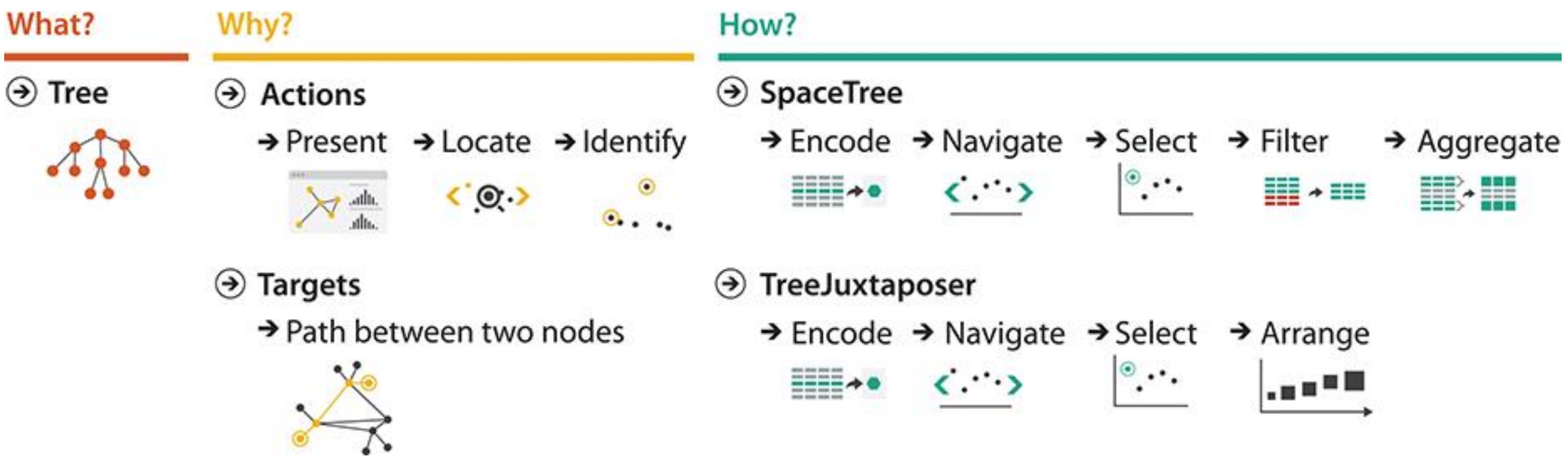
Analysis Framework

Yu-Shuen Wang, CS, NCTU

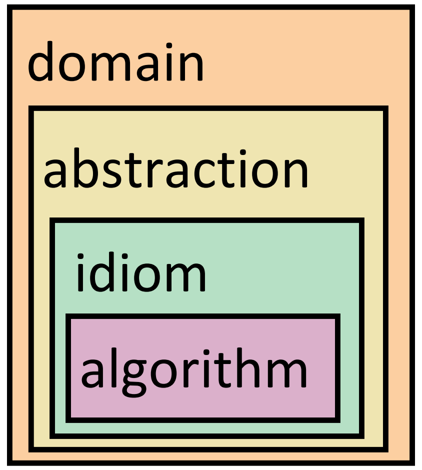
Visualization Analysis and Design. Tamara Munzner, with illustrations by Eamonn Maguire. A K Peters Visualization Series, CRC Press, 2014.

- What is shown?
  - Data abstraction
- Why is the user looking at it?
  - Task abstraction
- How is it shown?
  - Idiom: visual encoding and interaction

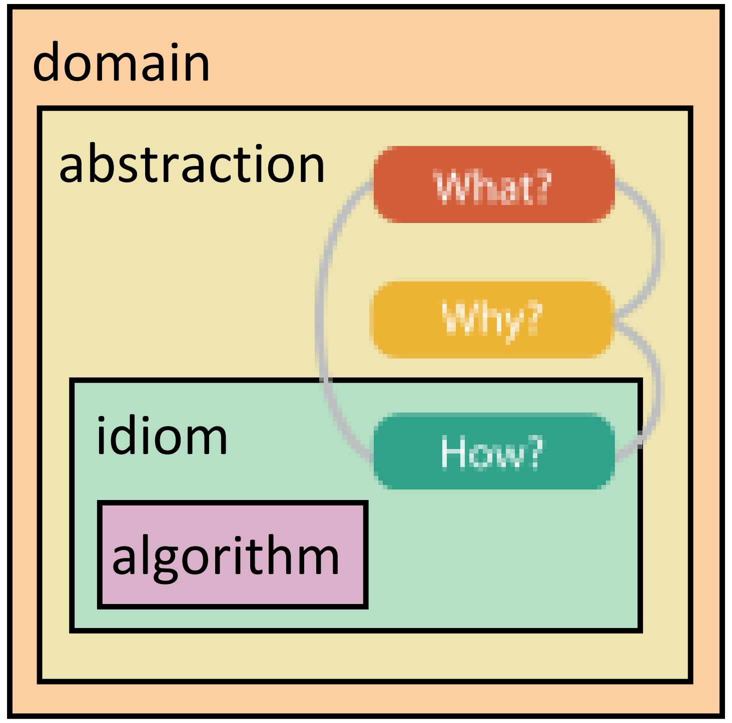


Analysis framework: Four levels, three questions

- *domain* situation
  – who are the target users?
- *abstraction*
  – translate from specifics of domain to vocabulary of vis
- what is shown? data abstraction
  - often don't just draw what you're given: transform to new form
- why is the user looking at it? task abstraction
- *idiom*
- how is it shown?
  - visual encoding idiom: how to draw
  - interaction idiom: how to manipulate
- *algorithm*
  – efficient computation



[A Nested Model of Visualization Design and Validation.
Munzner. IEEE TVCG 15(6):921-928, 2009 (Proc. InfoVis 2009).]



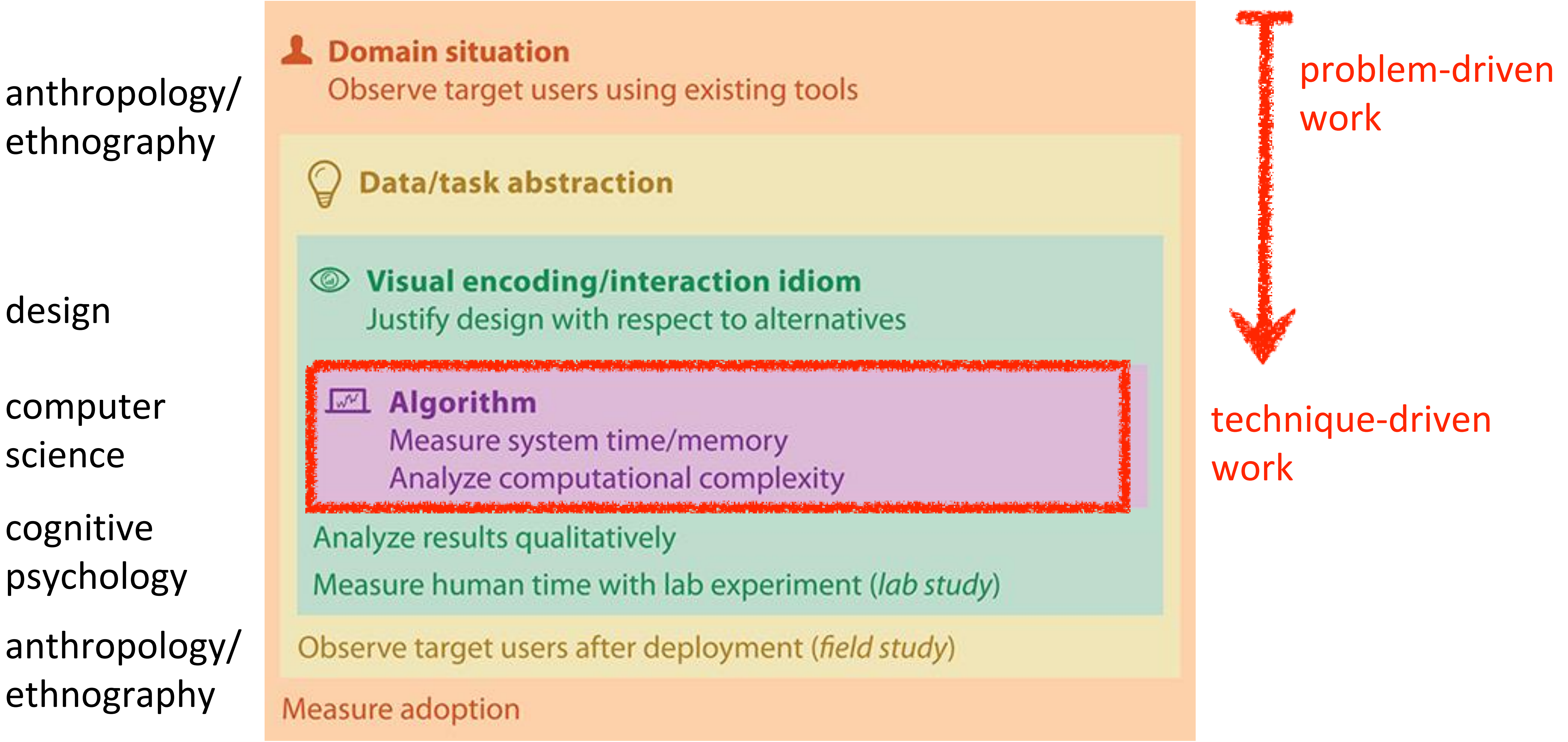
[A Multi-Level Typology of Abstract Visualization Tasks
Brehmer and Munzner. IEEE TVCG 19(12):2376-2385, 2013 (Proc. InfoVis 2013).]

Why is validation difficult?

- different ways to get it wrong at each level

Why is validation difficult?

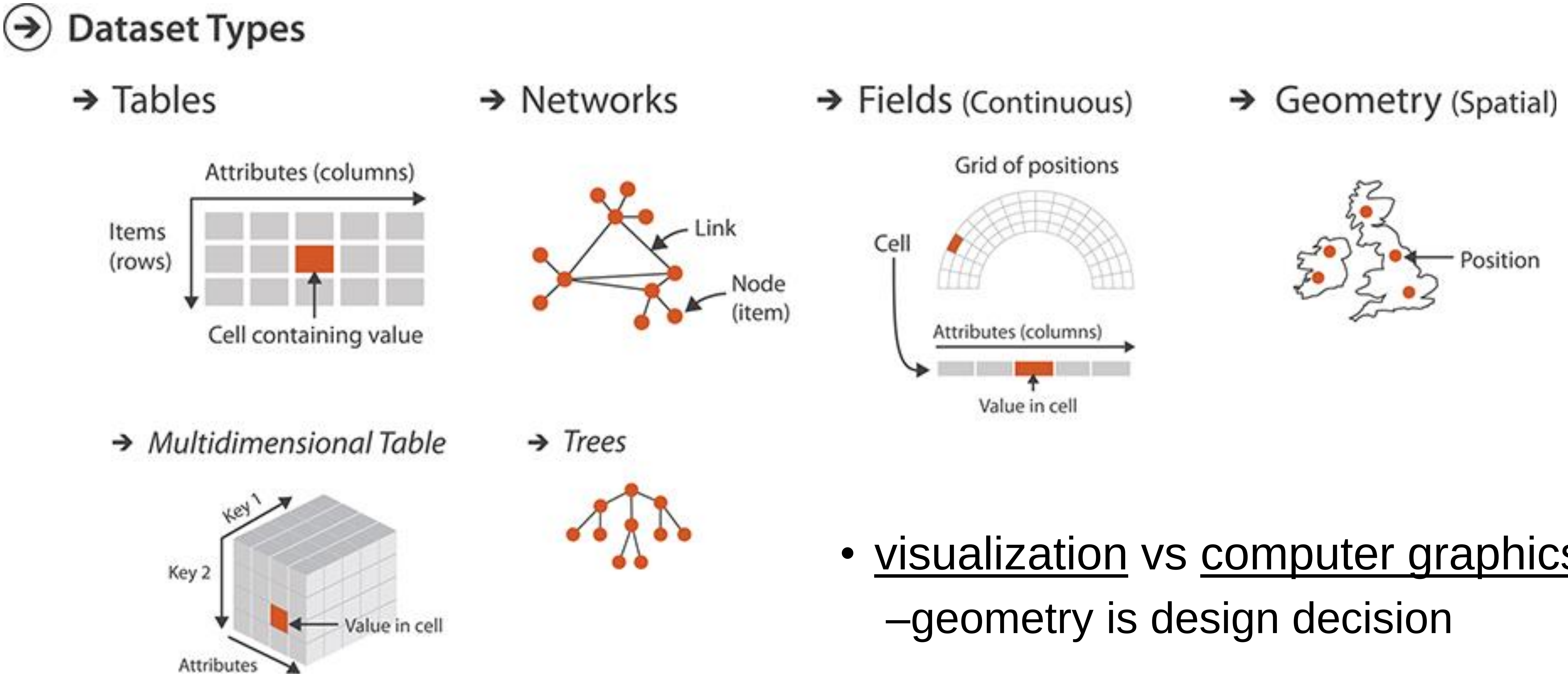
- solution: use methods from different fields at each level



[A Nested Model of Visualization Design and Validation. Munzner. IEEE TVCG 15(6):921-928, 2009 (Proc. InfoVis 2009).]

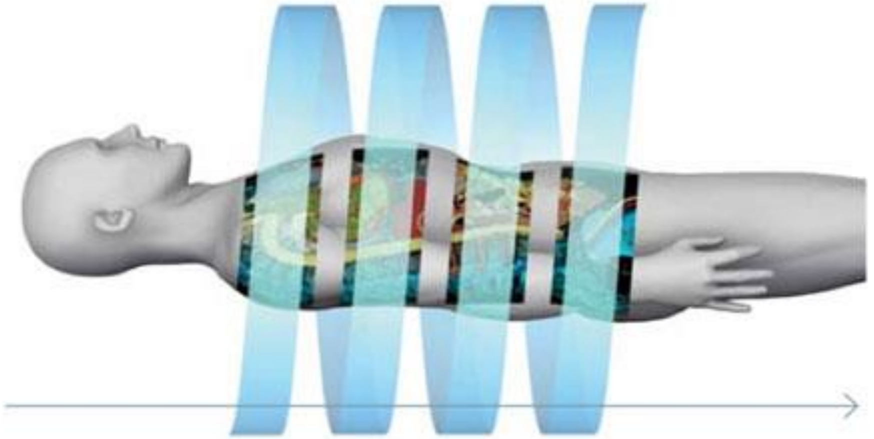
What?

