VISUALIZING THE INTERNET OF THINGS

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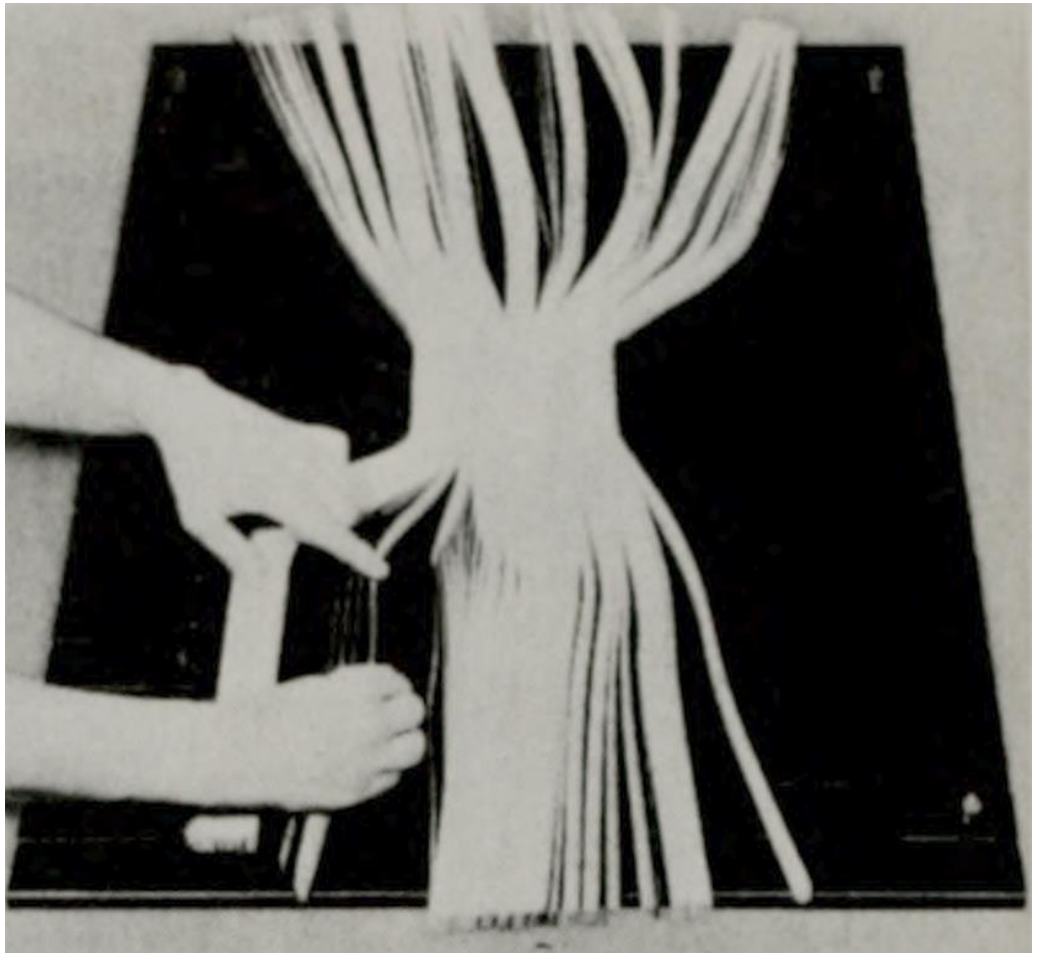
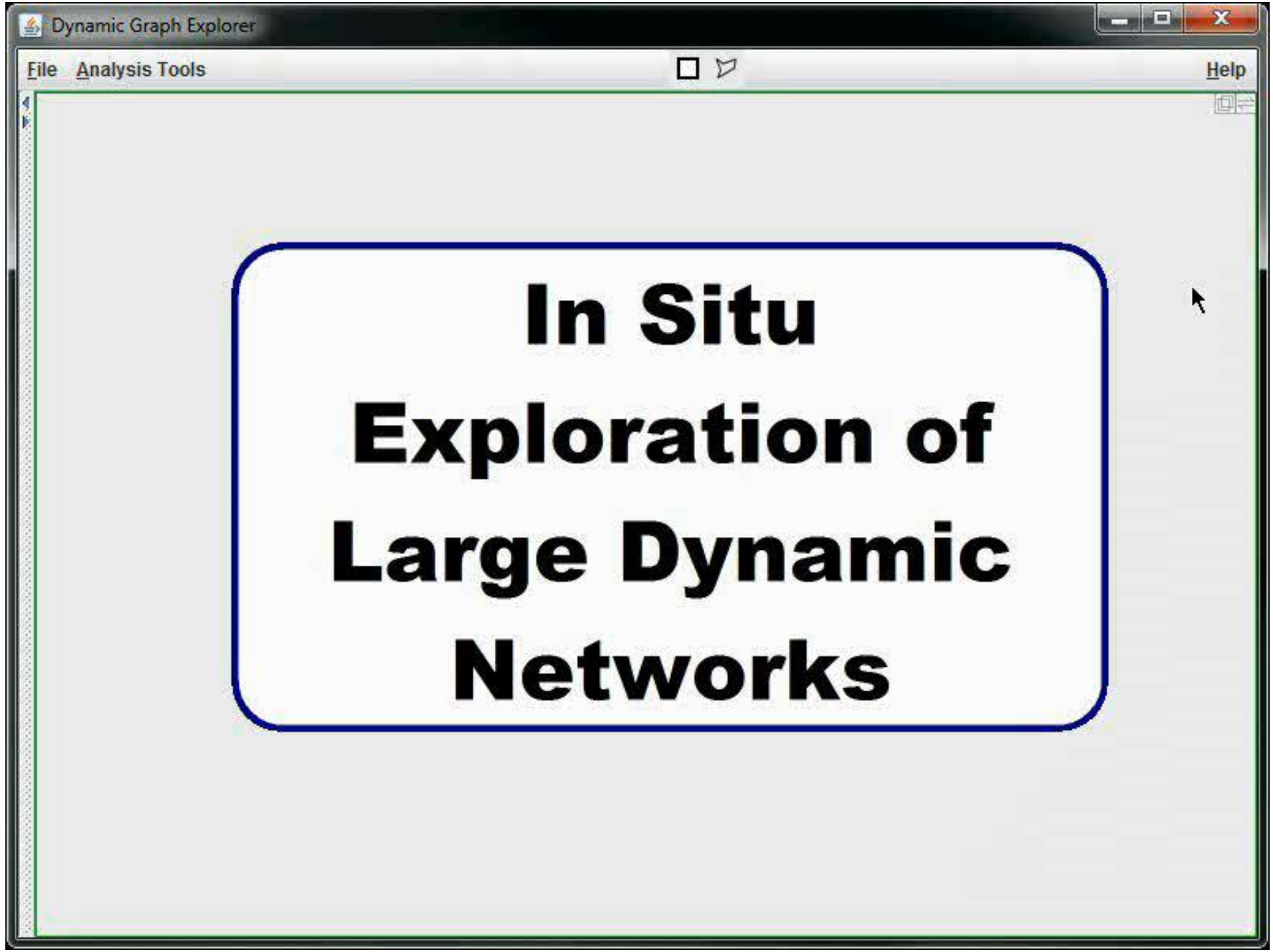
DEPARTMENT OF COMPUTER SCIENCE

PHYSICAL DATA VISUALIZATIONS





[Hadlak et al. 2011] - DOI: 10.1109/TVCG.2011.213

DATA VISUALIZATION

1. What makes a good visualization? – The Visualization Problem

1.1 Expressiveness: Show the data!

1.2 Effectiveness: Support the task!

1.3 Appropriateness: Suit the context!

2. How does a visualization work? – The Visualization Pipeline

2.1 Data Preparation: Analysis and Filtering

2.2 Data Representation: Mapping and Postprocessing

2.3 Data Display: Rendering and Interaction

3. How can we actually build visualizations? – JavaScript Visualization Frameworks

3.1 Imperative flavor: Raphaël.js

3.2 Functional flavor: D3.js

3.3 Declarative flavor: Vega.js / Vega-lite.js & Lyra

WHEN TO VISUALIZE DATA?

I		II		III		IV	
x	y	x	y	x	y	x	y
10.0	8.04	10.0	9.14	10.0	7.46	8.0	6.58
8.0	6.95	8.0	8.14	8.0	6.77	8.0	5.76
13.0	7.58	13.0	8.74	13.0	12.74	8.0	7.71
9.0	8.81	9.0	8.77	9.0	7.11	8.0	8.84
11.0	8.33	11.0	9.26	11.0	7.81	8.0	8.47
14.0	9.96	14.0	8.10	14.0	8.84	8.0	7.04
6.0	7.24	6.0	6.13	6.0	6.08	8.0	5.25
4.0	4.26	4.0	3.10	4.0	5.39	19.0	12.50
12.0	10.84	12.0	9.13	12.0	8.15	8.0	5.56
7.0	4.82	7.0	7.26	7.0	6.42	8.0	7.91
5.0	5.68	5.0	4.74	5.0	5.73	8.0	6.89

Mean(x) = 9.0

Mean(y) = 7.5

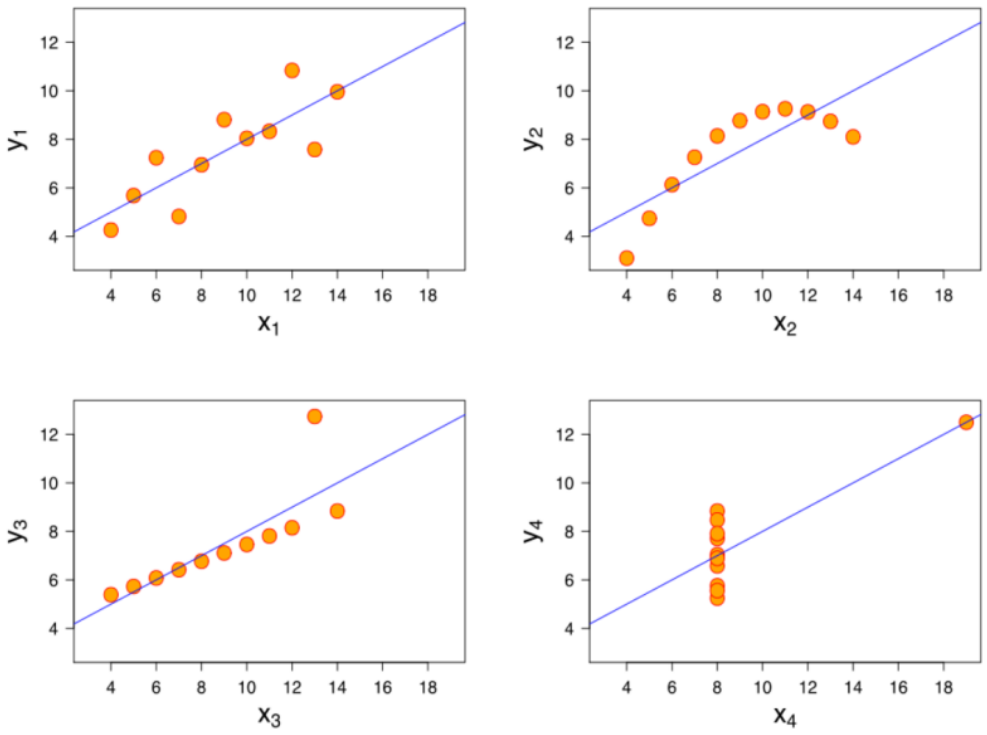
Variance(x) = 11.0

Variance(y) = 4.1

Correlation(x,y) = 0.816

Regression line:

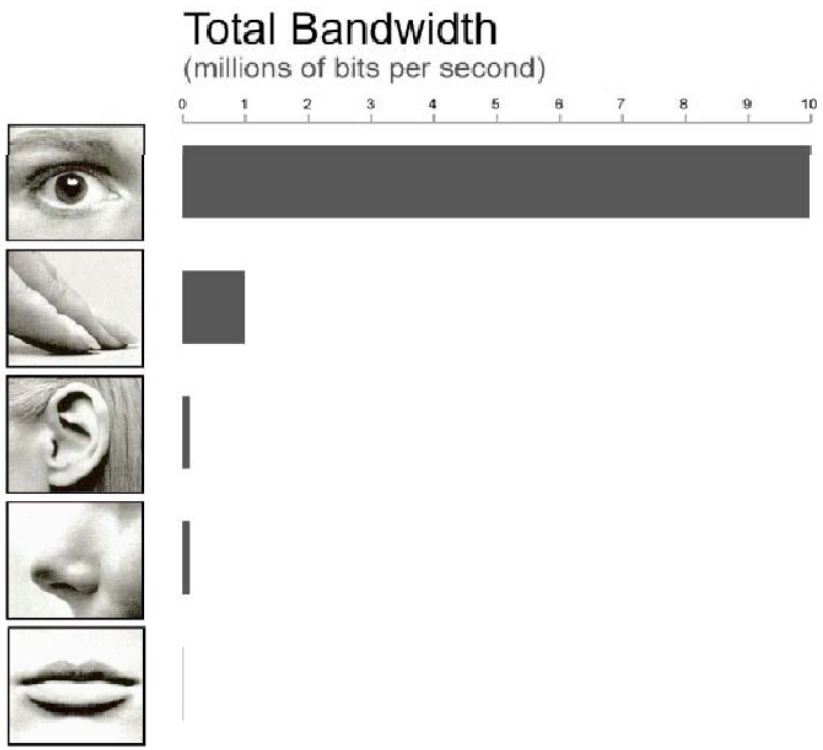
$y = 3.0 + 0.5x$



Source: [Anscombe 1973]

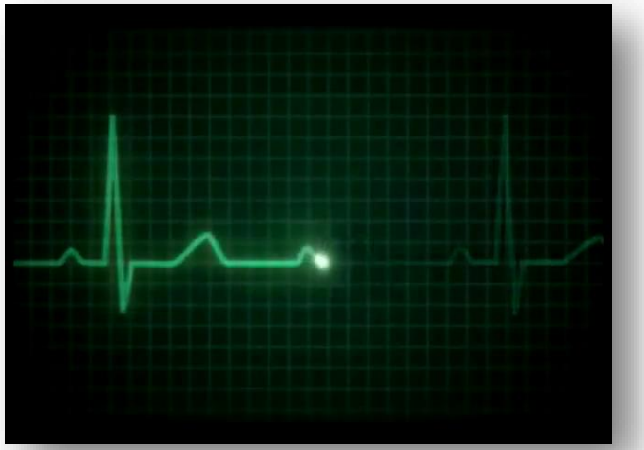
Image Source: Wikipedia

WHY TO *VISUALIZE* DATA?

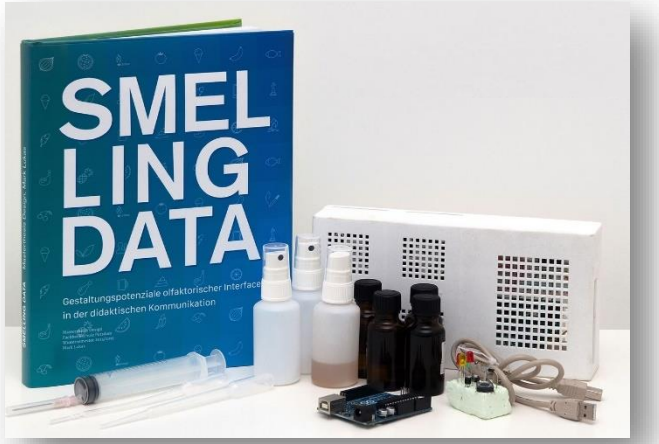


picture source: [Few 2006]

Haptic Displays – [Leithinger 2010]



Data Sonification



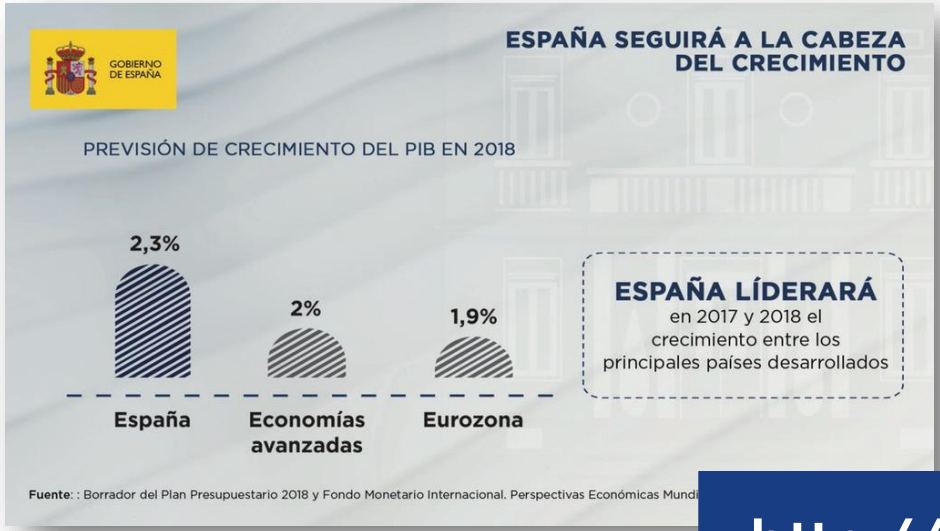
Olfactoric Interfaces – [Lukas 2015]

Edible Diagrams/Data Dishes – [Himmelspach 2015]

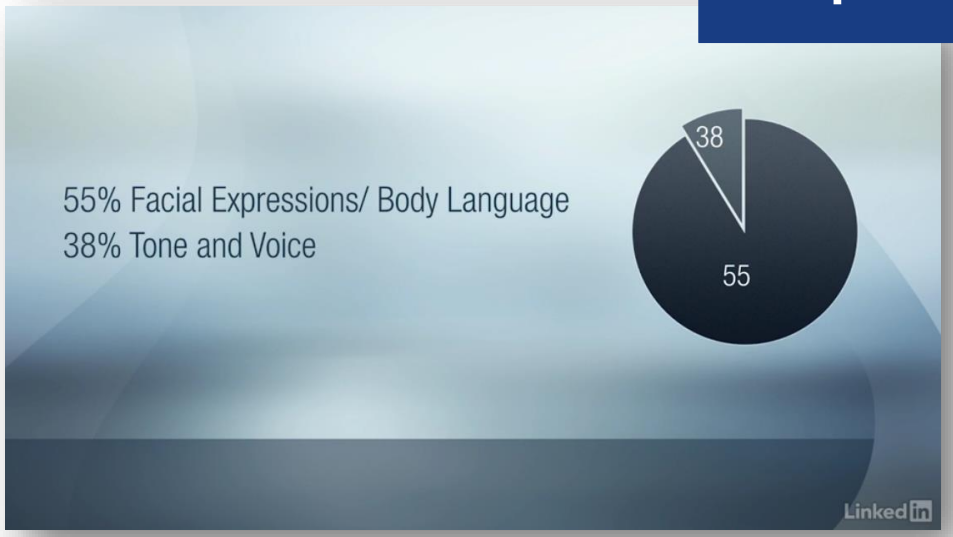
1. WHAT MAKES A GOOD VISUALIZATION?

Expressiveness: Show the data characteristics AND only the data characteristics!

Data ⟷ Graphics
matches



http://viz.wtf

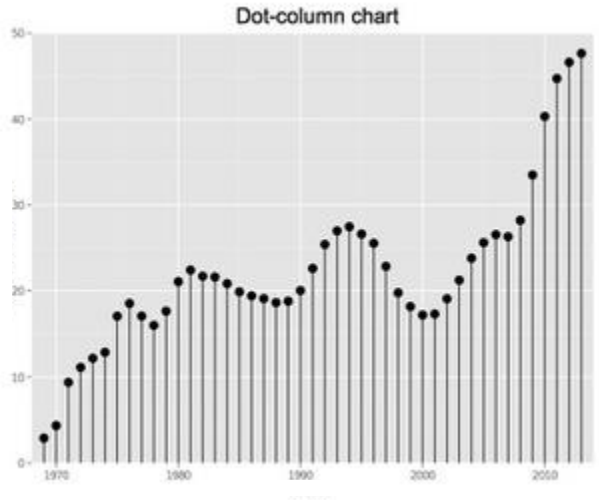


DATA TYPES

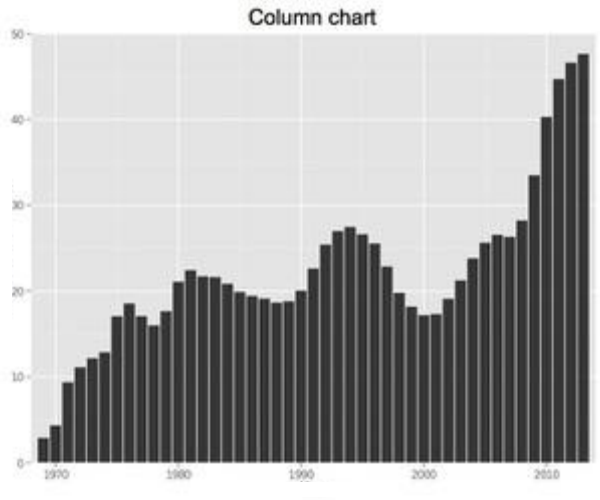
	Quantitative Data		Qualitative Data	
	Continuous Data	Discrete Data	Ordinal Data	Categorical Data
Interpolate	✓			
Difference	✓	✓		
Sort	✓	✓	✓	
Match	✓	✓	✓	✓

