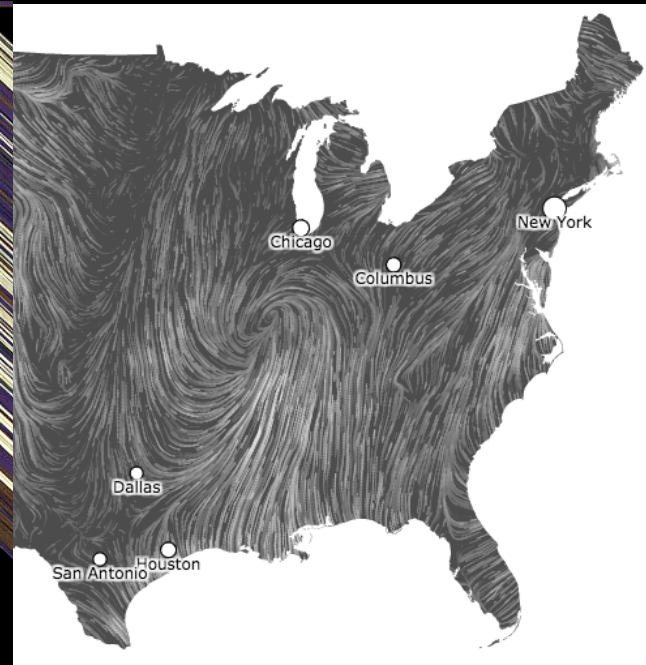
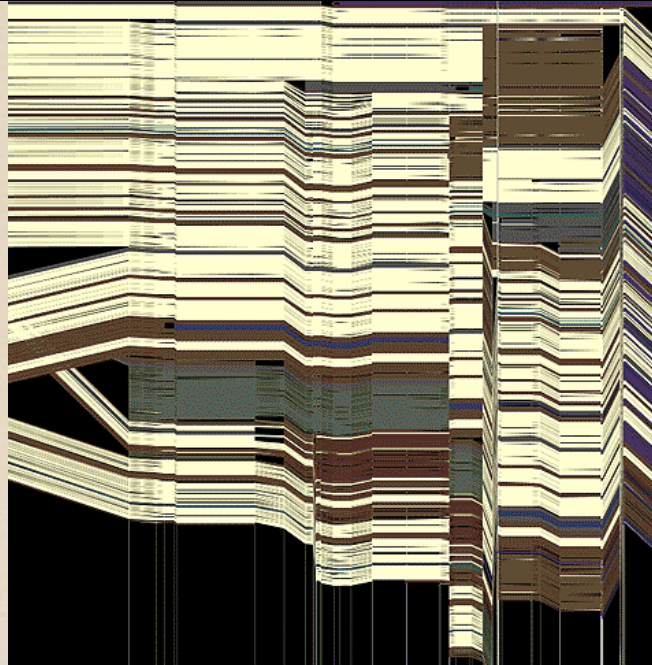
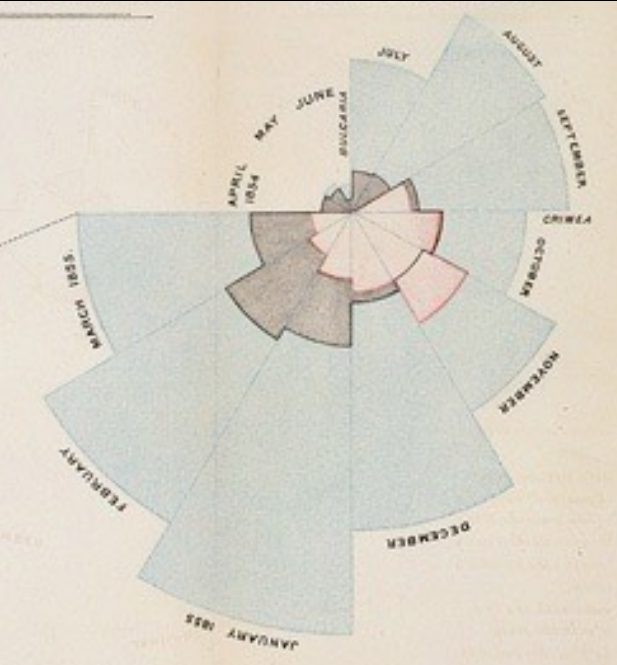


CSE 442 - Data Visualization

Interaction



Jeffrey Heer University of Washington

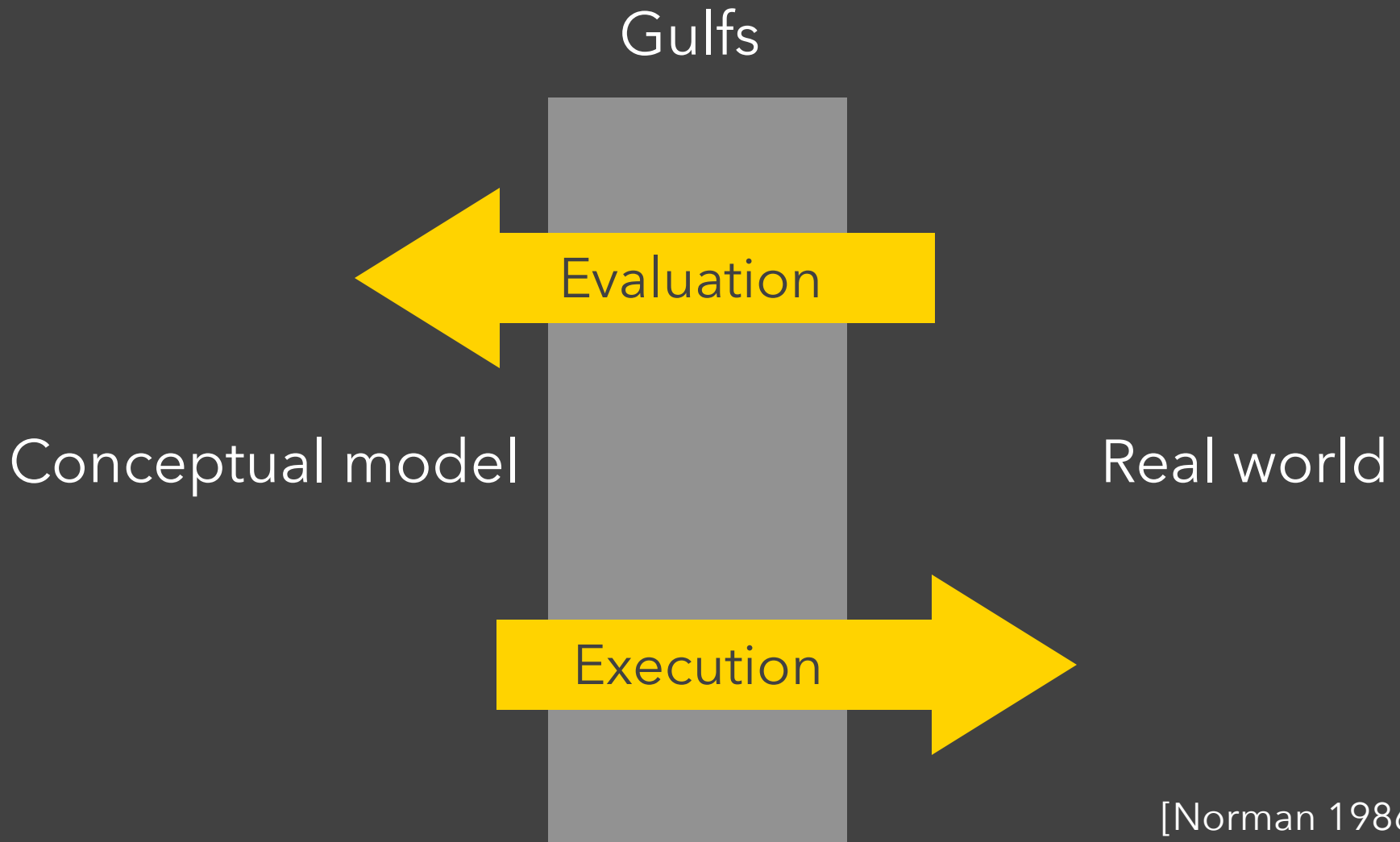
[There is an] apparent challenge that computational artifacts pose to the longstanding distinction between the physical and the social, in the special sense of those things that one designs, builds, and uses, on the one hand, and those things with which one communicates, on the other.

“Interaction” – in a sense previously reserved for describing a uniquely interpersonal activity – seems appropriately to characterize what goes on between people and certain machines as well.

Lucy Suchman, *Plans and Situated Actions*

Interaction between people and machines requires *mutual intelligibility* or *shared understanding*.

Gulfs of Execution & Evaluation



[Norman 1986]

Gulf of Execution

The difference between the user's intentions and the allowable actions.

Gulf of Evaluation

The amount of effort that the person must exert to interpret the state of the system and to determine how well the expectations and intentions have been met.

[Norman 1986]

Gulf of Evaluation

Gulf



Conceptual model:
 x, y related?

Real world:

x	y
0.67	0.79
0.32	0.63
0.39	0.72
0.27	0.85
0.71	0.43
0.63	0.09
0.03	0.03
0.20	0.54
0.51	0.38
0.11	0.33
0.46	0.46

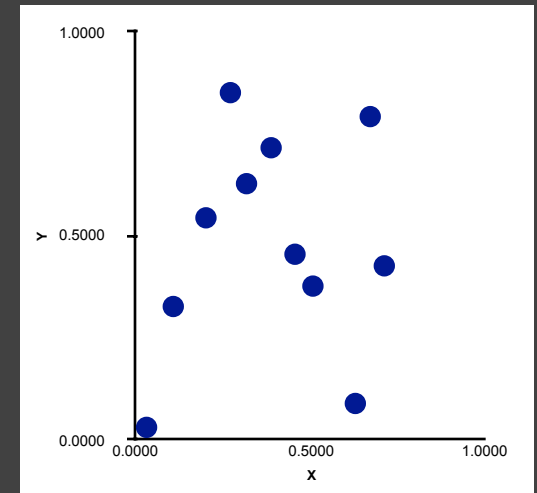
Gulf of Evaluation

Gulf



Conceptual model:
 x, y related?

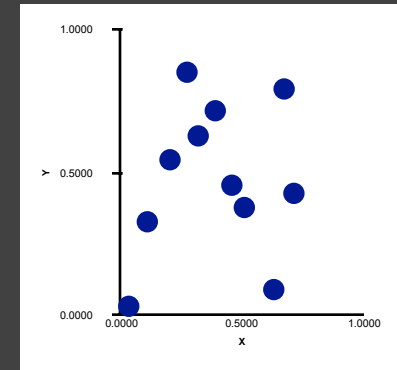
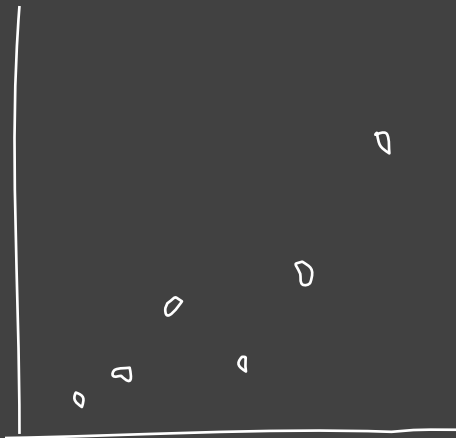
Real world:



Gulf of Execution

Gulf

Conceptual model:
Draw a scatterplot



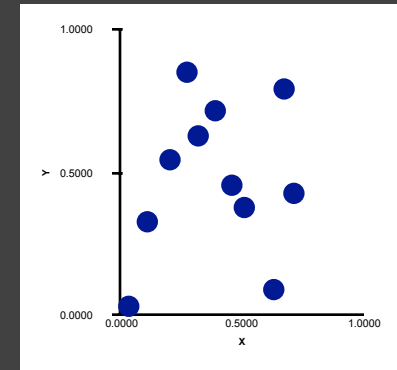
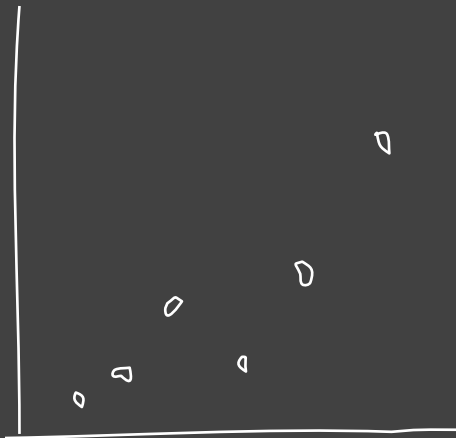
Real world

Move 90 30
Rotate 35
Pen down
...

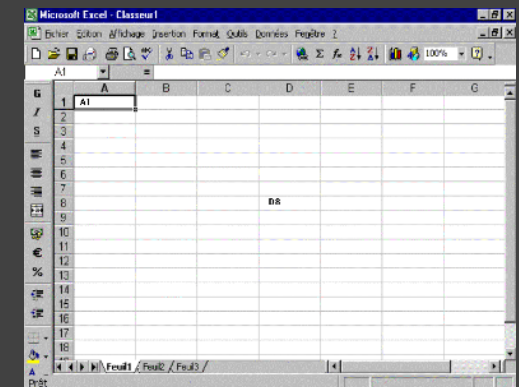
Gulf of Execution

Gulf

Conceptual model:
Draw a scatterplot



Real world



Gulf of Execution

The difference between the user's intentions and the allowable actions.

Gulf of Evaluation

The amount of effort that the person must exert to interpret the state of the system and to determine how well the expectations and intentions have been met.

[Norman 1986]

Interactive Visualization

Interaction Techniques

Are there “essential” interactive operations for exploratory data visualization?

Taxonomy of Interactions

Taxonomy of Interactions

Data and View Specification

Visualize, Filter, Sort, Derive

Data | Analytics

Sample - Superstore

Dimensions

- Customer
 - Customer Name
 - Segment
- Order
- Location
- Product
 - Category
 - Sub-Category
 - Manufacturer
 - Product Name
- Profit (bin)
- Region
- Measure Names

Measures

- Discount
- Profit
- Profit Ratio
- Quantity
- Sales
- Latitude (generated)
- Longitude (generated)
- Number of Records
- Measure Values

Pages

Filters

Marks

Automatic

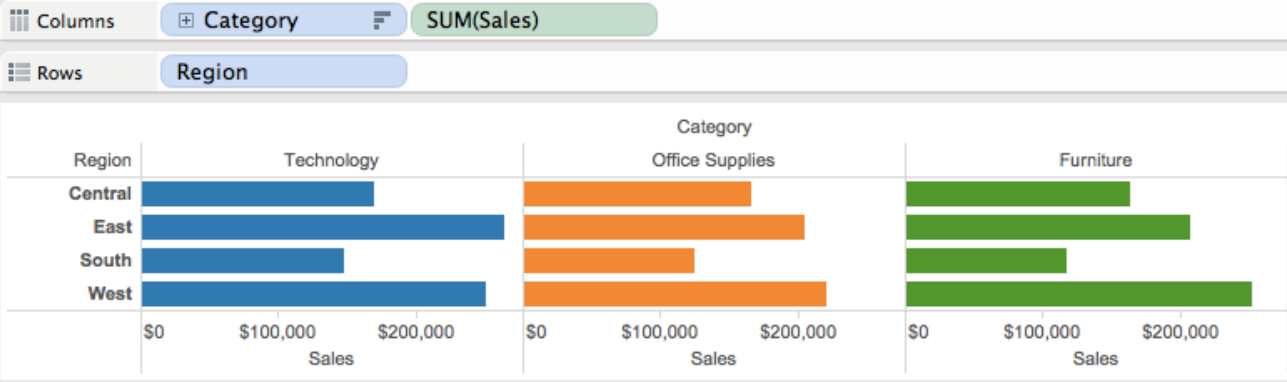
Color Size Label

Detail Tooltip

Category

Category

- Technology
- Office Supplies
- Furniture





Show Me

Data | Analytics

Sample - Superstore

Dimensions

- Customer
 - Customer Name
 - Segment
- Order
 - Location
- Product
 - Category
 - Sub-Category
 - Manufacturer
 - Product Name
- Profit (bin)
- Region
- Measure Names

Measures

- Discount
- Profit
- Profit Ratio
- Quantity
- Sales
- Latitude (generated)
- Longitude (generated)
- Number of Records
- Measure Values

Pages

Columns | Category | SUM(Sales)

Rows | Region

Filters

Marks

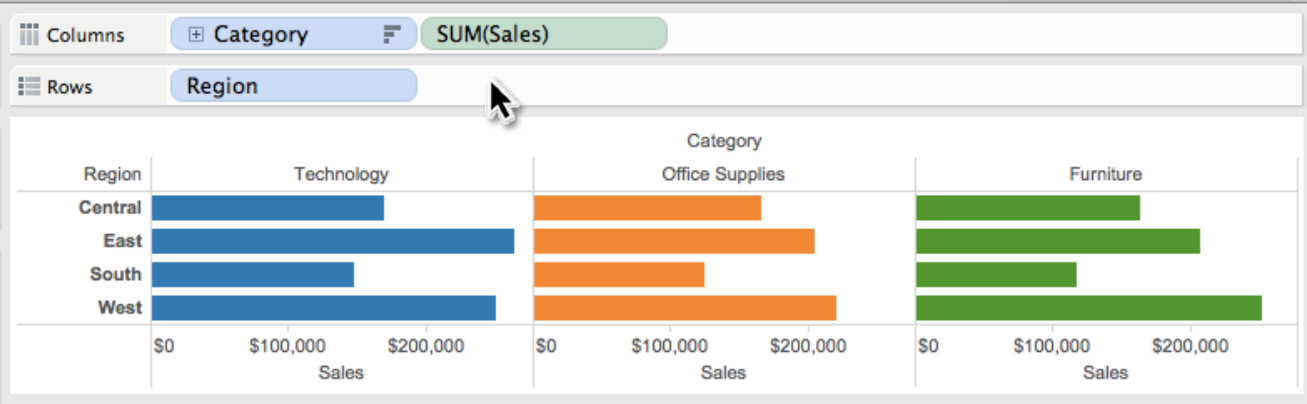
Automatic

Color | Size | Label

Detail | Tooltip

Category

Technology | Office Supplies | Furniture



Data | Analytics

Sample - Superstore

Dimensions

- Customer
 - Customer Name
 - Segment
- Order
- Location
- Product
 - Category
 - Sub-Category
 - Manufacturer
 - Product Name
- Profit (bin)
- Region
- Measure Names

Measures

- Discount
- Profit
- Profit Ratio
- Quantity
- Sales
- Latitude (generated)
- Longitude (generated)
- Number of Records
- Measure Values

Pages

Filters

Marks

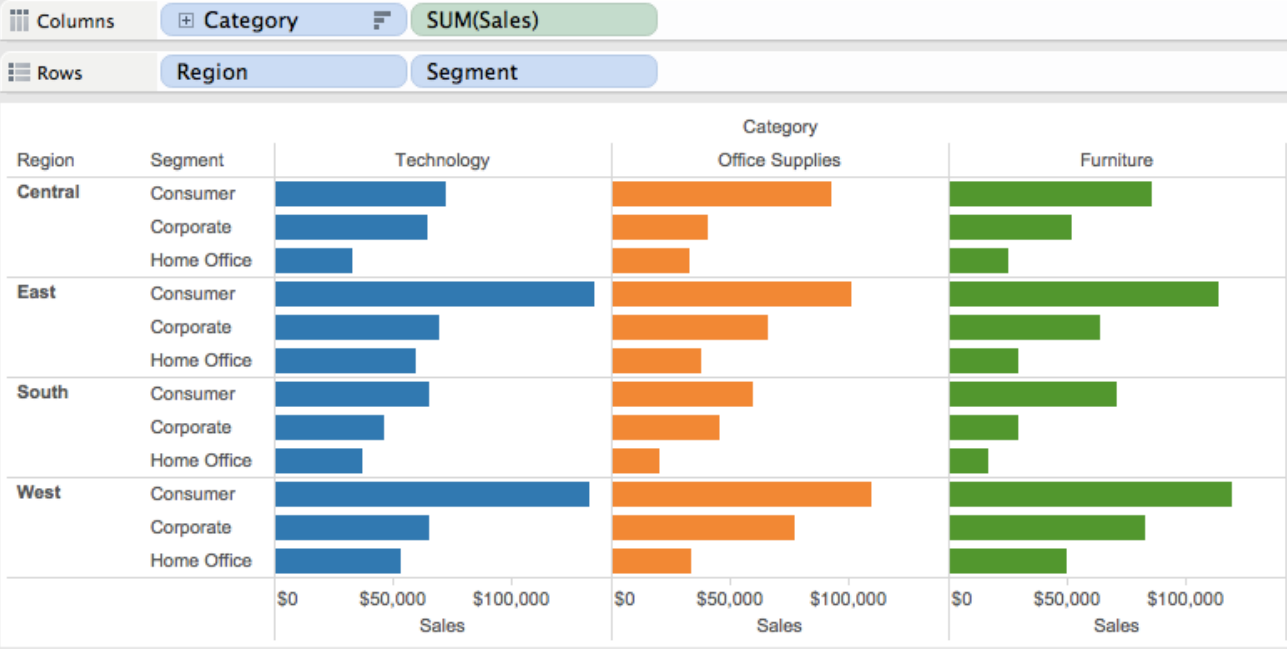
Automatic

Color Size Label

Detail Tooltip

Category

Technology Office Supplies Furniture



Data | Analytics

Sample - Superstore

Dimensions

- Customer
 - Customer Name
 - Segment
- Order
- Location
- Product
 - Category
 - Sub-Category
 - Manufacturer
 - Product Name
- Profit (bin)
- Region
- Measure Names

