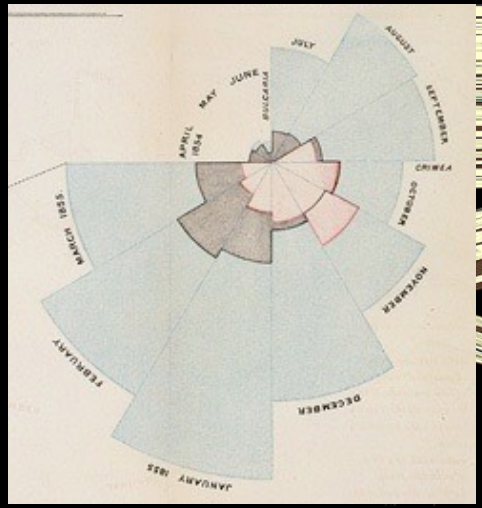
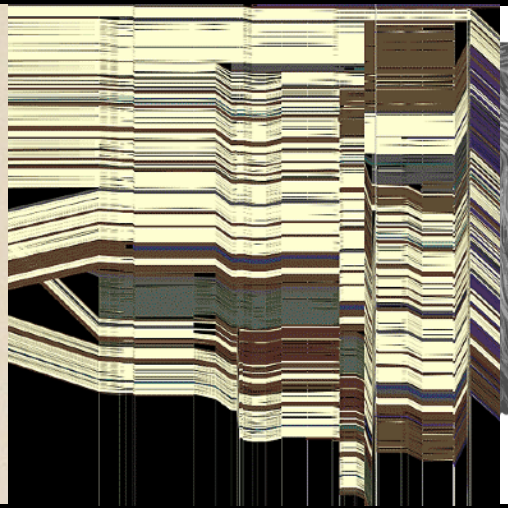
CSE 442 - Data Visualization

Interaction





Jeffrey Heer University of Washington

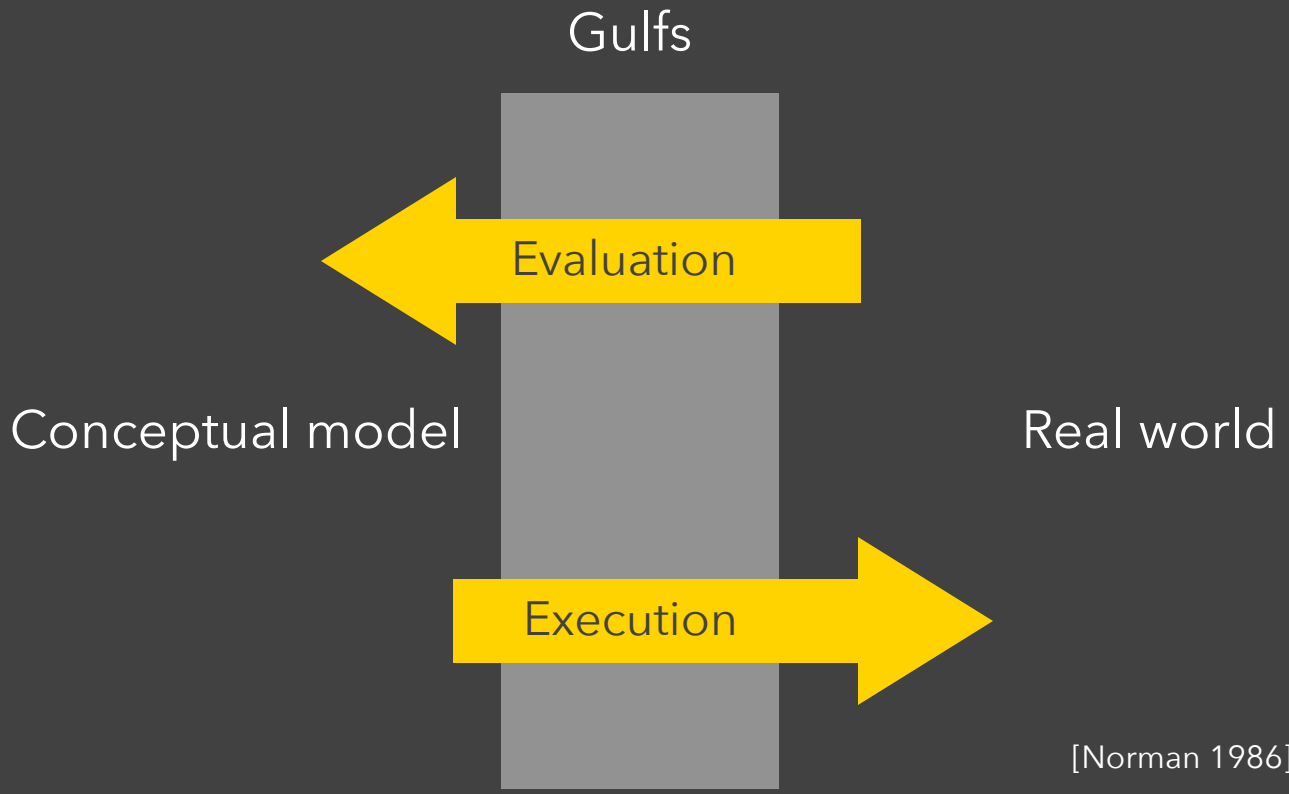
[There is an] apparent challenge that computational artifacts pose to the longstanding distinction between the physical and the social, in the special sense of those things that one designs, builds, and uses, on the one hand, and those things with which one communicates, on the other.

“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.

[Norman 1986]

Gulf of Execution

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

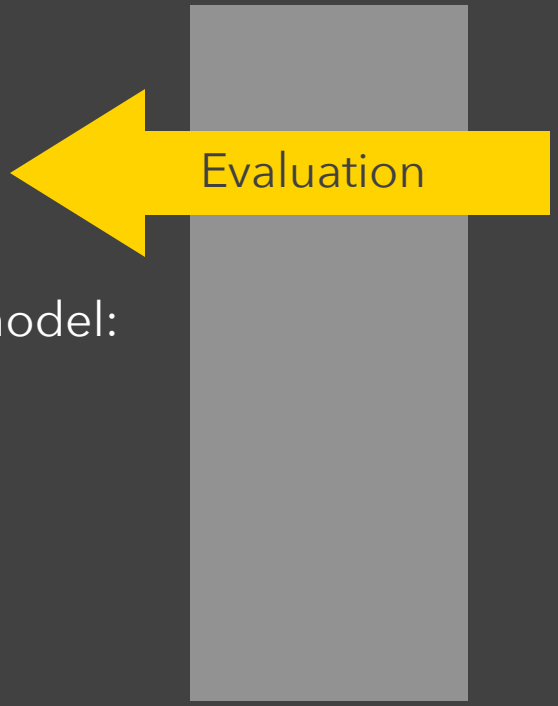
Gulf of Evaluation

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

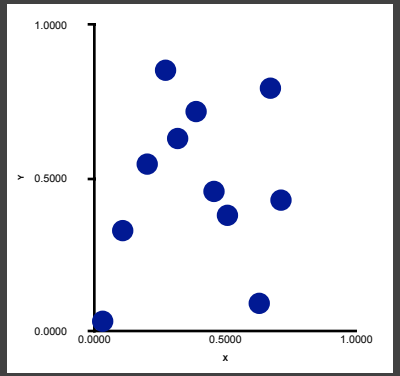
Gulf of Evaluation

Gulf

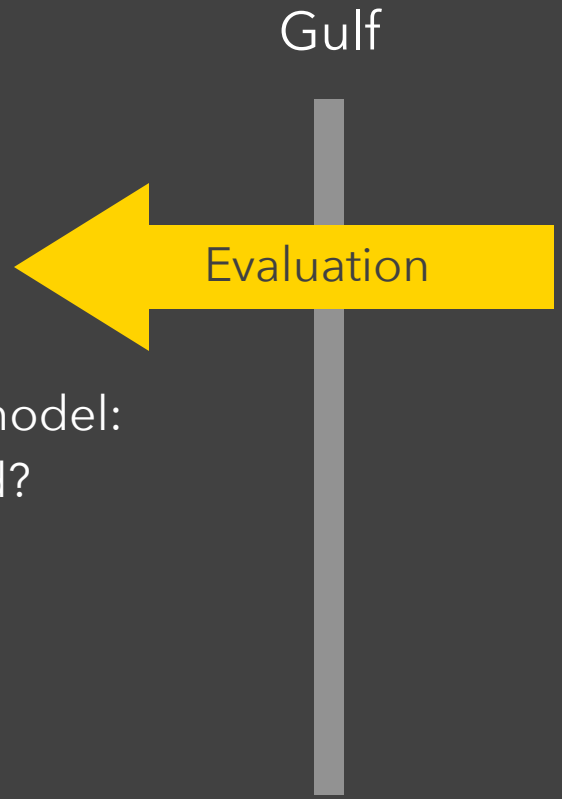
Evaluation

Conceptual model:
x, y related?

Real world:



Gulf of Evaluation



Real world:

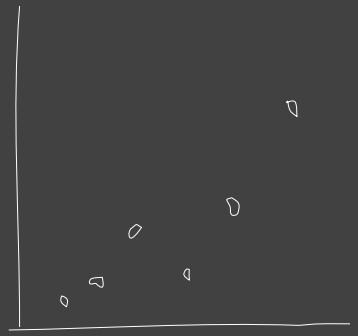
$\rho = -.29$

Conceptual model:
x, y correlated?

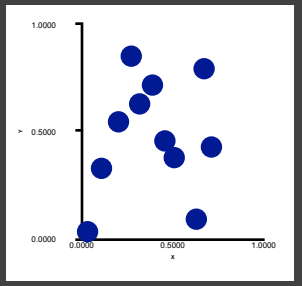
Gulf of Execution

Gulf

Conceptual model:
Draw a scatterplot



Execution



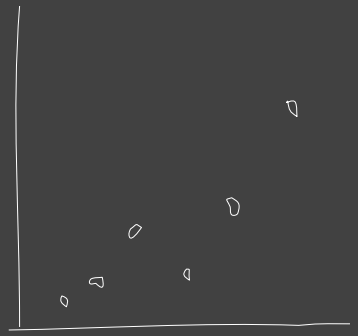
Real world

Move 90 30
Rotate 35
Pen down
…

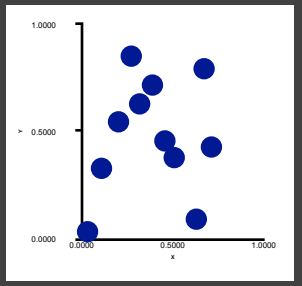
Gulf of Execution

Gulf

Conceptual model:
Draw a scatterplot



Execution



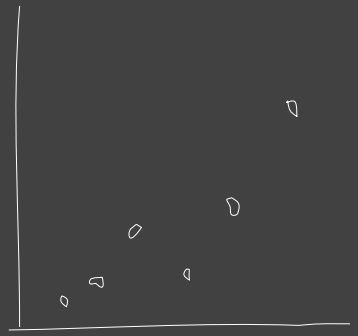
Real world

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

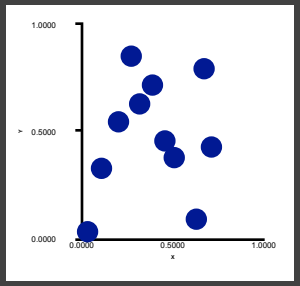
Gulf of Execution

Gulf

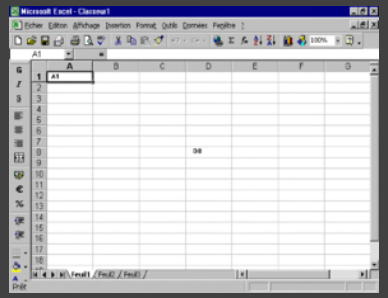
Conceptual model:
Draw a scatterplot



Execution



Real world



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[Norman 1986]

Interactive Visualization

Taxonomy of Interactions

Taxonomy of Interactions

Data and View Specification

Visualize, Filter, Sort, Derive

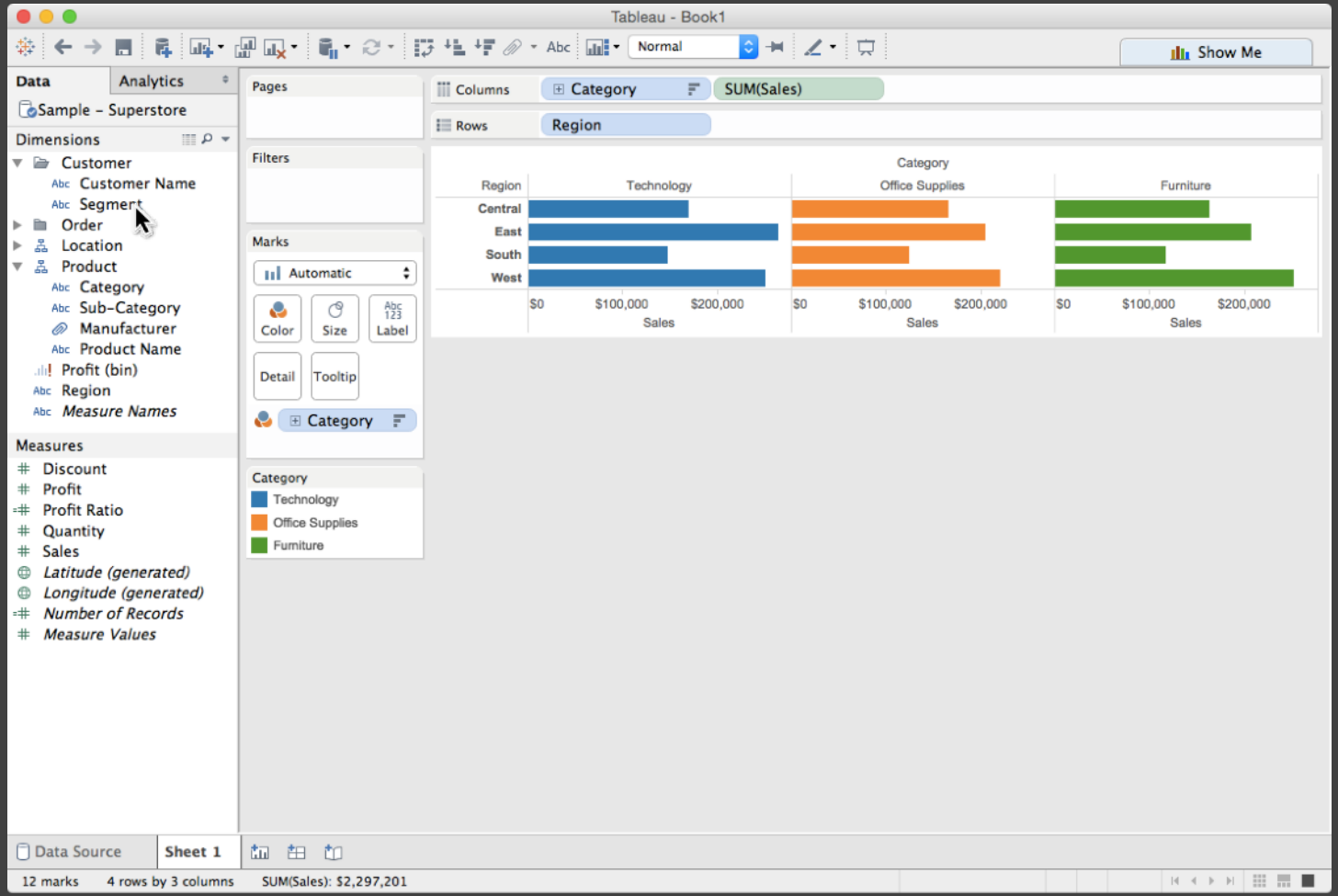


Tableau - Book1
Normal
Show Me
Data
Analytics
Sample – Superstore
Dimensions
Customer
Customer Name
Segment
Order
Location
Product
Category
Sub-Category
Manufacturer
Product Name
Profit (bin)
Region
Measure Names
Measures
Discount
Profit
Profit Ratio
Quantity
Sales
Latitude (generated)
Longitude (generated)
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
Category
Region
Technology
Office Supplies
Furniture
Central
East
South
West
$0
$100,000
$200,000
Sales
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

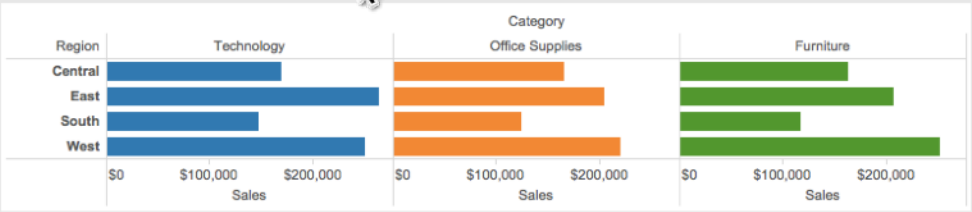
Color | Size | Label | Detail | Tooltip

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

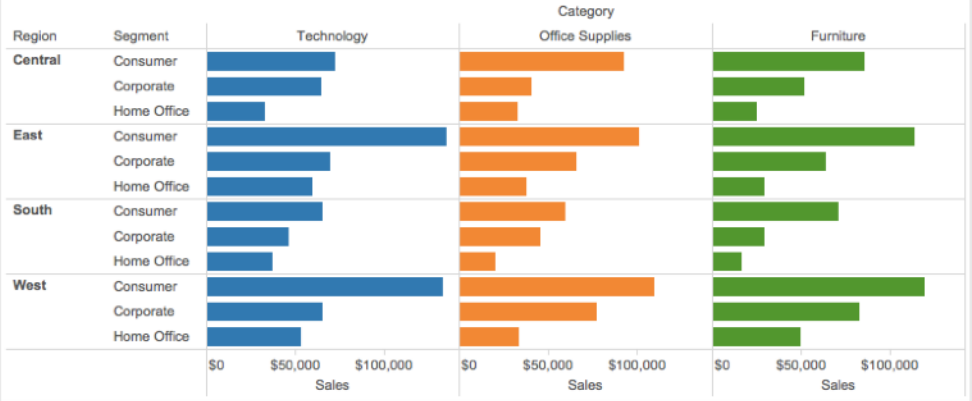
Category

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

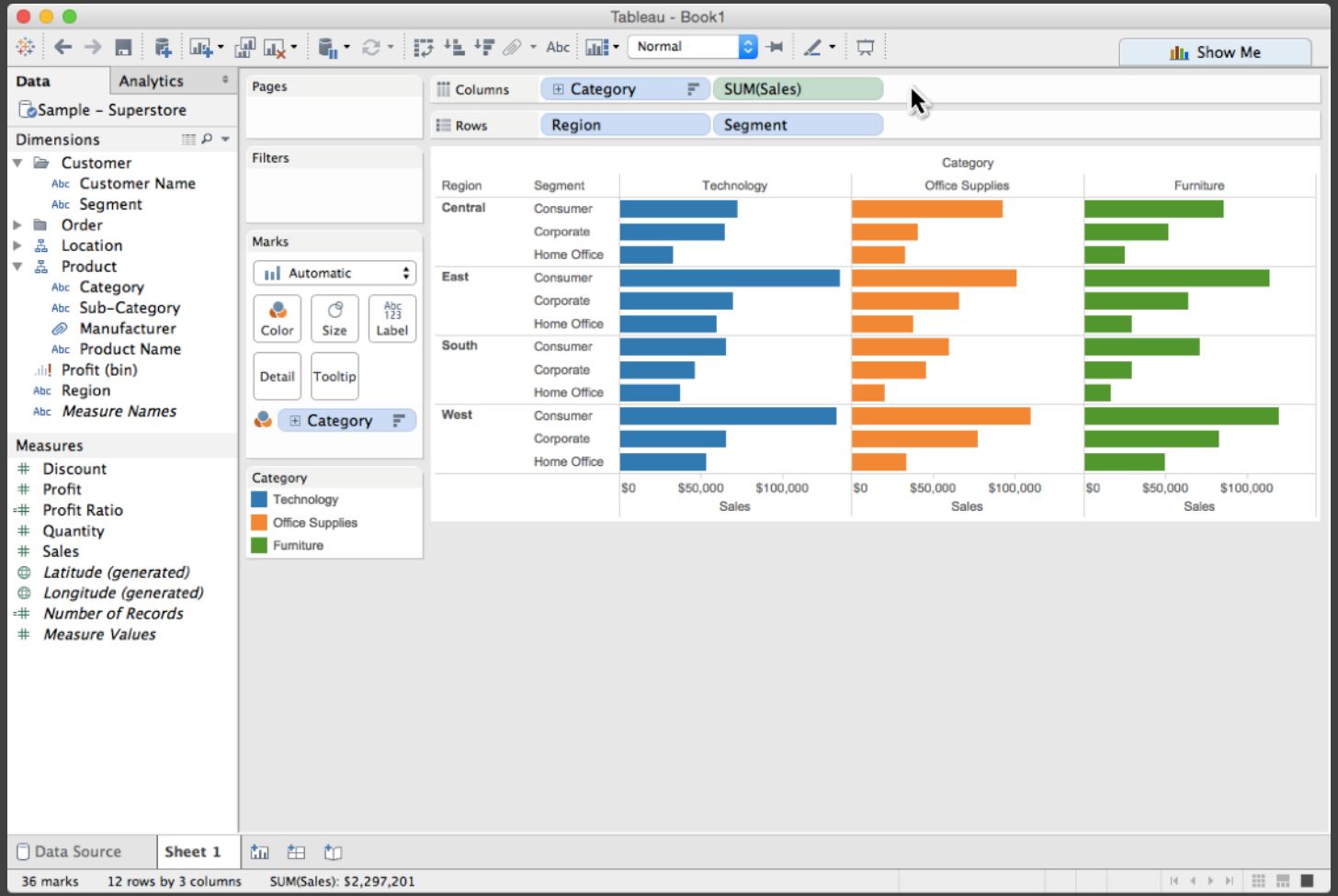


Tableau - Book1
Normal
Show Me
Data
Analytics
Sample – Superstore
Dimensions
Customer
Customer Name
Segment
Order
Location
Product
Category
Sub-Category
Manufacturer
Product Name
Profit (bin)
Region
Measure Names
Measures
Discount
Profit
Profit Ratio
Quantity
Sales
Latitude (generated)
Longitude (generated)
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
Category
Region
Segment
Technology
Office Supplies
Furniture
Central
East
South
West
Consumer
Corporate
Home Office
$0
$50,000
$100,000
Sales
Data Source
Sheet 1
36 marks
12 rows by 3 columns
SUM(Sales): $2,297,201

