VISUALIZATION TOOLS AND PARADIGMS

UNIVERSITY OF CALGARY

HOW CAN WE GENERATE GRAPHICAL REPRESENTATIONS?

WHAT TOOLS ARE CURRENTLY THE MOST INTERESTING?

WHEN & WHY TO CHOOSE DIFFERENT APPROACHES?

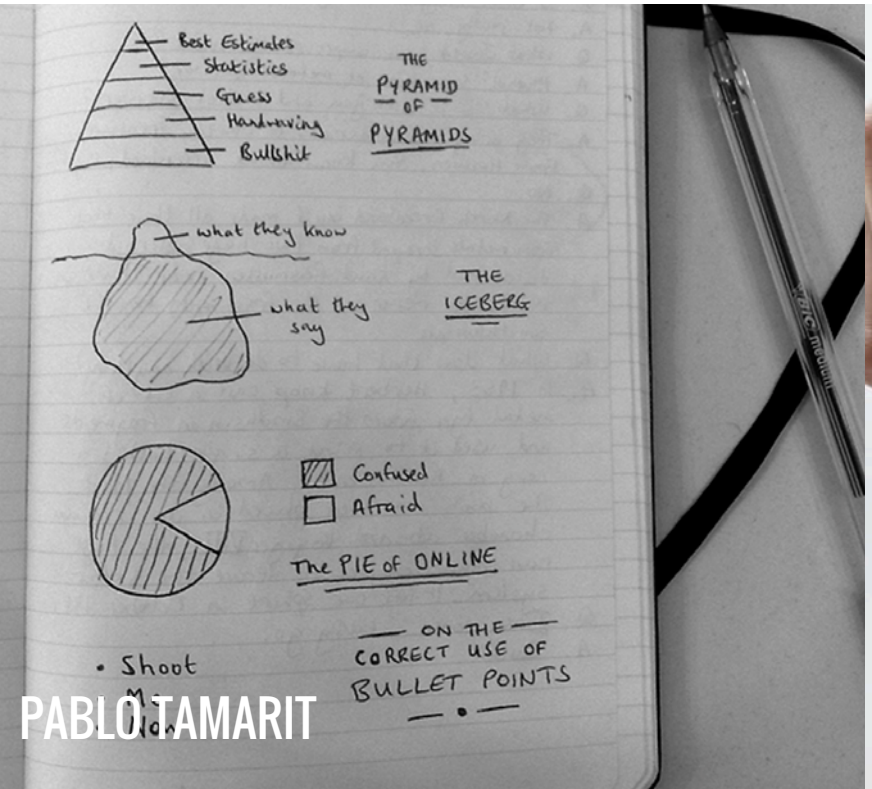
BRET VICTOR

DRAW USE CODE

DRAWING DYNAMIC VISUALIZATIONS
https://vimeo.com/66085662

DRAW

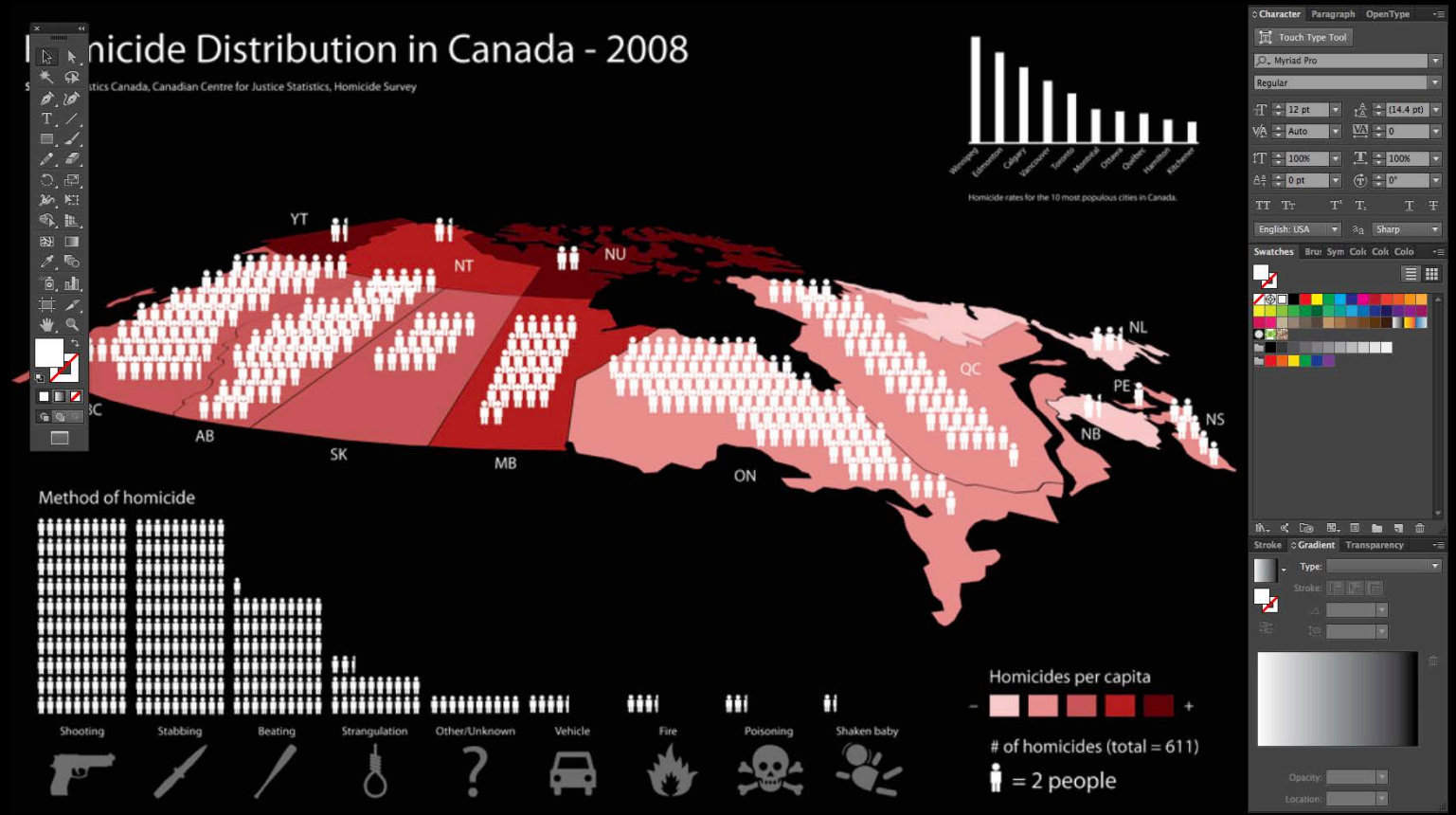
SKETCHING / CONSTRUCTING BY HAND



PABLO TAMARIT

SAMUEL HURON

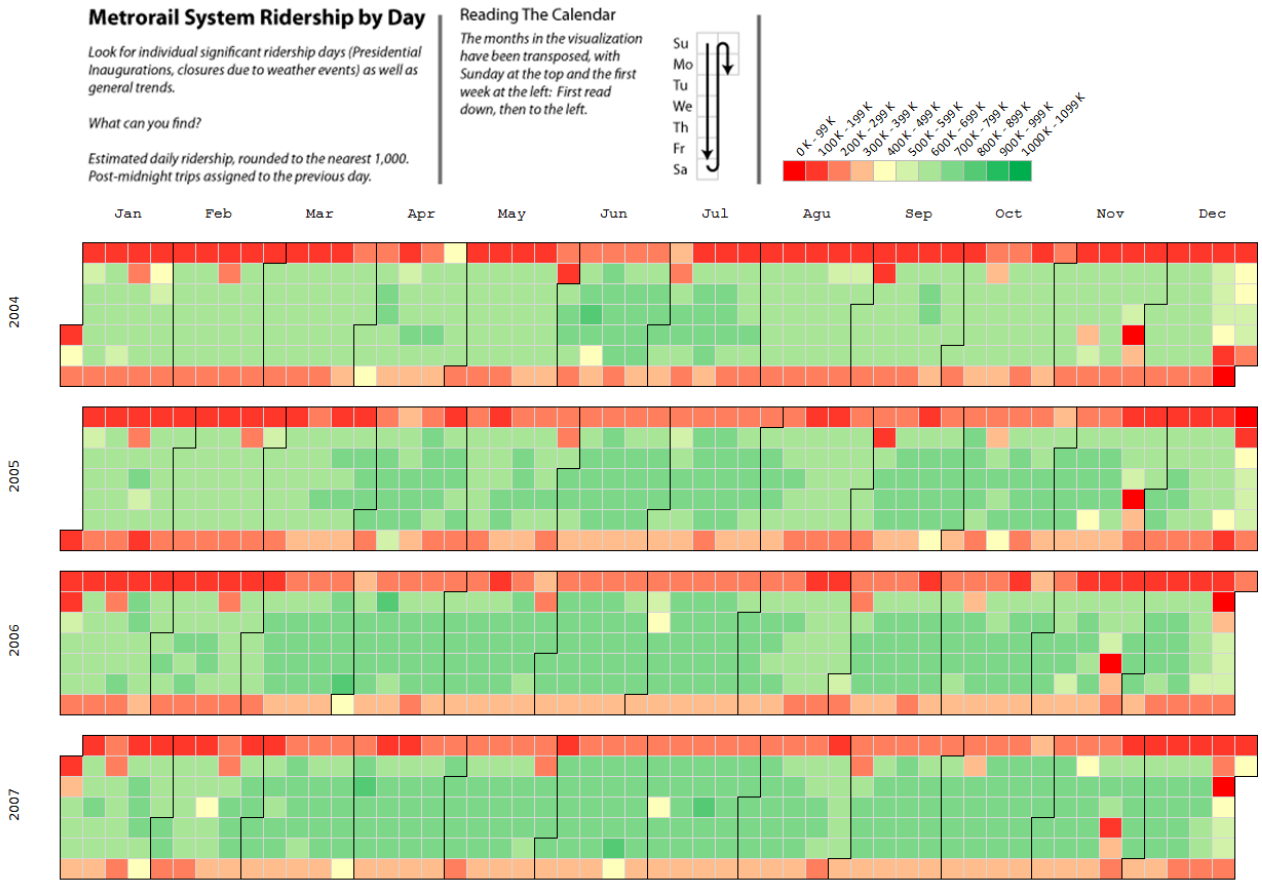
GRAPHIC DESIGN SOFTWARE
(ILLUSTRATOR, PHOTOSHOP, ETC.)

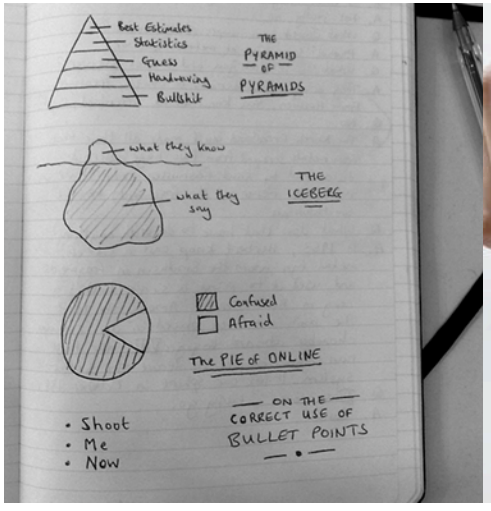


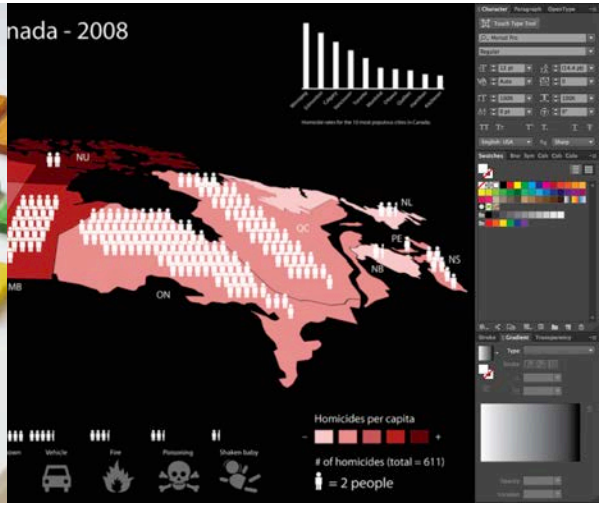
http://www.kristinaneuman.com/

“DRAWING” IN EXCEL

https://sites.google.com/site/e90e50fx/home/calendar-based-heatmap-in-excel







DRAW

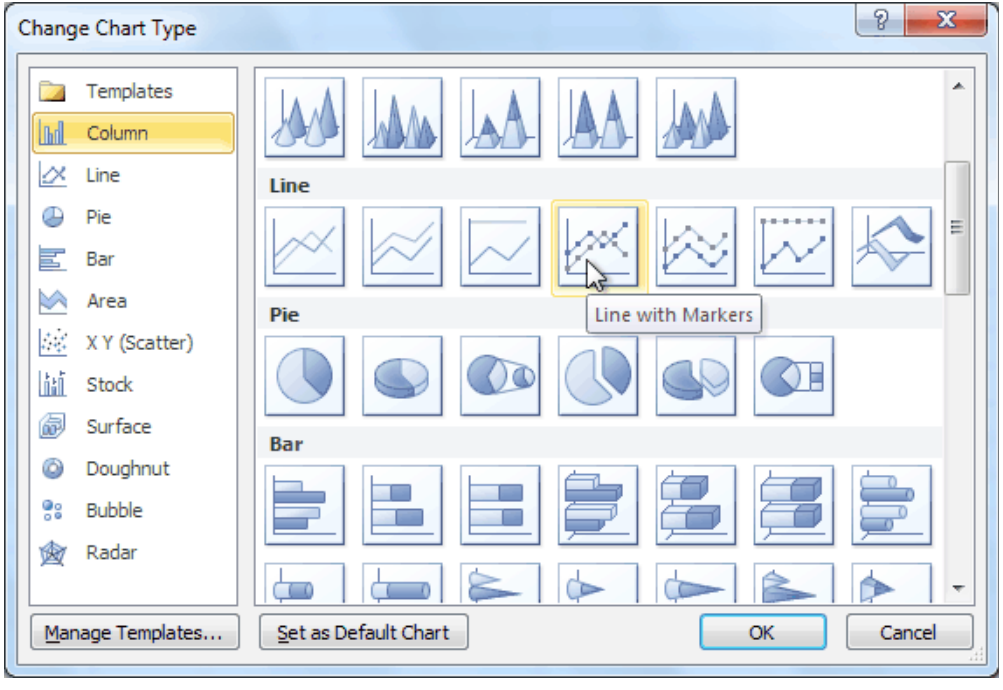
+ FLEXIBLE & EXPRESSIVE

- SCALES BADLY

- DESIGNS ARE ONE-OFFS

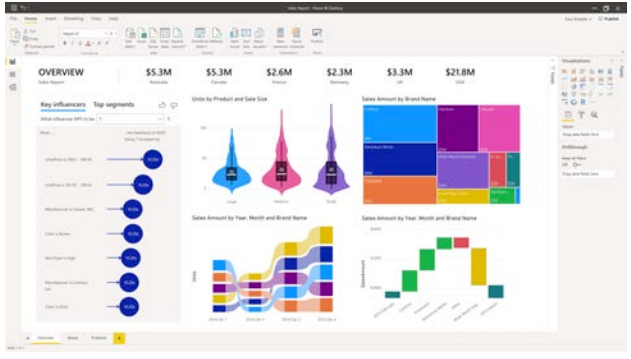
USE

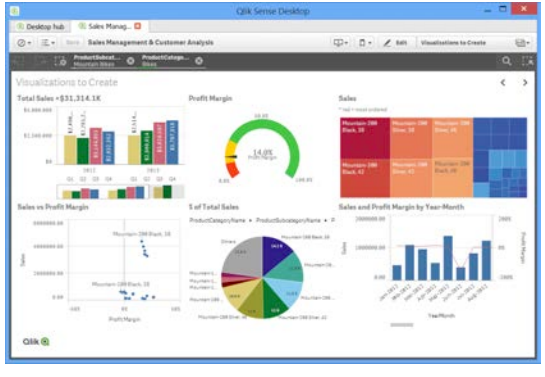
EXCEL


Change Chart Type
Templates
Column
Line
Pie
Bar
Area
X Y (Scatter)
Stock
Surface
Doughnut
Bubble
Radar
Line
Pie
Bar
Line with Markers
Manage Templates...
Set as Default Chart
OK
Cancel

