Data Visualization (CSCI 627/490)

Data & Tasks

Dr. David Koop

Example: JavaScript and the DOM

- Start with no real content, just divs:

```
<div id="firstSection"></div>
<div id="secondSection"></div>
<div id="finalSection"></div>
```

- Get existing elements:
  - `document.querySelector/querySelectorAll`
  - `document.getElementById`
- Programmatically add elements:
  - `document.createElement`
  - `document.createTextNode`
  - `Element.appendChild`
  - `Element.setAttribute`

Bears

Chicago, IL

2025-2026 NFC North Champions

What will happen next year?

Observable's HTML Templating

- Allows JavaScript expressions to be **inlined** in HTML (or SVG content)
- Use `${...}`
- Example:
  - [JavaScript] `name = "Prof. Koop"`
  - [HTML] `<p>Hello, my name is ${name}</p>`

Using Observable's HTML Templating

```
<div id="firstSection">
  <h1>Bears</h1><p>Chicago, IL</p>
</div>
<div id="secondSection">
  <h2>2025-2026 NFC North Champions</h2>
</div>
<div id="finalSection">
  ${scores.map((game) => html`<p>${game.date}:
        ${game.win ? "Win" : "Loss"} (${game.score})</p>`)}
  <img src="…mmiufe42puji9ifxqk0b.jpg" width="240"></img>
  <p>What will happen this year?</p>
</div>
```

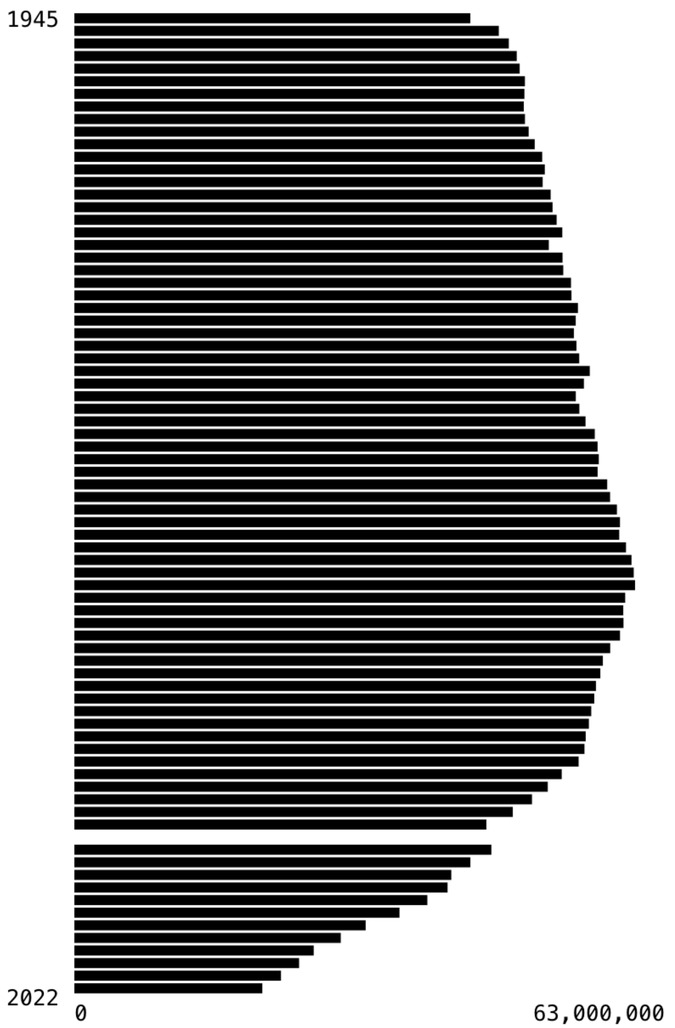
Notebook

SVG Manipulation Example

- Draw a horizontal bar chart
  - `var a = [6, 2, 6, 10, 7, 18, 0, 17, 20, 6];`
- Steps:
  - Programmatically create SVG
  - Create individual rectangle for each item
- Use `addEltToSvg` helper function or templating
- Use functions to calculate height/width
- Can add style rules
- Notebook

Assignment 2

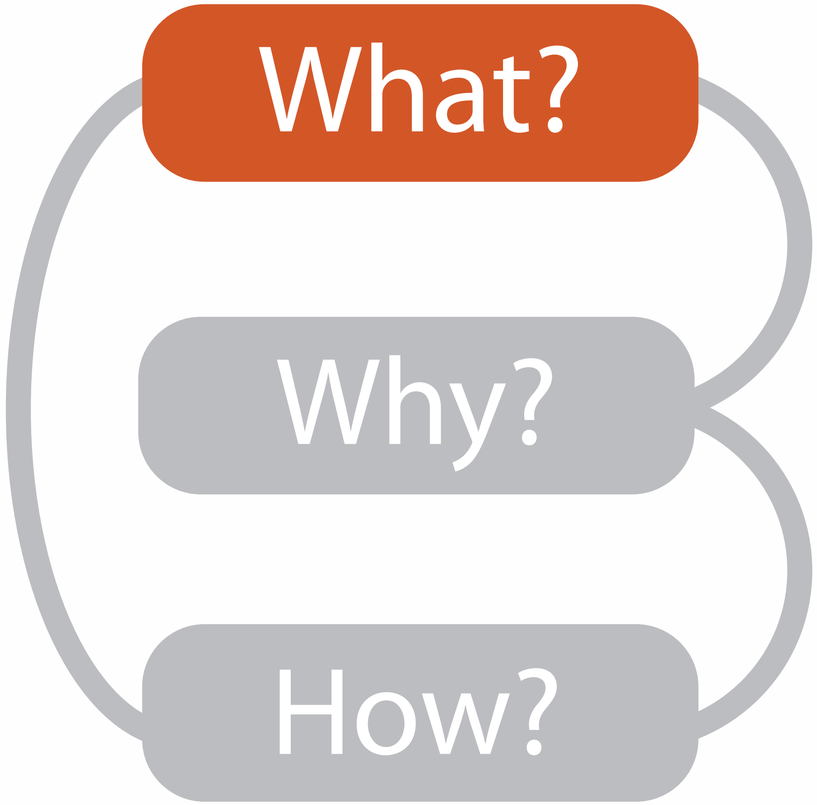
- Newspaper Circulation
- Data Processing in JavaScript
- Create Bar Charts using SVGs and JavaScript
- **Do not sort** the data for Parts 2 & 3
- [CSCI 627] Add Interaction



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

— T. Munzner

Data



- What? the data
- Why? the tasks
- How? the techniques

- Data visualization begins with data

[Munzner (ill. Maguire), 2014]

Data

- What is this data?

R011	42ND STREET & 8TH AVENUE	00228985	00008471	00000441	00001455	00000134	00033341	00071255
R170	14TH STREET-UNION SQUARE	00224603	00011051	00000827	00003026	00000660	00089367	00199841
R046	42ND STREET & GRAND CENTRAL	00207758	00007908	00000323	00001183	00003001	00040759	00096613

- **Semantics**: real-world meaning of the data
- **Type**: structural or mathematical interpretation
- Both often require **metadata**
  - Sometimes we can infer some of this information
  - Line between data and metadata isn't always clear

Semantics

- The meaning of the data
- Example: 94023, 90210, 02747, 60115

Semantics

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- Example: 94023, 90210, 02747, 60115
  - Attendance at college football games?

Semantics

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  - Salaries?

Semantics

- The meaning of the data
- Example: 94023, 90210, 02747, 60115
  - Attendance at college football games?
  - Salaries?
  - Zip codes?
- Cannot always infer based on what the data looks like
- Often require semantics to better understand data
- Column names help with semantics
- May also include rules about data: a zip code is part of an address that uniquely identifies a residence
- Useful for asking good questions about the data

Data

	REMOTE	STATION	FF	SEN/DIS	7-D AFAS UNL	D AFAS/RMF U	JOINT RR TKT	7-D UNL	30-D UNL
1	R011	42ND STREET & 8TH AVENUE	00228985	00008471	00000441	00001455	00000134	00033341	00071255
2	R170	14TH STREET-UNION SQUARE	00224603	00011051	00000827	00003026	00000660	00089367	00199841
3	R046	42ND STREET & GRAND CENTRAL	00207758	00007908	00000323	00001183	00003001	00040759	00096613
4	R012	34TH STREET & 8TH AVENUE	00188311	00006490	00000498	00001279	00003622	00035527	00067483
5	R293	34TH STREET - PENN STATION	00168768	00006155	00000523	00001065	00005031	00030645	00054376
6	R033	42ND STREET/TIMES SQUARE	00159382	00005945	00000378	00001205	00000690	00058931	00078644
7	R022	34TH STREET & 6TH AVENUE	00156008	00006276	00000487	00001543	00000712	00058910	00110466
8	R084	59TH STREET/COLUMBUS CIRCLE	00155262	00009484	00000589	00002071	00000542	00053397	00113966
9	R020	47-50 STREETS/ROCKEFELLER	00143500	00006402	00000384	00001159	00000723	00037978	00090745
10	R179	86TH STREET-LEXINGTON AVE	00142169	00010367	00000470	00001839	00000271	00050328	00125250
11	R023	34TH STREET & 6TH AVENUE	00134052	00005005	00000348	00001112	00000649	00031531	00075040
12	R029	PARK PLACE	00121614	00004311	00000287	00000931	00000792	00025404	00065362
13	R047	42ND STREET & GRAND CENTRAL	00100742	00004273	00000185	00000704	00001241	00022808	00068216