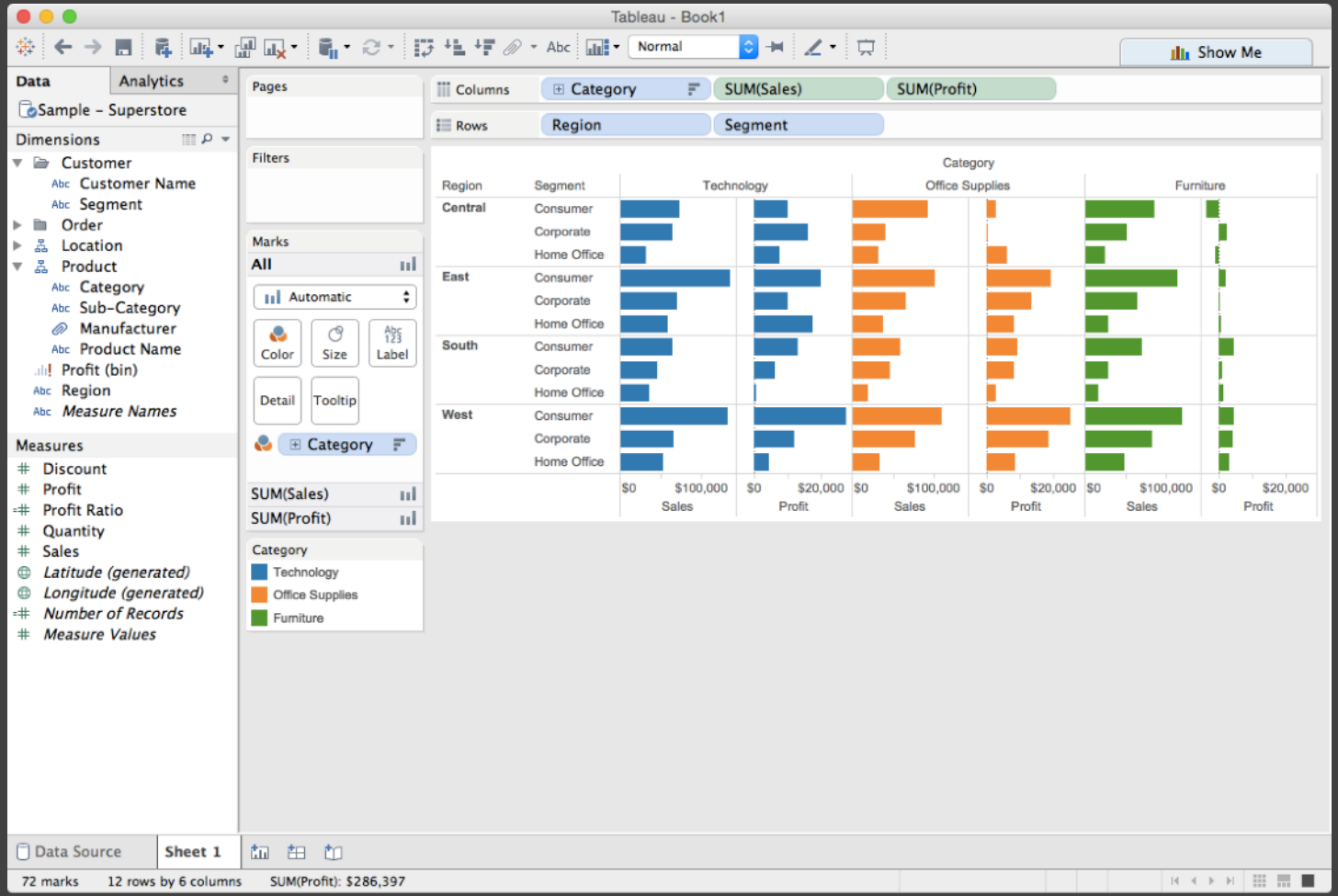


Tableau - Book1
Normal
Show Me
Data
Analytics
Sample – Superstore
Dimensions
Customer
Customer Name
Segment
Order
Location
Product
Category
Sub-Category
Manufacturer
Product Name
Profit (bin)
Region
Measure Names
Measures
Discount
Profit
Profit Ratio
Quantity
Sales
Latitude (generated)
Longitude (generated)
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
Category
Region
Segment
Technology
Office Supplies
Furniture
Central
East
South
West
Consumer
Corporate
Home Office
$0
$100,000
$20,000
Sales
Profit
Data Source
Sheet 1
72 marks
12 rows by 6 columns
SUM(Profit): $286,397

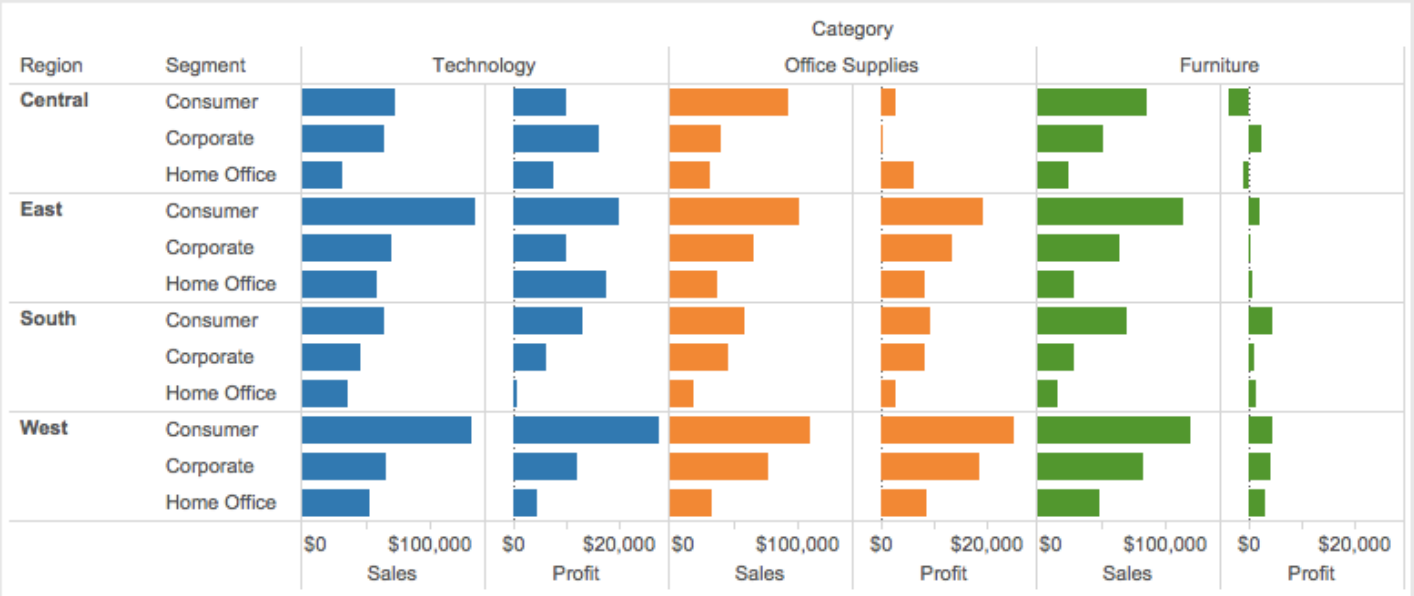
Tableau - Book1

Normal

Show Me

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

Rows: Region, Segment



Automatic

Color

Size

Label

Detail

Tooltip

Category

SUM(Sales)

SUM(Profit)

Category

Technology

Office Supplies

Furniture

Taxonomy of Interactions

Data and View Specification

Visualize, Filter, Sort, Derive

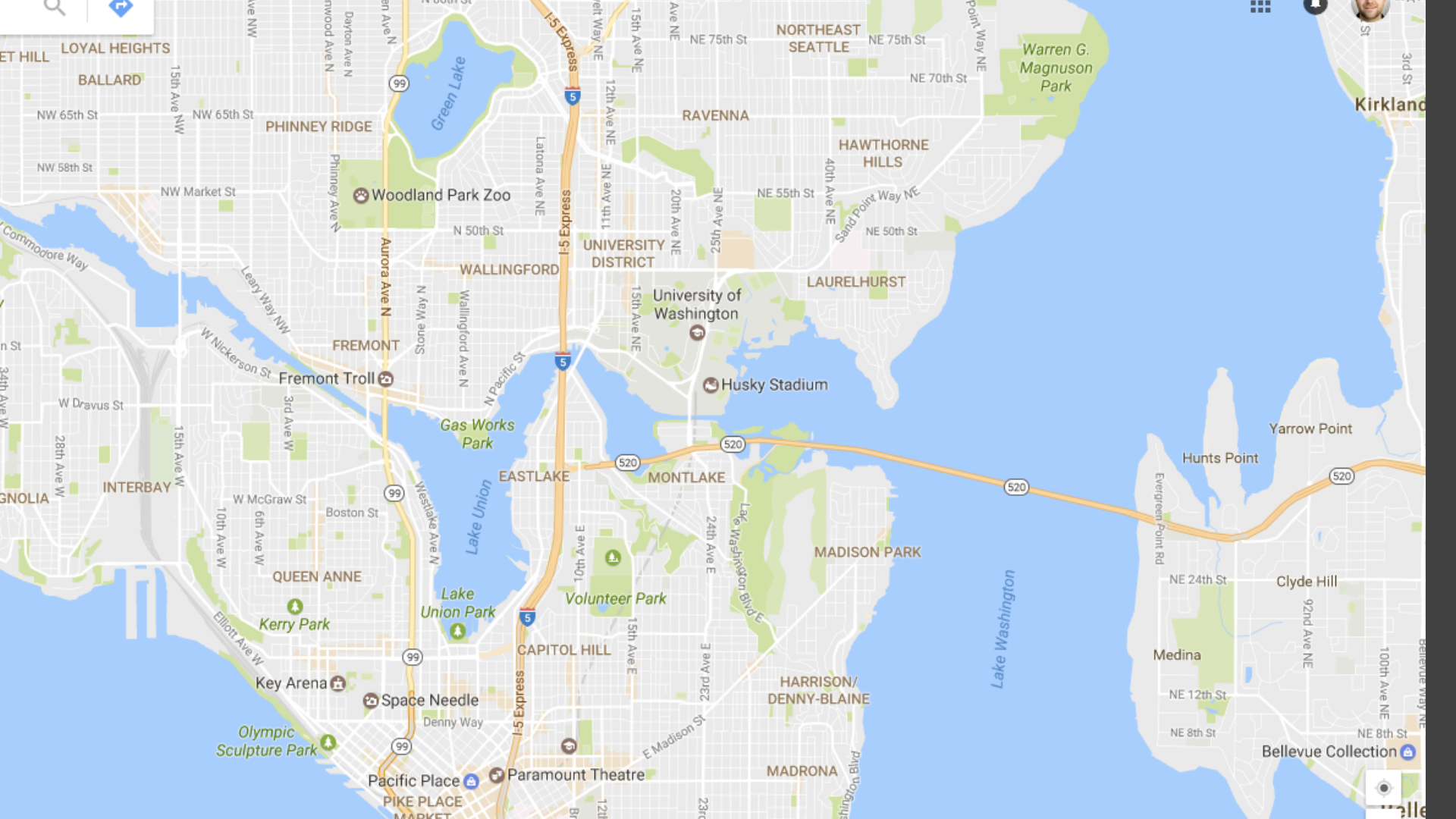
Taxonomy of Interactions

Data and View Specification

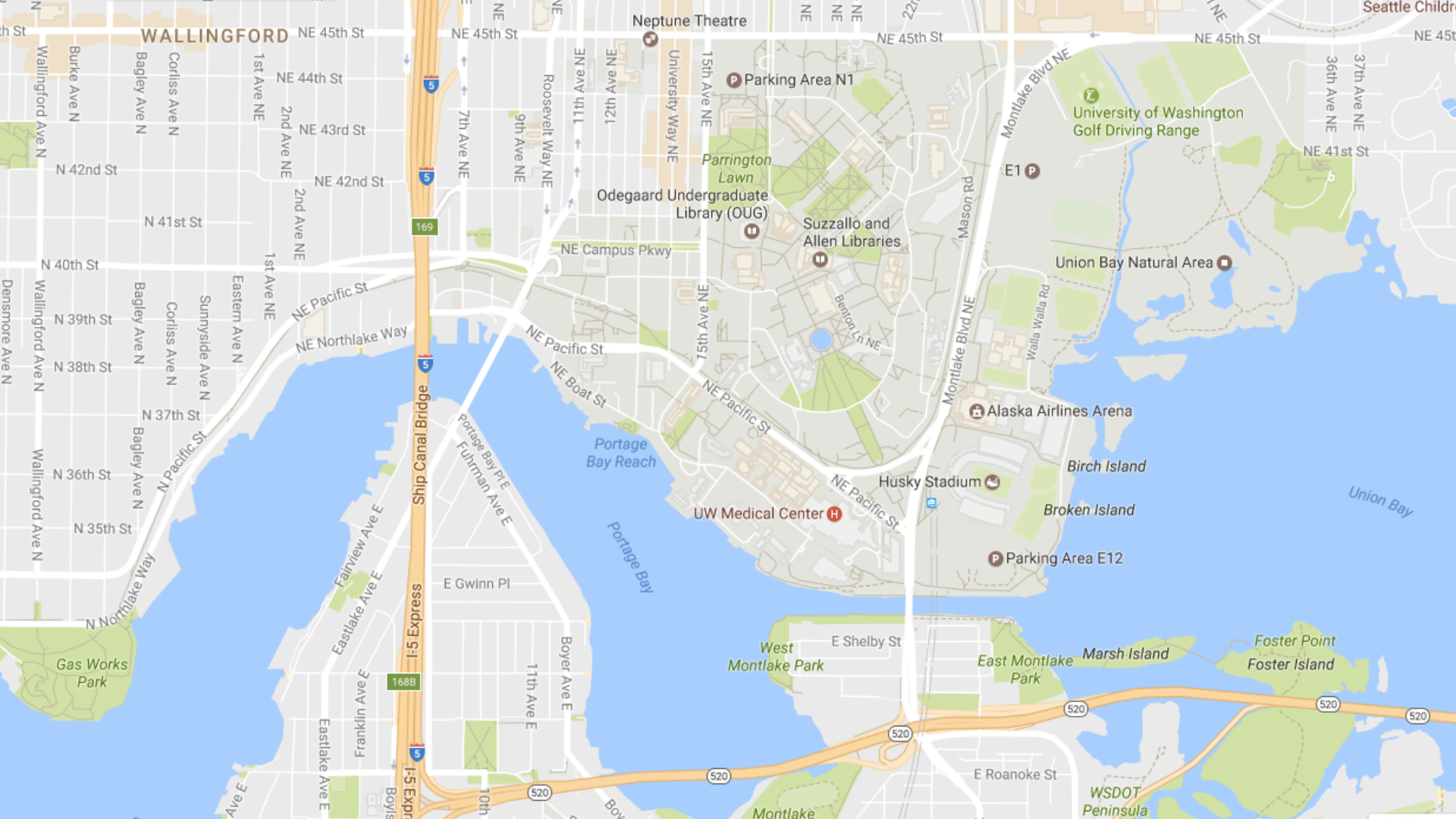
Visualize, Filter, Sort, Derive

View Manipulation

Select, Navigate, Coordinate, Organize



LOYAL HEIGHTS
BALLARD
PHINNEY RIDGE
Green Lake
NORTHEAST SEATTLE
RAVENNA
HAWTHORNE HILLS
Warren G. Magnuson Park
Kirkland
Woodland Park Zoo
UNIVERSITY DISTRICT
WALLINGFORD
LAURELHURST
University of Washington
FREMONT
Fremont Troll
Husky Stadium
Gas Works Park
EASTLAKE
MONTLAKE
INTERBAY
QUEEN ANNE
Lake Union
Lake Union Park
Volunteer Park
MADISON PARK
Kerry Park
CAPITOL HILL
Key Arena
Space Needle
Olympic Sculpture Park
HARRISON/ DENNY-BLAINE
MADRONA
Pacific Place
Paramount Theatre
PIKE PLACE MARKET
Lake Washington
Yarrow Point
Hunts Point
Clyde Hill
Medina
Bellevue Collection
I-5 Express
Aurora Ave N
Westlake Ave N
Lake Washington Blvd E
Evergreen Point Rd
Sand Point Way NE
Leary Way NW
Commodore Way
W Nickerson St
W Dravus St
W McGraw St
Boston St
Denny Way
E Madison St
NW 65th St
NW 58th St
NW Market St
N 50th St
NE 75th St
NE 70th St
NE 55th St
NE 50th St
NE 24th St
NE 12th St
NE 8th St


WALLINGFORD
NE 45th St
Neptune Theatre
Parking Area N1
University of Washington Golf Driving Range
NE 44th St
NE 43rd St
NE 42nd St
N 42nd St
N 41st St
NE 41st St
Parrington Lawn
Odegaard Undergraduate Library (OUG)
Suzzallo and Allen Libraries
E1
NE Campus Pkwy
N 40th St
Union Bay Natural Area
NE Pacific St
N 39th St
NE Northlake Way
N 38th St
N 37th St
N Pacific St
N 36th St
N 35th St
N Northlake Way
Ship Canal Bridge
I-5 Express
Portage Bay Reach
Portage Bay
NE Boat St
Alaska Airlines Arena
Husky Stadium
UW Medical Center
Birch Island
Broken Island
Union Bay
Parking Area E12
E Gwinn Pl
E Shelby St
West Montlake Park
East Montlake Park
Marsh Island
Foster Point
Foster Island
Gas Works Park
E Roanoke St
WSDOT Peninsula
Montlake
Montlake Blvd NE
Mason Rd
Walla Walla Rd
Benton Ln NE
Fuhrman Ave E
Portage Bay Pl E
Fairview Ave E
Eastlake Ave E
Franklin Ave E
Boyer Ave E
11th Ave E
Roosevelt Way NE
University Way NE
15th Ave NE
7th Ave NE
9th Ave NE
11th Ave NE
12th Ave NE
1st Ave NE
2nd Ave NE
Wallingford Ave N
Burke Ave N
Bagley Ave N
Corliss Ave N
Eastern Ave N
Sunnyside Ave N
Densmore Ave N
36th Ave NE
37th Ave NE
22nd
Seattle Children
5
169
168B
520

Taxonomy of Interactions

Data and View Specification

Visualize, Filter, Sort, Derive

View Manipulation

Select, Navigate, Coordinate, Organize

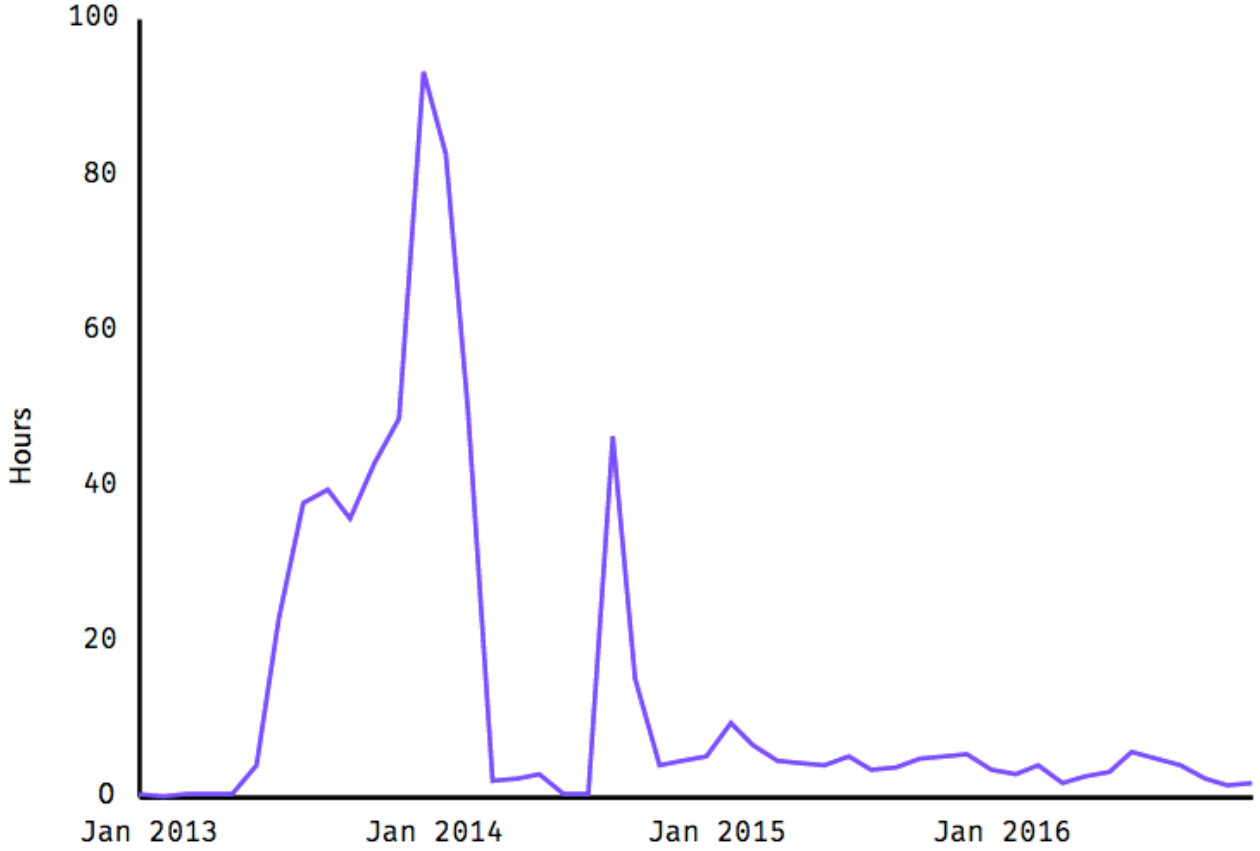
Taxonomy of Interactions

Data and View Specification
Visualize, Filter, Sort, Derive

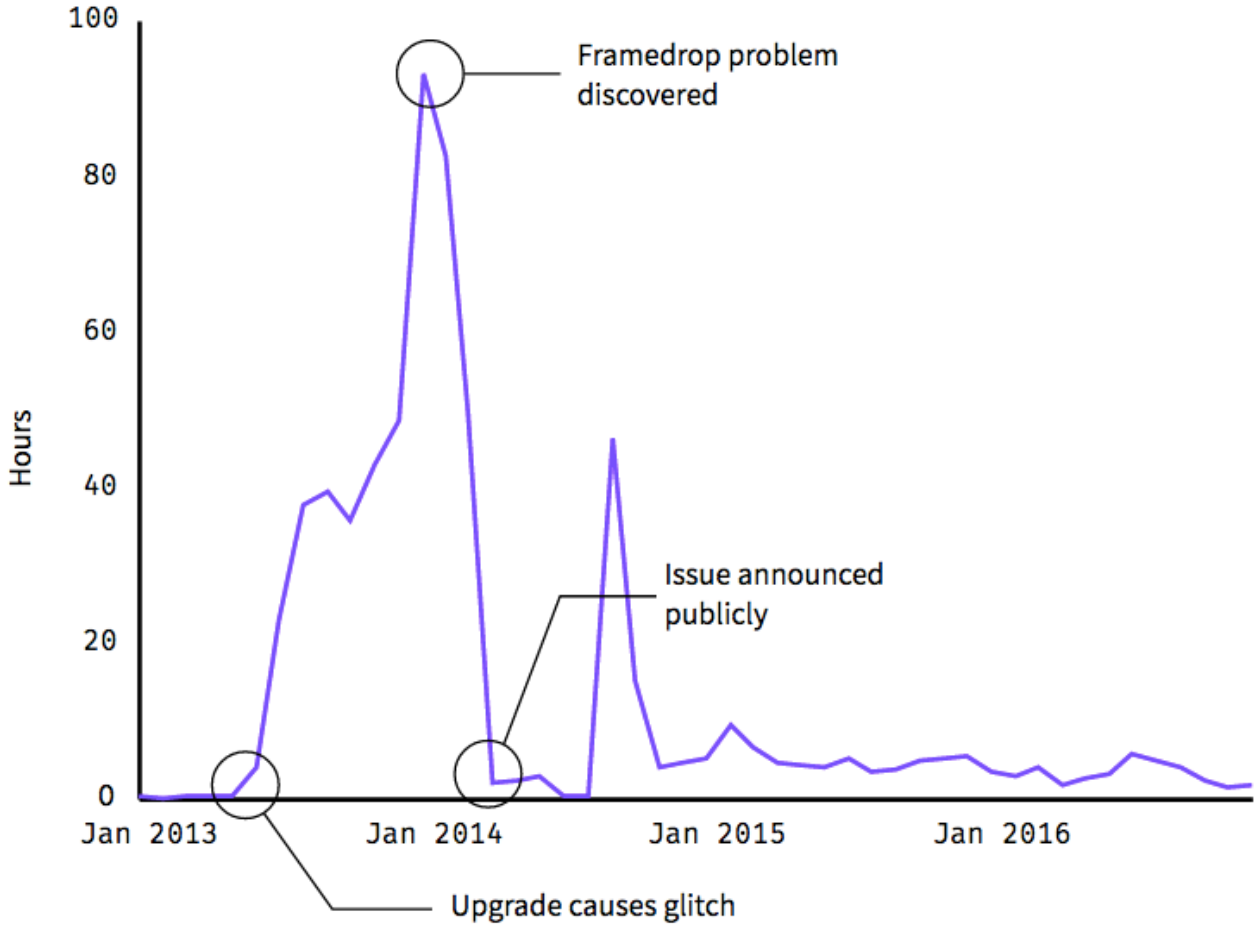
View Manipulation
Select, Navigate, Coordinate, Organize

