

# Information Visualization

# Data Abstraction

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**Lect 2, 9 Jan 2020**

**<http://www.cs.ubc.ca/~tmm/courses/436V-20>**

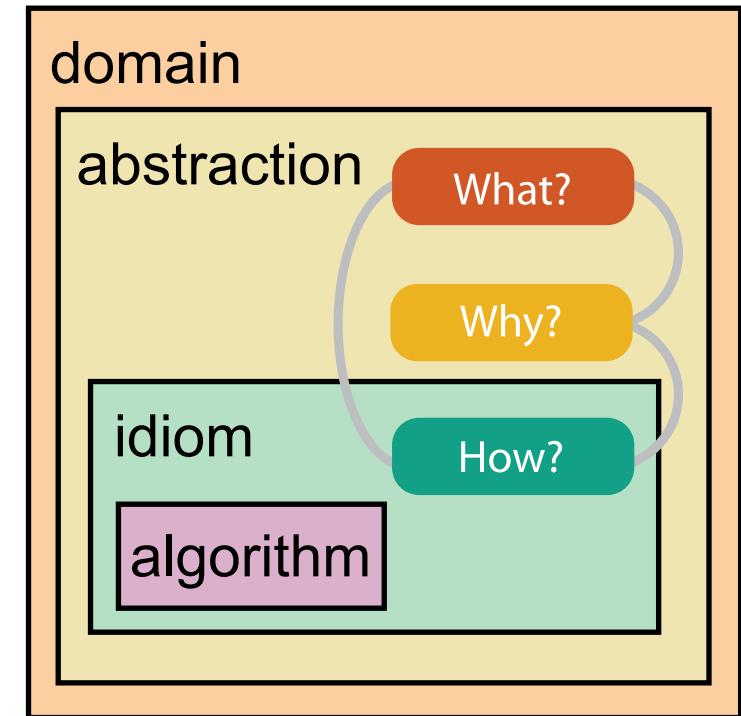
# Nested Model

# How to evaluate a visualization: So many methods, how to pick?

- Computational benchmarks?
  - quant: system performance, memory
- User study in lab setting?
  - quant: (human) time and error rates, preferences
  - qual: behavior/strategy observations
- Field study of deployed system?
  - quant: usage logs
  - qual: interviews with users, case studies, observations
- Analysis of results?
  - quant: metrics computed on result images
  - qual: consider what structure is visible in result images
- Justification of choices?
  - qual: perceptual principles, best practices

# Nested model: Four levels of visualization design

- *domain situation*
  - who are the target users?
- *abstraction*
  - translate from specifics of domain to **vocabulary** of visualization
    - **what** is shown? **data** abstraction
    - **why** is the user looking at it? **task** abstraction
      - often must transform data, guided by task
- *idiom*
  - **how** is it shown?
    - **visual encoding** idiom: how to draw
    - **interaction** idiom: how to manipulate
- *algorithm*
  - efficient computation



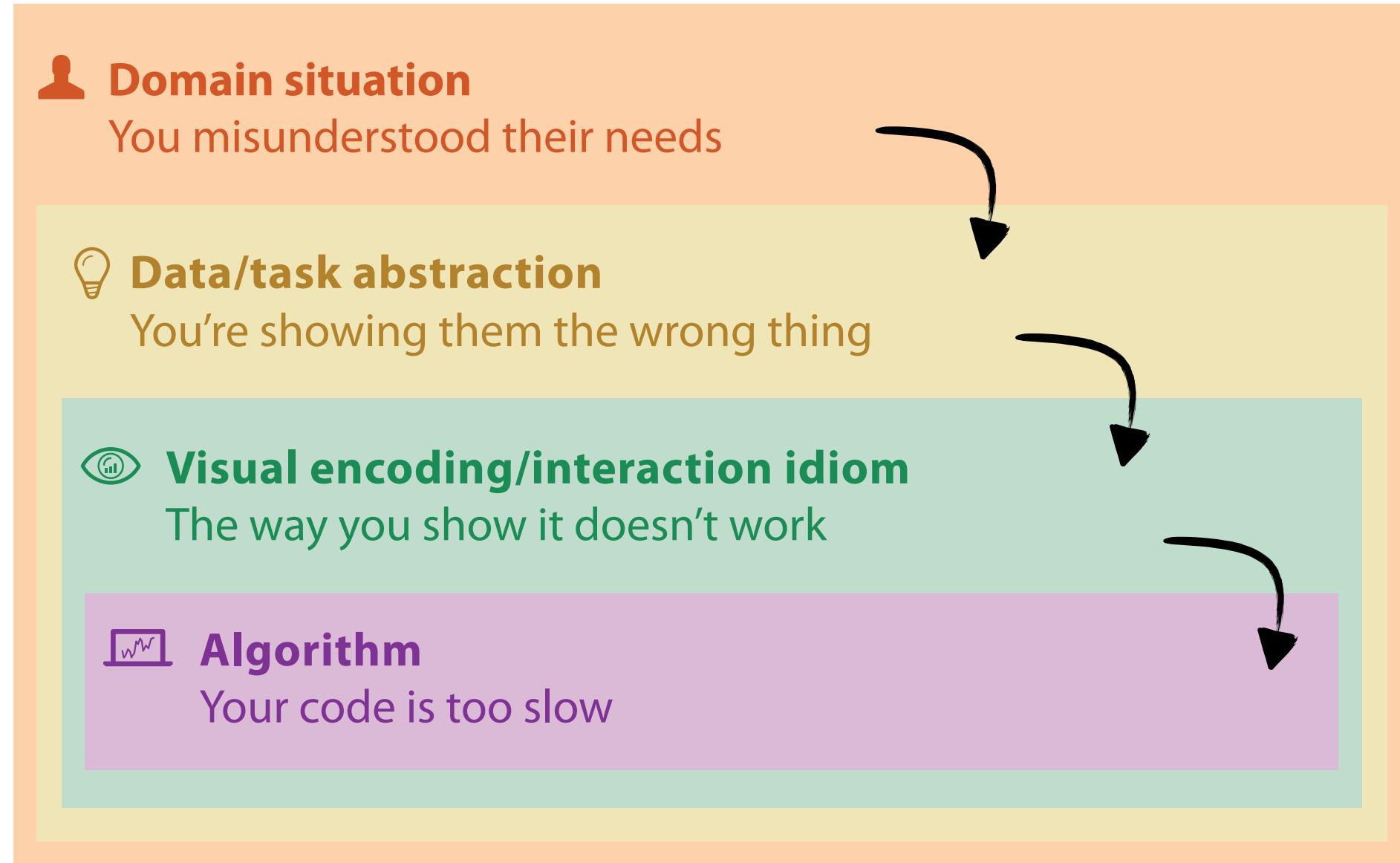
[A Nested Model of Visualization Design and Validation.  
Munzner. *IEEE TVCG* 15(6):921-928, 2009]

(*Proc. InfoVis 2009*).]

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

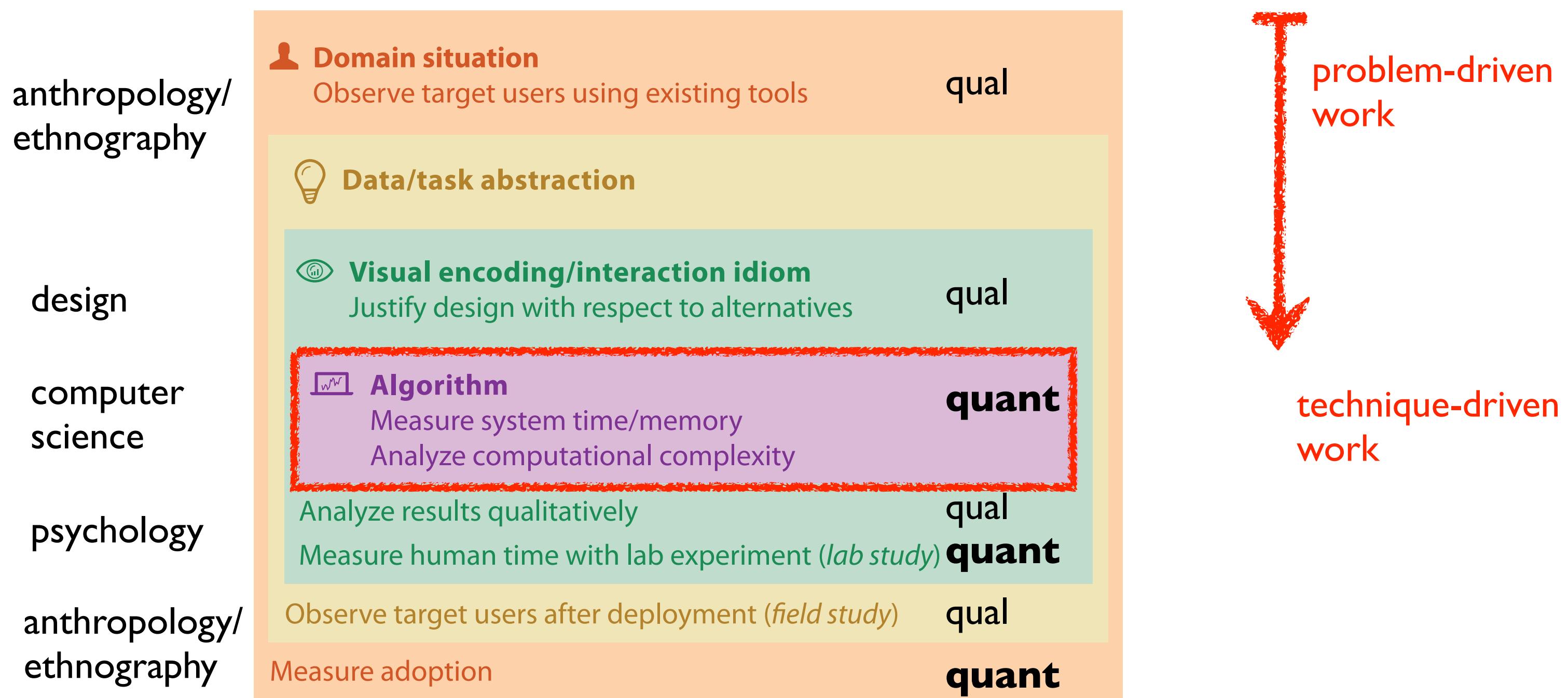
# Different threats to validity at each level

