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
0 1959-03-31  realgdp  2710.349
1 1959-03-31     infl     0.000
2 1959-03-31    unemp     5.800
3 1959-06-30  realgdp  2778.801
4 1959-06-30     infl     2.340
5 1959-06-30    unemp     5.100
6 1959-09-30  realgdp  2775.488
7 1959-09-30     infl     2.740
8 1959-09-30    unemp     5.300
9 1959-12-31  realgdp  2785.204
```

```
.pivot('date', 'item', 'value')
```

```
item        infl   realgdp  unemp
date
1959-03-31  0.00  2710.349    5.8
1959-06-30  2.34  2778.801    5.1
1959-09-30  2.74  2775.488    5.3
1959-12-31  0.27  2785.204    5.6
1960-03-31  2.31  2847.699    5.2
```

[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

```
number    one  two  three
state
Ohio        0    1      2
Colorado    3    4      5
```

`T`

```
state    Ohio  Colorado
number
one         0         3
two         1         4
three       2         5
```

`stack`

`unstack`

```
state     number
Ohio      one       0
          two       1
          three     2
Colorado  one       3
          two       4
          three     5
```

`unstack(0)`

[W. McKinney, Python for Data Analysis]

Assignment 8

- Last Assignment
- Data and Visualization
- Port of Entry Data

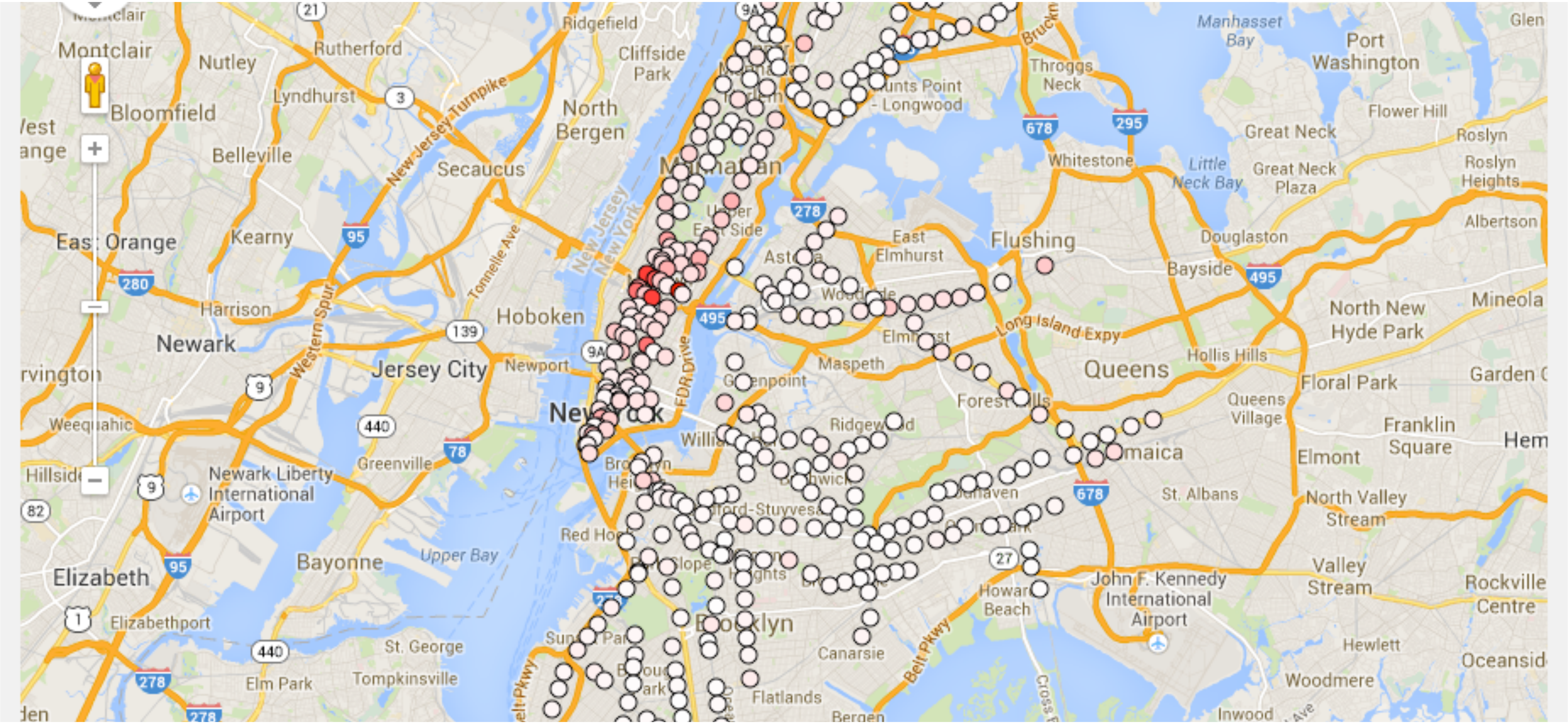
Data Exploration through Visualization

Transportation Data - NYC MTA

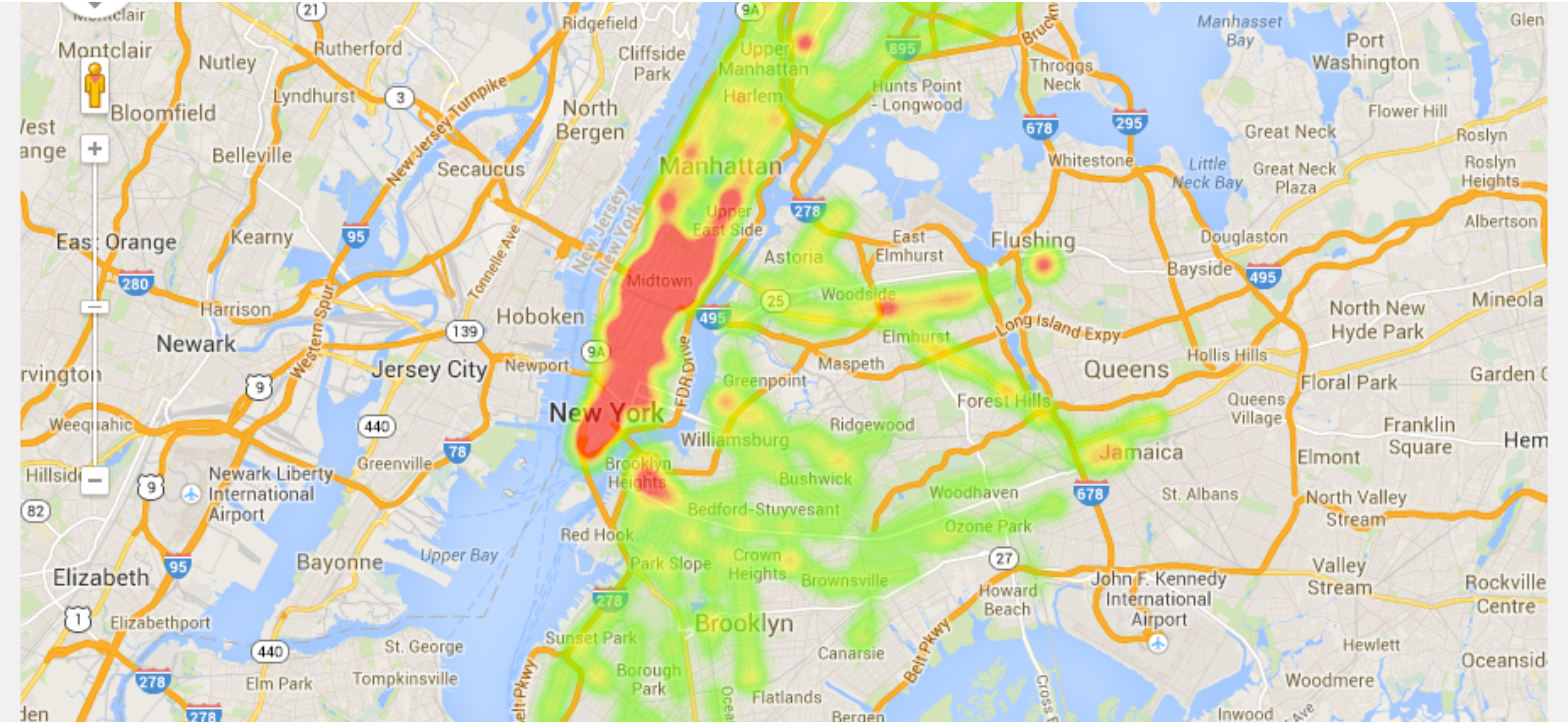
MTA Fare Data Exploration

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

MTA Fare Data Exploration



