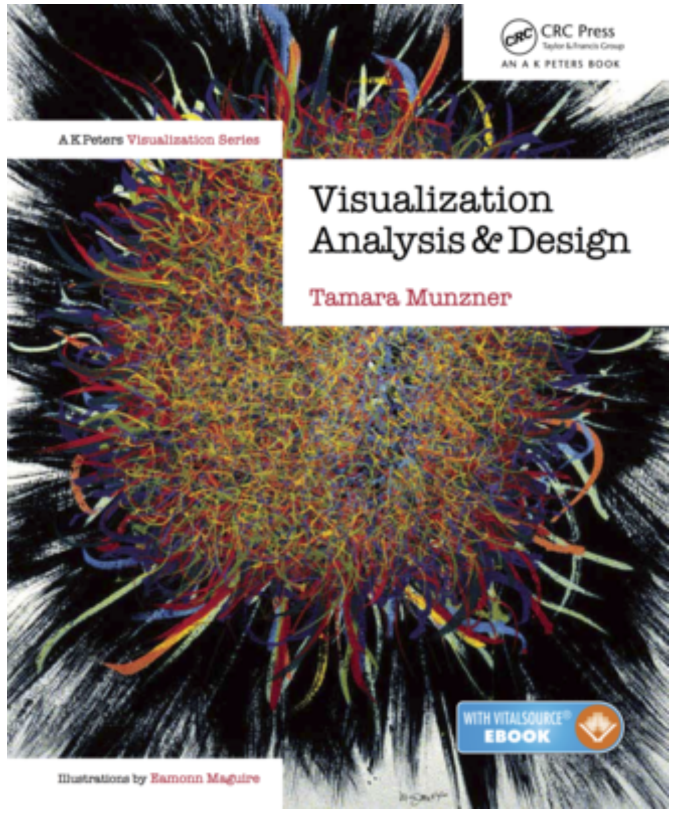
Visualization Analysis & Design
Half-Day Tutorial



Tamara Munzner
Department of Computer Science
University of British Columbia

@tamaramunzner

IEEE VIS 2023 Tutorial
October 2023, Melbourne Australia

http://www.cs.ubc.ca/~tmm/talks.html#halfdaycourse23

Visualization Analysis & Design, Half-Day Tutorial

- Session 1
  - Analysis: What, Why, How
  - Marks and Channels
  - Arrange Tabular & Spatial Data
- Session 2
  - Arrange Networks and Trees
  - Map Color and Other Channels
  - Manipulate & Facet
  - Reduce: Filter, Aggregate

@tamaramunzner @tamara@vis.social

http://www.cs.ubc.ca/~tmm/talks.html#halfdaycourse23

Defining visualization (vis)

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

Defining visualization (vis)

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

Why?...

Why have a human in the loop?

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

Why have a human in the loop?

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.

Why have a human in the loop?

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

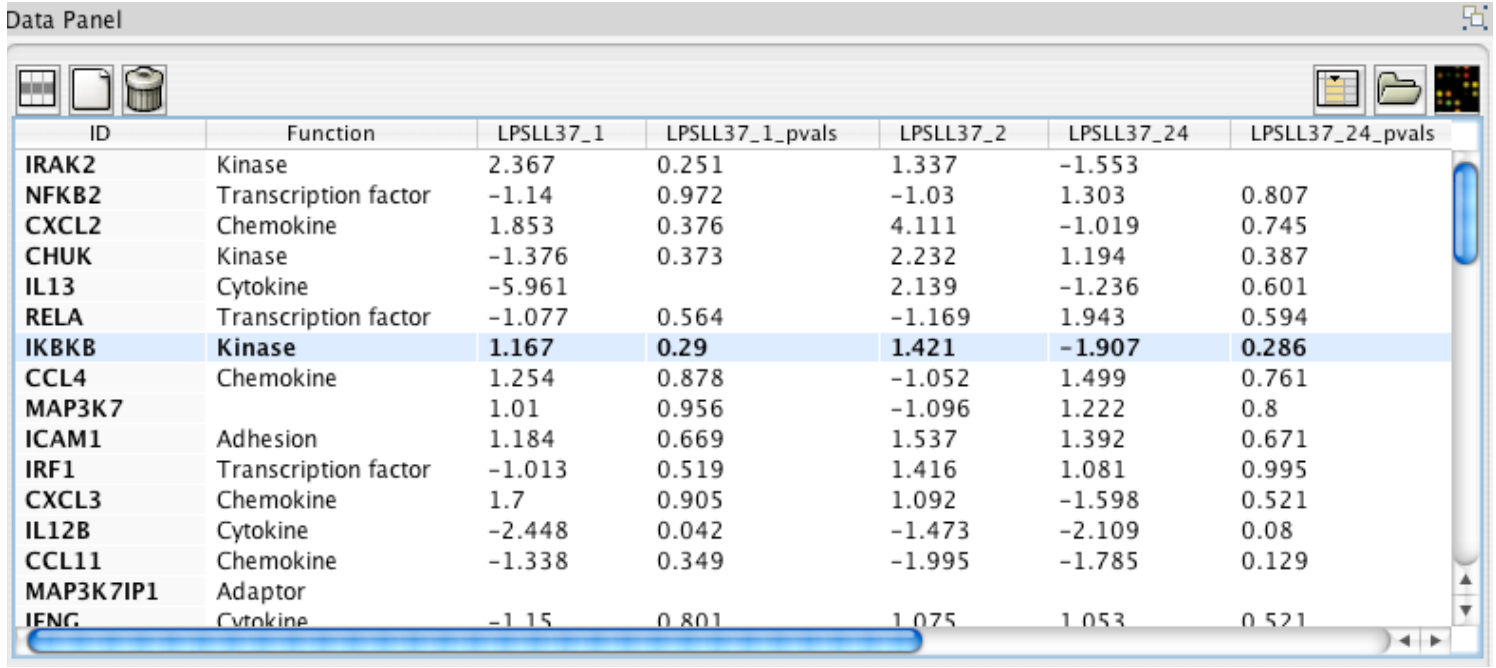
Visualization is suitable when there is a need to augment human capabilities rather than replace people with computational decision-making methods.

- don't need vis when fully automatic solution exists and is trusted
- many analysis problems ill-specified
  - don't know exactly what questions to ask in advance
- possibilities
  - long-term use for end users (ex: exploratory analysis of scientific data)
  - presentation of known results (ex: New York Times Upshot)
  - stepping stone to assess requirements before developing models
  - help automatic solution developers refine & determine parameters
  - help end users of automatic solutions verify, build trust

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



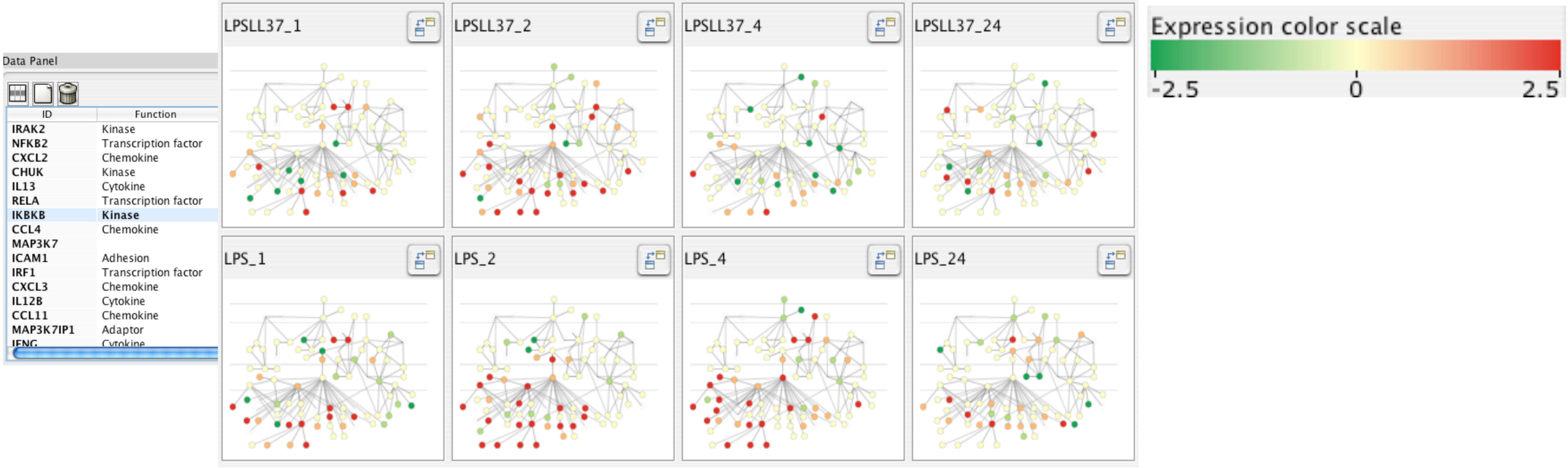
ID	Function	LPSLL37_1	LPSLL37_1_pvals	LPSLL37_2	LPSLL37_24	LPSLL37_24_pvals
IRAK2	Kinase	2.367	0.251	1.337	-1.553	
NFKB2	Transcription factor	-1.14	0.972	-1.03	1.303	0.807
CXCL2	Chemokine	1.853	0.376	4.111	-1.019	0.745
CHUK	Kinase	-1.376	0.373	2.232	1.194	0.387
IL13	Cytokine	-5.961		2.139	-1.236	0.601
RELA	Transcription factor	-1.077	0.564	-1.169	1.943	0.594
IKBKB	Kinase	1.167	0.29	1.421	-1.907	0.286
CCL4	Chemokine	1.254	0.878	-1.052	1.499	0.761
MAP3K7		1.01	0.956	-1.096	1.222	0.8
ICAM1	Adhesion	1.184	0.669	1.537	1.392	0.671
IRF1	Transcription factor	-1.013	0.519	1.416	1.081	0.995
CXCL3	Chemokine	1.7	0.905	1.092	-1.598	0.521
IL12B	Cytokine	-2.448	0.042	-1.473	-2.109	0.08
CCL11	Chemokine	-1.338	0.349	-1.995	-1.785	0.129
MAP3K7IP1	Adaptor					
IFNG	Cytokine	-1.15	0.801	1.075	1.053	0.521

[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 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



[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.]

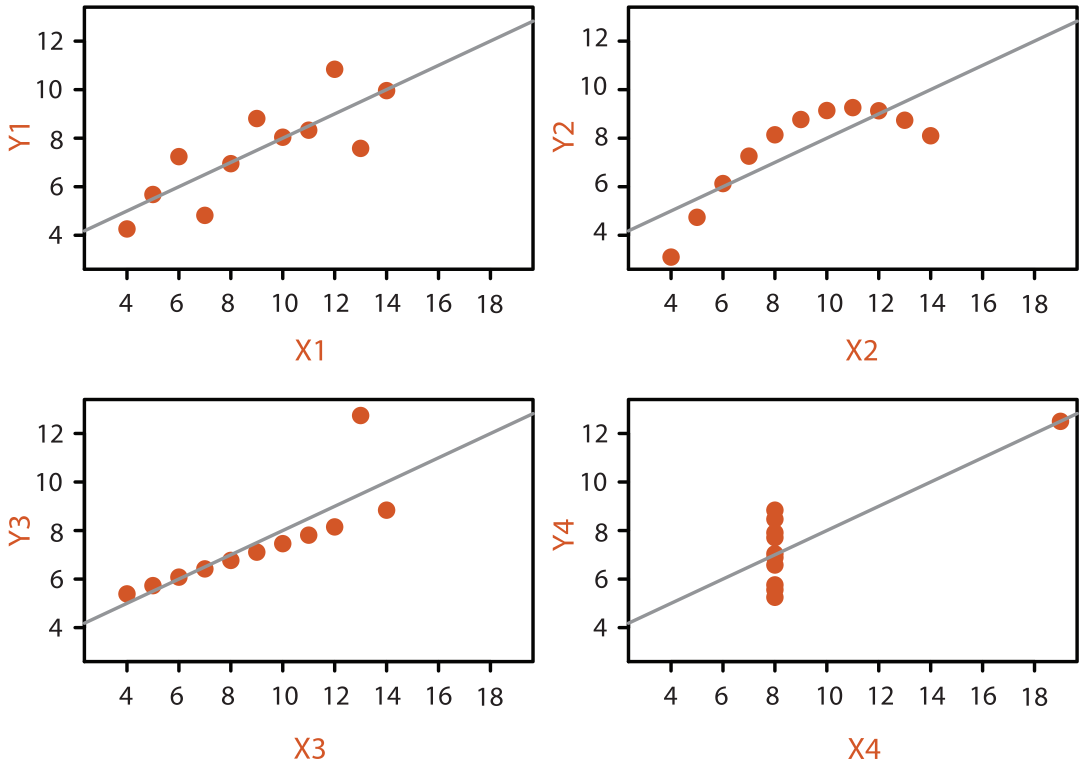
Why represent all the data?

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

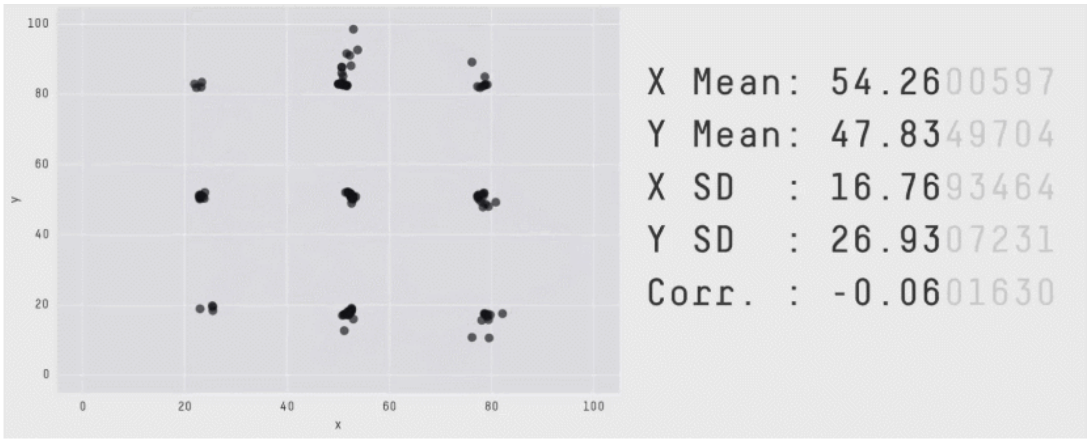
- summaries lose information, details matter
  - confirm expected and find unexpected patterns
  - assess validity of statistical model

Anscombe's Quartet

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



Datasaurus Dozen



Same Stats, Different Graphs: Generating Datasets with Varied Appearance and Identical Statistics through Simulated Annealing. CHI 2017. Matejka & Fitzmaurice

Why analyze?

- imposes structure on huge design space
  - scaffold to help you think systematically about choices
  - analyzing existing as stepping stone to designing new
  - most possibilities ineffective for particular task/data combination

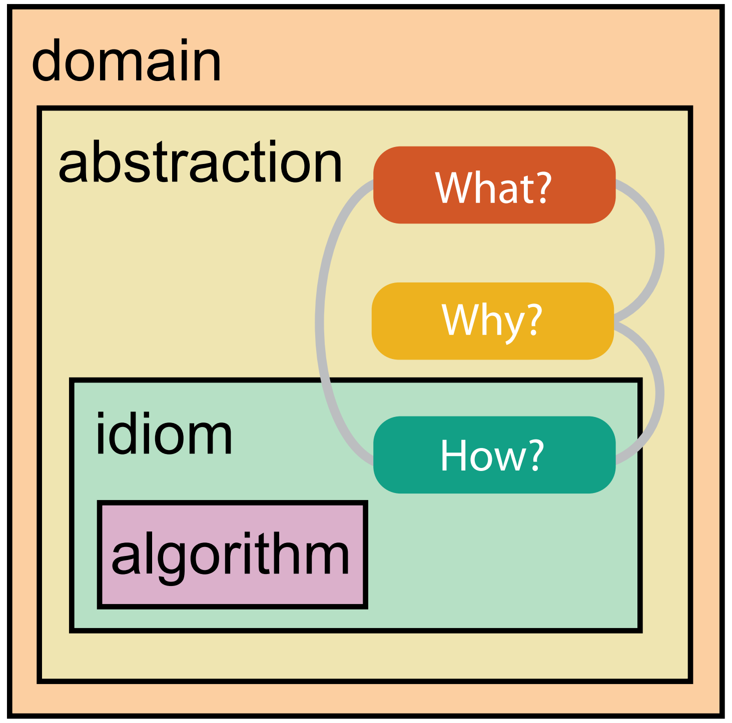
Analysis framework: Four levels, three questions

- *domain situation*
  - who are the target users?

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
    - **why** is the user looking at it? **task** abstraction

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

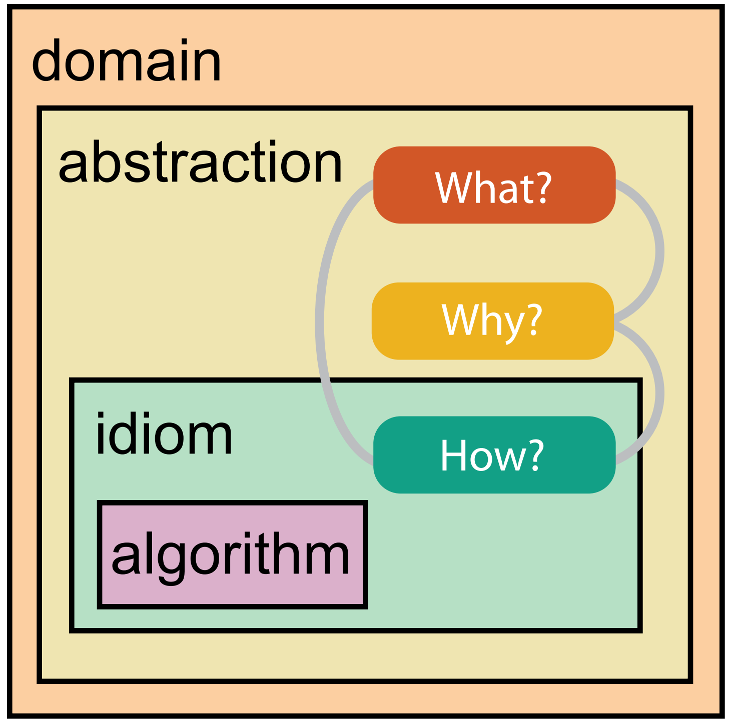


[A Multi-Level Typology of Abstract Visualization Tasks *Brehmer and Munzner. IEEE TVCG 19(12):2376-2385, 2013 (Proc. InfoVis 2013).*]

Analysis framework: Four levels, three questions

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

- *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

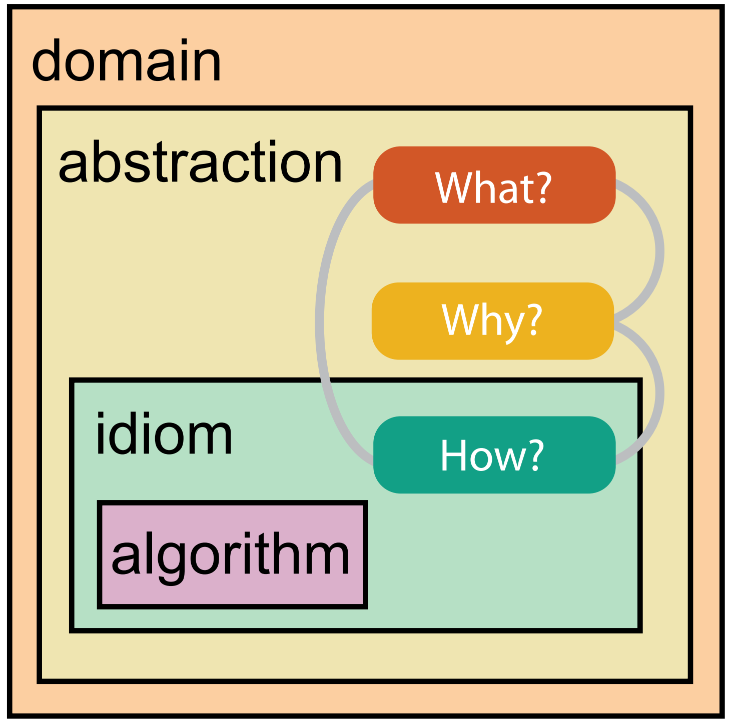


[A Multi-Level Typology of Abstract Visualization Tasks *Brehmer and Munzner. IEEE TVCG 19(12):2376-2385, 2013 (Proc. InfoVis 2013).*]

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
    - **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).*]



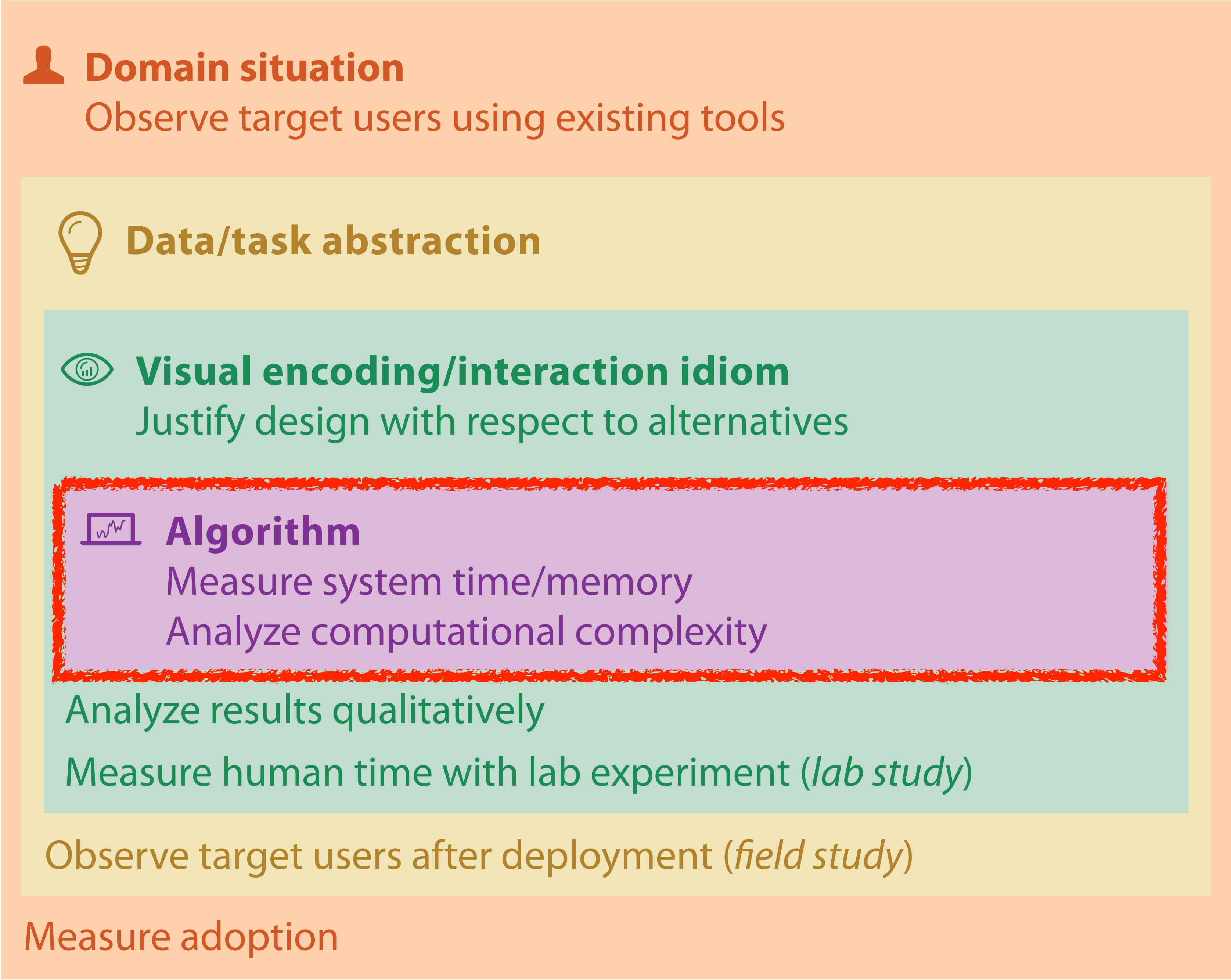
[A Multi-Level Typology of Abstract Visualization Tasks *Brehmer and Munzner. IEEE TVCG 19(12):2376-2385, 2013 (Proc. InfoVis 2013).*]

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

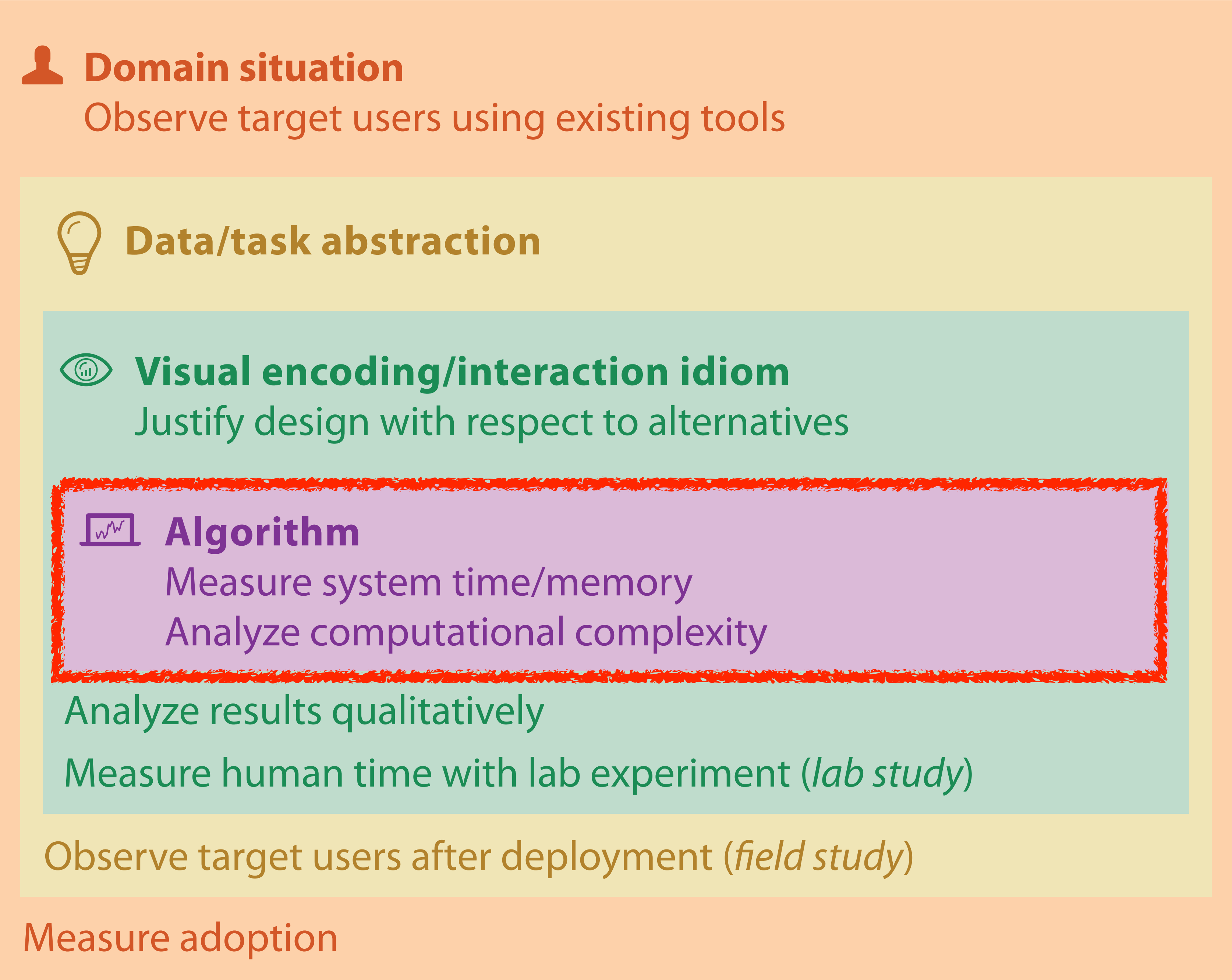


[A Nested Model of Visualization Design and Validation. Munzner. IEEE TVCG 15(6):921-928, 2009 (Proc. InfoVis 2009).]

Why is validation difficult?

- solution: use methods from different fields at each level

computer science

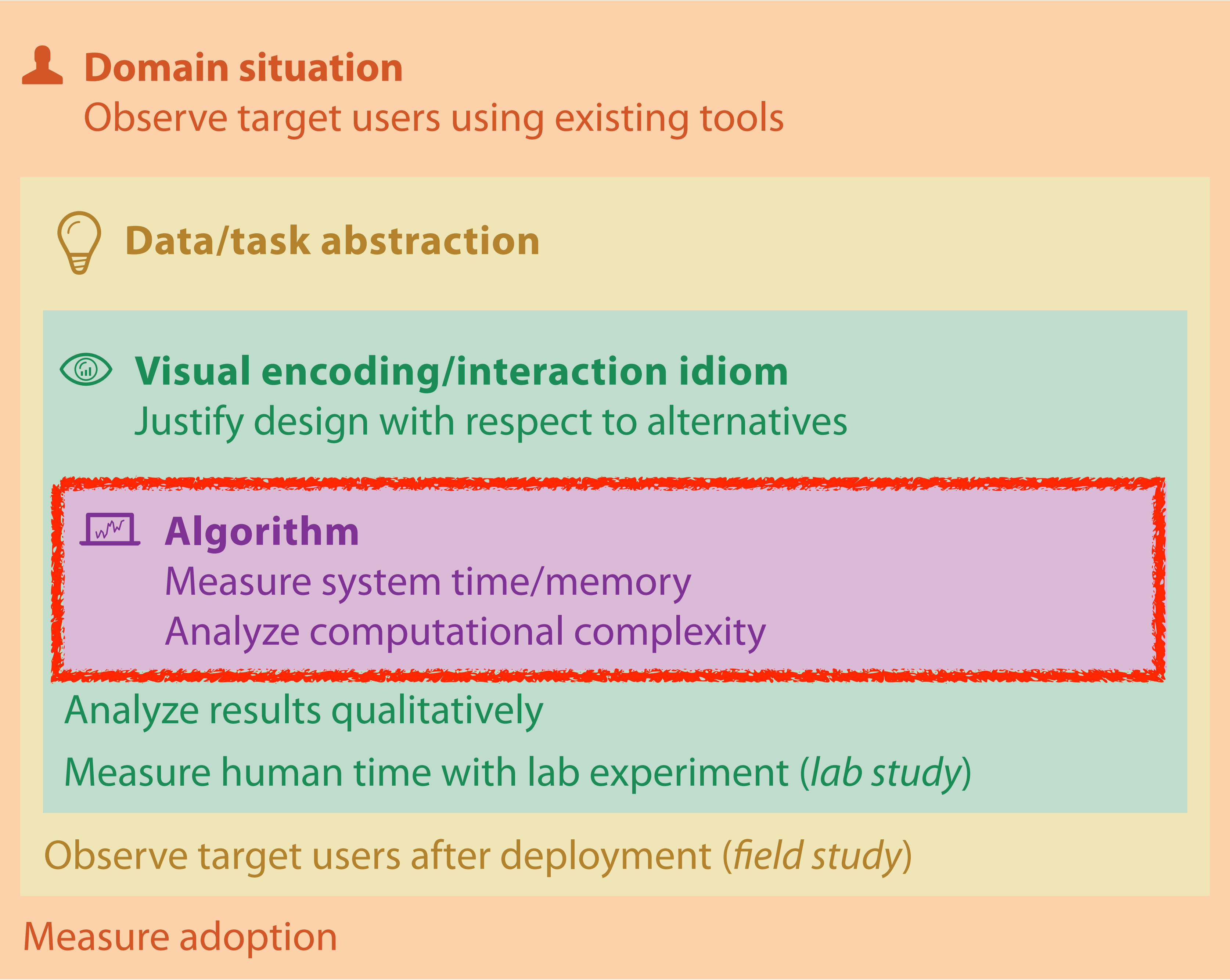


technique-driven work

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

Why is validation difficult?

- solution: use methods from different fields at each level



design

computer science

cognitive psychology

technique-driven work

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

Why is validation difficult?

- solution: use methods from different fields at each level

anthropology/ ethnography

Domain situation
Observe target users using existing tools

Data/task abstraction

design

Visual encoding/interaction idiom
Justify design with respect to alternatives

computer science

Algorithm
Measure system time/memory
Analyze computational complexity

cognitive psychology

Analyze results qualitatively
Measure human time with lab experiment (*lab study*)

anthropology/ ethnography

Observe target users after deployment (*field study*)

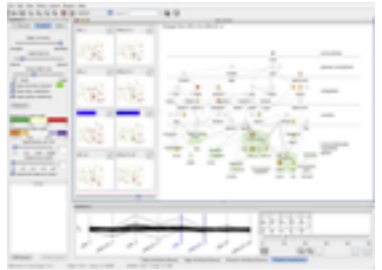
Measure adoption

problem-driven work (design study)

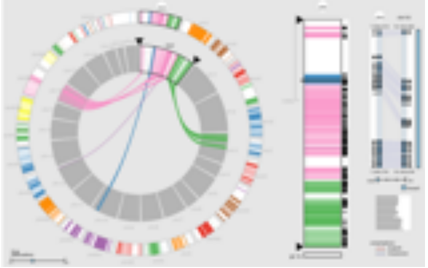
technique-driven work

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

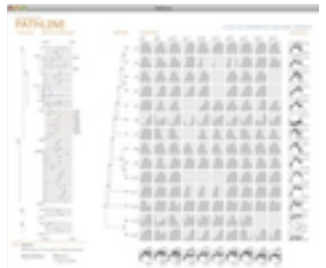
Design Study Methodology: Reflections from the Trenches and the Stacks



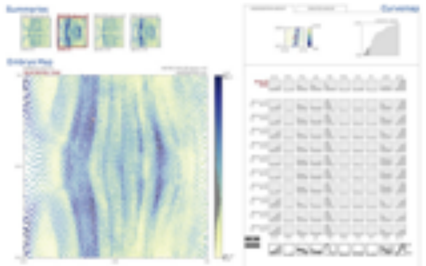
Cerebral
genomics



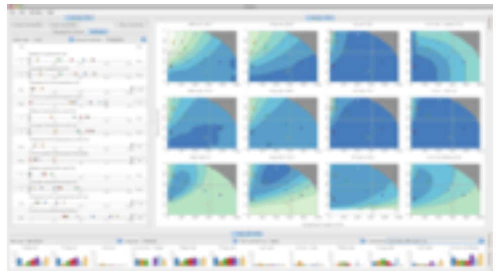
MizBee
genomics



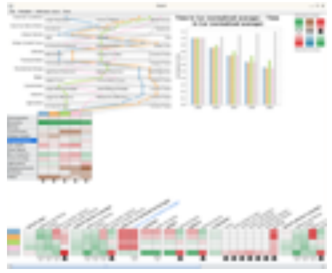
Pathline
genomics



MulteeSum
genomics



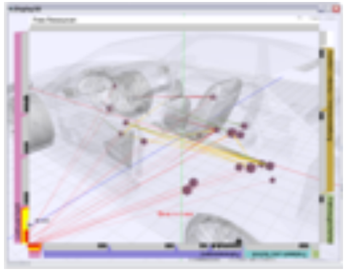
Vismon
fisheries management



QuestVis
sustainability

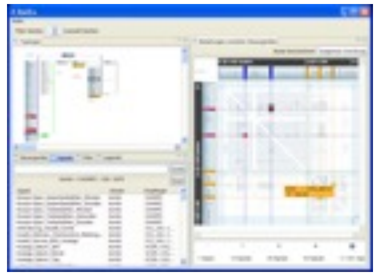
WiKeVis
in-car networks

MostVis
in-car networks

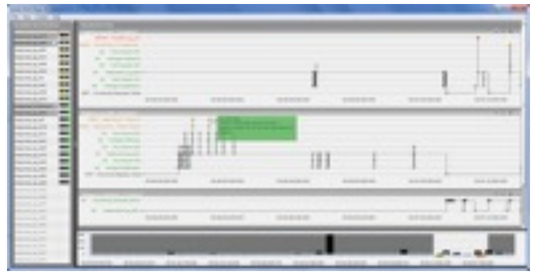


Car-X-Ray
in-car networks

ProgSpy2010
in-car networks



RelEx
in-car networks

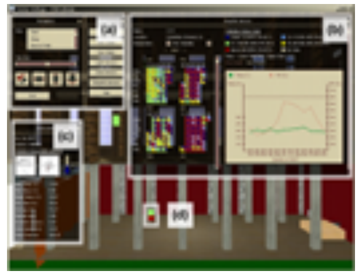


Cardiogram
in-car networks

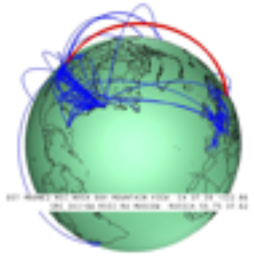
AutobahnVis
in-car networks

VisTra
in-car networks

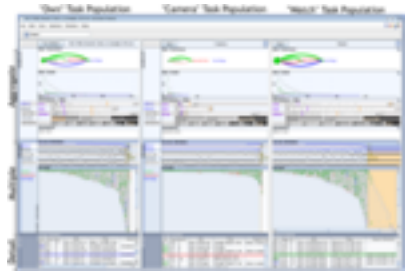
Constellation
linguistics



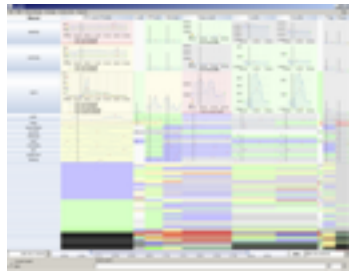
LibVis
cultural heritage



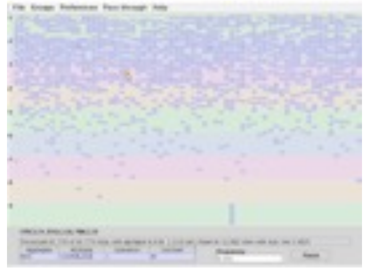
Caidants
multicast



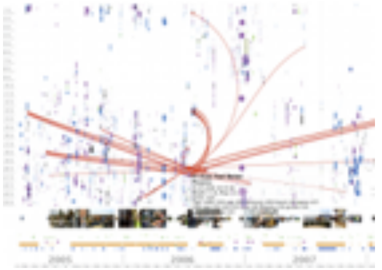
SessionViewer
web log analysis



LiveRAC
server hosting

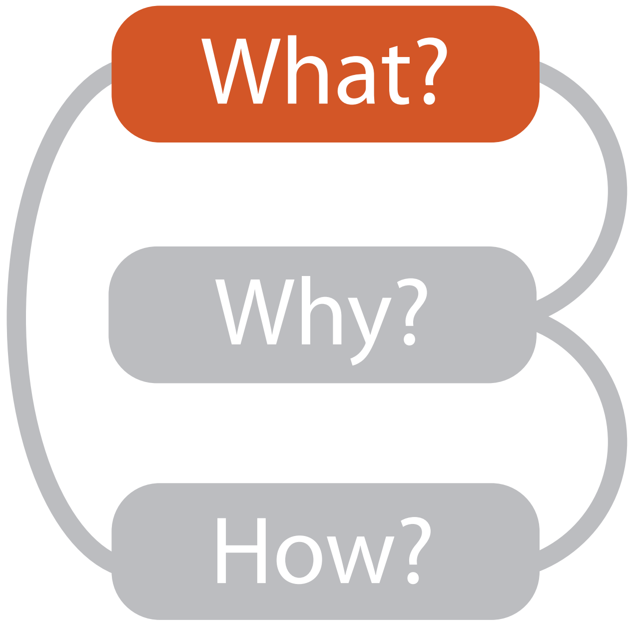


PowerSetViewer
data mining



LastHistory
music listening

[Sedlmair, Meyer, Munzner. IEEE Trans. Visualization and Computer Graphics 18(12): 2431-2440, 2012 (Proc. InfoVis 2012).]



What?

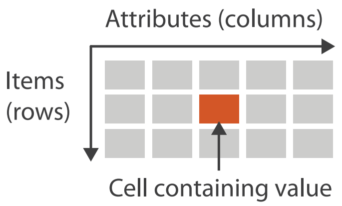
Datasets

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

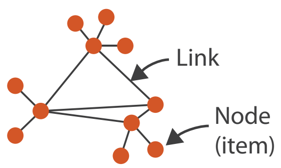
Data and Dataset Types

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

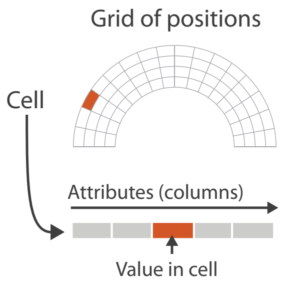
Dataset Types
- Tables



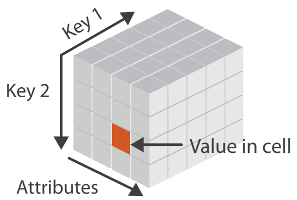
- Networks



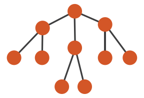
- Fields (Continuous)



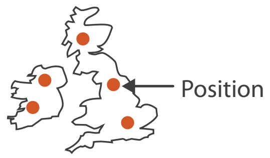
- *Multidimensional Table*



- *Trees*



- Geometry (Spatial)



Dataset Availability
- Static

- Dynamic

Attributes

Attribute Types
- Categorical

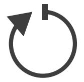
- Ordered
  - *Ordinal*

  - *Quantitative*

Ordering Direction
- Sequential

- Diverging

- Cyclic

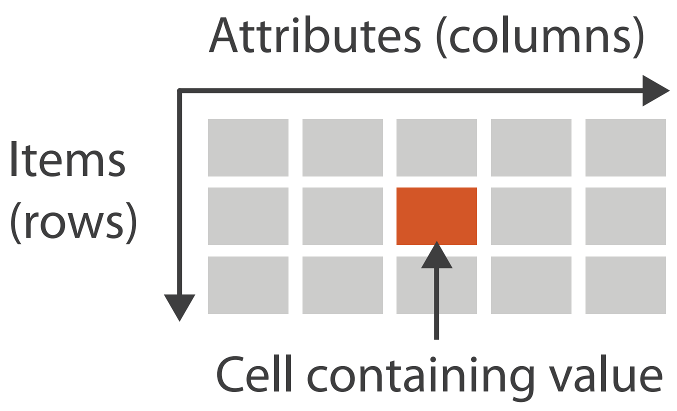


Three major datatypes

Three major datatypes

➔ Dataset Types

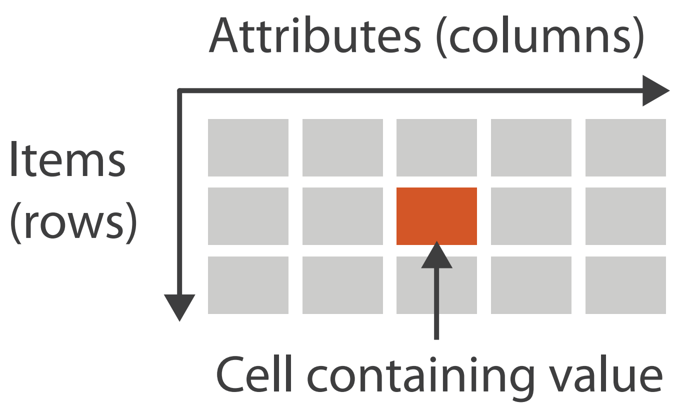
➔ Tables



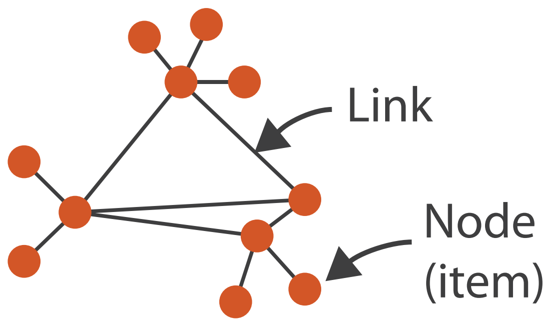
Three major datatypes

Dataset Types

Tables



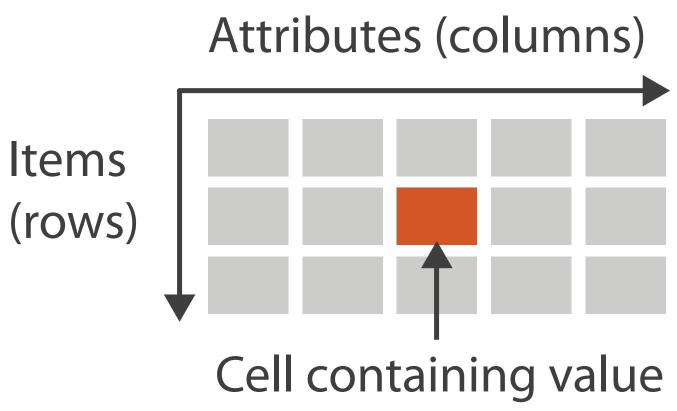
Networks



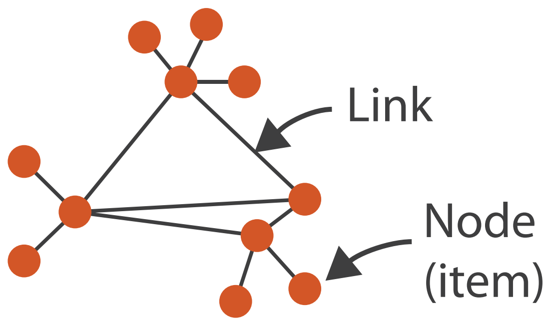
Three major datatypes

➔ Dataset Types

➔ Tables

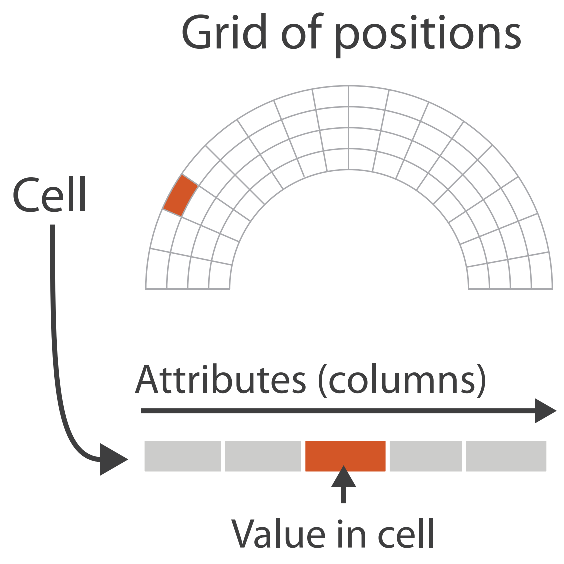


➔ Networks

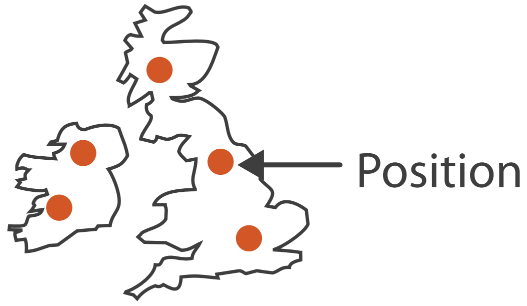


➔ Spatial

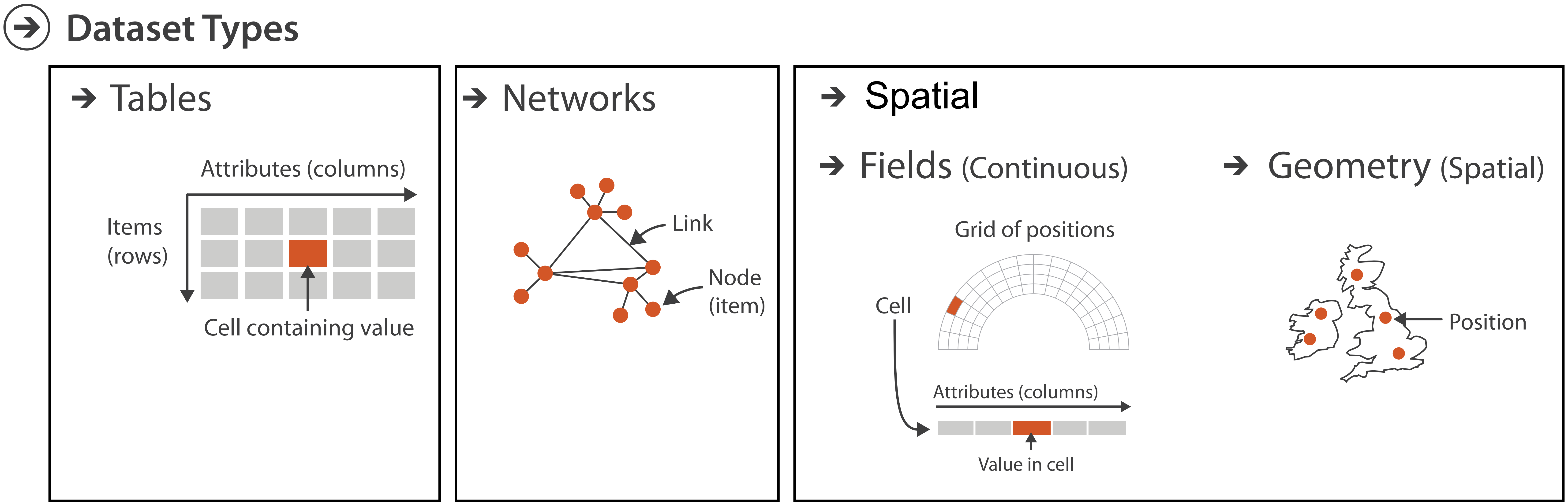
➔ Fields (Continuous)



➔ Geometry (Spatial)



Three major datatypes



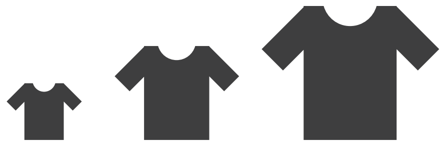
- visualization vs computer graphics
  – geometry is design decision

Attribute types

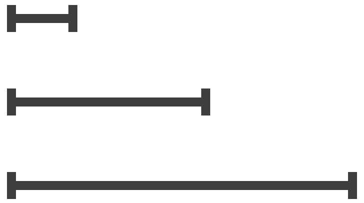
Attribute Types

- Categorical

- Ordered
  - *Ordinal*



  - *Quantitative*

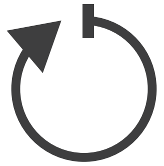


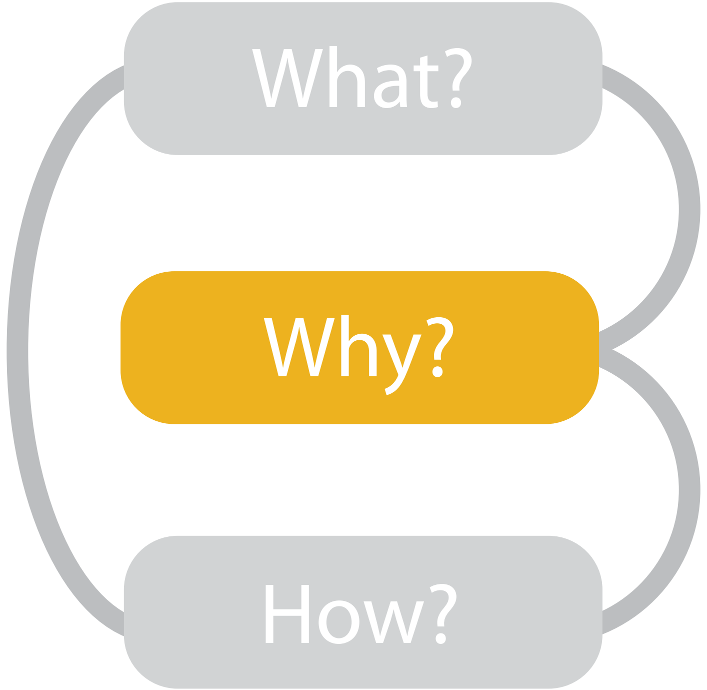
Ordering Direction

- Sequential

- Diverging

- Cyclic





Why?