Data Terminology

- Items
  - An **item** is an individual discrete entity
  - e.g. row in a table, node in a network
- Attributes
  - An **attribute** is some specific property that can be measured, observed, or logged
  - a.k.a. variable, (data) dimension
  - e.g. a column in a table

Items & Attributes

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		7/17/07
32	7/16/07	2-High	Medium Box		7/18/07
32	7/16/07	2-High	Medium Box		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	6/6/05	4-Not Specified	Small Pack	0.44	6/6/05
69	6/6/05	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

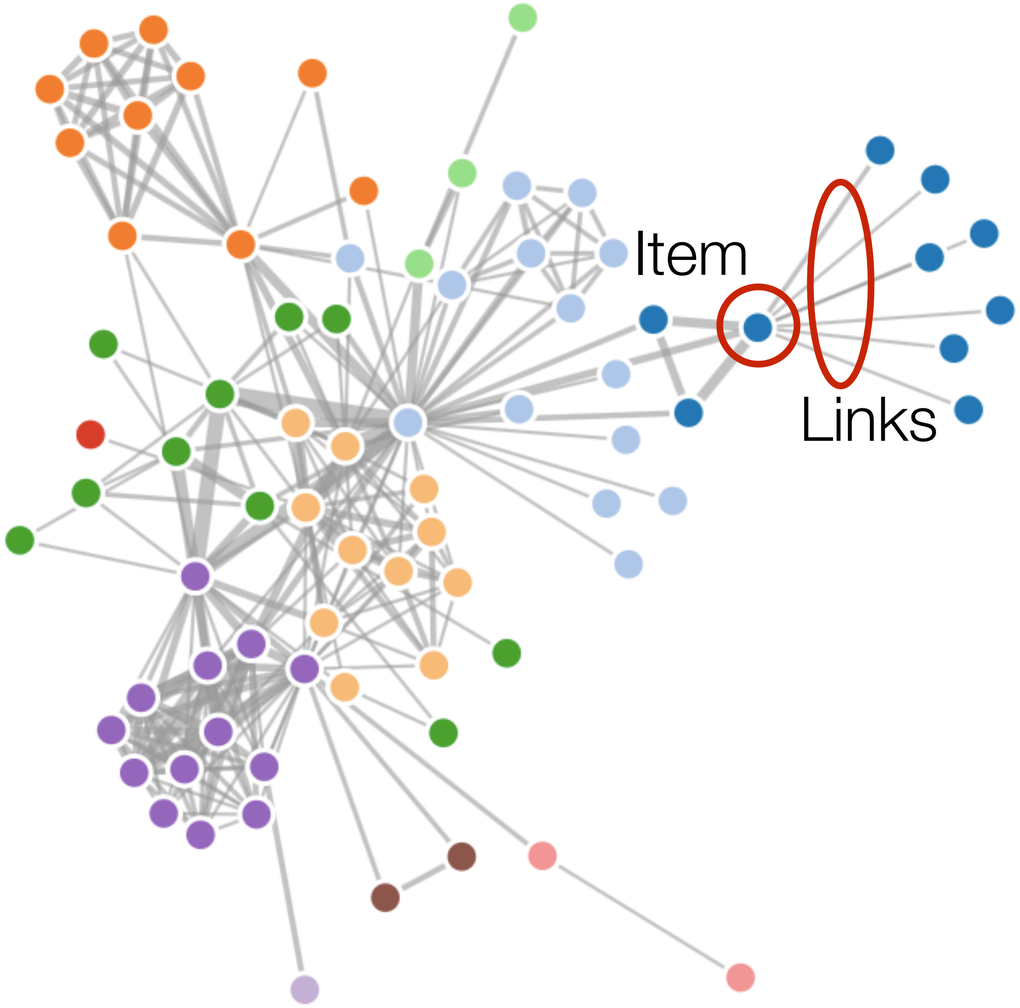
attribute

item

Data Types

- Nodes
  - Synonym for item but in the context of networks (graphs)
- Links
  - A **link** is a relation between two items
  - e.g. social network friends, computer network links

Items & Links

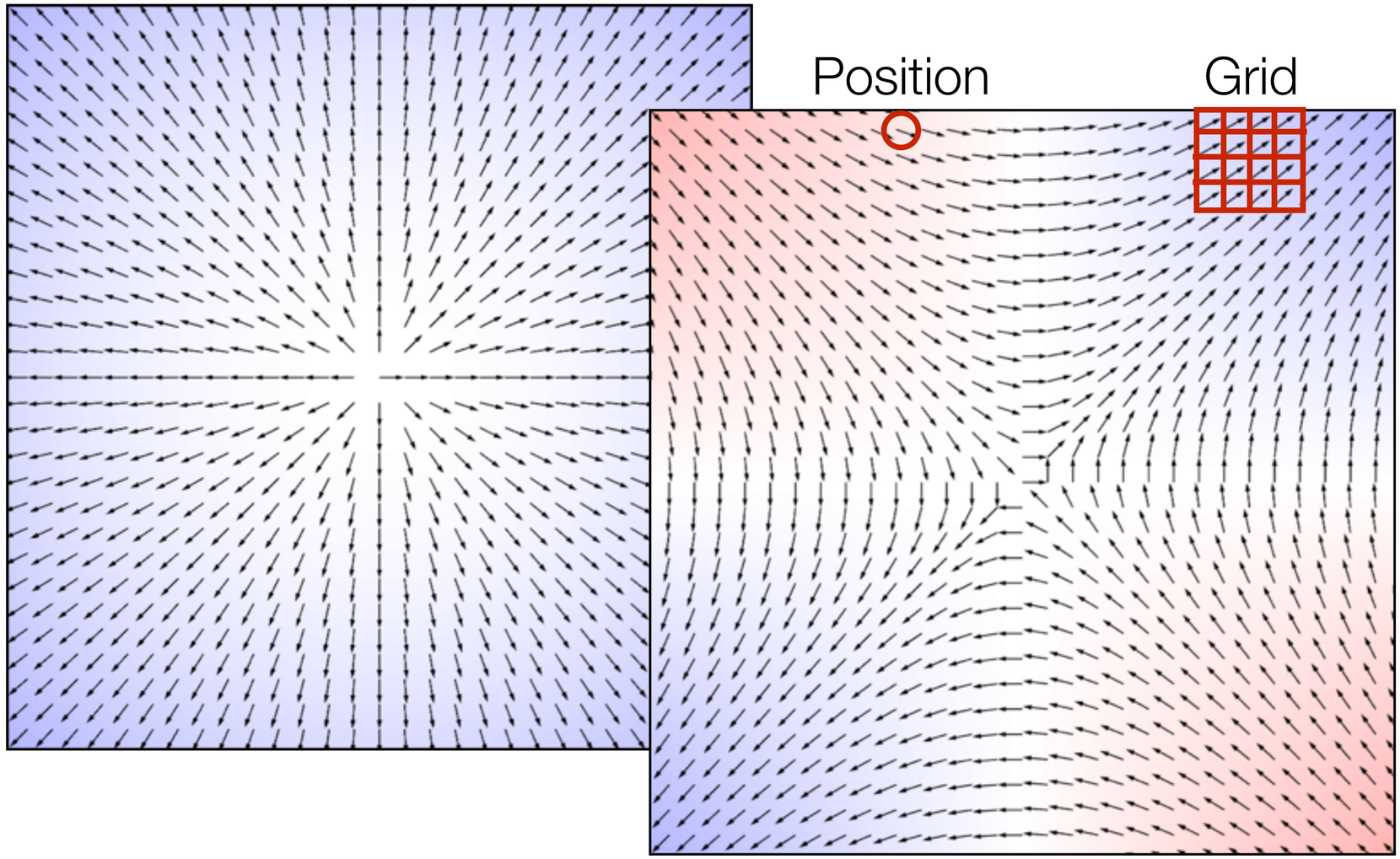


[Bostock, 2011]

Data Types

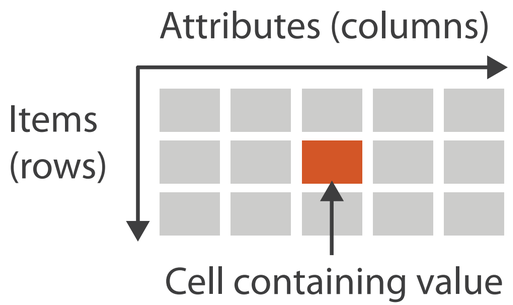
- Positions:
  - A **position** is a location in space (usually 2D or 3D)
  - May be subject to projections
  - e.g. cities on a map, a sampled region in an CT scan
- Grids:
  - A **grid** specifies how data is sampled both geometrically and topologically
  - e.g. how CT scan data is stored

