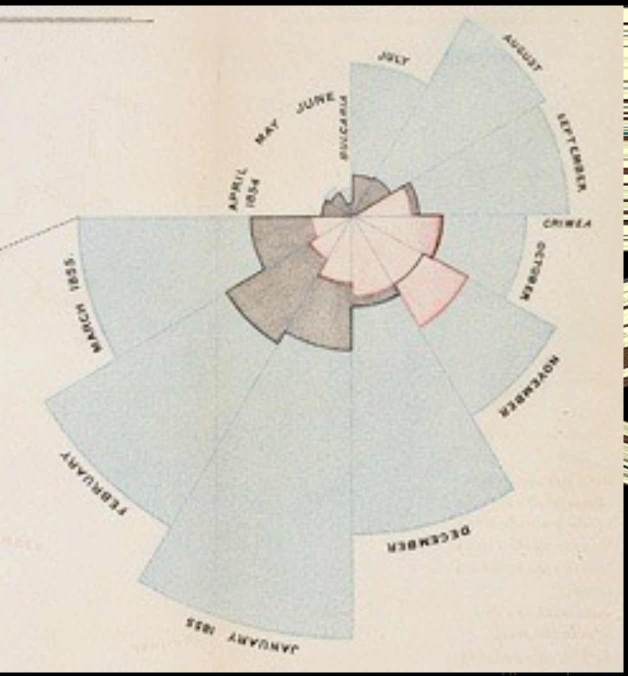
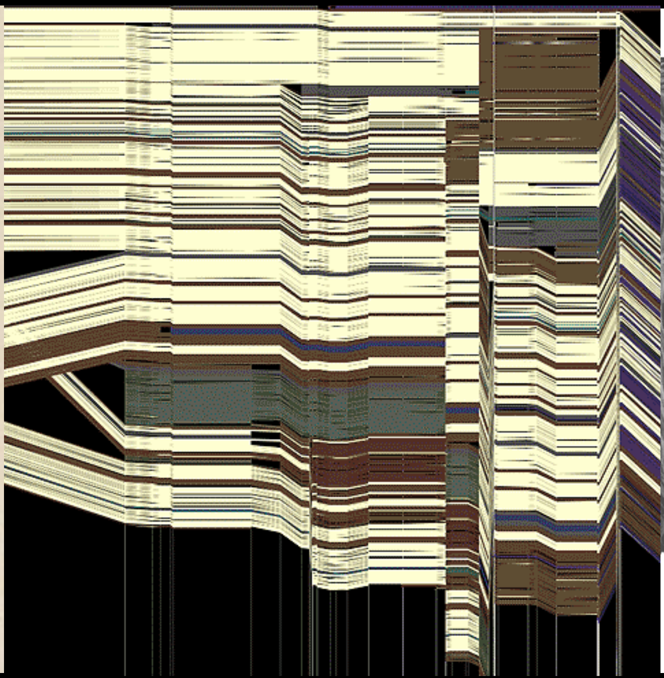
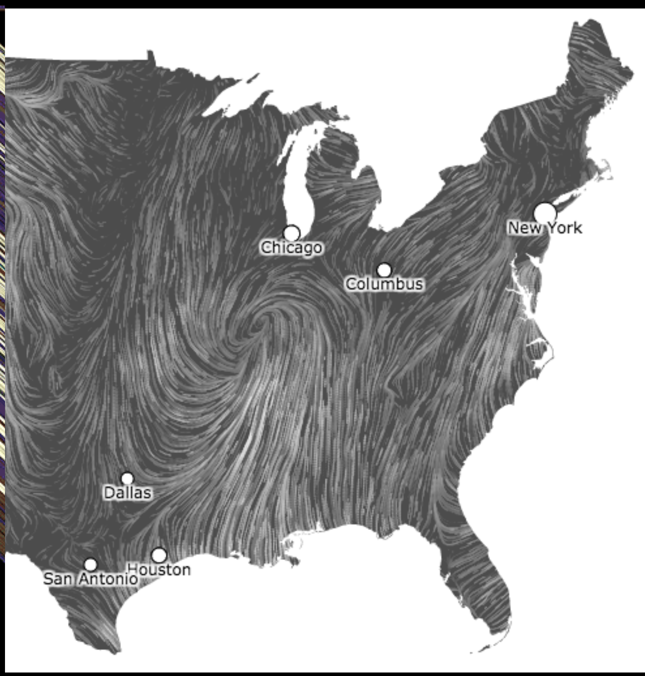
CSE 442 - Data Visualization

Visual Encoding Design







Jeffrey Heer University of Washington

Review: Expressiveness & Effectiveness / APT

Choosing Visual Encodings

Assume *k* visual encodings and *n* data attributes. We would like to pick the "best" encoding among a combinatorial set of possibilities of size $(n+1)^k$

Principle of Consistency
The properties of the image (visual variables) should match the properties of the data.

Principle of Importance Ordering
Encode the most important information in the most effective way.

Design Criteria [Mackinlay 86]

Expressiveness
A set of facts is *expressible* in a visual language if the sentences (i.e. the visualizations) in the language express all the facts in the set of data, and only the facts in the data.

Effectiveness
A visualization is more *effective* than another visualization if the information conveyed by one visualization is more readily perceived than the information in the other visualization.

Design Criteria *Translated*

Tell the truth and nothing but the truth
(don't lie, and don't lie by omission)

Use encodings that people decode better
(where better = faster and/or more accurate)

Effectiveness Rankings [Mackinlay 86]

QUANTITATIVE	ORDINAL	NOMINAL
Position	Position	Position
Length	Density (Value)	Color Hue
Angle	Color Sat	Texture
Slope	Color Hue	Connection
Area (Size)	Texture	Containment
Volume	Connection	Density (Value)
Density (Value)	Containment	Color Sat
Color Sat	Length	Shape
Color Hue	Angle	Length
Texture	Slope	Angle
Connection	Area (Size)	Slope
Containment	Volume	Area
Shape	Shape	Volume

Effectiveness Rankings [Mackinlay 86]

QUANTITATIVE	ORDINAL	NOMINAL
Position	**Position**	**Position**
Length	Density (Value)	Color Hue
Angle	Color Sat	Texture
Slope	Color Hue	Connection
Area (Size)	Texture	Containment
Volume	Connection	Density (Value)
Density (Value)	Containment	Color Sat
Color Sat	Length	Shape
Color Hue	Angle	Length
Texture	Slope	Angle
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Effectiveness Rankings [Mackinlay 86]

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Slope	**Color Hue**	Connection
Area (Size)	Texture	Containment
Volume	Connection	Density (Value)
Density (Value)	Containment	Color Sat
Color Sat	Length	Shape
Color Hue	Angle	Length
Texture	Slope	Angle
Connection	Area (Size)	Slope
Containment	Volume	Area
Shape	Shape	Volume

Mackinlay’s Design Algorithm

APT - “A Presentation Tool”, 1986

User formally specifies data model and type
Input: ordered list of data variables to show

APT searches over design space
Test expressiveness of each visual encoding
Generate encodings that pass test
Rank by perceptual effectiveness criteria

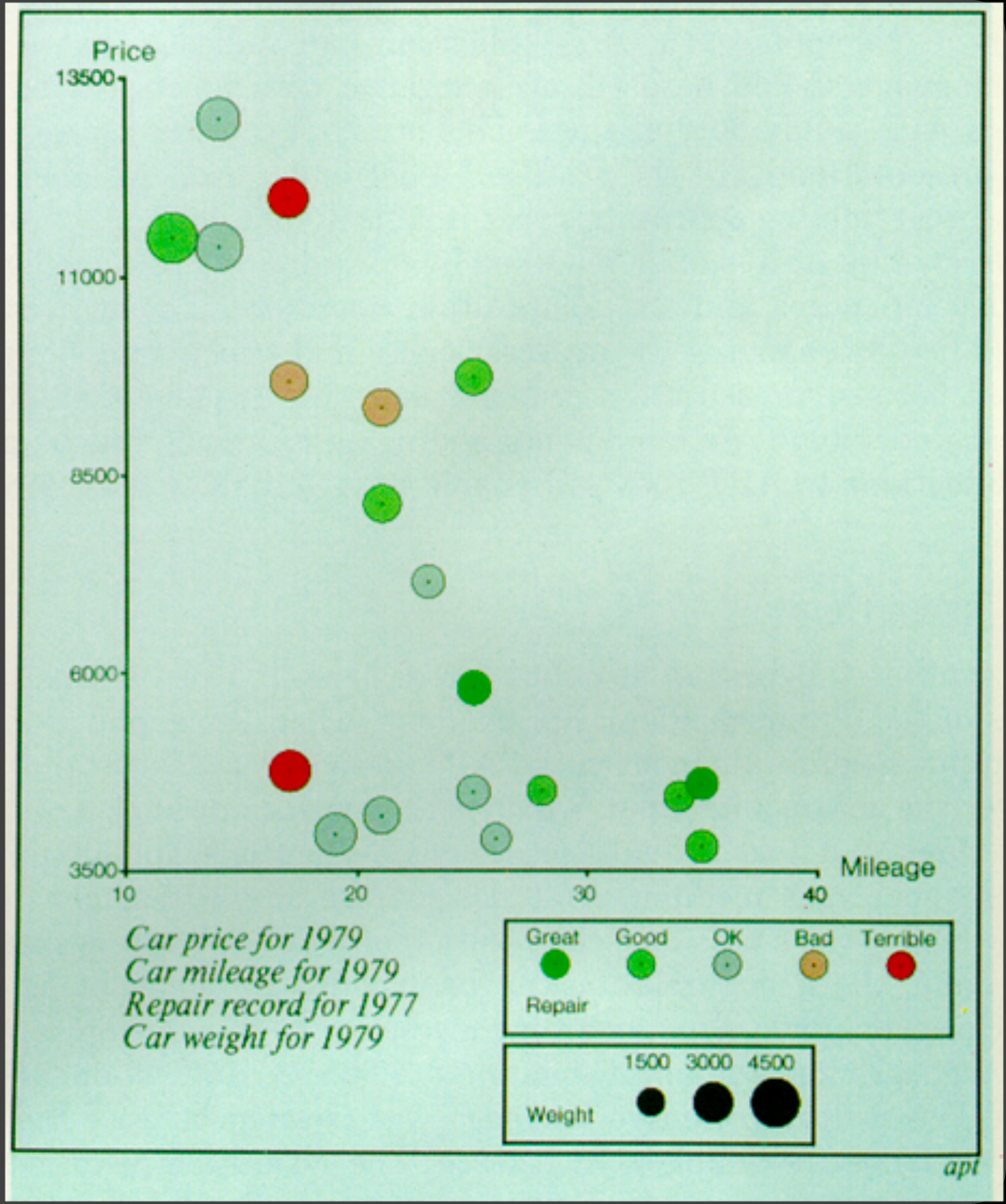
Output the “most effective” visualization

APT

Automatically generate chart for car data

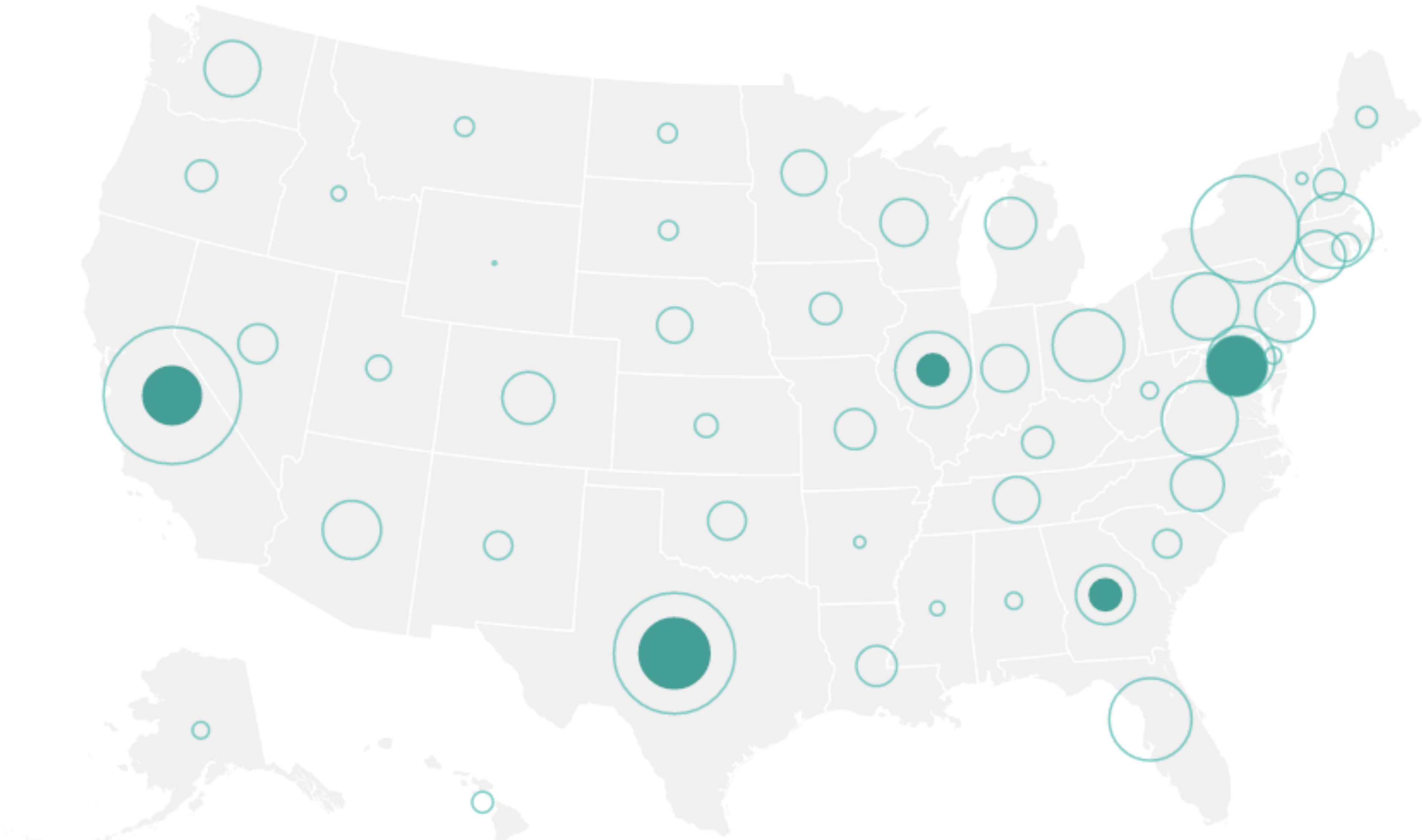
Input variables:

