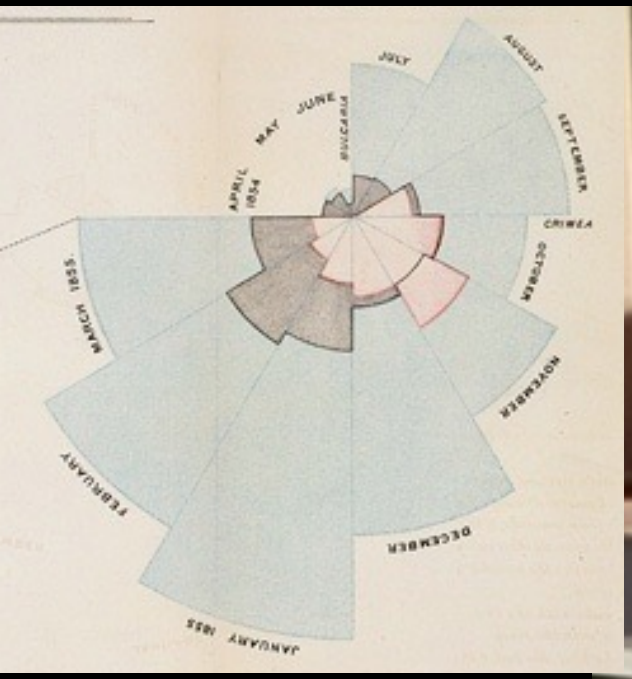
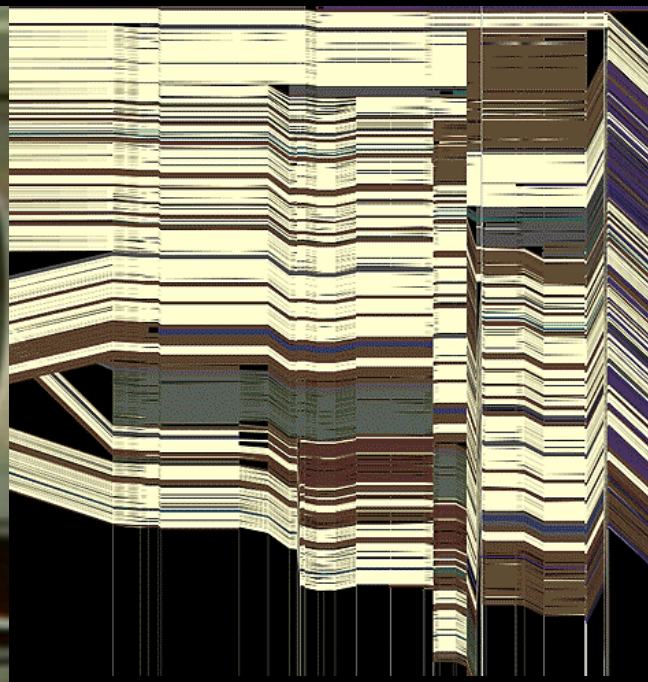
CSE 512 - Data Visualization

Interaction





Jeffrey Heer University of Washington

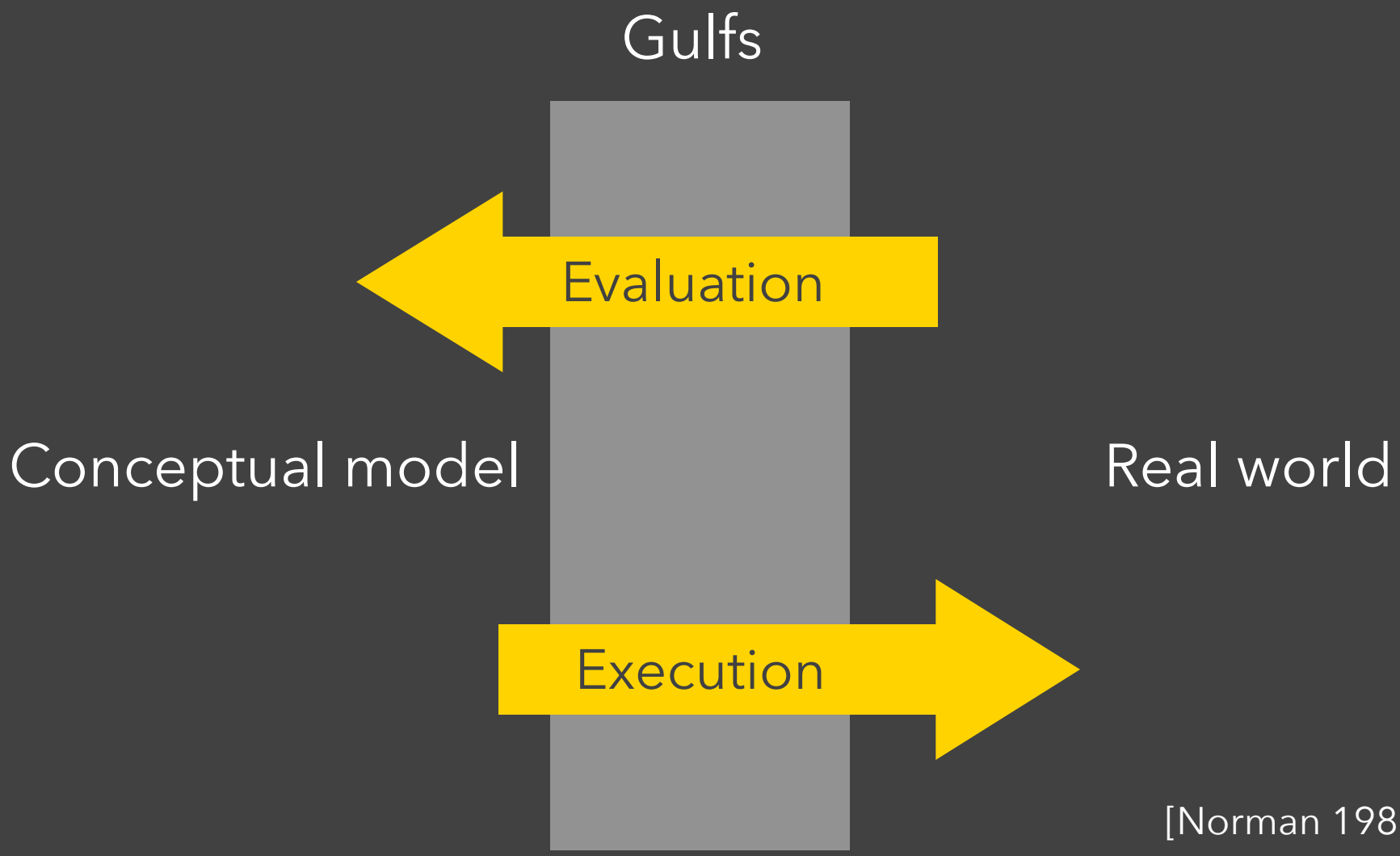
[There is an] apparent challenge that computational artifacts pose to the longstanding distinction between the physical and the social, in the special sense of those things that one designs, builds, and uses, on the one hand, and those things with which one communicates, on the other.

“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.

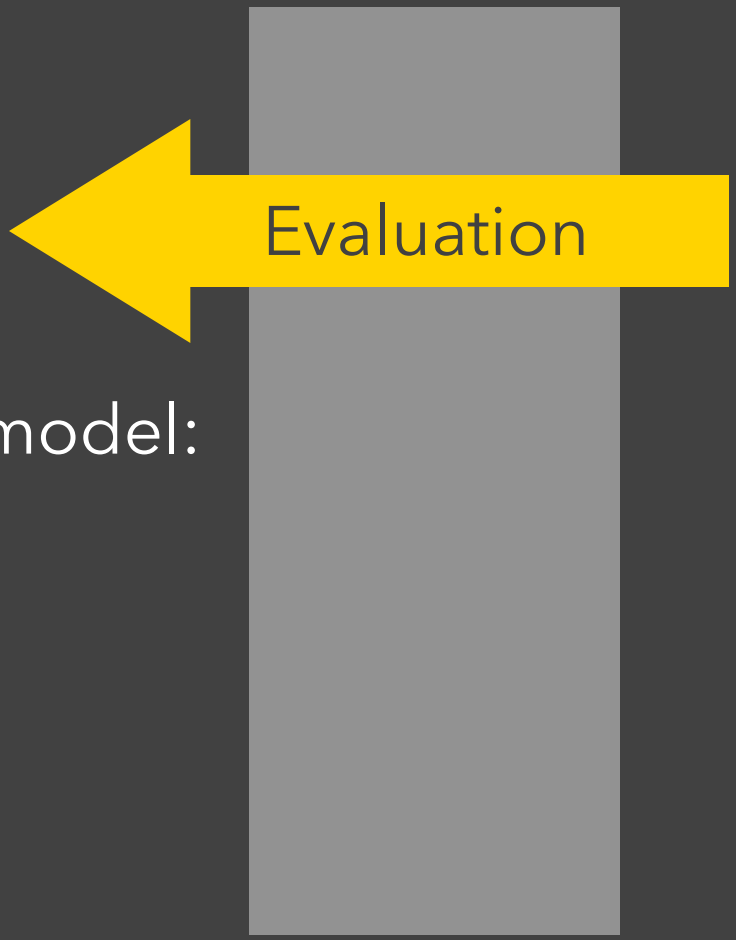
Gulf of Evaluation

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

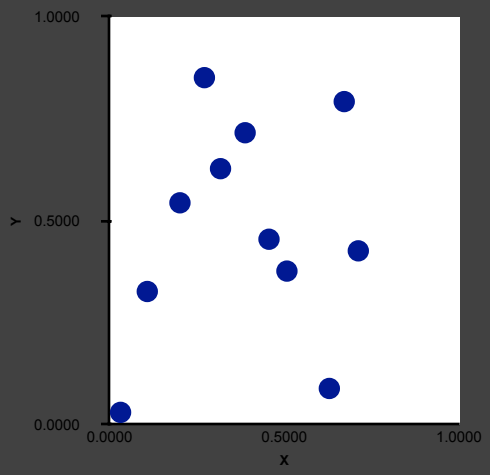
Gulf of Evaluation

Gulf

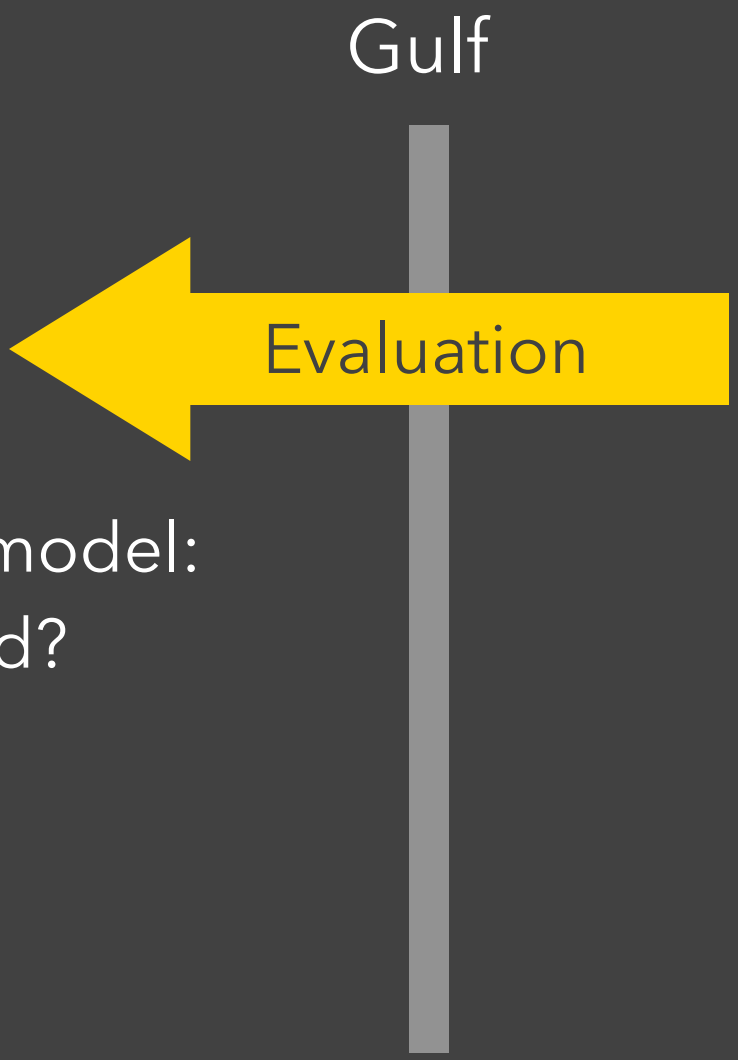
Evaluation

Conceptual model:
x, y related?

Real world:



Gulf of Evaluation



Real world:

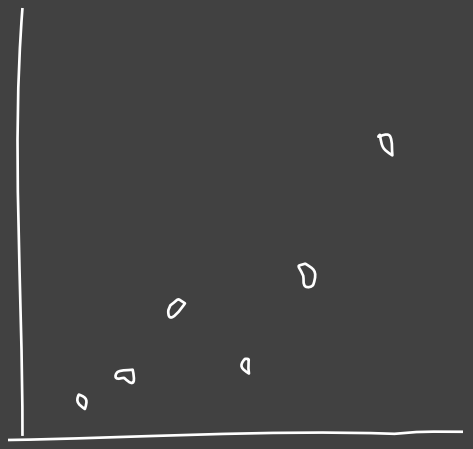
$\rho = -.29$

Conceptual model:
x, y correlated?

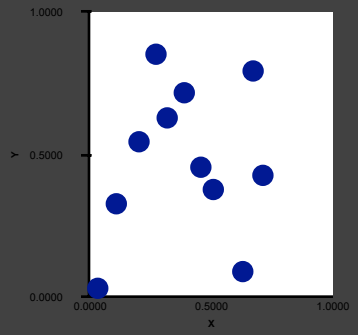
Gulf of Execution

Gulf

Conceptual model:
Draw a scatterplot



Execution



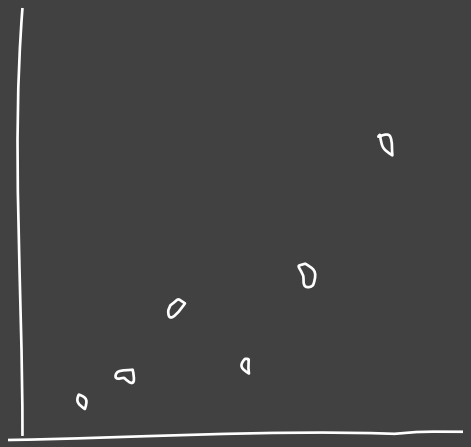
Real world

Move 90 30
Rotate 35
Pen down
…

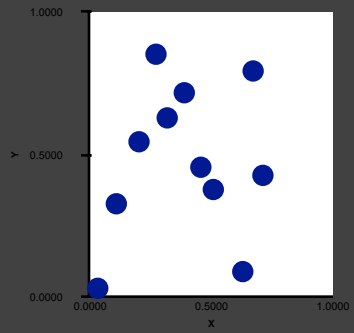
Gulf of Execution

Gulf

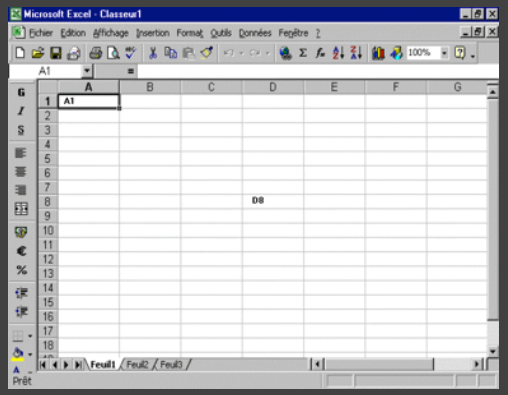
Conceptual model:
Draw a scatterplot



Execution



Real world



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

Taxonomy of Interactions

Data and View Specification
Visualize, Filter, Sort, Derive

View Manipulation
Select, Navigate, Coordinate, Organize

Taxonomy of Interactions

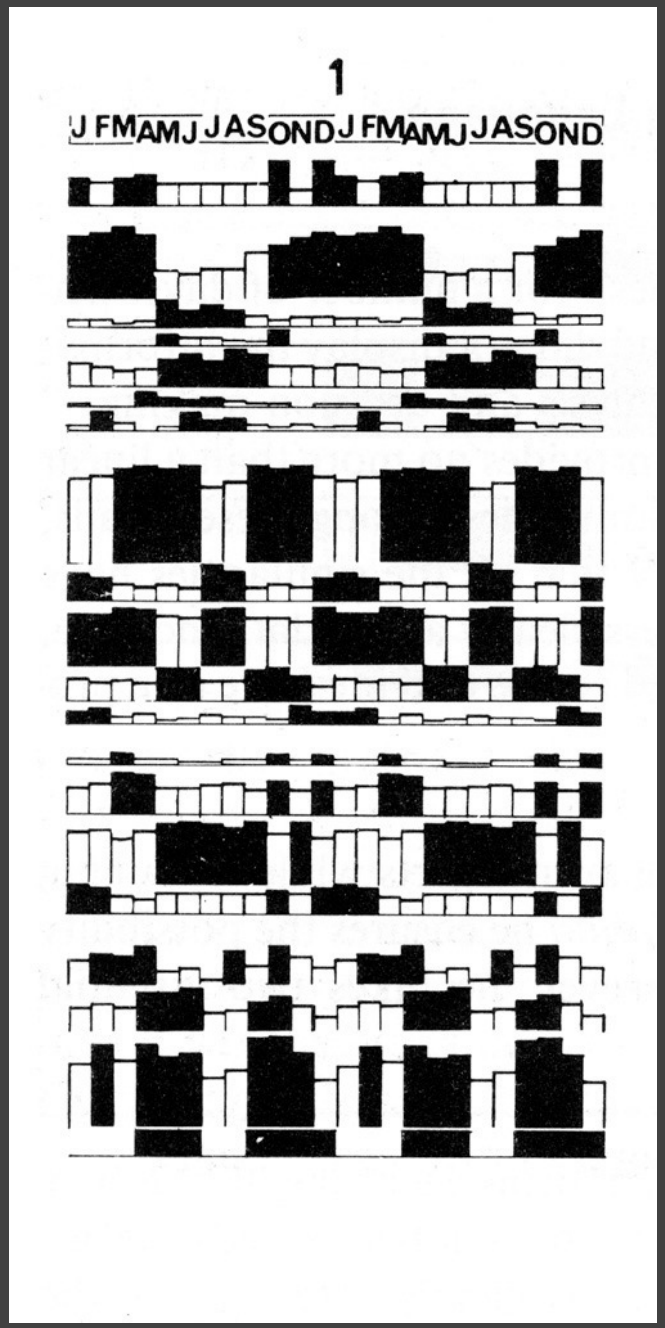
Data and View Specification
Visualize, Filter, Sort, Derive

View Manipulation
Select, Navigate, Coordinate, Organize

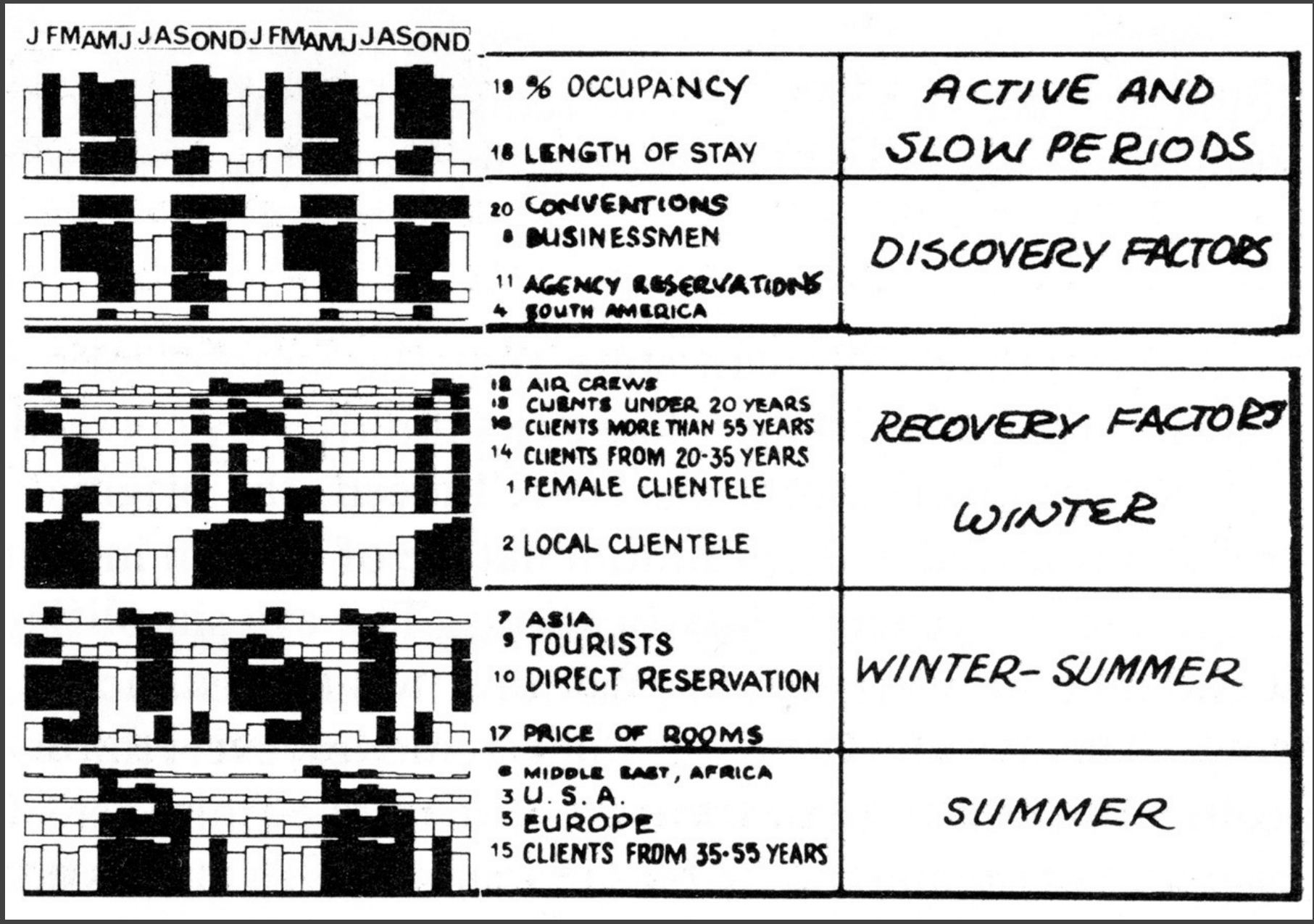
Process and Provenance
Record, Annotate, Share, Guide

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]



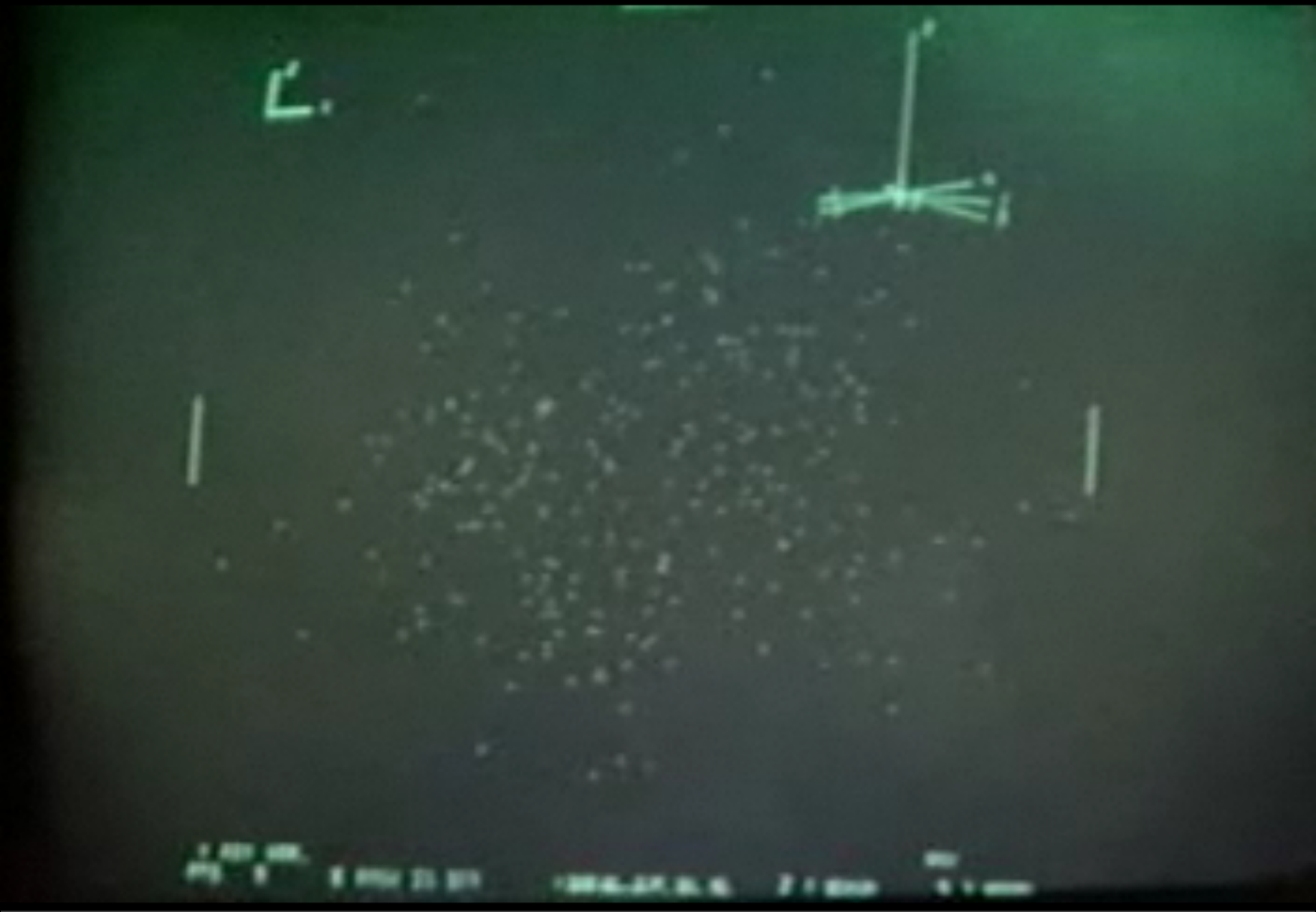
[Graphics and Graphic Information Processing, Bertin 81]

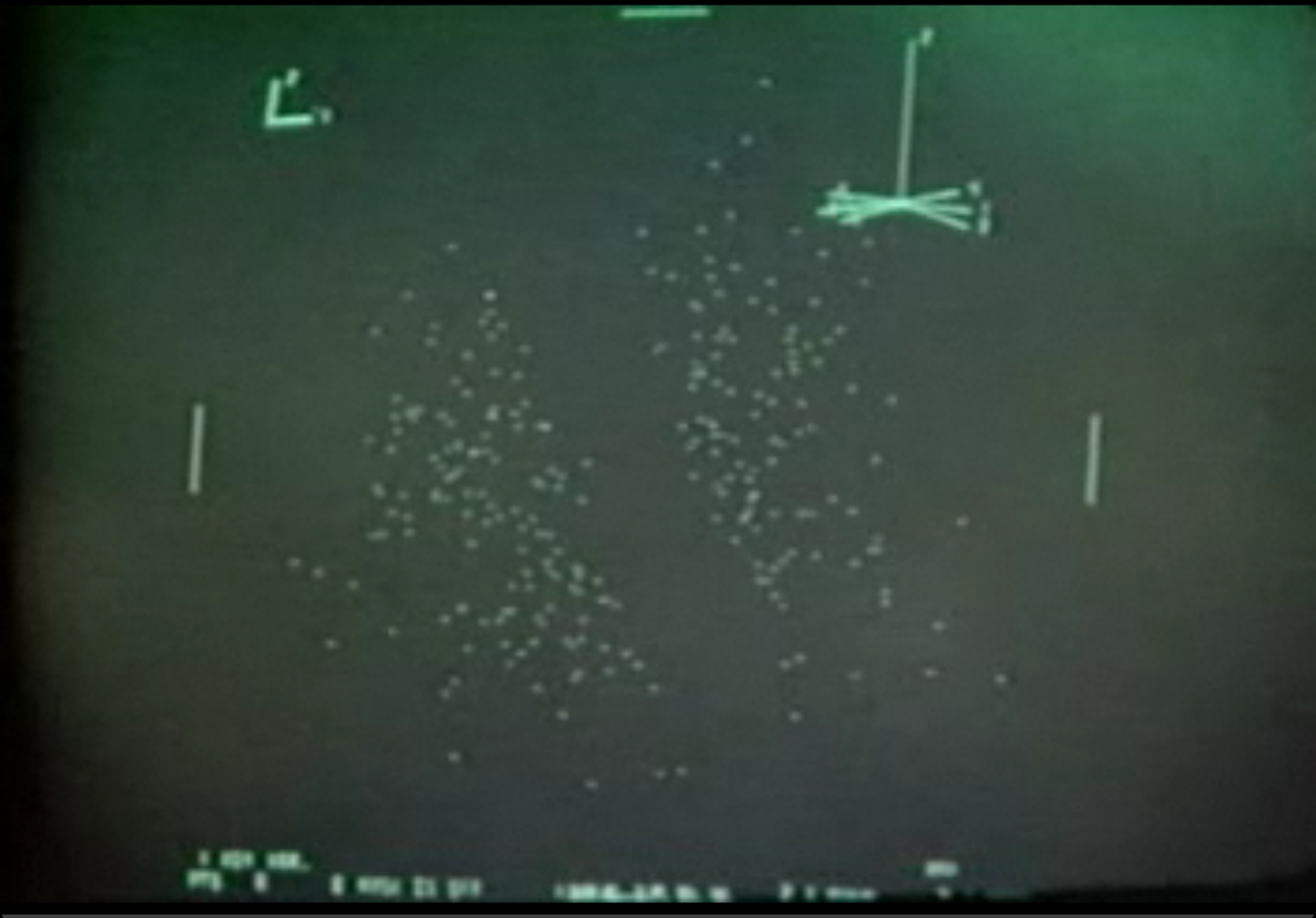
[Graphics and Graphic Information Processing, Bertin 81]

[Graphics and Graphic Information Processing, Bertin 81]

[Graphics and Graphic Information Processing, Bertin 81]

