Data Visualization Pitfalls to Avoid

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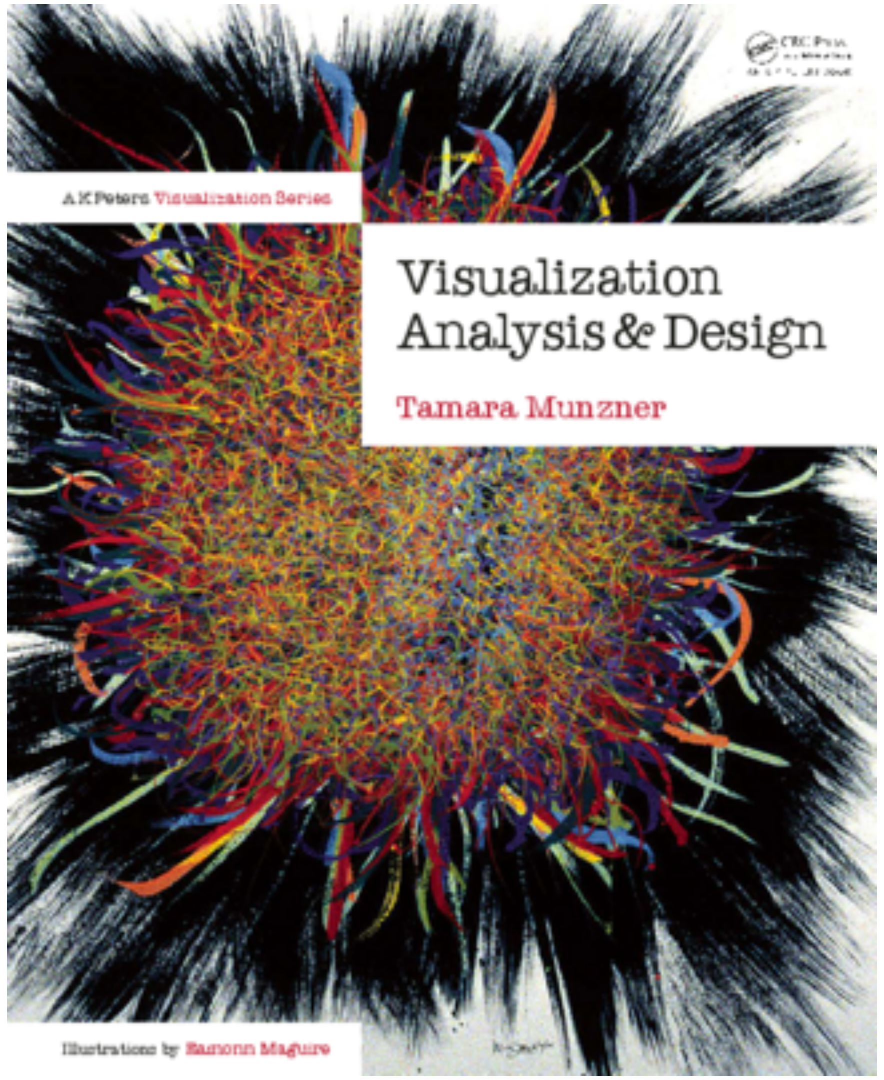
Visualization (vis) defined & motivated

Computer-based visualization systems provide visual representations of datasets designed to help people carry out tasks more effectively.

Visualization is suitable when there is a need to augment human capabilities rather than replace people with computational decision-making methods.

- human in the loop needs the details
  - doesn't know exactly what questions to ask in advance
  - longterm exploratory analysis
  - presentation of known results
  - stepping stone towards automation: refining, trustbuilding
- intended task, measurable definitions of effectiveness

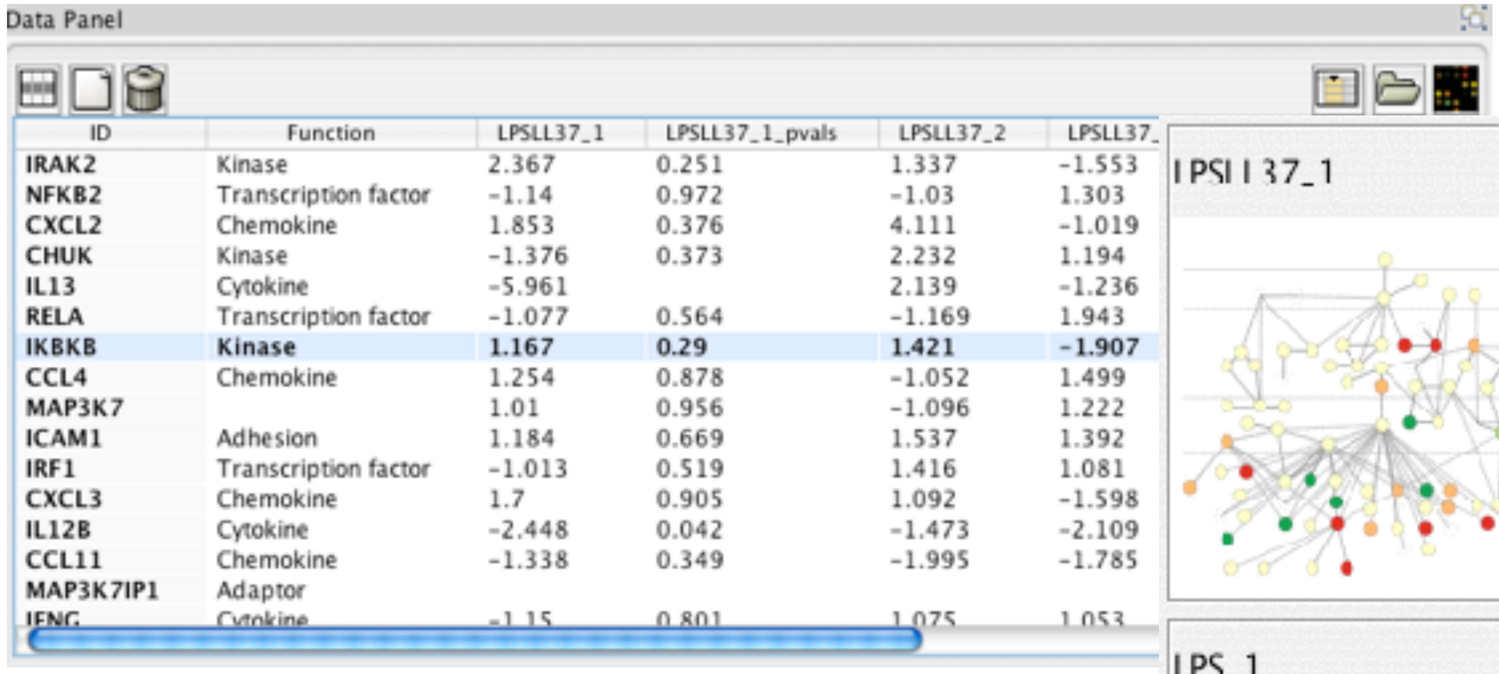


more at:
Visualization Analysis and Design, Chapter 1.
Munzner. AK Peters Visualization Series, CRC Press, 2014.

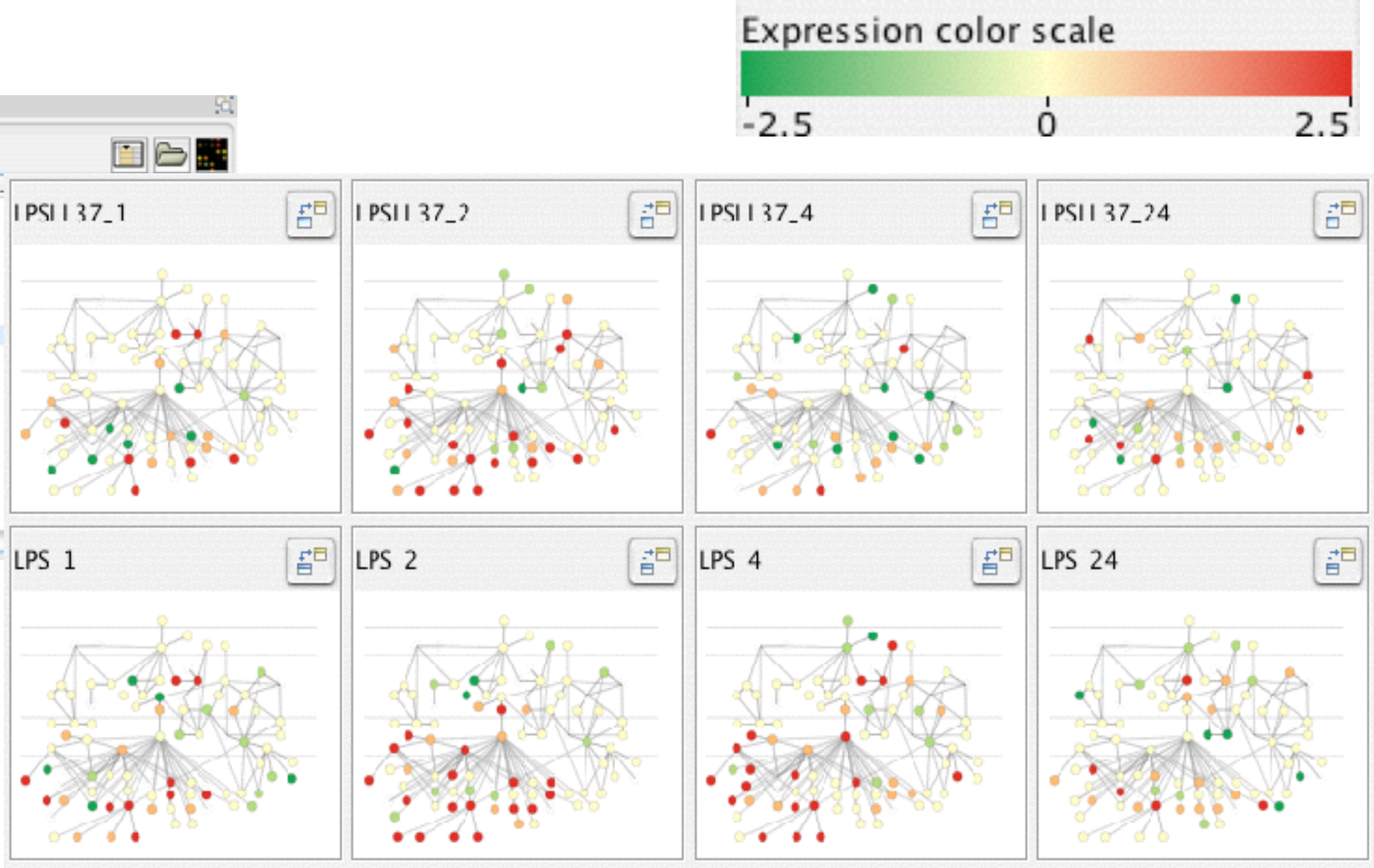
Why use an external representation?

Computer-based visualization systems provide visual representations of datasets designed to help people carry out tasks more effectively.

- external representation: replace cognition with perception



ID	Function	LPSLL37_1	LPSLL37_1_pvals	LPSLL37_2	LPSLL37_...
IRAK2	Kinase	2.367	0.251	1.337	-1.553
NFKB2	Transcription factor	-1.14	0.972	-1.03	1.303
CXCL2	Chemokine	1.853	0.376	4.111	-1.019
CHUK	Kinase	-1.376	0.373	2.232	1.194
IL13	Cytokine	-5.961		2.139	-1.236
RELA	Transcription factor	-1.077	0.564	-1.169	1.943
IKBKB	Kinase	1.167	0.29	1.421	-1.907
CCL4	Chemokine	1.254	0.878	-1.052	1.499
MAP3K7		1.01	0.956	-1.096	1.222
ICAM1	Adhesion	1.184	0.669	1.537	1.392
IRF1	Transcription factor	-1.013	0.519	1.416	1.081
CXCL3	Chemokine	1.7	0.905	1.092	-1.598
IL12B	Cytokine	-2.448	0.042	-1.473	-2.109
CCL11	Chemokine	-1.338	0.349	-1.995	-1.785
MAP3K7IP1	Adaptor				
IFNG	Cytokine	-1.15	0.801	1.075	1.053



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

Why represent all the data?

Computer-based visualization systems provide visual representations of datasets designed to help people carry out tasks more effectively.

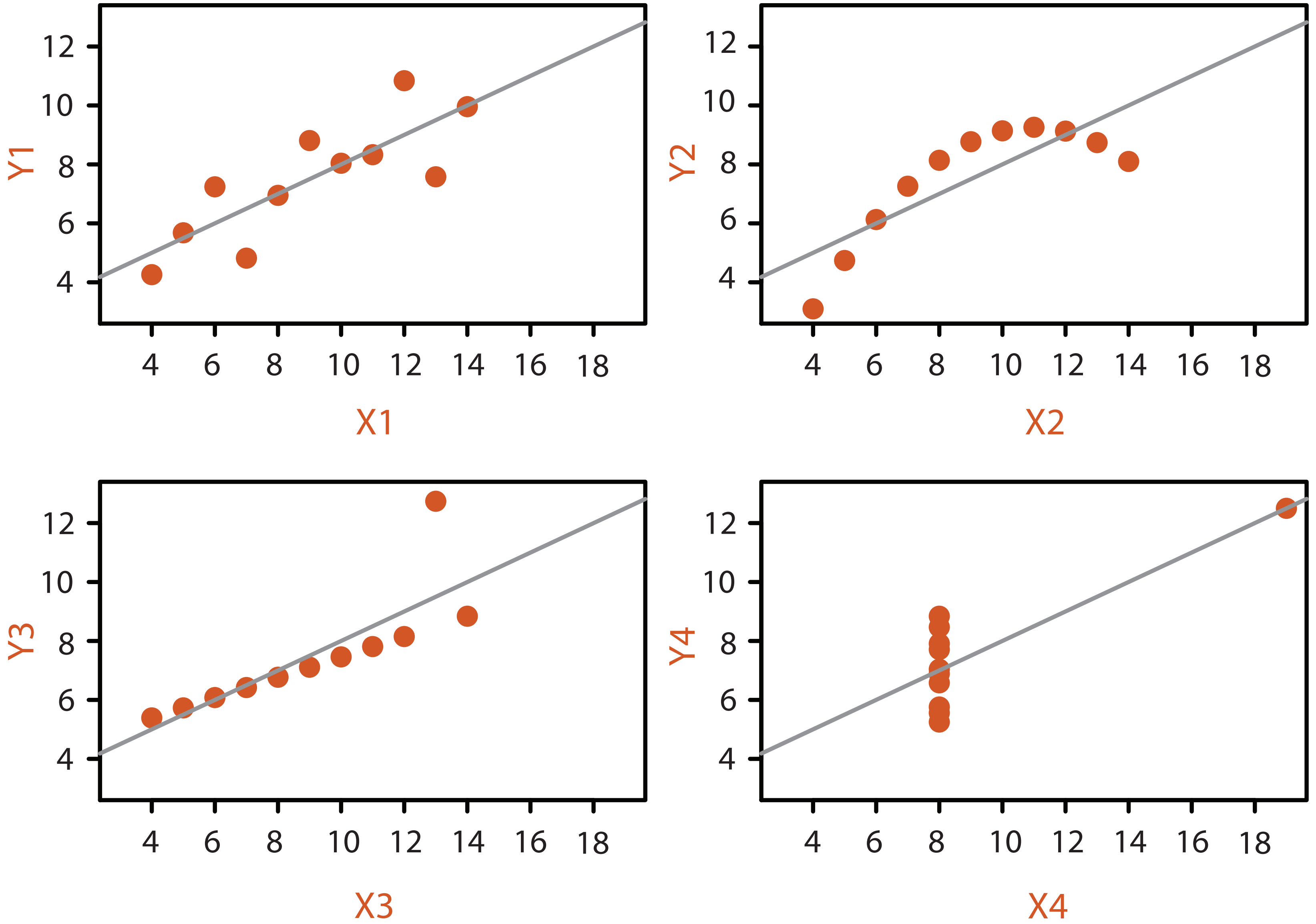
- summaries lose information, details matter
  - confirm expected and find unexpected patterns
  - assess validity of statistical model

Anscombe's Quartet

Identical statistics	
x mean	9
x variance	10
y mean	7.5
y variance	3.75
x/y correlation	0.816

https://www.youtube.com/watch?v=DbJyPELmhJc

Same Stats, Different Graphs



What resource limitations are we faced with?

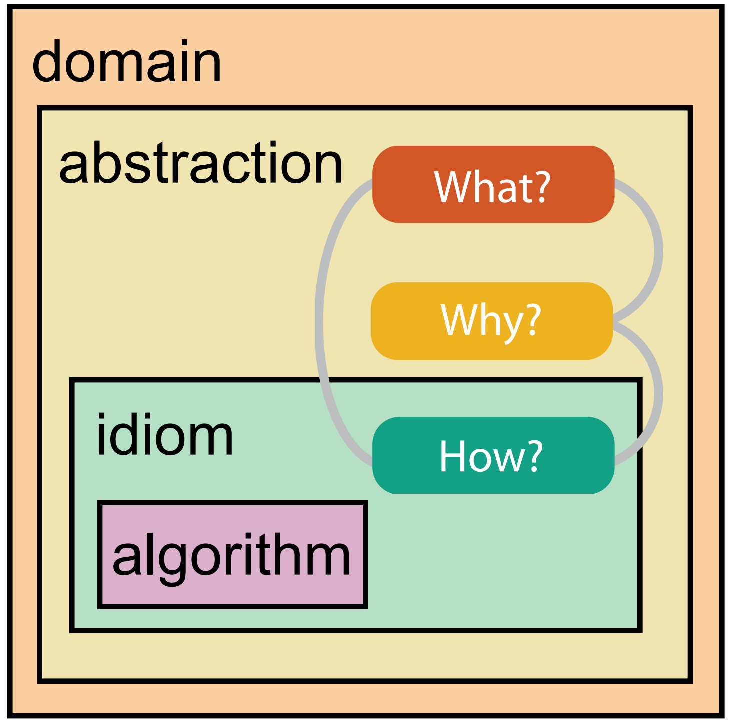
Vis designers must take into account three very different kinds of resource limitations: those of computers, of humans, and of displays.

- computational limits
  - processing time
  - system memory
- human limits
  - human attention and memory
- display limits
  - pixels are precious resource, the most constrained resource
  - **information density**: ratio of space used to encode info vs unused whitespace
    - tradeoff between clutter and wasting space, find sweet spot between dense and sparse

Nested model: Four levels of vis design

- *domain situation*
  - who are the target users?
- *abstraction*
  - translate from specifics of domain to vocabulary of vis
    - **what** is shown? **data** abstraction
    - **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).*]

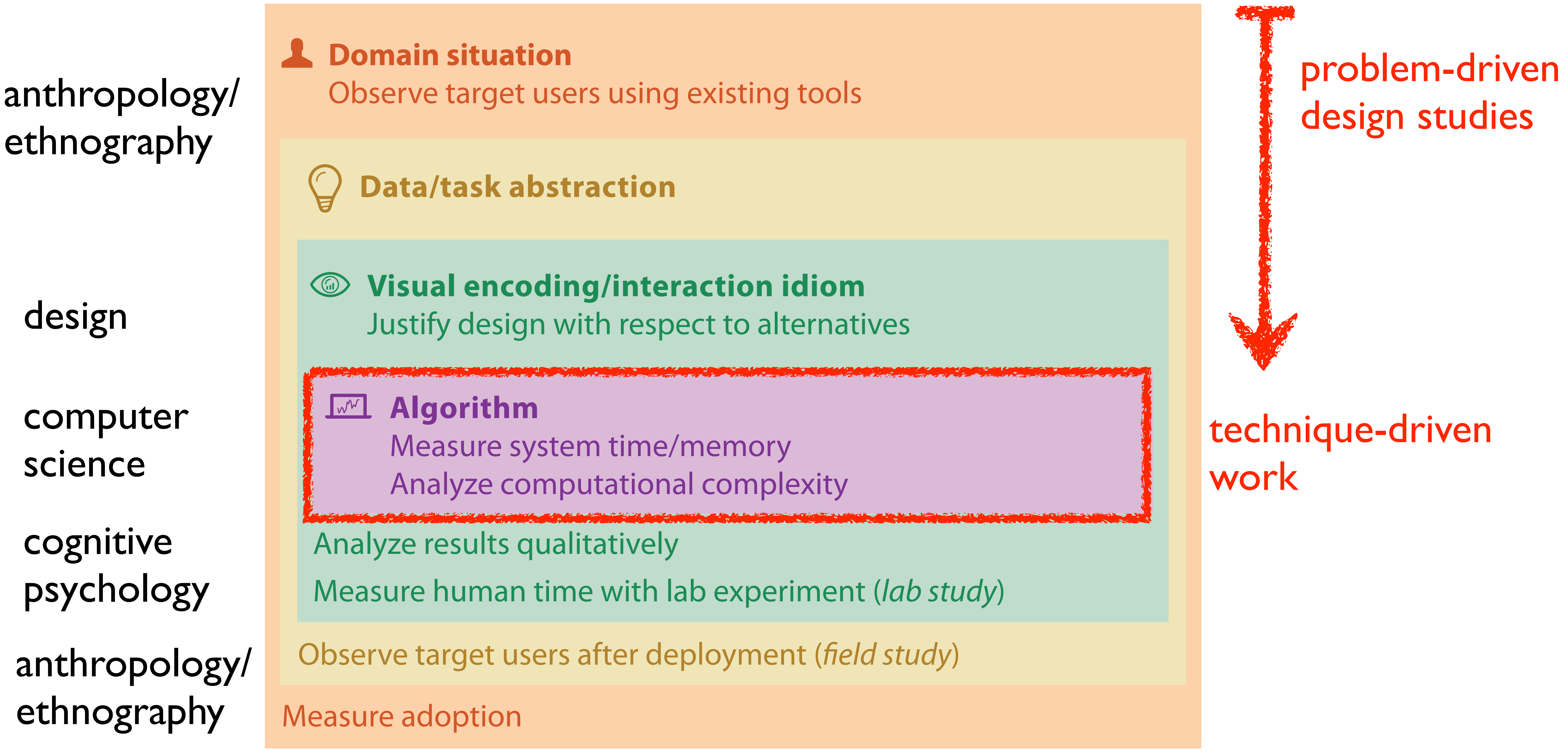


[A Multi-Level Typology of Abstract Visualization Tasks *Brehmer and Munzner. IEEE TVCG 19(12):2376-2385, 2013 (Proc. InfoVis 2013).*]

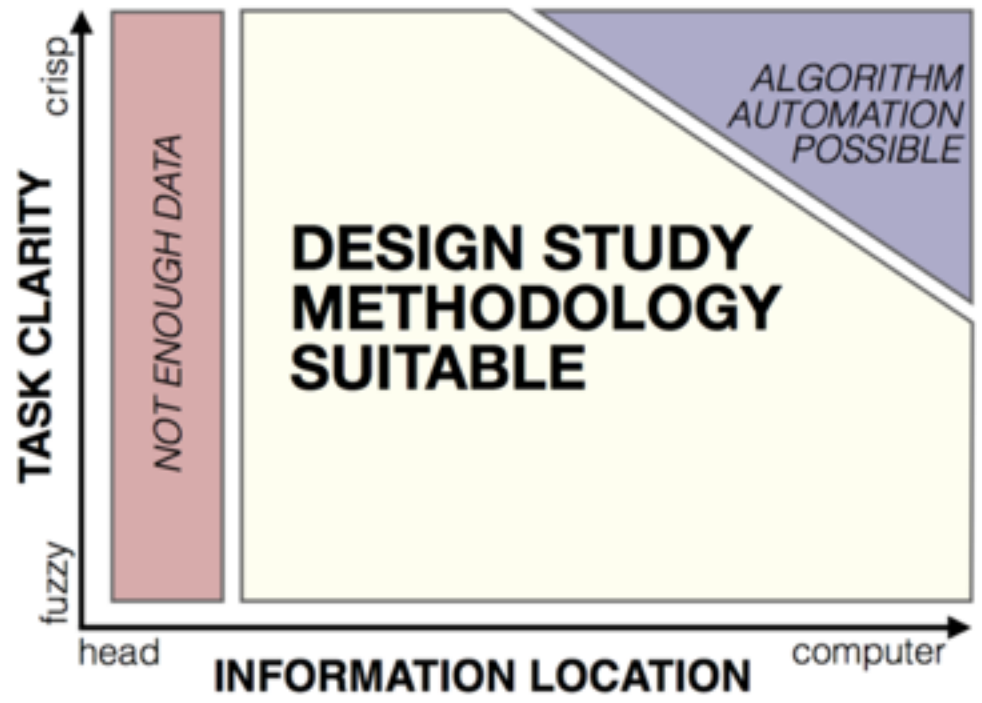
Threats to validity differ at each level

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

Evaluate success at each level with methods from different fields



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



Michael Sedlmair

Miriah Meyer

Design Study Methodology

Reflections from the Trenches and from the Stacks

http://www.cs.ubc.ca/labs/imager/tr/2012/dsm/

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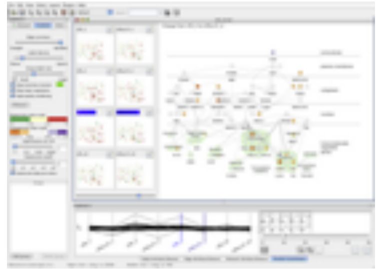
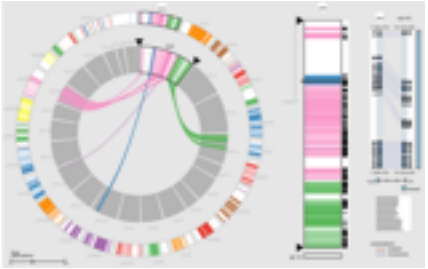
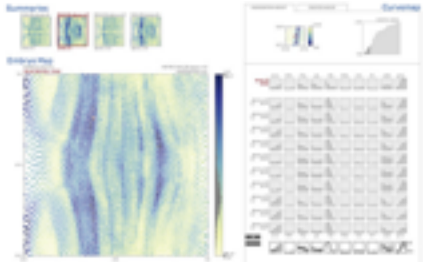
Design Study Methodology: Reflections from the Trenches and from the Stacks.
Sedlmair, Meyer, Munzner. IEEE Trans. Visualization and Computer Graphics 18(12): 2431-2440, 2012 (Proc. InfoVis 2012).

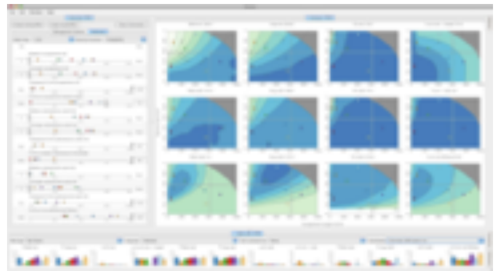
Design Studies: Lessons learned after 21 of them

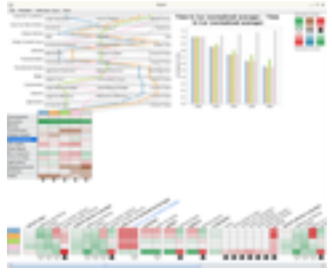

Cerebral
genomics


MizBee
genomics


Pathline
genomics

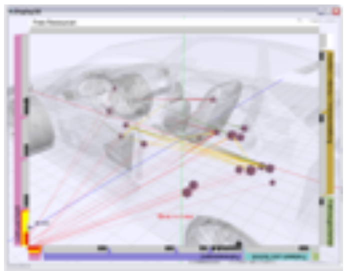

MulteeSum
genomics


Vismon
fisheries management


QuestVis
sustainability


WiKeVis
in-car networks


MostVis
in-car networks


Car-X-Ray
in-car networks


ProgSpy2010
in-car networks

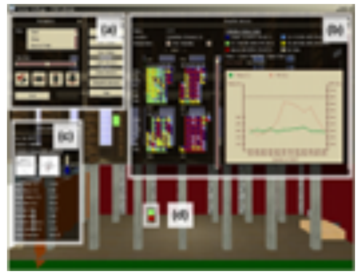

RelEx
in-car networks

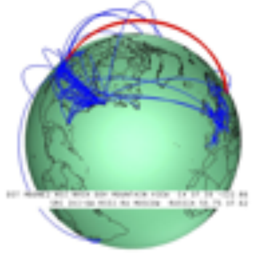

Cardiogram
in-car networks

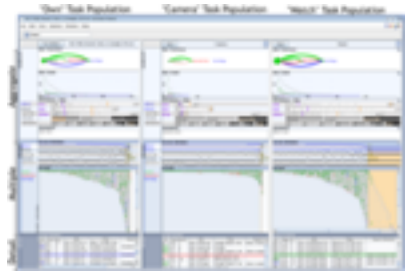

AutobahnVis
in-car networks

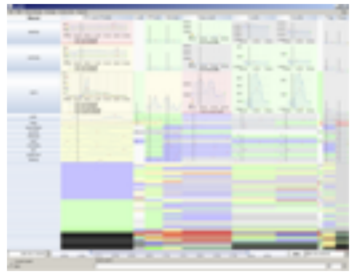

VisTra
in-car networks

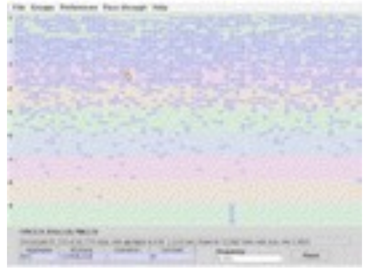

Constellation
linguistics

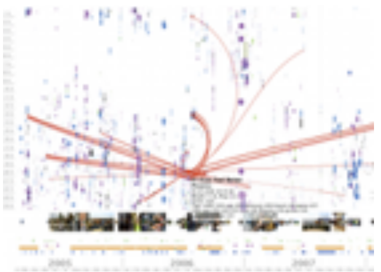

LibVis
cultural heritage


Caidants
multicast


SessionViewer
web log analysis

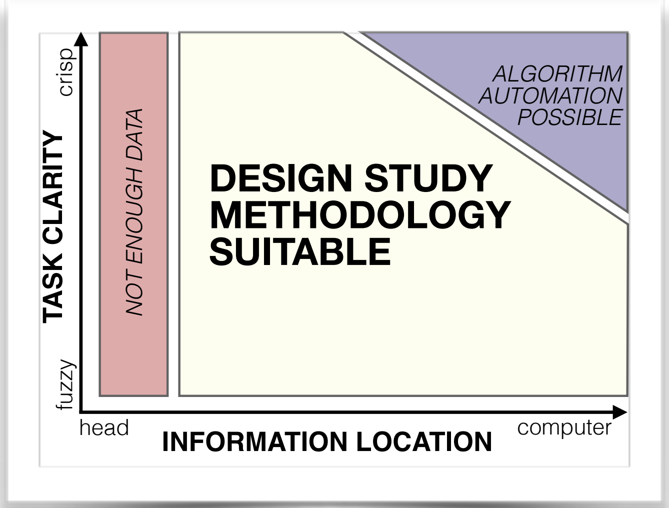

LiveRAC
server hosting


PowerSetViewer
data mining

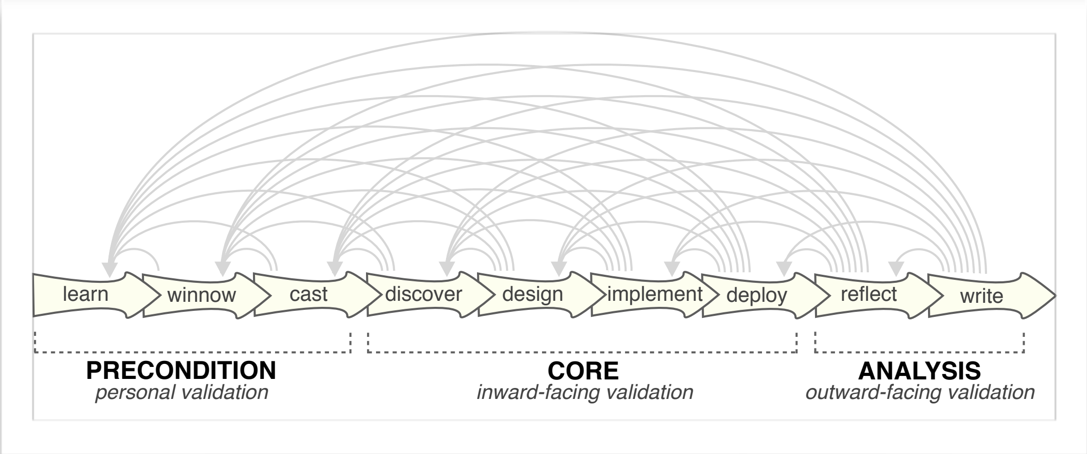

LastHistory
music listening

Methodology for Problem-Driven Work

- definitions



- 9-stage framework



- 32 pitfalls
  and how to avoid them

PF-1	premature advance: jumping forward over stages	general
PF-2	premature start: insufficient knowledge of vis literature	learn
PF-3	premature commitment: collaboration with wrong people	winnow
PF-4	no real data available (yet)	winnow
PF-5	insufficient time available from potential collaborators	winnow
PF-6	no need for visualization: problem can be automated	winnow
PF-7	researcher expertise does not match domain problem	winnow
PF-8	no need for research: engineering vs. research project	winnow
PF-9	no need for change: existing tools are good enough	winnow

What?

