

Programming Principles in Python (CSCI 503/490)

Visualization

Dr. David Koop

Problem: Variables stored in both rows & columns

Mexico Weather, Global Historical Climatology Network

id	year	month	element	d1	d2	d3	d4	d5	d6	d7	d8
MX17004	2010	1	tmax	—	—	—	—	—	—	—	—
MX17004	2010	1	tmin	—	—	—	—	—	—	—	—
MX17004	2010	2	tmax	—	27.3	24.1	—	—	—	—	—
MX17004	2010	2	tmin	—	14.4	14.4	—	—	—	—	—
MX17004	2010	3	tmax	—	—	—	—	32.1	—	—	—
MX17004	2010	3	tmin	—	—	—	—	14.2	—	—	—
MX17004	2010	4	tmax	—	—	—	—	—	—	—	—
MX17004	2010	4	tmin	—	—	—	—	—	—	—	—
MX17004	2010	5	tmax	—	—	—	—	—	—	—	—
MX17004	2010	5	tmin	—	—	—	—	—	—	—	—

[H. Wickham, 2014]

Problem: Variables stored in both rows & columns

Mexico Weather, Global Historical Climatology Network

id	year	month	element	d1	d2	d3	d4	d5	d6	d7	d8
MX17004	2010	1	tmax	—	—	—	—	—	—	—	—
MX17004	2010	1	tmin	—	—	—	—	—	—	—	—
MX17004	2010	2	tmax	—	27.3	24.1	—	—	—	—	—
MX17004	2010	2	tmin	—	14.4	14.4	—	—	—	—	—
MX17004	2010	3	tmax	—	—	—	—	32.1	—	—	—
MX17004	2010	3	tmin	—	—	—	—	14.2	—	—	—
MX17004	2010	4	tmax	—	—	—	—	—	—	—	—
MX17004	2010	4	tmin	—	—	—	—	—	—	—	—
MX17004	2010	5	tmax	—	—	—	—	—	—	—	—
MX17004	2010	5	tmin	—	—	—	—	—	—	—	—

Variable in columns: day; Variable in rows: tmax/tmin

[H. Wickham, 2014]

Solution: Melting + Pivot => Tidy Data

id	date	element	value
MX17004	2010-01-30	tmax	27.8
MX17004	2010-01-30	tmin	14.5
MX17004	2010-02-02	tmax	27.3
MX17004	2010-02-02	tmin	14.4
MX17004	2010-02-03	tmax	24.1
MX17004	2010-02-03	tmin	14.4
MX17004	2010-02-11	tmax	29.7
MX17004	2010-02-11	tmin	13.4
MX17004	2010-02-23	tmax	29.9
MX17004	2010-02-23	tmin	10.7

(a) Molten data

id	date	tmax	tmin
MX17004	2010-01-30	27.8	14.5
MX17004	2010-02-02	27.3	14.4
MX17004	2010-02-03	24.1	14.4
MX17004	2010-02-11	29.7	13.4
MX17004	2010-02-23	29.9	10.7
MX17004	2010-03-05	32.1	14.2
MX17004	2010-03-10	34.5	16.8
MX17004	2010-03-16	31.1	17.6
MX17004	2010-04-27	36.3	16.7
MX17004	2010-05-27	33.2	18.2

(b) Tidy data

[H. Wickham, 2014]

Melt

- Want to keep each observation separate (tidy), aka pivot_longer

	location	Temperature	Jan-2010	Feb-2010	Mar-2010
0	CityA	Predict	30	45	24
1	CityB	Actual	32	43	22

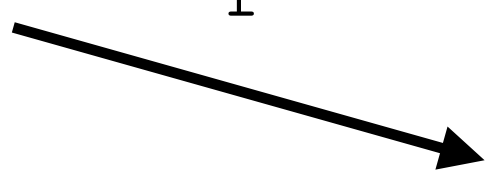
```
df.melt(id_vars=["location", "Temperature"],  
        var_name="Date", value_name="Value")
```

	location	Temperature	Date	Value
0	CityA	Predict	Jan-2010	30
1	CityB	Actual	Jan-2010	32
2	CityA	Predict	Feb-2010	45
3	CityB	Actual	Feb-2010	43
4	CityA	Predict	Mar-2010	24
5	CityB	Actual	Mar-2010	22

[AB Abhi]

Pivot

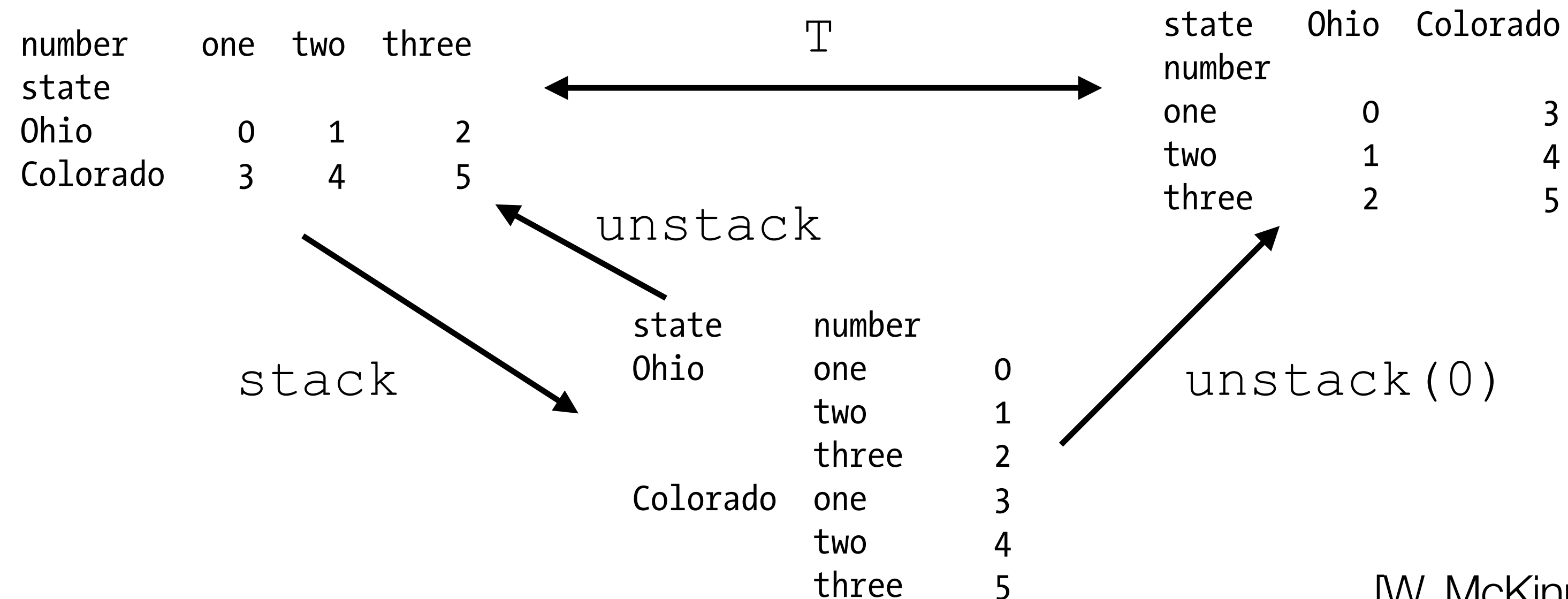
- Sometimes, we have data that is given in "long" format and we would like "wide" format (aka pivot_wider)
- Long format: column names are data values...
- Wide format: more like spreadsheet format
- Example:

	date	item	value		<code>.pivot('date', 'item', 'value')</code>			
0	1959-03-31	realgdp	2710.349		item	infl	realgdp	unemp
1	1959-03-31	infl	0.000		date			
2	1959-03-31	unemp	5.800		1959-03-31	0.00	2710.349	5.8
3	1959-06-30	realgdp	2778.801		1959-06-30	2.34	2778.801	5.1
4	1959-06-30	infl	2.340		1959-09-30	2.74	2775.488	5.3
5	1959-06-30	unemp	5.100		1959-12-31	0.27	2785.204	5.6
6	1959-09-30	realgdp	2775.488		1960-03-31	2.31	2847.699	5.2
7	1959-09-30	infl	2.740					
8	1959-09-30	unemp	5.300					
9	1959-12-31	realgdp	2785.204					

[W. McKinney, Python for Data Analysis]

Stack and Unstack

- `stack`: pivots from the columns into rows (may produce a Series!)
- `unstack`: pivots from rows into columns
- unstacking may add missing data
- stacking filters out missing data (unless `dropna=False`)
- can unstack at a different level by passing it (e.g. 0), defaults to innermost level



[W. McKinney, Python for Data Analysis]