PRIM-9, Tukey, Fisherkeller, Friedman 1972





Selection

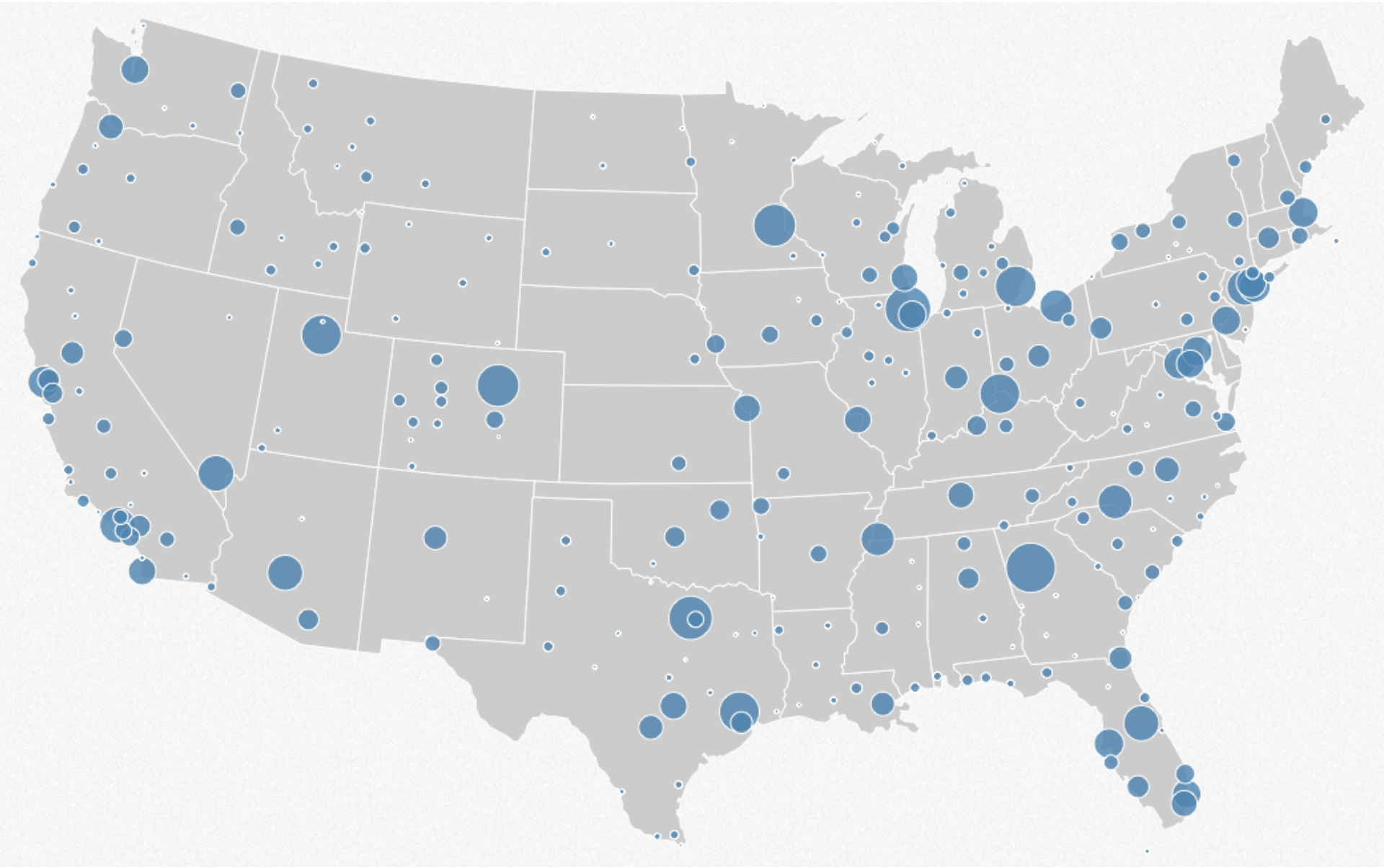
Basic Selection Methods

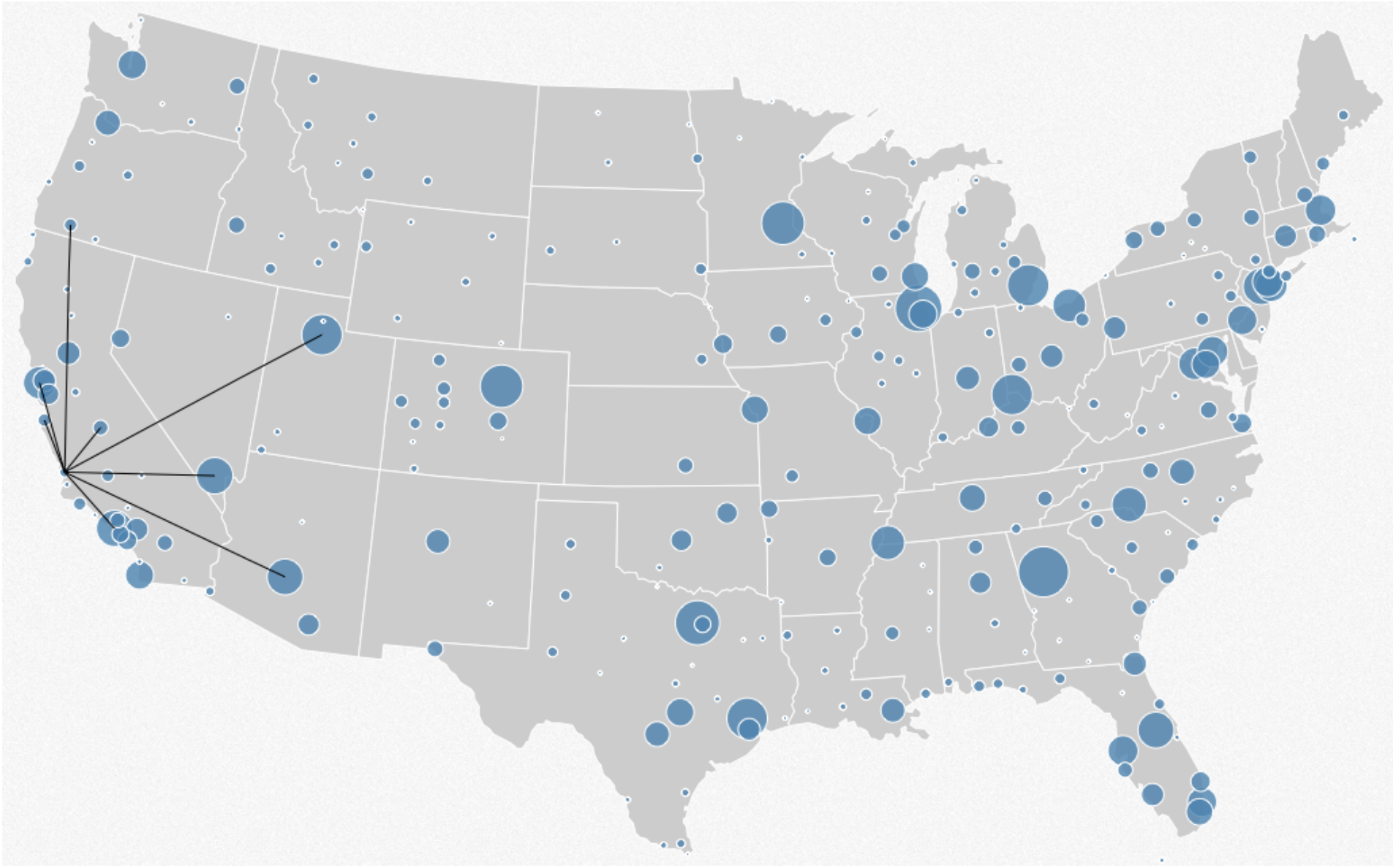
Point Selection

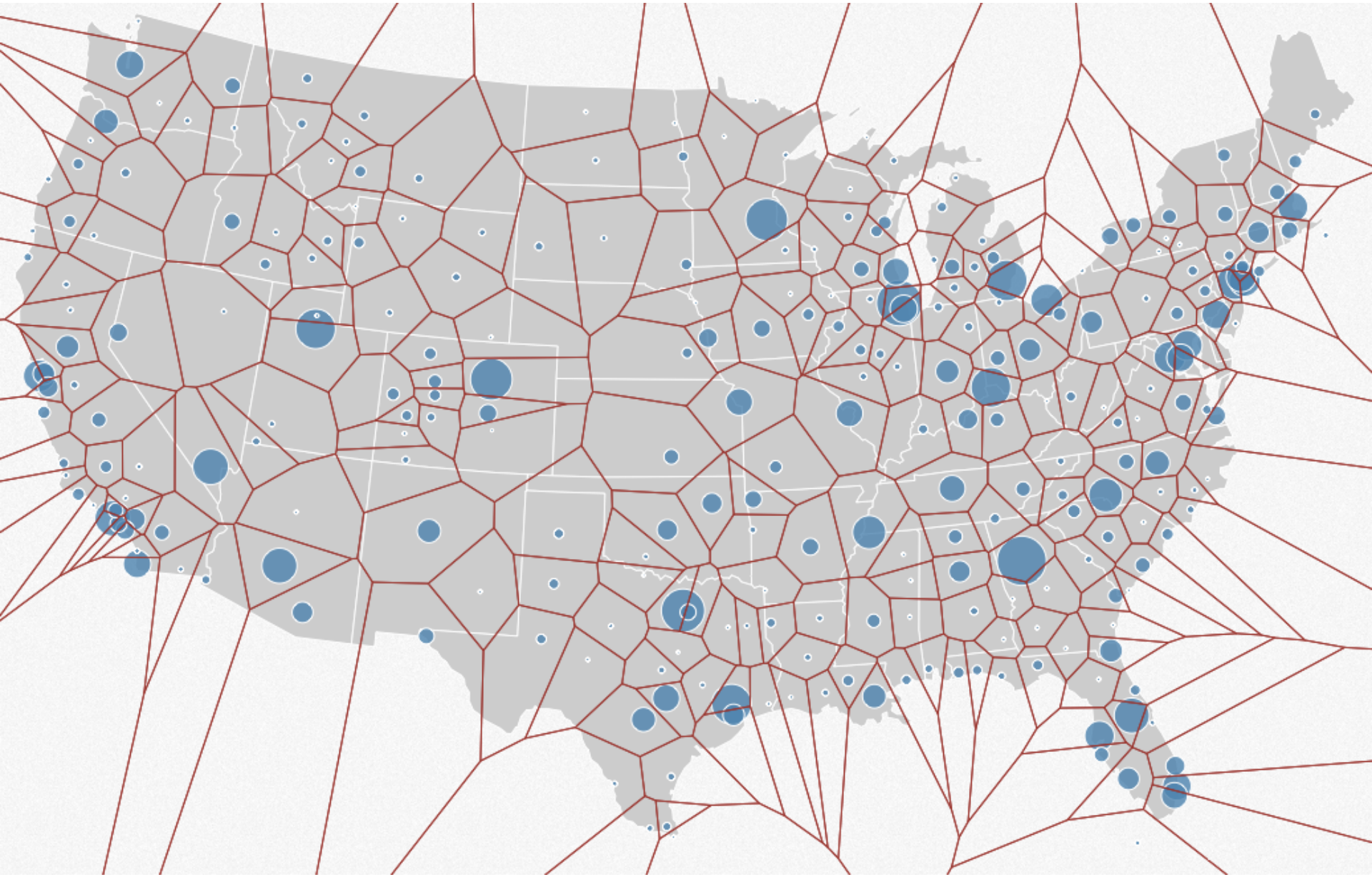
Mouse Hover / Click

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

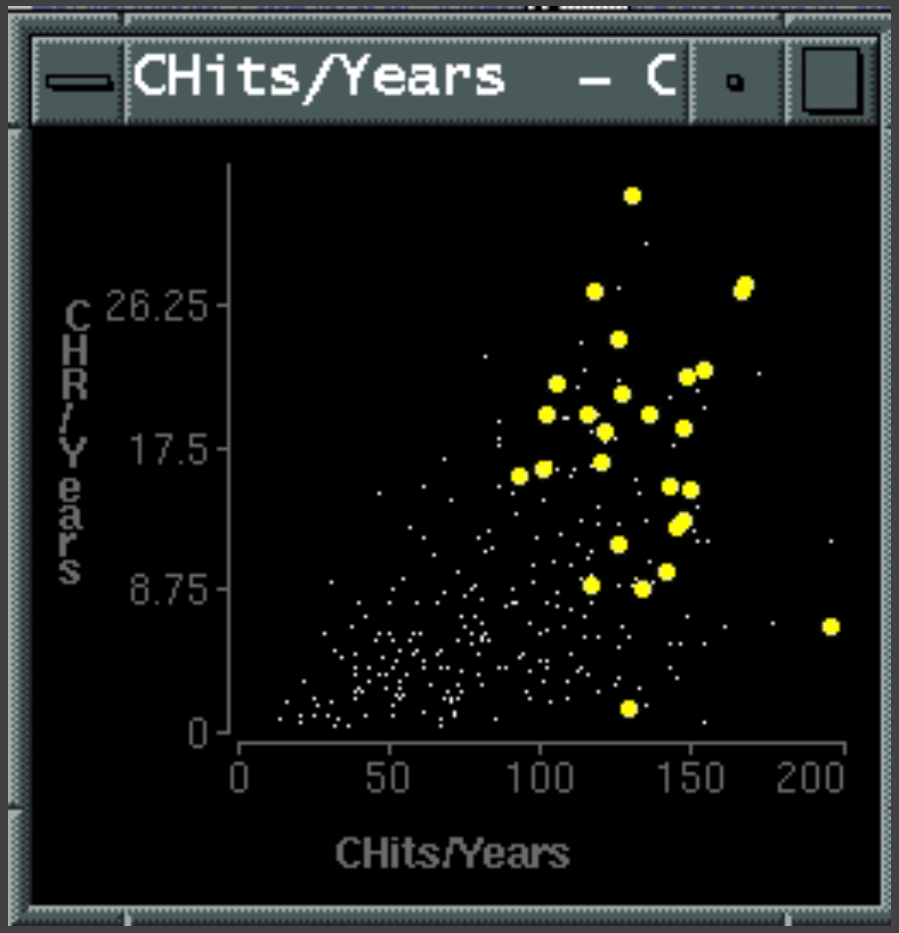
Rubber-band (rectangular) or Lasso (freehand)

Area cursors (“brushes”)

Brushing & Linking

Brushing

Direct attention to a subset of data [Wills 95]



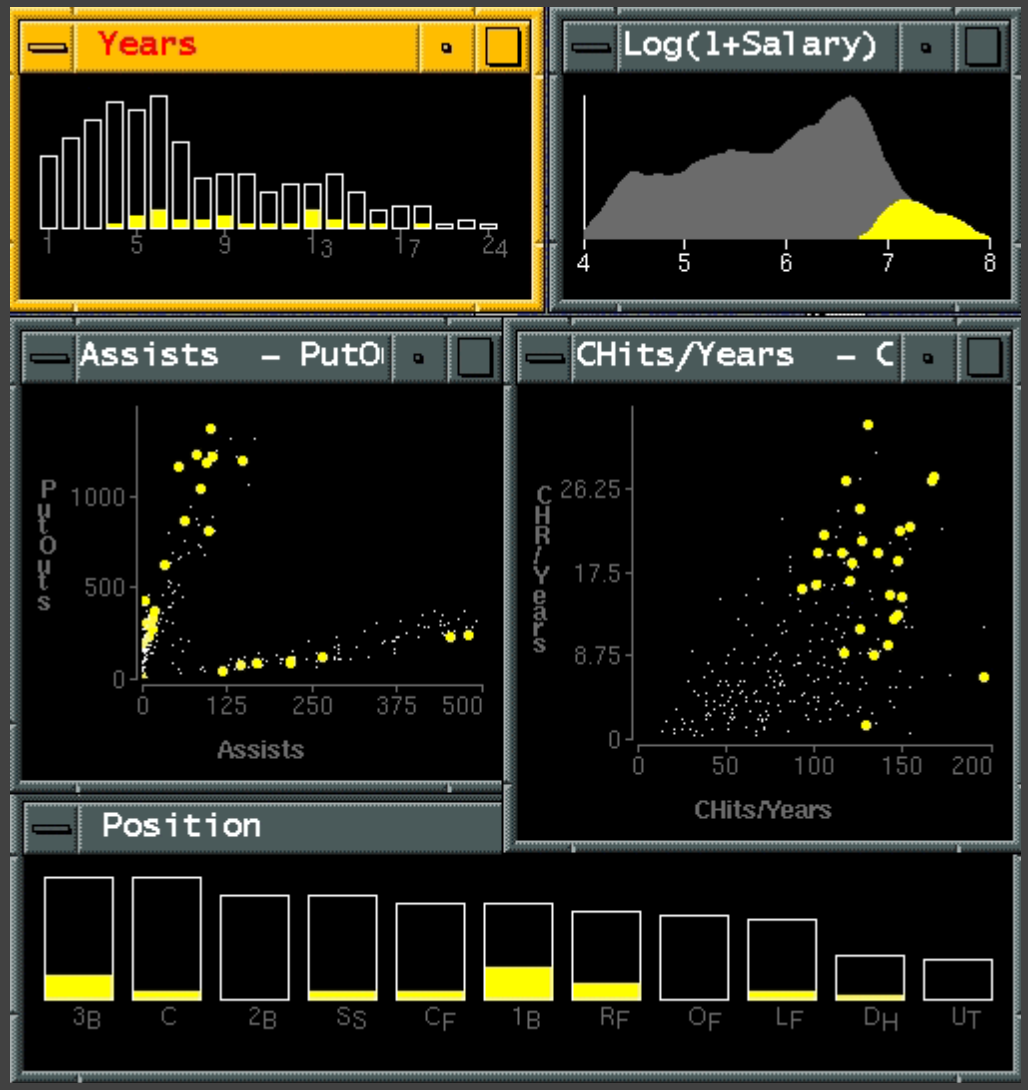
Brushing & Linking

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

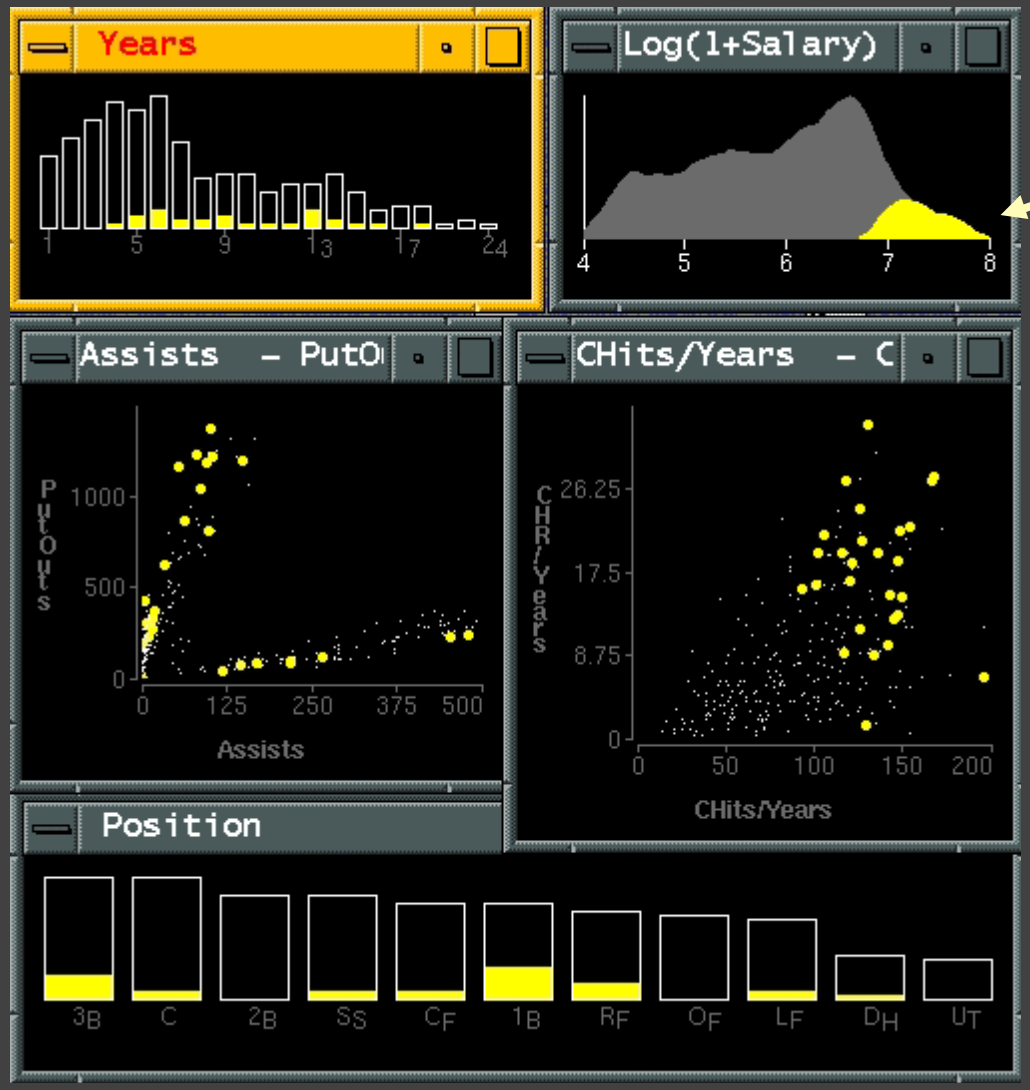
The components must be ***linked***
by *tuple* (matching data points), or
by *query* (matching range or values)

Brushing Scatterplots, Becker & Cleveland 1982

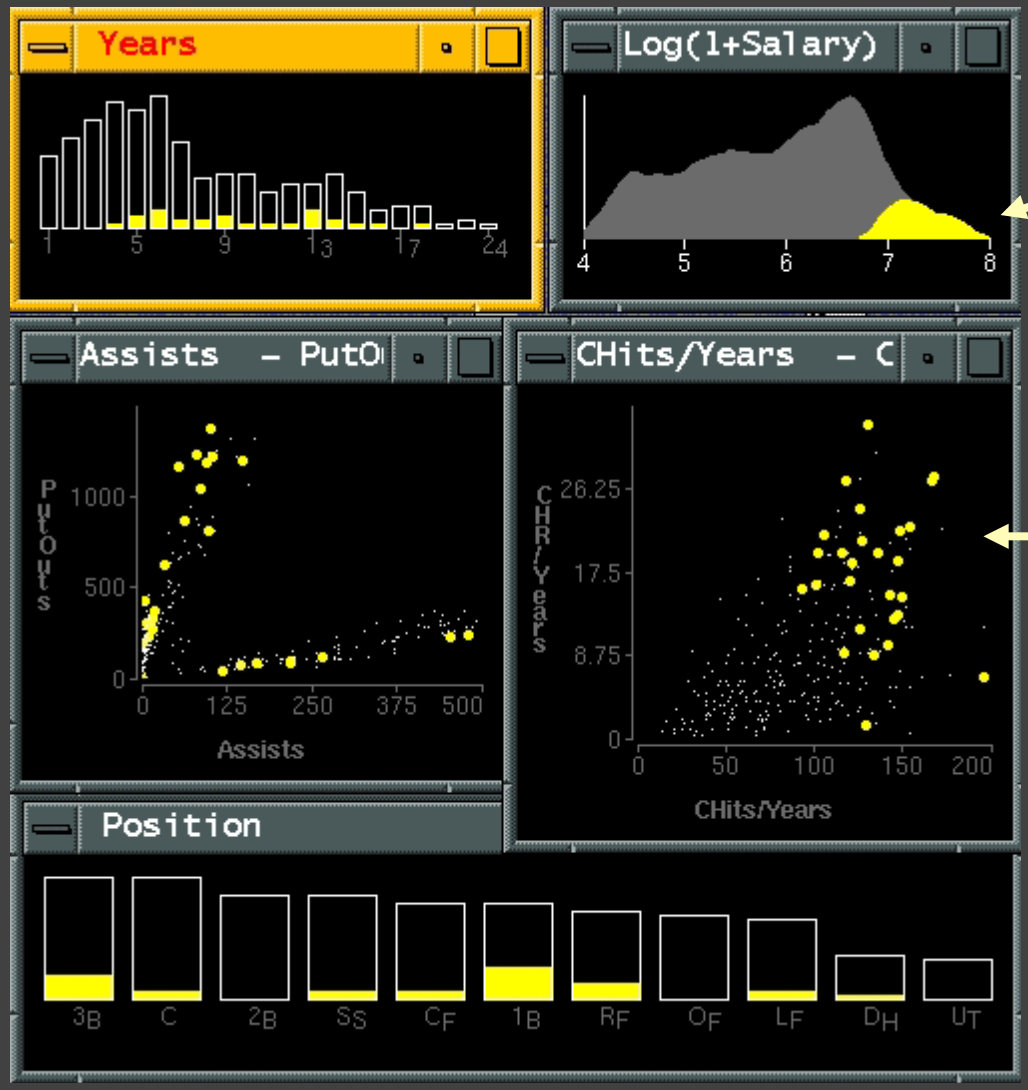
Baseball Statistics [Wills 95]



Baseball Statistics [Wills 95]



Baseball Statistics [Wills 95]

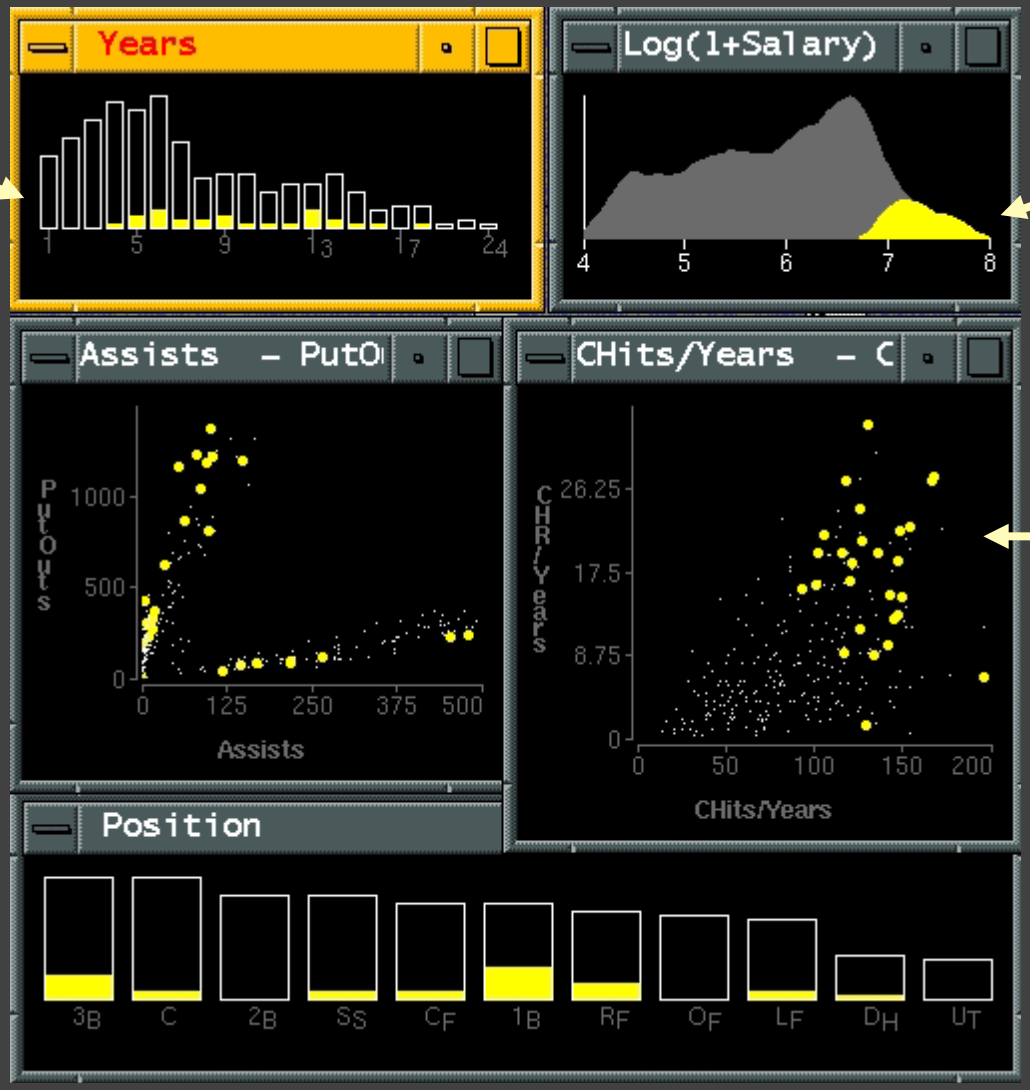


select high salaries

avg career HRs vs avg career hits (batting ability)

Baseball Statistics [Wills 95]

how long in majors

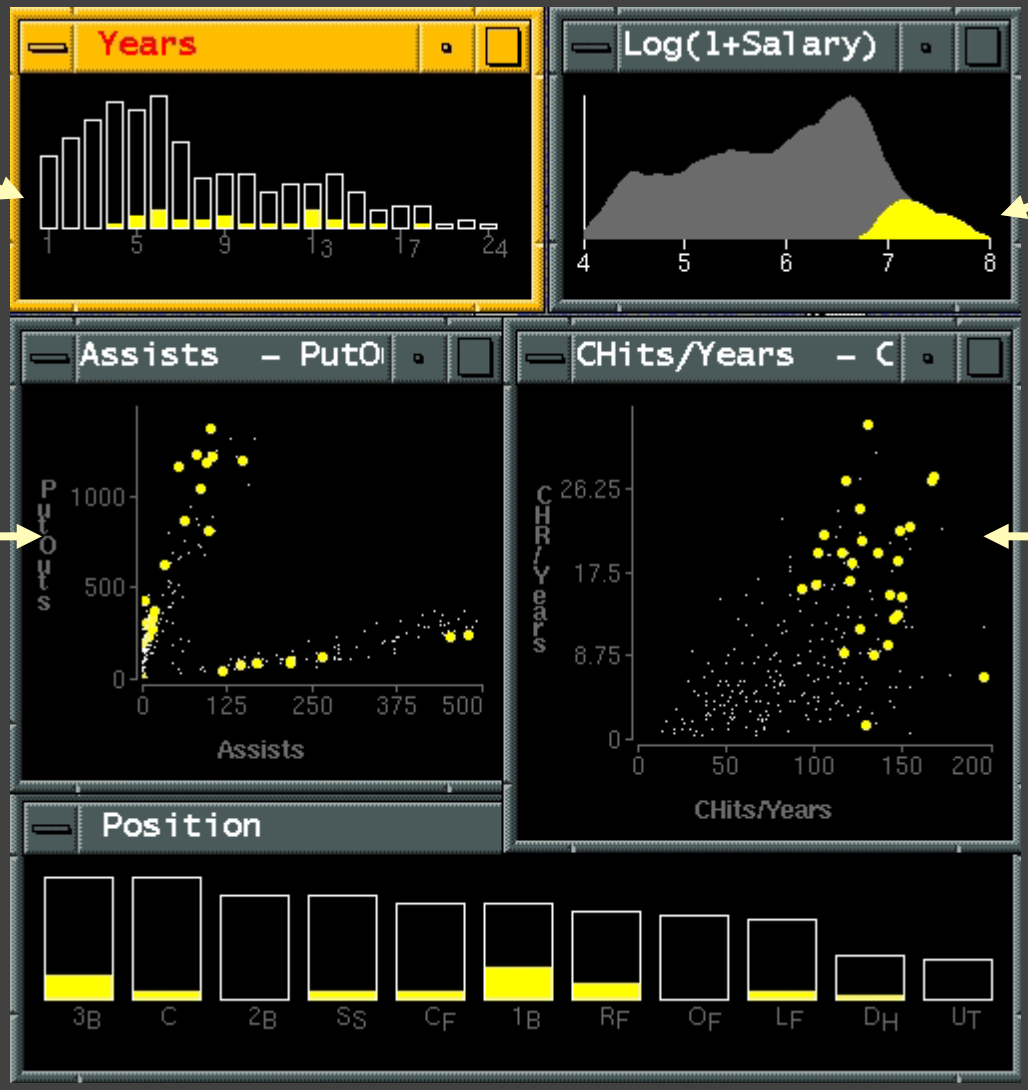


select high salaries

avg career HRs vs avg career hits (batting ability)

Baseball Statistics [Wills 95]

how long in majors



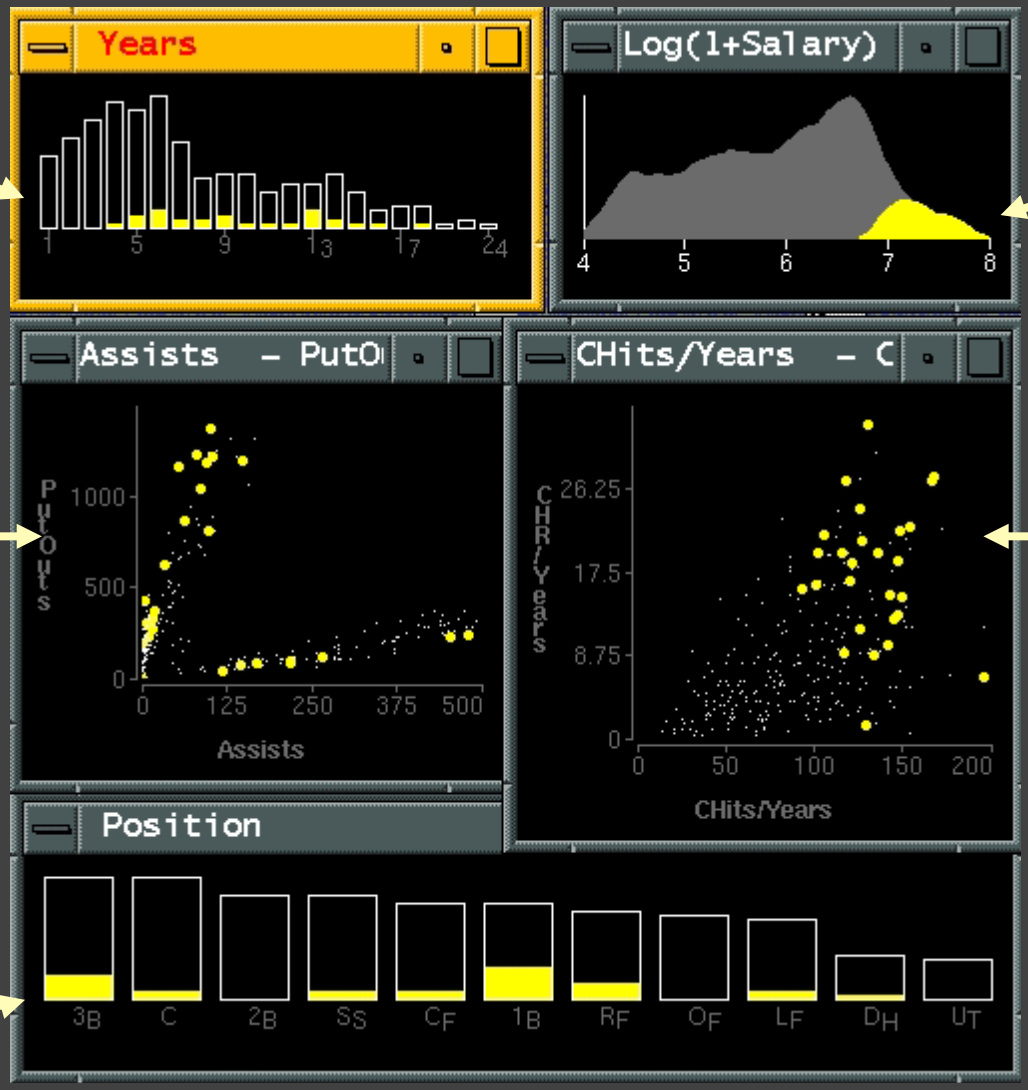
select high salaries

avg assists vs avg putouts (fielding ability)

avg career HRs vs avg career hits (batting ability)

Baseball Statistics [Wills 95]

how long in majors



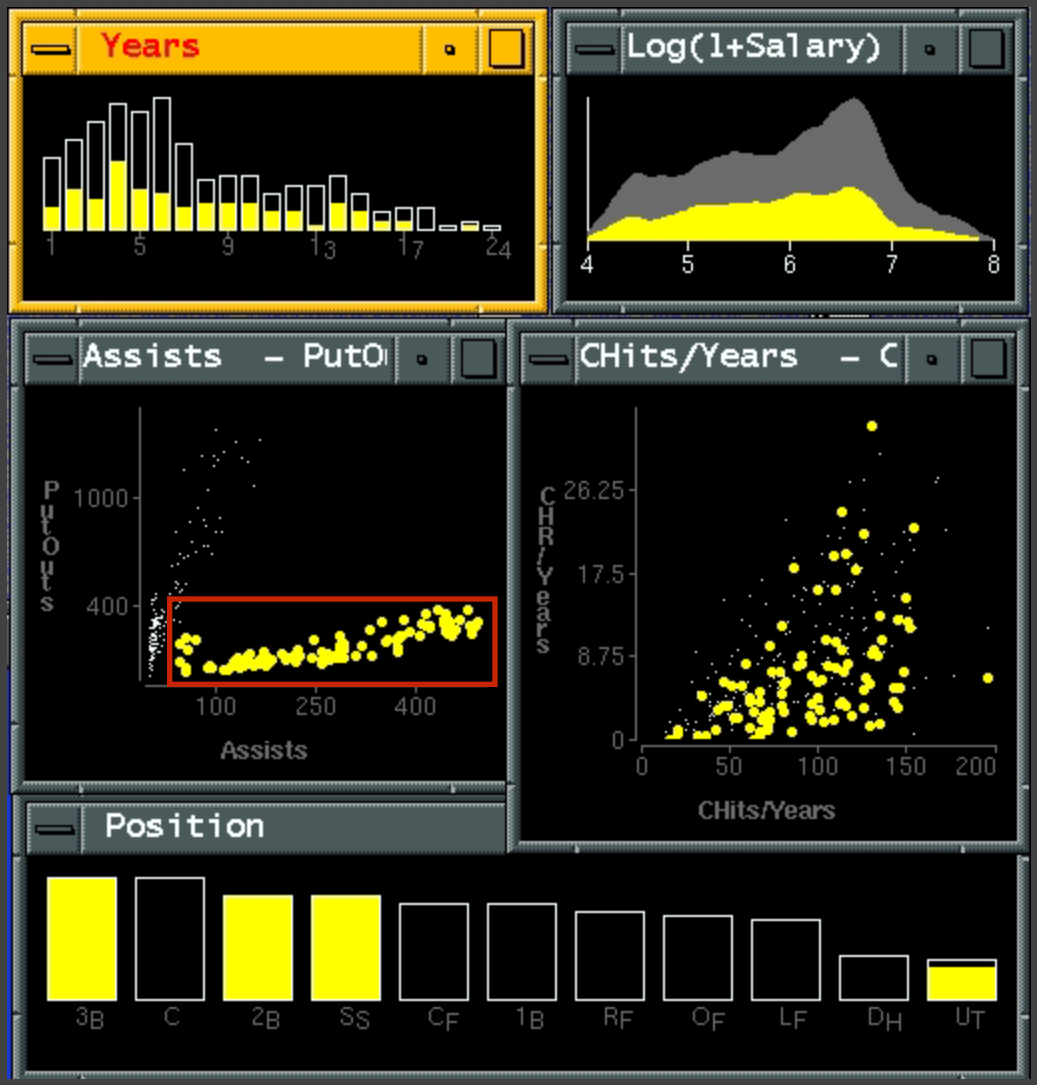
select high salaries

avg assists vs avg putouts (fielding ability)

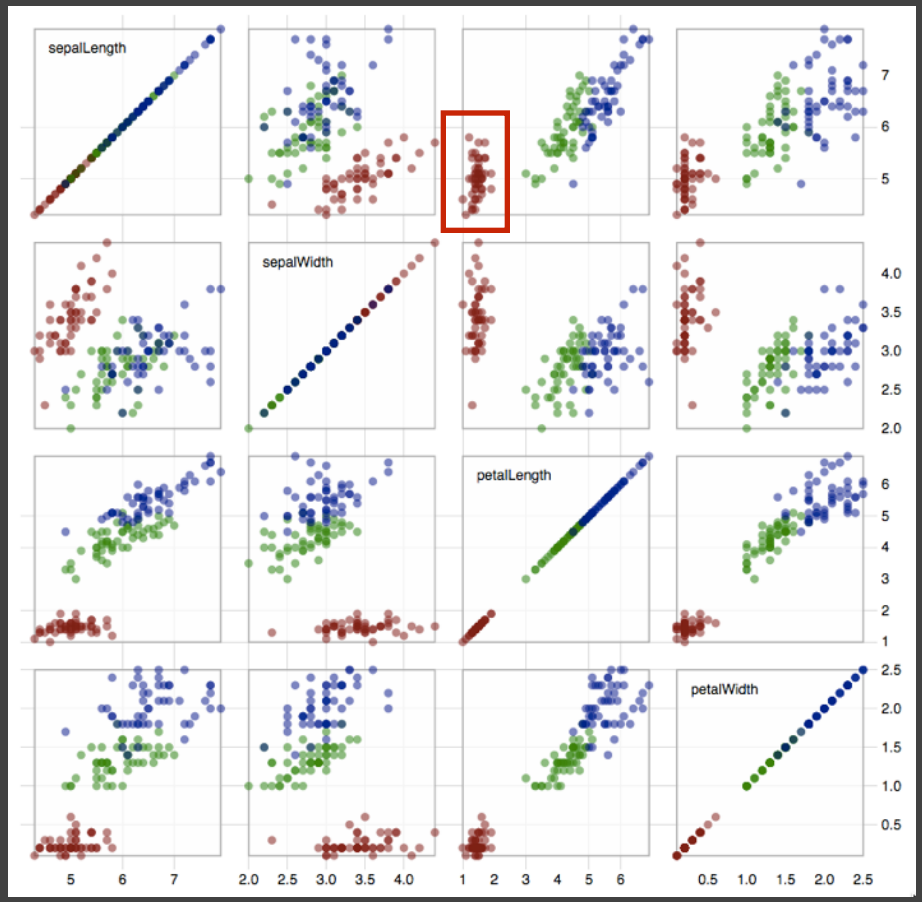
avg career HRs vs avg career hits (batting ability)