Why?

How?

What?

Datasets

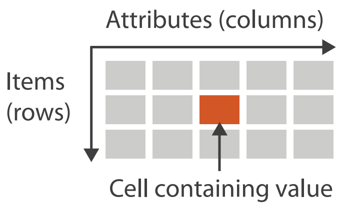
Data Types
- Items
- Attributes
- Links
- Positions
- Grids

Data and Dataset Types

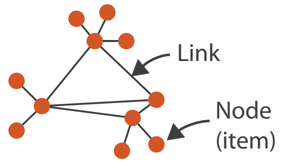
Tables	Networks & Trees	Fields	Geometry	Clusters, Sets, Lists
Items	Items (nodes)	Grids	Items	Items
Attributes	Links	Positions	Positions	
	Attributes	Attributes		

Dataset Types

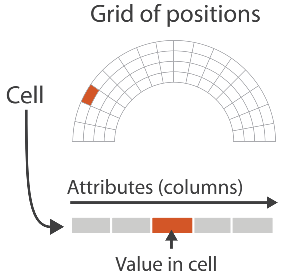
- Tables



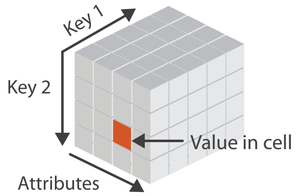
- Networks



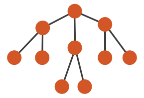
- Fields (Continuous)



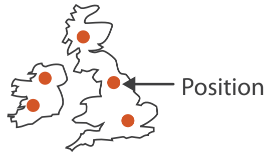
- *Multidimensional Table*



- *Trees*



- Geometry (Spatial)



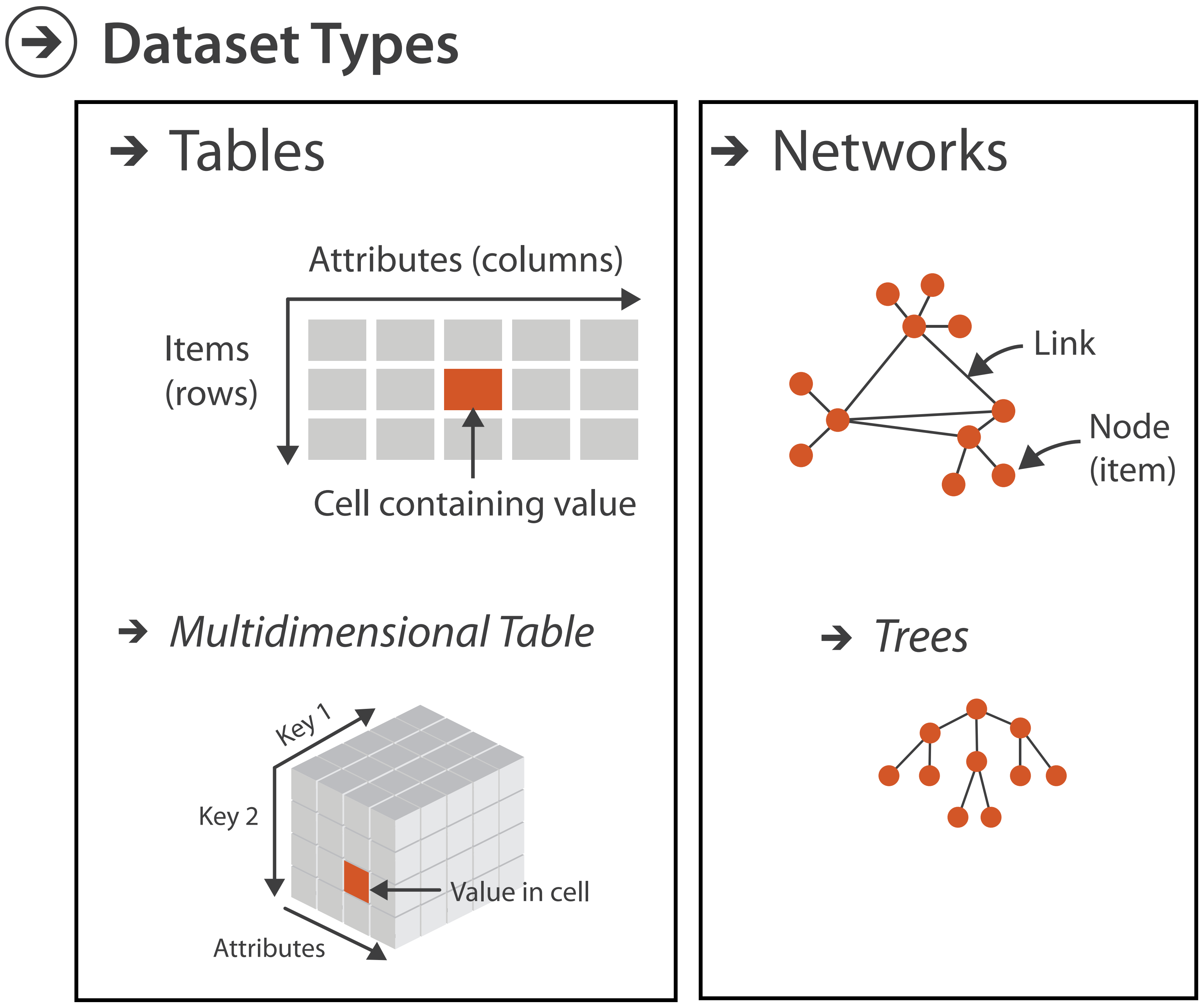
Dataset Availability
- Static
- Dynamic

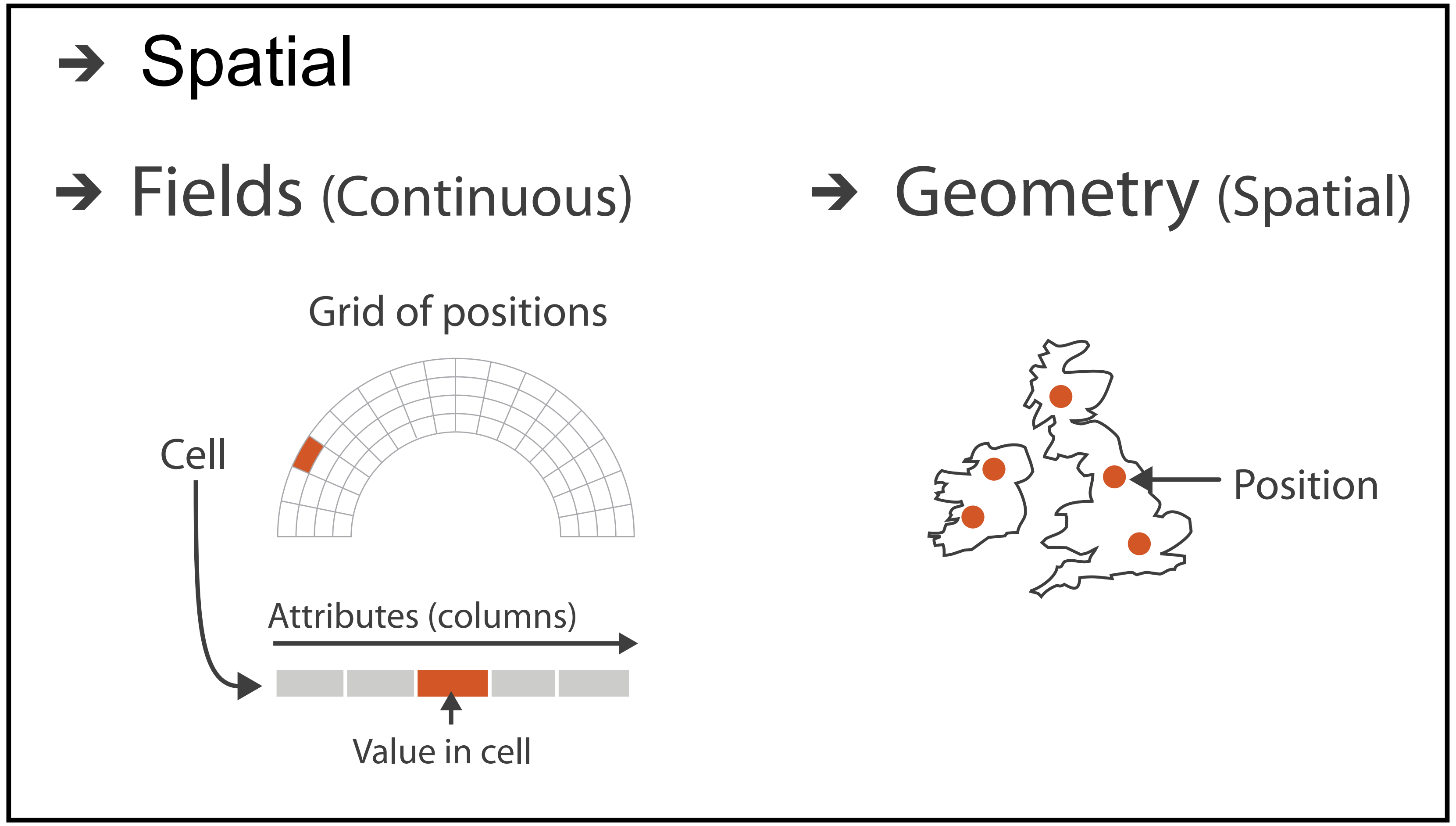
Attributes

Attribute Types
- Categorical
- Ordered
  - *Ordinal*
  - *Quantitative*

Ordering Direction
- Sequential
- Diverging
- Cyclic

Three major datatypes



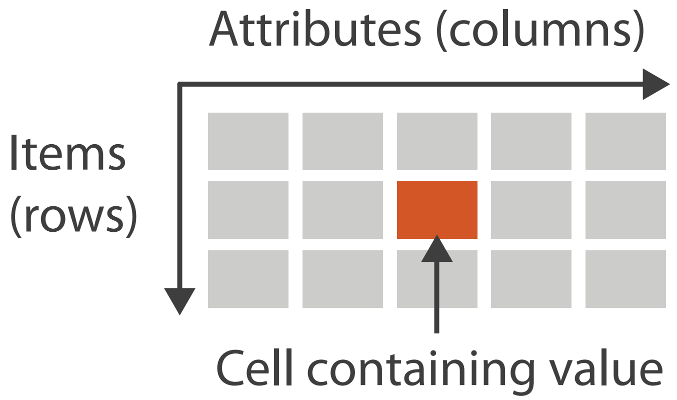


- visualization vs computer graphics
  - –geometry is design decision

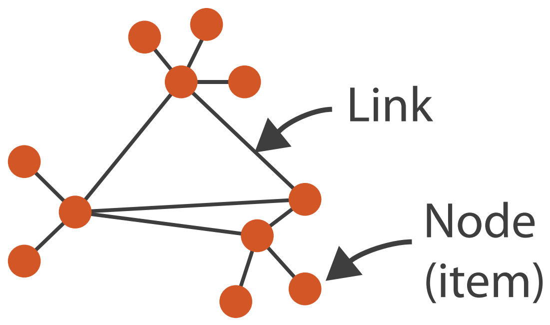
Types: Datasets and data

➔ Dataset Types

➔ Tables

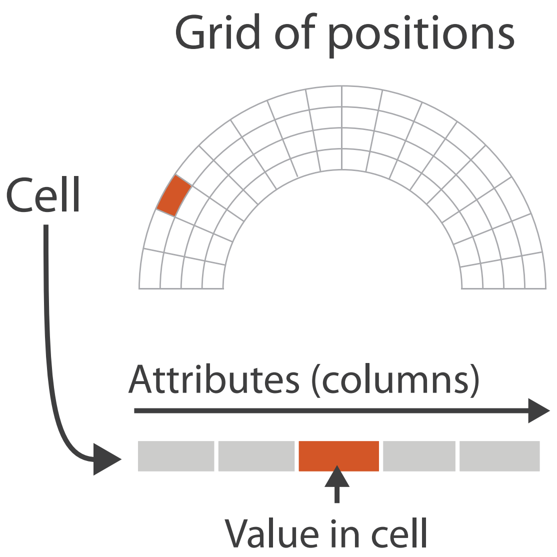


➔ Networks

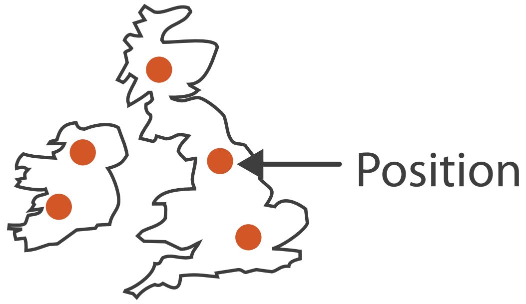


➔ Spatial

➔ Fields (Continuous)



➔ Geometry (Spatial)

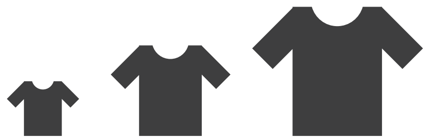


➔ Attribute Types

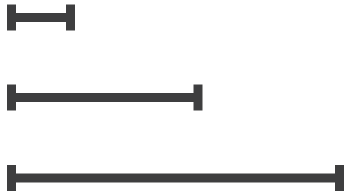
➔ Categorical

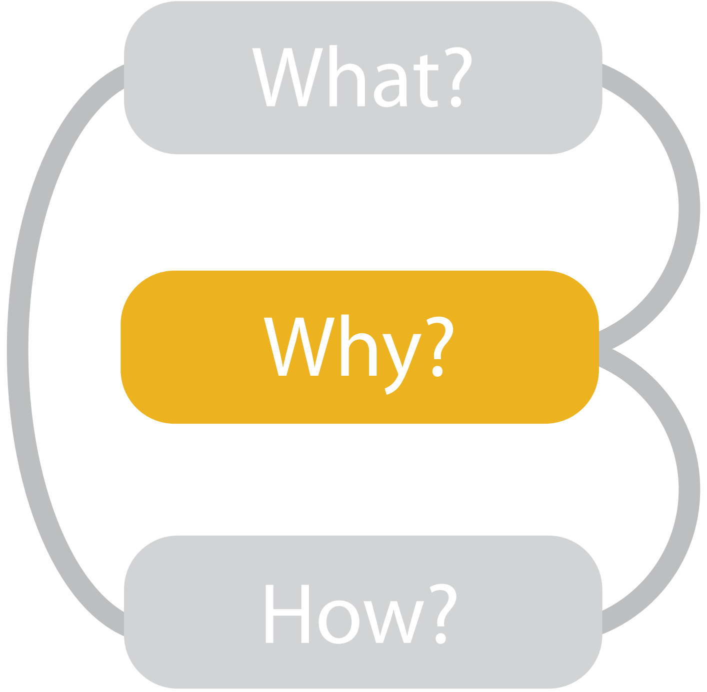
➔ Ordered

➔ *Ordinal*

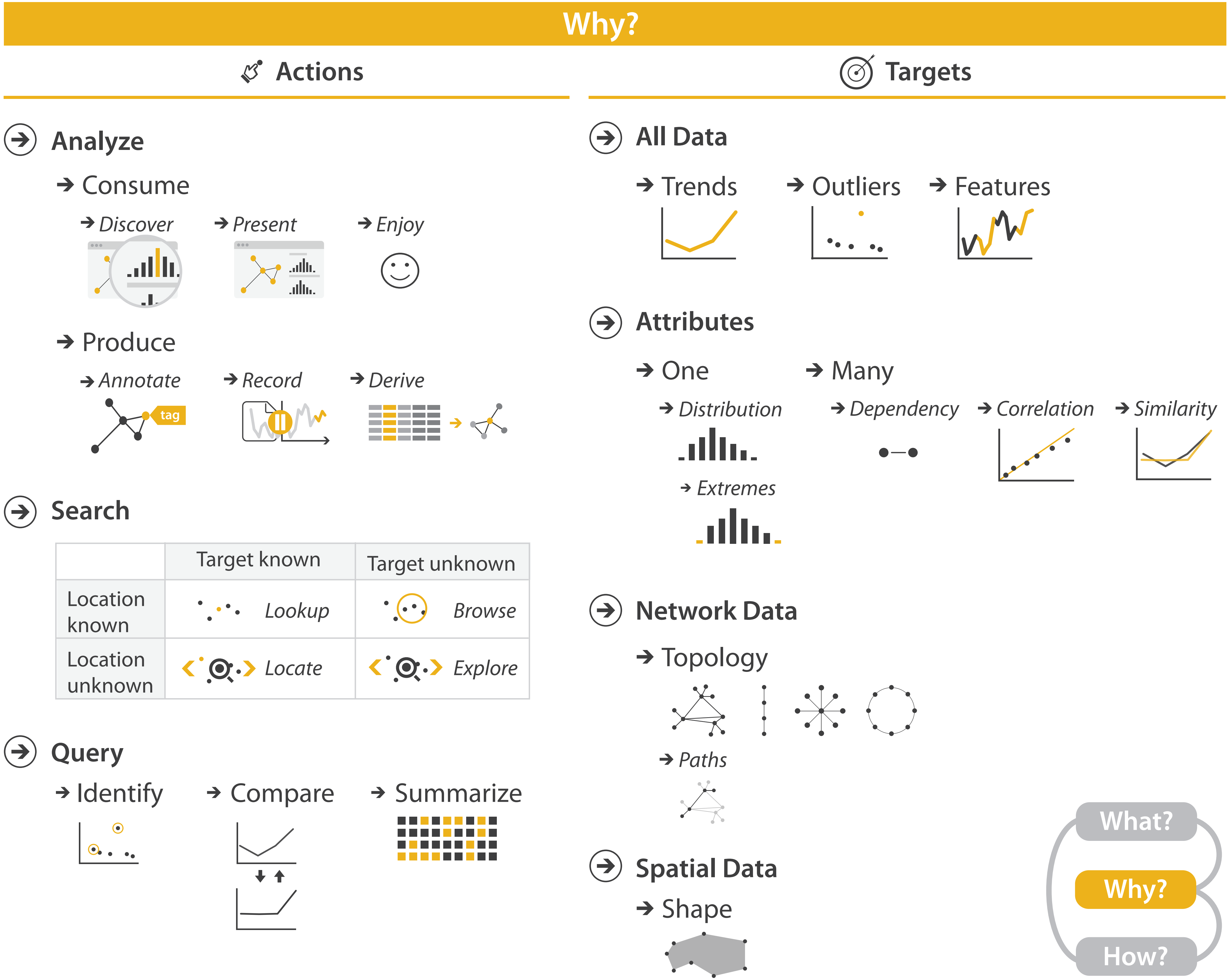


➔ *Quantitative*





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

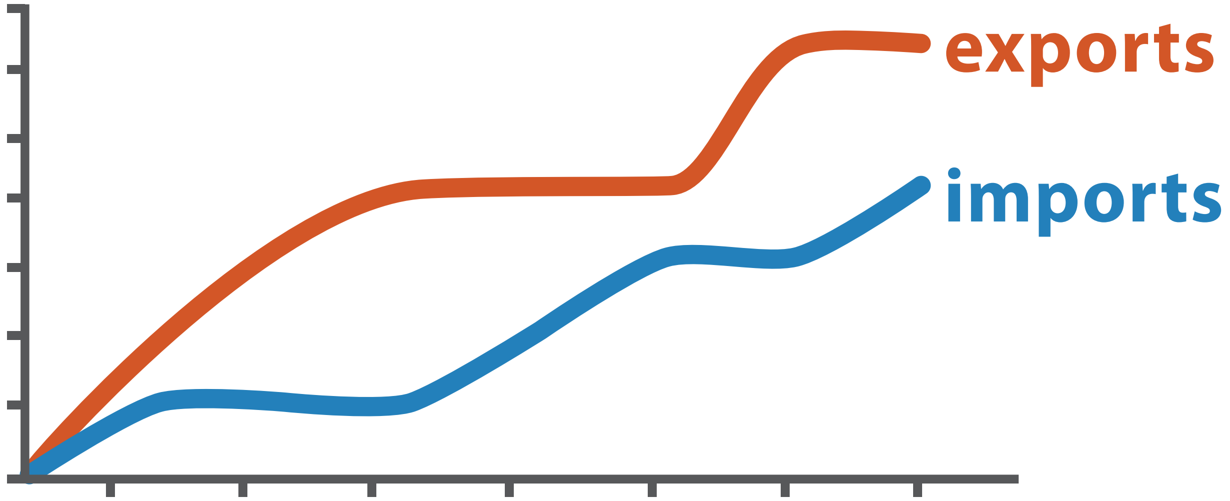


Actions: Analyze, Query

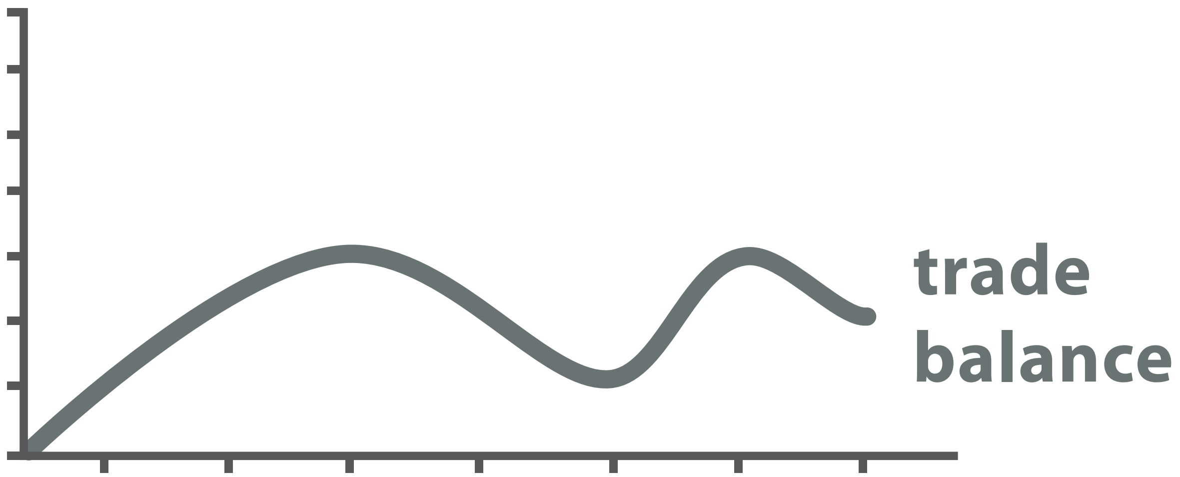
- analyze
  - consume
    - discover vs present
      - aka explore vs explain
    - enjoy
      - aka casual, social
  - produce
    - annotate, record, derive
- query
  - how much data matters?
    - one, some, all
- independent choices

Derive: Crucial Design Choice

- 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



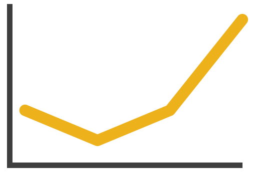
trade balance = exports − imports

Derived Data

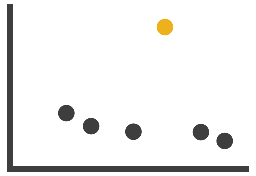
Targets

All Data

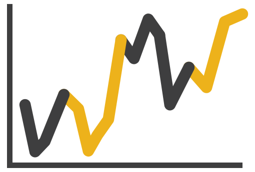
- Trends



- Outliers

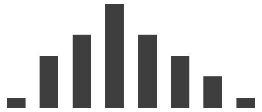


- Features

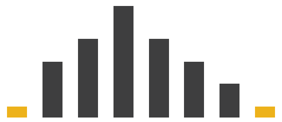


Attributes

- One
  - *Distribution*

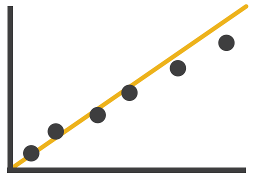


  - *Extremes*

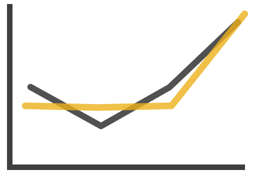


- Many
  - *Dependency*

  - *Correlation*

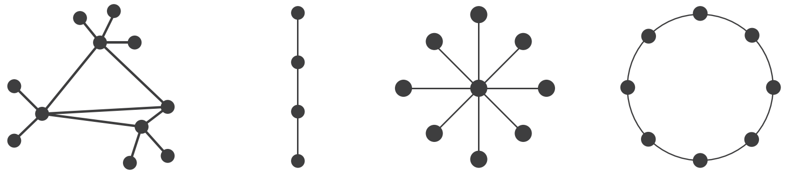


  - *Similarity*

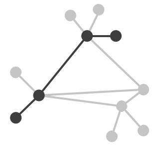


Network Data

- Topology

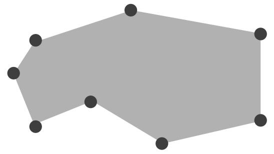


  - *Paths*

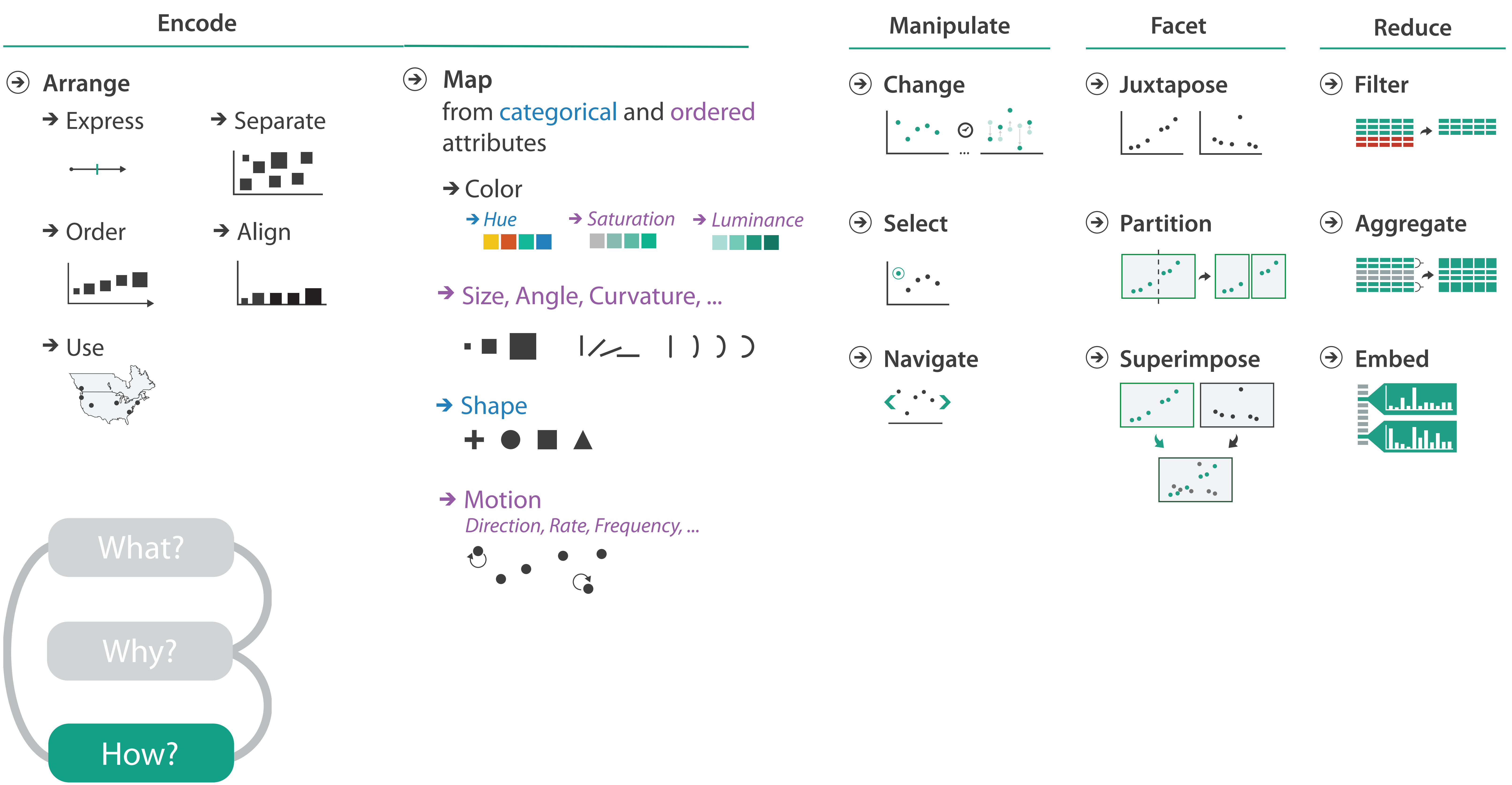


Spatial Data

- Shape



How?


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

How to encode: Arrange space, map channels

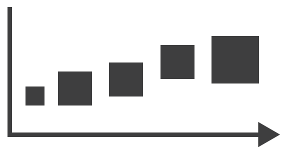
Encode

Arrange

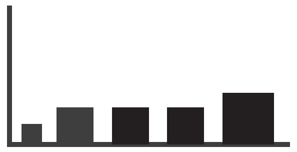
- Express

- Separate

- Order



- Align



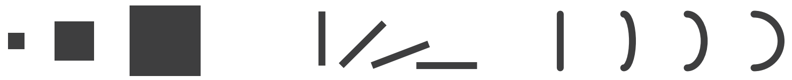
- Use

Map

from categorical and ordered attributes

- Color
  - *Hue*
  - *Saturation*
  - *Luminance*

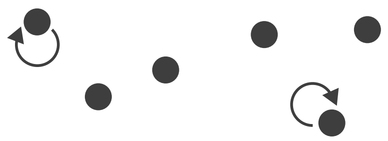
- Size, Angle, Curvature, ...



