Lecture 2
Abstraction

DTS204TC Data Visualisation

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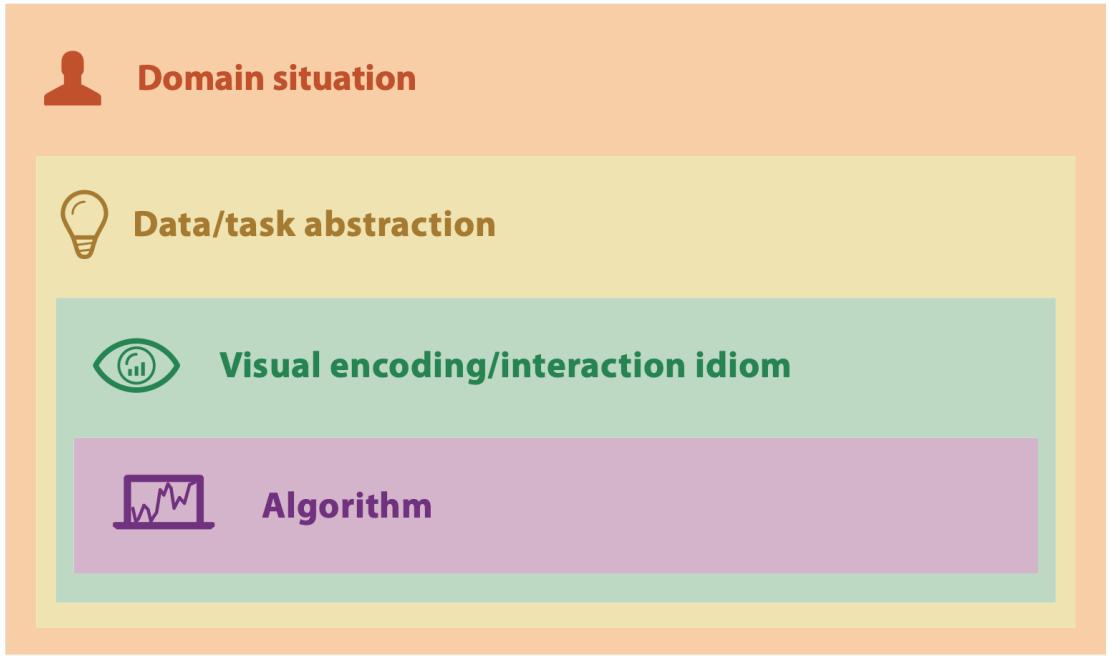
Review

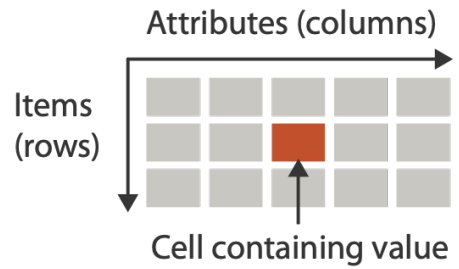
- Data Visualisation
  - Computer-based visualisation (vis) systems provide visual representations of datasets designed to help people carry out tasks more effectively.
- Nested Model



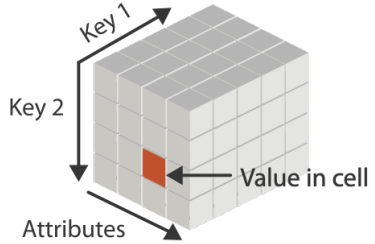
Dataset Types

Dataset Types

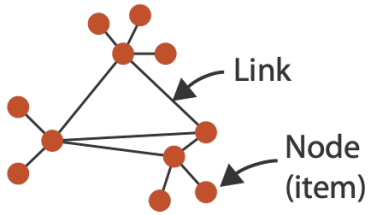
Tables



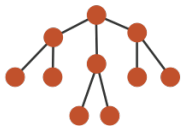
Multidimensional Table



Networks

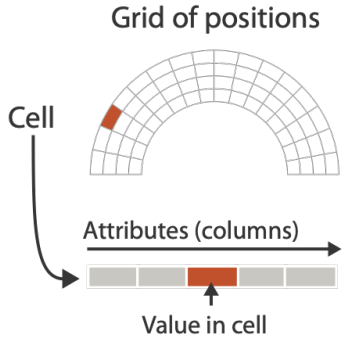


Trees



Spatial

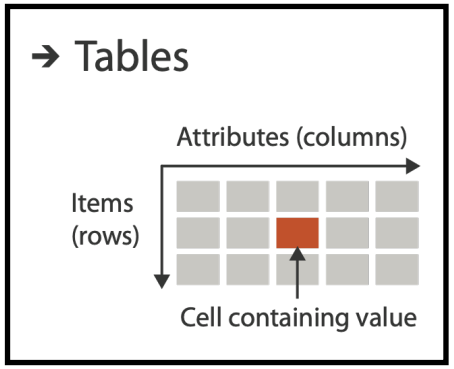
Fields (Continuous)



Geometry (Spatial)

Dataset Types (Table)

- Flat Table
  - one item per row
  - each column is an attribute
  - cell holds value for item-attribute pair
  - unique key



item: student

key *attributes: name, age, shirt size, favorite fruit*

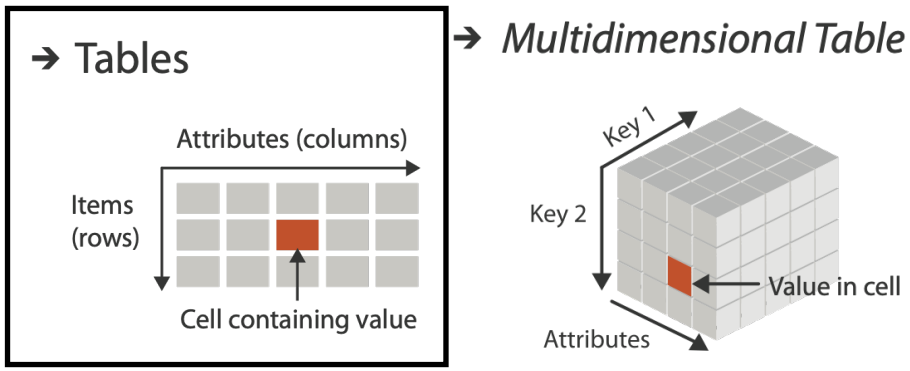
ID	Name	Age	Shirt Size	Favorite Fruit
1	Amy	8	S	Apple
2	Basil	7	S	Pear
3	Clara	9	M	Durian
4	Desmond	13	L	Elderberry
5	Ernest	12	L	Peach
6	Fanny	10	S	Lychee
7	George	9	M	Orange
8	Hector	8	L	Loquat
9	Ida	10	M	Pear
10	Amy	12	M	Orange