Actions

Analyze

- Consume
  - *Discover*
  - *Present*
  - *Enjoy*
- Produce
  - *Annotate*
  - *Record*
  - *Derive*

tag

Search

	Target known	Target unknown
Location known	*Lookup*	*Browse*
Location unknown	*Locate*	*Explore*

Query

- Identify
- Compare
- Summarize

Targets

All Data

- Trends
- Outliers
- Features

Attributes

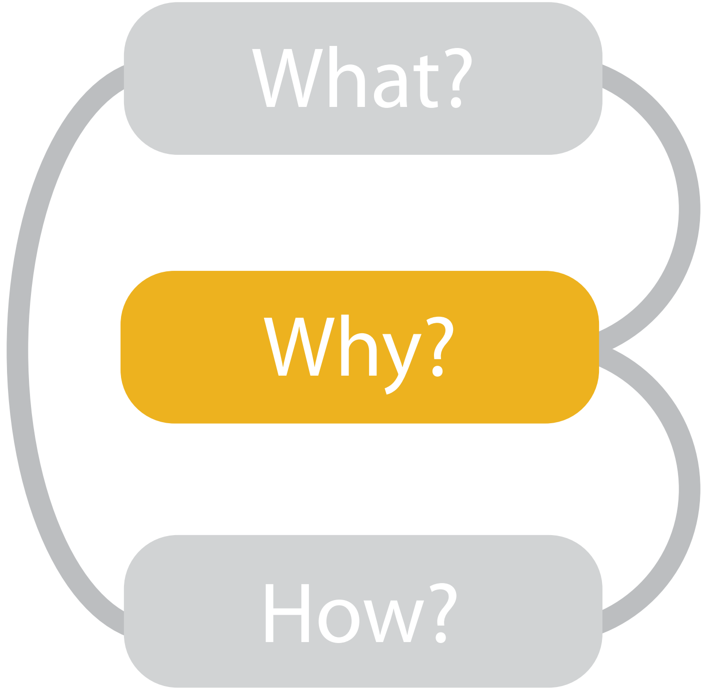
- One
  - *Distribution*
    - *Extremes*
- Many
  - *Dependency*
  - *Correlation*
  - *Similarity*

Network Data

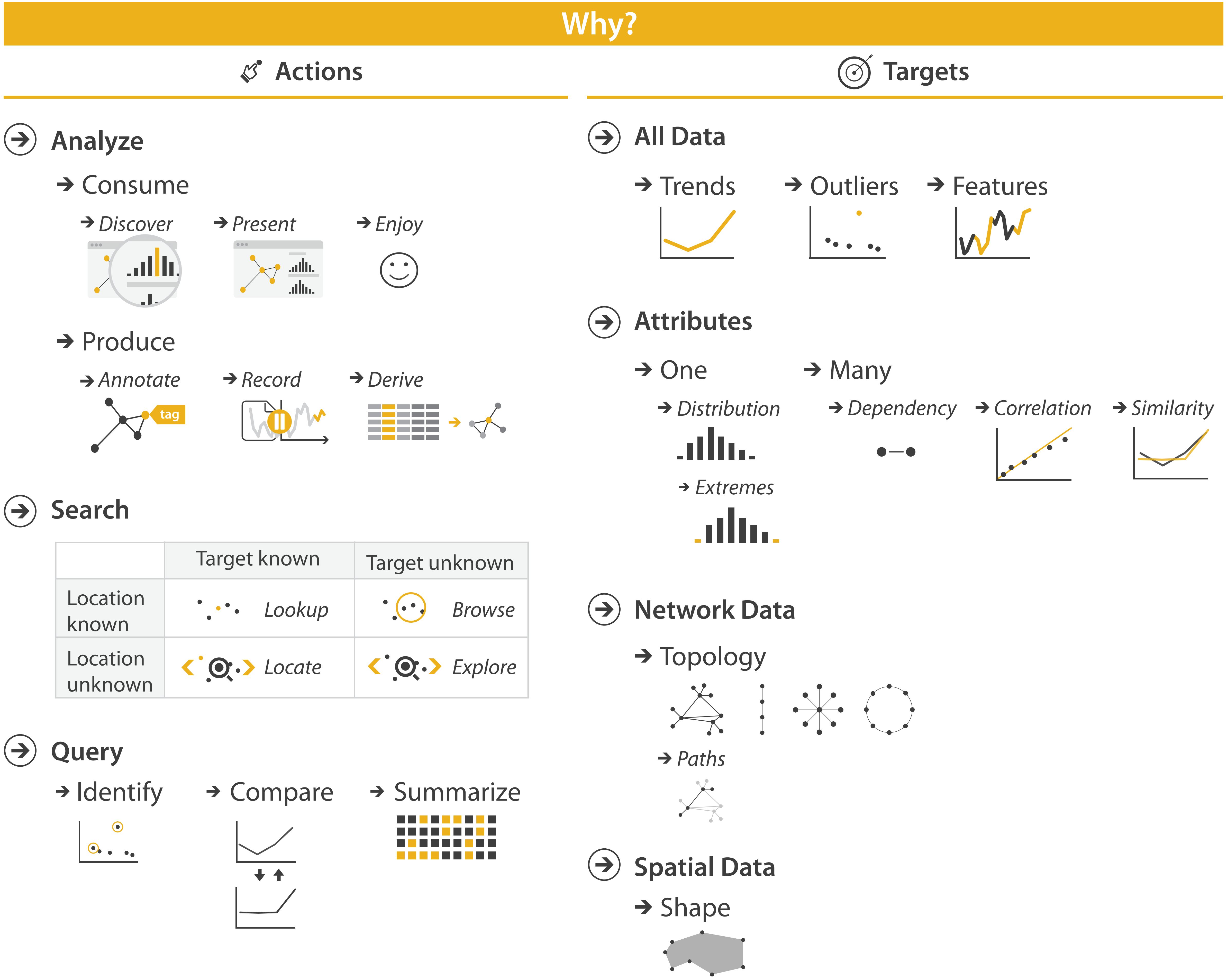
- Topology
  - *Paths*

Spatial Data

- Shape

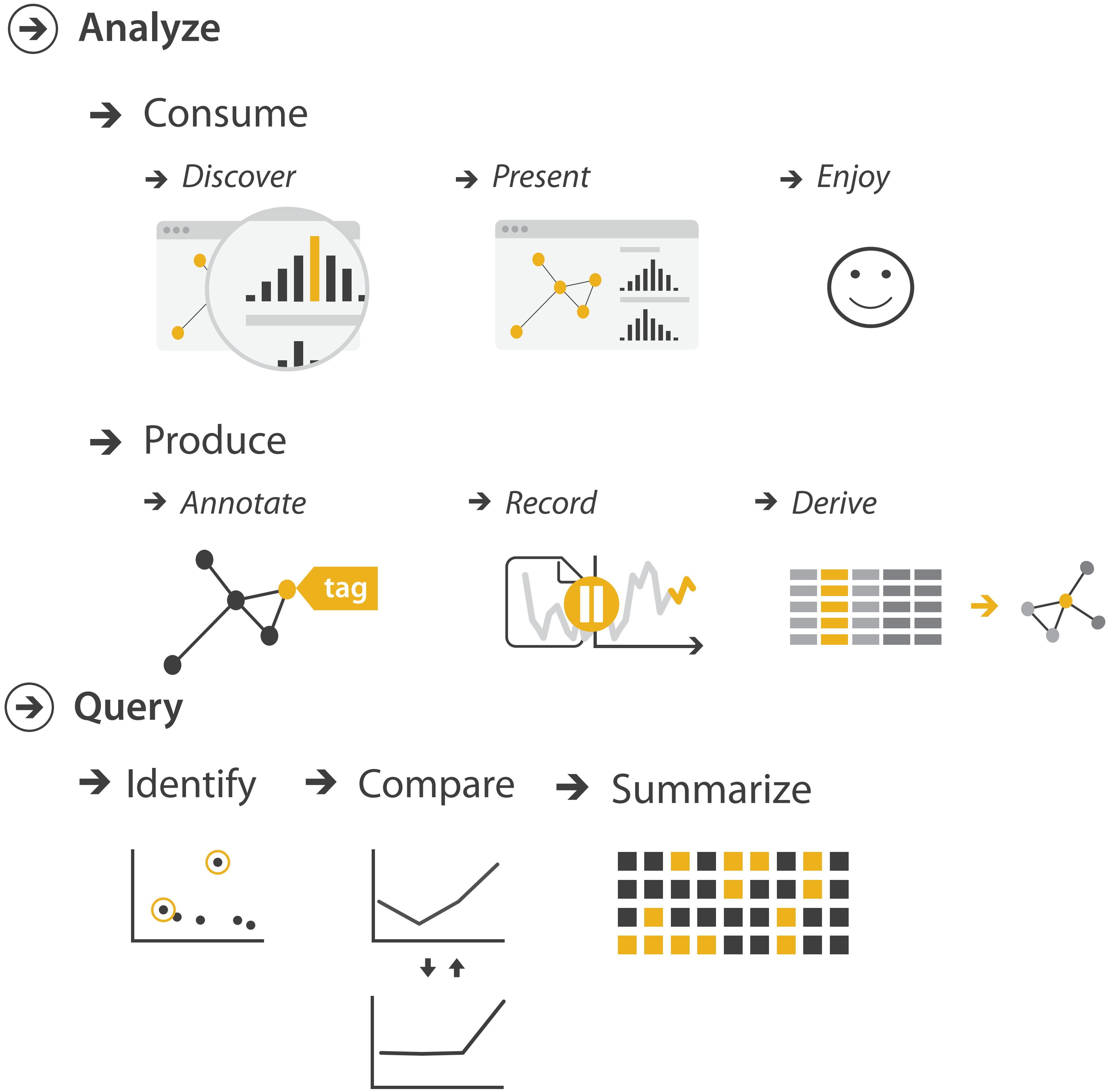


- {action, target} pairs
  - *discover distribution*
  - *compare trends*
  - *locate outliers*
  - *browse topology*



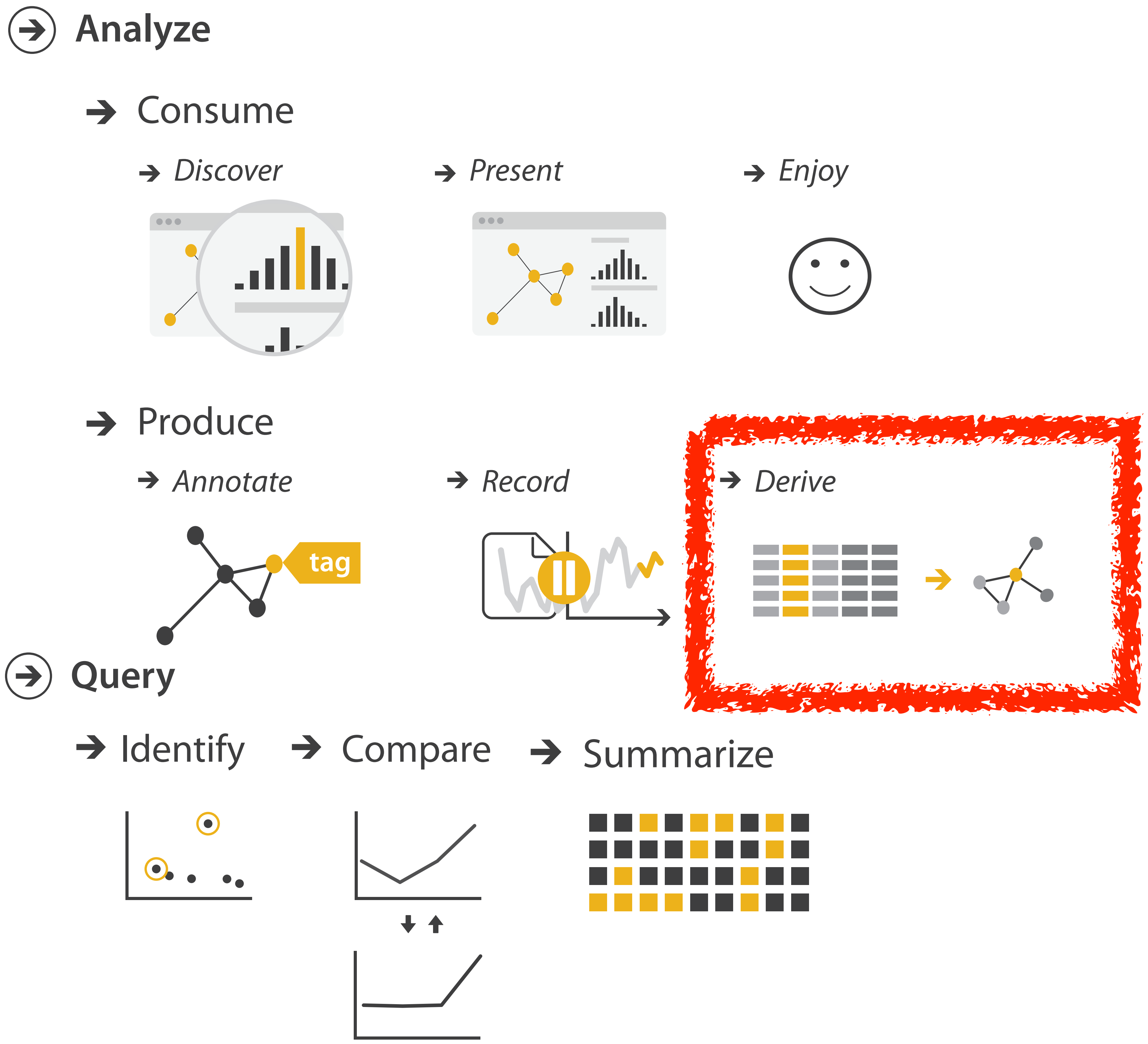
Actions: Analyze, Query

- 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
  - analyze, query, (search)



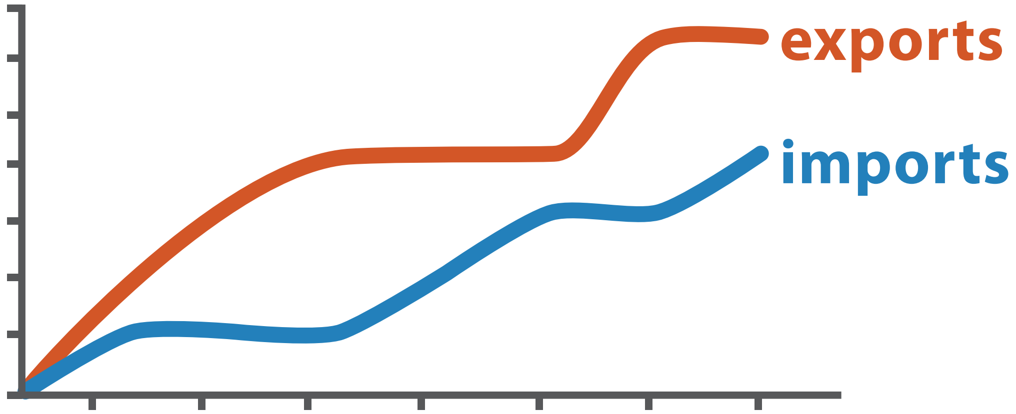
Actions: Analyze, Query

- 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
  - analyze, query, (search)

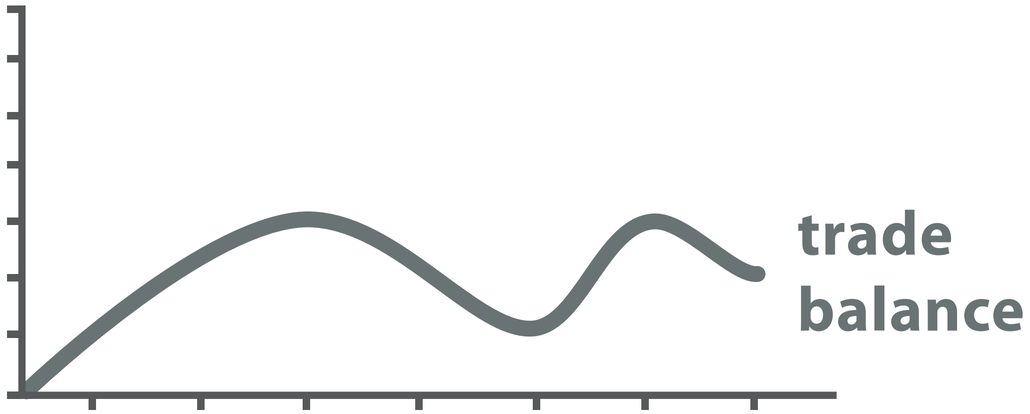


Derive

- don't necessarily 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



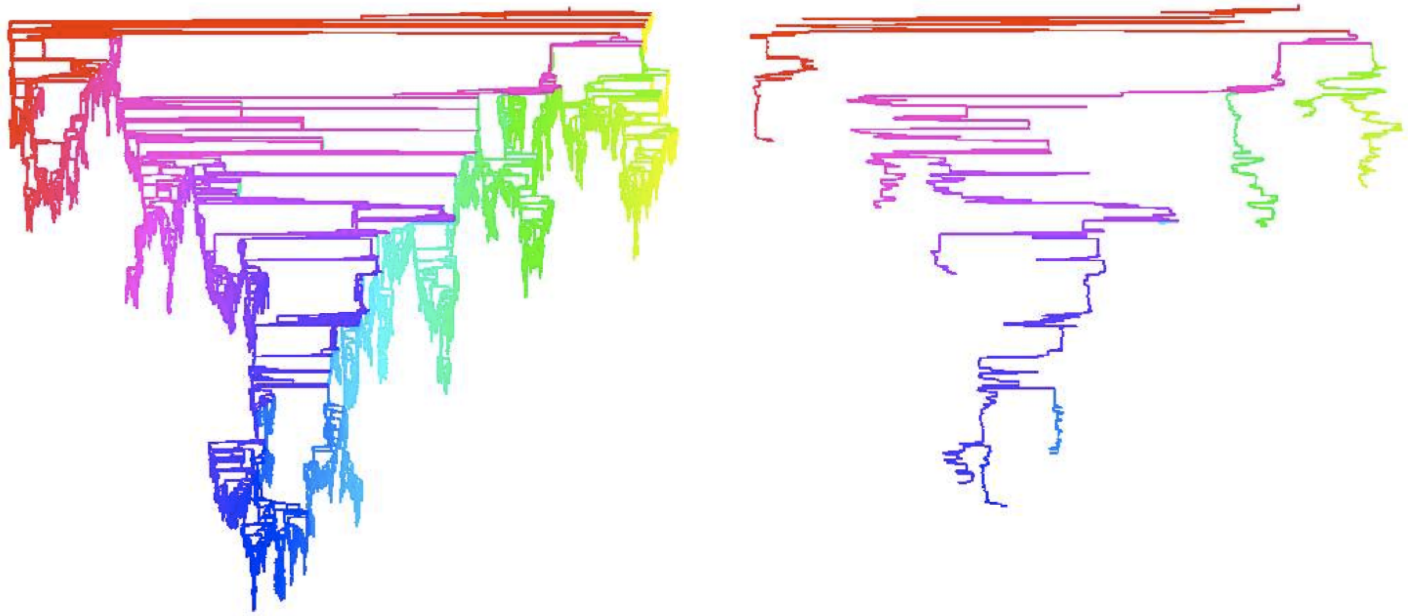
trade balance = *exports* − *imports*

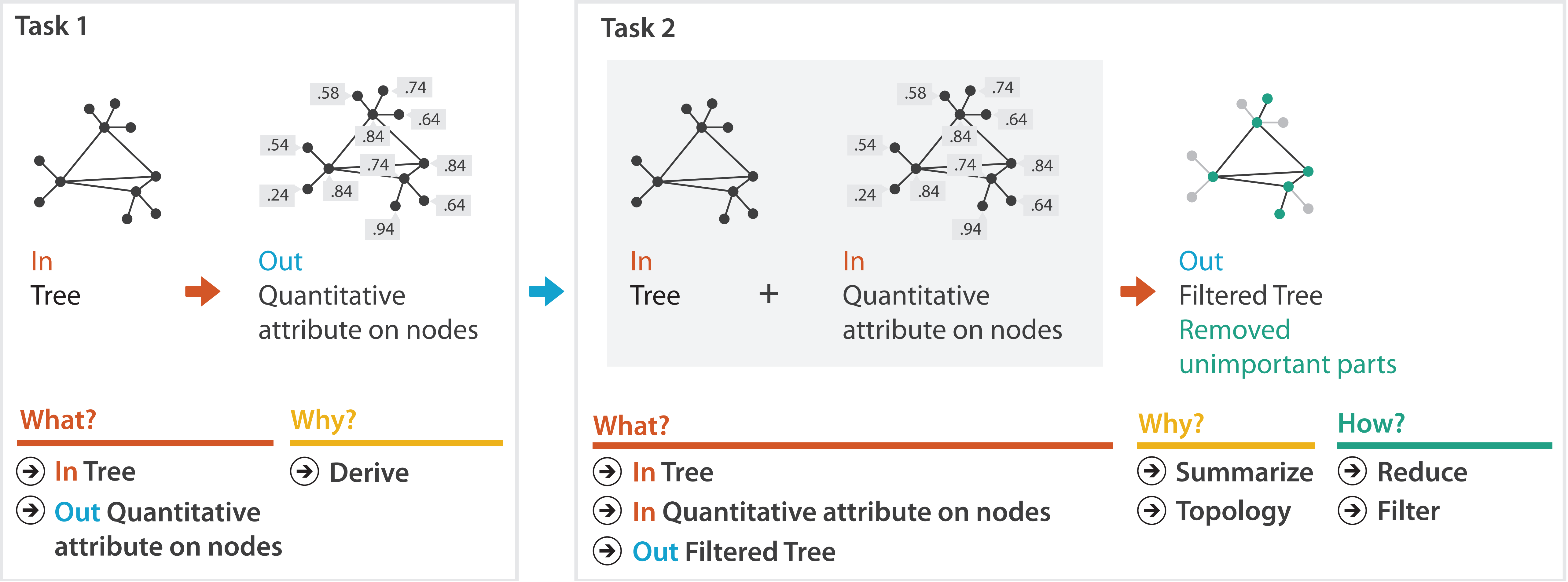
Derived Data

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.]

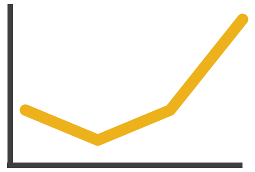




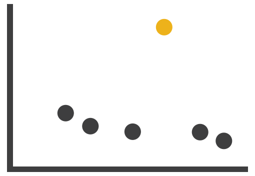
Why: Targets

➔ All Data

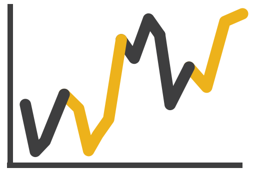
➔ Trends



➔ Outliers



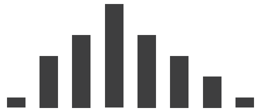
➔ Features



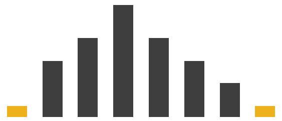
➔ Attributes

➔ One

➔ *Distribution*



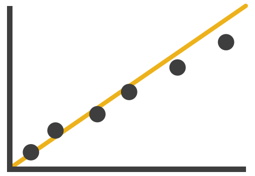
➔ *Extremes*



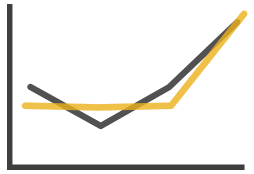
➔ Many

➔ *Dependency*

➔ *Correlation*

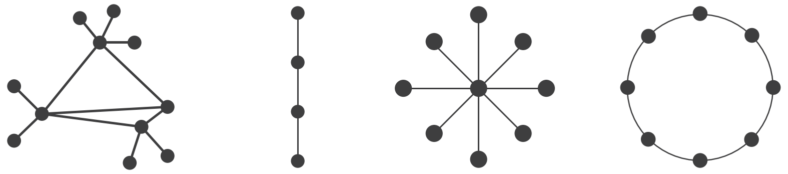


➔ *Similarity*

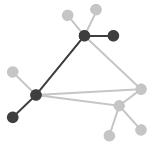


➔ Network Data

➔ Topology

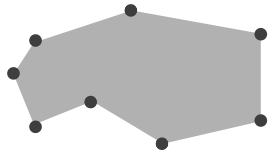


➔ *Paths*



➔ Spatial Data

➔ Shape



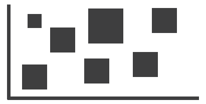
How?

Encode

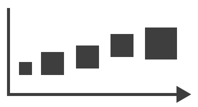
Arrange

→ Express

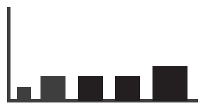
→ Separate



→ Order



→ Align



→ Use

Map

from categorical and ordered attributes

→ Color

→ *Hue*

→ *Saturation*

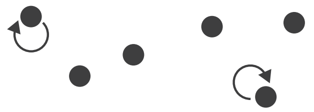
→ *Luminance*

→ Size, Angle, Curvature, ...

→ Shape

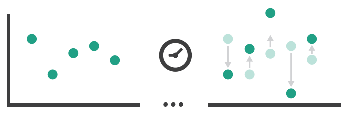
→ Motion

Direction, Rate, Frequency, ...

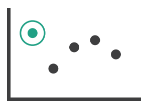


Manipulate

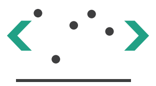
Change



Select

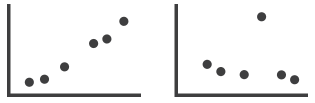


Navigate

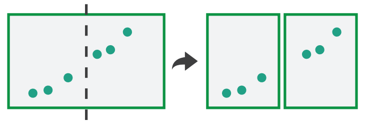


Facet

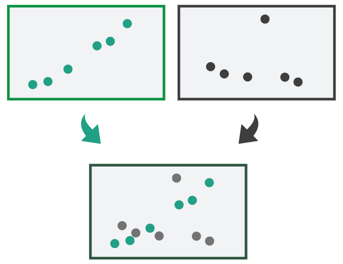
Juxtapose



Partition

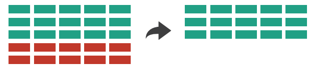


Superimpose

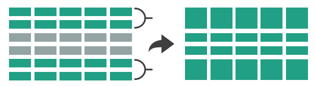


Reduce

Filter



Aggregate



Embed

What?

Why?

How?

Further reading

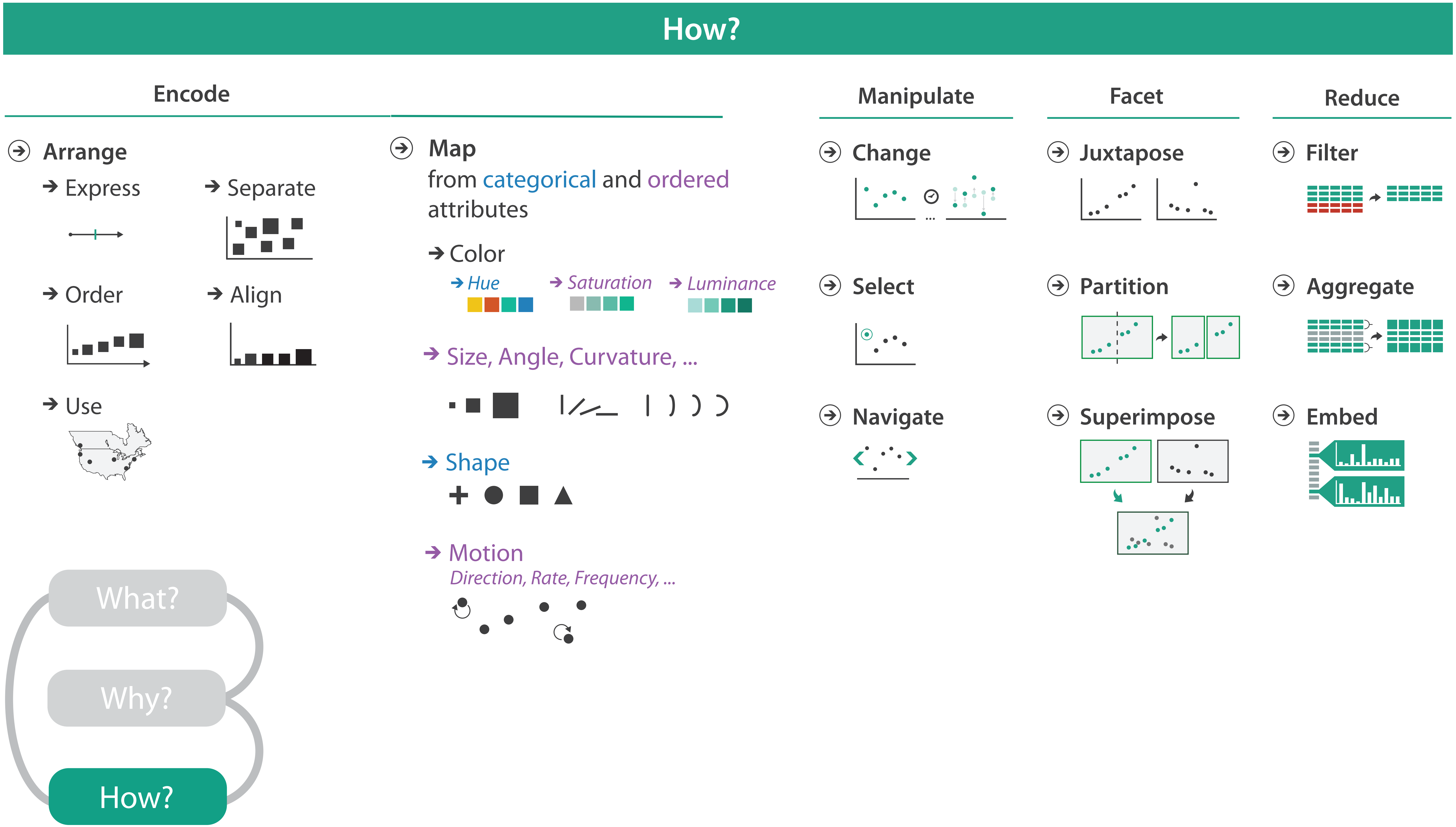
- Visualization Analysis and Design. Munzner. AK Peters Visualization Series, CRC Press, Nov 2014.
  - *Chap 1: What's Vis, and Why Do It?*
  - *Chap 2: What: Data Abstraction*
  - *Chap 3: Why: Task Abstraction*
- *A Multi-Level Typology of Abstract Visualization Tasks*. Brehmer and Munzner. IEEE Trans. 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.

Visualization Analysis & Design, Half-Day Tutorial

- Session 1
  - Analysis: What, Why, How
  - Marks and Channels
  - Arrange Tabular & Spatial Data
- Session 2
  - Arrange Networks and Trees
  - Map Color and Other Channels
  - Manipulate & Facet
  - Reduce: Filter, Aggregate

@tamaramunzner @tamara@vis.social

http://www.cs.ubc.ca/~tmm/talks.html#halfdaycourse23


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?

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, ...

What?

Why?

How?

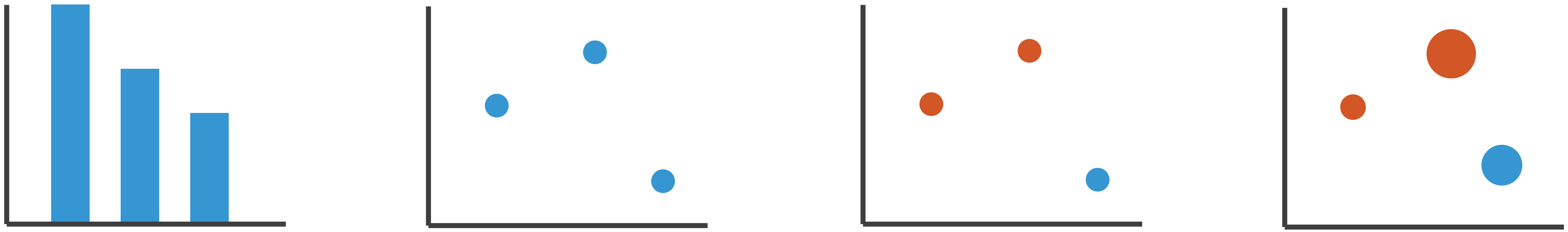
Manipulate
Change
Select
Navigate

Facet
Juxtapose
Partition
Superimpose

Reduce
Filter
Aggregate
Embed

Visual encoding

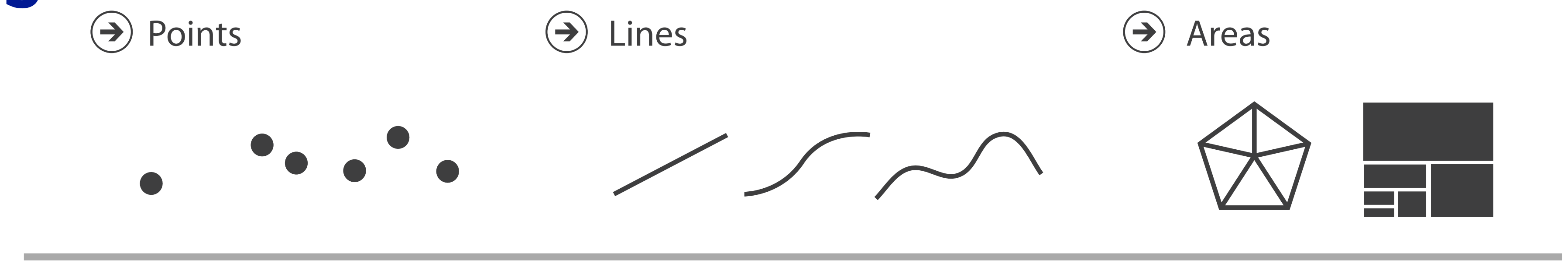
- analyze idiom structure



Definitions: Marks and channels

Definitions: Marks and channels

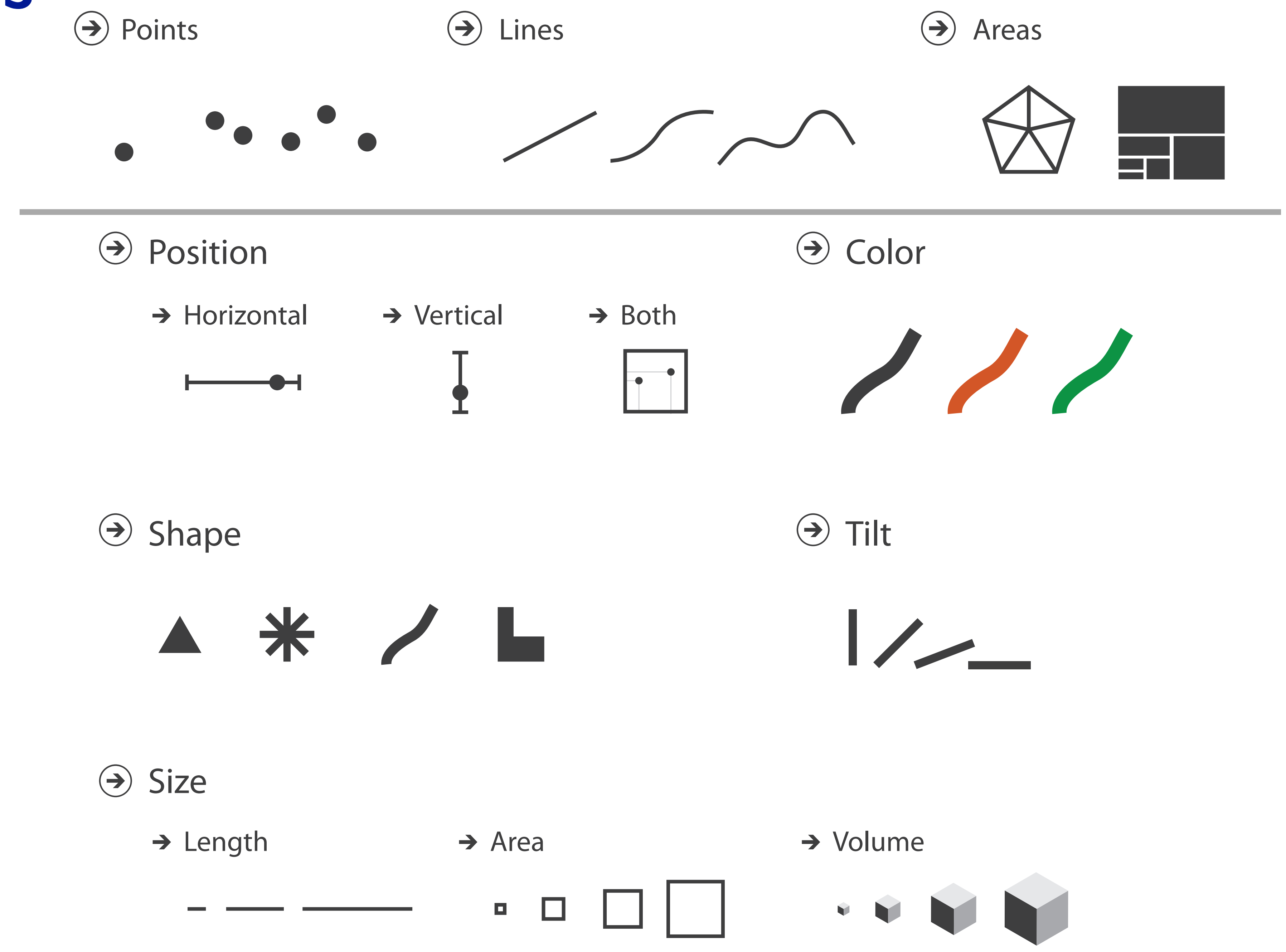
- marks
  - geometric primitives



Definitions: Marks and channels

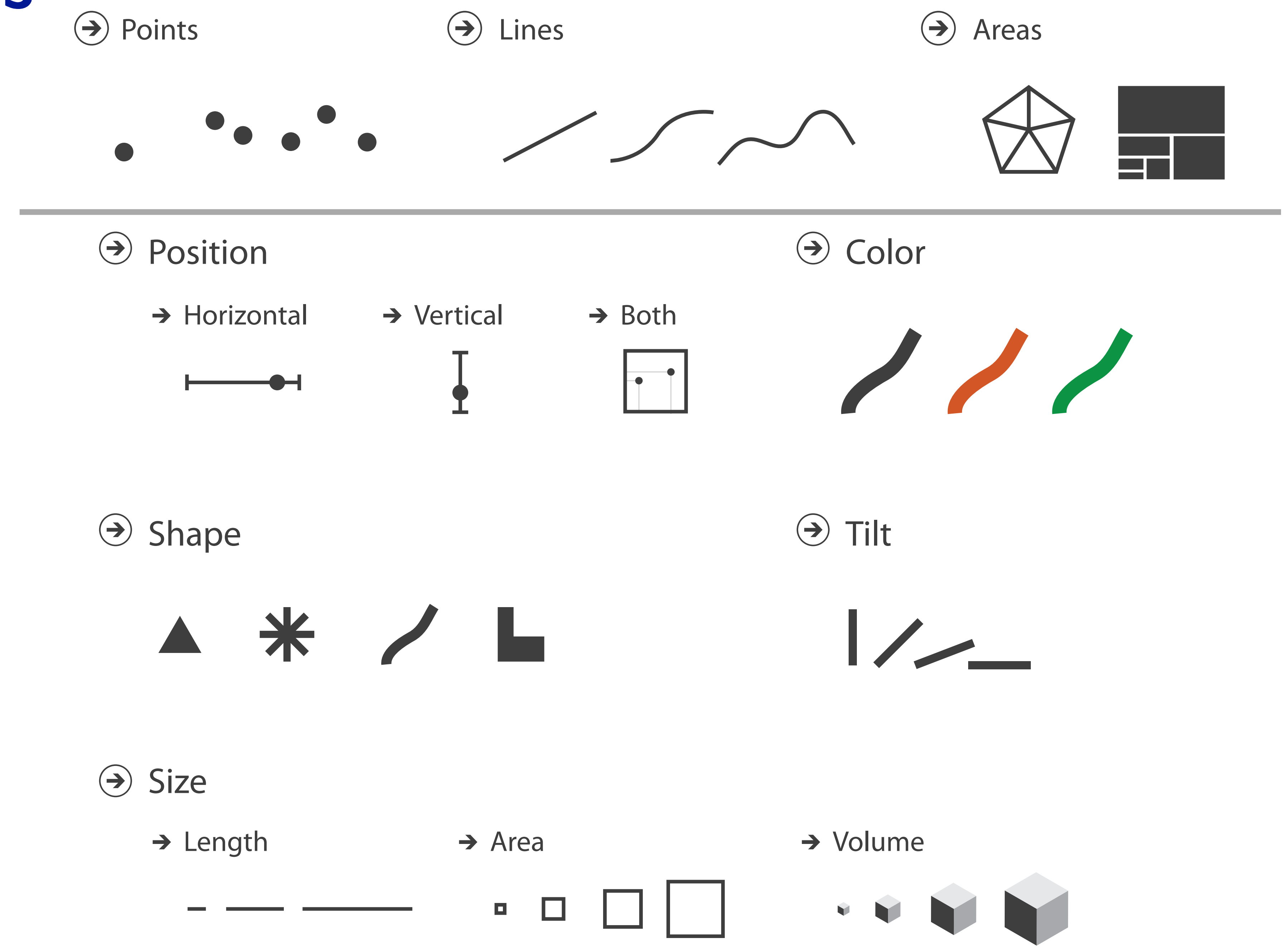
- marks
  - geometric primitives

- channels
  - control appearance of marks



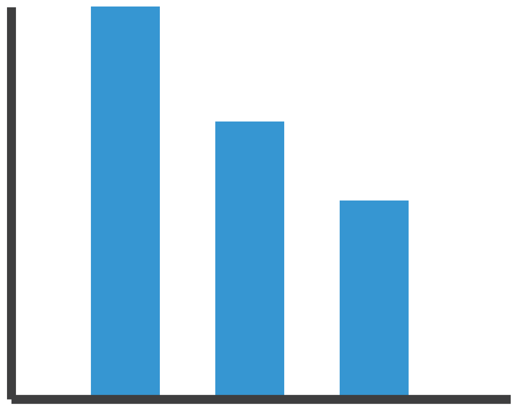
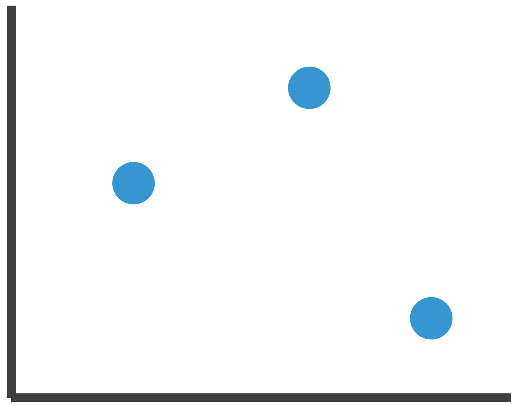
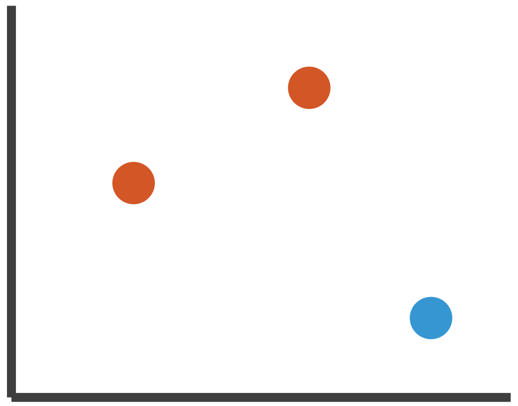
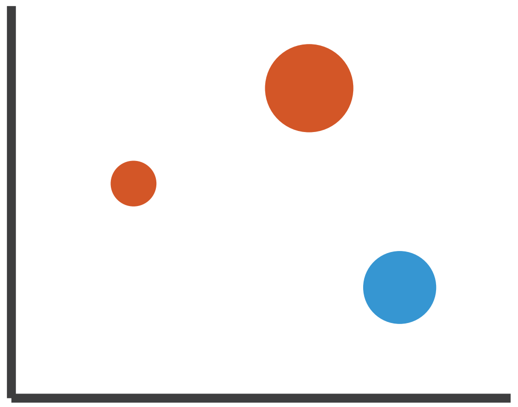
Definitions: Marks and channels

- marks
  - geometric primitives
- channels
  - control appearance of marks
- channel properties differ
  - type & amount of information that can be conveyed to human perceptual system



Visual encoding

- analyze idiom structure as combination of marks and channels

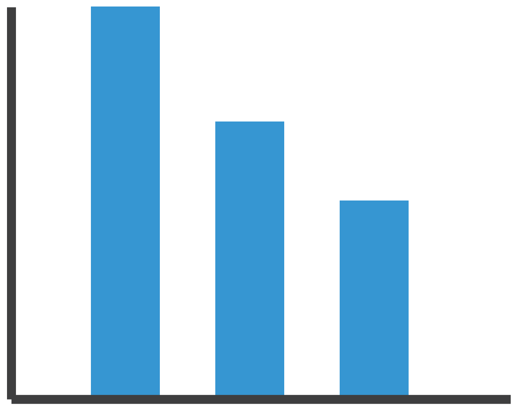





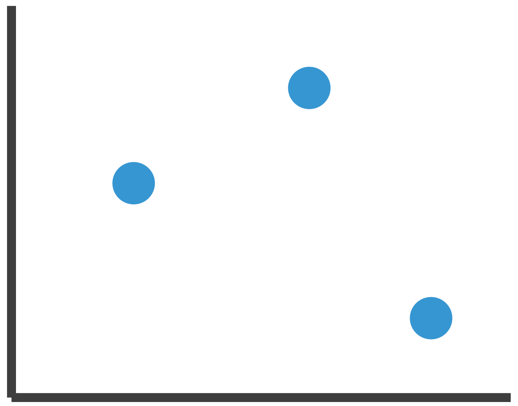
1:
vertical position

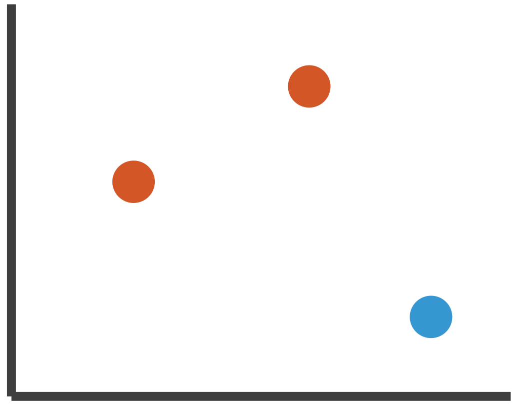
mark: line

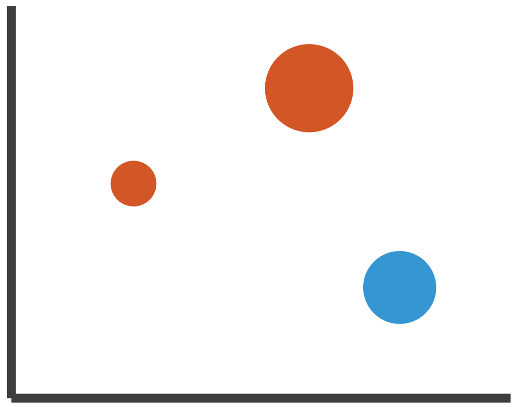
Visual encoding

- analyze idiom structure as combination of marks and channels









1:
vertical position

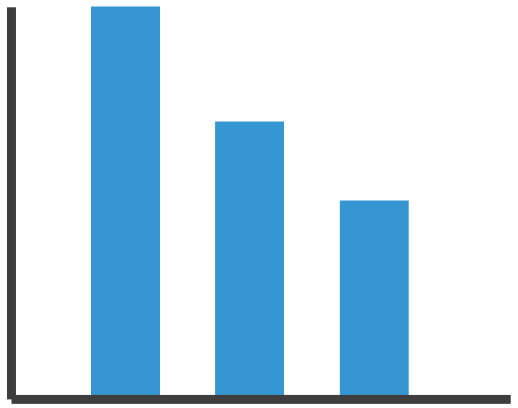
2:
vertical position
horizontal position

mark: line

mark: point

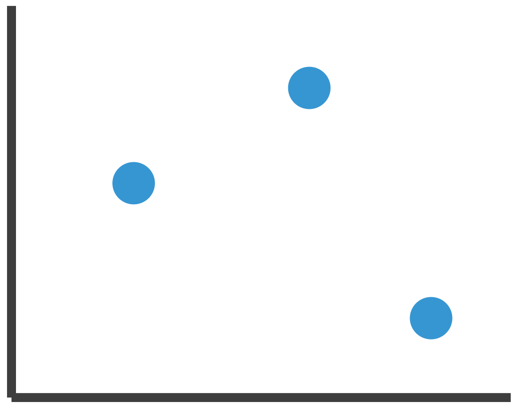
Visual encoding

- analyze idiom structure as combination of marks and channels



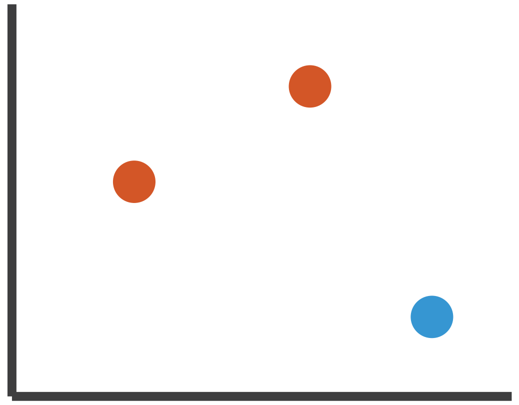
1:
vertical position

mark: line



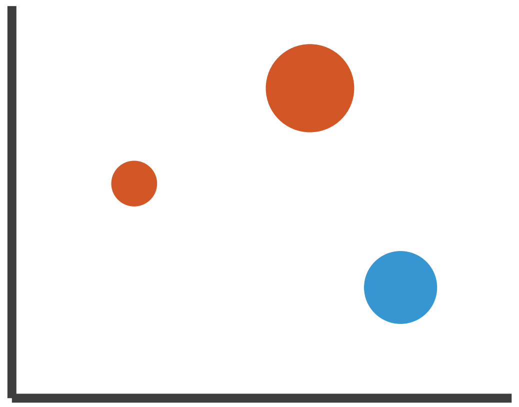
2:
vertical position
horizontal position

mark: point



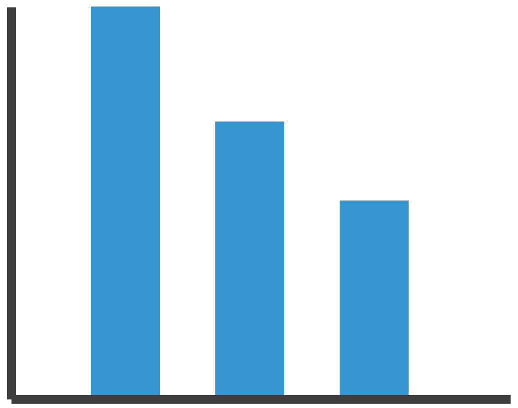
3:
vertical position
horizontal position
color hue

mark: point



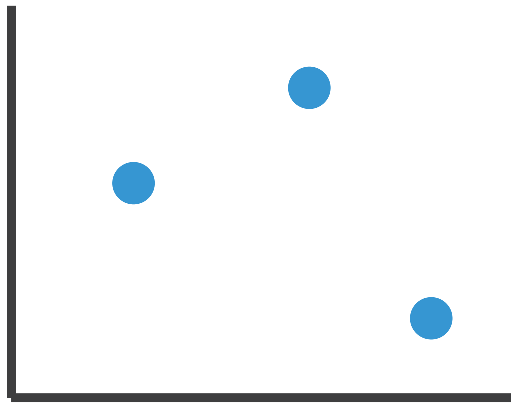
Visual encoding

- analyze idiom structure as combination of marks and channels



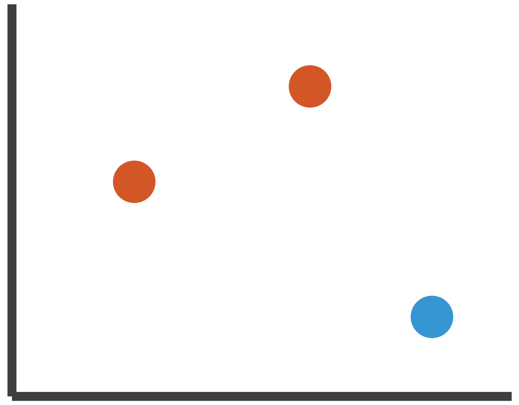
1:
vertical position

mark: line



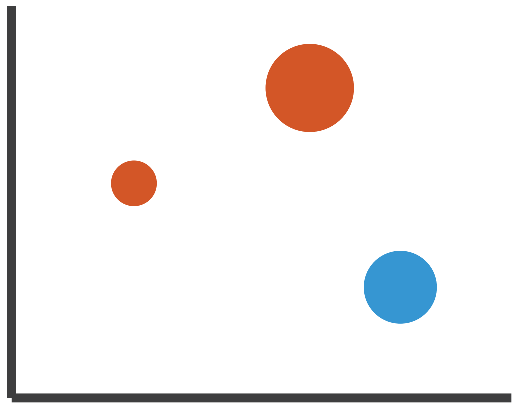
2:
vertical position
horizontal position

mark: point



3:
vertical position
horizontal position
color hue

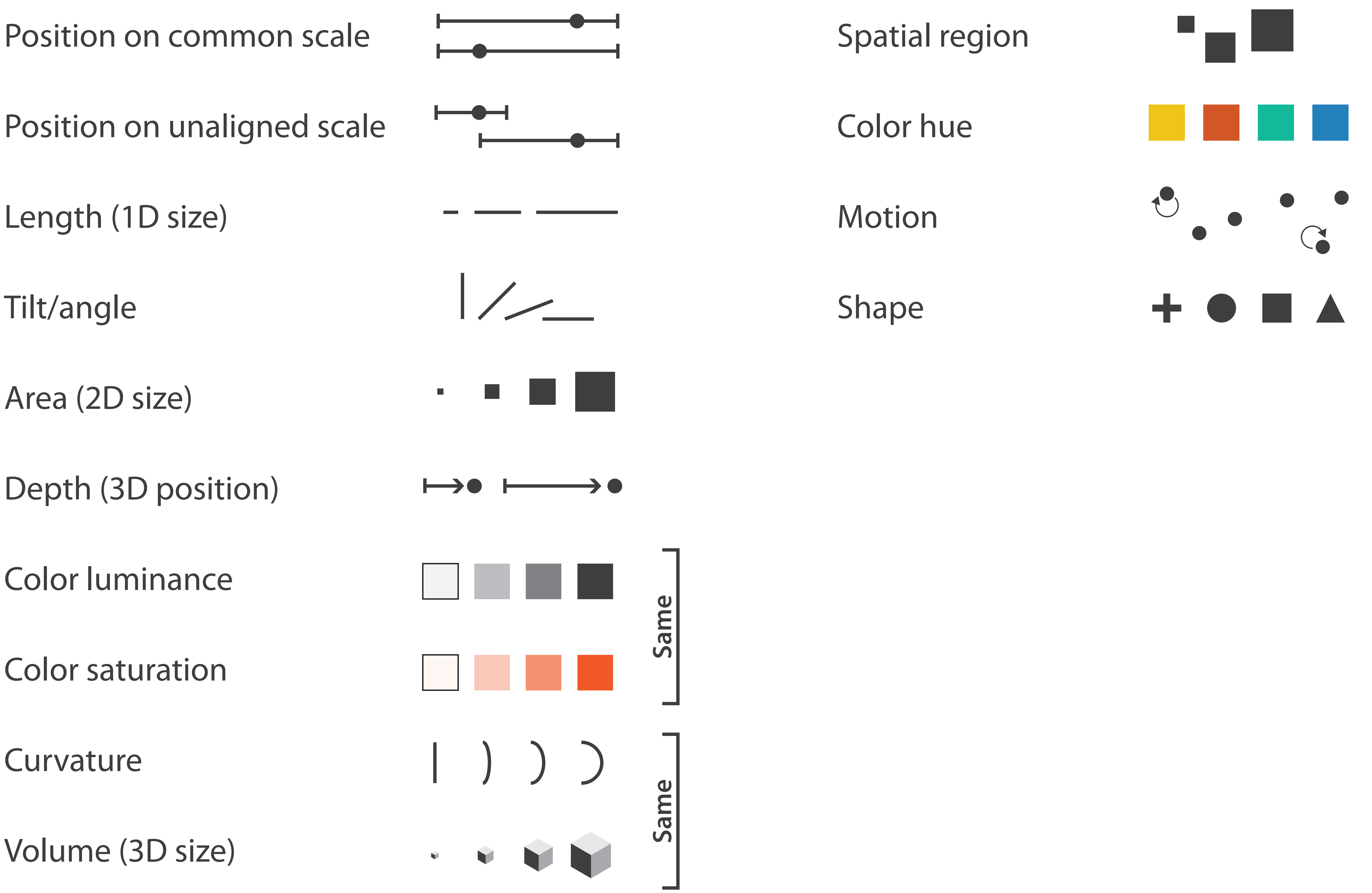
mark: point



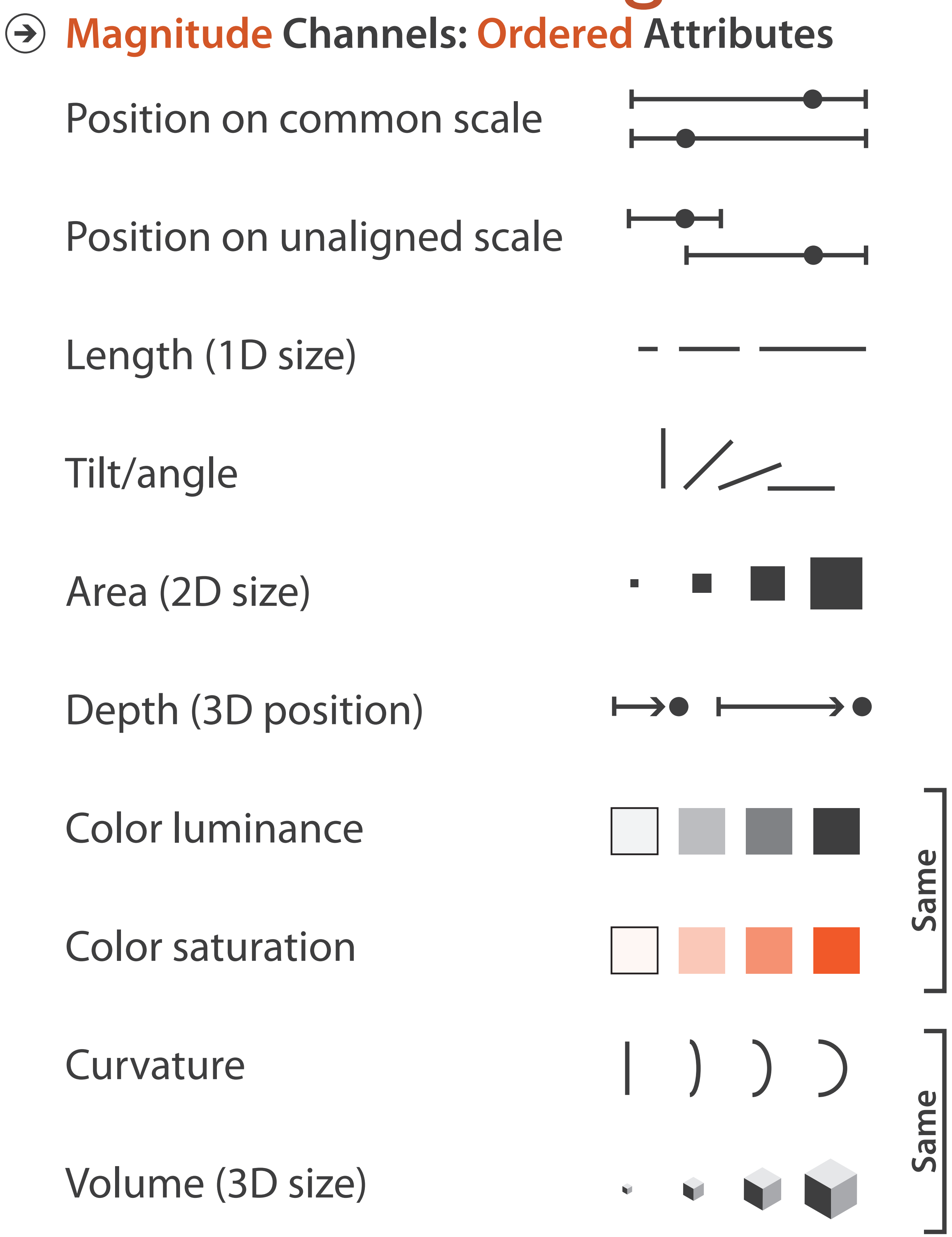
4:
vertical position
horizontal position
color hue
size (area)