MTA Fare Data Exploration



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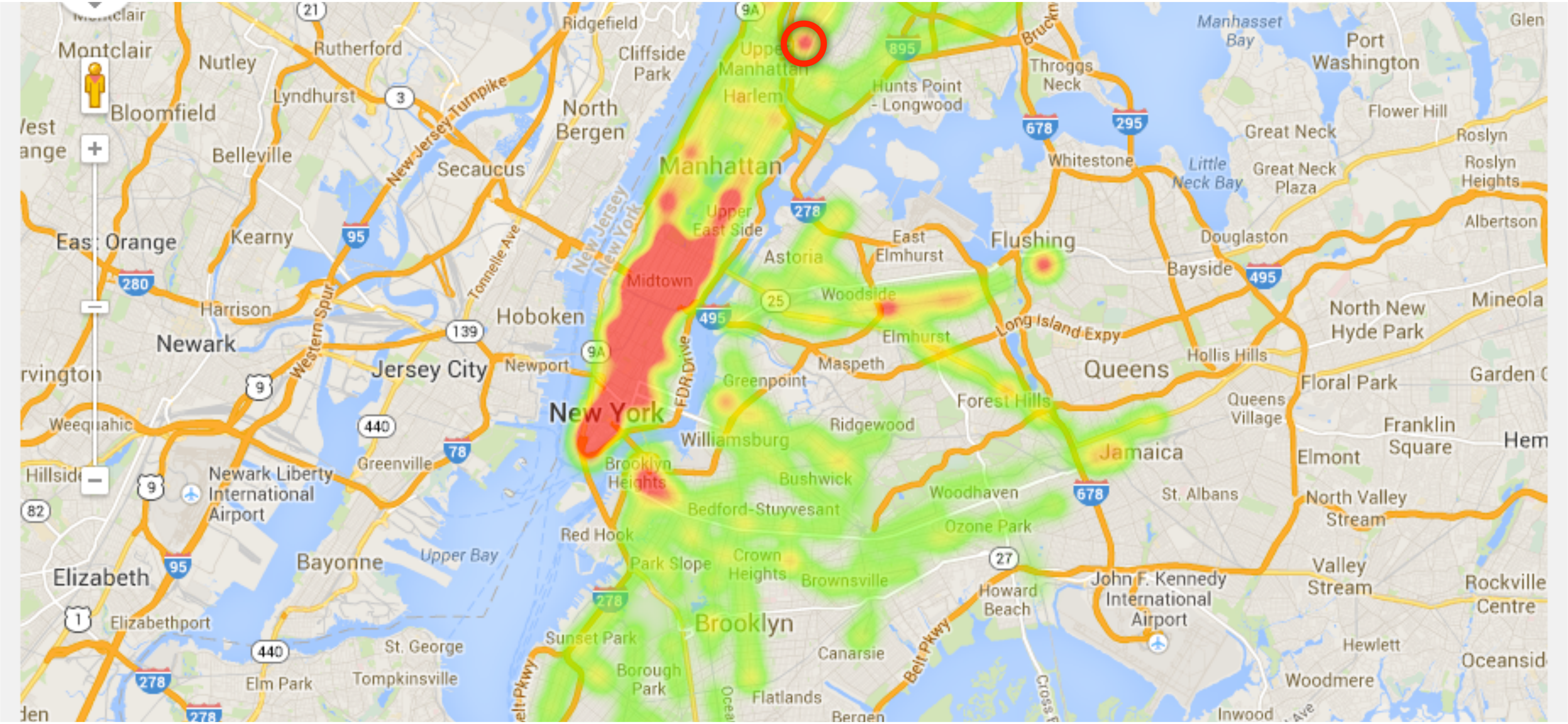

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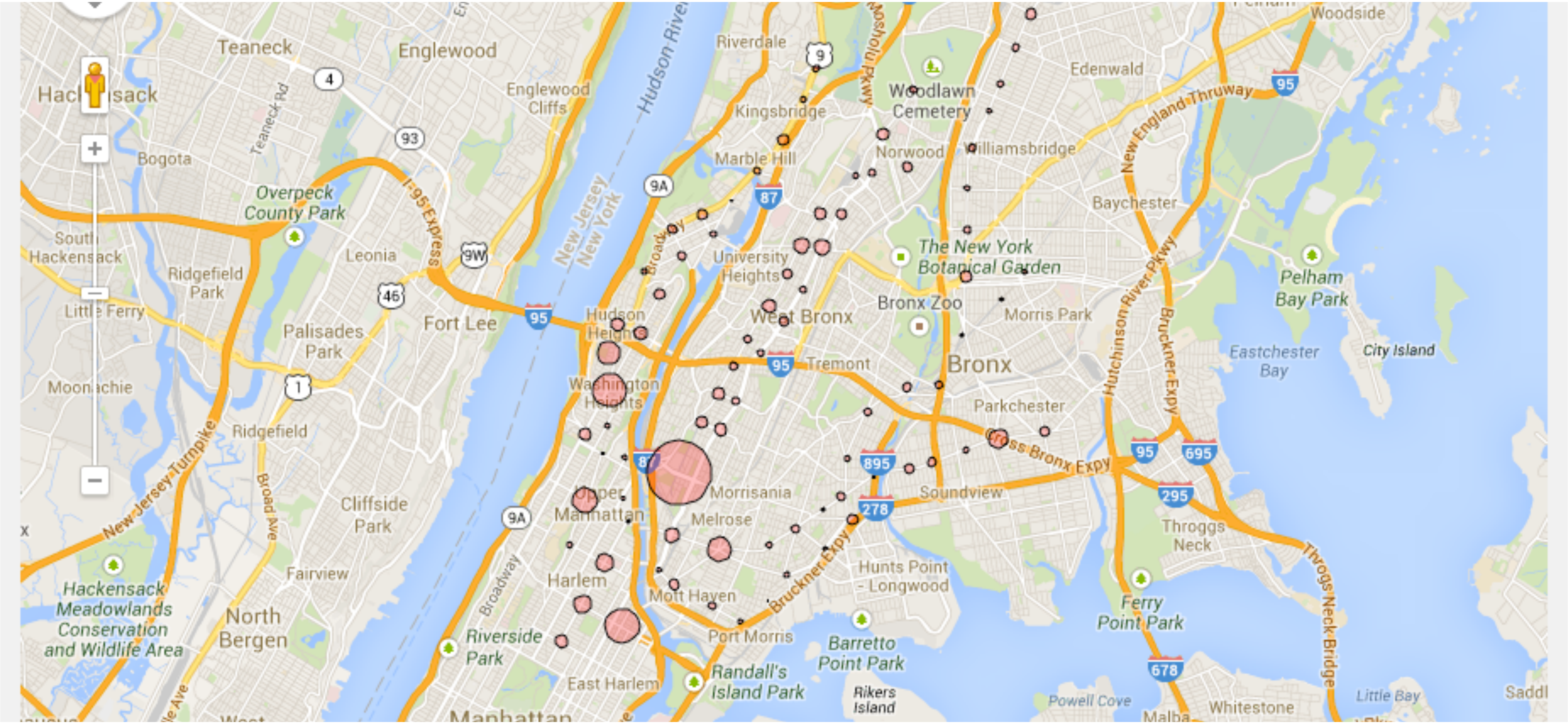

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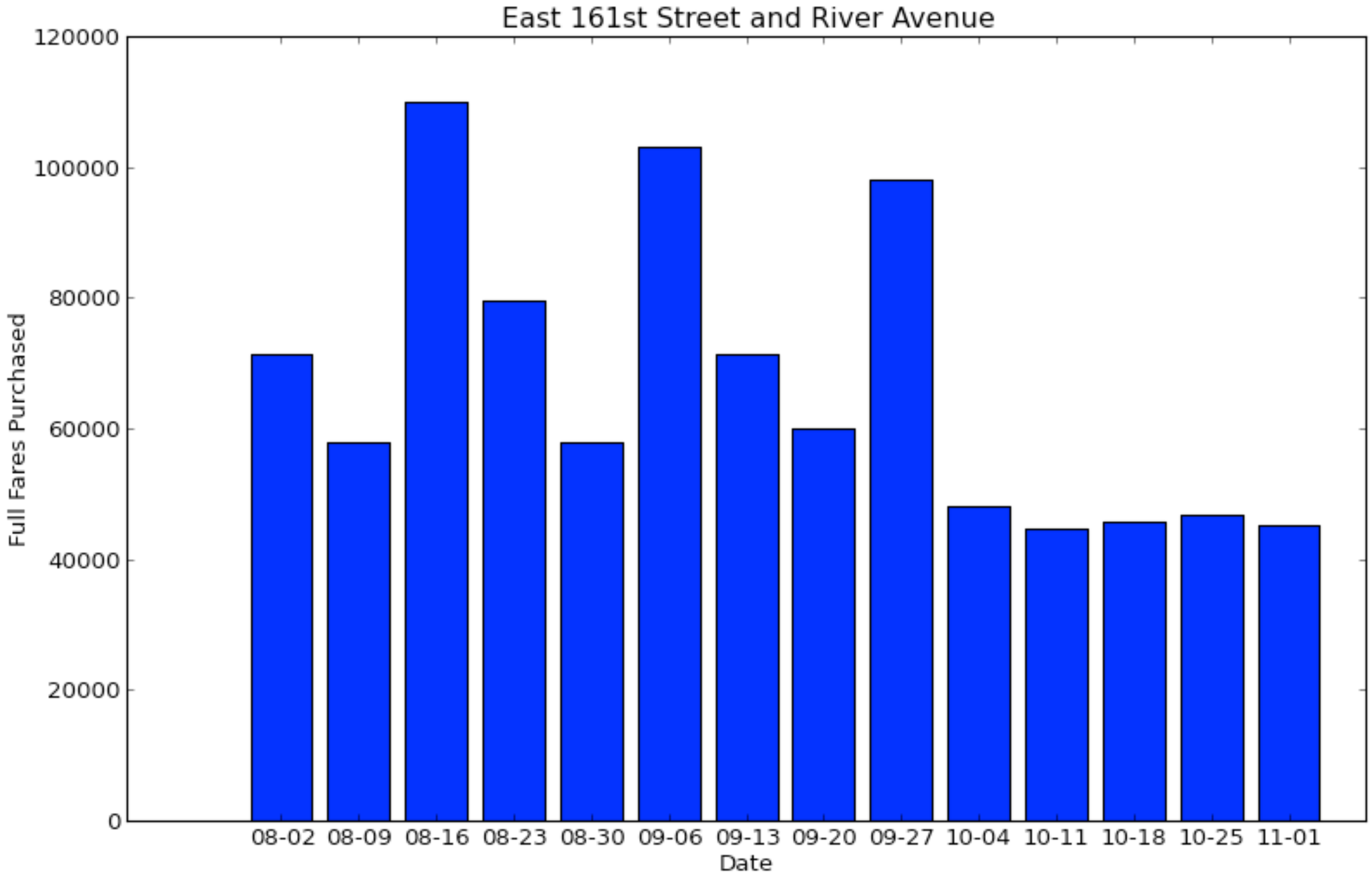

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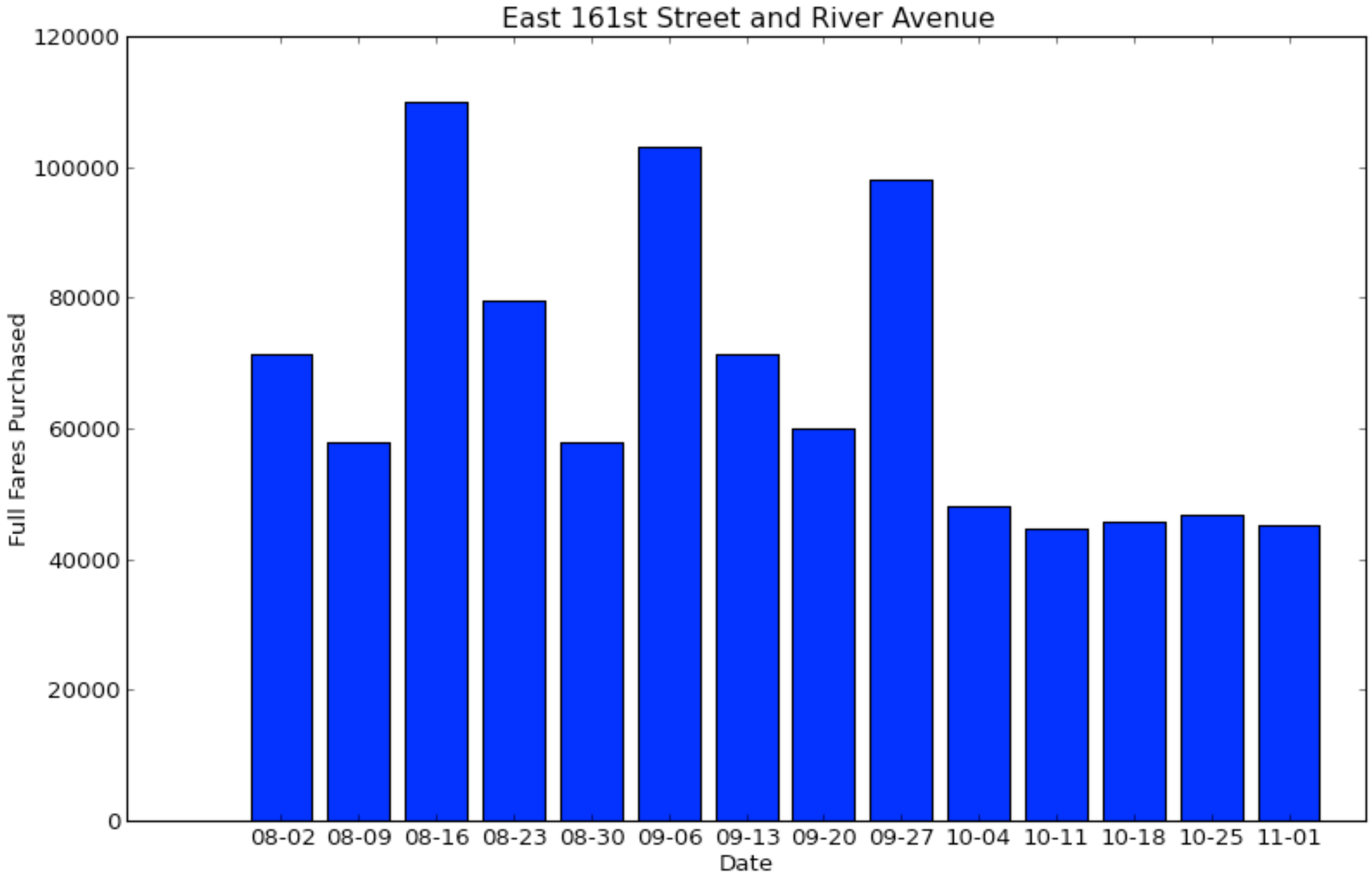
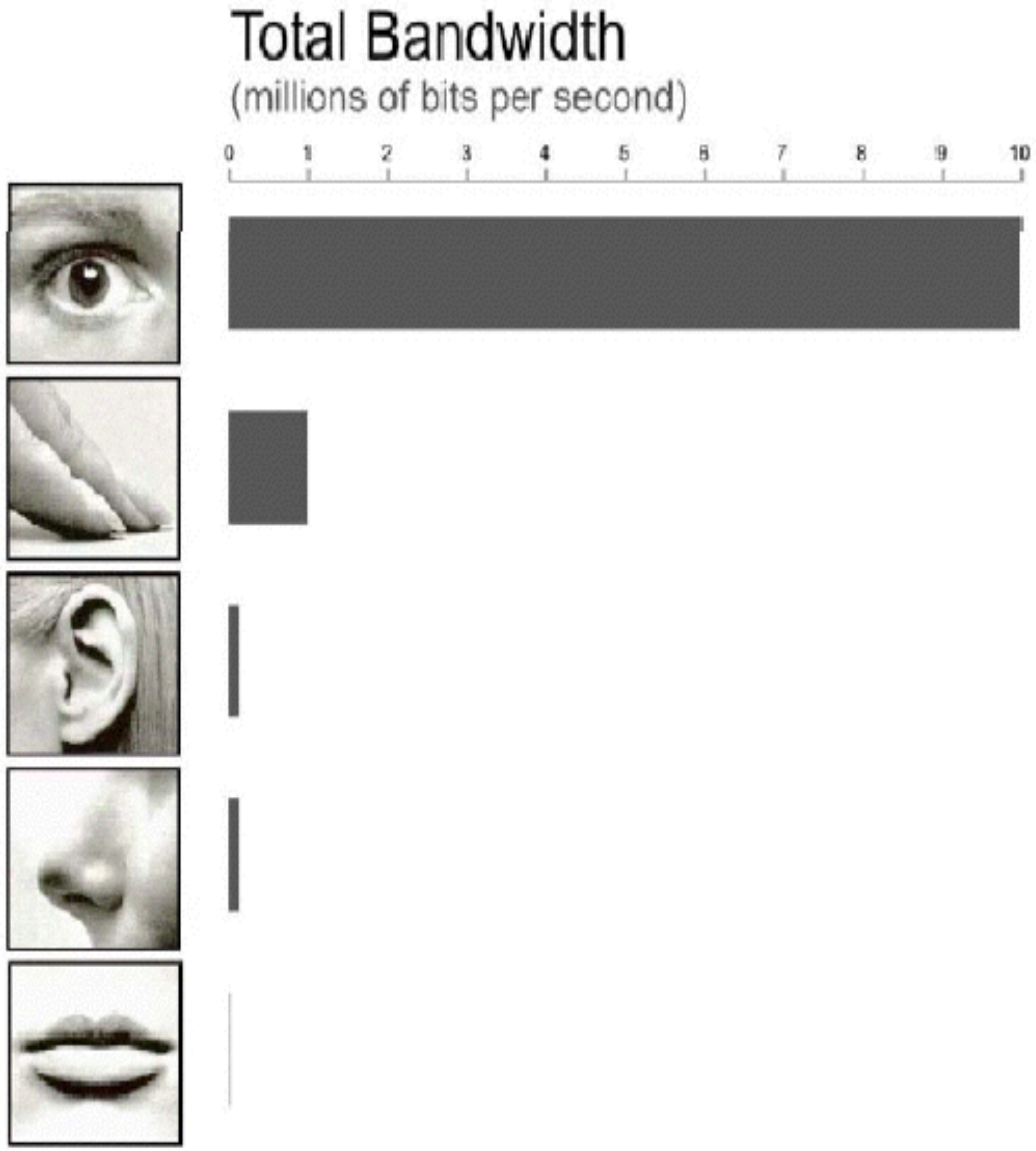


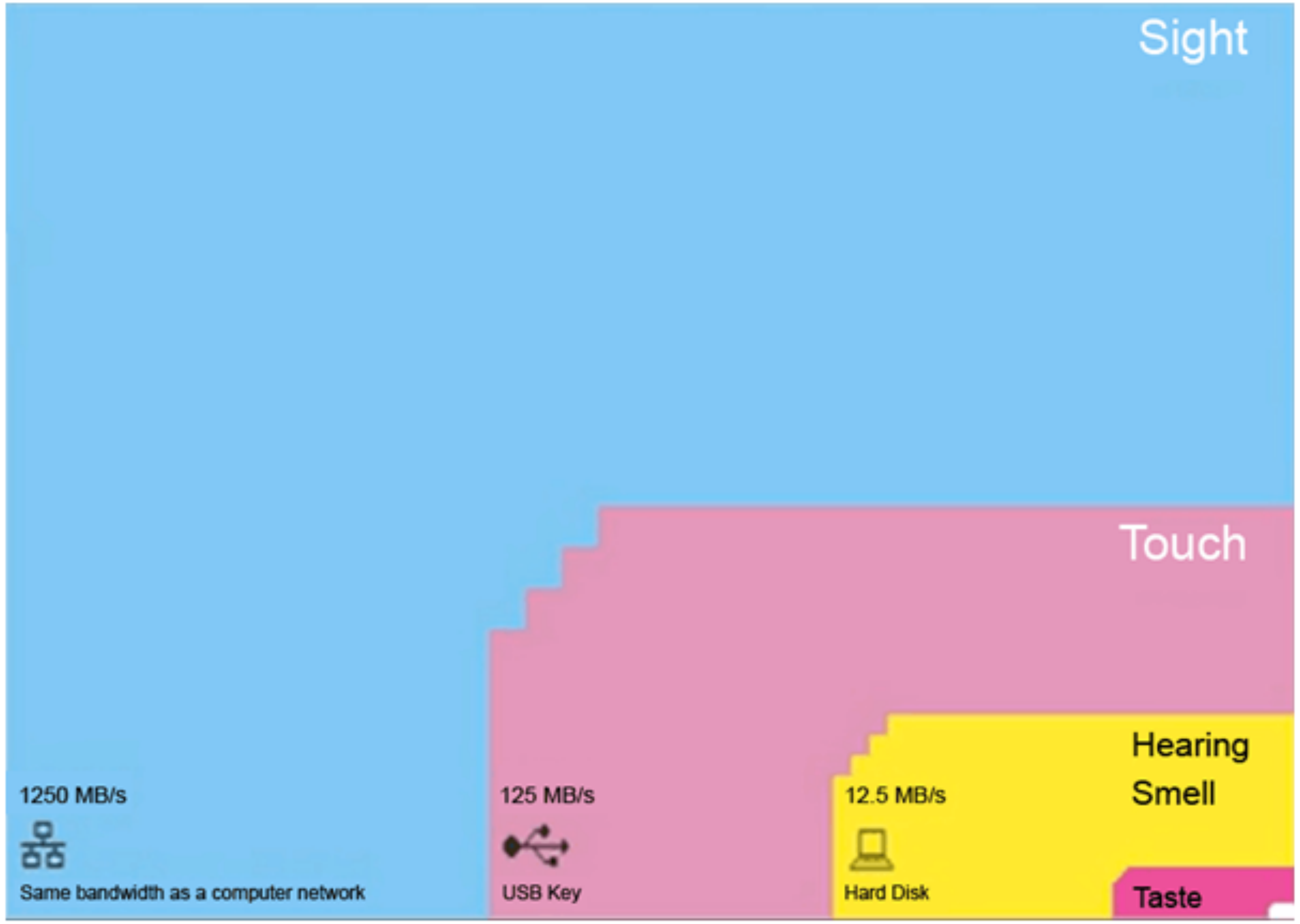
Definition of Visualization

"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]

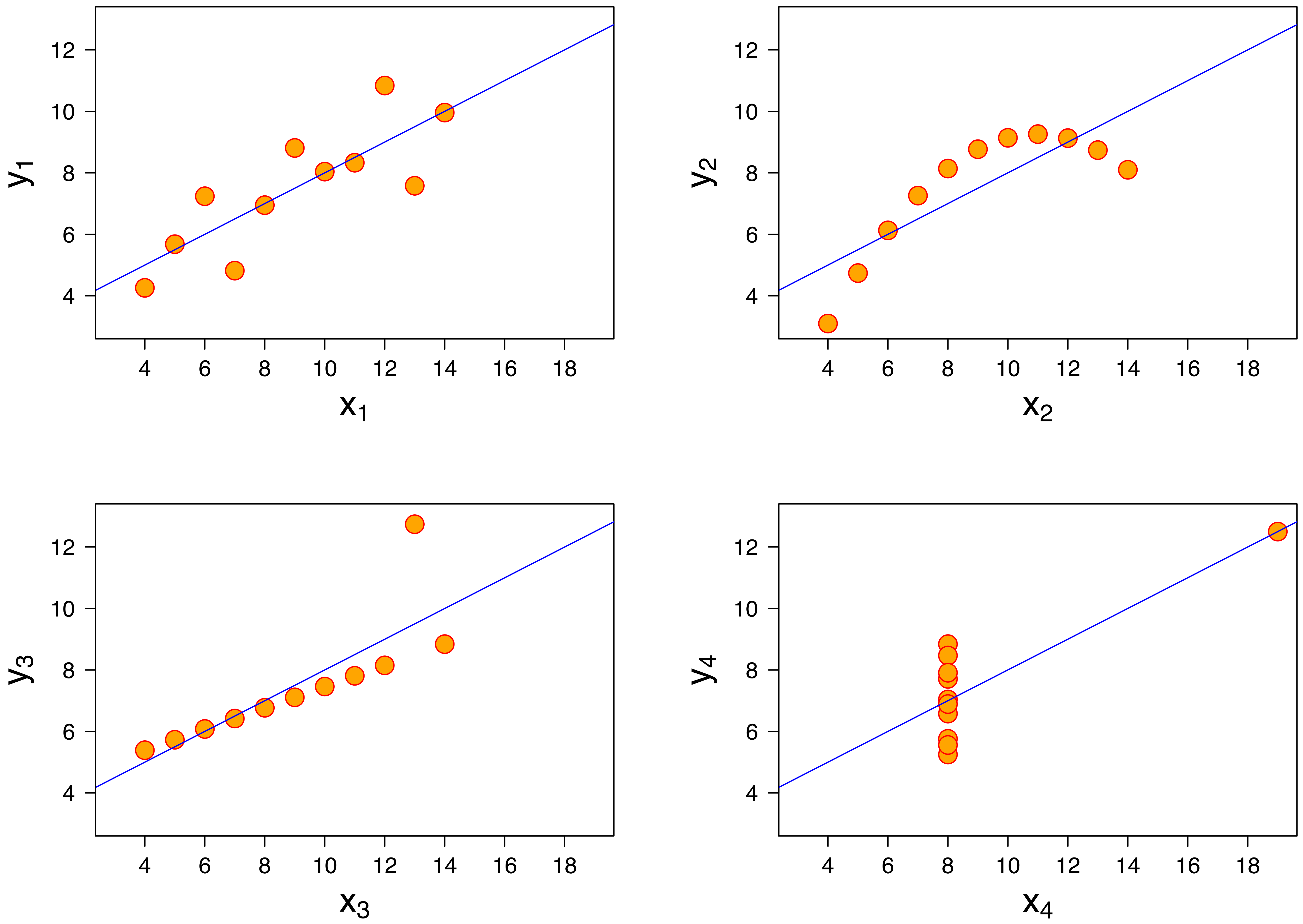
Why Visual?

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

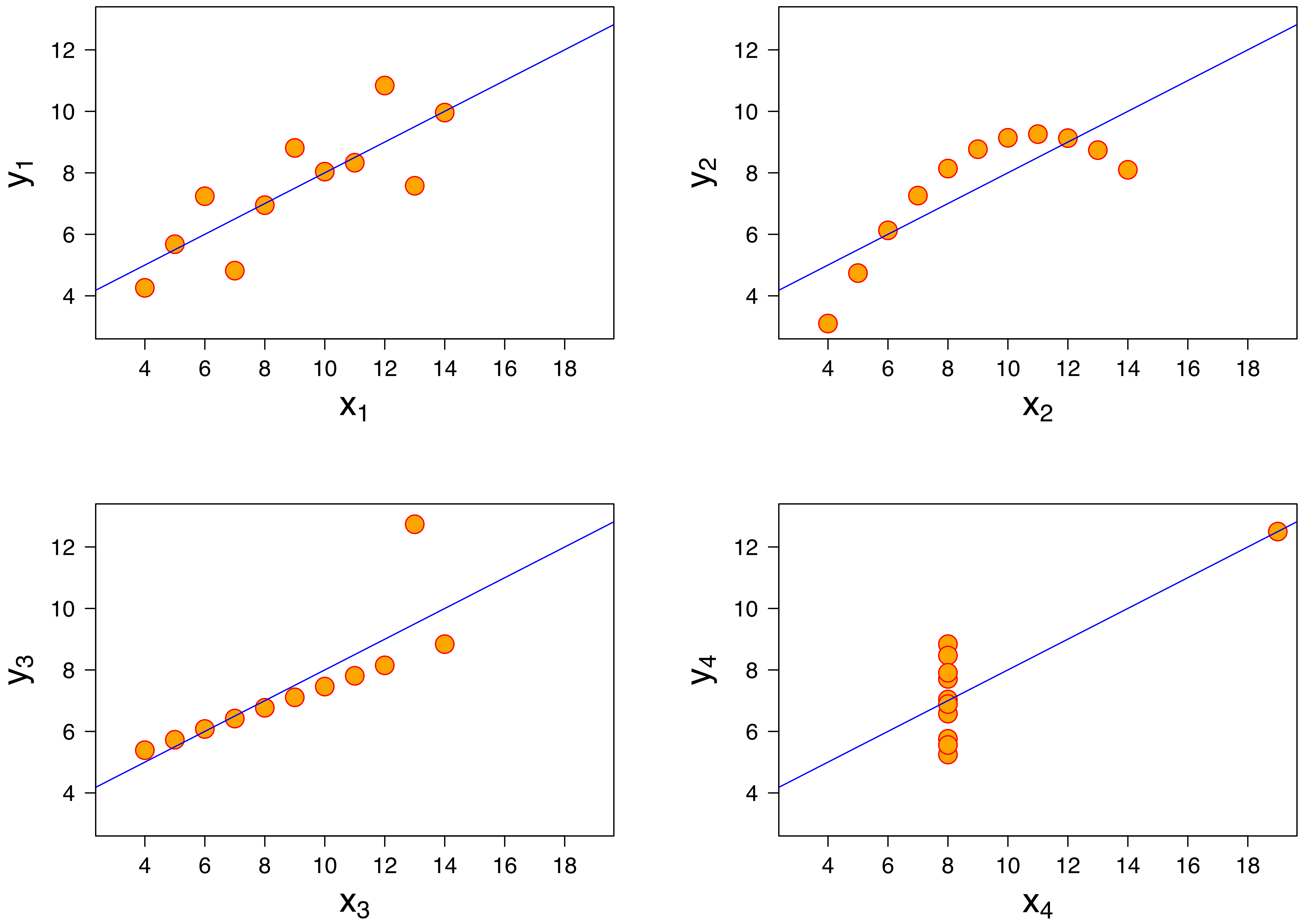
[F. J. Anscombe]

Why Visual?