Measures

- Discount
- Profit
- Profit Ratio
- Quantity
- Sales
- Latitude (generated)
- Longitude (generated)
- Number of Records
- Measure Values

Pages

Filters

Marks

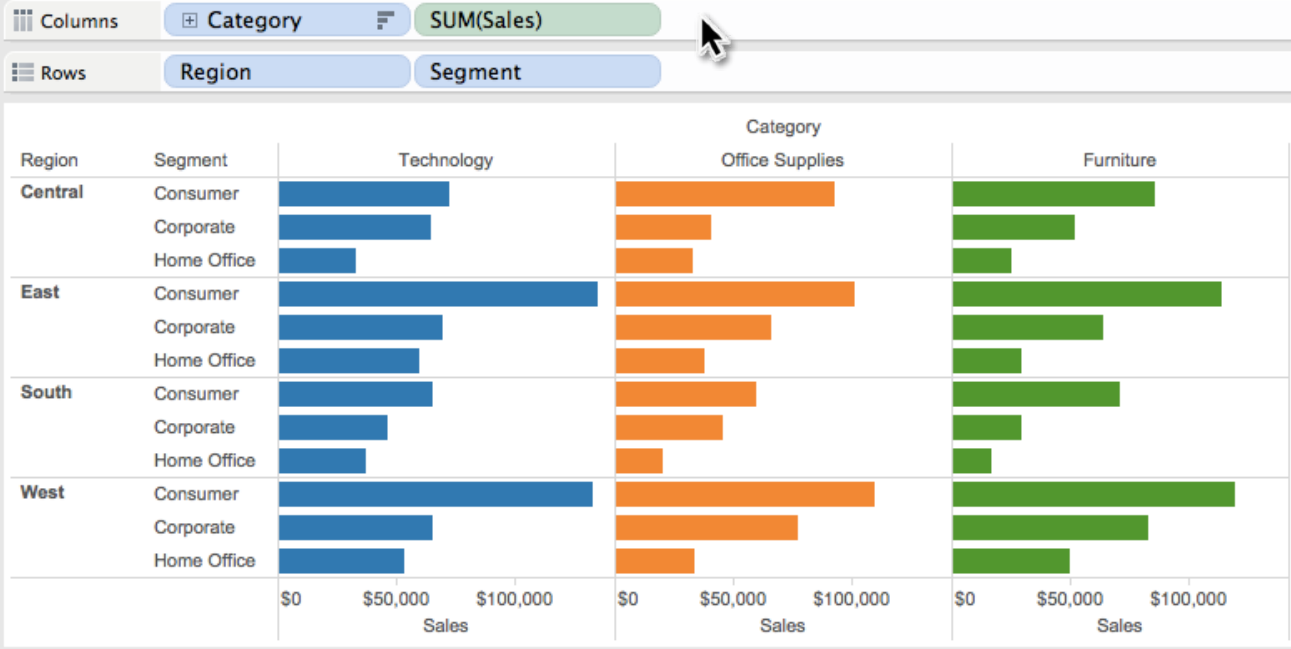
Automatic

Color Size Label

Detail Tooltip

Category

Technology
Office Supplies
Furniture



Data | Analytics

Sample - Superstore

Dimensions

- Customer
 - Customer Name
 - Segment
- Order
- Location
- Product
 - Category
 - Sub-Category
 - Manufacturer
 - Product Name
- Profit (bin)
- Region
- Measure Names

Measures

- Discount
- Profit
- Profit Ratio
- Quantity
- Sales
- Latitude (generated)
- Longitude (generated)
- Number of Records
- Measure Values

Pages

Filters

Marks

All

Automatic

Color | Size | Label

Detail | Tooltip

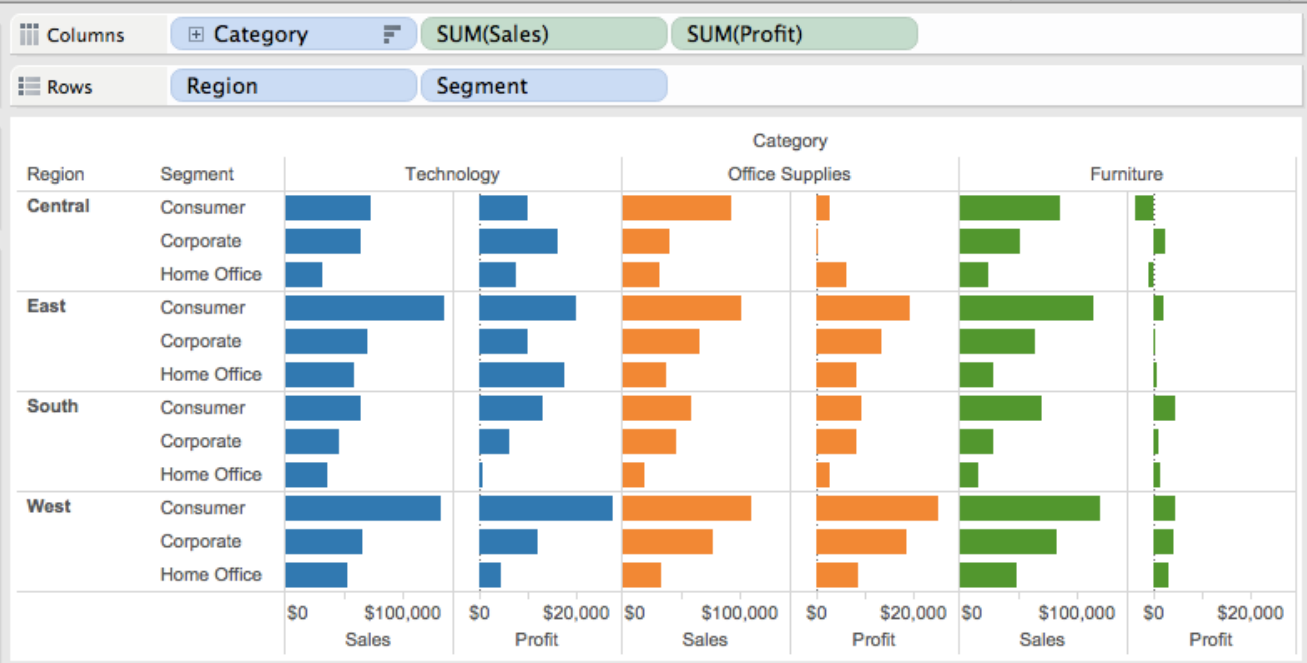
Category

SUM(Sales)

SUM(Profit)

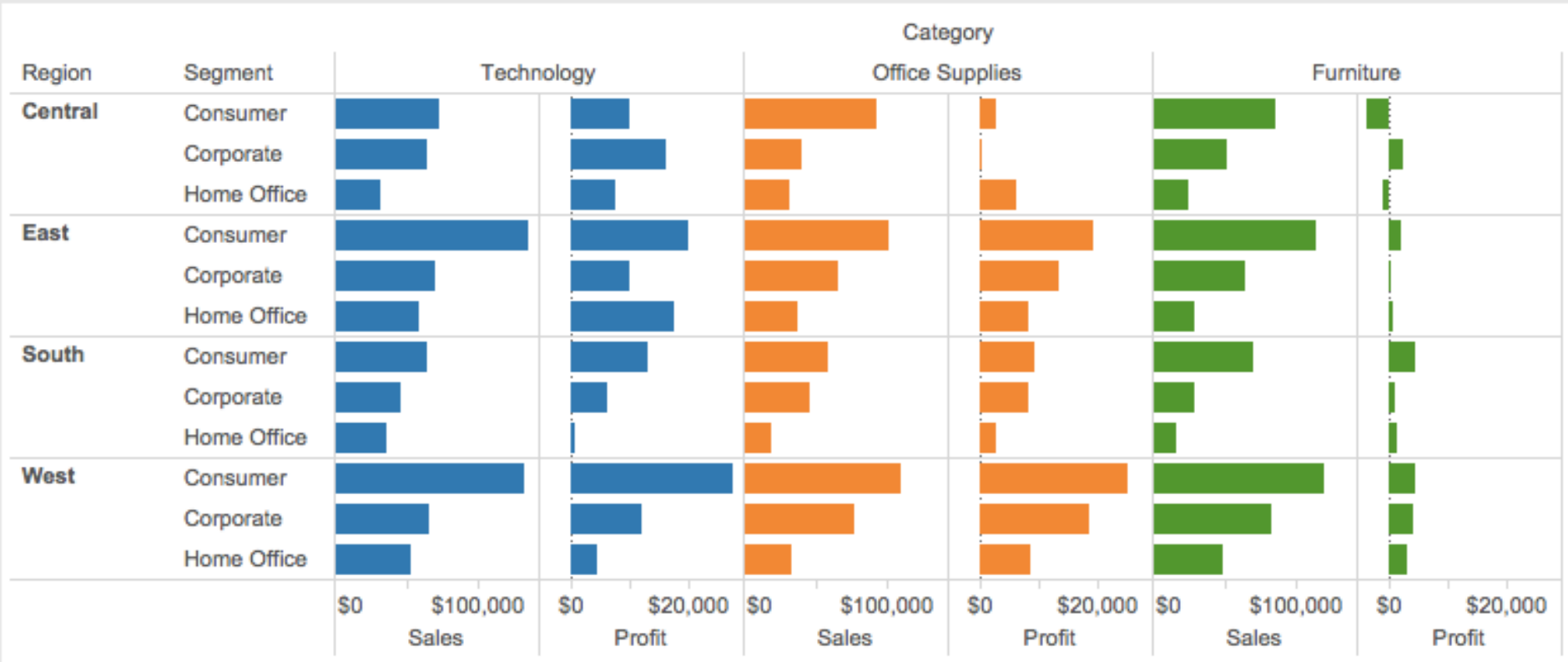
Category

- Technology
- Office Supplies
- Furniture



Columns **Category** ~~SUM(Sales)~~ **SUM(Profit)**

Rows **Region** **Segment**



Taxonomy of Interactions

Data and View Specification

Visualize, Filter, Sort, Derive

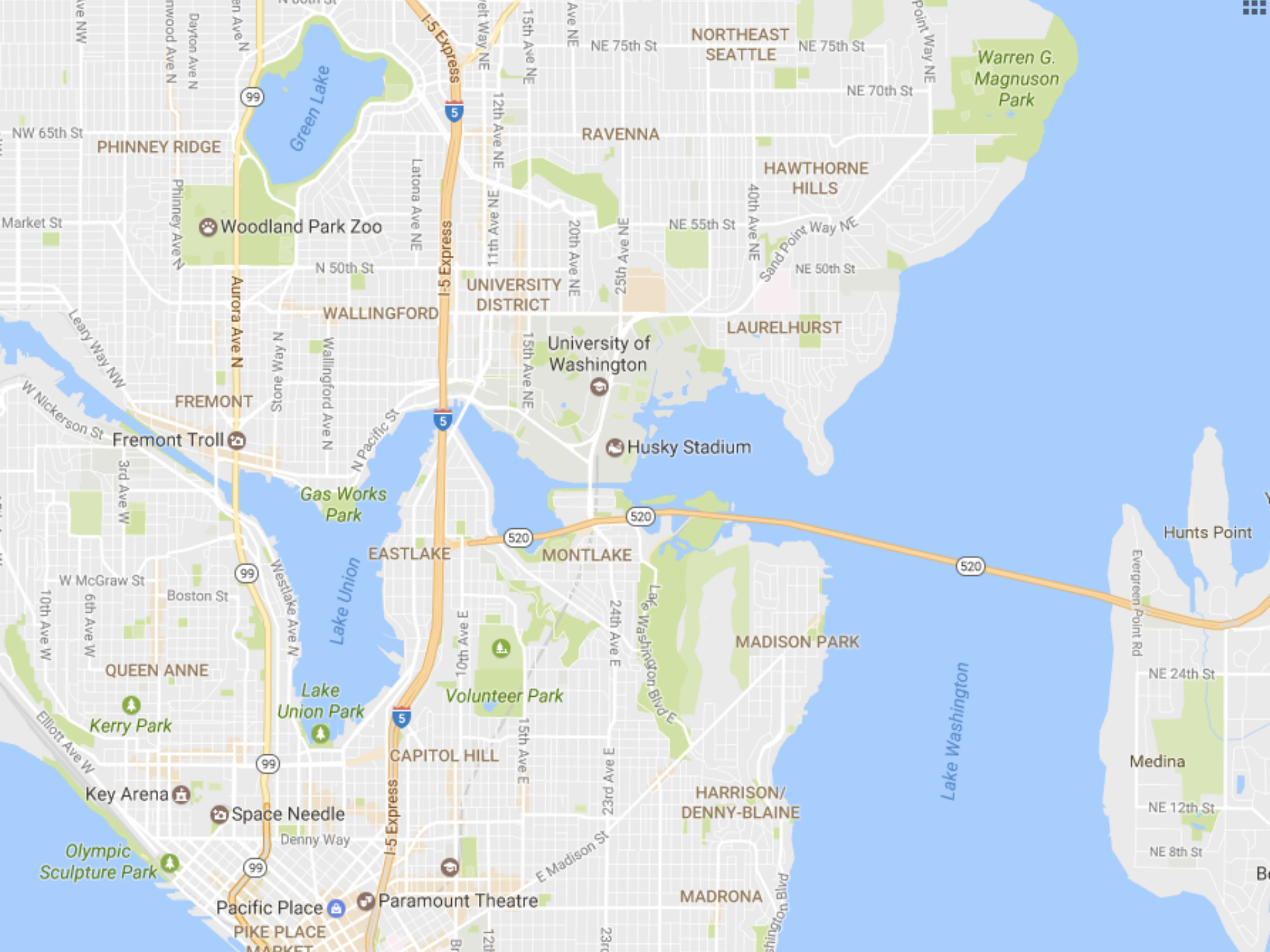
Taxonomy of Interactions

Data and View Specification

Visualize, Filter, Sort, Derive

View Manipulation

Select, Navigate, Coordinate, Organize



Warren G. Magnuson Park

Woodland Park Zoo

University of Washington

Husky Stadium

Gas Works Park

Lake Union Park

Volunteer Park

Kerry Park

Olympic Sculpture Park

Space Needle

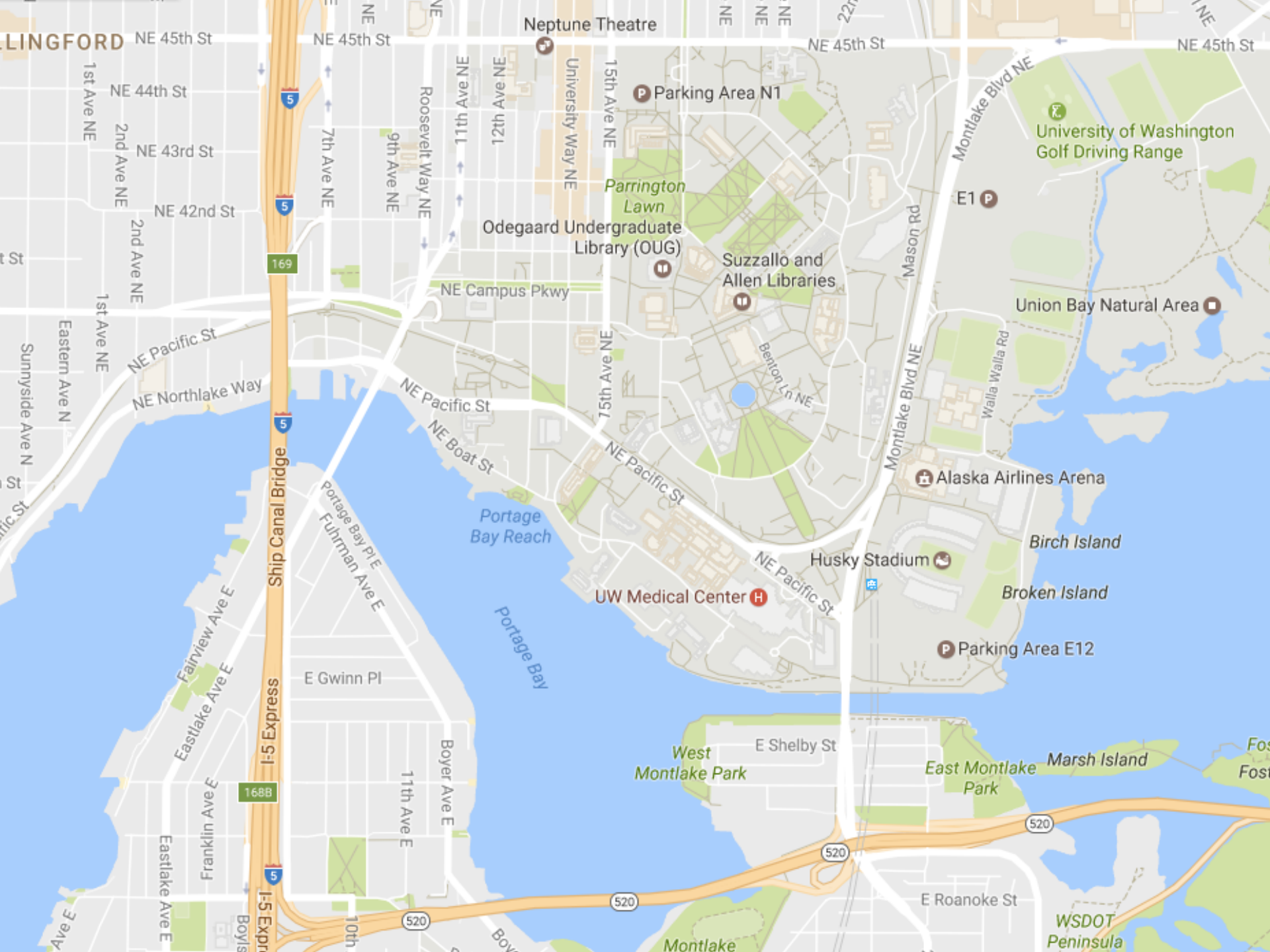
Paramount Theatre

HARRISON/DENNY-BLAINE

MADRONA

Hunts Point

Medina



LINGFORD

NE 45th St

NE 45th St

Neptune Theatre

NE 45th St

NE 45th St

1st Ave NE

NE 44th St

NE 45th St

Roosevelt Way NE

11th Ave NE

12th Ave NE

University Way NE

15th Ave NE

Parking Area N1

NE 45th St

University of Washington Golf Driving Range

NE 43rd St

NE 45th St

9th Ave NE

Roosevelt Way NE

Odegaard Undergraduate Library (OUG)