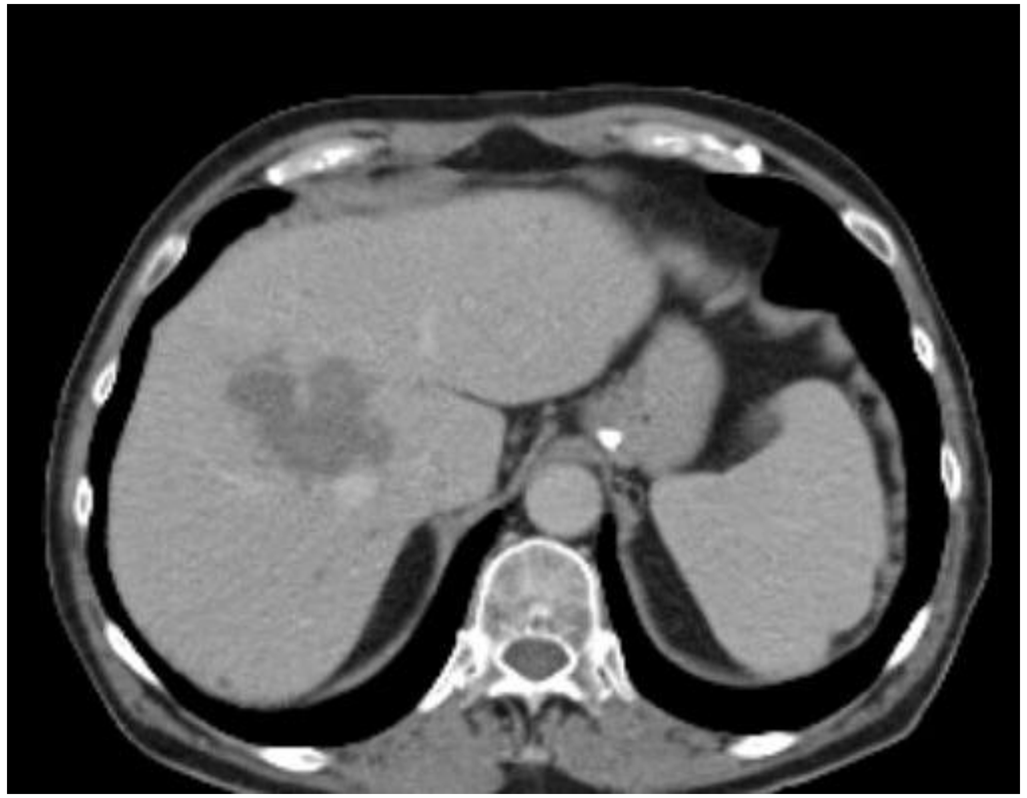
- Dataset
- Attribute

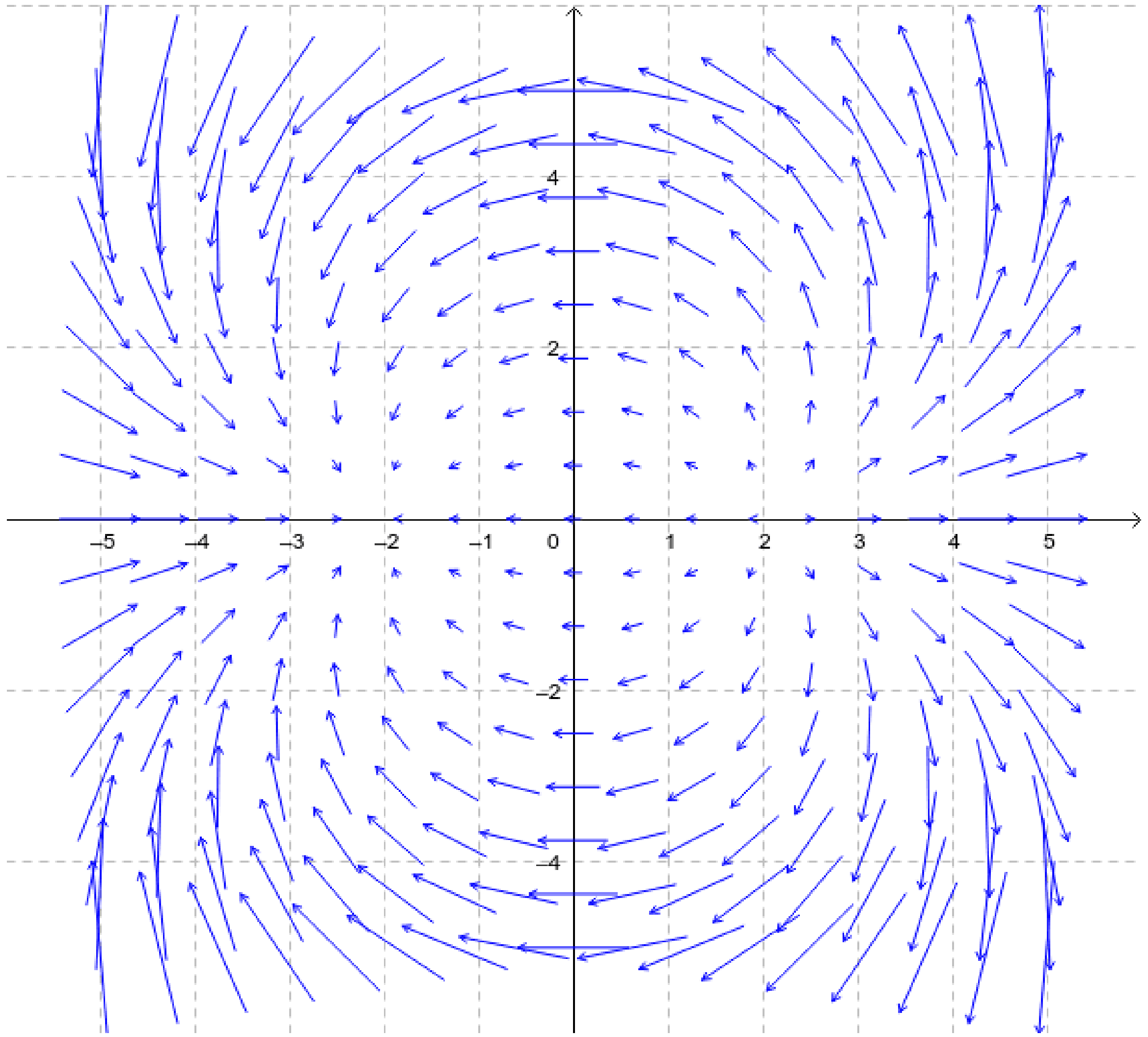


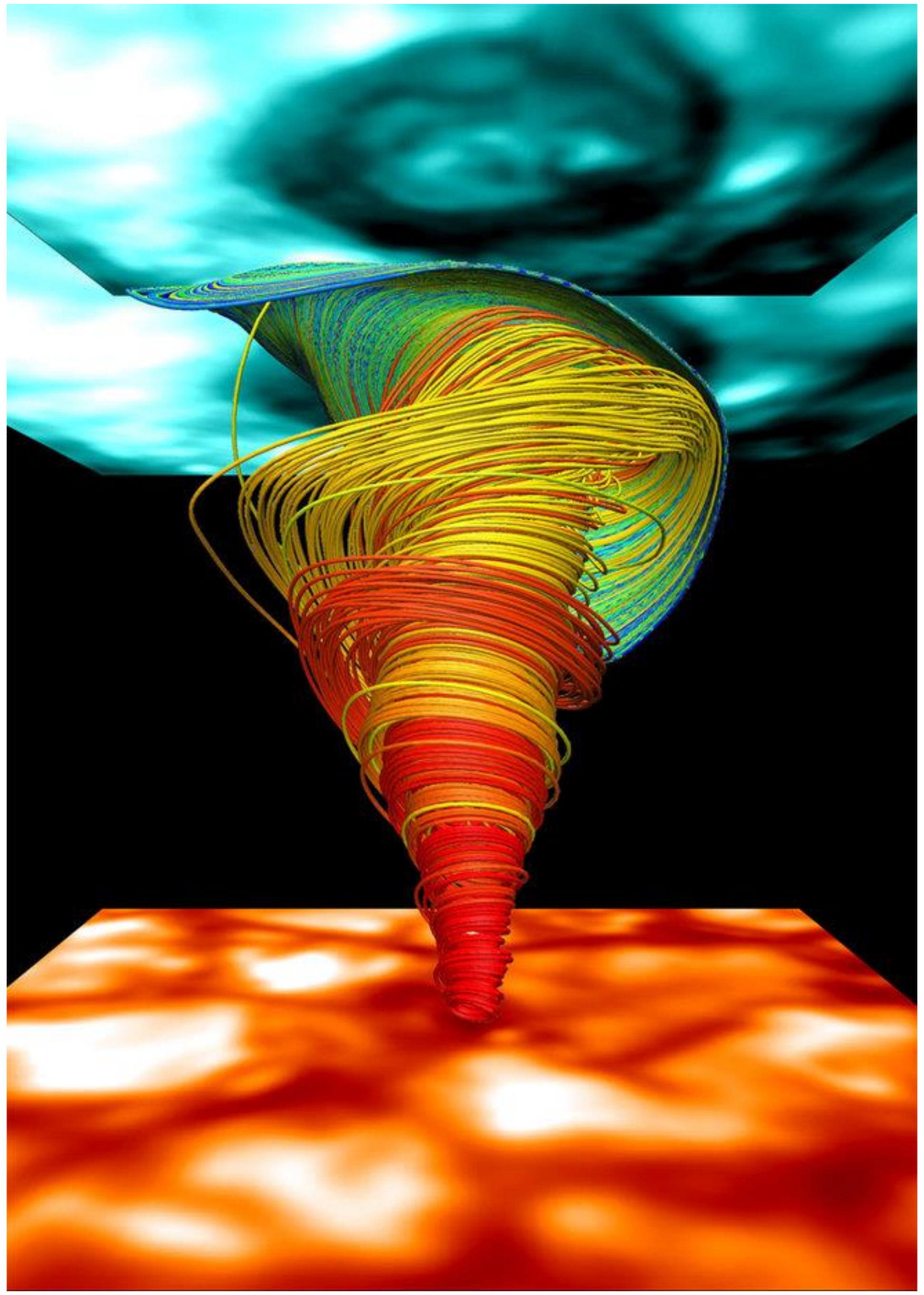
- visualization vs computer graphics
  - –geometry is design decision

Field data









➔ Data and Dataset Types

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

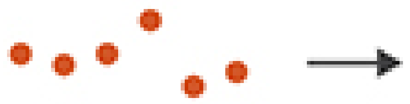
➔ Data Types

- ➔ Items
- ➔ Attributes
- ➔ Links
- ➔ Positions
- ➔ Grids

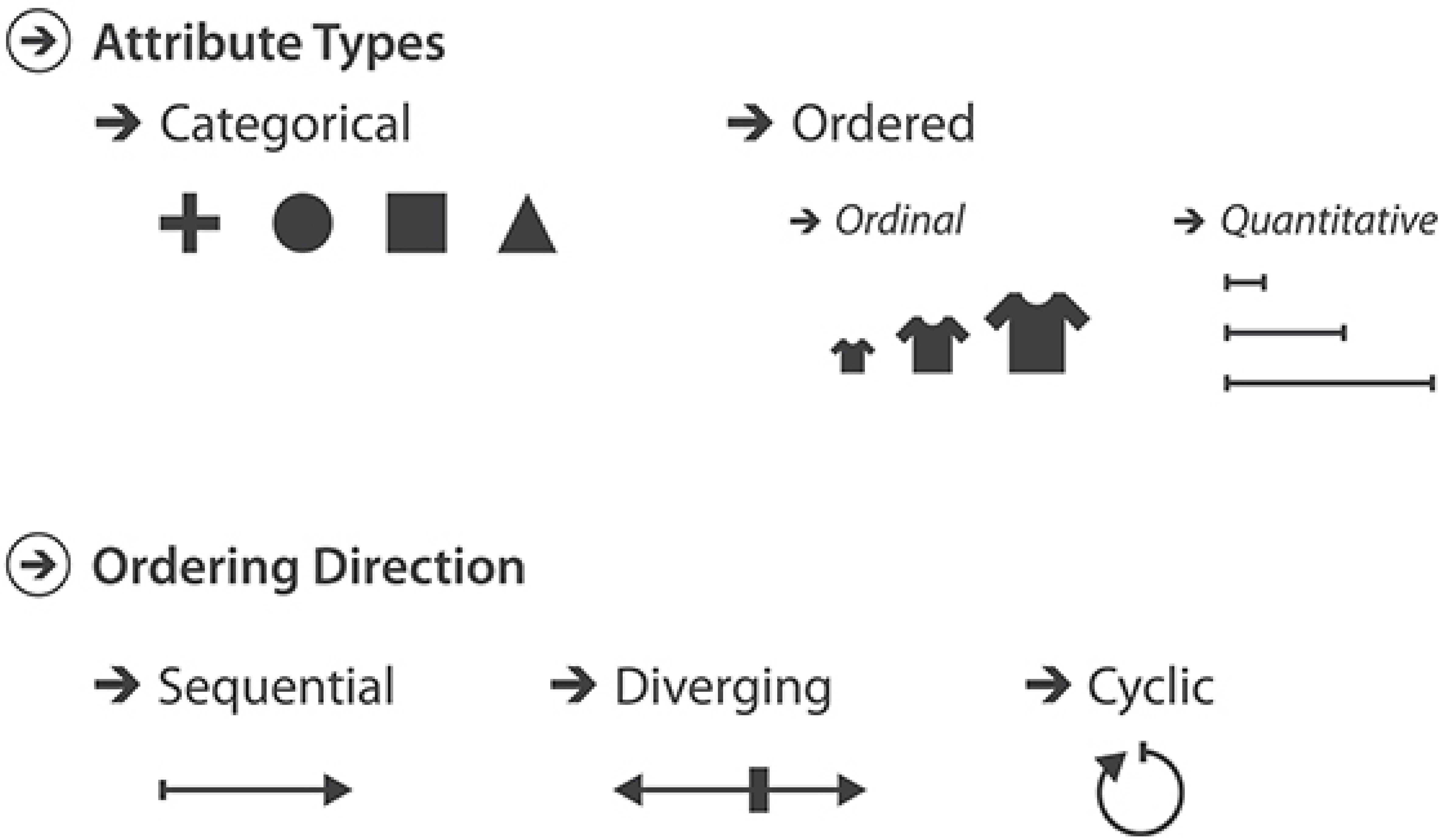
➔ Dataset Availability

- ➔ Static

- ➔ Dynamic



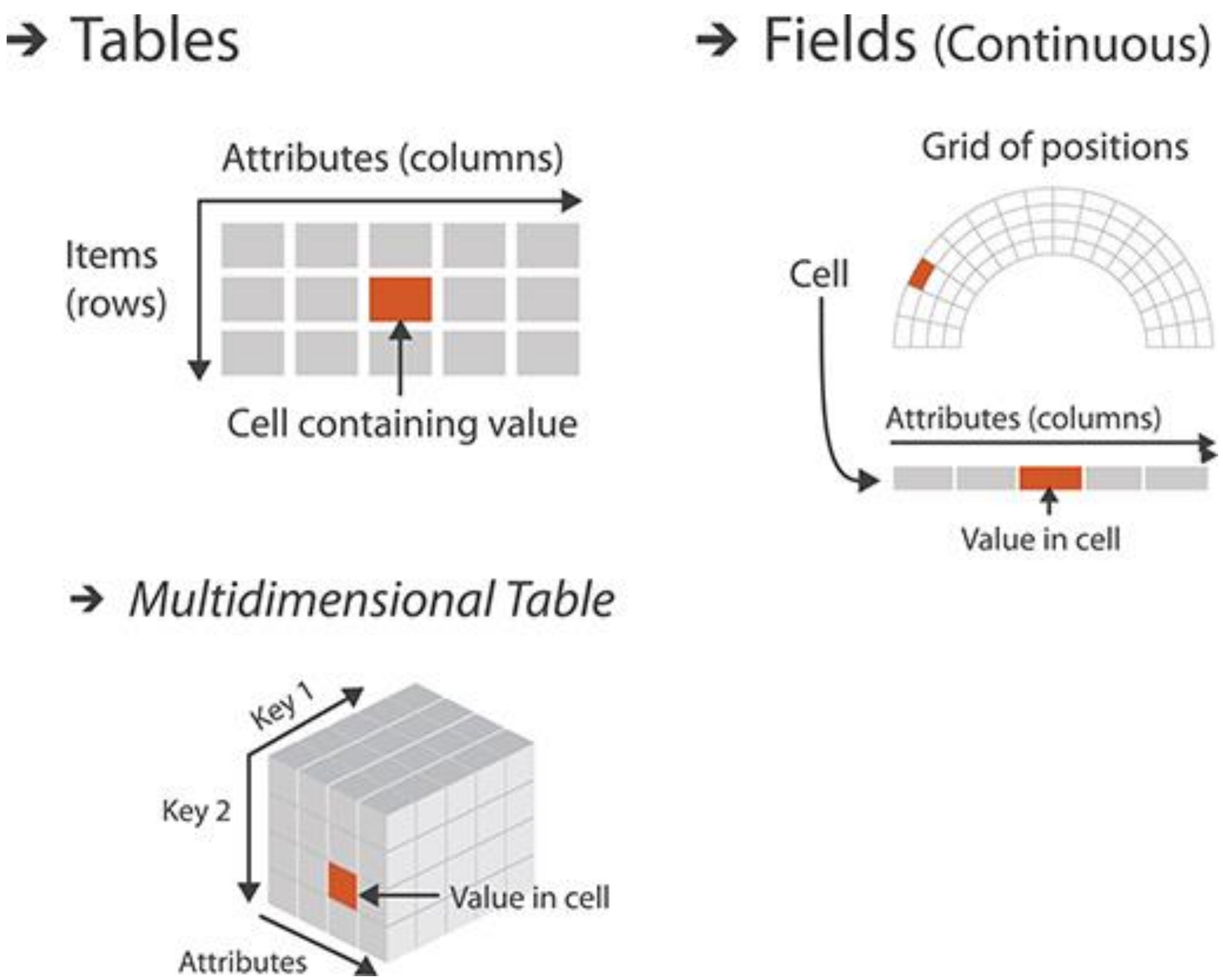
Attributes



Attribute Types
Categorical
Ordered
Ordinal
Quantitative
Ordering Direction
Sequential
Diverging
Cyclic

Key versus Value Semantics

Key as an index to look up value attributes



Temporal semantics

Time-varying

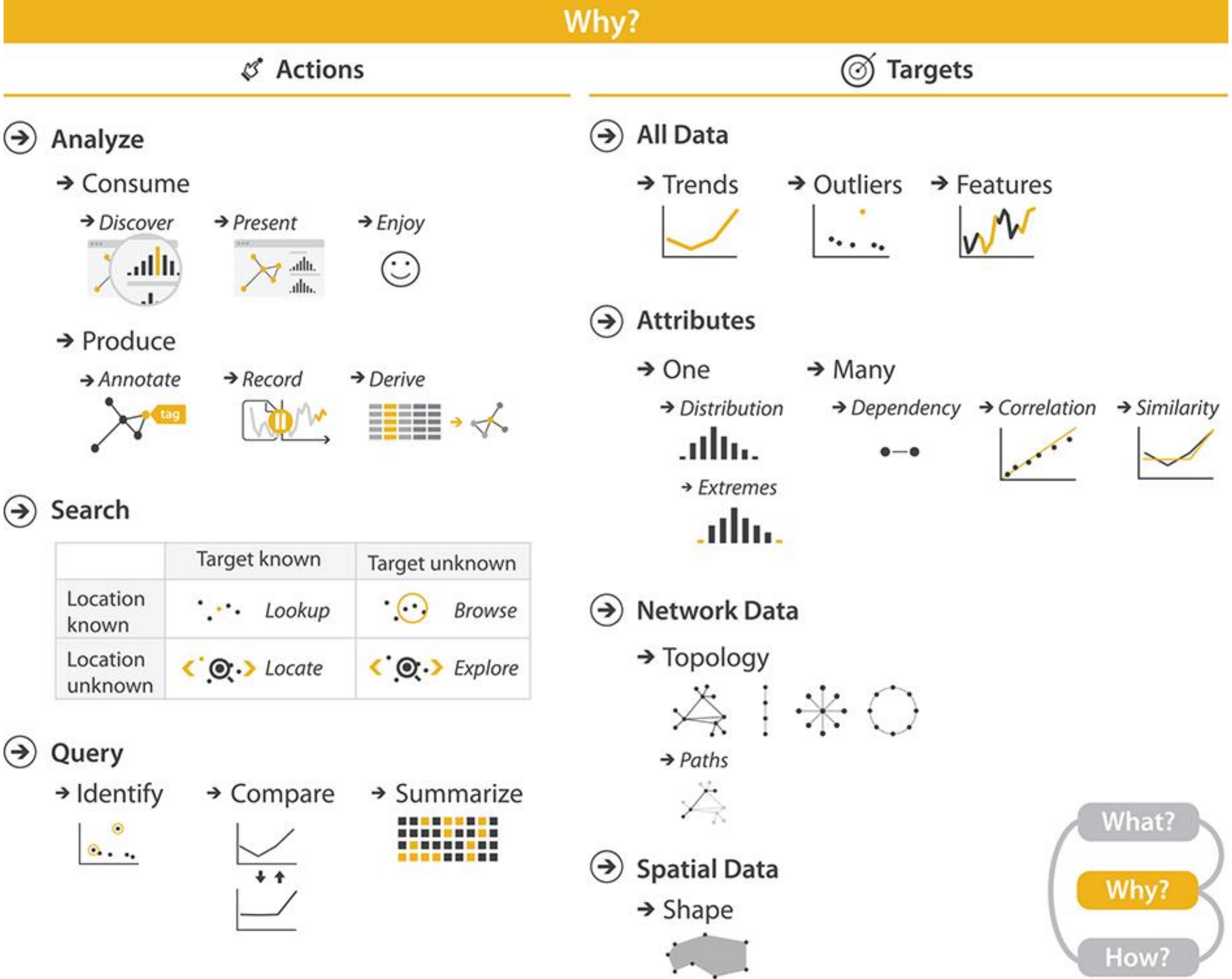
- Time is one of the key attributes (e.g., the location of each animal every second)
- Time-series
  - An ordered sequence of time-value pairs

Dynamic

- Time varying
- Stream: change in the running session

Why?