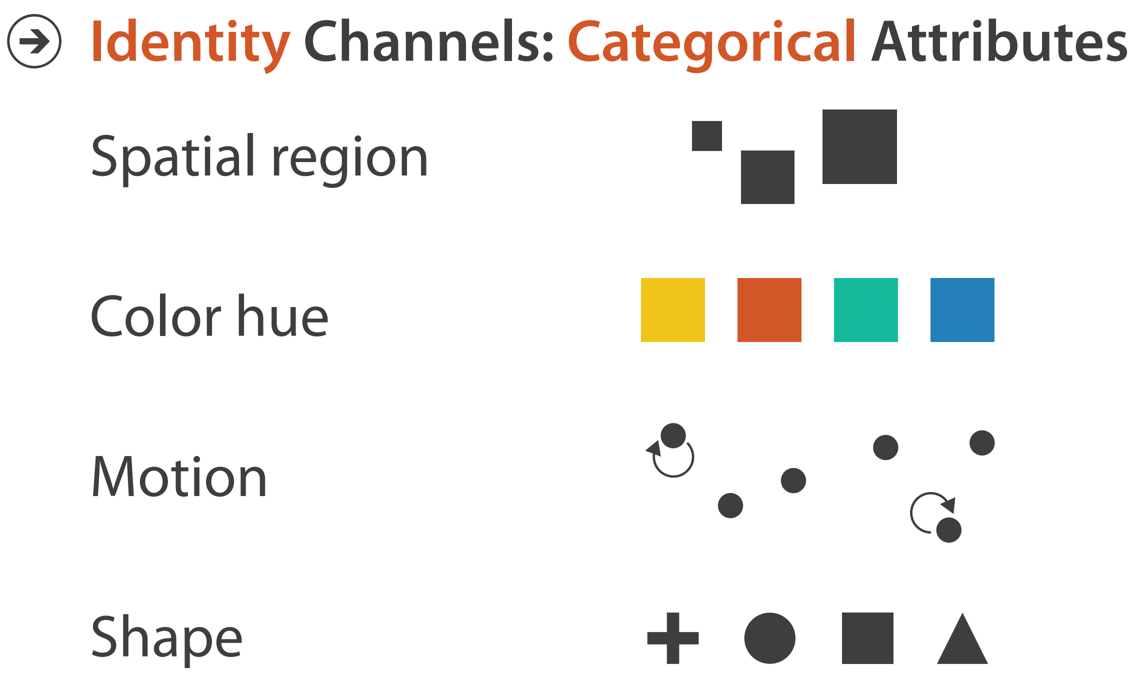
mark: point

Channels: Rankings



Channels: Rankings



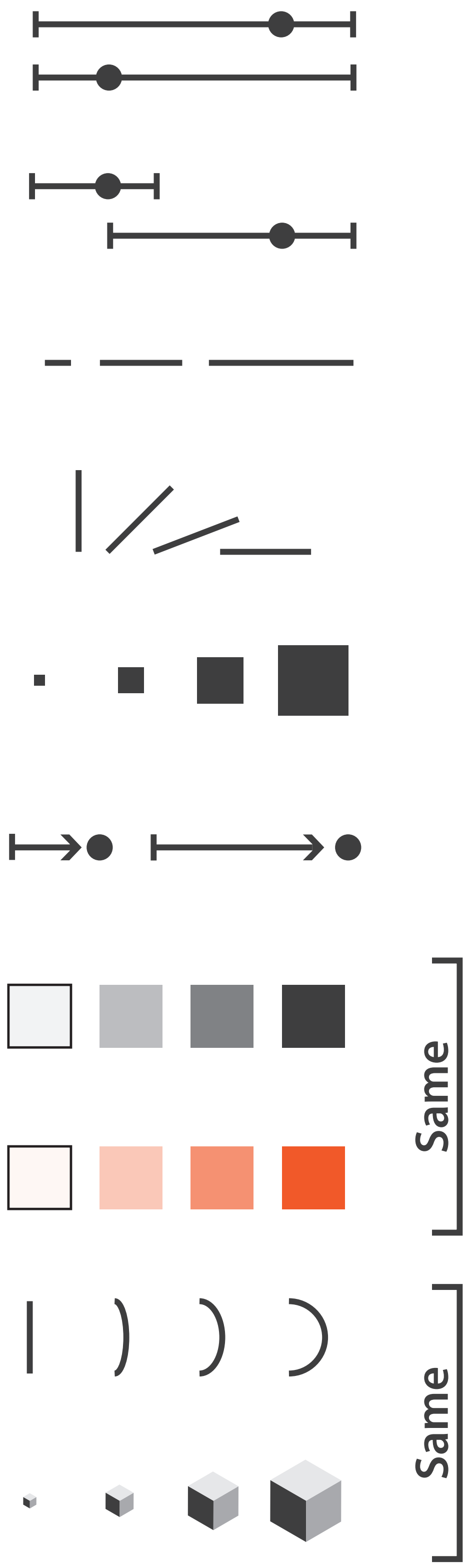


- expressiveness
  - match channel and data characteristics

Channels: Rankings

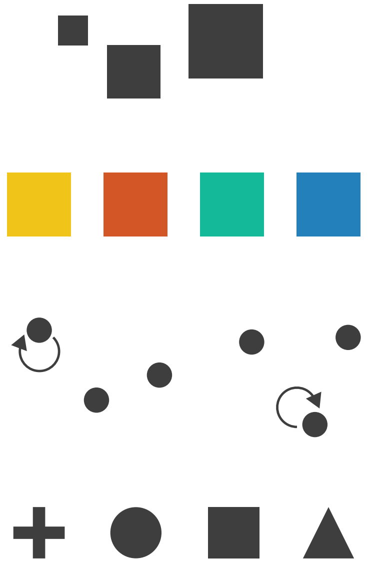
Magnitude Channels: Ordered Attributes

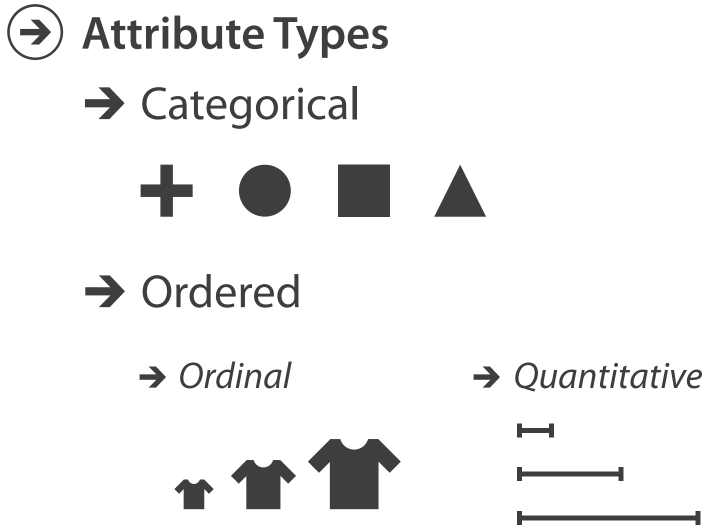
- Position on common scale
- Position on unaligned scale
- Length (1D size)
- Tilt/angle
- Area (2D size)
- Depth (3D position)
- Color luminance
- Color saturation
- Curvature
- Volume (3D size)



Identity Channels: Categorical Attributes

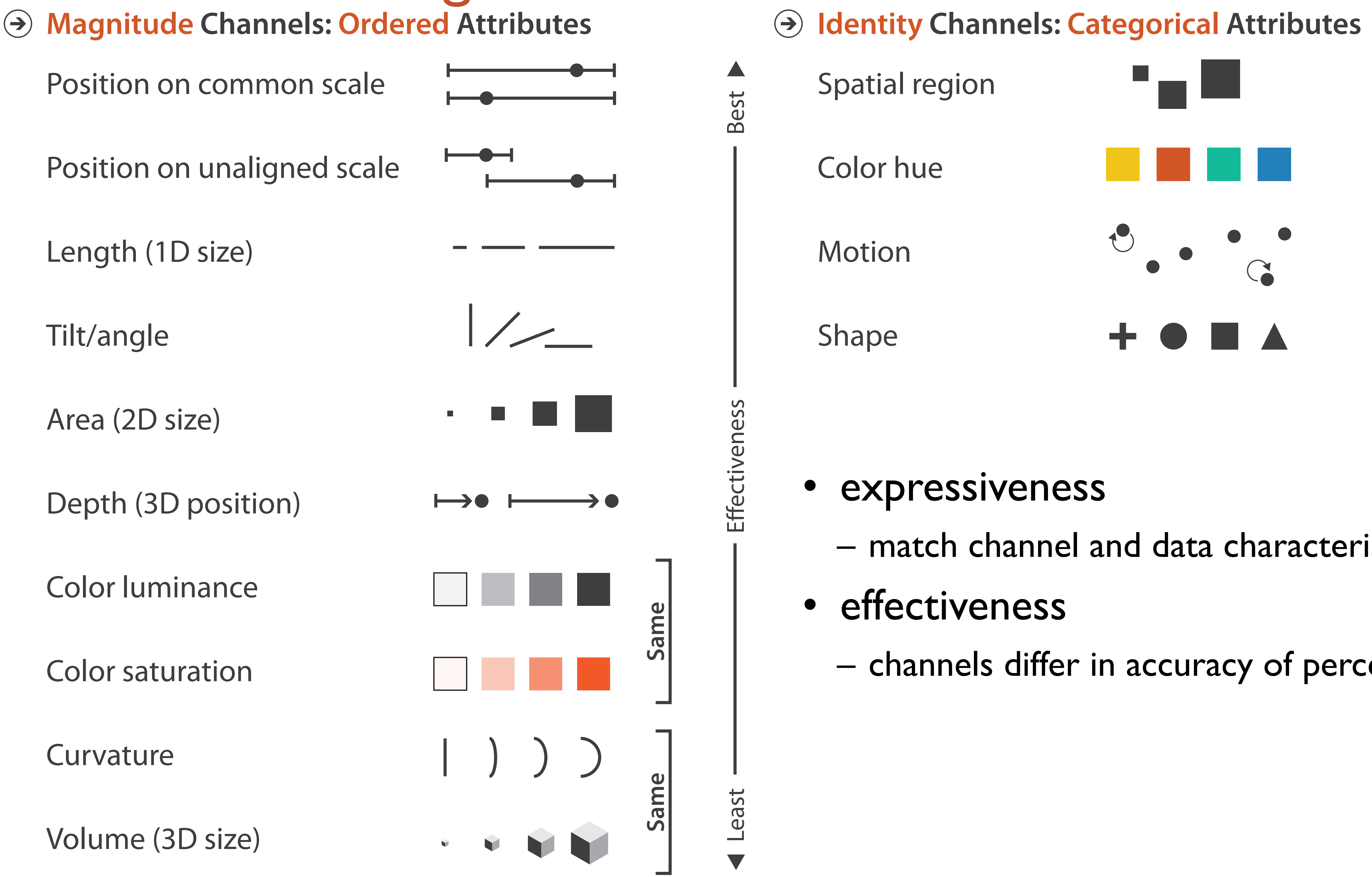
- Spatial region
- Color hue
- Motion
- Shape





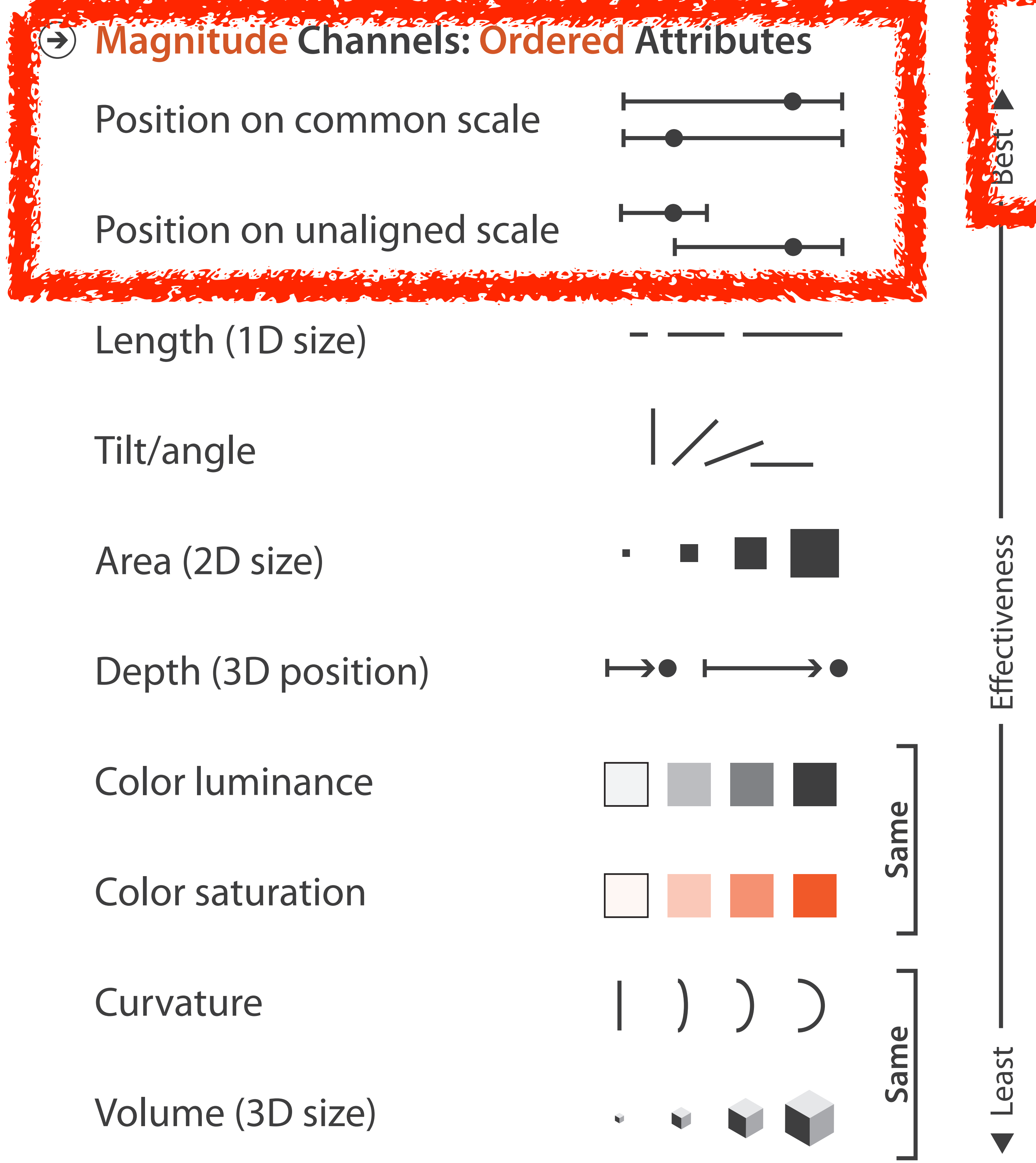
- expressiveness
  - match channel and data characteristics
  - magnitude for ordered
    - how much? which rank?
  - identity for categorical
    - what?

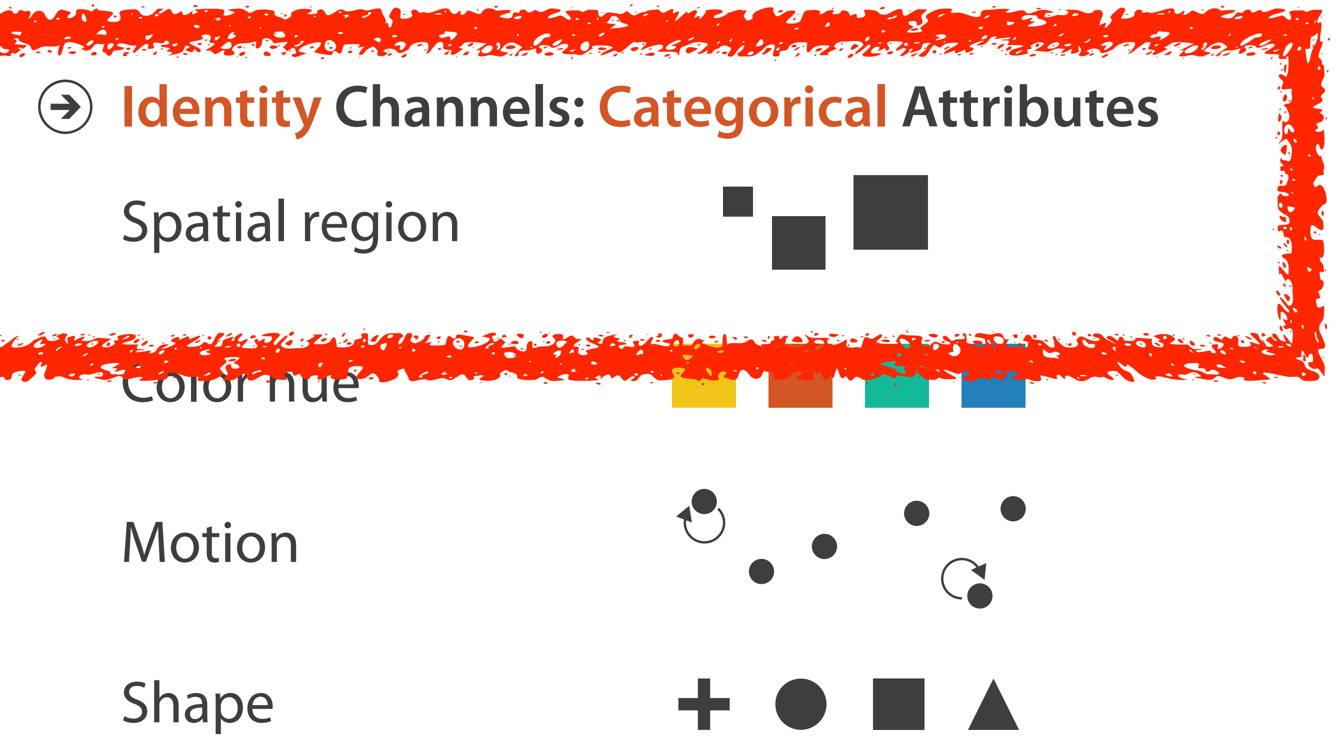
Channels: Rankings



- expressiveness
  - match channel and data characteristics
- effectiveness
  - channels differ in accuracy of perception

Channels: Rankings

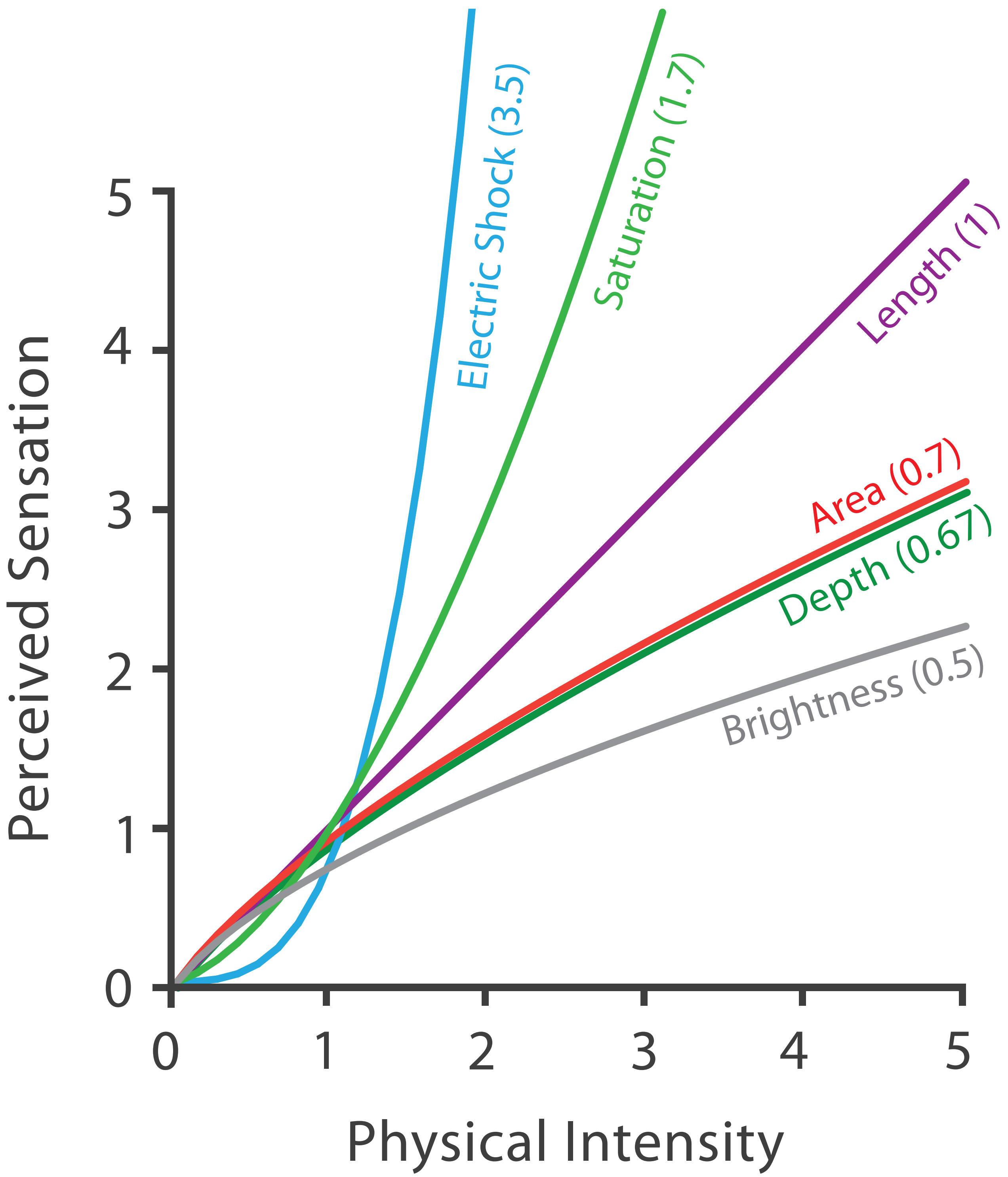




- expressiveness
  - match channel and data characteristics
- effectiveness
  - channels differ in accuracy of perception
  - spatial position ranks high for both

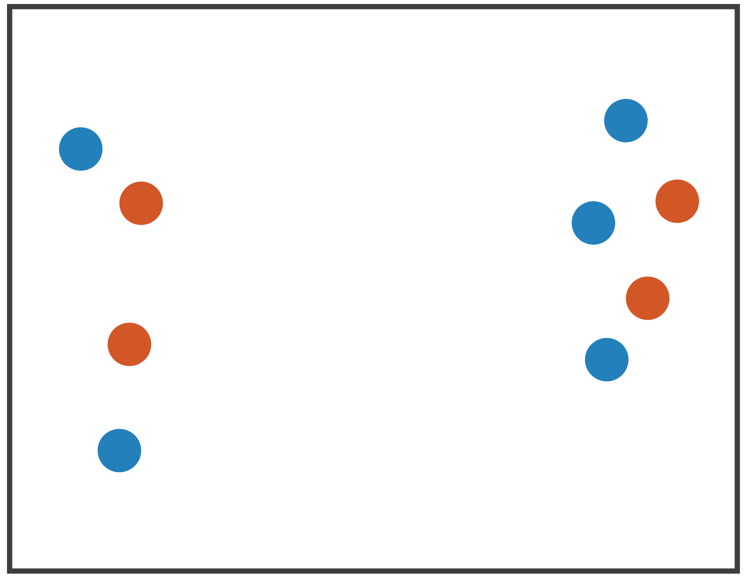
Accuracy: Fundamental Theory

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



Separability vs. Integrality

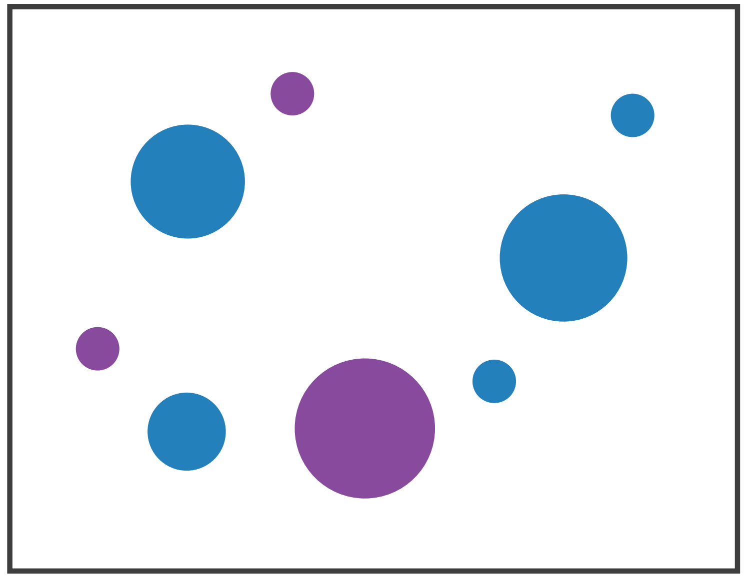
Position
+ Hue (Color)



Fully separable

2 groups each

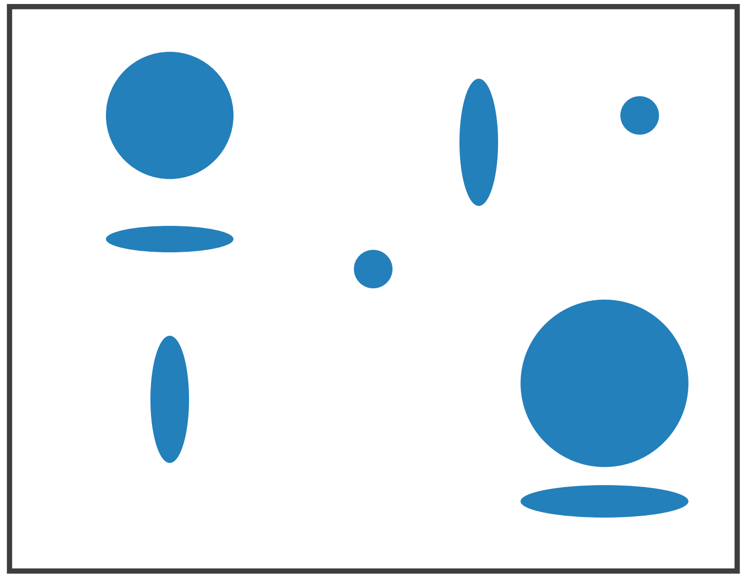
Size
+ Hue (Color)



Some interference

2 groups each

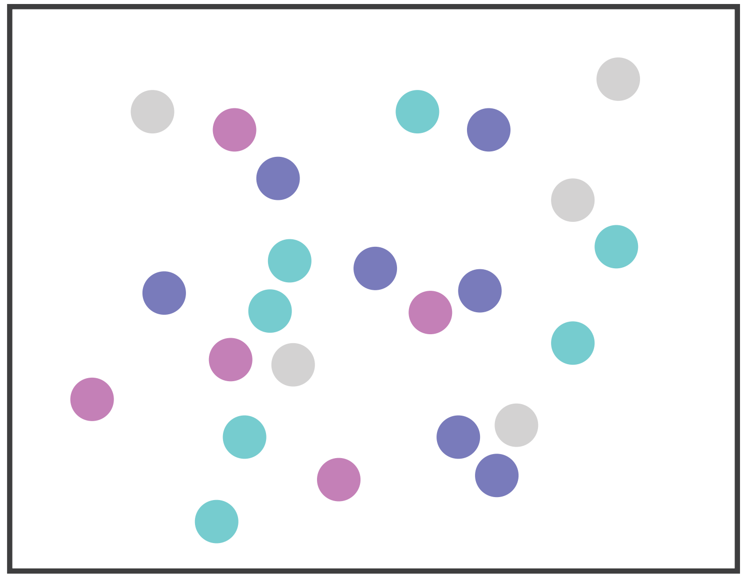
Width
+ Height



Some/significant interference

3 groups total: integral area

Red
+ Green



Major interference

4 groups total: integral hue

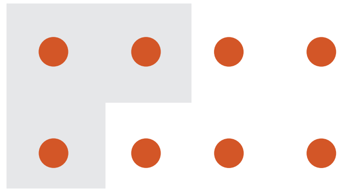
Grouping

- containment
- connection

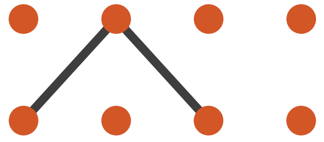
- proximity
  – same spatial region
- similarity
  – same values as other categorical channels

Marks as Links

Containment



Connection

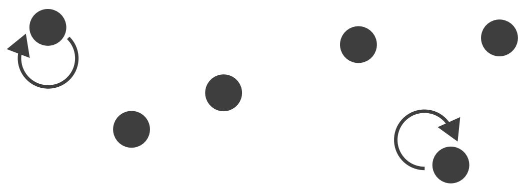


Identity Channels: Categorical Attributes

Spatial region

Color hue

Motion



Shape

Further reading

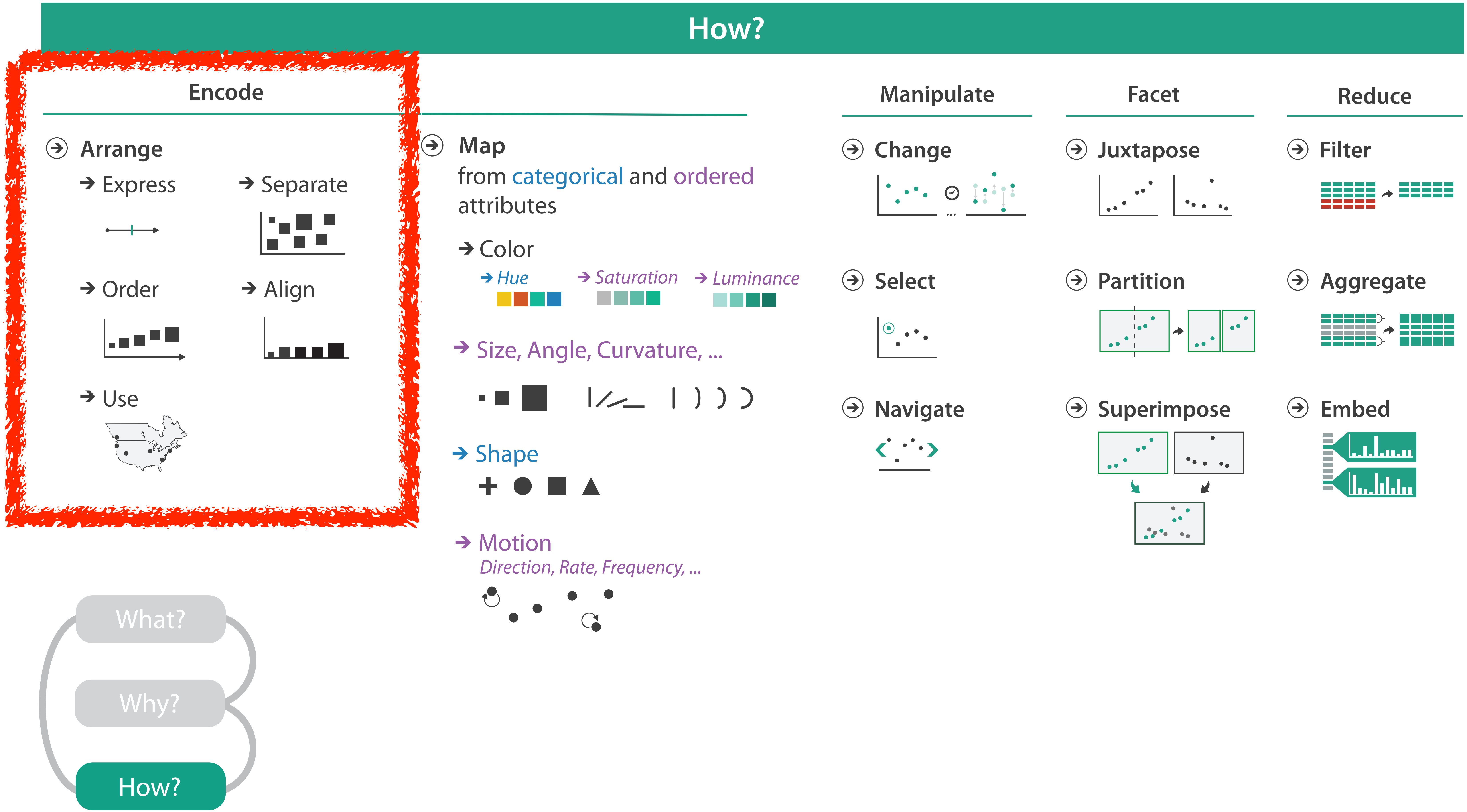
- Visualization Analysis and Design. Munzner. AK Peters Visualization Series, CRC Press, Nov 2014.
  - *Chap 5: Marks and Channels*
- *On the Theory of Scales of Measurement.* Stevens. Science 103:2684 (1946), 677–680.
- Psychophysics: Introduction to its Perceptual, Neural, and Social Prospects. Stevens. 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.

Visualization Analysis & Design, Half-Day Tutorial

- Session 1
  - Analysis: What, Why, How
  - Marks and Channels
  - Arrange Tabular & Spatial Data
- Session 2
  - Arrange Networks and Trees
  - Map Color and Other Channels
  - Manipulate & Facet
  - Reduce: Filter, Aggregate

@tamaramunzner @tamara@vis.social

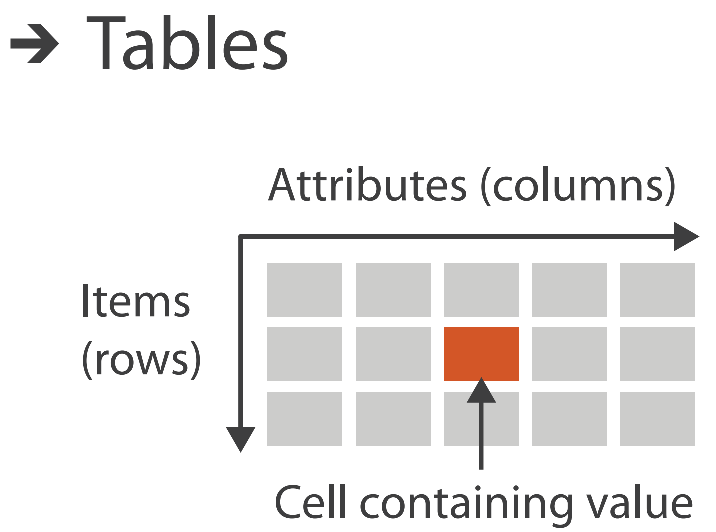
http://www.cs.ubc.ca/~tmm/talks.html#halfdaycourse23

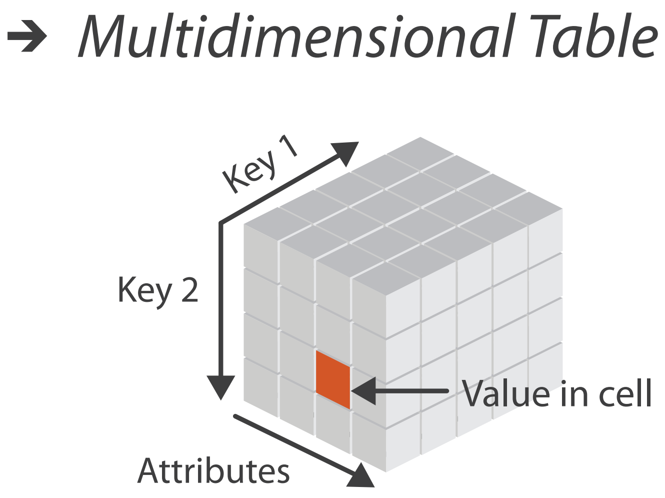


How?
Encode
Arrange
Express
Separate
Order
Align
Use
Map
from categorical and ordered attributes
Color
Hue
Saturation
Luminance
Size, Angle, Curvature, ...
Shape
Motion
Direction, Rate, Frequency, ...
Manipulate
Change
Select
Navigate
Facet
Juxtapose
Partition
Superimpose
Reduce
Filter
Aggregate
Embed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

Keys and values

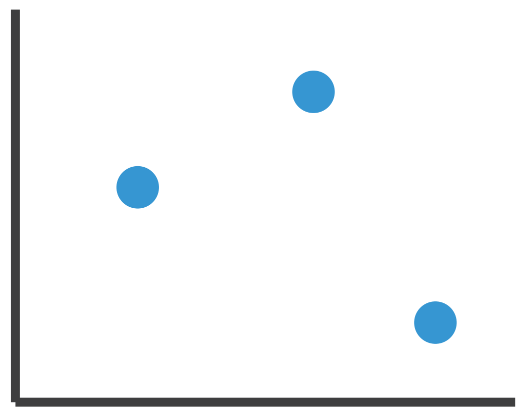
- key
  - independent attribute
  - used as unique index to look up items
  - simple tables: 1 key
  - multidimensional tables: multiple keys
- value
  - dependent attribute, value of cell
- classify arrangements by key count
  - 0, 1, 2, many...

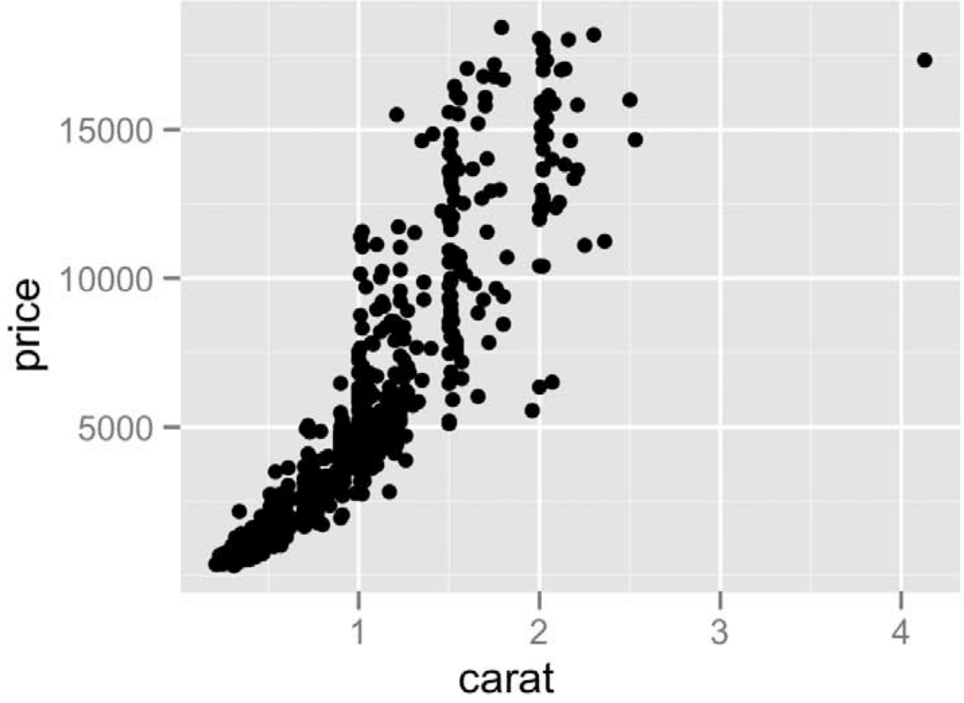


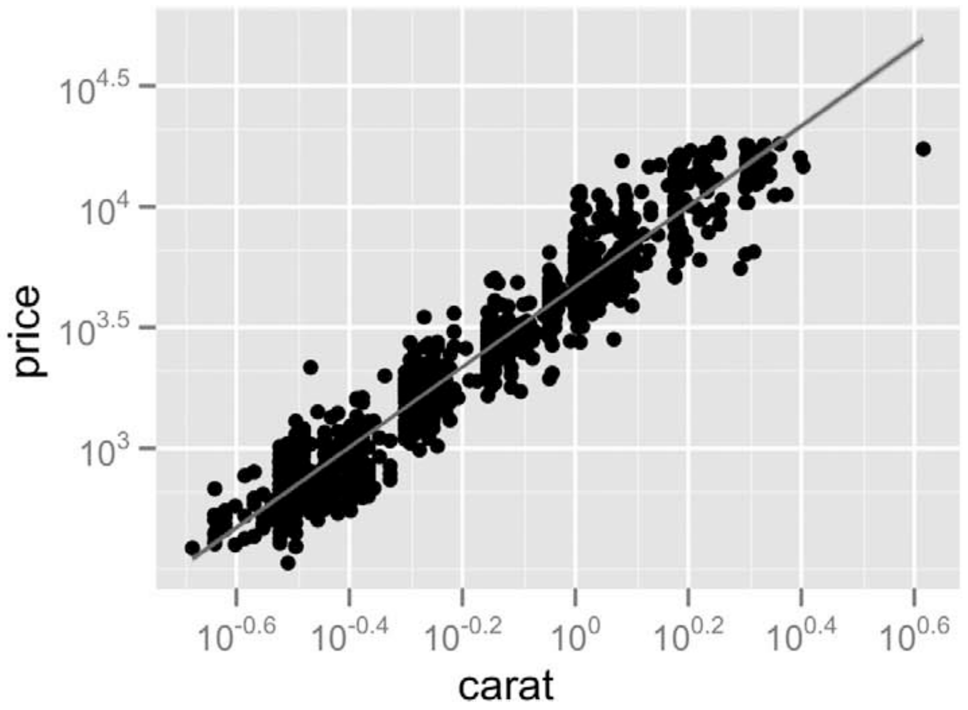


Idiom: **scatterplot**

- ***express*** values
  - quantitative attributes
- no keys, only values
  - data
    - 2 quant attribs
  - mark: points
  - channels
    - horiz + vert position
  - tasks
    - find trends, outliers, distribution, correlation, clusters
  - scalability
    - hundreds of items



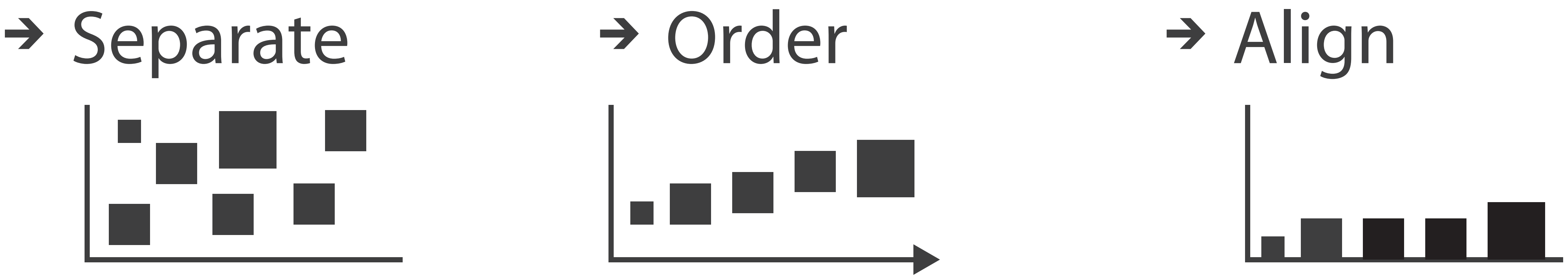




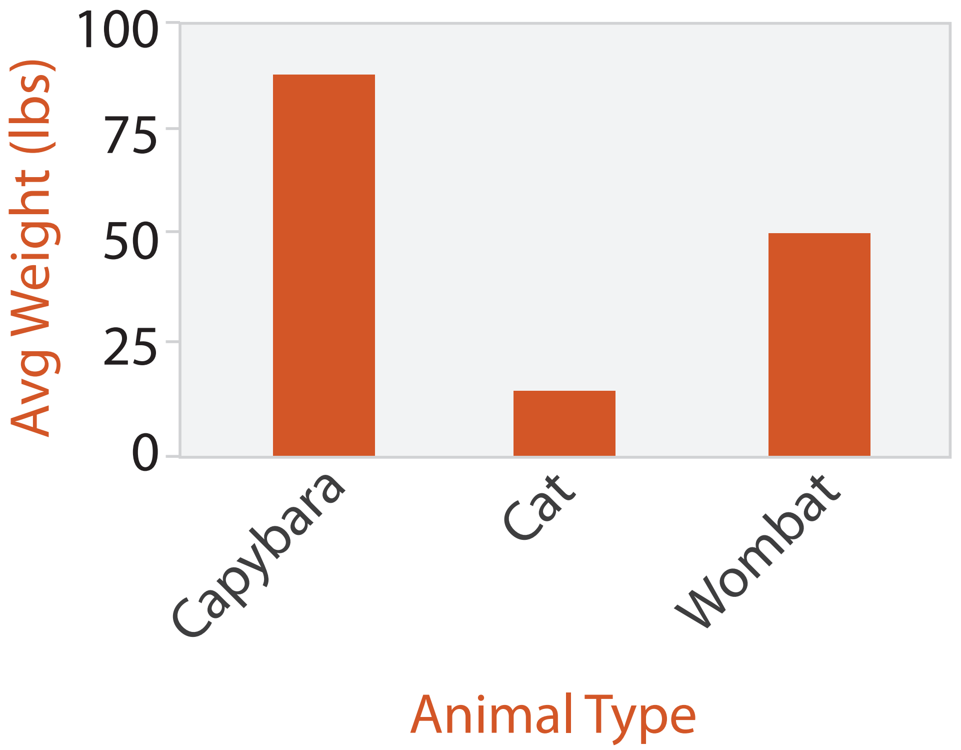
[A layered grammar of graphics. Wickham. Journ. Computational and Graphical Statistics 19:1 (2010), 3–28.]

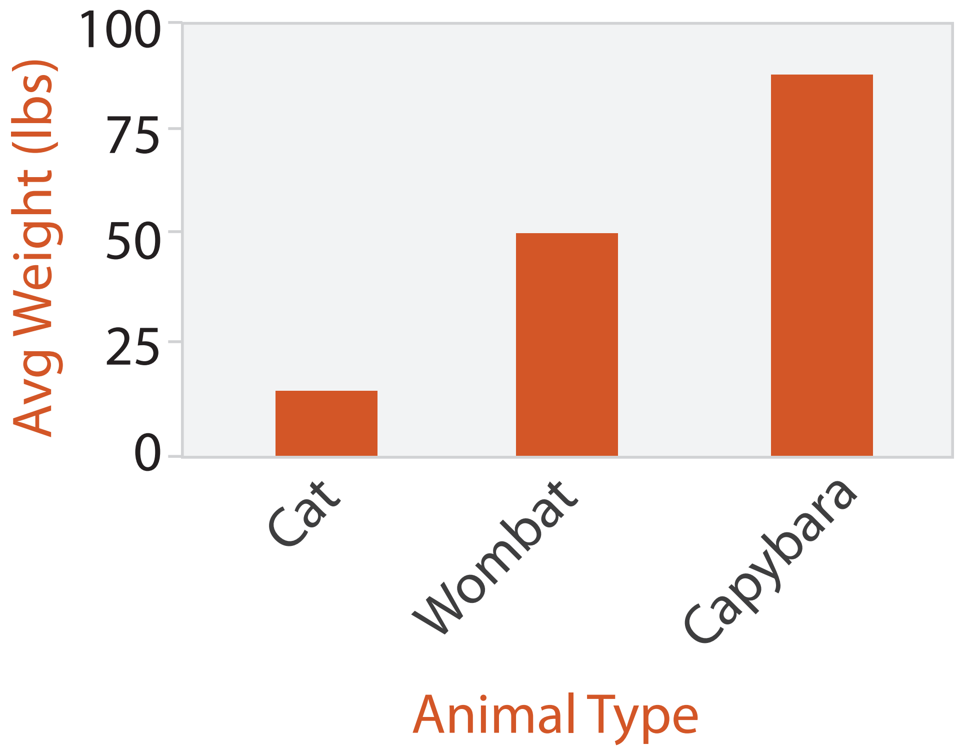
Some keys: Categorical regions

- regions: contiguous bounded areas distinct from each other
  - using space to **separate** (proximity)
  - following expressiveness principle for categorical attributes
- use ordered attribute to **order** and **align** regions



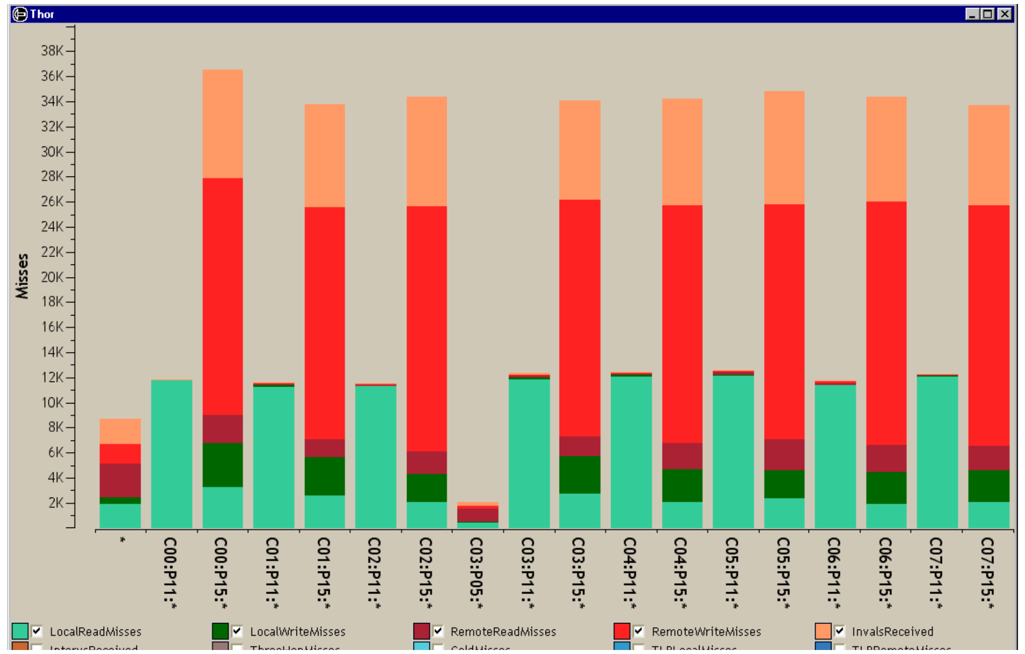
Idiom: **bar chart**





- one key, one value
  - data
    - 1 categ attrib, 1 quant attrib
  - mark: lines
  - channels
    - length to express quant value
    - spatial regions: one per mark
      - separated horizontally, aligned vertically
      - ordered by quant attrib
        - » by label (alphabetical), by length attrib (data-driven)
  - task
    - compare, lookup values
  - scalability
    - dozens to hundreds of levels for key attrib

Idiom: **stacked bar chart**



- one more key
  - data
    - 2 categ attrib, 1 quant attrib
  - mark: vertical stack of line marks
    - ***glyph***: composite object, internal structure from multiple marks
  - channels
    - length and color hue
    - spatial regions: one per glyph
      - aligned: full glyph, lowest bar component
      - unaligned: other bar components
  - task
    - part-to-whole relationship
  - scalability
    - several to one dozen levels for stacked attrib

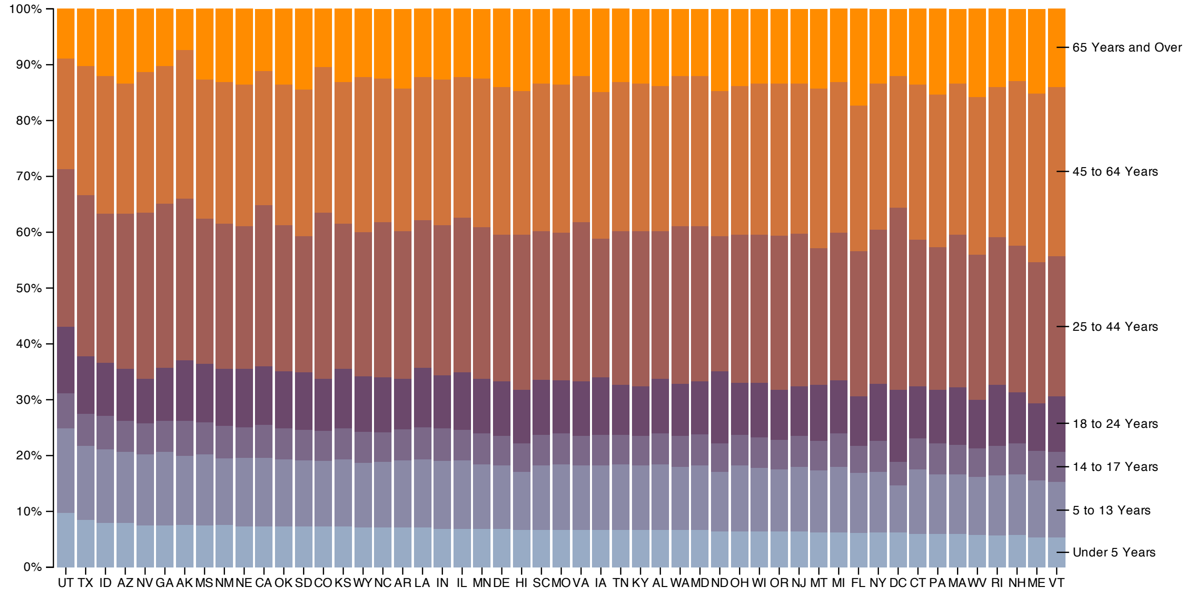
[Using Visualization to Understand the Behavior of Computer Systems. Bosch. Ph.D. thesis, Stanford Computer Science, 2001.]