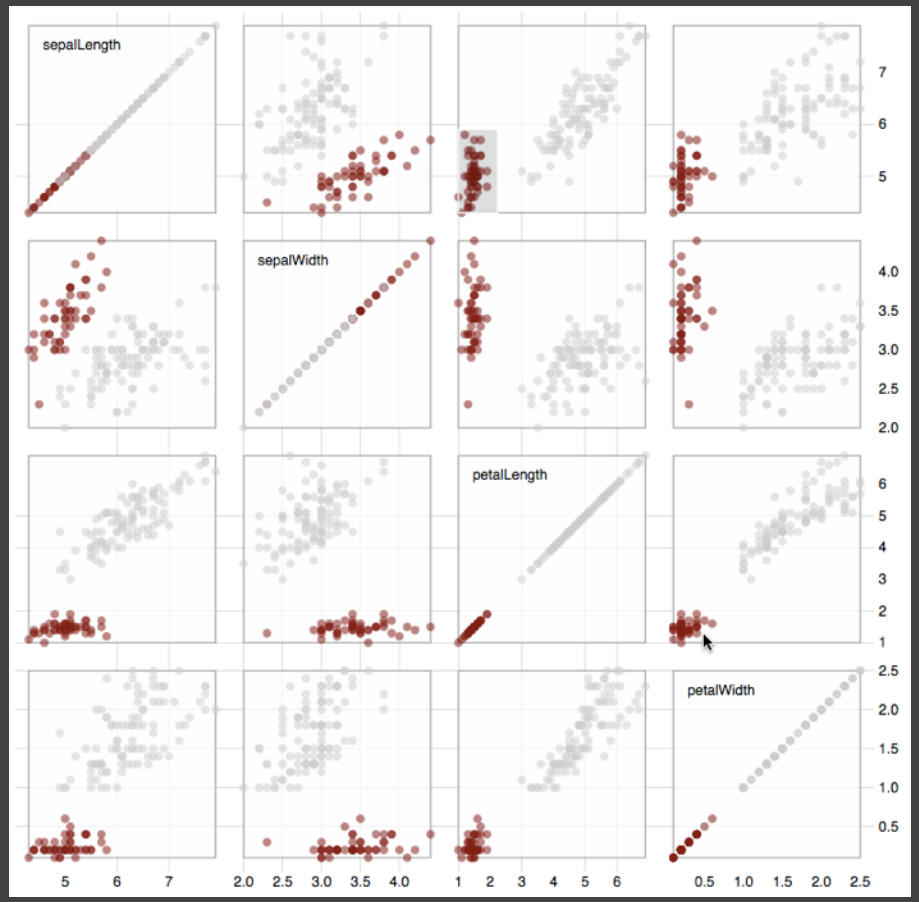
distribution of positions played

Linking Assists to Positions

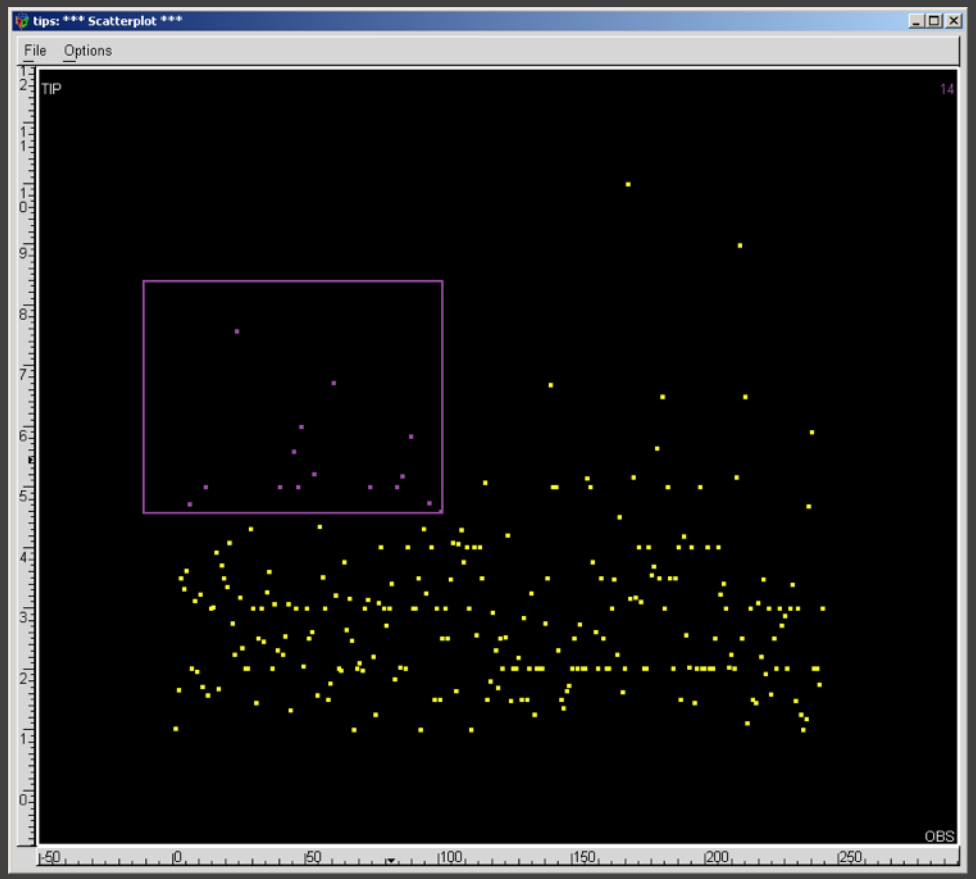


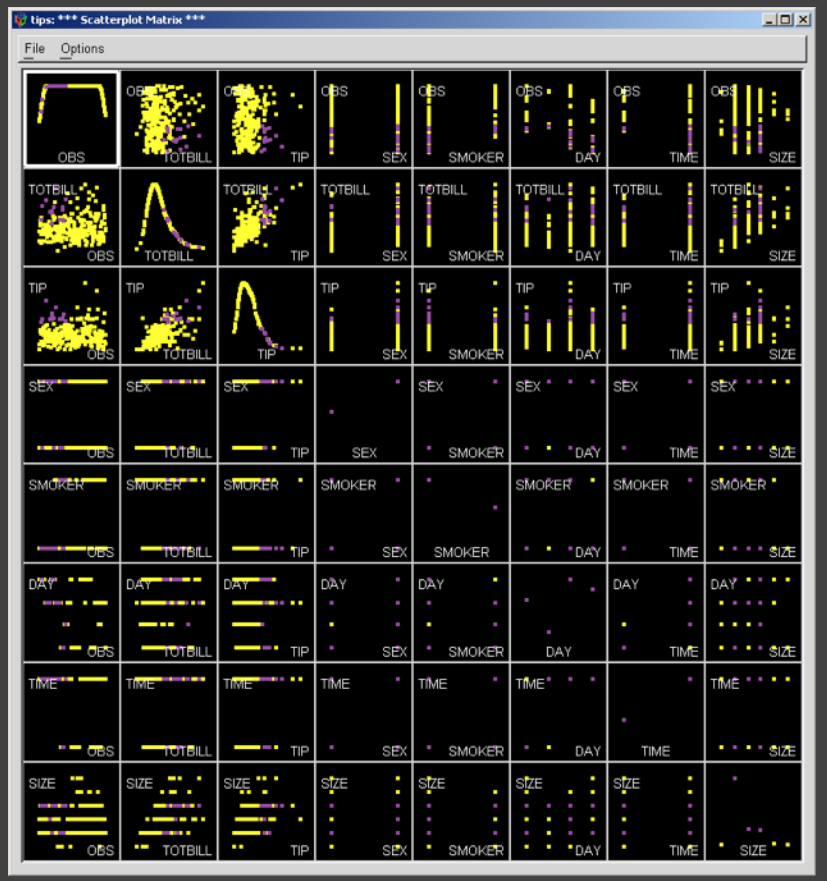
Brushing Scatterplots





Brushing in GGobi





http://www.ggobi.org/

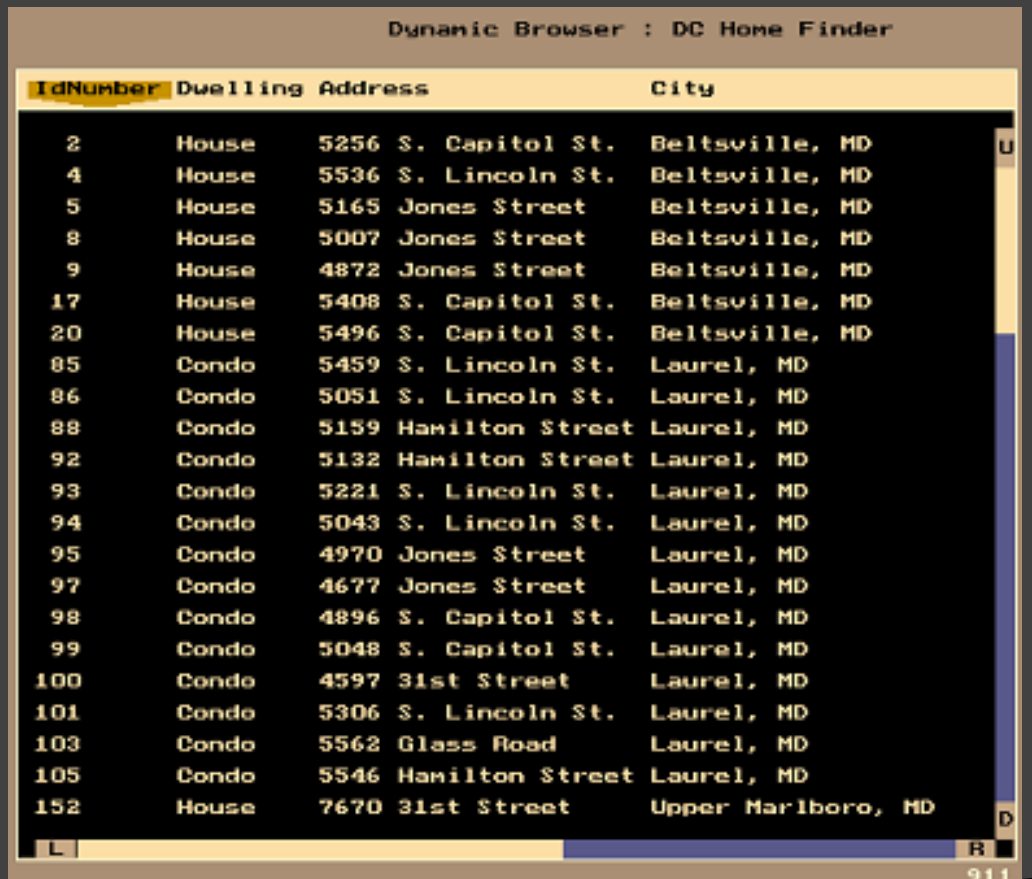
Dynamic Queries

Query & Results

SELECT house FROM seattle_homes

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

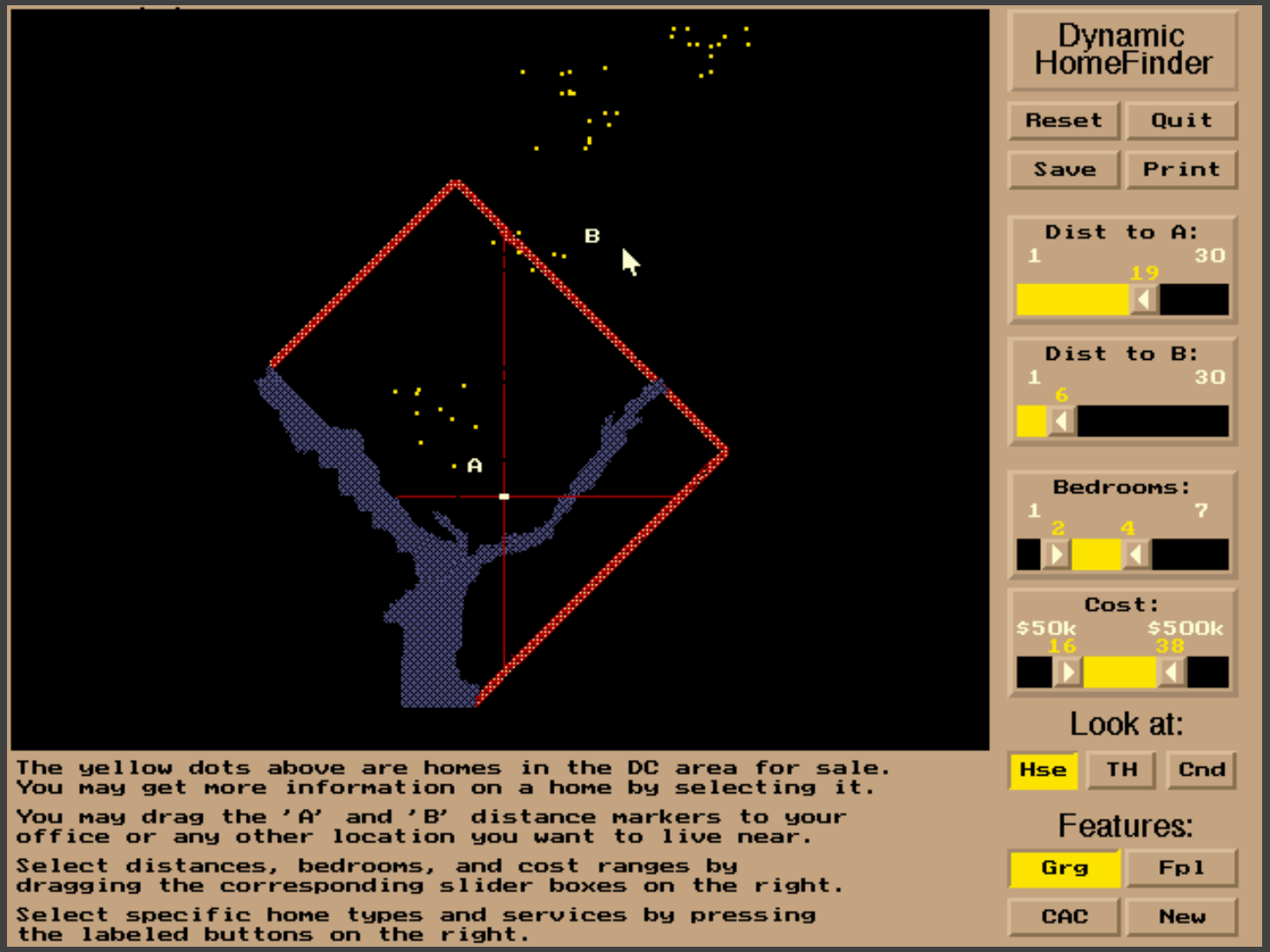
ORDER BY price



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

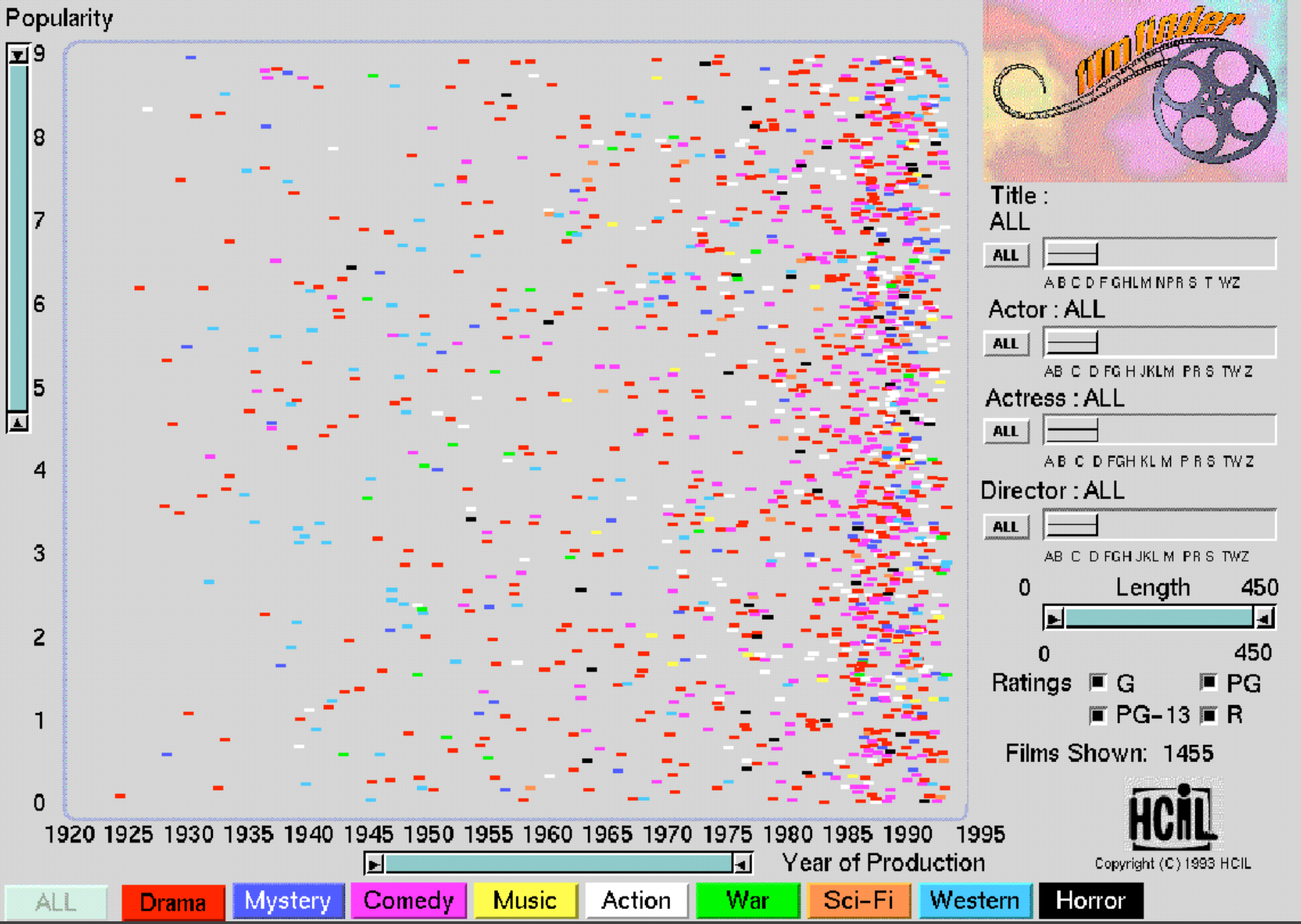
HomeFinder



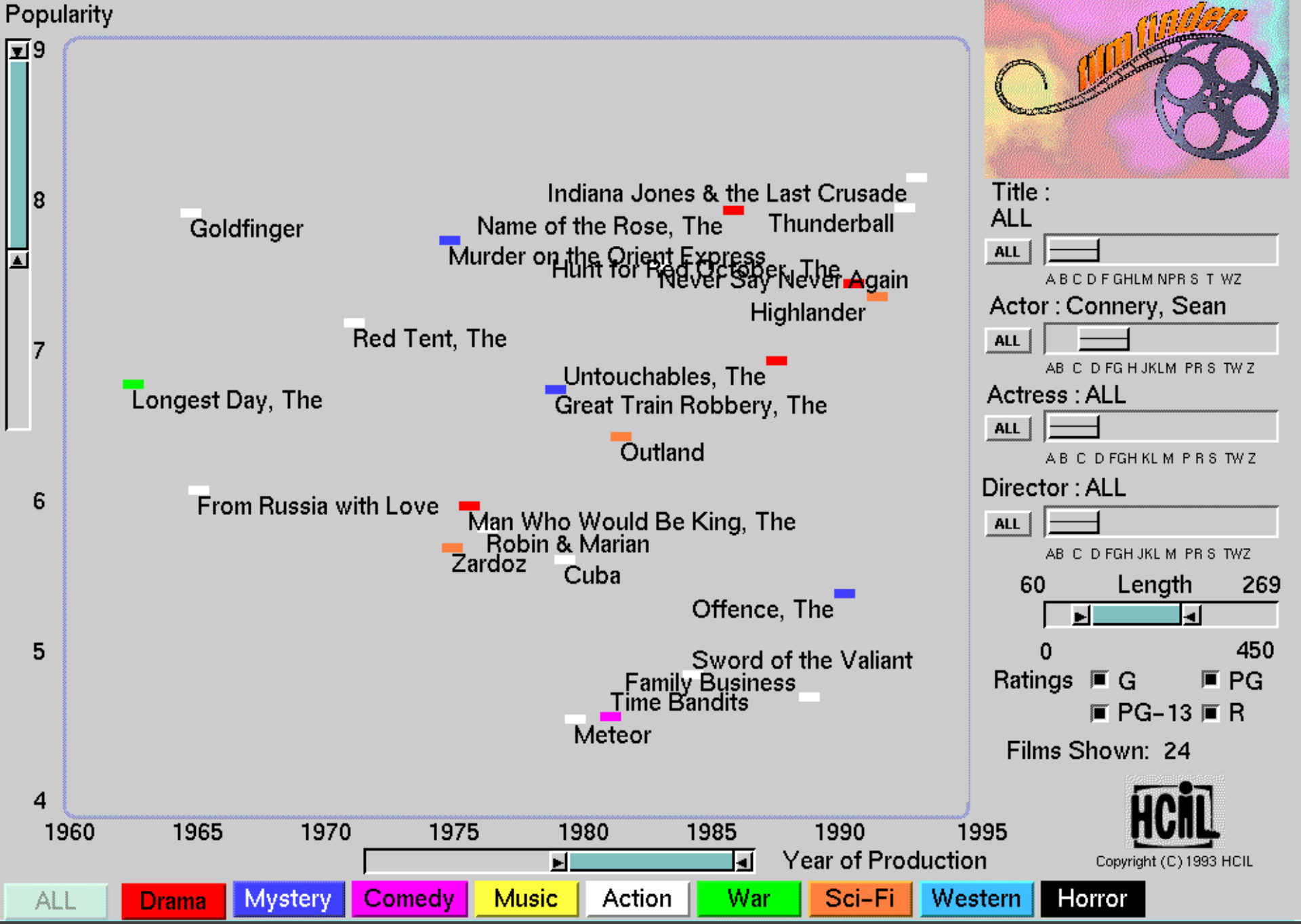
[Williamson and Shneiderman 92]

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

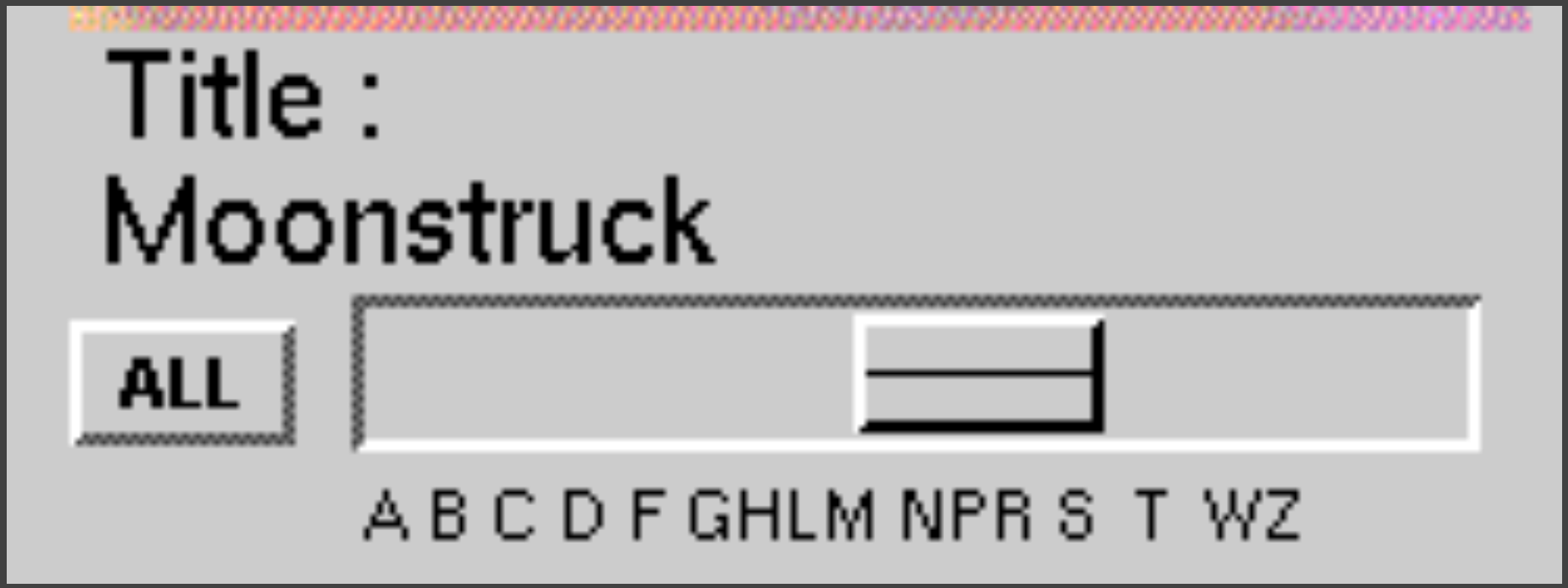


[Ahlberg and Shneiderman 94]

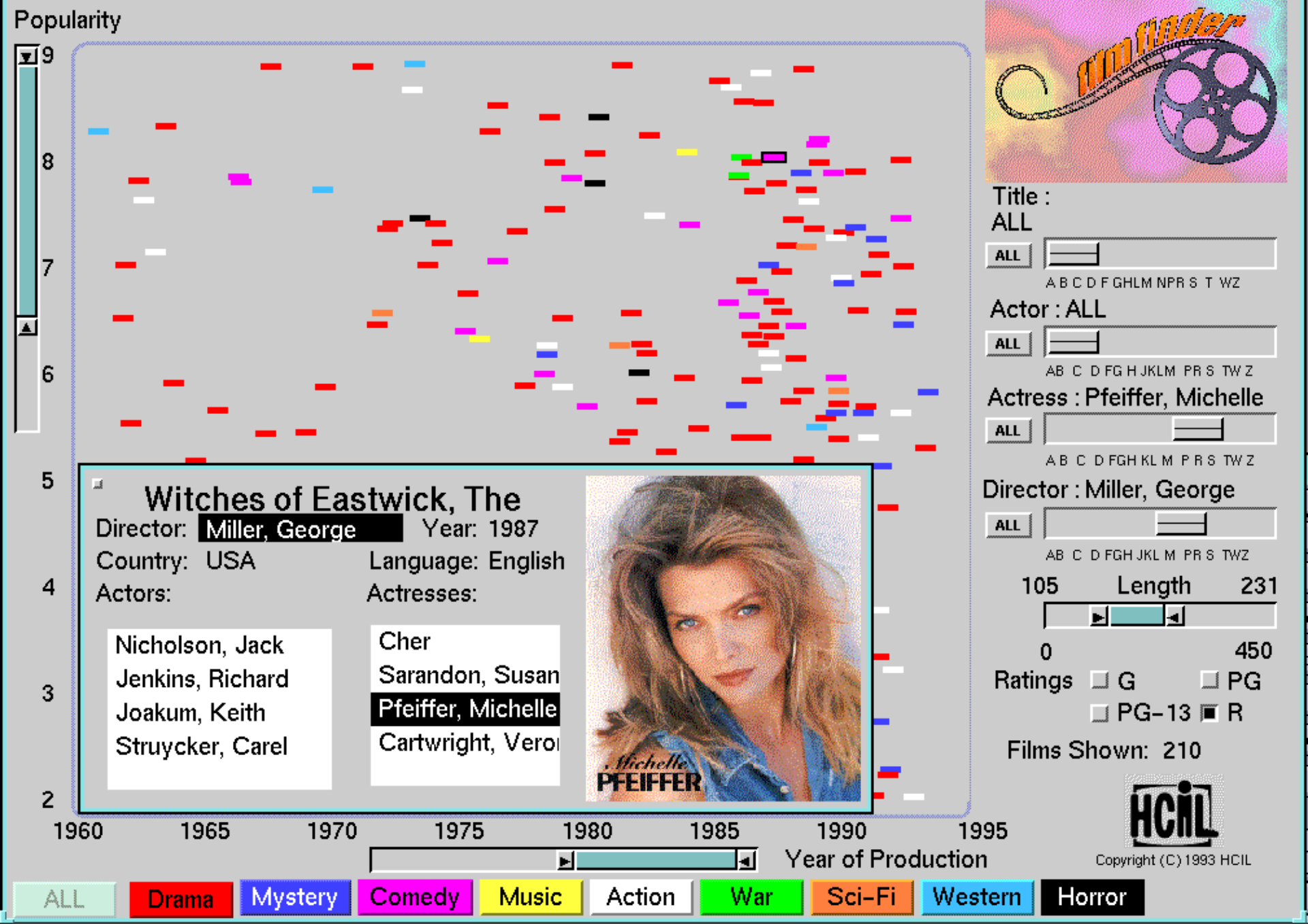


[Ahlberg and Shneiderman 94]

Alphaslider



[Ahlberg and Shneiderman 94]



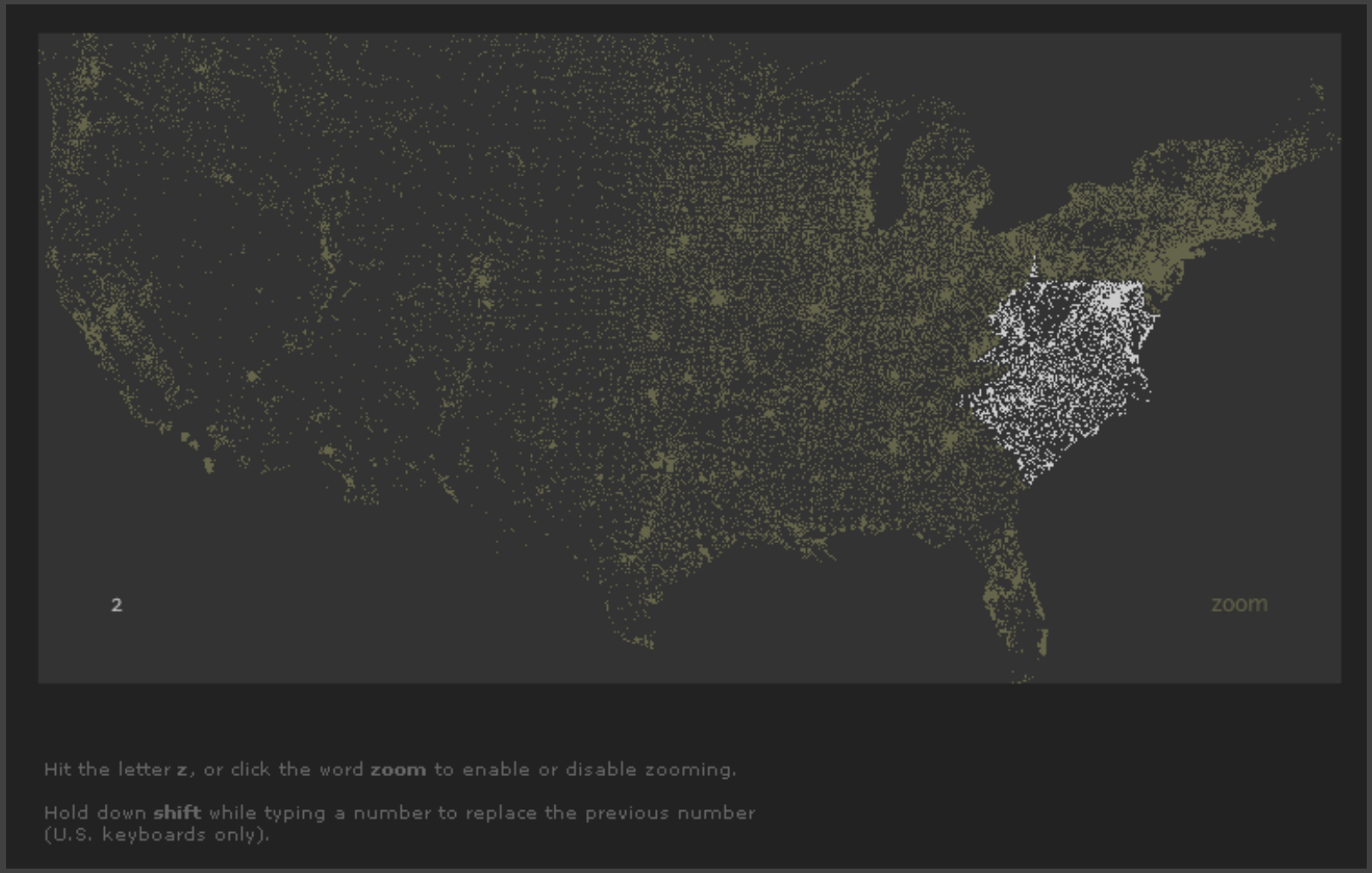
[Ahlberg and Shneiderman 94]

- The Attribute Explorer

Attribute Explorer [Spence & Tweedie 96]

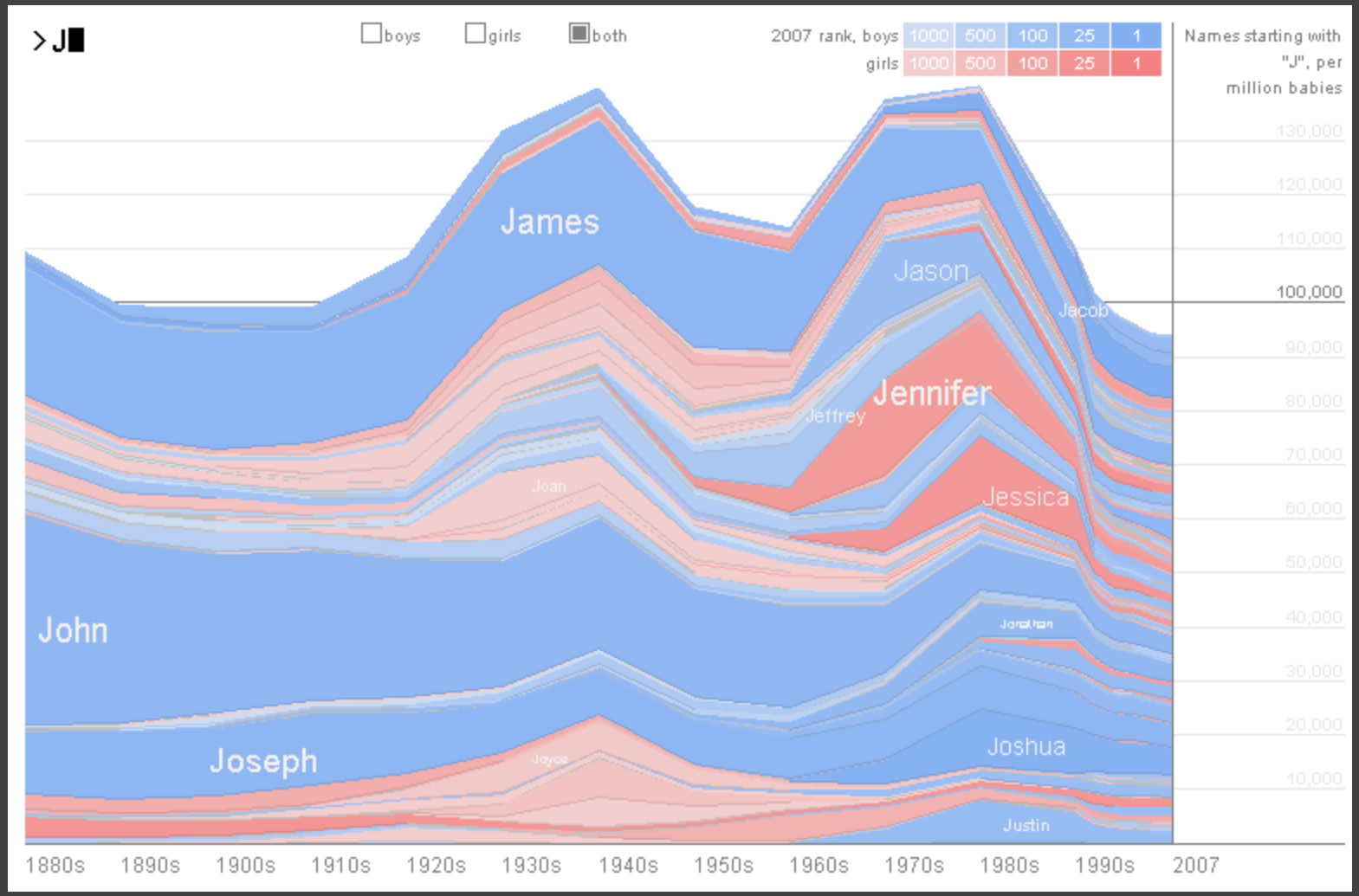
- Video Clip

Zipdecode [Fry 04]



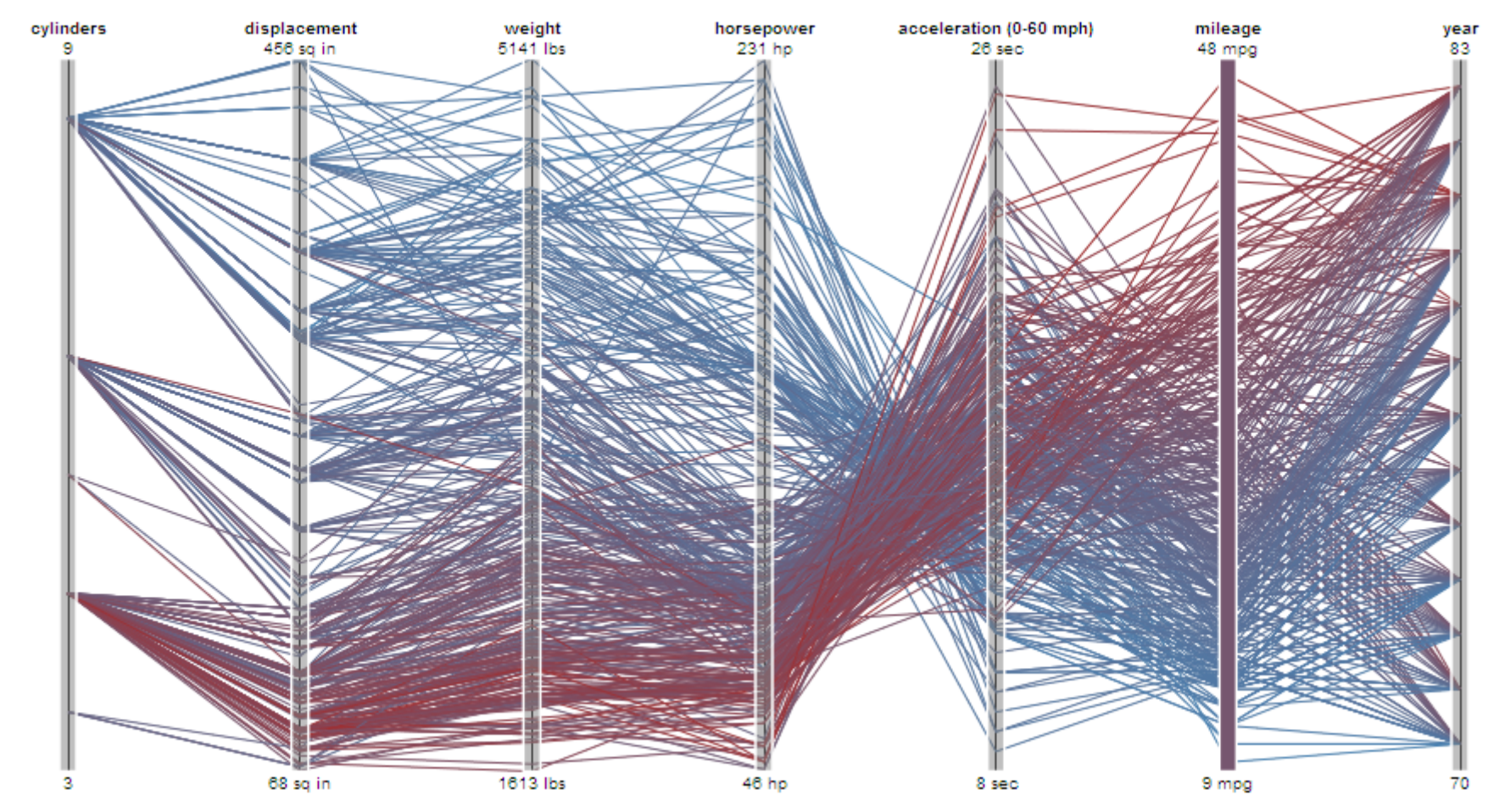
http://benfry.com/zipdecode/

NameVoyager [Wattenberg 06]

