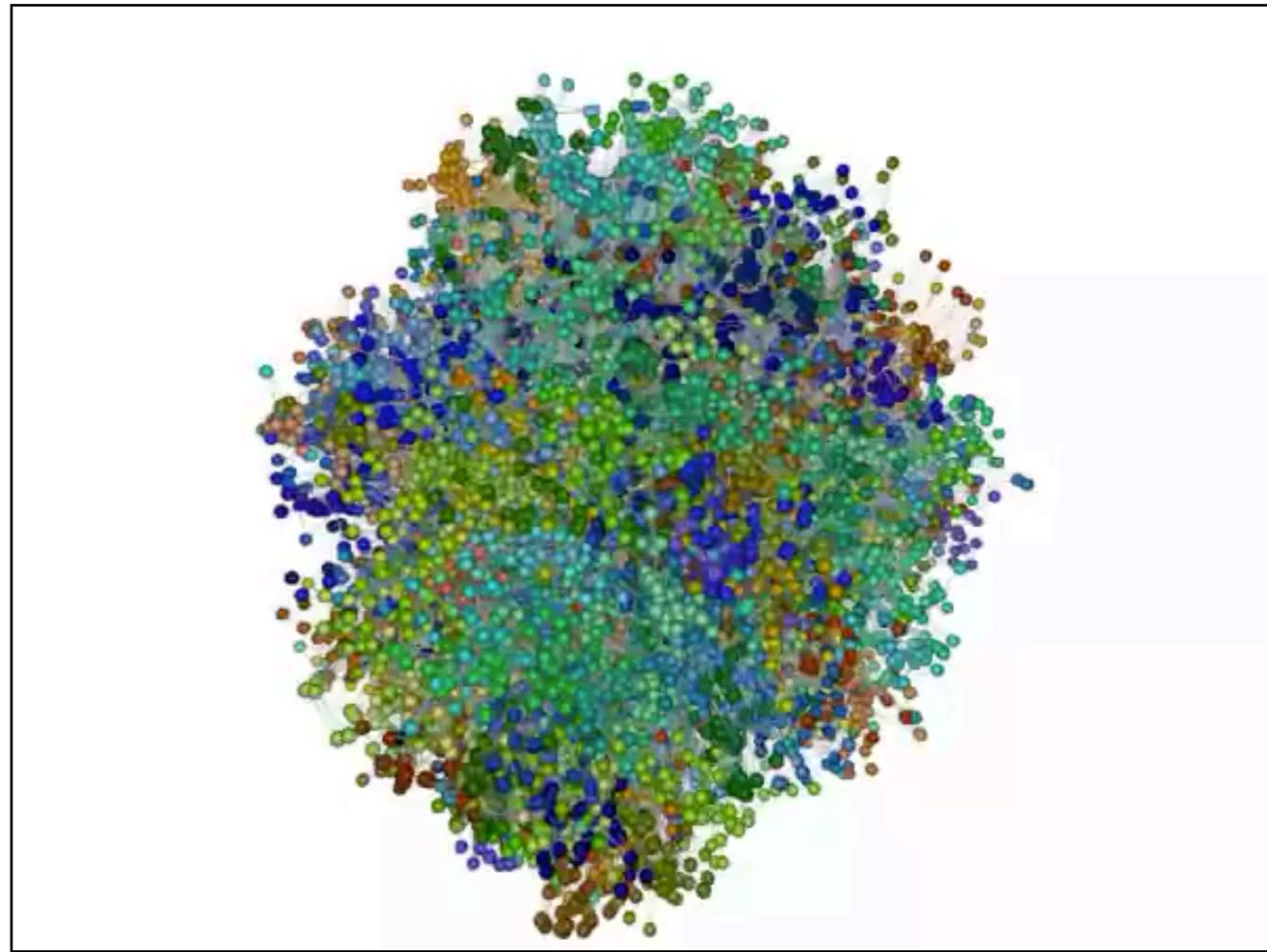
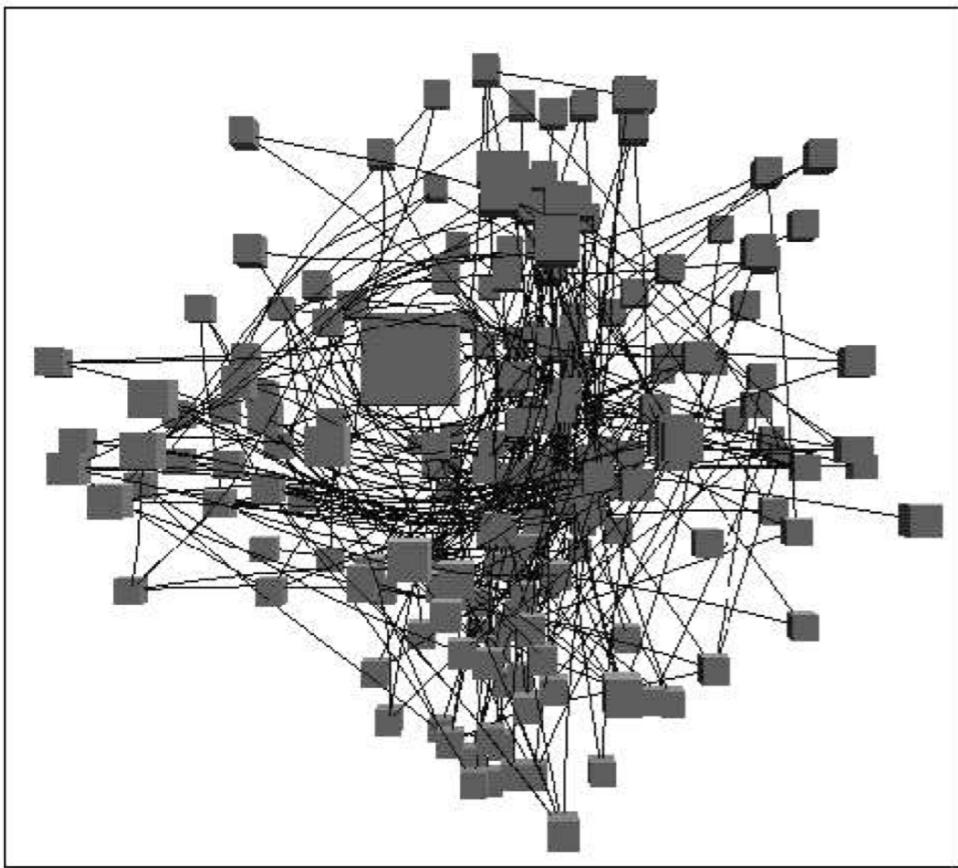


Figure 6.2. Resolving the 3D structure of the occluded parts of the scene is possible with interactive navigation, but that takes time and imposes cognitive load, even when sophisticated interaction idioms are used, as in this example of a node-link graph laid out in 3D space. From [Carpendale et al. 96, Figure 21].

