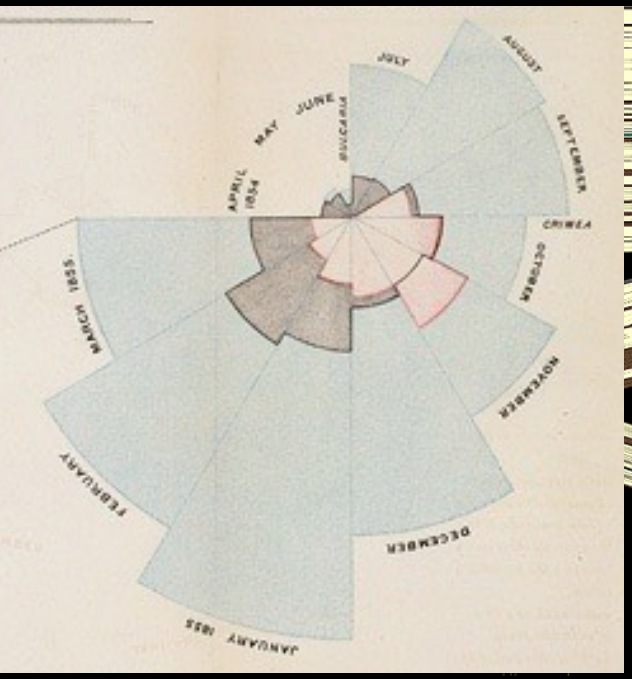
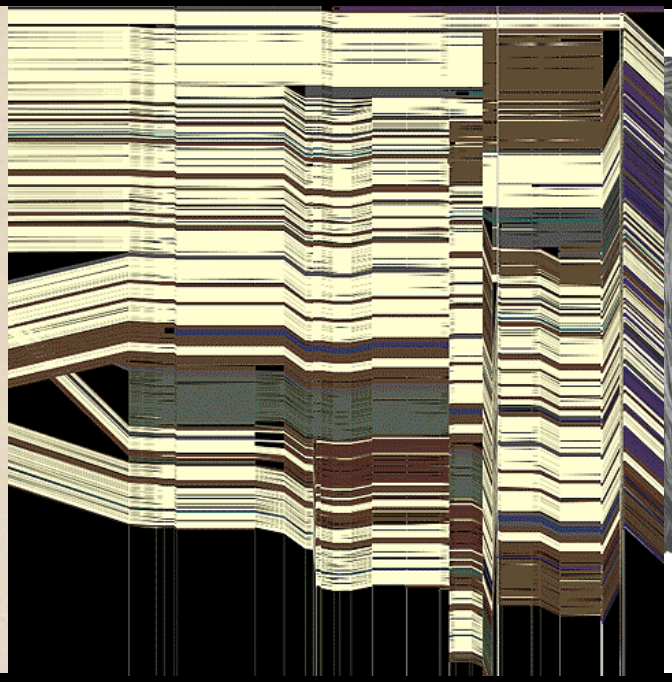
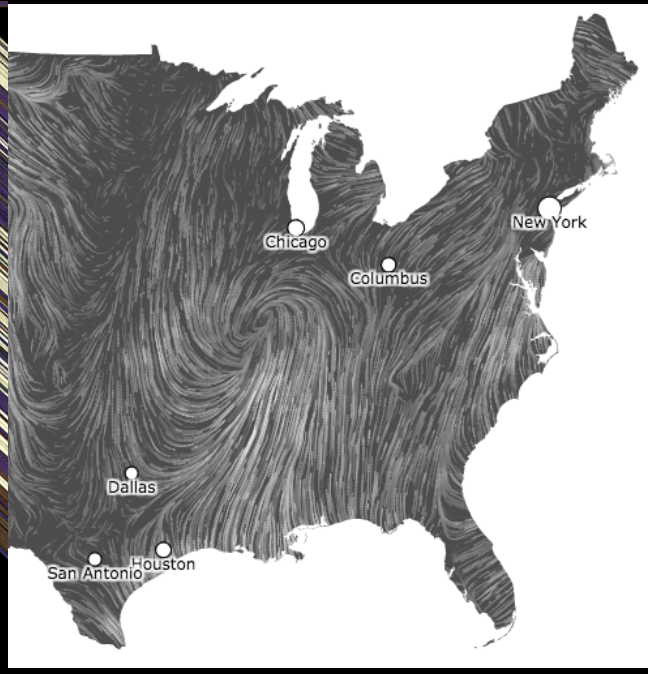
CSE 512 - Data Visualization

Interaction







Jeffrey Heer University of Washington

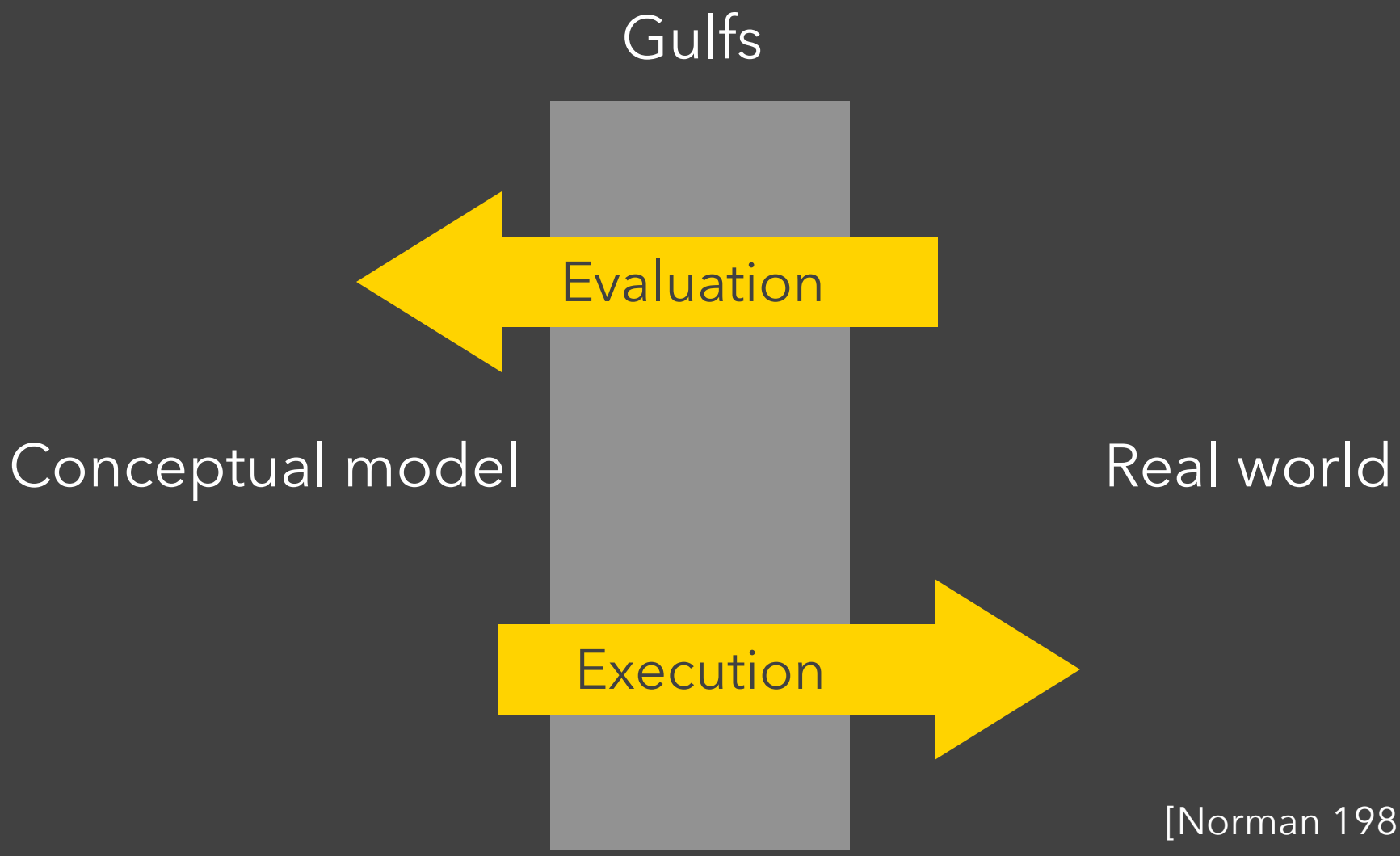
[There is an] apparent challenge that computational artifacts pose to the longstanding distinction between the physical and the social, in the special sense of those things that one designs, builds, and uses, on the one hand, and those things with which one communicates, on the other.

“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.

[Norman 1986]

Gulf of Execution

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

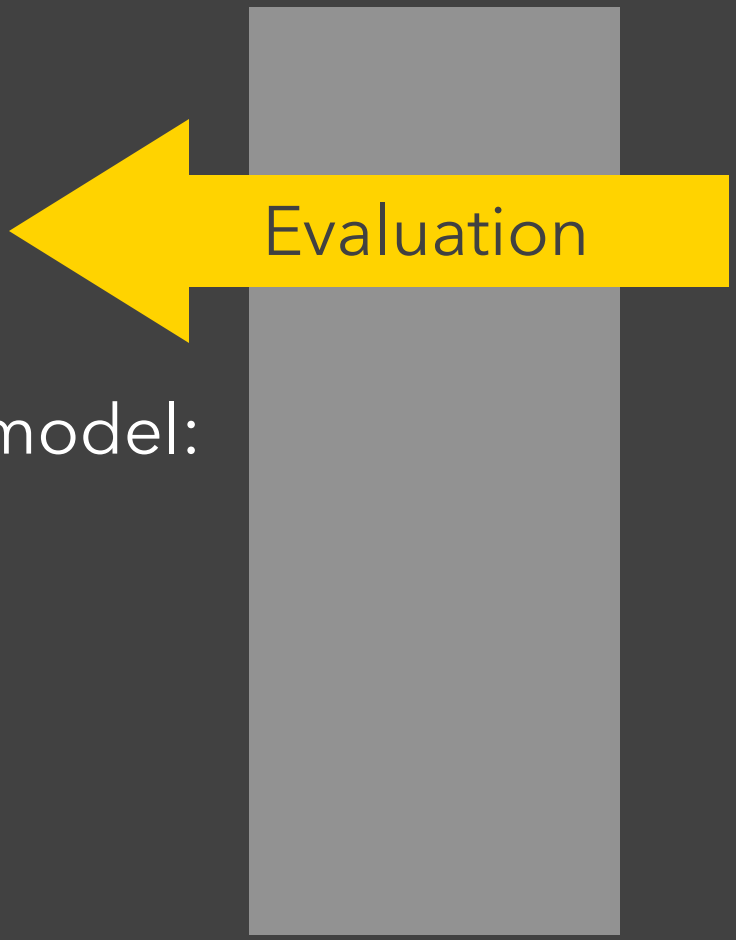
Gulf of Evaluation

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

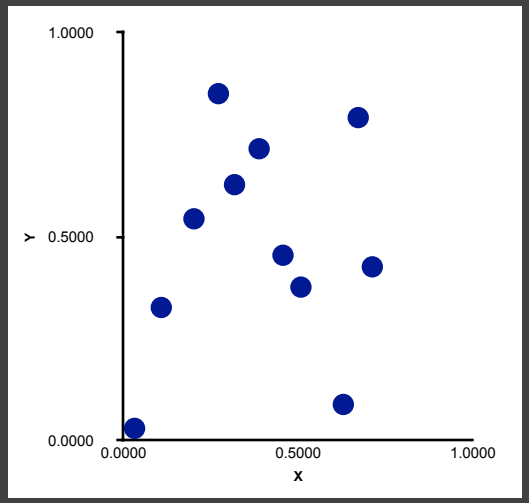
Gulf of Evaluation

Gulf

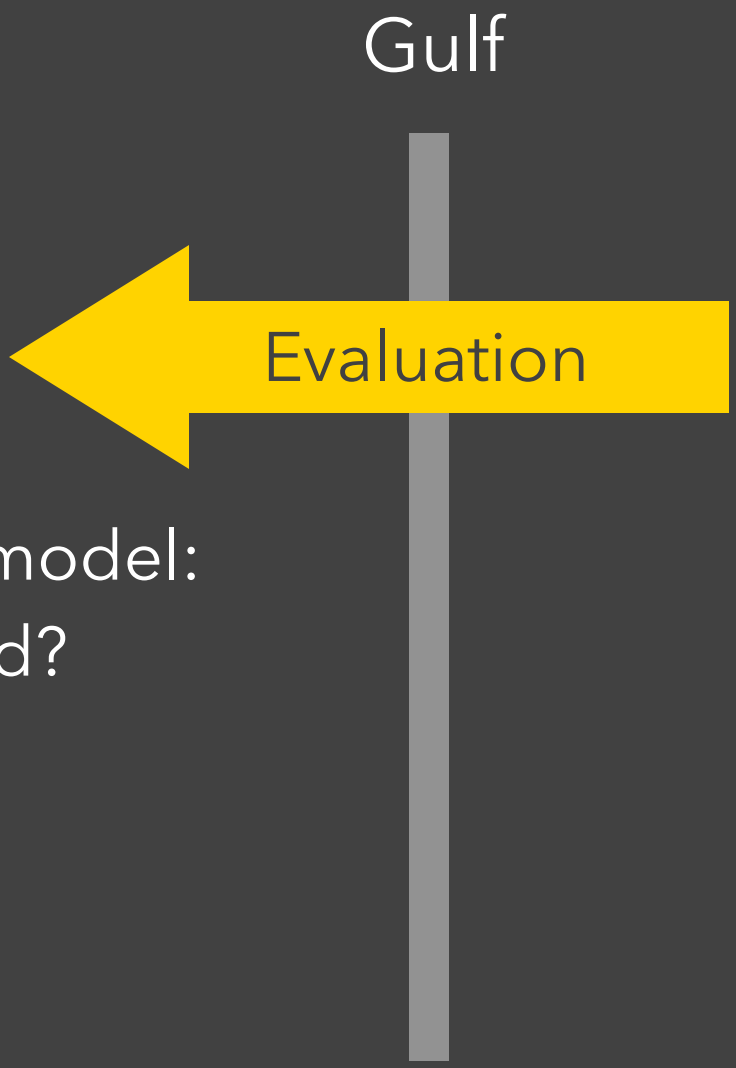
Evaluation

Conceptual model:
x, y related?

Real world:



Gulf of Evaluation



Real world:

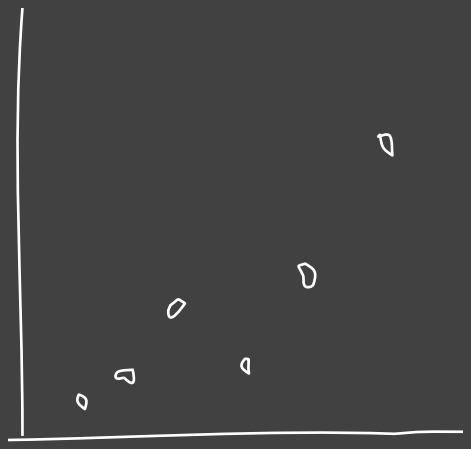
$\rho = -.29$

Conceptual model:
x, y correlated?

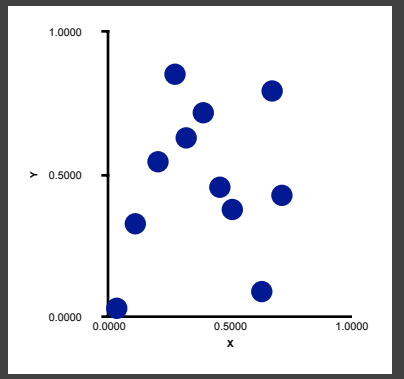
Gulf of Execution

Gulf

Conceptual model:
Draw a scatterplot



Execution



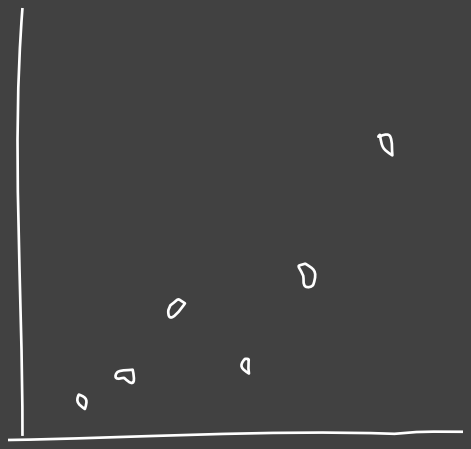
Real world

Move 90 30
Rotate 35
Pen down
…

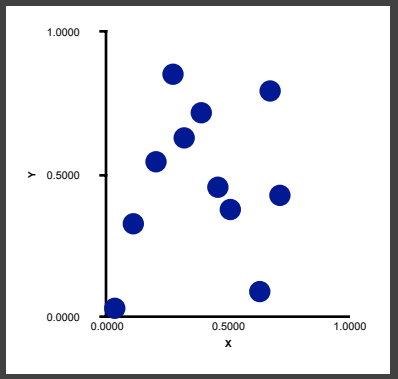
Gulf of Execution

Gulf

Conceptual model:
Draw a scatterplot



Execution



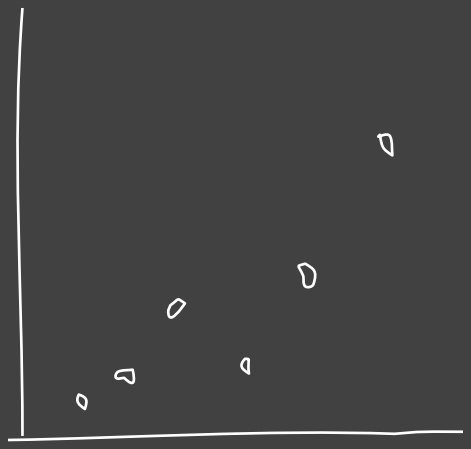
Real world

```
vl.markCircle()
  .encode(
    vl.x().fieldQ(…),
    vl.y().fieldQ(…)
  )
```

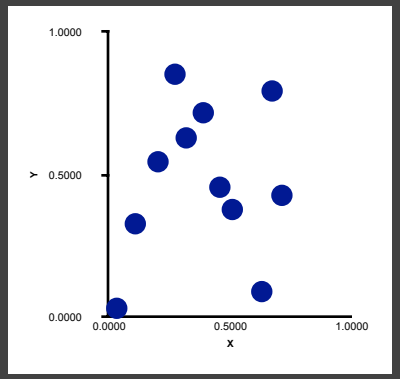
Gulf of Execution

Gulf

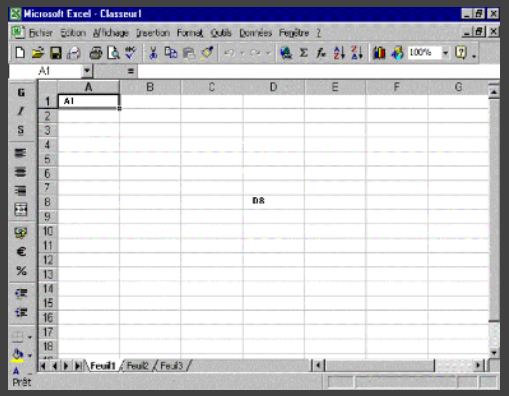
Conceptual model:
Draw a scatterplot



Execution



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

Tableau - Book1

Normal | 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

Filters

Marks

Automatic

Color | Size | Label | Detail | Tooltip

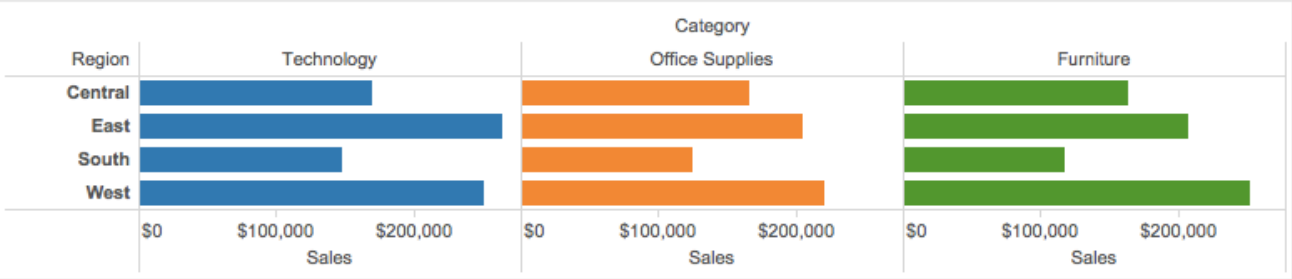
Category

Category

- Technology
- Office Supplies
- Furniture

Columns: Category | SUM(Sales)

Rows: Region



Data Source | Sheet 1

12 marks | 4 rows by 3 columns | SUM(Sales): $2,297,201

Tableau - Book1

Normal

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

Filters

Marks

Automatic

Color | Size | Label | Detail | Tooltip

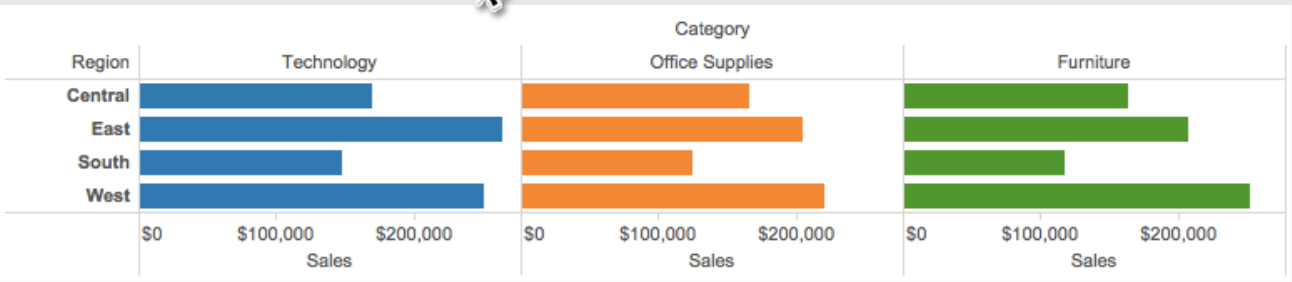
Category

Category

- Technology
- Office Supplies
- Furniture

Columns: Category | SUM(Sales)

Rows: Region



Data Source | Sheet 1

12 marks | 4 rows by 3 columns | SUM(Sales): $2,297,201

Tableau - Book1

Normal | 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

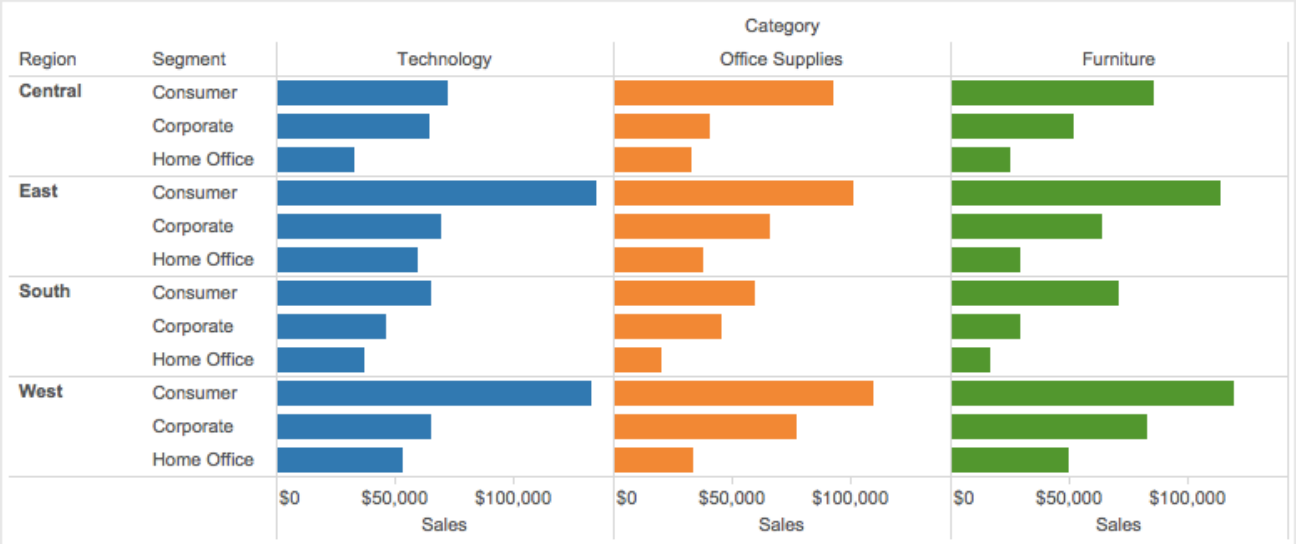
Filters

Marks
Automatic
Color | Size | Label | Detail | Tooltip
Category

Category
- Technology
- Office Supplies
- Furniture

Columns: Category | SUM(Sales)

Rows: Region | Segment



Data Source | Sheet 1

36 marks | 12 rows by 3 columns | SUM(Sales): $2,297,201

Tableau - Book1

Normal | 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

Filters

Marks

Automatic

Color | Size | Label | Detail | Tooltip

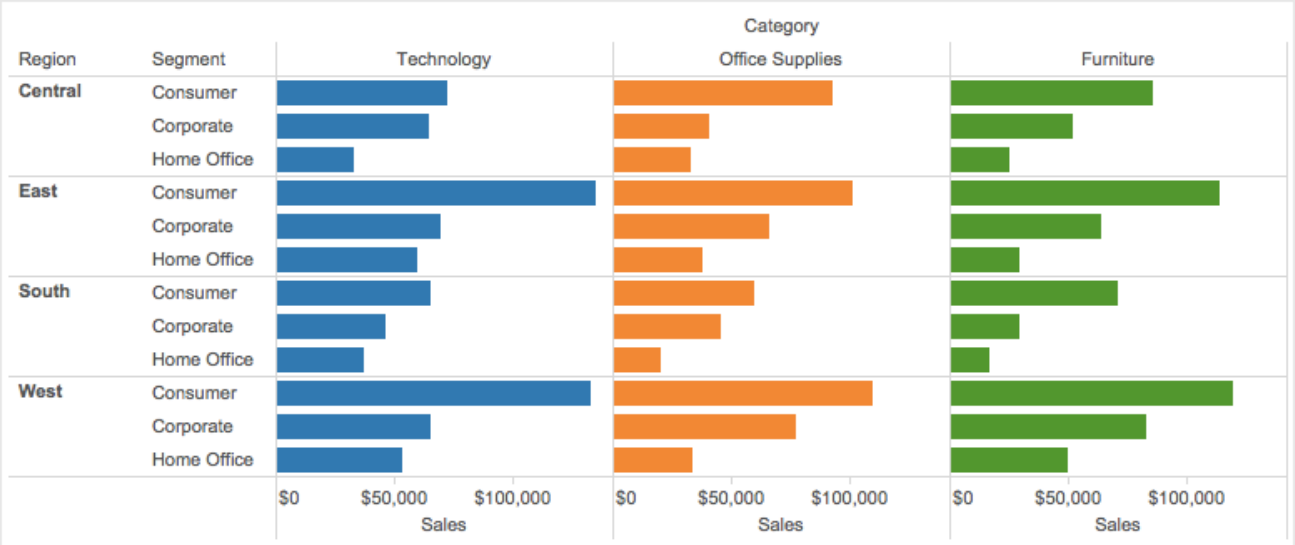
Category

Category

- Technology
- Office Supplies
- Furniture

Columns: Category | SUM(Sales)