Assignment 8

- Last Assignment
- Data and Visualization
- Out Soon

Quiz Wednesday

- Check your understanding of arrays and data frames

Data Exploration through Visualization

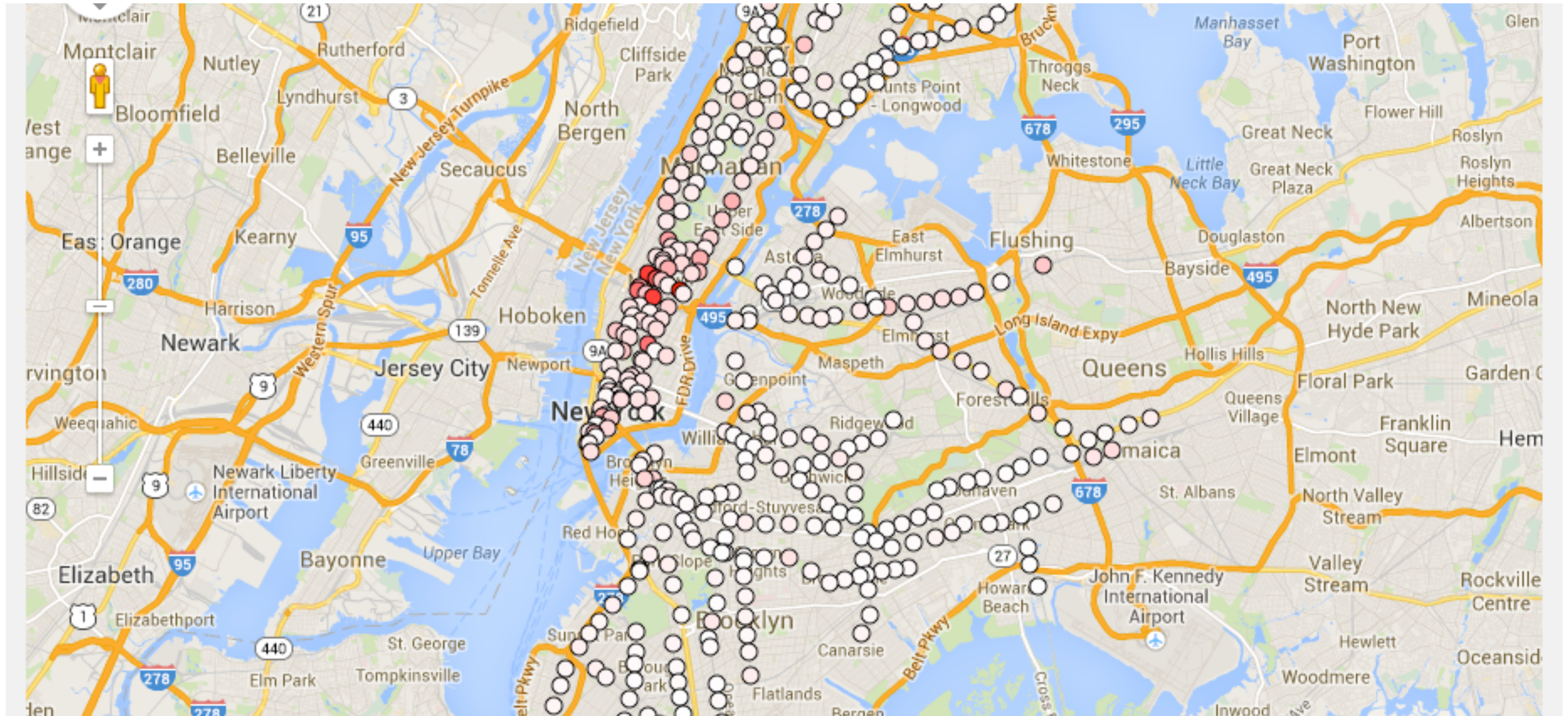
Transportation Data - NYC MTA



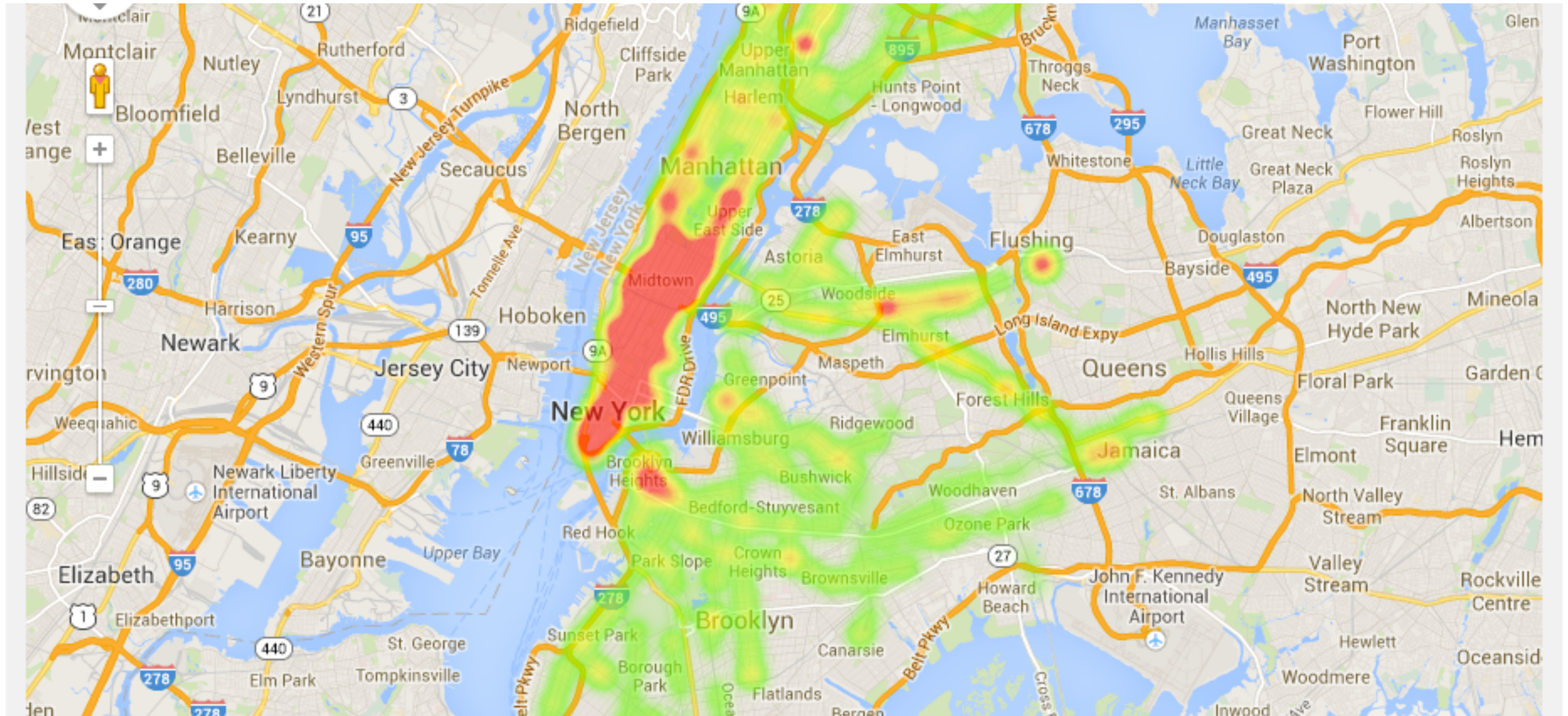
MTA Fare Data Exploration

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

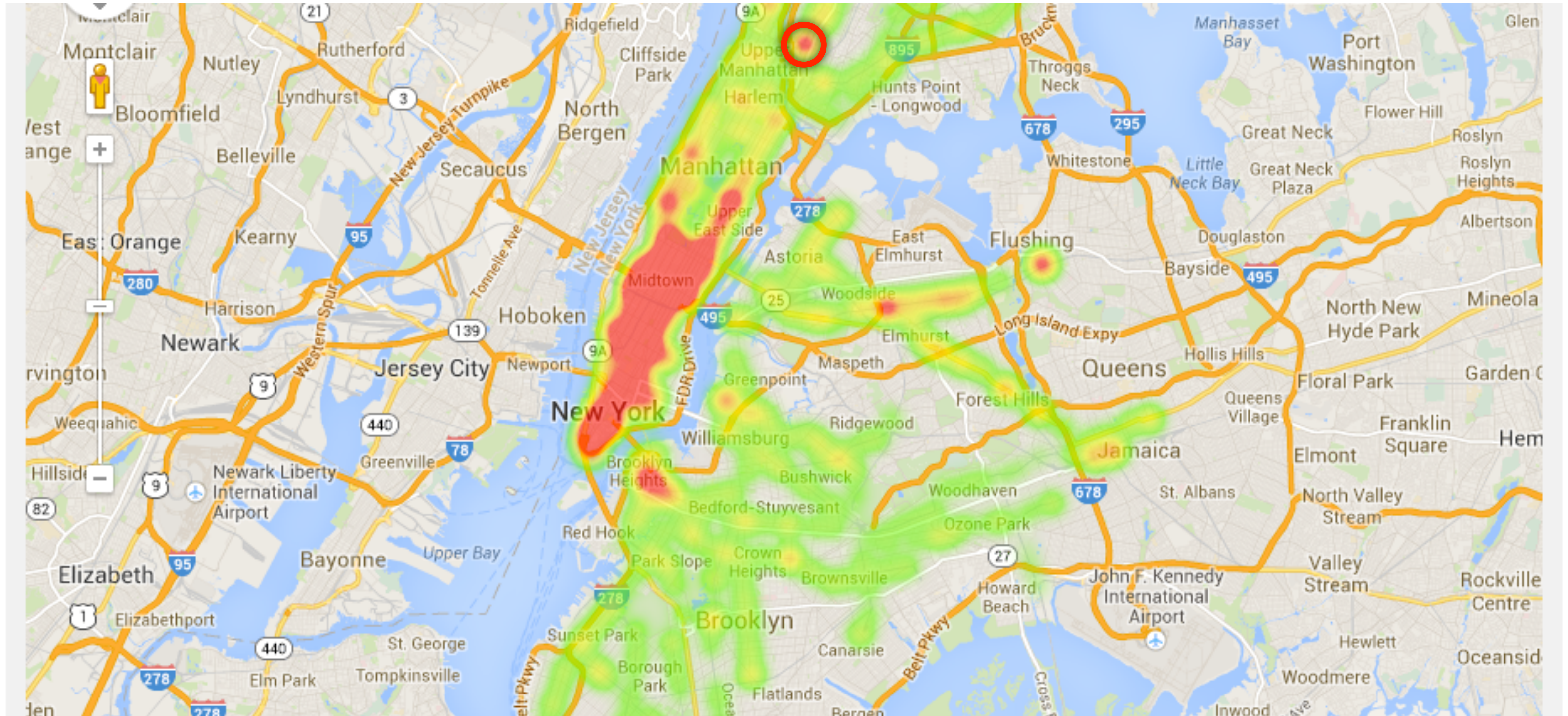
MTA Fare Data Exploration



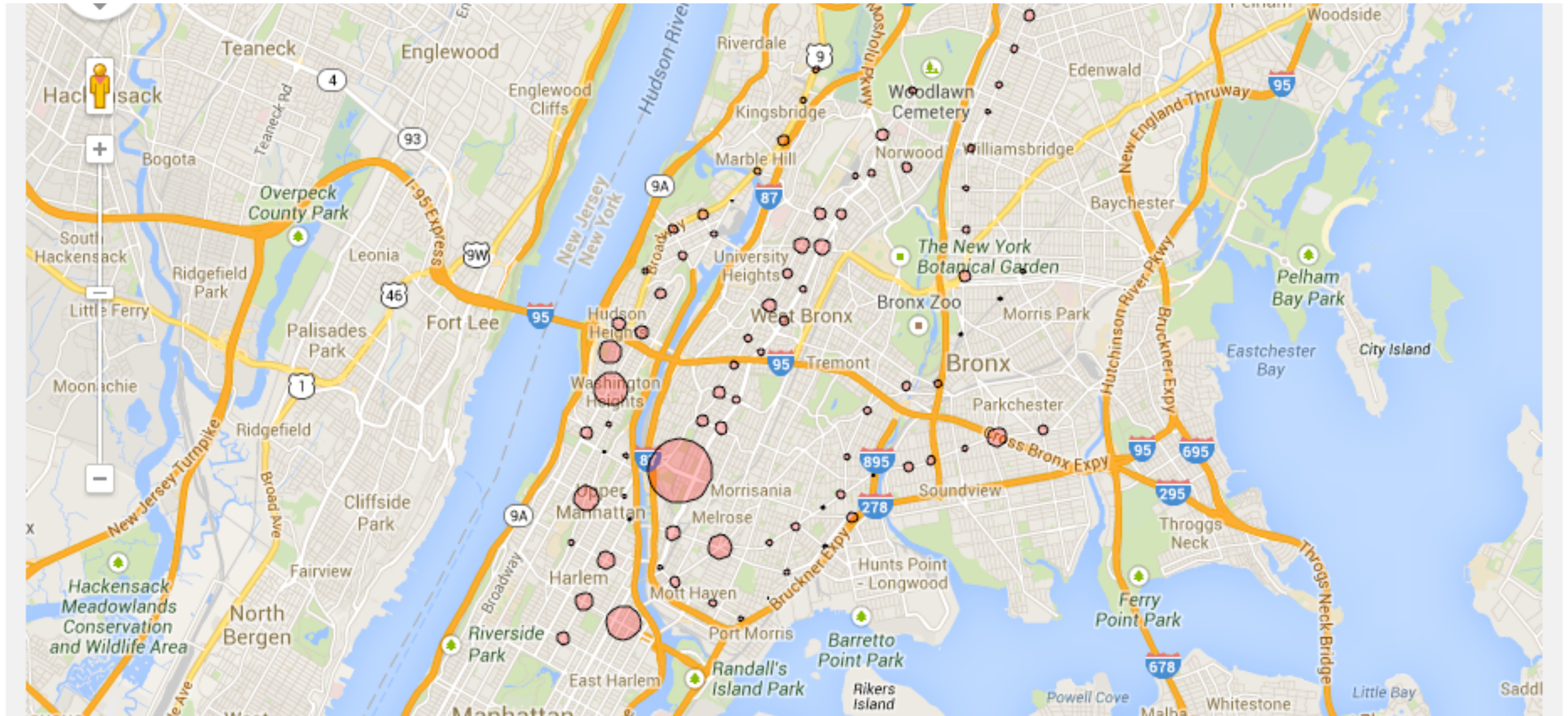
MTA Fare Data Exploration



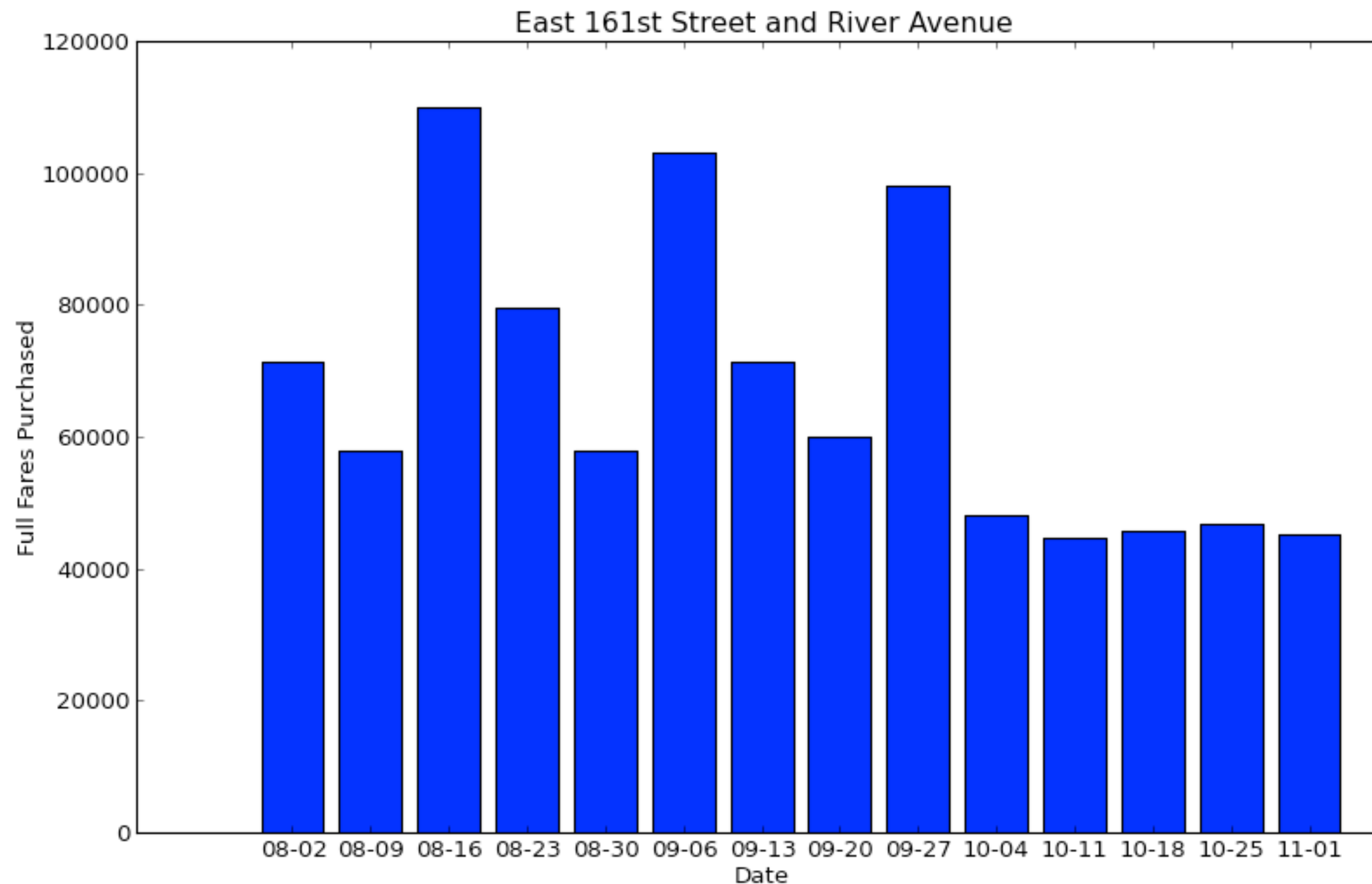
MTA Fare Data Exploration



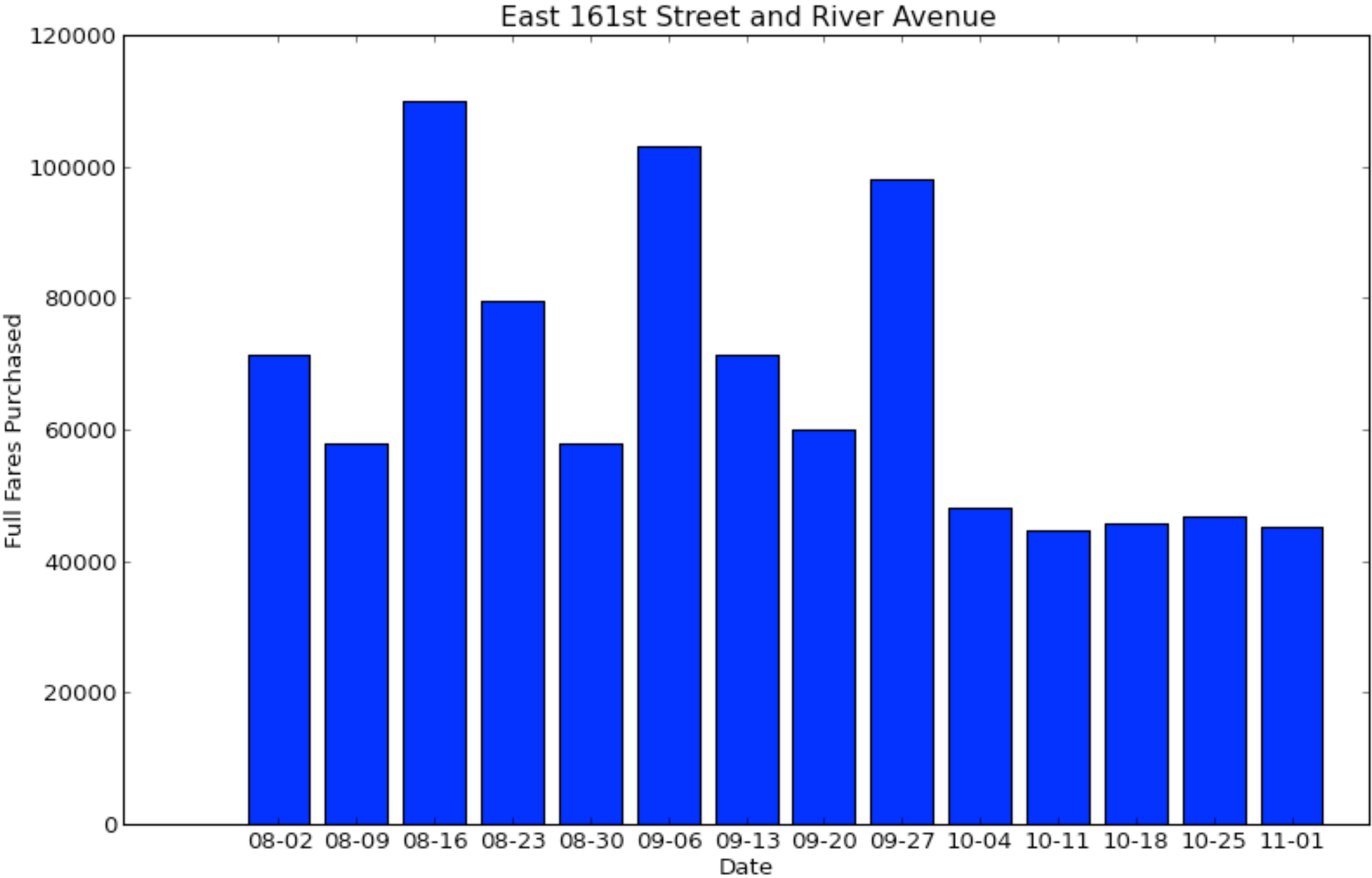
MTA Fare Data Exploration



MTA Fare Data Exploration



MTA Fare Data Exploration



New York Yankees

AUGUST						
SUN	MON	TUE	WED	THU	FRI	SAT
	yankees.com			1	2	3
					SD	SD
4	5	6	7	8	9	10
SD	CHW	CHW	CHW		DET	DET
11	12	13	14	15	16	17
DET	LAA	LAA	LAA	LAA	BOS	BOS
18	19	20	21	22	23	24
BOS		TOR	TOR	TOR	TB	TB
25	26	27	28	29	30	31
TB	TOR	TOR	TOR		BAL	BAL