1. Price
2. Mileage
3. Repair
4. Weight



Design Examples

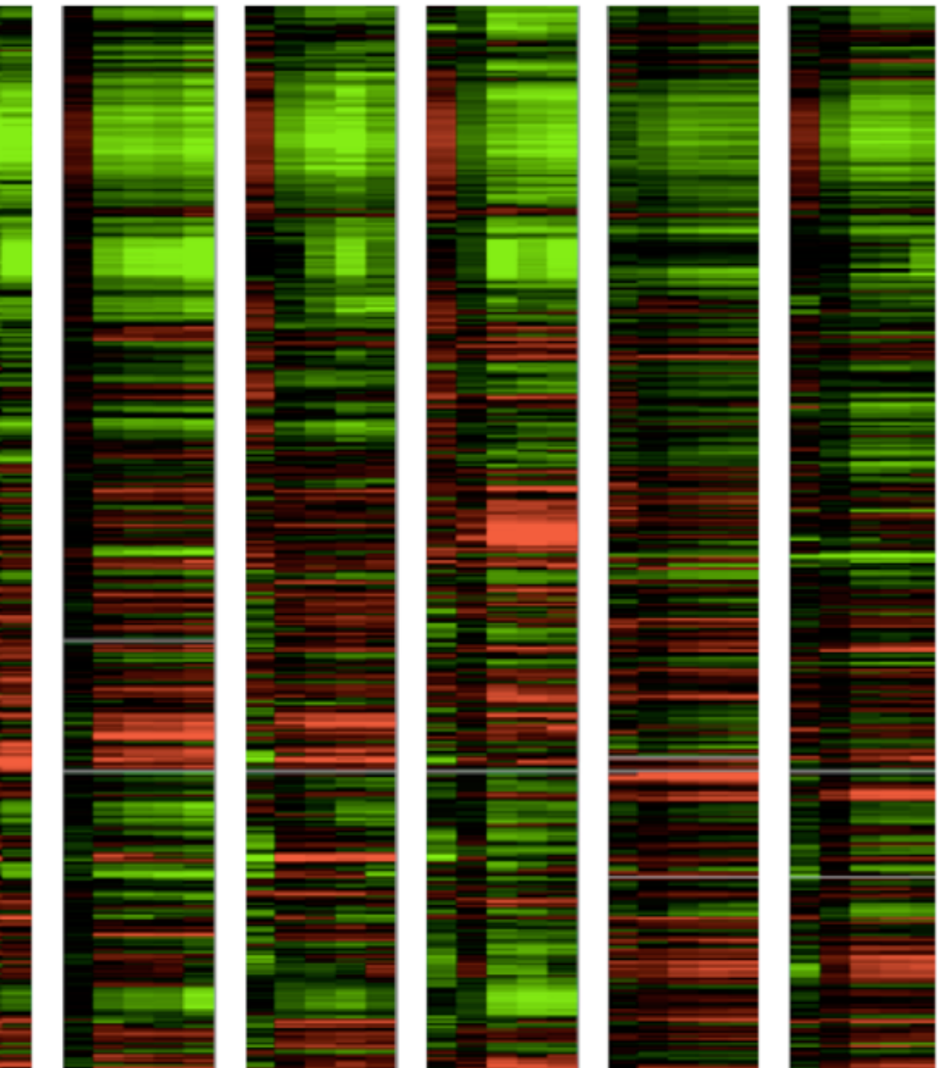
Color Encoding



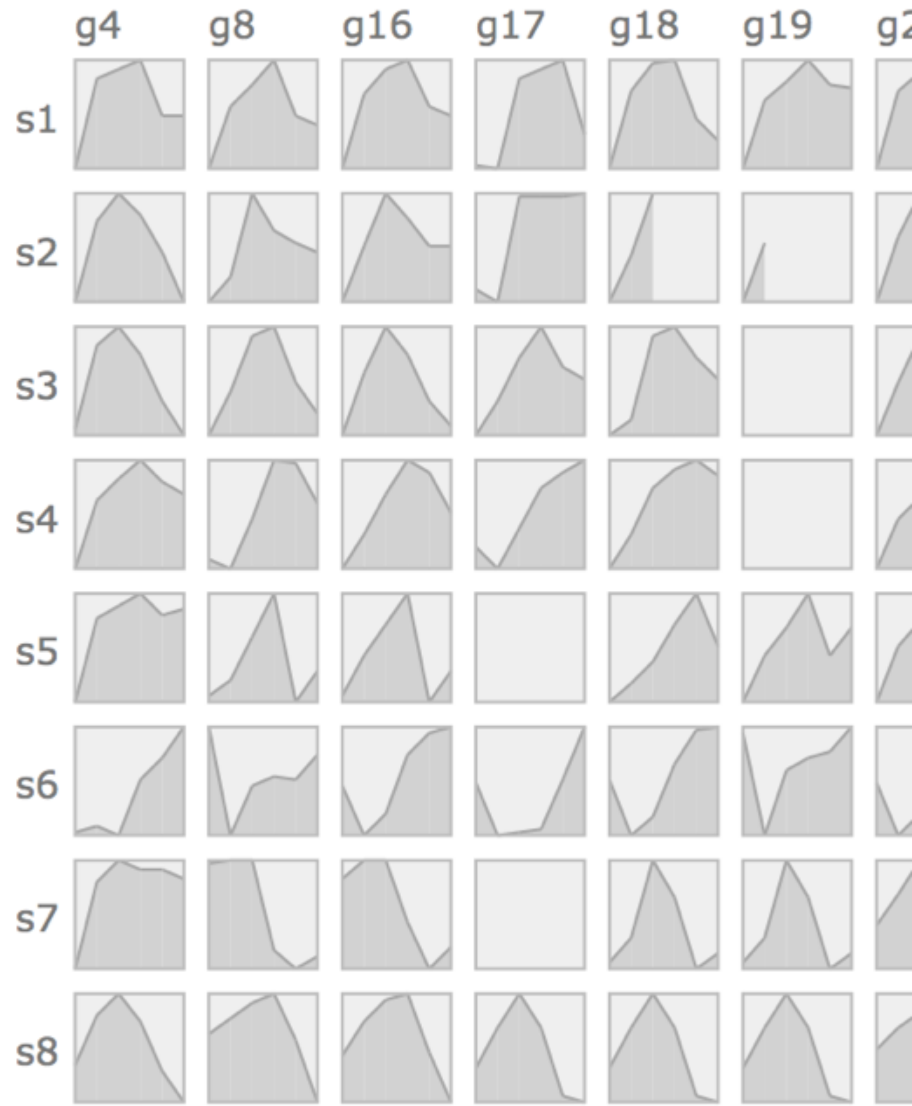
Area Encoding

Gene Expression Time-Series [Meyer et al '11]

Color Encoding



Position Encoding



Artery Visualization [Borkin et al '11]

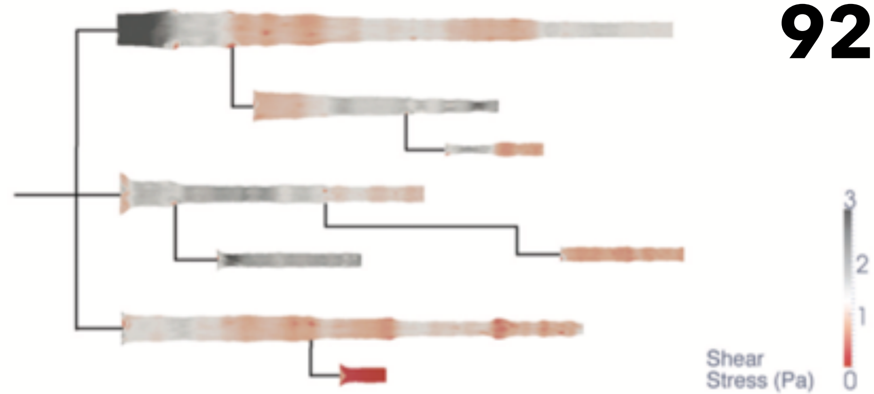
Rainbow Palette

Diverging Palette

2D

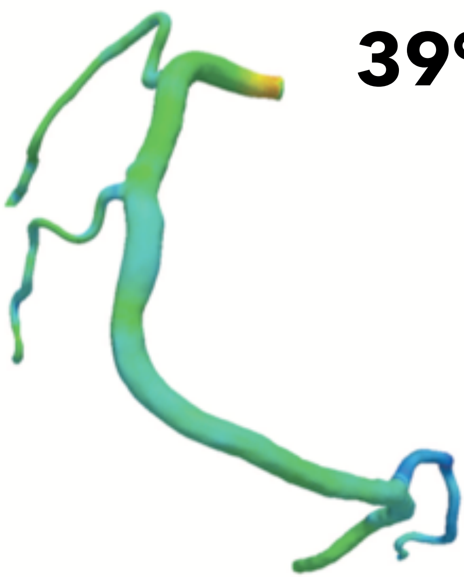
62%

92%



3D

39%



71%

Other Visual Encoding Channels?

A Design Space of Visual Encodings

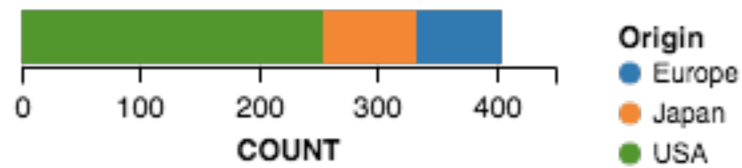
Mapping Data to Visual Variables

Assign **data fields** (e.g., with *N, O, Q* types) to **visual channels** (*x, y, color, shape, size, …*) for a chosen **graphical mark** type (*point, bar, line, …*).

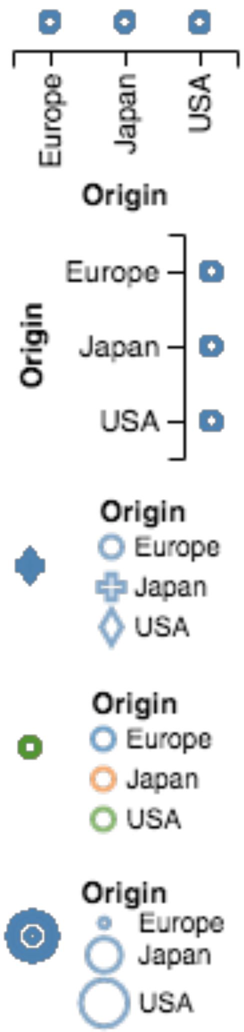
Additional concerns include choosing appropriate **encoding parameters** (*log scale, sorting, …*) and **data transformations** (*bin*, *group, aggregate, …*).

These options define a large combinatorial space, containing both useful and questionable charts!

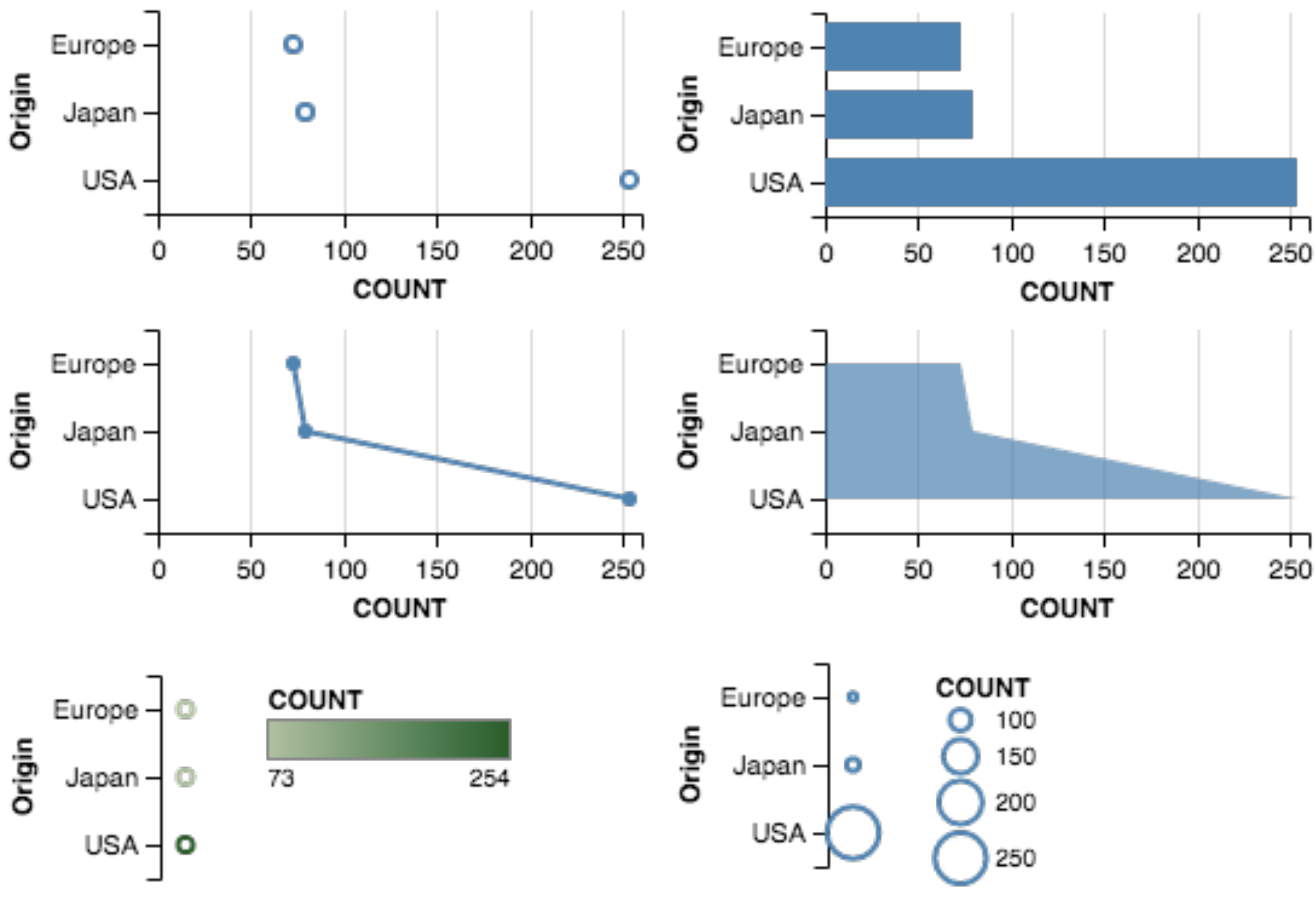
1D: Nominal



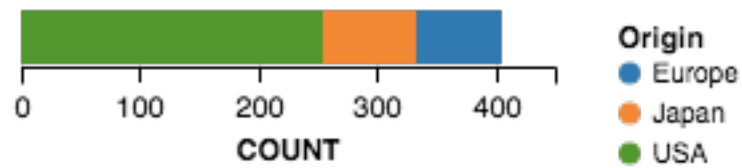
Raw



Aggregate (Count)

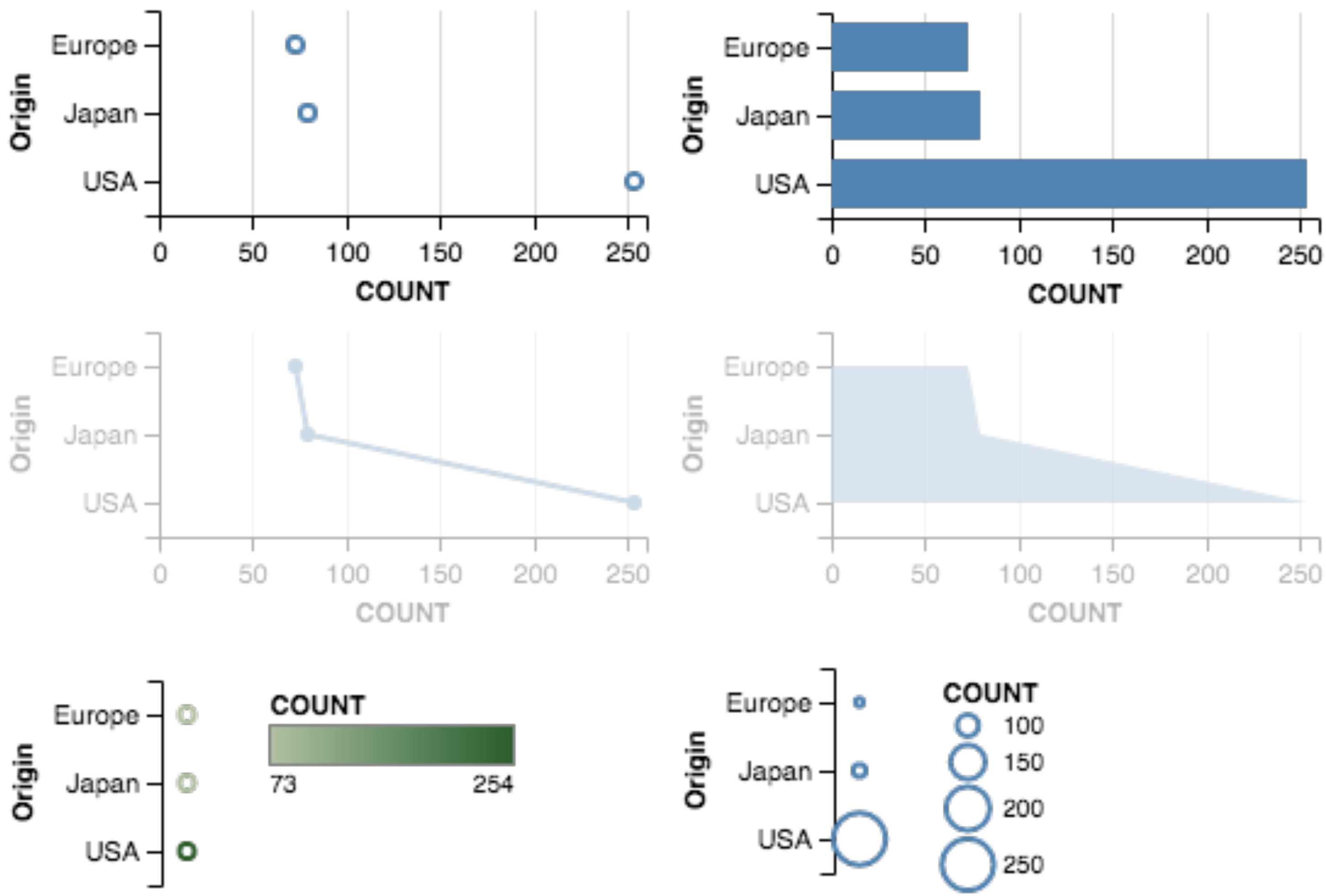


Expressive?