Rows: Region | Segment



Data Source | Sheet 1

36 marks | 12 rows by 3 columns | SUM(Sales): $2,297,201

Tableau - Book1

Normal | 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

Filters

Marks

All

Automatic

Color | Size | Label | Detail | Tooltip

Category

SUM(Sales)

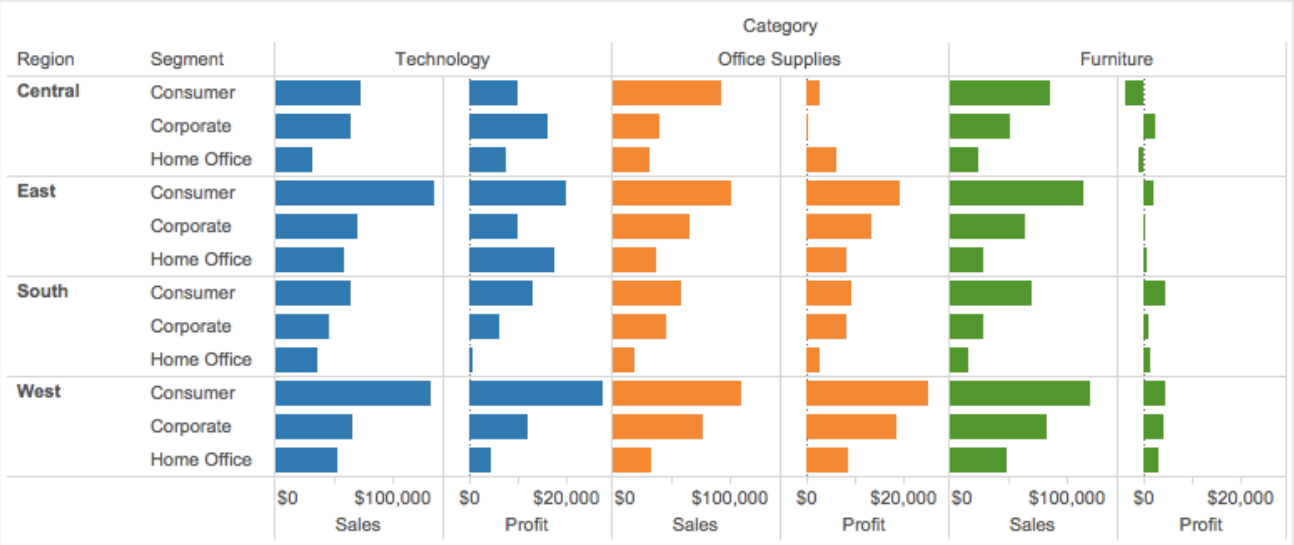
SUM(Profit)

Category

- Technology
- Office Supplies
- Furniture

Columns: Category | SUM(Sales) | SUM(Profit)

Rows: Region | Segment



Data Source | Sheet 1

72 marks | 12 rows by 6 columns | SUM(Profit): $286,397

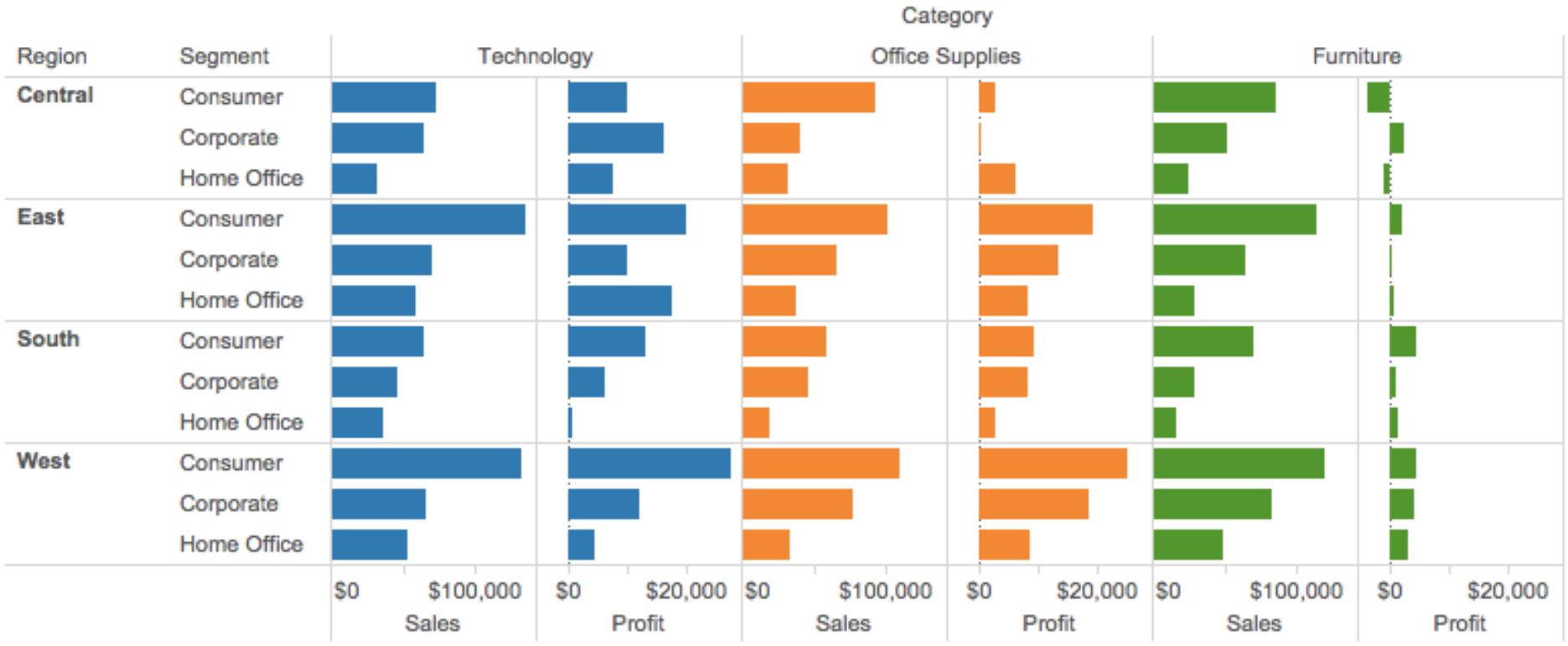
Tableau - Book1

Normal

Show Me

Columns: Category, SUM(Sales), SUM(Profit)

Rows: Region, Segment



Taxonomy of Interactions

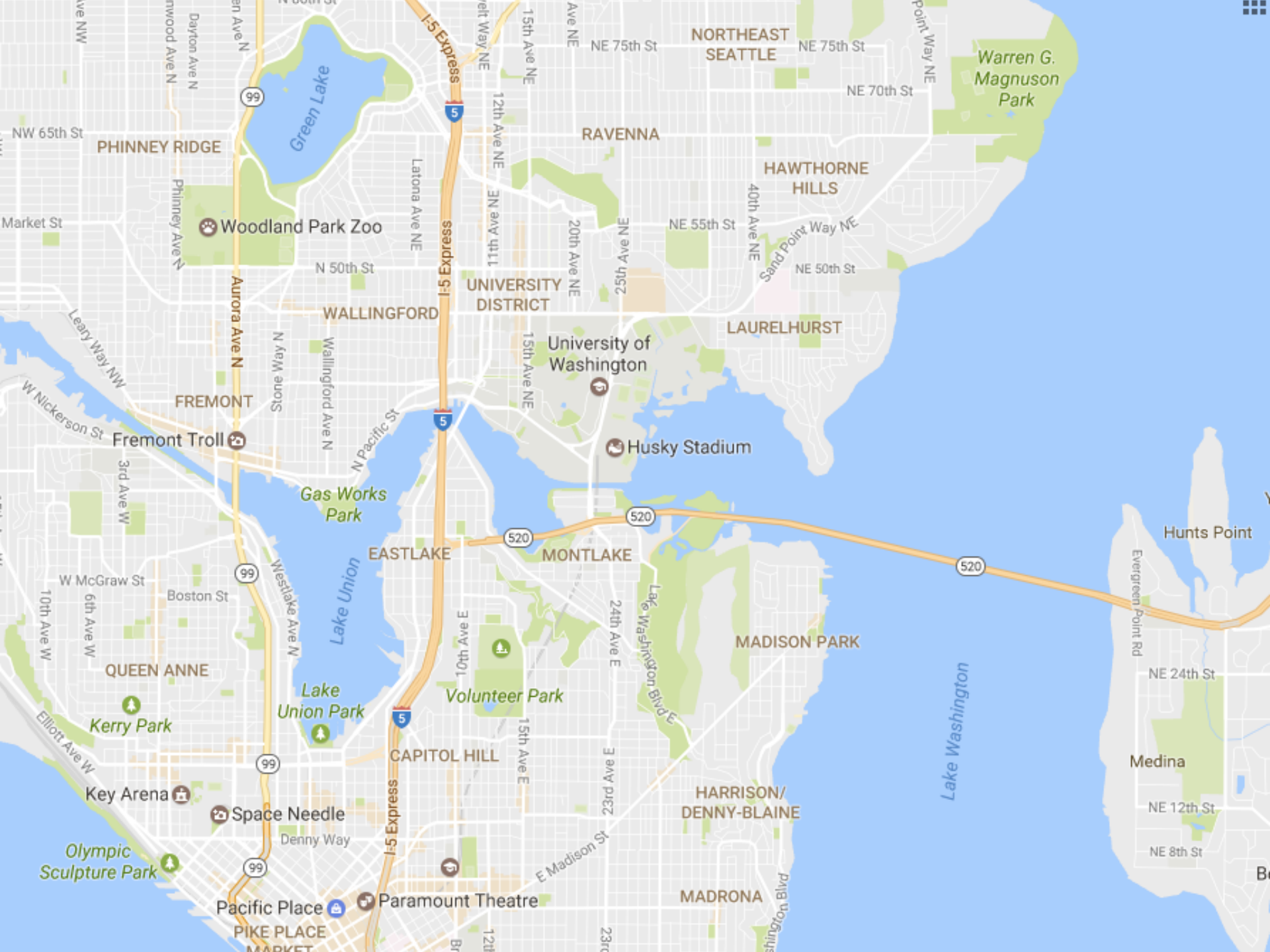
Data and View Specification

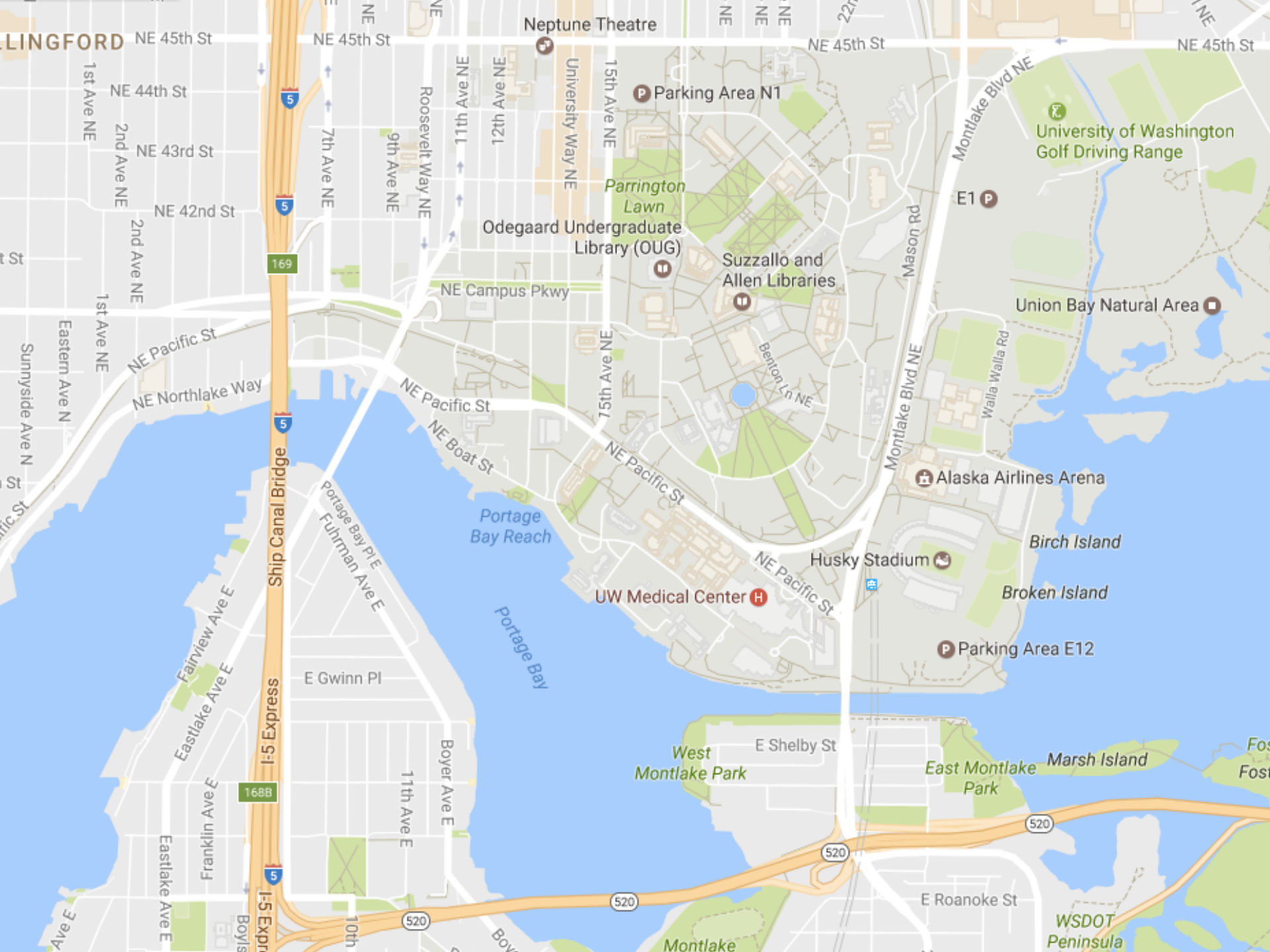
Visualize, Filter, Sort, Derive

Taxonomy of Interactions

Data and View Specification
Visualize, Filter, Sort, Derive

View Manipulation
Select, Navigate, Coordinate, Organize


NORTHEAST SEATTLE
NE 75th St
NE 70th St
Warren G. Magnuson Park
Green Lake
NW 65th St
PHINNEY RIDGE
RAVENNA
HAWTHORNE HILLS
Market St
Woodland Park Zoo
NE 55th St
N 50th St
NE 50th St
UNIVERSITY DISTRICT
WALLINGFORD
LAURELHURST
University of Washington
FREMONT
Fremont Troll
Husky Stadium
Gas Works Park
EASTLAKE
MONTLAKE
Hunts Point
Lake Union
MADISON PARK
QUEEN ANNE
Lake Union Park
Volunteer Park
Kerry Park
CAPITOL HILL
Medina
Key Arena
Space Needle
HARRISON/ DENNY-BLAINE
Olympic Sculpture Park
Denny Way
Lake Washington
NE 24th St
NE 12th St
NE 8th St
Pacific Place
Paramount Theatre
MADRONA
PIKE PLACE
I-5 Express
Aurora Ave N
Leary Way NW
W Nickerson St
W McGraw St
Boston St
Elliott Ave W
E Madison St
Lake Washington Blvd E
Evergreen Point Rd
Sand Point Way NE
Latona Ave NE
Wallingford Ave N
Stone Way N
Westlake Ave N
Phinney Ave N
Dayton Ave N
3rd Ave W
6th Ave W
10th Ave W
10th Ave E
15th Ave E
15th Ave NE
12th Ave NE
11th Ave NE
20th Ave NE
25th Ave NE
40th Ave NE
24th Ave E
23rd Ave E
N Pacific St
99
5
520



LLINGFORD
NE 45th St
NE 44th St
NE 43rd St
NE 42nd St
1st Ave NE
2nd Ave NE
7th Ave NE
9th Ave NE
Roosevelt Way NE
11th Ave NE
12th Ave NE
University Way NE
15th Ave NE
Neptune Theatre
Parking Area N1
Parrington Lawn
Odegaard Undergraduate Library (OUG)
Suzzallo and Allen Libraries
NE Campus Pkwy
Montlake Blvd NE
University of Washington Golf Driving Range
E1
Mason Rd
Union Bay Natural Area
Walla Walla Rd
Benton Ln NE
75th Ave NE
NE Pacific St
NE Northlake Way
Sunnyside Ave N
Eastern Ave N
NE Boat St
Alaska Airlines Arena
Portage Bay Reach
Portage Bay Pl E
Fuhrman Ave E
Ship Canal Bridge
Birch Island
Husky Stadium
UW Medical Center
Broken Island
Parking Area E12
Portage Bay
Fairview Ave E
Eastlake Ave E
E Gwinn Pl
I-5 Express
Boyer Ave E
11th Ave E
West Montlake Park
E Shelby St
East Montlake Park
Marsh Island
Franklin Ave E
168B
169
5
520
E Roanoke St
WSDOT Peninsula
Montlake

Taxonomy of Interactions

Data and View Specification
Visualize, Filter, Sort, Derive

View Manipulation
Select, Navigate, Coordinate, Organize

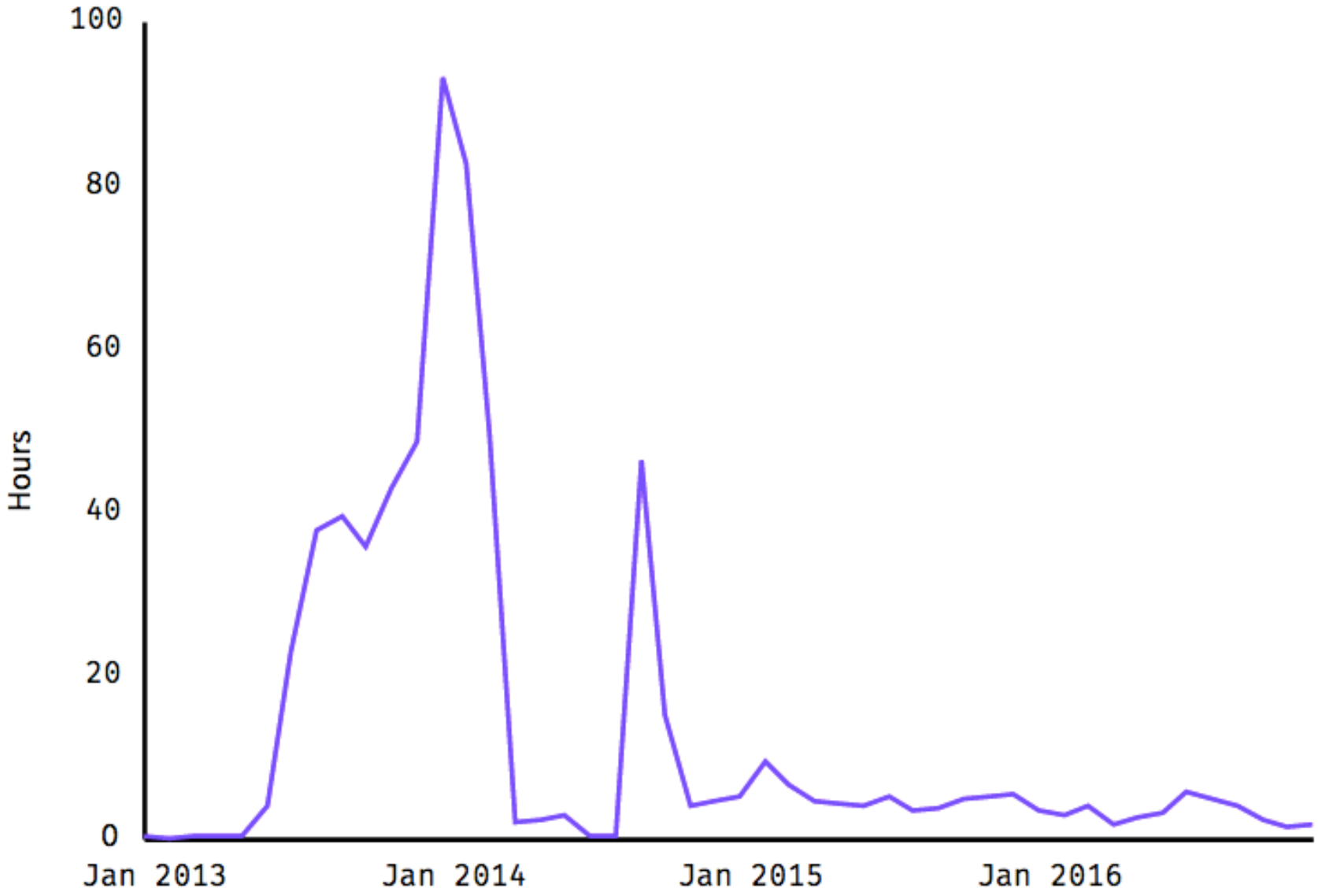
Taxonomy of Interactions

Data and View Specification
Visualize, Filter, Sort, Derive

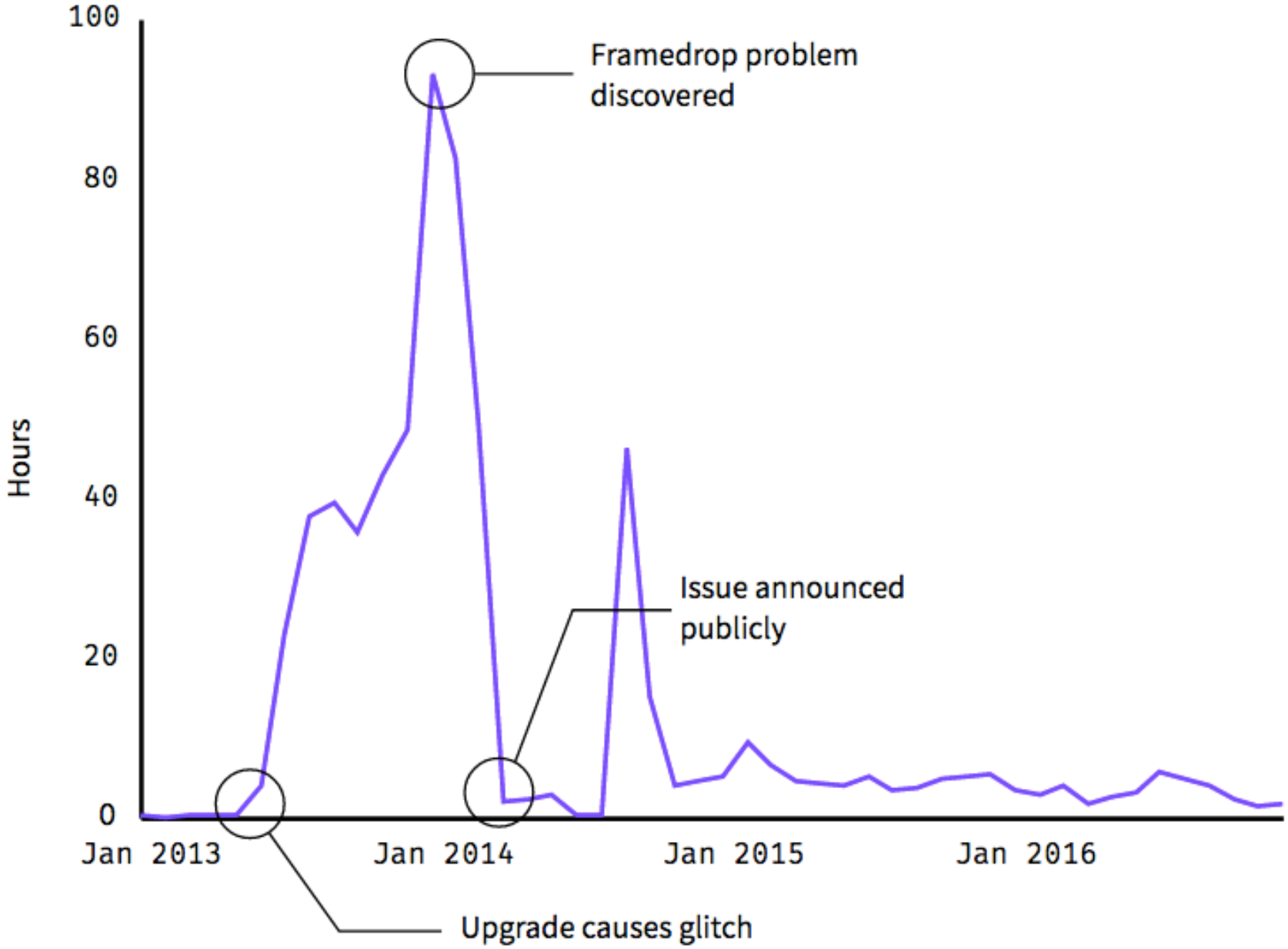
View Manipulation
Select, Navigate, Coordinate, Organize

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

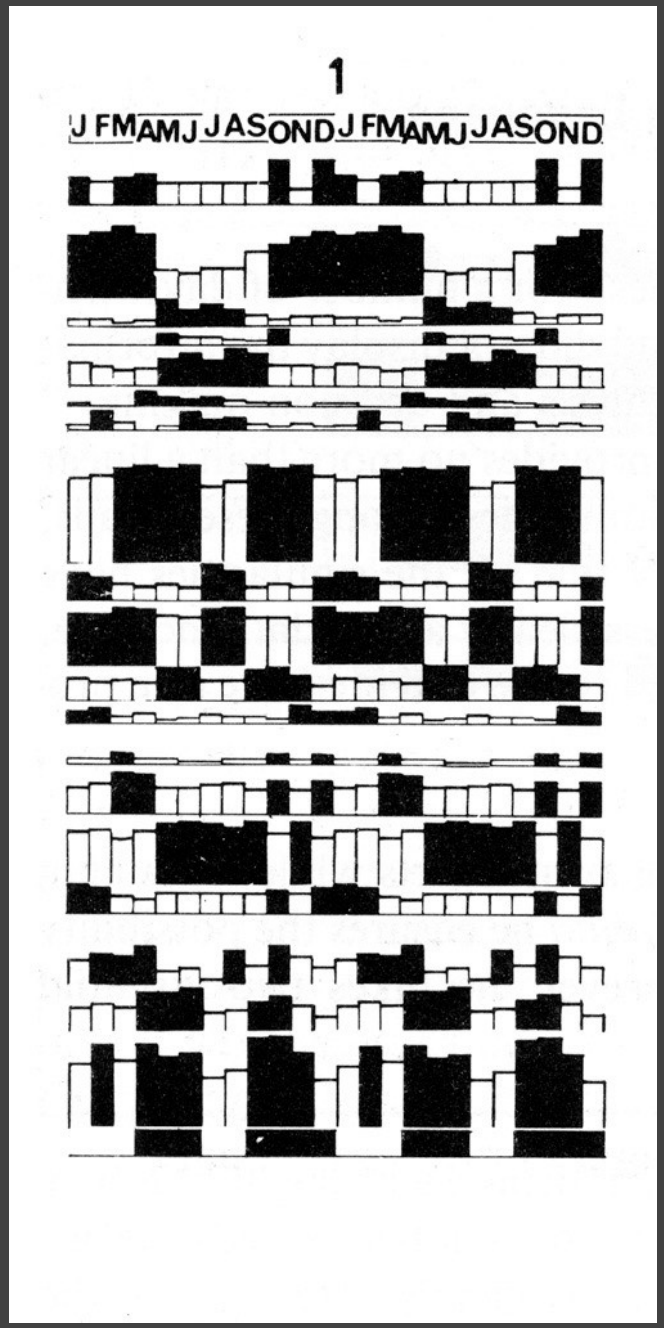
View Manipulation
Select, Navigate, Coordinate, Organize