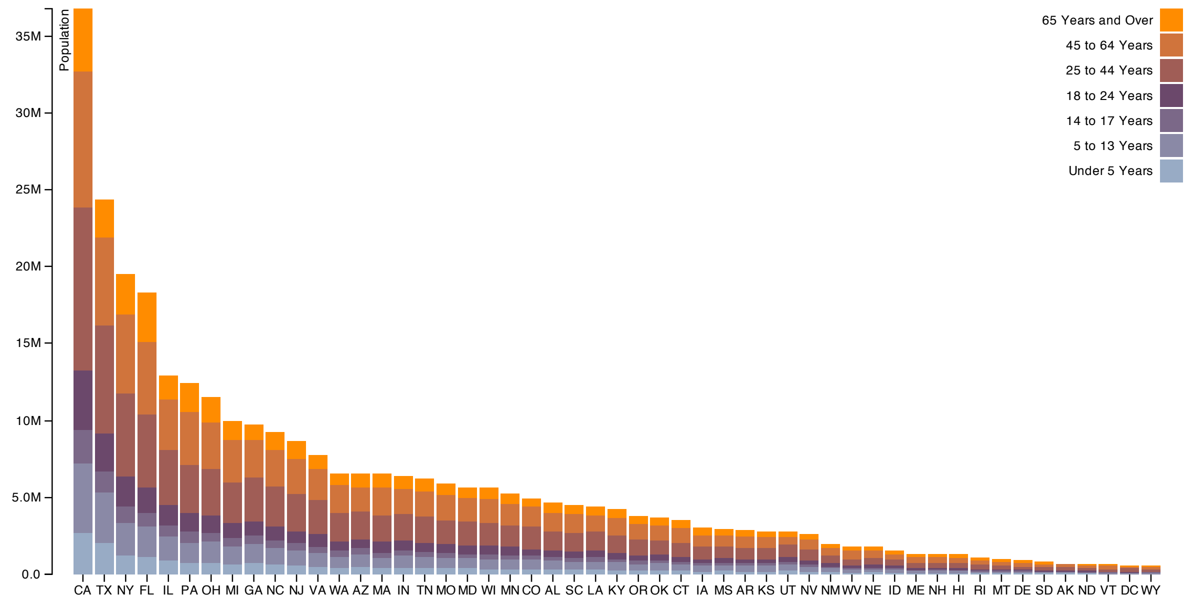
Idioms: **normalized stacked bar chart**

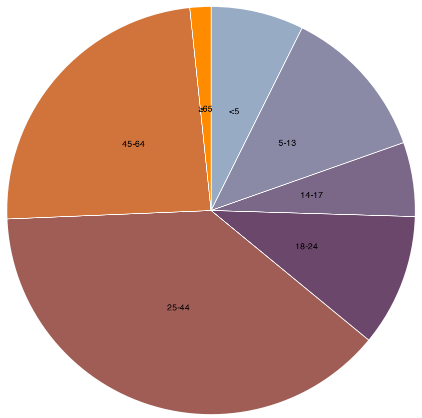
- task
  - part-to-whole judgements

- normalized stacked bar chart
  - stacked bar chart, normalized to full vert height
  - single stacked bar equivalent to full pie
    - high information density: requires narrow rectangle

- pie chart
  - information density: requires large circle





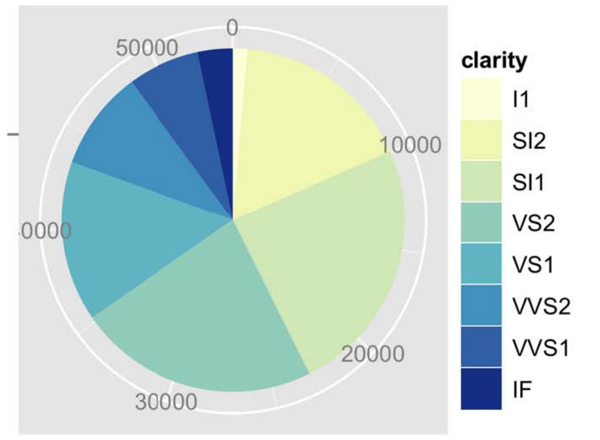


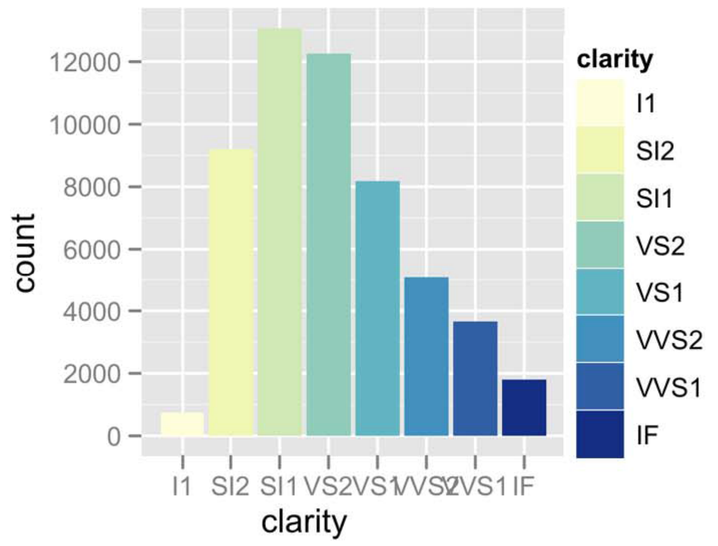
http://bl.ocks.org/mbostock/3887235,
http://bl.ocks.org/mbostock/3886208,
http://bl.ocks.org/mbostock/3886394.

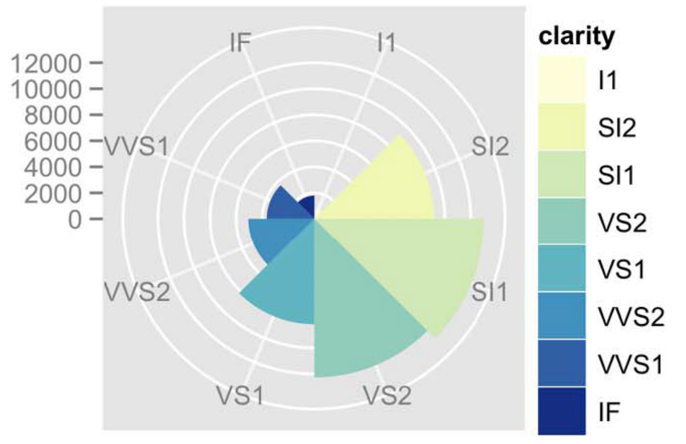
Idioms: **pie chart, coxcomb chart**

- pie chart
  - area marks with angle channel
  - accuracy: angle/area/arclength less accurate than line length
- data
  - 1 categ key attrib, 1 quant value attrib
- task
  - part-to-whole judgements

- coxcomb chart
  - more direct analog to bar charts
  - line marks, radial layout



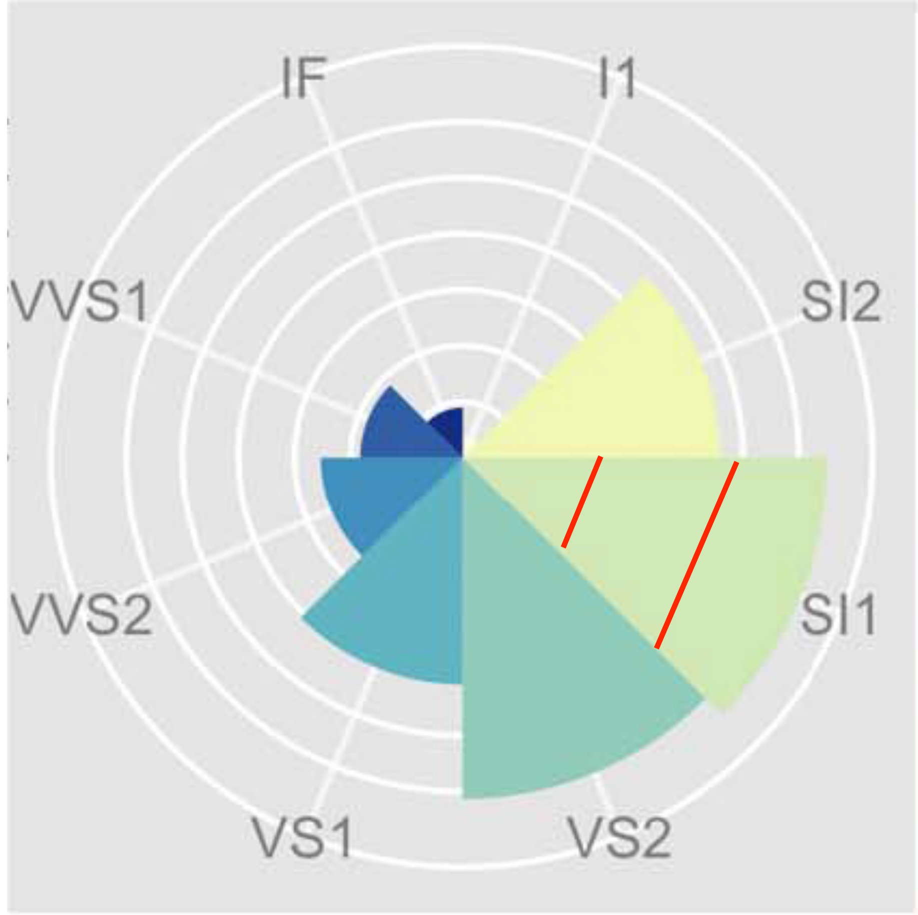




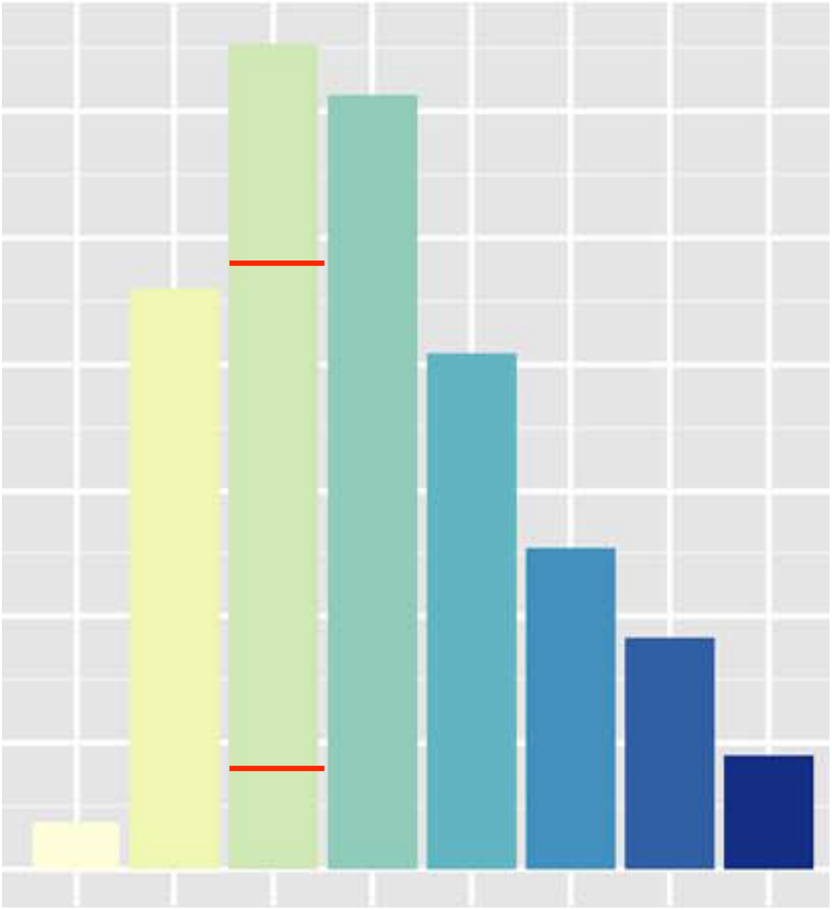
[A layered grammar of graphics. Wickham. Journ. Computational and Graphical Statistics 19:1 (2010), 3–28.]

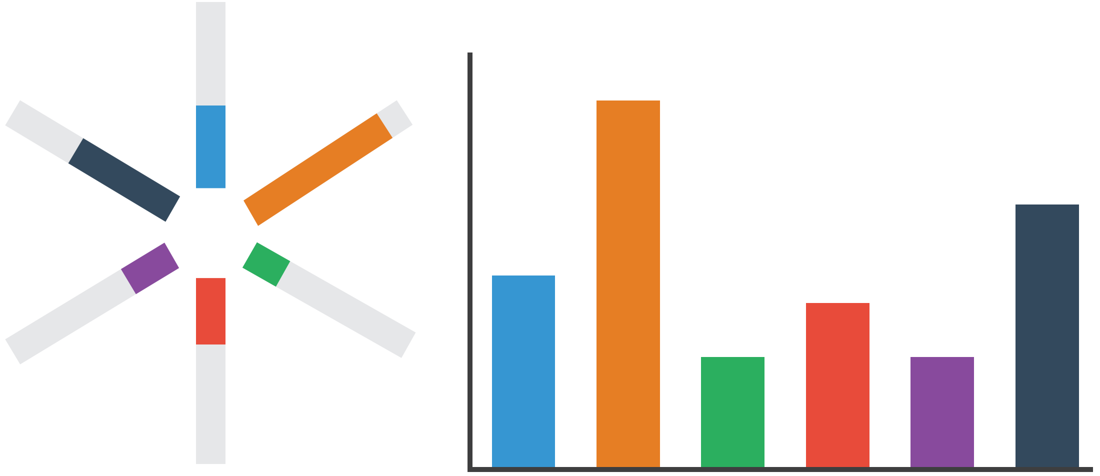
Coxcomb: perception

- encode: 1D length
- decode/perceive: 2D area
- nonuniform line/sector width as length increases
  - so area variation is nonlinear wrt line mark length!
- bar chart safer: uniform width, so area is linear with line mark length
  - both radial & rectilinear cases

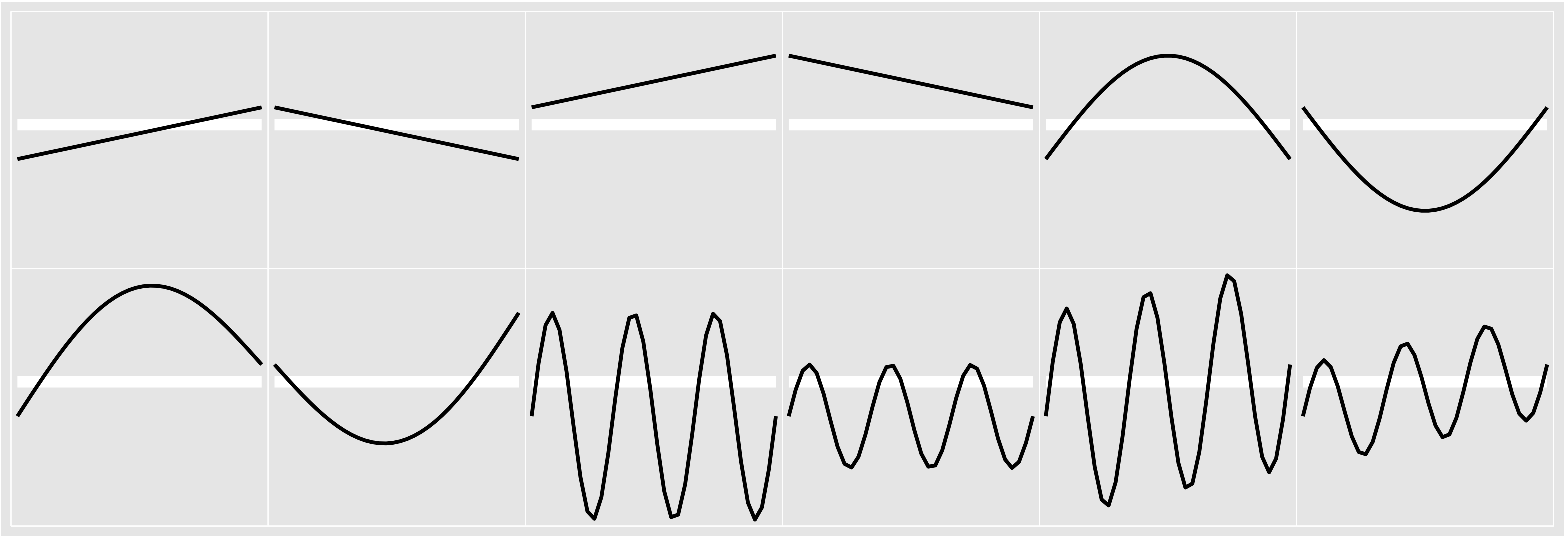


nonuniform width as length increases

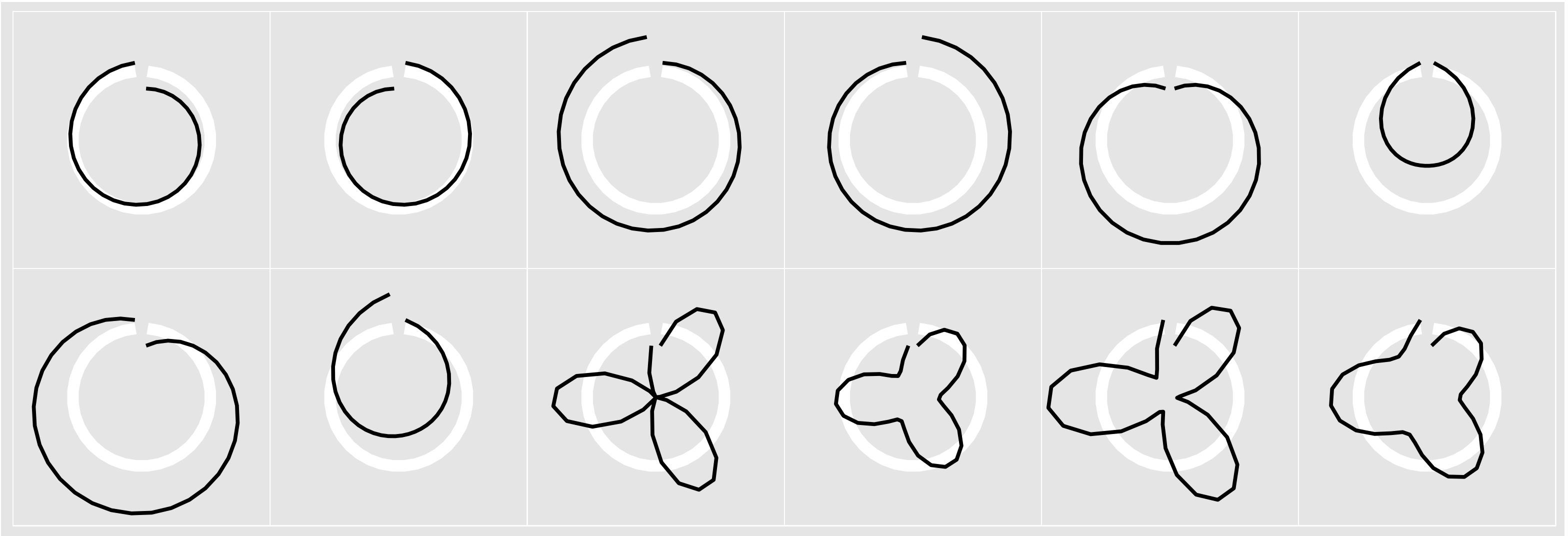

uniform width as length increases


radial & rectilinear bars: uniform width as length increases

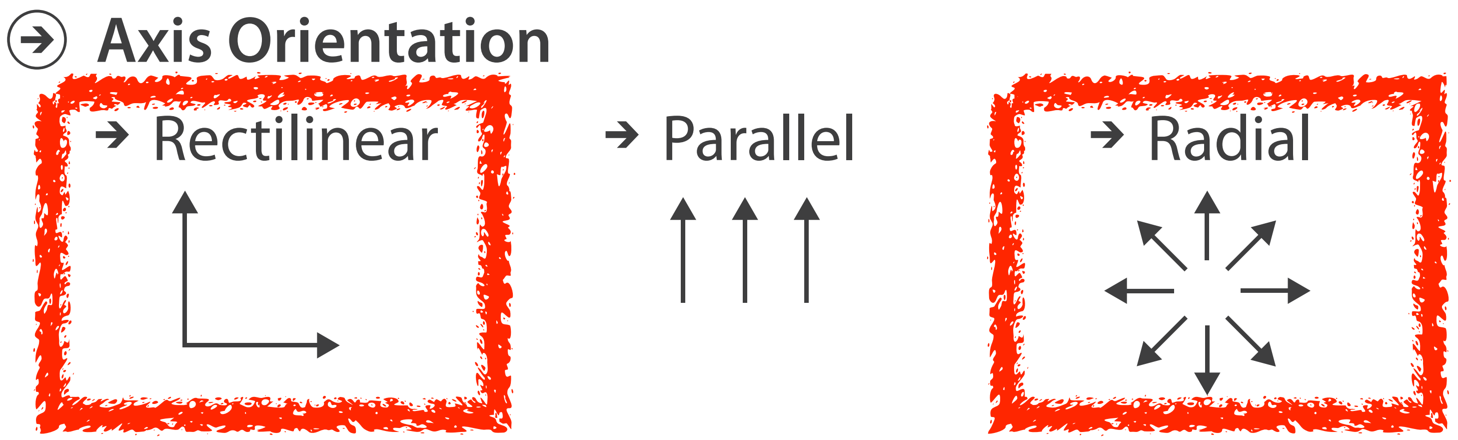
Idiom: **glyphmaps**



- rectilinear good for linear vs nonlinear trends



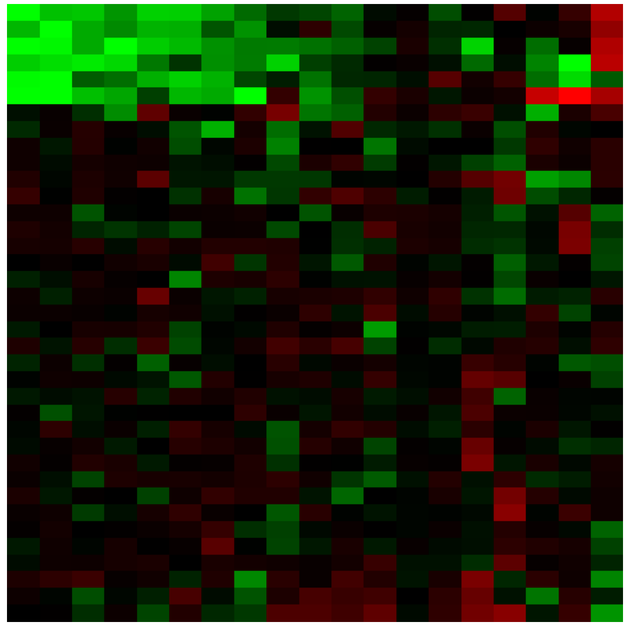
- radial good for cyclic patterns

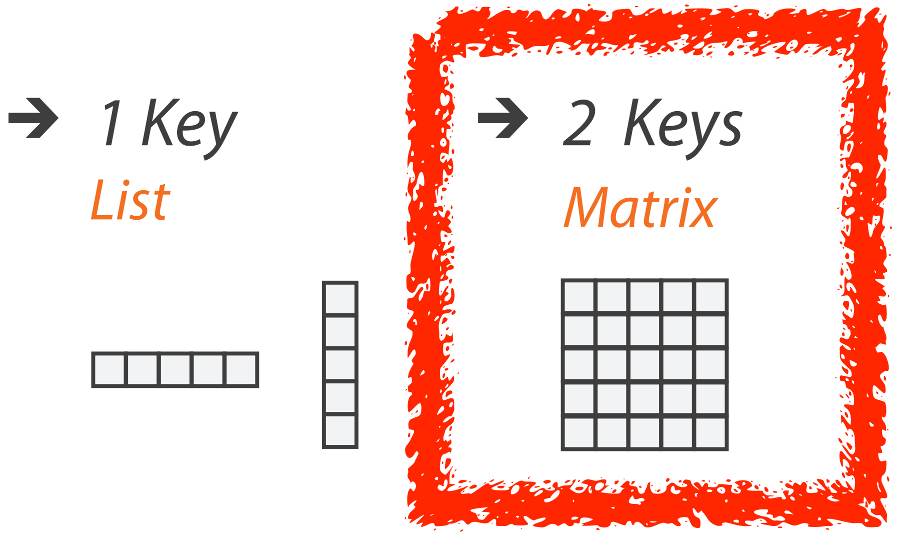


[Glyph-maps for Visually Exploring Temporal Patterns in Climate Data and Models. Wickham, Hofmann, Wickham, and Cook. Environmetrics 23:5 (2012), 382–393.]

Idiom: **heatmap**

- two keys, one value
  - data
    - 2 categ attribs (gene, experimental condition)
    - 1 quant attrib (expression levels)
  - marks: area
    - separate and align in 2D matrix
      - indexed by 2 categorical attributes
  - channels
    - color by quant attrib
      - (ordered diverging colormap)
  - task
    - find clusters, outliers
  - scalability
    - 1K categorical levels, 1M items; ~10 quantitative attribute levels



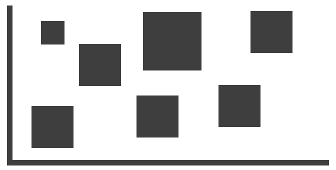


Arrange tables

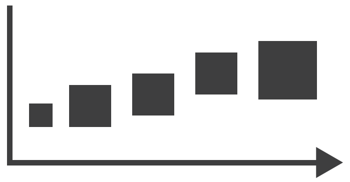
➔ Express Values

➔ Separate, Order, Align Regions

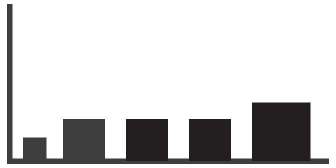
➔ Separate



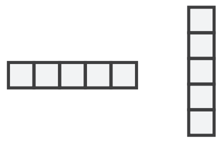
➔ Order



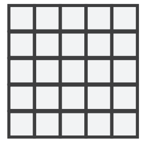
➔ Align



➔ *1 Key*
List

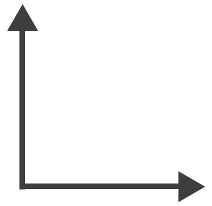


➔ *2 Keys*
Matrix

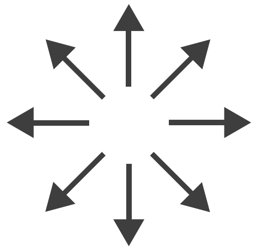


➔ Axis Orientation

➔ Rectilinear

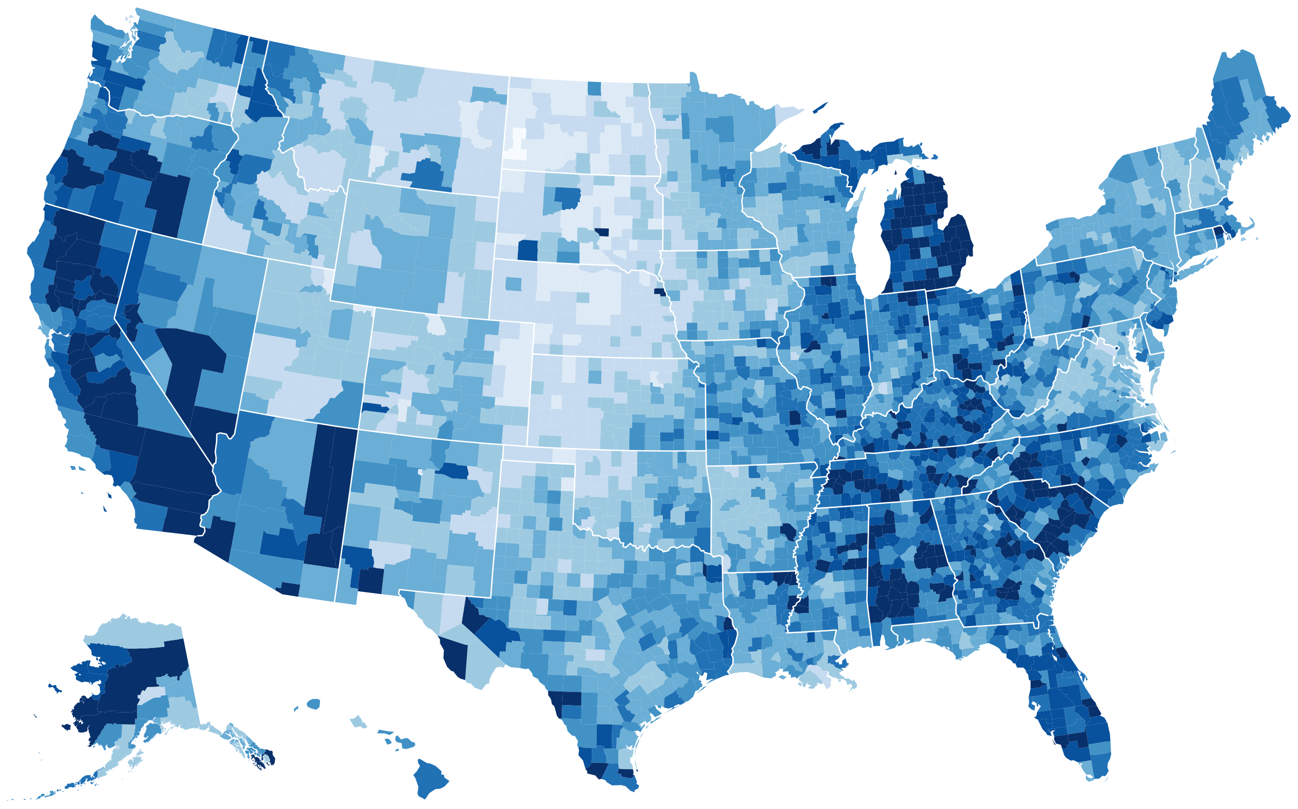


➔ Radial



Idiom: **choropleth map**

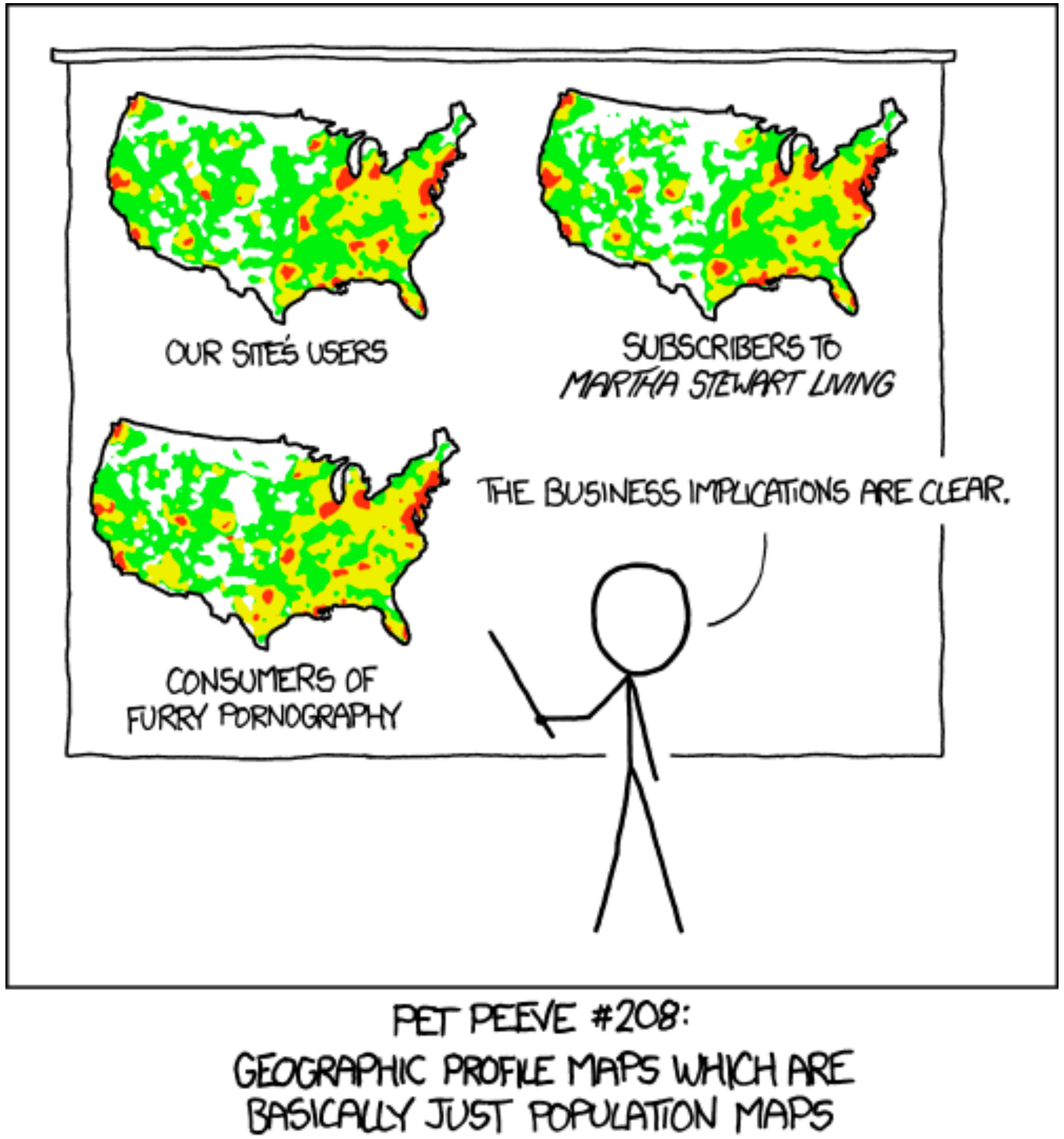
- use given spatial data
  - when central task is understanding spatial relationships
- data
  - geographic geometry
  - table with 1 quant attribute per region
- encoding
  - use given geometry for area mark boundaries
  - sequential segmented colormap [more later]



http://bl.ocks.org/mbostock/4060606

Beware: Population maps trickiness!

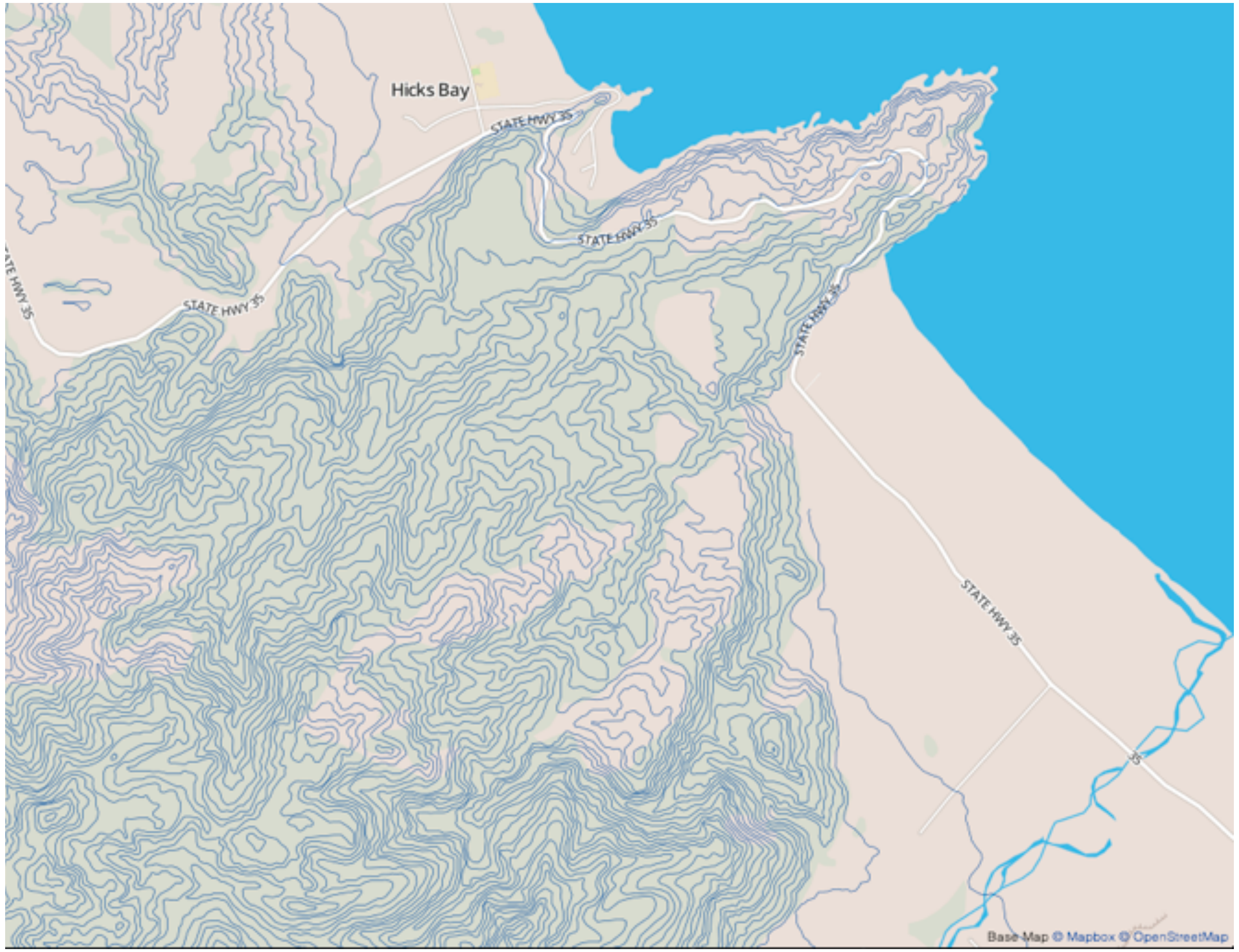
- spurious correlations: most attributes just show where people live
- consider when to normalize by population density
  - encode raw data values
    - tied to underlying population
  - but should use normalized values
    - eg unemployed people per 100 citizens
- general issue
  - absolute counts vs relative/normalized data
  - failure to normalize is common error



[https://xkcd.com/1138]

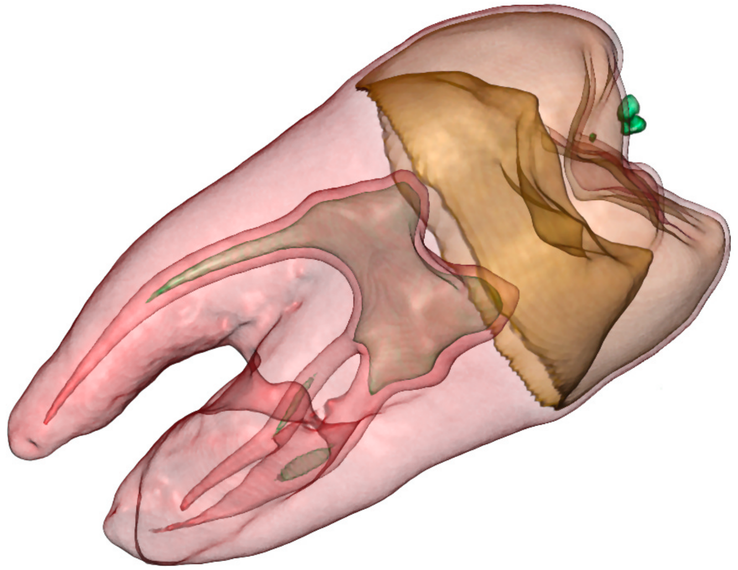
Idiom: **topographic map**

- data
  - geographic geometry
  - scalar spatial field
    - 1 quant attribute per grid cell
- derived data
  - isoline geometry
    - isocontours computed for specific levels of scalar values

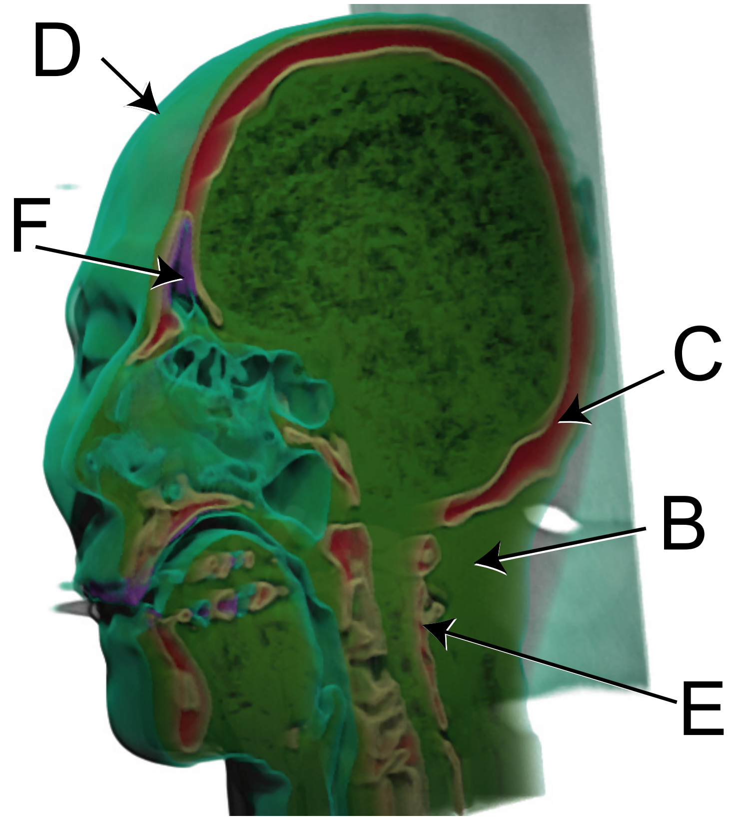


Land Information New Zealand Data Service

Idioms: **isosurfaces, direct volume rendering**



- data
  - scalar spatial field
    - 1 quant attribute per grid cell
- task
  - shape understanding, spatial relationships
- isosurface
  - derived data: isocontours computed for specific levels of scalar values
- direct volume rendering
  - transfer function maps scalar values to color, opacity
    - no derived geometry

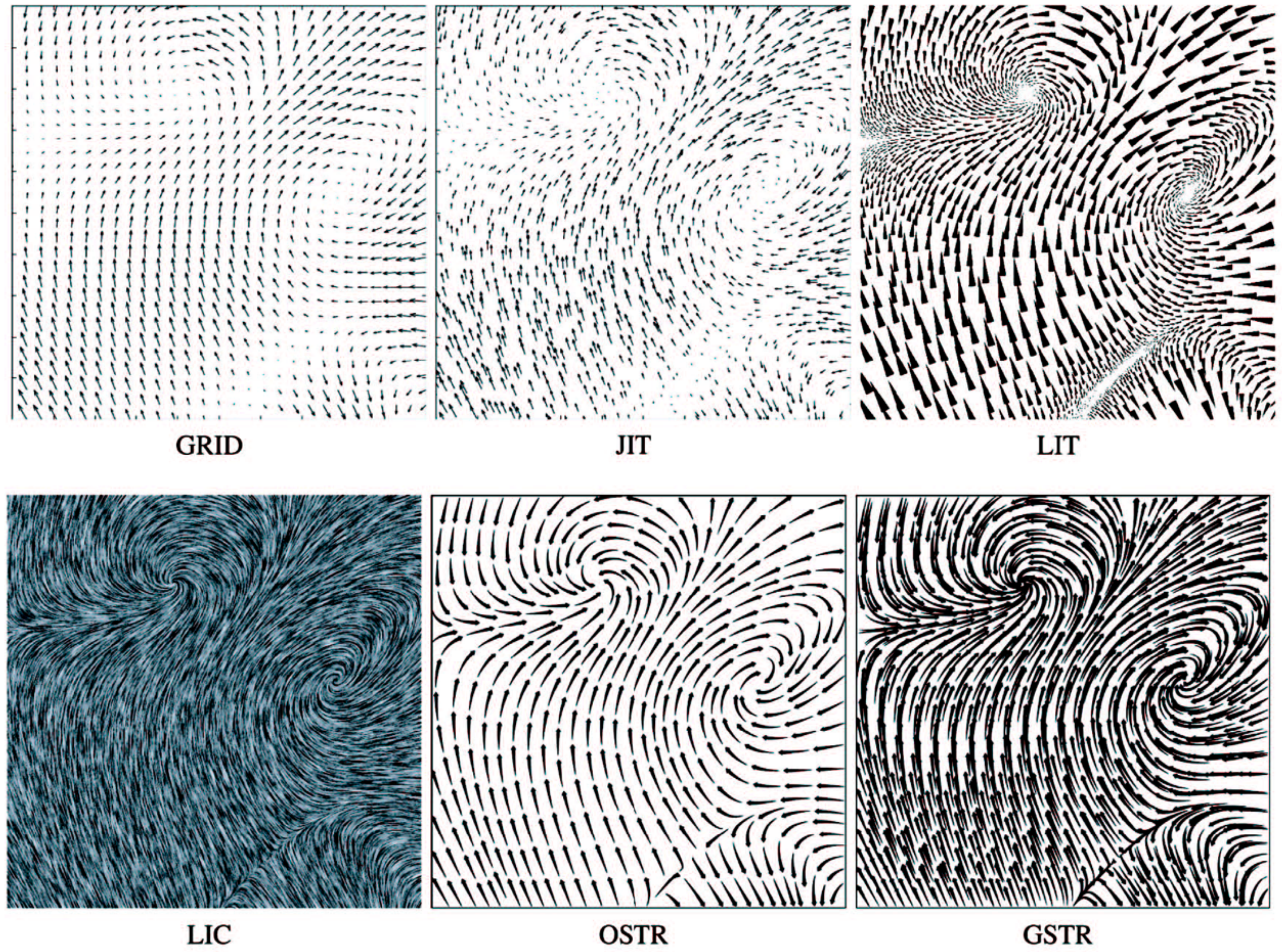


[Interactive Volume Rendering Techniques. Kniss. Master's thesis, University of Utah Computer Science, 2002.]

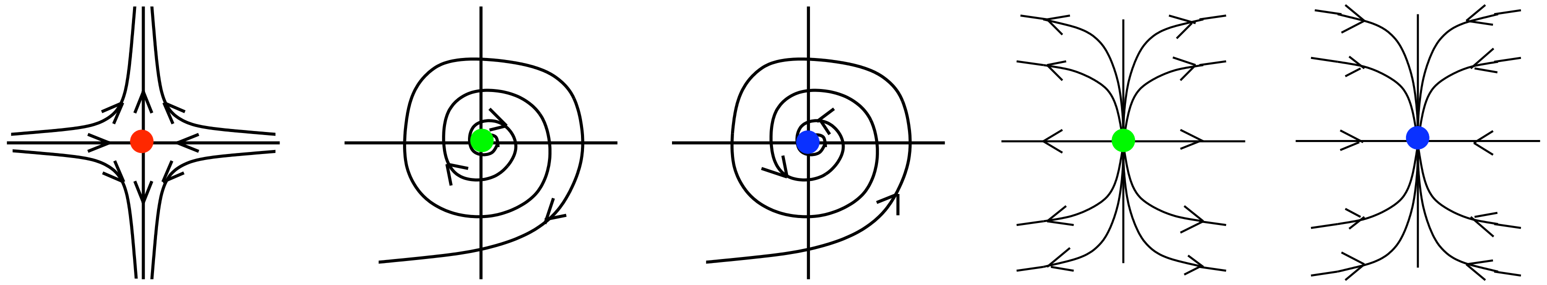
[Multidimensional Transfer Functions for Volume Rendering. Kniss, Kindlmann, and Hansen. In The Visualization Handbook, edited by Charles Hansen and Christopher Johnson, pp. 189–210. Elsevier, 2005.]

Vector and tensor fields

- data
  - many attribs per cell
- idiom families
  - flow glyphs
    - purely local
  - geometric flow
    - derived data from tracing particle trajectories
    - sparse set of seed points
  - texture flow
    - derived data, dense seeds
  - feature flow
    - global computation to detect features
      - encoded with one of methods above



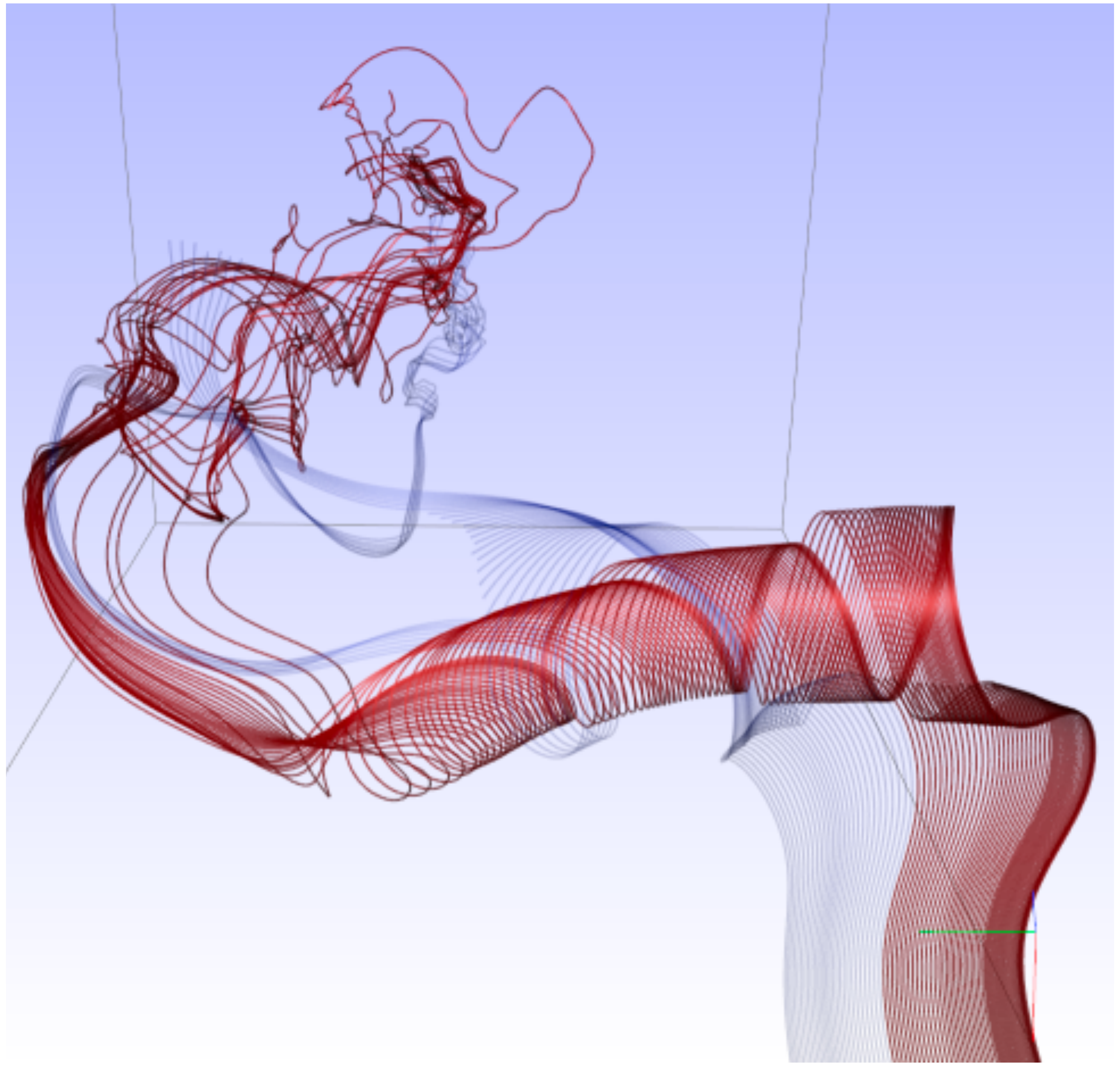
[Comparing 2D vector field visualization methods: A user study. Laidlaw et al. IEEE Trans. Visualization and Computer Graphics (TVCG) 11:1 (2005), 59–70.]



