# Visualization Analysis & Design

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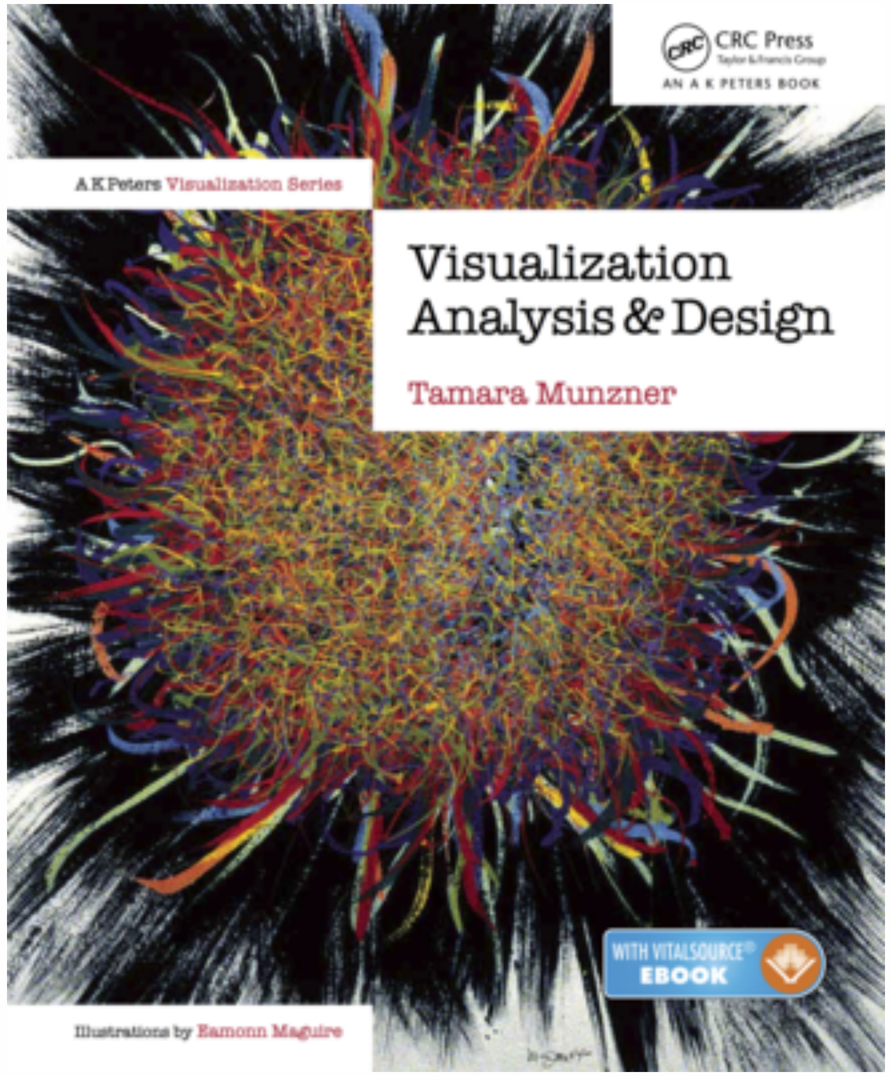
CRC Press
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A K Peters Visualization Series
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Tamara Munzner
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*University of Illinois at Chicago, Distinguished Lecture Series*
*April 9 2015, Chicago IL*

http://www.cs.ubc.ca/~tmm/talks.html#vad15chicago

# 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.**

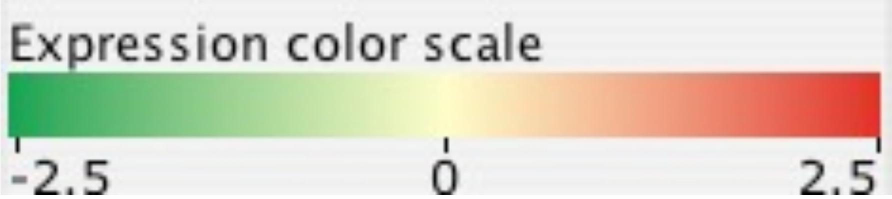
**Visualization is suitable when there is a need to augment human capabilities rather than replace people with computational decision-making methods.**

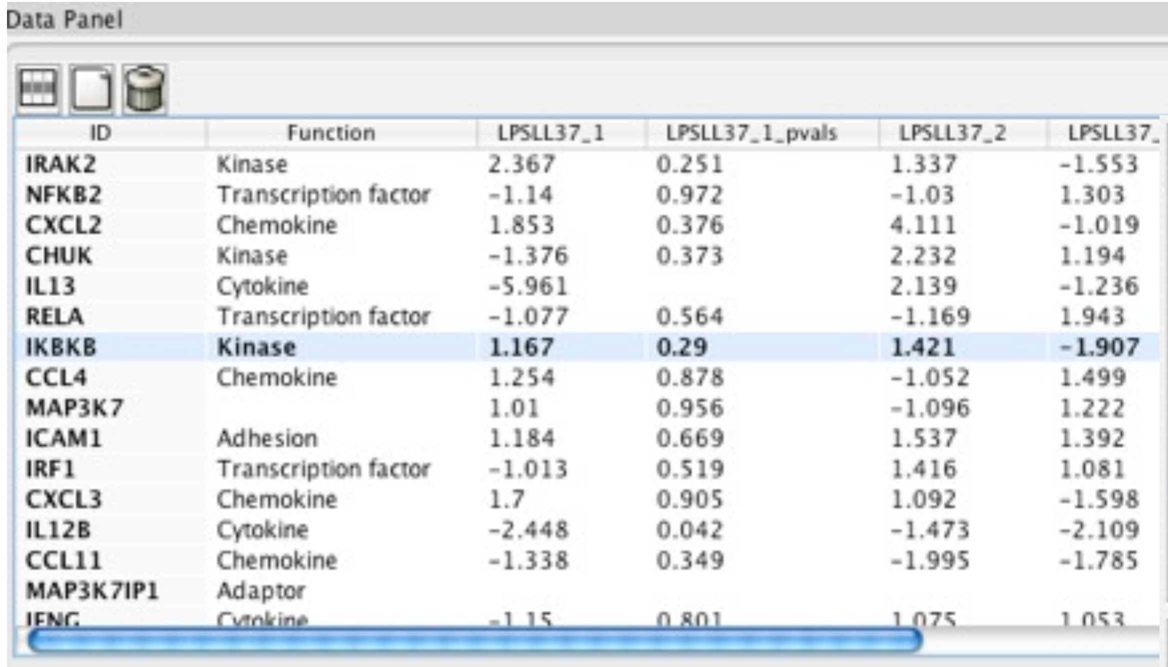
- don't need vis when fully automatic solution exists and is trusted
- many analysis problems ill-specified
  - don't know exactly what questions to ask in advance
- possibilities
  - long-term use for end users (e.g. exploratory analysis of scientific data)
  - presentation of known results
  - stepping stone to better understanding of requirements before developing models
  - help developers of automatic solution refine/debug, 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





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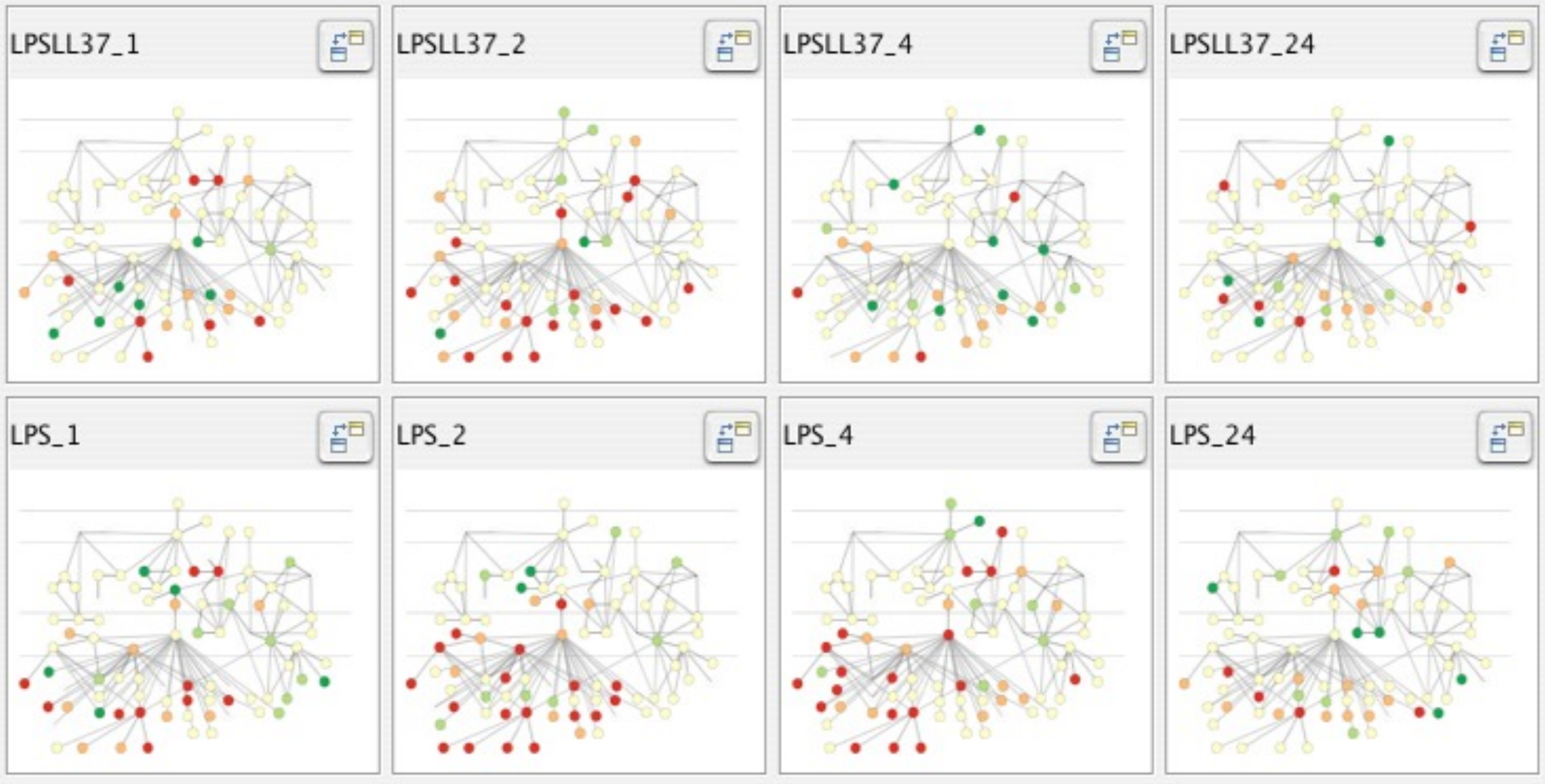
| NFKB2 | Transcription factor | -1.14 | 0.972 | -1.03 | 1.303 |
| CXCL2 | Chemokine | 1.853 | 0.376 | 4.111 | -1.019 |
| CHUK | Kinase | -1.376 | 0.373 | 2.232 | 1.194 |
| IL13 | Cytokine | -5.961 | | 2.139 | -1.236 |
| RELA | Transcription factor | -1.077 | 0.564 | -1.169 | 1.943 |
| IKBKB | Kinase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



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

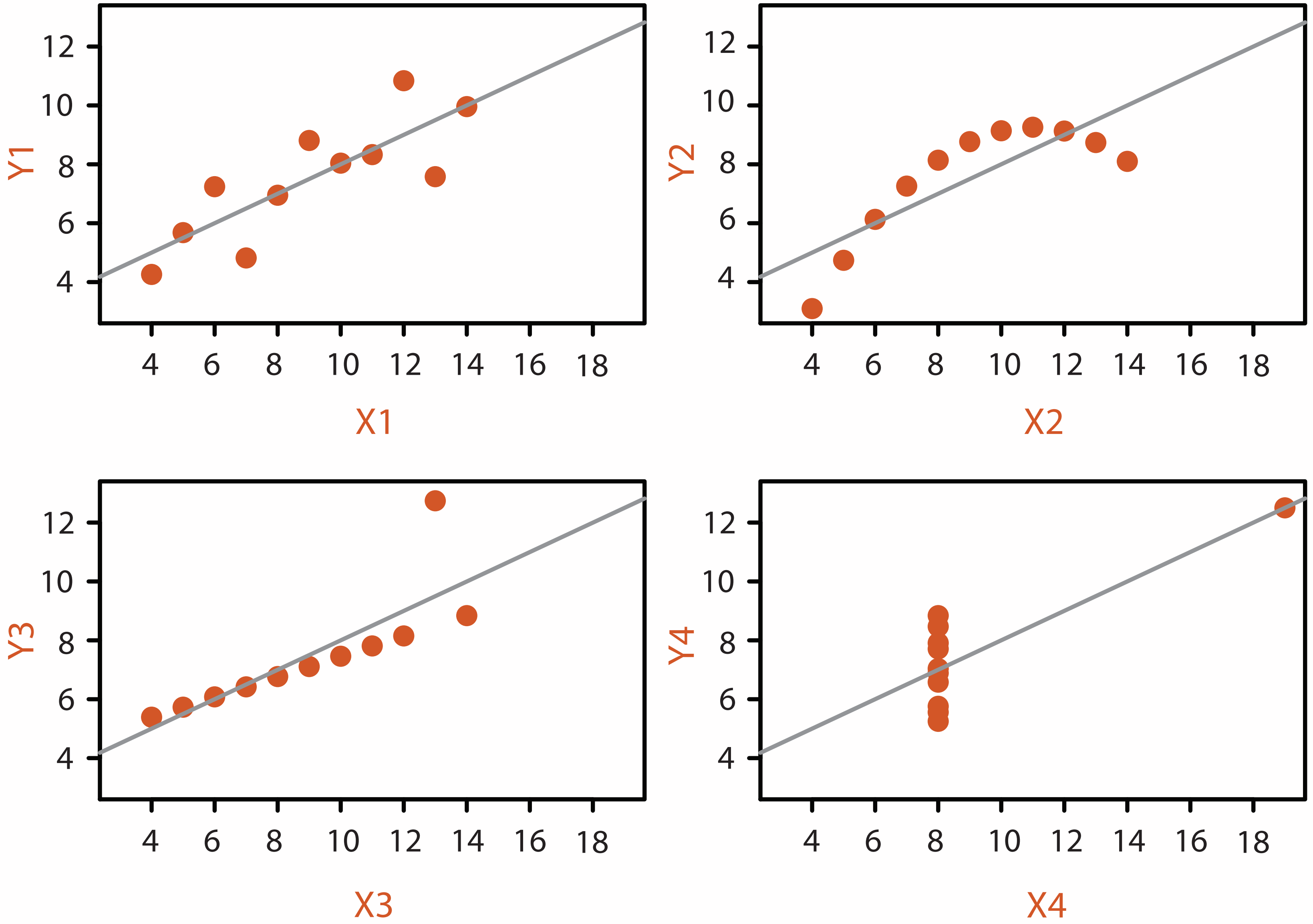
# Why represent all the data?

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

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

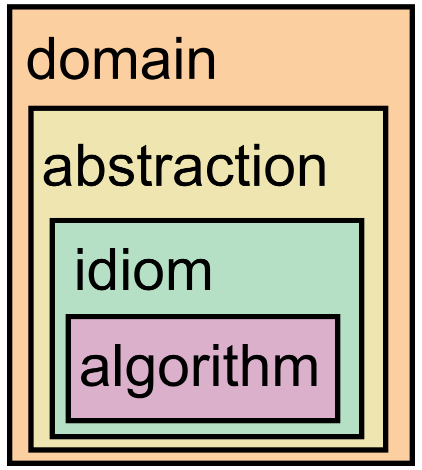
## Anscombe's Quartet

| Identical statistics | |
|---|---|
| x mean | 9 |
| x variance | 10 |
| y mean | 8 |
| y variance | 4 |
| x/y correlation | 1 |

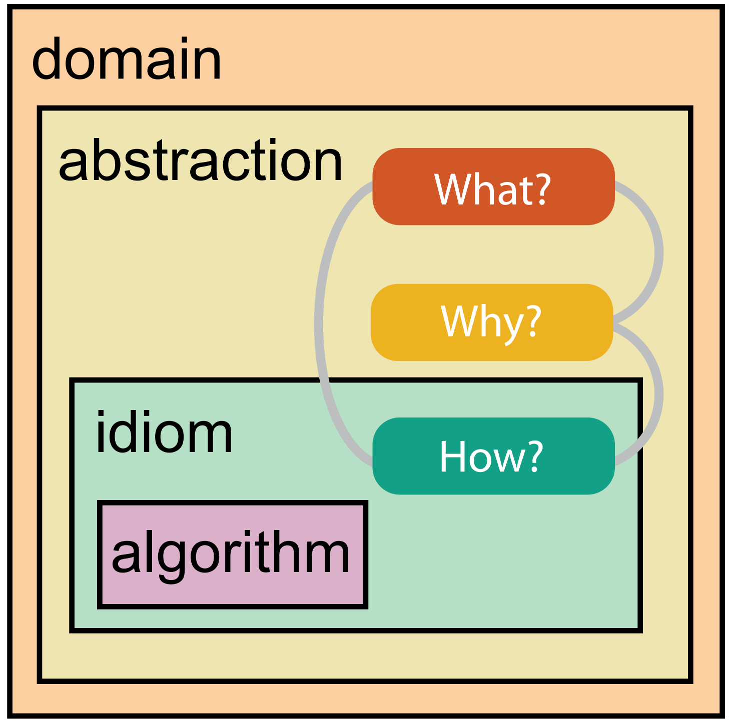


# Analysis framework: Four levels, three questions

- *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

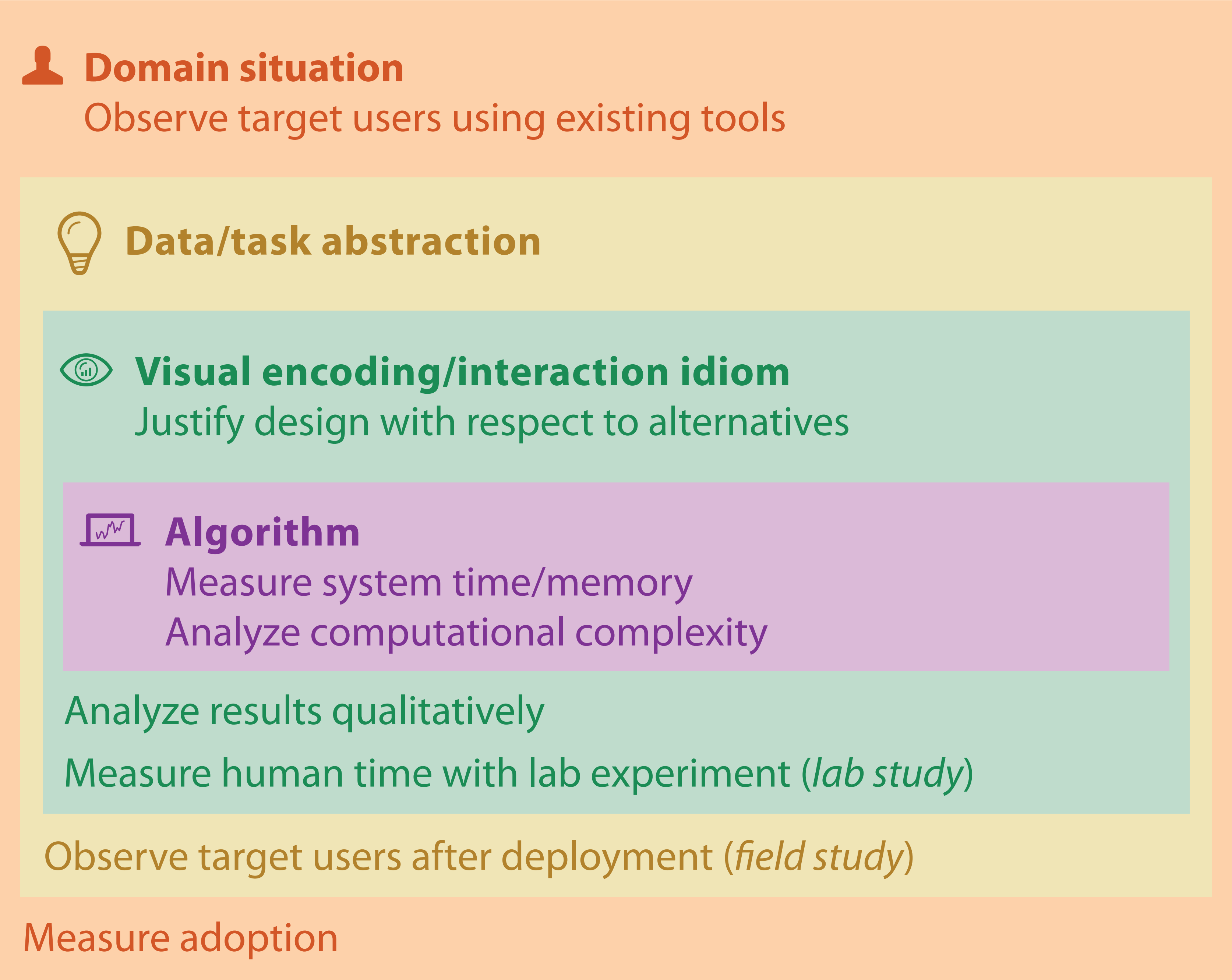


[A Nested Model of Visualization Design and Validation.
*Munzner. IEEE TVCG 15(6):921-928, 2009 (Proc. InfoVis 2009). ]*



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

# Validation methods from different fields for each level



anthropology/
ethnography

**Domain situation**
Observe target users using existing tools

**Data/task abstraction**

**Visual encoding/interaction idiom**
Justify design with respect to alternatives

design

**Algorithm**
Measure system time/memory
Analyze computational complexity

computer
science

Analyze results qualitatively

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

cognitive
psychology

anthropology/
ethnography

Observe target users after deployment (*field study*)

