

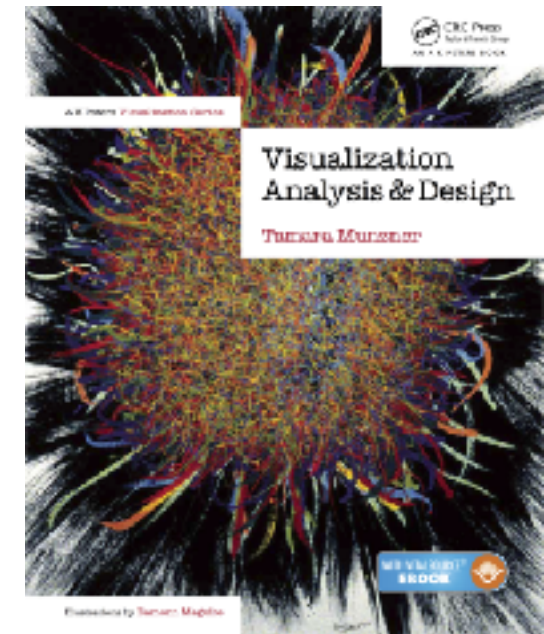
# Visualization Analysis & Design

## *Data Abstraction (Ch 2)*

**Tamara Munzner**

Department of Computer Science  
University of British Columbia

[@tamaramunzner](#)



# What does data mean?

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14, 2.6, 30, 30, 15, 100001

- What does this sequence of six numbers mean?

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14, 2.6, 30, 30, 15, 100001

- What does this sequence of six numbers mean?
  - two points far from each other in 3D space?

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  - something else??

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Basil, 7, S, Pear

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Basil, 7, S, Pear

- What about this data?



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Basil, 7, S, Pear

- What about this data?
  - food shipment of produce (basil & pear) arrived in satisfactory condition on 7th day of month

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Basil, 7, S, Pear

- What about this data?
  - food shipment of produce (basil & pear) arrived in satisfactory condition on 7th day of month
  - Basil Point neighborhood of city had 7 inches of snow cleared by the Pear Creek Limited snow removal service

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Basil, 7, S, Pear

- What about this data?
  - food shipment of produce (basil & pear) arrived in satisfactory condition on 7th day of month
  - Basil Point neighborhood of city had 7 inches of snow cleared by the Pear Creek Limited snow removal service
  - lab rat Basil made 7 attempts to find way through south section of maze, these trials used pear as reward food

# Now what?

- semantics: real-world meaning

Amy	8	S	Apple
Basil	7	S	Pear
Clara	9	M	Durian
Desmond	13	L	Elderberry
Ernest	12	L	Peach
Fanny	10	S	Lychee
George	9	M	Orange
Hector	8	L	Loquat
Ida	10	M	Pear
Amy	12	M	Orange

# Now what?

- semantics: real-world meaning

<b>Name</b>	<b>Age</b>	<b>Shirt Size</b>	<b>Favorite Fruit</b>
Amy	8	S	Apple
Basil	7	S	Pear
Clara	9	M	Durian
Desmond	13	L	Elderberry
Ernest	12	L	Peach
Fanny	10	S	Lychee
George	9	M	Orange
Hector	8	L	Loquat
Ida	10	M	Pear
Amy	12	M	Orange

# Now what?

- semantics: real-world meaning
- data types: structural or mathematical interpretation of data
  - item, link, attribute, position, (grid)
  - different from data types in programming!

Name	Age	Shirt Size	Favorite Fruit
Amy	8	S	Apple
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Amy	12	M	Orange

# Items & Attributes

- item: individual entity, discrete
  - eg patient, car, stock, city
  - "independent variable"

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Ida	10	M	Pear
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George	9	M	Orange
Hector	8	L	Loquat
Ida	10	M	Pear
Amy	12	M	Orange

item: person



# Items & Attributes

- **item**: individual entity, discrete
  - eg patient, car, stock, city
  - "independent variable"
- **attribute**: property that is measured, observed, logged...
  - eg height, blood pressure for patient
  - eg horsepower, make for car
  - "dependent variable"

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attributes: name, age, shirt size, fave fruit

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Fanny	10	S	Lychee
George	9	M	Orange
Hector	8	L	Loquat
Ida	10	M	Pear
Amy	12	M	Orange

item: person

# Other data types

- links
  - express relationship between two items
  - eg friendship on facebook, interaction between proteins
- positions
  - spatial data: location in 2D or 3D
  - pixels in photo, voxels in MRI scan, latitude/longitude
- grids
  - sampling strategy for continuous data

# Dataset types

Tables

Items

Attributes

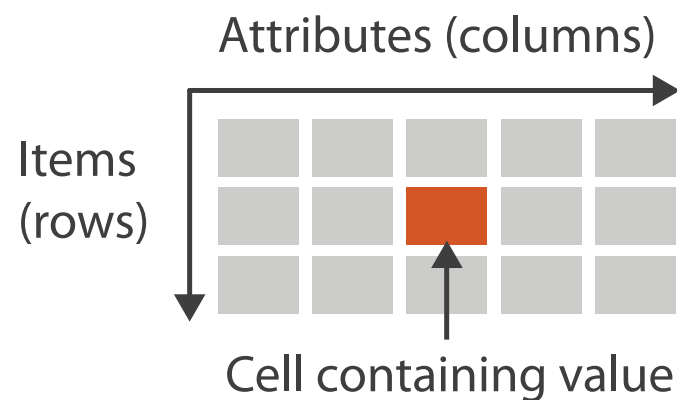
- flat table
  - one item per row
  - each column is attribute
  - cell holds value for item-attribute pair

attributes: name, age, shirt size, fave fruit

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Amy	8	S	Apple
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item: person

→ Tables



# Dataset types

Tables

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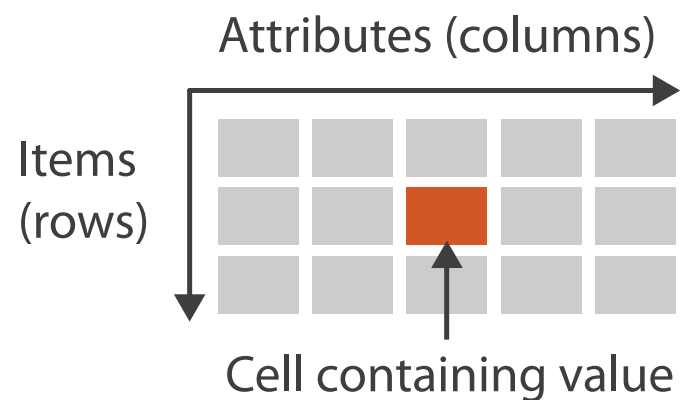
- flat table
  - one item per row
  - each column is attribute
  - cell holds value for item-attribute pair
  - unique key (could be implicit)

attributes: name, age, shirt size, fave fruit

ID	Name	Age	Shirt Size	Favorite Fruit
1	Amy	8	S	Apple
2	Basil	7	S	Pear
3	Clara	9	M	Durian
4	Desmond	13	L	Elderberry
5	Ernest	12	L	Peach
6	Fanny	10	S	Lychee
7	George	9	M	Orange
8	Hector	8	L	Loquat
9	Ida	10	M	Pear
10	Amy	12	M	Orange

item: person

→ Tables





# Table

A	B	C	S	T	U
Order ID	Order Date	Order Priority	Product Container	Product Base Margin	Ship Date
3	10/14/06	5-Low	Large Box	0.8	10/21/06
6	2/21/08	4-Not Specified	Small Pack	0.55	2/22/08
32	7/16/07	2-High	Small Pack	0.79	7/17/07
32	7/16/07	2-High	Jumbo Box	0.72	7/17/07
32	7/16/07	2-High	Medium Box	0.6	7/18/07
32	7/16/07	2-High	Medium Box	0.65	7/18/07
35	10/23/07	4-Not Specified	Wrap Bag	0.52	10/24/07
35	10/23/07	4-Not Specified	Small Box	0.58	10/25/07
36	11/3/07	1-Urgent	Small Box	0.55	11/3/07
65	3/18/07	1-Urgent	Small Pack	0.49	3/19/07
66	1/20/05	5-Low	Wrap Bag	0.56	1/20/05
69	6/4/05	4-Not Specified	Small Pack	0.44	6/6/05
69	6/4/05	4-Not Specified	Wrap Bag	0.6	6/6/05
70	12/18/06	5-Low	Small Box	0.59	12/23/06
70	12/18/06	5-Low	Wrap Bag	0.82	12/23/06
96	4/17/05	2-High	Small Box	0.55	4/19/05
97	1/29/06	3-Medium	Small Box	0.38	1/30/06
129	11/19/08	5-Low	Small Box	0.37	11/28/08
130	5/8/08	2-High	Small Box	0.37	5/9/08
130	5/8/08	2-High	Medium Box	0.38	5/10/08
130	5/8/08	2-High	Small Box	0.6	5/11/08
132	6/11/06	3-Medium	Medium Box	0.6	6/12/06
132	6/11/06	3-Medium	Jumbo Box	0.69	6/14/06
134	5/1/08	4-Not Specified	Large Box	0.82	5/3/08
135	10/21/07	4-Not Specified	Small Pack	0.64	10/23/07
166	9/12/07	2-High	Small Box	0.55	9/14/07
193	8/8/06	1-Urgent	Medium Box	0.57	8/10/06
194	4/5/08	3-Medium	Wrap Bag	0.42	4/7/08



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item



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item

attribute



# Table

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item

cell

attribute





# Dataset types

Tables

Items

Attributes

Networks &  
Trees

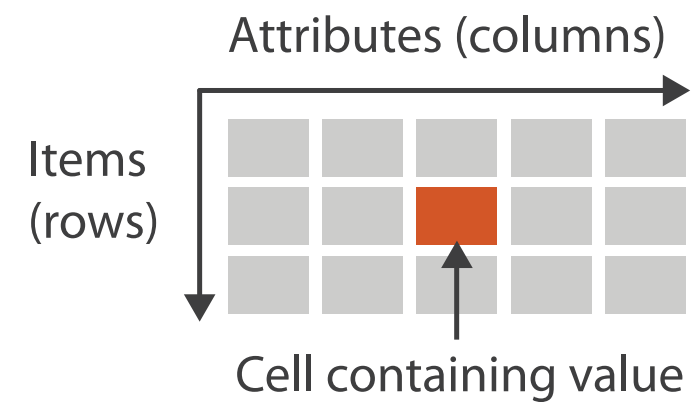
Items (nodes)