Adapted from [Stevens 1946] – DOI: 10.1126/science.103.2684.677

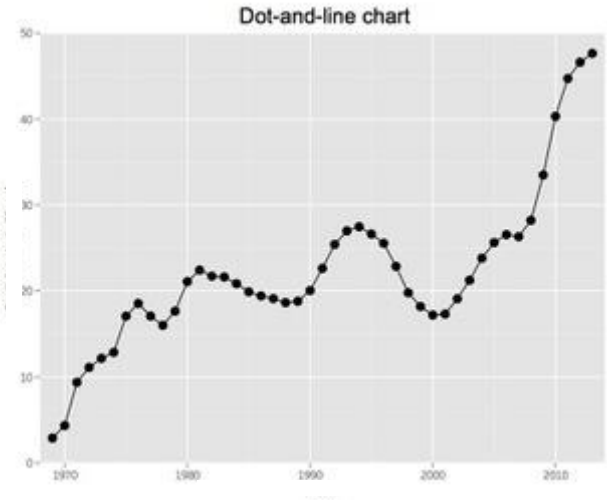
TEMPORAL DATA



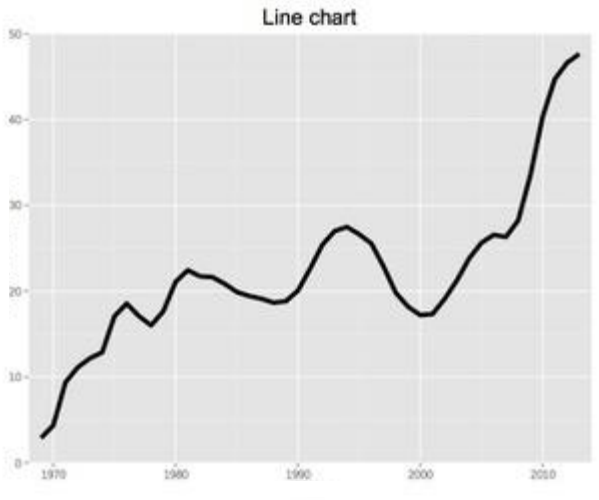
Time points



Time spans



Interpolated Time points

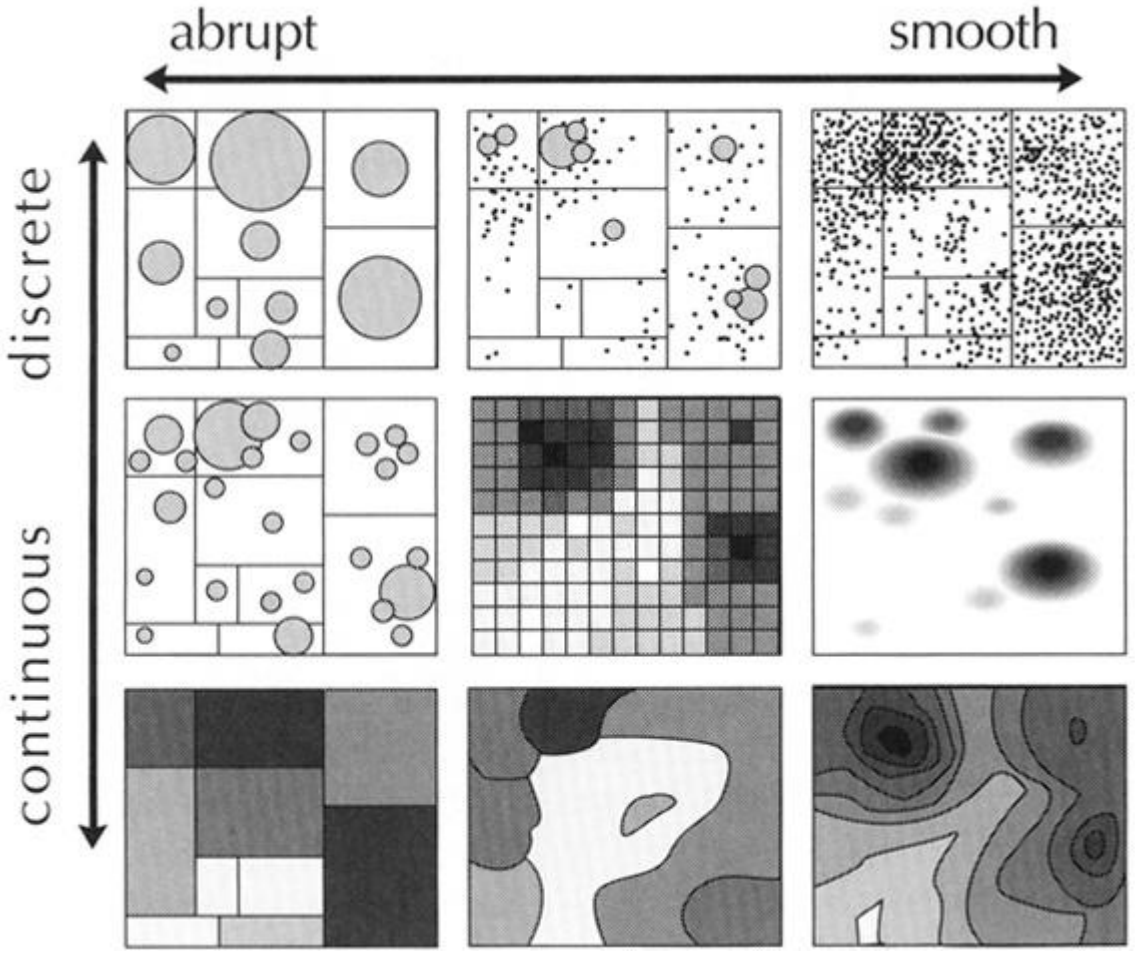


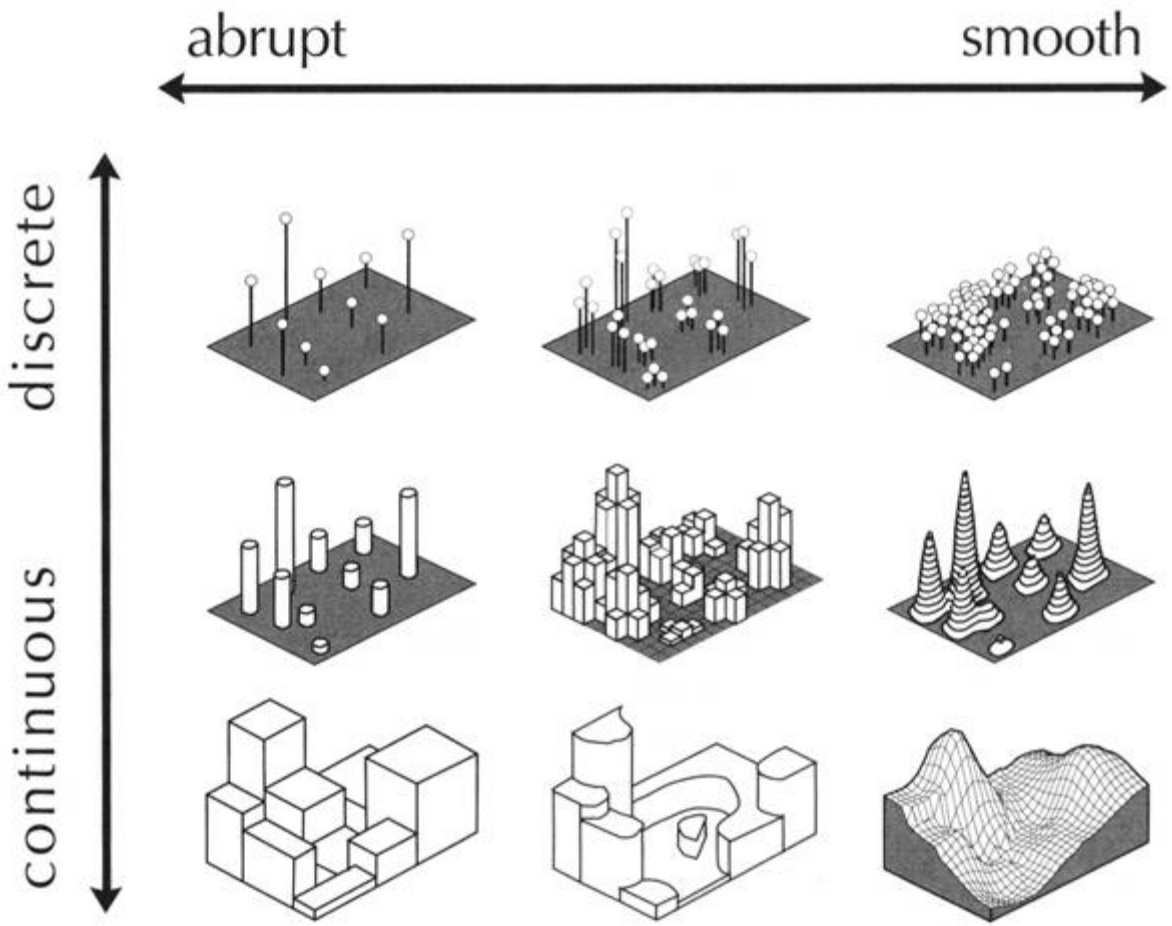
Continuous Time

Image source Peter Aldhous

SPATIAL DATA

Image source [MacEachren 1992]

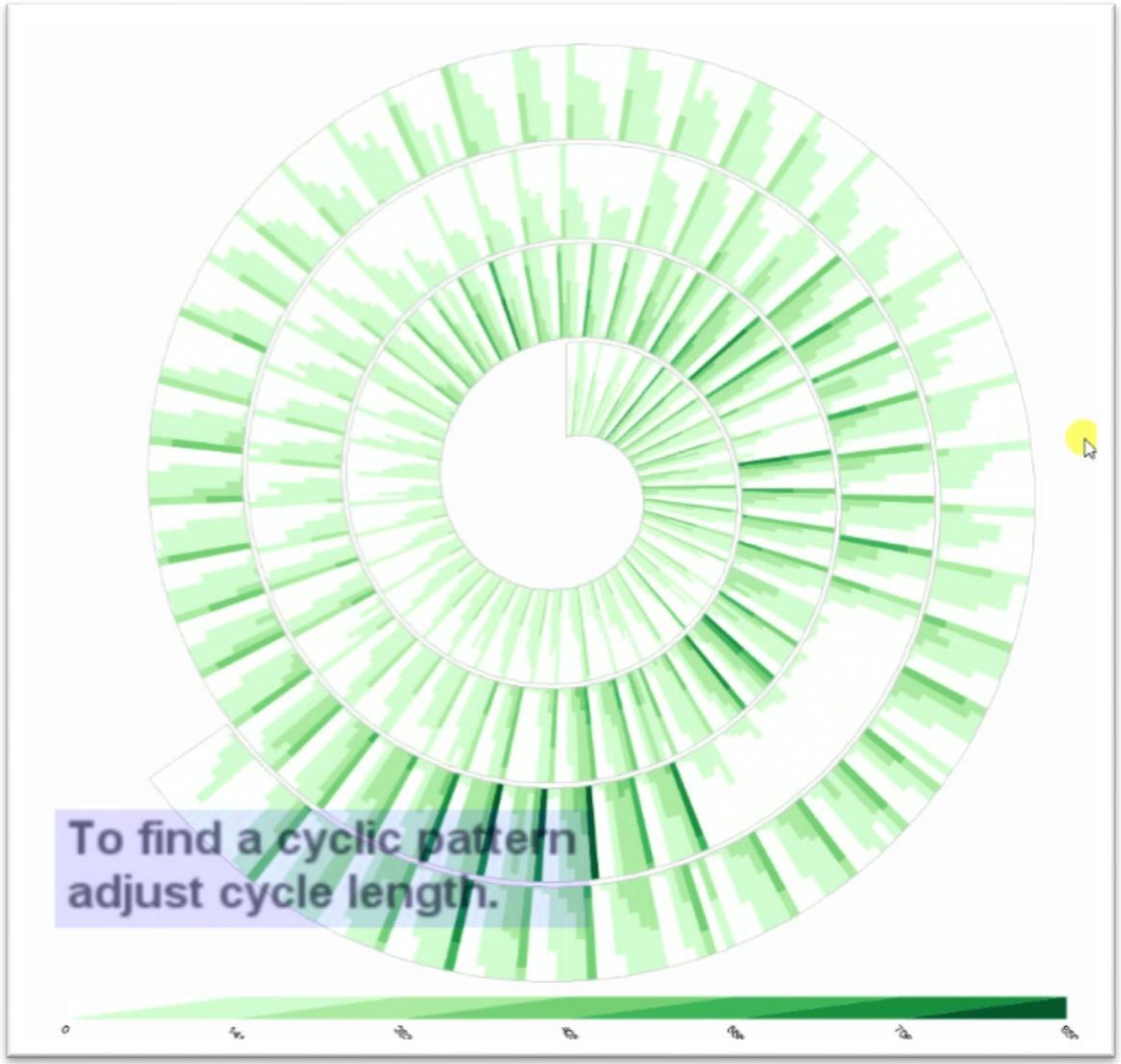




1. WHAT MAKES A GOOD VISUALIZATION?

Expressiveness: Show the data characteristics AND only the data characteristics!

Effectiveness: Choose a display that supports the intended visual task!



[Tominski & Schumann 2008]
Enhanced Interactive Spiral Display

1. WHAT MAKES A GOOD VISUALIZATION?

Common Abstract Visualization Tasks

Abstract Add Annotate Arrange Assign Associate Blend Bookmark
Browse Brush Calculate Categorize Change Characterize Clarify Classify
Clone Cluster **Compare** Compute Configure Connect Coordinate
Correlate Create Delete Delineate Derive Describe Determine Discover
Discuss Distinguish Edit Elaborate Encode Enjoy Establish Examine
Explore Extract Filter Find Generate Guide History Identify Infer
Inspect Learn Locate **Lookup** Manipulate Measure Merge Modify
Navigate Operate Organize Orient **Overview** Parse **Present** Query
Rank Recognize Reconfigure Record Redo Relate Relocate Remove
Restore Retrieve Reveal Revisit Scan Search Select Share Sort Specify
Split Summarize Transform Translate Undo Validate Visualize Zoom

1. WHAT MAKES A GOOD VISUALIZATION?

Expressiveness: Show the data characteristics AND only the data characteristics!

Effectiveness: Choose a display that supports the intended visual task!

Appropriateness: Match the graphic to the available resources! (runtime, memory, screen space,...)

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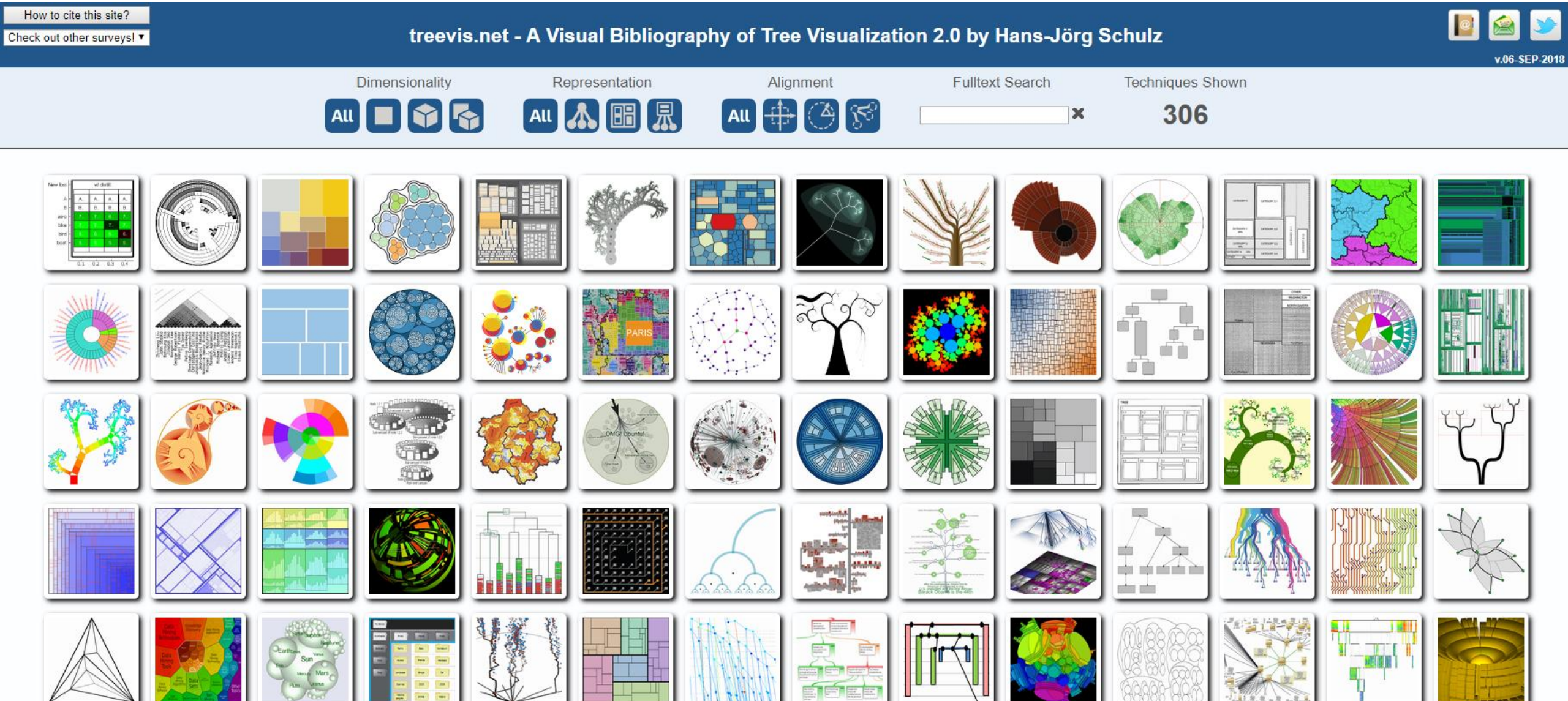
Visualization Problem