Positions and Grids

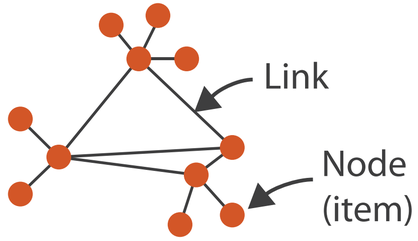


Dataset Types

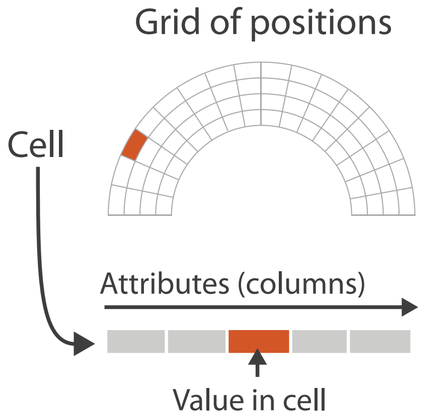
➔ Tables



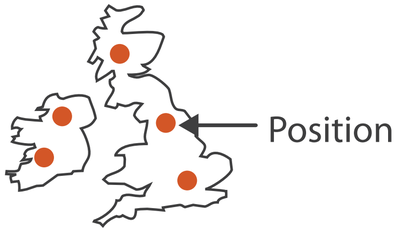
➔ Networks



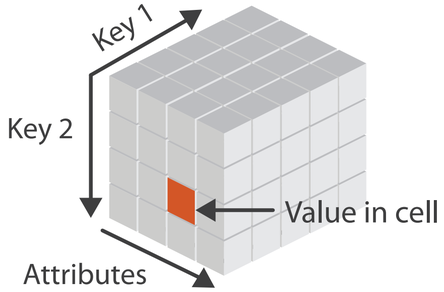
➔ Fields (Continuous)



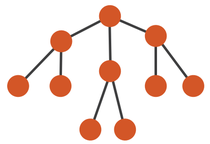
➔ Geometry (Spatial)



➔ *Multidimensional Table*



➔ *Trees*



[Munzner (ill. Maguire), 2014]

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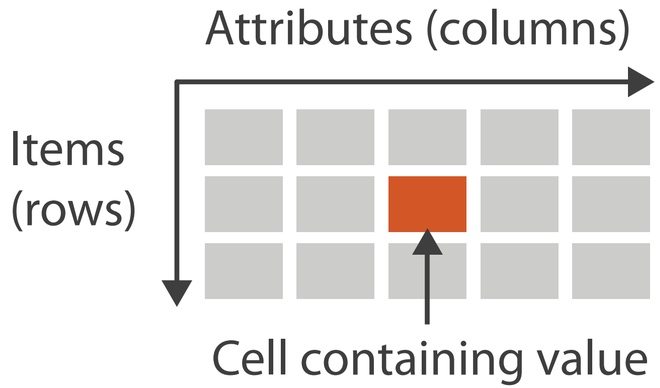
attribute

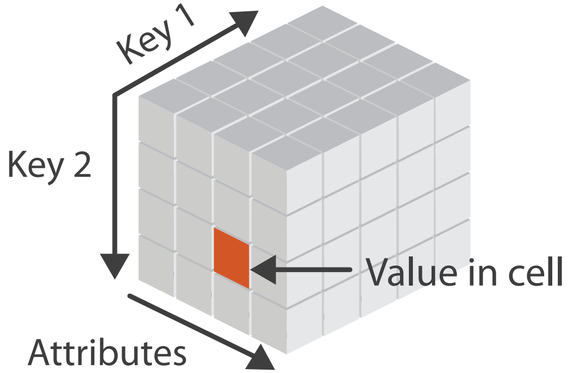
cell

item

Tables



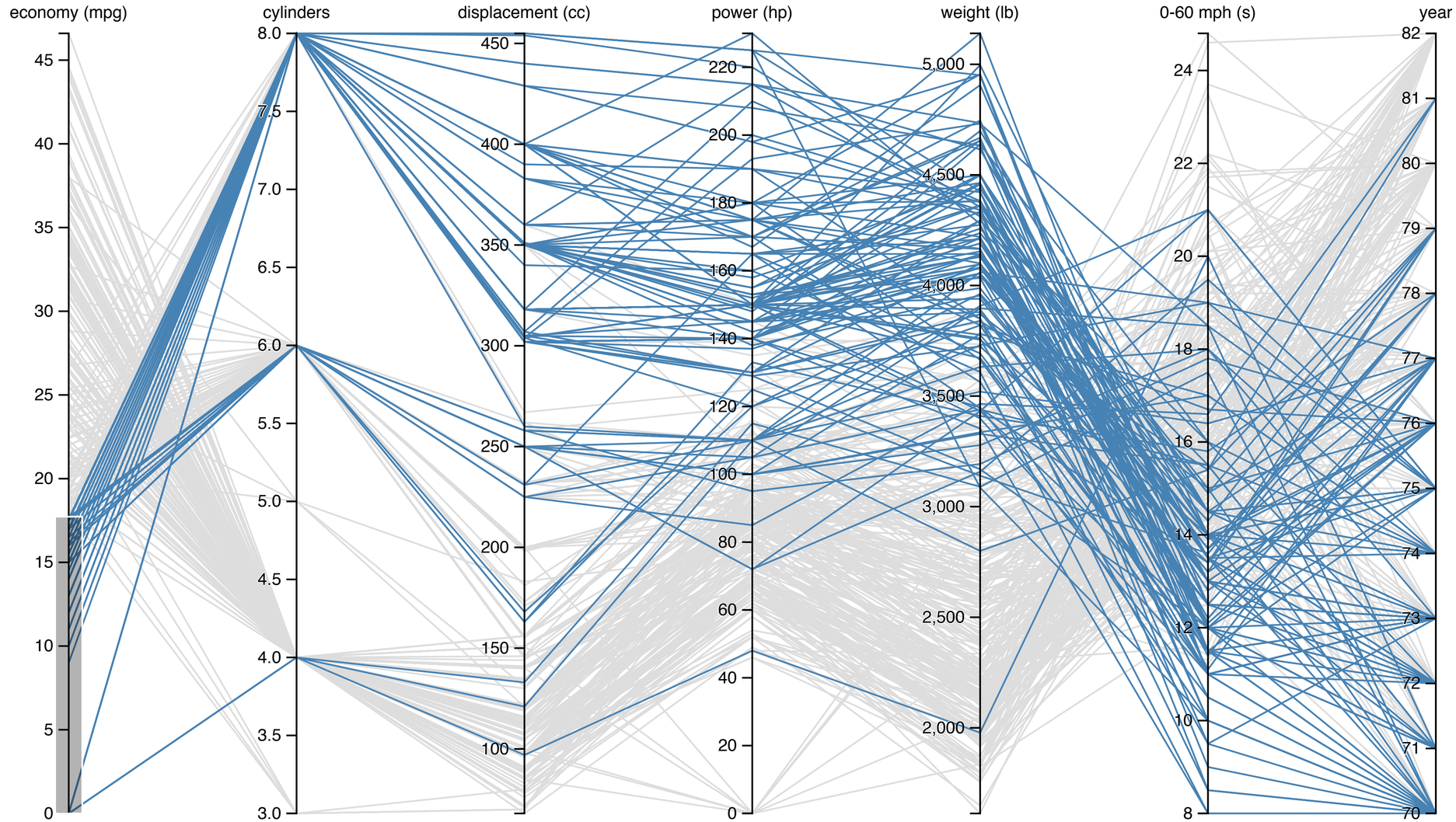
➔ *Multidimensional Table*



- Data organized by rows & columns
  - row ~ item (usually)
  - column ~ attribute
  - label ~ attribute name
- Key: identifies each item (row)
  - Usually **unique**
  - Allows **join** of data from 2+ tables
  - Compound key: key split among multiple columns, e.g. (state, year) for population
- Multidimensional:
  - Split compound key: data cube with (state, year)

[Munzner (ill. Maguire), 2014]