- Shape

- Motion

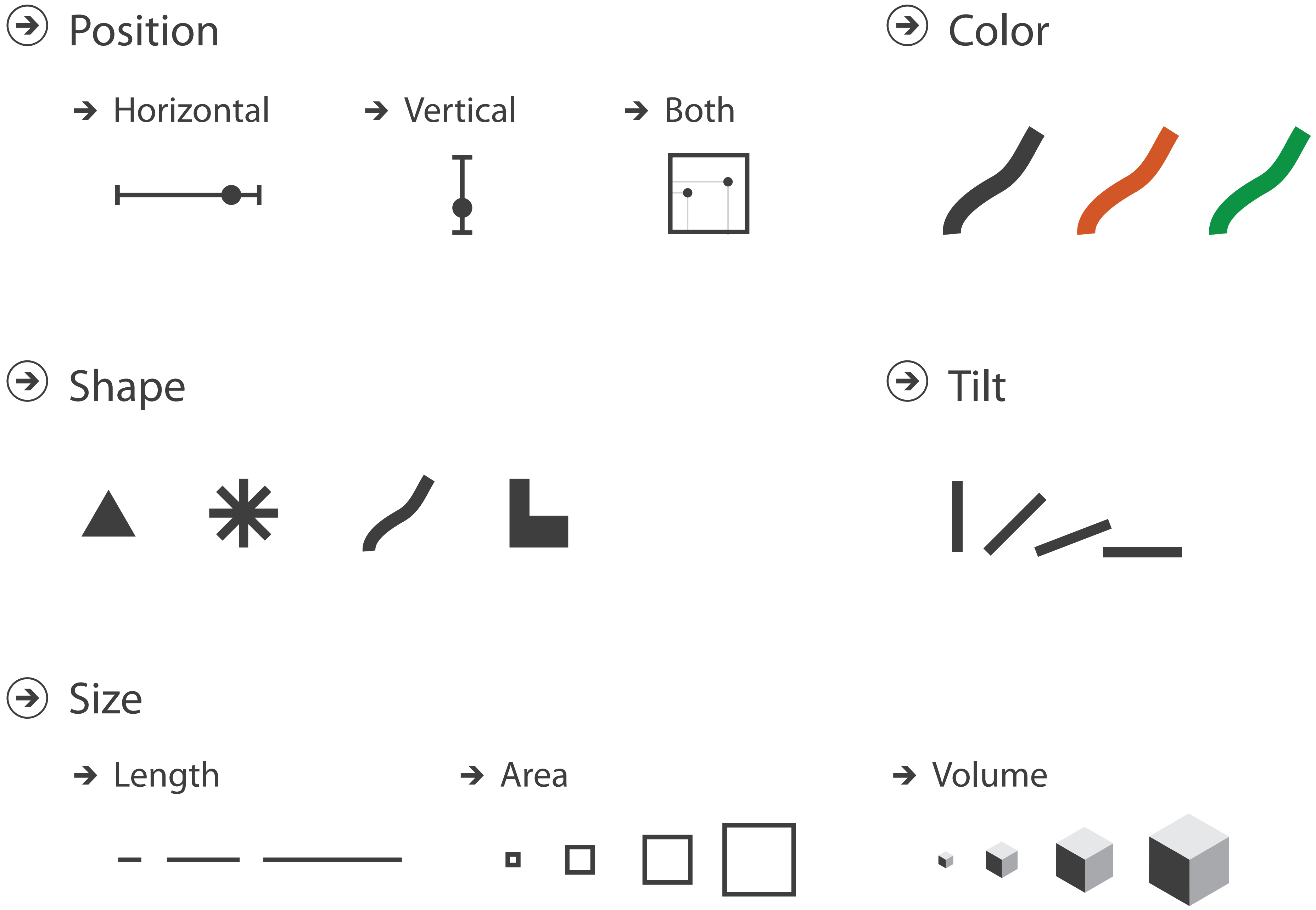
  Direction, Rate, Frequency, ...



Definitions: Marks and channels

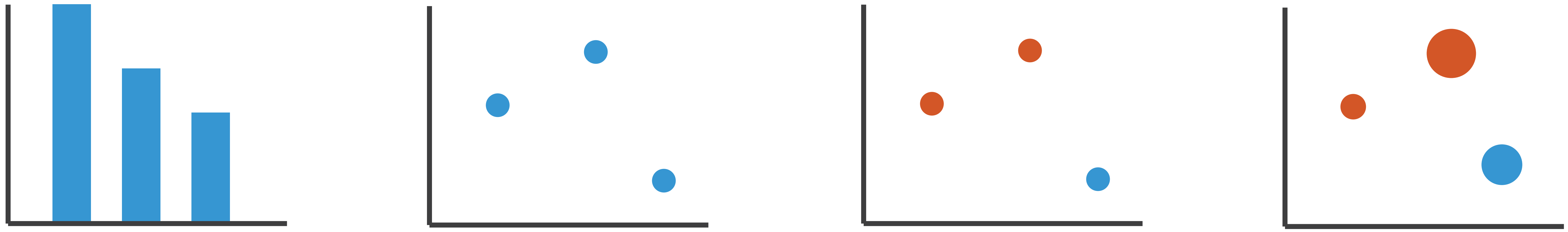
- marks
  - geometric primitives

- 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

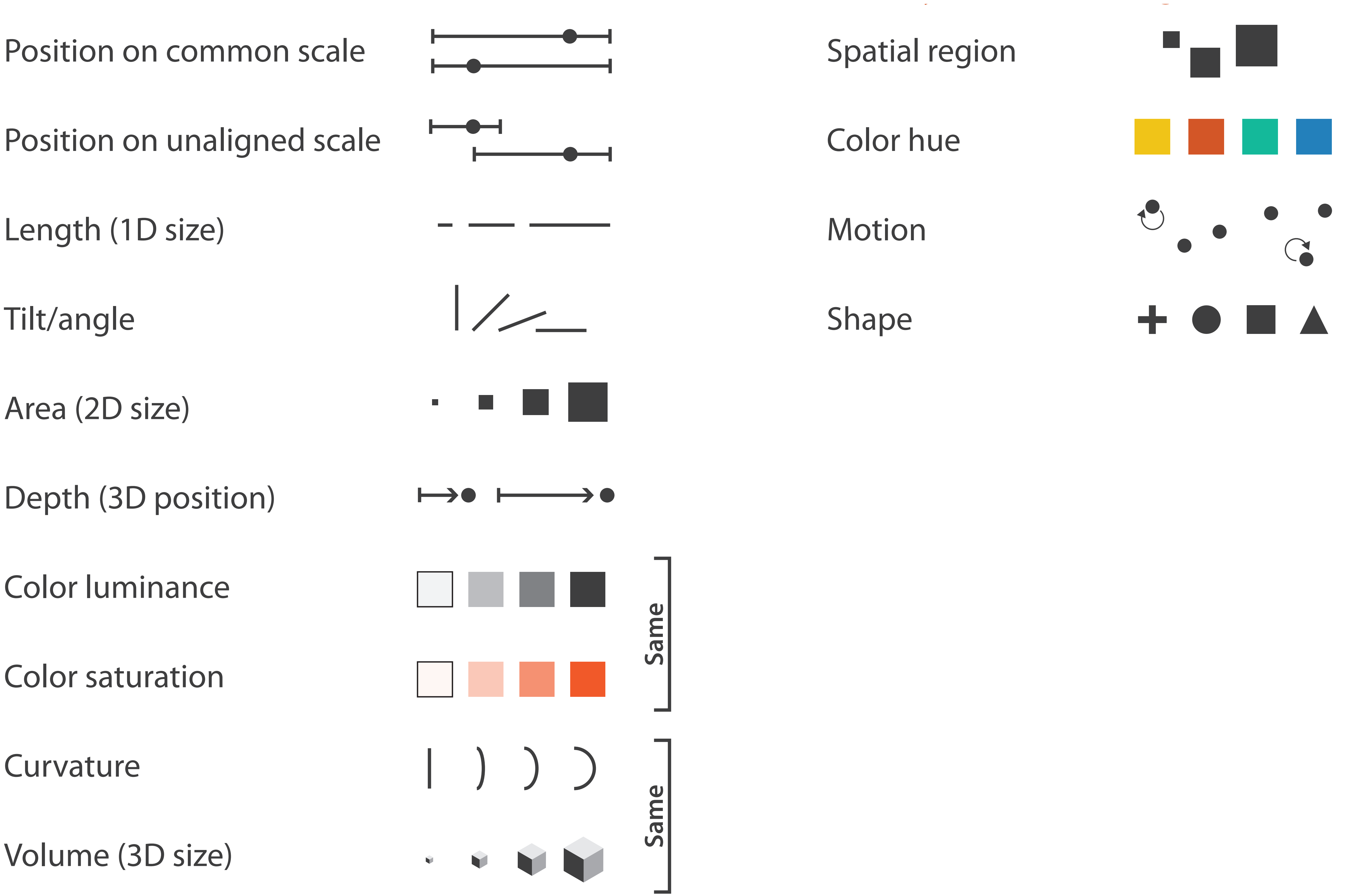
3:
vertical position
horizontal position
color hue

mark: point

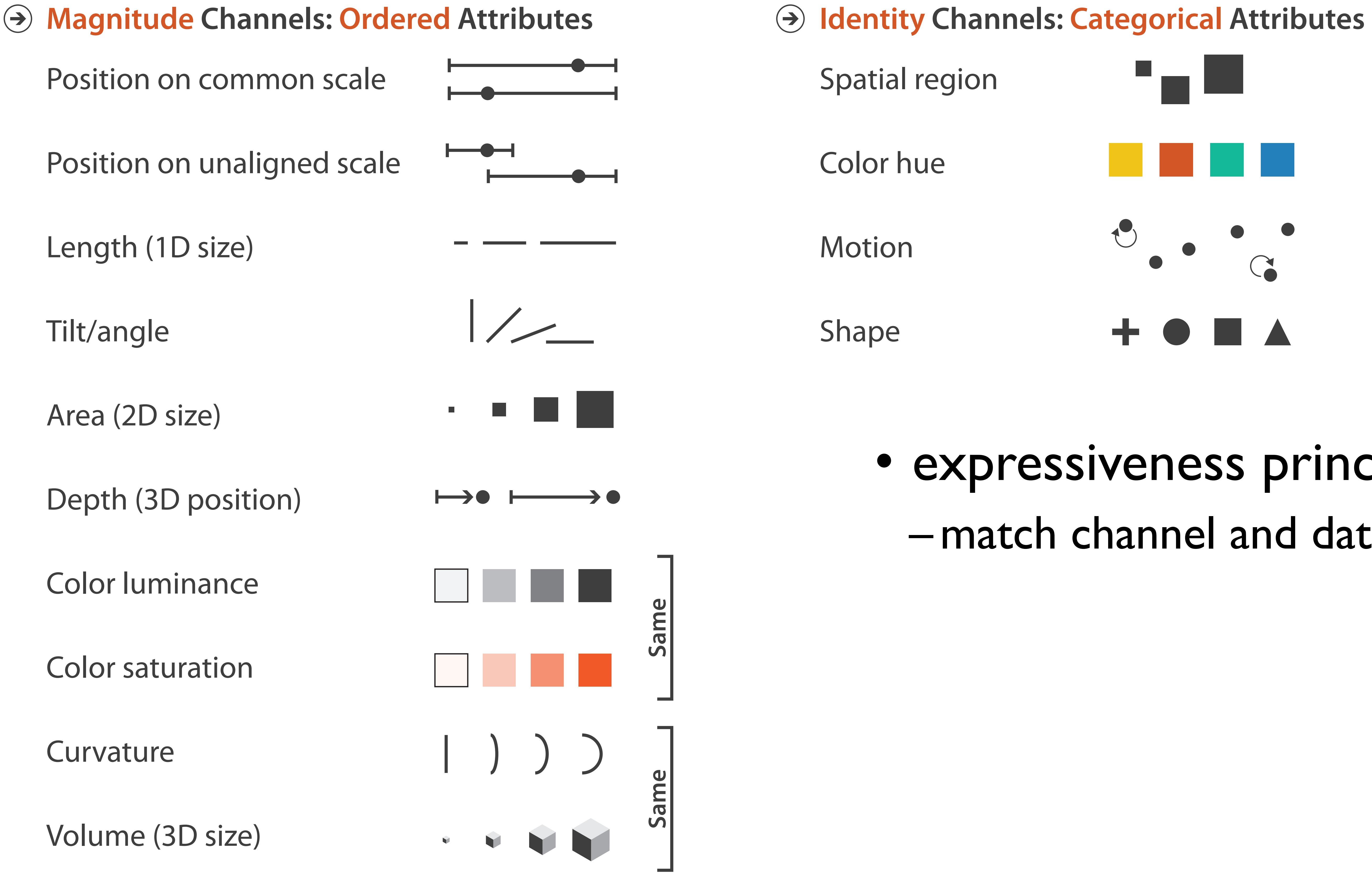
4:
vertical position
horizontal position
color hue
size (area)

mark: point

Channels

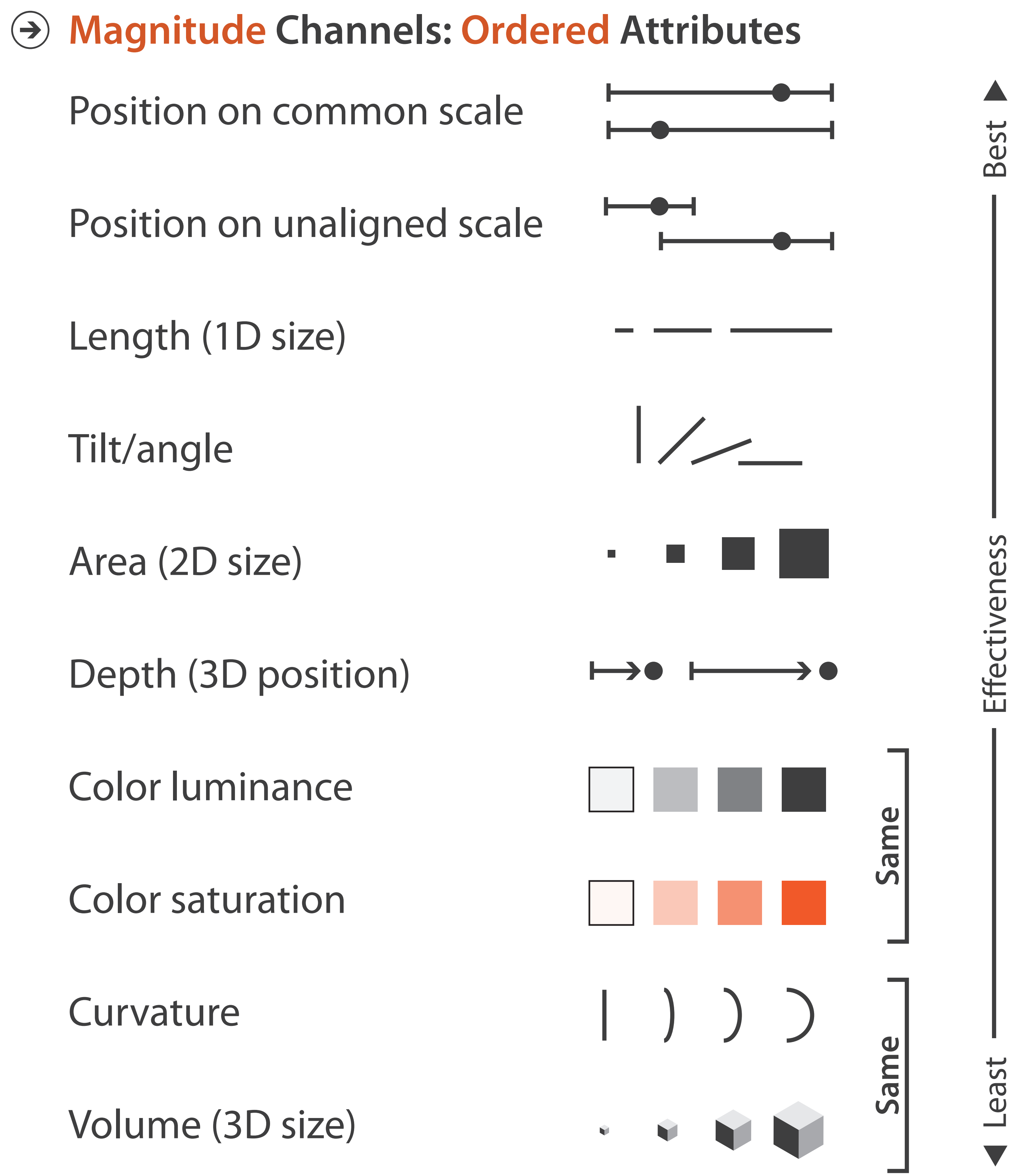

Position on common scale
Position on unaligned scale
Length (1D size)
Tilt/angle
Area (2D size)
Depth (3D position)
Color luminance
Color saturation
Curvature
Volume (3D size)
Same
Same
Spatial region
Color hue
Motion
Shape

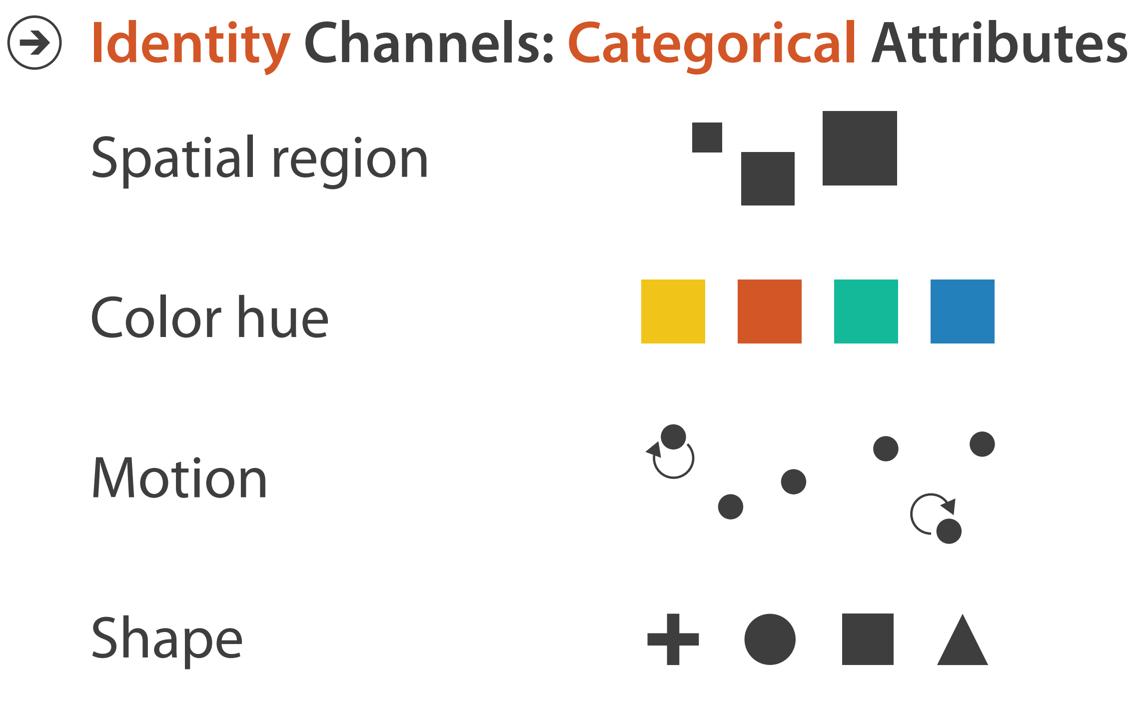
Channels: Matching Types



- expressiveness principle
  - match channel and data characteristics

Channels: Rankings

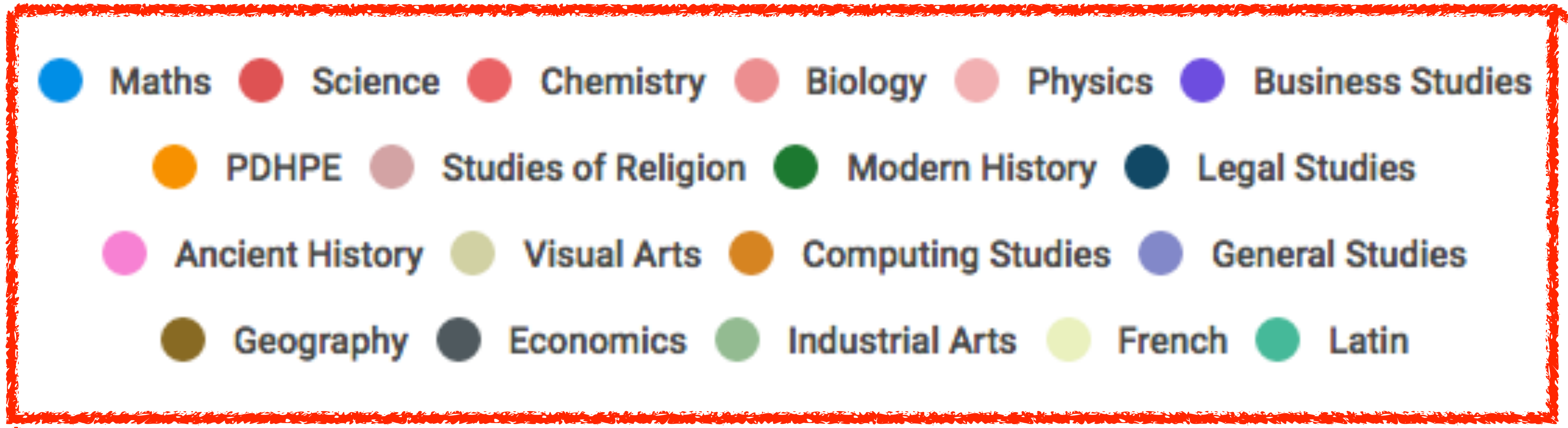


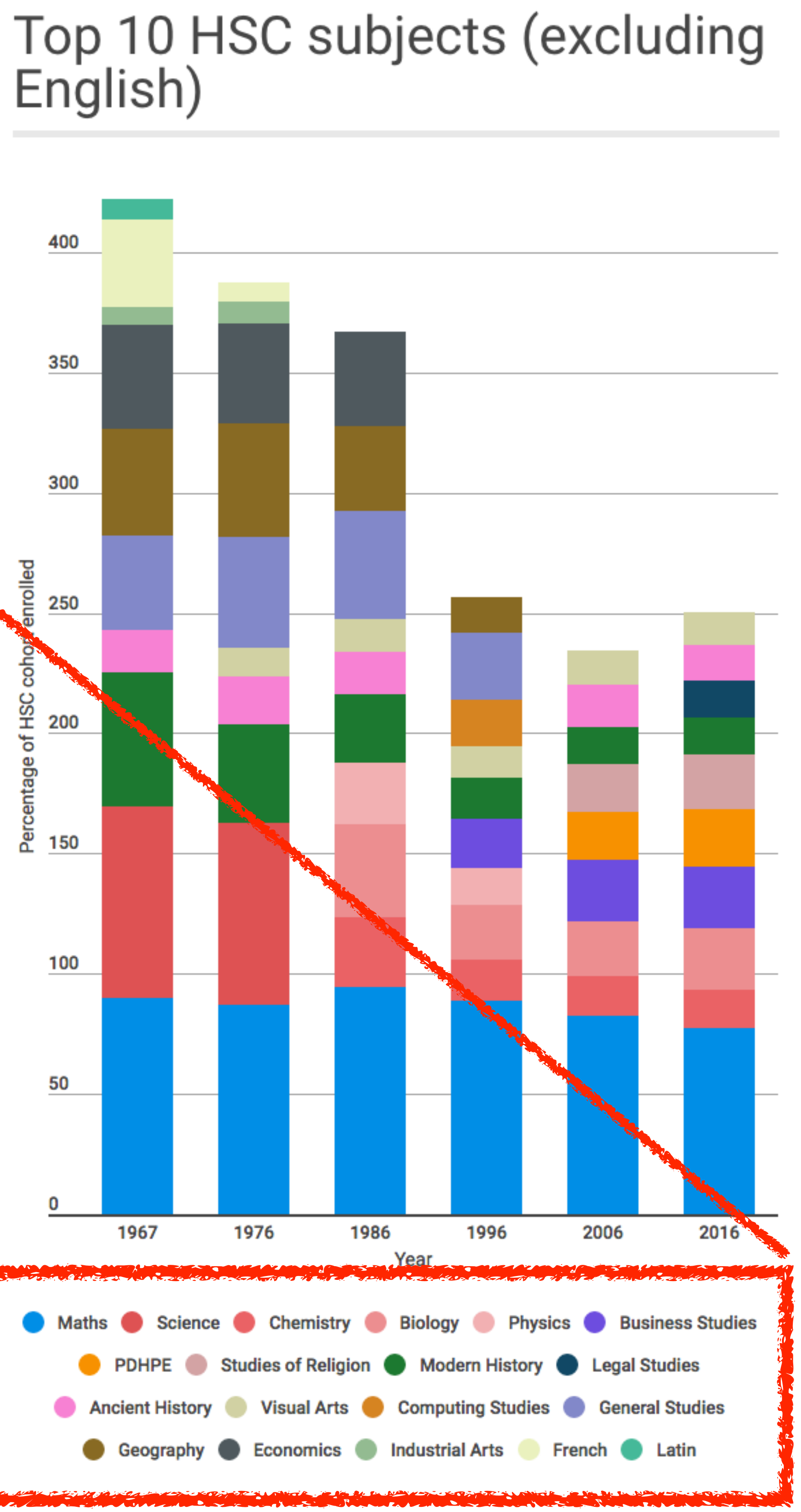


- expressiveness principle
  - match channel and data characteristics
- effectiveness principle
  - encode most important attributes with highest ranked channels

Challenges of Color

- what is wrong with this picture?



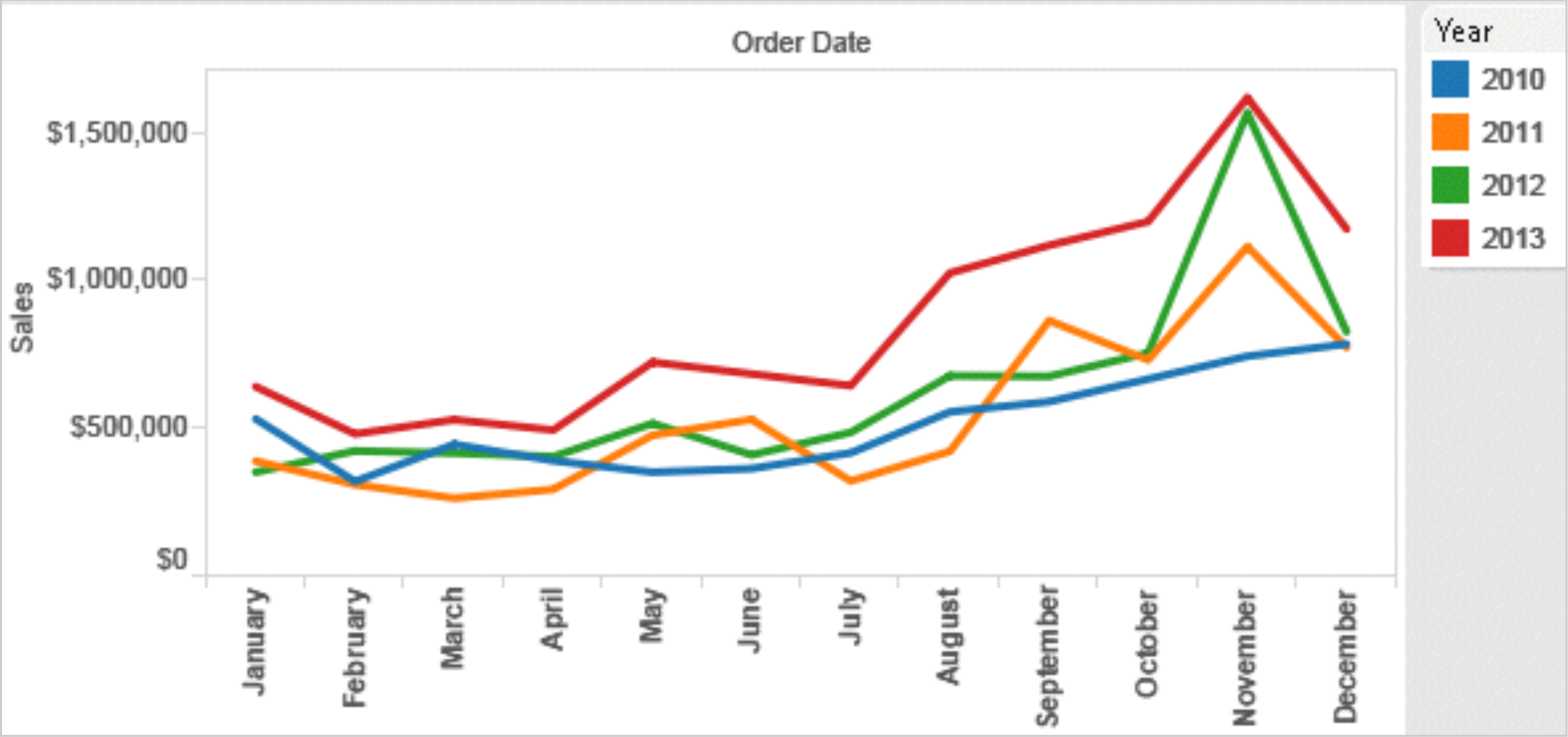


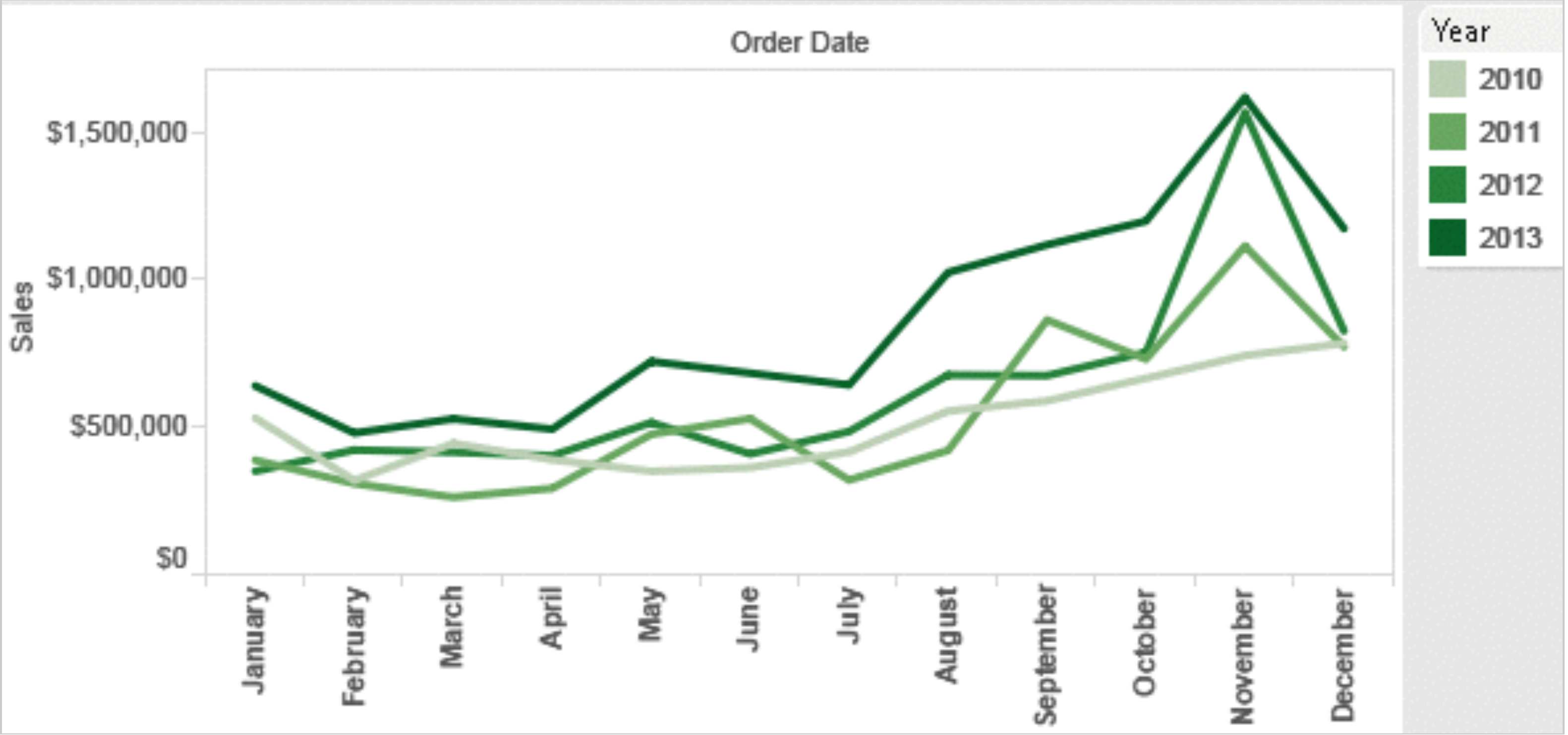
@WTFViz

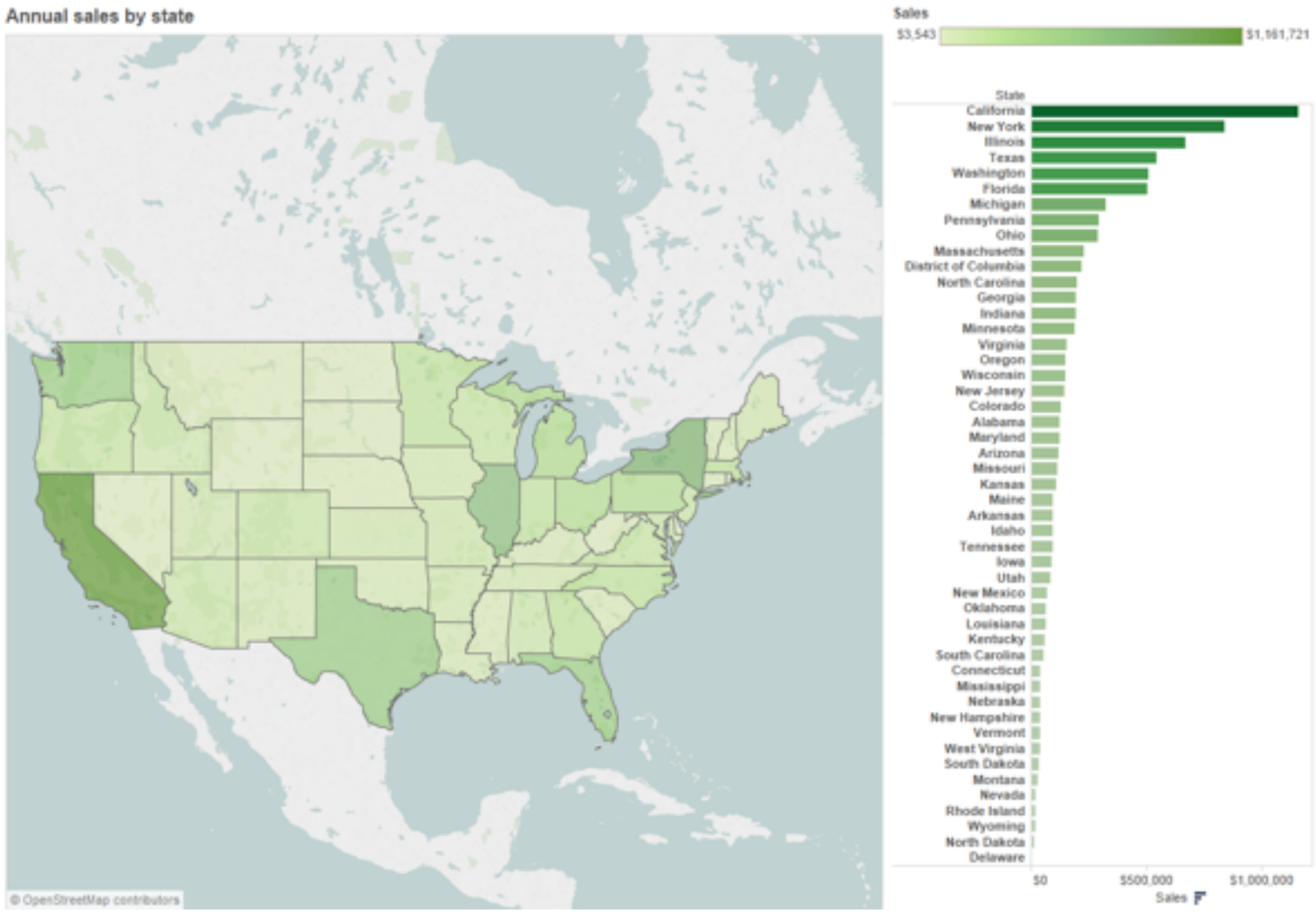
"visualizations that make no sense"

http://viz.wtf/post/150780948819/maths-enrolments-drop-to-lowest-rate-in-50-years