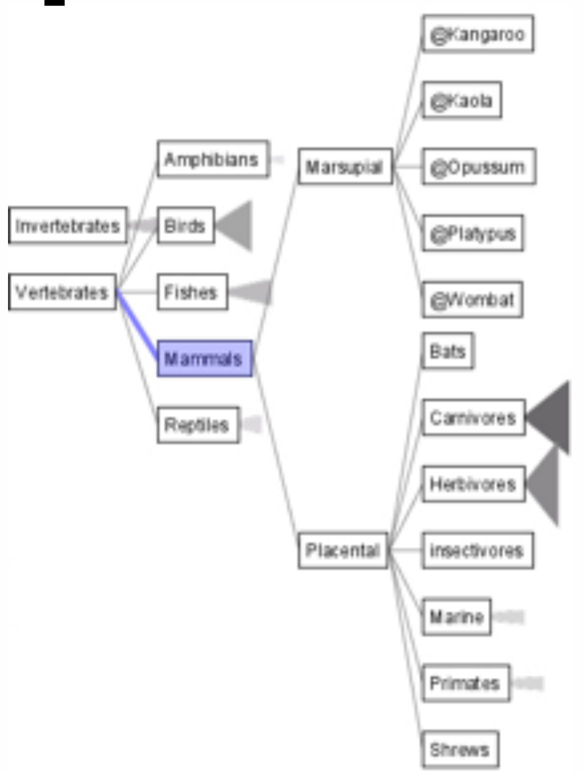
Measure adoption

- mismatch: cannot show idiom good with system timings
- mismatch: cannot show abstraction good with lab study

# Why analyze?

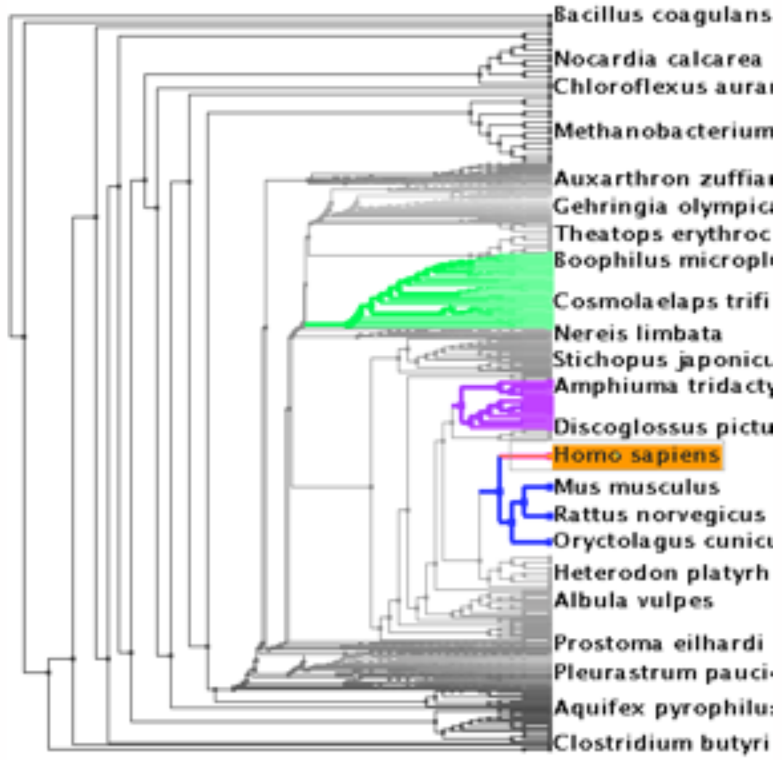
- imposes a structure on huge design space
  - scaffold to help you think systematically about choices
  - analyzing existing as stepping stone to designing new

## 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

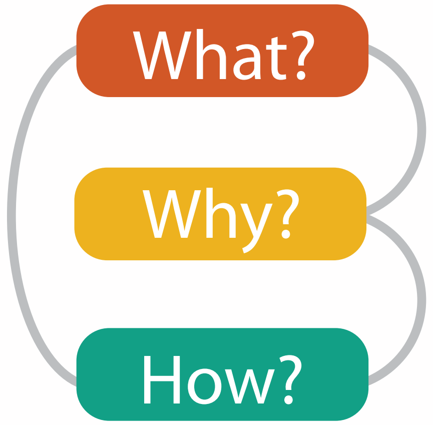
**How?**

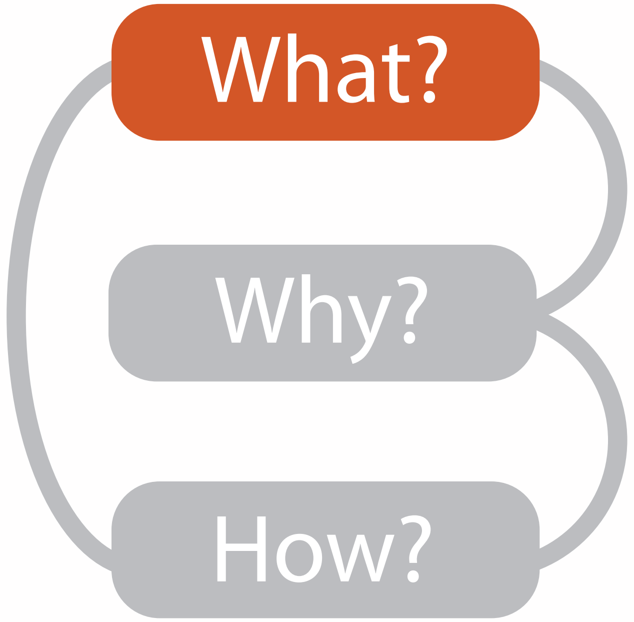
→ SpaceTree

→ Encode → Navigate → Select → Filter → Aggregate

→ TreeJuxtaposer

→ Encode → Navigate → Select → Arrange





# What?

## Datasets

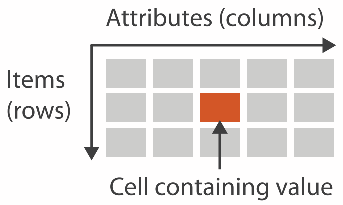
### Data Types
→ Items → Attributes → Links → Positions → Grids

### Data and Dataset Types

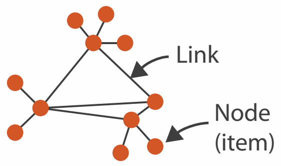
| Tables | Networks & Trees | Fields | Geometry | Clusters, Sets, Lists |
|---|---|---|---|---|
| Items | Items (nodes) | Grids | Items | Items |
| Attributes | Links | Positions | Positions | |
| | Attributes | Attributes | | |

### Dataset Types

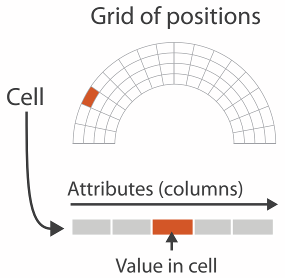
→ Tables



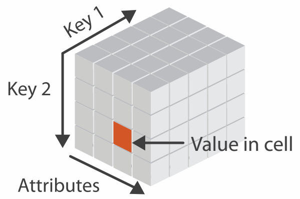
→ Networks



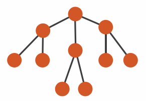
→ Fields (Continuous)



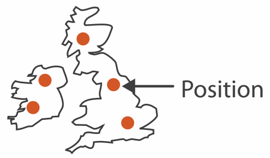
→ *Multidimensional Table*



→ *Trees*



→ Geometry (Spatial)



### Dataset Availability

→ Static

→ Dynamic

## Attributes

### Attribute Types

→ Categorical

✚ ● ■ ▲

→ Ordered

→ *Ordinal*

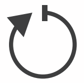
→ *Quantitative*

### Ordering Direction

→ Sequential

→ Diverging

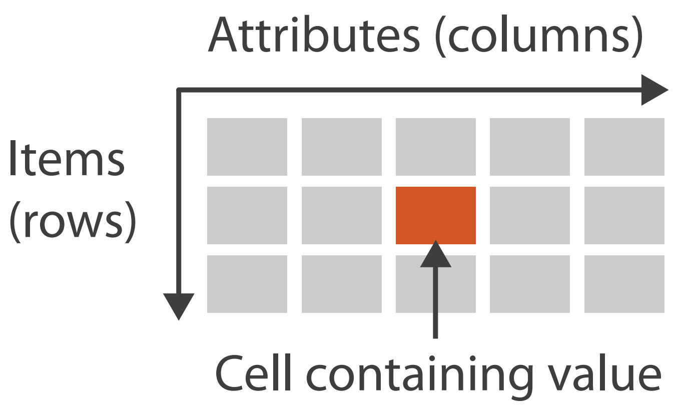
→ Cyclic



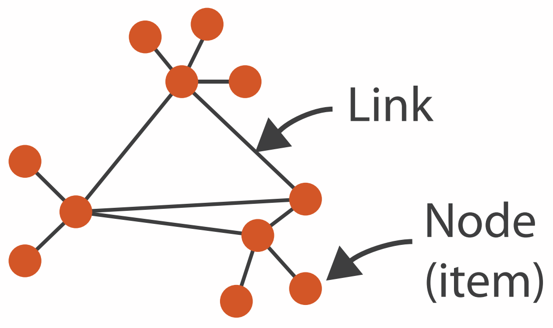
# Dataset and data types

## ➔ Dataset Types

### ➔ Tables

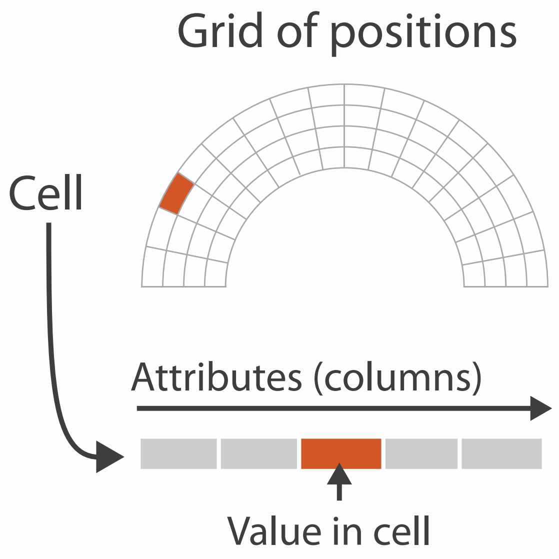


### ➔ Networks

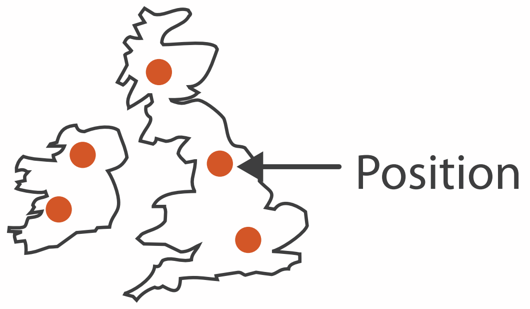


## Spatial

### ➔ Fields (Continuous)



### ➔ Geometry (Spatial)

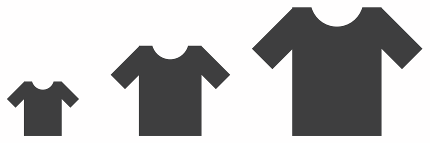


## ➔ Attribute Types

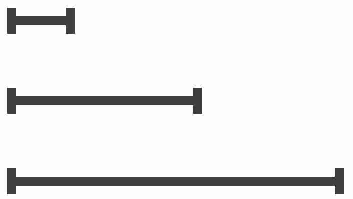
### ➔ Categorical

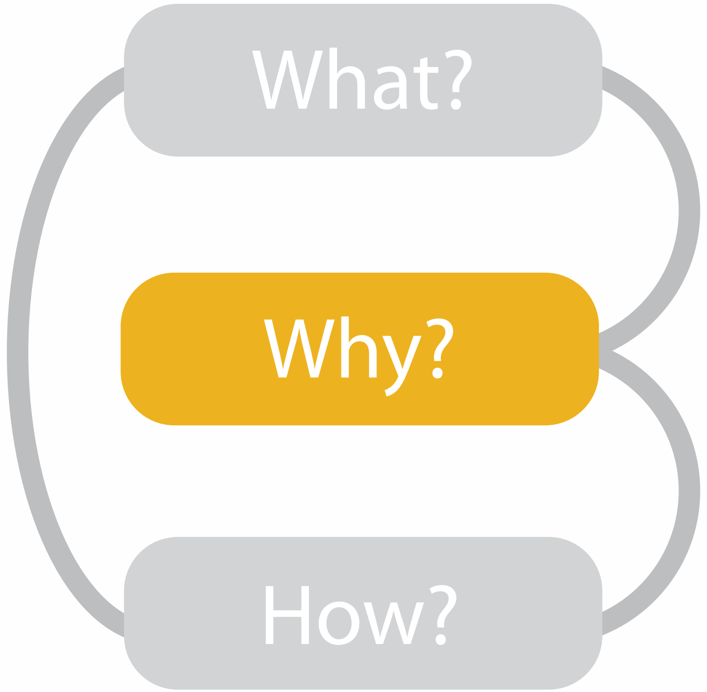
### ➔ Ordered

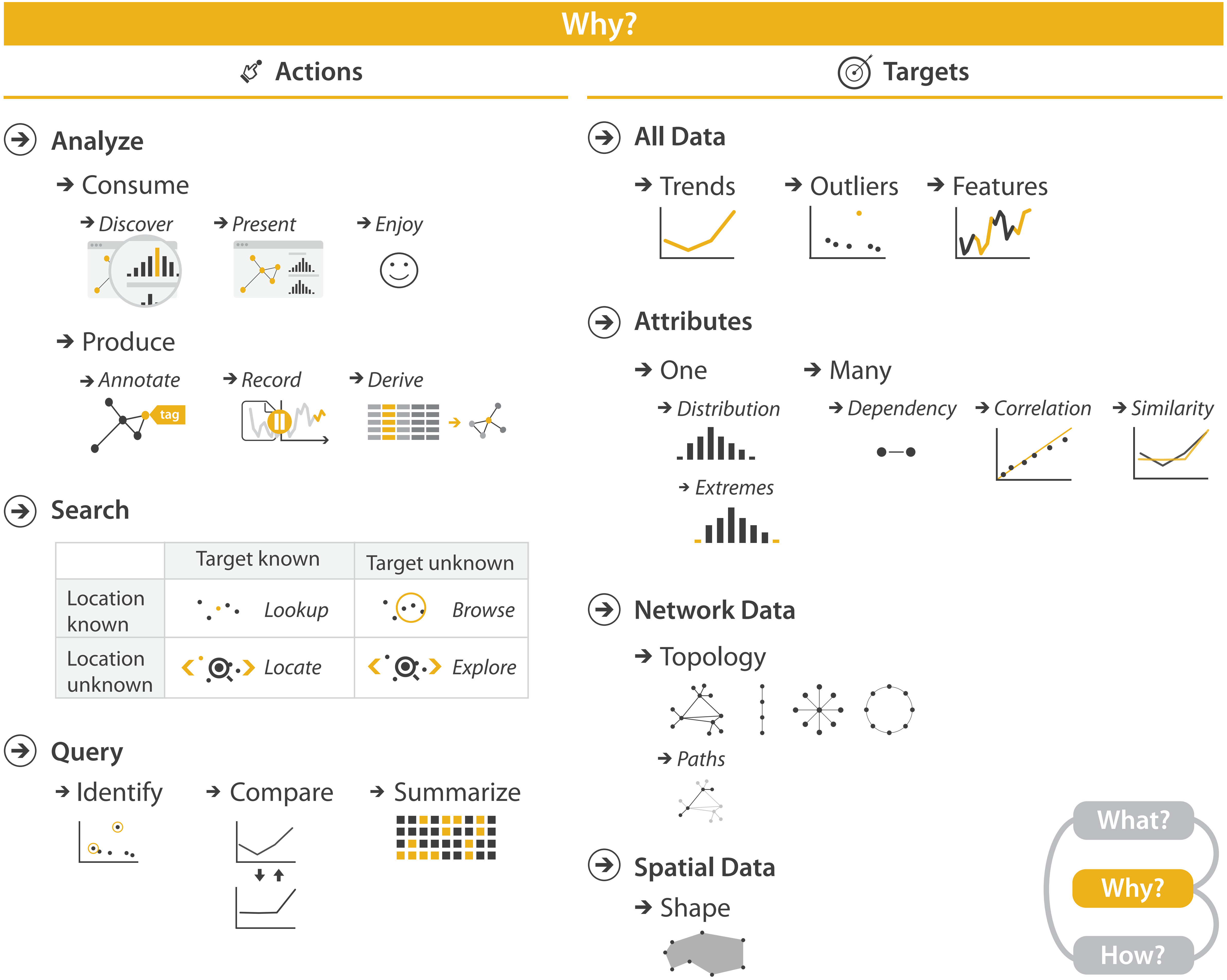
#### ➔ *Ordinal*



#### ➔ *Quantitative*







# 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*

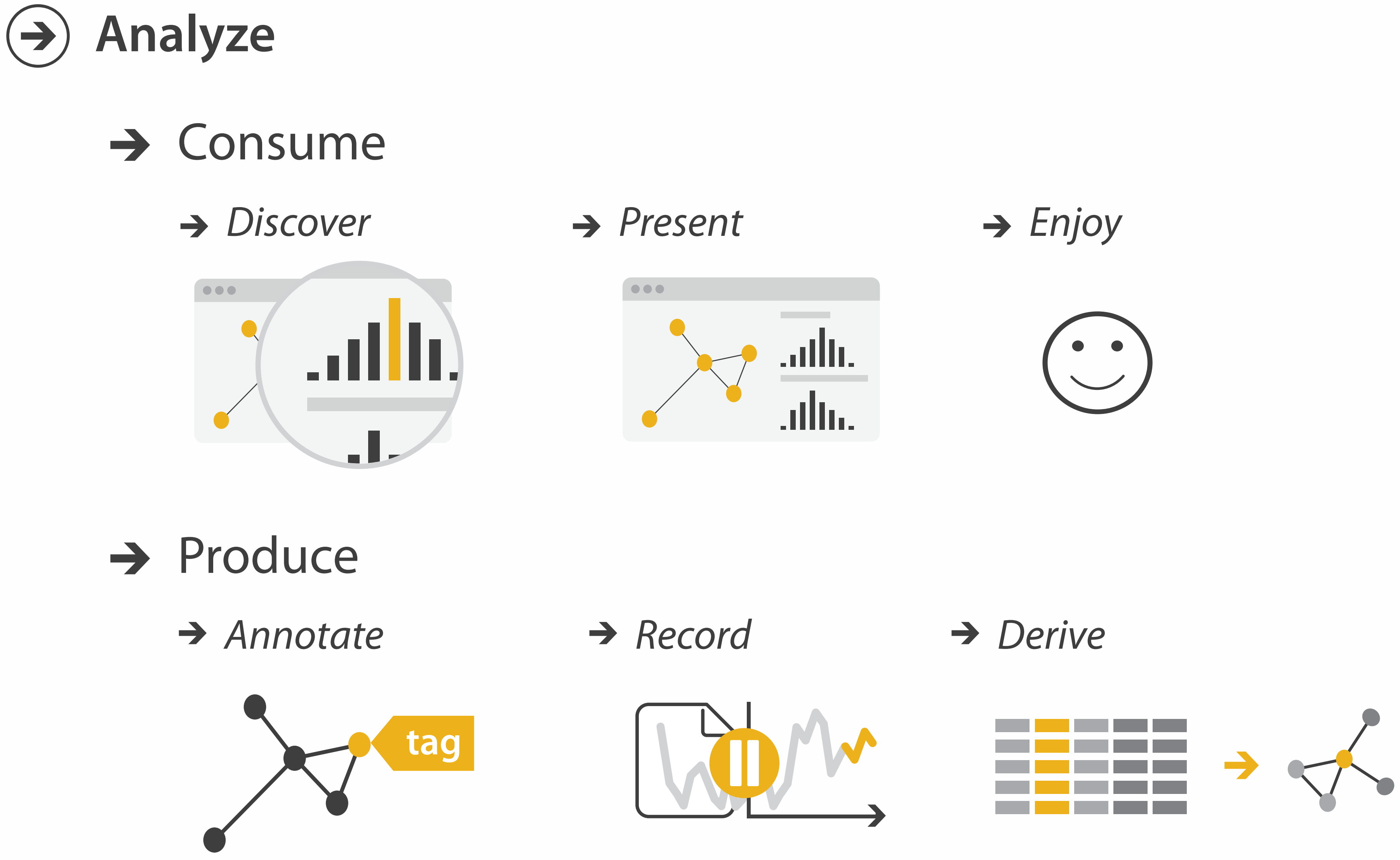
### Spatial Data

- Shape

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

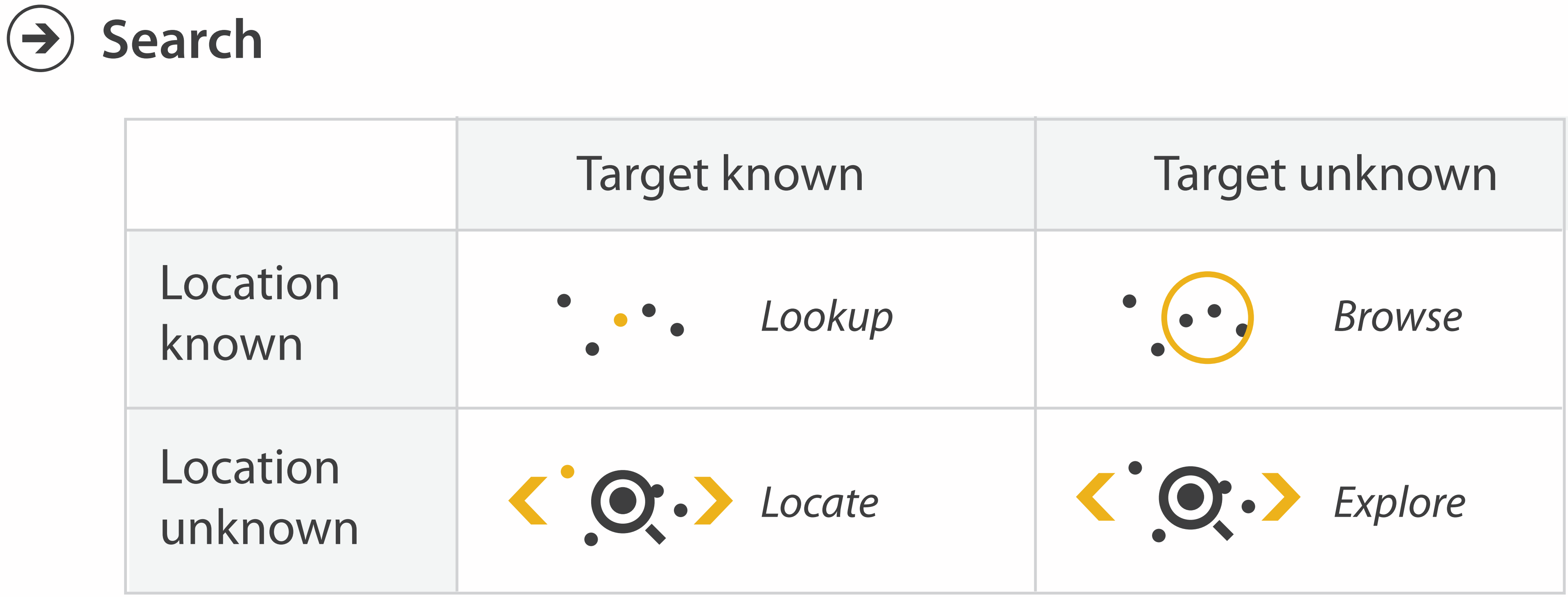
# Actions 1:Analyze

- consume
  - discover vs present
    - classic split
    - aka explore vs explain
  - enjoy
    - newcomer
    - aka casual, social
- produce
  - annotate, record
  - derive
    - crucial design choice