Table Visualizations

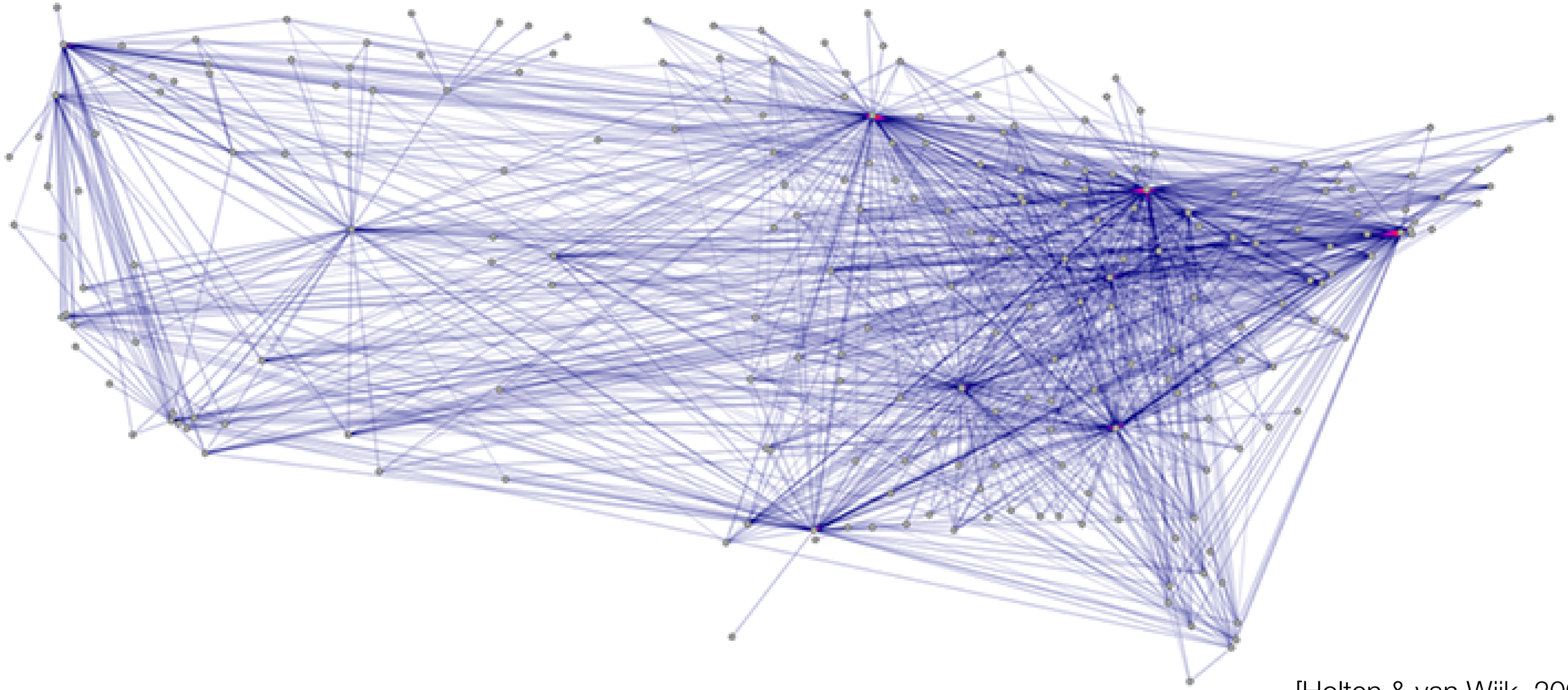


[M. Bostock, 2011]

Networks

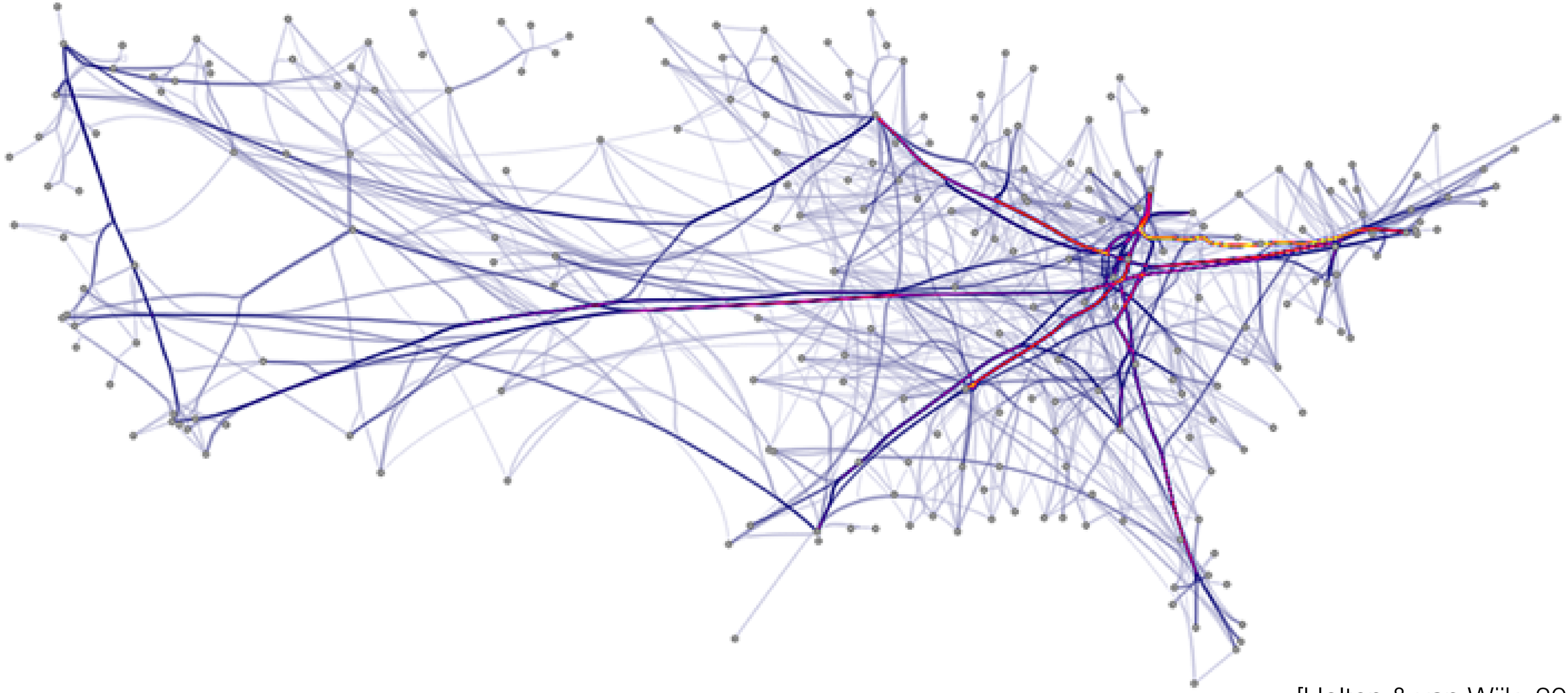
- Why networks instead of graphs?
- Tables can represent networks
  - Many-many relationships
  - Also can be stored as specific graph databases or files

Networks



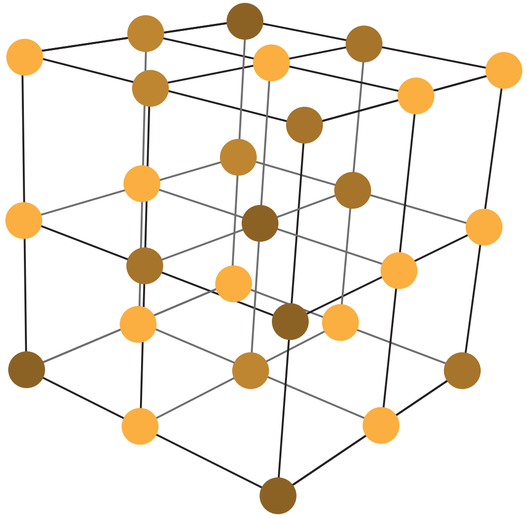
[Holten & van Wijk, 2009]

Networks



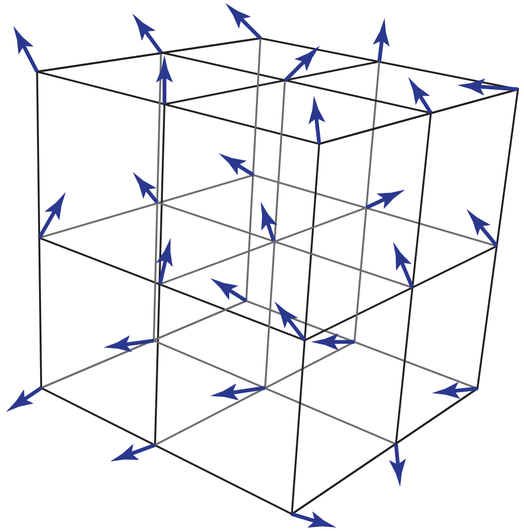
[Holten & van Wijk, 2009]

Fields



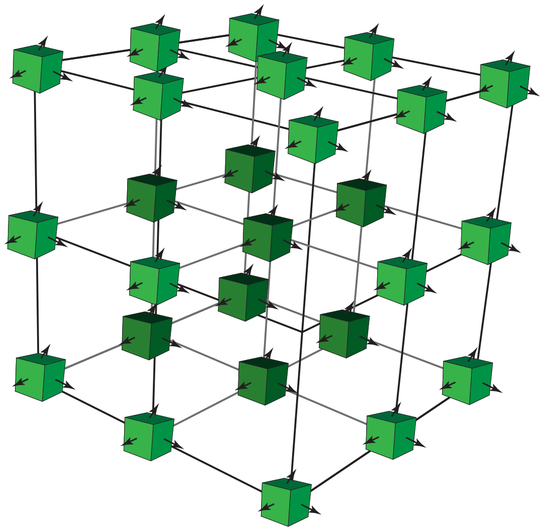
Scalar Fields

(Order-0 Tensor Fields)



Vector Fields

(Order-1 Tensor Fields)



Tensor Fields

(Order-2+)

Each point in space has an associated...