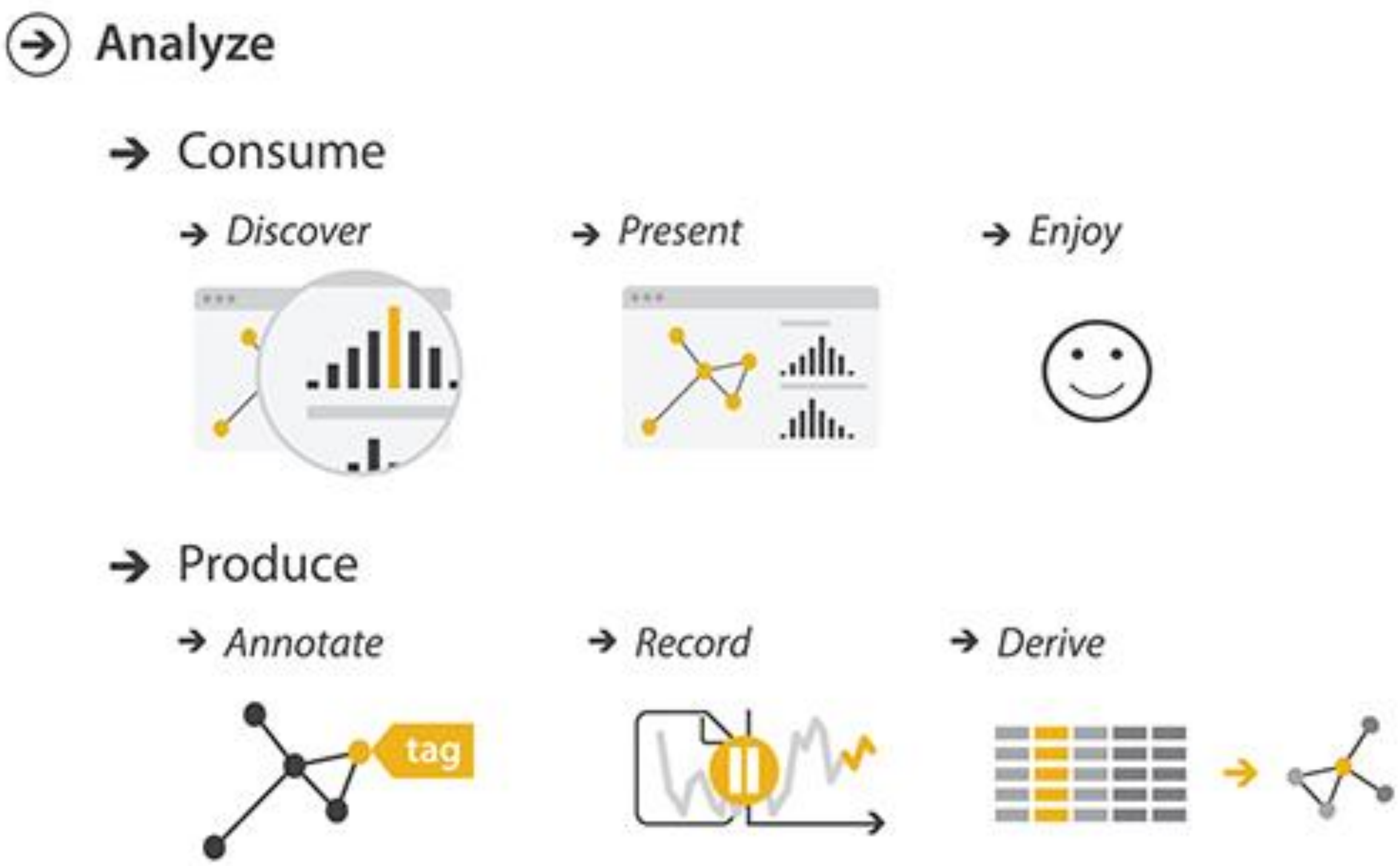
- {action, target} pairs
  - –*discover distribution*
  - –*compare trends*
  - –*locate outliers*
  - –*browse topology*



Actions: Analyze

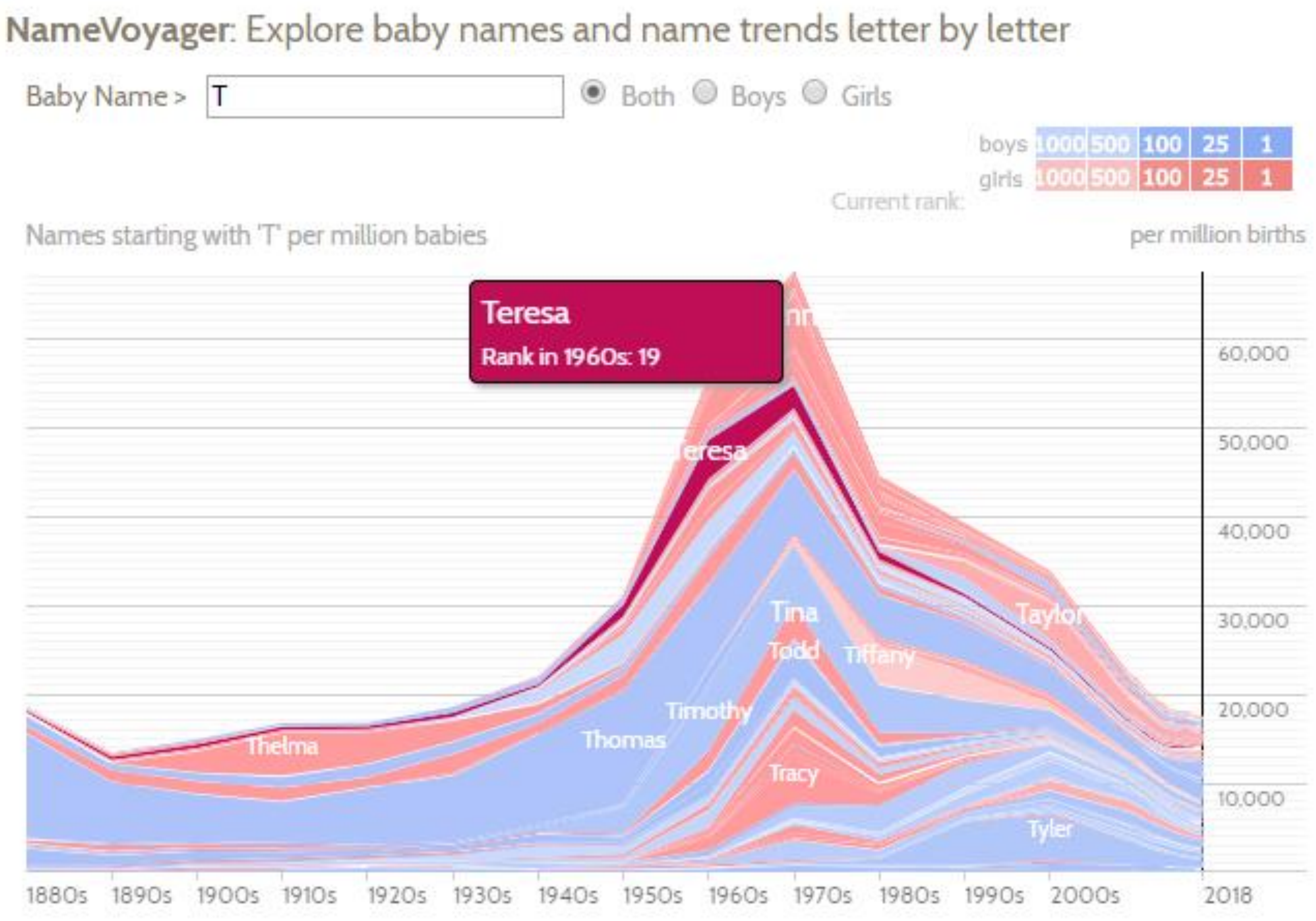
- **consume**
  - discover vs present
    - classic split
    - aka explore vs explain
  - enjoy
    - newcomer
    - aka casual, social

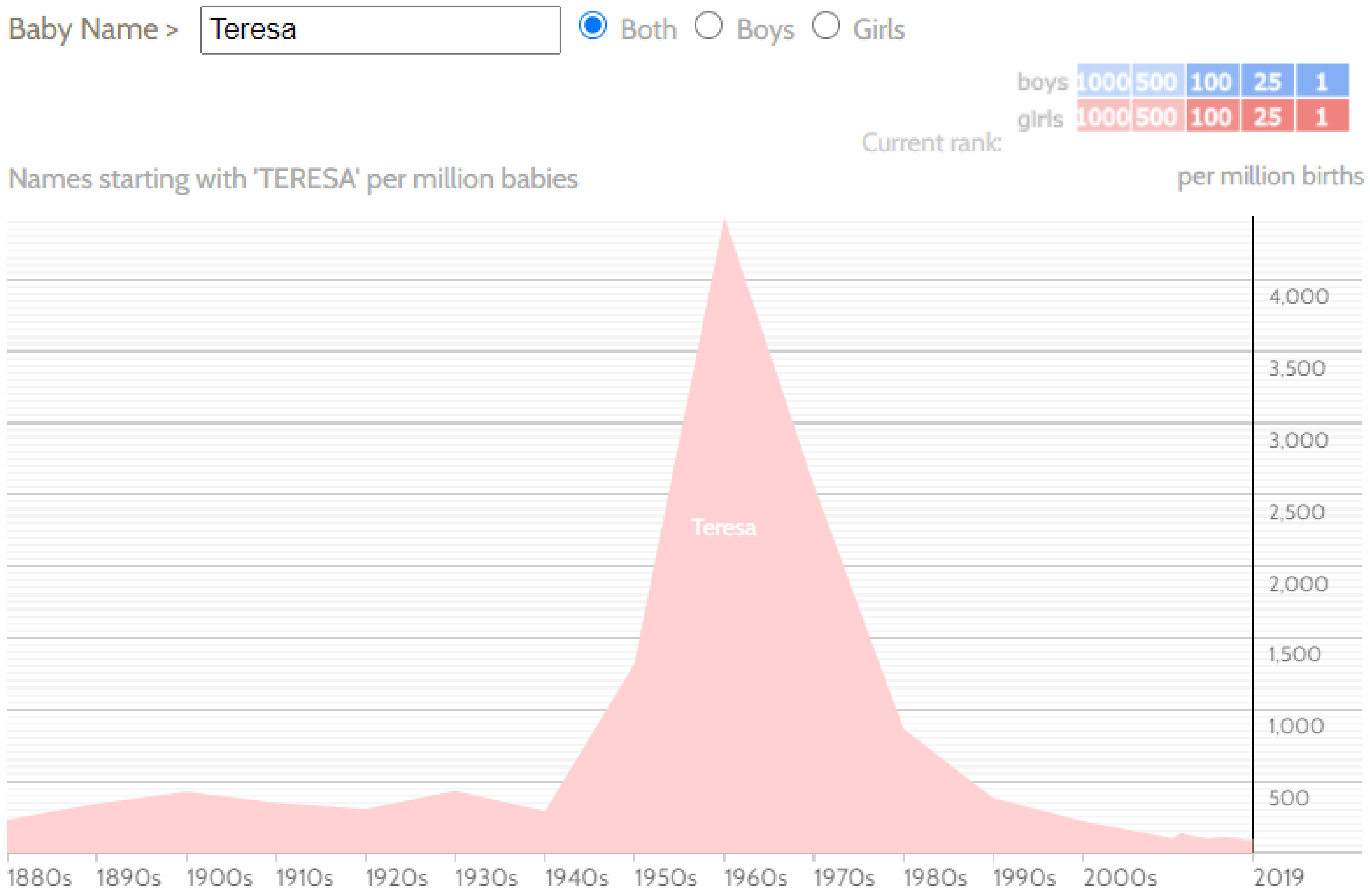
- **produce**
  - annotate, record
  - derive
    - crucial design choice



Enjoy

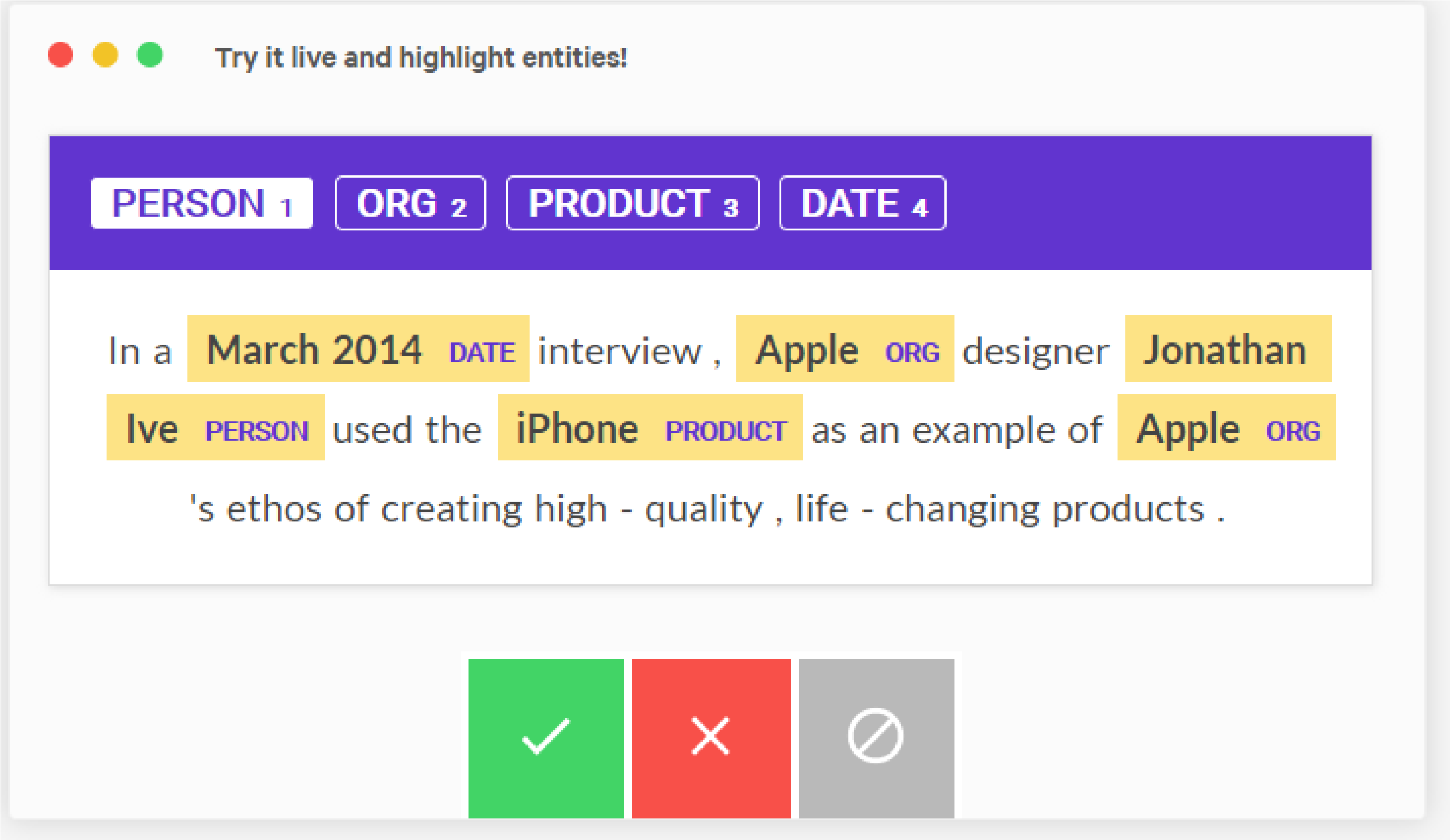
- Name Voyager





Annotate

LabelMe



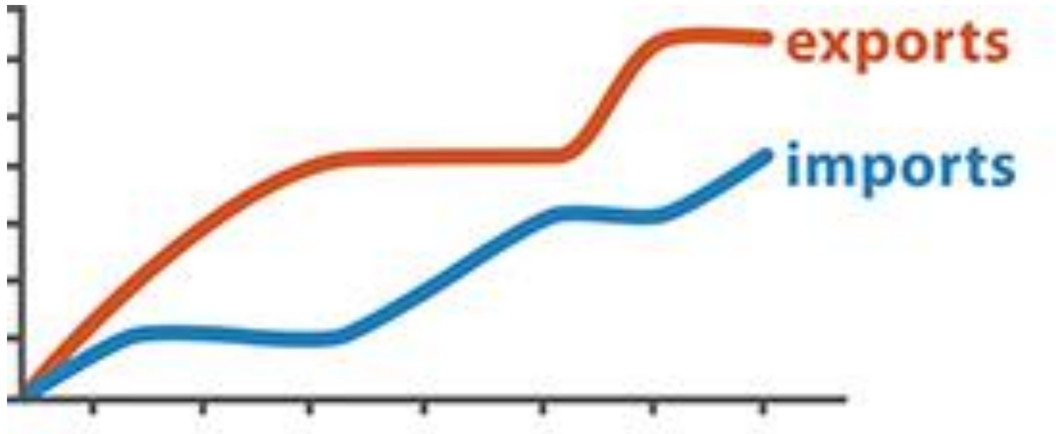
https://prodi.gy/

Record

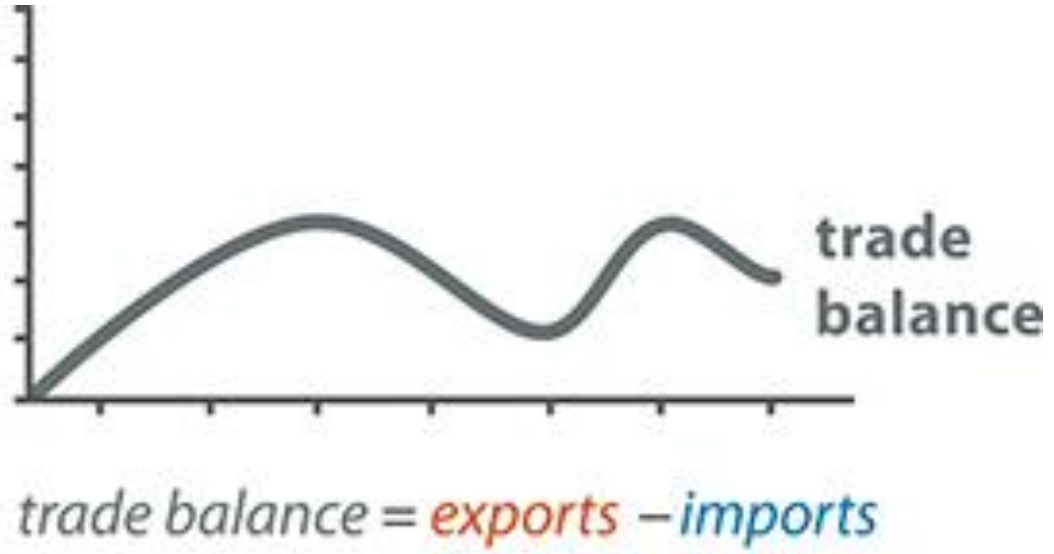
- Working history. [Heer et al. 08]

Derive

- don't just draw what you're given!
  - decide what the right thing to show is
  - create it with a series of transformations from the original dataset
  - draw that
- one of the four major strategies for handling complexity



