Introduction to Data Visualization

Adopted from Slides for CSE 512 – Data Visualization,
University of Washington, by Jeffrey Heer

Data & Image Models

The Big Picture

task
questions, goals
assumptions

data
physical data type
conceptual data type

domain
metadata
semantics
conventions

processing
algorithms

mapping
visual encoding

image
visual channel
graphical marks

Topics

Properties of Data

Properties of Images

Mapping Data to Images

Data

Data Models / Conceptual Models

Data models are formal descriptions
Math: sets with operations on them
Example: integers with + and x operators

Conceptual models are mental constructions
Include semantics and support reasoning

Examples (data vs. conceptual)
1D floats vs. temperatures (Celcius, Fahenheit)
3D vector of floats vs. spatial location

Taxonomy of Data Types (?)

1D (sets and sequences)
Temporal
2D (maps)
3D (shapes)
nD (relational)
Trees (hierarchies)
Networks (graphs)

Are there others?

The eyes have it: A task by data type taxonomy for information visualization [Shneiderman 96]

Nominal, Ordinal & Quantitative

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N - Nominal (labels or categories)

- Fruits: apples, oranges, …

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O - Ordered

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-

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-

Q - Ratio (zero fixed)

- Physical measurement: Length, Mass, Temp, …
- Counts and amounts

Nominal, Ordinal & Quantitative

N - Nominal (labels or categories)

- Operations: =, ≠

O - Ordered

- Operations: =, ≠, <, >

Q - Interval (location of zero arbitrary)

- Operations: =, ≠, <, >, -
- Can measure distances or spans

Q - Ratio (zero fixed)

- Operations: =, ≠, <, >, -, %
- Can measure ratios or proportions

From Data Model to N, O, Q

Data Model

32.5, 54.0, -17.3, …

Floating point numbers

Conceptual Model

Temperature (°C)

Data Type

Burned vs. Not-Burned (N)

Hot, Warm, Cold (O)

Temperature Value (Q)

Dimensions & Measures

Dimensions (~ independent variables)
Discrete variables describing data (N, O)
Categories, dates, binned quantities

Measures (~ dependent variables)
Data values that can be aggregated (Q)
Numbers to be analyzed
Aggregate as sum, count, avg, std. dev…

Example: U.S. Census Data

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People Count: # of people in group
Year: 1850 – 2000 (every decade)
Age: 0 – 90+
Sex: Male, Female
Marital Status: Single, Married, Divorced, …

Example: U.S. Census

People Count
Year
Age
Sex
Marital Status

2,348 data points

	A	B	C	D	E
1	year	age	marst	sex	people
2	1850	0	0	1	1483789
3	1850	0	0	2	1450376
4	1850	5	0	1	1411067
5	1850	5	0	2	1359668
6	1850	10	0	1	1260099
7	1850	10	0	2	1216114
8	1850	15	0	1	1077133
9	1850	15	0	2	1110619
10	1850	20	0	1	1017281
11	1850	20	0	2	1003841
12	1850	25	0	1	862547
13	1850	25	0	2	799482
14	1850	30	0	1	730638
15	1850	30	0	2	639636
16	1850	35	0	1	588487
17	1850	35	0	2	505012
18	1850	40	0	1	475911
19	1850	40	0	2	428185
20	1850	45	0	1	384211
21	1850	45	0	2	341254
22	1850	50	0	1	321343
23	1850	50	0	2	286580
24	1850	55	0	1	194080
25	1850	55	0	2	187208
26	1850	60	0	1	174976
27	1850	60	0	2	162236
28	1850	65	0	1	106827
29	1850	65	0	2	105534
30	1850	70	0	1	73677
31	1850	70	0	2	71762
32	1850	75	0	1	40834
33	1850	75	0	2	40229
34	1850	80	0	1	23449
35	1850	80	0	2	22949
36	1850	85	0	1	8186
37	1850	85	0	2	10511
38	1850	90	0	1	5259
39	1850	90	0	2	6569
40	1860	0	0	1	2120846
41	1860	0	0	2	2092162

Census: N, O, Q?

People Count	Q-Ratio
Year	Q-Interval *(O)*
Age	Q-Ratio *(O)*
Sex	N
Marital Status	N

Census: Dimension or Measure?

People Count	Measure
Year	Dimension
Age	Depends!
Sex	Dimension
Marital Status	Dimension

Data Transformation

Relational Data Model

Represent data as a **table** (*relation*)

Each **row** (*tuple*) represents a record

- Each record is a fixed-length tuple

Each **column** (*attribute*) represents a variable

- Each attribute has a *name* and a *data type*

A table's **schema** is the set of names and types

A **database** is a collection of tables (relations)

Relational Algebra [Codd '70]

Data Transformations (`sql`)

Projection (`select`) - selects columns

Selection (`where`) - filters rows

Sorting (`order by`)

Aggregation (`group by`, `sum`, `min`, `max`, …)

Combine relations (`union`, `join`, …)

Roll-Up and Drill-Down

Want to examine marital status in each decade?

Roll-up the data along the desired dimensions

$$\text{SELECT } \overbrace{\text{year, marst,}}^{\textbf{Dimensions}}\ \overbrace{\text{sum(people)}}^{\textbf{Measure}}$$

$$\text{FROM census}$$

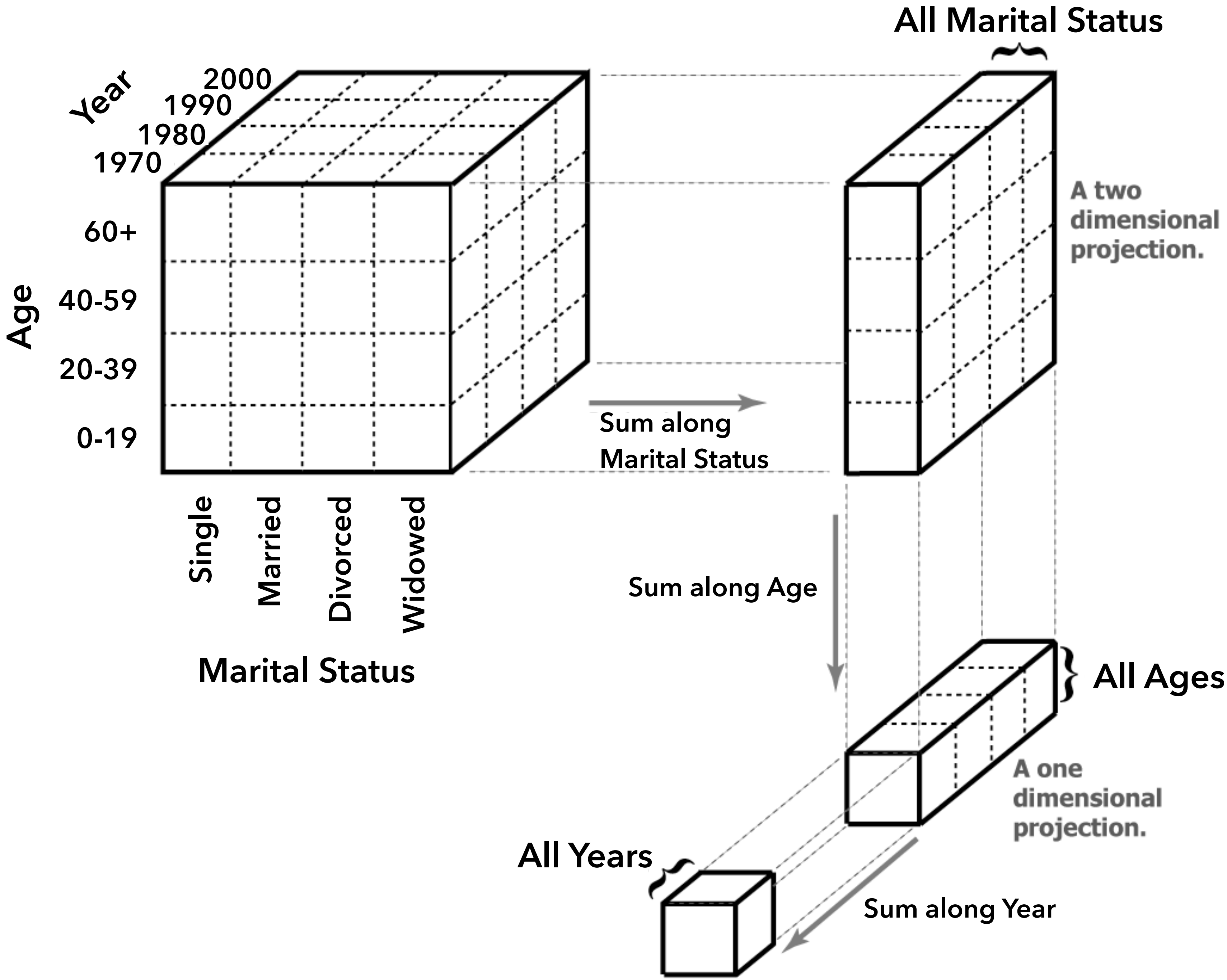
$$\text{GROUP BY } \underbrace{\text{year, marst;}}_{\textbf{Dimensions}}$$