INTERACTIVE TOOLS

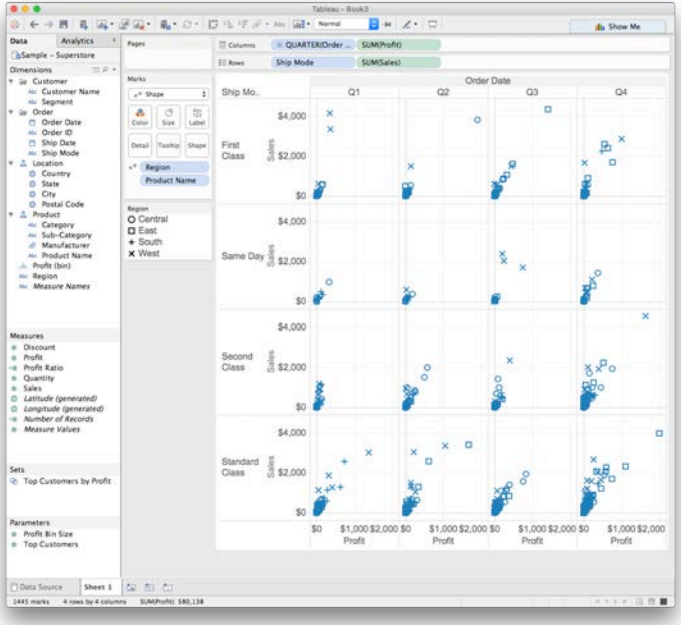
Power BI



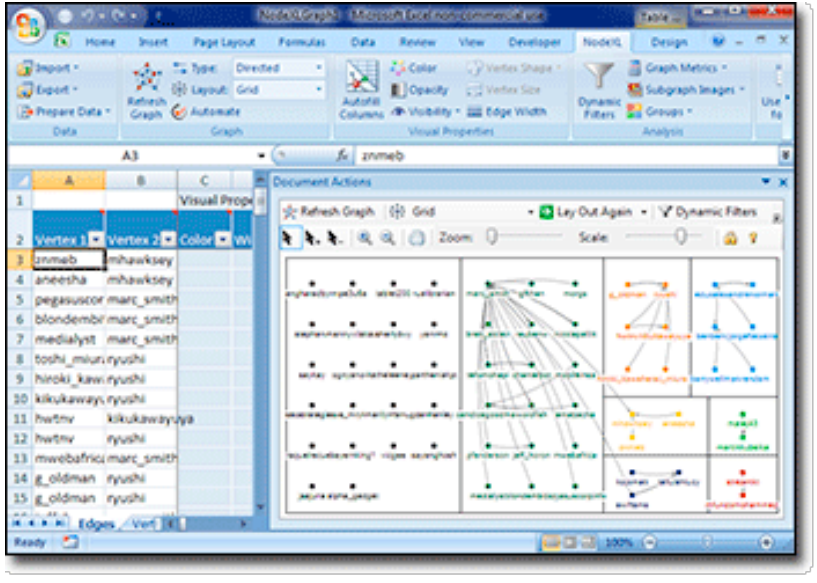


Qlik

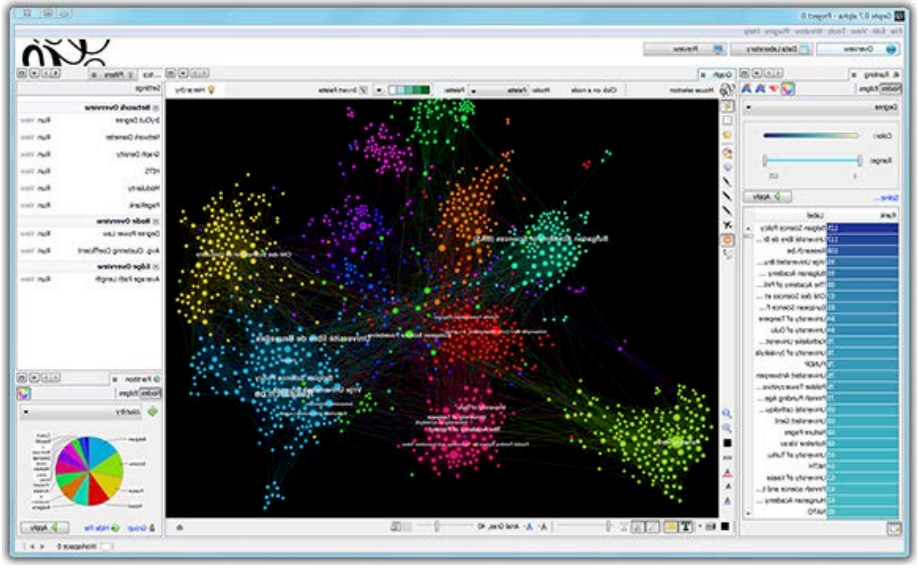
+ a b | e a u



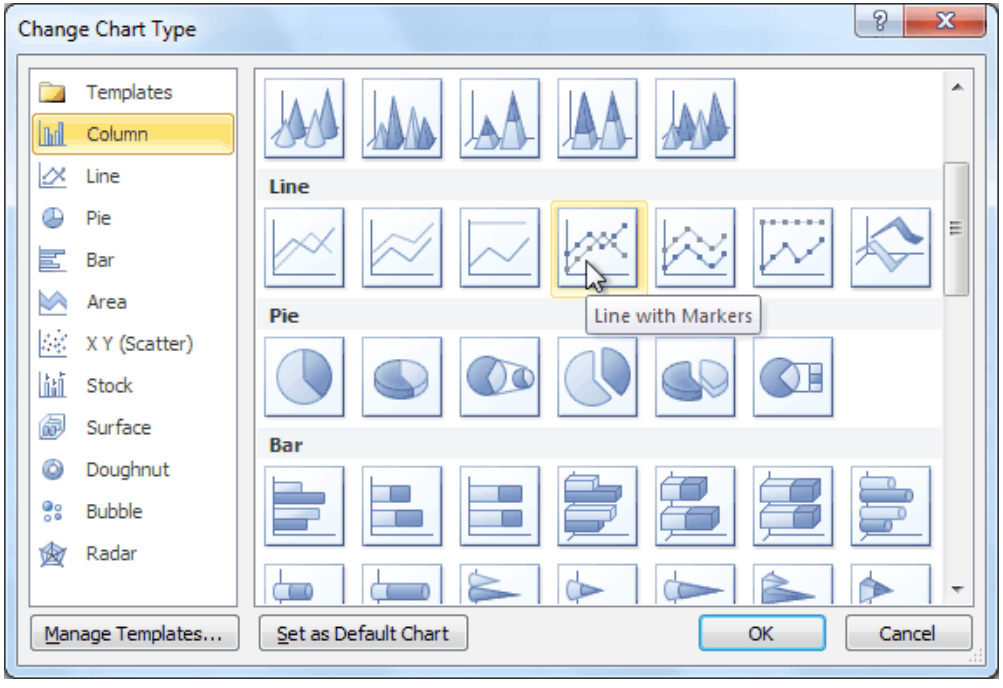
NETWORK AND GRAPH DATA



NodeXL



Gephi



USE

+ EASY
+ SCALABLE
- LIMITED FLEXIBILITY
- LIMITED EXPRESSIVENESS
- WHAT IF I NEED A NEW CHART TYPE?

We begin our derivation by disregarding the effects of _____,
and inquire into the condition _____ associated with the interaction of
_____ and _____. The theory _____ asserts that
_____ must be equal to _____, as indicated by the equation

_____ (1)

WHAT IF WE WROTE PAPERS THIS WAY?

CODE

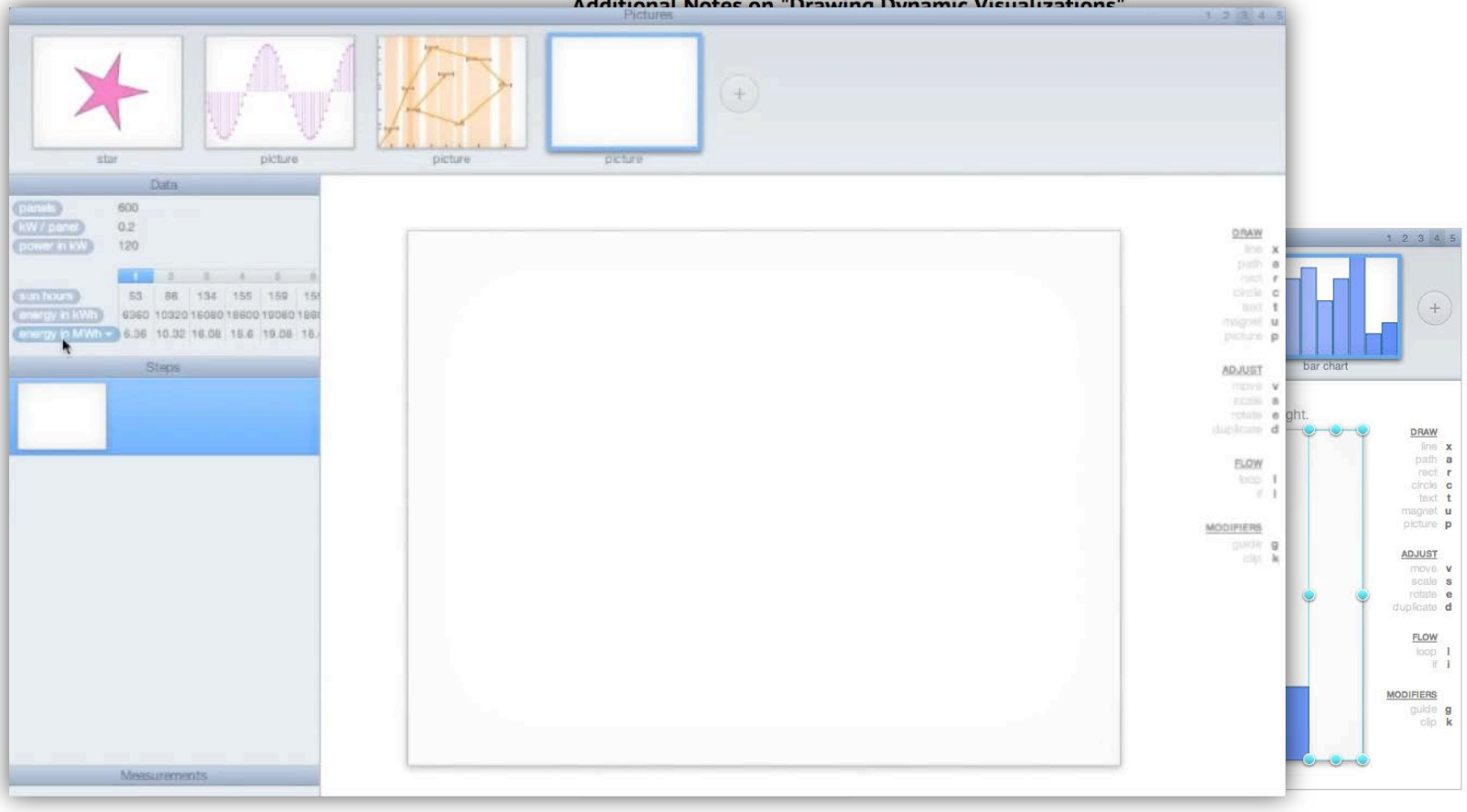
+ NEW, REUSABLE DESIGNS
+ SCALABLE
+ DYNAMIC & INTERACTIVE
~ EXPRESSIVE
- HARD

```
var diameter = 960,
    format = d3.format(",d"),
    color = d3.scale.category20c();

var bubble = d3.layout.pack()
    .sort(null)
    .size([diameter, diameter])
    .padding(1.5);

var svg = d3.select("body").append("svg")
    .attr("width", diameter)
    .attr("height", diameter)
    .attr("class", "bubble");

d3.json("flare.json", function(error, root) {
  if (error) throw error;

  var node = svg.selectAll(".node")
      .data(bubble.nodes(classes(root))
      .filter(function(d) { return !d.children; }))
    .enter().append("g")
      .attr("class", "node")
      .attr("transform", function(d) { return "translate

  node.append("title")
      .text(function(d) { return d.className + ": " + fo

  node.append("circle")
      .attr("r", function(d) { return d.r; })
      .style("fill", function(d) { return color(d.packag

  node.append("text")
      .attr("dy", ".3em")
      .style("text-anchor", "middle")
      .text(function(d) { return d.className.substring(0, d.r / 3); });
});

// Returns a flattened hierarchy containing all leaf nodes under the root.
function classes(root) {
  var classes = [];

  function recurse(name, node) {
    if (node.children) node.children.forEach(function(child) { recurse(node.name, child
    else classes.push({packageName: name, className: node.name, value: node.size});
  }

  recurse(null, root);
  return {children: classes};
}

d3.select(self.frameElement).style("height", diameter + "px");
```

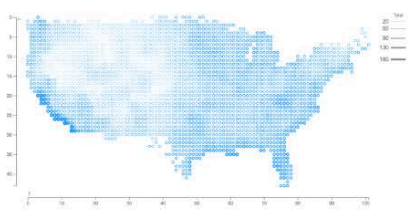
"BLINDLY MANIPULATING SYMBOLS"

DRAWING DYNAMIC VISUALIZATIONS

https://vimeo.com/66085662



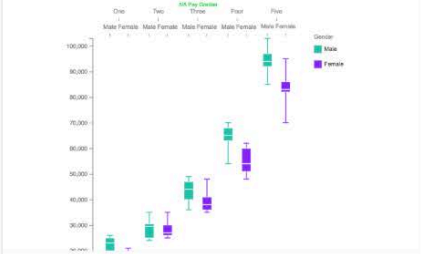
Click on each example to open it in Data Illustrator and to watch demo video. For best viewing experience, please use Google Chrome.