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



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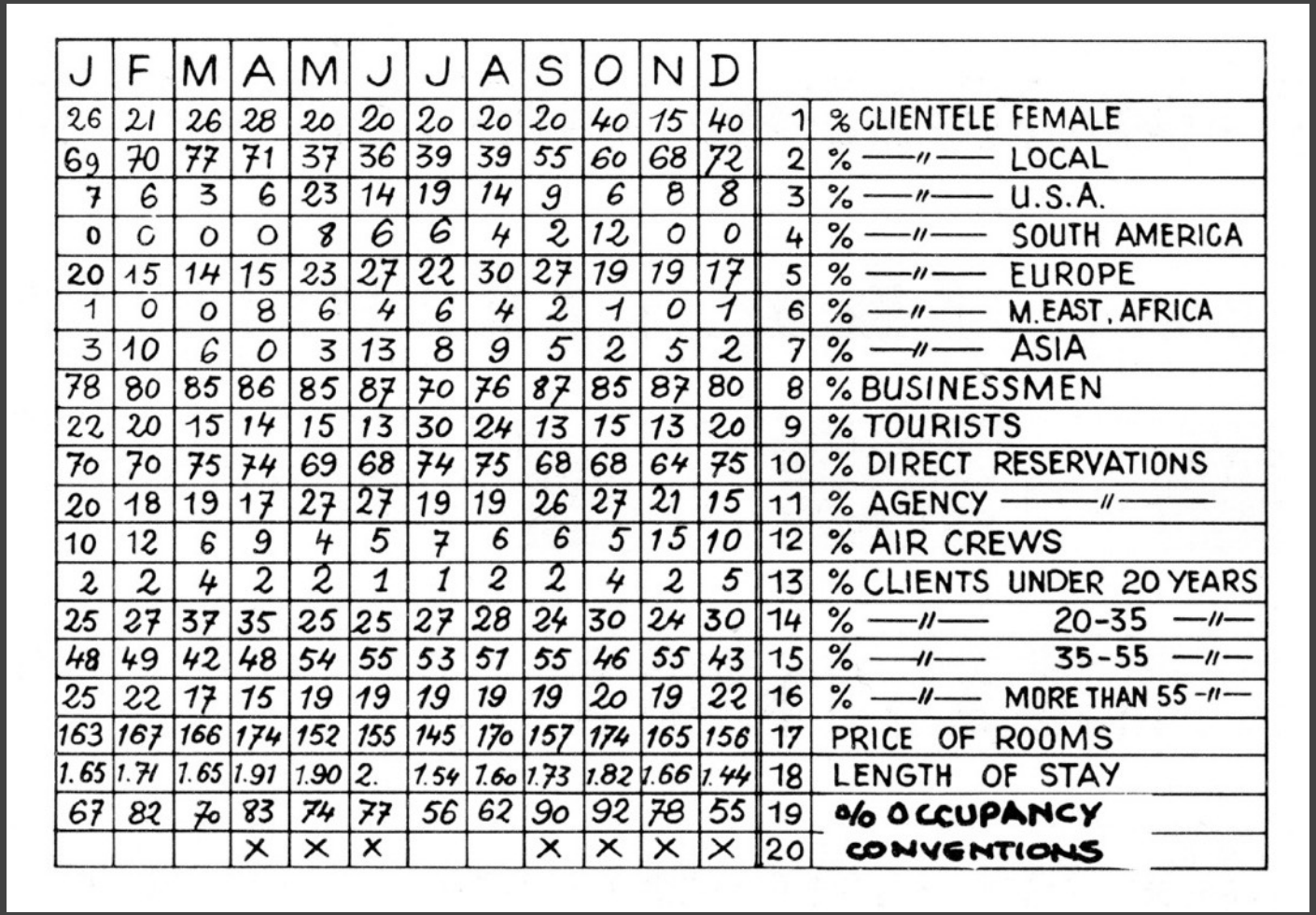
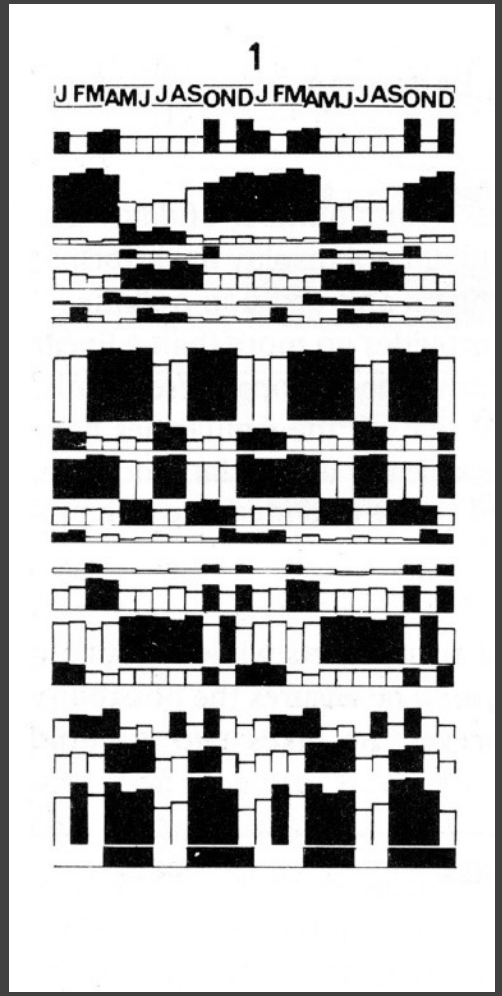
EXAMPLE:
Bertin's Hotel Data

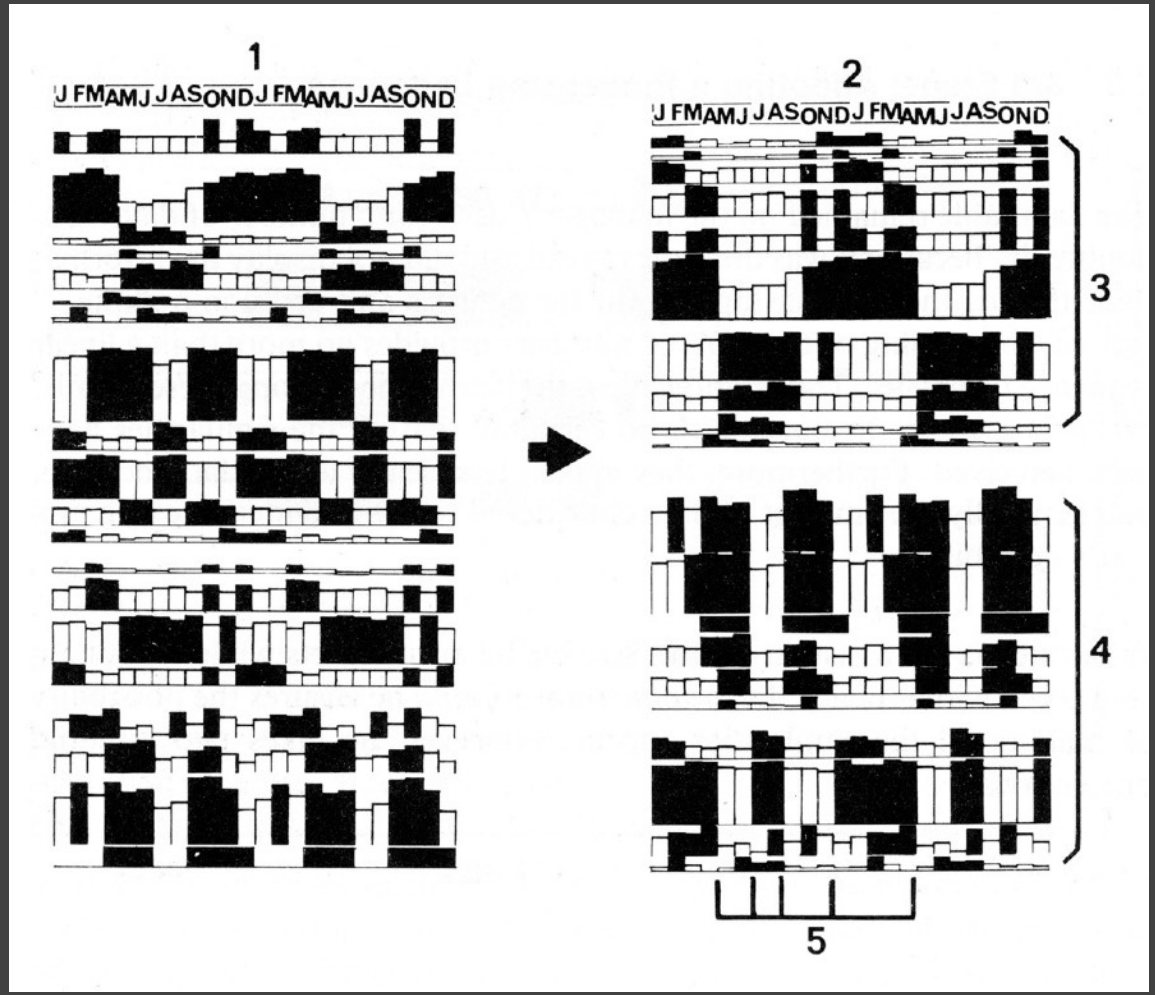


J	F	M	A	M	J	J	A	S	O	N	D		
26	21	26	28	20	20	20	20	20	40	15	40	1	% CLIENTELE FEMALE
69	70	77	71	37	36	39	39	55	60	68	72	2	% —〃— LOCAL
7	6	3	6	23	14	19	14	9	6	8	8	3	% —〃— U.S.A.
0	0	0	0	8	6	6	4	2	12	0	0	4	% —〃— SOUTH AMERICA
20	15	14	15	23	27	22	30	27	19	19	17	5	% —〃— EUROPE
1	0	0	8	6	4	6	4	2	1	0	1	6	% —〃— 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]



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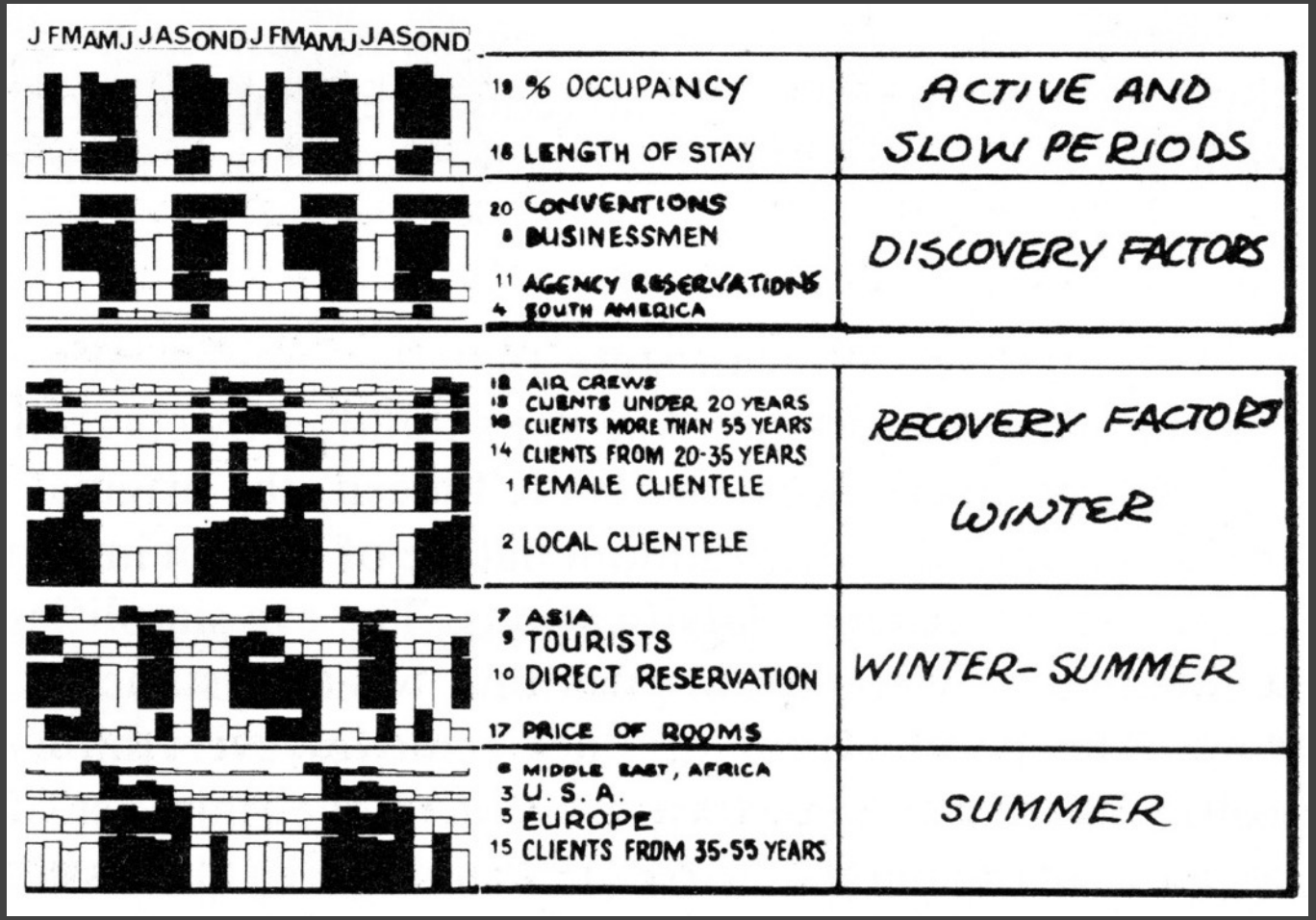

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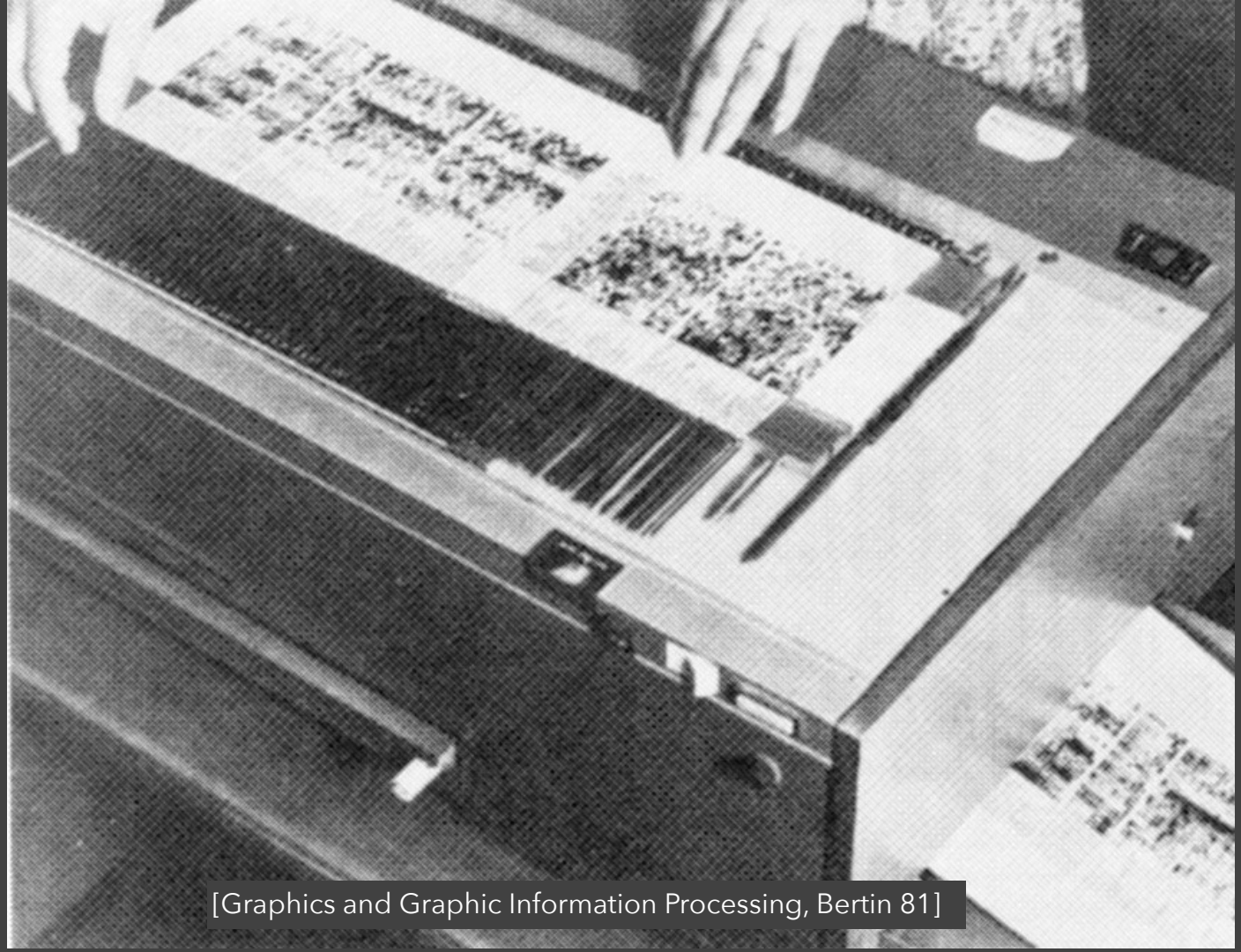
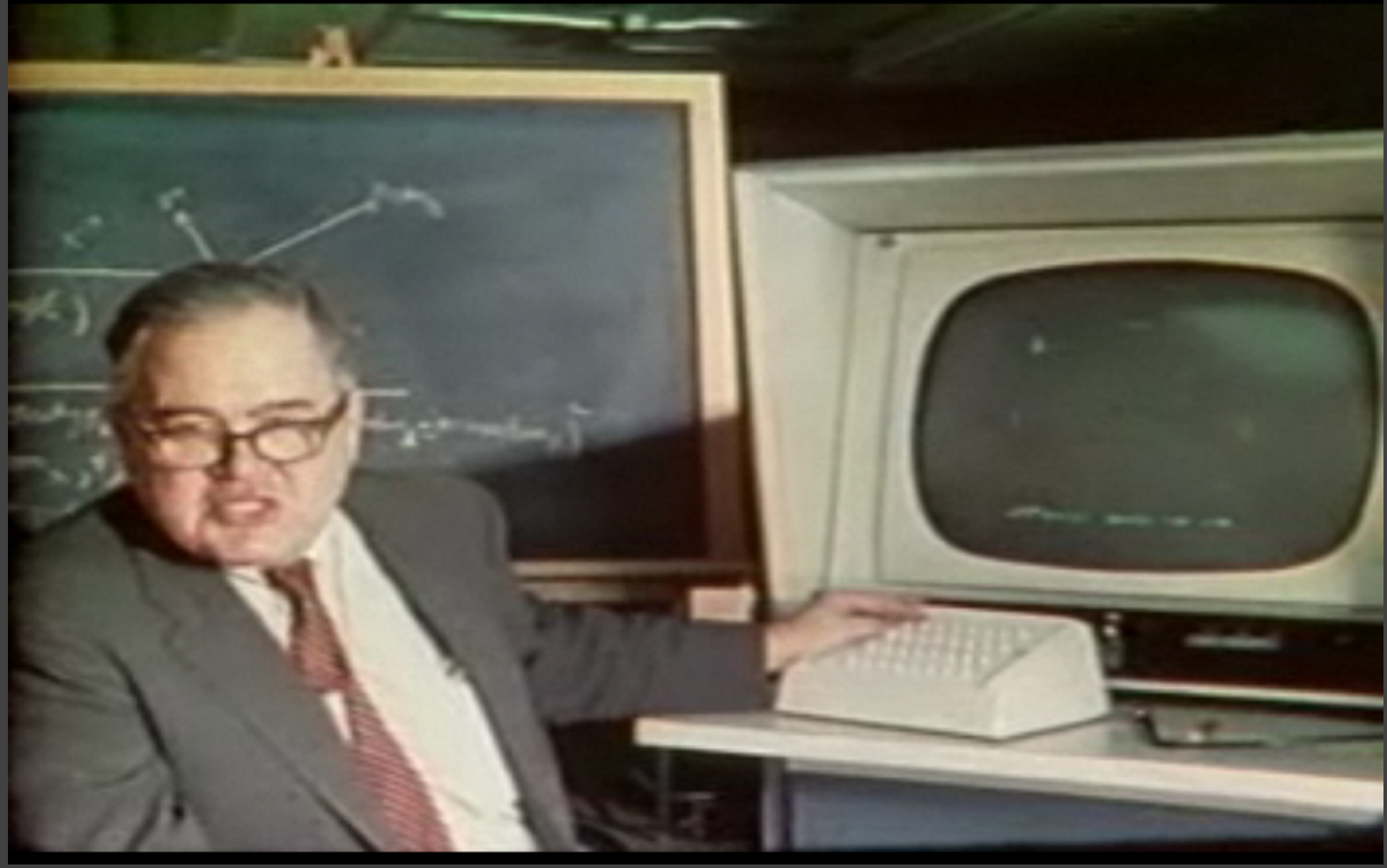


