Programming Principles in Python (CSCI 503/490)

Data Visualization

Dr. David Koop

Unpivot/Melt

- Many columns (wider) become two columns (longer): one with column name (variable), other with value

id	year	month	element	d1	d2	d3	d4	d5	d6	d7	d8
str	i32	i32	str	f64	f64	f64	f64	f64	f64	f64	f64
"MX000017004"	1955	4	"tmax"	31.0	31.0	31.0	32.0	33.0	32.0	32.0	33.0
"MX000017004"	1955	4	"tmin"	15.0	15.0	16.0	15.0	16.0	16.0	16.0	16.0
"MX000017004"	1955	5	"tmax"	31.0	31.0	31.0	30.0	30.0	30.0	31.0	31.0
"MX000017004"	1955	5	"tmin"	20.0	16.0	16.0	15.0	15.0	15.0	16.0	16.0
"MX000017004"	1955	6	"tmax"	30.0	29.0	28.0	27.0	28.0	26.0	23.0	27.0
…	…	…	…	…	…	…	…	…	…	…	…
"MX000017004"	2011	2	"tmin"	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
"MX000017004"	2011	3	"tmax"	NaN	NaN	NaN	NaN	33.2	NaN	NaN	NaN
"MX000017004"	2011	3	"tmin"	NaN	NaN	NaN	NaN	14.8	NaN	NaN	NaN
"MX000017004"	2011	4	"tmax"	NaN	35.0	NaN	NaN	NaN	NaN	NaN	NaN
"MX000017004"	2011	4	"tmin"	NaN	16.8	NaN	NaN	NaN	NaN	NaN	NaN

id	year	month	element	variable	value
str	i32	i32	str	str	f64
"MX000017004"	1955	4	"tmax"	"d1"	31.0
"MX000017004"	1955	4	"tmin"	"d1"	15.0
"MX000017004"	1955	5	"tmax"	"d1"	31.0
"MX000017004"	1955	5	"tmin"	"d1"	20.0
"MX000017004"	1955	6	"tmax"	"d1"	30.0
…	…	…	…	…	…
"MX000017004"	2011	2	"tmin"	"d31"	NaN
"MX000017004"	2011	3	"tmax"	"d31"	36.5
"MX000017004"	2011	3	"tmin"	"d31"	17.0
"MX000017004"	2011	4	"tmax"	"d31"	NaN
"MX000017004"	2011	4	"tmin"	"d31"	NaN

Unpivot/Melt

- Many columns (wider) become two columns (longer): one with column name (variable), other with value

id	year	month	element	d1	d2	d3	d4	d5	d6	d7	d8
str	i32	i32	str	f64	f64	f64	f64	f64	f64	f64	f64
"MX000017004"	1955	4	"tmax"	31.0	31.0	31.0	32.0	33.0	32.0	32.0	33.0
"MX000017004"	1955	4	"tmin"	15.0	15.0	16.0	15.0	16.0	16.0	16.0	16.0
"MX000017004"	1955	5	"tmax"	31.0	31.0	31.0	30.0	30.0	30.0	31.0	31.0
"MX000017004"	1955	5	"tmin"	20.0	16.0	16.0	15.0	15.0	15.0	16.0	16.0
"MX000017004"	1955	6	"tmax"	30.0	29.0	28.0	27.0	28.0	26.0	23.0	27.0
…	…	…	…	…	…	…	…	…	…	…	…
"MX000017004"	2011	2	"tmin"	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
"MX000017004"	2011	3	"tmax"	NaN	NaN	NaN	NaN	33.2	NaN	NaN	NaN
"MX000017004"	2011	3	"tmin"	NaN	NaN	NaN	NaN	14.8	NaN	NaN	NaN
"MX000017004"	2011	4	"tmax"	NaN	35.0	NaN	NaN	NaN	NaN	NaN	NaN
"MX000017004"	2011	4	"tmin"	NaN	16.8	NaN	NaN	NaN	NaN	NaN	NaN

id	year	month	element	variable	value
str	i32	i32	str	str	f64
"MX000017004"	1955	4	"tmax"	"d1"	31.0
"MX000017004"	1955	4	"tmin"	"d1"	15.0
"MX000017004"	1955	5	"tmax"	"d1"	31.0
"MX000017004"	1955	5	"tmin"	"d1"	20.0
"MX000017004"	1955	6	"tmax"	"d1"	30.0
…	…	…	…	…	…
"MX000017004"	2011	2	"tmin"	"d31"	NaN
"MX000017004"	2011	3	"tmax"	"d31"	36.5
"MX000017004"	2011	3	"tmin"	"d31"	17.0
"MX000017004"	2011	4	"tmax"	"d31"	NaN
"MX000017004"	2011	4	"tmin"	"d31"	NaN

Pivot

- Inverse of unpivot: two columns (longer) become many columns (wider) one column becomes column names (variable), other becomes values

id	year	month	element	variable	value
str	i32	i32	str	str	f64
"MX000017004"	1955	4	"tmax"	"d1"	31.0
"MX000017004"	1955	4	"tmin"	"d1"	15.0
"MX000017004"	1955	5	"tmax"	"d1"	31.0
"MX000017004"	1955	5	"tmin"	"d1"	20.0
"MX000017004"	1955	6	"tmax"	"d1"	30.0
…	…	…	…	…	…
"MX000017004"	2011	2	"tmin"	"d31"	NaN
"MX000017004"	2011	3	"tmax"	"d31"	36.5
"MX000017004"	2011	3	"tmin"	"d31"	17.0
"MX000017004"	2011	4	"tmax"	"d31"	NaN
"MX000017004"	2011	4	"tmin"	"d31"	NaN

id	year	month	variable	tmax	tmin
str	i32	i32	str	f64	f64
"MX000017004"	1955	4	"d1"	31.0	15.0
"MX000017004"	1955	5	"d1"	31.0	20.0
"MX000017004"	1955	6	"d1"	30.0	16.0
"MX000017004"	1955	7	"d1"	27.0	15.0
"MX000017004"	1955	8	"d1"	23.0	14.0
…	…	…	…	…	…
"MX000017004"	2010	12	"d31"	NaN	NaN
"MX000017004"	2011	1	"d31"	NaN	NaN
"MX000017004"	2011	2	"d31"	NaN	NaN
"MX000017004"	2011	3	"d31"	36.5	17.0
"MX000017004"	2011	4	"d31"	NaN	NaN

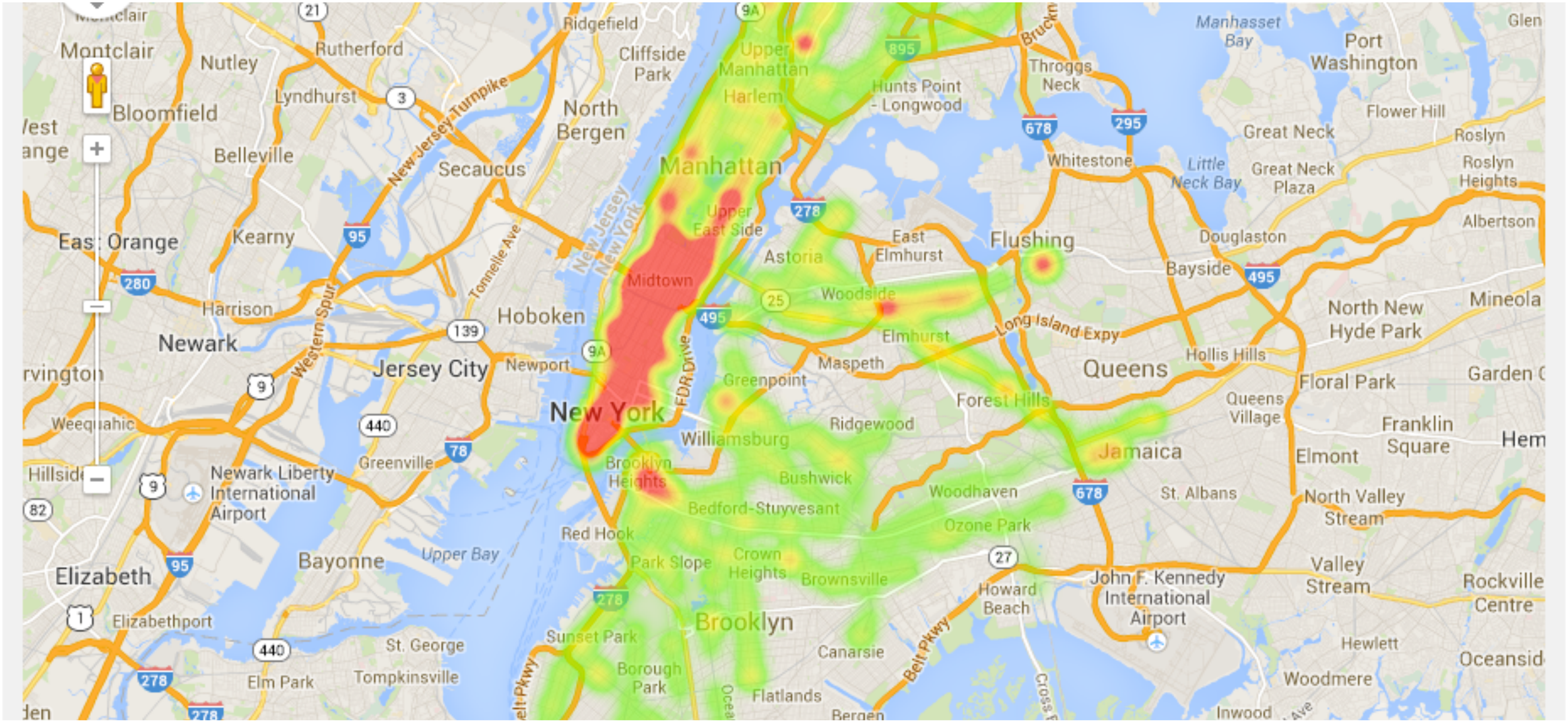
Pivot

- Inverse of unpivot: two columns (longer) become many columns (wider) one column becomes column names (variable), other becomes values