<https://kajeka.com/graphia/>

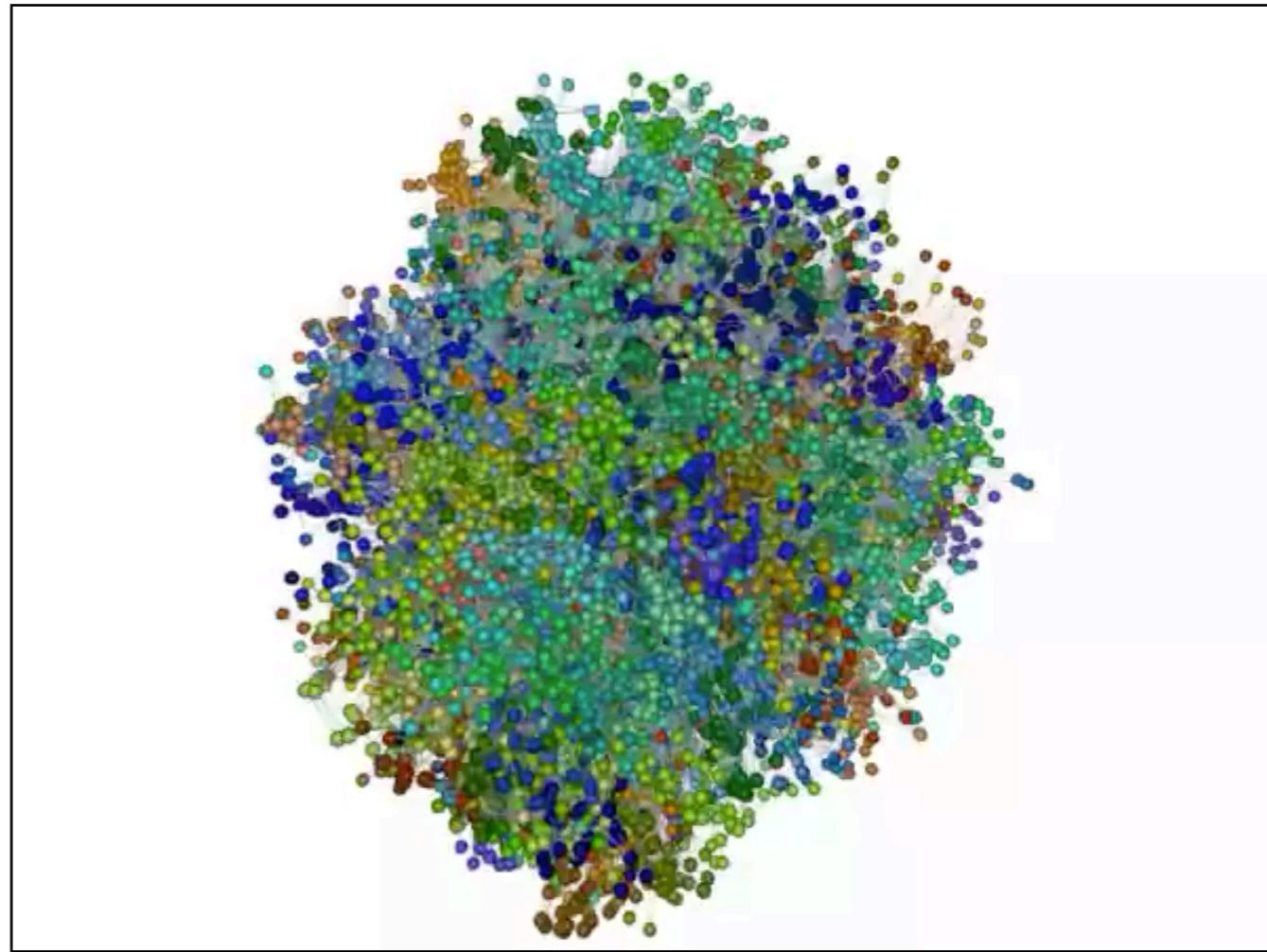
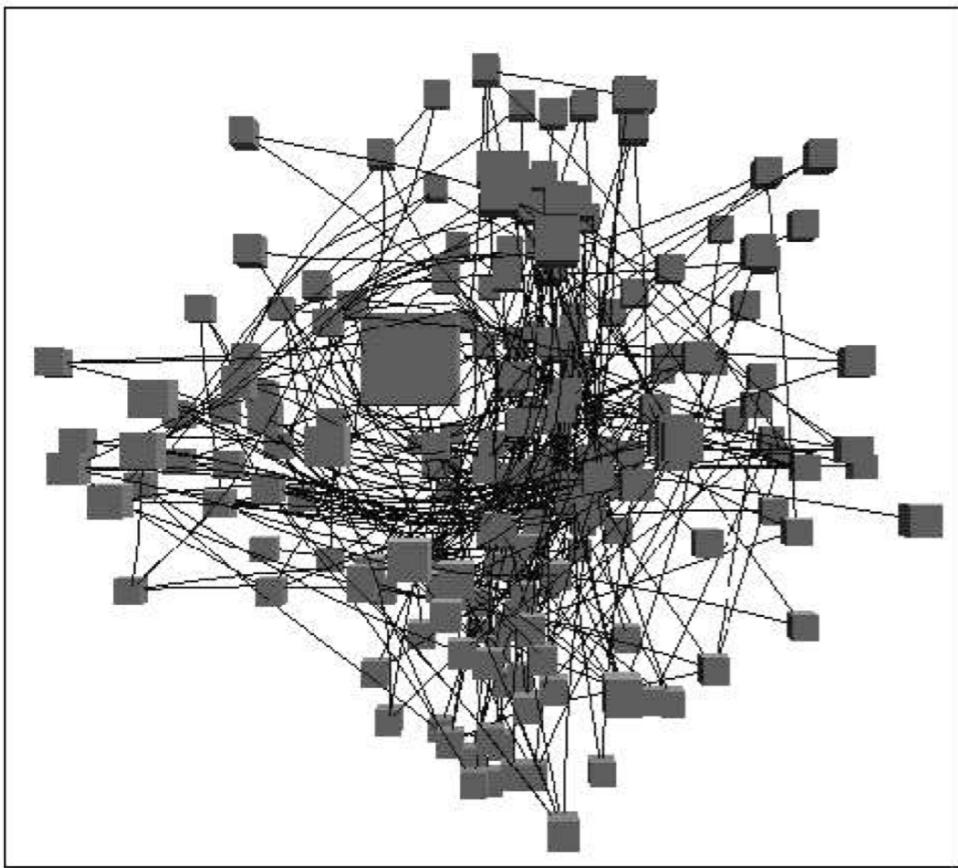