Original Data

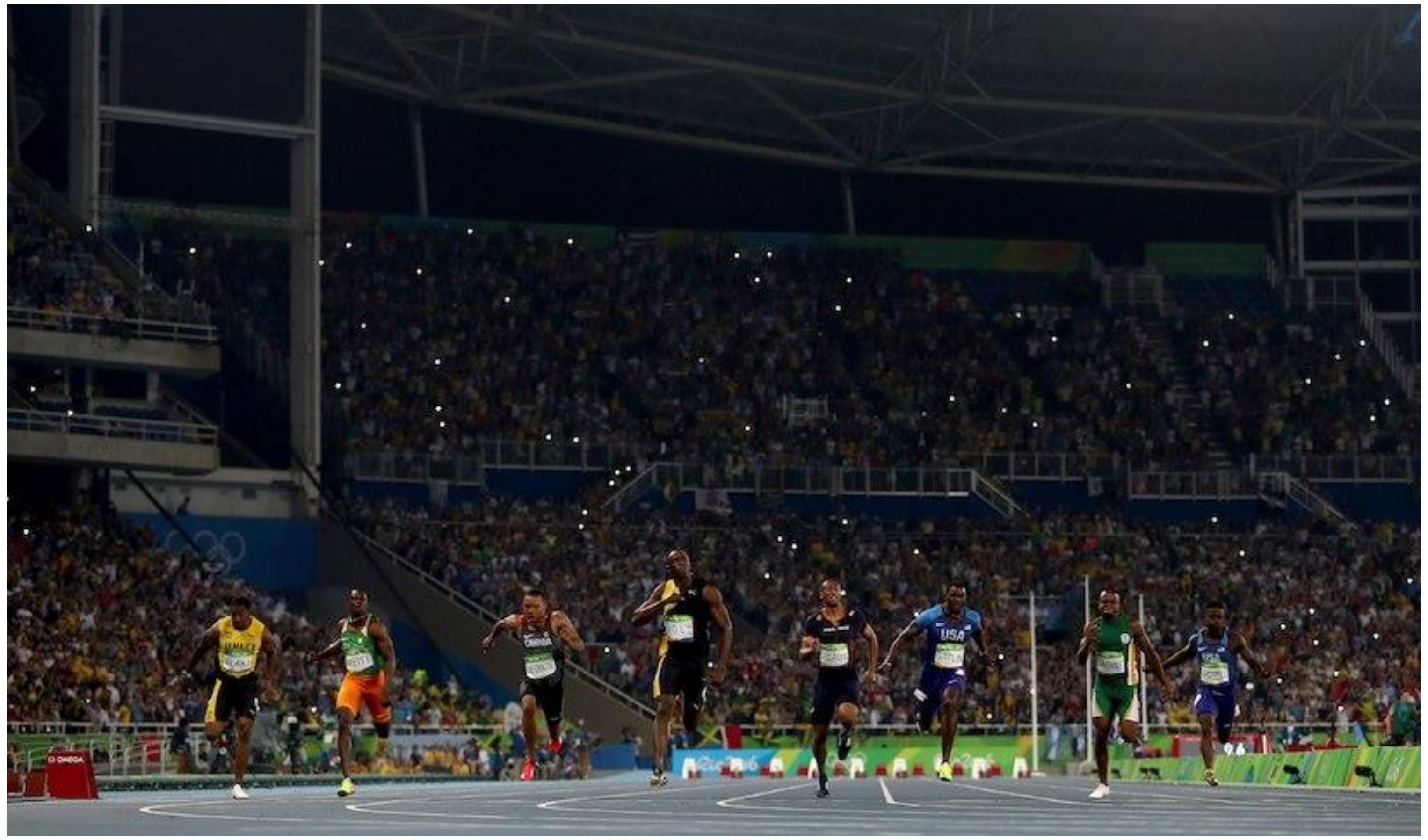


Derived Data

NY Times - **Men's 100-Meter Sprint**

- Olympic 2012

	Gold	Silver	Bronze
2012	9.63	9.75	9.79
2008	9.69	9.89	9.91
2004	9.85	9.86	9.87
…			

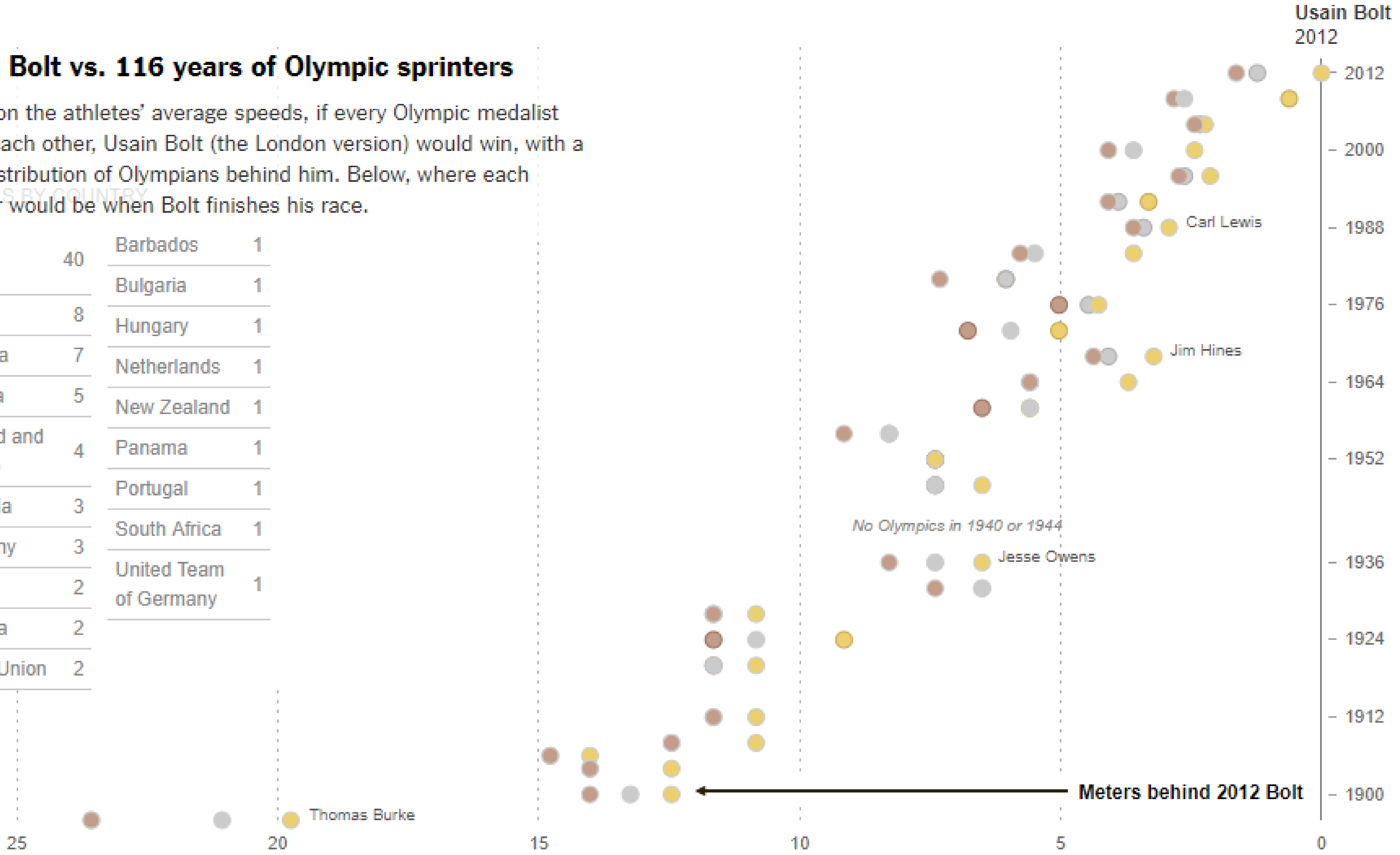


Usain Bolt vs. 116 years of Olympic sprinters

Based on the athletes' average speeds, if every Olympic medalist raced each other, Usain Bolt (the London version) would win, with a wide distribution of Olympians behind him. Below, where each sprinter would be when Bolt finishes his race.

MEDALS BY COUNTRY

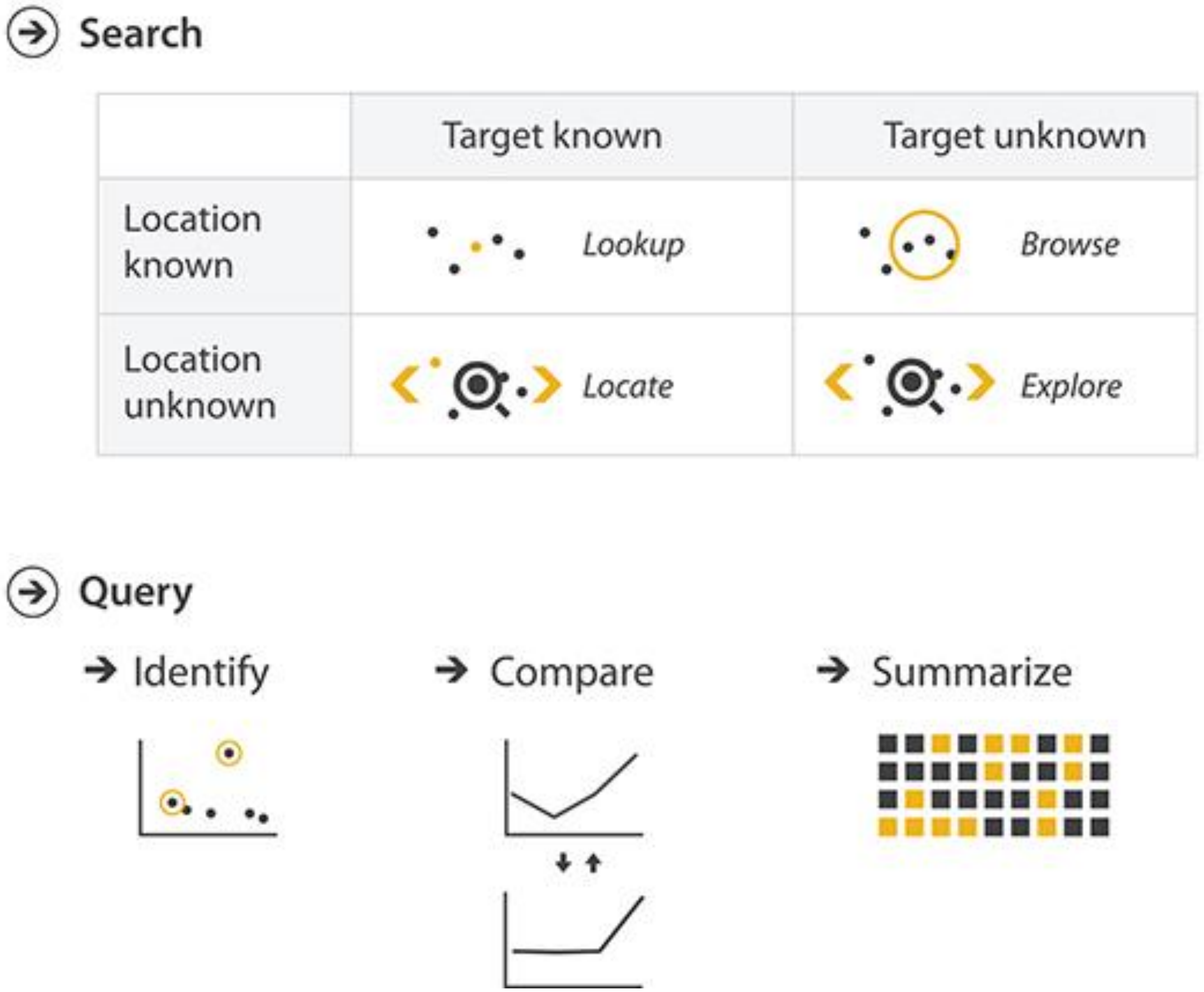
United States	40
Britain	8
Jamaica	7
Canada	5
Trinidad and Tobago	4
Australia	3
Germany	3
Cuba	2
Namibia	2
Soviet Union	2
Barbados	1
Bulgaria	1
Hungary	1
Netherlands	1
New Zealand	1
Panama	1
Portugal	1
South Africa	1
United Team of Germany	1



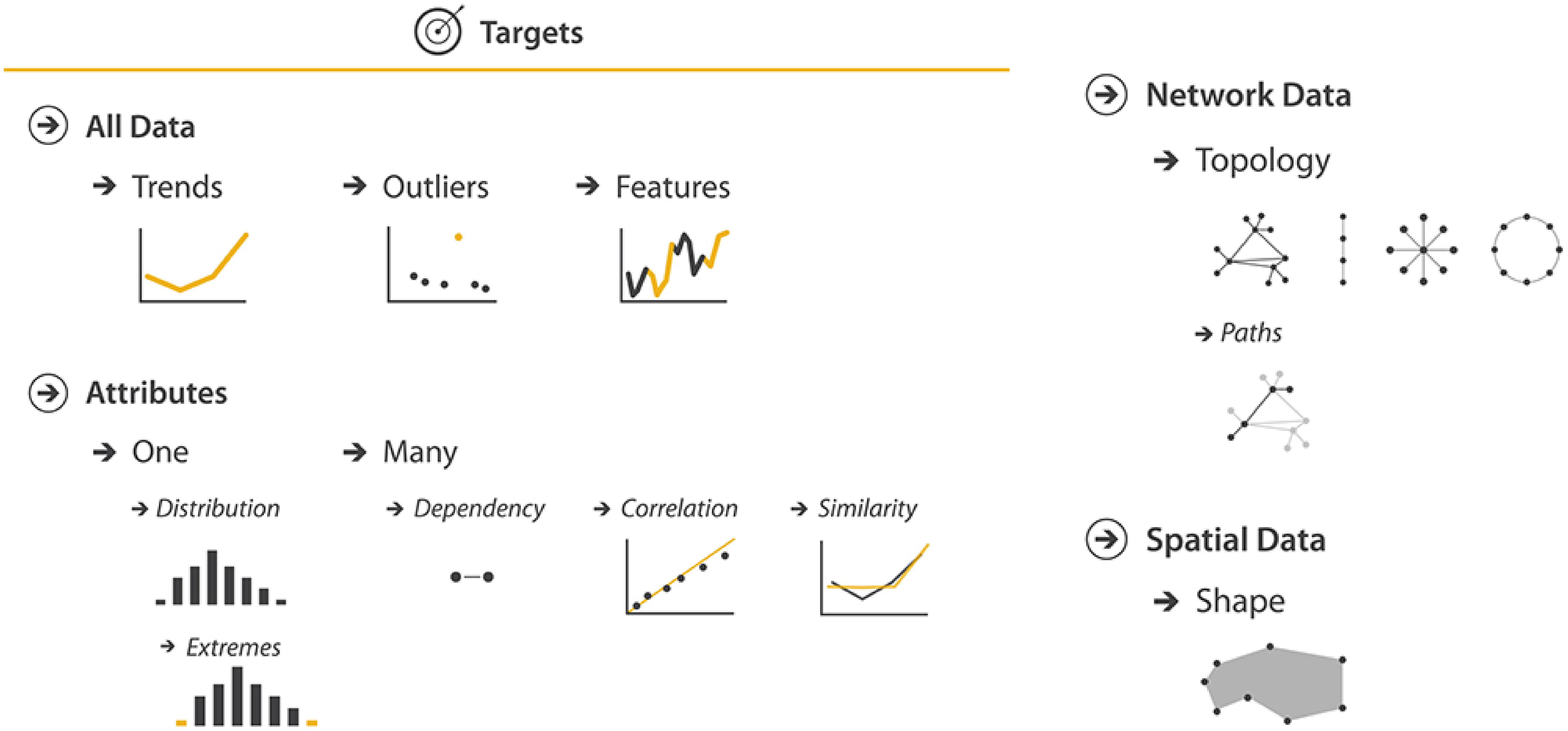
This chart includes medals for the United States and Australia in the "Intermediary" Games of 1906, which the I.O.C. does not formally recognize.

Actions: Search, query

- what does user know?
  - –target, location
- how much of the data matters?
  - –one, some, all
- independent choices for each of these three levels
  - –analyze, search, query
  - –mix and match



Why: Targets

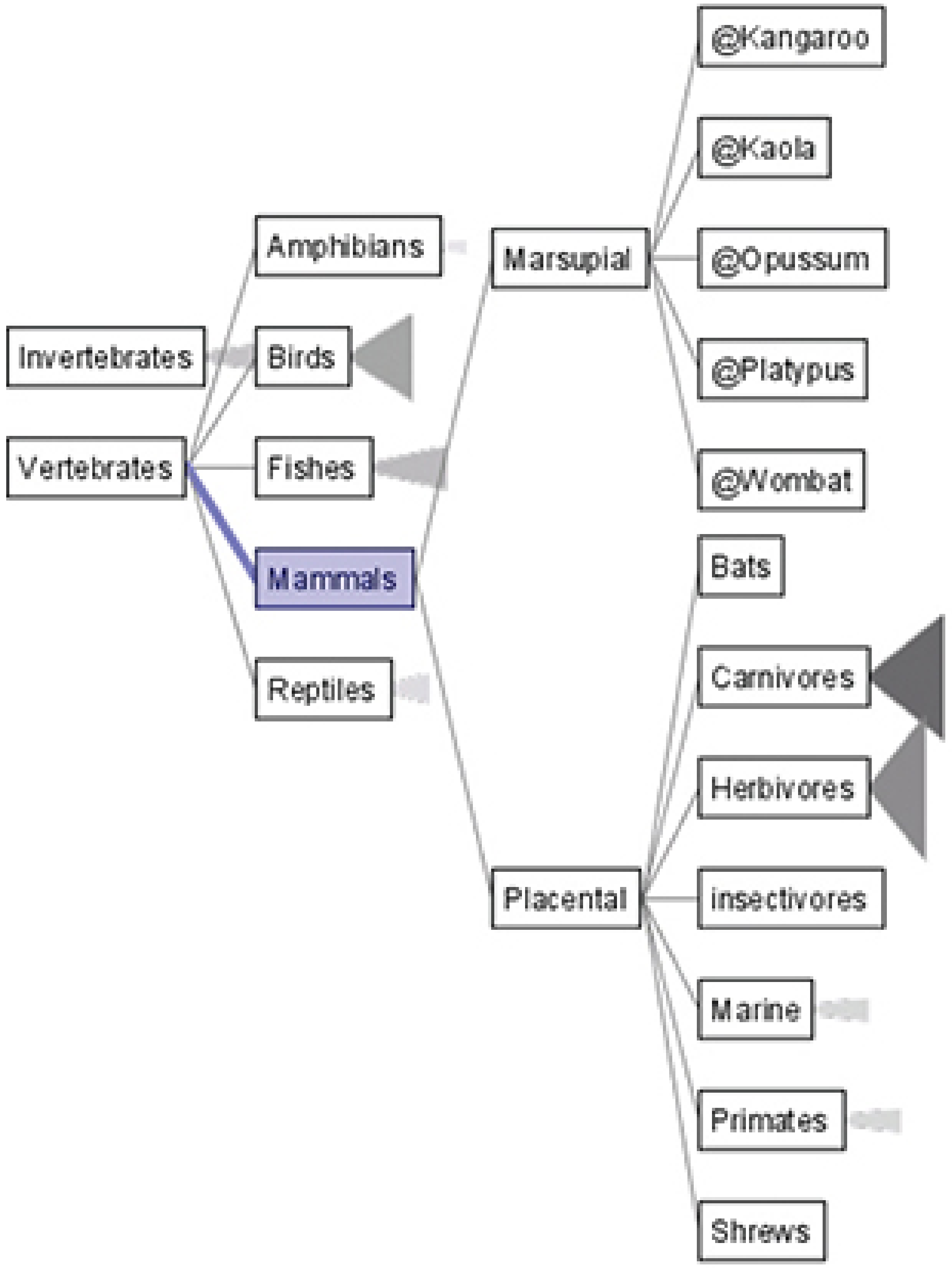

Targets
All Data
Trends
Outliers
Features
Attributes
One
Many
Distribution
Extremes
Dependency
Correlation
Similarity
Network Data
Topology
Paths
Spatial Data
Shape

A preview of How

How?