[Graphics and Graphic Information Processing, Bertin 81]

[Graphics and Graphic Information Processing, Bertin 81]

EXAMPLE:
Tukey et al.'s PRIM-9



PRIM-9, Tukey, Fisherkeller, Friedman 1972

Selection

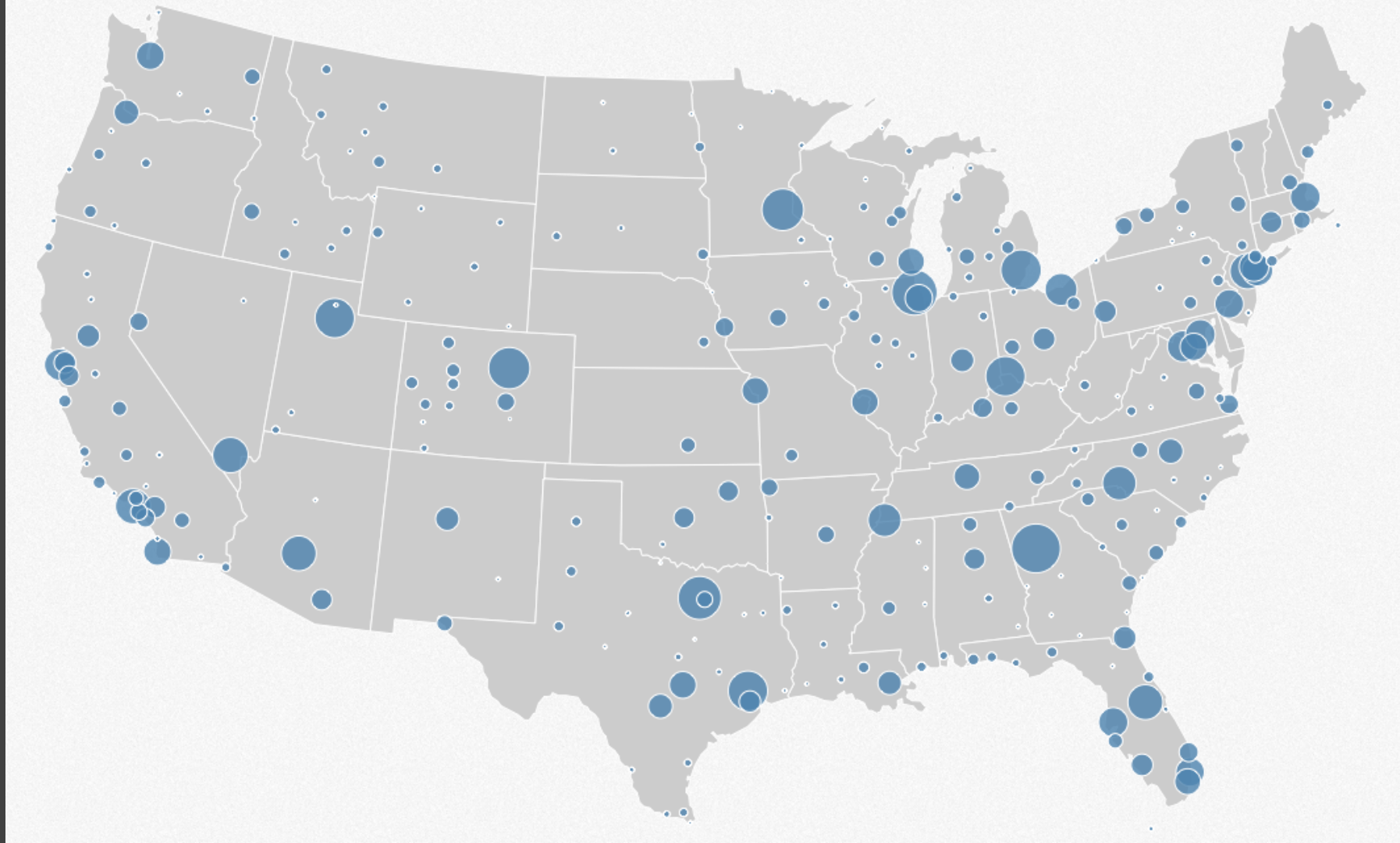
Basic Selection Methods

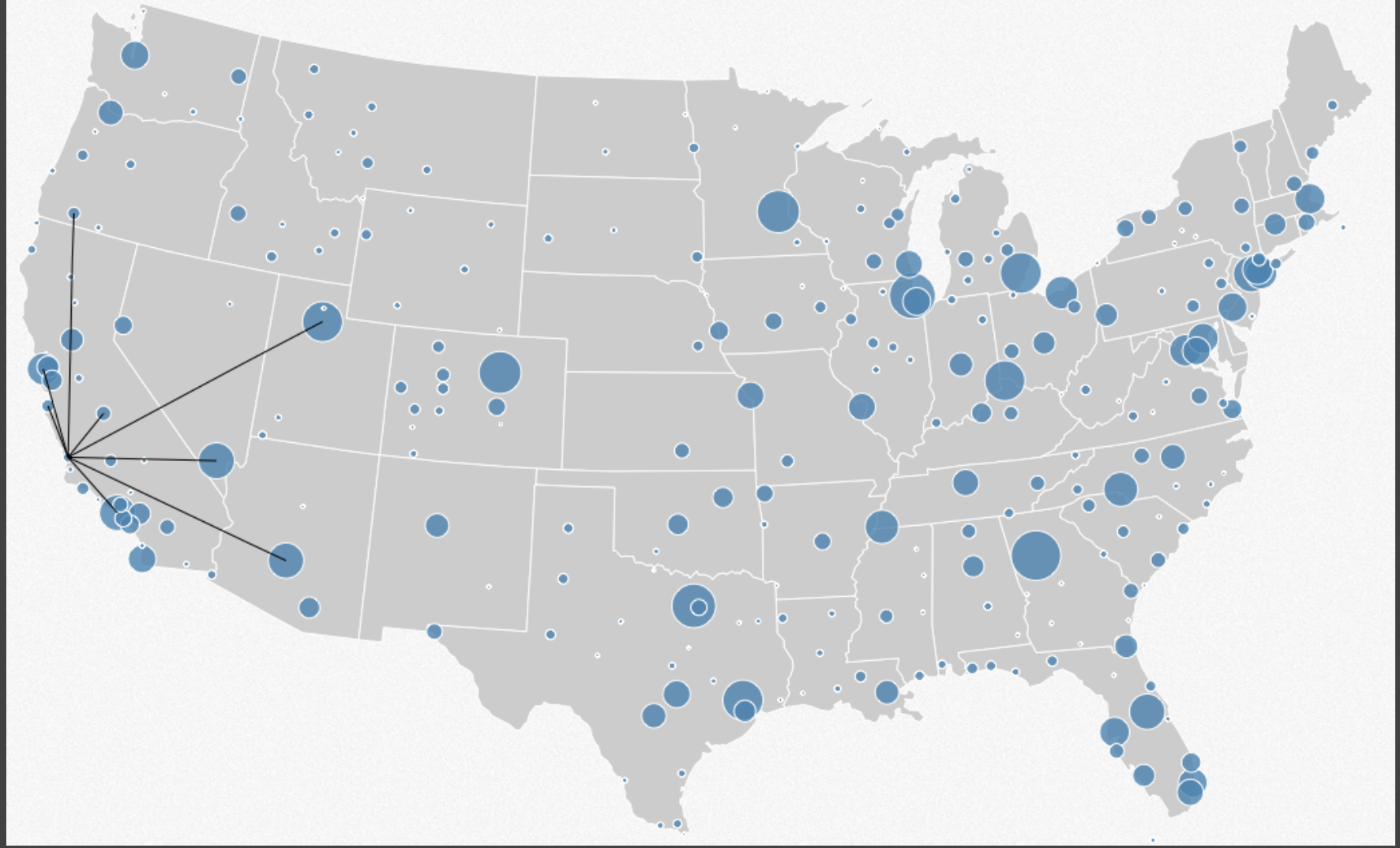
Point Selection

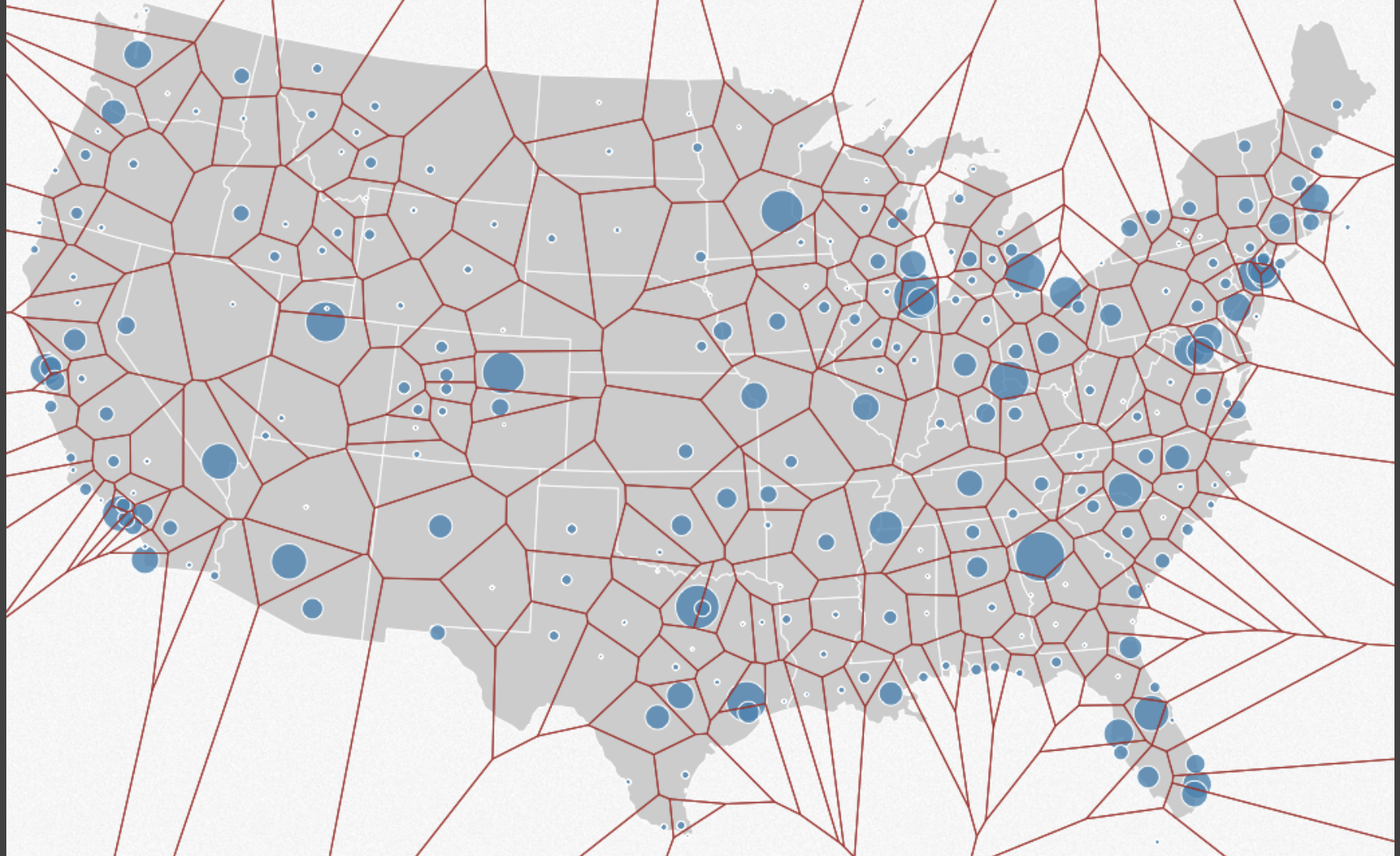
Mouse Hover / Click

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

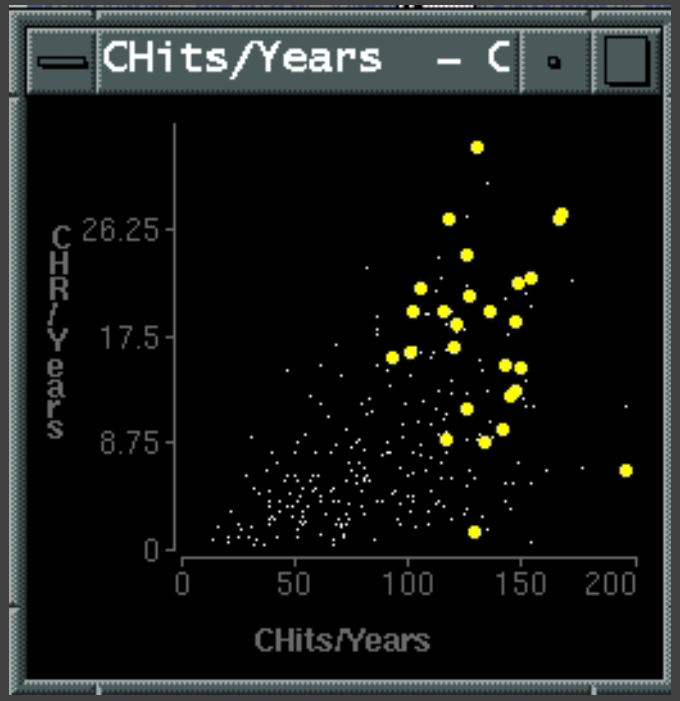
Rubber-band (rectangular) or Lasso (freehand)

Area cursors (“brushes”)

Brushing & Linking

Brushing

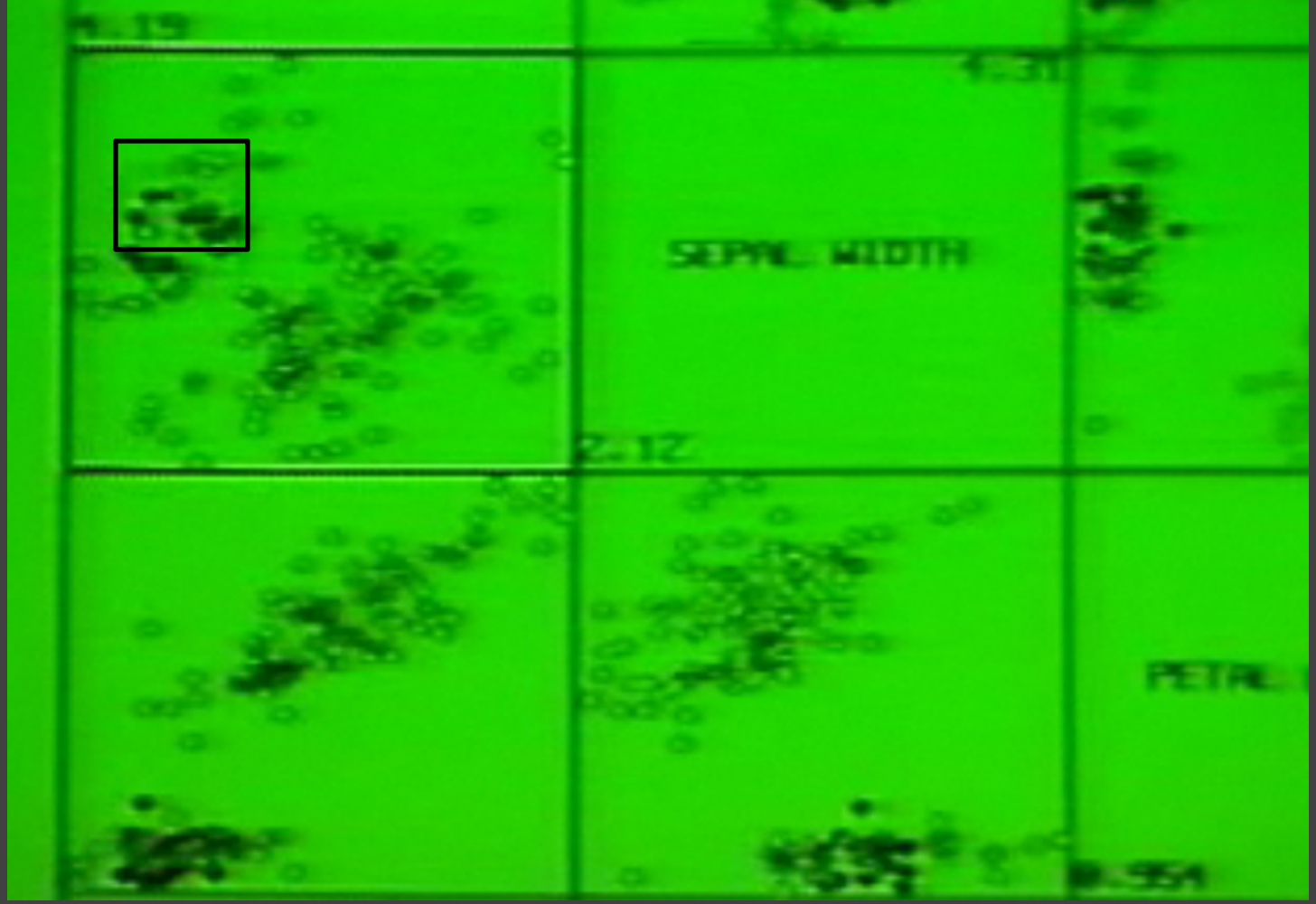
Direct attention to a subset of data [Wills 95]



Brushing & Linking

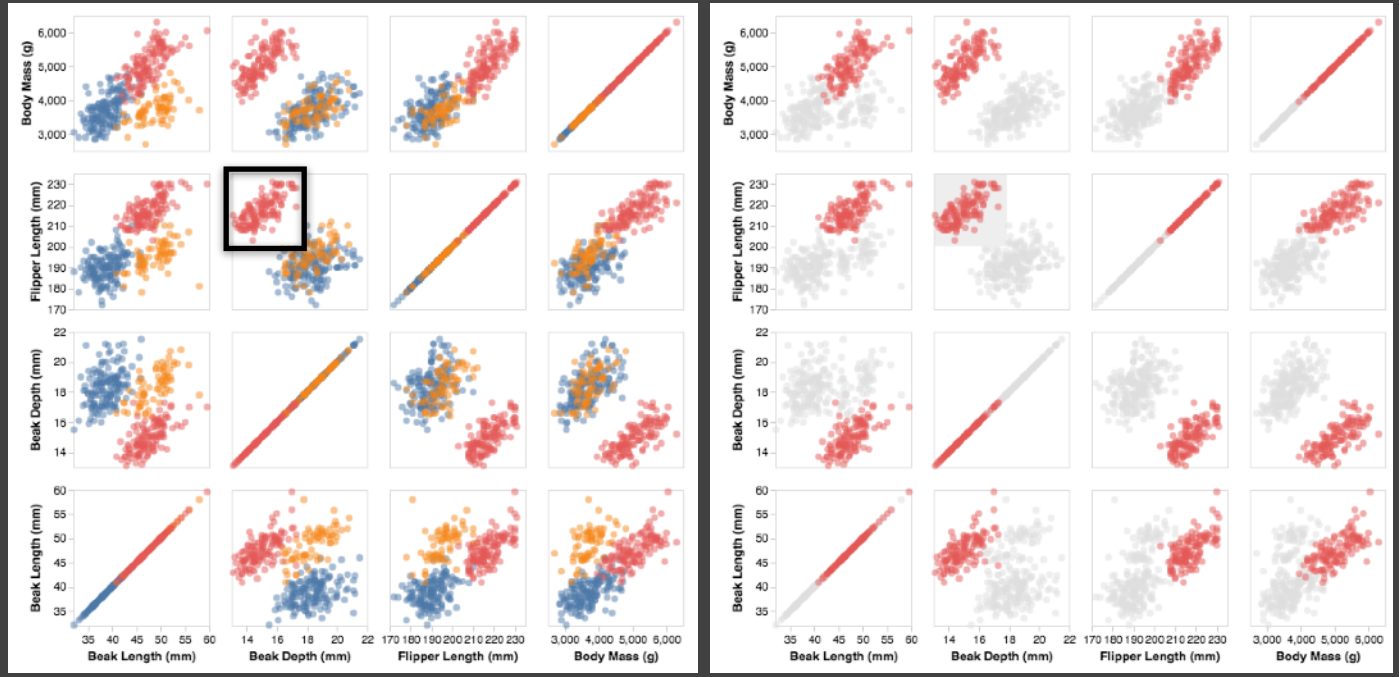
Select ("***brush***") a subset of data
See selected data in other views