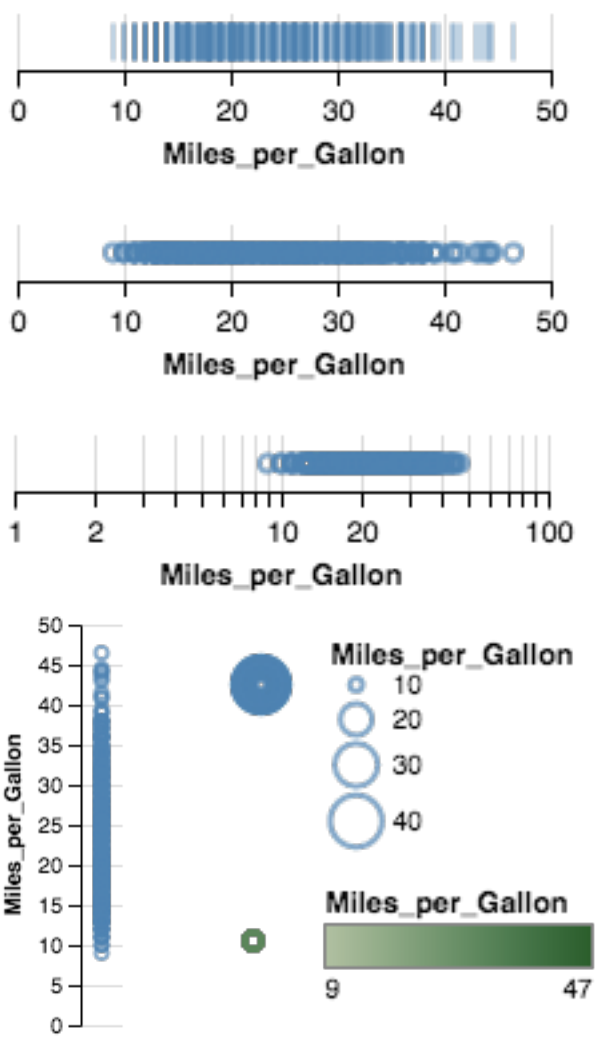
Raw

Aggregate (Count)

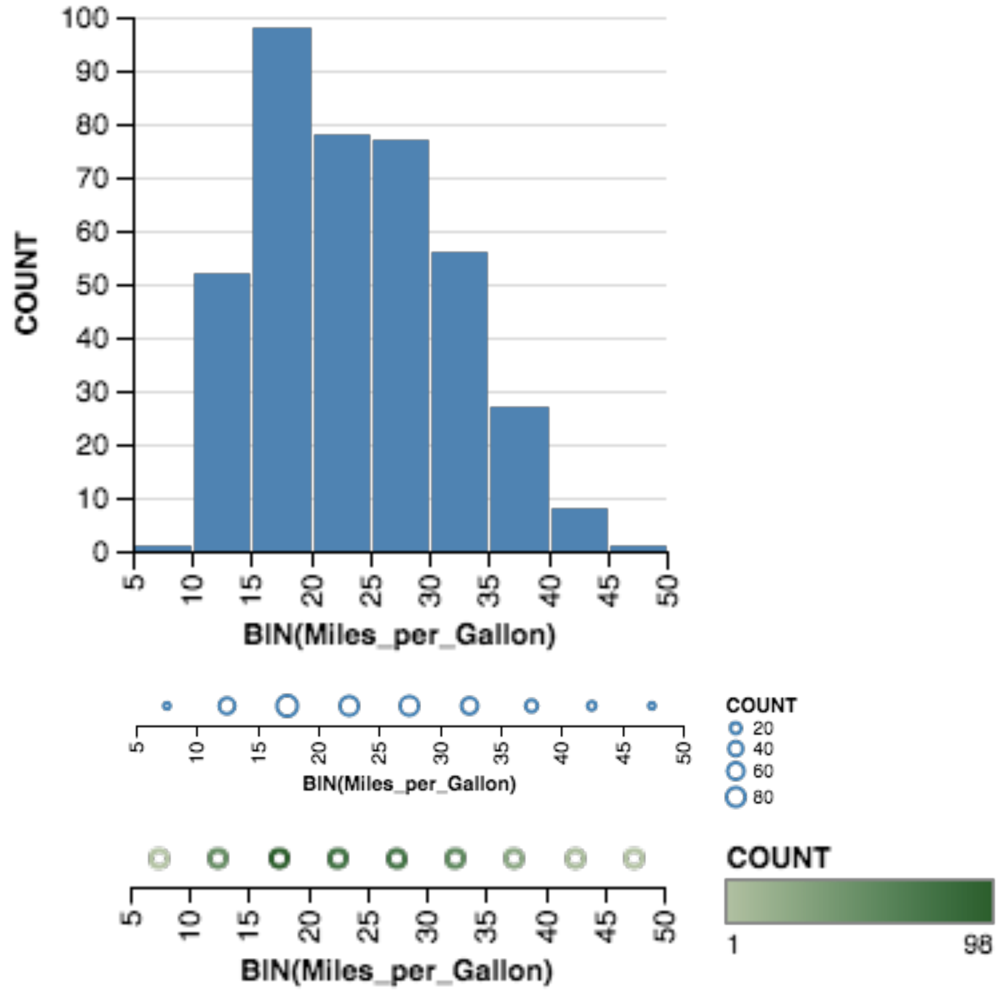


1D: Quantitative

Raw

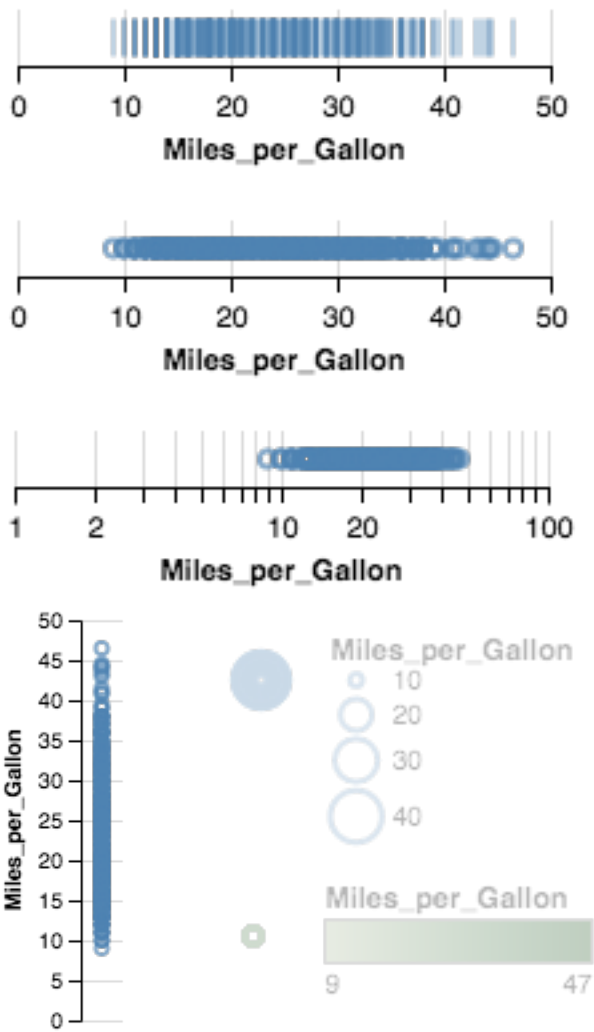


Aggregate (Count)

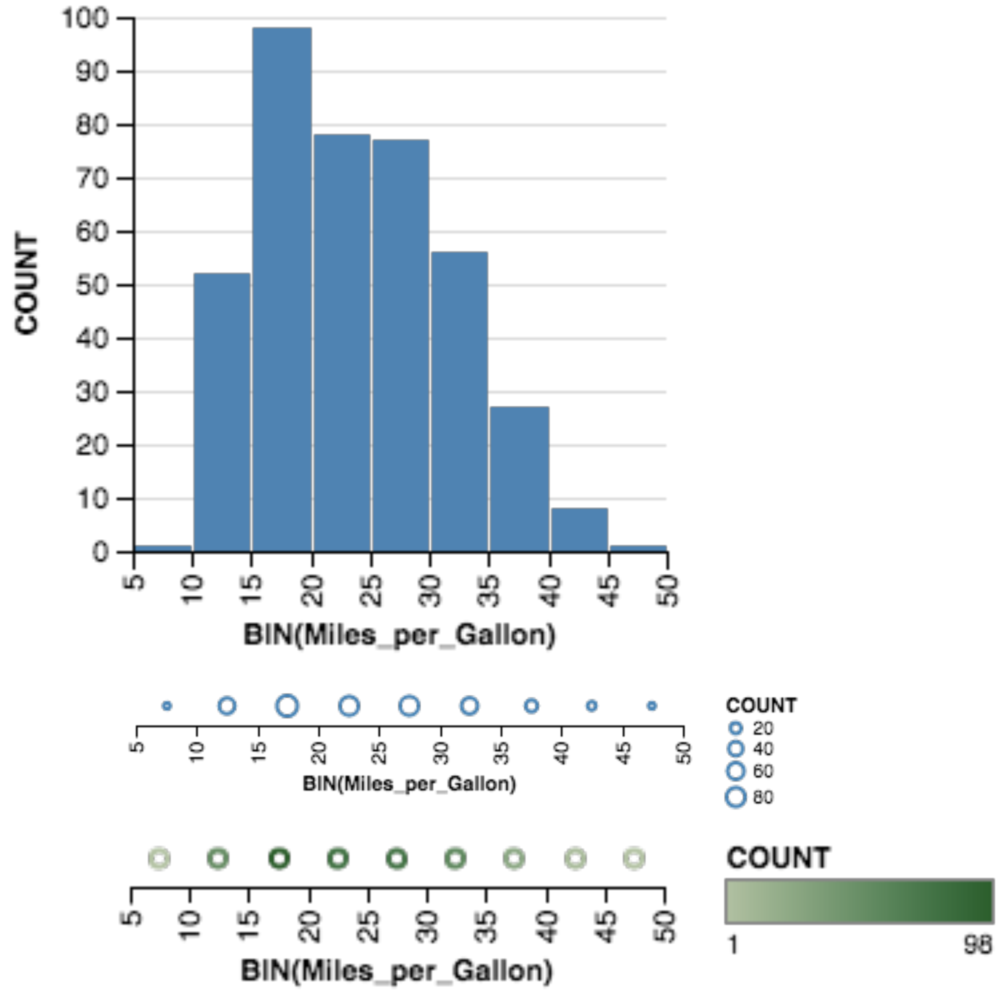


Expressive?

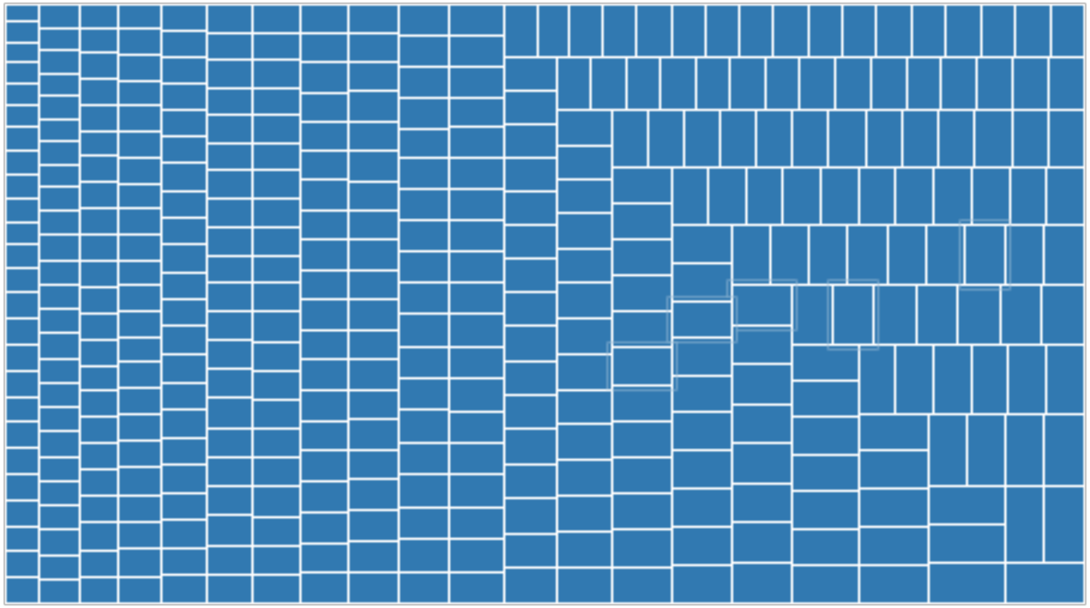
Raw



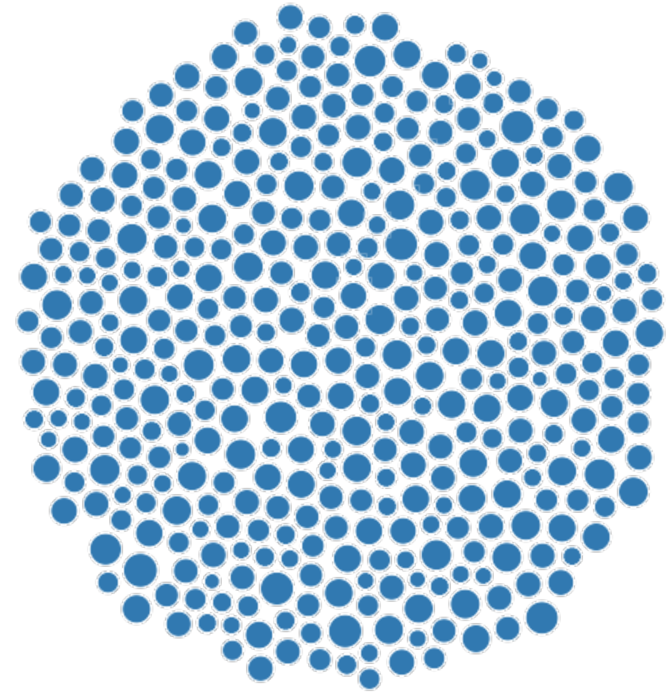
Aggregate (Count)



Raw (with Layout Algorithm)

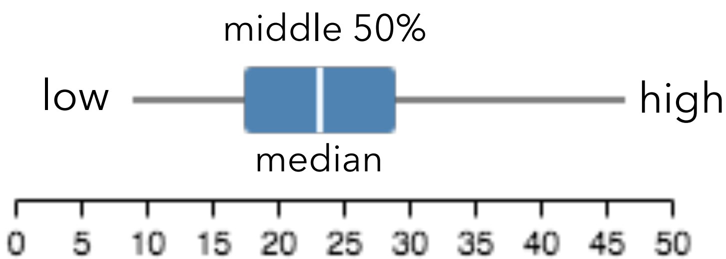


Treemap

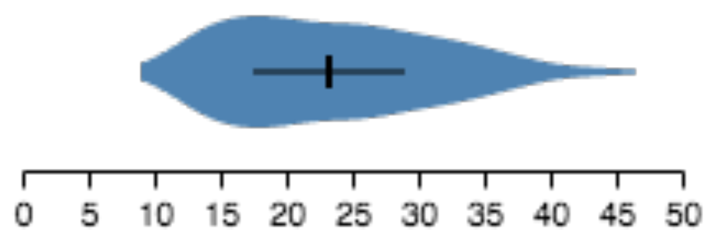


Bubble Chart

Aggregate (Distributions)