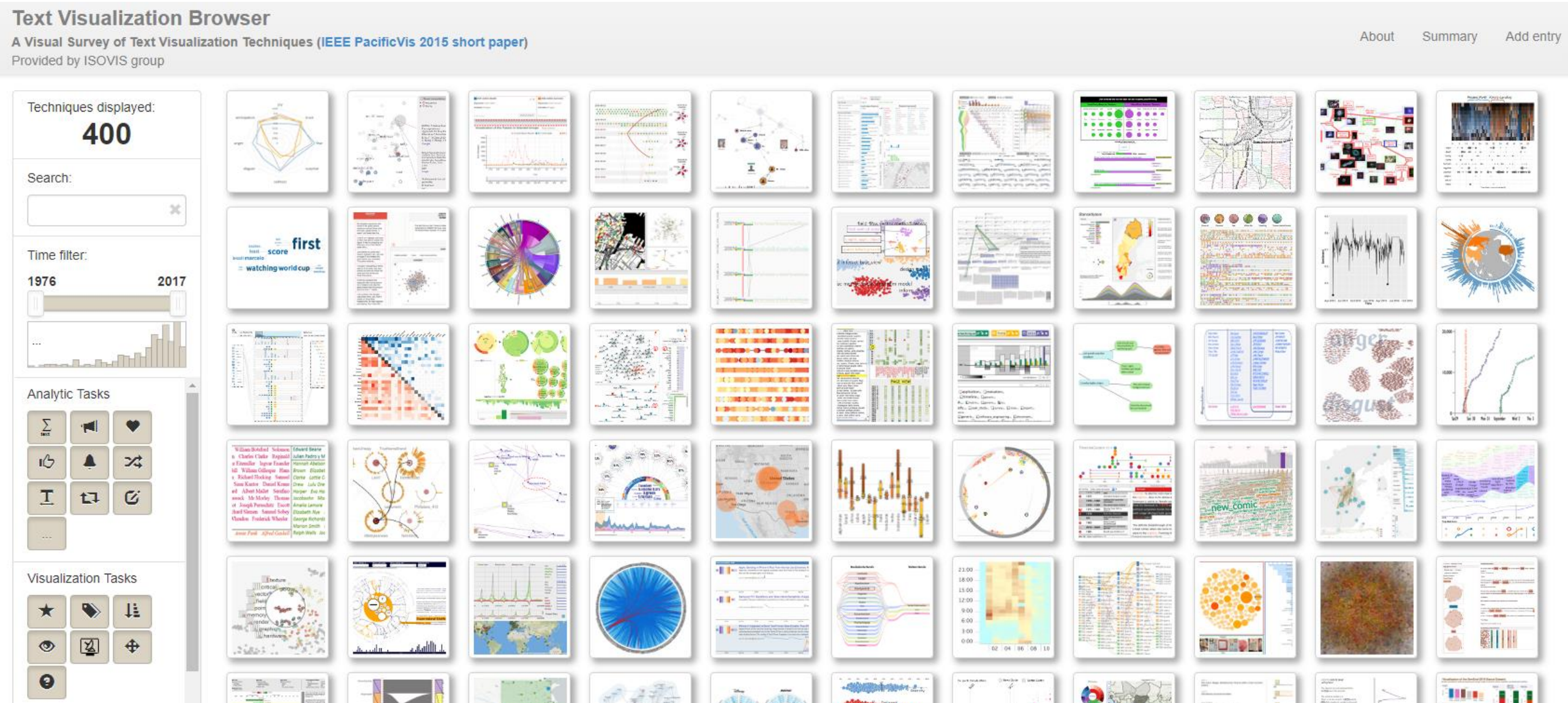
VISUALIZATION PROBLEM -> SOLUTION

http://treevis.net



VISUALIZATION PROBLEM -> SOLUTION

http://textvis.lnu.se

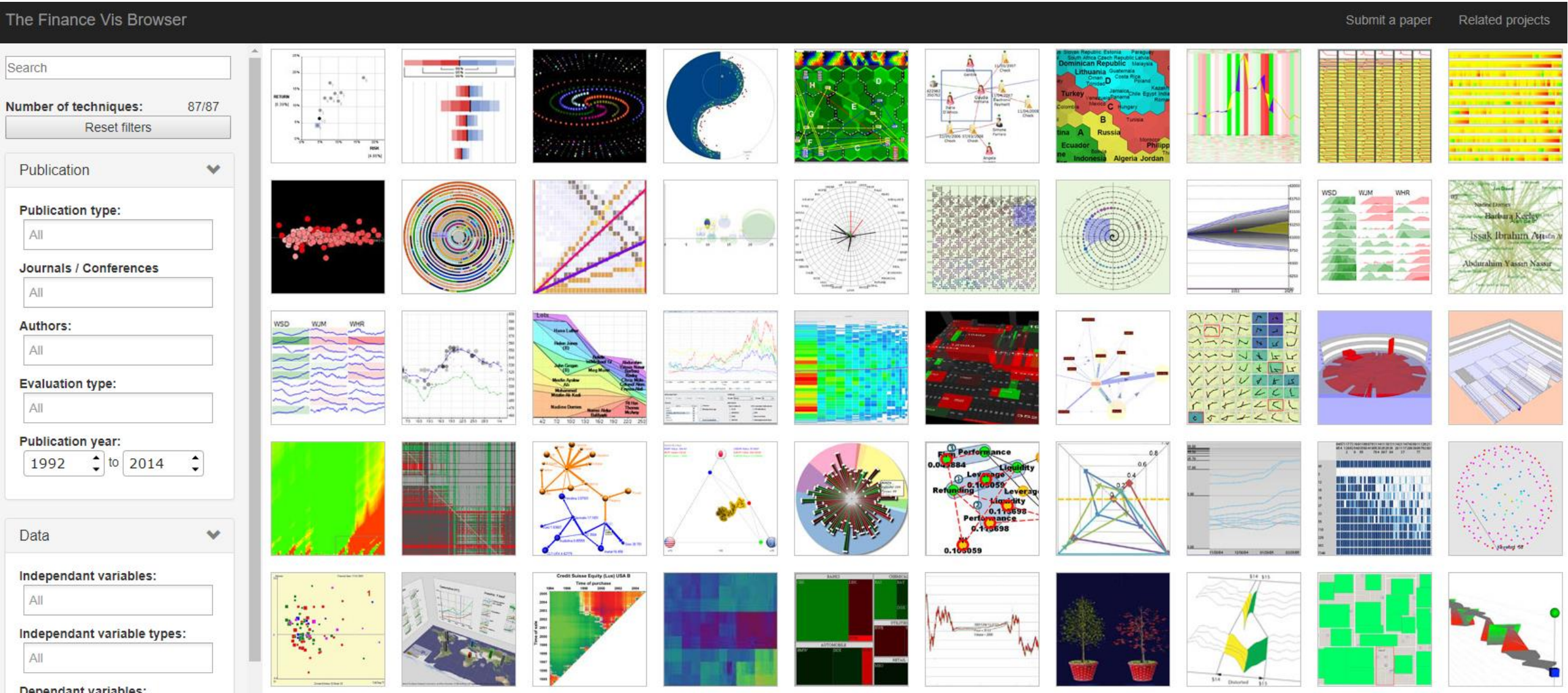


VISUALIZATION PROBLEM -> SOLUTION

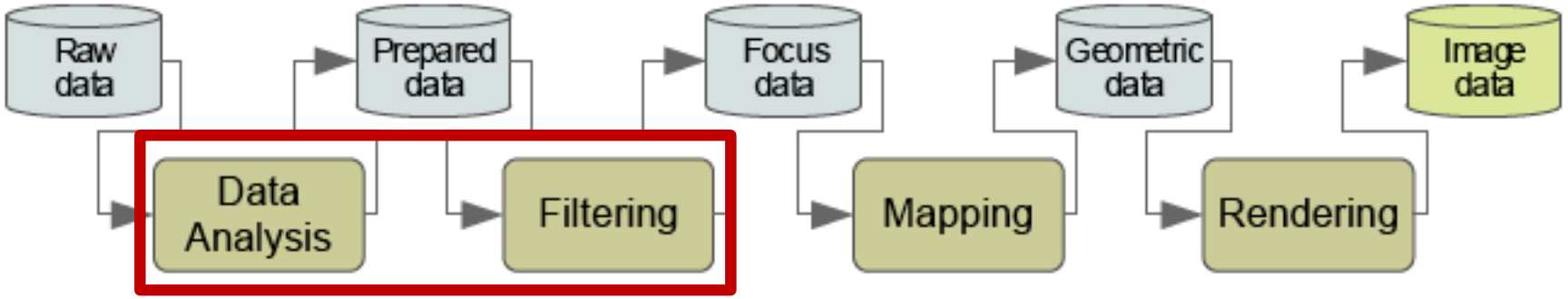
http://timeviz.net

VISUALIZATION PROBLEM -> SOLUTION

http://financevis.net



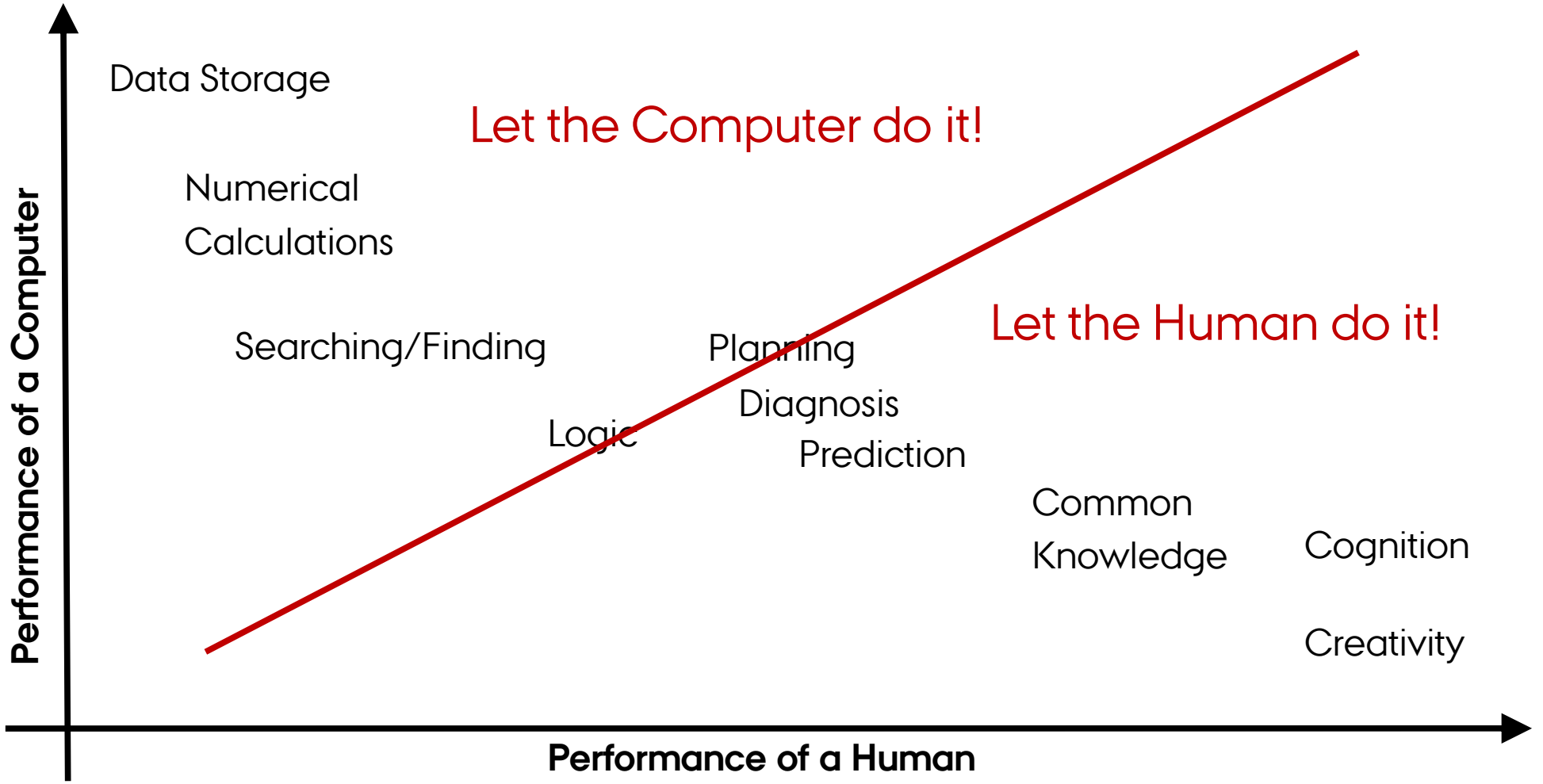
2. HOW DOES A VISUALIZATION WORK?



1. **Data Analysis:** data are prepared for visualization (e.g., by interpolating missing values, or correcting erroneous measurements)
2. **Filtering:** selection of data portions to be visualized
3. **Mapping:** focus data are mapped to geometric primitives (e.g., points, lines) and their attributes (e.g., color, position, size)
4. **Rendering:** geometric data are transformed to image data

Adapted from http://www.infovis-wiki.net

2.1 DATA PREPARATION



adapted from Daniel Keim, Uni. Konstanz

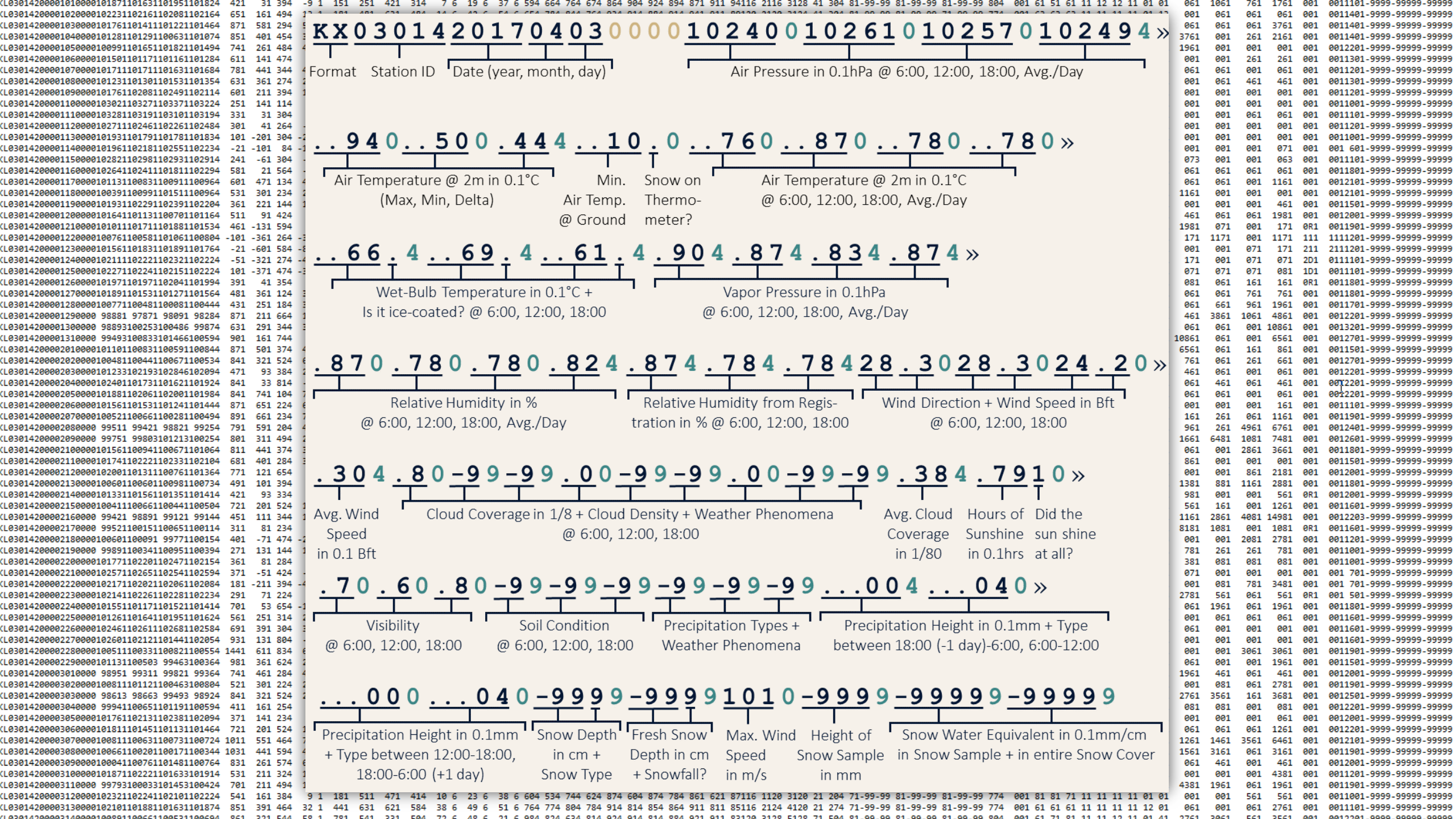
2.1 DATA PREPARATION

Preprocessing:

- Plausibility & Consistency Checks
- Data Imputation & Deduplication
- Clustering & Classification
- Dimensionality Reduction

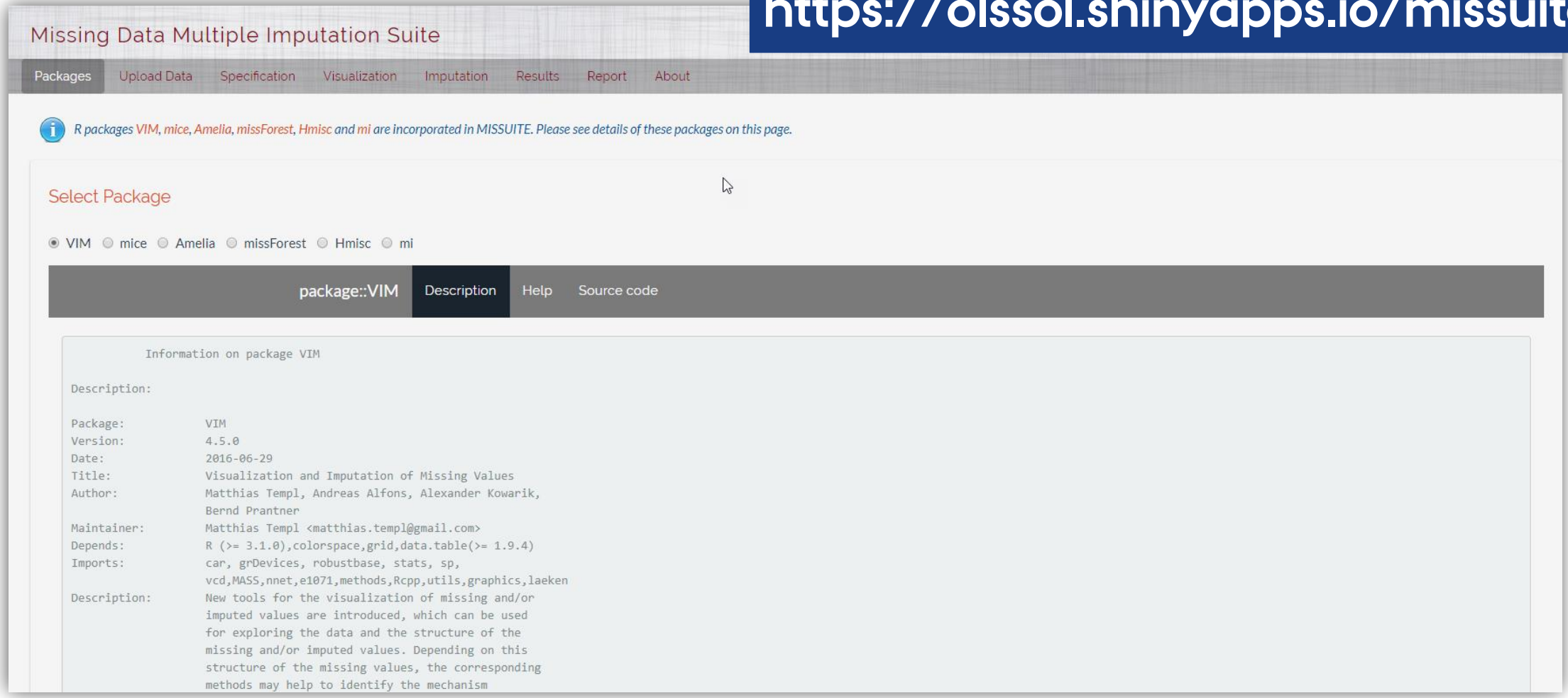
Filtering:

- Selection of Data Realm (e.g., Twitter Accounts from Denmark)
- Selection of Focus Data (e.g., my own Twitter Account)
- Selection of Context Data (e.g., only the Top-100 among my followers)


KX03014201704030000102400102610102570102494 »
Format
Station ID
Date (year, month, day)
Air Pressure in 0.1hPa @ 6:00, 12:00, 18:00, Avg./Day
..940..500.444..10.0..760..870..780..780 »
Air Temperature @ 2m in 0.1°C (Max, Min, Delta)
Min. Air Temp. @ Ground
Snow on Thermo-meter?
Air Temperature @ 2m in 0.1°C @ 6:00, 12:00, 18:00, Avg./Day
..66.4..69.4..61.4.904.874.834.874 »
Wet-Bulb Temperature in 0.1°C + Is it ice-coated? @ 6:00, 12:00, 18:00
Vapor Pressure in 0.1hPa @ 6:00, 12:00, 18:00, Avg./Day
.870.780.780.824.874.784.78428.3028.3024.20 »
Relative Humidity in % @ 6:00, 12:00, 18:00, Avg./Day
Relative Humidity from Regis-tration in % @ 6:00, 12:00, 18:00
Wind Direction + Wind Speed in Bft @ 6:00, 12:00, 18:00
.304.80-99-99.00-99-99.00-99-99.384.7910 »
Avg. Wind Speed in 0.1 Bft
Cloud Coverage in 1/8 + Cloud Density + Weather Phenomena @ 6:00, 12:00, 18:00
Avg. Cloud Coverage in 1/80
Hours of Sunshine in 0.1hrs
Did the sun shine at all?
.70.60.80-99-99-99-99-99-99...004...040 »
Visibility @ 6:00, 12:00, 18:00
Soil Condition @ 6:00, 12:00, 18:00
Precipitation Types + Weather Phenomena
Precipitation Height in 0.1mm + Type between 18:00 (-1 day)-6:00, 6:00-12:00
...000...040-9999-99991010-9999-99999-99999
Precipitation Height in 0.1mm + Type between 12:00-18:00, 18:00-6:00 (+1 day)
Snow Depth in cm + Snow Type
Fresh Snow Depth in cm + Snowfall?
Max. Wind Speed in m/s
Height of Snow Sample in mm
Snow Water Equivalent in 0.1mm/cm in Snow Sample + in entire Snow Cover

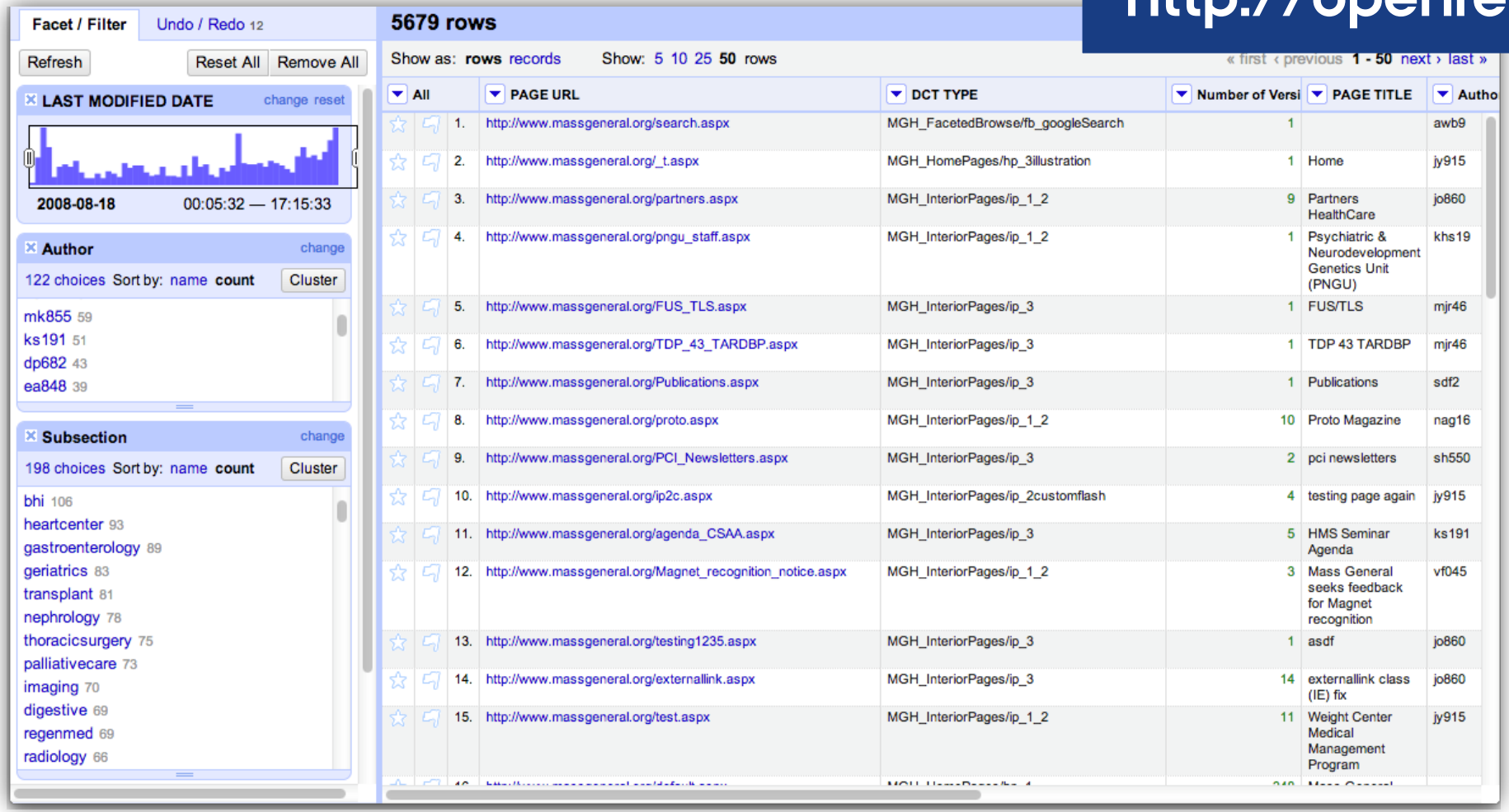
DATA IMPUTATION

https://olssol.shinyapps.io/missuite/



DATA DEDUPLICATION

http://openrefine.org



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	3.	http://www.massgeneral.org/partners.aspx	MGH_InteriorPages/ip_1_2	9	Partners HealthCare	jo860
	4.	http://www.massgeneral.org/pngu_staff.aspx	MGH_InteriorPages/ip_1_2	1	Psychiatric & Neurodevelopment Genetics Unit (PNGU)	khs19
	5.	http://www.massgeneral.org/FUS_TLS.aspx	MGH_InteriorPages/ip_3	1	FUS/TLS	mjr46
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	7.	http://www.massgeneral.org/Publications.aspx	MGH_InteriorPages/ip_3	1	Publications	sdf2
	8.	http://www.massgeneral.org/proto.aspx	MGH_InteriorPages/ip_1_2	10	Proto Magazine	nag16
	9.	http://www.massgeneral.org/PCI_Newsletters.aspx	MGH_InteriorPages/ip_3	2	pci newsletters	sh550
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	11.	http://www.massgeneral.org/agenda_CSAA.aspx	MGH_InteriorPages/ip_3	5	HMS Seminar Agenda	ks191
	12.	http://www.massgeneral.org/Magnet_recognition_notice.aspx	MGH_InteriorPages/ip_1_2	3	Mass General seeks feedback for Magnet recognition	vf045
	13.	http://www.massgeneral.org/testing1235.aspx	MGH_InteriorPages/ip_3	1	asdf	jo860
	14.	http://www.massgeneral.org/externallink.aspx	MGH_InteriorPages/ip_3	14	externallink class (IE) fix	jo860
	15.	http://www.massgeneral.org/test.aspx	MGH_InteriorPages/ip_1_2	11	Weight Center Medical Management Program	jy915