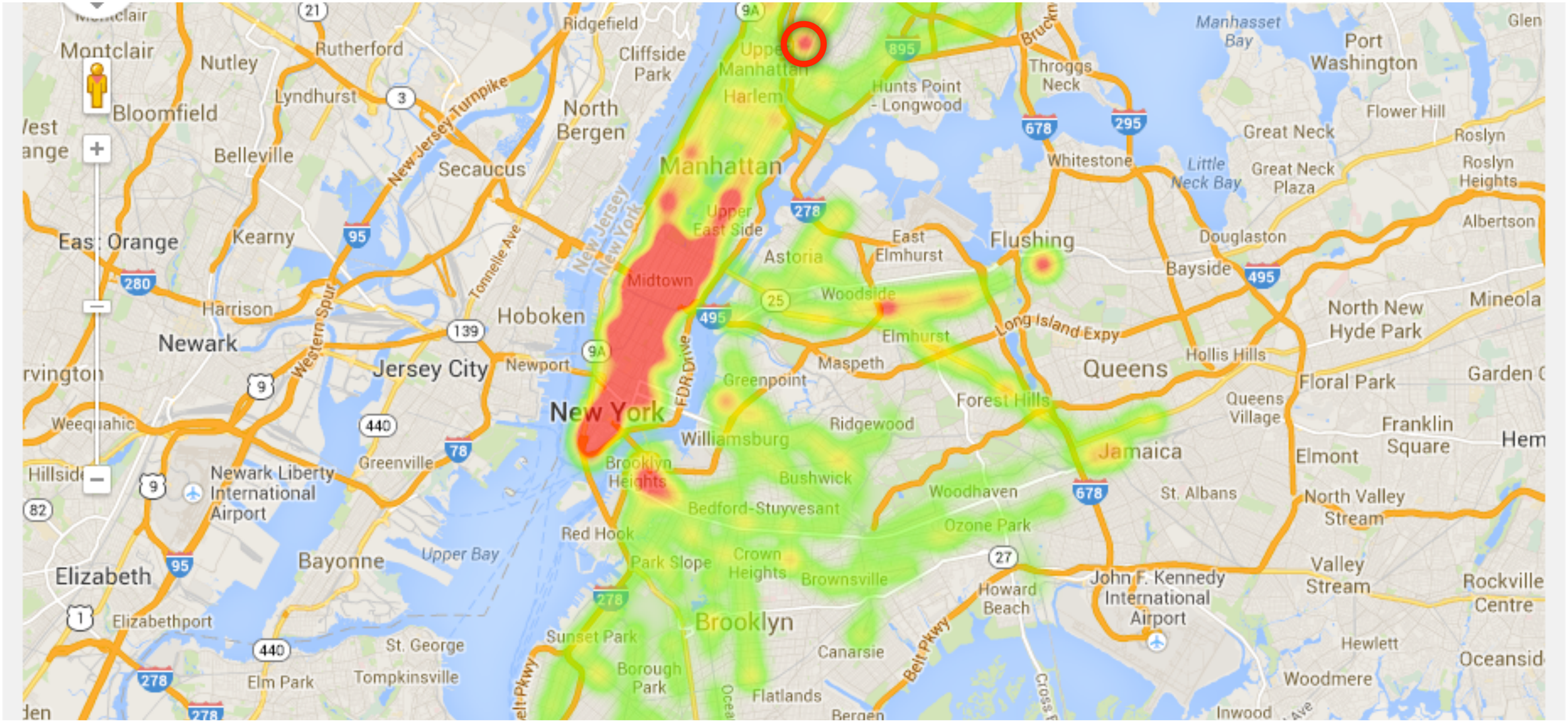
id	year	month	element	variable	value
str	i32	i32	str	str	f64
"MX000017004"	1955	4	"tmax"	"d1"	31.0
"MX000017004"	1955	4	"tmin"	"d1"	15.0
"MX000017004"	1955	5	"tmax"	"d1"	31.0
"MX000017004"	1955	5	"tmin"	"d1"	20.0
"MX000017004"	1955	6	"tmax"	"d1"	30.0
…	…	…	…	…	…
"MX000017004"	2011	2	"tmin"	"d31"	NaN
"MX000017004"	2011	3	"tmax"	"d31"	36.5
"MX000017004"	2011	3	"tmin"	"d31"	17.0
"MX000017004"	2011	4	"tmax"	"d31"	NaN
"MX000017004"	2011	4	"tmin"	"d31"	NaN

id	year	month	variable	tmax	tmin
str	i32	i32	str	f64	f64
"MX000017004"	1955	4	"d1"	31.0	15.0
"MX000017004"	1955	5	"d1"	31.0	20.0
"MX000017004"	1955	6	"d1"	30.0	16.0
"MX000017004"	1955	7	"d1"	27.0	15.0
"MX000017004"	1955	8	"d1"	23.0	14.0
…	…	…	…	…	…
"MX000017004"	2010	12	"d31"	NaN	NaN
"MX000017004"	2011	1	"d31"	NaN	NaN
"MX000017004"	2011	2	"d31"	NaN	NaN
"MX000017004"	2011	3	"d31"	36.5	17.0
"MX000017004"	2011	4	"d31"	NaN	NaN

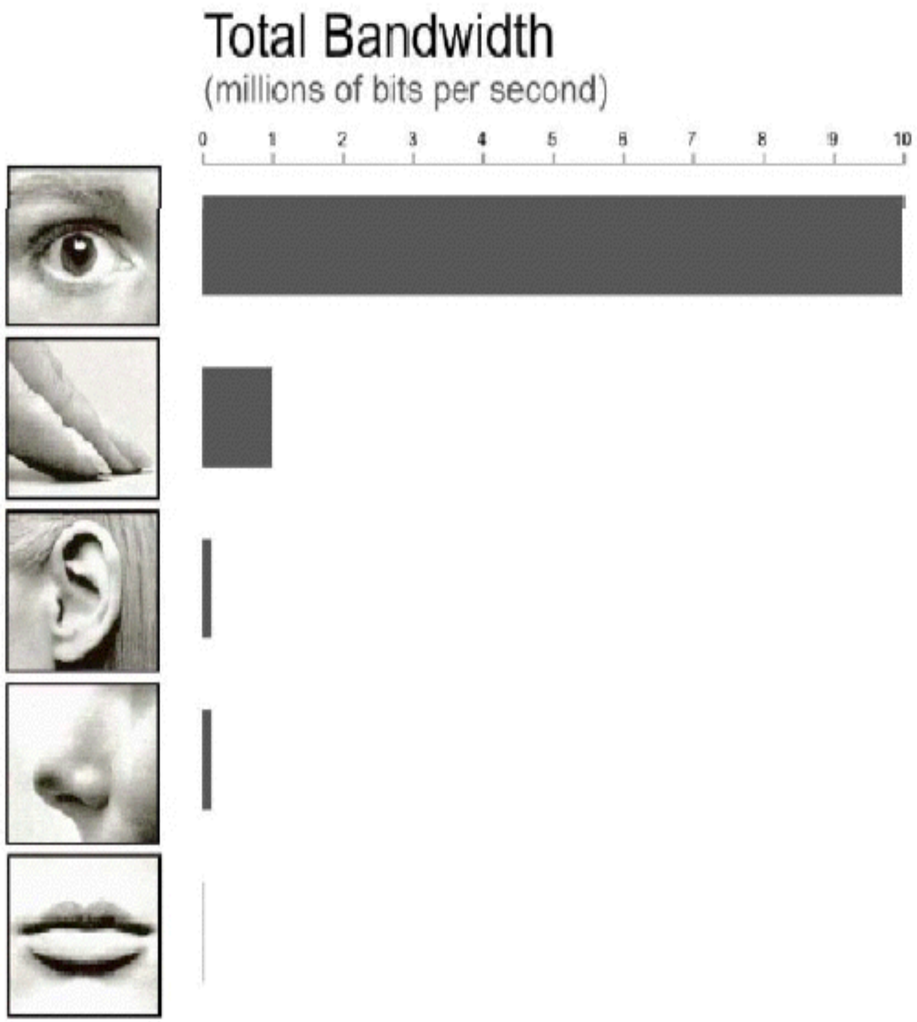
Exploring Data through Visualization



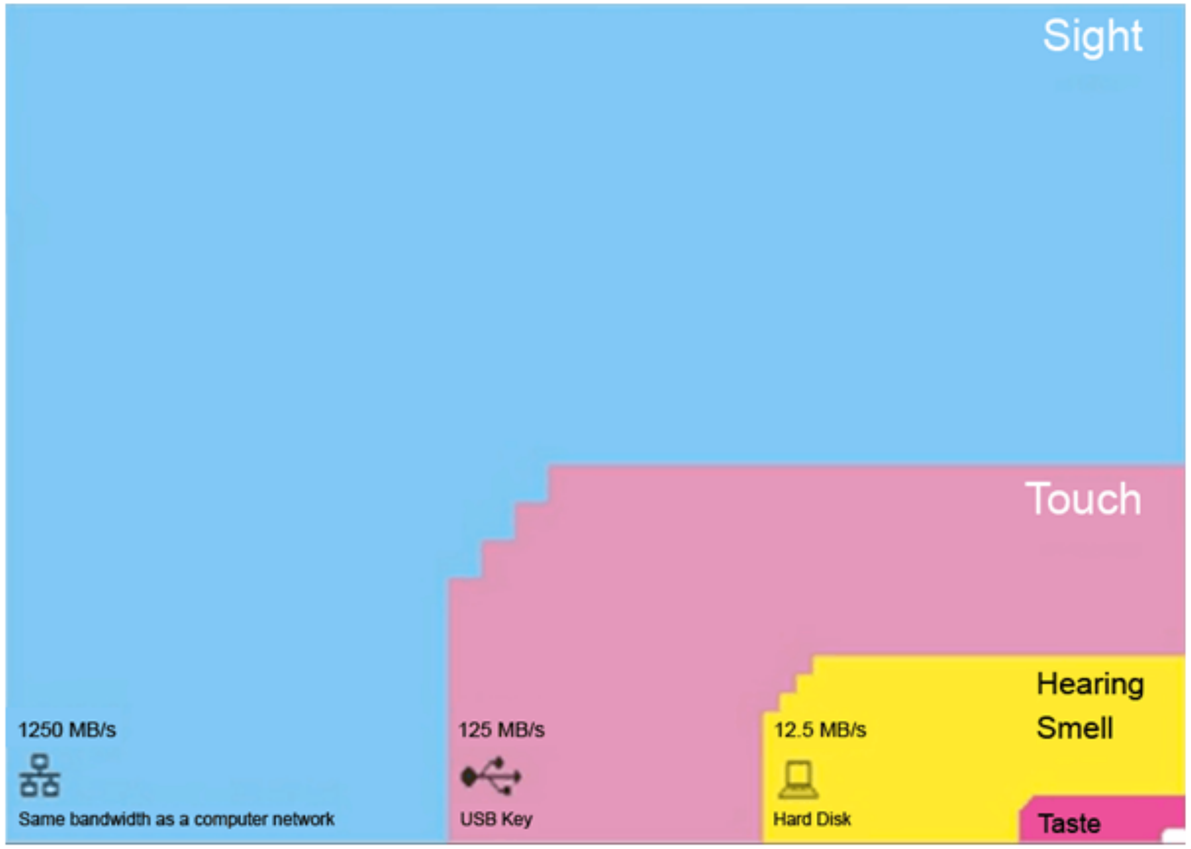
Exploring Data through Visualization



Why do we visualize data?