Dataset Types (Ta

	A	B	C	D	E	F	G	H
1	university	country	city	region	student_facu	international	faculty_count	
2	MIT	United State	Cambridge	North Ameri	4	3730	3,065	
3	University of	United Kingd	Oxford	Europe	3	8442	6,708	
4	Stanford Uni	United State	Stanford	North Ameri	3	3879	4,725	
5	University of	United Kingd	Cambridge	Europe	4	7925	5,800	
6	Harvard Univ	United State	Cambridge	North Ameri	5	5877	4,646	
7	Caltech	United State	Pasadena	North Ameri	2	692	968	
8	Imperial Coll	United Kingd	London	Europe	5	11143	8,000	
9	ETH Zurich	Switzerland	ZvºrichEurope		7	7733	2,719	
10	UCL	United Kingd	London	Europe	5	21824	7,195	
11	University of	United State	Chicago	North Ameri	6	4696	2,703	
12	NUS	Singapore	Singapore	Asia	7	7551	4,288	
13	NTU	Singapore	Singapore	Asia	6	6091	3,812	
14	University of	United State	Philadelphia	North Ameri	4	4636	5,154	
15	EPFL	Switzerland	Lausanne	Europe	6	6426	1,767	
16	Yale Univers	United State	New Haven	North Ameri	2	2537	5,391	
17	The Universi	United Kingd	Edinburgh	Europe	7	14637	4,832	
18	Tsinghua Un	China (Mainl	Beijing	Asia	6	5420	6,174	
19	Peking Unive	China (Mainl	Beijing	Asia	6	5436	5,302	
20	Columbia Un	United State	New York Cit	North Ameri	4	11252	7,087	
21	Princeton Un	United State	Princeton	North Ameri	8	1912	1,050	
22	Cornell Unive	United State	Ithaca	North Ameri	8	5675	2,843	
23	The Universi	Hong Kong S.	Hong Kong	Asia	7	8311	2,944	
24	The Universi	Japan	Tokyo	Asia	6	3983	4,473	
25	University of	United State	Ann Arbor	North Ameri	6	7341	7,132	
26	Johns Hopkin	United State	Baltimore	North Ameri	3	5070	4,855	
27	University of	Canada	Toronto	North Ameri	8	27536	9,881	
28								

Dataset Types (Table)

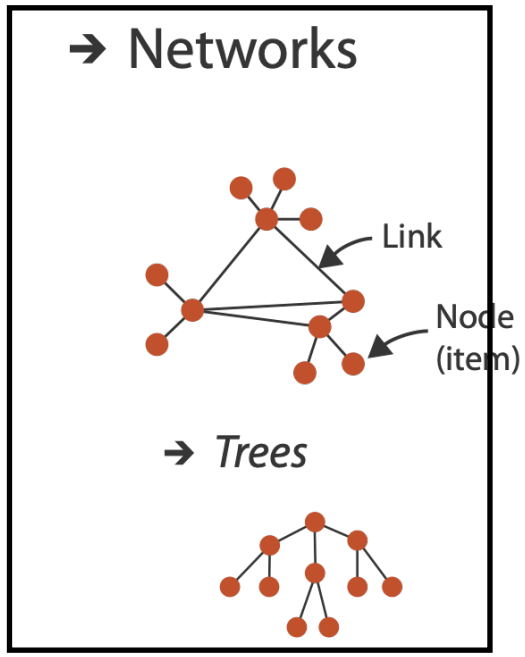
- Multidimensional Table
  - Indexing based on multiple keys



	A	B	C	D	E
1	#1.2				
2	1500	529			
3	GeneName	DESCRIPTION	TCGA-02-0001-01C-01R-0177-01	TCGA-02-0003-01A-01R-0177-01	TCGA-02-0004-01A-01R-0298-01
4	LTF	LTF	-1.265728057	2.377012066	4.123979585
5	POSTN	POSTN	2.662411805	3.932400324	5.031585377
6	TMSL8	TMSL8	-3.082217838	-2.243148513	-0.02313681
7	HLA-DQA1	HLA-DQA1	-1.739664398	4.577962344	3.127744964
8	RP11-35N6.1	RP11-35N6.1	-3.346352968	-2.895400157	-3.473035067
9	STMN2	STMN2	-2.578511106	-3.051605144	-1.729892888
10	DCX	DCX	-2.26078976	-2.529795801	-2.844966278
11	AGXT2L1	AGXT2L1	-2.639493611	-3.113204863	-0.403975027
12	IL13RA2	IL13RA2	-2.93596915	-1.873600916	2.976256911
13	SLN	SLN	-2.466718221	-2.208406749	1.025827904
14	MEOX2	MEOX2	-2.395054066	-1.062676046	1.783235317
15	COL11A1	COL11A1	1.211934832	-0.399392588	4.733608974
16	NNMT	NNMT	0.703745164	0.664082419	3.069030715
17	F13A1	F13A1	-0.224094042	2.222197544	1.171354775
18	CXCL14	CXCL14	-3.1309694	-1.395056071	2.569540659
19	MBP	MBP	-1.906390566	-2.037626447	-2.935744906
20	TF	TF	-4.334123292	-4.680680246	-2.975788866
21	KCND2	KCND2	-1.777692395	-2.100362021	-1.996306032

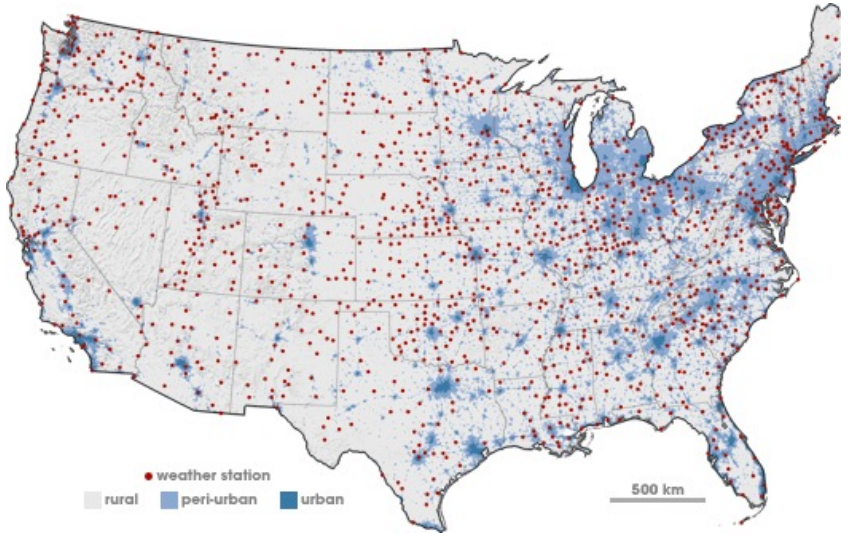
Dataset Types (Networks and Trees)

- Networks & Trees
  - Items(nodes)
  - Links
  - Attributes
  - Nodes (vertices) connected by links (edges)
  - Tree is special case: no cycles
    - often have roots and are directed



Dataset Types (Spatial)

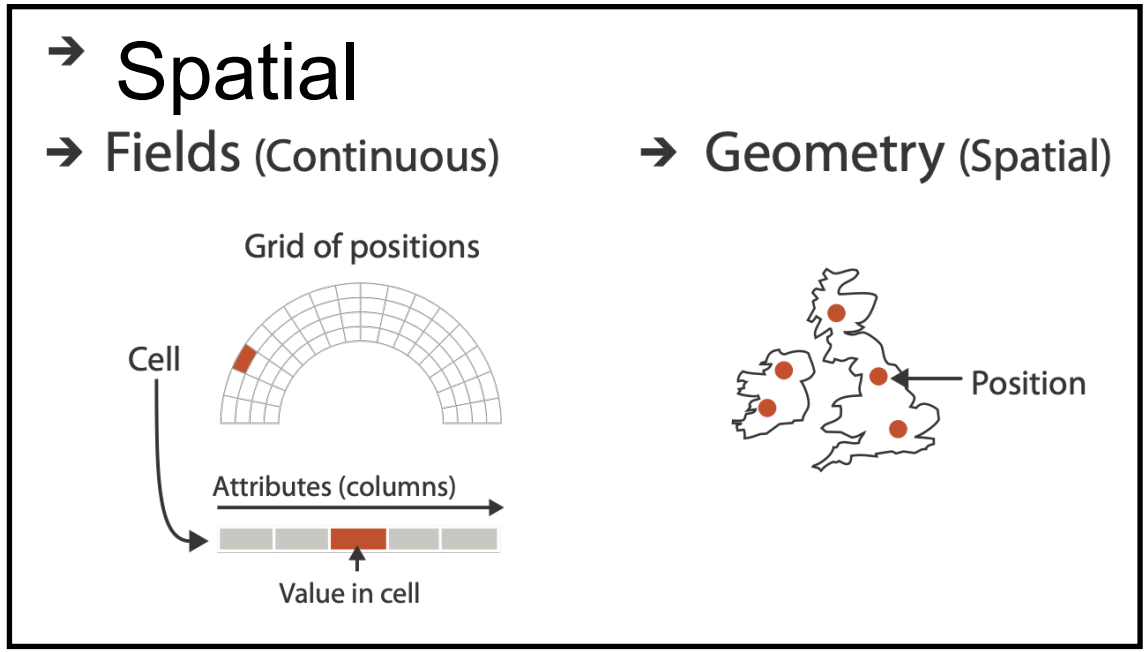
- Spatial Fields
  - attribute values associated with cells
    - Positions
  - cell contains value from continuous domain (temperature, pressure, wind velocity)
  - measured or simulated
  - Major concern
    - sampling: where attributes are measured
    - interpolation: how to model attributes elsewhere
    - grid types
  - Major divisions
    - attributes per cell: Scalar, Vector, Tensor