Links

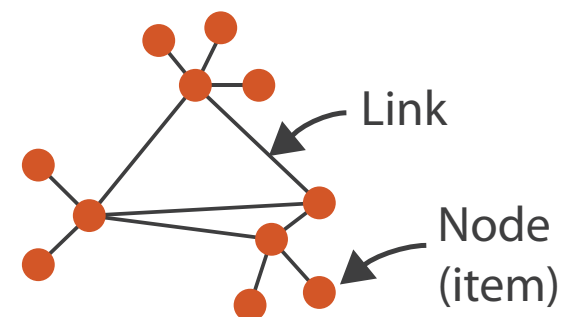
Attributes

- **network/graph**
  - nodes (vertices) connected by links (edges)
  - tree is special case: no cycles
    - often have roots and are directed

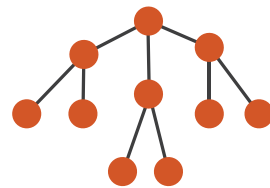
→ Tables



→ Networks



→ Trees



# Dataset types

Tables

Items

Attributes

Networks &  
Trees

Items (nodes)

Links

Attributes

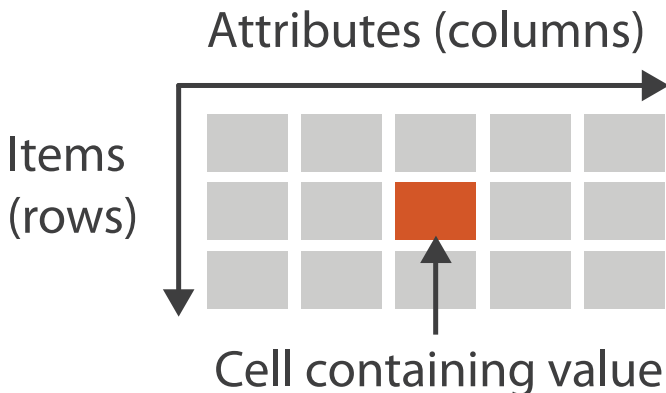
Fields

Grids

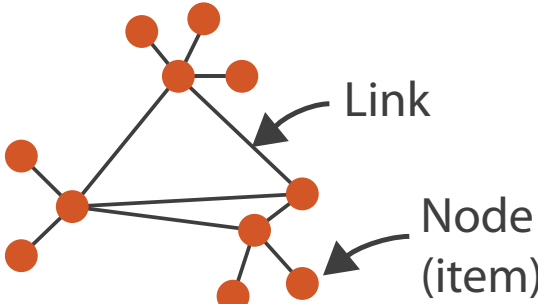
Positions

Attributes

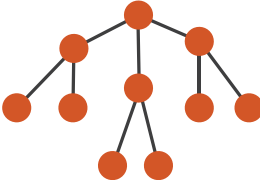
→ Tables



→ Networks

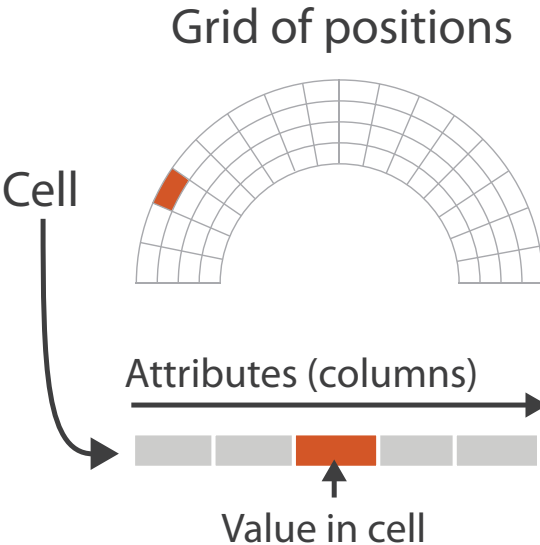


→ Trees



→ Spatial

→ Fields (Continuous)

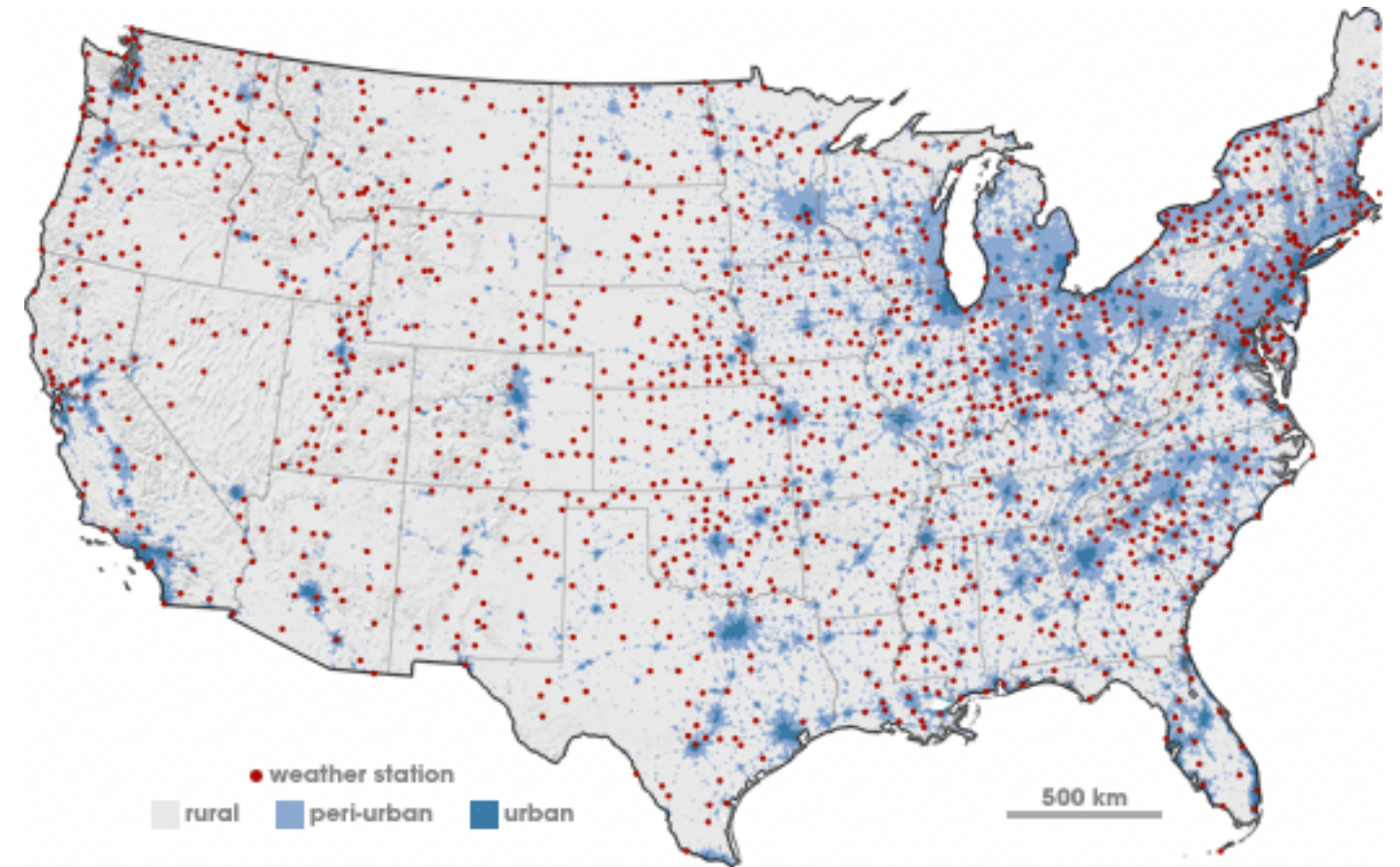
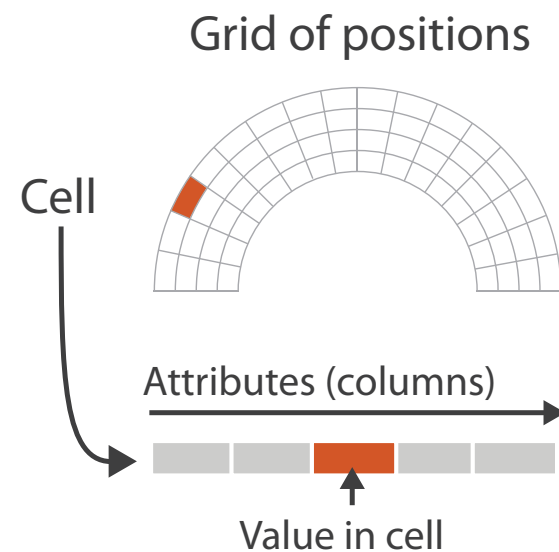


# Spatial fields

- attribute values associated w/ cells
- cell contains value from continuous domain
  - eg temperature, pressure, wind velocity
- measured or simulated

→ Spatial

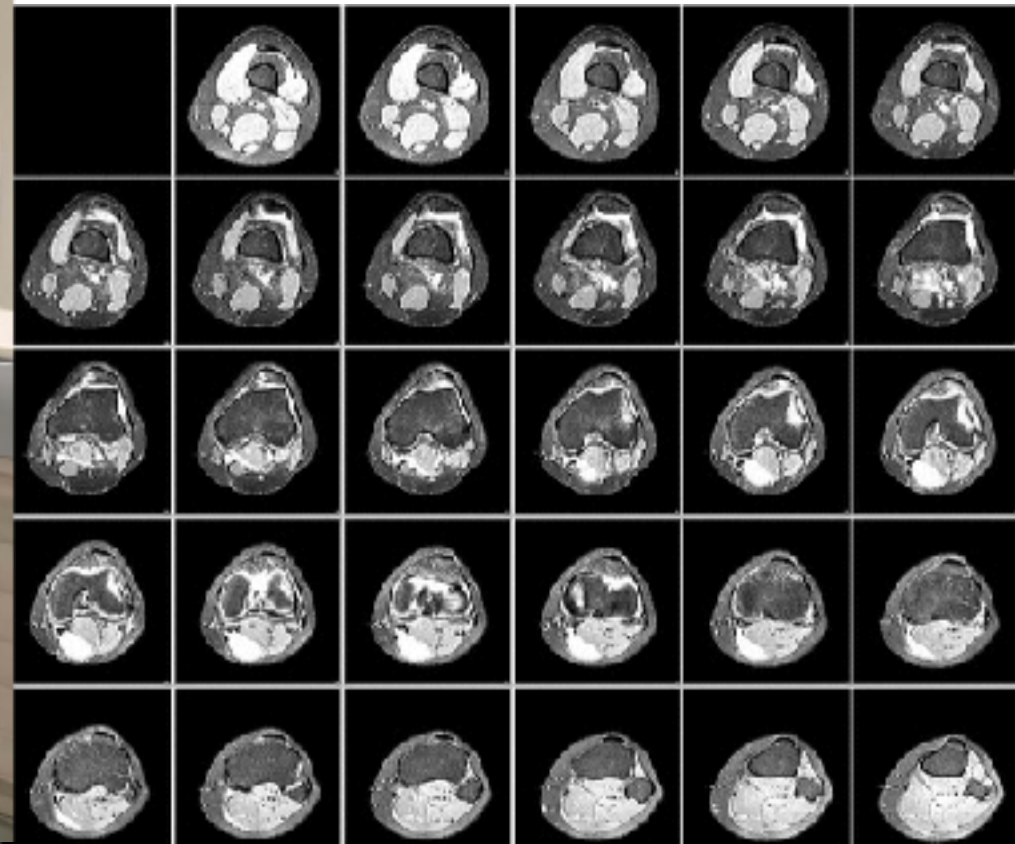
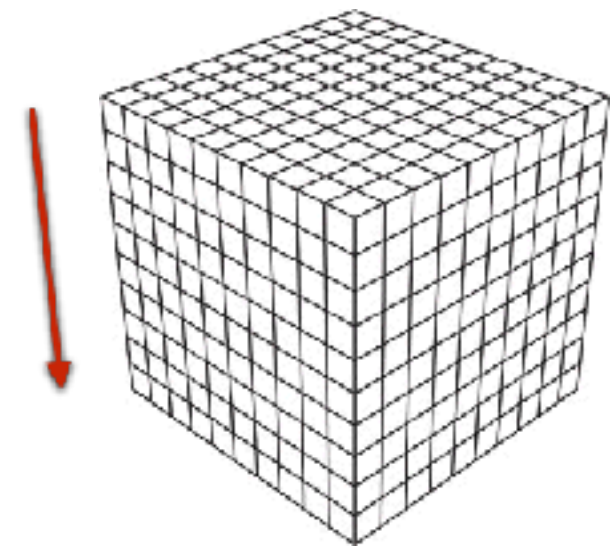
→ Fields (Continuous)