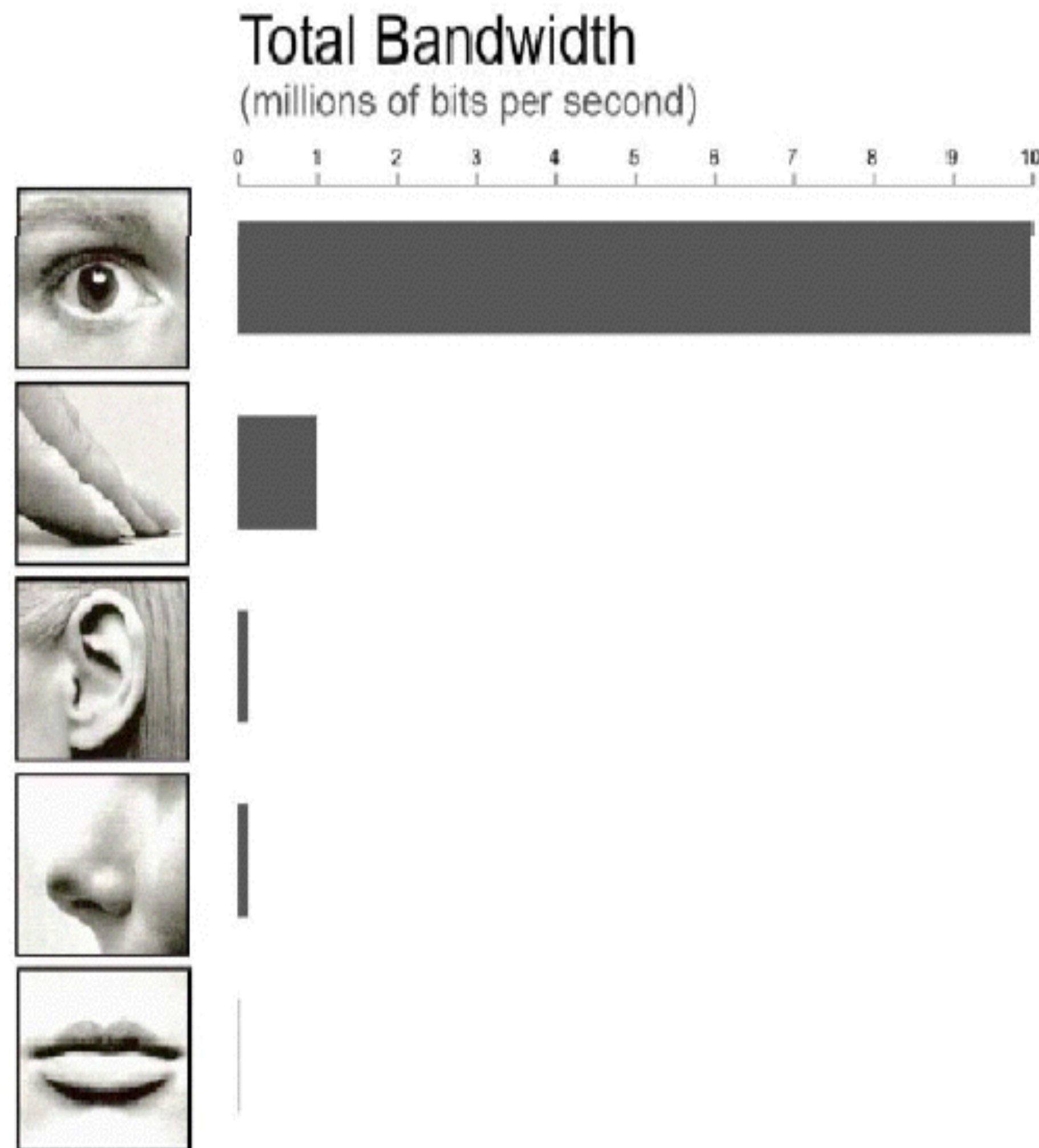
SEPTEMBER						
SUN	MON	TUE	WED	THU	FRI	SAT
1	2	3	4	5	6	7
BAL	CHW	CHW	CHW	BOS	BOS	BOS
8	9	10	11	12	13	14
BOS	BAL	BAL	BAL	BAL	BOS	BOS
15	16	17	18	19	20	21
BOS		TOR	TOR	TOR	SF	SF
22	23	24	25	26	27	28
SF		TB	TB	TB	HOU	HOU
29	30	ALL GAMES ARE EASTERN TIME.				
HOU						

♦ 2013 REGULAR SEASON SCHEDULE ♦

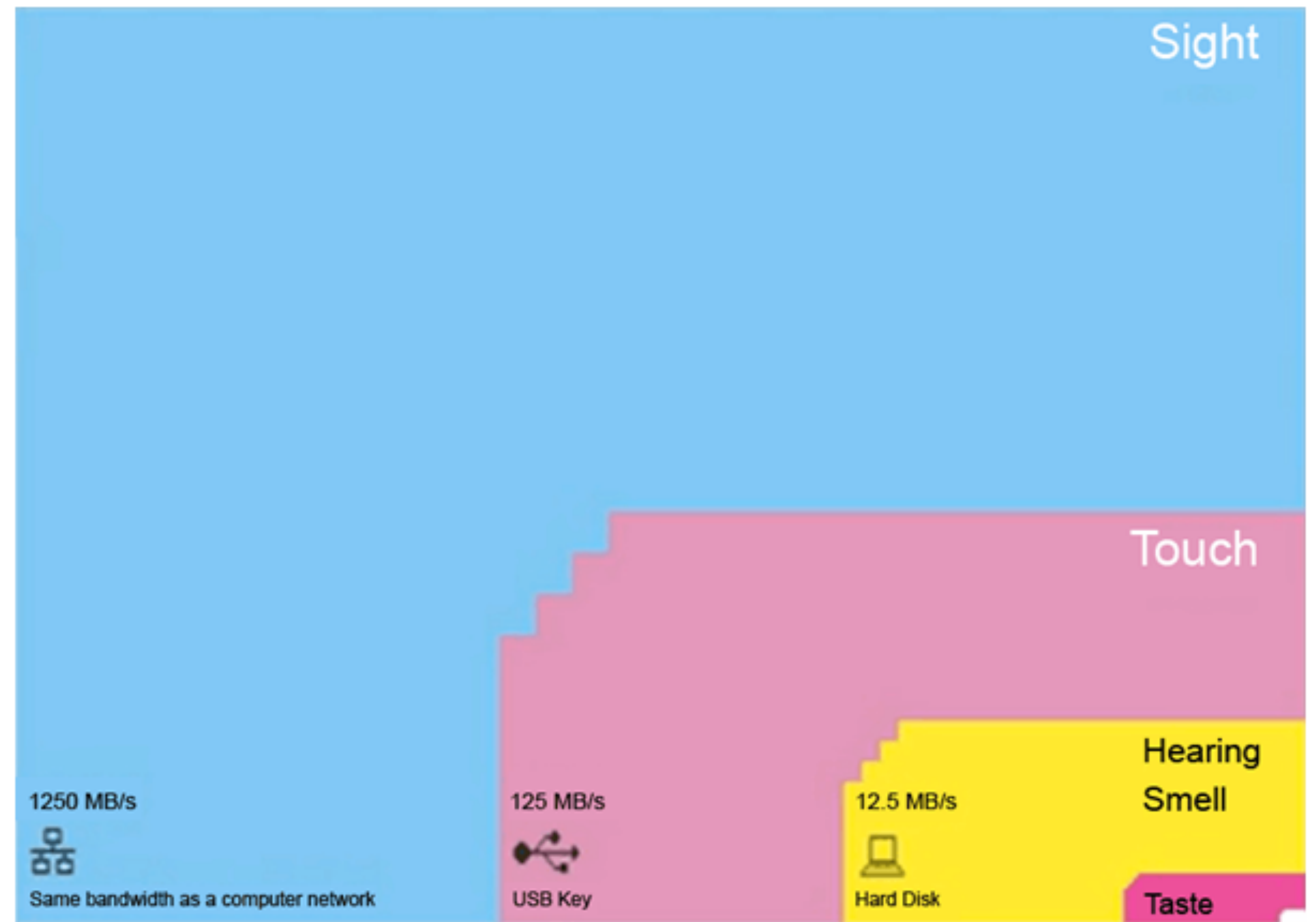
Definition of Visualization

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

Why do we visualize data?



[via A. Lex]



[T. Nørretranders]

Why Visual?

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

[F. J. Anscombe]

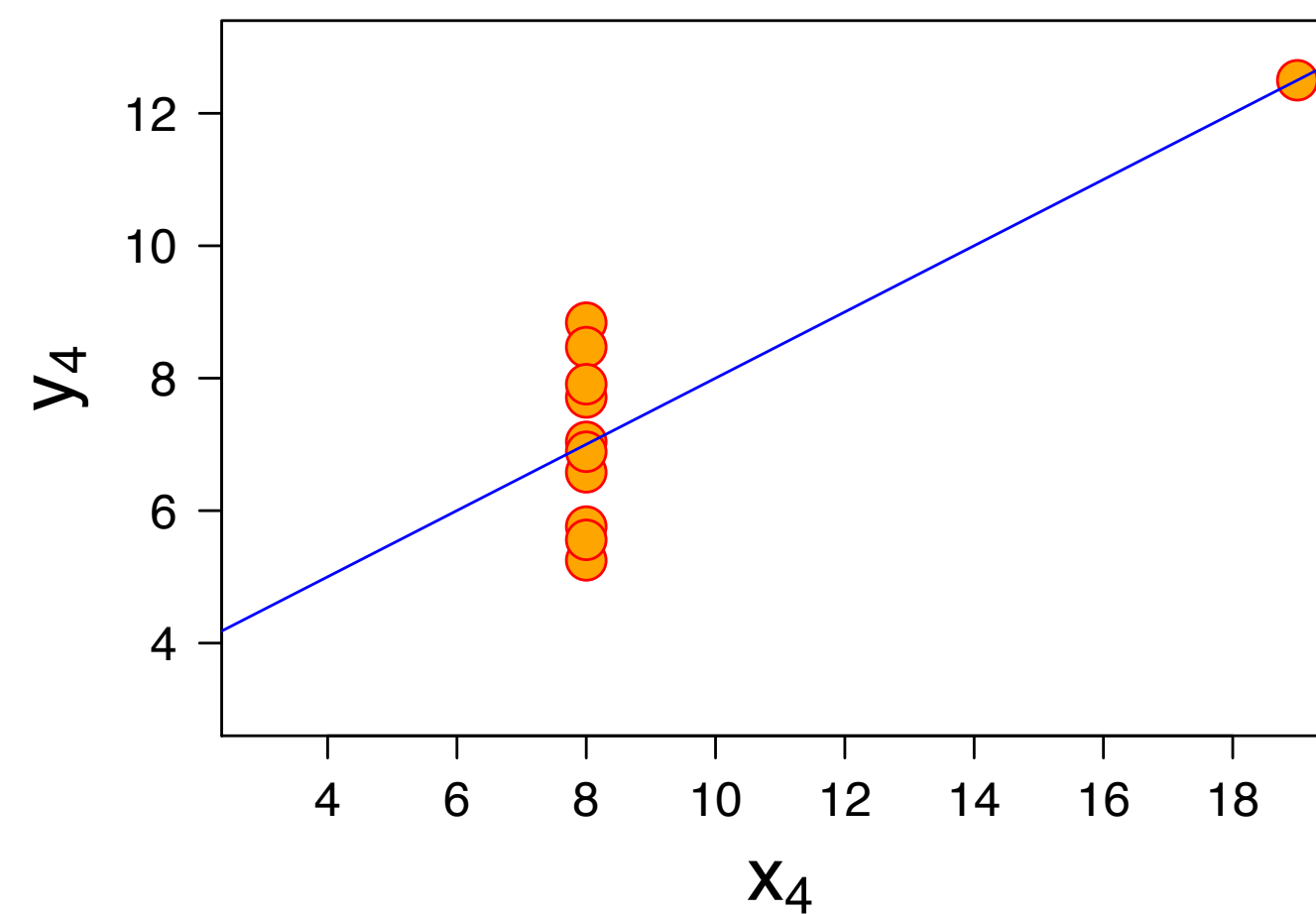
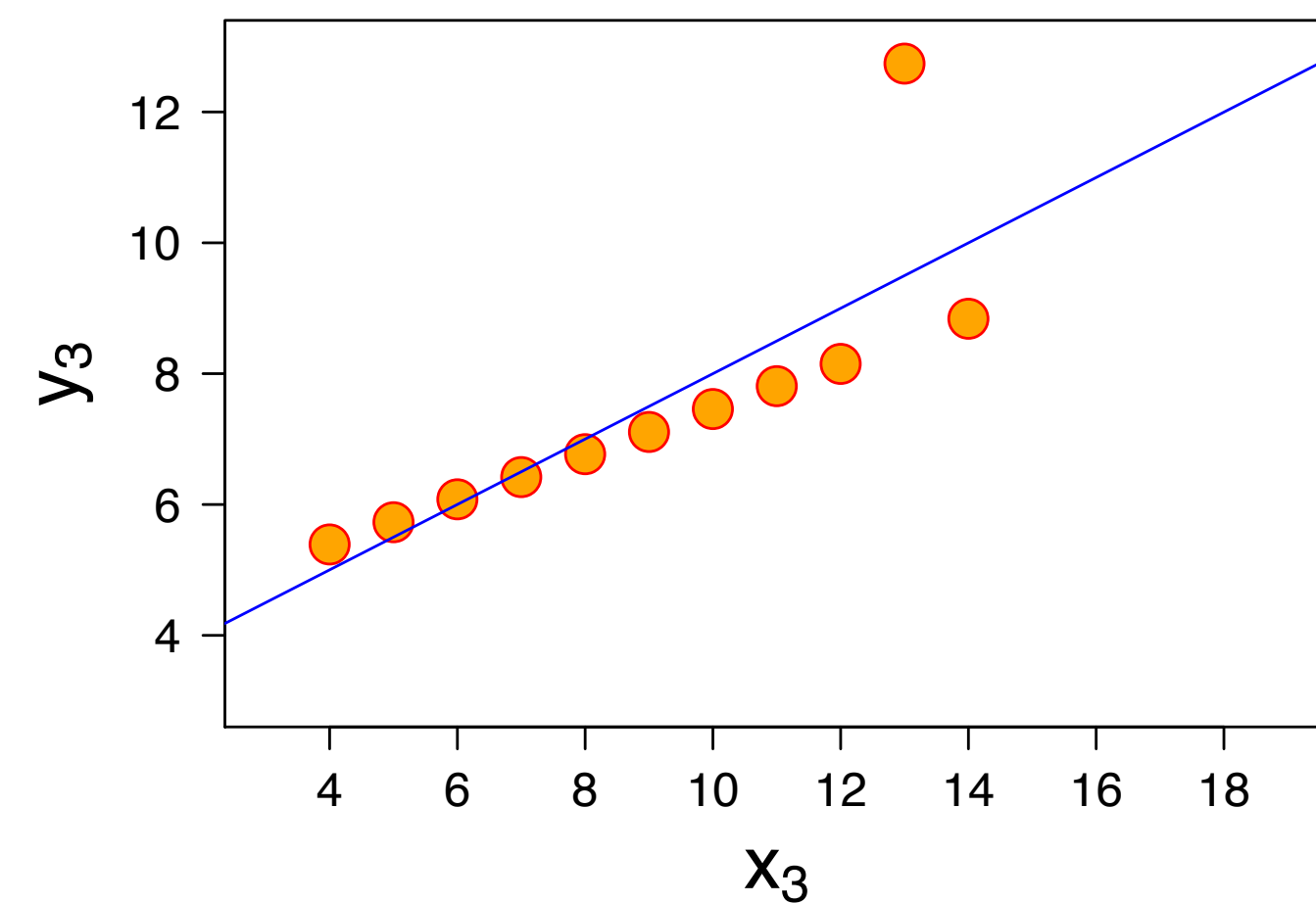
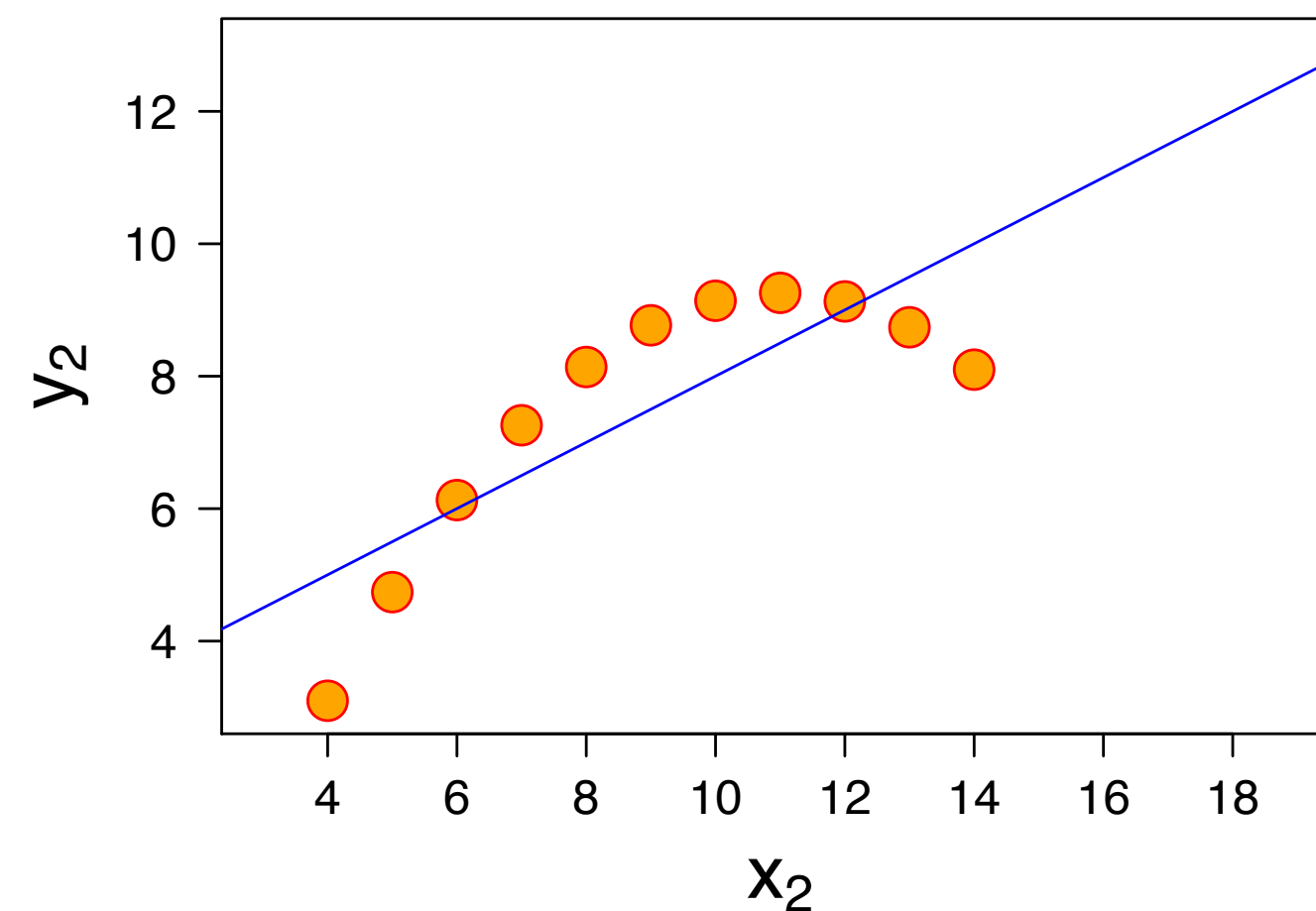
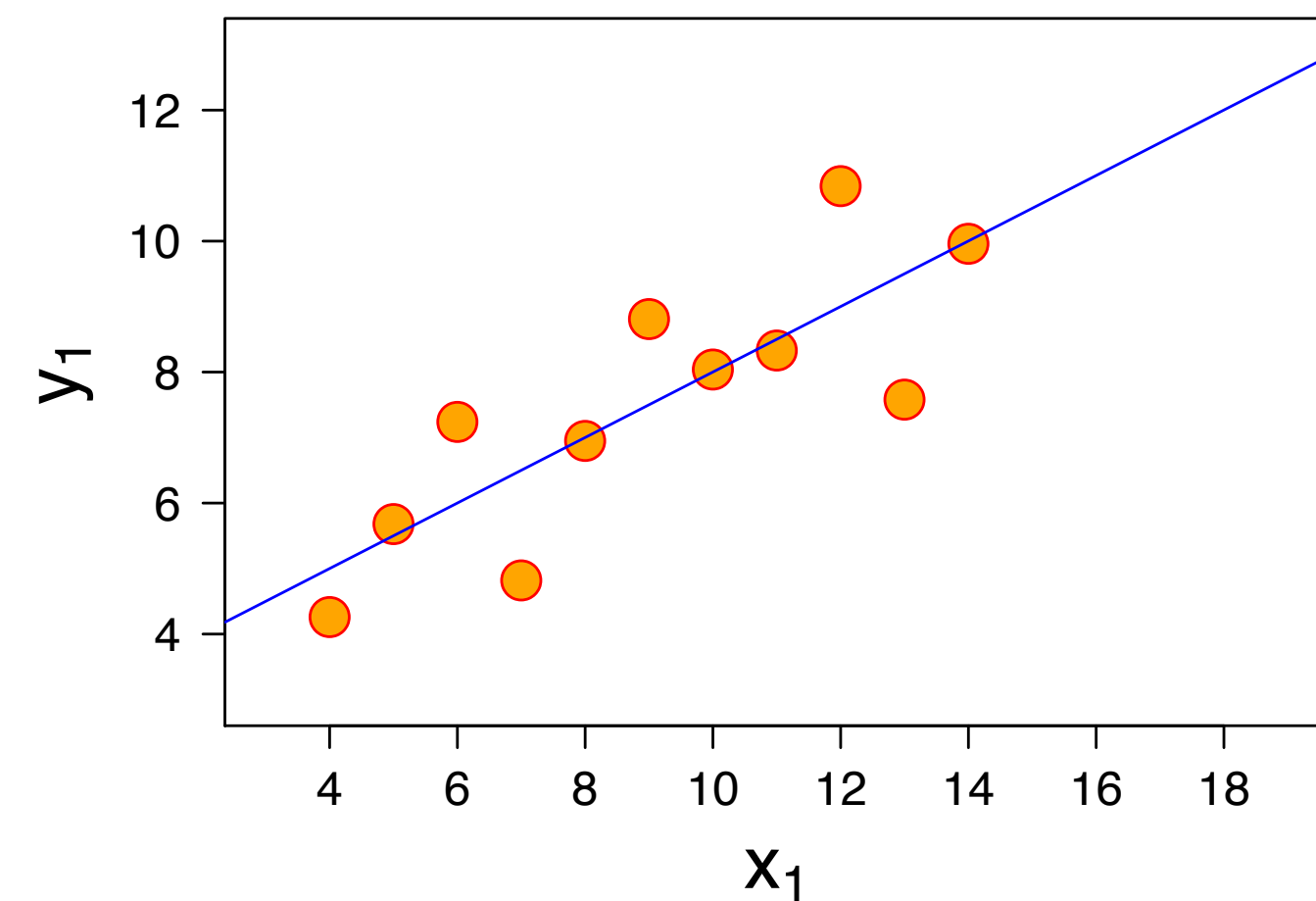
Why Visual?