# Actions II: Search

- what does user know?
  - target, location



Search

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

# Actions III: Query

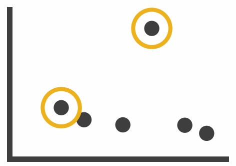
- what does user know?
  - target, location
- how much of the data matters?
  - one, some, all

➔ Search

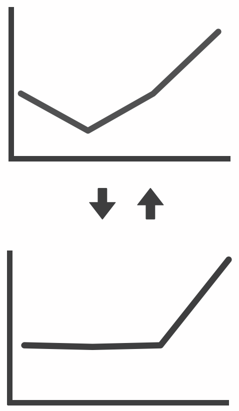
| | Target known | Target unknown |
|---|---|---|
| Location known | *Lookup* | *Browse* |
| Location unknown | *Locate* | *Explore* |

➔ Query

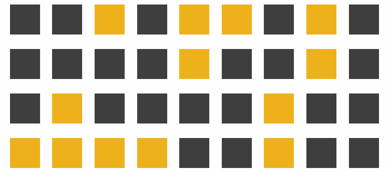
➔ Identify



➔ Compare



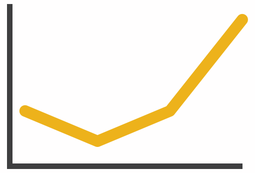
➔ Summarize



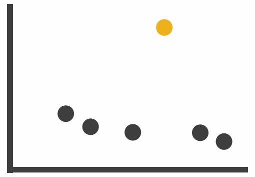
# Targets

## ➔ All Data

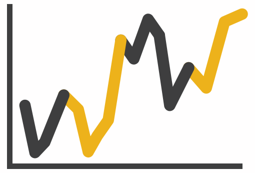
➔ Trends



➔ Outliers



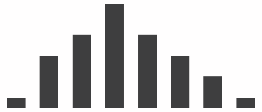
➔ Features



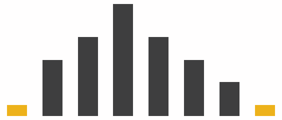
## ➔ Attributes

➔ One

➔ *Distribution*



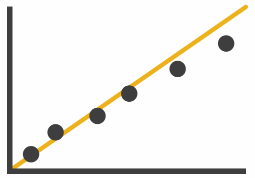
➔ *Extremes*



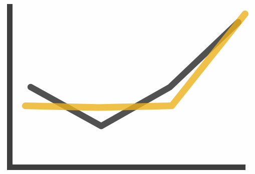
➔ Many

➔ *Dependency*

➔ *Correlation*

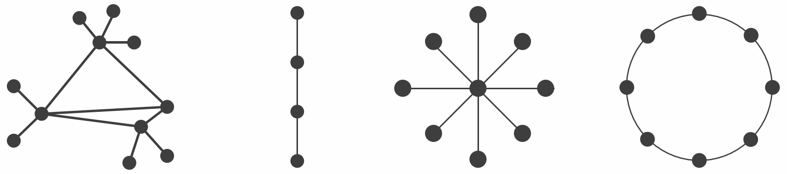


➔ *Similarity*

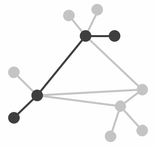


## ➔ Network Data

➔ Topology

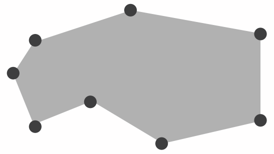


➔ *Paths*

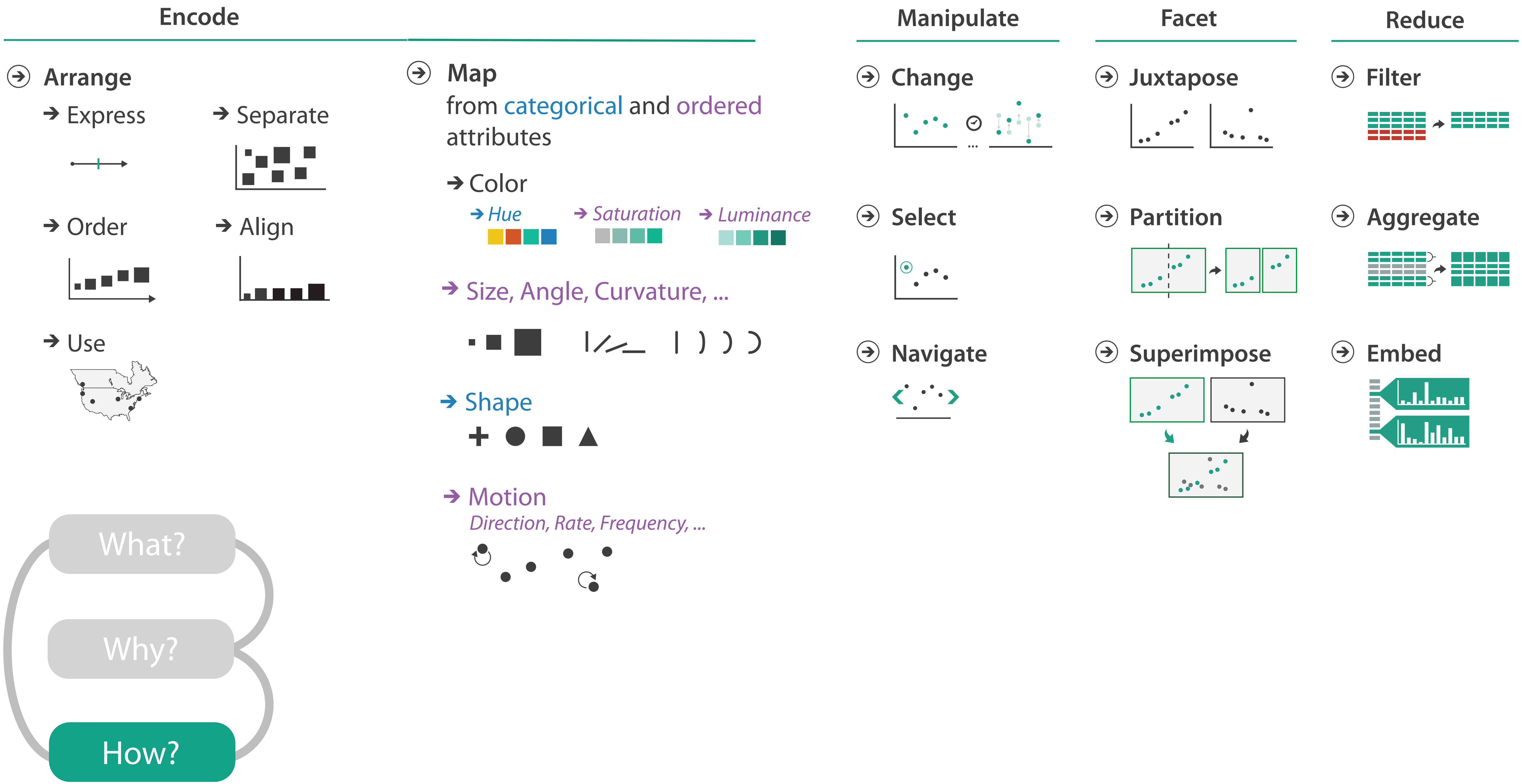


## ➔ Spatial Data

➔ Shape



# How?



## Encode

**Arrange**

- Express
- Separate
- Order
- Align
- Use

**Map**

from categorical and ordered attributes

- Color
  - Hue
  - Saturation
  - Luminance
- Size, Angle, Curvature, ...
- Shape
- Motion

*Direction, Rate, Frequency, ...*

## Manipulate

- Change
- Select
- Navigate

## Facet

- Juxtapose
- Partition
- Superimpose

## Reduce

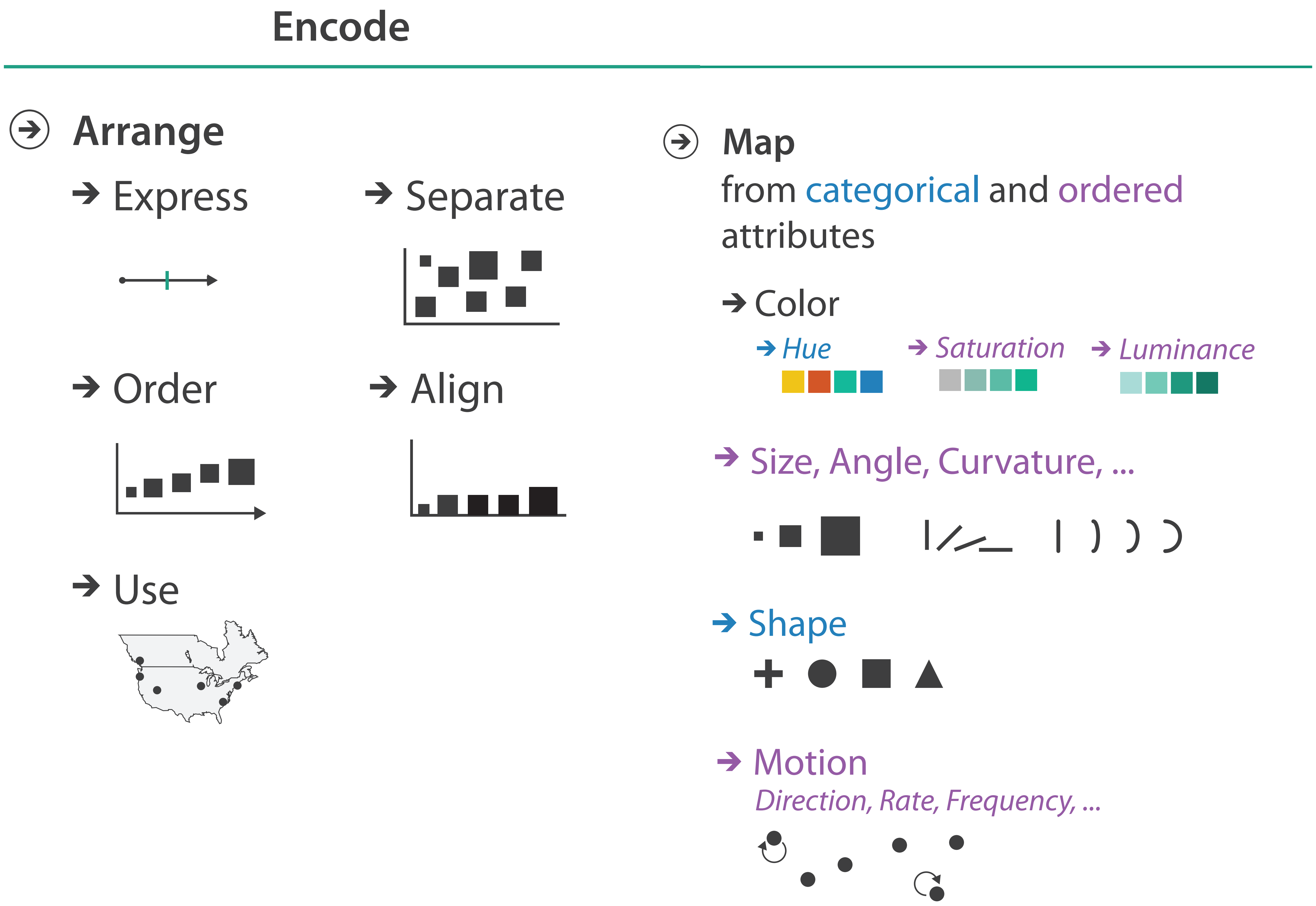
- Filter
- Aggregate
- Embed

What?

Why?

How?

# How to encode: Arrange space, map channels



**Encode**

**Arrange**

- Express
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**Map**

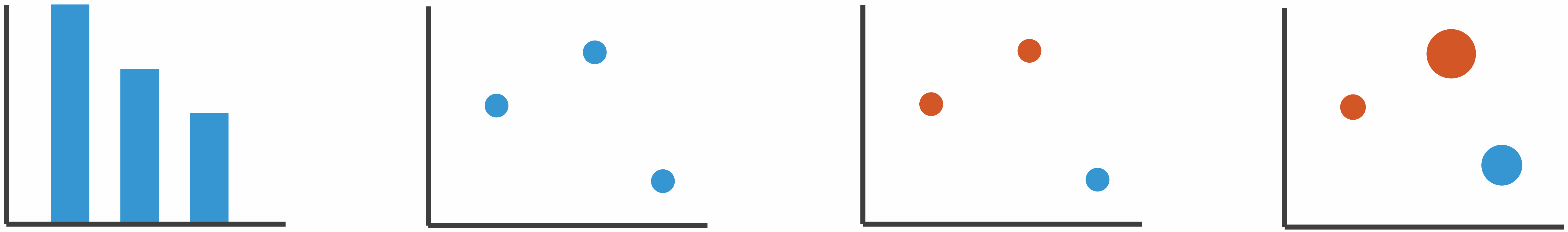
from categorical and ordered attributes

- Color
  - *Hue*
  - *Saturation*
  - *Luminance*
- Size, Angle, Curvature, ...
- Shape
- Motion

  *Direction, Rate, Frequency, ...*

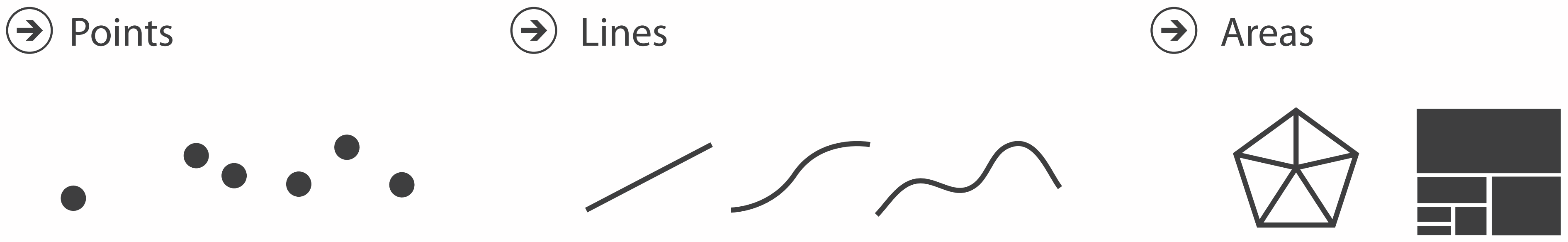
# Encoding visually

- analyze idiom structure



# Definitions: Marks and channels

- marks
  - geometric primitives

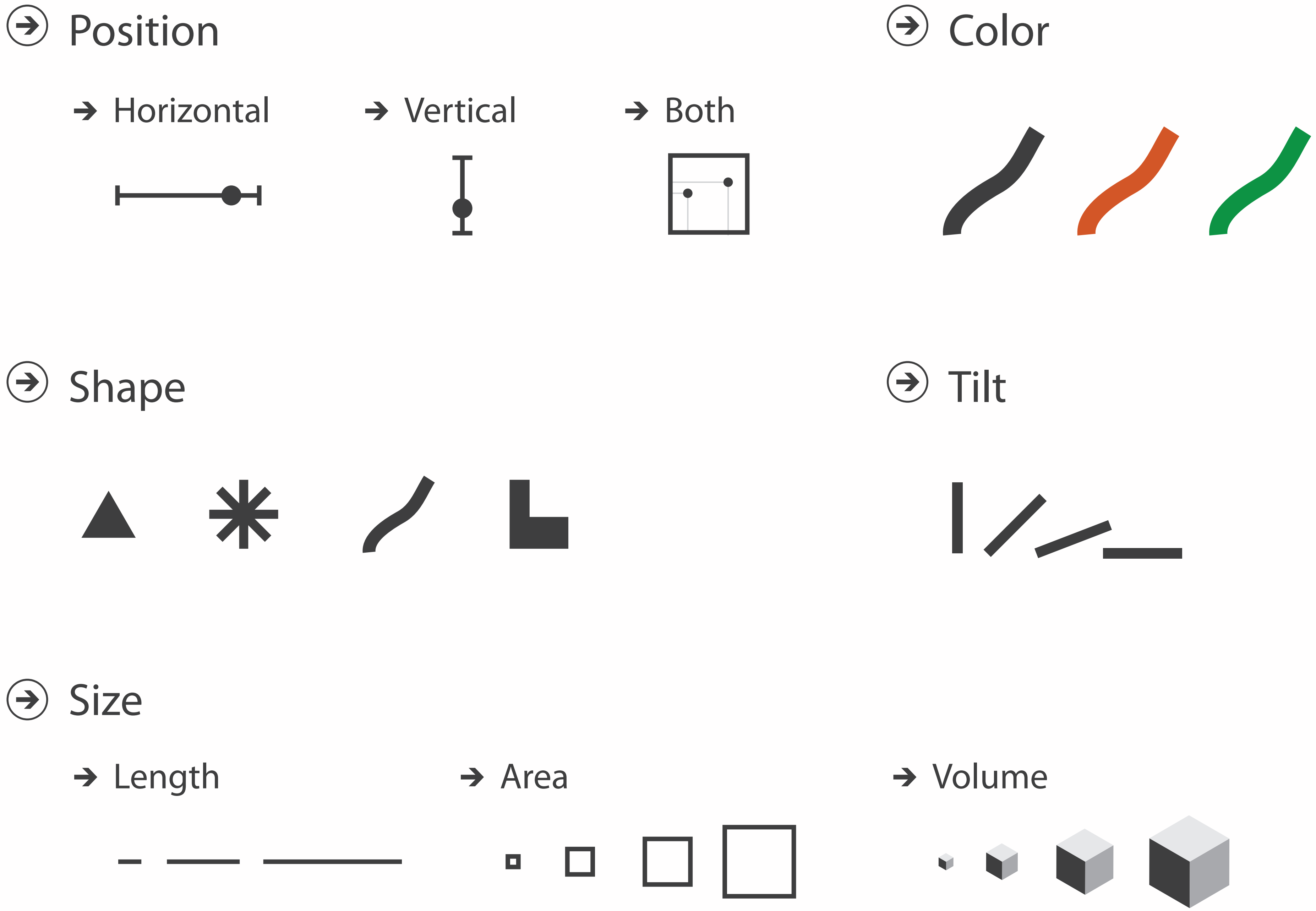


➔ Points

➔ Lines

➔ Areas

- channels
  - control appearance of marks



➔ Position

→ Horizontal

→ Vertical

→ Both

➔ Color

➔ Shape

➔ Tilt

➔ Size

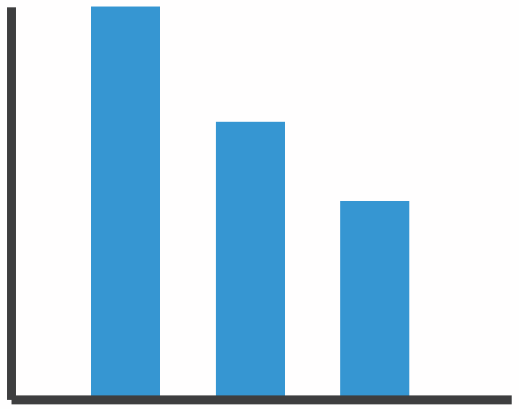
→ Length

→ Area

→ Volume

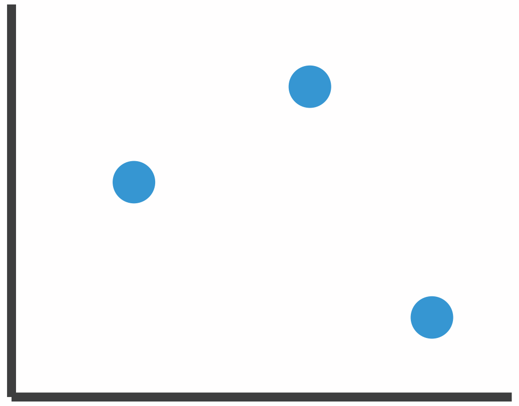
# Encoding visually with marks and channels