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

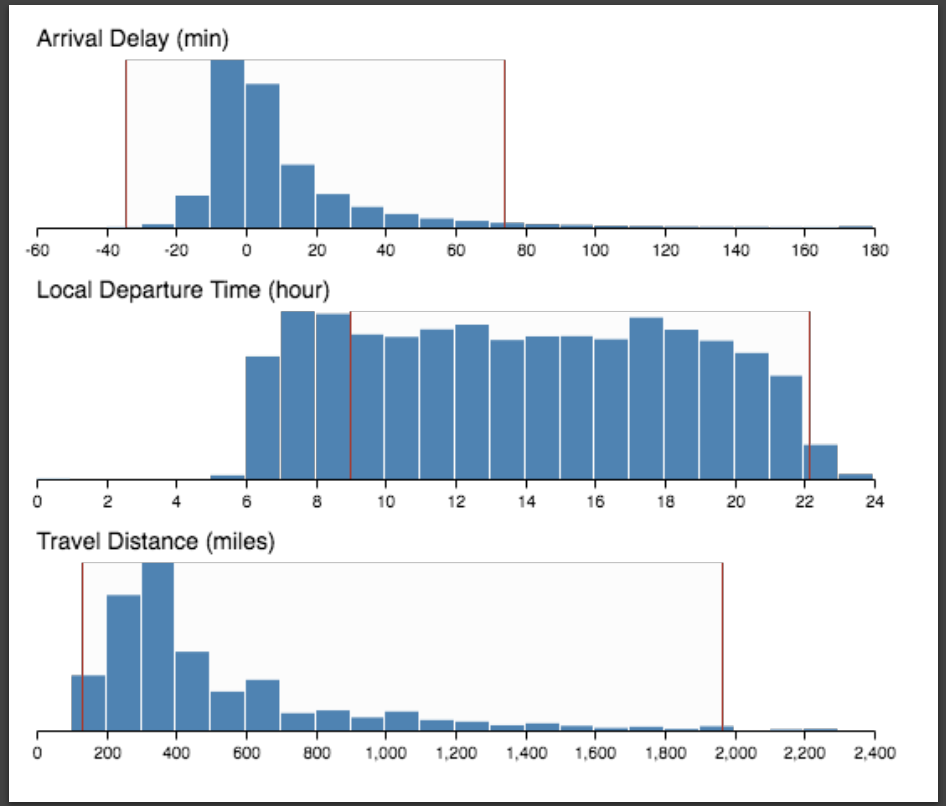


Brushing Scatterplots, Becker & Cleveland 1982

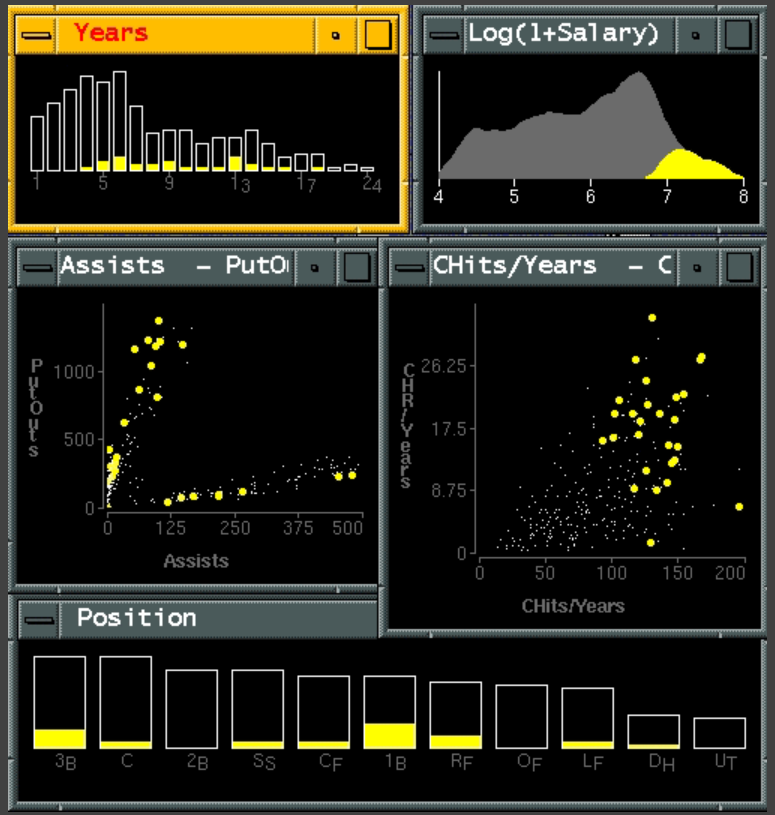
Brushing Scatterplots



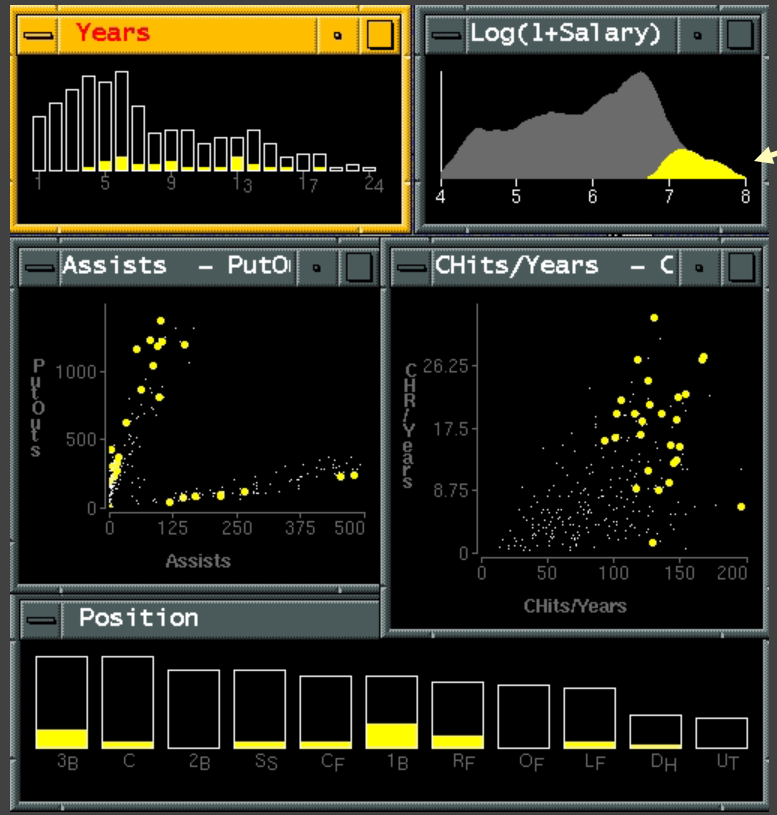
Cross-Filtering



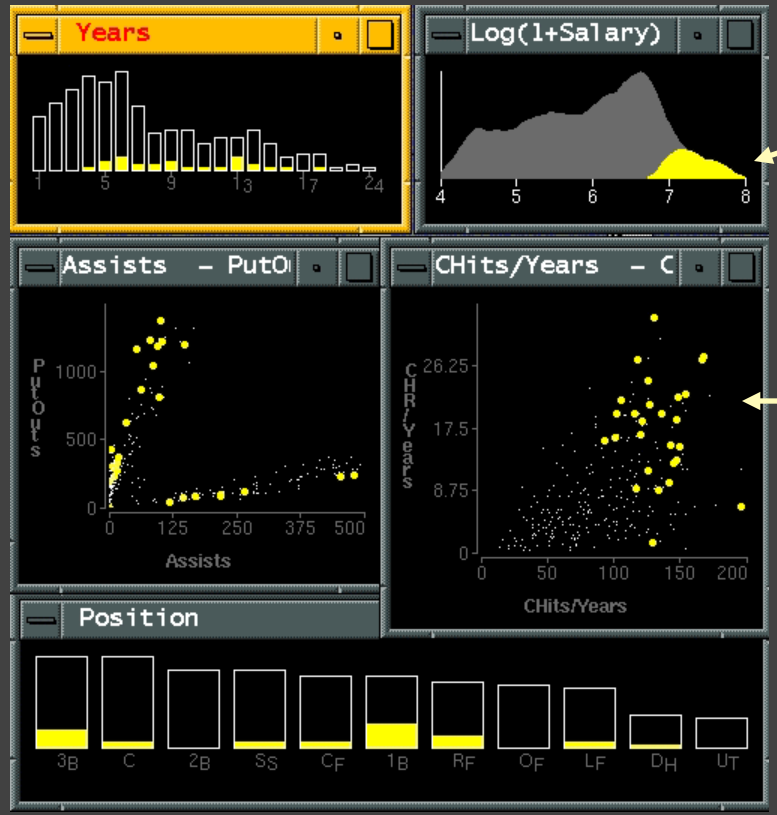
Baseball Statistics [Wills 95]



Baseball Statistics [Wills 95]



Baseball Statistics [Wills 95]

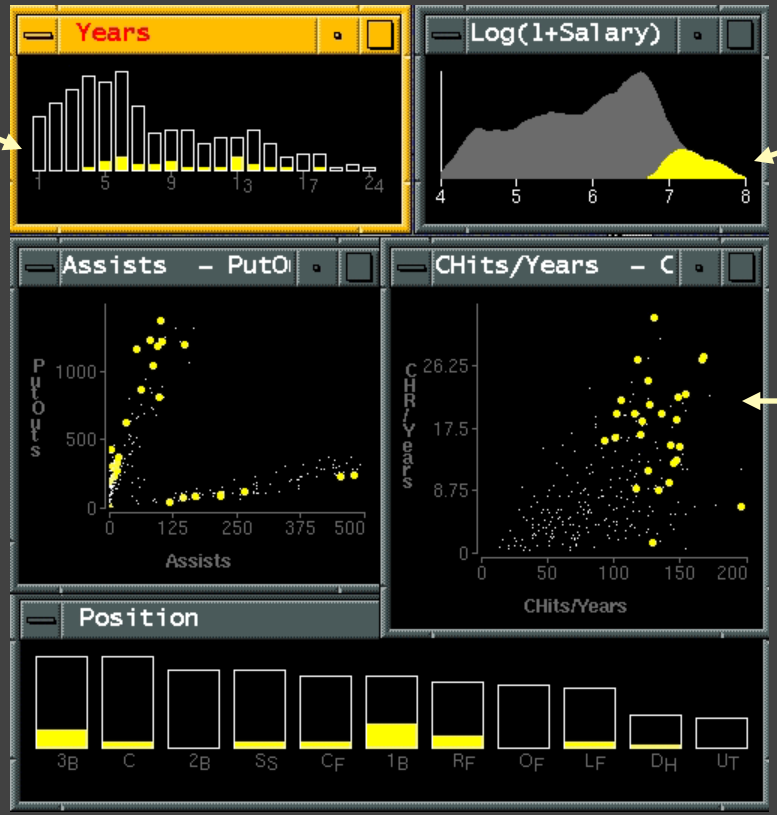


select high salaries

avg career HRs vs avg career hits (batting ability)

Baseball Statistics [Wills 95]

how long in majors



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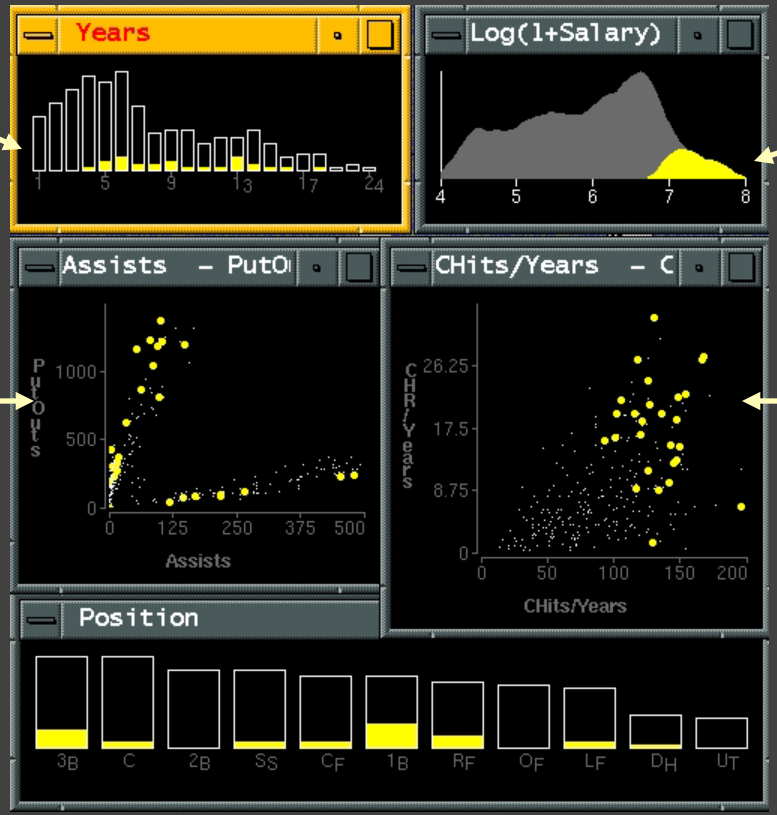
how long in majors



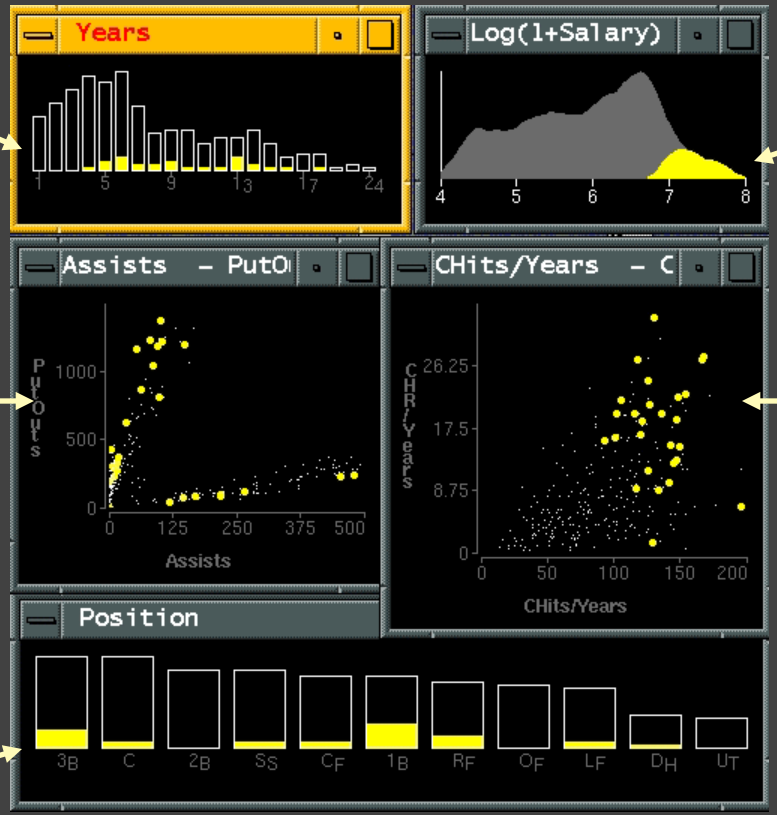
select high salaries

avg assists vs avg putouts (fielding ability)

avg career HRs vs avg career hits (batting ability)

Baseball Statistics [Wills 95]

how long in majors



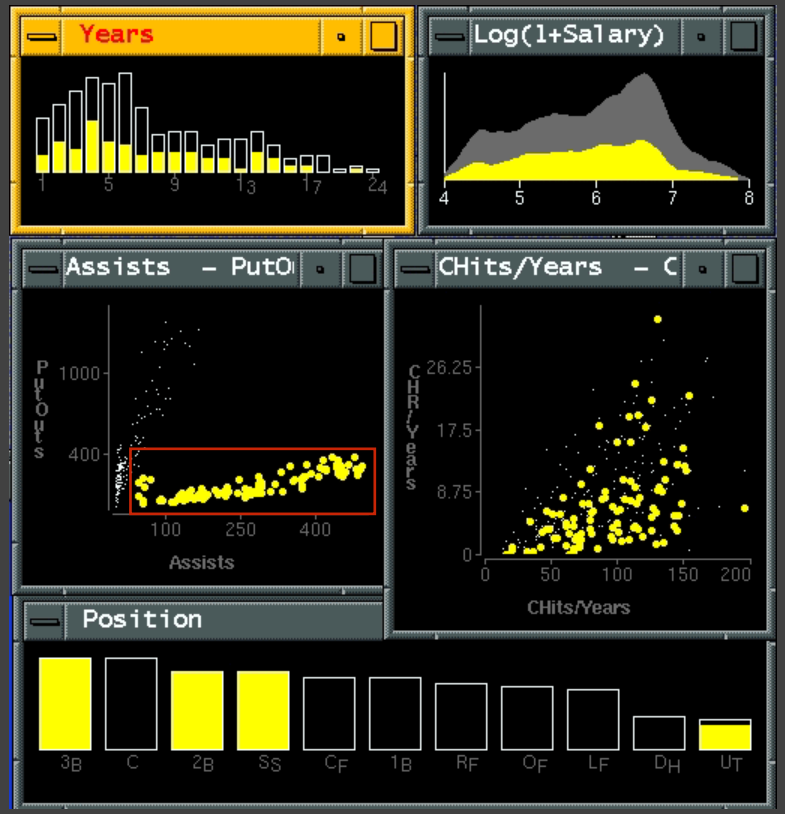
select high salaries

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

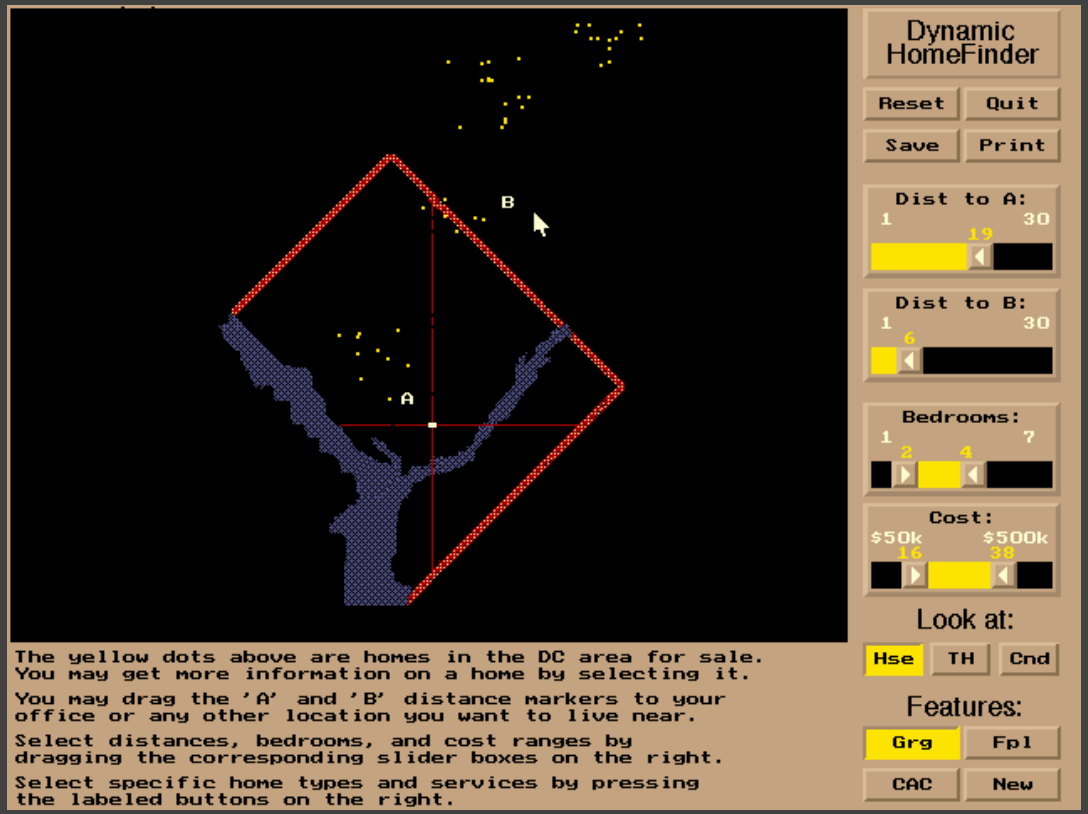
Design Time

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.