- cascading effects downstream

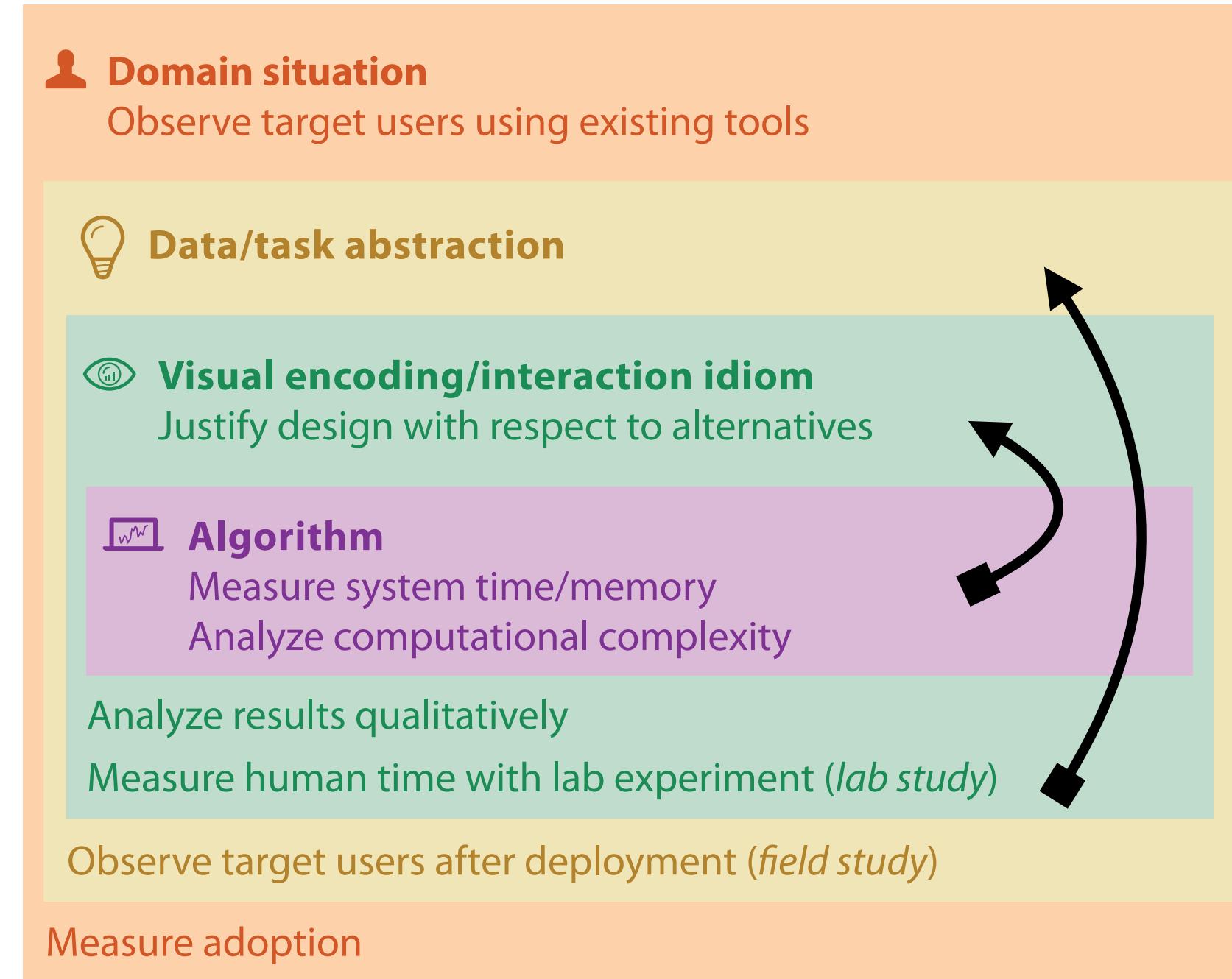


# Interdisciplinary: need methods from different fields at each level

- mix of qual and quant approaches (typically)



# Mismatches: Common problem



benchmarks can't  
confirm design

lab studies can't  
confirm task  
abstraction

# What: Data Abstraction

# What does data mean?

14, 2.6, 30, 30, 15, 100001

- What does this sequence of six numbers mean?
  - two points far from each other in 3D space?
  - two points close to each other in 2D space, with 15 links between them, and a weight of 100001 for the link?
  - something else??

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 neighbourhood 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

Name	Age	Shirt Size	Favorite Fruit
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
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

# 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"

attributes: name, age, shirt size, fave fruit

Name	Age	Shirt Size	Favorite Fruit
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

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

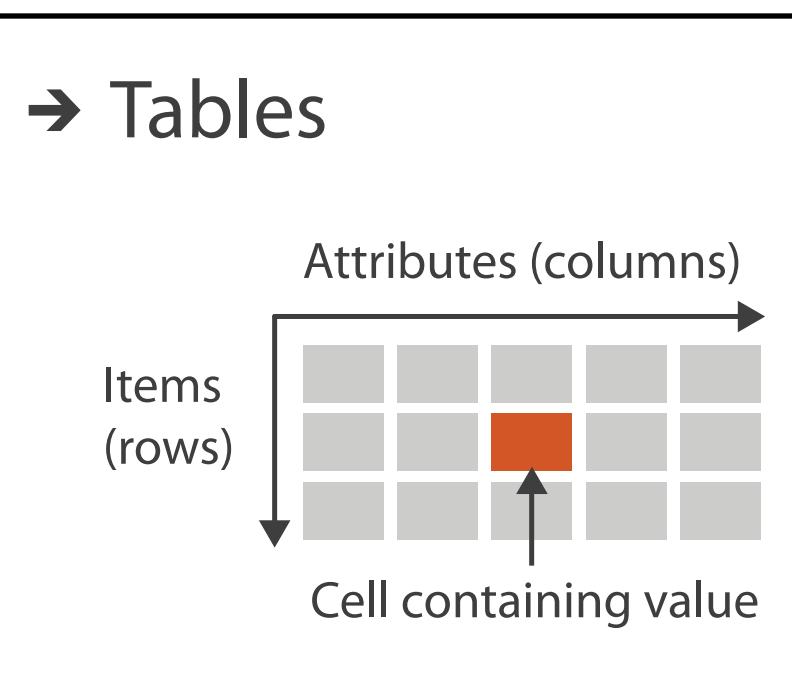
- flat table

- one item per row
- each column is attribute
- cell holds value

Tables

Items

Attributes



attributes: name, age, shirt size, fave fruit

Name	Age	Shirt Size	Favorite Fruit
Amy	8	S	Apple
Basil	7	S	Pear
Clara	9	M	Durian
Desmond	13	L	Elderberry
Ernest	12	L	Peach
Fanny	10	S	Lychee
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item: person

# Dataset types

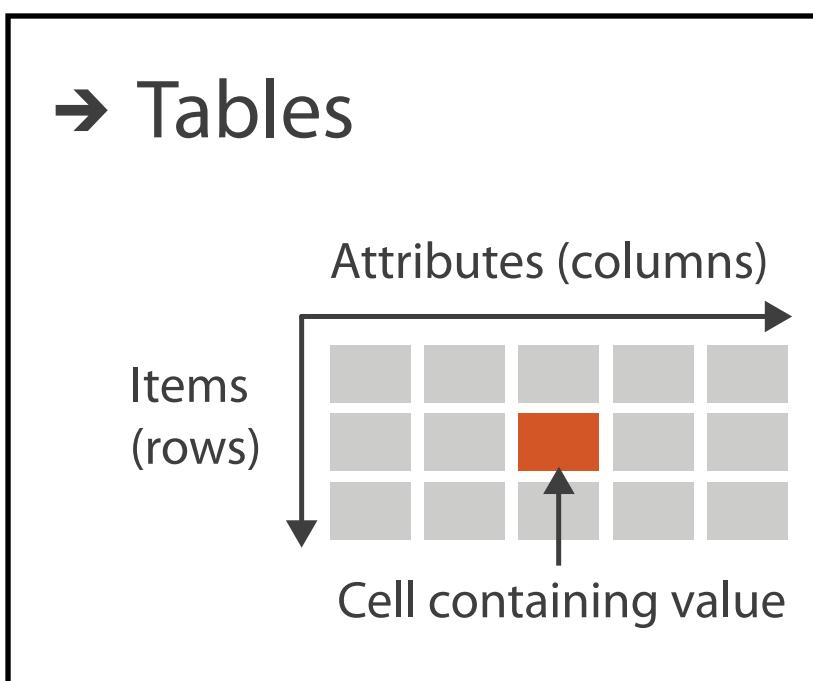
- flat table

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

Tables

Items

Attributes



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

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

# Table

A	B	C	S	T	U
Order ID	Order Date	Order Priority	Product Container	Product Base Margin	Ship Date
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35	10/23/07	4-Not Specified	Wrap Bag	0.52	10/24/07
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70	12/18/06	5-Low	Small Box	0.59	12/23/06
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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