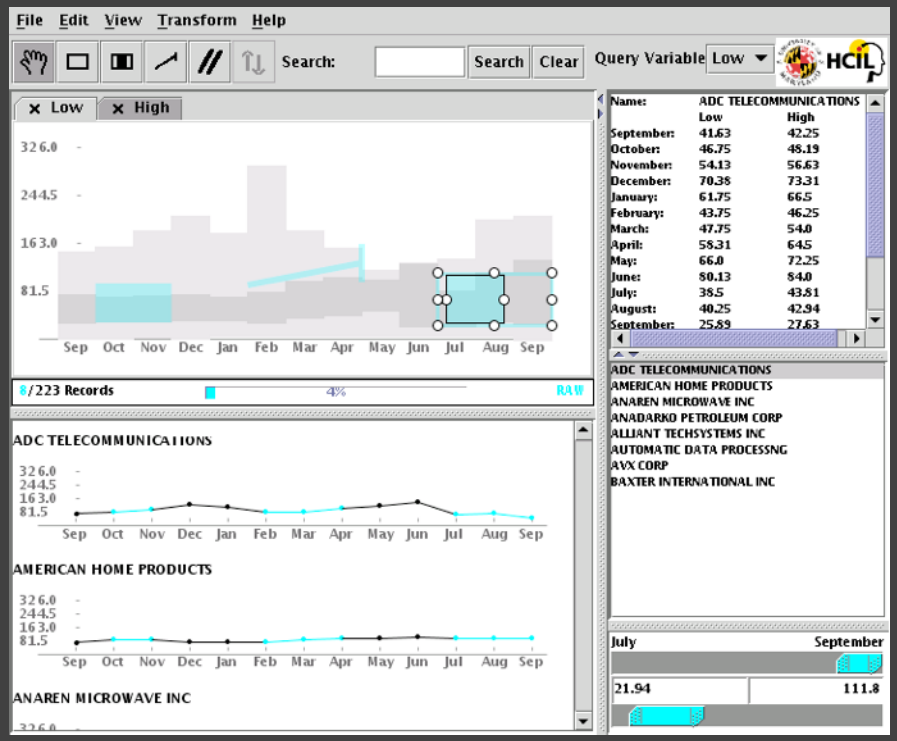


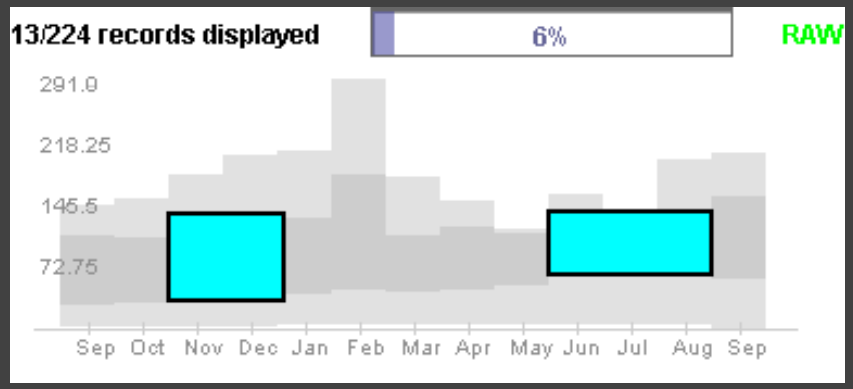
http://www.babynamewizard.com/voyager

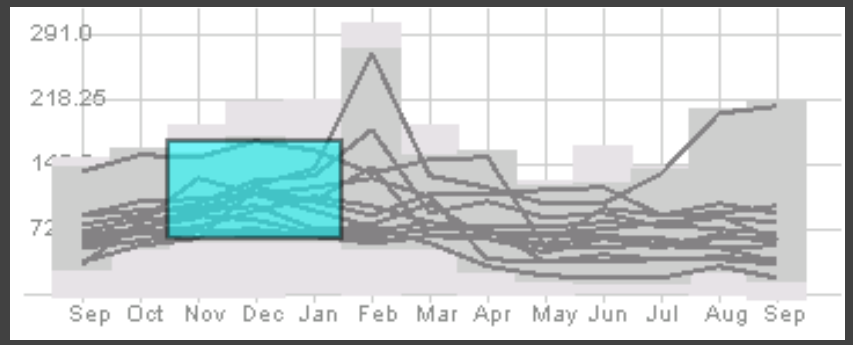
Parallel Coordinates [Inselberg]



TimeSearcher [Hocheiser 02]

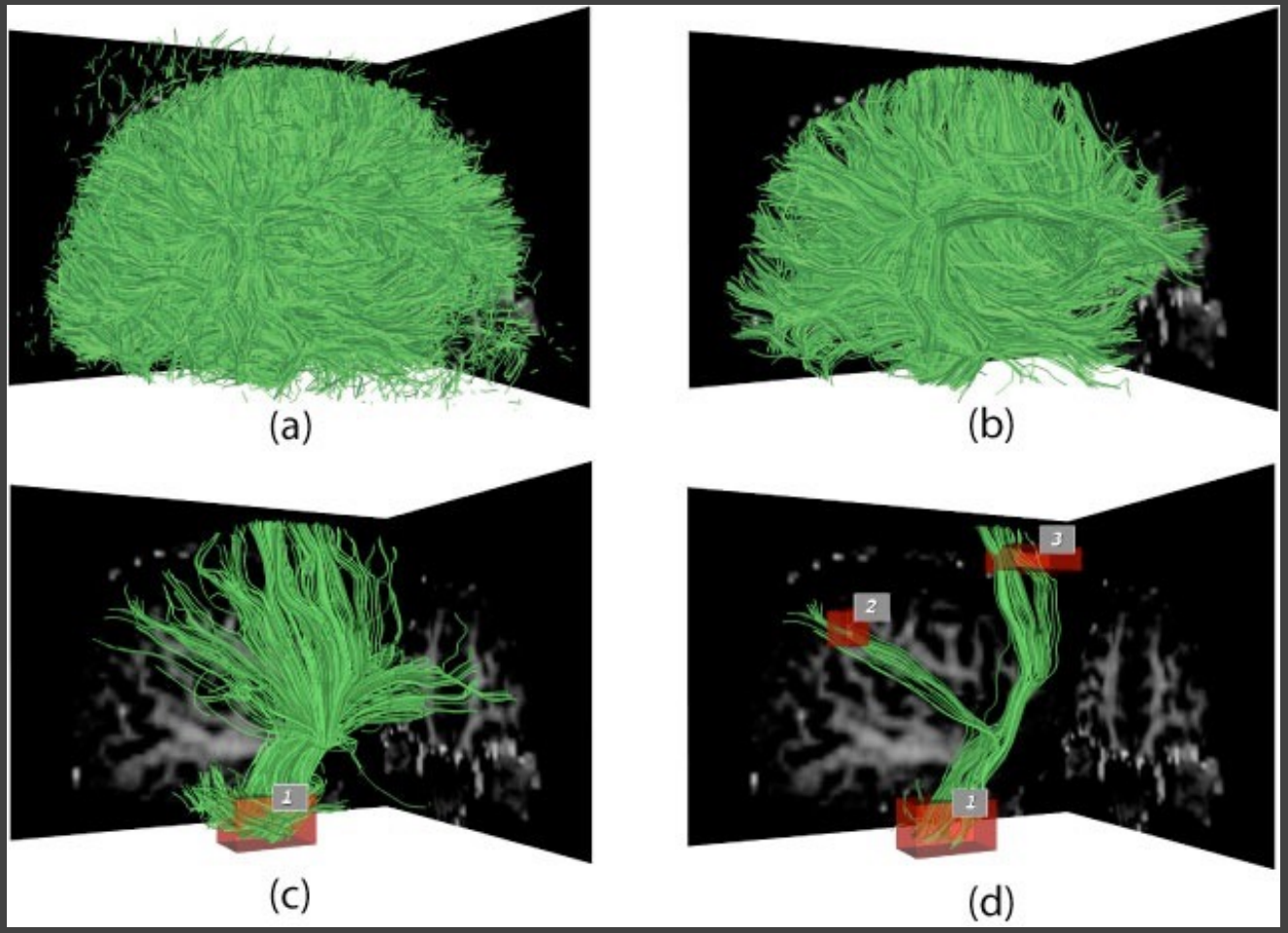




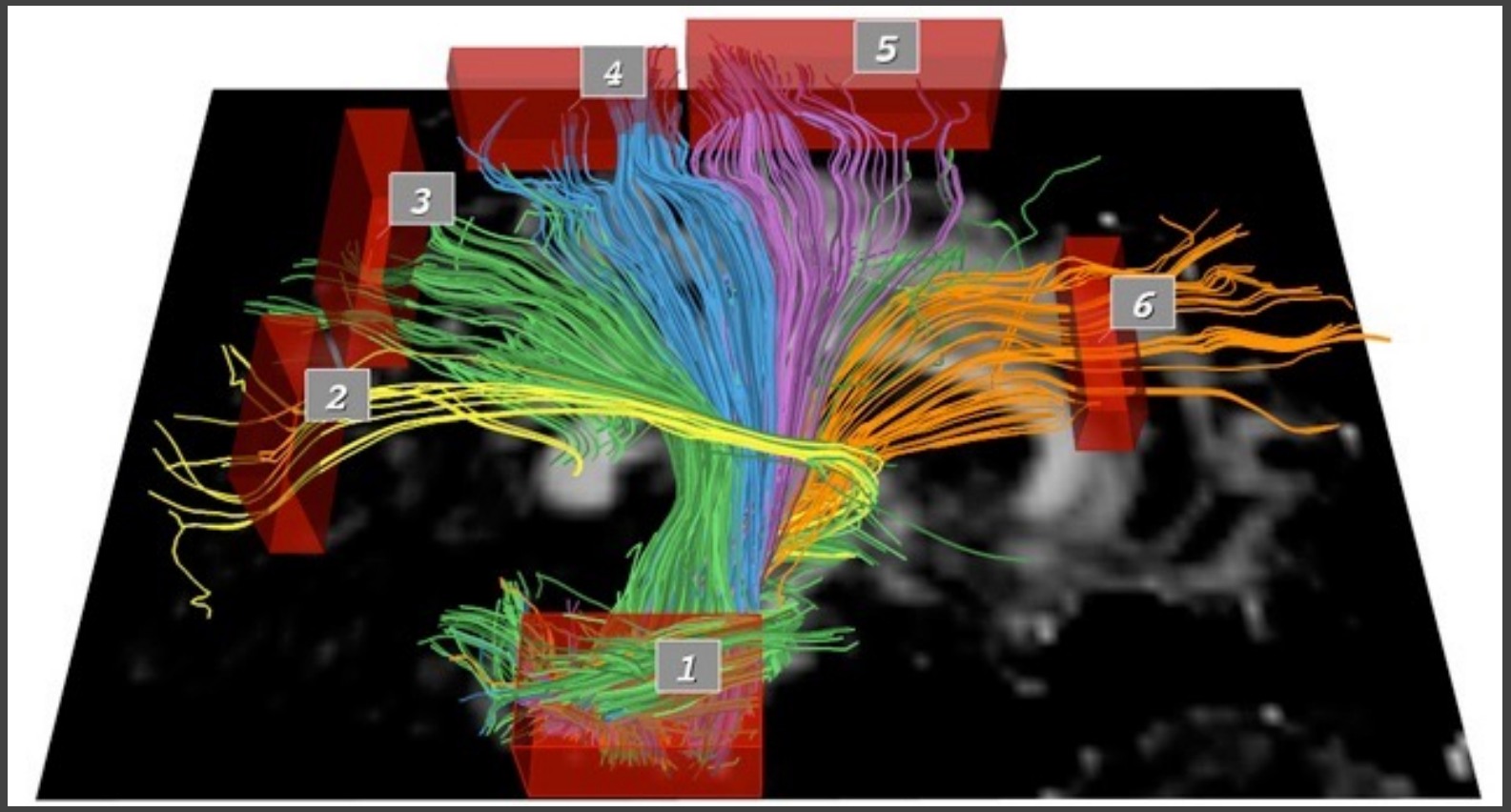


Builds on Wattenberg's [2001] idea for sketch-based queries of time-series data.

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

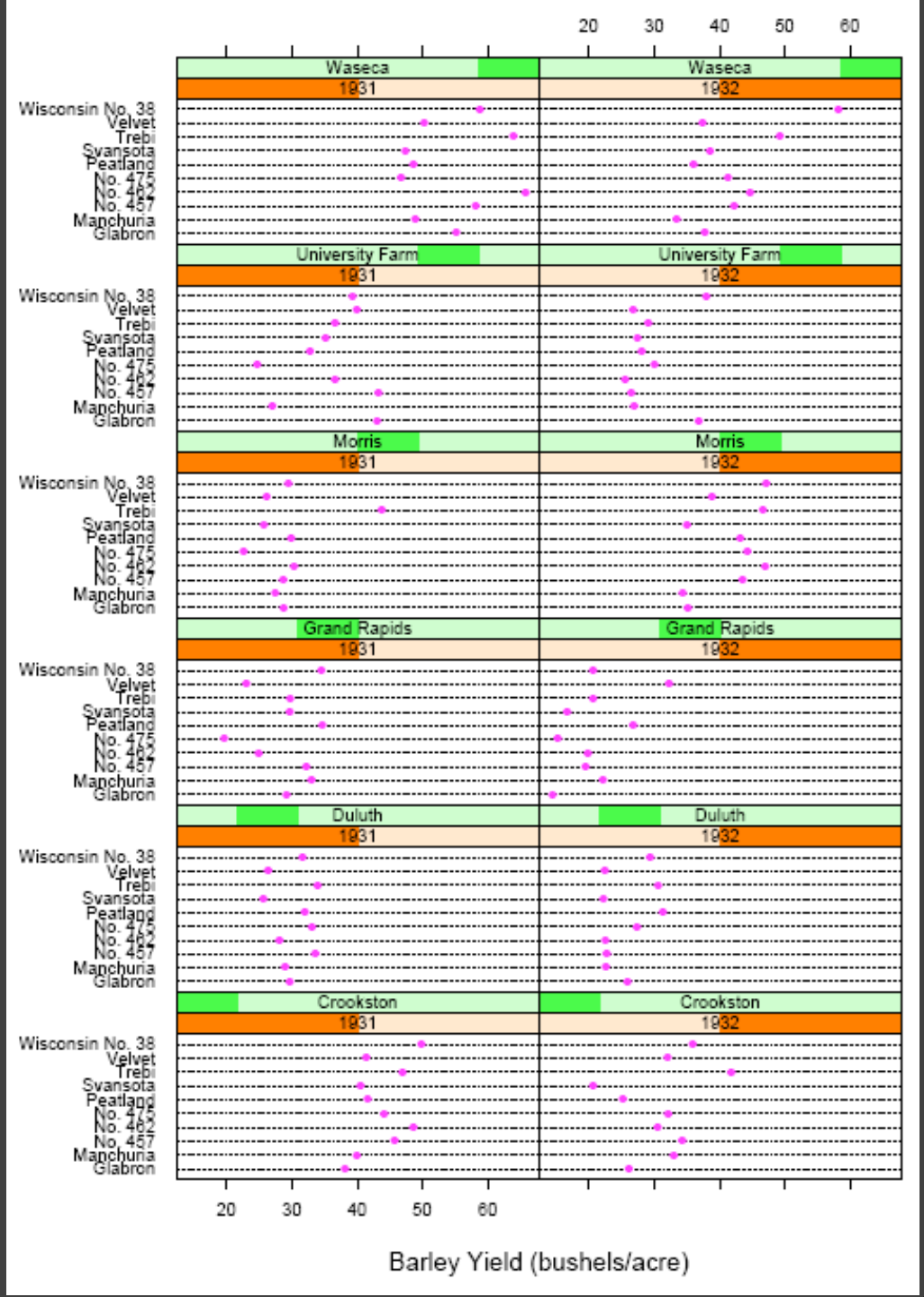
Amount of data shown limited by screen space

Who would use these kinds of tools?

Sorting

Trellis Display

[Becker, Cleveland, and Shyu 96]

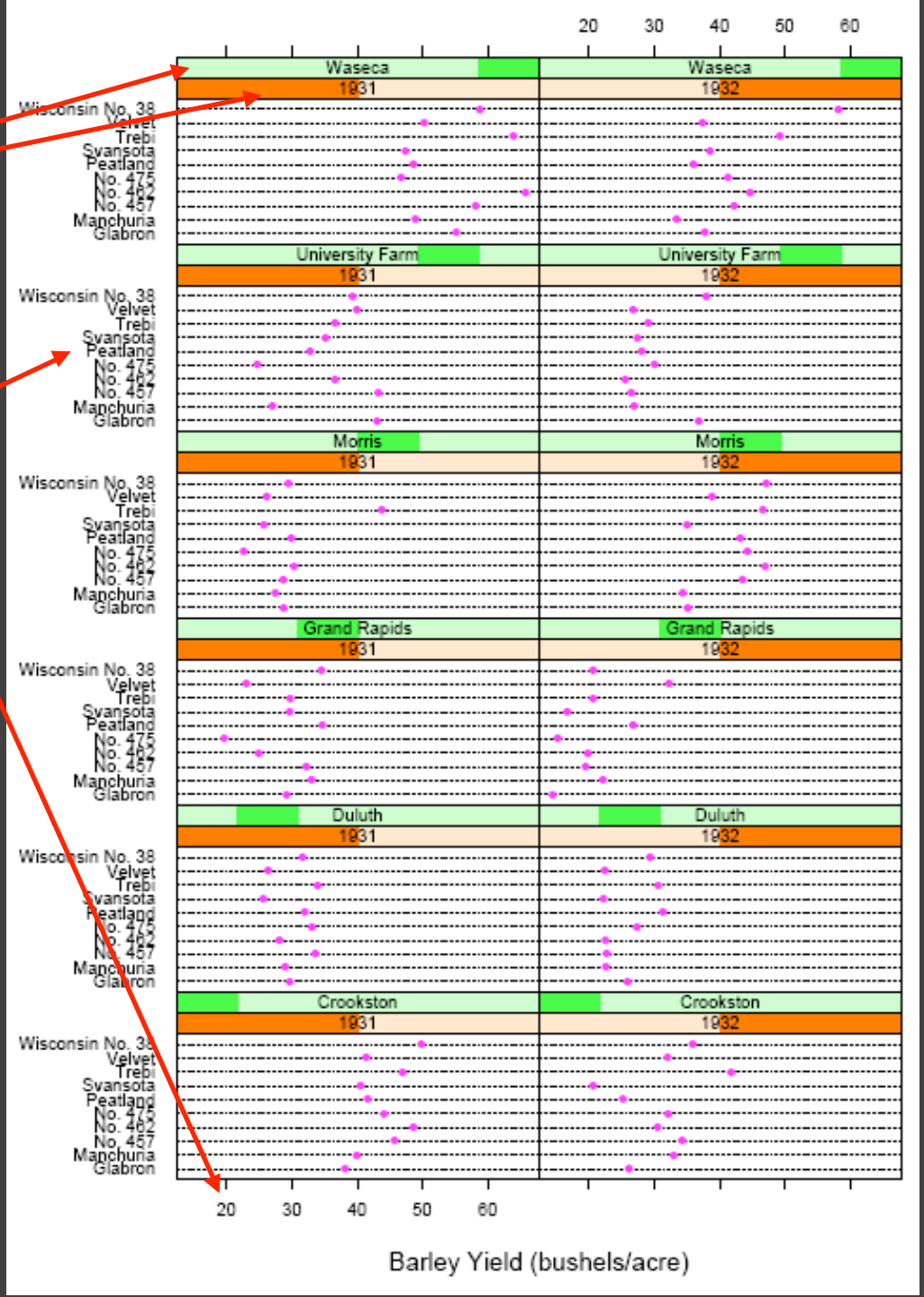


Condition variables

location, year

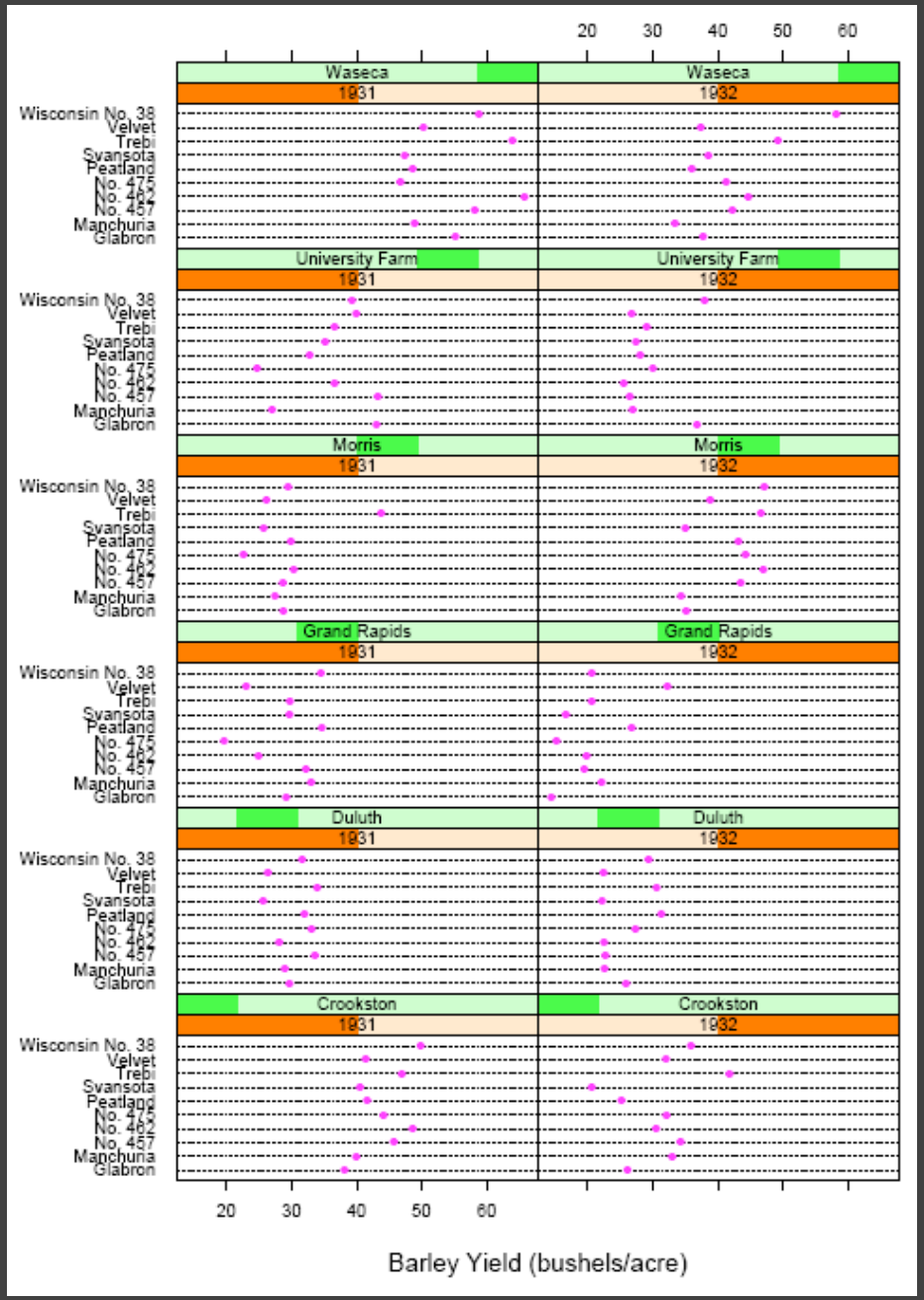
Panel variables

type, yield

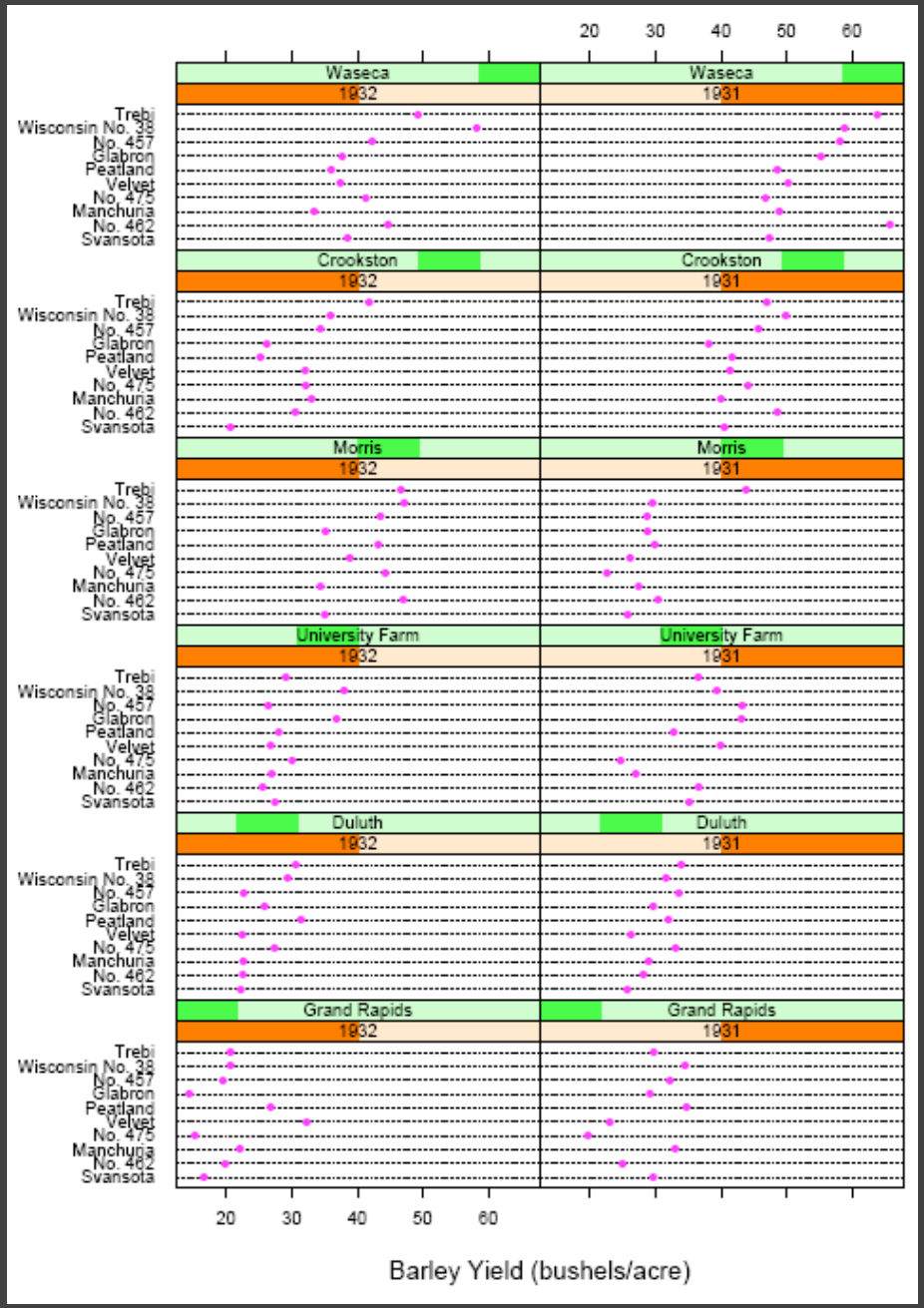


Trellis Display

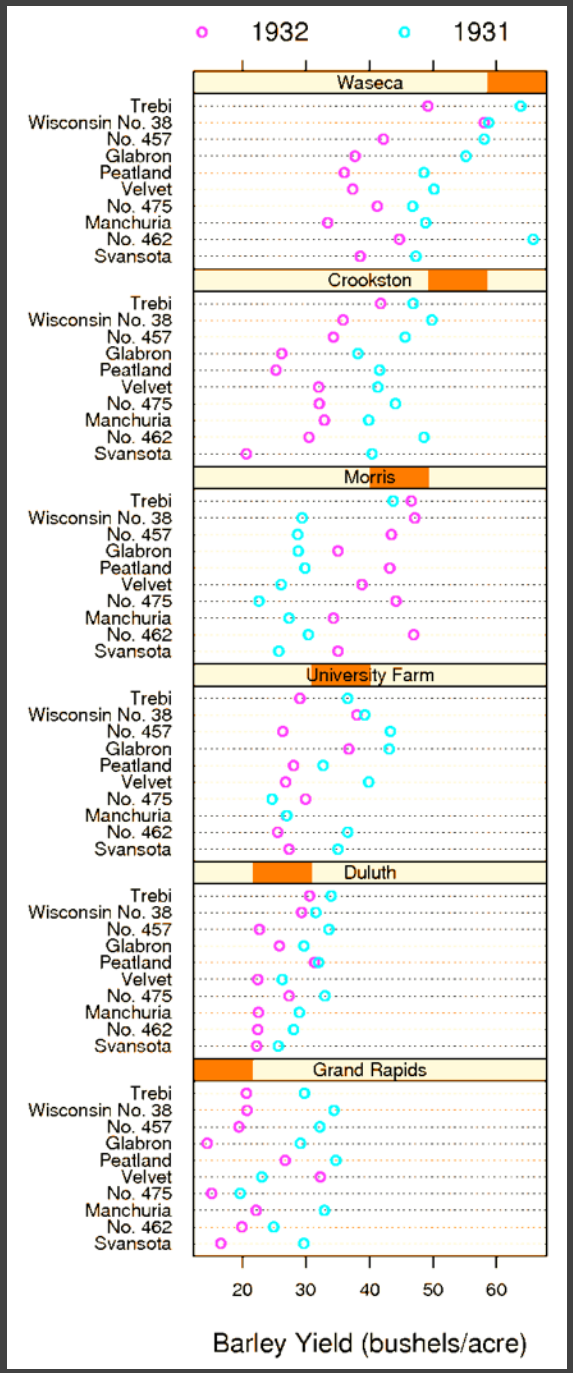
[Becker, Cleveland, and Shyu 96]



Alphabetical ordering



Main-effects ordering


1932
1931
Waseca
Trebi
Wisconsin No. 38
No. 457
Glabron
Peatland
Velvet
No. 475
Manchuria
No. 462
Svansota
Crookston
Trebi
Wisconsin No. 38
No. 457
Glabron
Peatland
Velvet
No. 475
Manchuria
No. 462
Svansota
Morris
Trebi
Wisconsin No. 38
No. 457
Glabron
Peatland
Velvet
No. 475
Manchuria
No. 462
Svansota
University Farm
Trebi
Wisconsin No. 38
No. 457
Glabron
Peatland
Velvet
No. 475
Manchuria
No. 462
Svansota
Duluth
Trebi
Wisconsin No. 38
No. 457
Glabron
Peatland
Velvet
No. 475
Manchuria
No. 462
Svansota
Grand Rapids
Trebi
Wisconsin No. 38
No. 457
Glabron
Peatland
Velvet
No. 475
Manchuria
No. 462
Svansota
20
30
40
50
60
Barley Yield (bushels/acre)

Graph Viewer

Graph Viewer

Roll-up by:

All

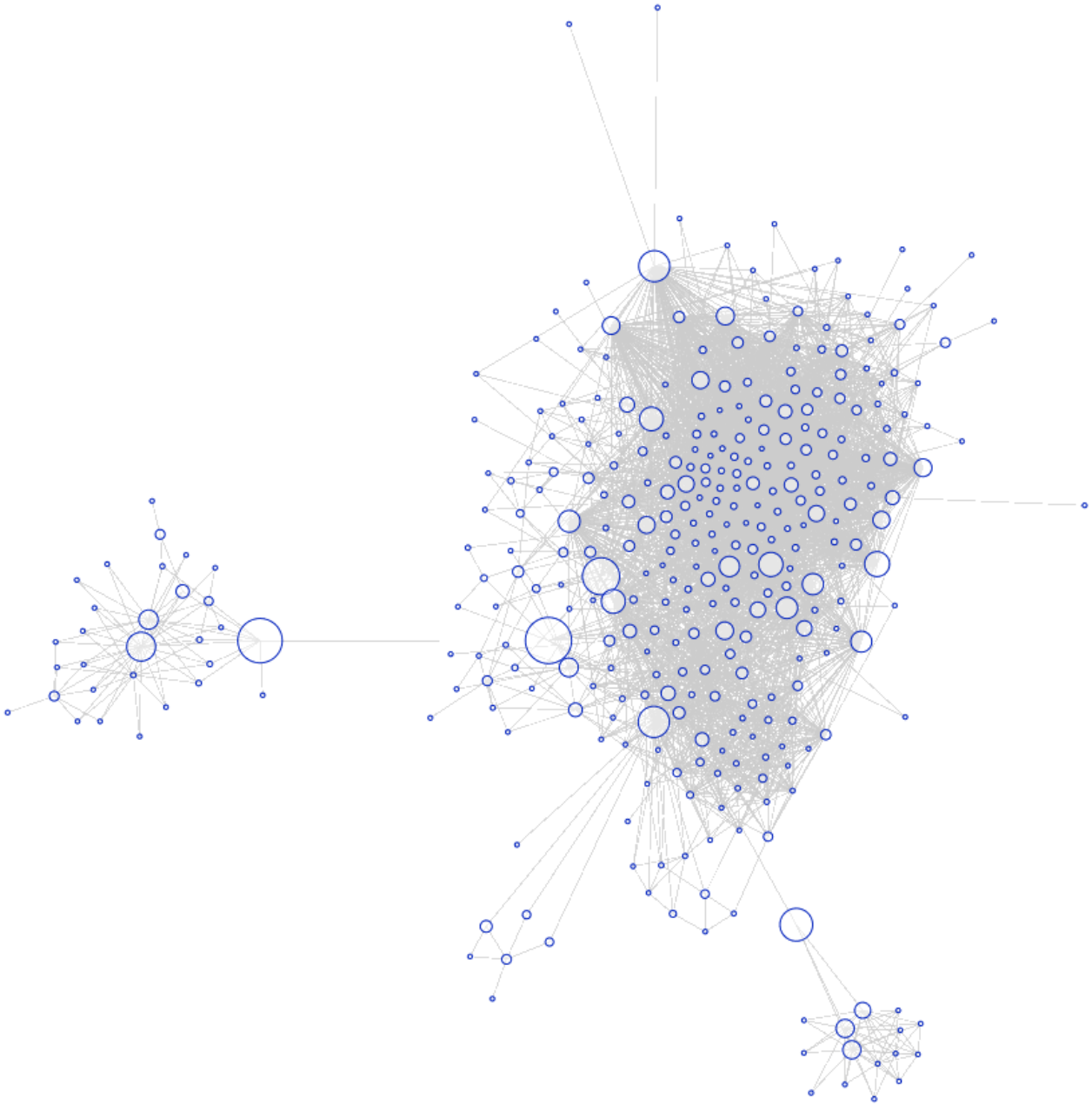
Visualization:

Node-Link

Sort by:

None

Edge centrality filters:



Images

Animate

Graph Viewer

Graph Viewer

Roll-up by:

All

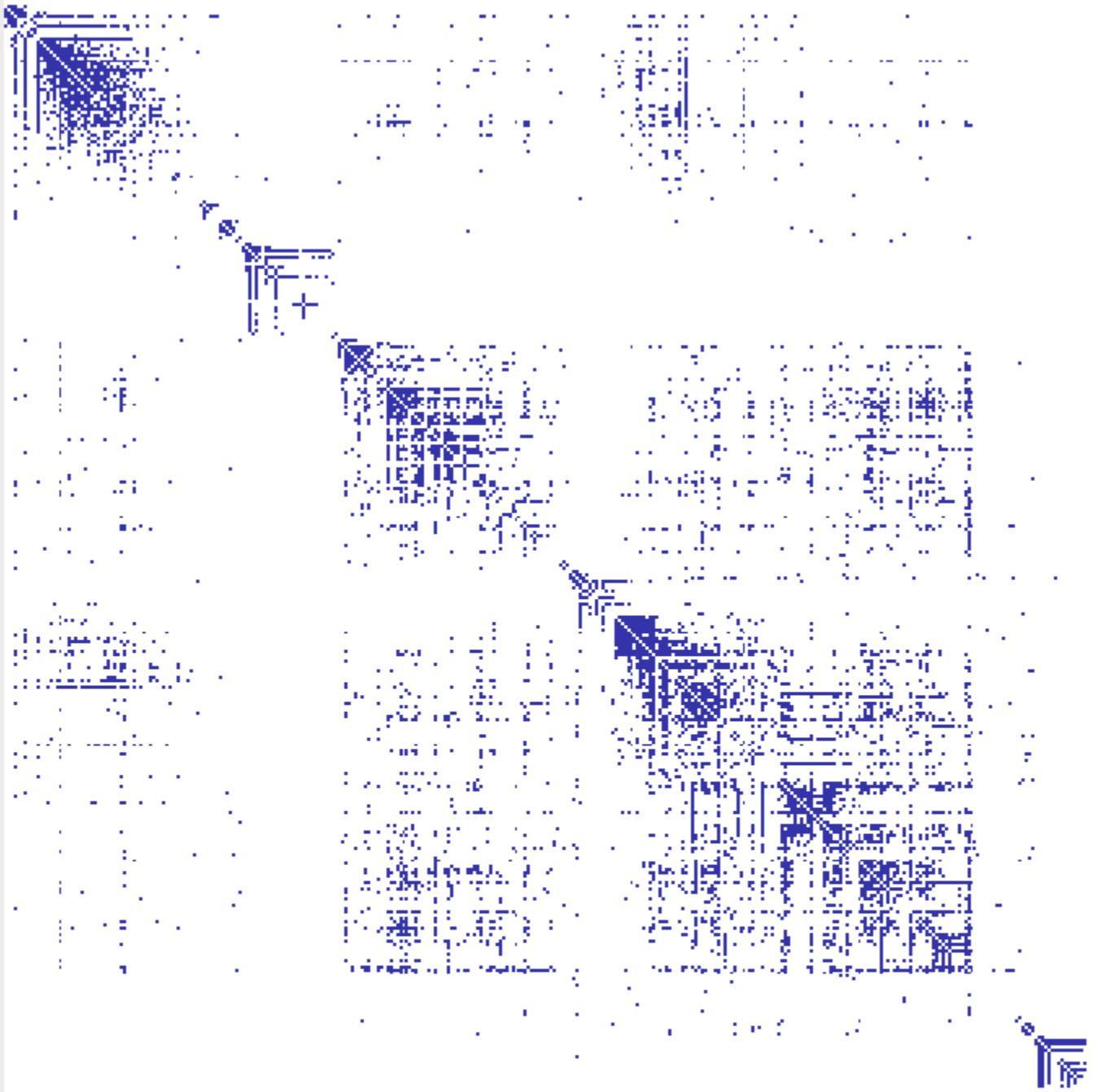
Visualization:

Matrix

Sort by:

Linkage

Edge centrality filters:



Graph Viewer

Graph Viewer

Roll-up by:

All

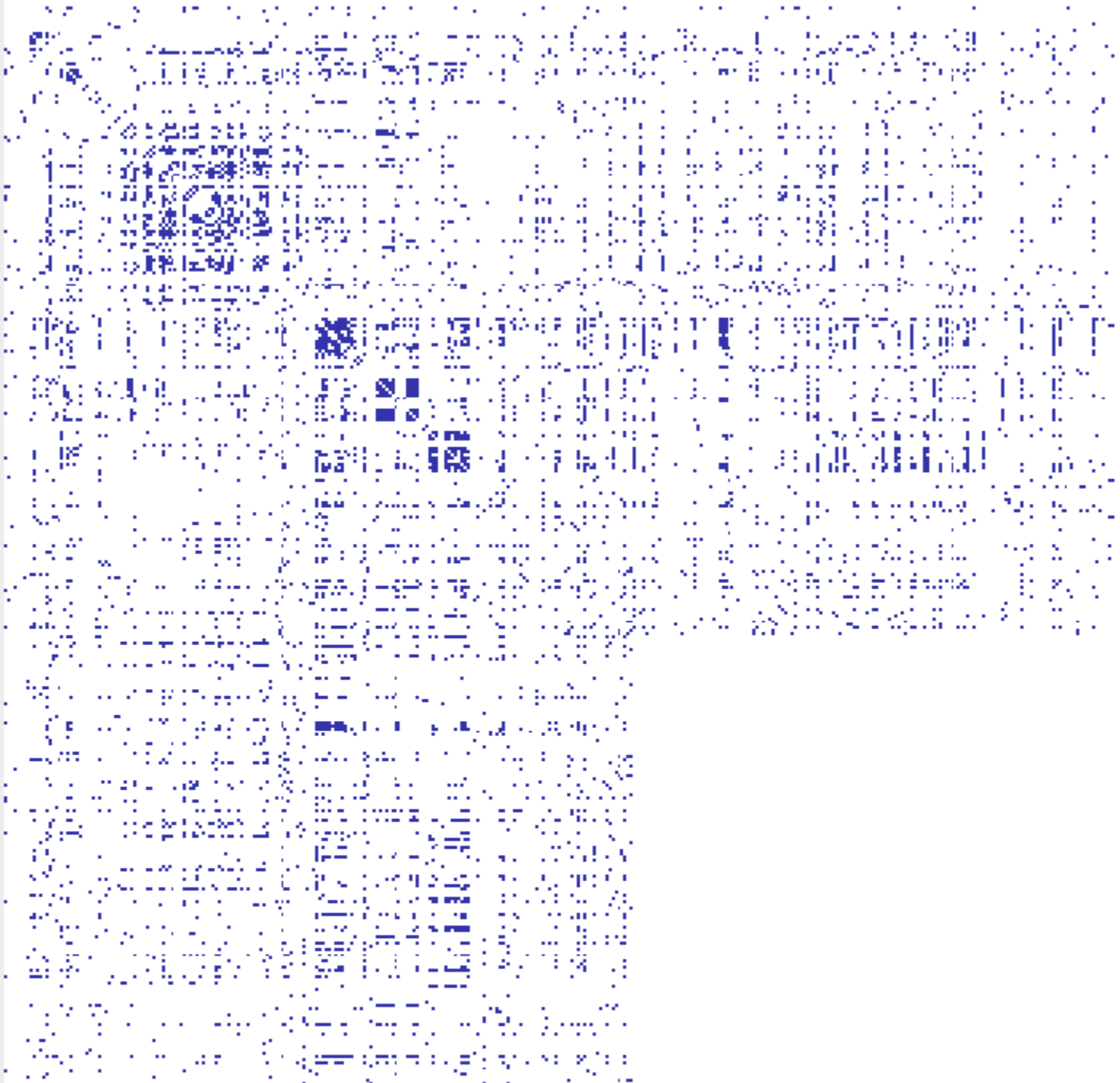
Visualization:

Matrix

Sort by:

None

Edge centrality filters:



Administrivia

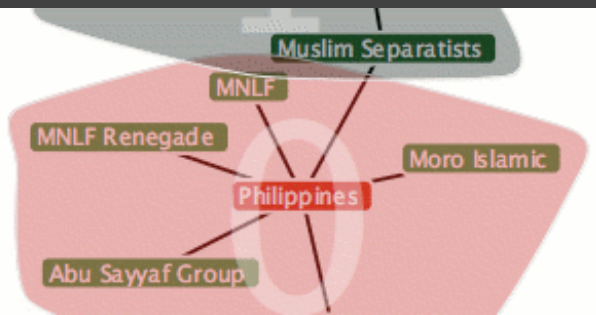
A3: Interactive Visualization

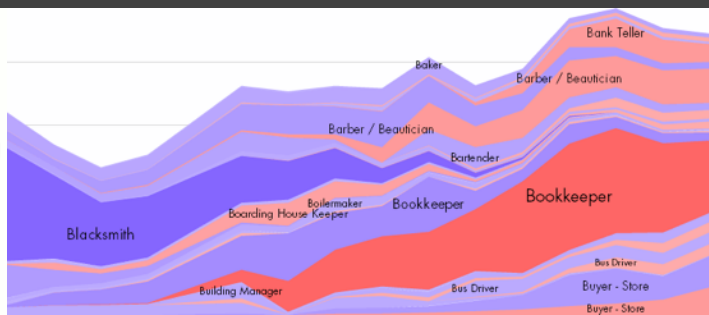
Create an interactive visualization application. Choose a data domain and an appropriate visualization technique.

1. Choose a data set and storyboard your interface
2. Implement the interface using tools of your choice
3. Submit your application and produce a final write-up

You should work in groups of 2-3.

Due by *5pm* on **Monday, May 4**

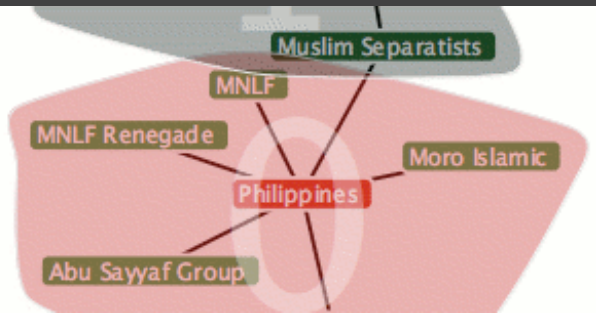


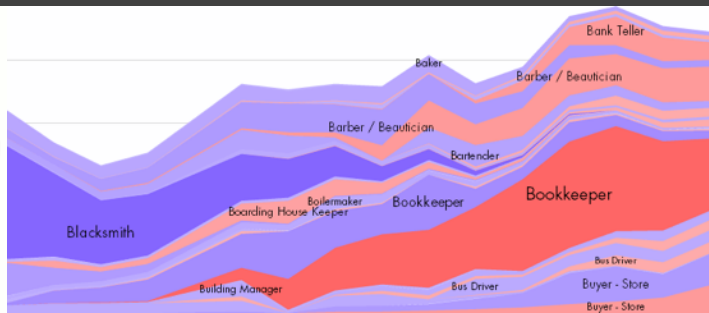


A3: Project Partners

For A3, you should work in **groups of 2-3**.

If you do not have a partner, you should:
Use the facilities on Canvas
Stay after class to meet potential partners



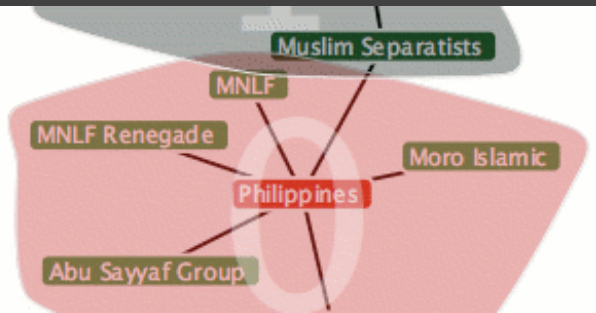


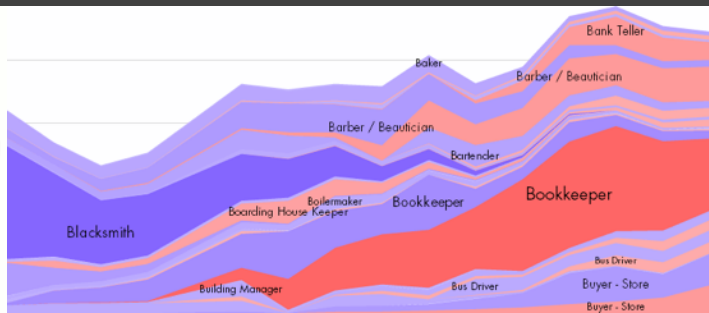
Assignment 3 Tips

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. Keep the design clean.

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





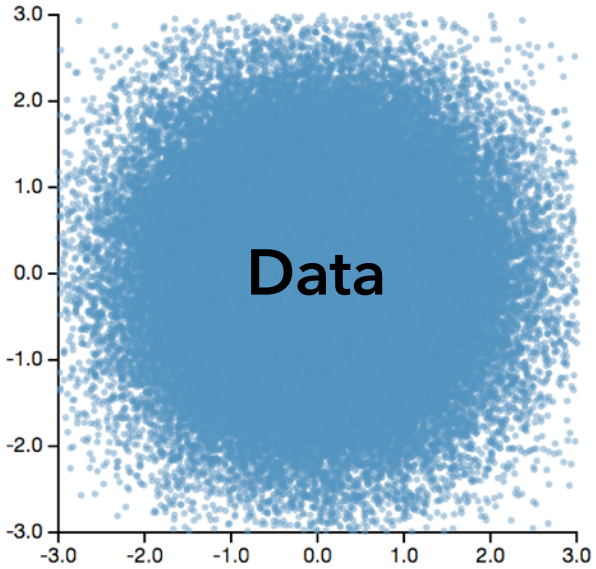
imMens

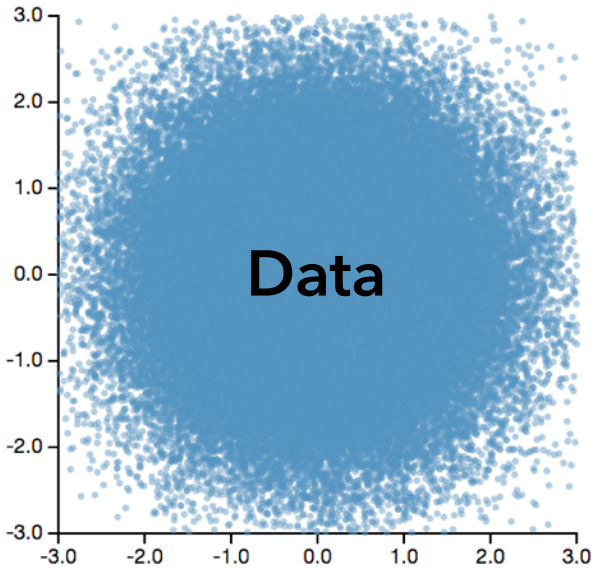
How can we visualize and interact with **billion+ record** databases in real-time?

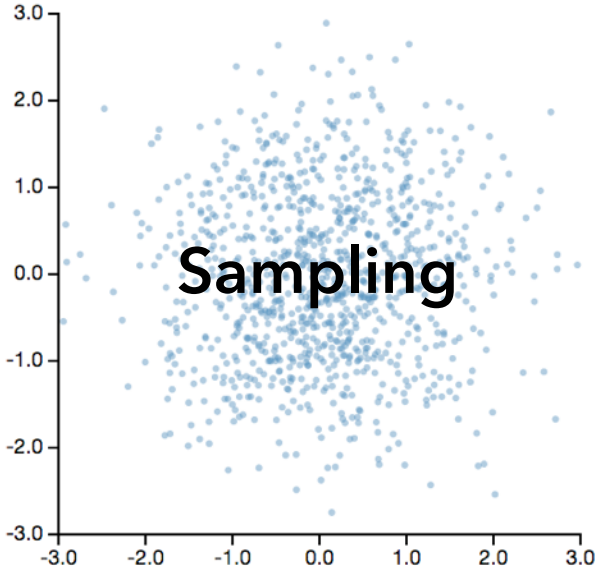
Two Challenges:

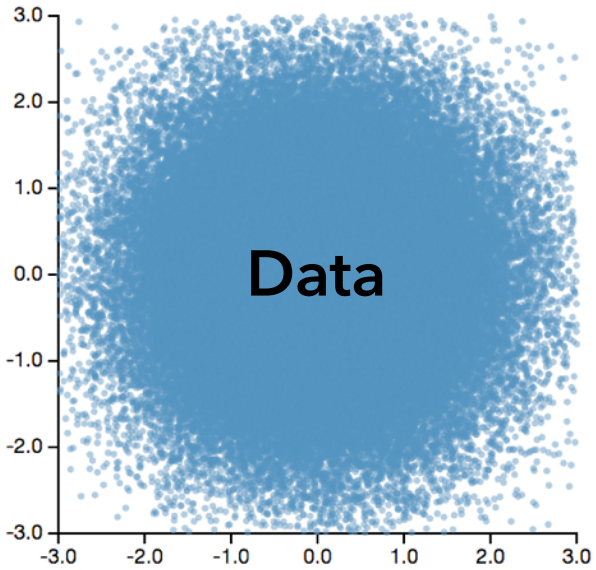
1. Effective **visual encoding**
2. Real-time **interaction**

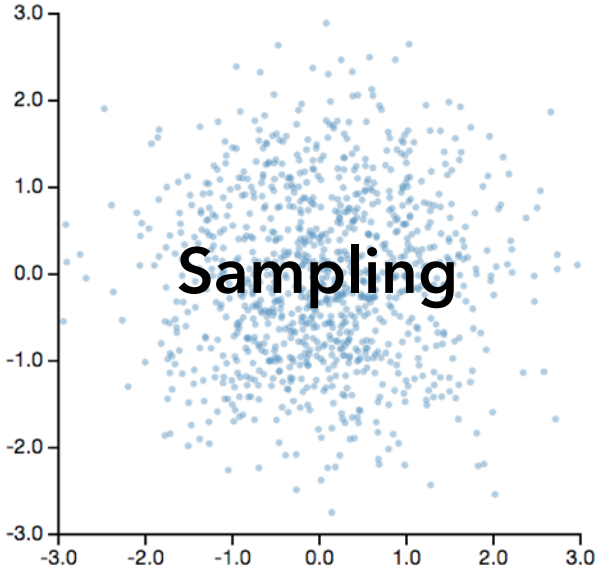
Perceptual and interactive scalability should be limited by the **chosen resolution** of the visualized data, not the number of records.

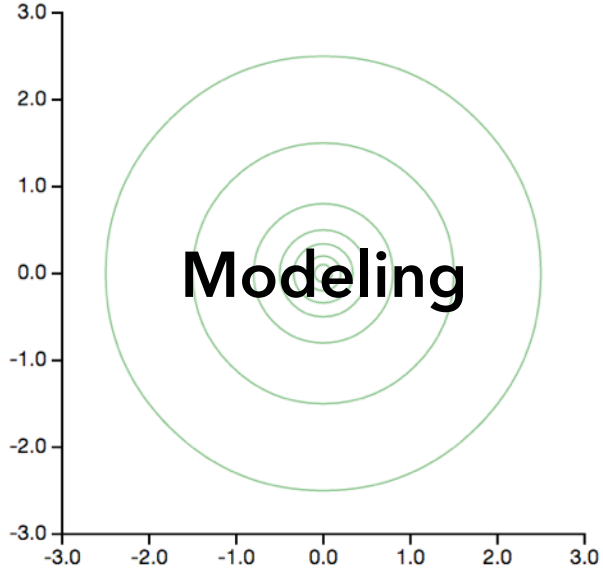

Data
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
-3.0
-2.0
-1.0
0.0
1.0
2.0
3.0

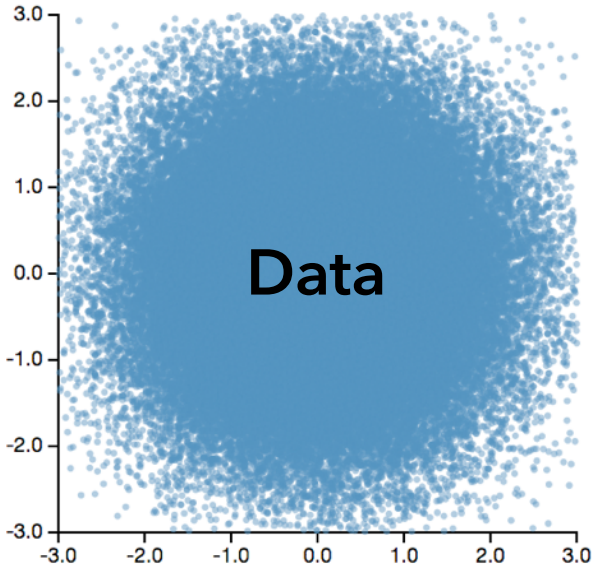

Data
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
-3.0
-2.0
-1.0
0.0
1.0
2.0
3.0

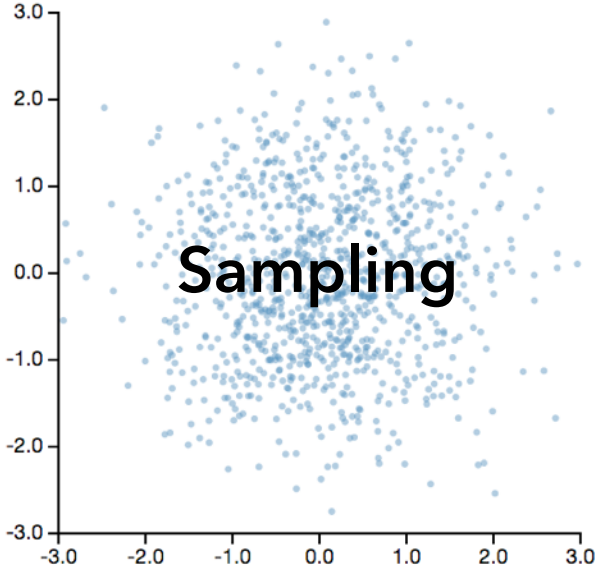

Sampling
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
-3.0
-2.0
-1.0
0.0
1.0
2.0
3.0

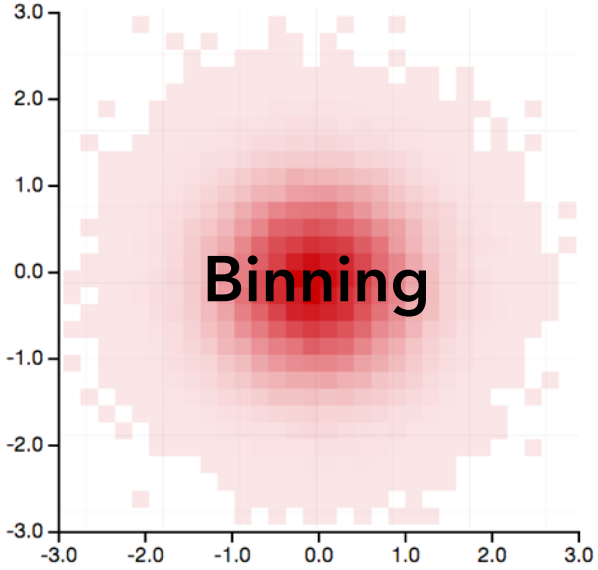

Data
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
-3.0
-2.0
-1.0
0.0
1.0
2.0
3.0

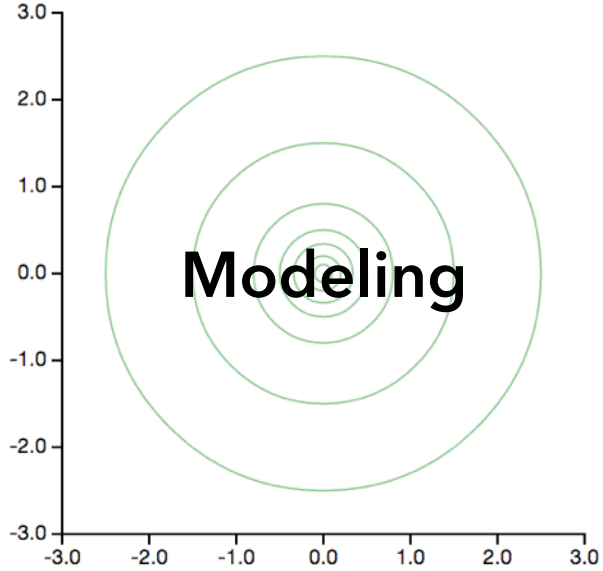

Sampling
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
-3.0
-2.0
-1.0
0.0
1.0
2.0
3.0

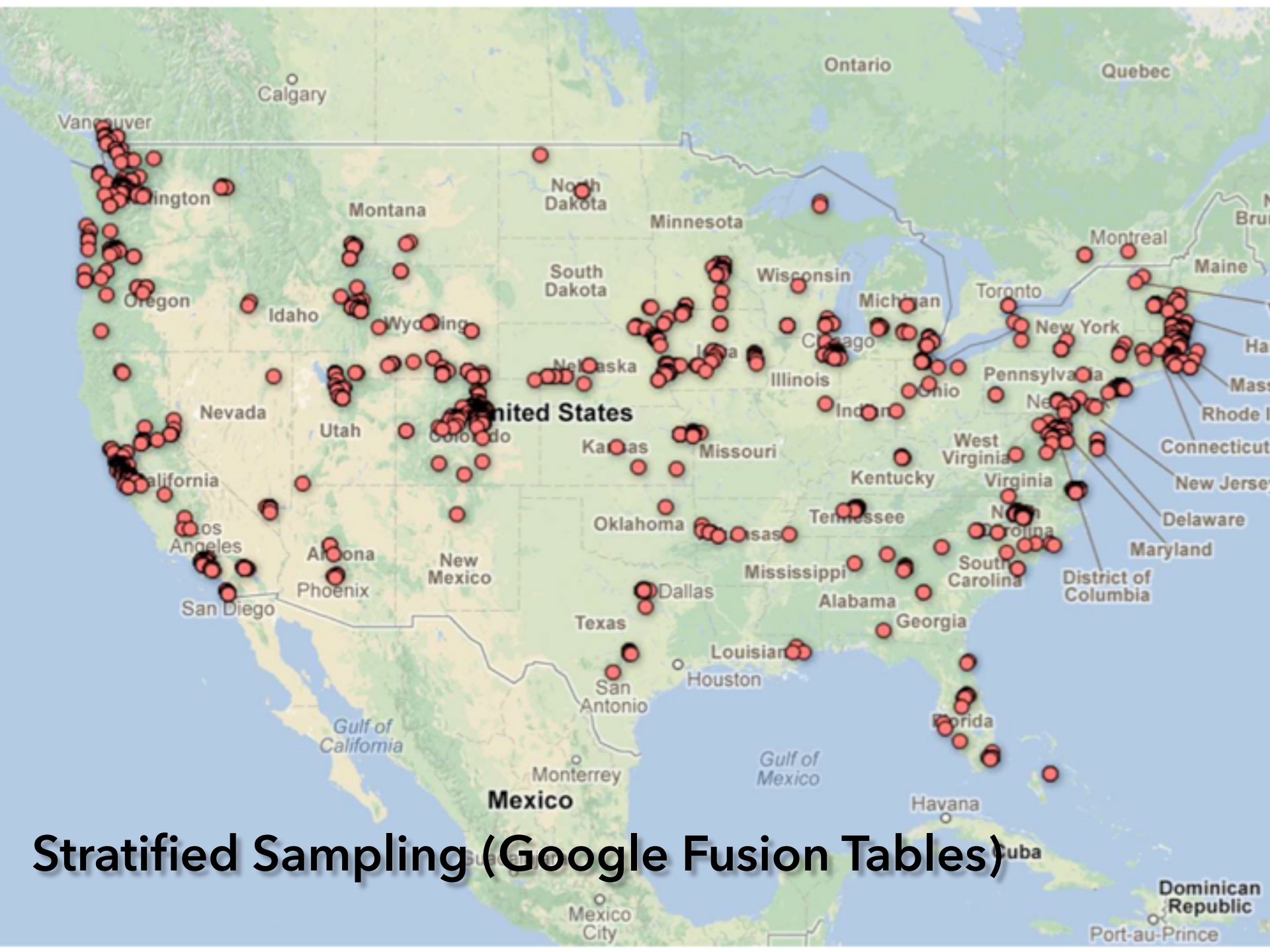

Modeling
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
-3.0
-2.0
-1.0
0.0
1.0
2.0
3.0


Data
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
-3.0
-2.0
-1.0
0.0
1.0
2.0
3.0

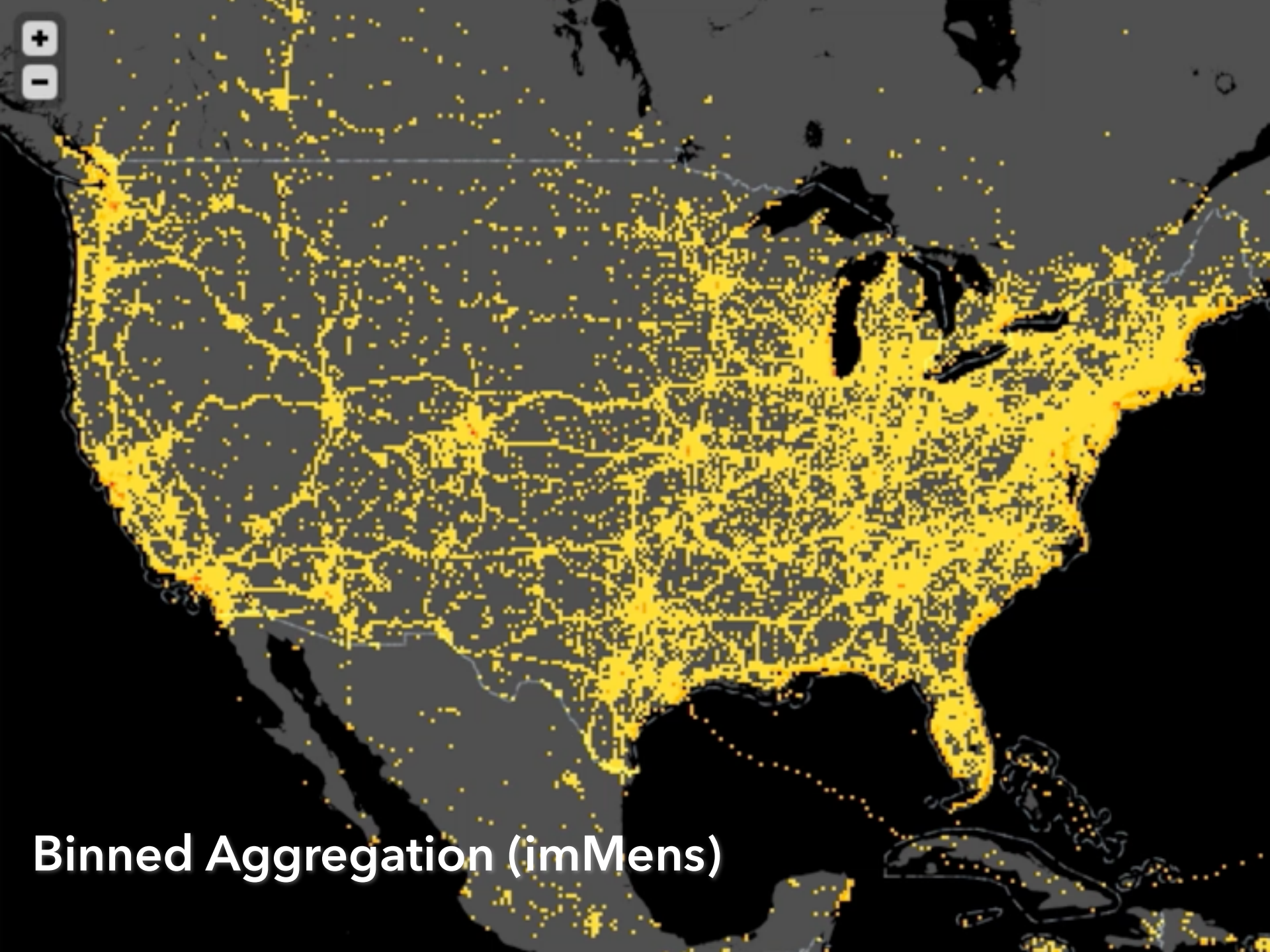

Sampling
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
-3.0
-2.0
-1.0
0.0
1.0
2.0
3.0

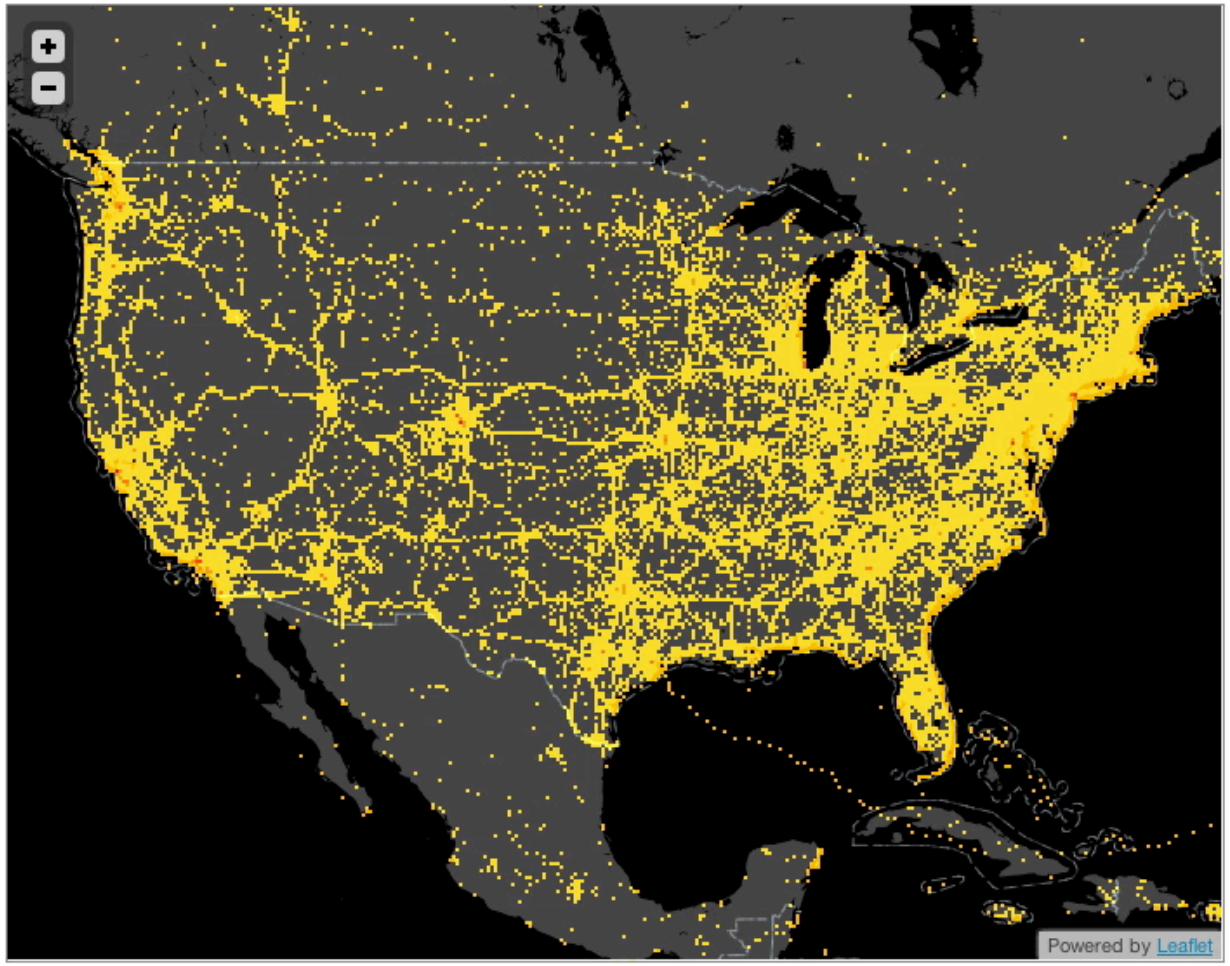

Binning
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
-3.0
-2.0
-1.0
0.0
1.0
2.0
3.0

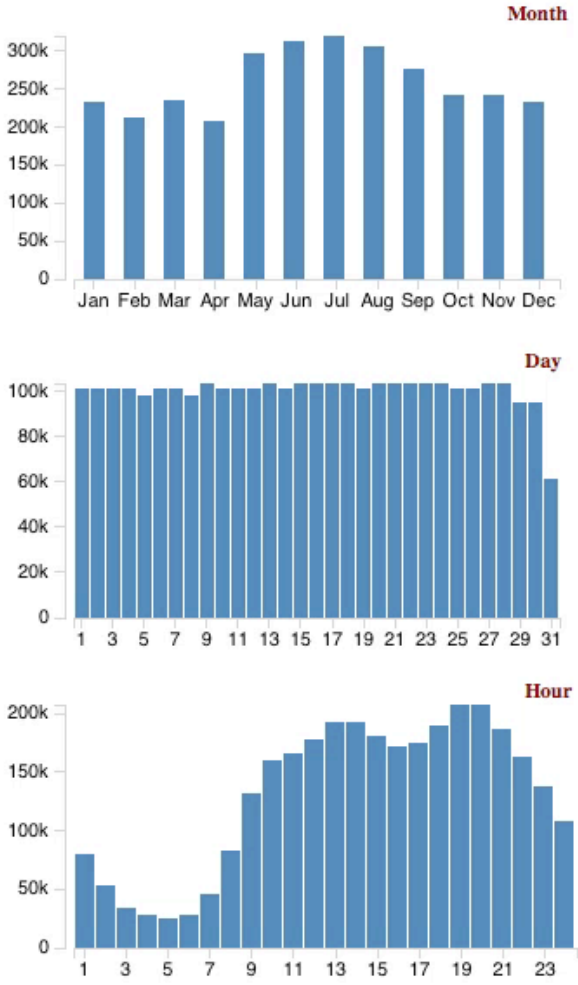

Modeling
3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
-3.0
-2.0
-1.0
0.0
1.0
2.0
3.0



Stratified Sampling (Google Fusion Tables)


Binned Aggregation (imMens)