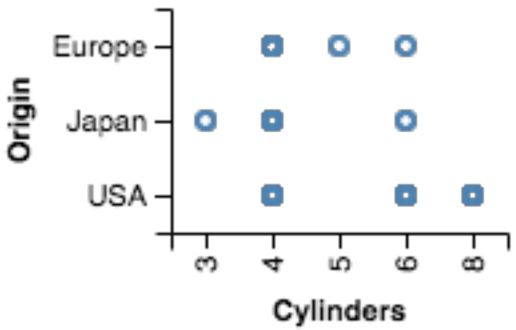
Box Plot

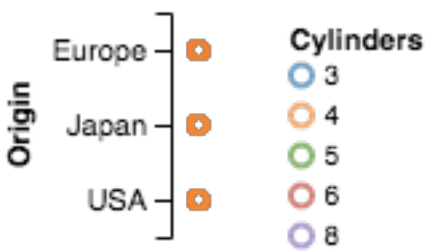


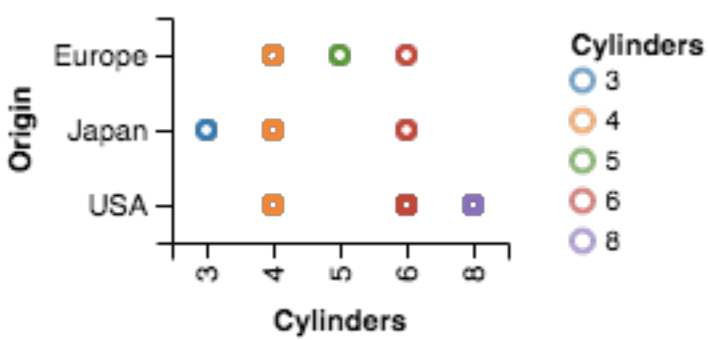
Violin Plot

2D: Nominal x Nominal

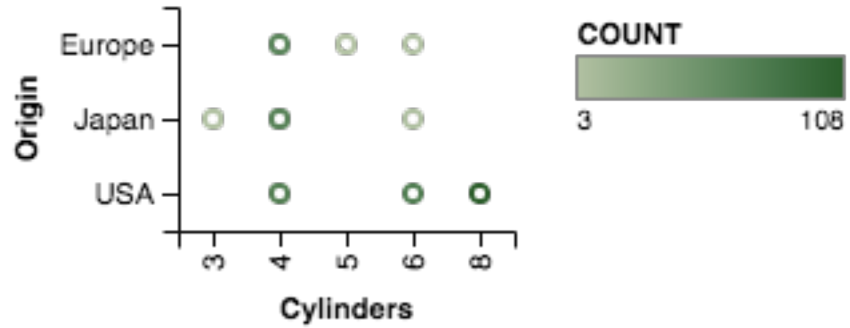
Raw

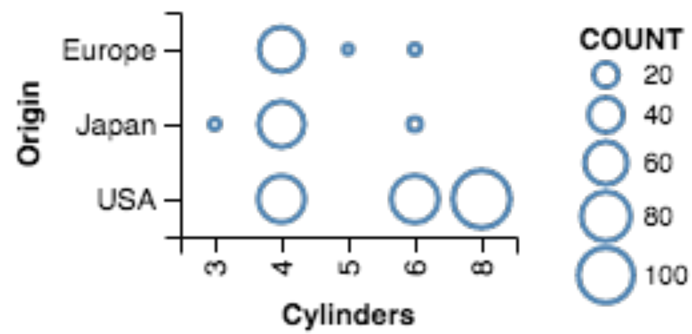


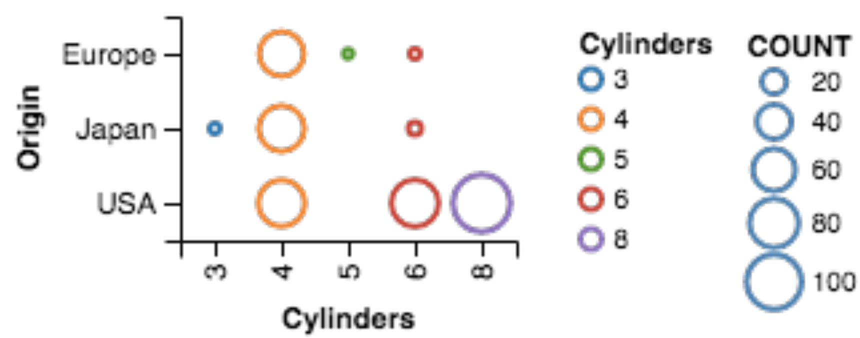




Aggregate (Count)

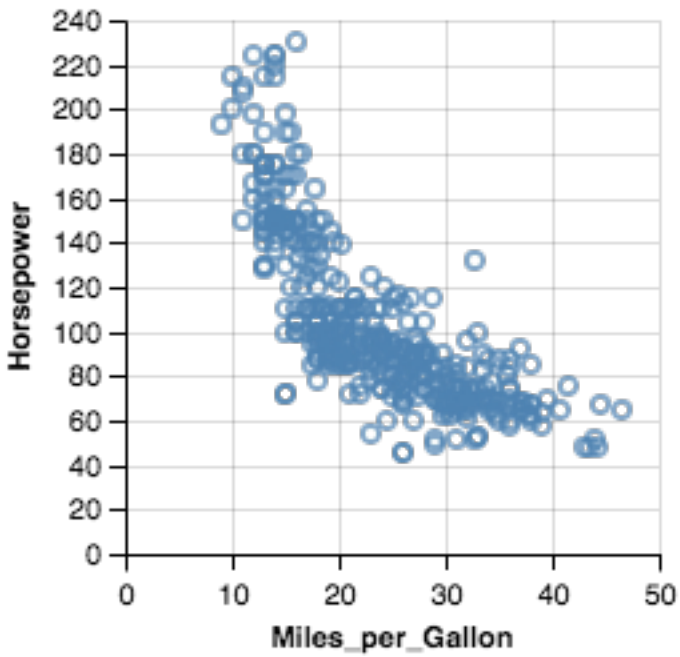


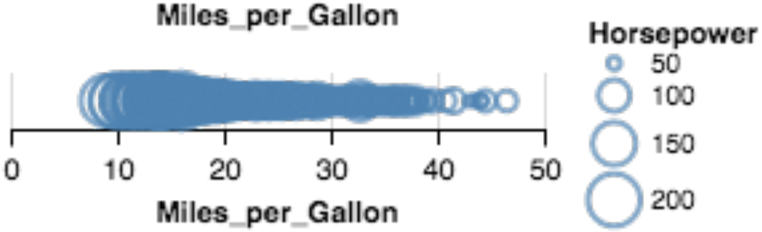


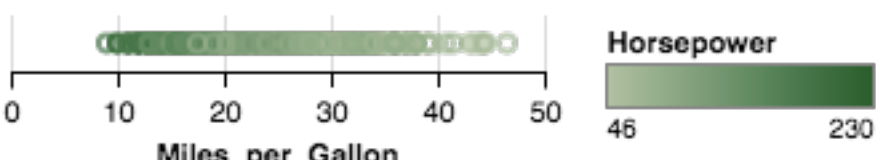


2D: Quantitative x Quantitative

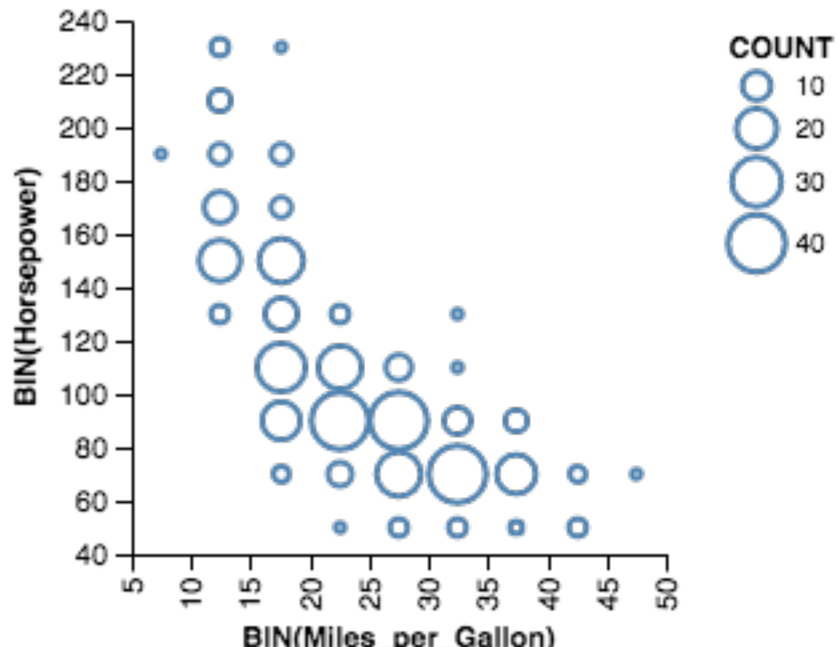
Raw





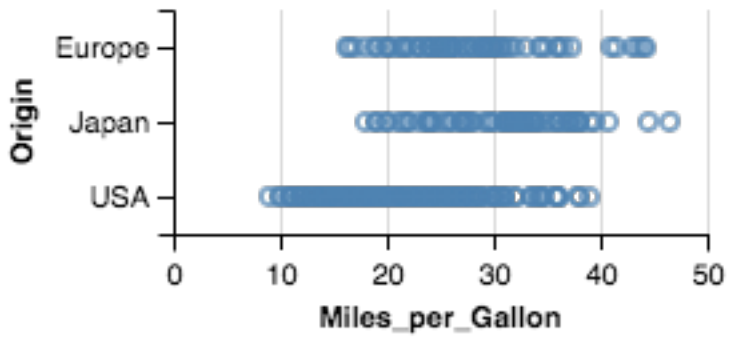


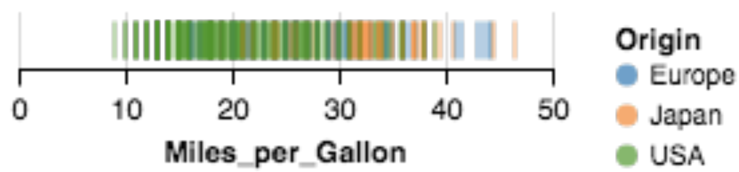
Aggregate (Count)

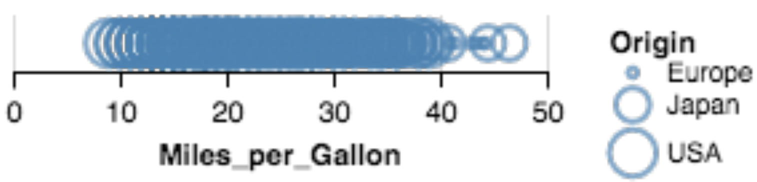


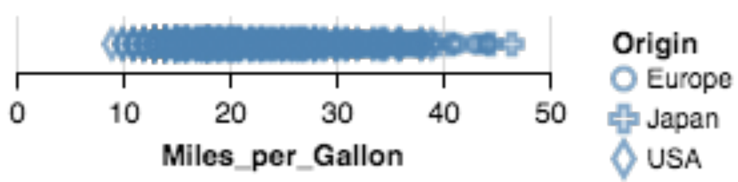
2D: Nominal x Quantitative

Raw

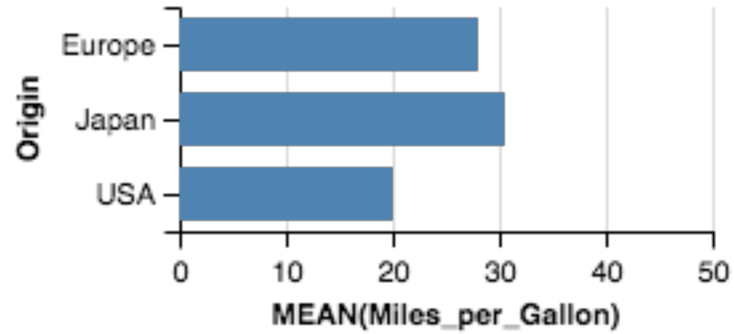


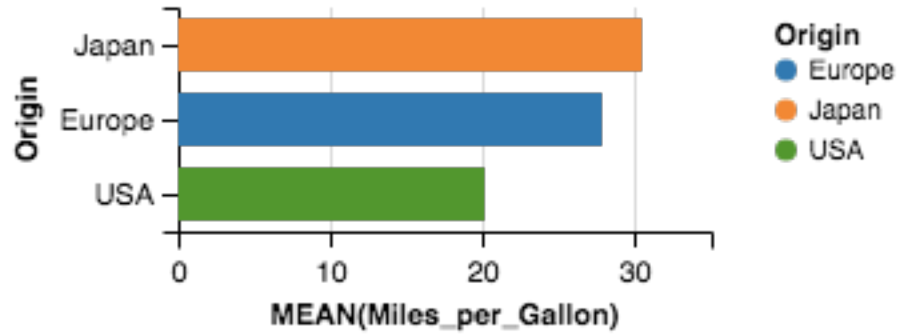




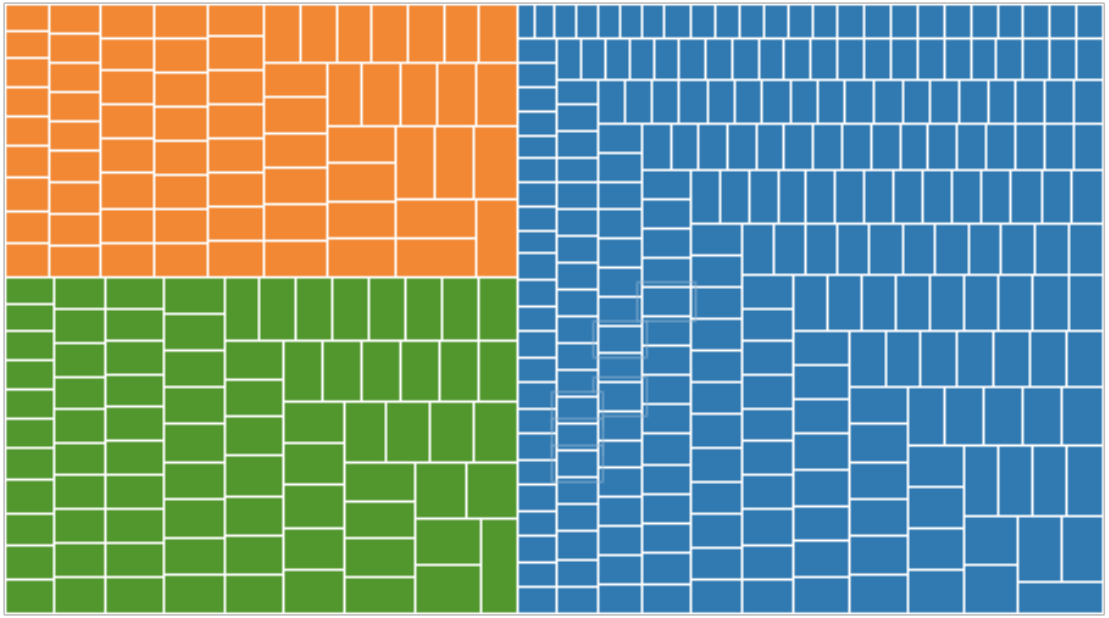


Aggregate (Mean)

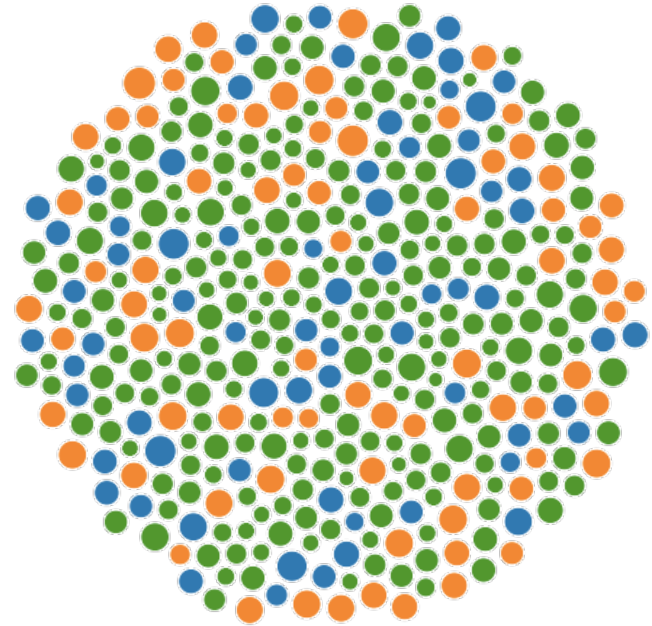




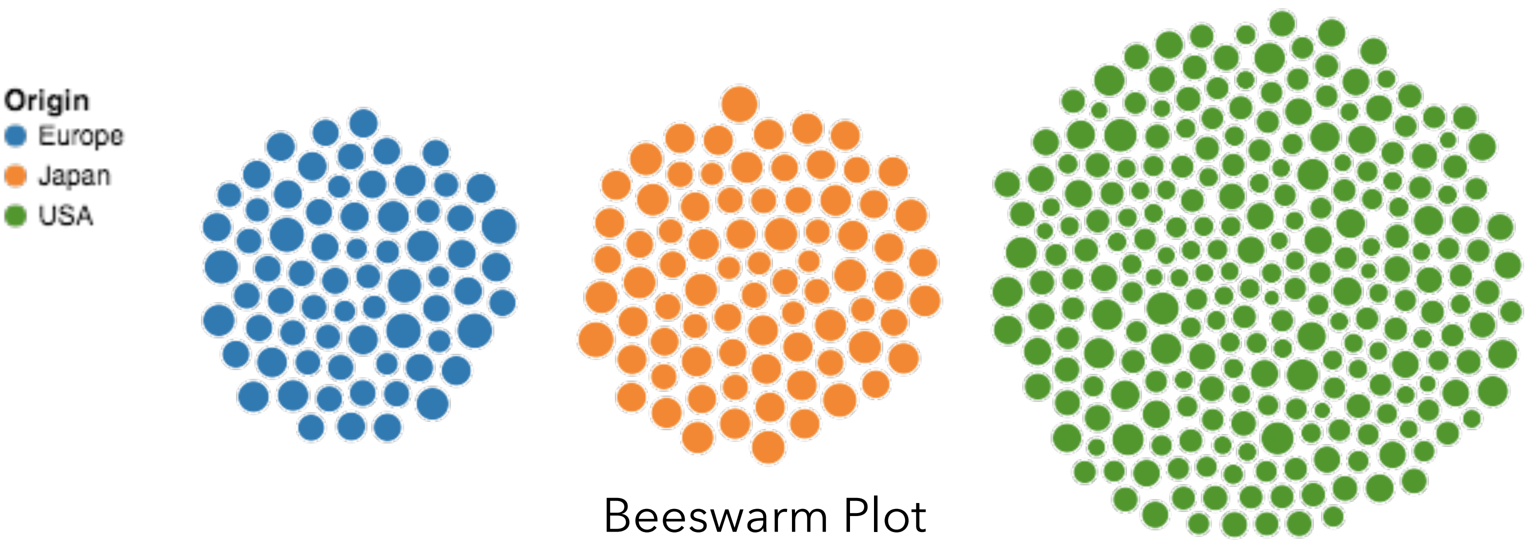
Raw (with Layout Algorithm)