[Topology tracking for the visualization of time-dependent two-dimensional flows. Tricoche, Wischgoll, Scheuermann, and Hagen. Computers & Graphics 26:2 (2002), 249–257.]

Idiom: **similarity-clustered streamlines**

- data
  - 3D vector field
- derived data (from field)
  - streamlines: trajectory particle will follow
- derived data (per streamline)
  - curvature, torsion, tortuosity
  - signature: complex weighted combination
  - compute cluster hierarchy across all signatures
  - encode: color and opacity by cluster
- tasks
  - find features, query shape
- scalability
  - millions of samples, hundreds of streamlines

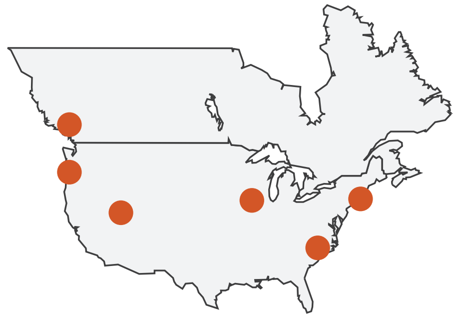


[Similarity Measures for Enhancing Interactive Streamline Seeding. McLoughlin,. Jones, Laramee, Malki, Masters, and. Hansen. IEEE Trans. Visualization and Computer Graphics 19:8 (2013), 1342–1353.]

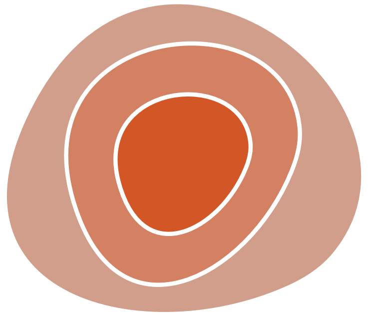
Arrange spatial data

➔ Use Given

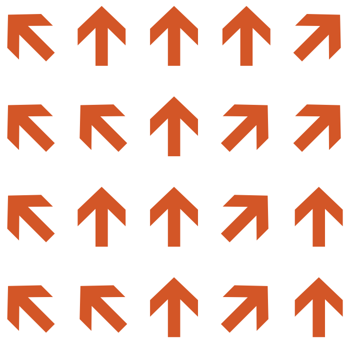
- ➔ Geometry
  - ➔ *Geographic*
  - ➔ *Other Derived*



- ➔ Spatial Fields
  - ➔ *Scalar Fields (one value per cell)*
    - ➔ *Isocontours*
    - ➔ *Direct Volume Rendering*



  - ➔ *Vector and Tensor Fields (many values per cell)*
    - ➔ *Flow Glyphs (local)*
    - ➔ *Geometric (sparse seeds)*
    - ➔ *Textures (dense seeds)*
    - ➔ *Features (globally derived)*



Further reading

- Visualization Analysis and Design. Munzner. AK Peters Visualization Series, CRC Press, Nov 2014.
  - *Chap 7: Arrange Tables, Chap 8: Arrange Spatial Data*
- Visualizing Data. Cleveland. Hobart Press, 1993.
- A Brief History of Data Visualization. Friendly. 2008. http://www.datavis.ca/milestones
- How Maps Work: Representation, Visualization, and Design. MacEachren. Guilford Press, 1995.
- Overview of visualization. Schroeder and. Martin. In The Visualization Handbook, edited by Charles Hansen and Christopher Johnson, pp. 3–39. Elsevier, 2005.
- Real-Time Volume Graphics. Engel, Hadwiger, Kniss, Reza-Salama, and Weiskopf. AK Peters, 2006.
- Overview of flow visualization. Weiskopf and Erlebacher. In The Visualization Handbook, edited by Charles Hansen and Christopher Johnson, pp. 261–278. Elsevier, 2005.

Visualization Analysis & Design, Half-Day Tutorial

- Session 1
  - Analysis: What, Why, How
  - Marks and Channels
  - Arrange Tabular & Spatial Data

Break

- Session 2
  - Arrange Networks and Trees
  - Map Color and Other Channels
  - Manipulate & Facet
  - Reduce: Filter, Aggregate

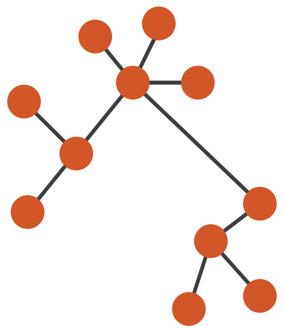
@tamaramunzner @tamara@vis.social

http://www.cs.ubc.ca/~tmm/talks.html#halfdaycourse23

Arrange networks and trees

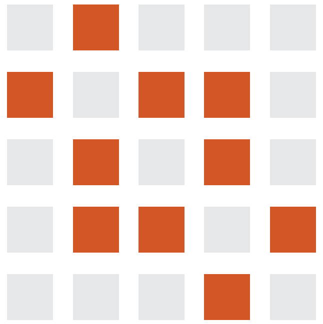
Node–Link Diagrams
Connection Marks

✓ NETWORKS ✓ TREES



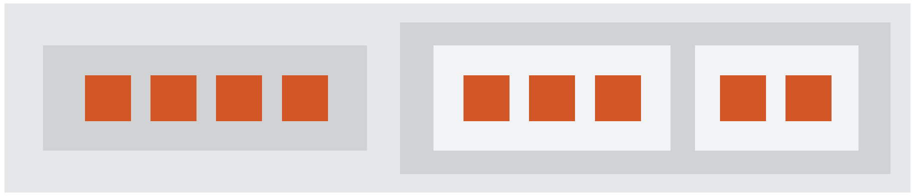
Adjacency Matrix
Derived Table

✓ NETWORKS ✓ TREES



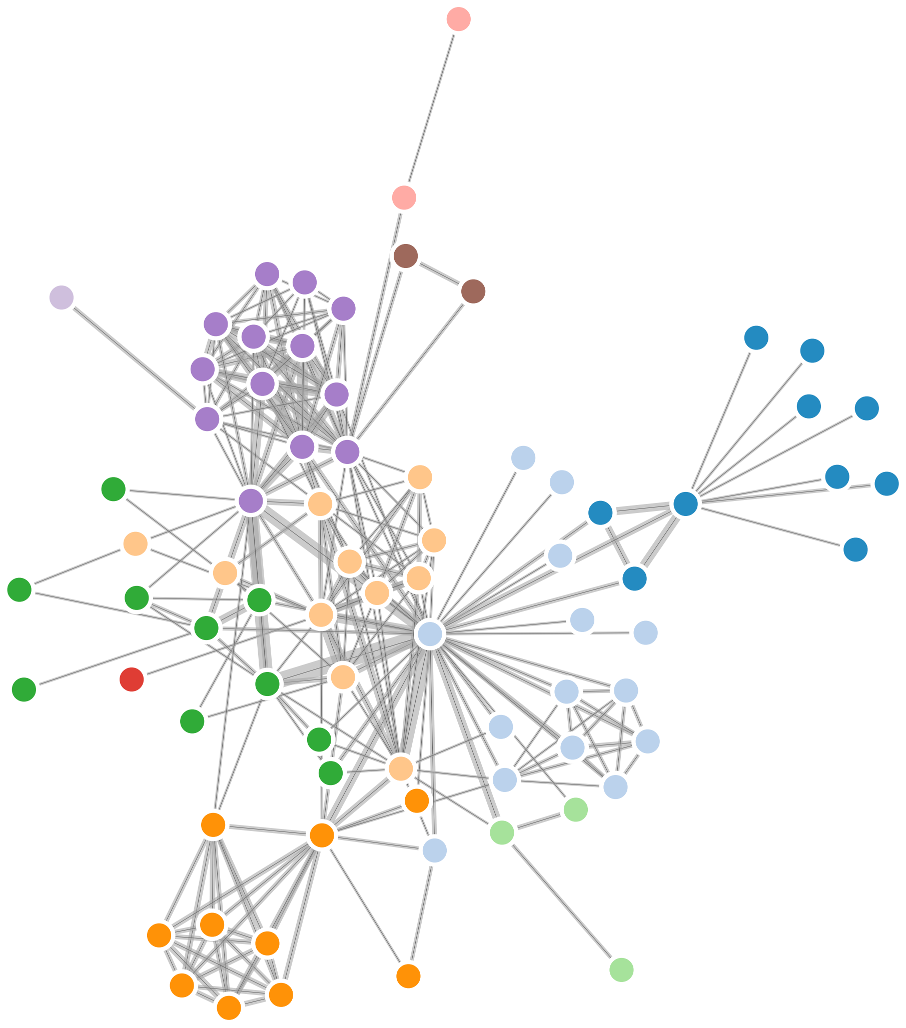
Enclosure
Containment Marks

✗ NETWORKS ✓ TREES



Idiom: **force-directed placement**

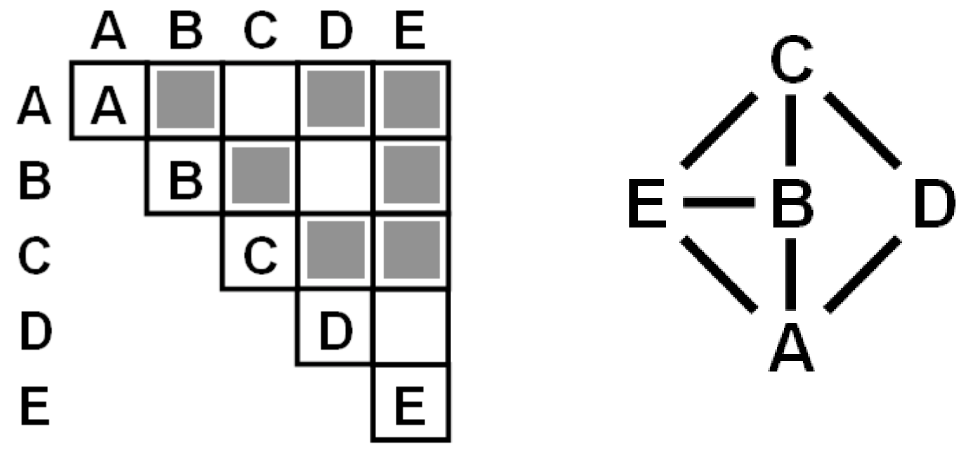
- visual encoding: node-link diagram
  - link connection marks, node point marks
- algorithm: energy minimization
  - analogy: nodes repel, links draw together like springs
  - optimization problem: minimize crossings
- spatial position: no meaning directly encoded
  - sometimes proximity meaningful
  - sometimes proximity arbitrary, artifact of layout algorithm
- tasks
  - explore topology; locate paths, clusters
- scalability
  - node/edge density E < 4N



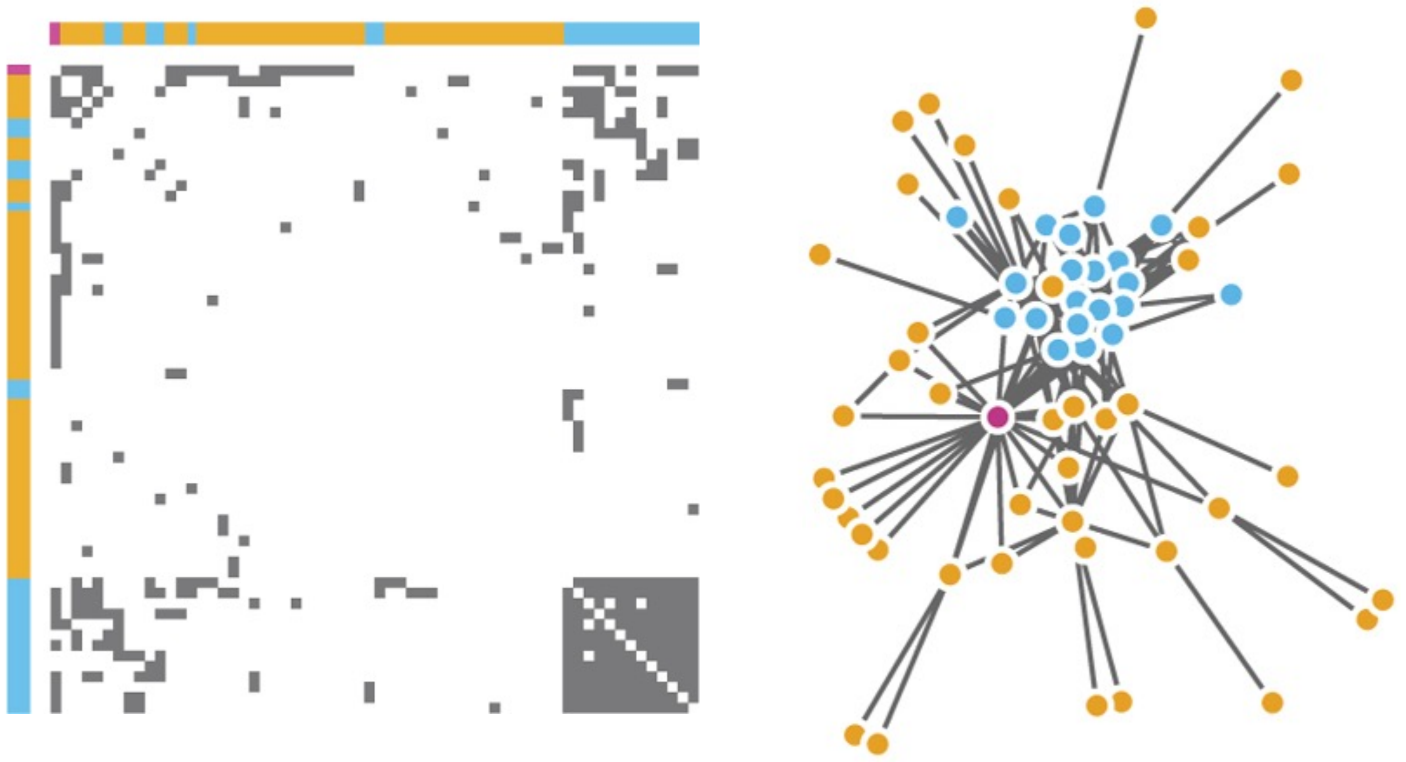
http://mbostock.github.com/d3/ex/force.html

Idiom: **adjacency matrix view**

- data: network
  - transform into same data/encoding as heatmap
- derived data: table from network
  - 1 quant attrib
    - weighted edge between nodes
  - 2 categ attribs: node list x 2
- visual encoding
  - cell shows presence/absence of edge
- scalability
  - 1K nodes, 1M edges



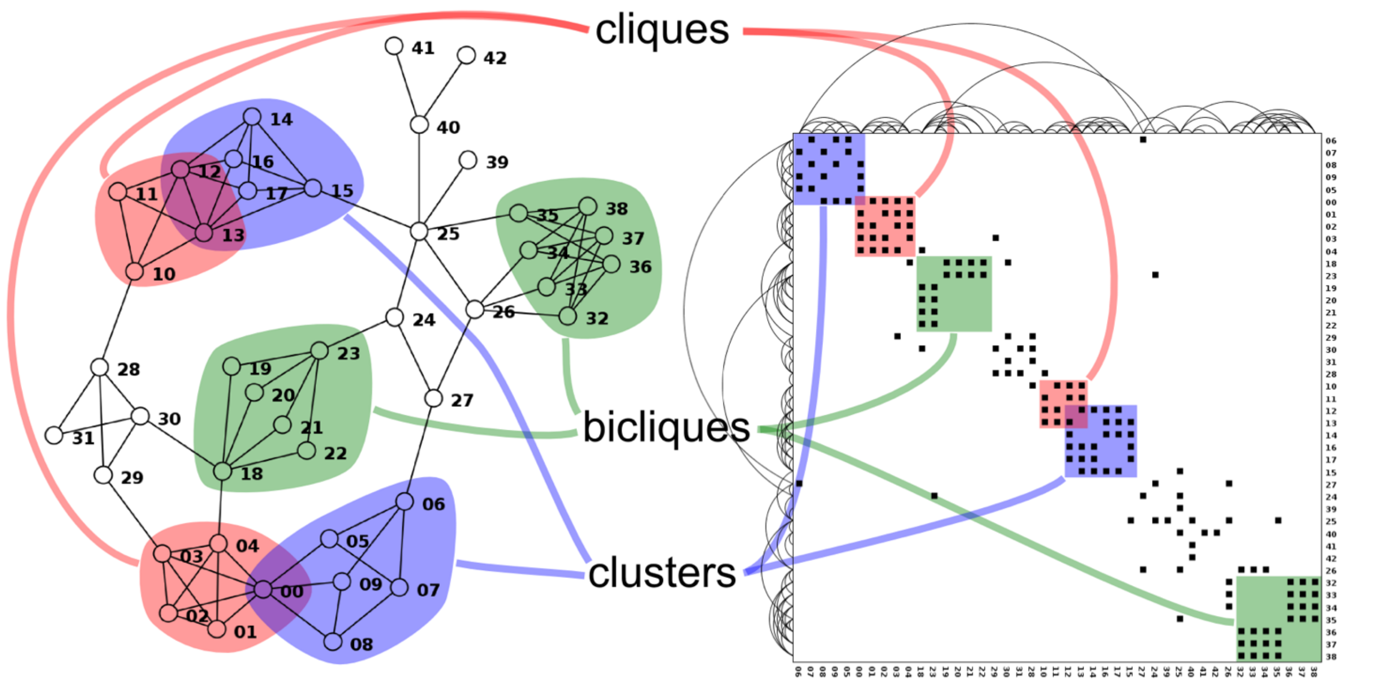
[NodeTrix: a Hybrid Visualization of Social Networks. Henry, Fekete, and McGuffin. IEEE TVCG (Proc. InfoVis) 13(6):1302-1309, 2007.]



[Points of view: Networks. Gehlenborg and Wong. Nature Methods 9:115.]

Connection vs. adjacency comparison

- adjacency matrix strengths
  - predictability, scalability, supports reordering
  - some topology tasks trainable
- node-link diagram strengths
  - topology understanding, path tracing
  - intuitive, no training needed
- empirical study
  - node-link best for small networks
  - matrix best for large networks
    - if tasks don't involve topological structure!

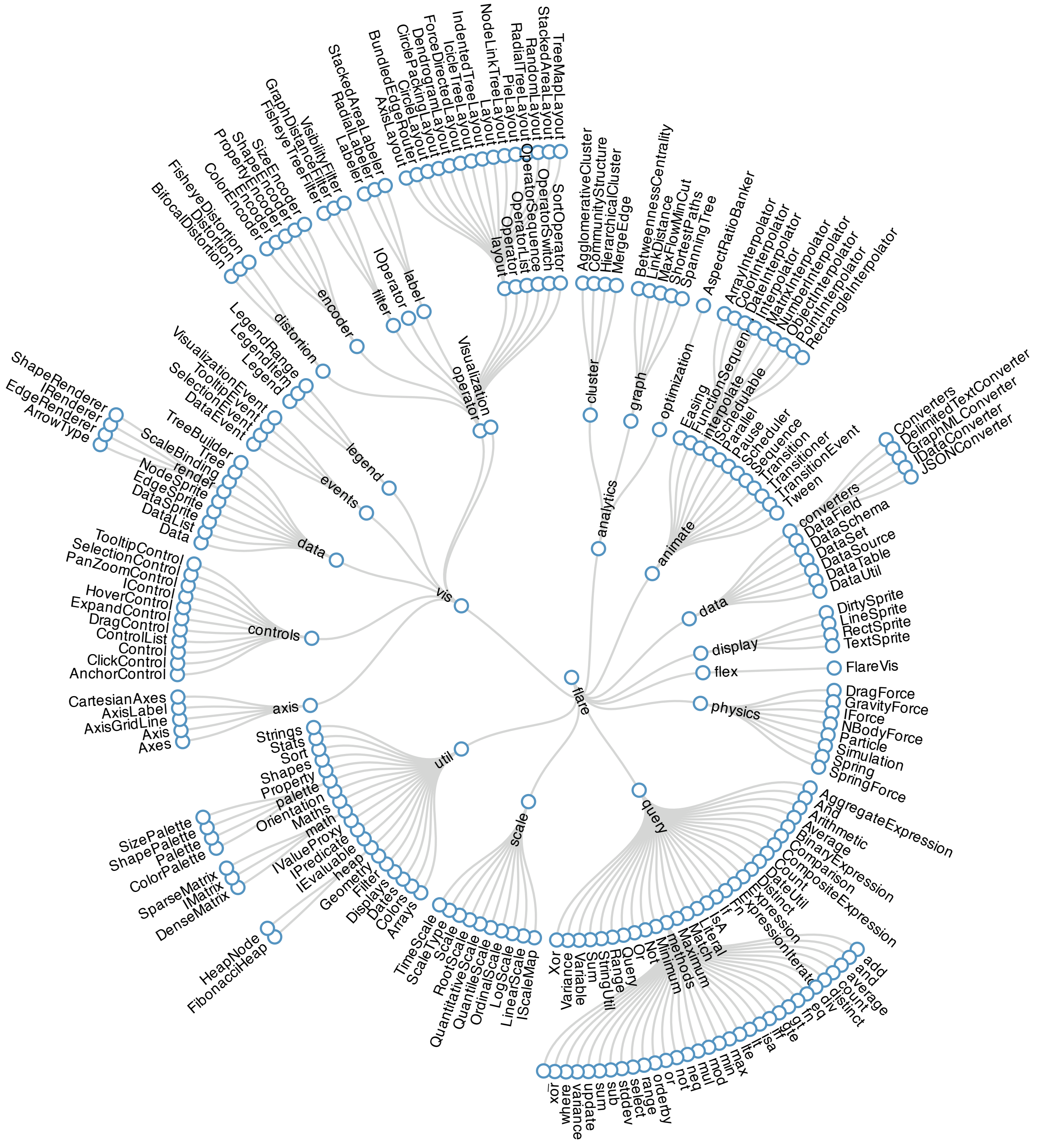


http://www.michaelmcguffin.com/courses/vis/patternsInAdjacencyMatrix.png

[On the readability of graphs using node-link and matrix-based representations: a controlled experiment and statistical analysis. Ghoniem, Fekete, and Castagliola. Information Visualization 4:2 (2005), 114–135.]

Idiom: **radial node-link tree**

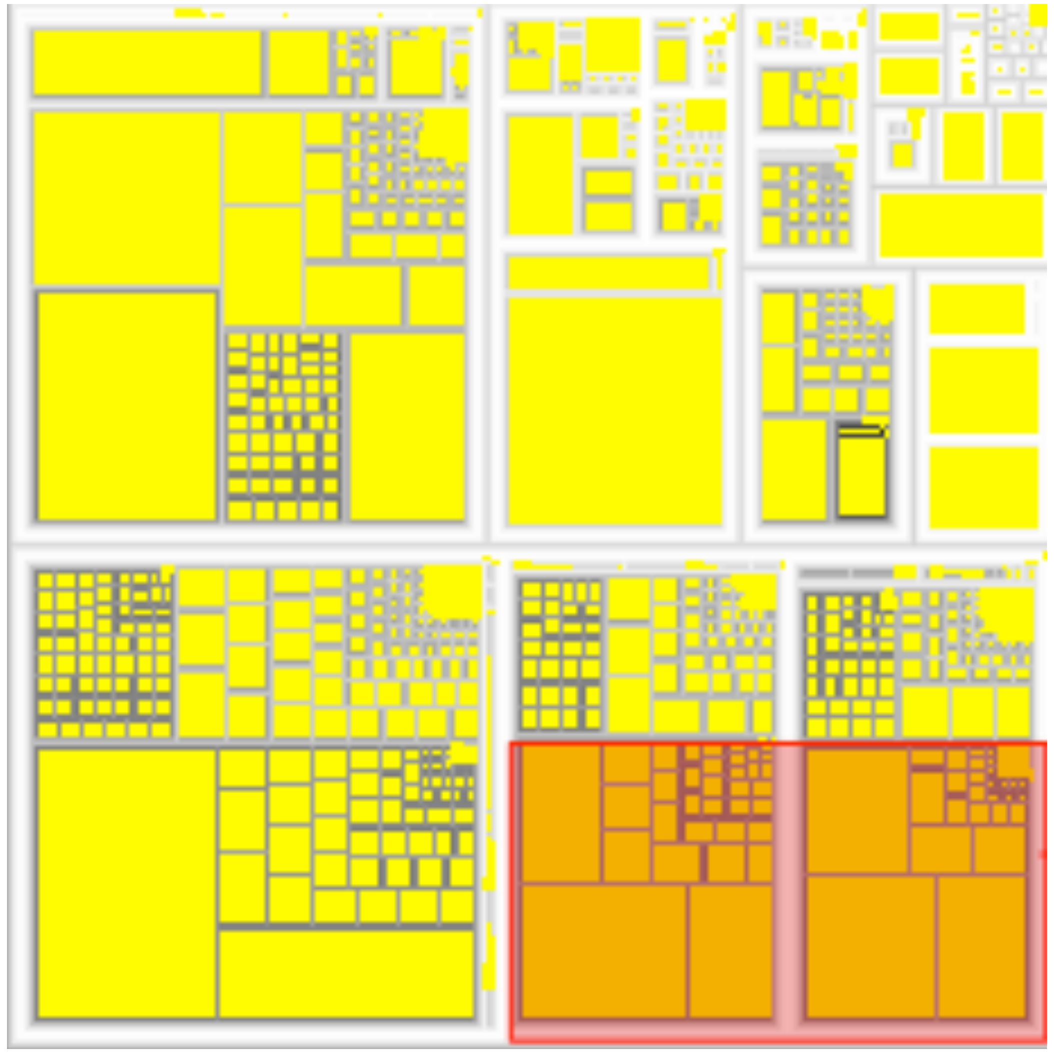
- data
  - tree
- encoding
  - link connection marks
  - point node marks
  - radial axis orientation
    - angular proximity: siblings
    - distance from center: depth in tree
- tasks
  - understanding topology, following paths
- scalability
  - 1K - 10K nodes



http://mbostock.github.com/d3/ex/tree.html

Idiom: **treemap**

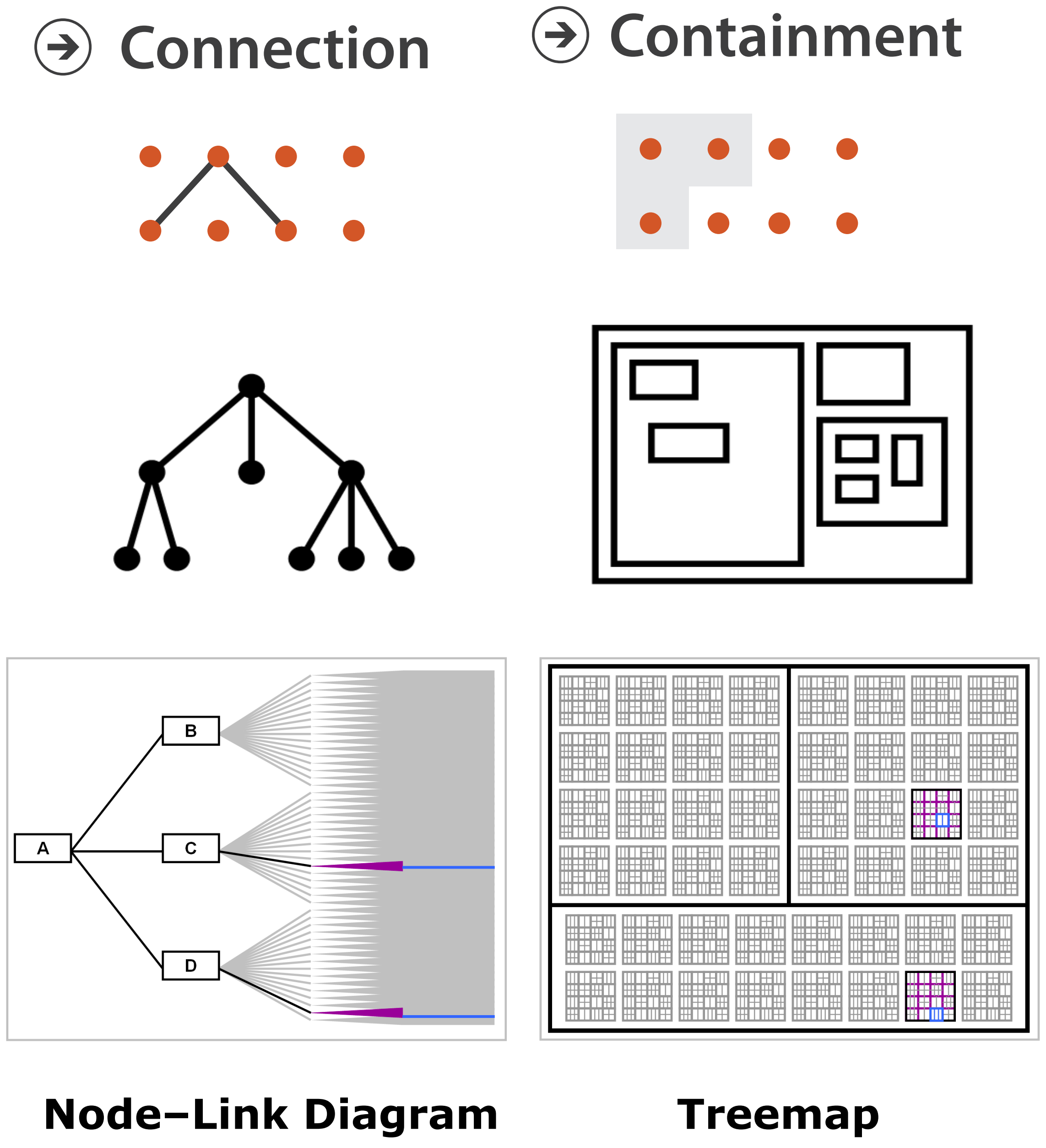
- data
  - tree
  - 1 quant attrib at leaf nodes
- encoding
  - area containment marks for hierarchical structure
  - rectilinear orientation
  - size encodes quant attrib
- tasks
  - query attribute at leaf nodes
- scalability
  - 1M leaf nodes



http://tulip.labri.fr/Documentation/3_7/userHandbook/html/ch06.html

Link marks: Connection and containment

- marks as links (vs. nodes)
  - common case in network drawing
  - 1D case: connection
    - ex: all node-link diagrams
    - emphasizes topology, path tracing
    - networks and trees
  - 2D case: containment
    - ex: all treemap variants
    - emphasizes attribute values at leaves (size coding)
    - only trees



[Elastic Hierarchies: Combining Treemaps and Node-Link Diagrams. Dong, McGuffin, and Chignell. Proc. InfoVis 2005, p. 57-64.]

Further reading

- Visualization Analysis and Design. Munzner. AK Peters Visualization Series, CRC Press, Nov 2014.
  - *Chap 9: Arrange Networks and Trees*
- Visual Analysis of Large Graphs: State-of-the-Art and Future Research Challenges. von Landesberger et al. Computer Graphics Forum 30:6 (2011), 1719–1749.
- Simple Algorithms for Network Visualization: A Tutorial. McGuffin. Tsinghua Science and Technology (Special Issue on Visualization and Computer Graphics) 17:4 (2012), 383–398.
- Drawing on Physical Analogies. Brandes. In Drawing Graphs: Methods and Models, LNCS Tutorial, 2025, edited by M. Kaufmann and D. Wagner, LNCS Tutorial, 2025, pp. 71–86. Springer-Verlag, 2001.
- http://www.treevis.net Treevis.net: A Tree Visualization Reference. Schulz. IEEE Computer Graphics and Applications 31:6 (2011), 11–15.
- Perceptual Guidelines for Creating Rectangular Treemaps. Kong, Heer, and Agrawala. IEEE Trans. Visualization and Computer Graphics (Proc. InfoVis) 16:6 (2010), 990–998.

Visualization Analysis & Design, Half-Day Tutorial

- Session 1
  - Analysis: What, Why, How
  - Marks and Channels
  - Arrange Tabular & Spatial Data
- Session 2
  - Arrange Networks and Trees
  - Map Color and Other Channels
  - Manipulate & Facet
  - Reduce: Filter, Aggregate

@tamaramunzner @tamara@vis.social

http://www.cs.ubc.ca/~tmm/talks.html#halfdaycourse23

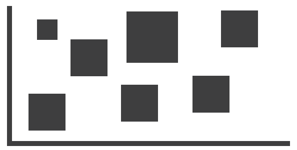
Idiom design choices: First half

Encode

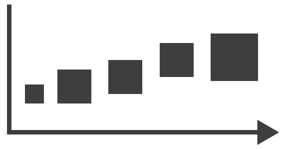
Arrange

→ Express

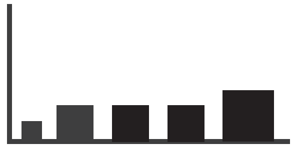
→ Separate



→ Order



→ Align



→ Use

Map

from categorical and ordered attributes

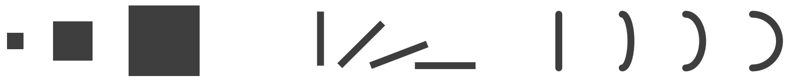
→ Color

→ *Hue*

→ *Saturation*

→ *Luminance*

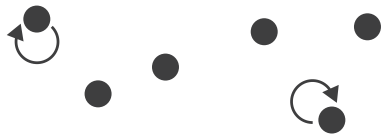
→ Size, Angle, Curvature, ...

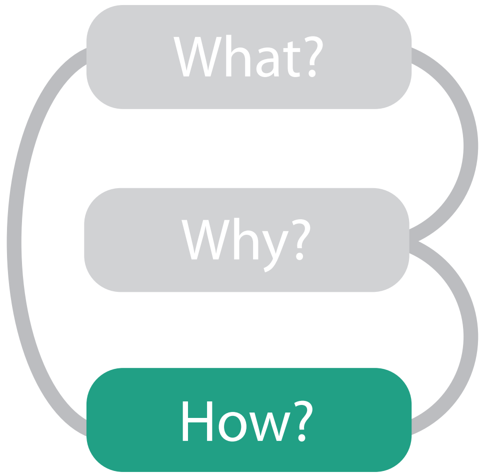


→ Shape

→ Motion

Direction, Rate, Frequency, ...





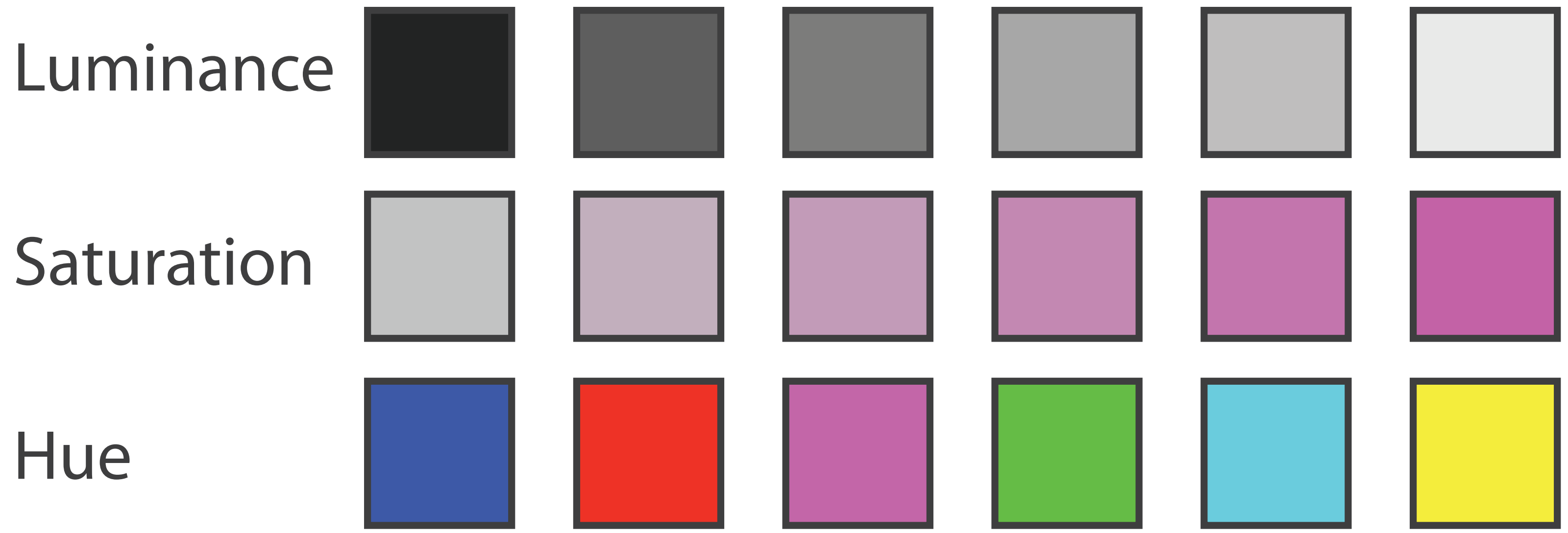
Decomposing color

- first rule of color: do not talk about color!
  - color is confusing if treated as monolithic

Decomposing color

- first rule of color: do not talk about color!
  - color is confusing if treated as monolithic

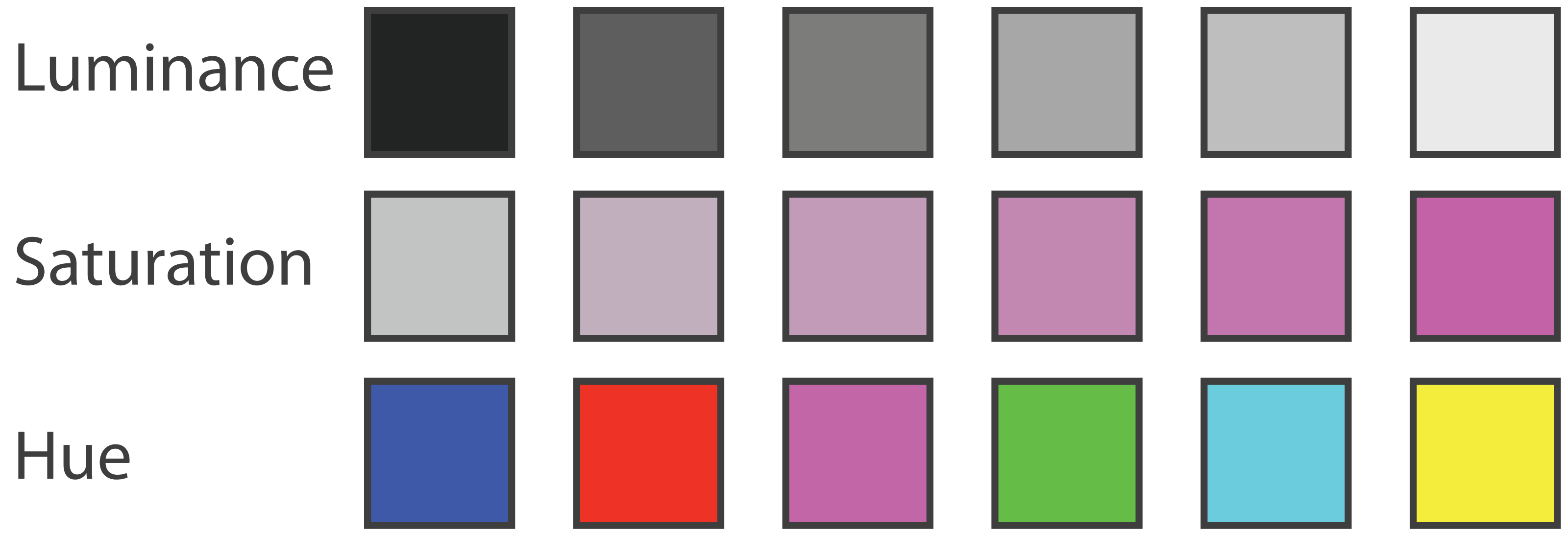
- decompose into three channels



Decomposing color

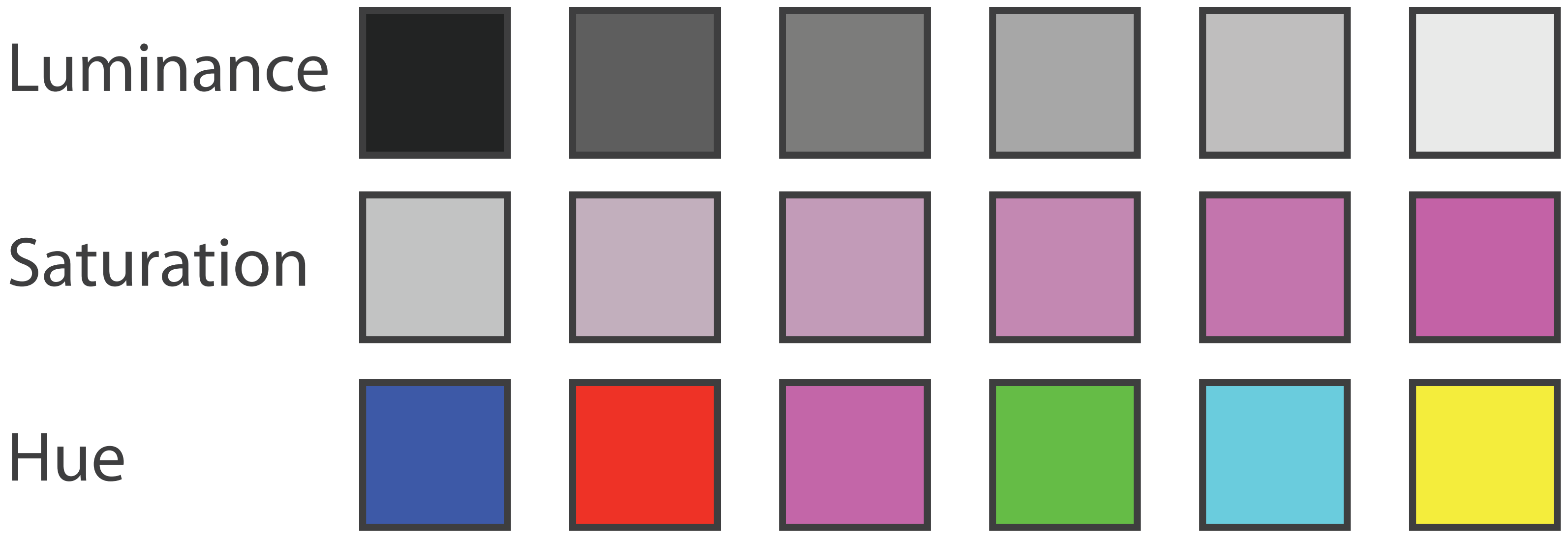
- first rule of color: do not talk about color!
  - color is confusing if treated as monolithic

- decompose into three channels
  - ordered can show magnitude
    - luminance
    - saturation
  - categorical can show identity
    - hue



Decomposing color

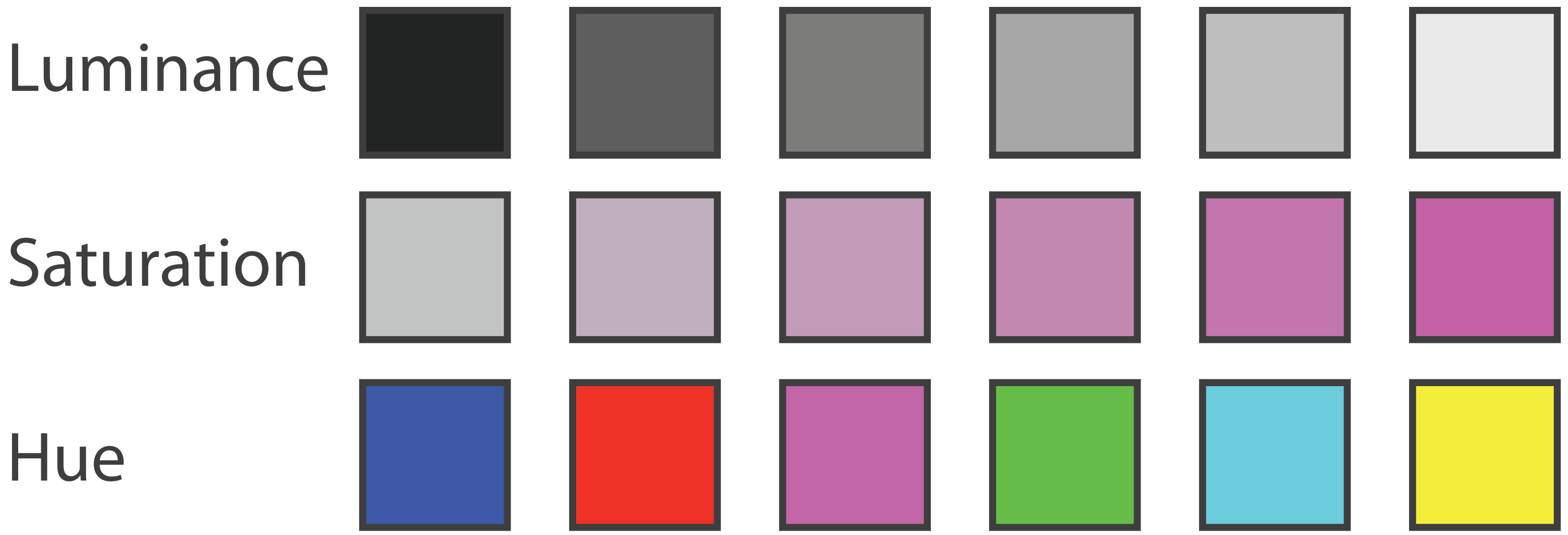
- first rule of color: do not talk about color!
  - color is confusing if treated as monolithic
- decompose into three channels
  - ordered can show magnitude
    - luminance
    - saturation
  - categorical can show identity
    - hue



- perceptual colorspace, in contrast to three channels of RGB

Decomposing color

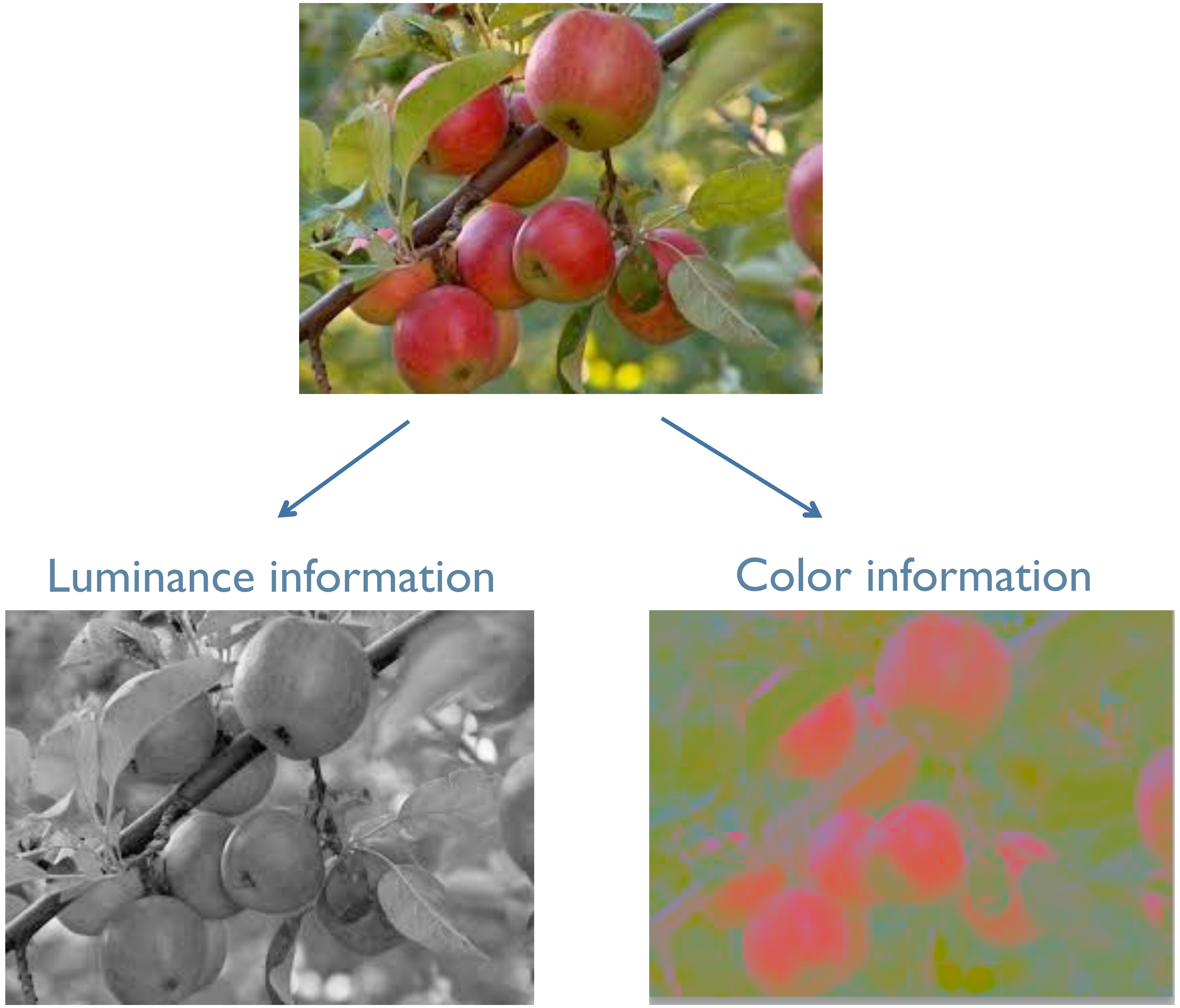
- first rule of color: do not talk about color!
  - color is confusing if treated as monolithic
- decompose into three channels
  - ordered can show magnitude
    - luminance
    - saturation
  - categorical can show identity
    - hue



- perceptual colorspace, in contrast to three channels of RGB

Luminance

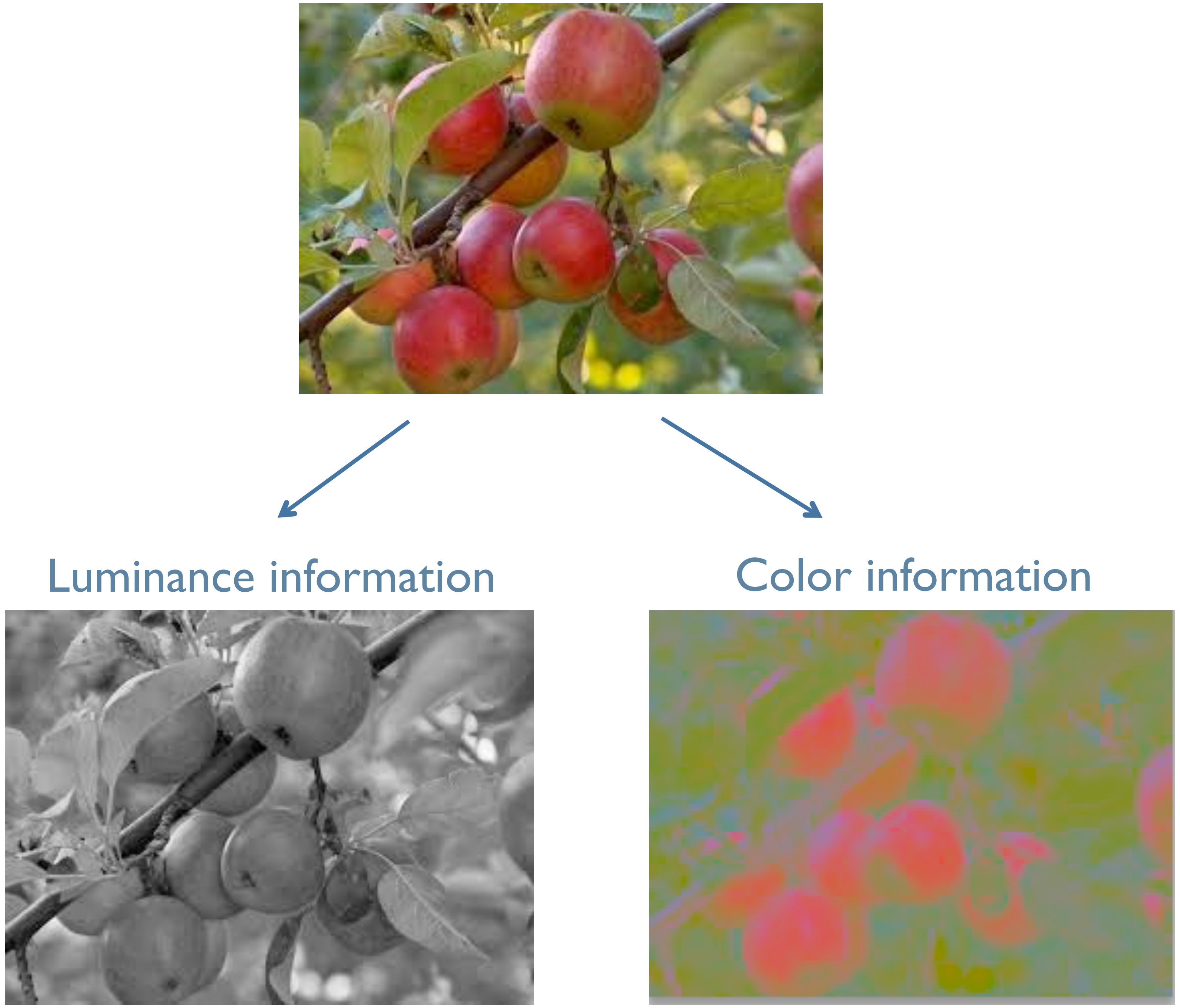
- need luminance for edge detection
  - fine-grained detail only visible through luminance contrast
  - legible text requires luminance contrast!