Dataset Types (Spatial)

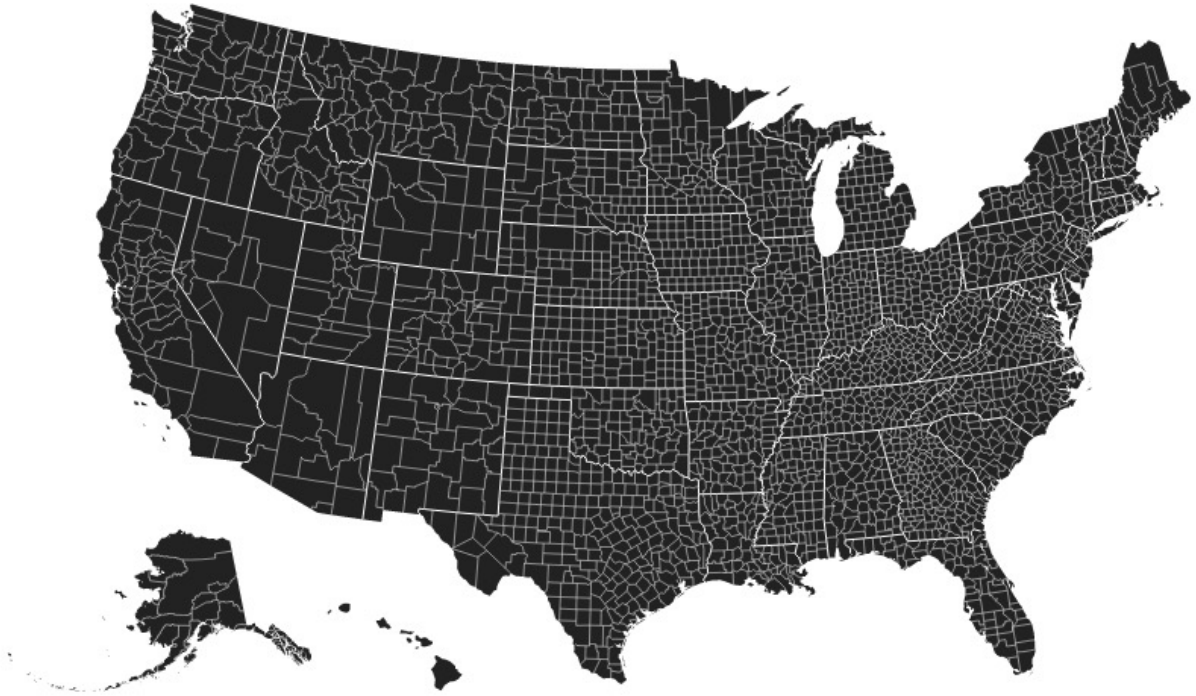
Geometry

- Items
- Positions



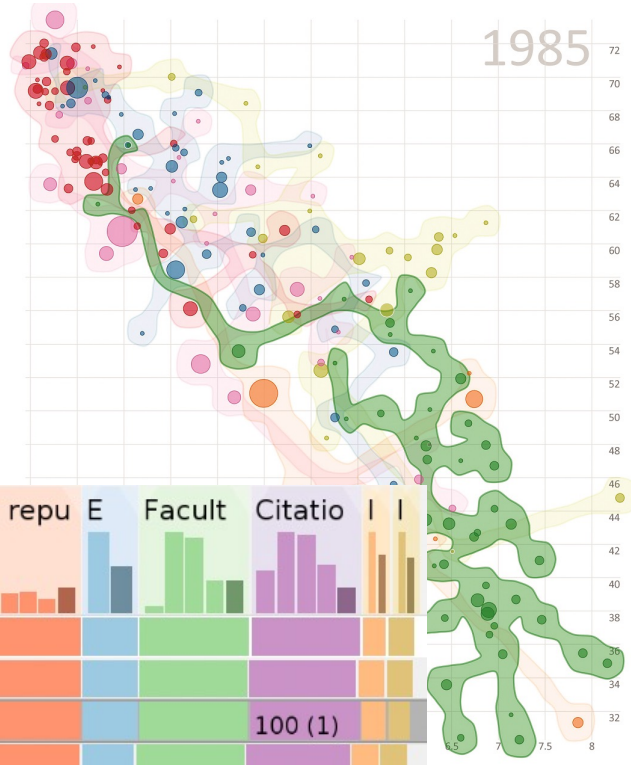
Dataset Types (Spatial)

- 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

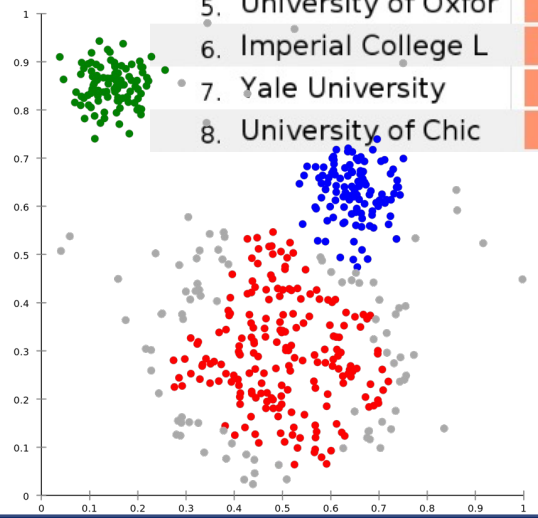


Other Dataset Types

- 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						



Data Types

What does data mean?