Treemap



Bubble Chart



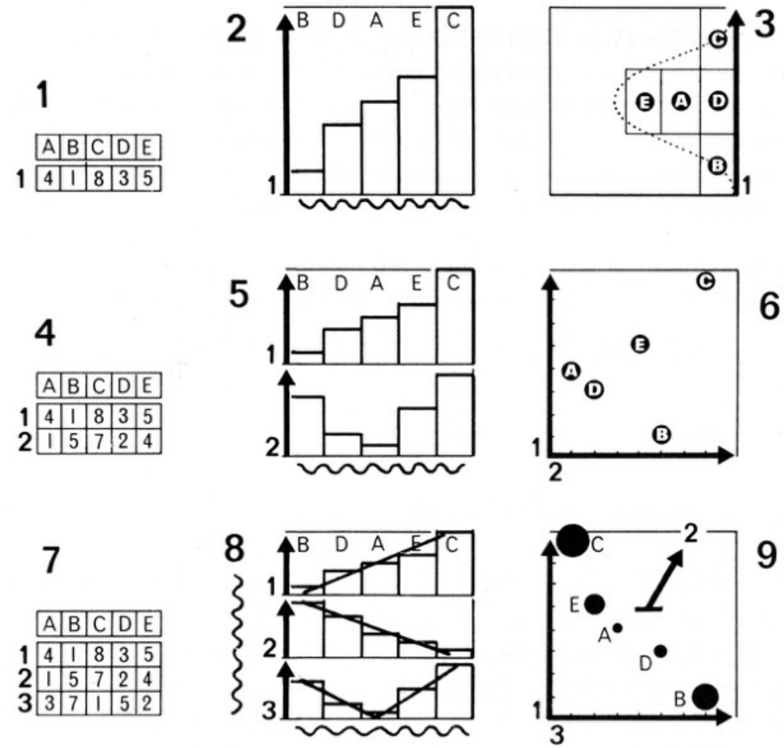
Beeswarm Plot

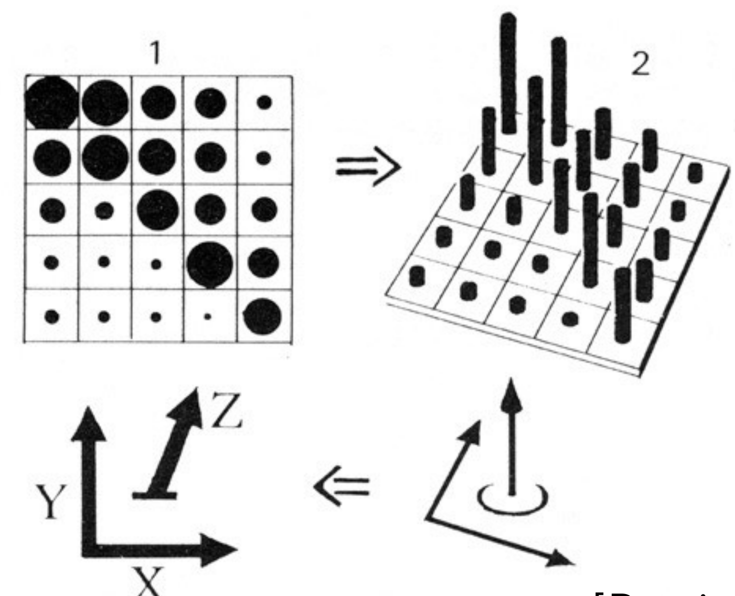
3D and Higher

Two variables [x,y]
Can map to 2D points.
Scatterplots, maps, …

Third variable [z]
Often use one of size, color, opacity, shape, *etc*. Or, one can further partition space.

What about 3D rendering?





[Bertin]

Administrivia

A2: Exploratory Data Analysis

Use visualization software to form & answer questions

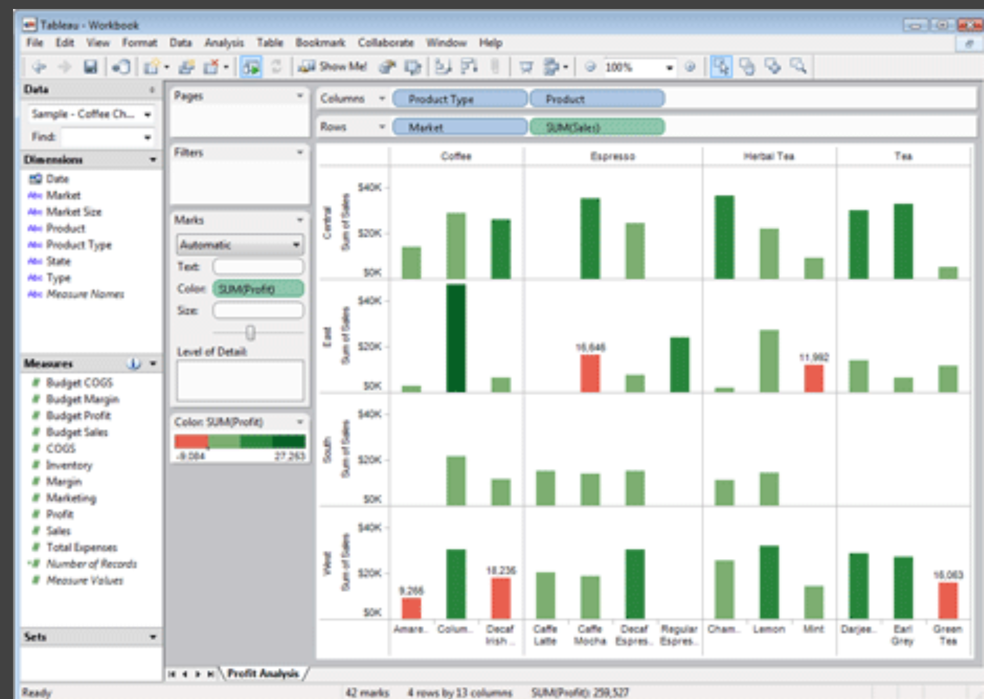
First steps:

Step 1: Pick domain & data

Step 2: Pose questions

Step 3: Profile the data

Iterate as needed



Create visualizations

Interact with data

Refine your questions

Author a report

Screenshots of most insightful views *(10+)*

Include titles and captions for each view

Due by 11:59pm

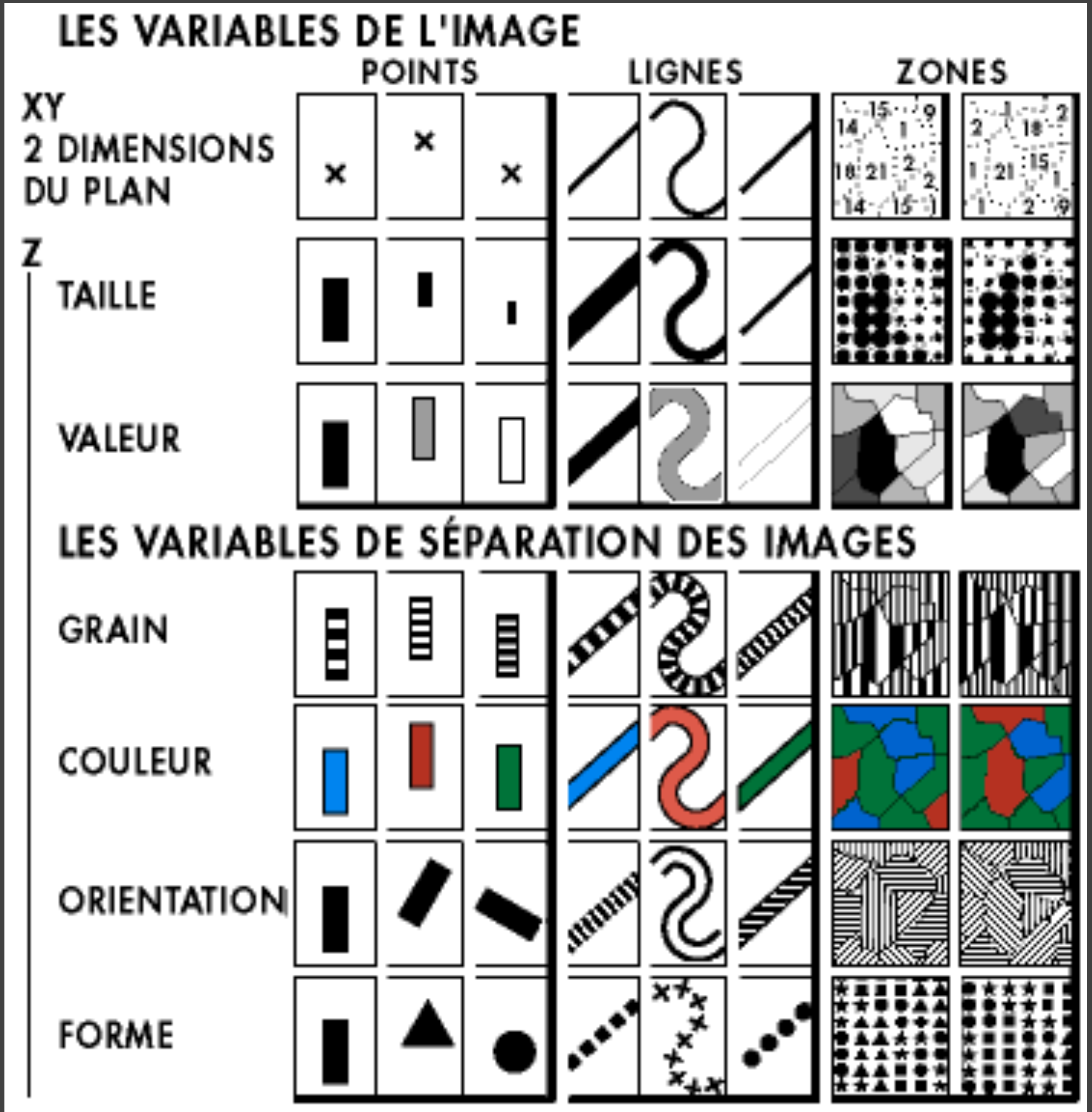
Monday, Oct 16

Multidimensional Data

Visual Encoding Variables

Position (X)
Position (Y)
Size
Value
Texture
Color
Orientation
Shape

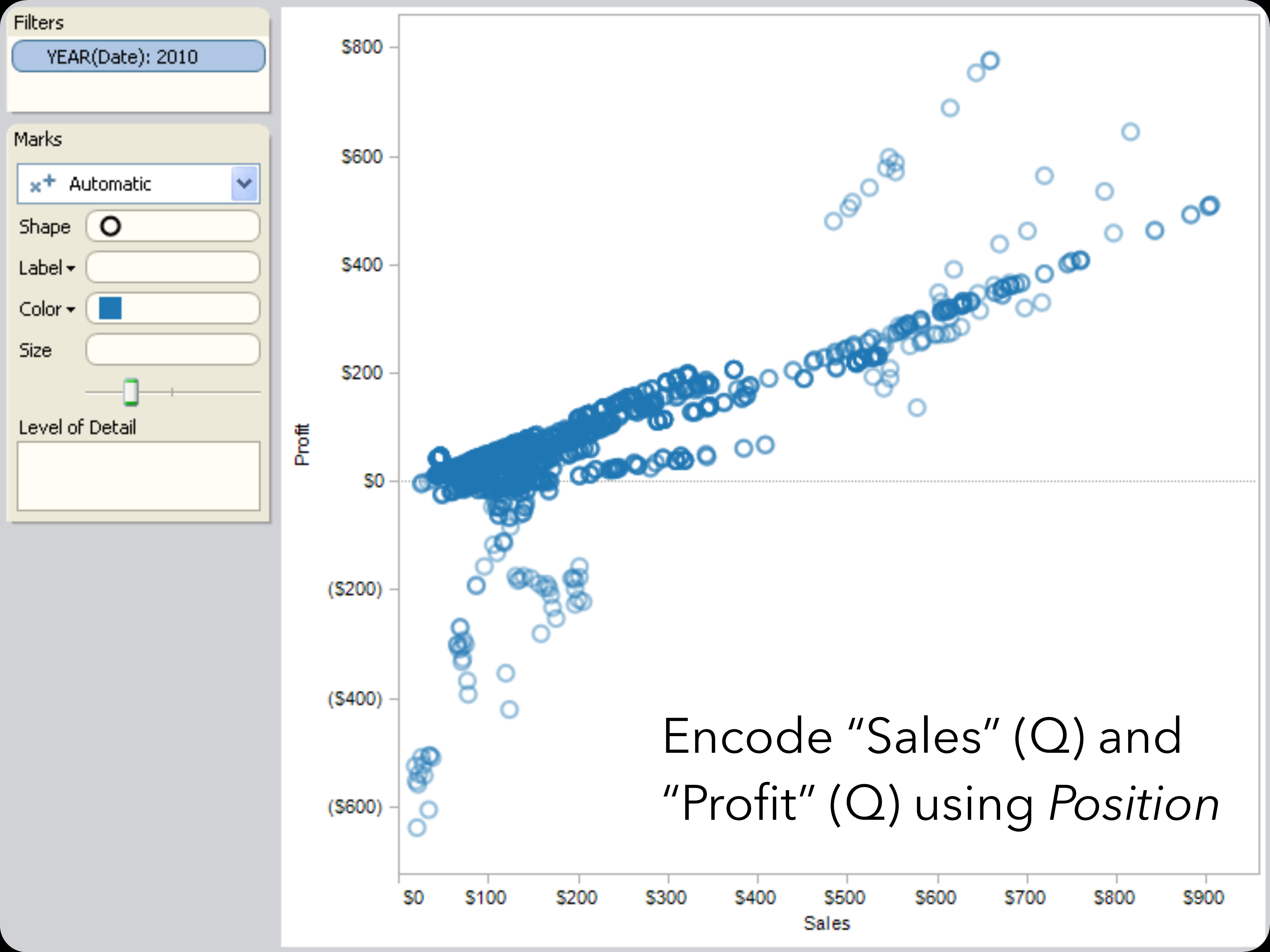
~8 dimensions?