The Pleasant Places to Live

Binned map showing pleasant weather days in the US.

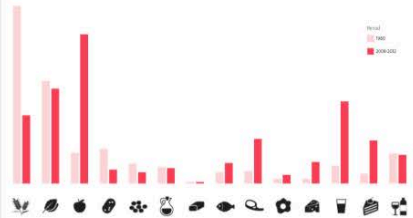
Open Example | Watch Demo



Gender Pay Gap - Box Plot

A box and whisker plot demonstrating the gender pay gap across salary grades.

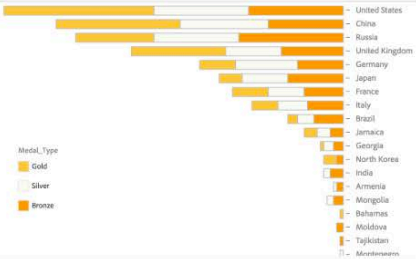
Open Example | Watch Demo



How Consumption Has Changed

How consumption of different types of food has changed since 1960

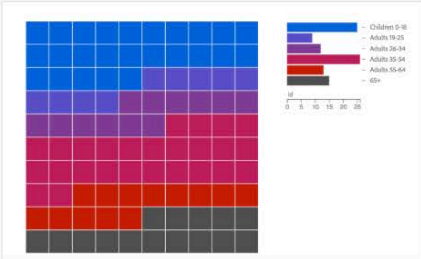
Open Example | Watch Demo



2012 Summer Olympic Medals

Stacked bar chart on the number of gold, silver and bronze medals by country

Open Example | Watch Demo



Population Distribution by Age

The distribution of population by age groups in the United States in 2016

Open Example | Watch Demo

Share of Women across Job Levels

The proportion of women declines in higher job titles.

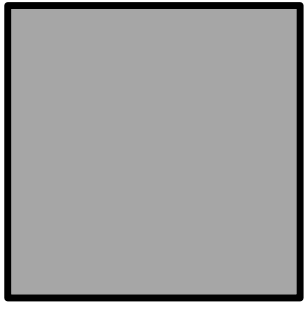
Open Example | Watch Demo

SPECIFYING VISUAL REPRESENTATIONS AS CODE

SOME DIFFERENT APPROACHES

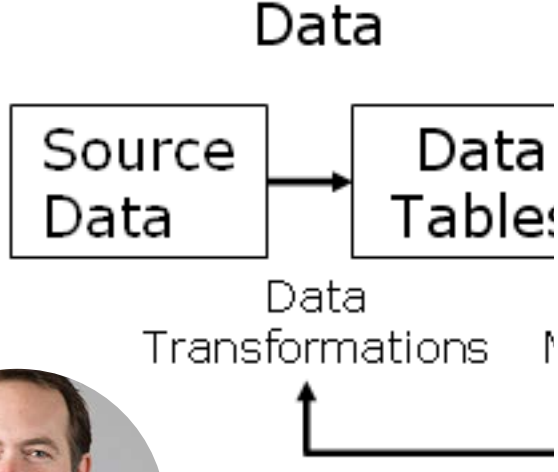
DRAWING PIXELS

```
background(255); // Setting the background to white
stroke(0); // Setting the outline (stroke) to black
fill(150); // Setting the interior of a shape (fill)
to grey rect(50,50,75,100); // Drawing the rectangle
```

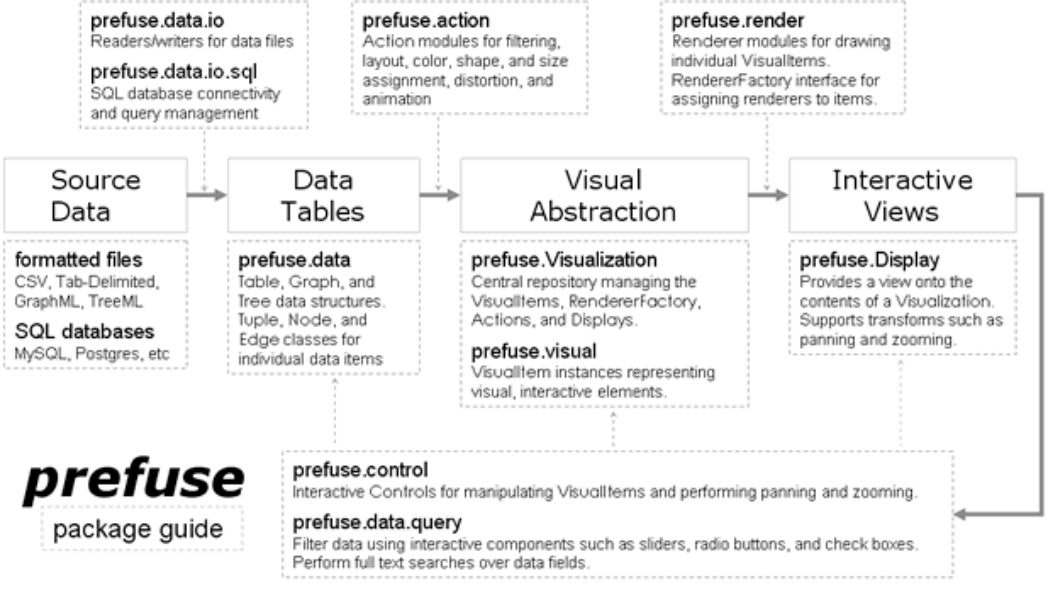


SOME DIFFERENT APPROACHES

COMPUTATIONALLY IMPLEMENTING VISUALIZATION REFERENCE MODEL

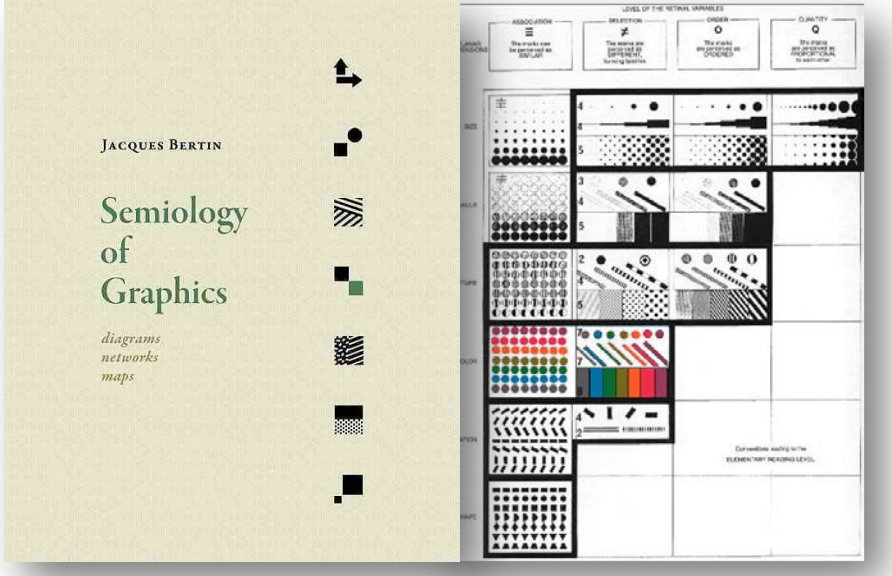


JEFF HEER 2005

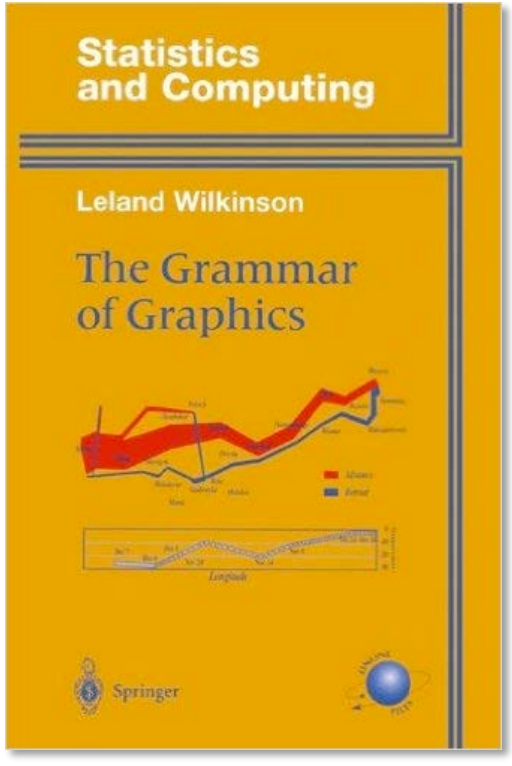


SOME DIFFERENT APPROACHES

DESCRIBING CONCEPTUAL PROPERTIES OF VISUALIZATIONS



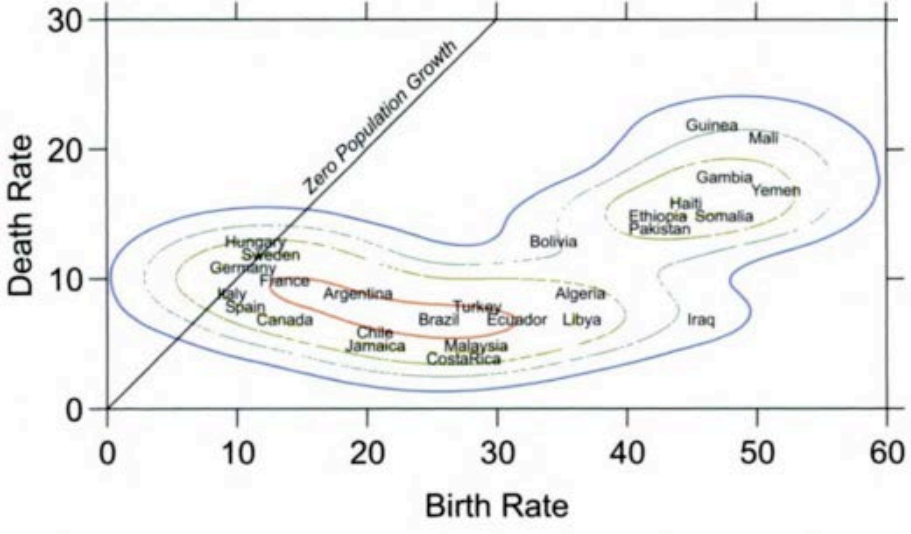
JACQUES BERTIN 1963



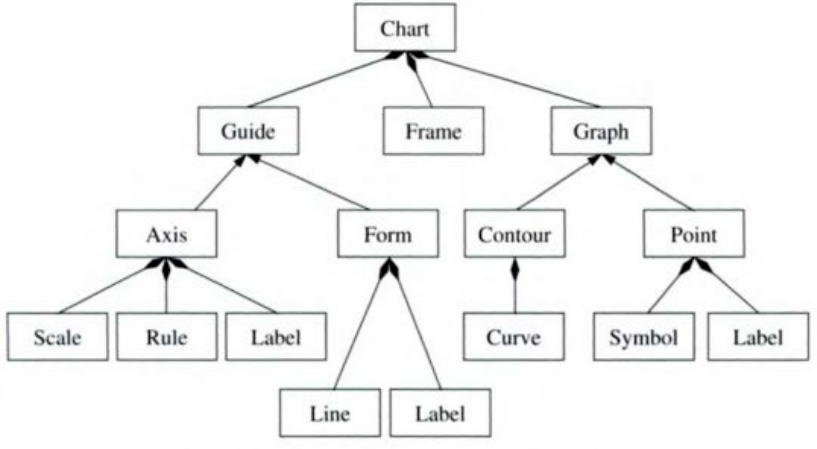
THE GRAMMAR OF GRAPHICS

LELAND WILKINSON 1999

A FORMAL LANGUAGE
FOR **DESCRIBING** DATA
GRAPHICS



ELEMENT: *point*(*position*(birth*death), *size*(0), *label*(country))
ELEMENT: *contour*(*position*(
smooth.density.kernel.epanechnikov.joint(birth*death)),
color.hue())
GUIDE: *form.line*(*position*((0,0),(30,30)), *label*("Zero Population Growth"))
GUIDE: *axis*(*dim*(1), *label*("Birth Rate"))
GUIDE: *axis*(*dim*(2), *label*("Death Rate"))