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

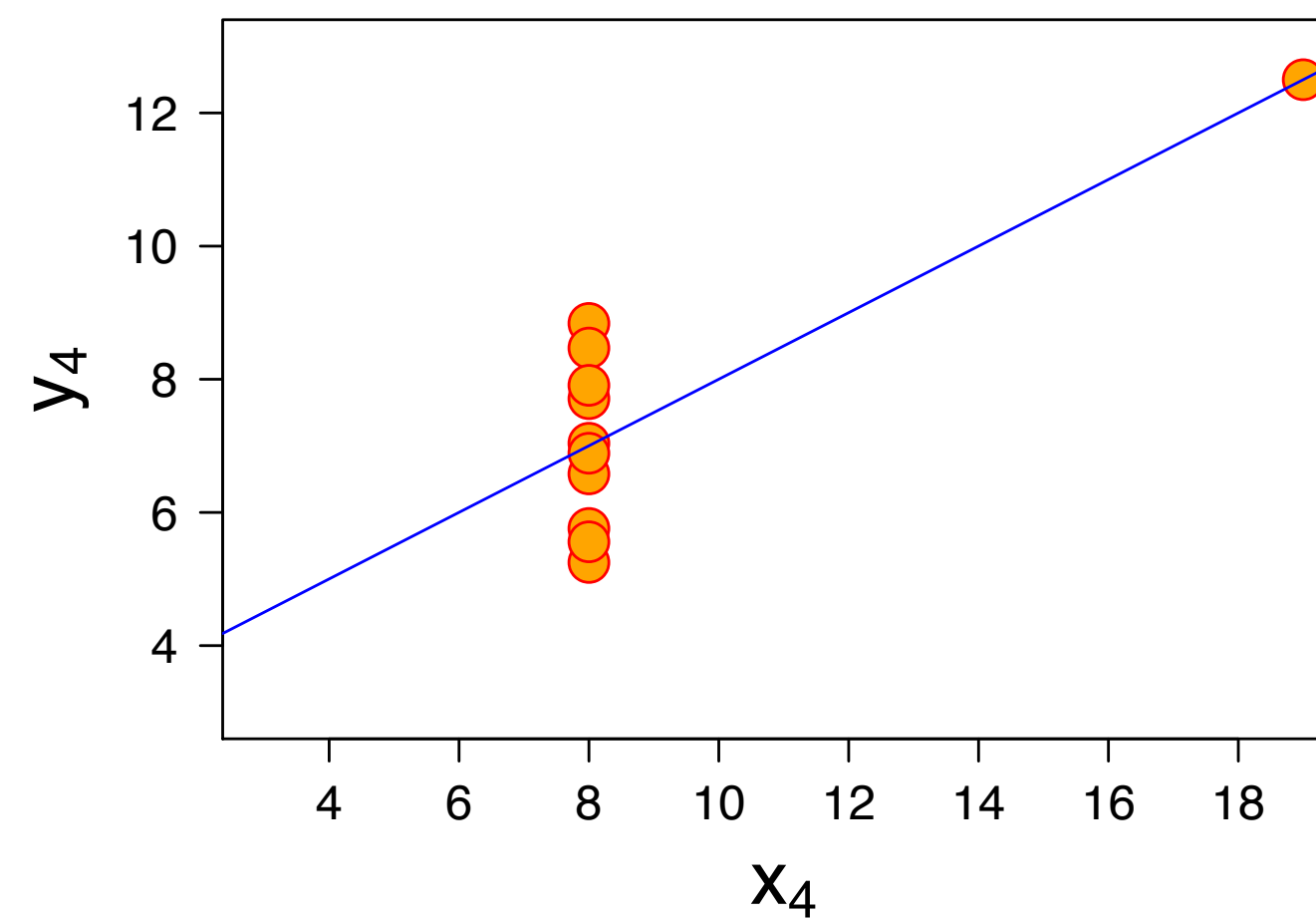
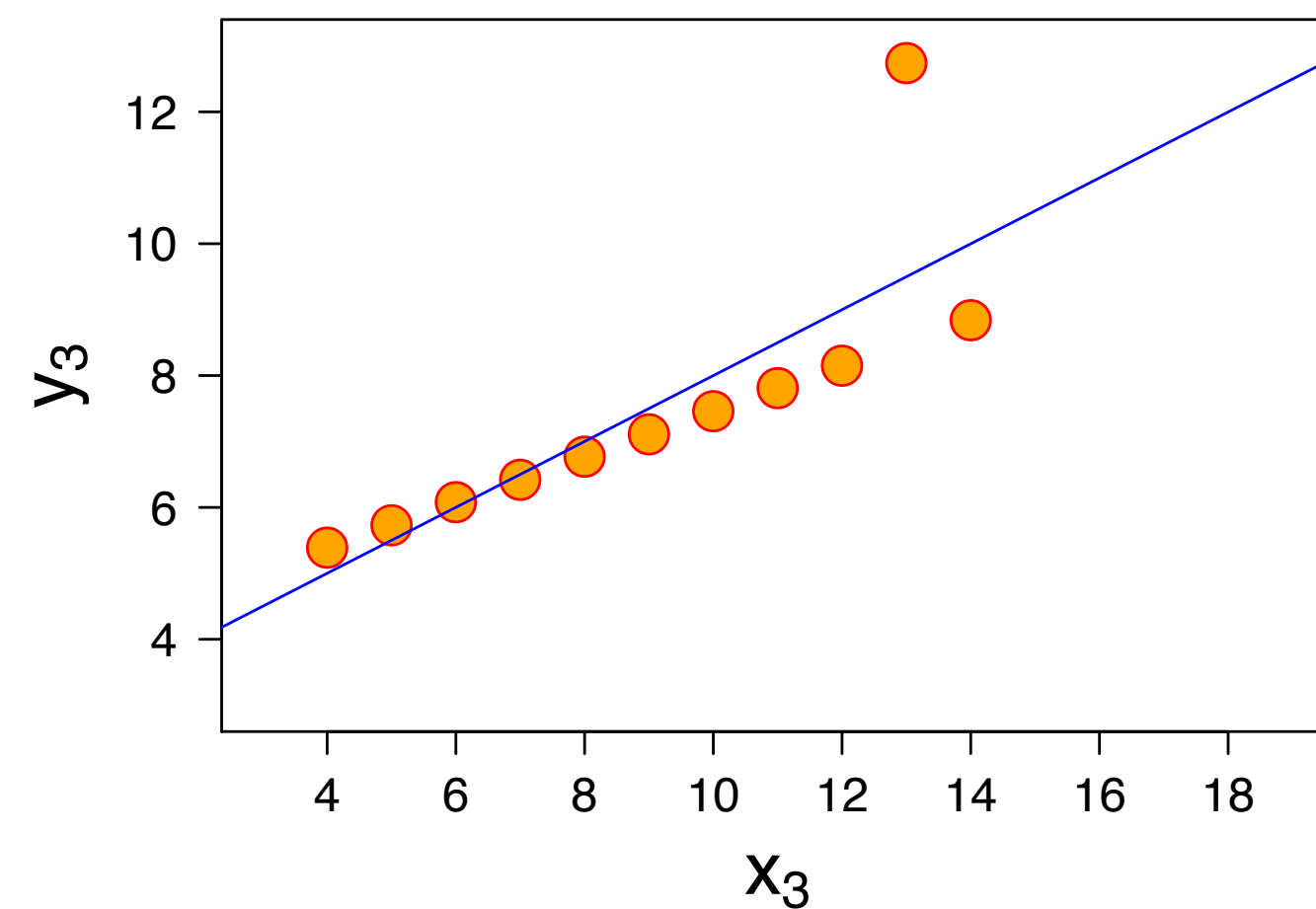
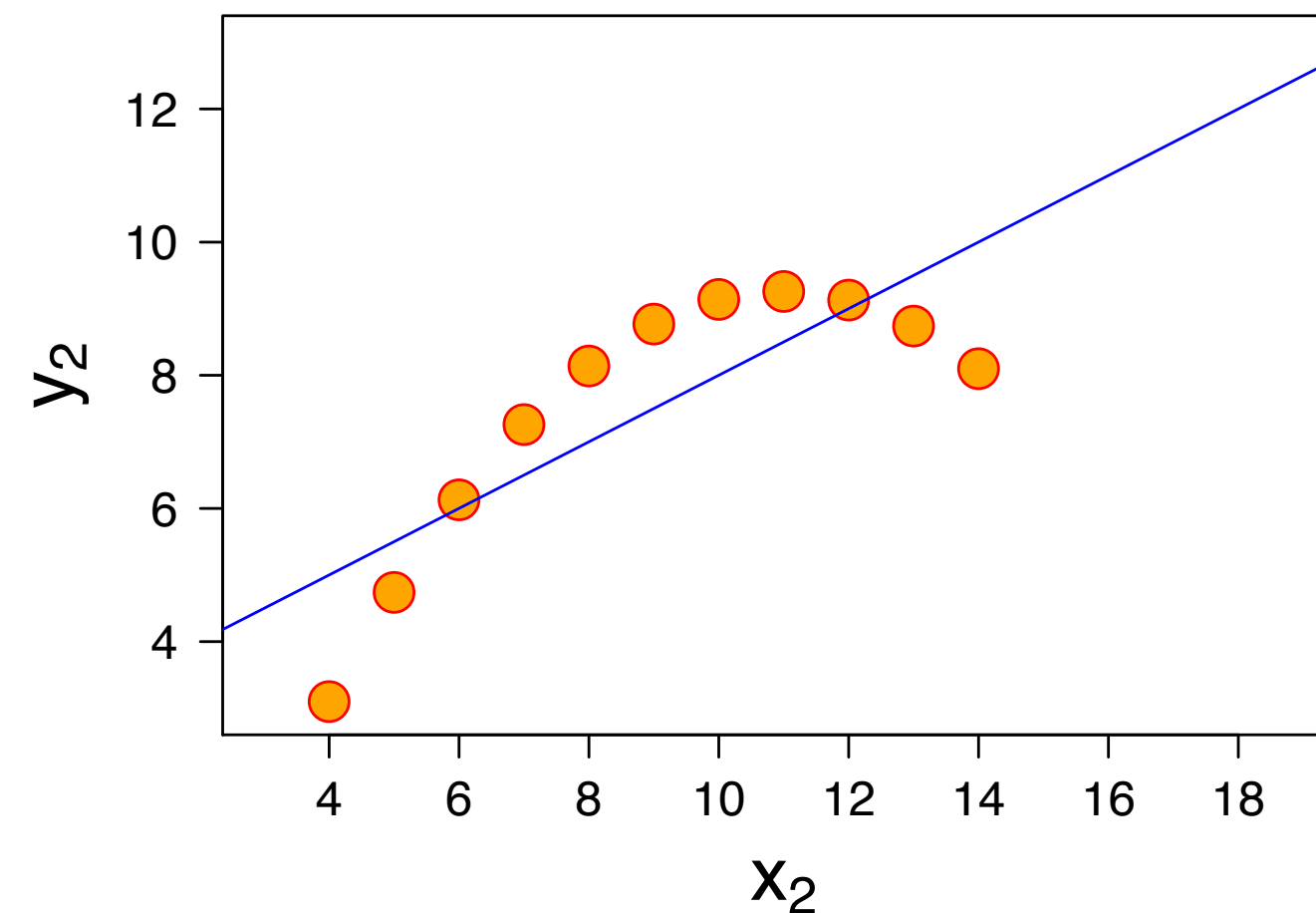
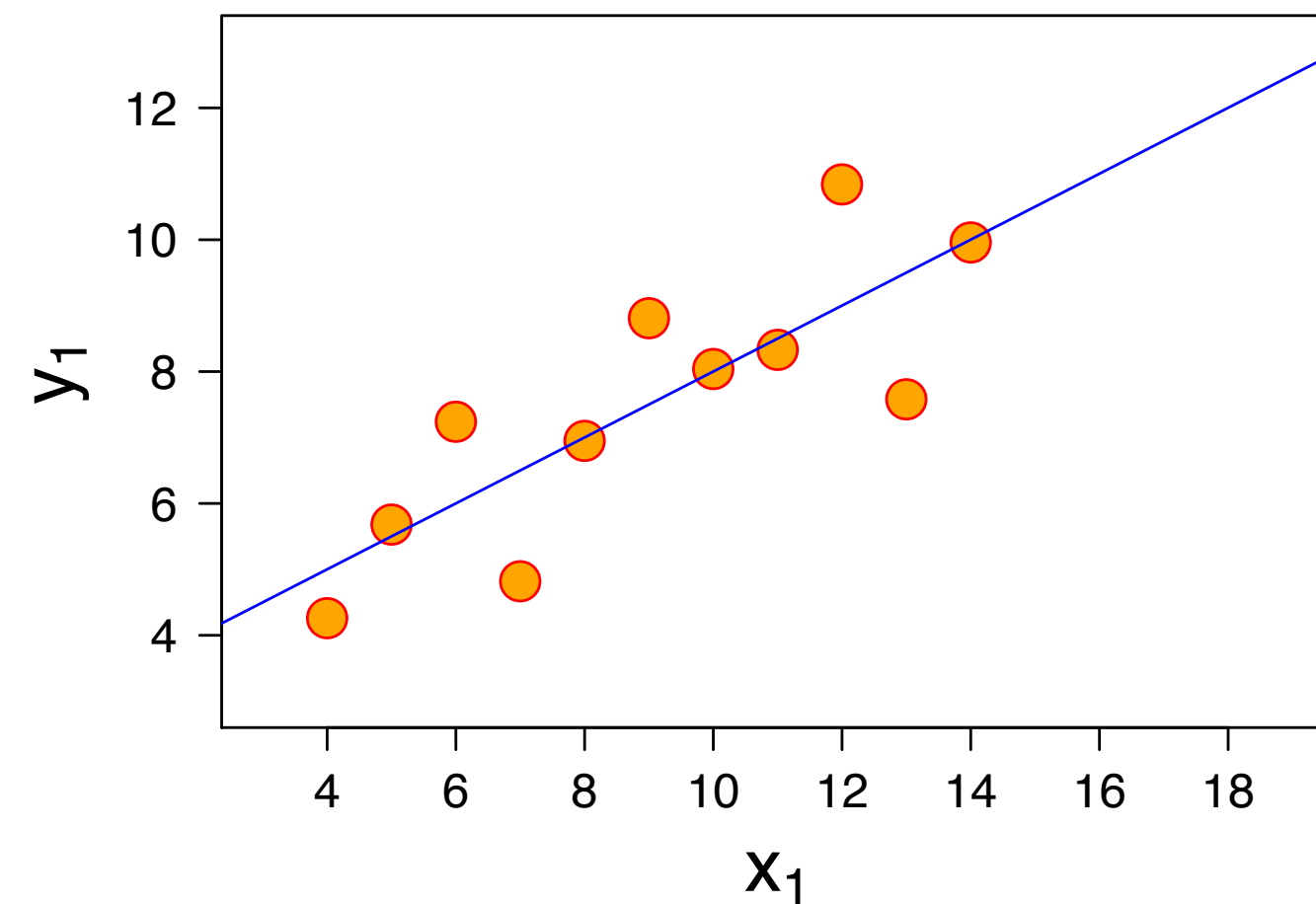
[F. J. Anscombe]