Process and Provenance
Record, Annotate, Share, Guide

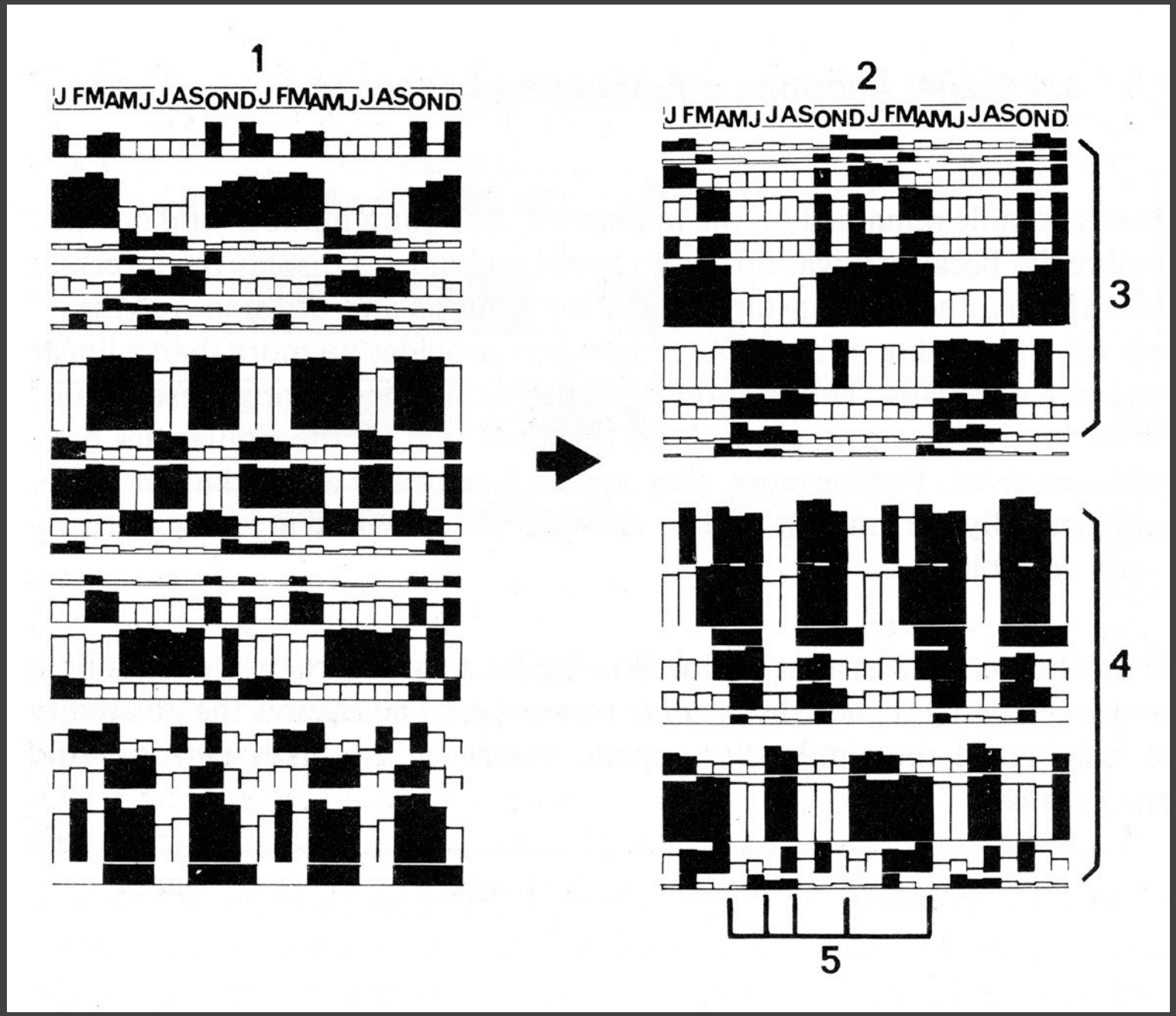
EXAMPLE:
Bertin's Hotel Data

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

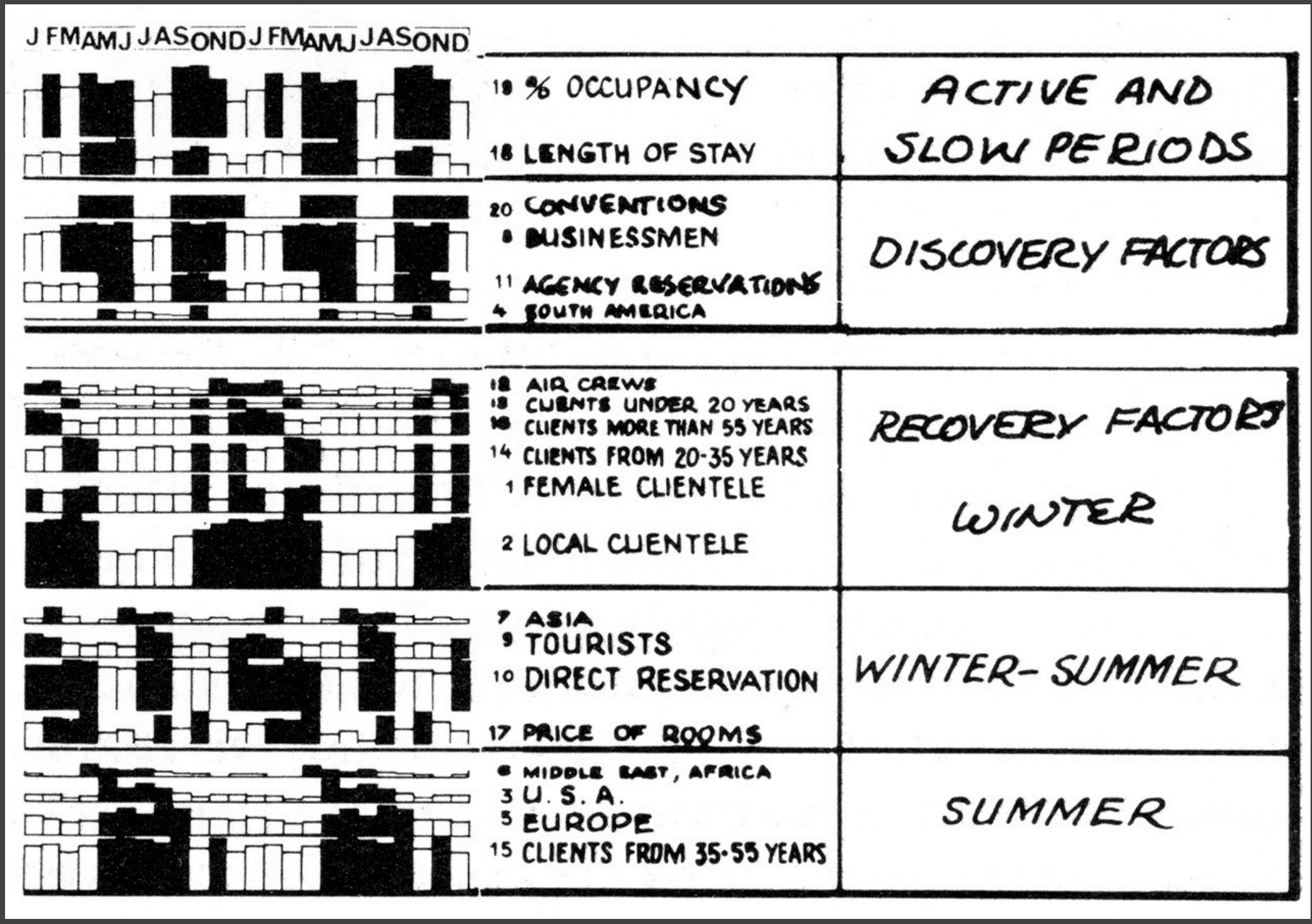
[Graphics and Graphic Information Processing, Bertin 81]



[Graphics and Graphic Information Processing, Bertin 81]



[Graphics and Graphic Information Processing, Bertin 81]



[Graphics and Graphic Information Processing, Bertin 81]

[Graphics and Graphic Information Processing, Bertin 81]

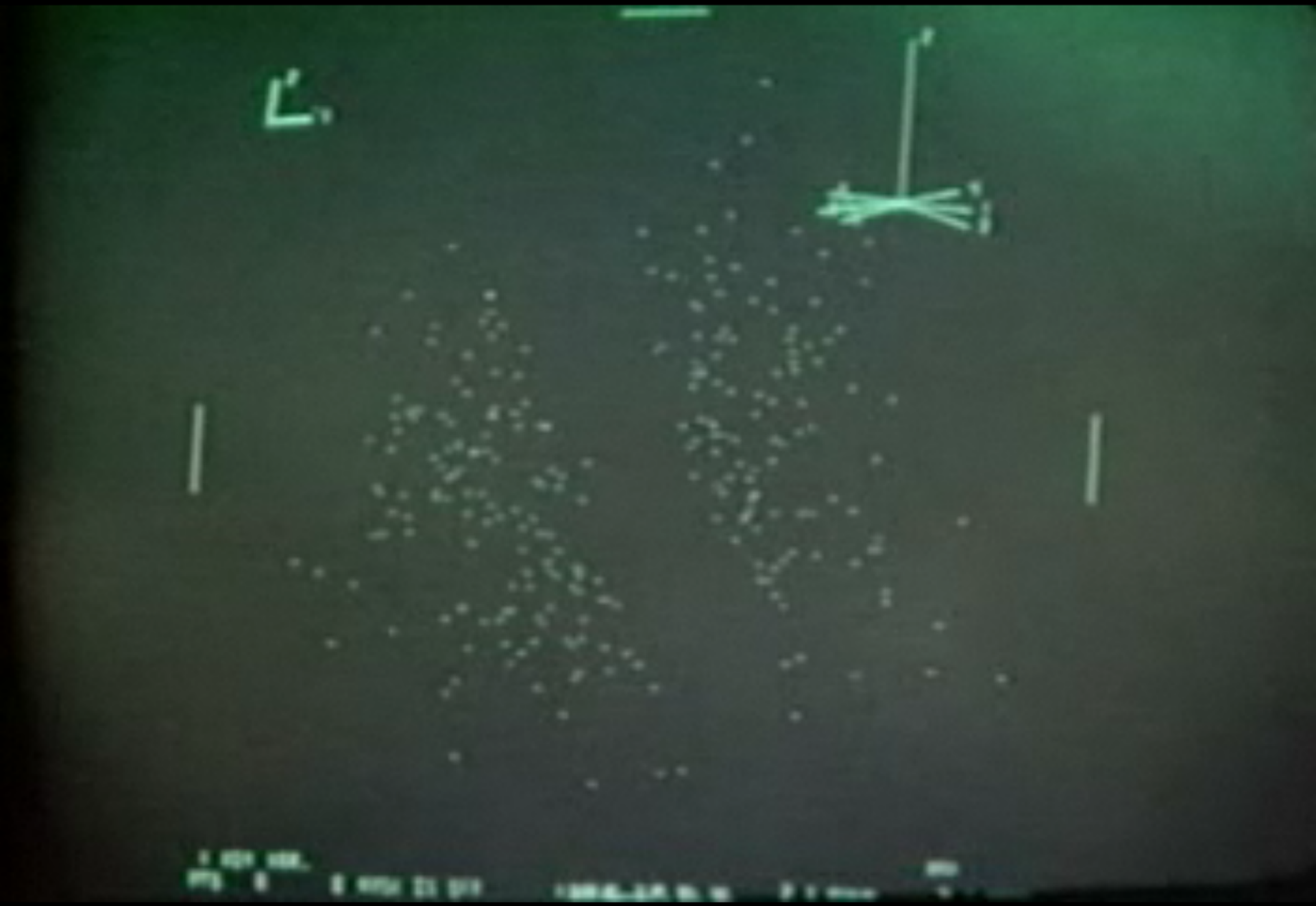
[Graphics and Graphic Information Processing, Bertin 81]

[Graphics and Graphic Information Processing, Bertin 81]

E X A M P L E :

Tukey et al.’s PRIM-9

PRIM-9, Tukey, Fisherkeller, Friedman 1972



Selection

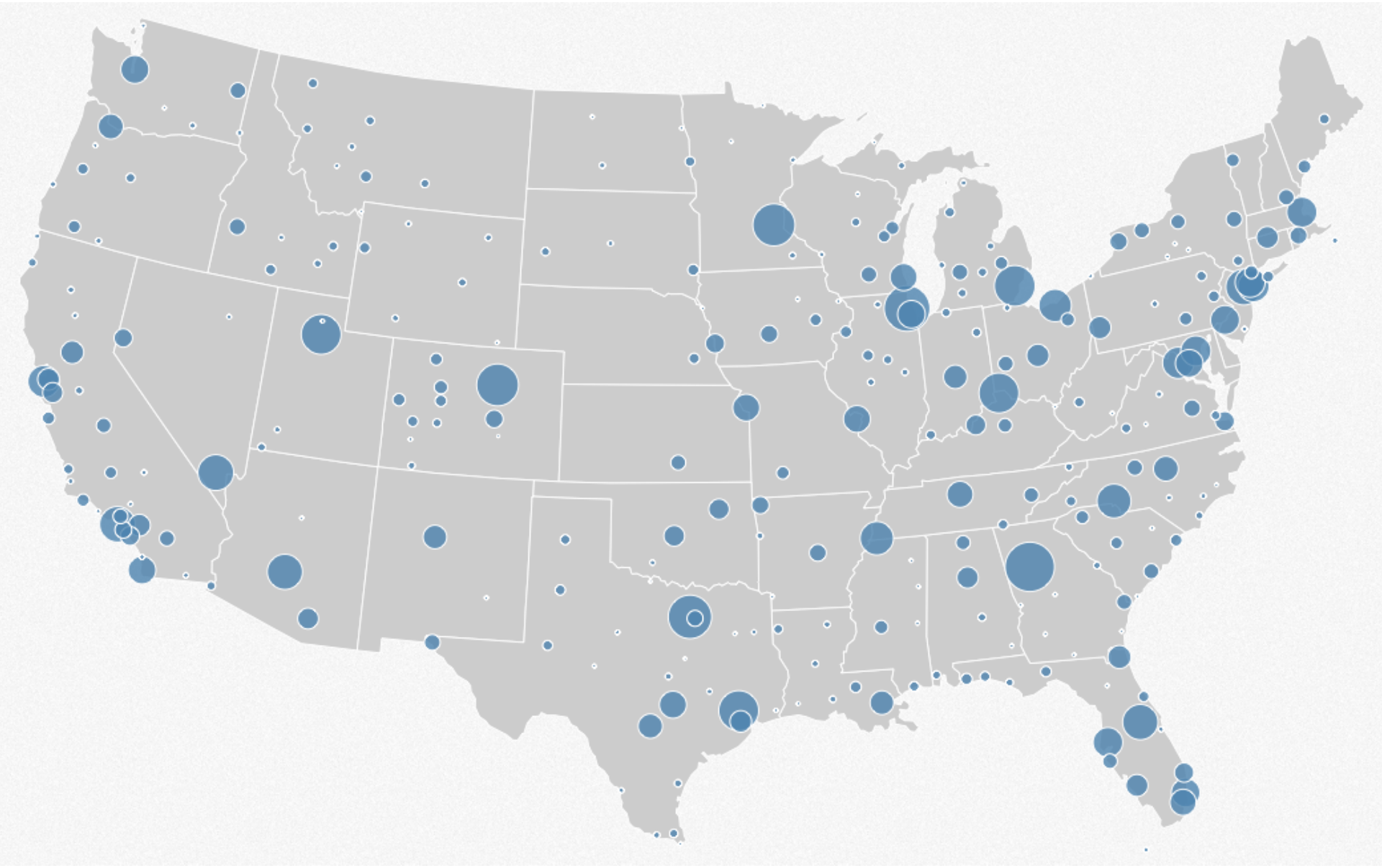
Basic Selection Methods

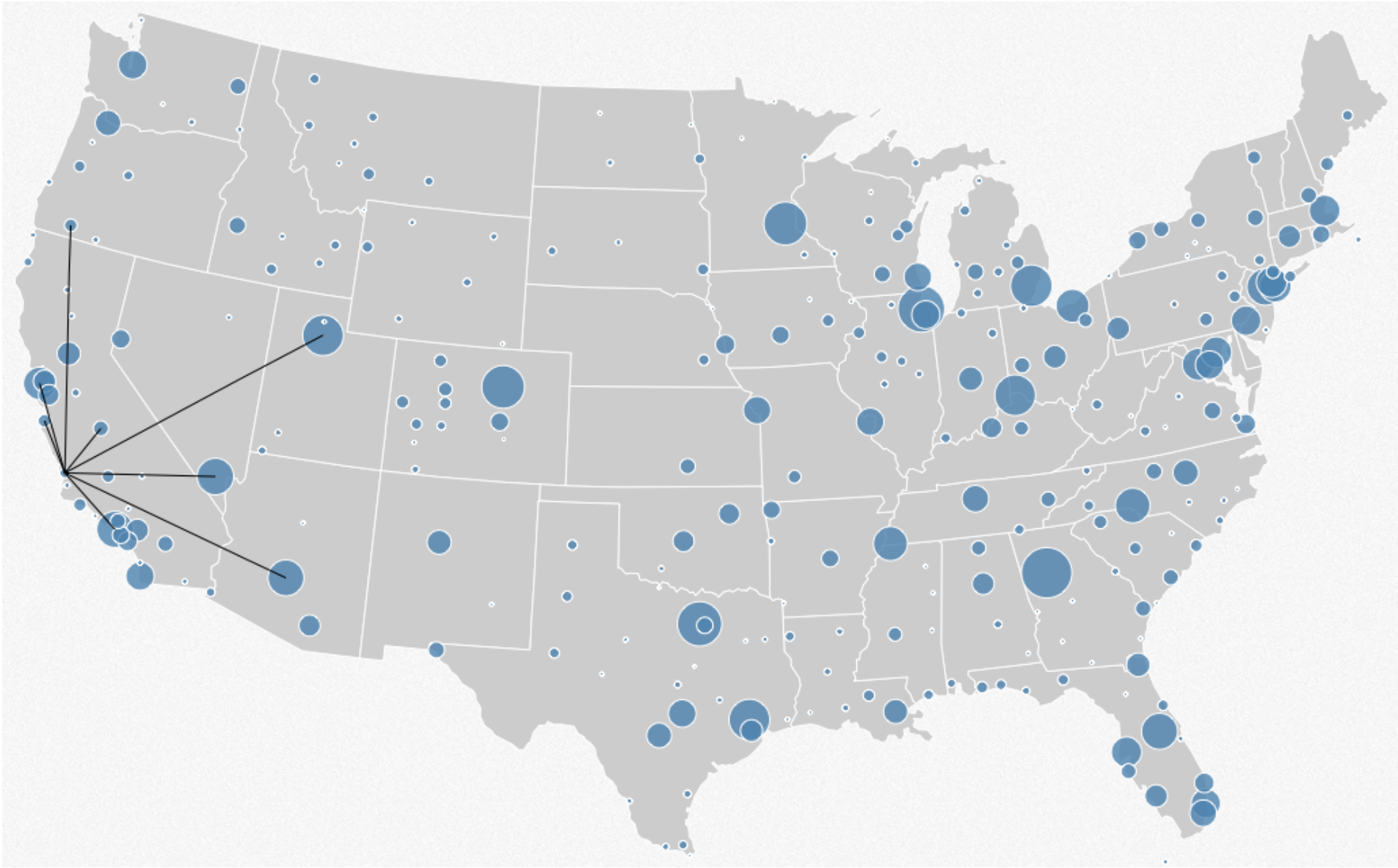
Point Selection

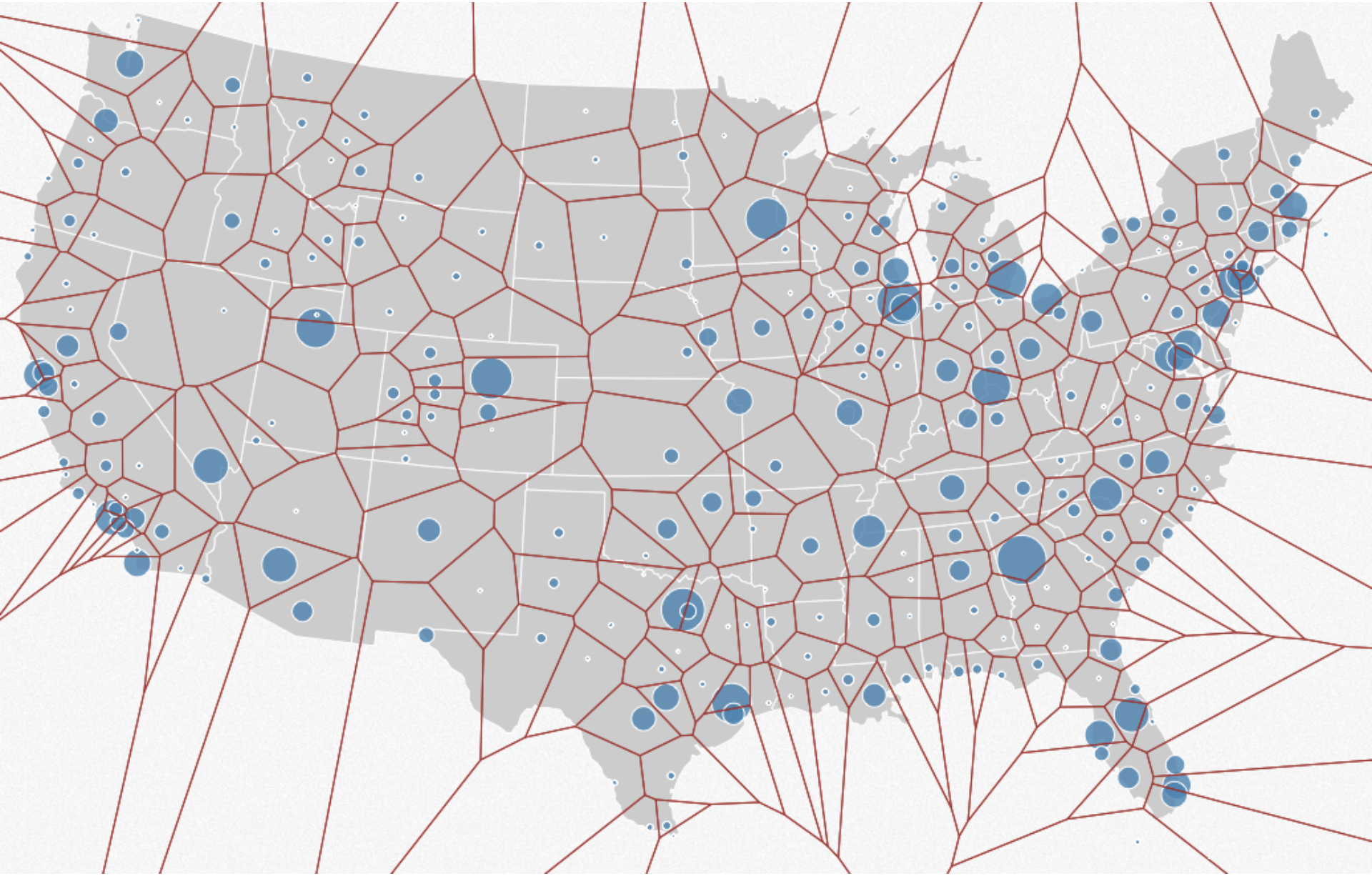
Mouse Hover / Click

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

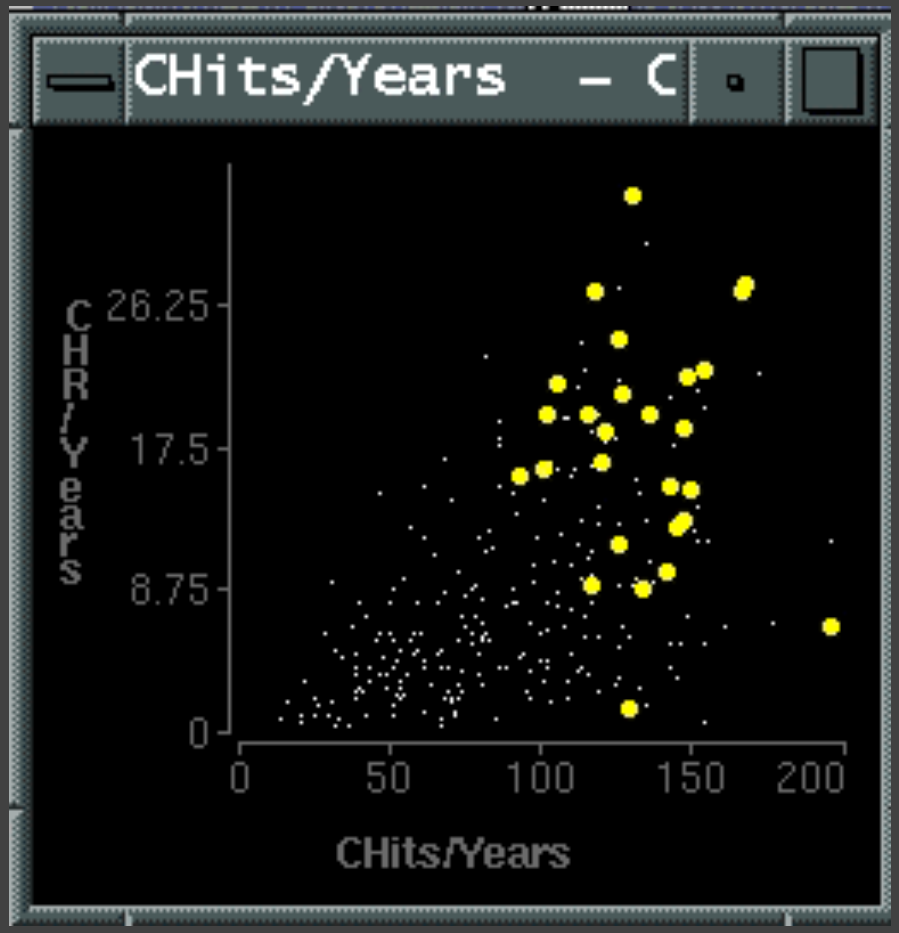
Rubber-band (rectangular) or Lasso (freehand)

Area cursors (“brushes”)