Parrington Lawn

Suzzallo and Allen Libraries

E1 P

NE 42nd St

169

NE Campus Pkwy

Union Bay Natural Area

t St

Sunnyside Ave N

Eastern Ave N

1st Ave NE

NE Pacific St

NE Northlake Way

NE Pacific St

Portage Bay Reach

75th Ave NE

Benton Ln NE

Montlake Blvd NE

Walla Walla Rd

Alaska Airlines Arena

Birch Island

St

Portage Bay Pl E
Fuhrman Ave E

NE Boat St

NE Pacific St

NE Pacific St

Husky Stadium

Broken Island

UW Medical Center

Parking Area E12

Fairview Ave E
Eastlake Ave E

E Gwinn Pl

Boyer Ave E

West Montlake Park

E Shelby St

East Montlake Park

Marsh Island

Franklin Ave E
Eastlake Ave E

168B

10th

520

520

520

520

E Roanoke St

WSDOT Peninsula

Ave E

Boyls

I-5 Express

5

I-5 Express

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I-5 Express

5

I-5 Express

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I-5 Express

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I-5 Express

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Taxonomy of Interactions

Data and View Specification

Visualize, Filter, Sort, Derive

View Manipulation

Select, Navigate, Coordinate, Organize

Taxonomy of Interactions

Data and View Specification

Visualize, Filter, Sort, Derive

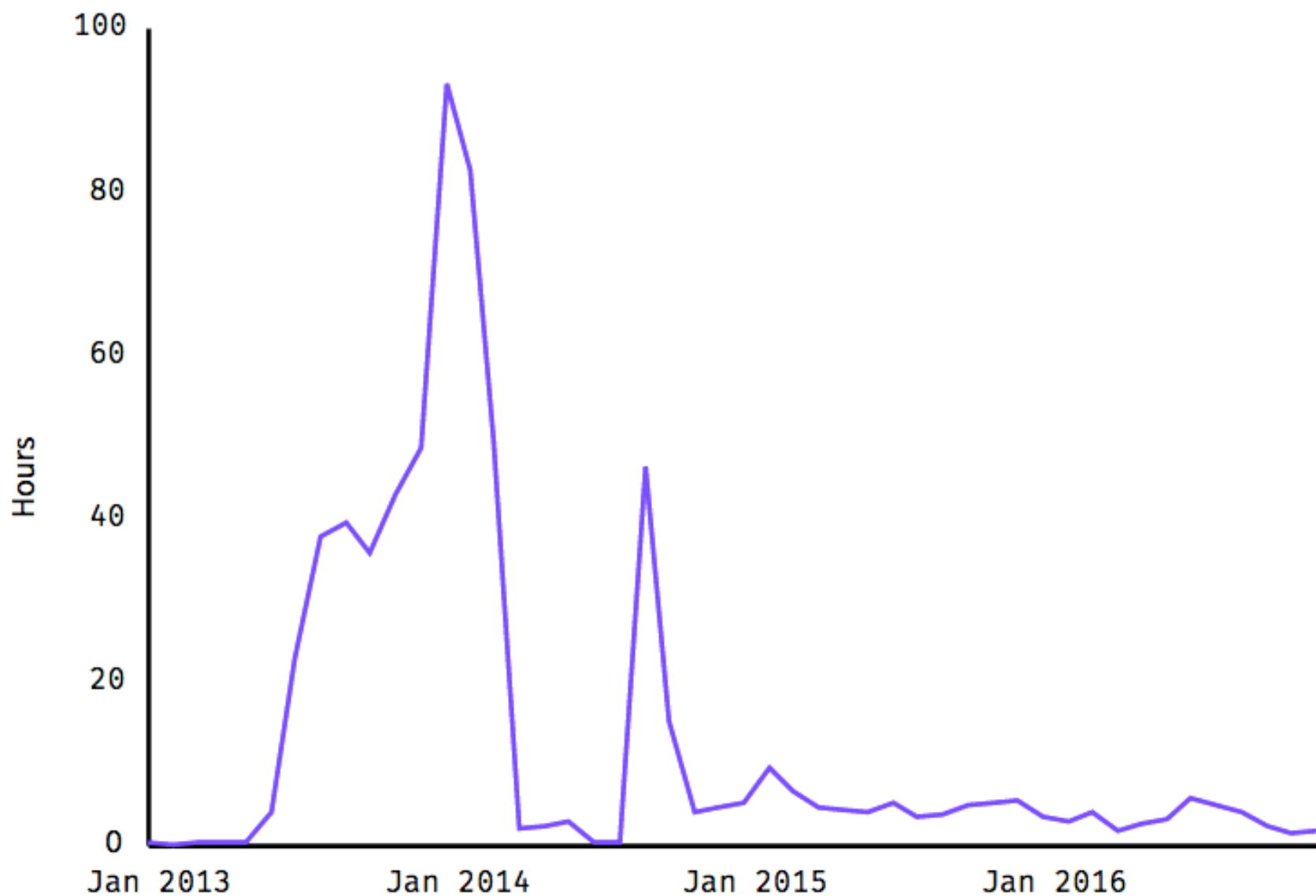
View Manipulation

Select, Navigate, Coordinate, Organize

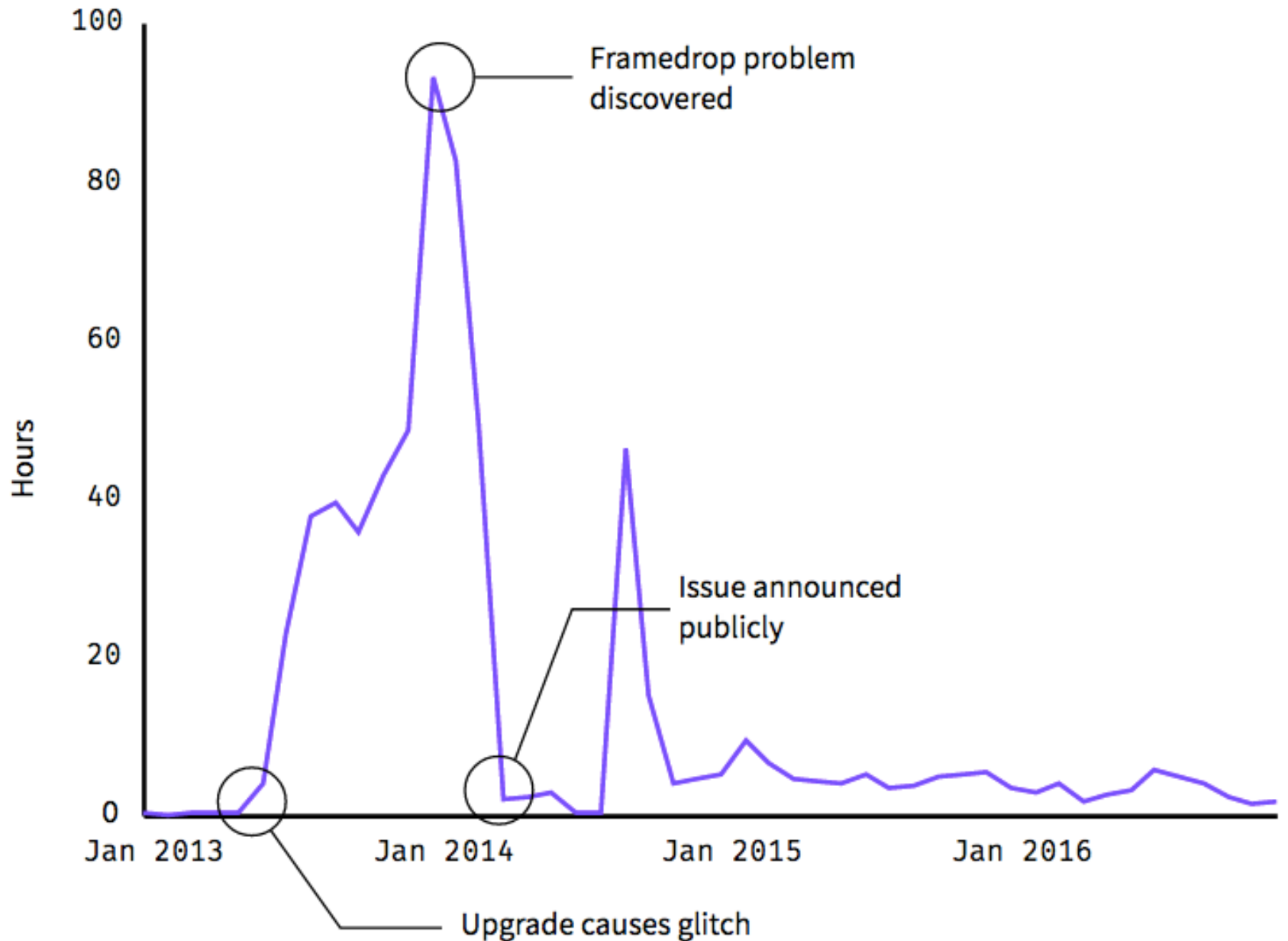
Process and Provenance

Record, Annotate, Share, Guide

Hours of footage lost each month due to dropped frames



Hours of footage lost each month due to dropped frames



Taxonomy of Interactions

Data and View Specification

Visualize, Filter, Sort, Derive

View Manipulation

Select, Navigate, Coordinate, Organize

Process and Provenance

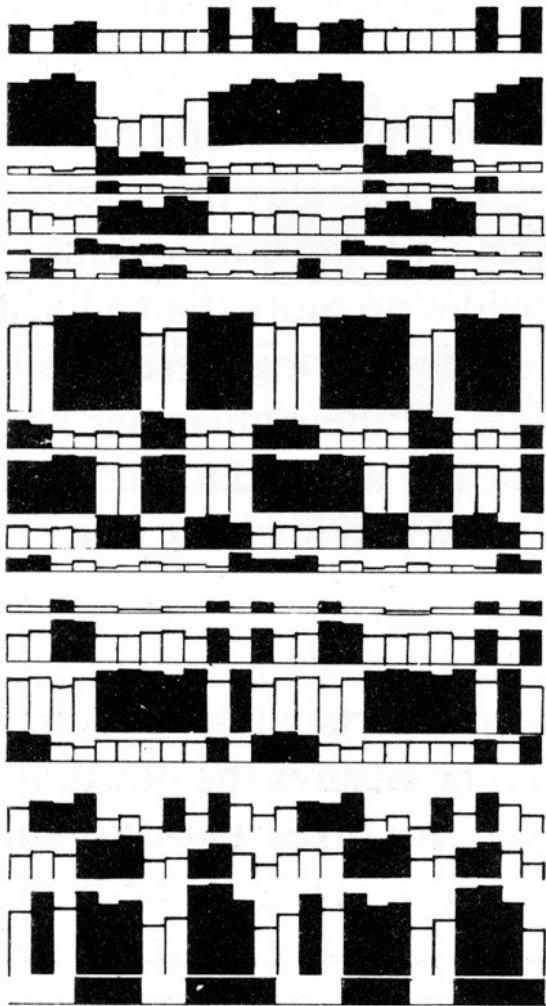
Record, Annotate, Share, Guide

EXAMPLE:
Bertin's Hotel Data

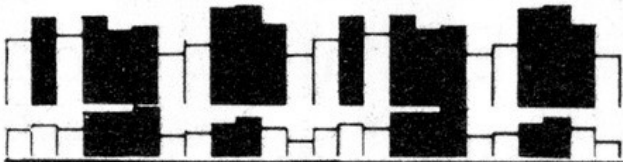
J	F	M	A	M	J	J	A	S	O	N	D		
26	21	26	28	20	20	20	20	20	40	15	40	1	% CLIENTELE FEMALE
69	70	77	71	37	36	39	39	55	60	68	72	2	% —" — LOCAL
7	6	3	6	23	14	19	14	9	6	8	8	3	% —" — U.S.A.
0	0	0	0	8	6	6	4	2	12	0	0	4	% —" — SOUTH AMERICA
20	15	14	15	23	27	22	30	27	19	19	17	5	% —" — EUROPE
1	0	0	8	6	4	6	4	2	1	0	1	6	% —" — M.EAST, AFRICA
3	10	6	0	3	13	8	9	5	2	5	2	7	% —" — ASIA
78	80	85	86	85	87	70	76	87	85	87	80	8	% BUSINESSMEN
22	20	15	14	15	13	30	24	13	15	13	20	9	% TOURISTS
70	70	75	74	69	68	74	75	68	68	64	75	10	% DIRECT RESERVATIONS
20	18	19	17	27	27	19	19	26	27	21	15	11	% AGENCY —" —
10	12	6	9	4	5	7	6	6	5	15	10	12	% AIR CREWS
2	2	4	2	2	1	1	2	2	4	2	5	13	% CLIENTS UNDER 20 YEARS
25	27	37	35	25	25	27	28	24	30	24	30	14	% —" — 20-35 —" —
48	49	42	48	54	55	53	51	55	46	55	43	15	% —" — 35-55 —" —
25	22	17	15	19	19	19	19	19	20	19	22	16	% —" — MORE THAN 55 —" —
163	167	166	174	152	155	145	170	157	174	165	156	17	PRICE OF ROOMS
1.65	1.71	1.65	1.91	1.90	2.	1.54	1.60	1.73	1.82	1.66	1.44	18	LENGTH OF STAY
67	82	70	83	74	77	56	62	90	92	78	55	19	% OCCUPANCY
			X	X	X			X	X	X	X	20	CONVENTIONS

1

J FMAMJ JASONDJ FMAMJ JASOND



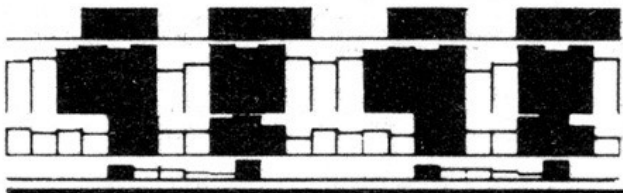
J F M A M J J A S O N D J F M A M J J A S O N D



18 % OCCUPANCY

18 LENGTH OF STAY

ACTIVE AND
SLOW PERIODS



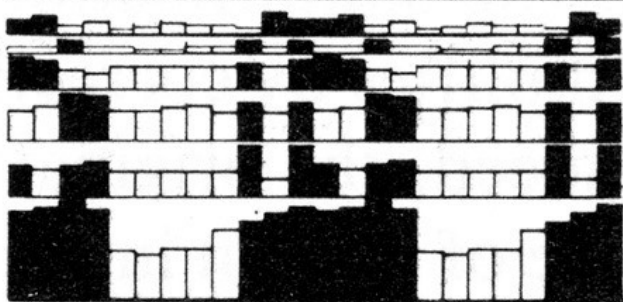
20 CONVENTIONS

8 BUSINESSMEN

11 AGENCY RESERVATIONS

4 SOUTH AMERICA

DISCOVERY FACTORS



18 AIR CREWS

18 CLIENTS UNDER 20 YEARS

18 CLIENTS MORE THAN 55 YEARS

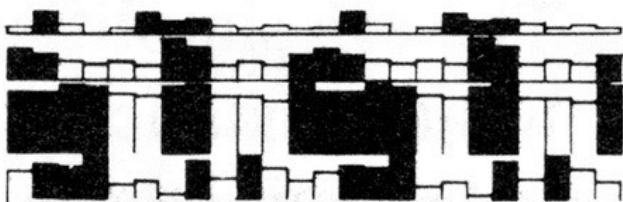
14 CLIENTS FROM 20-35 YEARS

1 FEMALE CLIENTELE

2 LOCAL CLIENTELE

RECOVERY FACTORS

WINTER



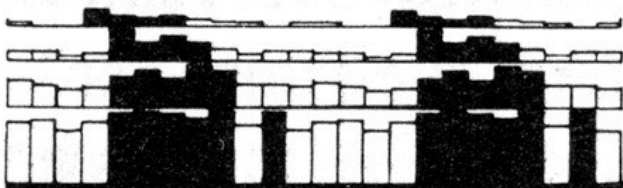
7 ASIA

9 TOURISTS

10 DIRECT RESERVATION

17 PRICE OF ROOMS

WINTER-SUMMER



6 MIDDLE EAST, AFRICA

3 U. S. A.

5 EUROPE

15 CLIENTS FROM 35-55 YEARS

SUMMER



[Graphics and Graphic Information Processing, Bertin 81]



[Graphics and Graphic Information Processing, Bertin 81]



[Graphics and Graphic Information Processing, Bertin 81]

EXAMPLE:

Tukey et al.'s PRIM-9



PRIM-9, Tukey, Fisherkeller, Friedman 1972

L.