Why Visual?



[F. J. Anscombe]

Why Visual?



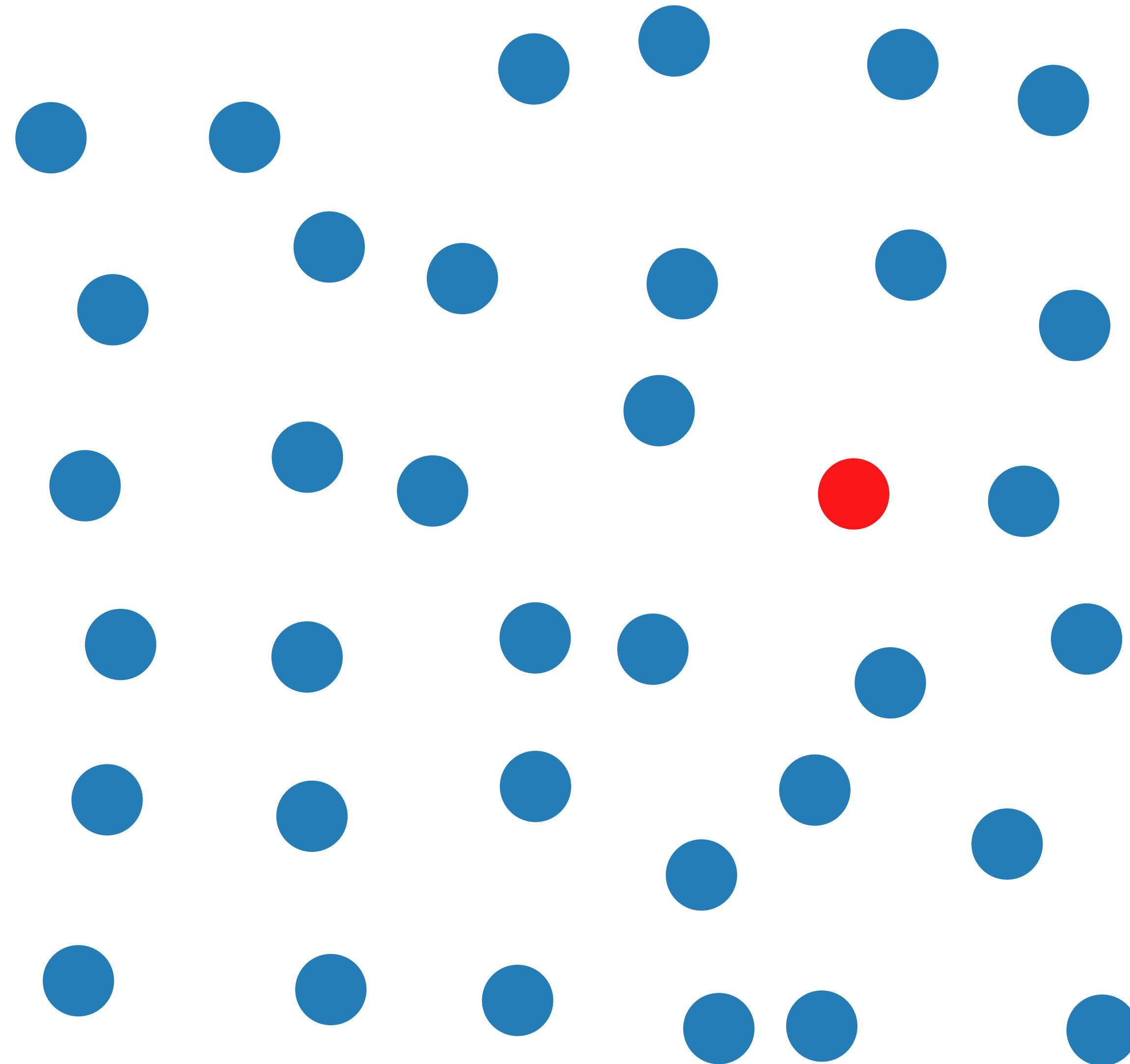
Mean of x	9
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[F. J. Anscombe]

Visualization Goals

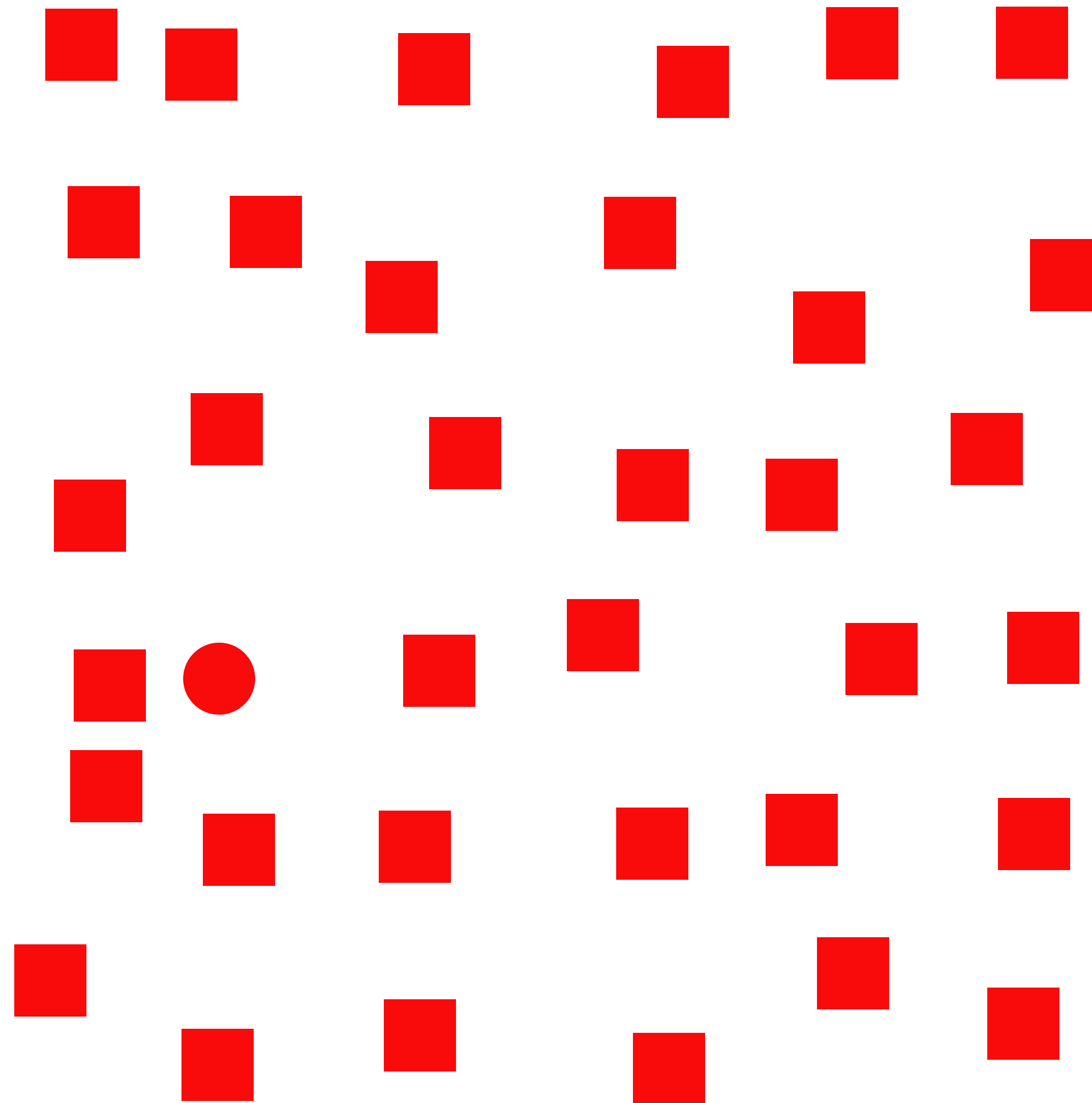
- "The purpose of visualization is **insight**, not pictures" – B. Shneiderman
- Identify patterns, trends
- Spot outliers
- Find similarities, correlation

Visual Pop-out



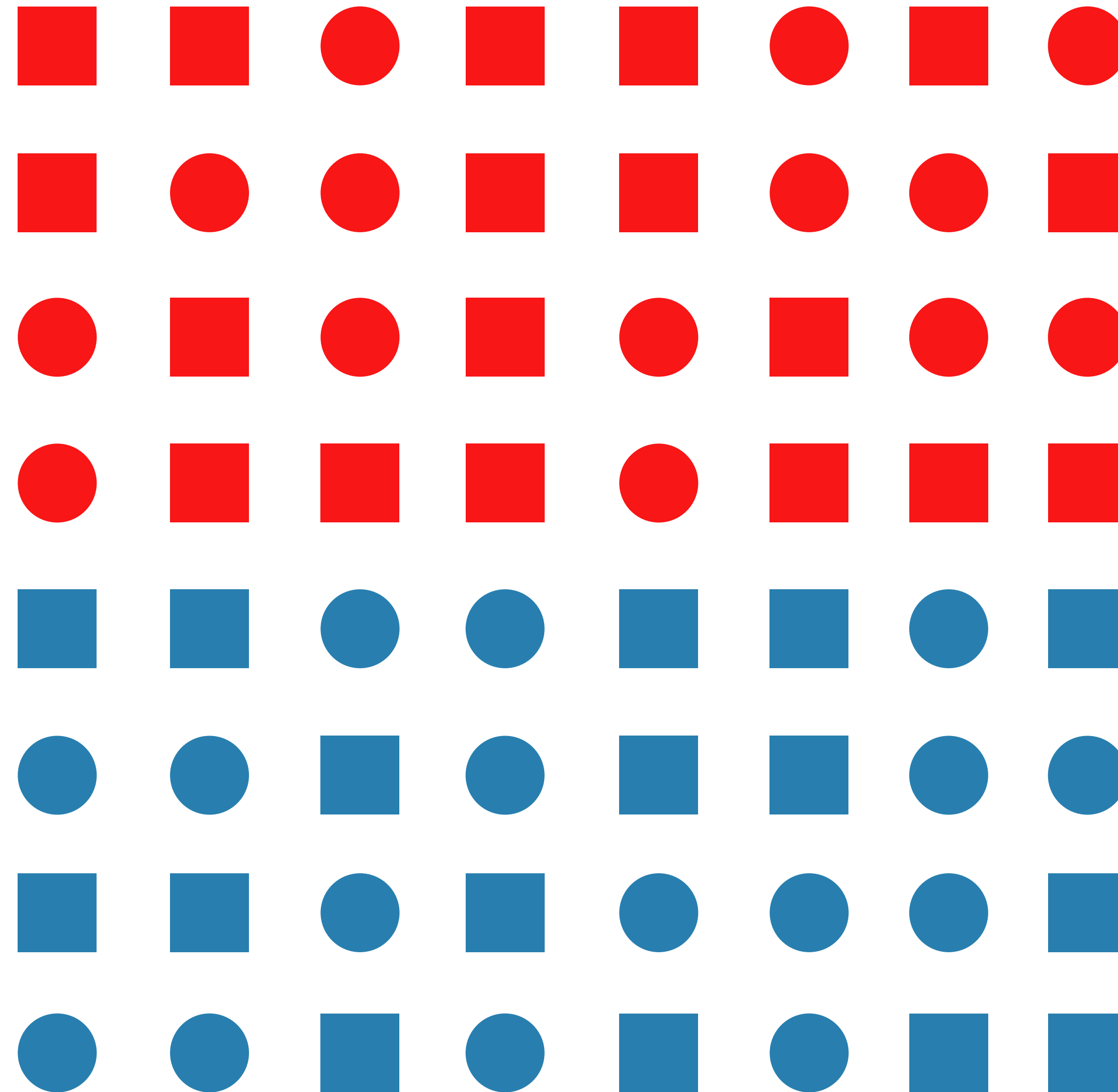
[C. G. Healey]