Roll-Up and Drill-Down

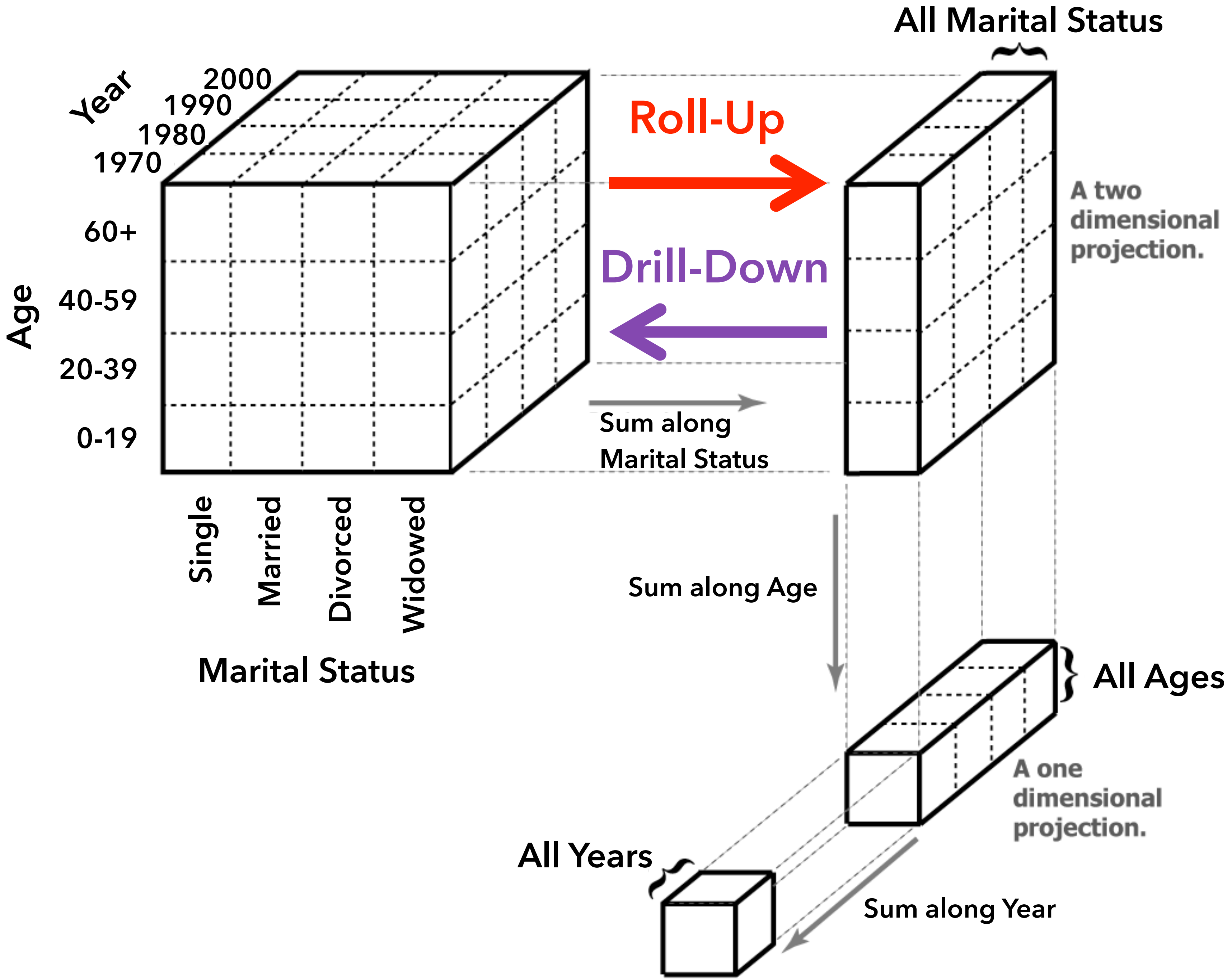
Need more detailed information?

Drill-down into additional dimensions

```
SELECT year, age, marst, sum(people)
FROM census
GROUP BY year, age, marst;
```



All Marital Status
Year
2000
1990
1980
1970
Age
60+
40-59
20-39
0-19
Single
Married
Divorced
Widowed
Marital Status
Sum along Marital Status
A two dimensional projection.
Sum along Age
All Ages
A one dimensional projection.
All Years
Sum along Year