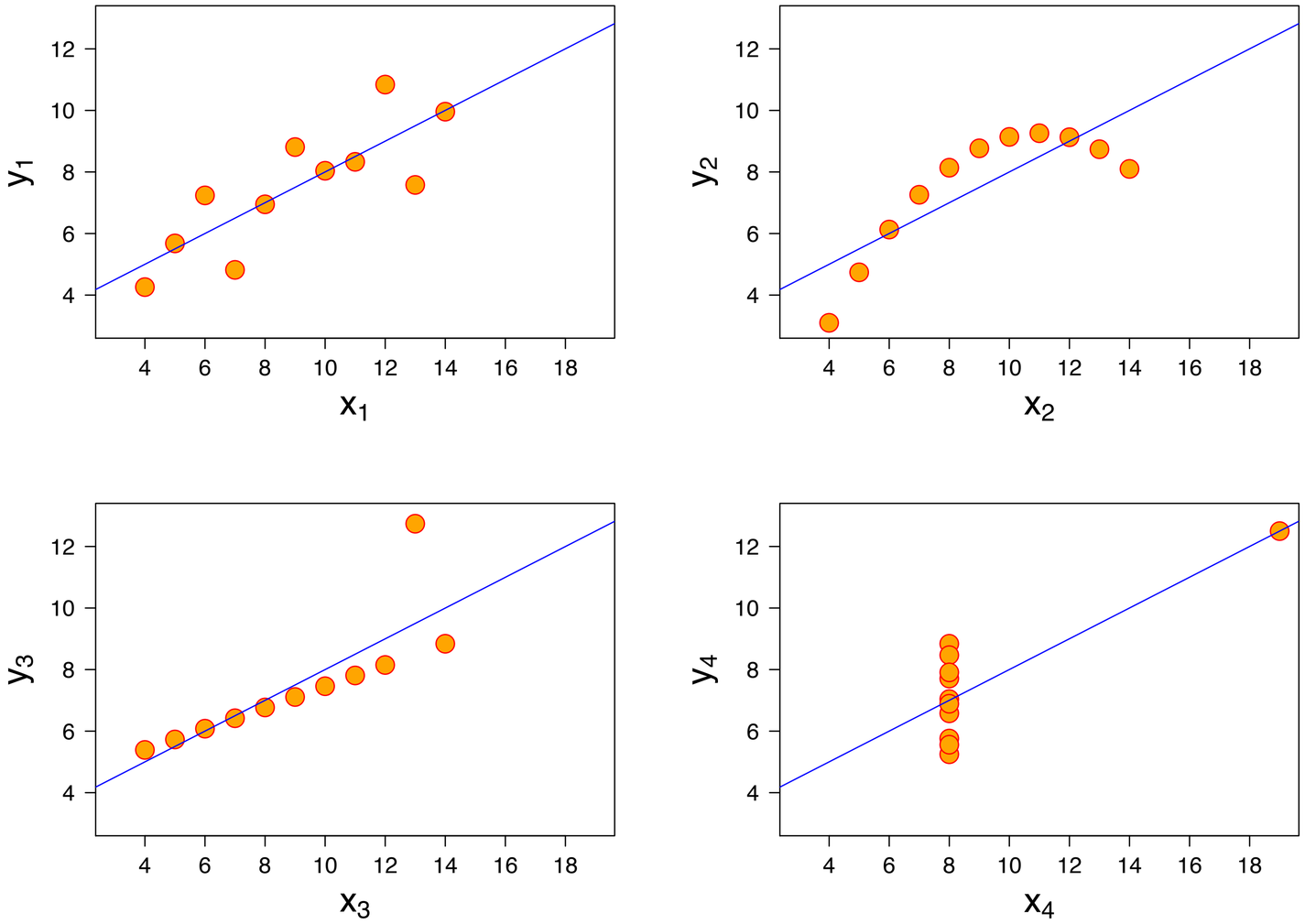


[via A. Lex]



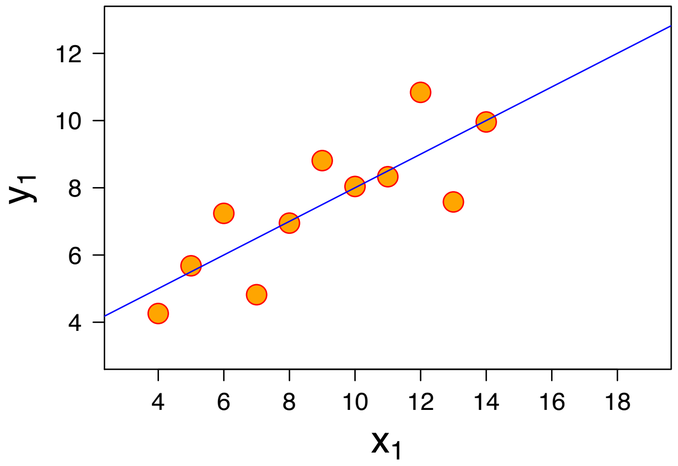
[T. Nørretranders]

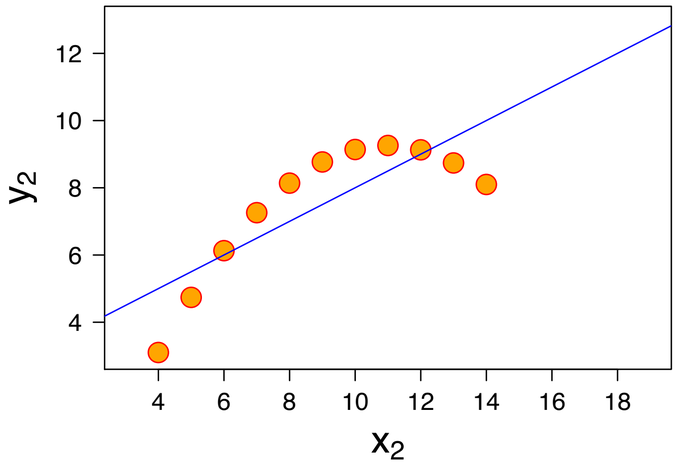
Why Visual?

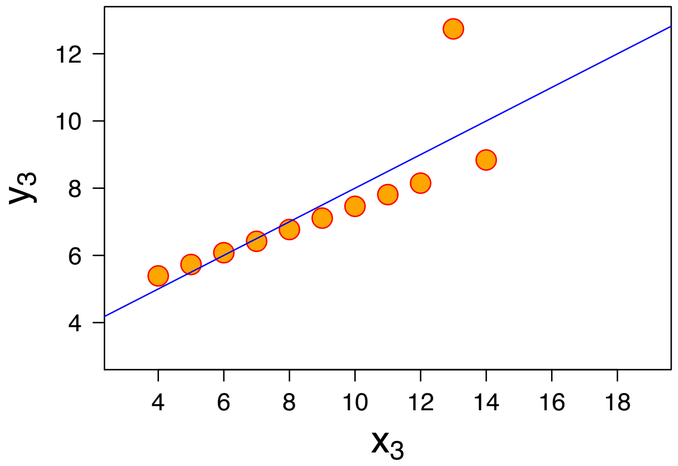


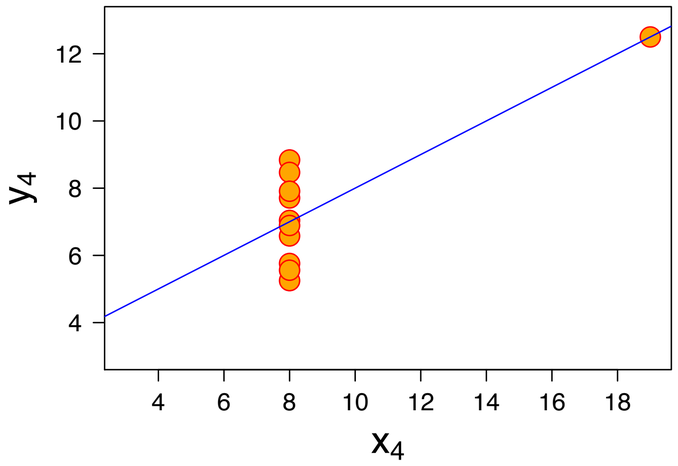
[F. J. Anscombe]

Why Visual?









Mean of x	9
Variance of x	11
Mean of y	7.50
Variance of y	4.122
Correlation	0.816

[F. J. Anscombe]

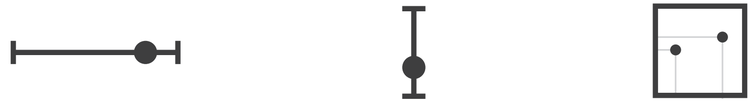
Visualization Goals

- "The purpose of visualization is **insight**, not pictures" – B. Schneiderman

- Identify patterns, trends
- Spot outliers
- Find similarities, correlation

Data is Encoded via Visual Channels

- **Position**
  - Horizontal
  - Vertical
  - Both



- **Color**

- **Shape**

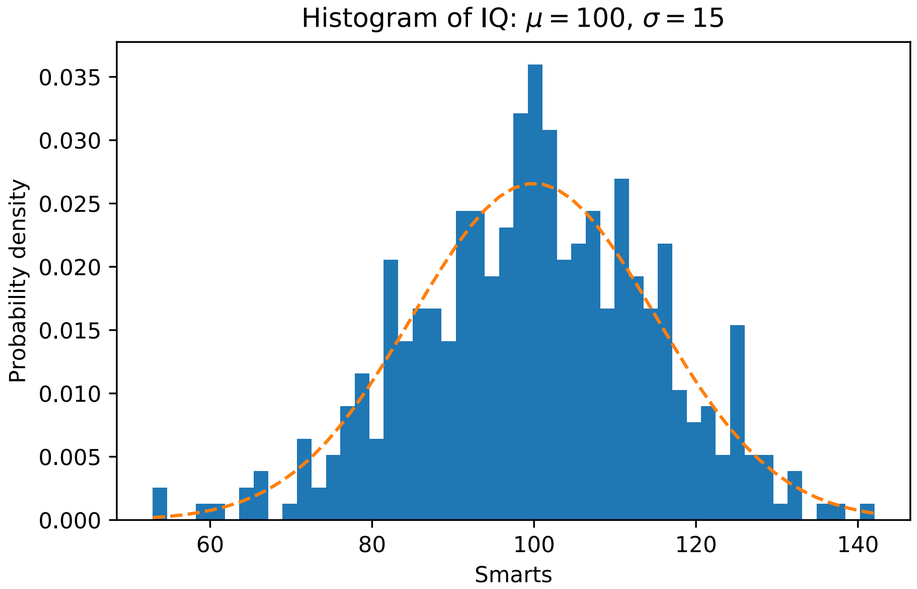
- **Tilt**

- **Size**
  - Length
  - Area
  - Volume

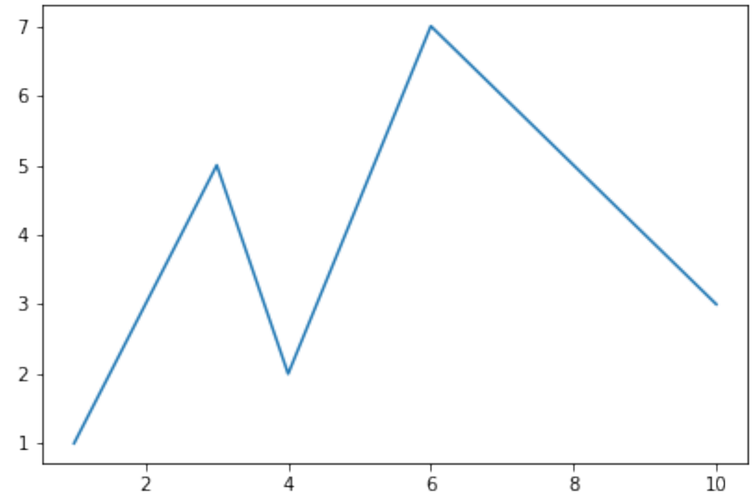
[Munzner (ill. Maguire), 2014]