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

Data Types

Name	Age	Shirt Size	Favorite Fruit
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George	9	M	Orange
Hector	8	L	Loquat
Ida	10	M	Pear
Amy	12	M	Orange

Data Types

- Data types: structural or mathematical interpretation of data
  - item, link, attribute, position, grid
- Data Type in vis is different from data type in programming.
  - ~~int, float, string, double …~~
  - Items, Attributes, Link, Positions, Grids

Data Types

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

Name	Age	Shirt Size	Favorite Fruit
Amy	8	S	Apple
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Ida	10	M	Pear
Amy	12	M	Orange

Data Types

- 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"

Name	Age	Shirt Size	Favorite Fruit
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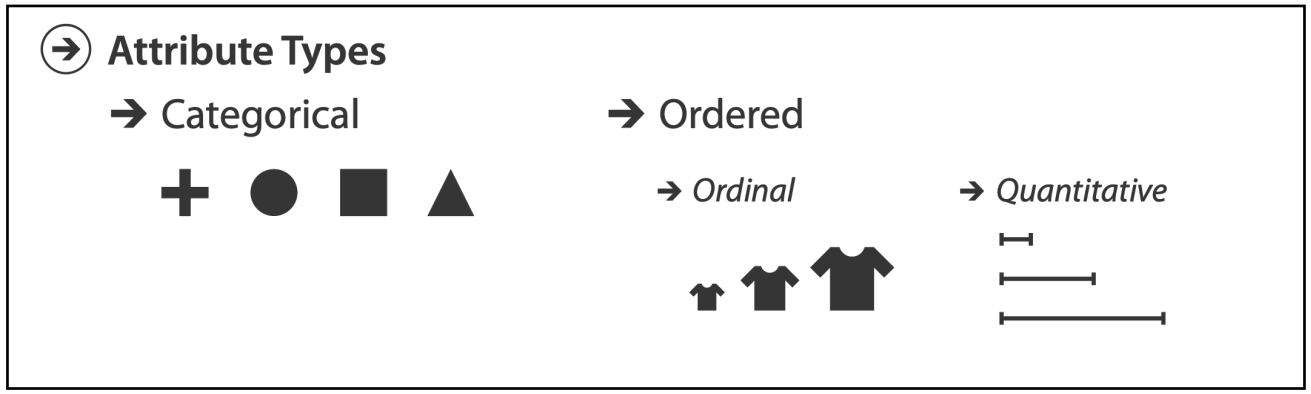
George	9	M	Orange
Hector	8	L	Loquat
Ida	10	M	Pear
Amy	12	M	Orange

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

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

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

Attribute Types

categorical
ordinal
quantitative

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
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130	5/8/08	2-High	Small Box	0.6	5/11/08
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Attribute Types

	A	B	C	D	E	F	G
1	university	country	city	region	student_faculty_ratio	international_students	faculty_count
2	MIT	United States	Cambridge	North America	4	3730	3,065
3	University of Oxford	United Kingdom	Oxford	Europe	3	8442	6,708
4	Stanford University	United States	Stanford	North America	3	3879	4,725
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7	Caltech	United States	Pasadena	North America	2	692	968
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9	ETH Zurich	Switzerland	ZvºrÍch	Europe	7	7733	2,719
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20	Columbia University	United States	New York Cit	North America	4	11252	7,087
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22	Cornell University	United States	Ithaca	North America	8	5675	2,843
23	The University of Hong Kong	Hong Kong SAR	Hong Kong	Asia	7	8311	2,944
24	The University of Tokyo	Japan	Tokyo	Asia	6	3983	4,473
25	University of Michigan-Ann Arbor	United States	Ann Arbor	North America	6	7341	7,132
26	Johns Hopkins University	United States	Baltimore	North America	3	5070	4,855
27	University of Toronto	Canada	Toronto	North America	8	27536	9,881

Data Abstraction

- **Translate from domain-specific language to generic visualization language**
- Three operations
  - 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 Abstraction

- Data model vs conceptual model
  - data model
    - mathematical abstraction
      - sets with operations, e.g: floats with * / - +
      - variable data types in programming languages
  - conceptual model
    - mental construction (semantics)
    - supports reasoning
    - typically based on understanding of tasks
  - data abstraction process relies on conceptual model
    - for transforming data if needed

Data Abstraction

- Data model vs conceptual model
  - data model: floats
    - 32.52, 54.06, -14.35, …
  - conceptual model
    - temperature

Data Abstraction

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

Data Abstraction

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

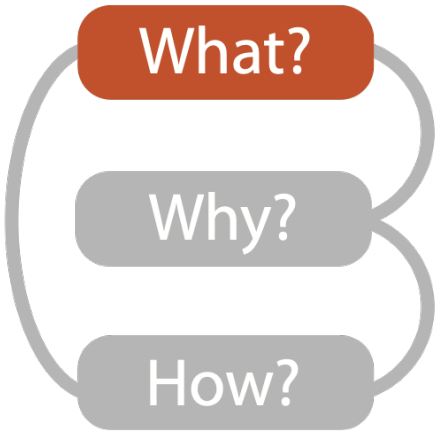
Data Abstraction

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

Data Abstraction

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

Data Abstraction



What?

Datasets

Data Types

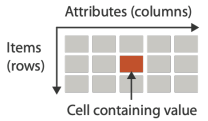
- Items
- Attributes
- Links
- Positions
- Grids

Data and Dataset Types

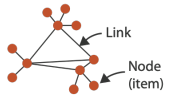
Tables	Networks & Trees	Fields	Geometry	Clusters, Sets, Lists
Items	Items (nodes)	Grids	Items	Items
Attributes	Links	Positions	Positions	
	Attributes	Attributes		

Dataset Types

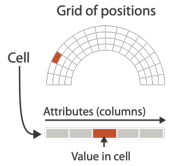
- Tables



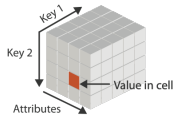
- Networks



- Fields (Continuous)



- *Multidimensional Table*



- *Trees*

- Geometry (Spatial)