Categorical vs ordered color



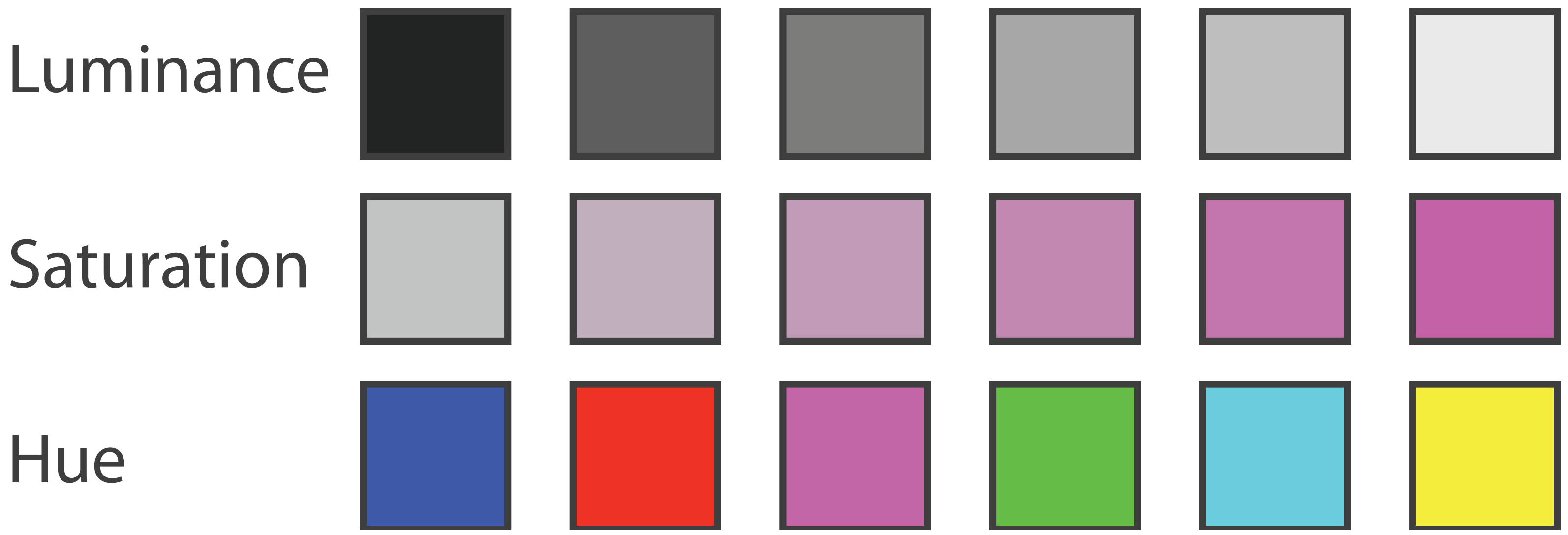




[Seriously Colorful: Advanced Color Principles & Practices. Stone. Tableau Customer Conference 2014.]

Decomposing color

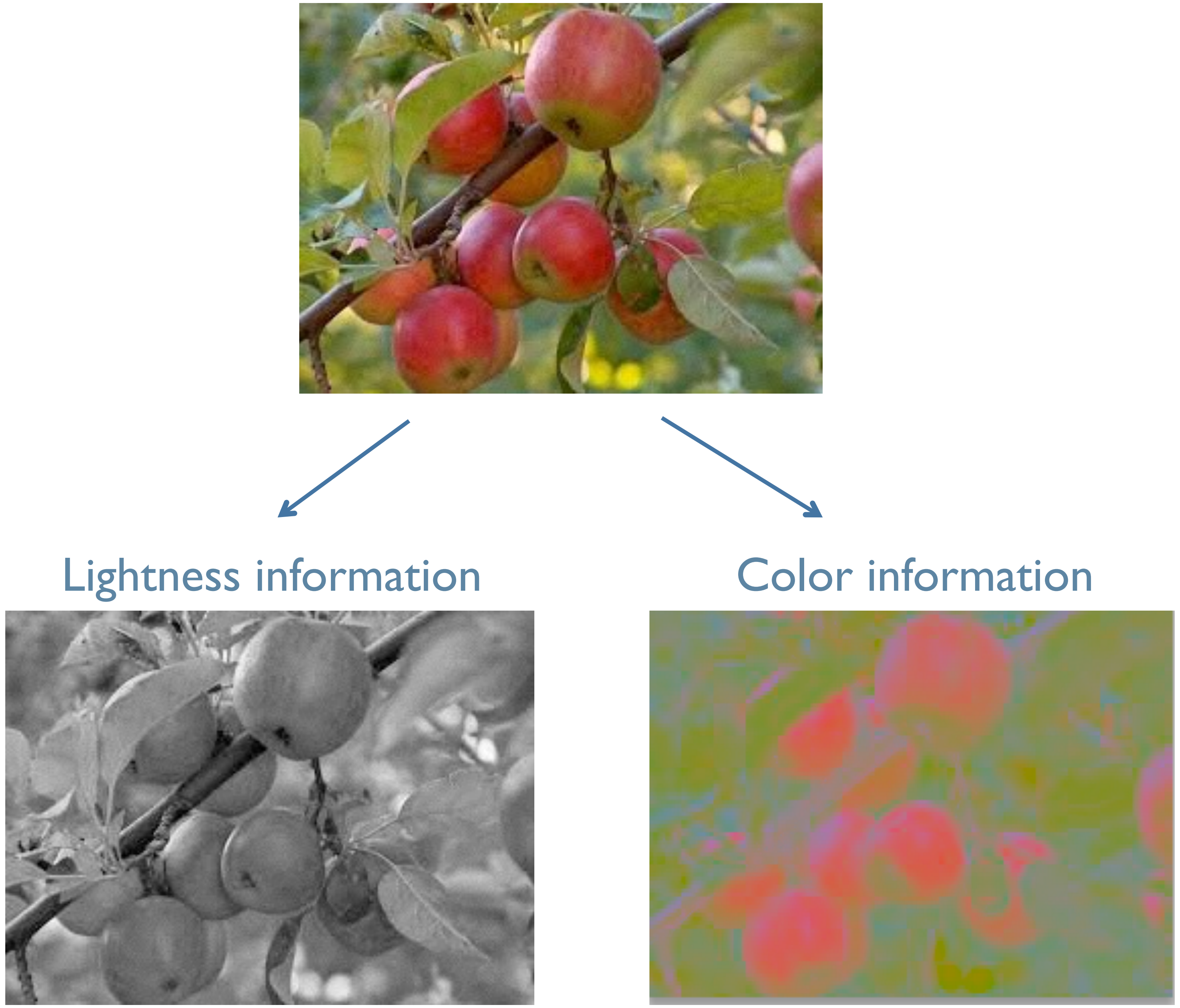
- first rule of color: do not talk about color!
  - color is confusing if treated as monolithic
- decompose into three channels
  - ordered can show magnitude
    - luminance
    - saturation
  - categorical can show identity
    - hue



- channels have different properties
  - what they convey directly to perceptual system
  - how much they can convey: how many discriminable bins can we use?

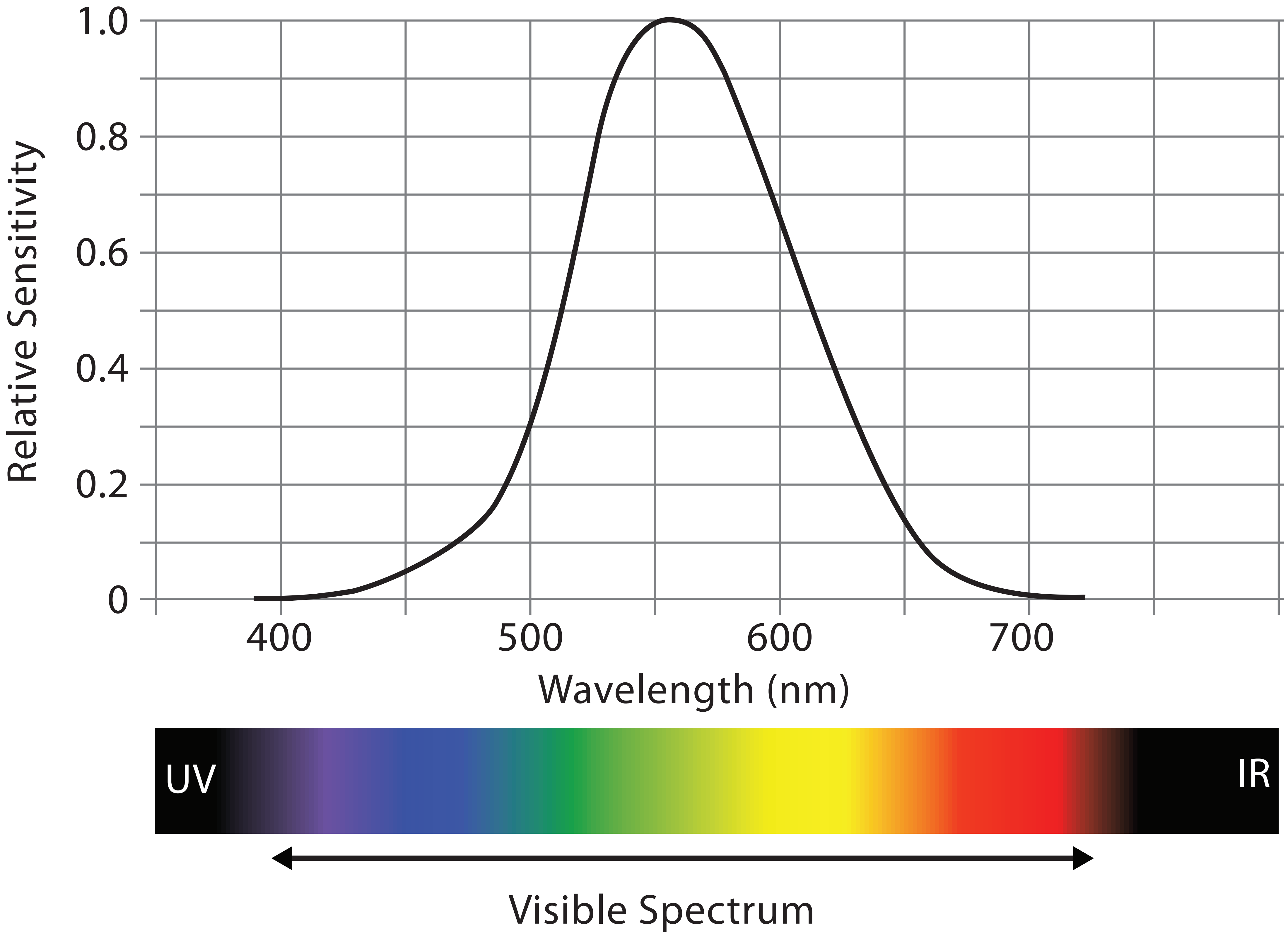
Luminance

- need luminance for edge detection
  - fine-grained detail only visible through luminance contrast
  - legible text requires luminance contrast!
- intrinsic perceptual ordering



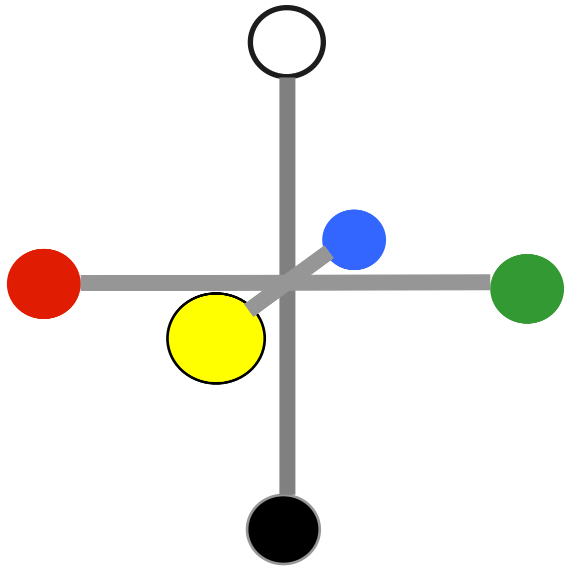
[Seriously Colorful: Advanced Color Principles & Practices. Stone.Tableau Customer Conference 2014.]

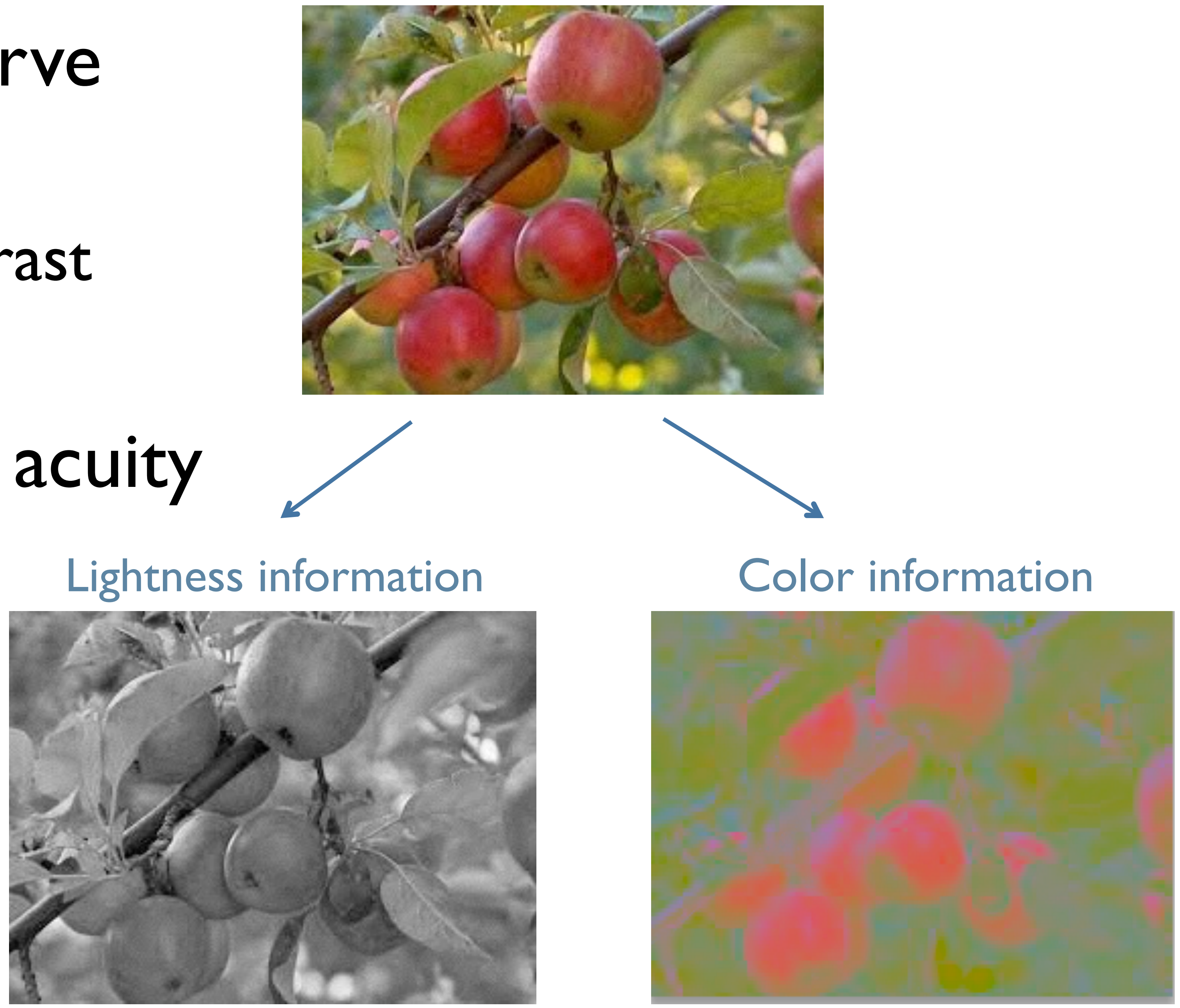
Spectral sensitivity



Opponent color and color deficiency

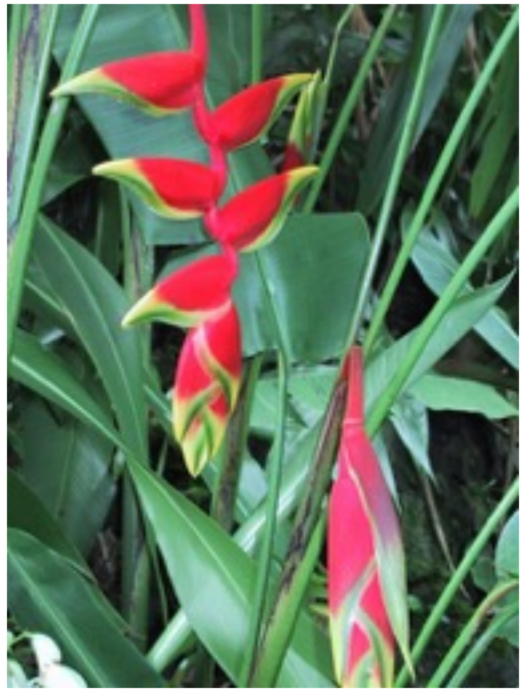
- perceptual processing before optic nerve
  - one achromatic luminance channel L
    - edge detection through luminance contrast
  - two chroma channels, R-G and Y-B axis
- "color blind" if one axis has degraded acuity
  - 8% of men are red/green color deficient
  - blue/yellow is rare



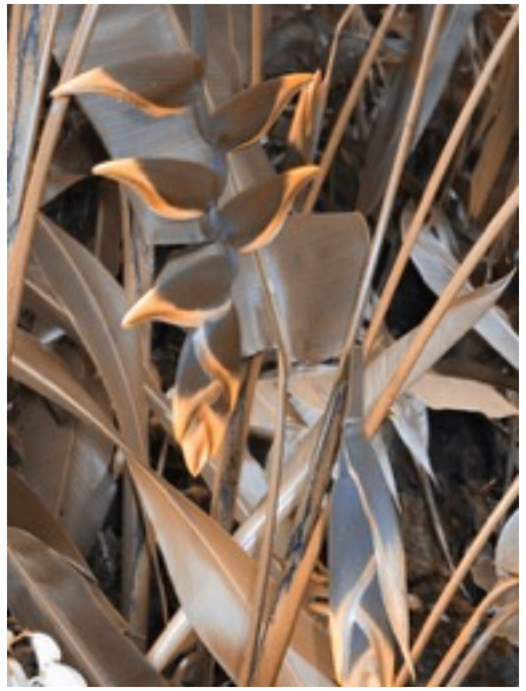


[Seriously Colorful: Advanced Color Principles & Practices. Stone. Tableau Customer Conference 2014.]

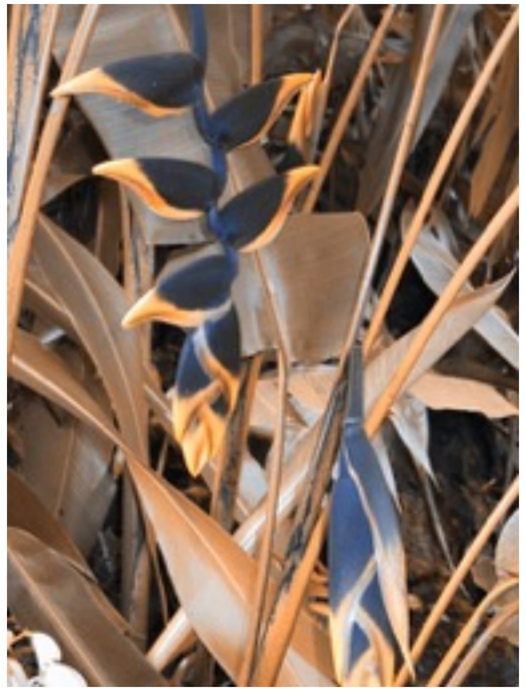
Designing for color deficiency: Check with simulator



Normal vision



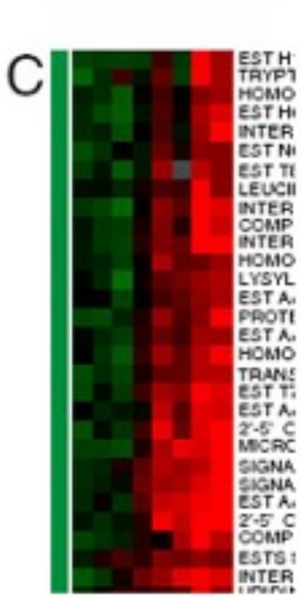
Deuteranope



Protanope

Tritanope

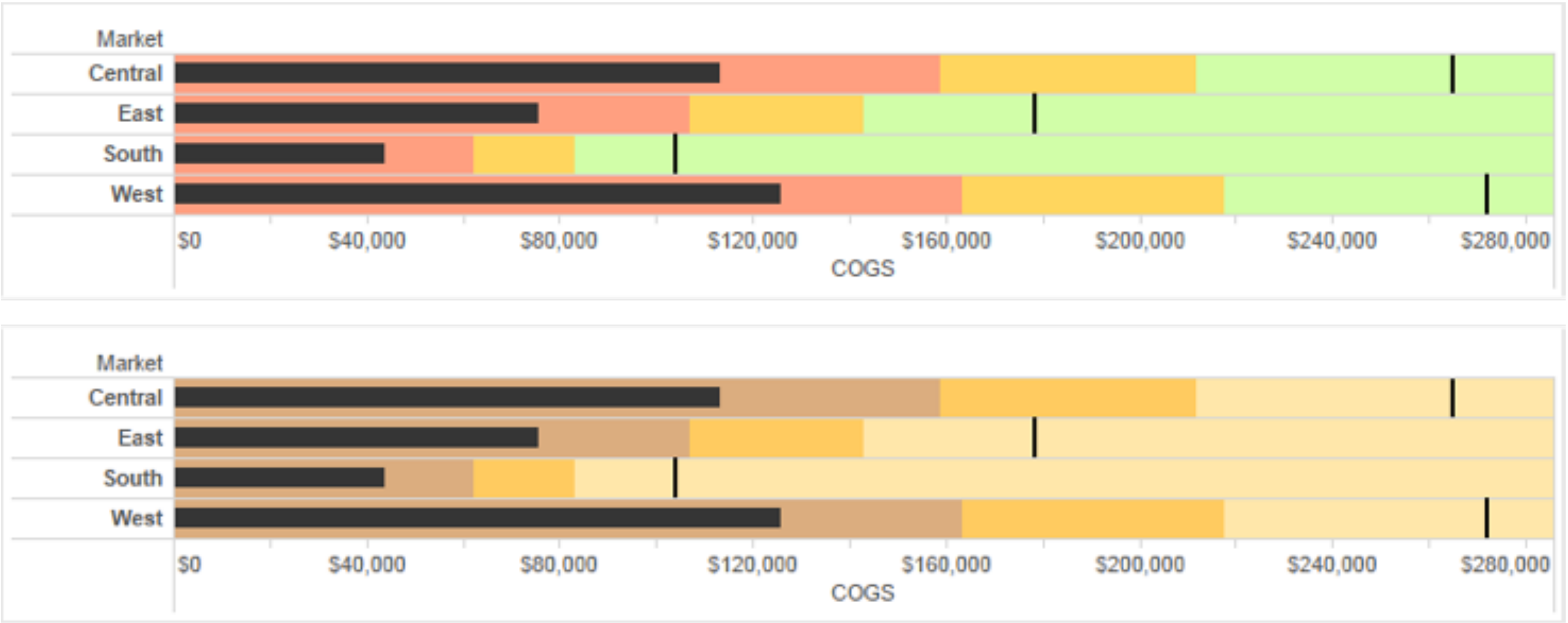
http://rehue.net



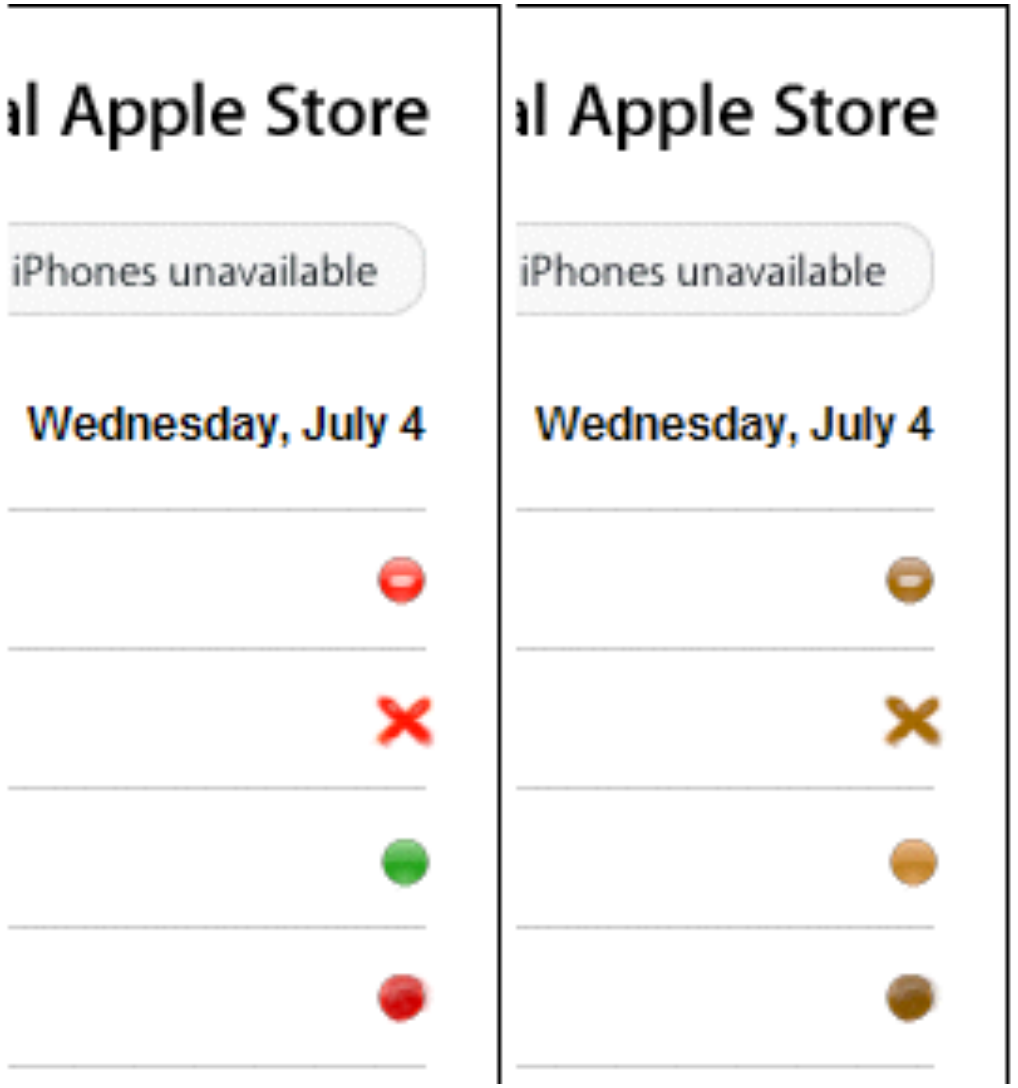
[Seriously Colorful: Advanced Color Principles & Practices. Stone.Tableau Customer Conference 2014.]

Designing for color deficiency: Avoid encoding by hue alone

- redundantly encode
  - vary luminance
  - change shape



Deuteranope simulation

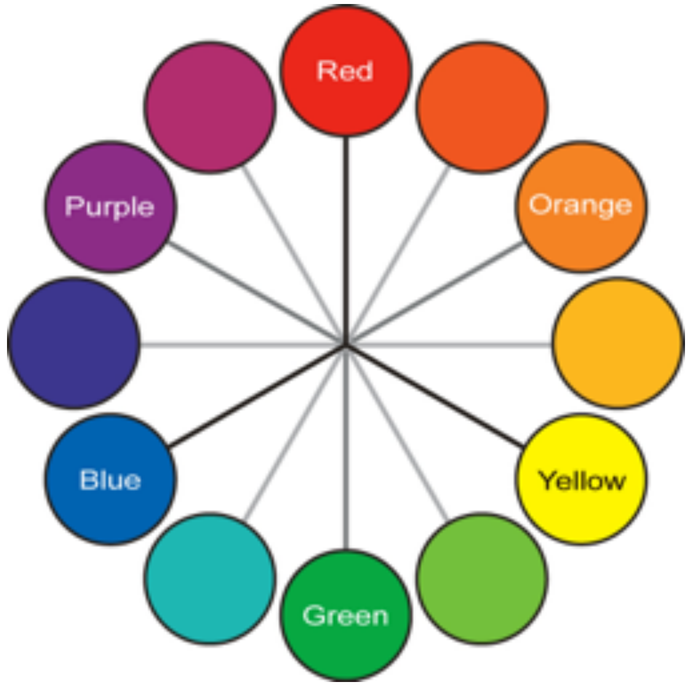


Change the shape

Vary luminance

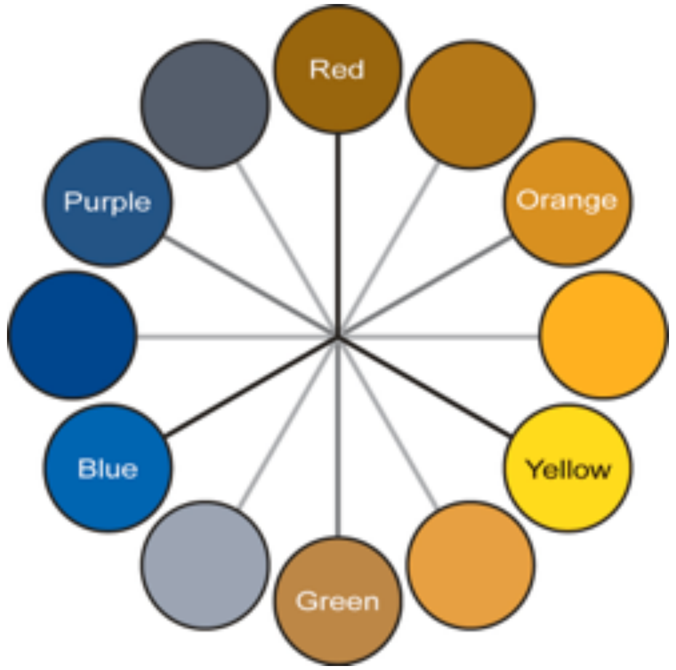
[Seriously Colorful: Advanced Color Principles & Practices. Stone. Tableau Customer Conference 2014.]