# Spatial fields

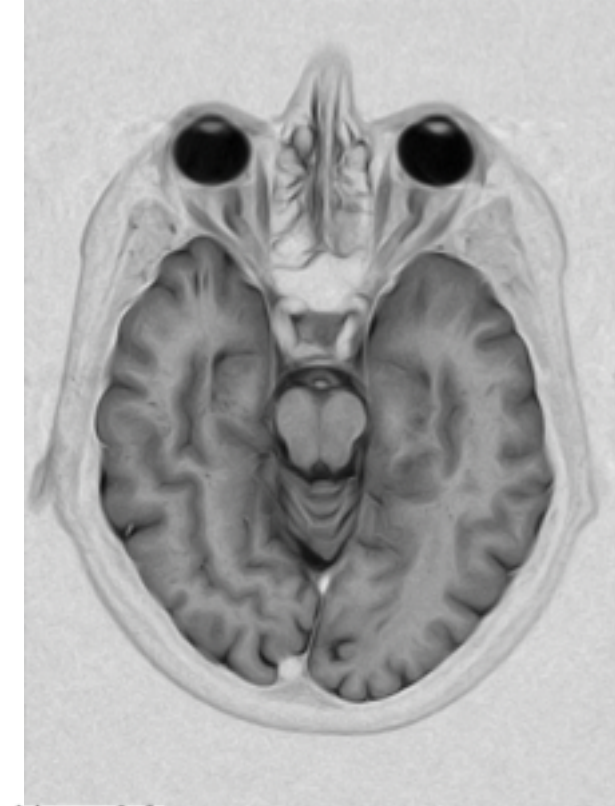
- attribute values associated w/ cells
- cell contains value from continuous domain
  - eg temperature, pressure, wind velocity
- measured or simulated
- major concerns
  - sampling:  
where attributes are measured
  - interpolation:  
how to model attributes elsewhere
  - grid types



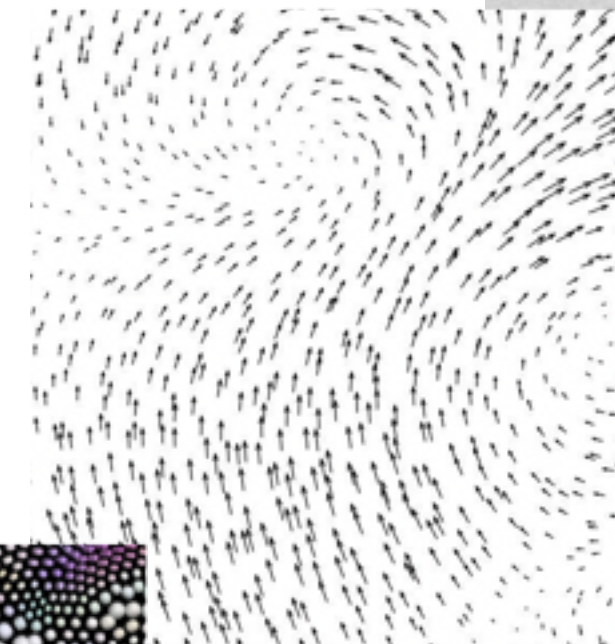
# Spatial fields

- attribute values associated w/ cells
- cell contains value from continuous domain
  - eg temperature, pressure, wind velocity
- measured or simulated
- major concerns
  - sampling:  
where attributes are measured
  - interpolation:  
how to model attributes elsewhere
  - grid types
- major divisions
  - attributes per cell:  
scalar (1), vector (2), tensor (many)