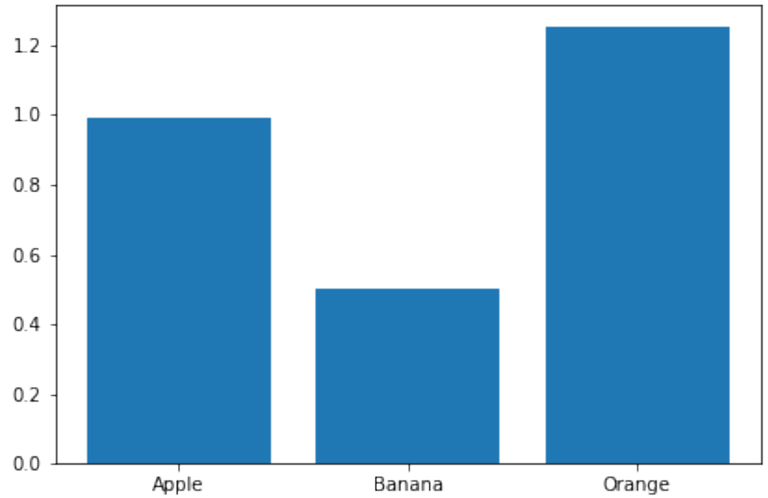
matplotlib

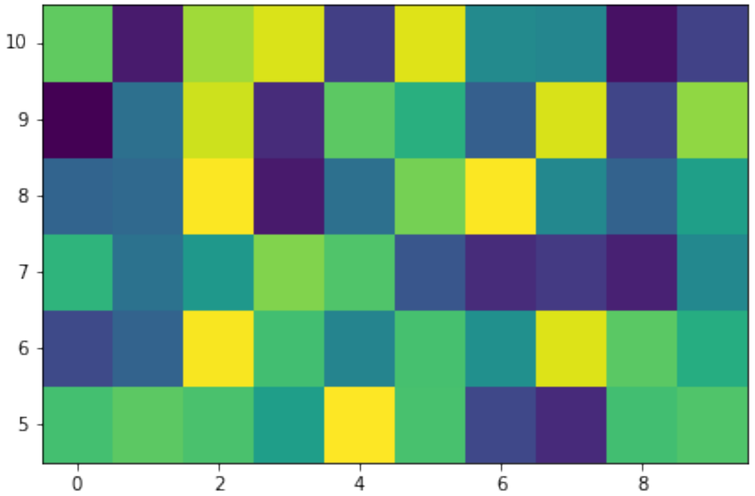
- Strengths:
  - Designed like Matlab
  - Many rendering backends
  - Can reproduce almost any plot
  - Proven, well-tested
- Weaknesses:
  - API is imperative
  - Not originally designed for the web
  - Dated styles

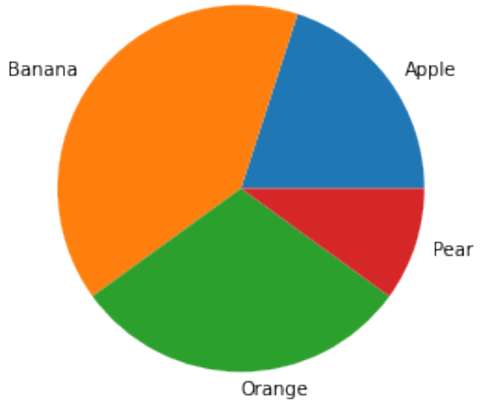


Many different types of charts









Many different types of charts

- Bar chart
  - `plt.bar(['Apple','Banana','Orange'],[0.99,0.50,1.25])`
- Grid Heatmap
  - `plt.pcolormesh(x, y, Z)`
- Pie chart:
  -
```
plt.pie([20,40,30,10],
        labels=['Apple','Banana','Orange','Pear'])
```

Assignment 8

- Due Friday, May 2
- Last Assignment
- Data and Visualization
- Use polars or pandas
- Must use matplotlib or altair where directed

Final Exam

- Monday, May 5, **12:00**-1:50pm in PM 103
- **More comprehensive** than Test 2
- Expect questions from topics covered on Test 1 and 2
- Expect questions from the last few weeks of class (data, visualization, machine learning)
- Similar format

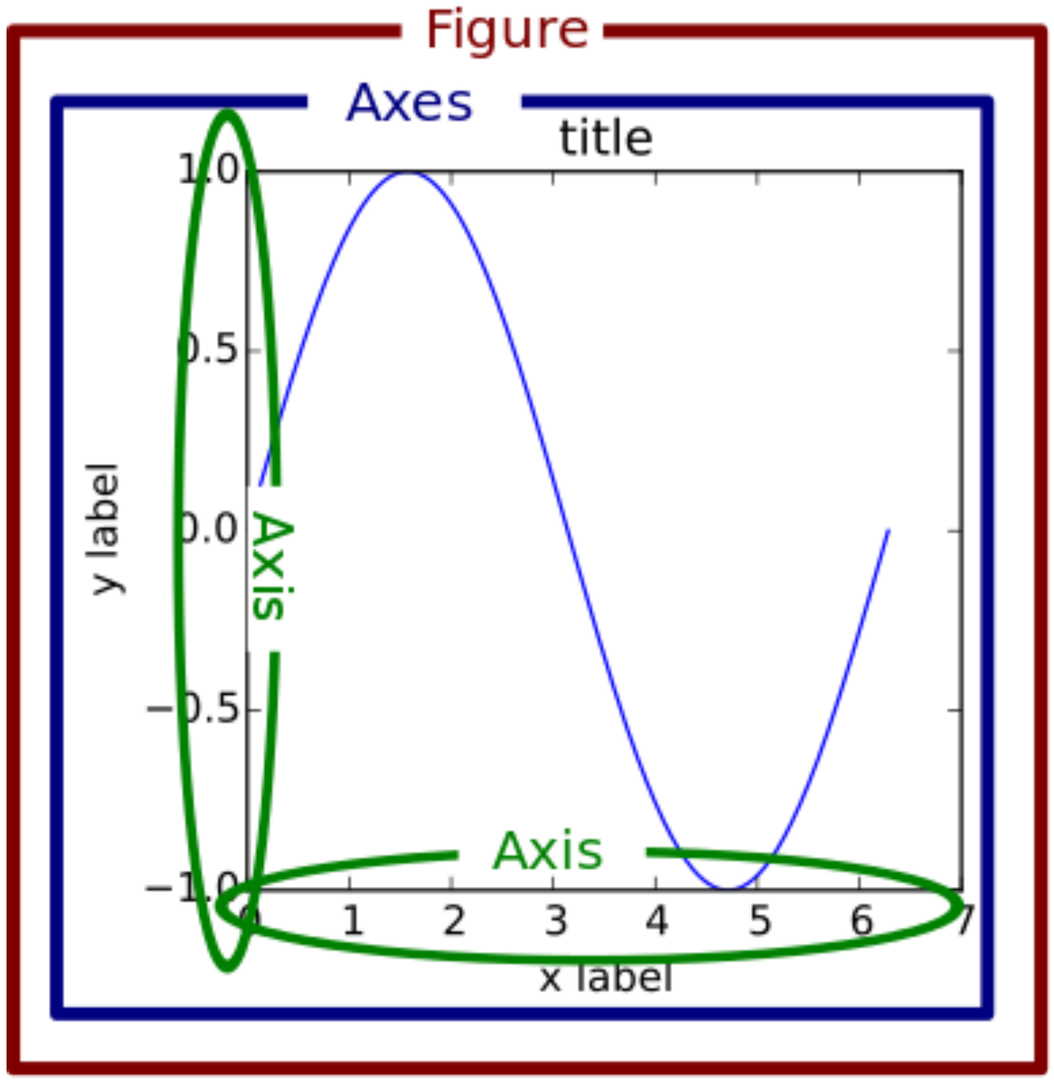
matplotlib tutorials

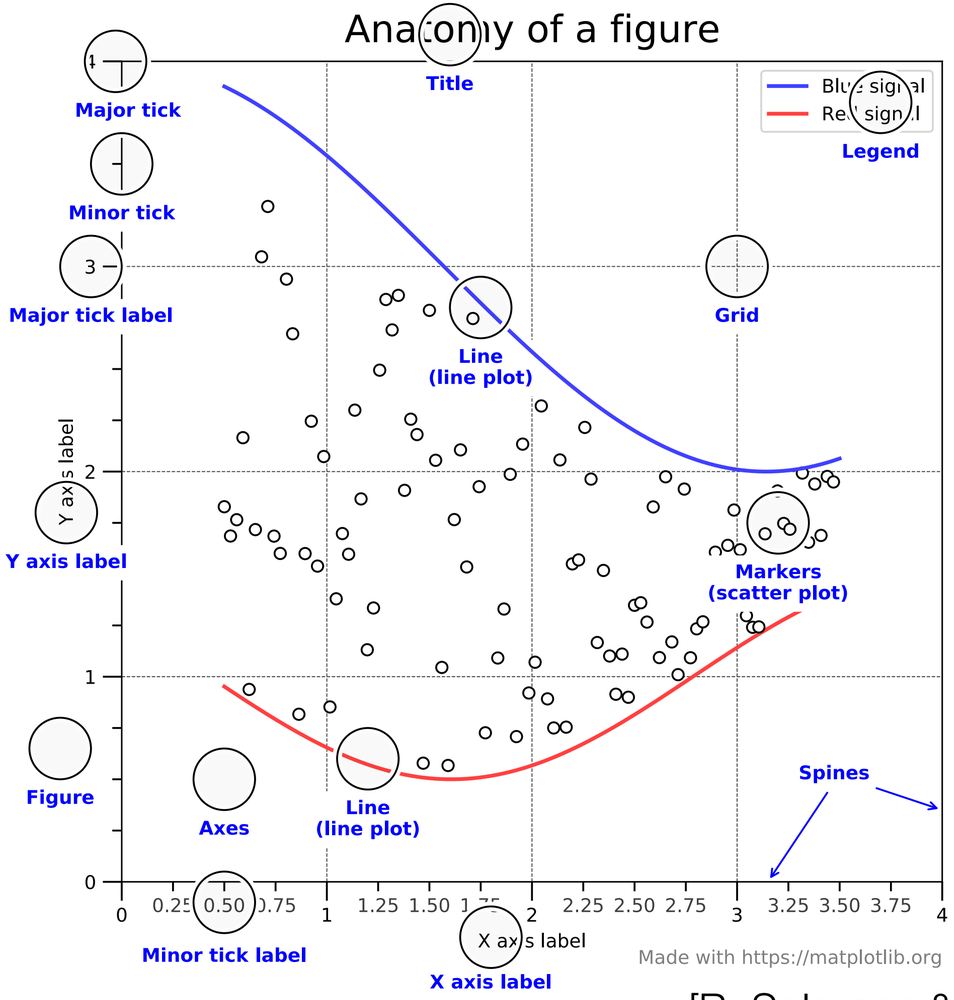
- https://matplotlib.org/stable/tutorials/index.html
- https://github.com/rougier/matplotlib-tutorial