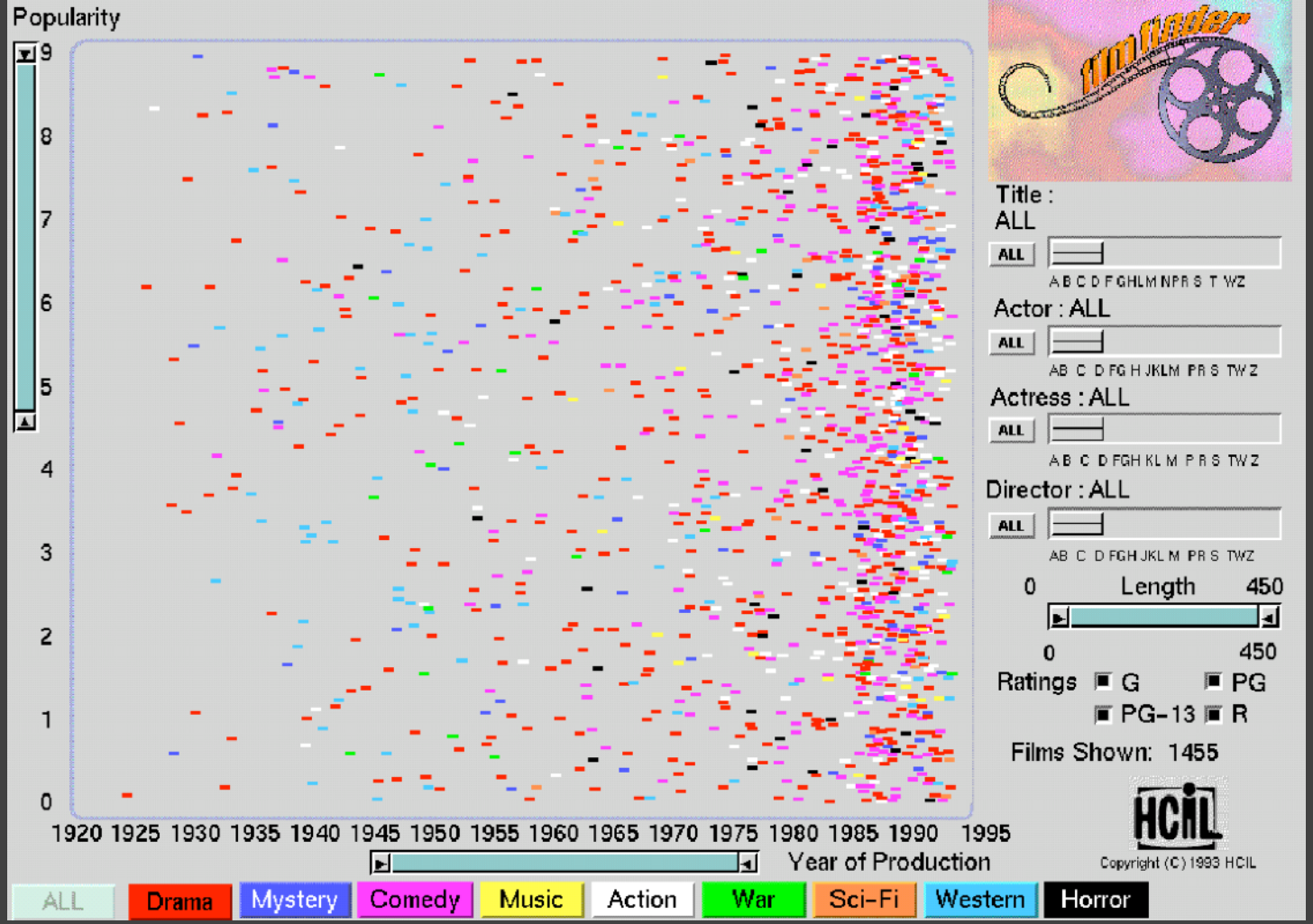
HomeFinder



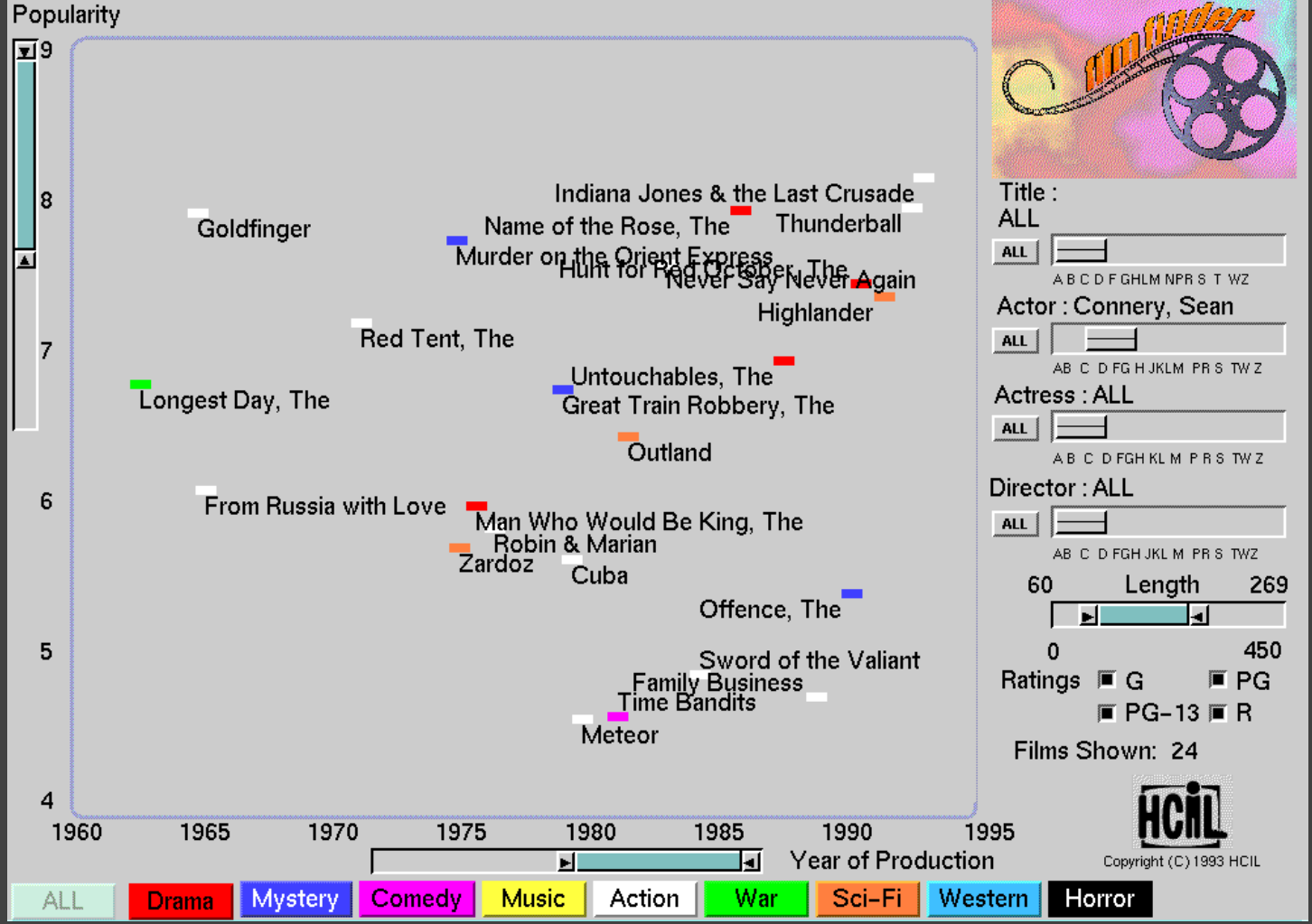
[Williamson and Shneiderman 92]

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

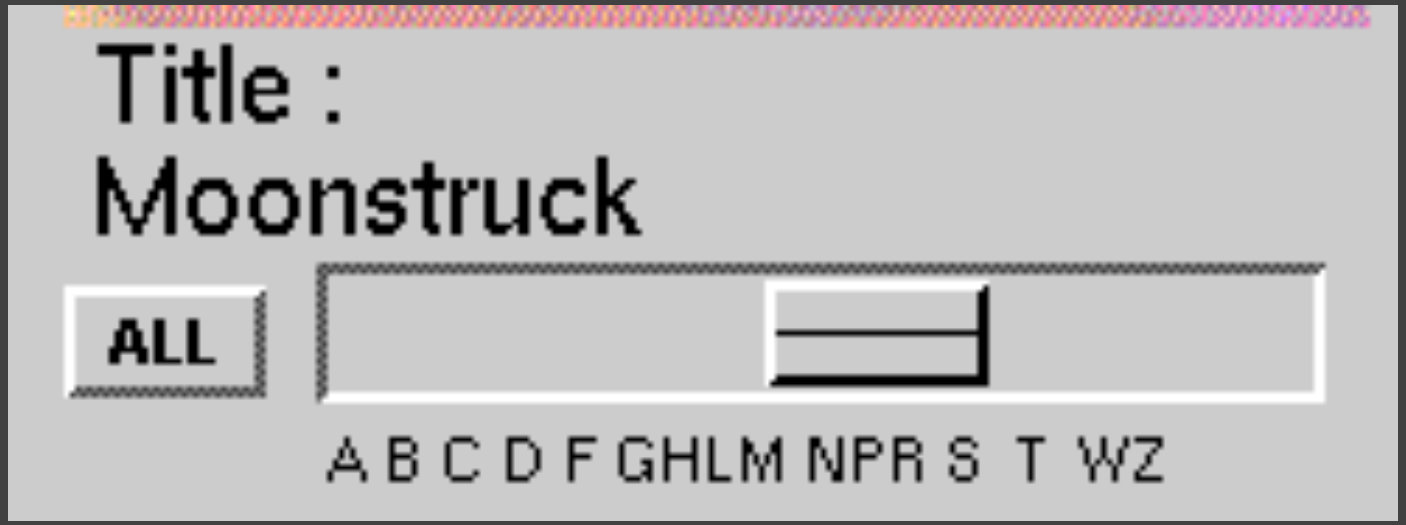


[Ahlberg and Shneiderman 94]

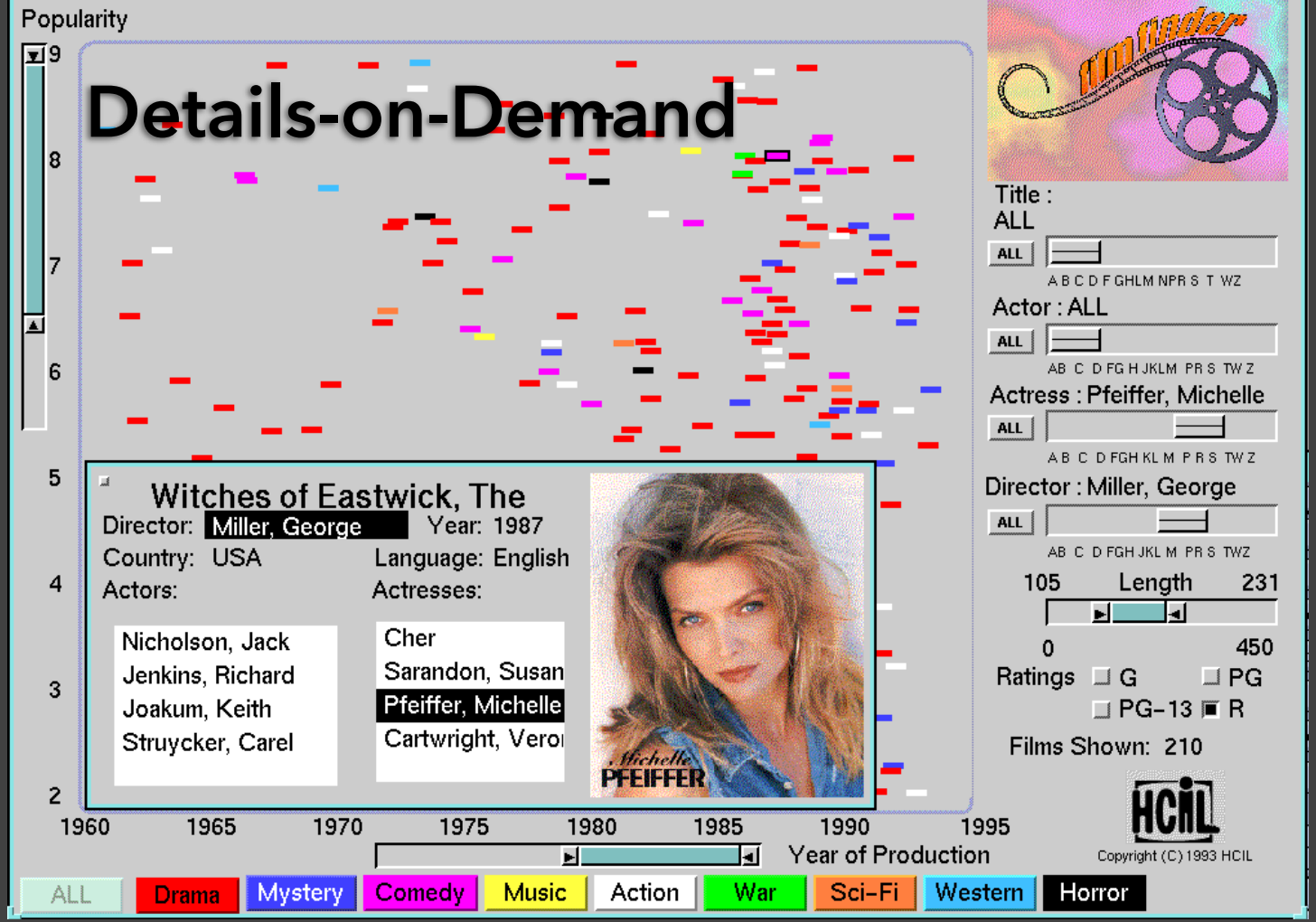


[Ahlberg and Shneiderman 94]

Alphaslider (?)



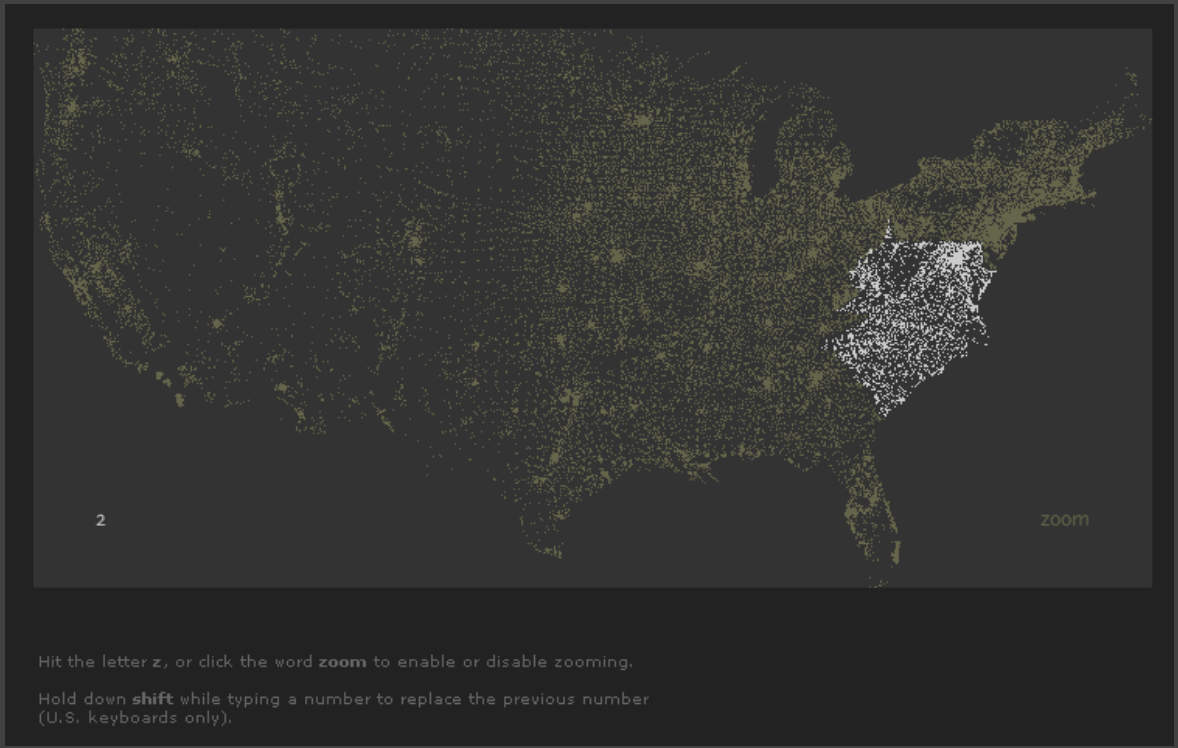
[Ahlberg and Shneiderman 94]



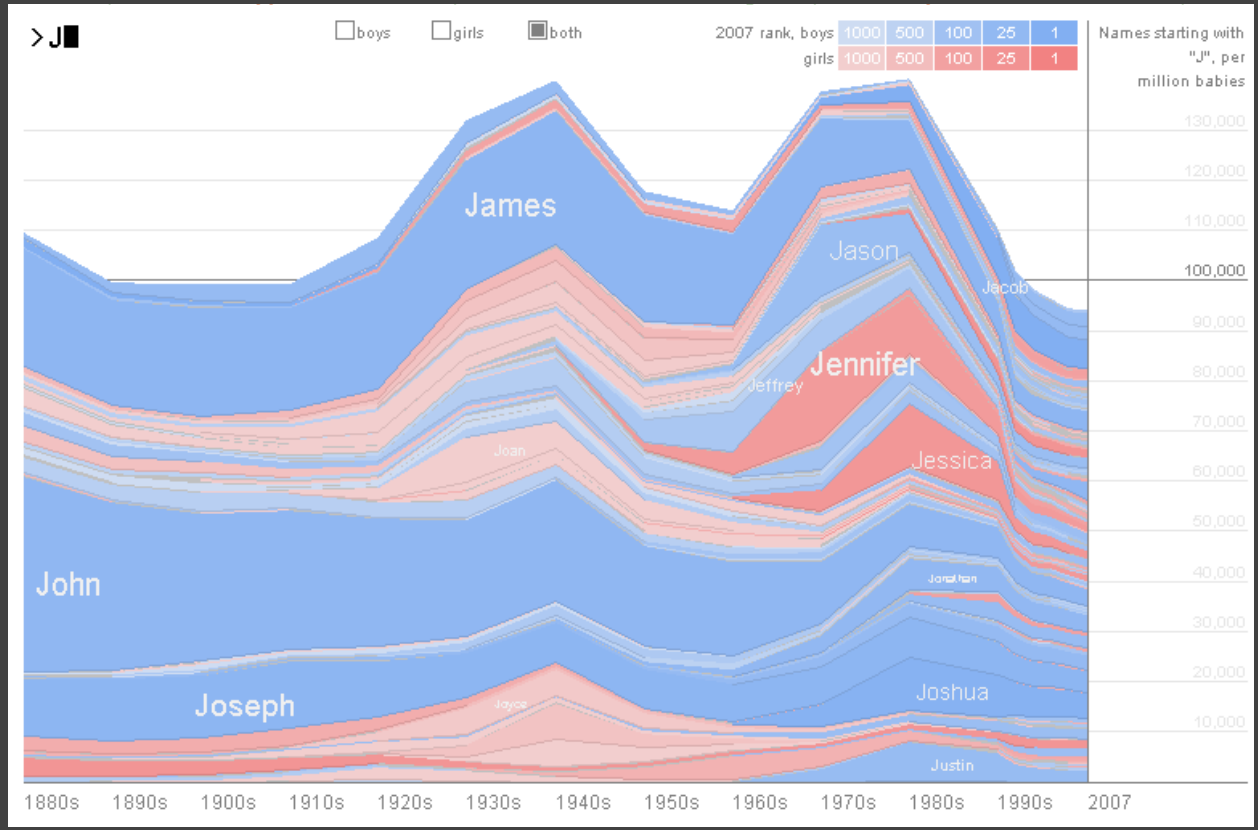
[Ahlberg and Shneiderman 94]

- The Attribute Explorer

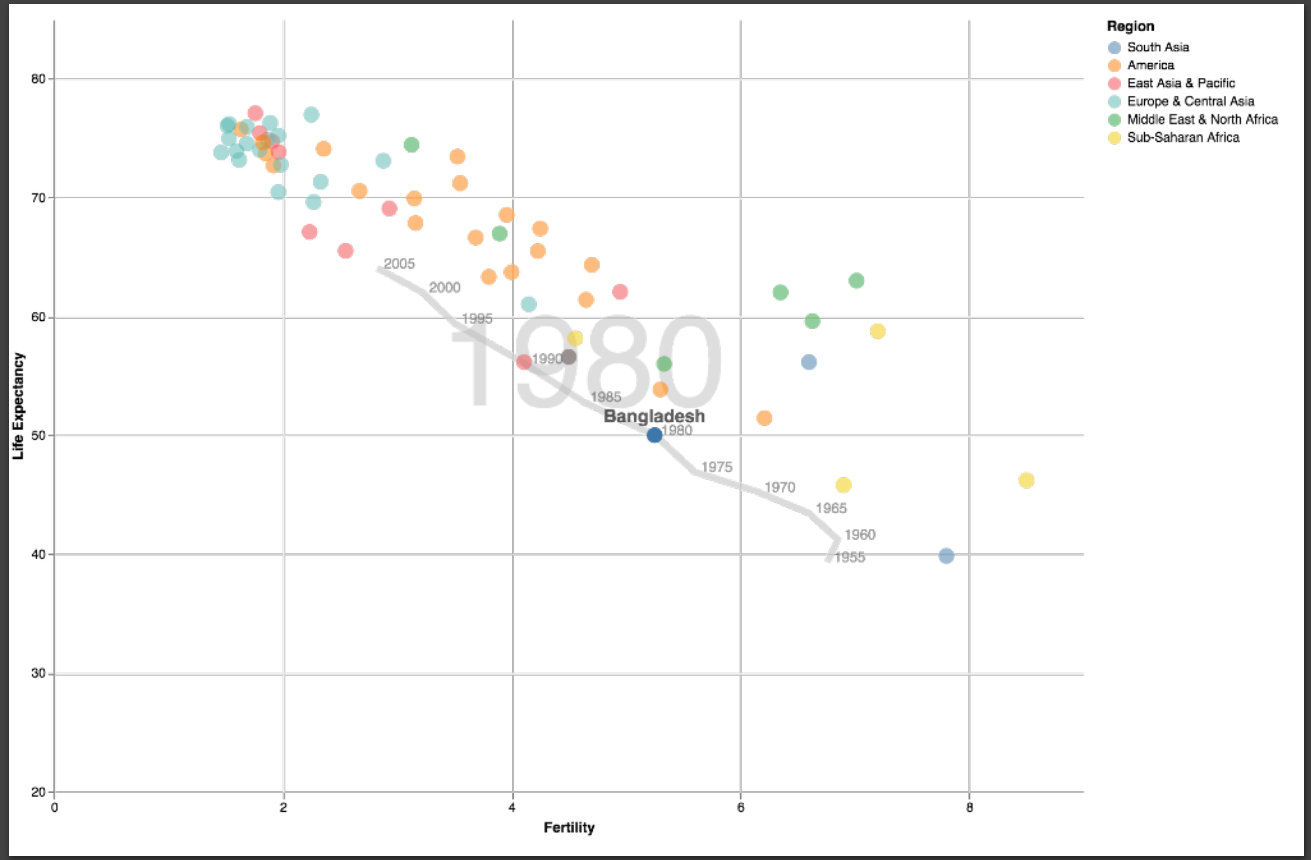
Zipdecode [Fry 04]