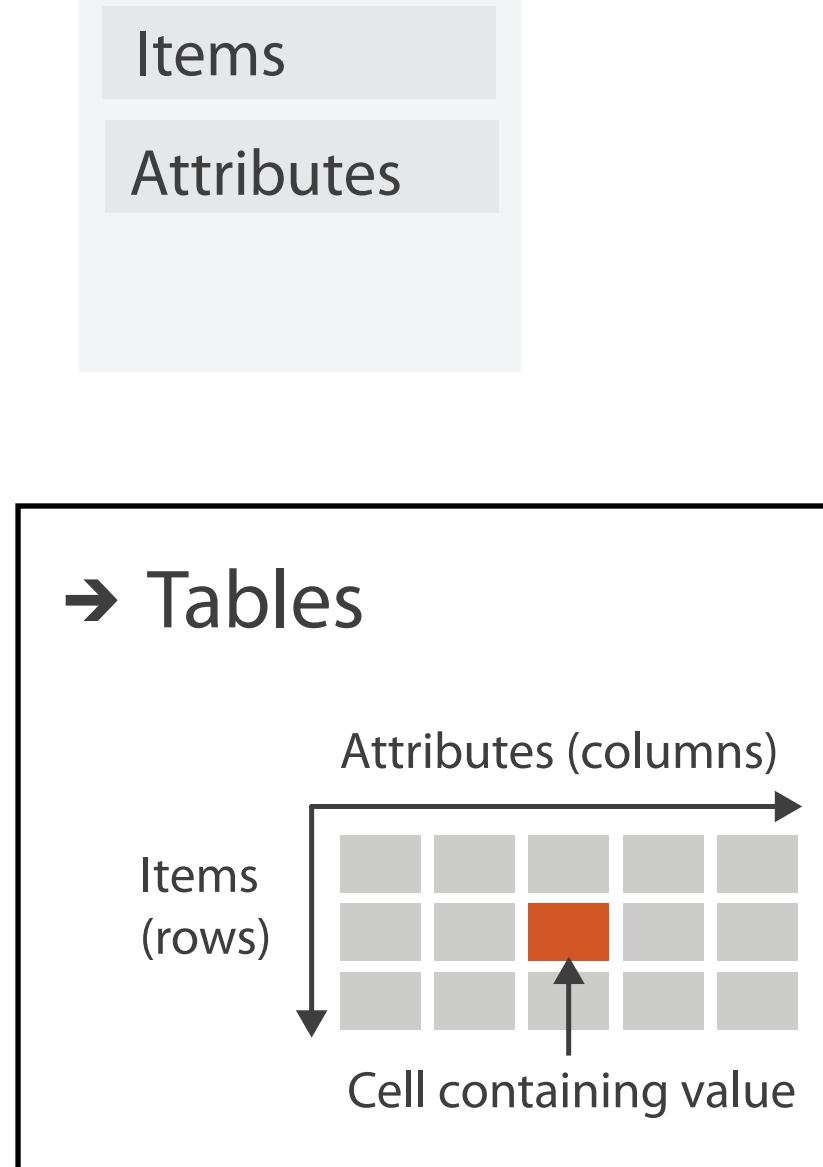
item

cell

attribute

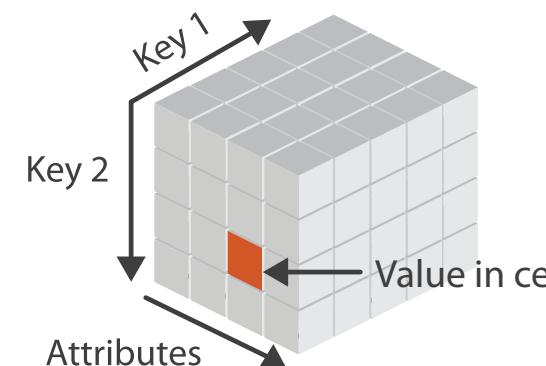
# Dataset types

Tables



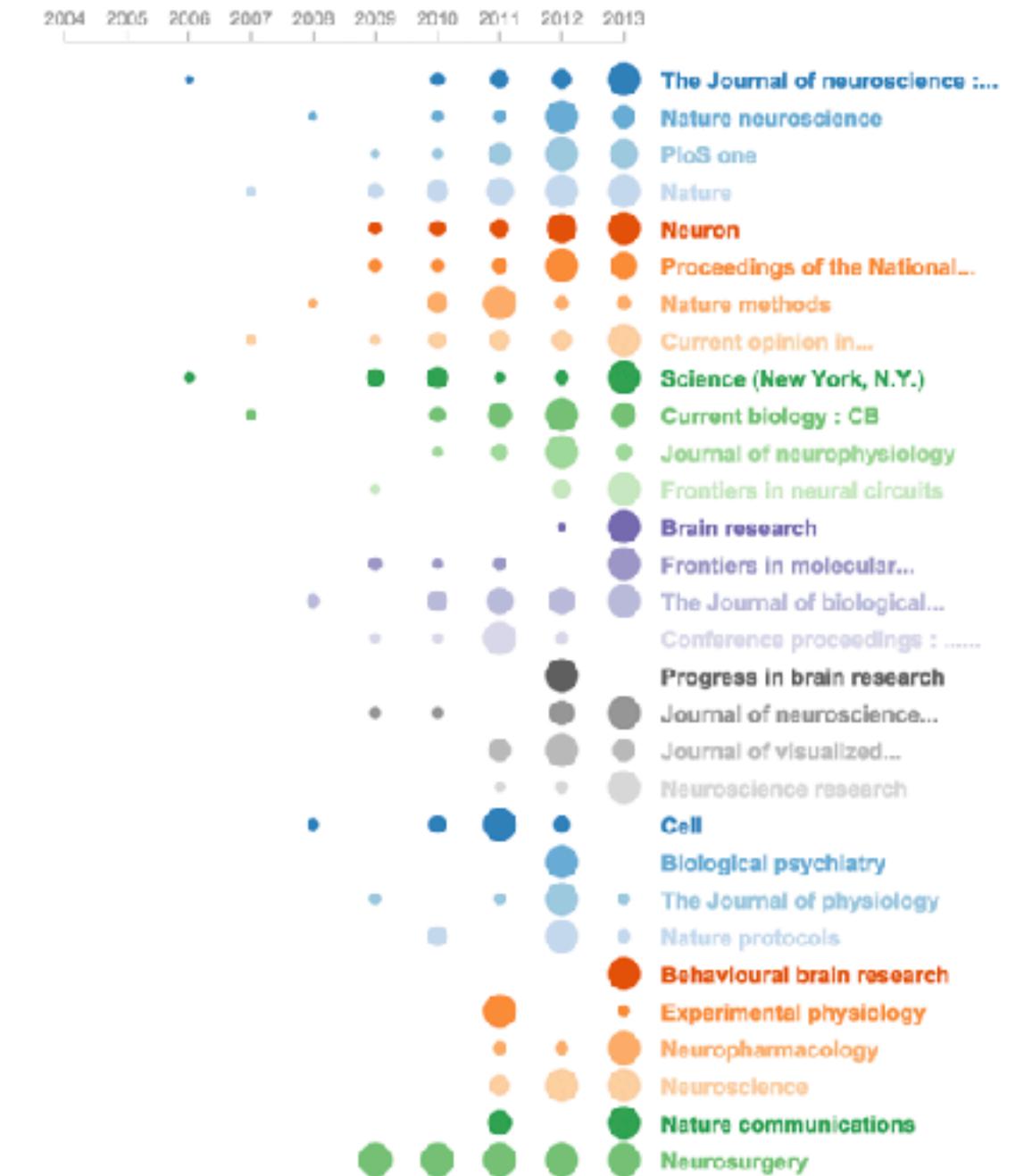
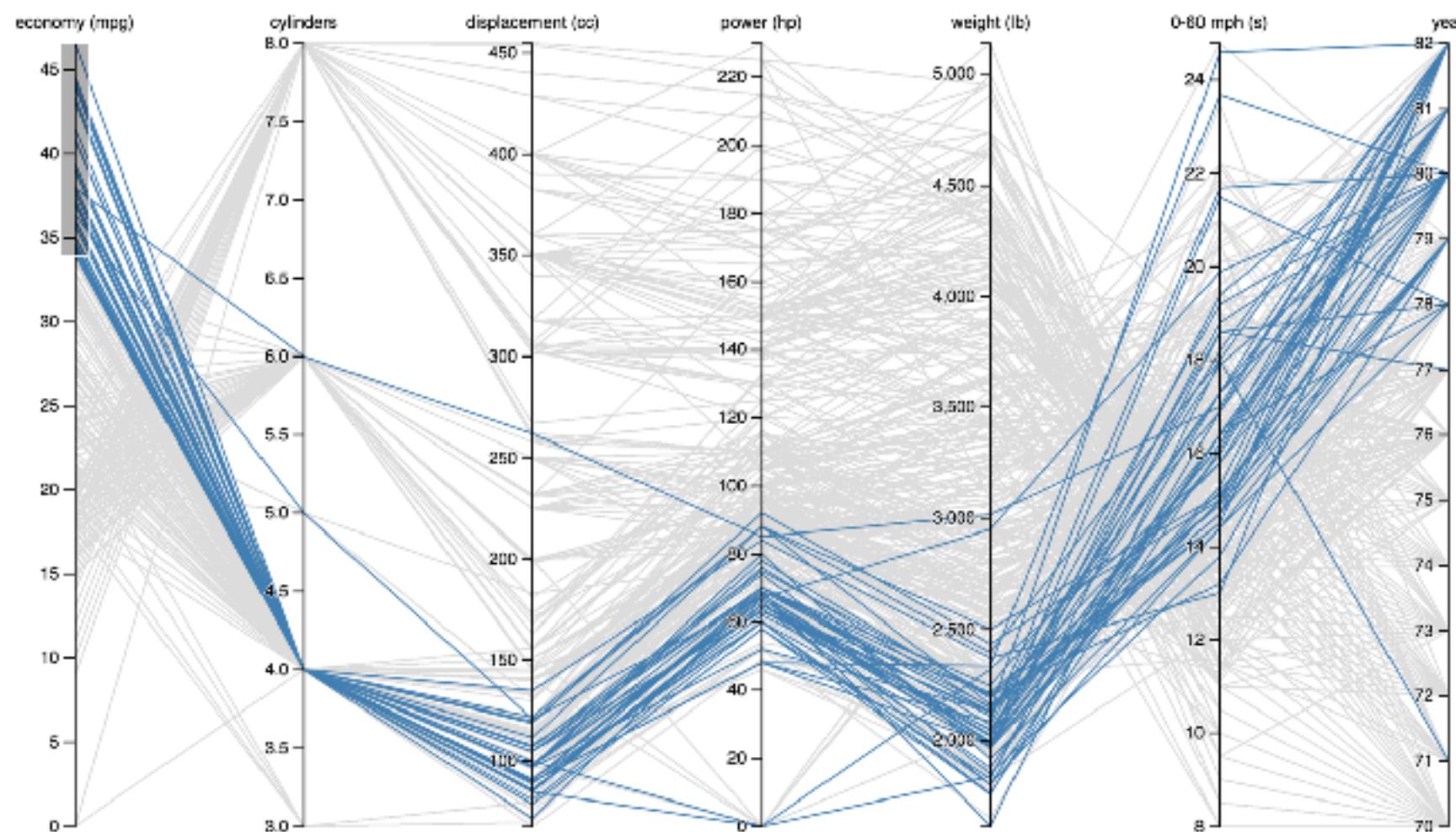
- multidimensional tables
  - indexing based on multiple keys
    - eg genes, patients

→ Multidimensional Table



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
1	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
4	3	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
5	4	3	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
6	5	4	3	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
7	6	5	4	3	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
8	7	6	5	4	3	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
9	8	7	6	5	4	3	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	9	8	7	6	5	4	3	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
11	10	9	8	7	6	5	4	3	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
12	11	10	9	8	7	6	5	4	3	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
13	12	11	10	9	8	7	6	5	4	3	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
14	13	12	11	10	9	8	7	6	5	4	3	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	1	1	1	1	1	1	1	1	1	1	1	1
16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	1	1	1	1	1	1	1	1	1	1	1
17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	1	1	1	1	1	1	1	1	1	1
18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	1	1	1	1	1	1	1	1	1
19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	1	1	1	1	1	1	1	1
20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	1	1	1	1	1	1	1
21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	1	1	1	1	1	1
22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	1	1	1	1	1

# Visualizing tables



# Dataset types

Tables

Items

Attributes

Networks &  
Trees

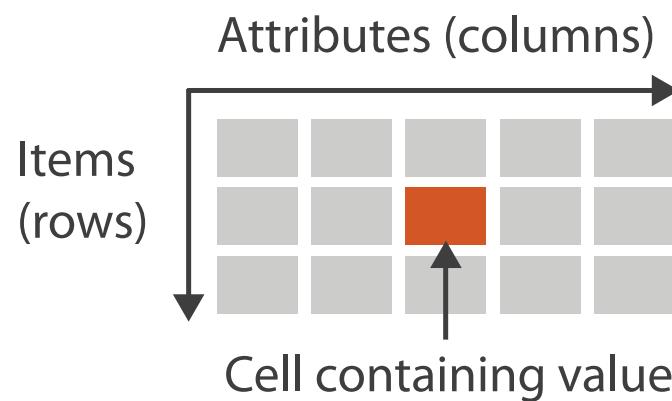
Items (nodes)