Brushing & Linking

Brushing

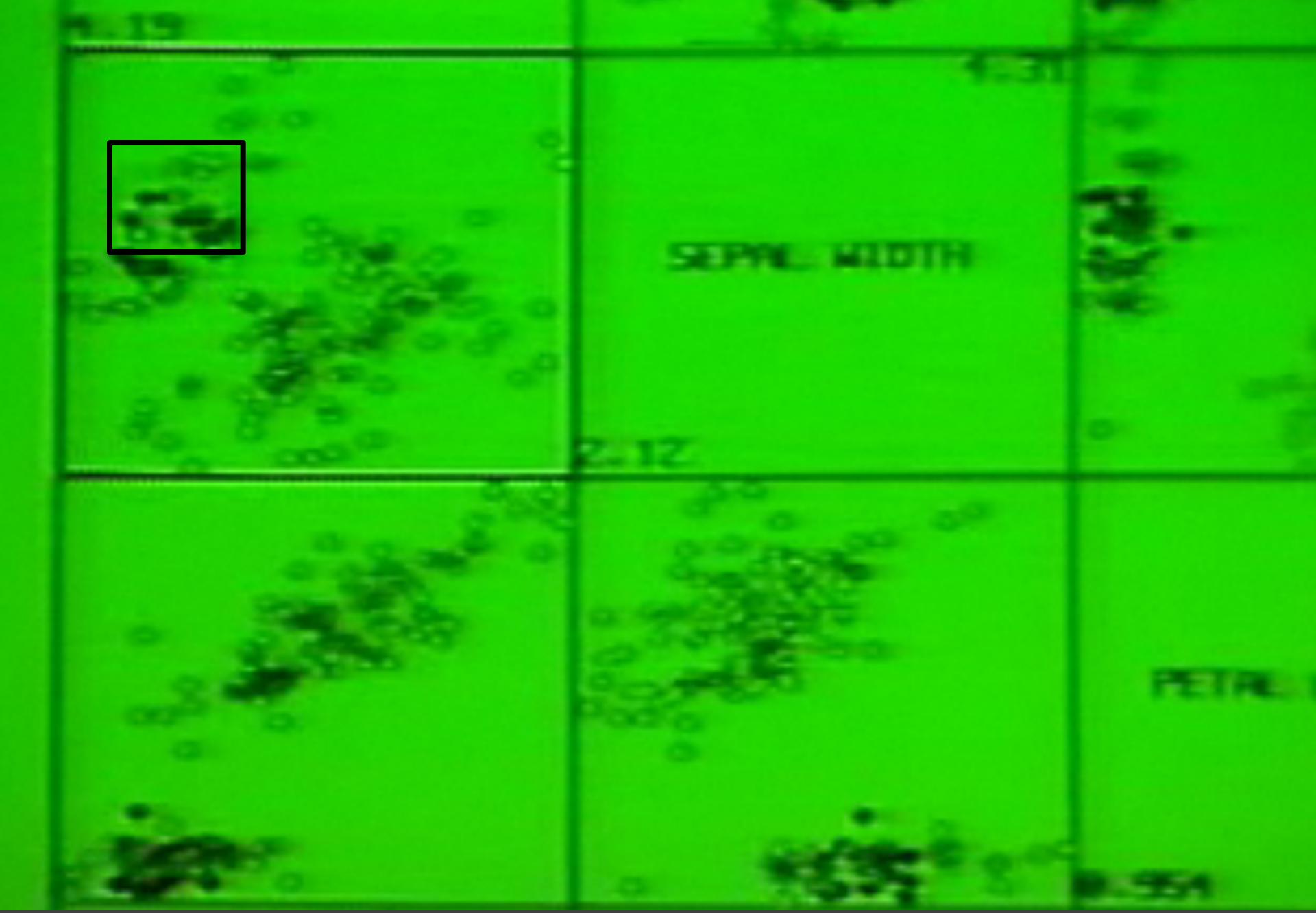
Direct attention to a subset of data [Wills 95]



Brushing & Linking

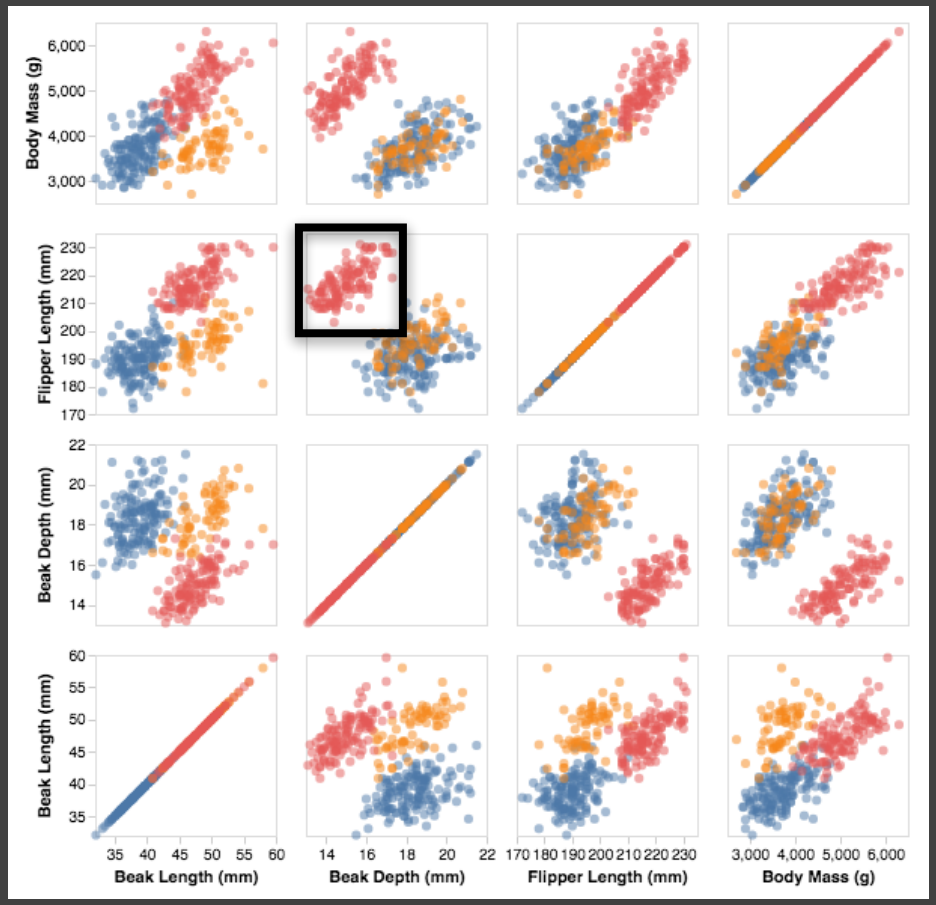
Select ("***brush***") a subset of data
See selected data in other views

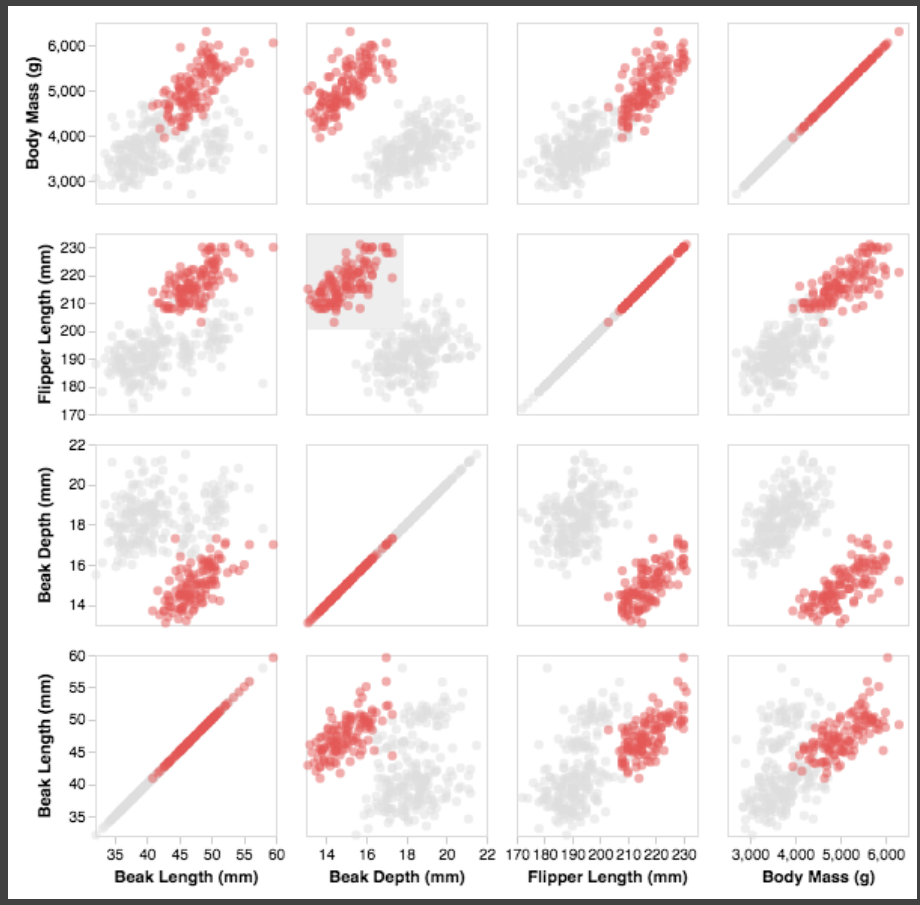
The components must be ***linked***
by *tuple* (matching data points), or
by *query* (matching range or values)



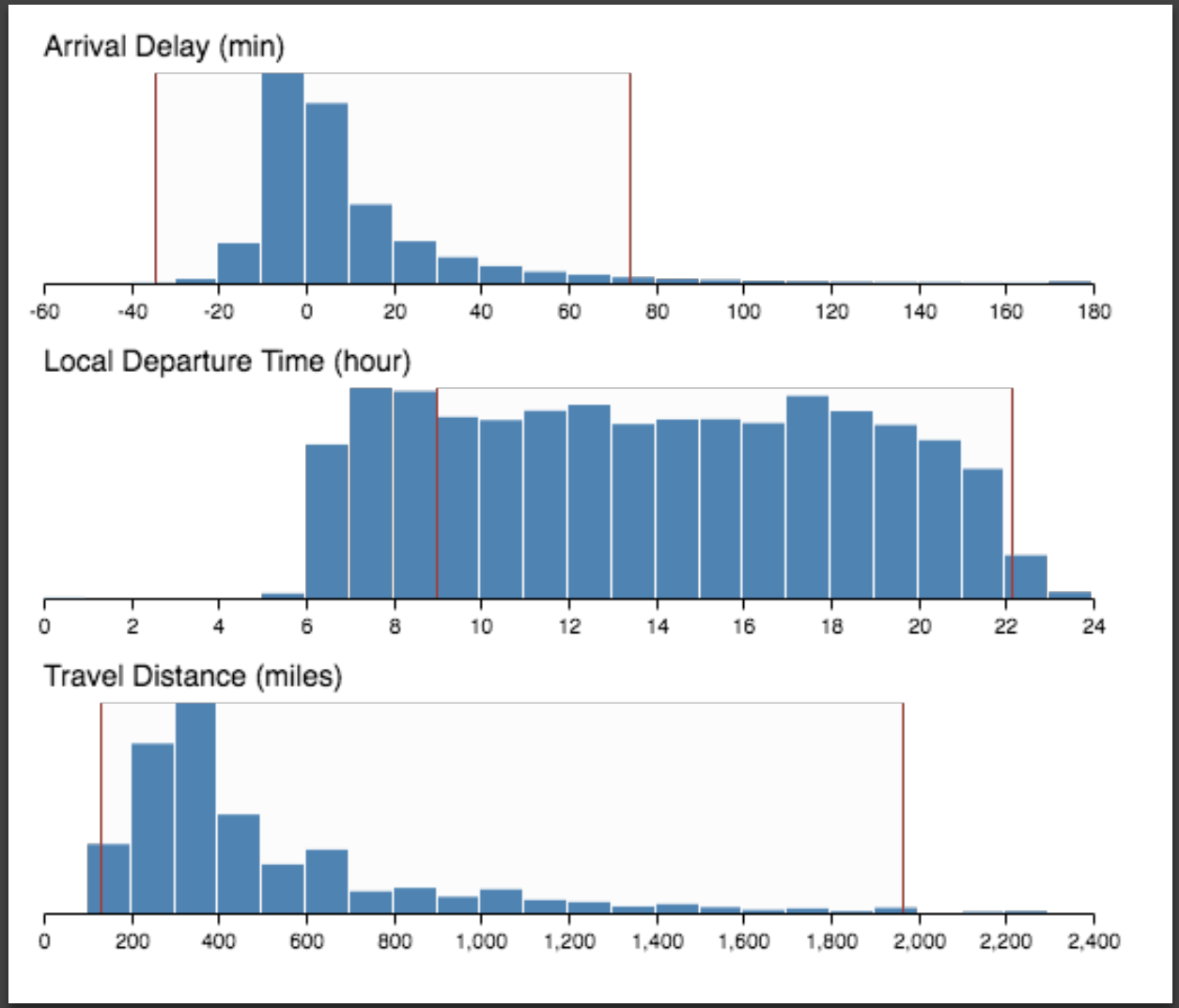
Brushing Scatterplots, Becker & Cleveland 1982

Brushing Scatterplots

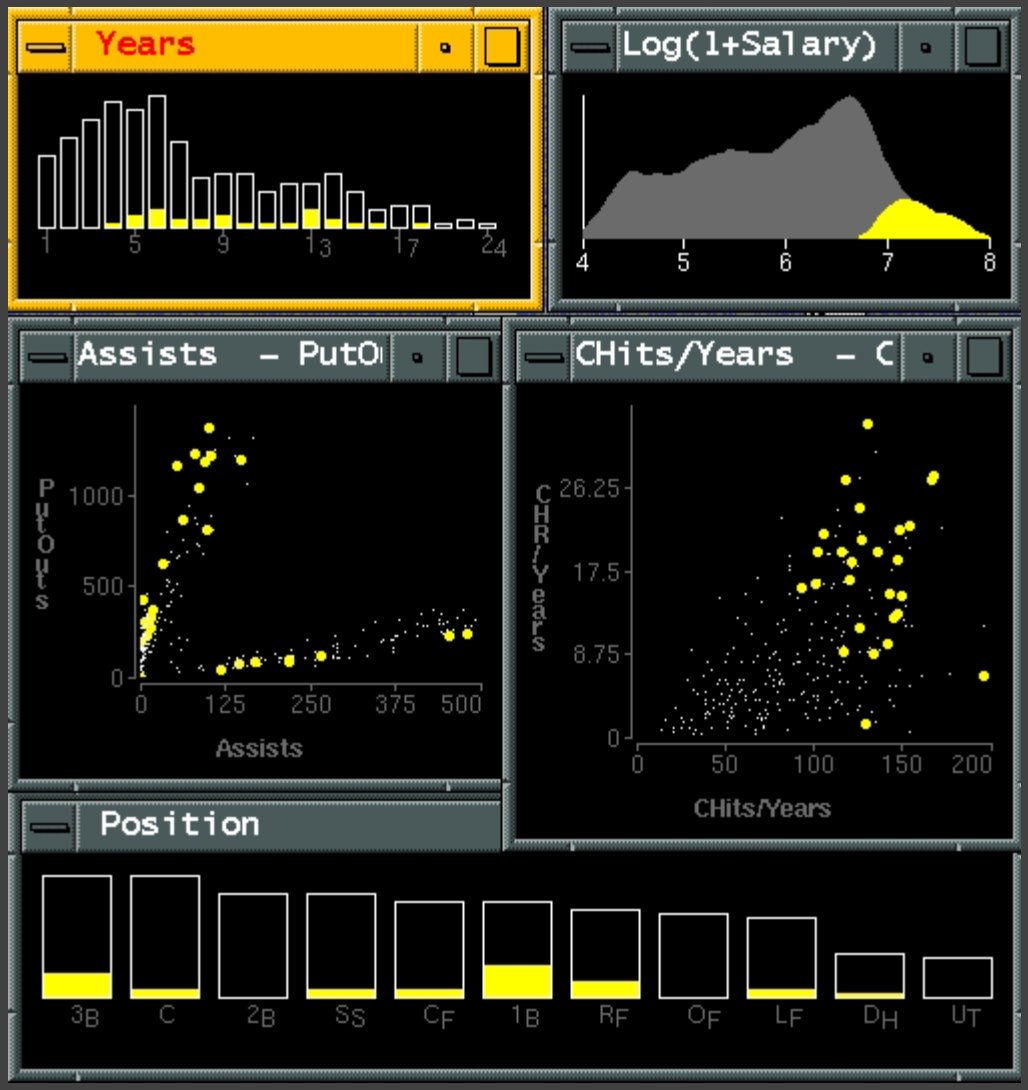




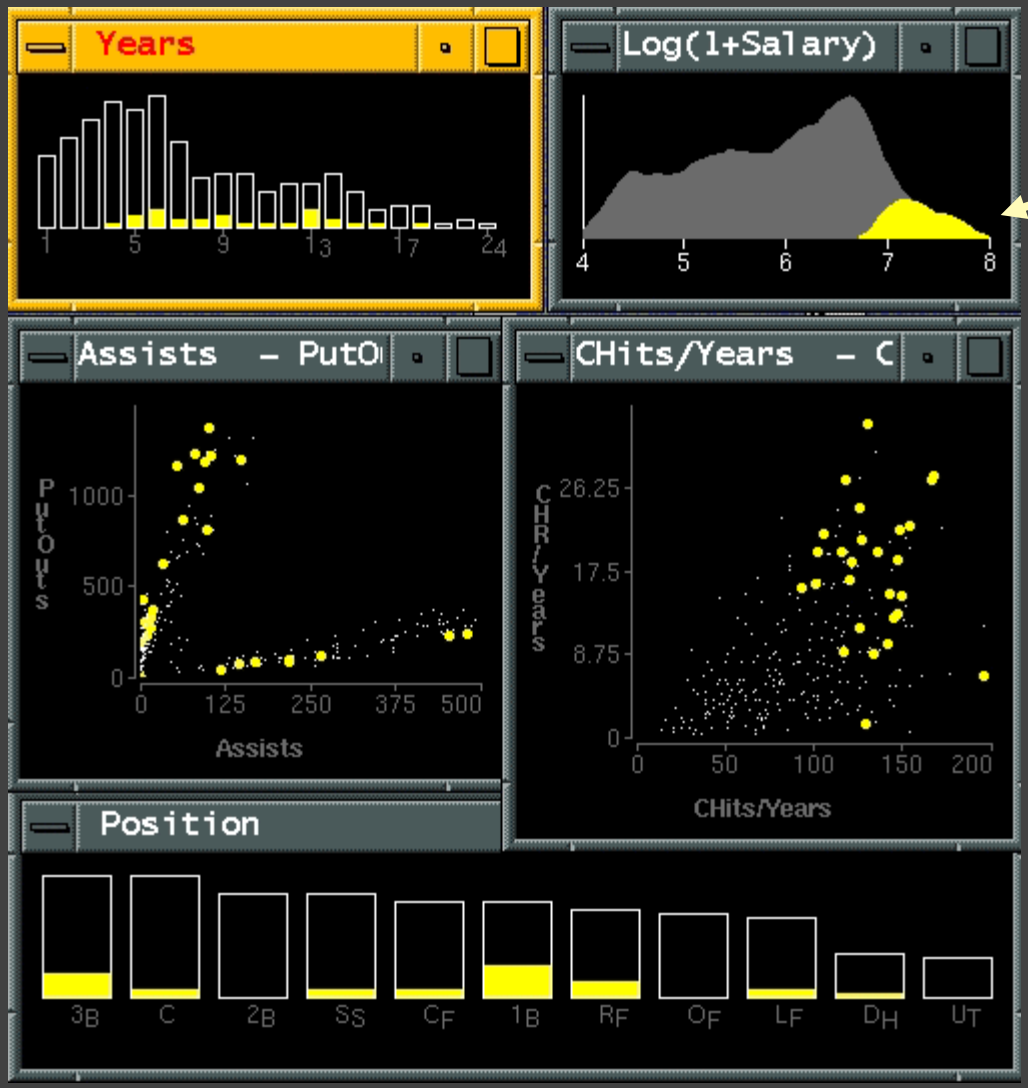
Cross-Filtering



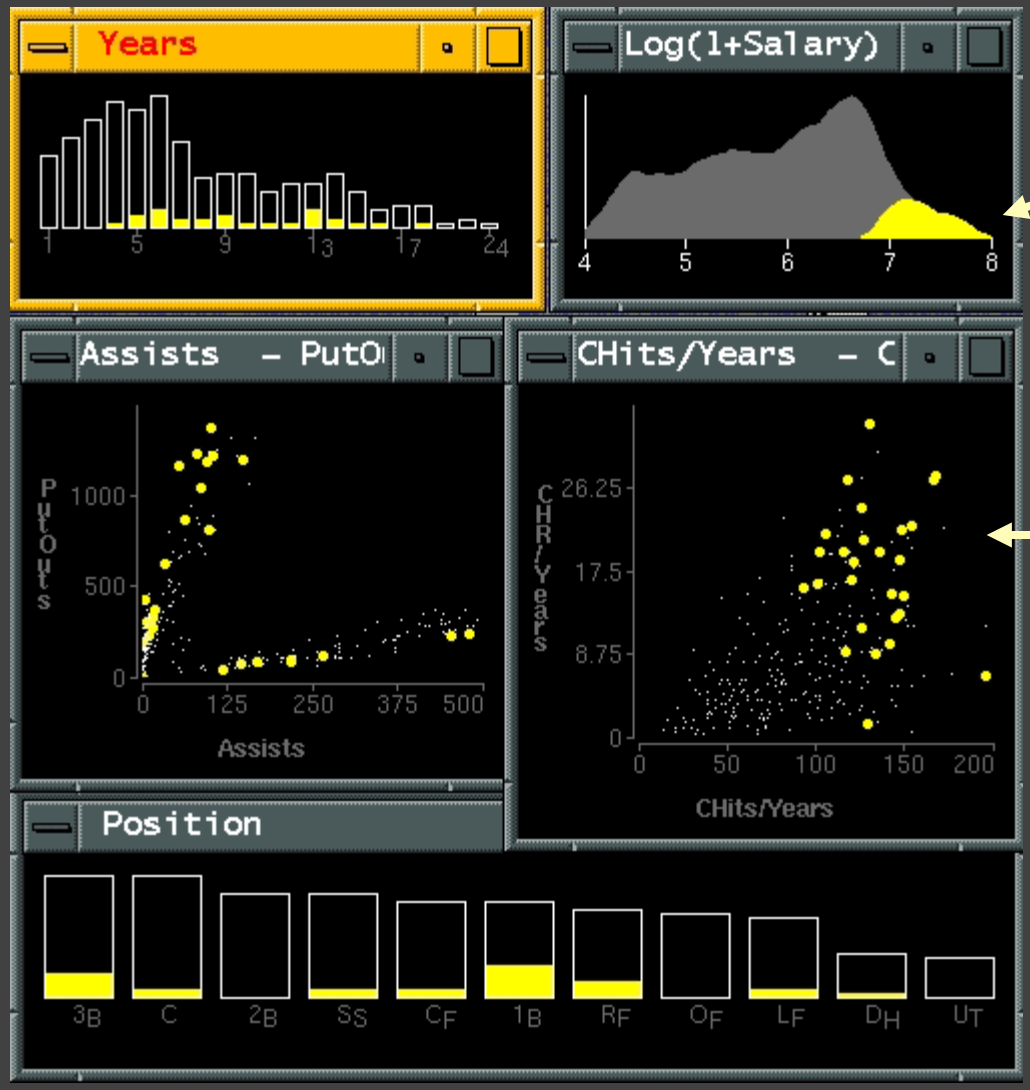
Baseball Statistics [Wills 95]



Baseball Statistics [Wills 95]



Baseball Statistics [Wills 95]

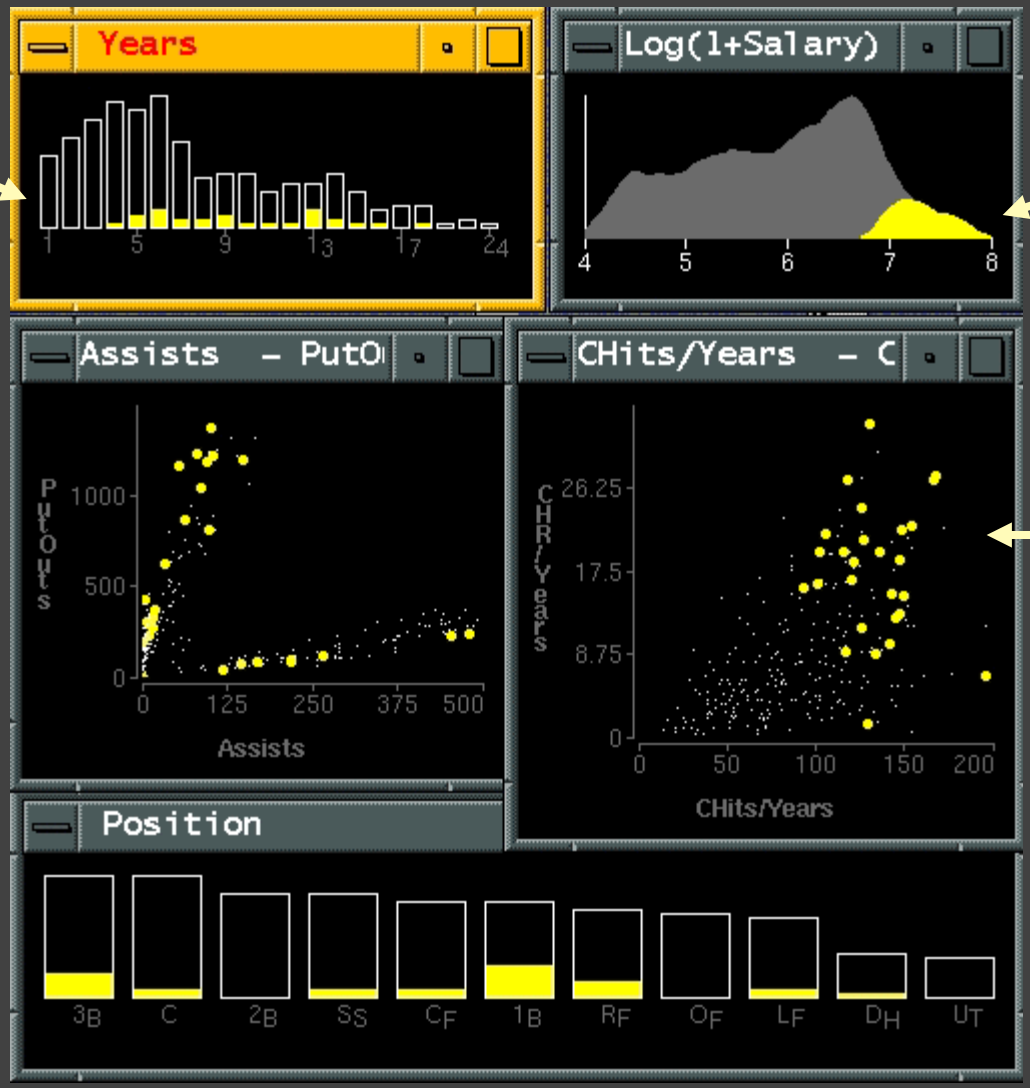


select high salaries

avg career HRs vs avg career hits (batting ability)