All Marital Status
Year
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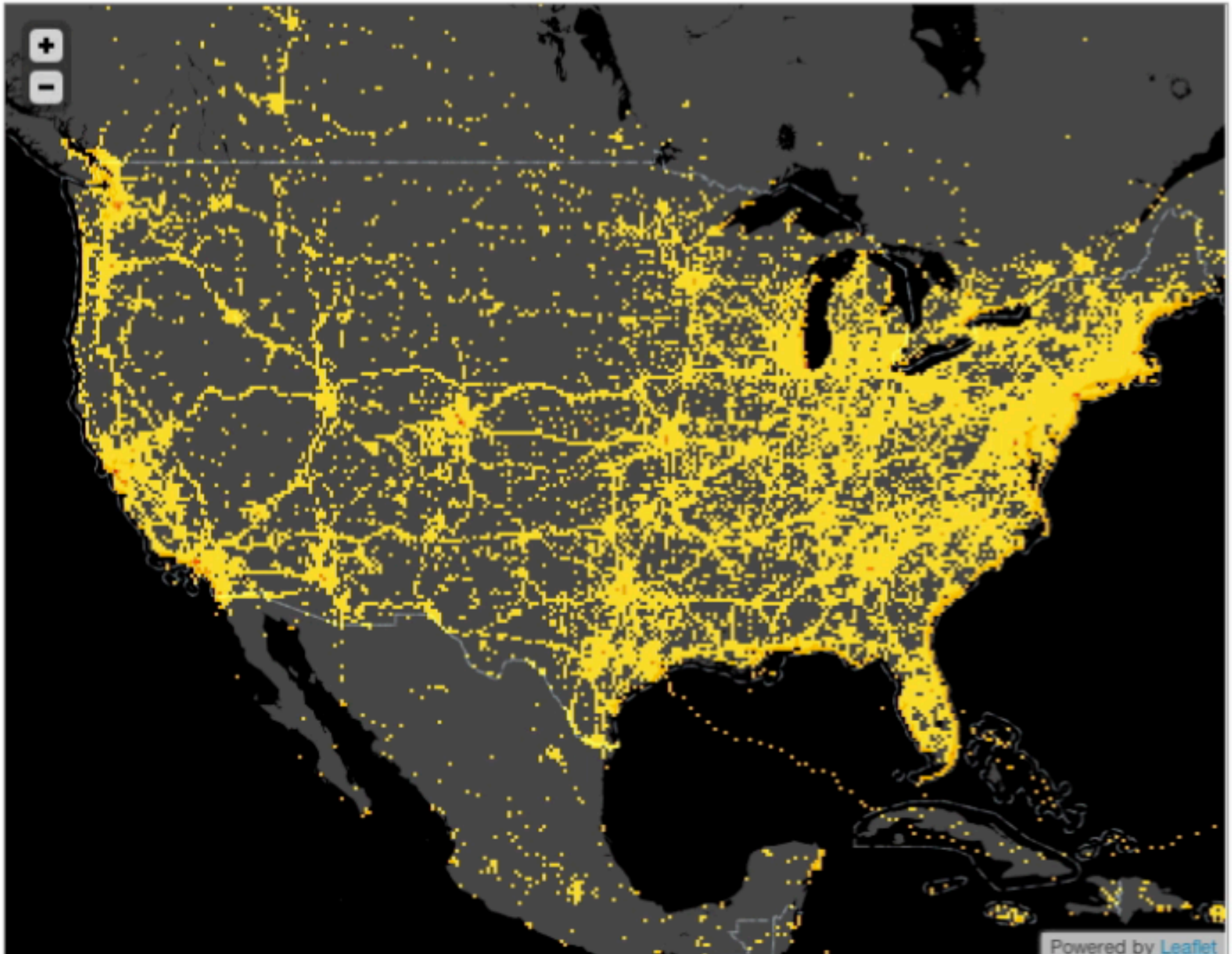
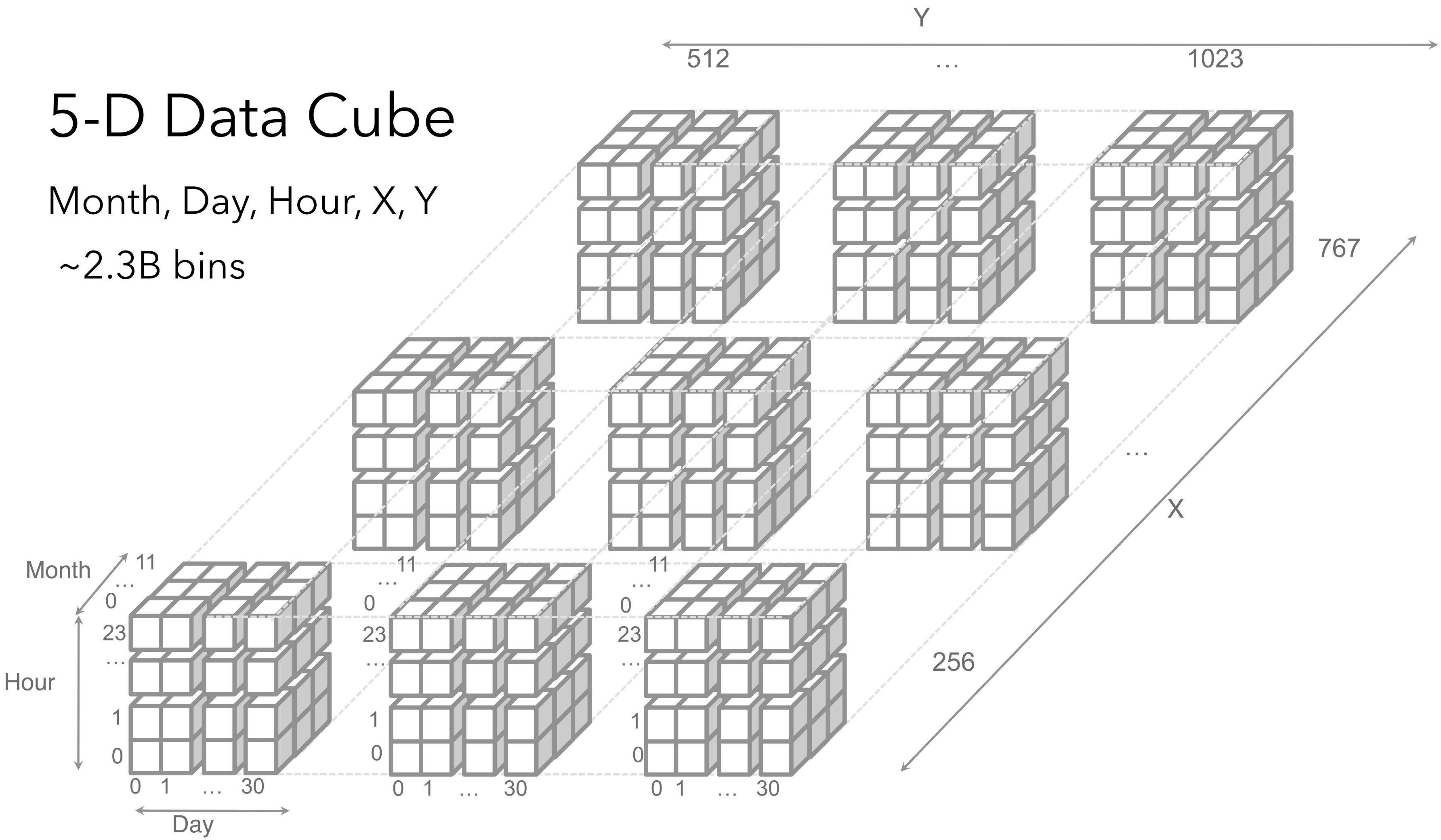