s_0

Scalar

$$\begin{bmatrix} v_0 \\ v_1 \\ v_2 \end{bmatrix}$$

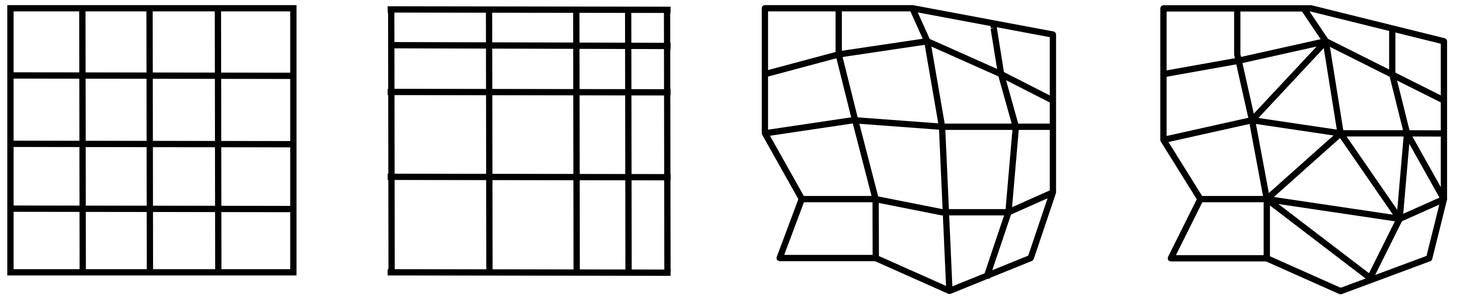
Vector

$$\begin{bmatrix} \sigma_{00} & \sigma_{01} & \sigma_{02} \\ \sigma_{10} & \sigma_{11} & \sigma_{12} \\ \sigma_{20} & \sigma_{21} & \sigma_{22} \end{bmatrix}$$

Tensor

Fields

- Difference between **continuous** and **discrete** values
- Examples: temperature, pressure, density
- **Grids** necessary to sample continuous data:

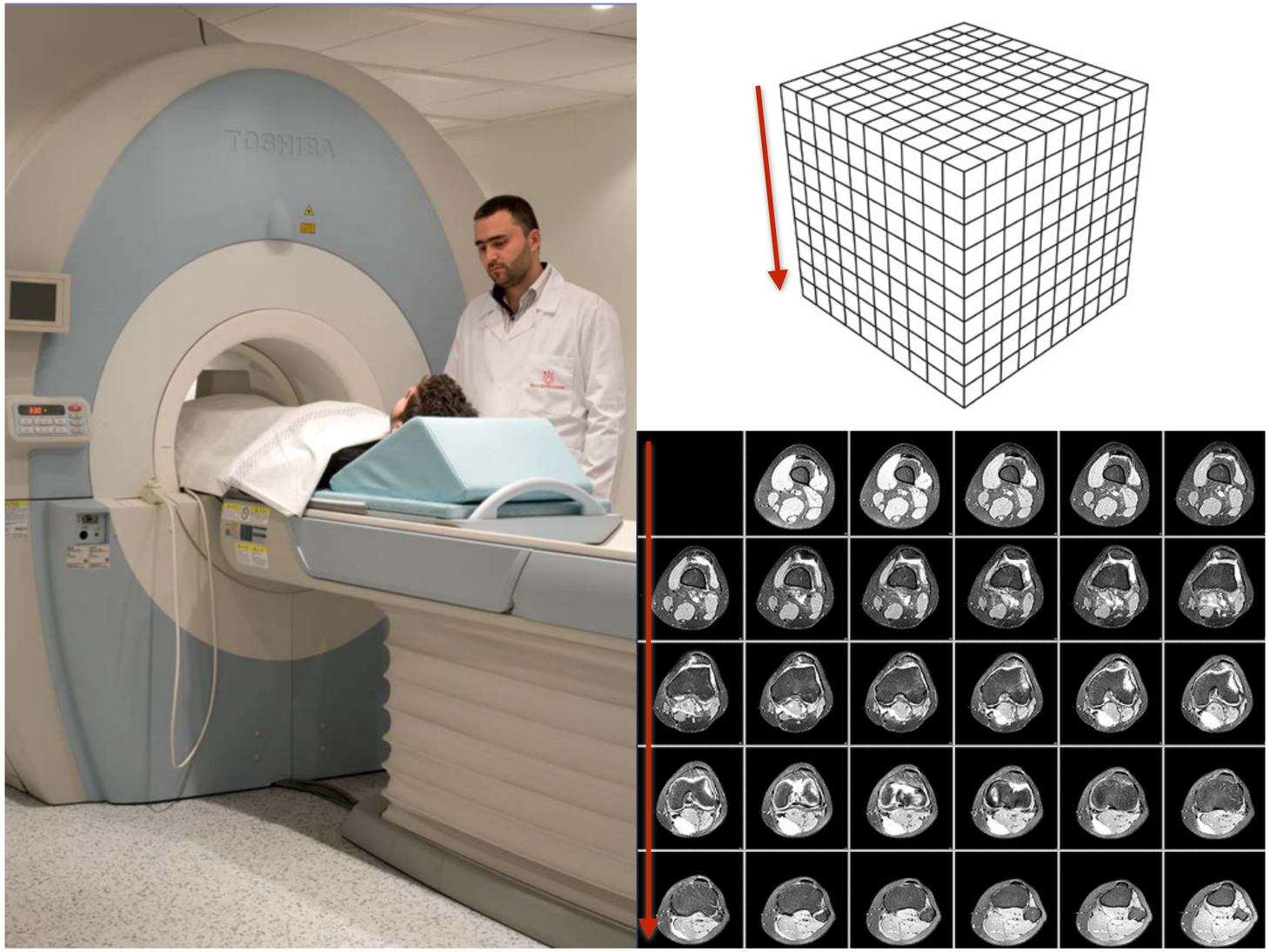


uniform rectilinear structured unstructured

[Weiskopf, Machiraju, Möller]

- **Interpolation**: “how to show values between the sampled points in ways that do not mislead”

Spatial Data Example: MRI

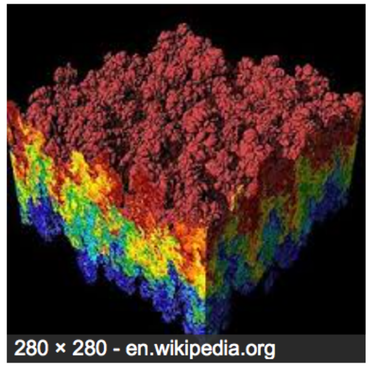


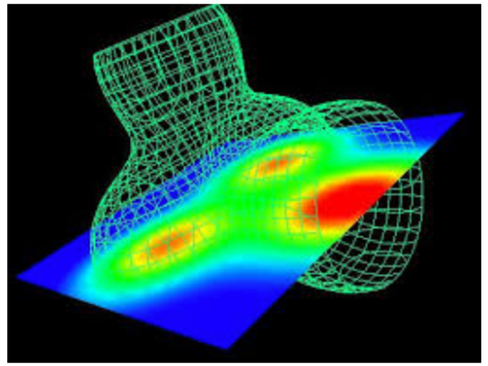
[via Levine, 2014]

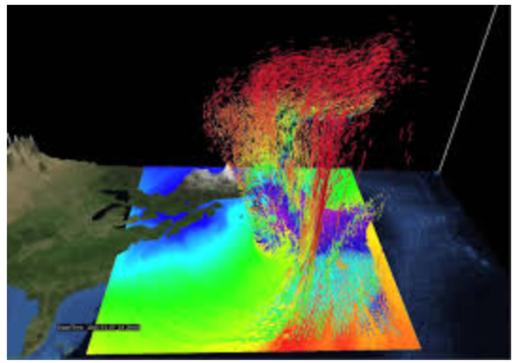
Scivis and Infovis

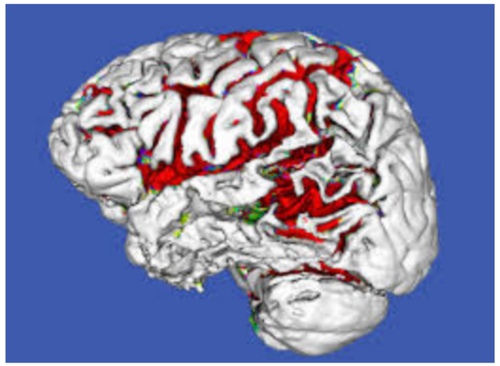
- Two subfields of visualization
- **Scivis** deals with data where the spatial position is given with data
  - Usually continuous data
  - Often displaying physical phenonema
  - Techniques like isosurfacing, volume rendering, vector field vis
- In **Infovis**, the data has no set spatial representation, designer chooses how to visually represent data