L,



Selection

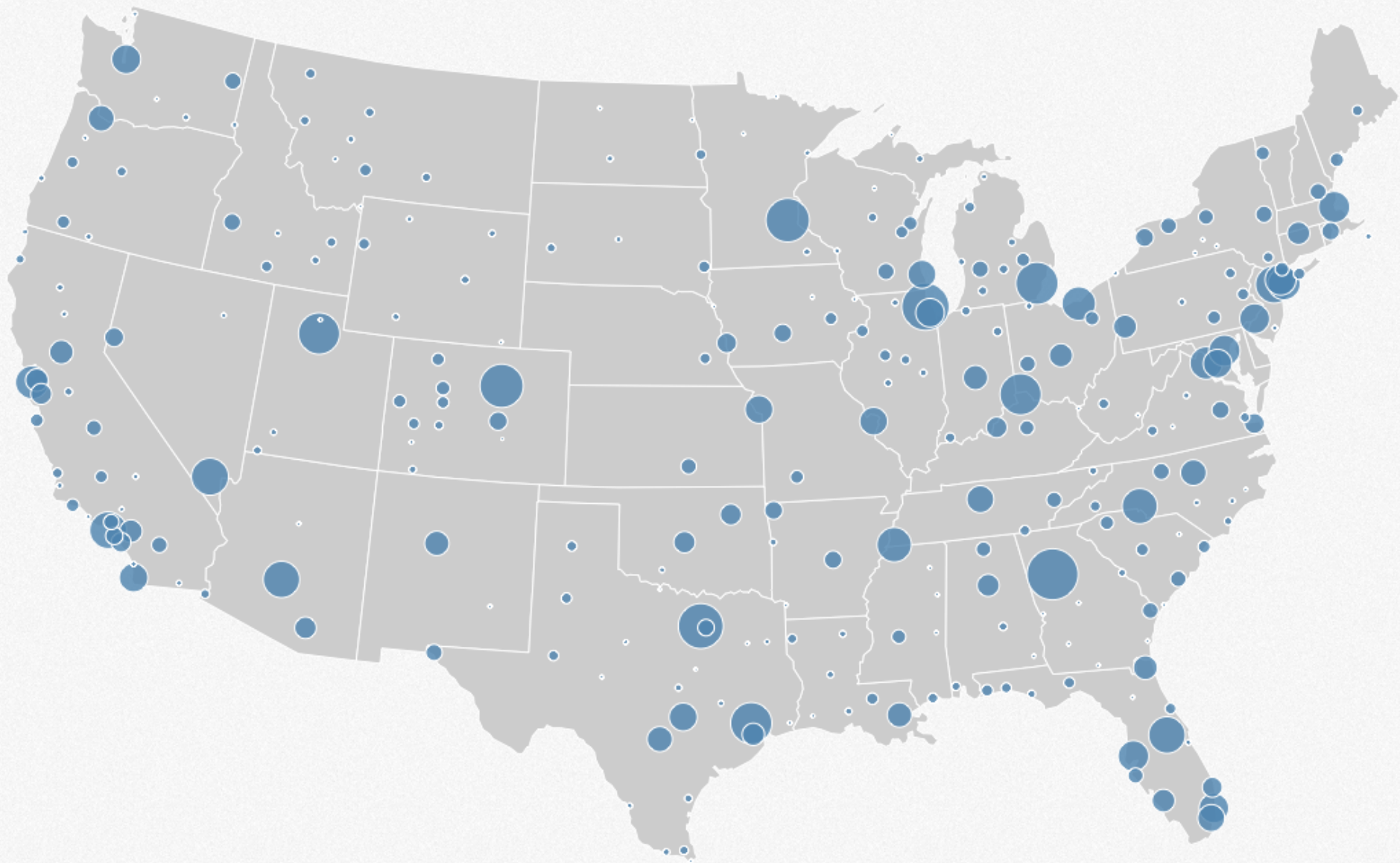
Basic Selection Methods

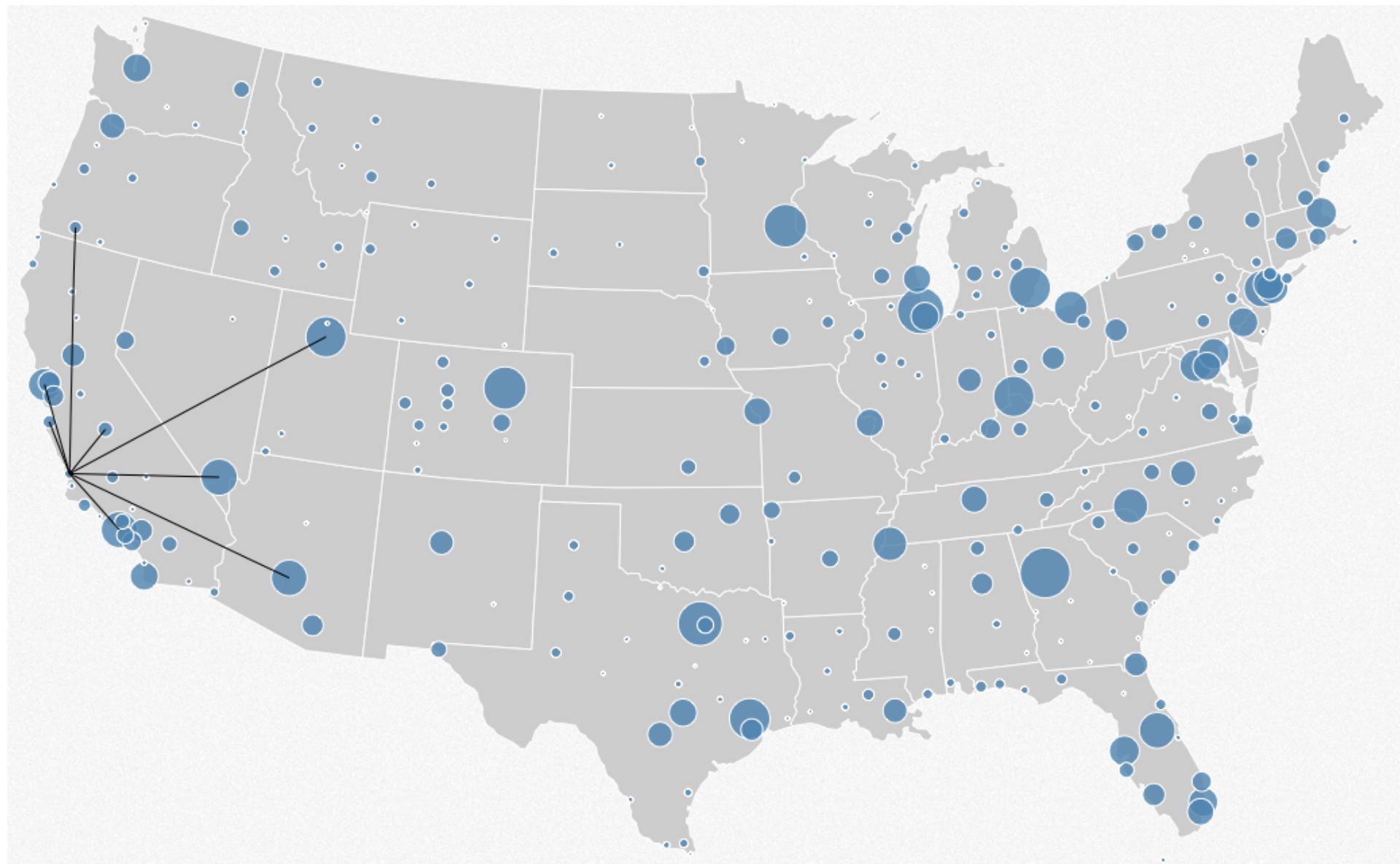
Point Selection

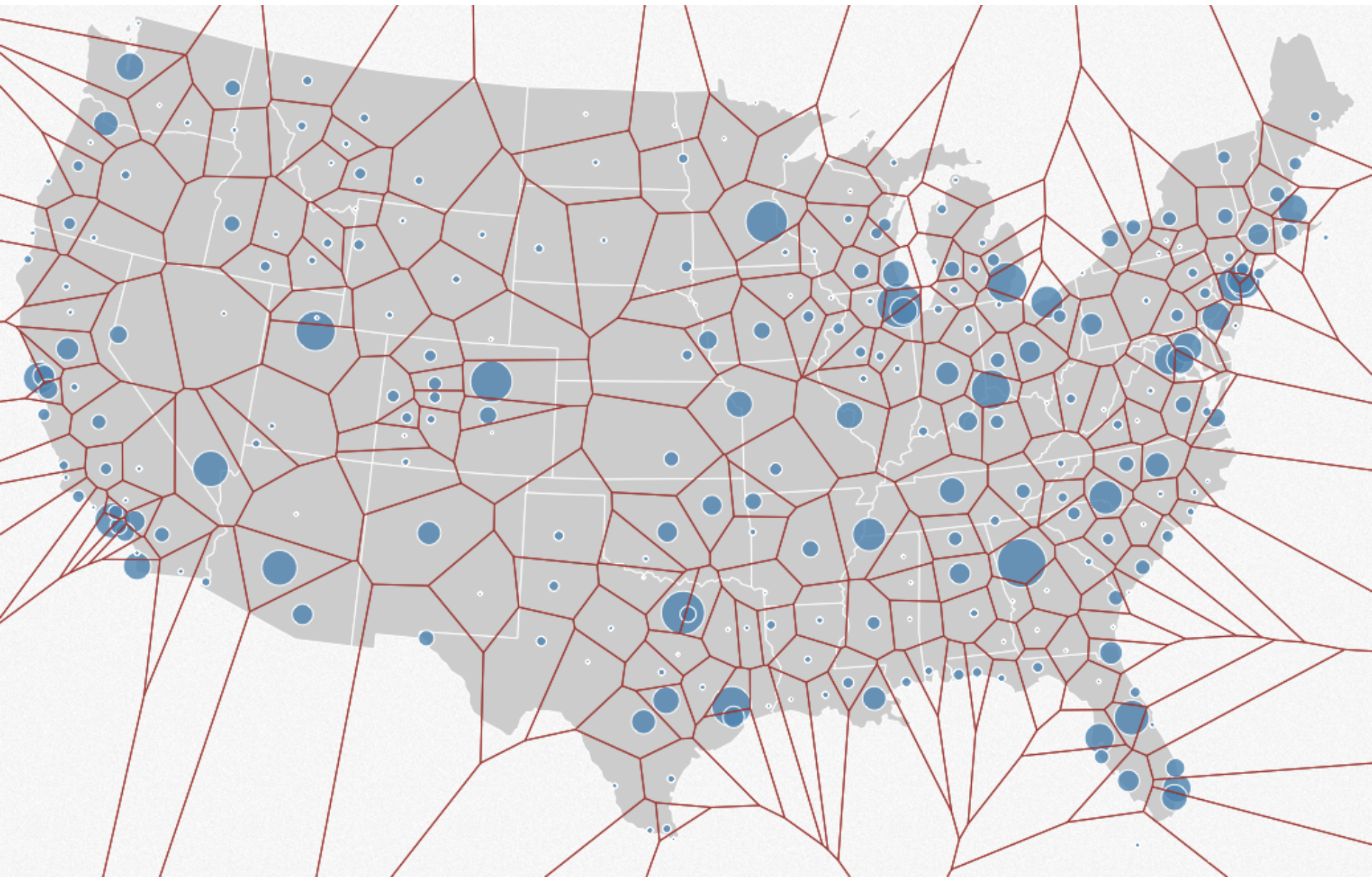
Mouse Hover / Click

Touch / Tap

Select Nearby Element (e.g., Bubble Cursor)







Basic Selection Methods

Point Selection

Mouse Hover / Click

Touch / Tap

Select Nearby Element (e.g., Bubble Cursor)

Region Selection

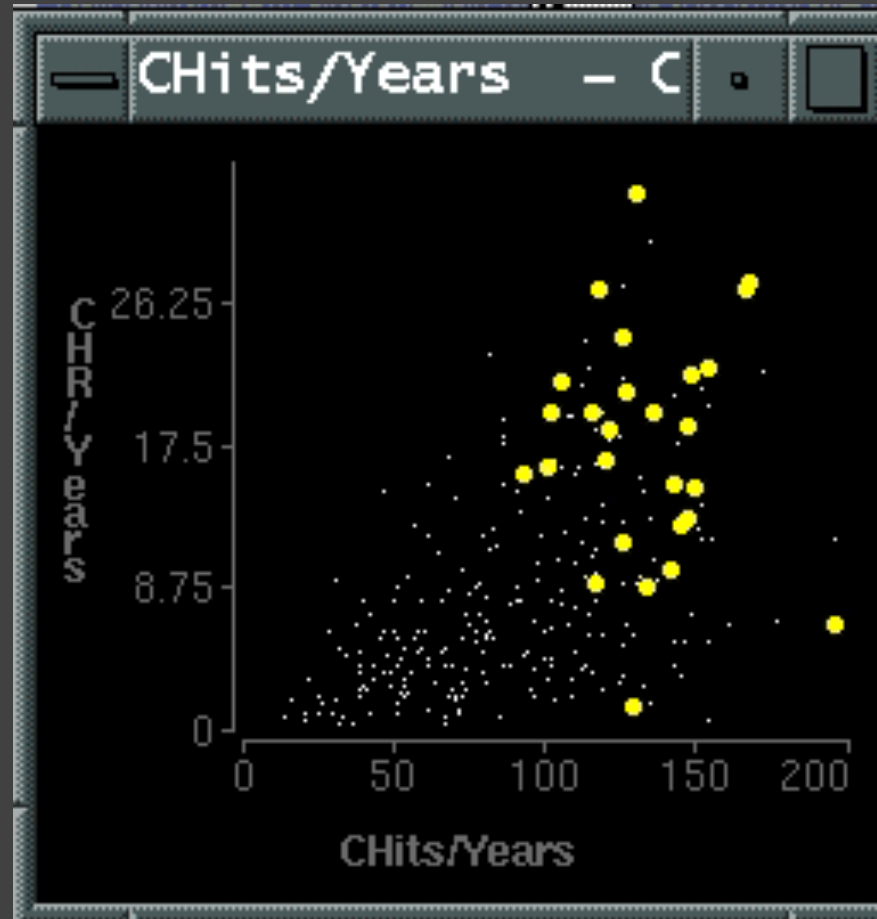
Rubber-band (rectangular) or Lasso (freehand)

Area cursors ("brushes")

Brushing & Linking

Brushing

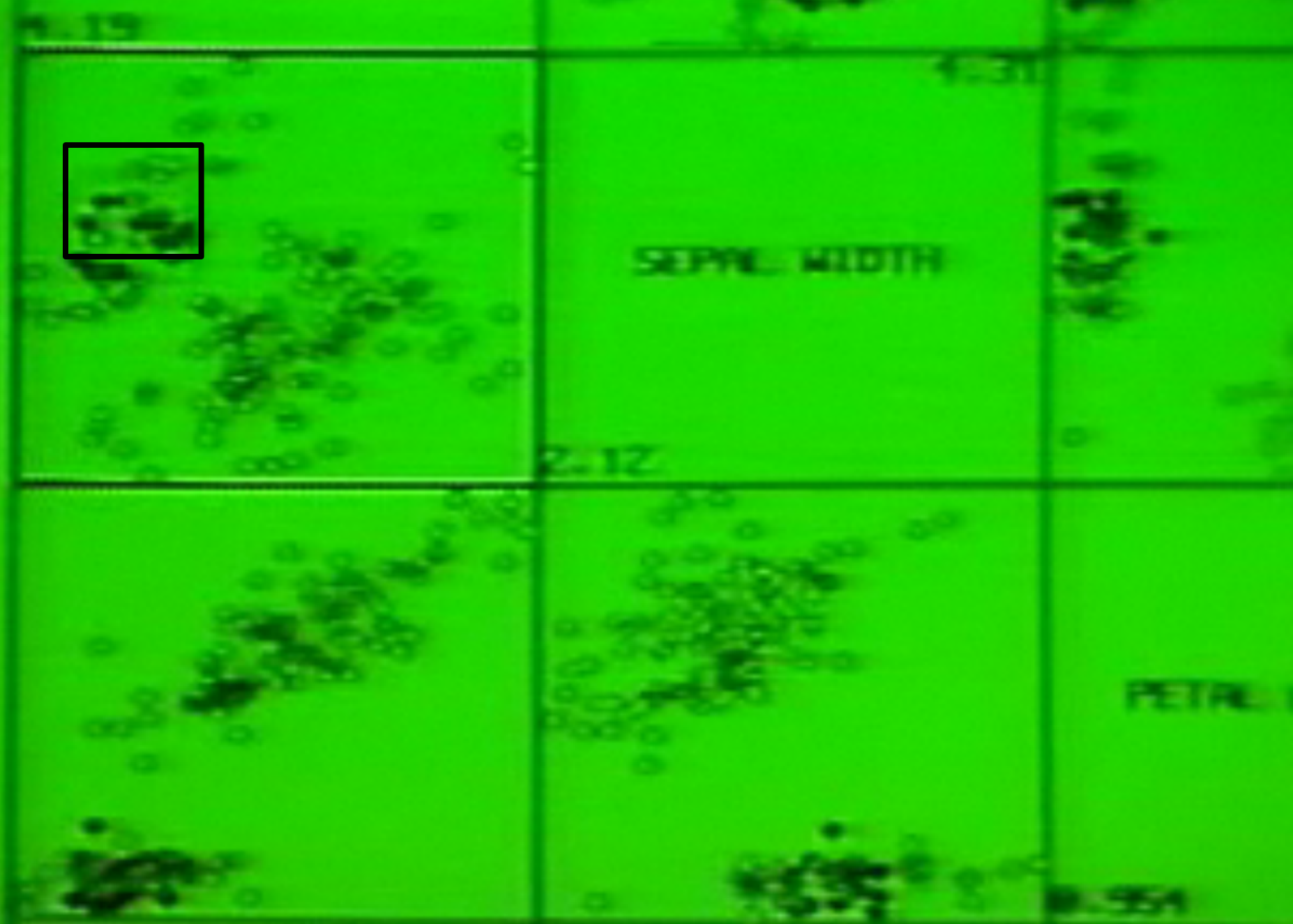
Direct attention to a subset of data [Wills 95]



Brushing & Linking

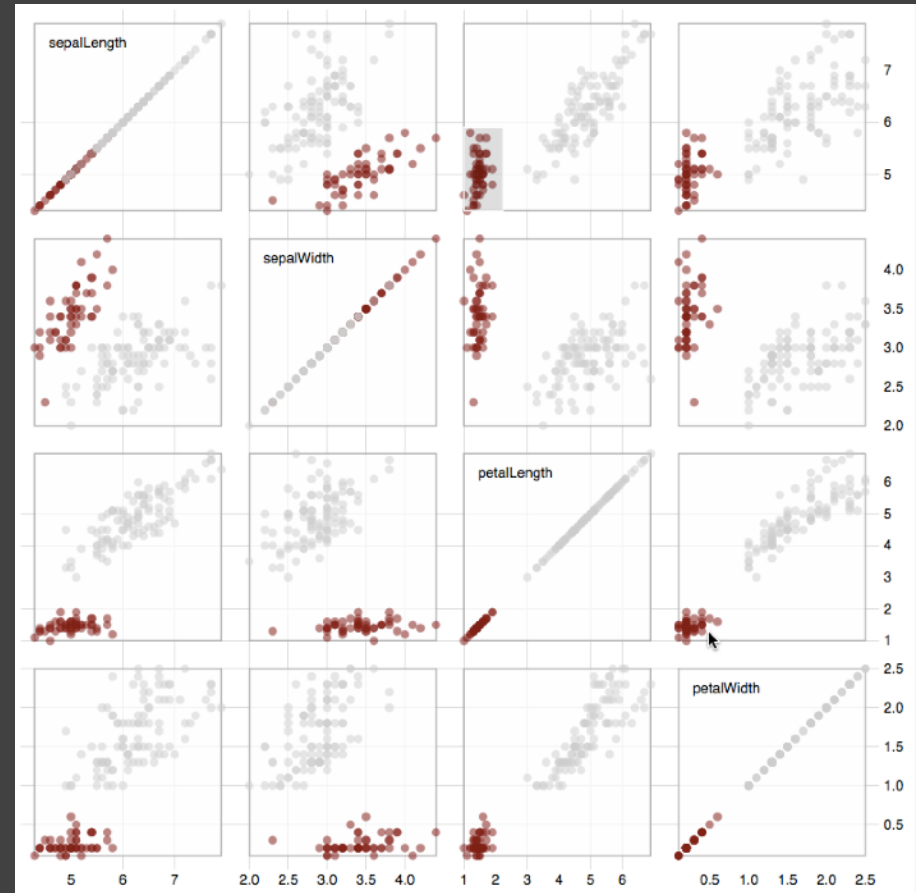
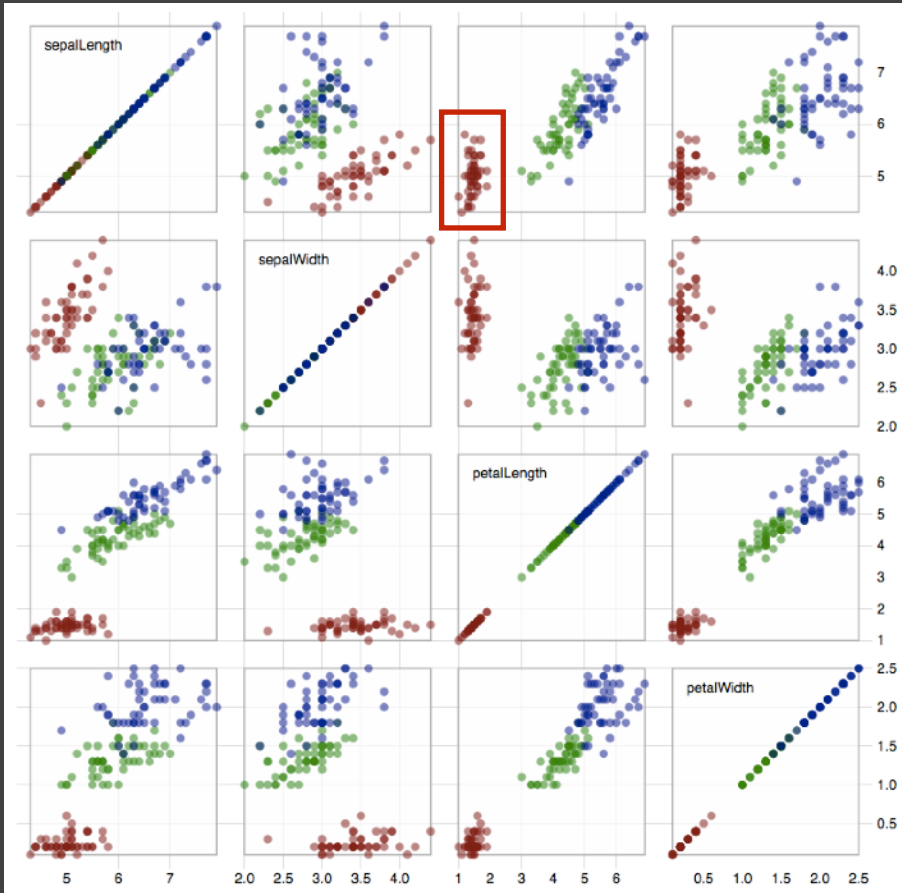
Select ("**brush**") a subset of data
See selected data in other views

The components must be **linked**
by *tuple* (matching data points), or
by *query* (matching range or values)



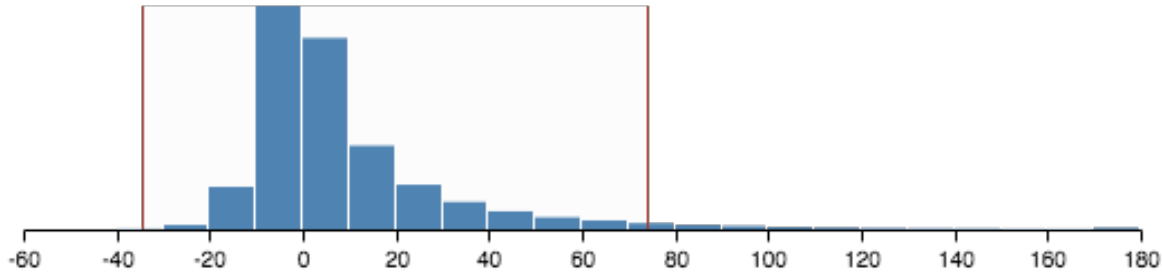
Brushing Scatterplots, Becker & Cleveland 1982

Brushing Scatterplots

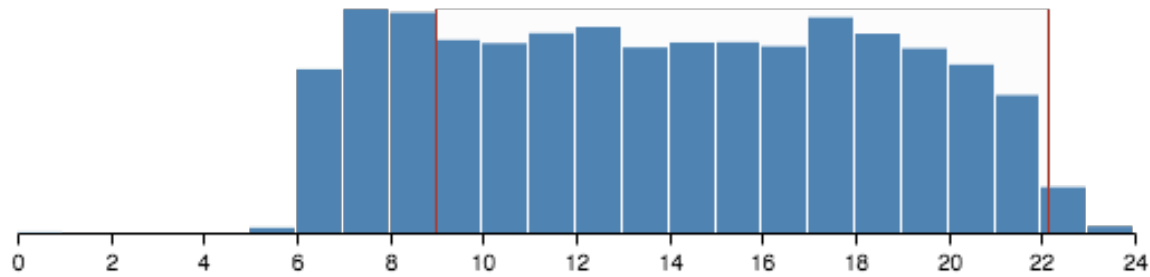


Cross-Filtering

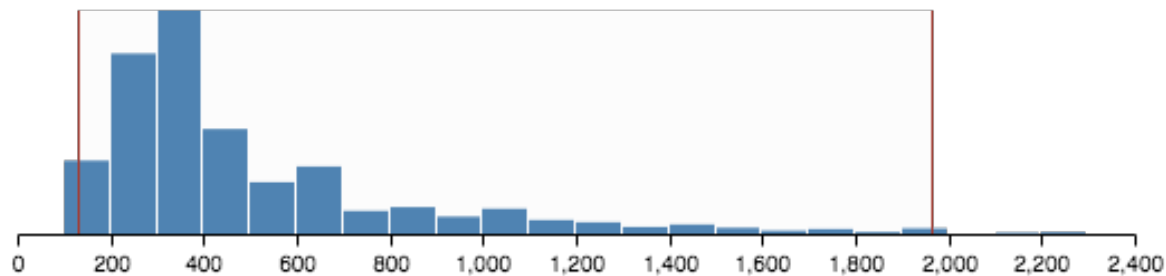
Arrival Delay (min)



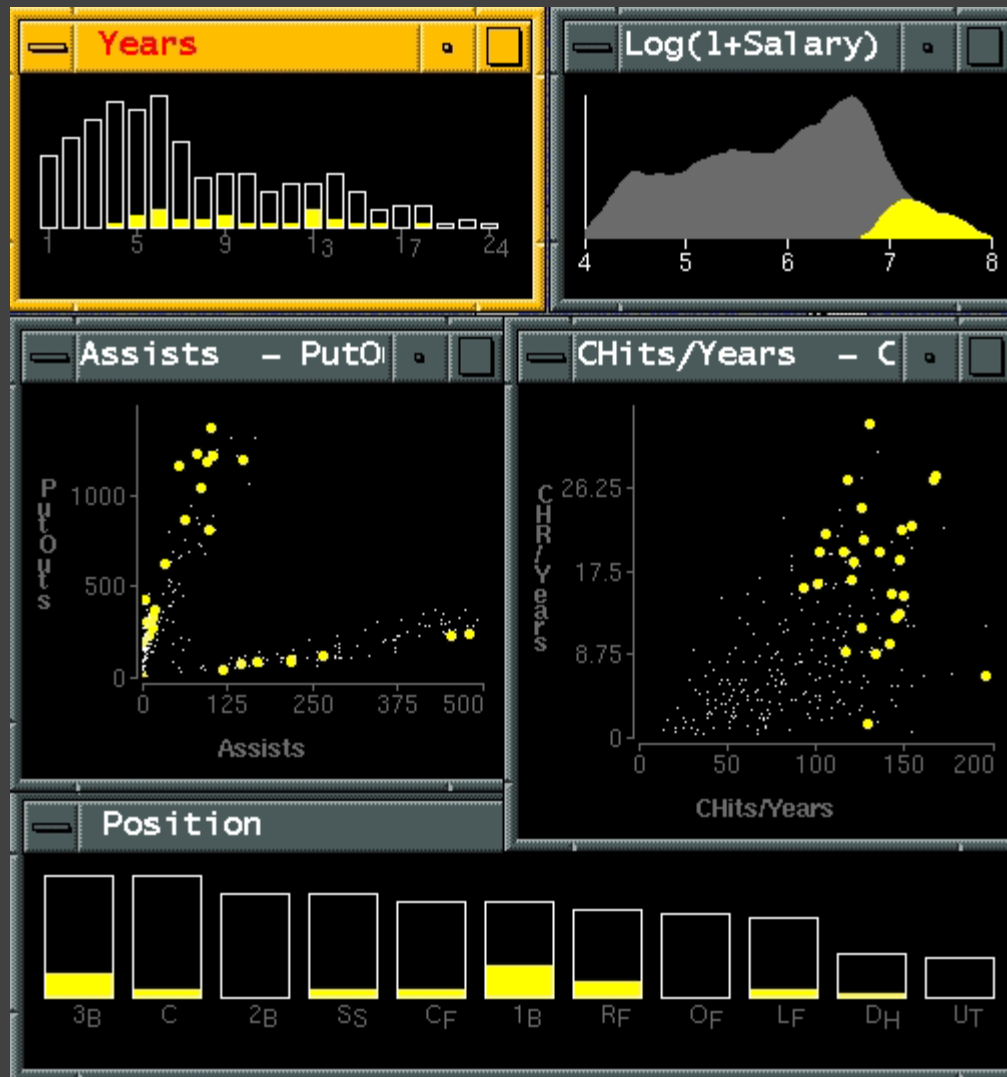
Local Departure Time (hour)



