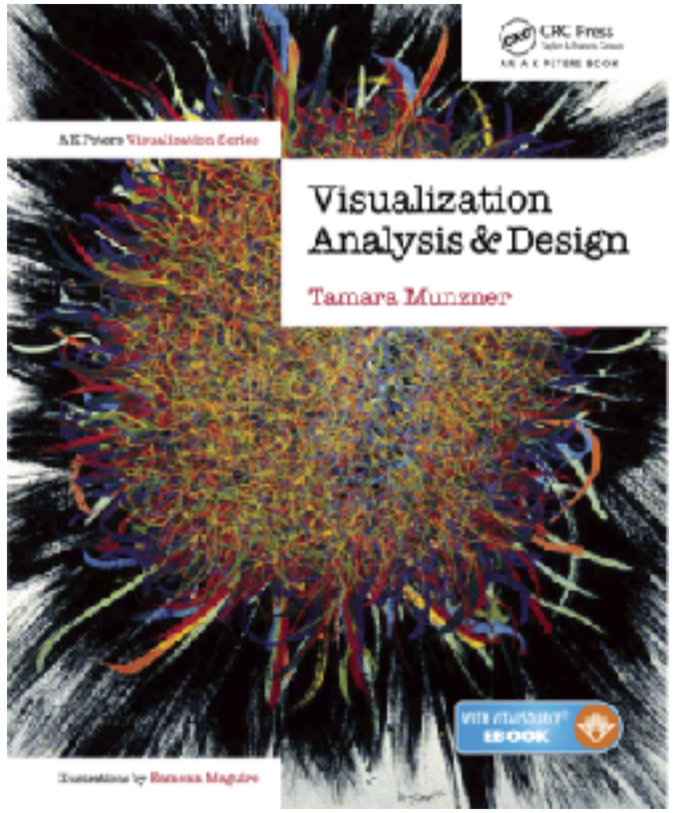
Visualization Analysis & Design

Half-Day Tutorial



Tamara Munzner
Department of Computer Science
University of British Columbia

@tamaramunzner

IEEE VIS 2020 Tutorial
October 2020, Salt Lake City UT (online)

http://www.cs.ubc.ca/~tmm/talks.html#halfdaycourse20

Visualization Analysis & Design, Half-Day Tutorial

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

- Session 2
  - Arrange Networks and Trees
  - Map Color and Other Channels
  - Manipulate: Change, Select, Navigate
  - Facet: Juxtapose, Partition, Superimpose
  - Reduce: Filter, Aggregate

@tamaramunzner

http://www.cs.ubc.ca/~tmm/talks.html#halfdaycourse20

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.

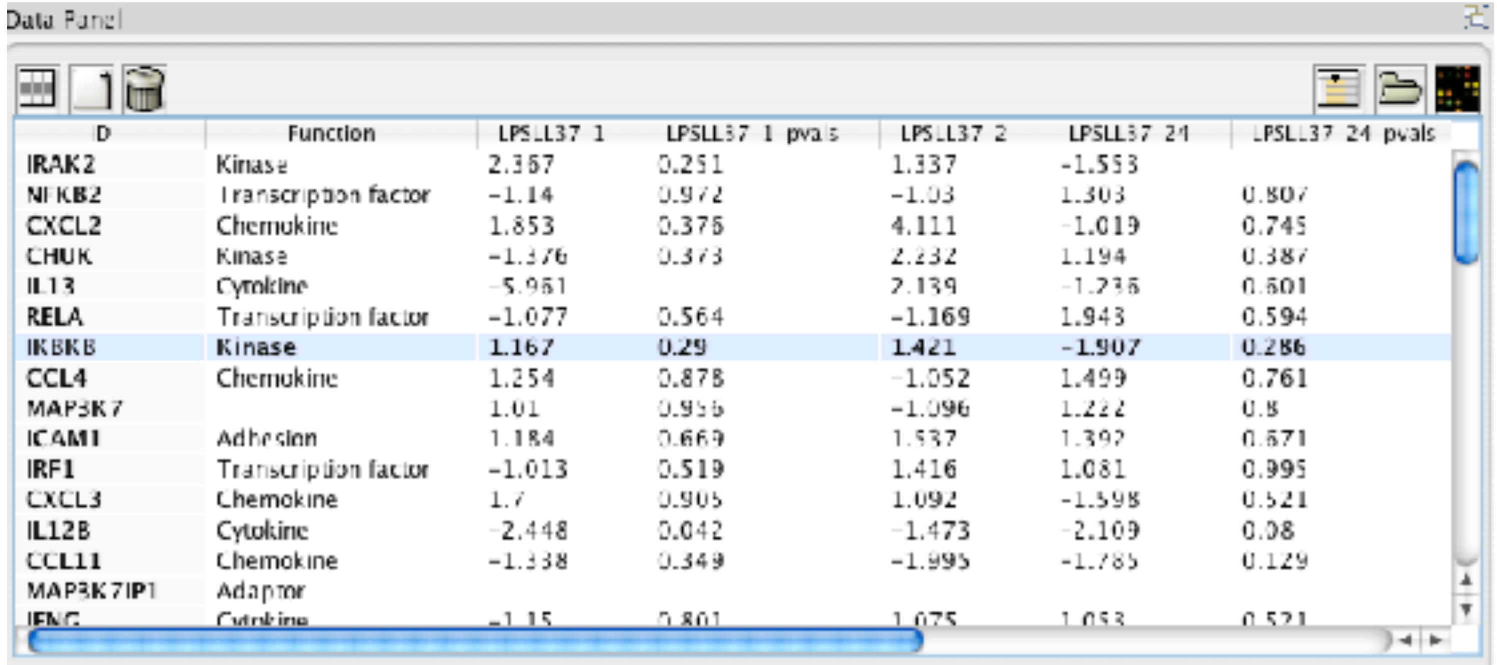
Visualization is suitable when there is a need to augment human capabilities rather than replace people with computational decision-making methods.

- 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



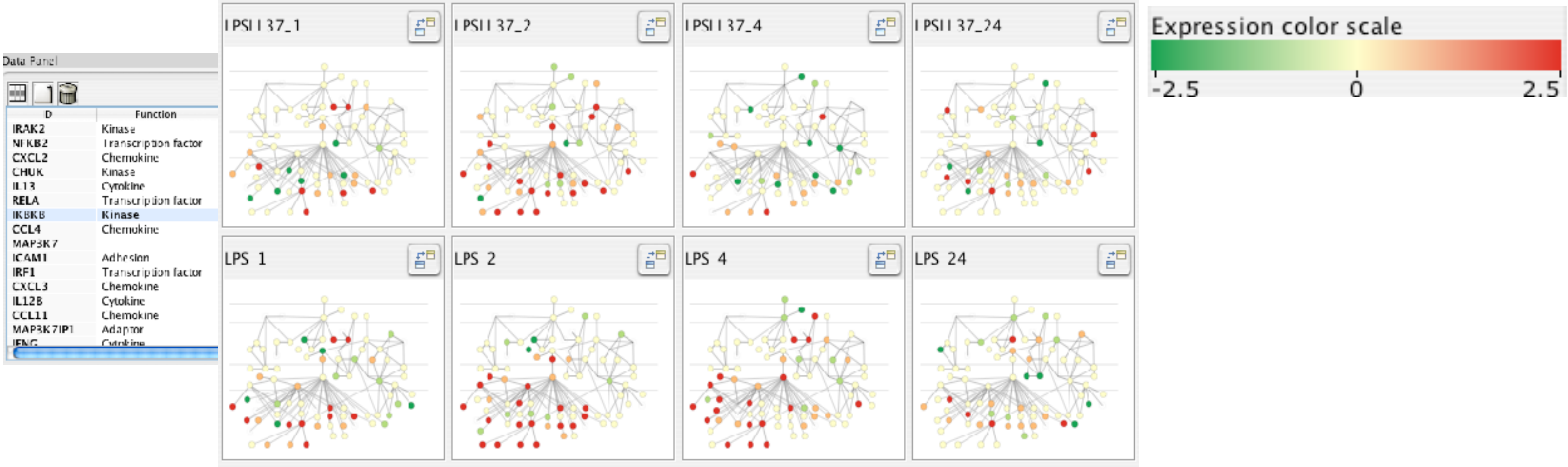
ID	Function	LPSLL37 1	LPSLL37 1 pvals	LPSLL37 2	LPSLL37 24	LPSLL37 24 pvals
IRAK2	Kinase	2.367	0.251	1.337	-1.553	
NFKB2	Transcription factor	-1.14	0.972	-1.03	1.303	0.807
CXCL2	Chemokine	1.853	0.376	4.111	-1.019	0.745
CHUK	Kinase	-1.376	0.373	2.232	1.194	0.387
IL13	Cytokine	-5.961		2.139	-1.236	0.601
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



Data Panel

D	Function
IRAK2	Kinase
NFKB2	Transcription factor
CXCL2	Chemokine
CHUK	Kinase
IL13	Cytokine
RELA	Transcription factor
IKBKB	Kinase
CCL4	Chemokine
MAP3K7	
ICAM1	Adhesion
IRF1	Transcription factor
CXCL3	Chemokine
IL12B	Cytokine
CCL11	Chemokine
MAP3K7IP1	Adaptor
IFNG	Cytokine

[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

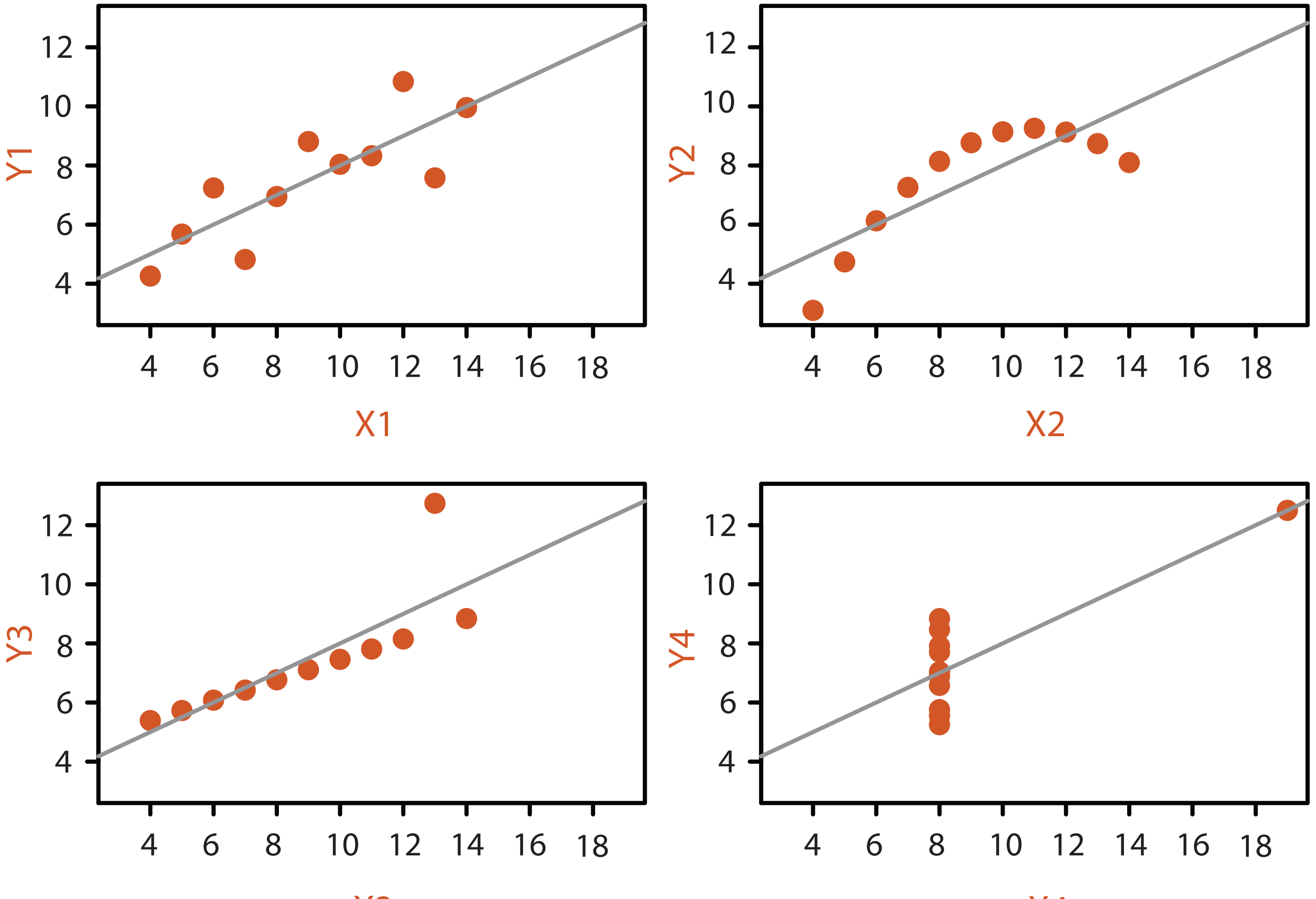
Anscombe’s Quartet

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

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



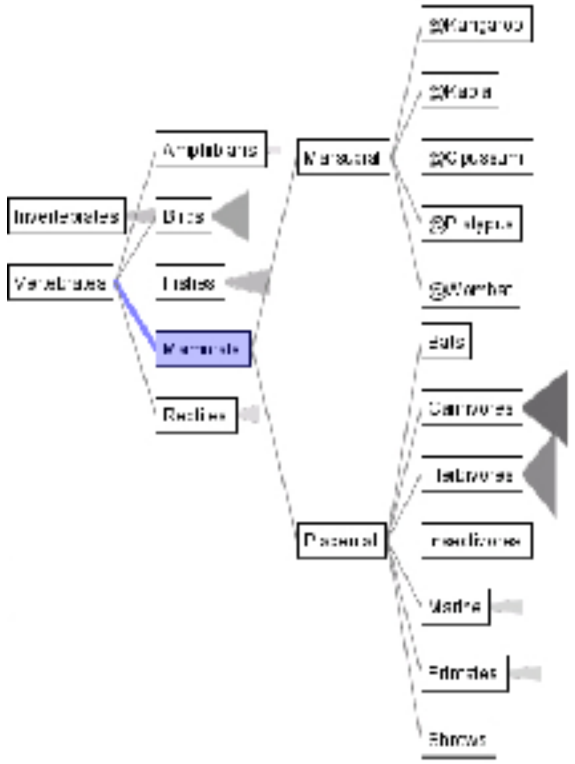
Anscombe's Quartet

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

Why analyze?

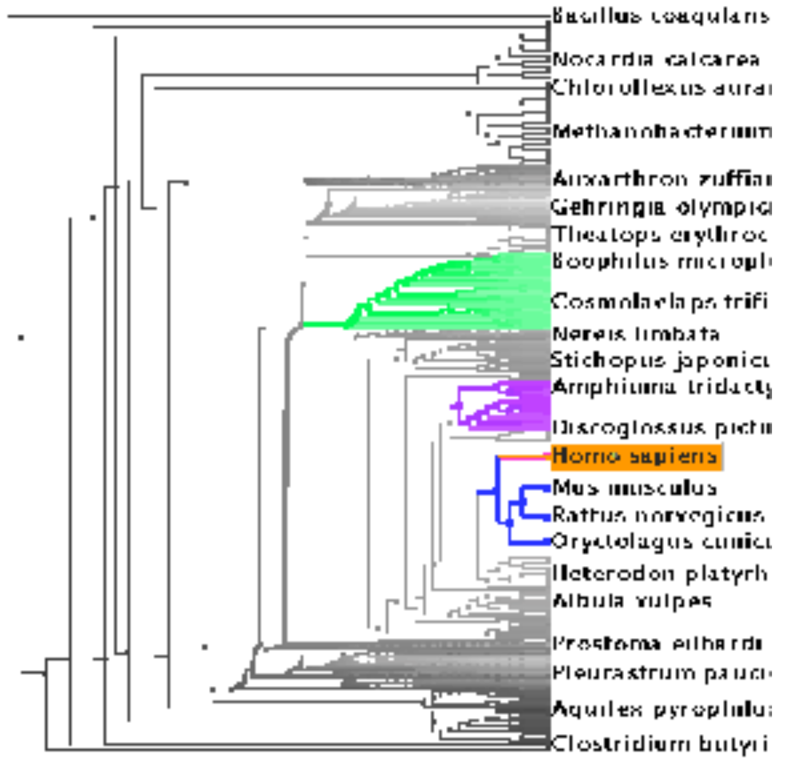
- imposes structure on huge design space
  - scaffold to help you think systematically about choices
  - analyzing existing as stepping stone to designing new
  - most possibilities ineffective for particular task/data combination

SpaceTree

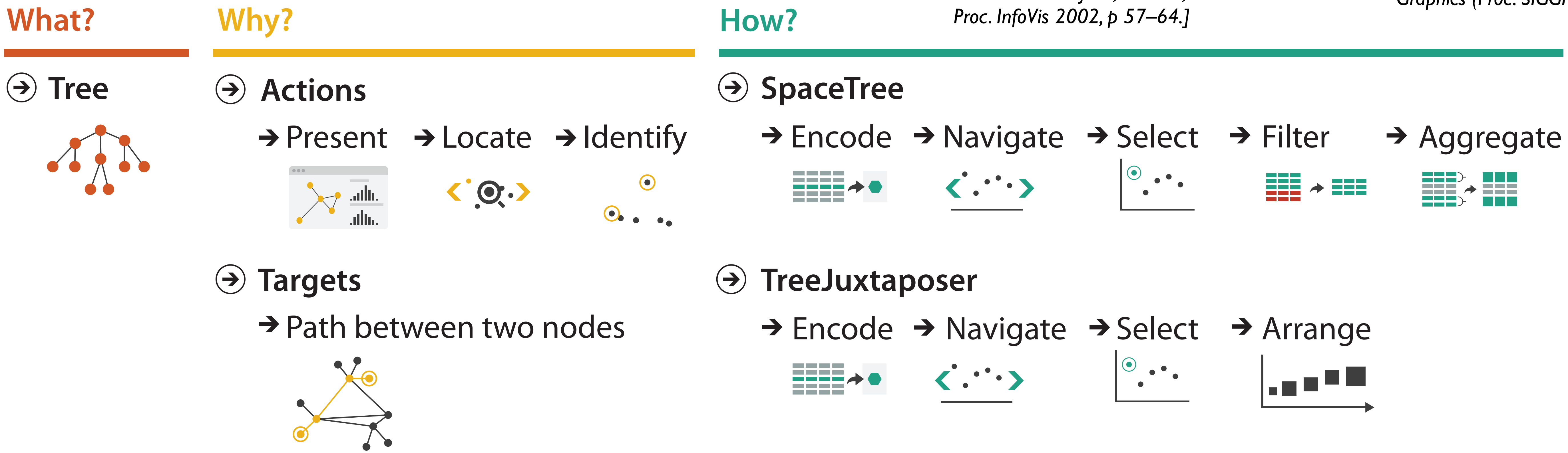


[SpaceTree: Supporting Exploration in Large Node Link Tree, Design Evolution and Empirical Evaluation. Grosjean, Plaisant, and Bederson. Proc. InfoVis 2002, p 57–64.]

TreeJuxtaposer



[TreeJuxtaposer: Scalable Tree Comparison Using Focus+Context With Guaranteed Visibility. ACM Trans. on Graphics (Proc. SIGGRAPH) 22:453– 462, 2003.]



What?

→ Tree

Why?

→ Actions

→ Present → Locate → Identify

→ Targets

→ Path between two nodes

How?

→ SpaceTree

→ Encode → Navigate → Select → Filter → Aggregate

→ TreeJuxtaposer

→ Encode → Navigate → Select → Arrange

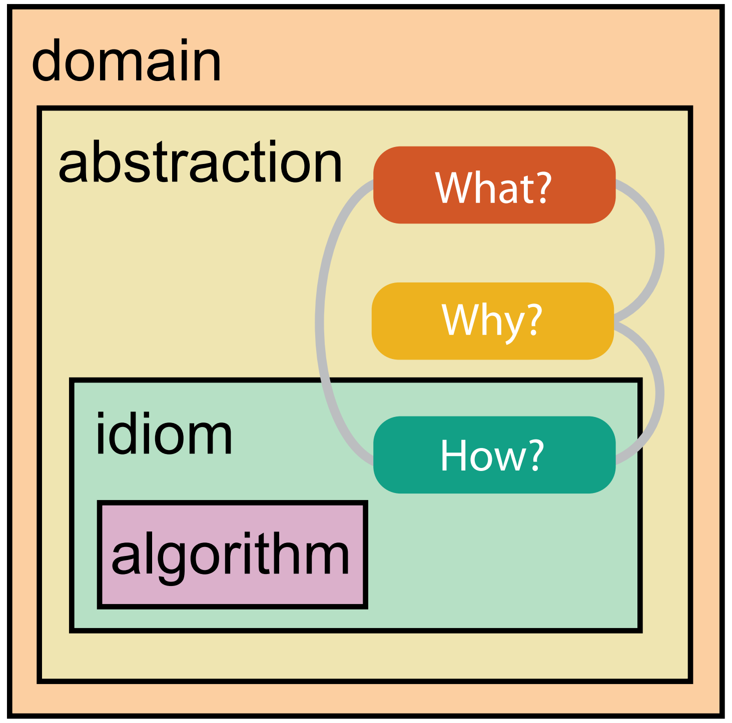
Analysis framework: Four levels, three questions

- *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).]

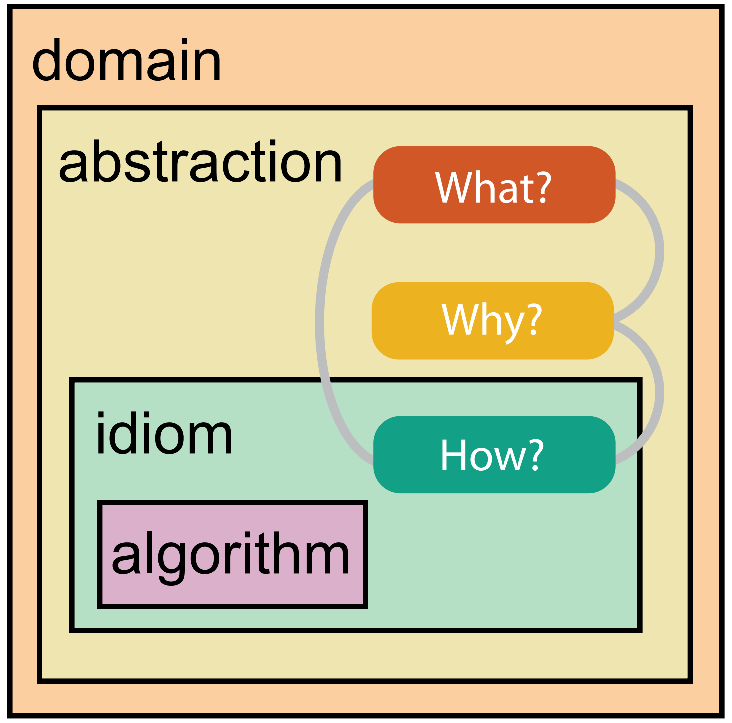


[A Multi-Level Typology of Abstract Visualization Tasks
Brehmer and Munzner. IEEE TVCG 19(12):2376-2385,
2013 (Proc. InfoVis 2013).]

Analysis framework: Four levels, three questions

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

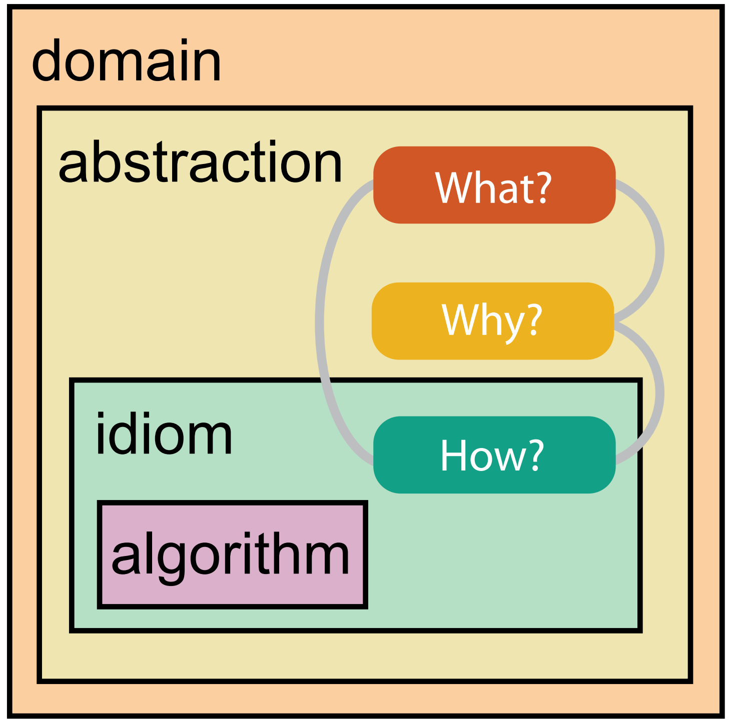


[A Multi-Level Typology of Abstract Visualization Tasks *Brehmer and Munzner. IEEE TVCG 19(12):2376-2385, 2013 (Proc. InfoVis 2013).*]

Analysis framework: Four levels, three questions

- *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

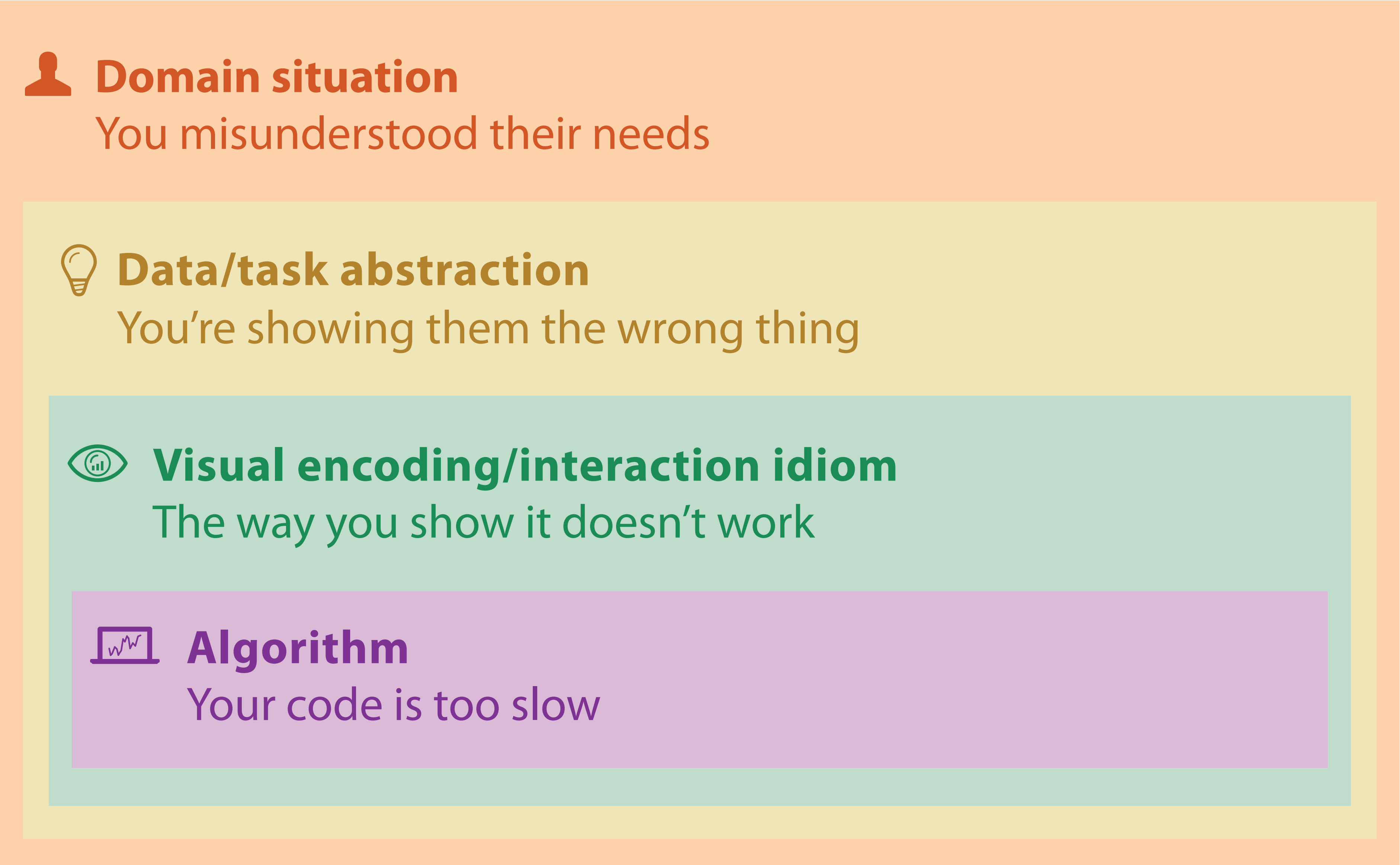
[A Nested Model of Visualization Design and Validation.
*Munzner. IEEE TVCG 15(6):921-928, 2009
(Proc. InfoVis 2009).*]



[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



Domain situation
You misunderstood their needs

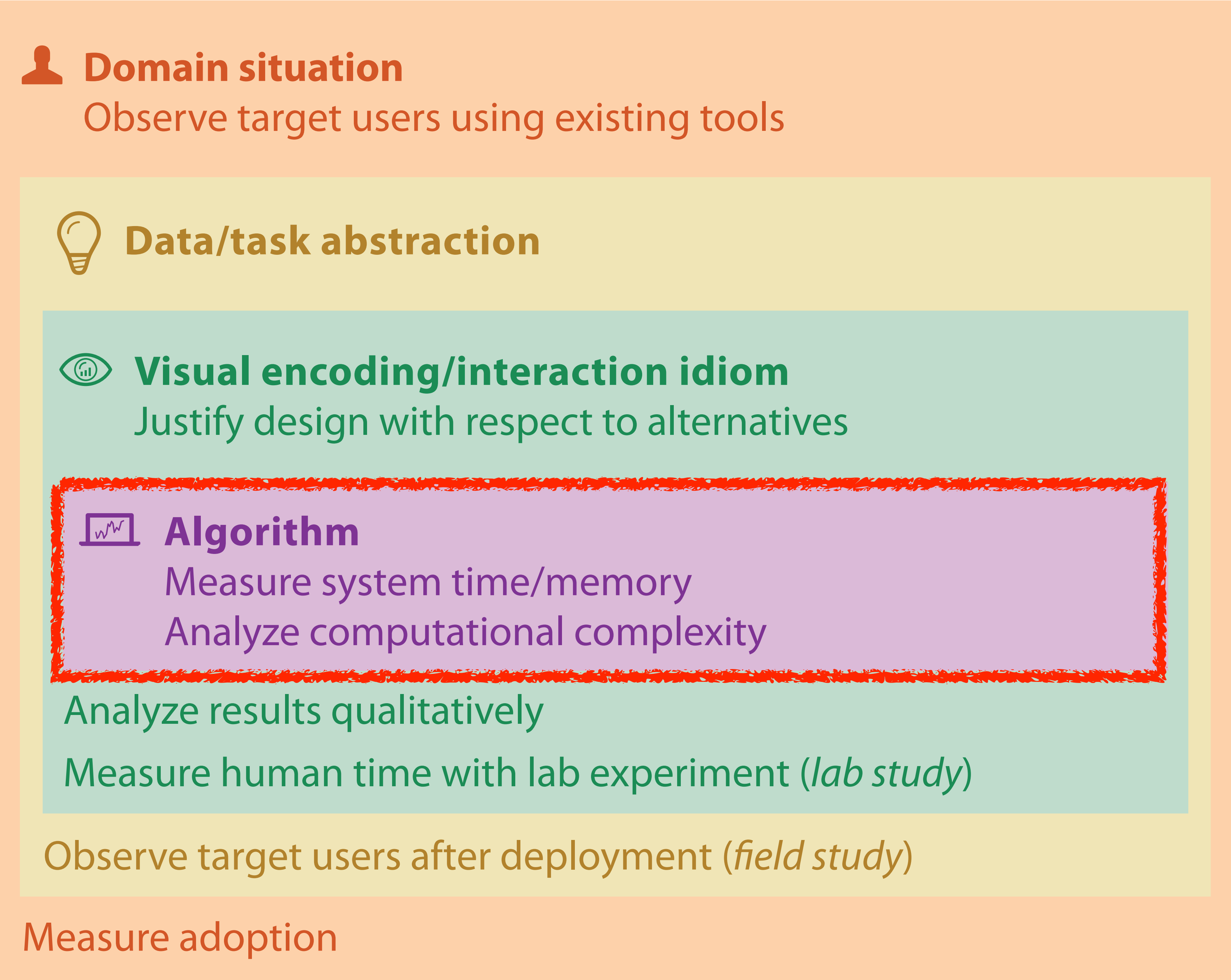
Data/task abstraction
You're showing them the wrong thing

Visual encoding/interaction idiom
The way you show it doesn't work

Algorithm
Your code is too slow

Why is validation difficult?

- solution: use methods from different fields at each level



Domain situation

Observe target users using existing tools

Data/task abstraction

Visual encoding/interaction idiom

Justify design with respect to alternatives

Algorithm

Measure system time/memory

Analyze computational complexity

Analyze results qualitatively

Measure human time with lab experiment (*lab study*)

Observe target users after deployment (*field study*)

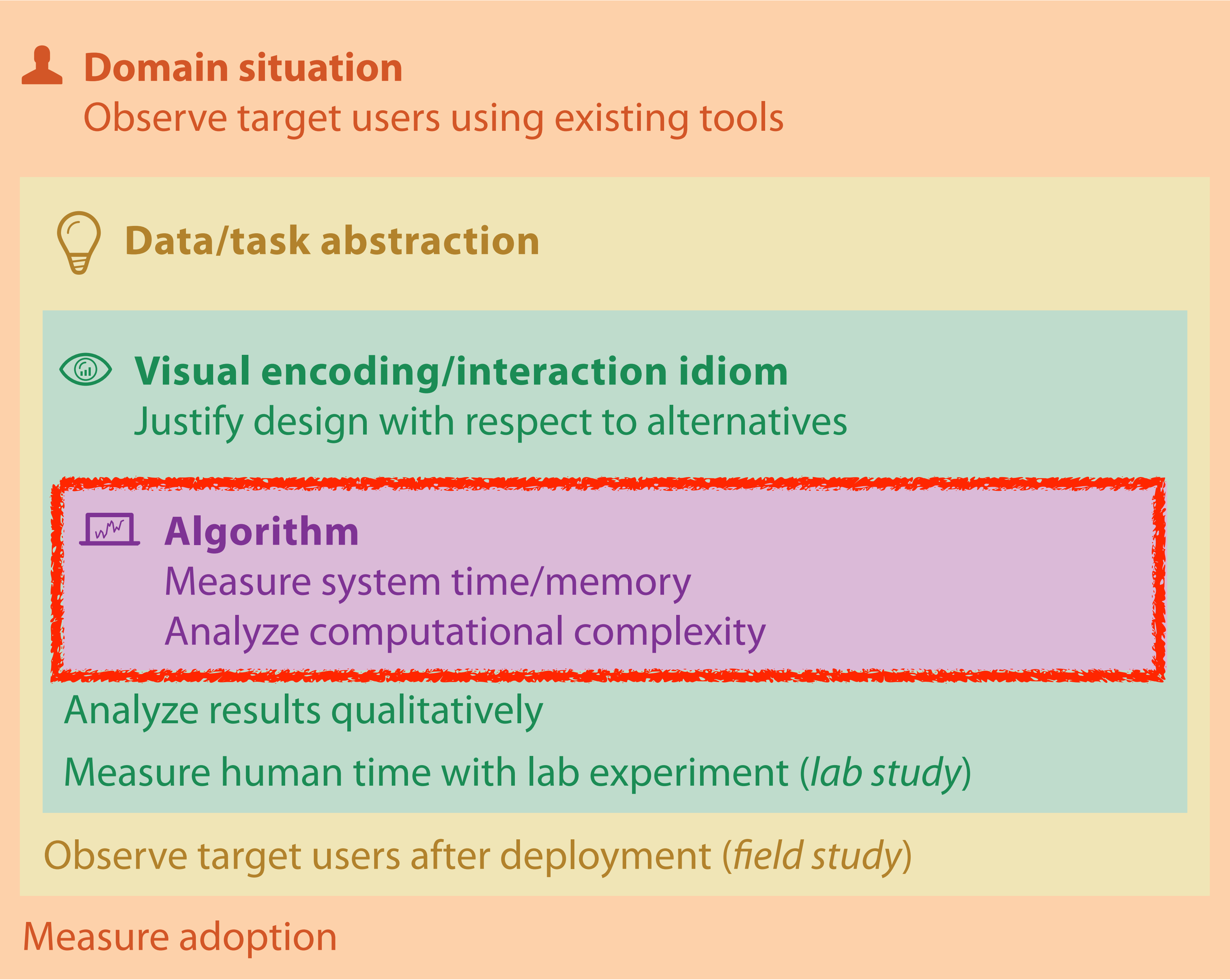
Measure adoption

[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



Domain situation

Observe target users using existing tools

Data/task abstraction

Visual encoding/interaction idiom

Justify design with respect to alternatives

Algorithm

Measure system time/memory

Analyze computational complexity

Analyze results qualitatively

Measure human time with lab experiment (*lab study*)

Observe target users after deployment (*field study*)

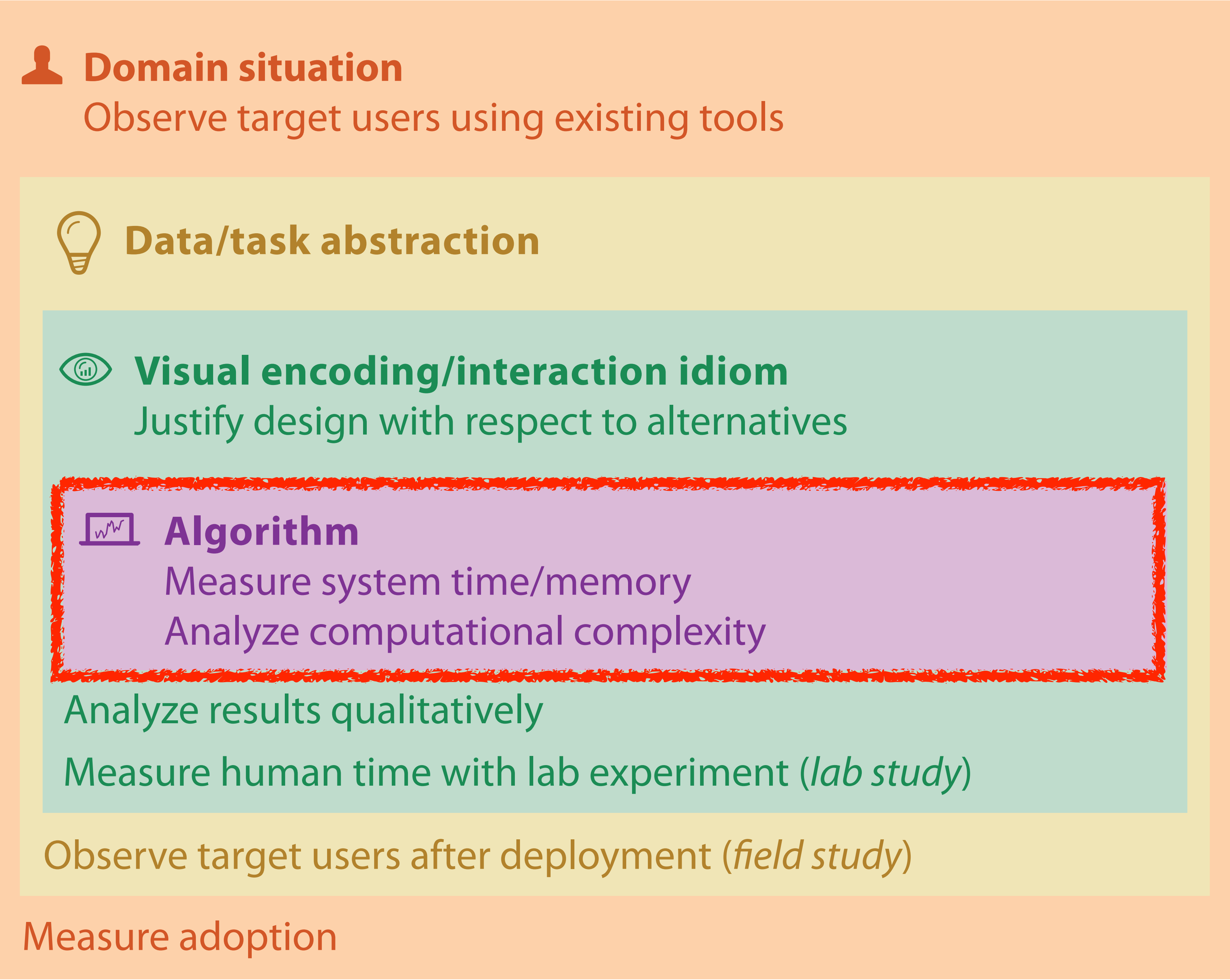
Measure adoption

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

Domain situation

Observe target users using existing tools

Data/task abstraction

Visual encoding/interaction idiom

Justify design with respect to alternatives

Algorithm

Measure system time/memory

Analyze computational complexity

Analyze results qualitatively

Measure human time with lab experiment (*lab study*)

Observe target users after deployment (*field study*)

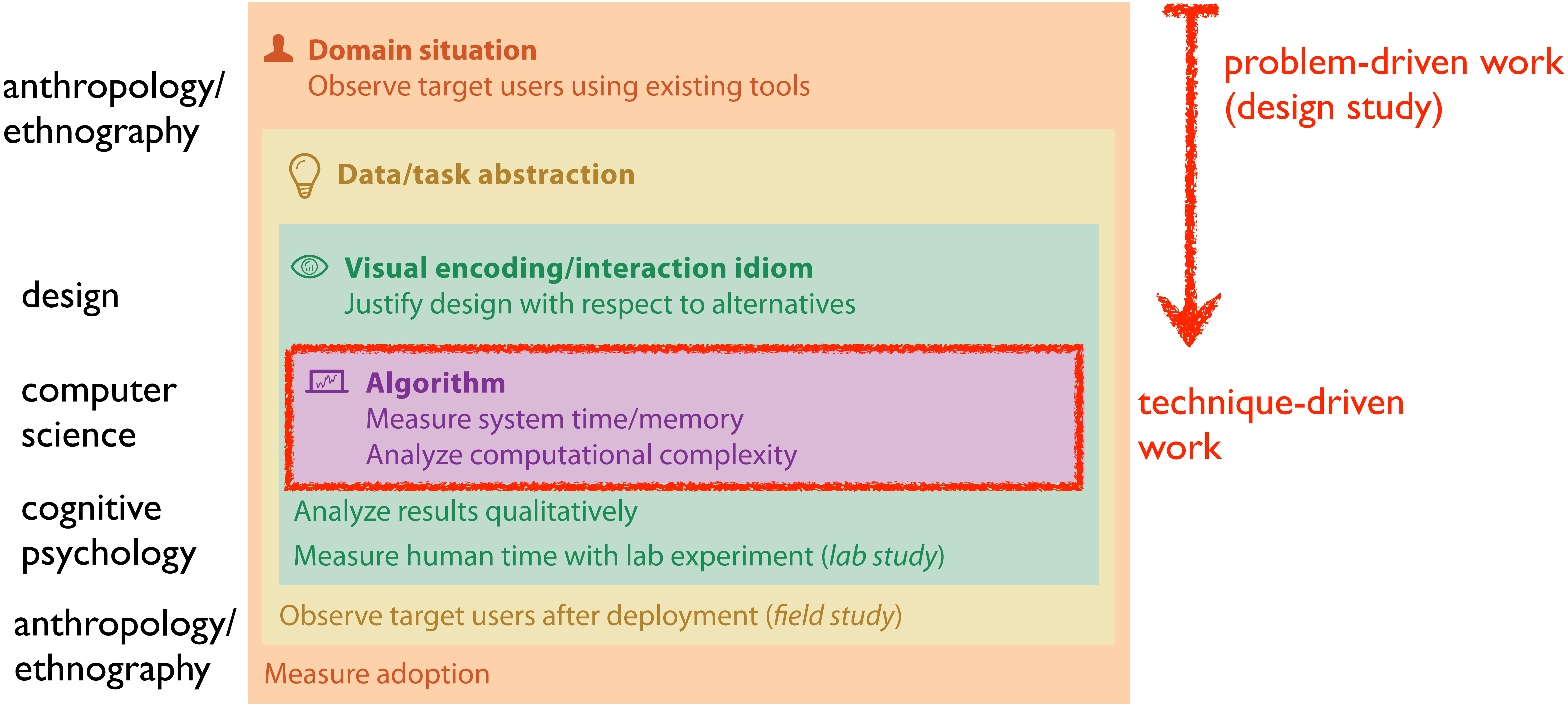
Measure adoption

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*)

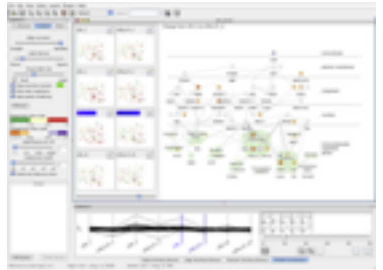
Measure adoption

problem-driven work (design study)

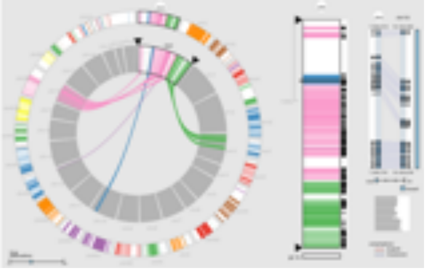
technique-driven work

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

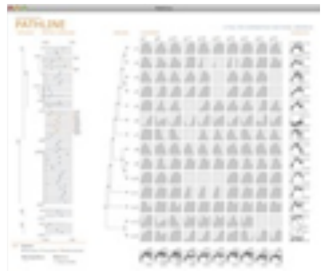
Design Studies: Lessons learned after 21 of them



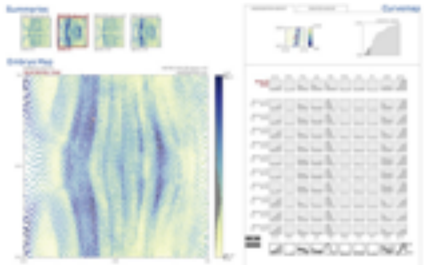
Cerebral
genomics



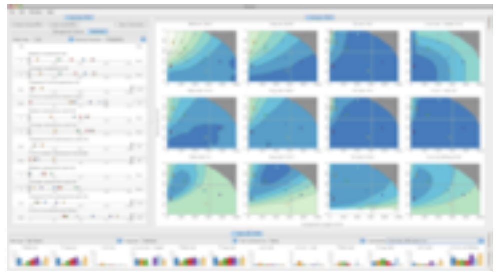
MizBee
genomics



Pathline
genomics



MulteeSum
genomics

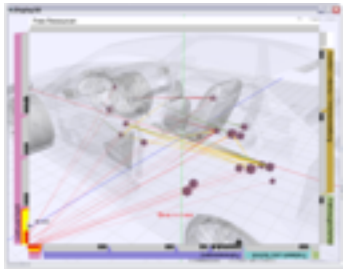


Vismon
fisheries management

QuestVis
sustainability

WiKeVis
in-car networks

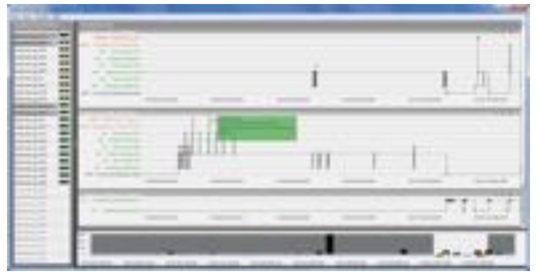
MostVis
in-car networks



Car-X-Ray
in-car networks

ProgSpy2010
in-car networks

RelEx
in-car networks

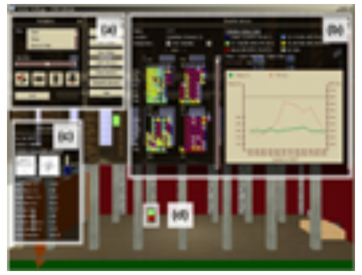


Cardiogram
in-car networks

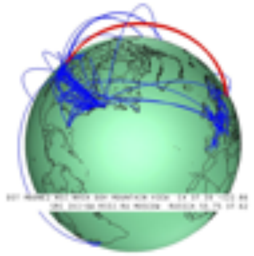
AutobahnVis
in-car networks

VisTra
in-car networks

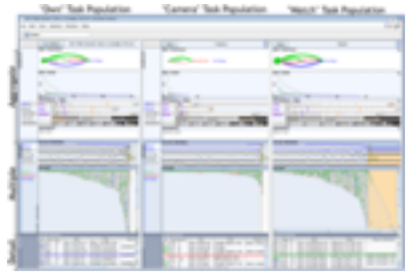
Constellation
linguistics



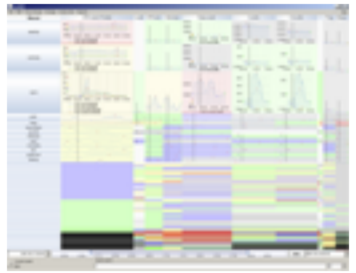
LibVis
cultural heritage



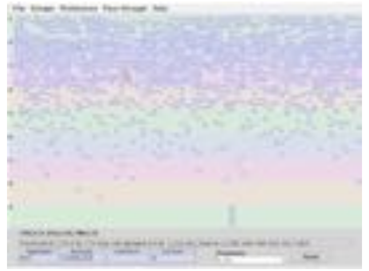
Caidants
multicast



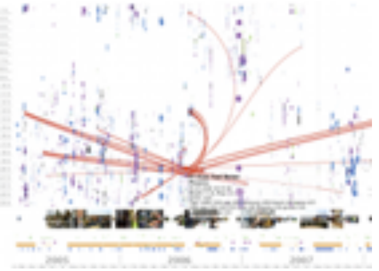
SessionViewer
web log analysis



LiveRAC
server hosting



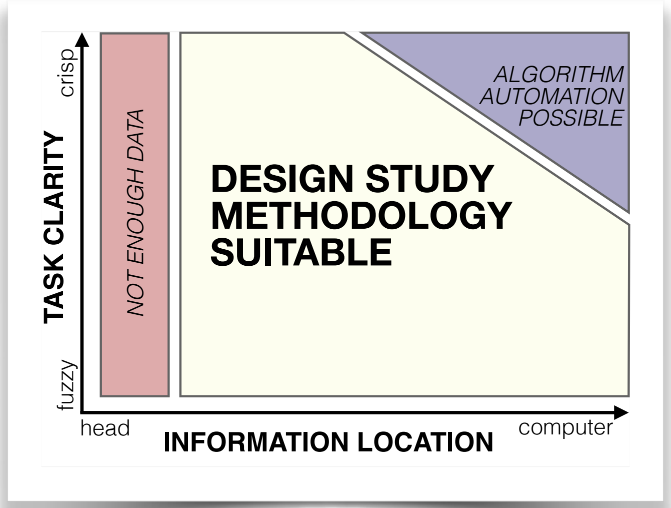
PowerSetViewer
data mining



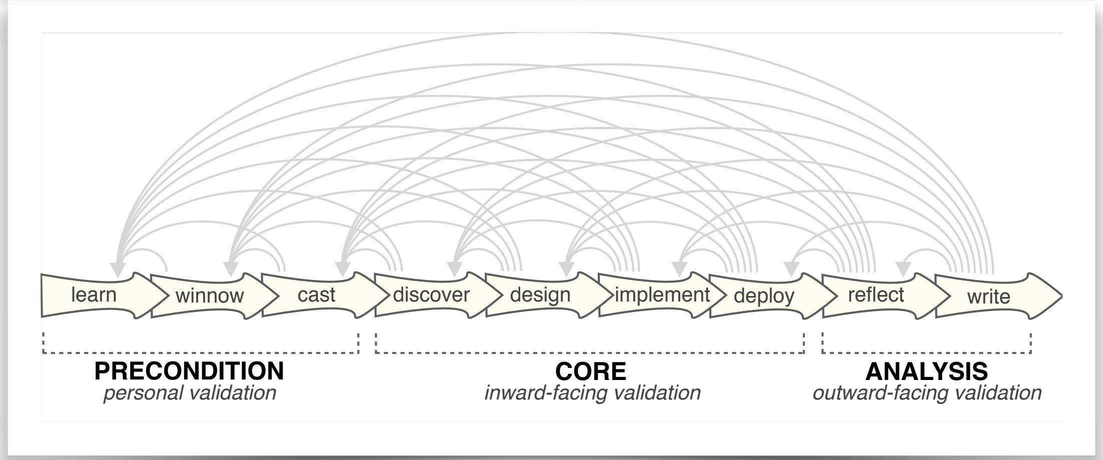
LastHistory
music listening

Design Study Methodology: Reflections from the Trenches and the Stacks

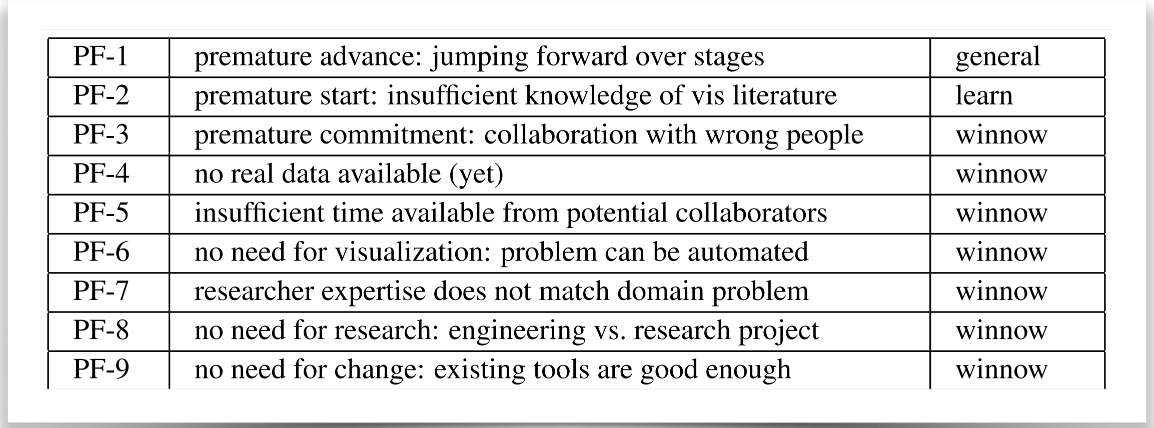
- definitions



- 9-stage framework

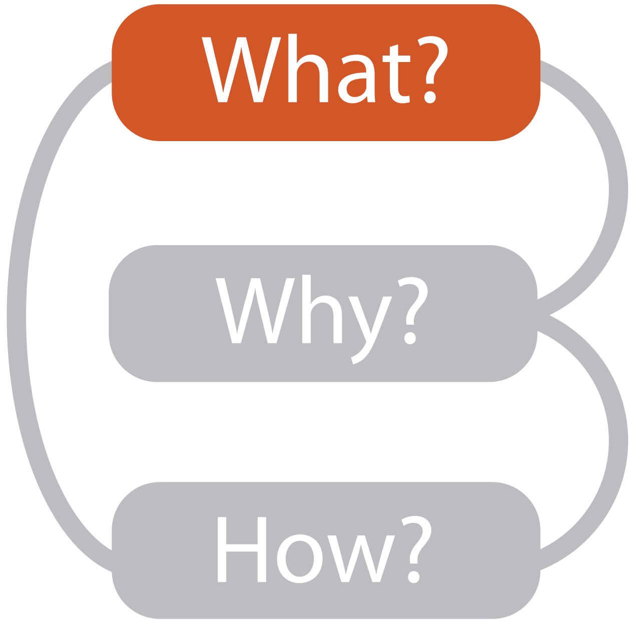


- 32 pitfalls
  and how to avoid them



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

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


What?

Why?

How?

What?

Datasets

➔ Data Types

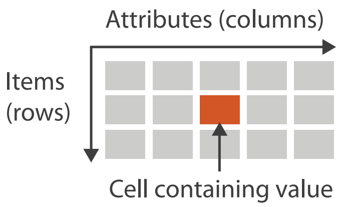
➔ Items ➔ Attributes ➔ Links ➔ Positions ➔ Grids

➔ Data and Dataset Types

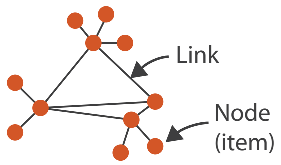
Tables	Networks & Trees	Fields	Geometry	Clusters, Sets, Lists
Items	Items (nodes)	Grids	Items	Items
Attributes	Links	Positions	Positions	
	Attributes	Attributes		

➔ Dataset Types

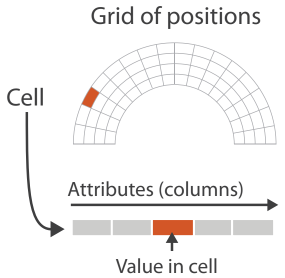
➔ Tables



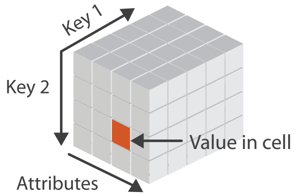
➔ Networks



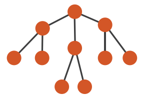
➔ Fields (Continuous)



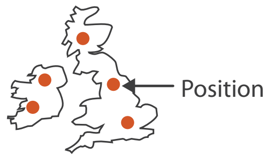
➔ *Multidimensional Table*



➔ *Trees*



➔ Geometry (Spatial)



➔ Dataset Availability

➔ Static

➔ Dynamic

Attributes

➔ Attribute Types

➔ Categorical

✚ ● ■ ▲

➔ Ordered

➔ *Ordinal*

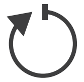
➔ *Quantitative*

➔ Ordering Direction

➔ Sequential

➔ Diverging

➔ Cyclic

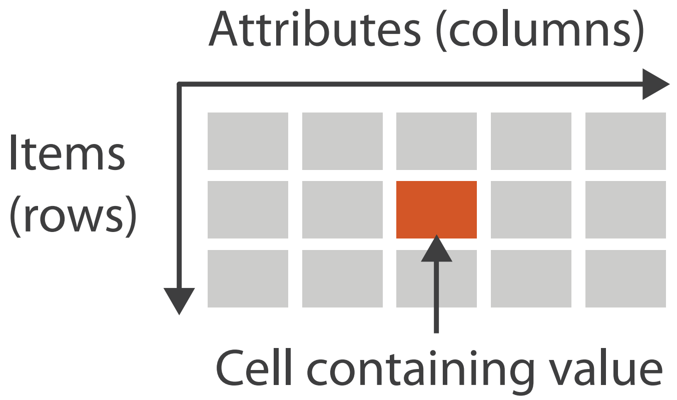


Three major datatypes

Three major datatypes

➔ Dataset Types

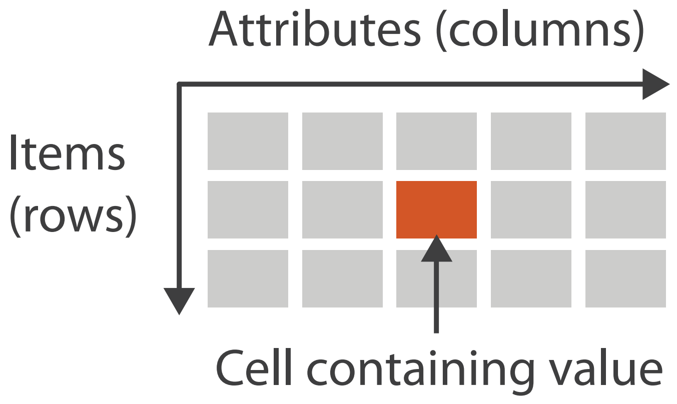
➔ Tables



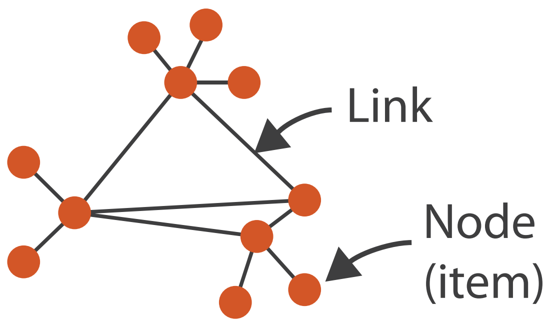
Three major datatypes

➔ Dataset Types

→ Tables



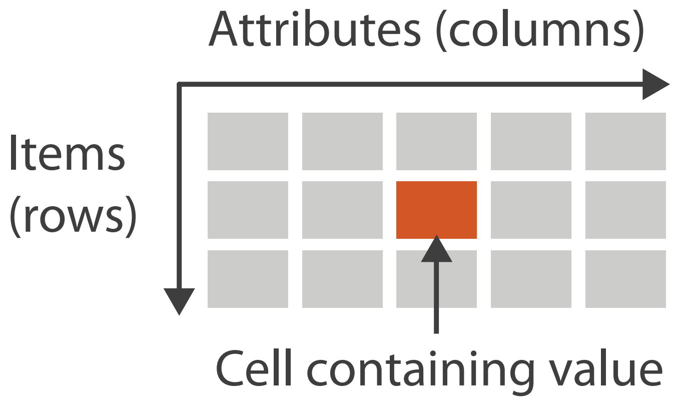
→ Networks



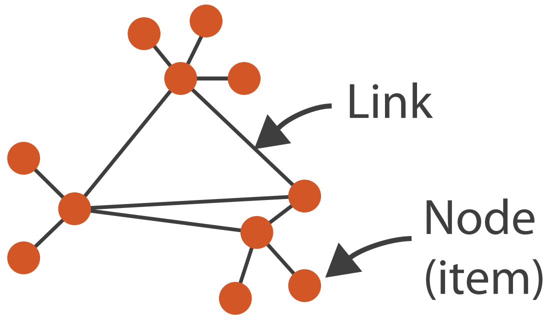
Three major datatypes

➔ Dataset Types

➔ Tables

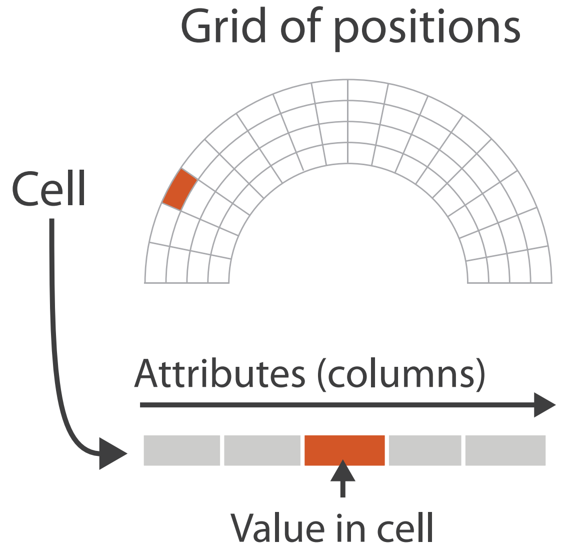


➔ Networks

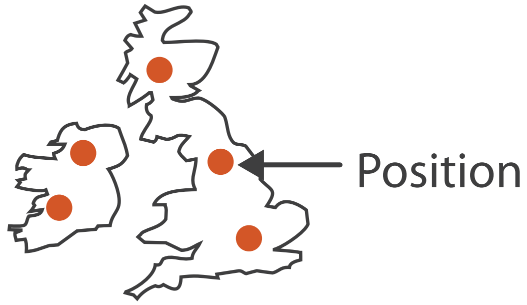


➔ Spatial

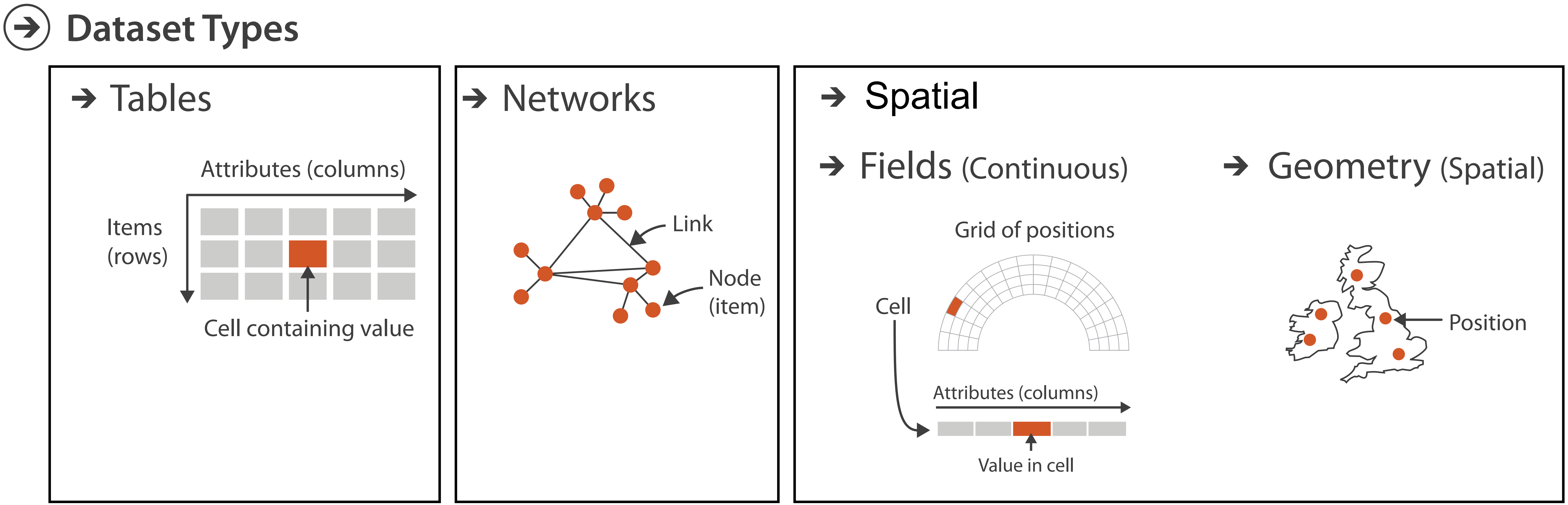
➔ Fields (Continuous)



➔ Geometry (Spatial)



Three major datatypes



➔ Dataset Types

➔ Tables

➔ Networks

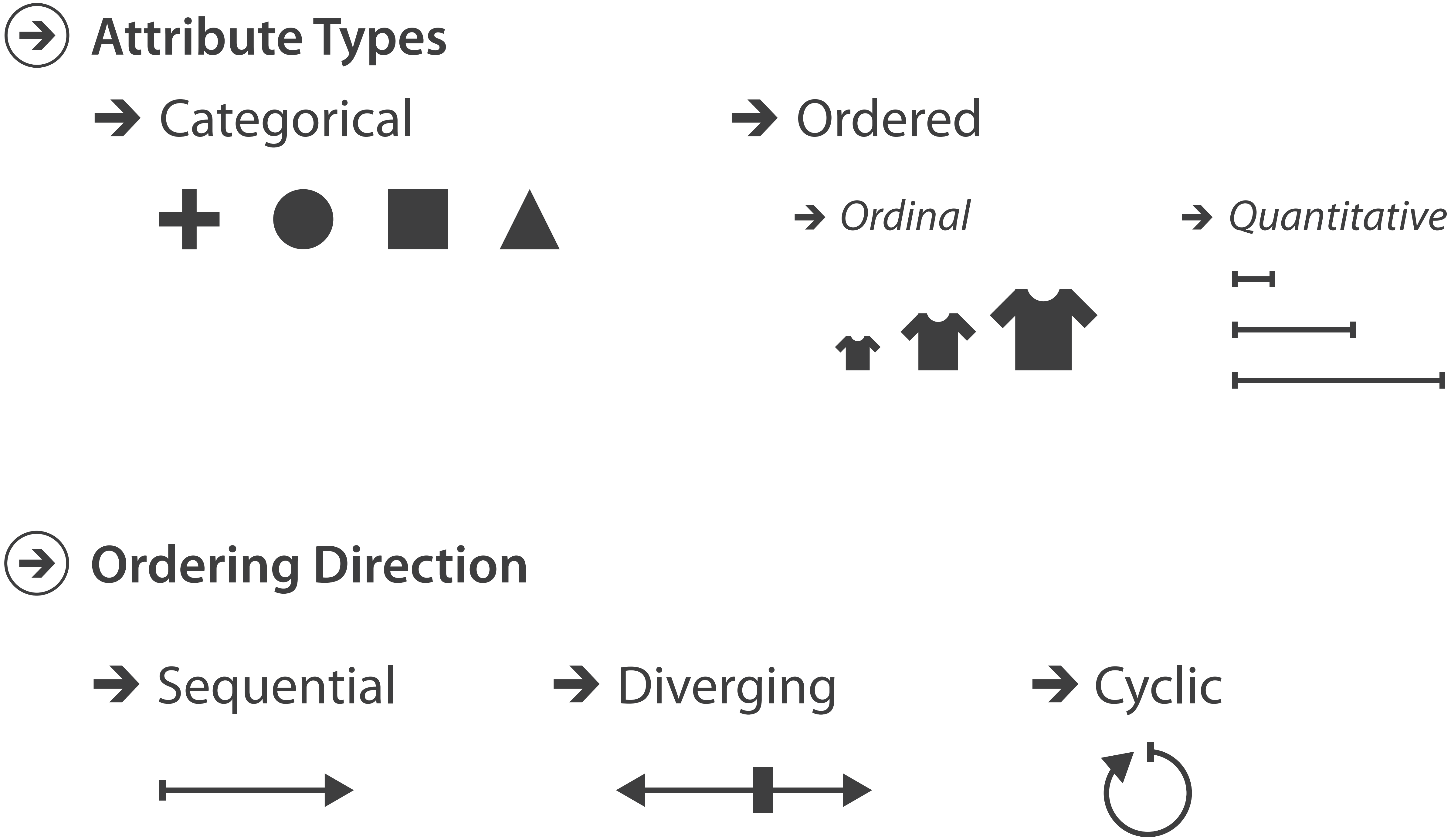
➔ Spatial

➔ Fields (Continuous)

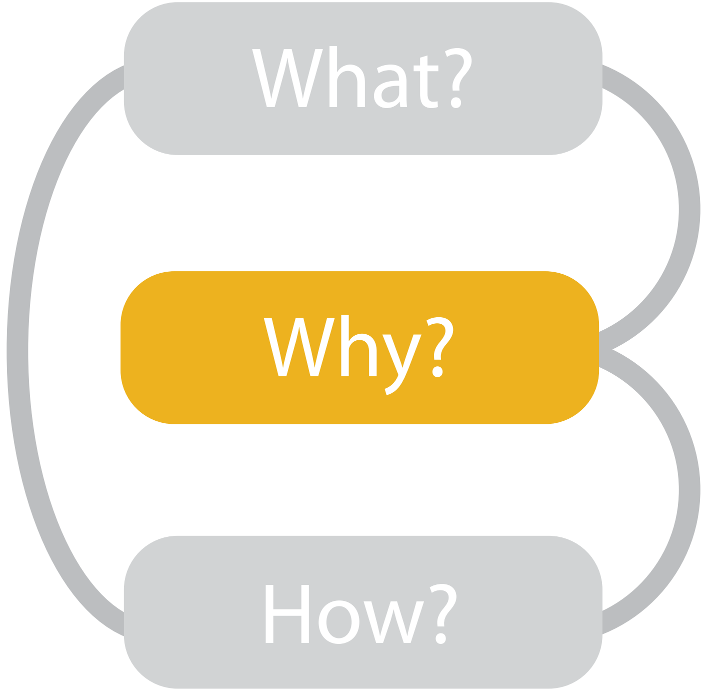
➔ Geometry (Spatial)

- 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

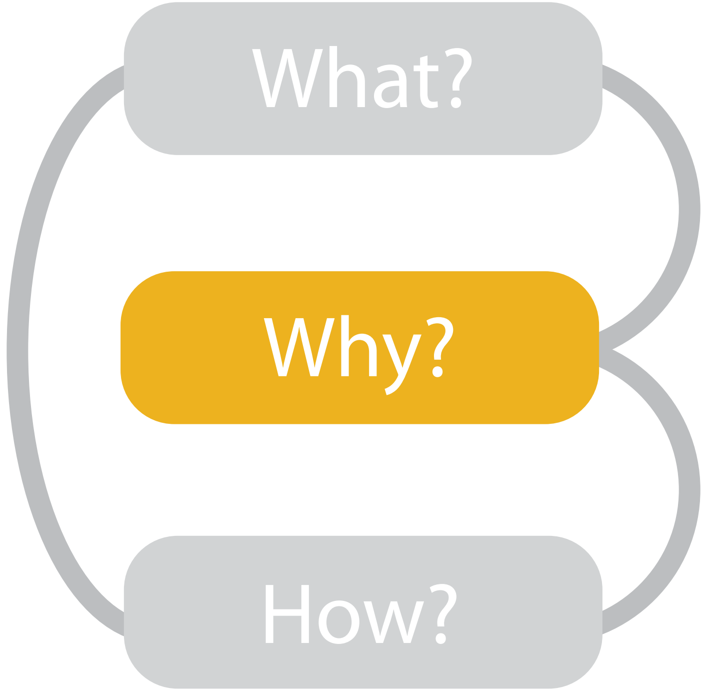
- One
  - *Distribution*
    - *Extremes*
- Many
  - *Dependency*
  - *Correlation*
  - *Similarity*

Network Data

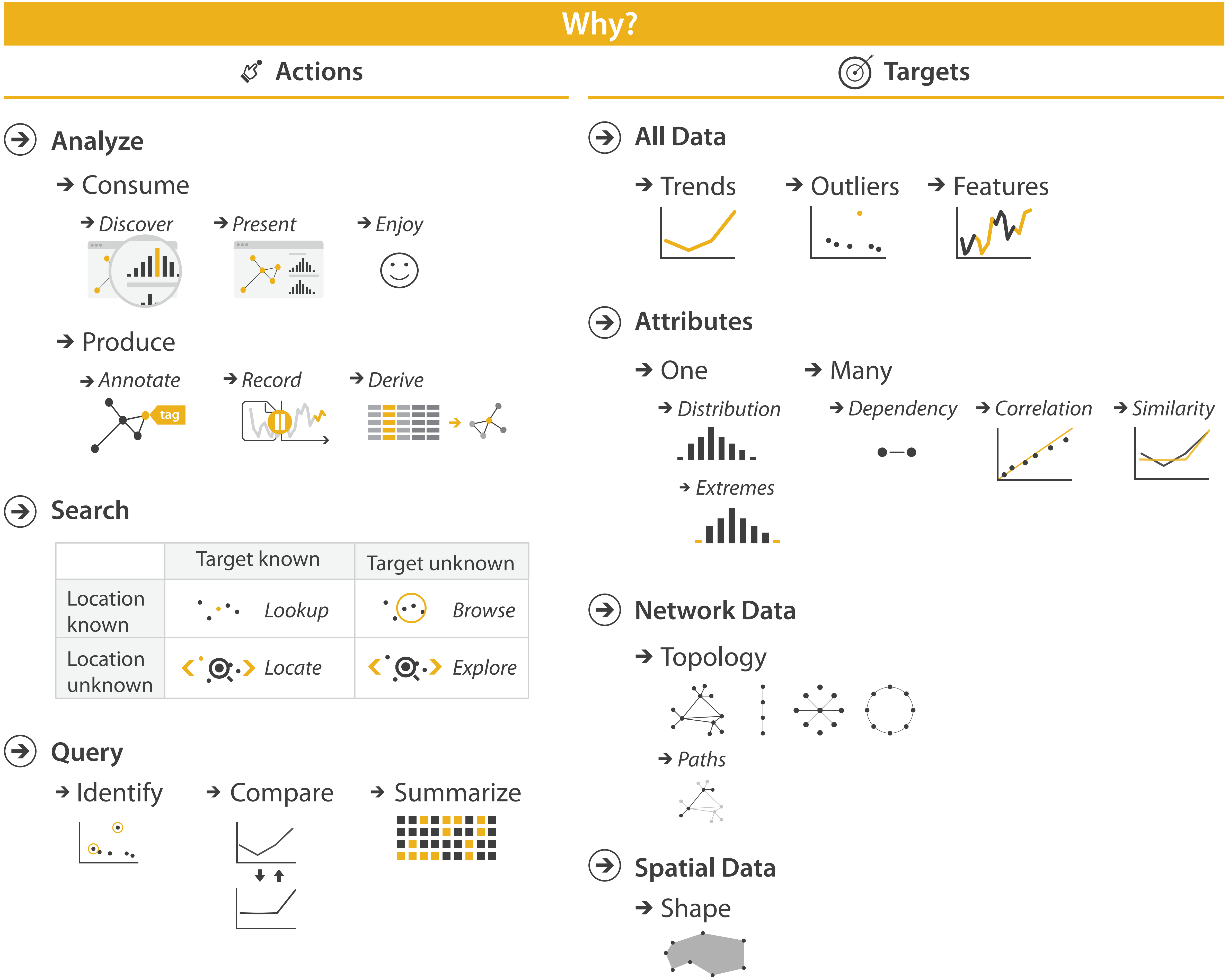
- Topology
  - *Paths*

Spatial Data

- Shape



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



Why?