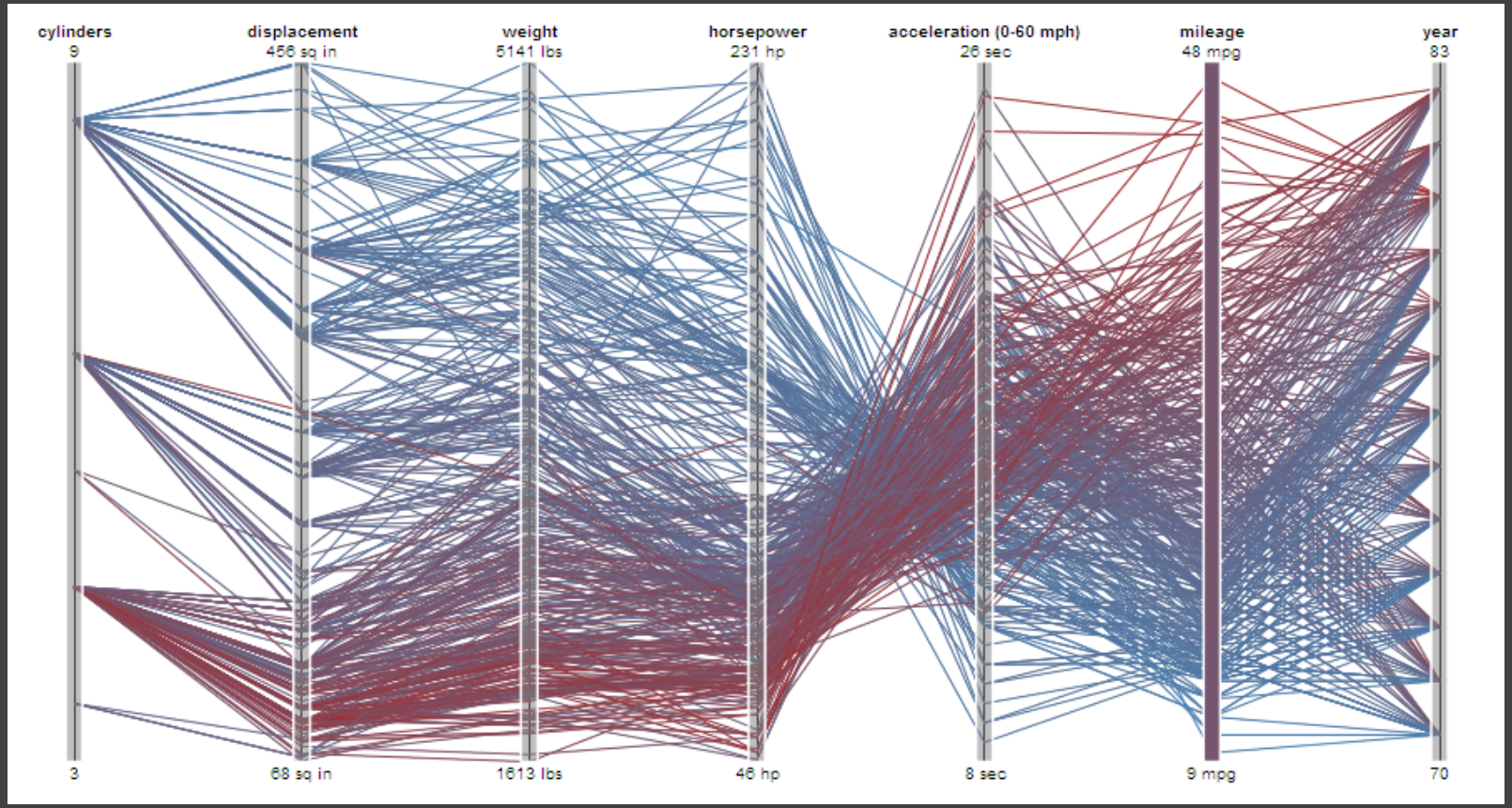
NameVoyager [Wattenberg 06]



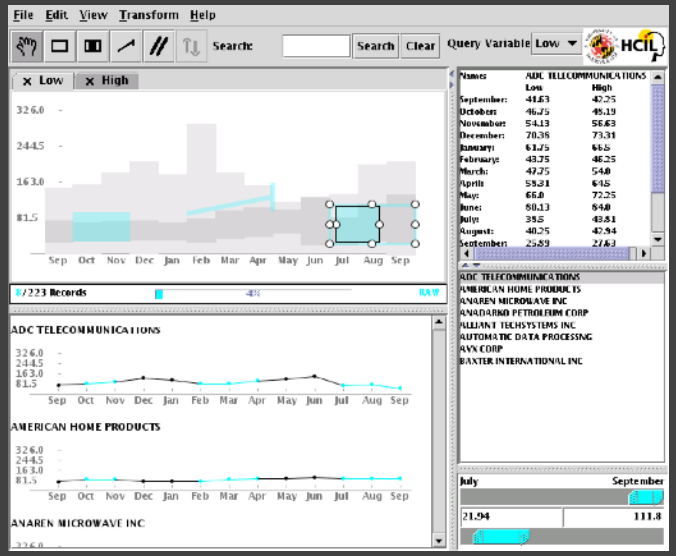
DimpVis [Kondo 14]

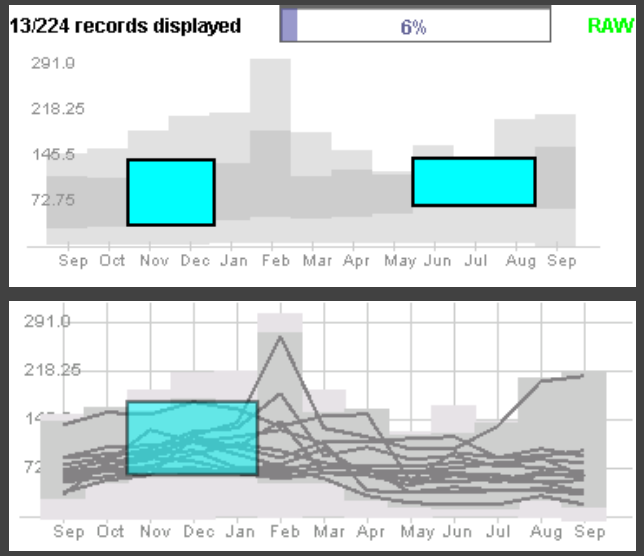


Parallel Coordinates [Inselberg]

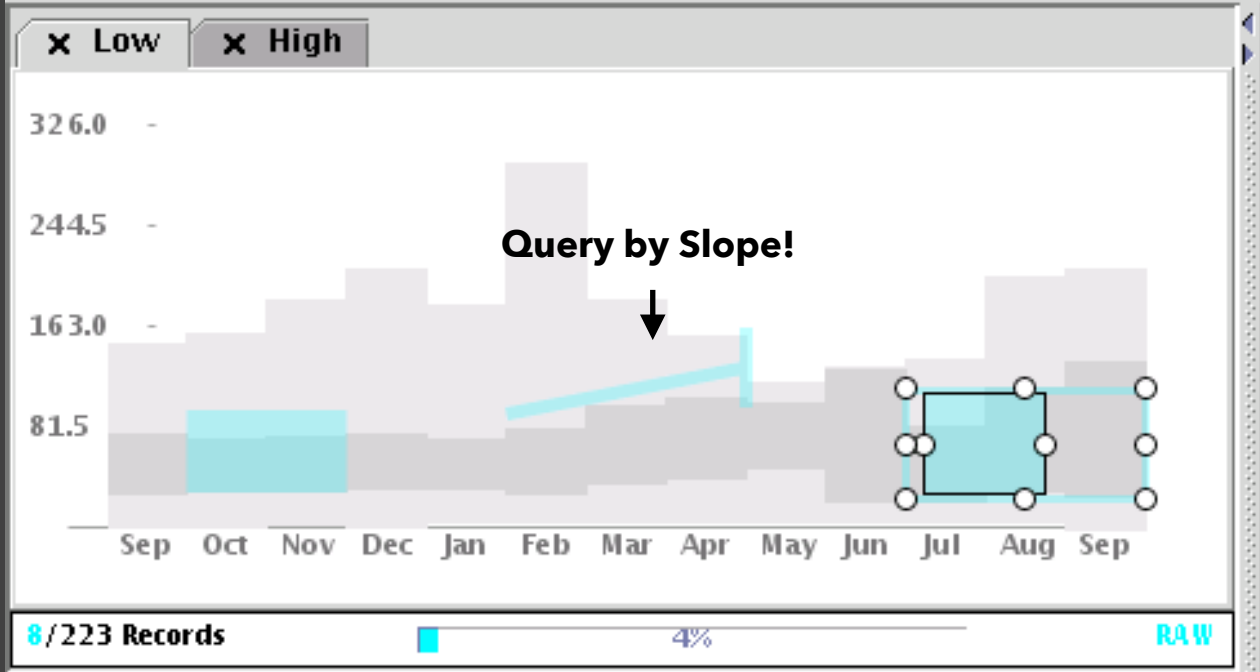


TimeSearcher [Hocheiser 02]



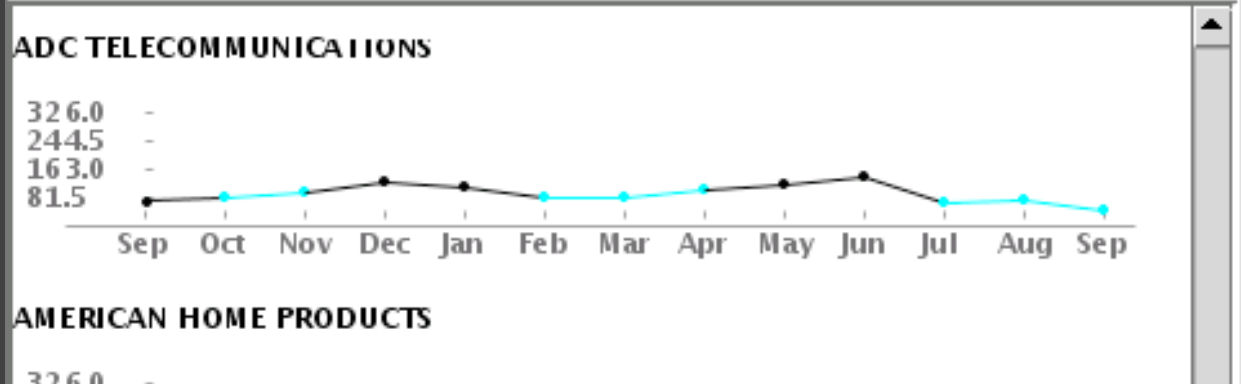


Builds on Wattenberg's [2001] idea for sketch-based queries of time-series data.

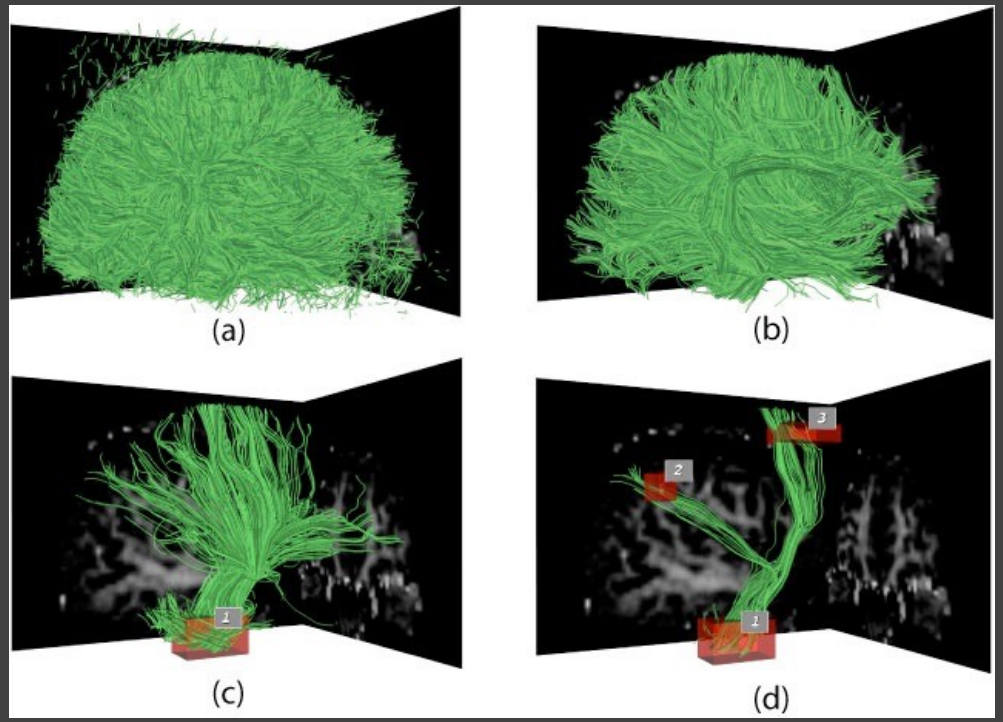


Name:	ADC TELECOMMUNI
	Low
September:	41.63
October:	46.75
November:	54.13
December:	70.38
January:	61.75
February:	43.75
March:	47.75
April:	58.31
May:	66.0
June:	80.13
July:	38.5
August:	40.25
September:	25.89

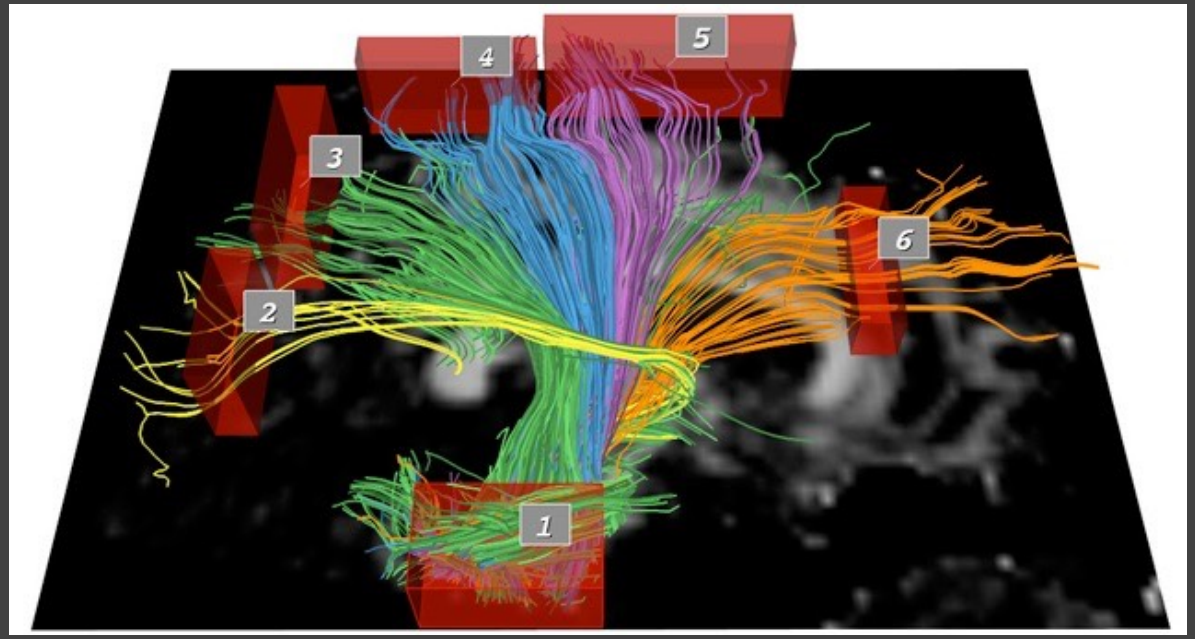
ADC TELECOMMUNICATIONS
AMERICAN HOME PRODUCTS
ANAREN MICROWAVE INC
ANADARKO PETROLEUM CORP
ALLIANT TECHSYSTEMS INC
AUTOMATIC DATA PROCESSNG
AVX CORP
BAXTER INTERNATIONAL INC



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

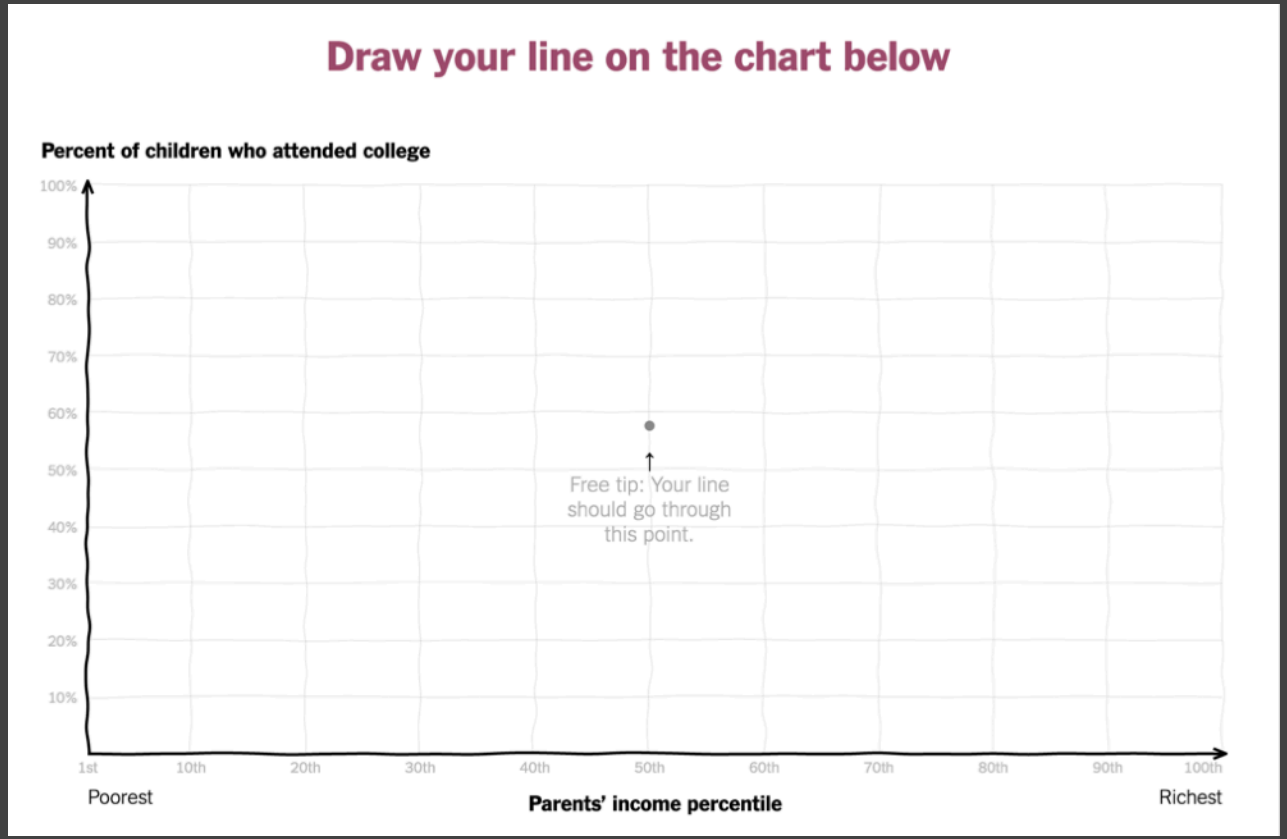
Lots of controls

Amount of data shown limited by screen space

Who would use these kinds of tools?

Prompting Reflection

You Draw It [Aisch et al. '15]



Interaction 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 viewers

Your two visualizations may address different questions.

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 **Tue 1/27 EOD**.

A2: Peer Reviews

You will be assigned two peer W2 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 to a A2 Peer Review thread on Ed, along with a link to a Google Form. You should submit two forms: one for each A2 peer review.

Due by **Tue 2/3 EOD**.

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."*

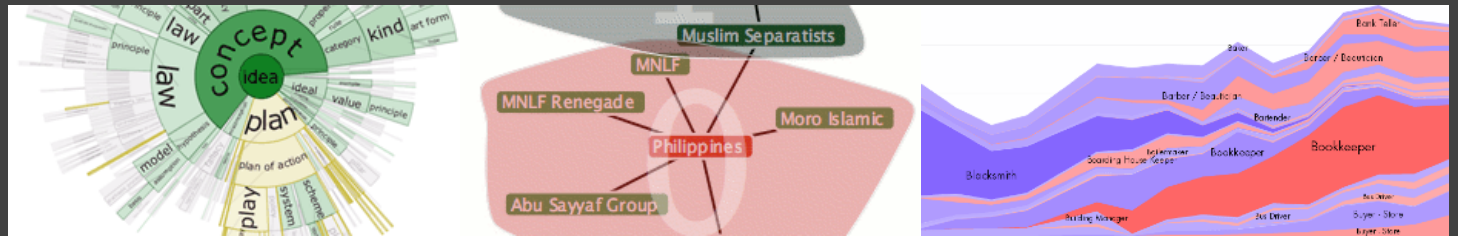
WHAT IF?

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 Visualization

Create an interactive visualization in a team of 1-3 people. Choose a dataset and a driving question, develop a visualization + interaction techniques, then deploy your visualization on the web.

1. Form team, topic & data and start prototyping.
2. Complete implementation and submit to Gradescope by *EOD* on **Tuesday, Feb 17**.



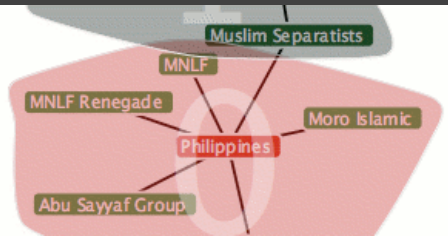
Form a Project Team

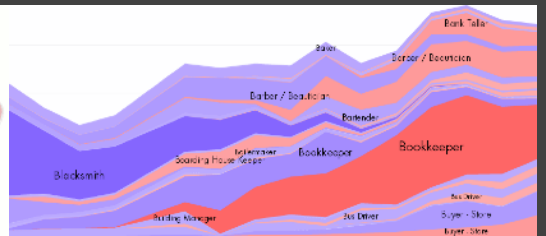
Form a **team of 1-3 people** for the A3 assignment.

Submit team composition using provided form.

If you're looking for team mates, you can post on Ed about your interests/skills/project ideas!

You may continue with the same team for the final project, or form a new team later. It's up to you.



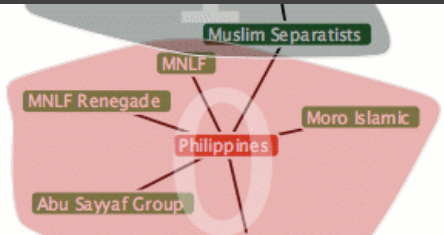


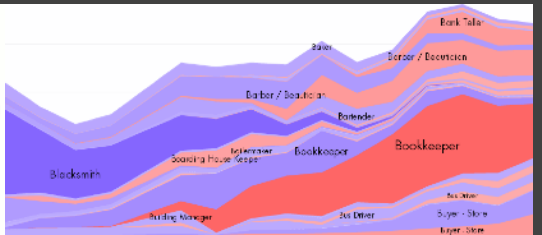
Requirements

Interactive. You must implement interaction methods! However, this is not only selection / filtering / tooltips. Also consider annotations or other narrative features to draw attention and provide additional context

Web-based. D3/Vega-Lite are encouraged, but not required. Deploy to web using GitLab pages.

Write-up. Provide design rationale.