Visual Pop-out



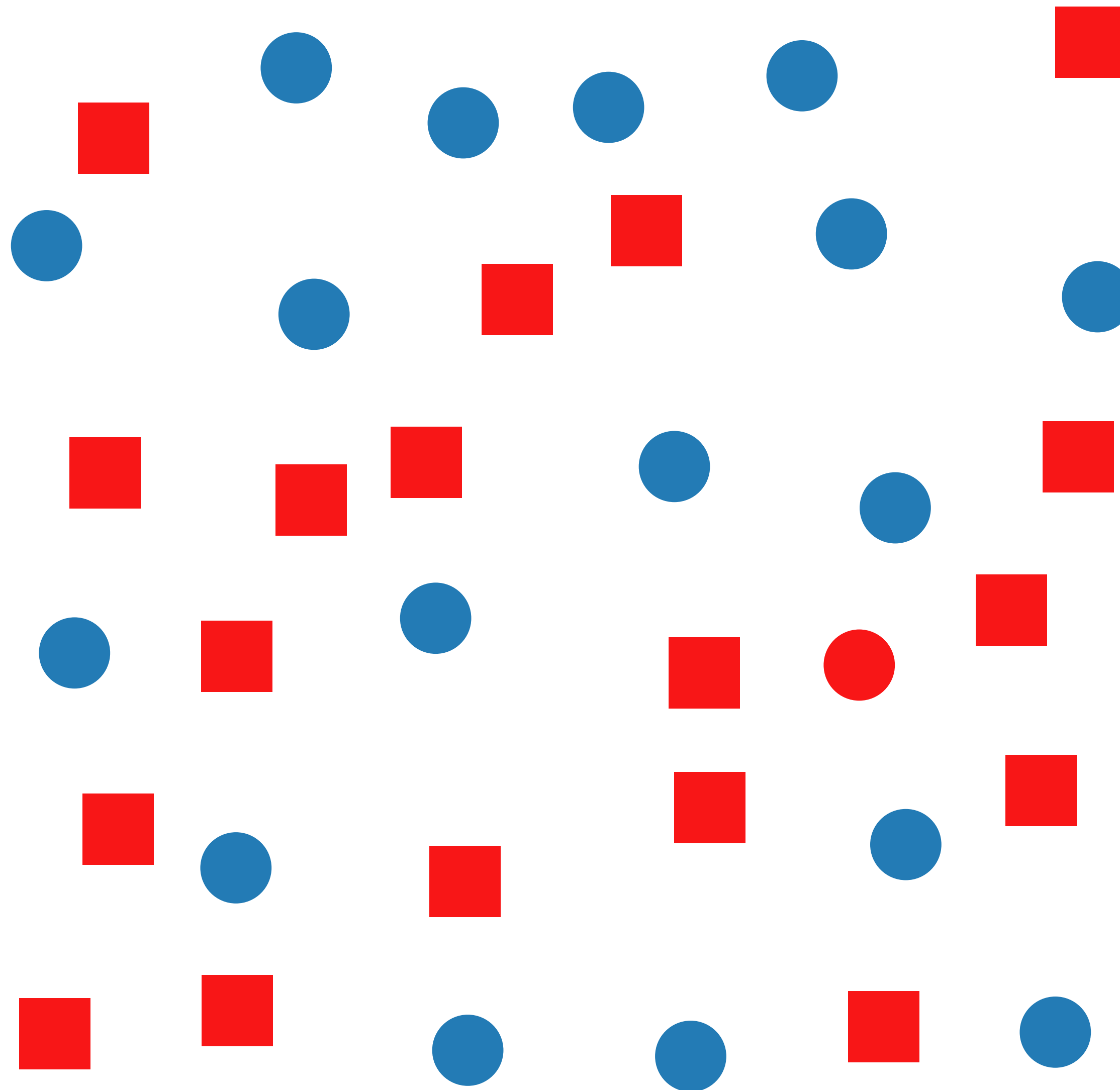
[C. G. Healey]

Visual Pop-out



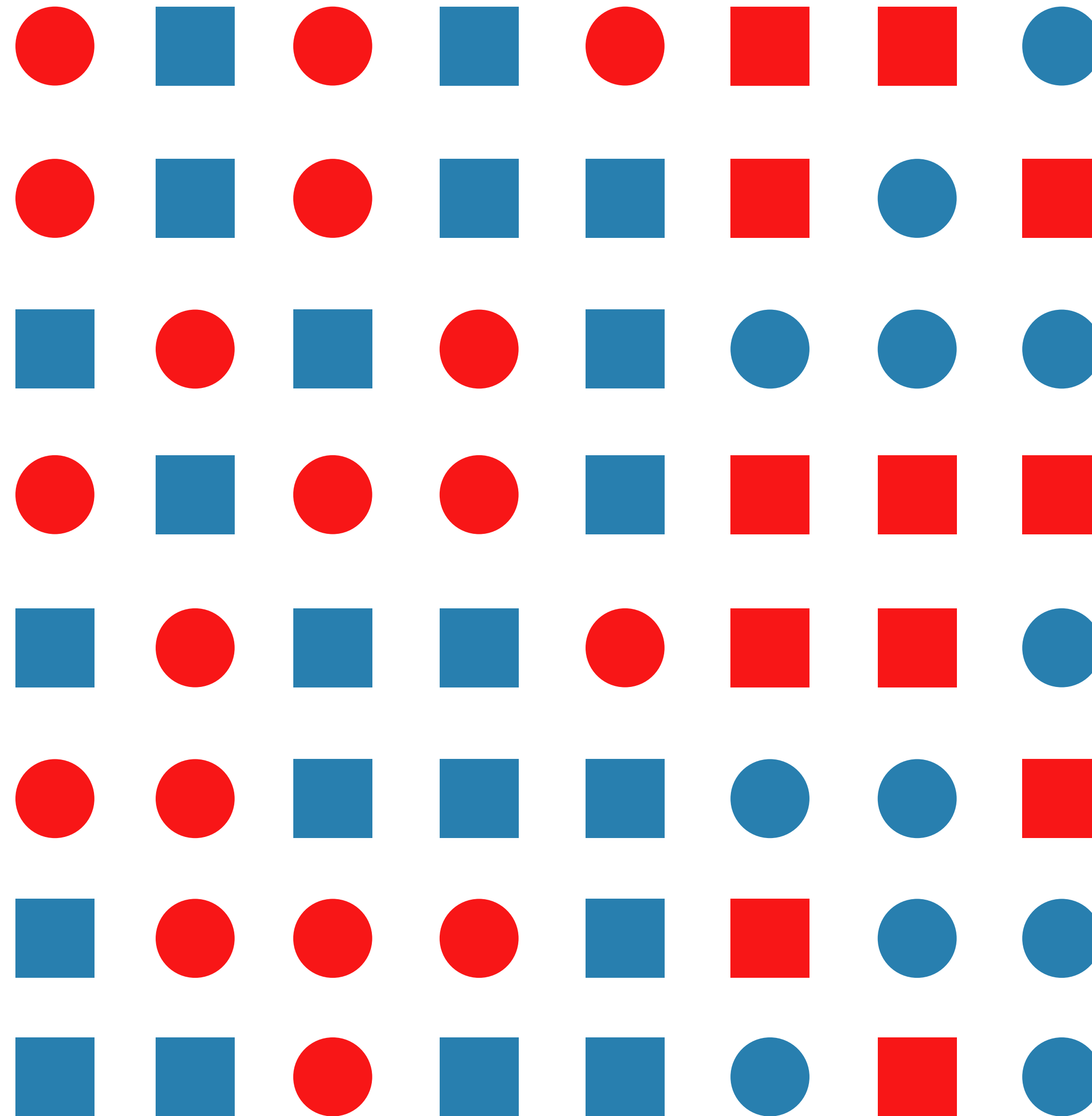
[C. G. Healey]

Visual Perception Limitations



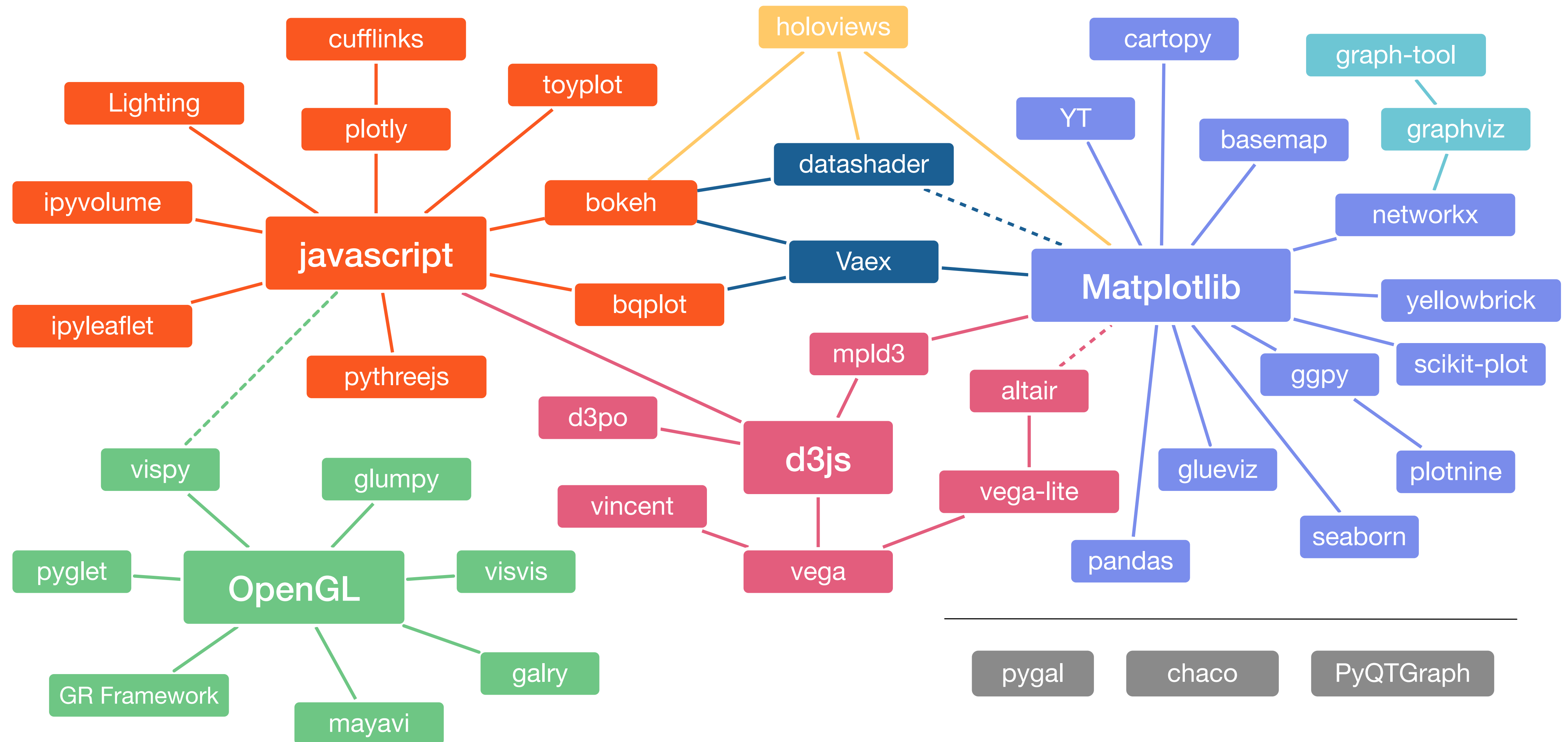
[C. G. Healey]

Visual Perception Limitations

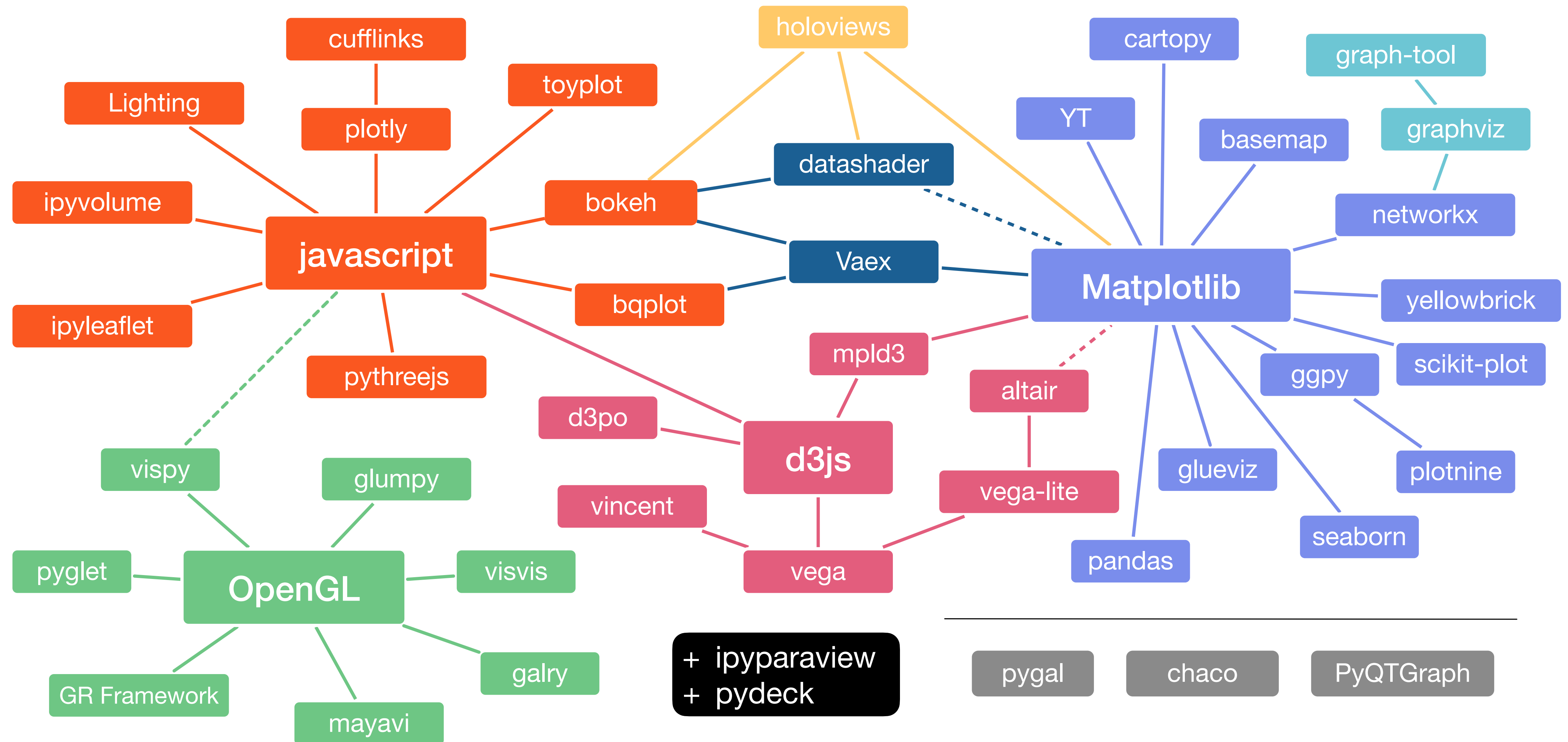


[C. G. Healey]