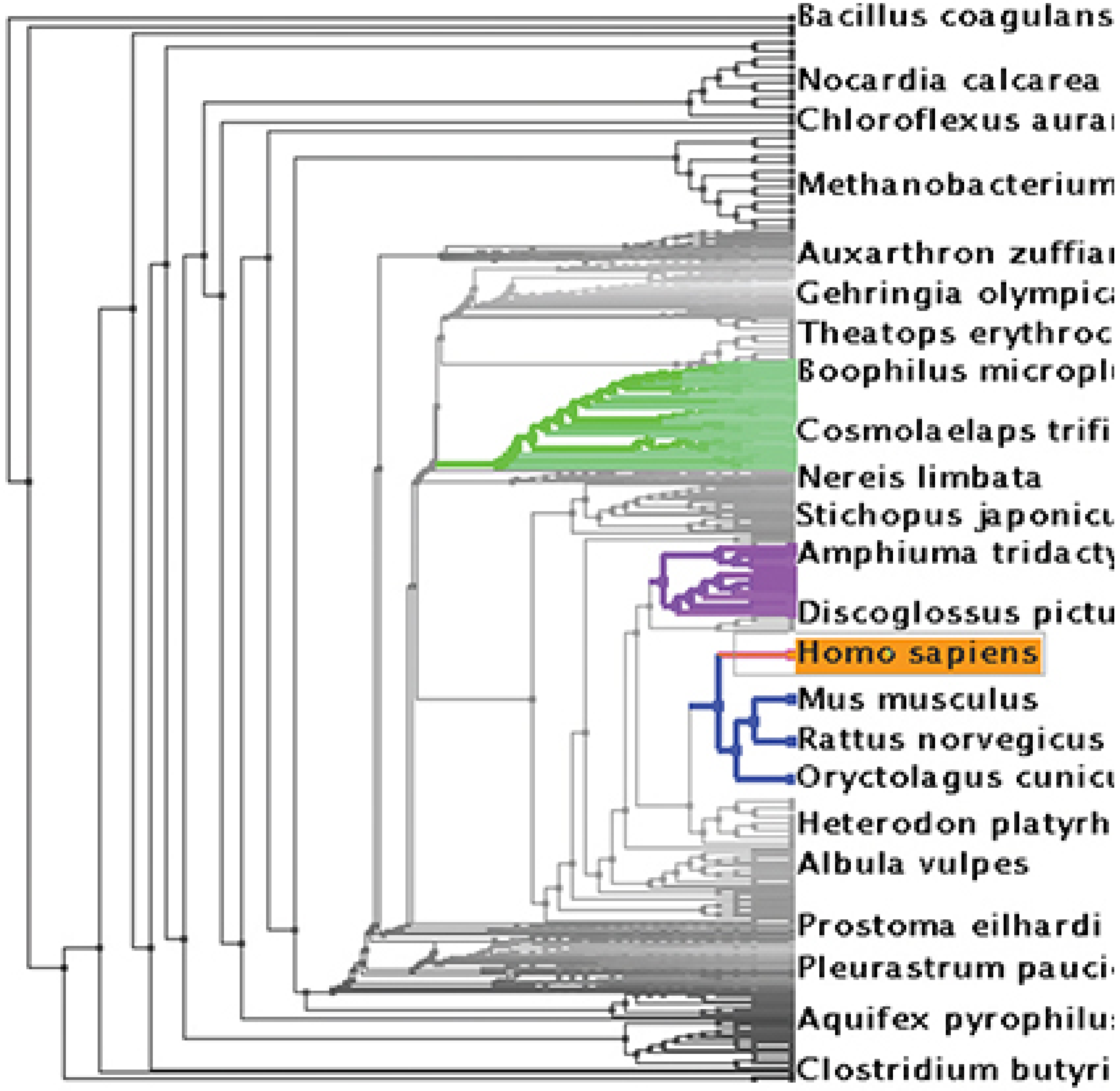
SpaceTree

→ Encode → Navigate → Select → Filter → Aggregate



TreeJuxtaposer

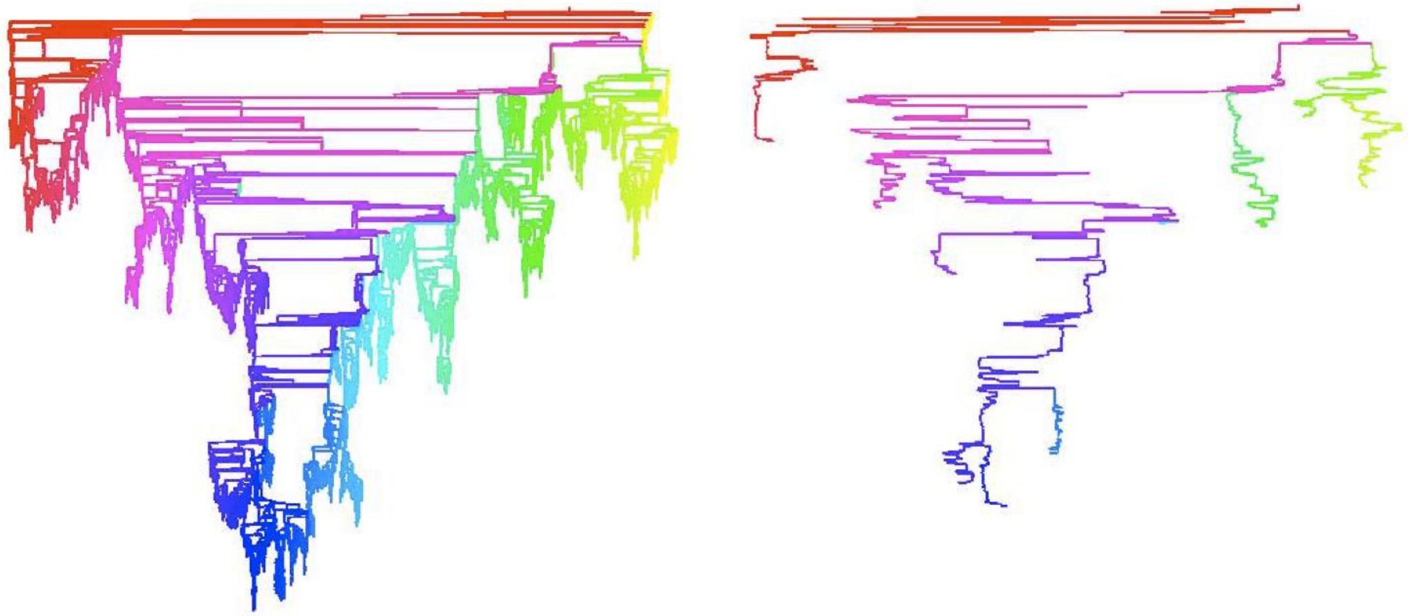
→ Encode → Navigate → Select → Arrange

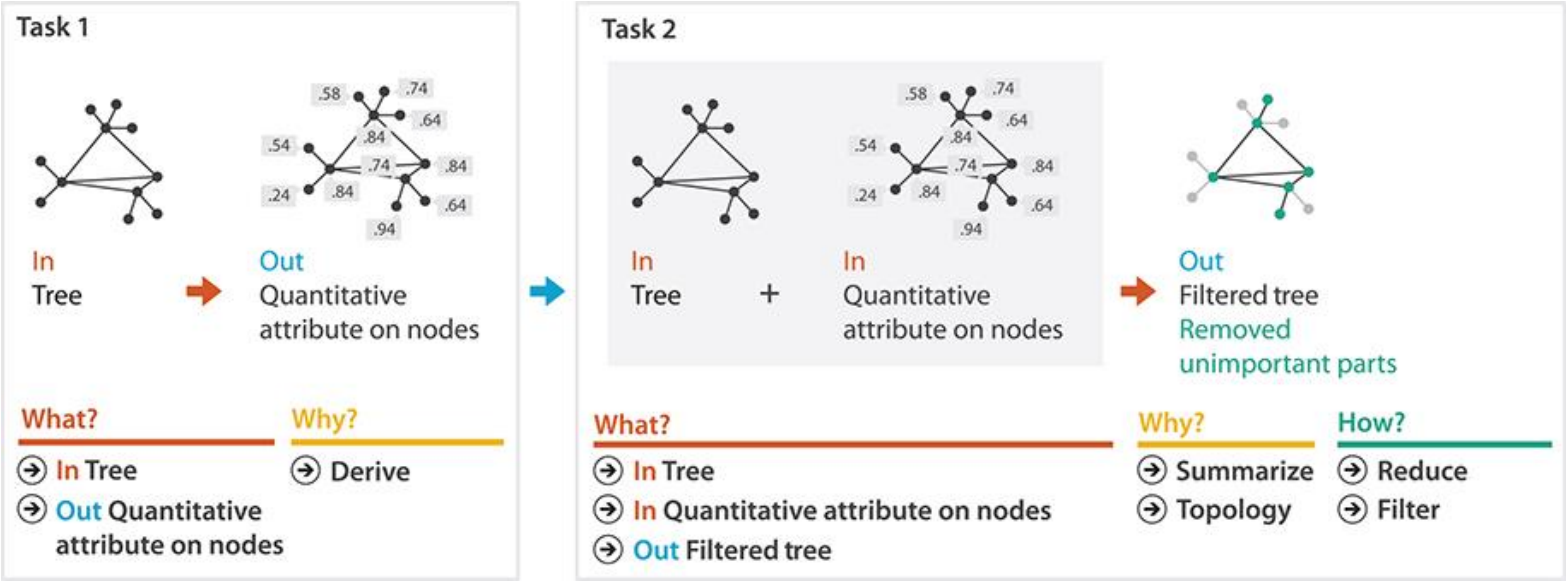


Analysis example: Derive one attribute

- Strahler number
  - centrality metric for trees/networks
  - derived quantitative attribute
  - draw top 5K of 500K for good skeleton

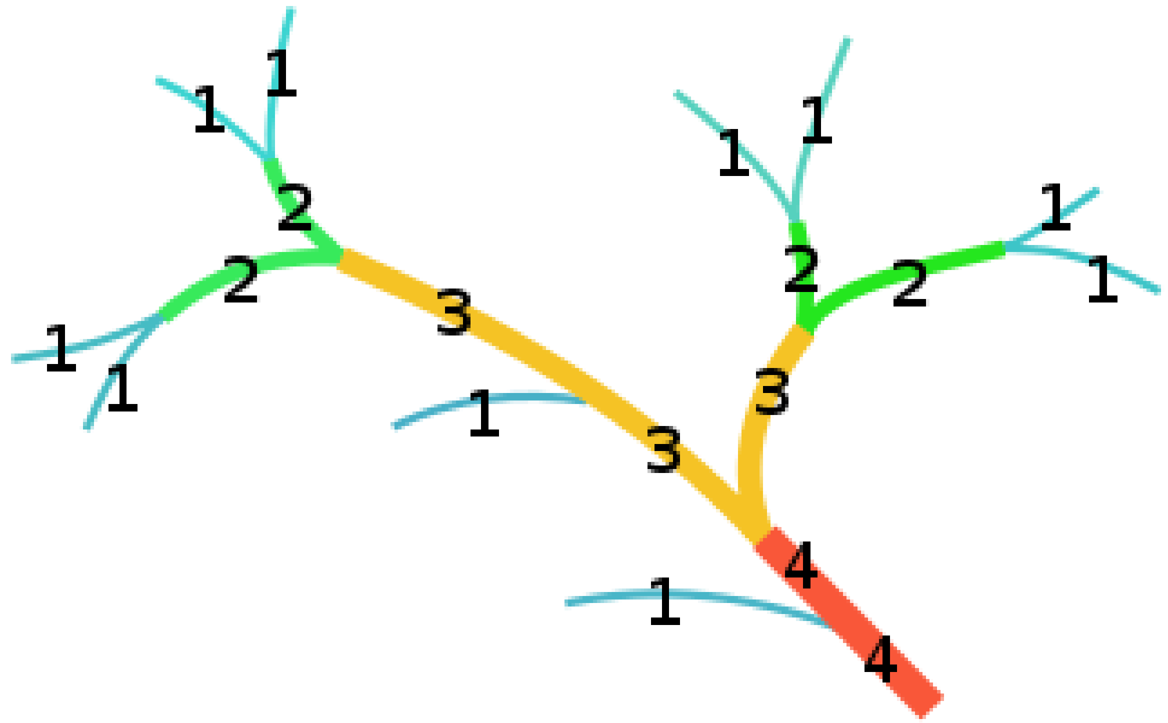
[Using Strahler numbers for real time visual exploration of huge graphs. Auber. Proc. Intl. Conf. Computer Vision and Graphics, pp. 56–69, 2002.]

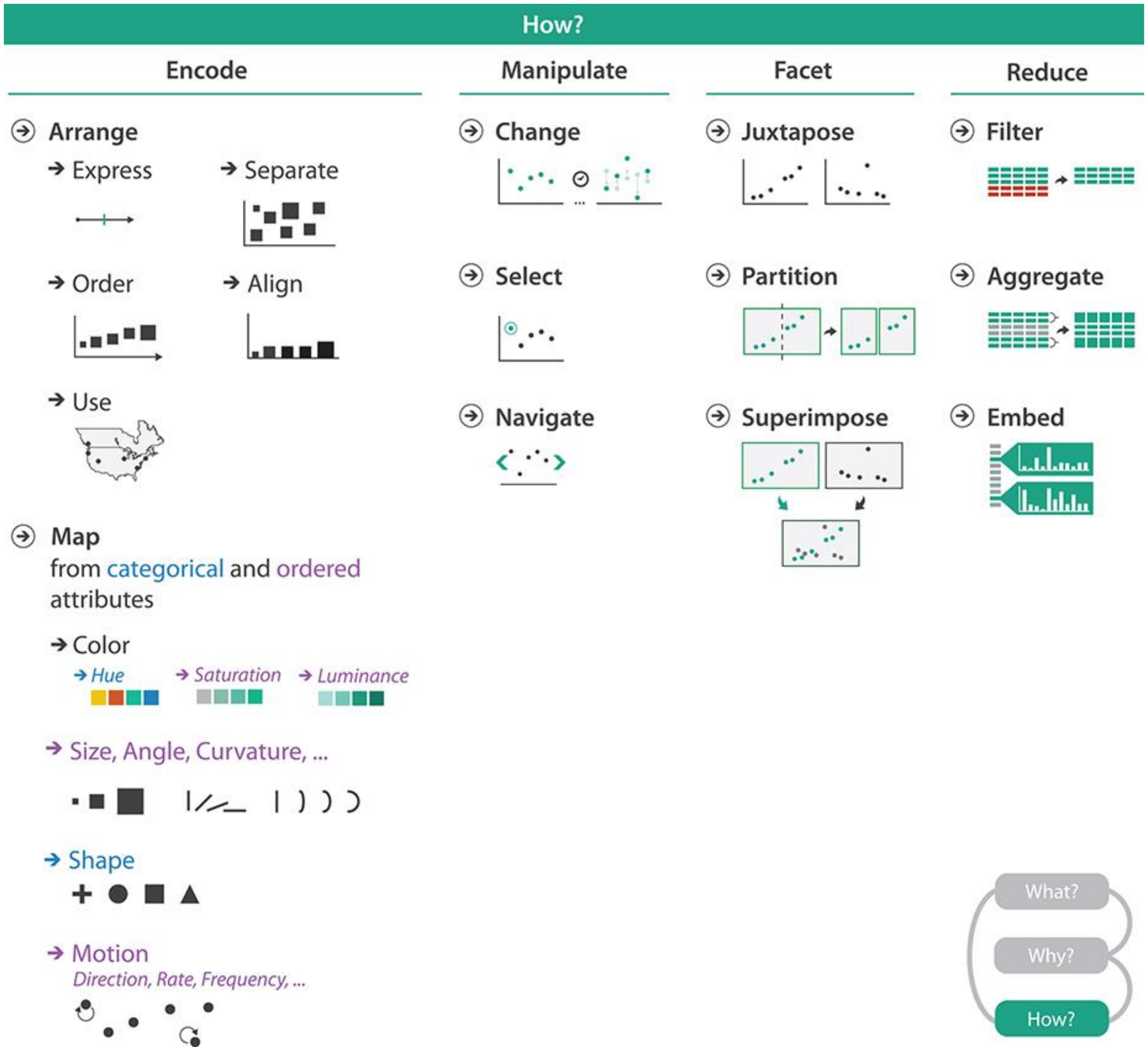




Strahler number

- If the node is a leaf (has no children), its Strahler number is one.
- If the node has one child with Strahler number i, and all other children have Strahler numbers less than i, then the Strahler number of the node is i again.
- If the node has two or more children with Strahler number i, and no children with greater number, then the Strahler number of the node is $i + 1$.




How?
Encode
Manipulate
Facet
Reduce
Arrange
Express
Separate
Order
Align
Use
Map
from categorical and ordered attributes
Color
Hue
Saturation
Luminance
Size, Angle, Curvature, ...
Shape
Motion
Direction, Rate, Frequency, ...
Change
Select
Navigate
Juxtapose
Partition
Superimpose
Filter
Aggregate
Embed
What?
Why?
How?

Further reading

- Visualization Analysis and Design. Munzner. AK Peters Visualization Series, CRC Press, 2014.
  - *Chap 2: What: Data Abstraction*
  - *Chap 3: Why: Task Abstraction*
- *A Multi-Level Typology of Abstract Visualization Tasks.* Brehmer and Munzner. IEEE Trans. Visualization and Computer Graphics (Proc. InfoVis) 19:12 (2013), 2376–2385.
- *Low-Level Components of Analytic Activity in Information Visualization.* Amar, Eagan, and Stasko. Proc. IEEE InfoVis 2005, p 111–117.
- *A taxonomy of tools that support the fluent and flexible use of visualizations.* Heer and Shneiderman. Communications of the ACM 55:4 (2012), 45–54.
- *Rethinking Visualization: A High-Level Taxonomy.* Tory and Möller. Proc. IEEE InfoVis 2004, p 151–158.
- Visualization of Time-Oriented Data. Aigner, Miksch, Schumann, and Tominski. Springer, 2011.