Actions

Analyze

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

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

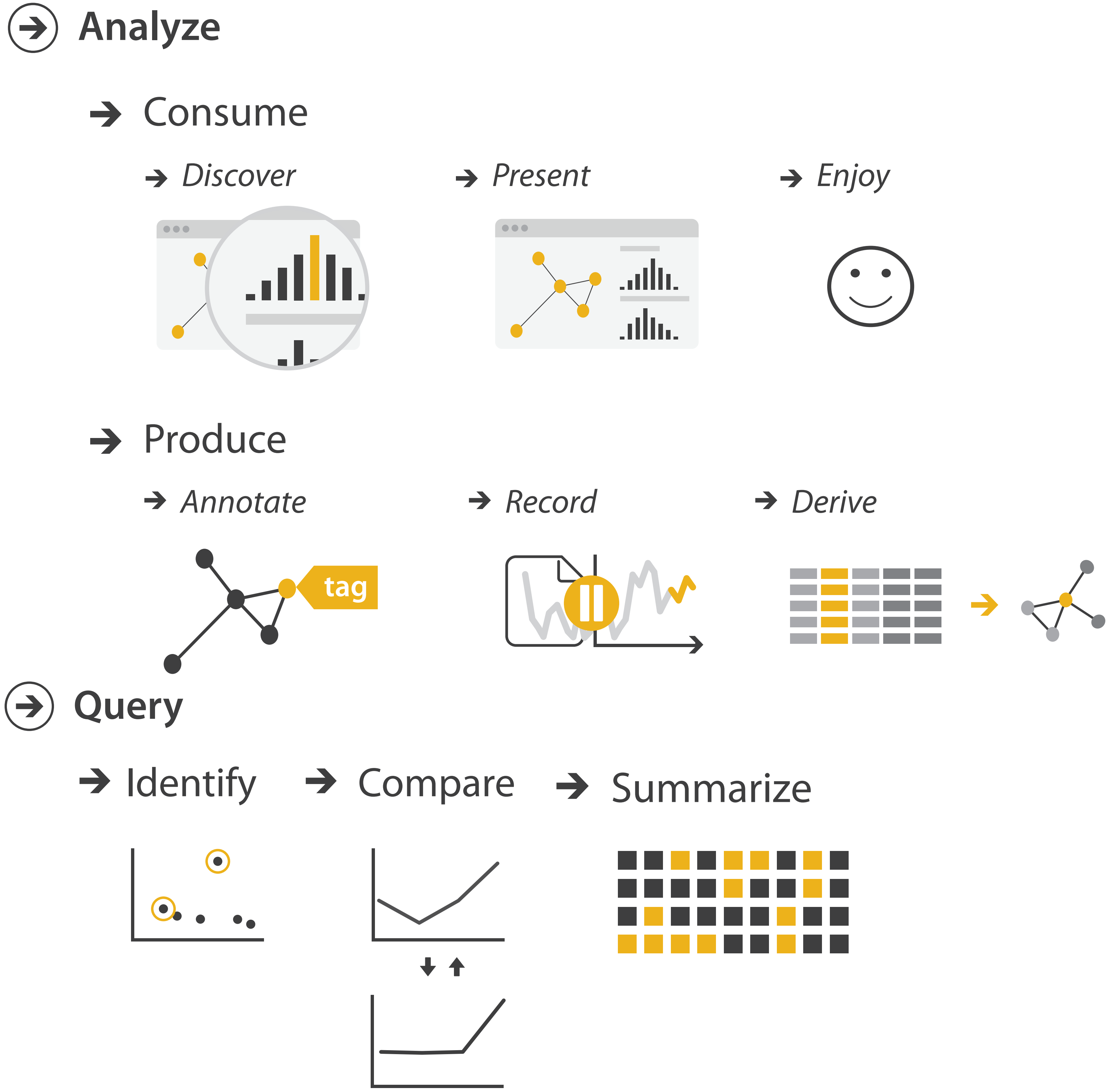
- Topology
  - *Paths*

Spatial Data

- Shape

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)



Analyze

→ Consume

→ *Discover* → *Present* → *Enjoy*

→ Produce

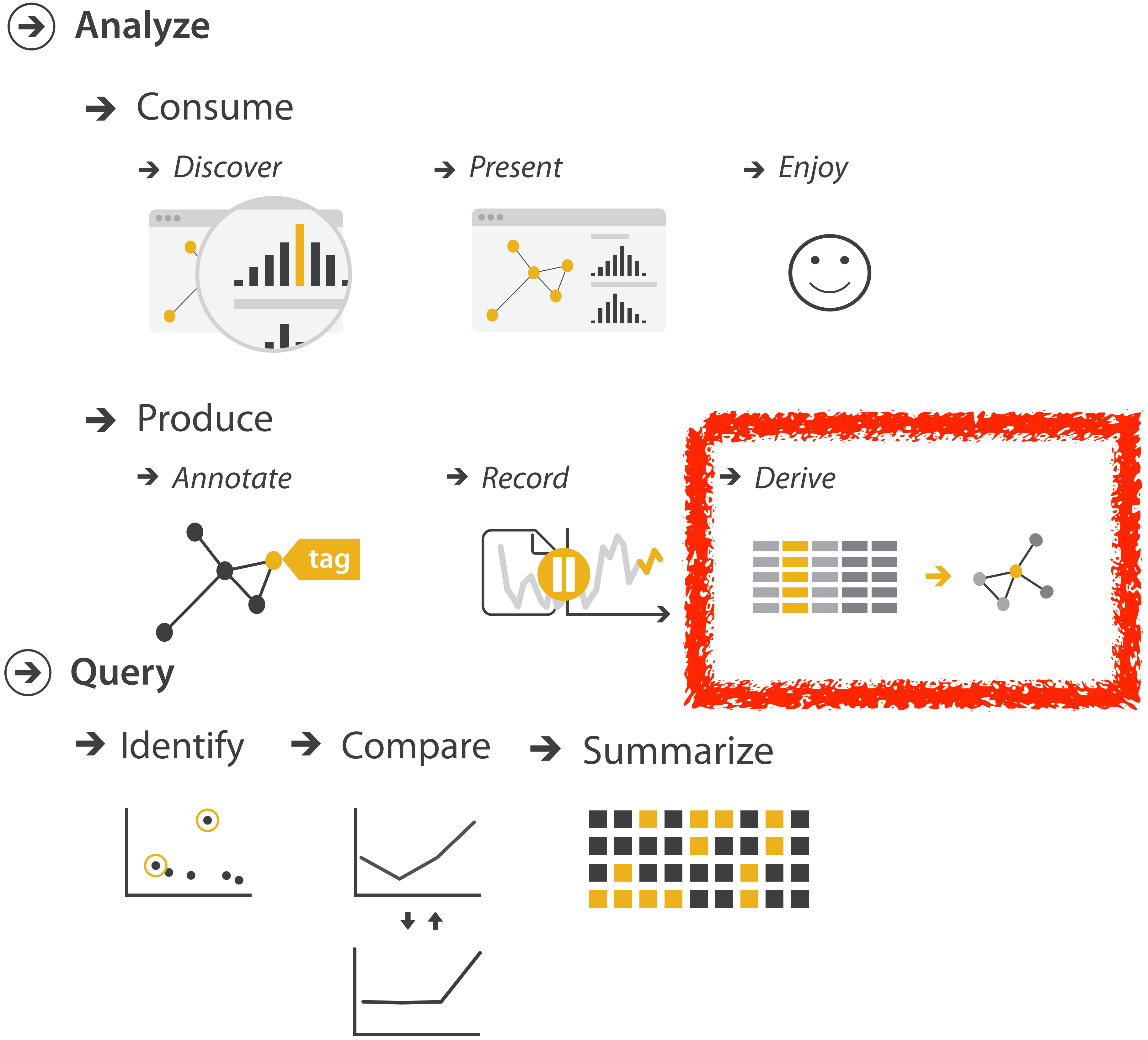
→ *Annotate* → *Record* → *Derive*

Query

→ Identify → Compare → Summarize

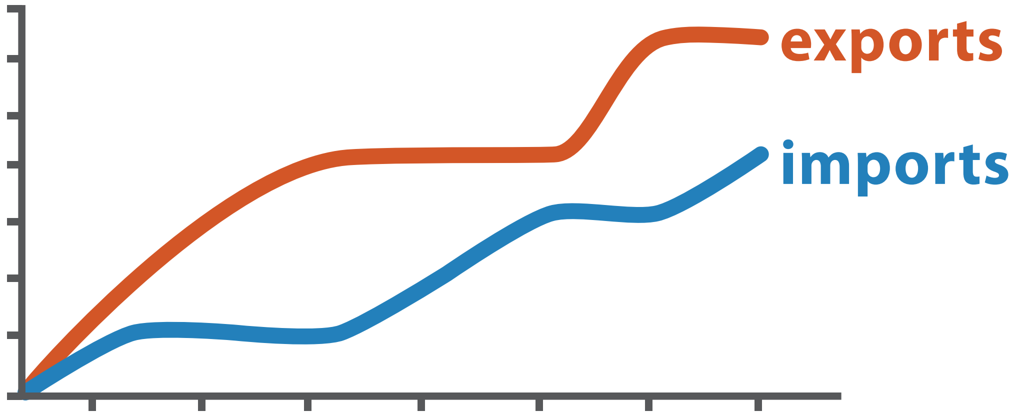
Actions: Analyze, Query

- 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)

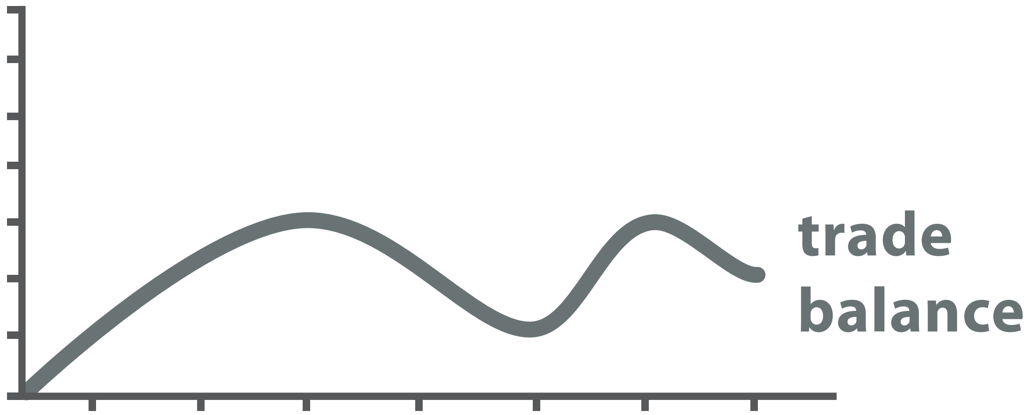


Derive

- 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



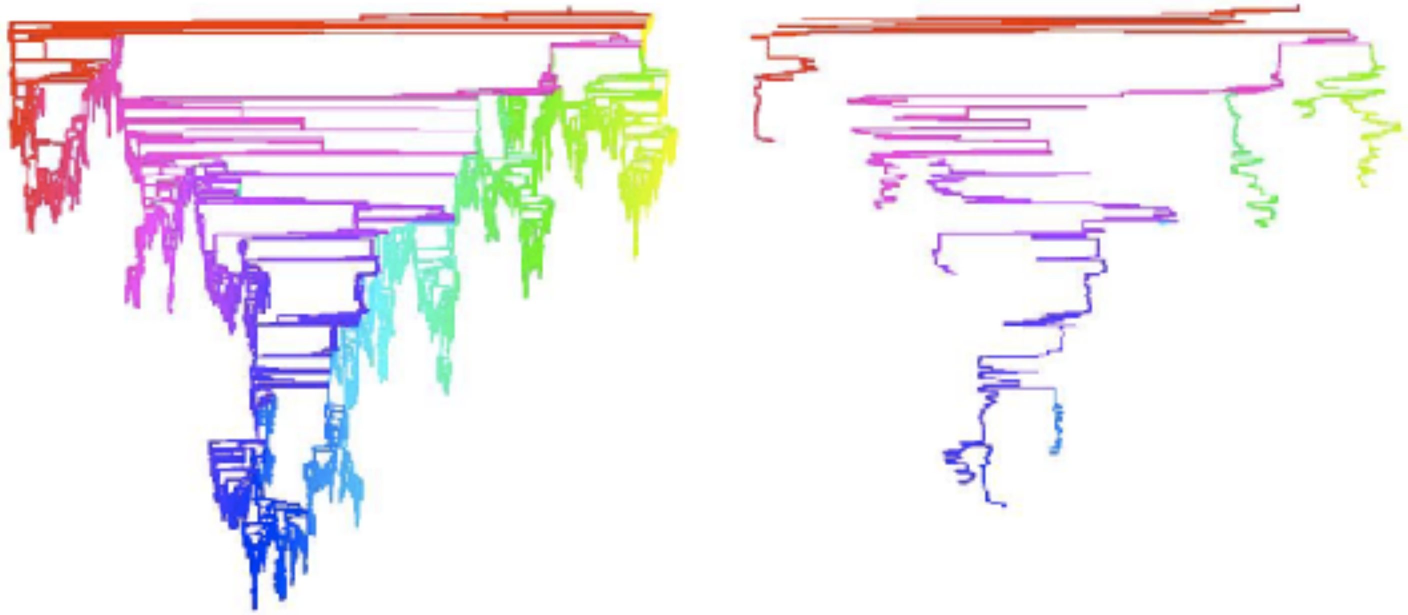
trade balance = exports − imports

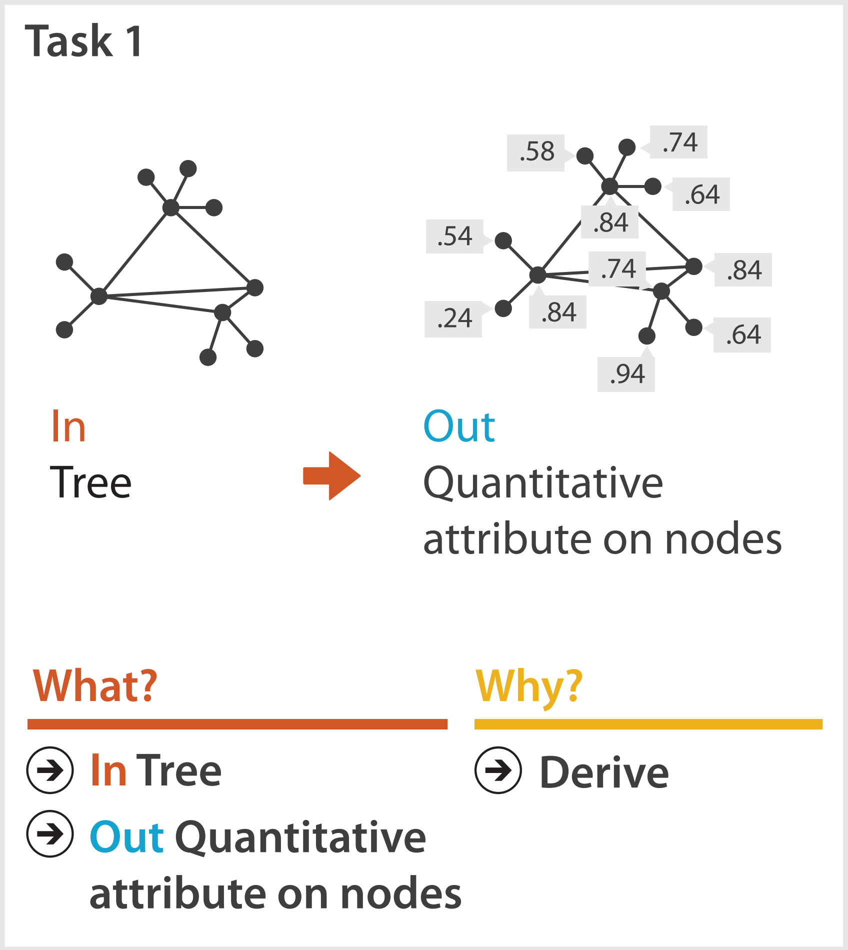
Derived Data

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.]





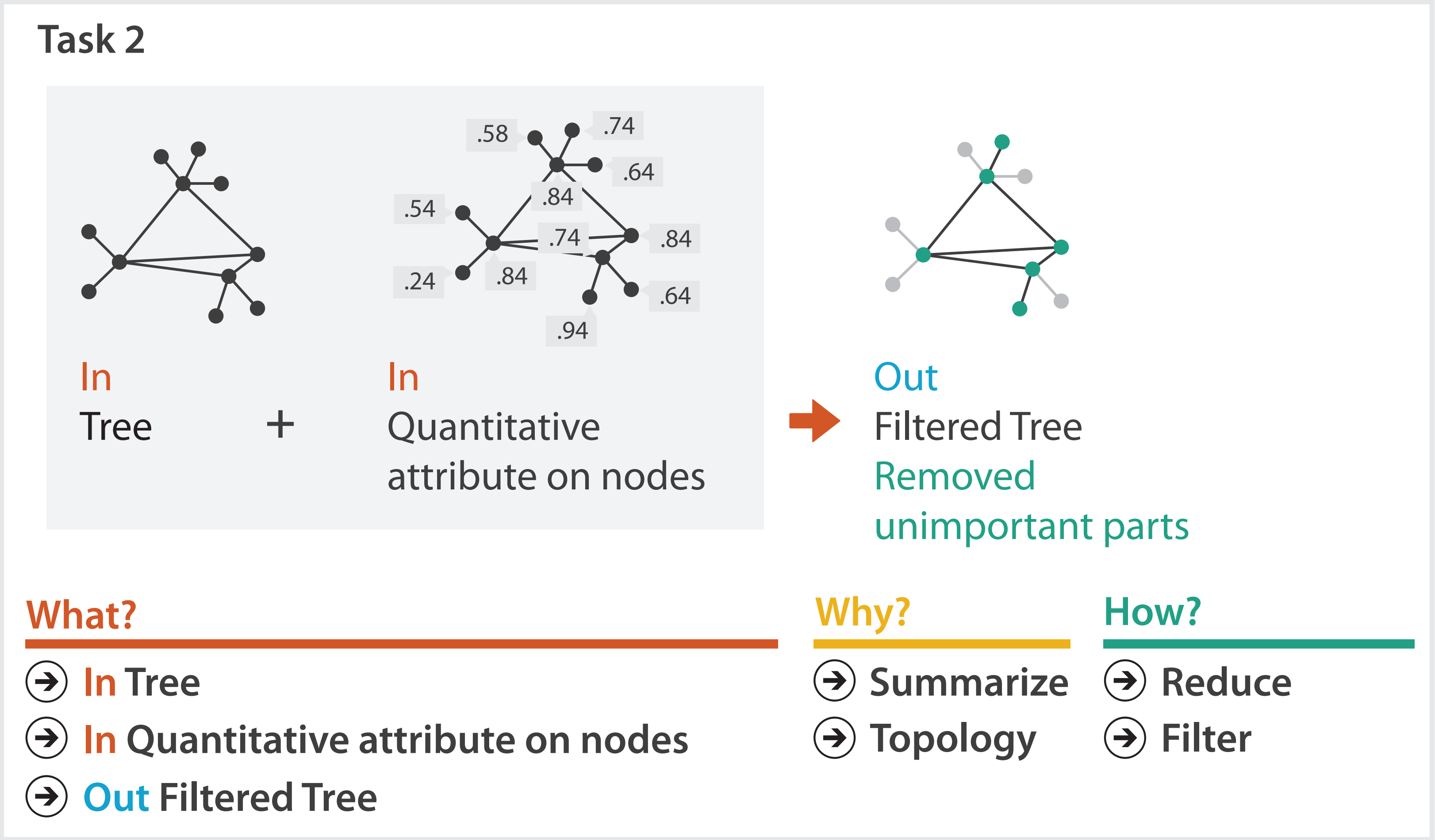
Task 1

In
Tree

Out
Quantitative attribute on nodes

What?
- In Tree
- Out Quantitative attribute on nodes

Why?
- Derive



Task 2

In
Tree

+

In
Quantitative attribute on nodes

Out
Filtered Tree
Removed unimportant parts

What?
- In Tree
- In Quantitative attribute on nodes
- Out Filtered Tree

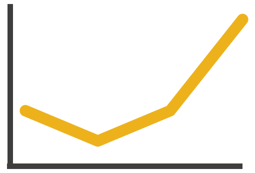
Why?
- Summarize
- Topology

How?
- Reduce
- Filter

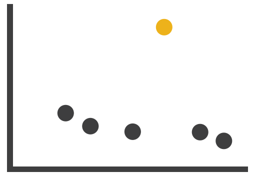
Why: Targets

All Data

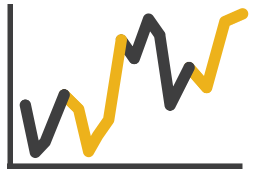
- Trends



- Outliers

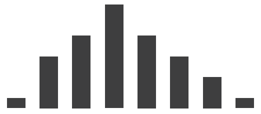


- Features

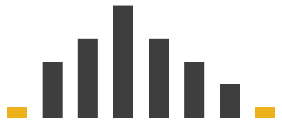


Attributes

- One
  - *Distribution*

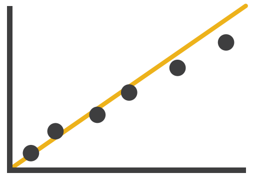


  - *Extremes*

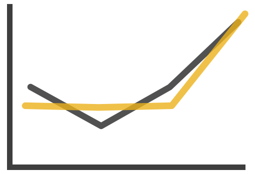


- Many
  - *Dependency*

  - *Correlation*

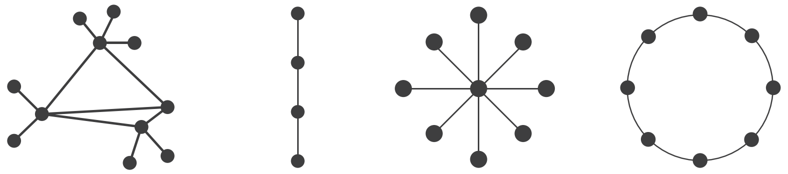


  - *Similarity*

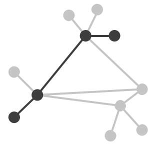


Network Data

- Topology

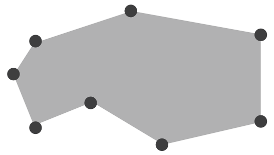


  - *Paths*



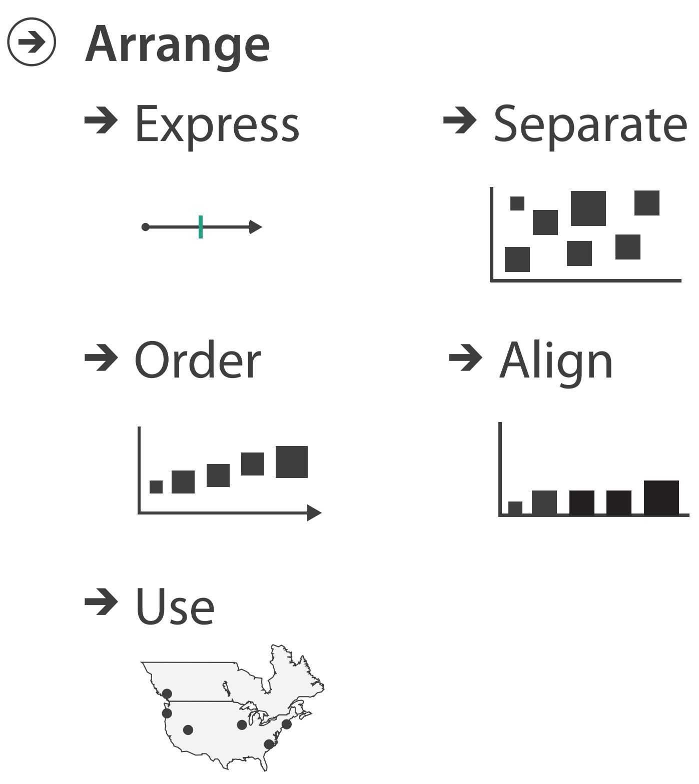
Spatial Data

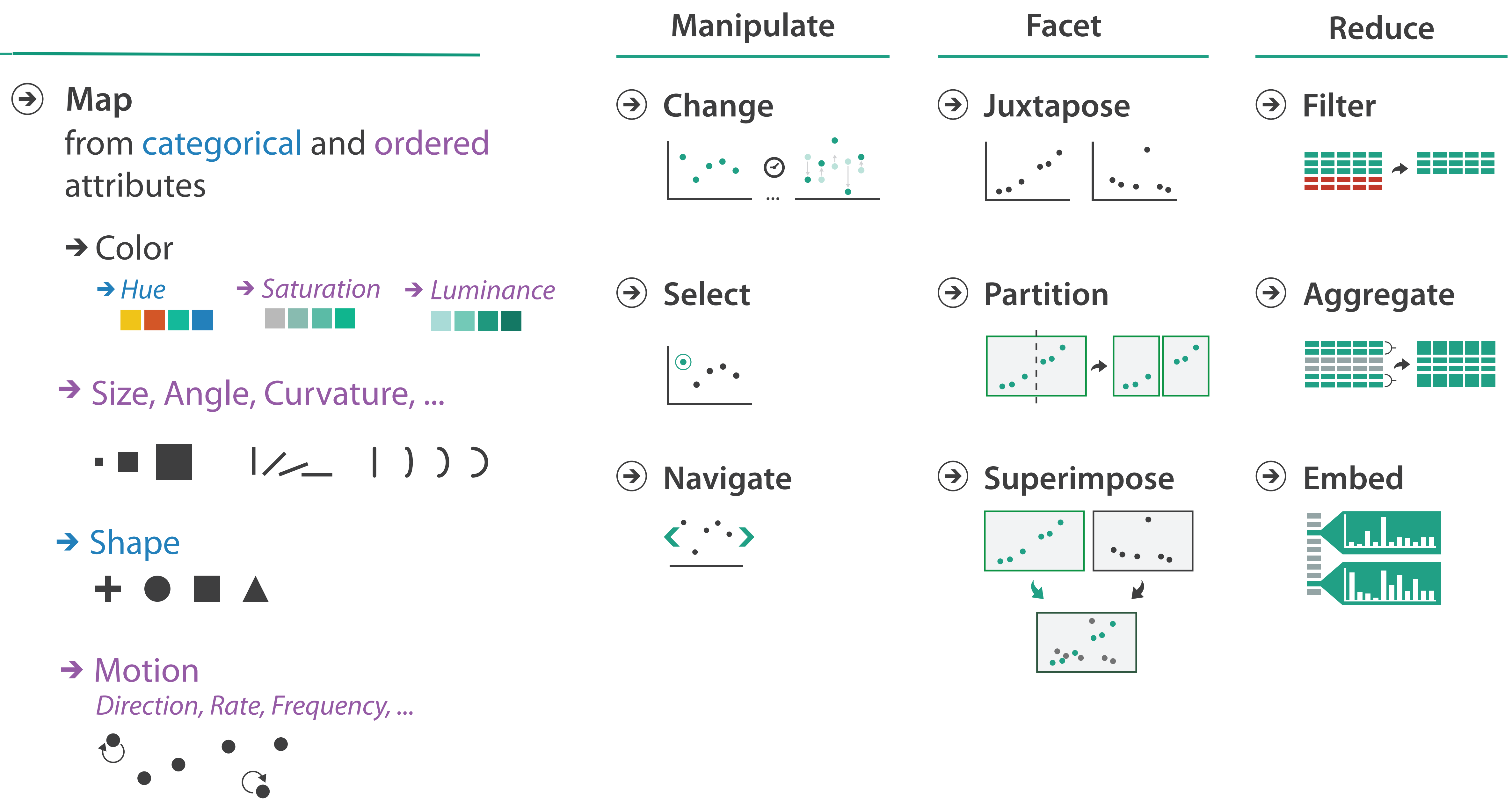
- Shape

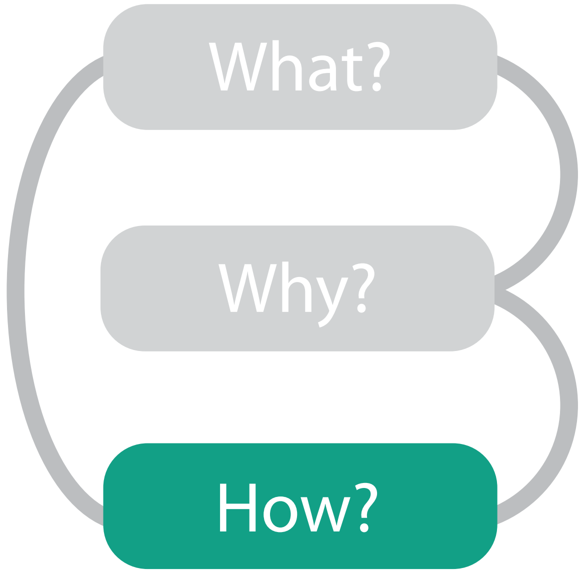


How?

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 Tables
  - Arrange Spatial Data
- Session 2
  - Arrange Networks and Trees
  - Map Color and Other Channels
  - Manipulate: Change, Select, Navigate
  - Facet: Juxtapose, Partition, Superimpose
  - Reduce: Filter, Aggregate

@tamaramunzner

http://www.cs.ubc.ca/~tmm/talks.html#halfdaycourse20

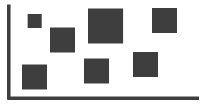
How?

Encode

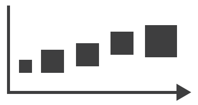
Arrange

→ Express

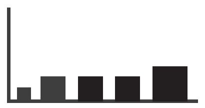
→ Separate



→ Order



→ Align



→ Use

Map

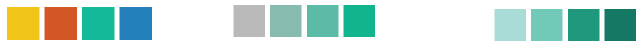
from categorical and ordered attributes

→ Color

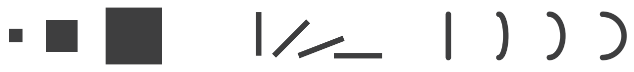
→ *Hue*

→ *Saturation*

→ *Luminance*



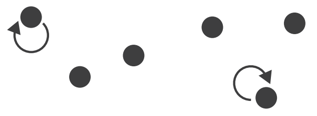
→ Size, Angle, Curvature, ...



→ Shape

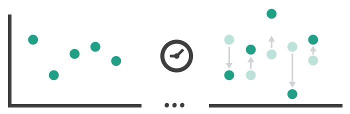
→ Motion

Direction, Rate, Frequency, ...

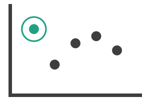


Manipulate

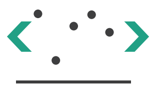
Change



Select

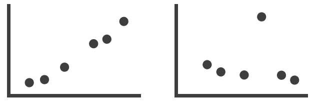


Navigate

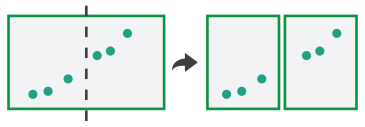


Facet

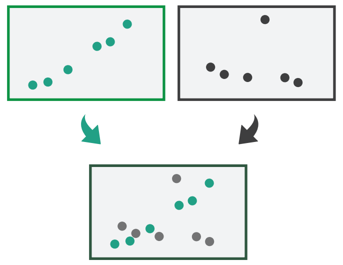
Juxtapose



Partition

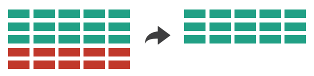


Superimpose

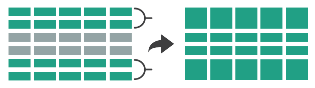


Reduce

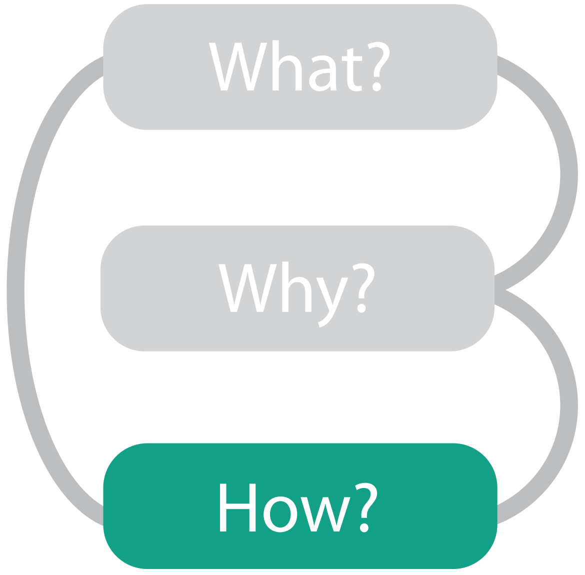
Filter



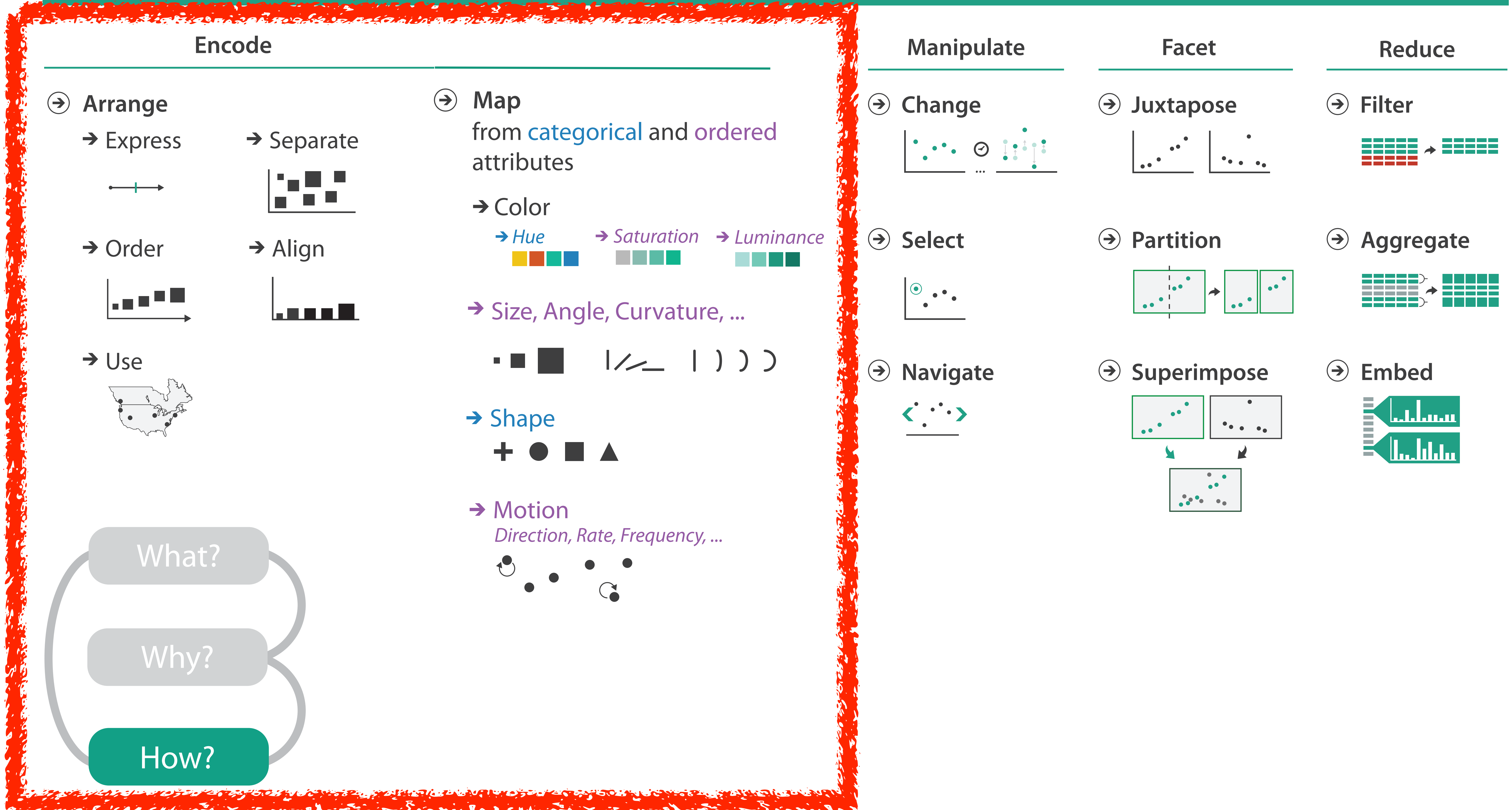
Aggregate



Embed



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

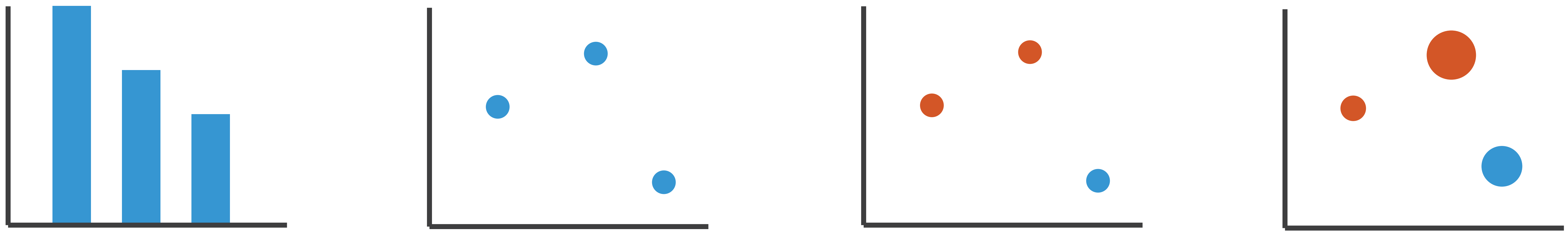
What?

Why?

How?

Visual encoding

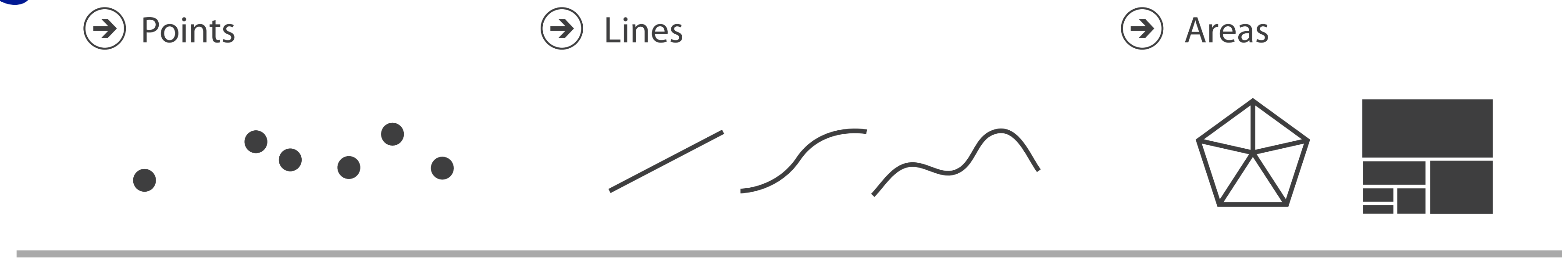
- analyze idiom structure



Definitions: Marks and channels

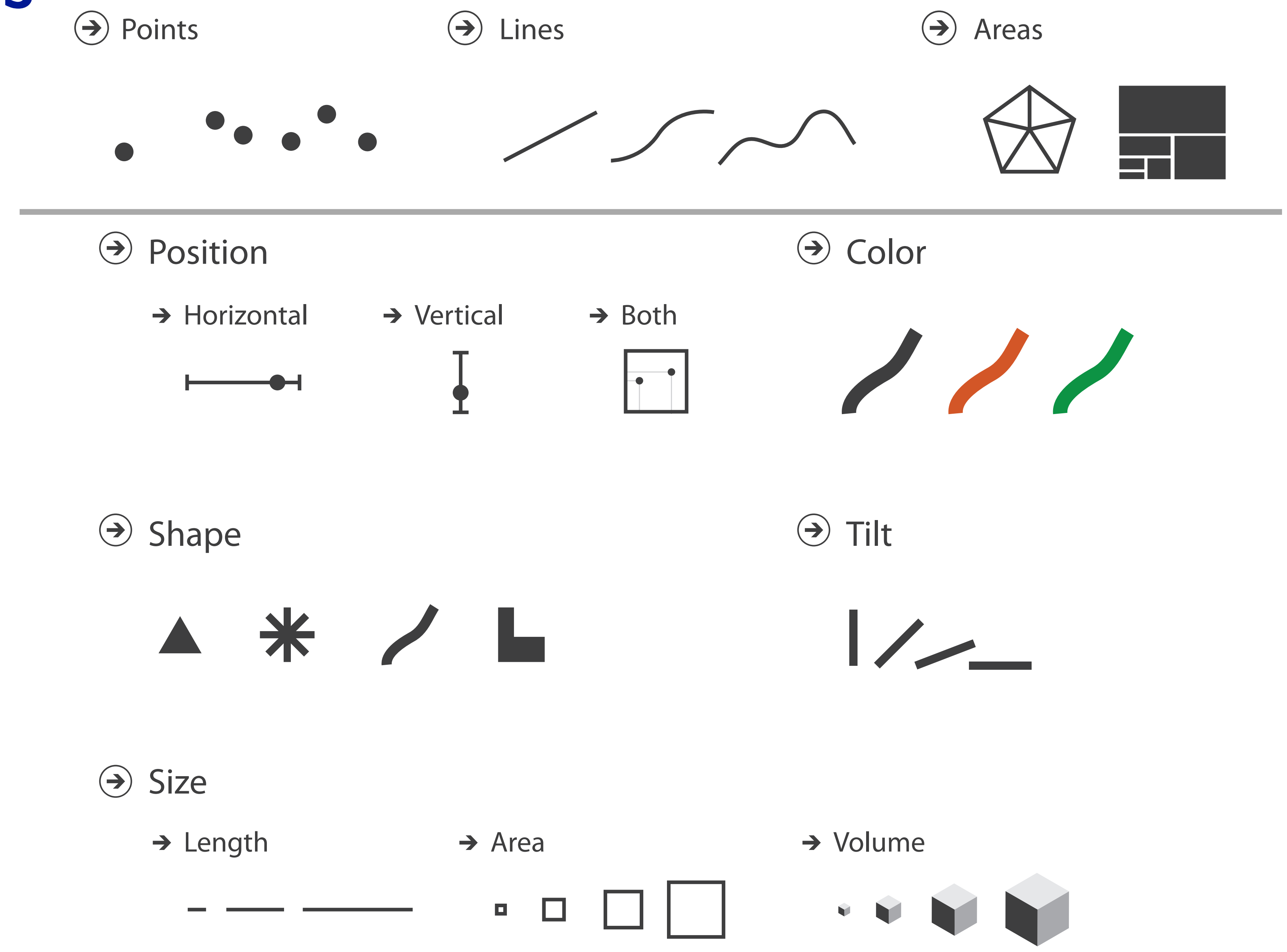
Definitions: Marks and channels

- marks
  - geometric primitives



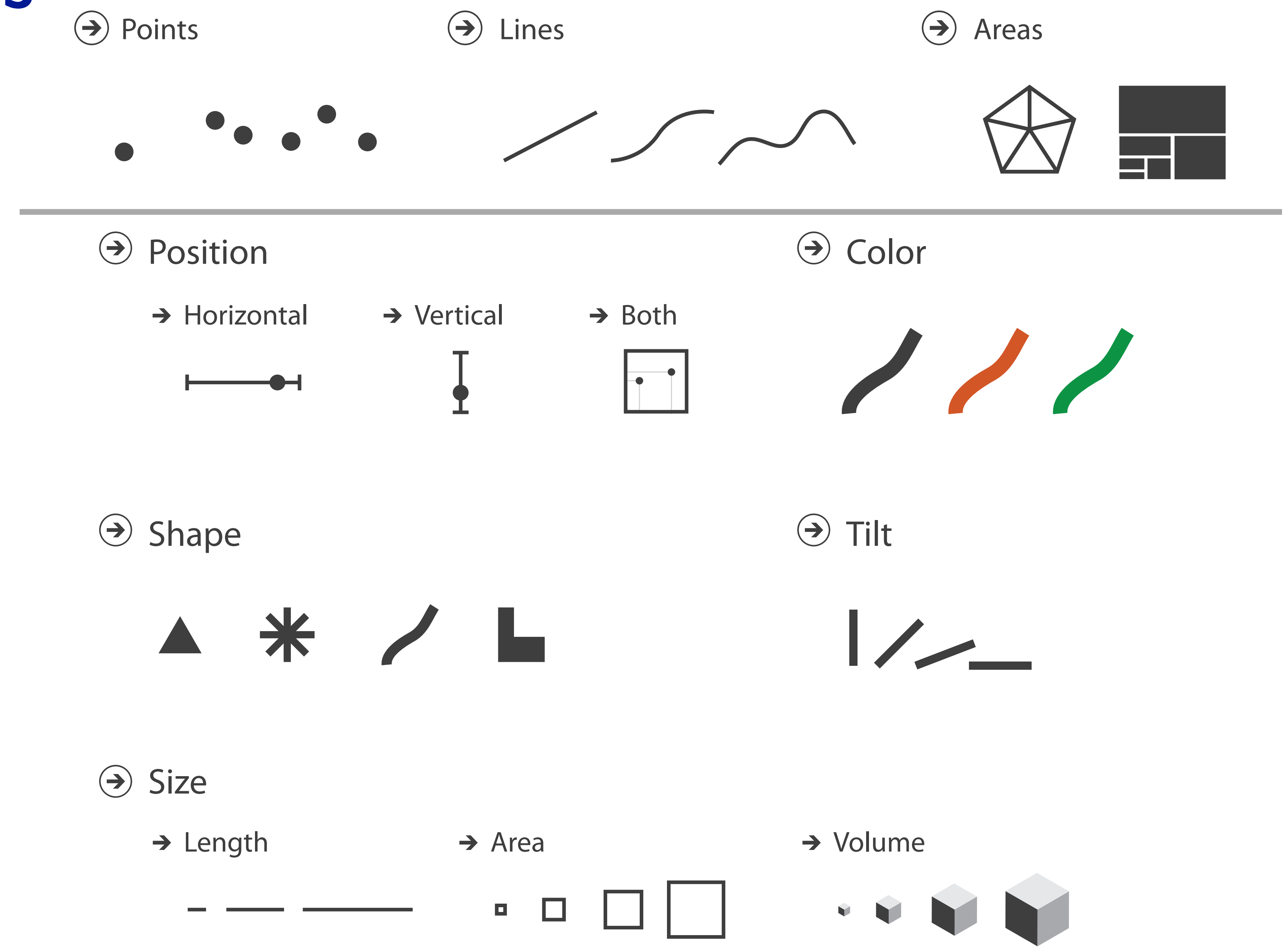
Definitions: Marks and channels

- marks
  - geometric primitives
- channels
  - control appearance of marks



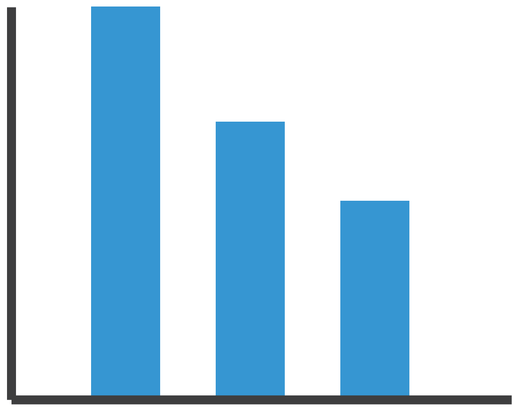
Definitions: Marks and channels

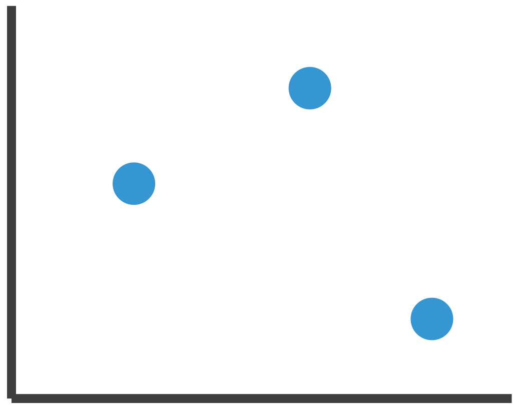
- marks
  - geometric primitives
- channels
  - control appearance of marks
- channel properties differ
  - type & amount of information that can be conveyed to human perceptual system

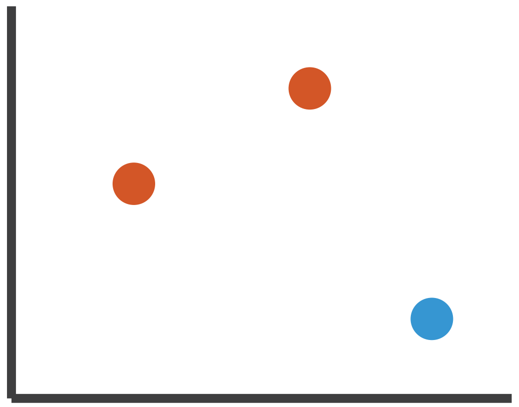


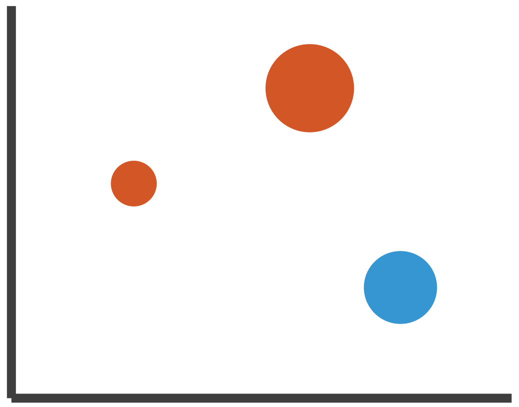
Visual encoding

- analyze idiom structure as combination of marks and channels







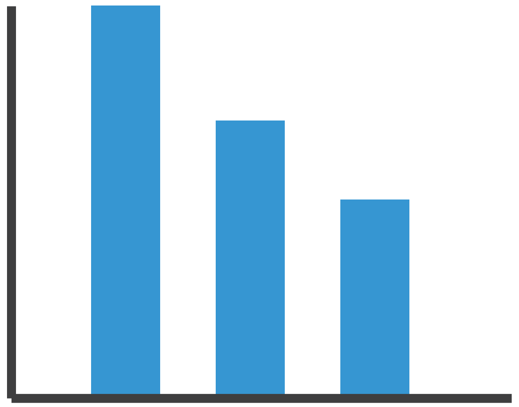


1:
vertical position

mark: line

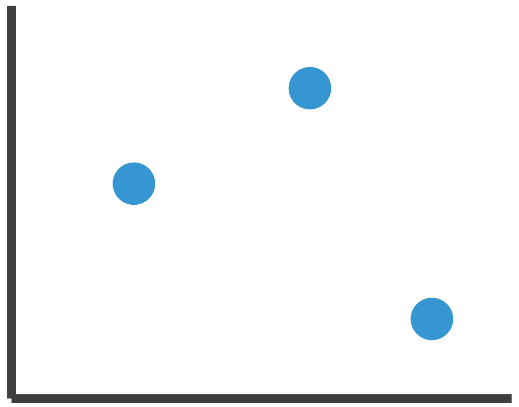
Visual encoding

- analyze idiom structure as combination of marks and channels



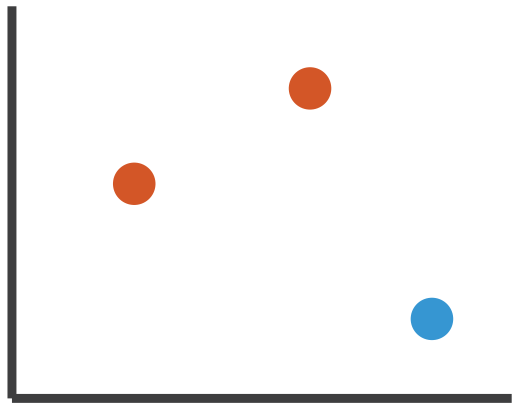
1:
vertical position

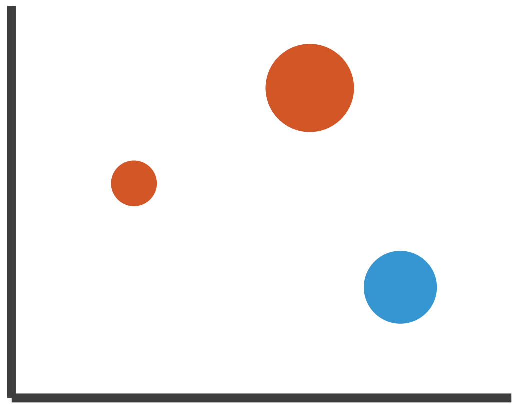
mark: line



2:
vertical position
horizontal position

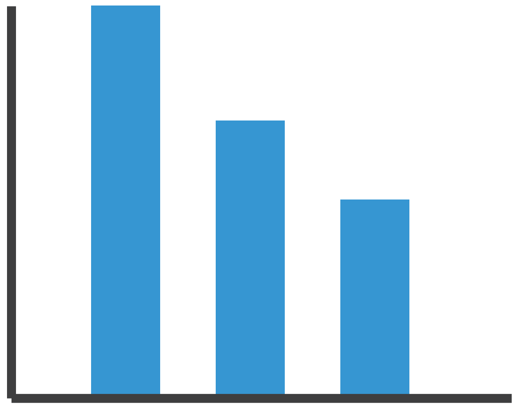
mark: point





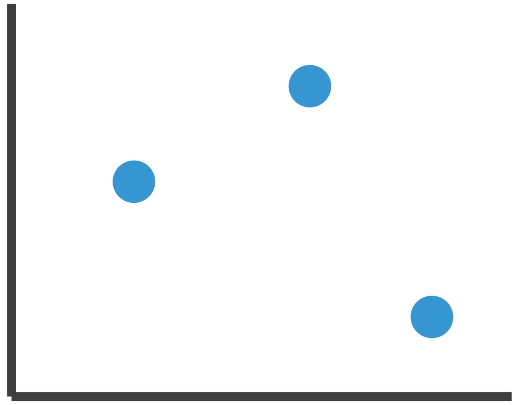
Visual encoding

- analyze idiom structure as combination of marks and channels



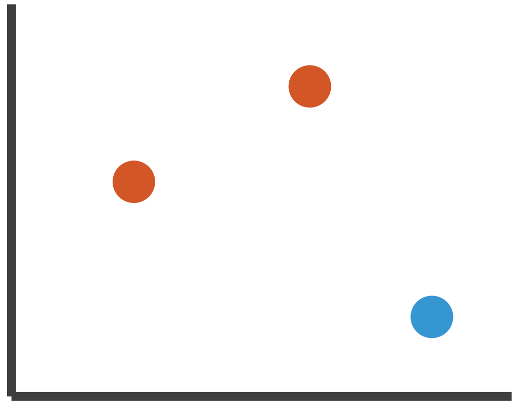
1:
vertical position

mark: line



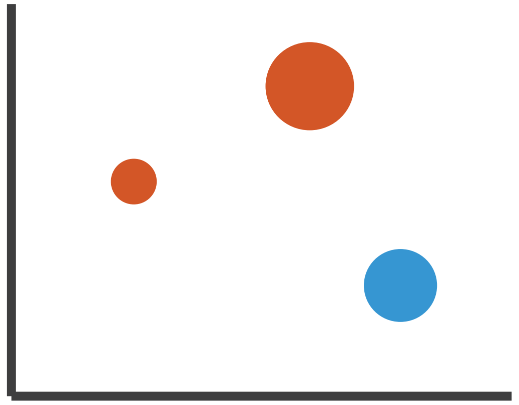
2:
vertical position
horizontal position

mark: point



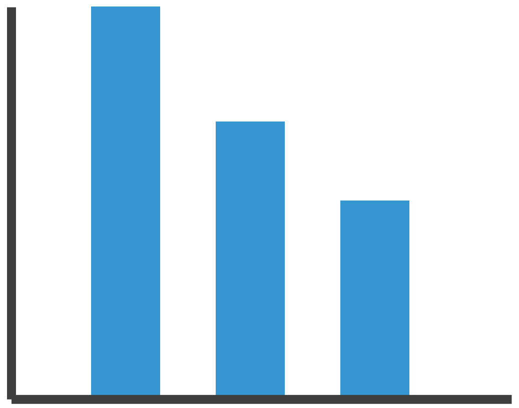
3:
vertical position
horizontal position
color hue

mark: point



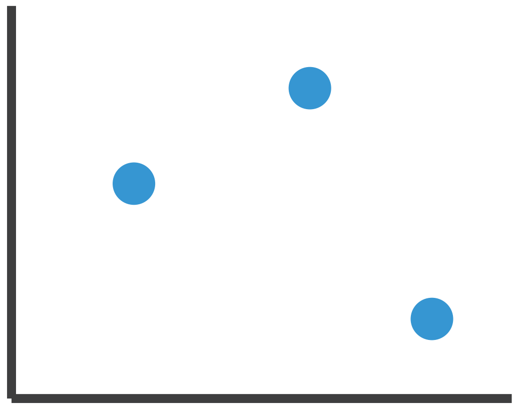
Visual encoding

- analyze idiom structure as combination of marks and channels



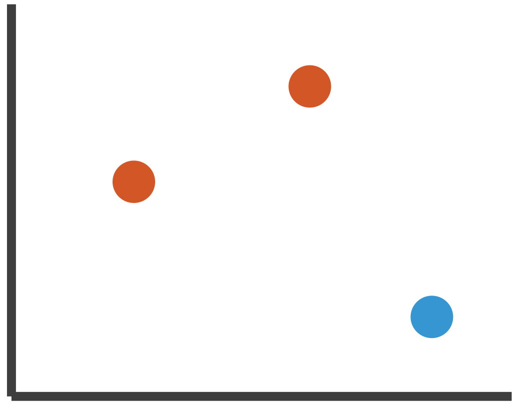
1:
vertical position

mark: line



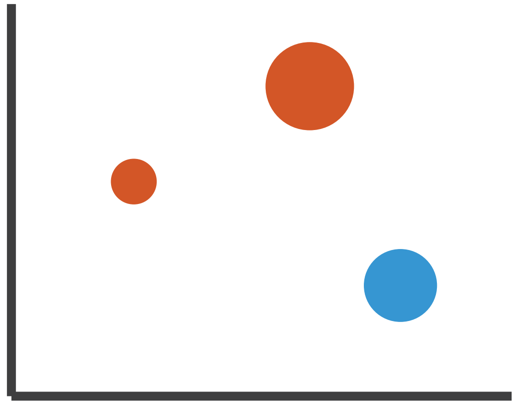
2:
vertical position
horizontal position

mark: point



3:
vertical position
horizontal position
color hue

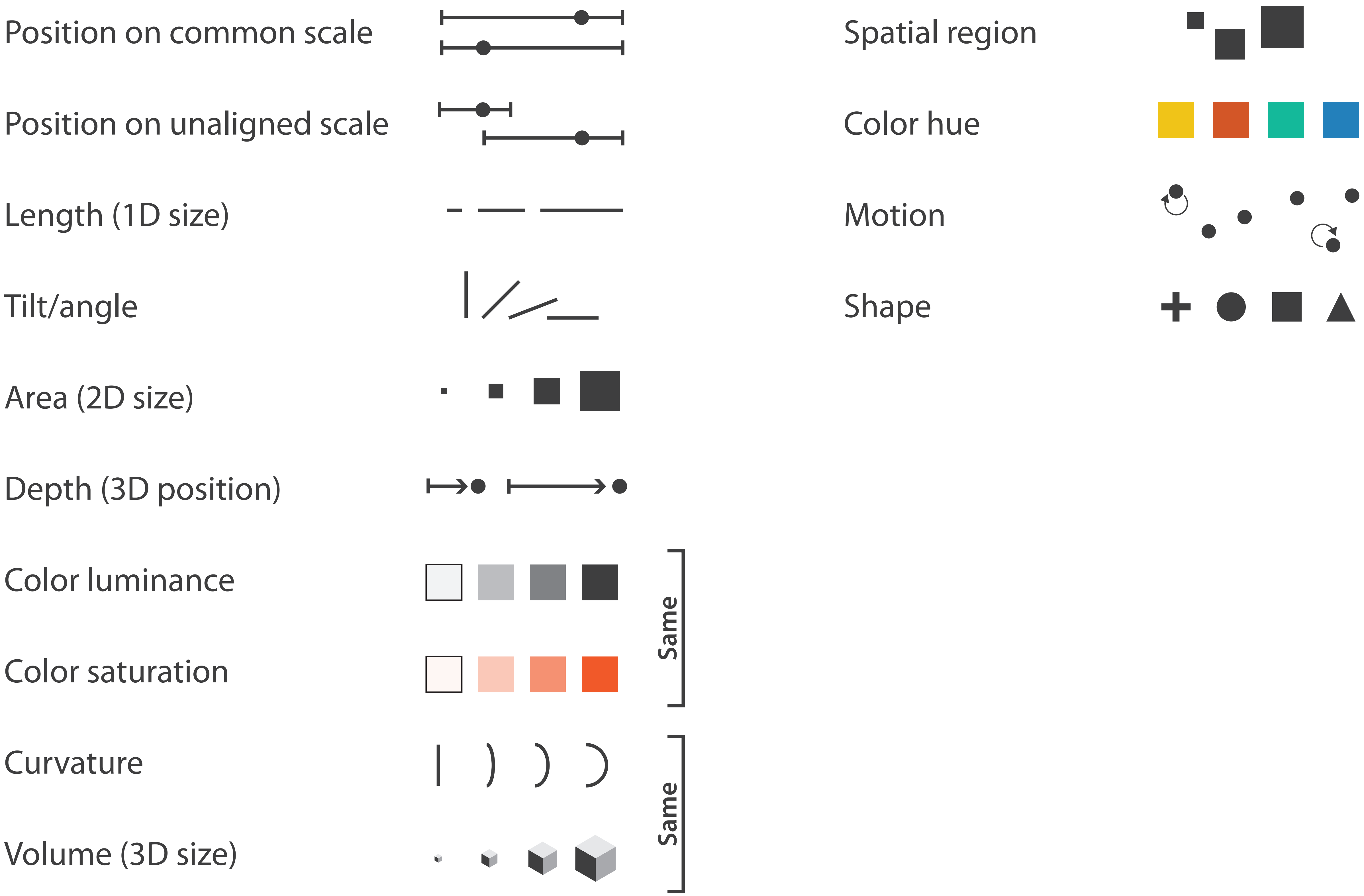
mark: point



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

mark: point

Channels: Rankings



Position on common scale

Position on unaligned scale

Length (1D size)