2.1 DATA PREPARATION

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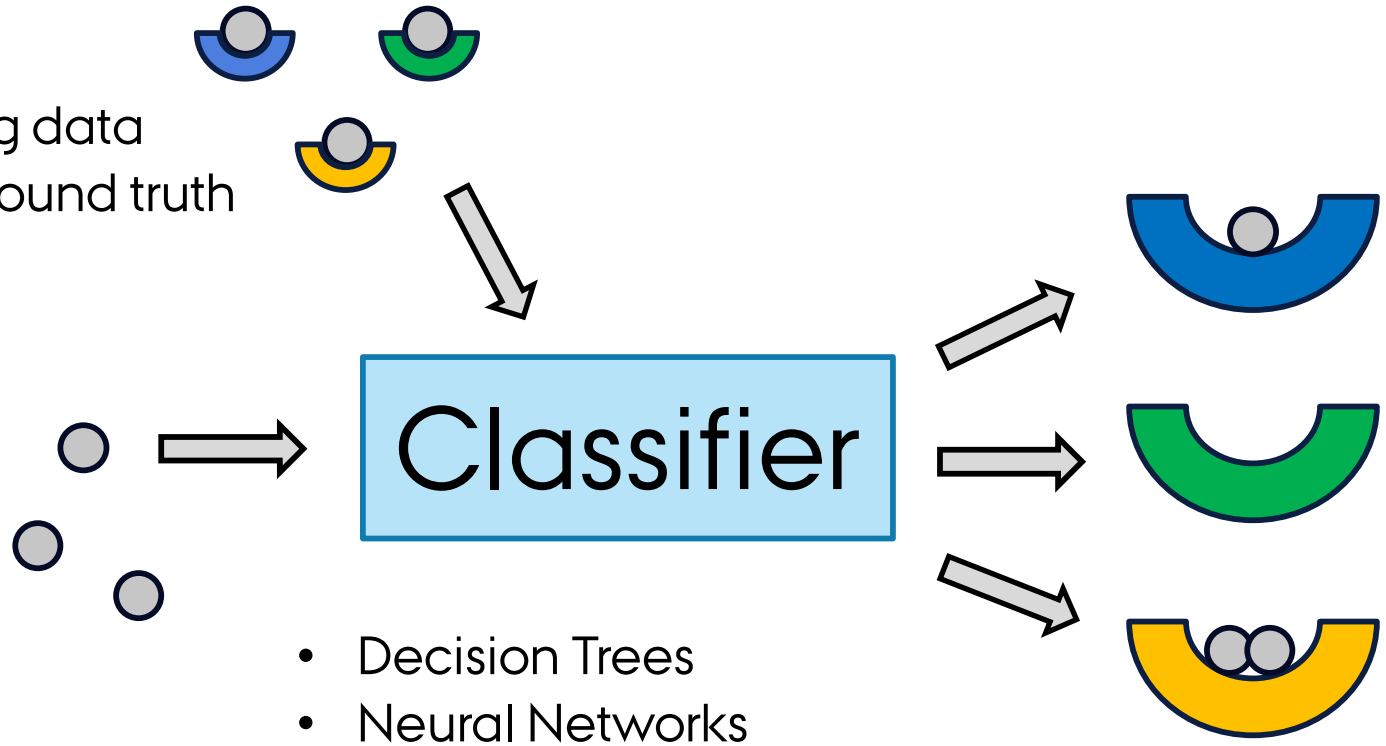
CLASSIFICATION – SUPERVISED LEARNING

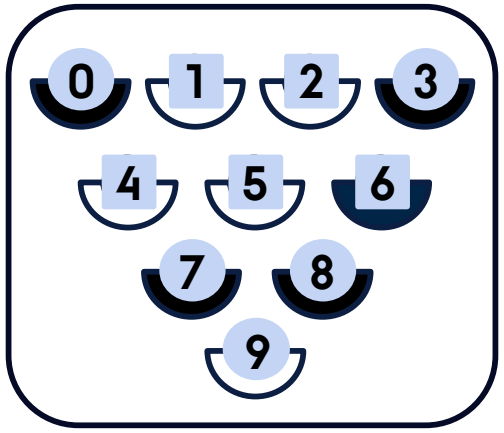


- Decision Trees
- Neural Networks
- Support Vector Machines
- Kernel Density Estimation
- ...

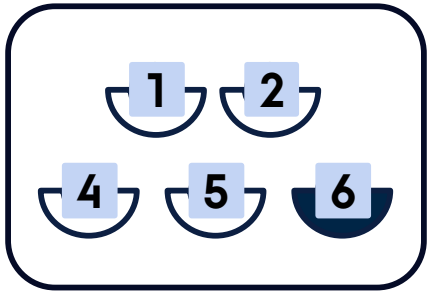
DECISION TREE EXAMPLE

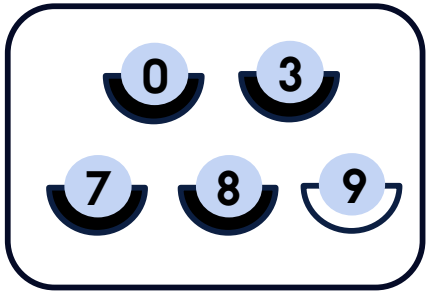
Entropy: $-\sum_i p_i \log p_i$

H=1.0



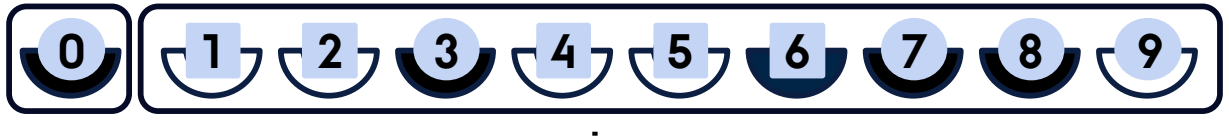
shape





H=-(5/10)(⅘log$_2$⅘ + ⅕log$_2$⅕) -(5/10)(⅕log$_2$⅕ + ⅘log$_2$⅘) = 0.72

value

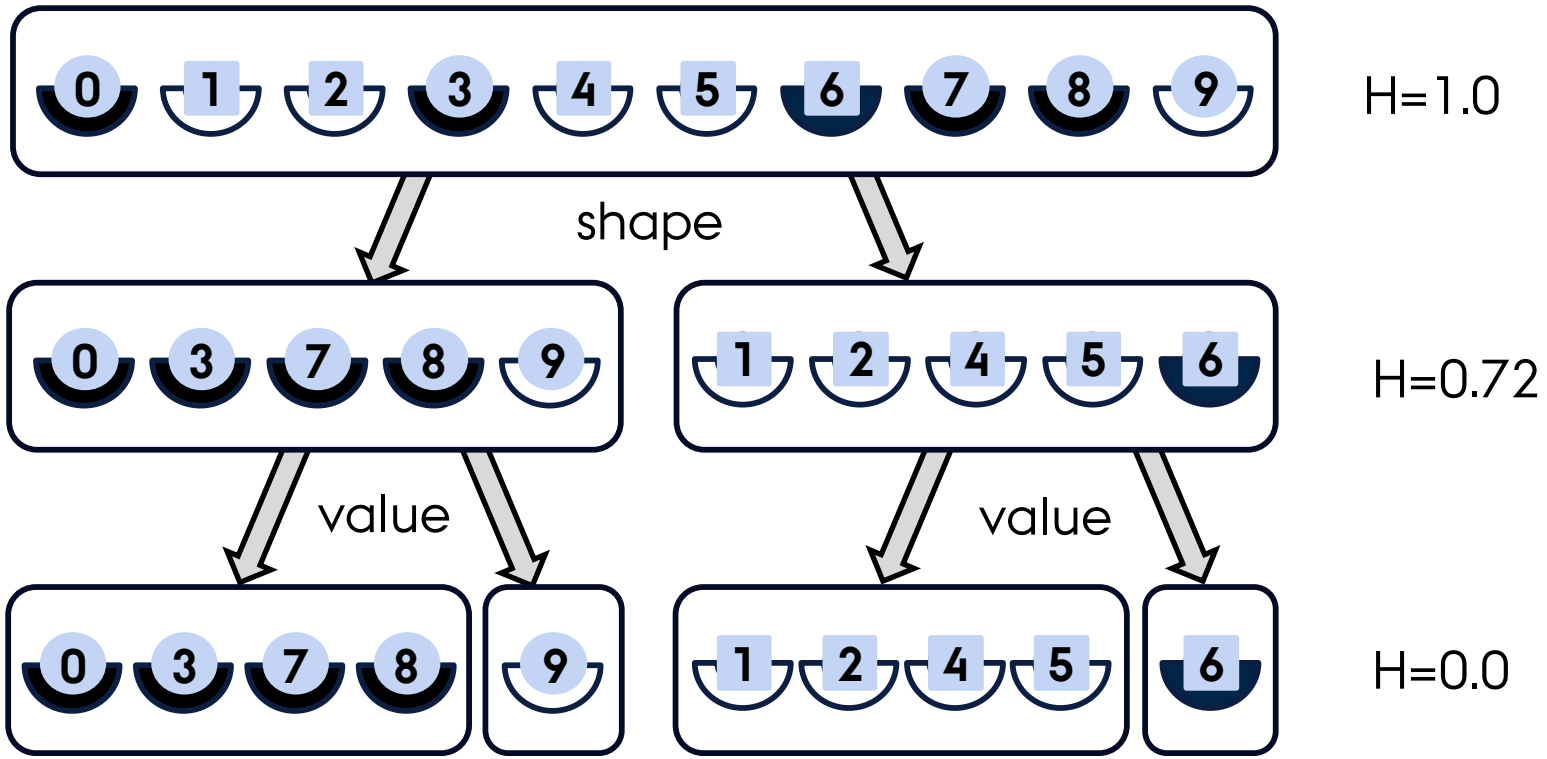


H=0.99

H=0.97

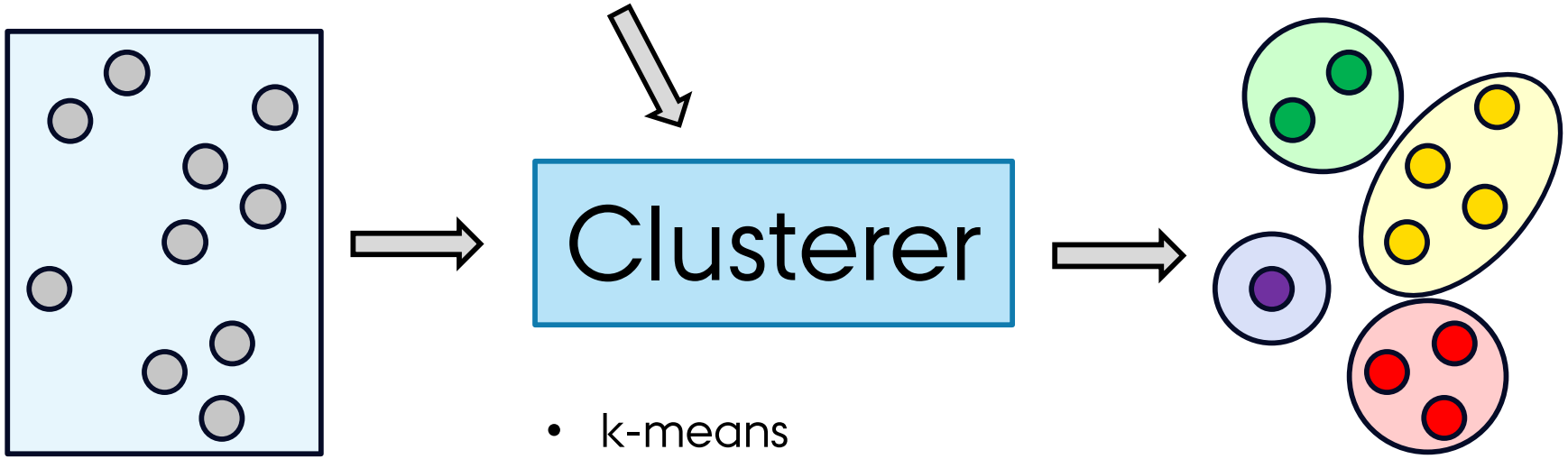
H=0.99

DECISION TREE EXAMPLE



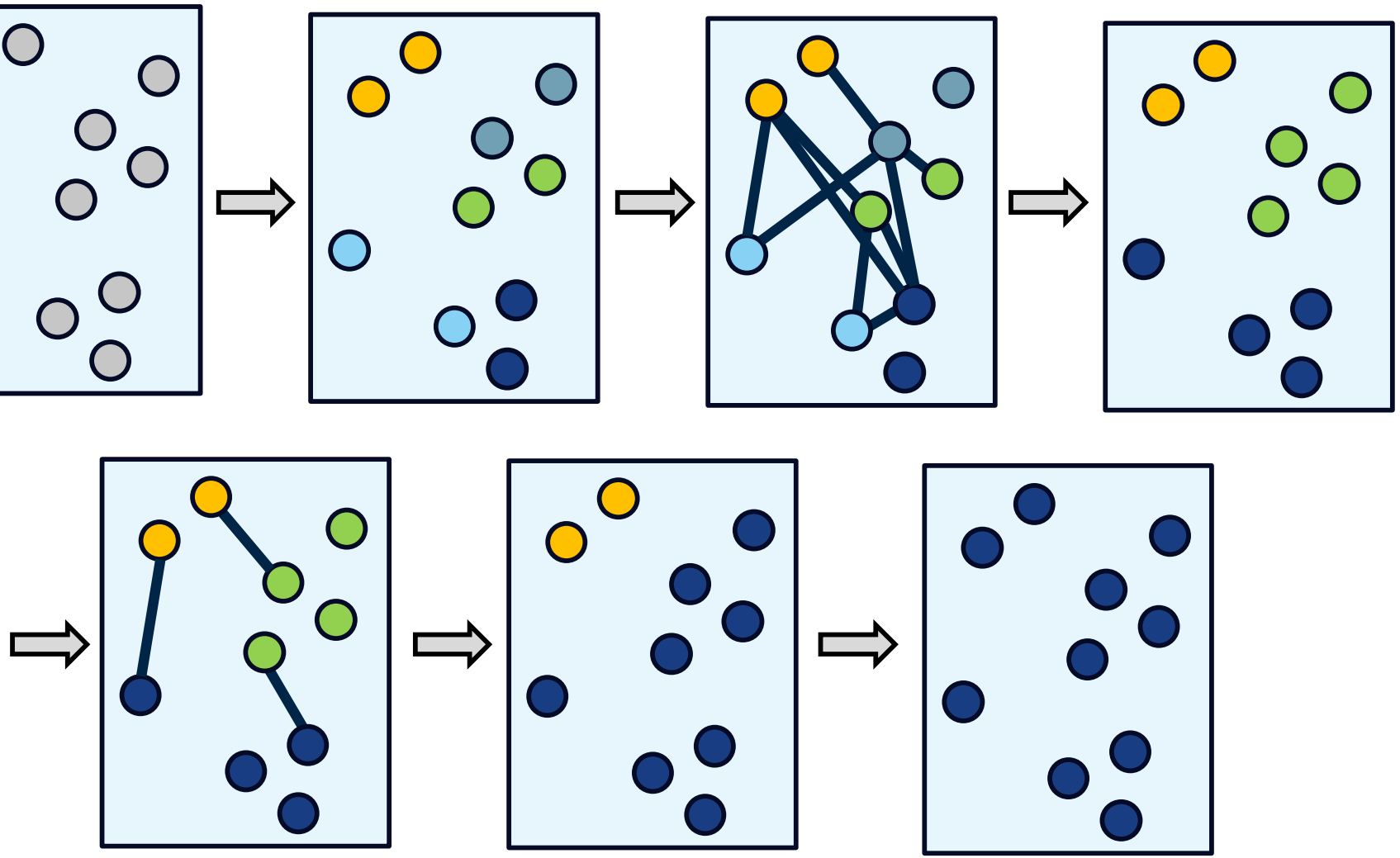
CLUSTERING – UNSUPERVISED LEARNING

Similarity metric / matrix

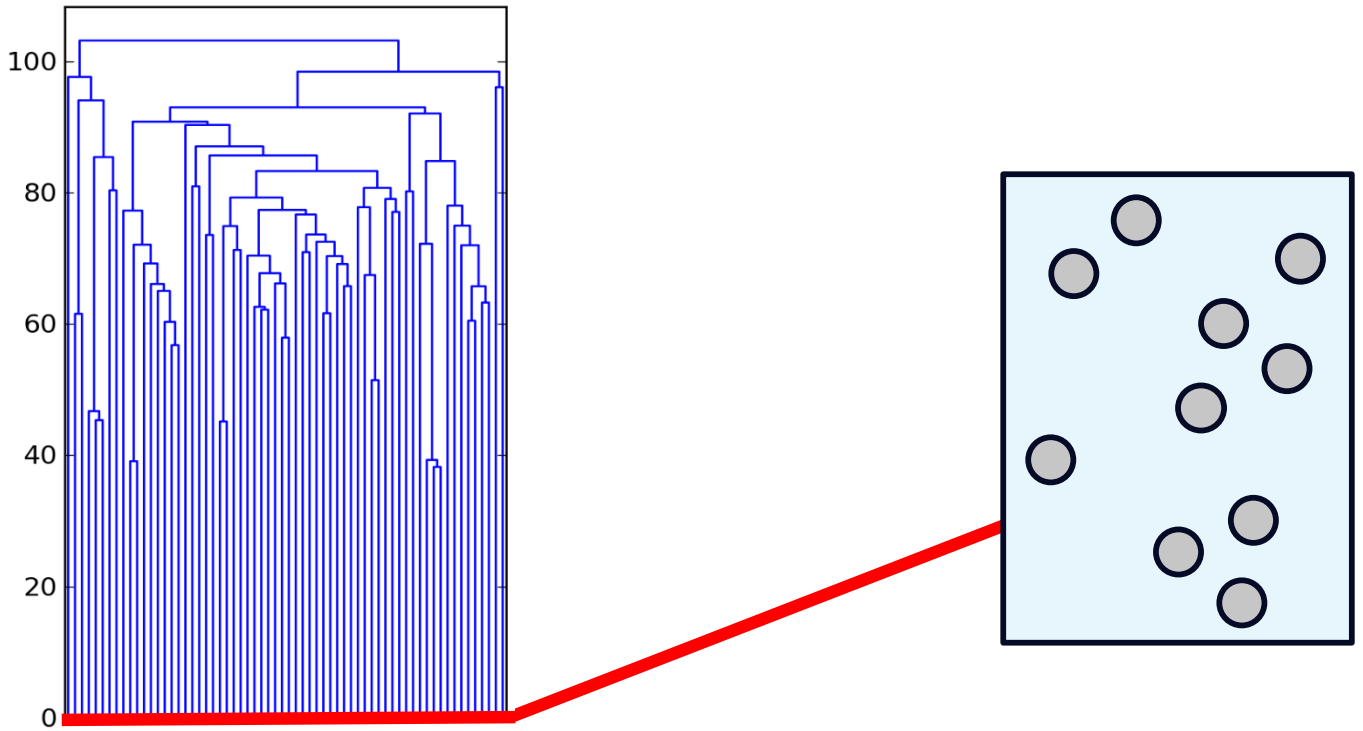


- k-means
- DBSCAN
- Hierarchical Clustering
- Spectral Clustering
- ...