Adding Labels

- `plt.xlabel`: set x label
- `plt.ylabel`: set y label
- `plt.title`: set title
-
```
plt.plot([1,3,4,6,10],[1,5,2,7,3])
plt.xlabel('Age')
plt.ylabel('Number of Jumps')
plt.title('Kangaroo Jumps Today')
```

Anatomy of a Figure





[B. Solomon & matplotlib]

Figure and Axes Objects

- pyplot is stateful, functions affect the "current" figure and axes
  - `plt.gcf()`: gets current figure
  - `plt.gca()`: gets current axes
  - Creates one if it doesn't exist!
- This is not aligned with object-based programming ideas
- Most methods in pyplot are translated to methods on the current axes (gca)
- We can instead call these directly, but first need to create them:

```
- fig, ax = plt.subplots() # "constructor-like" method
  ax.scatter([1,3,4,6,10],[1,5,2,7,3])
```

Object-Based Plotting

- `fig, ax = plt.subplots() # "constructor-like" method`
  `ax.scatter([1,3,4,6,10],[1,5,2,7,3])`
- Use getters/setters for labels and title
  - `ax.set_xlabel('Age')`
  - `ax.set_ylabel('Number of Jumps')`
  - `ax.set_title('Kangaroo Jumps Today')`
- We can also call methods on the figure:
  - `fig.tight_layout() # reduce margins`

Multiple Figures

- subplots allows multiple axes in the same figure:
  - `fig, ax = plt.subplots(2, 2, figsize=(10, 10)) # rows, then columns`
- `ax` is now a 2x2 numpy array
- Can put any type of visualization on each pair of axes
- ```
  ax[0,0].plot([1,3,4,6,10],[1,5,2,7,3])
  ax[0,1].bar(['Apple','Banana','Orange'],[0.99,0.50,1.25])
  ax[1,0].pcolormesh(x, y, Z)
  ax[1,1].pie([20,40,30,10],
              labels=['Apple','Banana','Orange','Pear'])
  ```
  ```

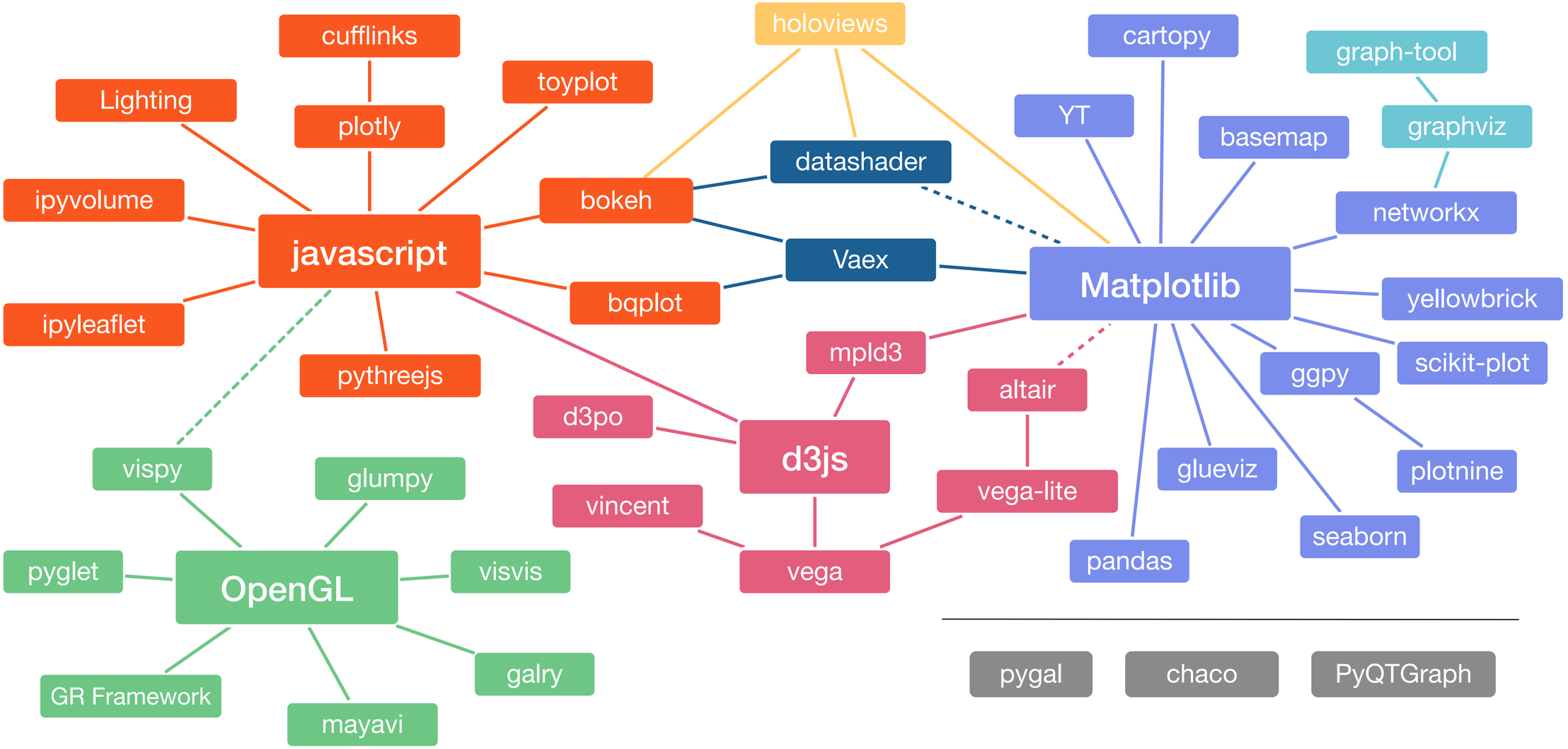
pandas Integration

- Can call many of these methods directly from pandas
- Handled through `kind` kwarg or `.plot` accessor
- It will try to guess a reasonable visualization, but may fail:
  - `fruit.plot()`
- Instead, specify x and y and other parameters:
  - `fruit.plot(kind='bar',x='name',y='price')`
  - `plt.bar(x='name',height='price',data=fruit) # SIMILAR`
  - `fruit.plot.scatter(x='price',y='count',c='name') # ERROR`
  -
```
colors = {'Apple': 'red','Orange': 'orange',
          'Banana': 'yellow','Pear': 'green'}
fruit.plot.scatter(x='price',y='count',
                   c=fruit['name'].map(colors))
```

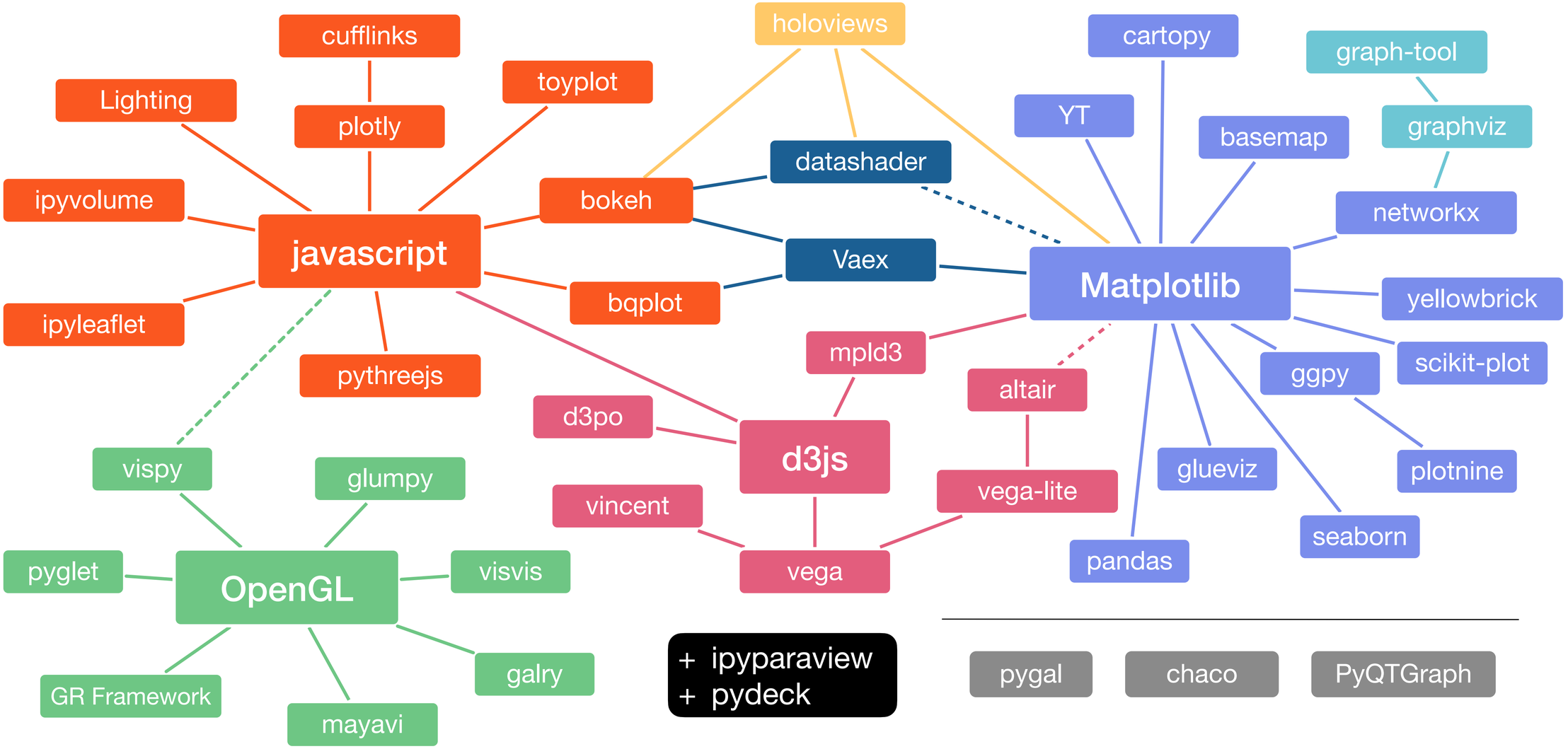
Extensions & Other Directions

- Seaborn:
  - ```
    import seaborn as sns
    sns.scatterplot(x='price',y='count',hue='name', data=fruit)
    ```
    ```