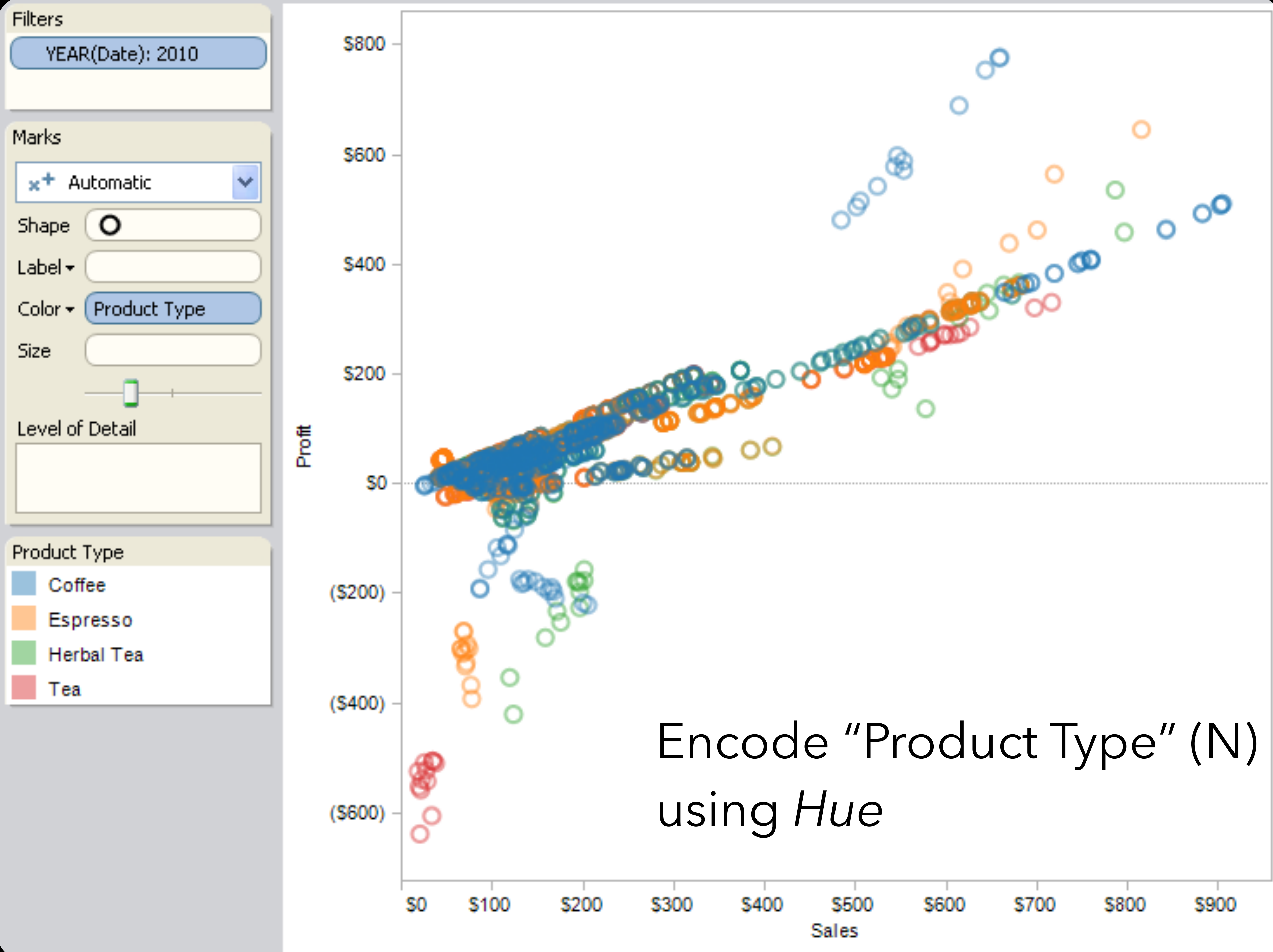


Example: Coffee Sales

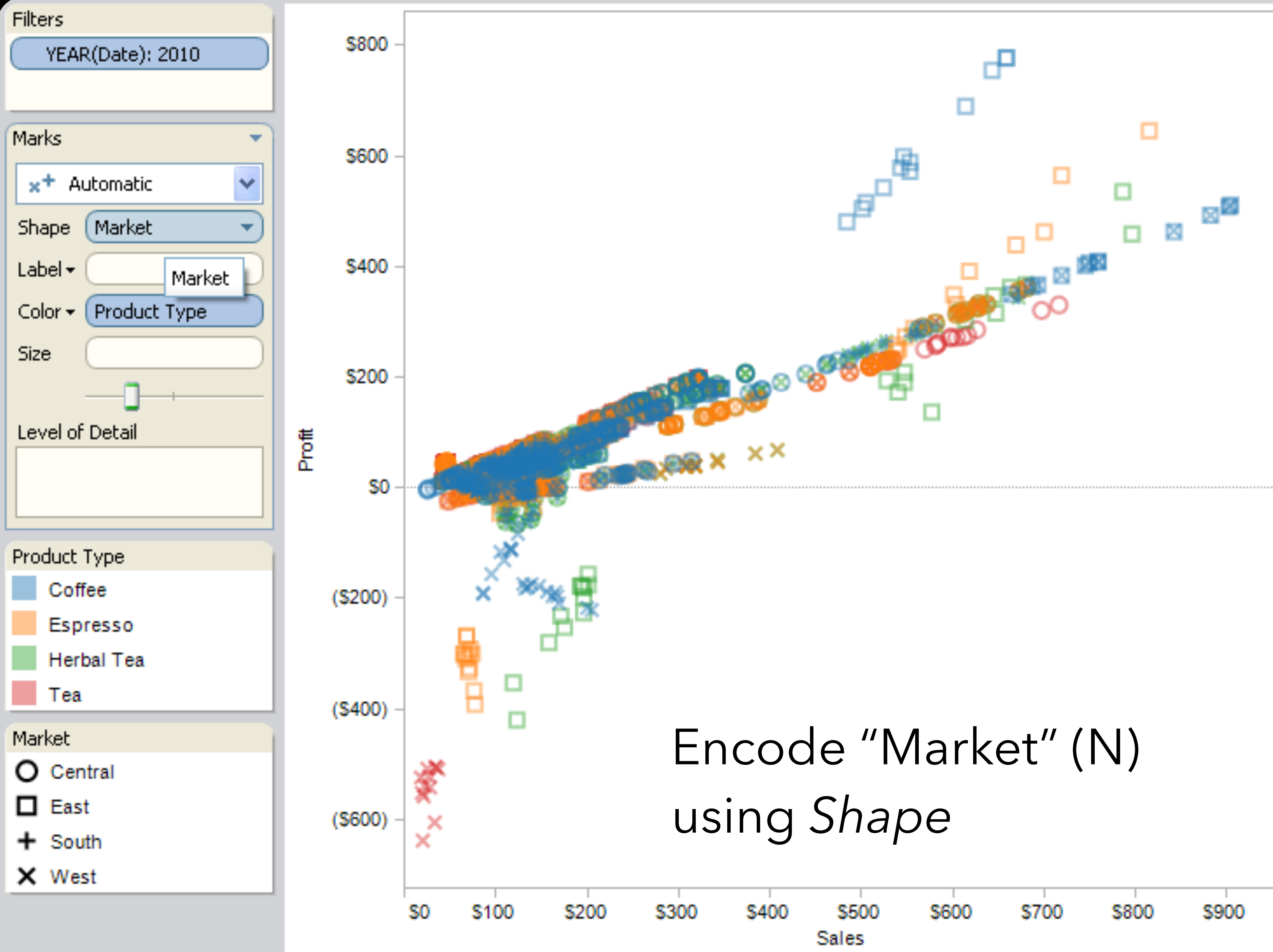
Sales figures for a fictional coffee chain

Sales	Q-Ratio
Profit	Q-Ratio
Marketing	Q-Ratio
Product Type	N {Coffee, Espresso, Herbal Tea, Tea}
Market	N {Central, East, South, West}

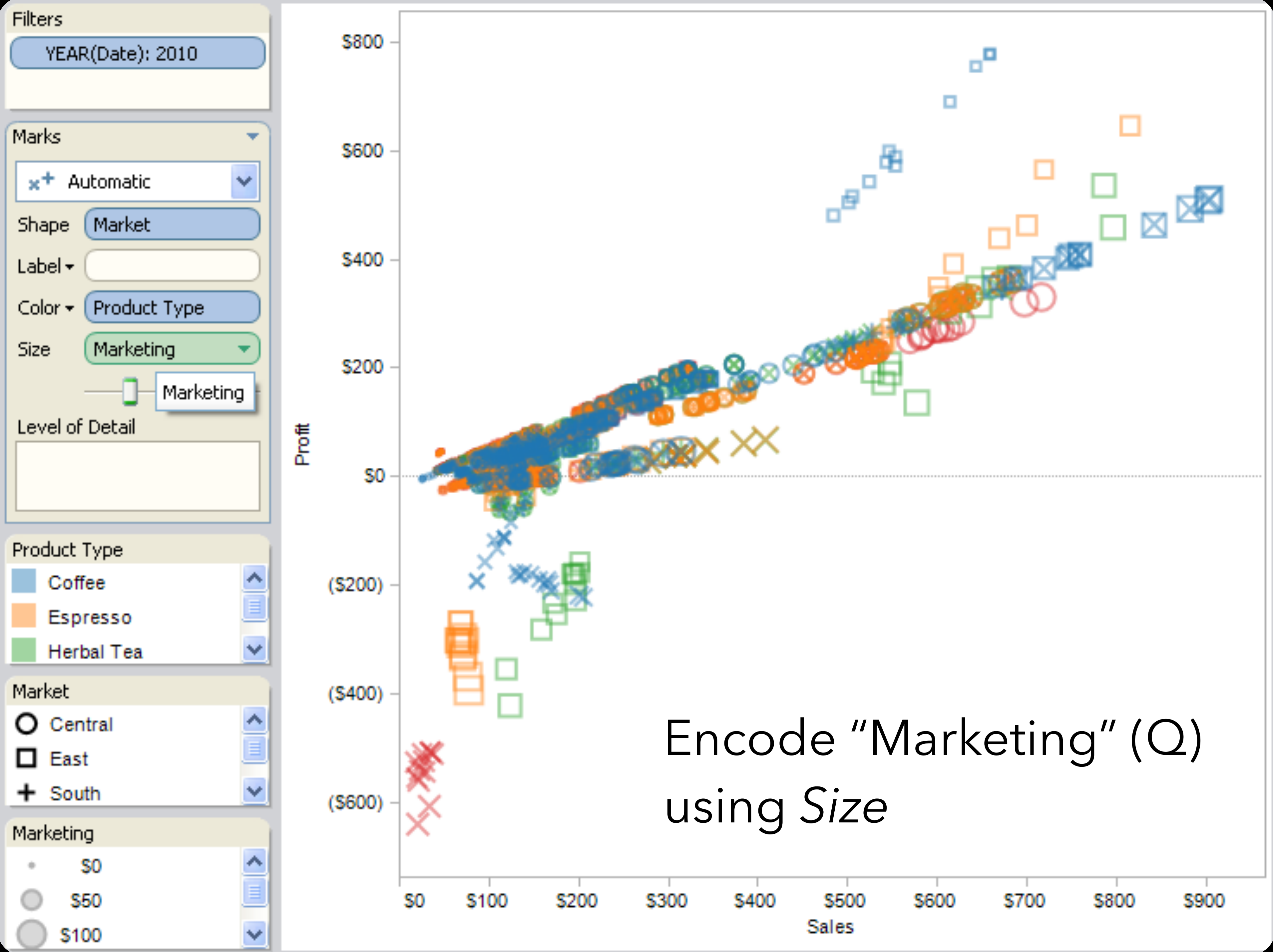

Filters
YEAR(Date): 2010
Marks
Automatic
Shape
Label
Color
Size
Level of Detail
$800
$600
$400
$200
$0
($200)
($400)
($600)
Profit
$0
$100
$200
$300
$400
$500
$600
$700
$800
$900
Sales
Encode "Sales" (Q) and "Profit" (Q) using *Position*



Encode "Product Type" (N) using *Hue*



Encode “Market” (N) using *Shape*



Encode “Marketing” (Q) using *Size*

Trellis Plots

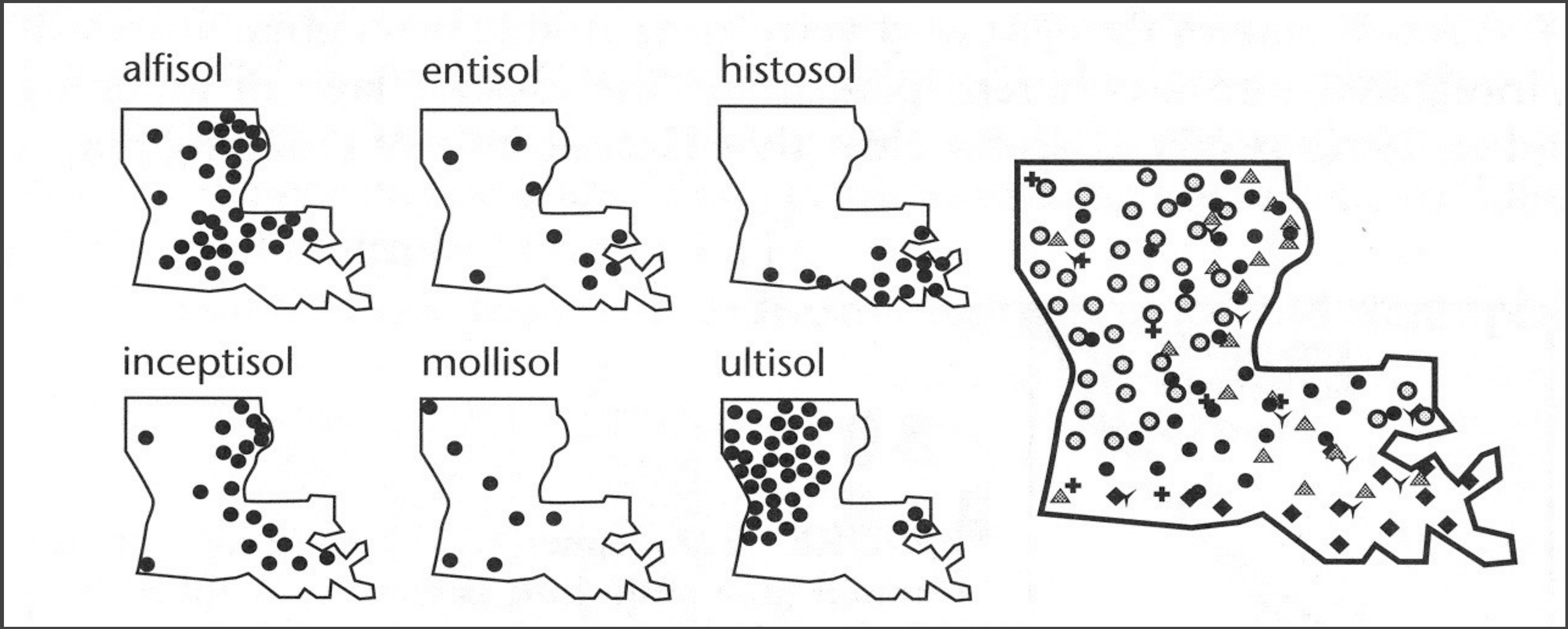
A *trellis plot* subdivides space to enable comparison across multiple plots.

Typically nominal or ordinal variables are used as dimensions for subdivision.

Small Multiples

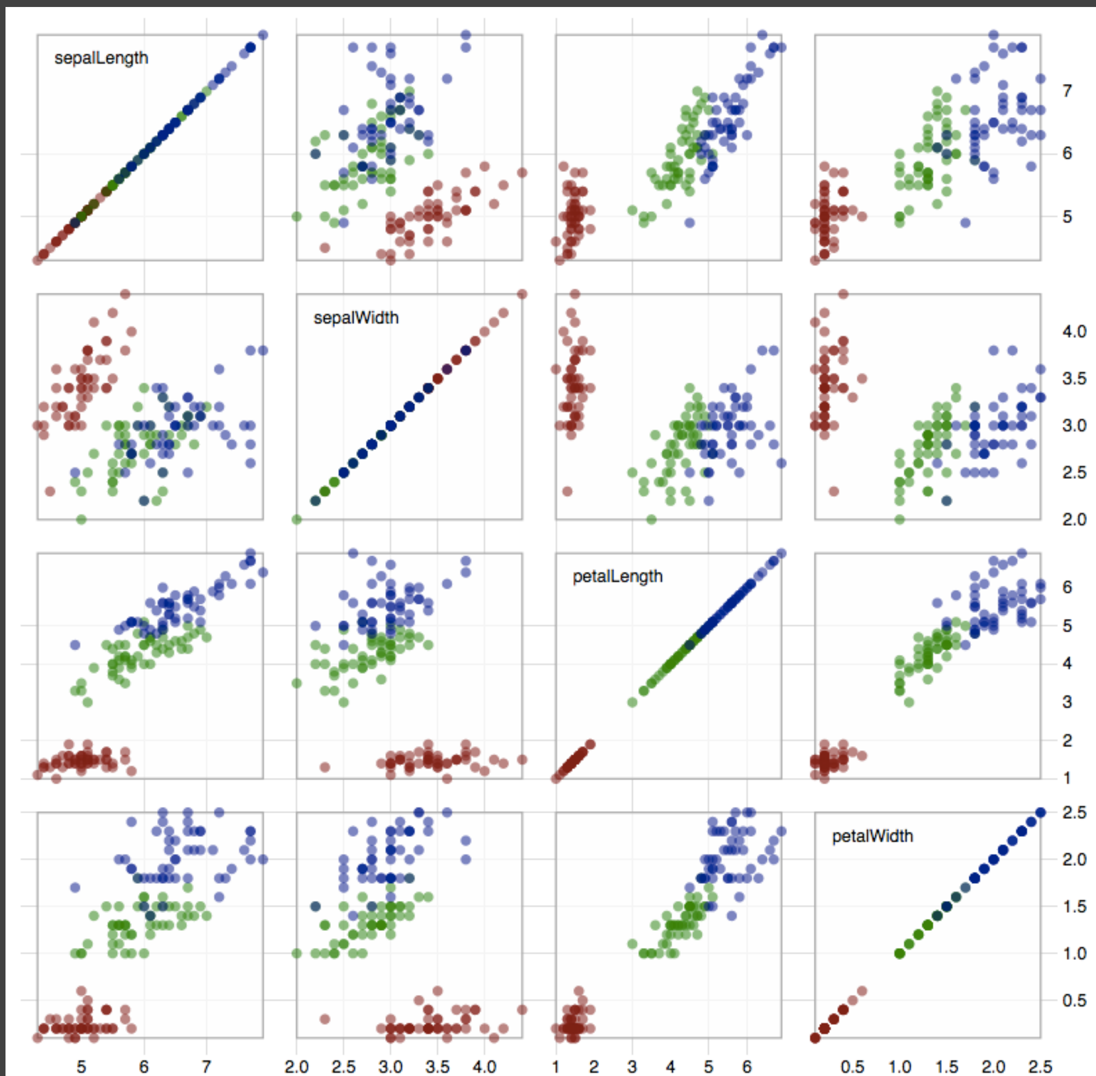
[MacEachren ’95, Figure 2.11, p. 38]

Small Multiples



[MacEachren '95, Figure 2.11, p. 38]

Scatterplot Matrix (SPLOM)



Scatter plots for pairwise comparison of each data dimension.