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

Luminance

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

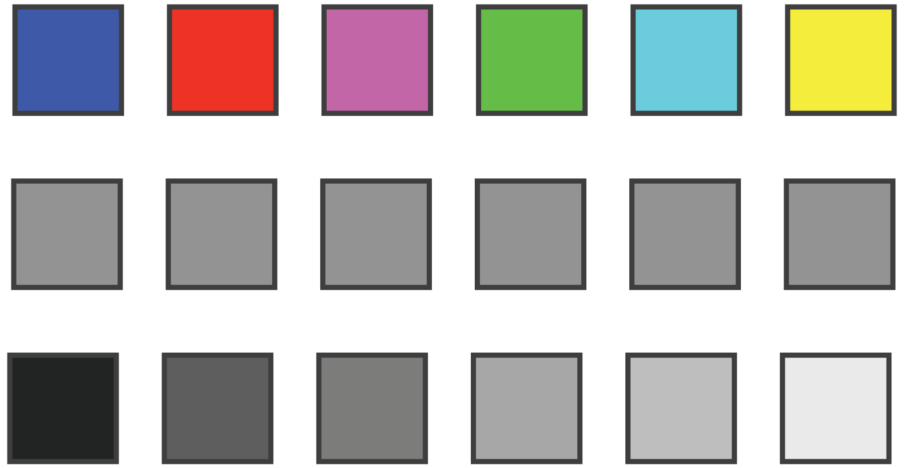


- HLS better than RGB for encoding but beware
  - L lightness ≠ L* luminance

Corners of the RGB color cube

L from HLS
All the same

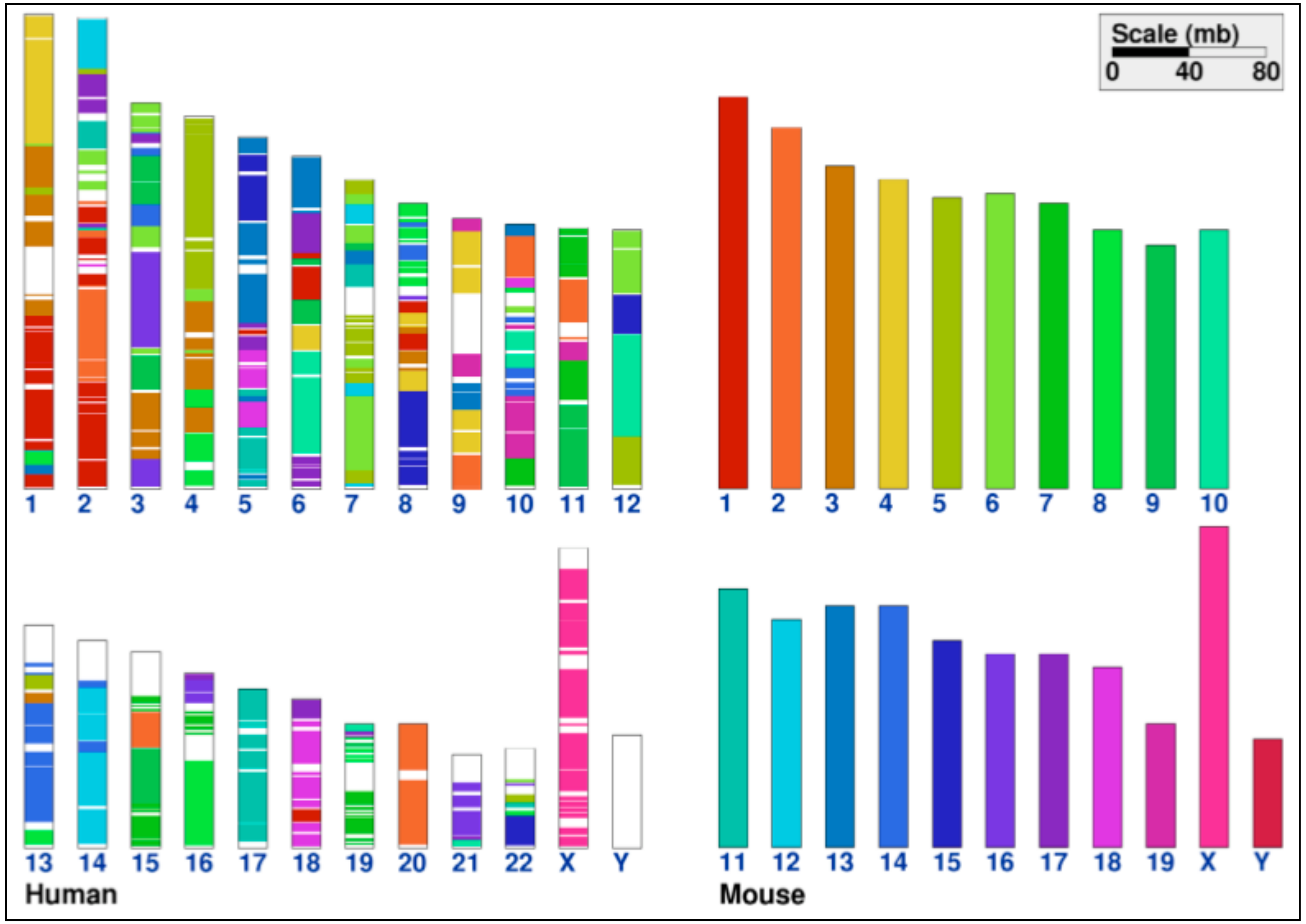
Luminance values



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

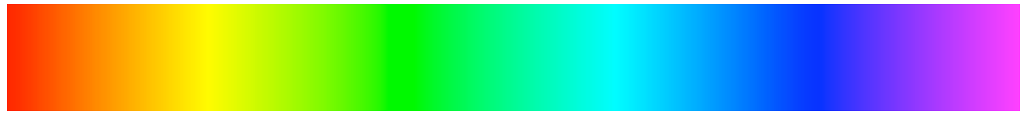
Categorical color: Discriminability constraints

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



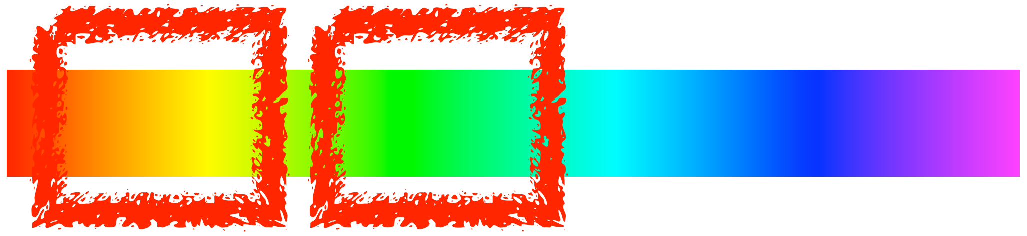
[Cinteny: flexible analysis and visualization of synteny and genome rearrangements in multiple organisms. Sinha and Meller. BMC Bioinformatics, 8:82, 2007.]

Ordered color: Rainbow is poor default



- problems
  - perceptually unordered
  - perceptually nonlinear

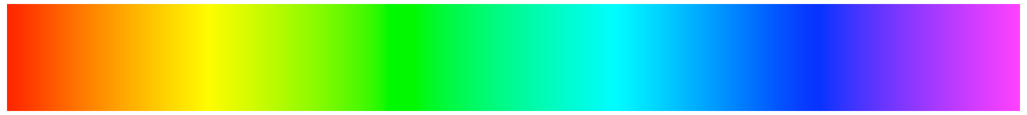
Ordered color: Rainbow is poor default

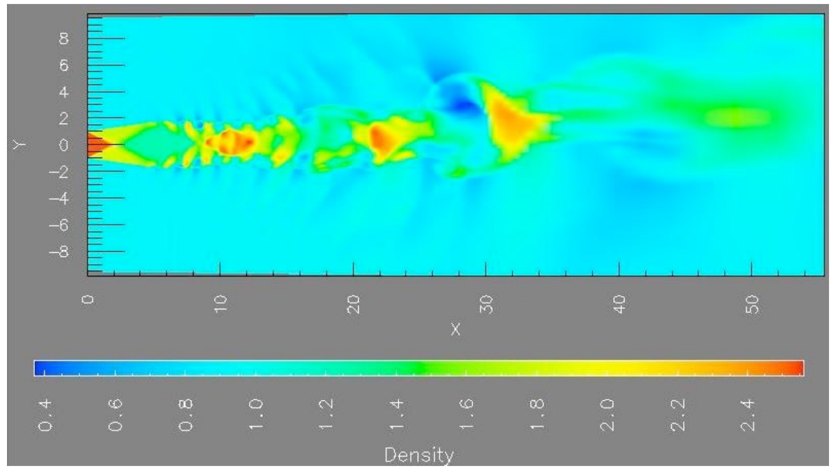


- problems
  - perceptually unordered
  - perceptually nonlinear

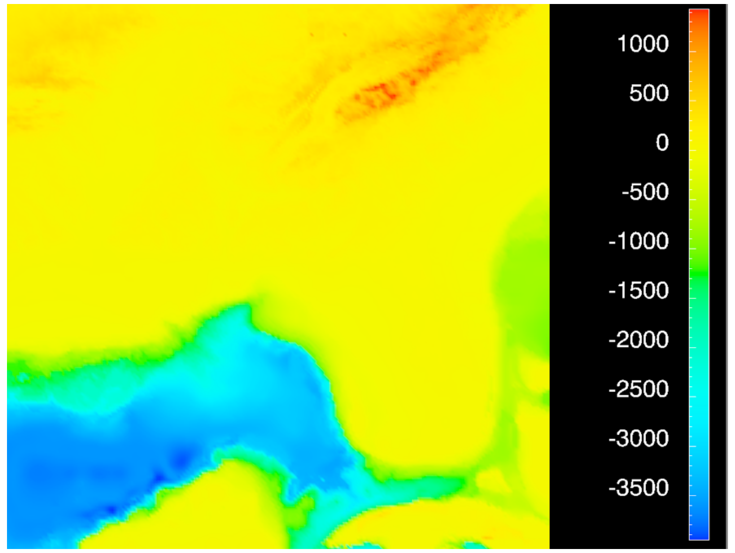
Ordered color: Rainbow is poor default

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





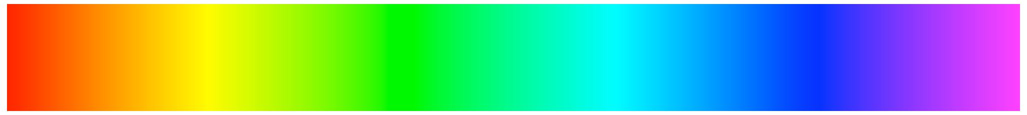
[A Rule-based Tool for Assisting Colormap Selection. Bergman,. Rogowitz, and. Treinish. Proc. IEEE Visualization (Vis), pp. 118–125, 1995.]

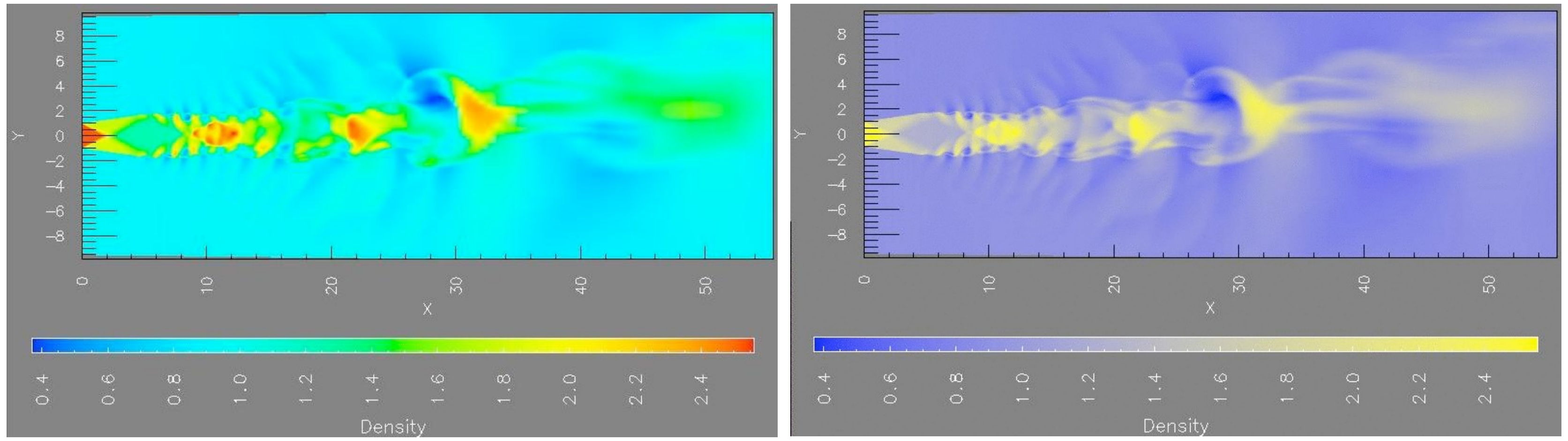


[Why Should Engineers Be Worried About Color? Treinish and Rogowitz 1998. http://www.research.ibm.com/people/l/lloydt/color/color.HTM]

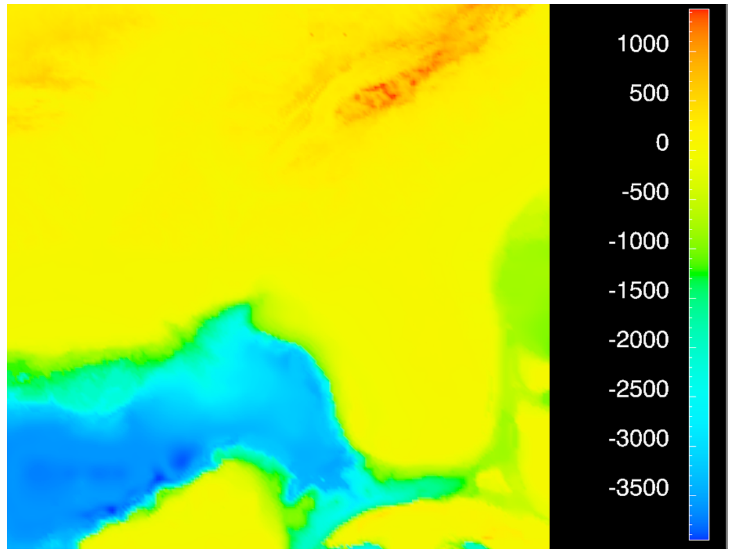
Ordered color: Rainbow is poor default

- problems
  - perceptually unordered
  - perceptually nonlinear
- benefits
  - fine-grained structure visible and nameable
- alternatives
  - large-scale structure: fewer hues





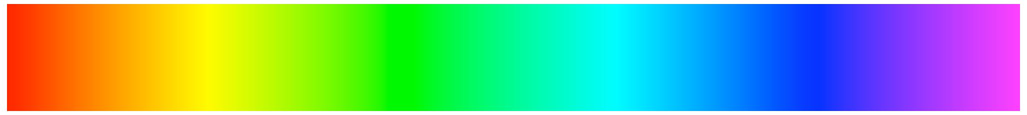
[A Rule-based Tool for Assisting Colormap Selection. Bergman,. Rogowitz, and. Treinish. Proc. IEEE Visualization (Vis), pp. 118–125, 1995.]

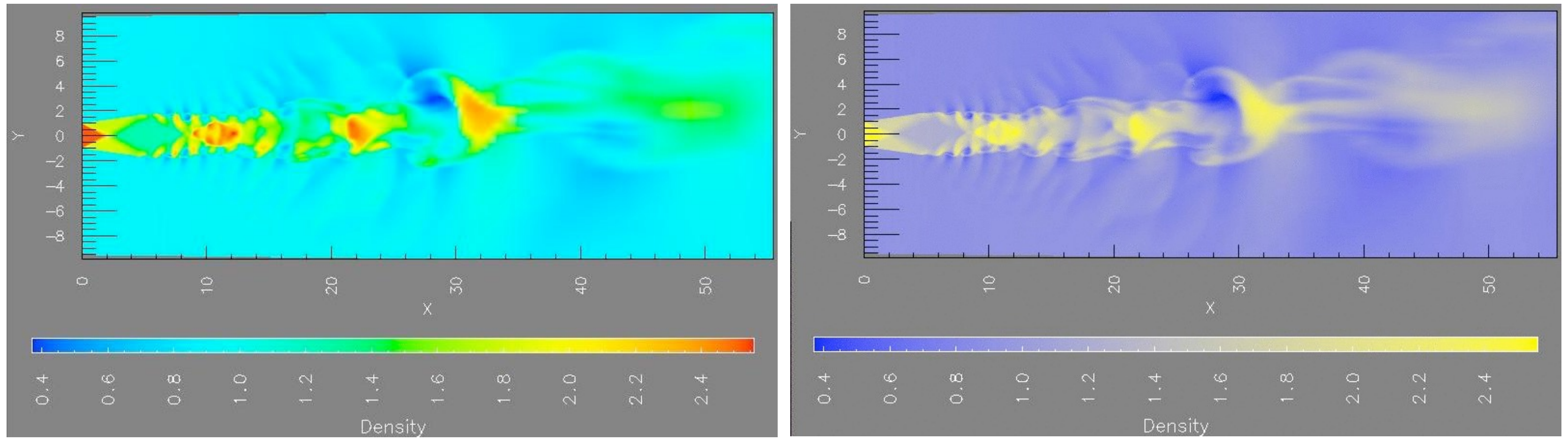


[Why Should Engineers Be Worried About Color? Treinish and Rogowitz 1998. http://www.research.ibm.com/people/l/lloydt/color/color.HTM]

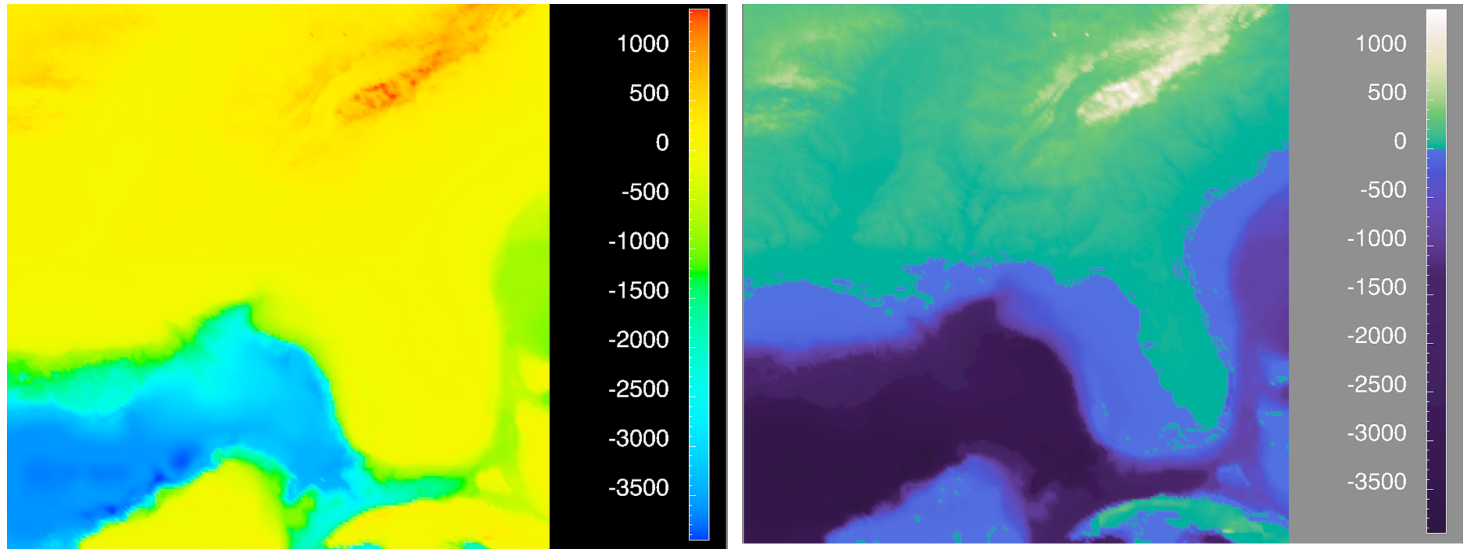
Ordered color: Rainbow is poor default

- problems
  - perceptually unordered
  - 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]





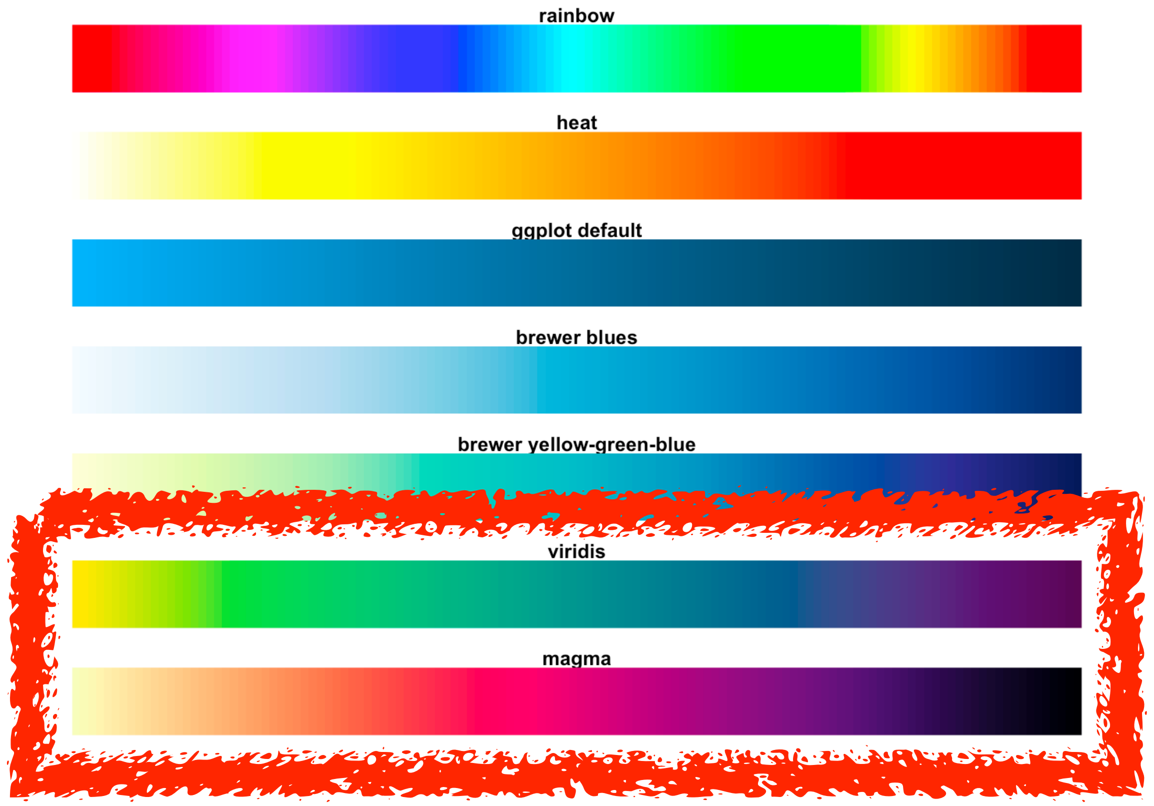
[A Rule-based Tool for Assisting Colormap Selection. Bergman,. Rogowitz, and. Treinish. Proc. IEEE Visualization (Vis), pp. 118–125, 1995.]

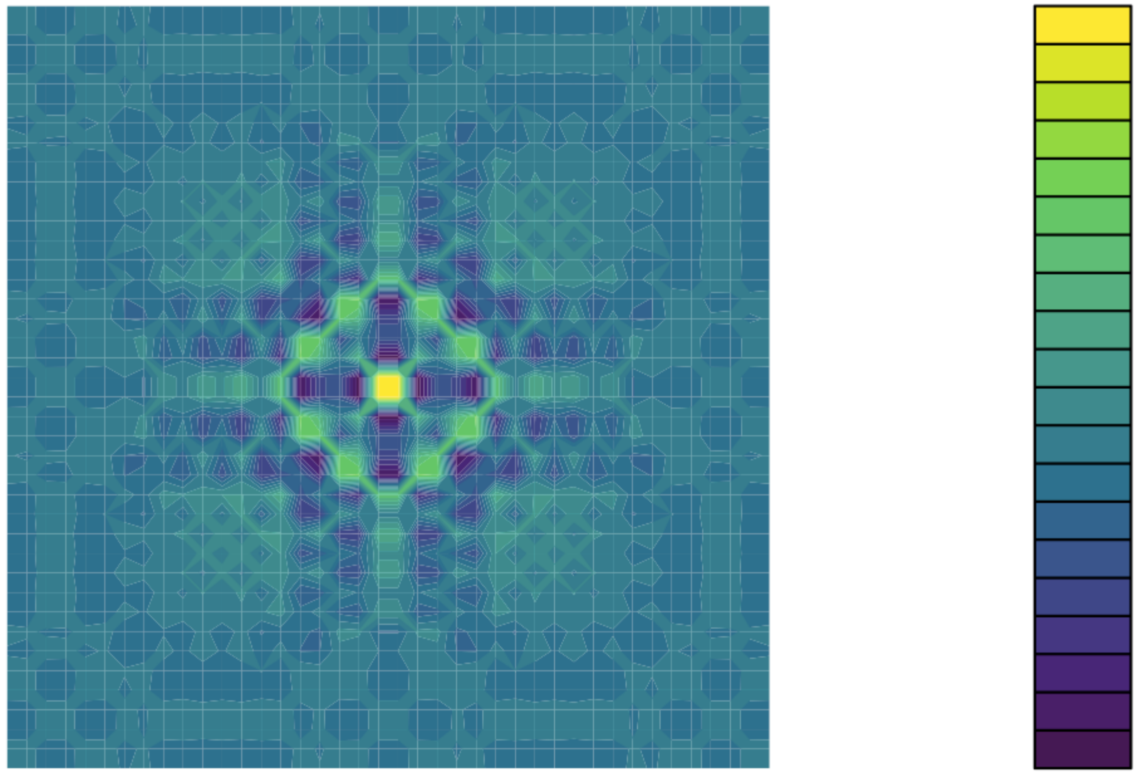


[Why Should Engineers Be Worried About Color? Treinish and Rogowitz 1998. http://www.research.ibm.com/people/l/lloydt/color/color.HTM]

Viridis / Magma

- monotonically increasing luminance, perceptually uniform
- colorful, colourblind-safe
  - R, python, D3

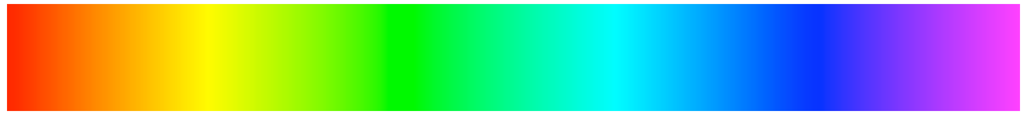


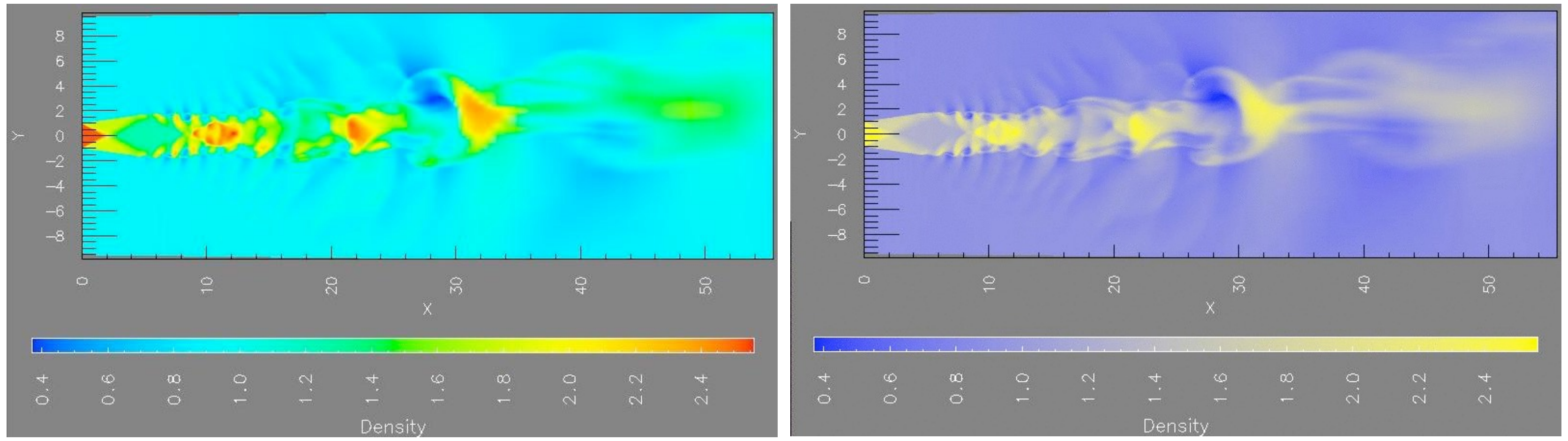


https://cran.r-project.org/web/packages/viridis/vignettes/intro-to-viridis.html

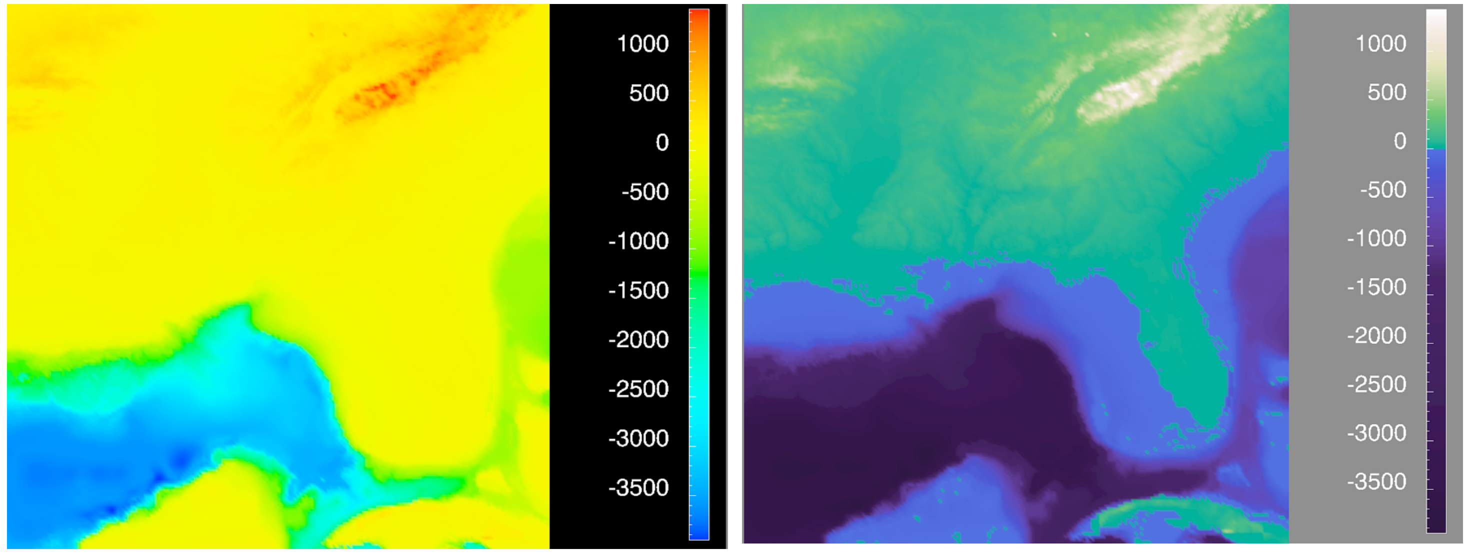
Ordered color: Rainbow is poor default

- problems
  - perceptually unordered
  - 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]
  - categorical: segmented saturated rainbow is good!

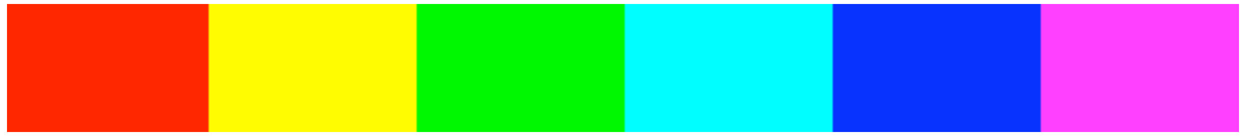




[A Rule-based Tool for Assisting Colormap Selection. Bergman,. Rogowitz, and. Treinish. Proc. IEEE Visualization (Vis), pp. 118–125, 1995.]



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

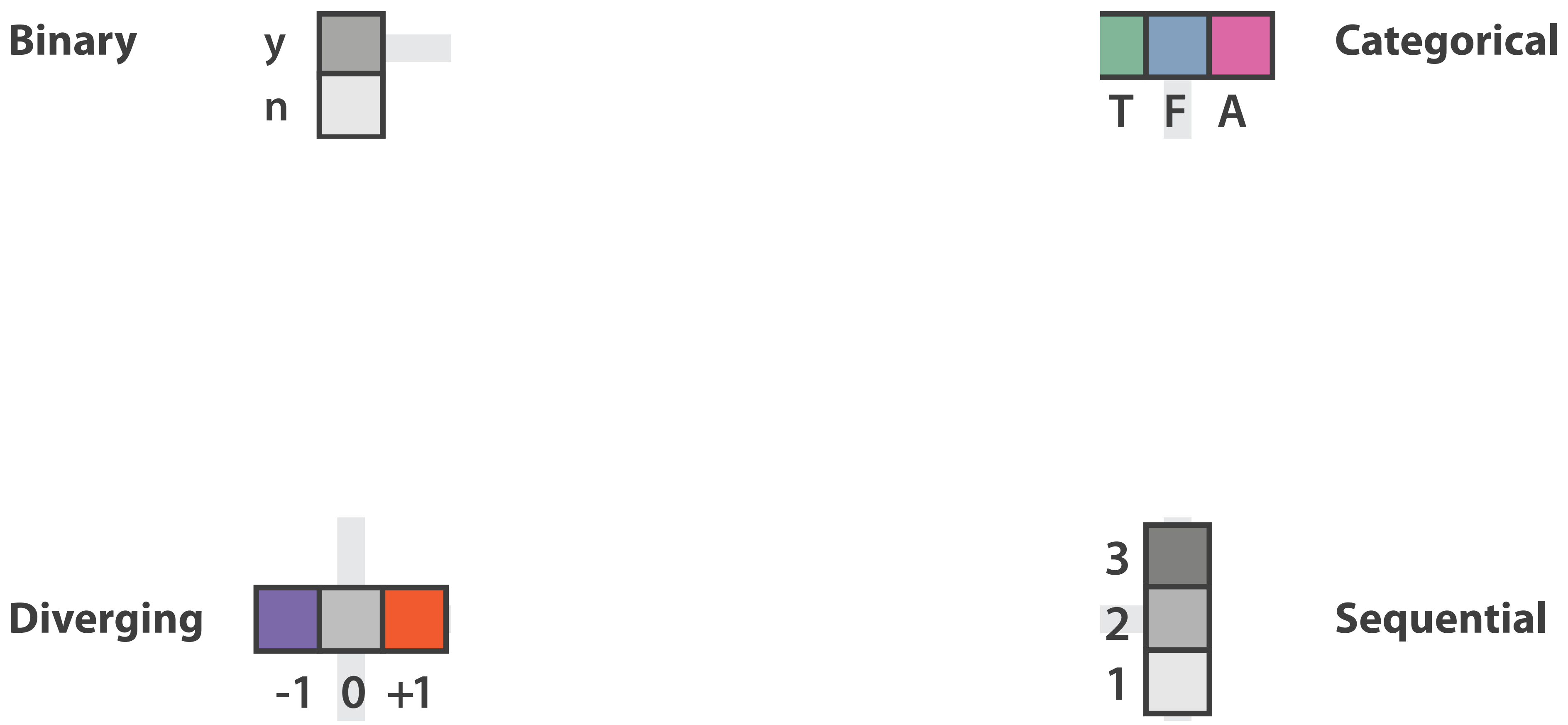


[Transfer Functions in Direct Volume Rendering: Design, Interface, Interaction. Kindlmann. SIGGRAPH 2002 Course Notes]

Colormaps

- Categorical

- Ordered
  - *Sequential*
  - *Diverging*



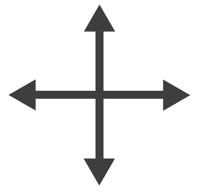
after [Color Use Guidelines for Mapping and Visualization. Brewer, 1994. http://www.personal.psu.edu/faculty/c/a/cab38/ColorSch/Schemes.html]

Colormaps

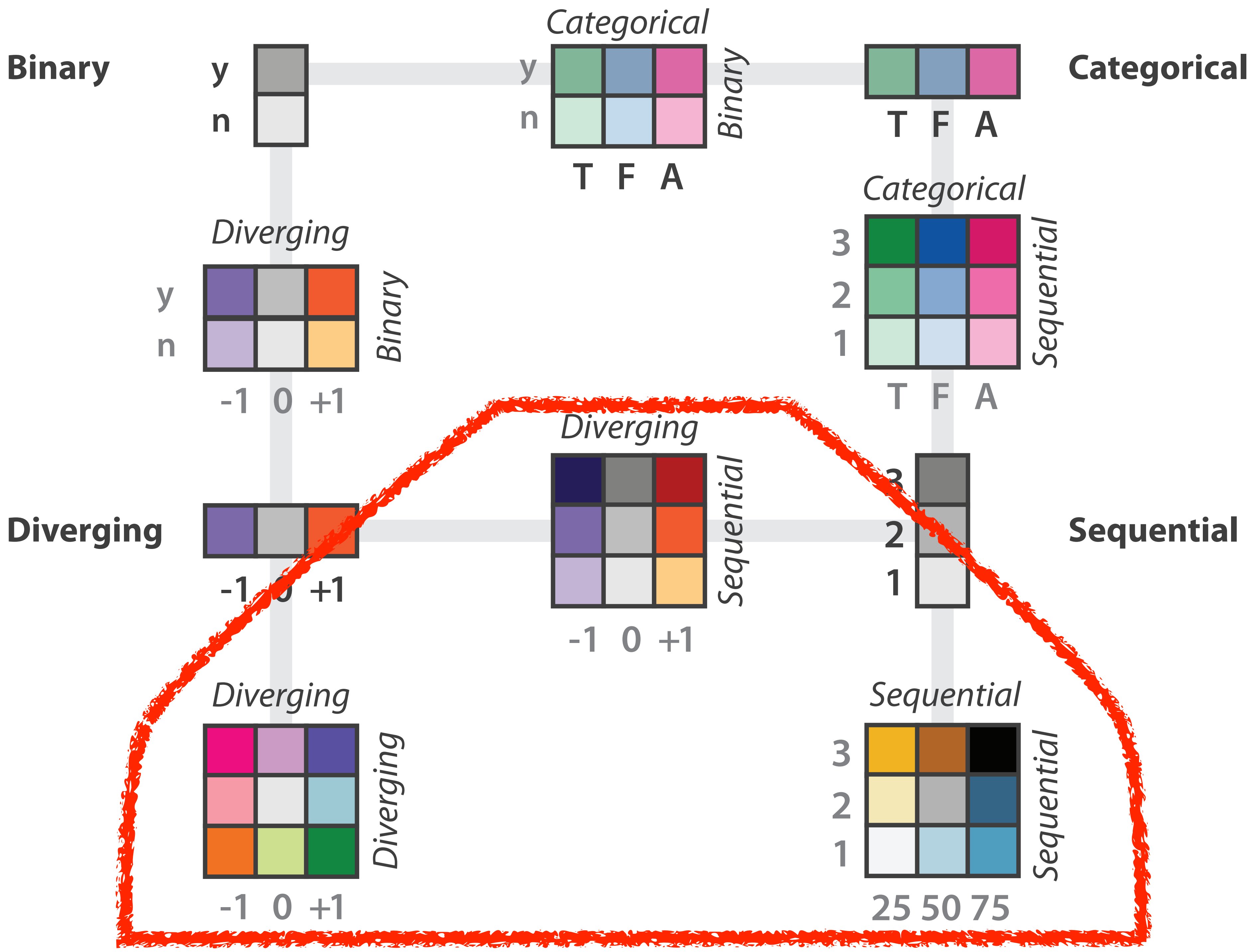
- → Categorical

- → Ordered
  - → *Sequential*
  - → *Diverging*

- → Bivariate



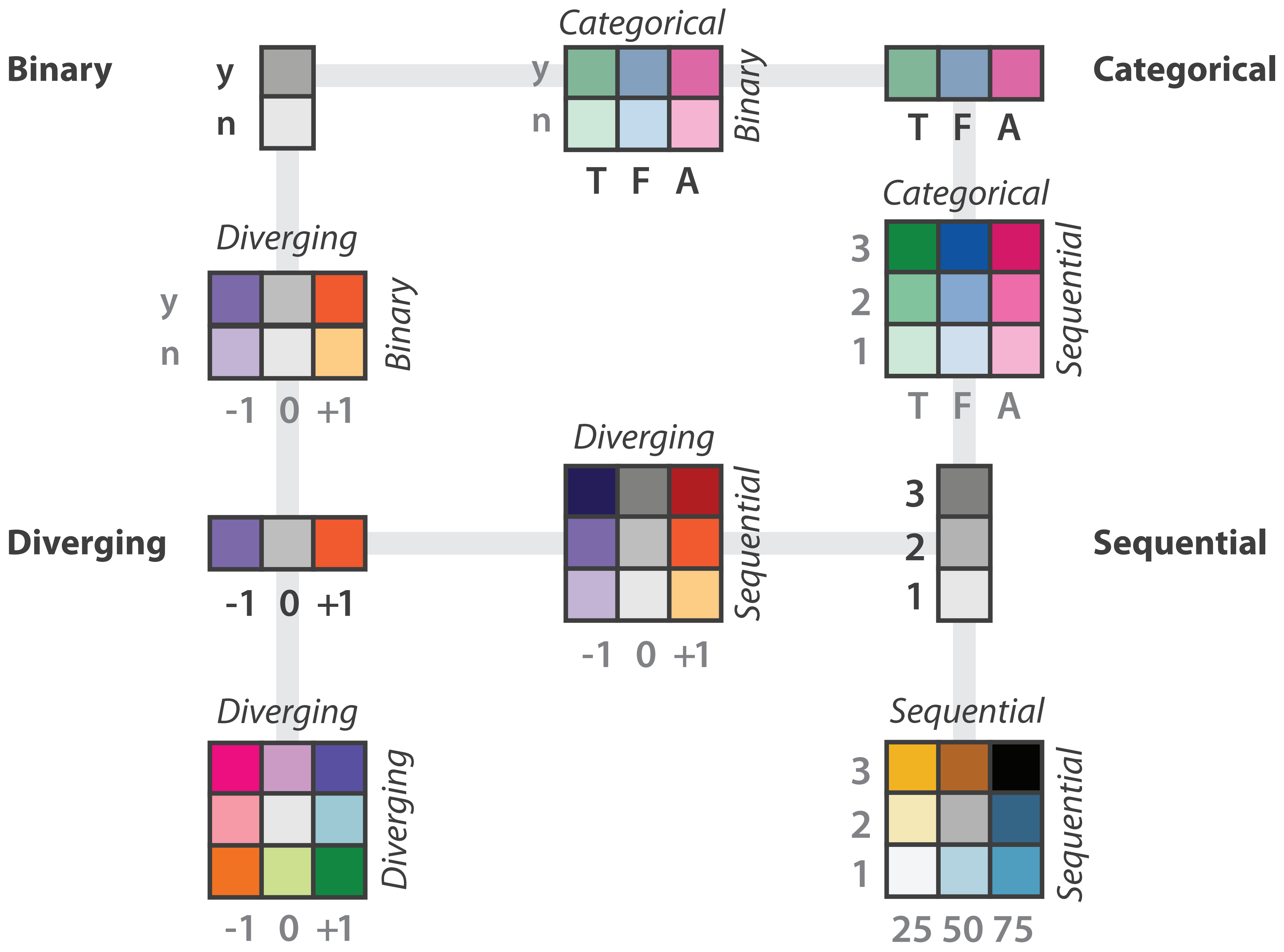
use with care if more than two levels (binary)!



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]

Further reading

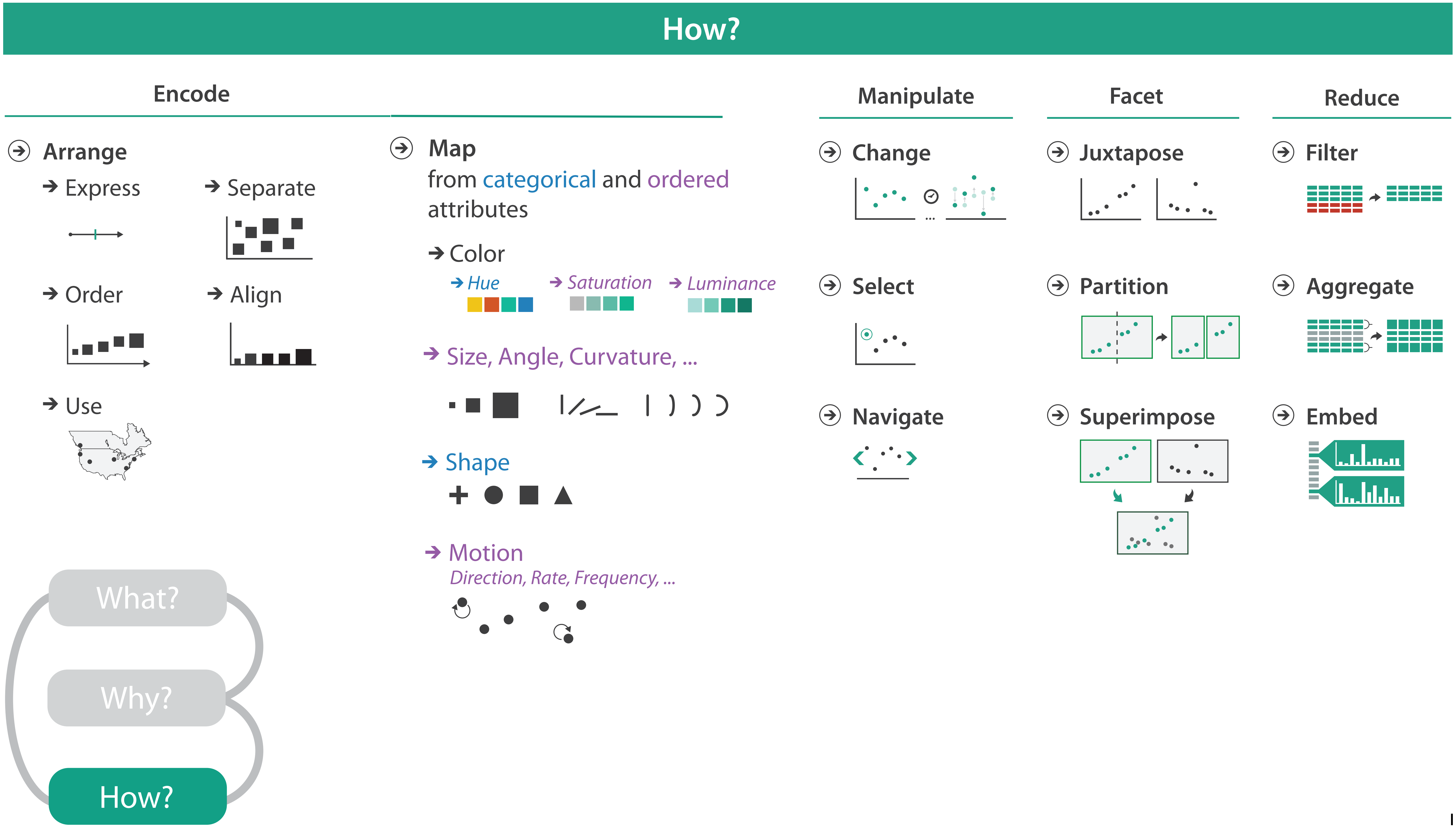
- Visualization Analysis and Design. Munzner. AK Peters Visualization Series, CRC Press, Nov 2014.
  - *Chap 10: Map Color and Other Channels*
- ColorBrewer, Brewer.
  - http://www.colorbrewer2.org
- *Color In Information Display*. Stone. IEEE Vis Course Notes, 2006.
  - http://www.stonesc.com/Vis06
- A Field Guide to Digital Color. Stone. AK Peters, 2003.
- *Rainbow Color Map (Still) Considered Harmful.* Borland and Taylor. IEEE Computer Graphics and Applications 27:2 (2007), 14–17.
- Visual Thinking for Design. Ware. Morgan Kaufmann, 2008.
- Information Visualization: Perception for Design, 3rd edition. Ware. Morgan Kaufmann /Academic Press, 2004.
- http://www.r-bloggers.com/using-the-new-viridis-colormap-in-r-thanks-to-simon-garnier/

Visualization Analysis & Design, Half-Day Tutorial

- Session 1
  - Analysis: What, Why, How
  - Marks and Channels
  - Arrange Tabular & Spatial Data
- Session 2
  - Arrange Networks and Trees
  - Map Color and Other Channels
  - Manipulate & Facet
  - Reduce: Filter, Aggregate

@tamaramunzner **@tamara@vis.social**

http://www.cs.ubc.ca/~tmm/talks.html#halfdaycourse23


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?

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

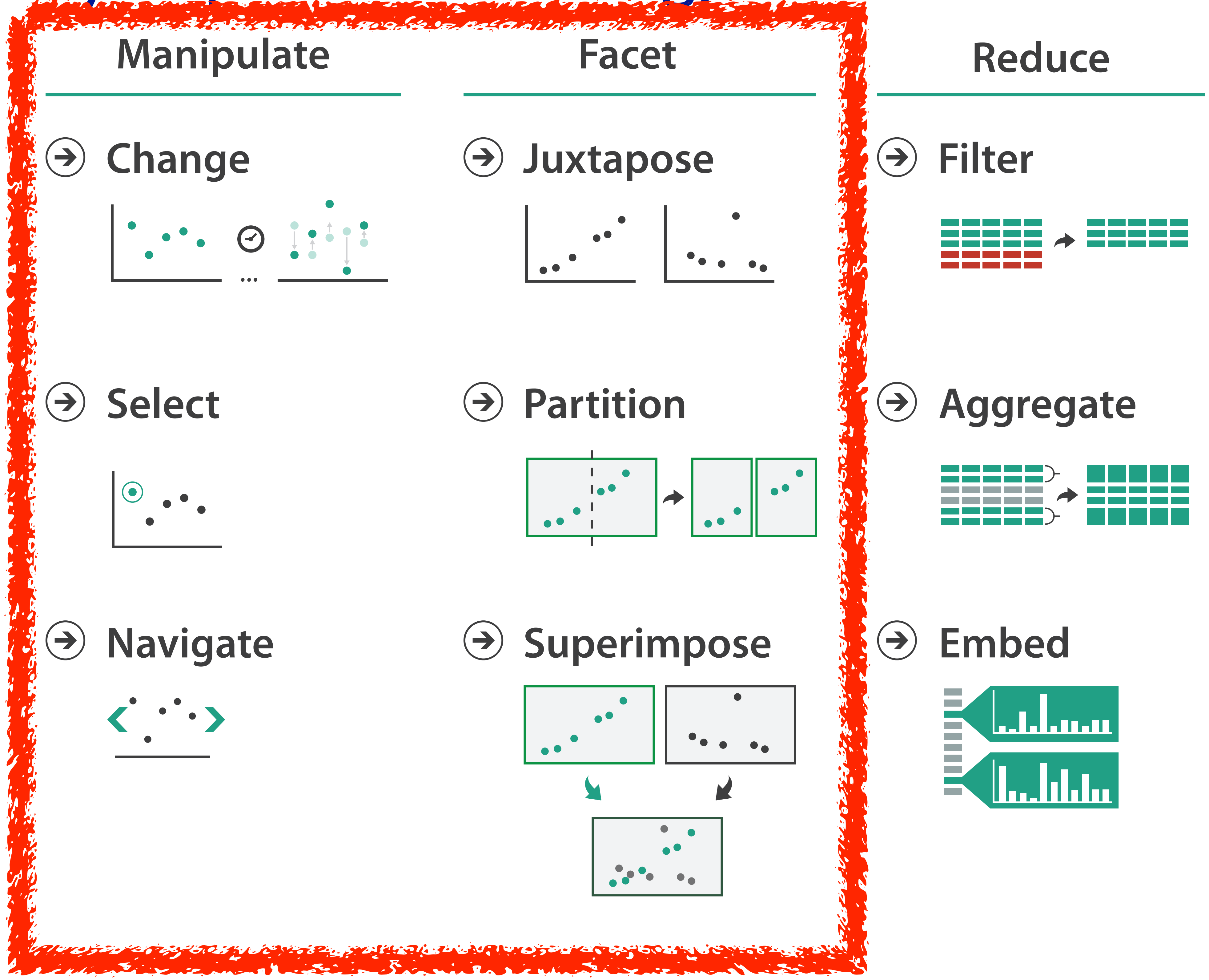
What?

Why?

How?