Links

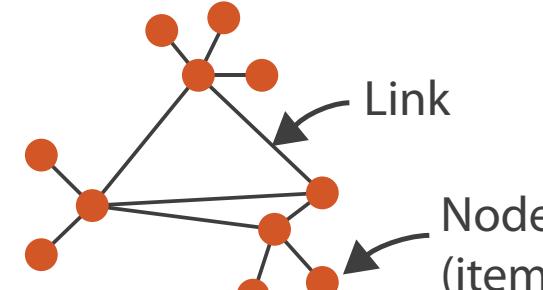
Attributes

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

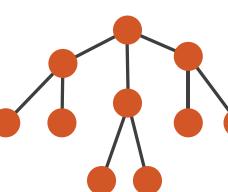
→ Tables



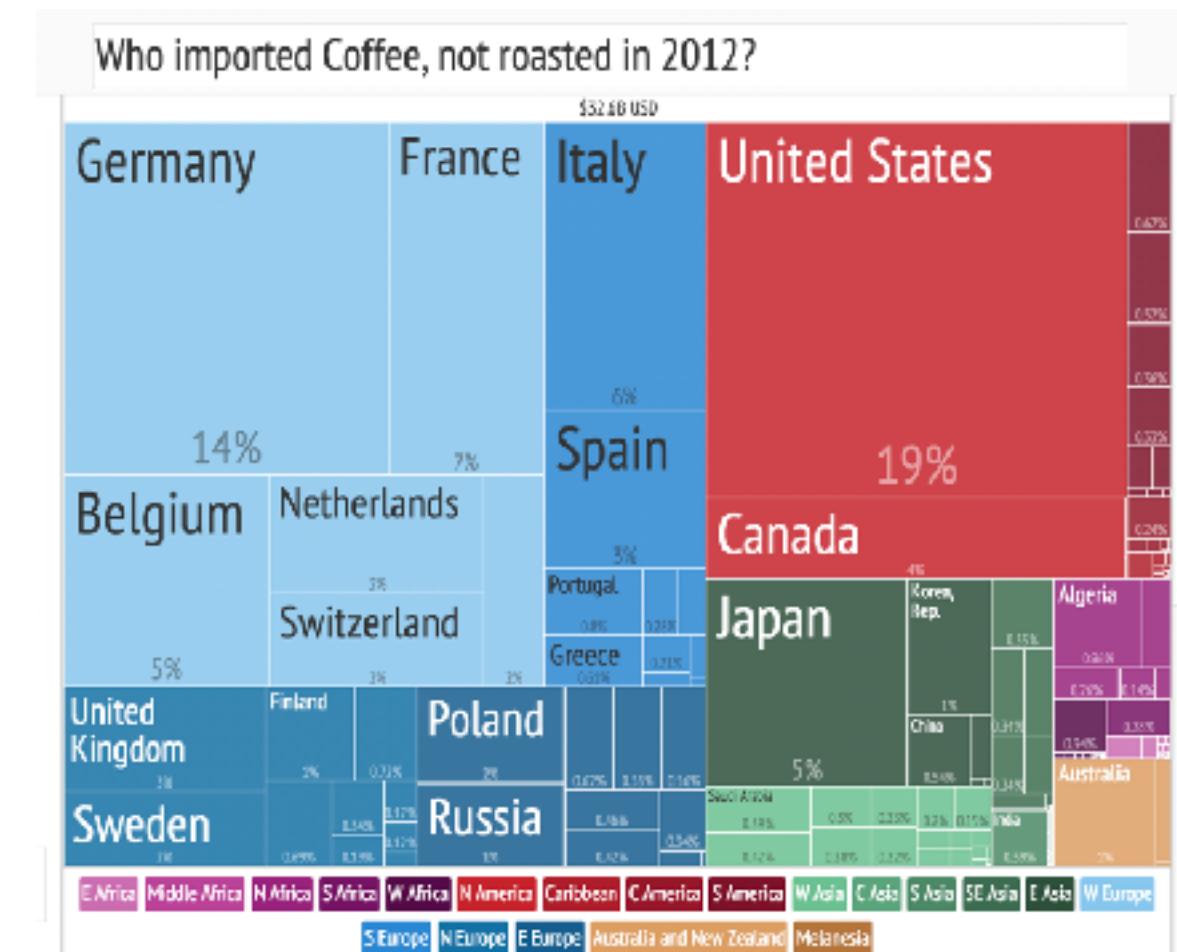
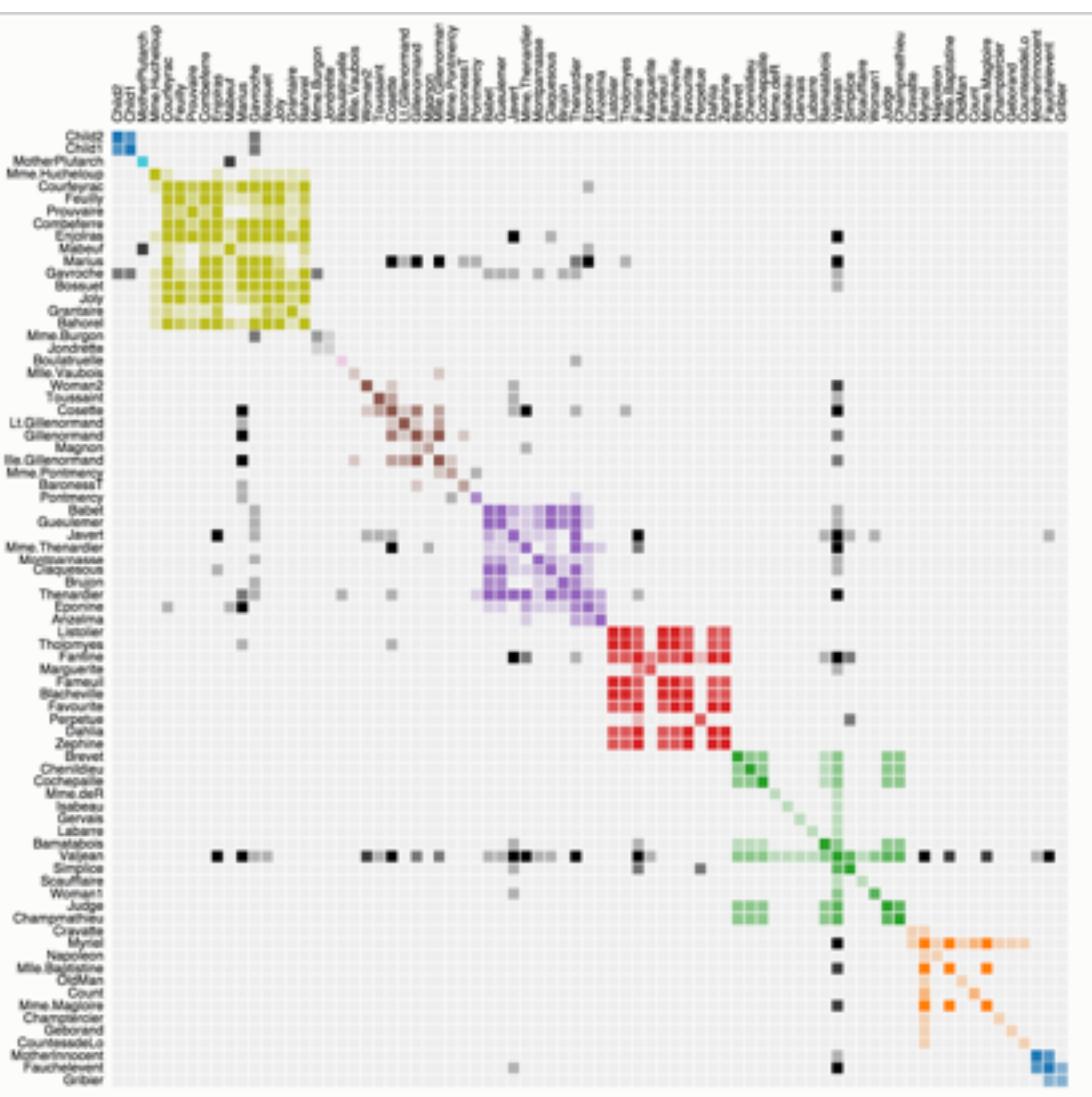
→ Networks



→ Trees



# Visualizing networks



# Dataset types

Tables

Items

Attributes

Networks & Trees

Items (nodes)

Links

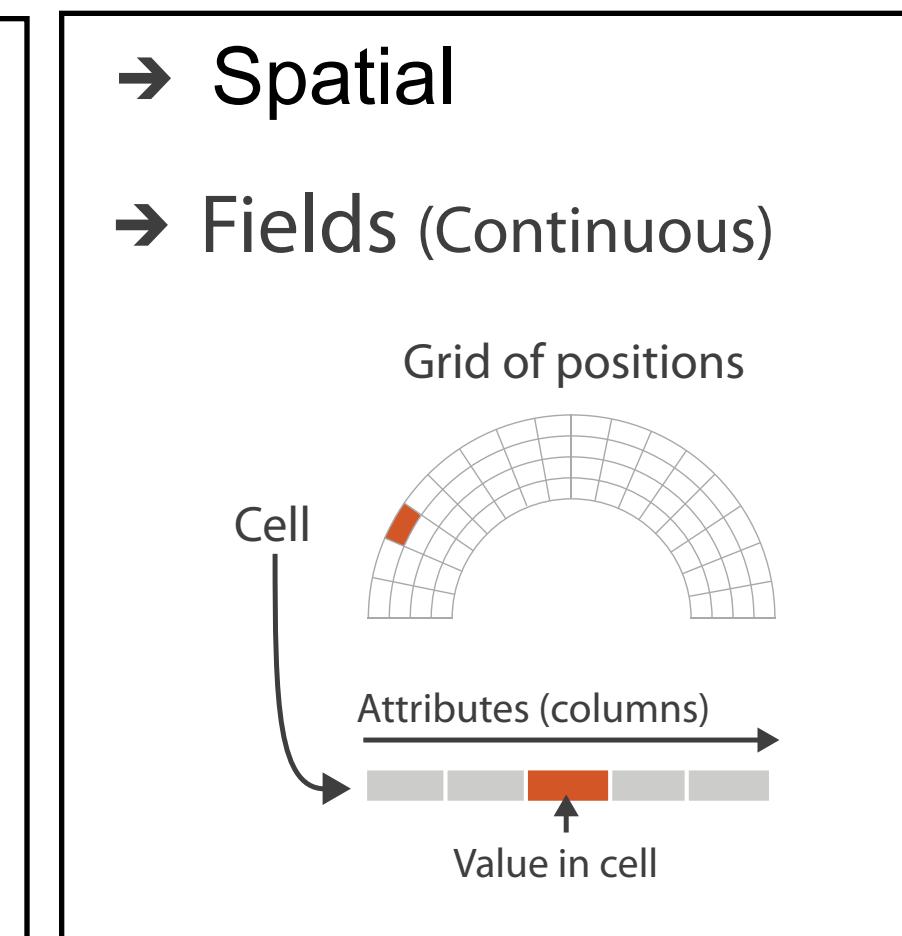
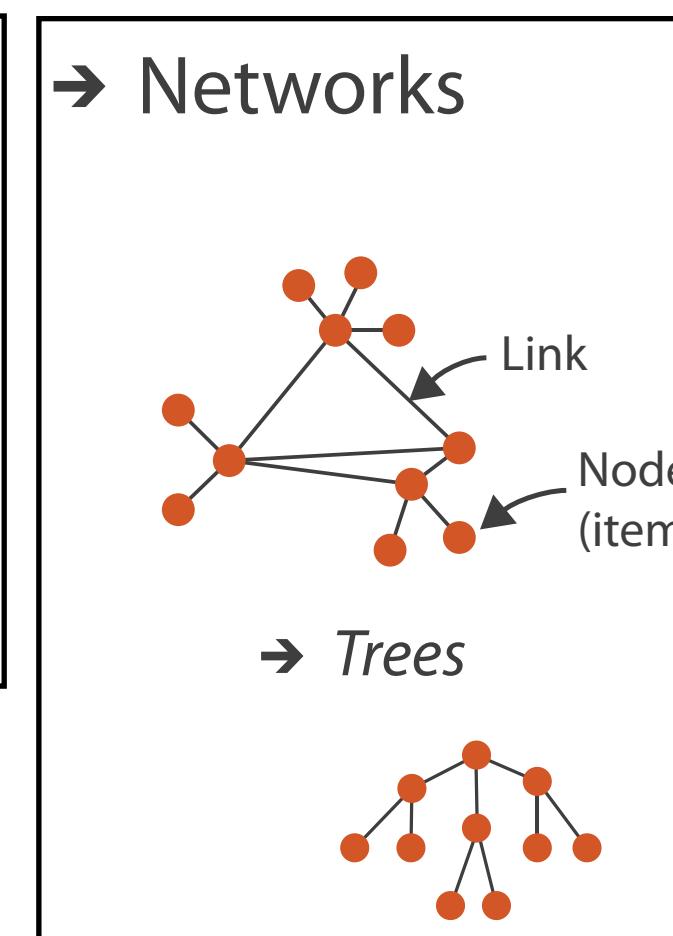
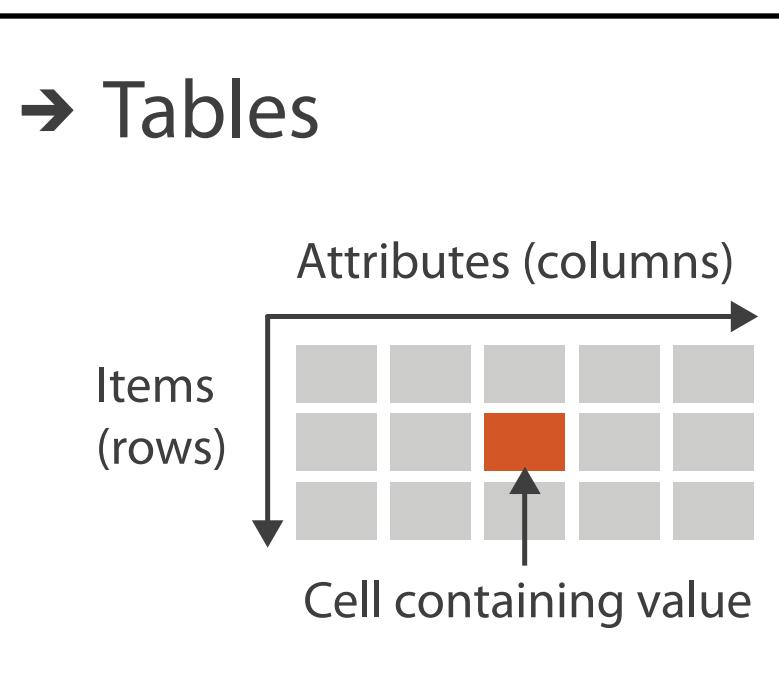
Attributes