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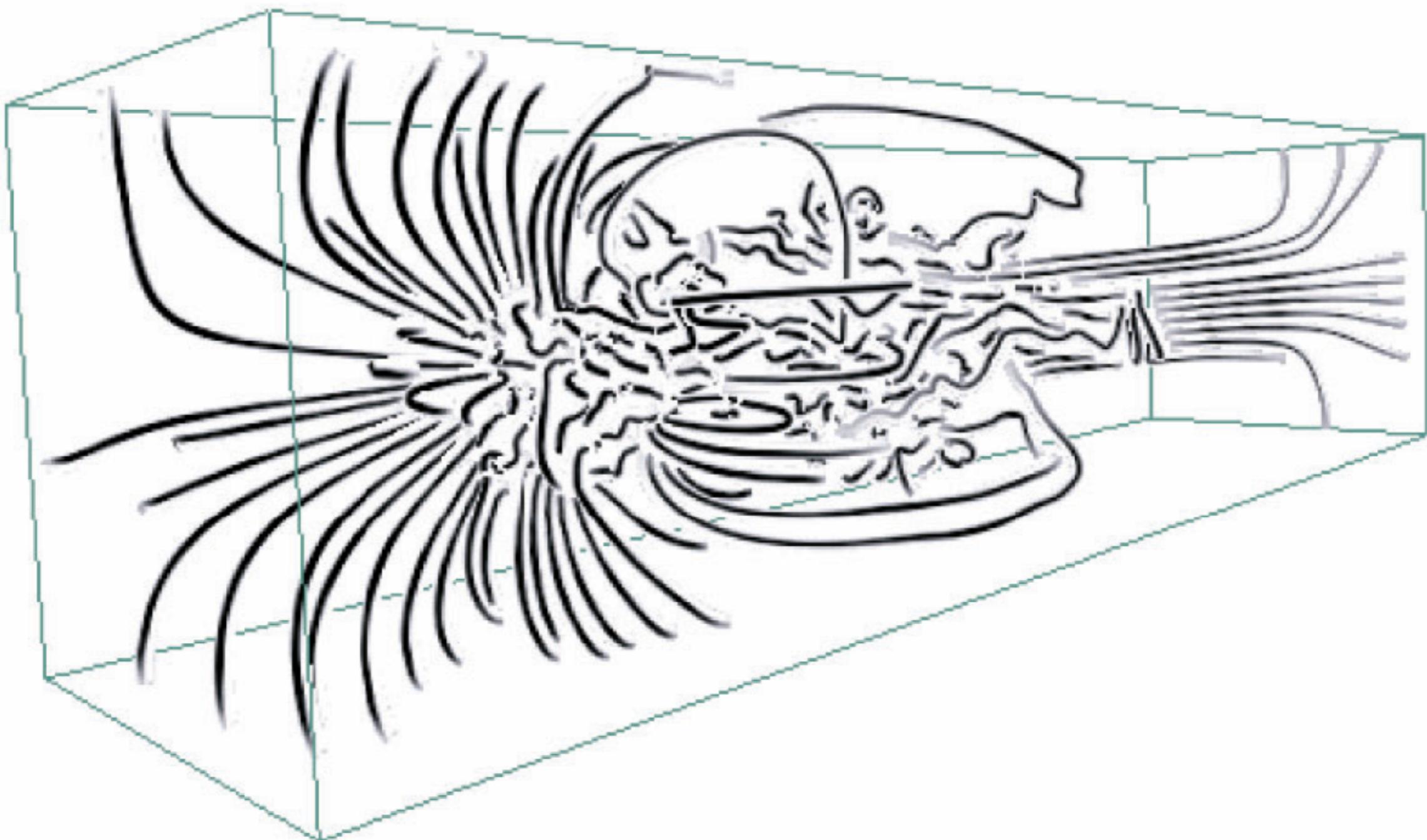
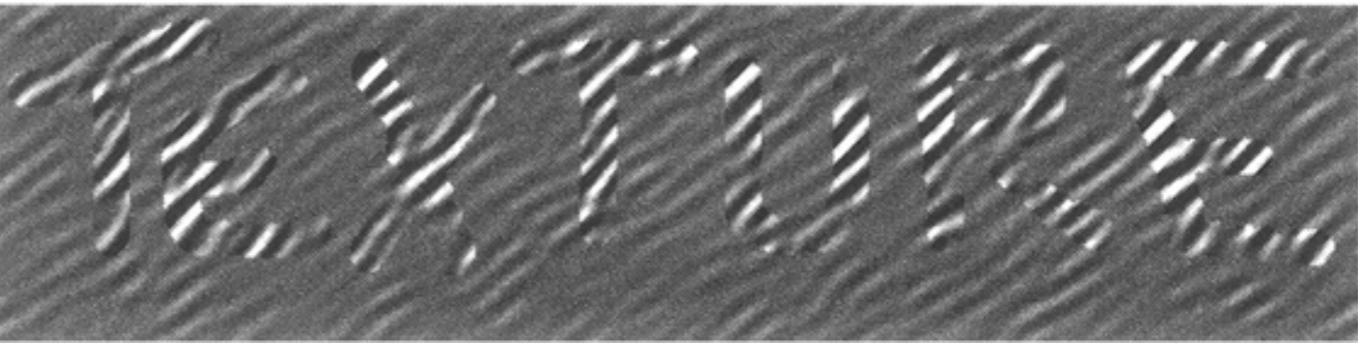
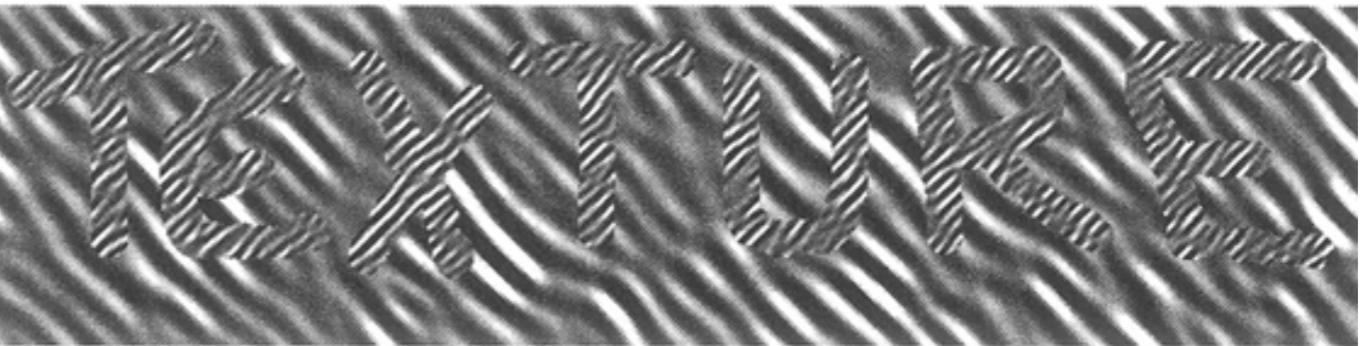
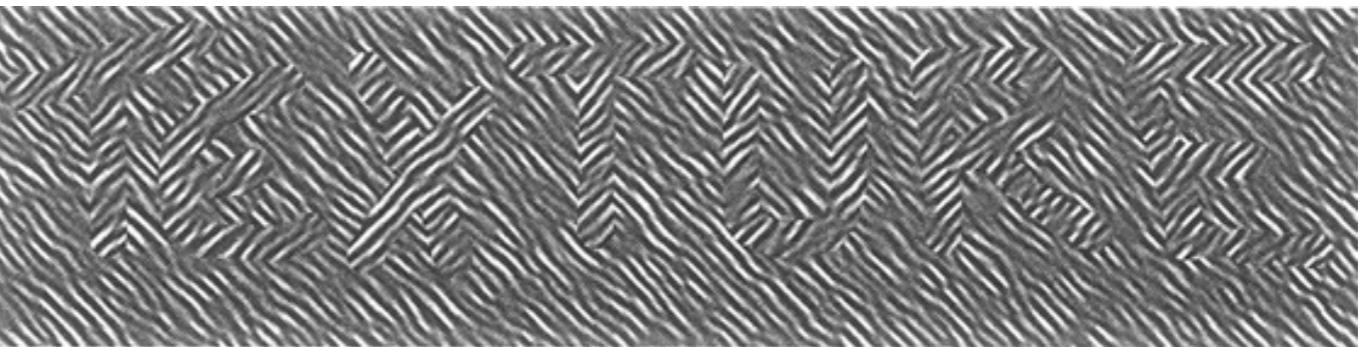


Figure 6.5. The use of 3D is well justified when the central task is shape understanding, as in this example of 3D streamline showing the patterns of fluid flow through a volume. From [Li and Shen 07, Figure 9].