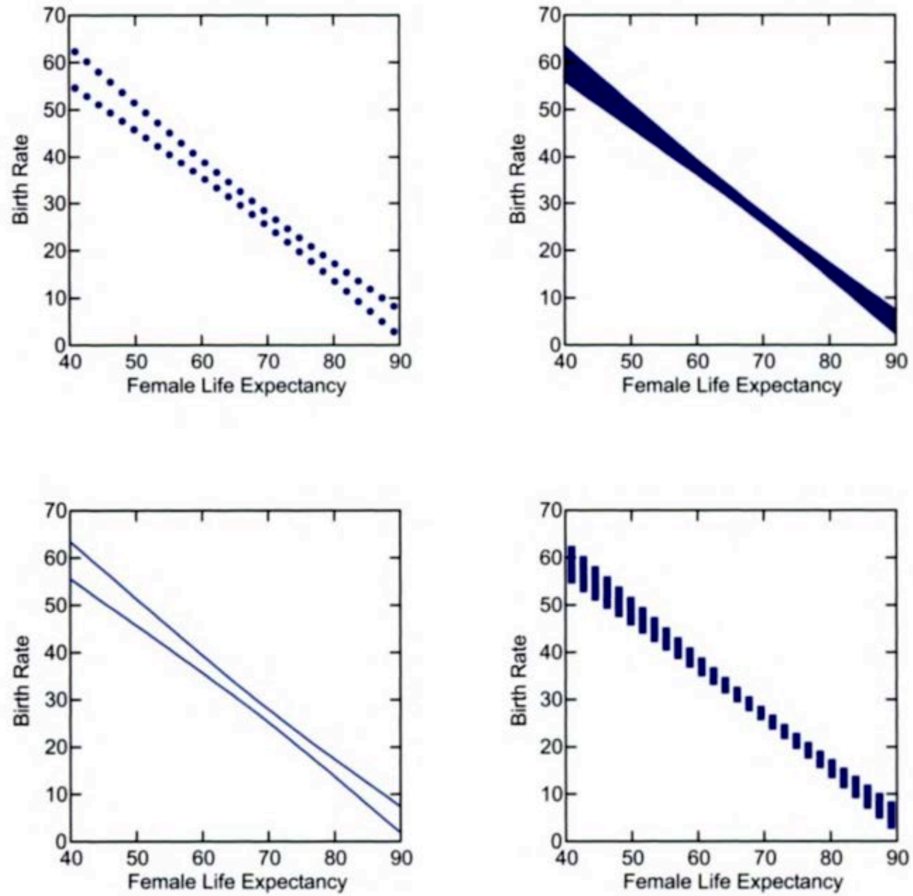
COMPOSABLE AND GENERATIVE LANGUAGES WAYS OF DESCRIBING A HUGE VARIETY OF CHART DESIGNS

ELEMENT: _point_(_position_(_region.confi.smooth.linear_(female*birth)))

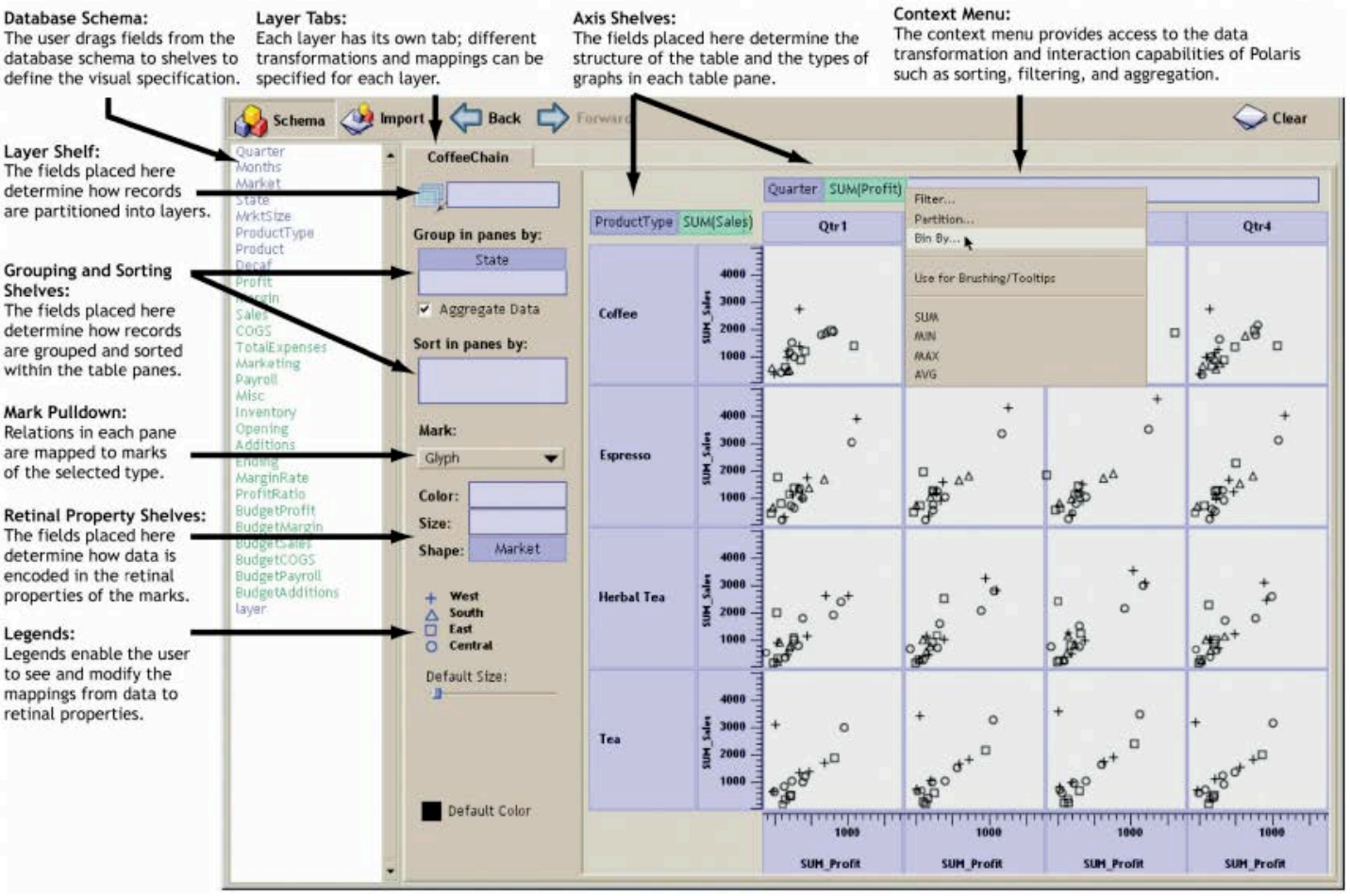
ELEMENT: _line_(_position_(_region.confi.smooth.linear_(female*birth)))

ELEMENT: _area_(_position_(_region.confi.smooth.linear_(female*birth)))

ELEMENT: _interval_(_position_(_region.confi.smooth.linear_(female*birth)))



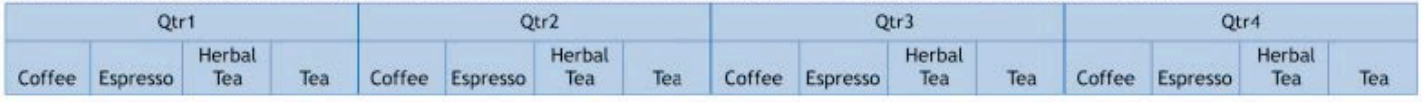
VizQL & POLARIS



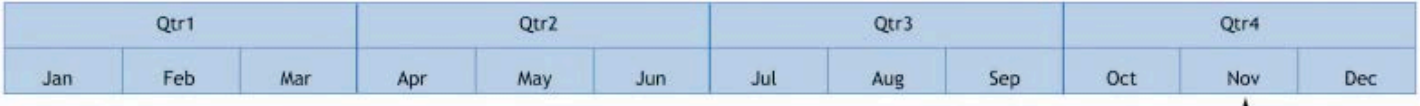
O = Quarter = {Qtr1, Qtr2, Qtr3, Qtr4} = Qtr1 + Qtr2 + Qtr3 + Qtr4:

O + O = Quarter + Product = {Qtr1, Qtr2, Qtr3, Qtr4, Coffee, Espresso, Herbal Tea, Tea}:

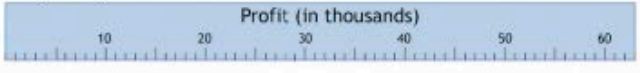
O x O = Quarter x Product = {(Qtr1,Coffee), (Qtr1,Espresso), (Qtr1,Herbal Tea), (Qtr1, Tea), (Qtr2, Coffee) ... (Qtr4, Tea)}:



O/O = Quarter / Month = {(Qtr1,Jan), (Qtr1,Feb), (Qtr1,Mar), (Qtr2, Apr), (Qtr2, May) ... (Qtr4, Dec)}:



Q = Profit = {Profit}:



The set entry (Qtr4,Nov) corresponds to this column

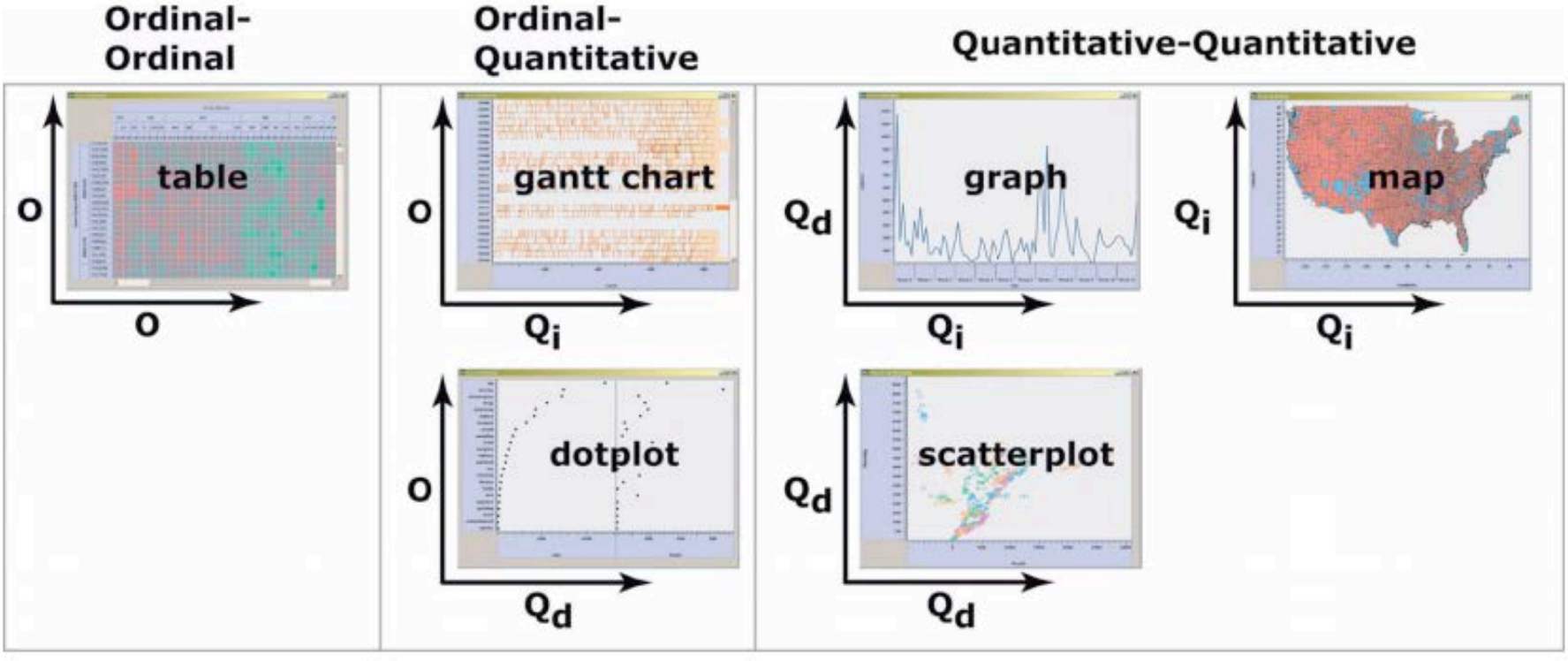
Q + Q = Profit + Sales = {Profit, Sales}:

O x Q = Quarter x Profit = {(Qtr1,Profit), (Qtr2, Profit), (Qtr3, Profit), (Qtr4, Profit)}:

Ordinal fields partition an axis into columns (or rows)

Quantitative fields are spatially encoded as axes

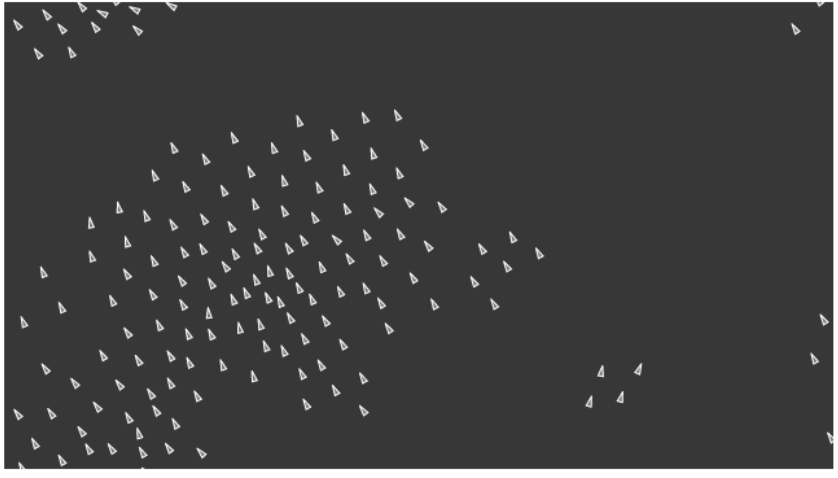
Quantitative fields: *Profit, Sales*
Ordinal fields: *Quarter, Months, Product*

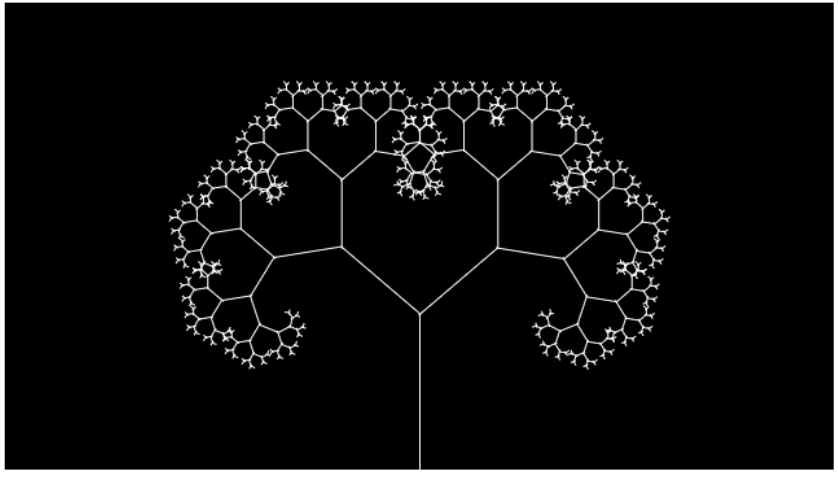

Ordinal-
Ordinal
Ordinal-
Quantitative
Quantitative-Quantitative
table
O
O
gantt chart
O
Qi
dotplot
O
Qd
graph
Qd
Qi
scatterplot
Qd
Qd
map
Qi
Qi