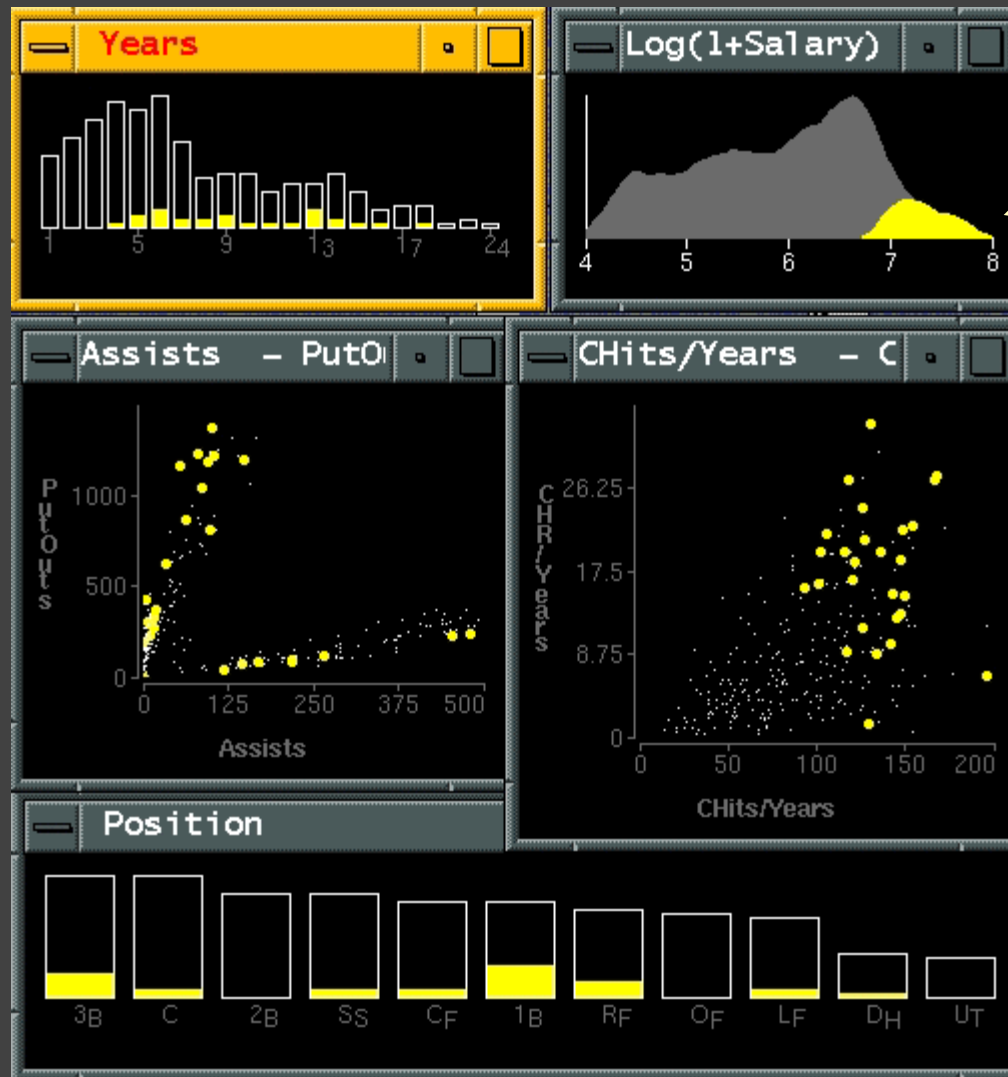
Travel Distance (miles)



Baseball Statistics [Wills 95]

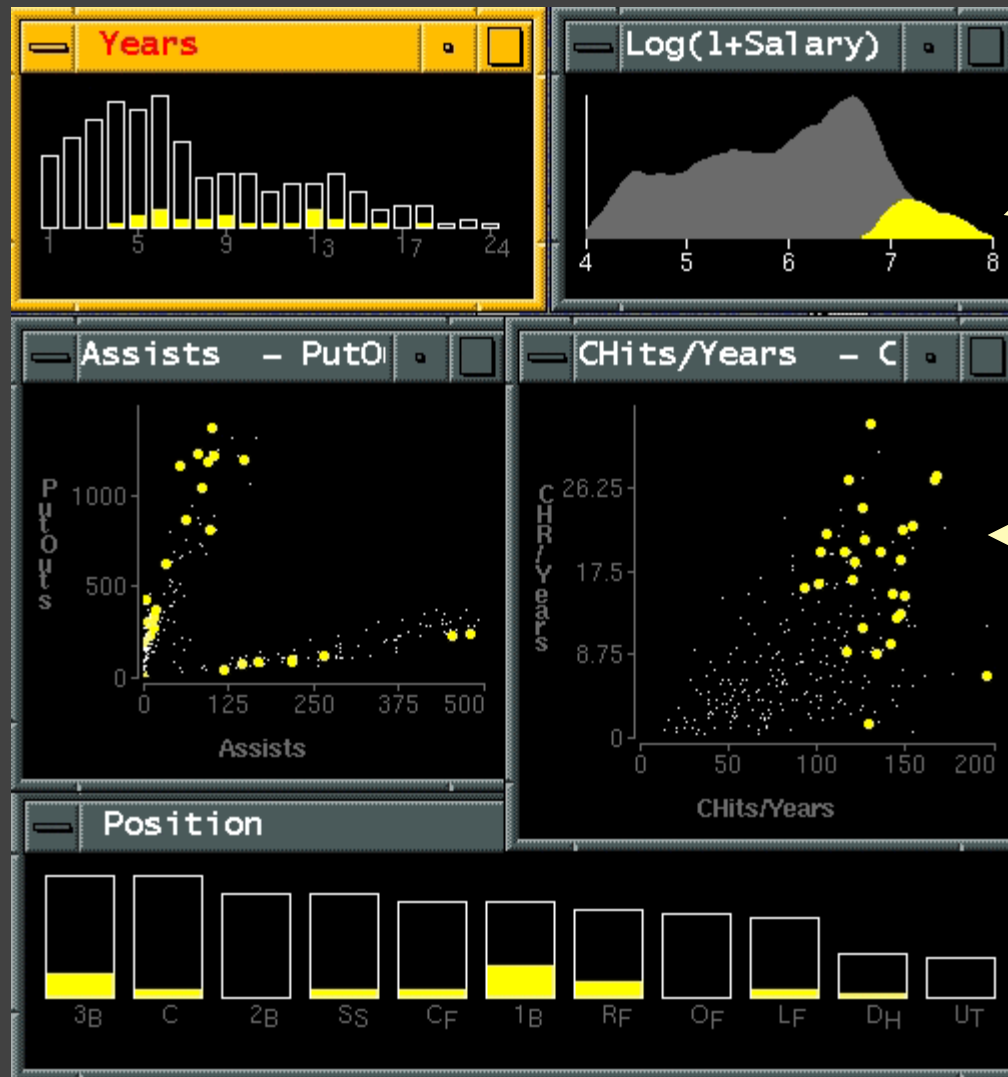


Baseball Statistics [Wills 95]



select high salaries

Baseball Statistics [Wills 95]

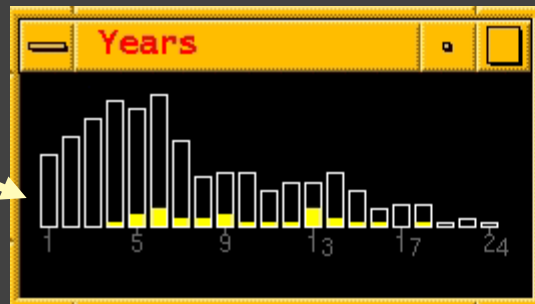


select high salaries

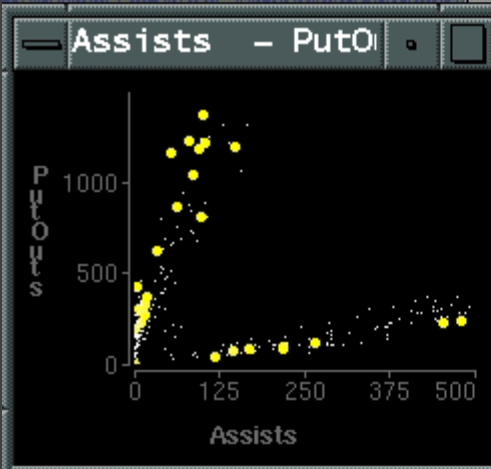
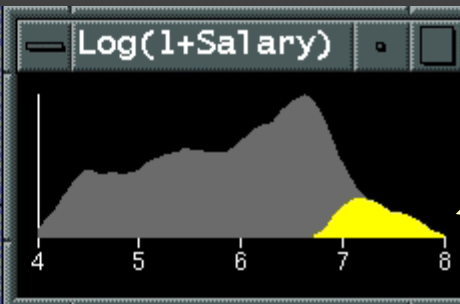
avg career HRs vs avg career hits (batting ability)

Baseball Statistics [Wills 95]

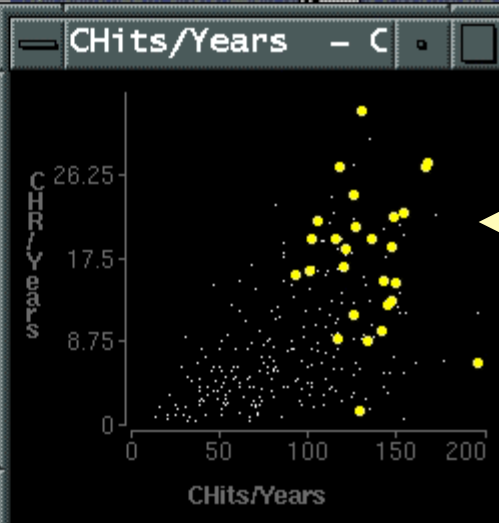
how long
in majors



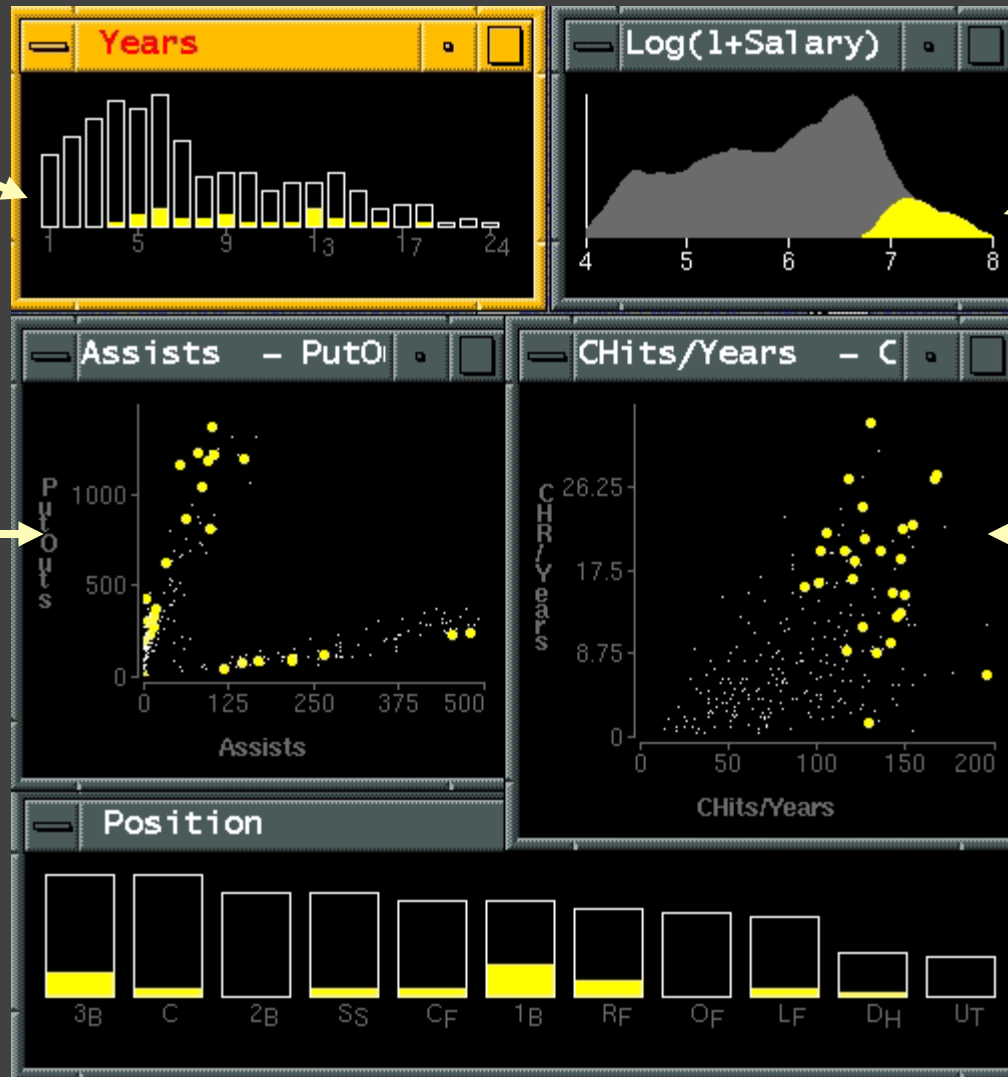
select high
salaries



avg career
HRs vs avg
career hits
(batting ability)



Baseball Statistics [Wills 95]



how long
in majors

select high
salaries

avg assists vs
avg putouts
(fielding ability)

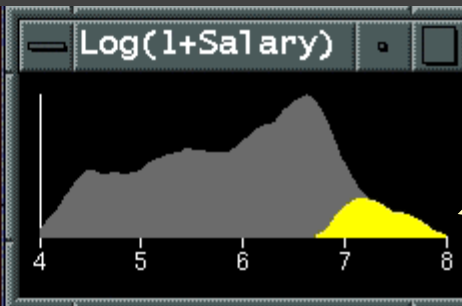
avg career
HRs vs avg
career hits
(batting ability)

Baseball Statistics [Wills 95]

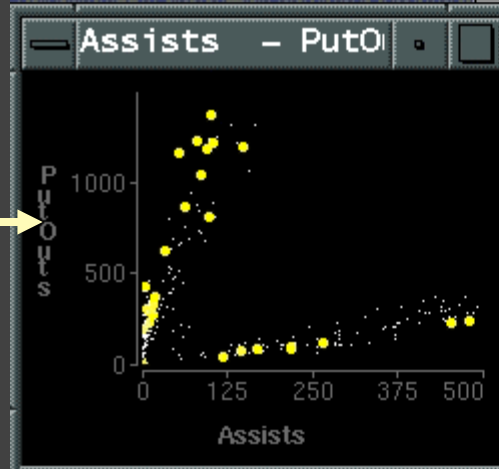
how long
in majors



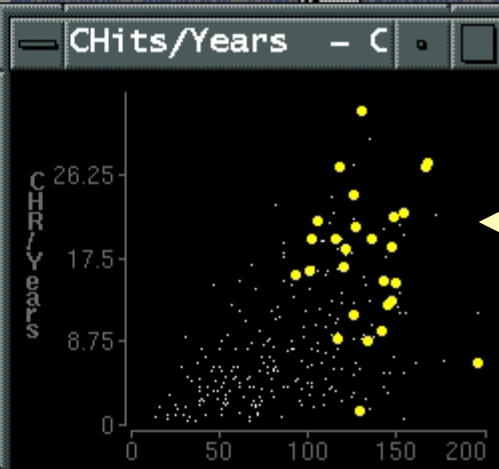
select high
salaries



avg assists vs
avg putouts
(fielding ability)



avg career
HRs vs avg
career hits
(batting ability)



distribution
of positions
played



Linking Assists to Positions



Dynamic Queries

Query & Results

```
SELECT house FROM seattle_homes
```

```
WHERE price < 1,000,000 AND bedrooms > 2
```

```
ORDER BY price
```

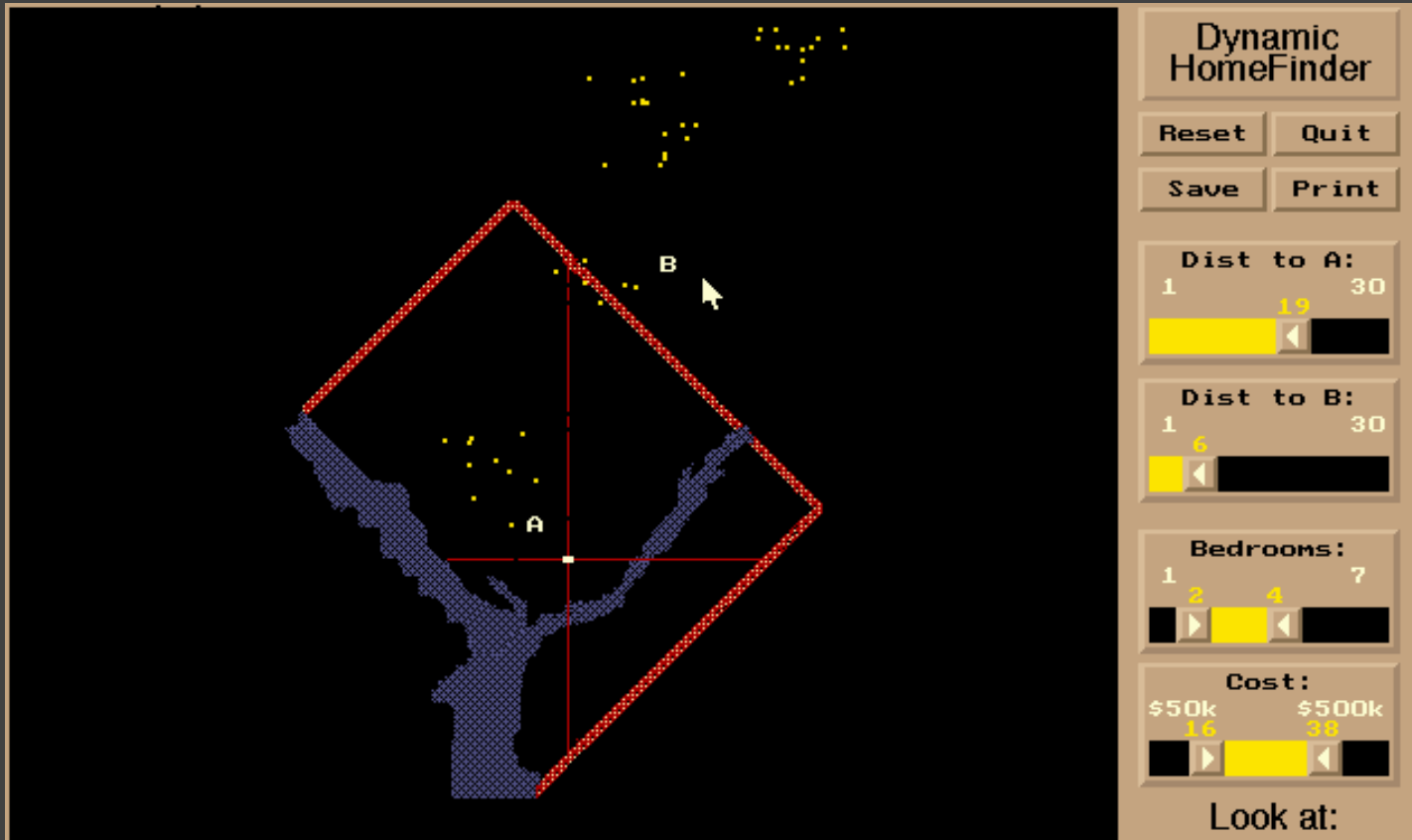
Dynamic Browser : DC Home Finder

IdNumber	Dwelling	Address	City
2	House	5256 S. Capitol St.	Beltsville, MD
4	House	5536 S. Lincoln St.	Beltsville, MD
5	House	5165 Jones Street	Beltsville, MD
8	House	5007 Jones Street	Beltsville, MD
9	House	4872 Jones Street	Beltsville, MD
17	House	5408 S. Capitol St.	Beltsville, MD
20	House	5496 S. Capitol St.	Beltsville, MD
85	Condo	5459 S. Lincoln St.	Laurel, MD
86	Condo	5051 S. Lincoln St.	Laurel, MD
88	Condo	5159 Hamilton Street	Laurel, MD
92	Condo	5132 Hamilton Street	Laurel, MD
93	Condo	5221 S. Lincoln St.	Laurel, MD
94	Condo	5043 S. Lincoln St.	Laurel, MD
95	Condo	4970 Jones Street	Laurel, MD
97	Condo	4677 Jones Street	Laurel, MD
98	Condo	4896 S. Capitol St.	Laurel, MD
99	Condo	5048 S. Capitol St.	Laurel, MD
100	Condo	4597 31st Street	Laurel, MD
101	Condo	5306 S. Lincoln St.	Laurel, MD
103	Condo	5562 Glass Road	Laurel, MD
105	Condo	5546 Hamilton Street	Laurel, MD
152	House	7670 31st Street	Upper Marlboro, MD

Issues with Textual Queries

1. For programmers
2. Rigid syntax
3. Only shows exact matches
4. Too few or too many hits
5. No hint on how to reformulate the query
6. Slow question-answer loop
7. Results returned as table

HomeFinder



The yellow dots above are homes in the DC area for sale. You may get more information on a home by selecting it.