- analyze idiom structure
  - as combination of marks and channels



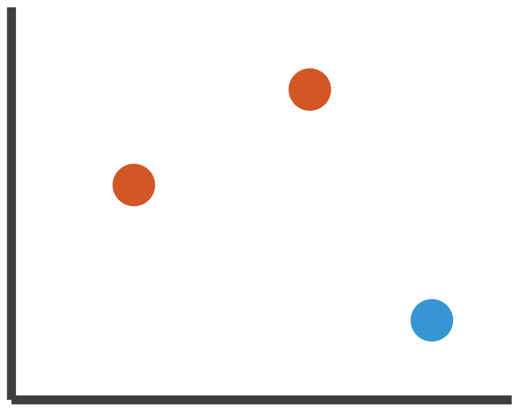
1:
vertical position

mark: line



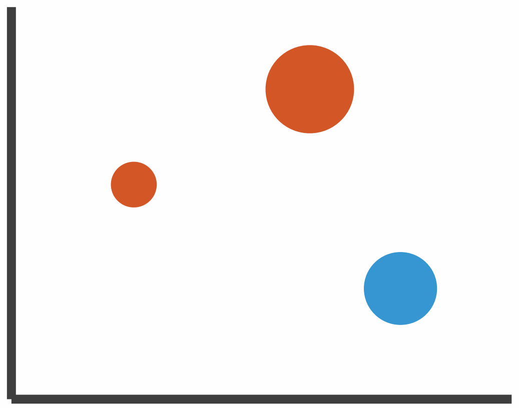
2:
vertical position
horizontal position

mark: point



3:
vertical position
horizontal position
color hue

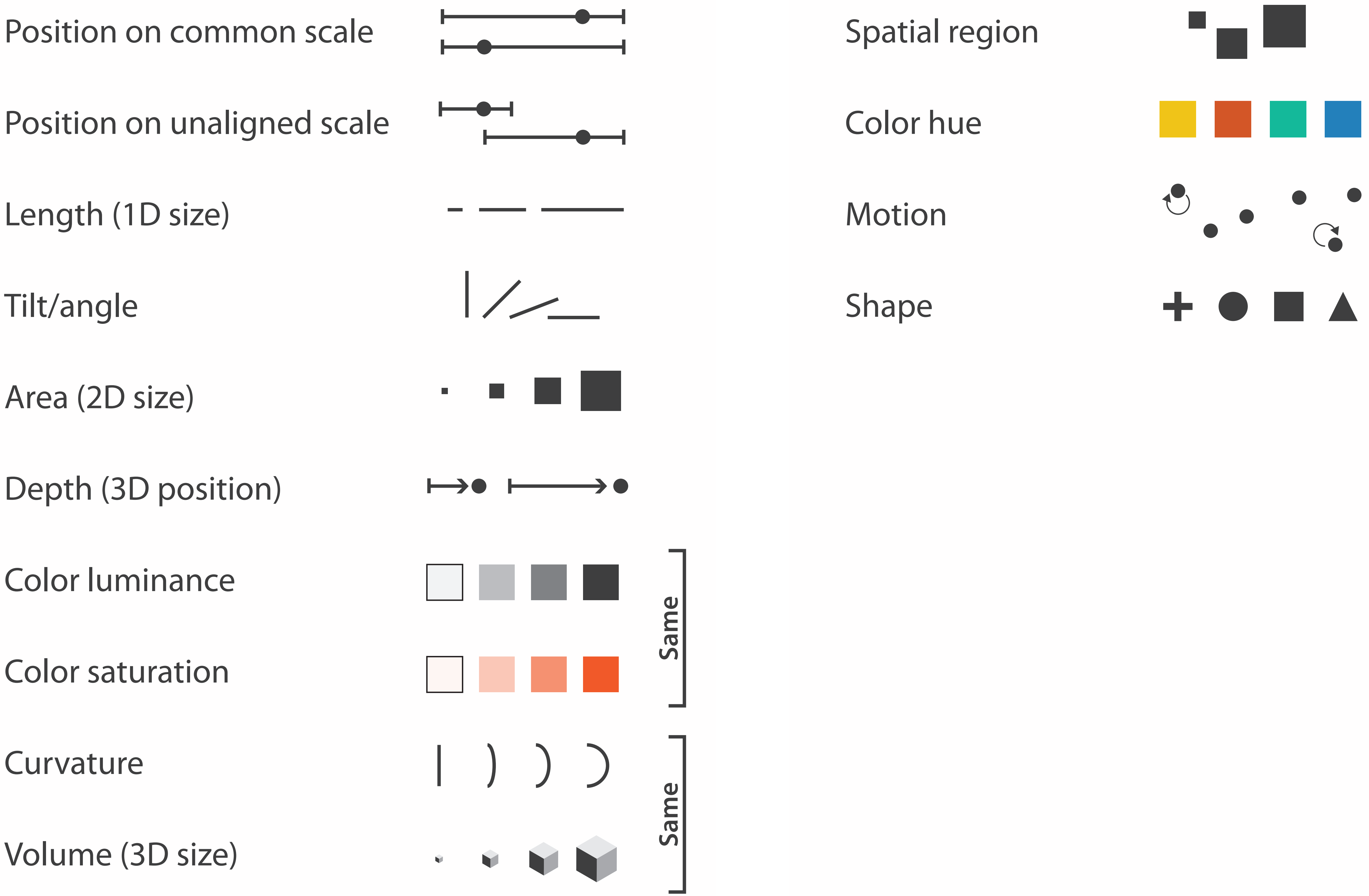
mark: point



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

mark: point

# Channels



Position on common scale

Position on unaligned scale

Length (1D size)

Tilt/angle

Area (2D size)

Depth (3D position)

Color luminance

Color saturation

Curvature

Volume (3D size)

Same

Same

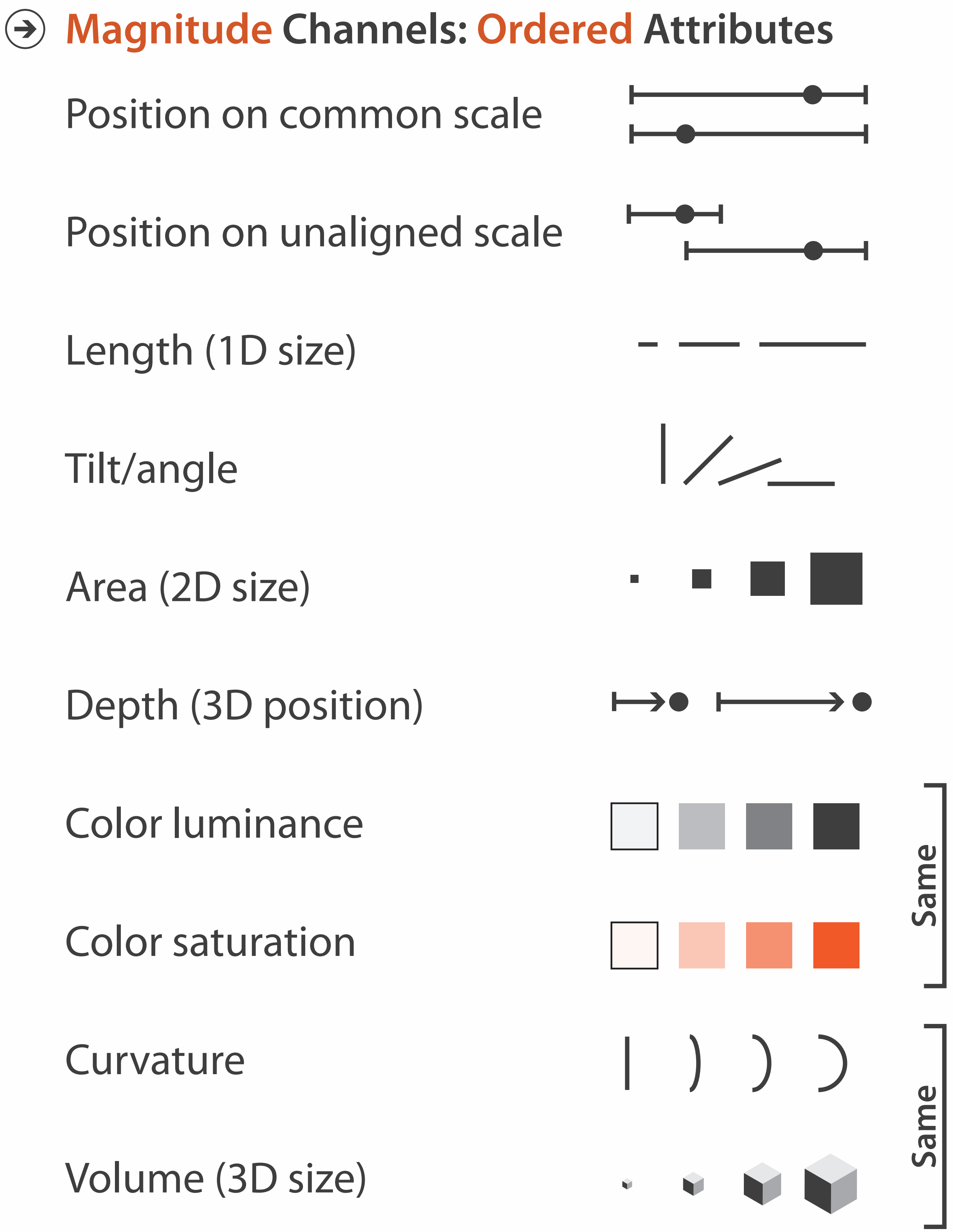
Spatial region

Color hue

Motion

Shape

# Channels: Matching Types



**Magnitude Channels: Ordered Attributes**

Position on common scale

Position on unaligned scale

Length (1D size)

Tilt/angle

Area (2D size)

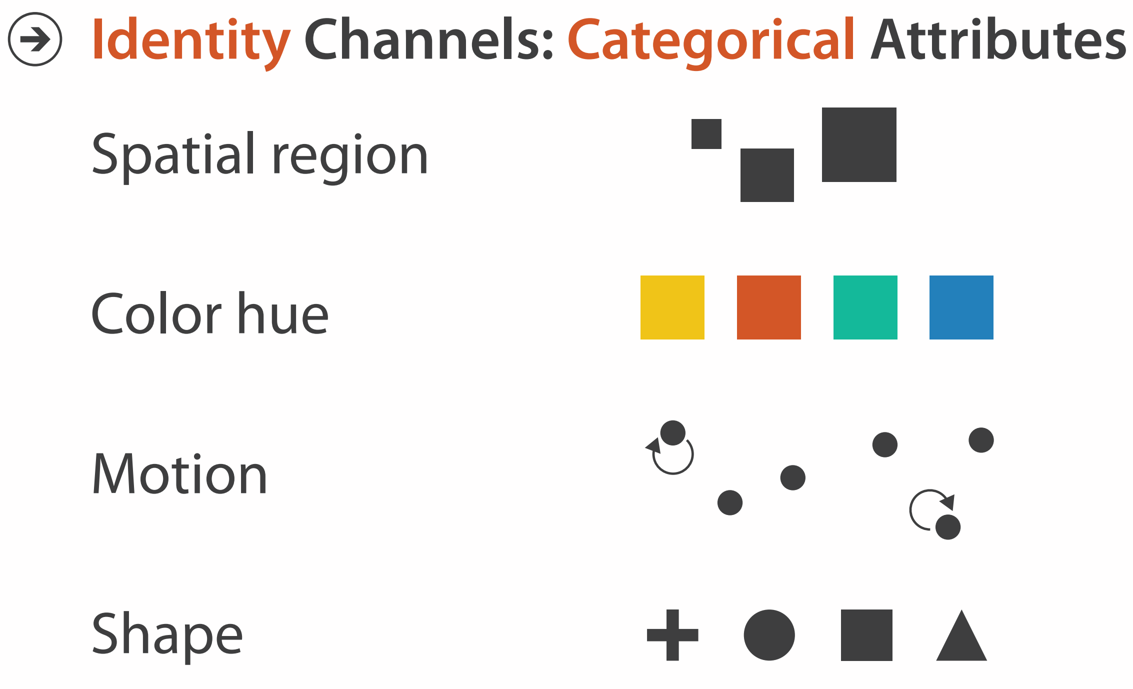
Depth (3D position)

Color luminance

Color saturation

Curvature

Volume (3D size)



**Identity Channels: Categorical Attributes**

Spatial region

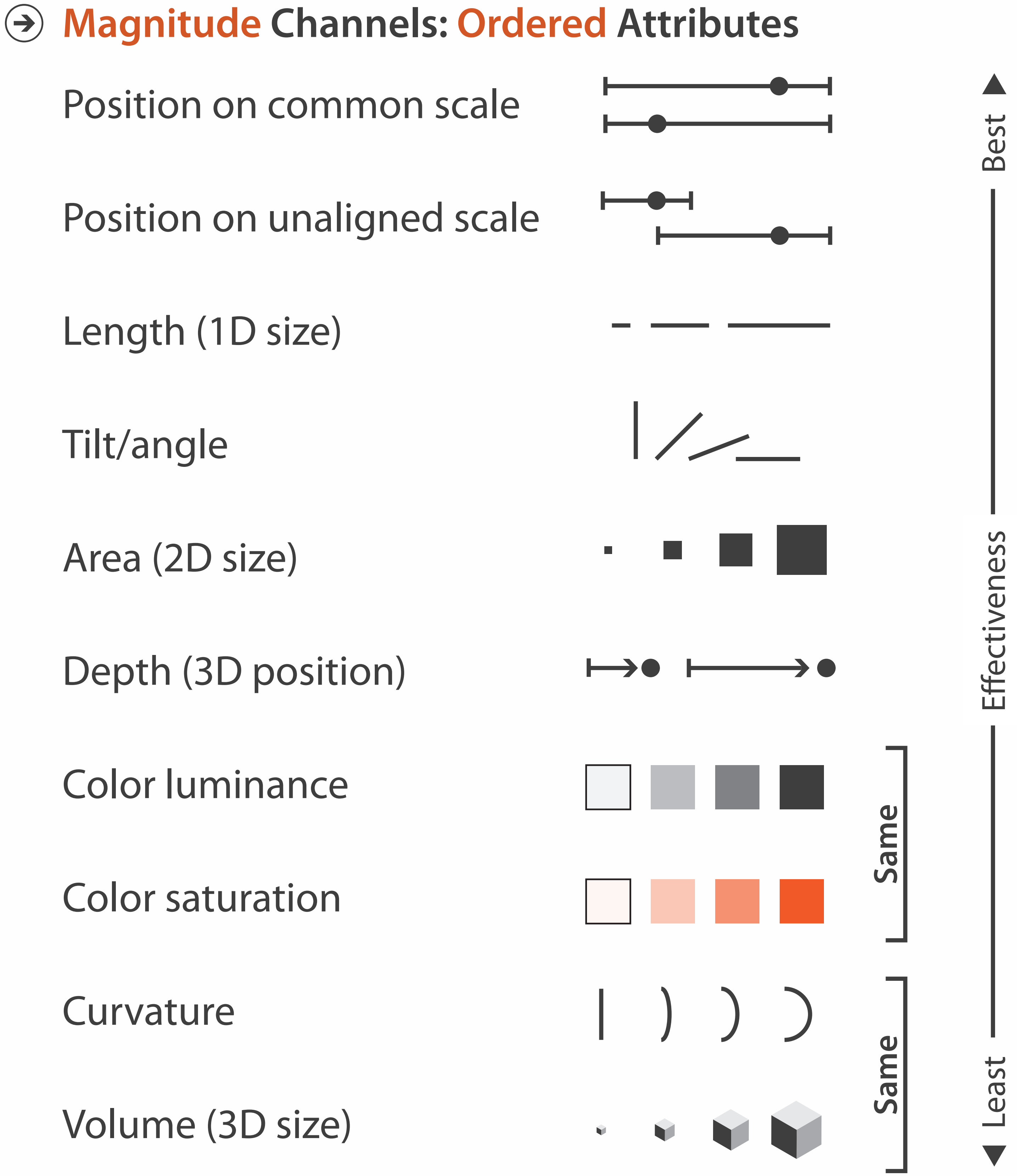
Color hue

Motion

Shape

- expressiveness principle
  - match channel and data characteristics

# Channels: Rankings



Magnitude Channels: Ordered Attributes

Position on common scale

Position on unaligned scale

Length (1D size)

Tilt/angle

Area (2D size)

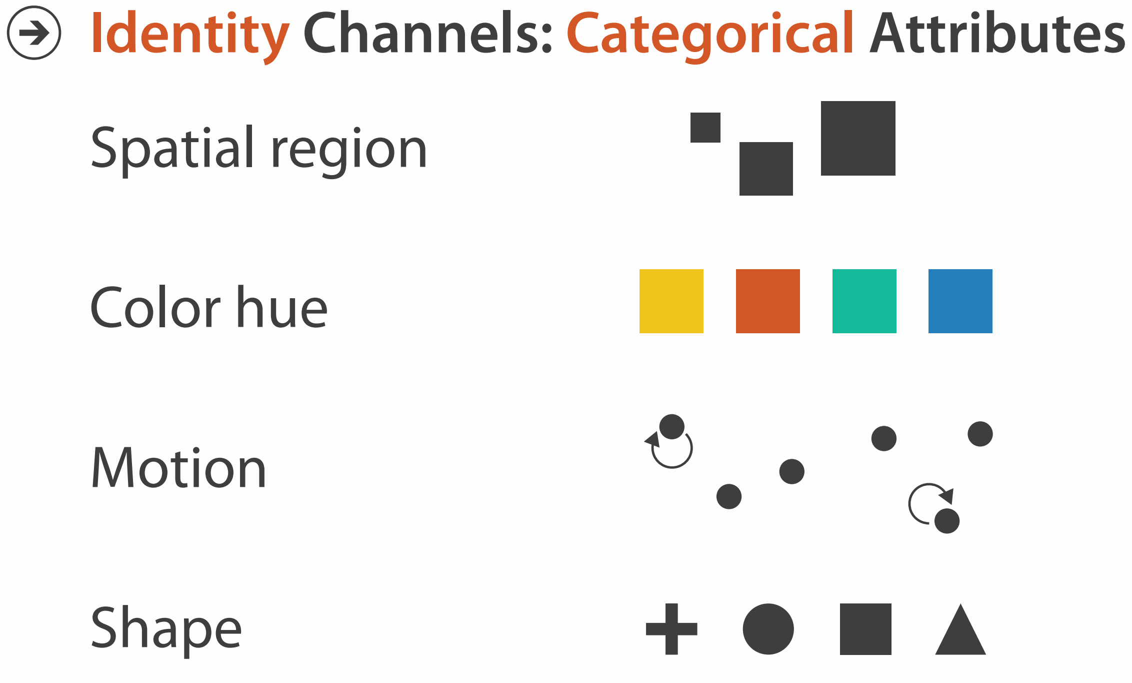
Depth (3D position)

Color luminance

Color saturation

Curvature

Volume (3D size)