[F. J. Anscombe]

Why Visual?



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

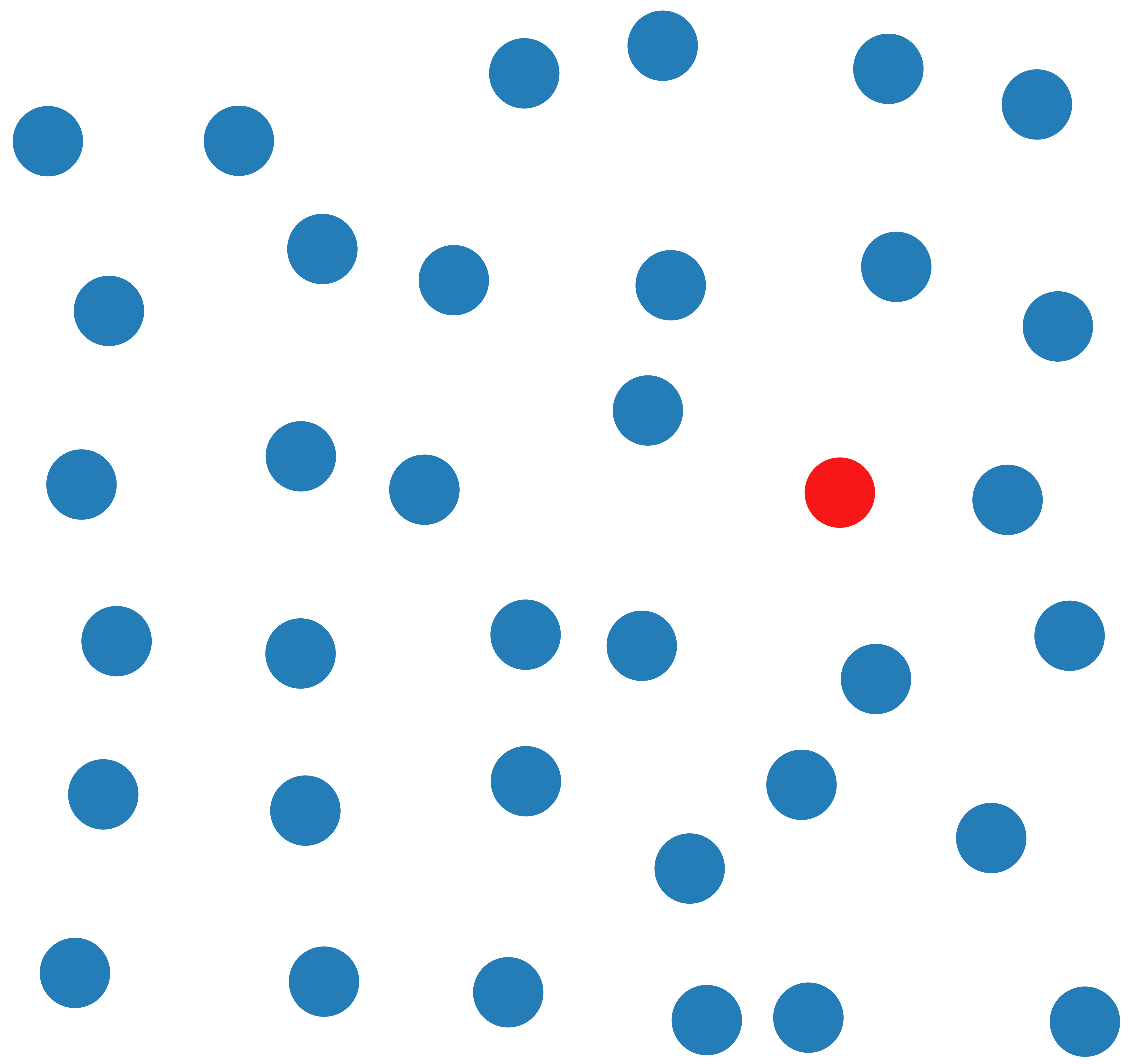
[F. J. Anscombe]

Visualization Goals

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

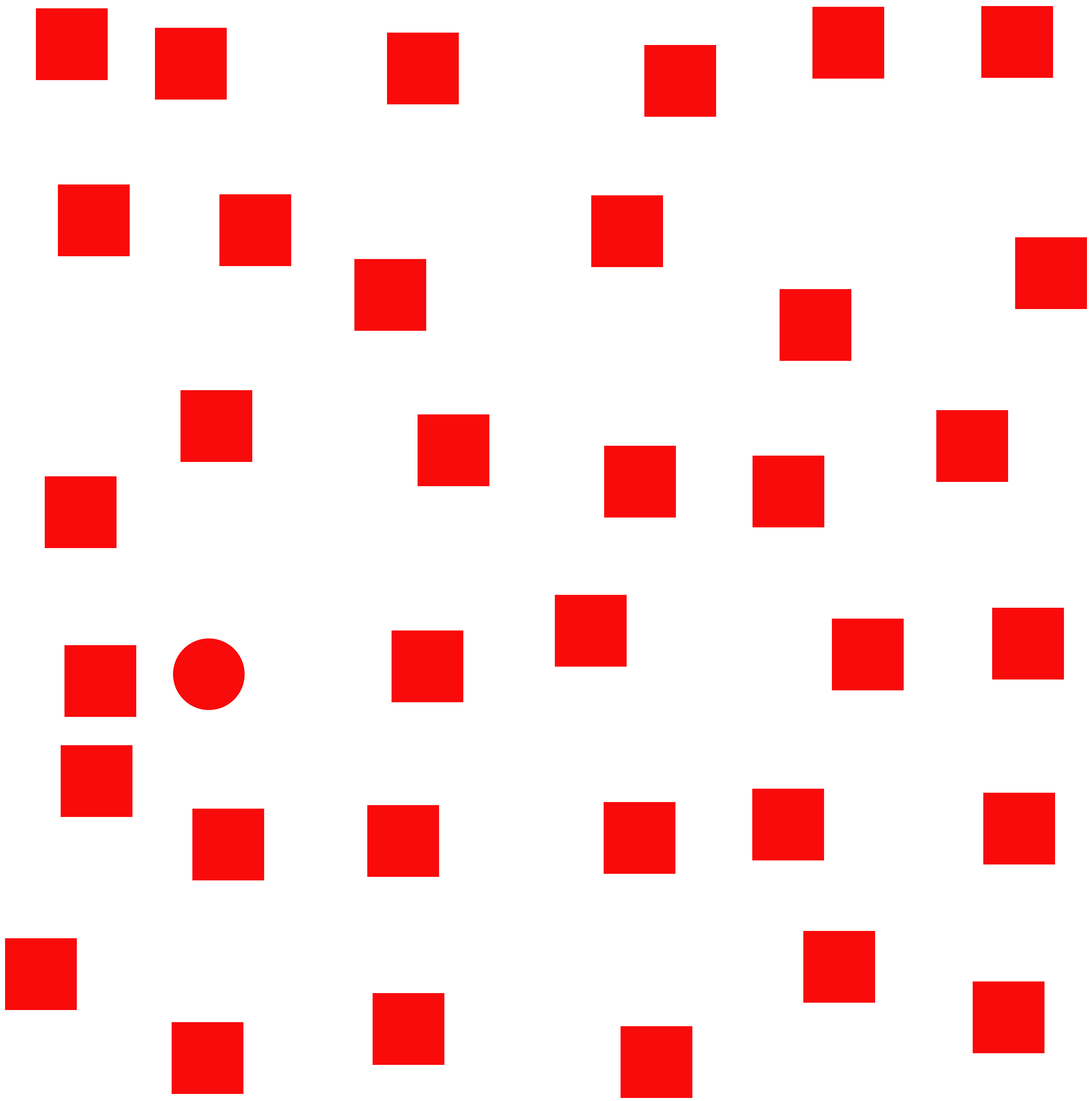
- Identify patterns, trends
- Spot outliers
- Find similarities, correlation

Visual Pop-out



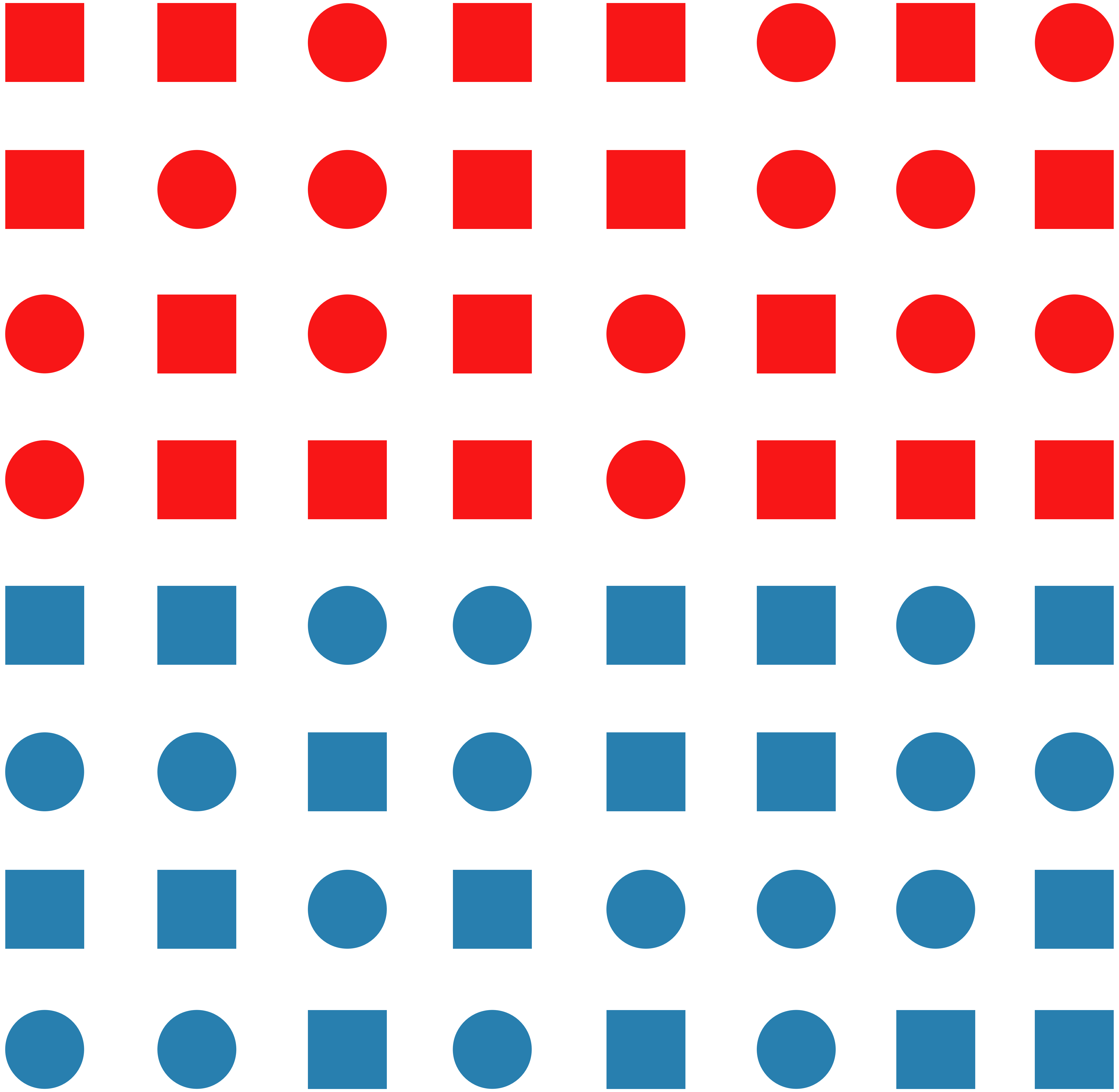
[C. G. Healey]

Visual Pop-out



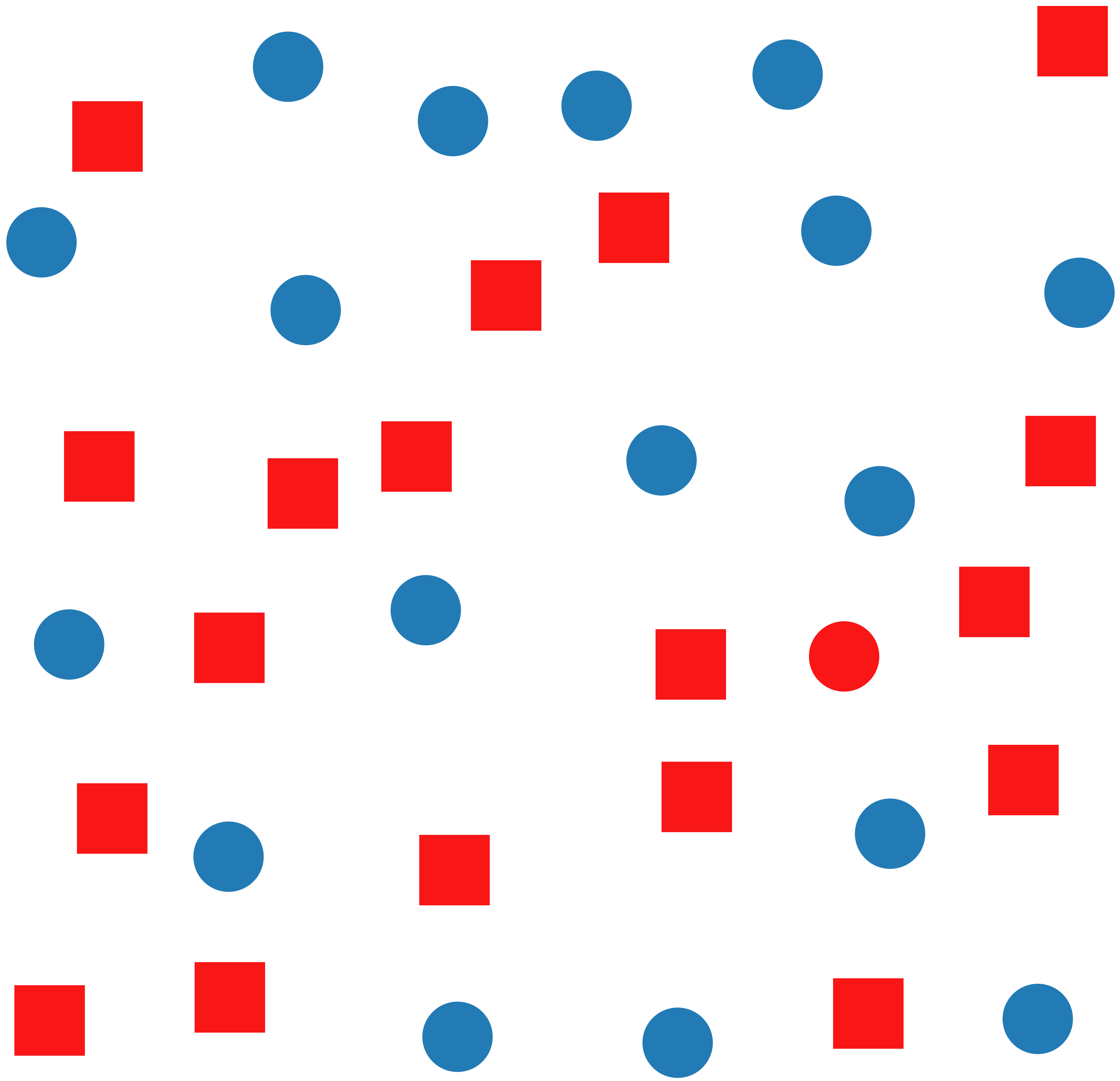
[C. G. Healey]