The Python Visualization Landscape



The Python Visualization Landscape



History of Vega-Lite & Altair

- "Grammar of Graphics", L. Wilkinson
- "A Layered Grammar of Graphics", H. Wickham
- ggplot: plotting library for R
- Vega: similar idea for Javascript/JSON (U. Washington, A. Satyanarayan)
  - "Declarative language for creating, saving, and sharing interactive visualization designs"
  - More focus on interaction and reactive signals
  - Separation between specification and runtime
- Vega-Lite: higher-level language than Vega (U. Washington, D. Moritz)
  - uses carefully designed rules to default settings

History of Vega-Lite & Altair

- Altair: Python interface to Vega-Lite (J. VanderPlas)
  - "spend more time understanding your data and its meaning"
  - Specify the what, minimize the amount of code directing the how
  - Python can write JSON specification just as well as any other language
  - Bindings make it more Python-friendly, integrate with pandas, add support for Jupyter, etc.
- Vega Fusion (J. Mease)
  - Scaling to larger datasets
  - Serverside scaling

Basic Example

- ```
  import altair as alt
  import pandas as pd
  data = pd.DataFrame({'x': [1,3,4,6,10],'y': [1,5,2,7,3]})
  alt.Chart(data).mark_line().encode(x='x', y='y')
  ```
- Easiest to use data from a pandas data frame
  - Another option is a csv or json file
  - Can support geo_interface, too
- `Chart` is the basic unit
- Mark: `.mark_*()` indicates the geometry created for each data item
- Encode: `.encode()` allows visual properties to be set to data attributes
  ```

Visual Marks

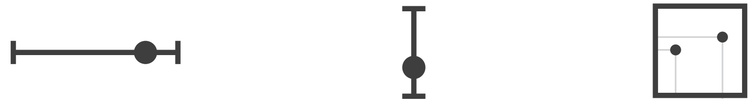
- **Marks** are the basic graphical elements in a visualization
- Marks classified by dimensionality:

Points **Lines** **Areas**

- Also can have surfaces, volumes
- Think of marks as a mathematical definition, or if familiar with tools like Adobe Illustrator or Inkscape, the path & point definitions
- Altair: area, bar, circle, geoshape, image, line, point, rect, rule, square, text, tick
  - Also compound marks: boxplot, errorband, errorbar

Encode via Visual Channels

- **Position**
  - Horizontal
  - Vertical
  - Both



- **Color**

- **Shape**

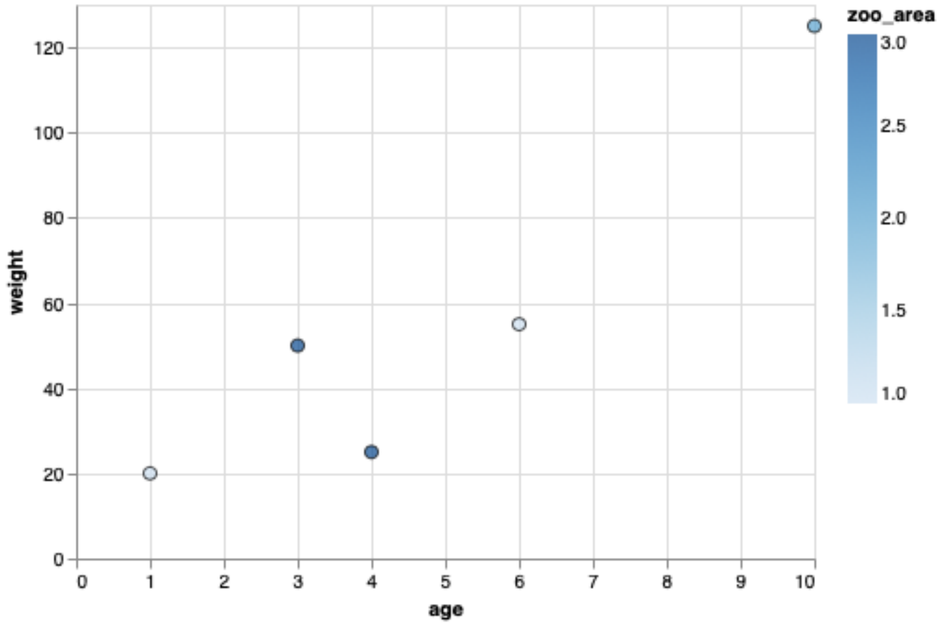
- **Tilt**

- **Size**
  - Length
  - Area
  - Volume

[Munzner (ill. Maguire), 2014]

Easily Explore Different Encodings