Baseball Statistics [Wills 95]

how long in majors

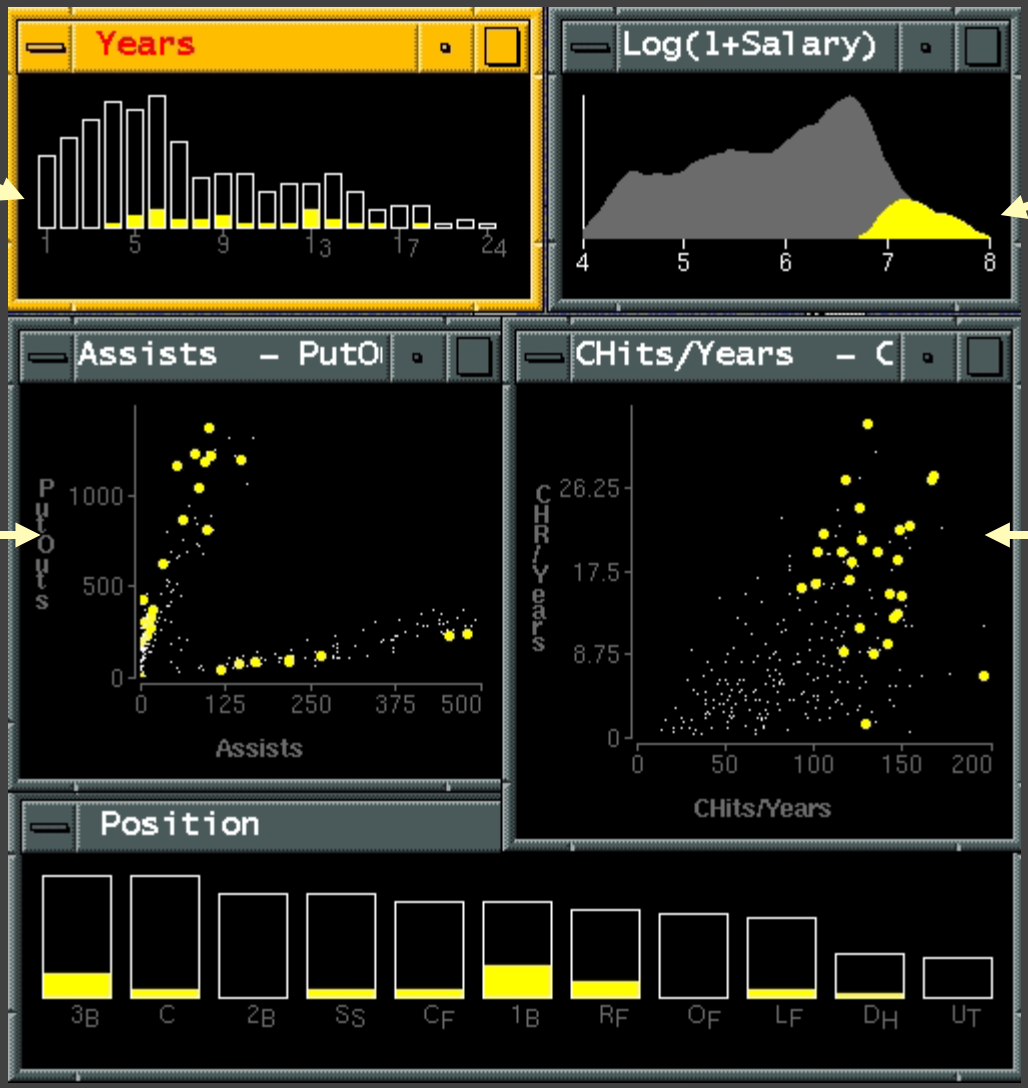


select high salaries

avg career HRs vs avg career hits (batting ability)

Baseball Statistics [Wills 95]

how long in majors



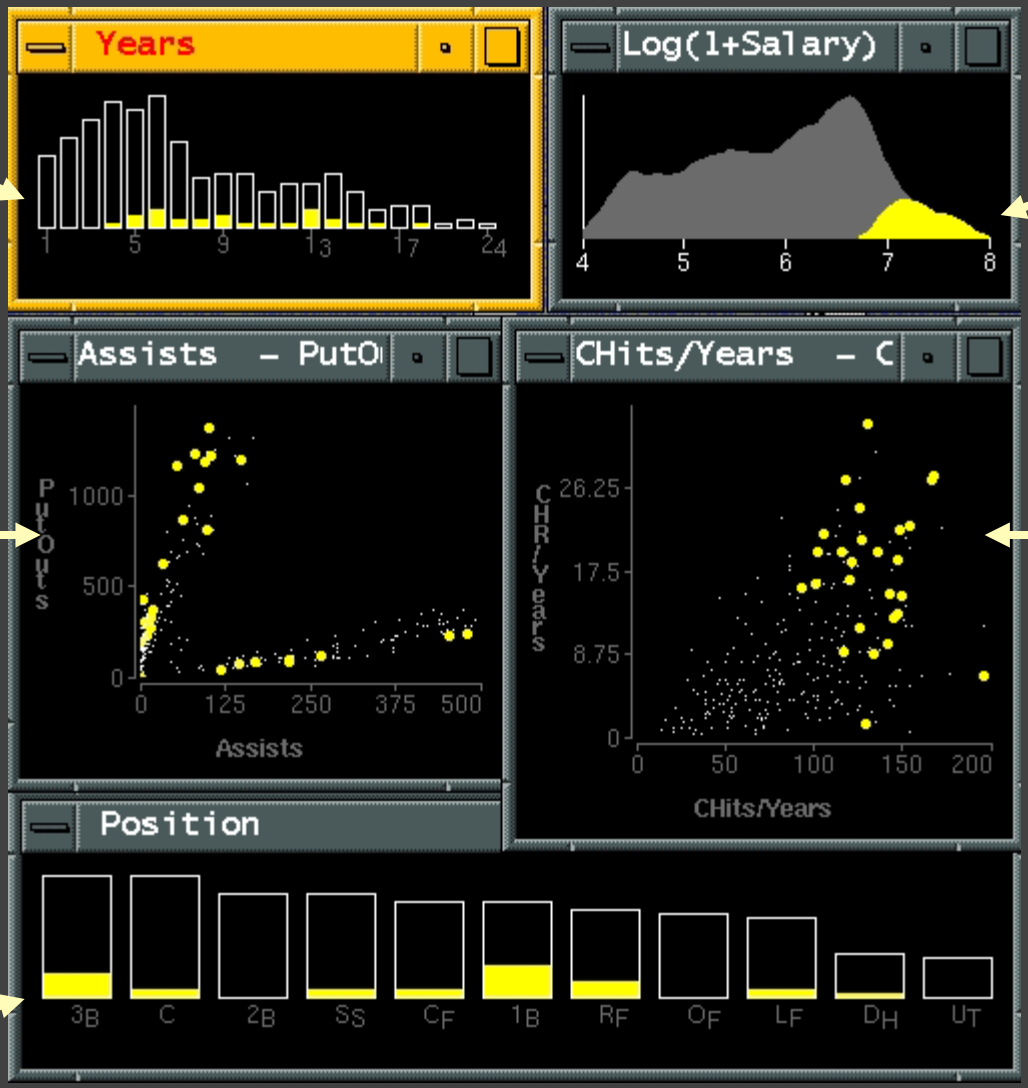
select high salaries

avg assists vs avg putouts (fielding ability)

avg career HRs vs avg career hits (batting ability)

Baseball Statistics [Wills 95]

how long in majors



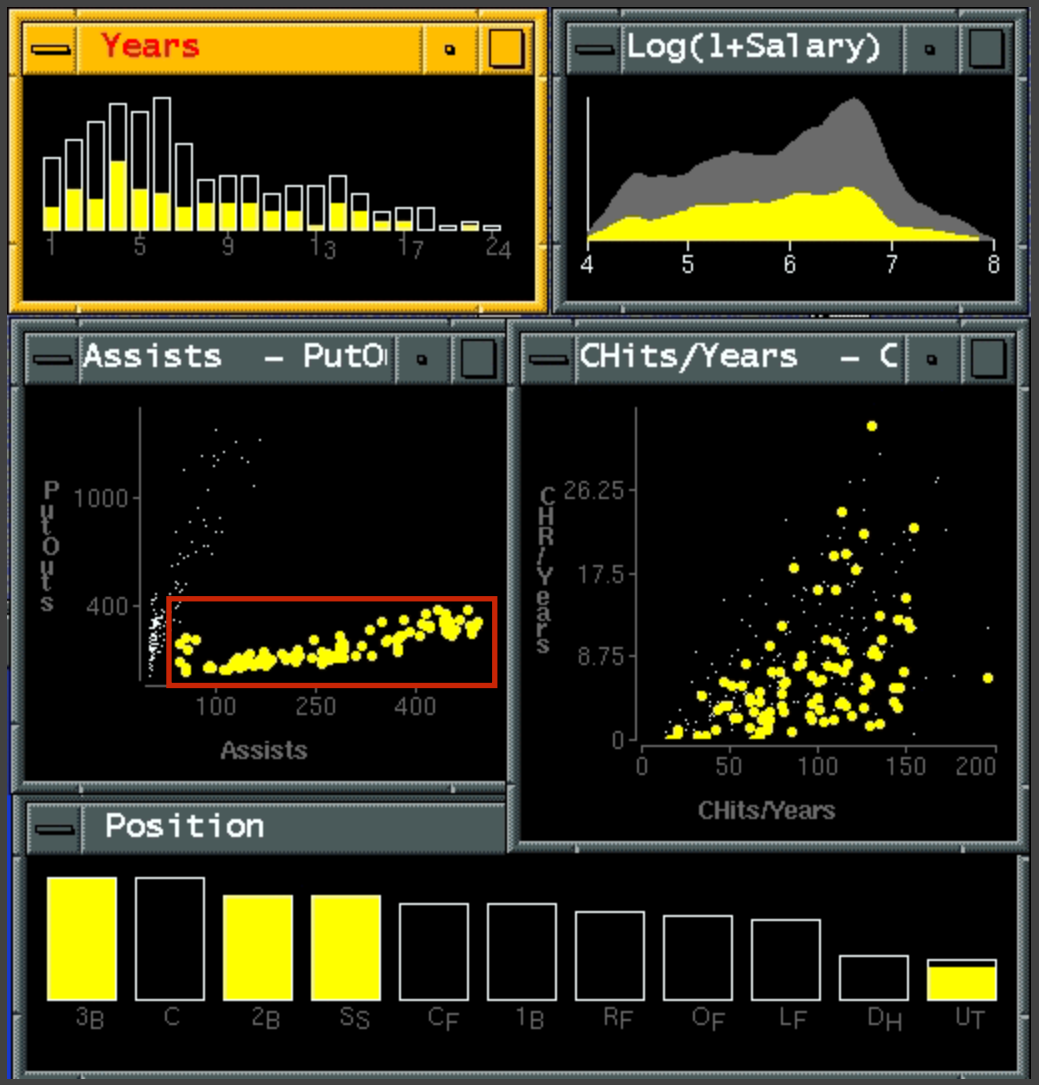
select high salaries

avg assists vs avg putouts (fielding ability)

avg career HRs vs avg career hits (batting ability)

distribution of positions played

Linking Assists to Positions



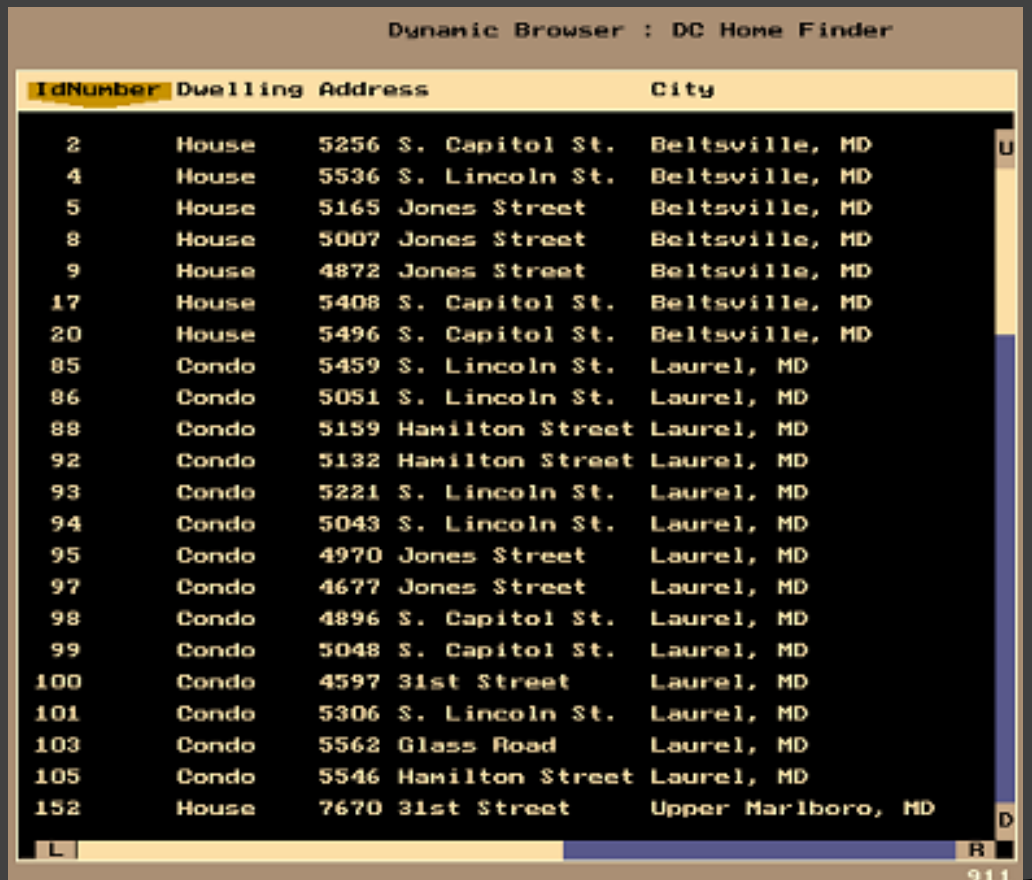
Dynamic Queries

Query & Results

SELECT house FROM seattle_homes

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

ORDER BY price



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

Poll Time!

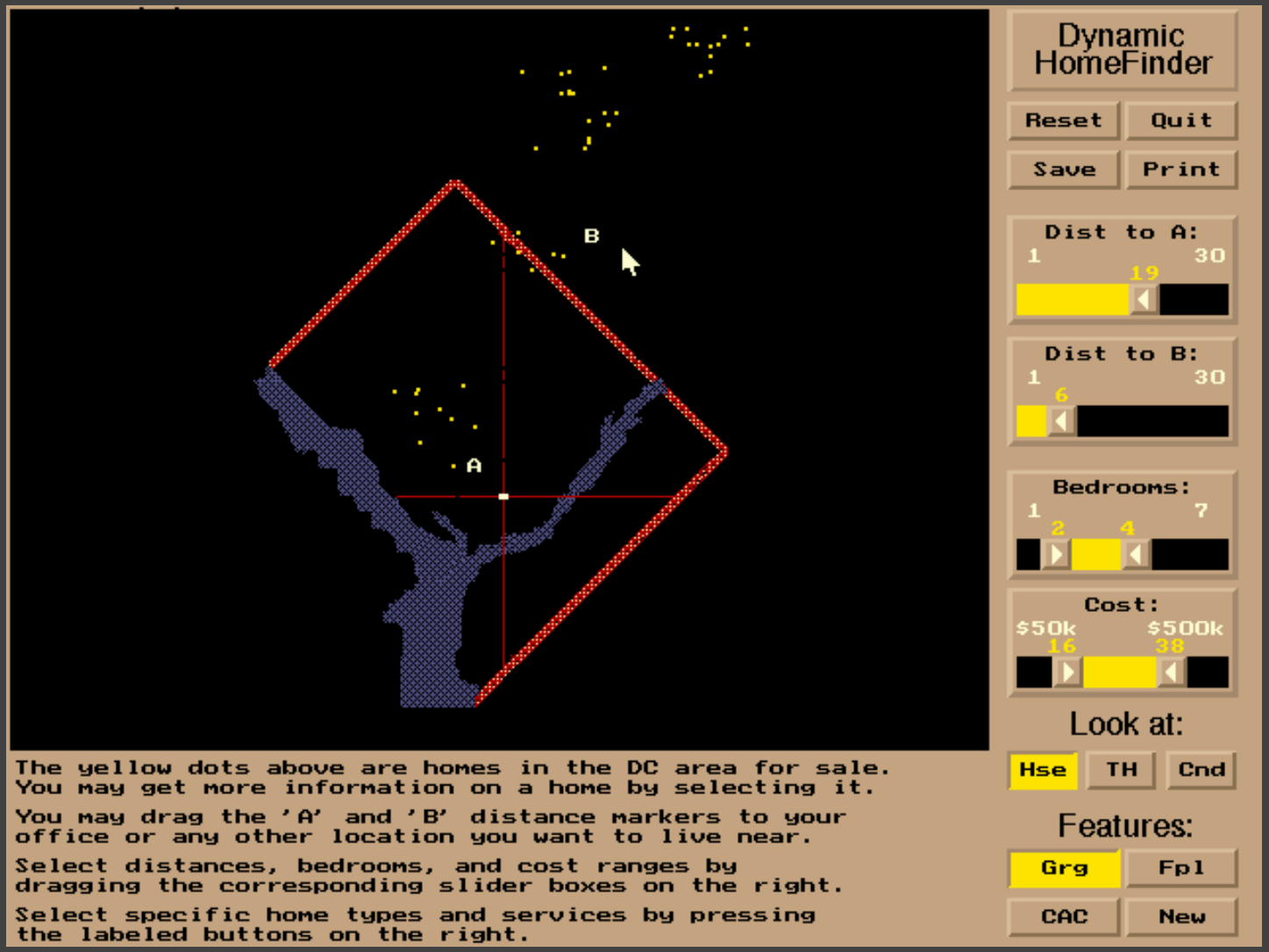
Given housing data with:

- price
- address
- type (house/condo/…)
- bedroom count
- bathroom count

What forms of interaction might be useful for house hunters? Think about the *task* first, then how to support it.

pollev.com/jheer

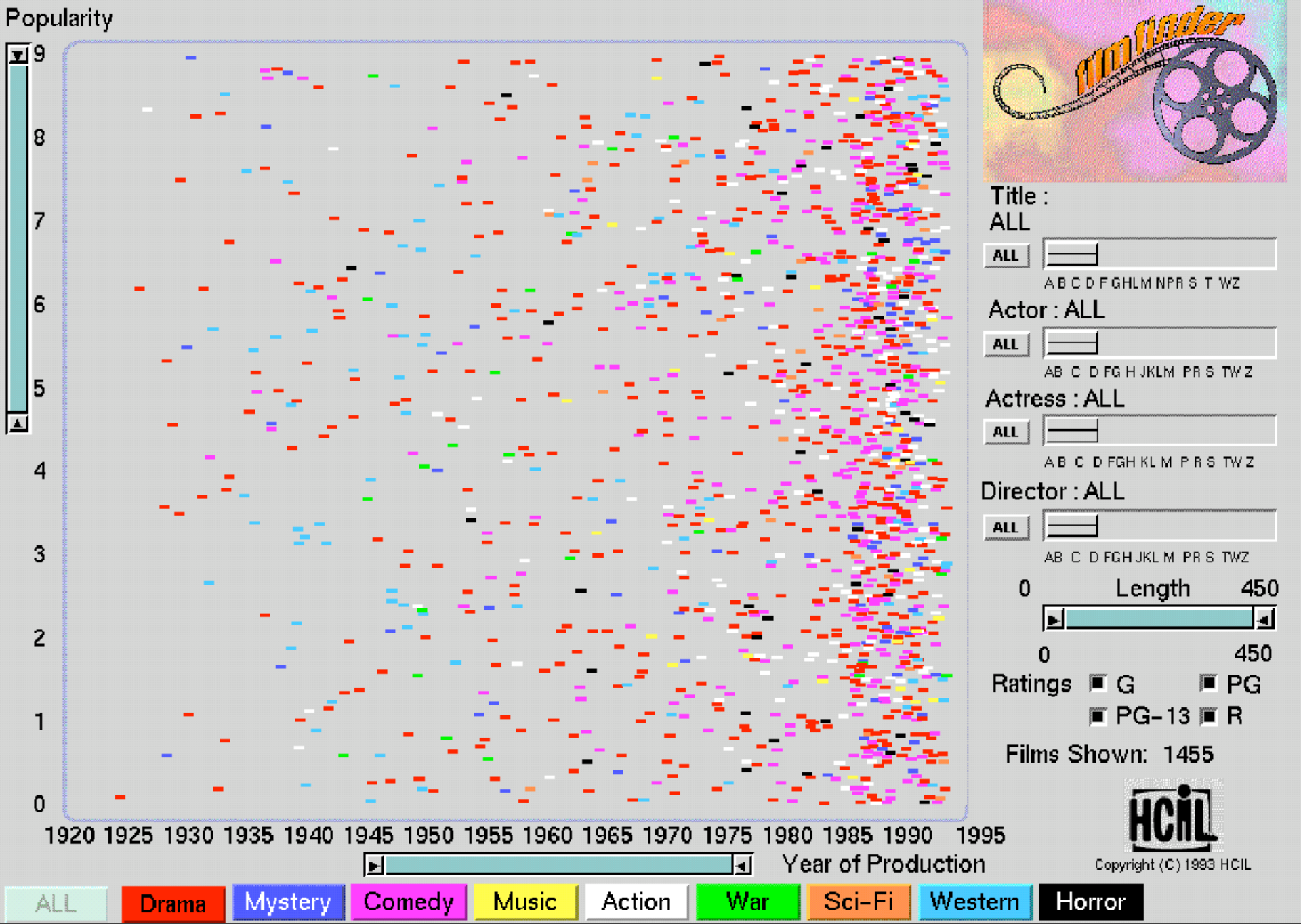
HomeFinder



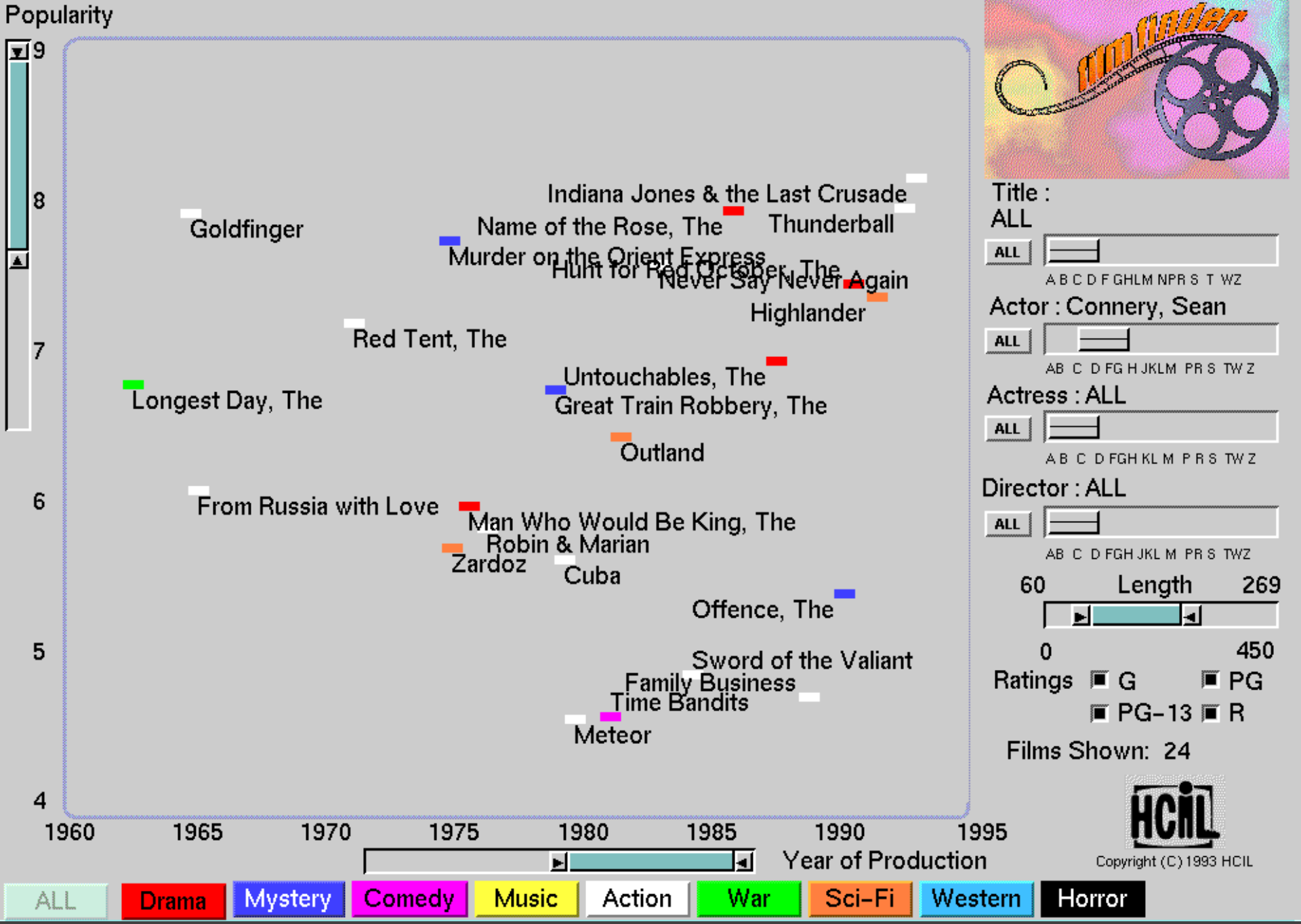
[Williamson and Shneiderman 92]

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

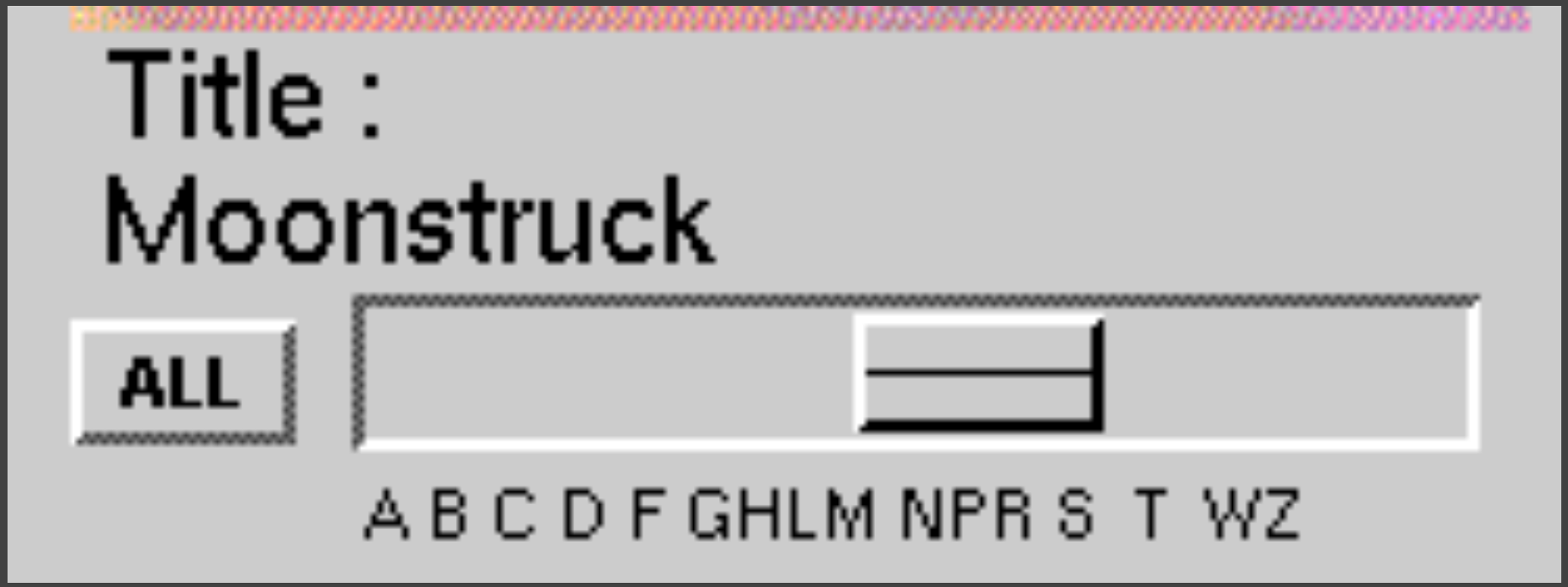


[Ahlberg and Shneiderman 94]