Visual Pop-out



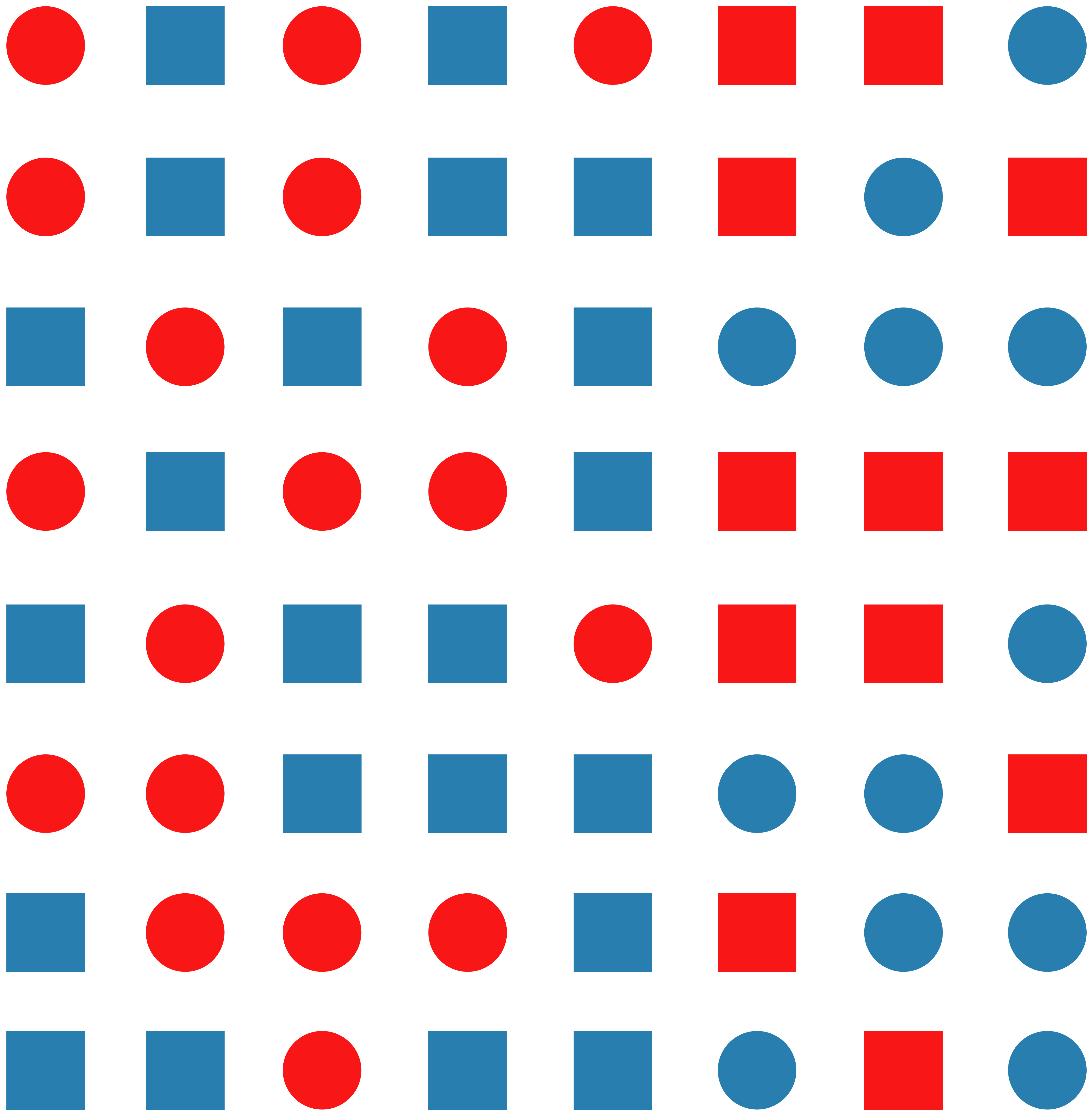
[C. G. Healey]

Visual Perception Limitations



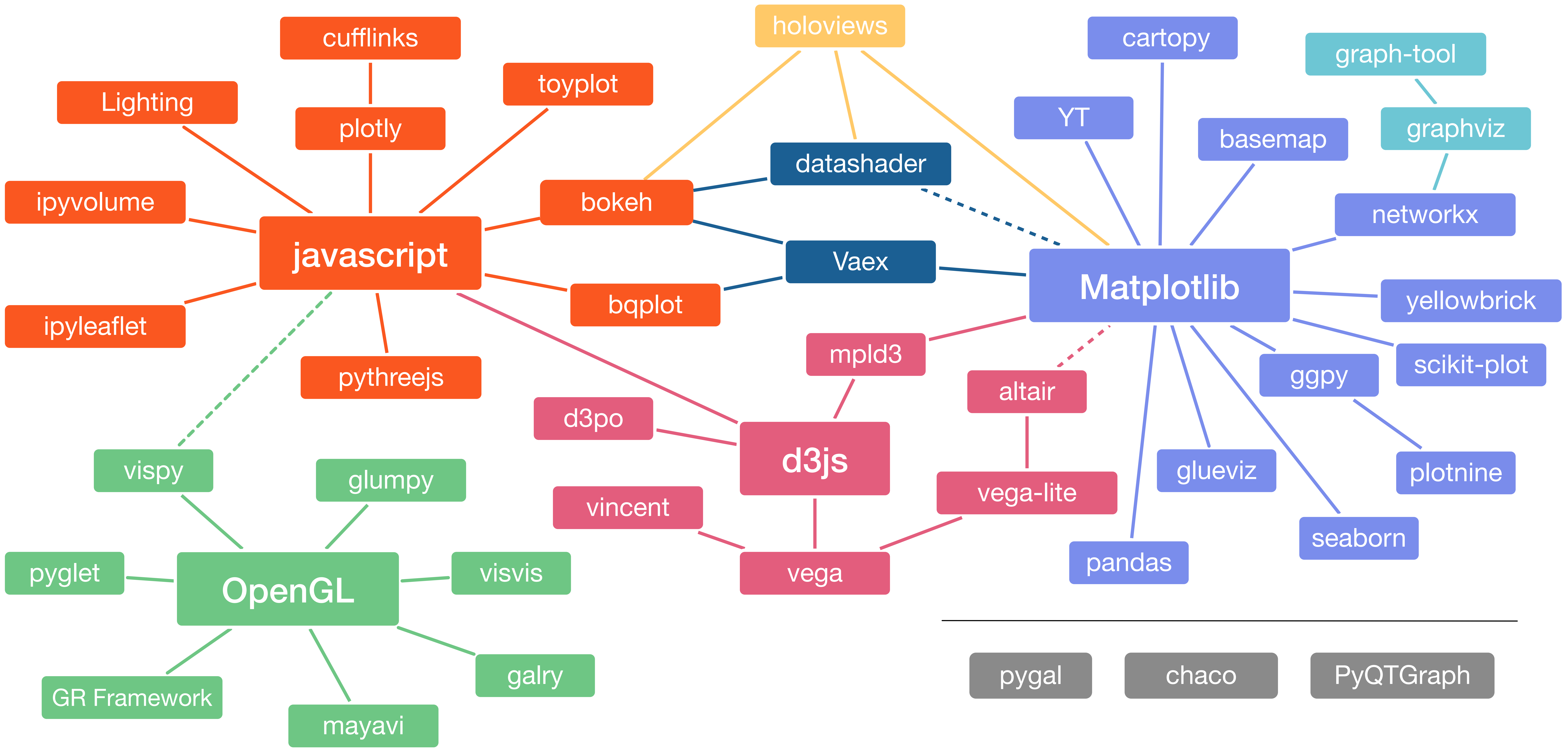
[C. G. Healey]

Visual Perception Limitations

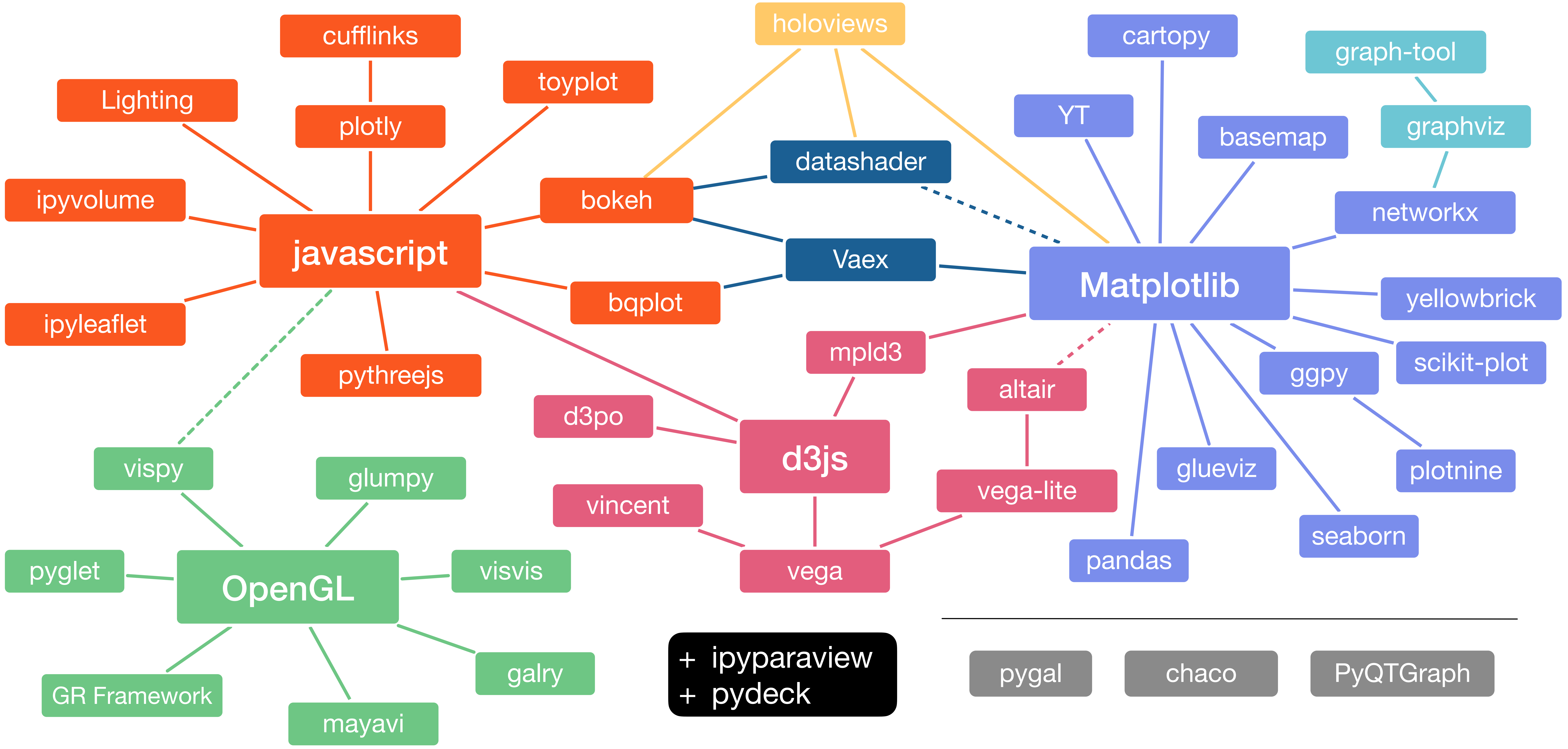


[C. G. Healey]

The Python Visualization Landscape



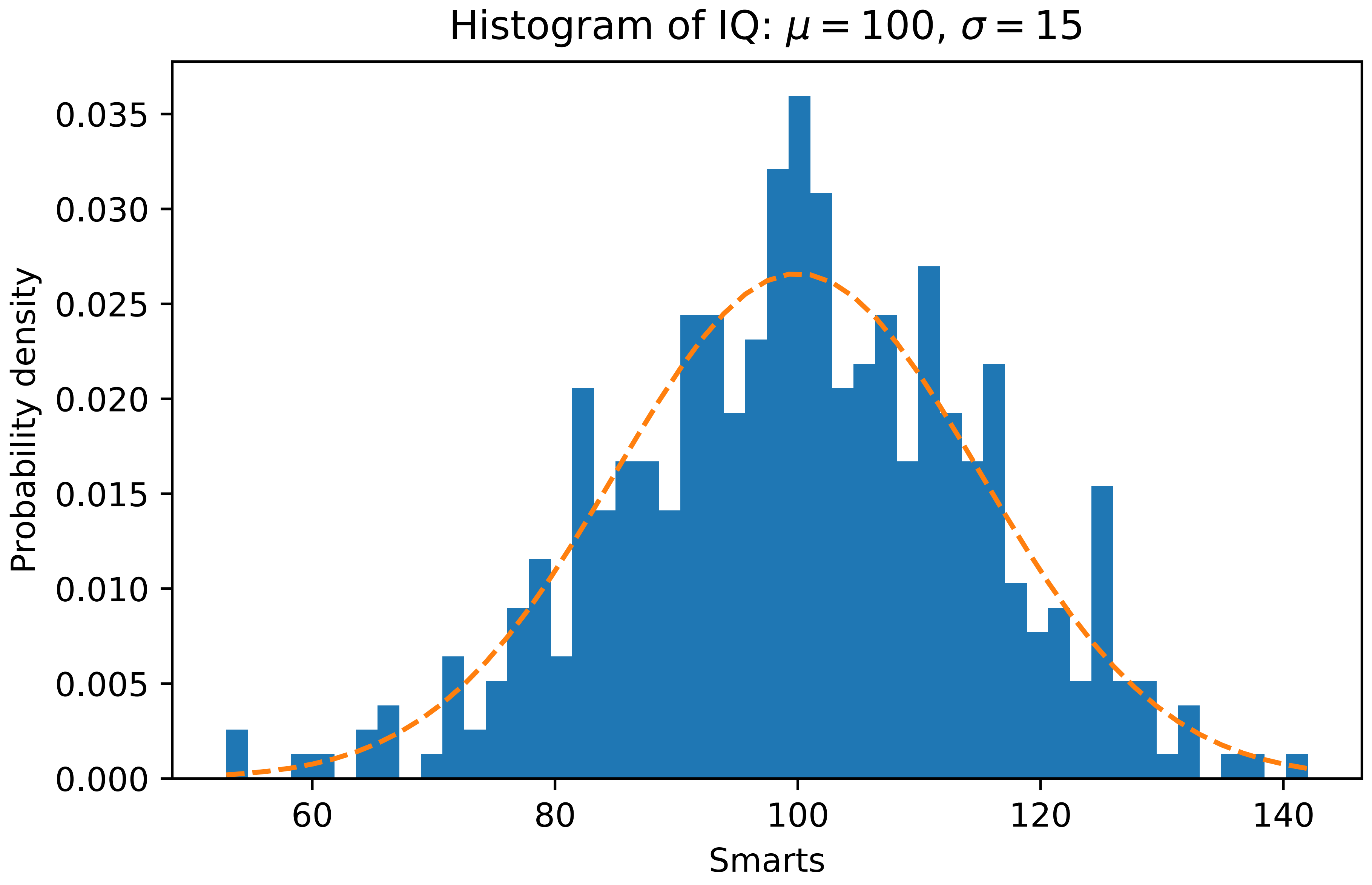
The Python Visualization Landscape



+ ipyparaview
+ pydeck

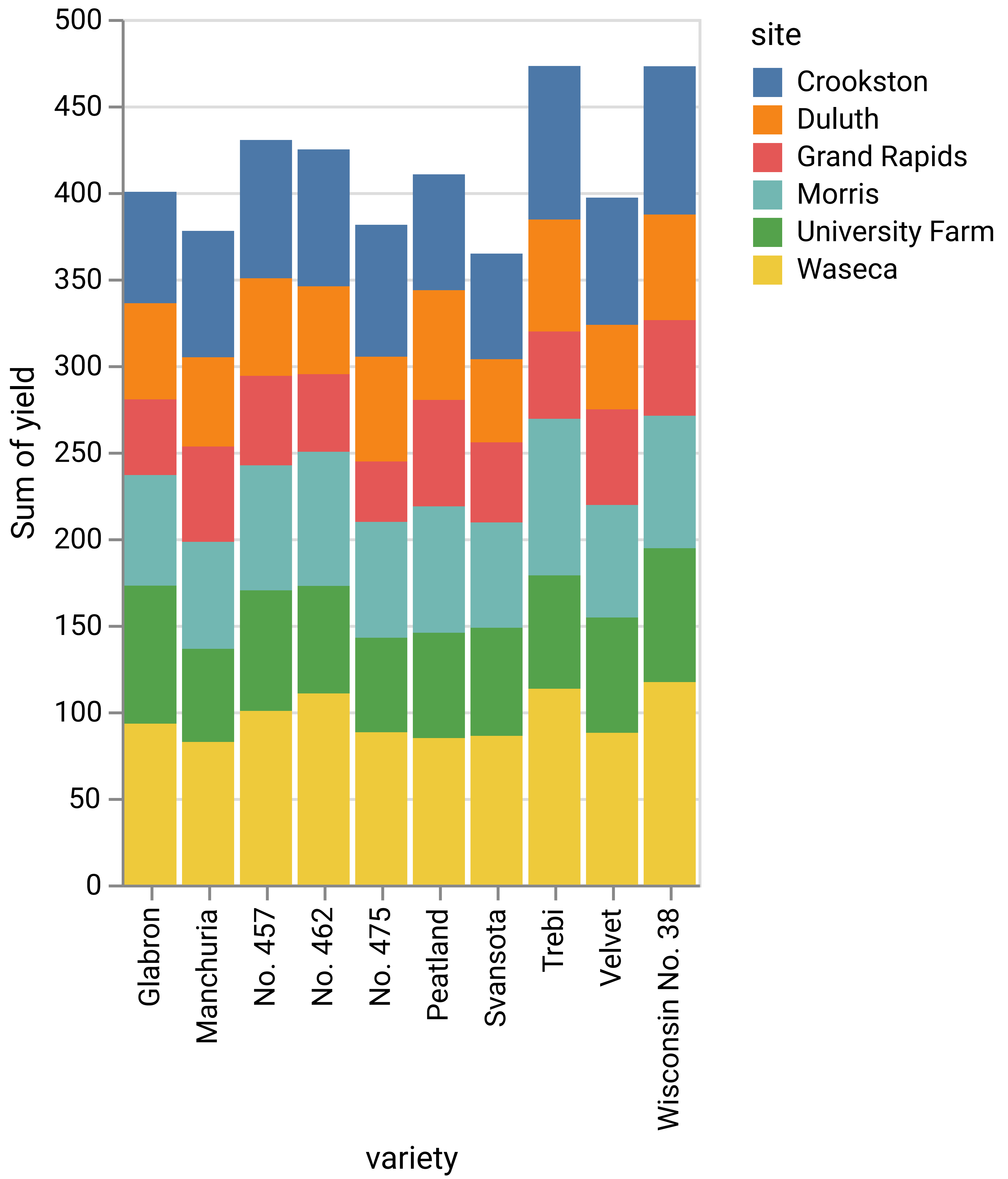
matplotlib

- 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