Tilt/angle

Area (2D size)

Depth (3D position)

Color luminance

Color saturation

Curvature

Volume (3D size)

Same

Same

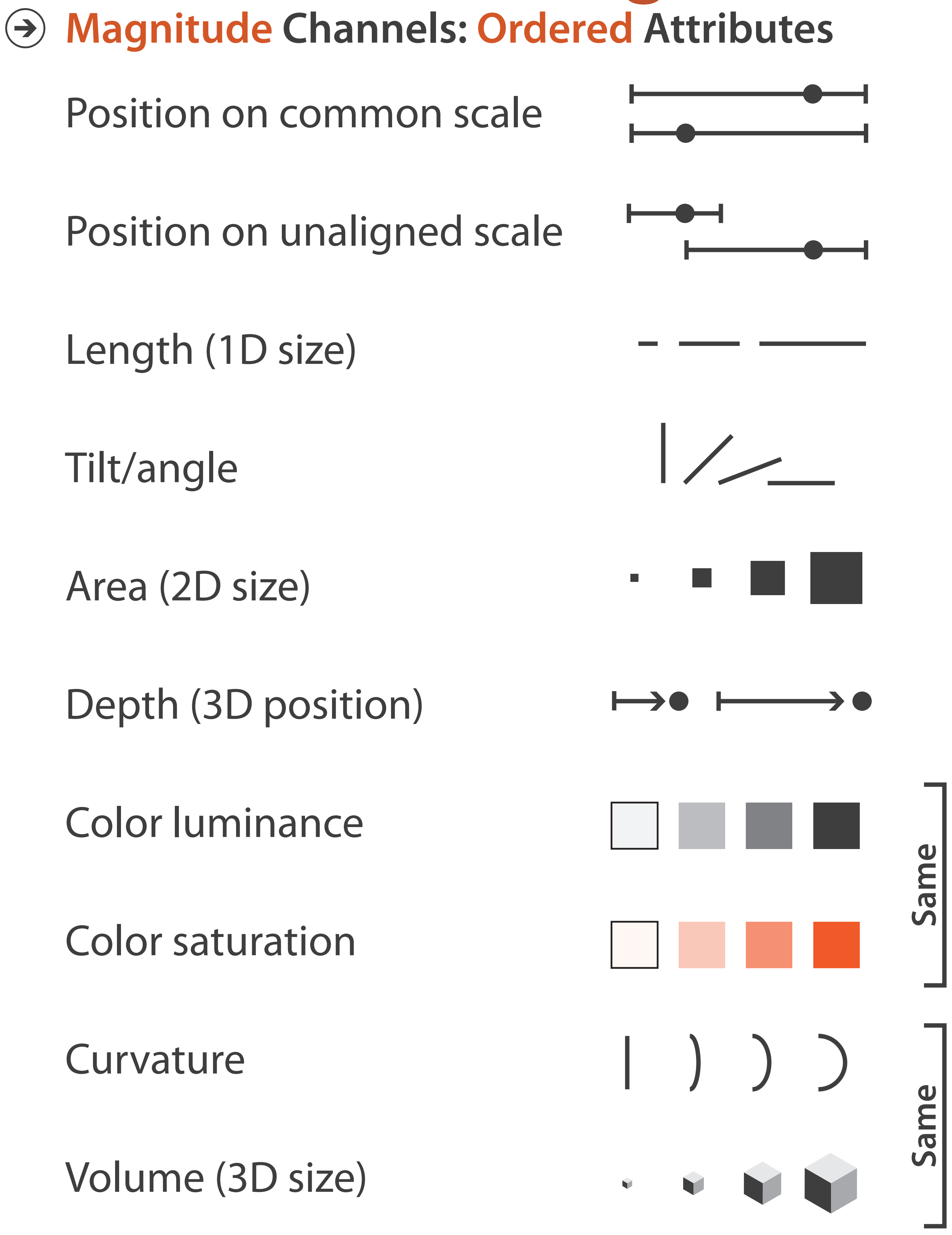
Spatial region

Color hue

Motion

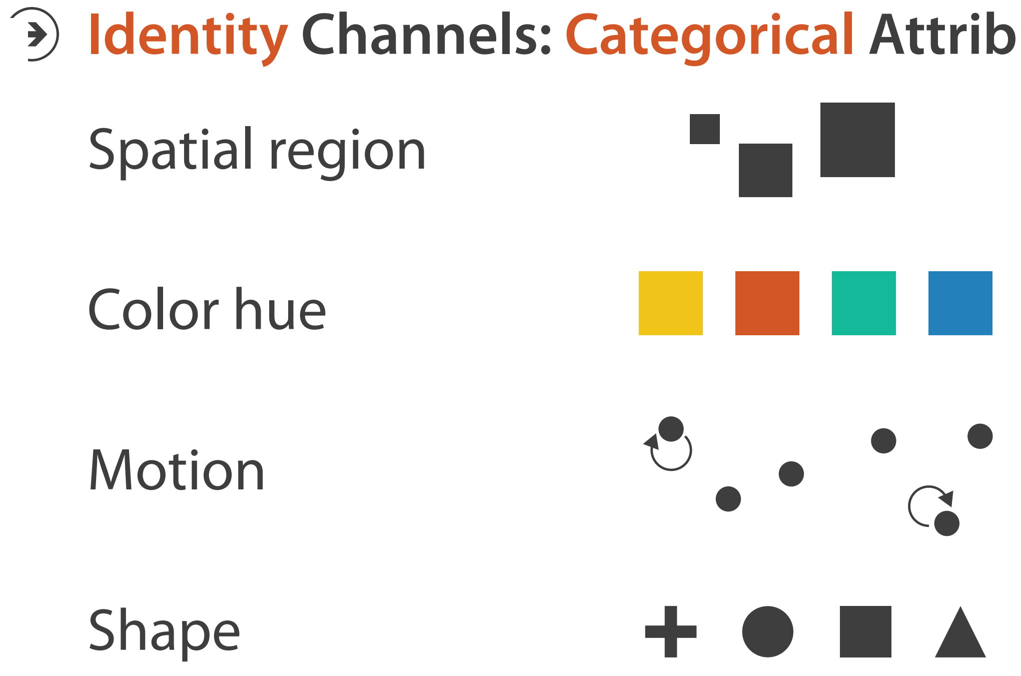
Shape

Channels: Rankings



Magnitude Channels: Ordered Attributes

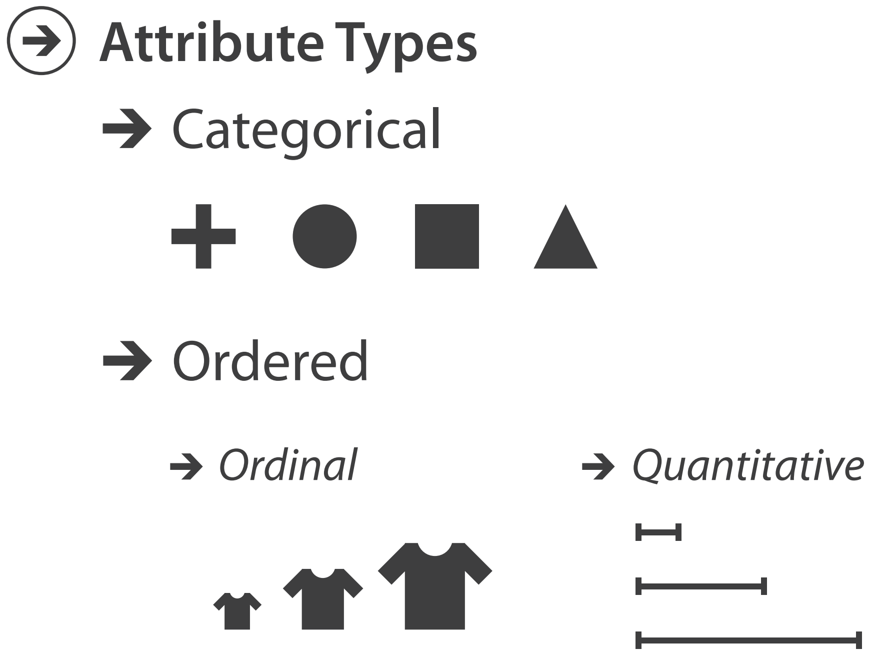
- Position on common scale
- Position on unaligned scale
- Length (1D size)
- Tilt/angle
- Area (2D size)
- Depth (3D position)
- Color luminance
- Color saturation
- Curvature
- Volume (3D size)



Identity Channels: Categorical Attributes

- Spatial region
- Color hue
- Motion
- Shape

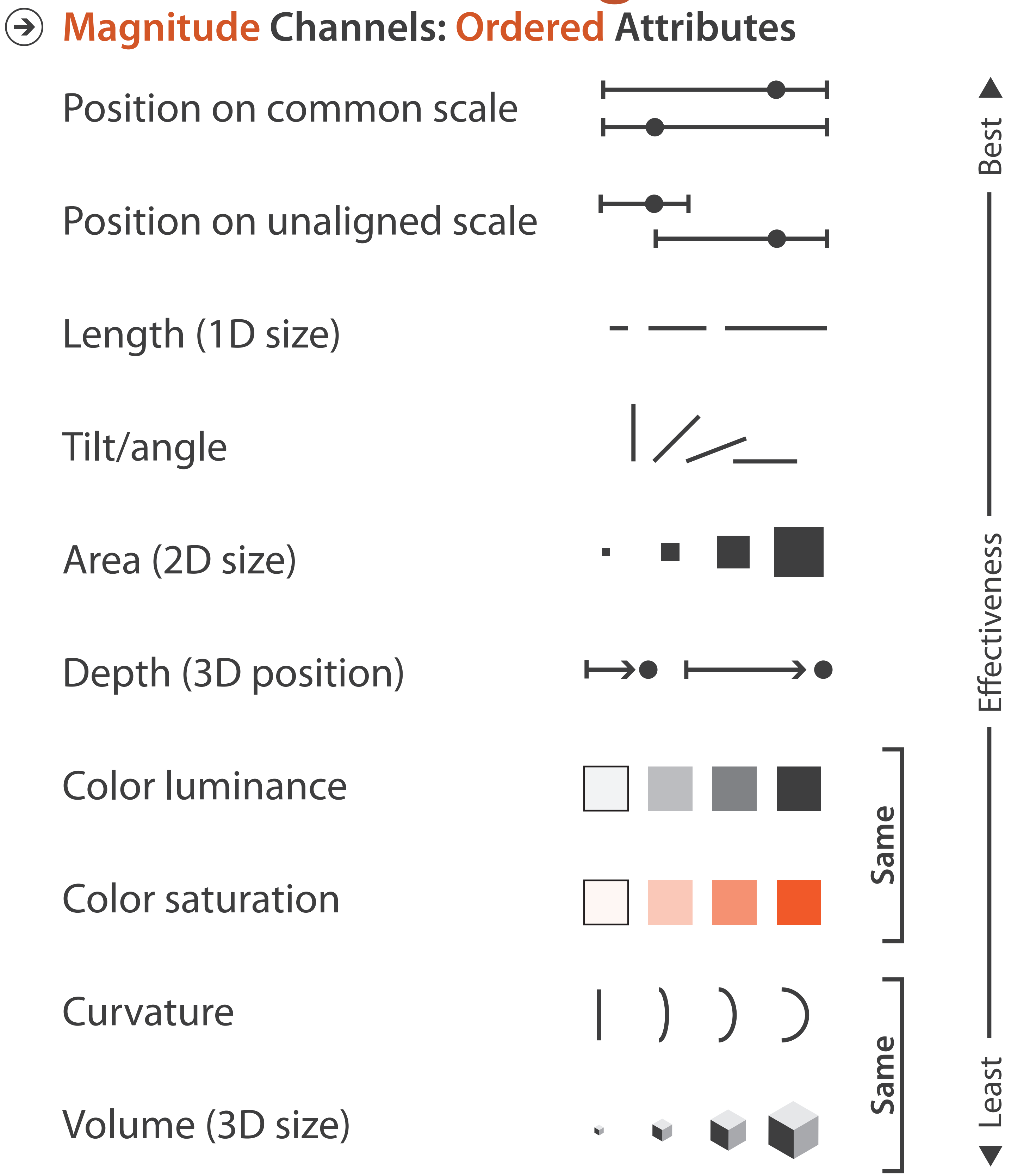
- expressiveness
  - – match channel and data characteristics



Attribute Types

- Categorical
- Ordered
  - *Ordinal*
  - *Quantitative*

Channels: Rankings



➔ Magnitude Channels: Ordered Attributes

Position on common scale

Position on unaligned scale

Length (1D size)

Tilt/angle

Area (2D size)

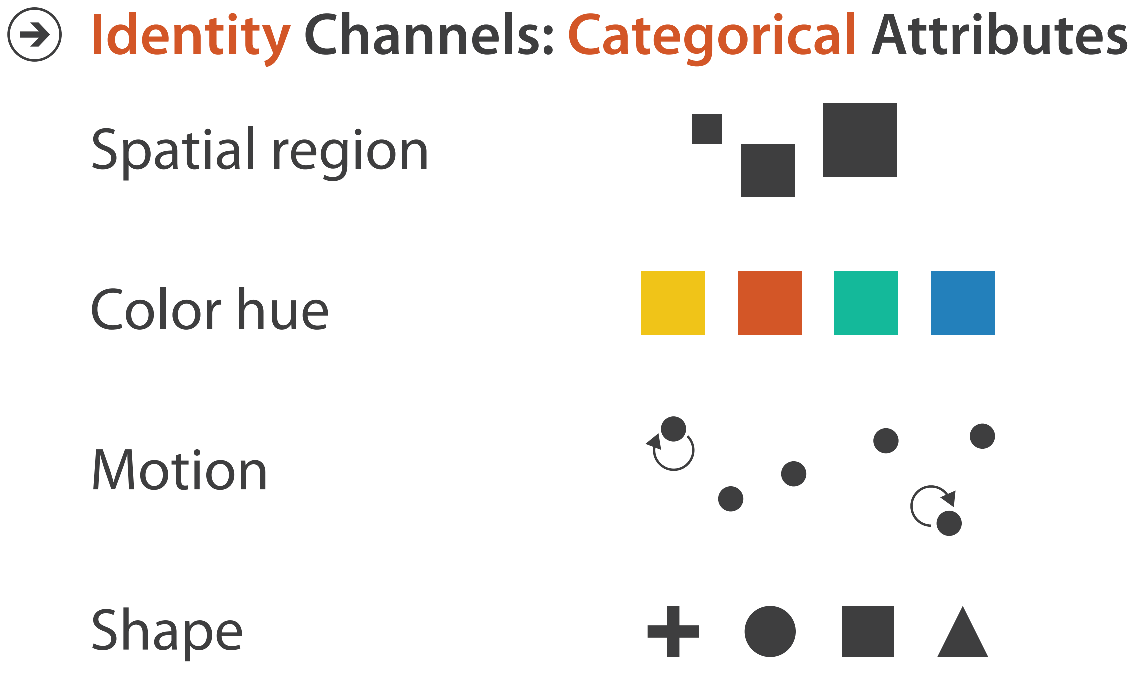
Depth (3D position)

Color luminance

Color saturation

Curvature

Volume (3D size)



➔ Identity Channels: Categorical Attributes

Spatial region

Color hue

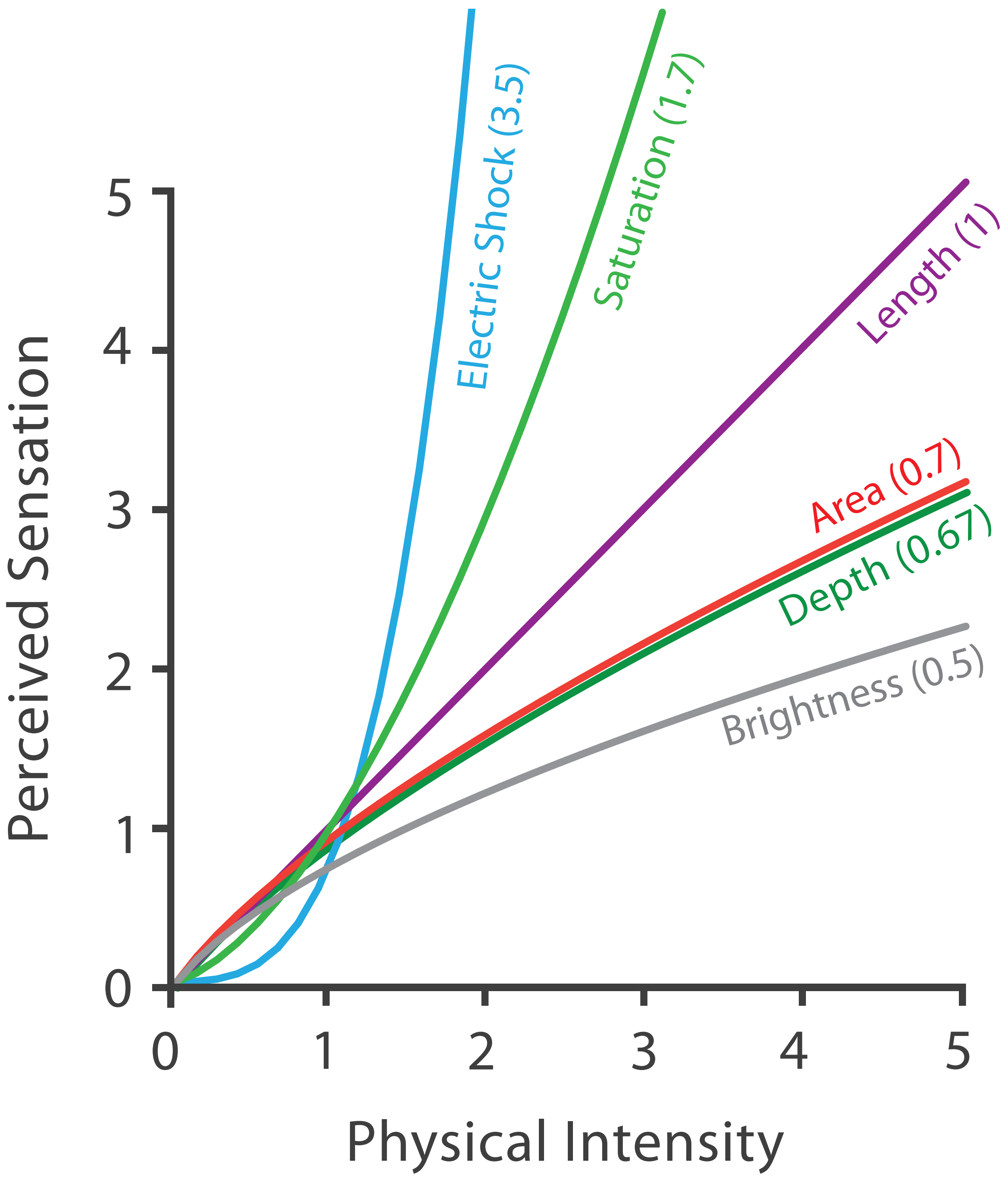
Motion

Shape

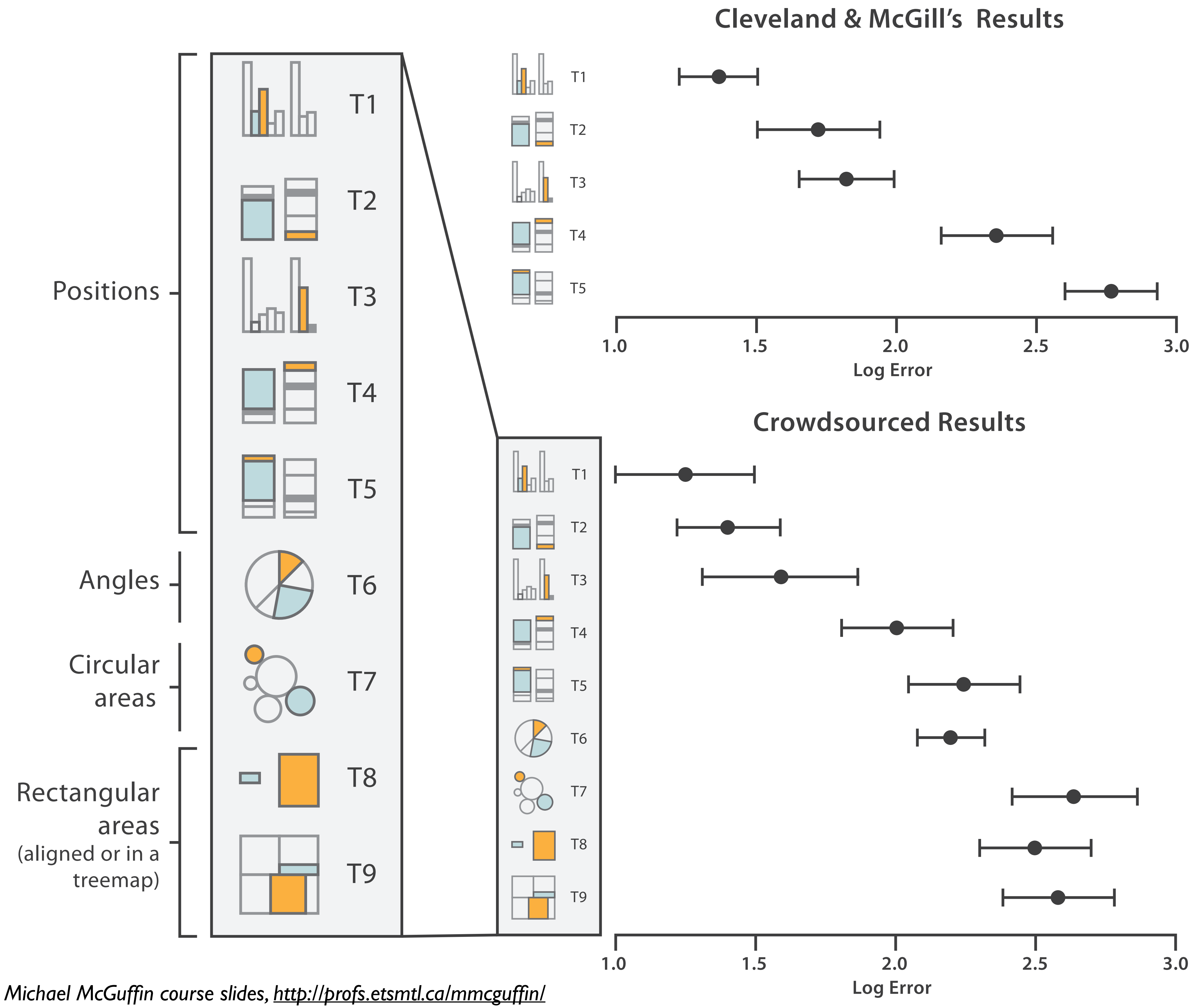
- expressiveness
  - – match channel and data characteristics
- effectiveness
  - – channels differ in accuracy of perception

Accuracy: Fundamental Theory

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



Accuracy: Vis experiments

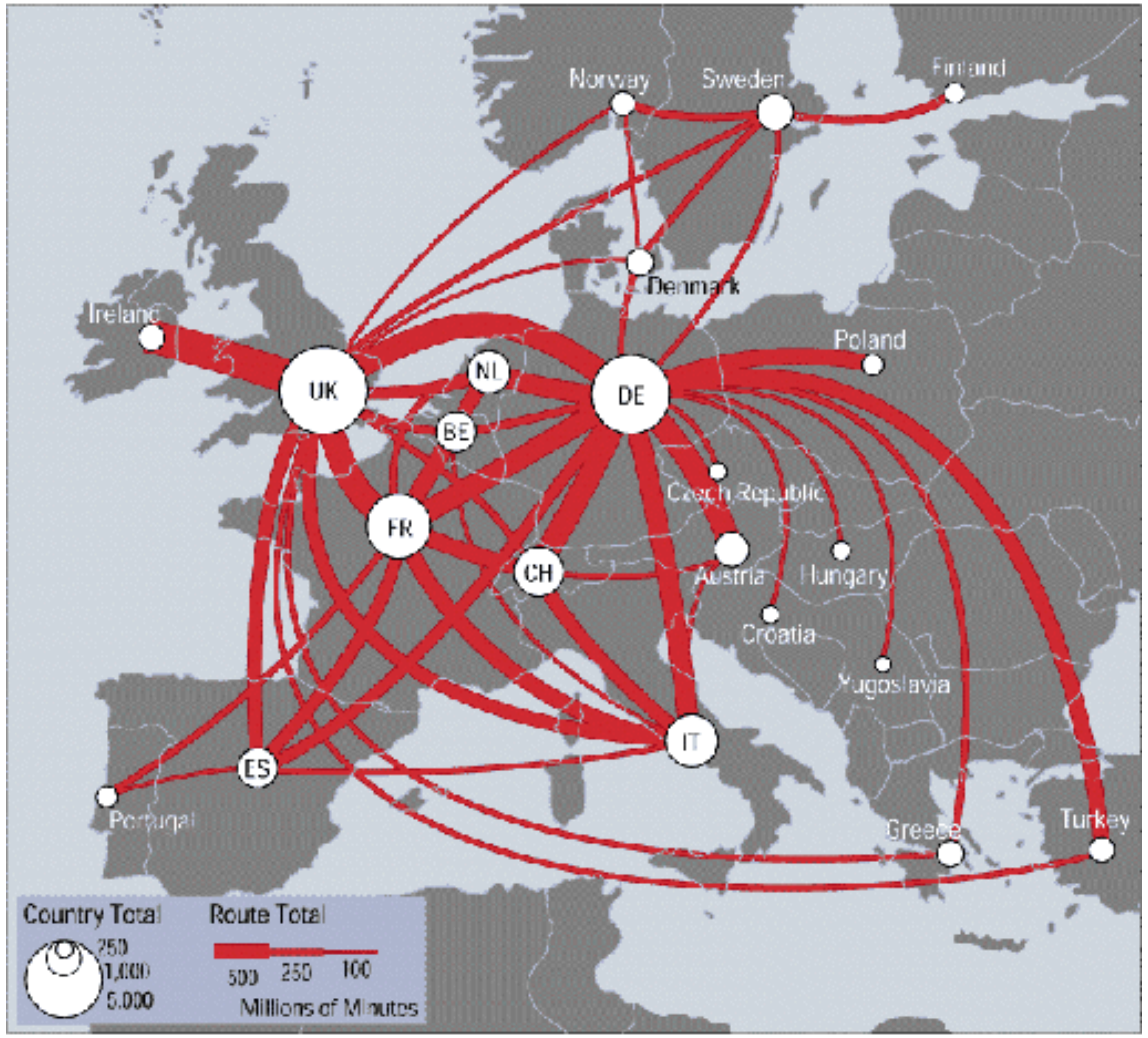


[Crowdsourcing Graphical Perception: Using Mechanical Turk to Assess Visualization Design. Heer and Bostock. Proc ACM Conf. Human Factors in Computing Systems (CHI) 2010, p. 203–212.]

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

Discriminability: How many usable steps?

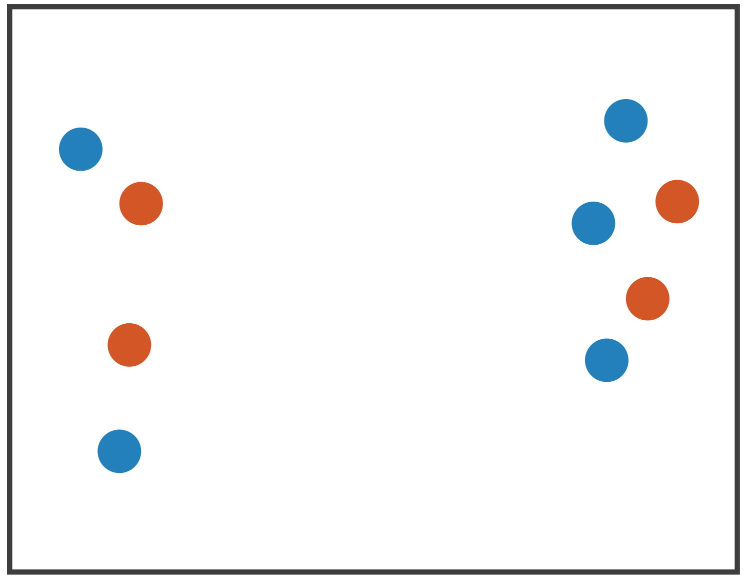
- must be sufficient for number of attribute levels to show
  - linewidth: few bins



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

Separability vs. Integrality

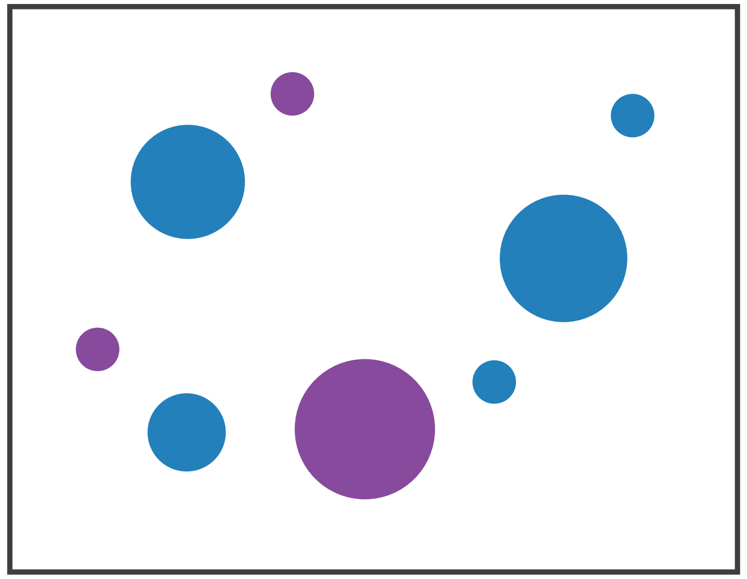
Position
+ Hue (Color)



Fully separable

2 groups each

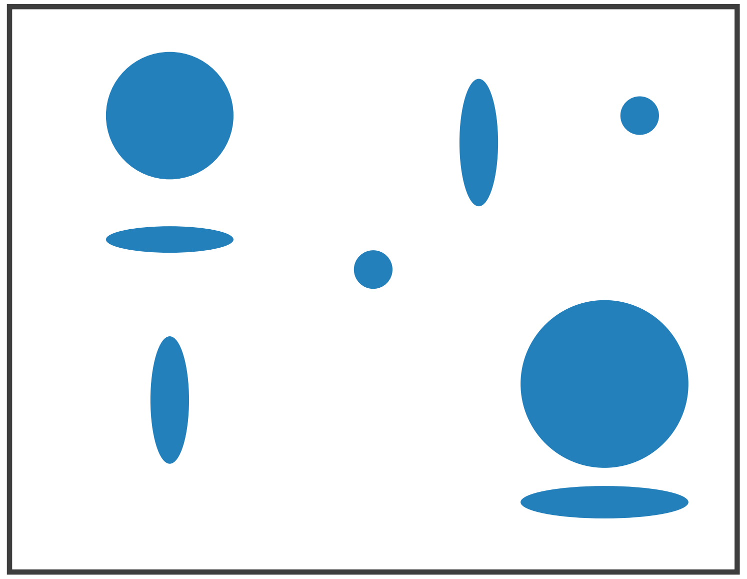
Size
+ Hue (Color)



Some interference

2 groups each

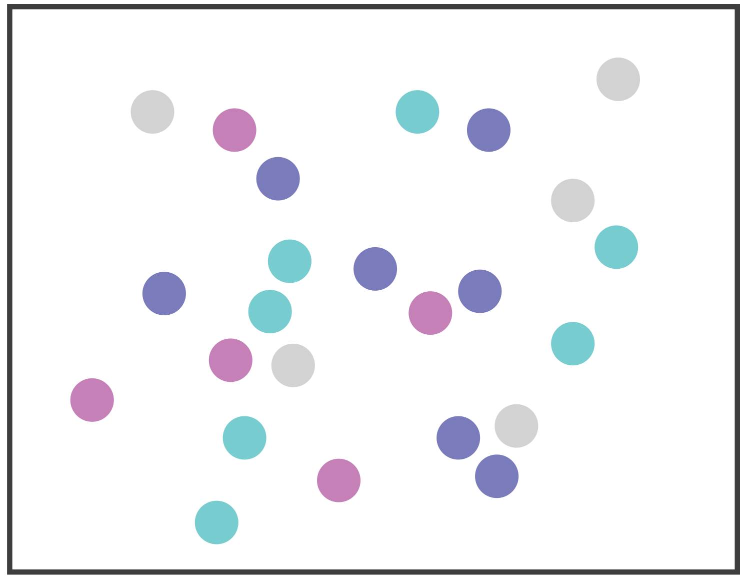
Width
+ Height



Some/significant interference

3 groups total:
integral area

Red
+ Green



Major interference

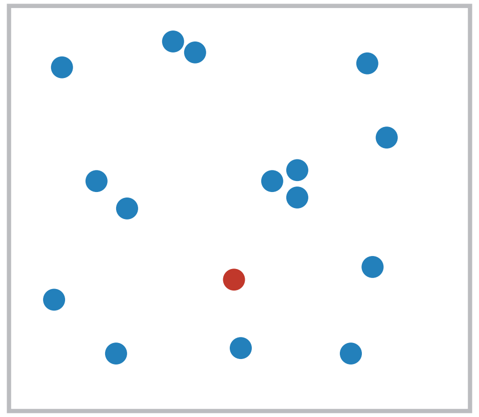
4 groups total:
integral hue

Popout

- find the red dot
  - how long does it take?

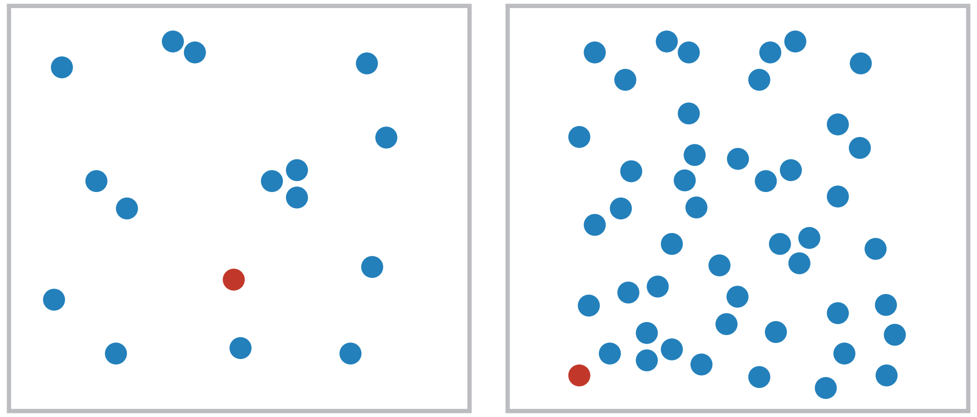
Popout

- find the red dot
  - how long does it take?



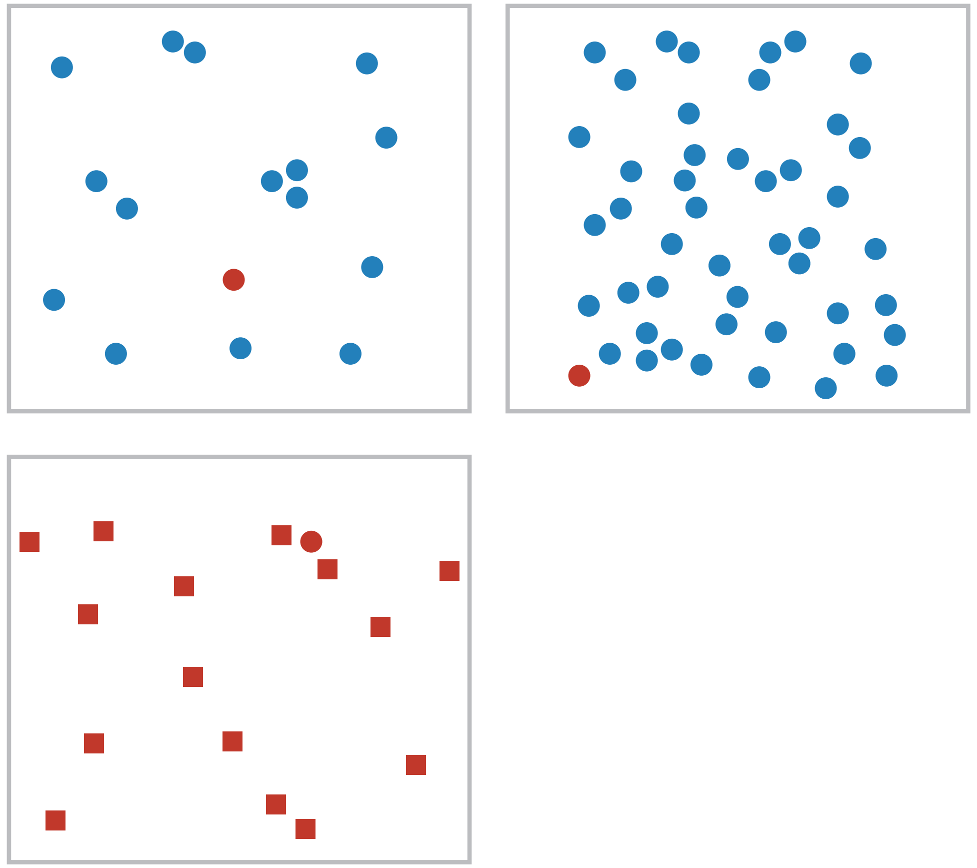
Popout

- find the red dot
  - how long does it take?



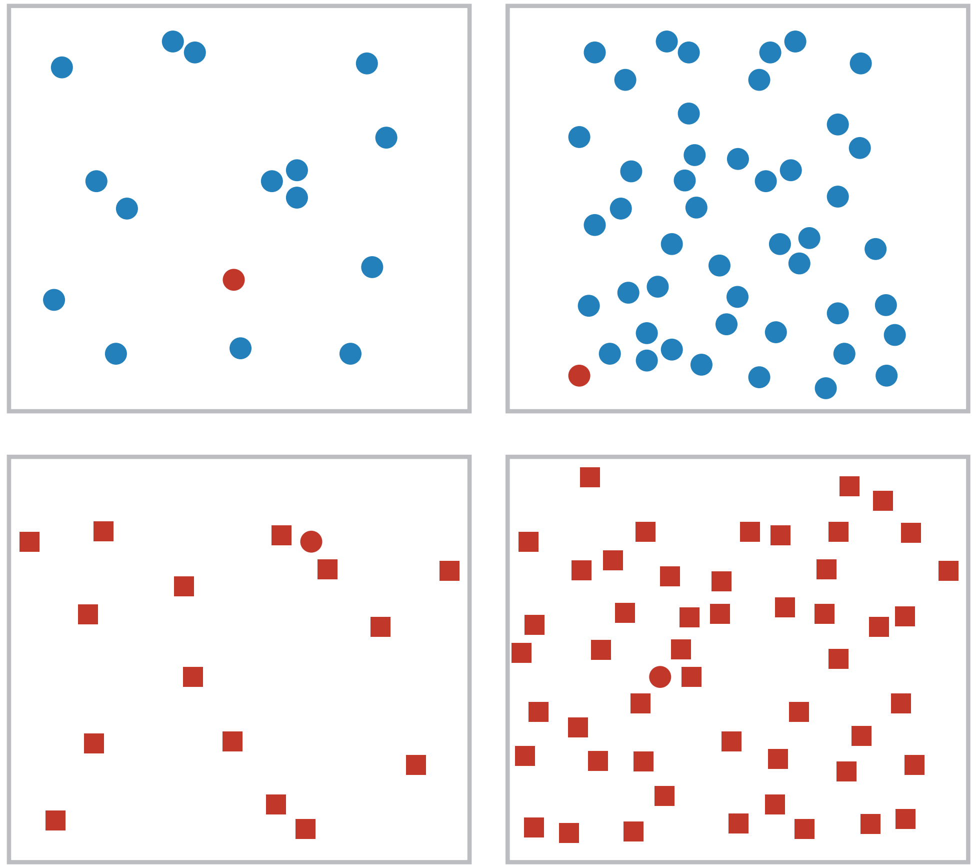
Popout

- find the red dot
  - how long does it take?



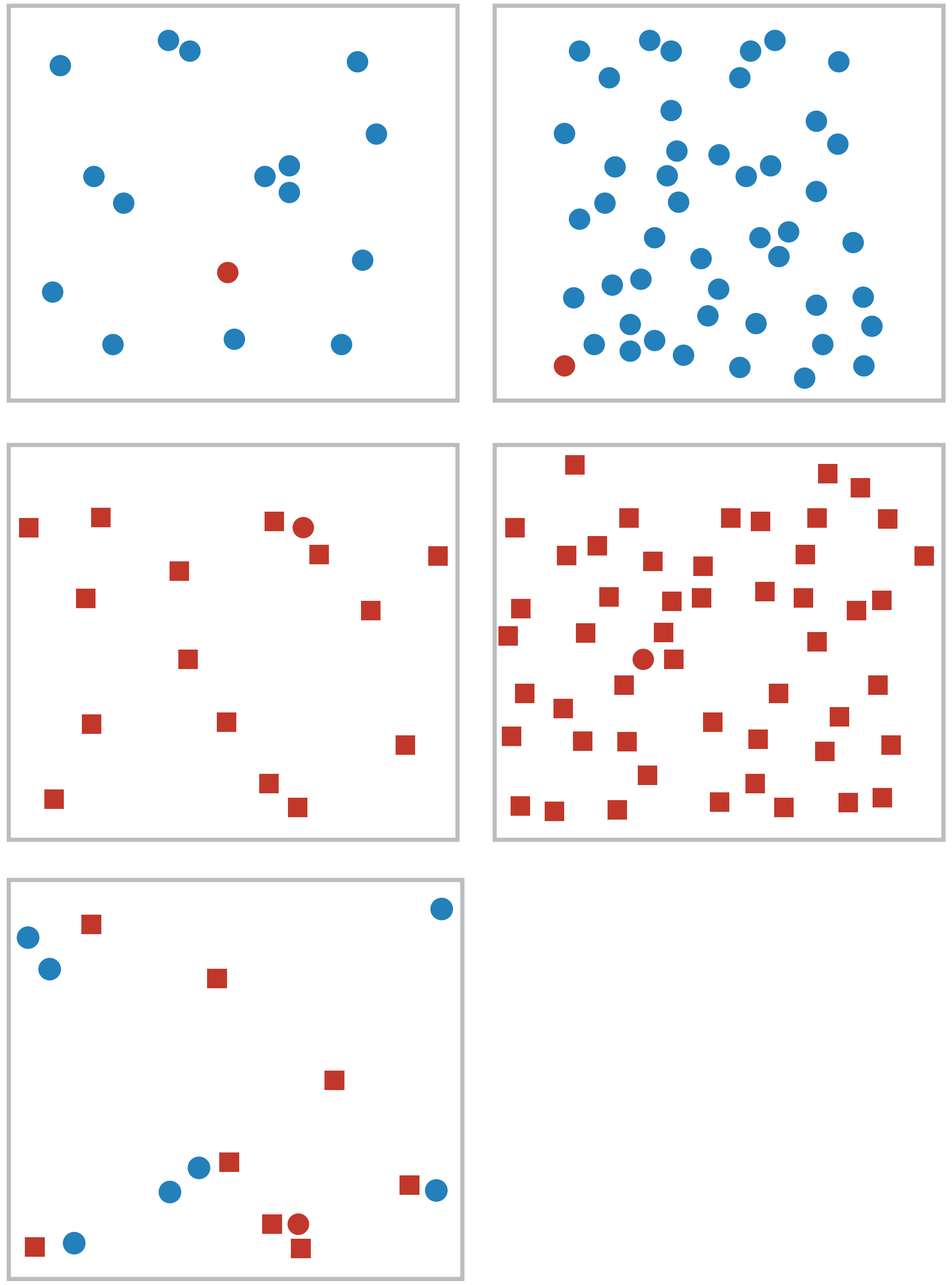
Popout

- find the red dot
  - how long does it take?



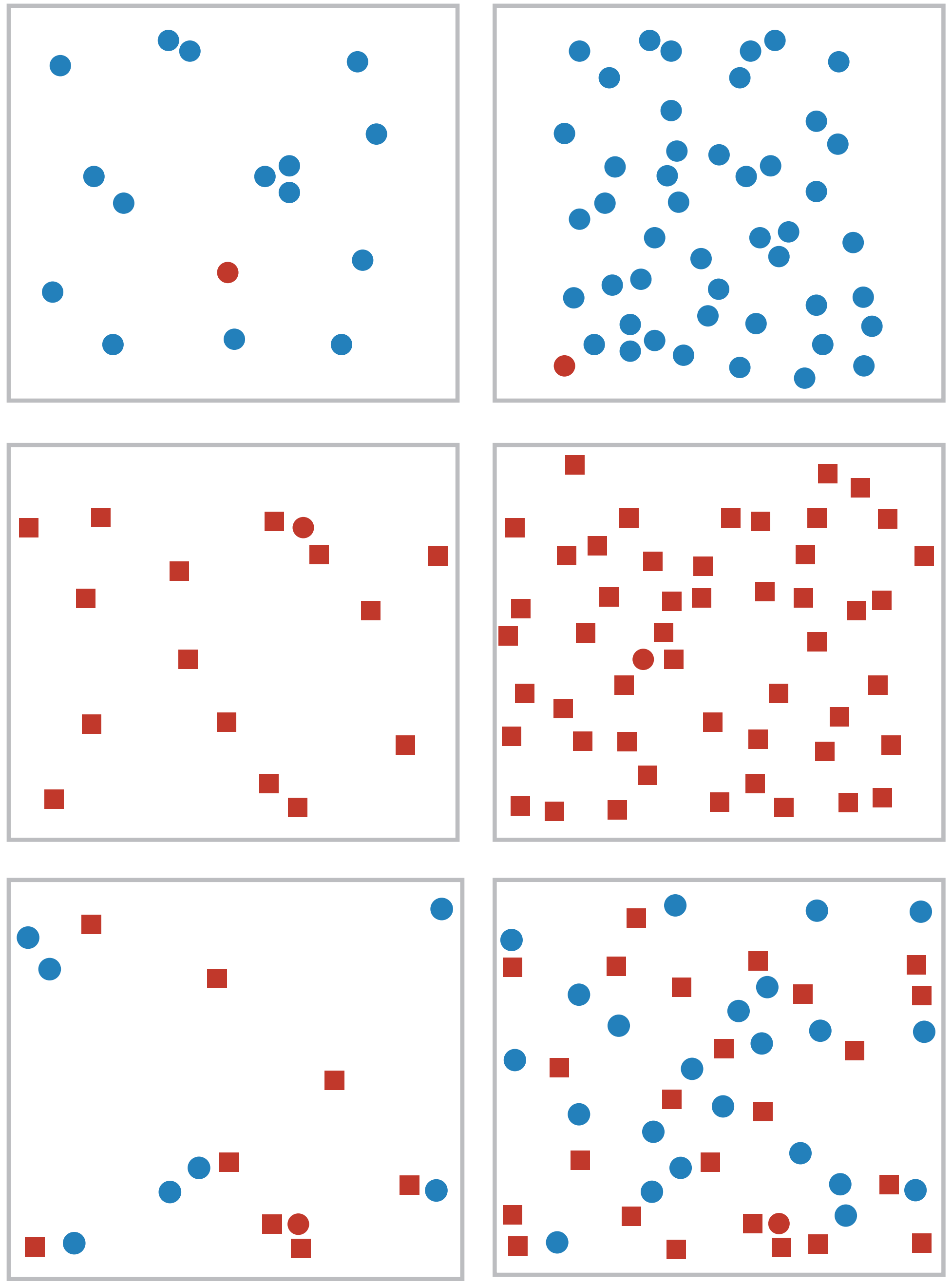
Popout

- find the red dot
  - how long does it take?



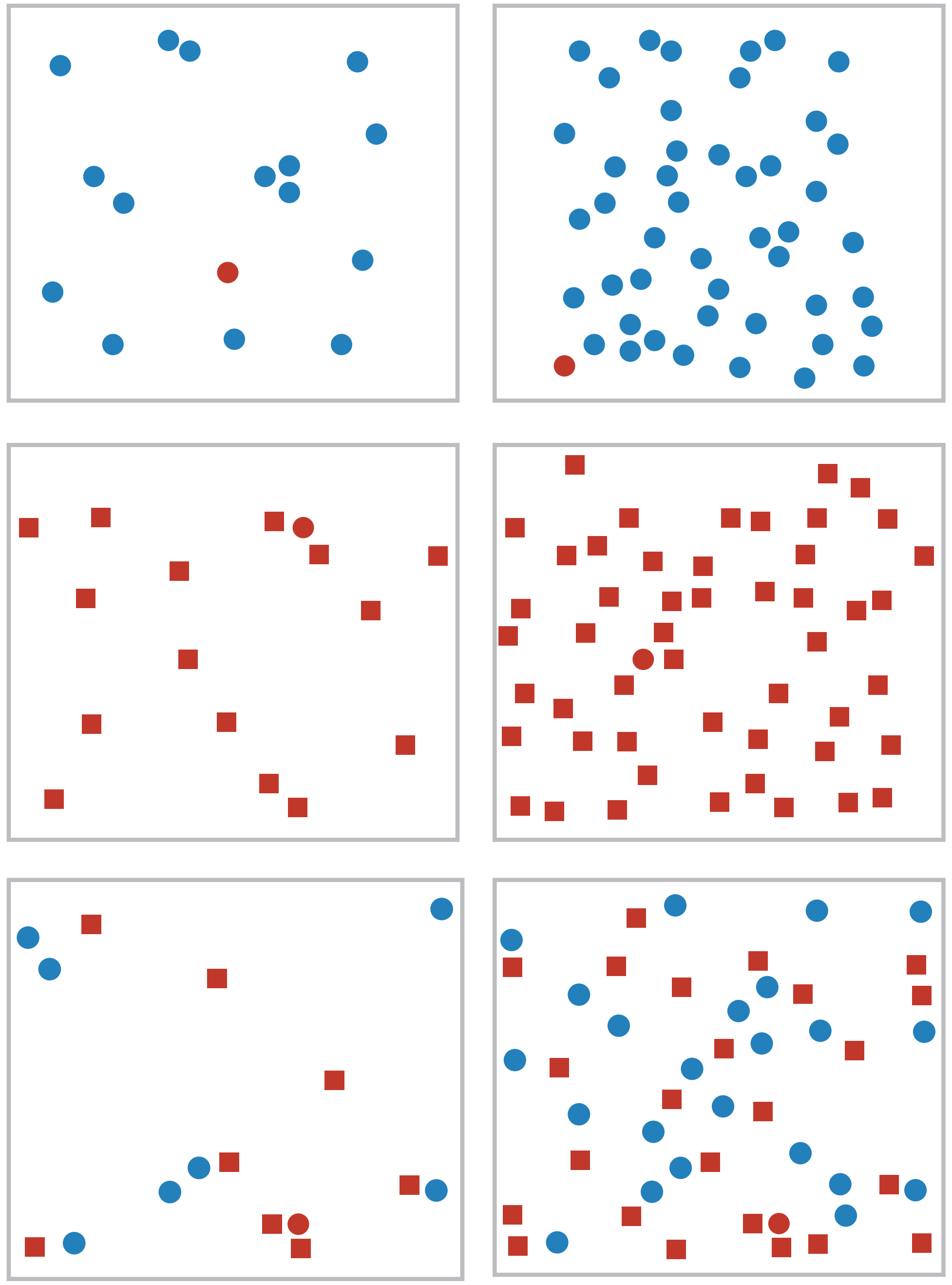
Popout

- find the red dot
  - how long does it take?

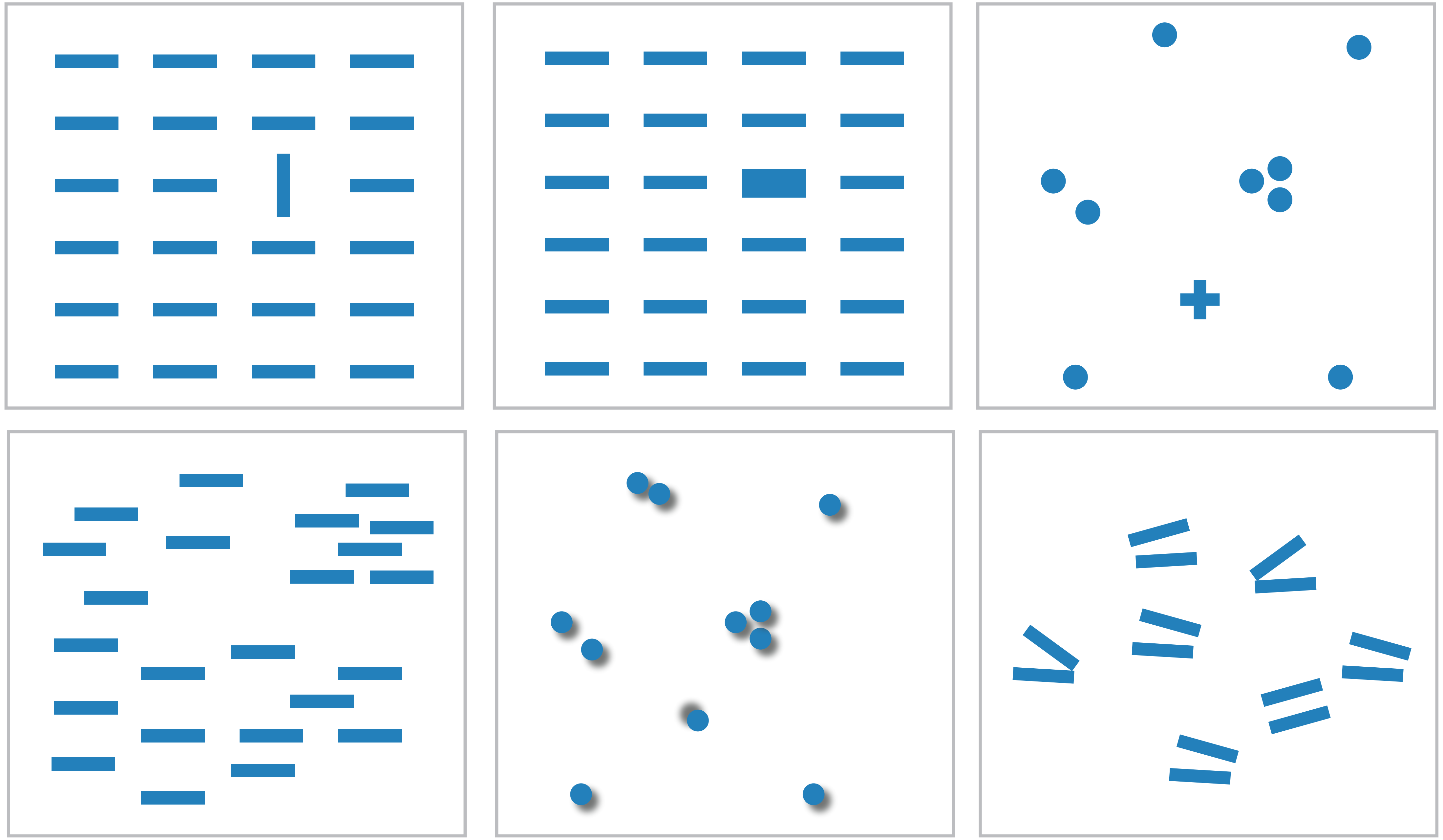


Popout

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

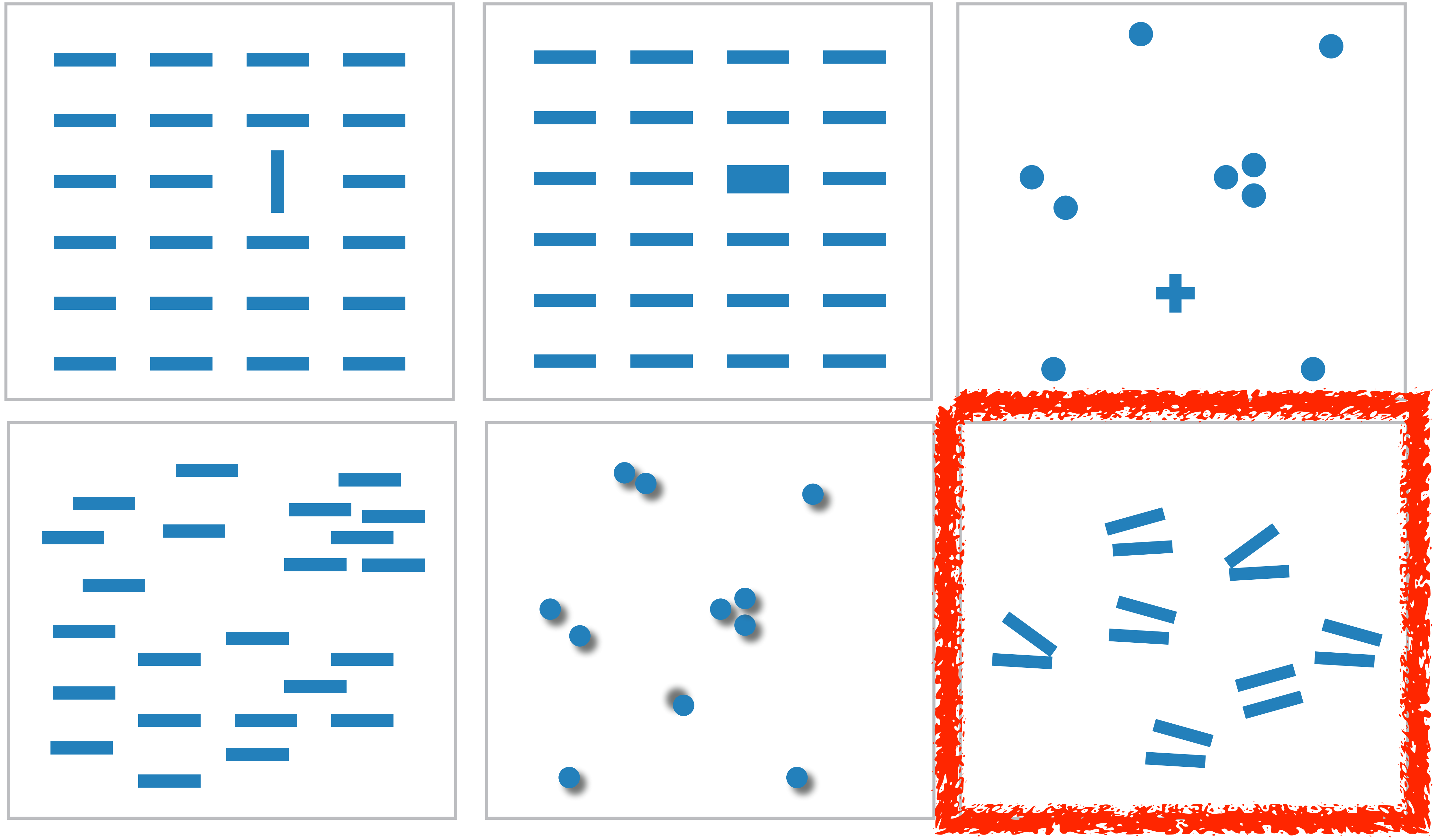


Popout



- many channels
  - –tilt, size, shape, proximity, shadow direction, ...

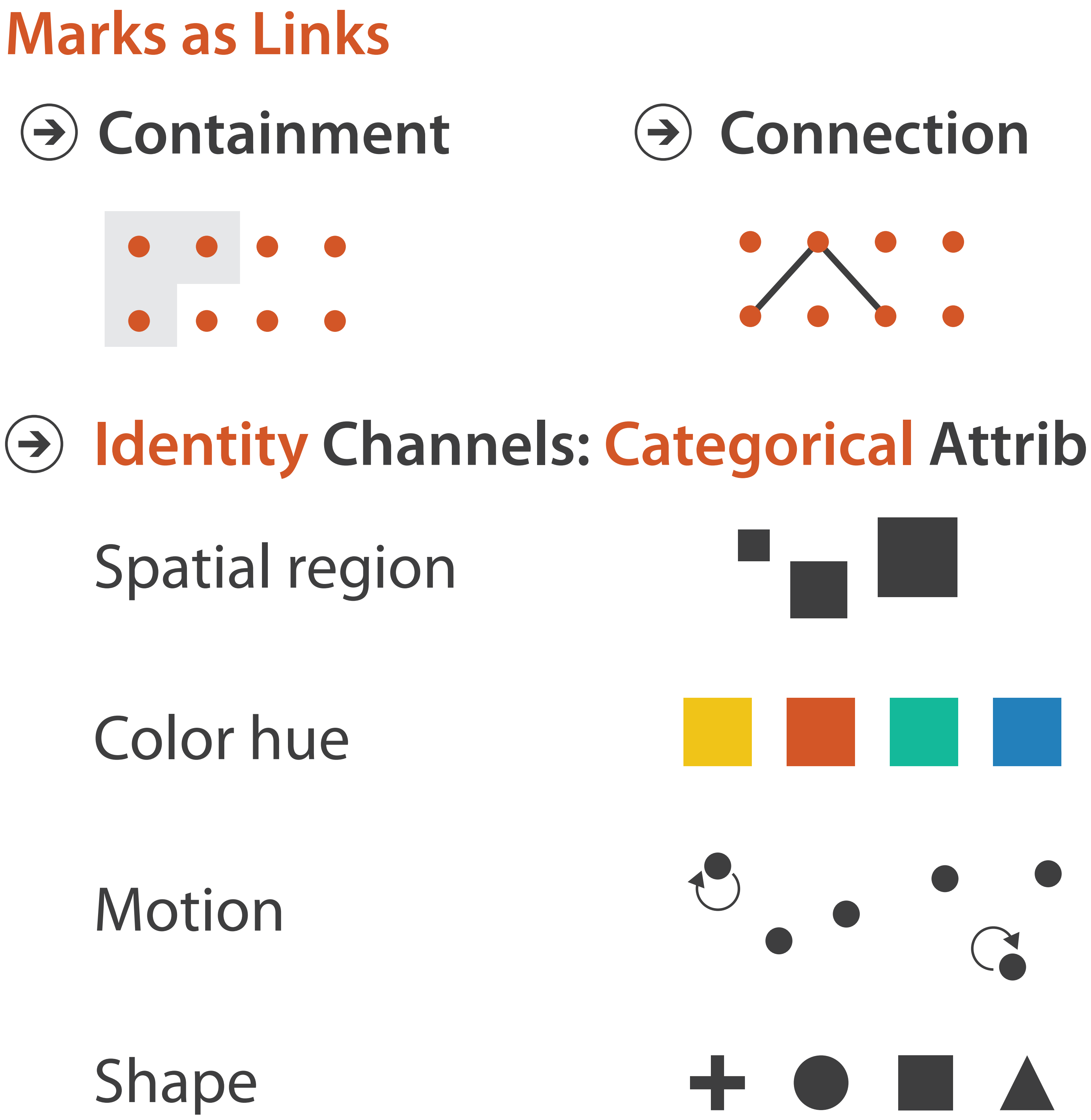
Popout



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

Grouping

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



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.

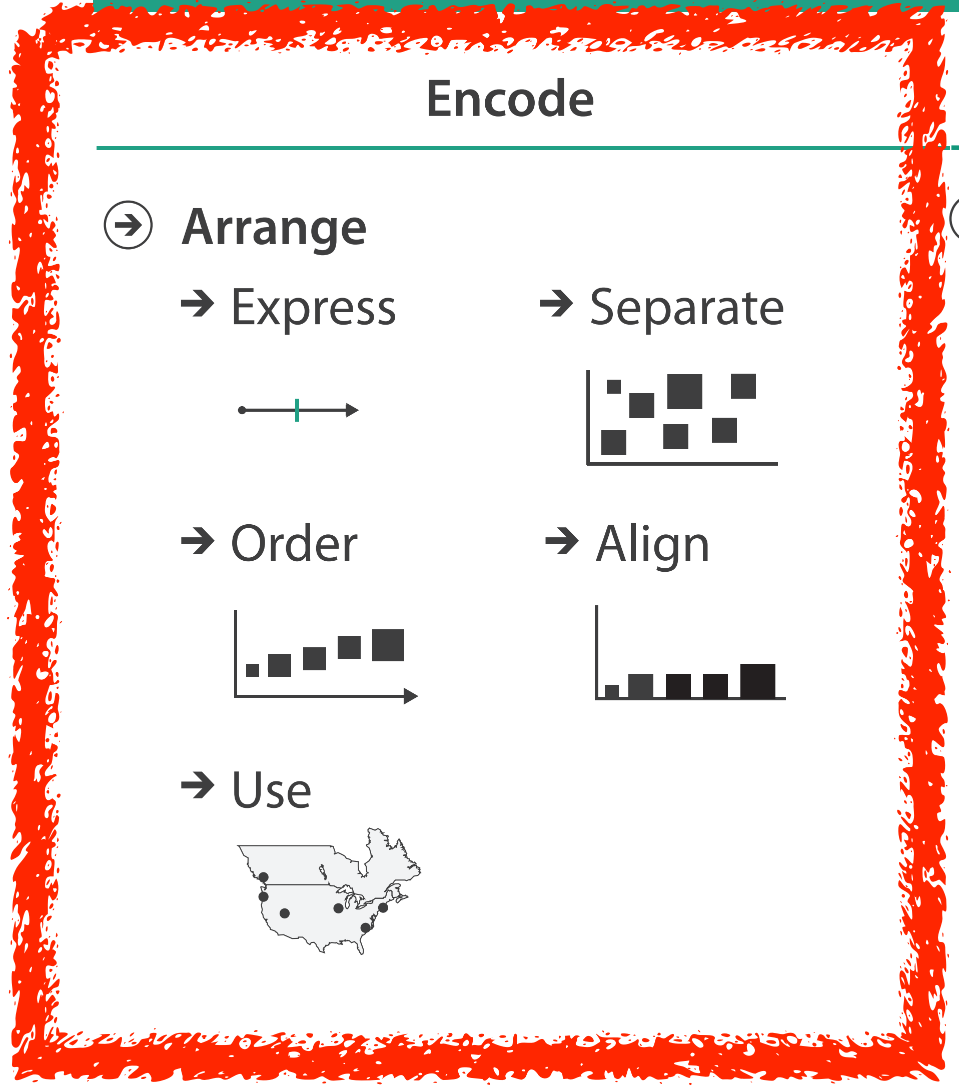
Visualization Analysis & Design, Half-Day Tutorial

- Session 1
  - Analysis: What, Why, How
  - Marks and Channels
  - Arrange Tables
  - Arrange Spatial Data
- Session 2
  - Arrange Networks and Trees
  - Map Color and Other Channels
  - Manipulate: Change, Select, Navigate
  - Facet: Juxtapose, Partition, Superimpose
  - Reduce: Filter, Aggregate

@tamaramunzner

http://www.cs.ubc.ca/~tmm/talks.html#halfdaycourse20

How?