Fields

Grids

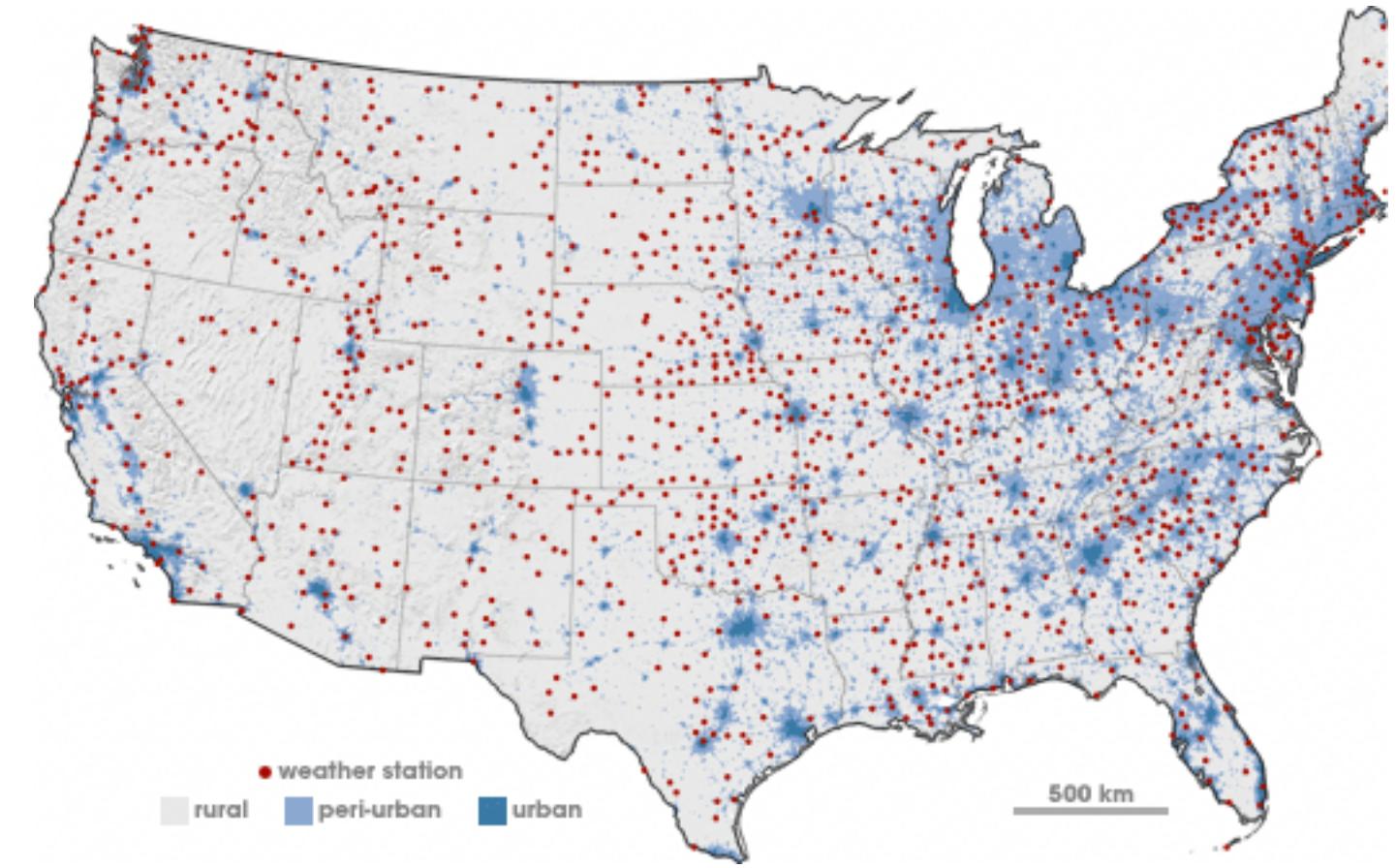
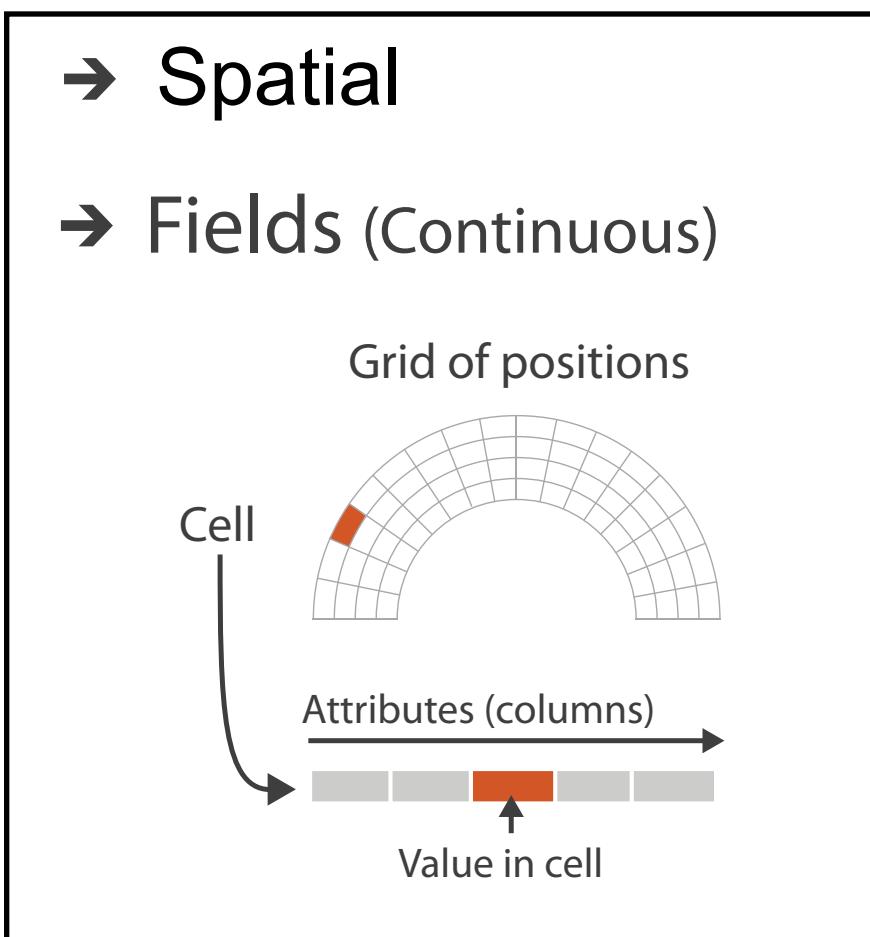
Positions

Attributes



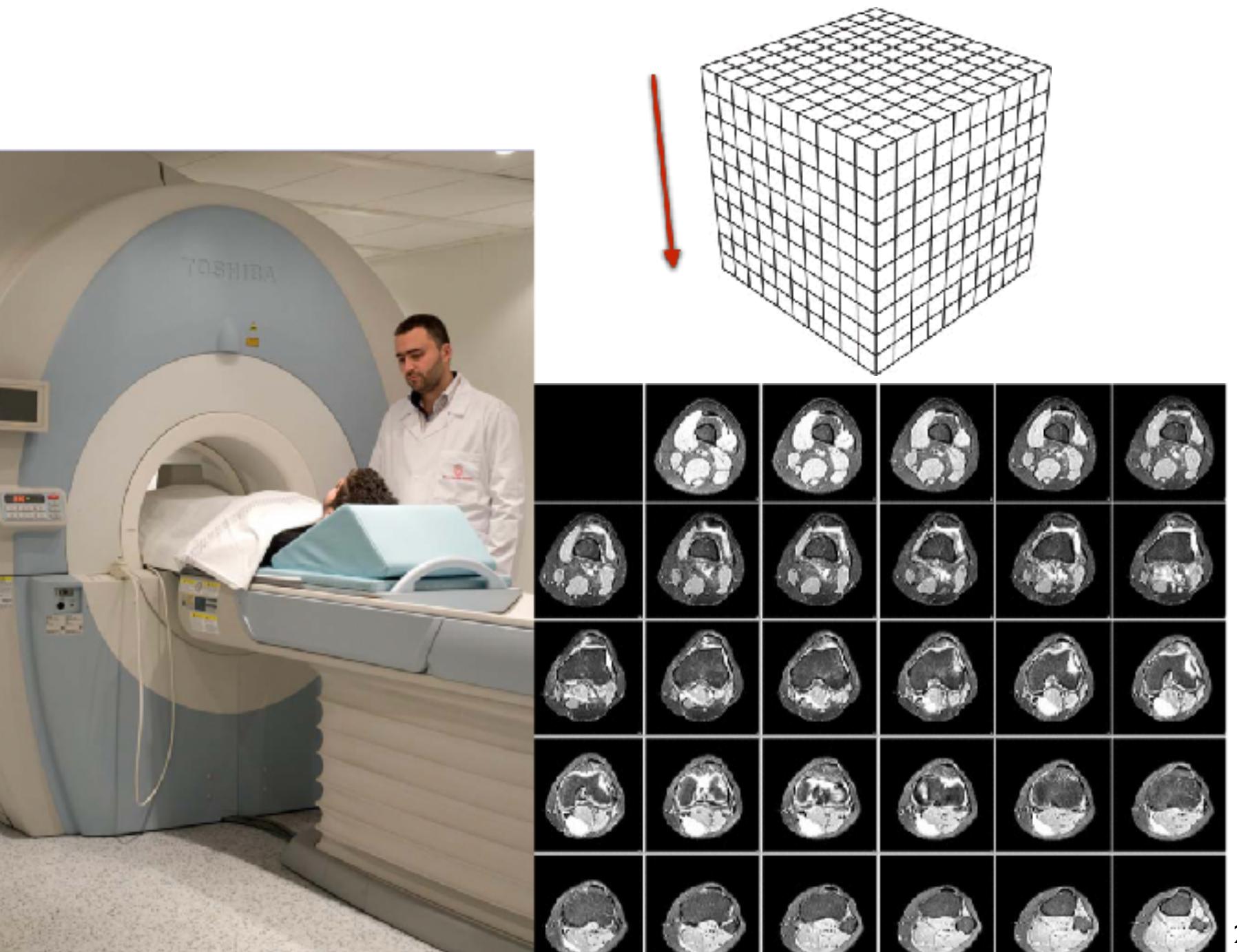
# Spatial fields

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



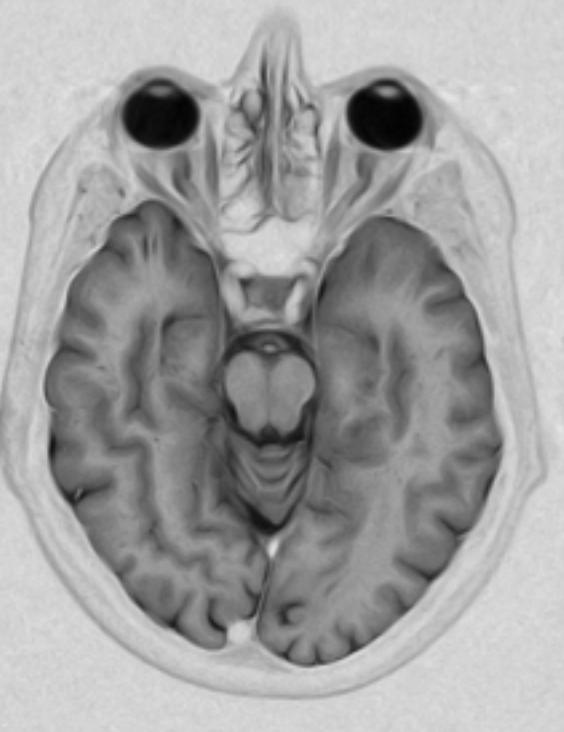
# Spatial fields

- attribute values associated with cells
- cell contains value from continuous domain
  - eg temperature, pressure, wind velocity
- measured or simulated
- beyond the scope of this class
  - sampling where attributes are measured
  - interpolation how to model attributes elsewhere
  - grid types