HIERARCHICAL CLUSTERING

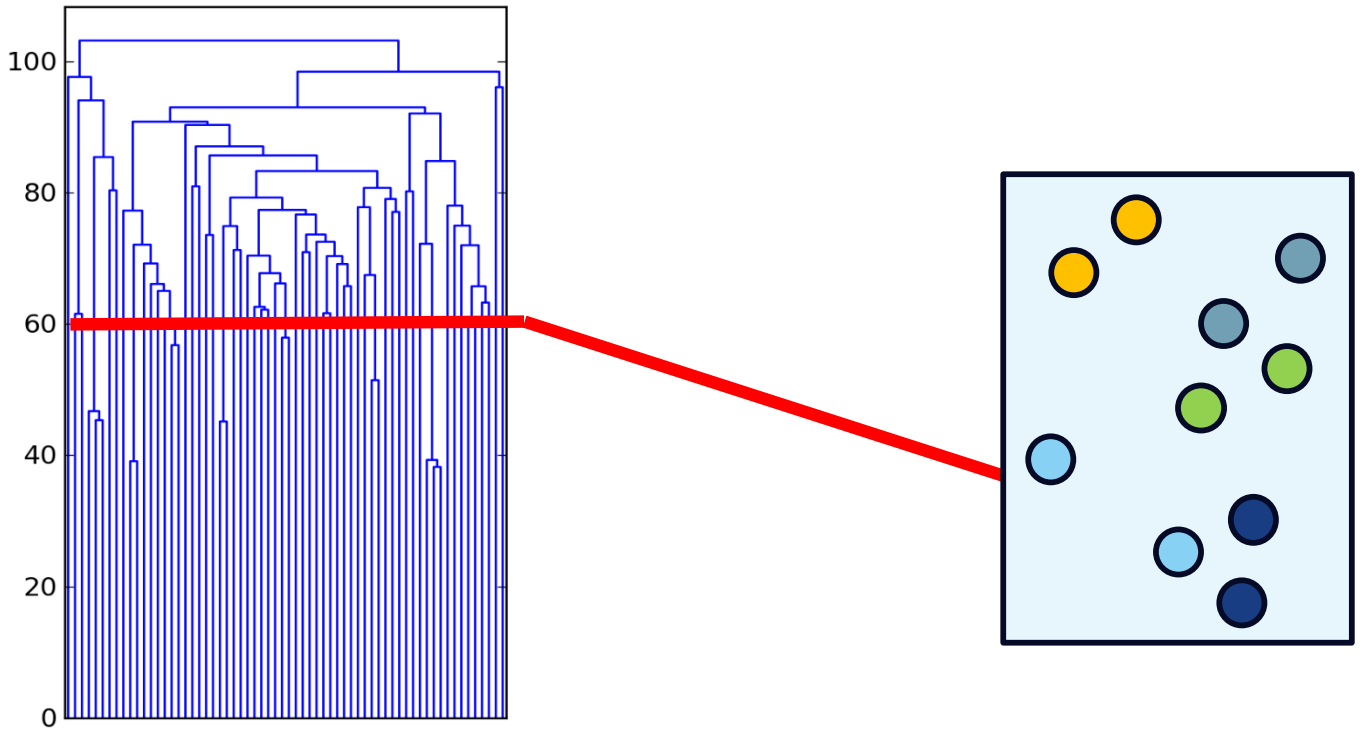


INTERACTIVE THRESHOLDING



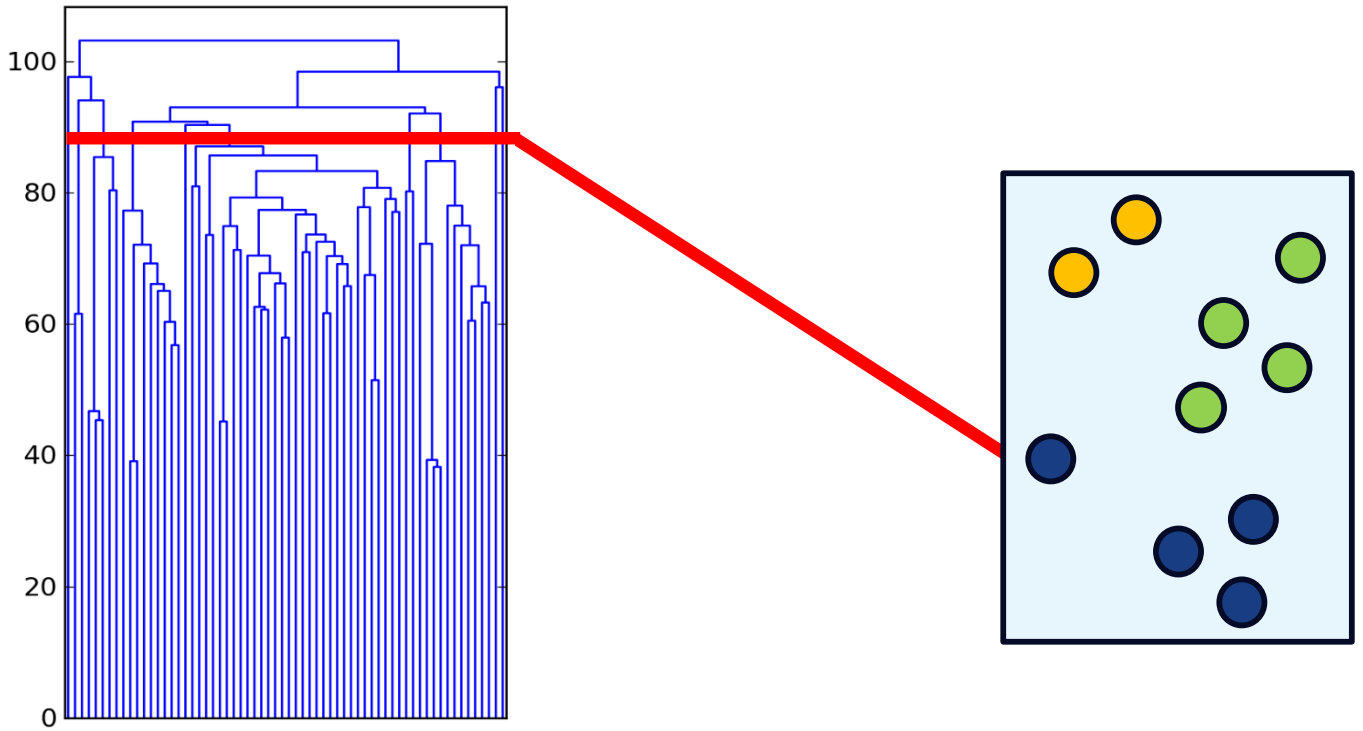
Dendrogram

INTERACTIVE THRESHOLDING



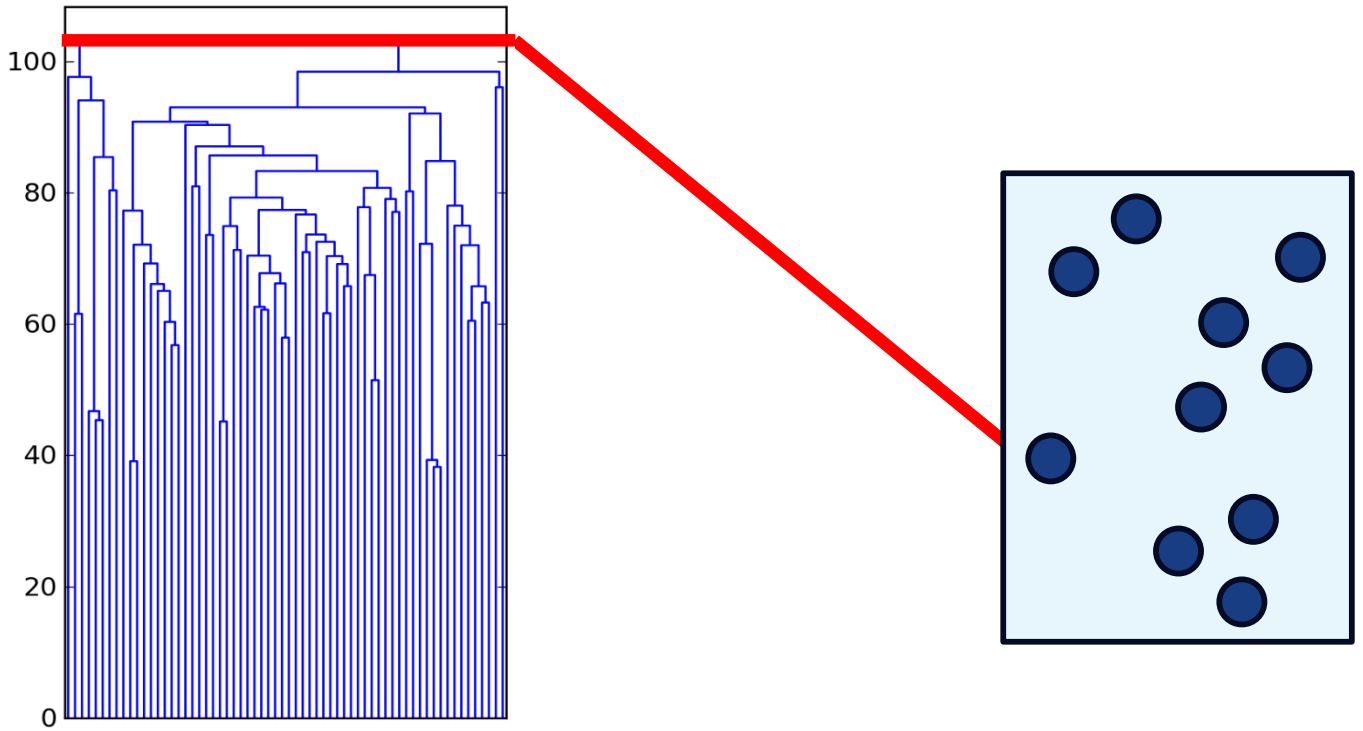
Dendrogram

INTERACTIVE THRESHOLDING

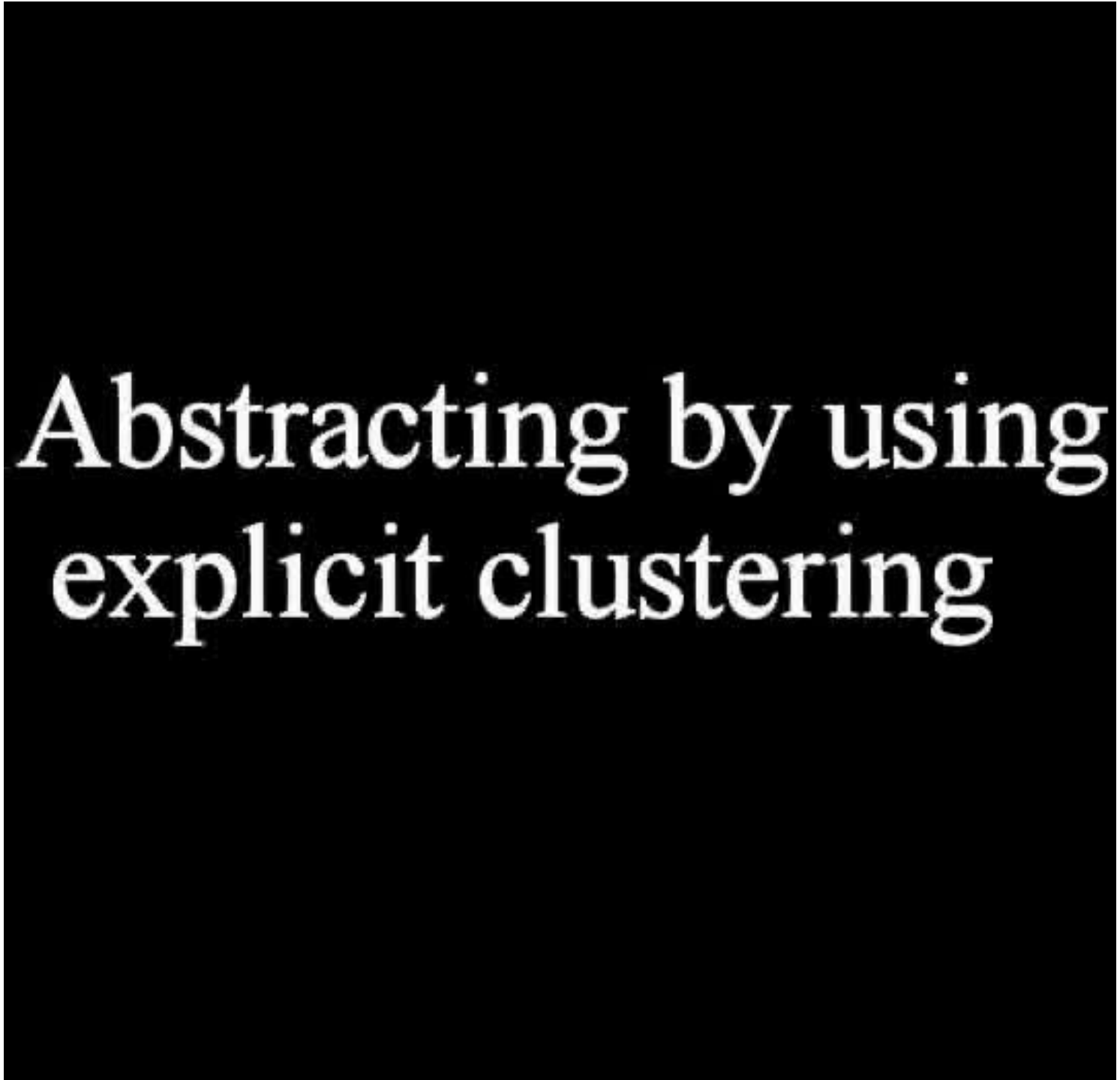


Dendrogram

INTERACTIVE THRESHOLDING



Dendrogram



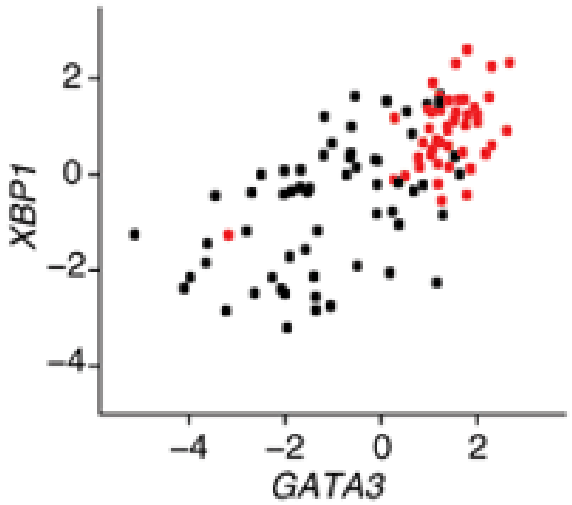
Source: v.Ham & Wijk 2004

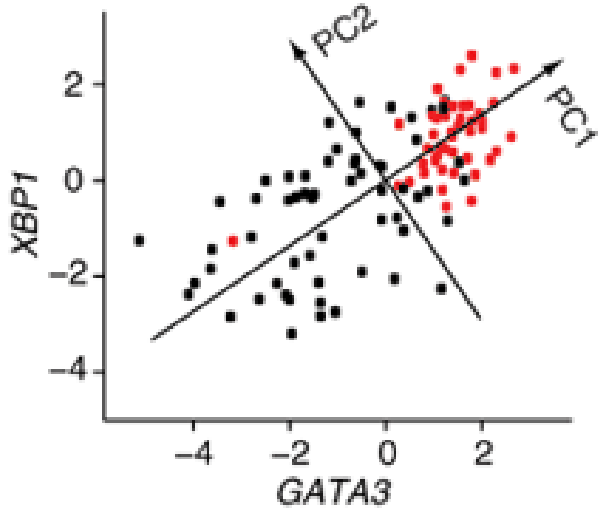
- Graph Visualization -

Source: Spindler et al. 2010

DIMENSIONALITY REDUCTION

Projecting HighD space onto LowD space through coordinate transformation along the directions of largest data spread





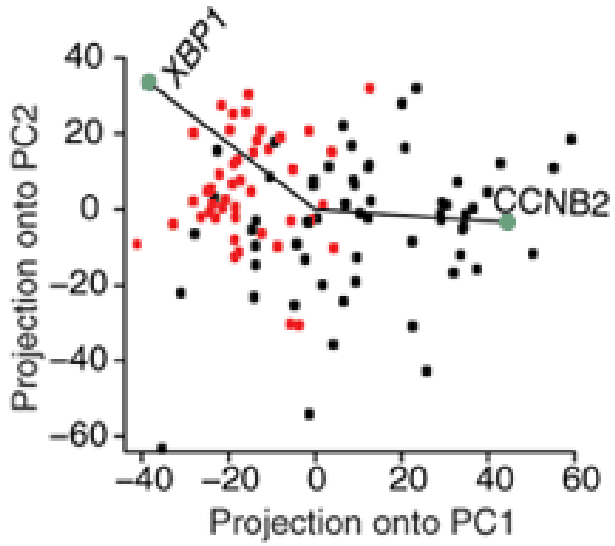


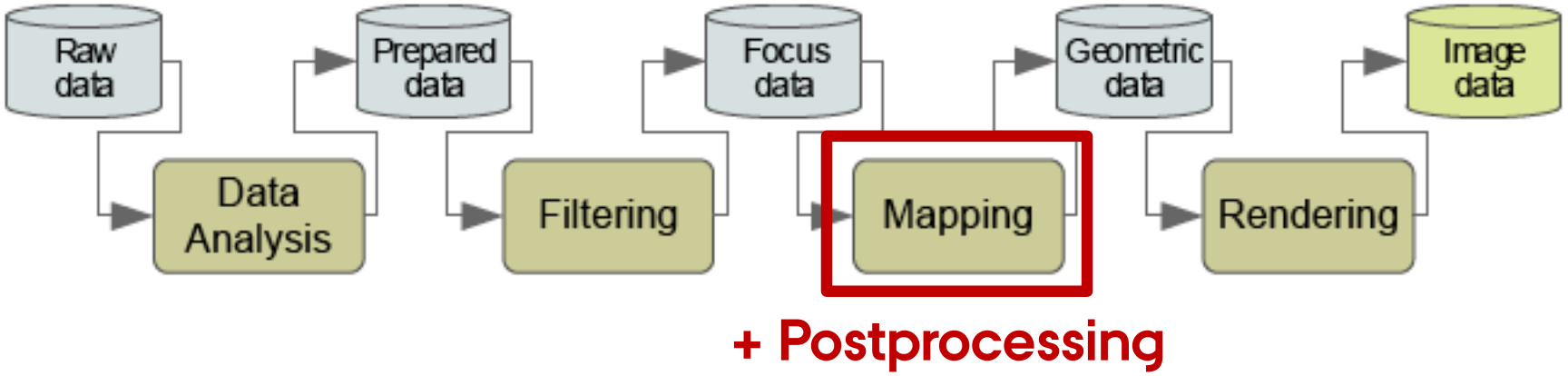
Image source [Ringnér 2008]

Common approaches:

- Principal Component Analysis (PCA)
- Multidimensional Scaling (MDS)

Disadvantage! Projection can be hard to read, as axes are meaningless...

2.1 DATA PREPARATION



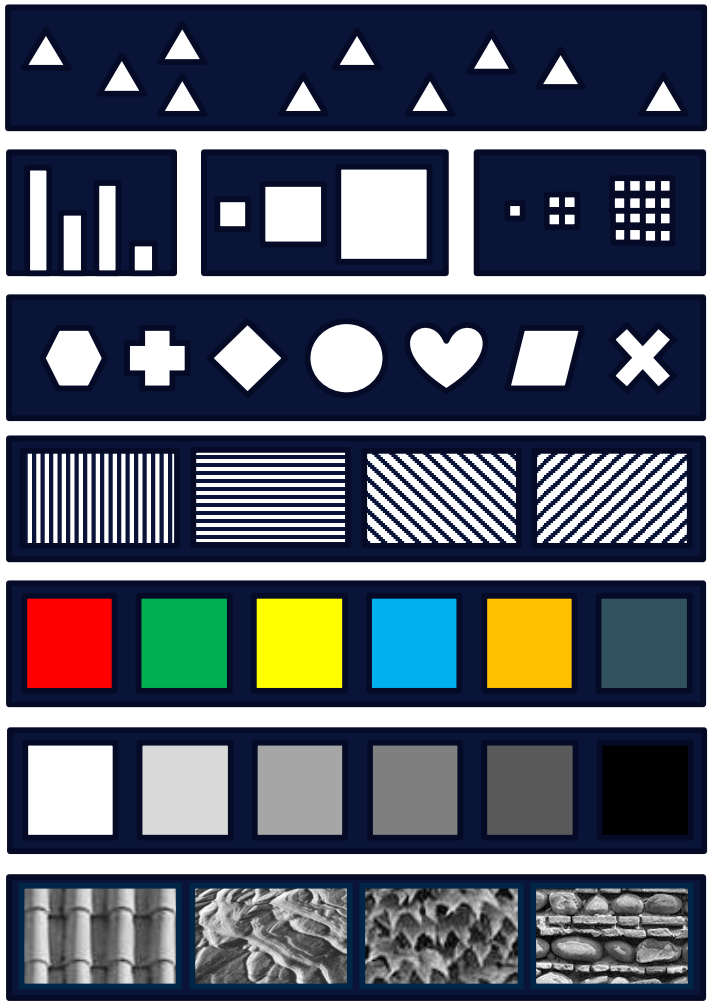
Filtering:

- Selection of Data Realm (e.g., Twitter Accounts from Denmark)
- Selection of Focus Data (e.g., my own Twitter Account)
- Selection of Context Data (e.g., only the Top-100 among my followers)

VISUAL VARIABLES

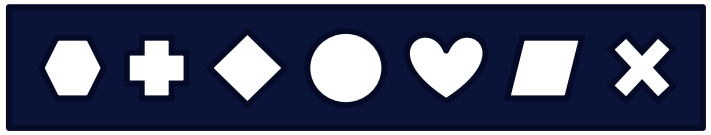
(adapted from S.Carpendale)

- **Position:** change in location
- **Size:** change in length, area, repetition
- **Shape:** change to the outer form
- **Orientation:** change in alignment
- **Color Hue:** change in hue at a given value
- **Color Saturation:** change from light to dark
- **Texture:** change in pattern



EXPRESSIVE DATA MAPPING

categorical data:



ordinal data:

discrete data:

continuous data:

EFFECTIVE DATA MAPPING

Categorical

Discrete / Continuous

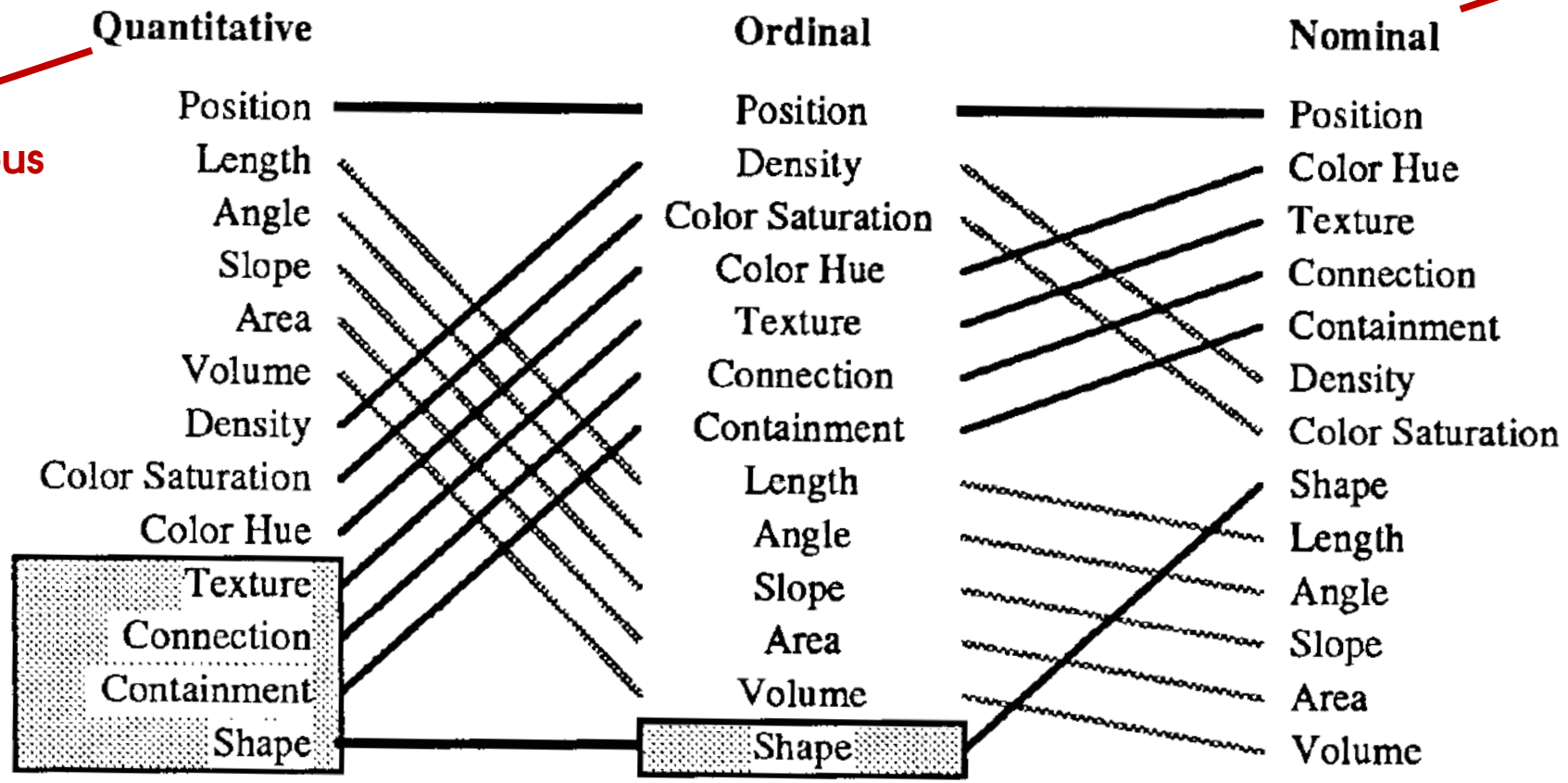


Fig. 15. Ranking of perceptual tasks. The tasks shown in the gray boxes are not relevant to these types of data.