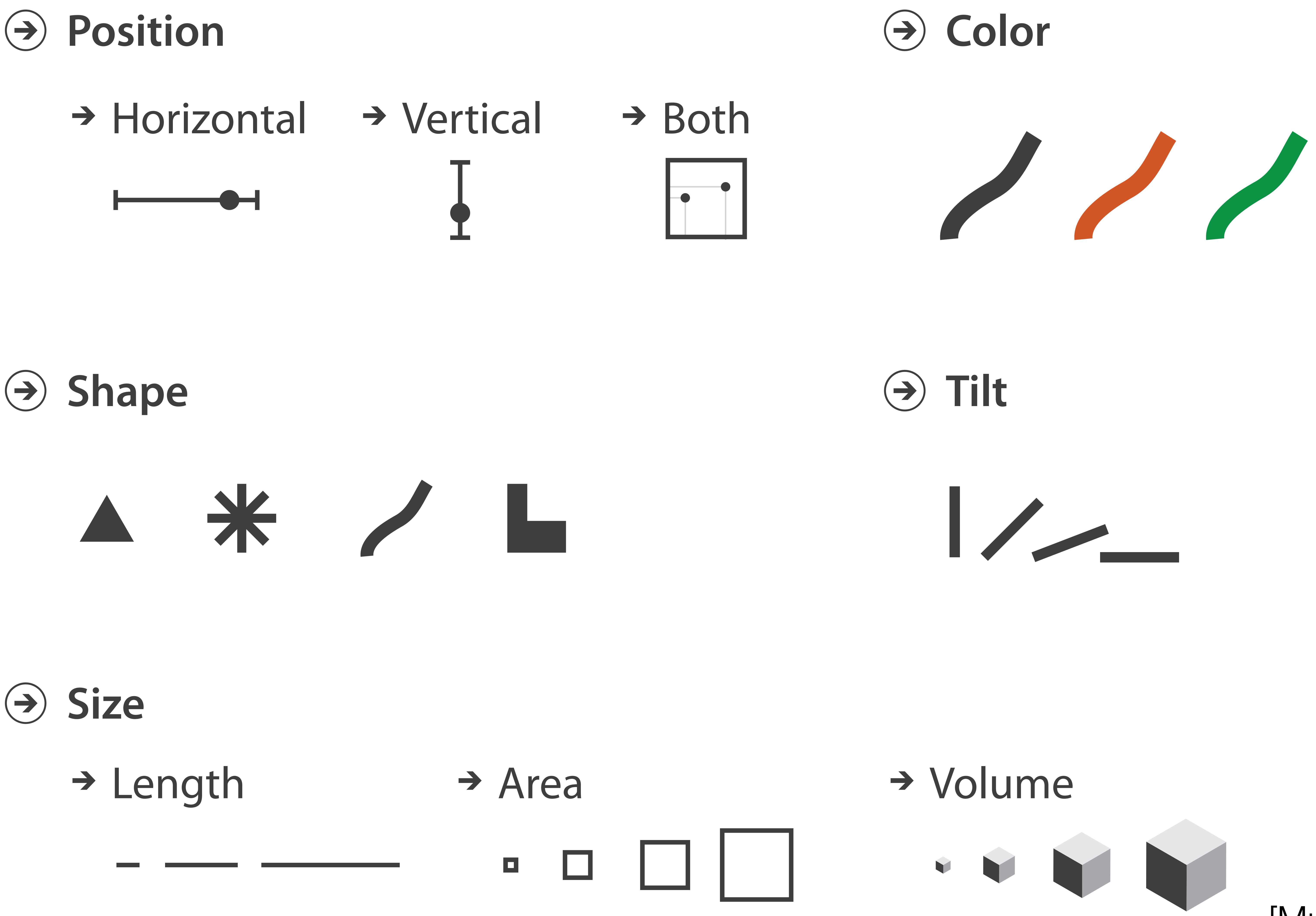
string	description
'.'	point
','	pixel
'o'	circle
'v'	triangle_down
'^'	triangle_up
'<'	triangle_left
'>'	triangle_right
'1'	tri_down
'2'	tri_up
'3'	tri_left
'4'	tri_right
'8'	octagon
's'	square

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

Markers

[Documentation (Notes Section])

Data is Encoded via Visual Channels

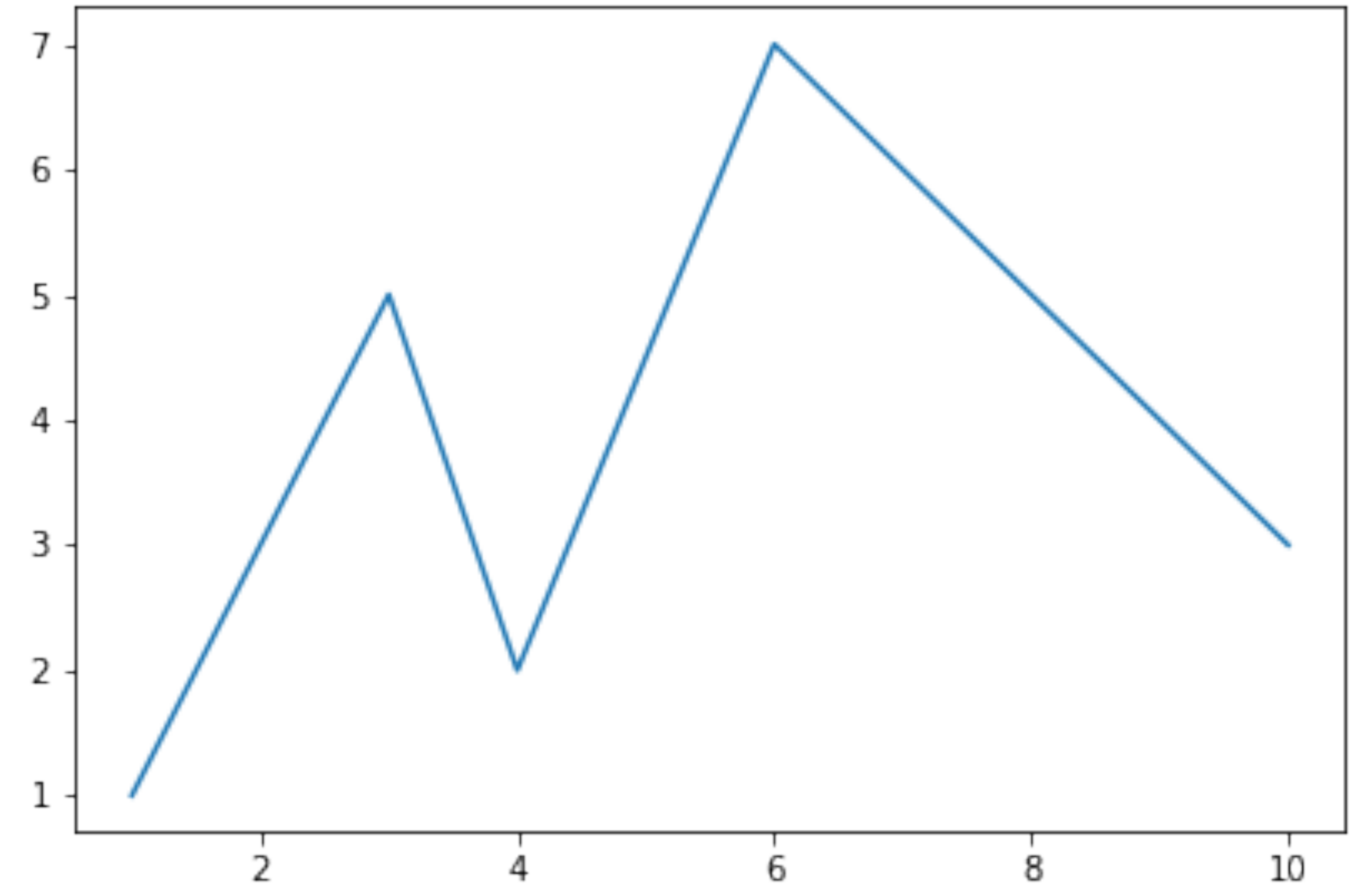


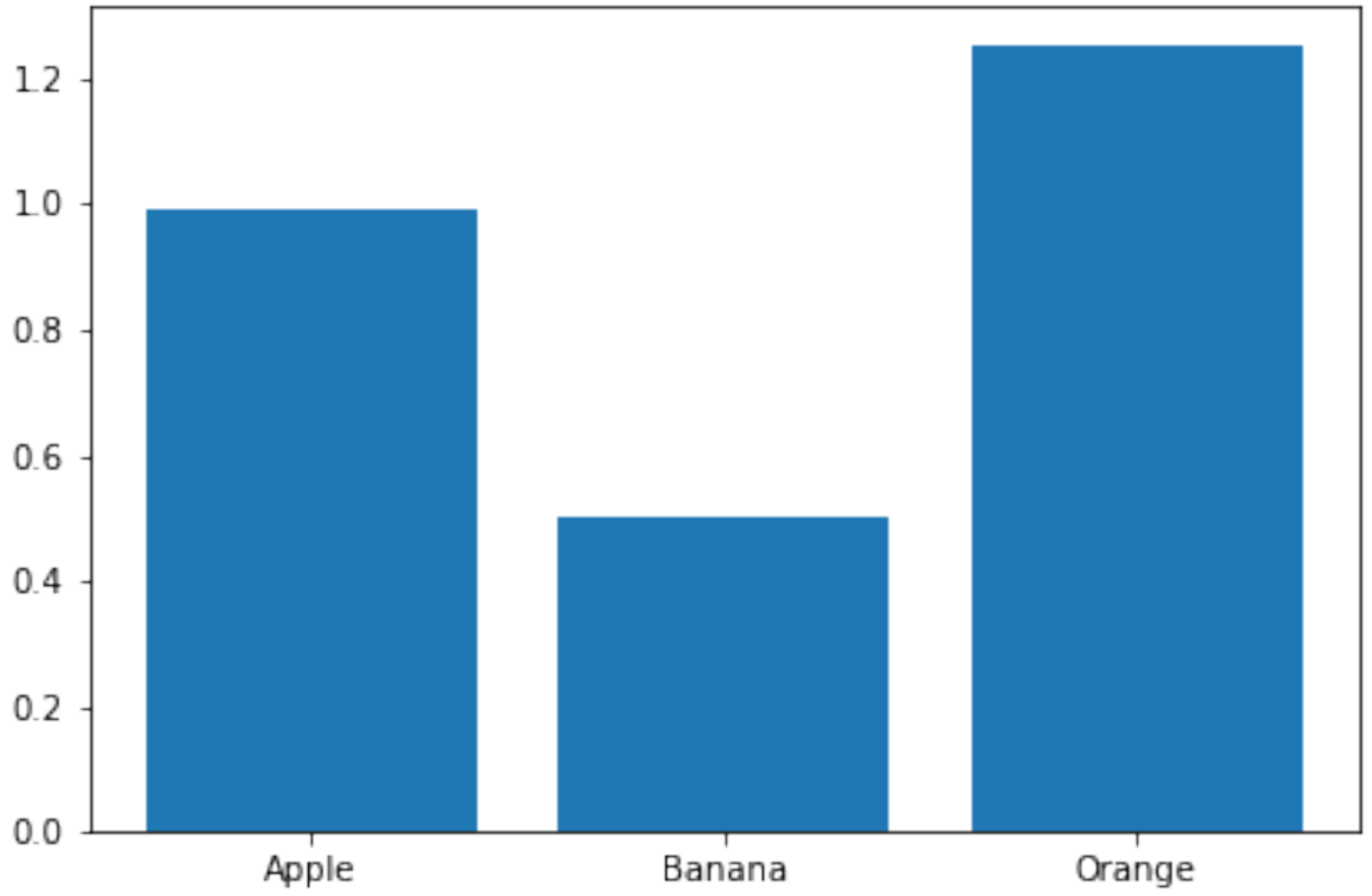
[Munzner (ill. Maguire), 2014]