Multiple Coordinated Views

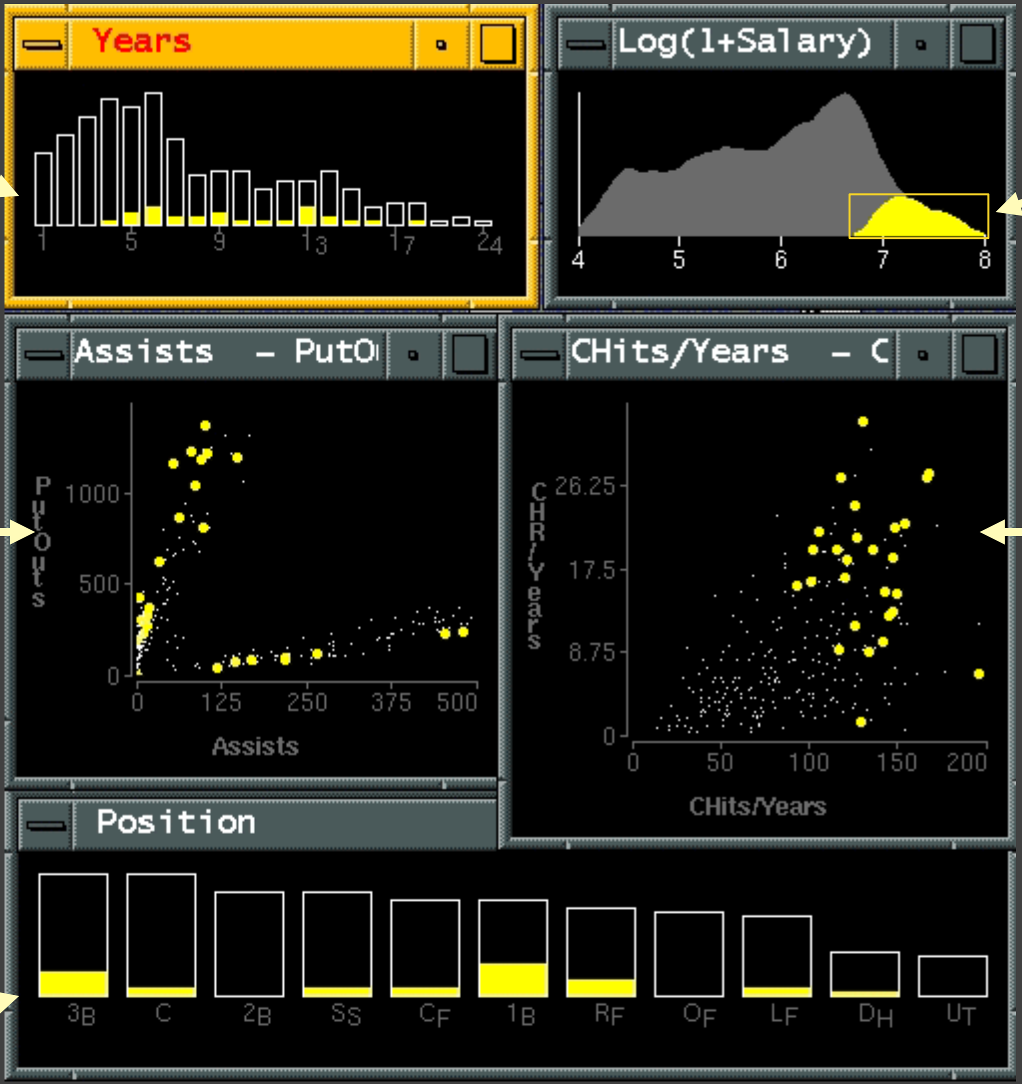
how long in majors

select high salaries

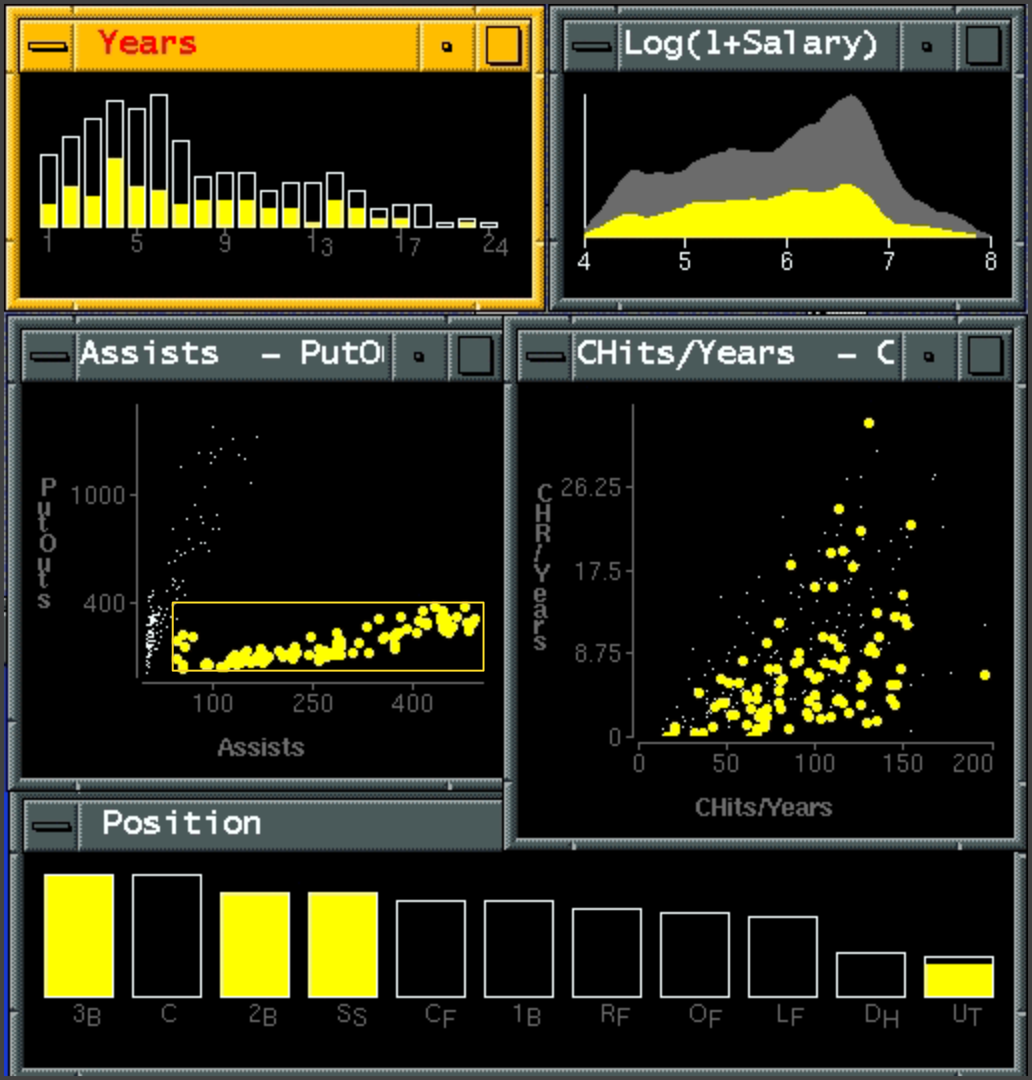
avg assists vs avg putouts (fielding ability)

avg career HRs vs avg career hits (batting ability)

distribution of positions played

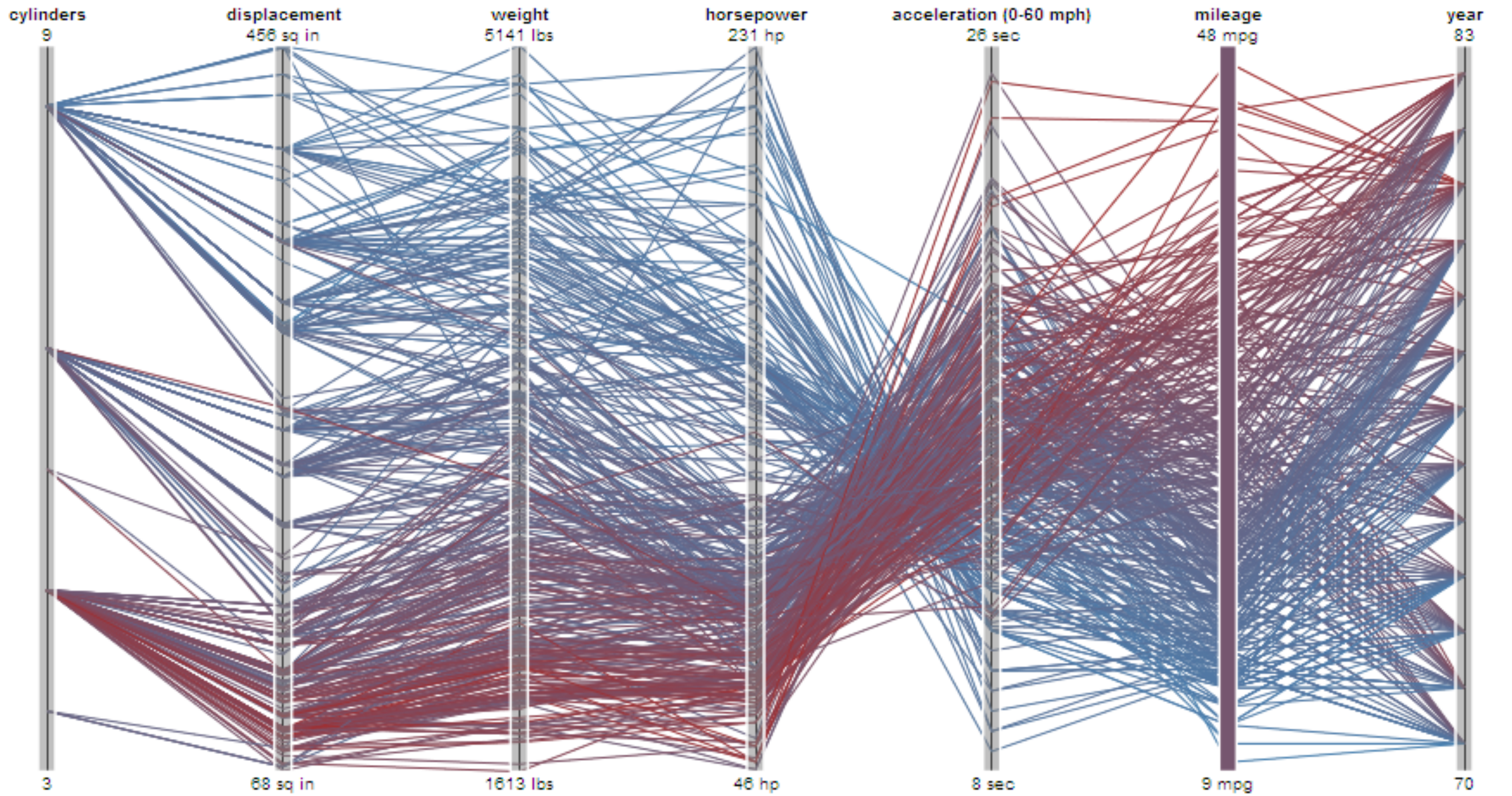


Linking Assists to Position



Parallel Coordinates

Parallel Coordinates [Inselberg]



Parallel Coordinates [Inselberg]

Visualize up to ~two dozen dimensions at once

1. Draw parallel axes for each variable
2. For each tuple, connect points on each axis

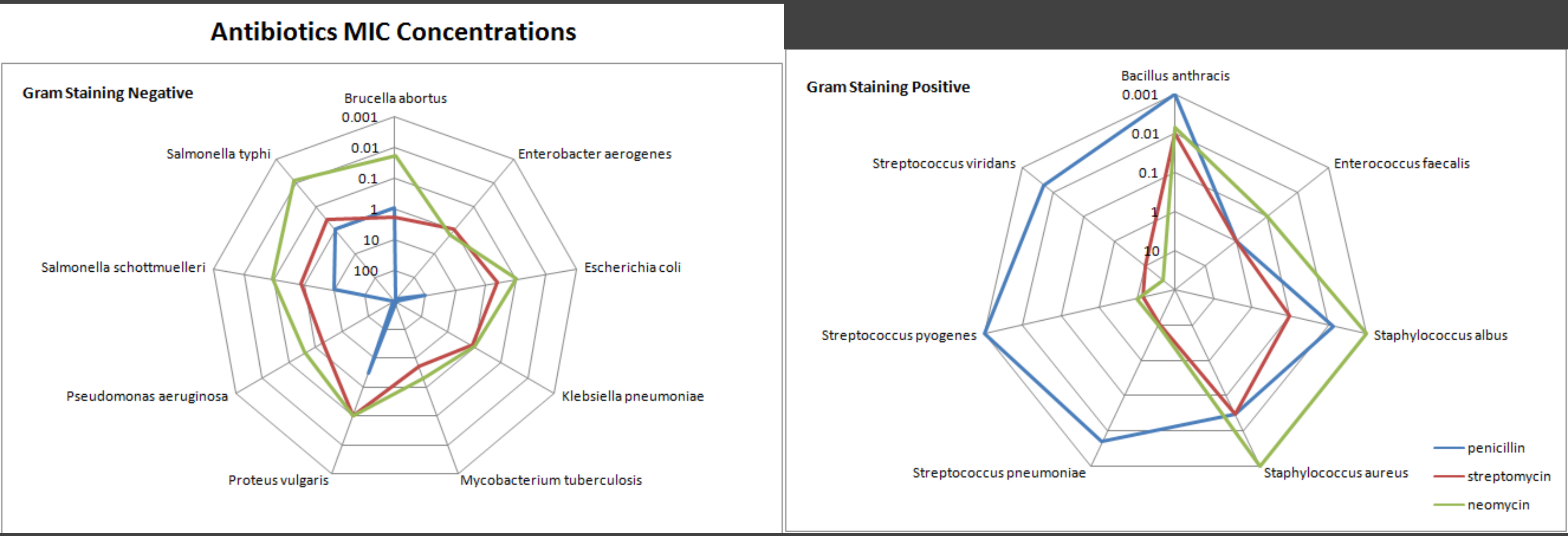
Between adjacent axes: line crossings imply neg. correlation, shared slopes imply pos. correlation.

Full plot can be cluttered. **Interactive selection** can be used to assess multivariate relationships.

Highly sensitive to axis **scale** and **ordering**.

Expertise required to use effectively!