Attributes

Attribute Types

- Categorical

- Ordered
  - *Ordinal*

  - *Quantitative*

Ordering Direction

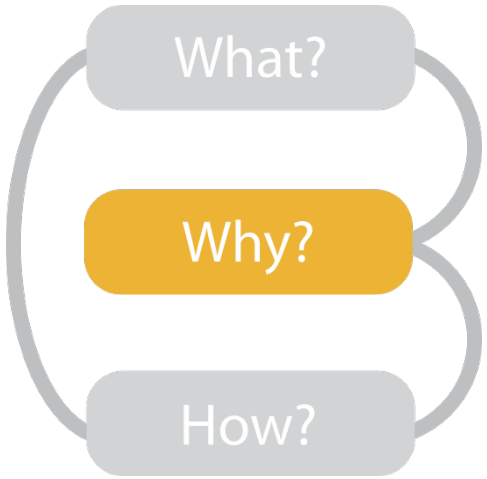
- Sequential

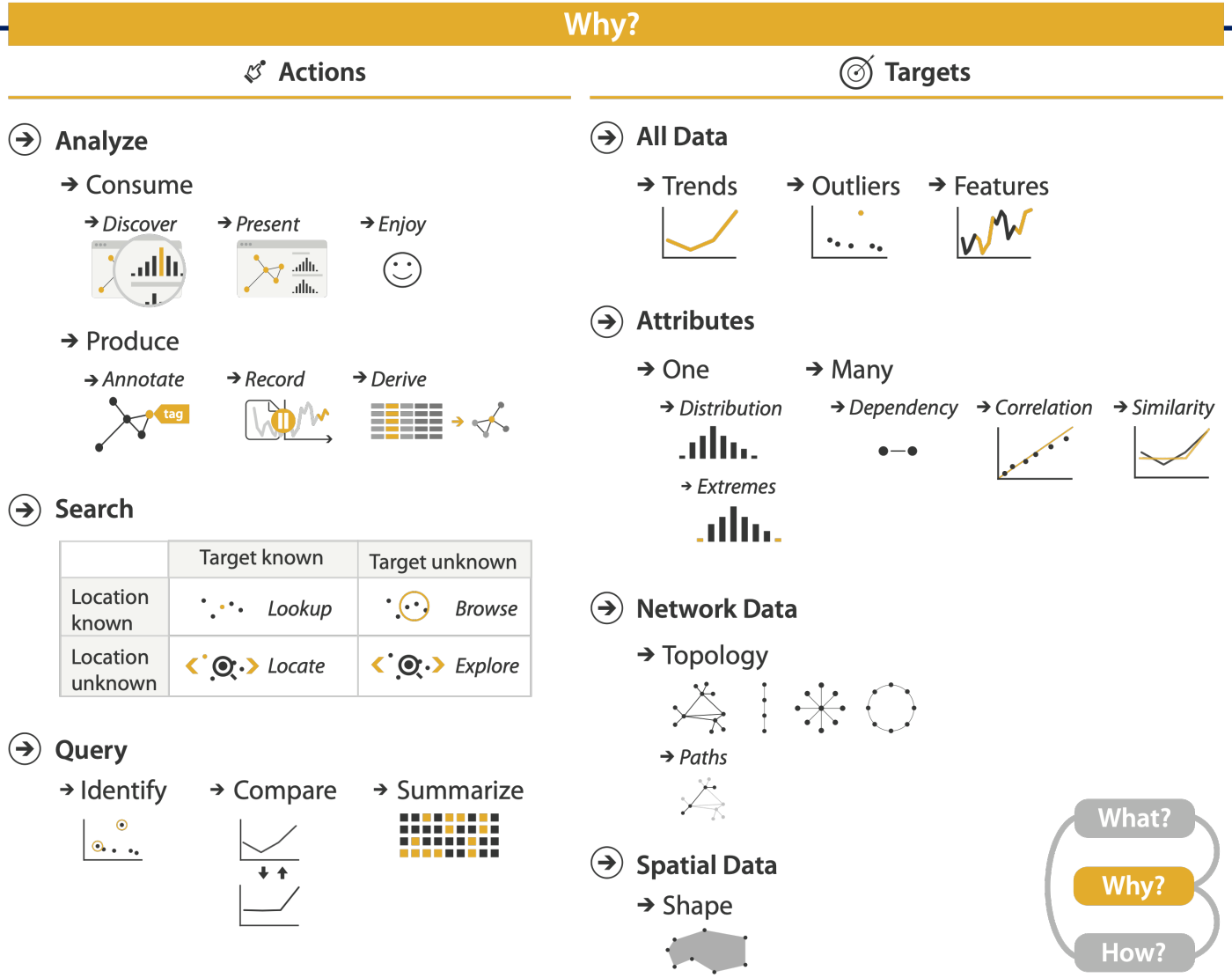
- Diverging

- Cyclic

Task Abstraction

- Why?
- {action, target}
  - discover distribution
  - compare trends
  - locate outliers
  - browse topology





Task Abstraction

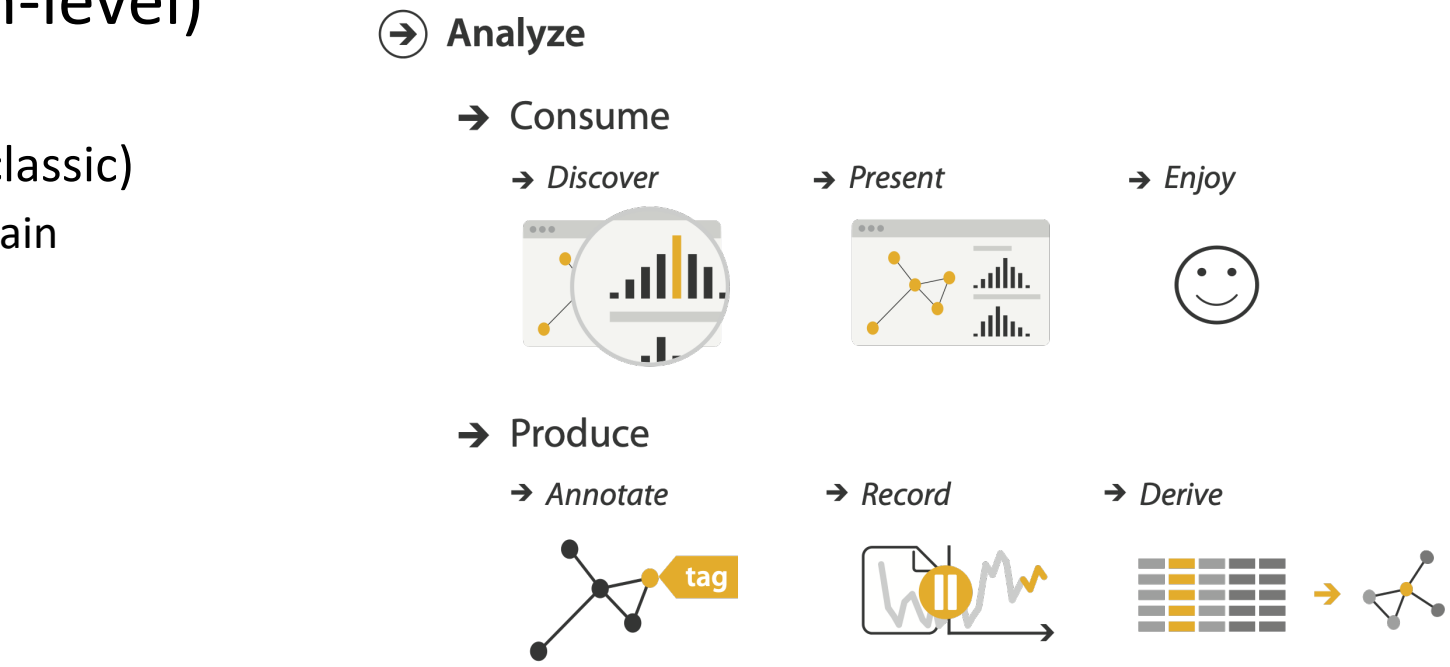
- Why analyse tasks
  - Abstract tasks are domain-independent
    - Two different domain problems → same task abstraction → same/similar solution
  - Visualization idioms are good for some tasks and bad for others

Task Abstraction

- Actions: Define the *verb* of the tasks
  - Analyze
    - high-level choices
  - Search
    - find a known/unknown item
  - Query
    - find out about characteristics item
- Targets: Define the *noun* of the task
  - what is being acted on

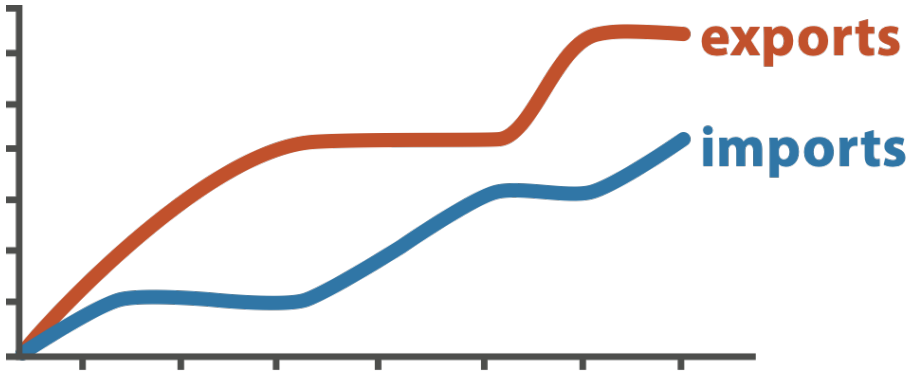
Task Abstraction

- Actions: Analyze (High-level)
  - consume
    - discover vs present (classic)
      - aka explore vs explain
    - enjoy
      - newcomer
      - aka casual, social
  - Produce
    - annotate
    - record
    - derive
      - cruicial design choice