Texture and Glyphs

Mapping to Texture

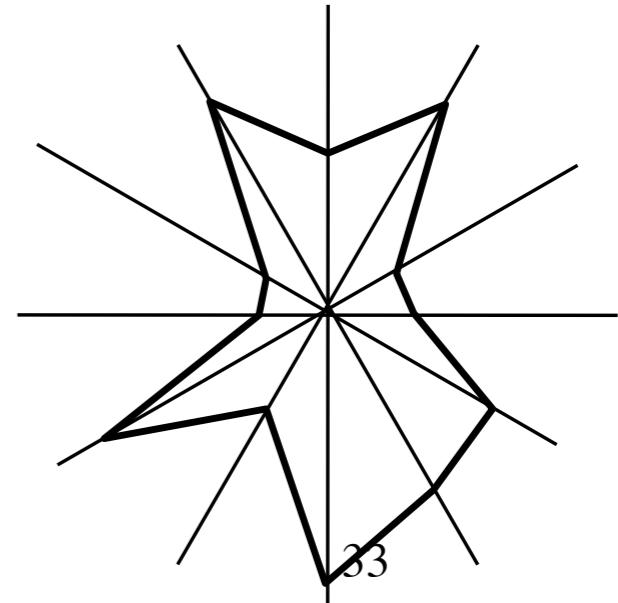
- Main parameters for texture
 - Orientation
 - Size
 - Contrast
- Alternatively [Tamura 78]:
 - Coarseness
 - Roughness
 - Contrast
 - Directionality
 - Line-likeness
 - Regularity



© W

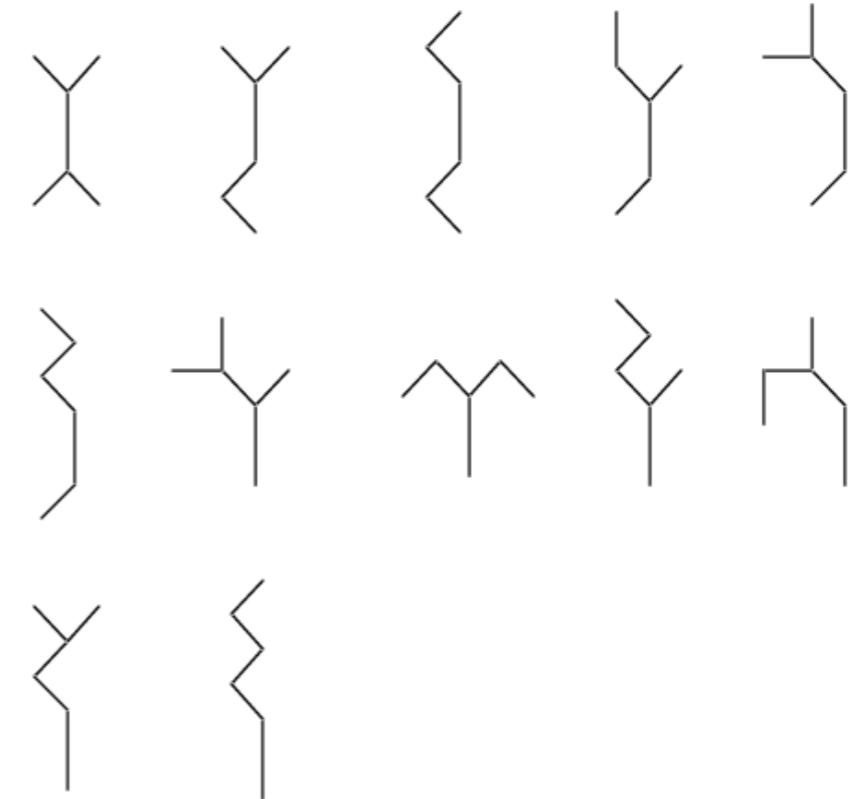
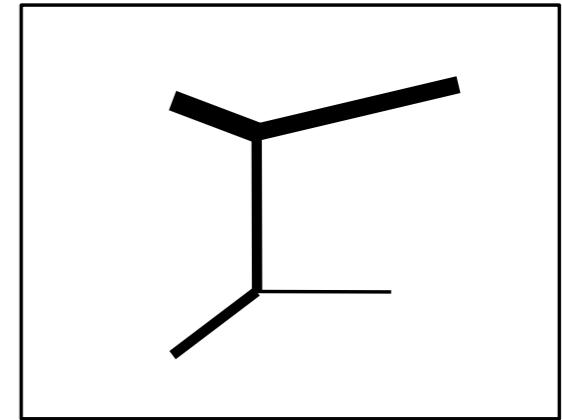
Glyphs

- Glyphs and icons
 - Consist of several components
- Features should be easy to distinguish and combine
- Icons should be separated from each other
- Mainly used for multivariate *discrete* data