Radar Plot / Star Graph

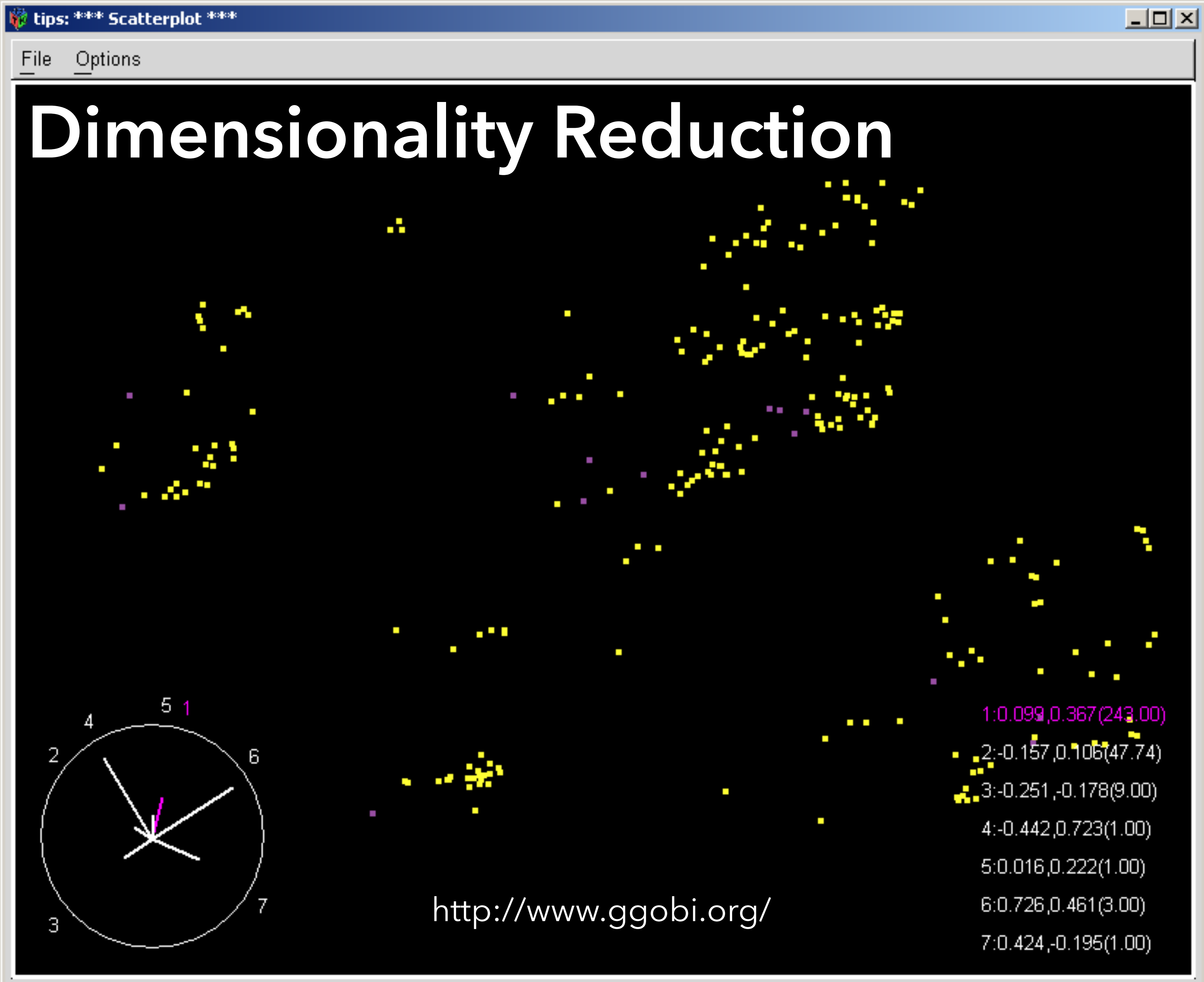


"Parallel" dimensions in polar coordinate space

Best if same units apply to each axis

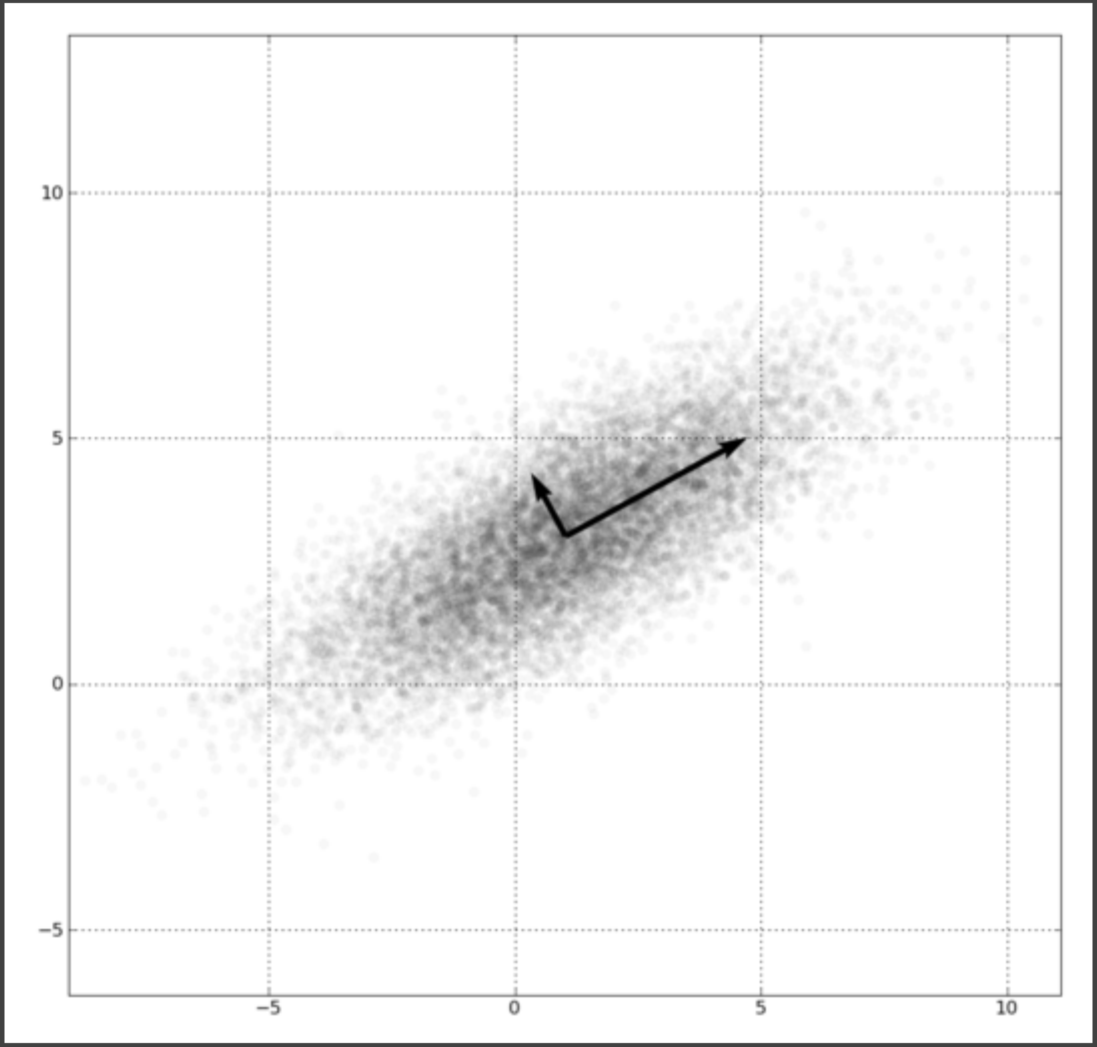
Dimensionality Reduction

Dimensionality Reduction



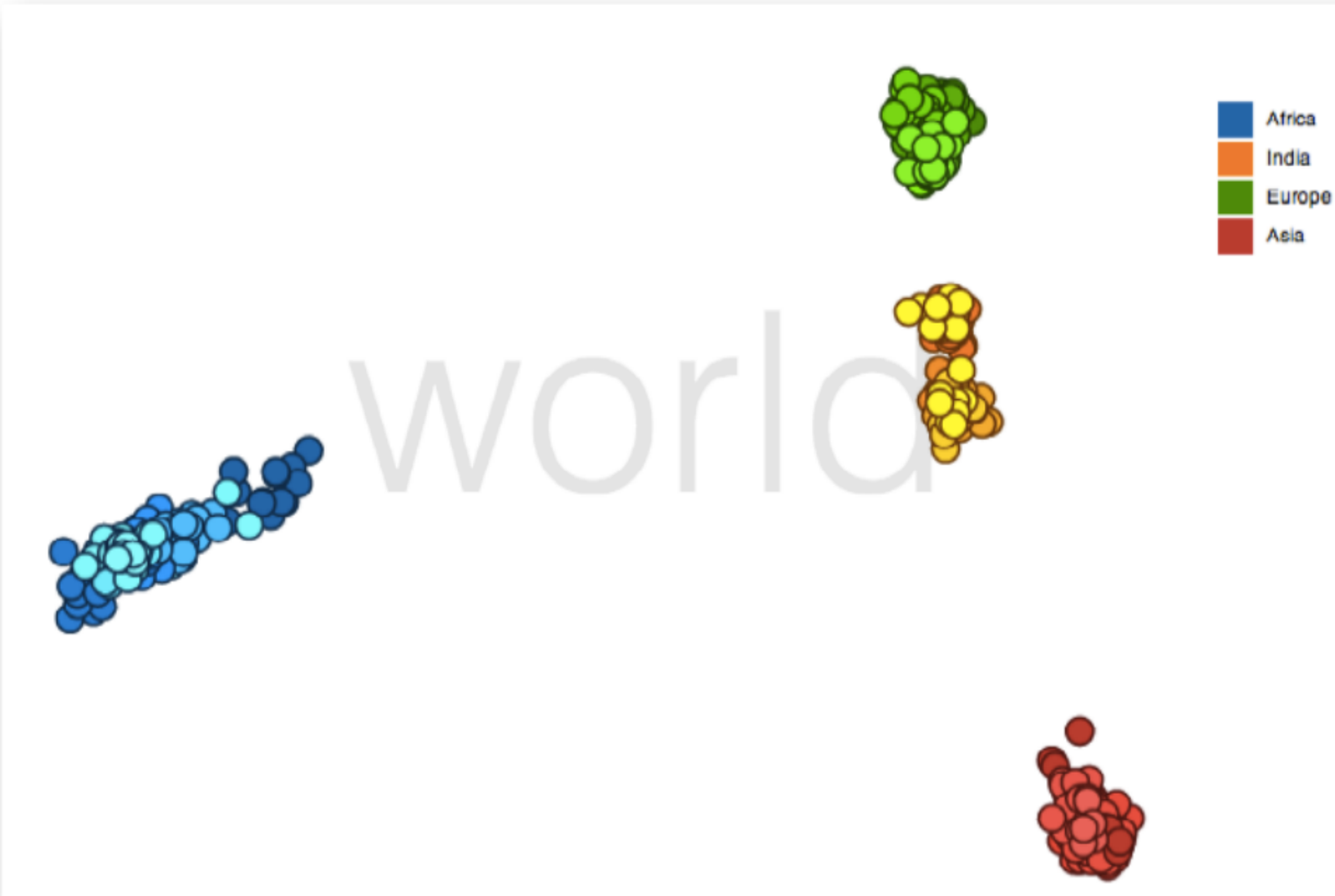
http://www.ggobi.org/

Principal Components Analysis

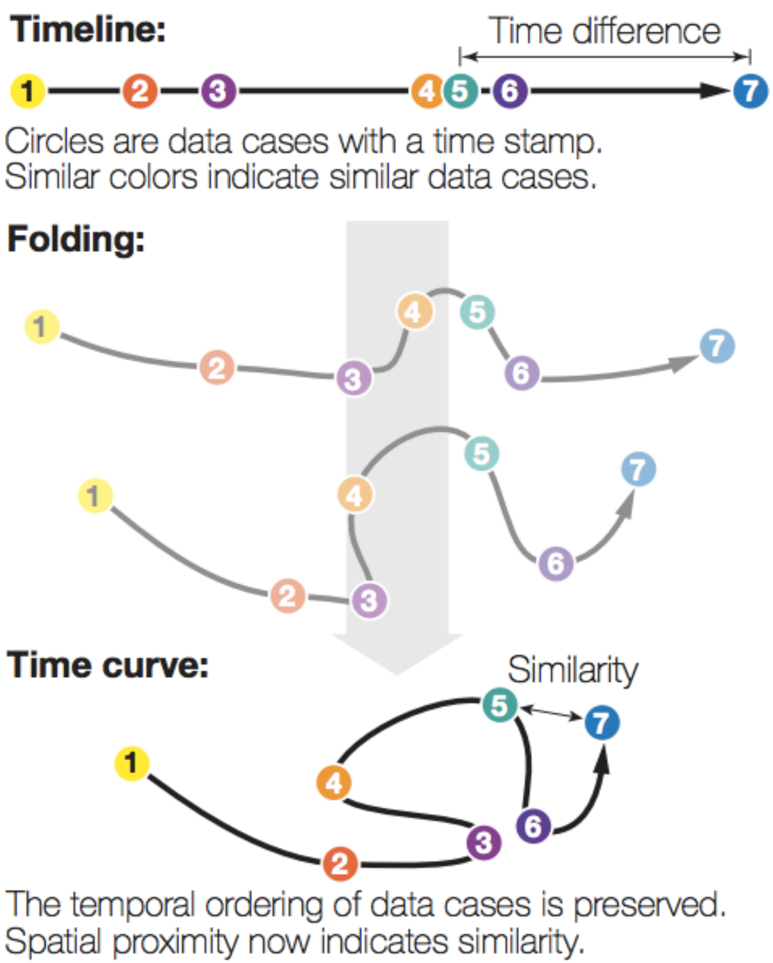


1. Mean-center the data.
2. Find ⊥ basis vectors that maximize the data variance.
3. Plot the data using the top vectors.

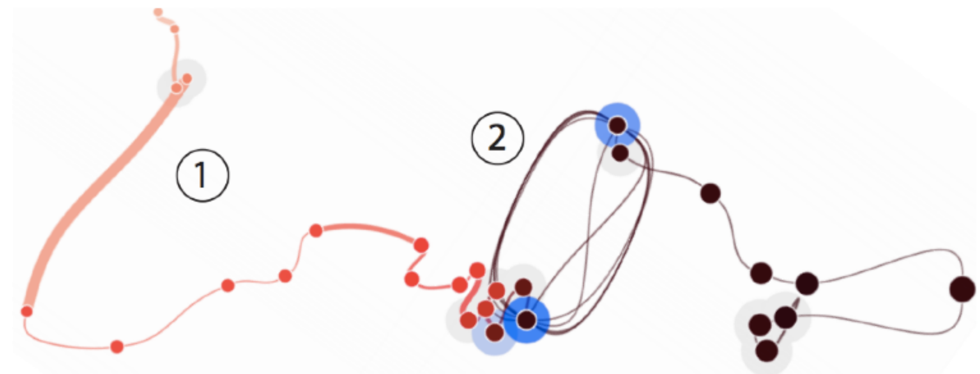
PCA of Genomes [Demiralp et al. '13]



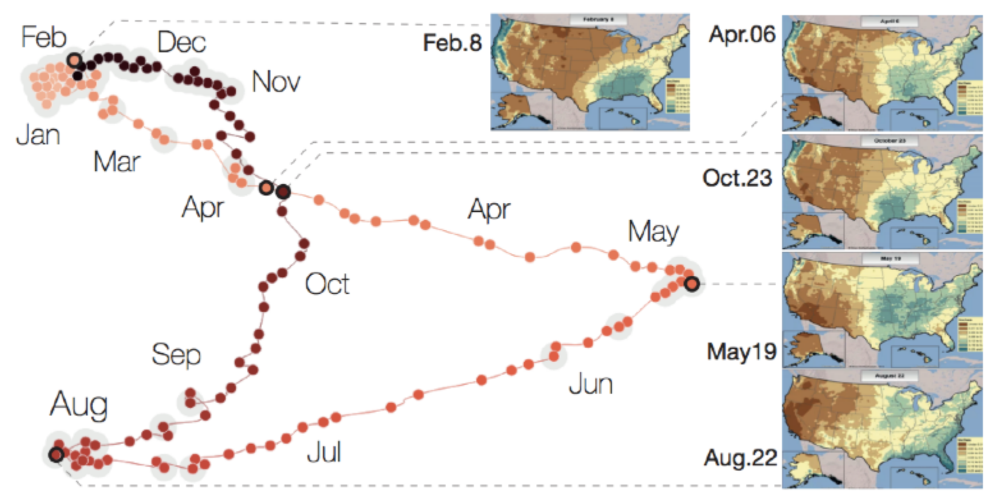
Time Curves [Bach et al. '16]



(a) Folding time



Wikipedia “Chocolate” Article



U.S. Precipitation over 1 Year

Many Reduction Techniques!

Principal Components Analysis (PCA)

Multidimensional Scaling (MDS)

Locally Linear Embedding (LLE)

t-Dist. Stochastic Neighbor Embedding (t-SNE)

Isomap

Auto-Encoder Neural Networks

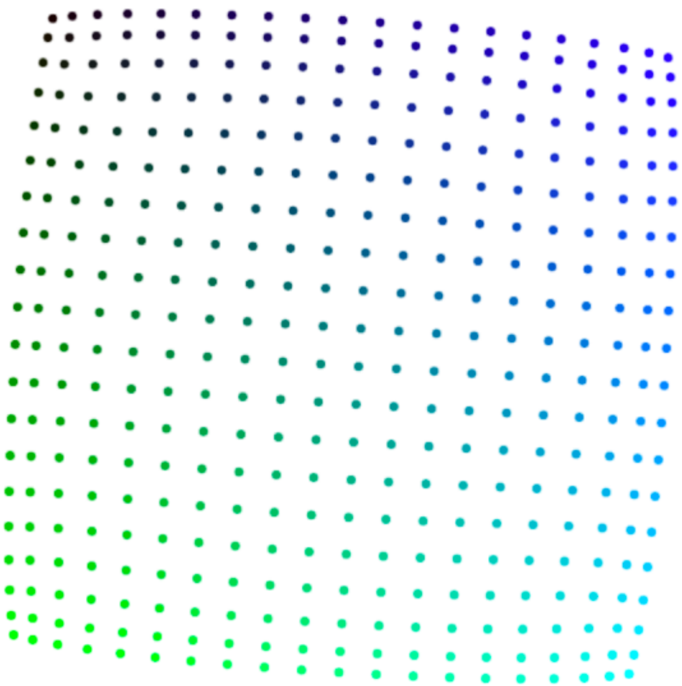
Topological Methods

…

Distill ABOUT PRIZE SUBMIT

How to Use t-SNE Effectively

Although extremely useful for visualizing high-dimensional data, t-SNE plots can sometimes be mysterious or misleading. By exploring how it behaves in simple cases, we can learn to use it more effectively.



Step 1,910

Points Per Side 20

Perplexity 10

Epsilon 5

A square grid with equal spacing between points. Try convergence at different sizes.

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Oct. 13 2016 | Citation: Wattenberg, et al., 2016

Visual Encoding Design

Use **expressive** and **effective** encodings
Avoid **over-encoding**
Reduce the problem space
Use **space** and **small multiples** intelligently
Use **interaction** to generate *relevant* views

Rarely does a single visualization answer all questions. Instead, the ability to generate appropriate visualizations quickly is critical!