Color deficiency: Reduces color to 2 dimensions

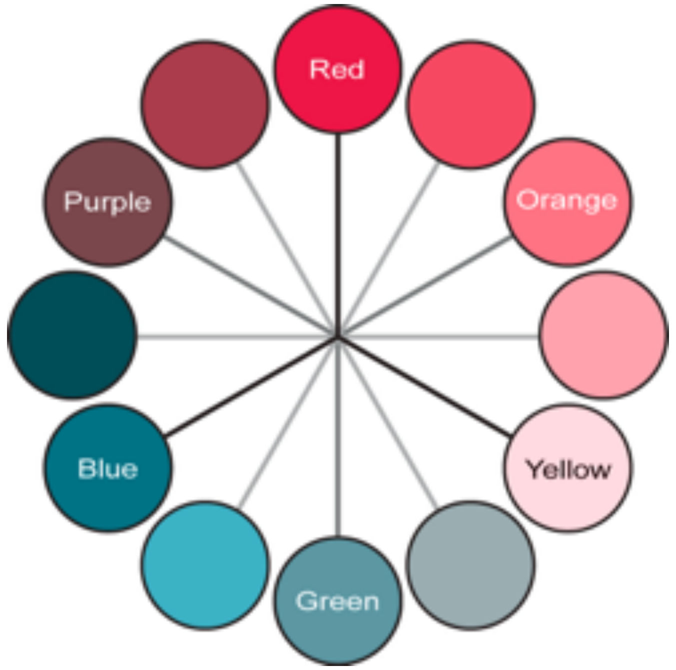


Normal

Protanope



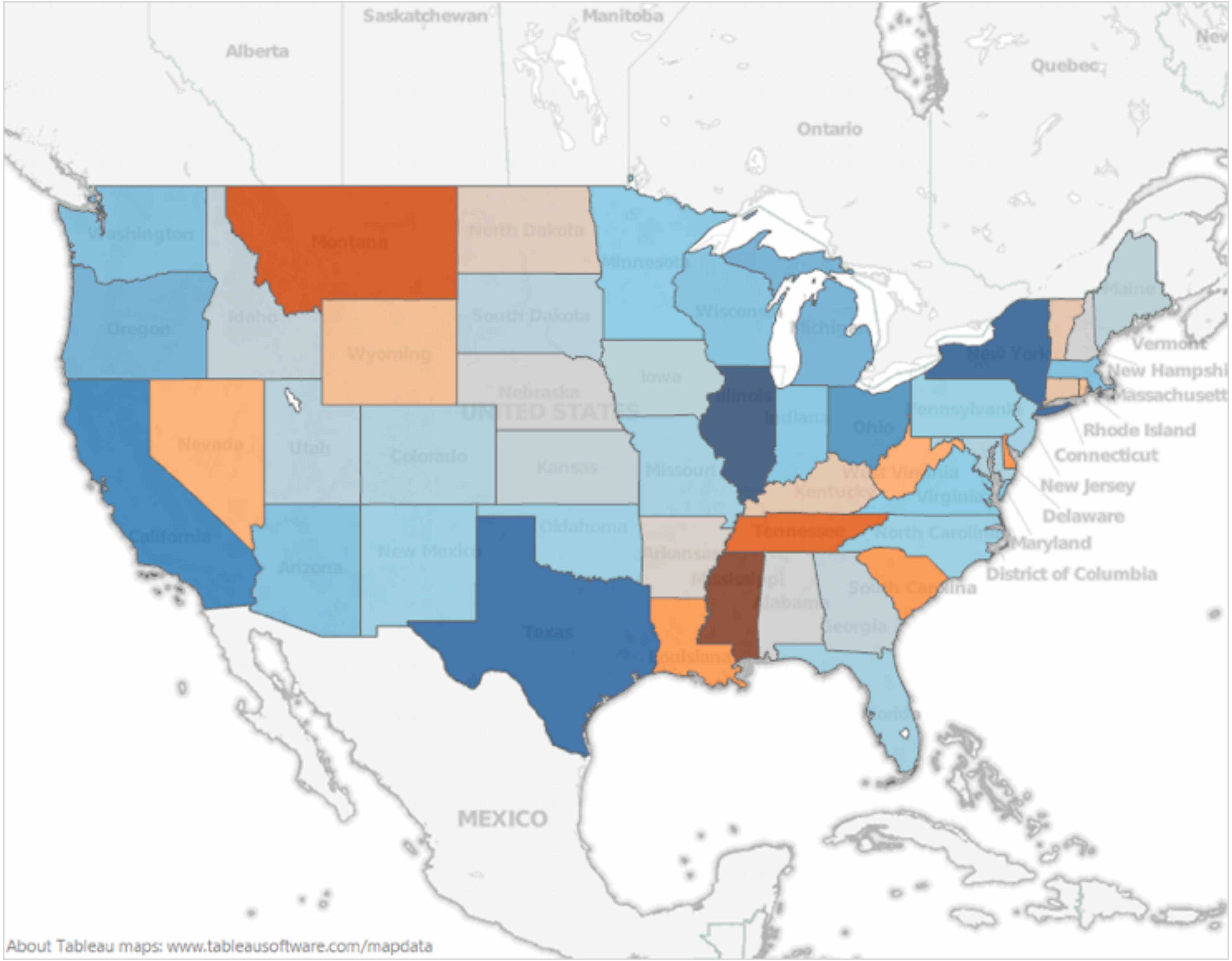
Deuteranope



Tritanope

[Seriously Colorful: Advanced Color Principles & Practices. Stone. Tableau Customer Conference 2014.]

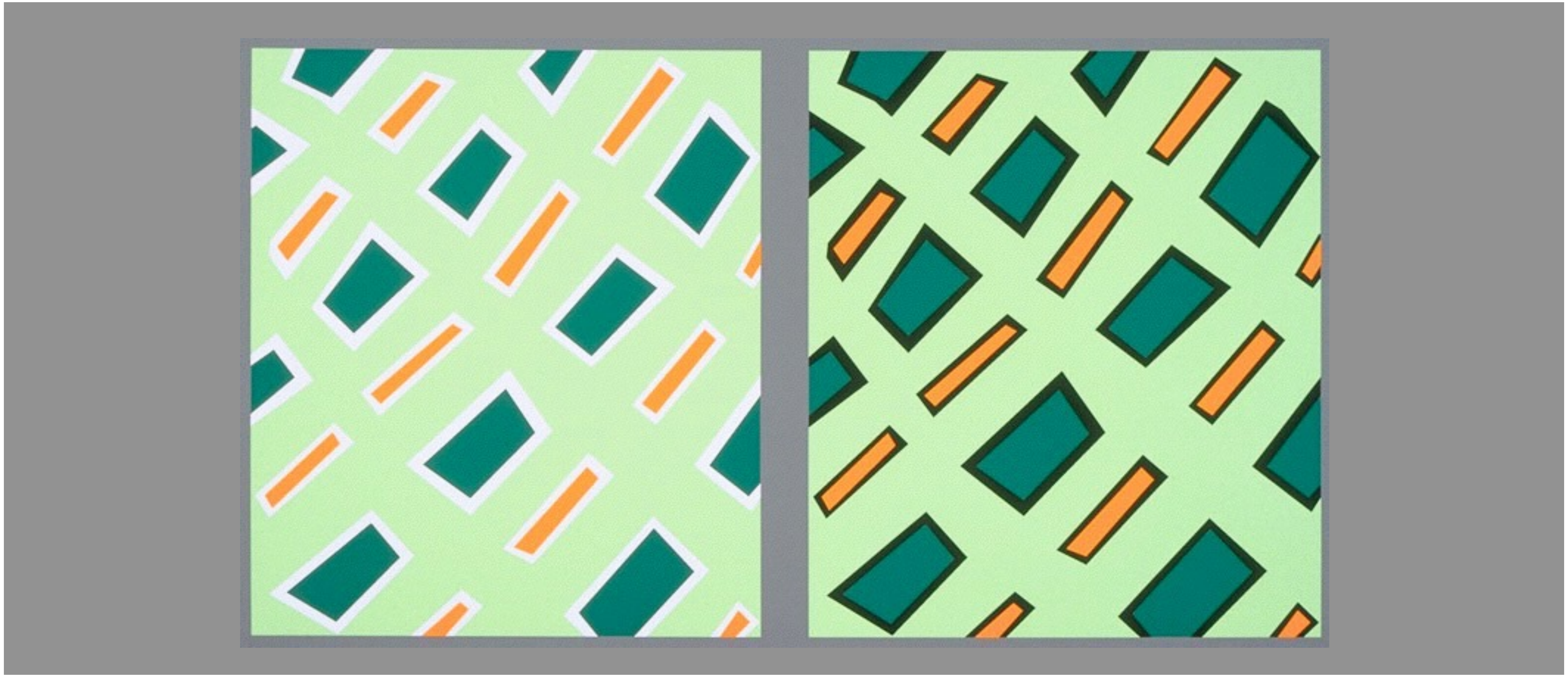
Designing for color deficiency: Blue-Orange is safe



[Seriously Colorful: Advanced Color Principles & Practices. Stone. Tableau Customer Conference 2014.]

Bezold Effect: Outlines matter

- color constancy: simultaneous contrast effect



[Seriously Colorful: Advanced Color Principles & Practices. Stone.Tableau Customer Conference 2014.]

Color/Lightness constancy: Illumination conditions

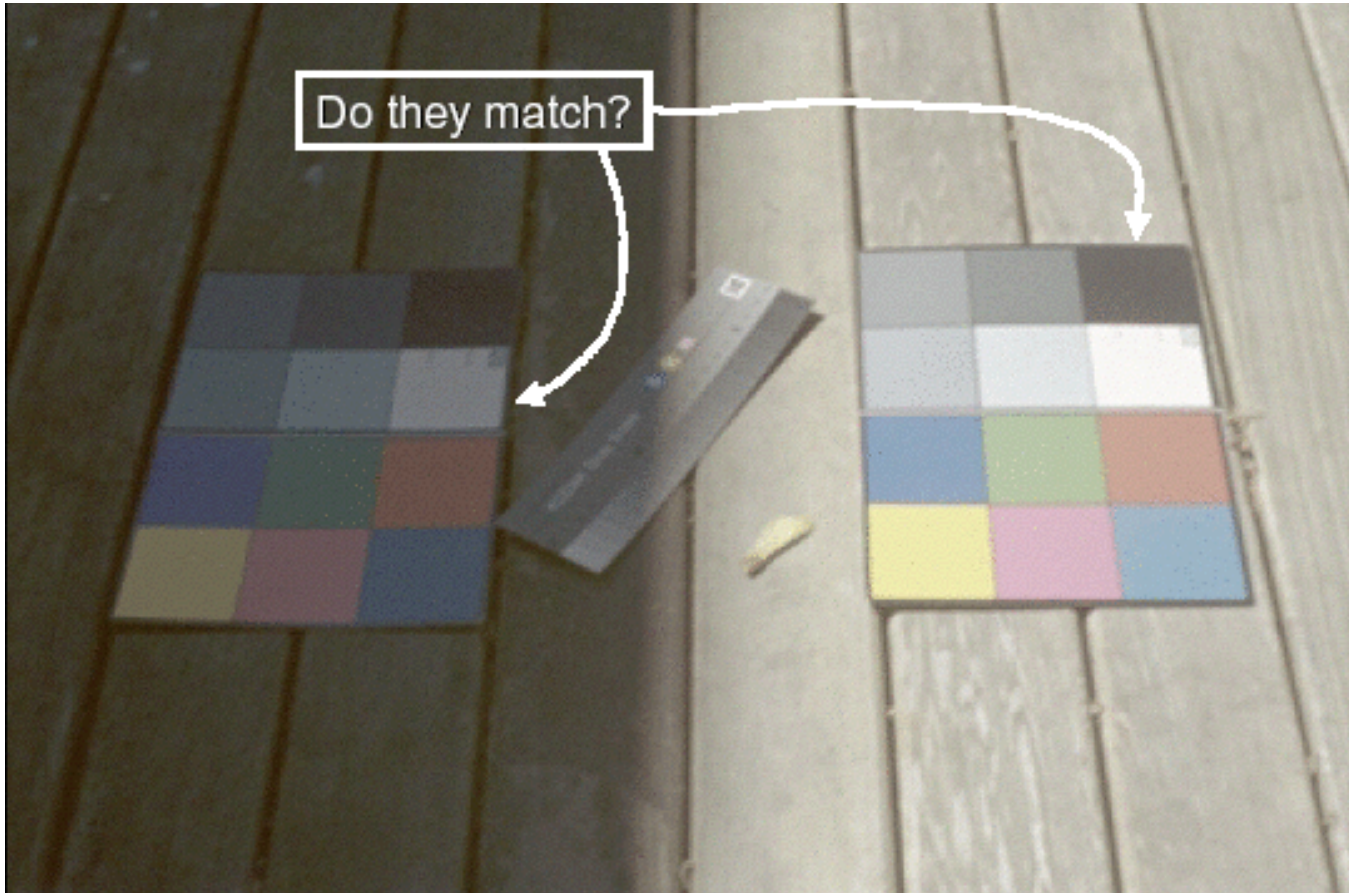


Image courtesy of John McCann

Color/Lightness constancy: Illumination conditions

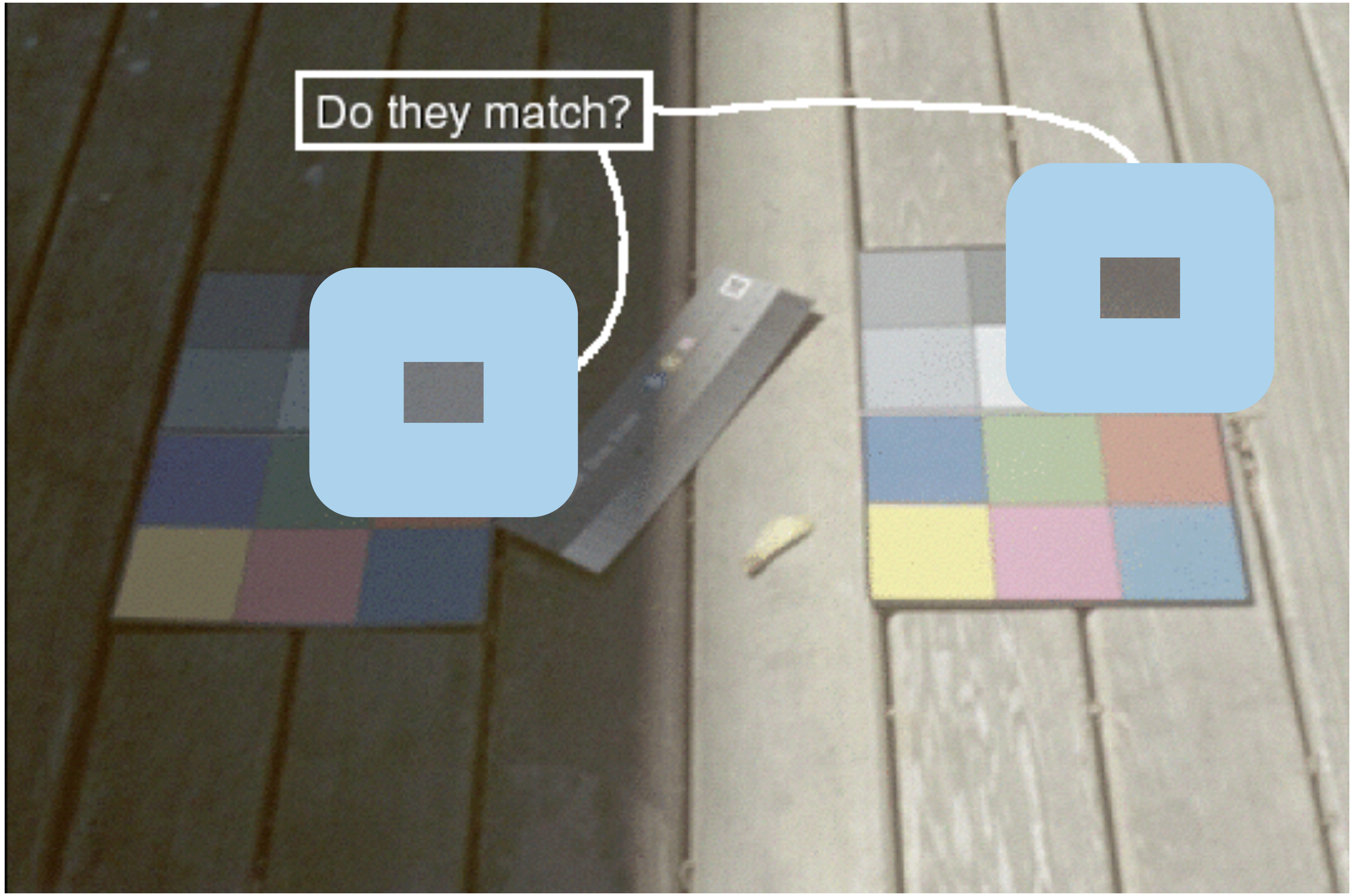
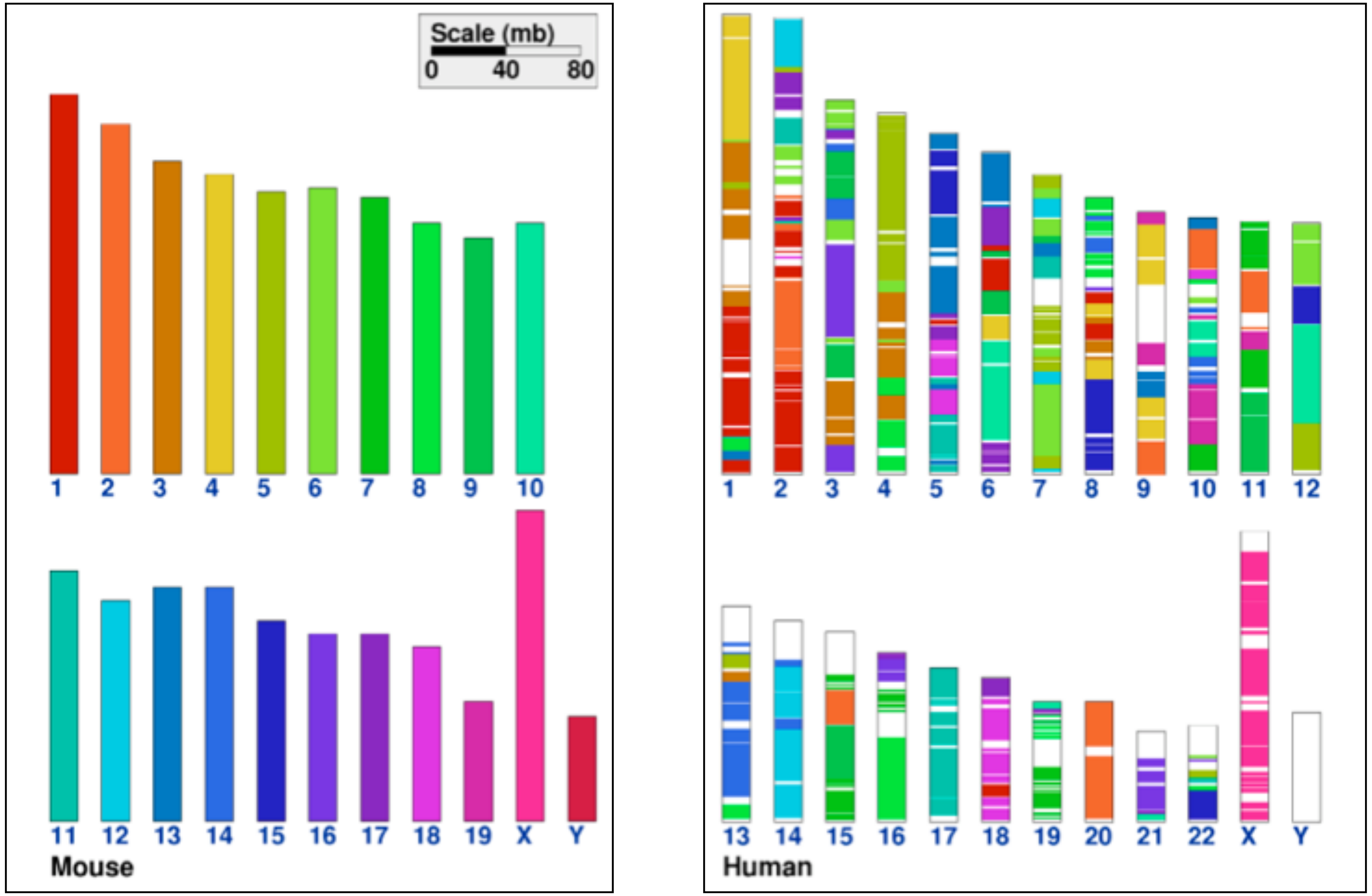


Image courtesy of John McCann

Categorical color: limited number of discriminable bins

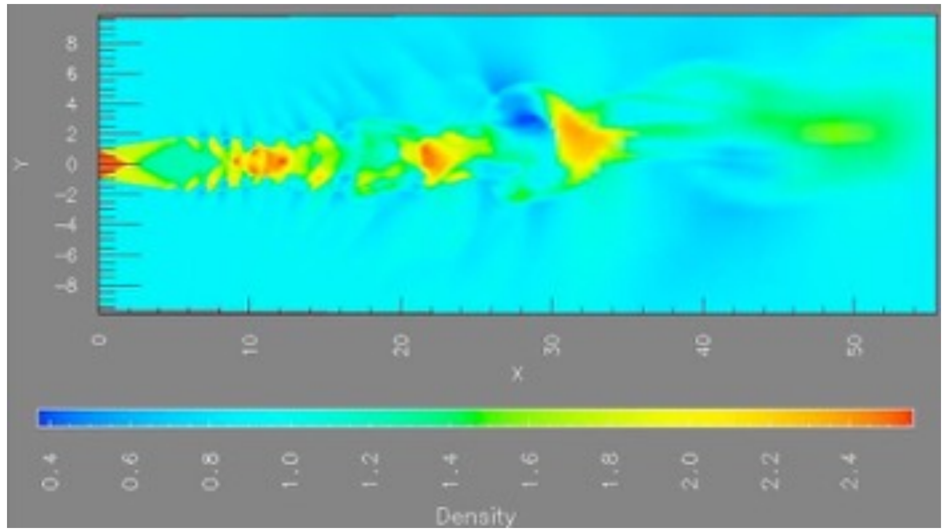
- human perception built on relative comparisons
  - great if color contiguous
  - surprisingly bad for absolute comparisons
- noncontiguous small regions of color
  - fewer bins than you want
  - rule of thumb: 6-12 bins, including background and highlights
  - alternatives? this afternoon!



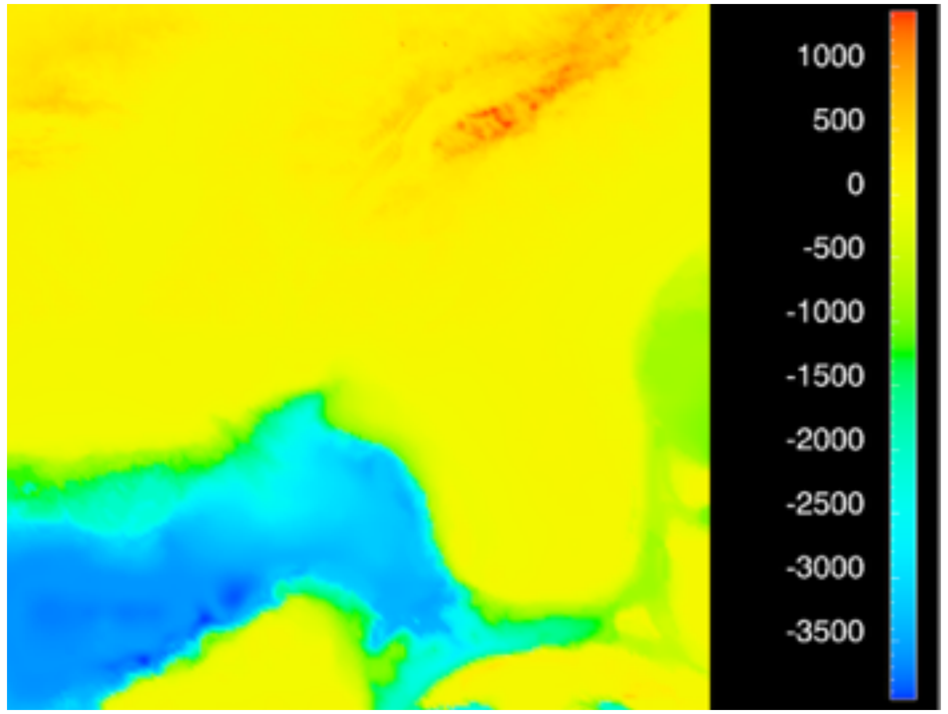
[Cinteny: flexible analysis and visualization of synteny and genome rearrangements in multiple organisms. Sinha and Meller. BMC Bioinformatics, 8:82, 2007.]

Ordered color: Rainbow is poor default

- problems
  - perceptually unordered
  - perceptually nonlinear
- benefits
  - fine-grained structure visible and nameable



[A Rule-based Tool for Assisting Colormap Selection. Bergman,. Rogowitz, and. Treinish. Proc. IEEE Visualization (Vis), pp. 118–125, 1995.]



[Why Should Engineers Be Worried About Color? Treinish and Rogowitz 1998. http://www.research.ibm.com/people/l/lloydt/color/color.HTM]

[Transfer Functions in Direct Volume Rendering: Design, Interface, Interaction. Kindlmann. SIGGRAPH 2002 Course Notes]

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  - fine-grained structure visible and nameable
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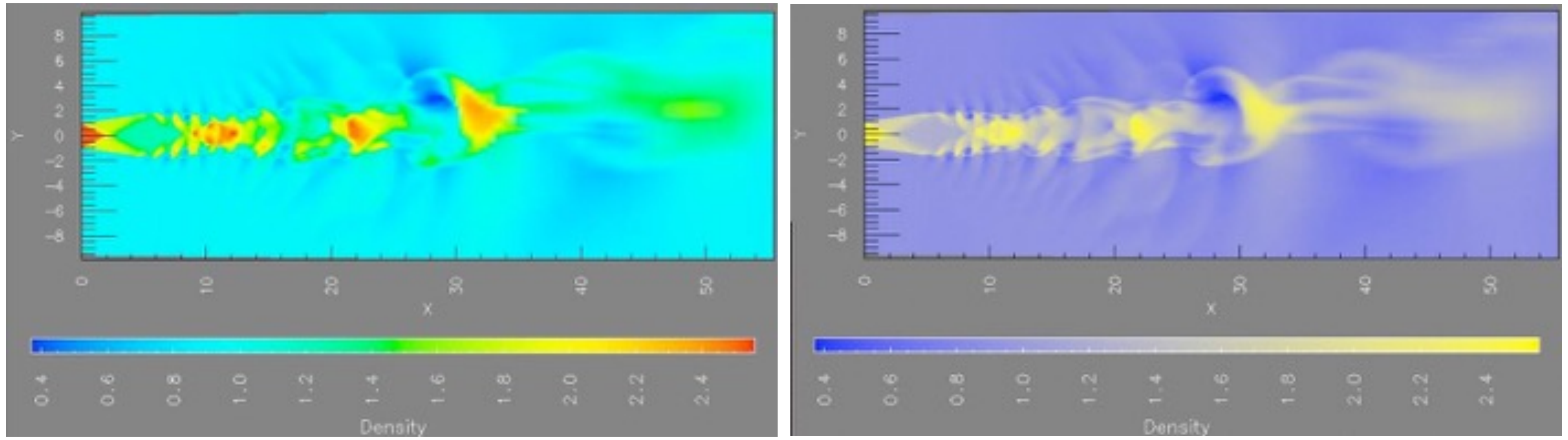
  - large-scale structure: fewer hues



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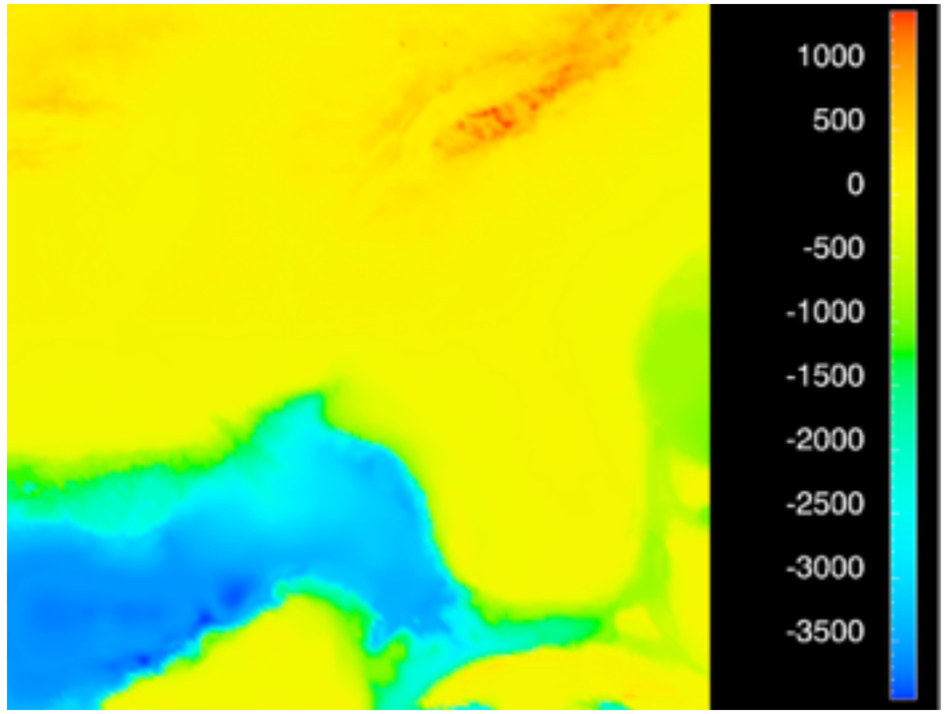

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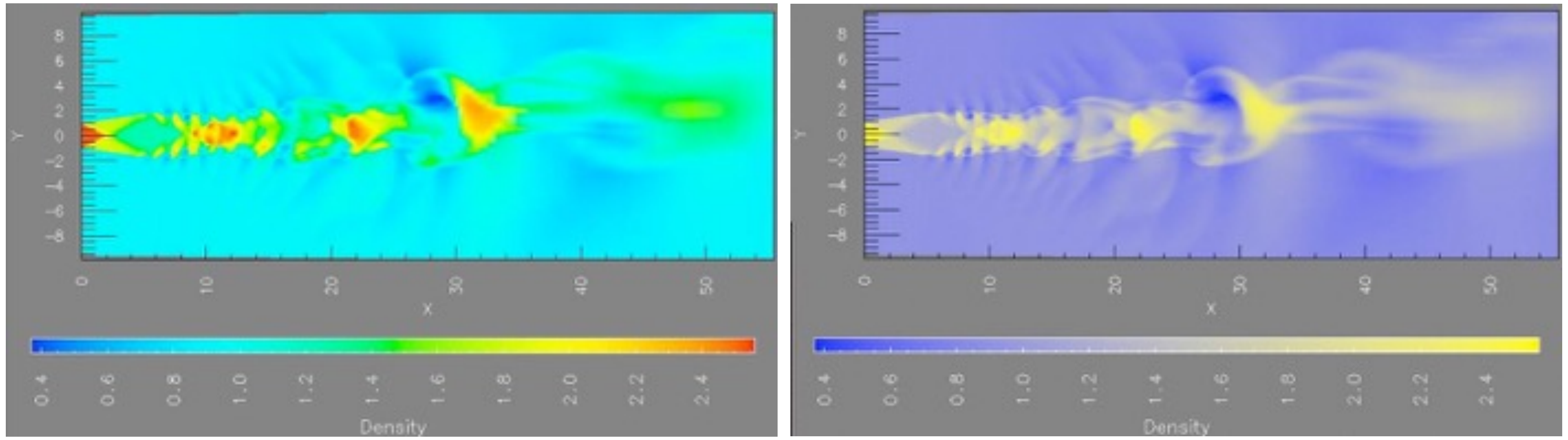
  - fine-grained structure visible and nameable
- alternatives
  - large-scale structure: fewer hues
  - fine structure: multiple hues with monotonically increasing luminance [eg viridis R/python]