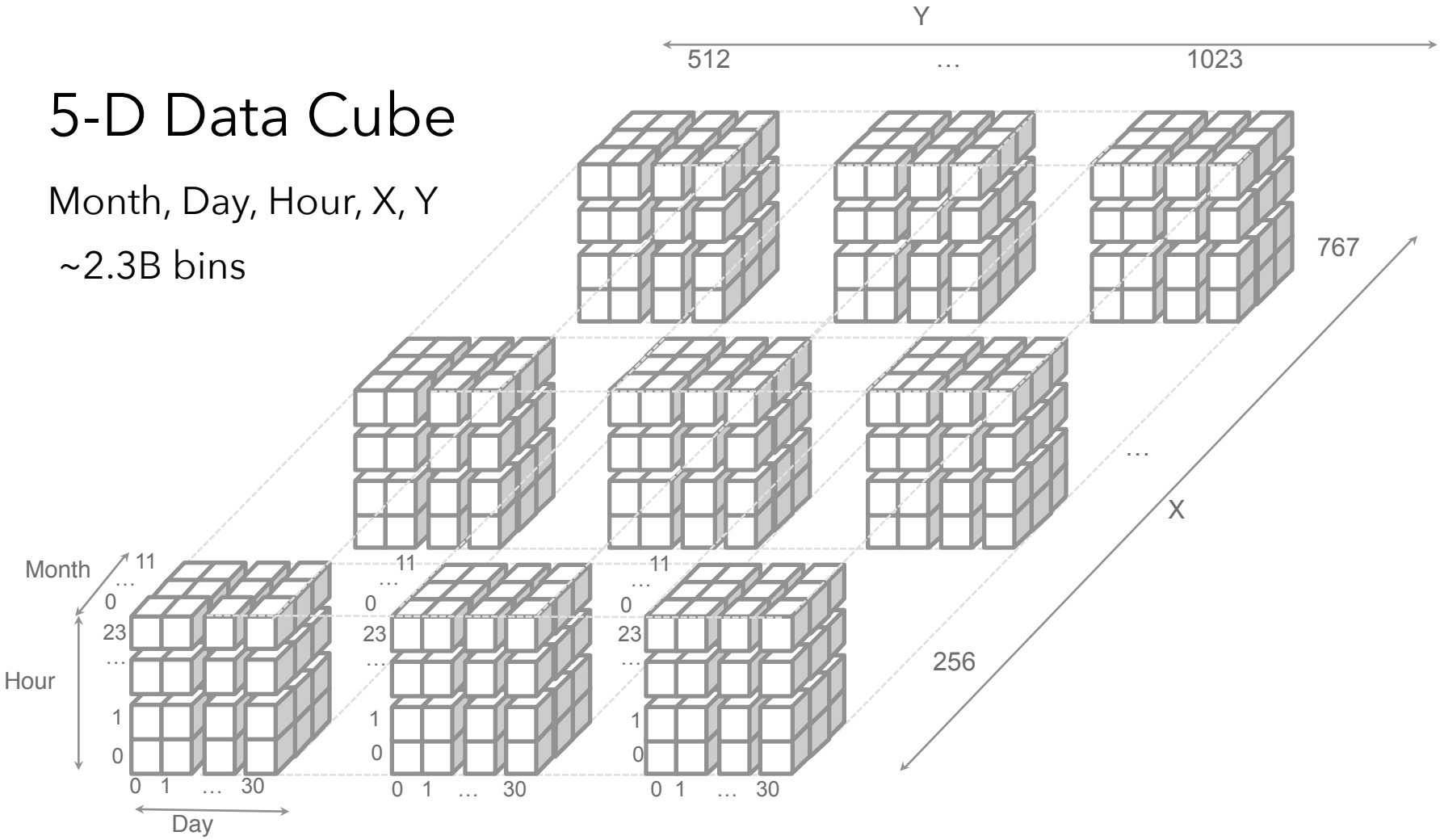
imMens: Real-Time Visual Querying of Big Data

with Zhicheng (Leo) Liu & Biye Jiang

5-D Data Cube

Month, Day, Hour, X, Y

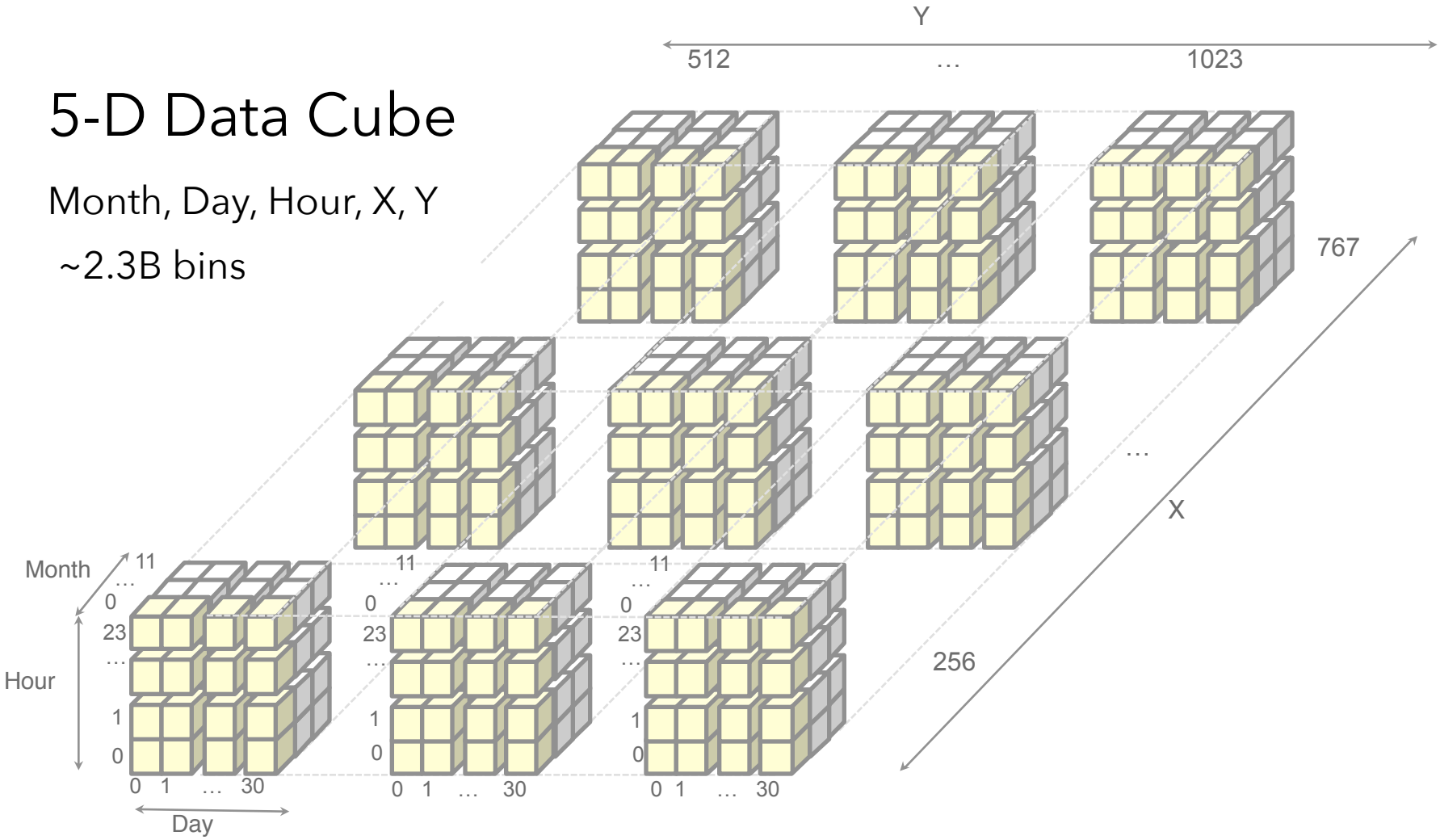
~2.3B bins

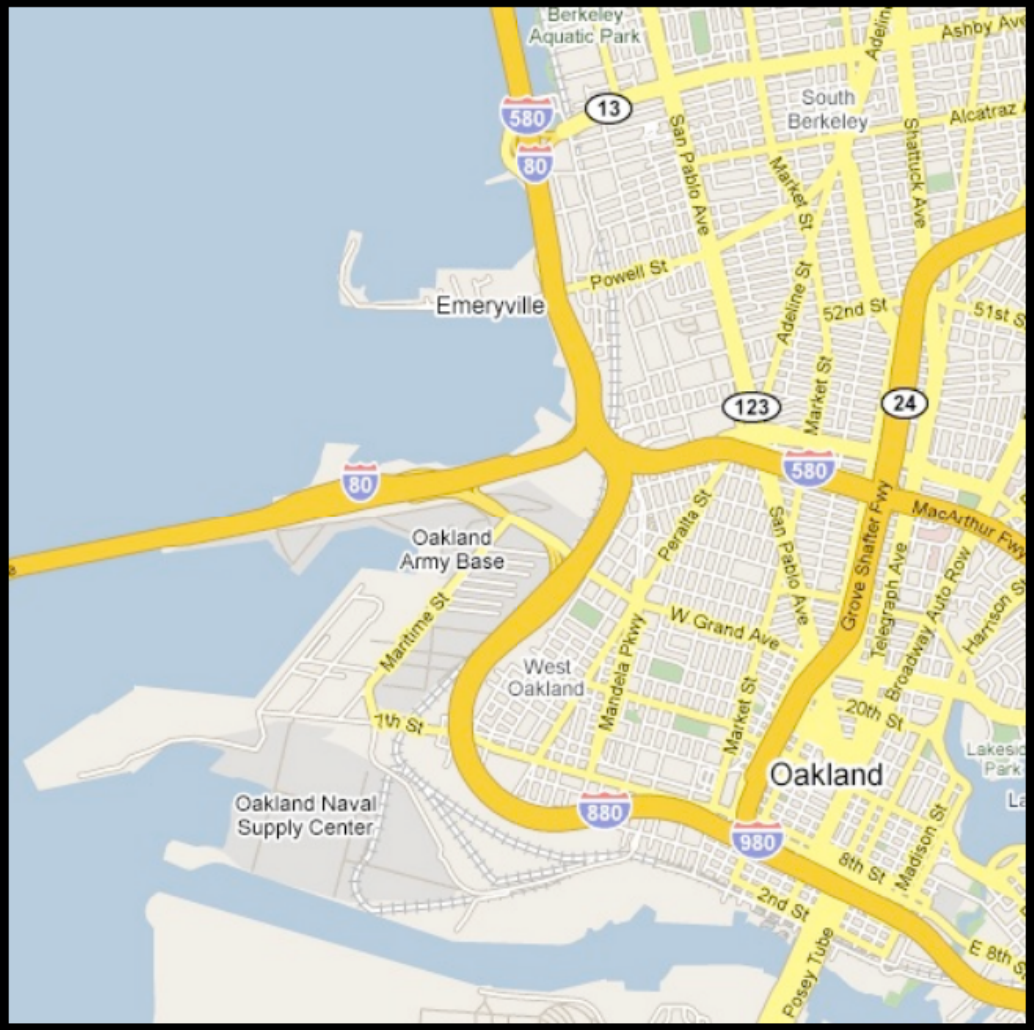


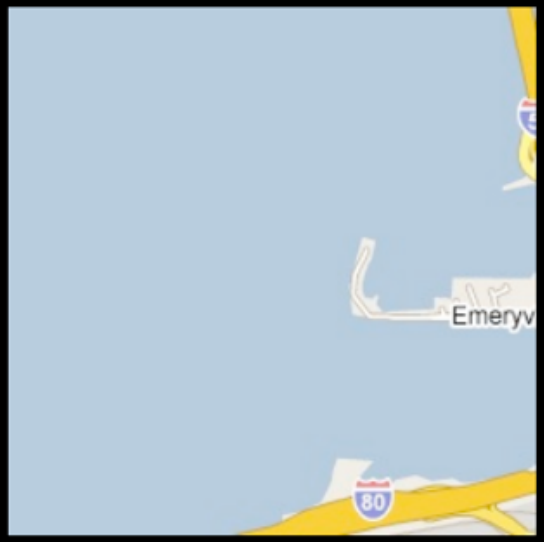
5-D Data Cube

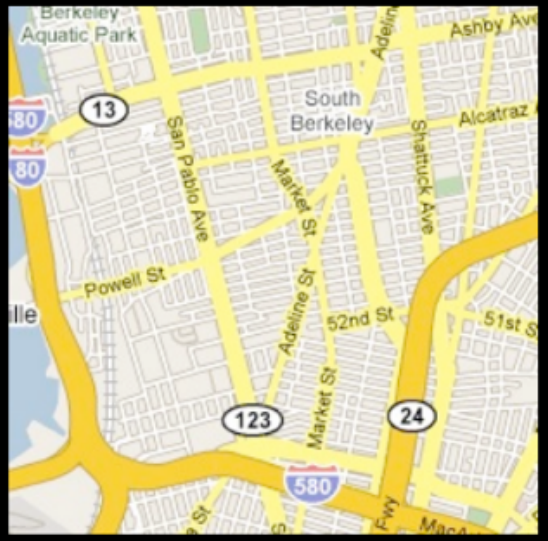
Month, Day, Hour, X, Y

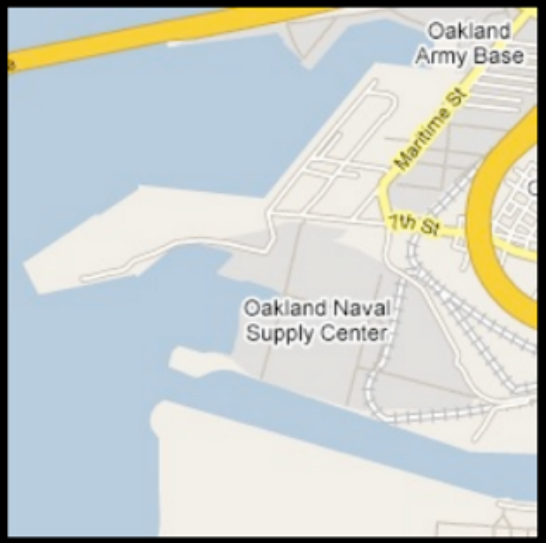
~2.3B bins

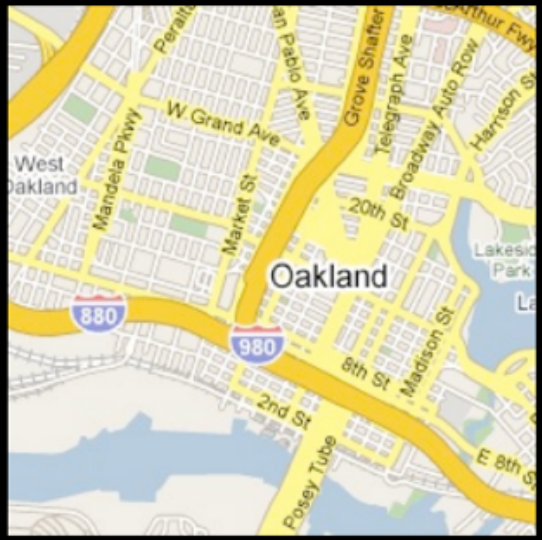



Berkeley Aquatic Park
Ashby Ave
580
13
South Berkeley
Alcatraz
80
San Pablo Ave
Market St
Shattuck Ave
Powell St
Emeryville
Adeline St
52nd St
51st St
123
Market St
24
80
580
MacArthur Fwy
Oakland Army Base
Peralta St
San Pablo Ave
Grove Shafter Fwy
Telegraph Ave
Broadway Auto Row
Harrison St
Maritime St
W Grand Ave
West Oakland
Mandela Pkwy
Market St
20th St
7th St
Oakland
Lakeside Park
880
980
Oakland Naval Supply Center
8th St
Madison St
2nd St
E 8th St
Posey Tube


Emeryv
80

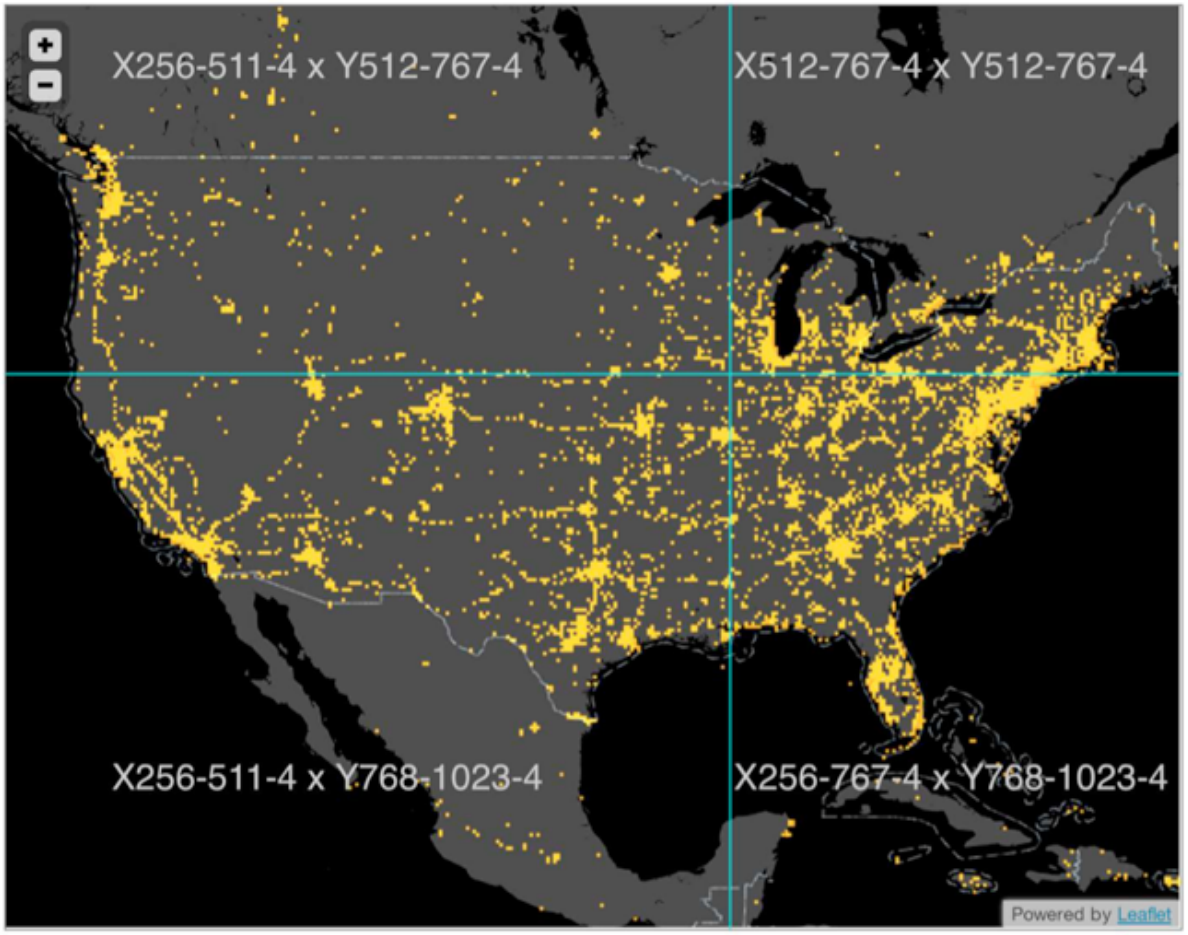

Berkeley
Aquatic Park
Ashby Ave
13
South
Berkeley
Alcatraz
San Pablo Ave
Market St
Shattuck Ave
Powell St
Adeline St
52nd St
51st S
123
24
580

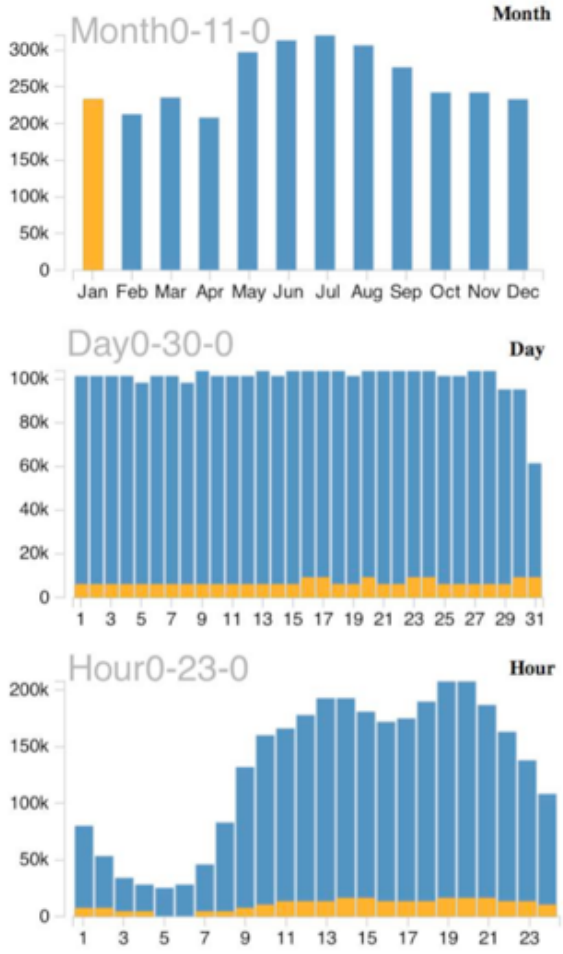

Oakland
Army Base
Maritime St
7th St
Oakland Naval
Supply Center

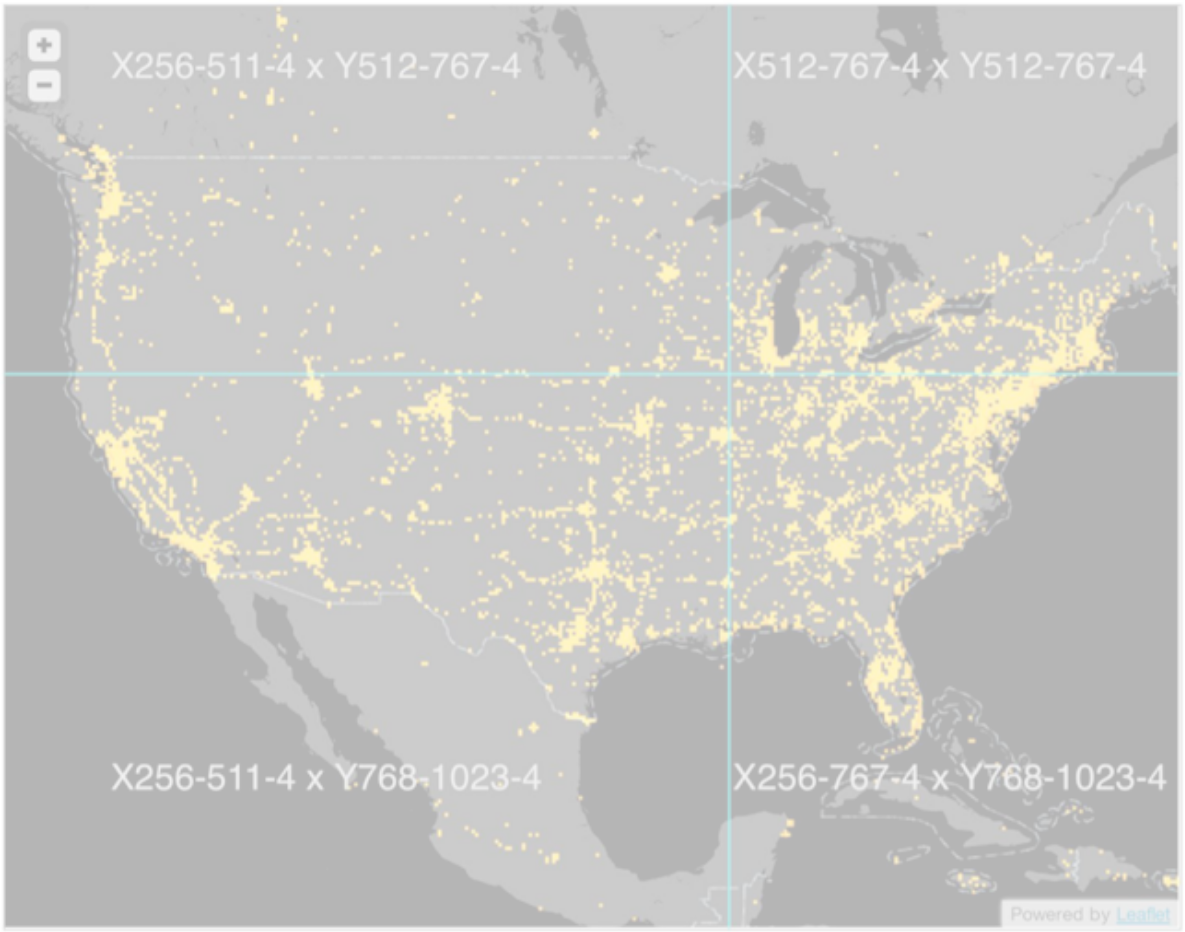

W Grand Ave
San Pablo Ave
Grove Shafter
Telegraph Ave
Broadway
Auto Row
Harrison St
Mandela Pkwy
West
Oakland
Market St
20th St
Oakland
880
980
8th St
Madison St
2nd St
Posey Tube
E 8th St

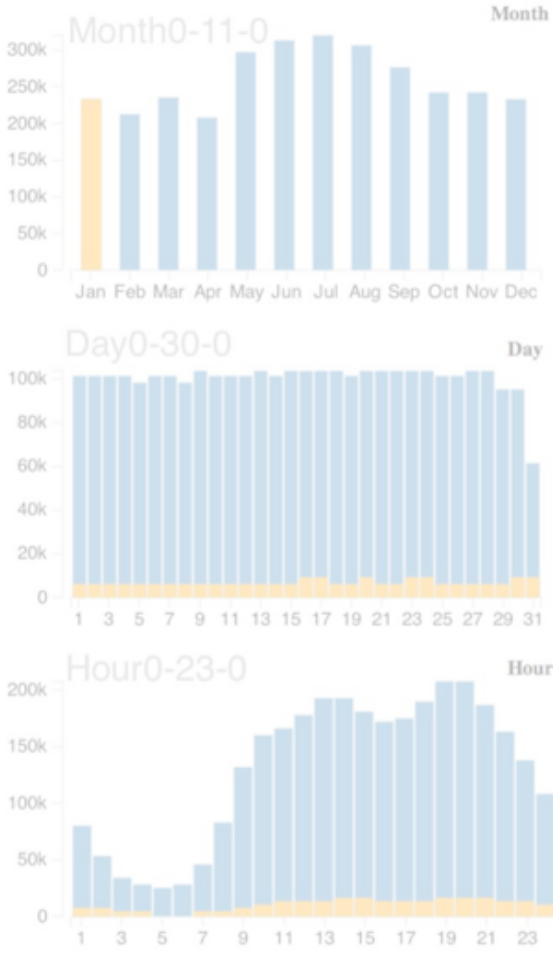
Multivariate Data Tiles

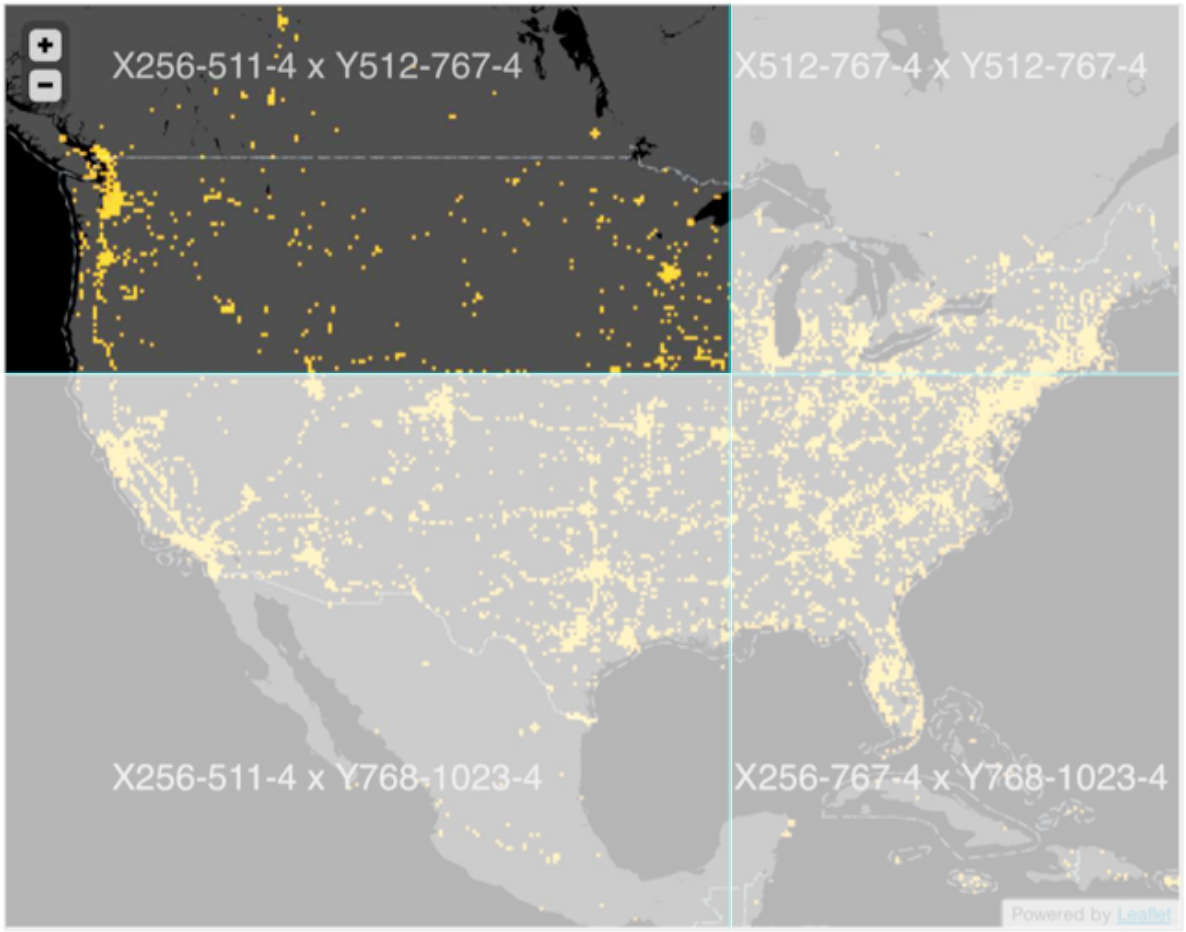
1. Send data, not pixels
2. Embed multi-dim data

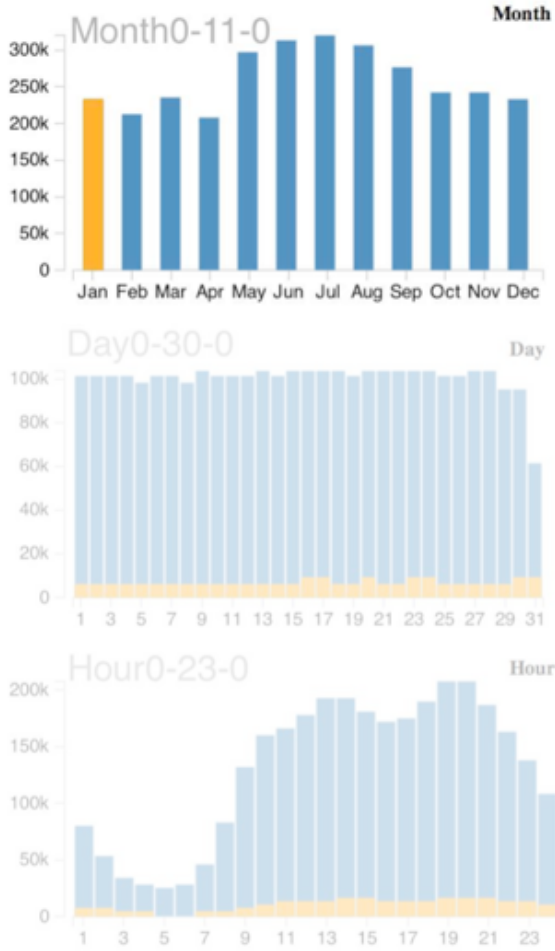

X256-511-4 x Y512-767-4
X512-767-4 x Y512-767-4
X256-511-4 x Y768-1023-4
X256-767-4 x Y768-1023-4
Powered by Leaflet

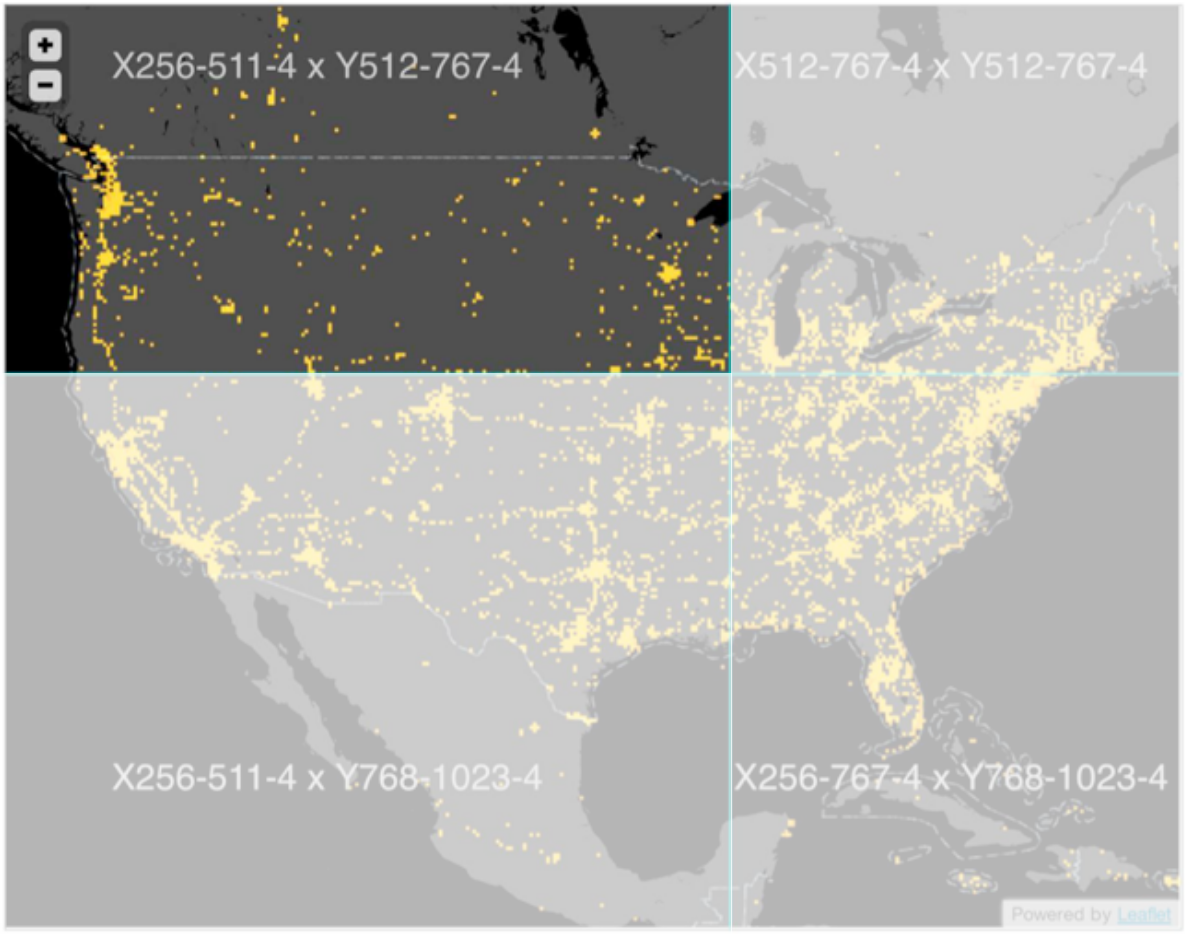

Month
Month0-11-0
300k
250k
200k
150k
100k
50k
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Day
Day0-30-0
100k
80k
60k
40k
20k
0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31
Hour
Hour0-23-0
200k
150k
100k
50k
0
1 3 5 7 9 11 13 15 17 19 21 23

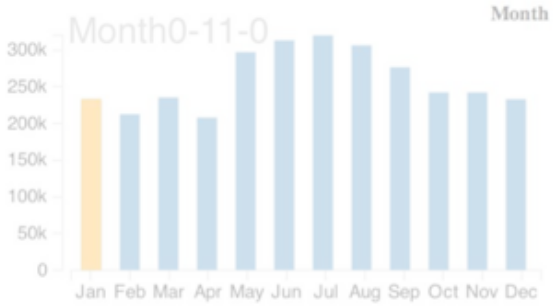

X256-511-4 x Y512-767-4
X512-767-4 x Y512-767-4
X256-511-4 x Y768-1023-4
X256-767-4 x Y768-1023-4
Powered by Leaflet

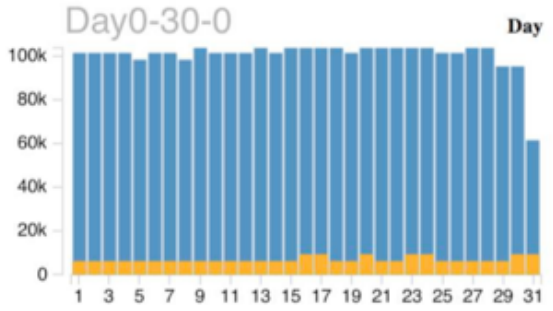

Month
Month0-11-0
300k
250k
200k
150k
100k
50k
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Day
Day0-30-0
100k
80k
60k
40k
20k
0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31
Hour
Hour0-23-0
200k
150k
100k
50k
0
1 3 5 7 9 11 13 15 17 19 21 23

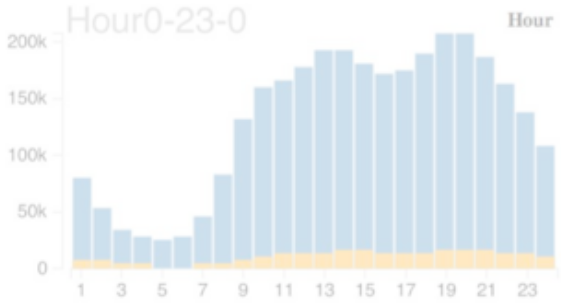

X256-511-4 x Y512-767-4
X512-767-4 x Y512-767-4
X256-511-4 x Y768-1023-4
X256-767-4 x Y768-1023-4
Powered by Leaflet