Reading visualization papers

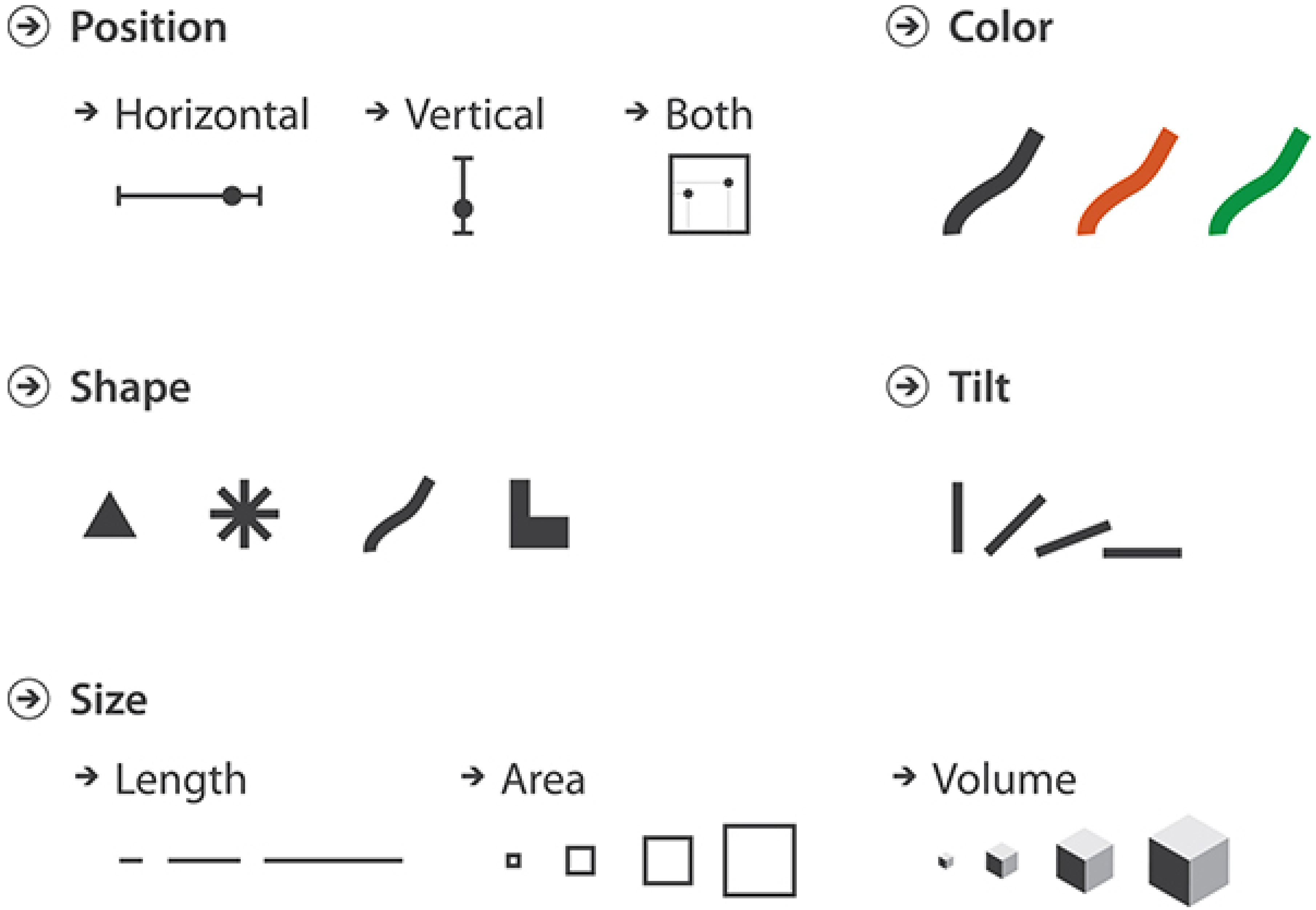
- one strategy: multiple passes
  - title
  - abstract, authors/affiliation
  - flip through, glance at figures, notice structure from section titles
  - skim intro, results/discussion (maybe conclusion)
  - fast read to get big ideas
    - if you don’t get something, just keep going
  - second pass to work through details
    - later parts may cast light on earlier parts for badly structured papers
  - third pass to dig deep
    - if it’s highly relevant, or you’re presenting it to class
- literature search
  - decide when to stop reading: is this relevant to my current concerns?

Marks and Channels

Definitions: Marks and channels

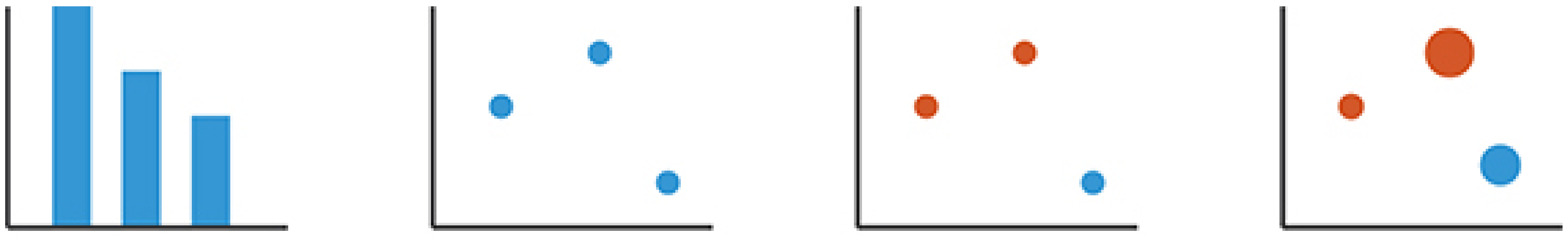
- marks
  - geometric primitives

- channels
  - control appearance of marks
  - can redundantly code with multiple channels



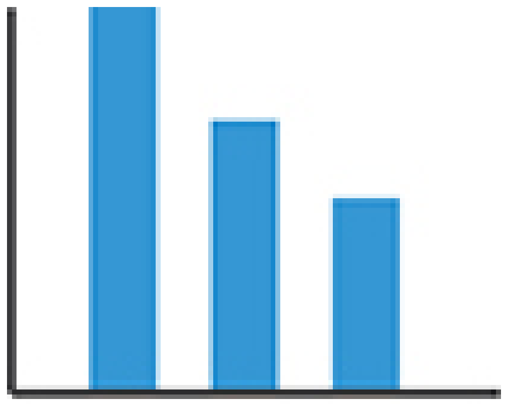
Visual encoding

- analyze idiom structure



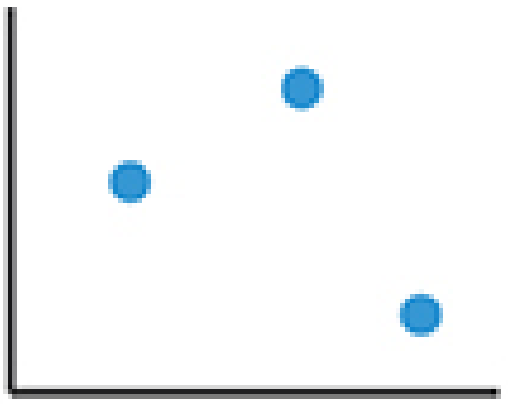
Visual encoding

- analyze idiom structure
  - as combination of marks and channels



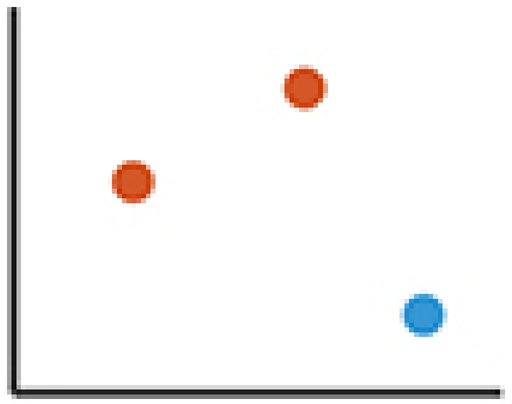
1:
vertical position

mark: line



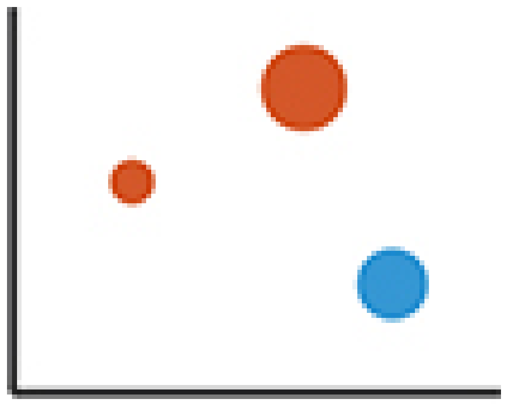
2:
vertical position
horizontal position

mark: point



3:
vertical position
horizontal position
color hue

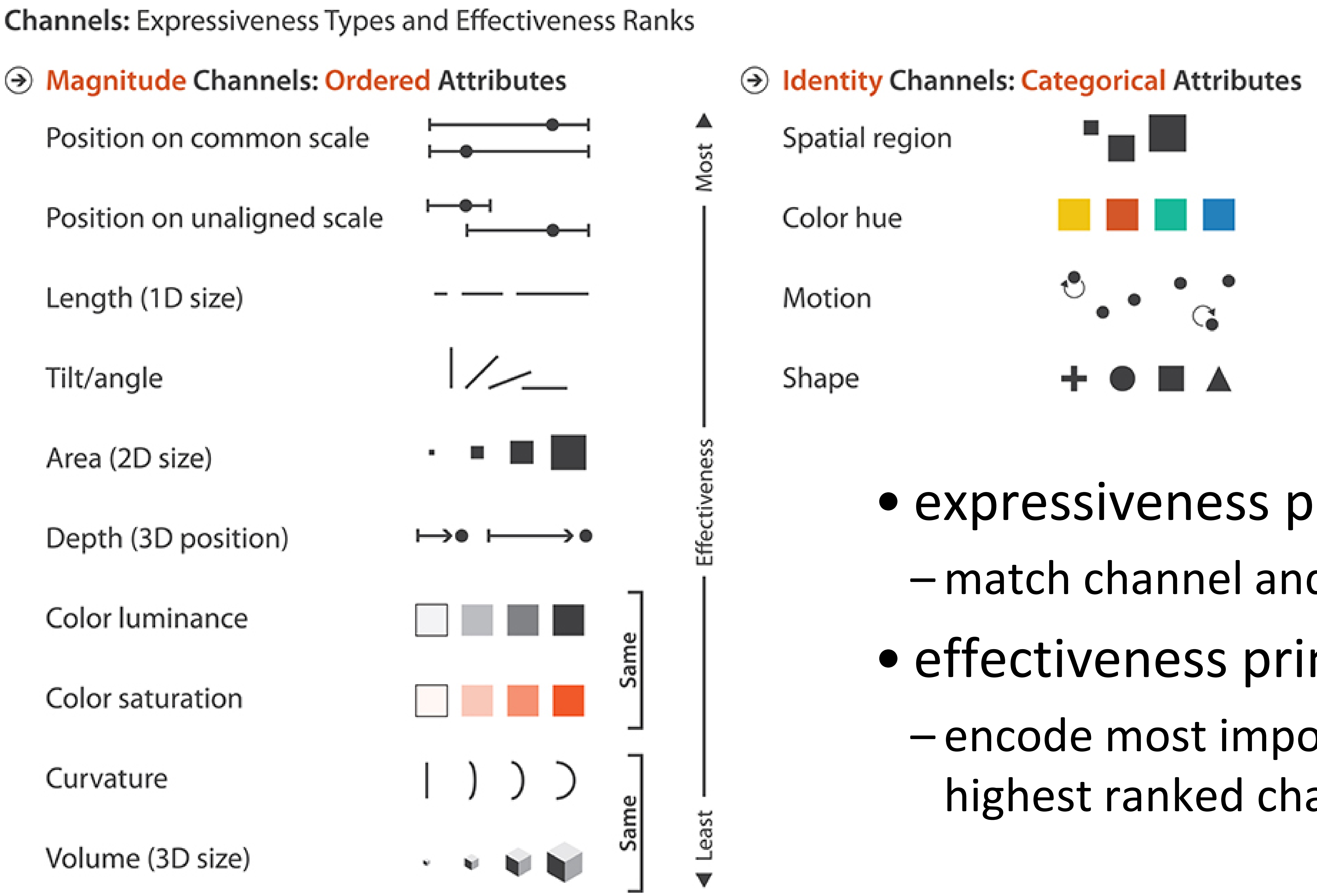
mark: point



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

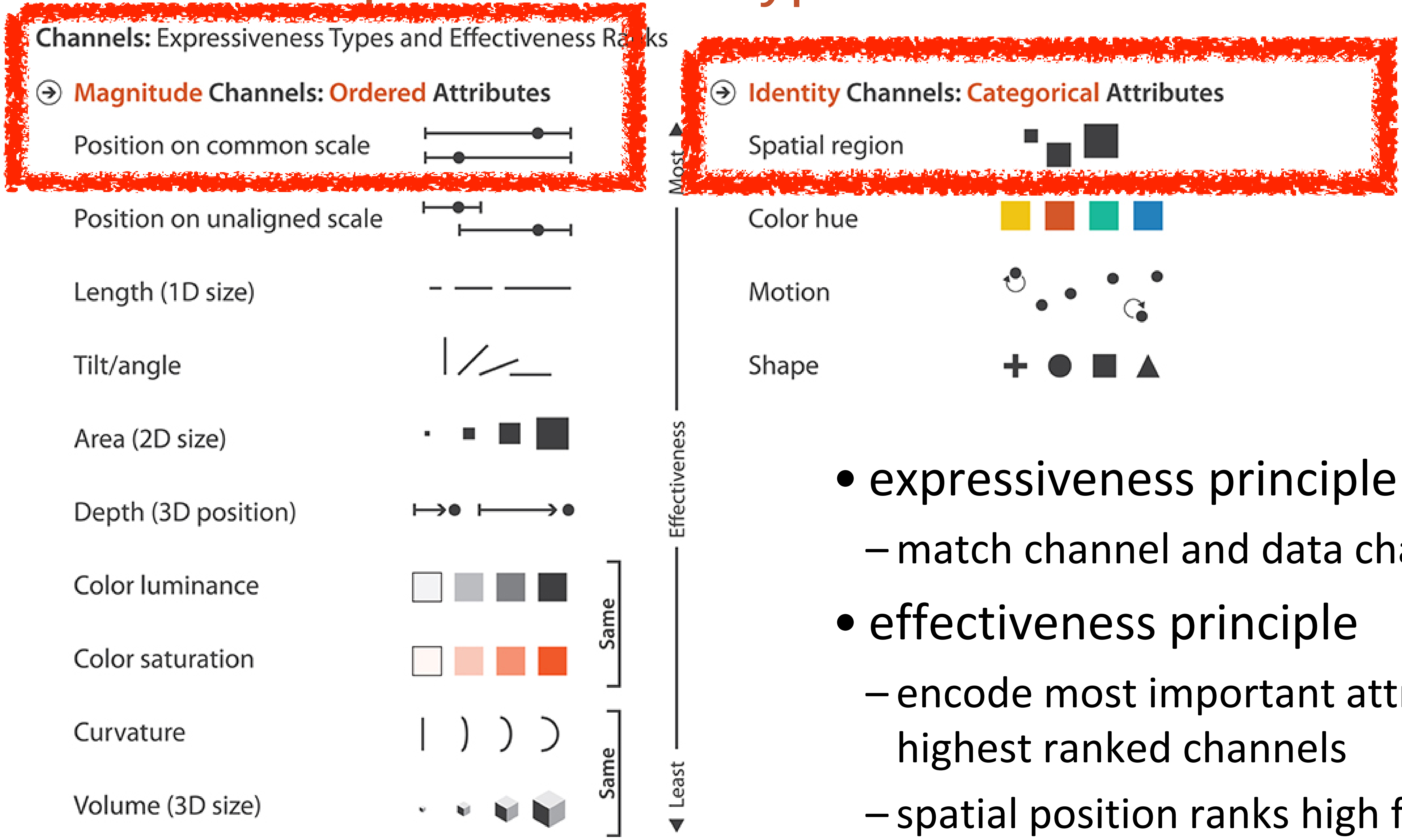
mark: point

Channels: Expressiveness types and effectiveness rankings



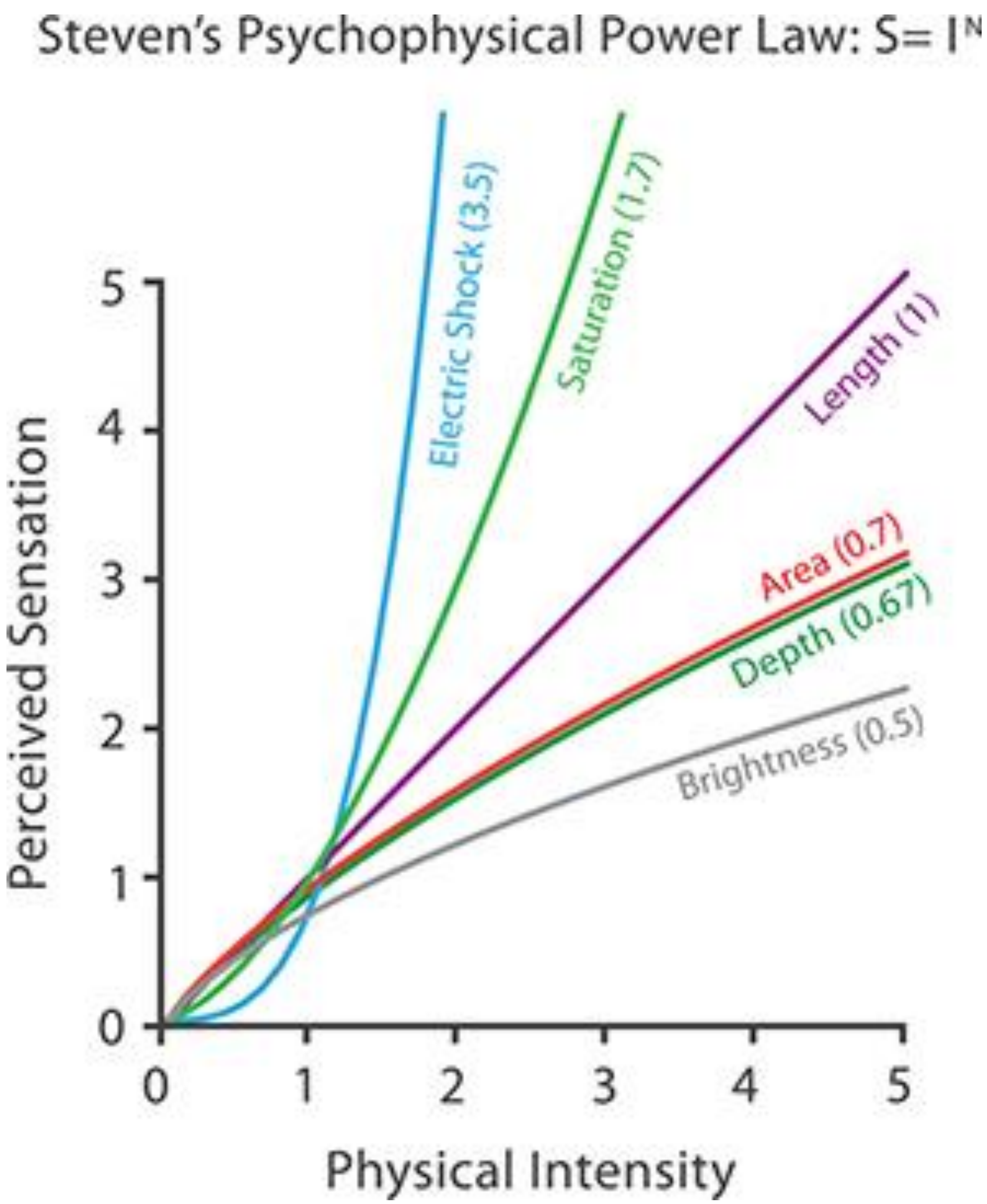
- expressiveness principle
  - match channel and data characteristics
- effectiveness principle
  - encode most important attributes with highest ranked channels