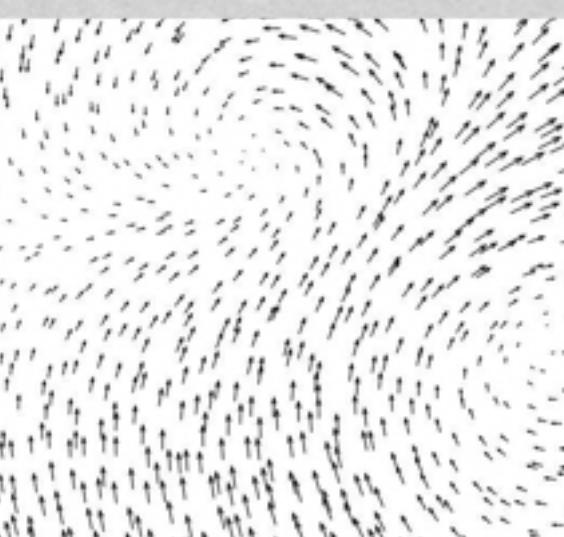


# Spatial fields

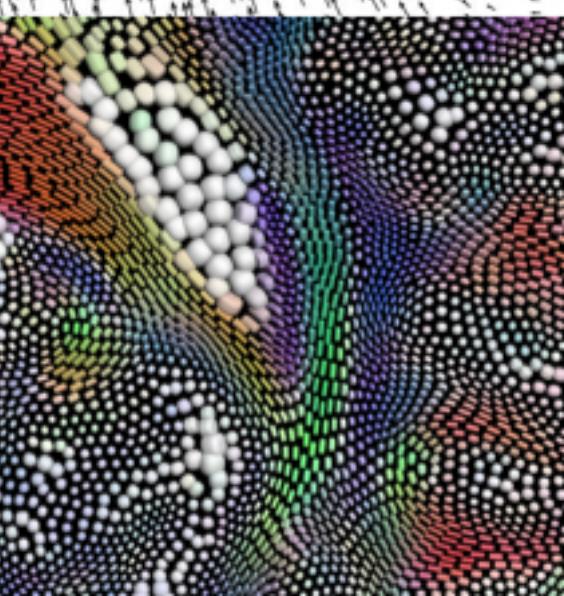
- attribute values associated with cells
- cell contains value from continuous domain
  - eg temperature, pressure, wind velocity
- measured or simulated
- beyond the scope of this class
  - sampling where attributes are measured
  - interpolation how to model attributes elsewhere
  - grid types, tensors



scalar



vector



tensor

# Dataset types

Tables

Items

Attributes

Networks & Trees

Items (nodes)

Links

Attributes

Fields

Grids

Positions

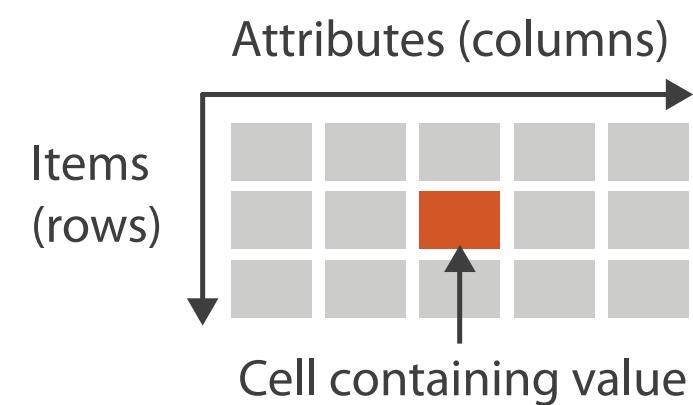
Attributes

Geometry

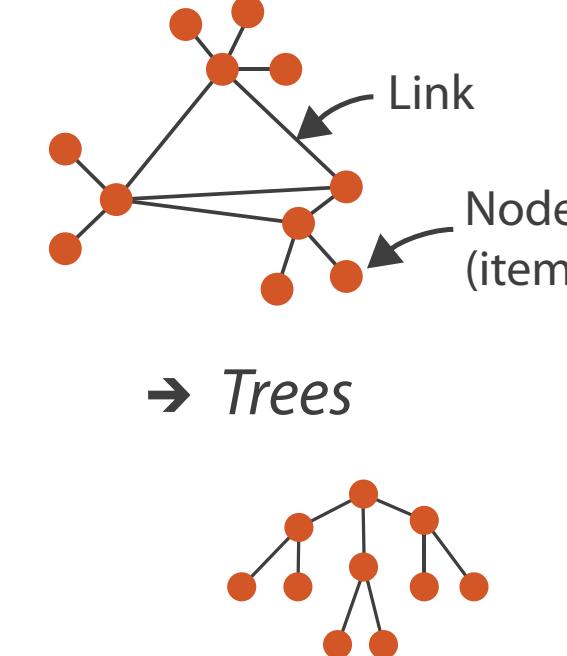
Items

Positions

→ Tables



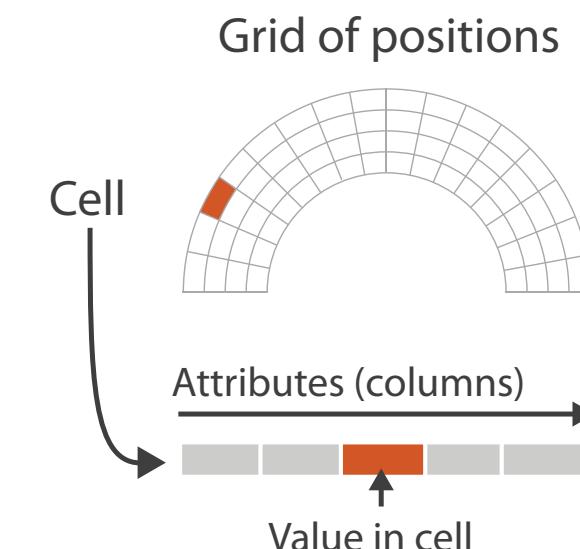
→ Networks



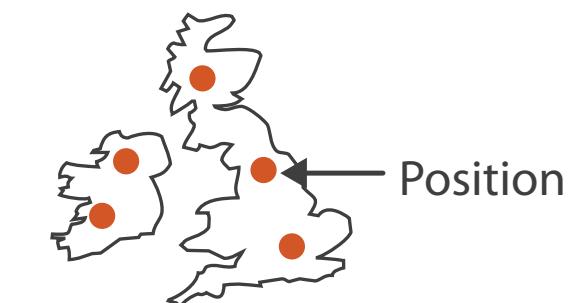
→ Trees

→ Spatial

→ Fields (Continuous)

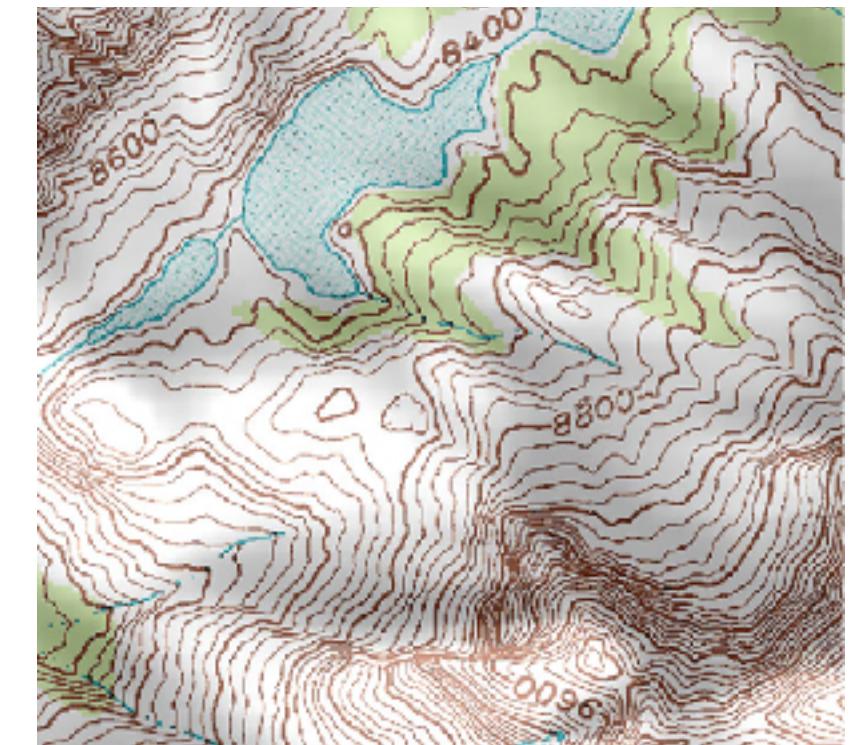


→ Geometry (Spatial)



# Geometry

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



# Dataset types

Tables

Items

Attributes

Networks & Trees

Items (nodes)