```
data = pd.DataFrame({
    'age': [1,3,4,6,10],
    'weight': [20,50,25,55,125],
    'zoo_area': [1,3,3,1,2],
    'num_scoops': [3,2,4,2,3]
})
alt.Chart(data).mark_point(
    filled=True, size=50,
    stroke='black',strokeWidth=1
).encode(
    x='age',
    y='weight',
    color='zoo_area'
)
```



Problem: zoo_area is not a continuous value,
nor is it ordered in any way!

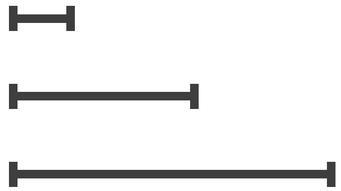
Data Attributes and Altair Types

➔ Categorical

➔ Ordered

➔ *Ordinal*

➔ *Quantitative*



[Munzner (ill. Maguire), 2014]

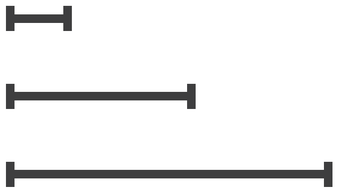
Data Attributes and Altair Types

➔ Categorical

➔ Ordered

➔ *Ordinal*

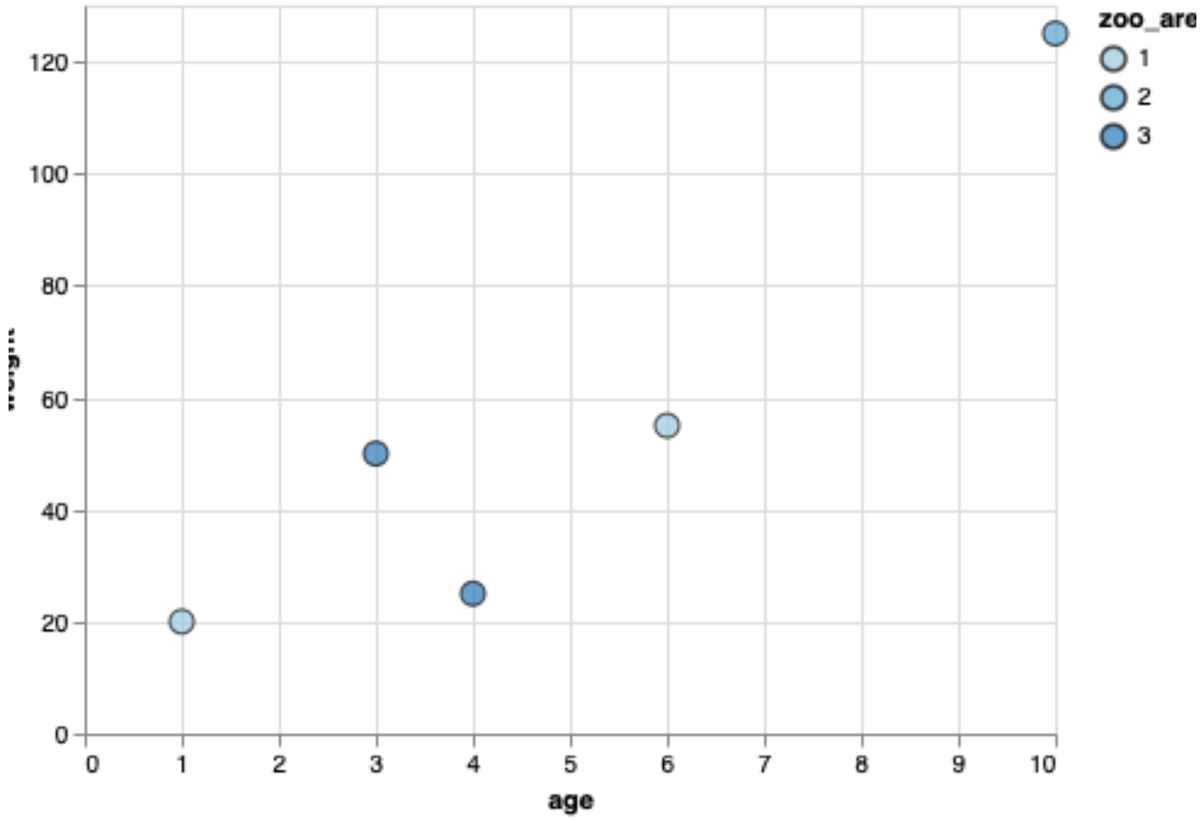
➔ *Quantitative*



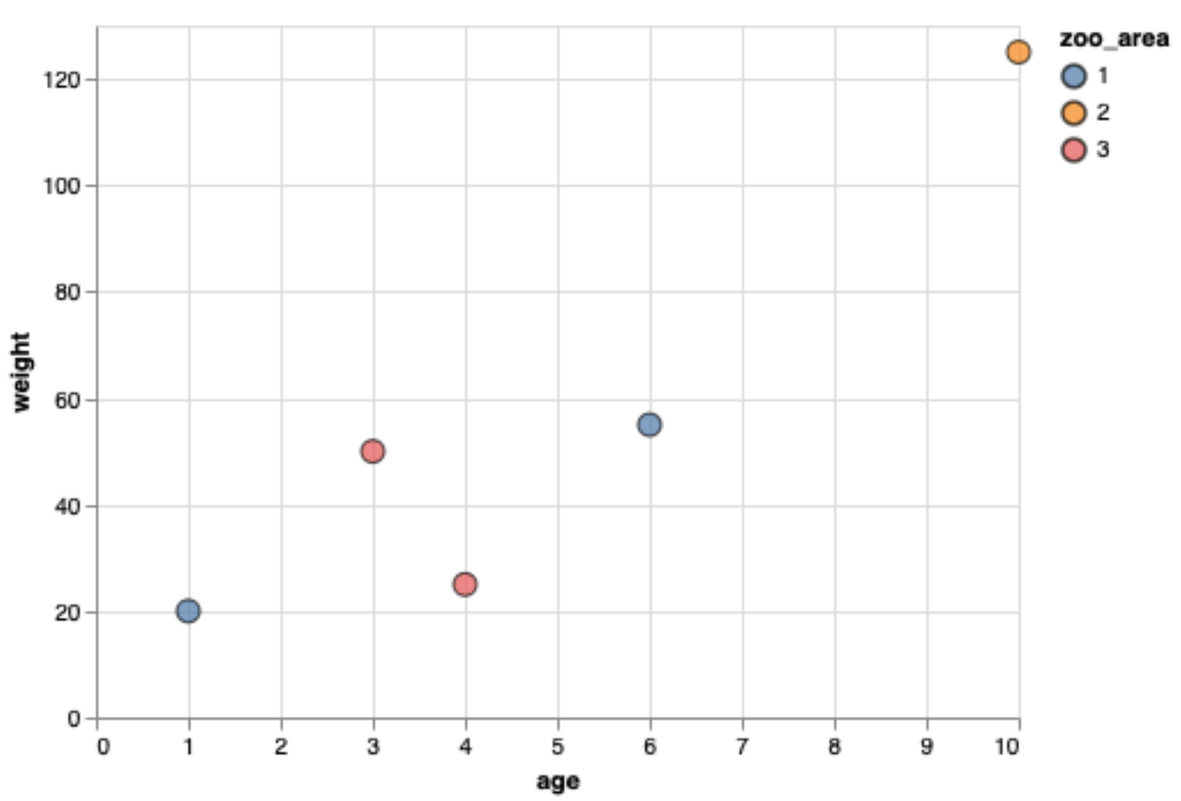
- Categorical data = Nominal (N)
- Ordinal data = Ordinal (O)
- Quantitative data = Quantitative (Q)
- Temporal data = Temporal (T)

[Munzner (ill. Maguire), 2014]

Specifying the Type



`zoo_area:O`



`zoo_area:N`

Different Channels for Different Attribute Types

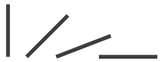
Magnitude Channels: Ordered Attributes

Position on common scale