Channels: Expressiveness types and effectiveness rankings

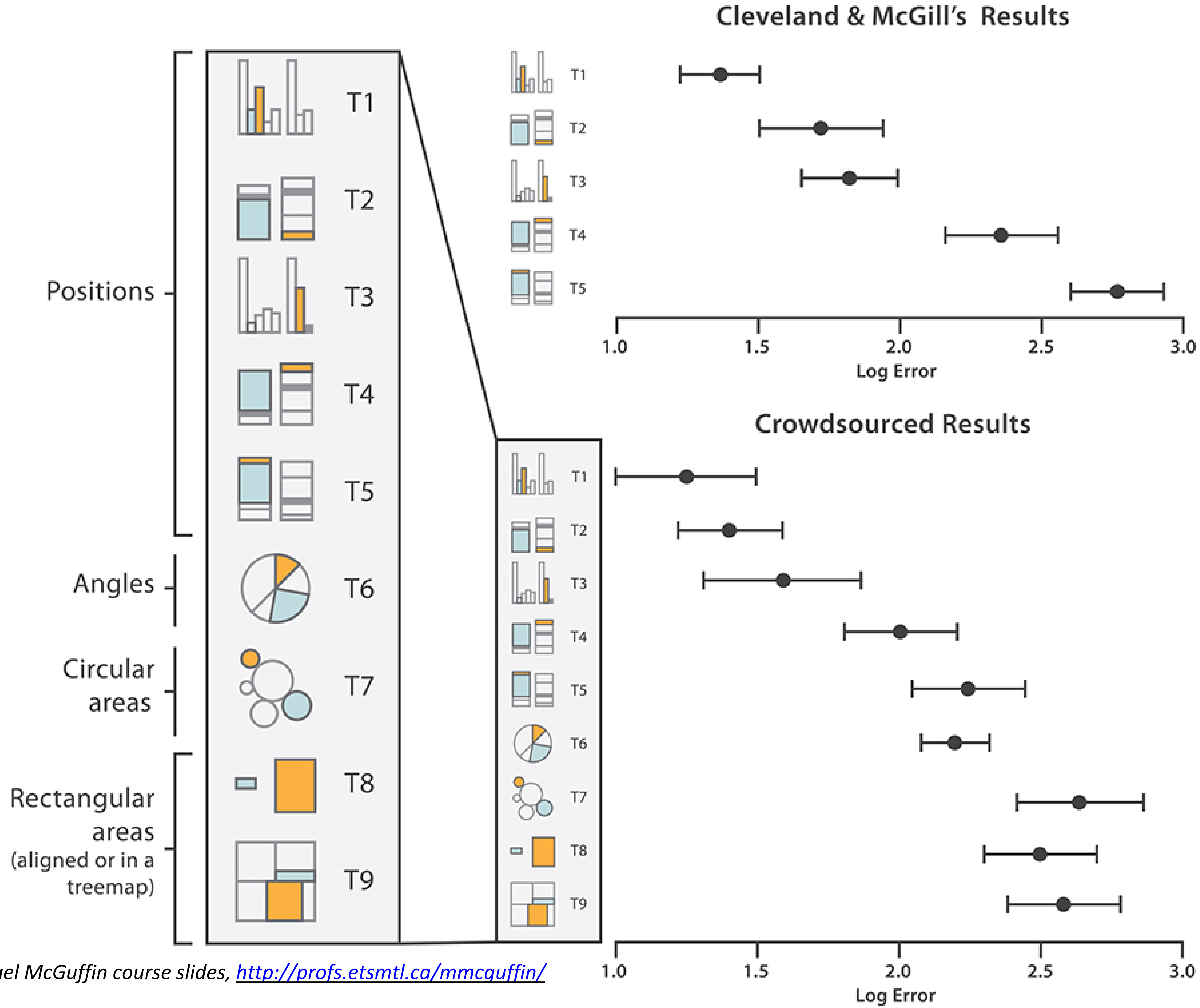


- expressiveness principle
  - match channel and data characteristics
- effectiveness principle
  - encode most important attributes with highest ranked channels
  - spatial position ranks high for both

Accuracy: Fundamental Theory



Accuracy: Vis experiments

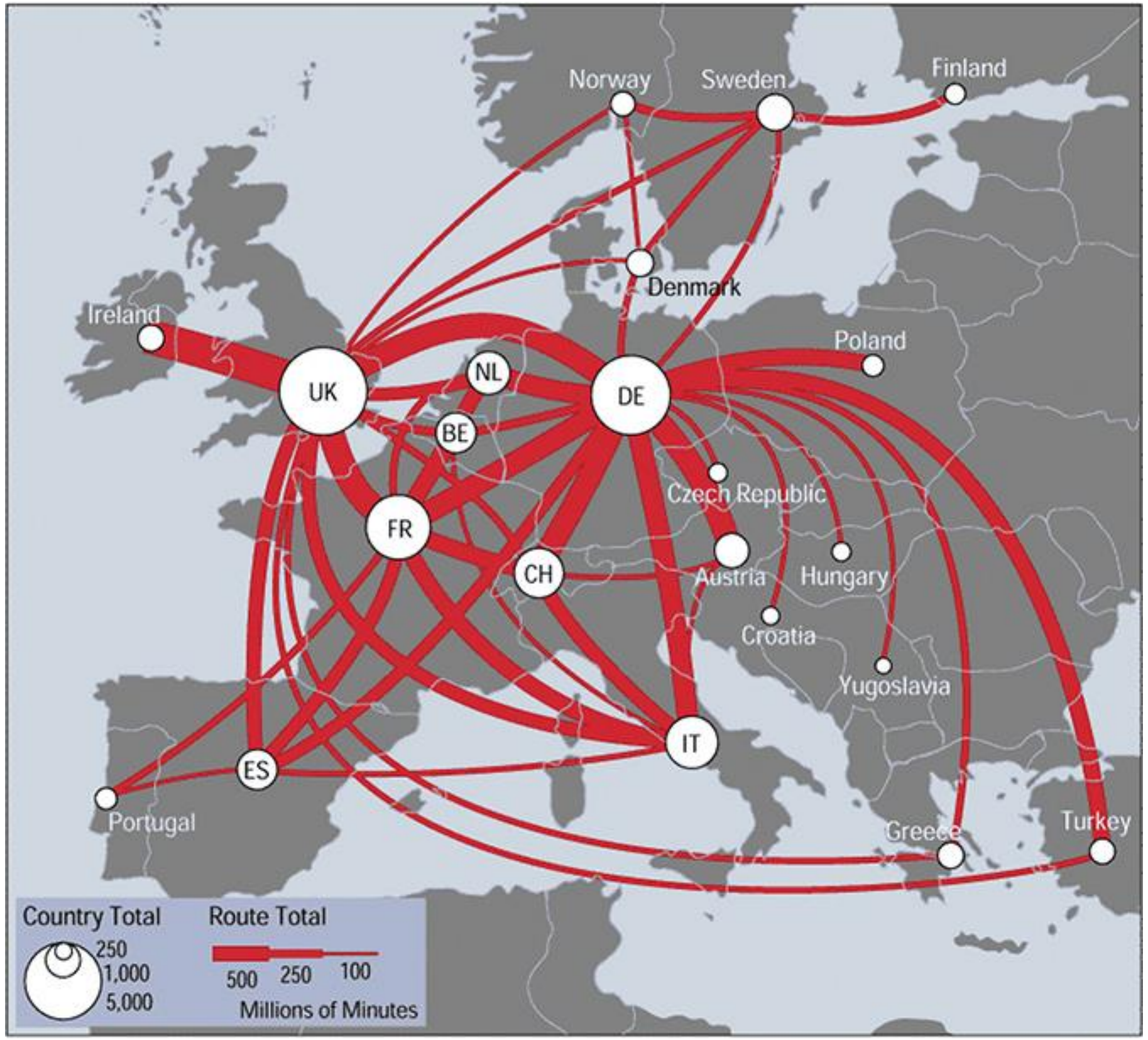


[Crowdsourcing Graphical Perception: Using Mechanical Turk to Assess Visualization Design. Heer and Bostock. Proc ACM Conf. Human Factors in Computing Systems (CHI) 2010, p. 203–212.]

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

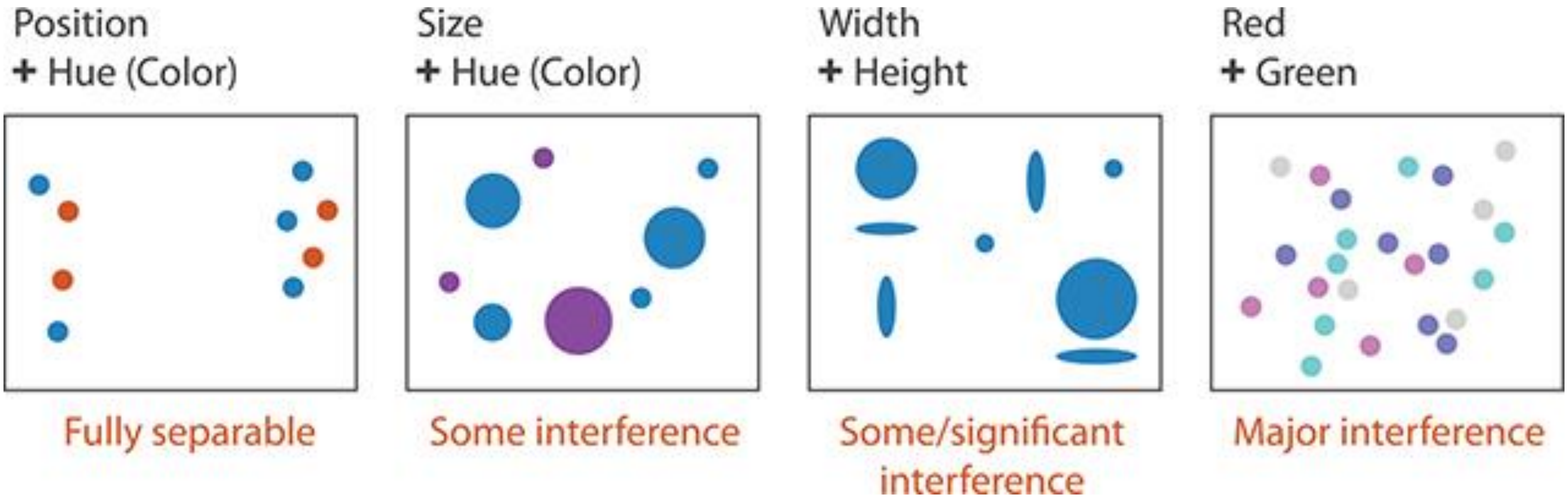
Discriminability: How many usable steps?