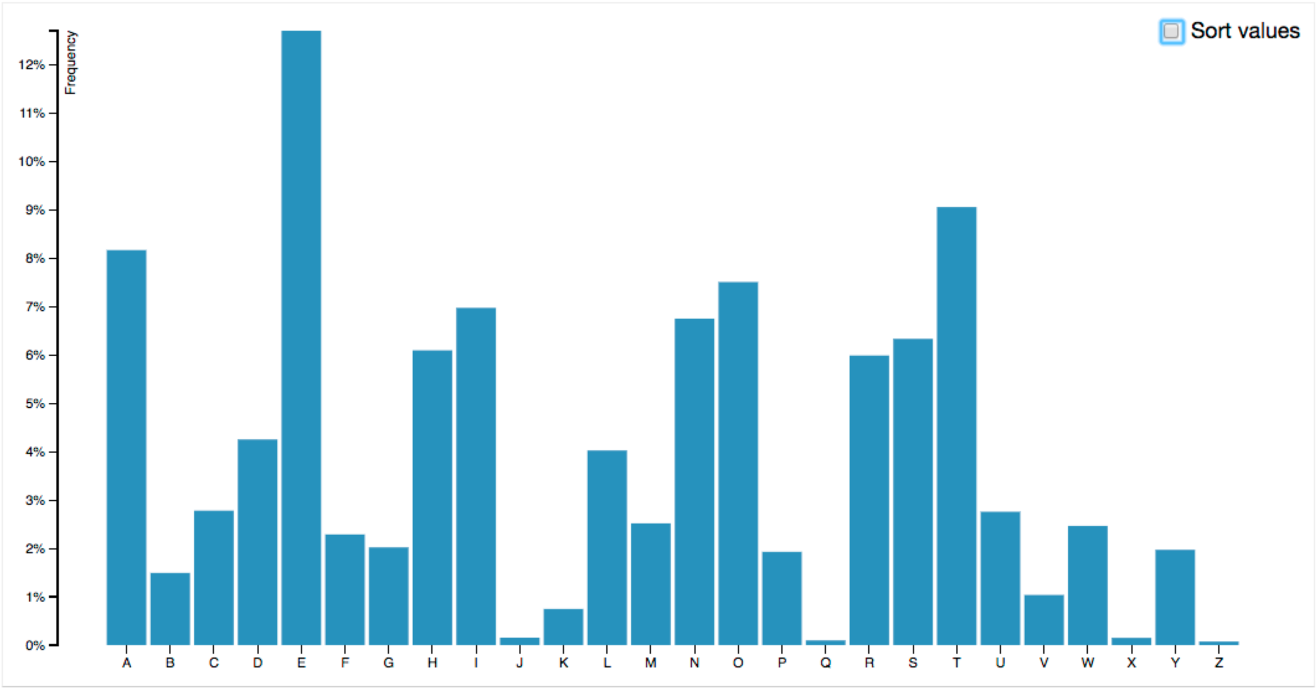
How to handle complexity: 1 previous strategy + 3 more

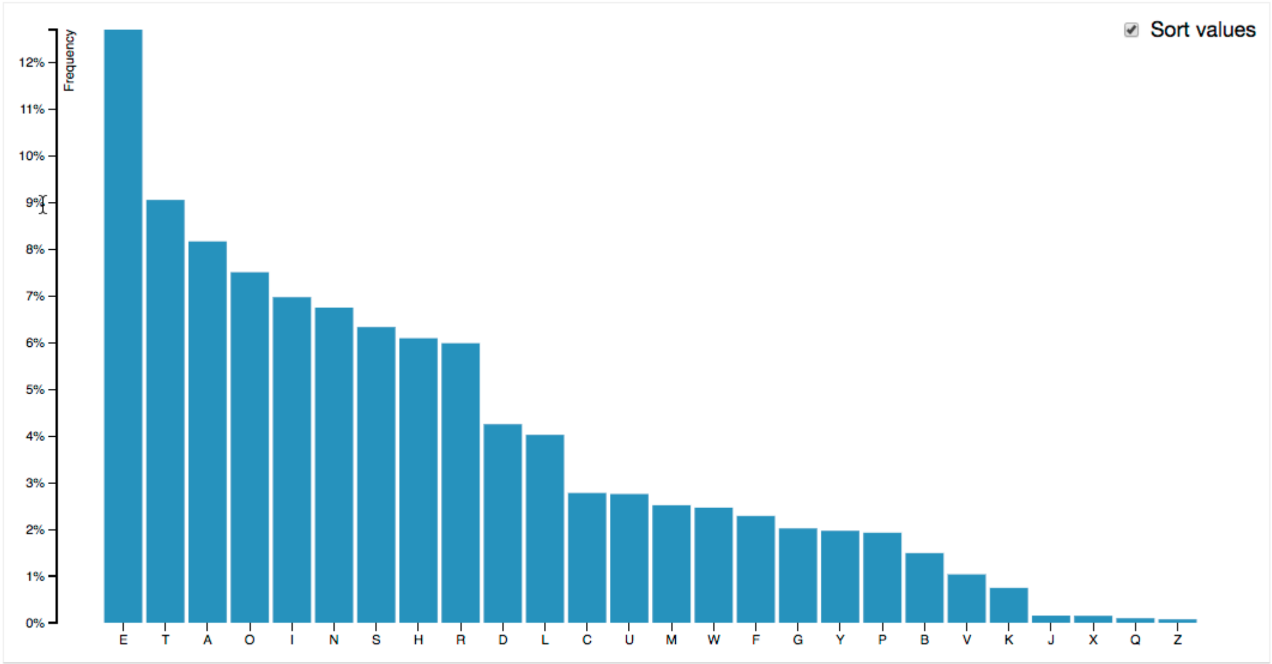
- derive new data to show within view
- change view over time
- facet across multiple views
- reduce items/attributes within single view



Idiom: **Change order/arrangement**

- what: simple table
- how: data-driven reordering
- why: find extreme values, trends



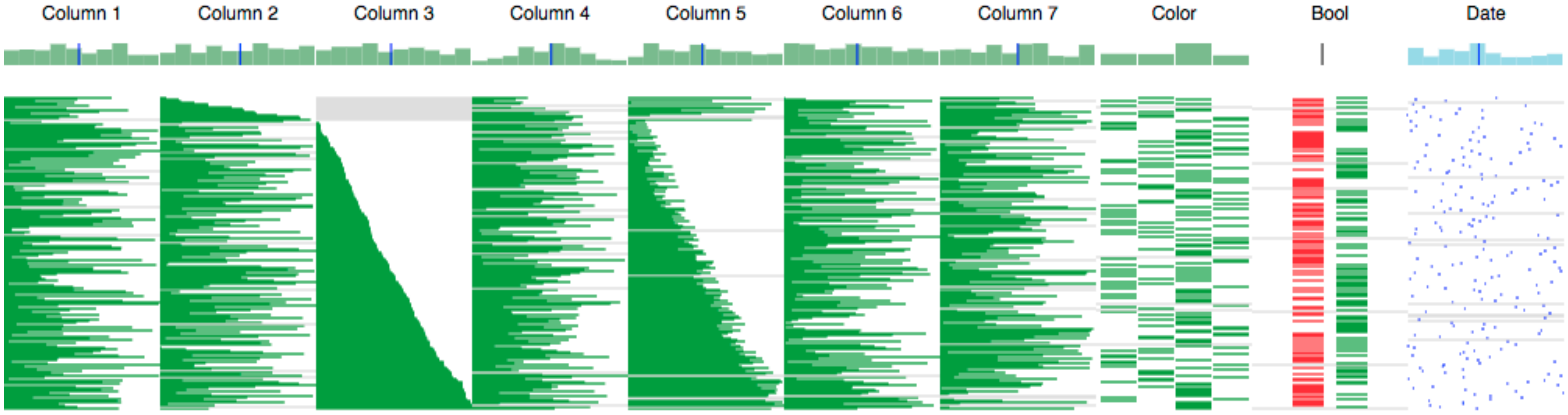


[Sortable Bar Chart](https://bl.ocks.org/mbostock/3885705)

Idiom: **Change order**

System: **DataStripes**

- what: table with many attributes
- how: data-driven reordering by selecting column
- why: find correlations between attributes



[http://carlmanaster.github.io/datastripes/]

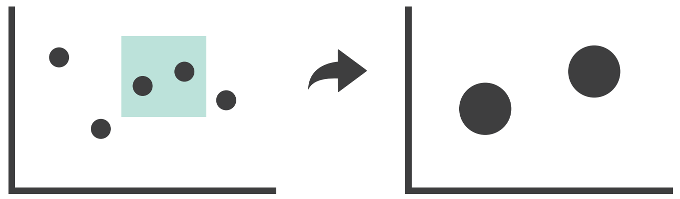
Navigate: Changing item visibility

- change viewpoint
  - changes which items are visible within view
  - camera metaphor
    - zoom
      - geometric zoom: familiar semantics
      - semantic zoom: adapt object representation based on available pixels
        - » dramatic change, or more subtle one
    - pan/translate
    - rotate
      - especially in 3D
  - constrained navigation
    - often with animated transitions
    - often based on selection set

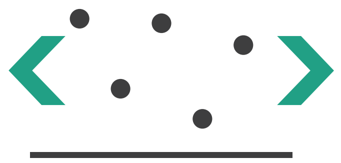
Navigate

→ Item Reduction

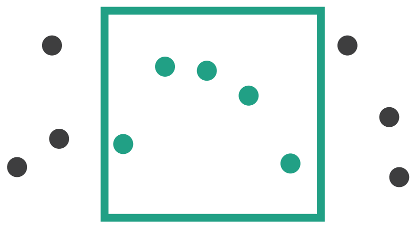
→ *Zoom*
Geometric or *Semantic*



→ *Pan/Translate*

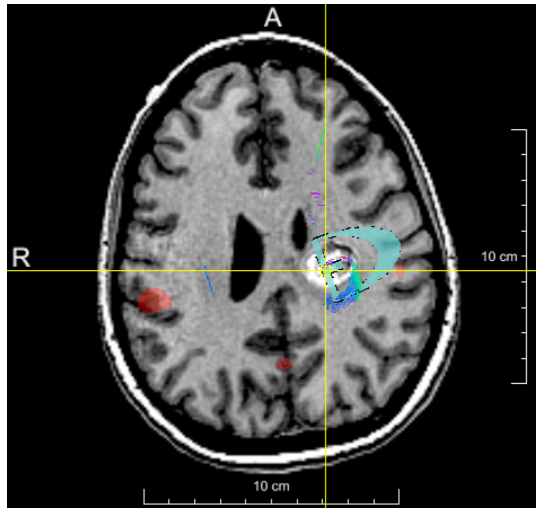


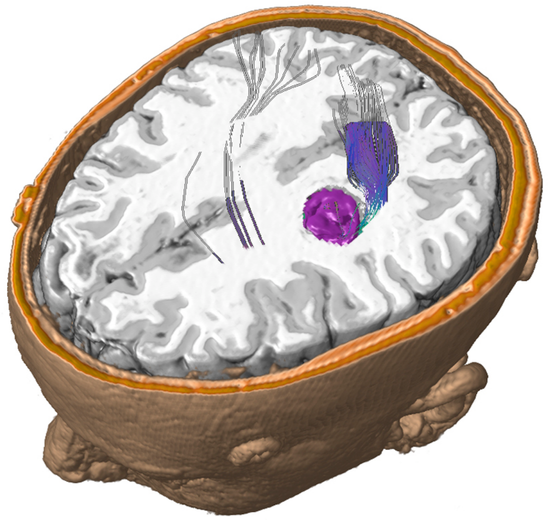
→ *Constrained*

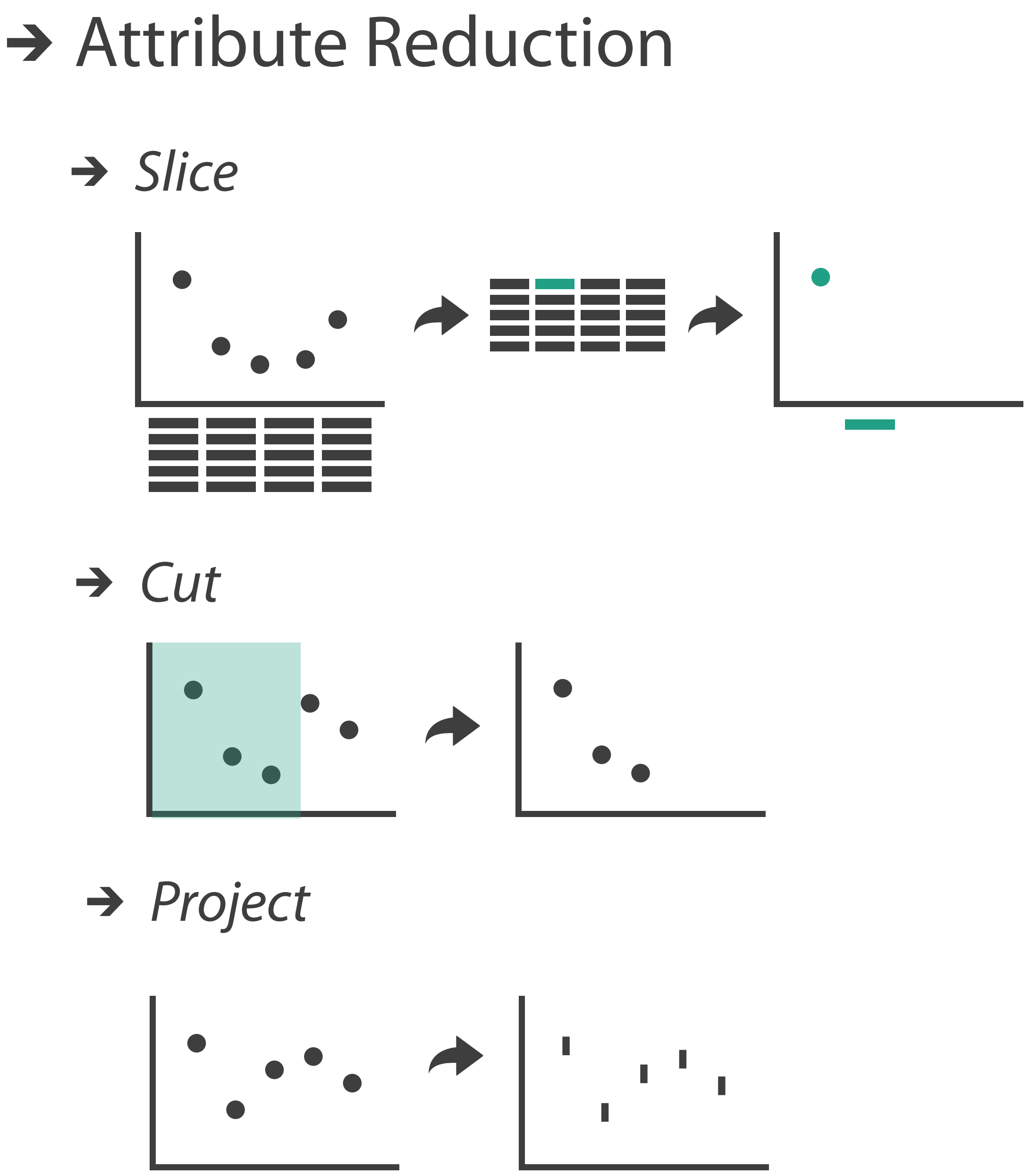


Navigate: Reducing attributes

- continuation of camera metaphor
  - slice
    - show only items matching specific value for given attribute: slicing plane
    - axis aligned, or arbitrary alignment
  - cut
    - show only items on far slide of plane from camera
  - project
    - change mathematics of image creation
      - orthographic
      - perspective
      - many others: Mercator, cabinet, ...



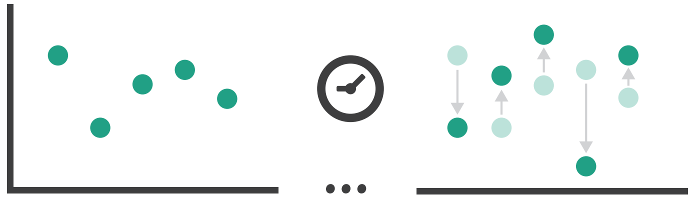




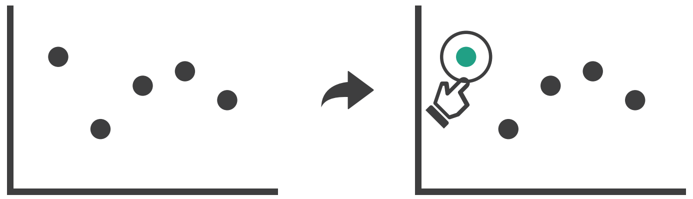
[Interactive Visualization of Multimodal Volume Data for Neurosurgical Tumor Treatment. Rieder, Ritter, Raspe, and Peitgen. Computer Graphics Forum (Proc. EuroVis 2008) 27:3 (2008), 1055–1062.]

Manipulate

➔ Change over Time



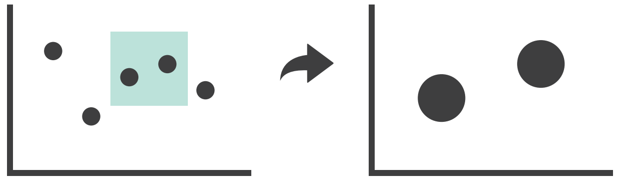
➔ Select



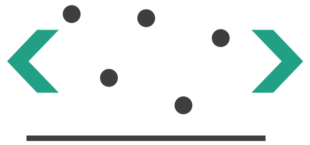
➔ Navigate

➔ Item Reduction

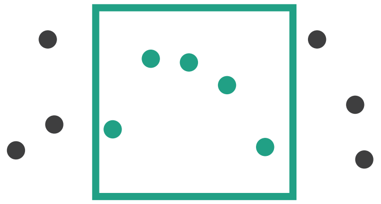
➔ *Zoom*
Geometric or *Semantic*



➔ *Pan/Translate*



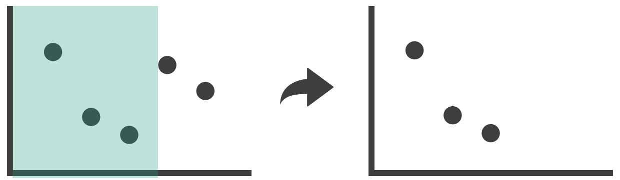
➔ *Constrained*



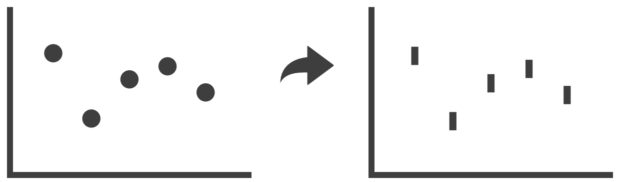
➔ Attribute Reduction

➔ *Slice*

➔ *Cut*

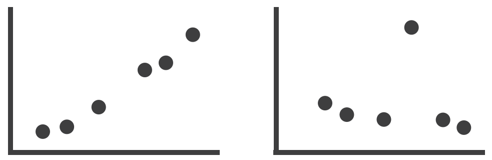


➔ *Project*

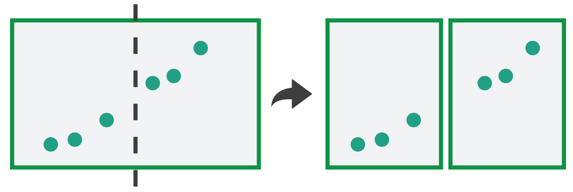


Facet

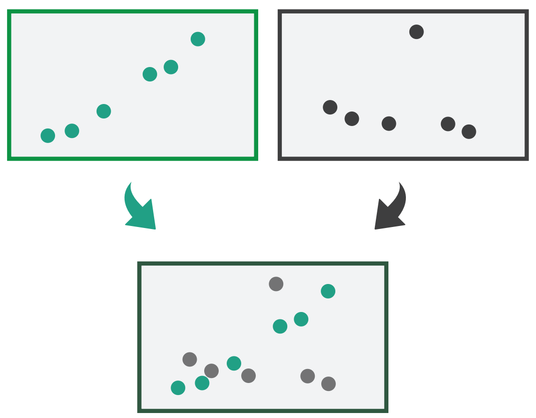
- Juxtapose



- Partition



- Superimpose



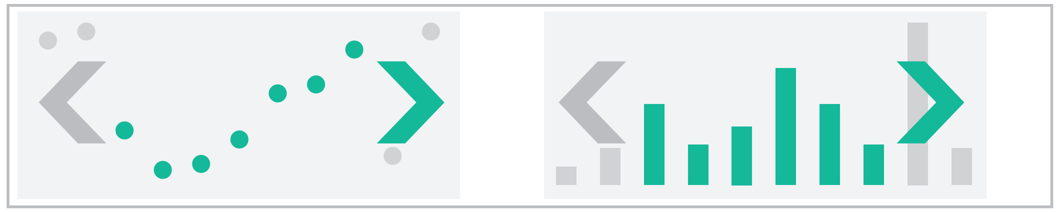
Juxtapose and coordinate views

➔ Share Encoding: Same/Different

➔ *Linked Highlighting*

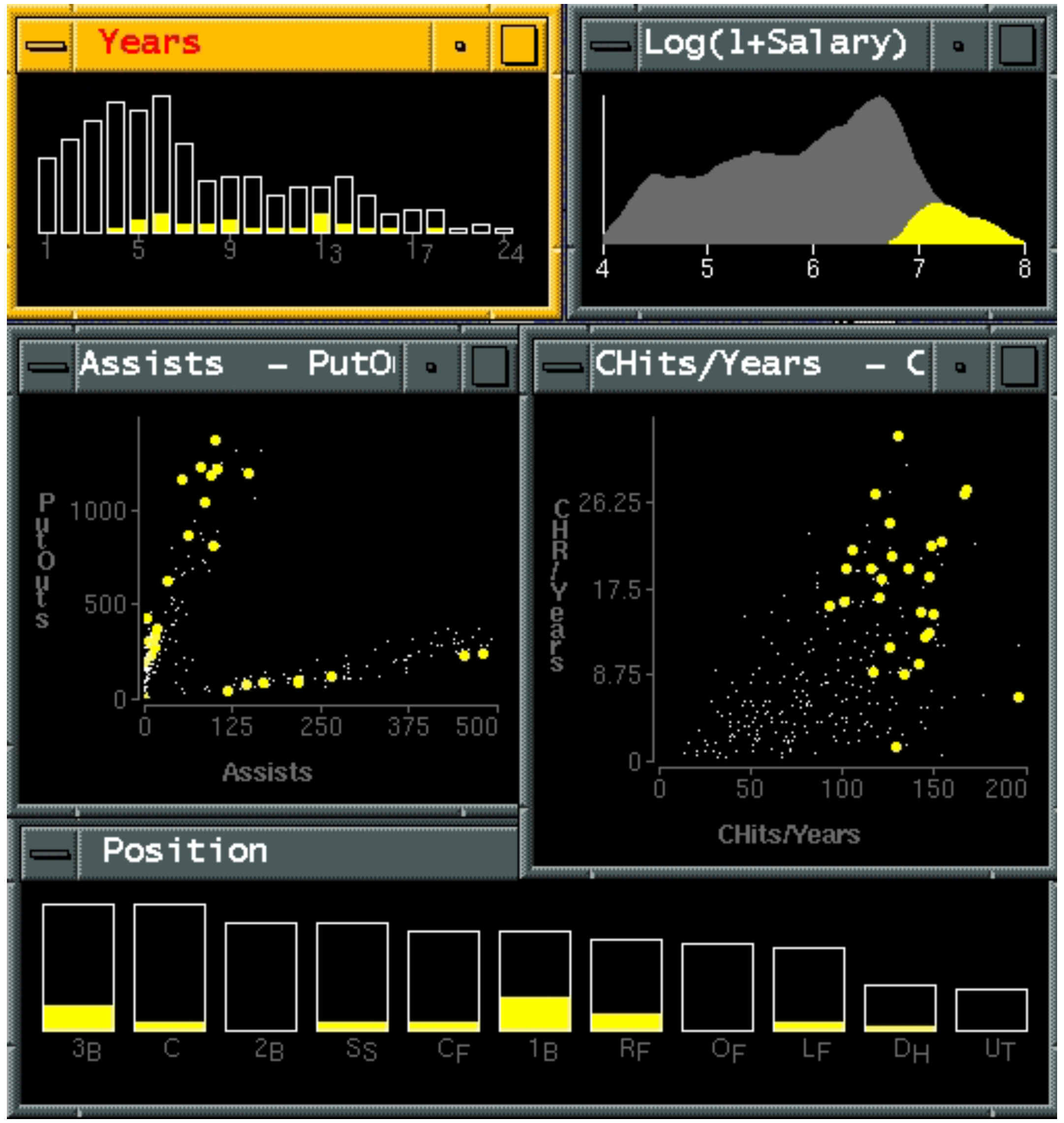
➔ Share Data: All/Subset/None

➔ Share Navigation



Idiom: **Linked highlighting**

System: **EDV**



- see how regions contiguous in one view are distributed within another
  - powerful and pervasive interaction idiom
- encoding: different
  - *multiform*
- data: all shared
  - all **items** shared
  - different **attributes** across the views
- aka: brushing and linking

[Visual Exploration of Large Structured Datasets. Wills. Proc. New Techniques and Trends in Statistics (NTTS), pp. 237–246. IOS Press, 1995.]

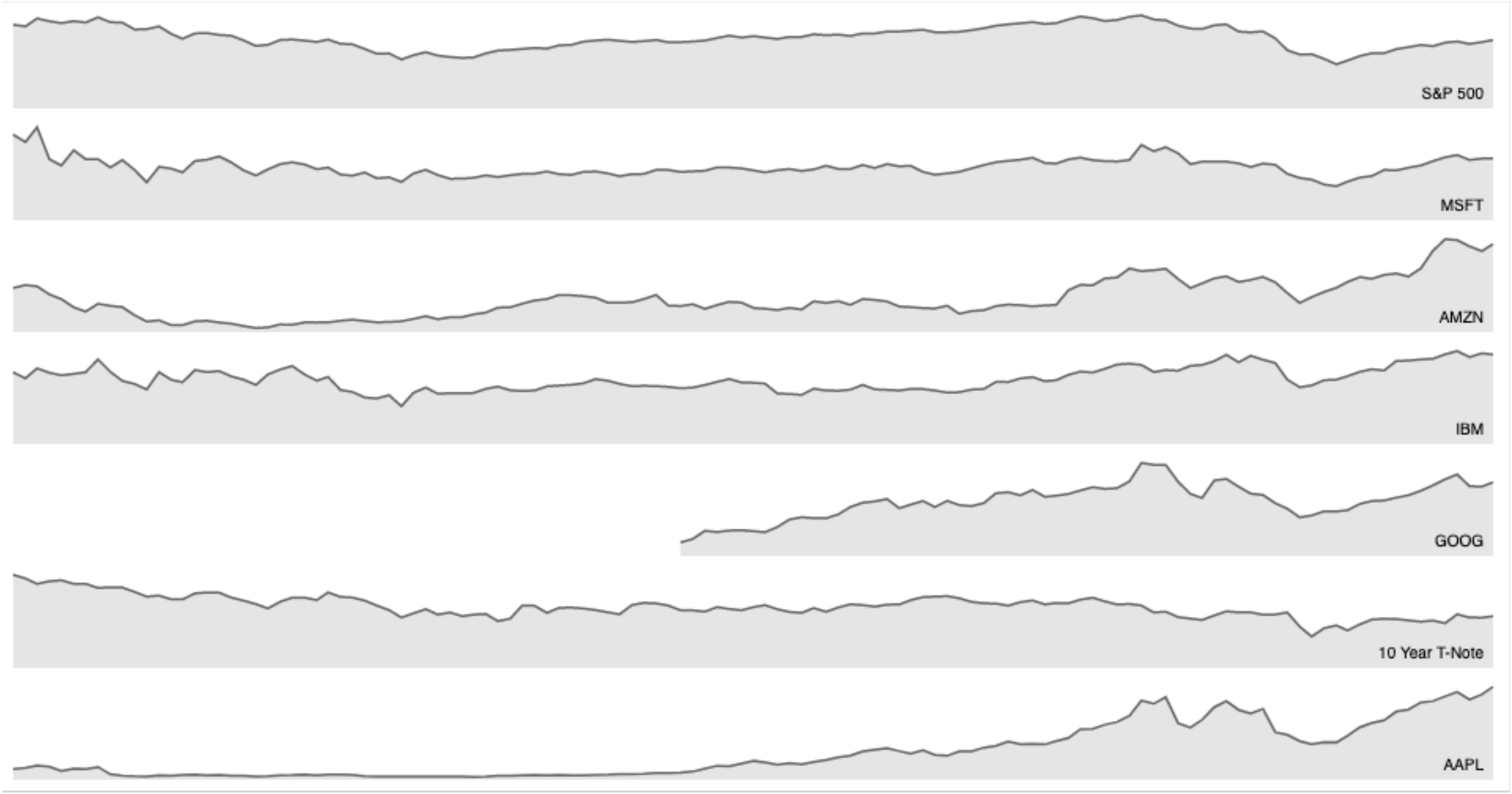
Idiom: **Overview-detail views** System: **Google Maps**

- encoding: same or different
  - ex: same (birds-eye map)
- data: subset shared
  - viewpoint differences: subset of data items
- navigation: shared
  - bidirectional linking
- other differences
  - (window size)

[A Review of Overview+Detail, Zooming, and Focus+Context Interfaces. Cockburn, Karlson, and Bederson. ACM Computing Surveys 41:1 (2008), 1–31.]

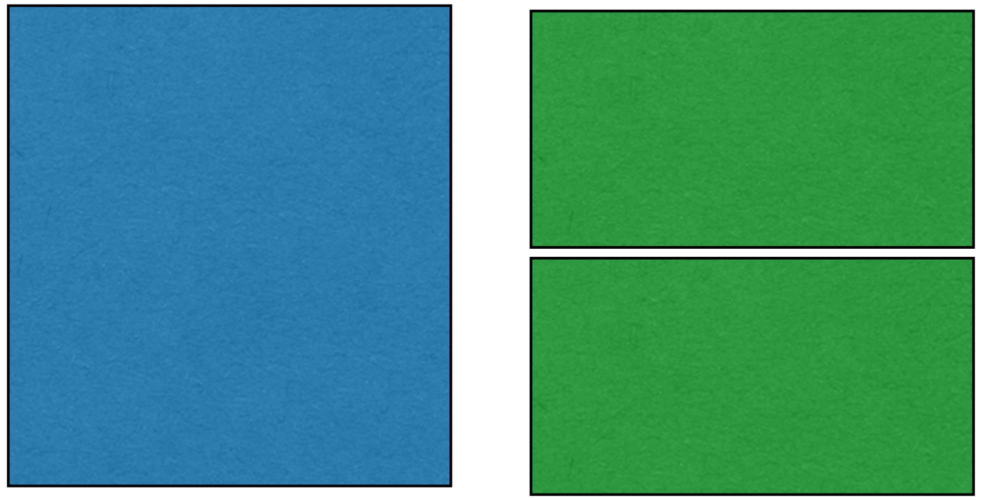
Idiom: **Small multiples**

- encoding: same
  - ex: line charts
- data: none shared
  - different slices of dataset
    - items or attributes
    - ex: stock prices for different companies



[https://bl.ocks.org/mbostock/1157787]

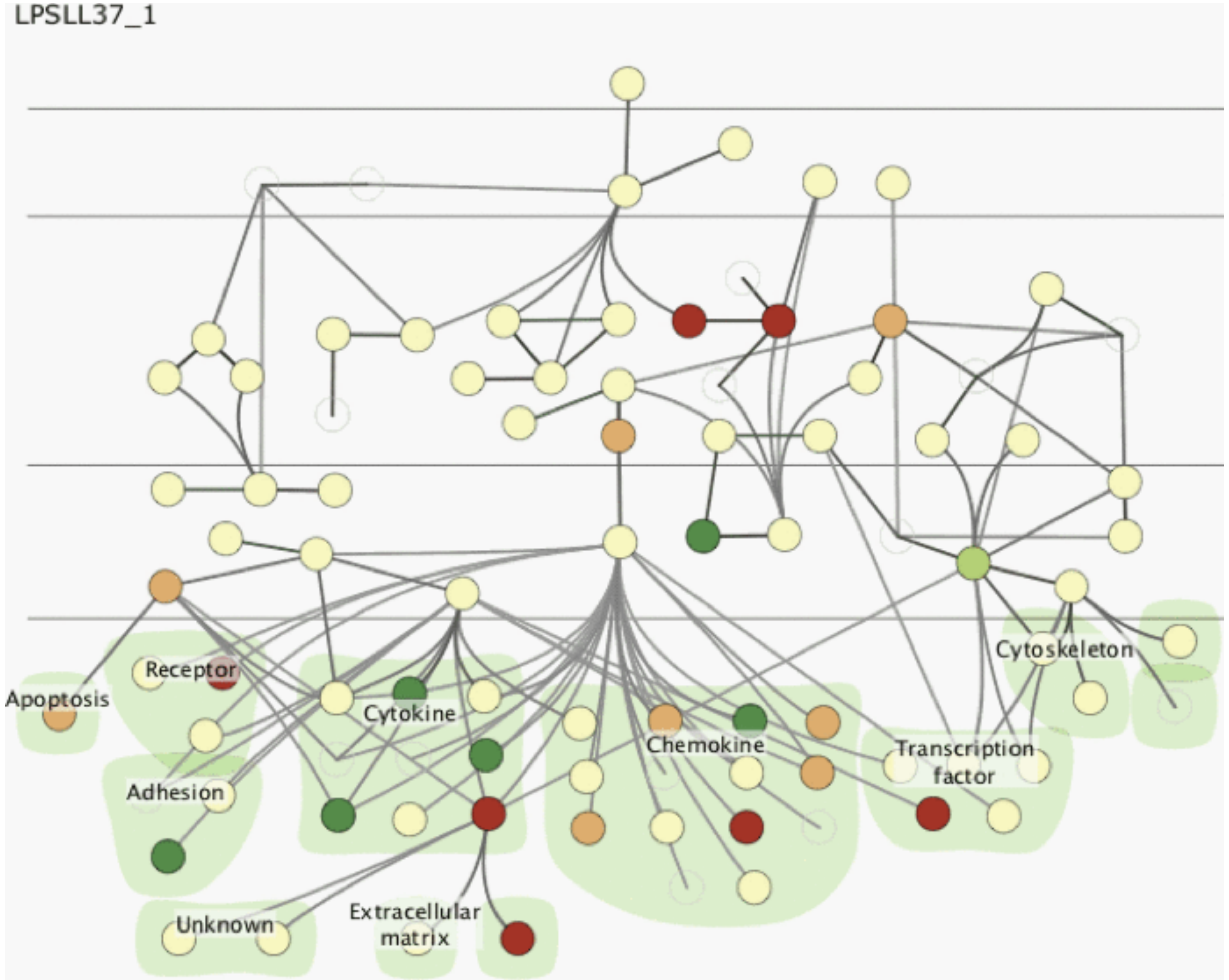
Juxtapose views: tradeoffs



- juxtapose costs
  - display area
    - 2 views side by side: each has only half the area of one view
- juxtapose benefits
  - cognitive load: eyes vs memory
    - lower cognitive load: move eyes between 2 views
    - higher cognitive load: compare single changing view to memory of previous state

Juxtapose vs animate

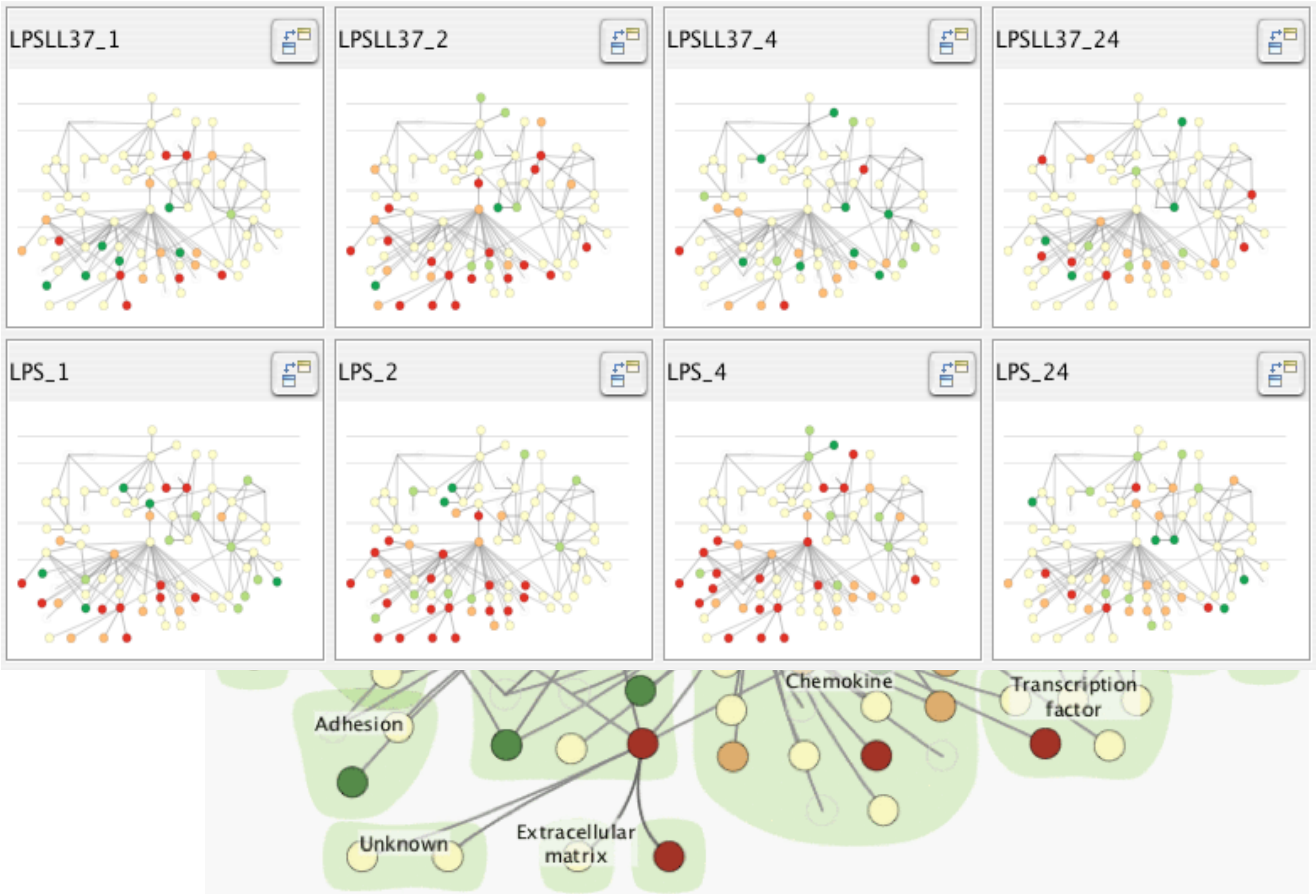
- animate: hard to follow if many scattered changes or many frames
  - vs easy special case: animated transitions



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

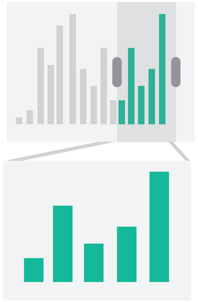
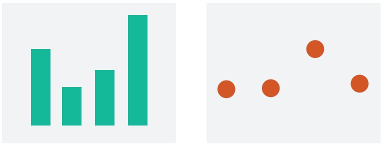
Juxtapose vs animate

- animate: hard to follow if many scattered changes or many frames
  - vs easy special case: animated transitions
- juxtapose: easier to compare across small multiples
  - different conditions (color), same gene (layout)



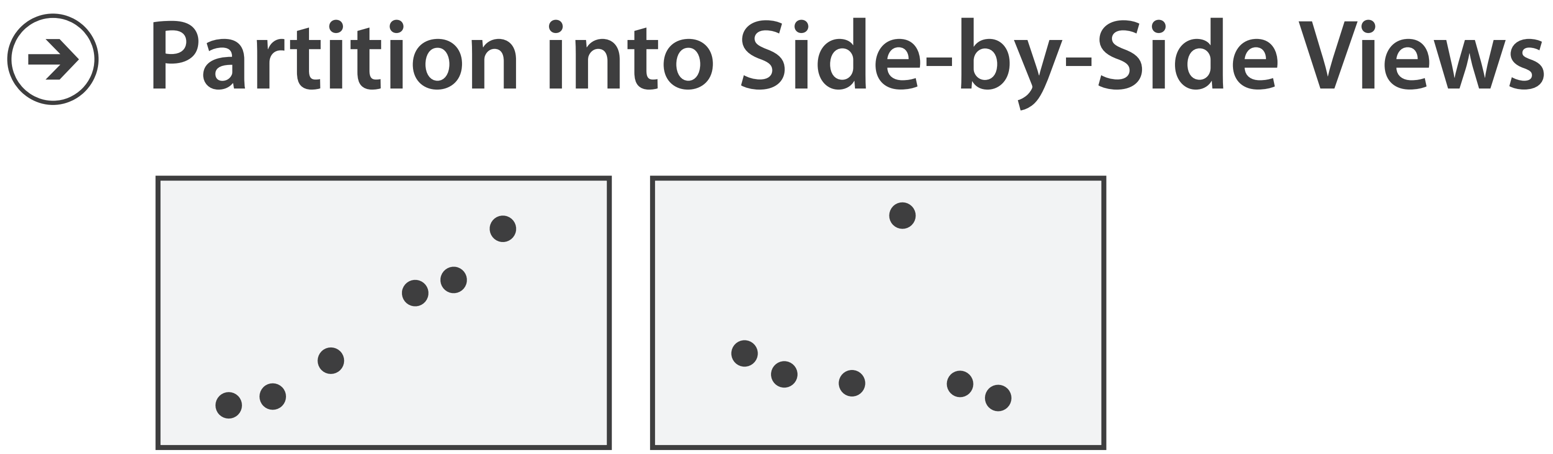
[Cerebral: Visualizing Multiple Experimental Conditions on a Graph with Biological Context. Barsky, Munzner, Gardy, and Kincaid. IEEE Trans. Visualization and Computer Graphics (Proc. InfoVis 2008) 14:6 (2008), 1253–1260.]

Coordinate views: Design choice interaction

		Data		
		All	Subset	None
Encoding	Same	Redundant	 Overview/ Detail	 Small Multiples
	Different	 Multiform	 Multiform, Overview/ Detail	No Linkage

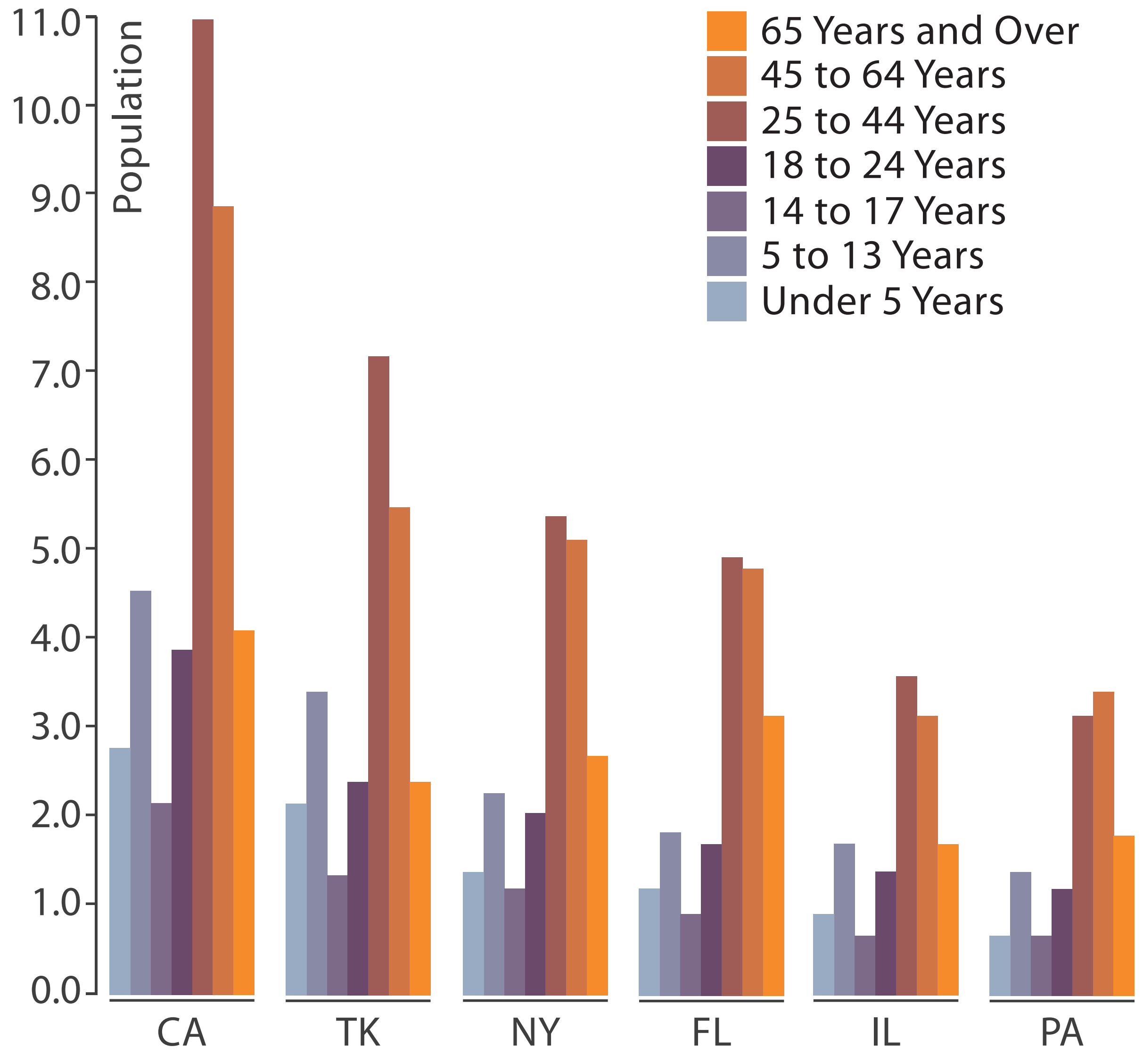
Partition into views

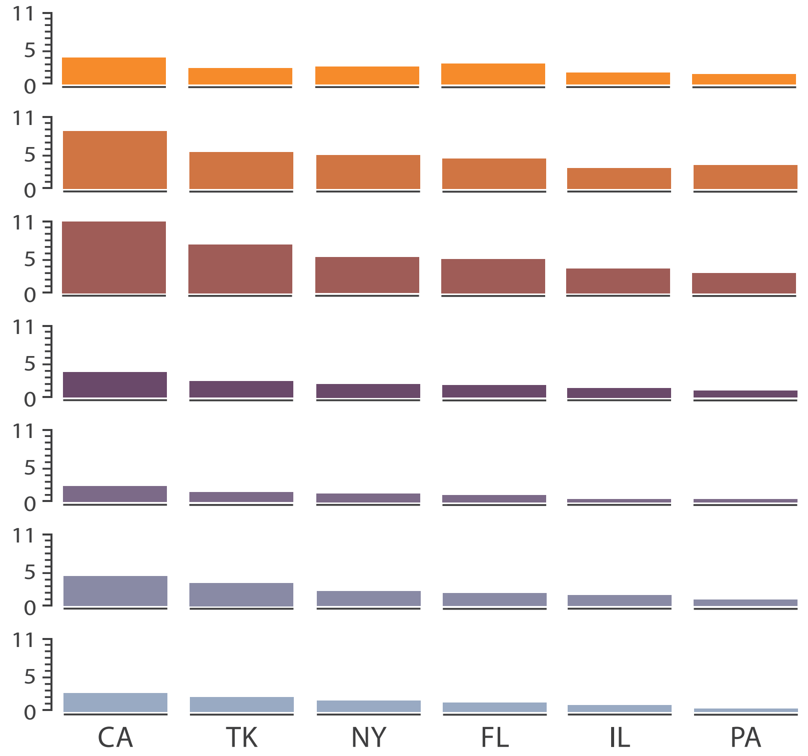
- how to divide data between views
  - split into regions by attributes
  - encodes association between items using spatial proximity
  - order of splits has major implications for what patterns are visible



Partitioning: List alignment

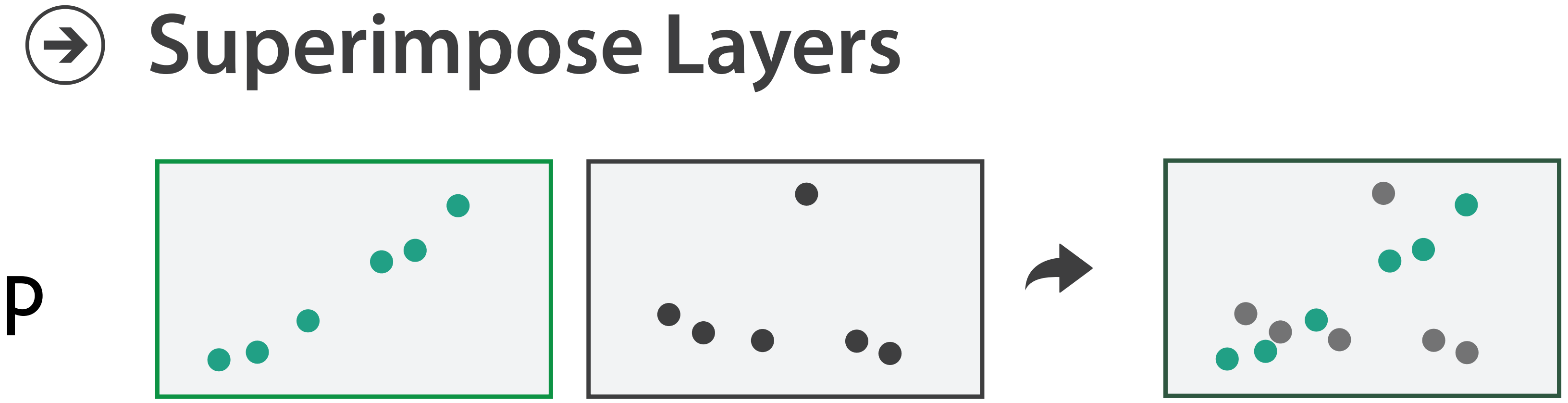
- single bar chart with grouped bars
  - split by state into regions
    - complex glyph within each region showing all ages
  - compare: easy within state, hard across ages
- small-multiple bar charts
  - split by age into regions
    - one chart per region
  - compare: easy within age, harder across states





Superimpose layers

- ***layer***: set of objects spread out over region
  - each set is visually distinguishable group
  - extent: whole view
- design choices
  - how many layers, how to distinguish?
    - encode with different, nonoverlapping channels
    - two layers achieveable, three with careful design
  - small static set, or dynamic from many possible?