VISUALIZATION LANGUAGES AND TOOLKITS

DESKTOP

PROCESSING / P5.js



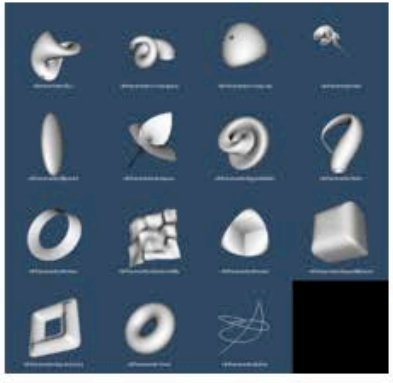
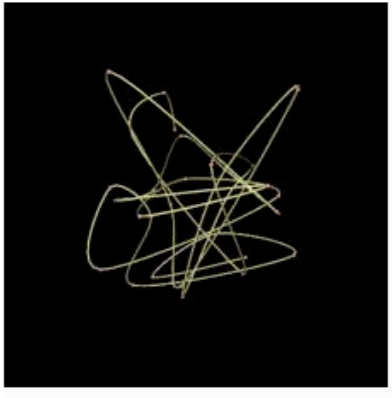
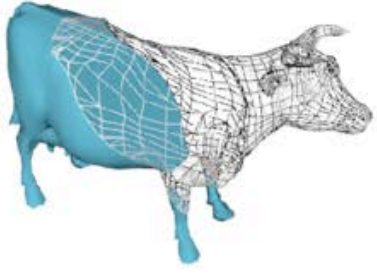
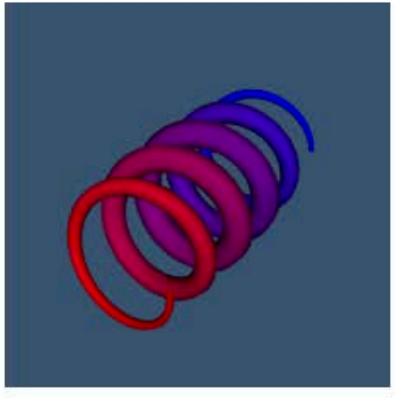


TARGETED AT ARTISTS & NON-EXPERTS

DESIGNED TO MAKE **DRAWING** & **INTERACTION** EASY

NO VISUALIZATION PRIMITIVES

VTK (VISUALIZATION TOOLKIT)

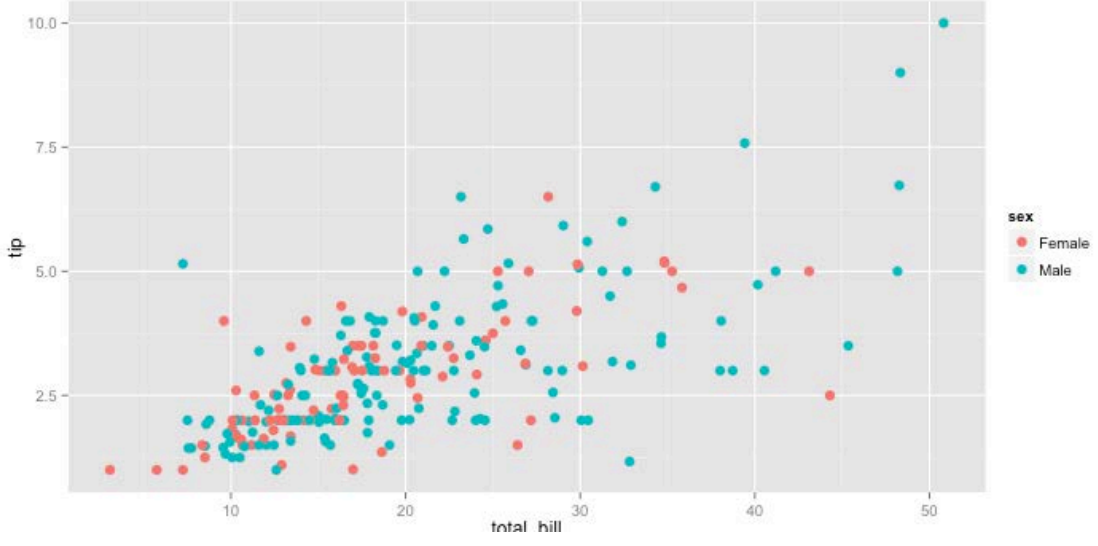
ESPECIALLY COMMON FOR SCIENTIFIC VISUALIZATION

C++ (Python, Java, and Tcl WRAPPERS)

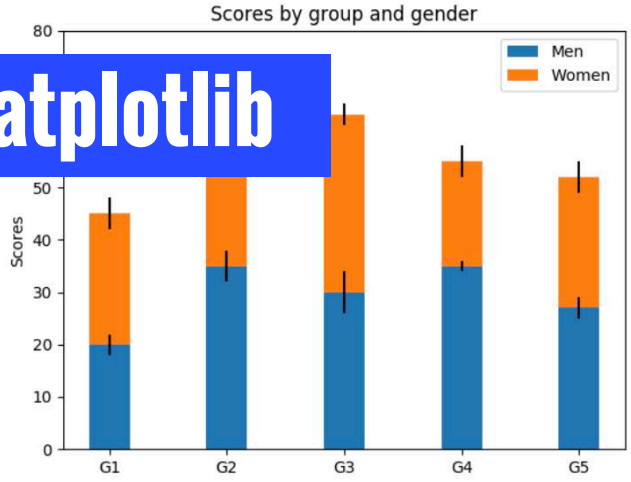
GGPLOT2

PLOTTING IN **R** BASED ON THE **GRAMMAR OF GRAPHICS**

```
layer_point <- geom_point(
  mapping = aes(x = total_bill, y = tip, color = sex),
  data = tips,
  size = 3
)
ggplot() + layer_point
```

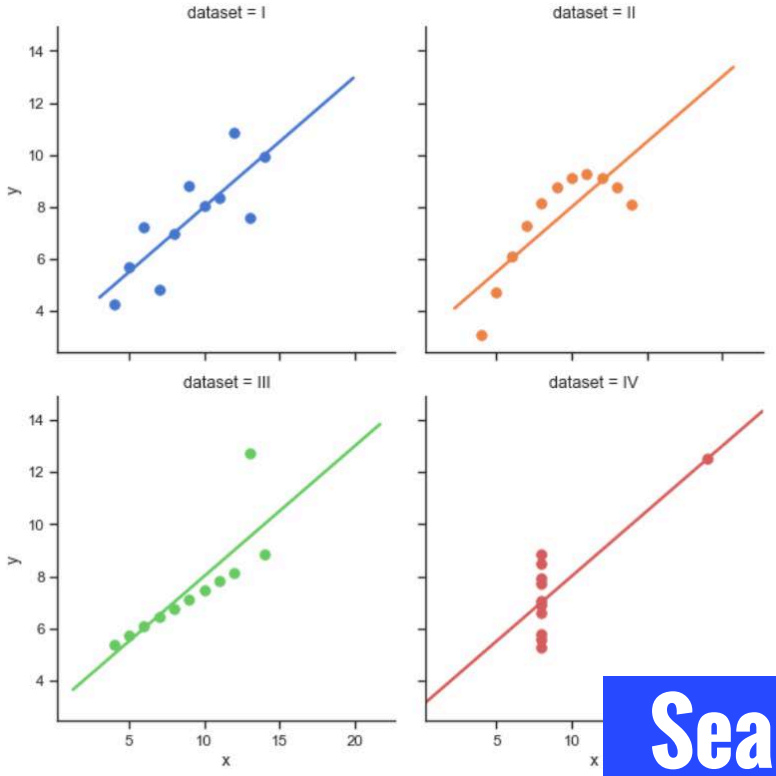


Matplotlib




```
import numpy as np
import matplotlib.pyplot as plt


N = 5
menMeans = (20, 35, 30, 35, 27)
womenMeans = (25, 32, 34, 20, 25)
menStd = (2, 3, 4, 1, 2)
womenStd = (3, 5, 2, 3, 3)
ind = np.arange(N)    # the x locations for the groups
width = 0.35       # the width of the bars: can also be l

p1 = plt.bar(ind, menMeans, width, yerr=menStd)
p2 = plt.bar(ind, womenMeans, width,
             bottom=menMeans, yerr=womenStd)

plt.ylabel('Scores')
plt.title('Scores by group and gender')
plt.xticks(ind, ('G1', 'G2', 'G3', 'G4', 'G5'))
plt.yticks(np.arange(0, 81, 10))
plt.legend((p1[0], p2[0]), ('Men', 'Women'))

plt.show()
```

Seaborn



Python source code: [download source: anscombes_quartet.py]

```
import seaborn as sns
sns.set(style="ticks")

# Load the example dataset for Anscombe's quartet
df = sns.load_dataset("anscombe")

# Show the results of a linear regression within each dataset
sns.lmplot(x="x", y="y", col="dataset", hue="dataset", data=df,
           col_wrap=2, ci=None, palette="muted", height=4,
           scatter_kws={"s": 50, "alpha": 1})
```

VISUALIZATION LANGUAGES AND TOOLKITS

WEB

WHY DEVELOP FOR THE WEB?

NOW THE **DOMINANT PLATFORM FOR VIS CONSUMPTION**

INTEGRATE VISUALIZATIONS INTO WEB PAGES AND APPLICATIONS

LEVERAGE **OTHER HTML5/JS LIBRARIES** AND TOOLS

DEBUG AND TUNE IN THE BROWSER

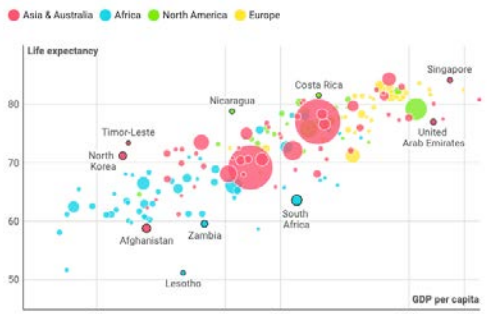
GOOGLE CHARTS

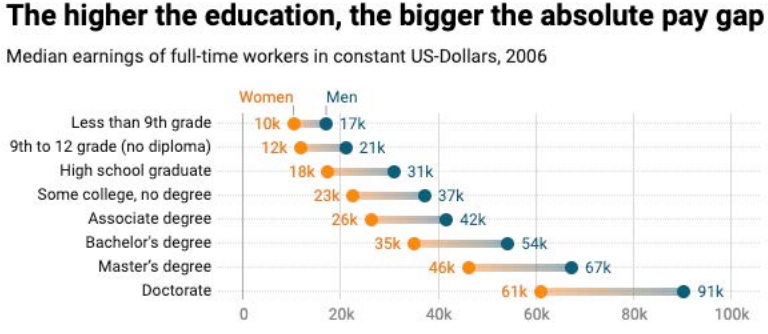
EASY TO INSERT **PREDEFINED CHARTS TYPES** INTO PAGES AND STYLE THEM

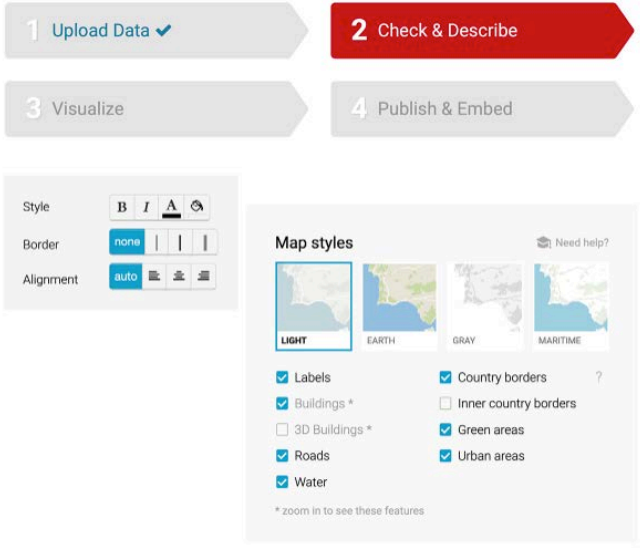
```
// Callback that creates and populates a data table,
// instantiates the pie chart, passes in the data and
// draws it.
function drawChart() {

  // Create the data table.
  var data = new google.visualization.DataTable();
  data.addColumn('string', 'Topping');
  data.addColumn('number', 'Slices');
  data.addRows([
    ['Mushrooms', 3],
    ['Onions', 1],
    ['Olives', 1],
    ['Zucchini', 1],
    ['Pepperoni', 2]
  ]);

  // Set chart options
  var options = {'title':'How Much Pizza I Ate Last Night',
                 'width':400,
                 'height':300};

  // Instantiate and draw our chart, passing in some options.
  var chart = new google.visualization.PieChart(document.getElementById('chart_div'));
  chart.draw(data, options);
}
```