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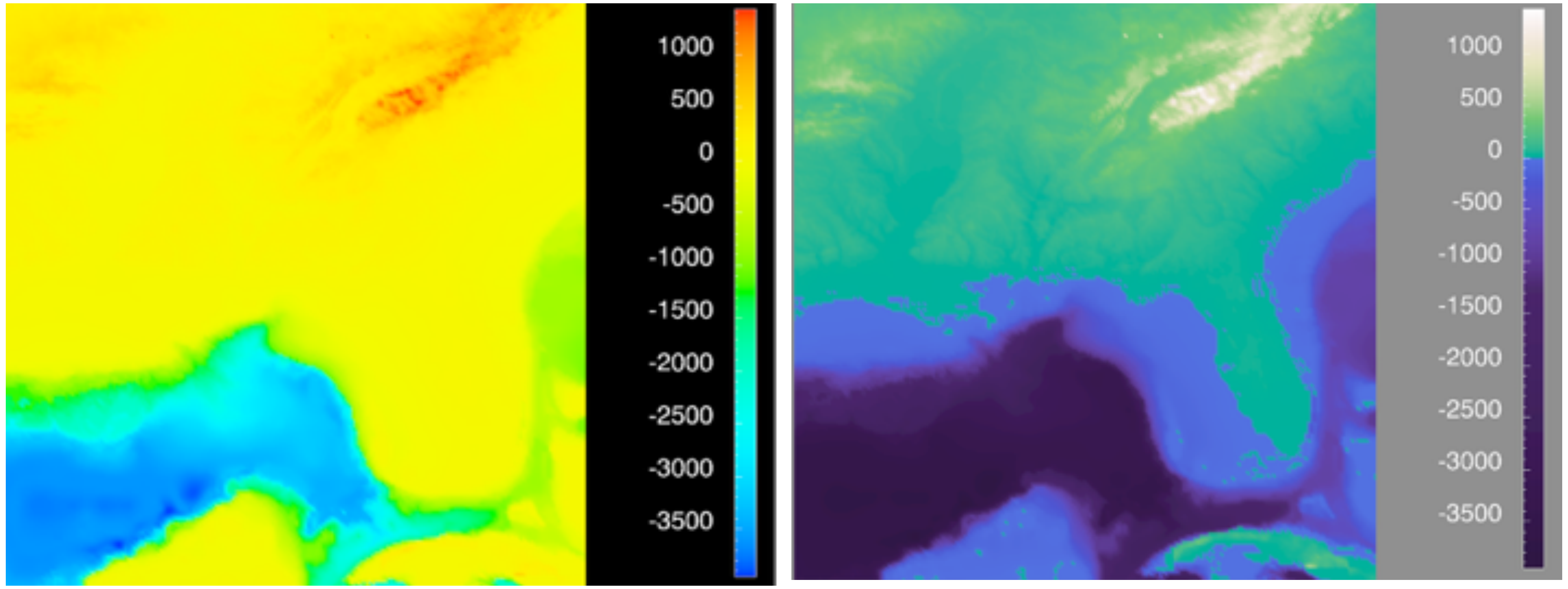

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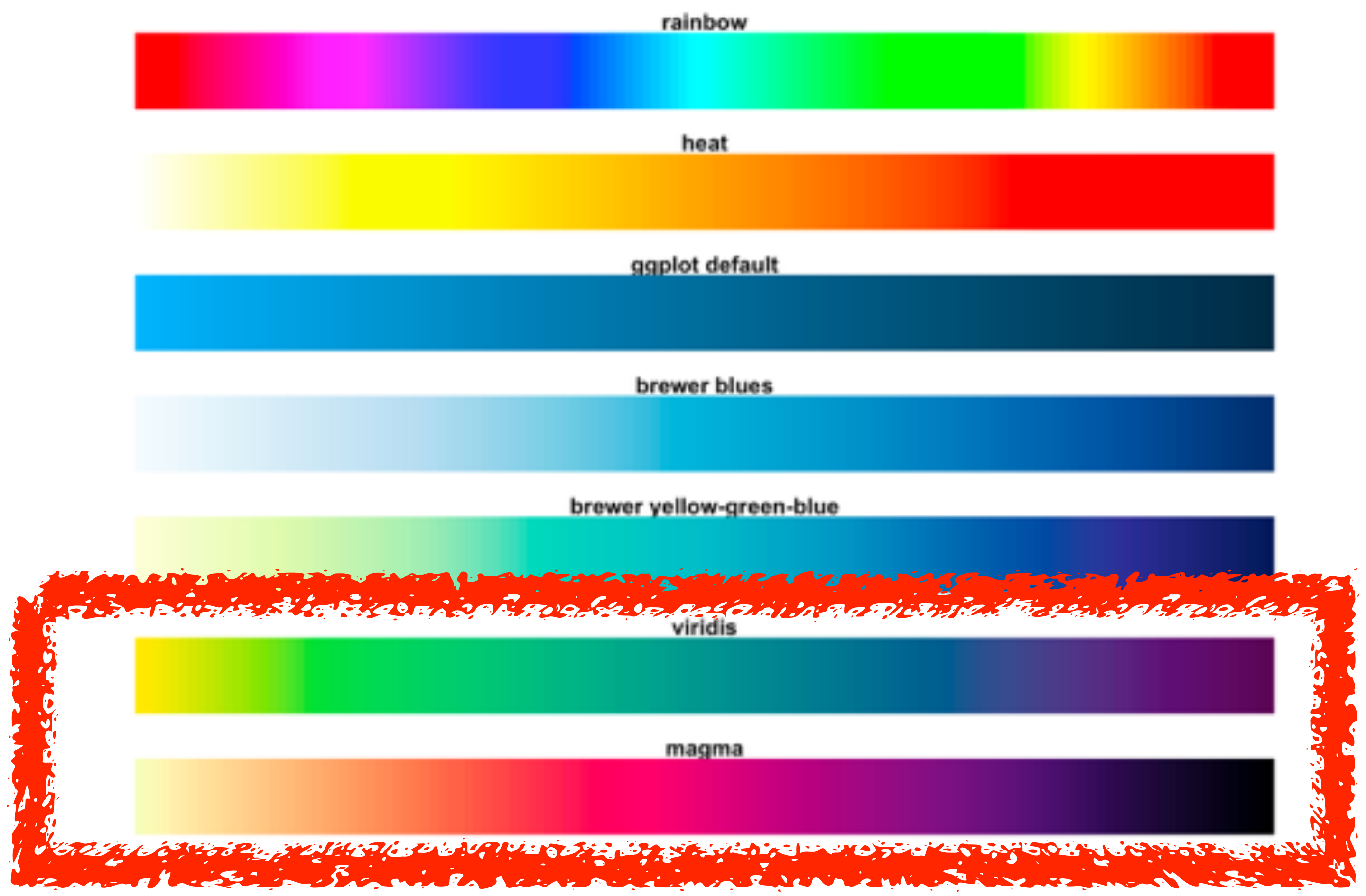
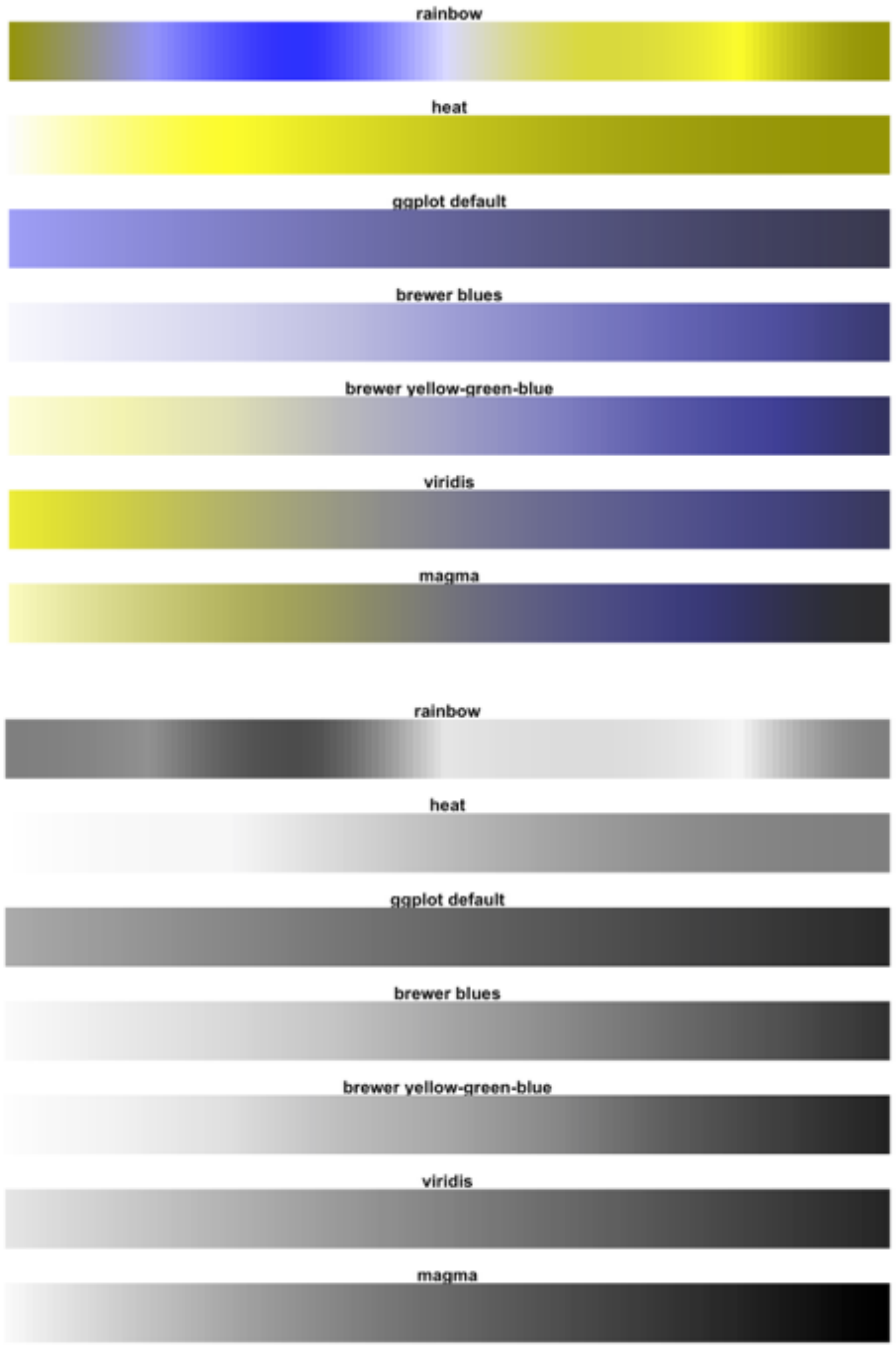
[Transfer Functions in Direct Volume Rendering: Design, Interface, Interaction. Kindlmann. SIGGRAPH 2002 Course Notes]

Viridis

- colorful, perceptually uniform, colorblind-safe, monotonically increasing luminance



https://cran.r-project.org/web/packages/viridis/vignettes/intro-to-viridis.html



Ordered color: Rainbow is poor default

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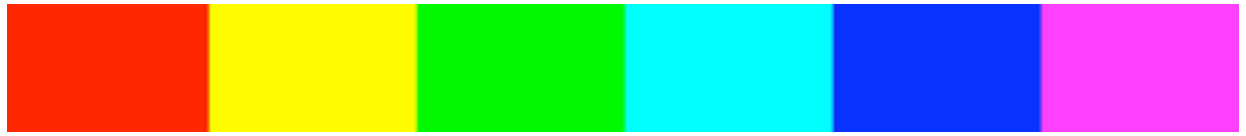
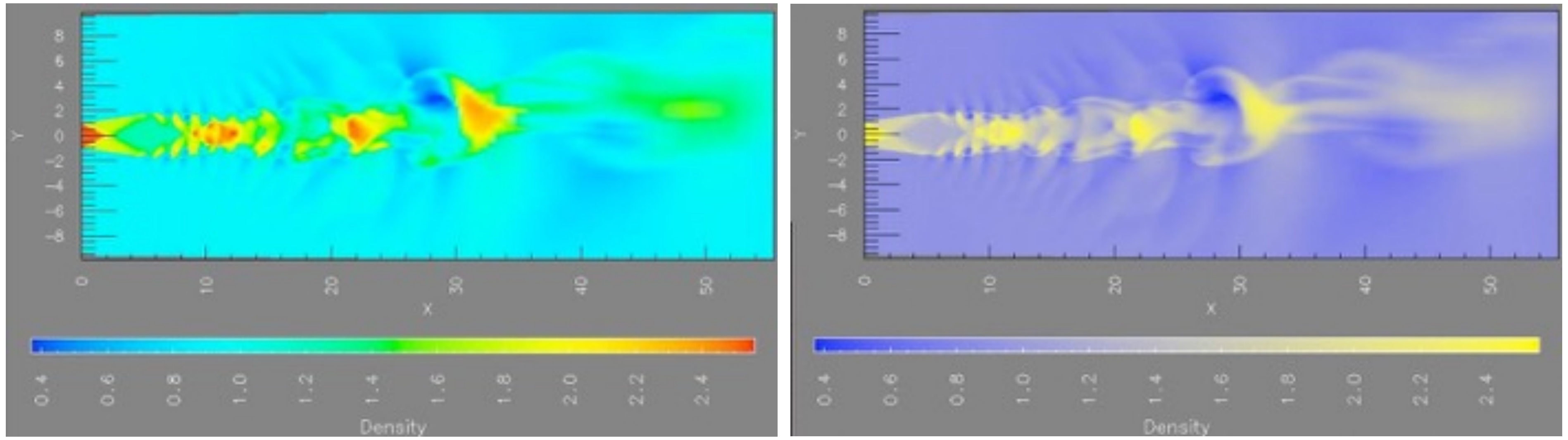
  - perceptually nonlinear
- benefits
  - fine-grained structure visible and nameable
- alternatives
  - large-scale structure: fewer hues
  - fine structure: multiple hues with monotonically increasing luminance [eg viridis R/python]
  - segmented rainbows for binned or categorical





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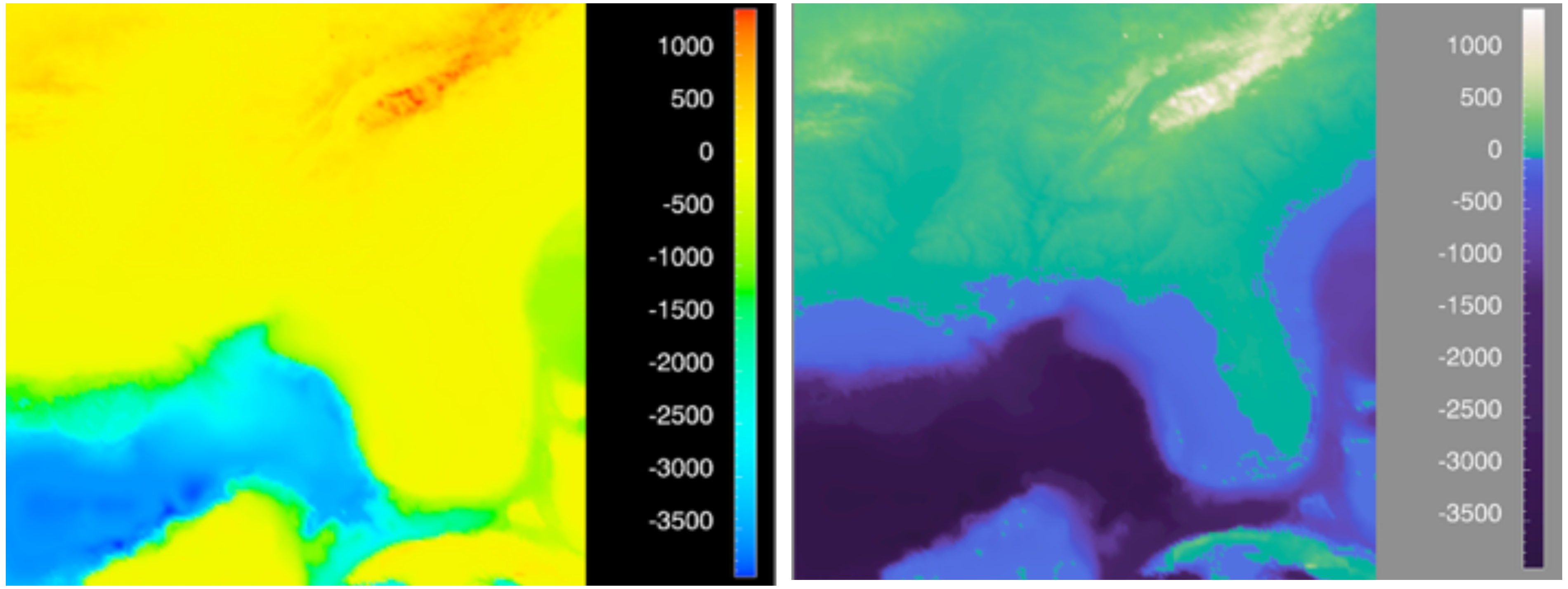


[Why Should Engineers Be Worried About Color? Treinish and Rogowitz 1998. http://www.research.ibm.com/people/l/lloydt/color/color.HTM]

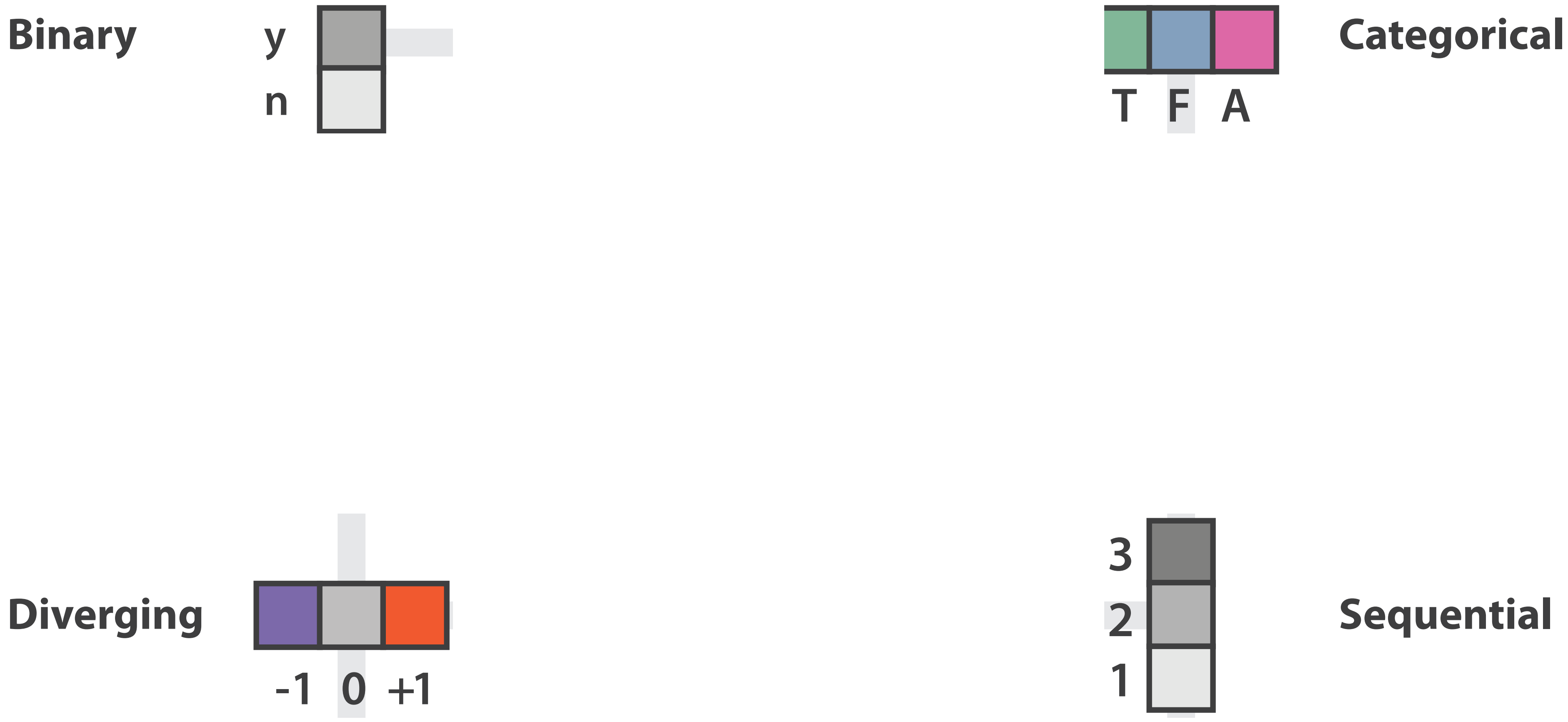
[Transfer Functions in Direct Volume Rendering: Design, Interface, Interaction. Kindlmann. SIGGRAPH 2002 Course Notes]

Colormaps

- Categorical

- Ordered
  - *Sequential*

  - *Diverging*



after [Color Use Guidelines for Mapping and Visualization. Brewer, 1994. http://www.personal.psu.edu/faculty/c/a/cab38/ColorSch/Schemes.html]

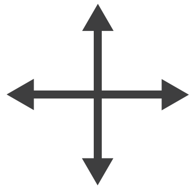
Colormaps

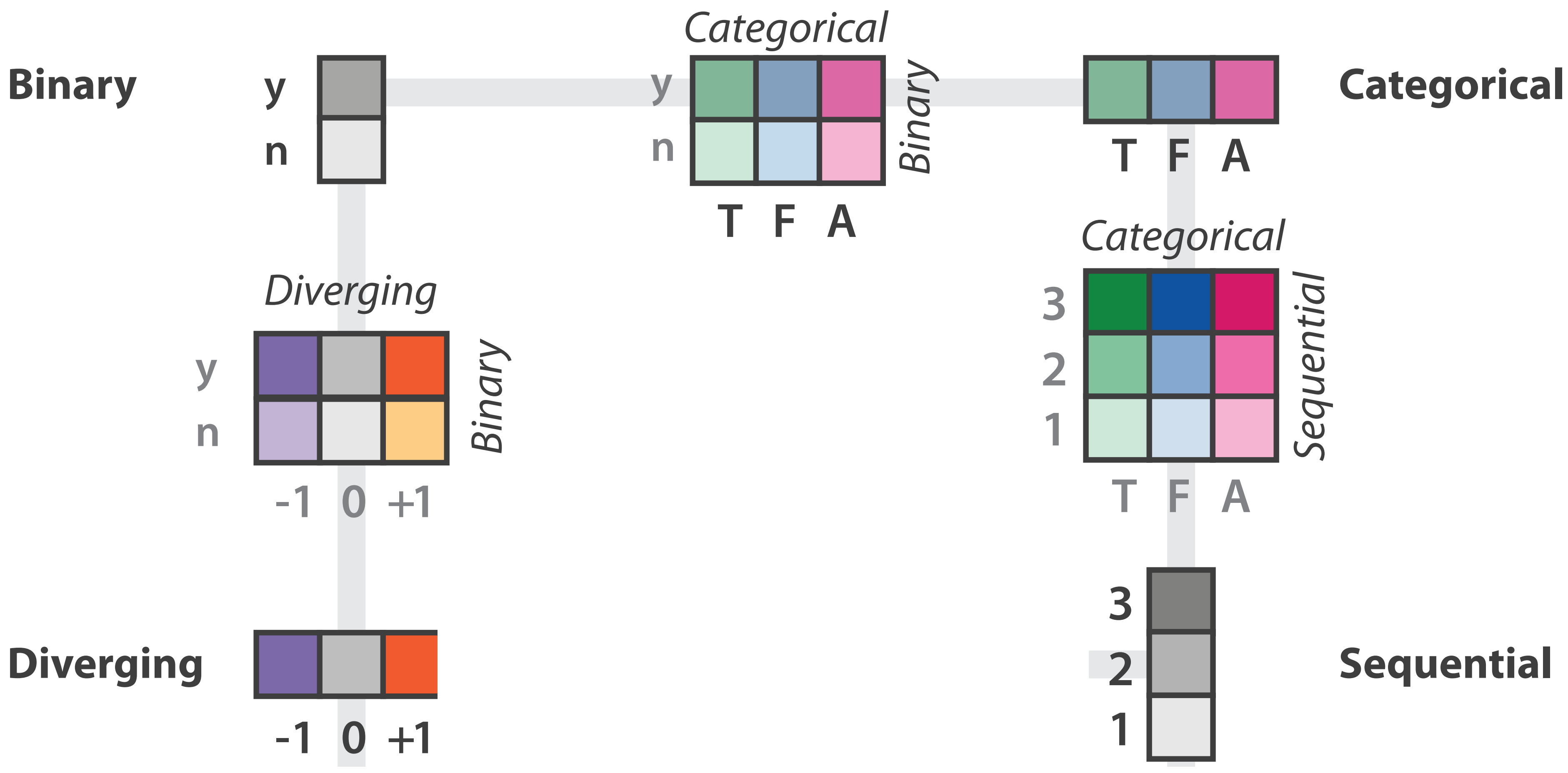
- Categorical

- Ordered
  - *Sequential*

  - *Diverging*

- Bivariate





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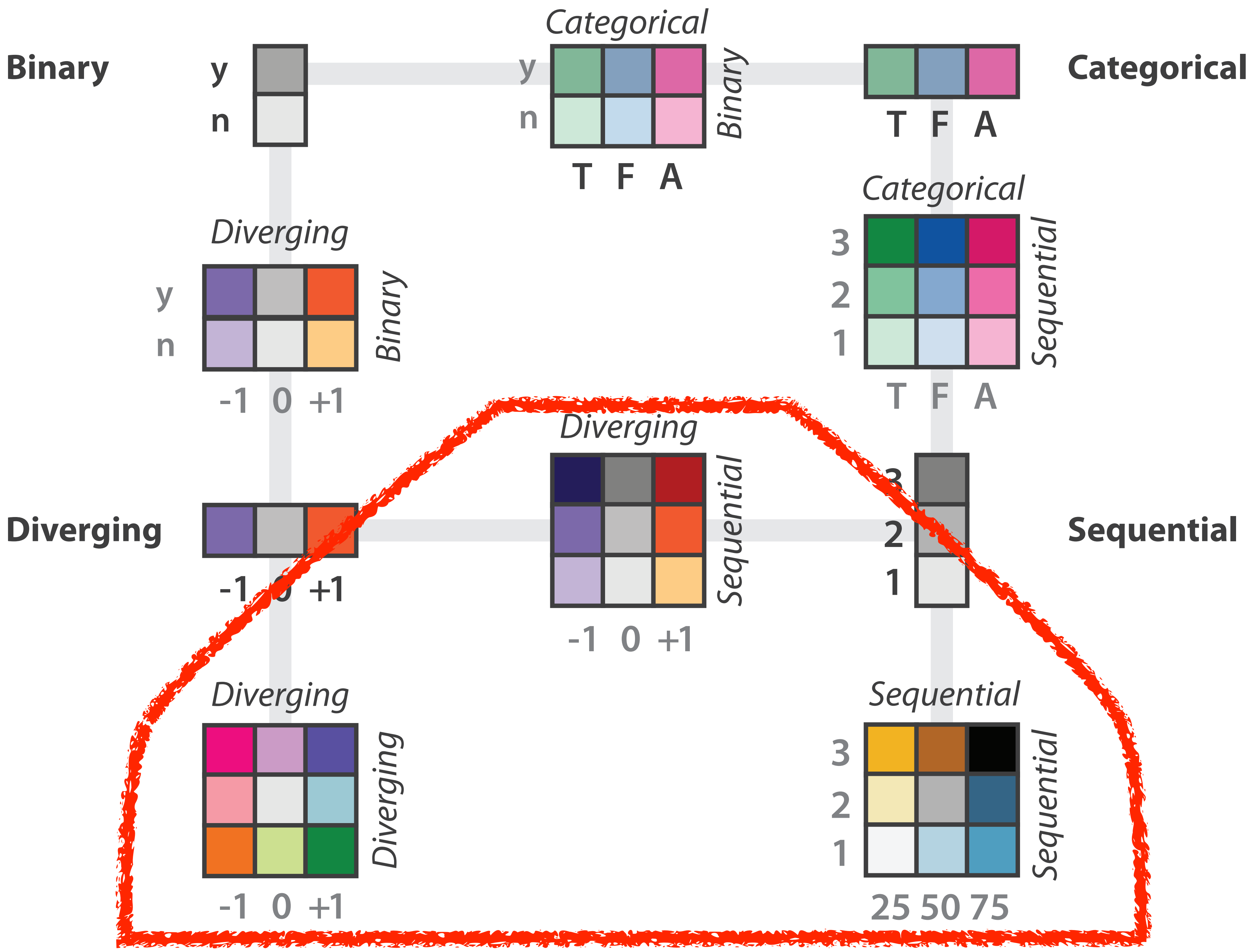
Colormaps

- Categorical
- Ordered
  - *Sequential*
  - *Diverging*
- Bivariate

use with care!