The Python Visualization Landscape

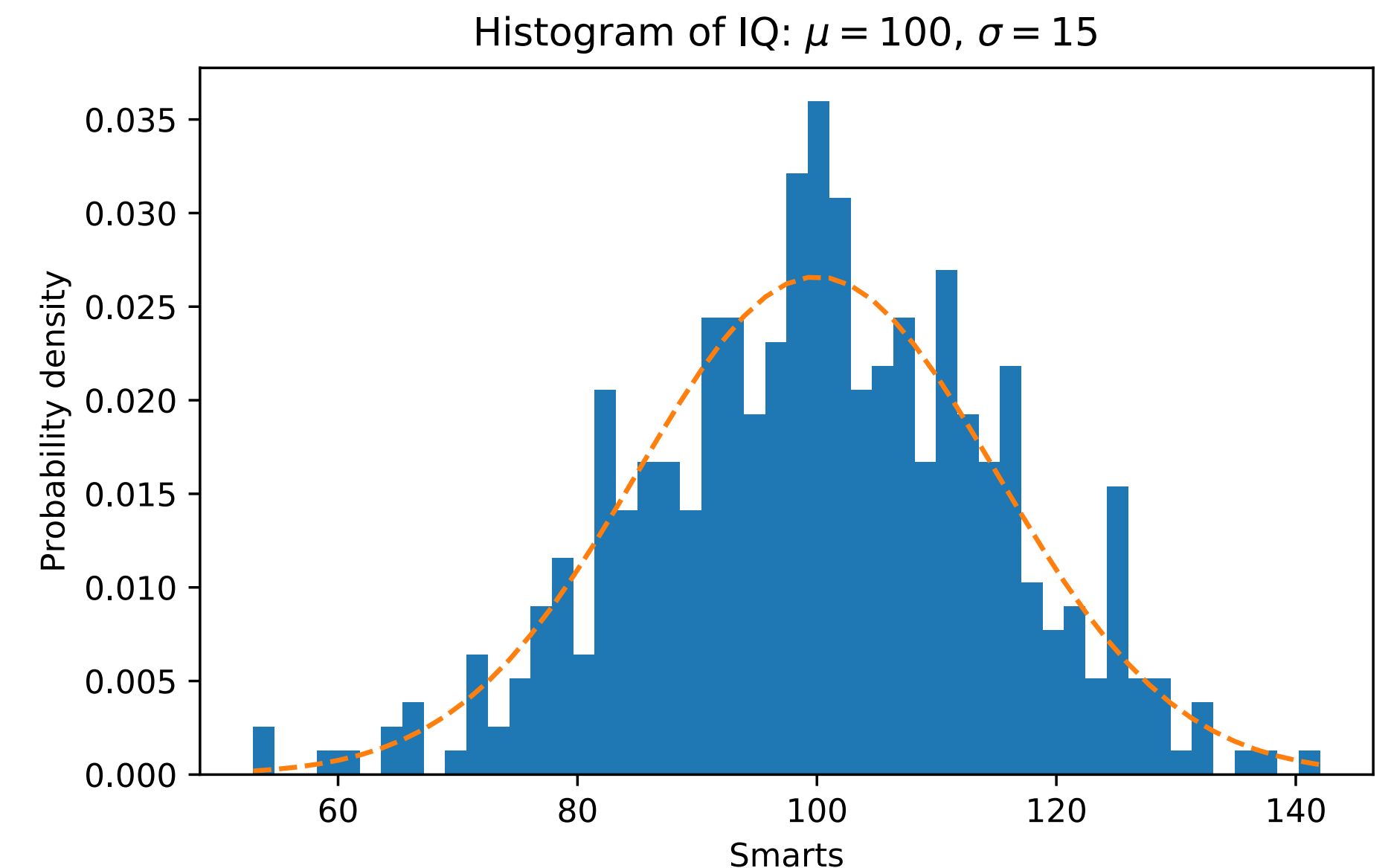


The Python Visualization Landscape



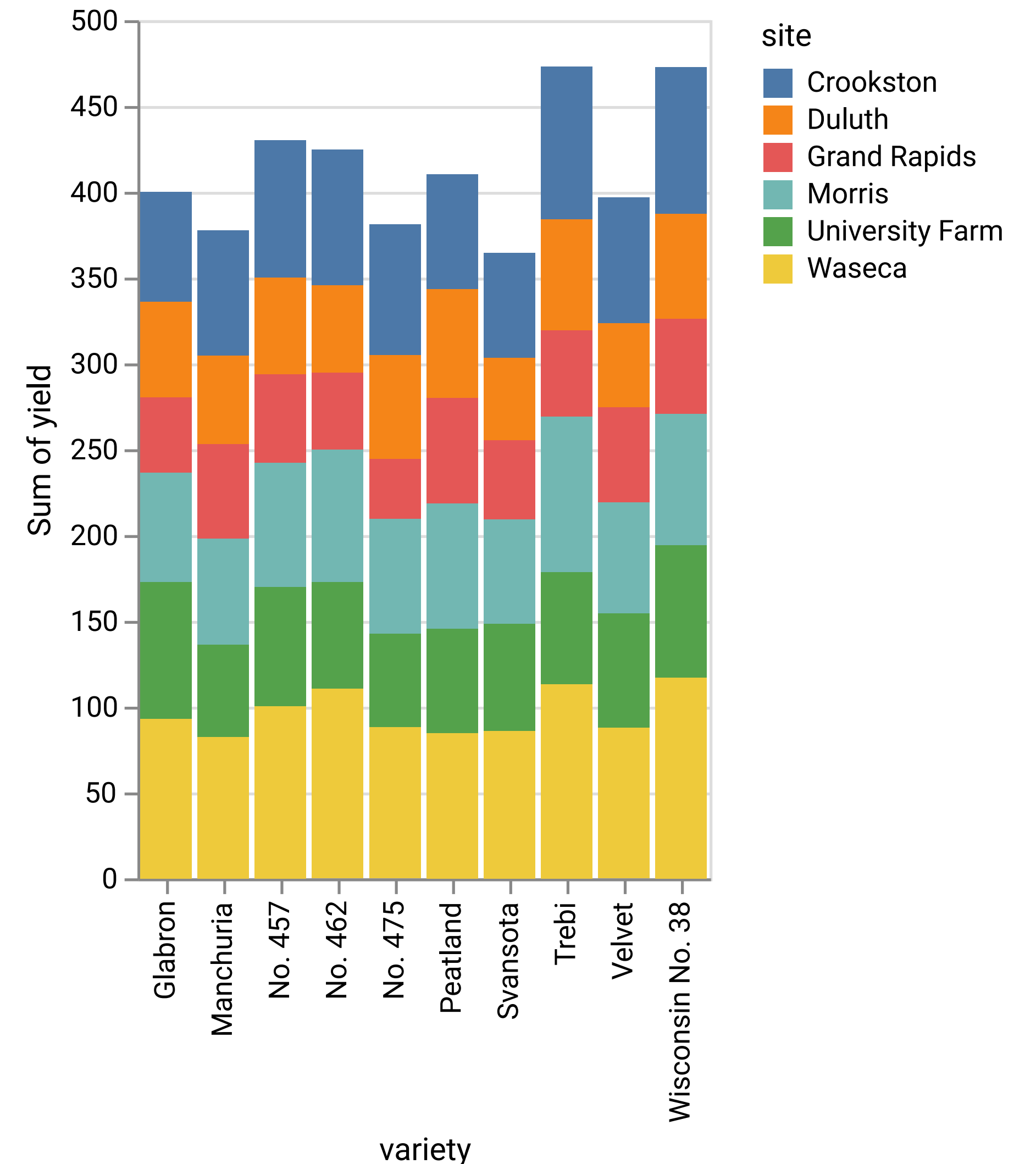
matplotlib

- 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



Altair

- Declarative Visualization
 - Specify **what** instead of how
 - Separate specification from execution
- Based on VegaLite which is browser-based
- Strengths:
 - Declarative visualization
 - Web technologies
- Drawbacks:
 - Moving data between Python and JS
 - Sometimes longer specifications



Matplotlib History

- "In the beginning was matplotlib" – J. VanderPlas
- Started by John D. Hunter, a neurobiologist ~2003
- John tragically passed away in 2012, community-led now
- Before Python, John had Perl scripts that called C++ mathematical programs that wrote data files that were plotted using Matlab (then gnuplot)
- Sought a solution that was Matlab users would be more comfortable with
 - Imports "hidden" by importing into the global namespace
 - pylab mode: match terminology of Matlab (at the cost of overriding core python functions/definitions)

Lots of Changes Since

- pylab is "strongly discouraged nowadays and deprecated." [[docs](#)]
- stateful plotting using pyplot still exists, but...
- also object-oriented methods to build and customize plots now
- Integrated output in JupyterLab
- Many derivative libraries (e.g. seaborn) that build on matplotlib core
- Can use more directly from pandas

matplotlib tutorials

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

Basic Example

- `import matplotlib.pyplot as plt`
`plt.plot([1, 5, 2, 7, 3])`
- Default is line plot
- x-values are implicit (`range(5)`)
- Can add x-values
 - `plt.plot([1, 3, 4, 6, 10], [1, 5, 2, 7, 3])`
- Can change type of plot
 - `plt.scatter([1, 3, 4, 6, 10], [1, 5, 2, 7, 3])`
 - `plt.plot([1, 3, 4, 6, 10], [1, 5, 2, 7, 3], 'o')` # format string

Plot Formats

- Can specify color, marker, and linestyle in format string
 - `plt.plot([1, 3, 4, 6, 10], [1, 5, 2, 7, 3], 'ro-')`
- Can also specify these via keyword arguments:
 - `plt.plot([1, 3, 4, 6, 10], [1, 5, 2, 7, 3],
color='red', marker='s', linestyle='dashed')`
- Other keyword arguments, too:
 - `plt.plot([1, 3, 4, 6, 10], [1, 5, 2, 7, 3],
color='red', marker='s', linestyle='dashed',
linewidth=3, markersize=12)`

Format Reference

string	color
'b'	blue
'g'	green
'r'	red
'c'	cyan
'm'	magenta
'y'	yellow
'k'	black
'w'	white

Color shortcuts

string	description
'-'	solid
'--'	dashed
'-.'	dash-dot
':'	dotted

Line Styles

string	description
'.'	point
','	pixel
'o'	circle
'v'	triangle_down
'^'	triangle_up
'<'	triangle_left
'>'	triangle_right
'1'	tri_down
'2'	tri_up
'3'	tri_left
'4'	tri_right
'8'	octagon
's'	square

Markers

string	description
'p'	pentagon
'P'	plus (filled)
'*'	star
'h'	hexagon1
'H'	hexagon2
'+'	plus
'x'	x
'X'	x (filled)
'D'	diamond
'd'	thin_diamond
' '	vline
'_'	hline

[[Documentation](#) (Notes Section)]