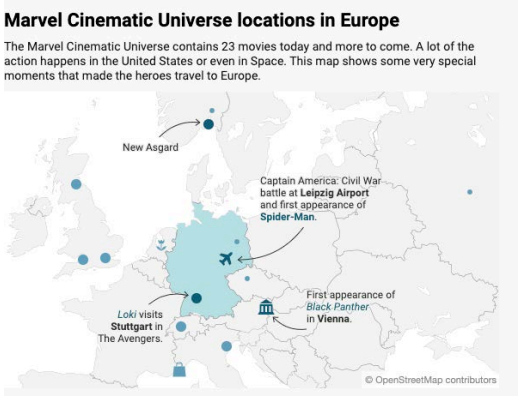
DATAWRAPPER

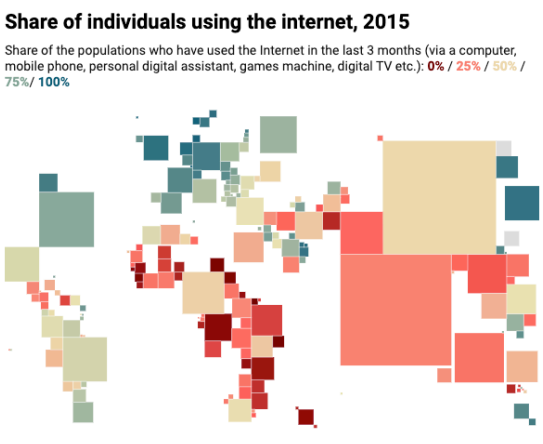
LOTS OF COMMON CHART TYPES WITH INTERACTIVITY VIA A **VISUAL INTERFACE**





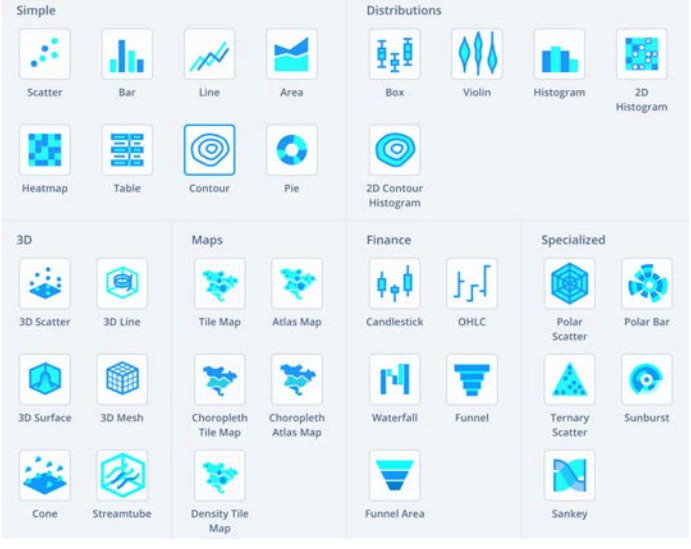


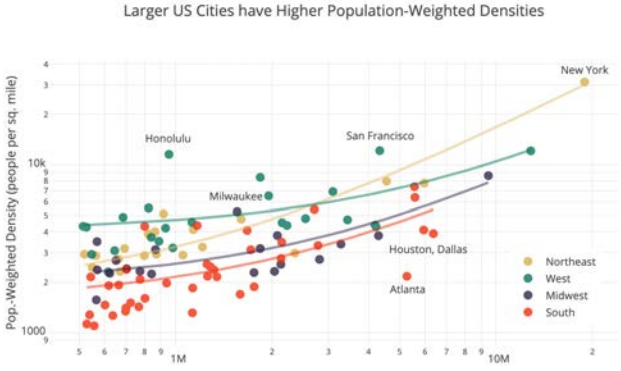


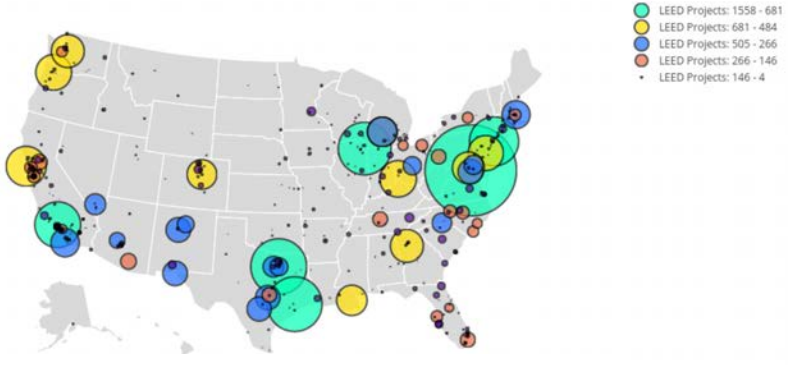


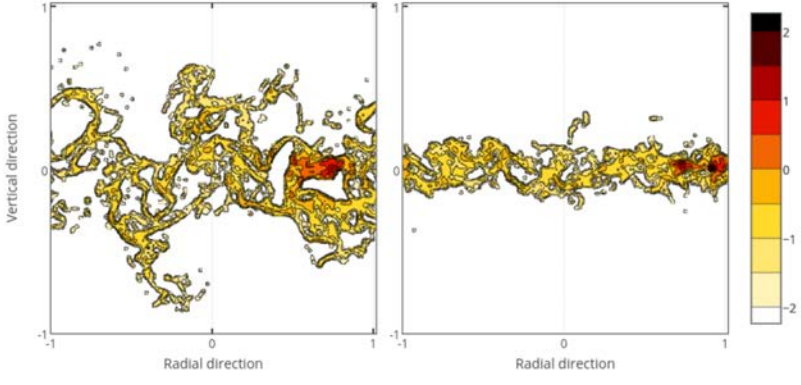
PLOT.LY

LARGE VOCABULARY OF CHART TEMPLATES + **VISUAL INTERFACE + SCRIPTING**









D3.JS

Data-Driven Documents

D3.JS

JAVASCRIPT / HTML5 / SVG / CSS

DYNAMIC DOCUMENT MANIPULATION AND VISUALIZATION

SUPPORT FOR BINDING DATA TO ELEMENTS,
HANDLING SCALES & LAYOUTS, ANIMATION,
AND MUCH MORE!

DECLARATIVE VISUALIZATION DESIGN

(SORT OF LIKE **JQUERY** FOR VISUALIZATION)

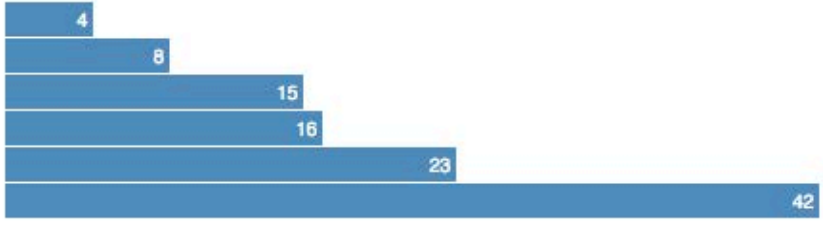
IMPERATIVE

```
var paragraphs = document.getElementsByTagName("p");
for (var i = 0; i < paragraphs.length; i++) {
  var paragraph = paragraphs.item(i);
  paragraph.style.setProperty("color", "white", null);
}
```

DECLARATIVE

```
d3.selectAll("p").style("color", "white");
```

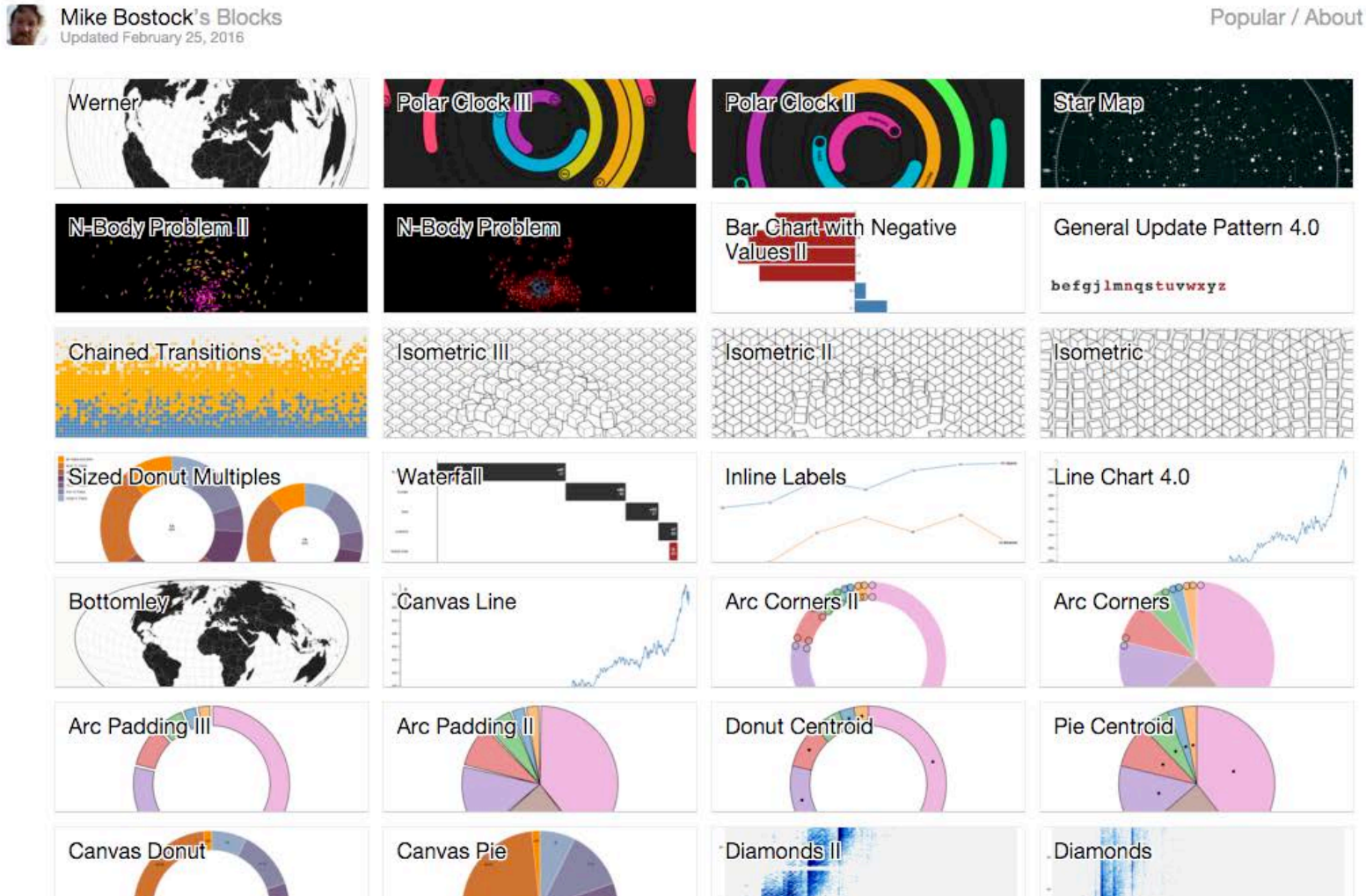
```
var data = [4, 8, 15, 16, 23, 42];
```




```
<!DOCTYPE html>
<style>

.chart div {
  font: 10px sans-serif;
  background-color: steelblue;
  text-align: right;
  padding: 3px;
  margin: 1px;
  color: white;
}

</style>
<div class="chart">
  <div style="width: 40px;">4</div>
  <div style="width: 80px;">8</div>
  <div style="width: 150px;">15</div>
  <div style="width: 160px;">16</div>
  <div style="width: 230px;">23</div>
  <div style="width: 420px;">42</div>
</div>
```

```
var data = [4, 8, 15, 16, 23, 42];

d3.select(".chart")
  .selectAll("div")
    .data(data)
  .enter().append("div")
    .style("width", function(d) { return d * 10 + "px"; })
    .text(function(d) { return d; });
```

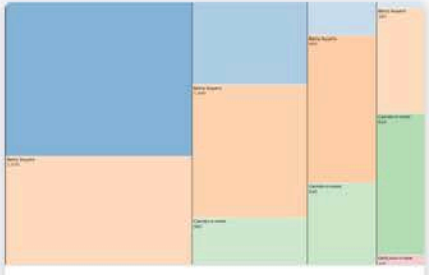
GREAT TUTORIALS & A HUGE LIBRARY OF EXAMPLES



Visualization

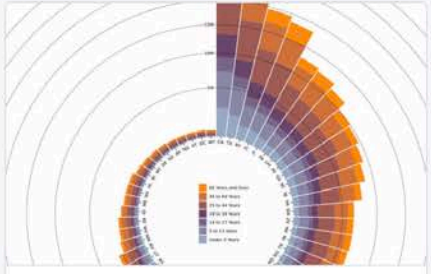
Explore and explain patterns in quantitative data using D3 and Vega.