Static visual layering

- foreground layer: roads
  - hue, size distinguishing main from minor
  - high luminance contrast from background
- background layer: regions
  - desaturated colors for water, parks, land areas
- user can selectively focus attention

[Get it right in black and white. Stone. 2010. http://www.stonesc.com/wordpress/2010/03/get-it-right-in-black-and-white]

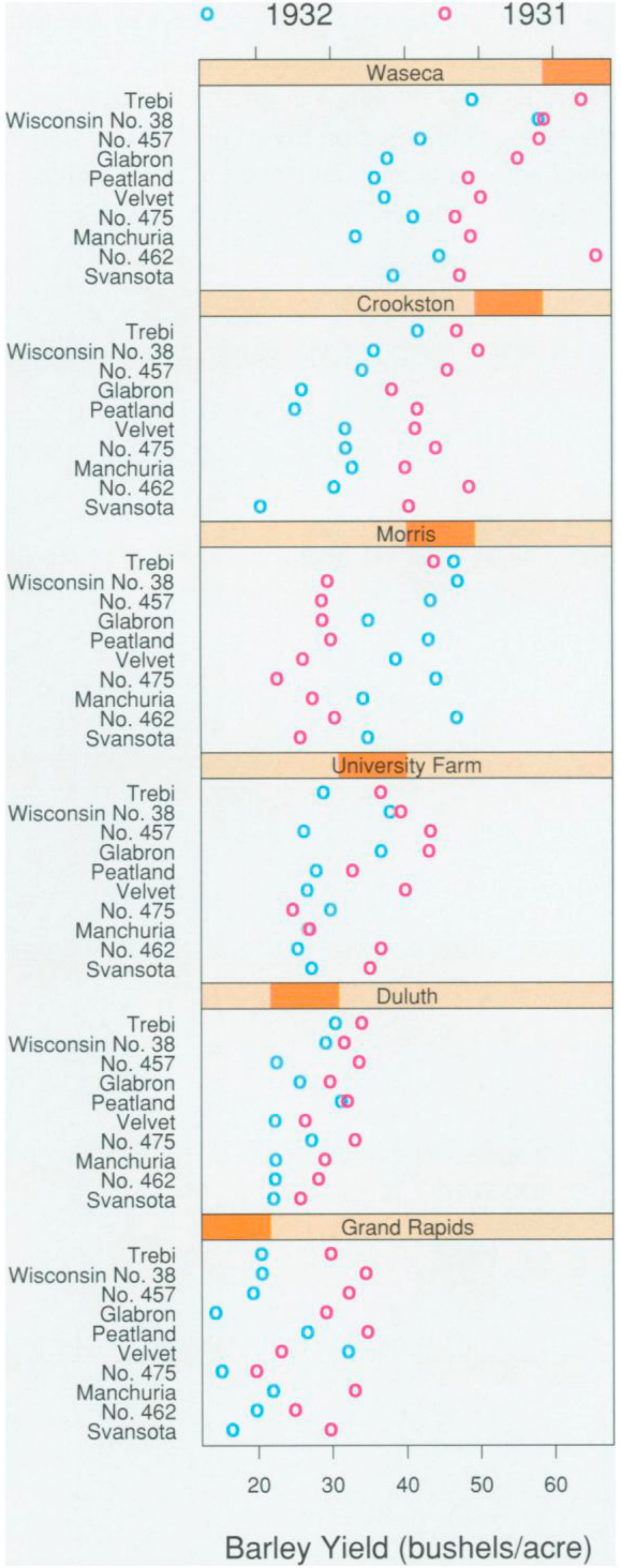
Static visual layering

- foreground layer: roads
  - hue, size distinguishing main from minor
  - high luminance contrast from background
- background layer: regions
  - desaturated colors for water, parks, land areas
- user can selectively focus attention
- "get it right in black and white"
  - check luminance contrast with greyscale view

[Get it right in black and white. Stone. 2010. http://www.stonesc.com/wordpress/2010/03/get-it-right-in-black-and-white]

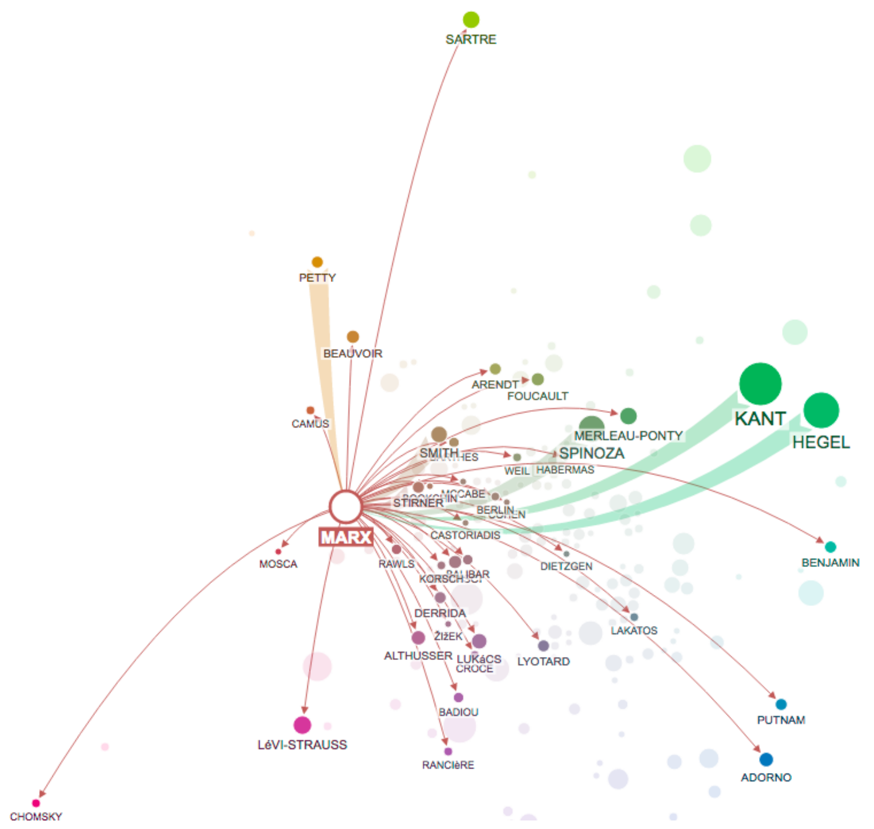
Idiom: **Trellis plots**

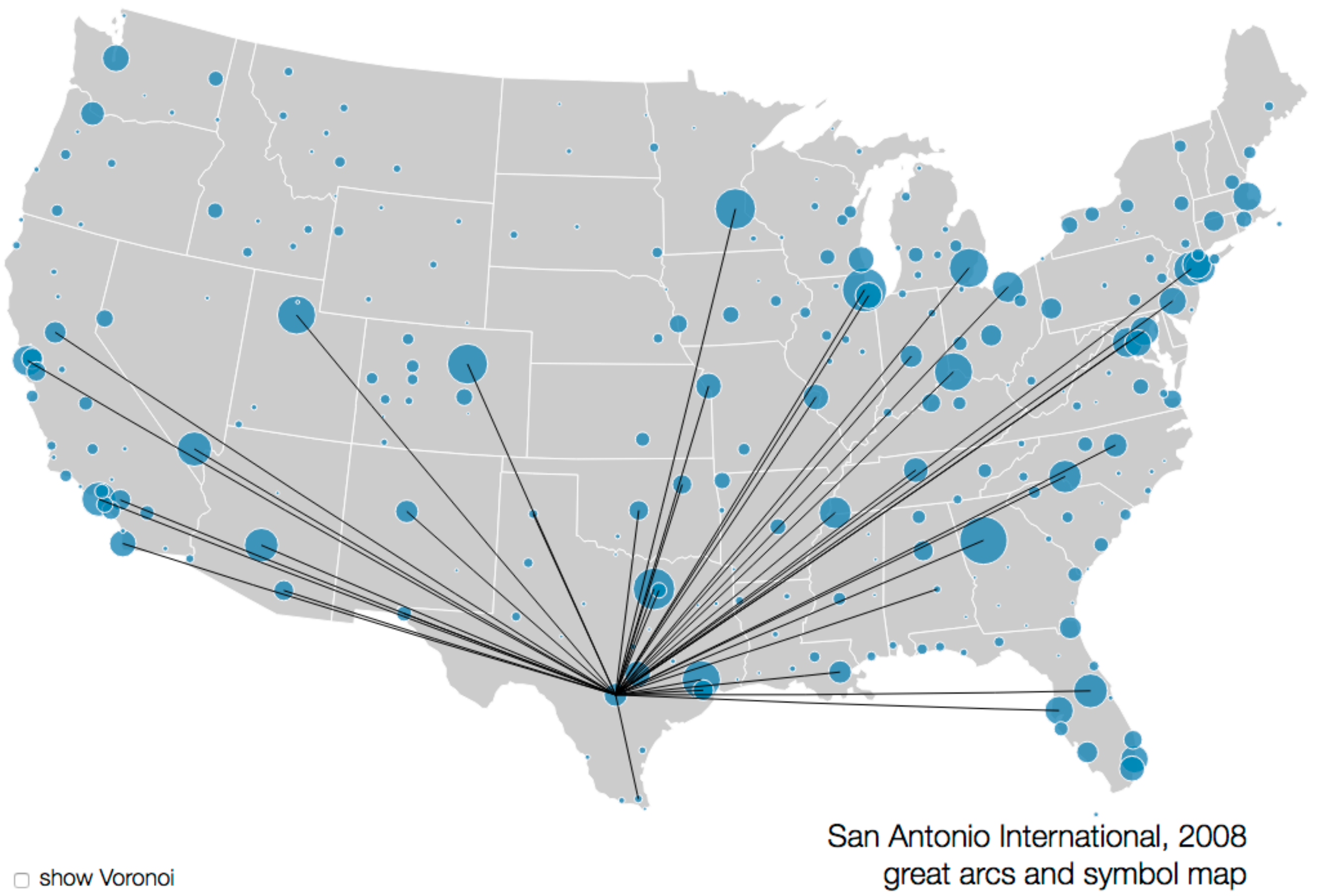
- superimpose within same frame
  - color code by year
- partitioning
  - split by site, rows are wheat varieties
- main-effects ordering
  - derive value of median for group, use to order
  - order rows within view by variety median
  - order views themselves by site median



Dynamic visual layering

- interactive based on selection
- one-hop neighbour highlighting demos: click vs hover (lightweight)





http://mariandoerk.de/edgemaps/demo/

http://mbostock.github.io/d3/talk/20111116/airports.html

Further reading

- Visualization Analysis and Design. Munzner. AK Peters Visualization Series, CRC Press, 2014.
    - *–Chap 11: Manipulate View & Chap 12: Facet Into Multiple Views*
- *Animated Transitions in Statistical Data Graphics. Heer and Robertson. IEEE Trans. on Visualization and Computer Graphics (Proc. InfoVis 07) 13:6 (2007), 1240– 1247.*
- *Smooth and efficient zooming and panning. van Wijk and Nuij. Proc. IEEE Symp. Information Visualization (InfoVis), pp. 15–22, 2003.*
- *Starting Simple - adding value to static visualisation through simple interaction. Dix and Ellis. Proc. Advanced Visual Interfaces (AVI), pp. 124–134, 1998.*
- *A Review of Overview+Detail, Zooming, and Focus+Context Interfaces.* Cockburn, Karlson, and Bederson. ACM Computing Surveys 41:1 (2008), 1–31.
- *Zooming versus multiple window interfaces: Cognitive costs of visual comparisons.* Plumlee and Ware. ACM Trans. on Computer-Human Interaction (ToCHI) 13:2 (2006), 179–209.
- *Exploring the Design Space of Composite Visualization.* Javed and Elmqvist. Proc. Pacific Visualization Symp. (PacificVis), pp. 1–9, 2012.
- *Visual Comparison for Information Visualization.* Gleicher, Albers, Walker, Jusufi, Hansen, and Roberts. Information Visualization 10:4 (2011), 289–309.
- *Cross-Filtered Views for Multidimensional Visual Analysis.* Weaver. IEEE Trans. Visualization and Computer Graphics 16:2 (Proc. InfoVis 2010), 192–204, 2010.
- *Linked Data Views.* Wills. In Handbook of Data Visualization, Computational Statistics, edited by Unwin, Chen, and Härdle, pp. 216–241. Springer-Verlag, 2008.
- *Glyph-based Visualization: Foundations, Design Guidelines, Techniques and Applications.* Borgo, Kehrer, Chung, Maguire, Laramee, Hauser, Ward, and Chen. In Eurographics State of the Art Reports, pp. 39–63, 2013.

Visualization Analysis & Design, Half-Day Tutorial

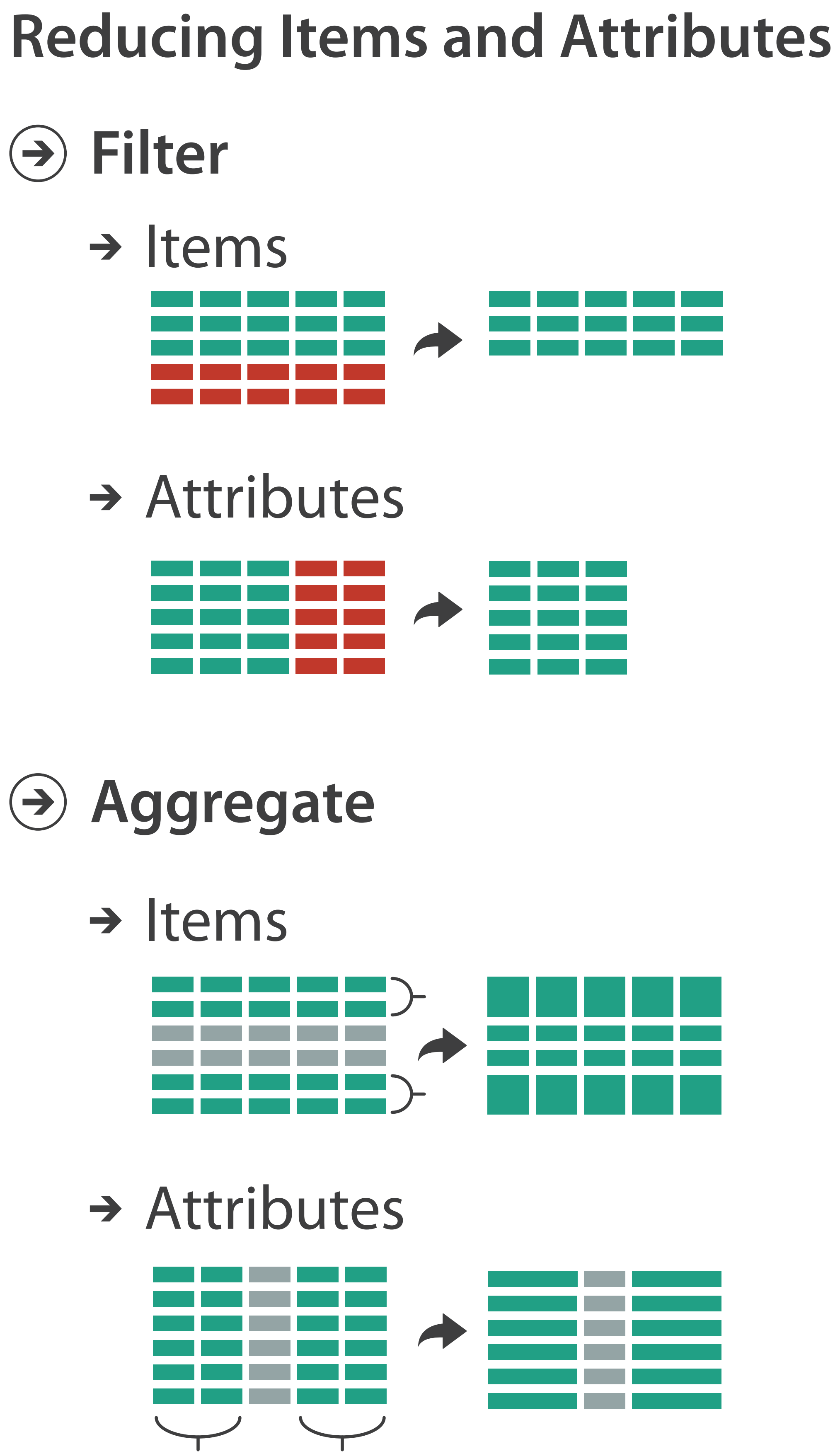
- Session 1
  - Analysis: What, Why, How
  - Marks and Channels
  - Arrange Tabular & Spatial Data
- Session 2
  - Arrange Networks and Trees
  - Map Color and Other Channels
  - Manipulate & Facet
  - Reduce: Filter, Aggregate

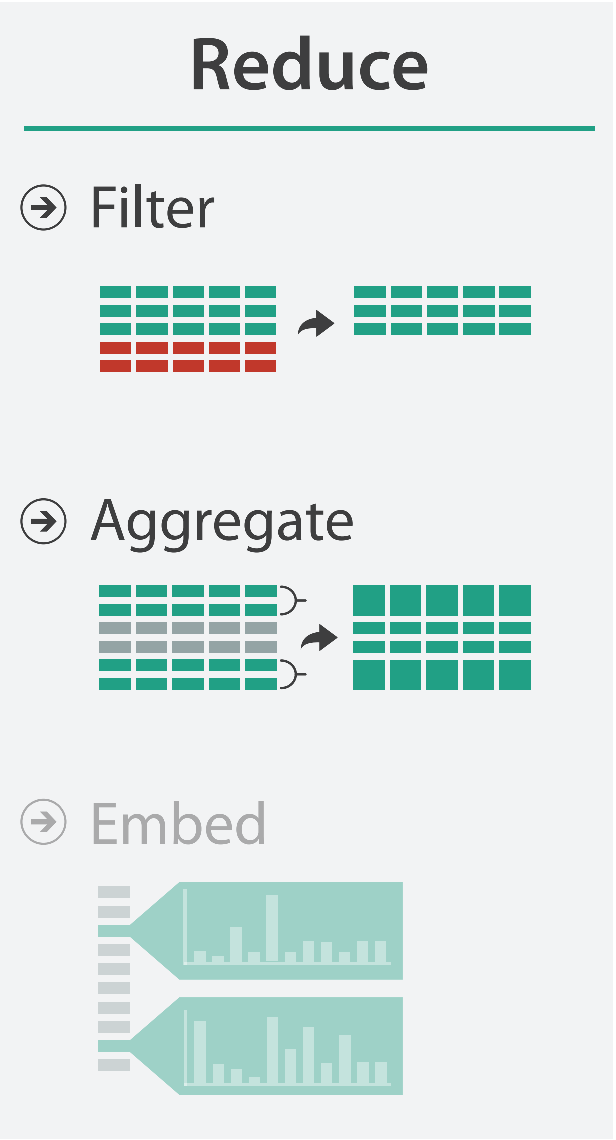
@tamaramunzner @tamara@vis.social

http://www.cs.ubc.ca/~tmm/talks.html#halfdaycourse23

Reduce items and attributes

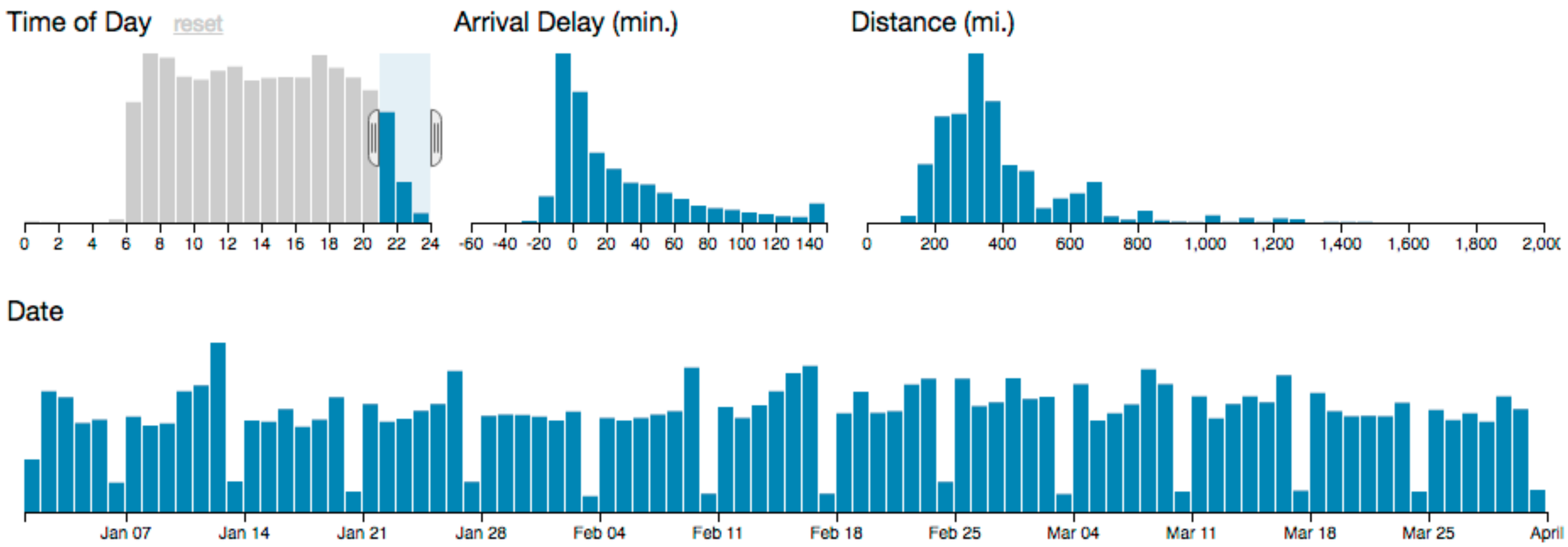
- reduce/increase: inverses
- filter
  - pro: straightforward and intuitive
    - to understand and compute
  - con: out of sight, out of mind
- aggregation
  - pro: inform about whole set
  - con: difficult to avoid losing signal
- not mutually exclusive
  - combine filter, aggregate
  - combine reduce, change, facet





Idiom: **cross filtering** System: **Crossfilter**

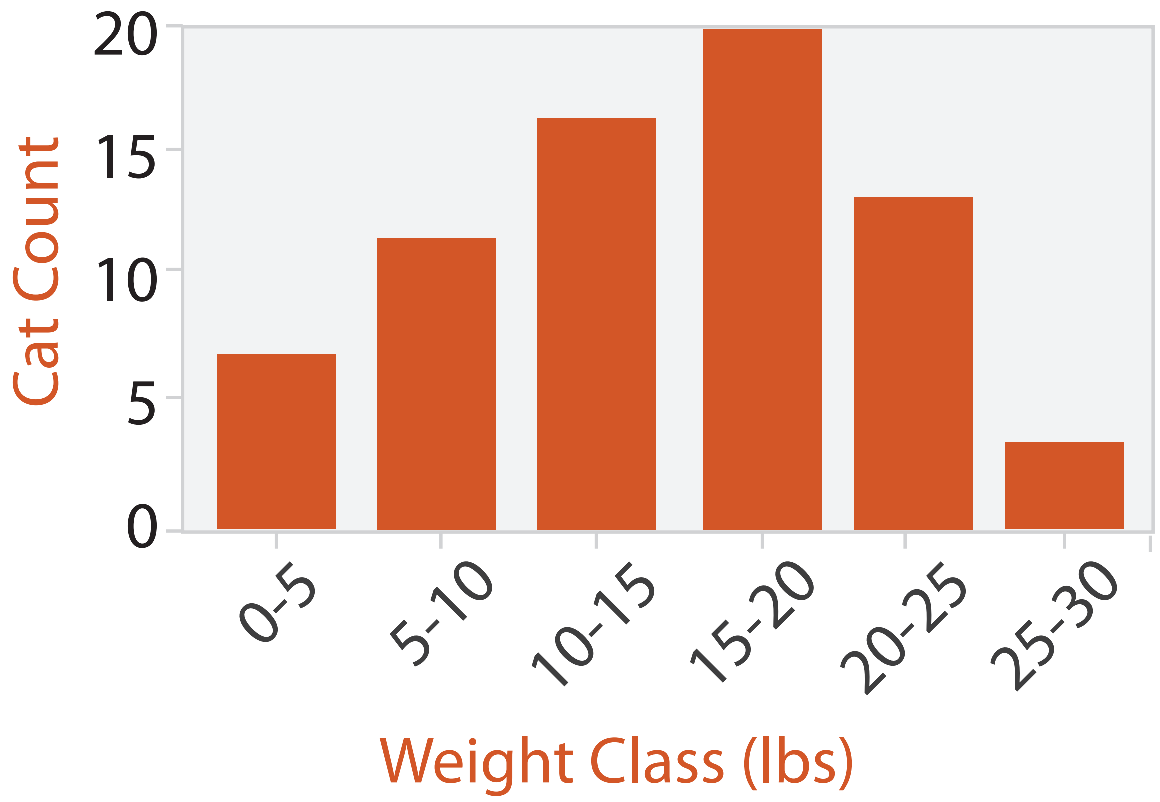
- item filtering
- coordinated views/controls combined
  - all scented histogram bisliders update when any ranges change



[*http://square.github.io/crossfilter/*]

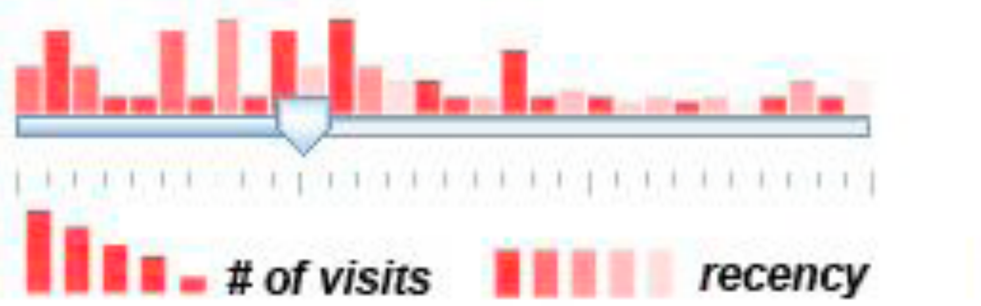
Idiom: **histogram**

- static item aggregation
- task: find distribution
- data: table
- derived data
  - new table: keys are bins, values are counts
- bin size crucial
  - pattern can change dramatically depending on discretization
  - opportunity for interaction: control bin size on the fly

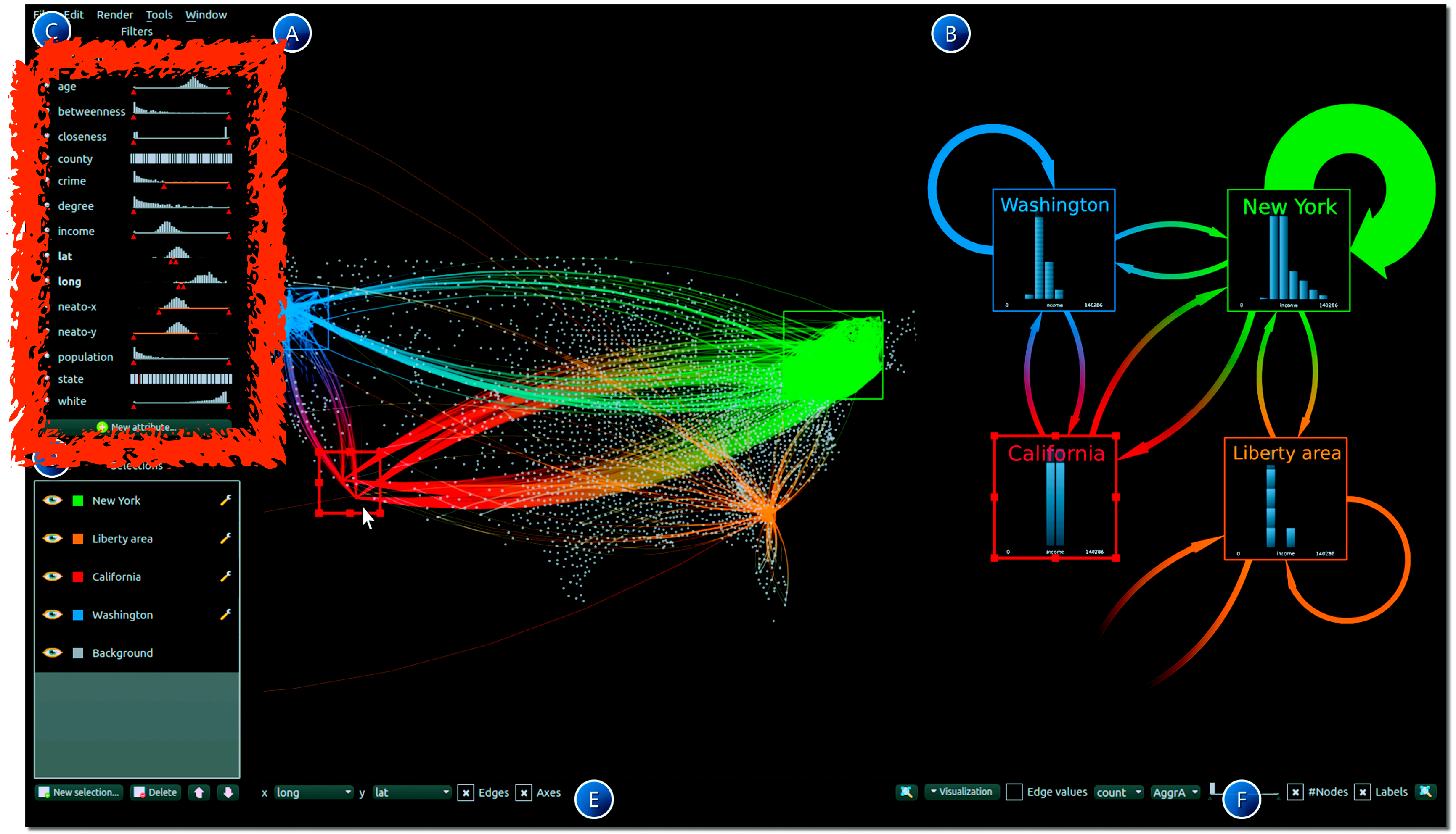


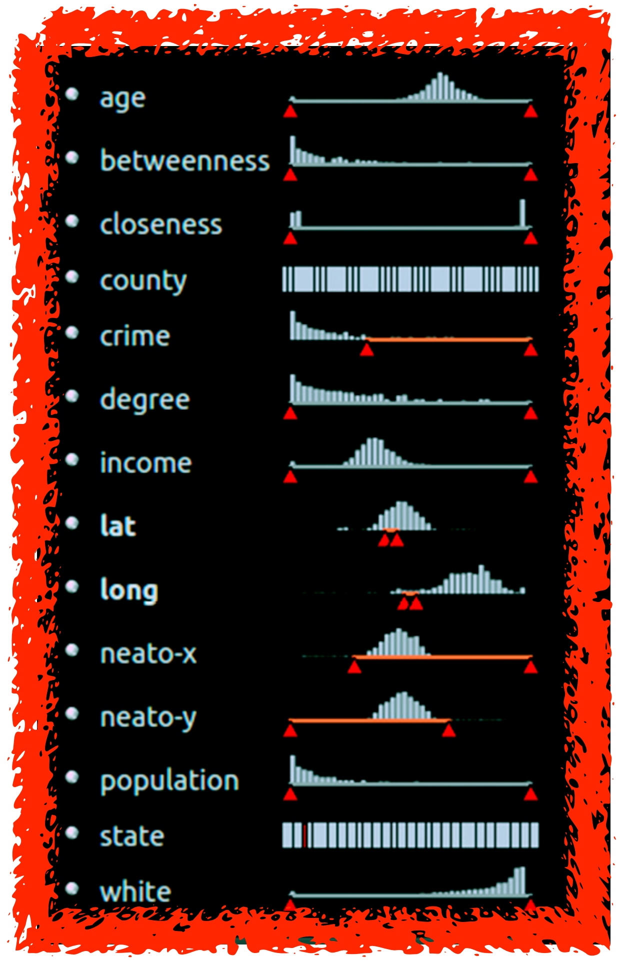
Idiom: **scented widgets**

- augmented widgets show ***information scent***
  – better cues for *information foraging*: show whether value in drilling down further vs looking elsewhere
- concise use of space: histogram on slider



[Scented Widgets: Improving Navigation Cues with Embedded Visualizations. Willett, Heer, and Agrawala. IEEE TVCG (Proc. InfoVis 2007) 13:6 (2007), 1129–1136.]

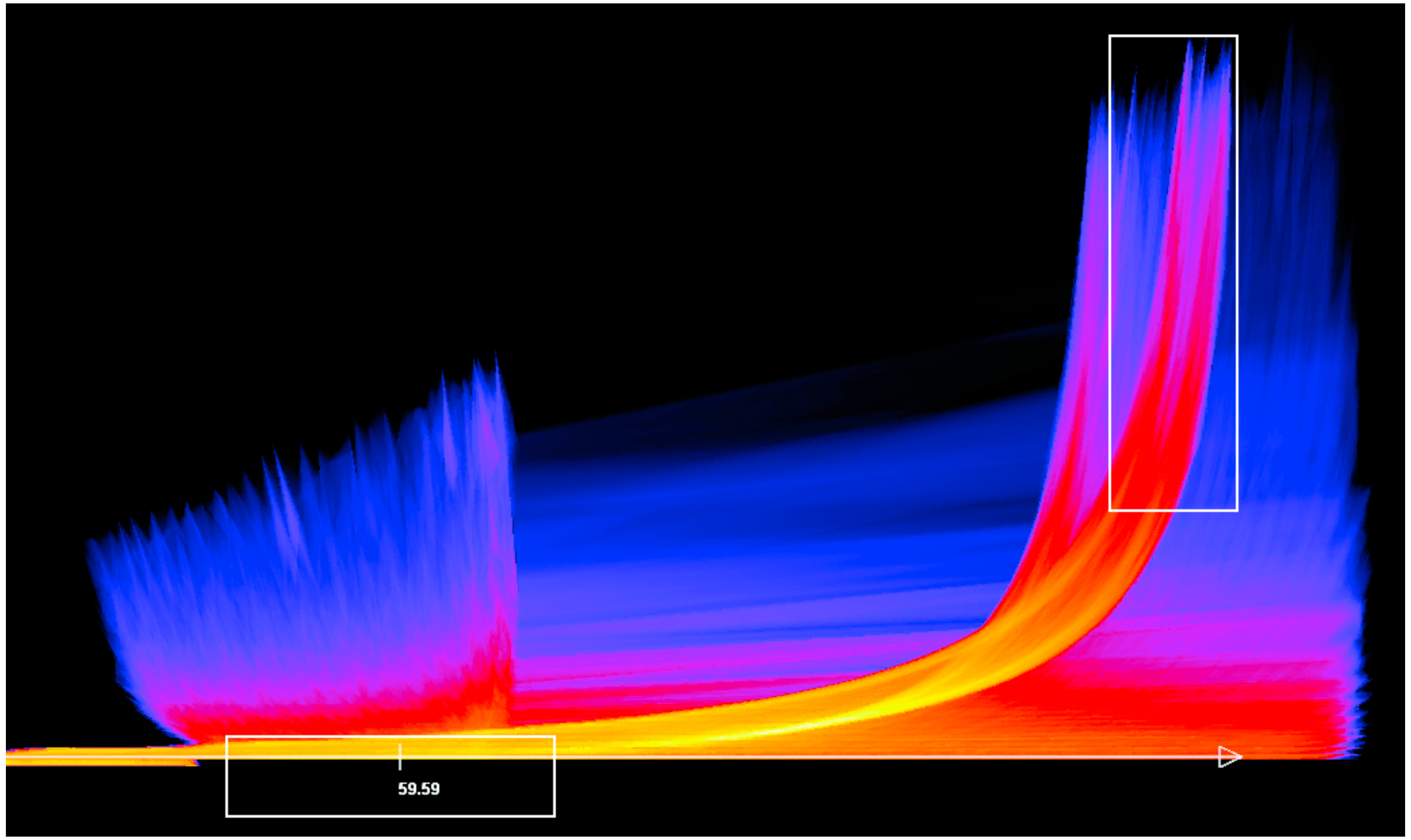




[Multivariate Network Exploration and Presentation: From Detail to Overview via Selections and Aggregations. van den Elzen, van Wijk, IEEE TVCG 20(12): 2014 (Proc. InfoVis 2014).]

Idiom: **Continuous scatterplot**

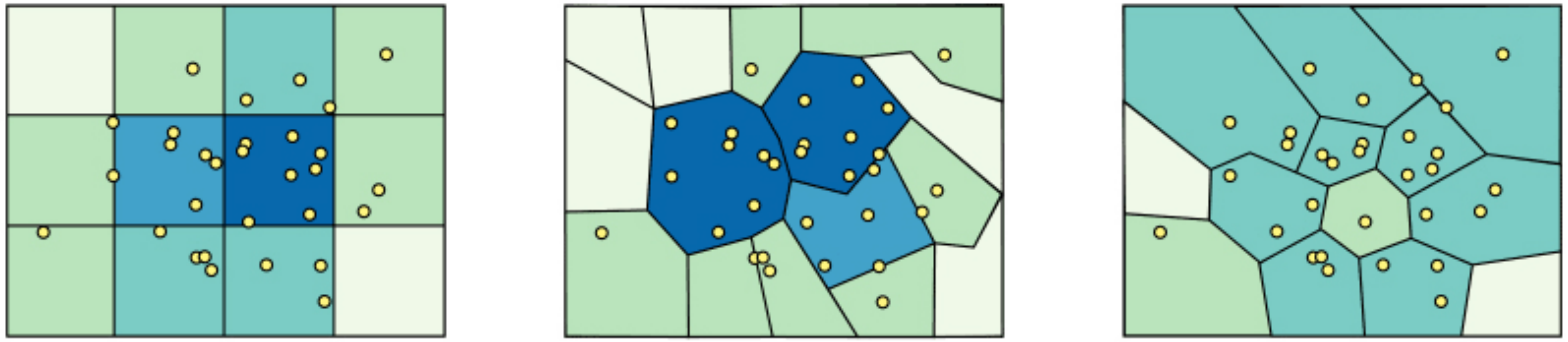
- static item aggregation
- data: table
- derived data: table
  - key attribs x,y for pixels
  - quant attrib: overplot density
- dense space-filling 2D matrix
- color: sequential categorical hue + ordered luminance colormap
- scalability
  - no limits on overplotting: millions of items



[Continuous Scatterplots. Bachthaler and Weiskopf. IEEE TVCG (Proc. Vis 08) 14:6 (2008), 1428–1435. 2008.]

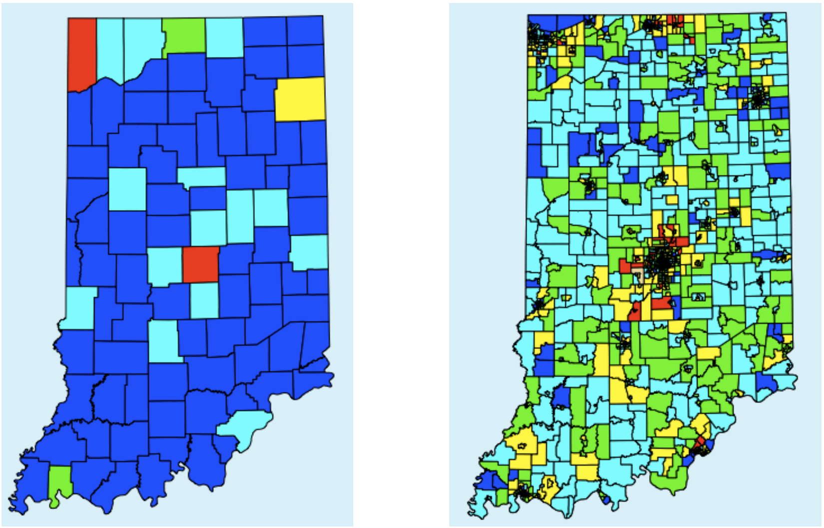
Spatial aggregation

- MAUP: Modifiable Areal Unit Problem
  - changing boundaries of cartographic regions can yield dramatically different results
  - zone effects



[http://www.e-education.psu/edu/geog486/l4_p7.html, Fig 4.cg.6]

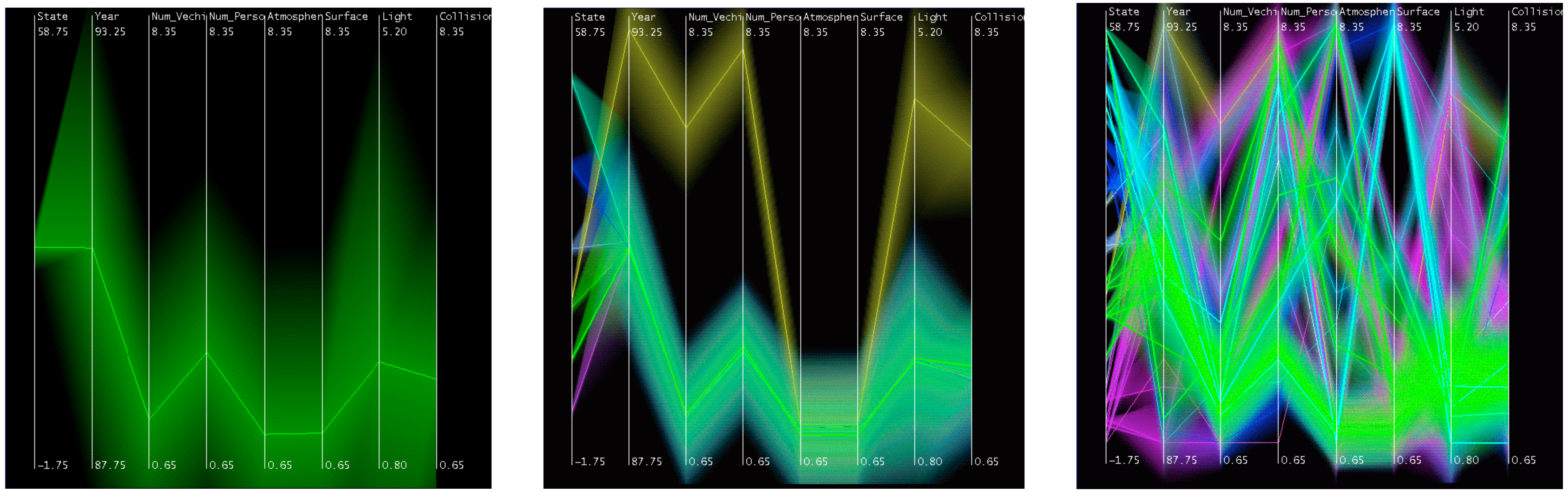
  - scale effects



https://blog.cartographica.com/blog/2011/5/19/the-modifiable-areal-unit-problem-in-gis.html

Idiom: **Hierarchical parallel coordinates**

- dynamic item aggregation
- derived data: ***hierarchical clustering***
- encoding:
  - cluster band with variable transparency, line at mean, width by min/max values
  - color by proximity in hierarchy



[Hierarchical Parallel Coordinates for Exploration of Large Datasets. Fua, Ward, and Rundensteiner. Proc. IEEE Visualization Conference (Vis '99), pp. 43– 50, 1999.]

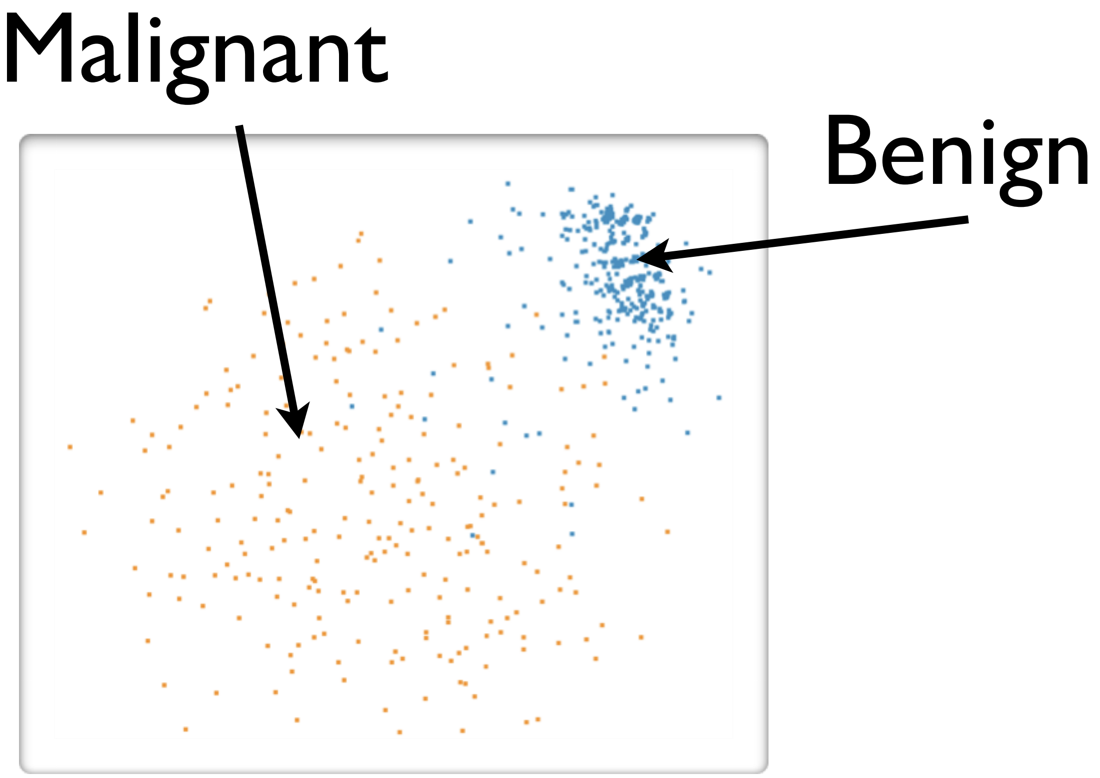
Dimensionality reduction

- attribute aggregation
  - derive low-dimensional target space from high-dimensional measured space
  - use when you can’t directly measure what you care about
    - true dimensionality of dataset conjectured to be smaller than dimensionality of measurements
    - latent factors, hidden variables

Tumor
Measurement Data

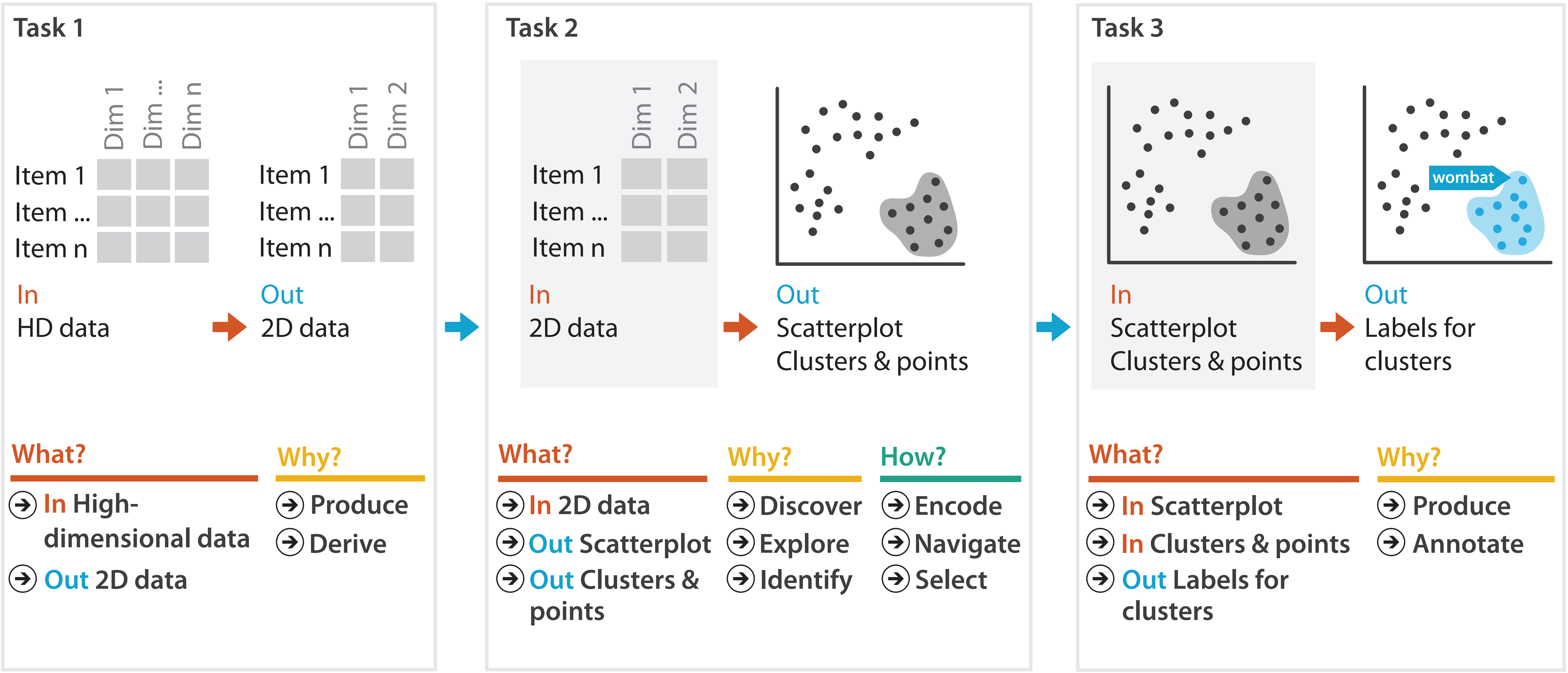
data: 9D measured space

DR



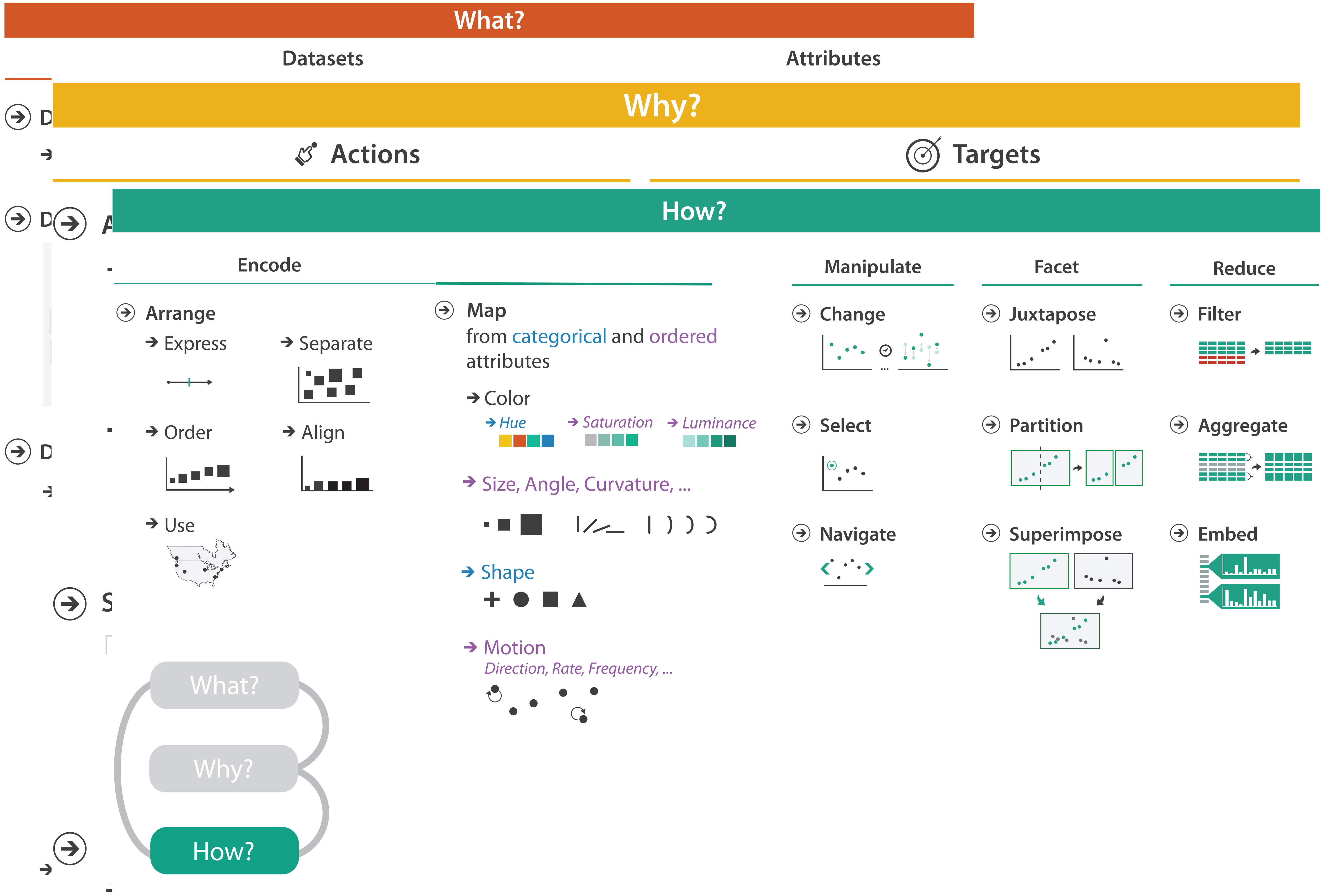
derived data:
2D target space

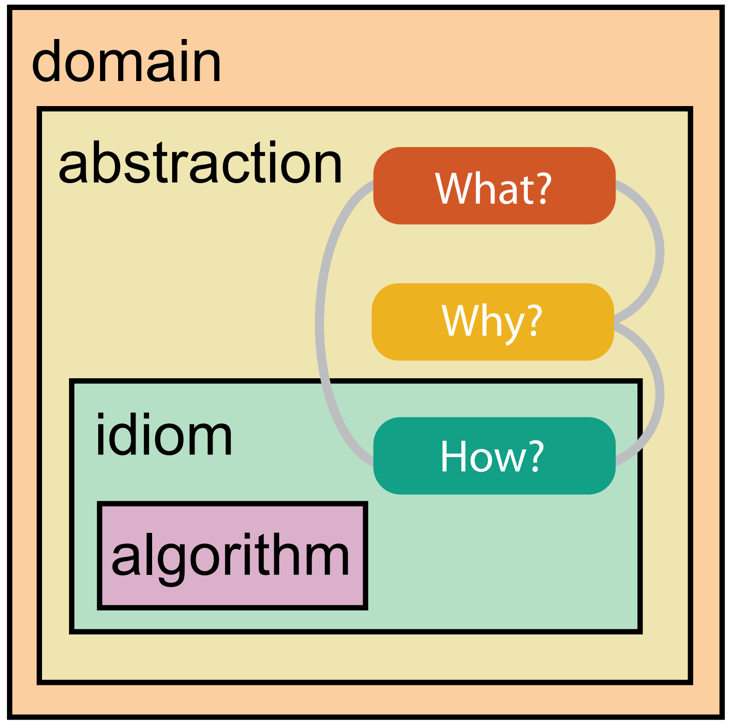
Idiom: **Dimensionality reduction for documents**



Further reading

- Visualization Analysis and Design. Munzner. AK Peters Visualization Series, CRC Press, 2014.
  - *Chap 13: Reduce Items and Attributes*
- *Hierarchical Aggregation for Information Visualization: Overview, Techniques and Design Guidelines.* Elmqvist and Fekete. IEEE Transactions on Visualization and Computer Graphics 16:3 (2010), 439–454.
- *A Review of Overview+Detail, Zooming, and Focus+Context Interfaces*. Cockburn, Karlson, and Bederson. ACM Computing Surveys 41:1 (2008), 1–31.
- *A Guide to Visual Multi-Level Interface Design From Synthesis of Empirical Study Evidence.* Lam and Munzner. Synthesis Lectures on Visualization Series, Morgan Claypool, 2010.


What?
Datasets
Attributes
Why?
Actions
Targets
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?

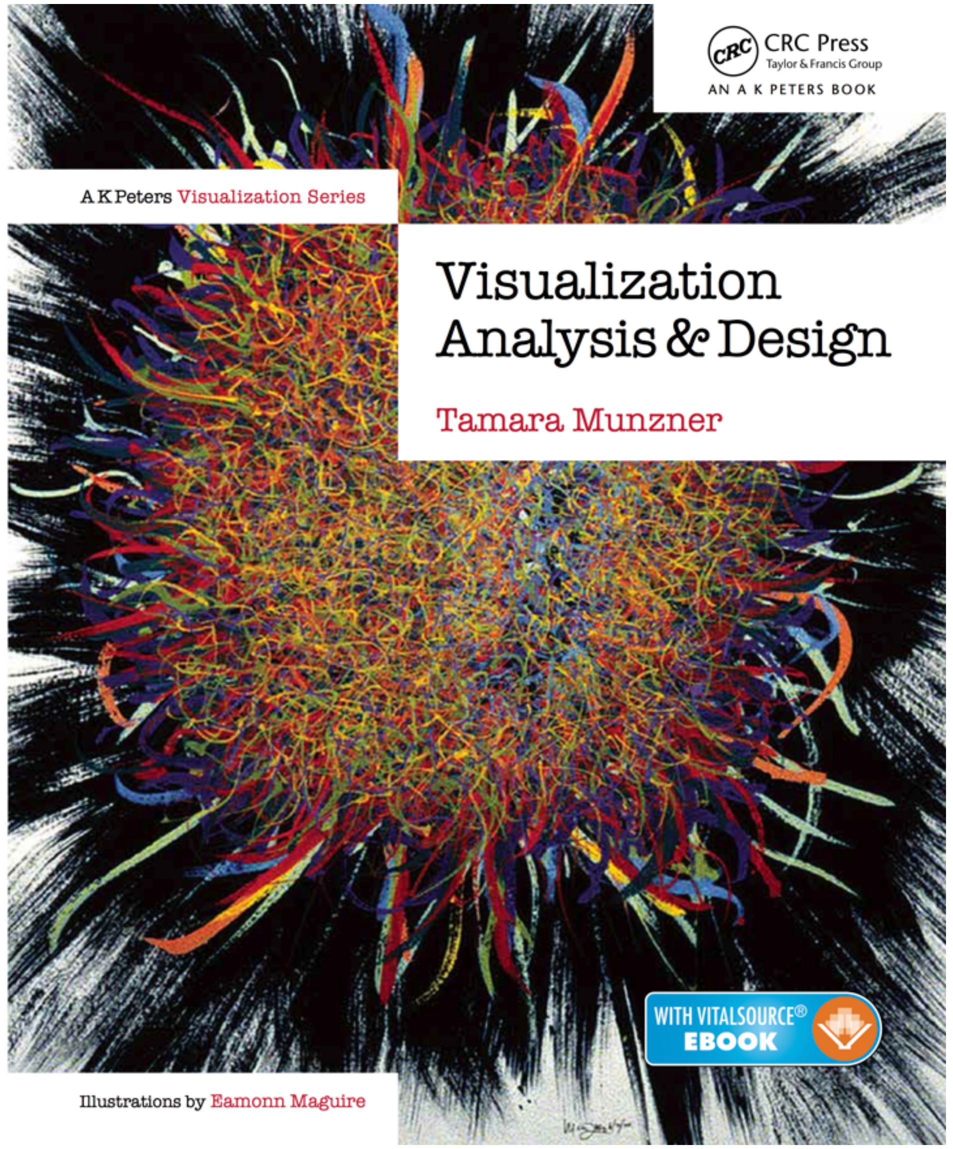

domain
abstraction
What?
Why?
idiom
How?
algorithm

More information

- this tutorial
  http://www.cs.ubc.ca/~tmm/talks.html#halfdaycourse23
- book
  http://www.cs.ubc.ca/~tmm/vadbook
  - http://www.crcpress.com/product/isbn/9781466508910
  - illustration acknowledgement: Eamonn Maguire

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

- VIS23 book table from CRC/Routledge
  - physical table
  - virtual bookshop: https://bit.ly/IEEEVIS23



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

@tamara@vis.social

@tamaramunzner