Encode

Arrange

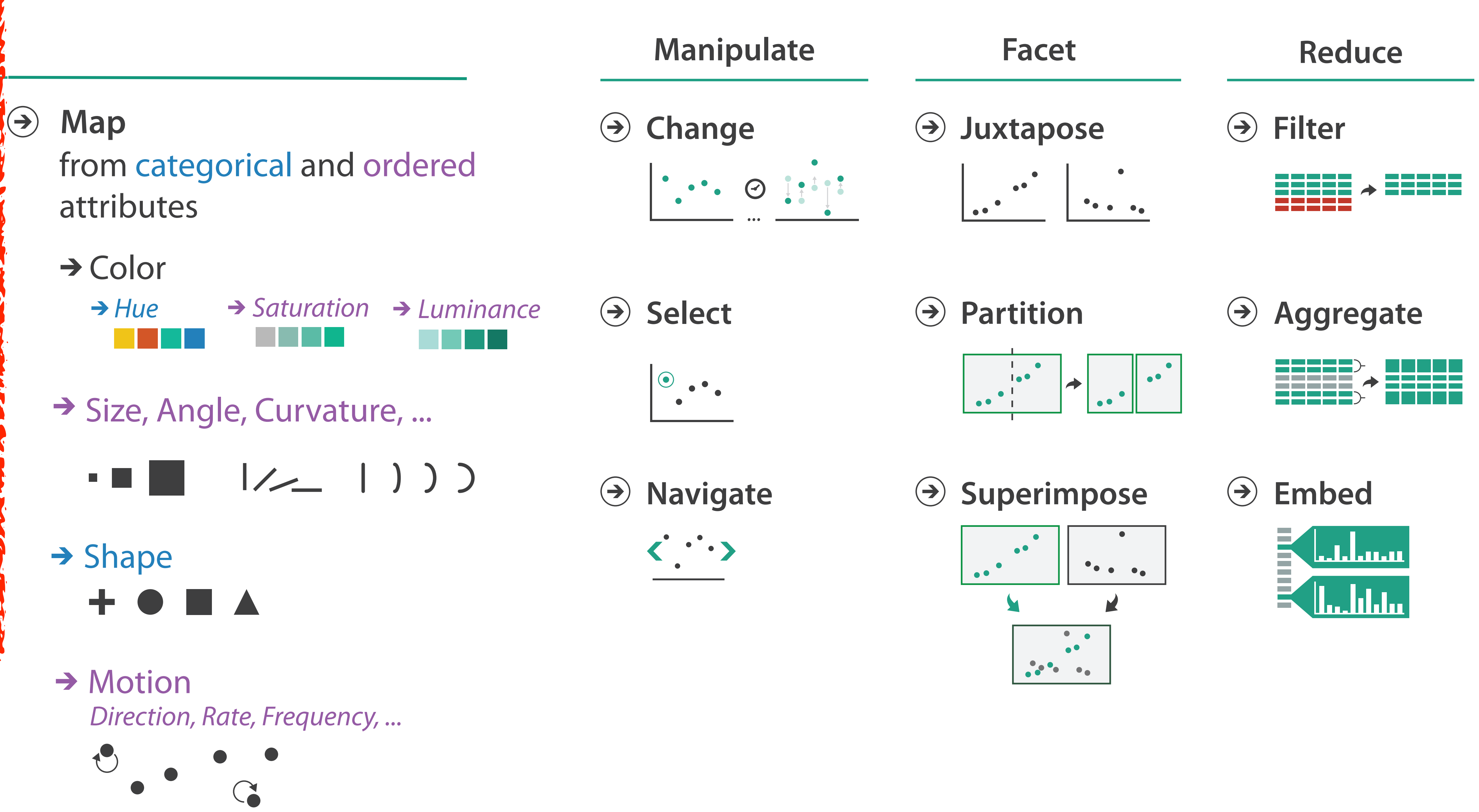
→ Express

→ 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

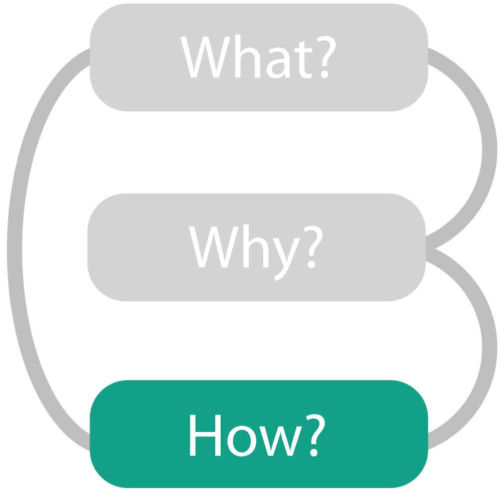
Superimpose

Reduce

Filter

Aggregate

Embed



What?

Why?

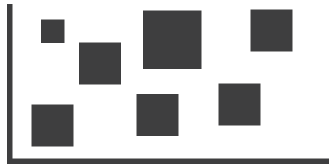
How?

Arrange tables

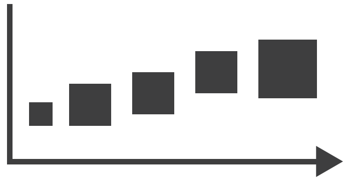
➔ Express Values

➔ Separate, Order, Align Regions

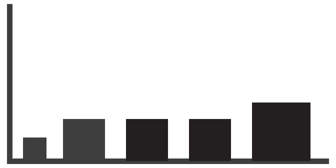
→ Separate



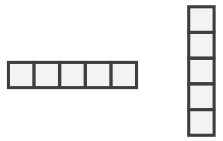
→ Order



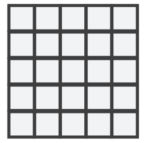
→ Align



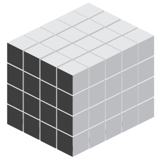
→ *1 Key*
List



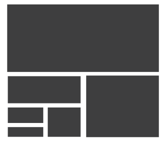
→ *2 Keys*
Matrix



→ *3 Keys*
Volume

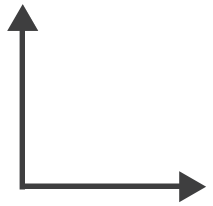


→ *Many Keys*
Recursive Subdivision

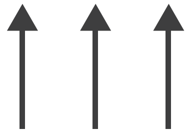


➔ Axis Orientation

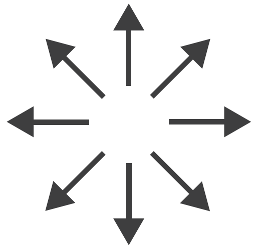
→ Rectilinear



→ Parallel

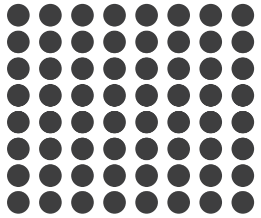


→ Radial

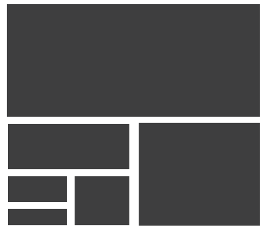


➔ Layout Density

→ Dense



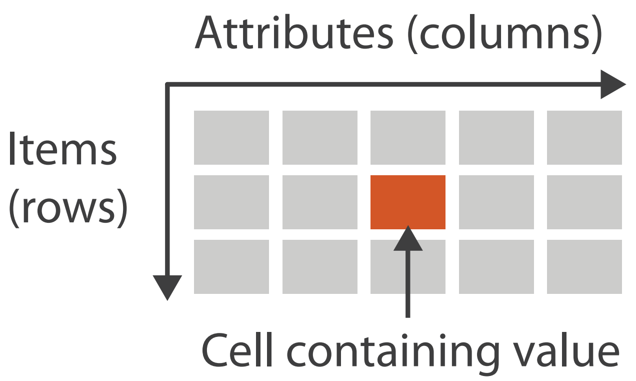
→ Space-Filling



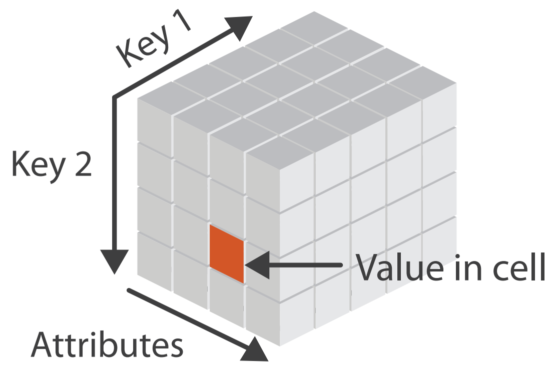
Keys and values

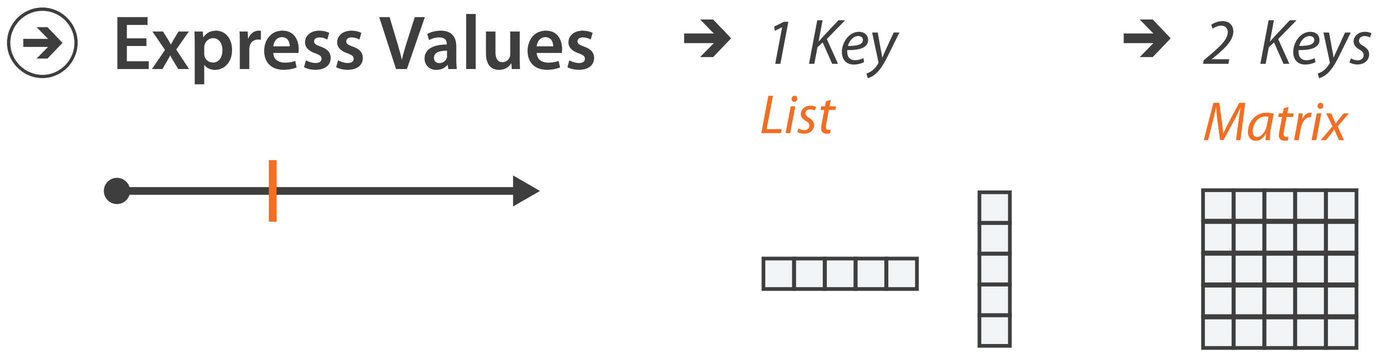
- key
  - independent attribute
  - used as unique index to look up items
  - simple tables: 1 key
  - multidimensional tables: multiple keys
- value
  - dependent attribute, value of cell
- classify arrangements by key count
  - 0, 1, 2, many...

→ Tables



→ *Multidimensional Table*

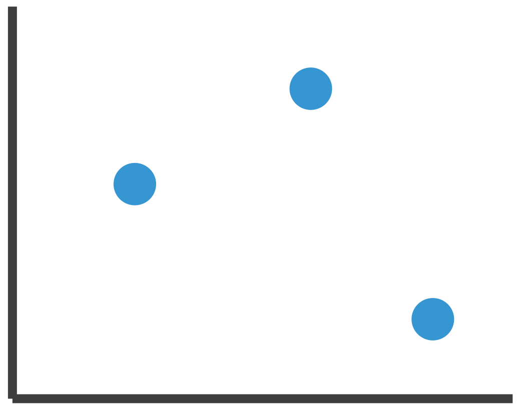


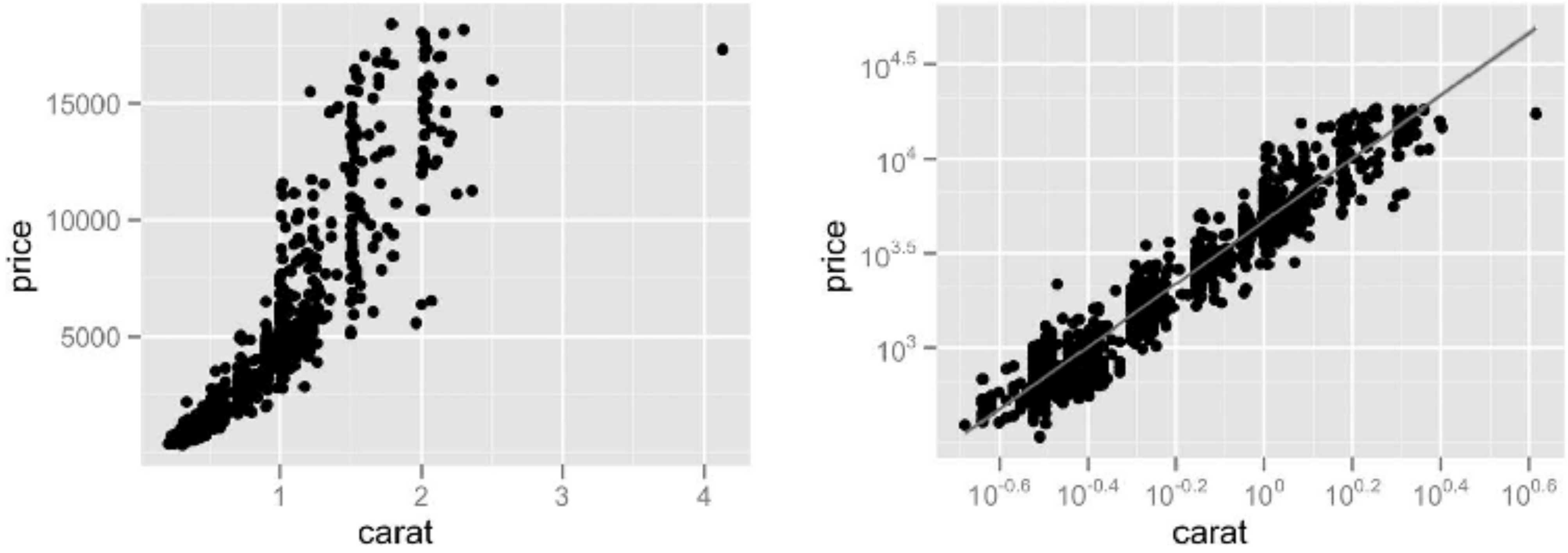


Idiom: **scatterplot**

- ***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

➔ Express Values



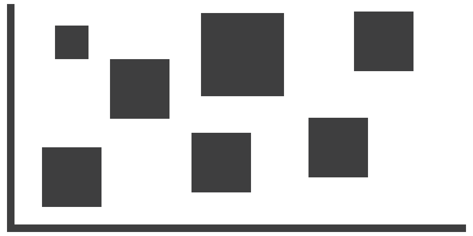


[A layered grammar of graphics. Wickham. Journ. Computational and Graphical Statistics 19:1 (2010), 3–28.]

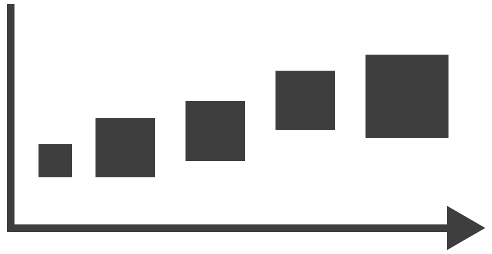
Some keys: Categorical regions

- 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

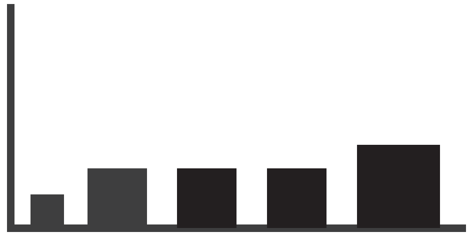
→ Separate



→ Order

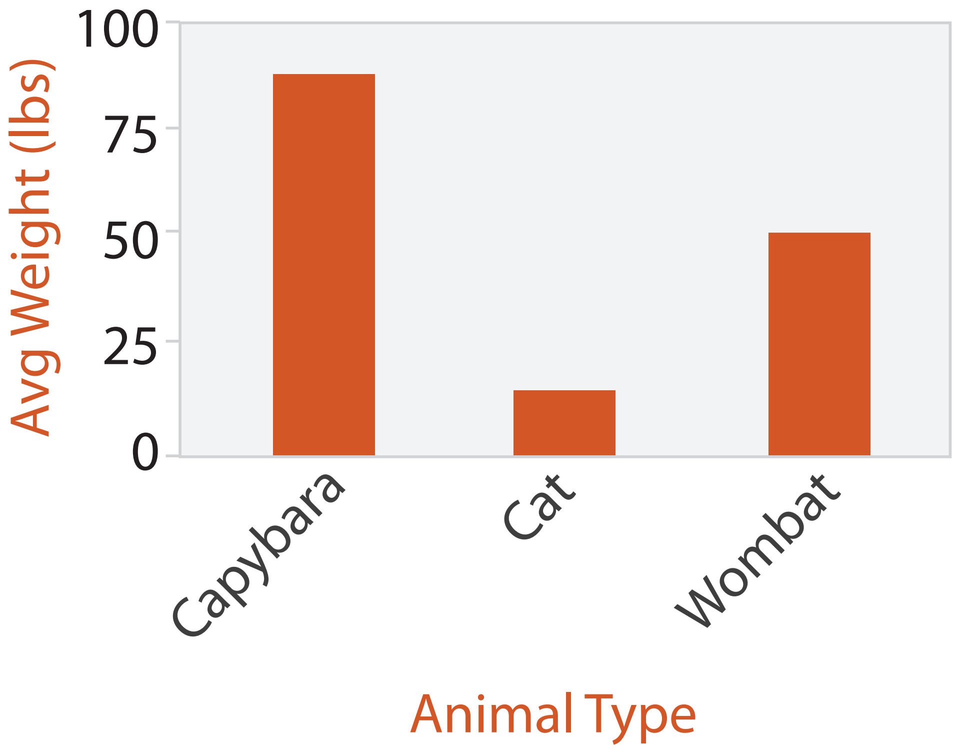


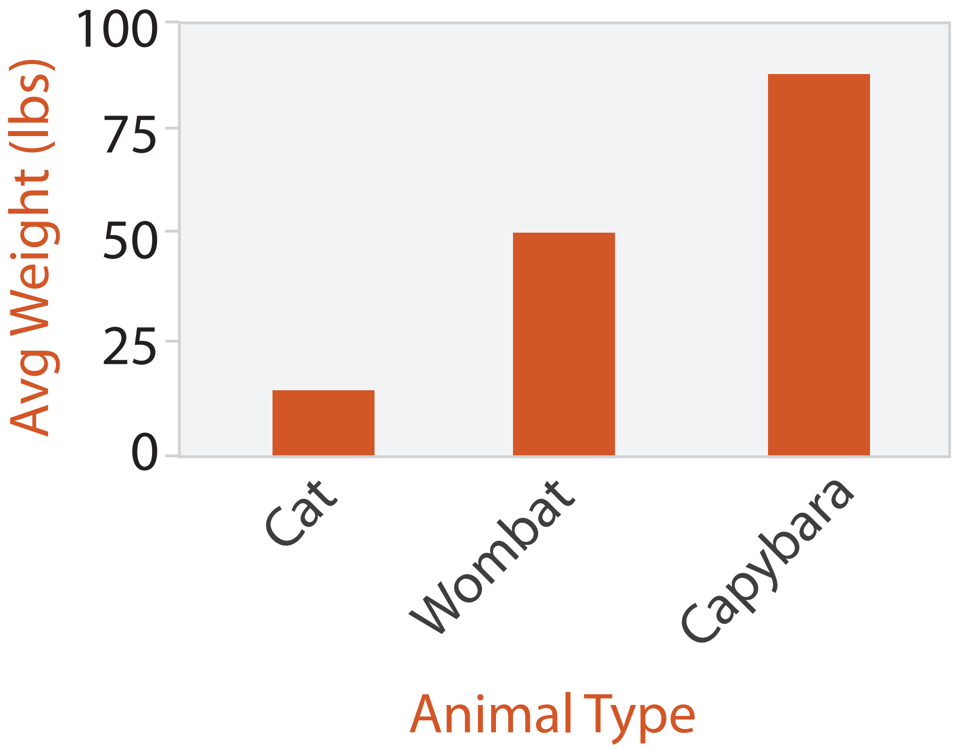
→ Align



Idiom: **bar chart**

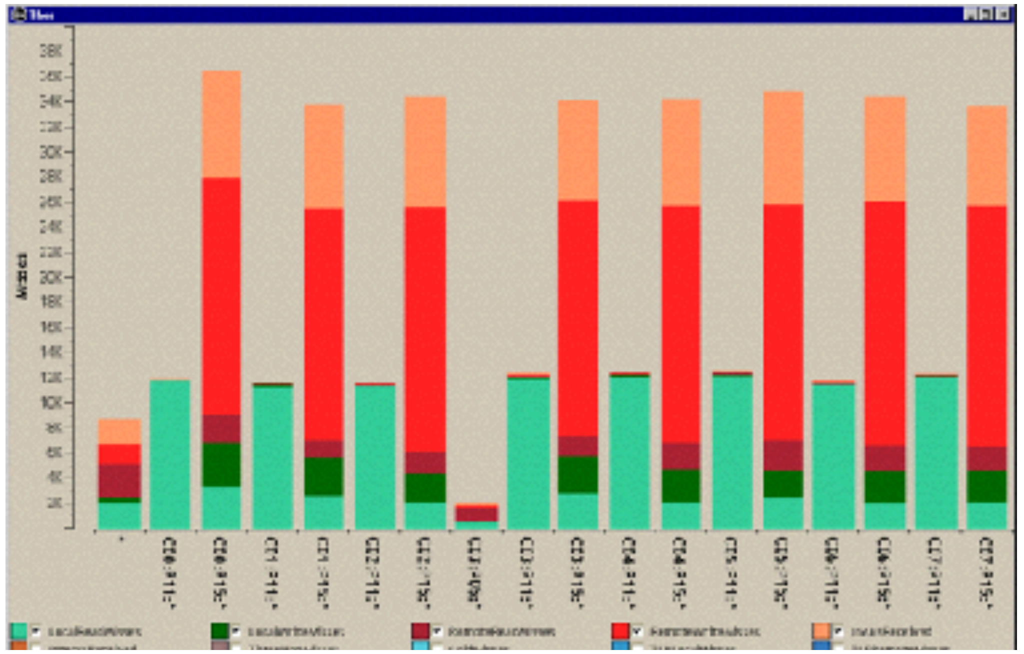
- one key, one value
  - data
    - 1 categ attrib, 1 quant attrib
  - mark: lines
  - channels
    - length to express quant value
    - spatial regions: one per mark
      - separated horizontally, aligned vertically
      - ordered by quant attrib
        - » by label (alphabetical), by length attrib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





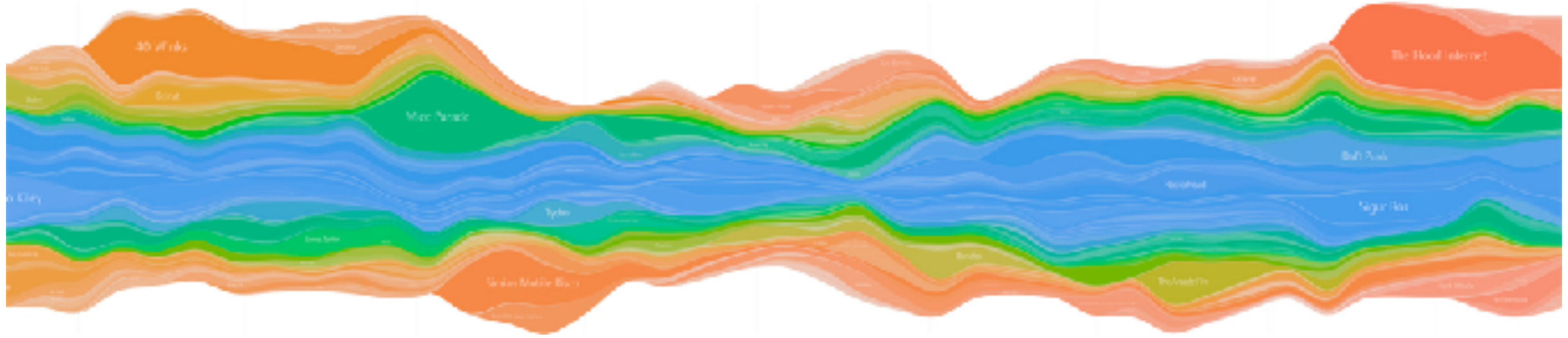
Idiom: **stacked bar chart**

- 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.]

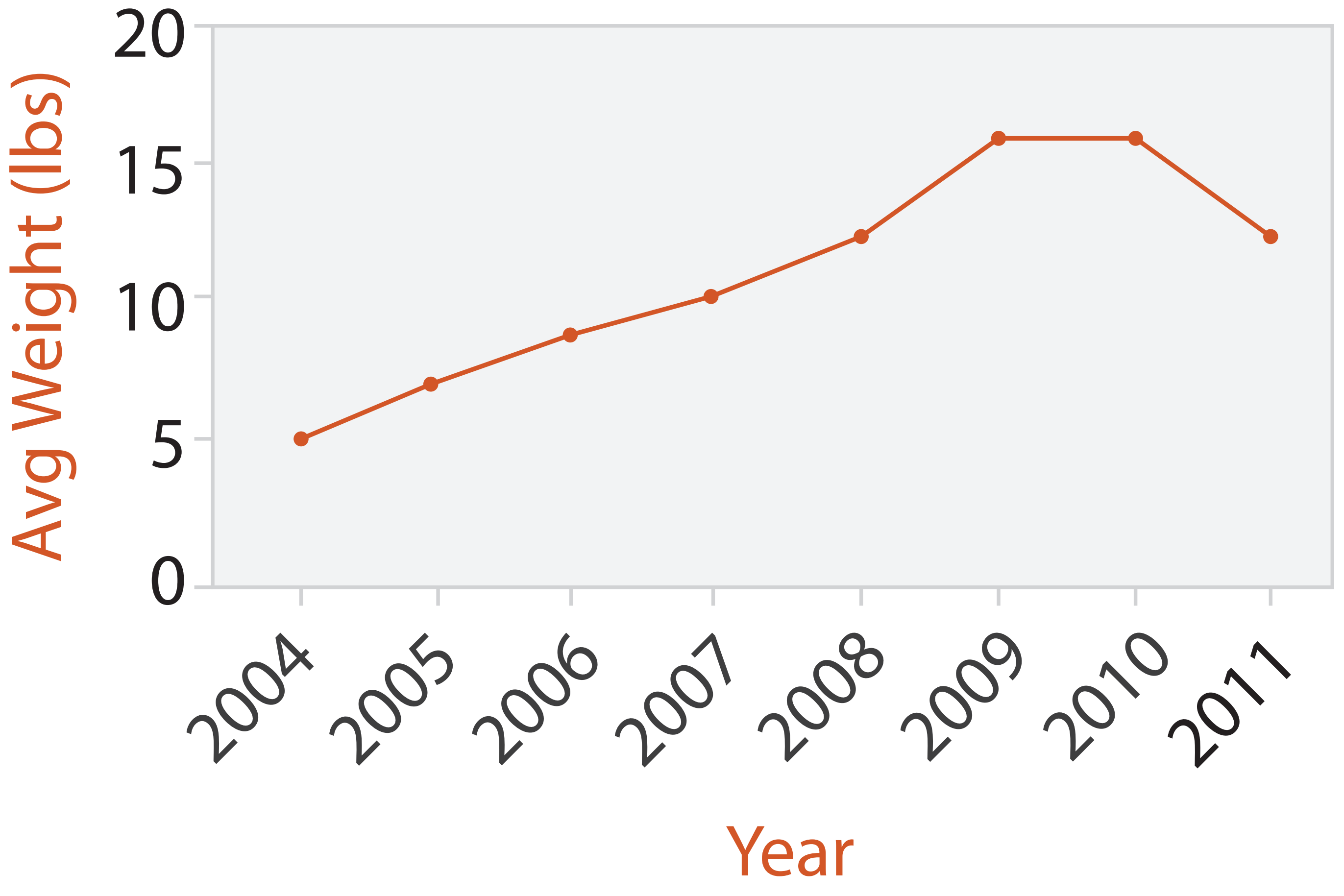
Idiom: **streamgraph**



[Stacked Graphs Geometry & Aesthetics. Byron and Wattenberg. IEEE Trans. Visualization and Computer Graphics (Proc. InfoVis 2008) 14(6): 1245–1252, (2008).]

- generalized stacked graph
  - emphasizing horizontal continuity
    - vs vertical items
  - data
    - 1 categ key attrib (artist)
    - 1 ordered key attrib (time)
    - 1 quant value attrib (counts)
  - derived data
    - geometry: layers, where height encodes counts
    - 1 quant attrib (layer ordering)
  - scalability
    - hundreds of time keys
    - dozens to hundreds of artist keys
      - more than stacked bars: most layers don't extend across whole chart

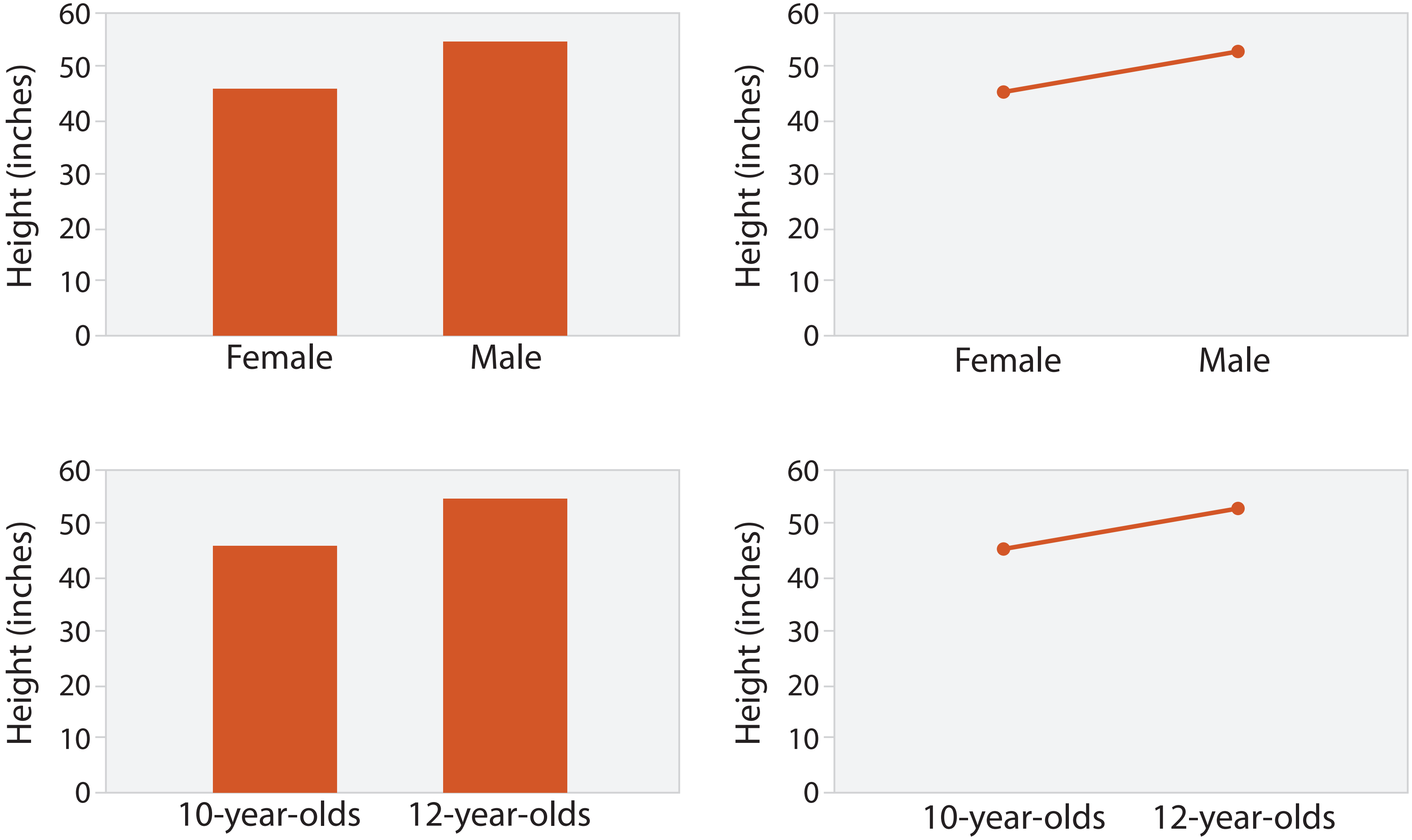
Idiom: **line chart / dot plot**



- one key, one value
  - data
    - 2 quant attribs
  - mark: points
    - line connection marks between them
  - channels
    - aligned lengths to express quant value
    - separated and ordered by key attrib into horizontal regions
  - task
    - find trend
      - connection marks emphasize ordering of items along key axis by explicitly showing relationship between one item and the next

Choosing bar vs line charts

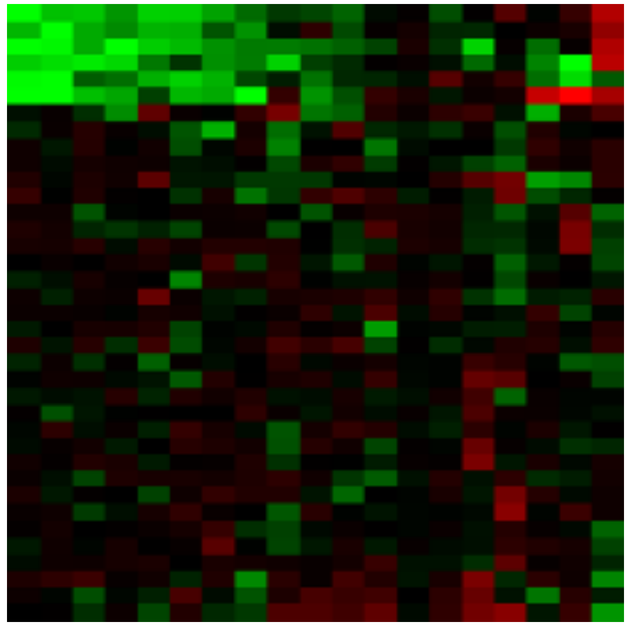
- depends on type of key attrib
  - bar charts if categorical
  - line charts if ordered
- do not use line charts for categorical key attribs
  - violates expressiveness principle
    - implication of trend so strong that it overrides semantics!
      - "The more male a person is, the taller he/she is"

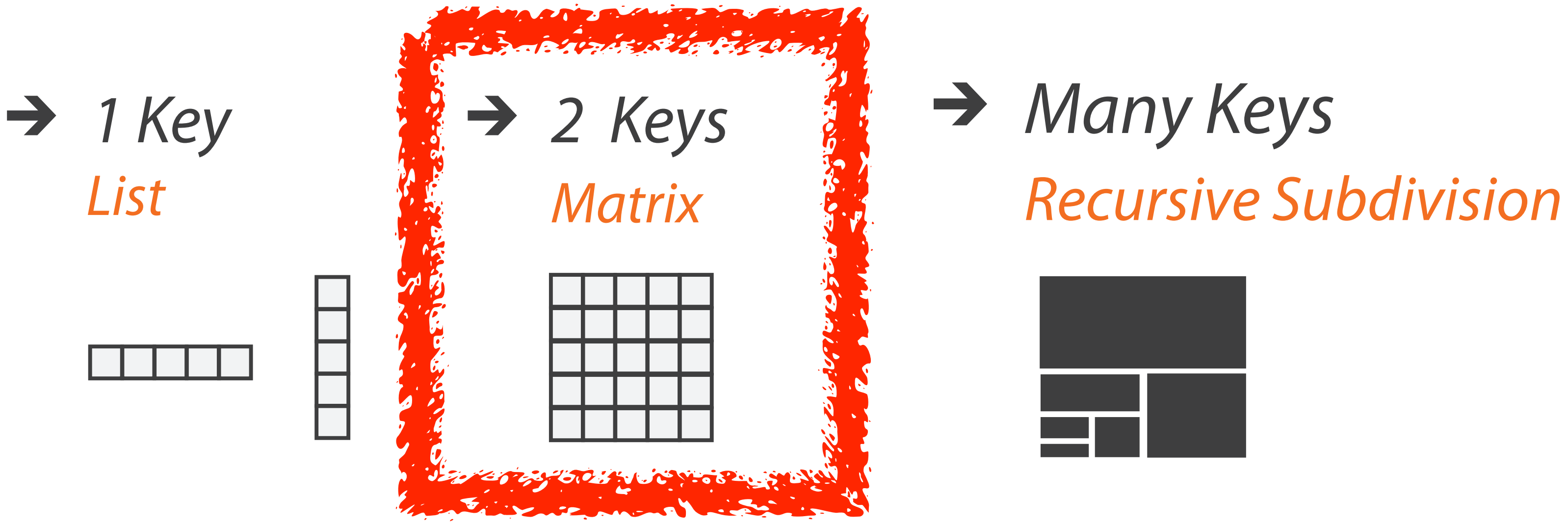


after [Bars and Lines: A Study of Graphic Communication. Zacks and Tversky. Memory and Cognition 27:6 (1999), 1073–1079.]

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





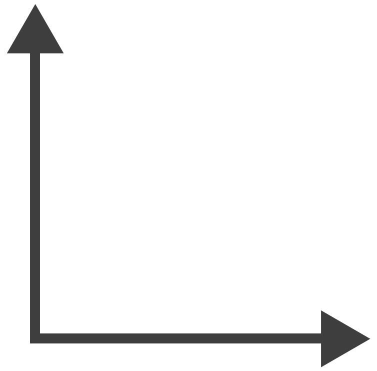
➔ 1 Key
List

➔ 2 Keys
Matrix

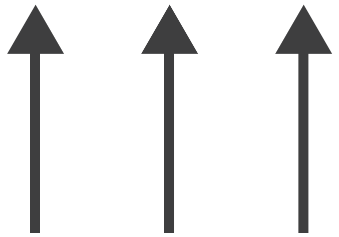
➔ Many Keys
Recursive Subdivision

Axis Orientation

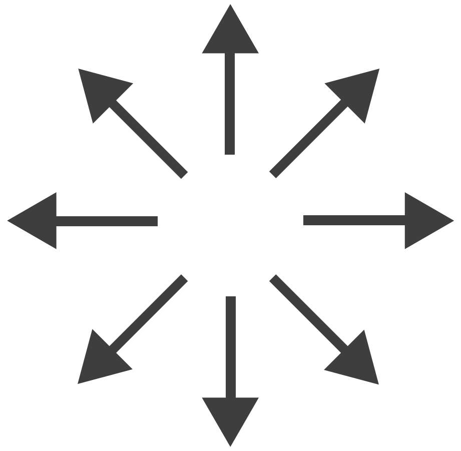
- Rectilinear



- Parallel

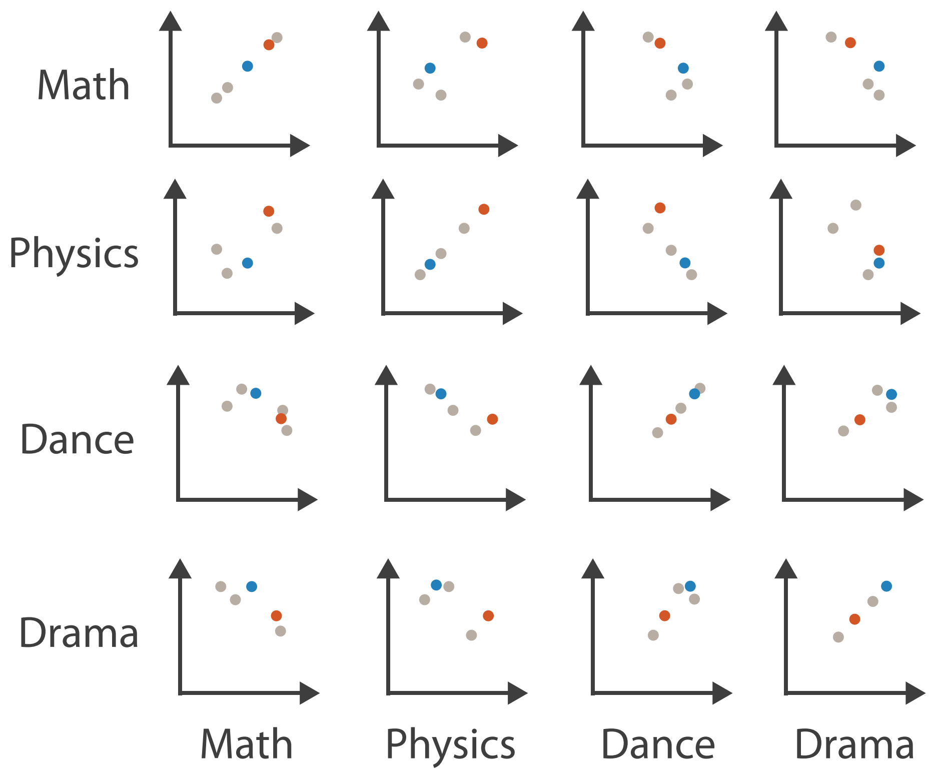


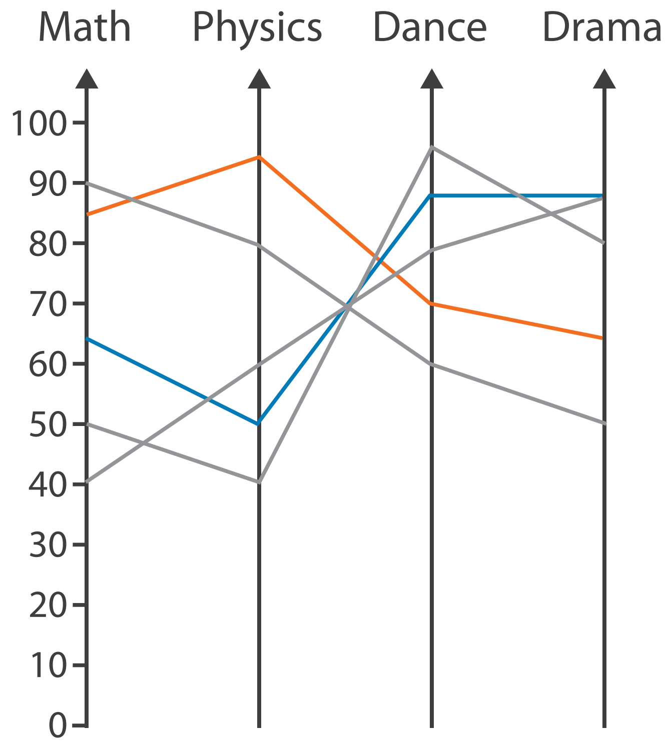
- Radial



Idioms: **scatterplot matrix, parallel coordinates**

- scatterplot matrix (SPLOM)
  - rectilinear axes, point mark
  - all possible pairs of axes
  - scalability
    - one dozen attribs
    - dozens to hundreds of items
- parallel coordinates
  - parallel axes, jagged line representing item
  - rectilinear axes, item as point
    - axis ordering is major challenge
  - scalability
    - dozens of attribs
    - hundreds of items


Scatterplot Matrix


Parallel Coordinates

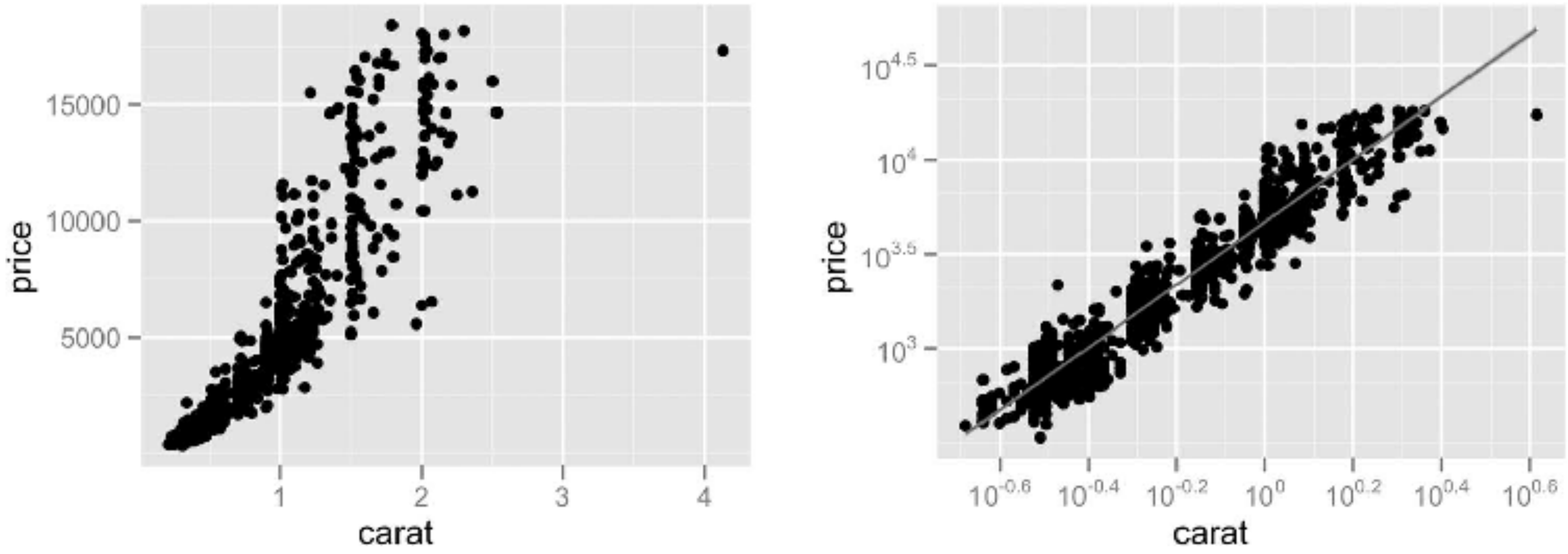
Table

Math	Physics	Dance	Drama
85	95	70	65
90	80	60	50
65	50	90	90
50	40	95	80
40	60	80	90

after [Visualization Course Figures. McGuffin, 2014. [*http://www.michaelmcguffin.com/courses/vis/]*](http://www.michaelmcguffin.com/courses/vis/)

Task: Correlation

- scatterplot matrix
  - positive correlation
    - diagonal low-to-high
  - negative correlation
    - diagonal high-to-low
  - uncorrelated
- parallel coordinates
  - positive correlation
    - parallel line segments
  - negative correlation
    - all segments cross at halfway point
  - uncorrelated
    - scattered crossings



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

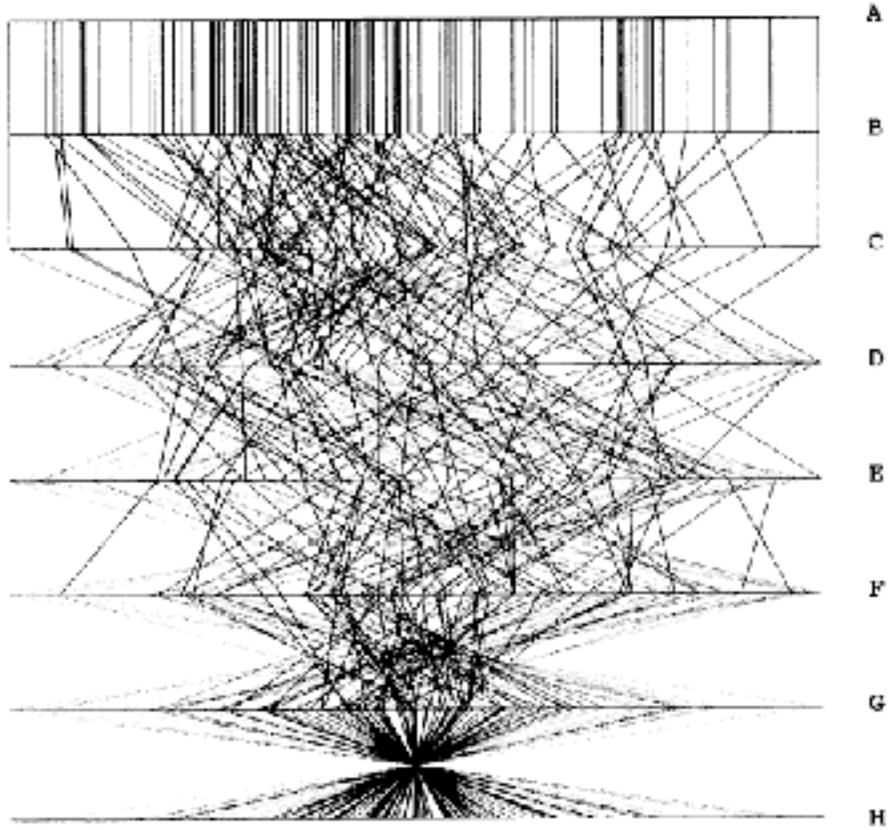
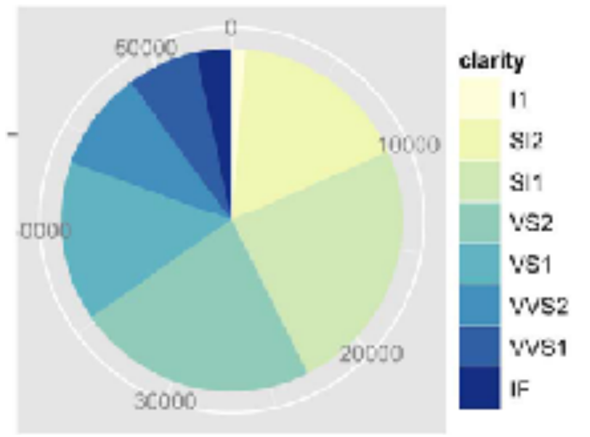


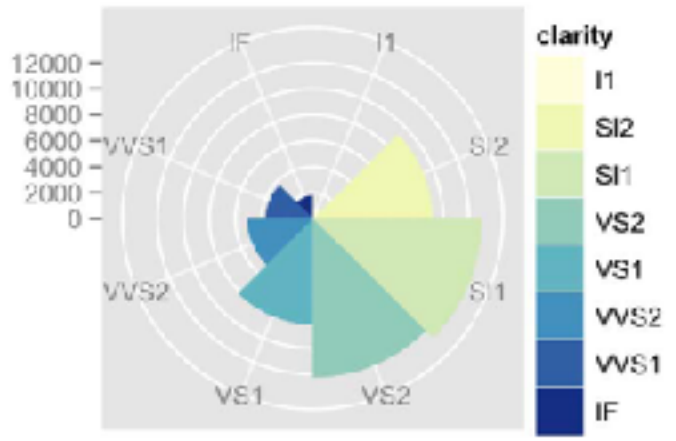
Figure 3. Parallel Coordinate Plot of Six-Dimensional Data Illustrating Correlations of ρ = 1, .8, .2, 0, −.2, −.8, and −1.

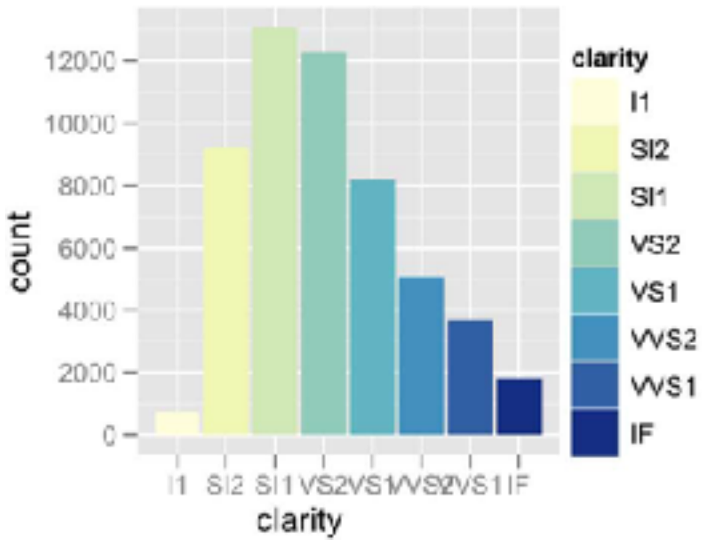
[Hyperdimensional Data Analysis Using Parallel Coordinates. Wegman. Journ. American Statistical Association 85:411 (1990), 664–675.]

Idioms: **pie chart, polar area chart**

- pie chart
  - area marks with angle channel
  - accuracy: angle/area much less accurate than line length
    - arclength also less accurate than line length
- polar area chart
  - area marks with length channel
  - more direct analog to bar charts
- data
  - 1 categ key attrib, 1 quant value attrib
- task
  - part-to-whole judgements



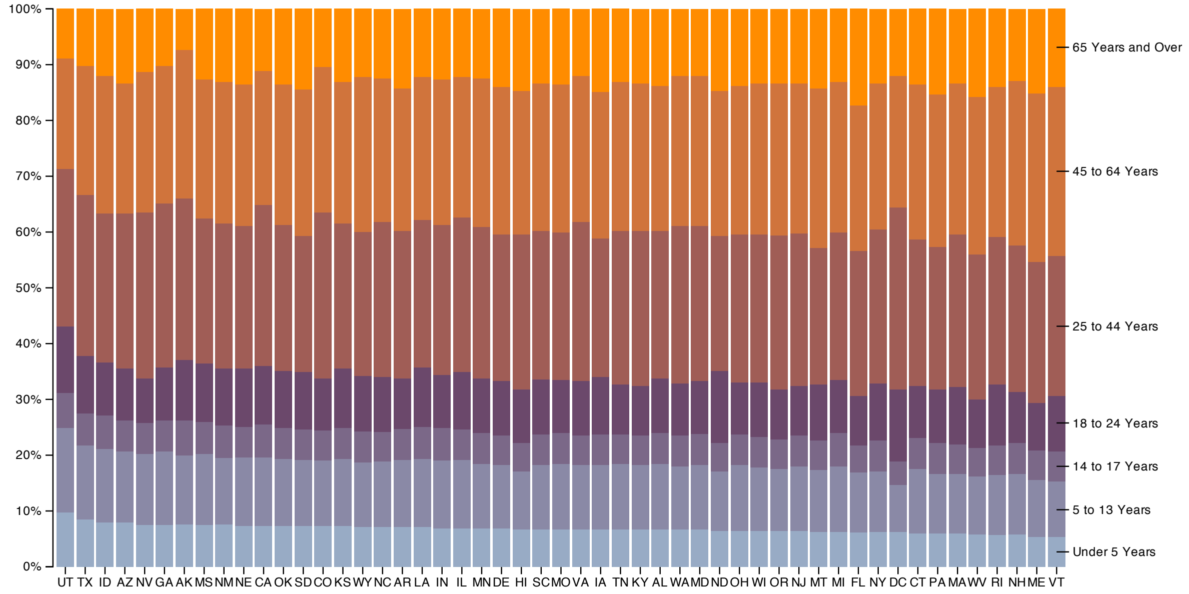


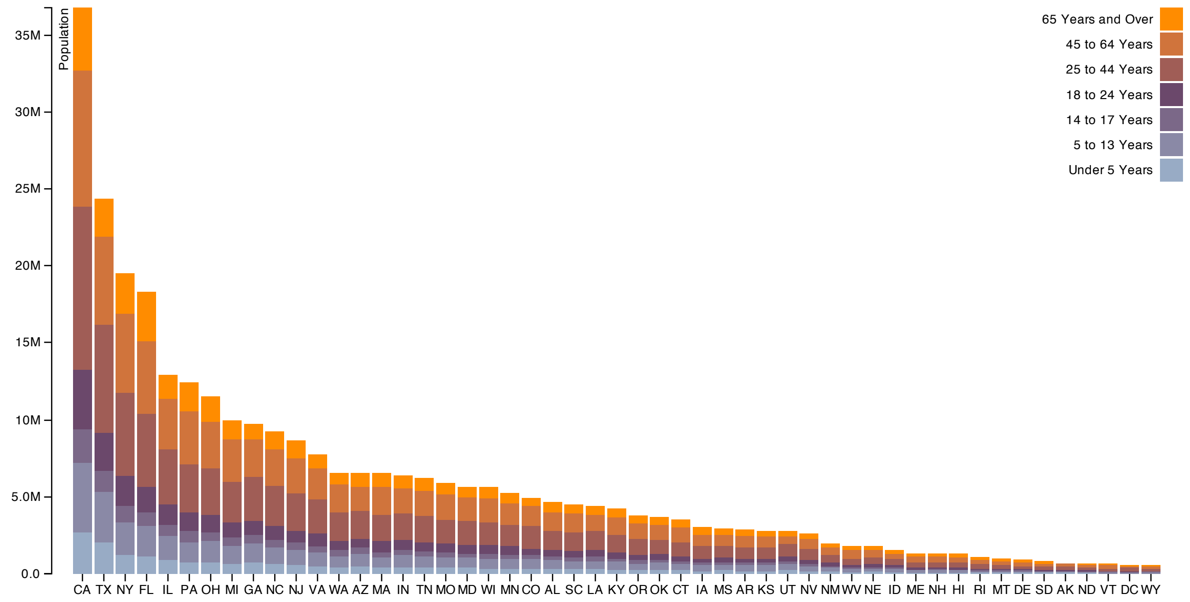


[A layered grammar of graphics. Wickham. Journ. Computational and Graphical Statistics 19:1 (2010), 3–28.]

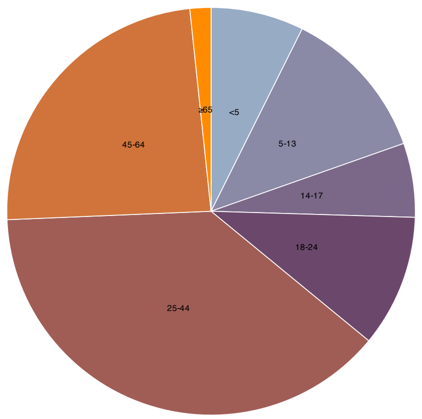
Idioms: **normalized stacked bar chart**

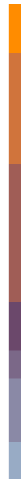
- task
  - part-to-whole judgements
- normalized stacked bar chart
  - stacked bar chart, normalized to full vert height
  - single stacked bar equivalent to full pie
    - high information density: requires narrow rectangle
- pie chart
  - information density: requires large circle





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

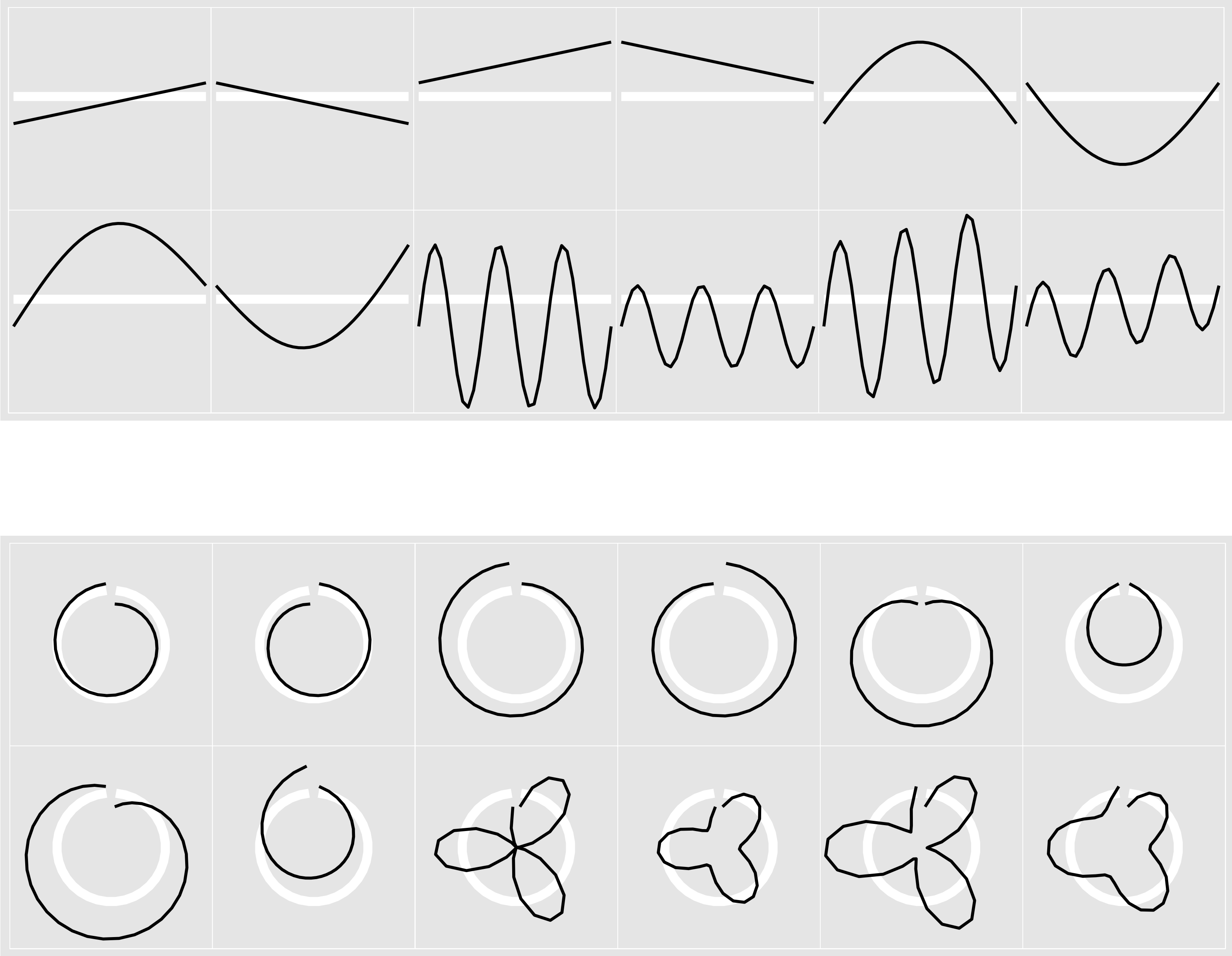




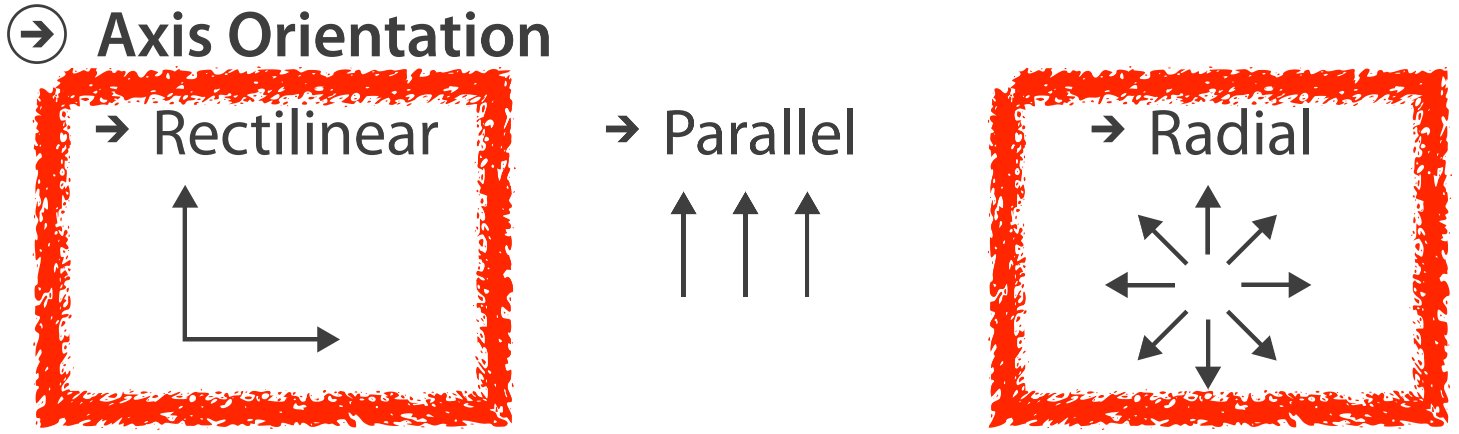
Idiom: **glyphmaps**

- 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.]



Axis Orientation

→ Rectilinear

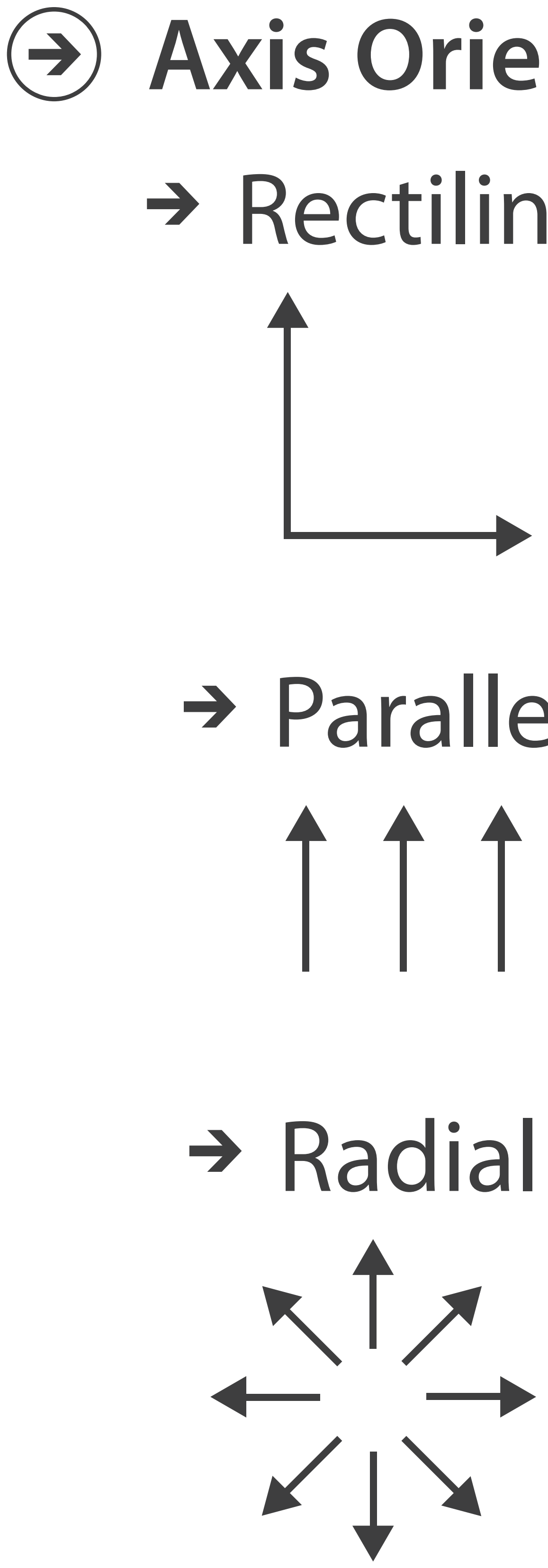
→ Parallel

→ Radial

Orientation limitations

- rectilinear: scalability wrt #axes
    - 2 axes best
    - 3 problematic
        - more in afternoon
    - 4+ impossible
- parallel: unfamiliarity, training time
- radial: perceptual limits
    - angles lower precision than lengths
    - asymmetry between angle and length
        - can be exploited!

[Uncovering Strengths and Weaknesses of Radial Visualizations - an Empirical Approach. Diehl, Beck and Burch. IEEE TVCG (Proc. InfoVis) 16(6):935--942, 2010.]