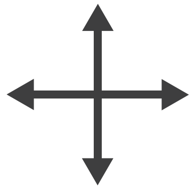
after [Color Use Guidelines for Mapping and Visualization. Brewer, 1994. http://www.personal.psu.edu/faculty/c/a/cab38/ColorSch/Schemes.html]

Colormaps

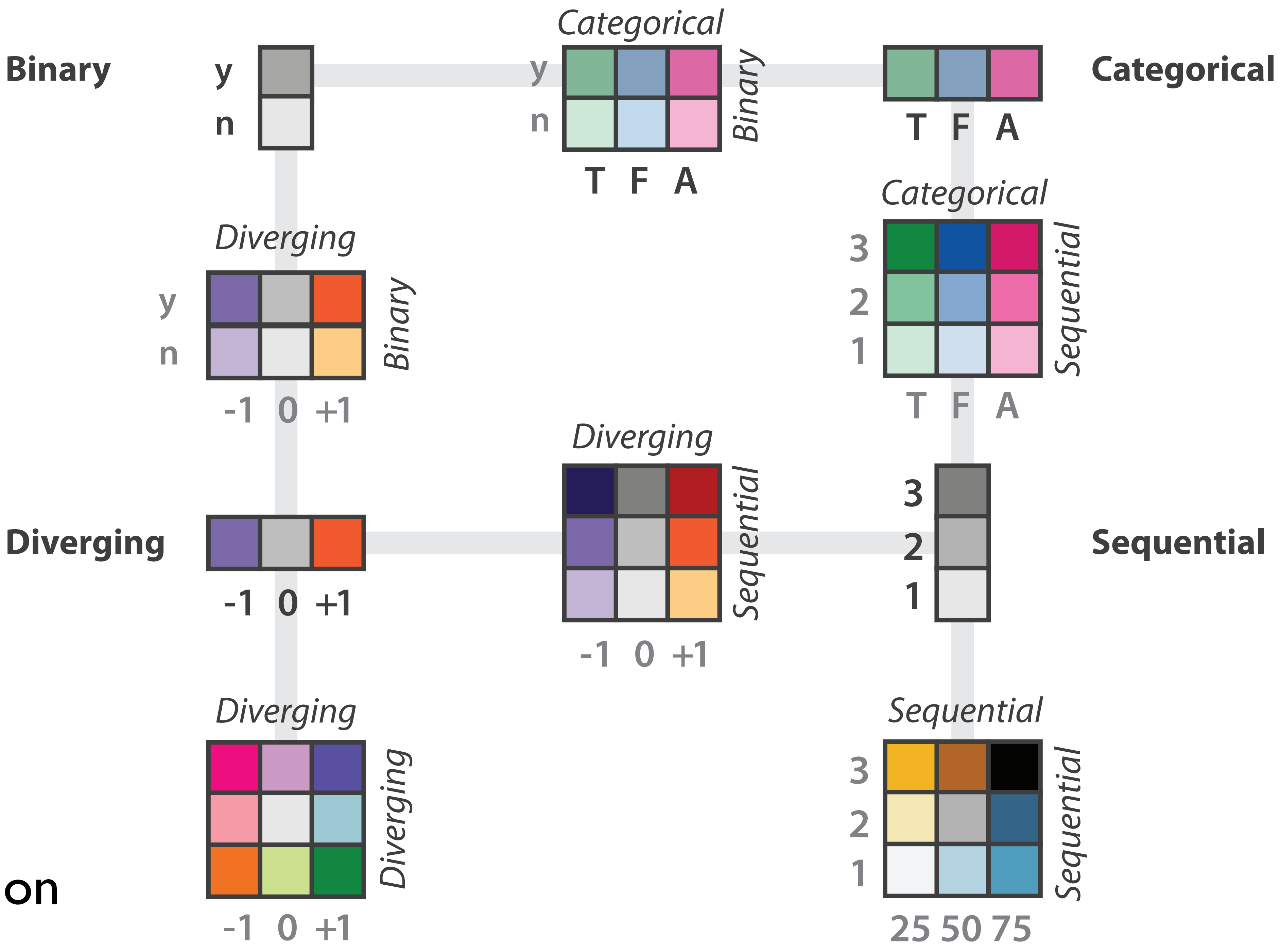
- ➔ Categorical

- ➔ Ordered
  - ➔ *Sequential*
  - ➔ *Diverging*

- ➔ Bivariate



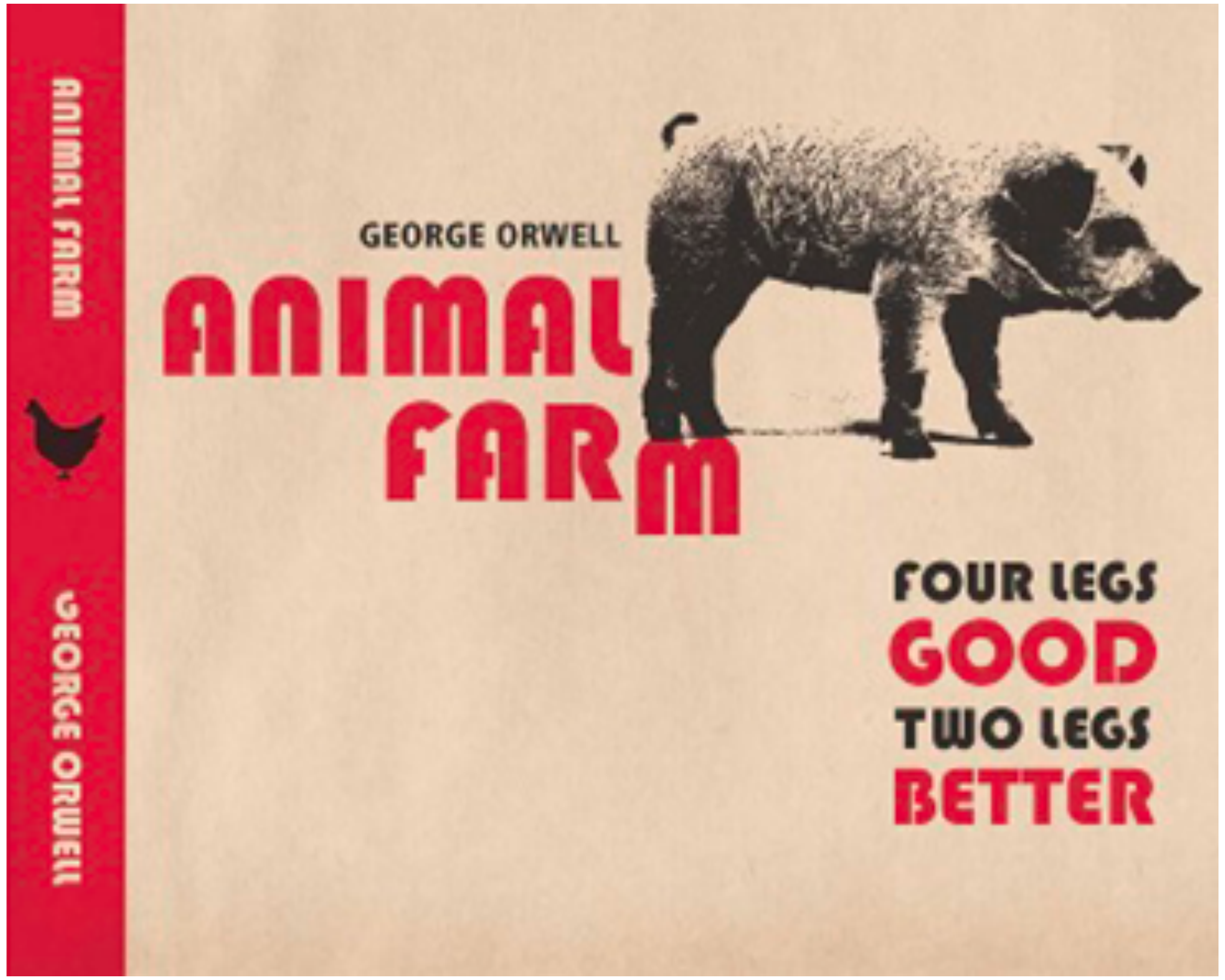
- color channel interactions
  - size heavily affects salience
    - small regions need high saturation
    - large need low saturation
  - saturation & luminance: 3-4 bins max
    - also not separable from transparency



after [Color Use Guidelines for Mapping and Visualization. Brewer, 1994. http://www.personal.psu.edu/faculty/c/a/cab38/ColorSch/Schemes.html]

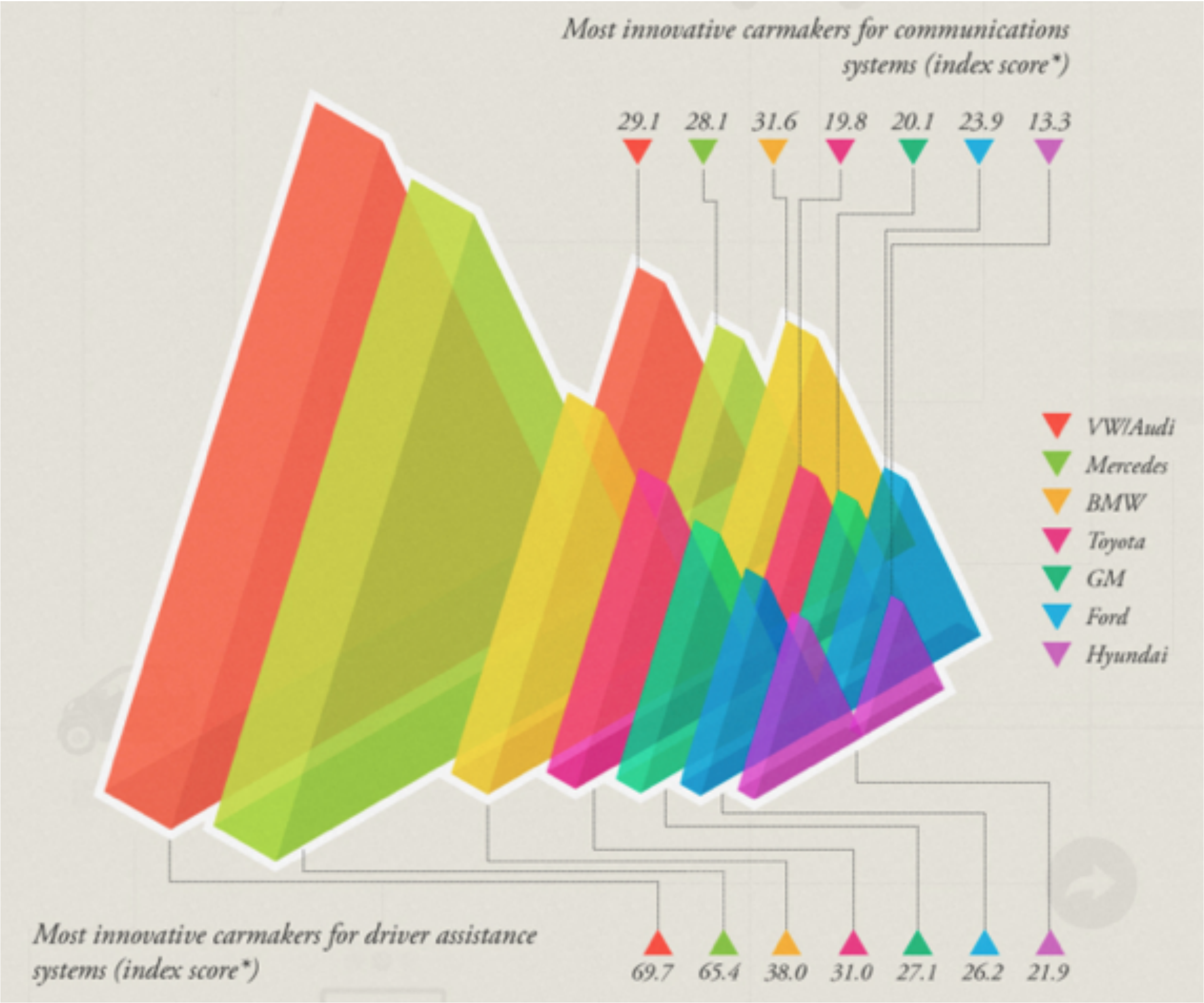
Visual encoding: 2D vs 3D

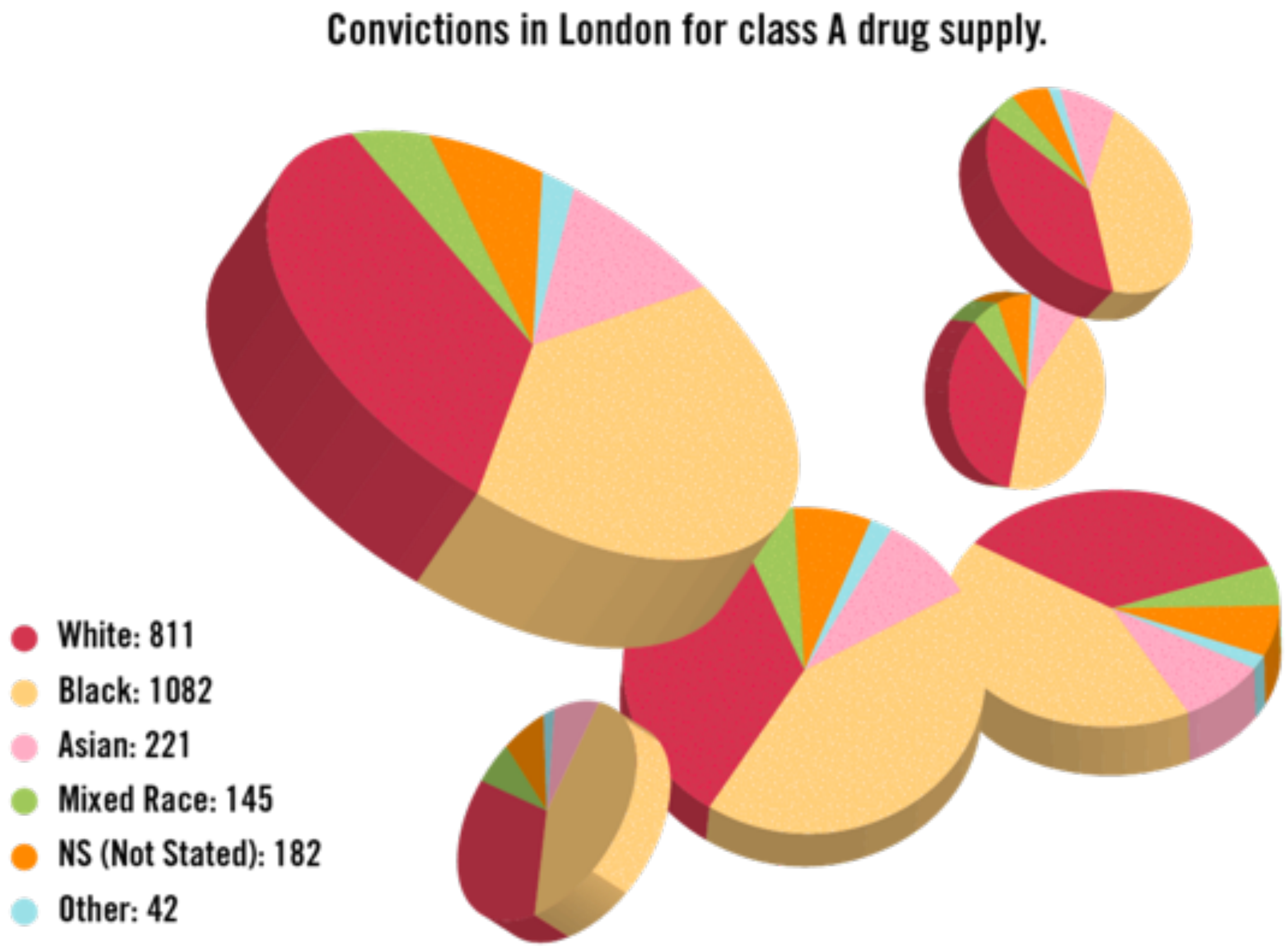
- 2D good, 3D better?
  - not so fast…



http://amberleyromo.com/images/Bookcover/Animal-Farm.png

Unjustified 3D all too common, in the news and elsewhere



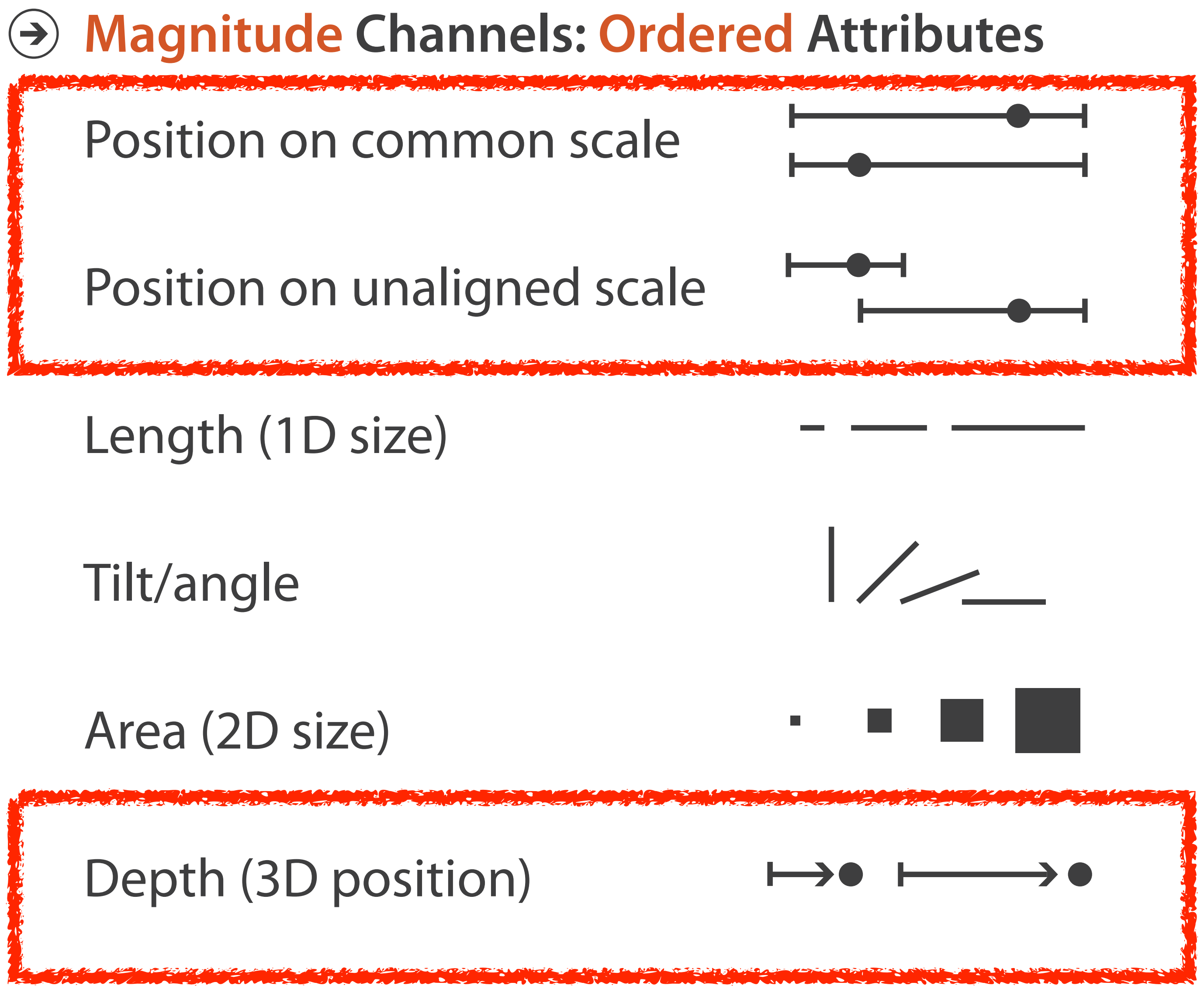


http://viz.wtf/post/137826497077/eye-popping-3d-triangles

http://viz.wtf/post/139002022202/designer-drugs-ht-ducqn

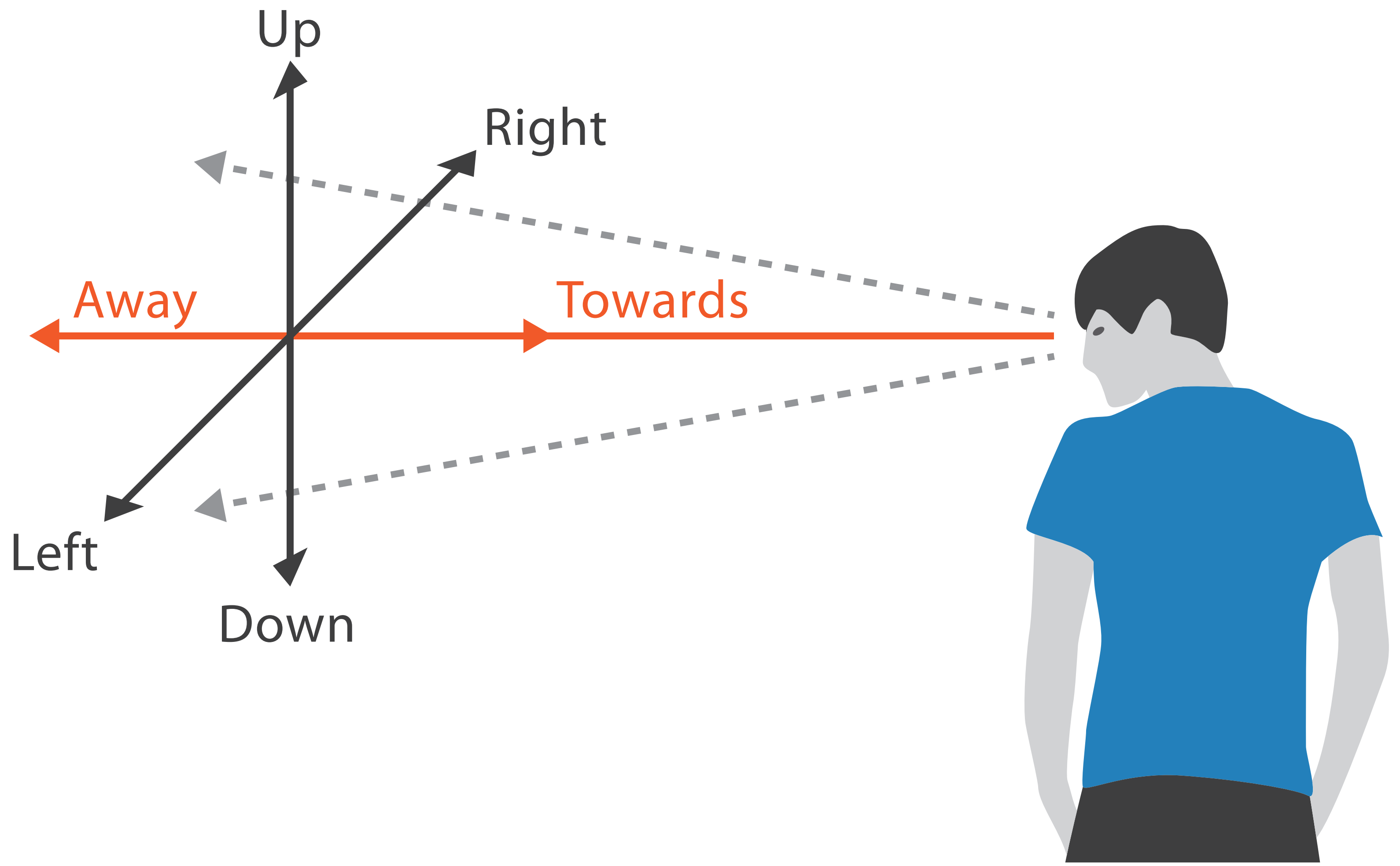
Depth vs power of the plane

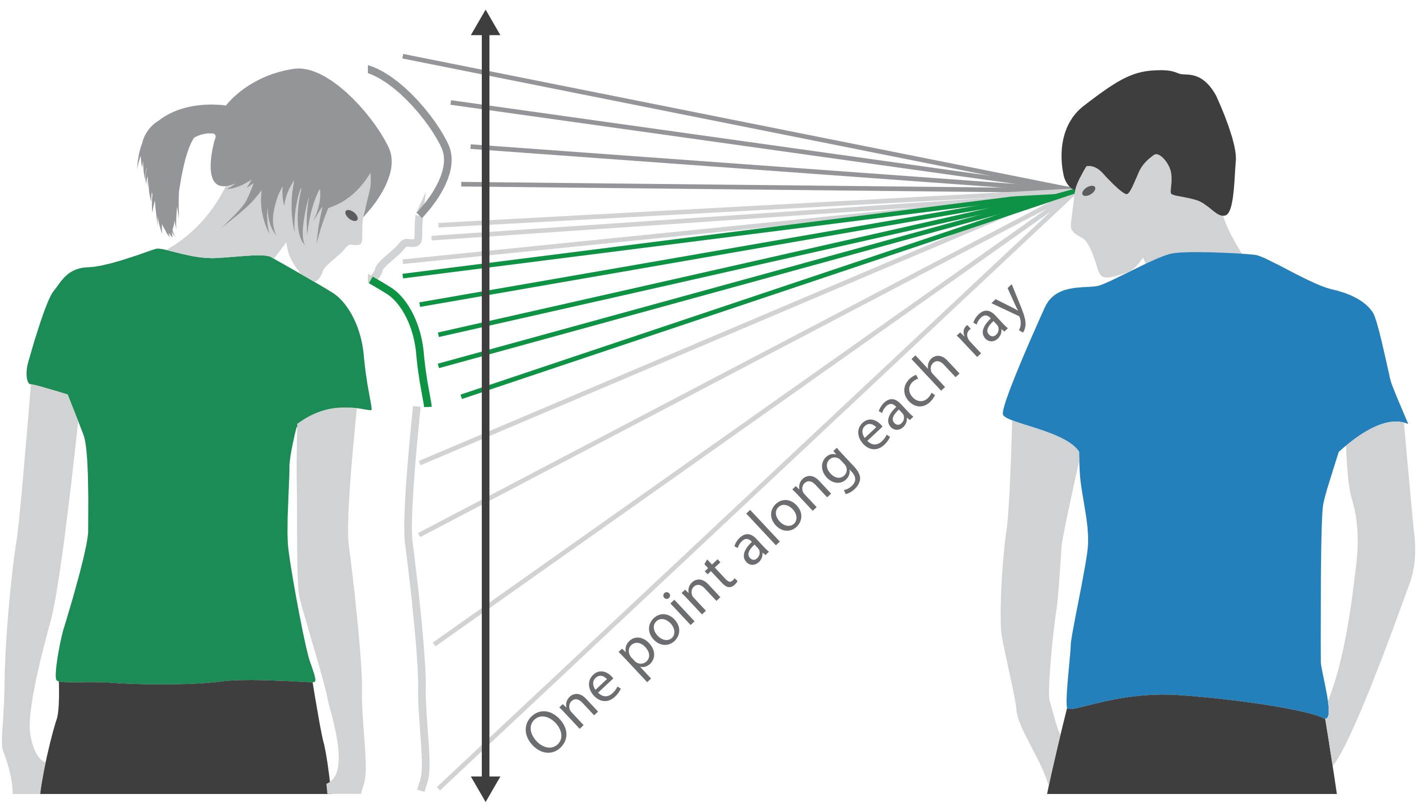
- high-ranked spatial position channels: **planar** spatial position
  - not depth!



Life in 3D?…

- 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

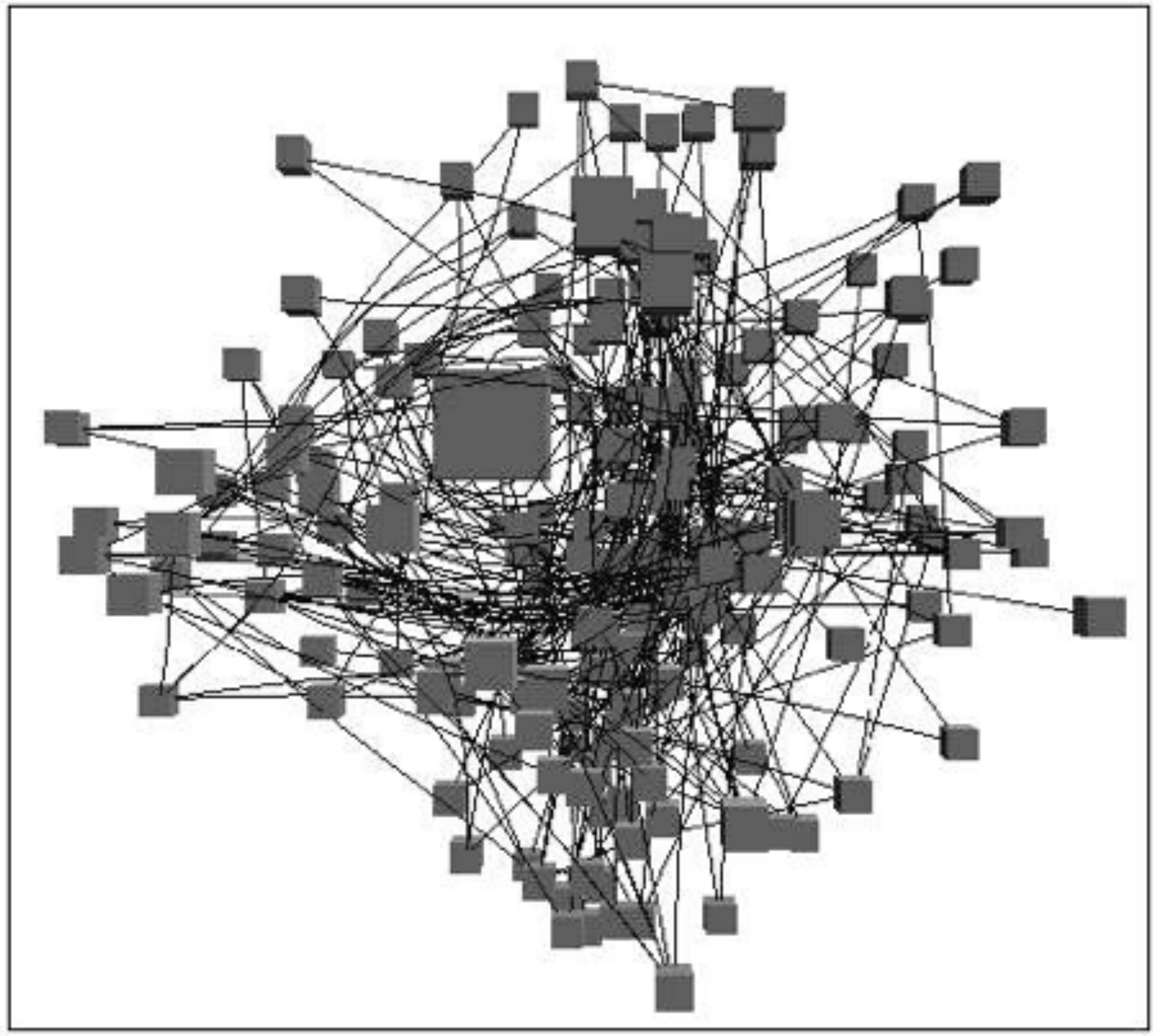




[adapted from Visual Thinking for Design. Ware. Morgan Kaufmann 2010.]

Occlusion hides information

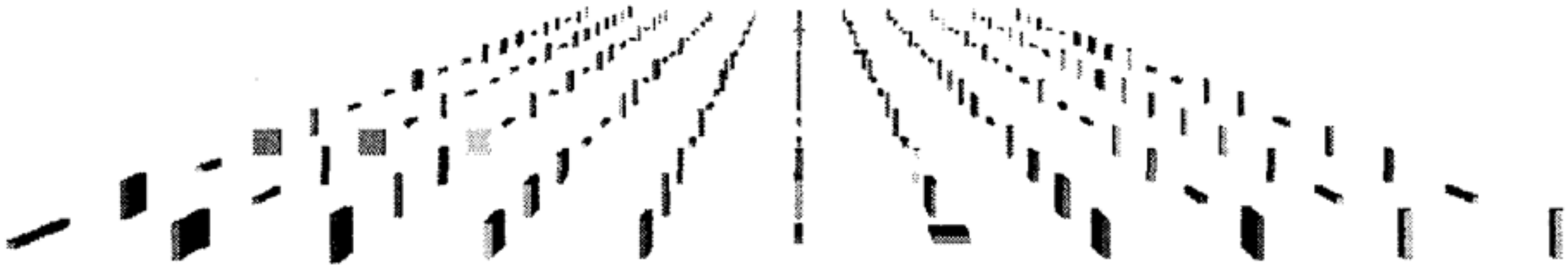
- occlusion
- interaction complexity



[Distortion Viewing Techniques for 3D Data. Carpendale et al. InfoVis 1996.]

Perspective distortion loses information

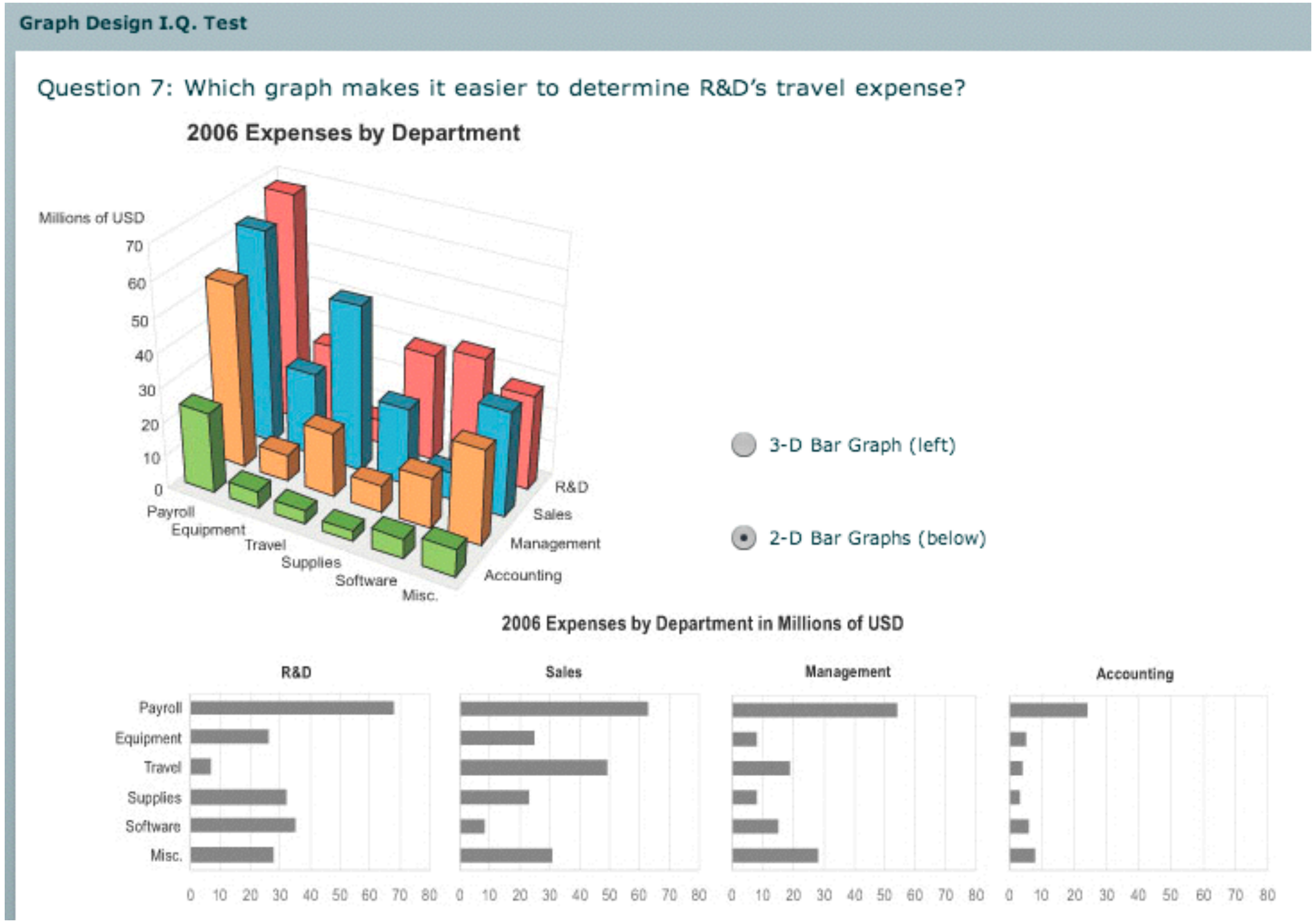
- perspective distortion
  - –interferes with all size channel encodings
  - –power of the plane is lost!