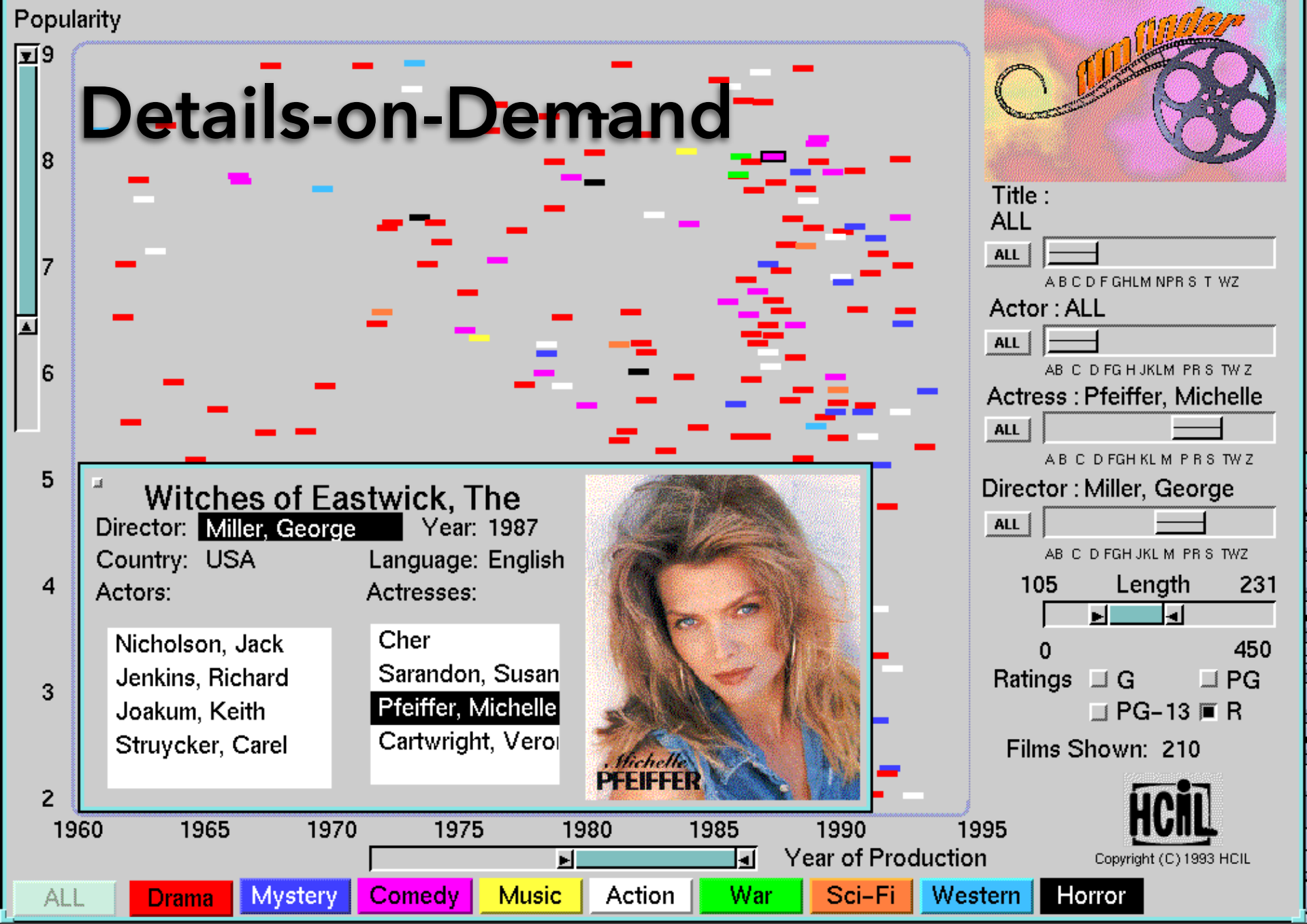


[Ahlberg and Shneiderman 94]

Alphaslider (?)



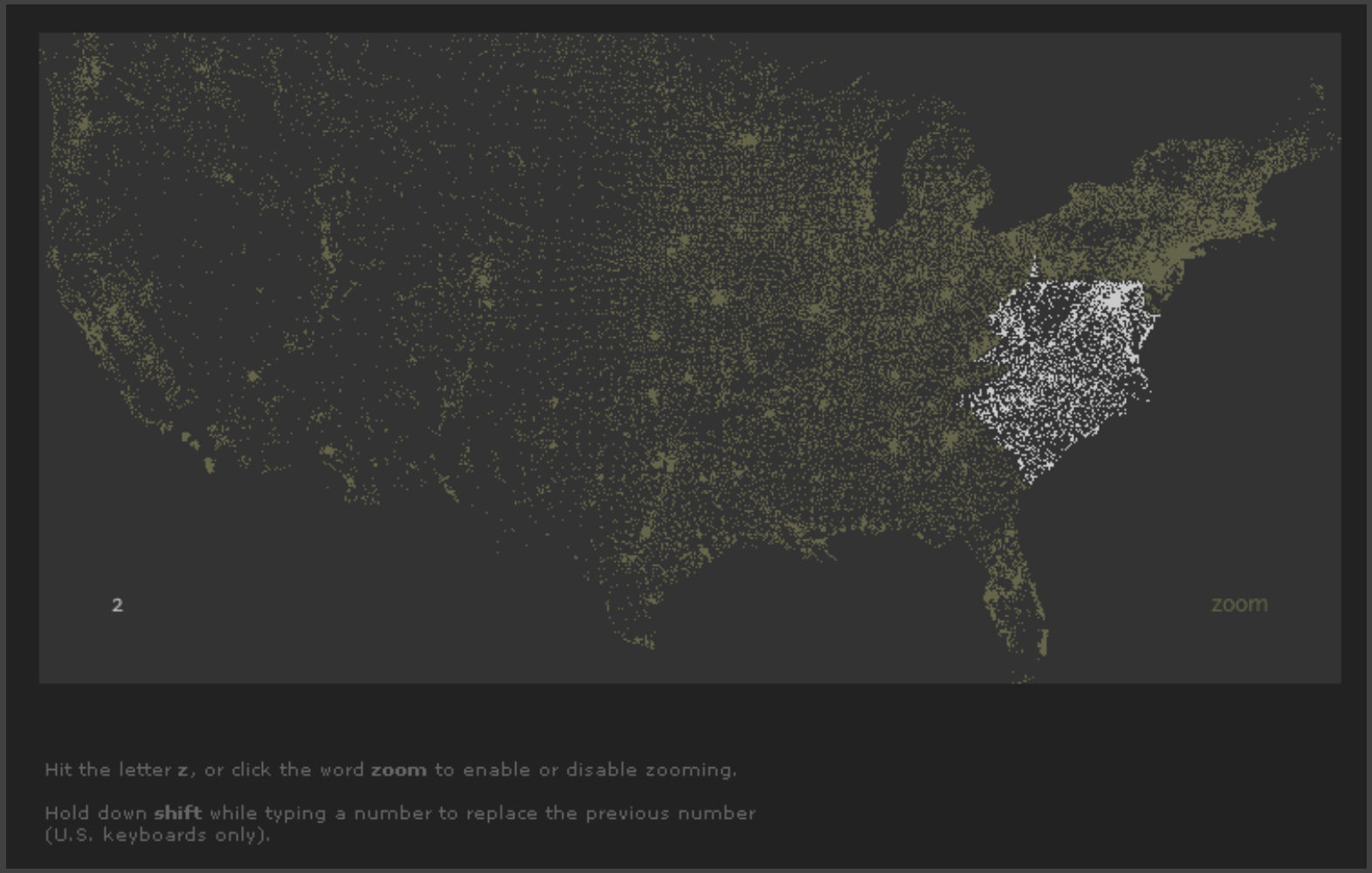
[Ahlberg and Shneiderman 94]



[Ahlberg and Shneiderman 94]

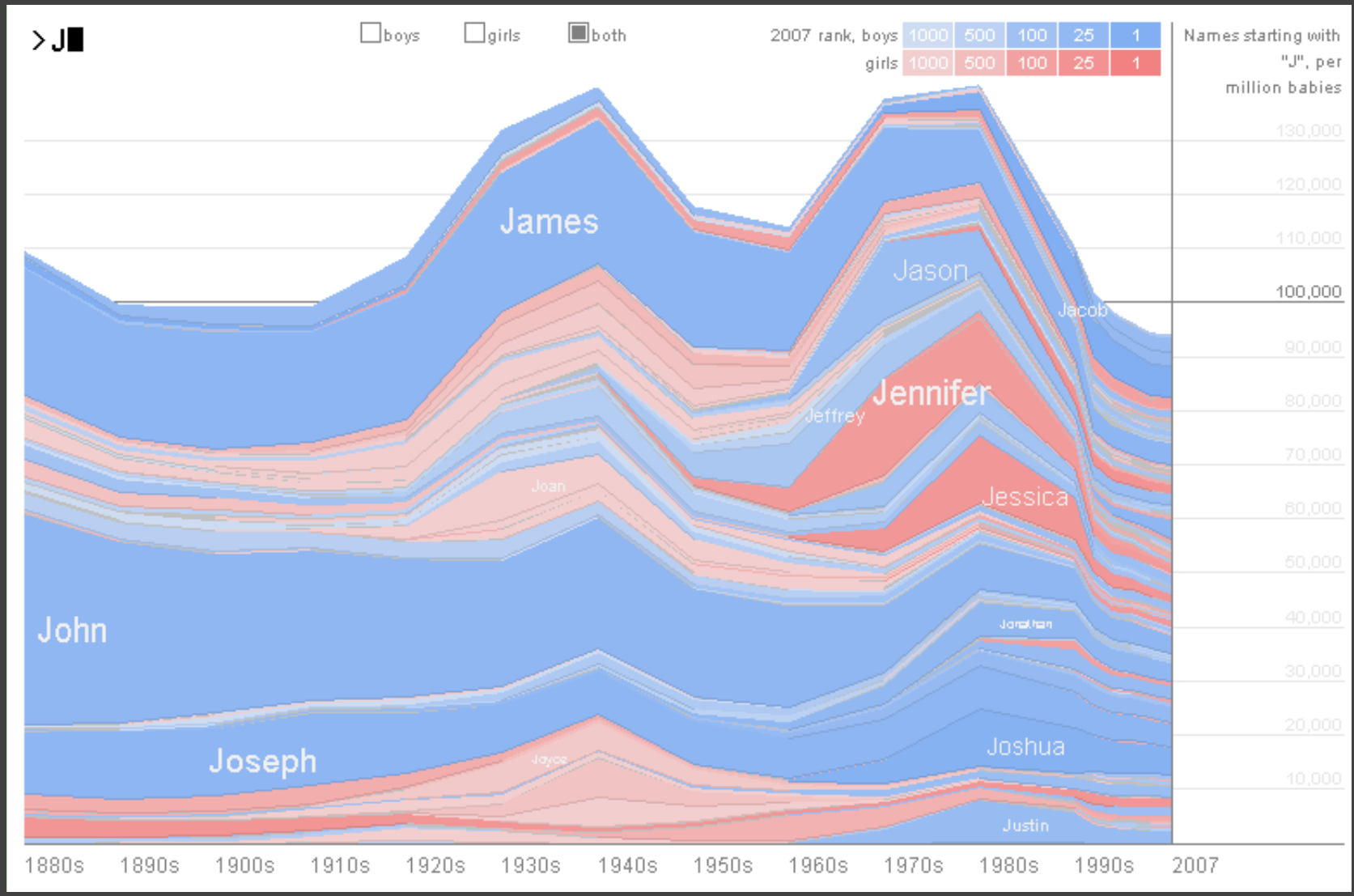
- The Attribute Explorer

Zipdecode [Fry 04]

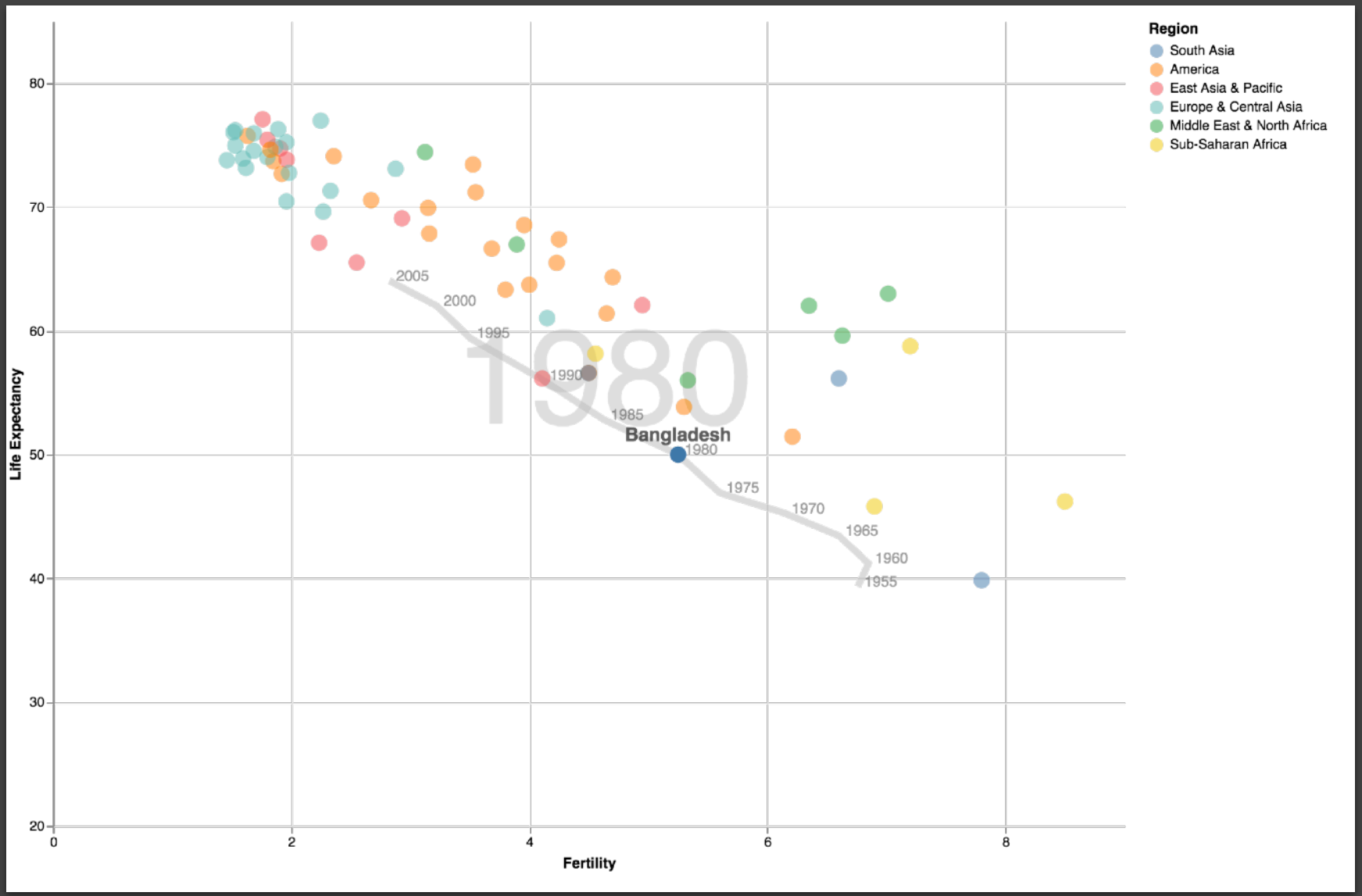


http://benfry.com/zipdecode/

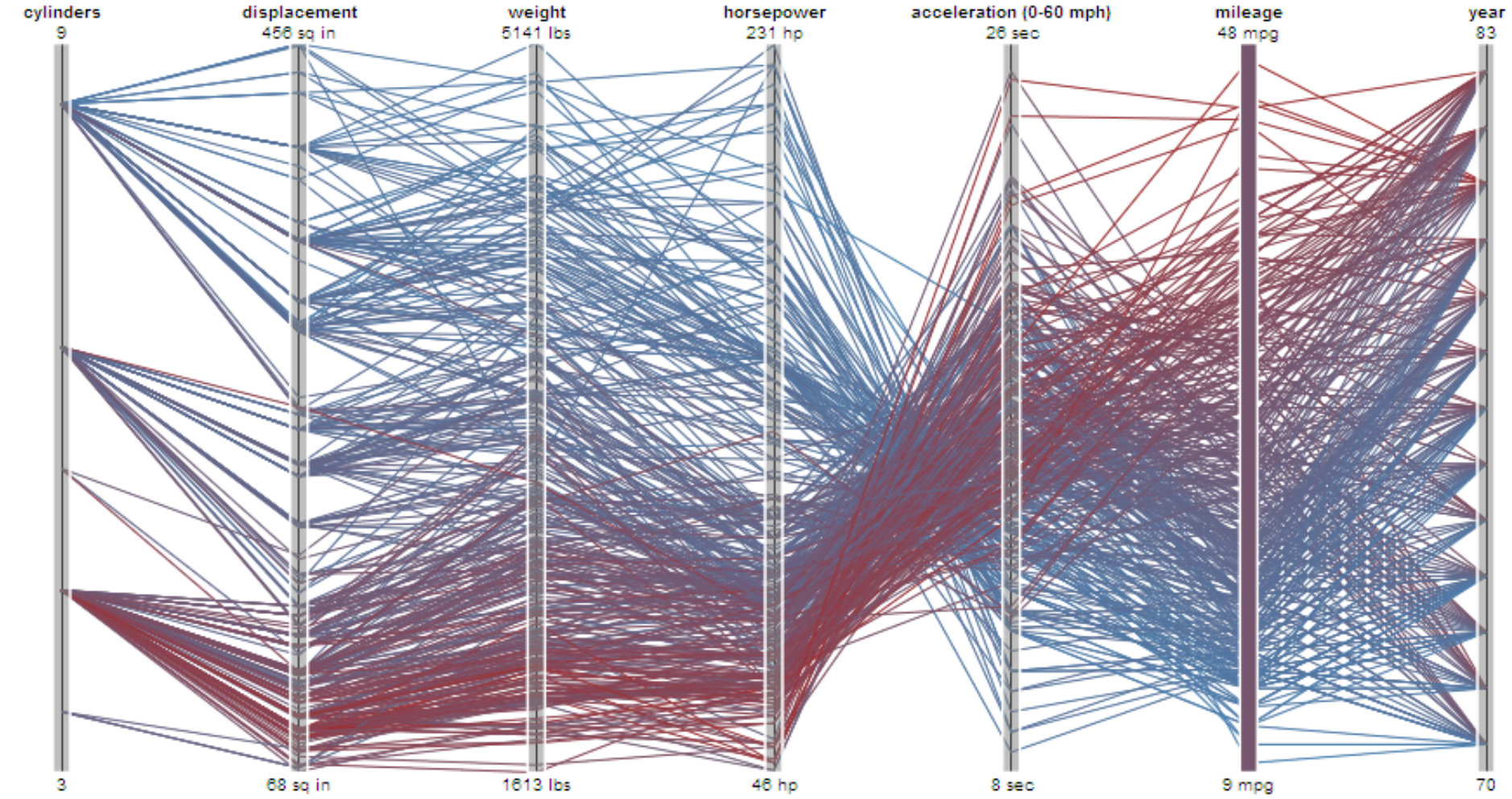
NameVoyager [Wattenberg 06]



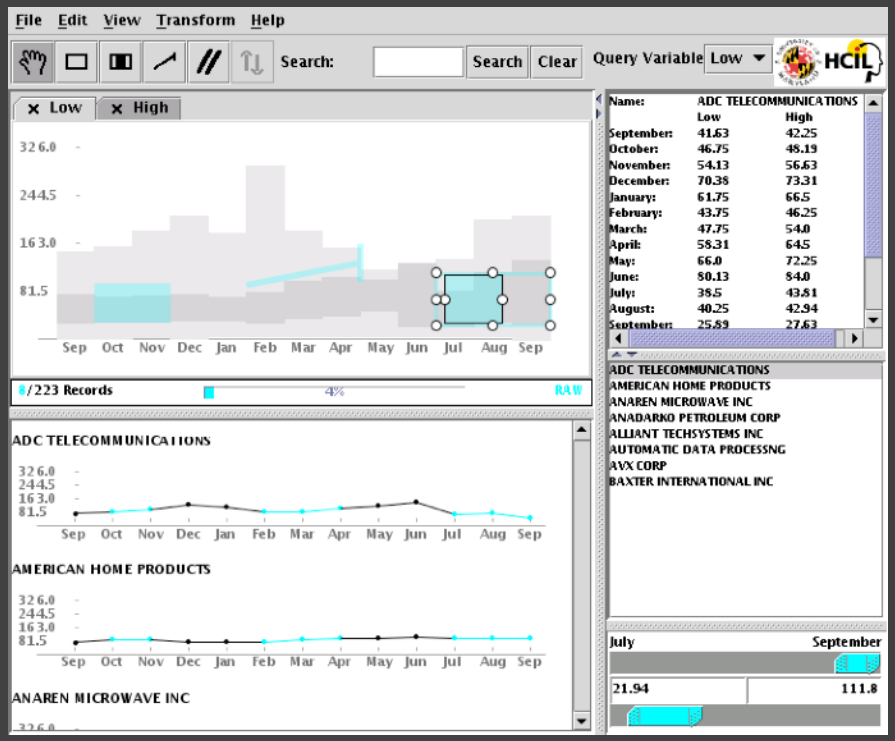
DimpVis [Kondo 14]

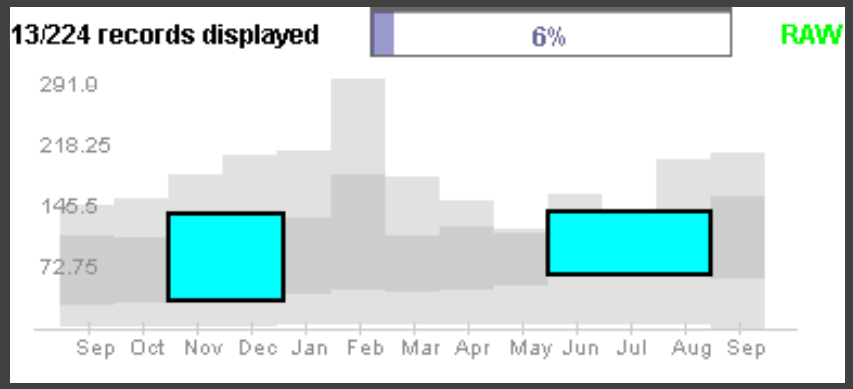


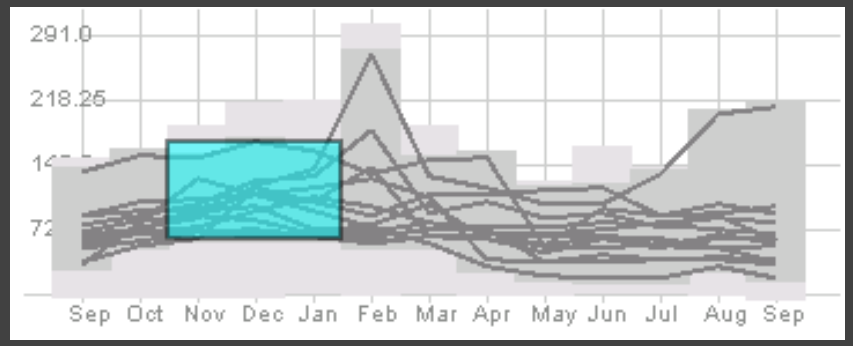
Parallel Coordinates [Inselberg]



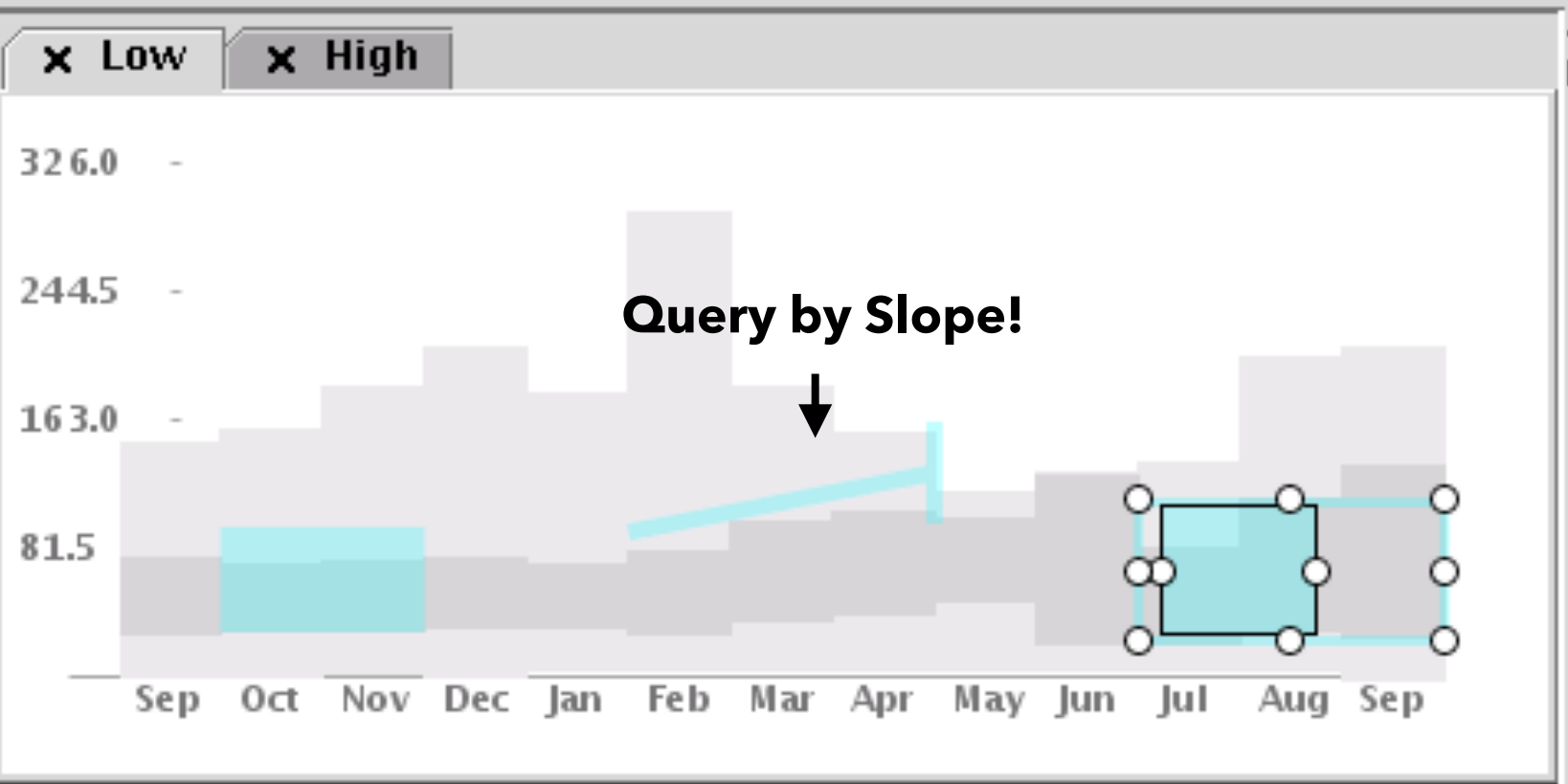
TimeSearcher [Hocheiser 02]