➔ Axis Orientation

➔ Rectilinear

➔ Parallel

➔ Radial

Further reading

- Visualization Analysis and Design. Munzner. AK Peters Visualization Series, CRC Press, Nov 2014.
  - *Chap 7: Arrange Tables*
- Visualizing Data. Cleveland. Hobart Press, 1993.
- A Brief History of Data Visualization. Friendly. 2008. http://www.datavis.ca/milestones

Visualization Analysis & Design, Half-Day Tutorial

- Session 1
  - Analysis: What, Why, How
  - Marks and Channels
  - Arrange Tables
  - Arrange Spatial Data
- Session 2
  - Arrange Networks and Trees
  - Map Color and Other Channels
  - Manipulate: Change, Select, Navigate
  - Facet: Juxtapose, Partition, Superimpose
  - Reduce: Filter, Aggregate

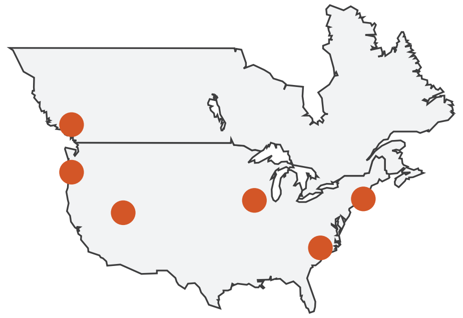
@tamaramunzner

http://www.cs.ubc.ca/~tmm/talks.html#halfdaycourse20

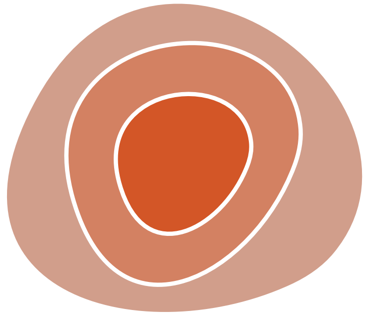
Arrange spatial data

➔ Use Given

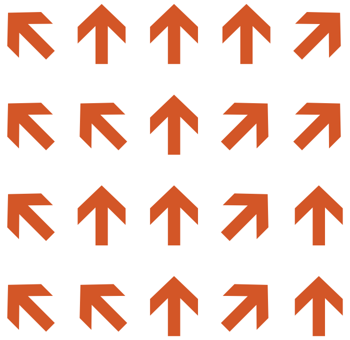
- ➔ Geometry
    - ➔ *Geographic*
    - ➔ *Other Derived*



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

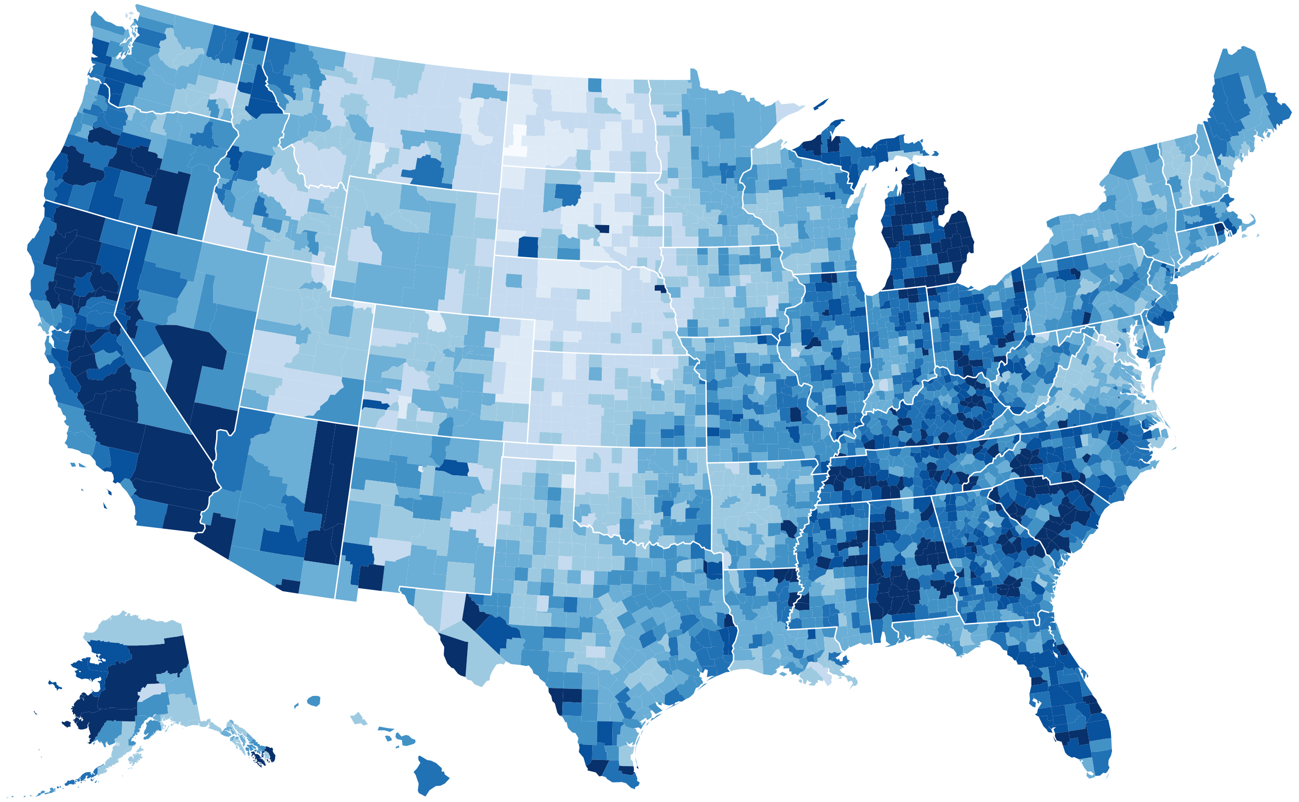


- ➔ *Vector and Tensor Fields (many values per cell)*
    - ➔ *Flow Glyphs (local)*
    - ➔ *Geometric (sparse seeds)*
    - ➔ *Textures (dense seeds)*
    - ➔ *Features (globally derived)*



Idiom: **choropleth map**

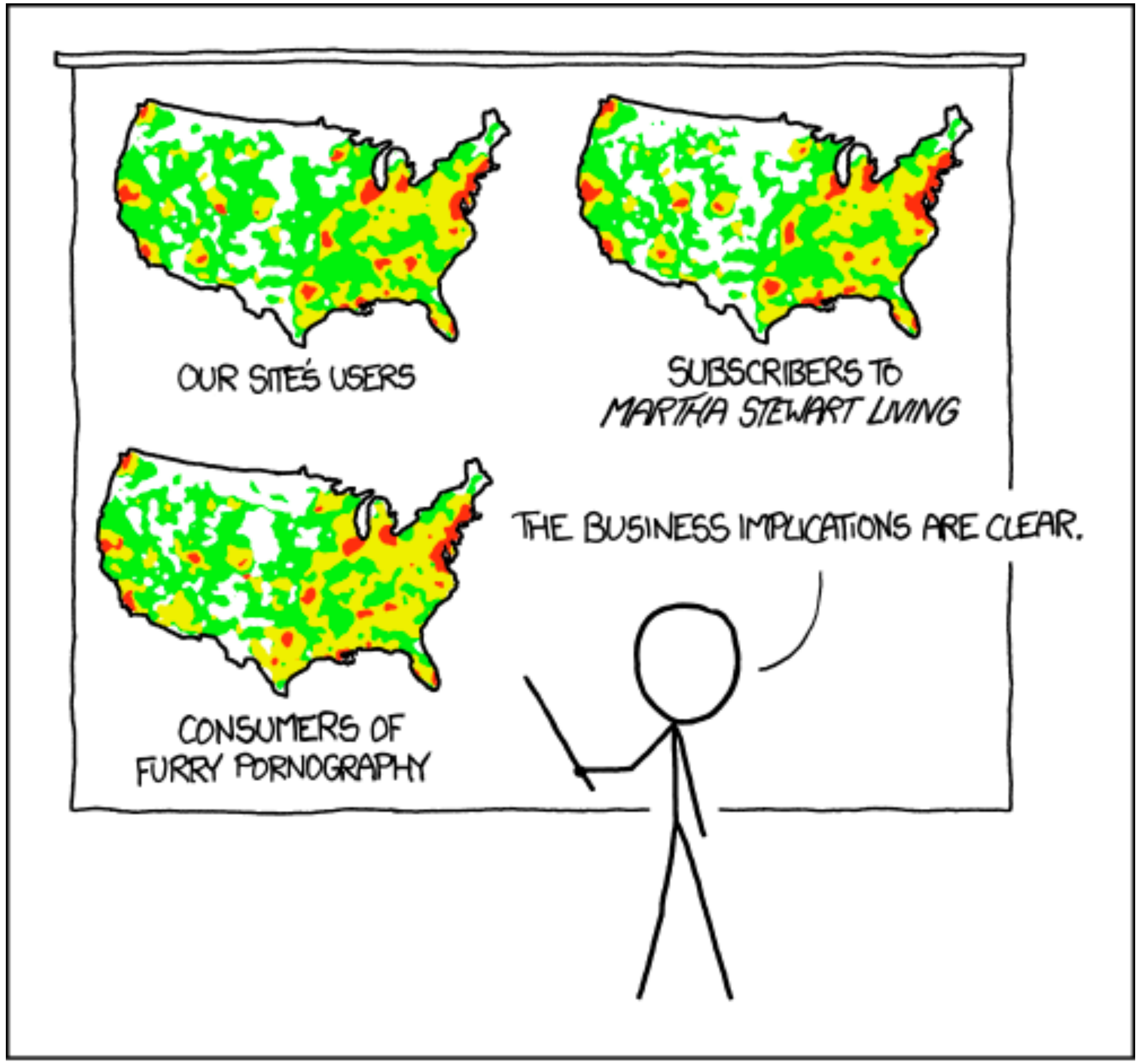
- use given spatial data
  - when central task is understanding spatial relationships
- data
  - geographic geometry
  - table with 1 quant attribute per region
- encoding
  - use given geometry for area mark boundaries
  - sequential segmented colormap [more later]



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

Beware: Population maps trickiness!

- consider when to normalize by population density
- general issue
  - absolute counts vs relative/normalized data

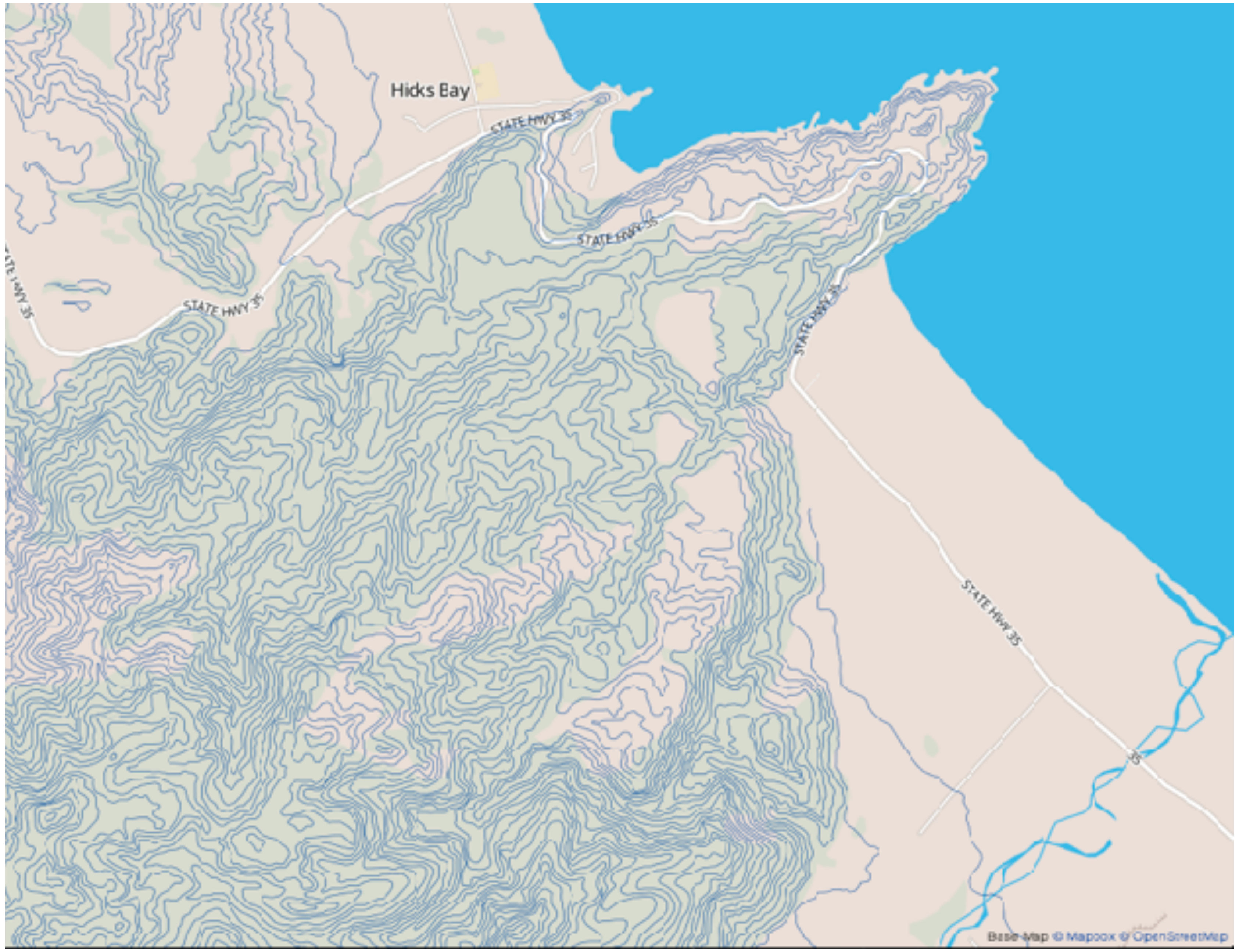

OUR SITE'S USERS
SUBSCRIBERS TO *MARTHA STEWART LIVING*
CONSUMERS OF FURRY PORNOGRAPHY
THE BUSINESS IMPLICATIONS ARE CLEAR.

PET PEEVE #208:
GEOGRAPHIC PROFILE MAPS WHICH ARE BASICALLY JUST POPULATION MAPS

[https://xkcd.com/1138]

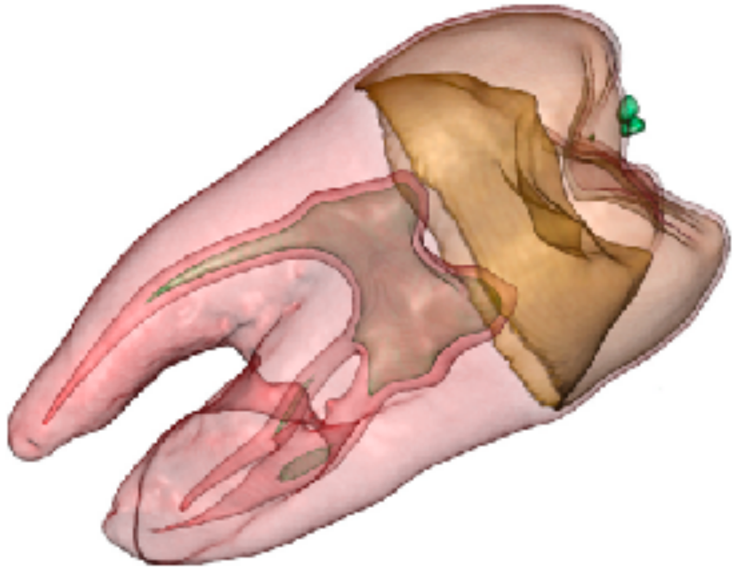
Idiom: **topographic map**

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

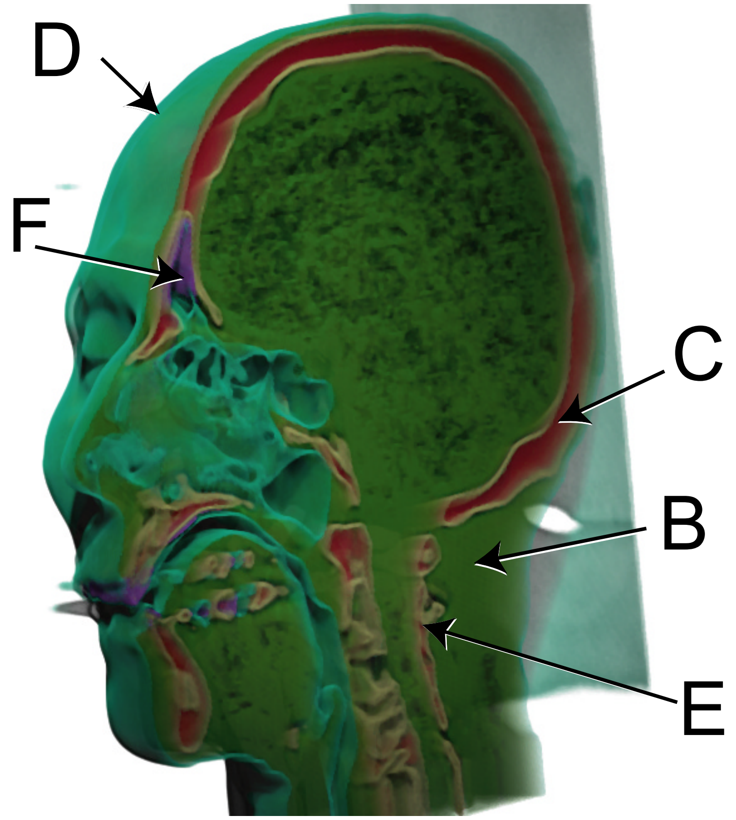


Land Information New Zealand Data Service

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

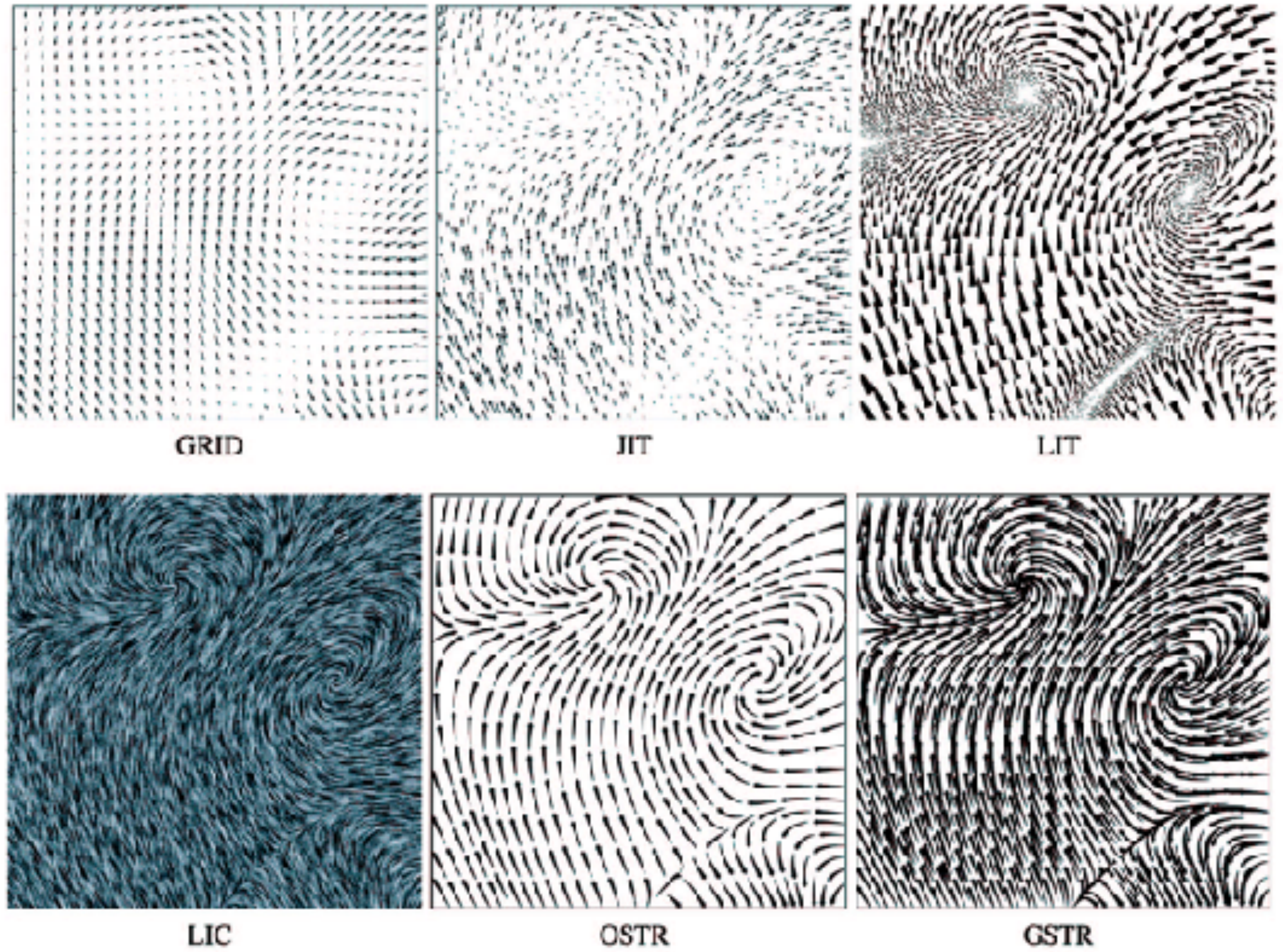


[Interactive Volume Rendering Techniques. Kniss. Master's thesis, University of Utah Computer Science, 2002.]

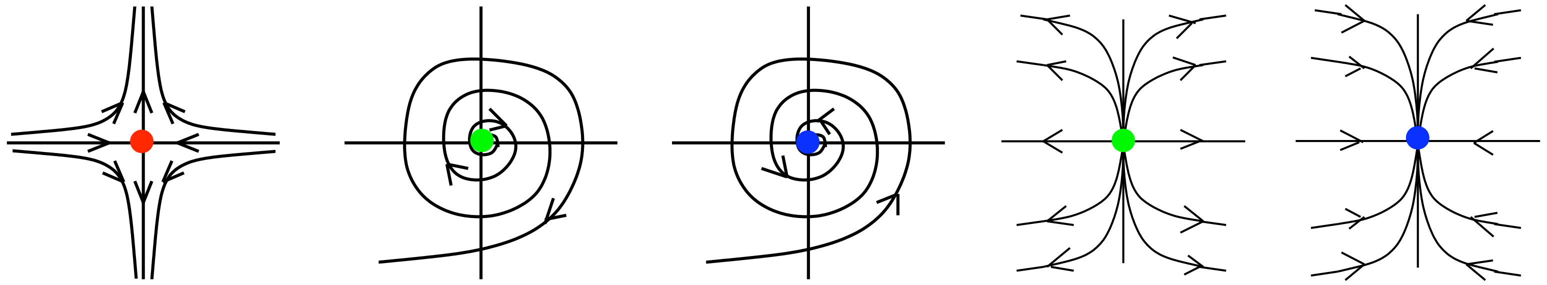
[Multidimensional Transfer Functions for Volume Rendering. Kniss, Kindlmann, and Hansen. In The Visualization Handbook, edited by Charles Hansen and Christopher Johnson, pp. 189–210. Elsevier, 2005.]

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



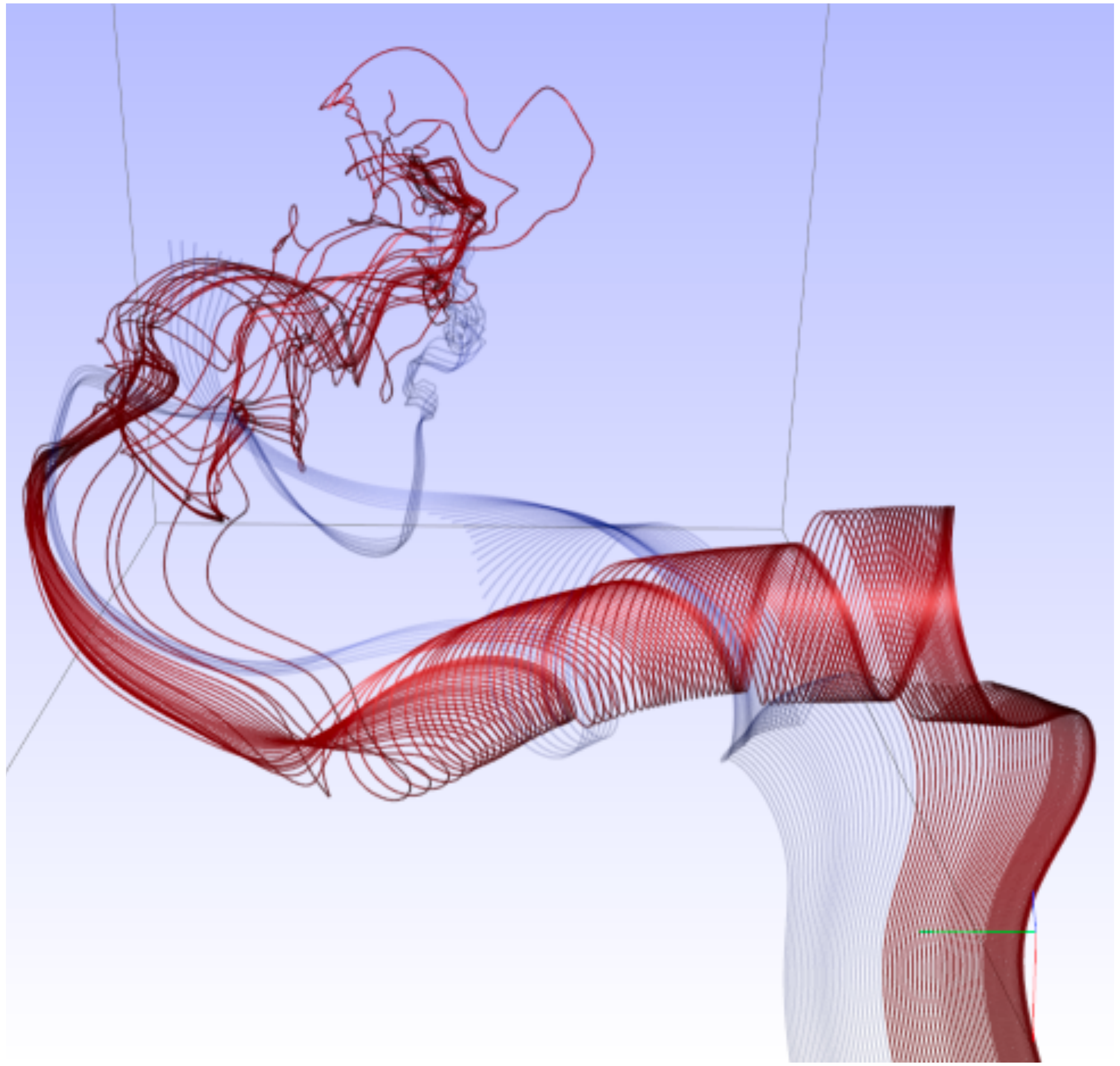
[Comparing 2D vector field visualization methods: A user study. Laidlaw et al. IEEE Trans. Visualization and Computer Graphics (TVCG) 11:1 (2005), 59–70.]



[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.]

Further reading

- Visualization Analysis and Design. Munzner. AK Peters Visualization Series, CRC Press, 2014.
  - *Chap 8: Arrange Spatial Data*
- 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 Tables
  - Arrange Spatial Data
- Session 2
  - Arrange Networks and Trees
  - Map Color and Other Channels
  - Manipulate: Change, Select, Navigate
  - Facet: Juxtapose, Partition, Superimpose
  - Reduce: Filter, Aggregate

@tamaramunzner

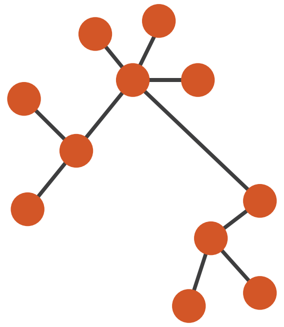
http://www.cs.ubc.ca/~tmm/talks.html#halfdaycourse20

Arrange networks and trees

➔ Node–Link Diagrams

Connection Marks

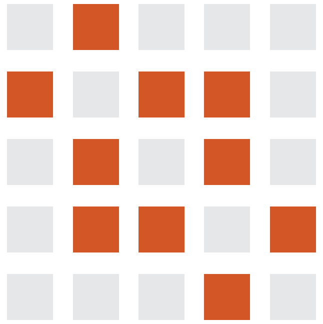
✓ NETWORKS ✓ TREES



➔ Adjacency Matrix

Derived Table

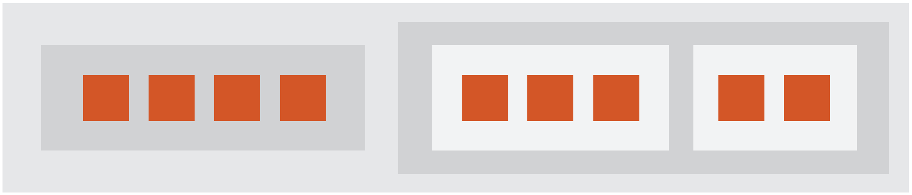
✓ NETWORKS ✓ TREES



➔ Enclosure

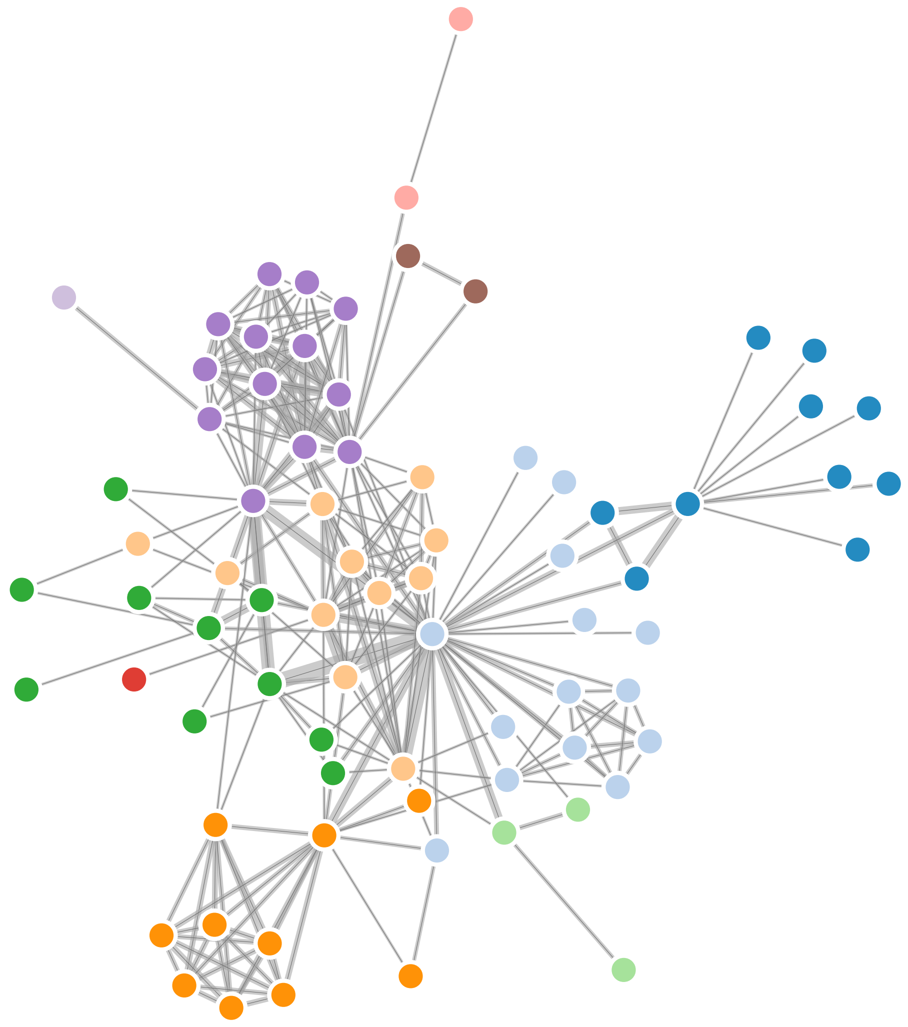
Containment Marks

✗ NETWORKS ✓ TREES



Idiom: **force-directed placement**

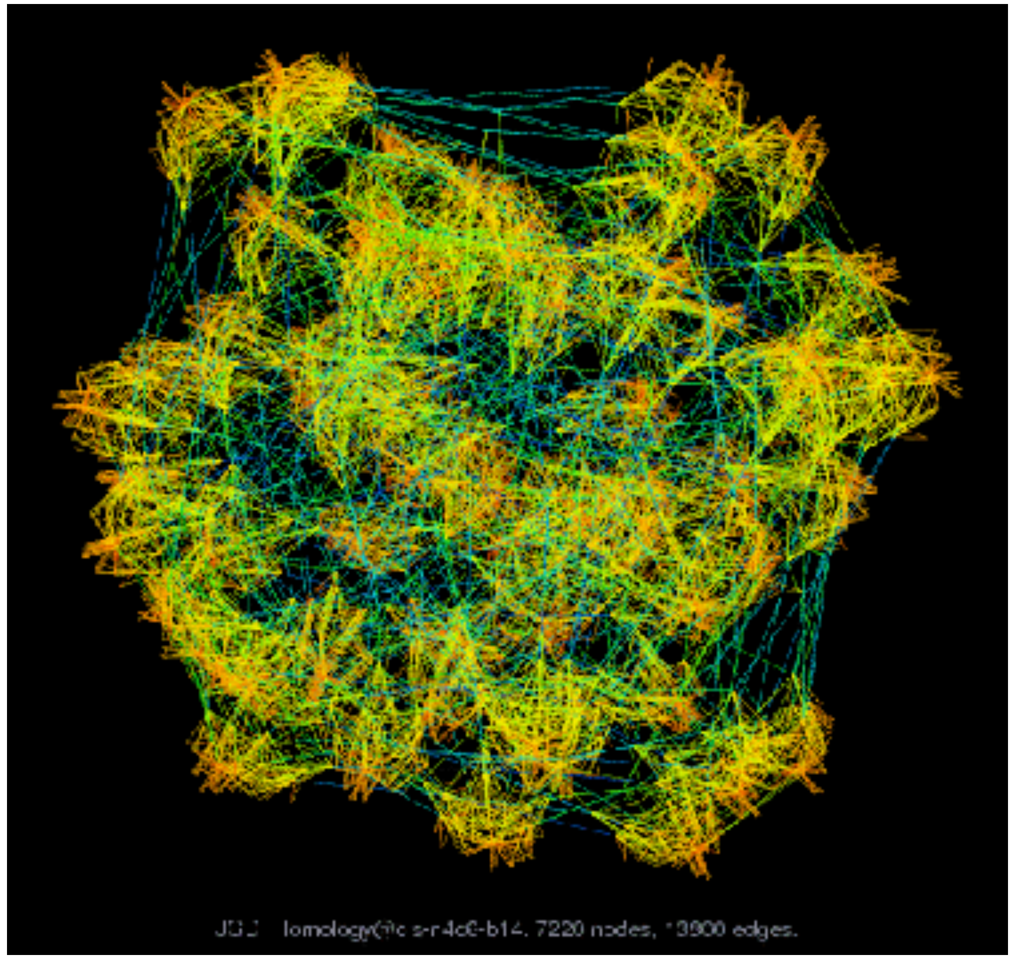
- visual encoding: node-link diagram
  - link connection marks, node point marks
- algorithm: energy minimization
  - analogy: nodes repel, links draw together like springs
  - optimization problem: minimize crossings
- spatial position: no meaning directly encoded
  - sometimes proximity meaningful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



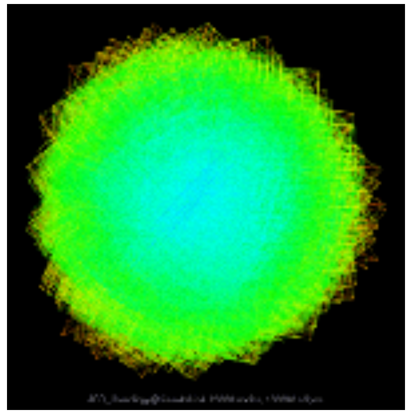
http://mbostock.github.com/d3/ex/force.html

Idiom: **sfdp** (multi-level force-directed placement)

- data
  - original: network
  - derived: cluster hierarchy atop it
- considerations
  - better algorithm for same encoding technique
    - same: fundamental use of space
    - hierarchy used for algorithm speed/quality but not shown explicitly
- scalability
  - nodes, edges: 1K-10K
  - hairball problem still hits eventually



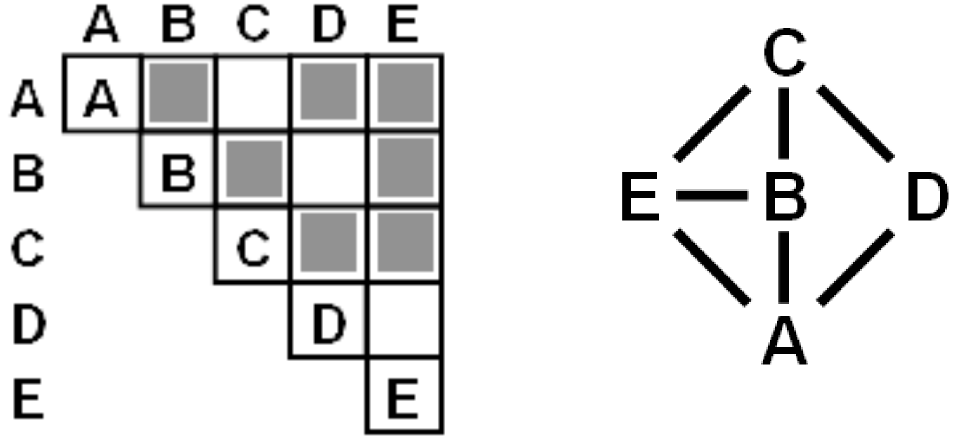
[Efficient and high quality force-directed graph drawing. Hu. The Mathematica Journal 10:37–71, 2005.]



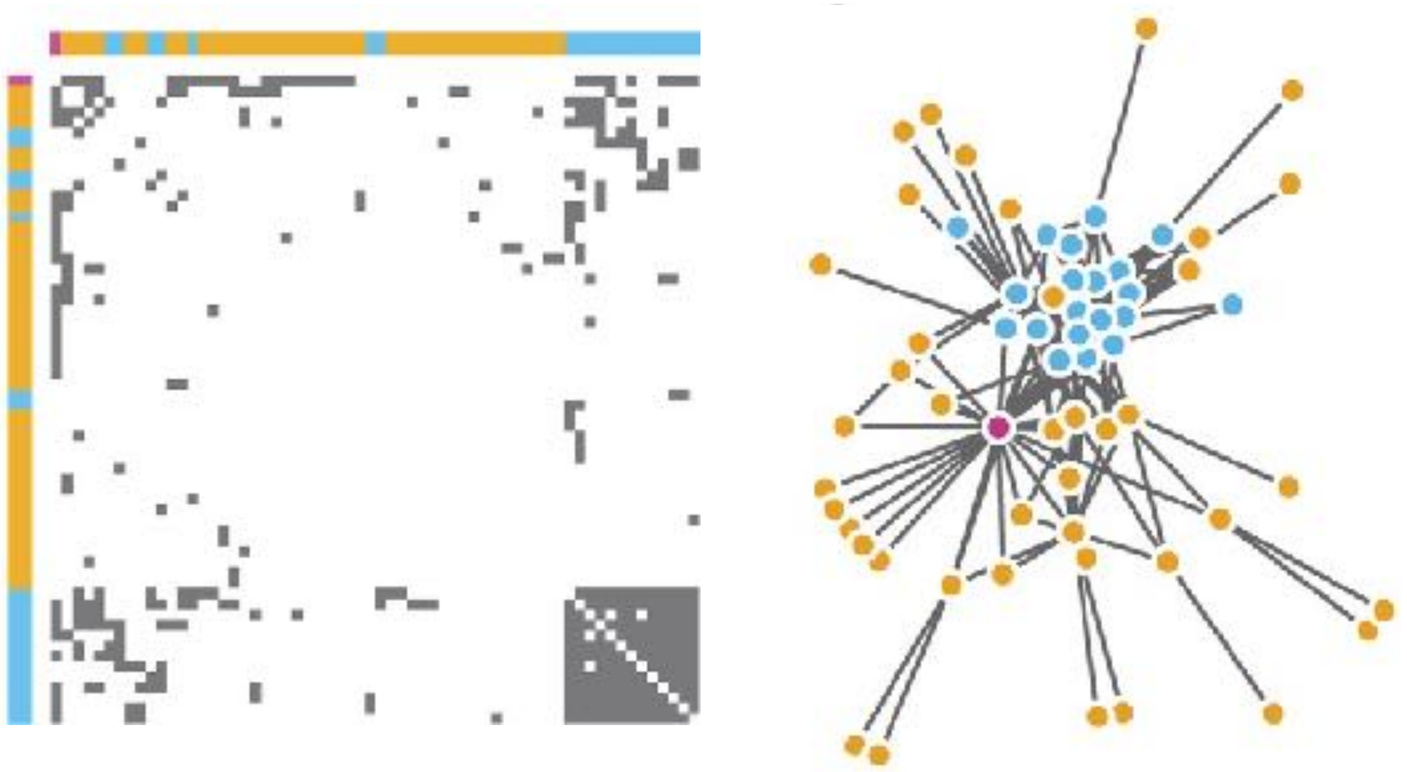
http://www.research.att.com/yifanhu/GALLERY/GRAPHS/index1.html

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



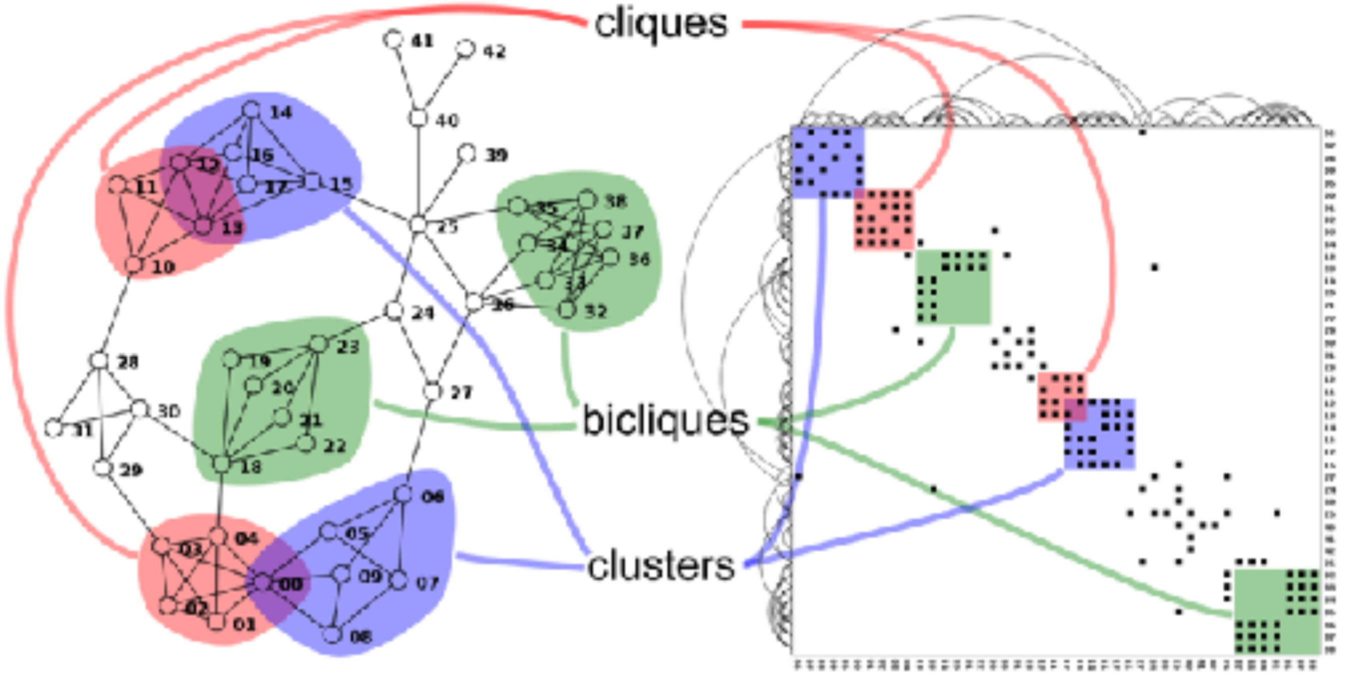
[NodeTrix: a Hybrid Visualization of Social Networks. Henry, Fekete, and McGuffin. IEEE TVCG (Proc. InfoVis) 13(6):1302-1309, 2007.]



[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!

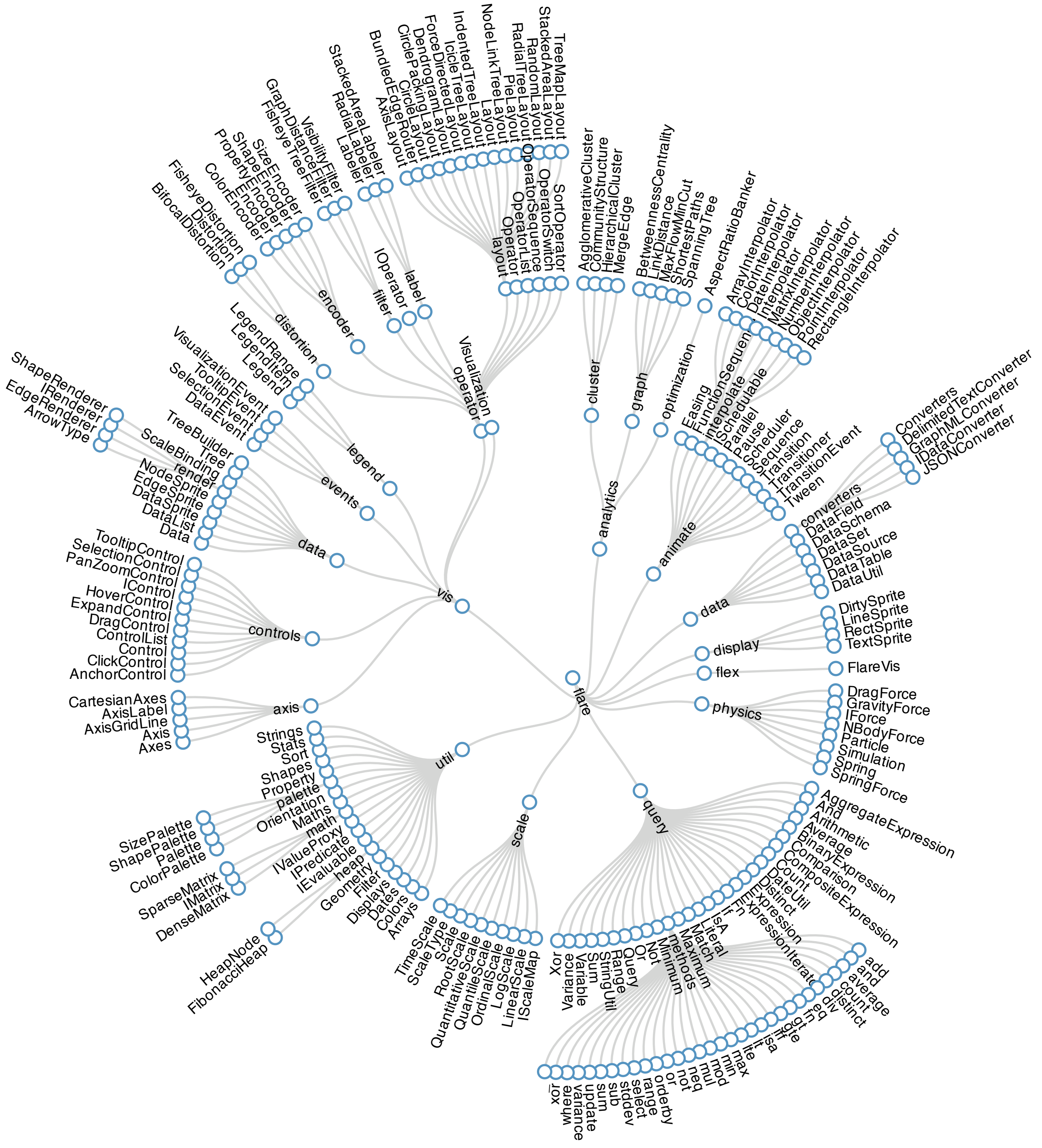


http://www.michaelmcguffin.com/courses/vis/patternsInAdjacencyMatrix.png

[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**

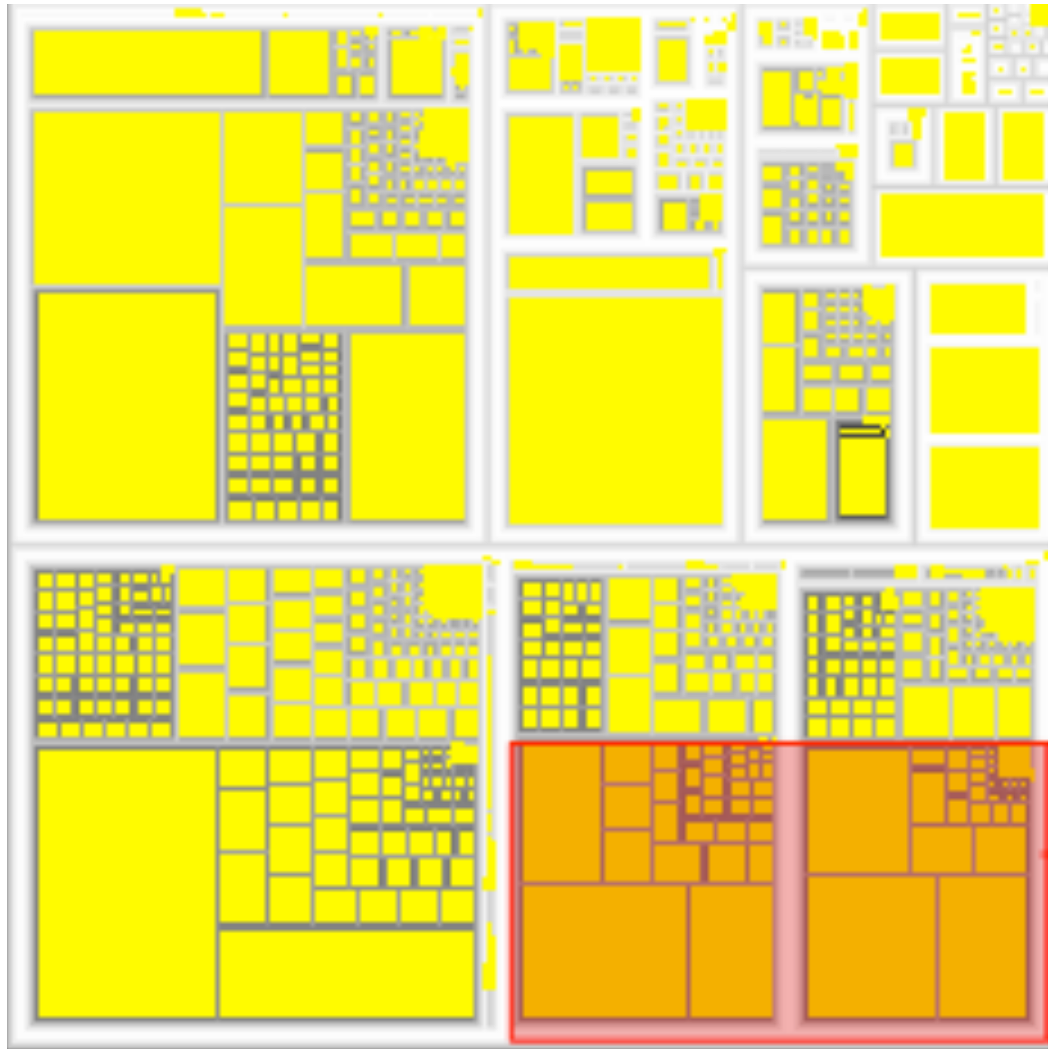
- data
  - tree
- encoding
  - link connection marks
  - point node marks
  - radial axis orientation
    - angular proximity: siblings
    - distance from center: depth in tree
- tasks
  - understanding topology, following paths
- scalability
  - 1K - 10K nodes



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

Idiom: **treemap**

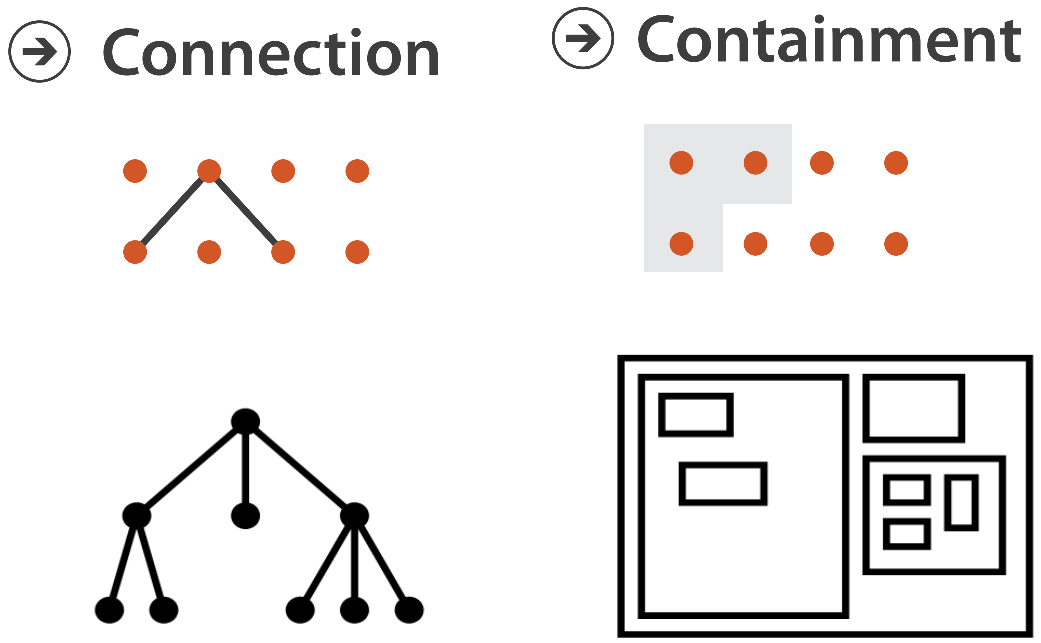
- data
  - tree
  - 1 quant attrib at leaf nodes
- encoding
  - area containment marks for hierarchical structure
  - rectilinear orientation
  - size encodes quant attrib
- tasks
  - query attribute at leaf nodes
- scalability
  - 1M leaf nodes

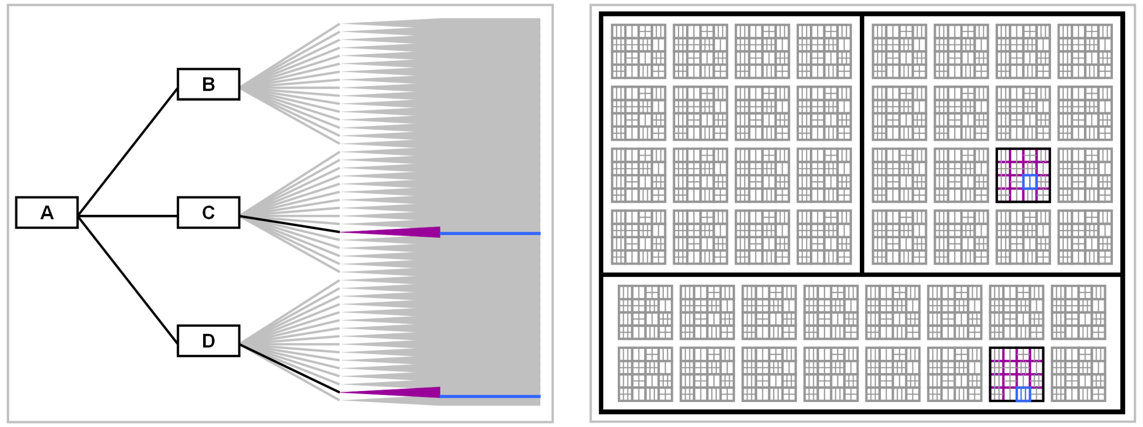


http://tulip.labri.fr/Documentation/3_7/userHandbook/html/ch06.html

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





Node–Link Diagram

Treemap

[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 Tables
  - Arrange Spatial Data

- Session 2
  - Arrange Networks and Trees
  - Map Color and Other Channels
  - Manipulate: Change, Select, Navigate
  - Facet: Juxtapose, Partition, Superimpose
  - Reduce: Filter, Aggregate

@tamaramunzner

http://www.cs.ubc.ca/~tmm/talks.html#halfdaycourse20

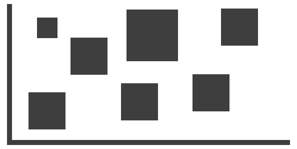
Idiom design choices: First half

Encode

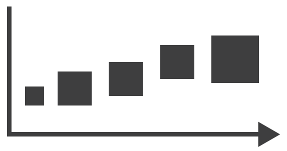
Arrange

→ Express

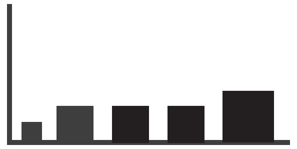
→ Separate



→ Order



→ Align



→ Use

Map

from categorical and ordered attributes

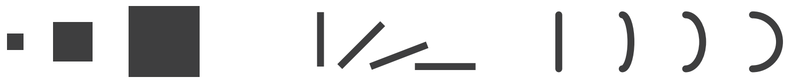
→ Color

→ *Hue*

→ *Saturation*

→ *Luminance*

→ Size, Angle, Curvature, ...

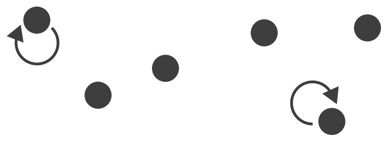


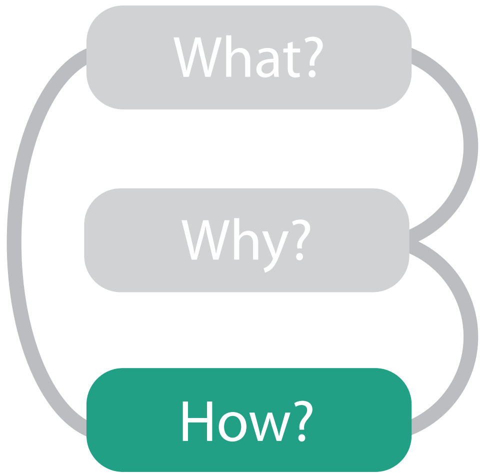
→ Shape

✚ ● ■ ▲

→ Motion

Direction, Rate, Frequency, ...





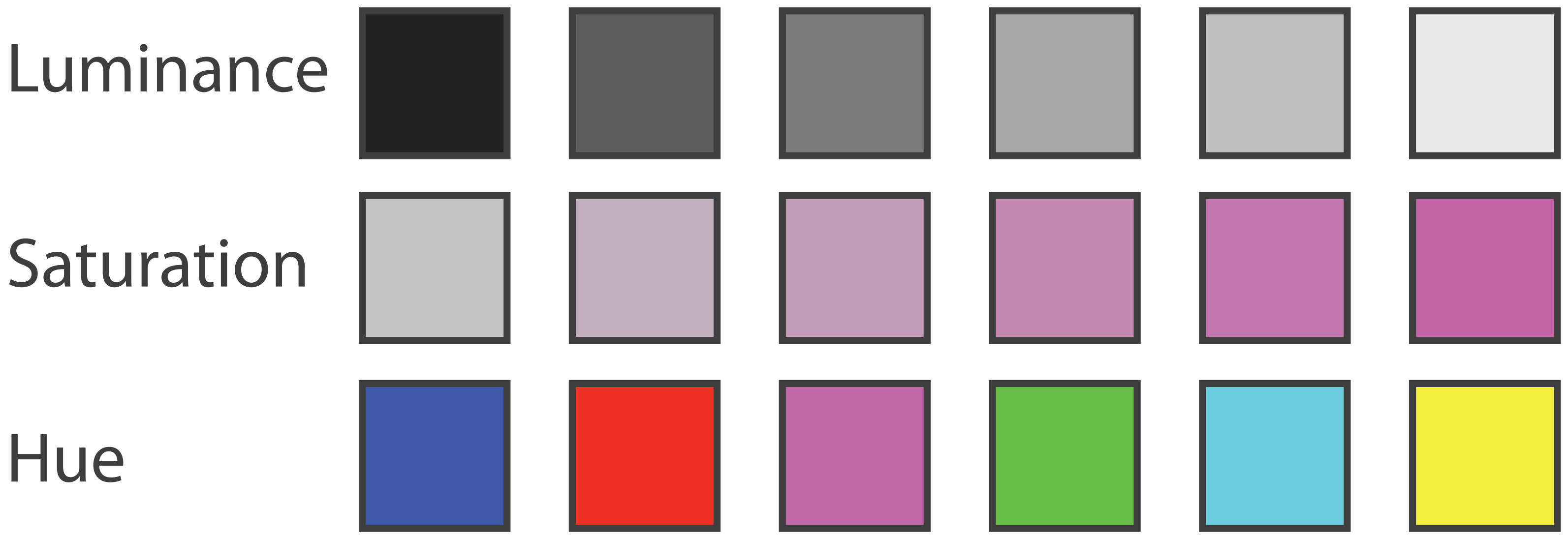
Decomposing color

- 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

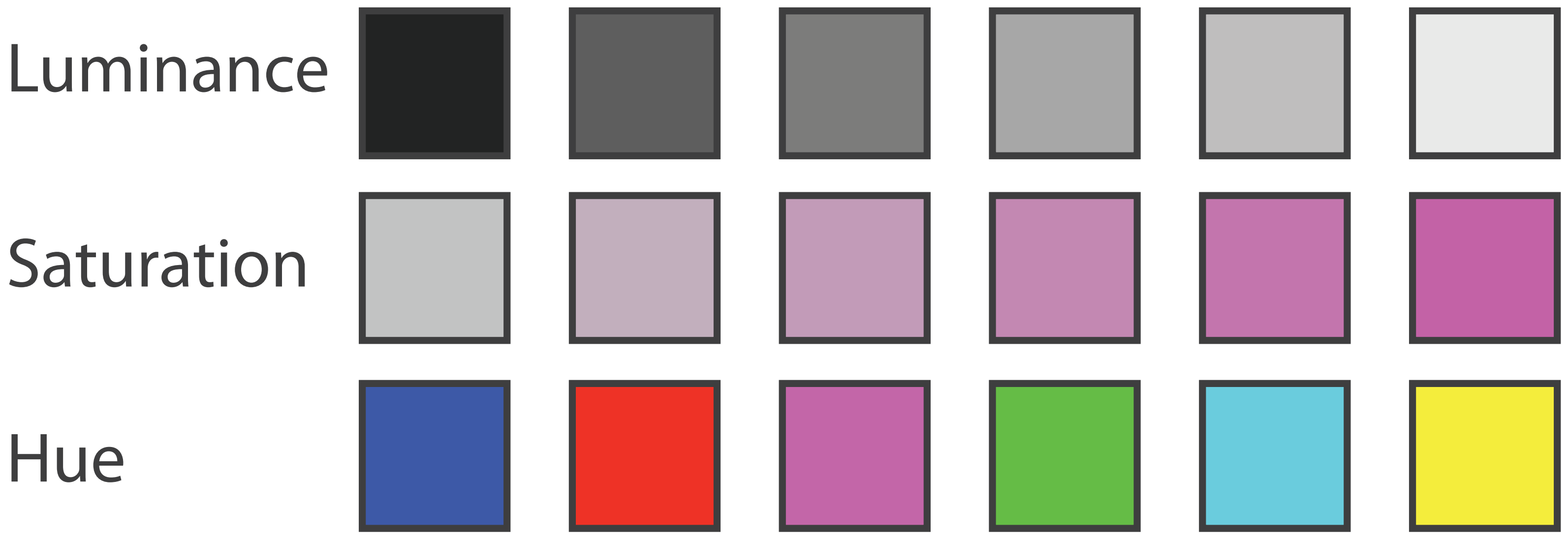
- decompose into three channels



Decomposing color

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

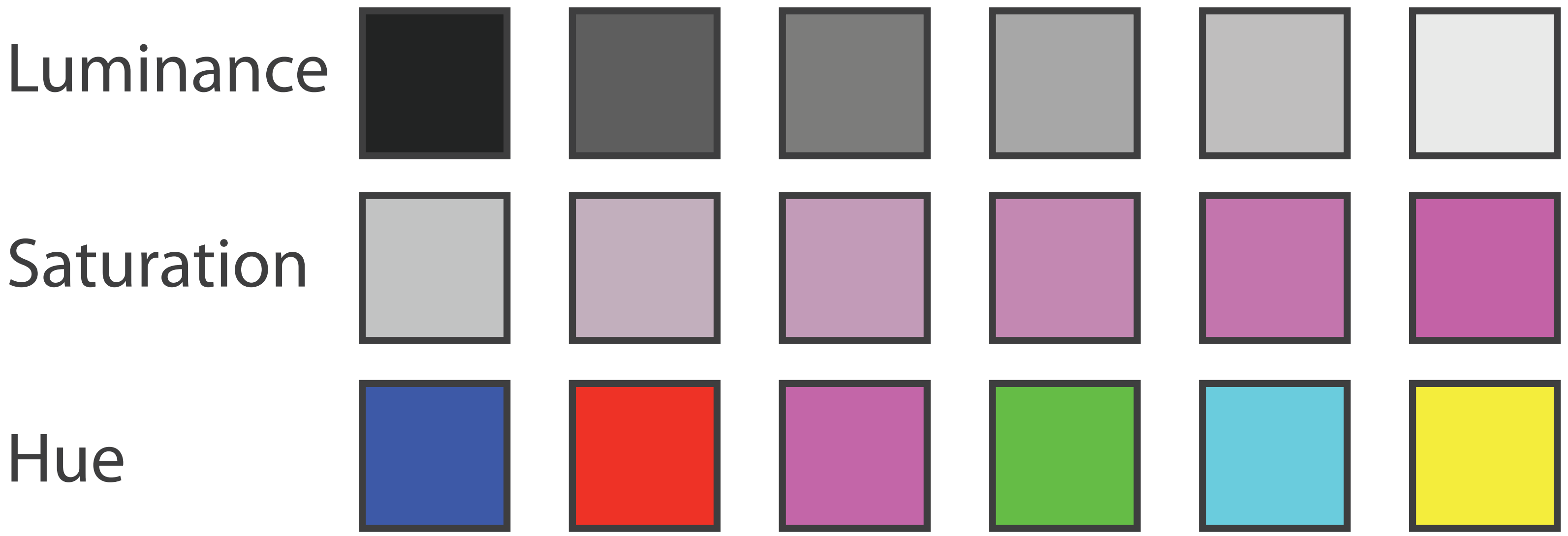
- decompose into three channels
  - ordered can show magnitude
    - luminance
    - saturation
  - categorical can show identity
    - hue



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

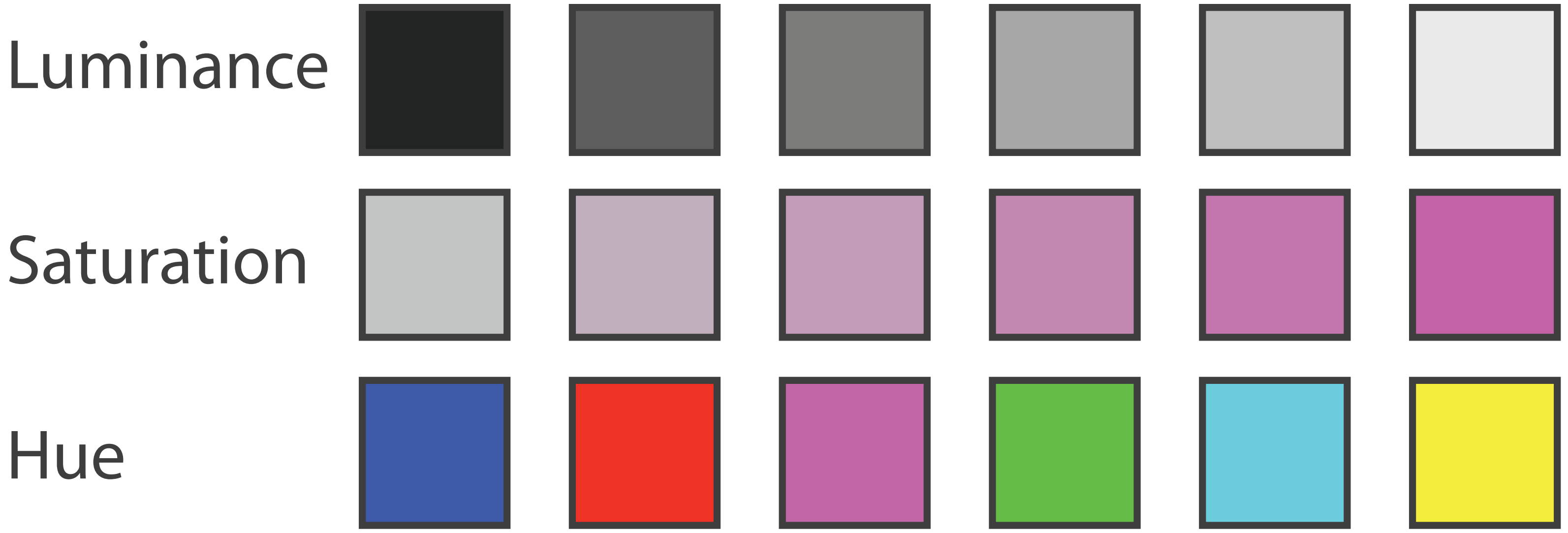


- perceptual colorspace, in contrast to three channels of RGB

Decomposing color

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

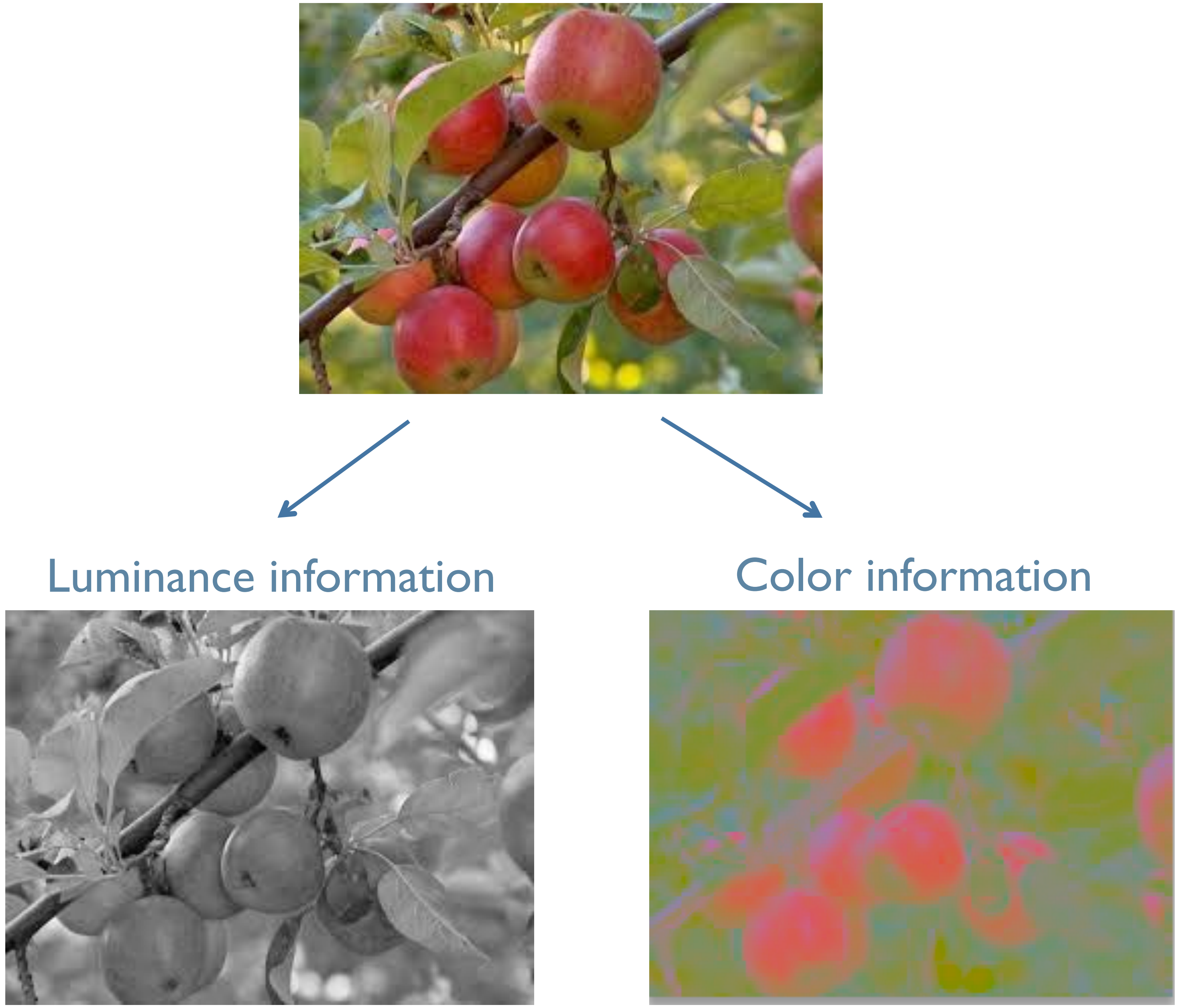
- decompose into three channels
  - ordered can show magnitude
    - luminance
    - saturation
  - categorical can show identity
    - hue



- 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!