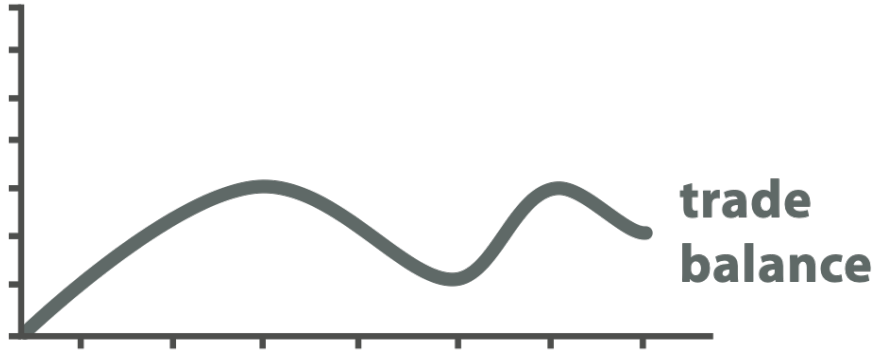


Task Abstraction

- Derived
  - Summarize the trend of the trade balance



Original Data



trade balance = *exports* – *imports*

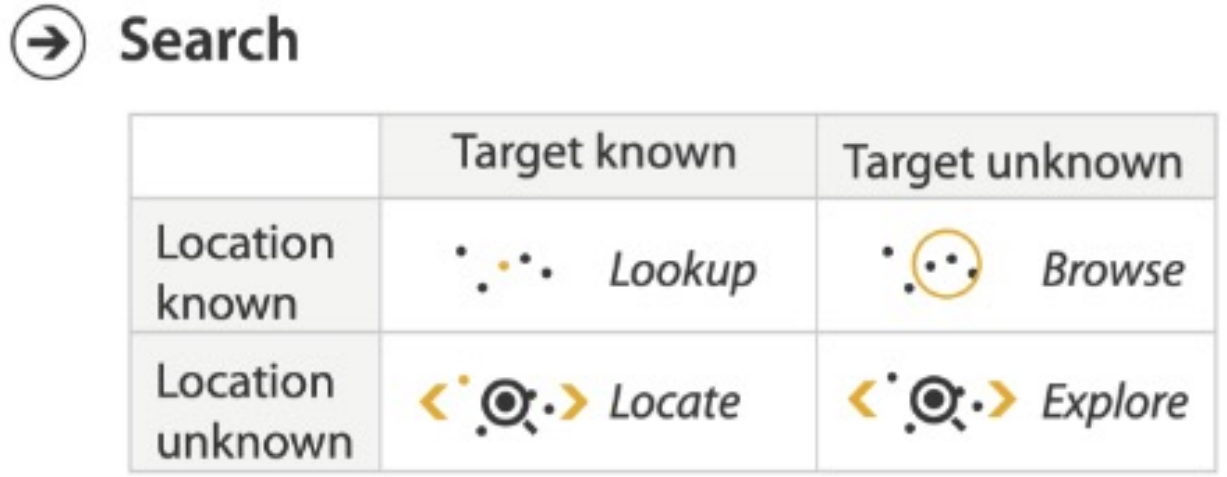
Derived Data

Task Abstraction

- Derived: When to derive data
  - Large data? → Aggregate
  - Complex data? → Simplify
  - Dimensionality reduction
  - Network/tree analytics (clusters, centralities)
  - Don't make the user think!

Task Abstraction

- Actions: Search (Mid-level) {target, location}
  - Lookup
    - word in dictionary (alphabetical order)
  - Locate
    - keys in your house
    - node in network
  - Browse
    - books in bookstore
  - Explore
    - find cool student in new dormitory



Task Abstraction

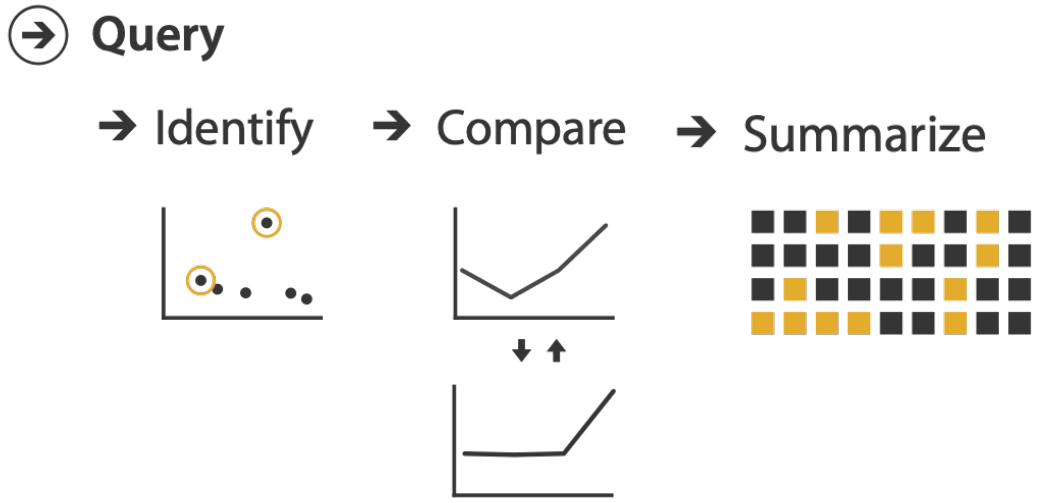
- Actions: Search (Mid-level) {target, location}
  - Target
    - I know what I'm looking for
    - E.g., what's the salary of the CEO? **Target known**
    - E.g., who has the highest salary? **Target unknown**
  - Location
    - I know where the mark is going to be located in the chart
    - Scales ordered alphabetically

Search

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

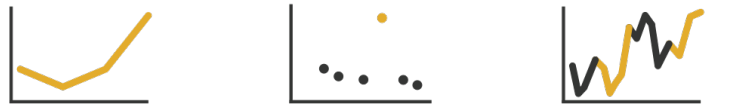
Task Abstraction

- Actions: Query (Low-Level) How much of the data matter?
  - Identify: one object
  - Compare: some objects
  - Summarize: all objects

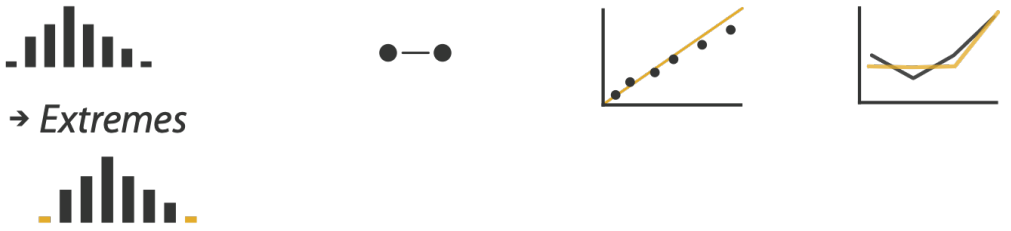


Task Abstraction

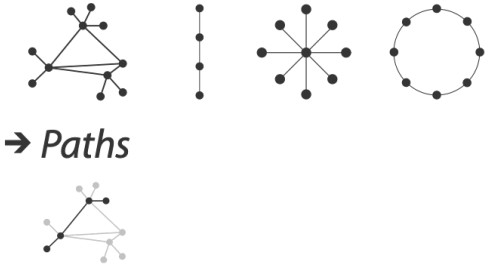
- Targets
  - **All Data**
    - Trends
    - Outliers
    - Features



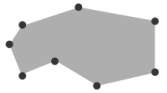
  - **Attributes**
    - One
      - *Distribution*
      - *Extremes*
    - Many
      - *Dependency*
      - *Correlation*
      - *Similarity*