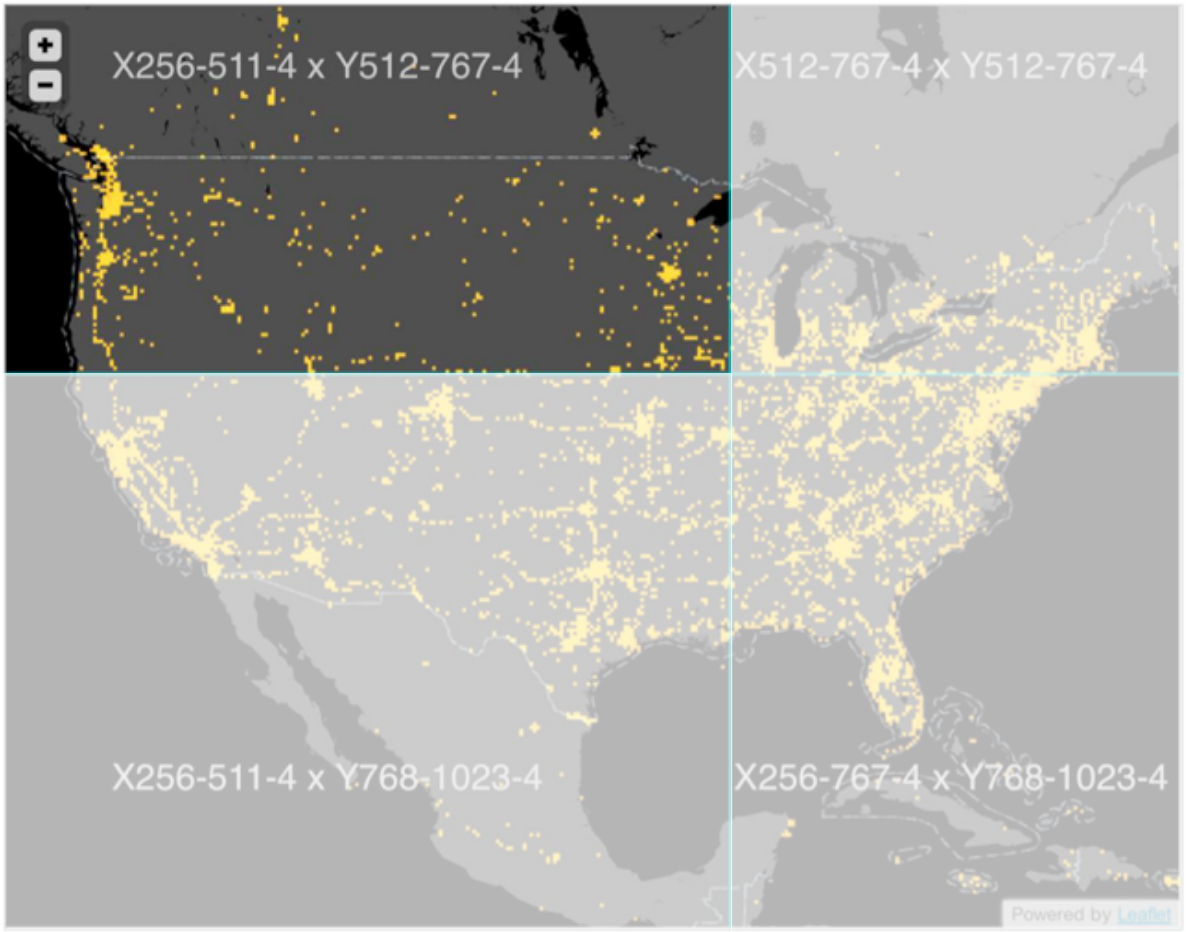

Month
Month0-11-0
300k
250k
200k
150k
100k
50k
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Day0-30-0
Day
100k
80k
60k
40k
20k
0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31
Hour0-23-0
Hour
200k
150k
100k
50k
0
1 3 5 7 9 11 13 15 17 19 21 23


X256-511-4 x Y512-767-4
X512-767-4 x Y512-767-4
X256-511-4 x Y768-1023-4
X256-767-4 x Y768-1023-4
Powered by Leaflet

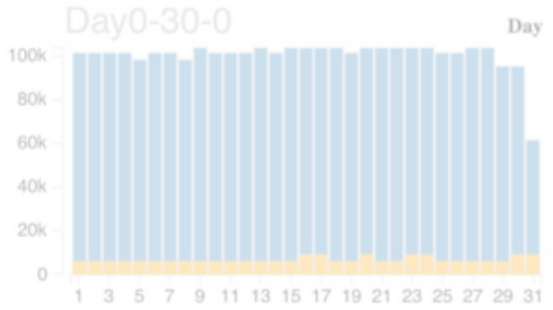

Month
Month0-11-0
300k
250k
200k
150k
100k
50k
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

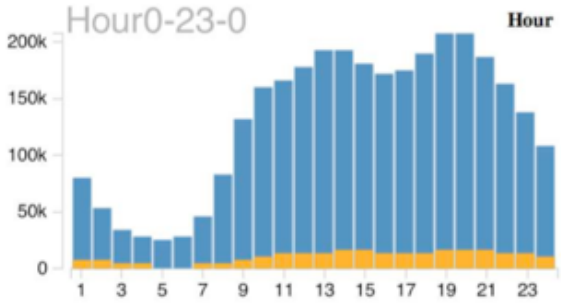

Day0-30-0
Day
100k
80k
60k
40k
20k
0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31

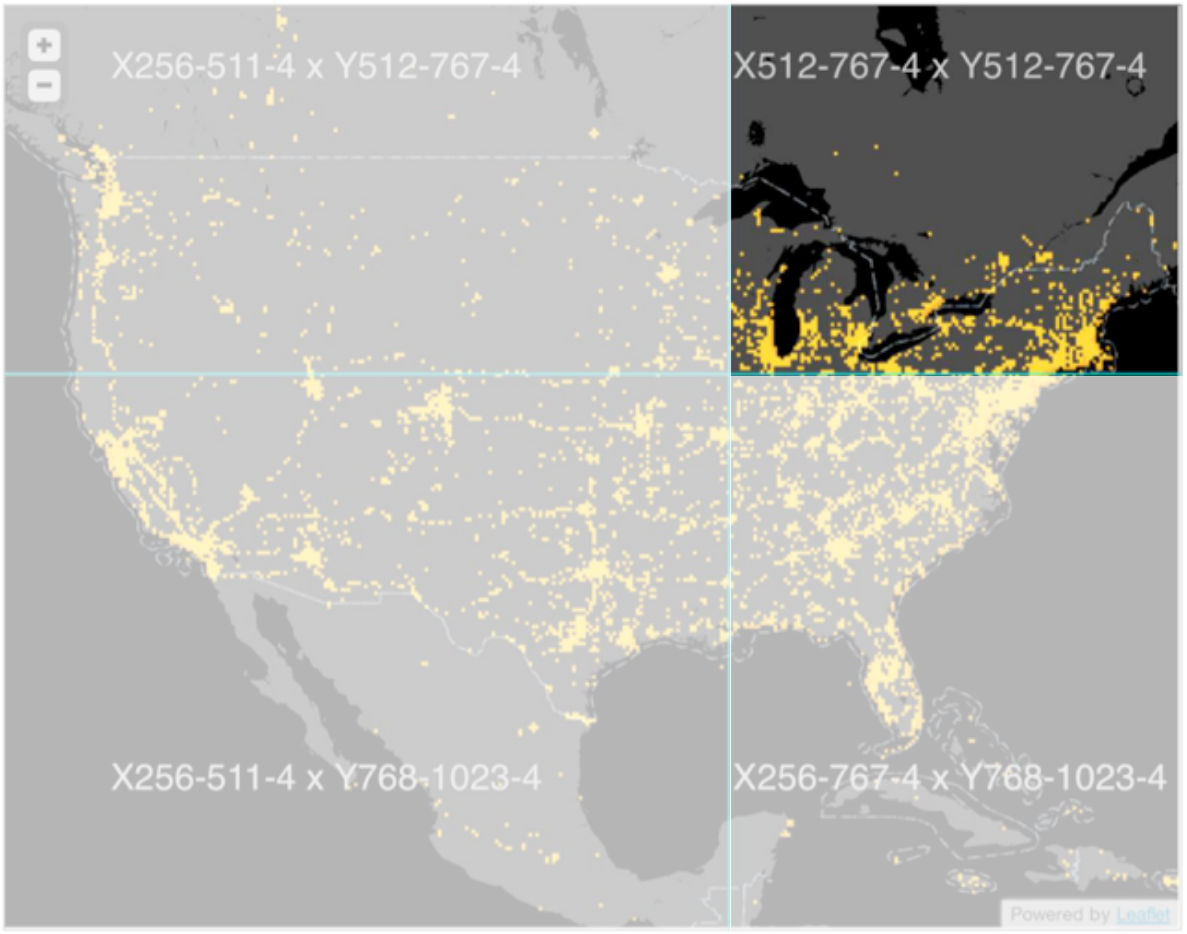

Hour0-23-0
Hour
200k
150k
100k
50k
0
1 3 5 7 9 11 13 15 17 19 21 23

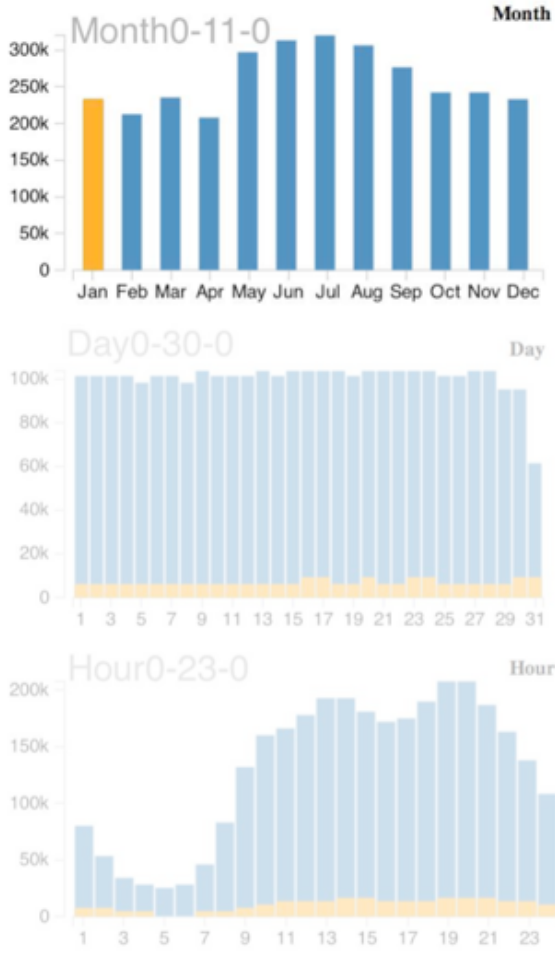

X256-511-4 x Y512-767-4
X512-767-4 x Y512-767-4
X256-511-4 x Y768-1023-4
X256-767-4 x Y768-1023-4
Powered by Leaflet

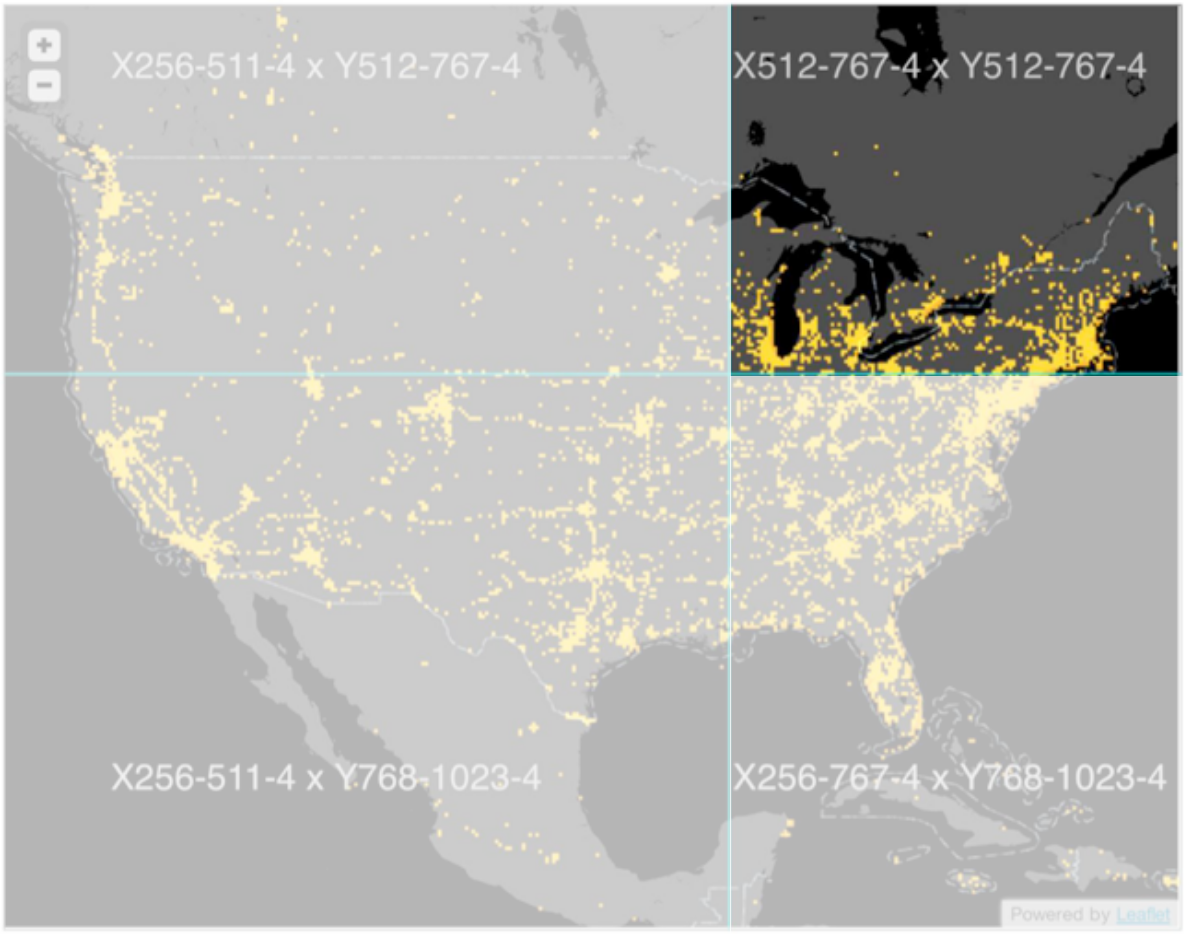

Month
Month0-11-0
300k
250k
200k
150k
100k
50k
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

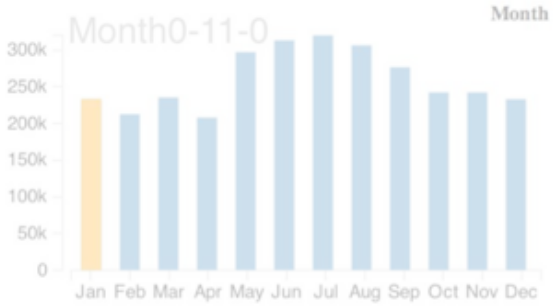

Day0-30-0
Day
100k
80k
60k
40k
20k
0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31

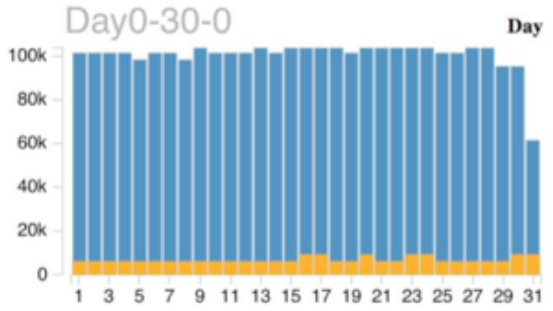

Hour0-23-0
Hour
200k
150k
100k
50k
0
1 3 5 7 9 11 13 15 17 19 21 23

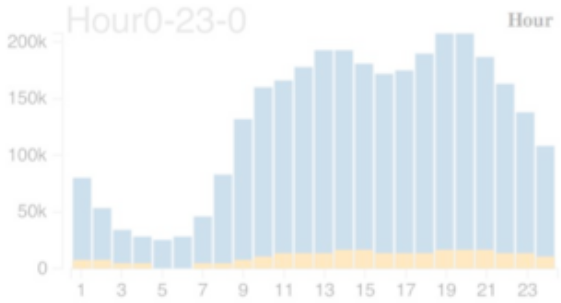

X256-511-4 x Y512-767-4
X512-767-4 x Y512-767-4
X256-511-4 x Y768-1023-4
X256-767-4 x Y768-1023-4
Powered by Leaflet

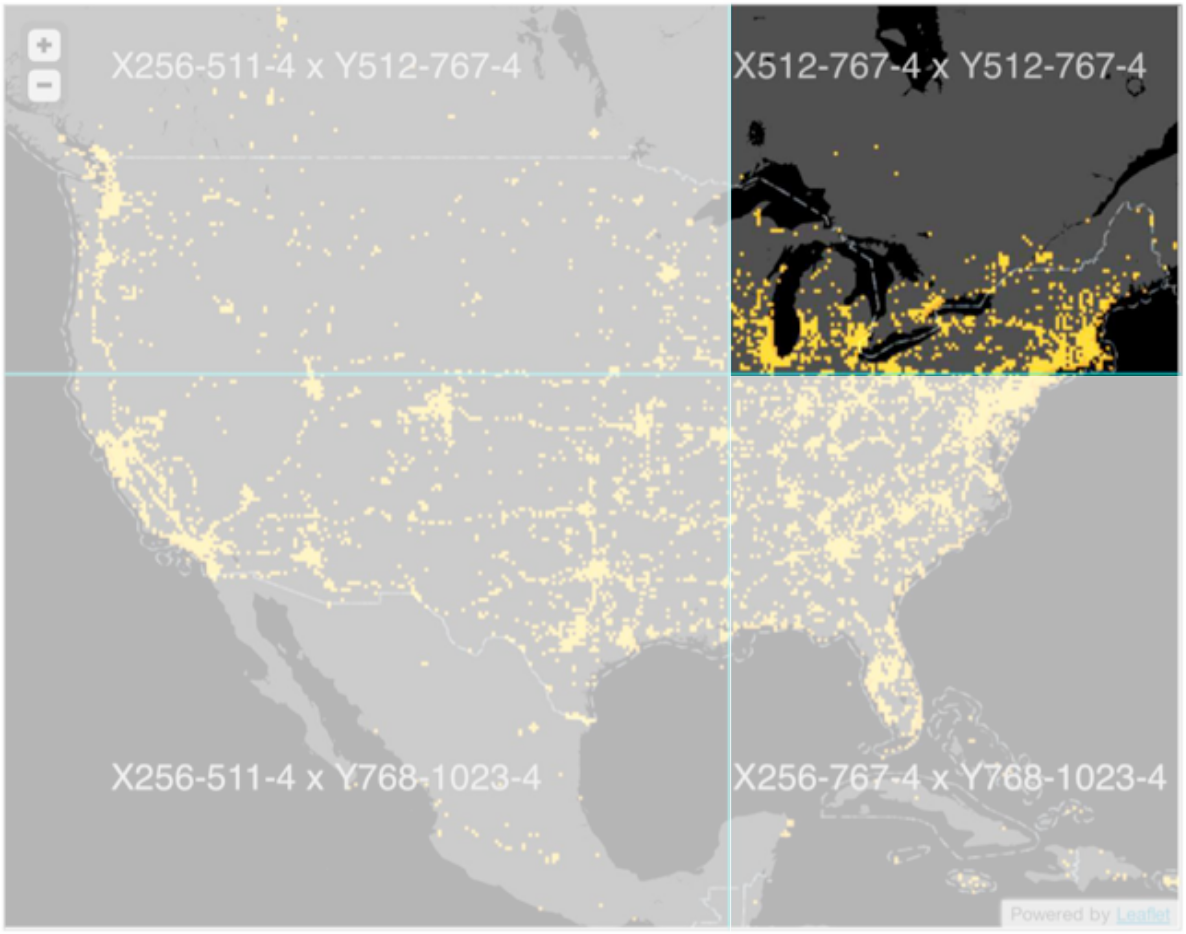

Month
Month0-11-0
300k
250k
200k
150k
100k
50k
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Day0-30-0
Day
100k
80k
60k
40k
20k
0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31
Hour0-23-0
Hour
200k
150k
100k
50k
0
1 3 5 7 9 11 13 15 17 19 21 23


X256-511-4 x Y512-767-4
X512-767-4 x Y512-767-4
X256-511-4 x Y768-1023-4
X256-767-4 x Y768-1023-4
Powered by Leaflet

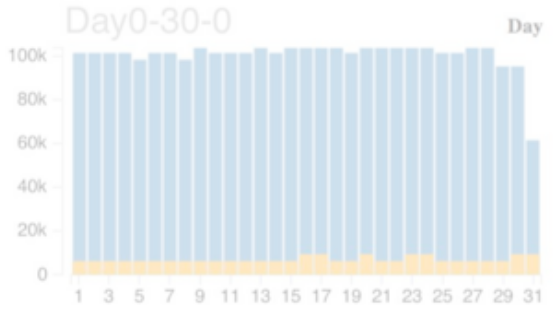

Month
Month0-11-0
300k
250k
200k
150k
100k
50k
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

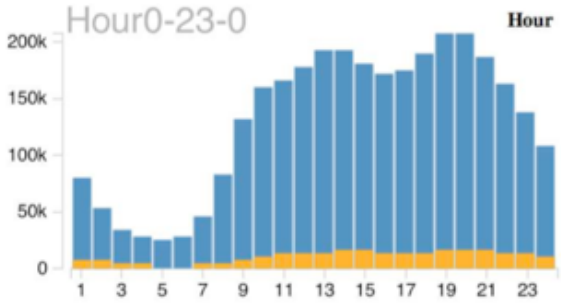

Day0-30-0
Day
100k
80k
60k
40k
20k
0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31

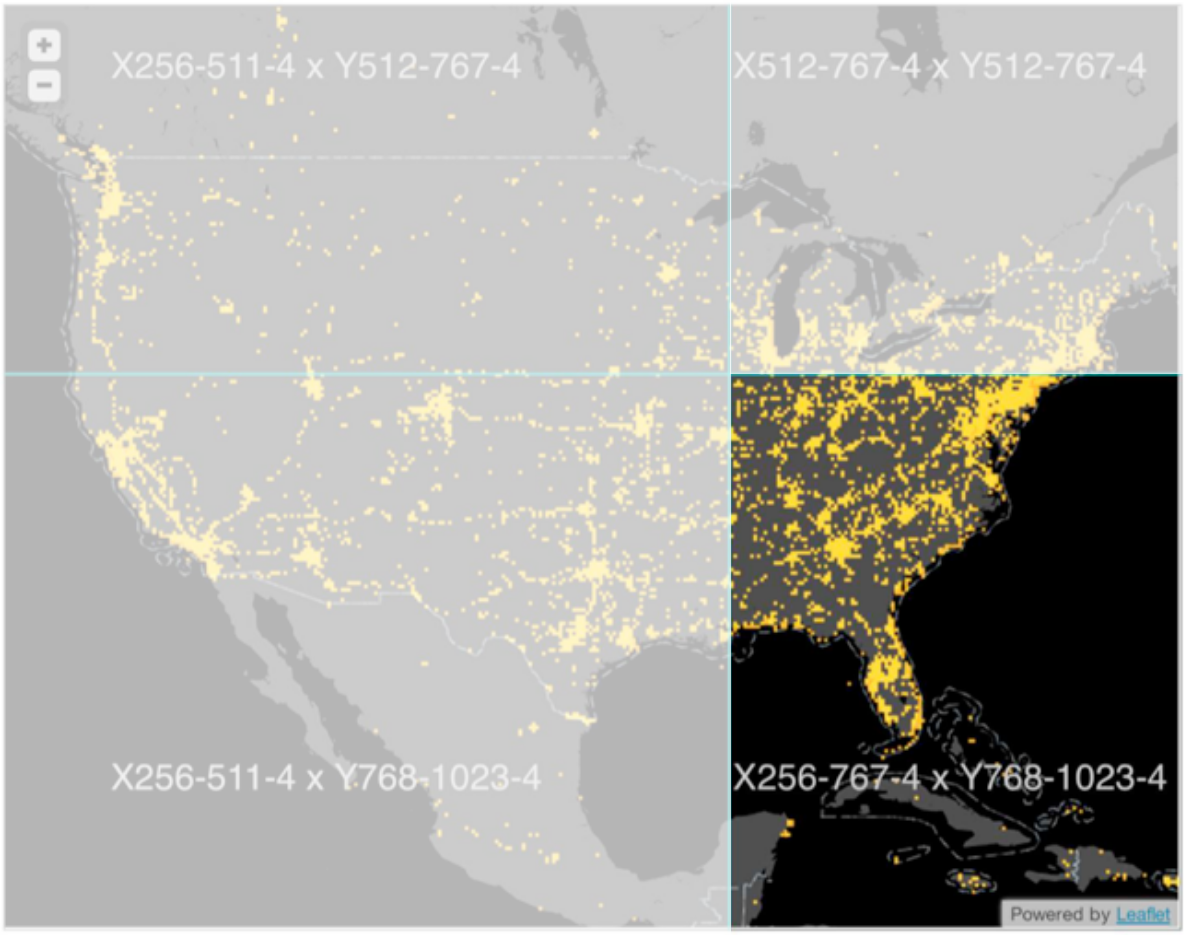

Hour0-23-0
Hour
200k
150k
100k
50k
0
1 3 5 7 9 11 13 15 17 19 21 23

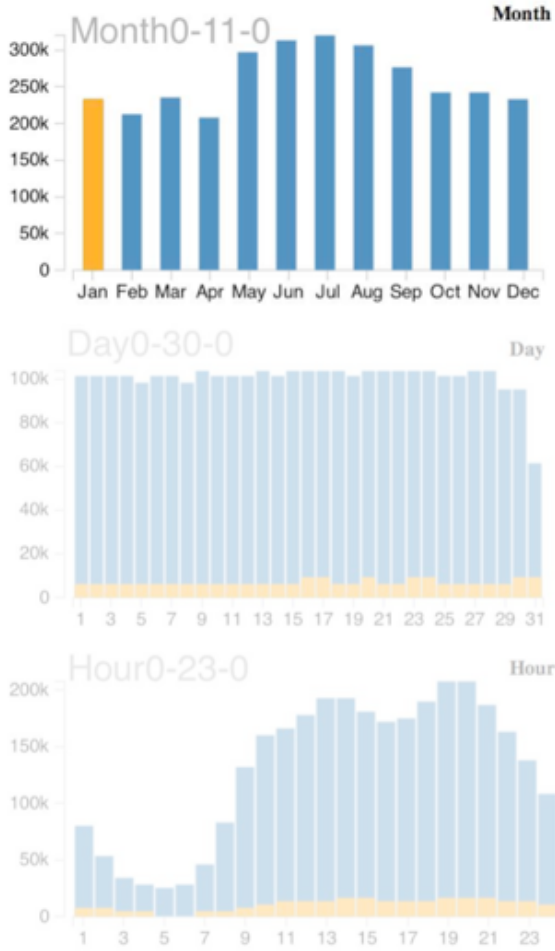

X256-511-4 x Y512-767-4
X512-767-4 x Y512-767-4
X256-511-4 x Y768-1023-4
X256-767-4 x Y768-1023-4
Powered by Leaflet

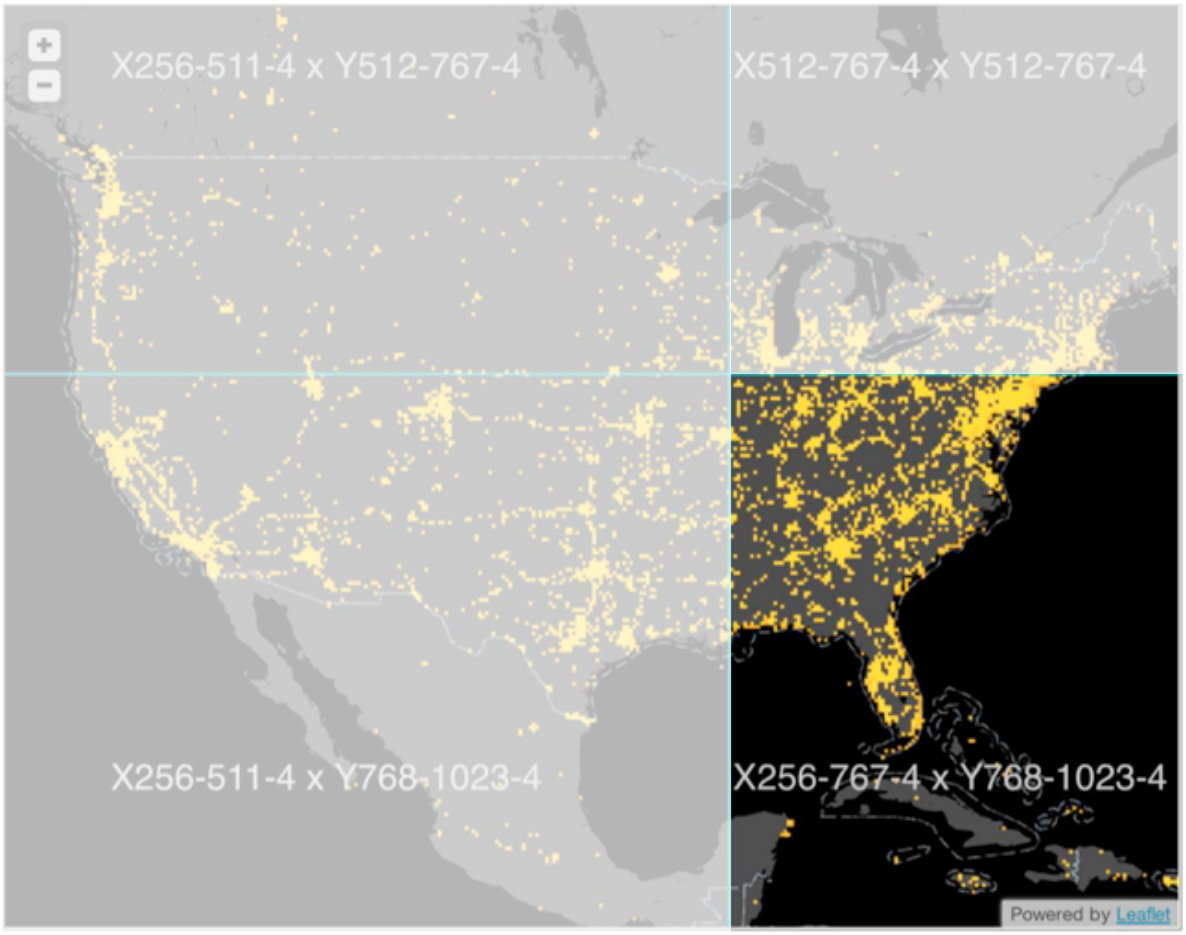

Month
Month0-11-0
300k
250k
200k
150k
100k
50k
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

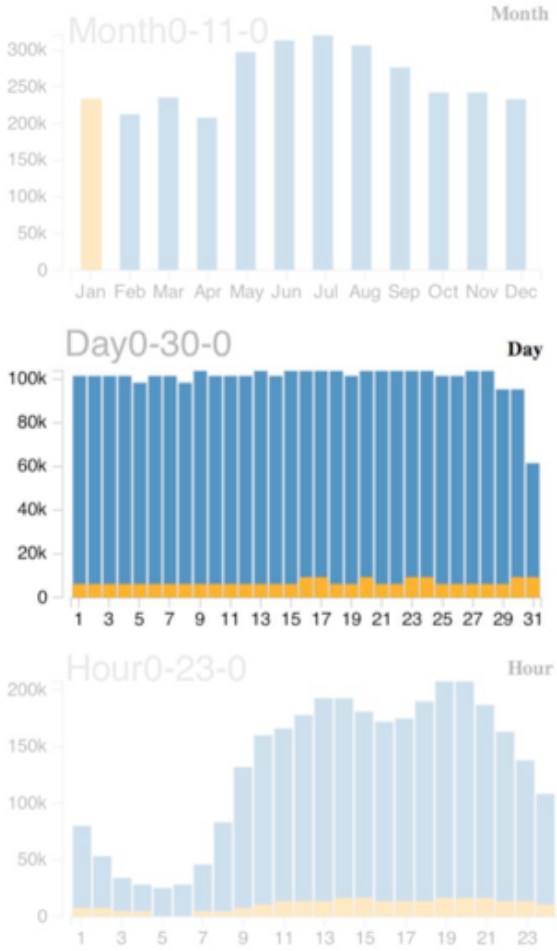

Day0-30-0
Day
100k
80k
60k
40k
20k
0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31

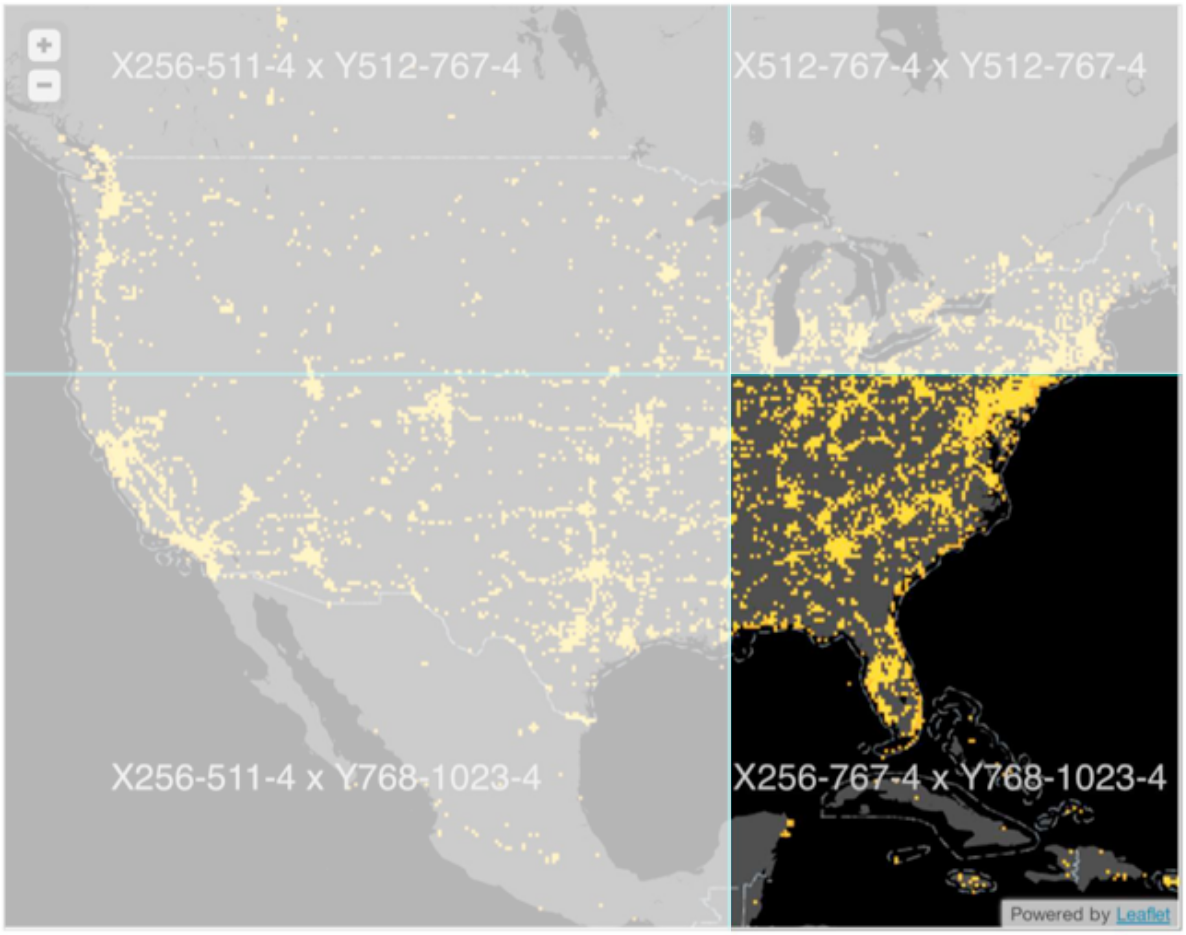

Hour0-23-0
Hour
200k
150k
100k
50k
0
1 3 5 7 9 11 13 15 17 19 21 23

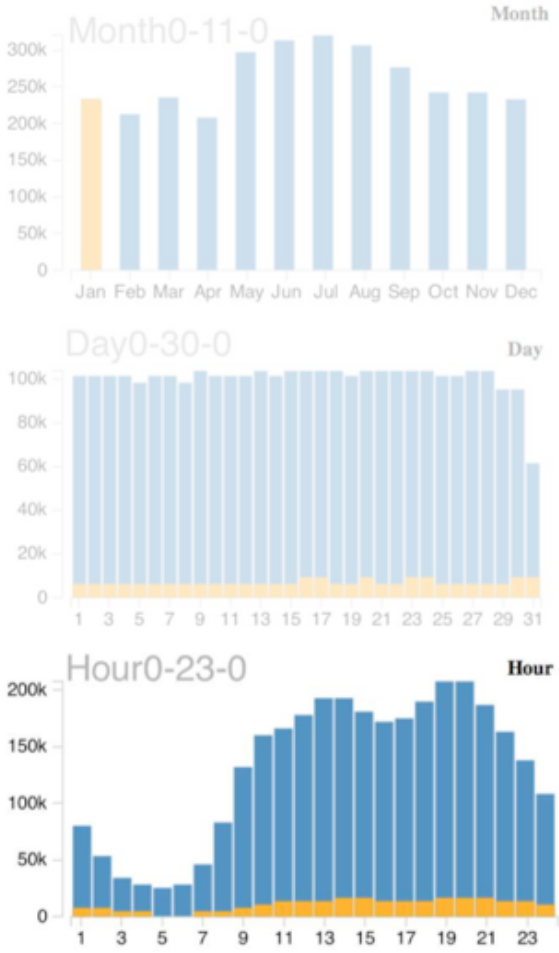

X256-511-4 x Y512-767-4
X512-767-4 x Y512-767-4
X256-511-4 x Y768-1023-4
X256-767-4 x Y768-1023-4
Powered by Leaflet