Luminance information

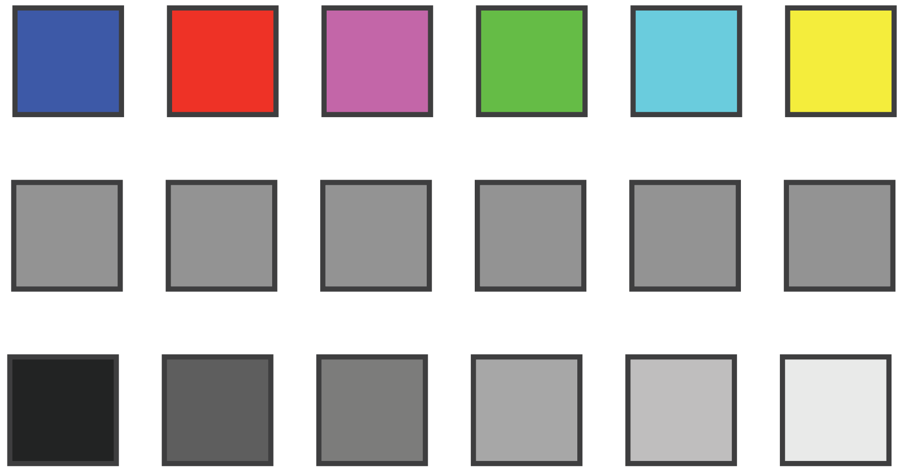
Color information

[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!

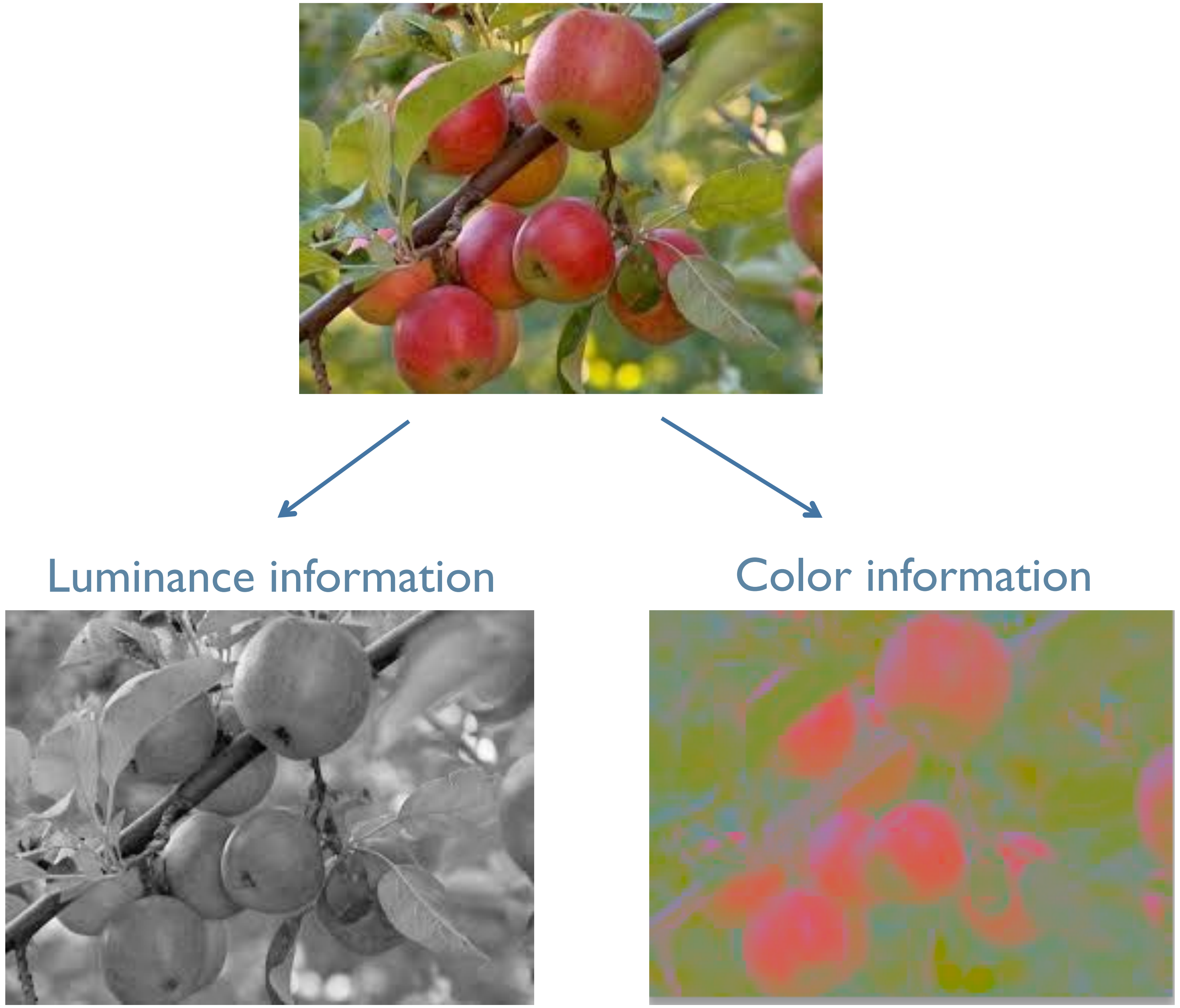
- HLS better than RGB for encoding but beware
  - L lightness ≠ L* luminance



Corners of the RGB color cube

L from HLS
All the same

Luminance values



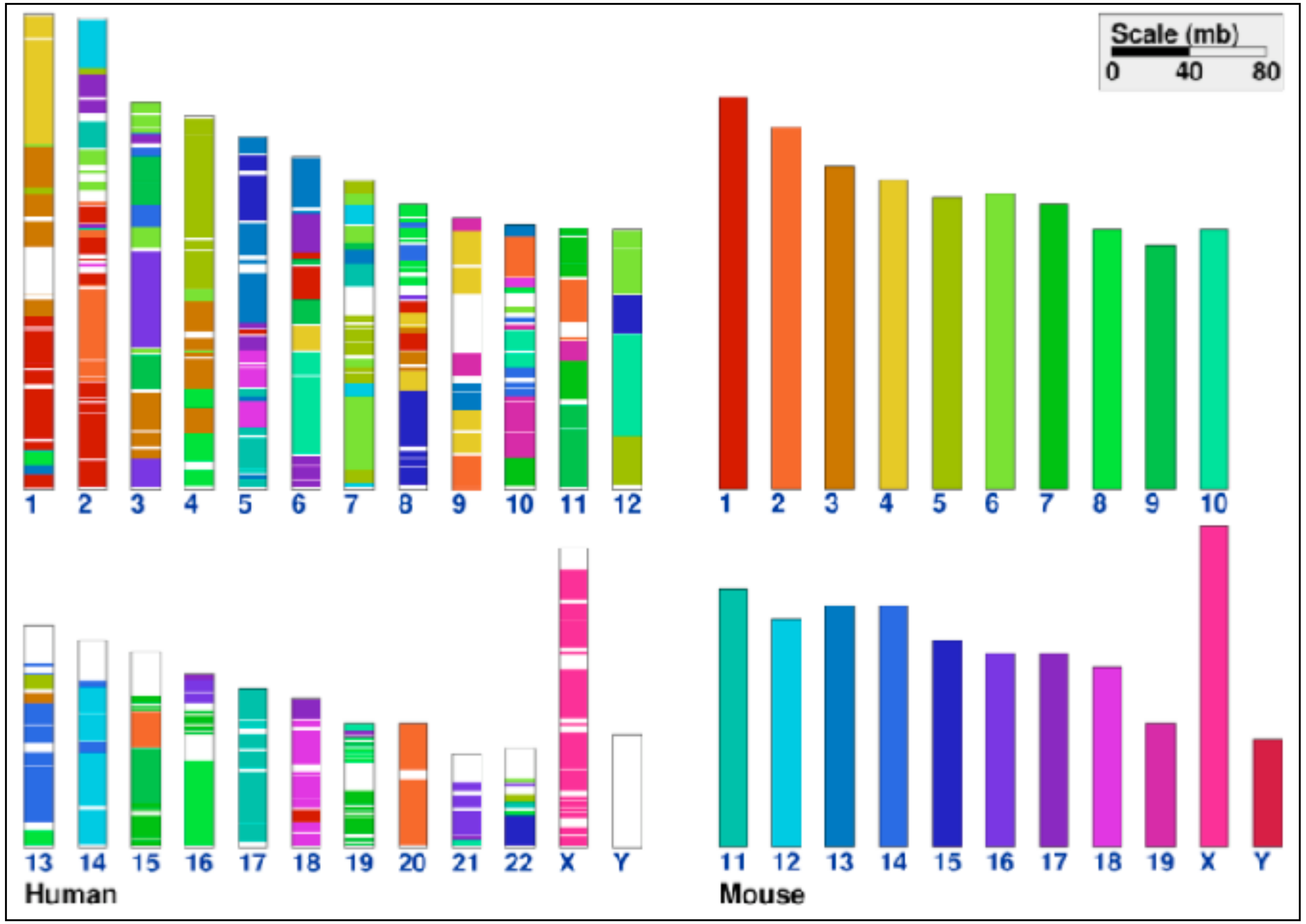
Luminance information

Color information

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

Categorical color: Discriminability constraints

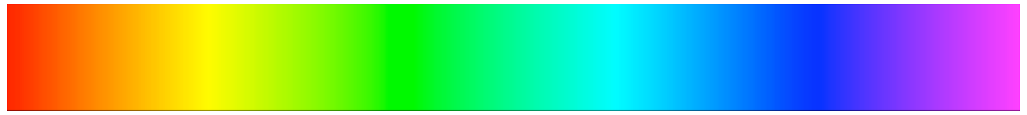
- noncontiguous small regions of color: only 6-12 bins



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

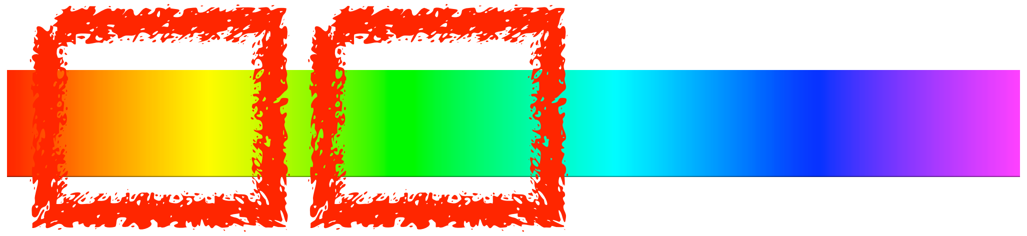
Ordered color: Rainbow is poor default

- problems
  - perceptually unordered
  - perceptually nonlinear



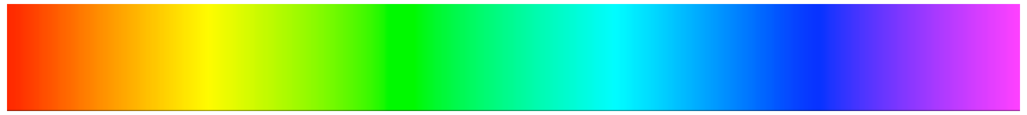
Ordered color: Rainbow is poor default

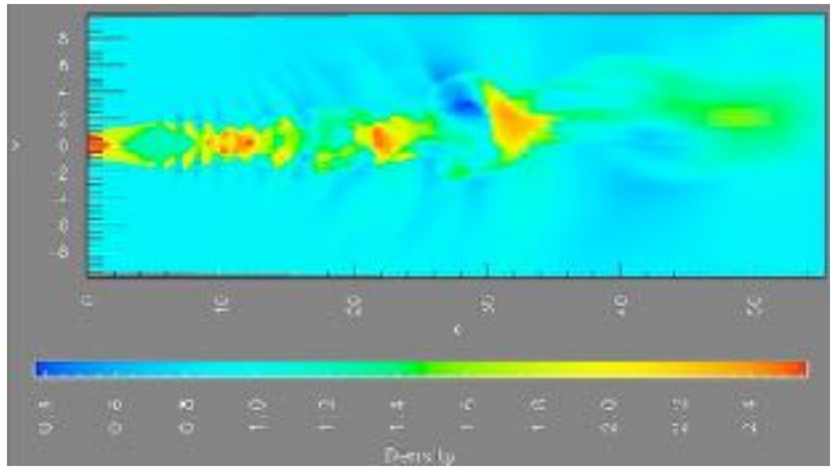
- problems
  - perceptually unordered
  - perceptually nonlinear



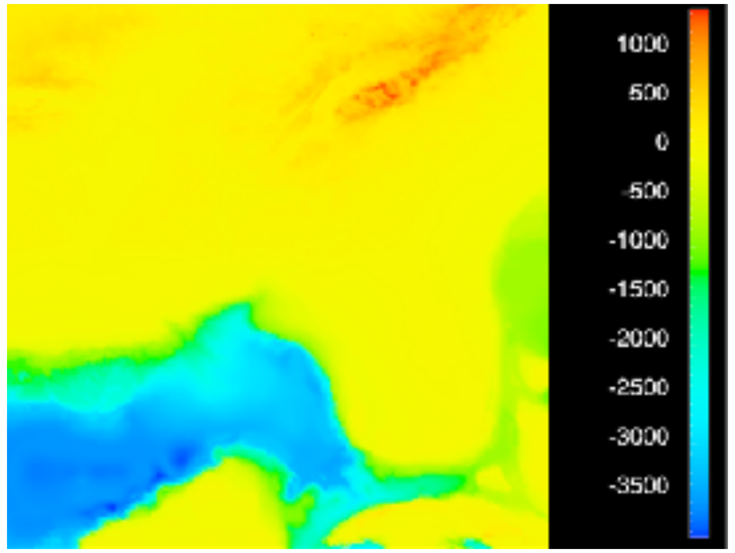
Ordered color: Rainbow is poor default

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





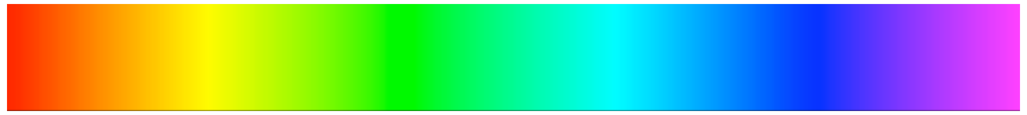
[A Rule-based Tool for Assisting Colormap Selection. Bergman,. Rogowitz, and. Treinish. Proc. IEEE Visualization (Vis), pp. 118–125, 1995.]

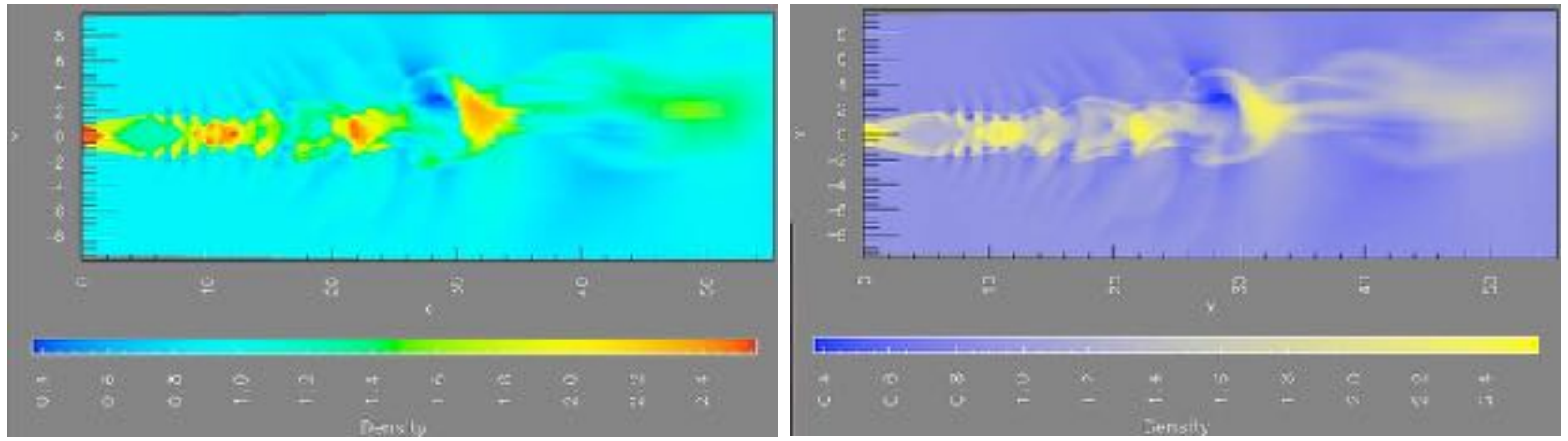


[Why Should Engineers Be Worried About Color? Treinish and Rogowitz 1998. http://www.research.ibm.com/people/l/lloydt/color/color.HTM]

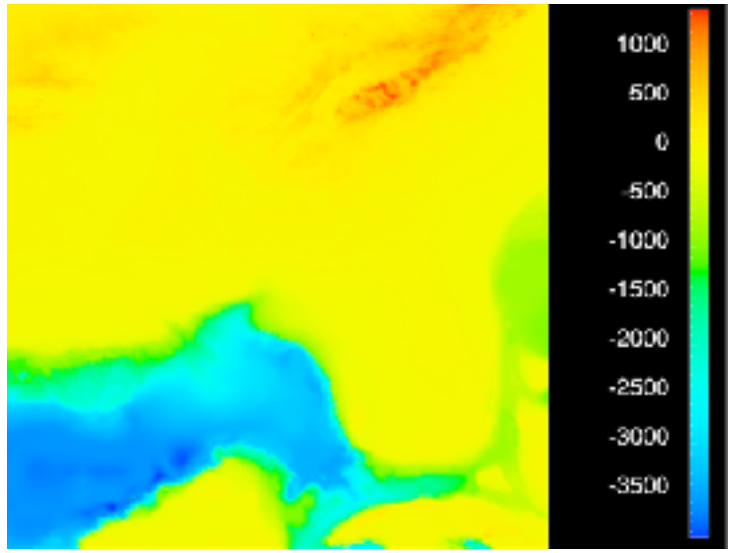
Ordered color: Rainbow is poor default

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





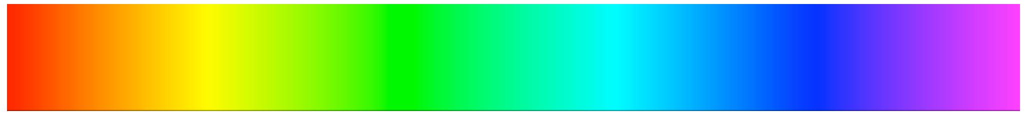
[A Rule-based Tool for Assisting Colormap Selection. Bergman,. Rogowitz, and. Treinish. Proc. IEEE Visualization (Vis), pp. 118–125, 1995.]

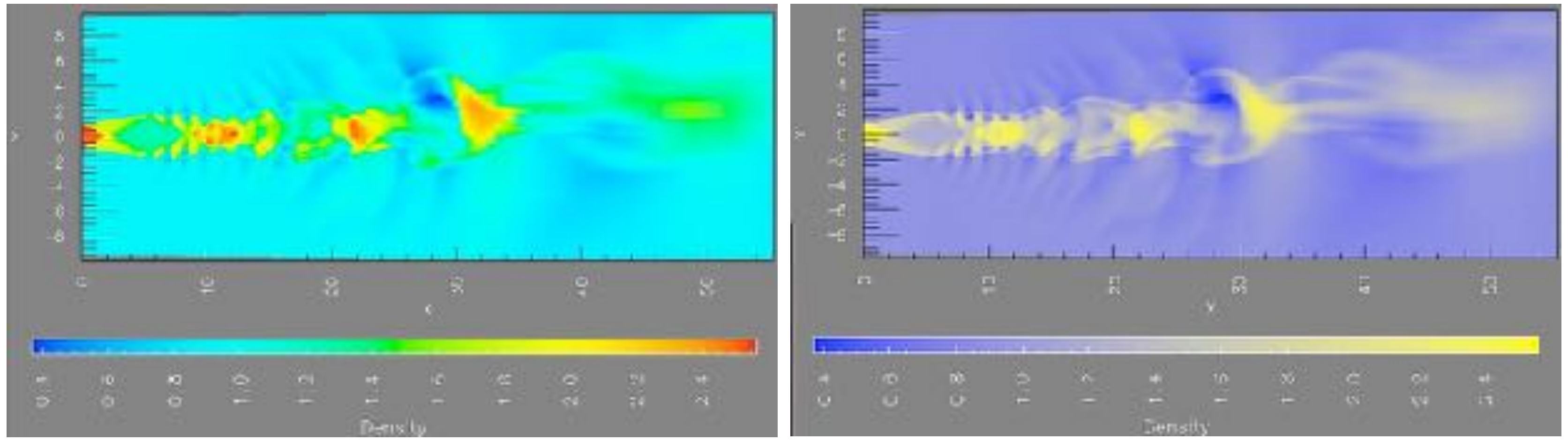


[Why Should Engineers Be Worried About Color? Treinish and Rogowitz 1998. http://www.research.ibm.com/people/l/lloydt/color/color.HTM]

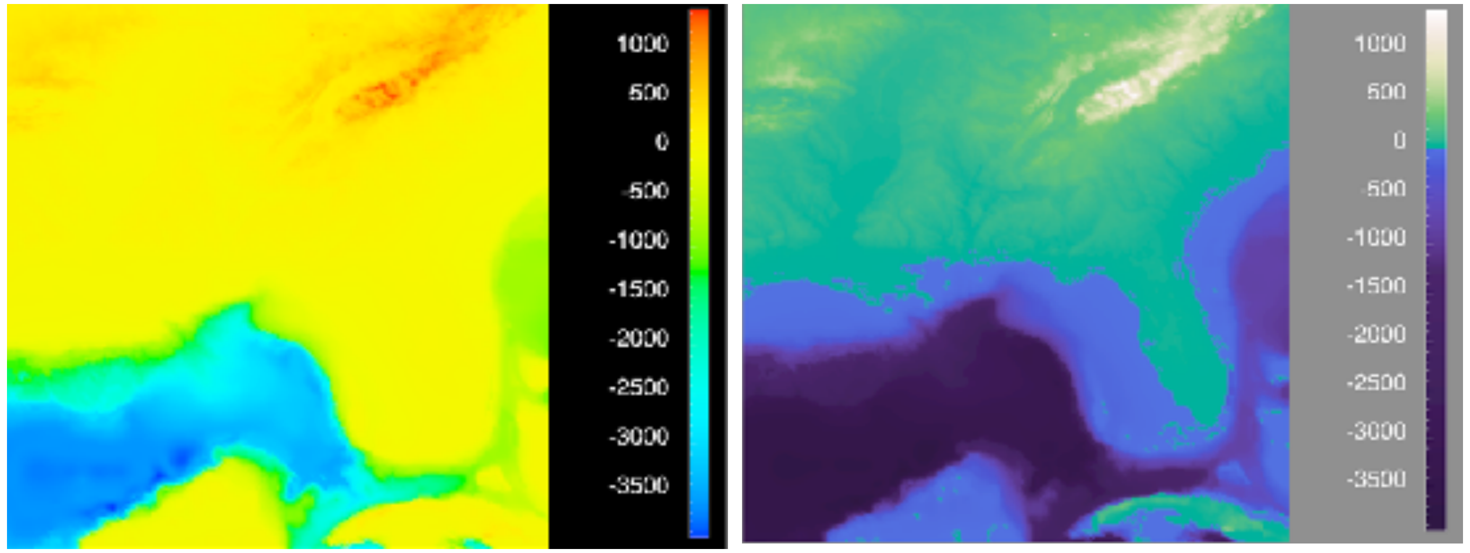
Ordered color: Rainbow is poor default

- 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]





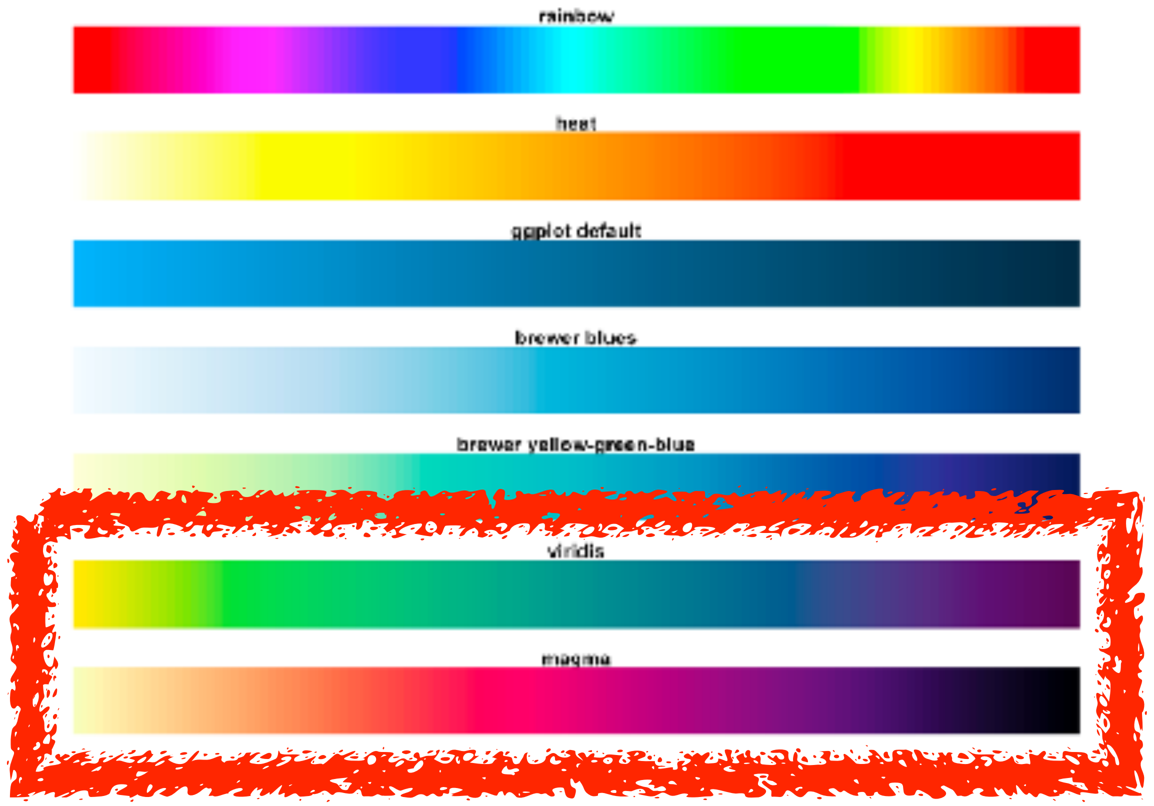
[A Rule-based Tool for Assisting Colormap Selection. Bergman,. Rogowitz, and. Treinish. Proc. IEEE Visualization (Vis), pp. 118–125, 1995.]

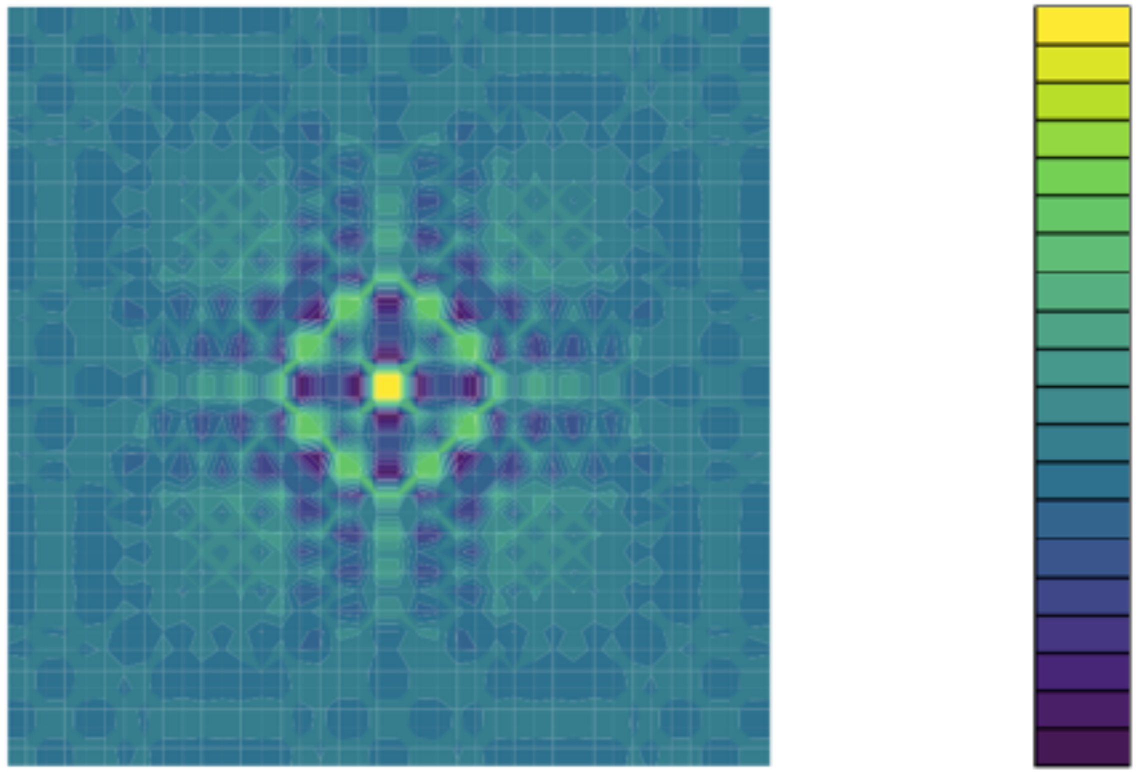


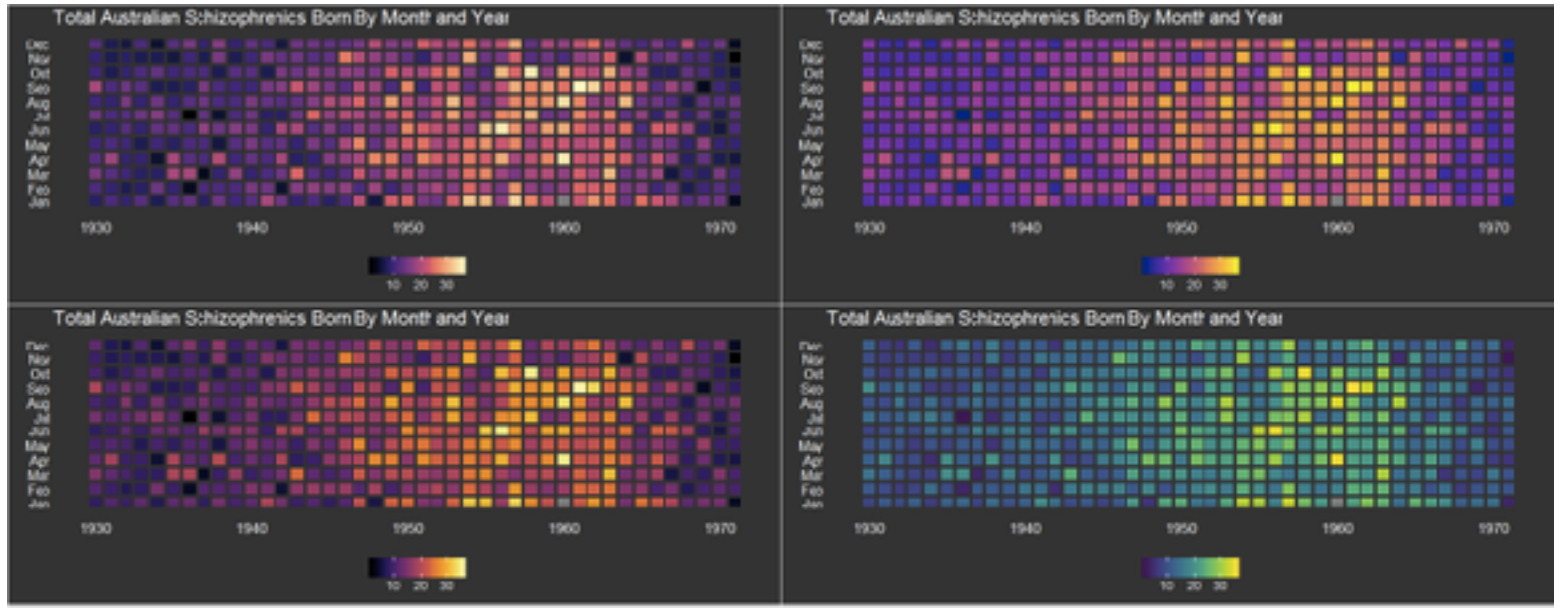
[Why Should Engineers Be Worried About Color? Treinish and Rogowitz 1998. http://www.research.ibm.com/people/l/lloydt/color/color.HTM]

Viridis / Magma

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



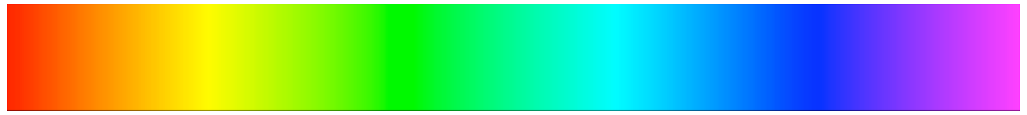


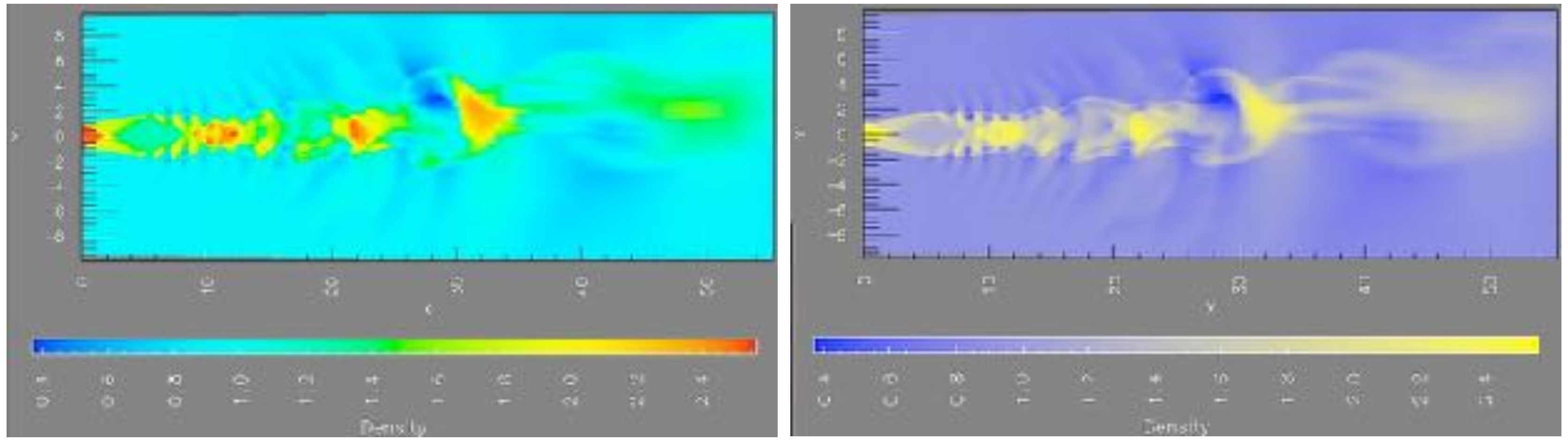


https://cran.r-project.org/web/packages/viridis/vignettes/intro-to-viridis.html

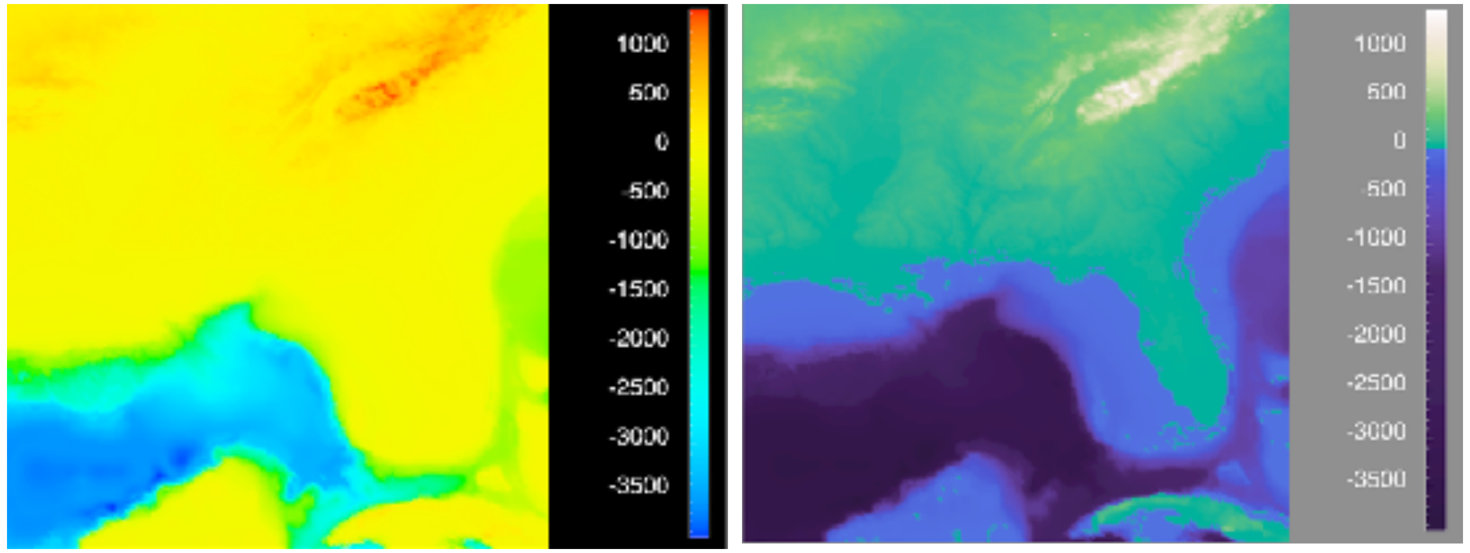
Ordered color: Rainbow is poor default

- 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!

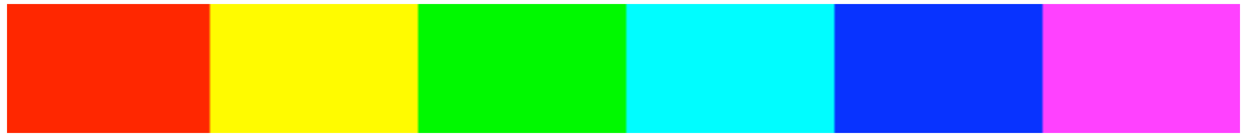




[A Rule-based Tool for Assisting Colormap Selection. Bergman,. Rogowitz, and. Treinish. Proc. IEEE Visualization (Vis), pp. 118–125, 1995.]



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



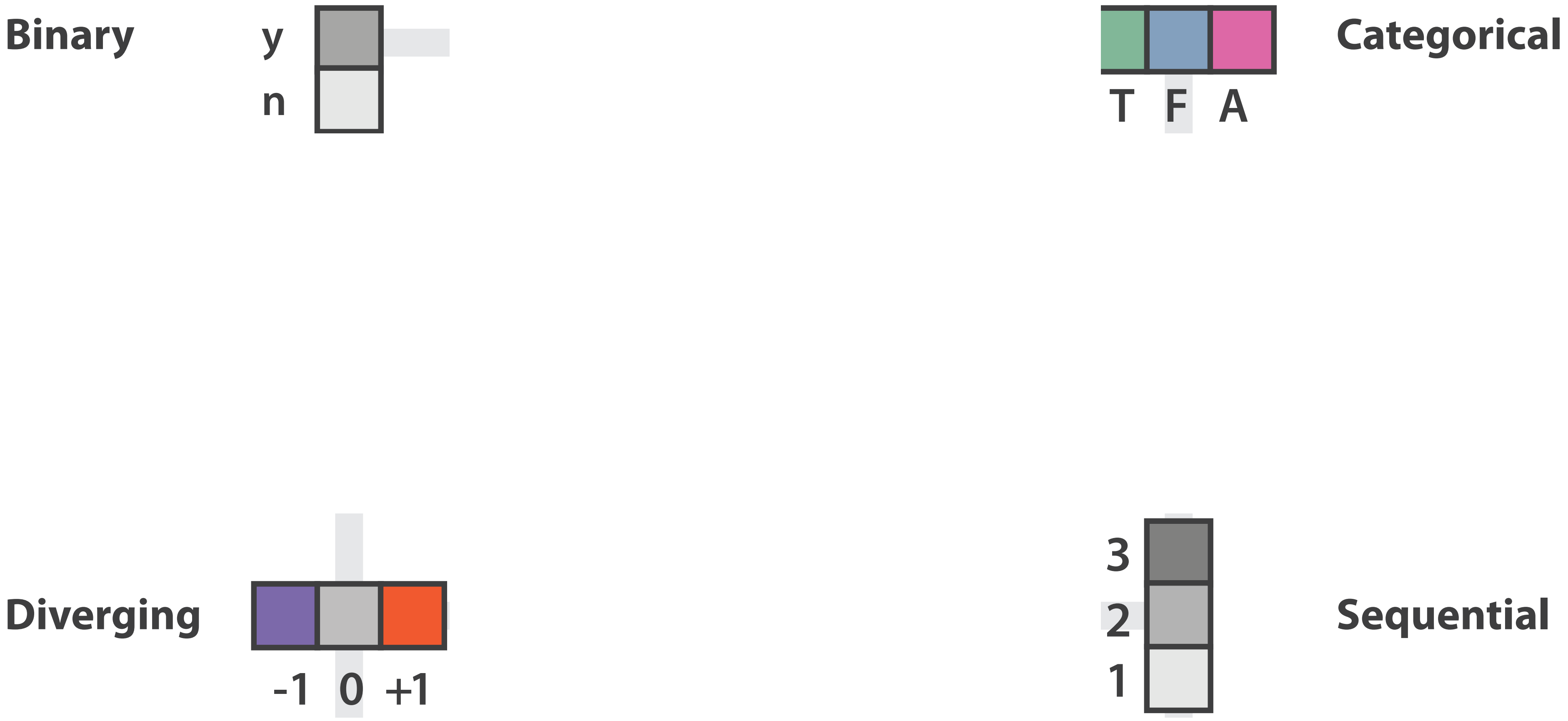
[Transfer Functions in Direct Volume Rendering: Design, Interface, Interaction. Kindlmann. SIGGRAPH 2002 Course Notes]

Colormaps

- ➔ Categorical

  🟨🟧🟩🟦

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



Binary

y

n

Categorical

T F A

Diverging

-1 0 +1

3

2

1

Sequential

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

Colormaps

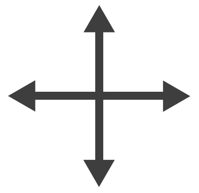
- → Categorical

  🟨🟧🟩🟦

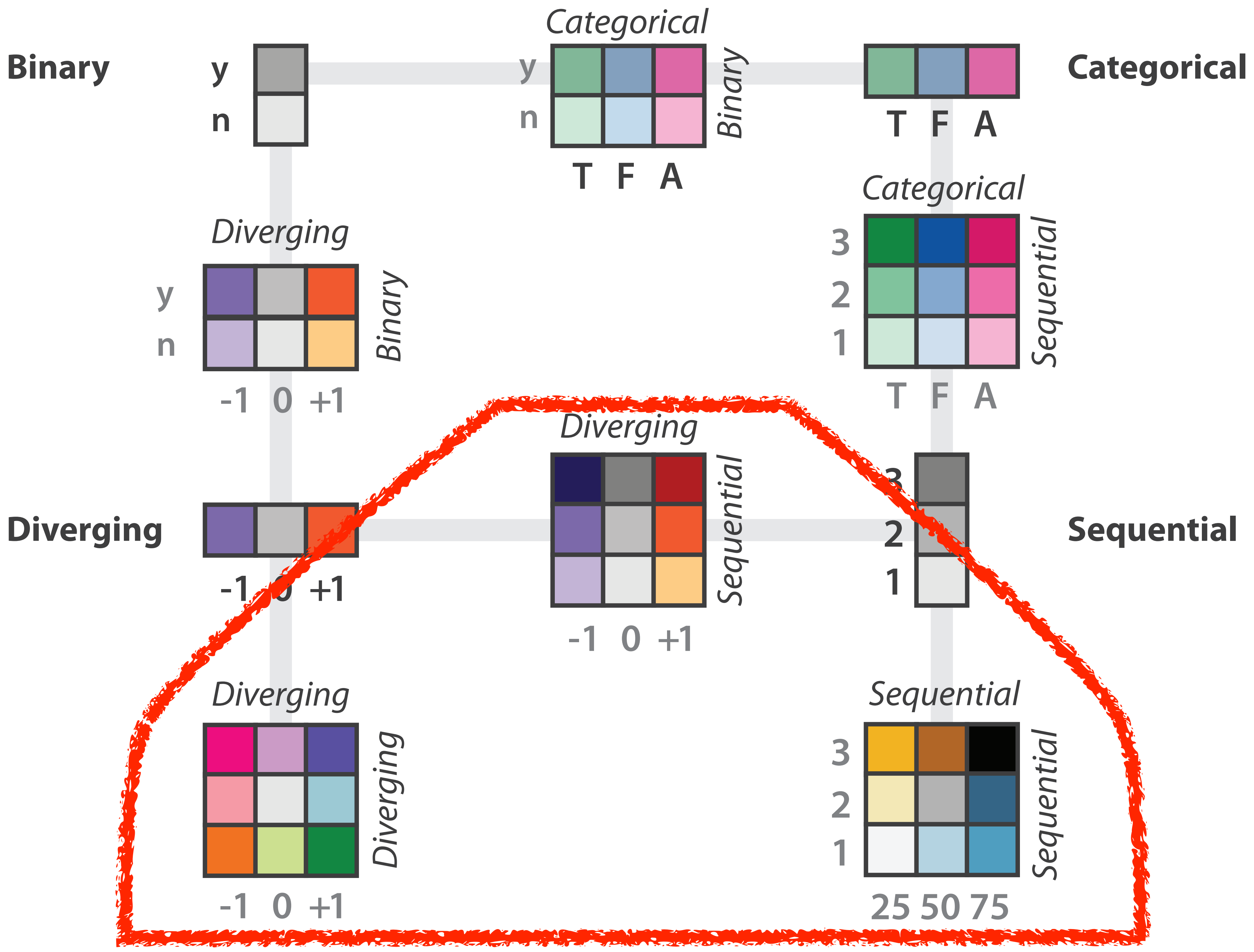
- → Ordered
  - → *Sequential*

  - → *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]

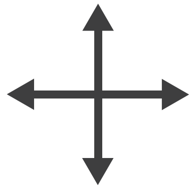
Colormaps

- ➔ Categorical

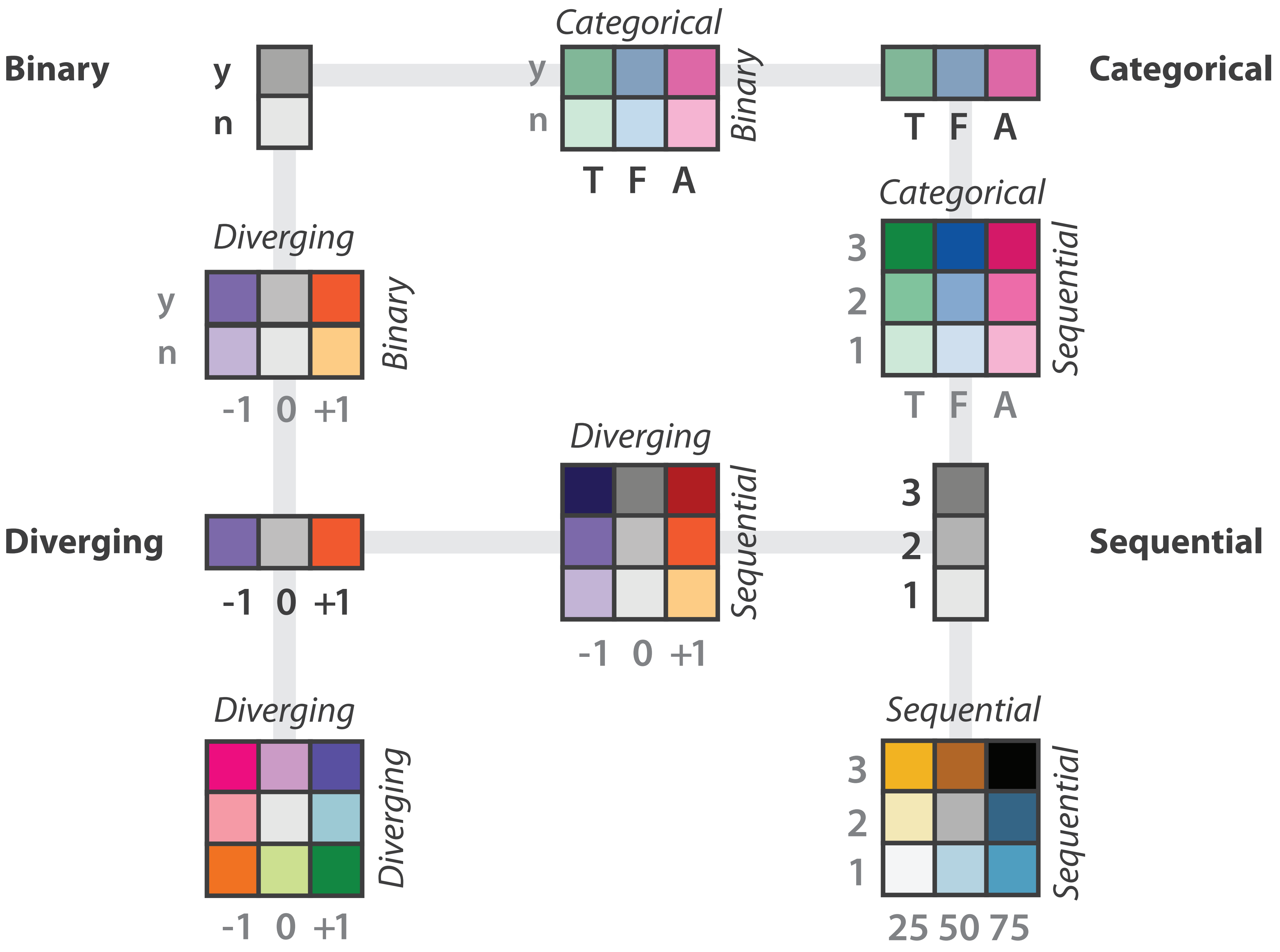
  🟨🟧🟩🟦

- ➔ 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

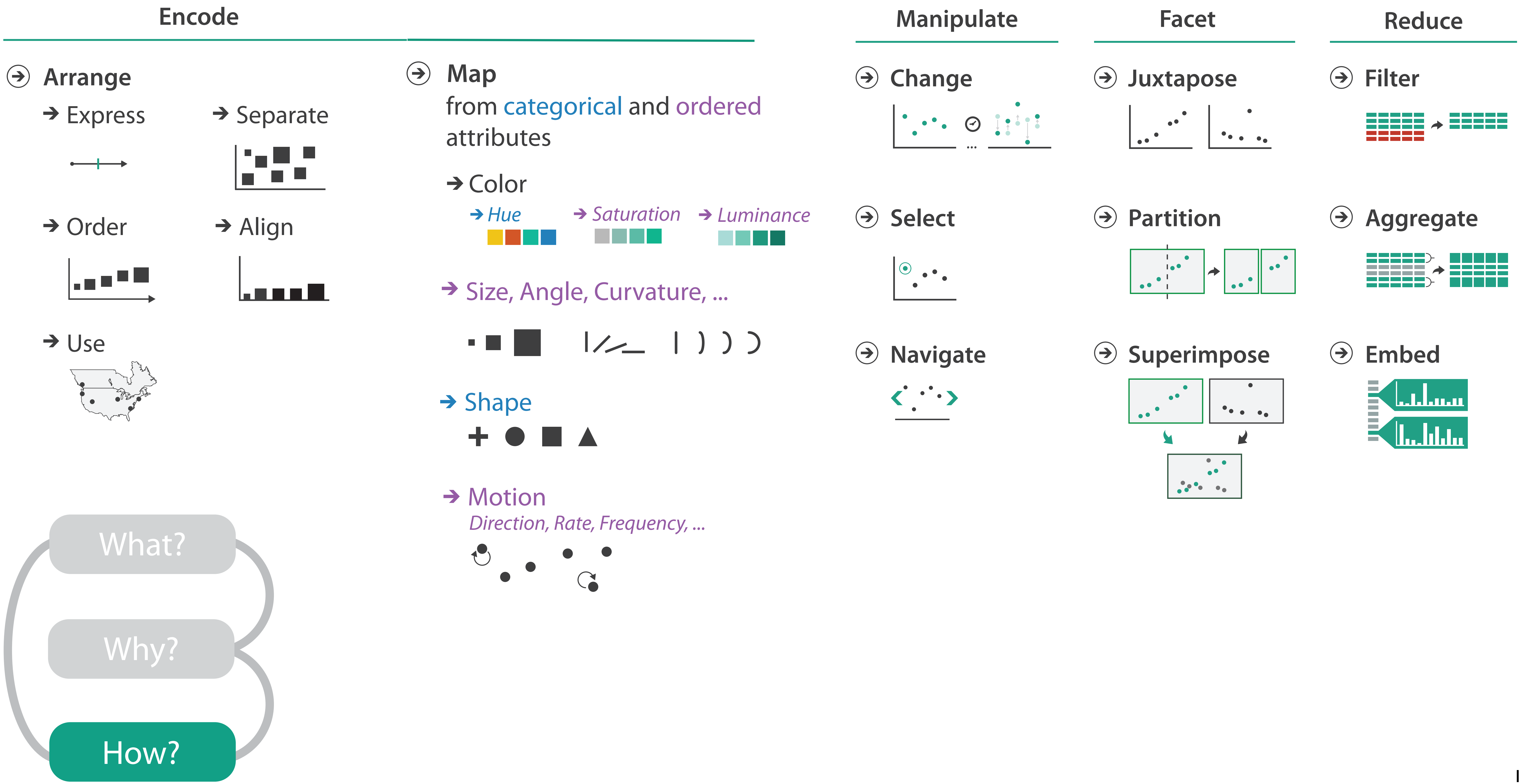
- Session 1
  - Analysis: What, Why, How
  - Marks and Channels
  - Arrange Tables
  - Arrange Spatial Data

- Session 2
  - Arrange Networks and Trees
  - Map Color and Other Channels
  - Manipulate: Change, Select, Navigate
  - Facet: Juxtapose, Partition, Superimpose
  - Reduce: Filter, Aggregate

@tamaramunzner

http://www.cs.ubc.ca/~tmm/talks.html#halfdaycourse20

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

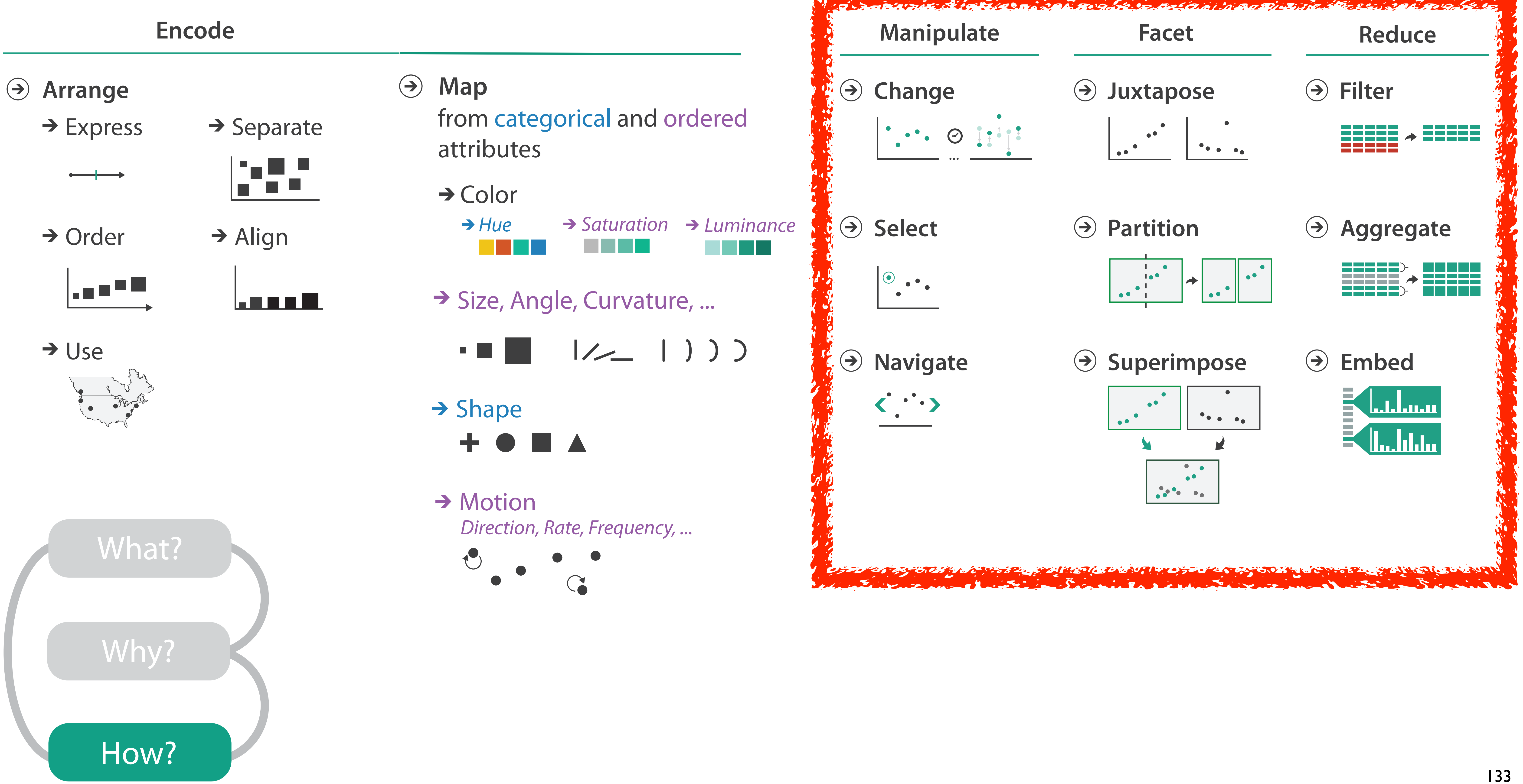
Reduce

Filter

Aggregate

Embed

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

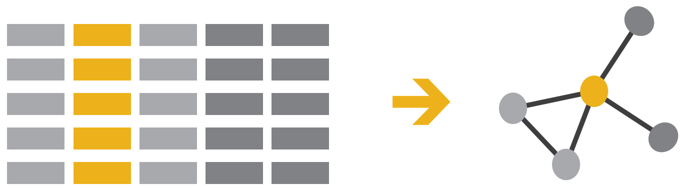
What?

Why?

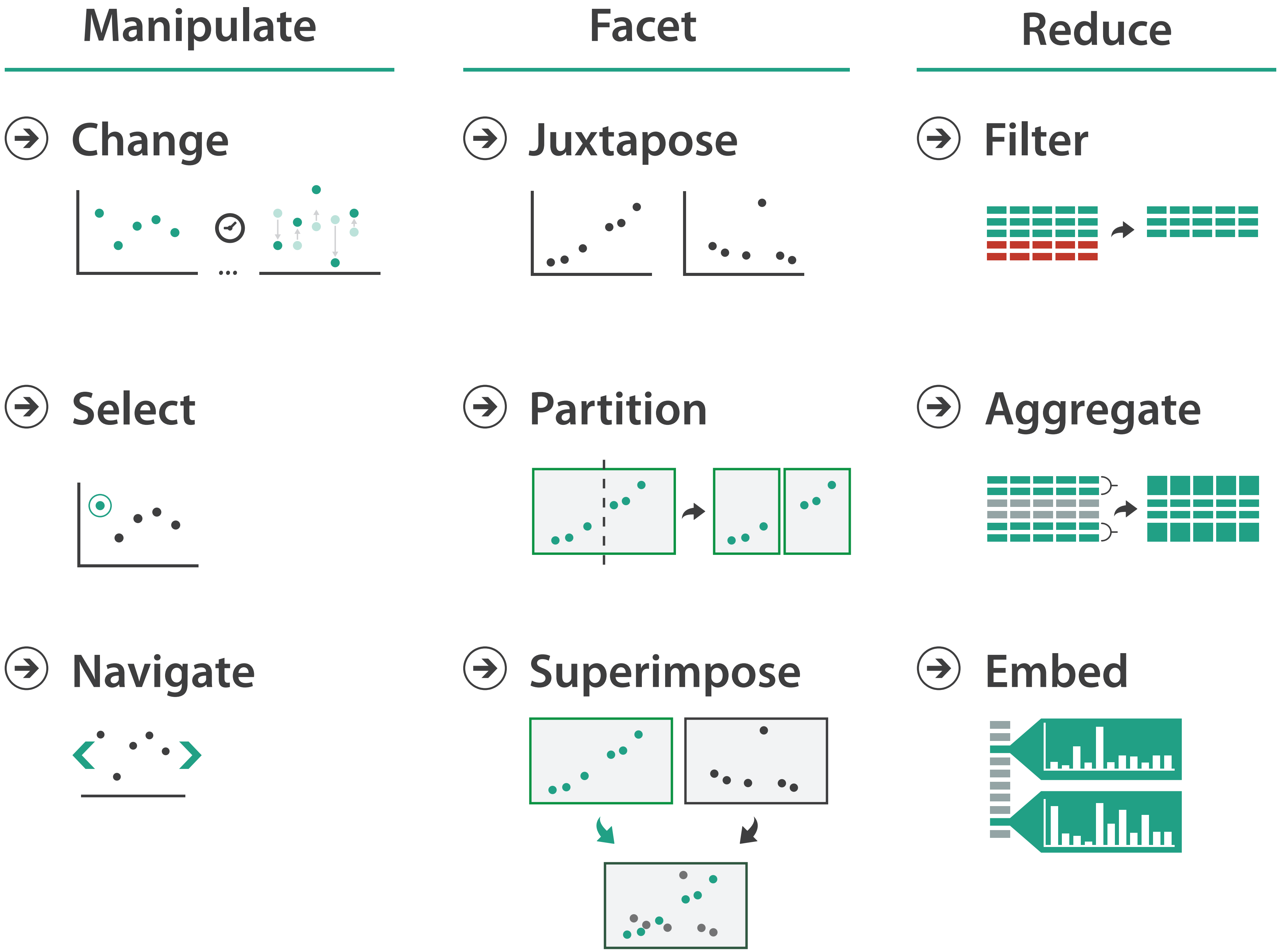
How?