[Mackinlay 1986]

DOI: 10.1145/22949.22950

CAREFUL WITH THE COLORS!

Not all color scales are created ~~equal~~ equidistant!

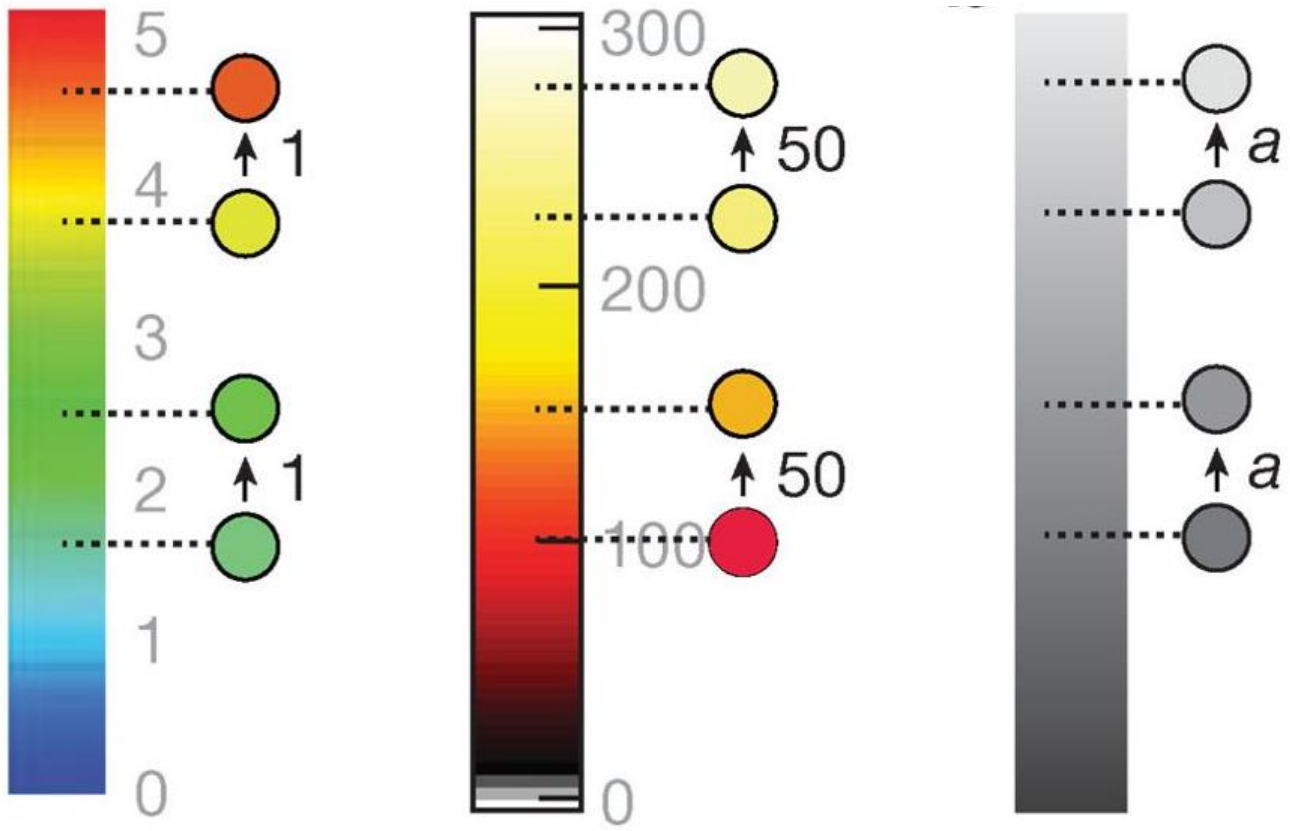
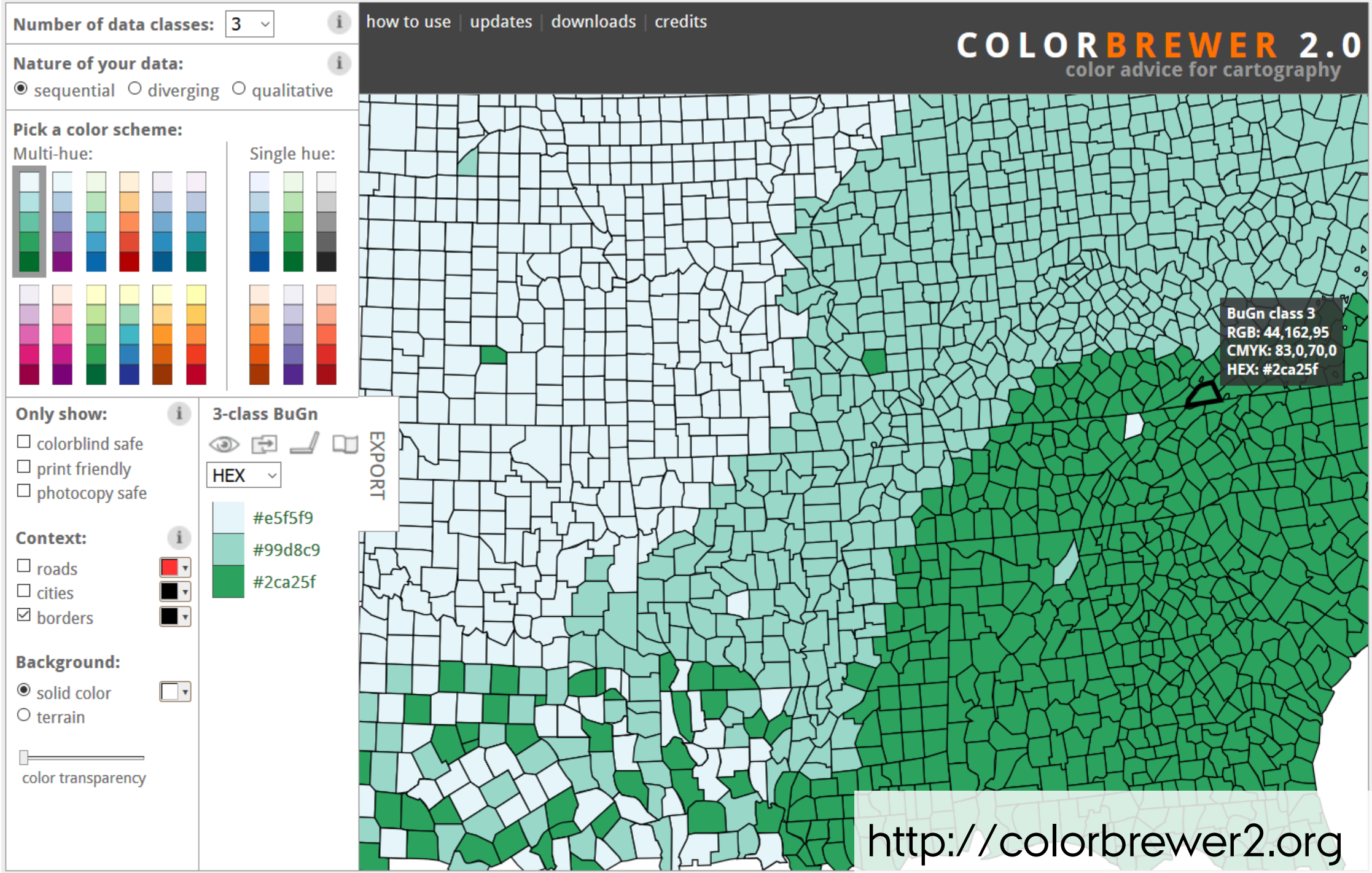


Image source: Nature Methods – Points of View Column, B.Wong 2011


Number of data classes: 3
Nature of your data:
sequential
diverging
qualitative
Pick a color scheme:
Multi-hue:
Single hue:
Only show:
colorblind safe
print friendly
photocopy safe
Context:
roads
cities
borders
Background:
solid color
terrain
color transparency
3-class BuGn
EXPORT
HEX
#e5f5f9
#99d8c9
#2ca25f
how to use
updates
downloads
credits
COLORBREWER 2.0
color advice for cartography
BuGn class 3
RGB: 44,162,95
CMYK: 83,0,70,0
HEX: #2ca25f
http://colorbrewer2.org

MAKING YOUR OWN COLOR SCALES

Use chroma.js!

```
chroma.brewer.OrRd
```

```
chroma.scale(['#fafa6e','#2A4858']).mode('lch').colors(6)
```

POSTPROCESSING: ASPECT RATIO

[Cleveland et al. 1988]

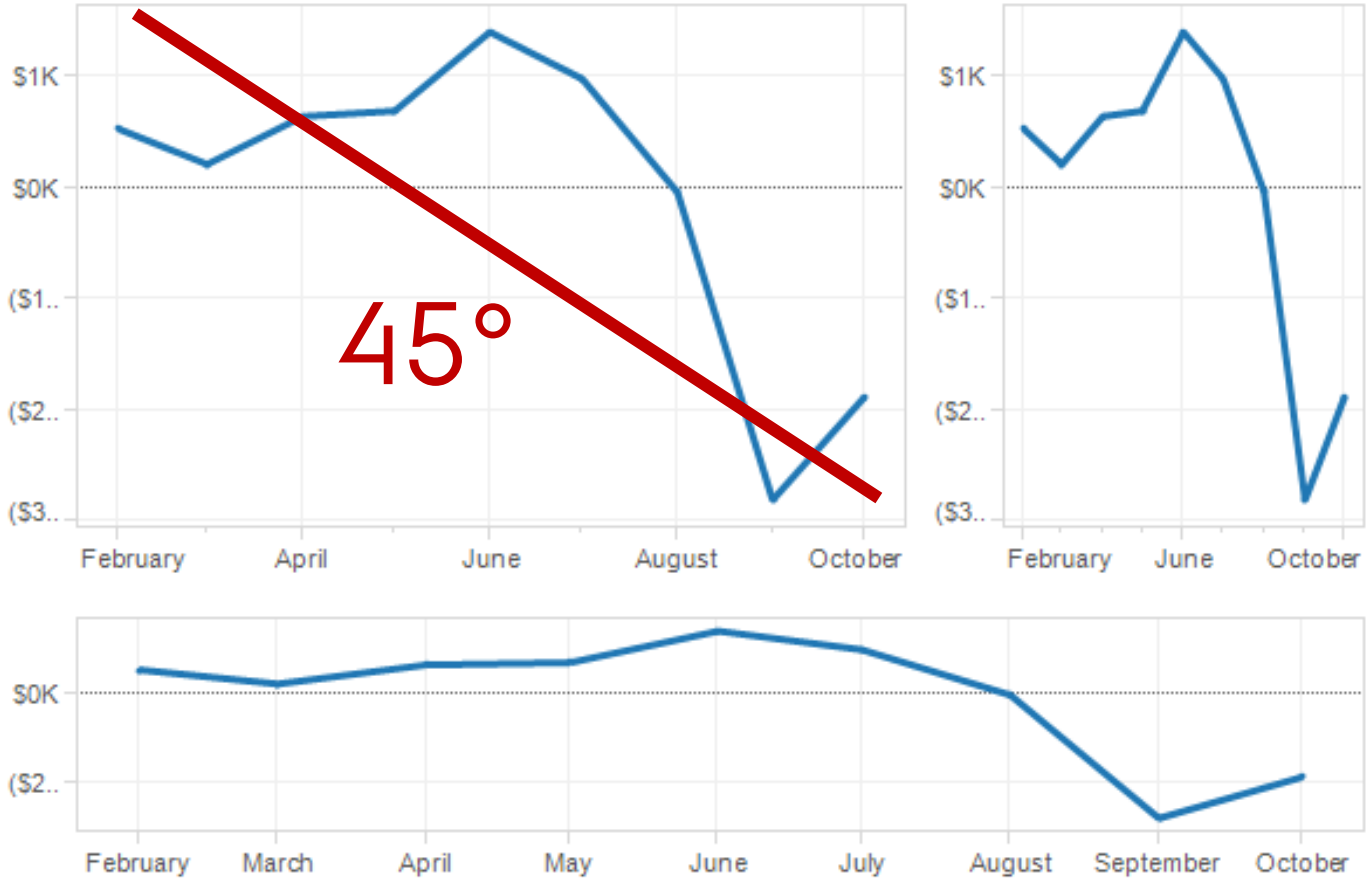


Image source: R.Kosara / eagereyes.org

POSTPROCESSING: AXES, GRID, TICK MARKS

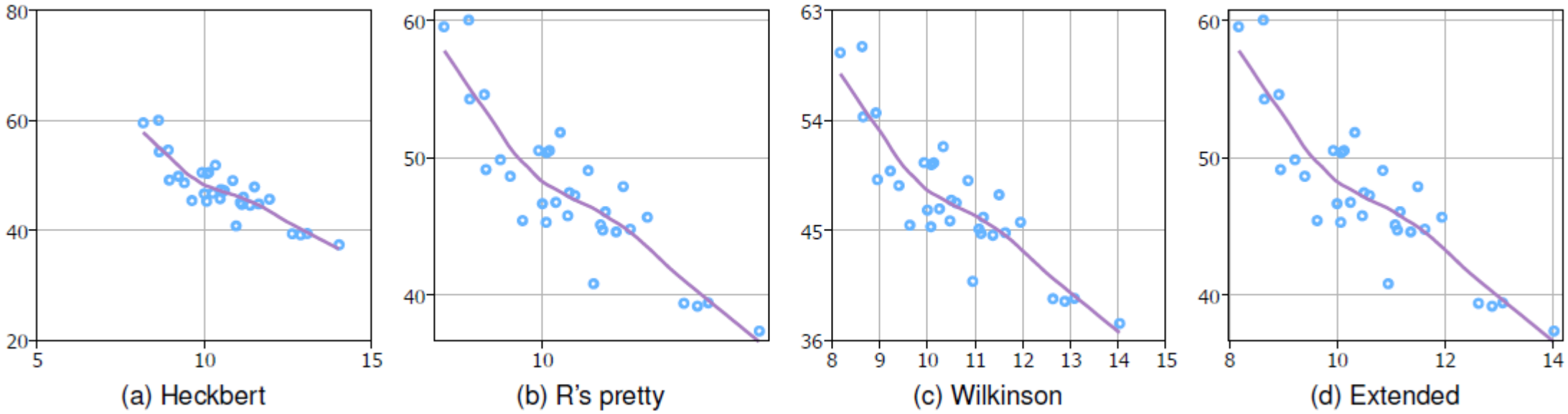


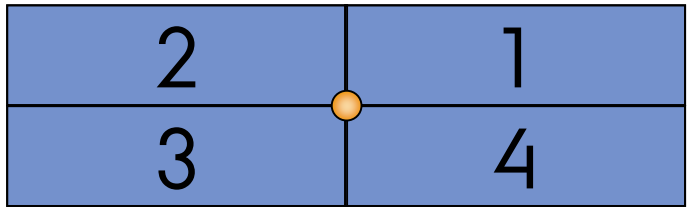
Image source: Talbot et al. 2010

POSTPROCESSING: LABELING

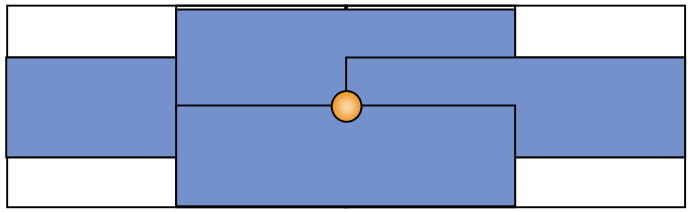
adapted from [Luboschik et al. 2008]
DOI: 10.1109/TVCG.2008.152

STAGE 1: Attempt to place a plain label

1. The 4-Position Model



2. The 8-Position Model



3. The Slider Model

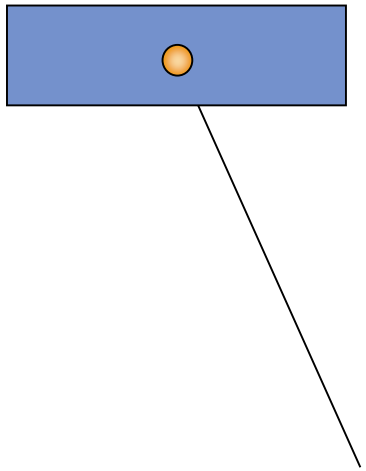
POSTPROCESSING: LABELING

adapted from [Luboschik et al. 2008]
DOI: 10.1109/TVCG.2008.152

STAGE 2: Attempt to place an excentric label

Move the label along a spiral path until a suitable position is found.

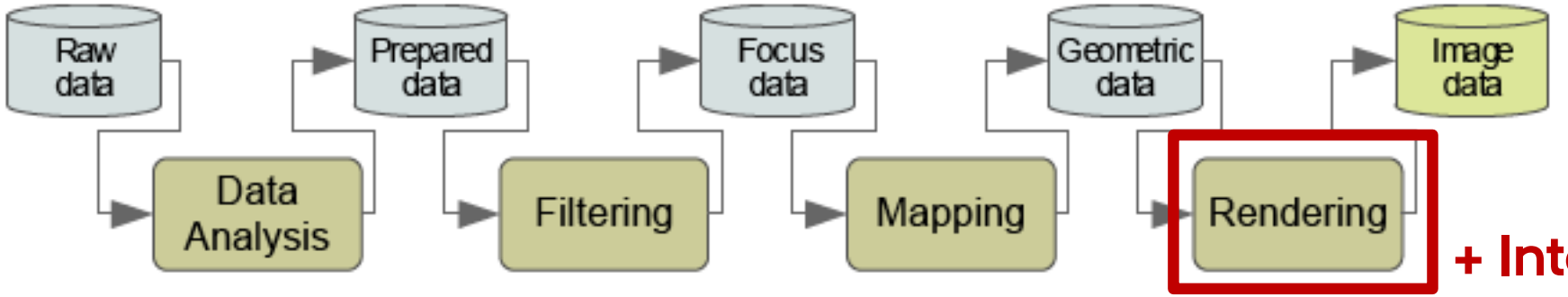
How to do the collision detection efficiently?
Particles → Video



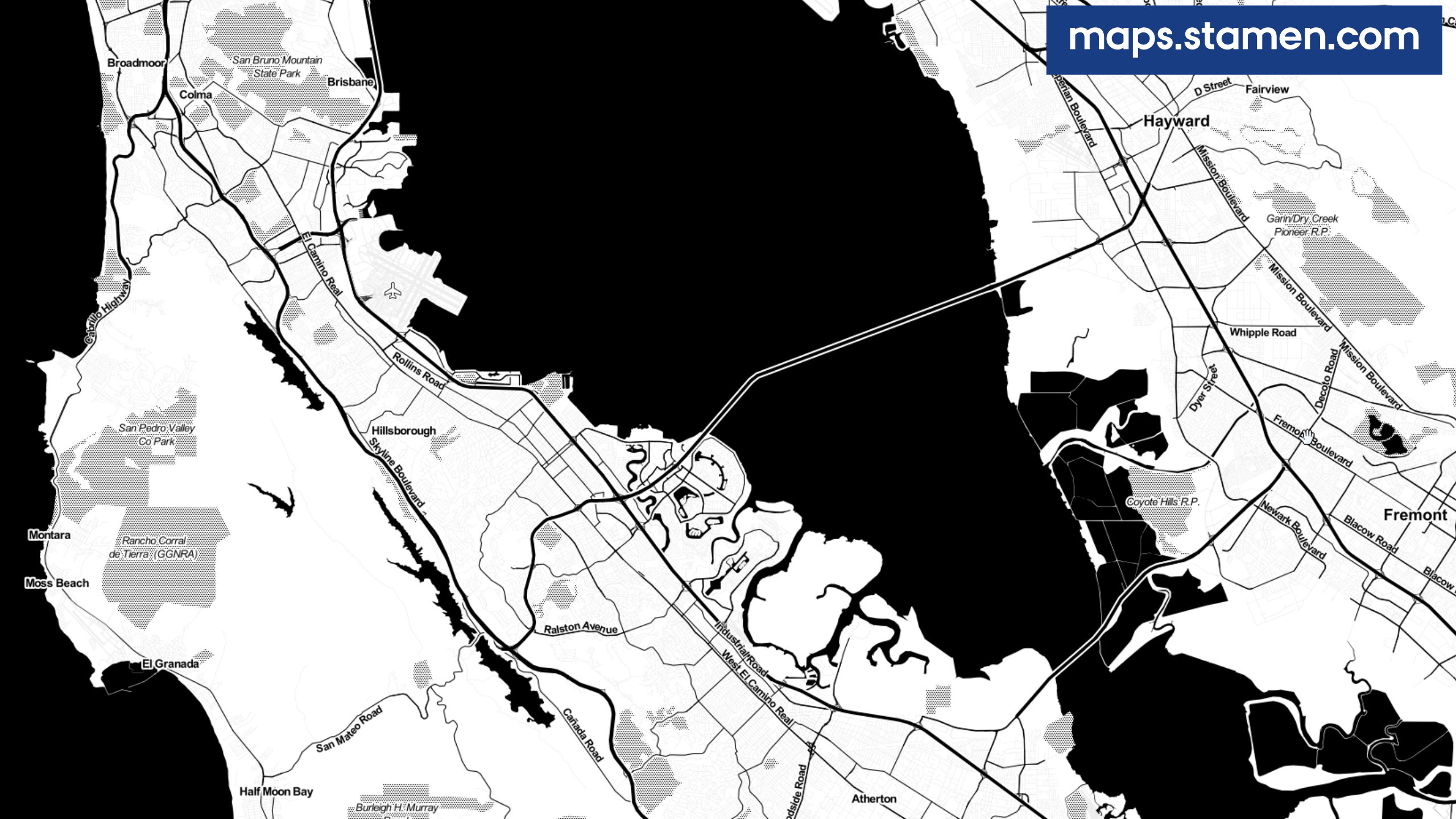
Particle-based conflict detection.