  - **Network Data**
    - Topology
    - *Paths*



  - **Spatial Data**
    - Shape



Task Abstraction

- Targets (All data)
  - Trends (or patterns): e.g., are sales increasing?
  - Outliers: one or some that aren't like the others
  - Features: task-dependent (e.g., a V-shaped recession)

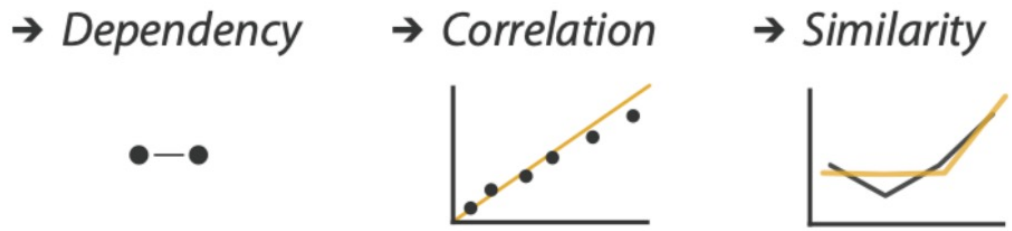
Task Abstraction

- Targets (Attribute)
  - Distribution (e.g., GDP distribution across multiple countries)
  - Extremes (e.g., country with highest GDP)

Task Abstraction

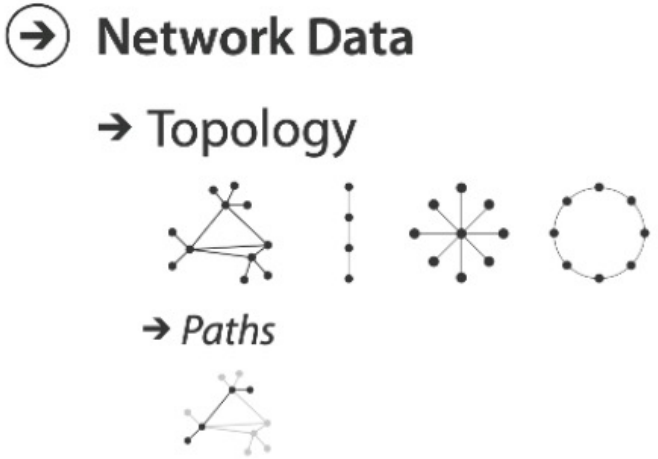
- Targets (Many attributes)
  - Dependency (e.g., do all NBA players attended college?)
  - Correlation (e.g., do higher-paid players score more?)
  - Similarity (e.g., do Curry and Harden shoot the same?)

➔ Many



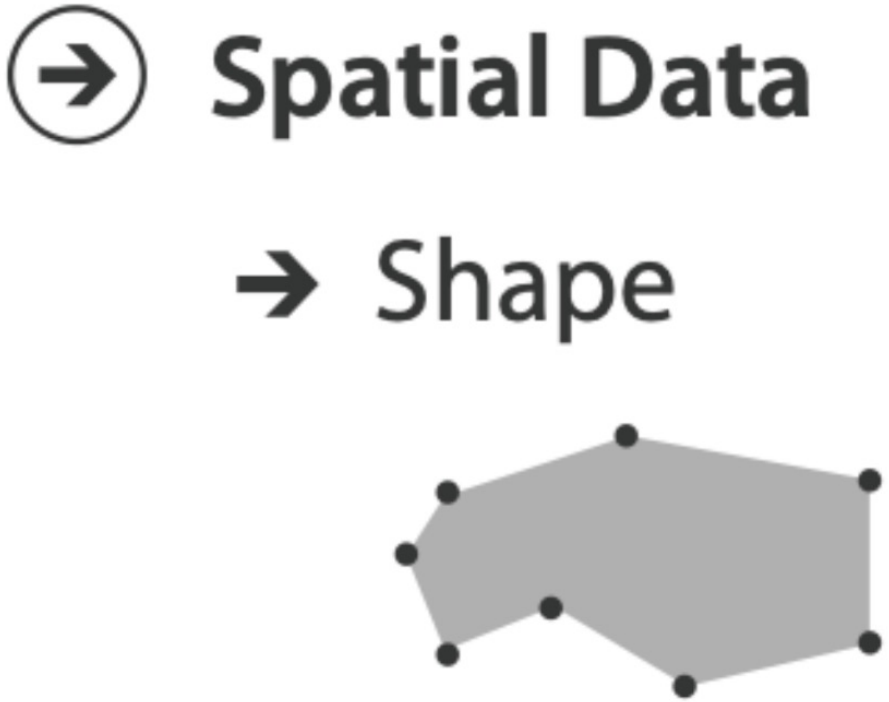
Task Abstraction

- Targets (Networks)
  - Topology (e.g., do all my classmates follow each other?)
  - Paths (e.g., who do I know on LinkedIn that knows Bill Gates?)



Task Abstraction

- Shape (e.g., is there a park within 100 feet of every school?)



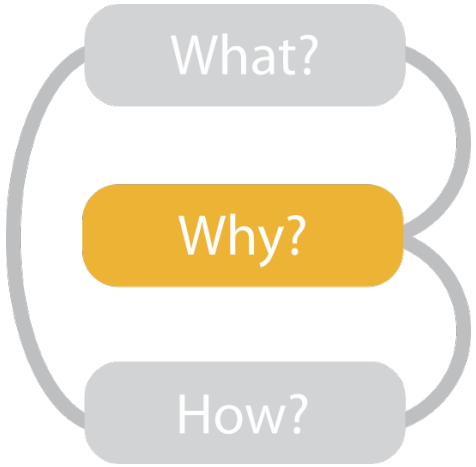
Task Abstraction

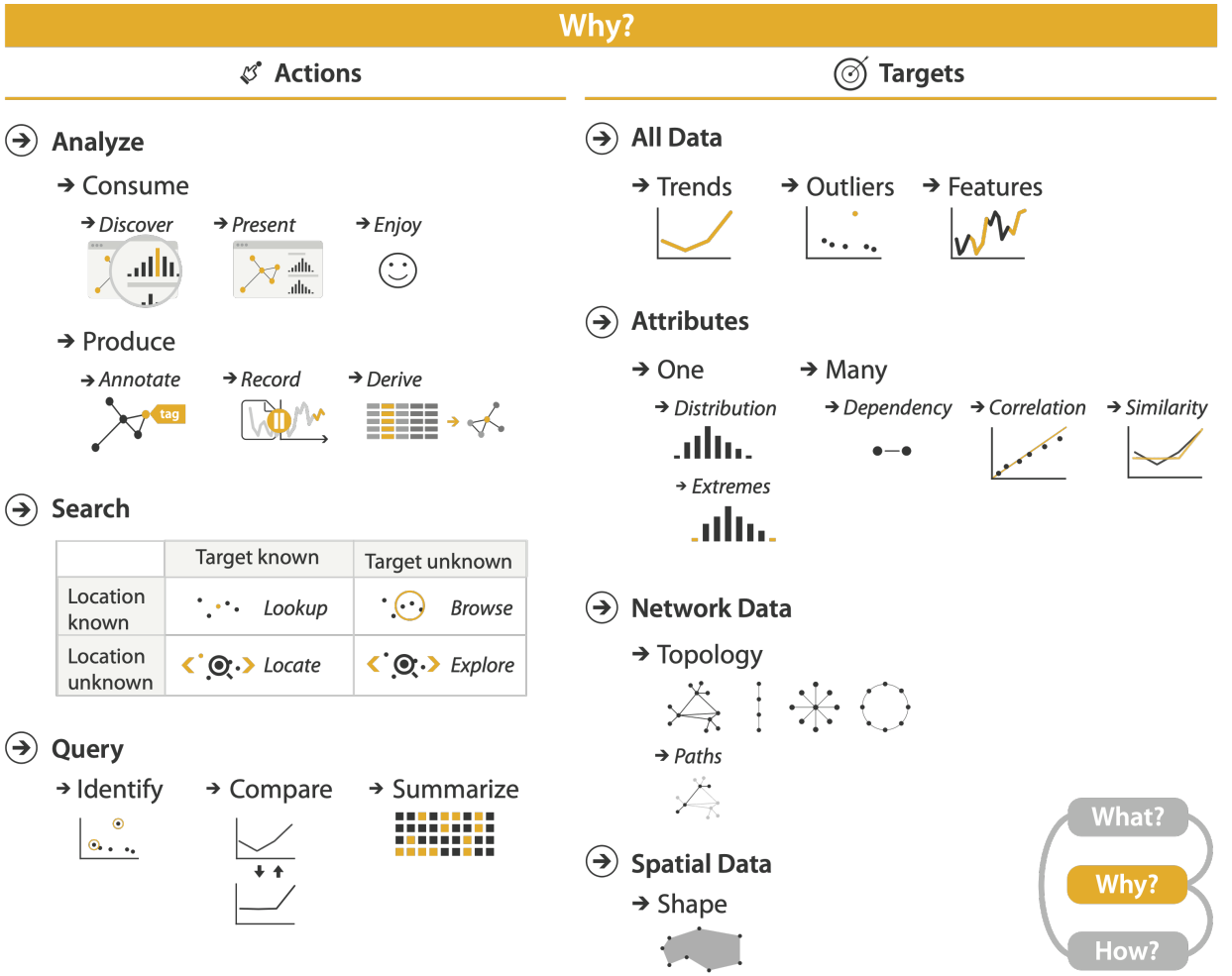
- Do the task abstraction:
  - Economists want to classify what type of recession was generated by the Covid 19 pandemic in different countries.