How to handle complexity: 1 previous strategy + 3 more

→ *Derive*



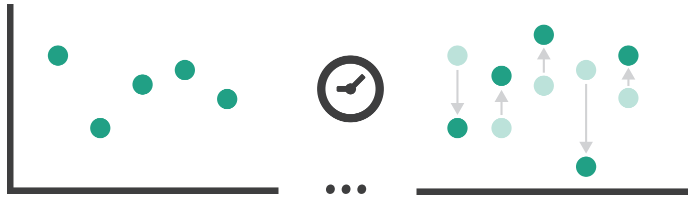
- derive new data to show within view
- change view over time
- facet across multiple views
- reduce items/attributes within single view



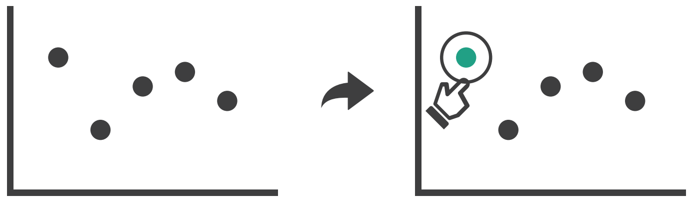
Manipulate	Facet	Reduce
→ Change	→ Juxtapose	→ Filter
→ Select	→ Partition	→ Aggregate
→ Navigate	→ Superimpose	→ Embed

Manipulate

➔ Change over Time



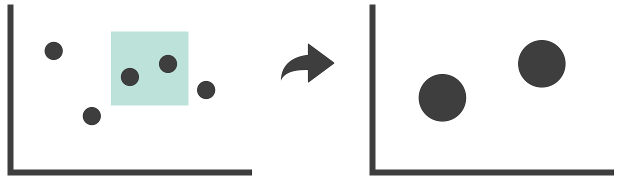
➔ Select



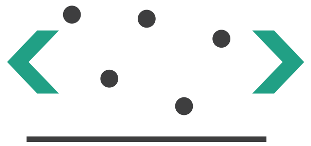
➔ Navigate

➔ Item Reduction

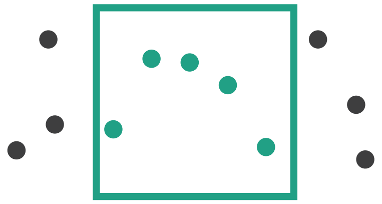
➔ *Zoom*
Geometric or *Semantic*



➔ *Pan/Translate*

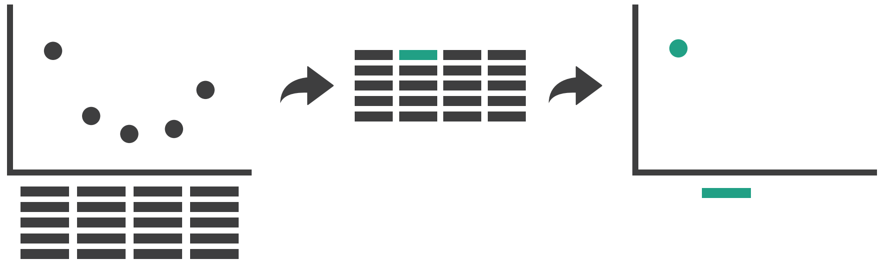


➔ *Constrained*

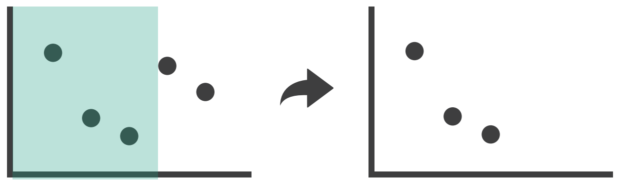


➔ Attribute Reduction

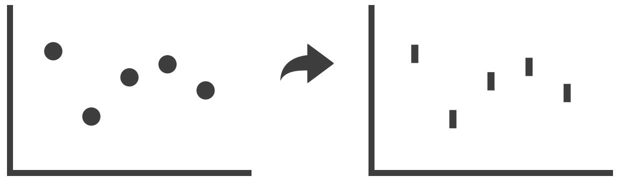
➔ *Slice*



➔ *Cut*

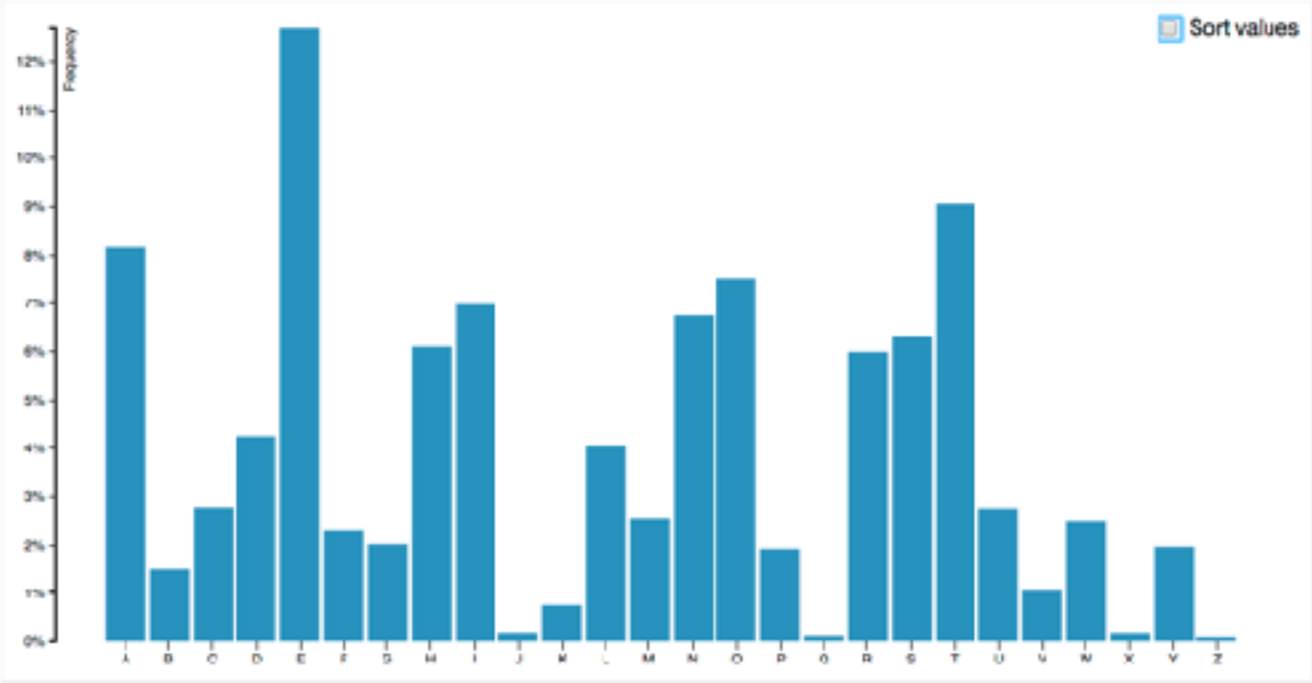


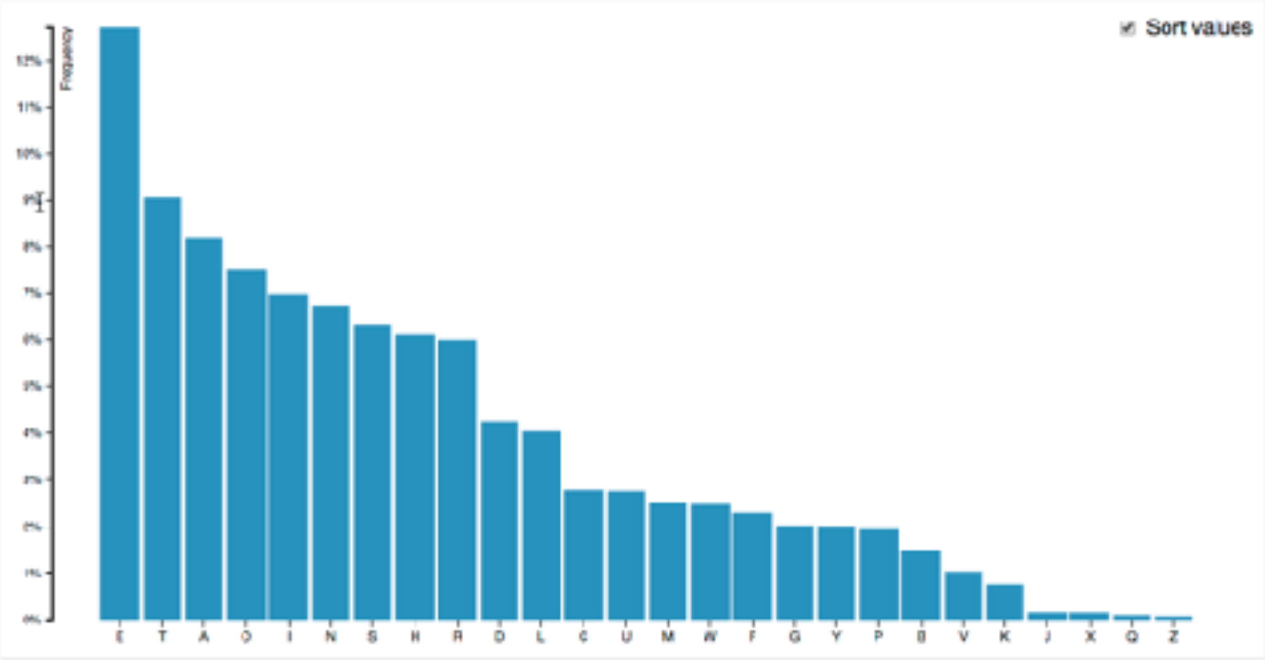
➔ *Project*



Idiom: **Change order/arrangement**

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



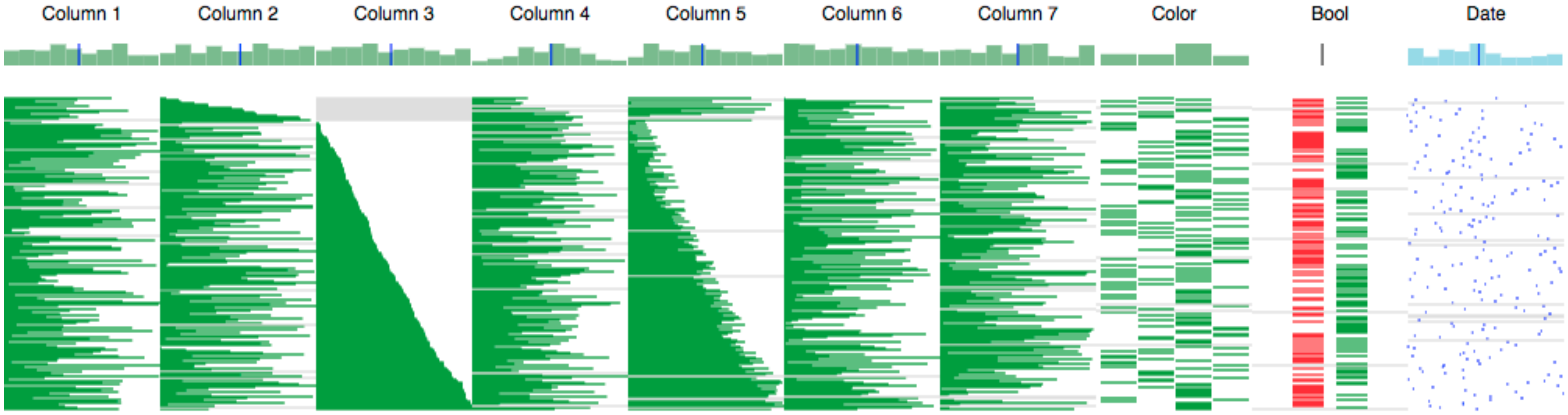


[Sortable Bar Chart](https://bl.ocks.org/mbostock/3885705)

Idiom: **Change order**

System: **DataStripes**

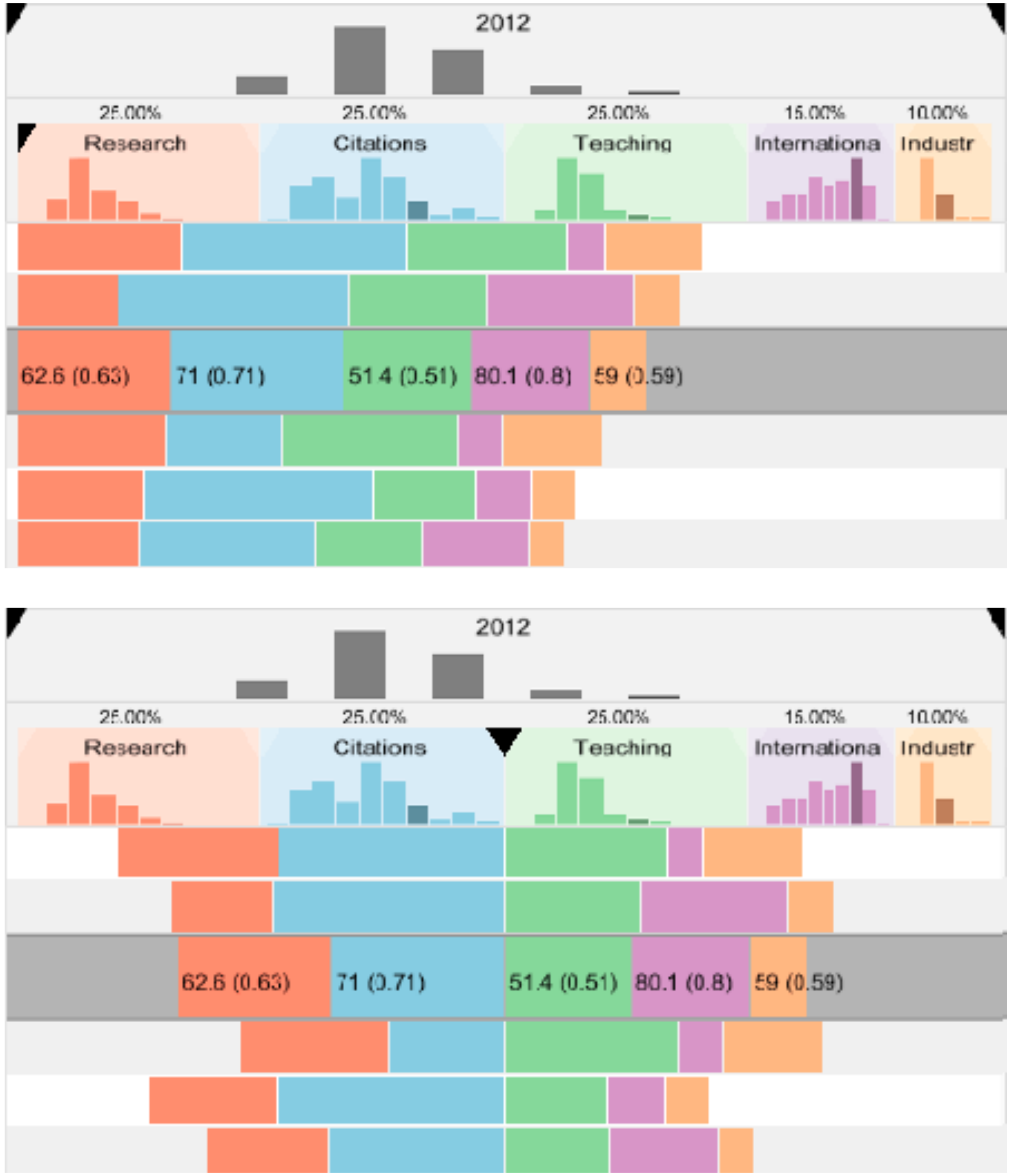
- what: table with many attributes
- how: data-driven reordering by selecting column
- why: find correlations between attributes



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

Idiom: **Change align**

- stacked bars
  - easy to compare
    - first segment
    - total bar
- align to different segment
  - supports flexible comparison



System: **LineUp**

[LineUp:Visual Analysis of Multi-Attribute Rankings.Gratzl, Lex, Gehlenborg, Pfister, and Streit. IEEE Trans.Visualization and Computer Graphics (Proc. InfoVis 2013) 19:12 (2013), 2277–2286.]

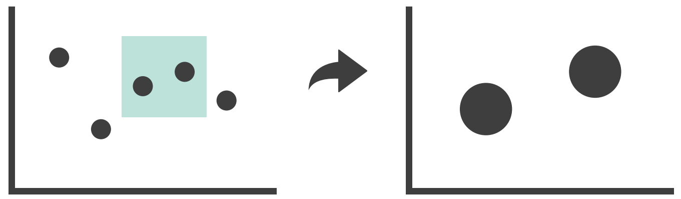
Navigate: Changing item visibility

- 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

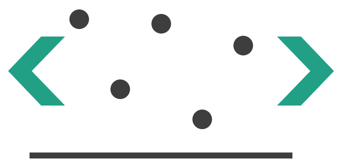
➔ **Navigate**

➔ Item Reduction

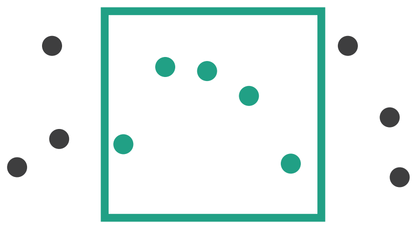
➔ *Zoom*
Geometric or *Semantic*



➔ *Pan/Translate*



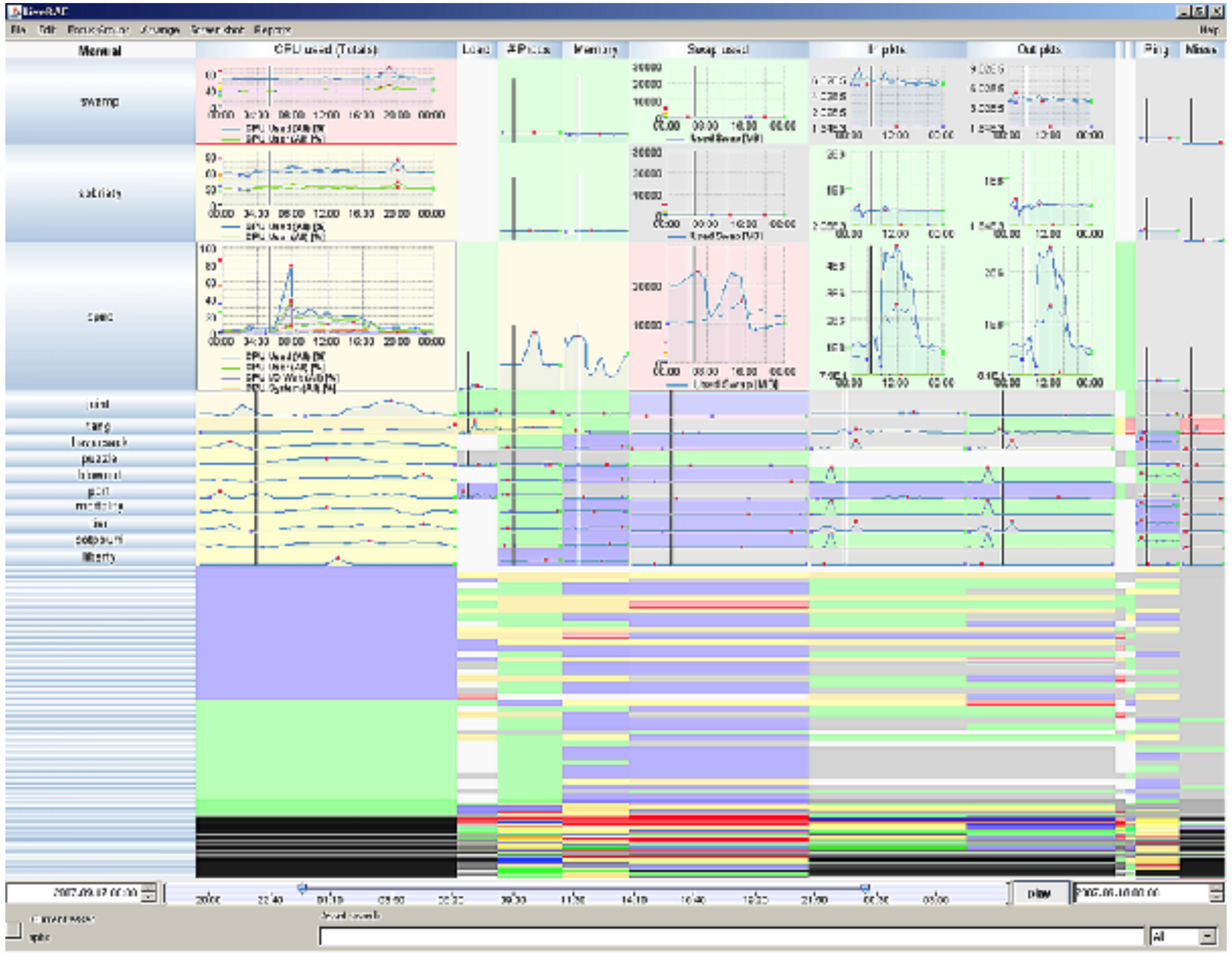
➔ *Constrained*



Idiom: **Semantic zooming**

System: **LiveRAC**

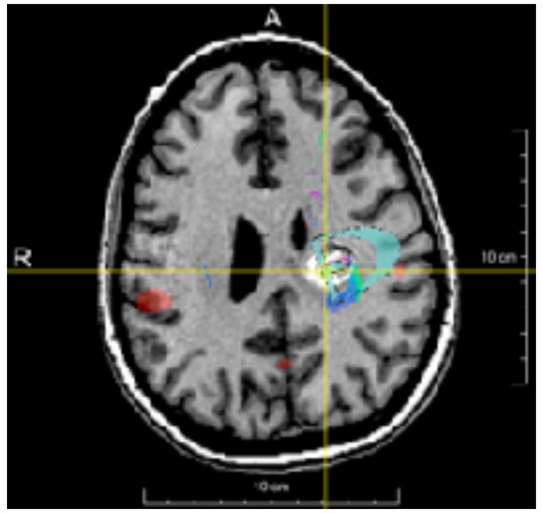
- visual encoding change
  - colored box
  - sparkline
  - simple line chart
  - full chart: axes and tickmarks

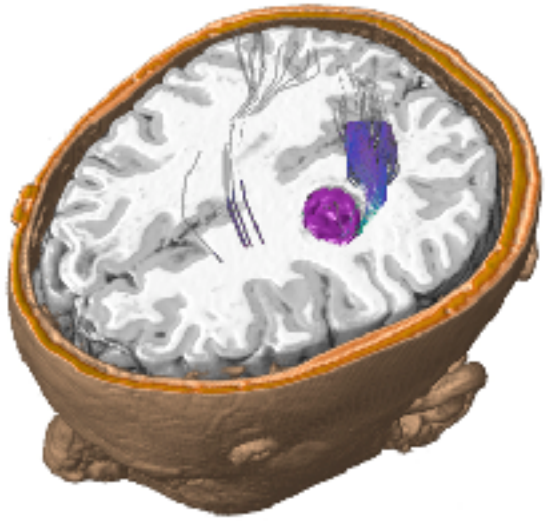


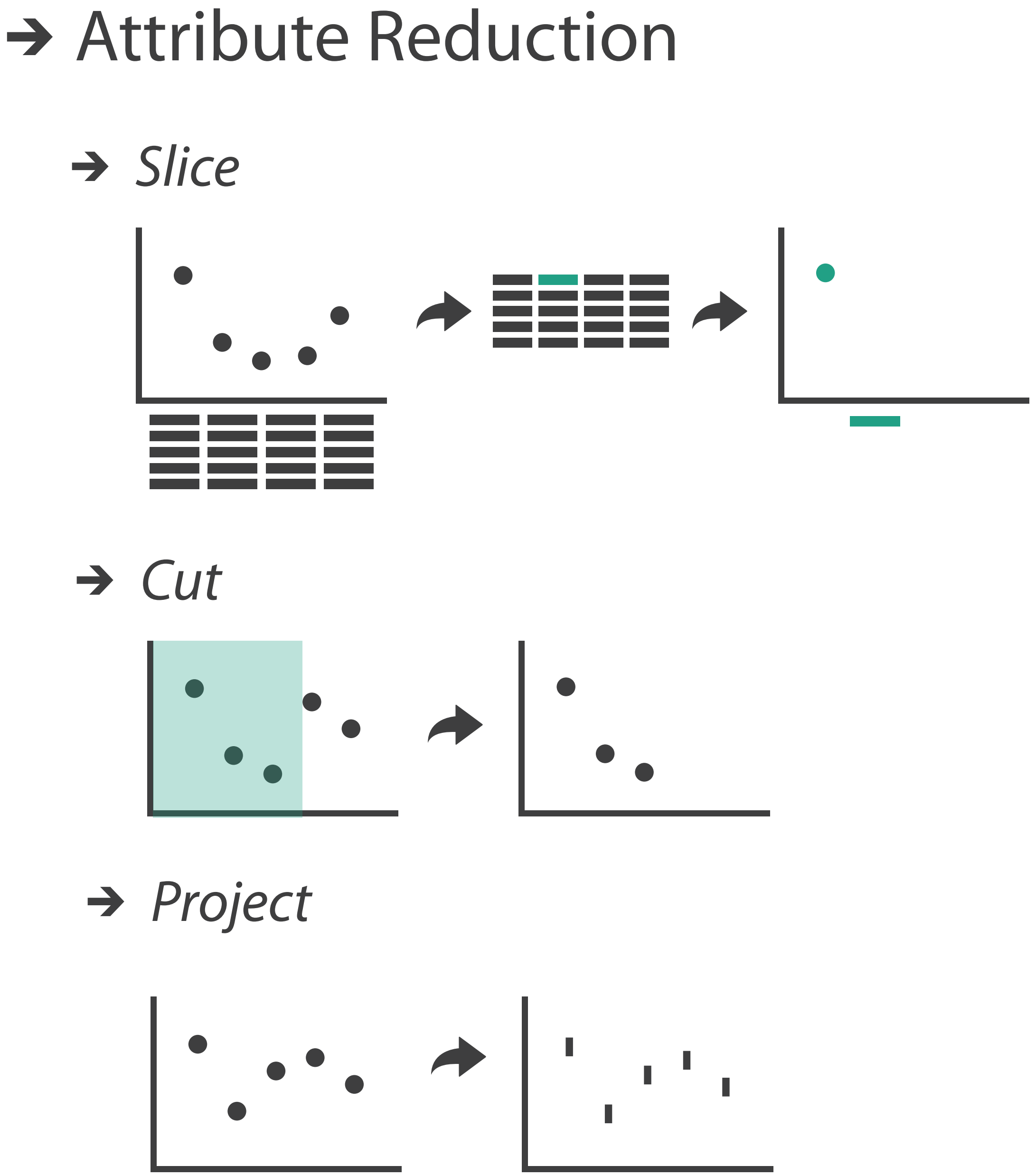
[LiveRAC - Interactive Visual Exploration of System Management Time-Series Data. McLachlan, Munzner, Koutsofios, and North. Proc. ACM Conf. Human Factors in Computing Systems (CHI), pp. 1483–1492, 2008.]

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.]

Further reading

- Visualization Analysis and Design. Munzner. AK Peters Visualization Series, CRC Press, 2014.
  - *Chap 11: Manipulate View*
- *Animated Transitions in Statistical Data Graphics*. Heer and Robertson. IEEE Trans. on Visualization and Computer Graphics (Proc. InfoVis 07) 13:6 (2007), 1240– 1247.
- *Selection: 524,288 Ways to Say "This is Interesting"*. Wills. Proc. IEEE Symp. Information Visualization (InfoVis), pp. 54–61, 1996.
- *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.

Visualization Analysis & Design, Half-Day Tutorial

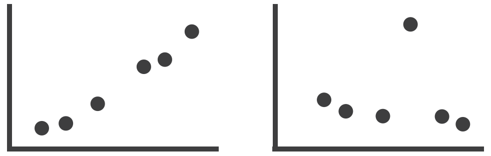
- Session 1
  - Analysis: What, Why, How
  - Marks and Channels
  - Arrange Tables
  - Arrange Spatial Data
- Session 2
  - Arrange Networks and Trees
  - Map Color and Other Channels
  - Manipulate: Change, Select, Navigate
  - Facet: Juxtapose, Partition, Superimpose
  - Reduce: Filter, Aggregate

@tamaramunzner

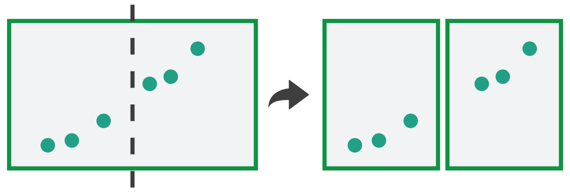
http://www.cs.ubc.ca/~tmm/talks.html#halfdaycourse20

Facet

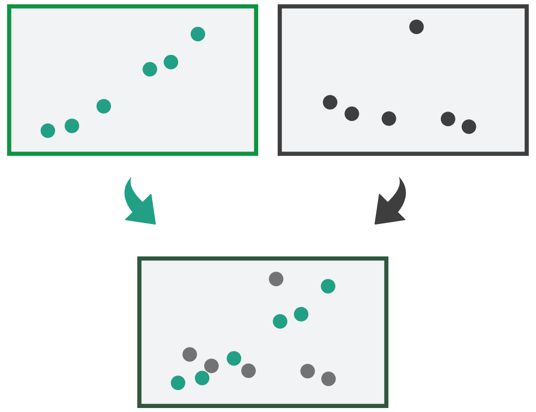
- Juxtapose



- Partition

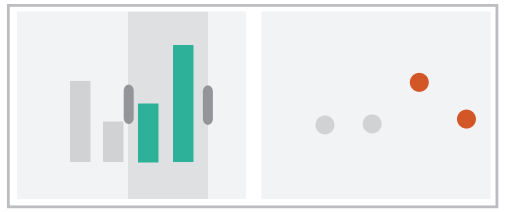


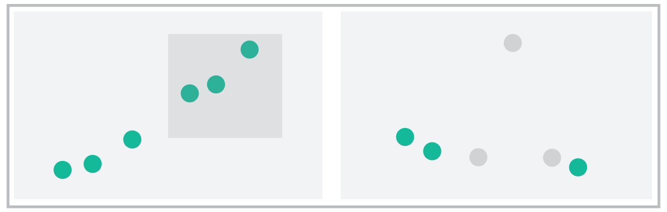
- Superimpose



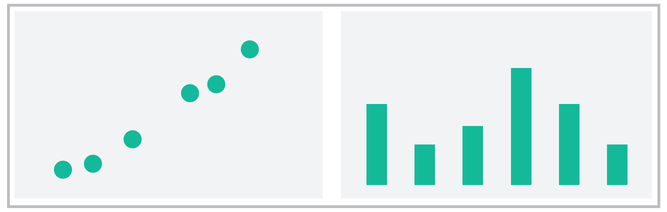
Juxtapose and coordinate views

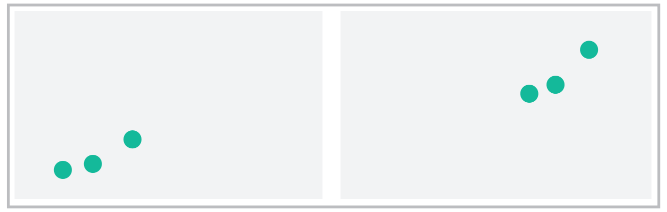
- Share Encoding: Same/Different
  - *Linked Highlighting*

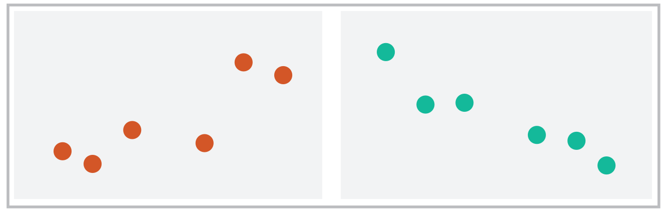




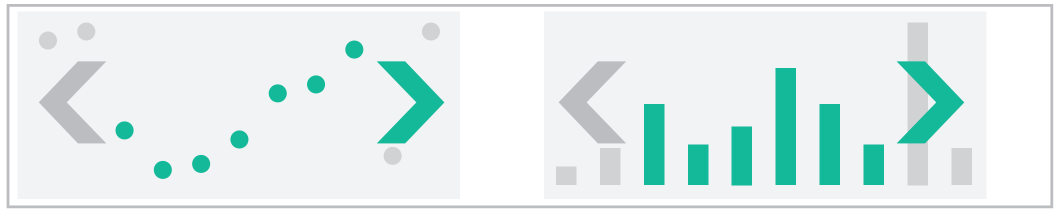
- Share Data: All/Subset/None







- Share Navigation

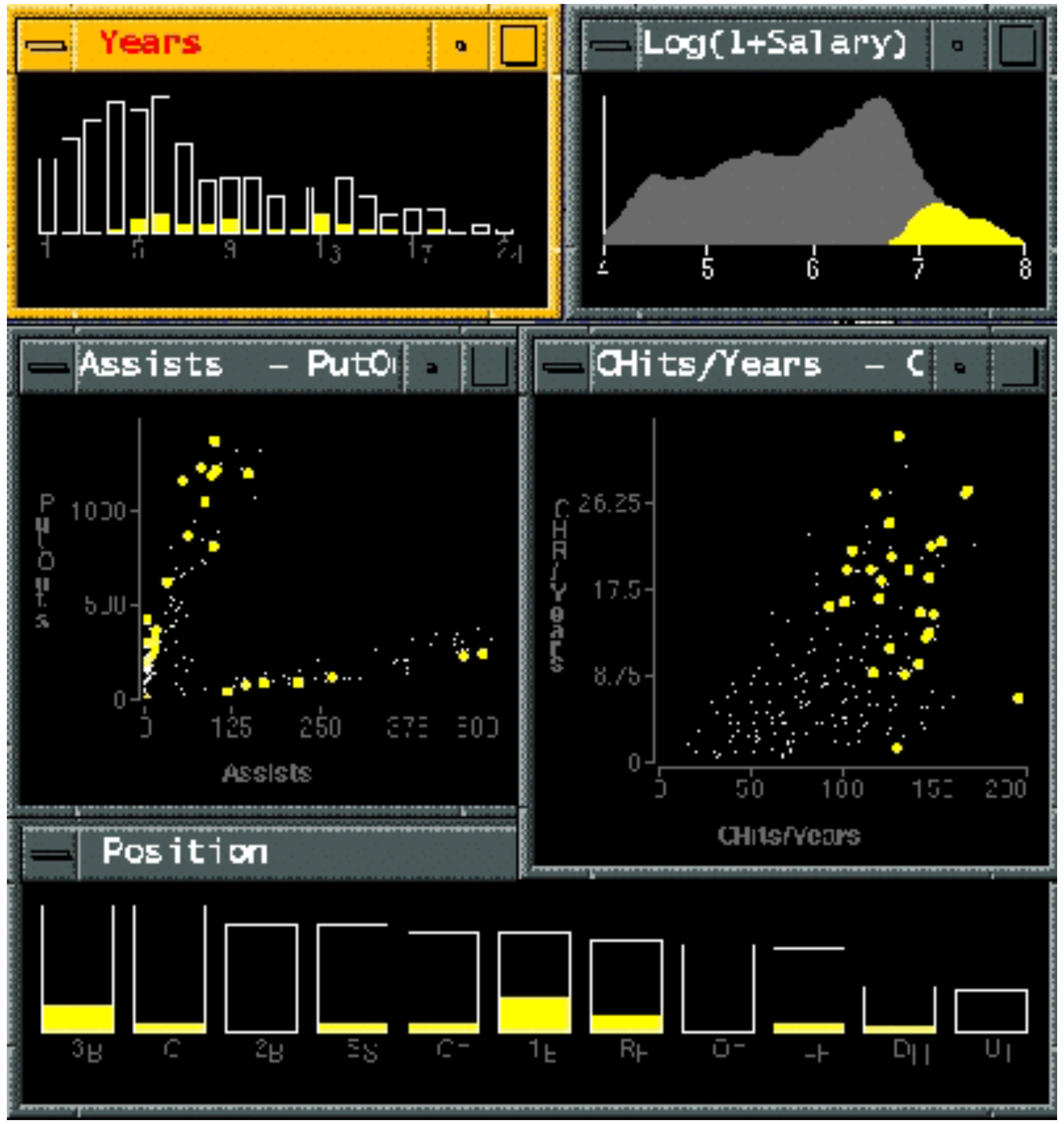


Idiom: **Linked highlighting**

System: **EDV**

- see how regions contiguous in one view are distributed within another
  - powerful and pervasive interaction idiom

- encoding: different
  - multiform
- data: all shared



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

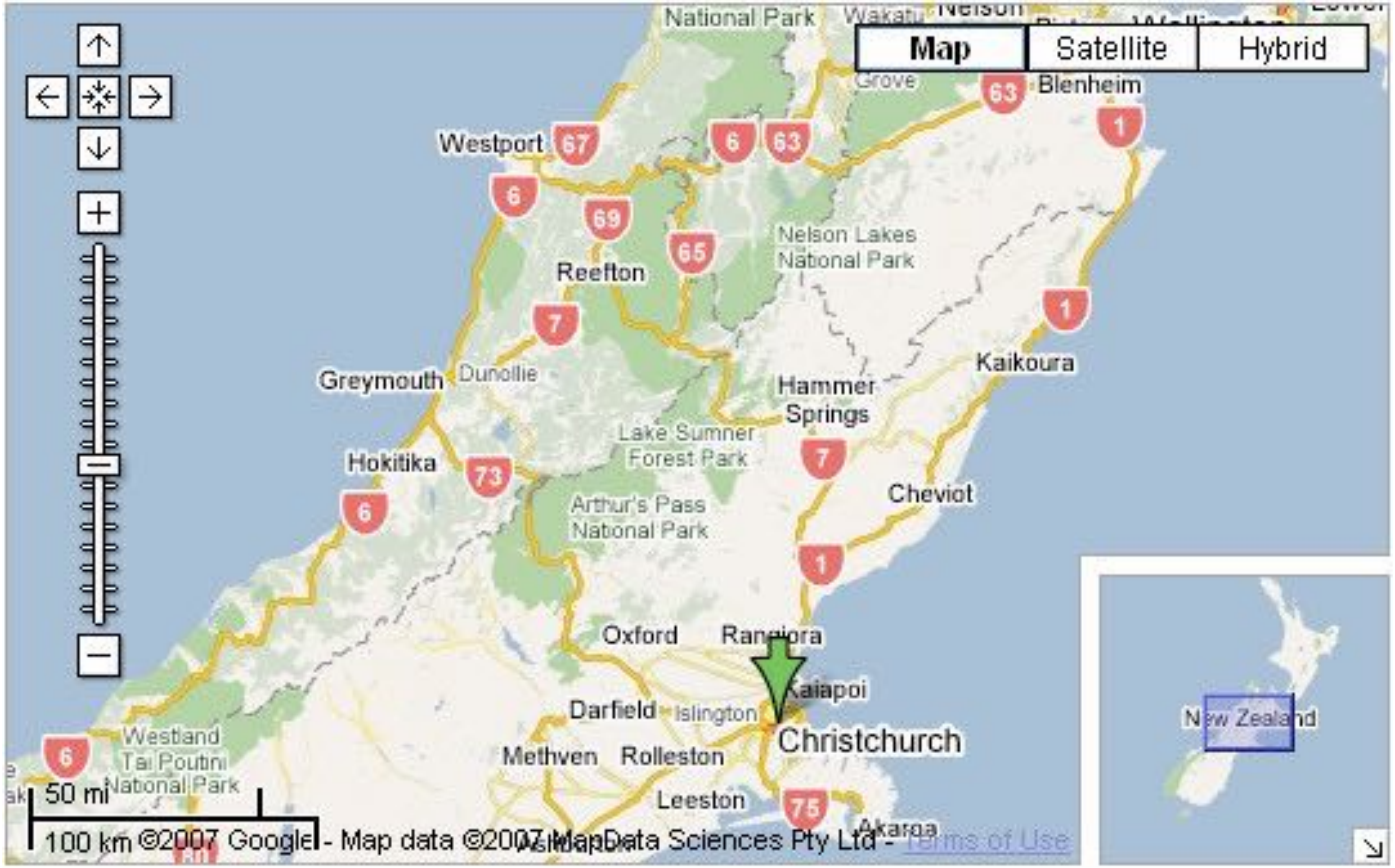
Idiom: **bird's-eye maps**

System: **Google Maps**

- encoding: same
- data: subset shared
- navigation: shared
  - bidirectional linking

- differences
  - viewpoint
  - (size)

- ***overview-detail***

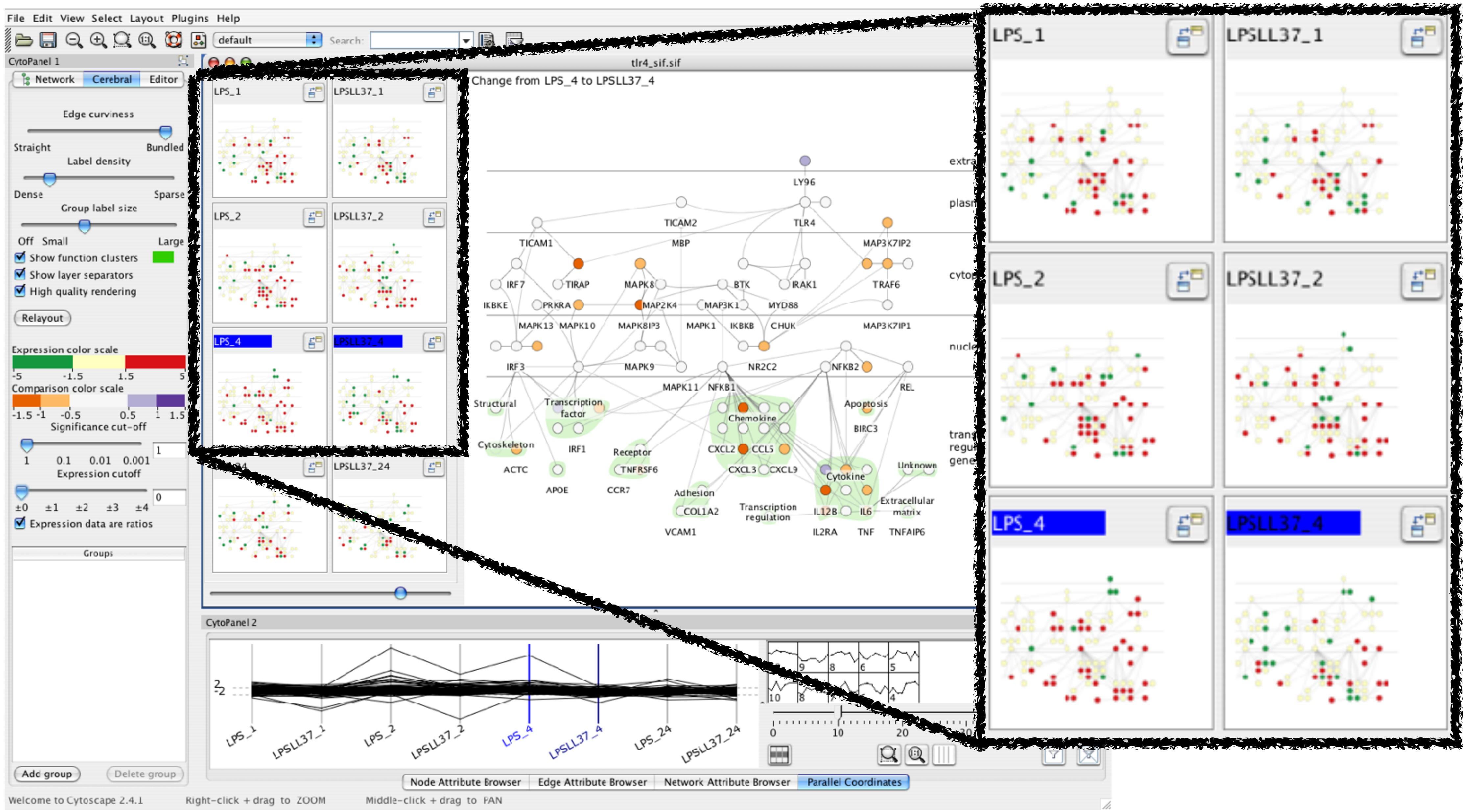


[A Review of Overview+Detail, Zooming, and Focus+Context Interfaces. Cockburn, Karlson, and Bederson. ACM Computing Surveys 41:1 (2008), 1–31.]

Idiom: **Small multiples**

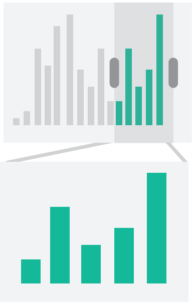
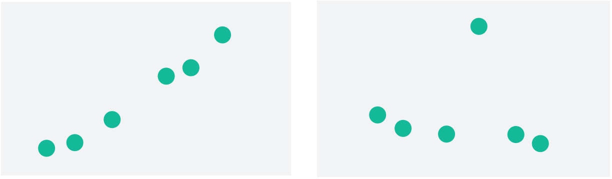
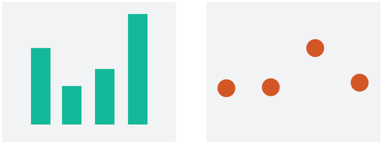
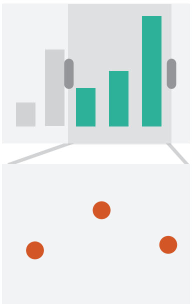
System: **Cerebral**

- encoding: same
- data:
  - different items: different condition keys, same gene keys
  - same attributes: expression values for node colors
  - (same network layout for nodes=genes)
- navigation: shared

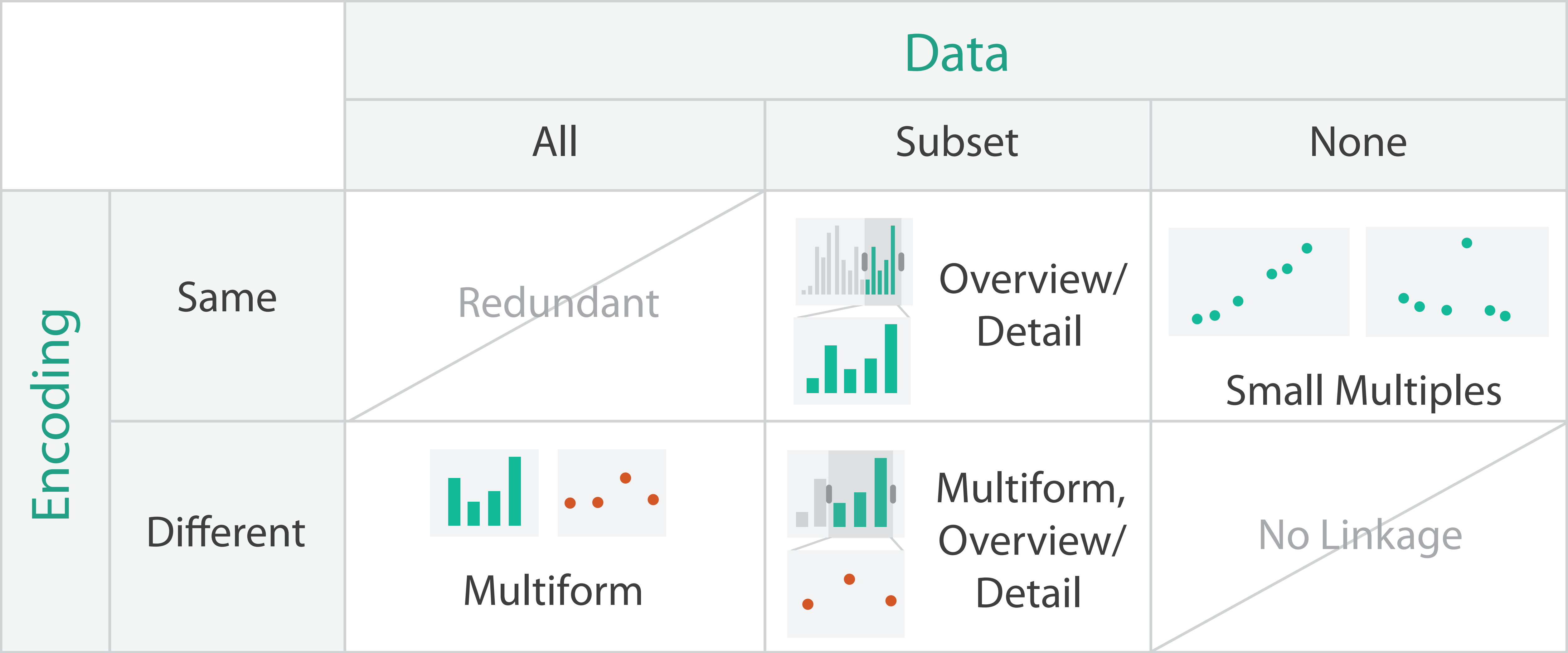


[Cerebral: Visualizing Multiple Experimental Conditions on a Graph with Biological Context. Barsky, Munzner, Gardy, and Kincaid. IEEE Trans. Visualization and Computer Graphics (Proc. InfoVis 2008) 14:6 (2008), 1253–1260.]

Coordinate views: Design choice interaction

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

Coordinate views: Design choice interaction

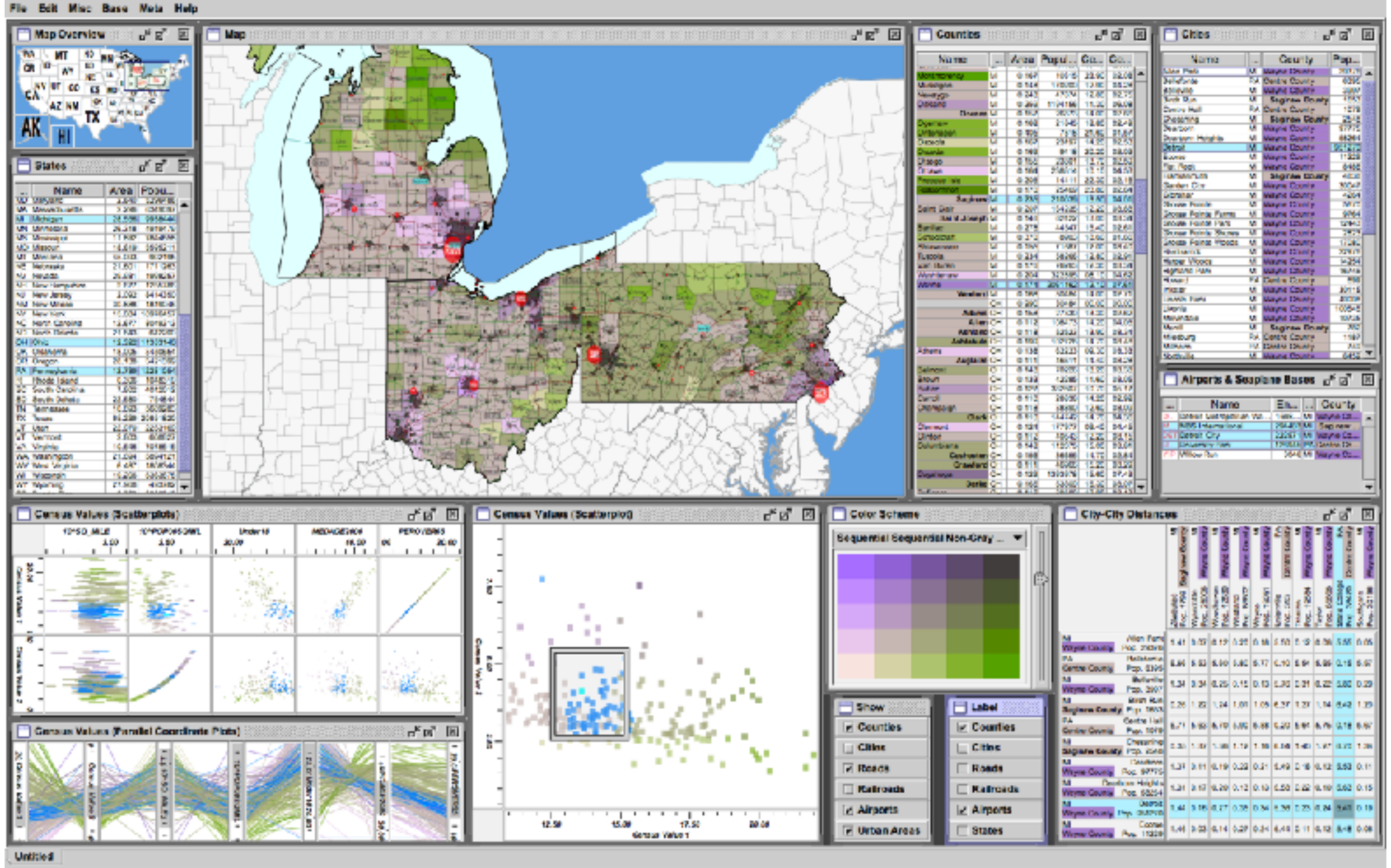


		Data		
		All	Subset	None
Encoding	Same	Redundant	Overview/ Detail	Small Multiples
	Different	Multiform	Multiform, Overview/ Detail	No Linkage

- why juxtapose views?
  - benefits: eyes vs memory
    - lower cognitive load to move eyes between 2 views than remembering previous state with single changing view
  - costs: display area, 2 views side by side each have only half the area of one view

System: **Improvise**

- investigate power of multiple views
  - pushing limits on view count, interaction complexity
  - how many is ok?
    - open research question
  - reorderable lists
    - easy lookup
    - useful when linked to other encodings

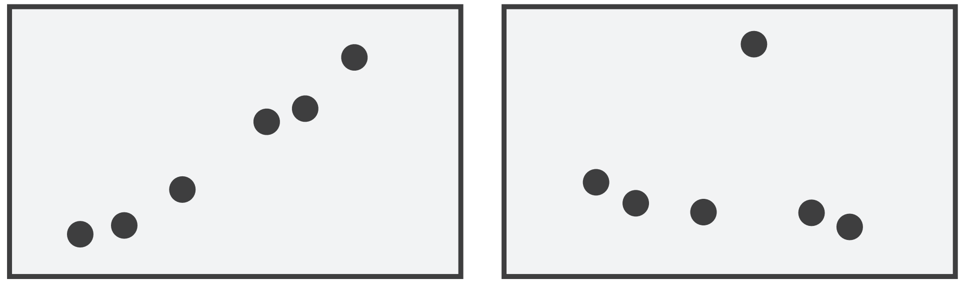

File Edit Misc Base Meta Help
Map Overview
Map
Counties
Cities
States
Airports & Seaplane Bases
Census Values (Scatterplots)
Census Values (Scatterplot)
Color Scheme
Sequential Sequential Non-Gray
City-City Distances
Census Values (Parallel Coordinate Plots)
Show
Counties
Cities
Roads
Railroads
Airports
Urban Areas
Label
Counties
Cities
Roads
Railroads
Airports
States
Untitled

[Building Highly-Coordinated Visualizations In Improvise. Weaver.
Proc. IEEE Symp. Information Visualization (InfoVis), pp. 159–166, 2004.]

Partition into views

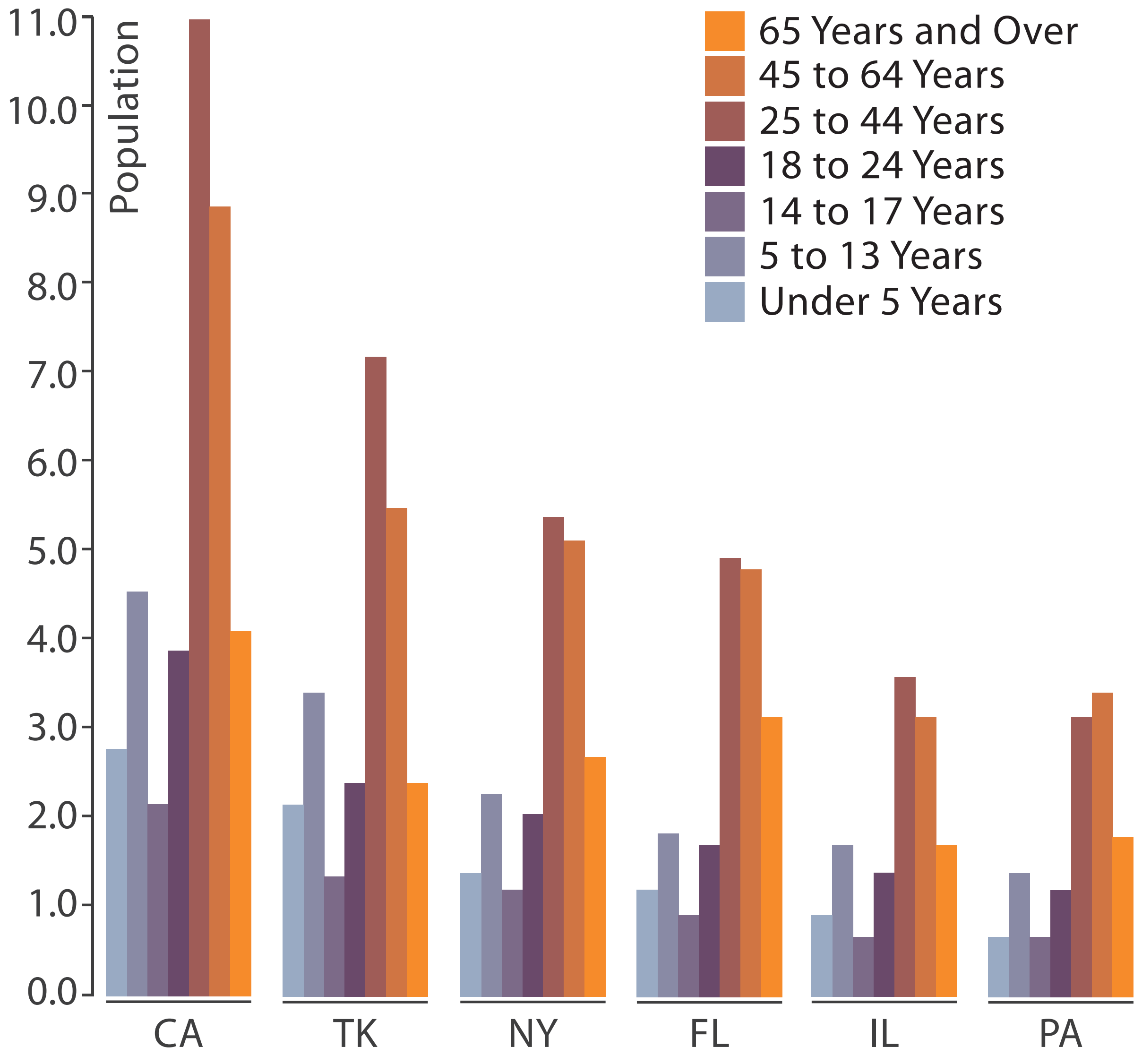
- how to divide data between views
  - split into regions by attributes
  - encodes association between items using spatial proximity
  - order of splits has major implications for what patterns are visible

➔ Partition into Side-by-Side Views

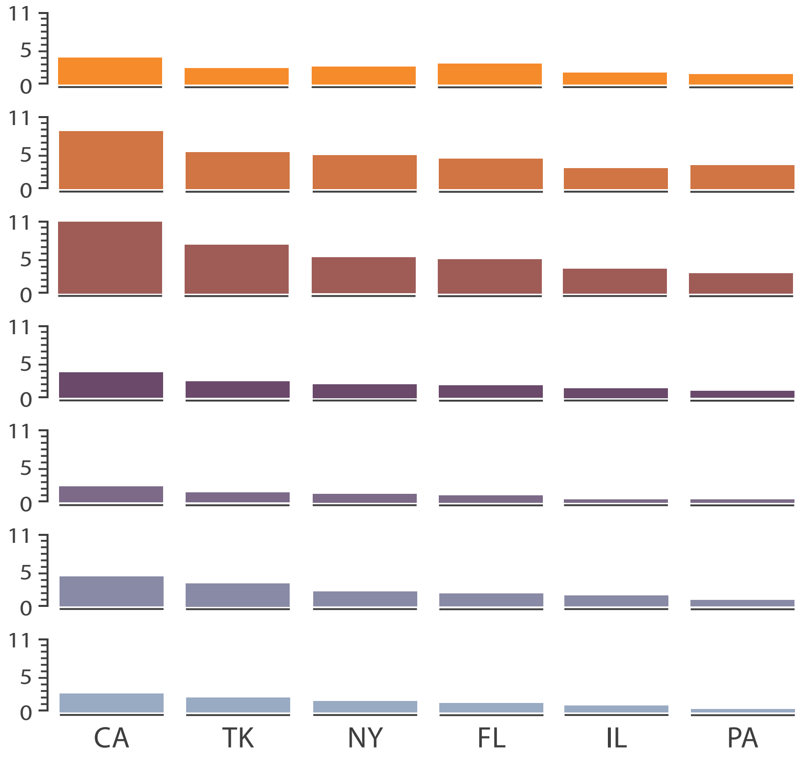


Partitioning: List alignment

- 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

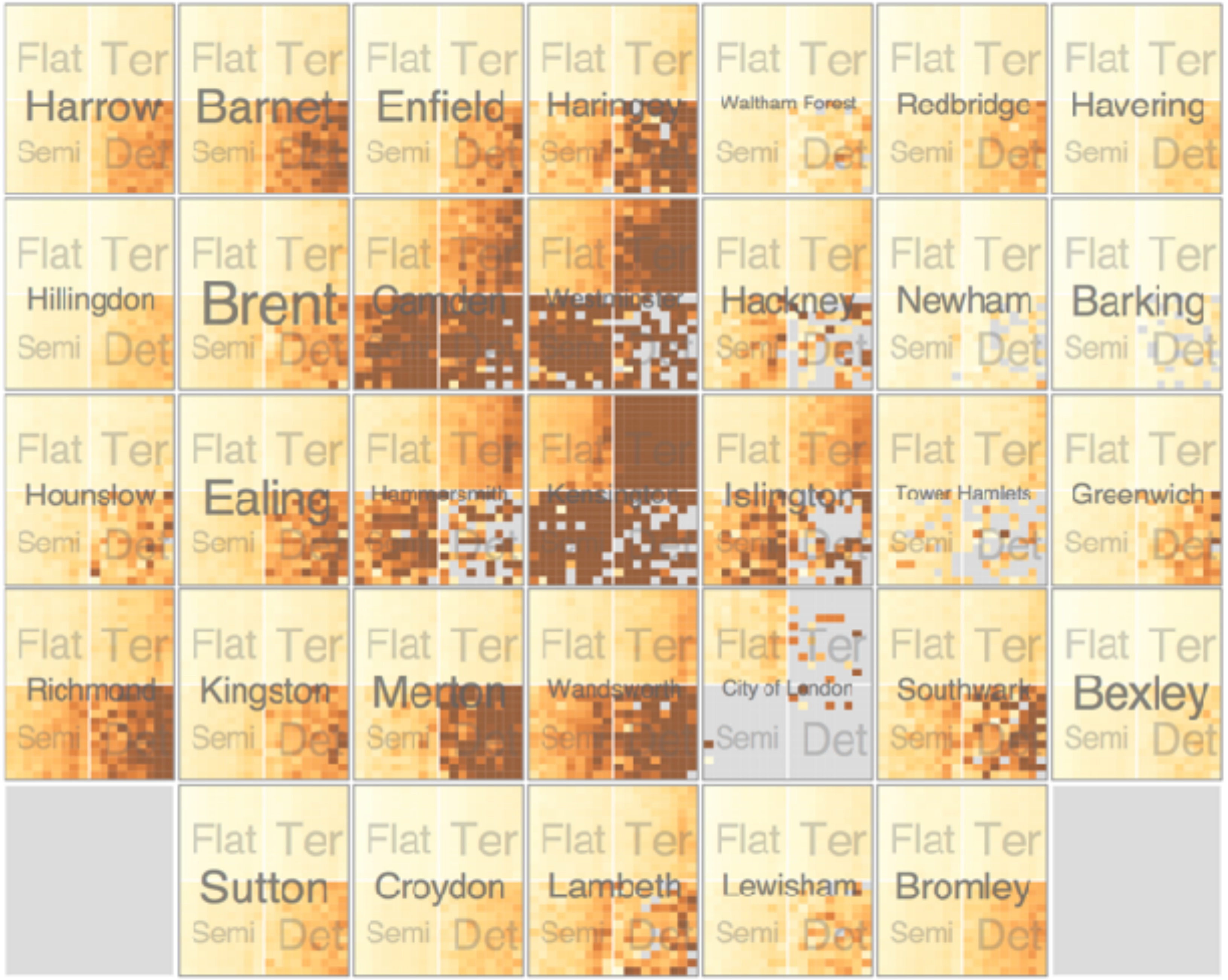


Partitioning: Recursive subdivision

System: **HIVE**

- split by neighborhood
- then by type
- then time
  - years as rows
  - months as columns
- color by price

- neighborhood patterns
  - where it's expensive
  - where you pay much more for detached type



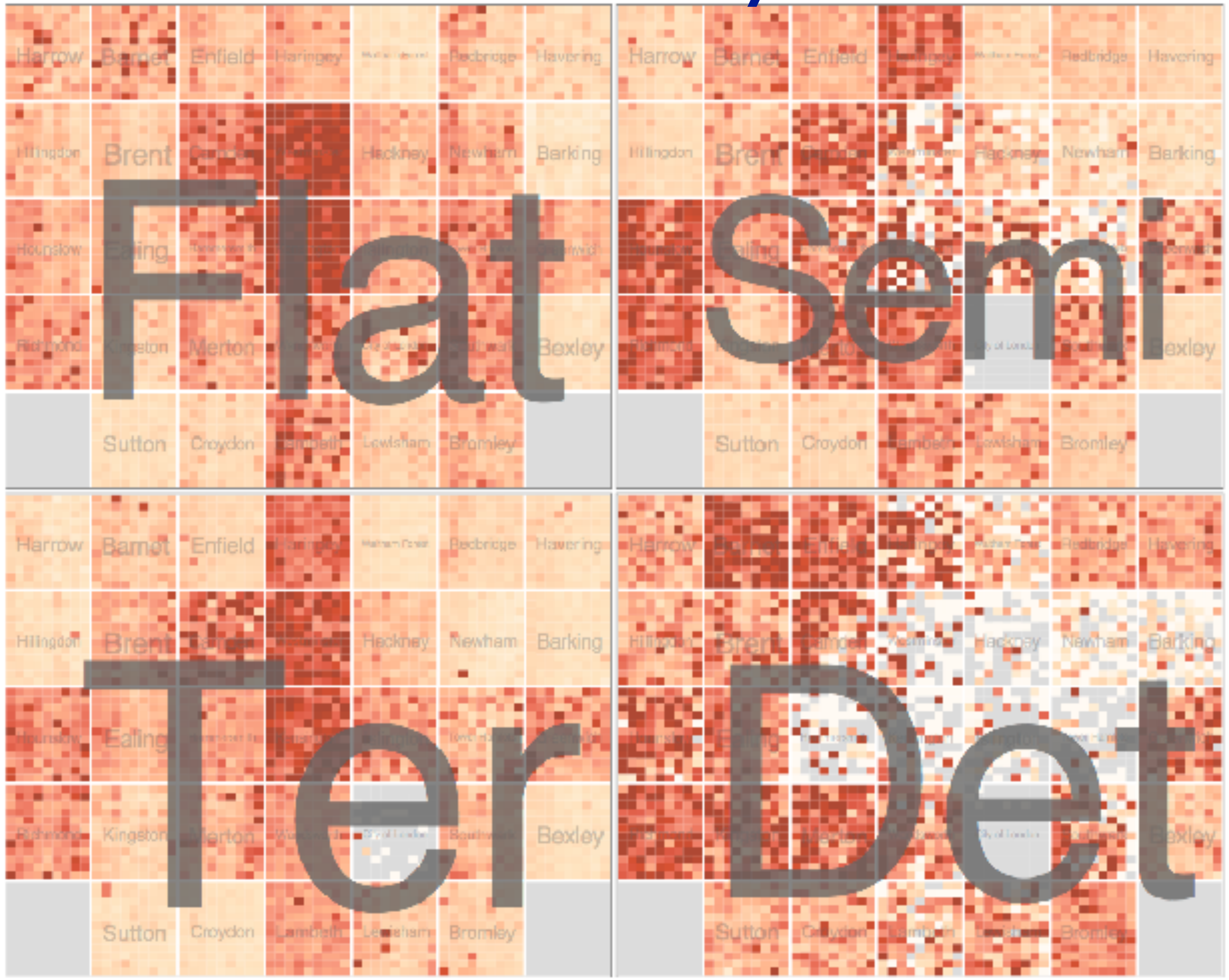
[Configuring Hierarchical Layouts to Address Research Questions. Slingsby, Dykes, and Wood. IEEE Transactions on Visualization and Computer Graphics (Proc. InfoVis 2009) 15:6 (2009), 977–984.]

Partitioning: Recursive subdivision

System: **HIVE**

- switch order of splits
  - type then neighborhood
- switch color
  - by price variation

- type patterns
  - within specific type, which neighborhoods inconsistent

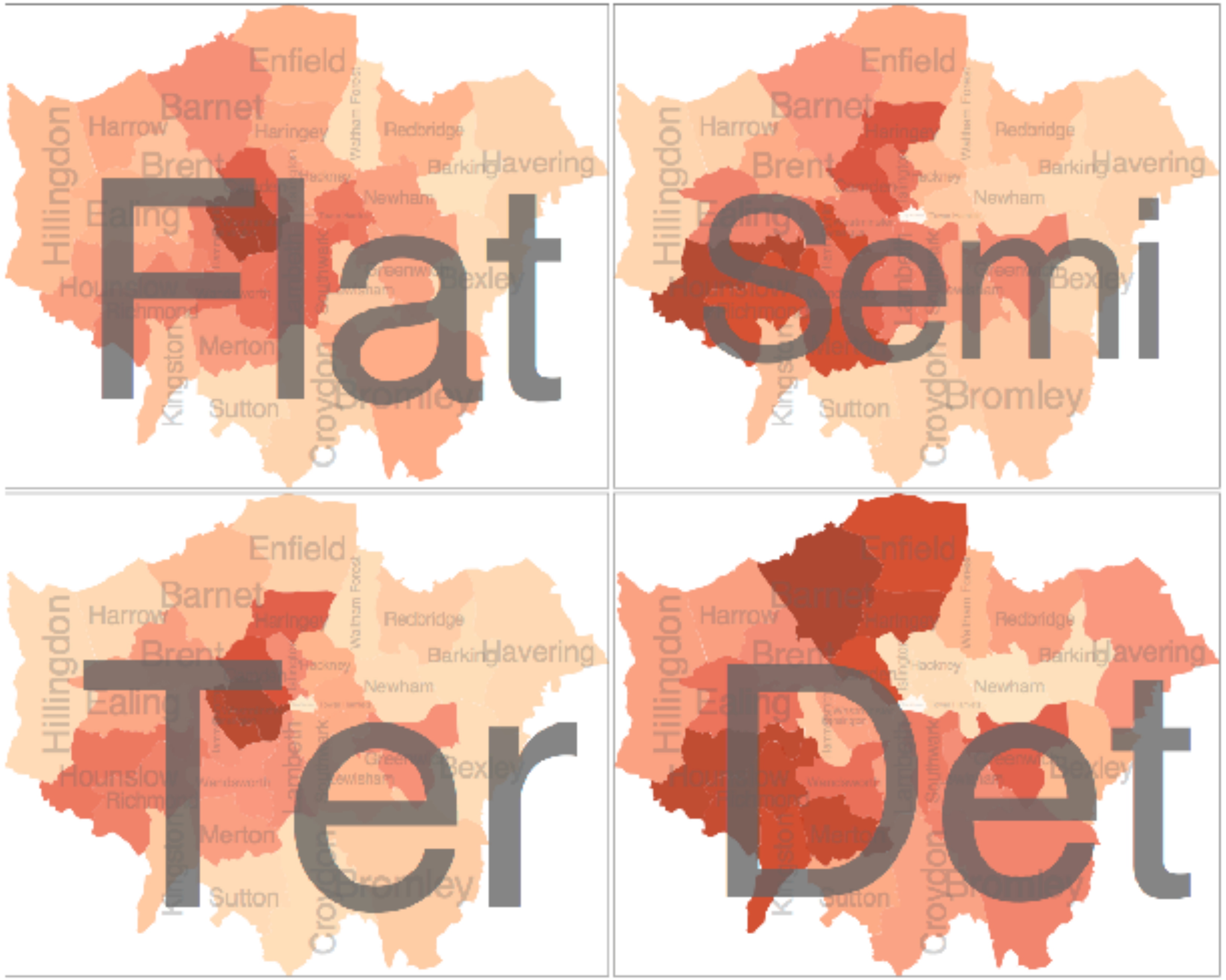


[Configuring Hierarchical Layouts to Address Research Questions. Slingsby, Dykes, and Wood. IEEE Transactions on Visualization and Computer Graphics (Proc. InfoVis 2009) 15:6 (2009), 977–984.]