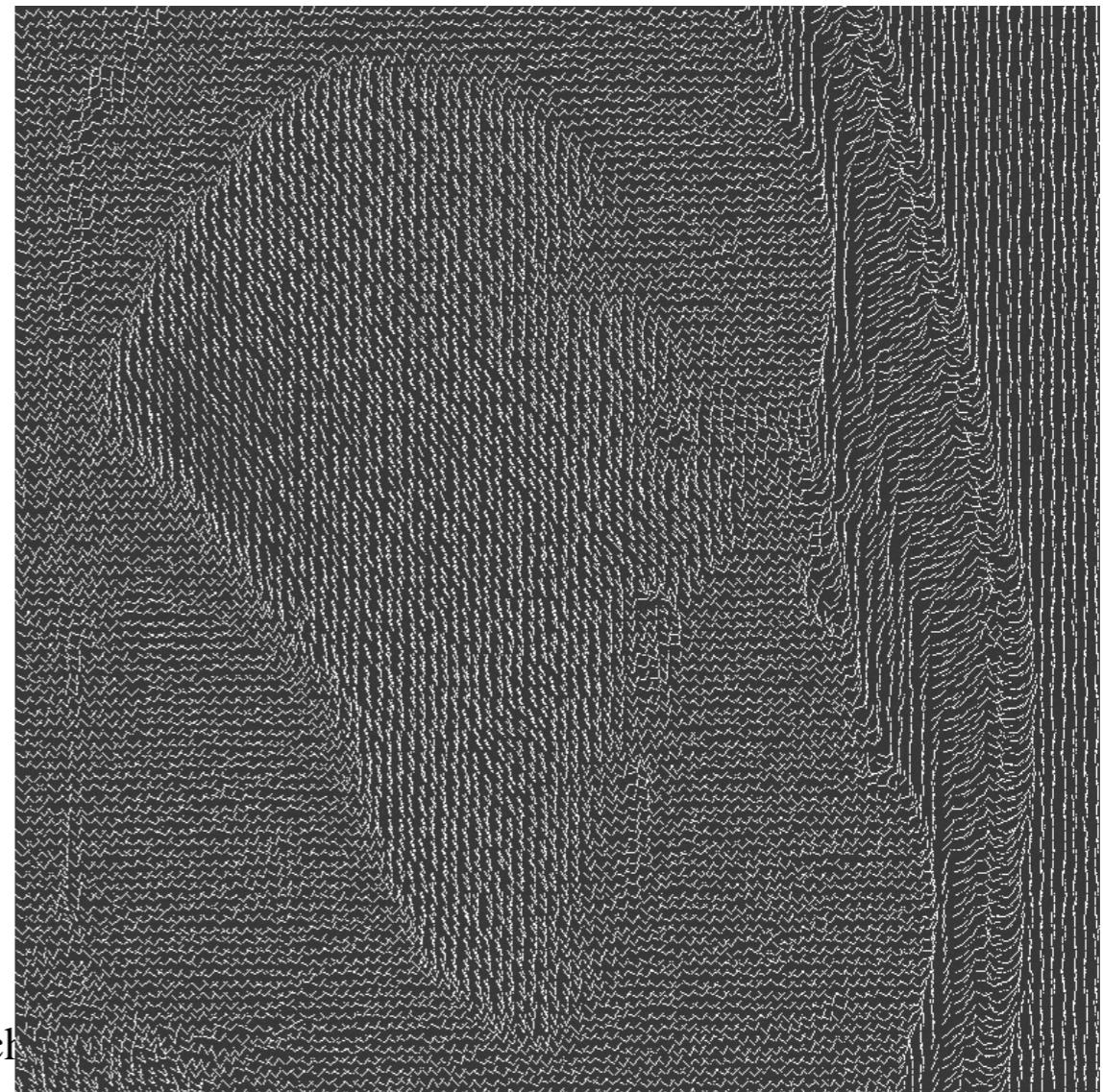
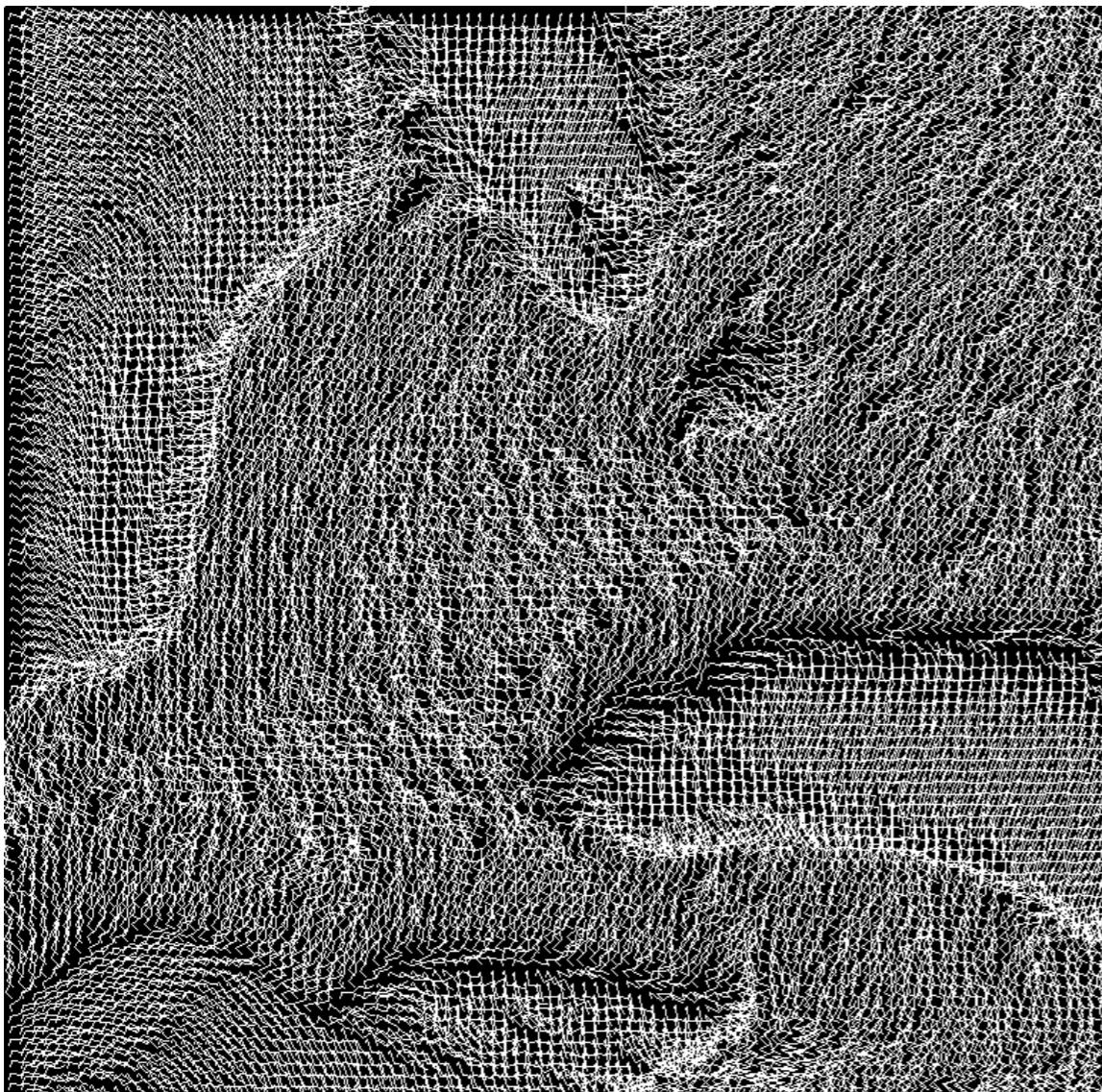
Glyphs

- Stick-figure icon [Picket & Grinstein 88]
- 2D figure with 4 limbs
- Coding of data via
 - Length
 - Thickness
 - Angle with vertical axis
- 12 attributes
- Exploits the human capability to recognize patterns/textures



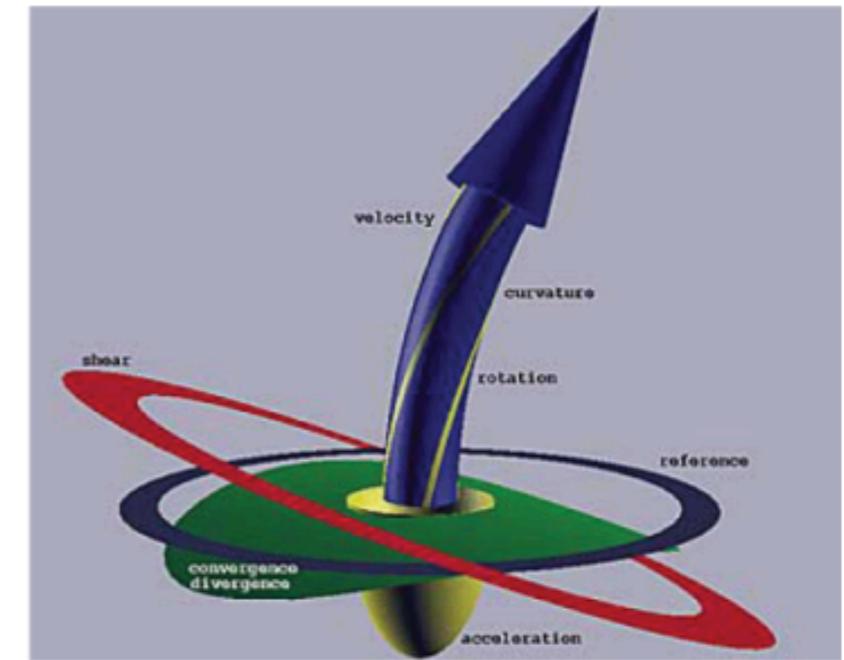
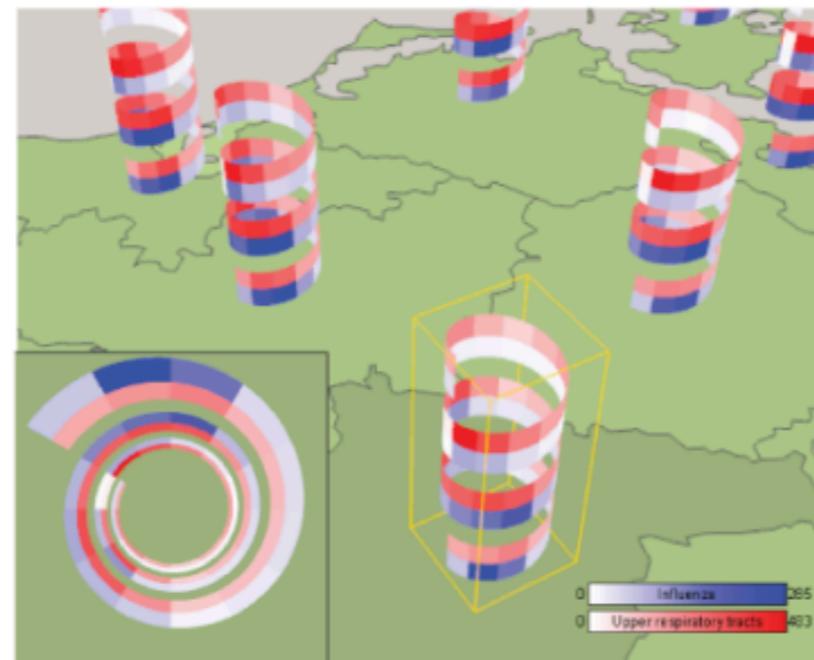
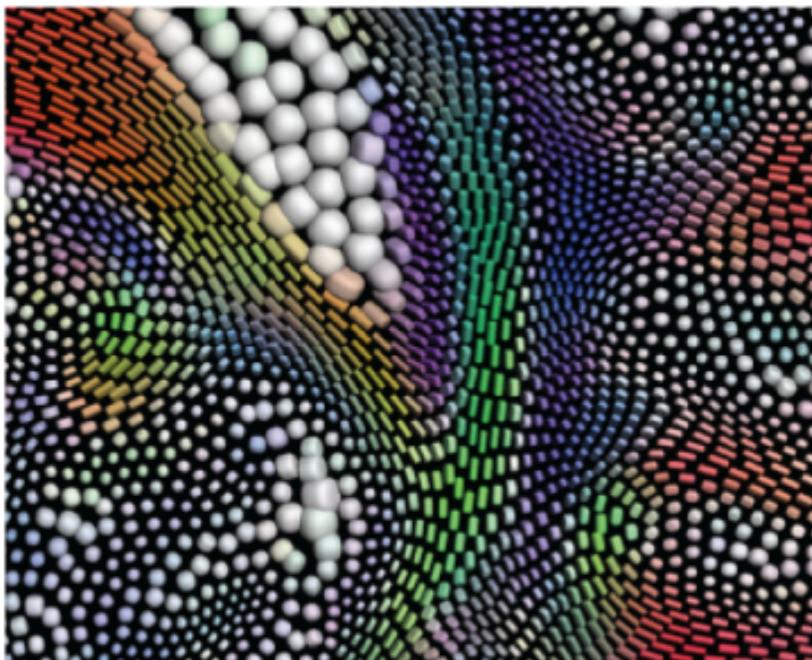
Glyphs