Identity Channels: Categorical Attributes

Spatial region

Color hue

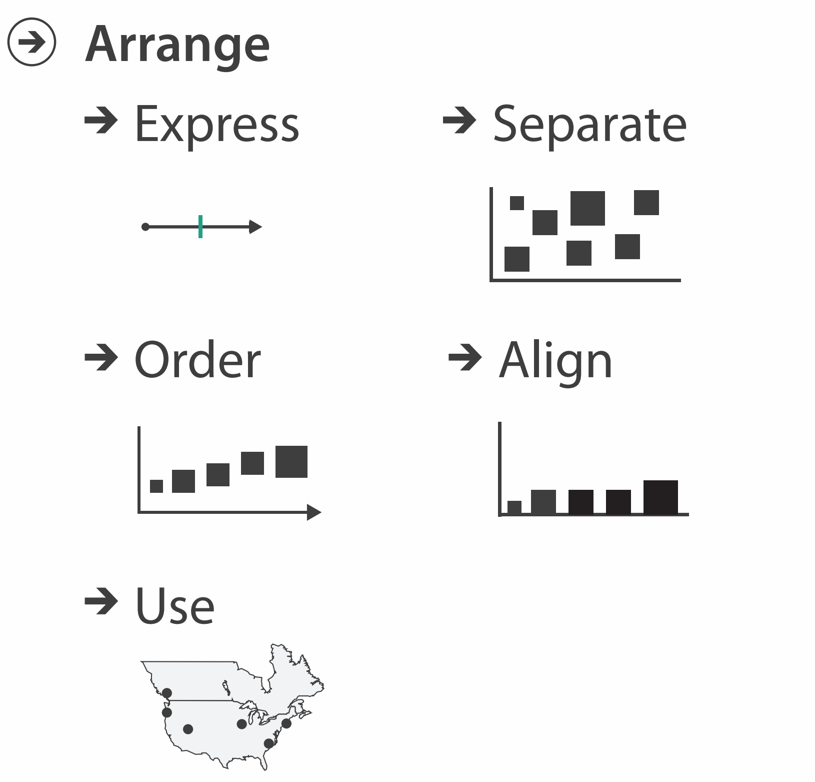
Motion

Shape

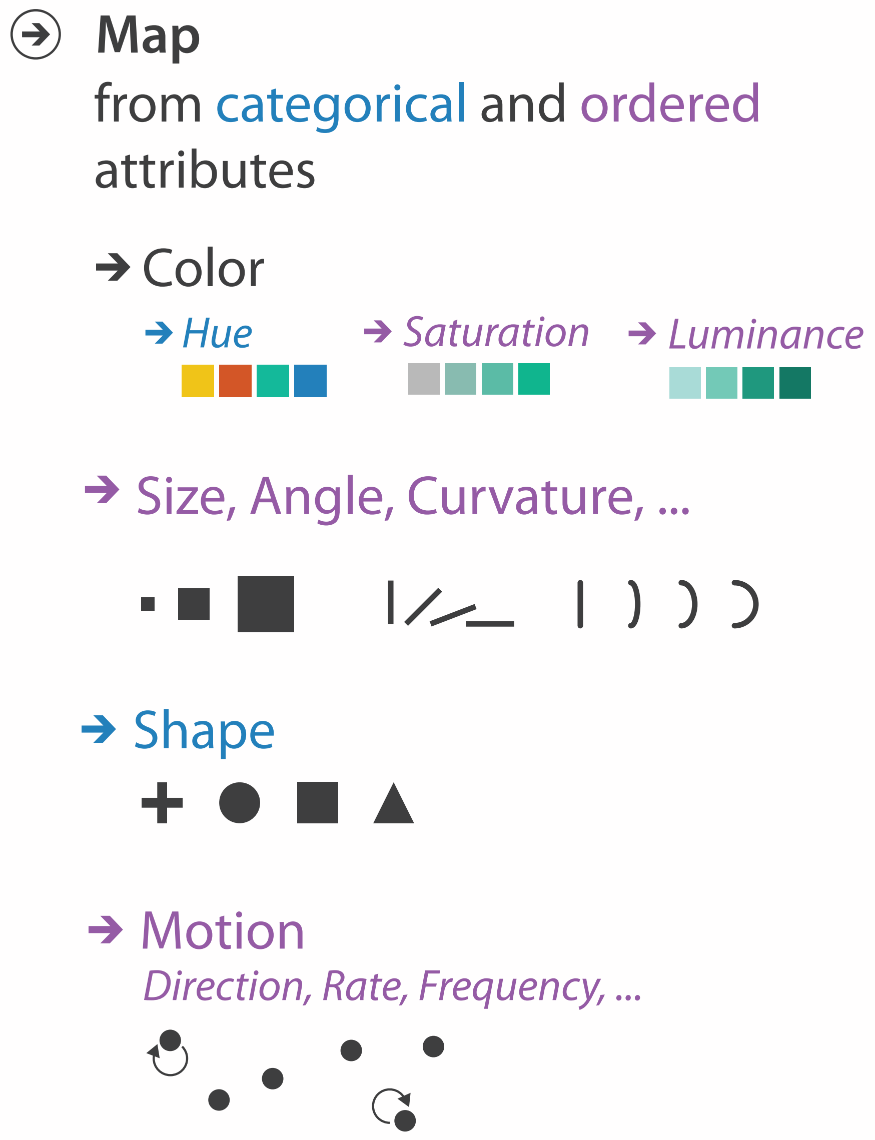
- expressiveness principle
  - match channel and data characteristics
- effectiveness principle
  - encode most important attributes with highest ranked channels

# How?

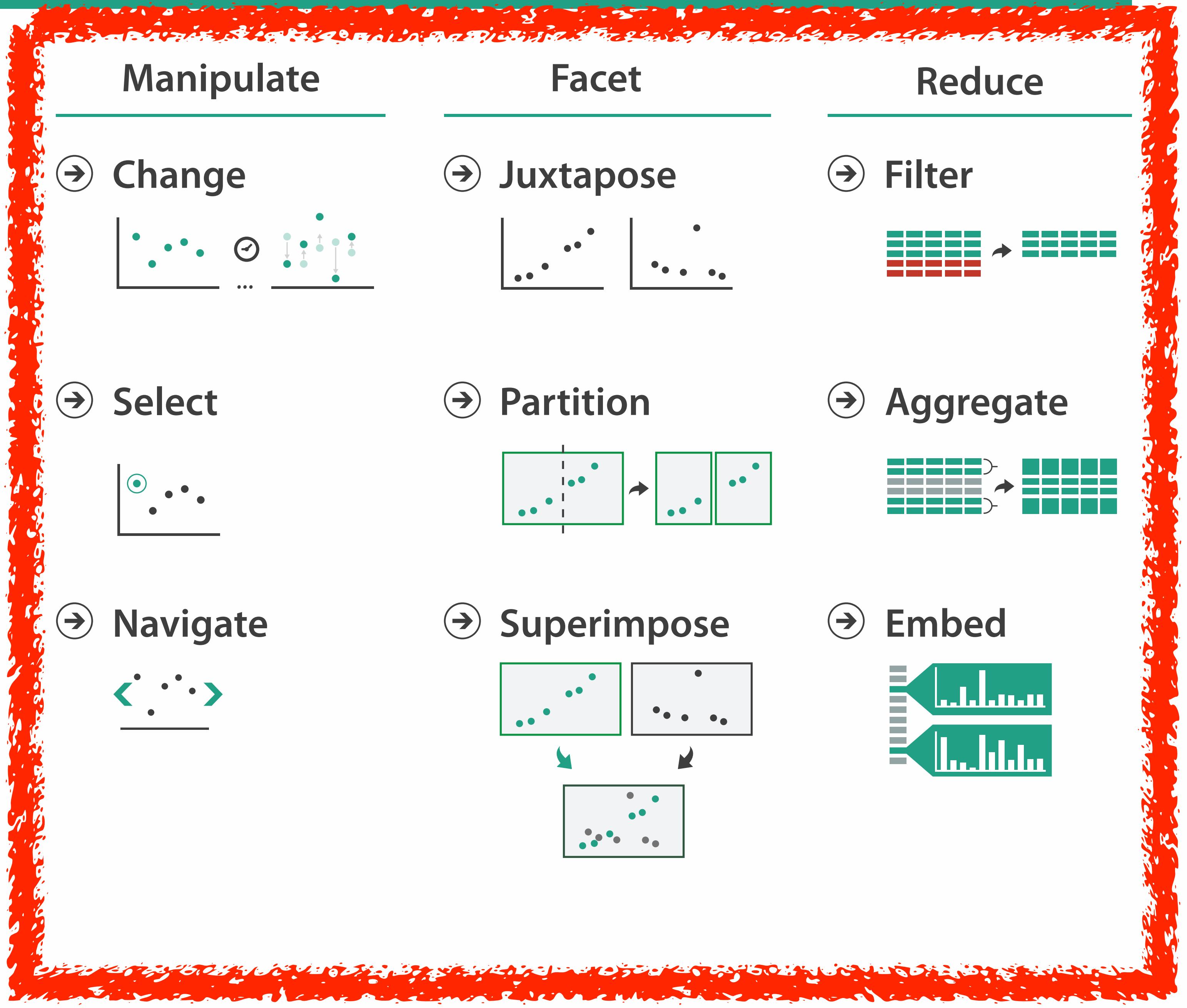
## Encode



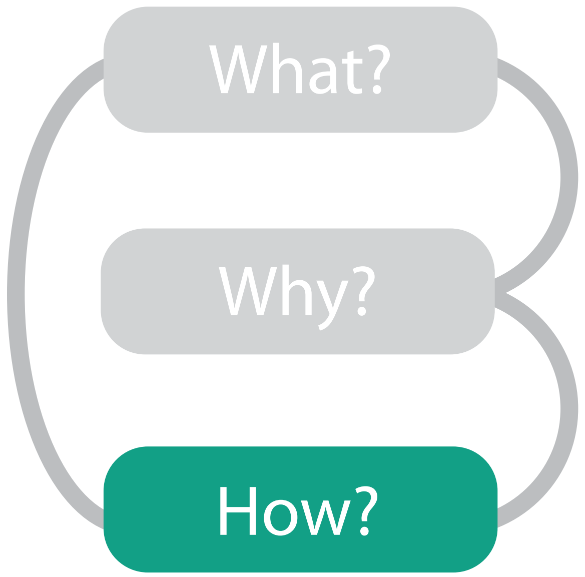
Arrange
→ Express
→ Separate
→ Order
→ Align
→ Use



Map
from categorical and ordered attributes
→ Color
→ Hue
→ Saturation
→ Luminance
→ Size, Angle, Curvature, ...
→ Shape
→ Motion
Direction, Rate, Frequency, ...



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

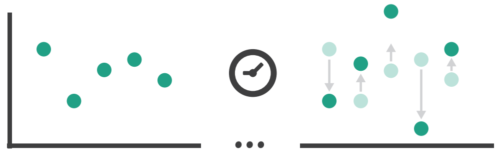


What?
Why?
How?

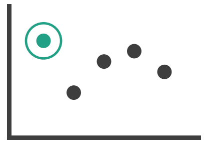
# How to handle complexity: 3 more strategies + 1 previous

### Manipulate

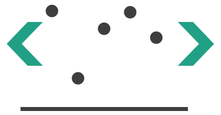
➔ Change



➔ Select

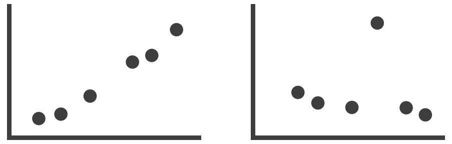


➔ Navigate

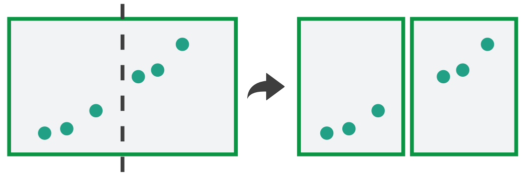


### Facet

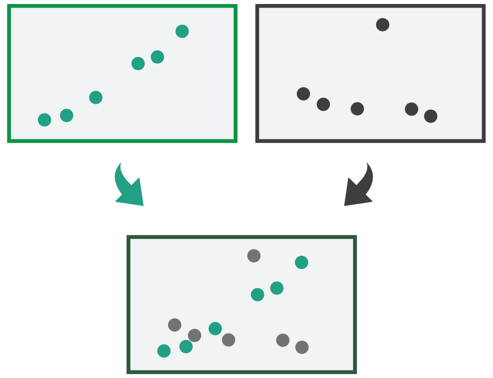
➔ Juxtapose



➔ Partition

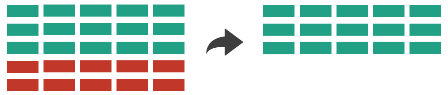


➔ Superimpose

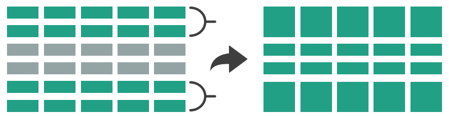


### Reduce

➔ Filter

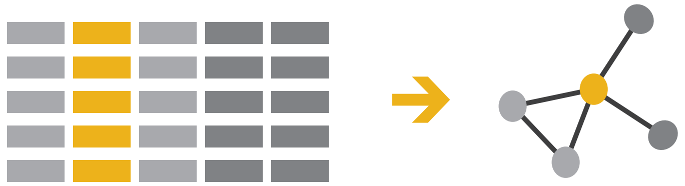


➔ Aggregate



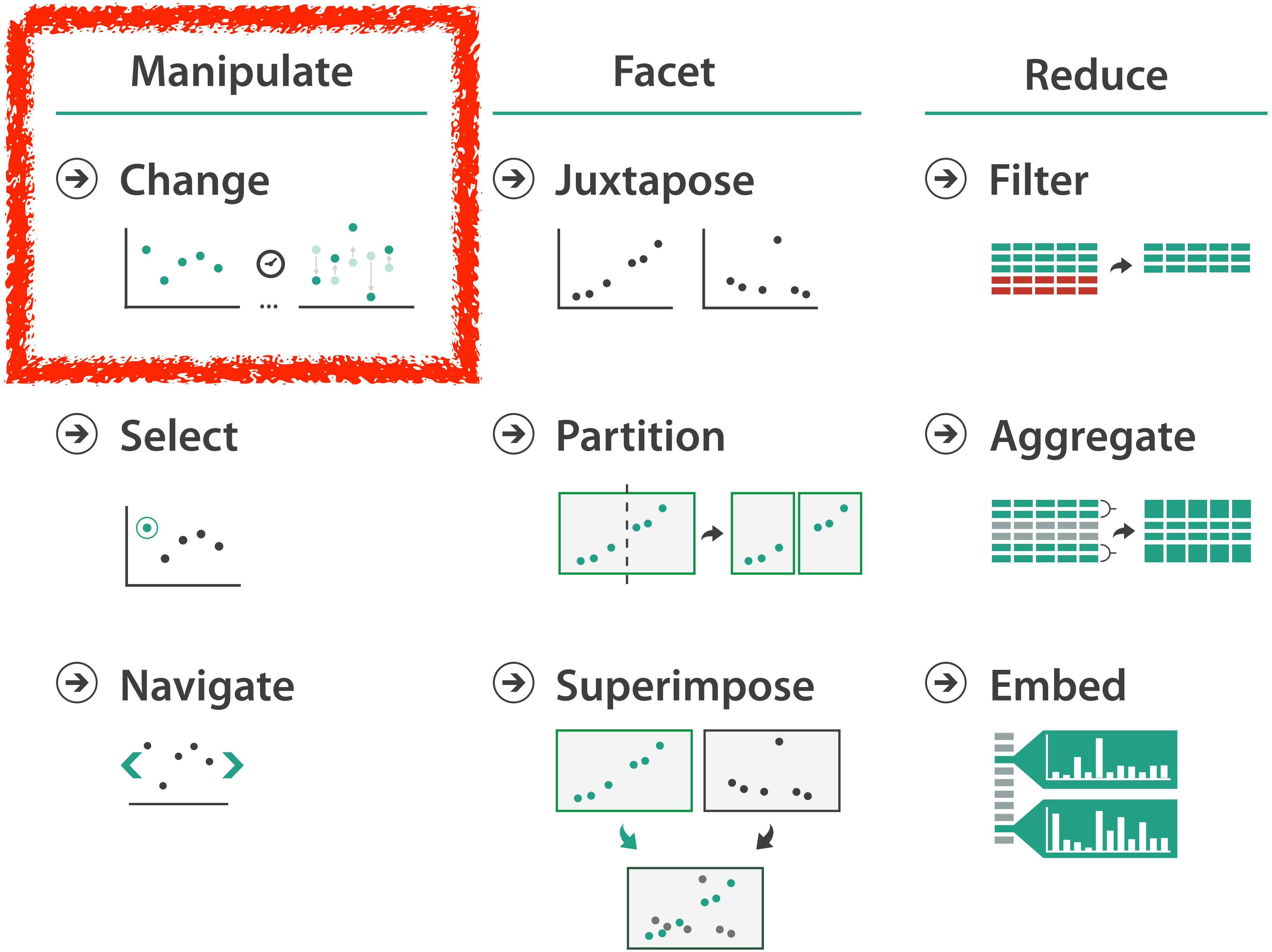
➔ Embed

→ *Derive*



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

# How to handle complexity: 3 more strategies + 1 previous



Manipulate

Change

Select

Navigate

Facet

Juxtapose

Partition

Superimpose

Reduce

Filter

Aggregate

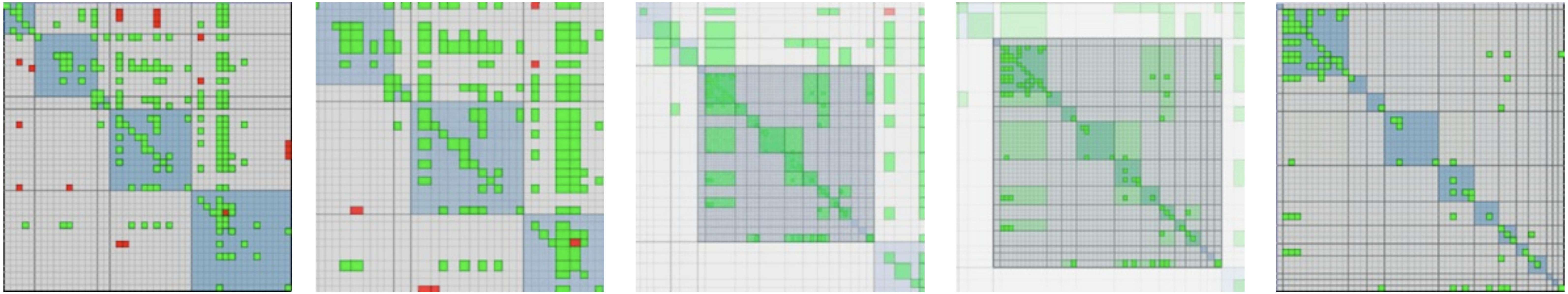
Embed

Derive

- change over time
  - most obvious & flexible of the 4 strategies

# Idiom: **Animated transitions**

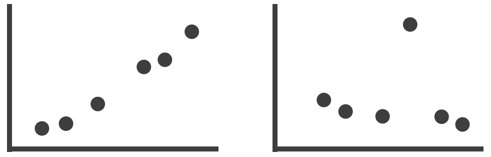
- smooth transition from one state to another
  - alternative to jump cuts
  - support for item tracking when amount of change is limited
- example: multilevel matrix views
  - scope of what is shown narrows down
    - middle block stretches to fill space, additional structure appears within
    - other blocks squish down to increasingly aggregated representations



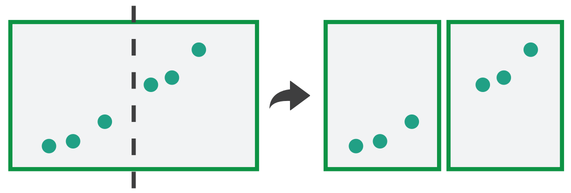
*[Using Multilevel Call Matrices in Large Software Projects. van Ham. Proc. IEEE Symp. Information Visualization (InfoVis), pp. 227–232, 2003.]*

# Facet

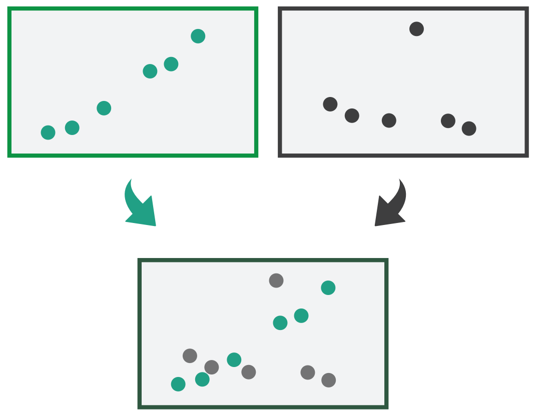
- Juxtapose



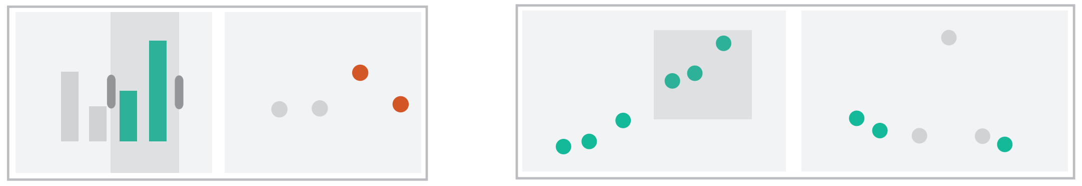
- Partition



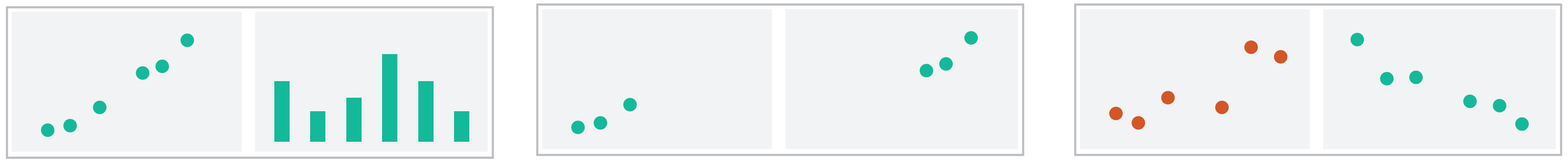
- Superimpose



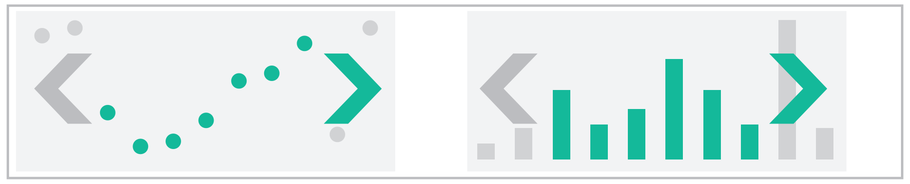
- Coordinate Multiple Side By Side Views
  - Share Encoding: Same/Different
    - *Linked Highlighting*