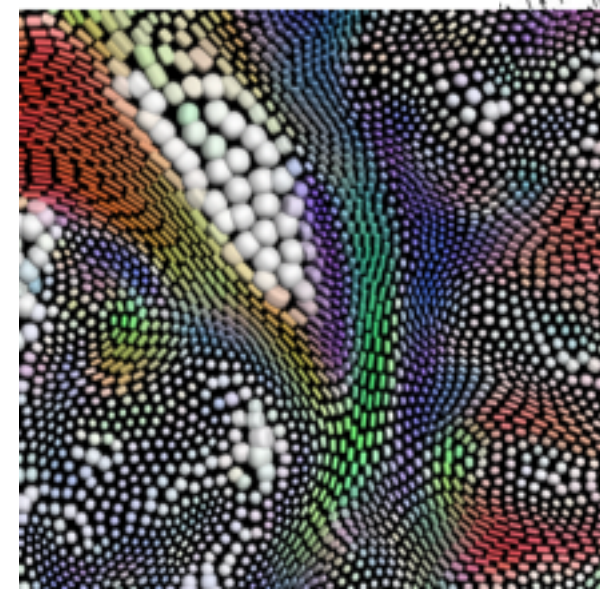
scalar



vector

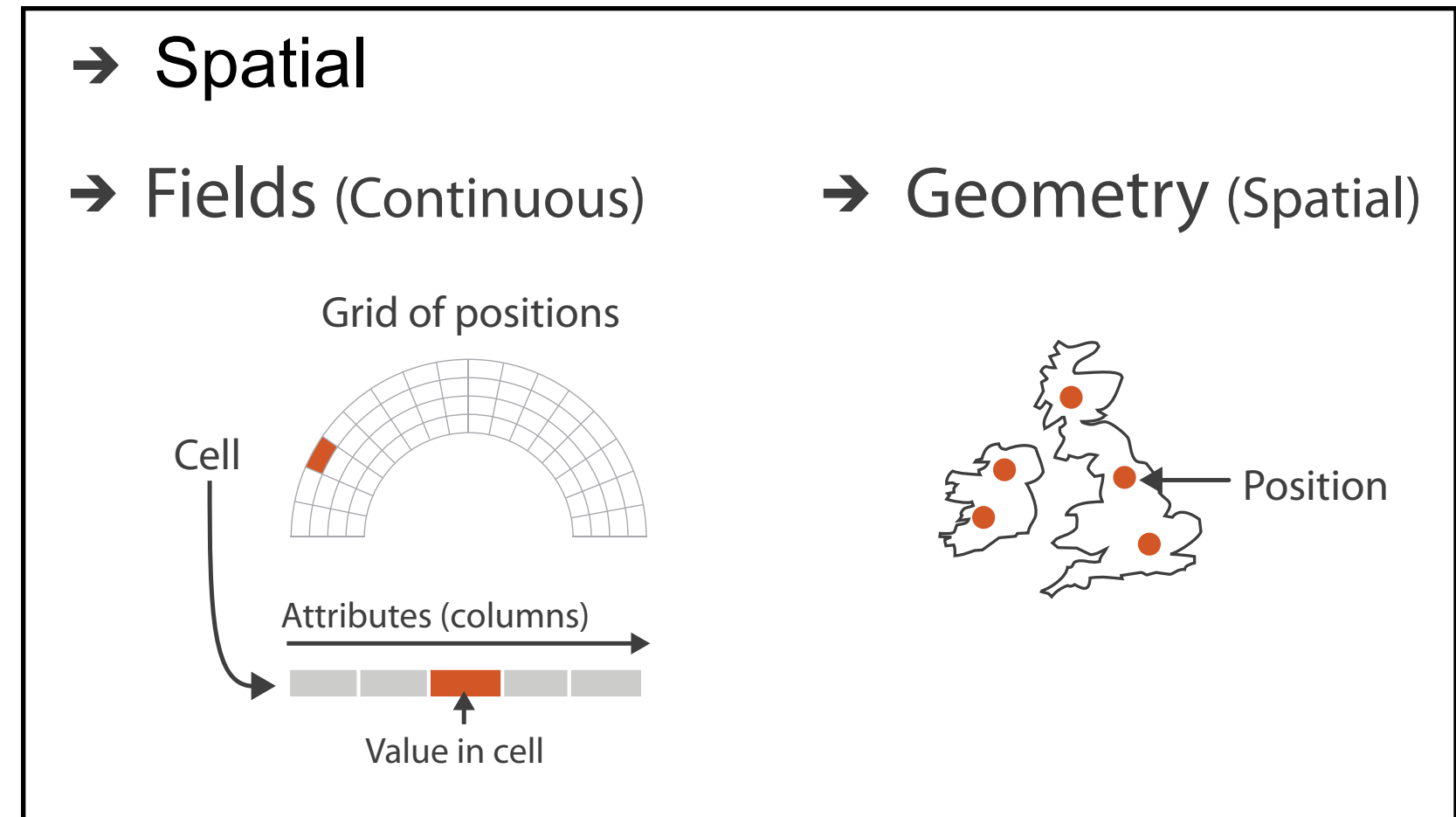
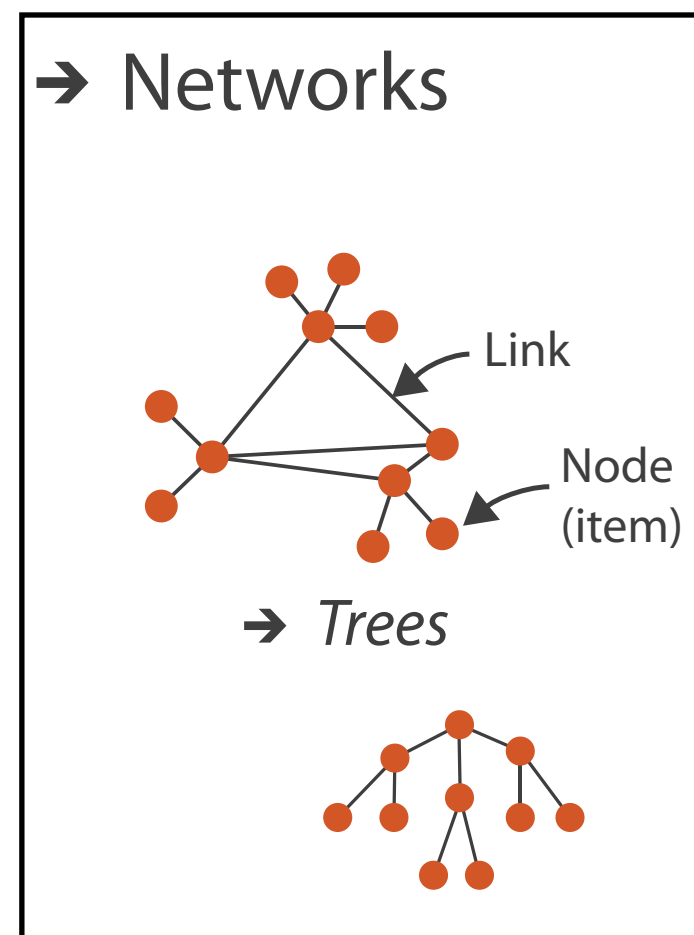
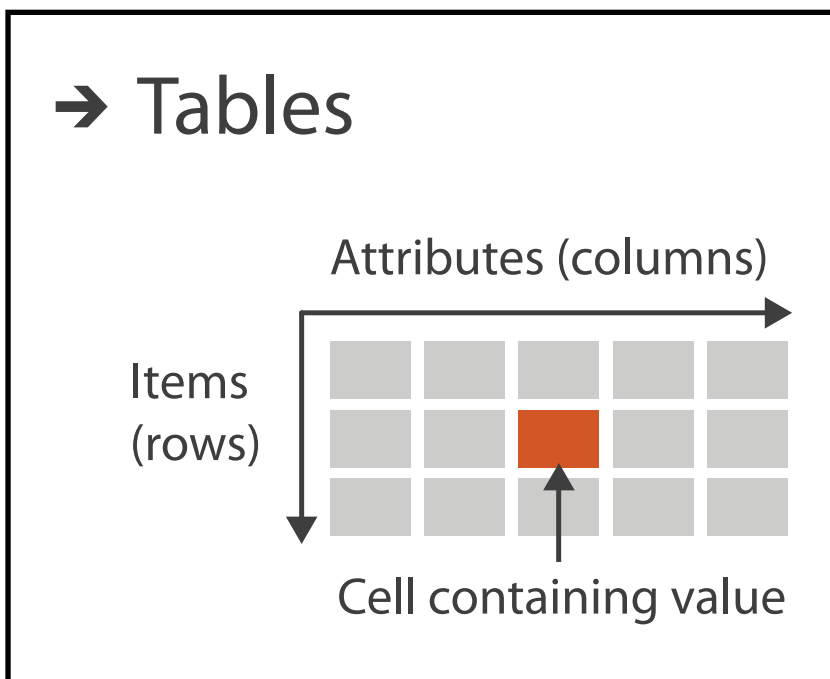
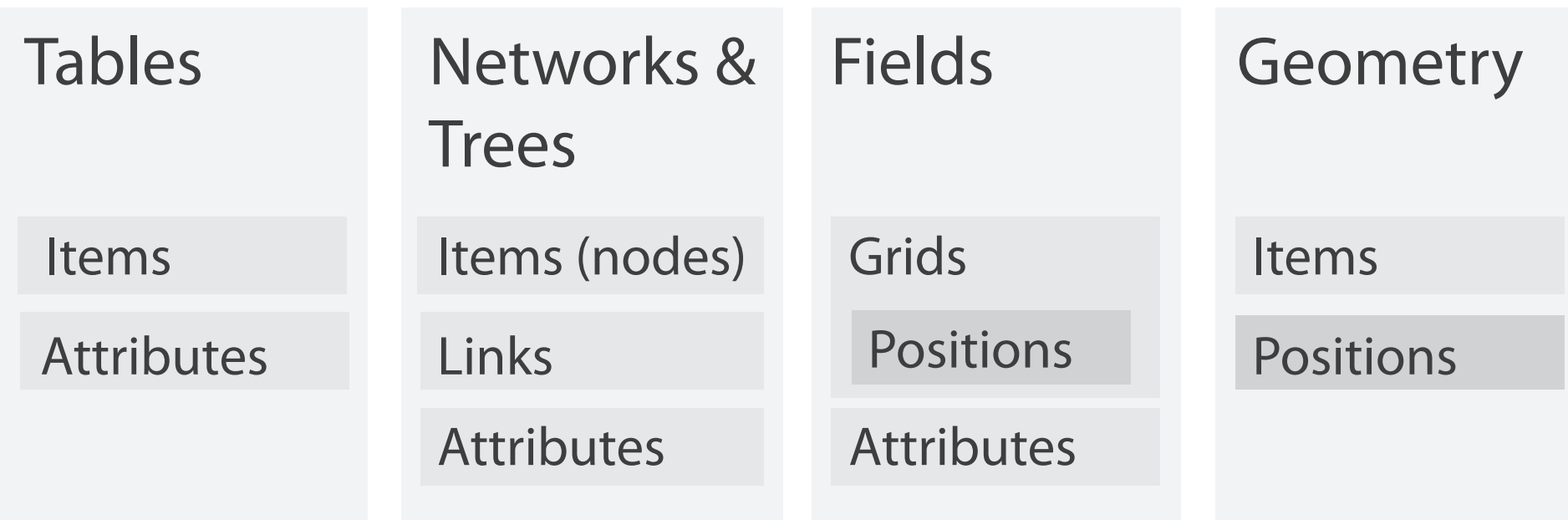