Task Abstraction

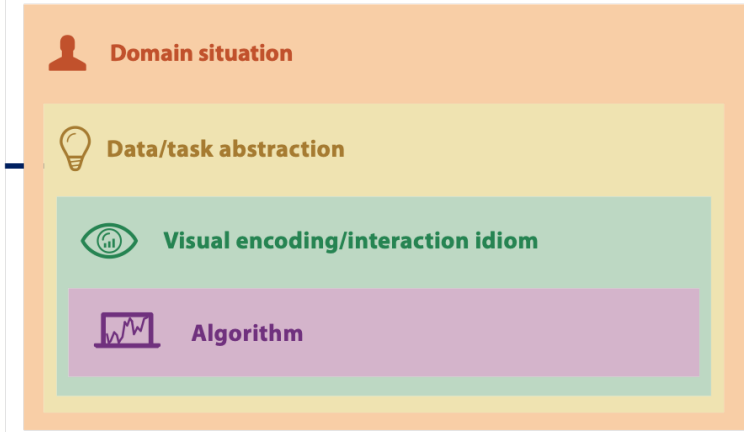
- Do the task abstraction:
  - Economists want to classify what type of recession was generated by the Covid 19 pandemic in different countries.
  - Compare the shape of the GDP over time per country **(compare, trend/features)**

Task Abstraction





Abstraction

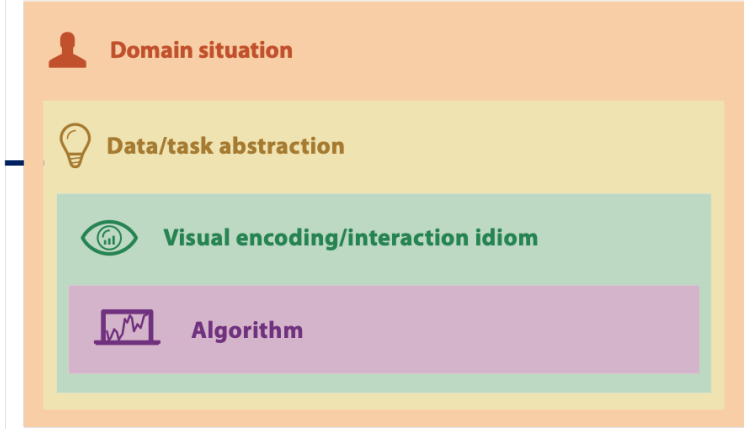


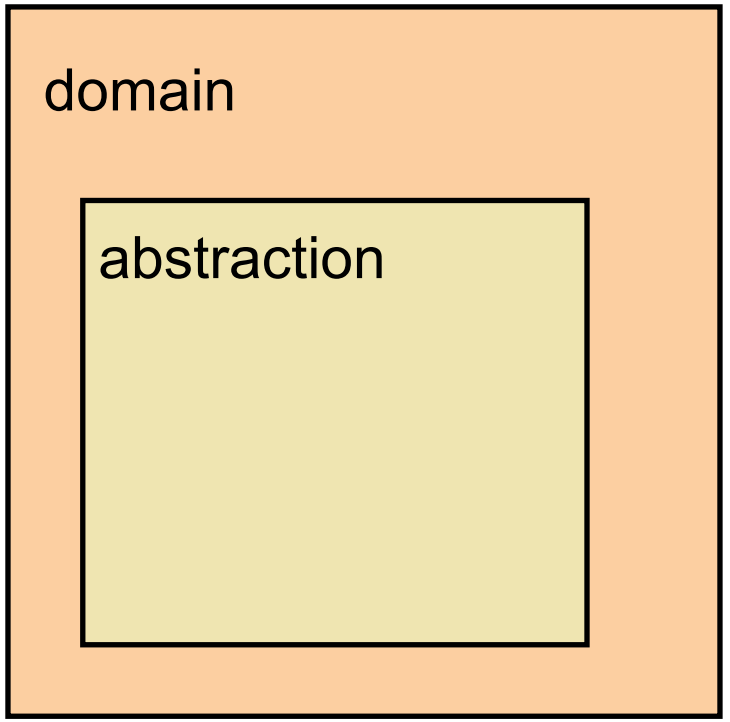
- From domain to abstraction
  - domain characterization: details of application domain
    - group of users, target domain, their questions & data
      - varies wildly by domain
      - must be specific enough to get traction
    - domain questions/problems
      - break down into simpler abstract tasks

domain

Abstraction

- From domain to abstraction
  - domain characterization: details of application domain
    - group of users, target domain, their questions & data
      - varies wildly by domain
      - must be specific enough to get traction
    - domain questions/problems
      - break down into simpler abstract tasks
  - abstraction: data & task
    - map *what* and *why* into generalized terms
      - identify tasks that users wish to perform, or already do
      - find data types that will support those tasks
        - possibly transform /derive if need be





Abstraction

- interplay: task and data abstraction
  - need to use data abstraction within task abstraction
    - to specify your targets!
    - but task abstraction can lead you to transform the data
  - iterate back and forth
    - first pass data, first pass task, second pass data, ...

Visualisation Material

- vis examples
  - Map of the Market (1998): https://www.bewitched.com/marketmap.html
  - NAPOLEON‘S MARCH: https://www.edwardtufte.com/tufte/posters
  - Lineup: Multi-attribute Rankings: https://jku-vds-lab.at/tools/lineup/

Summary

- Dataset Type
  - Table, Network, Spatial
- Data Type
  - Items, Attributes, Link, Positions, Grids
- Attribute Type
  - categorical, ordered
- Data Abstraction
  - Translate from domain-specific language to generic visualization language
- Task Abstraction
  - {action, target}
- Abstraction