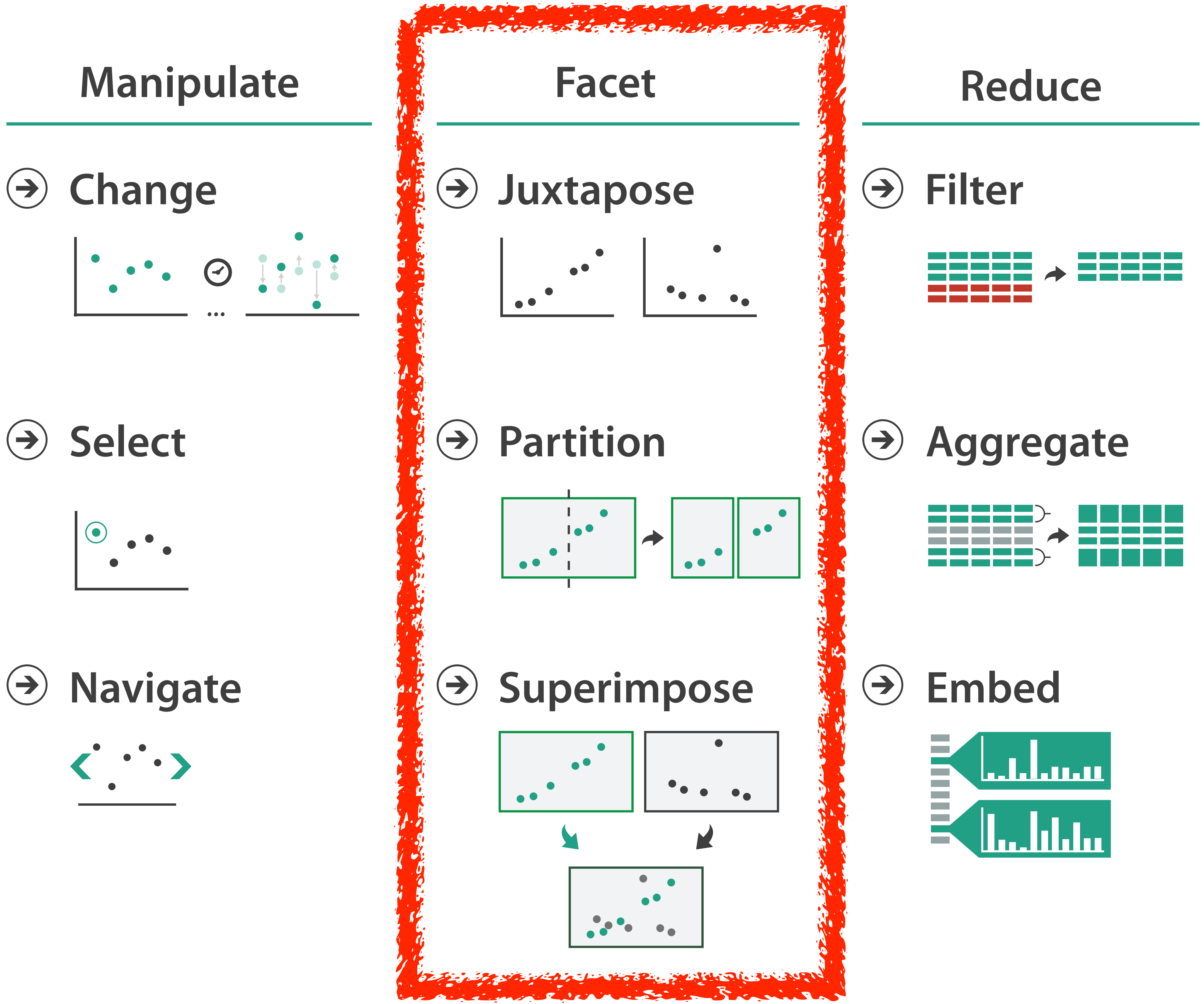
  - Share Data: All/Subset/None



  - Share Navigation



# How to handle complexity: 3 more strategies + 1 previous



Manipulate

Change

Select

Navigate

Facet

Juxtapose

Partition

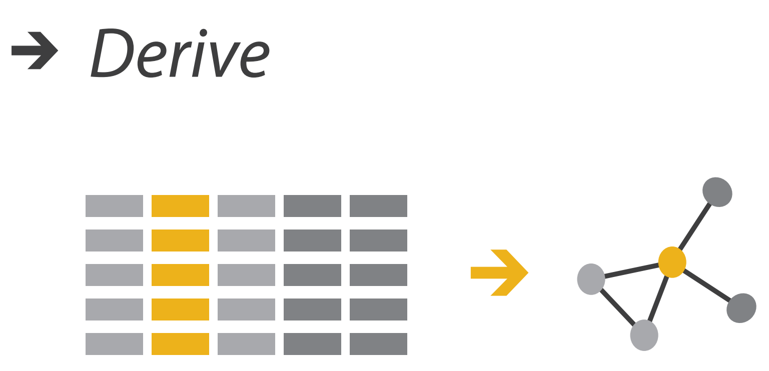
Superimpose

Reduce

Filter

Aggregate

Embed



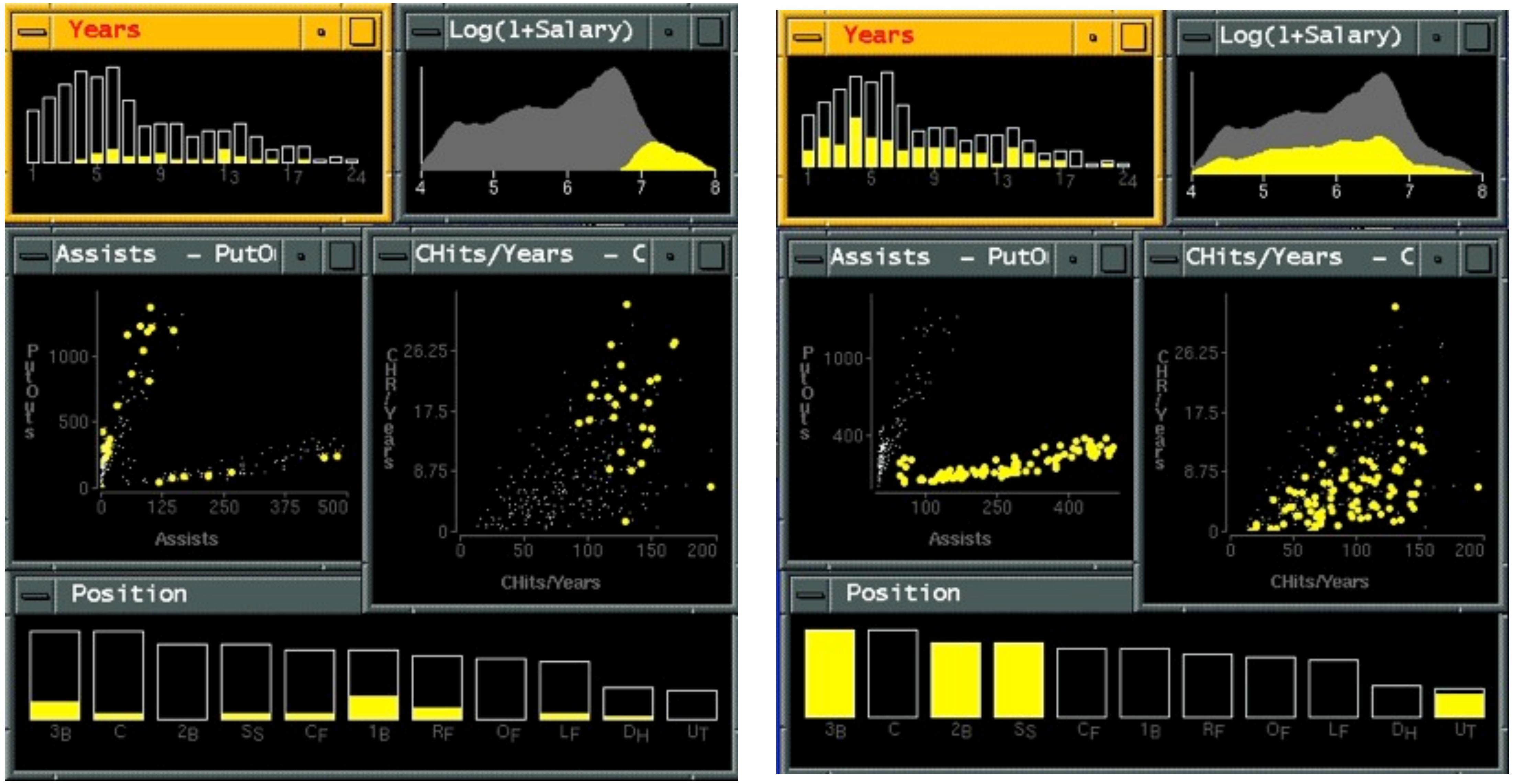
Derive

- facet data across multiple views

# 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.]*

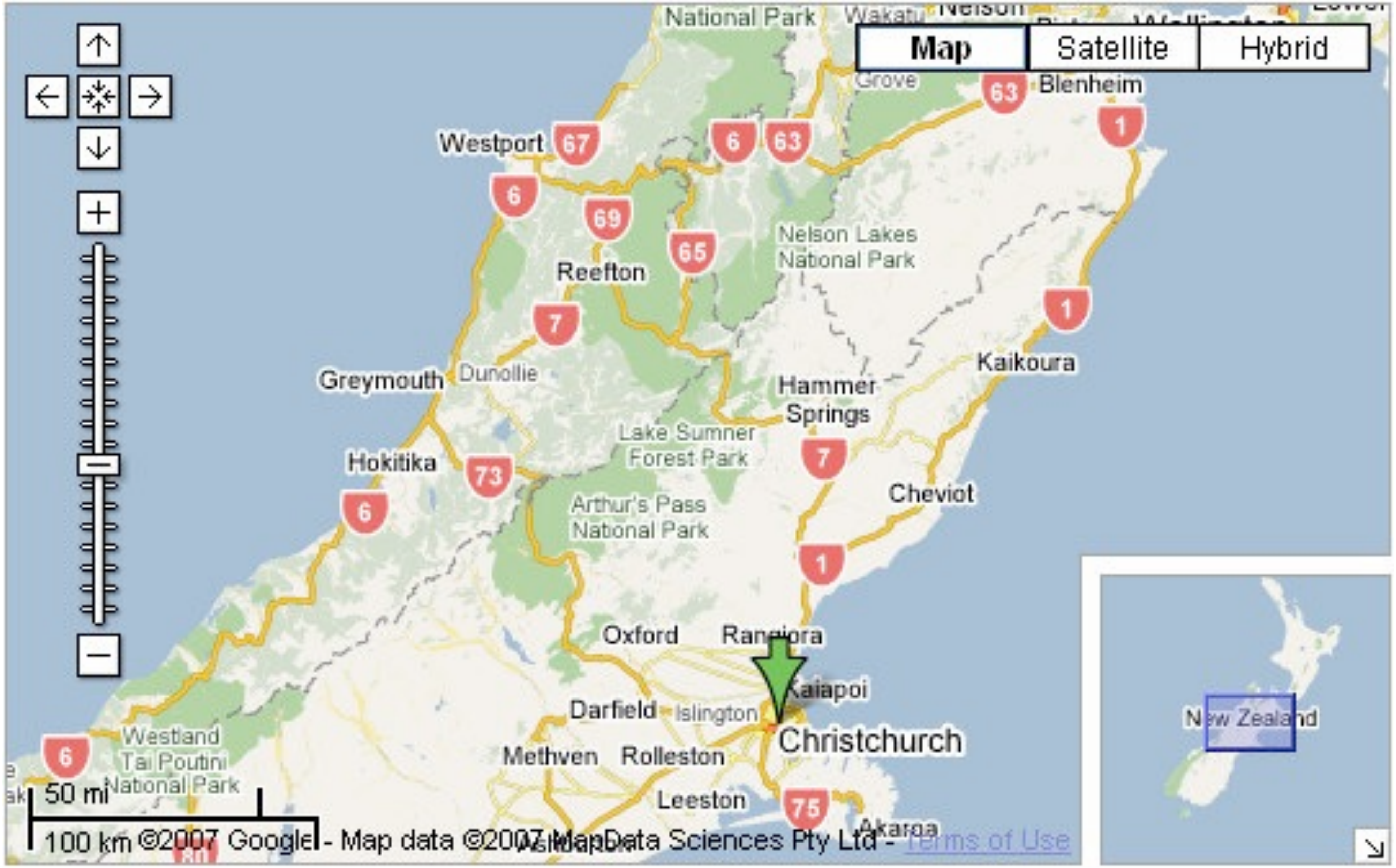
# Idiom: **bird's-eye maps**

# System: **Google Maps**

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

- differences
  - viewpoint
  - (size)

- ***overview-detail***

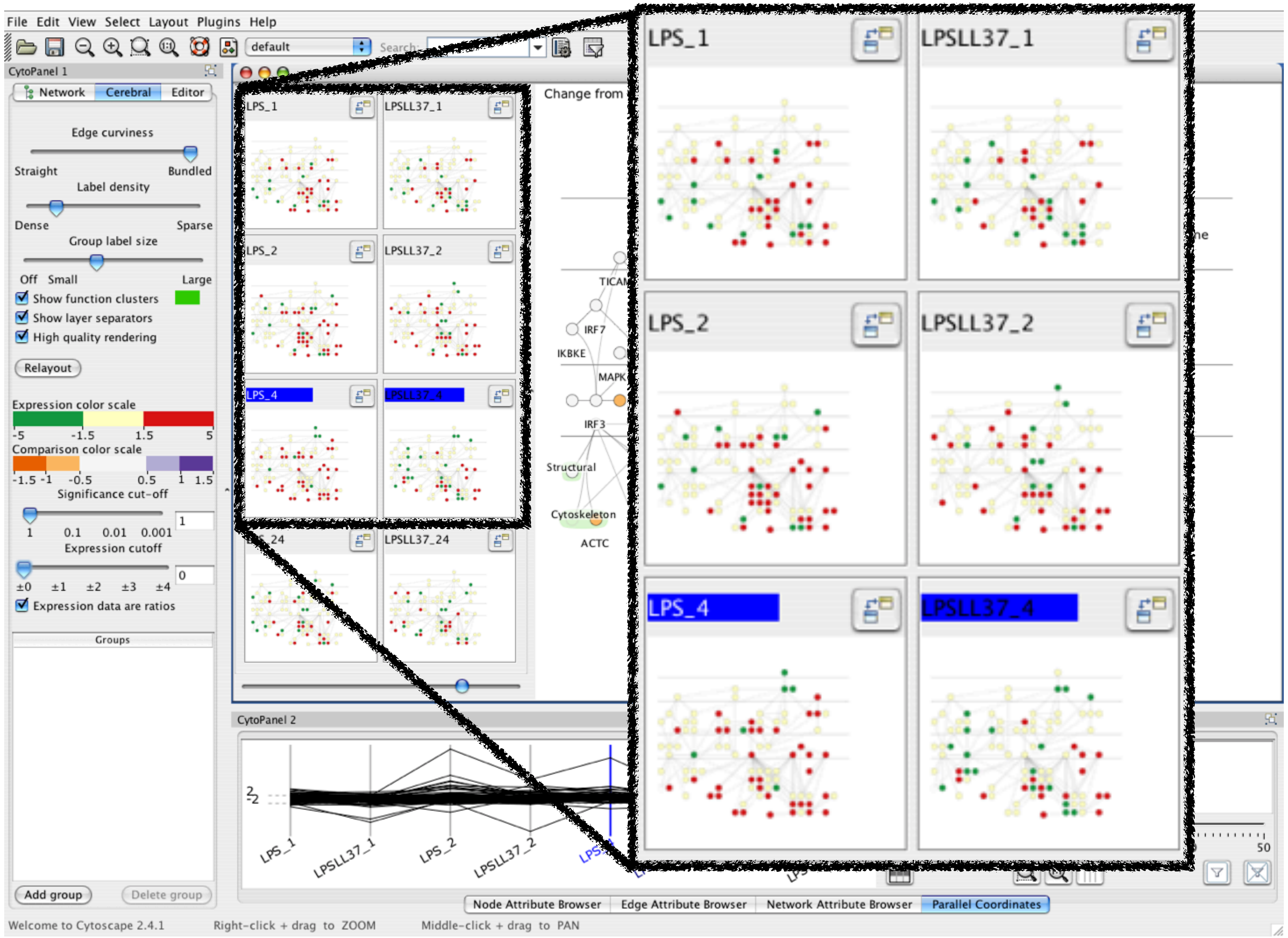


*[A Review of Overview+Detail, Zooming, and Focus+Context Interfaces. Cockburn, Karlson, and Bederson. ACM Computing Surveys 41:1 (2008), 1–31.]*

# Idiom: **Small multiples**

# System: **Cerebral**

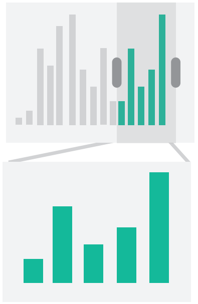
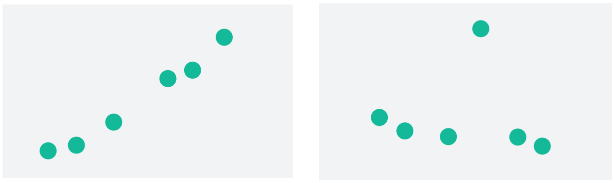
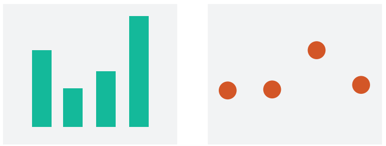
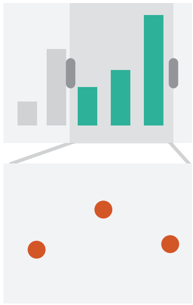
- encoding: same
- data: none shared
  - different attributes for node colors
  - (same network layout)
- navigation: shared



☑ Show function clusters 🟩
☑ Show layer separators
☑ High quality rendering
☑ Expression data are ratios

*[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

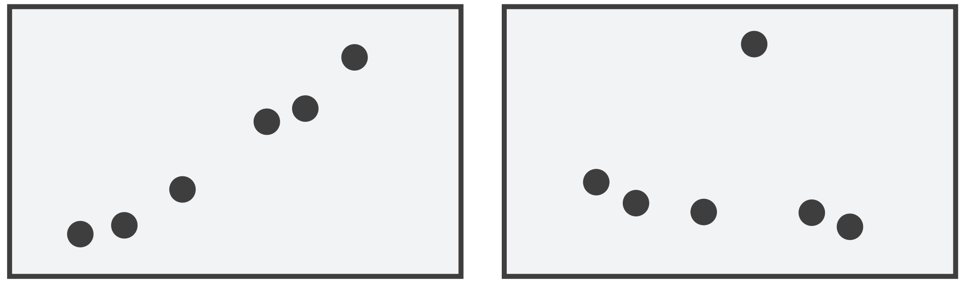
| | | Data | | |
|---|---|---|---|---|
| | | All | Subset | None |
| Encoding | Same | Redundant |  Overview/ Detail |  Small Multiples |
| | Different |  Multiform |  Multiform, Overview/ Detail | No Linkage |

- 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

# Partition into views

- how to divide data between views
  - encodes association between items using spatial proximity
  - major implications for what patterns are visible
  - split according to attributes
- design choices
  - how many splits
    - all the way down: one mark per region?
    - stop earlier, for more complex structure within region?
  - order in which attribs used to split
  - how many views