tensor





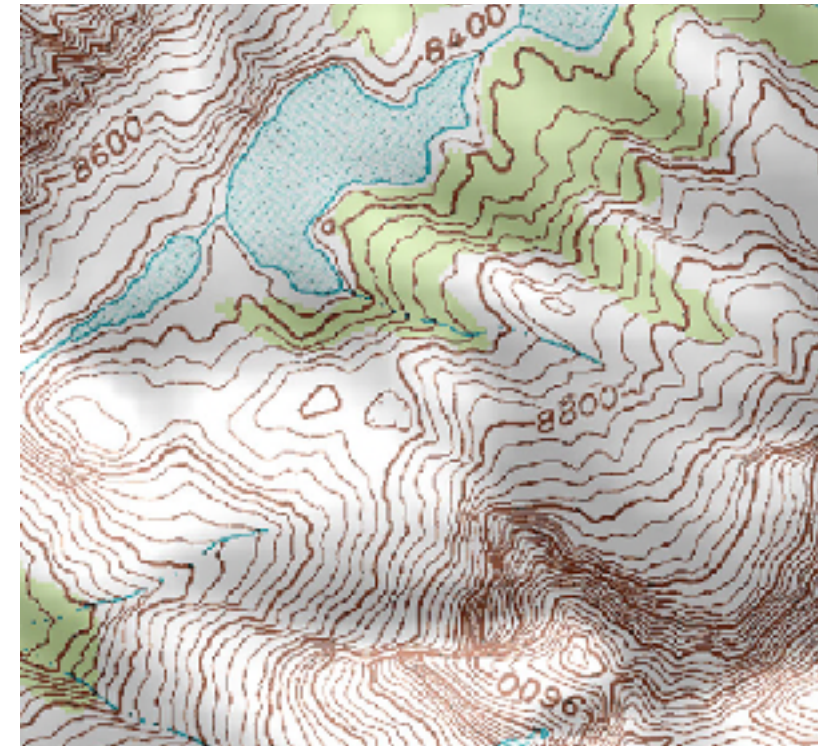
# Dataset types



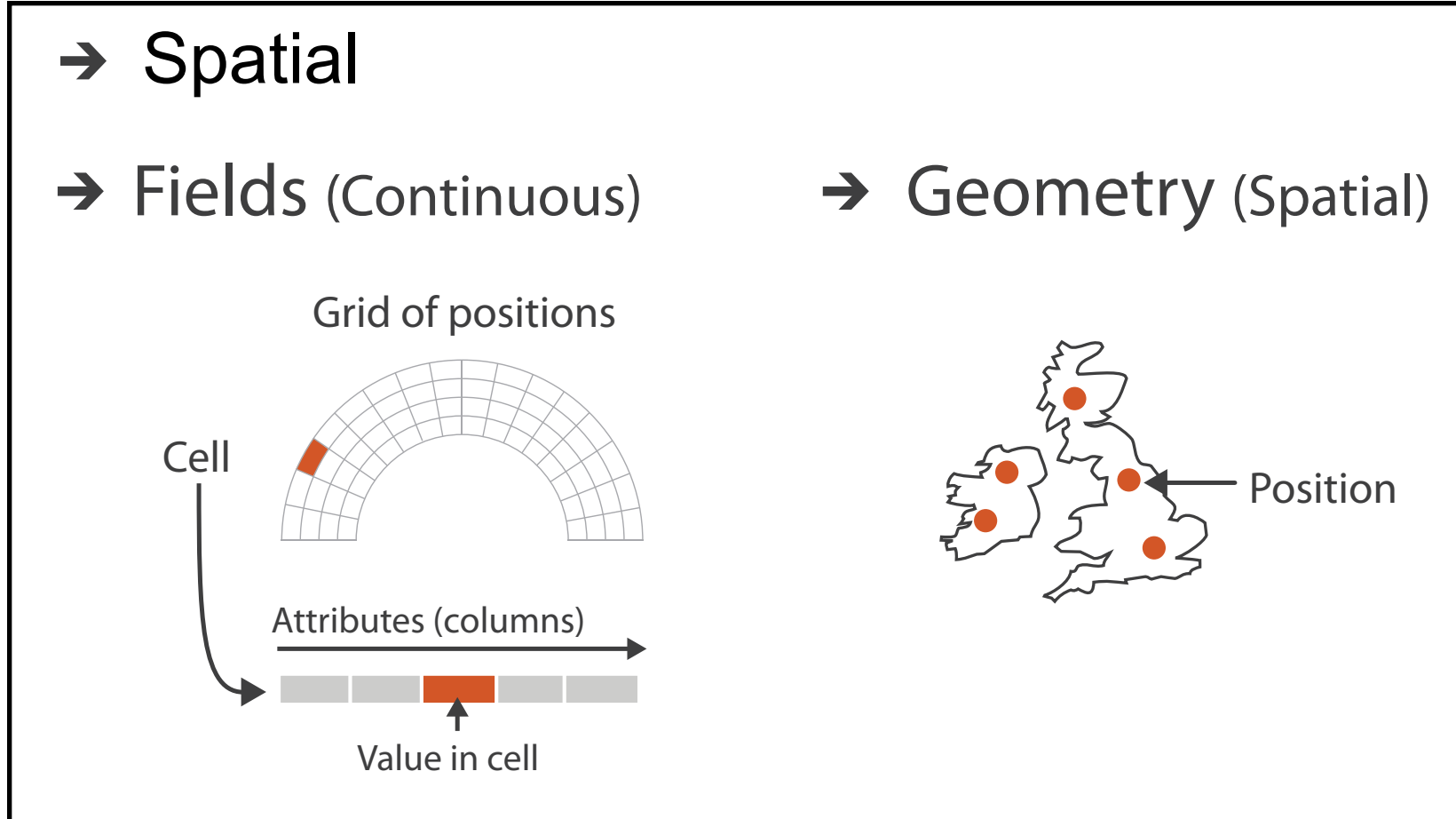
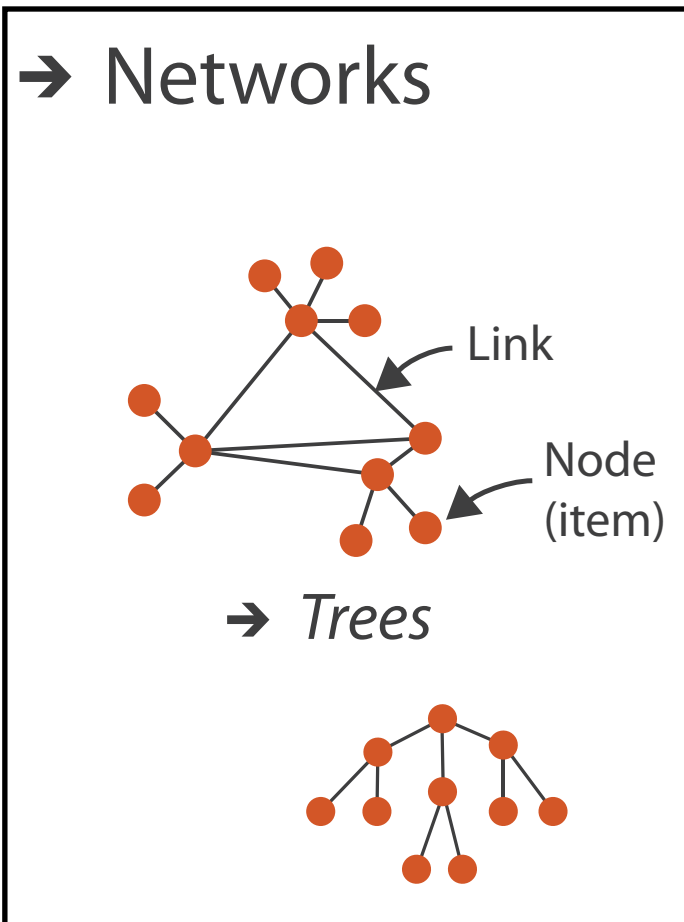
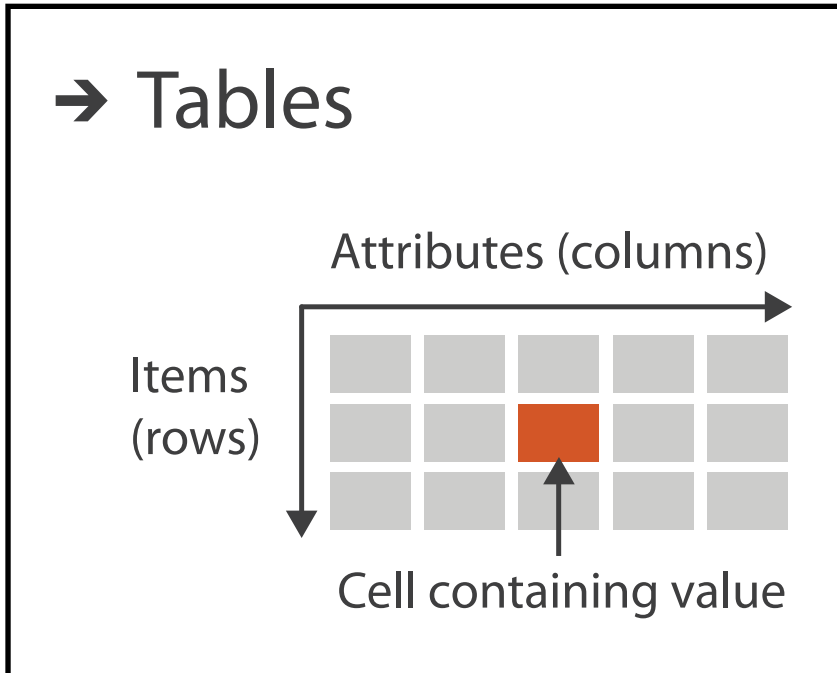
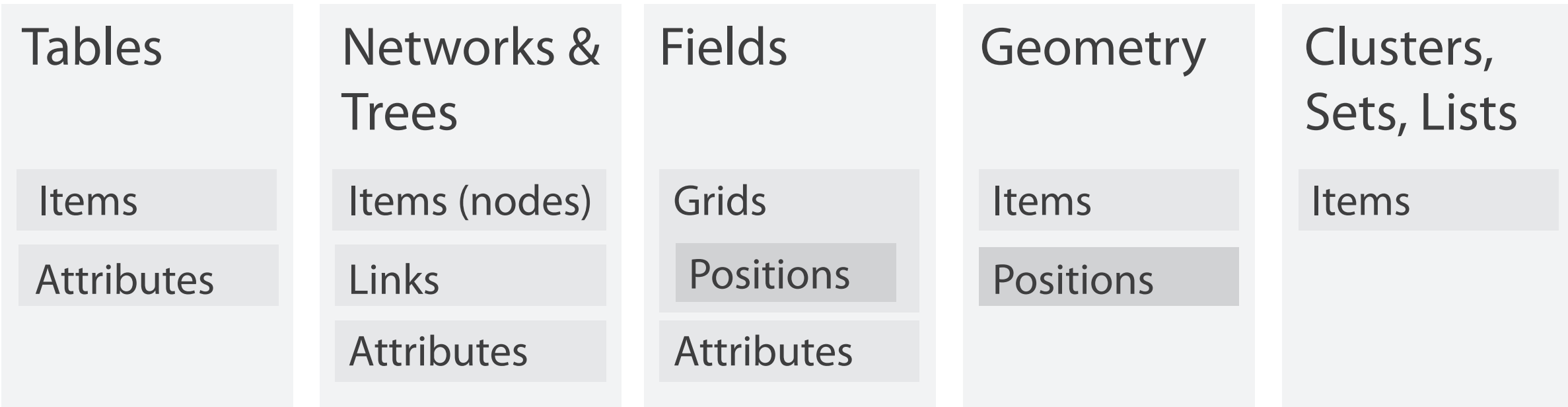


# Geometry

- shape of items
- explicit spatial positions / regions
  - points, lines, curves, surfaces, volumes
- boundary between computer graphics and visualization
  - graphics: geometry taken as given
  - vis: geometry is result of a design decision