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



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

Separability vs. Integrality



2 groups each

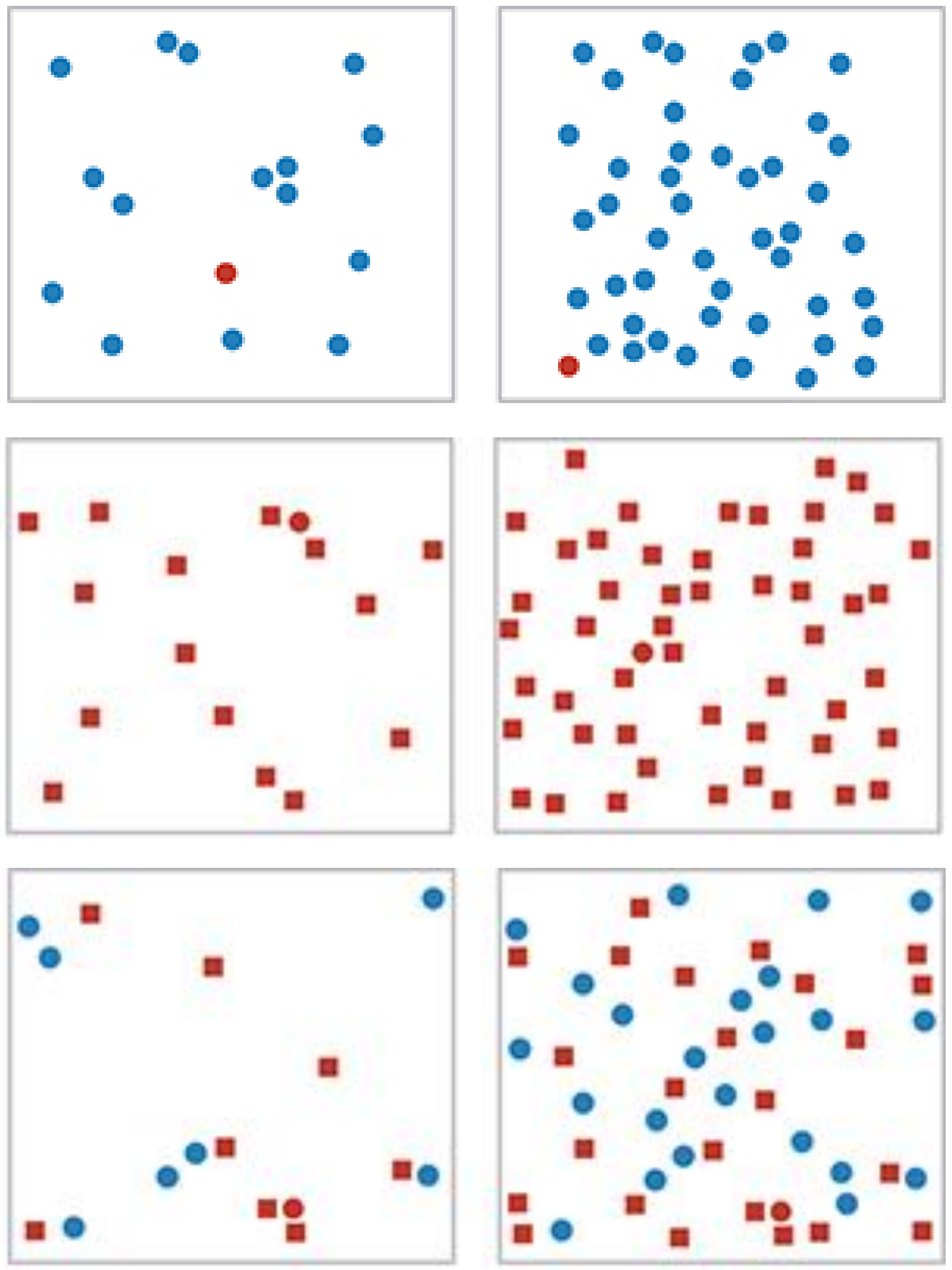
2 groups each

3 groups total: integral area

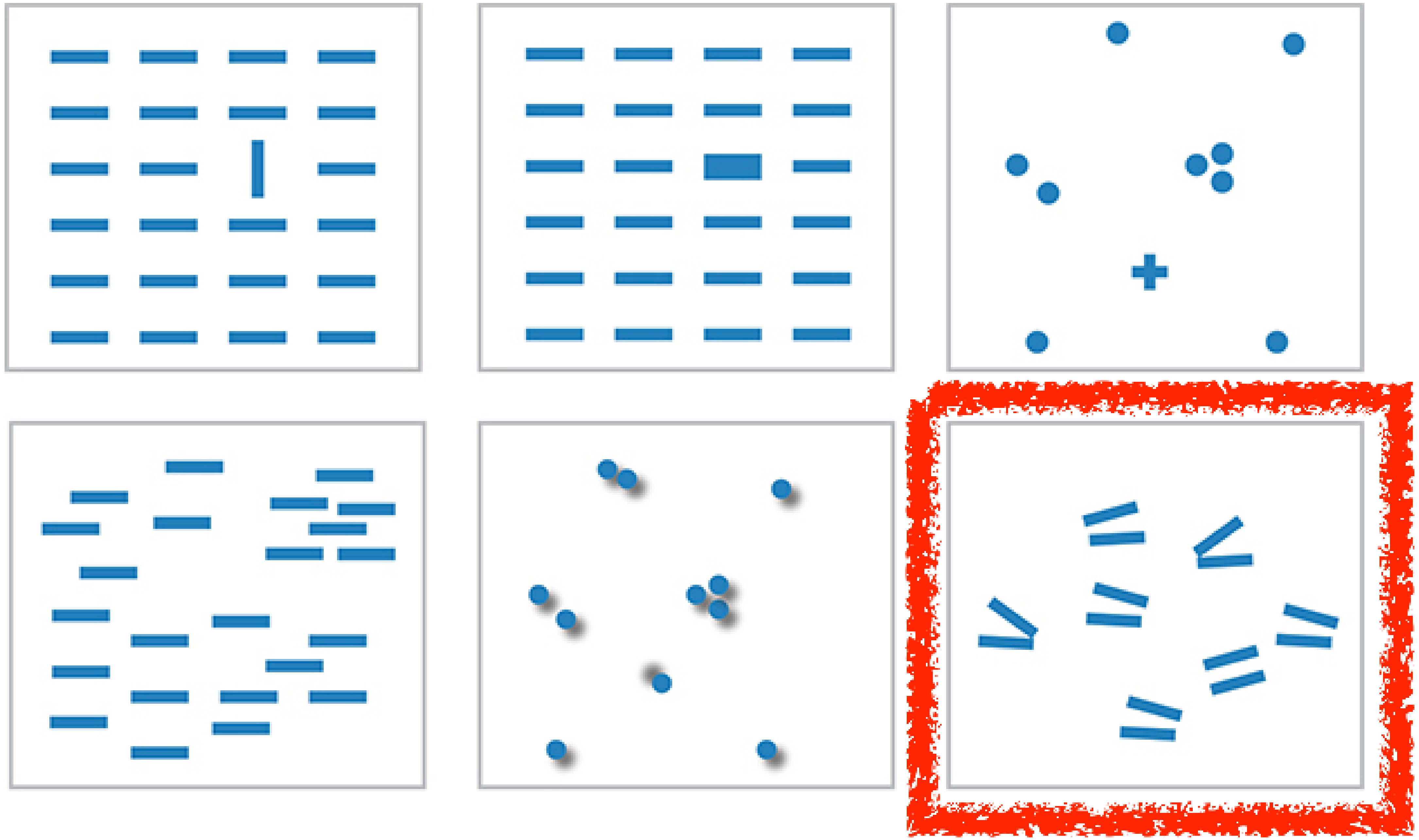
4 groups total: integral hue

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



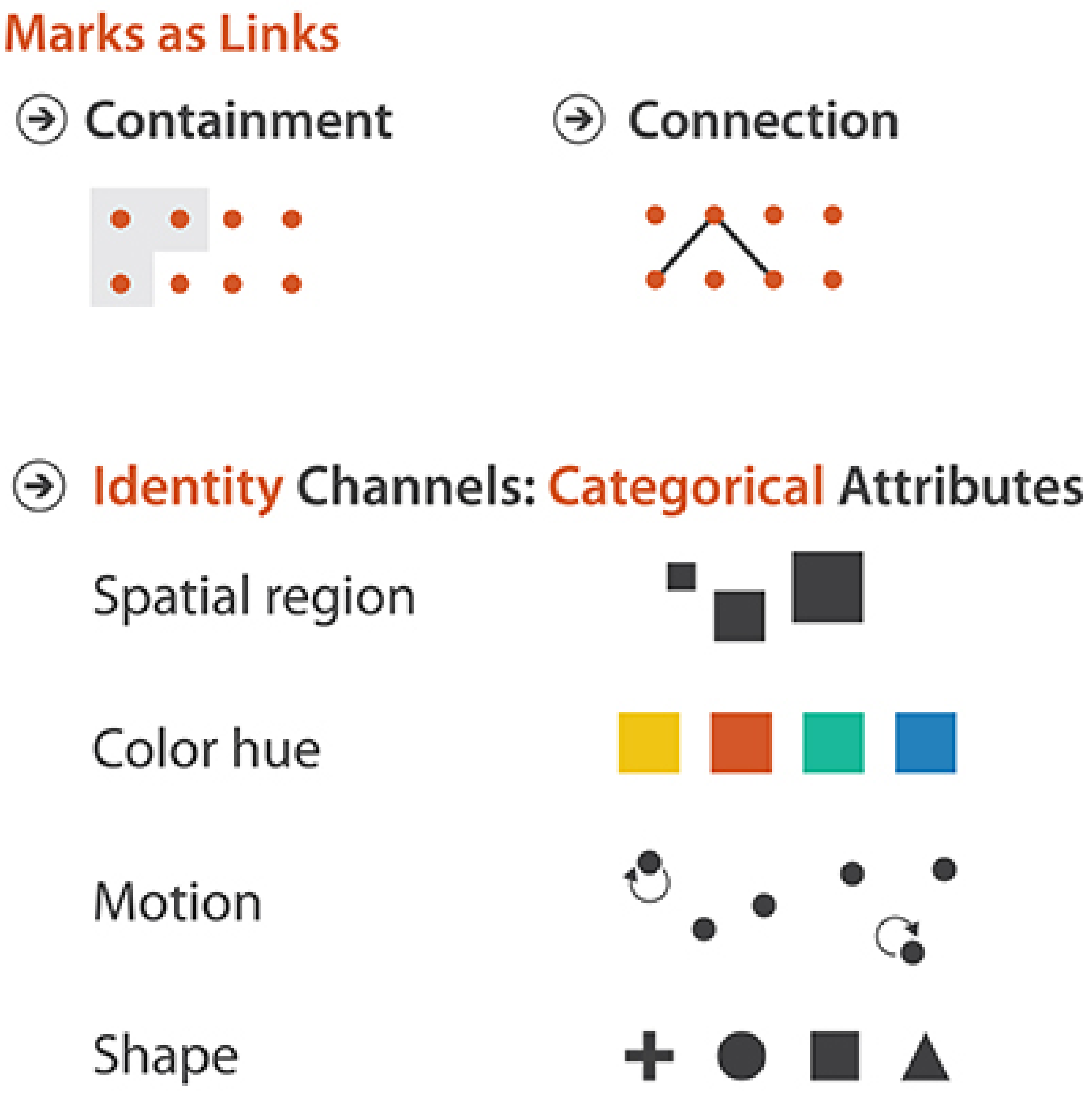
Popout



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

Grouping

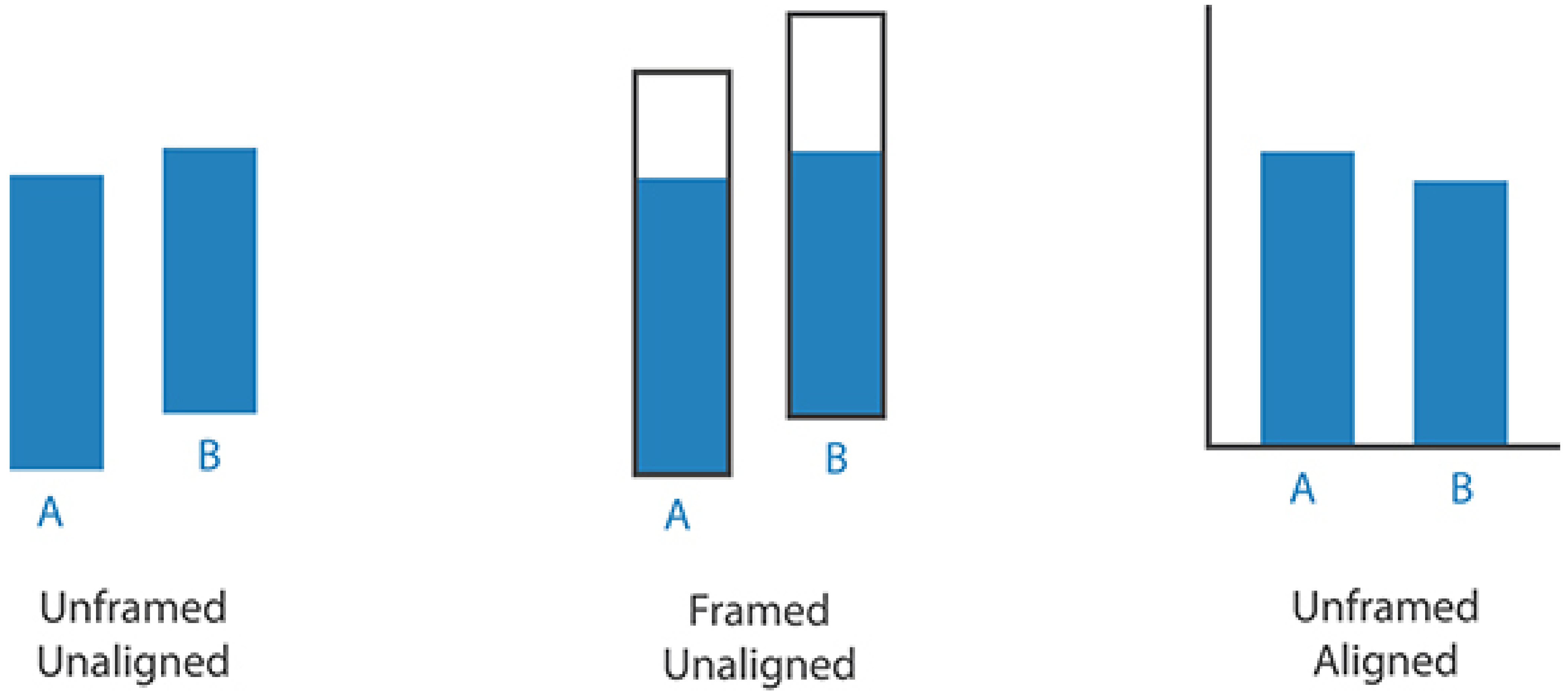
- containment
- connection



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

Relative vs. absolute judgements

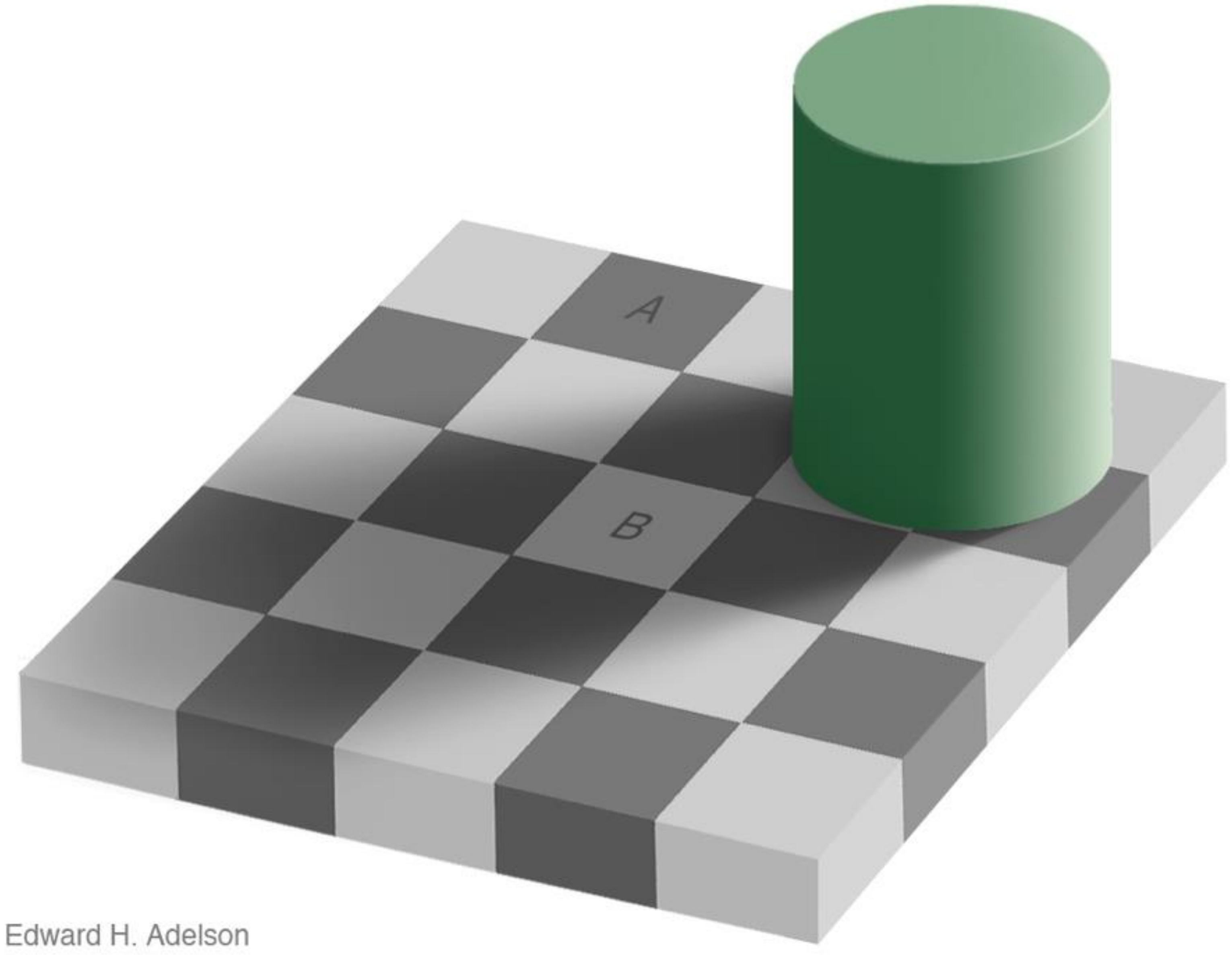
- perceptual system mostly operates with relative judgements, not absolute
  - that’s why accuracy increases with common frame/scale and alignment
  - Weber’s Law: ratio of increment to background is constant
    - filled rectangles differ in length by 1:9, difficult judgement
    - white rectangles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

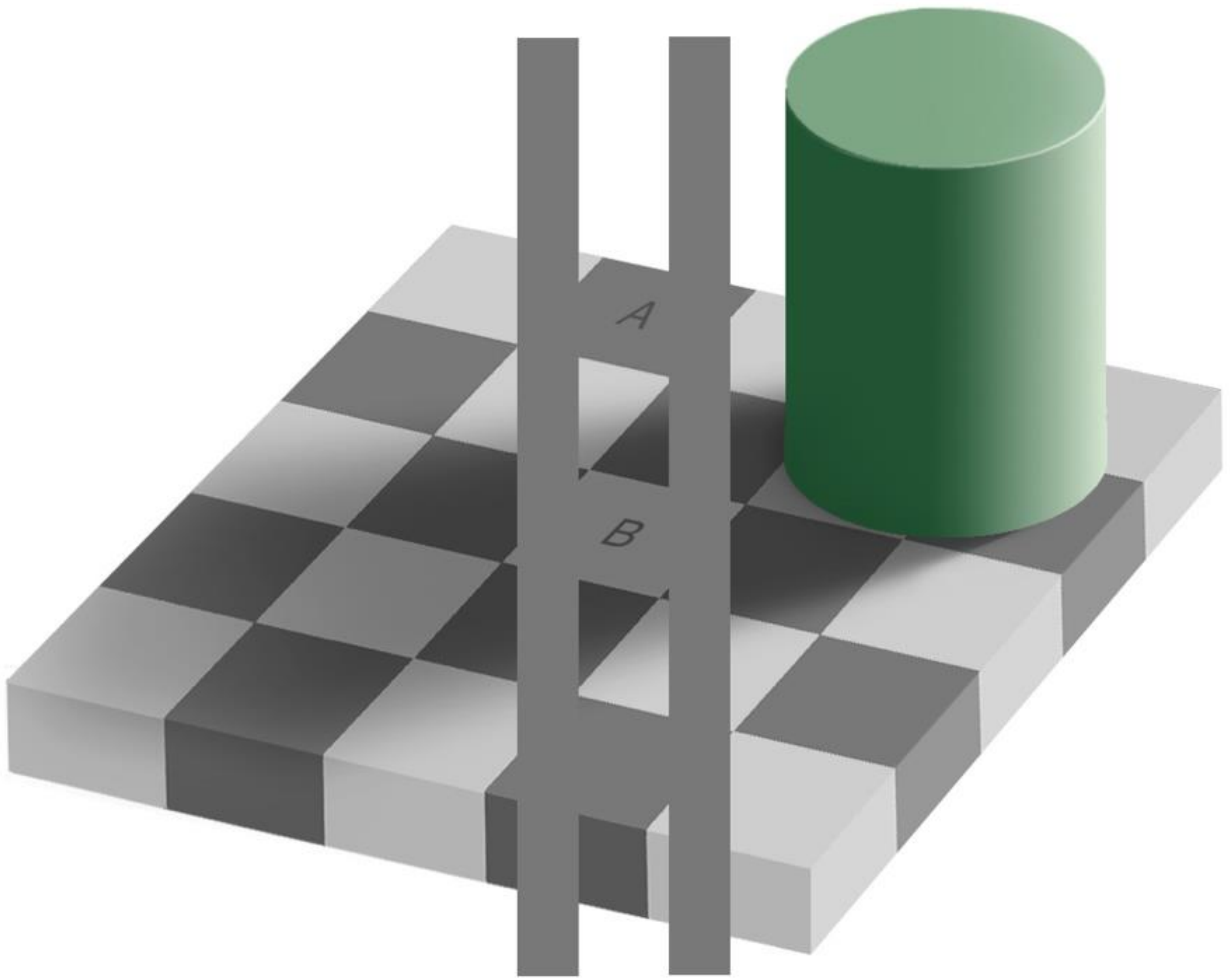


after [Graphical Perception: Theory, Experimentation, and Application to the Development of Graphical Methods. Cleveland and McGill. Journ. American Statistical Association 79:387 (1984), 531–554.]

Relative luminance judgements

- perception of luminance is contextual based on contrast with surroundings

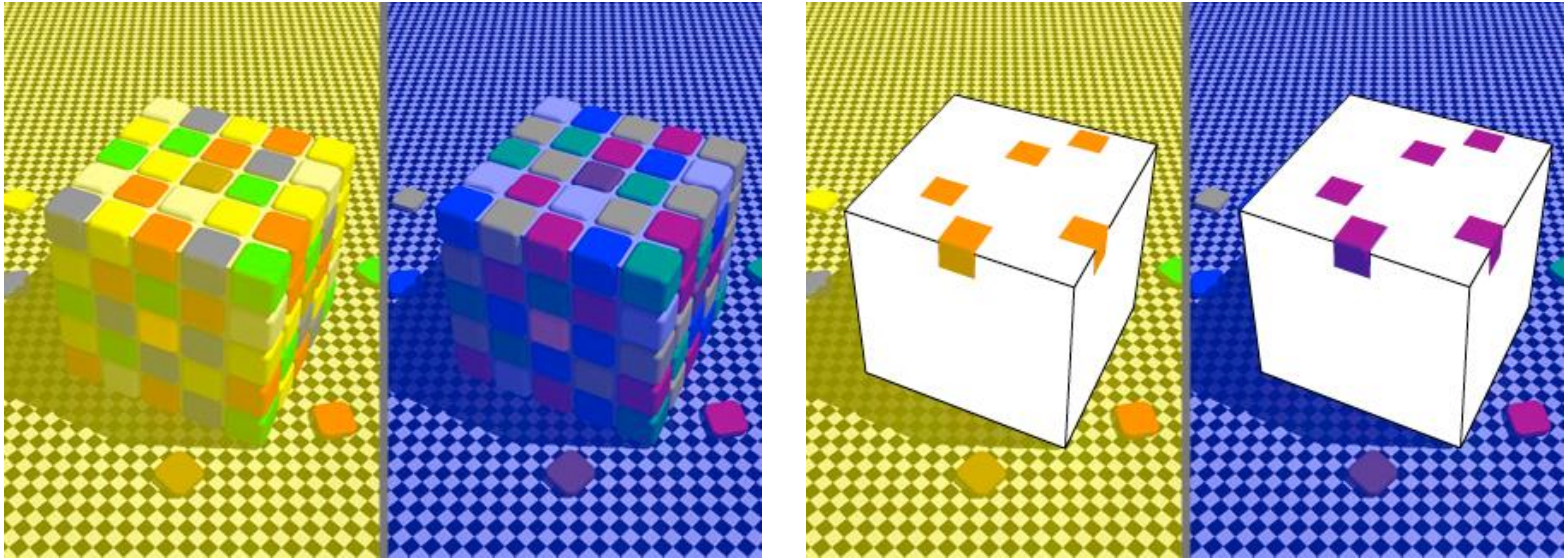




http://persci.mit.edu/gallery/checkershadow

Relative color judgements

- color constancy across broad range of illumination conditions



http://www.purveslab.net/seeforyourself/

Further reading

- Visualization Analysis and Design. Munzner. AK Peters Visualization Series, CRC Press, 2014.
  - *Chap 5: Marks and Channels*
- *On the Theory of Scales of Measurement.* Stevens. Science 103:2684 (1946), 677–680.
- Psychophysics: Introduction to its Perceptual, Neural, and Social Prospects. Stevens. Wiley, 1975.
- *Graphical Perception: Theory, Experimentation, and Application to the Development of Graphical Methods.* Cleveland and McGill. Journ. American Statistical Association 79:387 (1984), 531–554.
- *Perception in Vision*. Healey. http://www.csc.ncsu.edu/faculty/healey/PP
- Visual Thinking for Design. Ware. Morgan Kaufmann, 2008.
- Information Visualization: Perception for Design, 3rd edition. Ware. Morgan Kaufmann /Academic Press, 2004.