Data is Encoded via Visual Channels

➔ Position

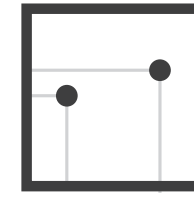
➔ Horizontal



➔ Vertical



➔ Both



➔ Color



➔ Shape



➔ Tilt

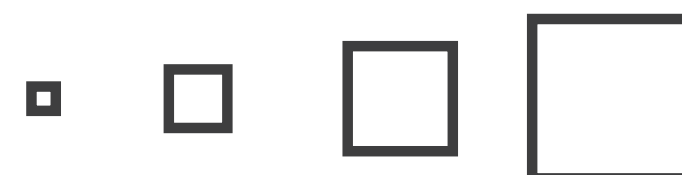


➔ Size

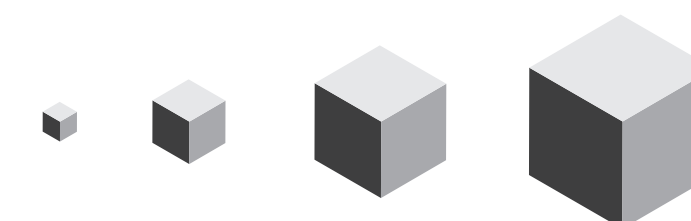
➔ Length



➔ Area



➔ Volume

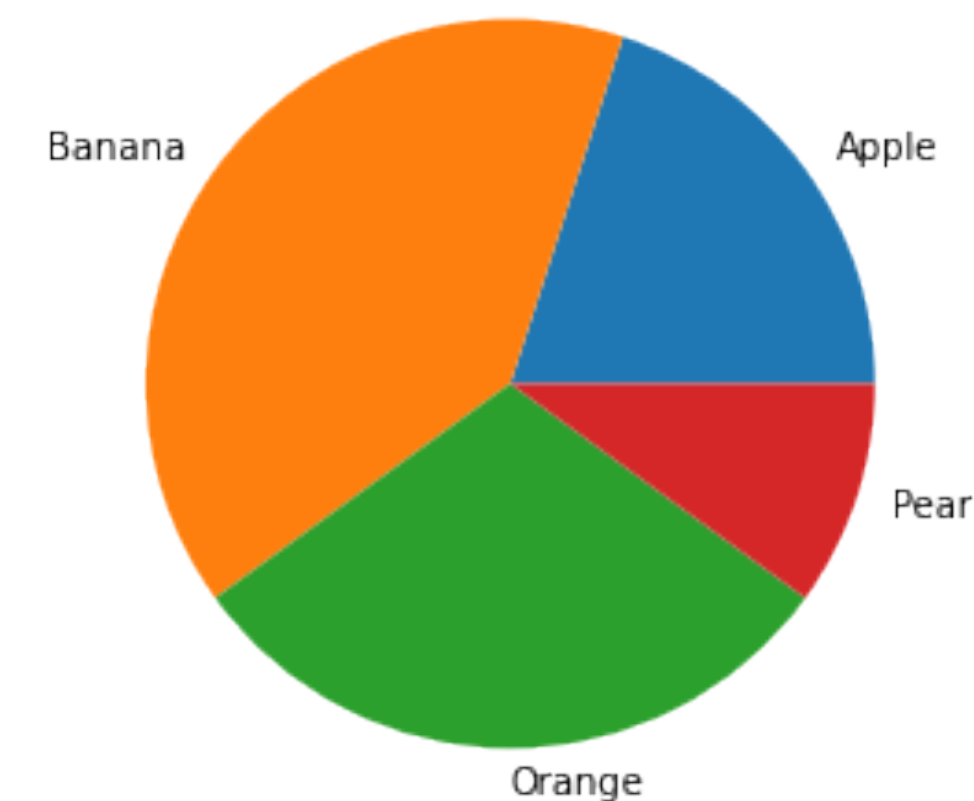
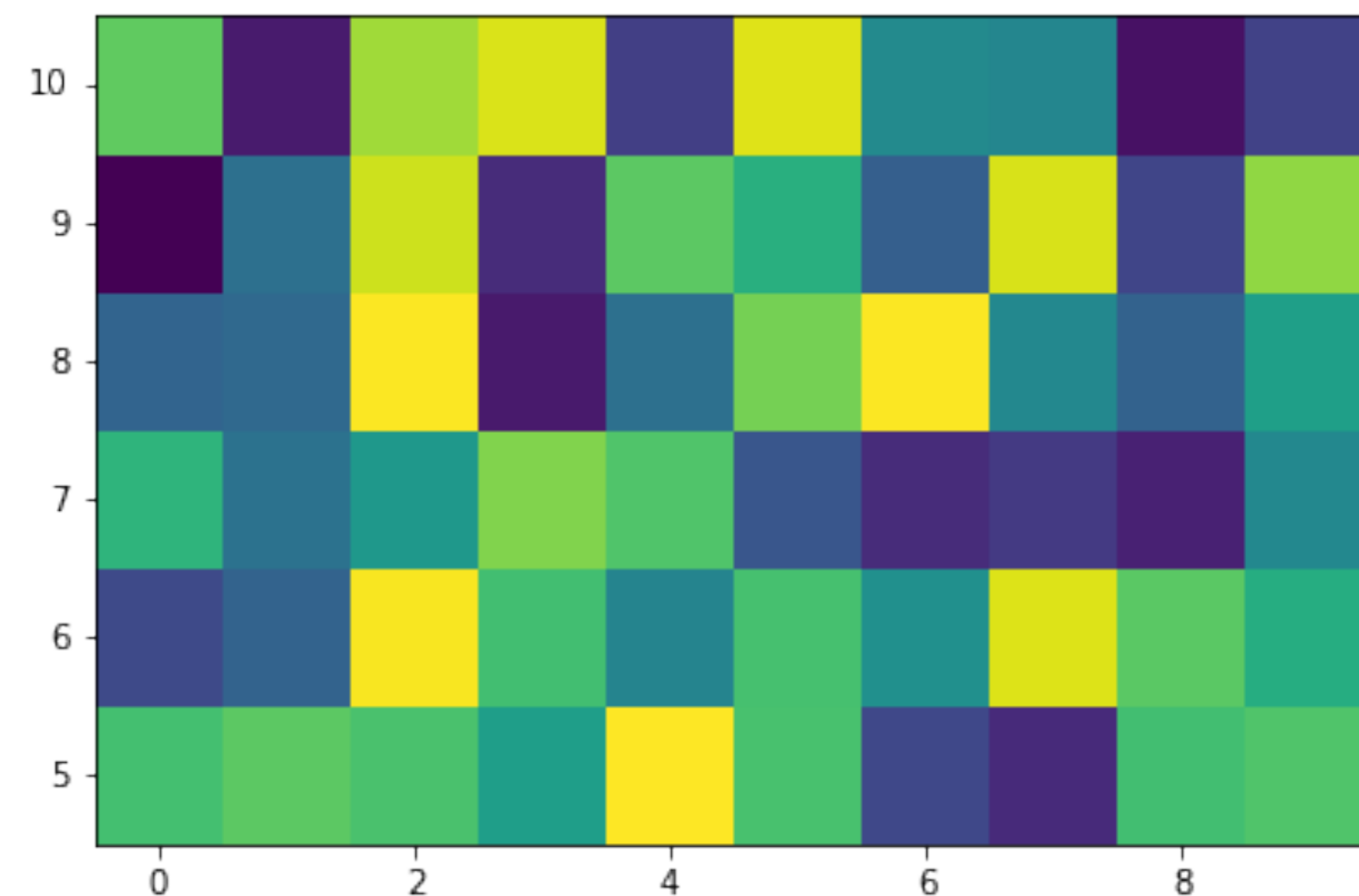
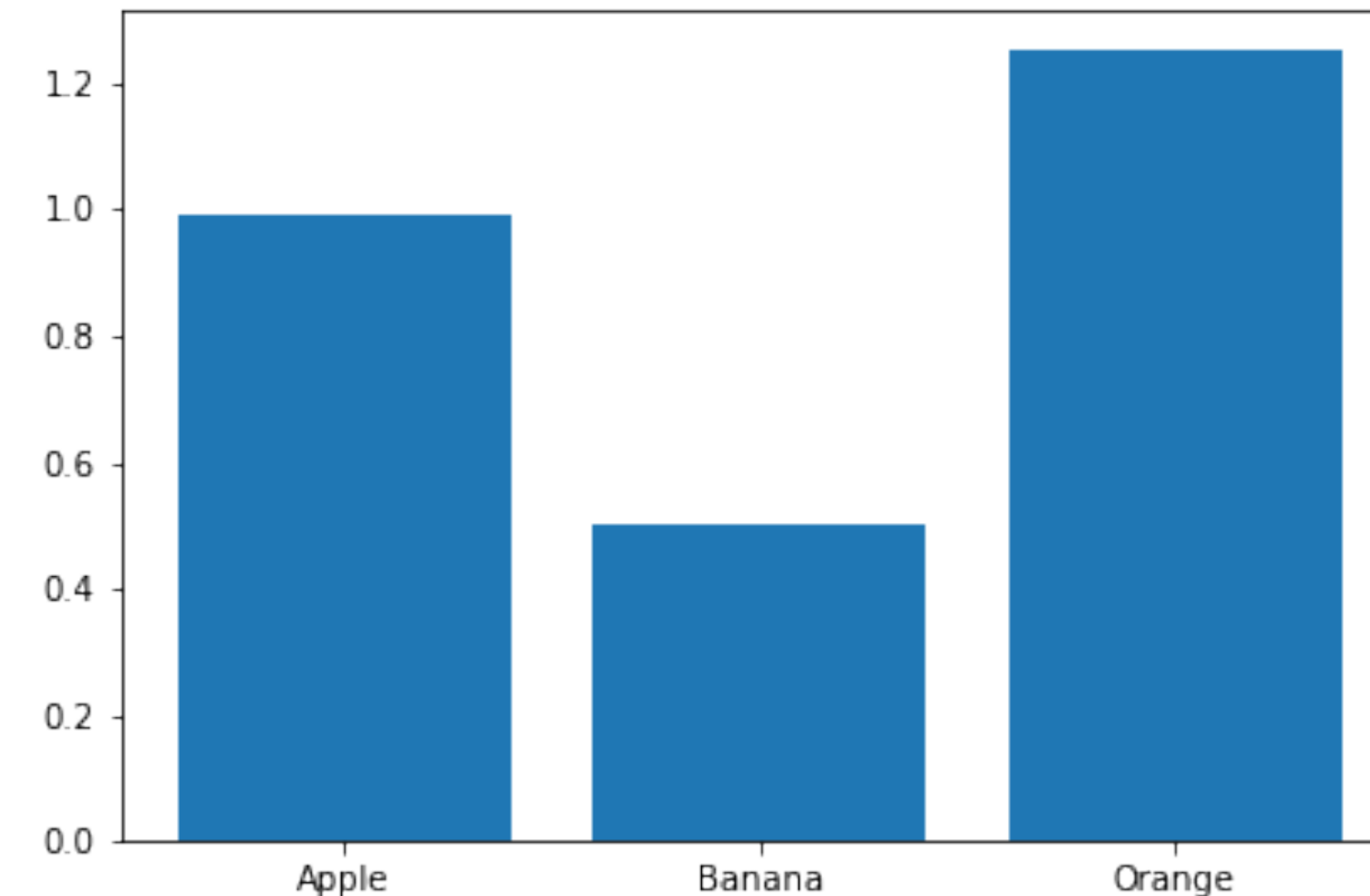
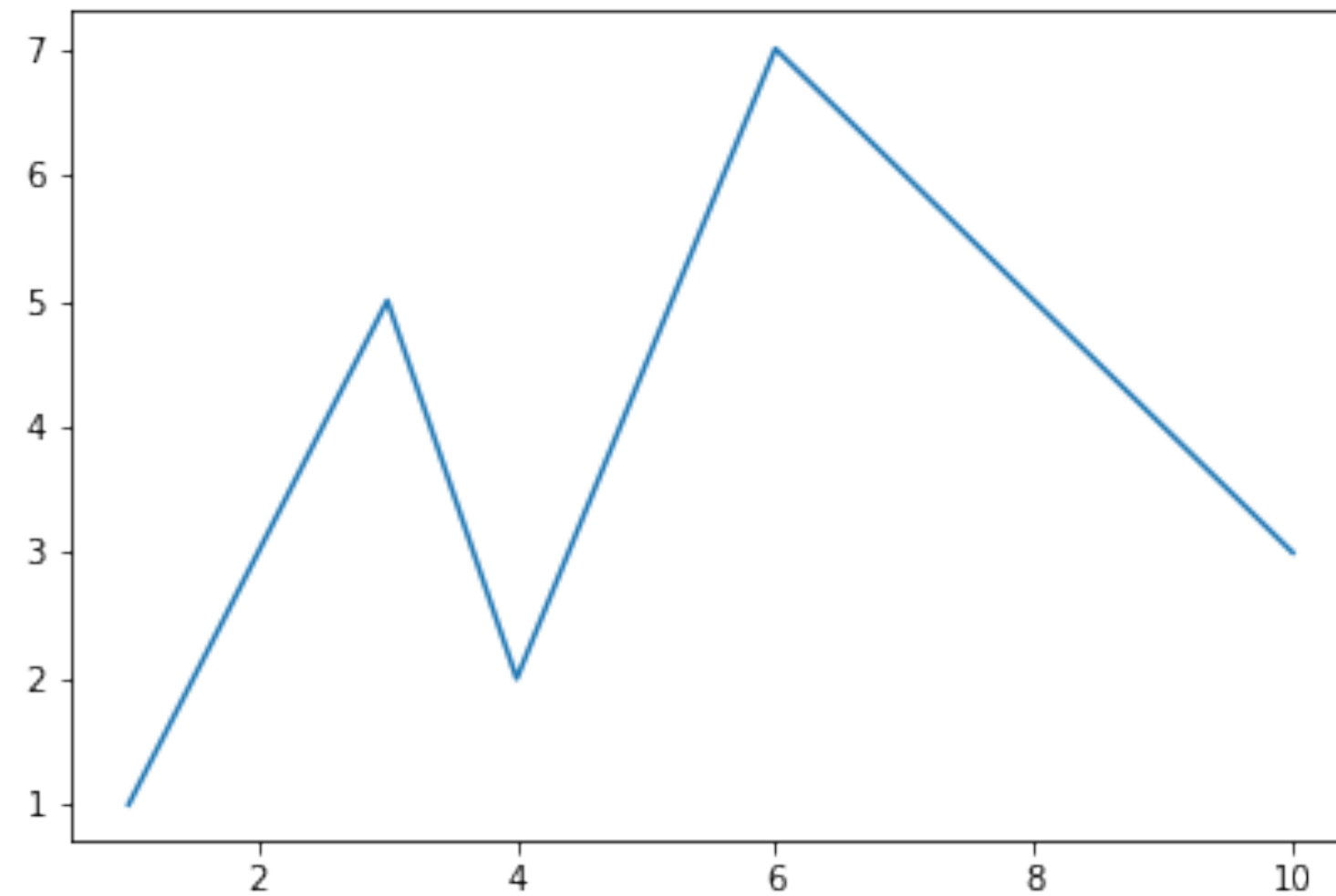


[Munzner (ill. Maguire), 2014]

Encoding Data Attributes via Channels

- ```
data = {'age': [1, 3, 4, 6, 10],
 'num_jumps': [1, 5, 2, 7, 3],
 'weight': [20, 50, 25, 55, 25],
 'num_scoops': [3, 2, 4, 2, 3]}
plt.scatter('age', 'num_jumps', c='num_scoops', s='weight',
 data=data)
```
- `data` is a dictionary that contains information about each data item (first animal has `age=1`, `num_jumps=1`, `weight=20`, `num_scoops=3`)
- `x` and `y` are referenced as parts of the array
- `s` is marker size
- `c` is color and numbers are mapped to colors

# 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:

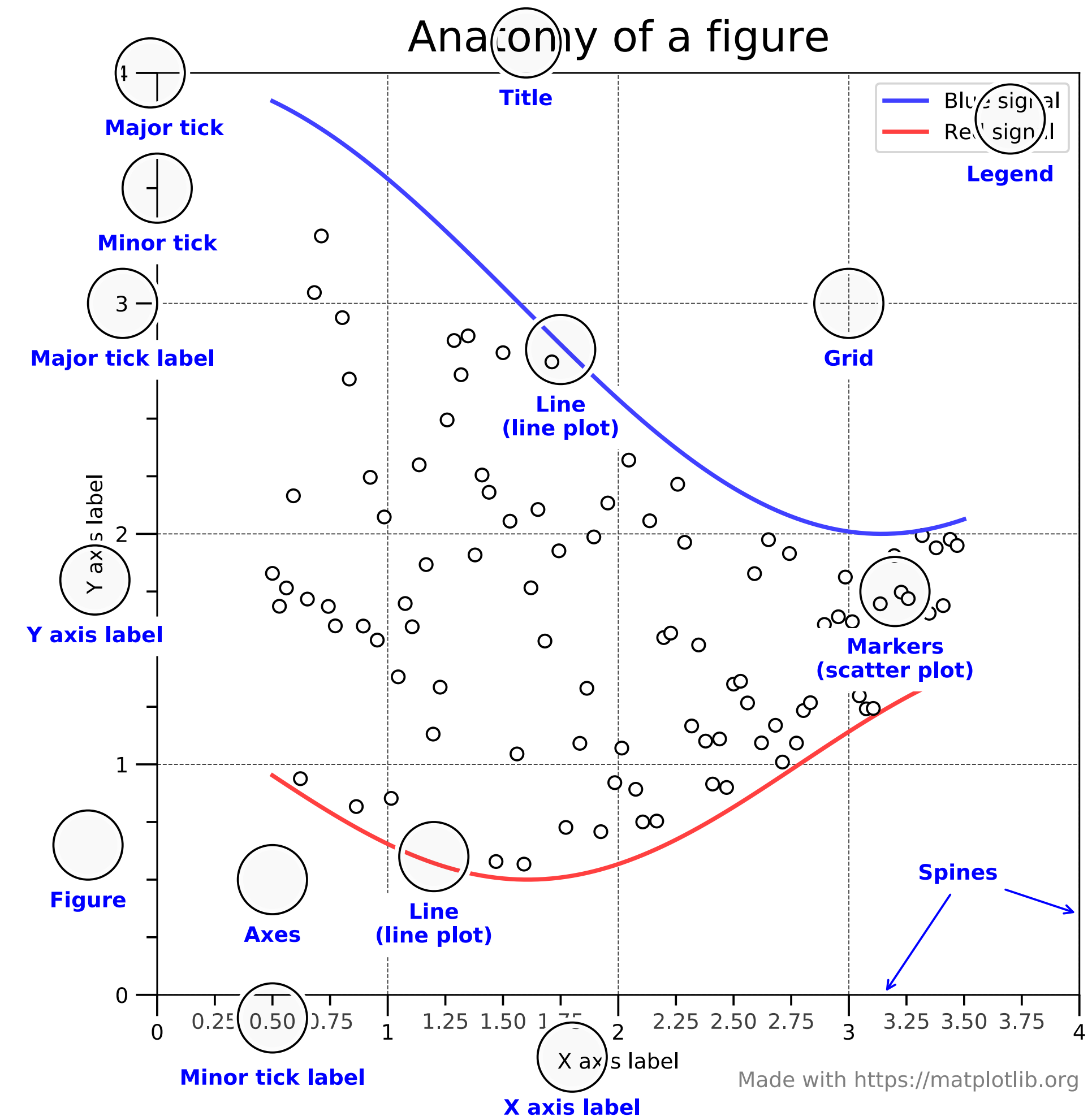
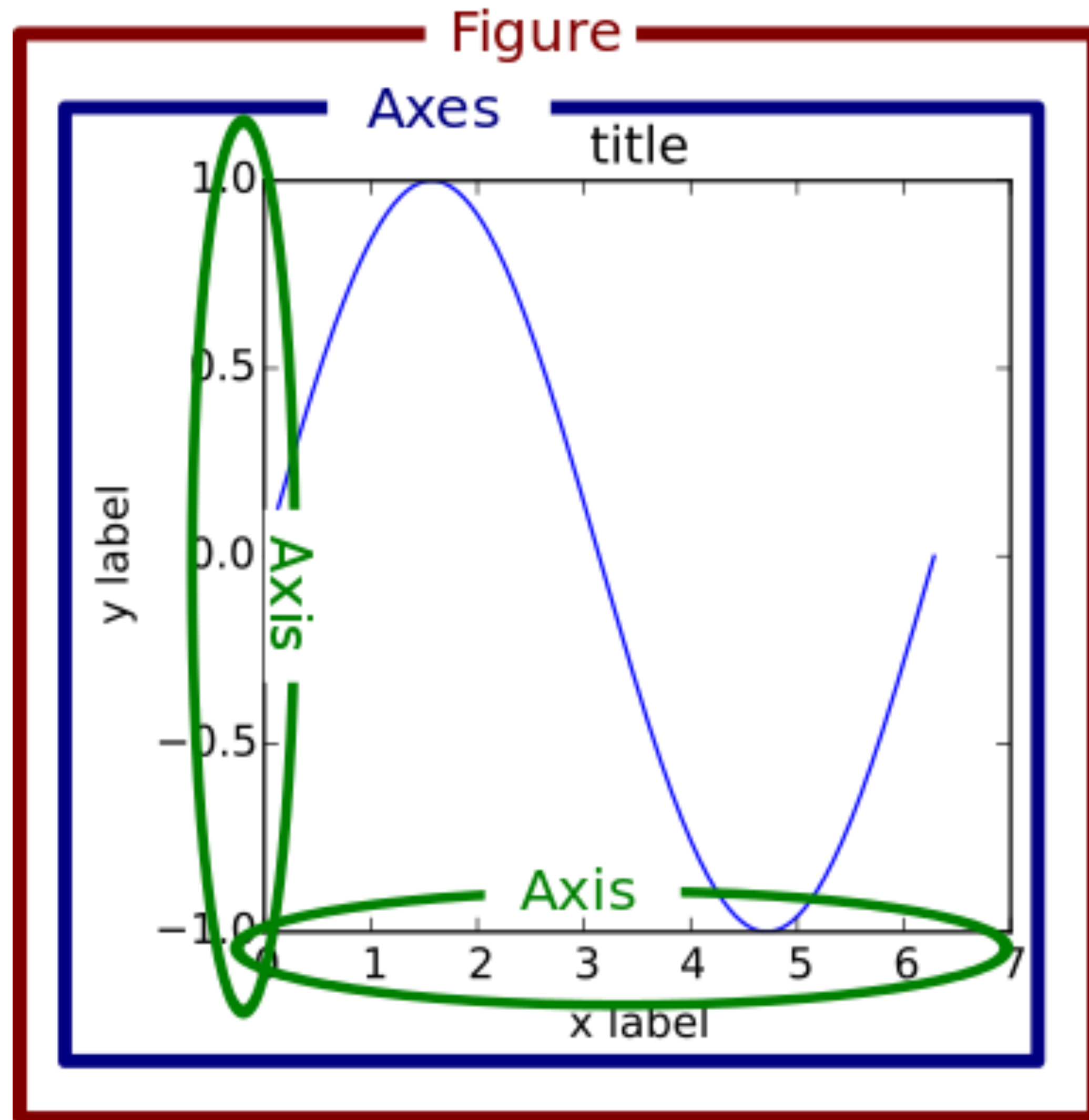
- `plt.pie([20, 40, 30, 10],  
labels=['Apple', 'Banana', 'Orange', 'Pear'])`

# 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'])
```