Links

Attributes

Fields

Grids

Positions

Attributes

Geometry

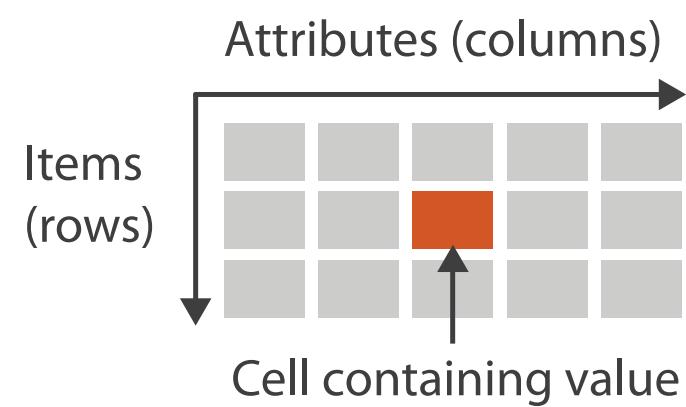
Items

Positions

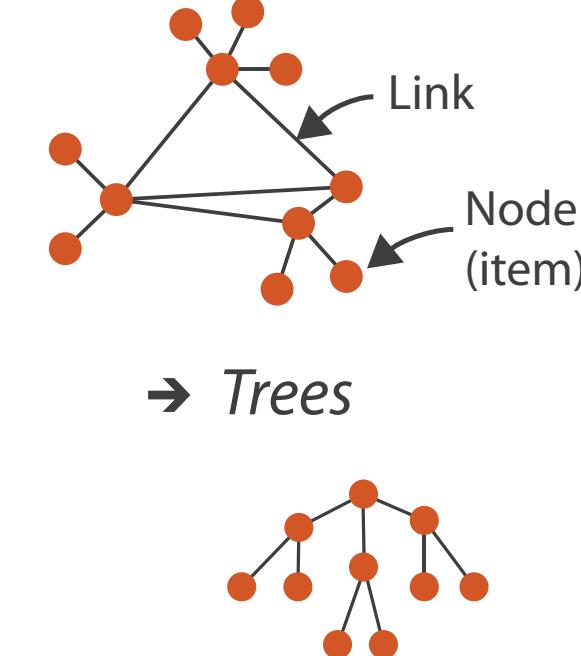
Clusters,  
Sets, Lists

Items

→ Tables

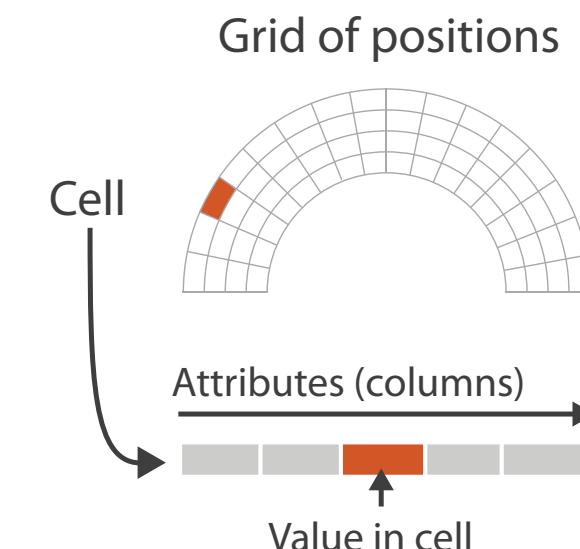


→ Networks

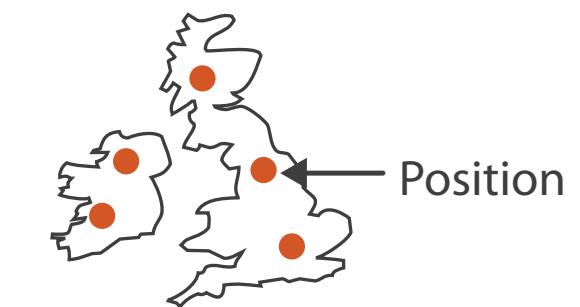


→ Spatial

→ Fields (Continuous)

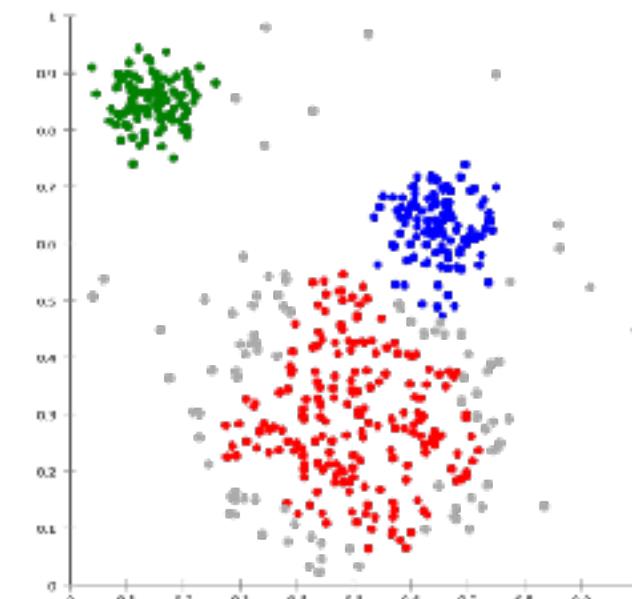
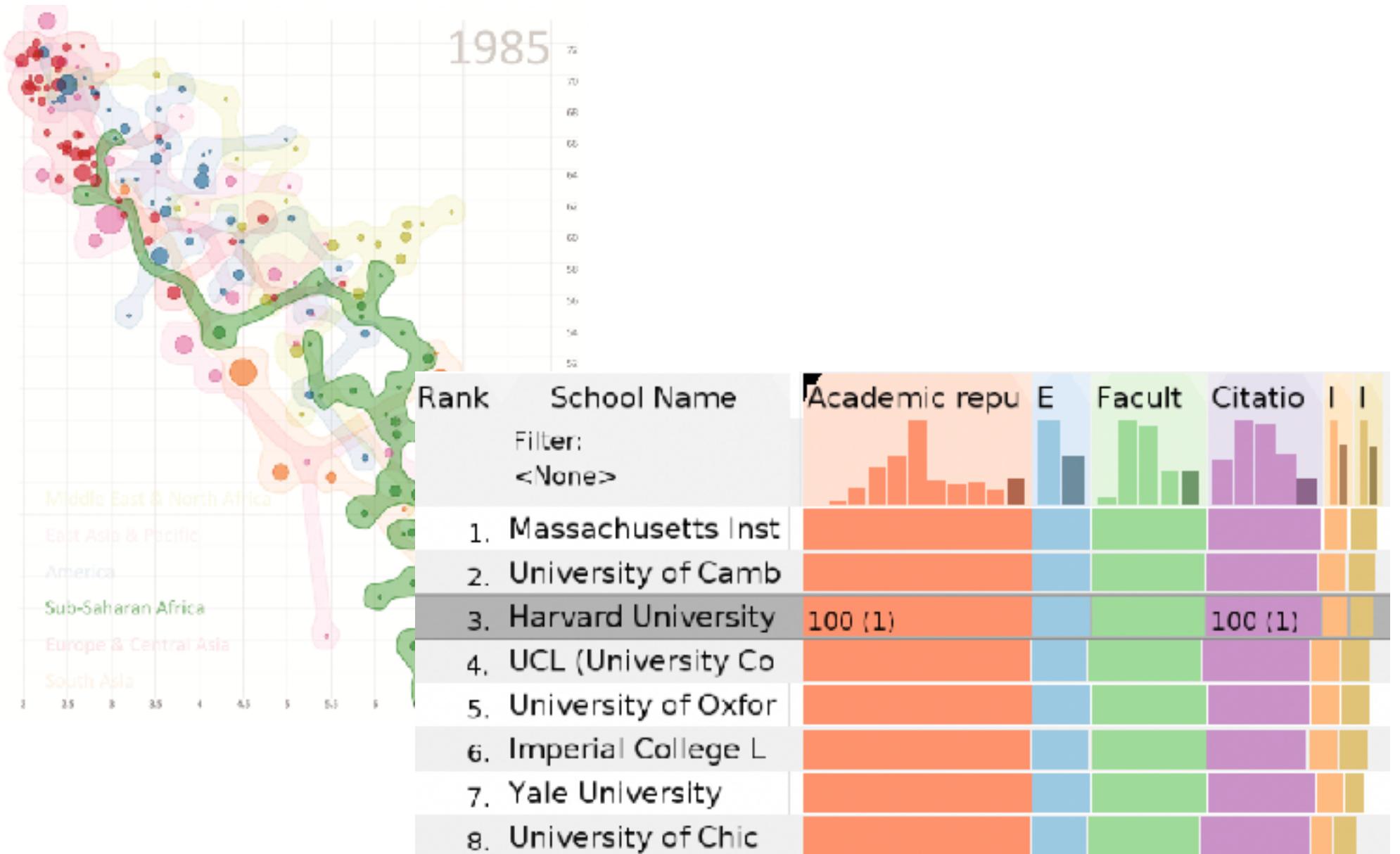


→ Geometry (Spatial)



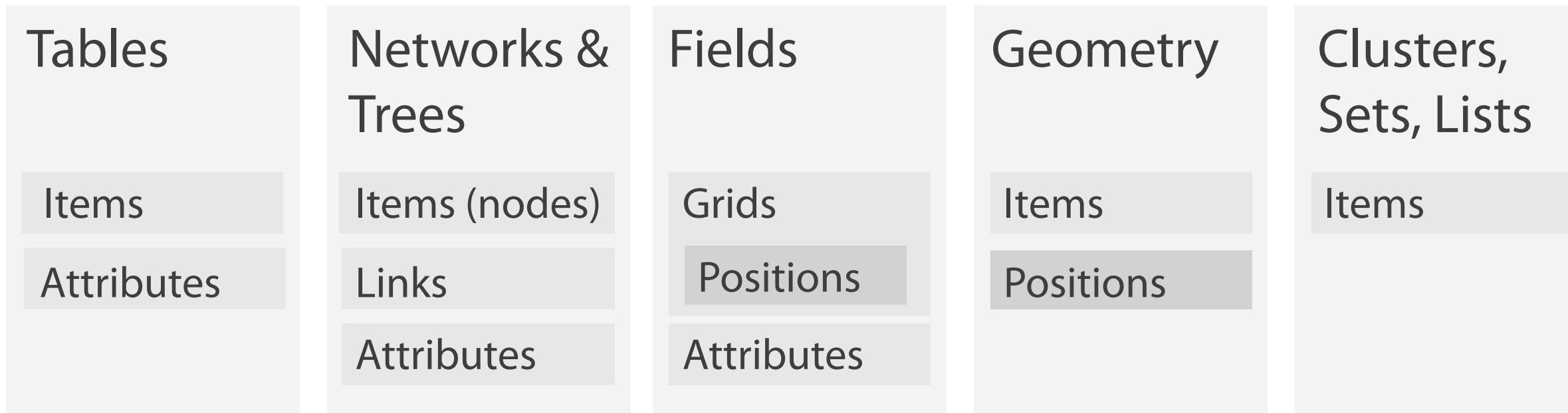
# Collections

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



# 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

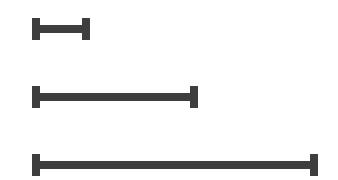


→ Ordered

→ *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	D	E	F	G
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	