You may drag the 'A' and 'B' distance markers to your office or any other location you want to live near.

Select distances, bedrooms, and cost ranges by dragging the corresponding slider boxes on the right.

Select specific home types and services by pressing the labeled buttons on the right.

Dynamic HomeFinder

Reset Quit

Save Print

Dist to A:
1 30
19

Dist to B:
1 30
6

Bedrooms:
1 2 4 7

Cost:
\$50k \$500k
16 38

Look at:
Hse TH Cnd

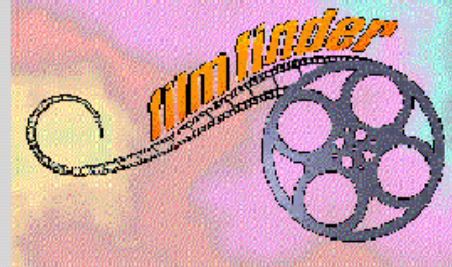
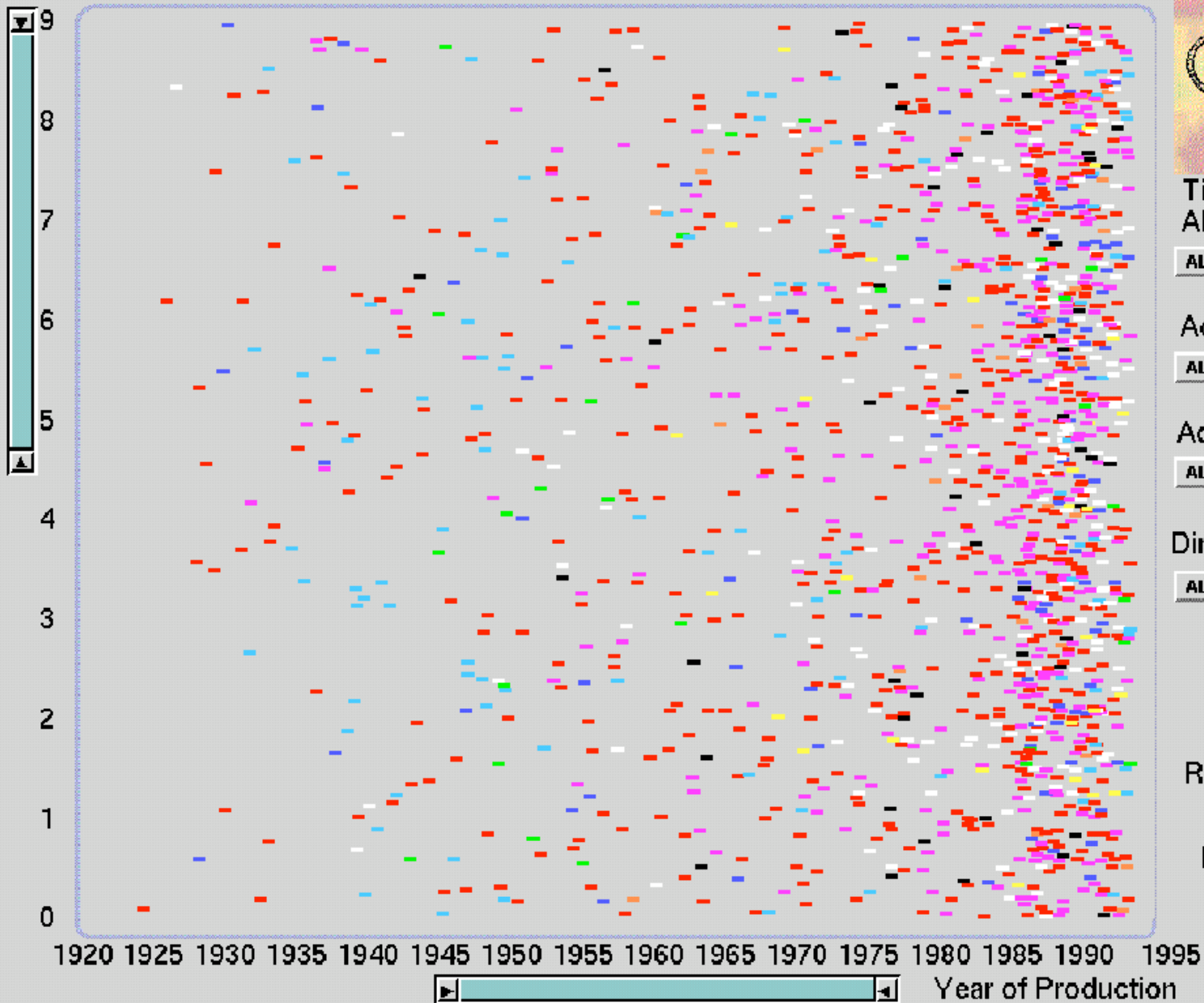
Features:
Grg Fp1
CAC New

[Williamson and Shneiderman 92]

Direct Manipulation

1. Visual representation of objects and actions
2. Rapid, incremental and reversible actions
3. Selection by pointing (not typing)
4. Immediate and continuous display of results

Popularity



Title : ALL

ALL ABCDFGHLMNPRSTWZ

Actor : ALL

ALL ABCDFGHJKLM PRSTWZ

Actress : ALL

ALL ABCDFGHJKLM PRSTWZ

Director : ALL

ALL ABCDFGHJKLM PRSTWZ

0 Length 450

0 450

Ratings G PG PG-13 R

Films Shown: 1455

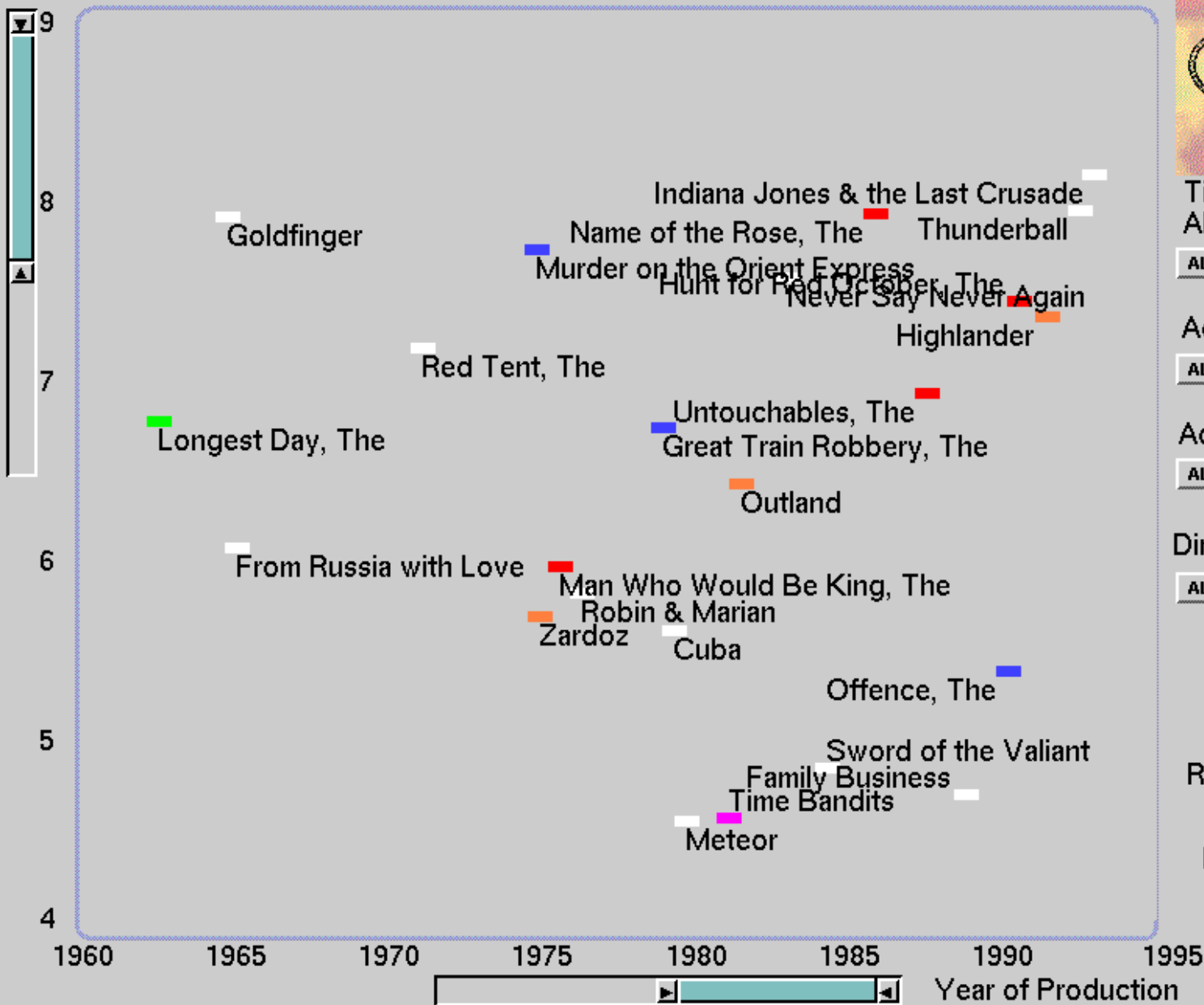


Copyright (C) 1993 HCIL

- ALL
- Drama
- Mystery
- Comedy
- Music
- Action
- War
- Sci-Fi
- Western
- Horror

[Ahlberg and Shneiderman 94]

Popularity



Title : ALL
 ALL
A B C D F G H L M N P R S T W Z

Actor : Connery, Sean
 ALL
AB C D FG H J K L M PR S TW Z

Actress : ALL
 ALL
AB C D FGH K L M P R S TW Z

Director : ALL
 ALL
AB C D FGH JKL M PR S TW Z

60 Length 269

0 450
 Ratings G PG
 PG-13 R

Films Shown: 24



Copyright (C) 1993 HCIL

- ALL
- Drama
- Mystery
- Comedy
- Music
- Action
- War
- Sci-Fi
- Western
- Horror

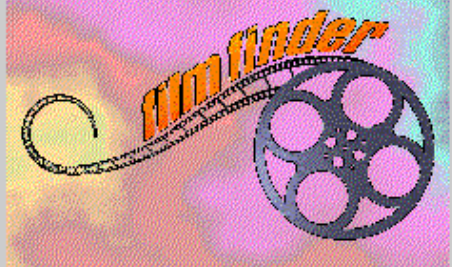
Alphaslider (?)

Title :

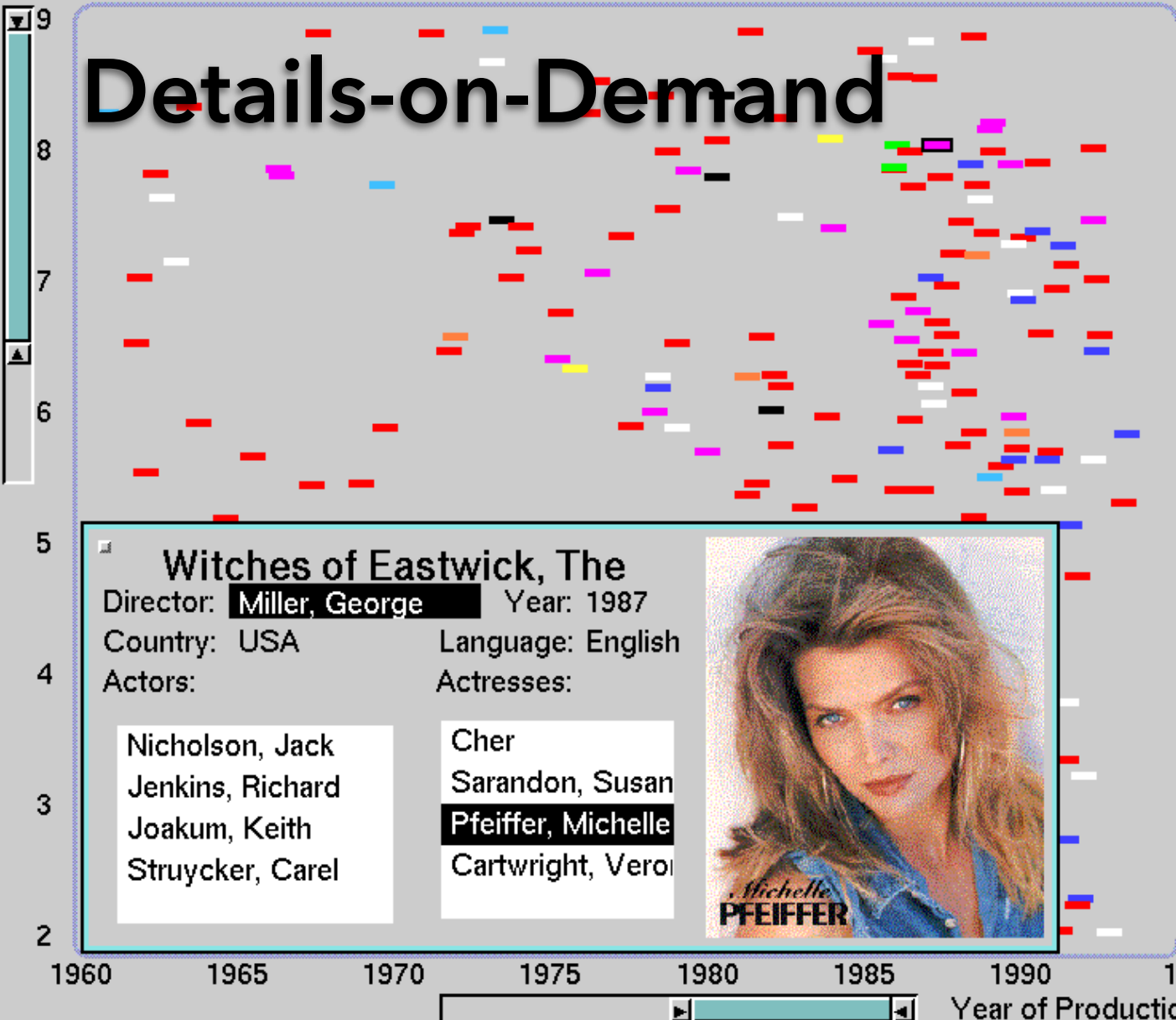
Moonstruck

ALL

A B C D F G H L M N P R S T W Z




Details-on-Demand



Witches of Eastwick, The
 Director: **Miller, George** Year: 1987
 Country: USA Language: English
 Actors: Actresses:

Nicholson, Jack	Cher
Jenkins, Richard	Sarandon, Susan
Joakum, Keith	Pfeiffer, Michelle
Struycker, Carel	Cartwright, Veron



Title : ALL
 ALL
 A B C D F G H L M N P R S T W Z

Actor : ALL
 ALL
 A B C D F G H J K L M P R S T W Z

Actress : Pfeiffer, Michelle
 ALL
 A B C D F G H K L M P R S T W Z

Director : Miller, George
 ALL
 A B C D F G H J K L M P R S T W Z

105 Length 231
 0 450

Ratings G PG
 PG-13 R

Films Shown: 210



Copyright (C) 1993 HCIL

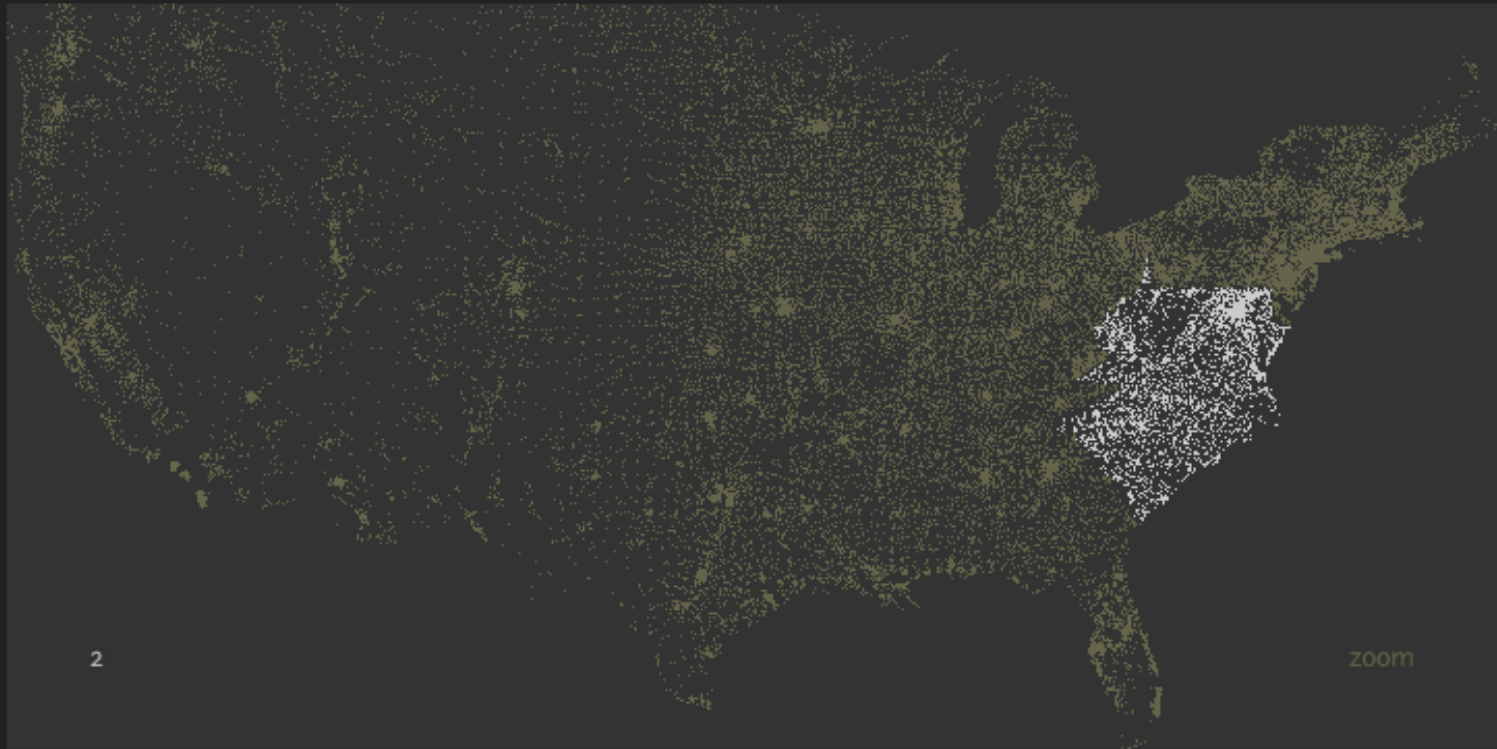
- ALL
- Drama
- Mystery
- Comedy
- Music
- Action
- War
- Sci-Fi
- Western
- Horror

- The Attribute Explorer

Attribute Explorer [Spence & Tweedie 96]

- Video Clip

Zipdecode [Fry 04]

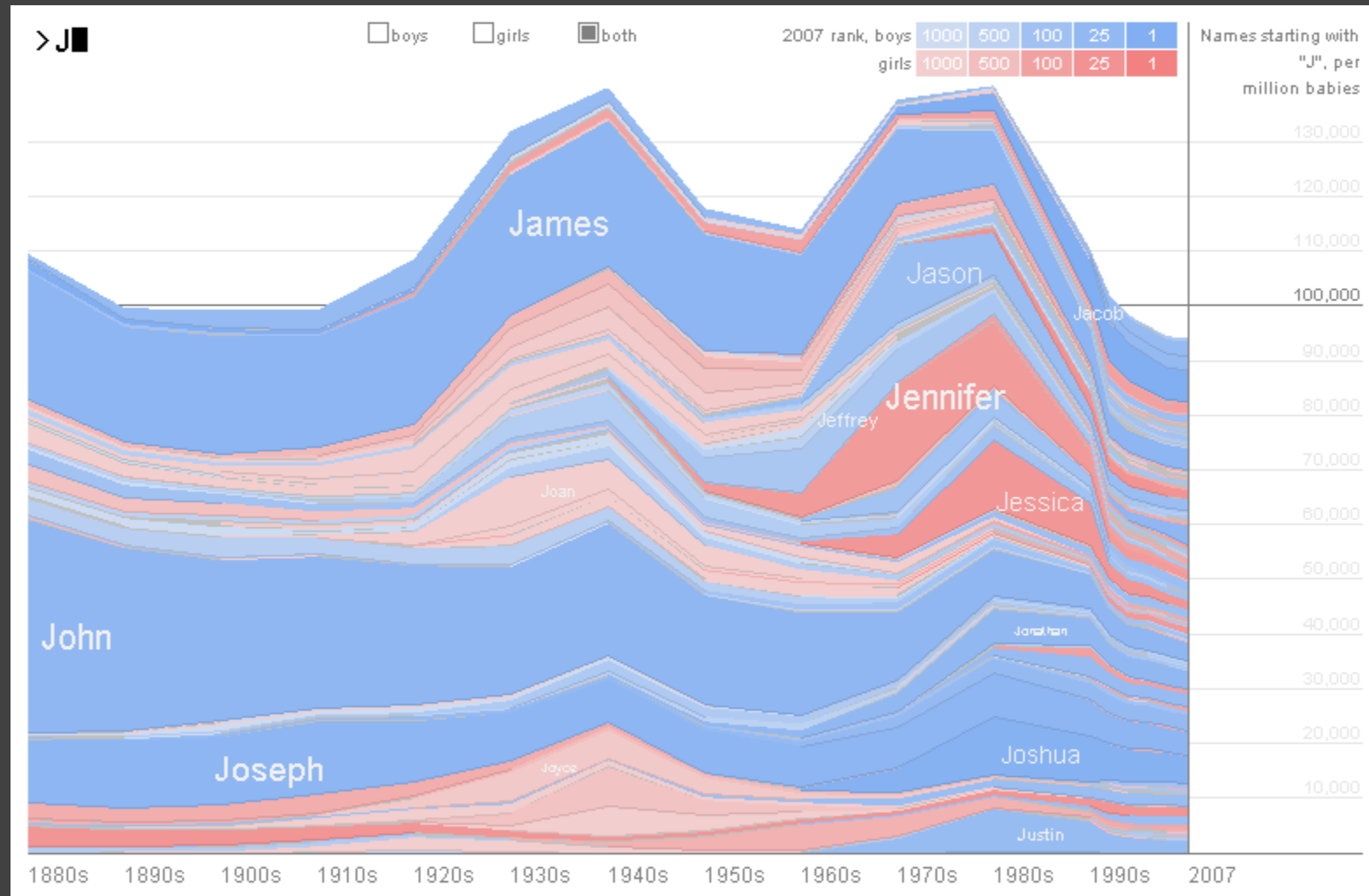


Hit the letter **z**, or click the word **zoom** to enable or disable zooming.