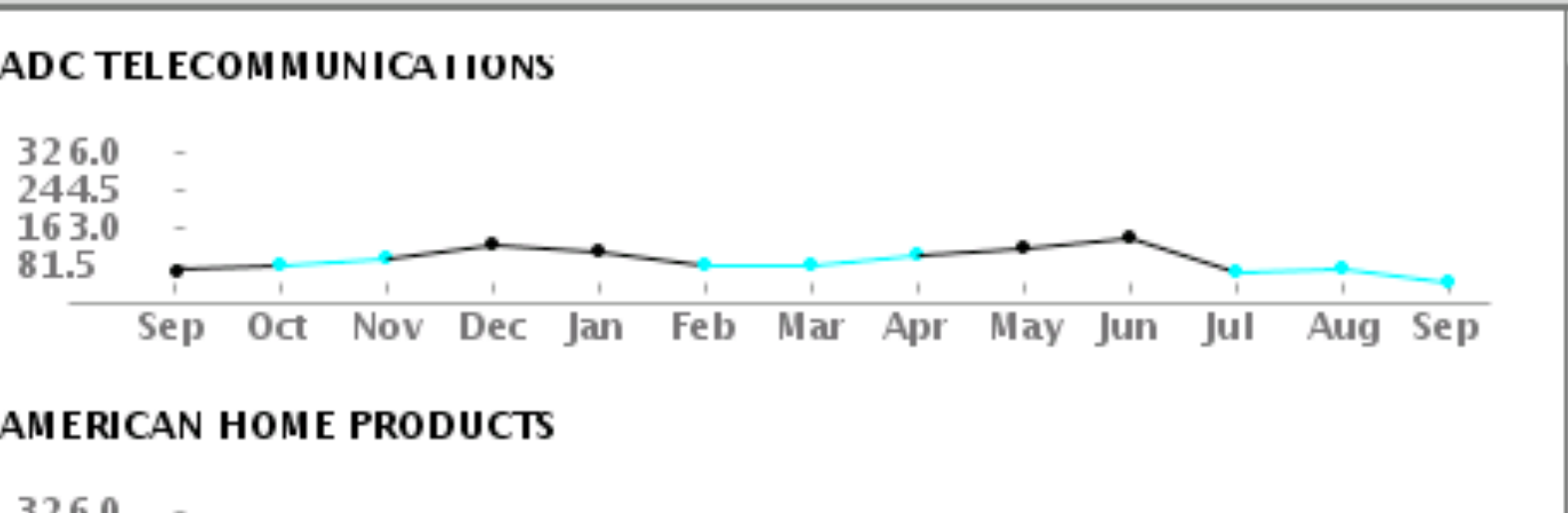






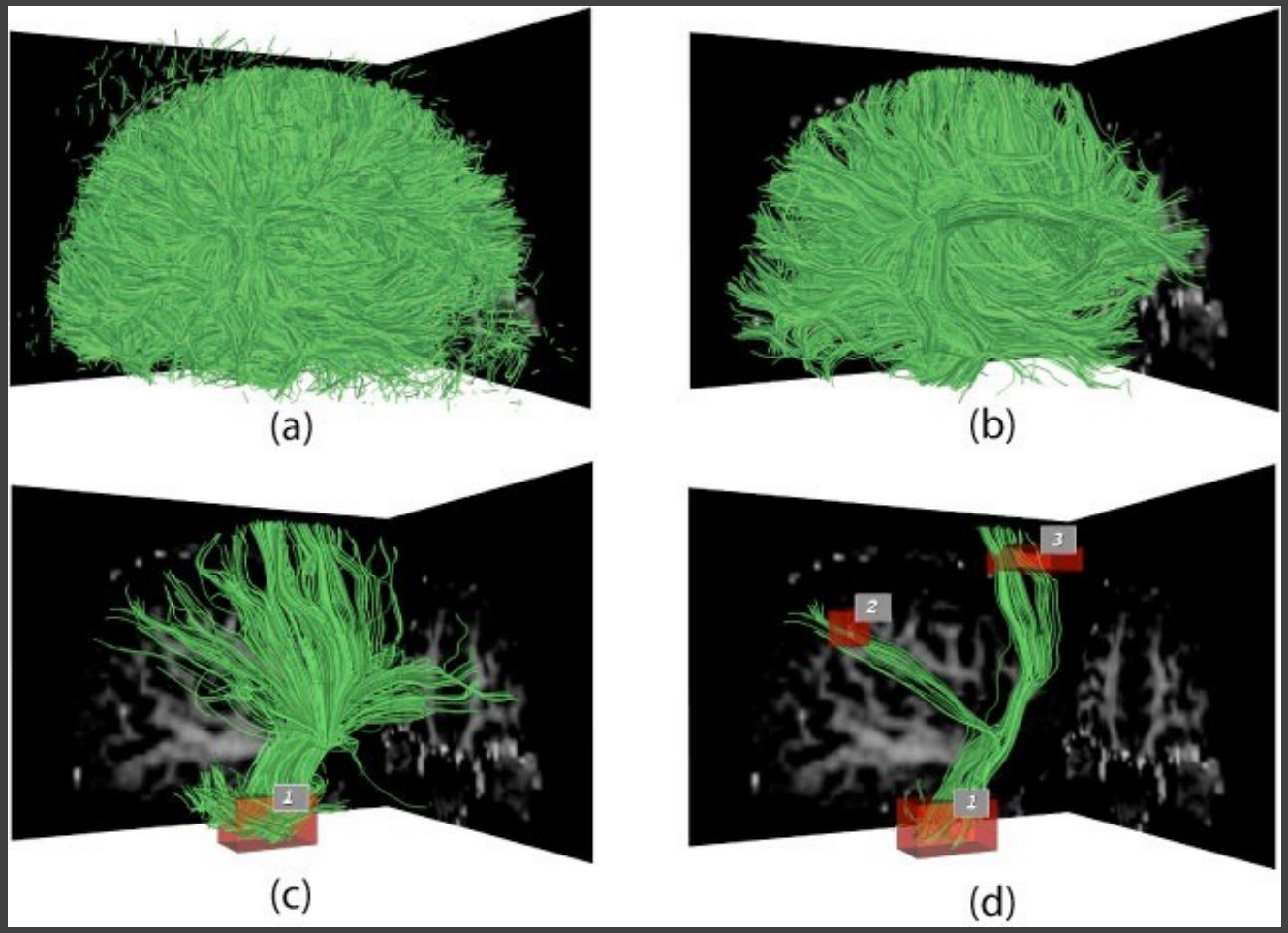
Builds on Wattenberg's [2001] idea for sketch-based queries of time-series data.


Low
High
326.0
244.5
163.0
81.5
Query by Slope!
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
8/223 Records
4%
RAW

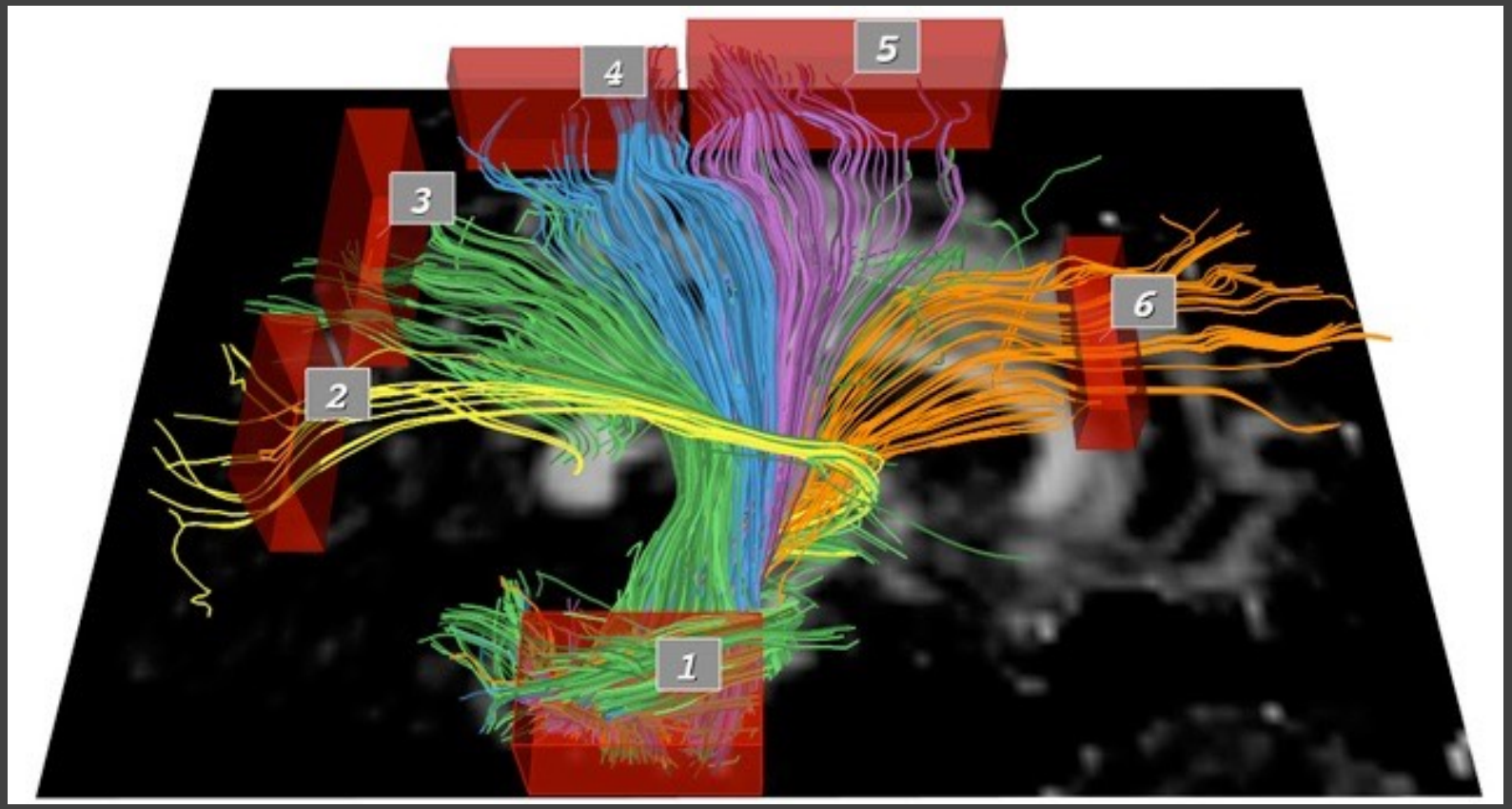

ADC TELECOMMUNICATIONS
326.0
244.5
163.0
81.5
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
AMERICAN HOME PRODUCTS

Name:
September:
October:
November:
December:
January:
February:
March:
April:
May:
June:
July:
August:
September:
ADC TELECOMM
AMERICAN HOM
ANAREN MICRO
ANADARKO PE
ALLIANT TECHS
AUTOMATIC DA
AVX CORP
BAXTER INTERN

3D Dynamic Queries [Akers 04]



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

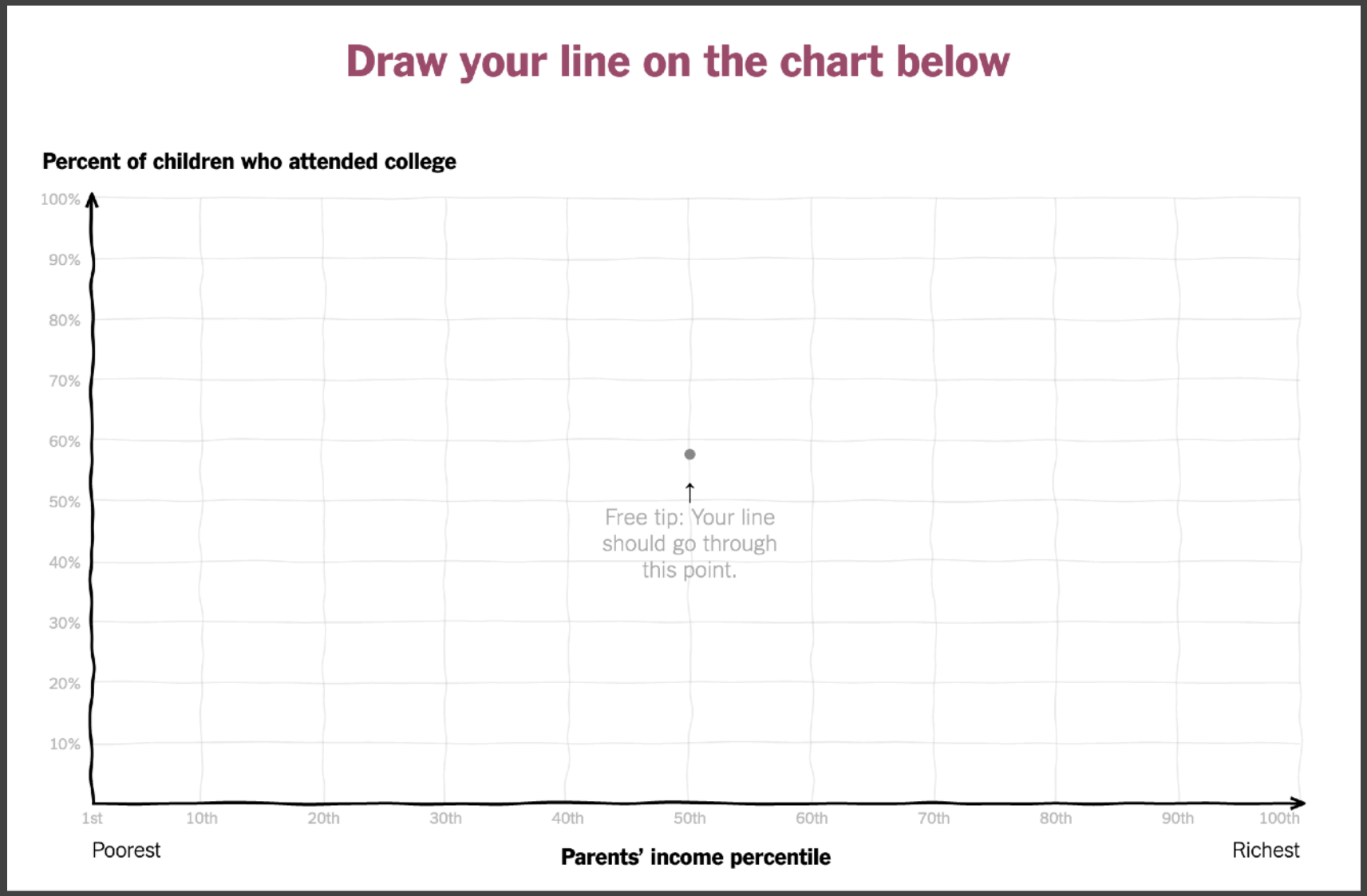
Lots of controls

Amount of data shown limited by screen space

Who would use these kinds of tools?

Prompting Reflection

You Draw It [Aisch et al. '15]



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: Deceptive Visualization

Design **two** static visualizations for a dataset:

1. An *earnest* visualization that faithfully conveys the data
2. A *deceptive* visualization that tries to mislead readers

Your two visualizations should address the same question.

Try to design a deceptive visualization that appears to be earnest. *Can you trick your classmates and course staff?*

You are free to choose your own dataset, but we have also provided some preselected datasets for you.

Submit two images and a brief write-up on Gradescope.

Due by Mon **1/15 11:59pm**.

DONE

A2 Peer Reviews

By Thursday 4/18 you will be assigned two peer A2 submissions to review. For each:

- Try to determine which is earnest and which is deceptive
- Share a rationale for how you made this determination
- Share feedback using the “I Like / I Wish / What If” rubric

Assigned reviews will be posted on the A2 Peer Review page on Canvas, along with a link to a Google Form. You should submit two forms: one for each A2 peer review.

Due by **Tue 4/23 11:59pm**.

I Like… / I Wish… / What If?

I LIKE…
Praise for design ideas and/or well-executed implementation details. *Example: "I like the navigation through time via the slider; the patterns observed as one moves forward are compelling!"*

I WISH…
Constructive statements on how the design might be improved or further refined. *Example: "I wish moving the slider caused the visualization to update immediately, rather than the current lag."*

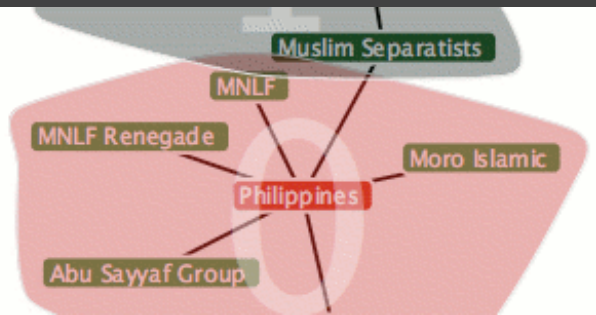
WHAT IF?
Suggest alternative design directions, or even wacky half-baked ideas. *Example: "What if we got rid of the slider and enabled direct manipulation navigation by dragging data points directly?"*

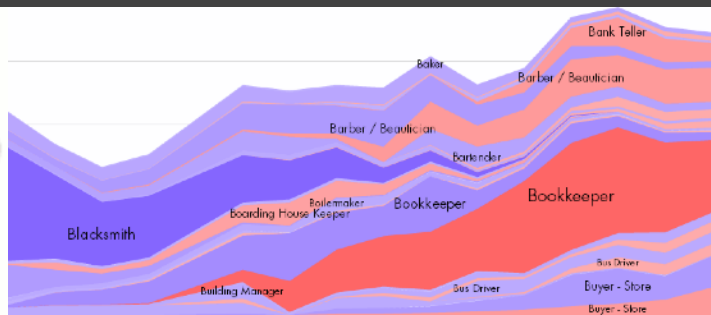
A3: Interactive Prototype

Create an interactive visualization. Choose a driving question for a dataset and develop an appropriate visualization + interaction techniques, then deploy your visualization on the web.

Due by *11:59pm* on **Monday, May 6**.

Work in project teams of 3-4 people.





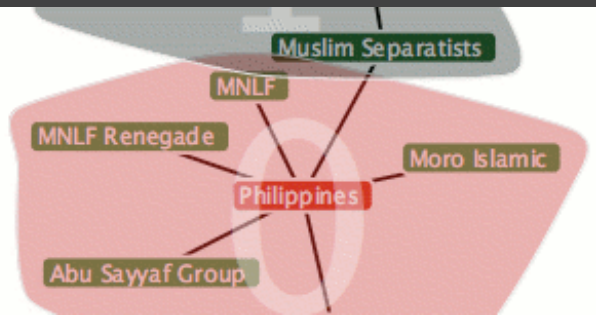
Form A3 + Final Project Team

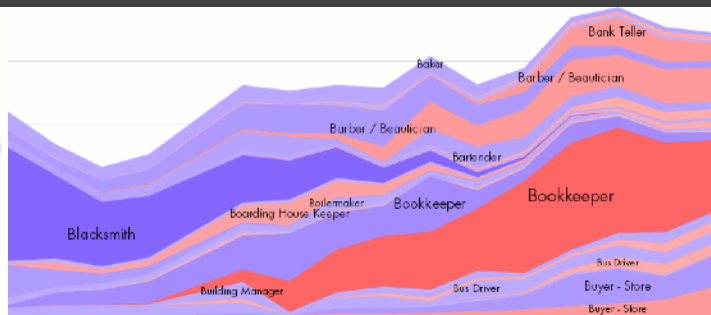
Form a **team of 3-4** for A3 and the Final Project.

Submit signup form by **Thu 4/25, 11:59pm**.

If you do not have team mates, post on Ed about your interests/skills/project ideas!

We will send out a reminder early next week.

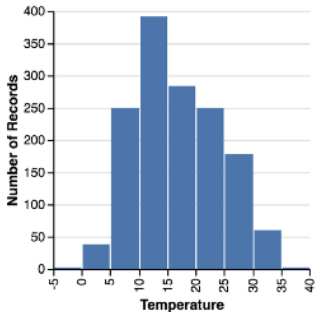




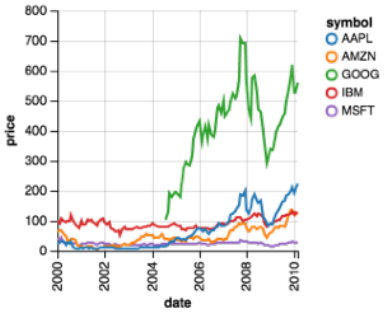
An Interaction Grammar (Vega-Lite Selections)

Satyanarayan, Moritz, Wongsuphasawat, Heer. *TVCG'17*

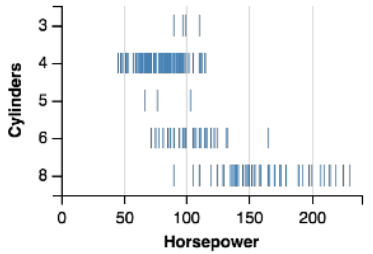
Histogram



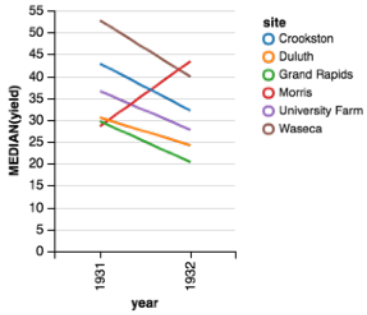
Line Chart



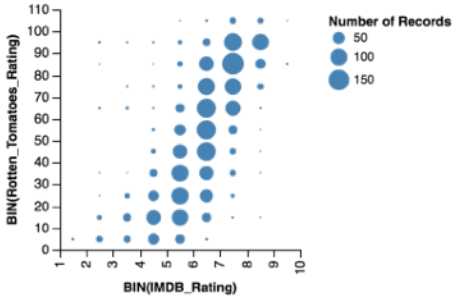
Strip Plot



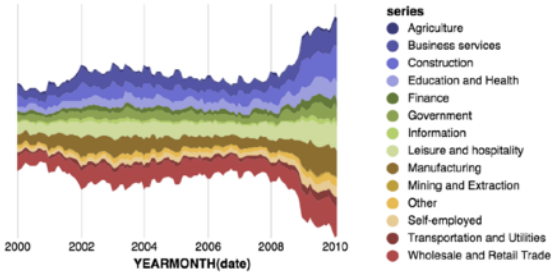
Slope Graph



Binned Scatter Plot

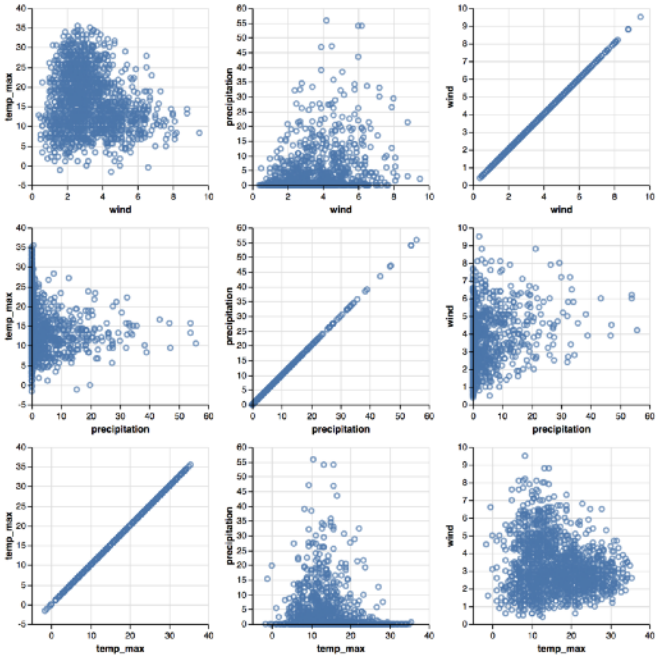


Area Chart

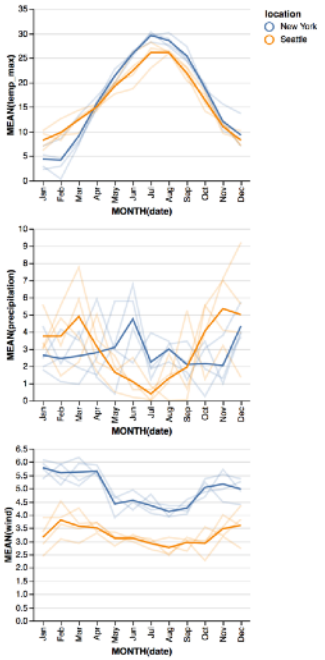


Vega-Lite: A Grammar of Graphics

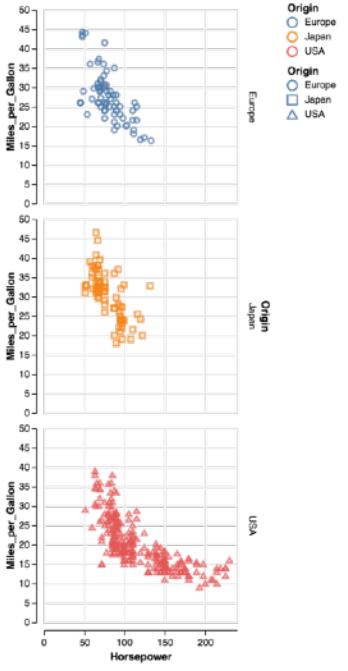
Scatter Plot Matrix



Concat & Layered Views

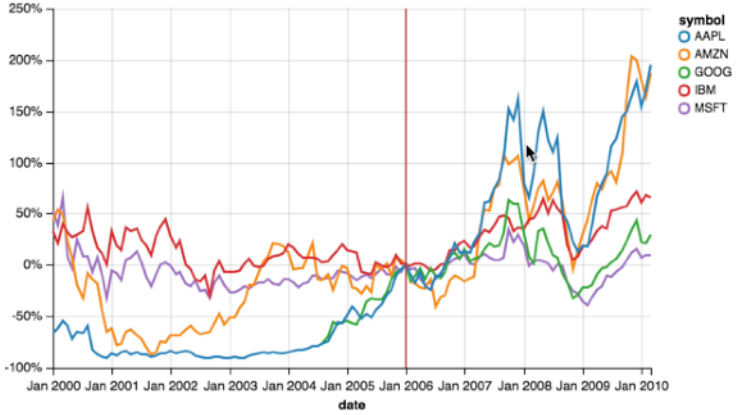


Faceted Views

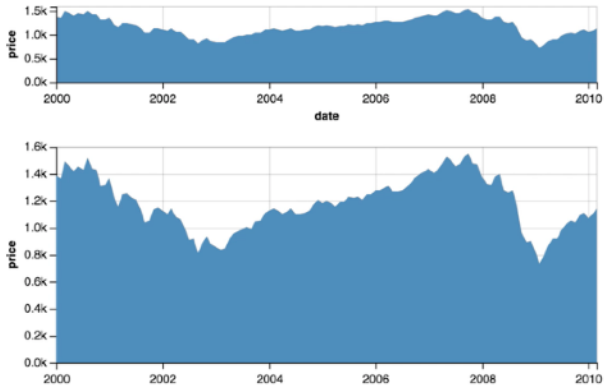


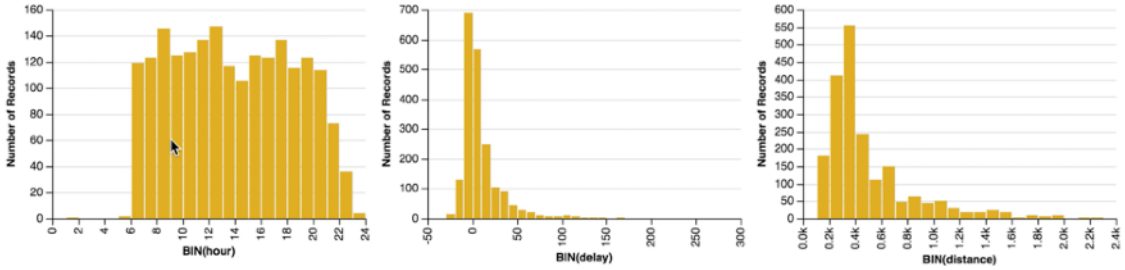
Vega-Lite: A Grammar of Multi-View Graphics