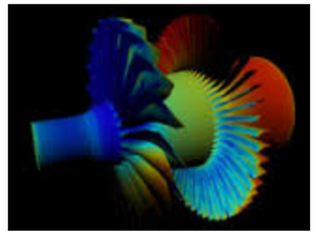
SciVis

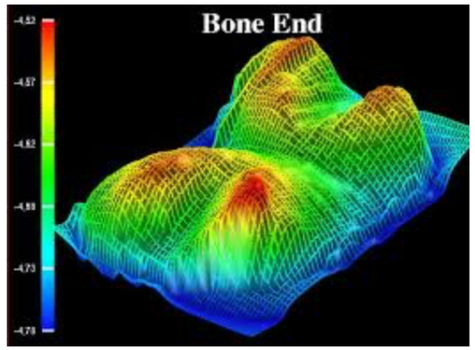


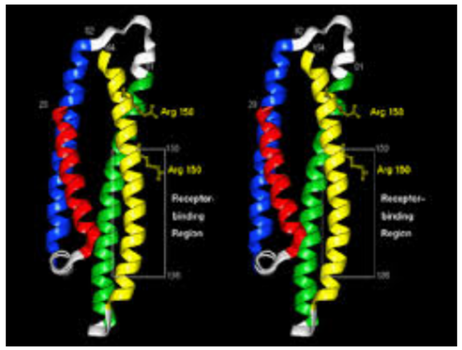


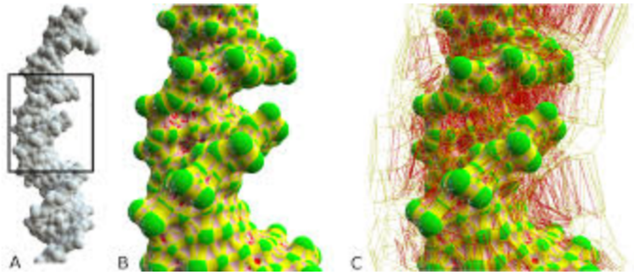


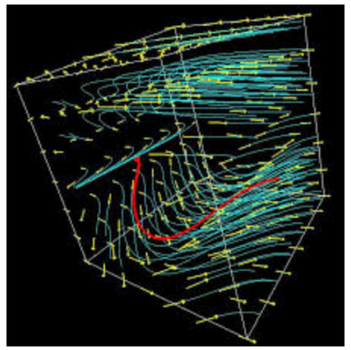


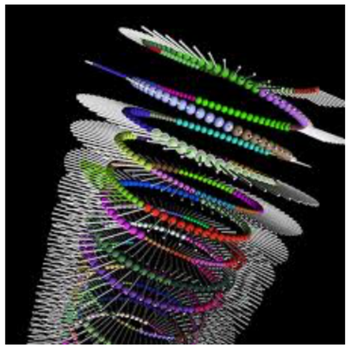


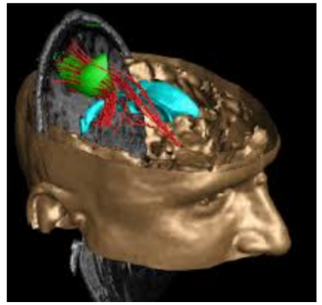


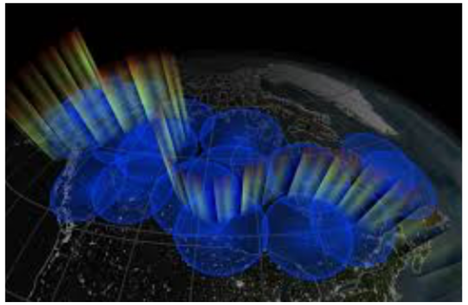


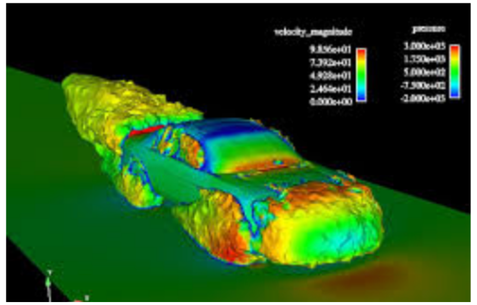


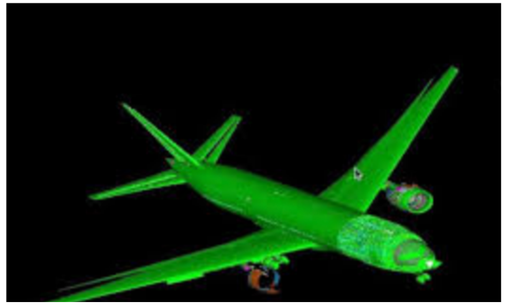






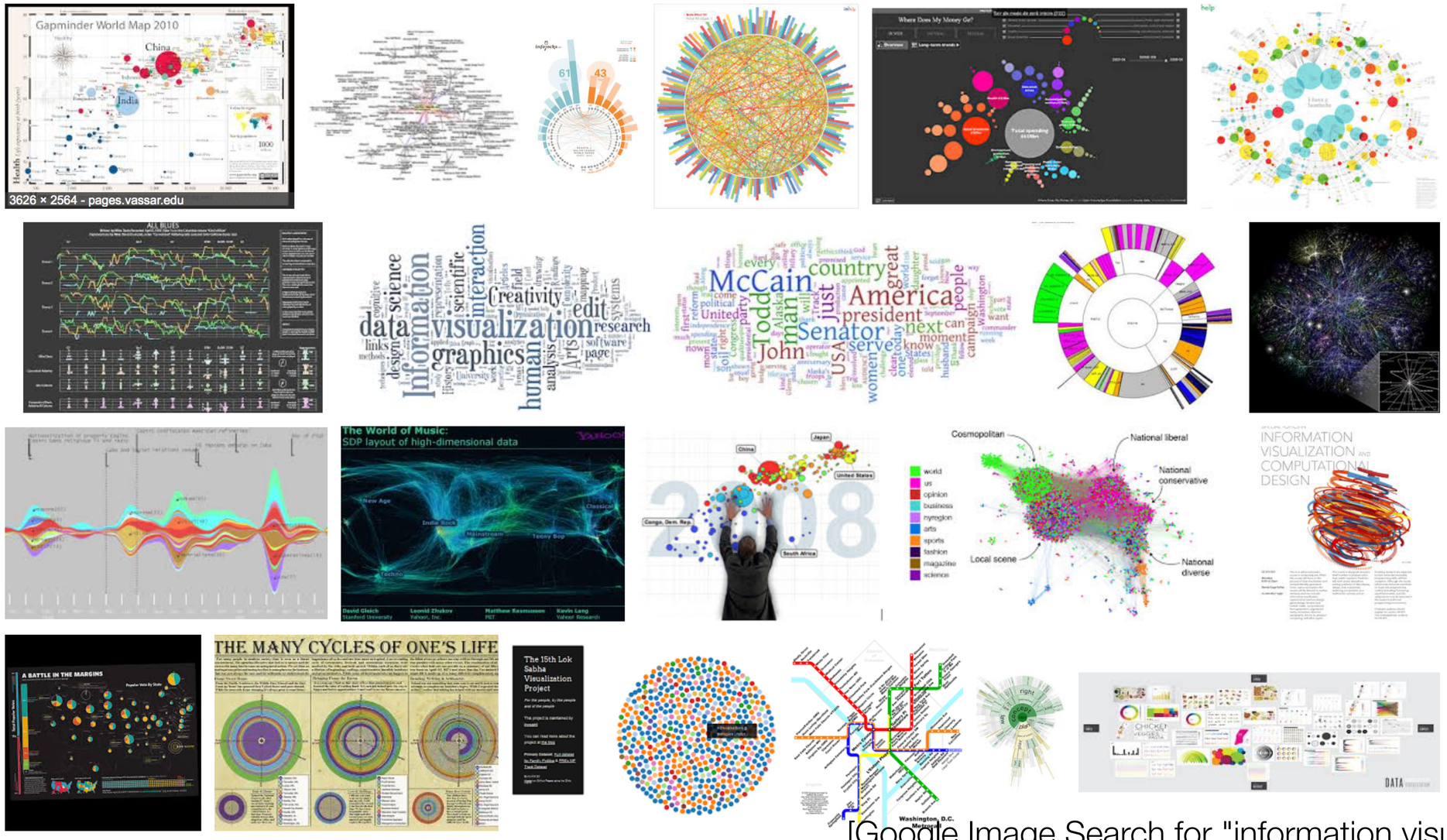






[Google Image Search for "scientific visualization", 2017]