# Dataset types

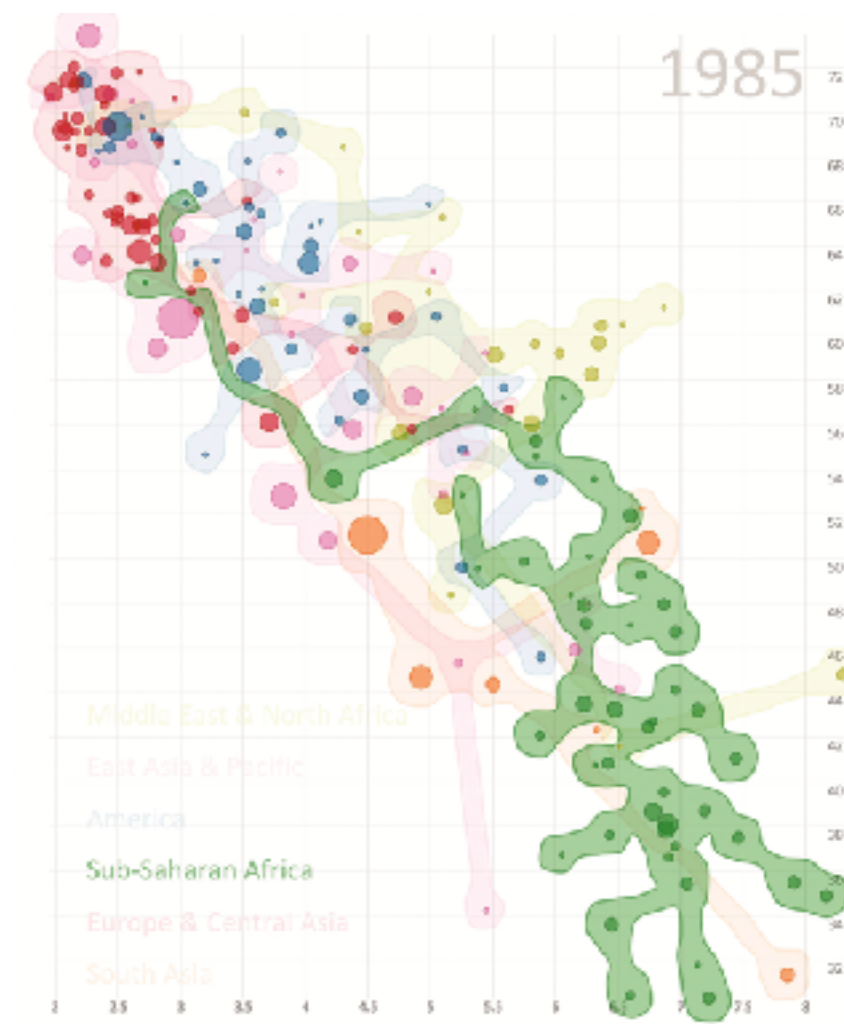


# Collections

- how we group items

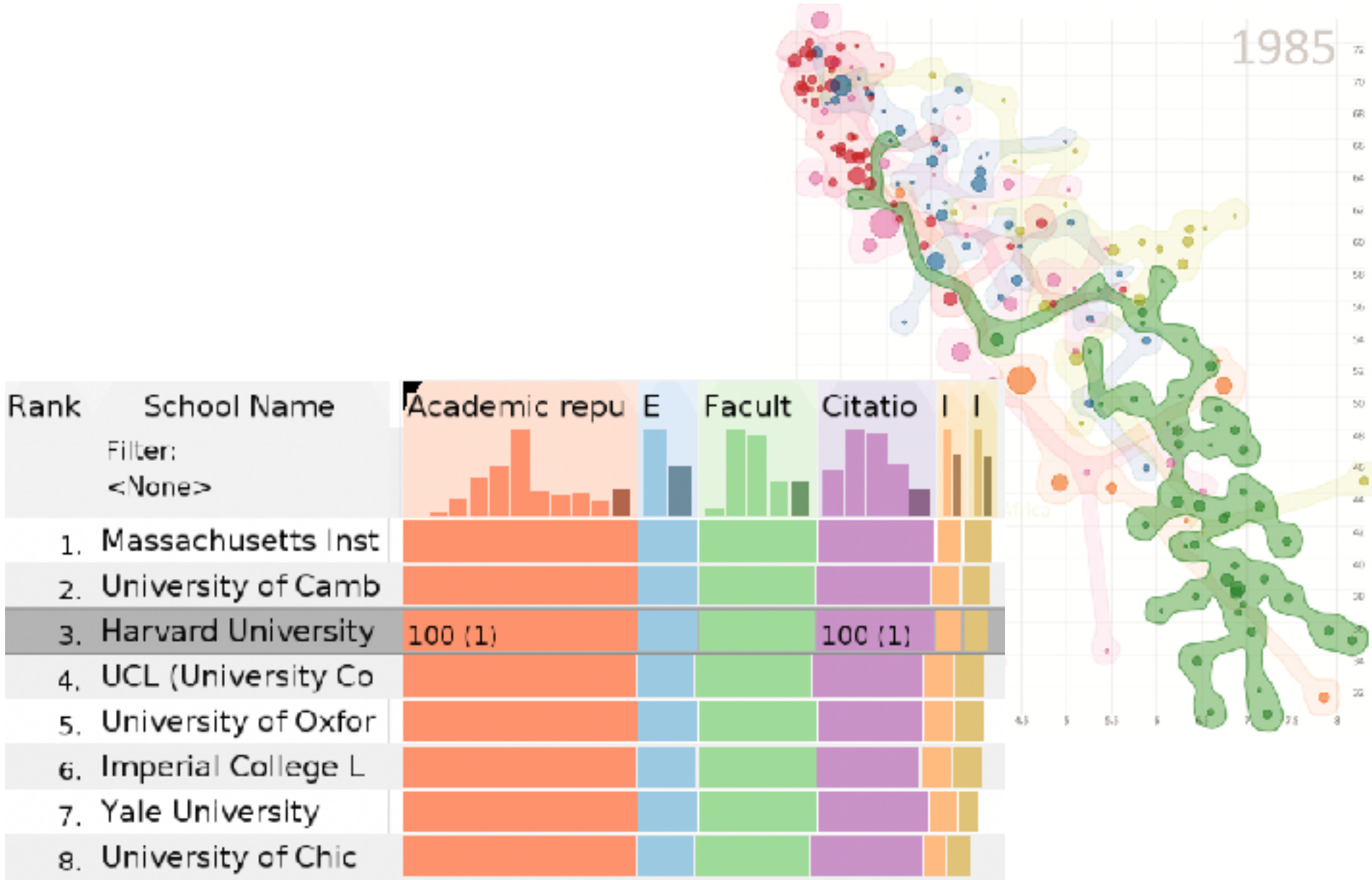
# Collections

- how we group items
- sets
  - unique items, unordered



# Collections

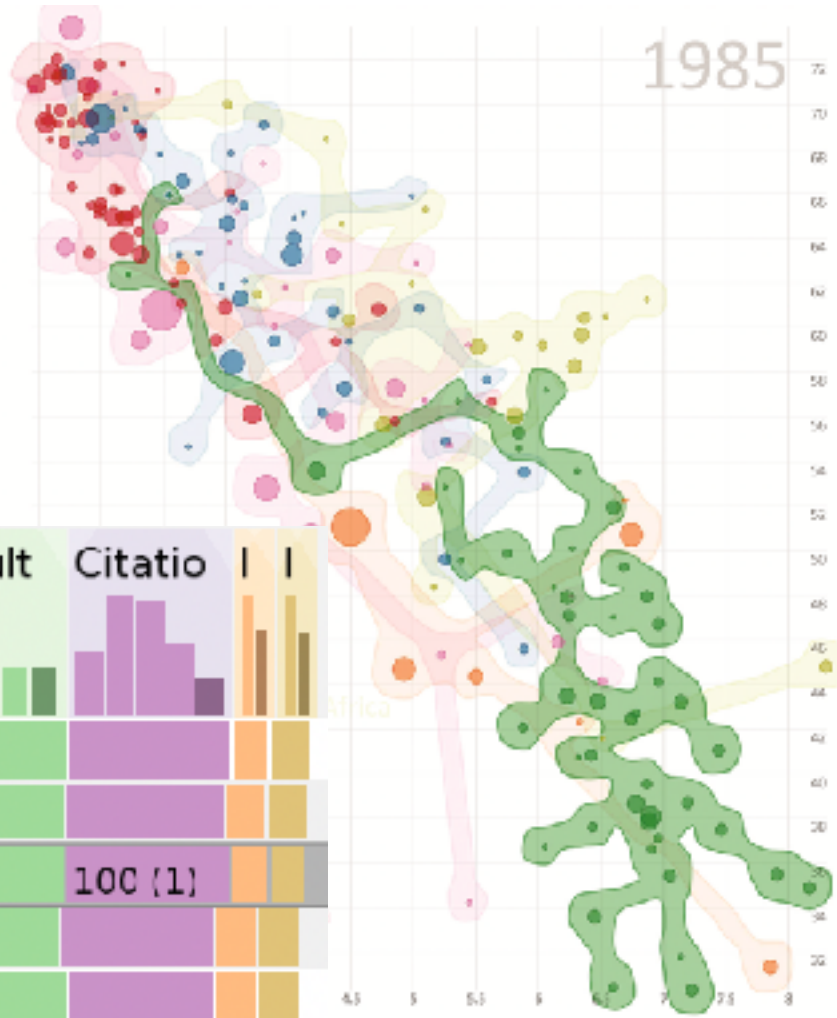
- how we group items
- sets
  - unique items, unordered
- lists
  - ordered, duplicates possible



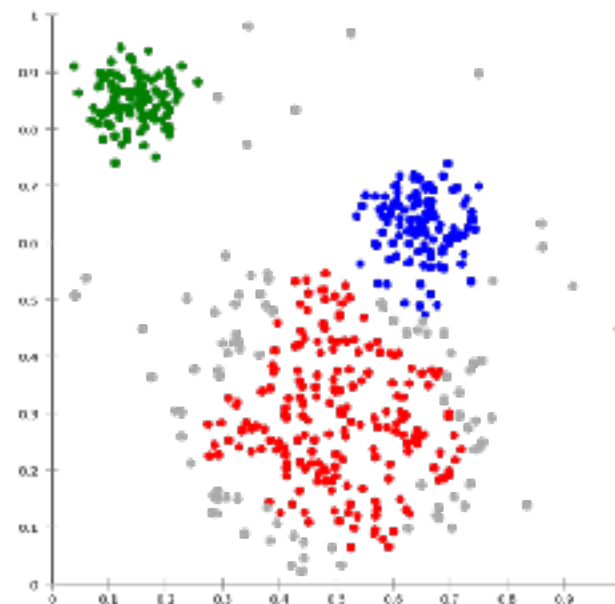


# Collections

- how we group items
- sets
  - unique items, unordered
- lists
  - ordered, duplicates possible
- clusters
  - groups of similar items

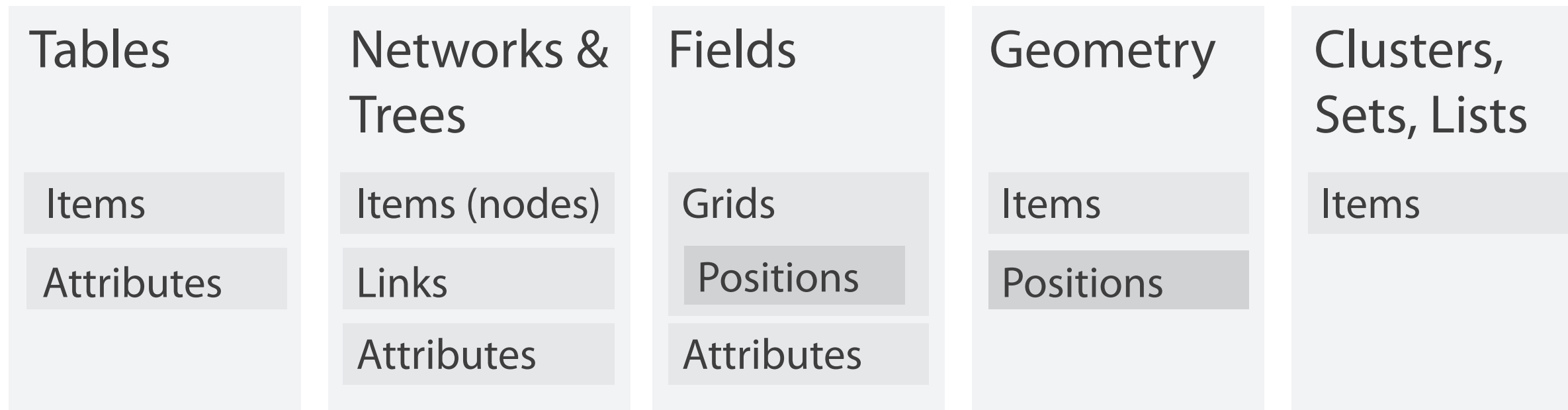


Rank	School Name	Academic repu	E	Facult	Citatio	I	I
	Filter: <None>						
1.	Massachusetts Inst						
2.	University of Camb						
3.	Harvard University	100 (1)			100 (1)		
4.	UCL (University Co						
5.	University of Oxfor						
6.	Imperial College L						
7.	Yale University						
8.	University of Chic						