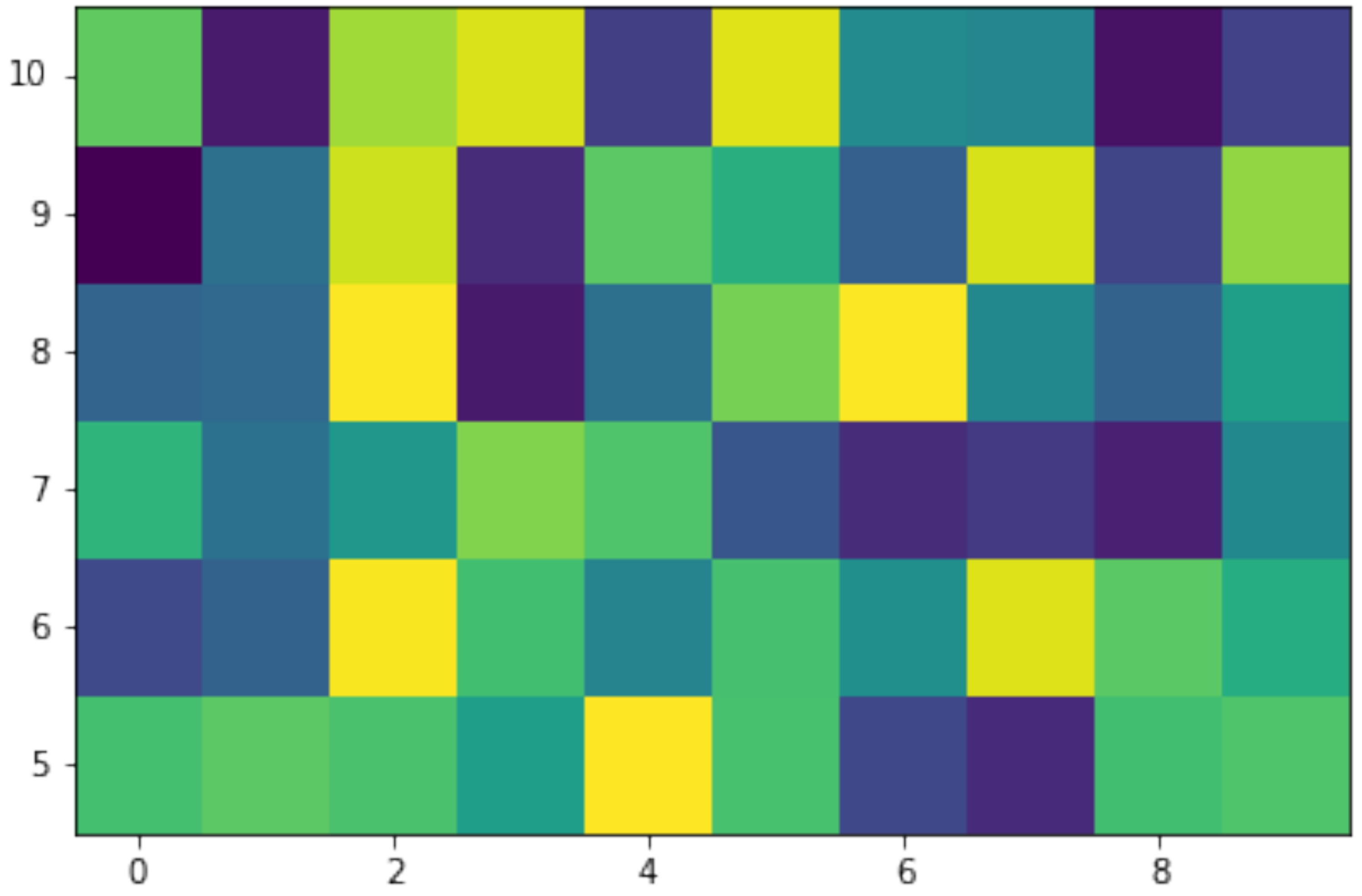
Encoding Data Attributes via Channels

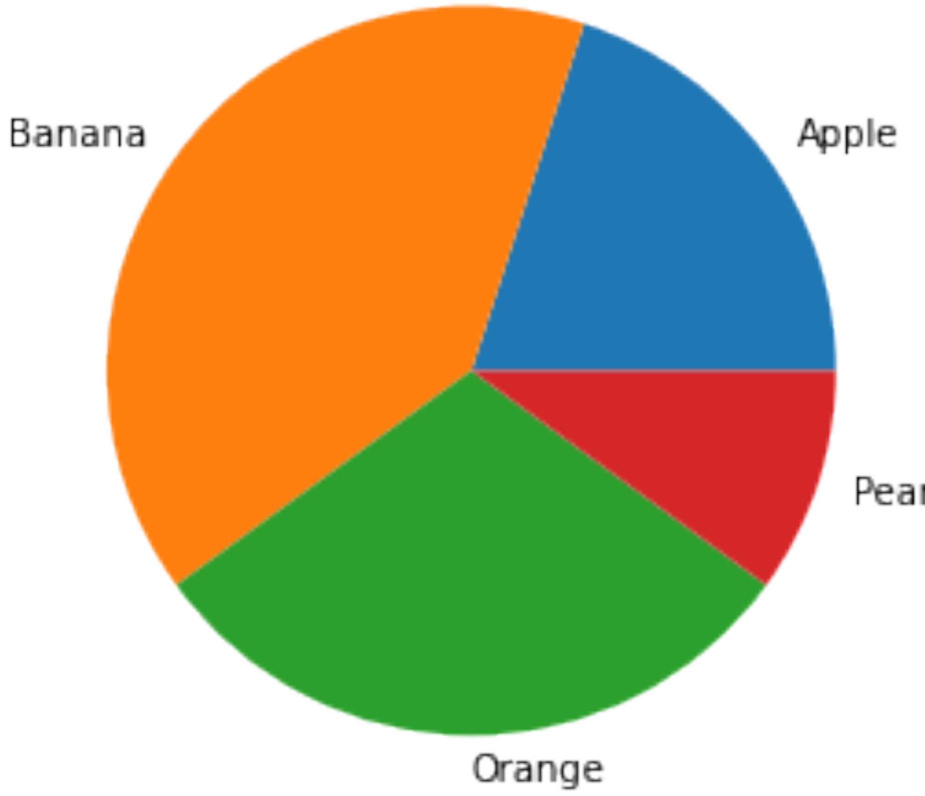
- ```
  data = {'age': [1,3,4,6,10],
          'num_jumps': [1,5,2,7,3],
          'weight': [20,50,25,55,25],
          'num_scoops': [3,2,4,2,3]}
  plt.scatter('age','num_jumps',c='num_scoops',s='weight',
              data=data)
  ```
- `data` is a dictionary that contains information about each data 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