Powered by Leaflet

5-D Data Cube

Month, Day, Hour, X, Y

~2.3B bins



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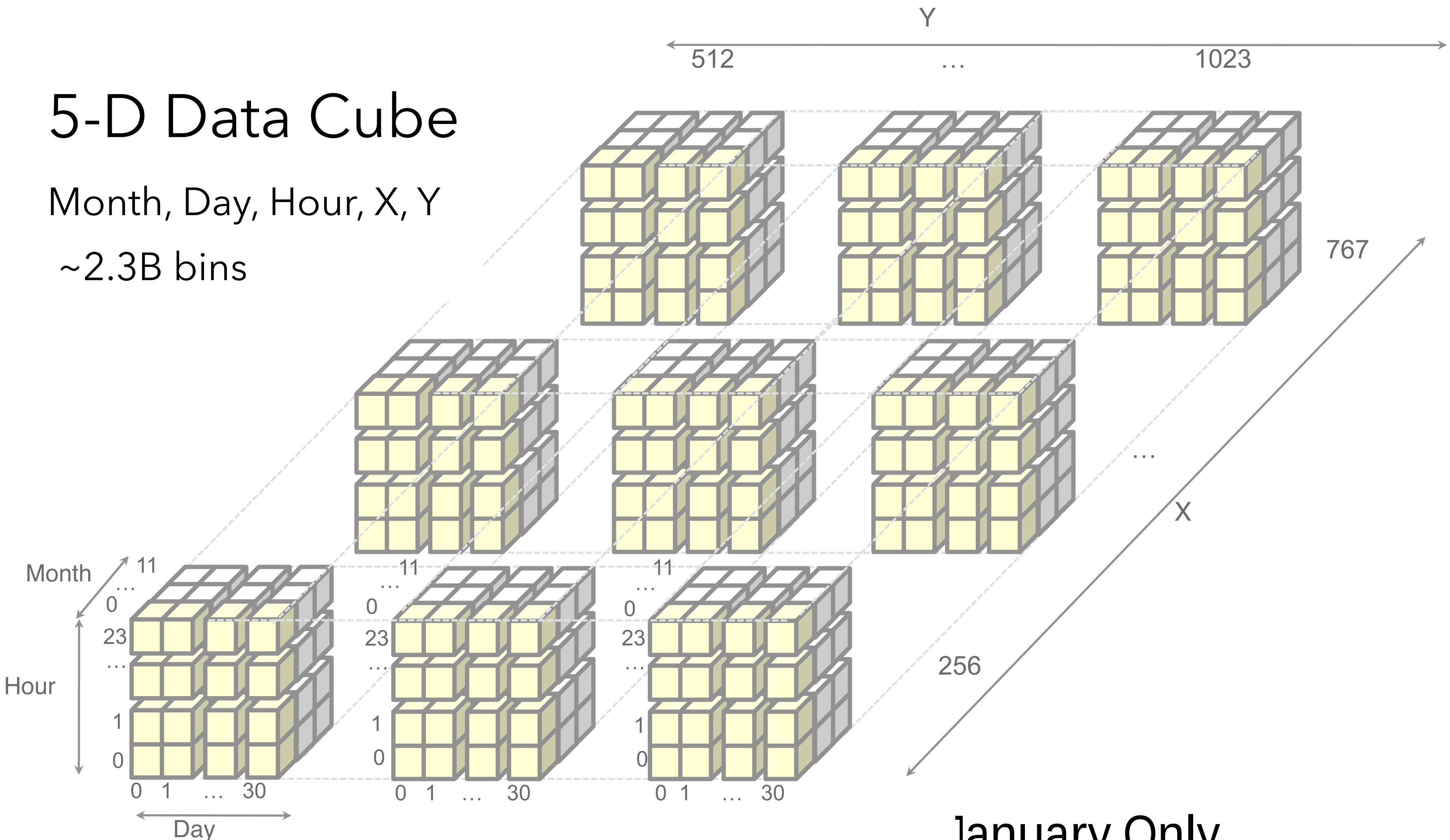
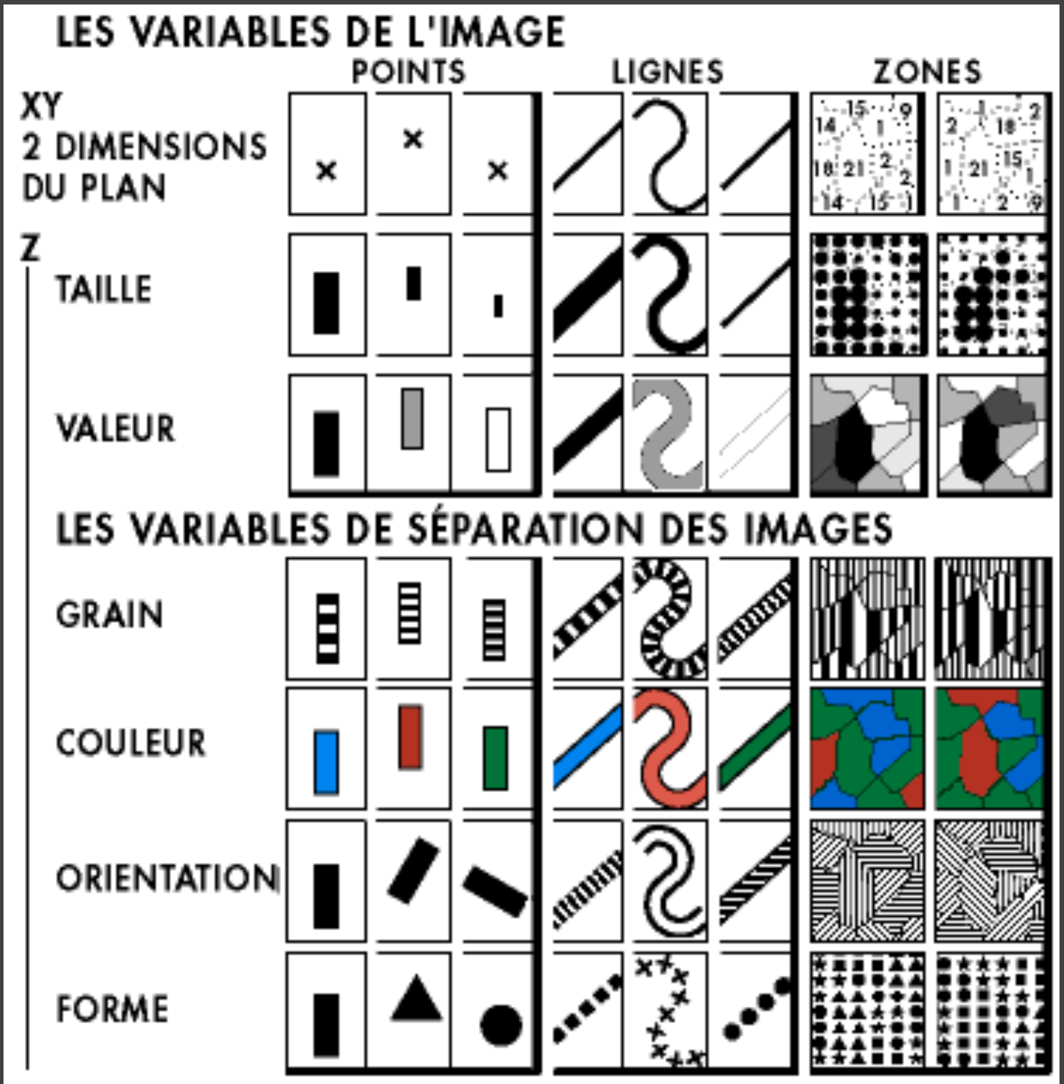


January Only

Visual Encoding Variables

Position (x 2)
Size
Value
Texture
Color
Orientation
Shape

Others?



Bertin's "Levels of Organization"

Position	N	O	Q
Size	N	O	Q
Value	N	O	Q
Texture	N	O	
Color	N		
Orientation	N		
Shape	N		

Nominal

Ordinal

Quantitative

Note: **Q** $\subset$ **O** $\subset$ **N**

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]

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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

Design Considerations

Title, labels, legend, captions, source!

Expressiveness and Effectiveness
Avoid unexpressive marks (lines? gradients?)
Use perceptually effective encodings
Don’t distract: faint gridlines, pastel highlights/fills
The “elimination diet” approach – start minimal

Support comparison and pattern perception
Between elements, to a reference line, or to totals

Design Considerations

Transform data (e.g., invert, log, normalize)
Are model choices (regression lines) appropriate?

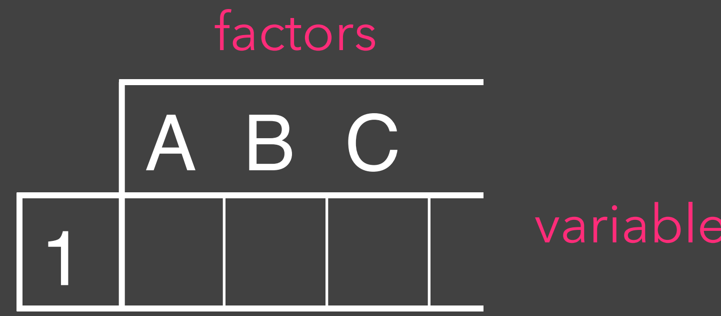
Group / sort data by meaningful dimensions

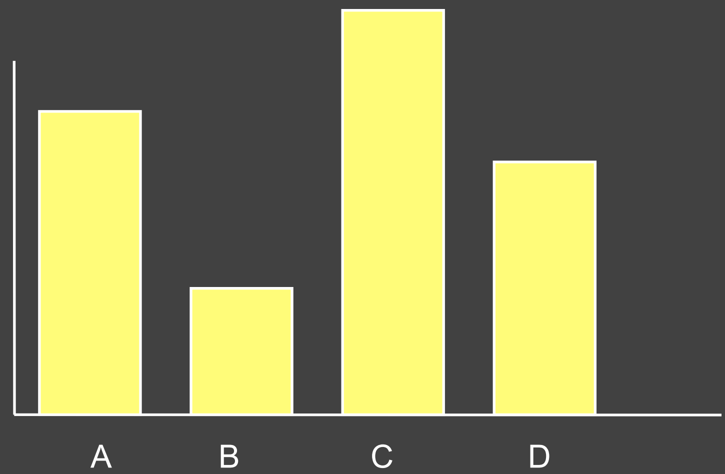
Reduce cognitive overhead
Minimize visual search, minimize ambiguity
Avoid legend lookups if direct labeling works
Avoid color mappings with indiscernible colors

Be consistent! Visual inferences should consistently support data inferences.