[Luboschik et al. 2008]
DOI: 10.1109/TVCG.2008.152

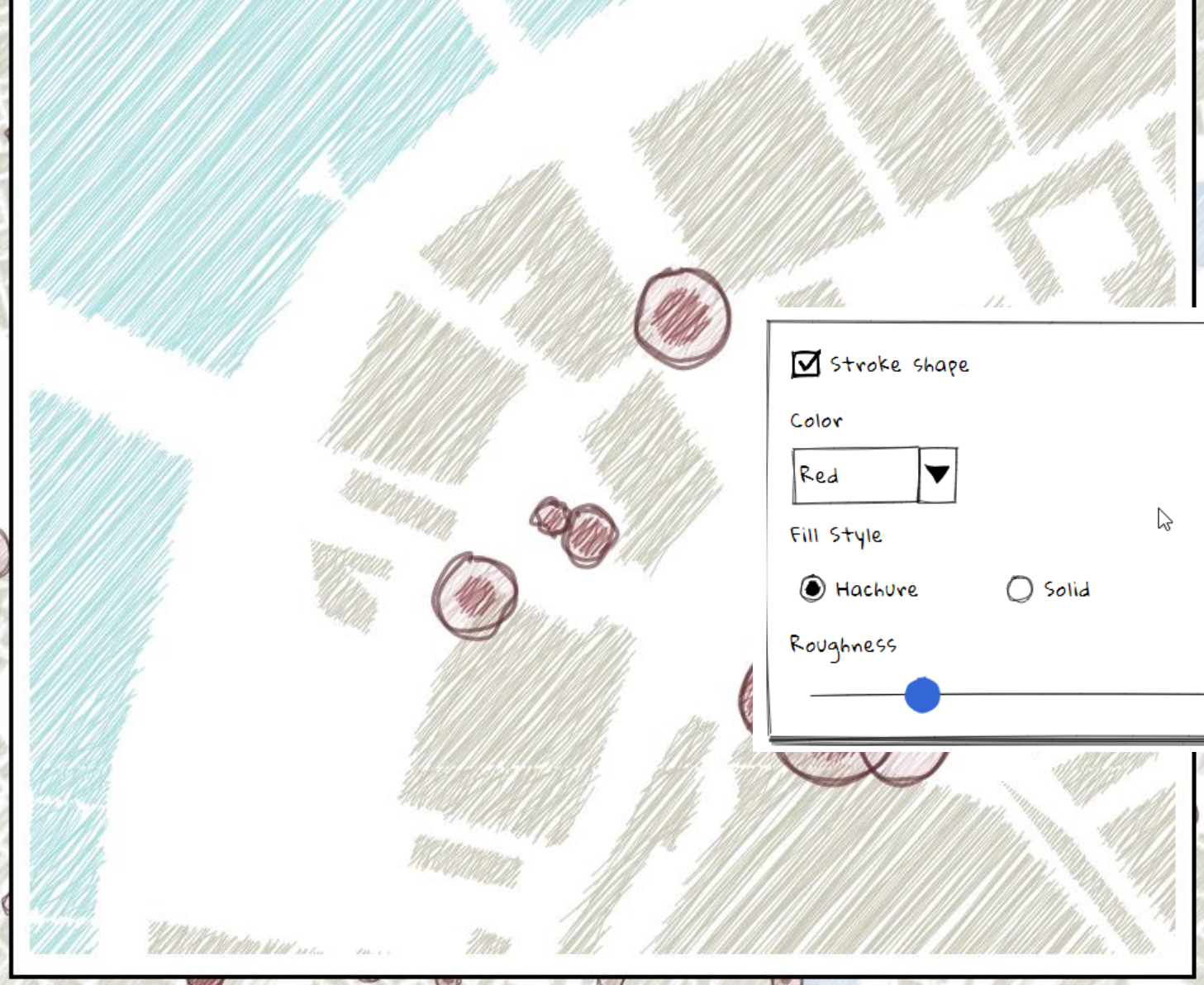
FROM GEOMETRY TO THE IMAGE

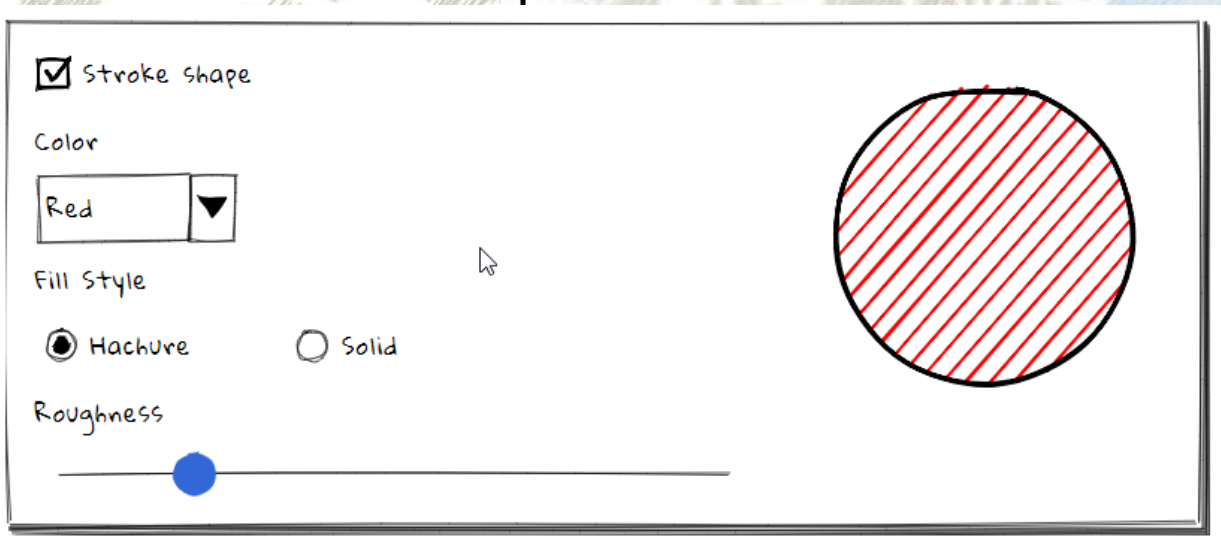



maps.stamen.com


maps.stamen.com
Broadmoor
Colma
San Bruno Mountain State Park
Brisbane
El Camino Real
Rollins Road
Hillsborough
Skyline Boulevard
San Pedro Valley Co Park
Montara
Moss Beach
Rancho Corral de Tierra (GGNRA)
El Granada
Ralston Avenue
Industrial Road
West El Camino Real
Cañada Road
San Mateo Road
Half Moon Bay
Burleigh H. Murray
Atherton
Redwood Boulevard
Hayward
D Street
Fairview
Mission Boulevard
Garin/Dry Creek Pioneer R.P.
Whipple Road
Dyer Street
Decoto Road
Fremont Boulevard
Coyote Hills R.P.
Newark Boulevard
Blacow Road
Fremont

rough.js (+ wired.js)





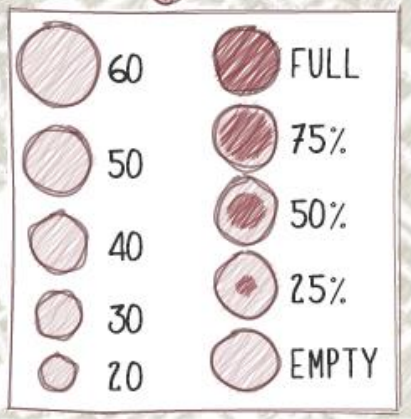
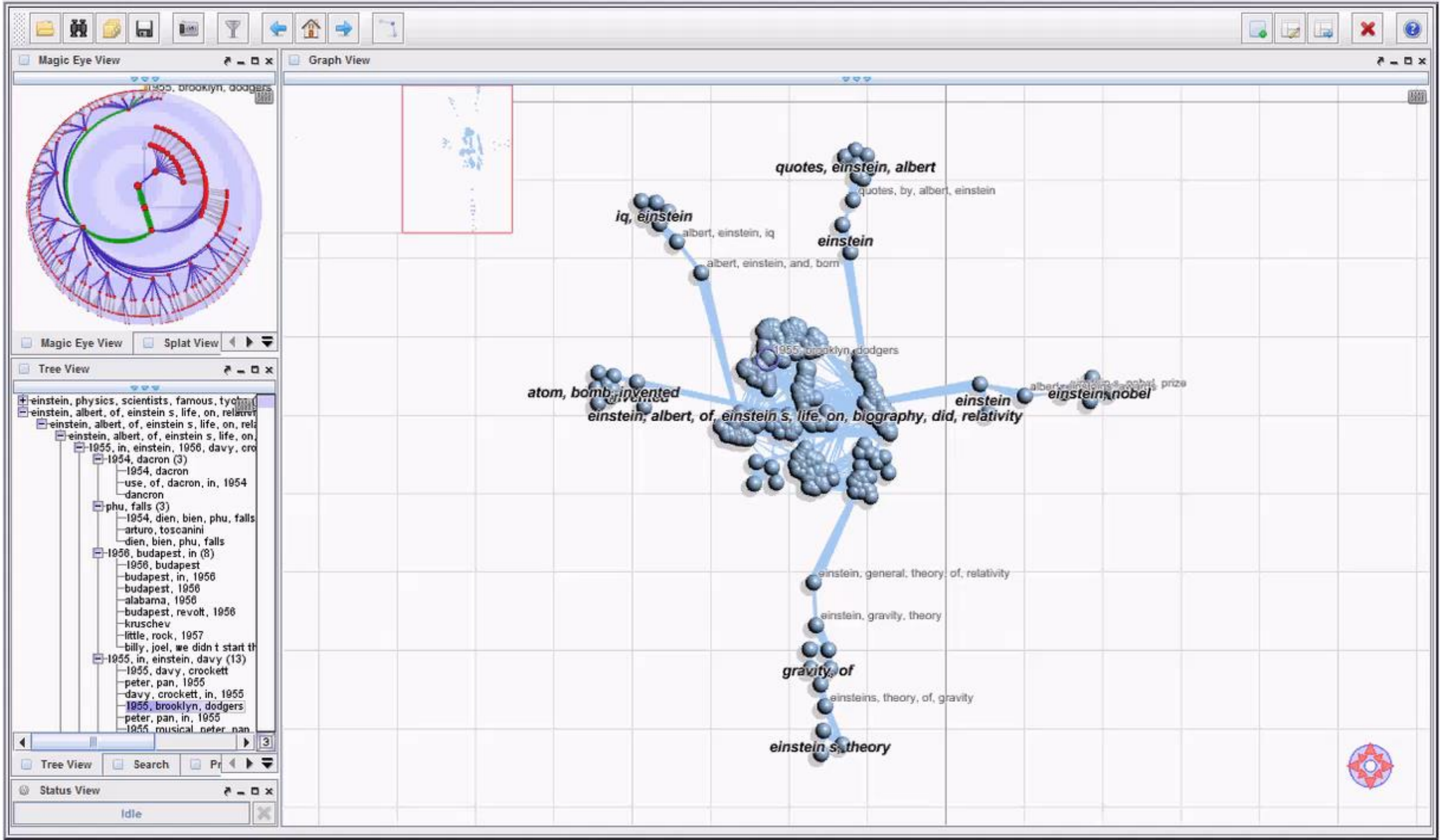


Image source [Wood et al. 2012]


Magic Eye View
Graph View
Splat View
Tree View
Search
Status View
Idle
quotes, einstein, albert
quotes, by, albert, einstein
iq, einstein
albert, einstein, iq
einstein
albert, einstein, and, born
1955, brooklyn, dodgers
atom, bomb, invented
einstein, albert, of, einstein s, life, on, biography, did, relativity
einstein
einstein, nobel
einstein, general, theory, of, relativity
einstein, gravity, theory
gravity, of
einsteins, theory, of, gravity
einstein s, theory
einstein, physics, scientists, famous, tycoon
einstein, albert, of, einstein s, life, on, relativ
einstein, albert, of, einstein s, life, on, rela
einstein, albert, of, einstein s, life, on,
1955, in, einstein, 1956, davy, cro
1954, dacron (3)
1954, dacron
use, of, dacron, in, 1954
dancron
phu, falls (3)
1954, dien, bien, phu, falls
arturo, toscanini
dien, bien, phu, falls
1956, budapest, in (8)
1956, budapest
budapest, in, 1956
budapest, 1956
alabama, 1956
budapest, revolt, 1956
kruschev
little, rock, 1957
billy, joel, we didn t start th
1955, in, einstein, davy (13)
1955, davy, crockett
peter, pan, 1955
davy, crockett, in, 1955
1955, brooklyn, dodgers
peter, pan, in, 1955
1955, musical, peter, pan

THE PRACTICAL PART...

Tools introduced so far:

- http://openrefine.org
- https://olssol.shinyapps.io/missuite/
- http://treevis.net
- http://textvis.lnu.se
- http://timeviz.net
- http://financevis.net
- http://colorbrewer2.org
- https://gka.github.io/chroma.js/
- http://maps.stamen.com
- https://roughjs.com + https://wiredjs.com

But... we still need tools to create the actual visualization!

- https://dmitrybaranovskiy.github.io/raphael/
- https://www.vincentbroute.fr/mapael/
- https://fperucic.github.io/treant-js/
- https://d3js.org
- https://vega.github.io
- http://idl.cs.washington.edu/projects/lyra/
- https://vega.github.io/voyager2/

IMPERATIVE FLAVOR: RAPHAËL.JS

To create a graphics like this:

```
<svg width="500" height="300">
  <circle cx="250" cy="150" r="50" stroke="#000" stroke-width="1" fill="#FFF" />
</svg>
```

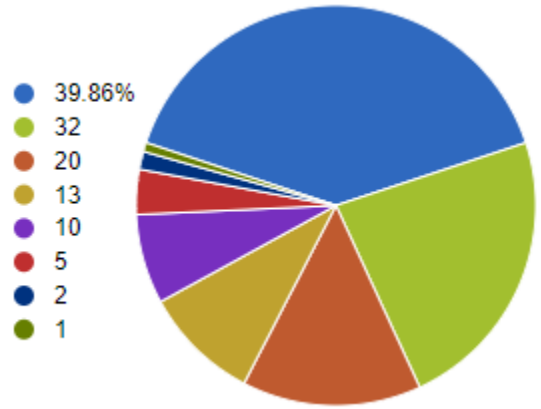
...you use Raphaël functions like these:

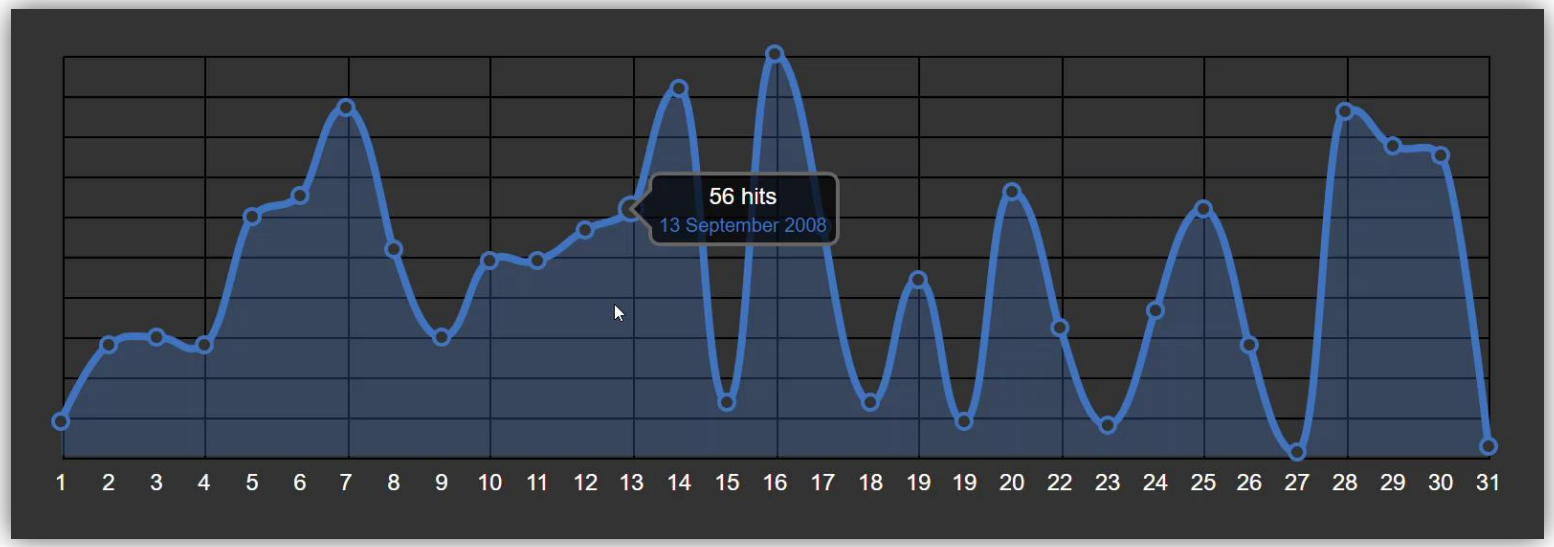
```
<div id="container"></div>
<script src="raphael-2.2.1.min.js"> </script>
<script>
  var chart= Raphael("container", 500, 300);
  var dot= chart.circle(250, 150, 50).attr({fill:"#FFF", stroke:"#000", "stroke-width":1});
</script>
```

IMPERATIVE FLAVOR: RAPHAËL.JS

Different plugins built on top of Raphaël provide charting primitives:

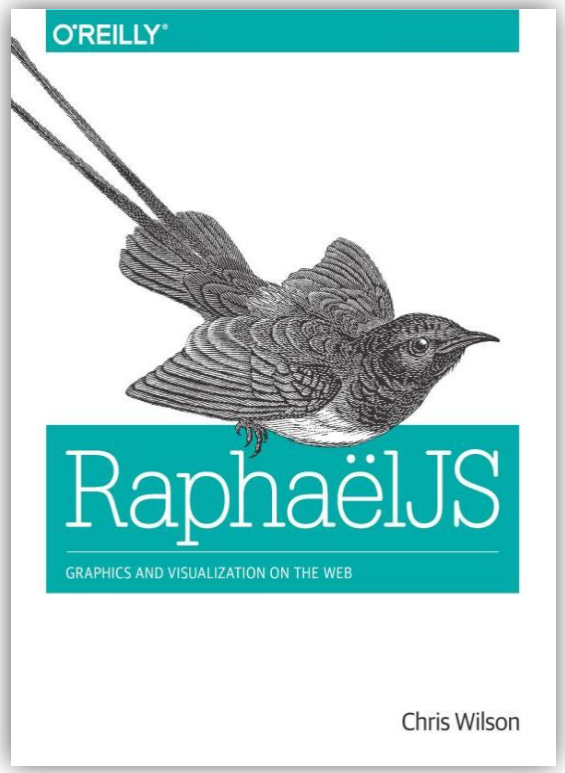
```
r.piechart(320, 240, 100, [55,20,13,32,5,1,2,10], { legend:["%%.%%"], legendpos:"west" });
```

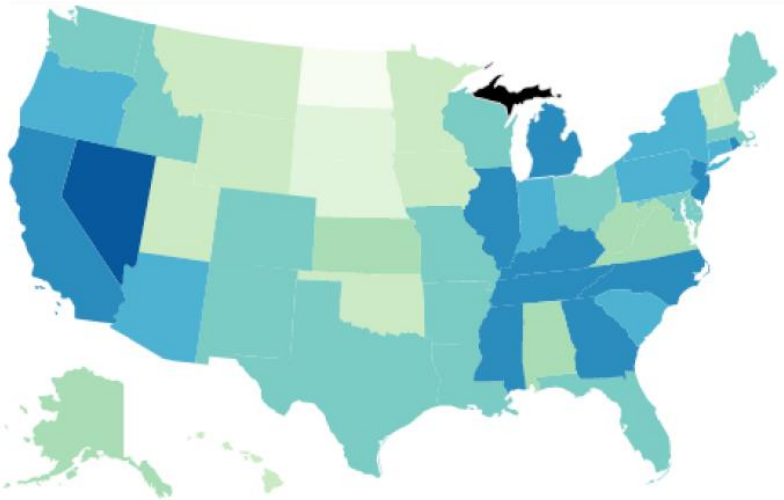


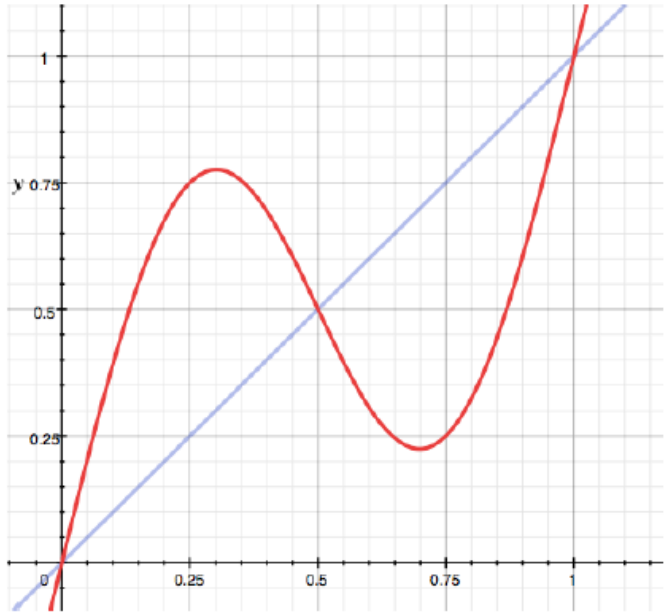


Check out e.g., jQuery Mapael for geospatial visualizations or Treant.js for hierarchical visualizations!