- Stick-figure icon



Glyph Design

- Can vary from small and simple to large and complex



Borgo et al.: **Glyph-based Visualization: Foundations, Design Guidelines, Techniques and Applications.** Eurographics (State of the Art Reports), 2013

<http://www.cs.swan.ac.uk/~csbob/research/star/glyph/borgo13glyph7feb.pdf>

Time

Using Time as an Encoding Channel

- External vs. Internal Memory
 - Easy to compare views by moving eyes
 - Hard to compare view with memory of what you saw
- Recall: Visualization's purpose is to serve as an external aid to **augment** working memory

ComParrot

by Bonnie J. Malcolm

Can you spot 12 differences between these pictures?



ComParrot

by Bonnie J. Malcolm

Can you spot 12 differences between these pictures?



ComParrot

by Bonnie J. Malcolm

Can you spot 12 differences between these pictures?



www.comparrotpuzzles.com © 2001 Bonnie J. Malcolm



by Bonnie J. Malcolm

Can you spot 12 differences between these pictures?



Solution: 1. Top tree leaf removed. 2. Nose line on left giraffe removed. 3. Shadow on lower left coconut removed. 4. Leaf vein below gecko removed. 5. Ear line on left giraffe removed. 6. Bottom spot on right giraffe colored in. 7. Small leaf at right of tree colored in. 8. Horn on right giraffe moved. 9. Spot on left giraffe moved. 10. Branch on left side shorter. 11. Gecko tail longer. 12. Gecko eye missing.

Good Use: Storytelling

Hans Rosling shows the best stats you've ever seen | Video on TED.com

http://www.ted.com/talks/hans_rosling_shows_the_best_stats_you_ve_ever_seen.html

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TALKS

Hans Rosling shows the best stats you've ever seen

TED2006, Filmed Feb 2006; Posted Jun 2006



3,471,109 Views [Like](#) 33k

INTERACTIVE TRANSCRIPT

ABOUT THE SPEAKER

ABOUT THIS TALK

You've never seen data presented like this. With the drama and urgency of a sportscaster, statistics guru Hans Rosling debunks myths about the so-called "developing world."

THE ROLEX ARTS INITIATIVE PAIRS ESTABLISHED MENTORS WITH EMERGING PROTÉGÉS FOR A YEAR OF CREATIVE COLLABORATION

00:17 | 19:53 Share Rate

WHAT TO WATCH NEXT

Bad Use: Comparing Complex State Changes Over Time

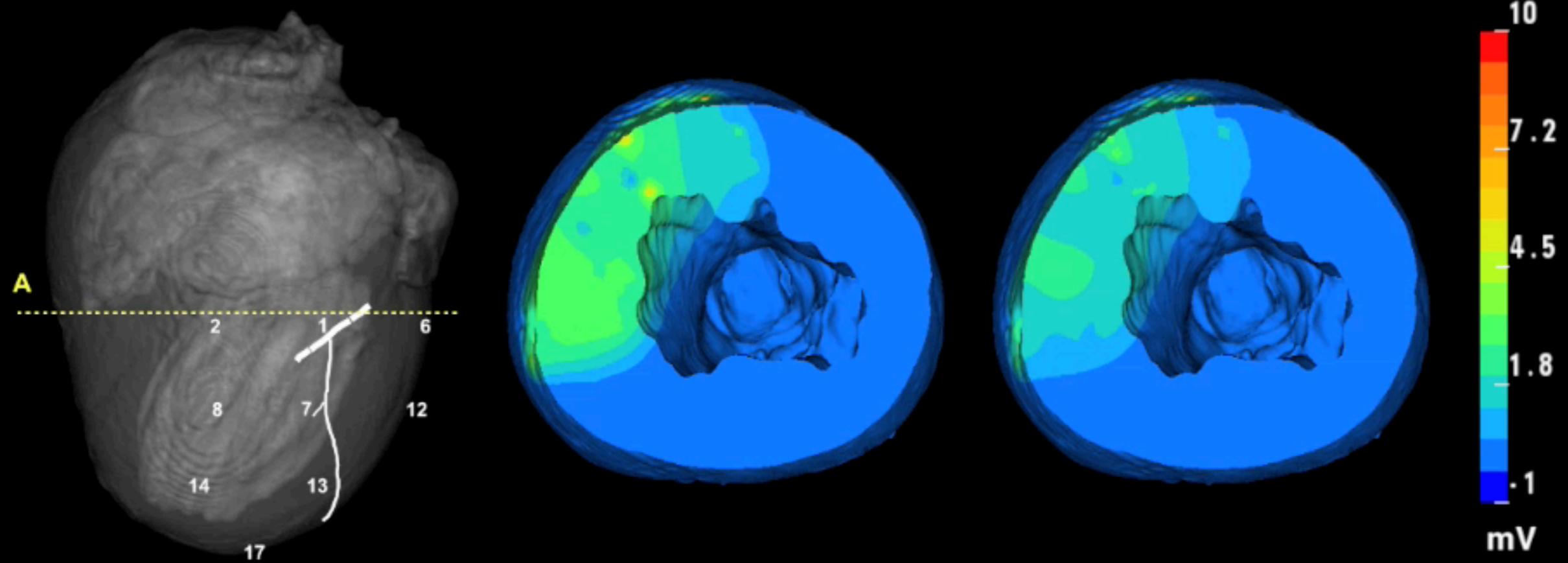
RSM-09-11-03 Canine In Situ Model

Progression of ST Elevated Regions (ST 40)