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

3D vs 2D bar charts

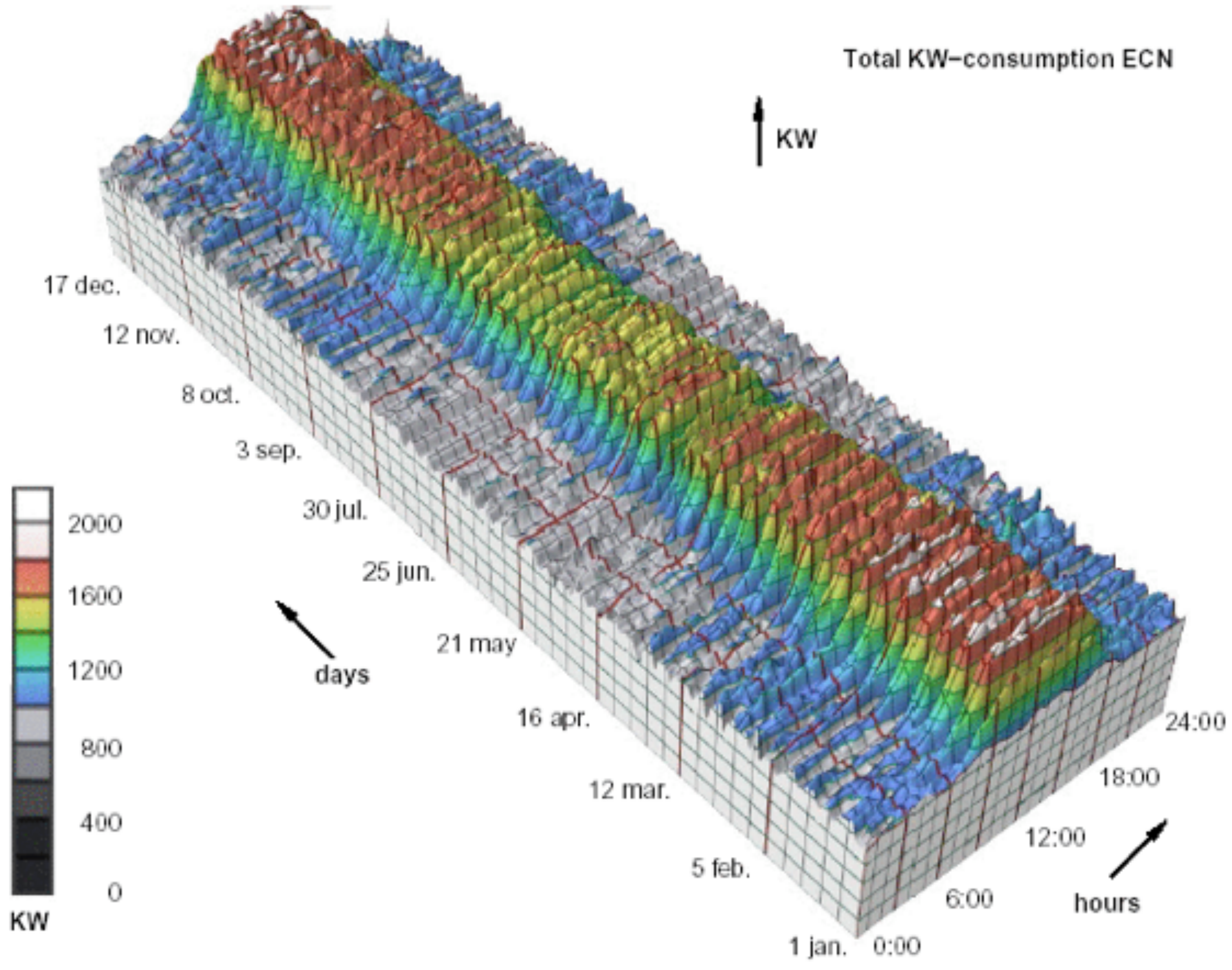
- 3D bars never a good idea!



[http://perceptualedge.com/files/GraphDesignIQ.html]

No unjustified 3D example: Time-series data

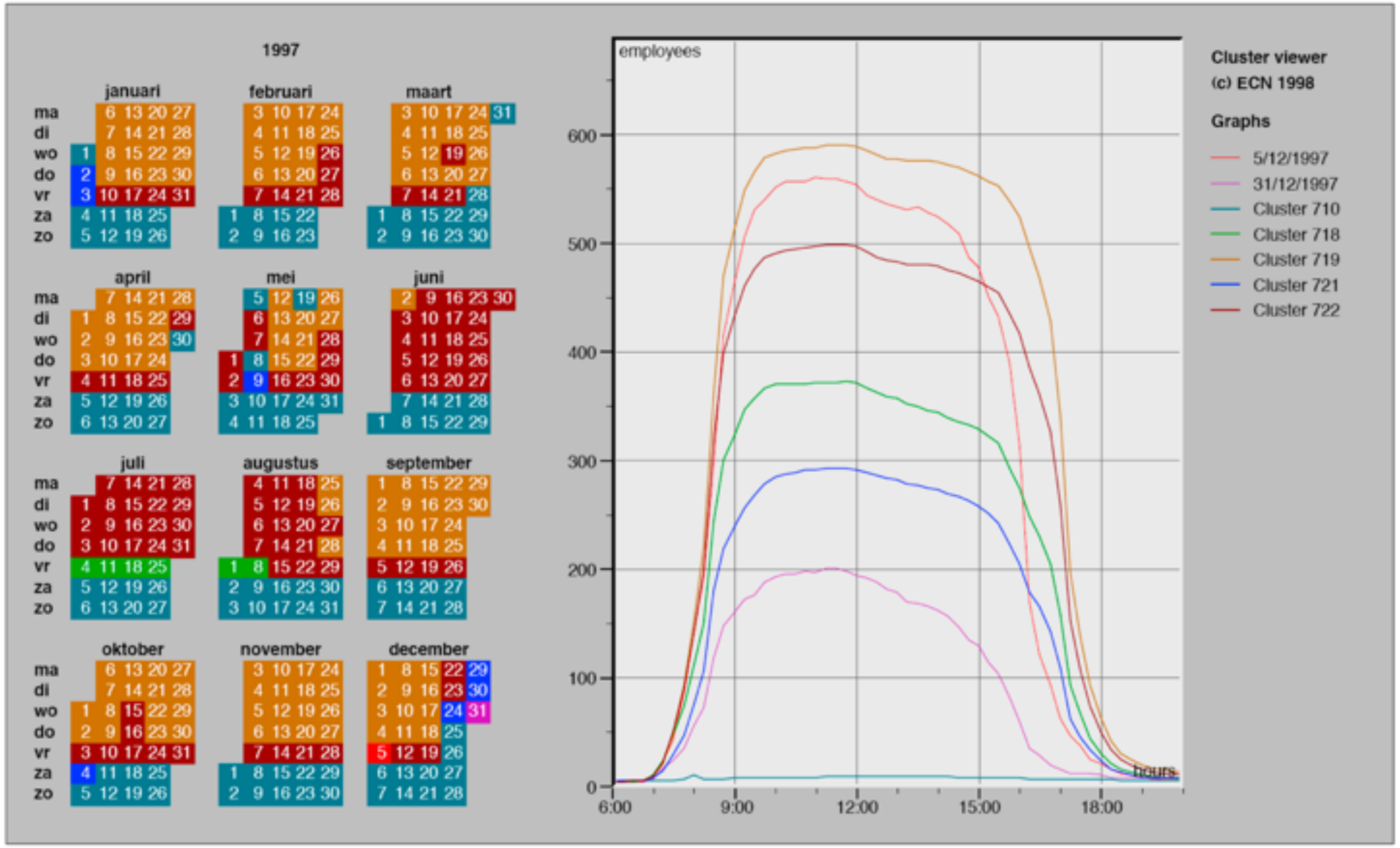
- extruded curves: detailed comparisons impossible



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

No unjustified 3D example: Transform for new data abstraction

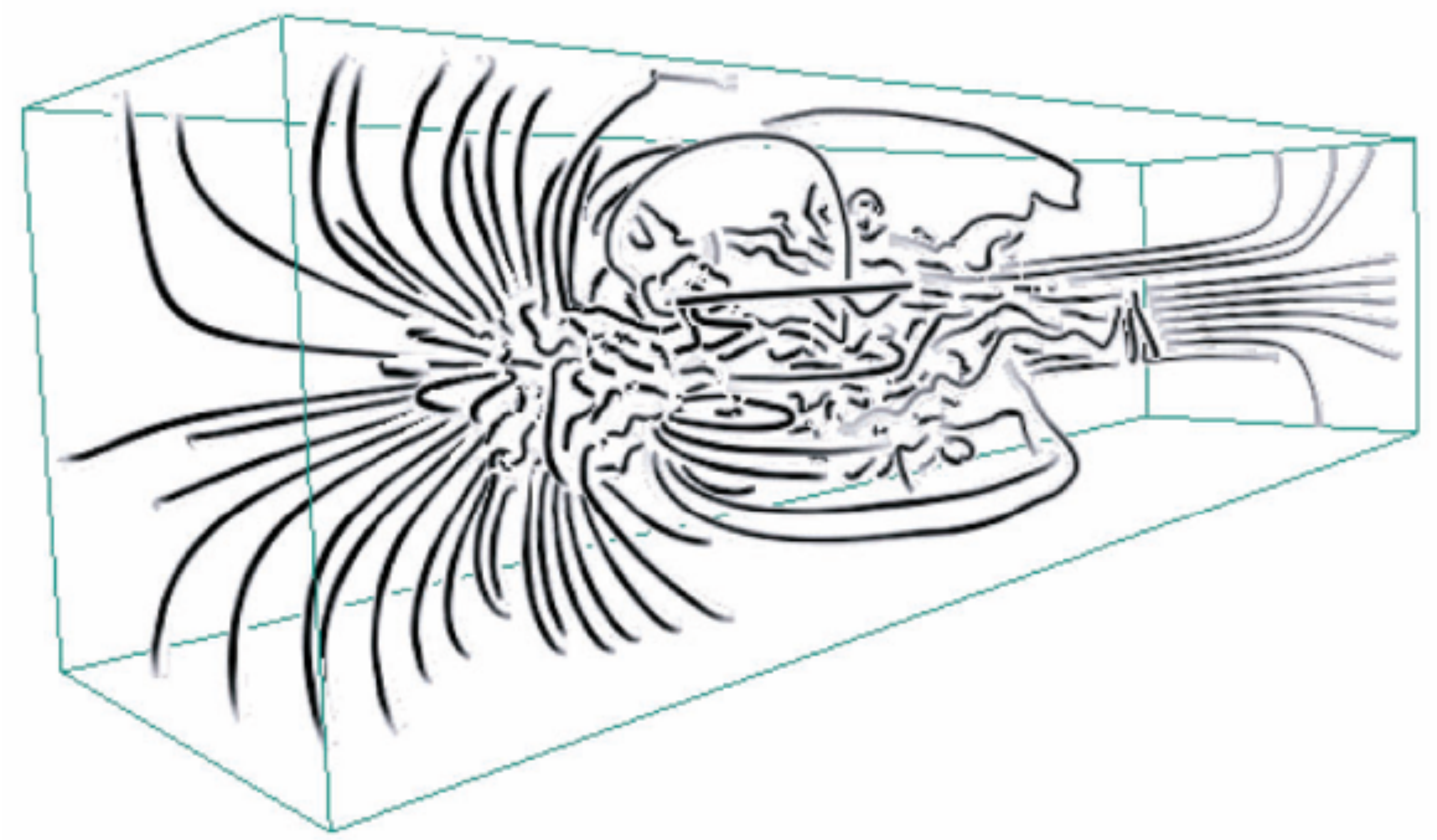
- derived data: cluster hierarchy
- juxtapose multiple views: calendar, superimposed 2D curves



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

Justified 3D: shape perception

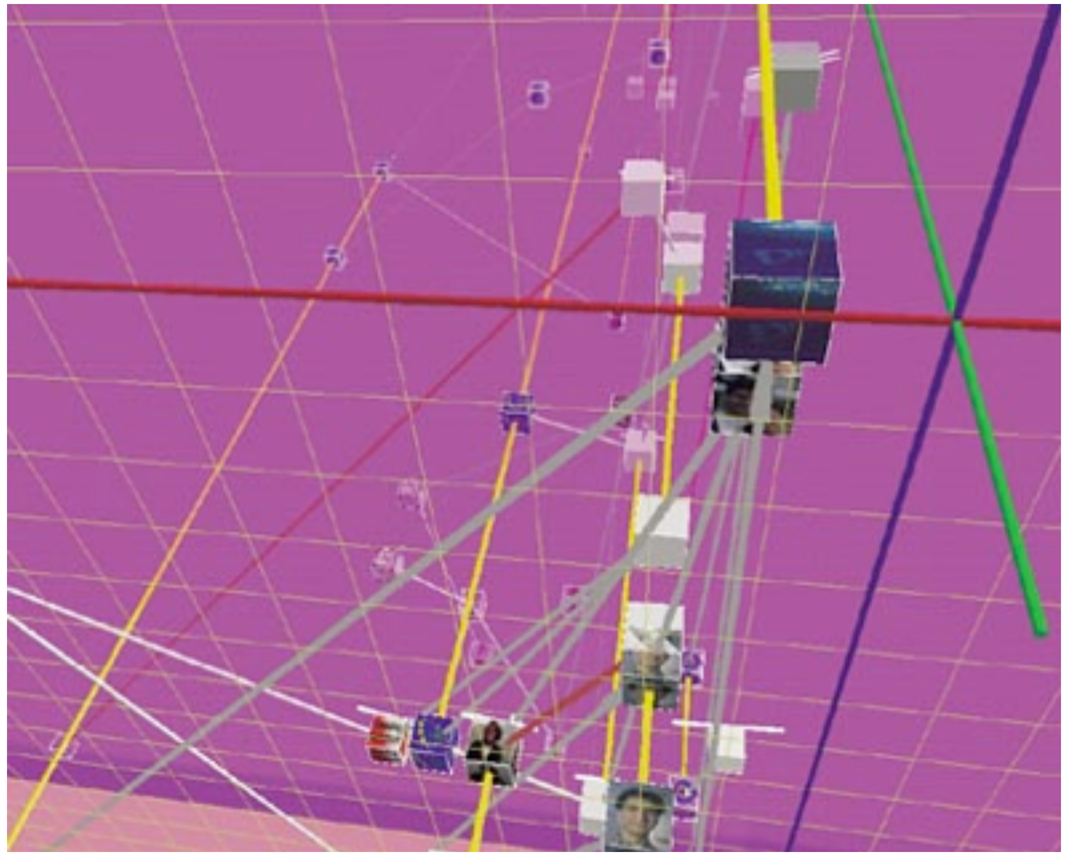
- benefits outweigh costs when task is shape perception for 3D spatial data
  – interactive navigation supports synthesis across many viewpoints



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

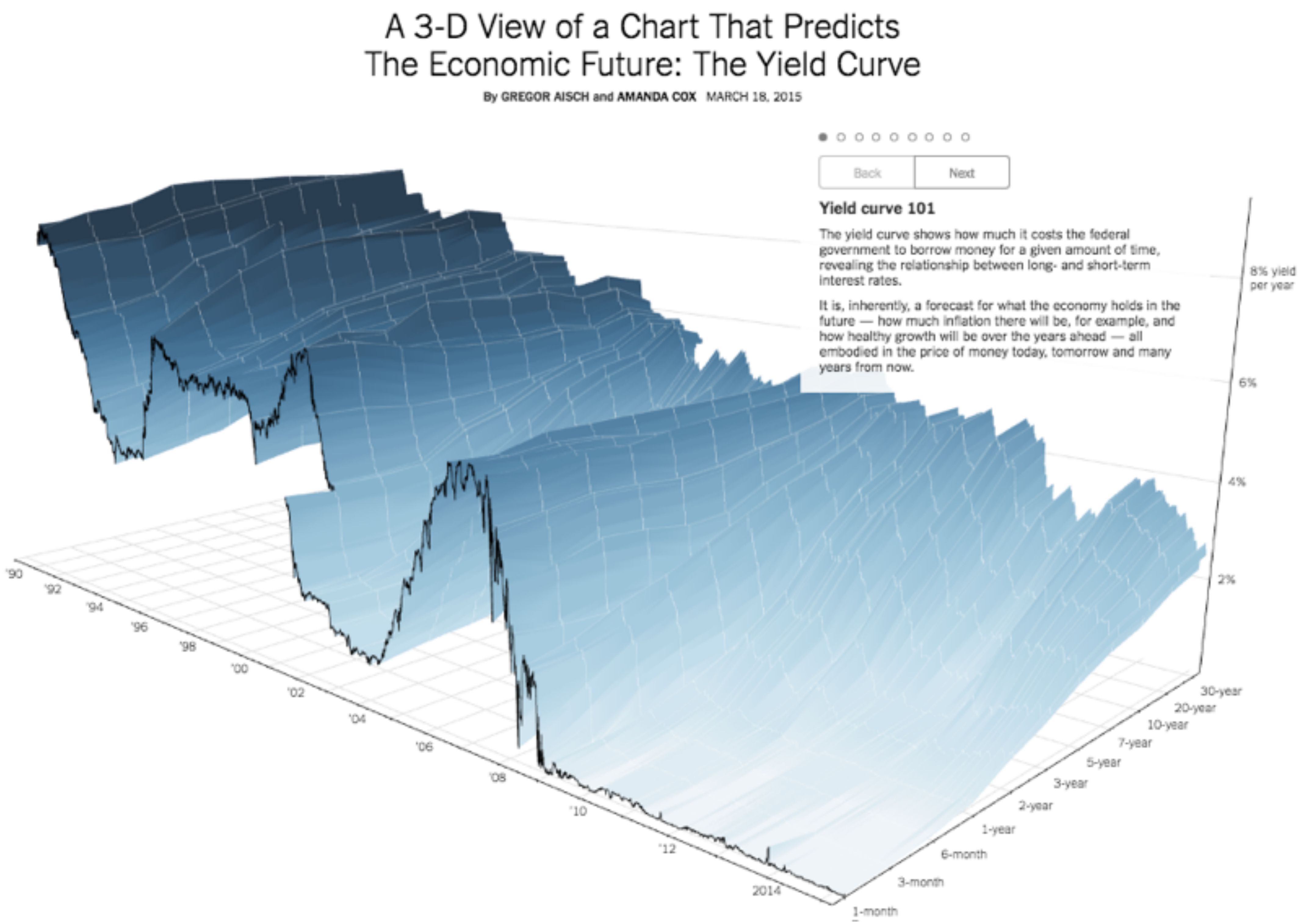
No unjustified 3D

- 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 dimensional Web history. Frecon and Smith. Proc. InfoVis 1999]

Justified 3D: Economic growth curve

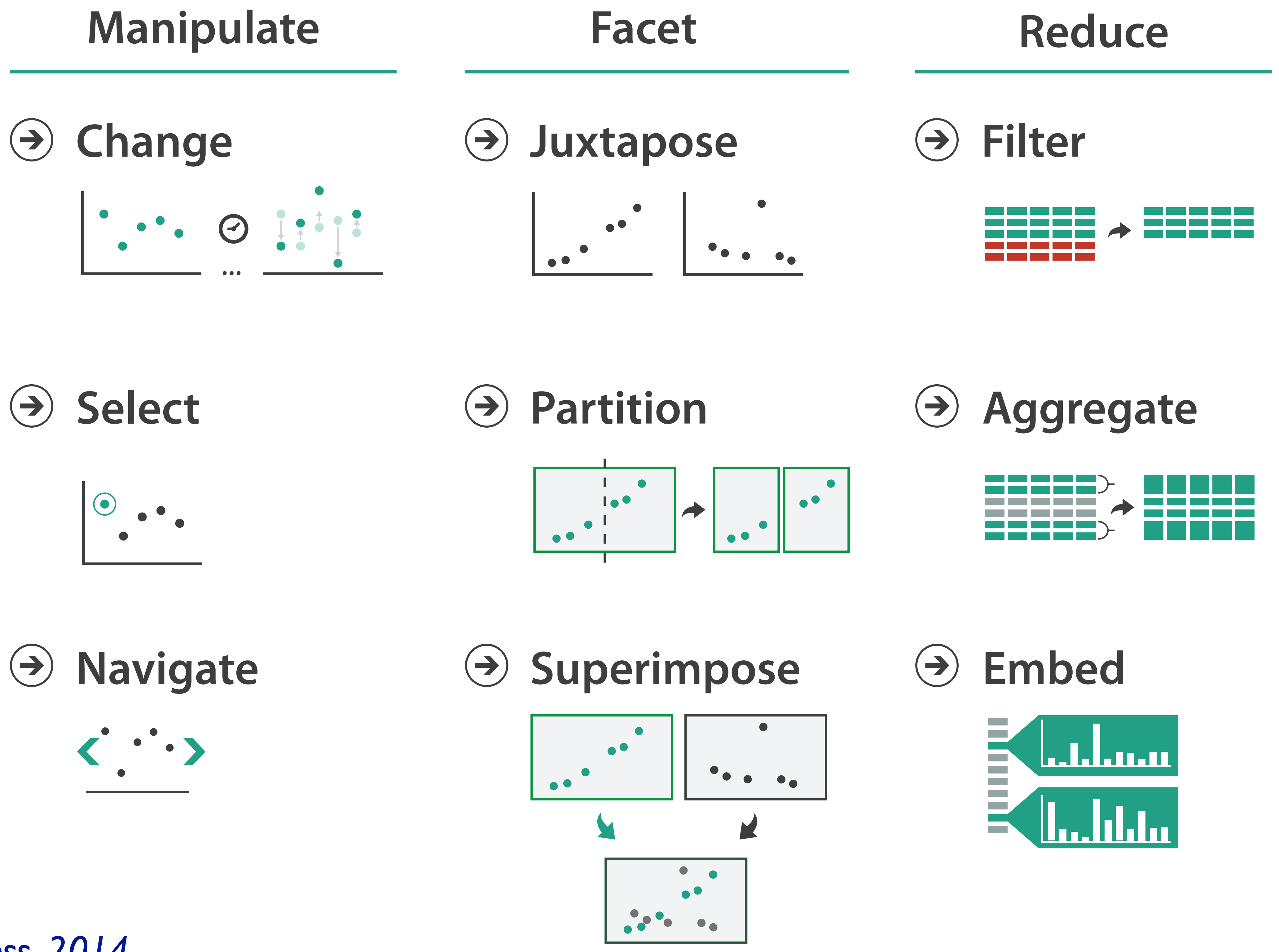


http://www.nytimes.com/interactive/2015/03/19/upshot/3d-yield-curve-economic-growth.html

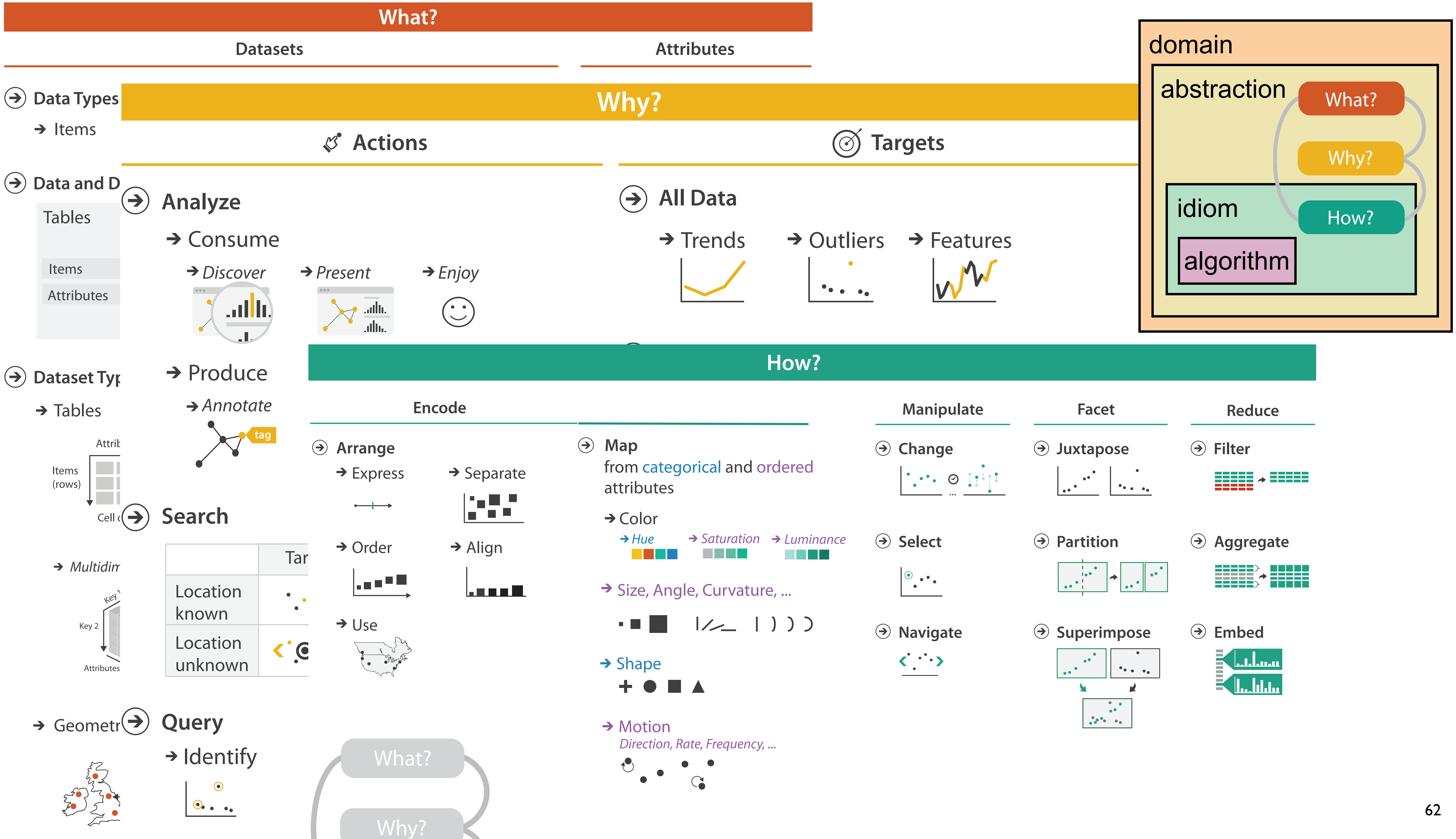
Four strategies to handle complexity: More this afternoon!

➔ *Derive*

- derive new data to show within view
- change view over time
- facet across multiple views
- reduce items/attributes within single view



more at:
Visualization Analysis and Design.
Munzner. AK Peters Visualization Series, CRC Press, 2014.


What?
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Size, Angle, Curvature, ...
Shape
Motion
Direction, Rate, Frequency, ...
Change
Select
Navigate
Juxtapose
Partition
Superimpose
Filter
Aggregate
Embed
What?
Why?

More Information

@tamaramunzner

- this talk
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- afternoon session in more depth
  www.cs.ubc.ca/~tmm/talks.html#vad17can-aft

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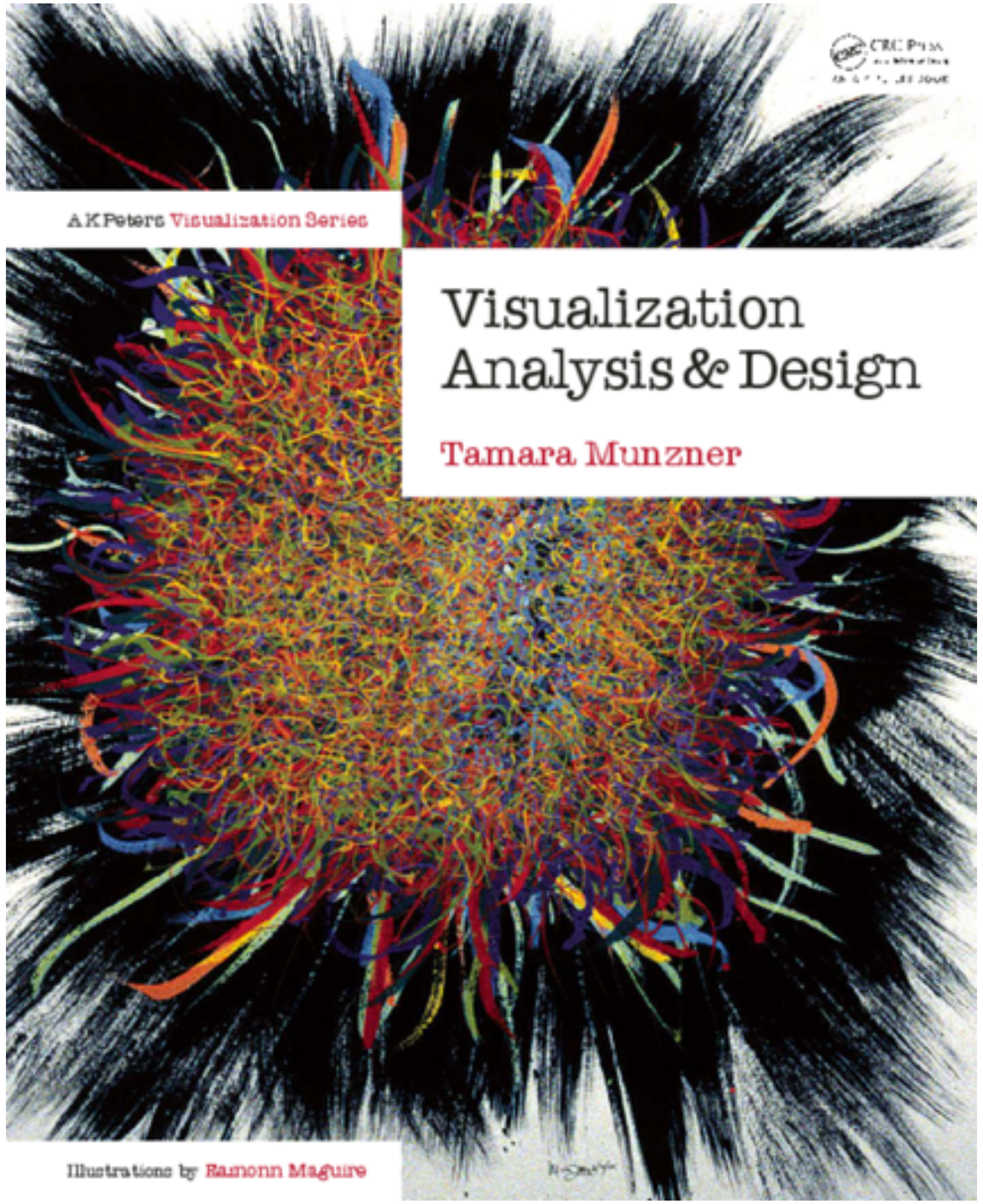

Visualization Analysis and Design.
Munzner. A K Peters Visualization Series, CRC Press, Visualization Series, 2014.