# Dataset and data types

## → Data and Dataset Types



## → Data Types

→ Items    → Attributes    → Links    → Positions    → Grids

# Attribute types

- which classes of values & measurements?
- categorical (nominal)
  - compare equality
  - no implicit ordering
- ordered
  - ordinal
    - less/greater than defined
  - quantitative
    - meaningful magnitude
    - arithmetic possible

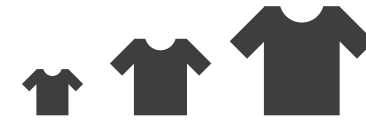
## ➔ Attribute Types

➔ Categorical

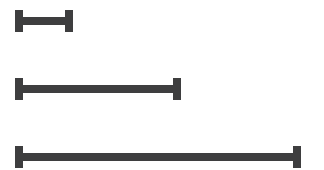


➔ Ordered

➔ *Ordinal*



➔ *Quantitative*





# Table

A	B	C	S	T	U
Order ID	Order Date	Order Priority	Product Container	Product Base Margin	Ship Date
3	10/14/06	5-Low	Large Box	0.8	10/21/06
6	2/21/08	4-Not Specified	Small Pack	0.55	2/22/08
32	7/16/07	2-High	Small Pack	0.79	7/17/07
32	7/16/07	2-High	Jumbo Box	0.72	7/17/07
32	7/16/07	2-High	Medium Box	0.6	7/18/07
32	7/16/07	2-High	Medium Box	0.65	7/18/07
35	10/23/07	4-Not Specified	Wrap Bag	0.52	10/24/07
35	10/23/07	4-Not Specified	Small Box	0.58	10/25/07
36	11/3/07	1-Urgent	Small Box	0.55	11/3/07
65	3/18/07	1-Urgent	Small Pack	0.49	3/19/07
66	1/20/05	5-Low	Wrap Bag	0.56	1/20/05
69	6/4/05	4-Not Specified	Small Pack	0.44	6/6/05
69	6/4/05	4-Not Specified	Wrap Bag	0.6	6/6/05
70	12/18/06	5-Low	Small Box	0.59	12/23/06
70	12/18/06	5-Low	Wrap Bag	0.82	12/23/06
96	4/17/05	2-High	Small Box	0.55	4/19/05
97	1/29/06	3-Medium	Small Box	0.38	1/30/06
129	11/19/08	5-Low	Small Box	0.37	11/28/08
130	5/8/08	2-High	Small Box	0.37	5/9/08
130	5/8/08	2-High	Medium Box	0.38	5/10/08
130	5/8/08	2-High	Small Box	0.6	5/11/08
132	6/11/06	3-Medium	Medium Box	0.6	6/12/06
132	6/11/06	3-Medium	Jumbo Box	0.69	6/14/06
134	5/1/08	4-Not Specified	Large Box	0.82	5/3/08
135	10/21/07	4-Not Specified	Small Pack	0.64	10/23/07
166	9/12/07	2-High	Small Box	0.55	9/14/07
193	8/8/06	1-Urgent	Medium Box	0.57	8/10/06
194	4/5/08	3-Medium	Wrap Bag	0.42	4/7/08



**categorical**  
**ordinal**  
**quantitative**

A	B	C	S	I	U
Order ID	Order Date	Order Priority	Product Container	Product Base Margin	Ship Date
3	10/14/06	5-Low	Large Box	0.8	10/21/06
6	2/21/08	4-Not Specified	Small Pack	0.55	2/22/08
32	7/16/07	2-High	Small Pack	0.79	7/17/07
32	7/16/07	2-High	Jumbo Box	0.72	7/17/07
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35	10/23/07	4-Not Specified	Wrap Bag	0.52	10/24/07
35	10/23/07	4-Not Specified	Small Box	0.58	10/25/07
36	11/3/07	1-Urgent	Small Box	0.55	11/3/07
65	3/18/07	1-Urgent	Small Pack	0.49	3/19/07
66	1/20/05	5-Low	Wrap Bag	0.56	1/20/05
69	6/4/05	4-Not Specified	Small Pack	0.44	6/6/05
69	6/4/05	4-Not Specified	Wrap Bag	0.6	6/6/05
70	12/18/06	5-Low	Small Box	0.59	12/23/06
70	12/18/06	5-Low	Wrap Bag	0.82	12/23/06
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129	11/19/08	5-Low	Small Box	0.37	11/28/08
130	5/8/08	2-High	Small Box	0.37	5/9/08
130	5/8/08	2-High	Medium Box	0.38	5/10/08
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132	6/11/06	3-Medium	Medium Box	0.6	6/12/06
132	6/11/06	3-Medium	Jumbo Box	0.69	6/14/06
134	5/1/08	4-Not Specified	Large Box	0.82	5/3/08
135	10/21/07	4-Not Specified	Small Pack	0.64	10/23/07
166	9/12/07	2-High	Small Box	0.55	9/14/07
193	8/8/06	1-Urgent	Medium Box	0.57	8/10/06

# Other data concerns

## ➔ Attribute Types

➔ Categorical

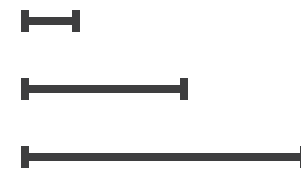


➔ Ordered

➔ Ordinal



➔ Quantitative



## ➔ Ordering Direction

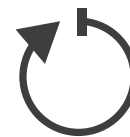
➔ Sequential



➔ Diverging



➔ Cyclic



## ➔ Dataset Availability

➔ Static



➔ Dynamic



# Data abstraction: Three operations

- translate from domain-specific language to generic visualization language
- identify dataset type(s), attribute types
- identify cardinality
  - how many items in the dataset?
  - what is cardinality of each attribute?
    - number of levels for categorical data
    - range for quantitative data
- consider whether to transform data
  - guided by understanding of task

# Data vs conceptual models

- data model
  - mathematical abstraction
    - sets with operations, eg floats with  $*$  / - +
    - variable data types in programming languages
- conceptual model
  - mental construction (semantics)
  - supports reasoning
  - typically based on understanding of tasks [stay tuned!]
- data abstraction process relies on conceptual model
  - for transforming data if needed

# Data vs conceptual model, example

# Data vs conceptual model, example

- data model: floats
  - 32.52, 54.06, -14.35, ...

# Data vs conceptual model, example

- data model: floats
  - 32.52, 54.06, -14.35, ...
- conceptual model
  - temperature



# Data vs conceptual model, example

- data model: floats
  - 32.52, 54.06, -14.35, ...
- conceptual model
  - temperature
- multiple possible data abstractions

# Data vs conceptual model, example

- data model: floats
  - 32.52, 54.06, -14.35, ...
- conceptual model
  - temperature
- multiple possible data abstractions
  - continuous to 2 significant figures: quantitative
    - task: forecasting the weather

# Data vs conceptual model, example

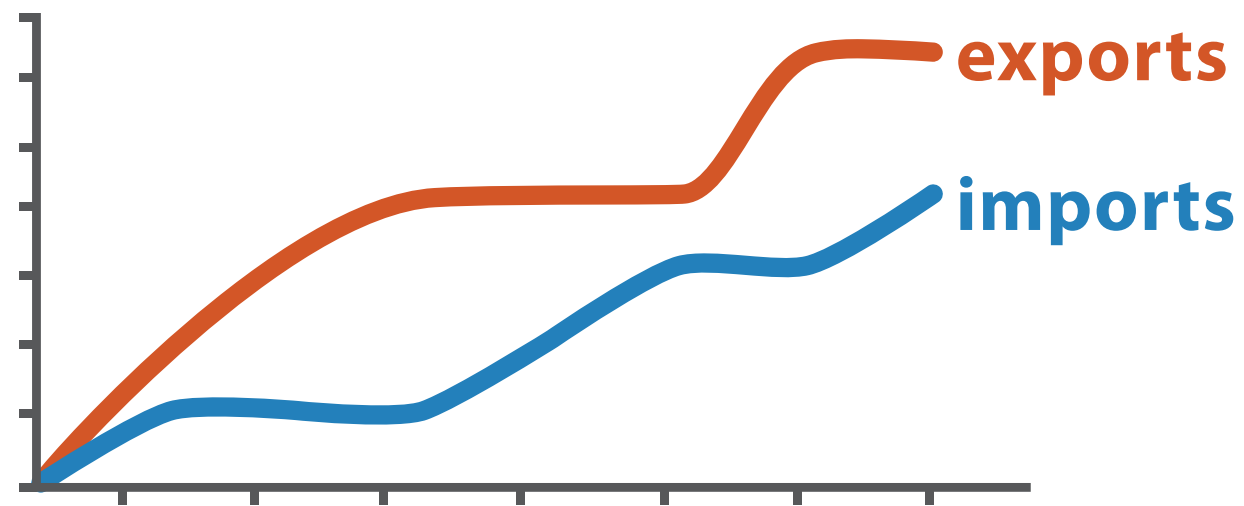
- data model: floats
  - 32.52, 54.06, -14.35, ...
- conceptual model
  - temperature
- multiple possible data abstractions
  - continuous to 2 significant figures: quantitative
    - task: forecasting the weather
  - hot, warm, cold: ordinal
    - task: deciding if bath water is ready

# Data vs conceptual model, example

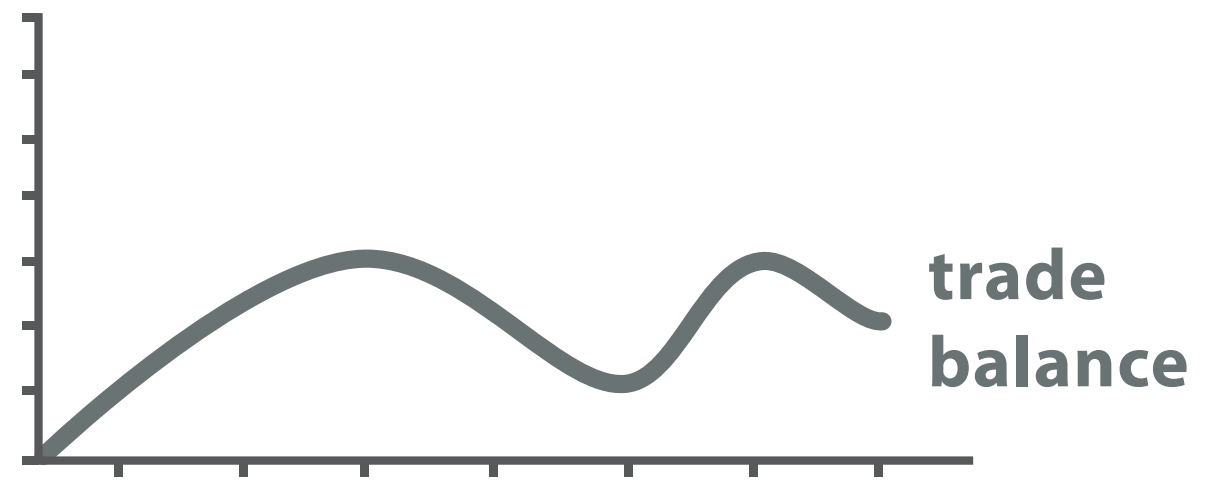
- data model: floats
  - 32.52, 54.06, -14.35, ...
- conceptual model
  - temperature
- multiple possible data abstractions
  - continuous to 2 significant figures: quantitative
    - task: forecasting the weather
  - hot, warm, cold: ordinal
    - task: deciding if bath water is ready
  - above freezing, below freezing: categorical
    - task: decide if I should leave the house today