By Observable



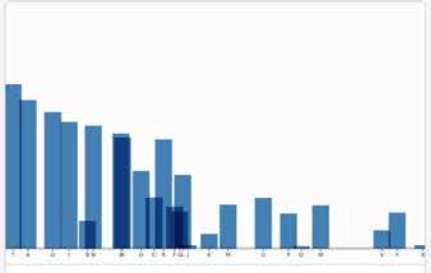
D3 Marimekko Chart

Mike Bostock on Jan 7 ♡4



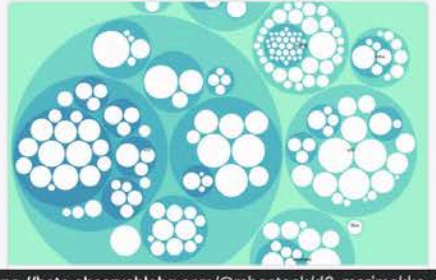
D3 Radial Stacked Bar Chart II

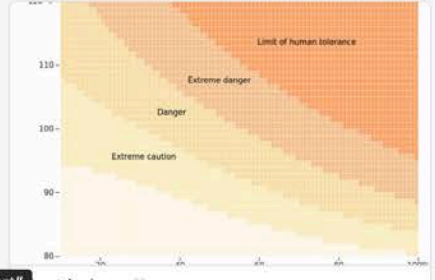
Mike Bostock on Jan 6 ♡1



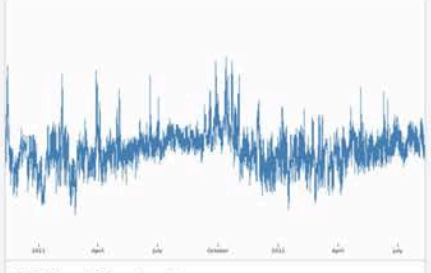
D3 Sortable Bar Chart

Mike Bostock on Nov 29 ♡9



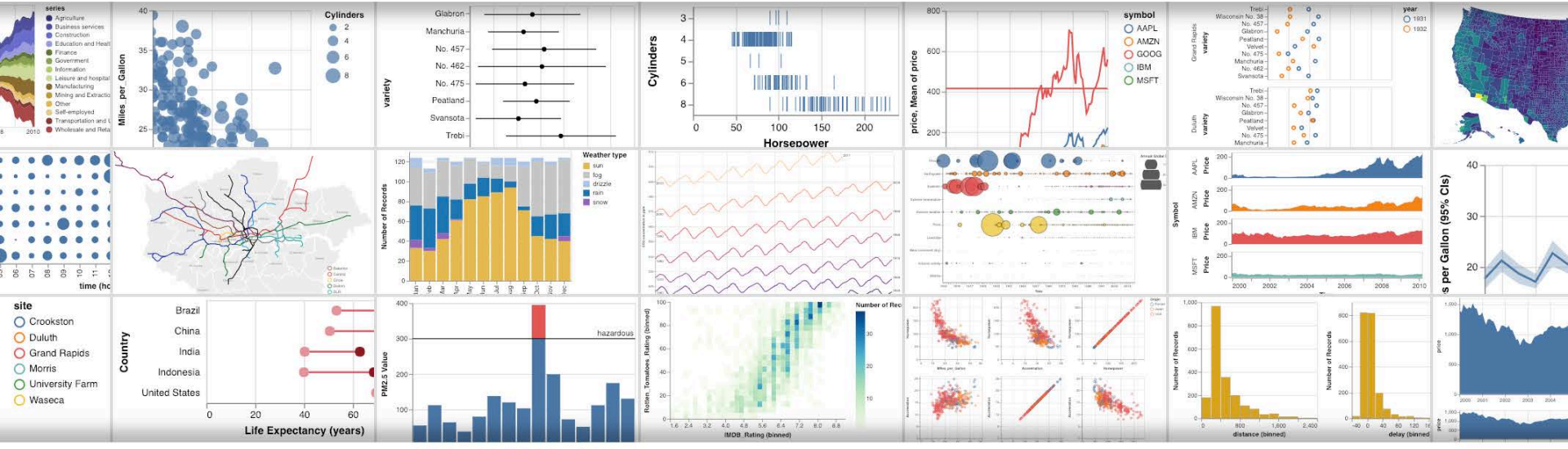


eat index

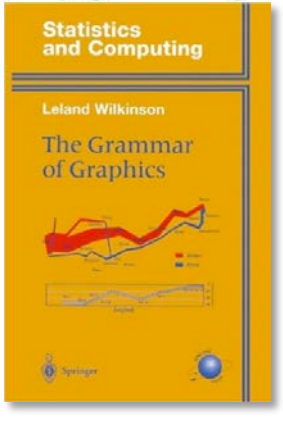


D3 Band Chart

Vega-Lite – A Grammar of Interactive Graphics

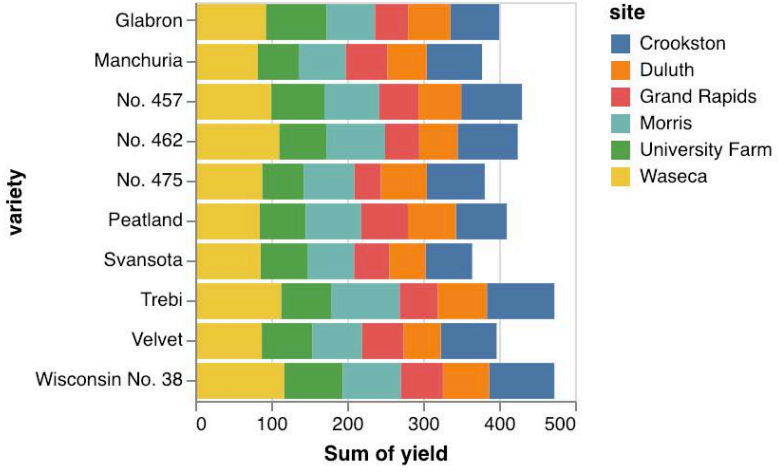


Vega-Lite is a high-level grammar of interactive graphics. It provides a concise JSON syntax for rapidly generating visualizations to support analysis. Vega-Lite specifications can be compiled to Vega specifications.



A simple, powerful JSON syntax for authoring interactive visualizations inspired by Wilkinson's Grammar of Graphics.

Horizontal Stacked Bar Chart

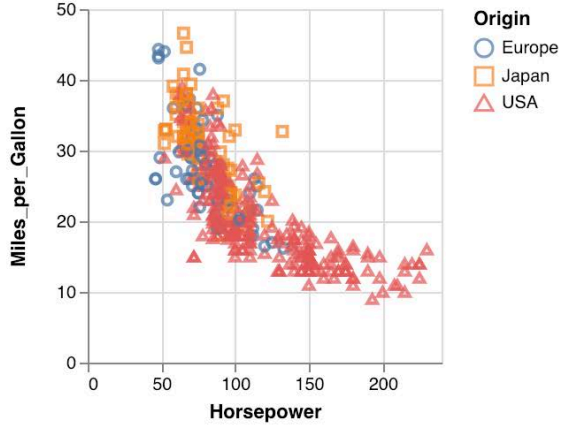


View this example in the online editor

Vega-Lite JSON Specification

```
{
  "$schema": "https://vega.github.io/schema/vega-lite/v3.json",
  "data": {"url": "data/barley.json"},
  "mark": "bar",
  "encoding": {
    "x": {"aggregate": "sum", "field": "yield", "type": "quantitative"},
    "y": {"field": "variety", "type": "nominal"},
    "color": {"field": "site", "type": "nominal"}
  }
}
```

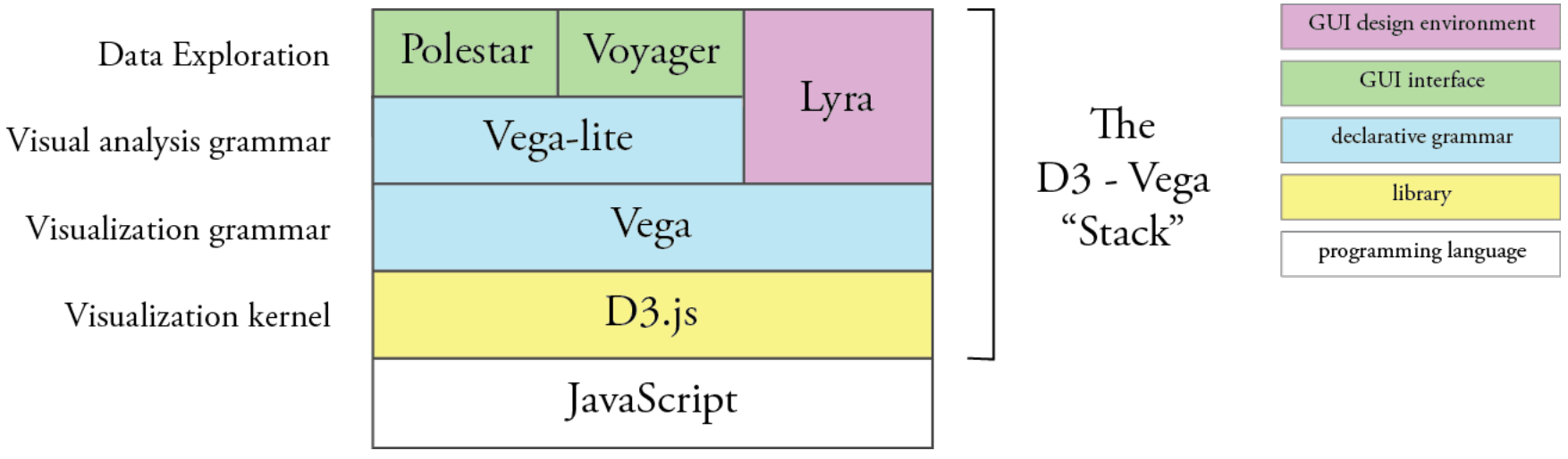
Colored Scatterplot



View this example in the online editor

Vega-Lite JSON Specification

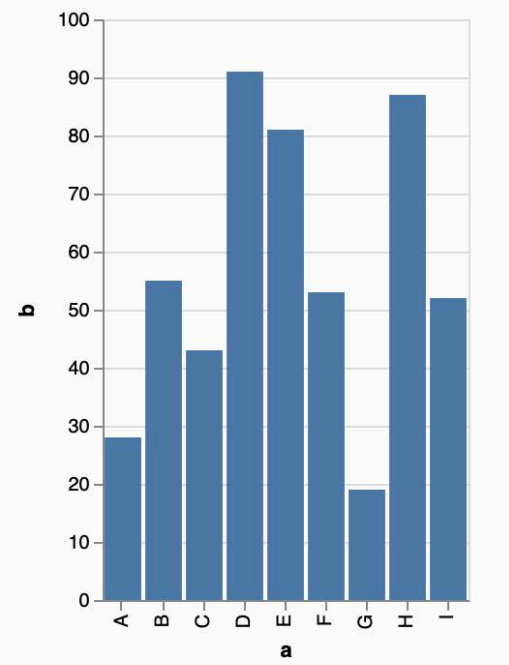
```
{
  "$schema": "https://vega.github.io/schema/vega-lite/v3.json",
  "description": "A scatterplot showing horsepower and miles per
gallons.",
  "data": {"url": "data/cars.json"},
  "mark": "point",
  "encoding": {
    "x": {"field": "Horsepower", "type": "quantitative"},
    "y": {"field": "Miles_per_Gallon", "type": "quantitative"},
    "color": {"field": "Origin", "type": "nominal"},
    "shape": {"field": "Origin", "type": "nominal"}
  }
}
```


Data Exploration
Visual analysis grammar
Visualization grammar
Visualization kernel
Polestar
Voyager
Lyra
Vega-lite
Vega
D3.js
JavaScript
The
D3 - Vega
"Stack"
GUI design environment
GUI interface
declarative grammar
library
programming language

Altair

Python wrappers for Vega-Lite!

Works with Pandas, Jupyter, etc.



Save as SVG Save as PNG View Source O

Vega-Lite JSON Specification


```
{
  "$schema": "https://vega.github.io/schema/vega-lite/v3.json",
  "description": "A simple bar chart with embedded data.",
  "data": {
    "values": [
      {"a": "A","b": 28}, {"a": "B","b": 55}, {"a": "C","b": 43},
      {"a": "D","b": 91}, {"a": "E","b": 81}, {"a": "F","b": 53},
      {"a": "G","b": 19}, {"a": "H","b": 87}, {"a": "I","b": 52}
    ]
  },
  "mark": "bar",
  "encoding": {
    "x": {"field": "a", "type": "ordinal"},
    "y": {"field": "b", "type": "quantitative"}
  }
}
```

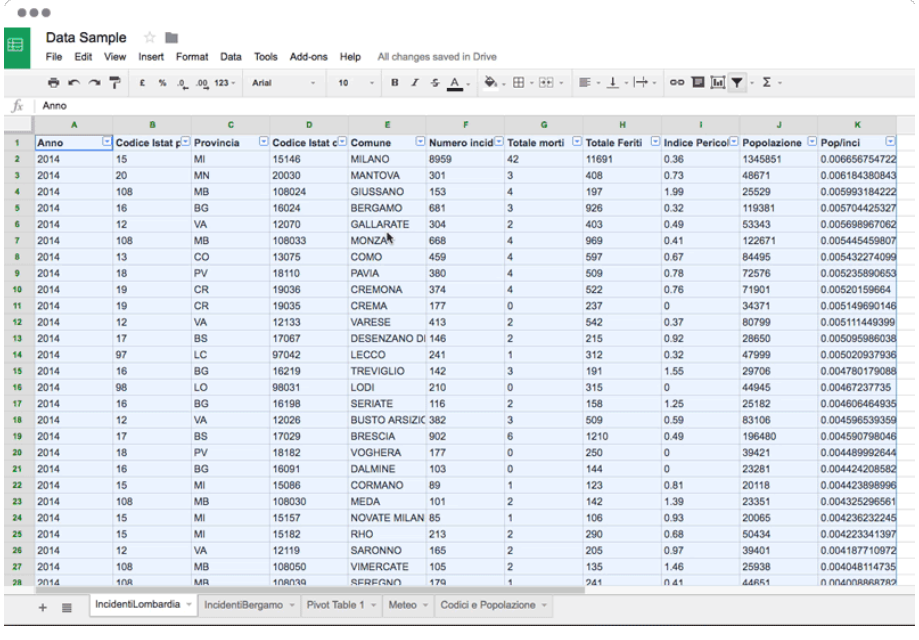

Display a menu

```
import altair as alt
import pandas as pd

source = pd.DataFrame({
    'a': ['A', 'B', 'C', 'D', 'E', 'F', 'G', 'H', 'I'],
    'b': [28, 55, 43, 91, 81, 53, 19, 87, 52]
})

alt.Chart(source).mark_bar().encode(
    x='a',
    y='b'
)
```

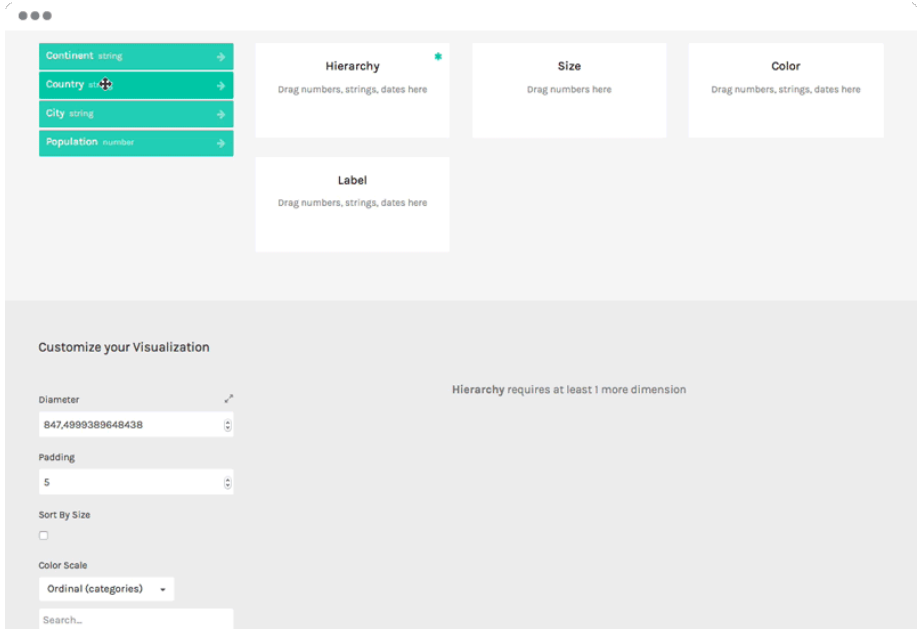
OTHER USEFUL LIBRARIES

RAWGraphs

The missing link between spreadsheets and data visualization.