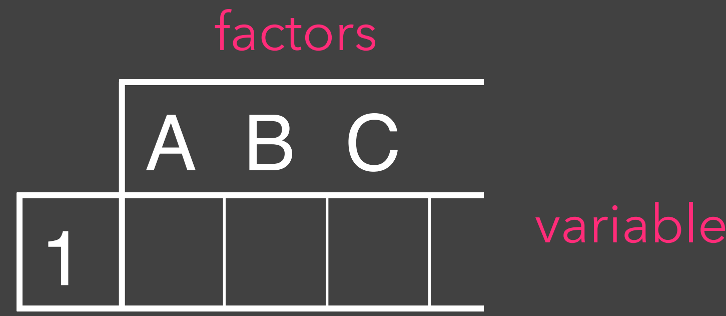
The Design Space of Visual Encodings

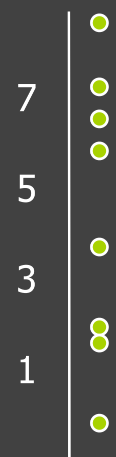
Univariate Data

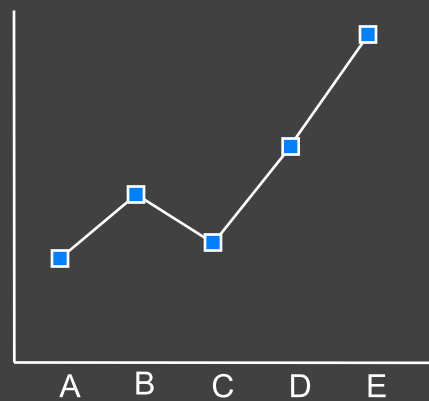


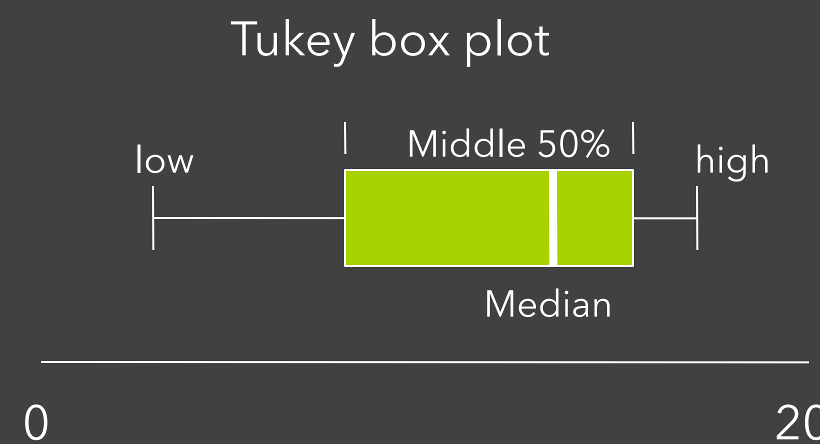


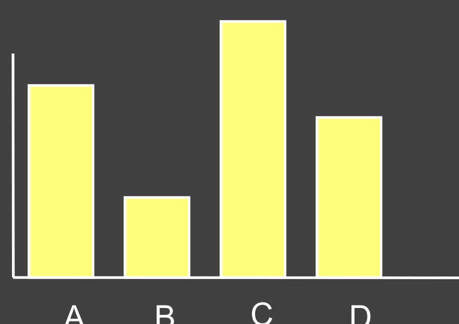
Univariate Data





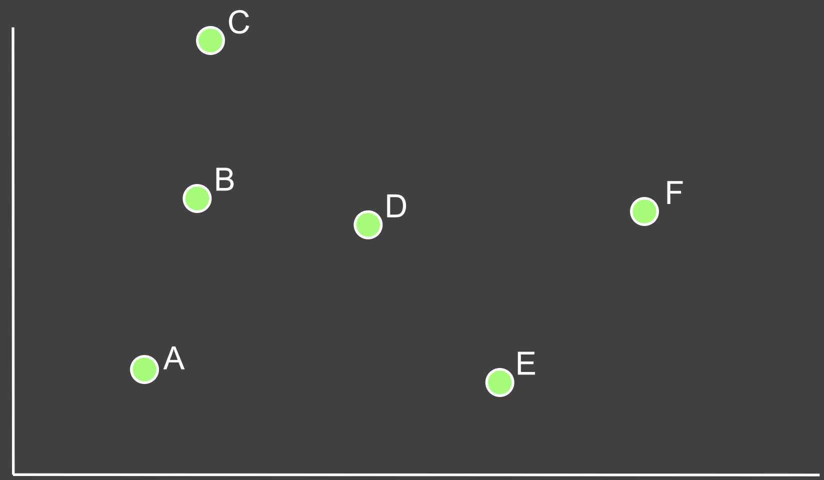






Bivariate Data

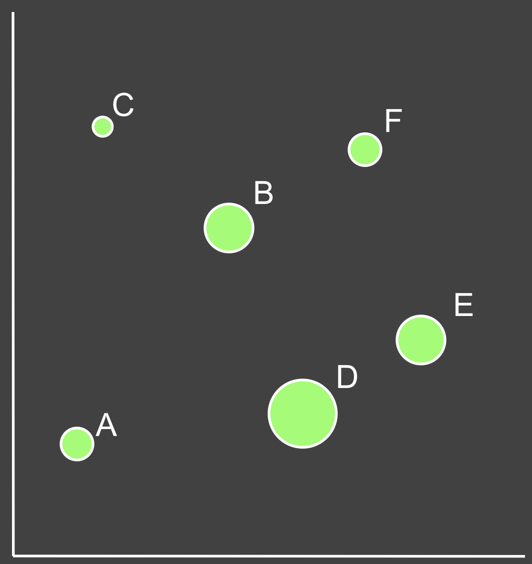