Hold down **shift** while typing a number to replace the previous number (U.S. keyboards only).

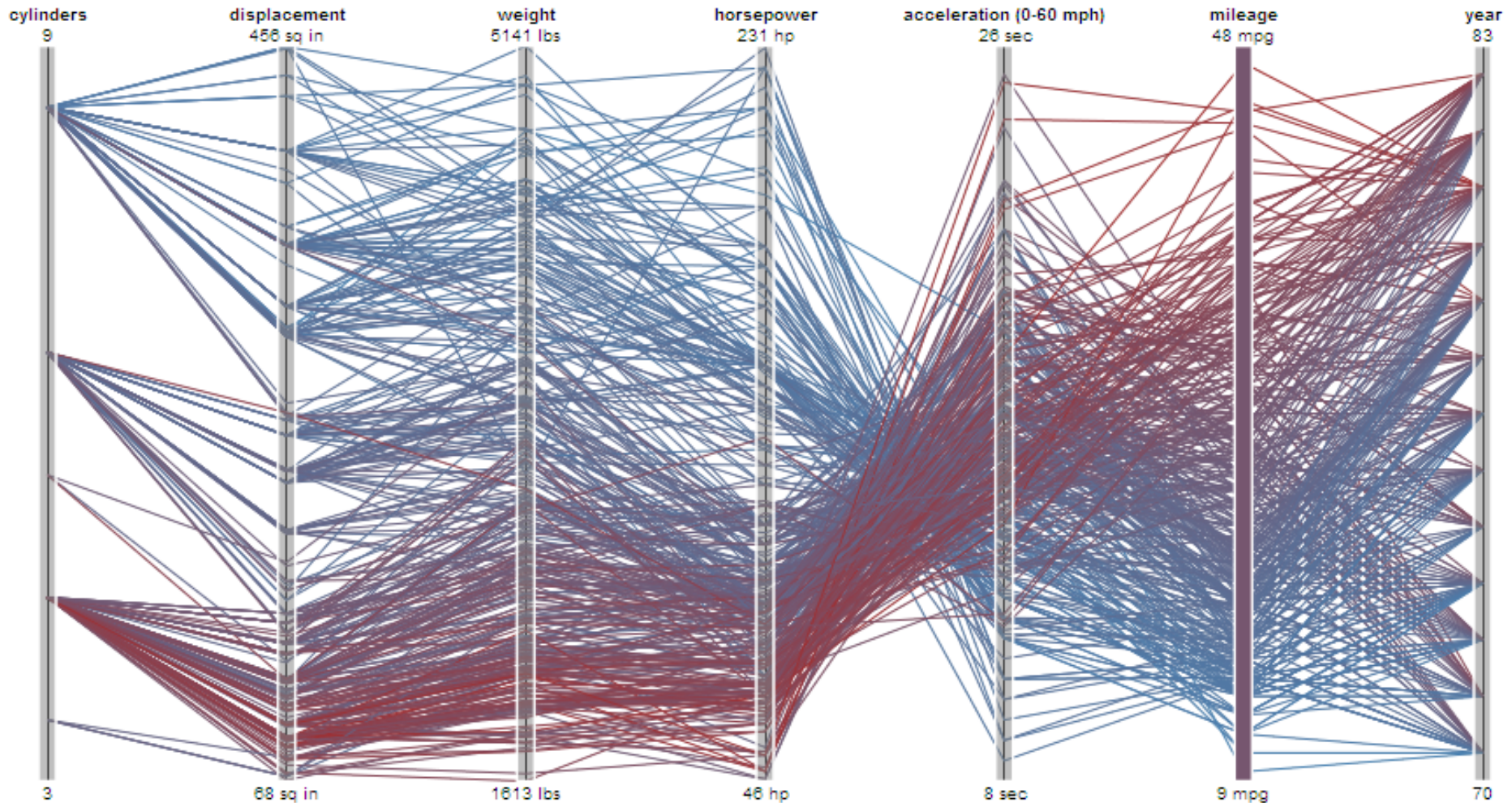
<http://benfry.com/zipdecode/>

NameVoyager [Wattenberg 06]

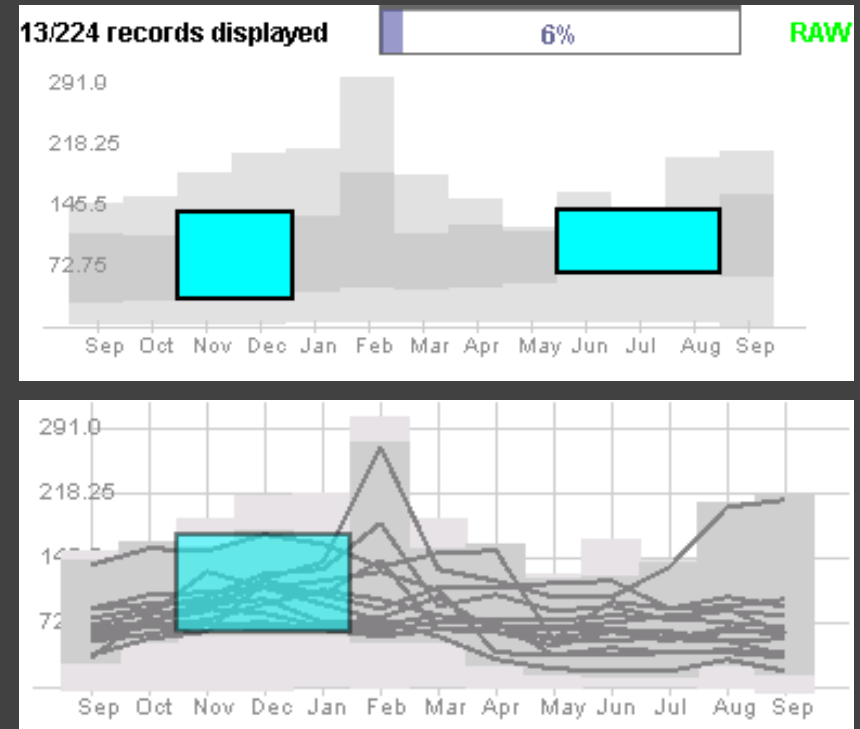
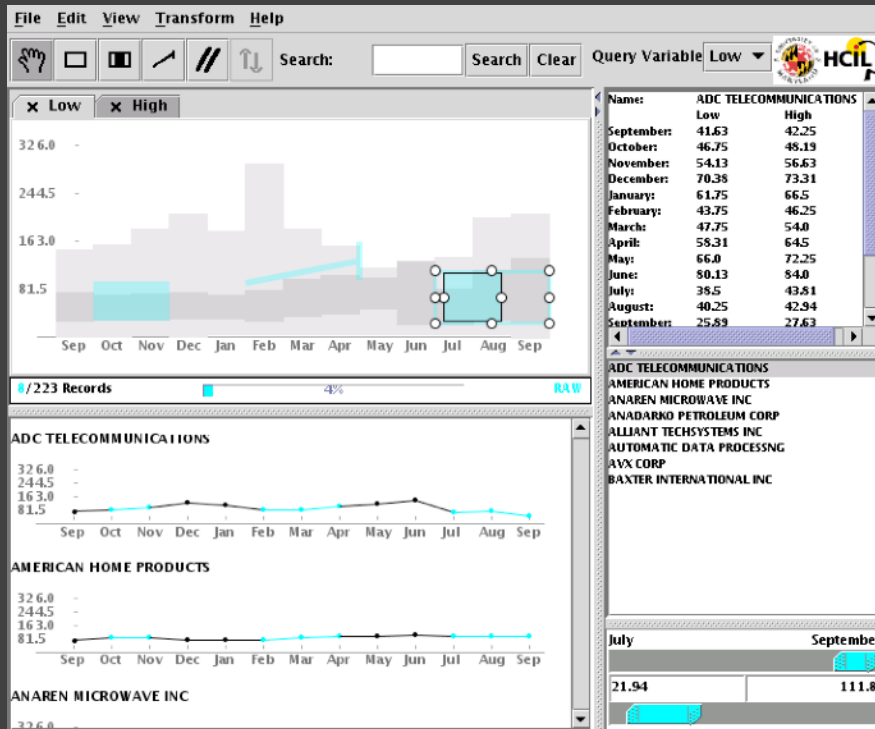


<http://www.babynamewizard.com/voyager>

Parallel Coordinates [Inselberg]



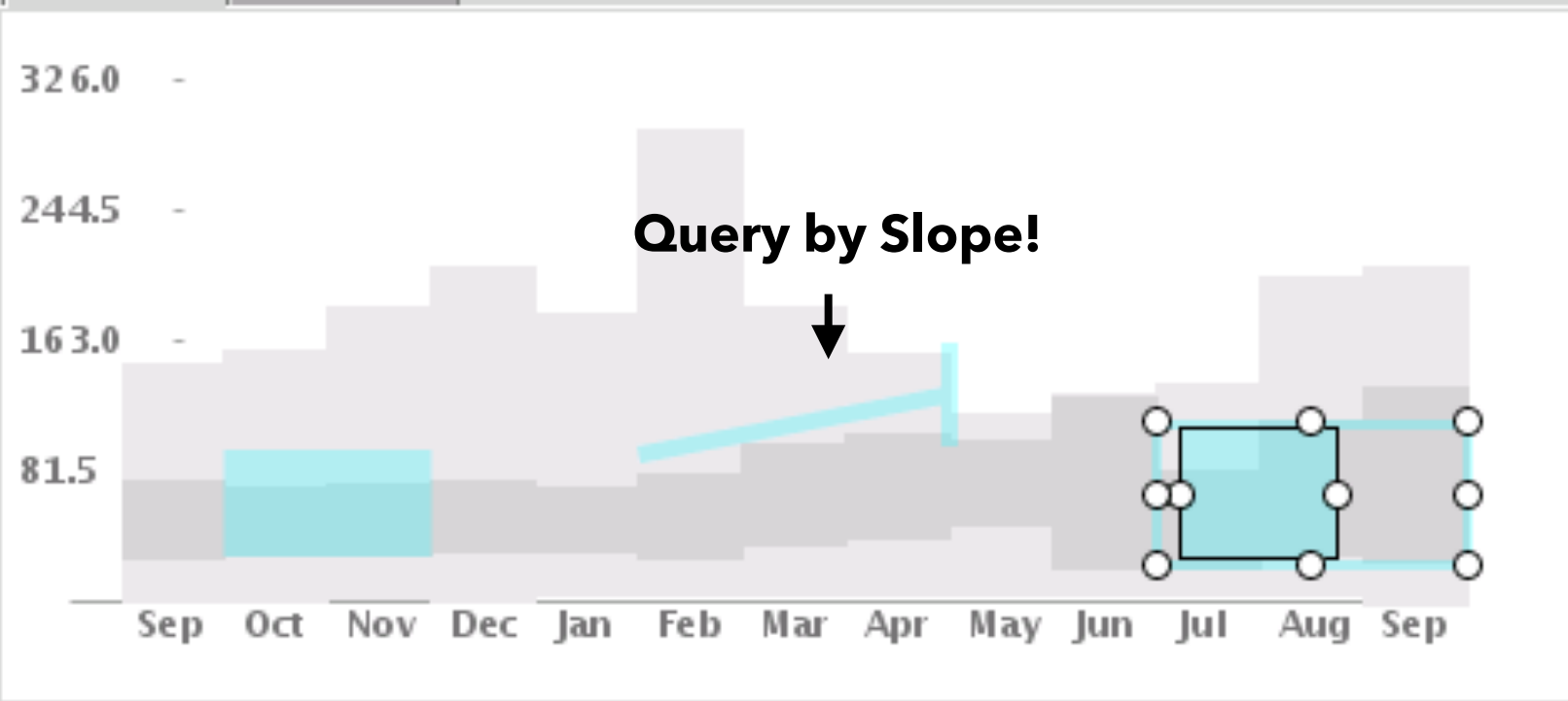
TimeSearcher [Hocheiser 02]



Builds on Wattenberg's [2001] idea for sketch-based queries of time-series data.

X Low

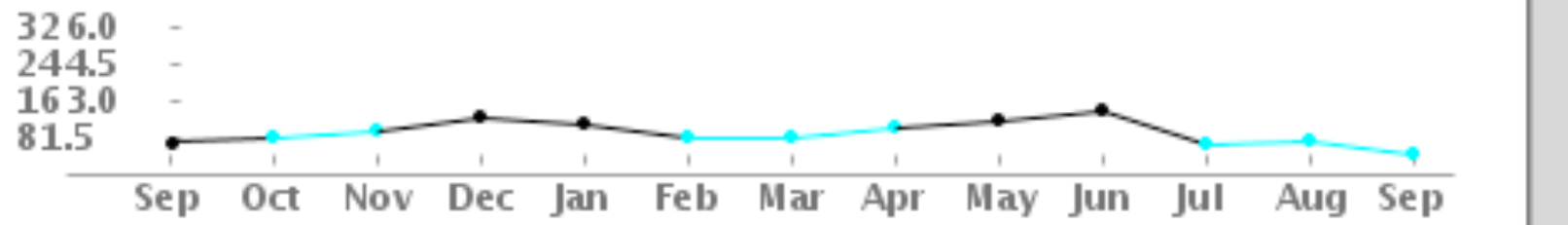
X High



- Name:
- September:
- October:
- November:
- December:
- January:
- February:
- March:
- April:
- May:
- June:
- July:
- August:
- September:

8/223 Records ■ 4% RAW

ADC TELECOMMUNICATIONS



AMERICAN HOME PRODUCTS

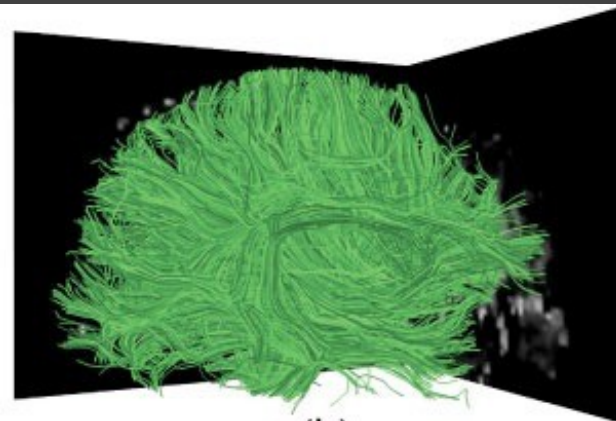


- ADC TELECOMM
- AMERICAN HOM
- ANAREN MICRO
- ANADARKO PET
- ALLIANT TECHS
- AUTOMATIC DA
- AVX CORP
- BAXTER INTERN

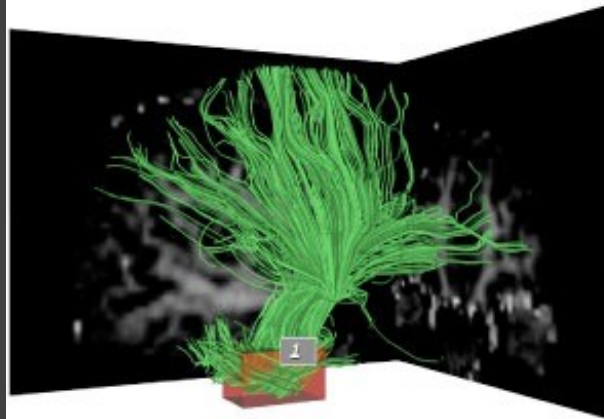
3D Dynamic Queries [Akers 04]



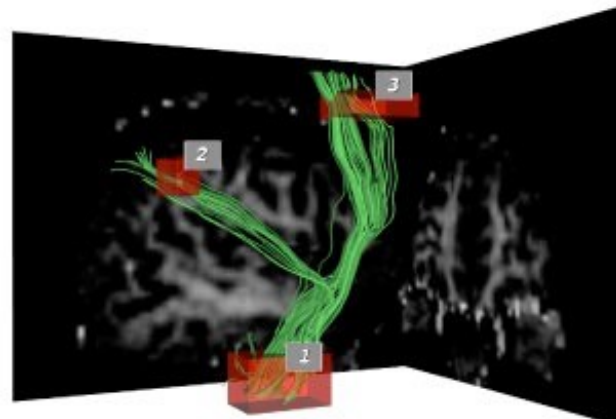
(a)



(b)

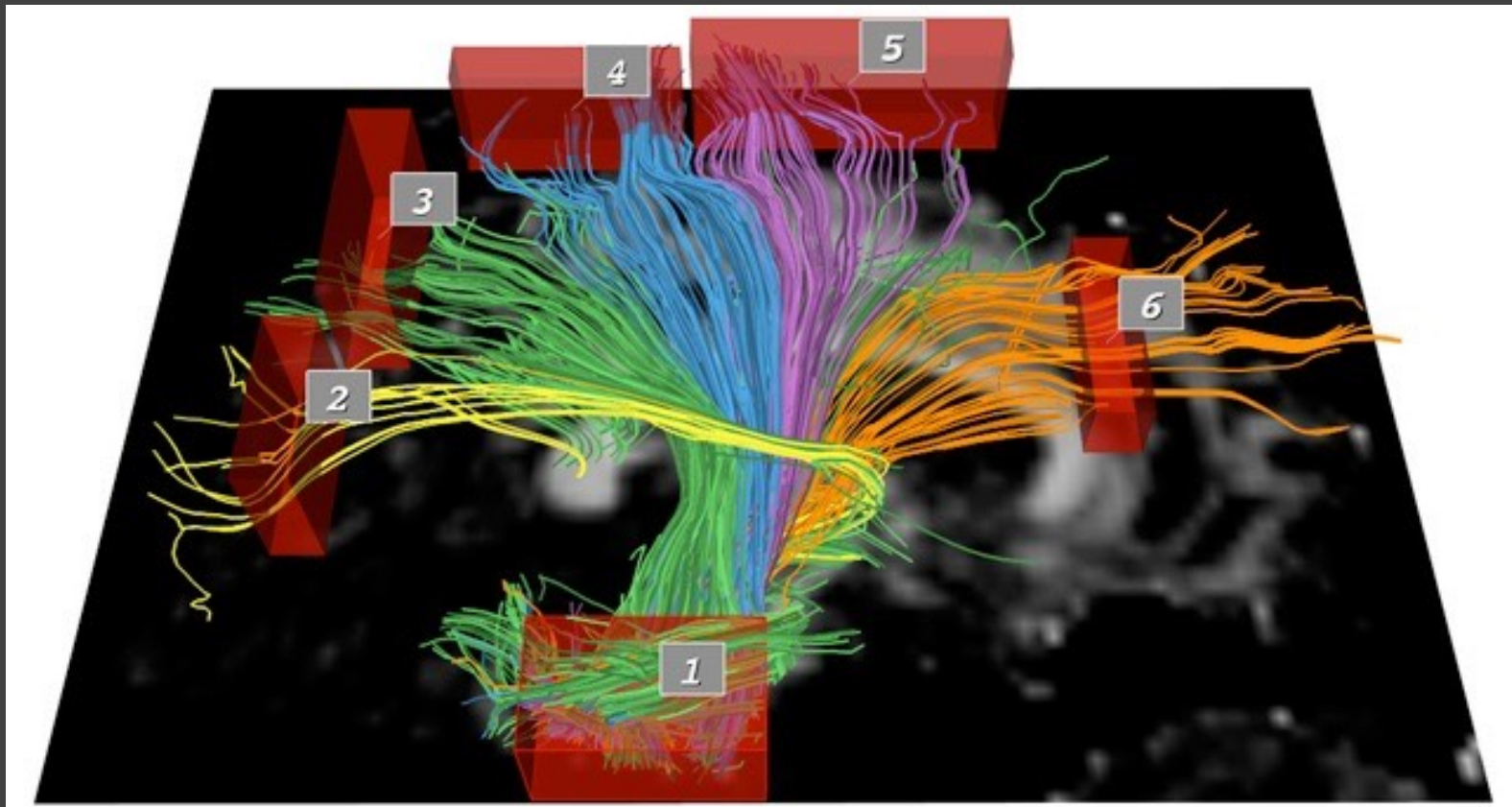


(c)



(d)

3D Dynamic Queries [Akers 04]



Pros & Cons

Pros

Controls useful for both novices and experts
Quick way to explore data

Pros & Cons

Pros

Controls useful for both novices and experts
Quick way to explore data

Cons

Simple queries
Lots of controls
Amount of data shown limited by screen space
Who would use these kinds of tools?