Axial Plane A

Demand

Supply



Flow Rate: 35ml

Pacing Rate: 400ms

Occlusion Cycle: 15

Bad Use: Comparing Complex State Changes Over Time

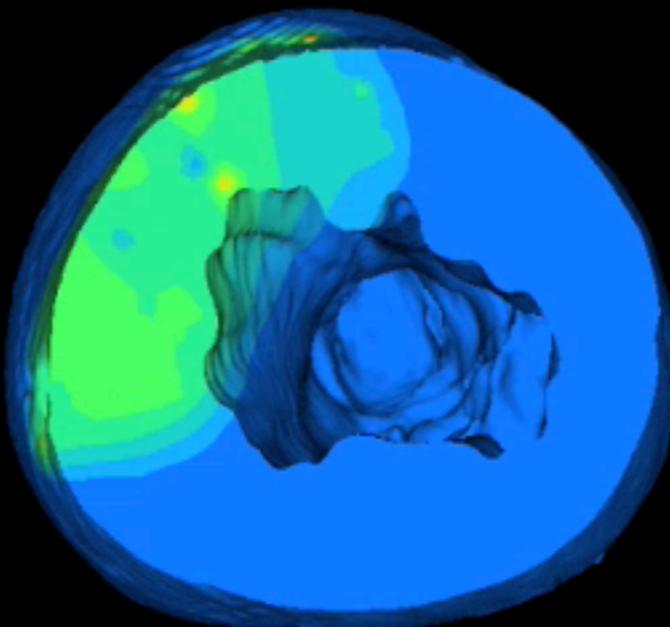
RSM-09-11-03 Canine In Situ Model

Progression of ST Elevated Regions (ST 40)

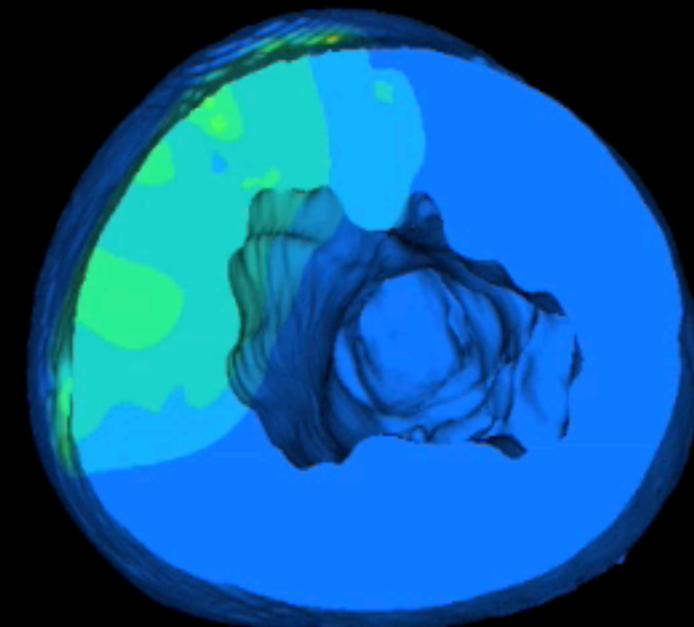
Axial Plane A



Demand



Supply



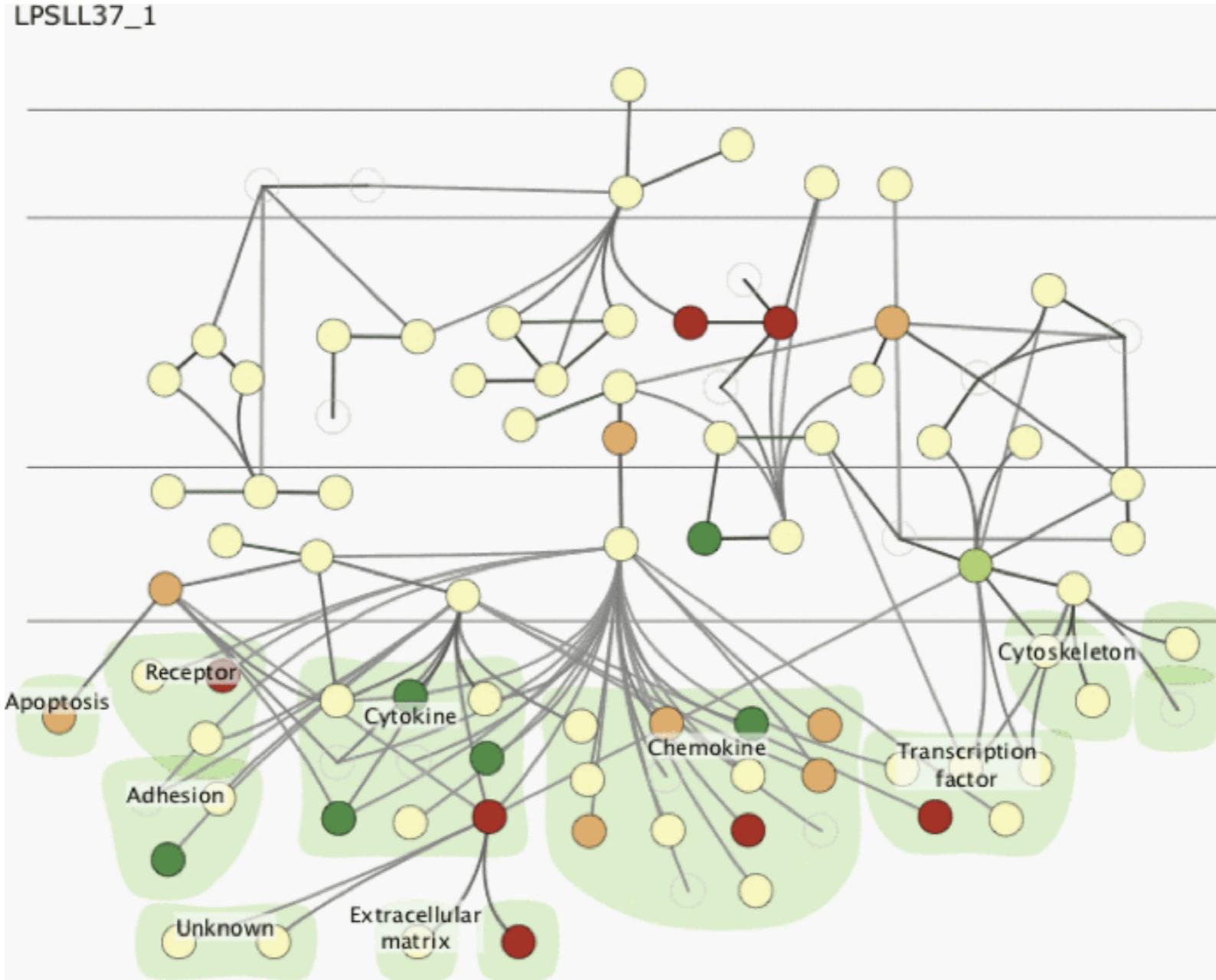
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Pacing Rate: 400ms