	A	B	C	
1				
2				



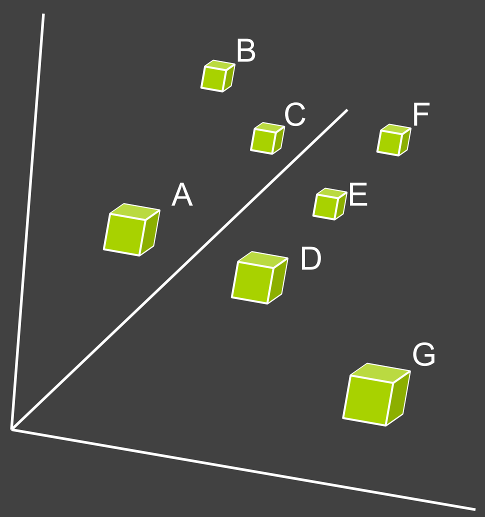
Scatter plot is common

Trivariate Data

	A	B	C
1			
2			
3			



3D scatter plot is possible

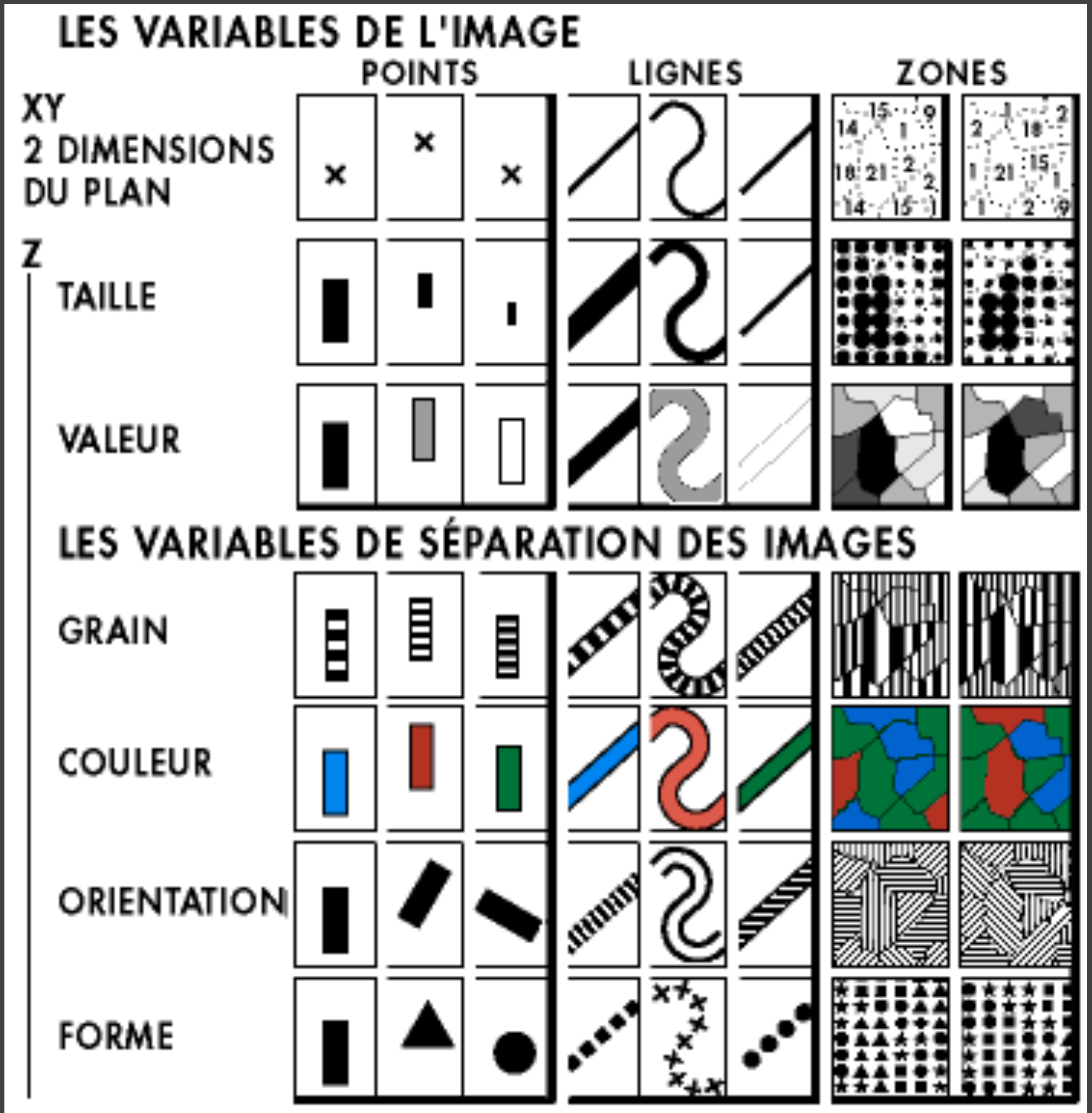


Multidimensional Data

Visual Encoding Variables

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

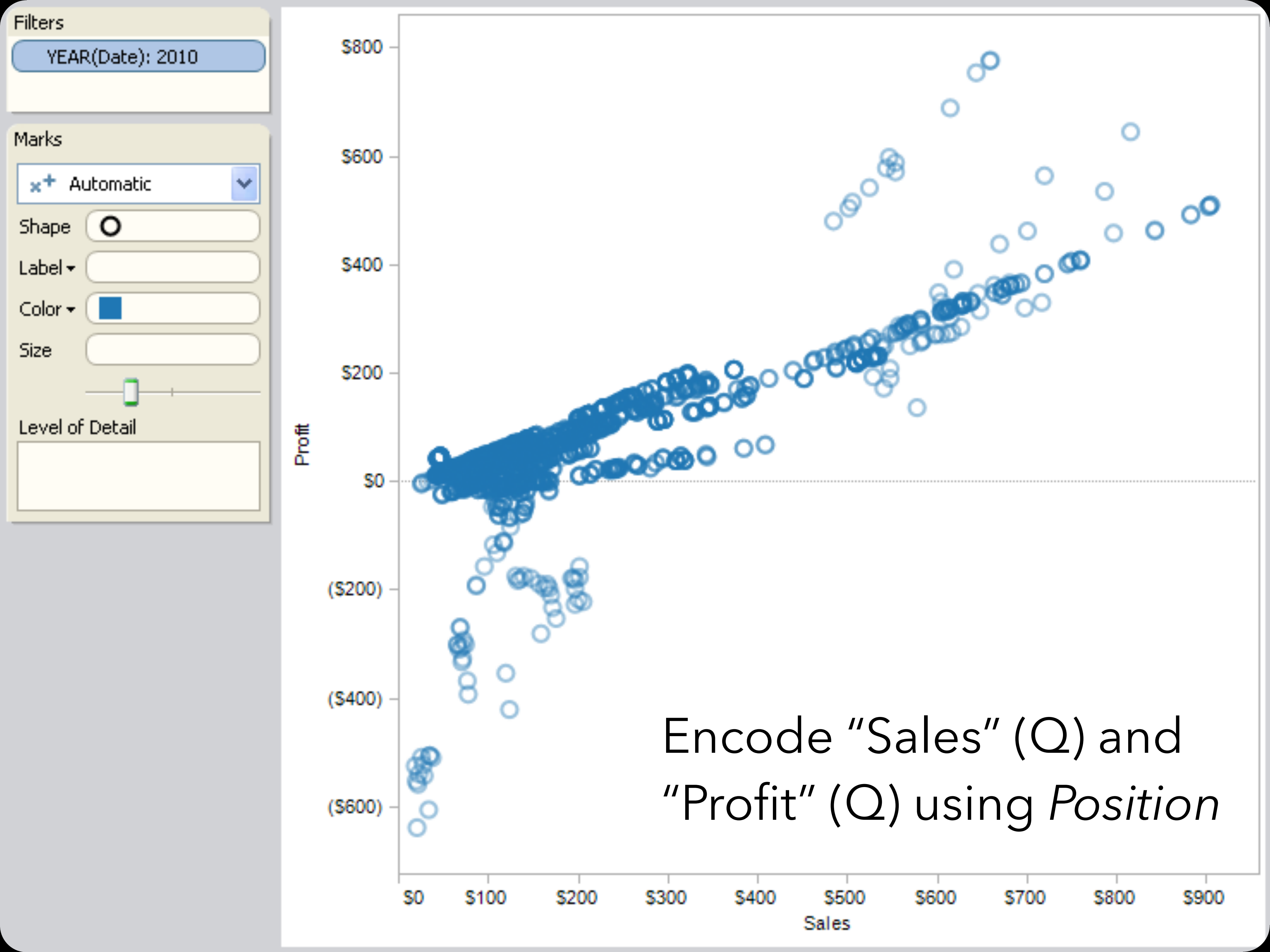
~8 dimensions?