Summary

Most visualizations are interactive

Even passive media elicit interactions

Good visualizations are task dependent

Pick the right interaction technique

Consider the semantics of the data domain

Fundamental interaction techniques

Selection / Annotation, Sorting, Navigation,

Brushing & Linking, Dynamic Queries

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

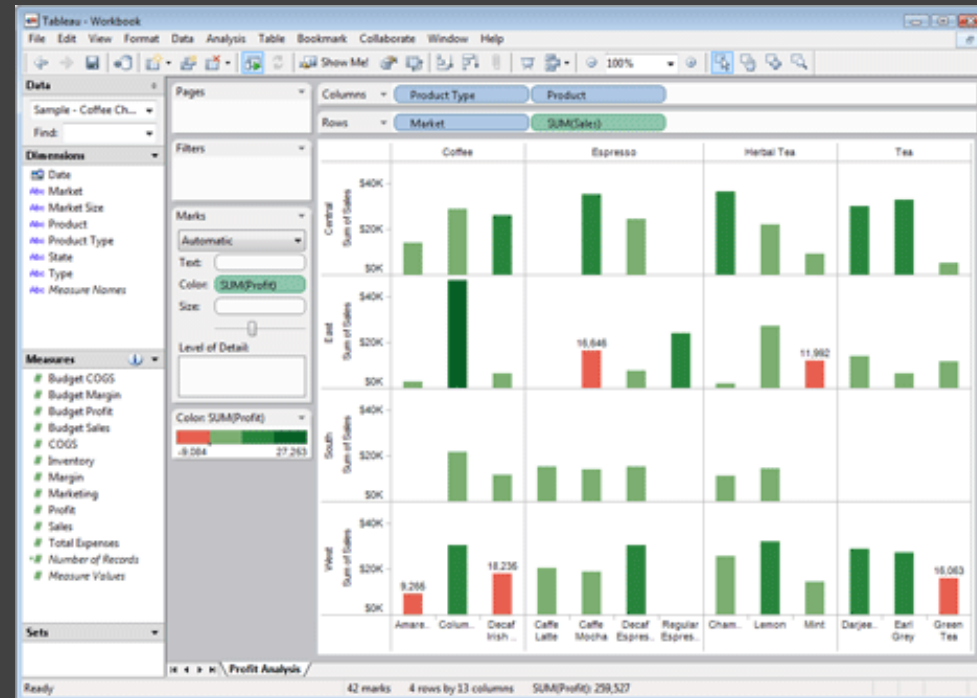
Interact with data

Refine your questions

Author a report

Screenshots of most insightful views (10+)

Include titles and captions for each view



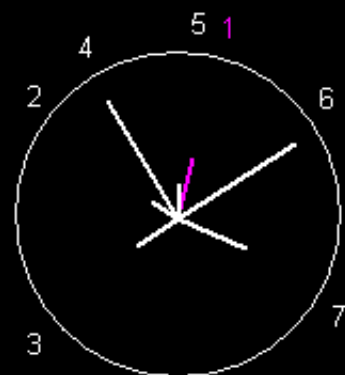
Due by 11:59pm

Tuesday, Oct 16

Dimensionality Reduction

File Options

Dimensionality Reduction



<http://www.ggobi.org/>

1:0.099,0.367(243.00)

2:-0.157,0.106(47.74)

3:-0.251,-0.178(9.00)

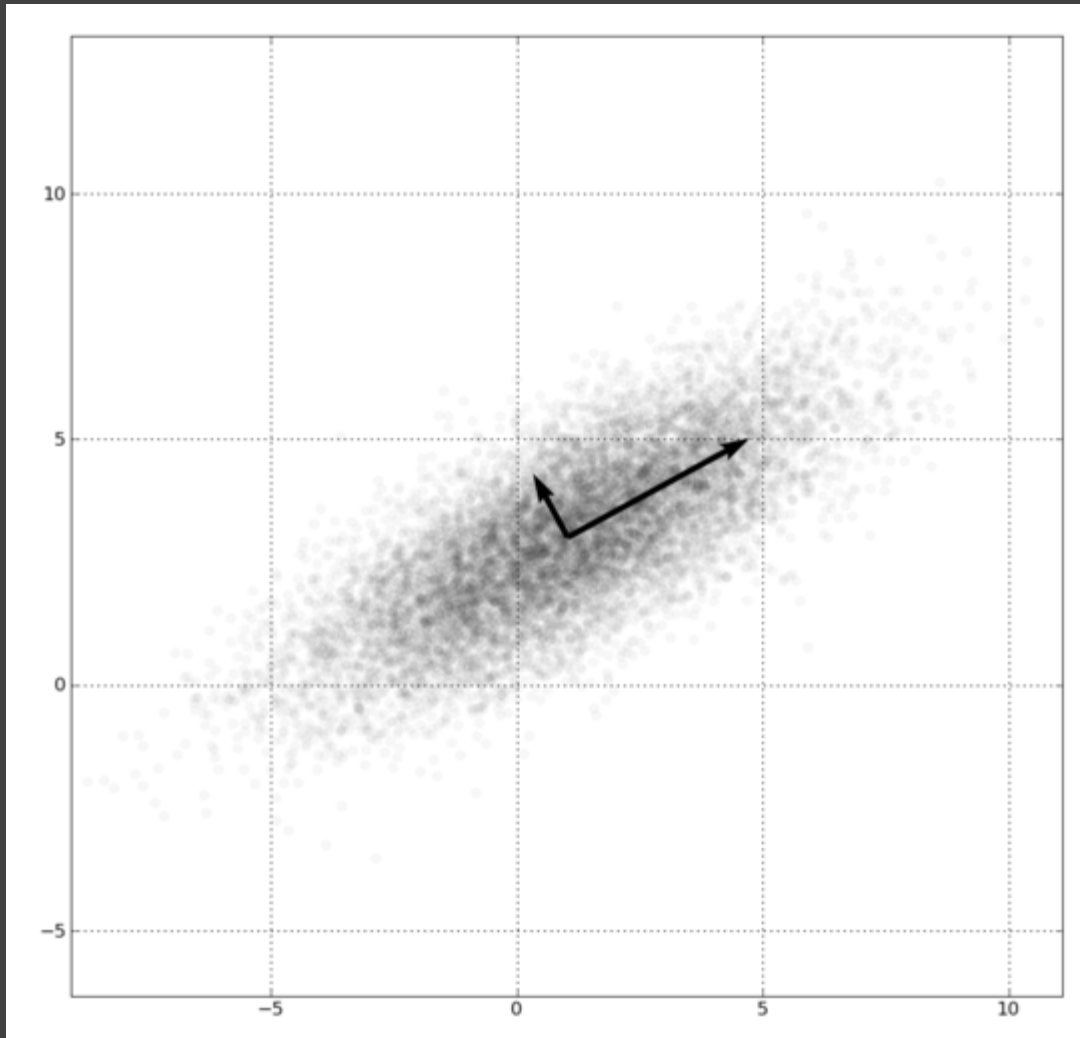
4:-0.442,0.723(1.00)

5:0.016,0.222(1.00)

6:0.726,0.461(3.00)

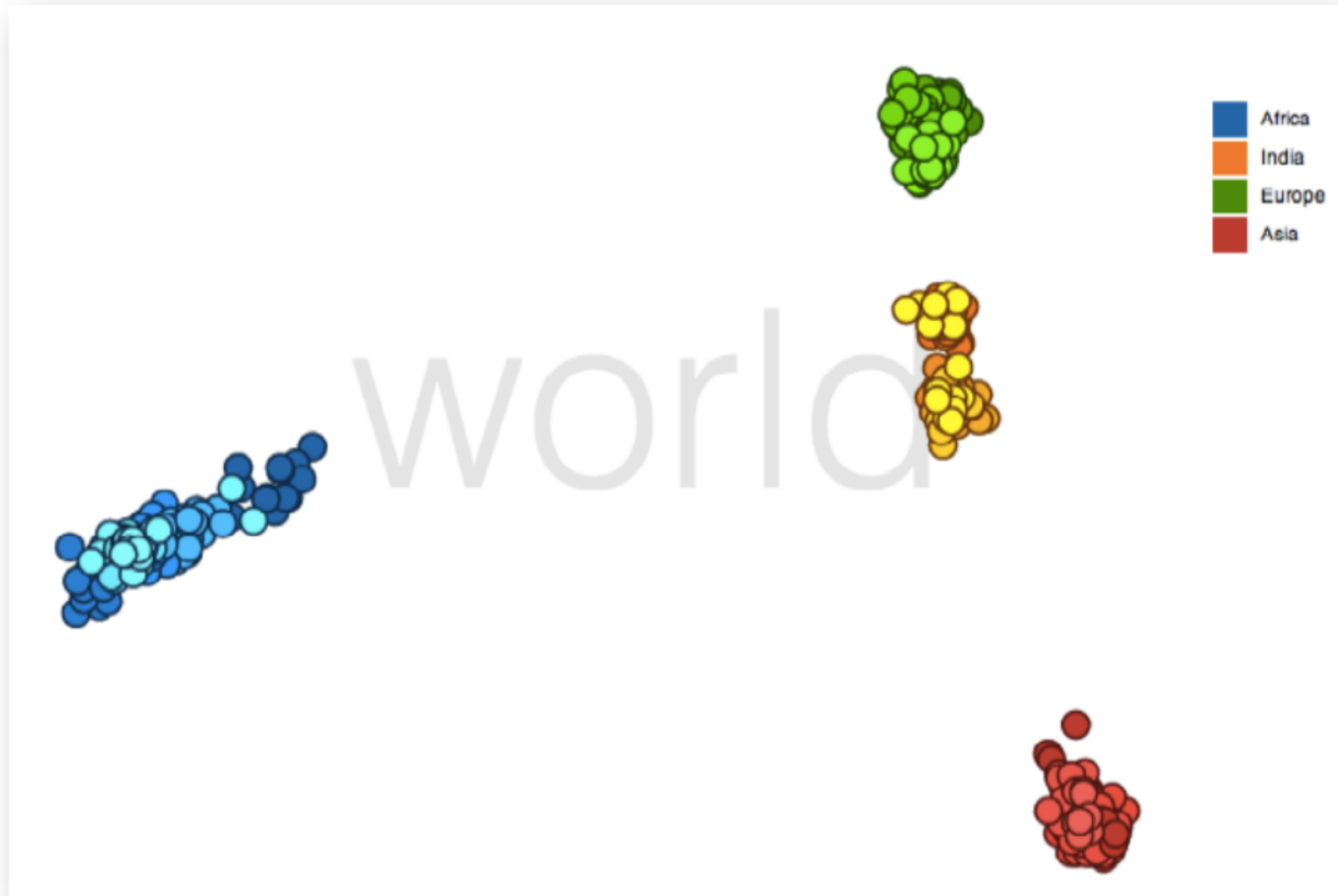
7:0.424,-0.195(1.00)

Principal Components Analysis



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

PCA of Genomes [Demiralp et al. '13]



Many Reduction Techniques!

General Strategies:

Matrix Factorization

Nearest Neighbor (Topological) Methods

Popular Techniques:

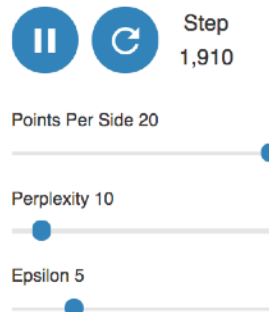
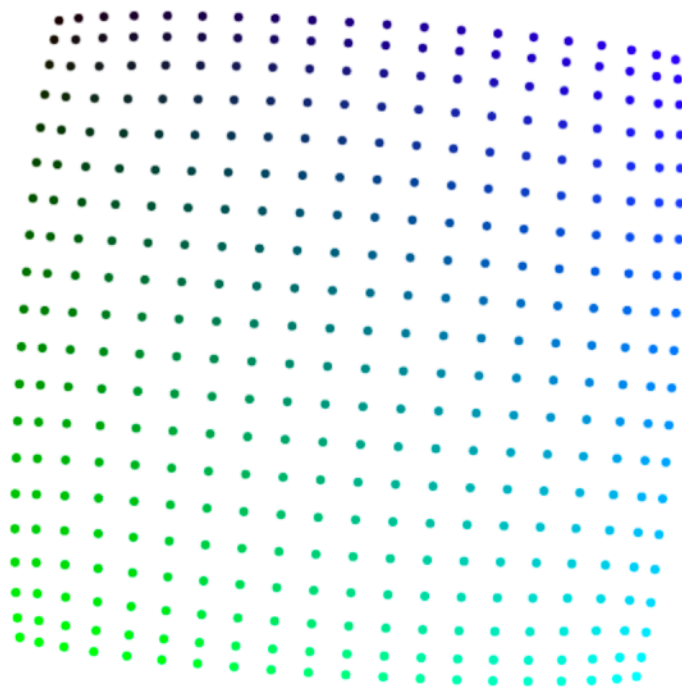
Principal Components Analysis (PCA)

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

Uniform Manifold Approx. & Projection (UMAP)

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.



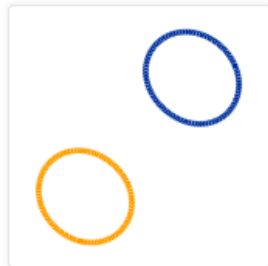
A square grid with equal spacing between points. Try convergence at different sizes.

distill.pub

Visualizing t-SNE [Wattenberg et al. '16]



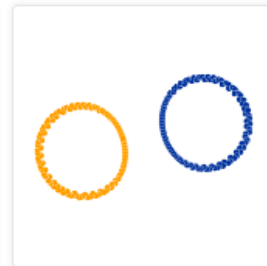
Original



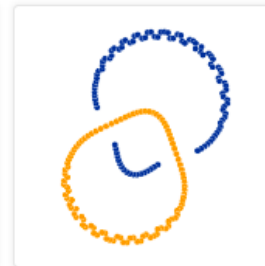
Perplexity: 2
Step: 5,000



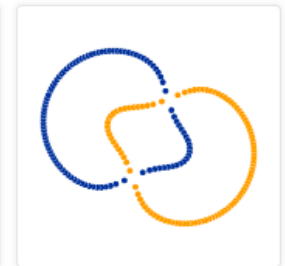
Perplexity: 5
Step: 5,000



Perplexity: 30
Step: 5,000



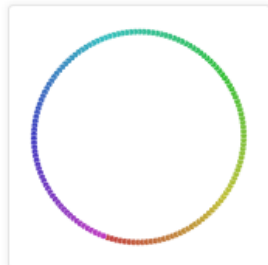
Perplexity: 50
Step: 5,000



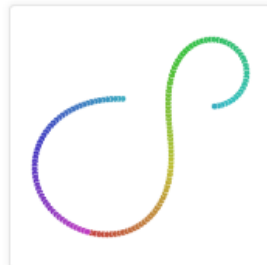
Perplexity: 100
Step: 5,000



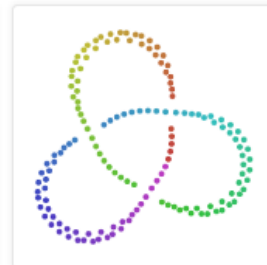
Original



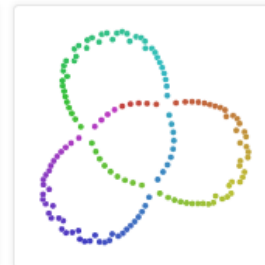
Perplexity: 2
Step: 5,000



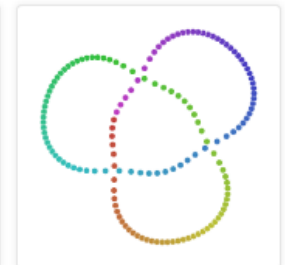
Perplexity: 5
Step: 5,000



Perplexity: 30
Step: 5,000



Perplexity: 50
Step: 5,000



Perplexity: 100
Step: 5,000

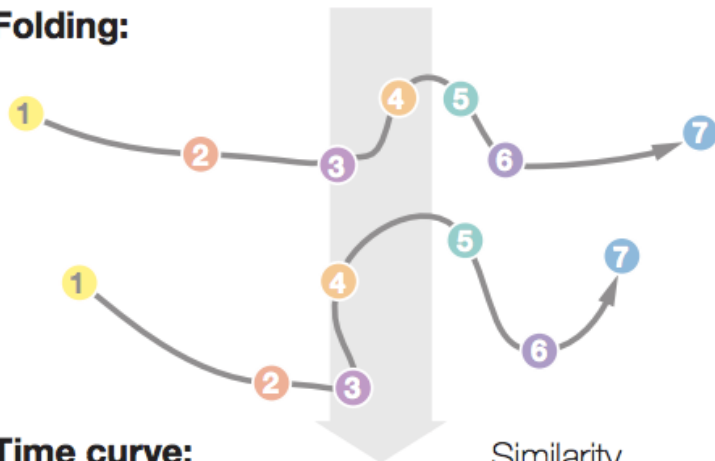
Time Curves [Bach et al. '16]

Timeline:



Circles are data cases with a time stamp.
Similar colors indicate similar data cases.

Folding:

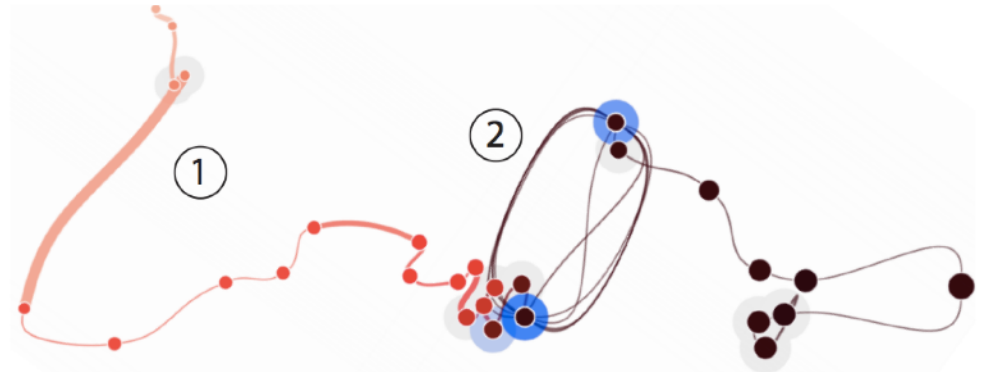


Time curve:

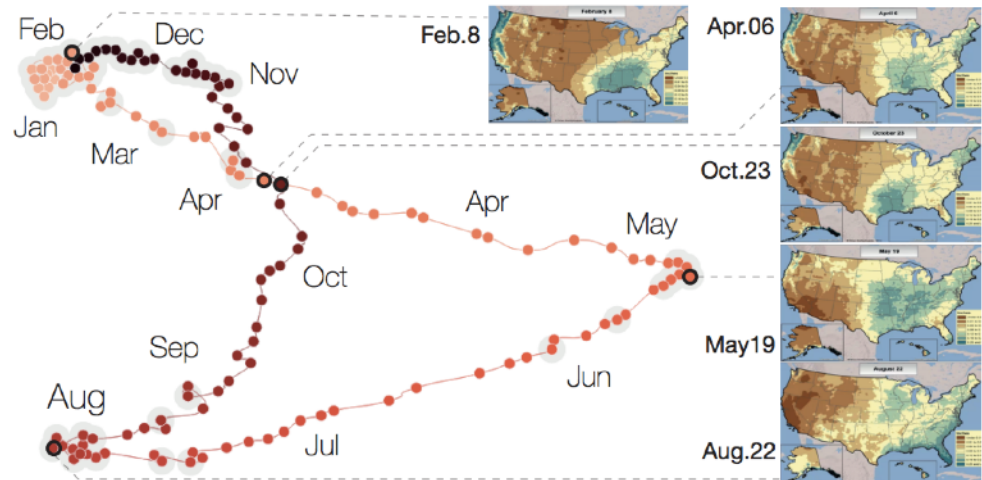


The temporal ordering of data cases is preserved.
Spatial proximity now indicates similarity.

(a) Folding time



Wikipedia "Chocolate" Article



U.S. Precipitation over 1 Year