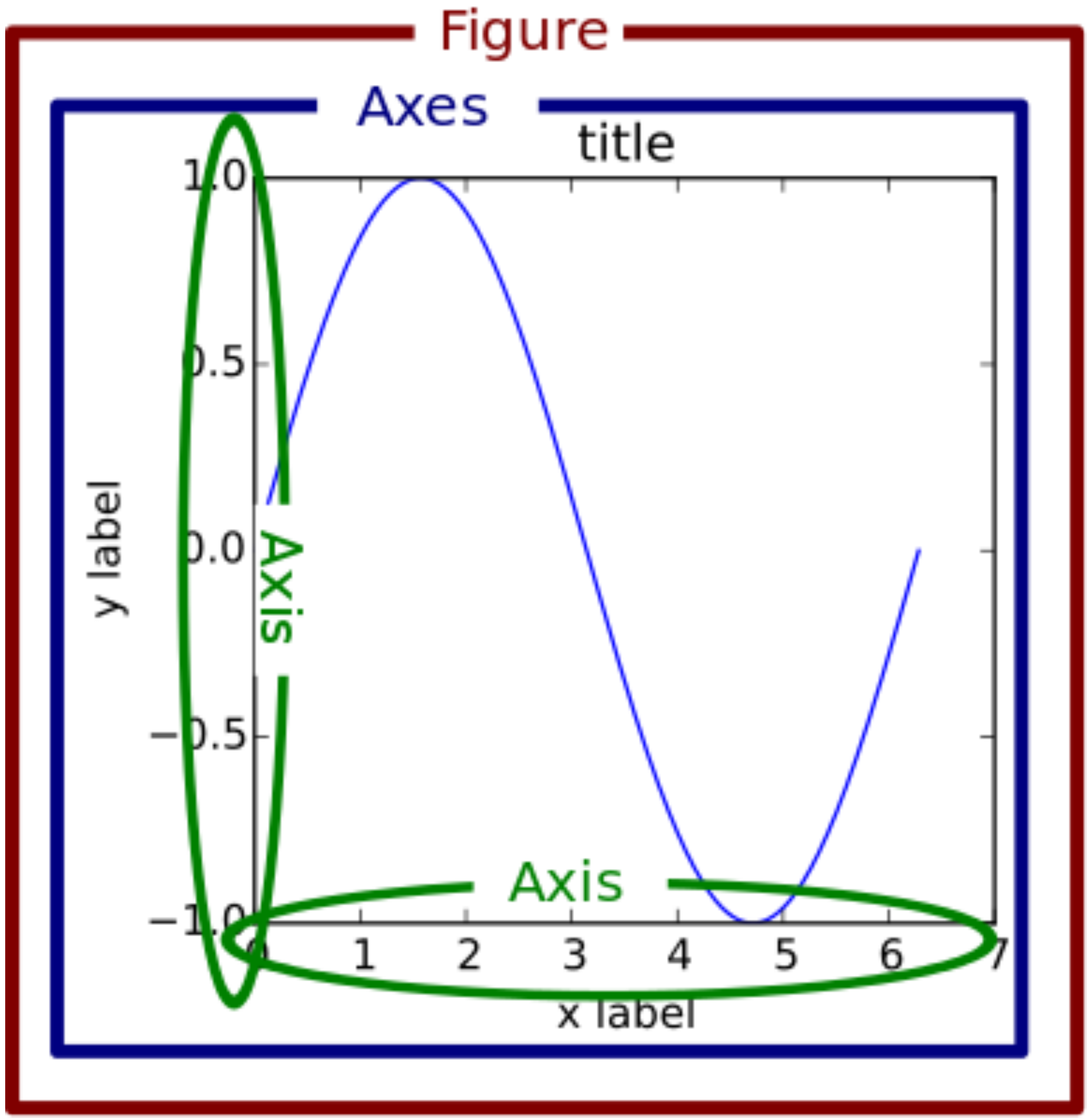
Many different types of charts

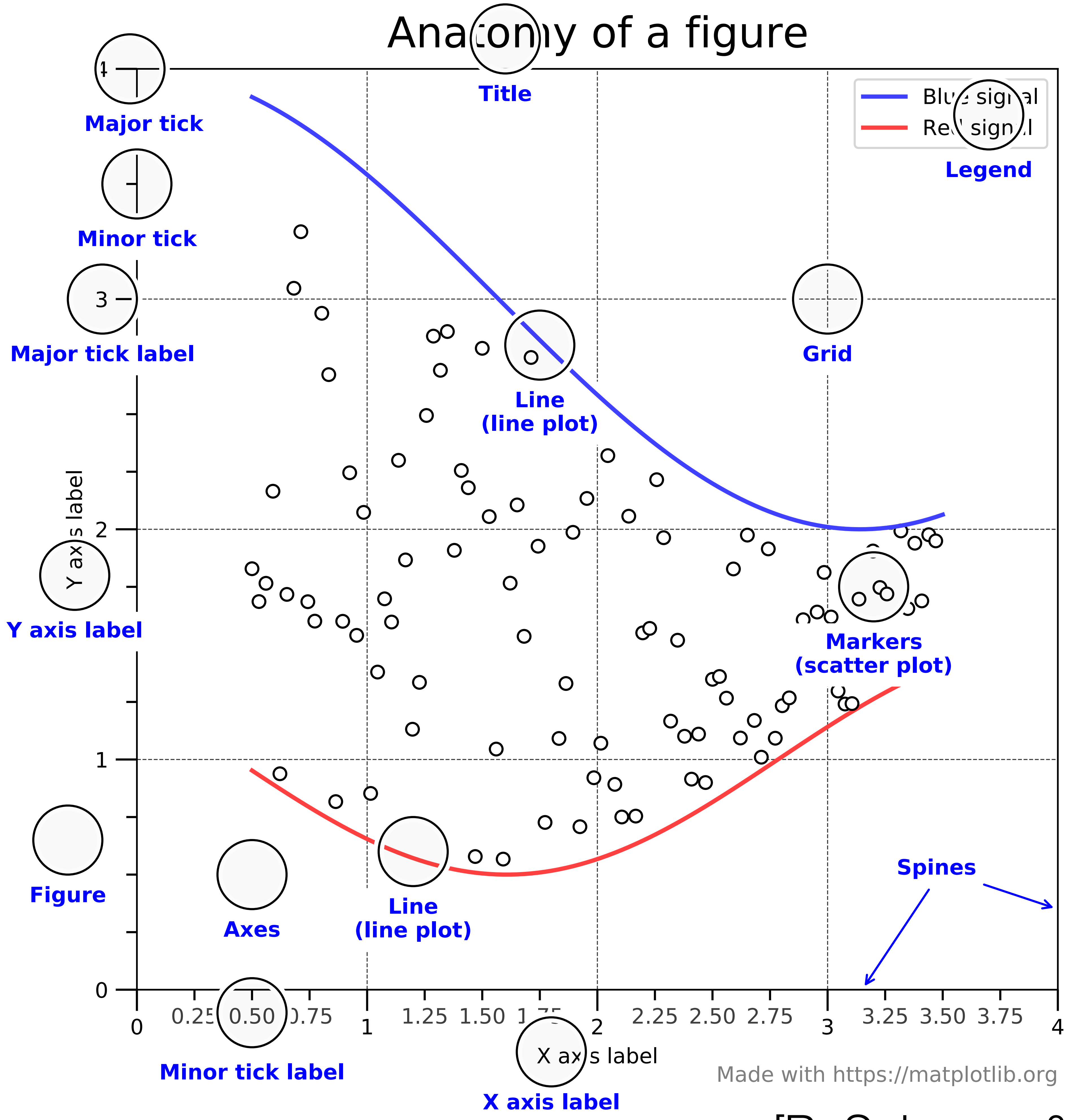
- Bar chart
  - `plt.bar(['Apple','Banana','Orange'],[0.99,0.50,1.25])`
- Grid Heatmap
  - `plt.pcolormesh(x, y, Z)`
- Pie chart:
  - ```
    plt.pie([20,40,30,10],
            labels=['Apple','Banana','Orange','Pear'])
    ```
    ```

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'])
  ```
  ```

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)
    ```
    ```