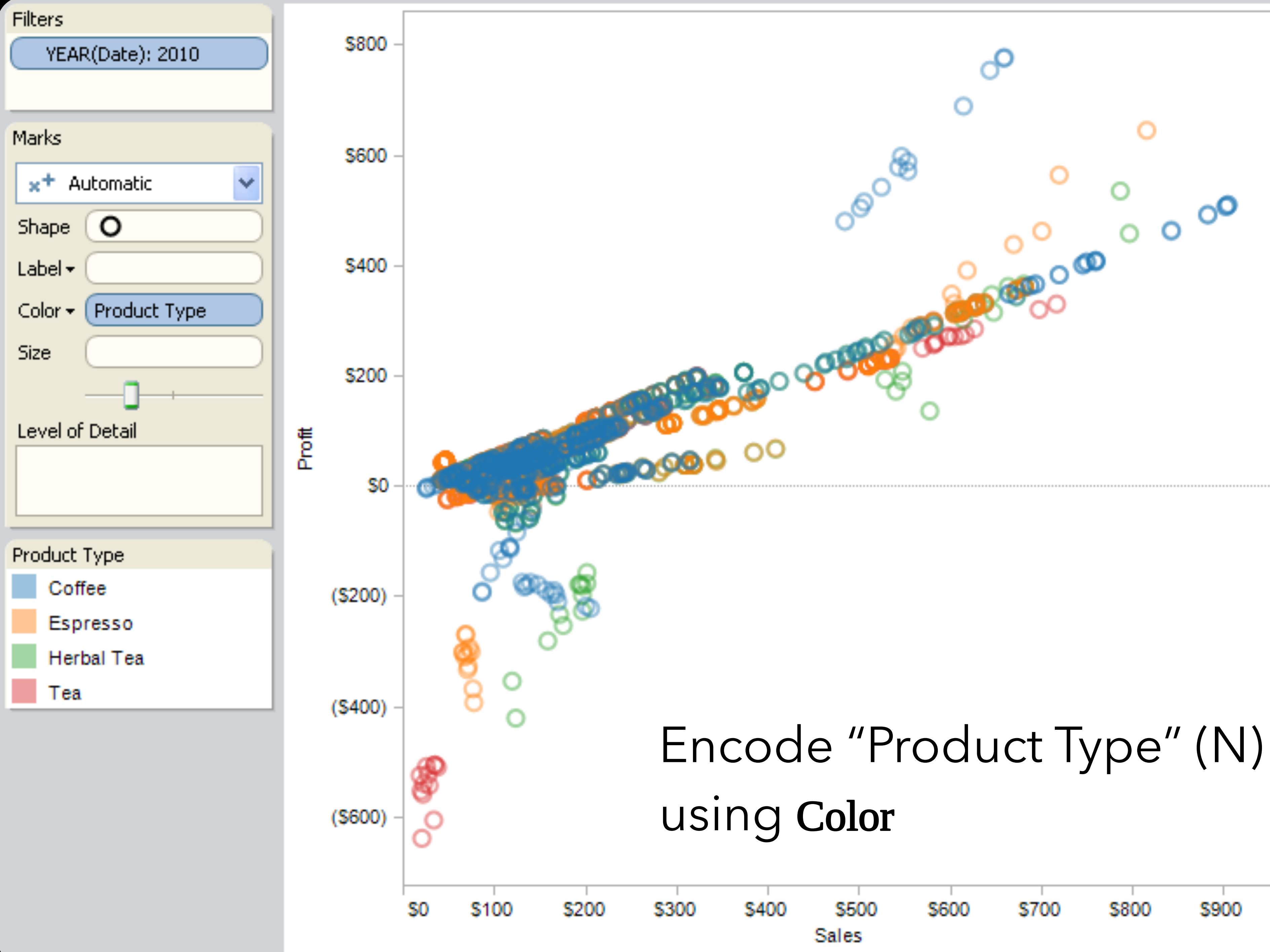
Example: Coffee Sales

Sales figures for a fictional coffee chain

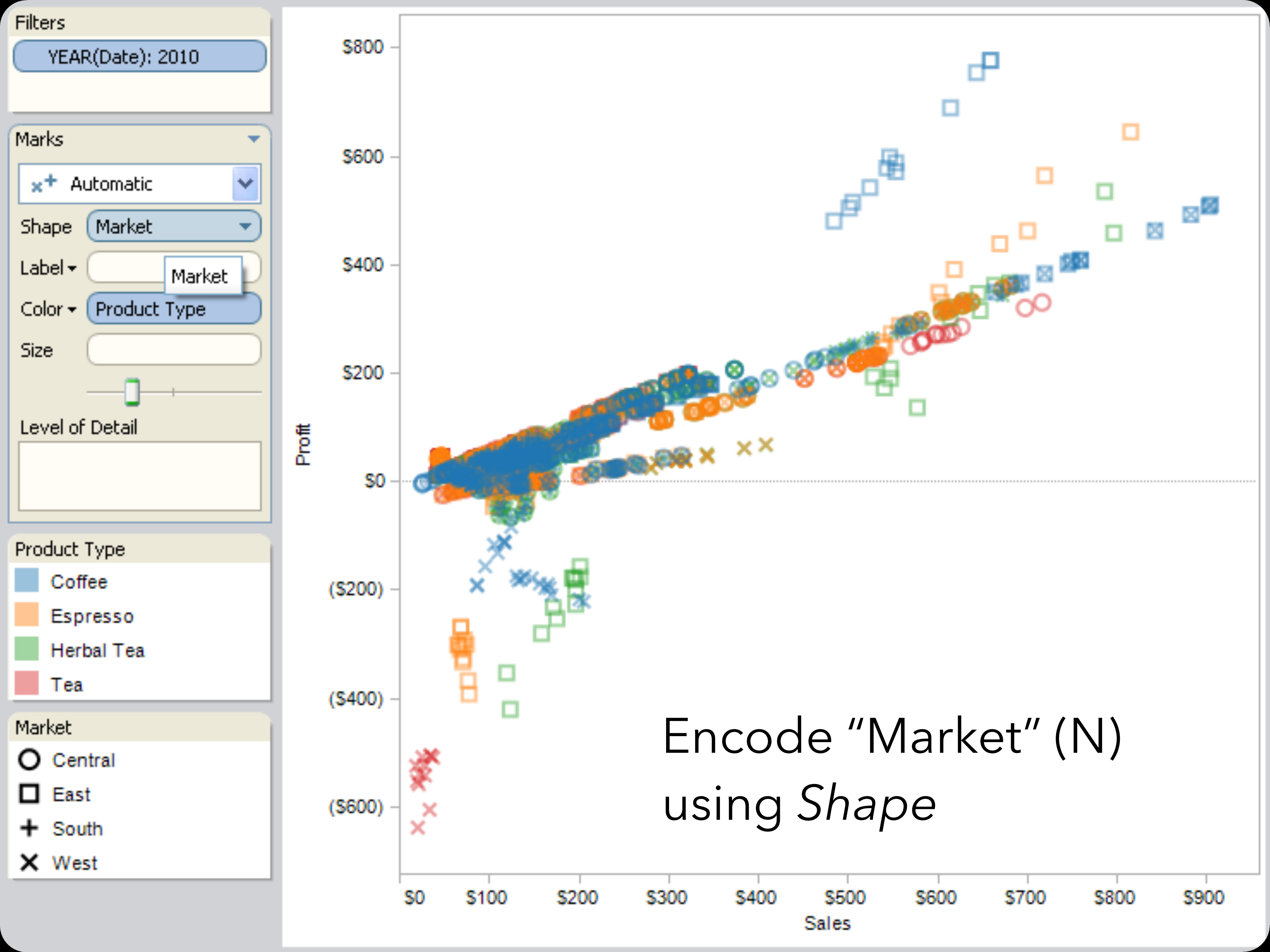
Sales	Q-Ratio
Profit	Q-Ratio
Marketing	Q-Ratio
Product Type	N {Coffee, Espresso, Herbal Tea, Tea}
Market	N {Central, East, South, West}