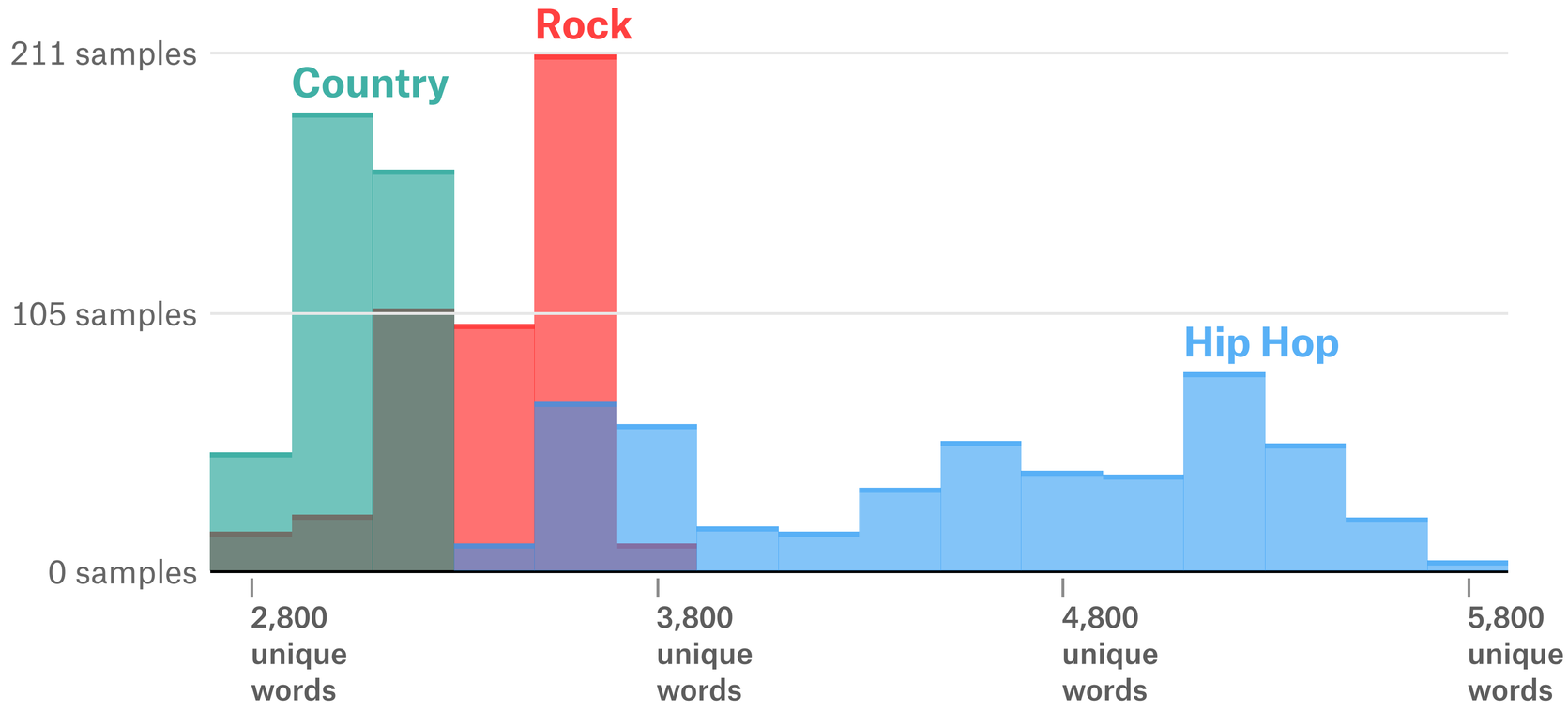
InfoVis



[Google Image Search for "information visualization", 2017]

Sets & Lists

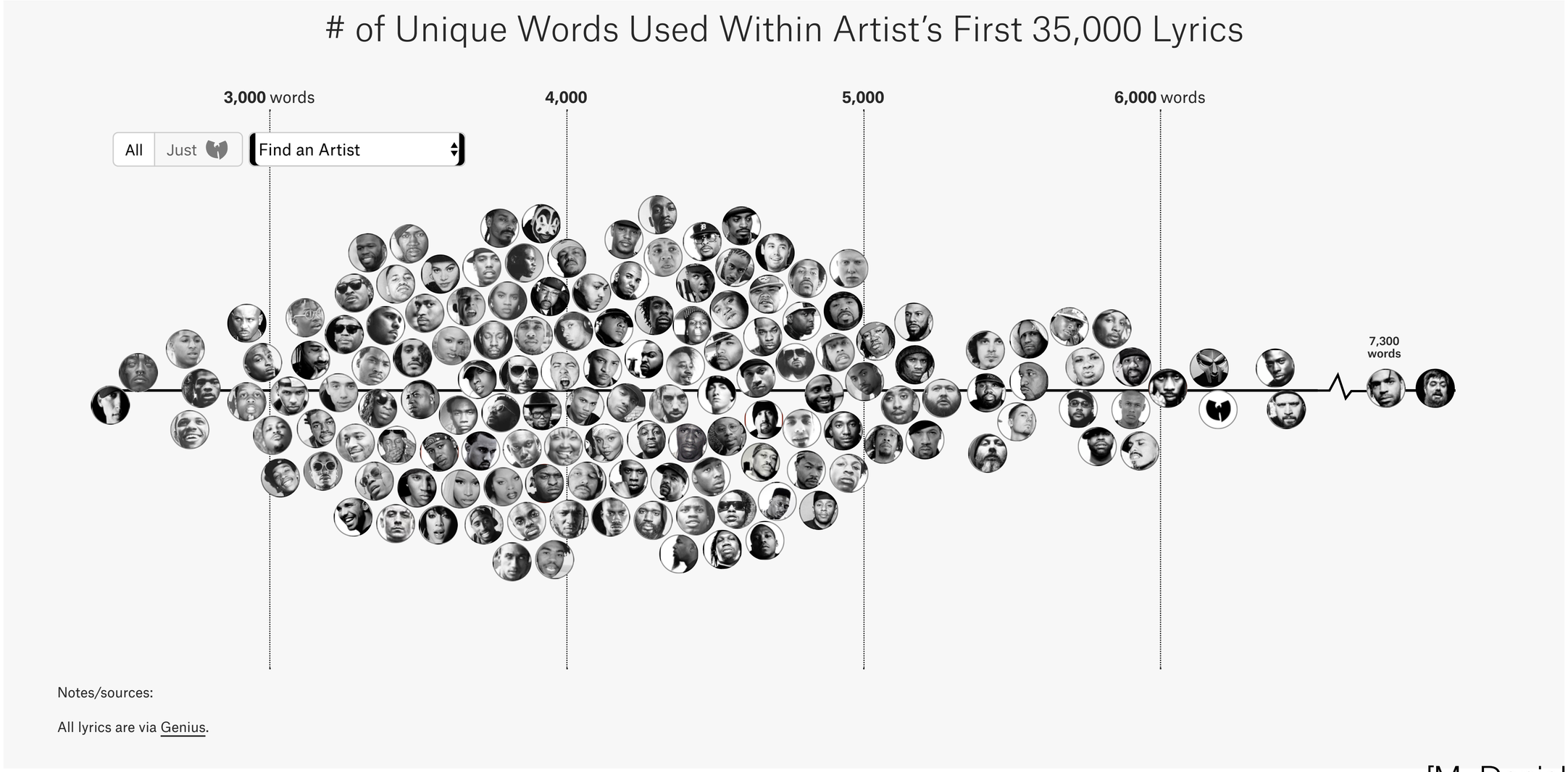
of Unique Words Used in 500 Random Samples of 35,000 Lyrics from Country, Rock, Hip Hop



Raw Lyrics Data via John W. Miller

[M. Daniels, 2019]

Sets & Lists



[M. Daniels, 2019]

Sets & Lists

[M. Daniels, 2019]

Attribute Types

➔ Categorical

➔ Ordered

➔ *Ordinal*

➔ *Quantitative*

[Munzner (ill. Maguire), 2014]

Categorial, Ordinal, and 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
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 Spec		0.6	6/6/05
70	12/18/06	5-Low		0.59	12/23/06
70	12/18/06	5-Low		0.82	12/23/06
96	4/17/05	2-High		0.55	4/19/05
97	1/29/06	3-Medium		0.38	1/30/06
129	11/19/08	5-Low		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

quantitative
ordinal
categorical

Categorial, Ordinal, and 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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quantitative
ordinal
categorical

Data Model vs. Conceptual Model

- Data Model: raw data that has a specific data type (e.g. floats):
  - Temperature Example: [32.5, 54.0, -17.3] (floats)
- Conceptual Model: how we think about the data
  - Includes semantics, reasoning
  - Temperature Example:
    - Quantitative: [32.50, 54.00, -17.30]

[via A. Lex, 2015]

Data Model vs. Conceptual Model

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    - Quantitative: [32.50, 54.00, -17.30]
    - Ordered: [warm, hot, cold]

[via A. Lex, 2015]

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  - Temperature Example:
    - Quantitative: [32.50, 54.00, -17.30]
    - Ordered: [warm, hot, cold]
    - Categorical: [not burned, burned, not burned]

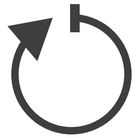
[via A. Lex, 2015]

Ordering Direction

➔ Sequential

➔ Diverging

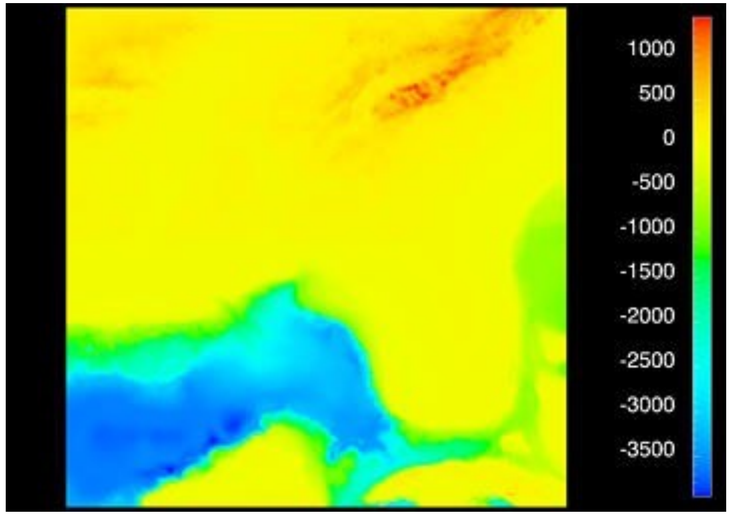
➔ Cyclic



[Munzner (ill. Maguire), 2014]

Sequential and Diverging Data

- Sequential: homogenous range from a minimum to a maximum
  - Examples: Land elevations, ocean depths
- Diverging: can be deconstructed into two sequences pointing in opposite directions
  - Has a **zero point** (not necessary 0)
  - Example: Map of both land elevation and ocean depth