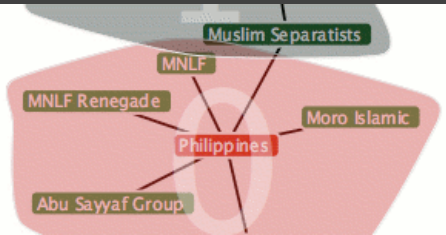


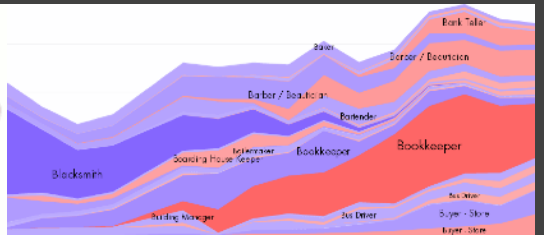
Interactive Prototype Tips

Start now. It will take longer than you think.

Keep it simple. Choose a *minimal* set of interactions that enables users to explore and generate interesting insights. Do not feel obligated to convey *everything* about the data: focus on a compelling subset.

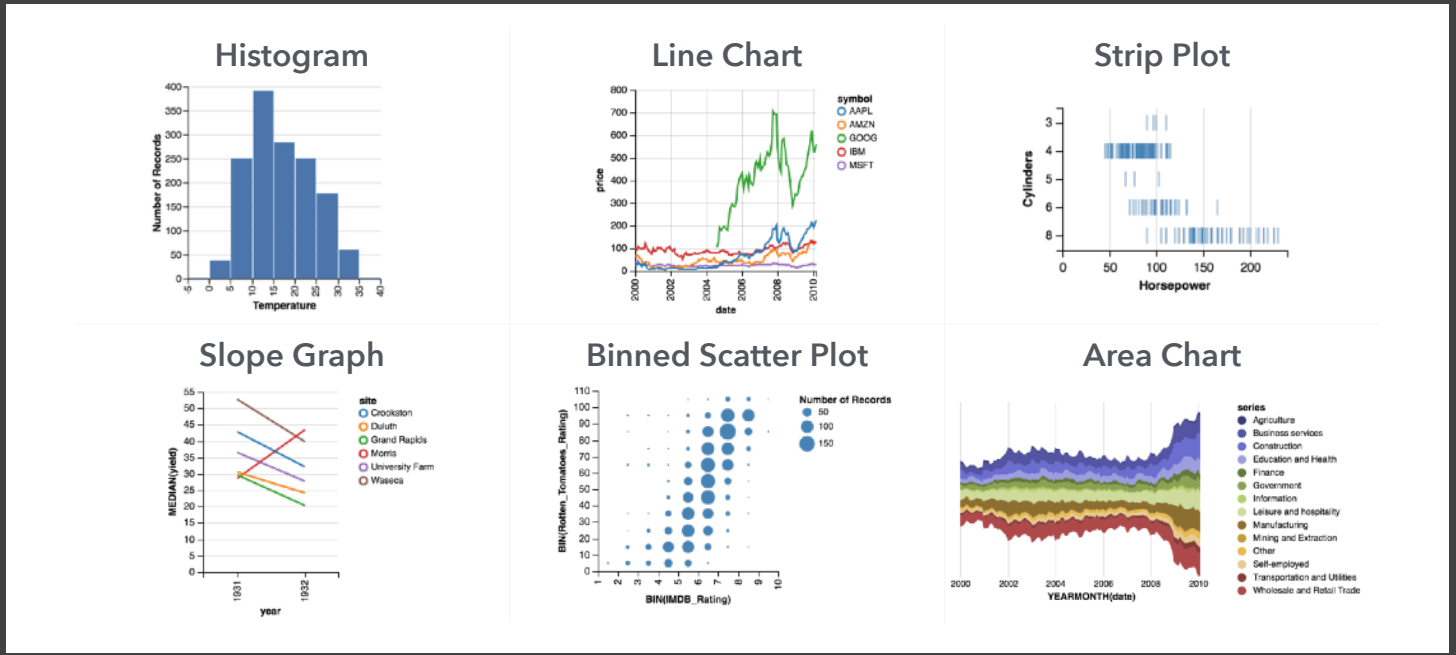
Promote engagement. How do your chosen interactions reveal interesting observations?





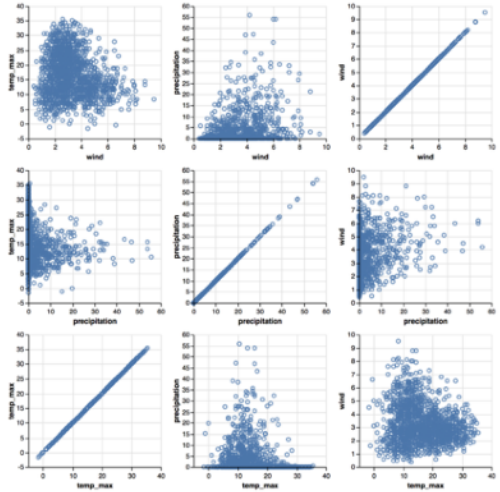
An Interaction Grammar (Vega-Lite Selections)

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

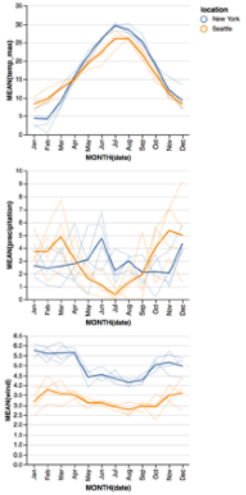


Vega-Lite: A Grammar of Graphics

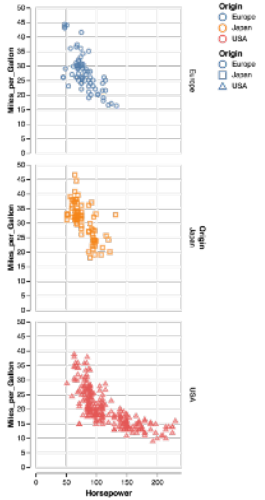
Scatter Plot Matrix



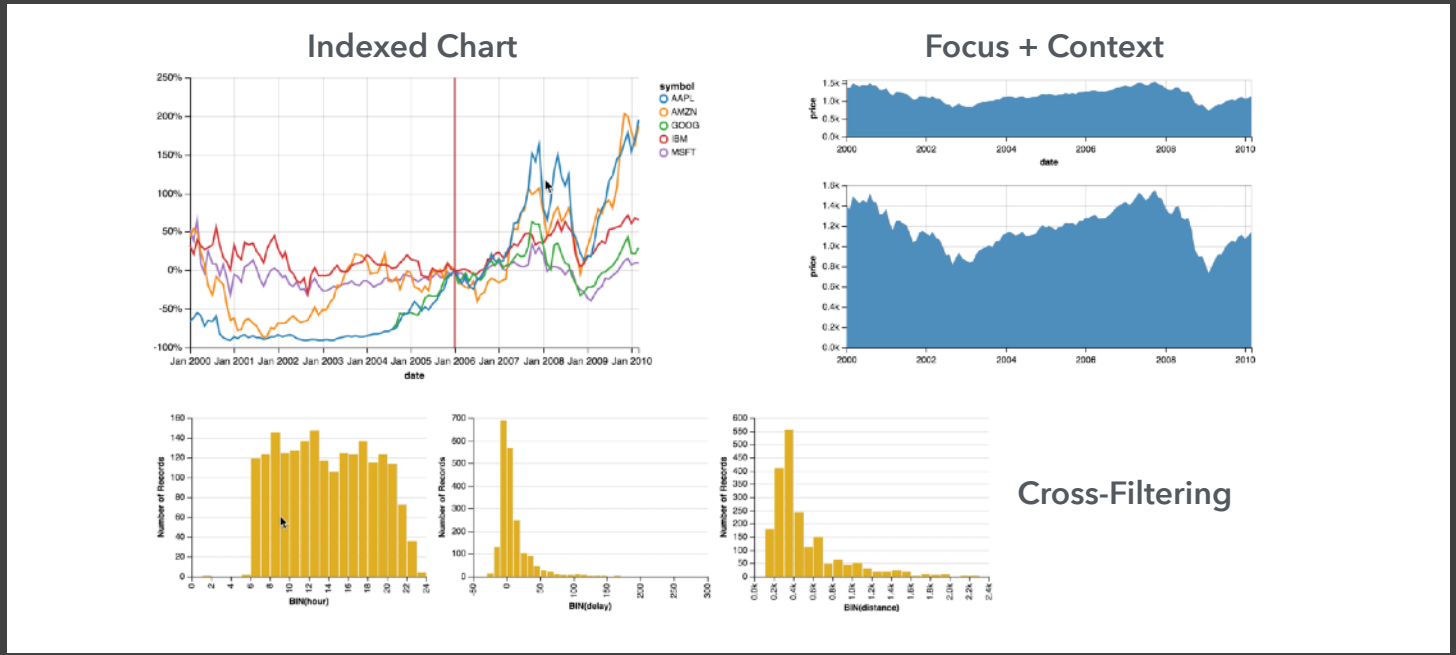
Concat & Layered Views



Faceted Views

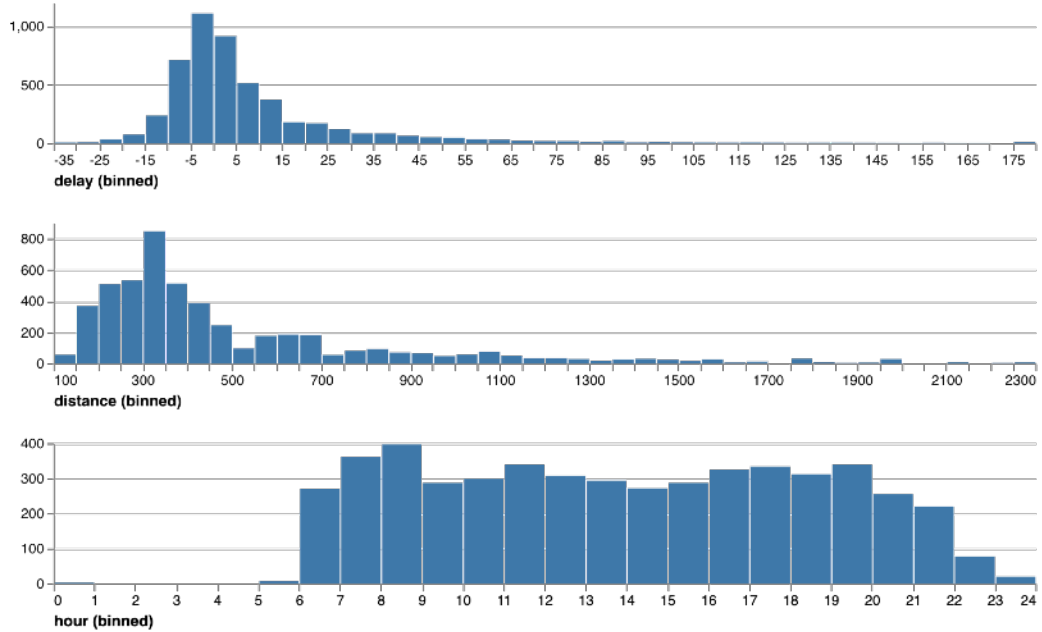


Vega-Lite: A Grammar of Multi-View Graphics

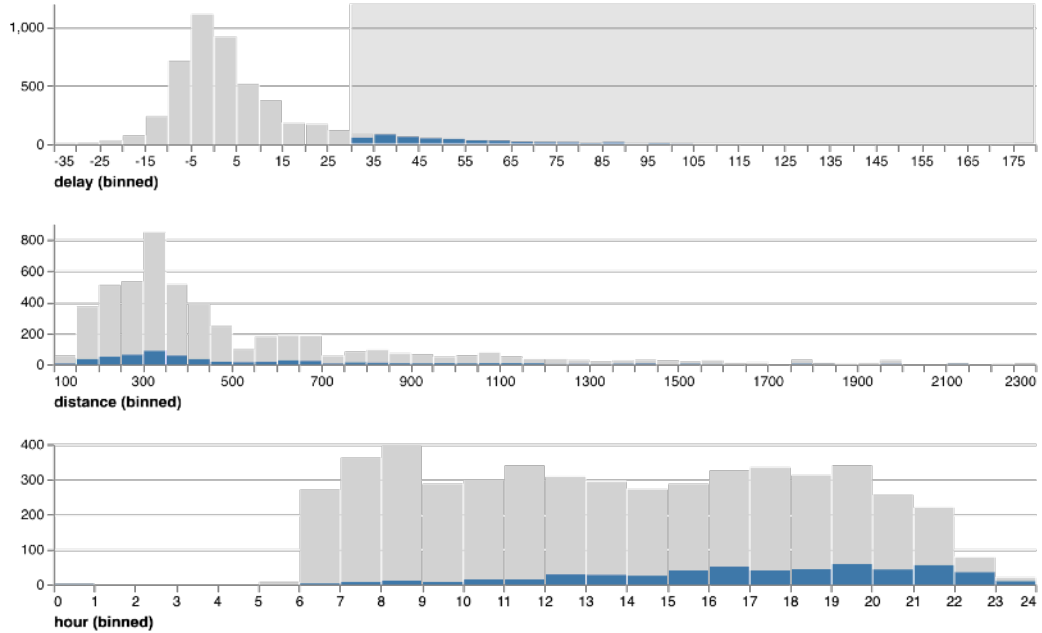


Vega-Lite: A Grammar of Interactive Graphics

Cross-Filtering in Vega-Lite

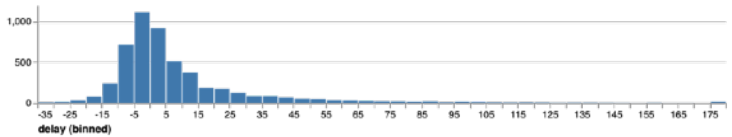


Cross-Filtering in Vega-Lite



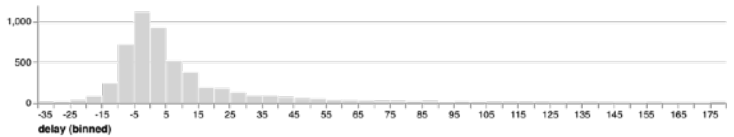
Cross-Filtering in Vega-Lite

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



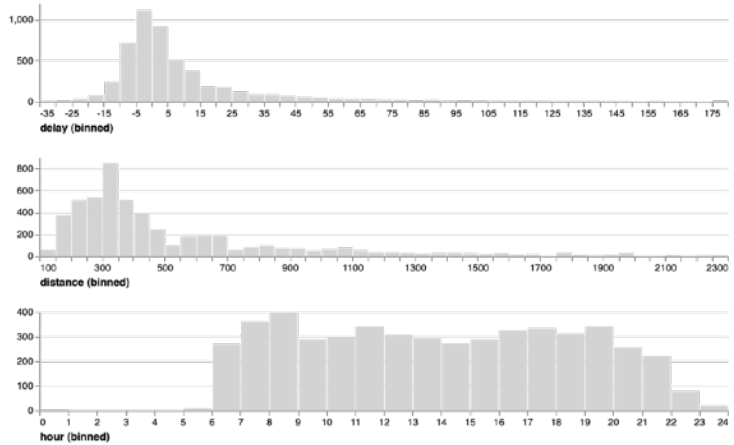
Cross-Filtering in Vega-Lite

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



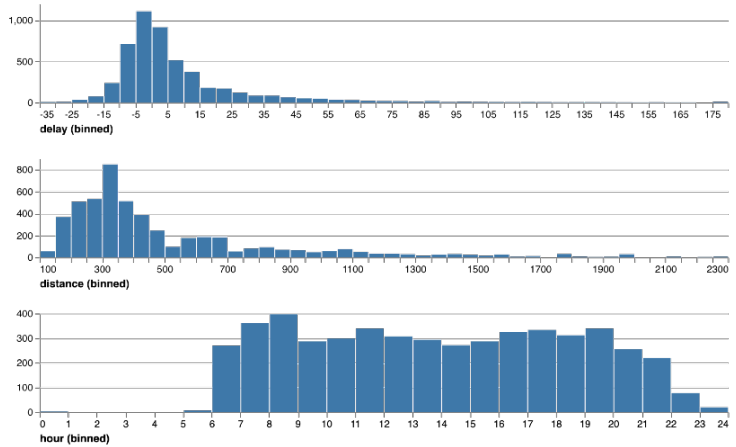
Cross-Filtering in Vega-Lite

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



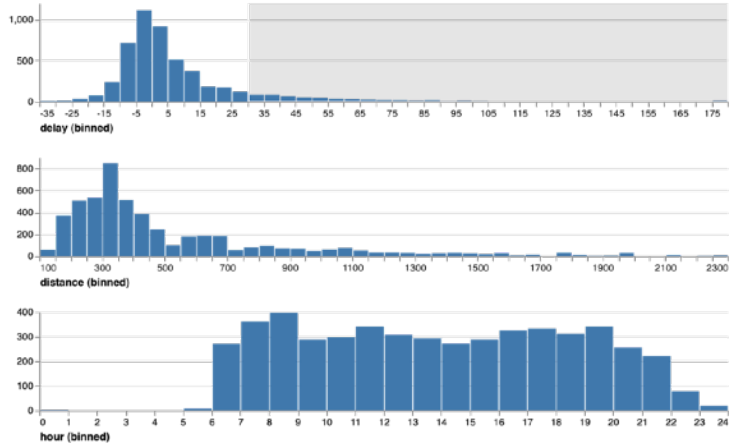
Cross-Filtering in Vega-Lite

```
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')
```



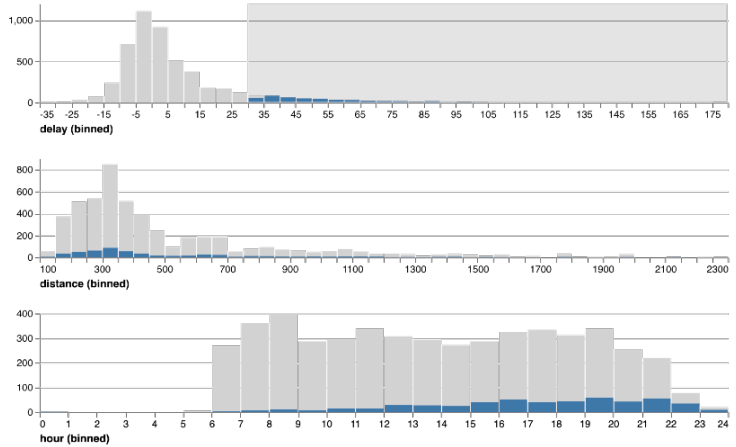
Cross-Filtering in Vega-Lite

```
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')
```



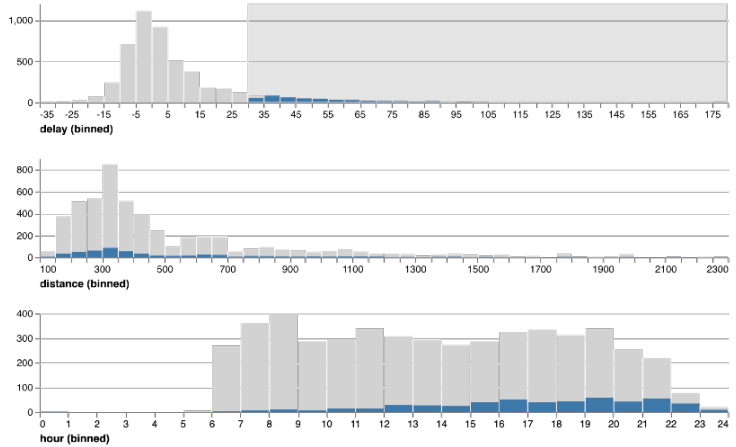
Cross-Filtering in Vega-Lite

```
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

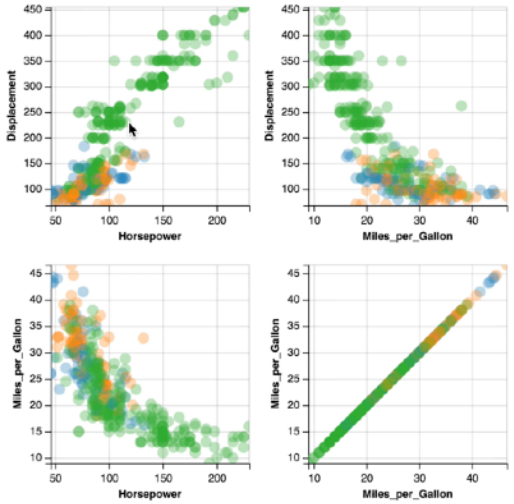
Scale inversion: visual space → data space

Predicate: test if a data record is selected

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

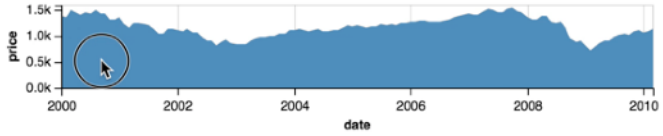
Selections

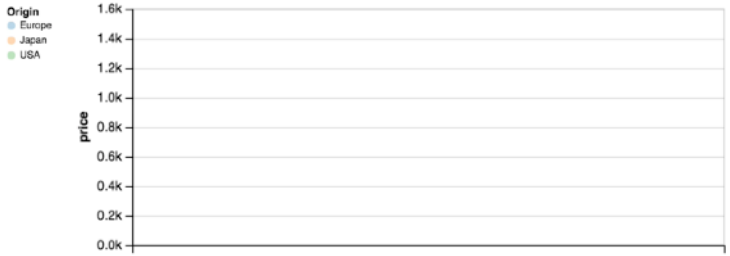
Selections *invert* scales and *parameterize* graphics

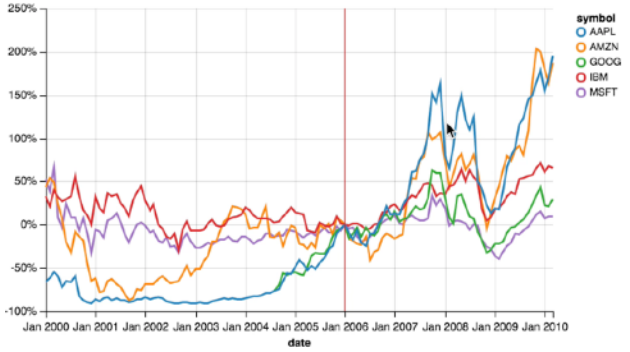


Bind selection to scale domains:
Synchronized Pan & Zoom!

Overview + Detail







Parameterized Transformations