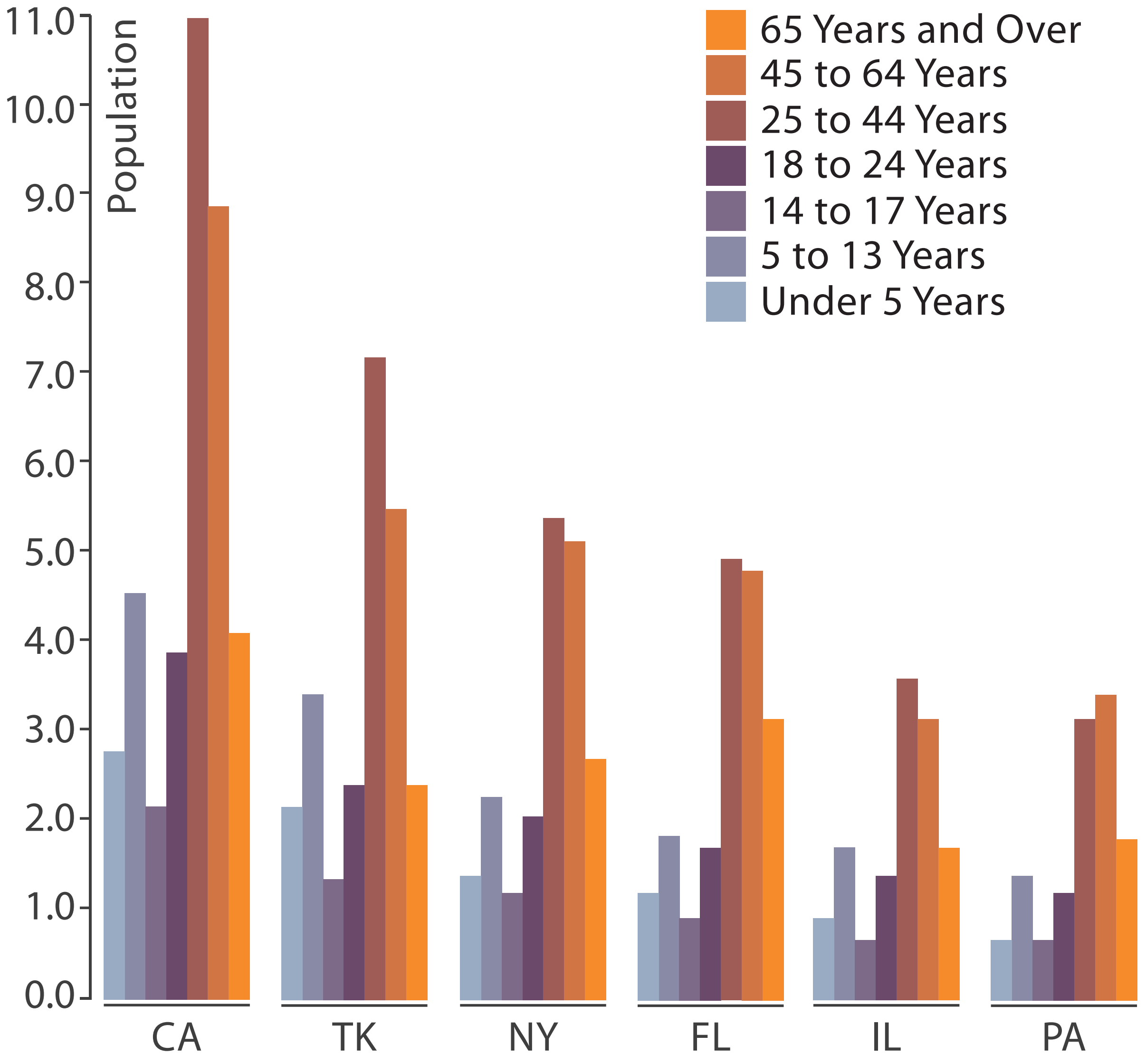
➔ Partition into Side-by-Side Views

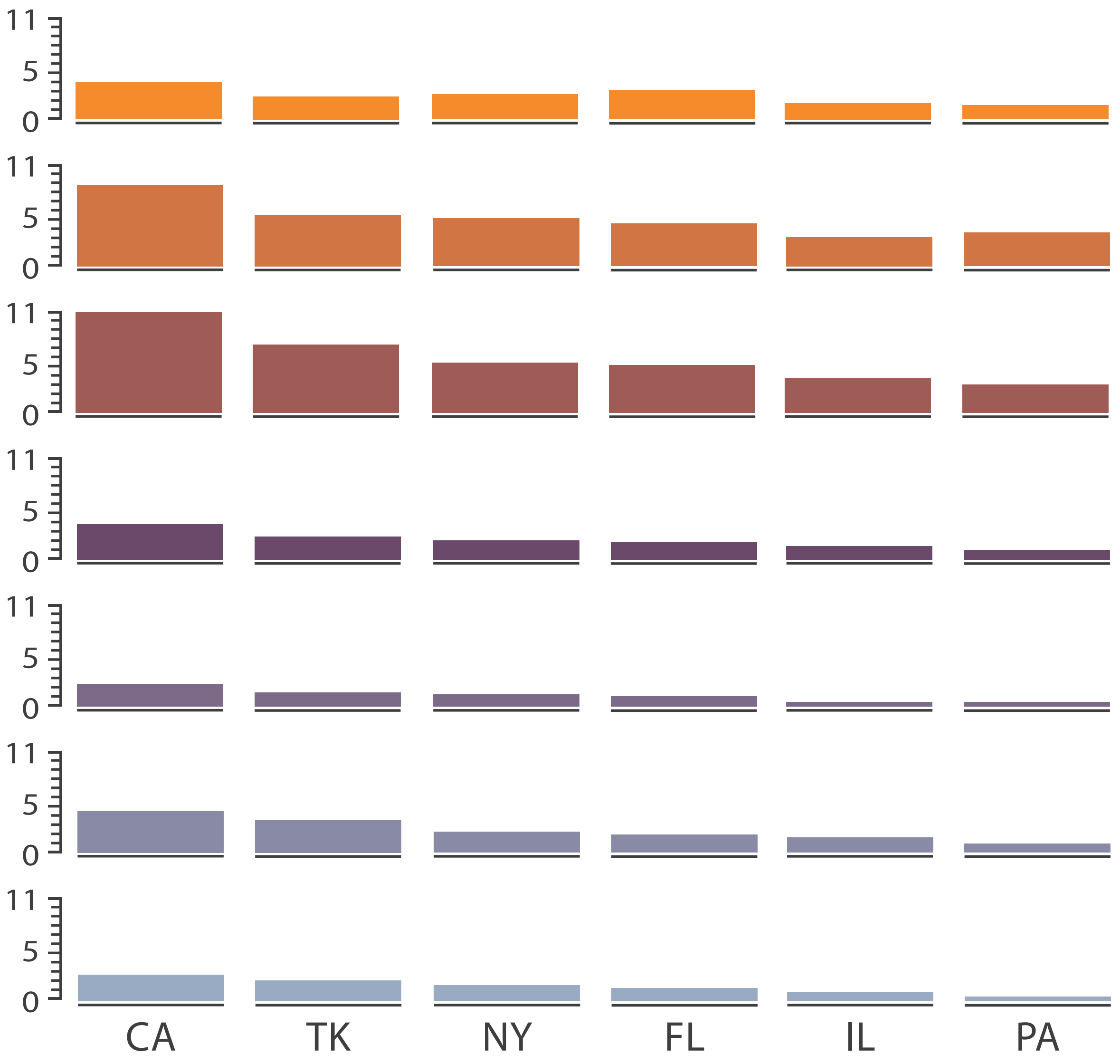


# Partitioning: List alignment

- 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

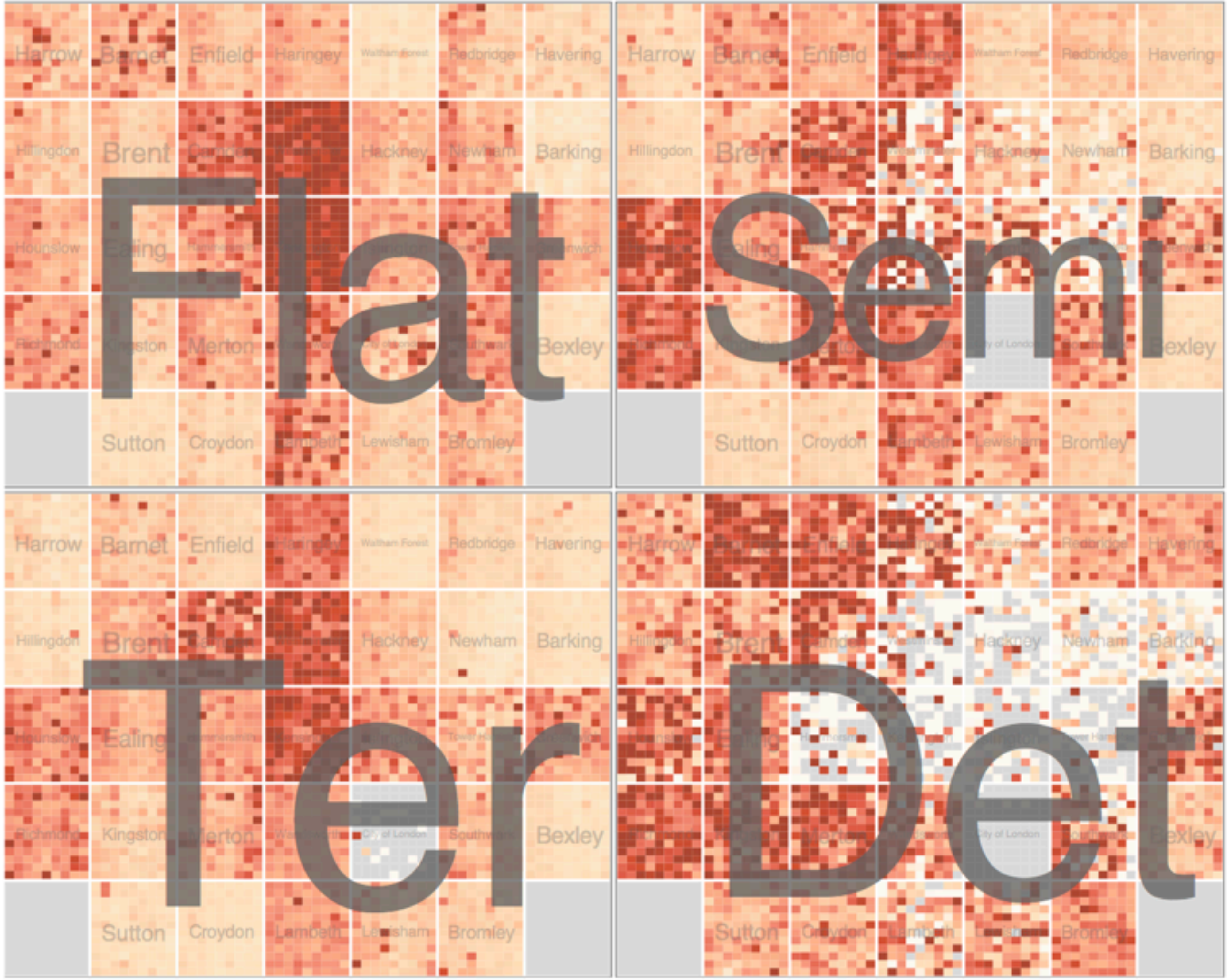




# Partitioning: Recursive subdivision

System: **HIVE**

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

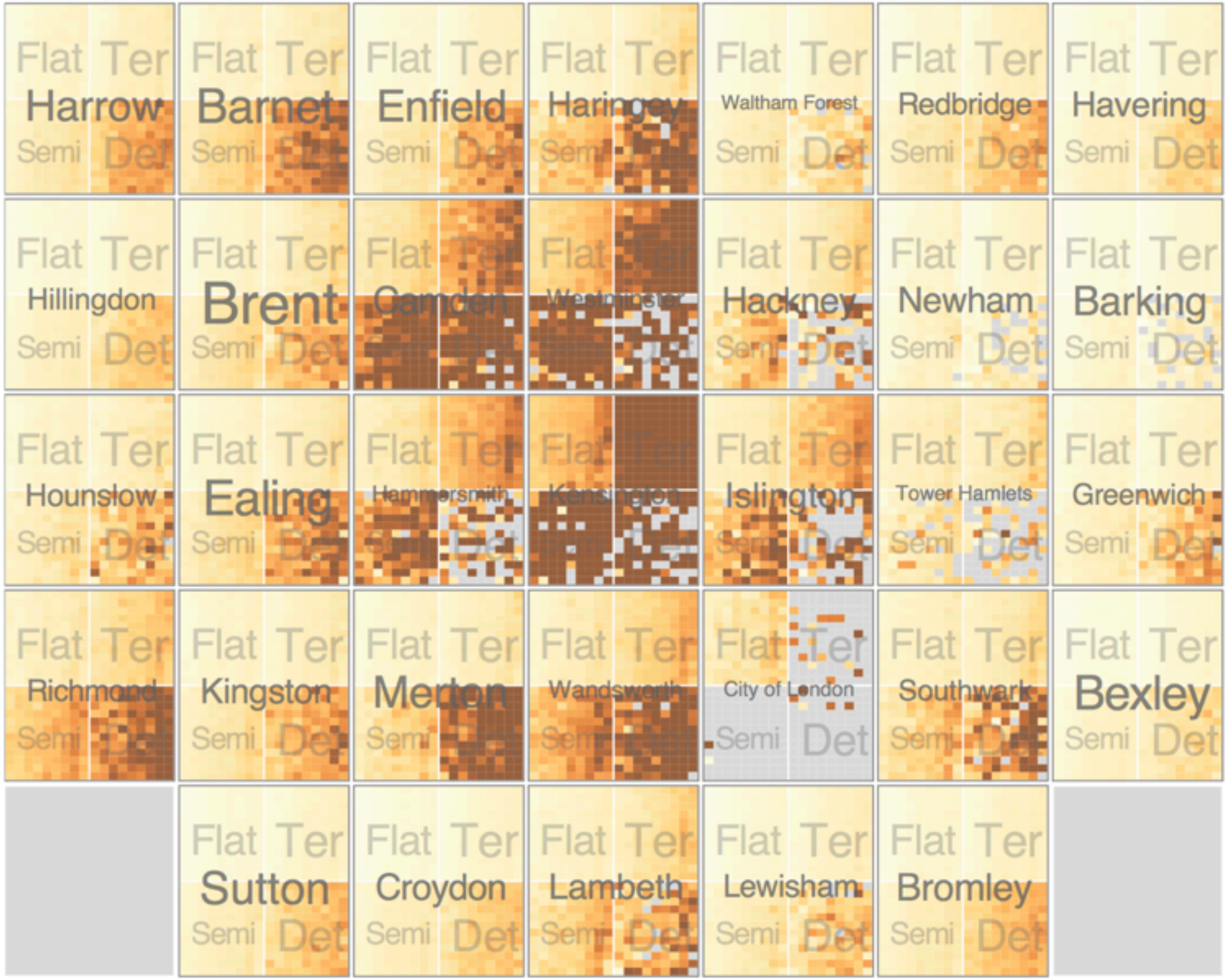


*[Configuring Hierarchical Layouts to Address Research Questions. Slingsby, Dykes, and Wood. IEEE Transactions on Visualization and Computer Graphics (Proc. InfoVis 2009) 15:6 (2009), 977–984.]*

# Partitioning: Recursive subdivision

System: **HIVE**

- switch order of splits
  - – neighborhood then type
- very different patterns

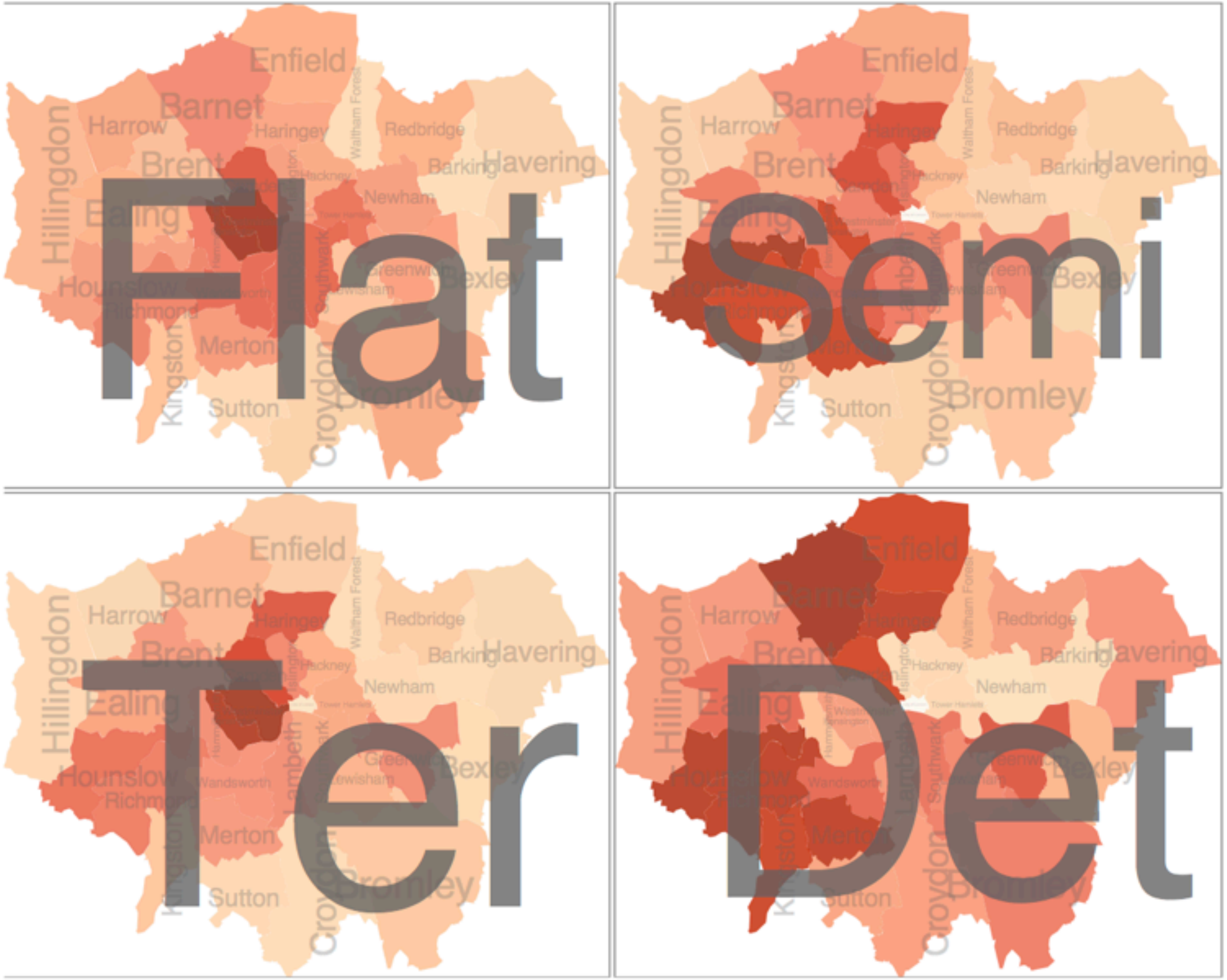


*[Configuring Hierarchical Layouts to Address Research Questions. Slingsby, Dykes, and Wood. IEEE Transactions on Visualization and Computer Graphics (Proc. InfoVis 2009) 15:6 (2009), 977–984.]*