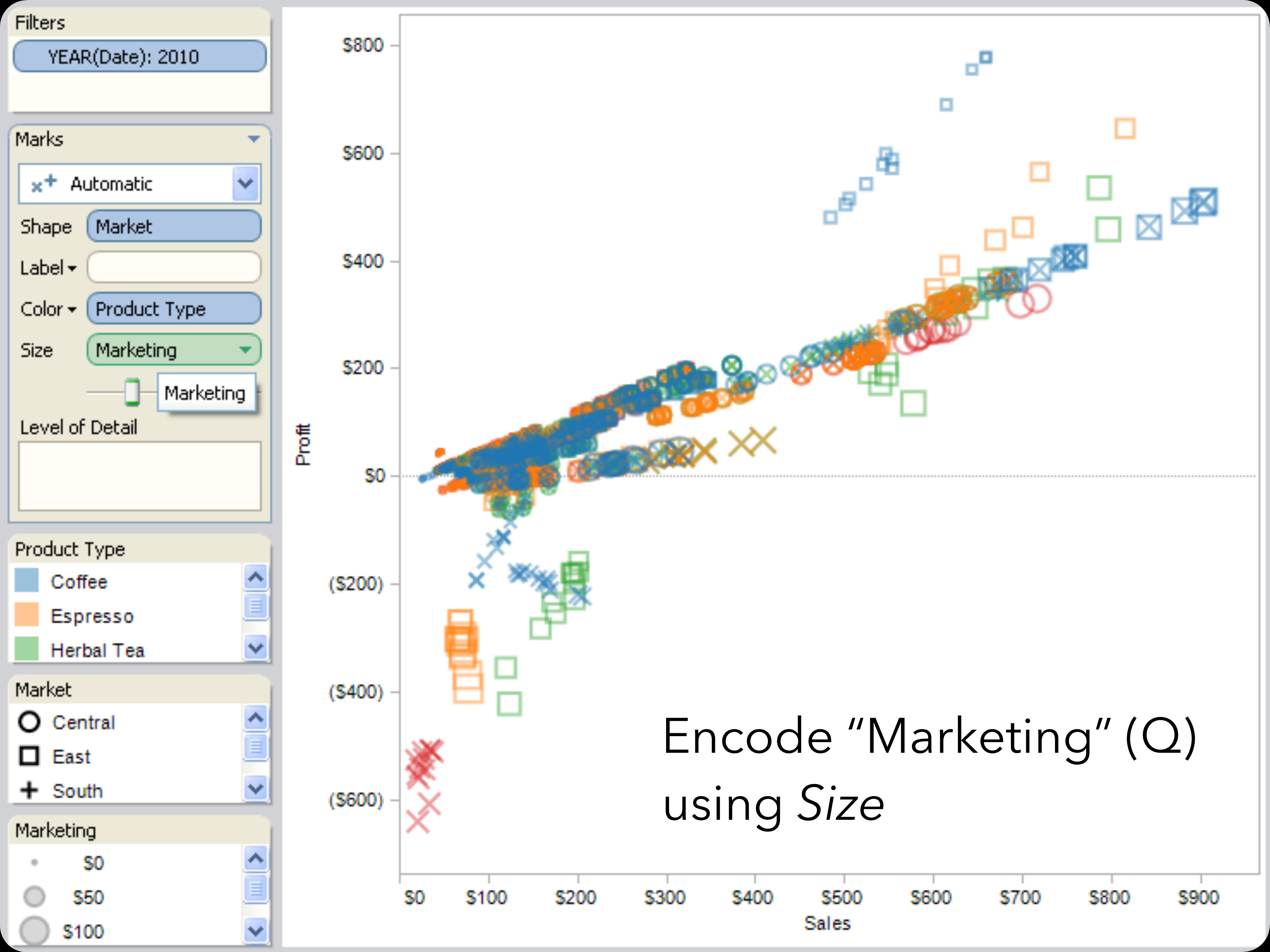
Encode "Sales" (Q) and "Profit" (Q) using *Position*



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

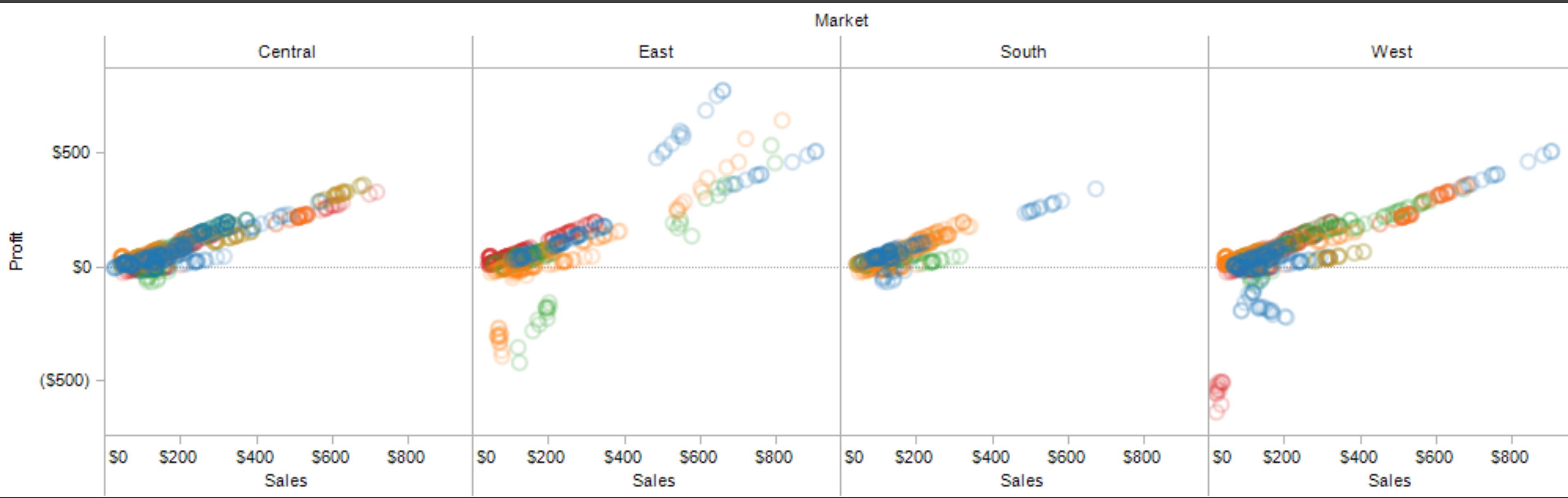


Encode "Market" (N) using *Shape*



Encode “Marketing” (Q) using *Size*

Trellis Plots



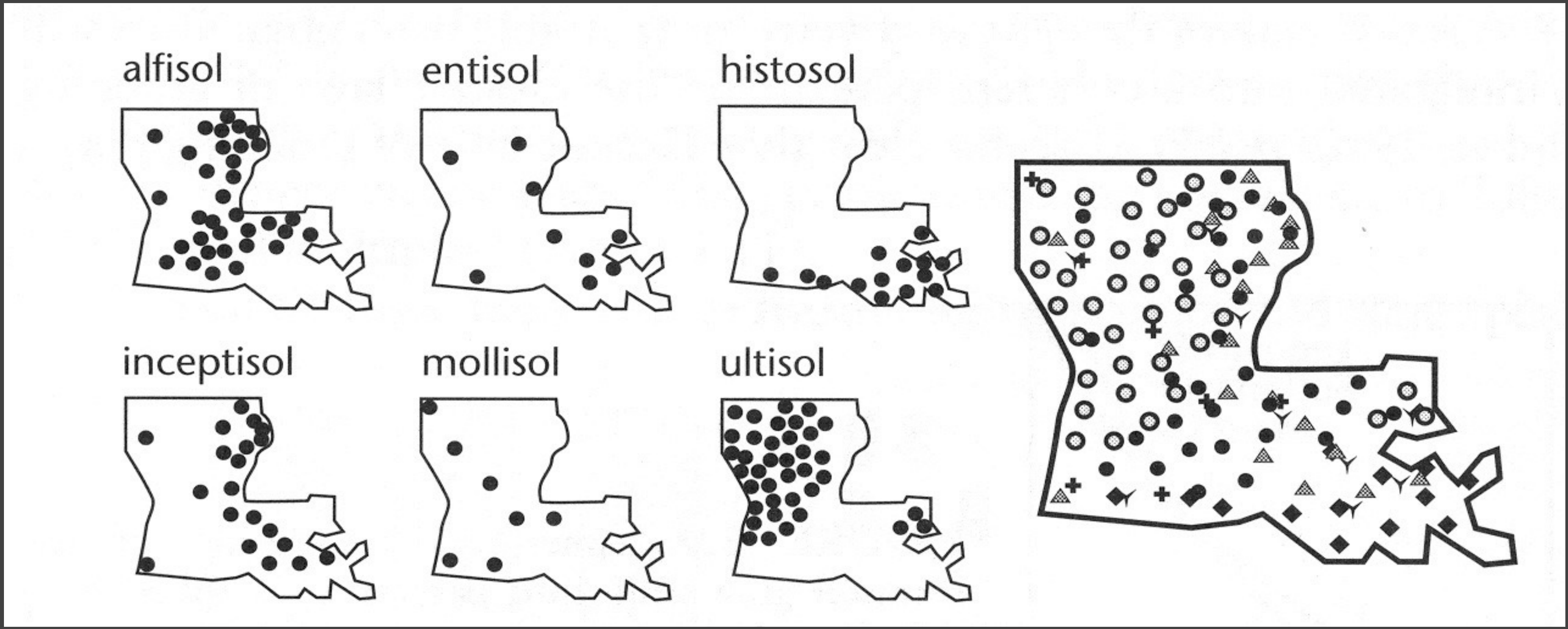
A *trellis plot* subdivides space to enable comparison across multiple plots.

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.