Position on unaligned scale

Length (1D size)

Tilt/angle



Area (2D size)

Depth (3D position)

Color luminance

Color saturation

Curvature

Volume (3D size)

Identity Channels: Categorical Attributes

Spatial region

Color hue

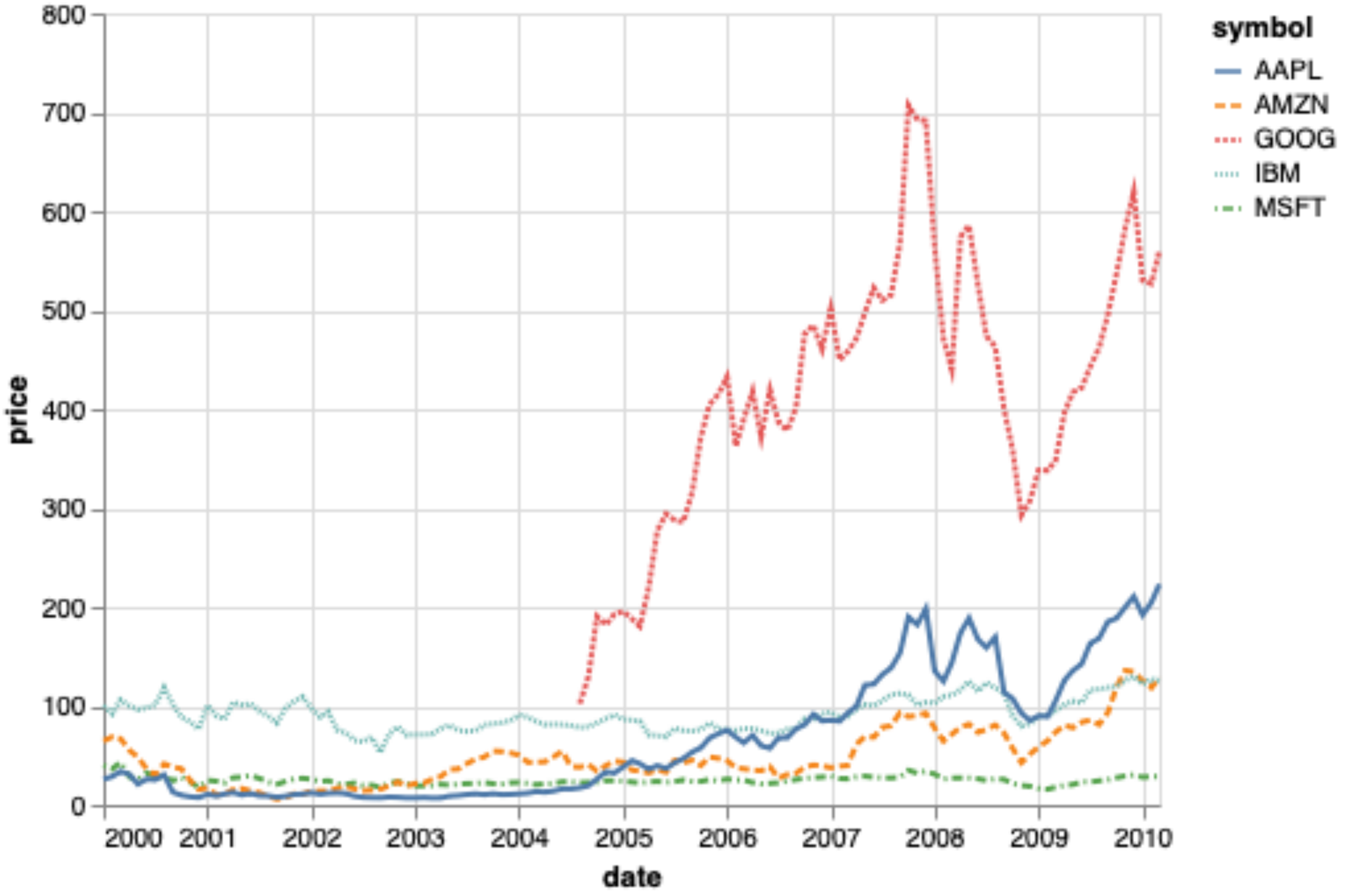
Motion

Shape

Altair will use its rules to pick whether to use color hue or saturation based on the type

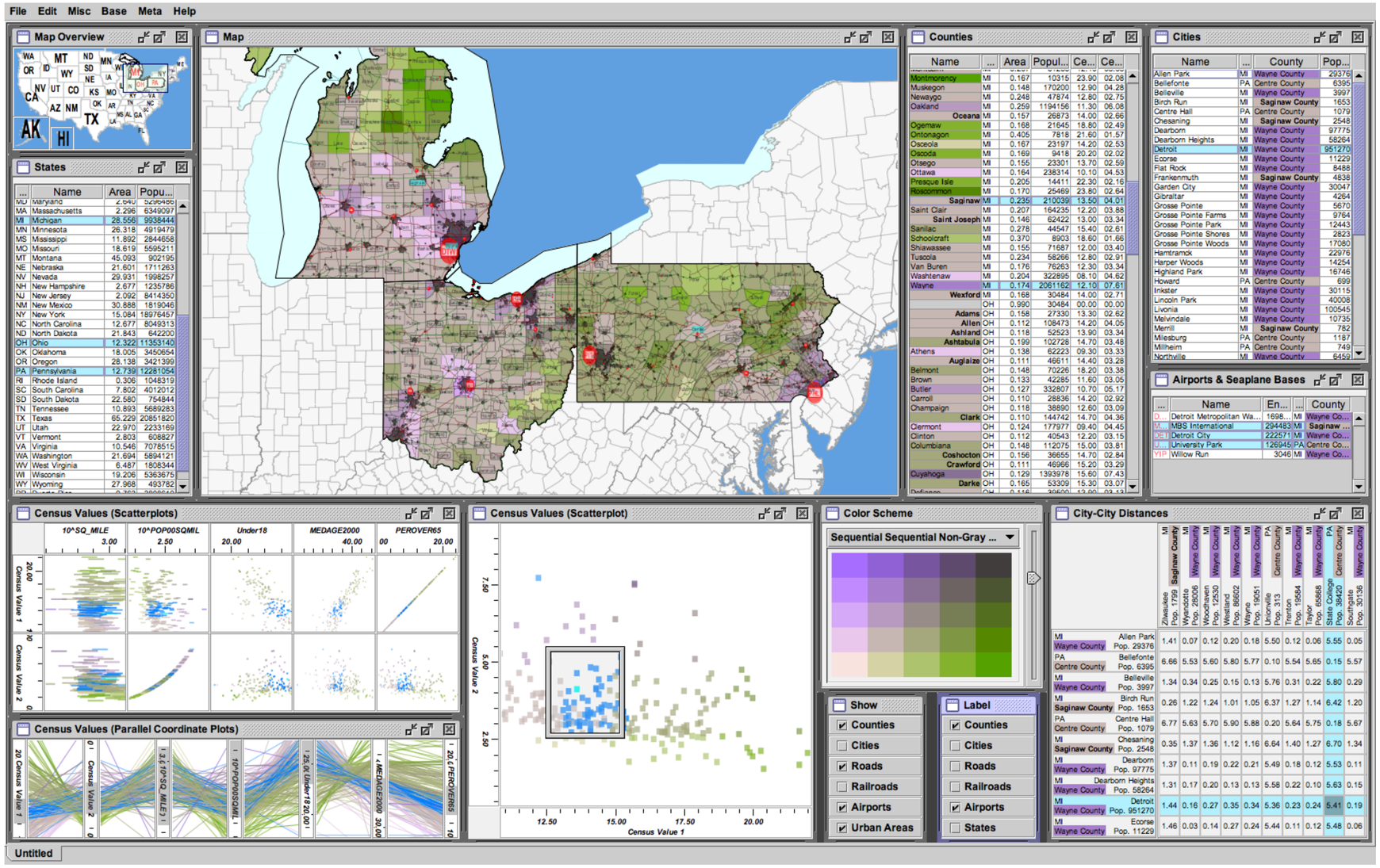
[Munzner (ill. Maguire), 2014]

Multiple Views in Visualization



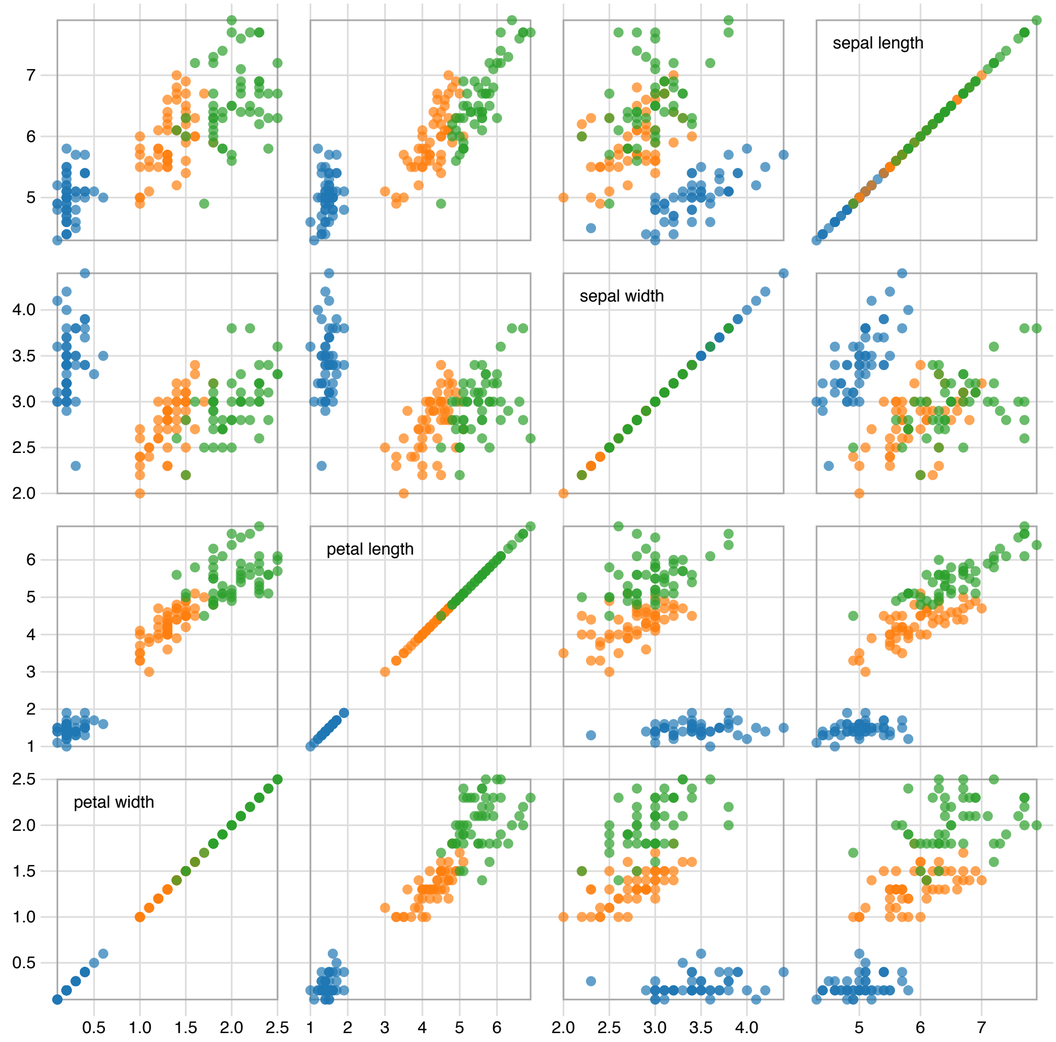
[Altair]

Multiple Views in Visualization



[Improvise, Weaver, 2004]

Multiple Views in Visualization

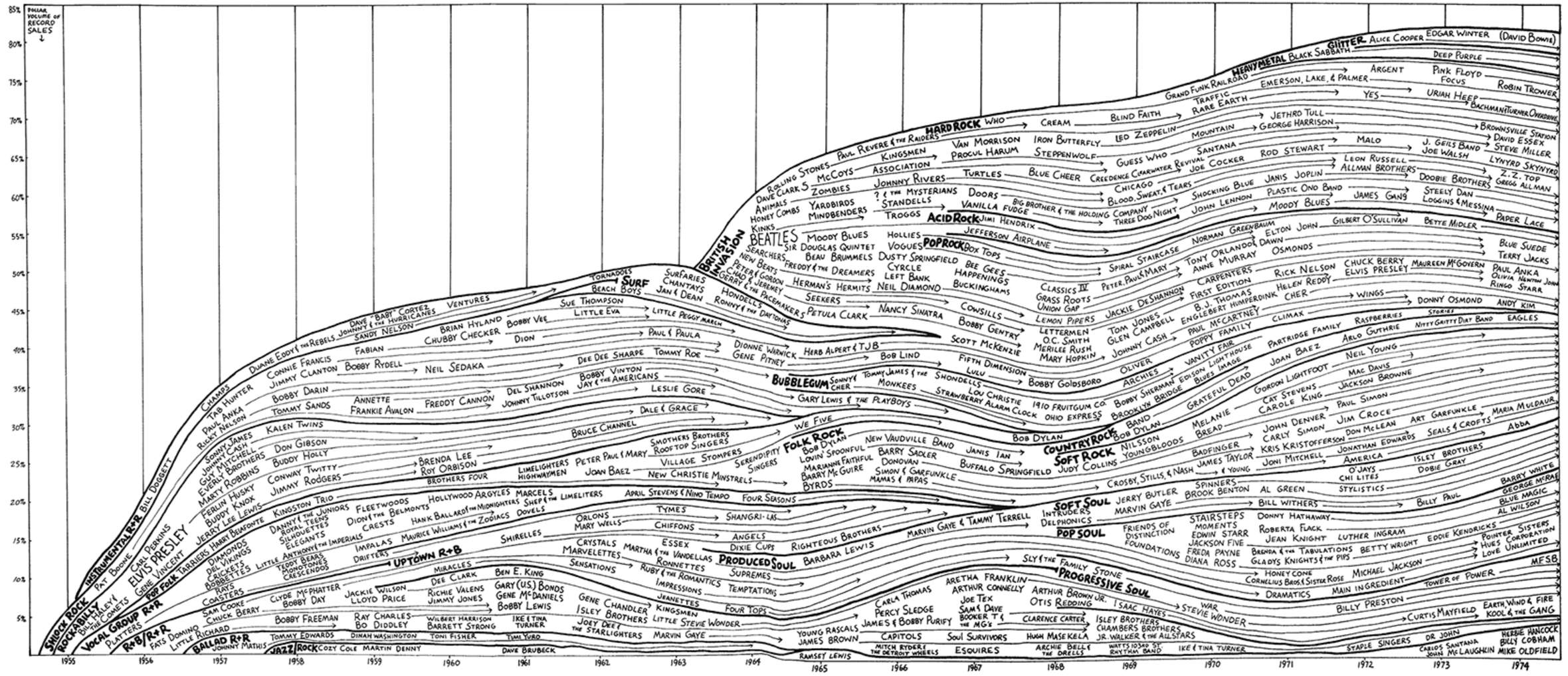


[M. Bostock]

Altair Supports Concatenation, Layering, & Repetition

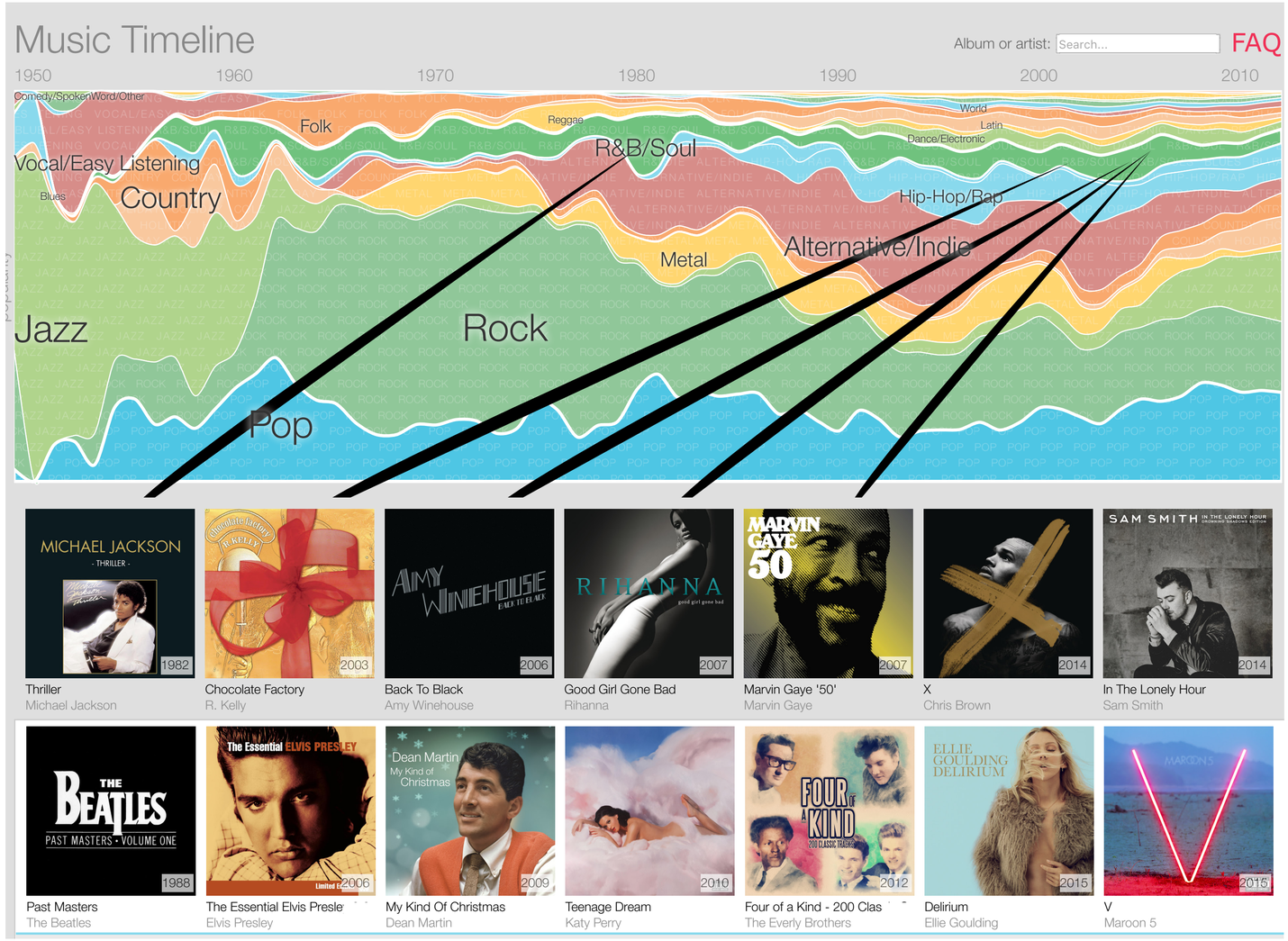
- Layering:
  - + Operator
- Concatenation:
  - Horizontal: | operator
  - Vertical: & operator
- Repetition
  - Use of .repeat for layout
  - Reference repeated variables in the encoding

Visualization



[Rock 'N' Roll is Here to Pay, R. Garofalo, 1977 (via Tufte)]

Also Visualization, but with Interaction



[Music Timeline, Google Research (no working version)]