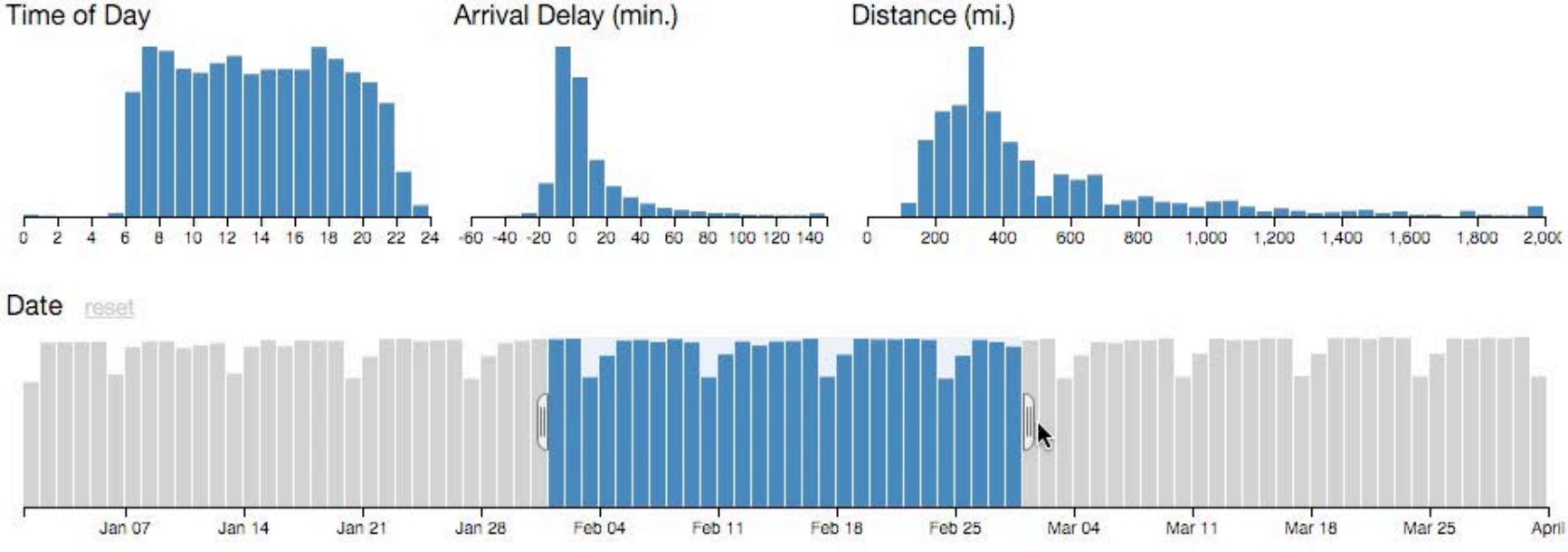


Anno	Codice Istat p	Provincia	Codice Istat c	Comune	Numero incid	Totale morti	Totale Feriti	Indice Perico	Popolazione	Pop/inci
2014	15	MI	15146	MILANO	8959	42	11691	0.36	1345851	0.006656754722
2014	20	MN	20030	MANTOVA	301	3	408	0.73	48671	0.006184380843
2014	108	MB	108024	GIUSSANO	153	4	197	1.99	25529	0.005993184222
2014	16	BG	16024	BERGAMO	681	3	926	0.32	119381	0.005704425327
2014	12	VA	12070	GALLARATE	304	2	403	0.49	53343	0.005698967062
2014	108	MB	108033	MONZA	668	4	969	0.41	122671	0.005445459807
2014	13	CO	13075	COMO	459	4	597	0.67	84495	0.005432274099
2014	18	PV	18110	PAVIA	380	4	509	0.78	72576	0.005235890653
2014	19	CR	19036	CREMONA	374	4	522	0.76	71901	0.00520159664
2014	19	CR	19035	CREMA	177	0	237	0	34371	0.005149690146
2014	12	VA	12133	VARESE	413	2	542	0.37	80799	0.005111449399
2014	17	BS	17067	DESENZANO DI	146	2	215	0.92	28650	0.005095986038
2014	97	LC	97042	LECCO	241	1	312	0.32	47999	0.005020937936
2014	16	BG	16219	TREVIGLIO	142	3	191	1.55	29706	0.004780179088
2014	98	LO	98031	LODI	210	0	315	0	44945	0.00467237735
2014	16	BG	16198	SERIATE	116	2	158	1.25	25182	0.004606464935
2014	12	VA	12026	BUSTO ARSIZIO	382	3	509	0.59	83106	0.004596539359
2014	17	BS	17029	BRESCIA	902	6	1210	0.49	196480	0.004590798046
2014	18	PV	18182	VOGHERA	177	0	250	0	39421	0.004489992644
2014	16	BG	16091	DALMINE	103	0	144	0	23281	0.004424208582
2014	15	MI	15086	CORMANO	89	1	123	0.81	20118	0.004423898996
2014	108	MB	108030	MEDA	101	2	142	1.39	23351	0.004325296561
2014	15	MI	15157	NOVATE MILAN	85	1	106	0.93	20065	0.004236232245
2014	15	MI	15182	RHO	213	2	290	0.68	50434	0.004223341397
2014	12	VA	12119	SARONNO	165	2	205	0.97	39401	0.004187710972
2014	108	MB	108050	VIMERCATE	105	2	135	1.46	25938	0.004048114735
2014	108	MB	108039	SEREGNO	179	1	241	0.41	44651	0.004008868782



Square

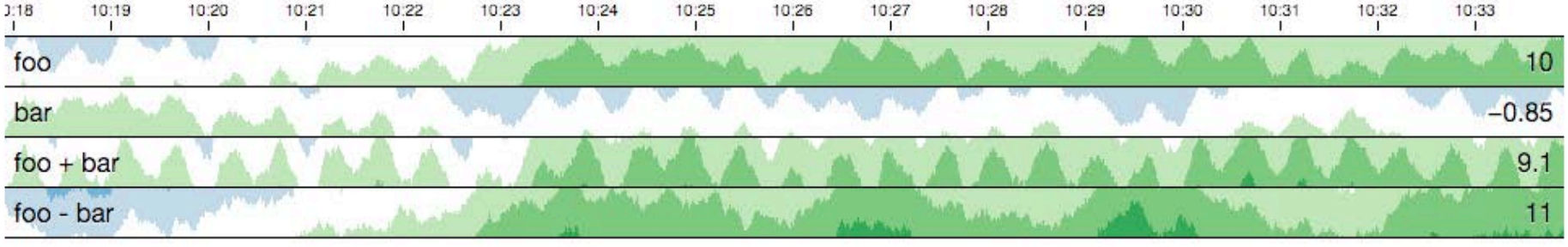
Crossfilter



Square

Cubism.js

Time Series Visualization

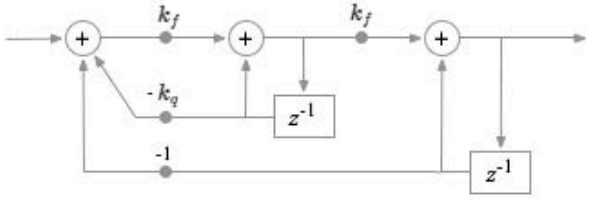


Mouseover or use the arrow keys to inspect values.
Open in a new window.

Cubism.js is a D3 plugin for visualizing time series. Use Cubism to construct better realtime dashboards, pulling data from Graphite, Cube and other sources. Cubism is available under the Apache License on GitHub.

Tangle http://worrydream.com/Tangle/

Below is a simplified digital adaptation of the analog state variable filter.



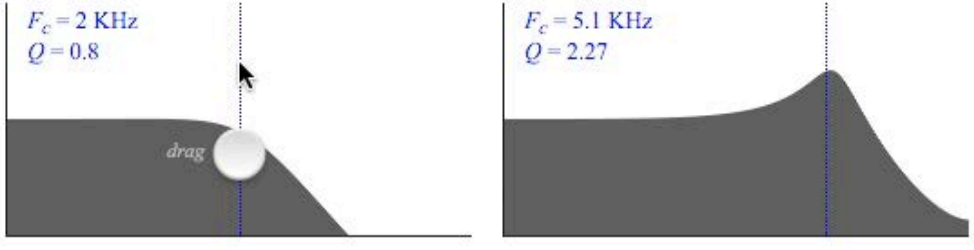
This topology is particularly useful for embedded audio processing, because F_c (cutoff frequency) and Q (resonance) are controlled by independent coefficients, k_f and k_q. (With most filters, the coefficients are functions of both parameters, which precludes pre-calculated lookup tables.)

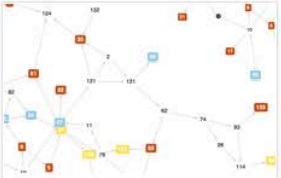
The coefficients and transfer function are:

$$k_f = 2sin(\pi\frac{F_c}{Fs}) \qquad k_q = \frac{1}{Q}$$

$$H(z) = \frac{{k_f}^2}{1-(2-k_f(k_f+k_q))z^{-1}+(1-k_fk_q)z^{-2}}$$

Some example frequency responses:



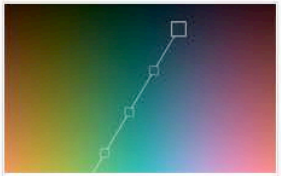


Arbor.js

A library of force-directed layout algorithms plus abstractions for graph organi

CartoDB

A web service for mapping, analyzing and building applications with data.

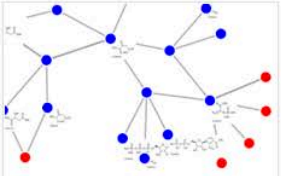


Chroma.js

Interactive color space explorer that allows to preview a set of linear

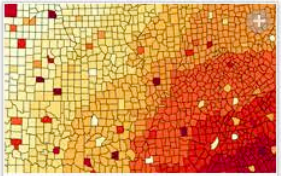
Circos

A software package for visualizing data in a circular layout.



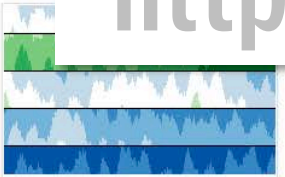
Cola.js

A library for arranging networks using constraint-based optimization



ColorBrewer

A web tool for selecting colors for maps.



Cubism.js

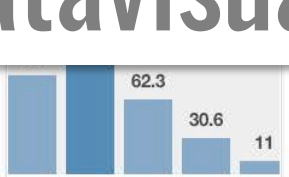
A library for creating interactive time series and horizon graphs based on D3.js

Cytoscape

An application for visualizing complex networks and integrating these with any type of attribute data.

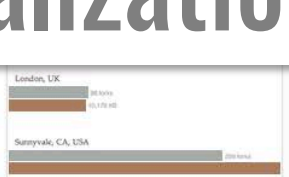
D3.js

An small, flexible and efficient library to create and manipulate interactive documents based on data.



Dance.js

A simple data-driven visualization framework based on Data.js and Underscore.js

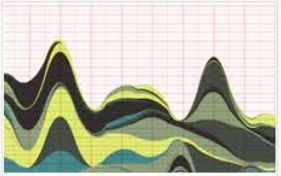


Data.js

A data representation framework providing a uniform interface to domain data.

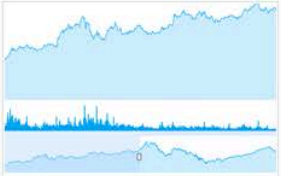
DataWrangler

An interactive web application for data cleaning and transformation.



Degrafa

A powerful declarative graphics framework for rich user interfaces, data visualizations and mapping.



Envision.js

A library for creating fast, dynamic and interactive time series visualizations.

Flare

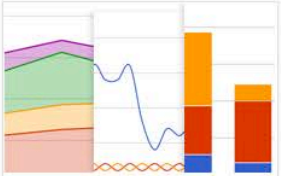
A set of software tools for creating rich interactive data visualizations in ActionScript.

GeoCommons

A public community and set of tools to access, visualize and analyze data with compelling map visualizations.

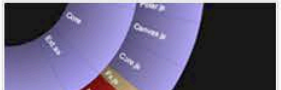
Gephi

A visualization and exploration platform for networks with dynamic and hierarchical graphs.



Google Chart Tools

A collection of simple to use, customizable and free to use interactive charts and data tools.



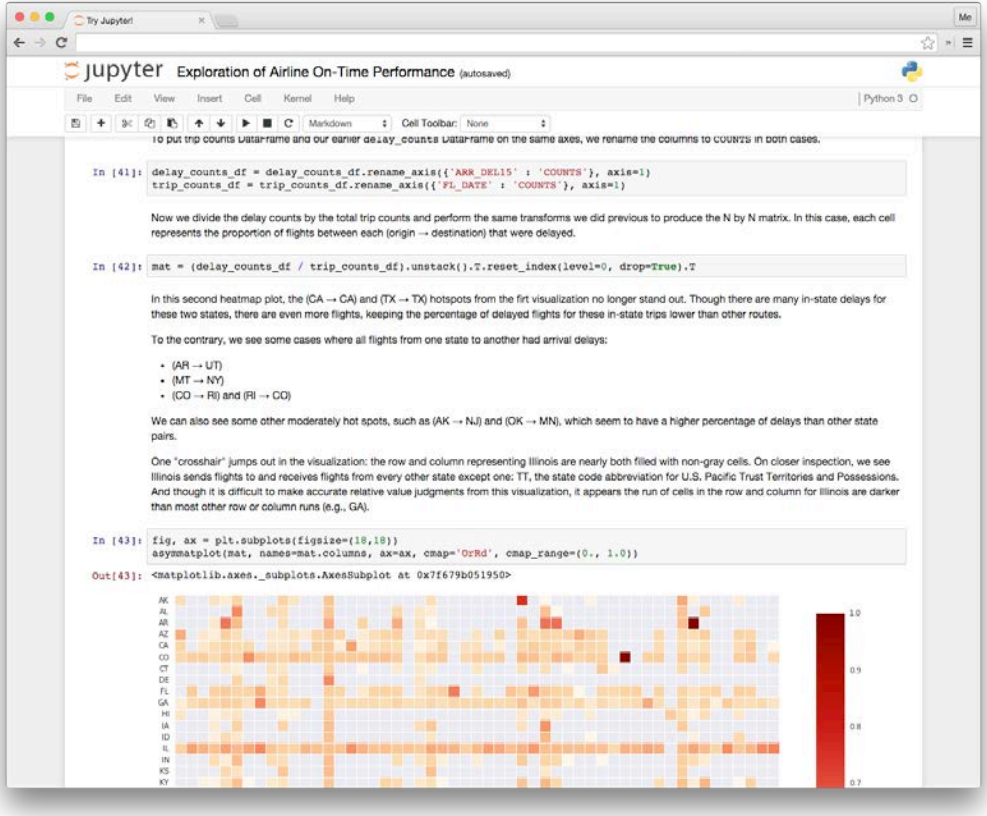
WHAT TO USE?

There are **many** different visualization tools available.

Need to balance tradeoffs:

- Expressiveness (Can I create the visualization I want/need?)
- Speed & Flexibility (How quickly can I generate, modify, and explore?)
- Reproducibility (Can I re-run the analysis? Re-generate the vis with new data?)
- Presentation (Can I style? Annotate? Share?)
- Interoperability (Can I integrate with other tools and applications?)

THIS COURSE: WHY TABLEAU + JUPYTER?



QUESTIONS?