Indexed Chart



Focus + Context

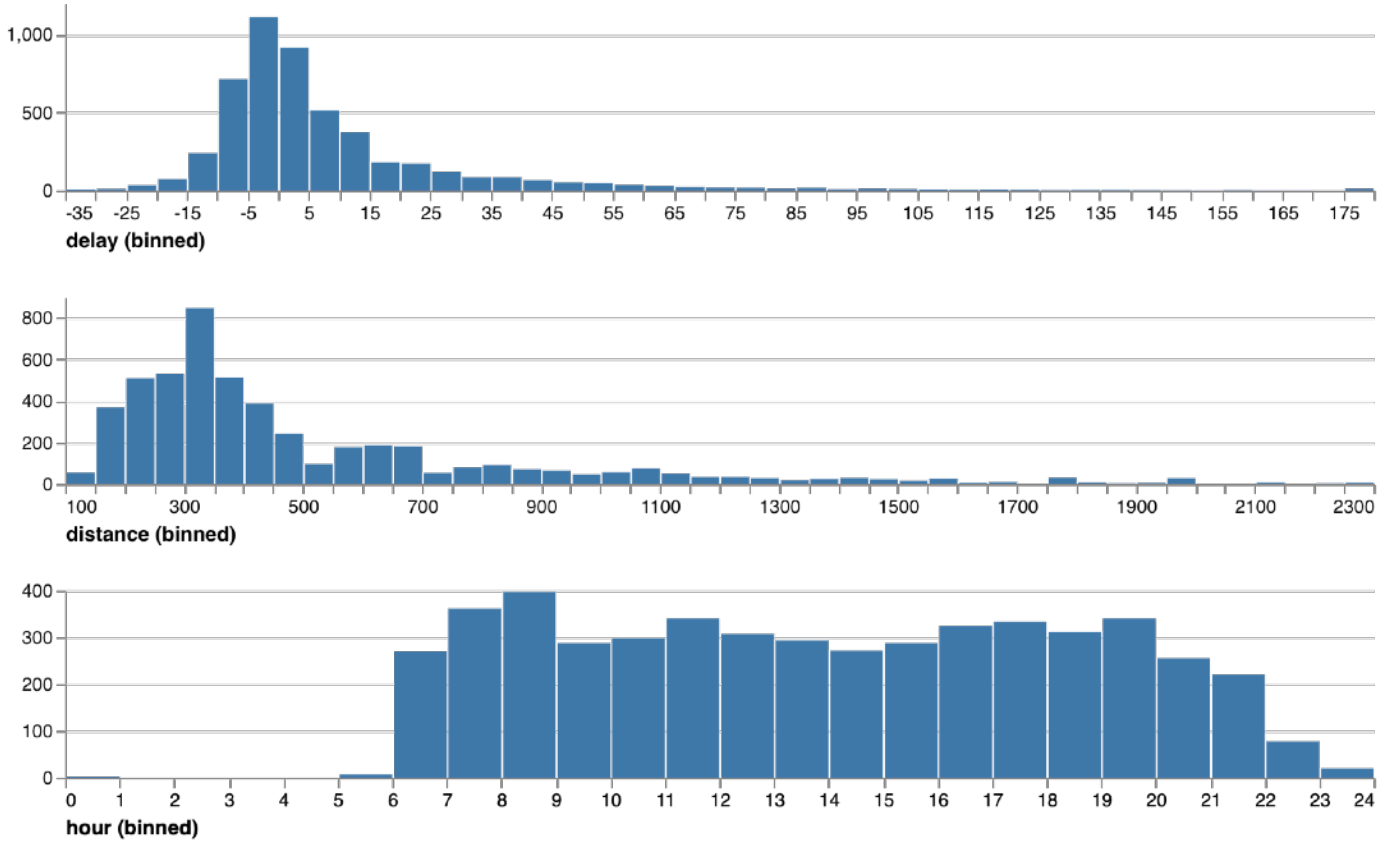




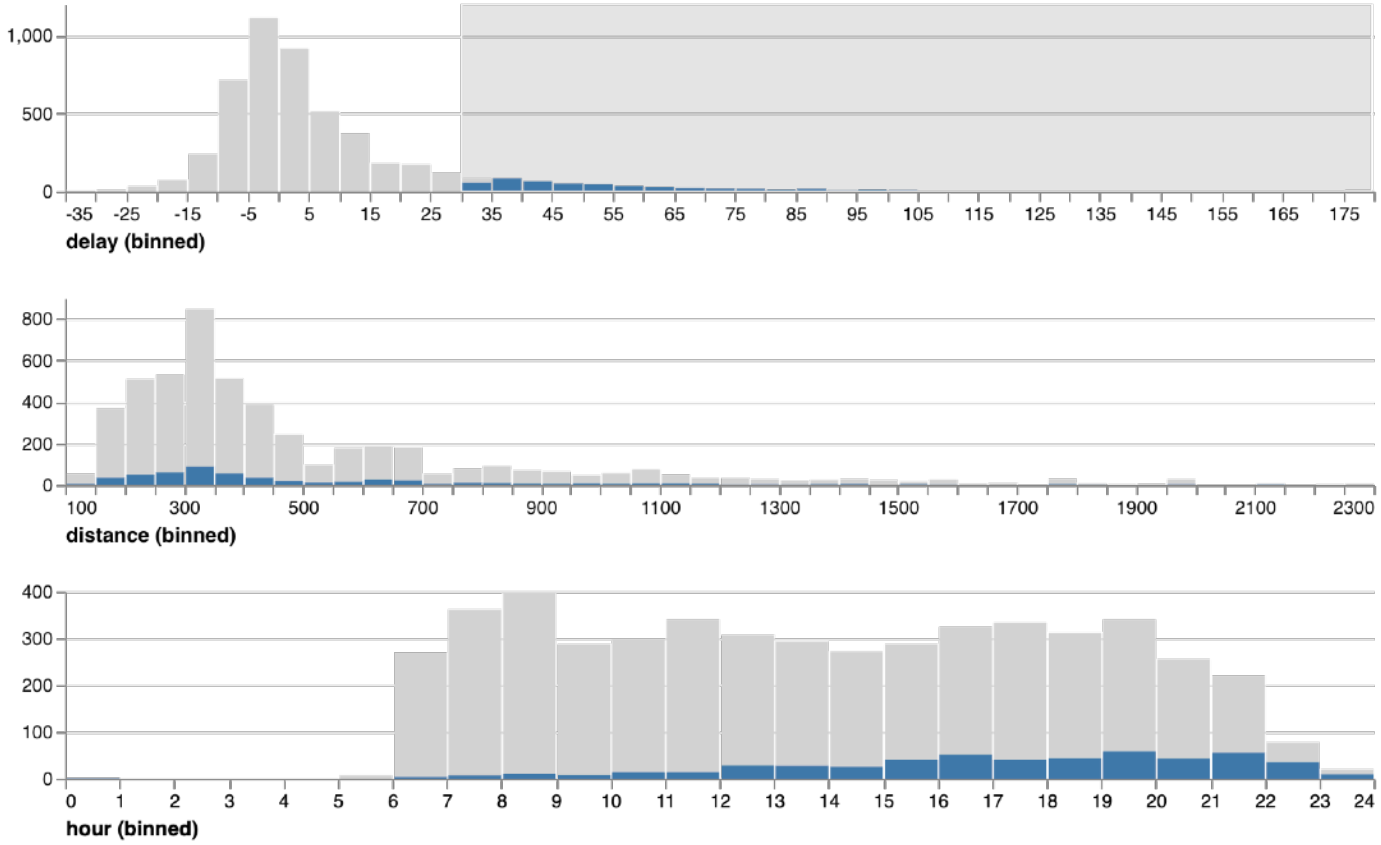
Cross-Filtering

Vega-Lite: A Grammar of Interactive Graphics

Cross-Filtering in Vega-Lite

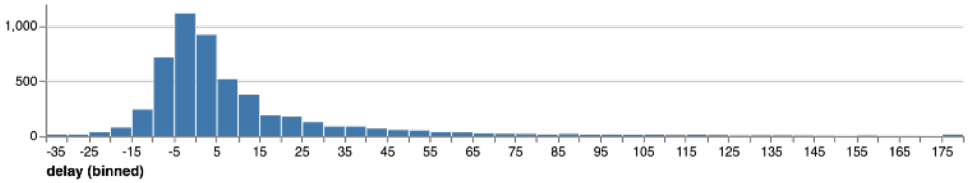


Cross-Filtering in Vega-Lite



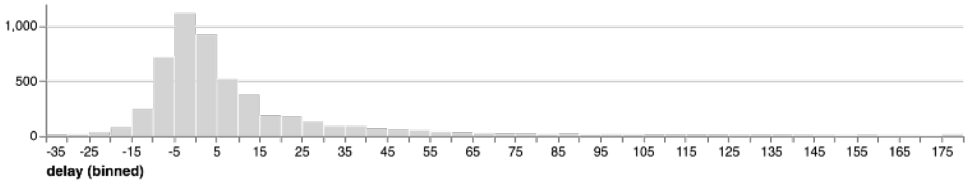
Cross-Filtering in Vega-Lite

```
markBar().encode(
  x().fieldQ('delay').bin(true),
  y().count()
).data('data/flights.json')
```



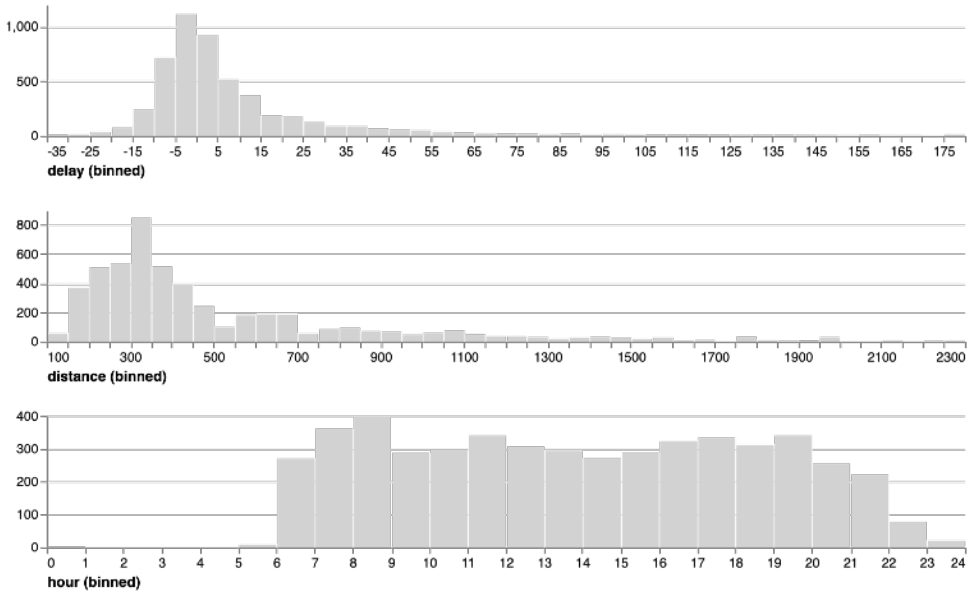
Cross-Filtering in Vega-Lite

```
markBar().encode(
  x().fieldQ('delay').bin(true),
  y().count(),
  color().value('lightgrey')
).data('data/flights.json')
```



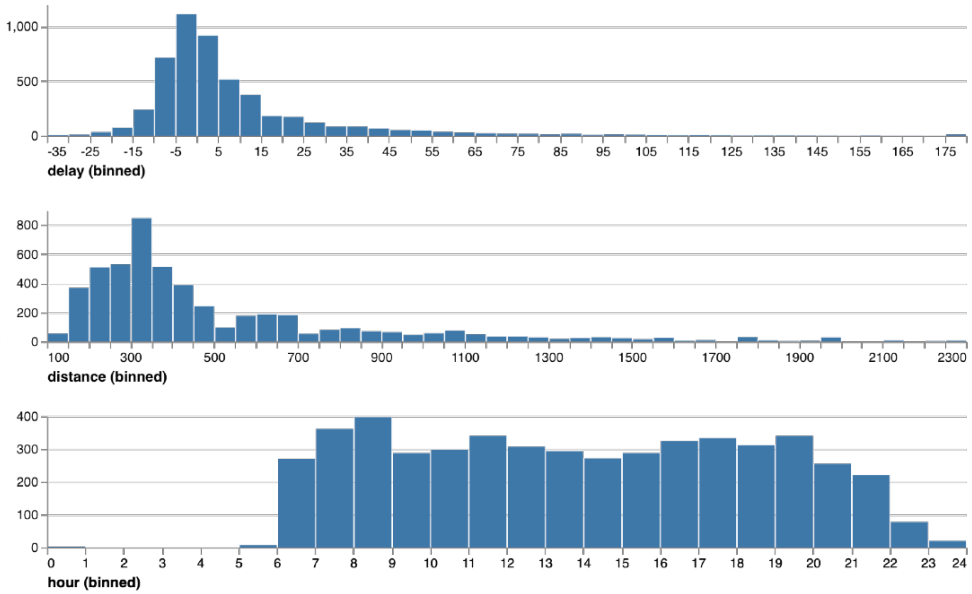
Cross-Filtering in Vega-Lite

```
markBar().encode(
  x().fieldQ(repeat('row').bin(true),
  y().count(),
  color().value('lightgrey')
)
.repeat({
  row: ['delay', 'distance', ‘hour’]
 })
.data('data/flights.json')
```



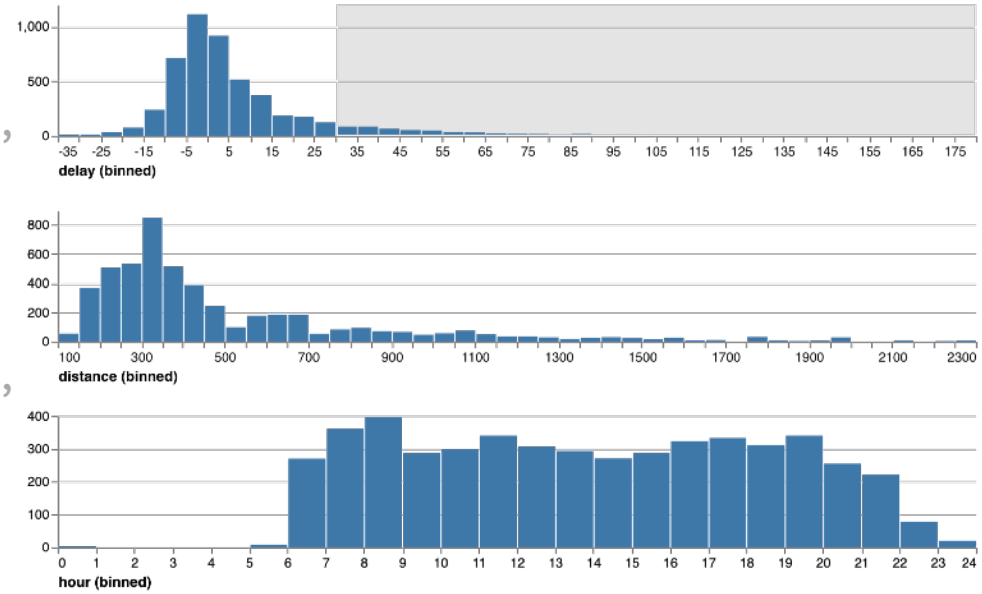
Cross-Filtering in Vega-Lite

```
layer(
  markBar().encode(
    x().fieldQ(repeat('row')).bin(true),
    y().count(),
    color().value('lightgrey')
  ),
  markBar().encode(
    x().fieldQ(repeat('row')).bin(true),
    y().count()
  )
)
.repeat({
  row: ['delay', 'distance', 'hour']
})
.data('data/flights.json')
```



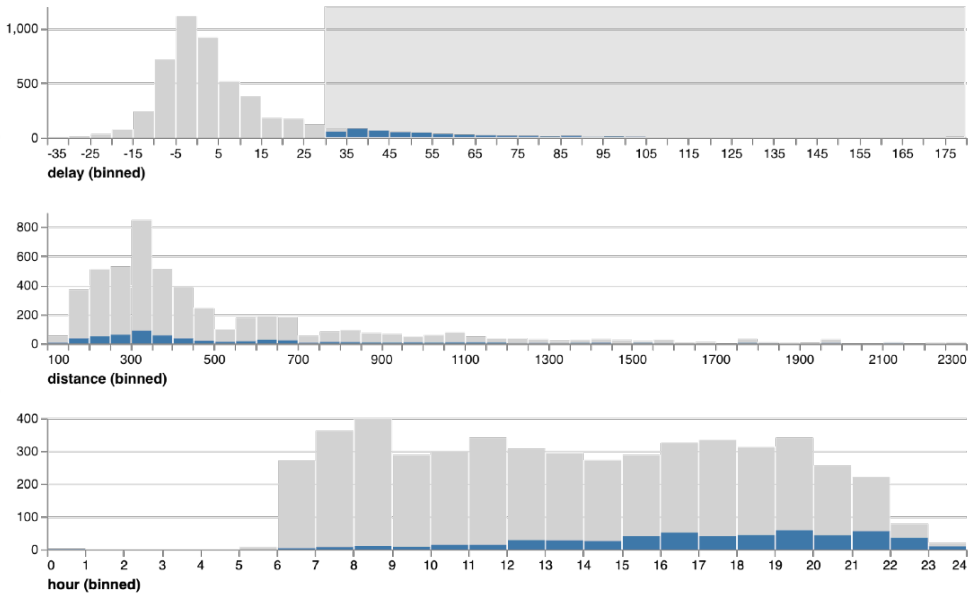
Cross-Filtering in Vega-Lite

```
brush = selectInterval().encodings('x')

layer(
  markBar().encode(
    x().fieldQ(repeat('row')).bin(true),
    y().count(),
    color().value('lightgrey')
  ).params(brush),
  markBar().encode(
    x().fieldQ(repeat('row')).bin(true),
    y().count()
  )
)
.repeat({
  row: ['delay', 'distance', 'hour']
})
.data('data/flights.json')
```



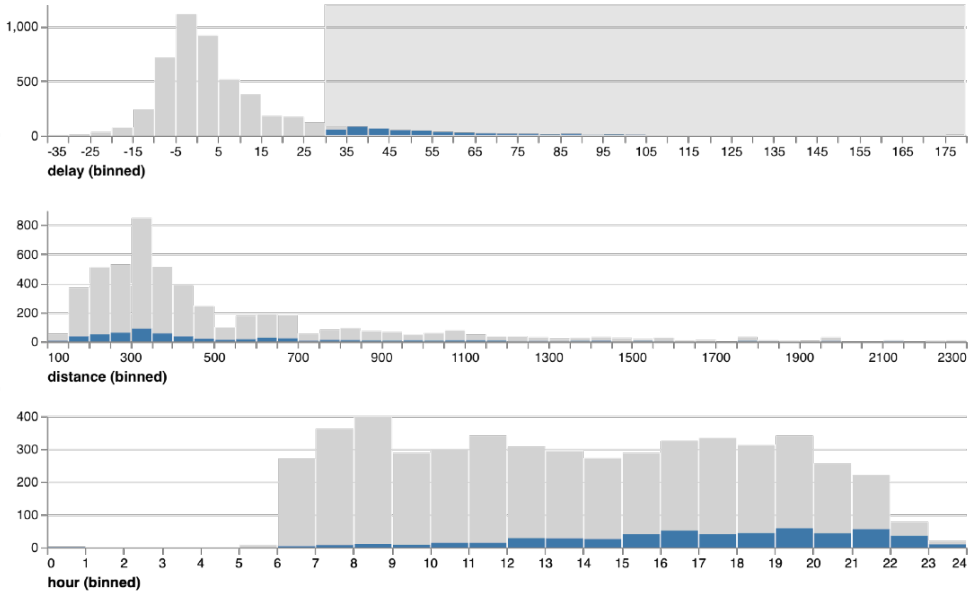
Cross-Filtering in Vega-Lite

```
brush = selectInterval.encodings('x')

layer(
  markBar().encode(
    x().fieldQ(repeat('row')).bin(true),
    y().count(),
    color().value('lightgrey')
  ).params(brush),
  markBar().encode(
    x().fieldQ(repeat('row')).bin(true),
    y().count()
  ).transform(filter(brush))
)
.repeat({
  row: ['delay', 'distance', 'hour']
})
.data('data/flights.json')
```



Cross-Filtering in Vega-Lite

```
brush = selectInterval.encodings('x')

layer(
  markBar().encode(
    x().fieldQ(repeat('row')).bin(true),
    y().count(),
    color().value('lightgrey')
  ).params(brush),
  markBar().encode(
    x().fieldQ(repeat('row')).bin(true),
    y().count()
  ).transform(filter(brush))
)
.repeat({
  row: ['delay', 'distance', 'hour']
})
.data('data/flights.json')
```



Multi-view interactive graphics in ~10 lines of code

What constitutes a selection?

Input handlers: click, shift-click, drag, zoom, …

Bindings

- **Inputs**: interactive brush, query widgets
- **Axis scales**: pan / zoom a scale domain
- **Legends**: interactive selection

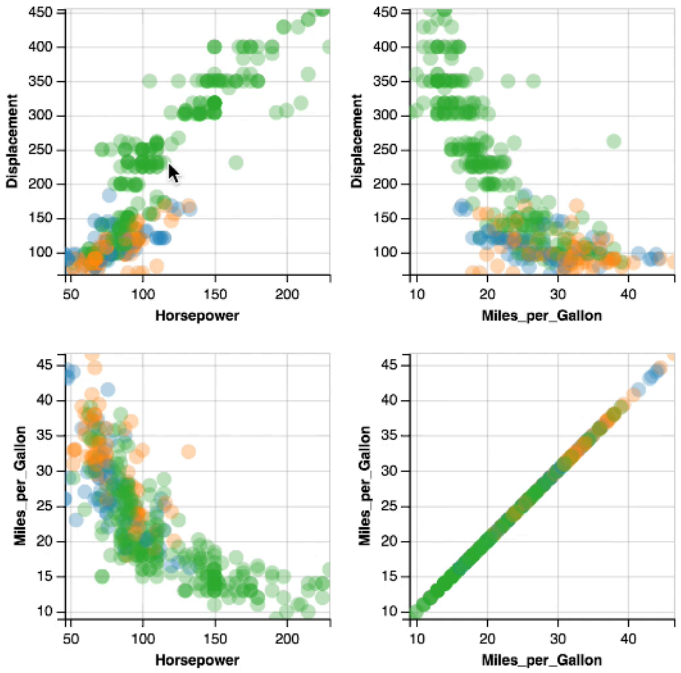
Scale inversion: visual space → data space

Predicate: test if a data record is selected

A selection can then *parameterize* data transformations and visual encodings.

Selections

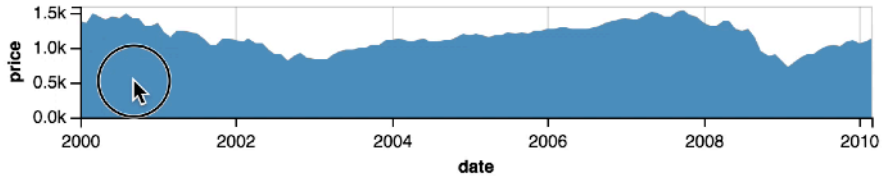
Selections *invert* scales and *parameterize* graphics

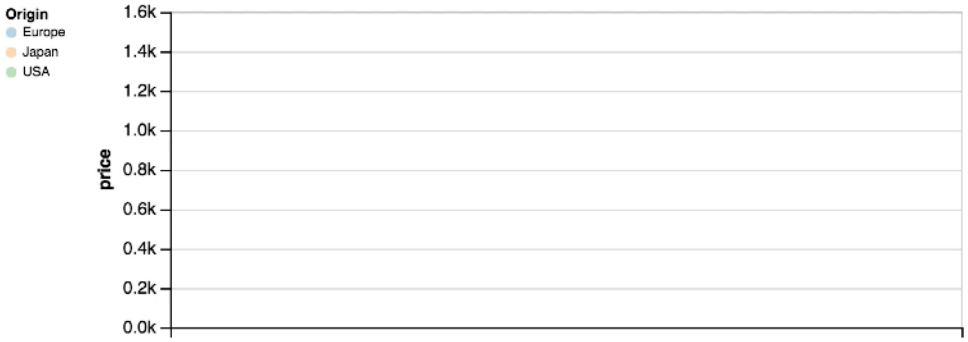


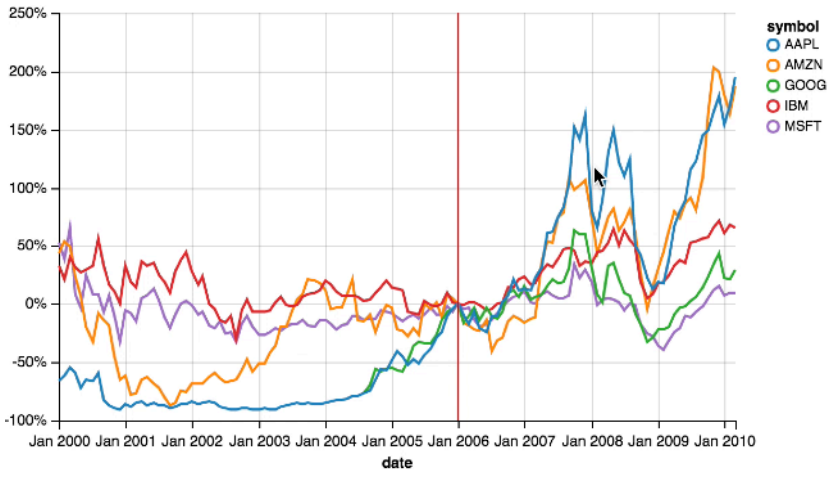
Bind selection to scale domains:

Synchronized Pan & Zoom!

Overview + Detail







Parameterized Transformations