[Rogowitz & Treinish, 1998]

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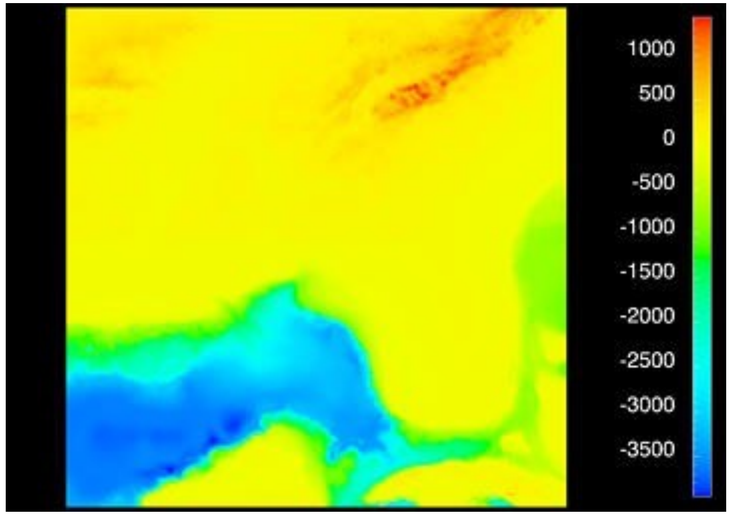
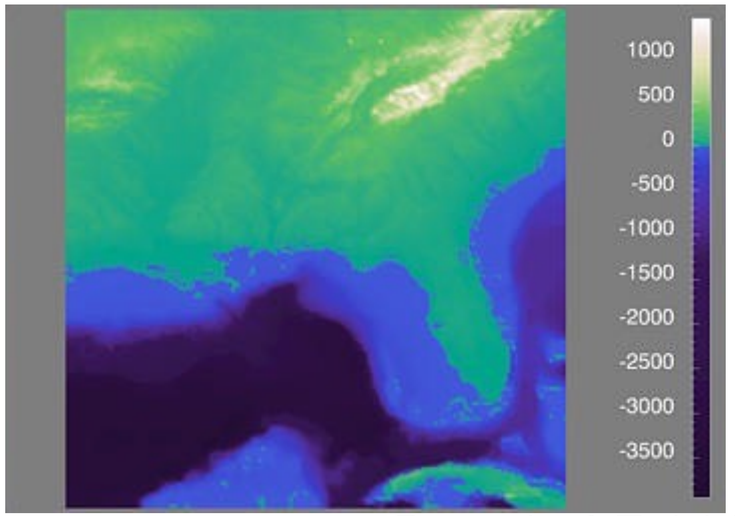
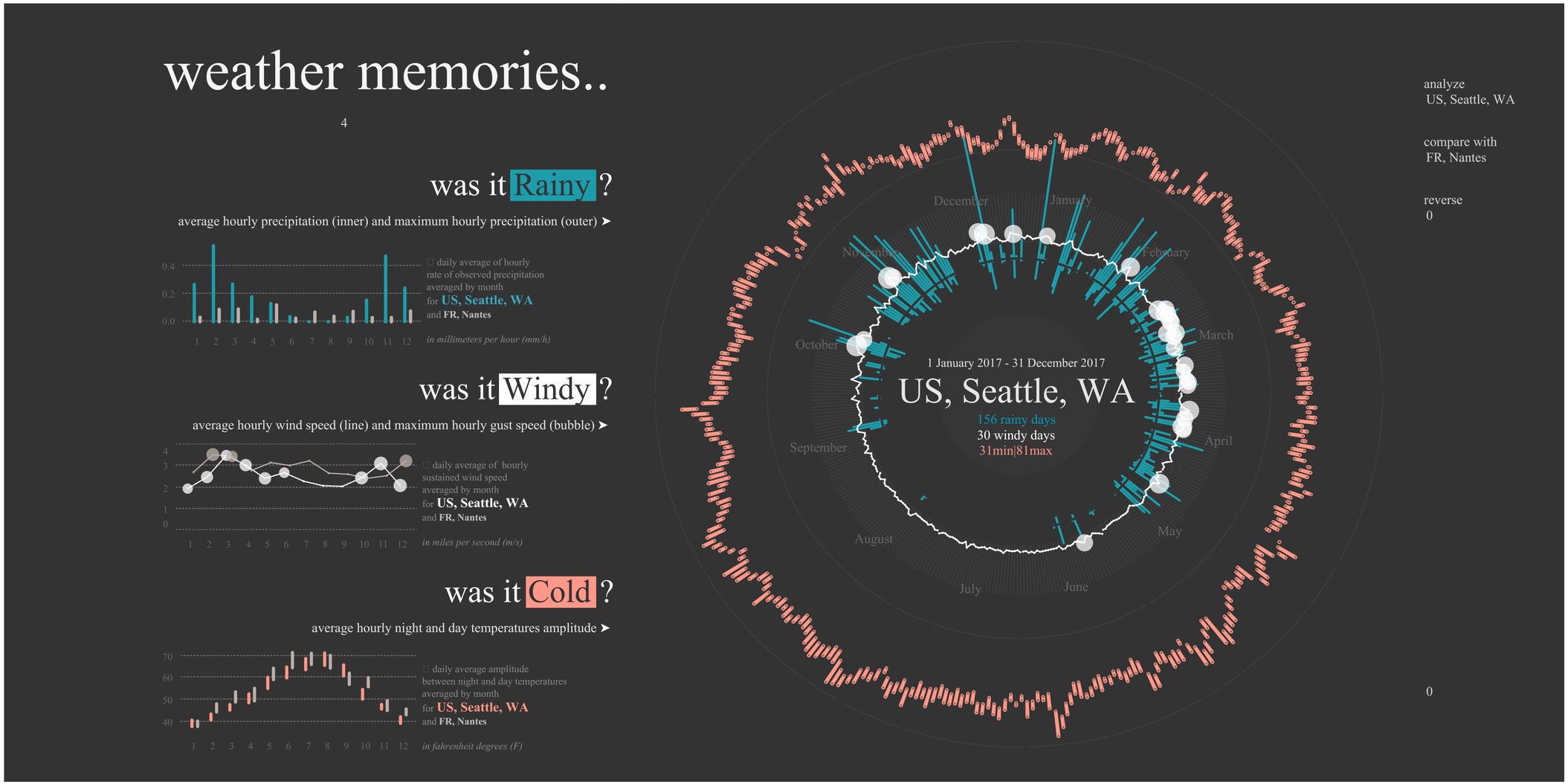




[Rogowitz & Treinish, 1998]

Cyclic Data



[Weather Memories, L. Tavernier, 2018]

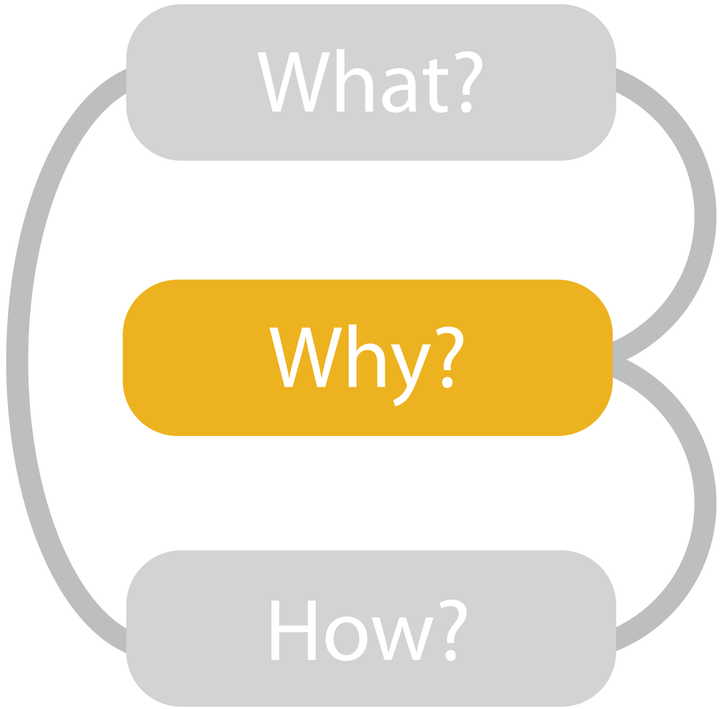
“Computer-based visualization systems provide visual representations of datasets designed to help people carry out **tasks** more effectively.”

— T. Munzner

Tasks

- Why? Understand data, but what do I want to do with it?
- Levels: High (Produce/Consume), Mid (Search), Low (Queries)
- Another key concern: Who?
  - Designer <-> User (A spectrum)
  - Complex <-> Easy to Use
  - General <-> Context-Specific
  - Flexible <-> Constrained
  - Varied Data <-> Specific Data

Tasks



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

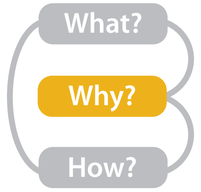
- One
  - *Distribution*
  - *Extremes*
- Many
  - *Dependency*
  - *Correlation*
  - *Similarity*

Network Data

- Topology
  - *Paths*

Spatial Data

- Shape



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