IMPERATIVE FLAVOR: RAPHAËL.JS



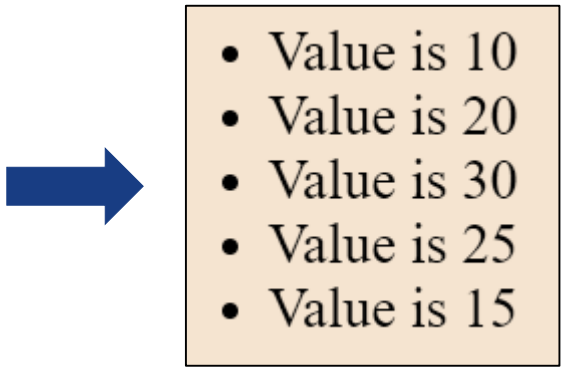




FUNCTIONAL FLAVOR: D3.JS

```
<script type = "text/javascript" src = "d3-5.7.0.min.js"></script>
<body>
  <ul id = "list">
    <li></li>
    <li></li>
    <li></li>
    <li></li>
    <li></li>
  </ul>

  <script>
    d3.select("#list").selectAll("li").data([10, 20, 30, 25, 15])
      .text(function(d) { return "Value is " + d; });
  </script>
 </body>
```



FUNCTIONAL FLAVOR: D3.JS

```
<script type = "text/javascript" src = "d3-5.7.0.min.js"></script>
<body>
  <ul id = "list">
    <li></li>
    <li></li>
  </ul>
```

- Existing value is 10
- Existing value is 20
- New value is 30
- New value is 25
- New value is 15

```
  <script>
    d3.select("#list").selectAll("li").data([10, 20, 30, 25, 15])
      .text(function(d) { return "Existing value is " + d; })
      .enter().append("li").text(function(d) { return "New value is " + d; });
  </script>
</body>
```

`enter()` returns all data items for which no document element exists

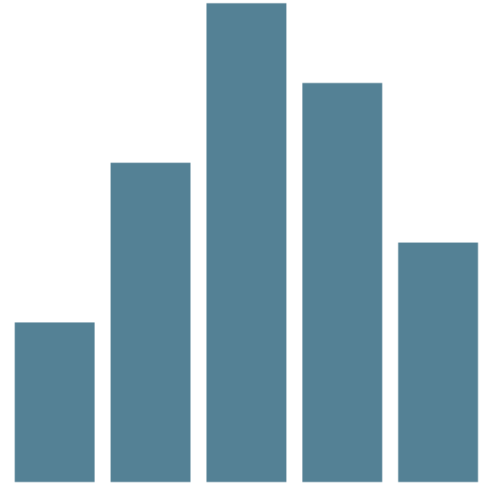
FUNCTIONAL FLAVOR: D3.JS

```
<script type = "text/javascript" src = "d3-5.7.0.min.js"></script>
<body>
  <ul id = "list">
    <li></li>
    <li></li>
    <li></li>
    <li></li>
    <li></li>
    <li></li>
  </ul>
  <script>
    d3.select("#list").selectAll("li").data([10, 20, 30, 25, 15])
      .text(function(d) { return "Existing value is " + d; })
      .enter().append("li").text(function(d) { return "New value is " + d; })
      .exit().remove();
  </script>
 </body>
```

- Existing value is 10
- Existing value is 20
- Existing value is 30
- Existing value is 25
- Existing value is 15

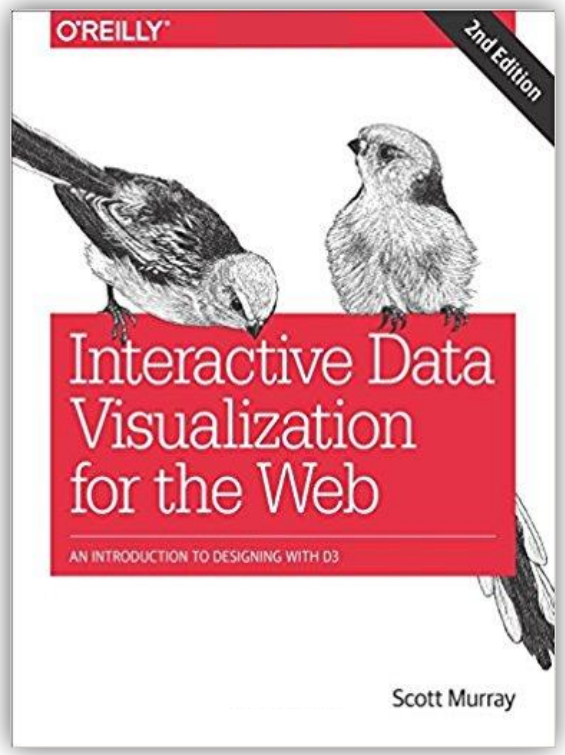
`exit()` returns all document elements for which no data items exist

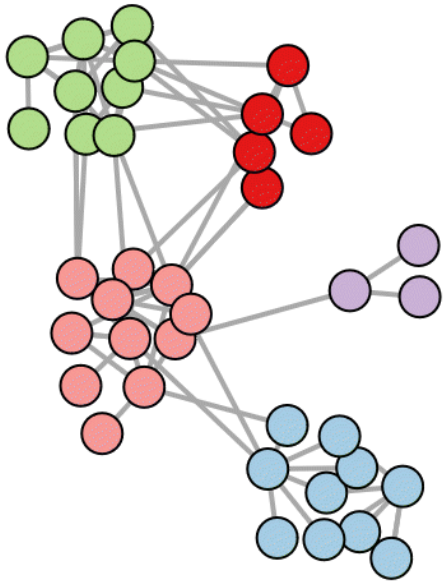
FUNCTIONAL FLAVOR: D3.JS

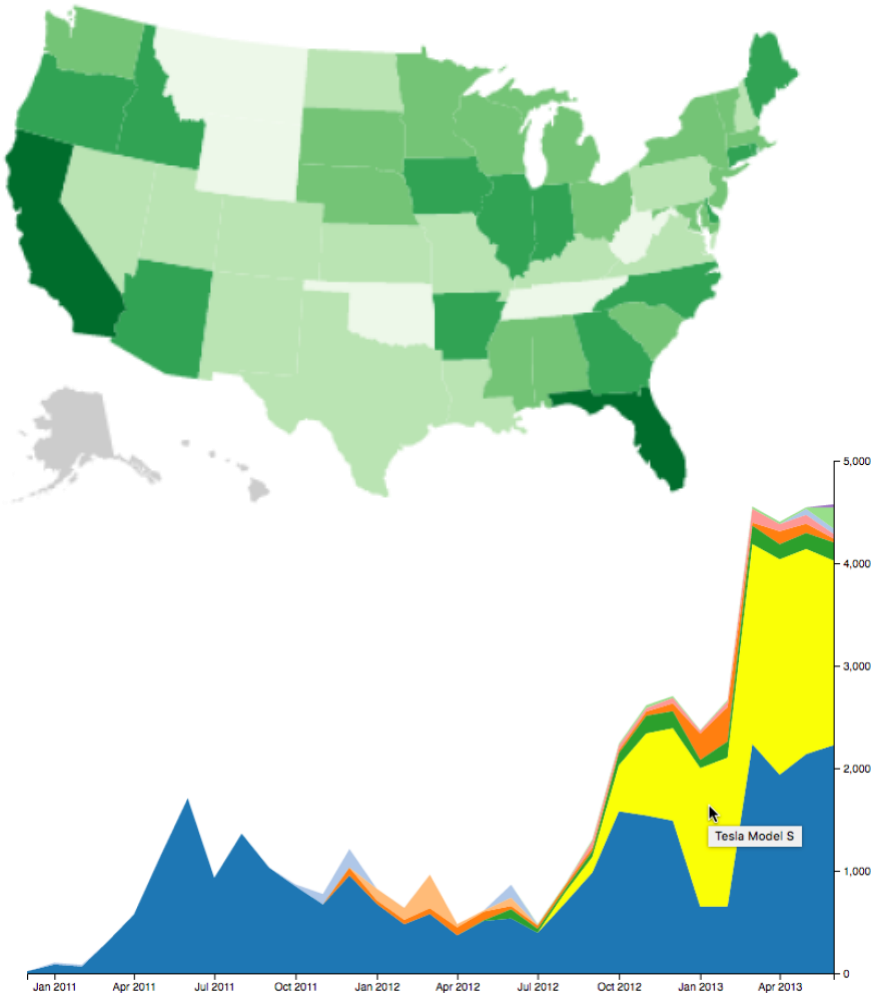


```
<script type = "text/javascript" src = "d3-5.7.0.min.js"></script>
<body>
  <svg id="chart" width="500" height="300" />
  <script>
     var data = [10, 20, 30, 25, 15];
     var scaleFactor = 10, barWidth = 50, gapWidth = 10;
     var graph = d3.select("#chart").selectAll("rect").data(data).enter()
                   .append("rect")
                   .attr("width", barWidth)
                   .attr("height", function(d) { return scaleFactor * d; })
                   .attr("x", function(d, i) { return i * (barWidth + gapWidth); })
                   .attr("y", function(d) { return 300 - scaleFactor * d; })
                   .attr("fill", "#548195");
  </script>
</body>
```

FUNCTIONAL FLAVOR: D3.JS





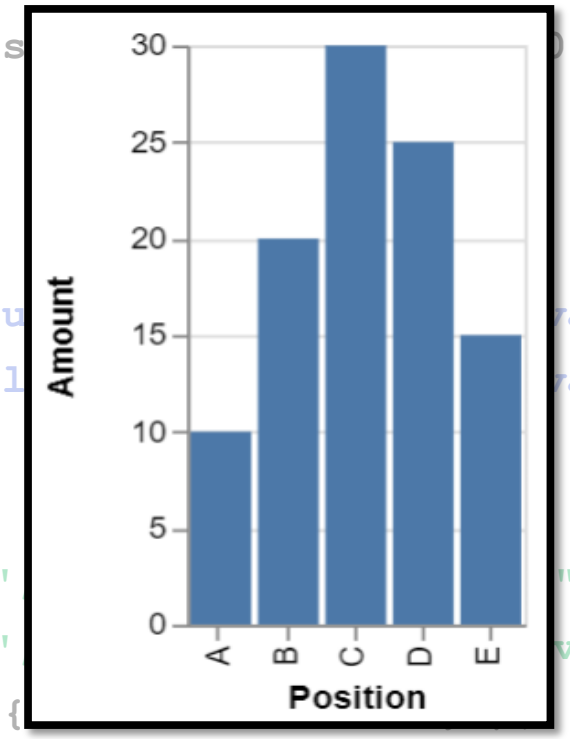


DECLARATIVE FLAVOR: VEGA/VEGA-LITE.JS

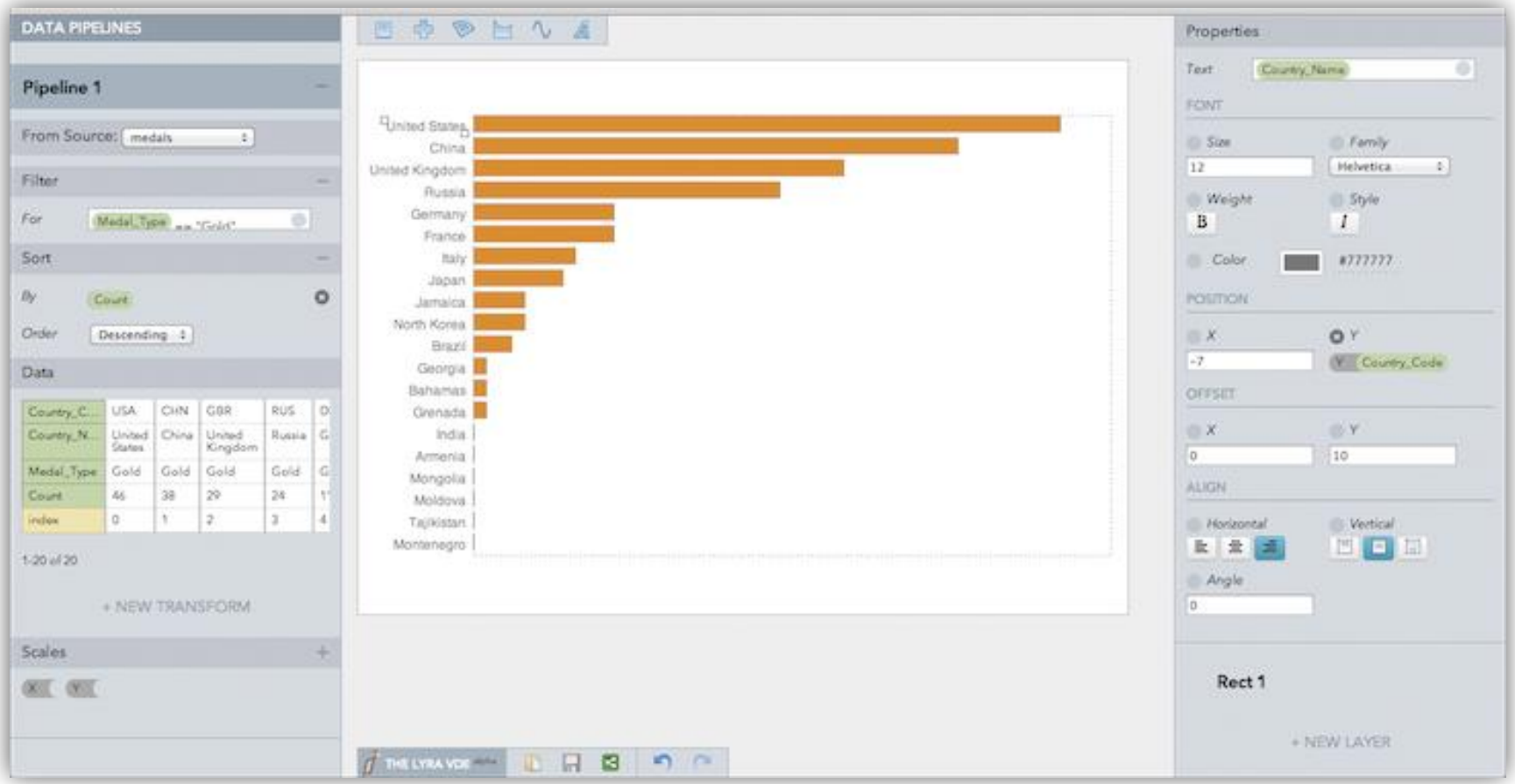
```
<script type = "text/javascript" src = "vega-4.2.0.js"></script>
<script type = "text/javascript" src = "vega-lite-2.6.0.js"></script>
<script type = "text/javascript" src = "vega-embed-3.20.0.js"></script>
<body>
  <div id="chart" />
  <script>
    var visSpec = { "data": {"values": [ {"key":"A", "val":10}, {"key":"B", "val":20},
                  {"key":"C", "val":30}, {"key":"D", "val":25}, {"key":"E", "val":15} ] },
                   "mark": "bar",
                   "encoding": {
              "x": {"field": "key", "type": "nominal", "axis": {"title": "Position"}},
              "y": {"field": "val", "type": "quantitative", "axis": {"title": "Amount"}} } };
    vegaEmbed("#chart", visSpec, {"actions": false} );
   </script>
 </body>
```

DECLARATIVE FLAVOR: VEGA/VEGA-LITE.JS

```
<script type = "text/javascript" src = "vega-4.2.0.js"></script>
<script type = "text/javascript" src = "vega-lite-2.6.0.js"></script>
<script type = "text/javascript" s                    0.0.js"></script>
<body>
  <div id="chart" />
  <script>
    var visSpec = { "data": {"valu                    val":10}, {"key":"B", "val":20},
                    {"key":"C", "val                  val":25}, {"key":"E", "val":15} ] },
                     "mark": "bar",
                     "encoding": {
                "x": {"field": "key"                  "axis": {"title": "Position"}},
                "y": {"field": "val"                  ve", "axis": {"title": "Amount"}} } };
    vegaEmbed("#chart", visSpec, {
   </script>
 </body>
```



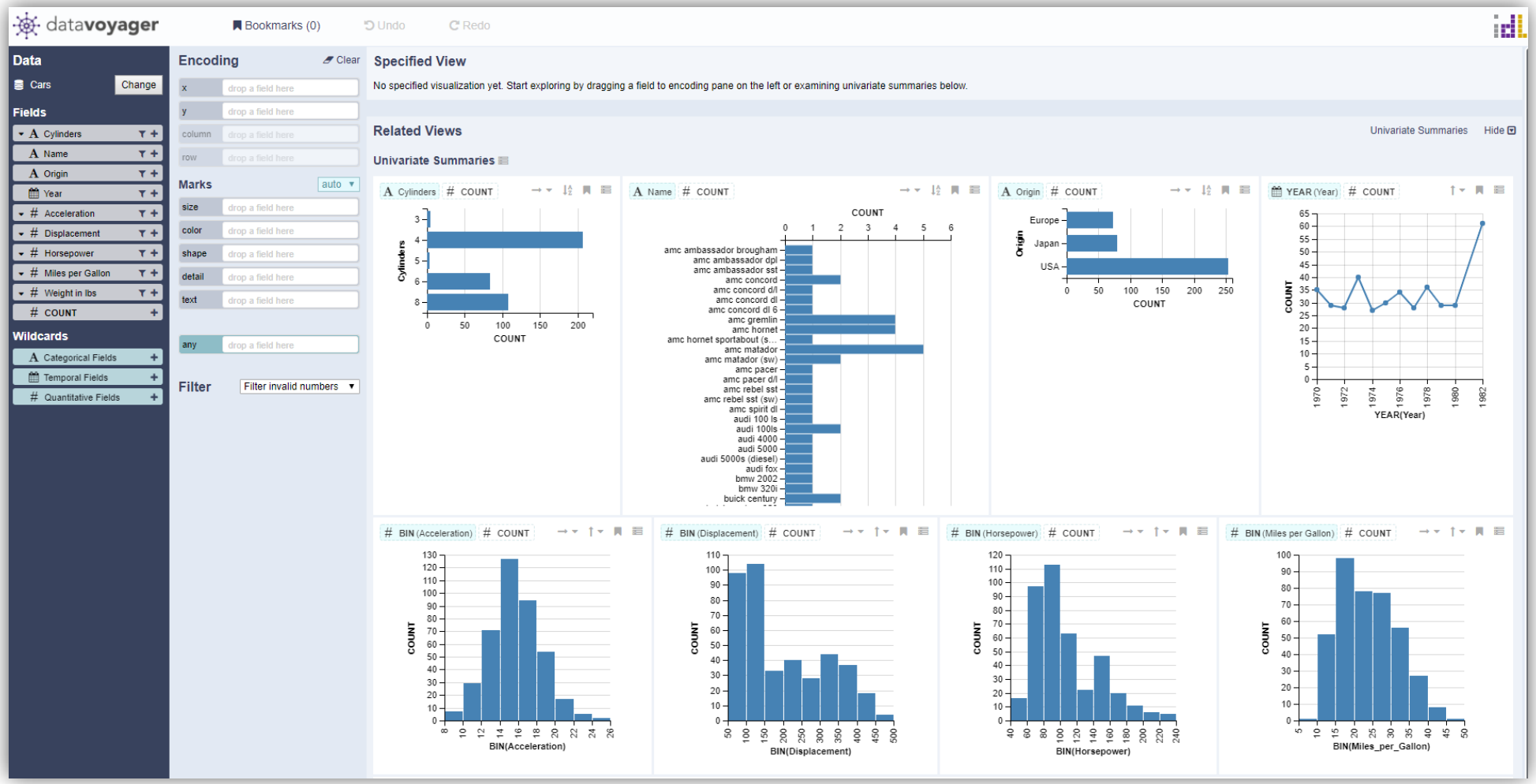
THE LYRA VISUALIZATION EDITOR



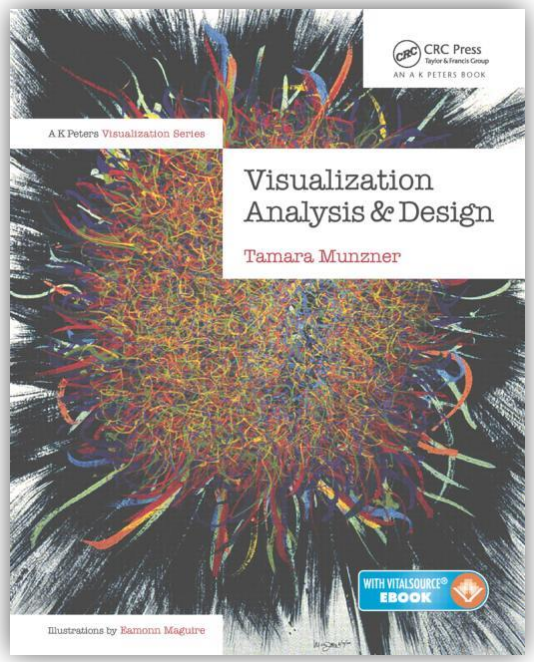
https://idl.cs.washington.edu/projects/lyra/

THE DATA VOYAGER

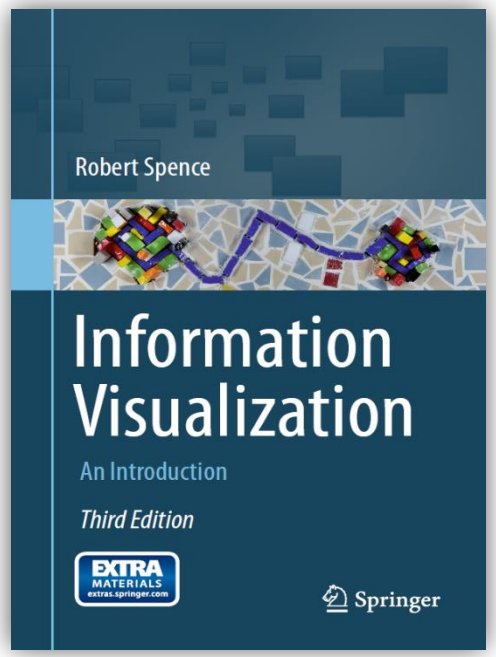
https://vega.github.io/voyager2/



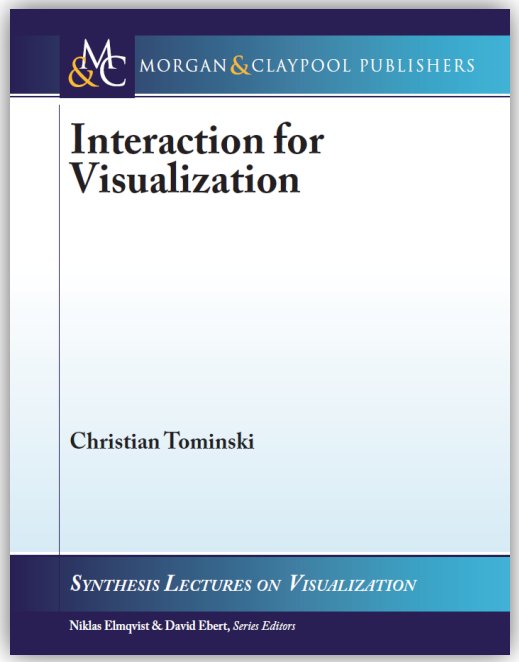
FURTHER READING



Tamara Munzner:
Visualization Analysis and Design



Robert Spence:
Information Visualization.
An Introduction, 3rd Edition



Christian Tominski:
Interaction for Visualization

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