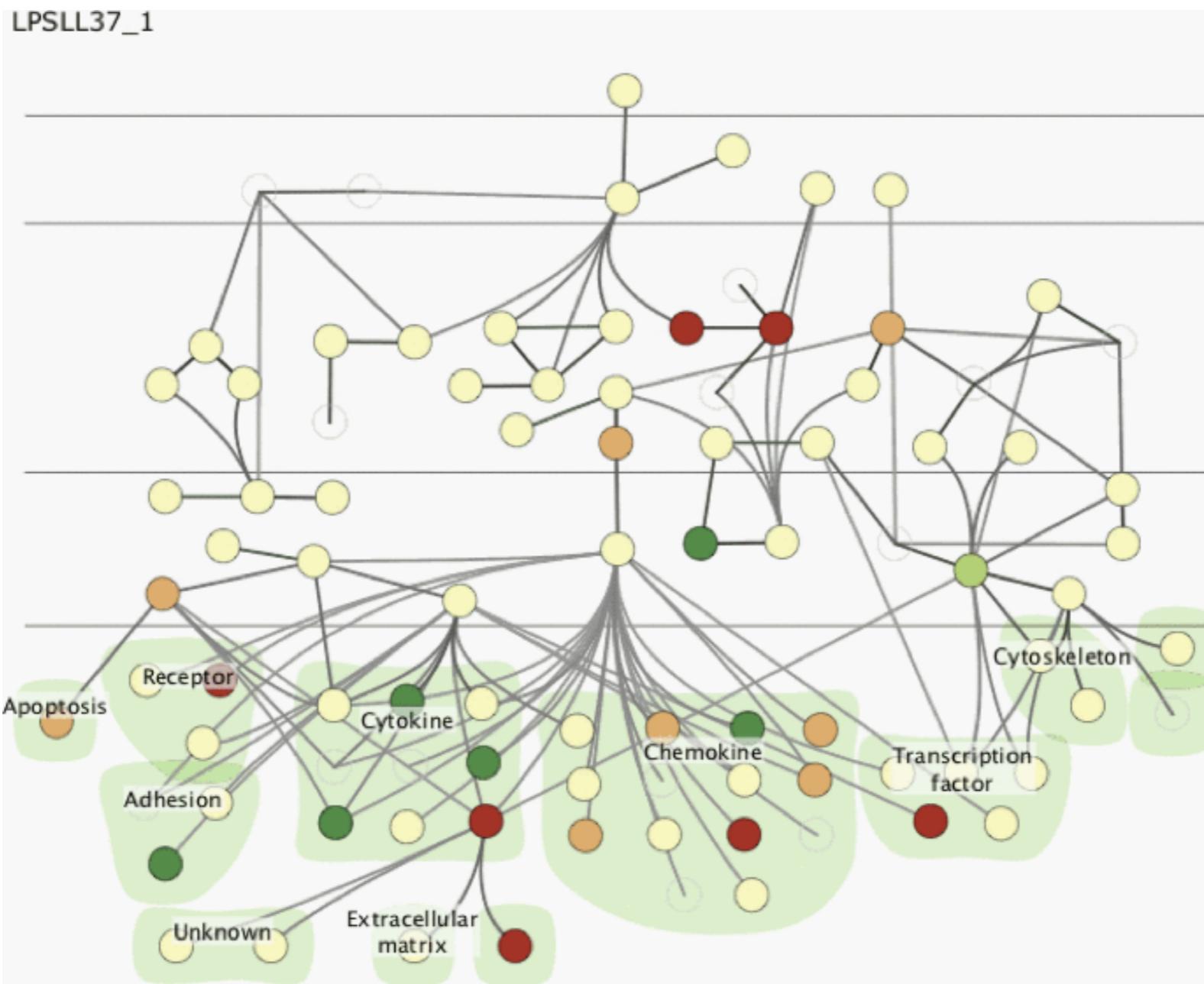
Occlusion Cycle: 15

Bad Use: Multiple States with Multiple Changes

LPSLL37_1

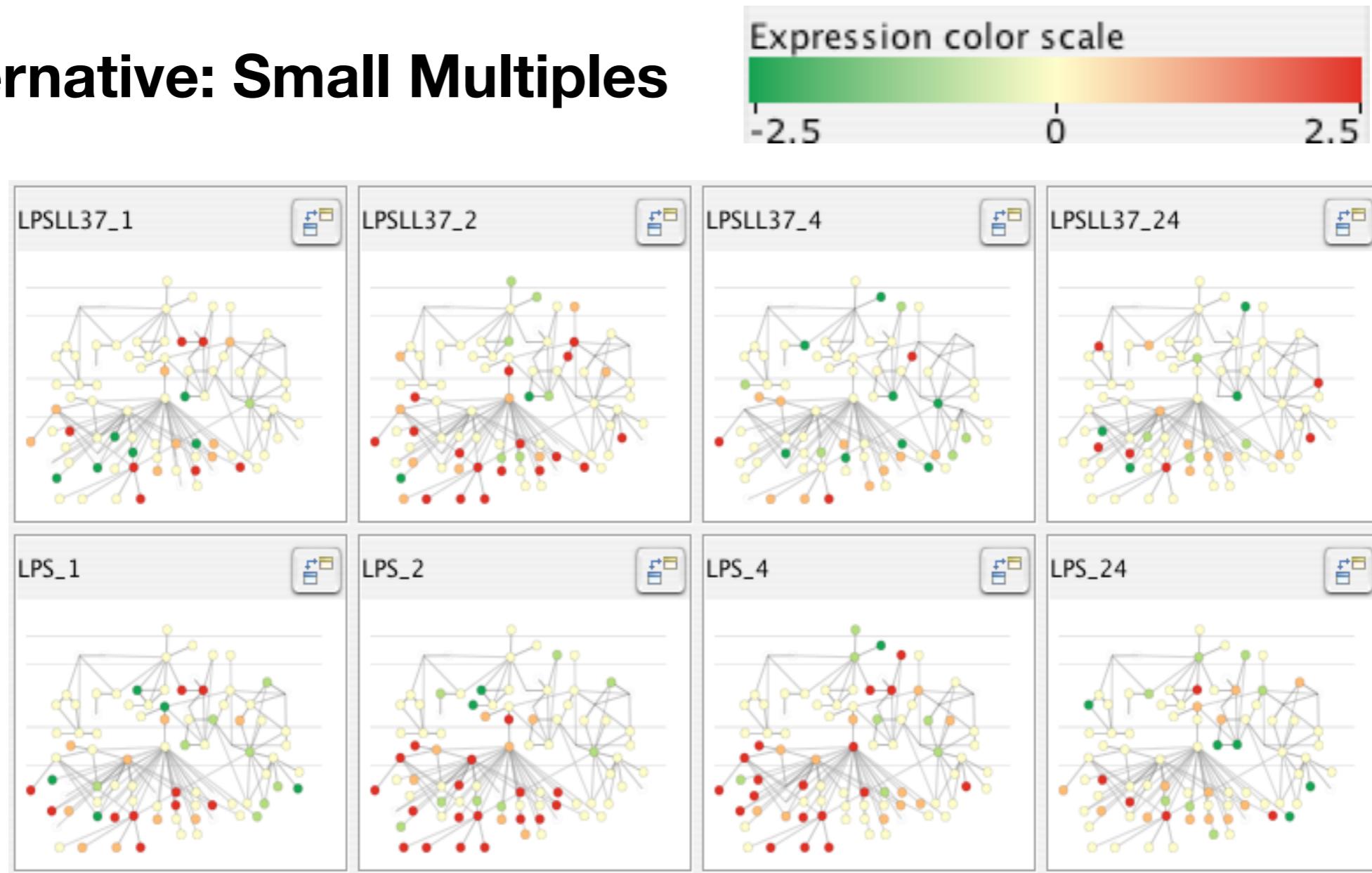


Bad Use: Multiple States with Multiple Changes



Bad Use: Multiple States with Multiple Changes

Alternative: Small Multiples



Barsky et al. Cerebral: visualizing multiple experimental conditions
on a graph with biological context. IEEE TVCG 2008

Lec09 Reading

- Munzner, Ch. 10.1-10.3
- Muth, Which color scale to use when visualizing data. (All 4 parts).
- Many recommended readings and resources!!

Reminder

Assignment 02

Assigned: Monday, February 6

Due: Monday, February 20, 4:59:59 pm

Reminder

Project Milestone 01

Assigned: Monday, January 25

Due: Wednesday, February 22, 4:59:59 pm