# Partitioning: Recursive subdivision

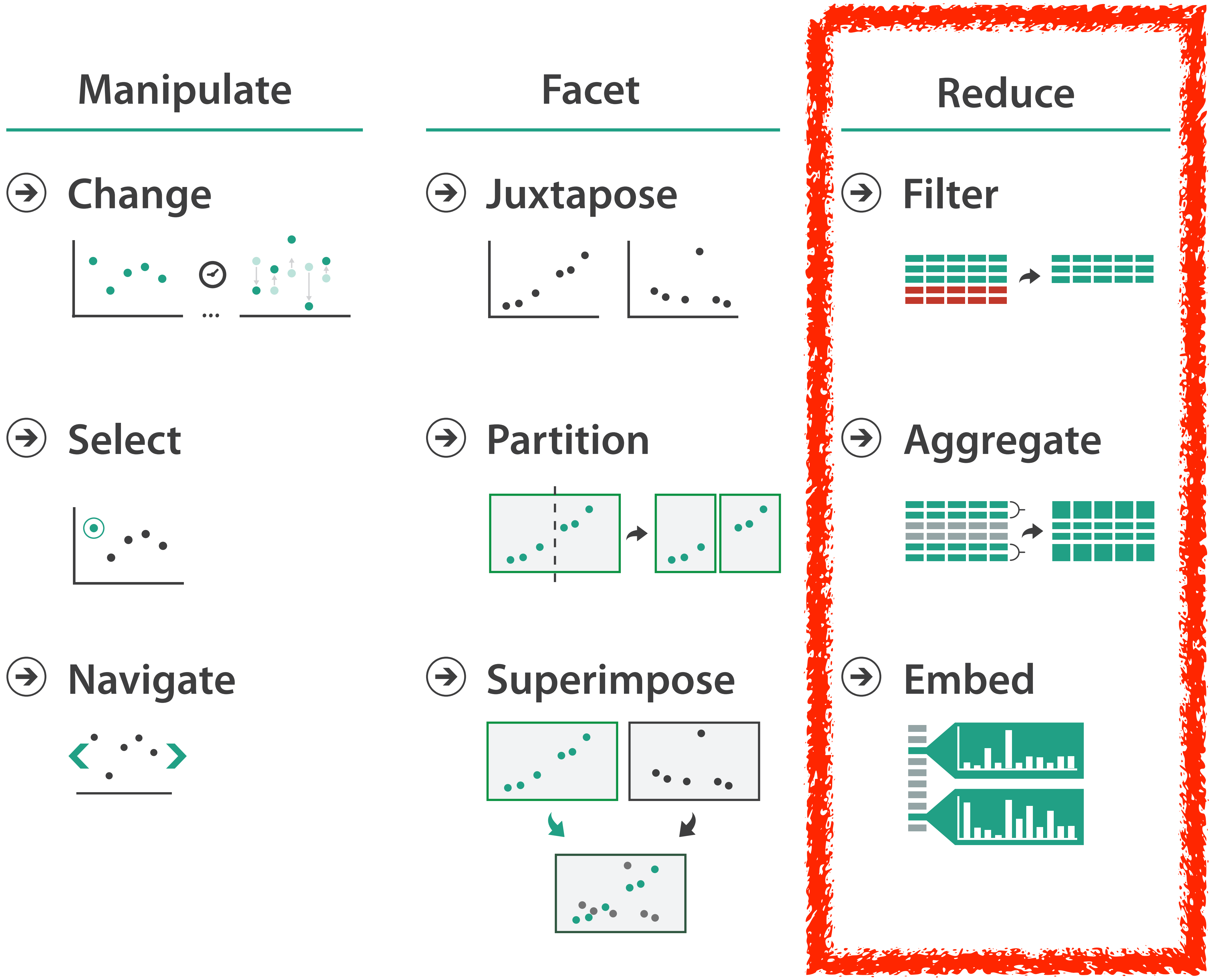
System: **HIVE**

- 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.]*

# How to handle complexity: 3 more strategies + 1 previous



Manipulate

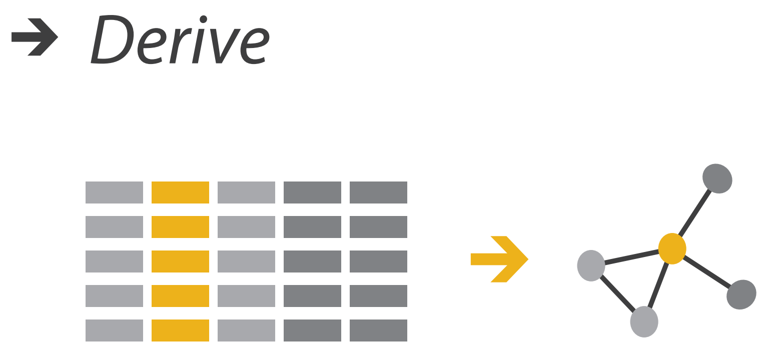
- Change
- Select
- Navigate

Facet

- Juxtapose
- Partition
- Superimpose

Reduce

- Filter
- Aggregate
- Embed

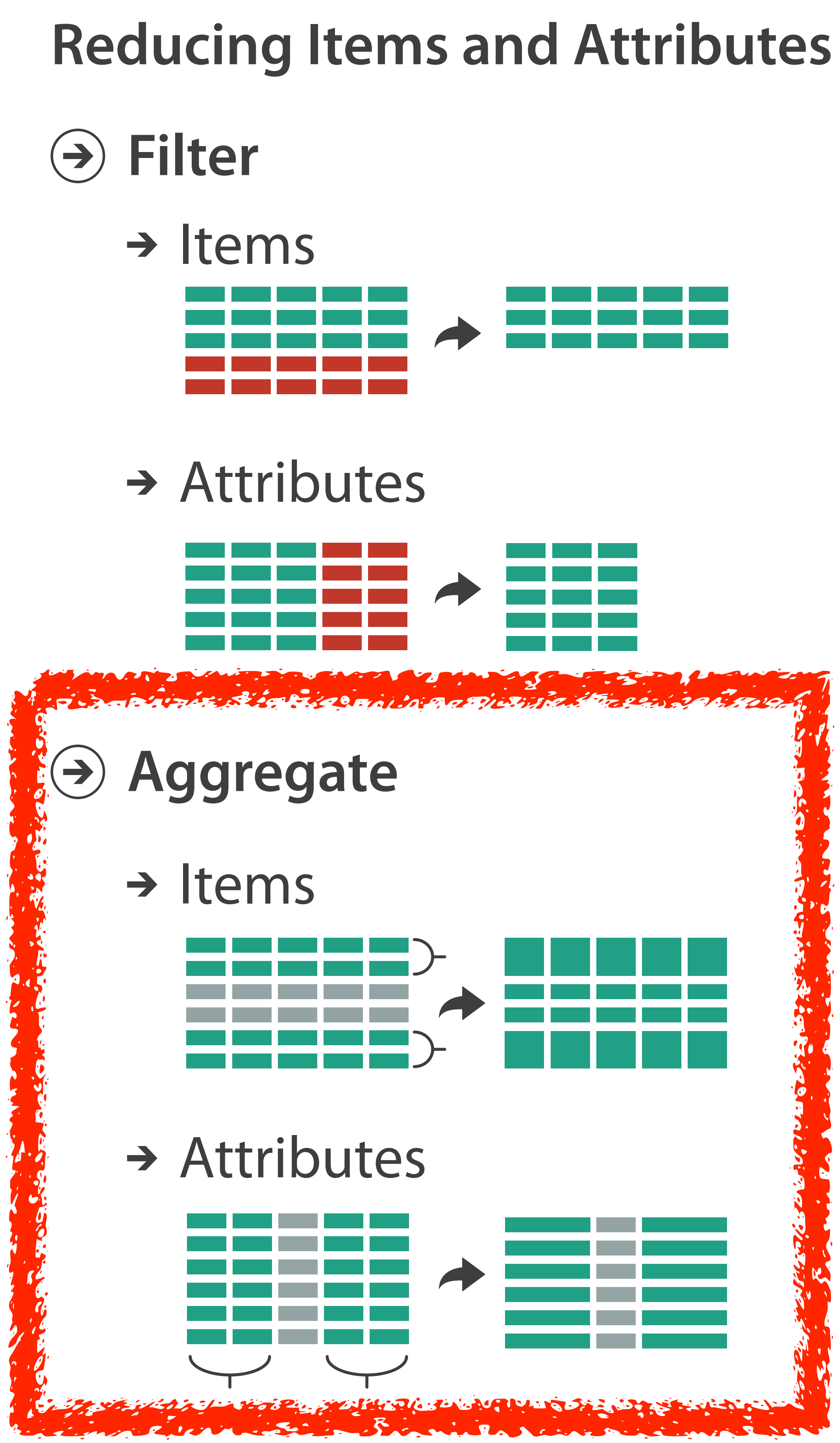


→ *Derive*

- reduce what is shown within single view

# 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, facet, change, derive



Reducing Items and Attributes

Filter

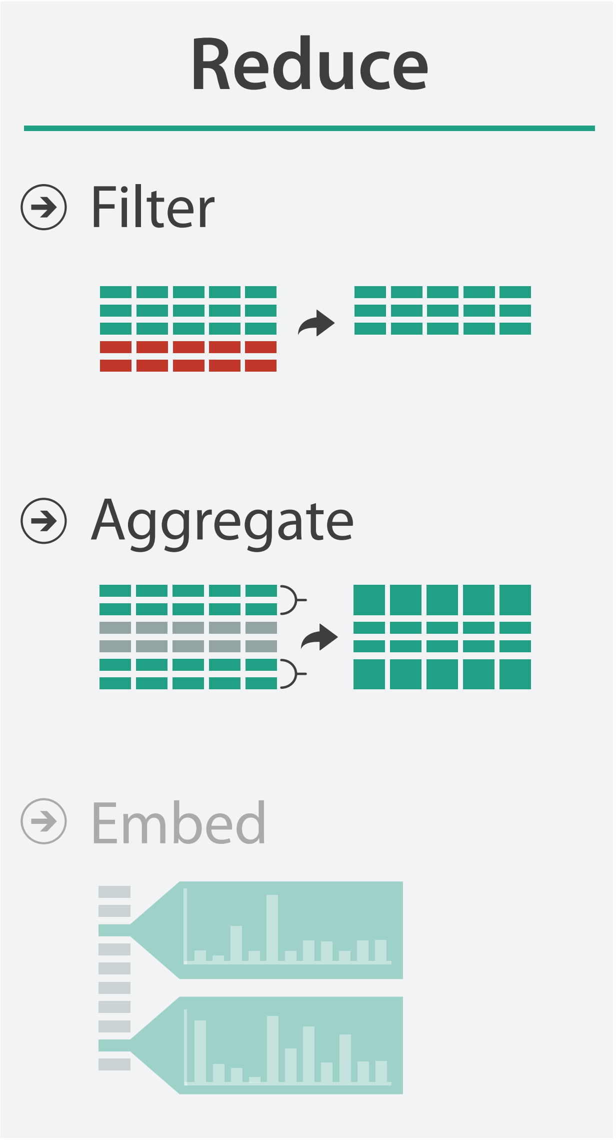
→ Items

→ Attributes

Aggregate

→ Items

→ Attributes



Reduce

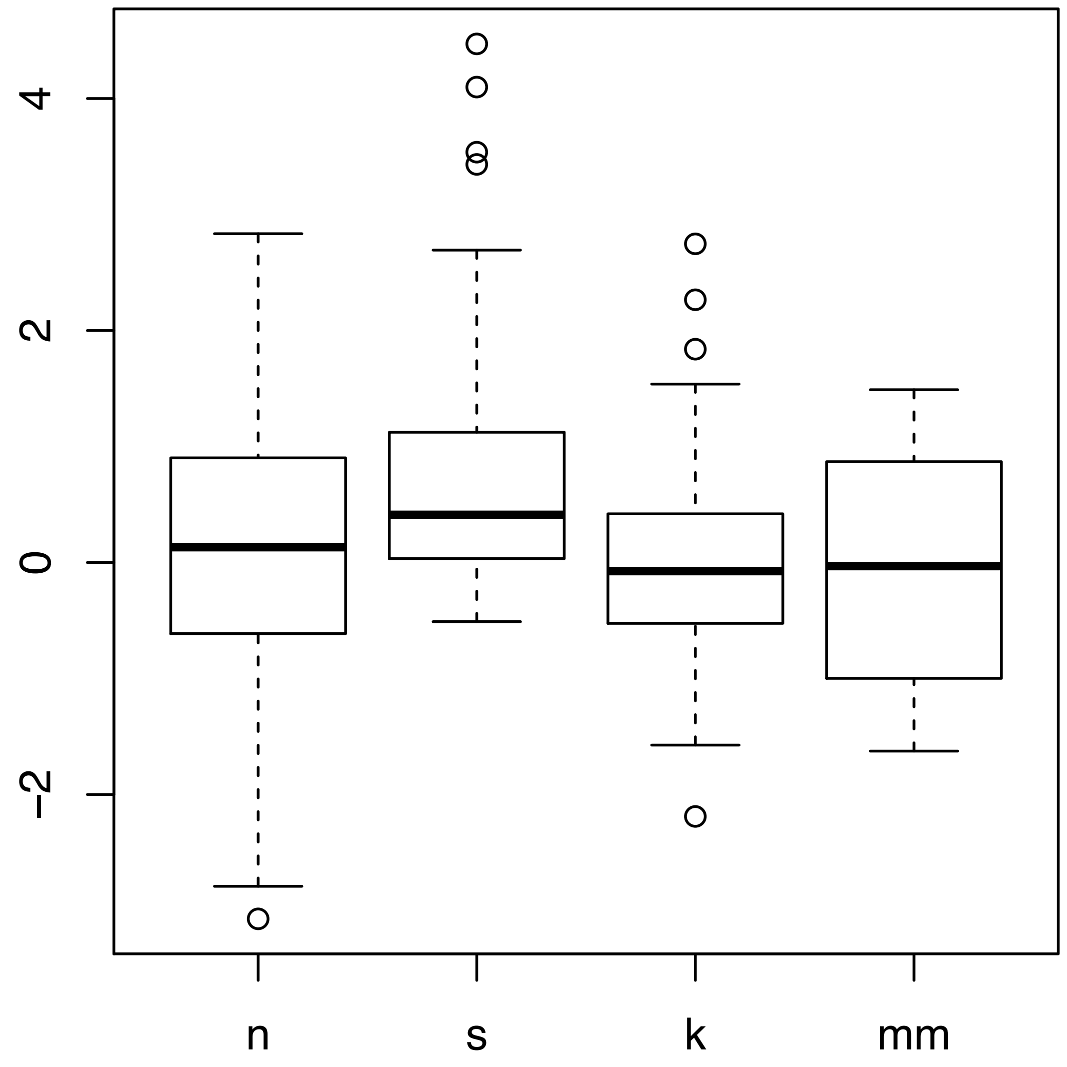
Filter

Aggregate

Embed

# Idiom: **boxplot**

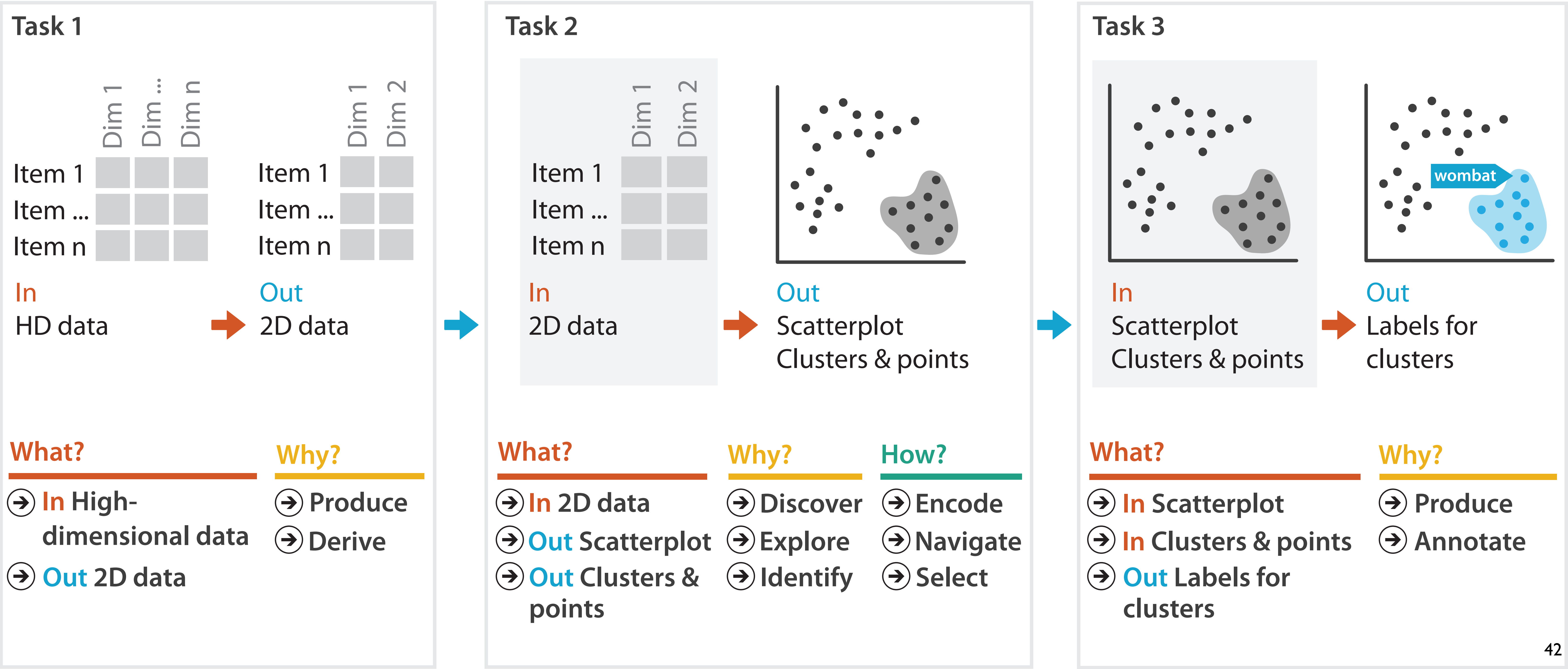
- static item aggregation
- task: find distribution
- data: table
- derived data
  - – 5 quant attribs
    - median: central line
    - lower and upper quartile: boxes
    - lower upper fences: whiskers
      - – values beyond which items are outliers
  - – outliers beyond fence cutoffs explicitly shown



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

# Idiom: **Dimensionality reduction for documents**

- attribute aggregation
  - derive low-dimensional target space from high-dimensional measured space



**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

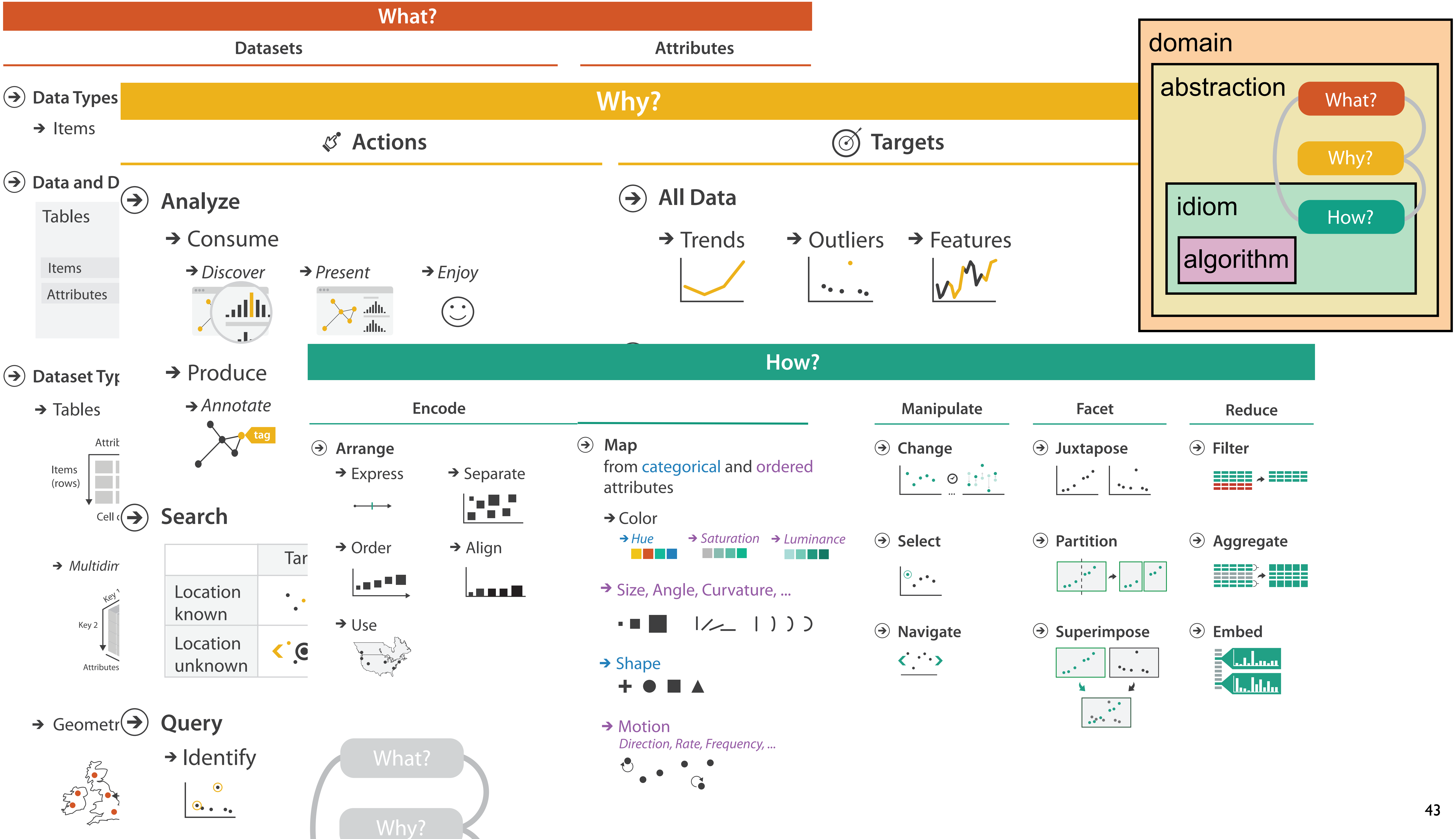
Out
Labels for clusters

**What?**

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

**Why?**

- ➔ Produce
- ➔ Annotate



What?

Datasets

Attributes

Data Types

Items

Data and D

Tables

Items

Attributes

Dataset Typ

Tables

Attrib

Items (rows)

Cell c

Multidir

Key 1

Key 2

Attributes

Geometr

Why?

Actions

Targets

Analyze

Consume

*Discover*

*Present*

*Enjoy*

Produce

*Annotate*

tag

Search

Tar

Location known

Location unknown

Query

Identify

All Data

Trends

Outliers

Features

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

domain

abstraction

What?

Why?

idiom

How?

algorithm

What?

Why?

# More Information

- this talk

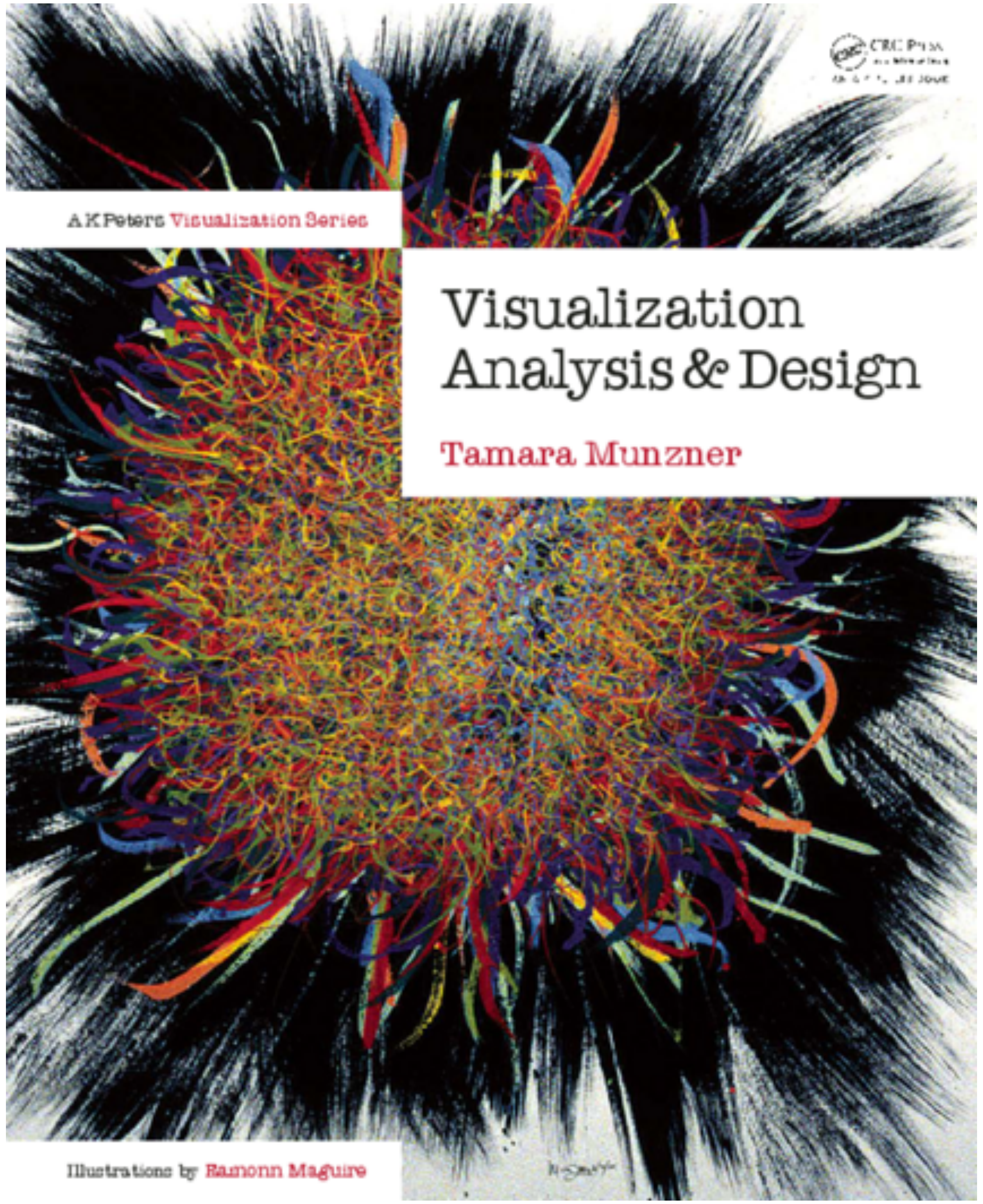
  http://www.cs.ubc.ca/~tmm/talks.html#vad15chicago

- book page (including tutorial lecture slides)
  http://www.cs.ubc.ca/~tmm/vadbook
  - 20% promo code for book+ebook combo: HVN17
  - http://www.crcpress.com/product/isbn/9781466508910
  - illustrations: Eamonn Maguire

- papers, videos, software, talks, full courses

  http://www.cs.ubc.ca/group/infovis

  http://www.cs.ubc.ca/~tmm


CRC Press
A K Peters Visualization Series
Visualization Analysis & Design
Tamara Munzner
Illustrations by Eamonn Maguire

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