# Derived attributes

- derived attribute: compute from originals
  - simple change of type
  - acquire additional data
  - complex transformation



Original Data



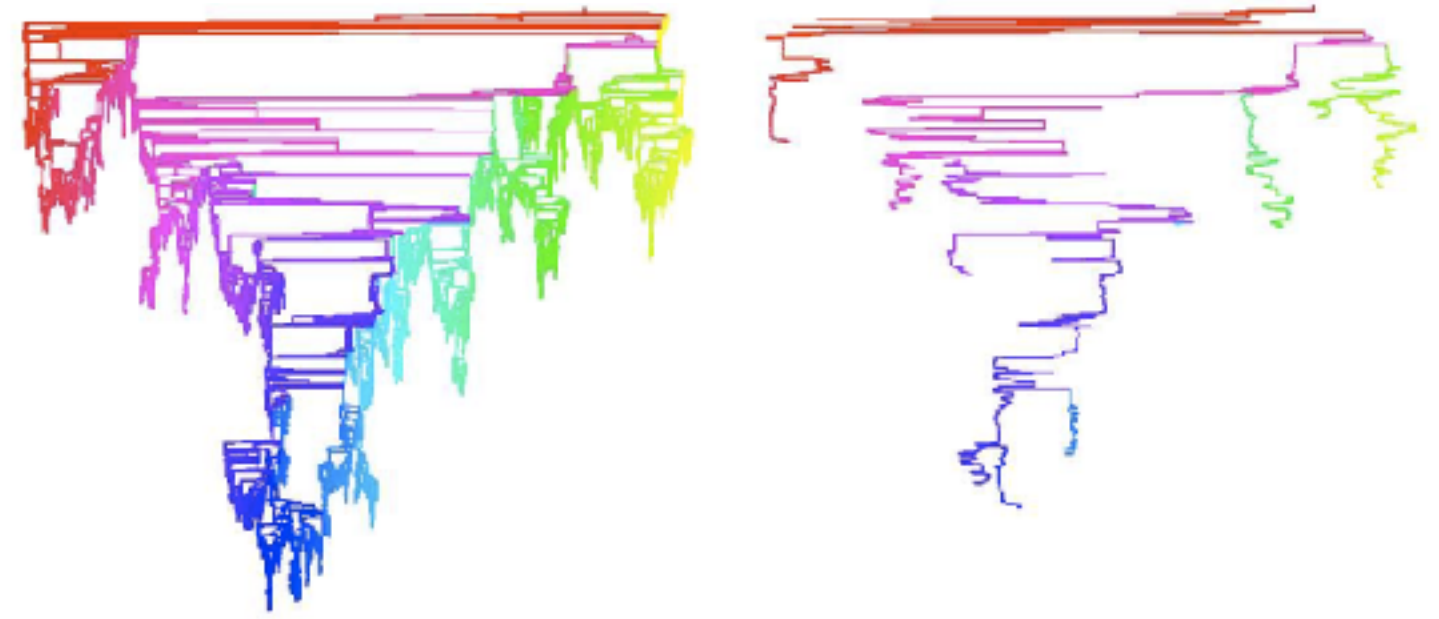
$$\text{trade balance} = \text{exports} - \text{imports}$$

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  
**Why?** → Derive  
 → Out Quantitative attribute on nodes

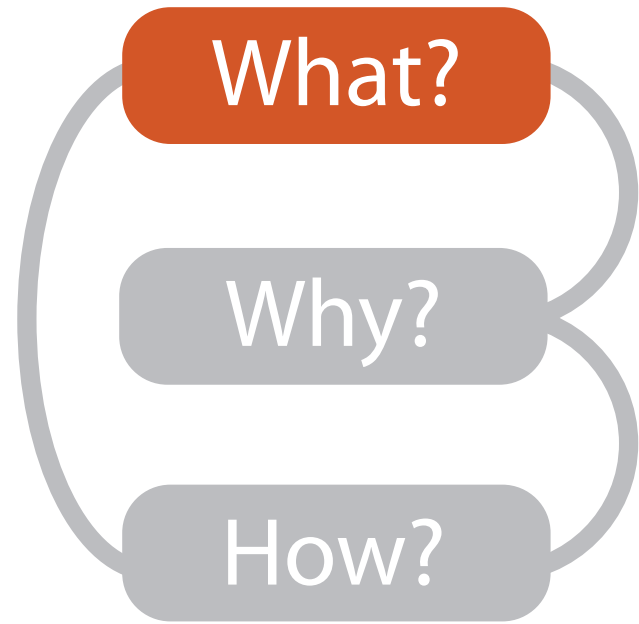
**Task 2**

**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



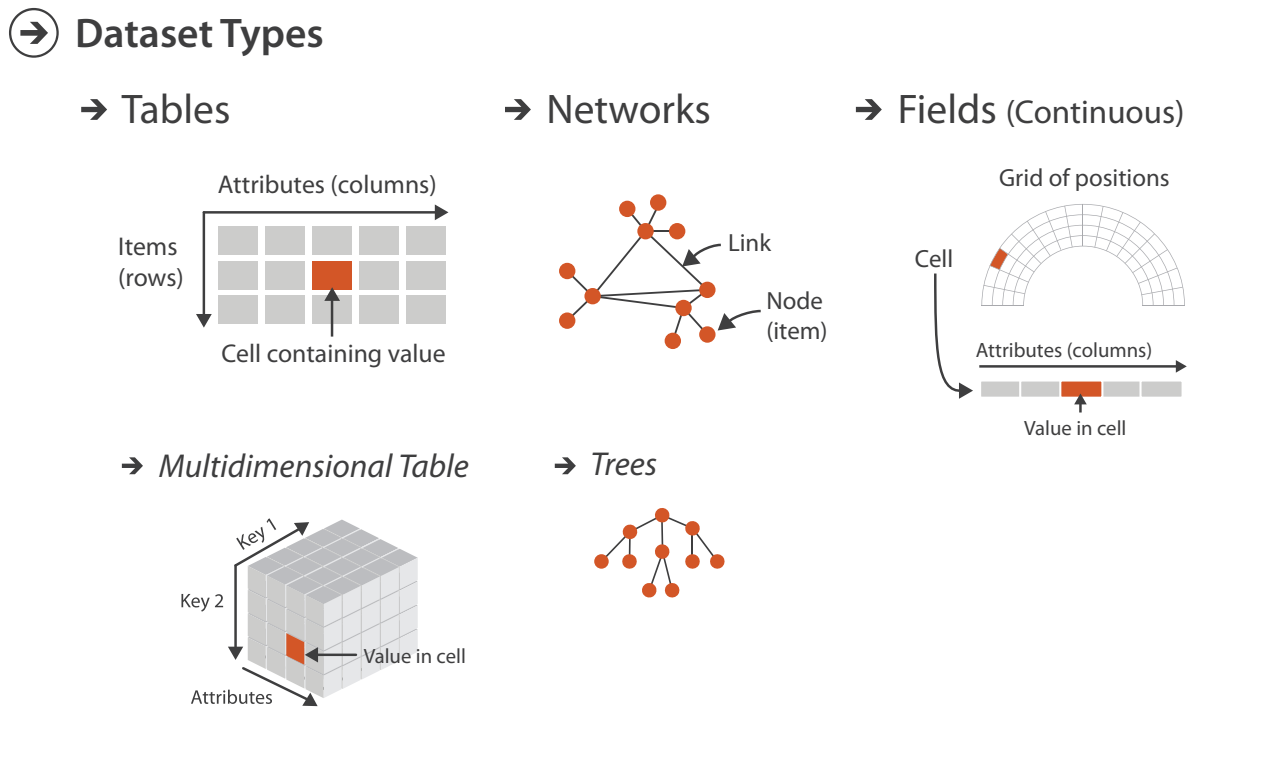
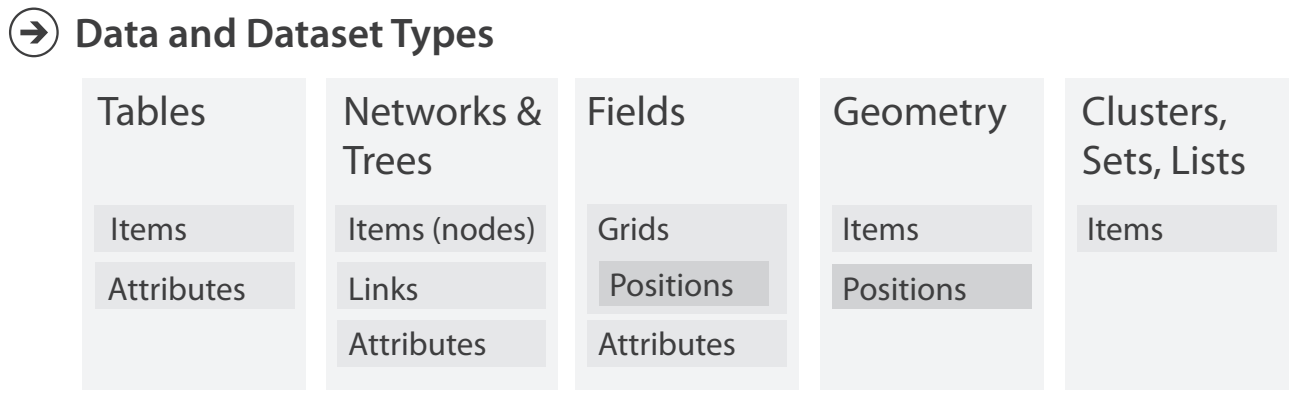
# What?

## Datasets

## Attributes

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

- ➔ Attribute Types
  - ➔ Categorical
    - + ● ■ ▲
  - ➔ Ordered
    - ➔ Ordinal
      - 👕 👕 👕
    - ➔ Quantitative
      - ┆ ┆ ┆



- ➔ Ordering Direction
  - ➔ Sequential
    -
  - ➔ Diverging
    - ←→
  - ➔ Cyclic
    - ↻