Partitioning: Recursive subdivision

System: **HIVE**

- different encoding for second-level regions
  - – choropleth maps

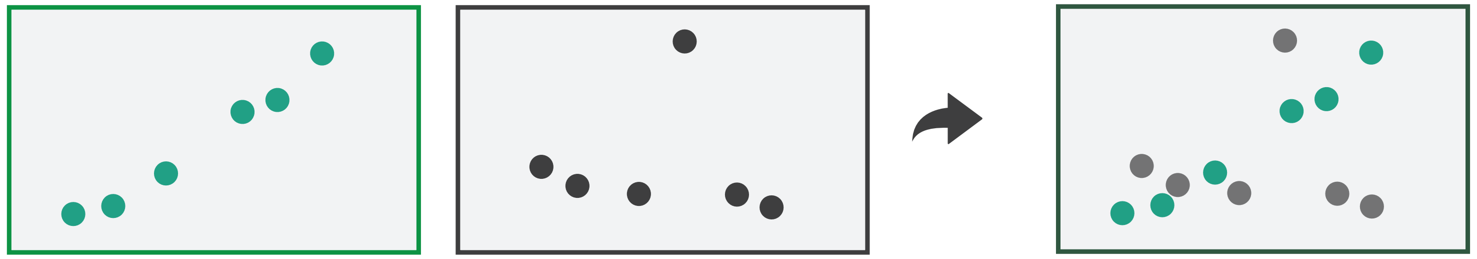


[Configuring Hierarchical Layouts to Address Research Questions. Slingsby, Dykes, and Wood. IEEE Transactions on Visualization and Computer Graphics (Proc. InfoVis 2009) 15:6 (2009), 977–984.]

Superimpose layers

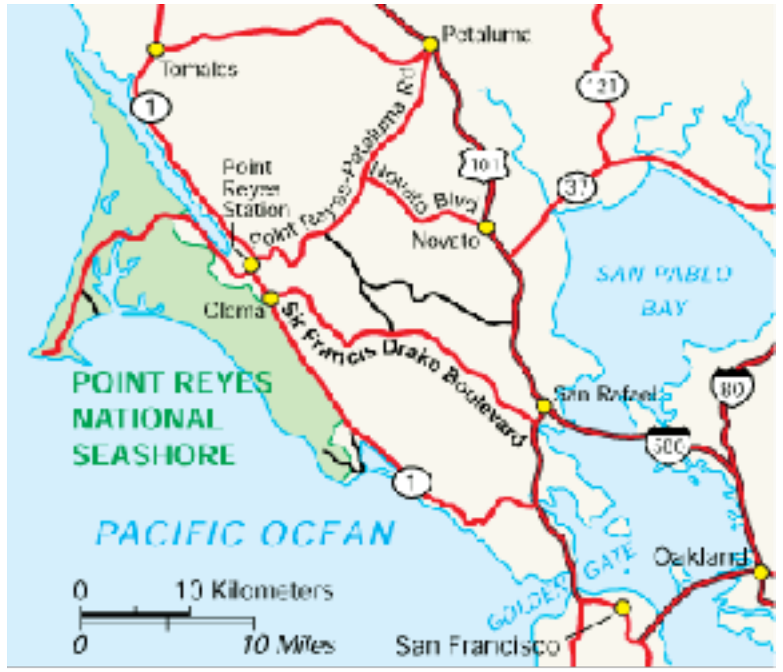
- ***layer***: set of objects spread out over region
  - each set is visually distinguishable group
  - extent: whole view
- design choices
  - how many layers, how to distinguish?
    - encode with different, nonoverlapping channels
    - two layers achieveable, three with careful design
  - small static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

➔ Superimpose Layers



Static visual layering

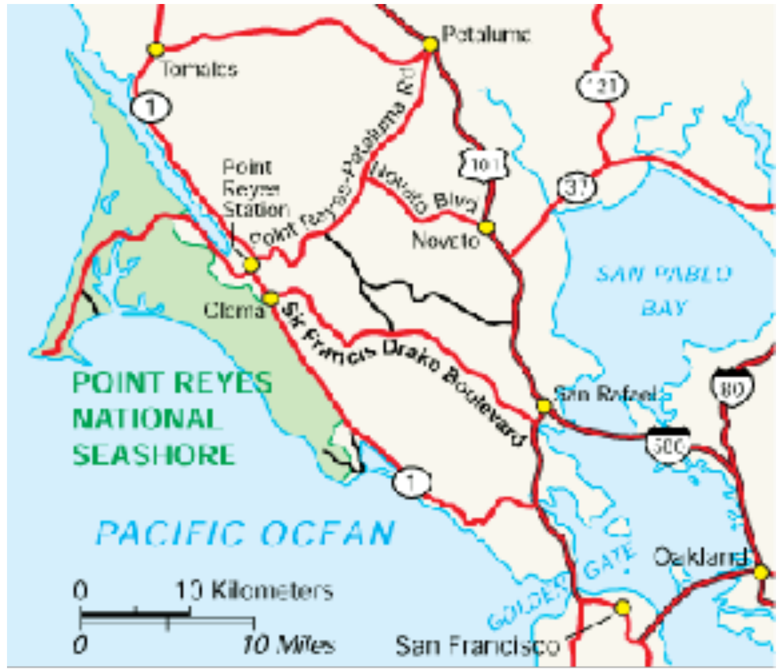
- foreground layer: roads
  - hue, size distinguishing main from minor
  - high luminance contrast from background
- background layer: regions
  - desaturated colors for water, parks, land areas
- user can selectively focus attention

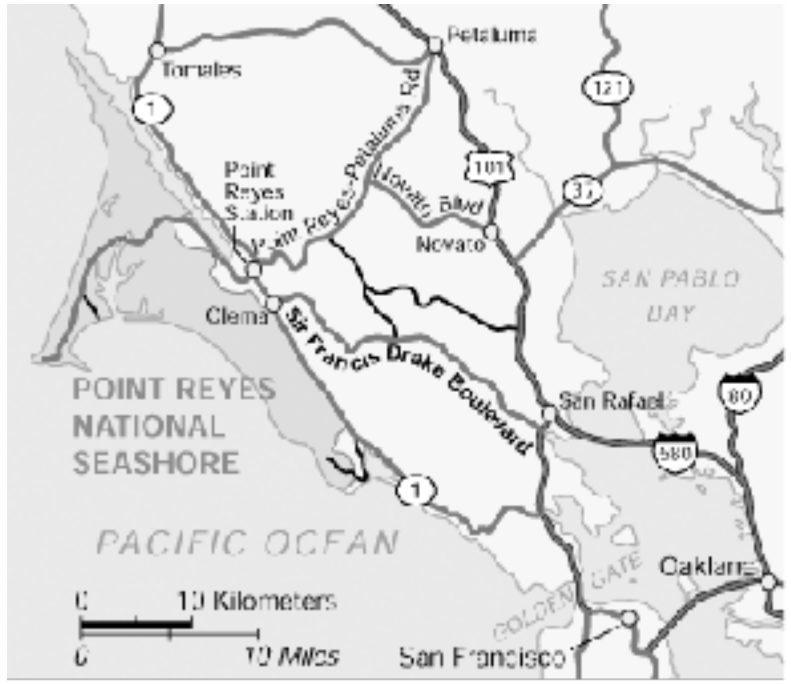


[Get it right in black and white. Stone. 2010. http://www.stonesc.com/wordpress/2010/03/get-it-right-in-black-and-white]

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



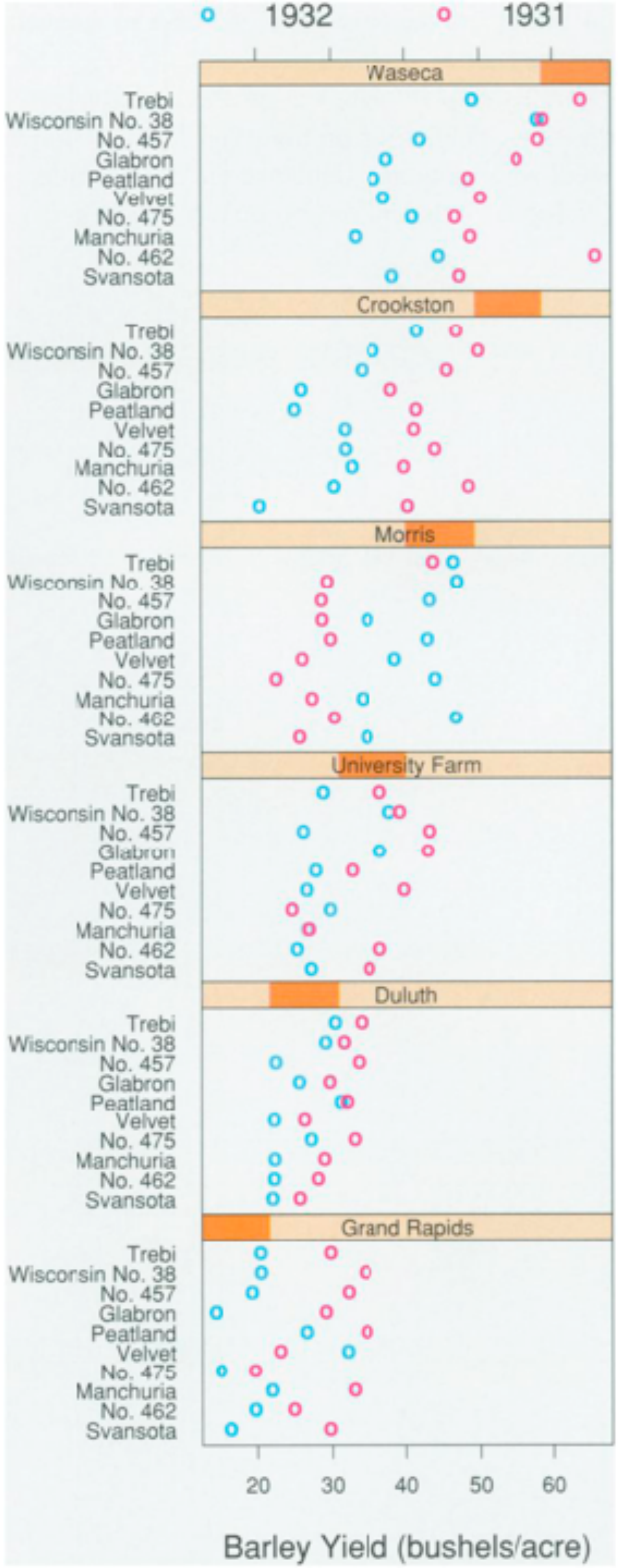


[Get it right in black and white. Stone. 2010. http://www.stonesc.com/wordpress/2010/03/get-it-right-in-black-and-white]

Idiom: **Trellis plots**

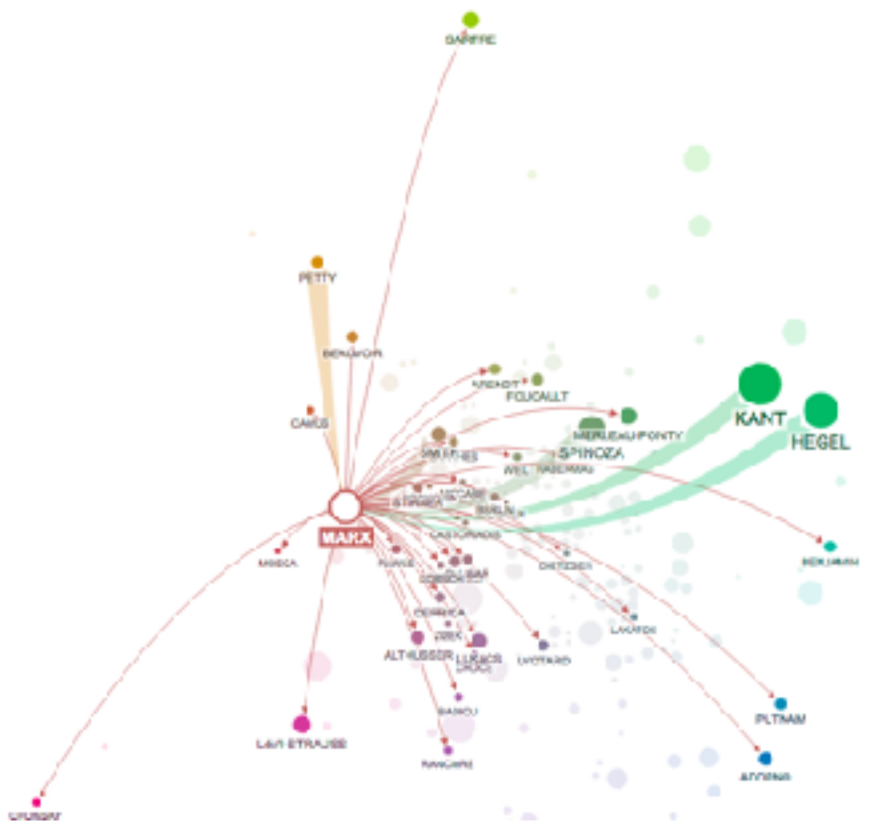
- superimpose within same frame
  - color code by year

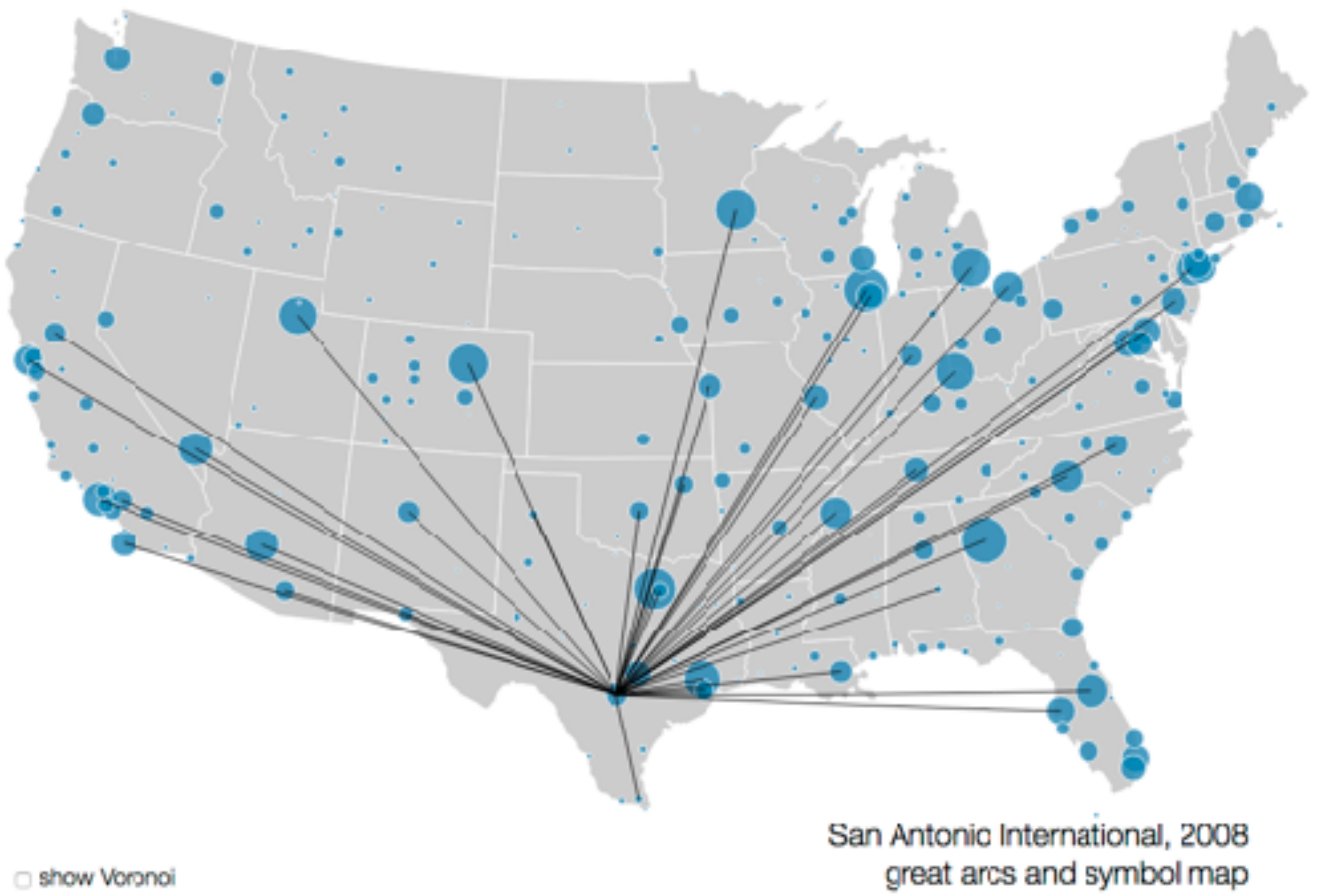
- partitioning
  - split by site, rows are wheat varieties
- main-effects ordering
  - derive value of median for group, use to order
  - order rows within view by variety median
  - order views themselves by site median



Dynamic visual layering

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




□ show Voronoi

San Antonio International, 2008
great arcs and symbol map

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 12: Facet Into Multiple Views*
- *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.
- *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.
- *Guidelines for Using Multiple Views in Information Visualizations*. Baldonado, Woodruff, and Kuchinsky. In Proc. ACM Advanced Visual Interfaces (AVI), pp. 110–119, 2000.
- *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

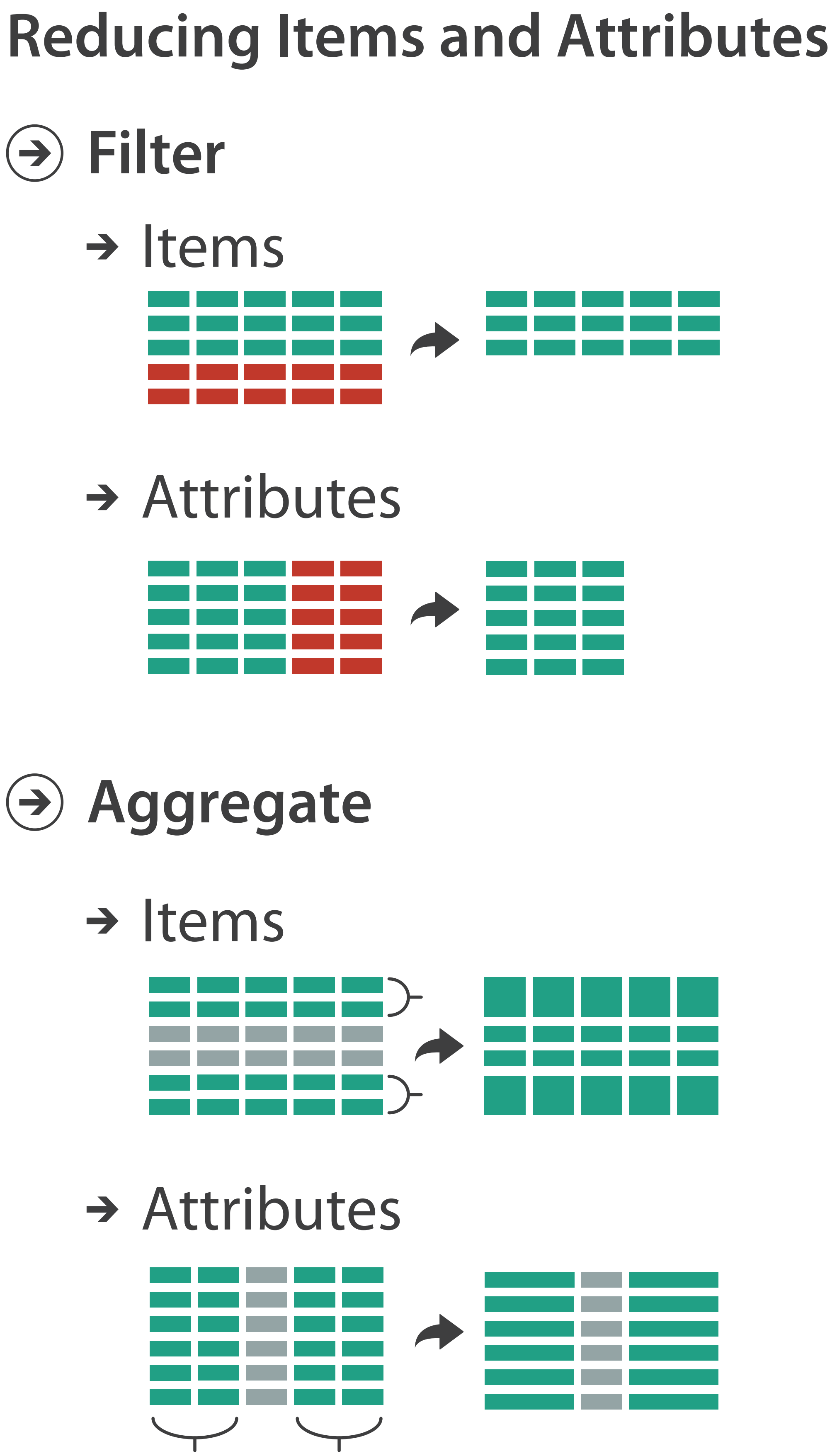
- Session 1
  - Analysis: What, Why, How
  - Marks and Channels
  - Arrange Tables
  - Arrange Spatial Data
- Session 2
  - Arrange Networks and Trees
  - Map Color and Other Channels
  - Manipulate: Change, Select, Navigate
  - Facet: Juxtapose, Partition, Superimpose
  - Reduce: Filter, Aggregate

@tamaramunzner

http://www.cs.ubc.ca/~tmm/talks.html#halfdaycourse20

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



Reducing Items and Attributes

Filter

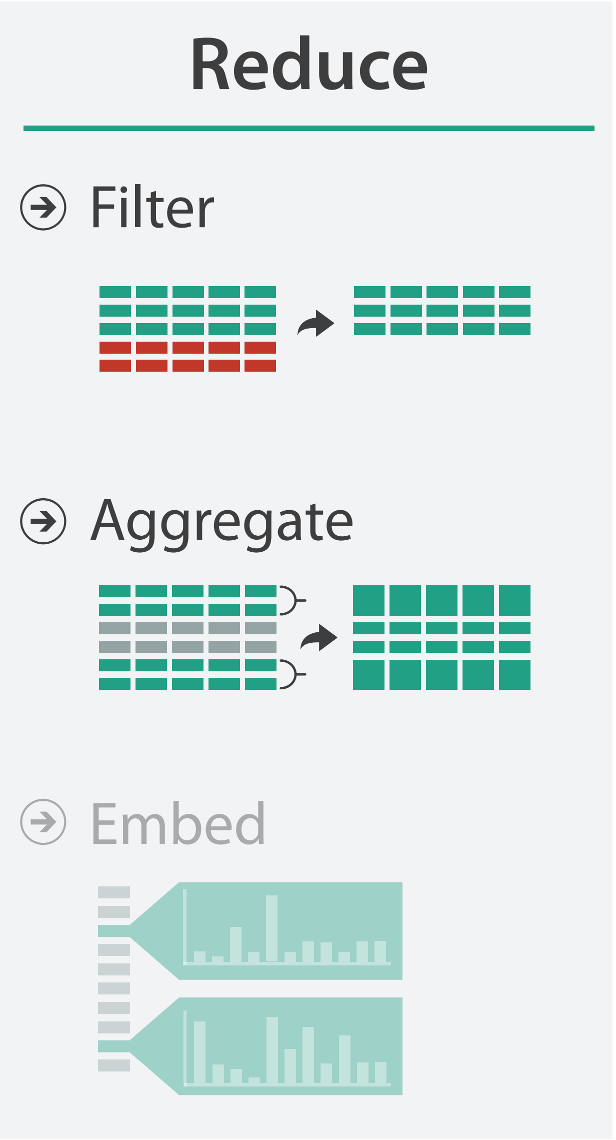
→ Items

→ Attributes

Aggregate

→ Items

→ Attributes



Reduce

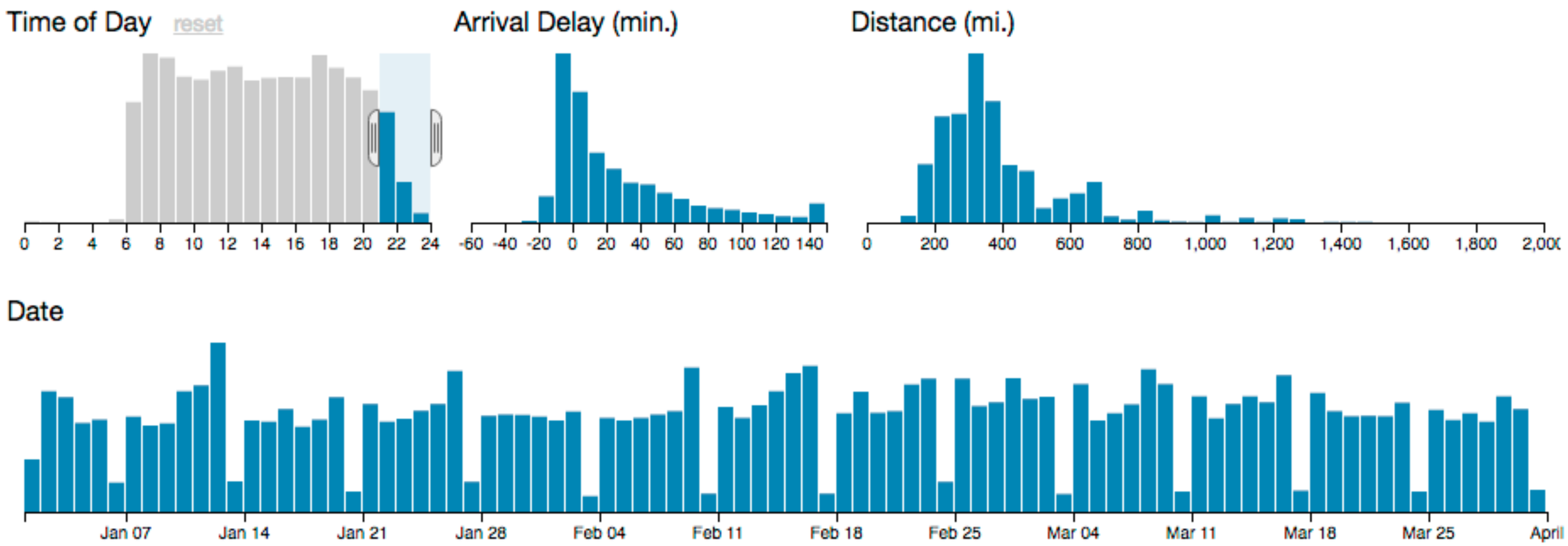
Filter

Aggregate

Embed

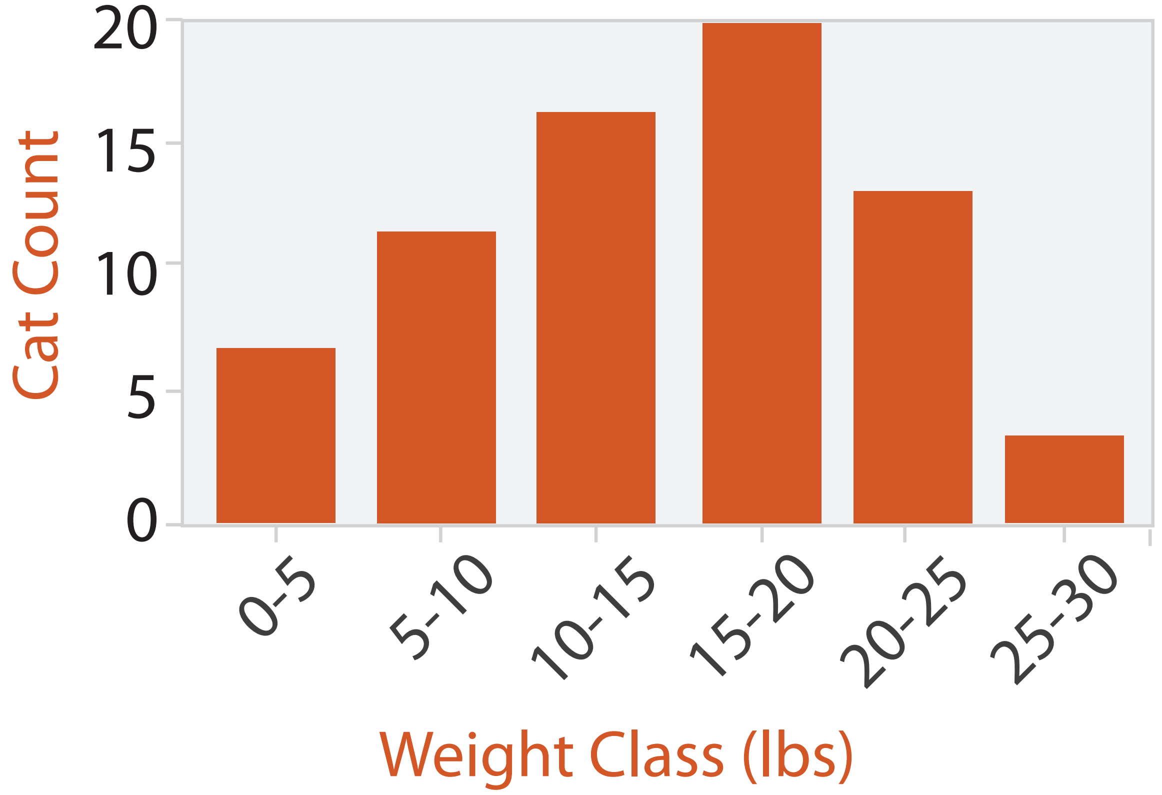
Idiom: **cross filtering** System: **Crossfilter**

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



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

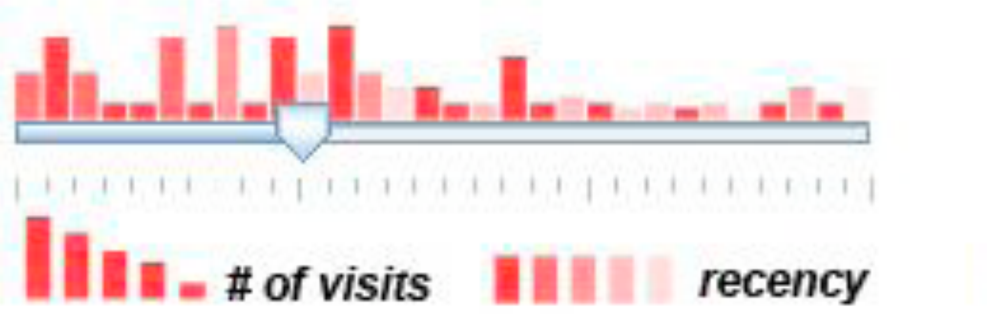
Idiom: **histogram**



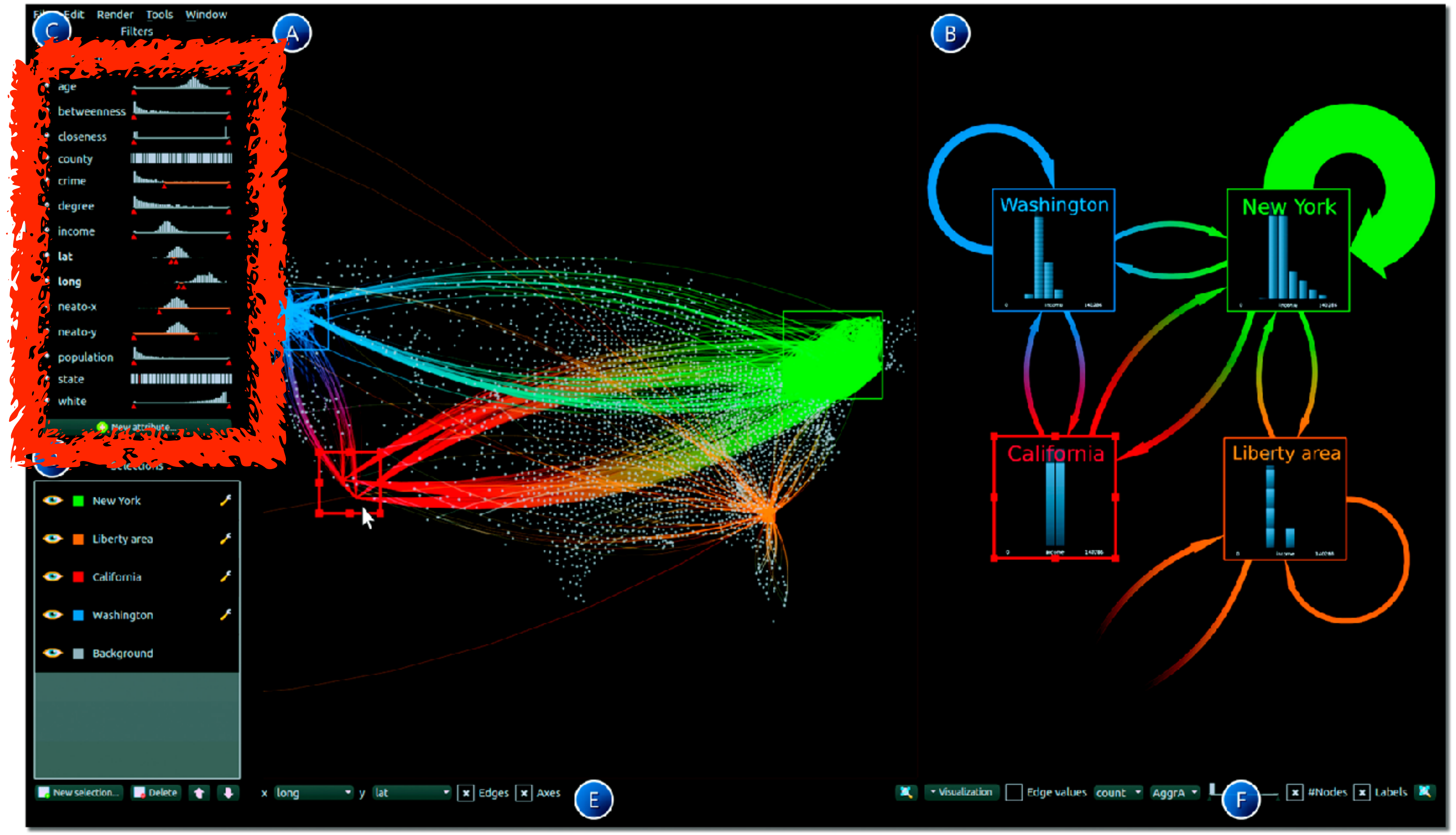
- static item aggregation
- task: find distribution
- data: table
- derived data
  - new table: keys are bins, values are counts
- bin size crucial
  - pattern can change dramatically depending on discretization
  - opportunity for interaction: control bin size on the fly

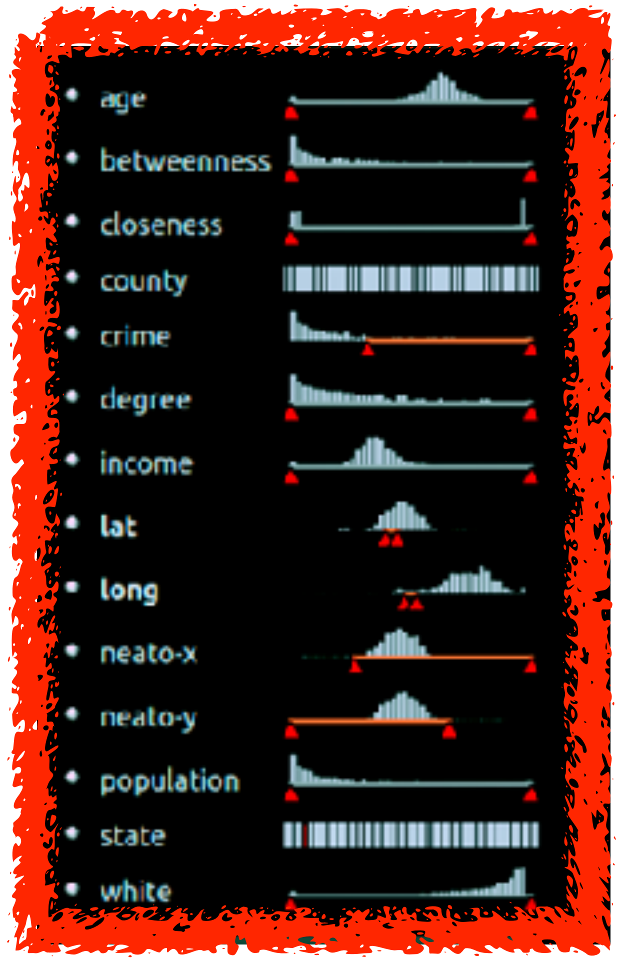
Idiom: **scented widgets**

- 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.]

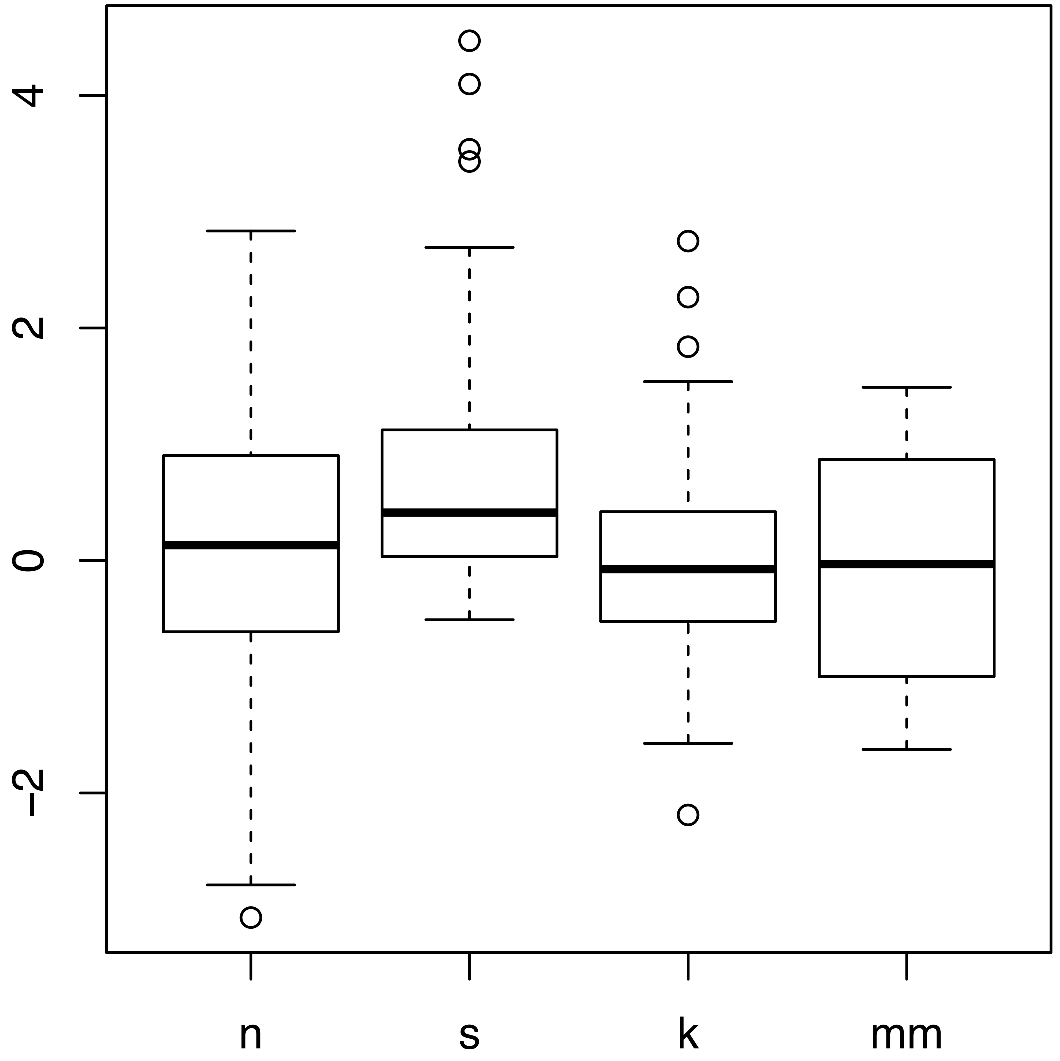




[Multivariate Network Exploration and Presentation: From Detail to Overview via Selections and Aggregations. van den Elzen, van Wijk, IEEE TVCG 20(12): 2014 (Proc. InfoVis 2014).]

Idiom: **boxplot**

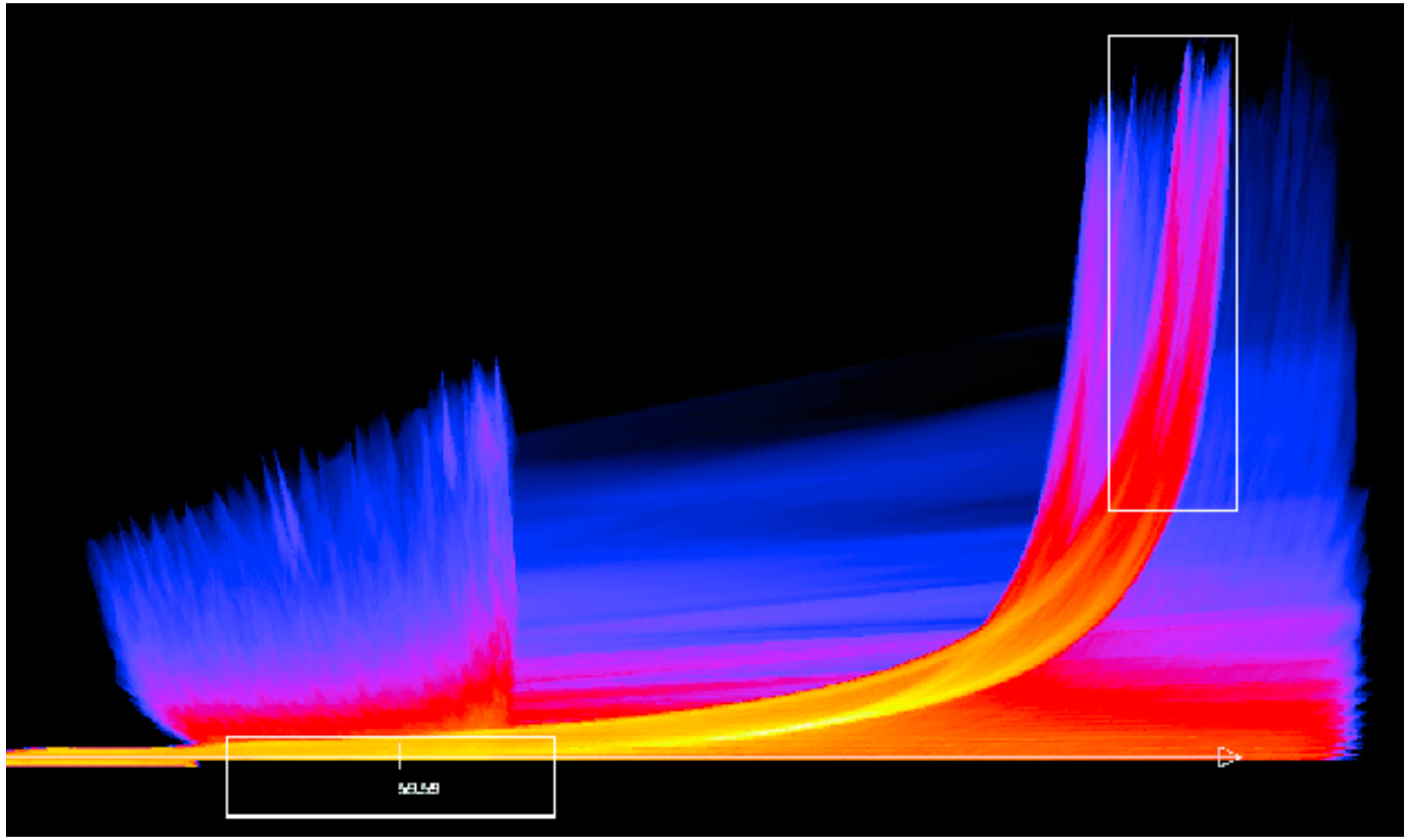
- static item aggregation
- task: find distribution
- data: table
- derived data
  - 5 quant attribs
    - median: central line
    - lower and upper quartile: boxes
    - lower upper fences: whiskers
      - values beyond which items are outliers
  - outliers beyond fence cutoffs explicitly shown



[40 years of boxplots. Wickham and Stryjewski. 2012. had.co.nz]

Idiom: **Continuous scatterplot**

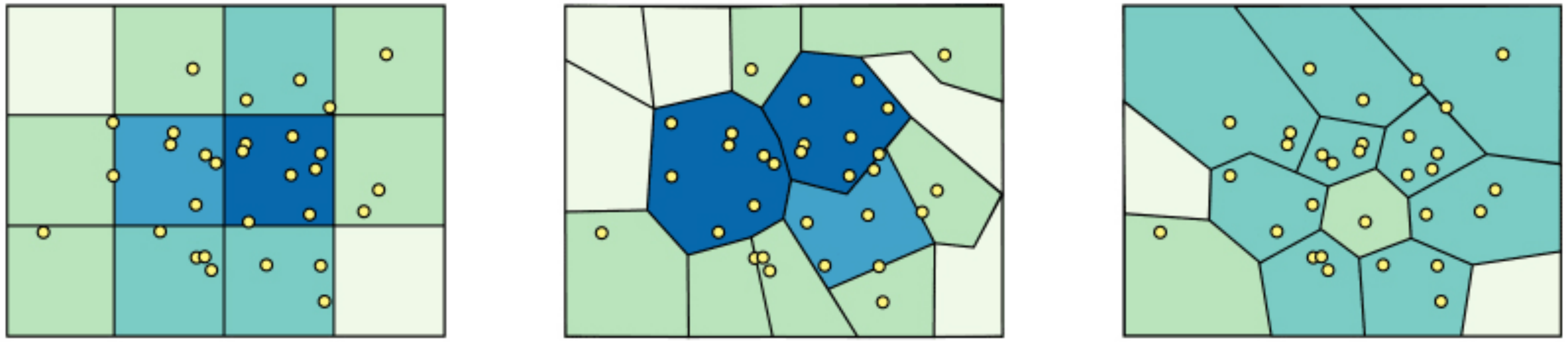
- static item aggregation
- data: table
- derived data: table
  - key attribs x,y for pixels
  - quant attrib: overplot density
- dense space-filling 2D matrix
- color: sequential categorical hue + ordered luminance colormap
- scalability
  - no limits on overplotting: millions of items



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

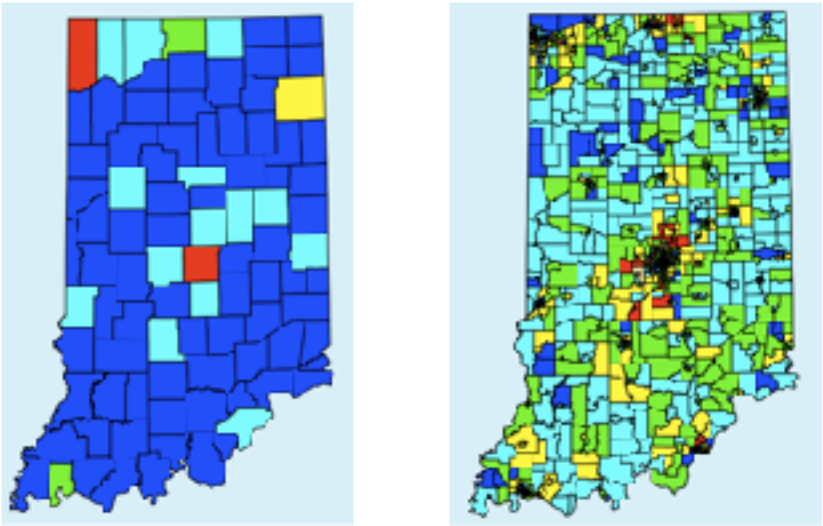
Spatial aggregation

- 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]

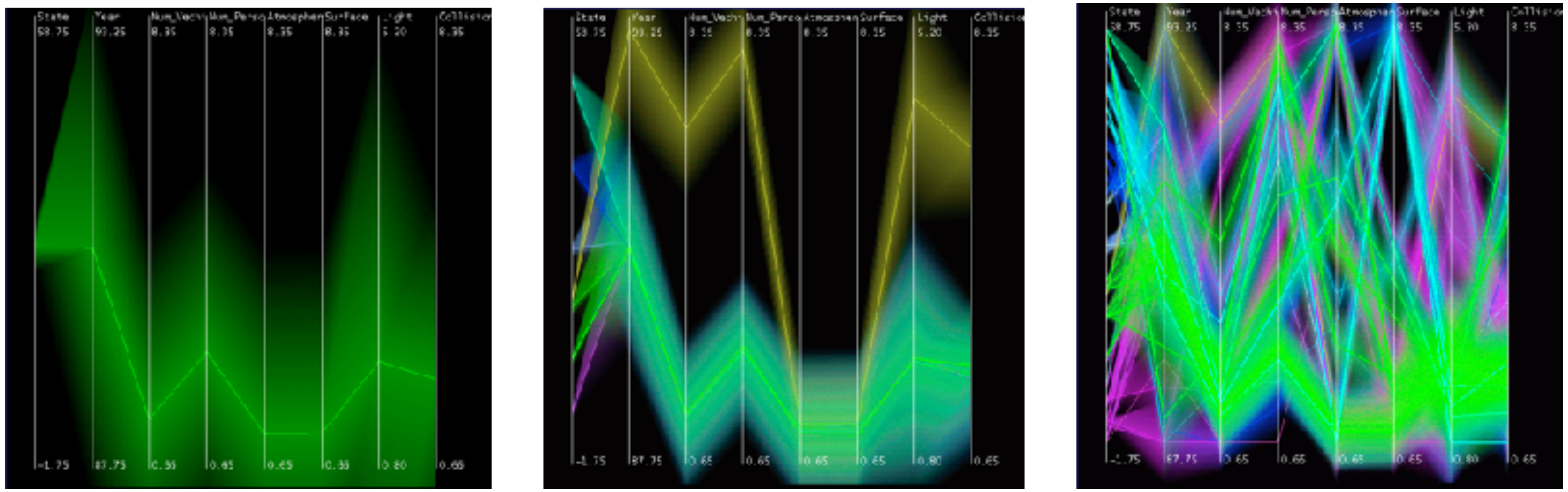
  - scale effects



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.]

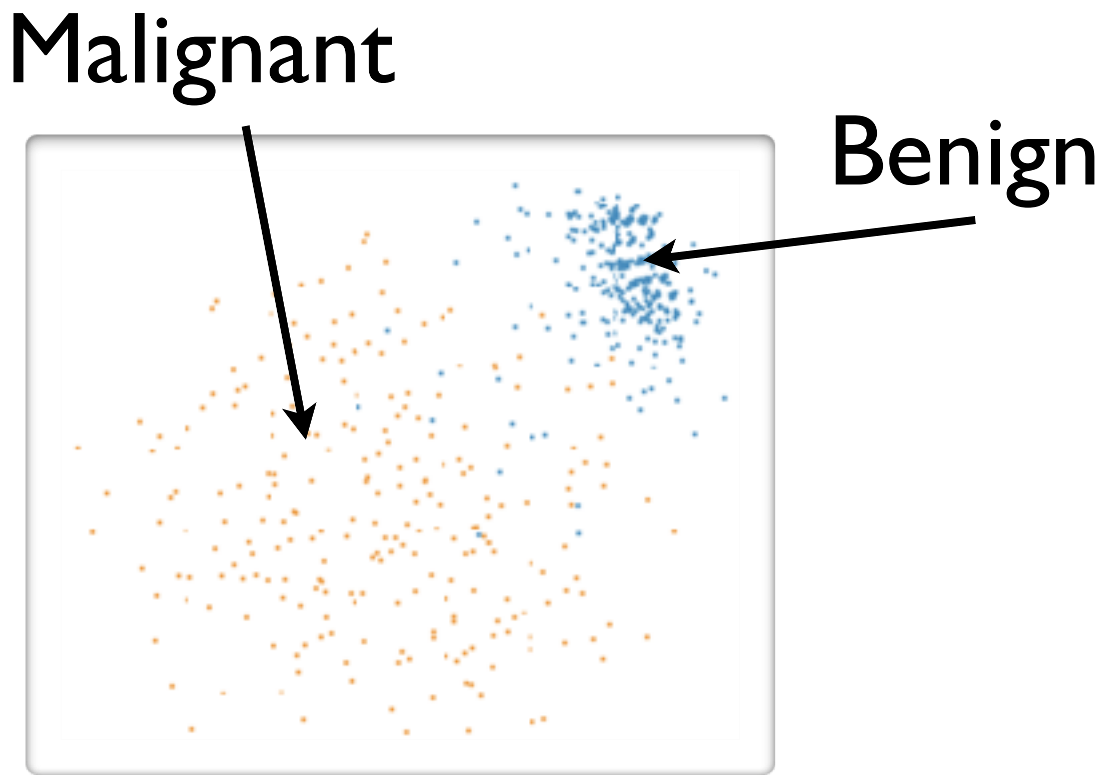
Dimensionality reduction

- 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

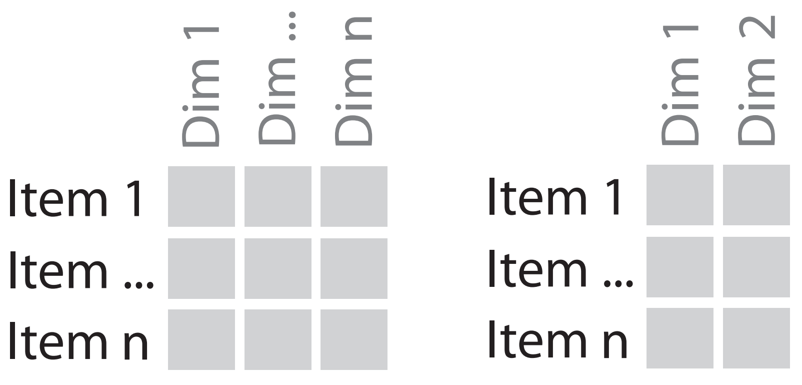
DR



derived data:
2D target space

Idiom: **Dimensionality reduction for documents**

Task 1



In
HD data

➔

Out
2D data

What?

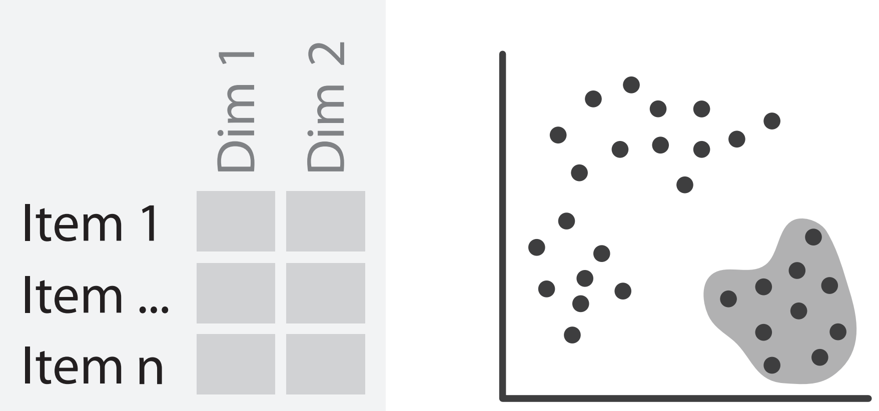
- ➔ In High-dimensional data
- ➔ Out 2D data

Why?

- ➔ Produce
- ➔ Derive

➔

Task 2



In
2D data

➔

Out
Scatterplot
Clusters & points

What?

- ➔ In 2D data
- ➔ Out Scatterplot
- ➔ Out Clusters & points

Why?

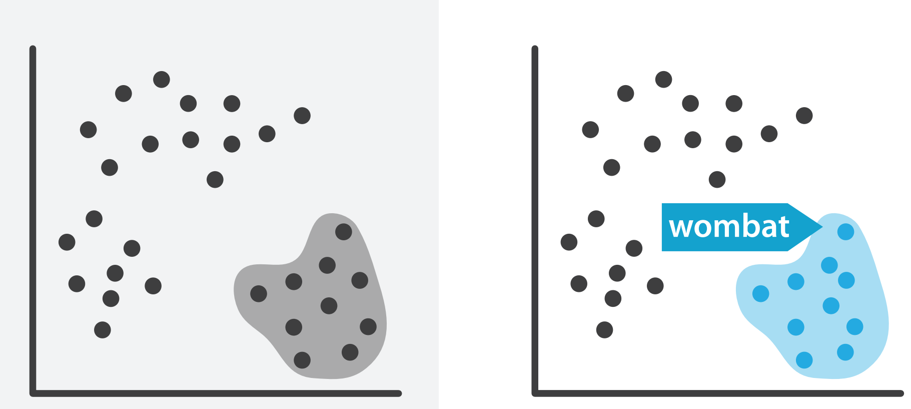
- ➔ Discover
- ➔ Explore
- ➔ Identify

How?

- ➔ Encode
- ➔ Navigate
- ➔ Select

➔

Task 3



In
Scatterplot
Clusters & points

➔

Out
Labels for clusters

What?

- ➔ In Scatterplot
- ➔ In Clusters & points
- ➔ Out Labels for clusters

Why?

- ➔ Produce
- ➔ Annotate

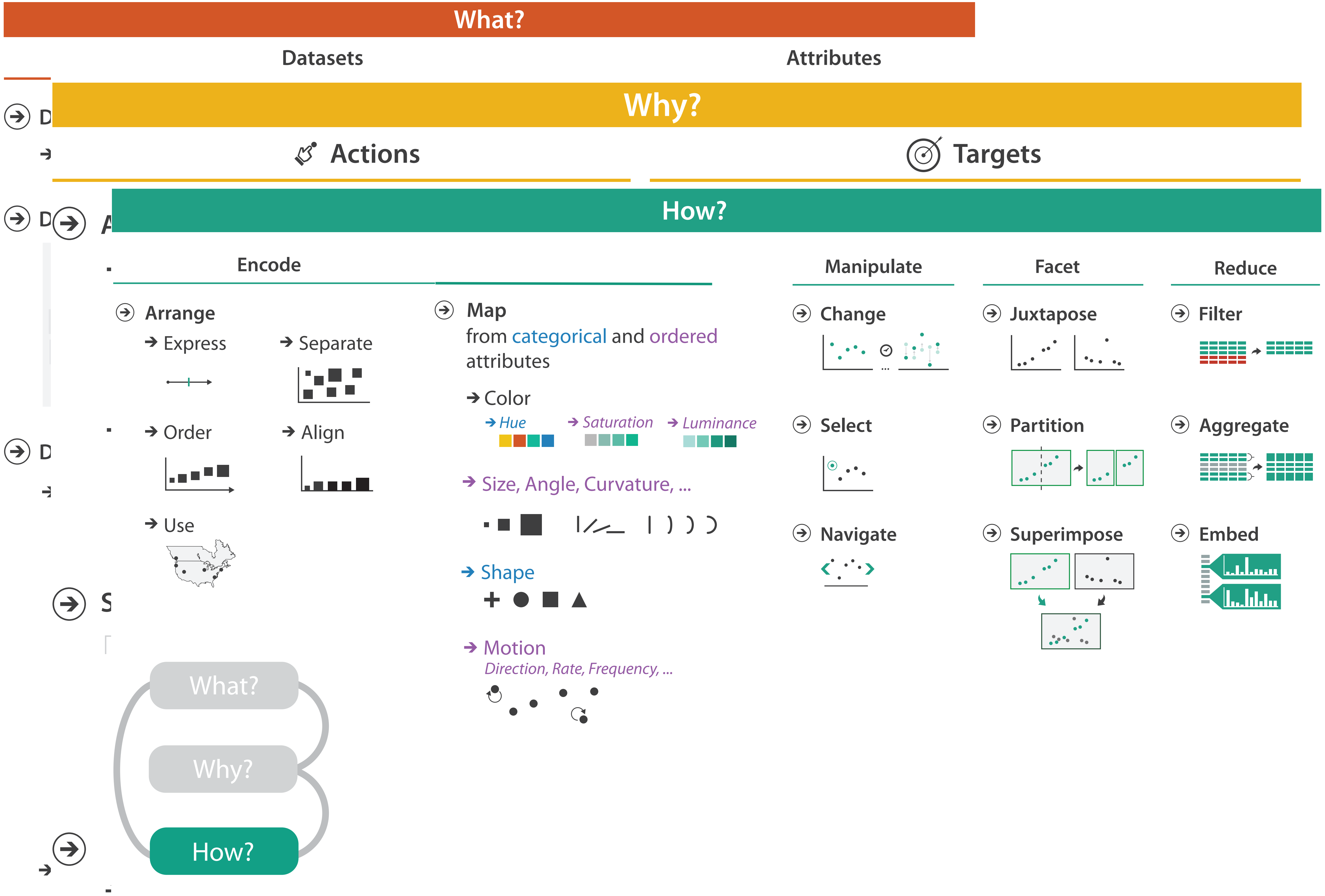
Further reading

- 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.

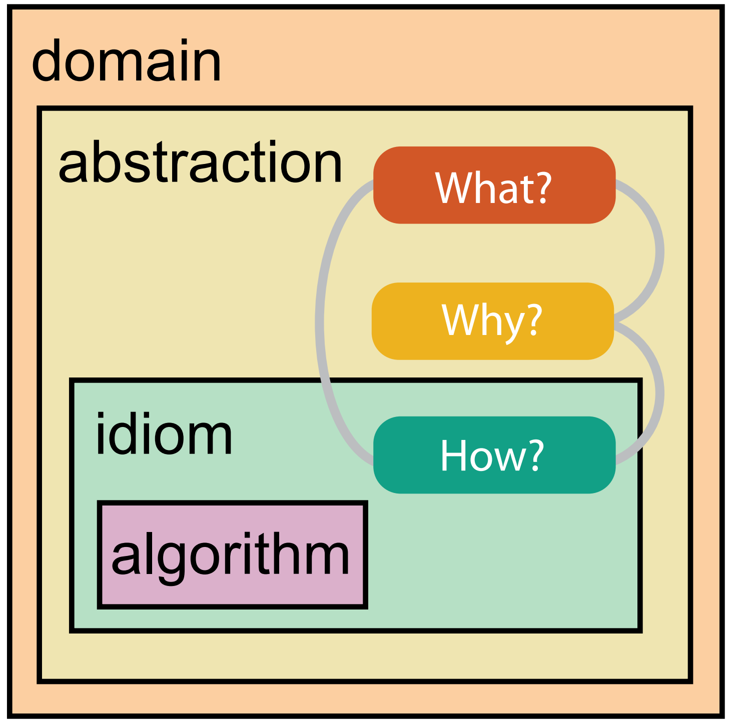
Not covered

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

- Embed: Focus+Context



What?
Datasets
Attributes
Why?
Actions
Targets
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?



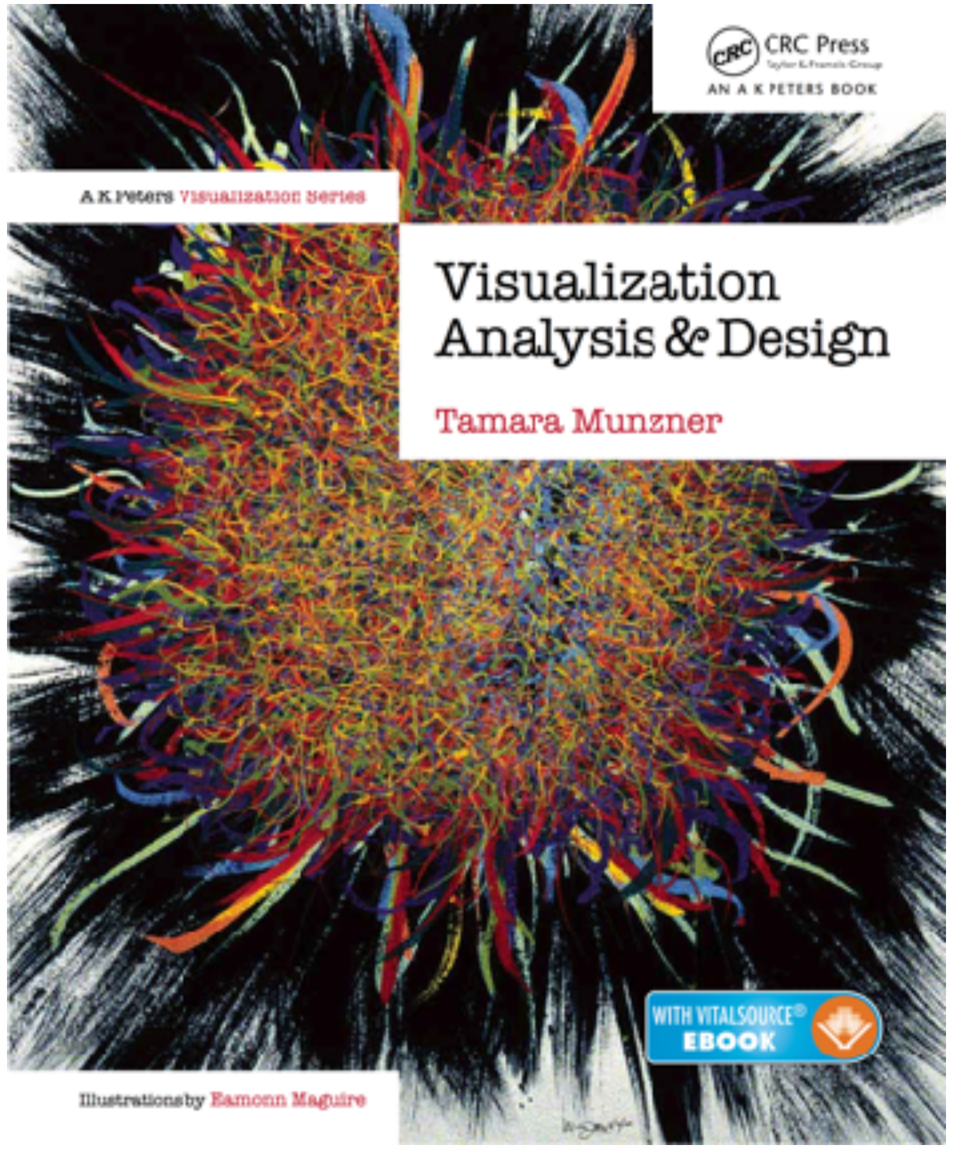
domain
abstraction
What?
Why?
idiom
How?
algorithm

More information

- this tutorial
  http://www.cs.ubc.ca/~tmm/talks.html#halfdaycourse20

- book
  http://www.cs.ubc.ca/~tmm/vadbook
  - 20% promo code for book+ebook combo: HVN17
  - 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


CRC Press
Taylor & Francis Group
AN A K PETERS BOOK
A K Peters Visualization Series
Visualization Analysis & Design
Tamara Munzner
WITH VITALSOURCE® EBOOK
Illustrations by Eamonn Maguire

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

@tamaramunzner