## Quiz: What kind of variable?

- 50 meter race times
- college major
- Amazon rating for product
- product name

# Other data concerns

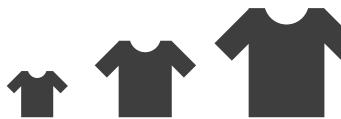
## → Attribute Types

→ Categorical

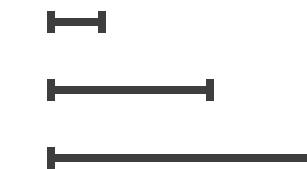


→ Ordered

→ *Ordinal*



→ *Quantitative*



## → Ordering Direction

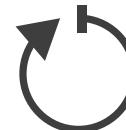
→ Sequential



→ Diverging



→ Cyclic



## → Dataset Availability

→ Static

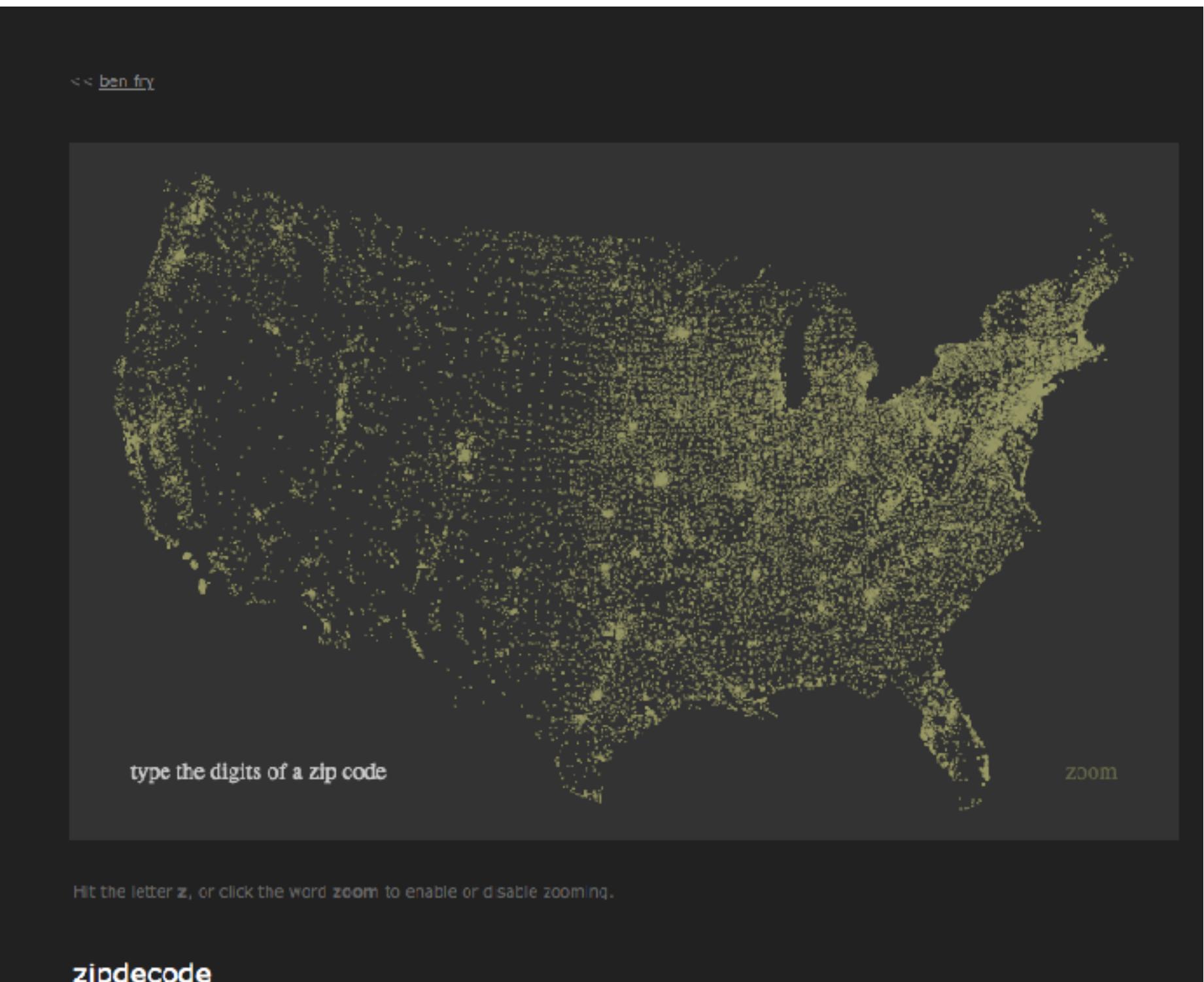


→ Dynamic



# Hierarchical data

- multi-level structure
  - space
  - time
  - others
- example: zipdecode



<https://benfry.com/zipdecode/>

# 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

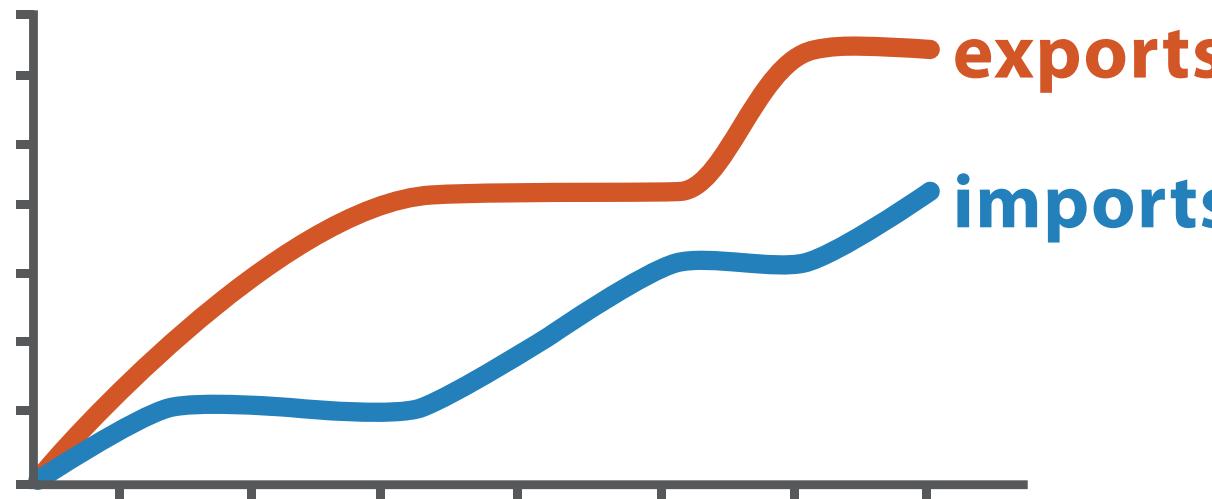
- data model
  - mathematical abstraction
    - sets with operations, eg floats with \* / - +
    - variable data types in programming languages
- conceptual model
  - mental construction (semantics)
  - supports reasoning
  - typically based on understanding of tasks [stay tuned, next week]
- data abstraction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

# Data vs conceptual model, example

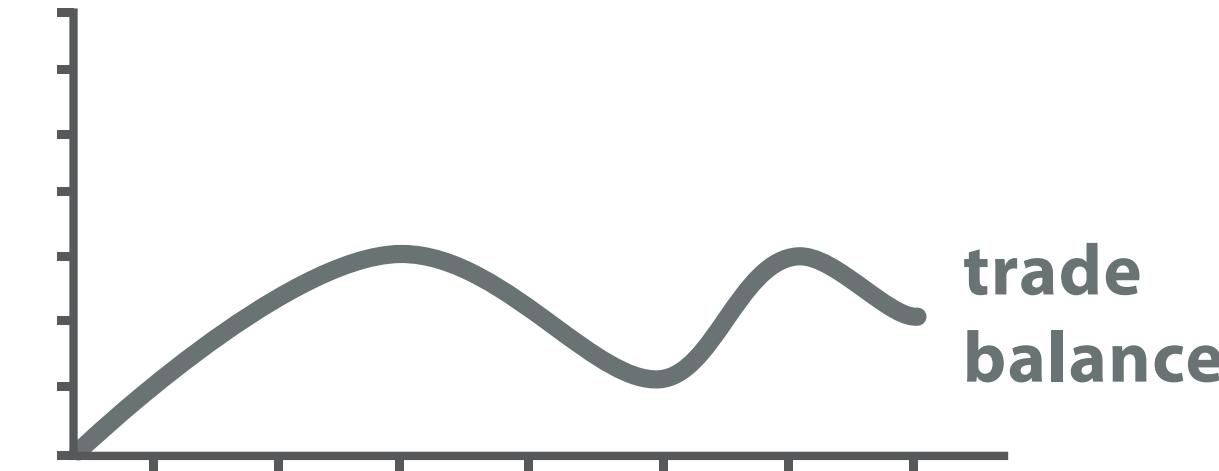
- data model: floats
  - 32.52, 54.06, -14.35, ...
- conceptual model
  - temperature
- multiple possible data abstractions
  - continuous to 2 significant figures: quantitative
    - task: forecasting the weather
  - hot, warm, cold: ordinal
    - task: deciding if bath water is ready
  - above freezing,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



Original Data



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

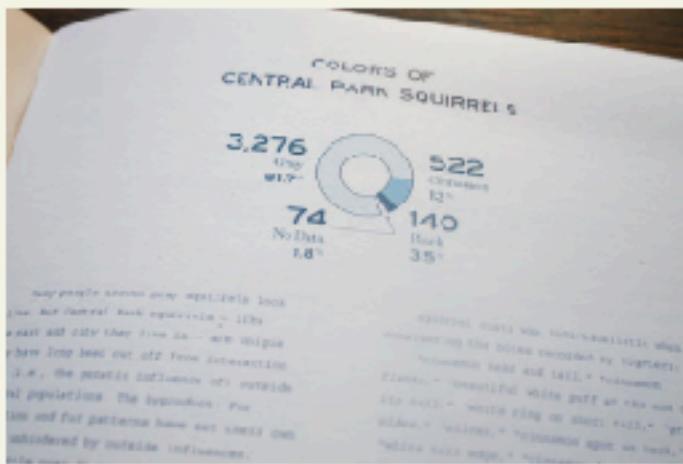
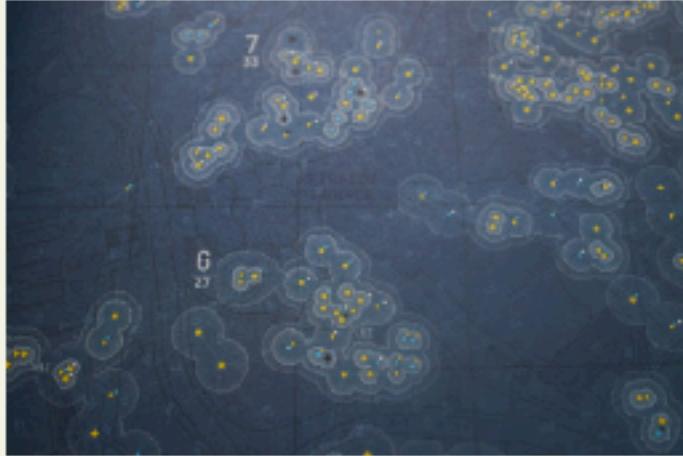
Derived Data

# Data abstraction practice

- 2018 Central Park Squirrel Census

[https://  
www.thesquirrelcensus.com/](https://www.thesquirrelcensus.com/)

[https://  
data.cityofnewyork.us/  
Environment/2018-Central-  
Park-Squirrel-Census-  
Squirrel-Data/vfnx-vebw](https://data.cityofnewyork.us/Environment/2018-Central-Park-Squirrel-Census-Squirrel-Data/vfnx-vebw)



# What?

## Datasets

## Attributes

### → Data Types

→ Items    → Attributes    → Links    → Positions    → Grids

### → Attribute Types

→ Categorical



### → Data and Dataset Types

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

→ Ordered

→ Ordinal

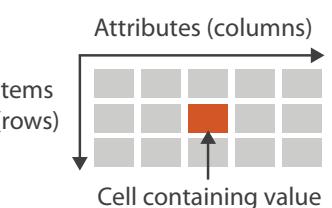


→ Quantitative

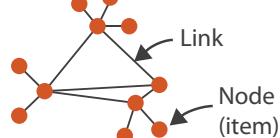


### → Dataset Types

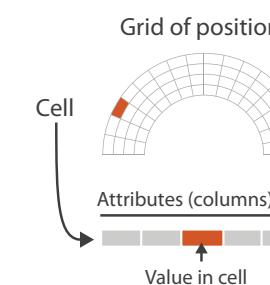
→ Tables



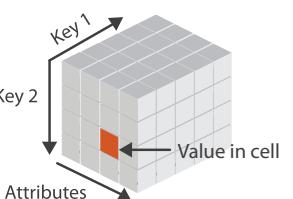
→ Networks



→ Fields (Continuous)



→ Multidimensional Table



→ Trees



### → Ordering Direction

→ Sequential



→ Diverging



→ Cyclic



→ Geometry (Spatial)



→ Dataset Availability

→ Static



→ Dynamic



# **Todo this week**

- D3 videos to watch this week
  - refresher only if you need it: JS/HTML [90 min]
  - Intro to HTML/CSS/SVG [35 min]
  - Intro to D3.js [45 min]
- Quiz I to do this week, due by Fri Jan 10, 8am
- remember, no in-person labs this week!
- Foundations Exercise I out today (Thu Jan 9)
  - due Wed Jan 15

# Credits

- Visualization Analysis and Design (Ch 2)
- Alex Lex & Miriah Meyer, <http://dataviscourse.net/>