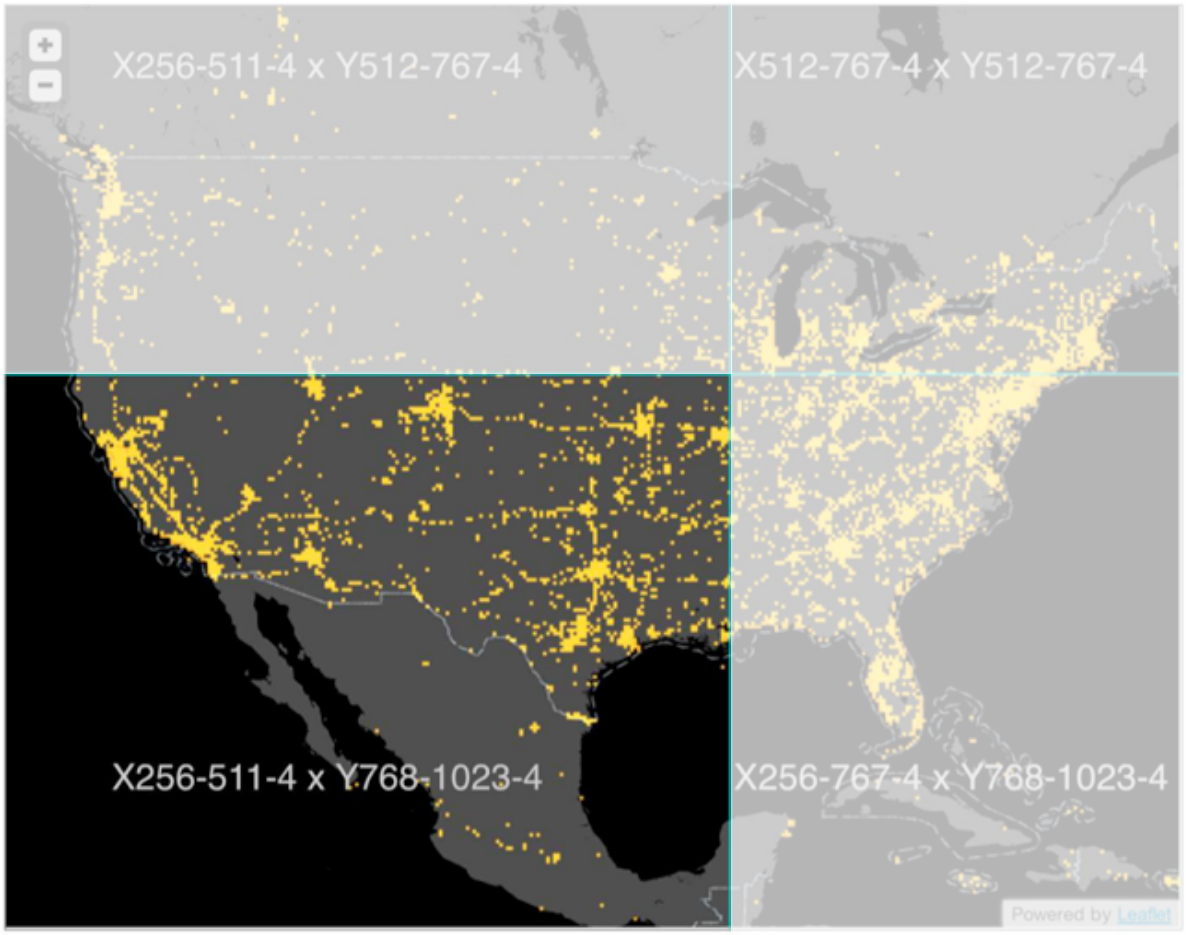

Month
Month0-11-0
300k
250k
200k
150k
100k
50k
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Day0-30-0
Day
100k
80k
60k
40k
20k
0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31
Hour0-23-0
Hour
200k
150k
100k
50k
0
1 3 5 7 9 11 13 15 17 19 21 23


X256-511-4 x Y512-767-4
X512-767-4 x Y512-767-4
X256-511-4 x Y768-1023-4
X256-767-4 x Y768-1023-4
Powered by Leaflet

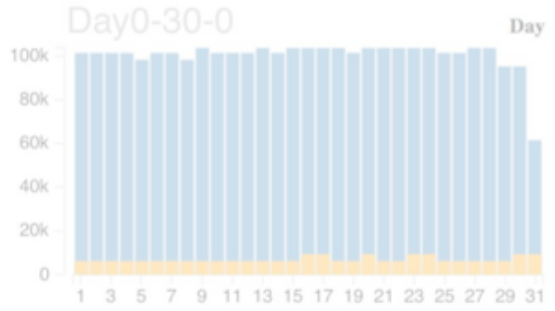

Month
Month0-11-0
300k
250k
200k
150k
100k
50k
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Day0-30-0
Day
100k
80k
60k
40k
20k
0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31
Hour0-23-0
Hour
200k
150k
100k
50k
0
1 3 5 7 9 11 13 15 17 19 21 23

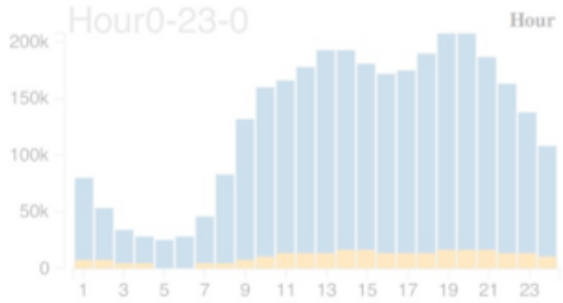

X256-511-4 x Y512-767-4
X512-767-4 x Y512-767-4
X256-511-4 x Y768-1023-4
X256-767-4 x Y768-1023-4
Powered by Leaflet

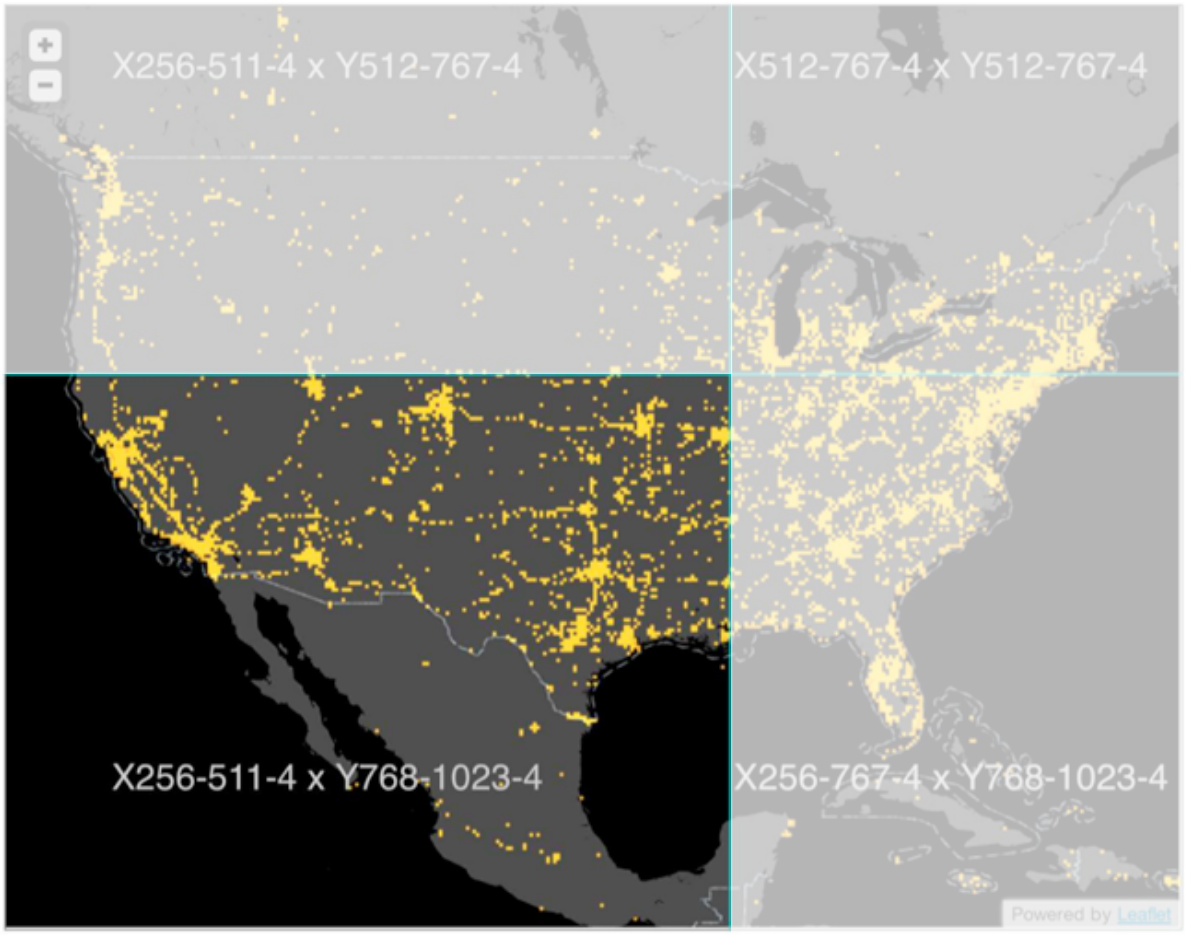

Month
Month0-11-0
300k
250k
200k
150k
100k
50k
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Day
Day0-30-0
100k
80k
60k
40k
20k
0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31
Hour
Hour0-23-0
200k
150k
100k
50k
0
1 3 5 7 9 11 13 15 17 19 21 23


X256-511-4 x Y512-767-4
X512-767-4 x Y512-767-4
X256-511-4 x Y768-1023-4
X256-767-4 x Y768-1023-4
Powered by Leaflet

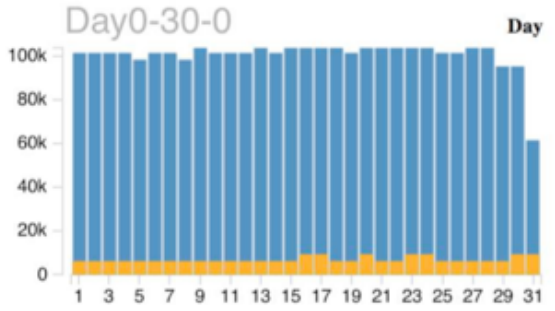

Month
Month0-11-0
300k
250k
200k
150k
100k
50k
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

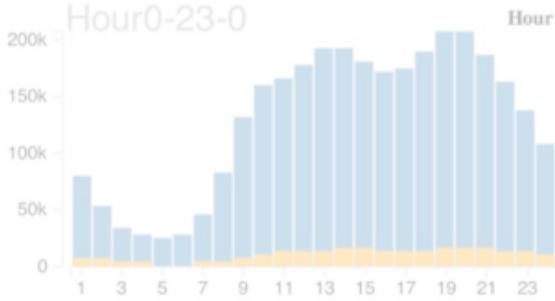

Day0-30-0
Day
100k
80k
60k
40k
20k
0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31

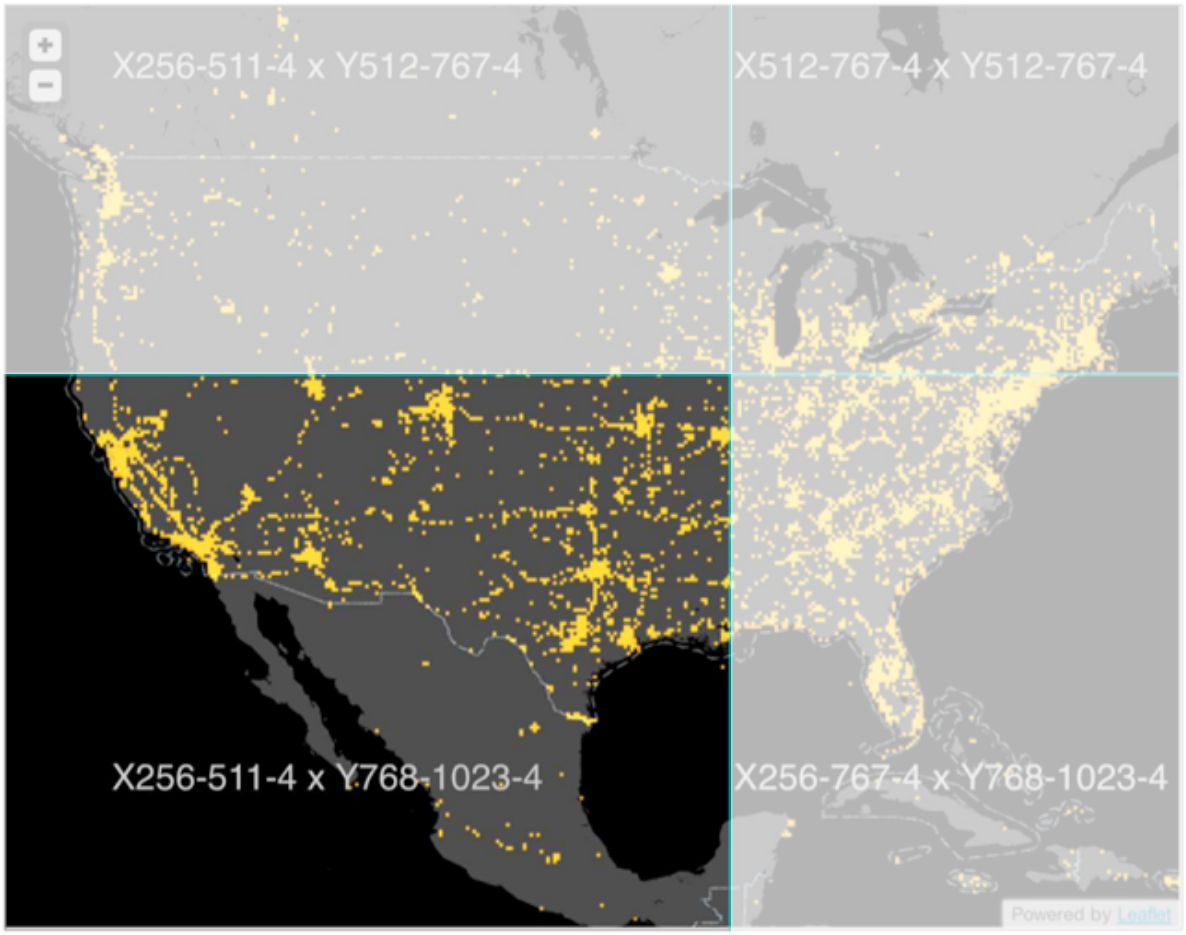

Hour0-23-0
Hour
200k
150k
100k
50k
0
1 3 5 7 9 11 13 15 17 19 21 23


X256-511-4 x Y512-767-4
X512-767-4 x Y512-767-4
X256-511-4 x Y768-1023-4
X256-767-4 x Y768-1023-4
Powered by Leaflet

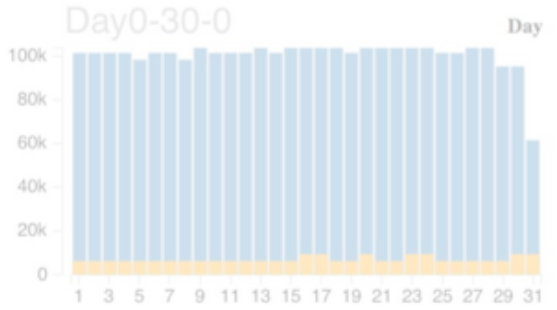

Month
Month0-11-0
300k
250k
200k
150k
100k
50k
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

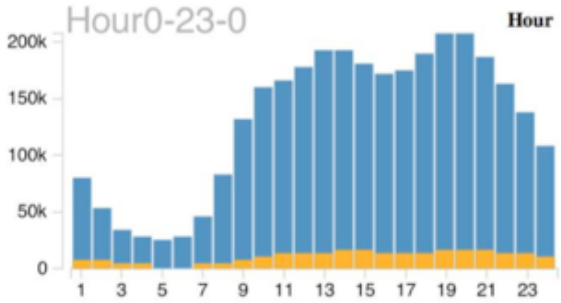

Day0-30-0
Day
100k
80k
60k
40k
20k
0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31

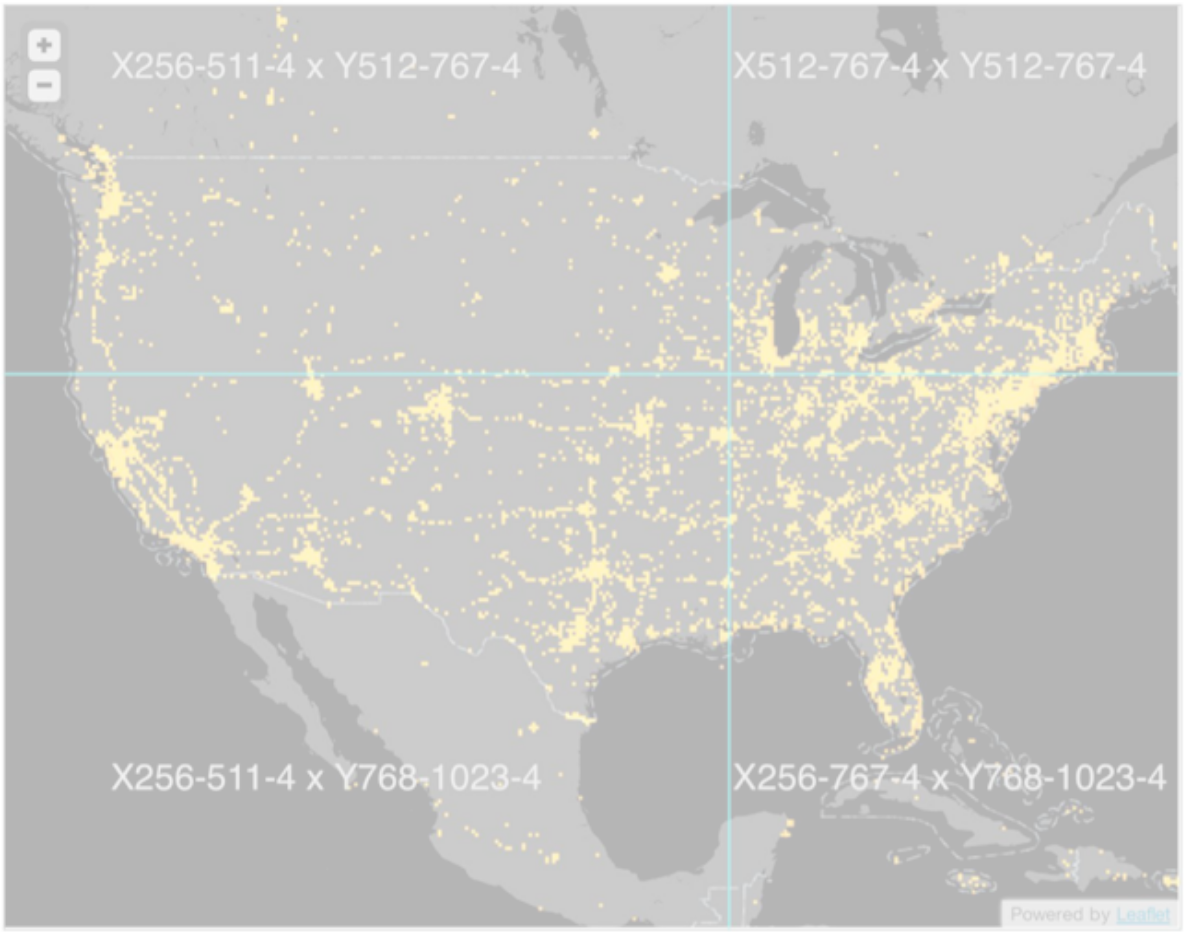

Hour0-23-0
Hour
200k
150k
100k
50k
0
1 3 5 7 9 11 13 15 17 19 21 23

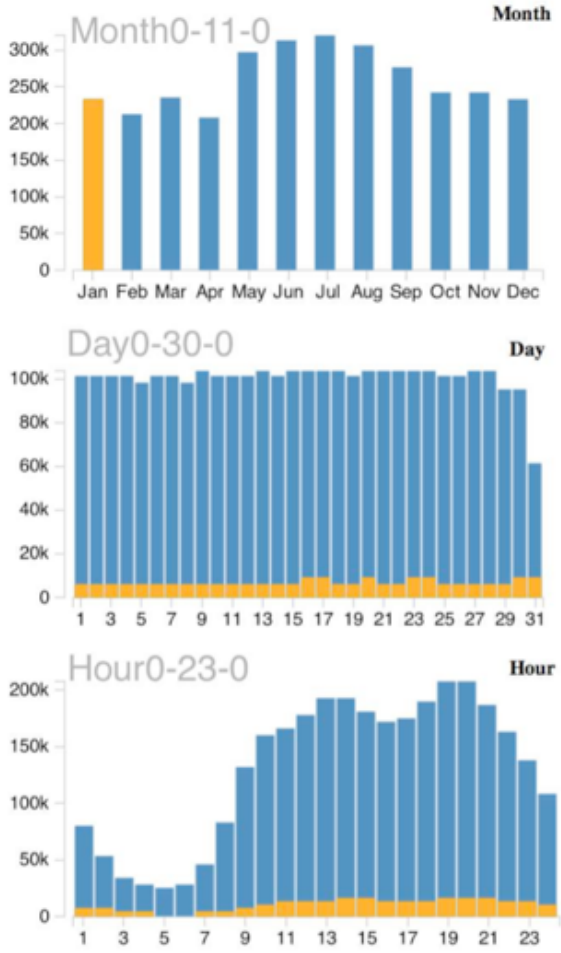

X256-511-4 x Y512-767-4
X512-767-4 x Y512-767-4
X256-511-4 x Y768-1023-4
X256-767-4 x Y768-1023-4
Powered by Leaflet

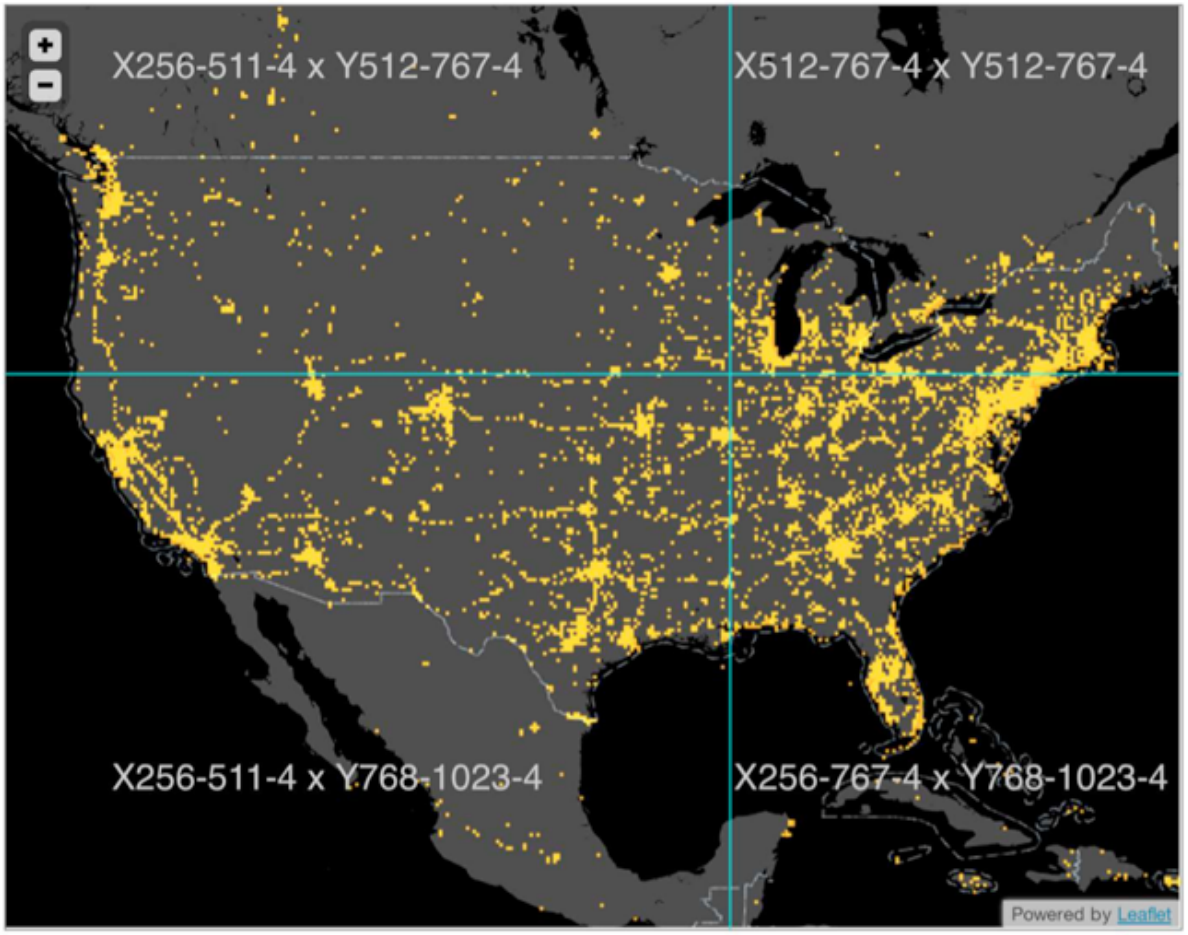

Month
Month0-11-0
300k
250k
200k
150k
100k
50k
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

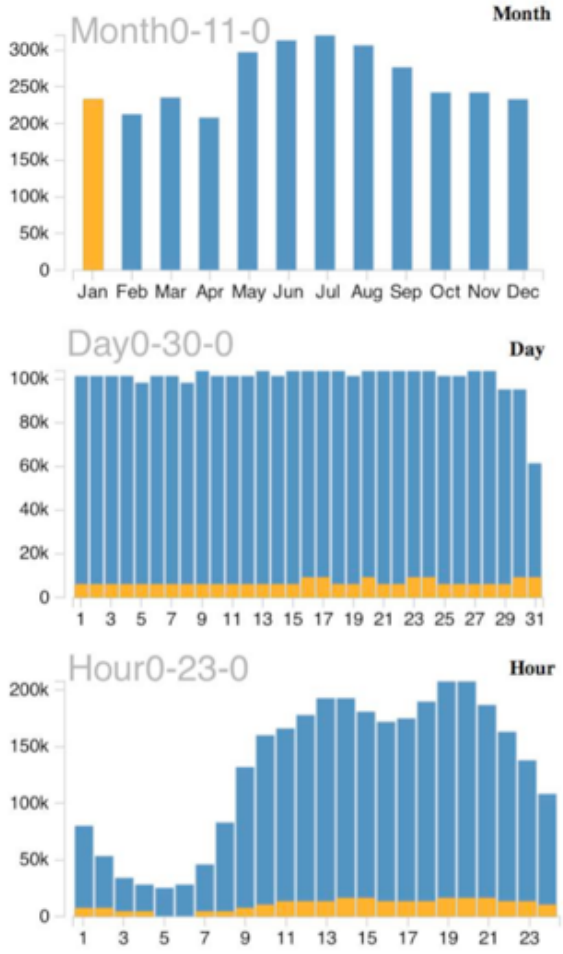

Day0-30-0
Day
100k
80k
60k
40k
20k
0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31


Hour0-23-0
Hour
200k
150k
100k
50k
0
1 3 5 7 9 11 13 15 17 19 21 23

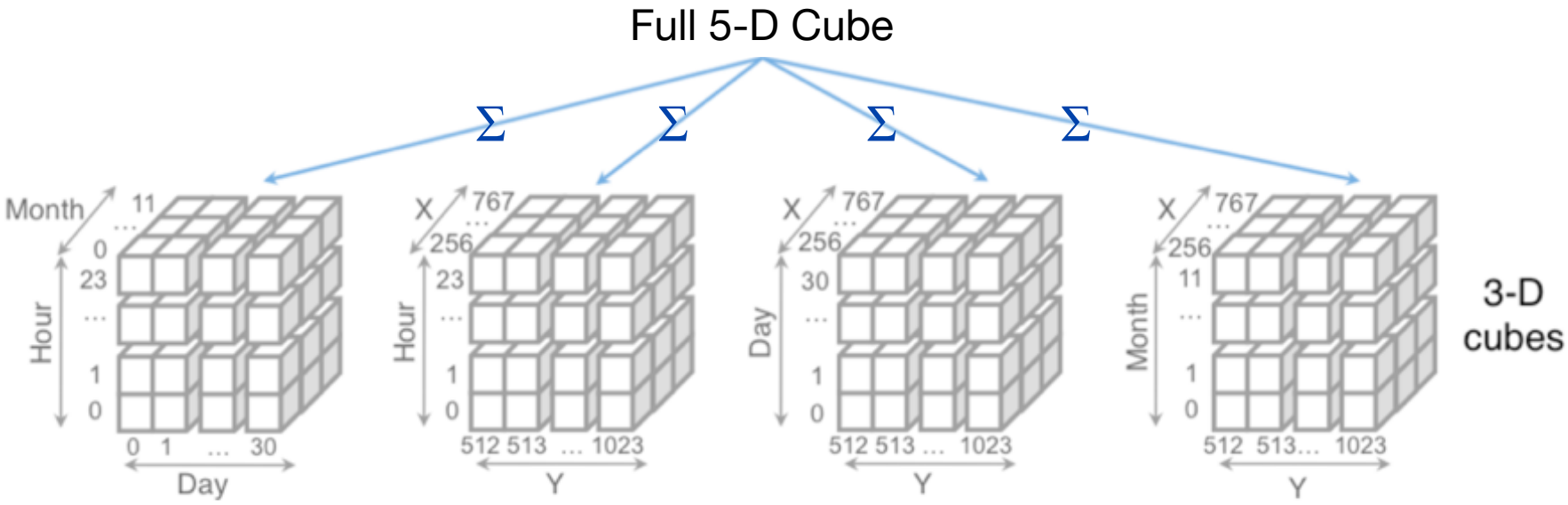

X256-511-4 x Y512-767-4
X512-767-4 x Y512-767-4
X256-511-4 x Y768-1023-4
X256-767-4 x Y768-1023-4
Powered by Leaflet


Month
Month0-11-0
300k
250k
200k
150k
100k
50k
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Day
Day0-30-0
100k
80k
60k
40k
20k
0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31
Hour
Hour0-23-0
200k
150k
100k
50k
0
1 3 5 7 9 11 13 15 17 19 21 23

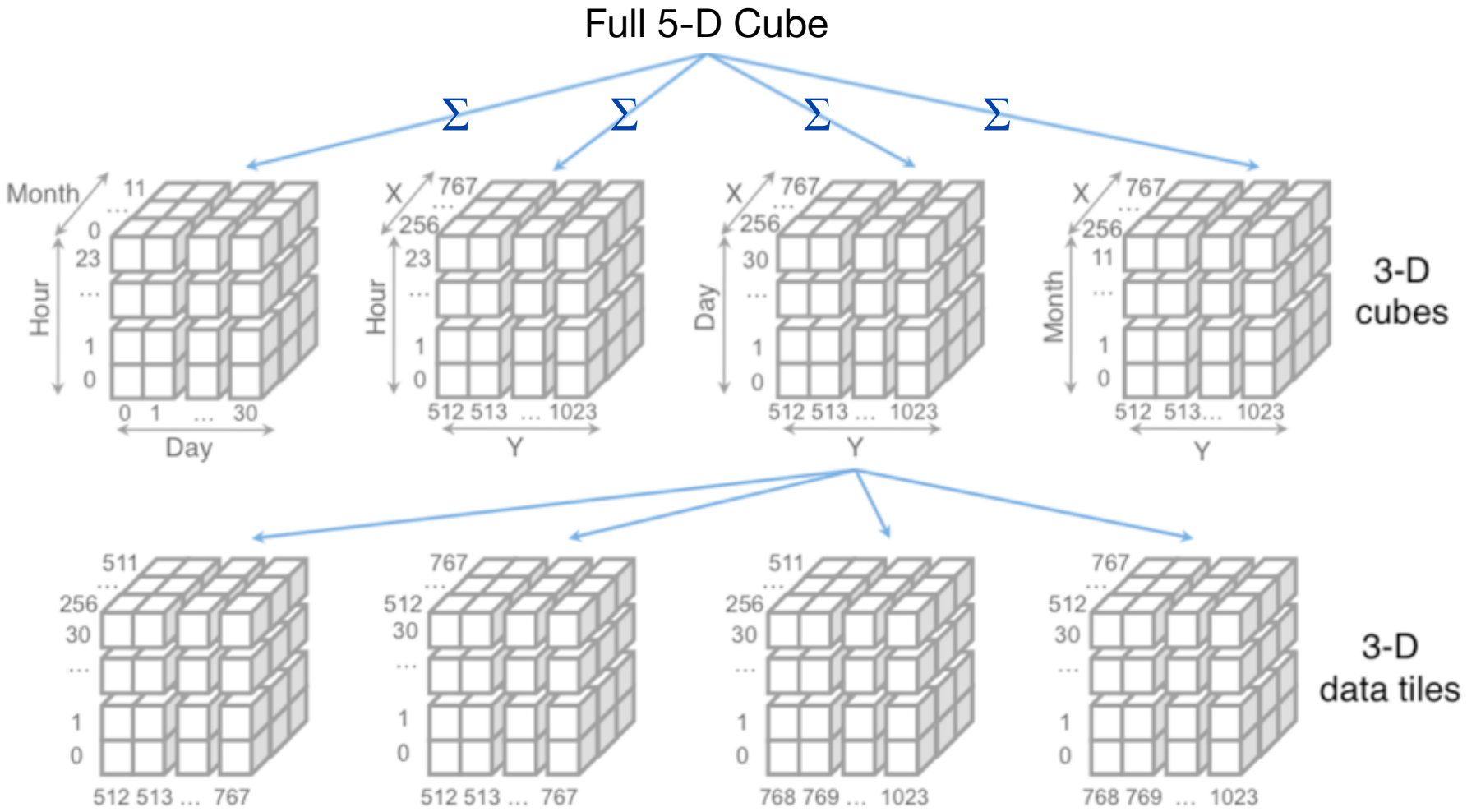

X256-511-4 x Y512-767-4
X512-767-4 x Y512-767-4
X256-511-4 x Y768-1023-4
X256-767-4 x Y768-1023-4
Powered by Leaflet


Month
Month0-11-0
300k
250k
200k
150k
100k
50k
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Day
Day0-30-0
100k
80k
60k
40k
20k
0
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31
Hour
Hour0-23-0
200k
150k
100k
50k
0
1 3 5 7 9 11 13 15 17 19 21 23

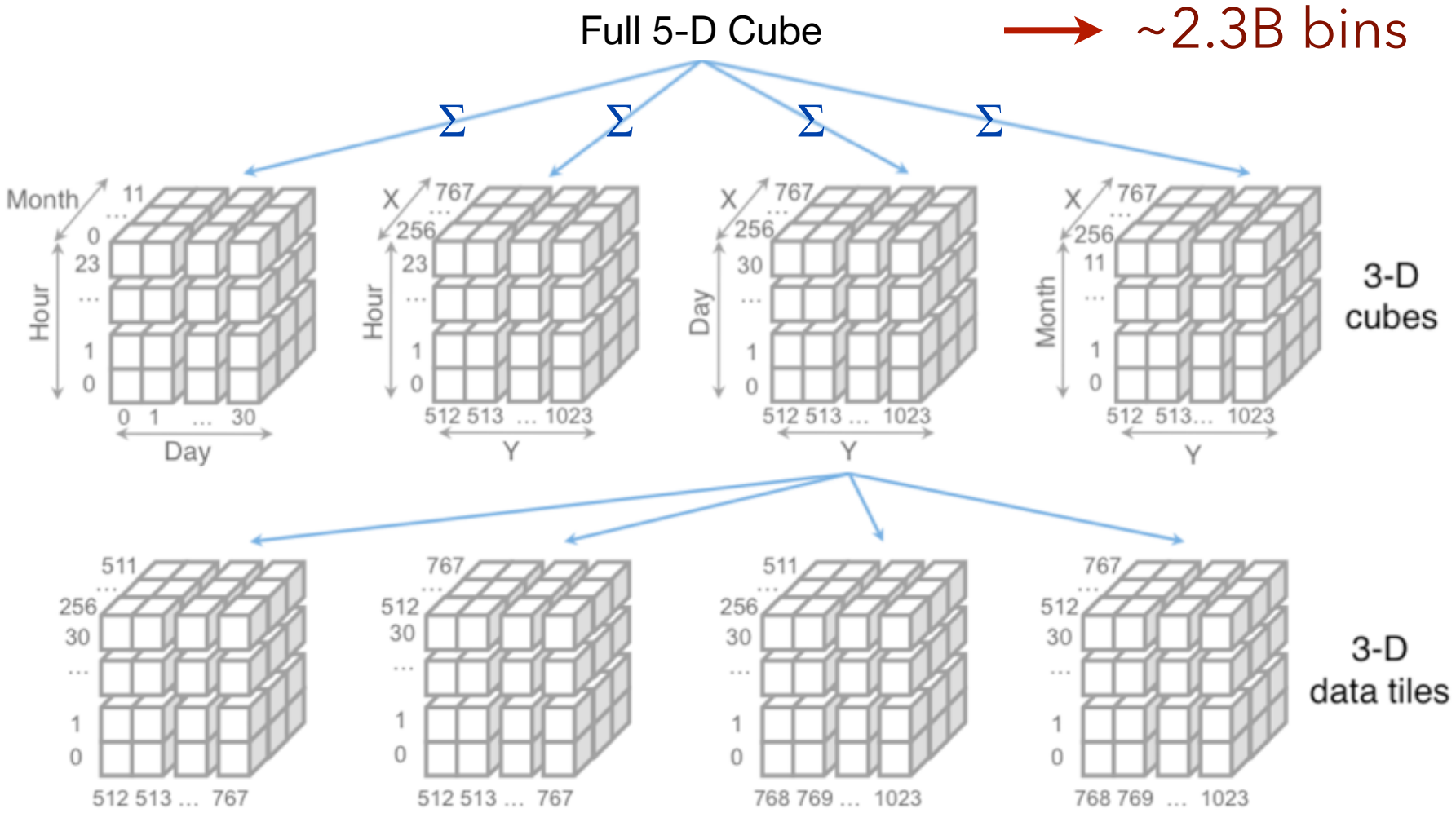
Full 5-D Cube



For any pair of 1D or 2D binned plots, the maximum number of dimensions needed to support brushing & linking is **four**.



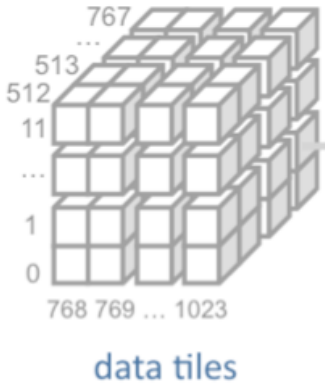
13 3-D Data Tiles


Full 5-D Cube
~2.3B bins
Σ
Σ
Σ
Σ
Month
Hour
Day
X
Hour
Y
X
Day
Y
X
Month
Y
3-D cubes
3-D data tiles
13 3-D Data Tiles
~17.6M bins
(in 352KB!)

Multivariate Data Tiles

1. Send data, not pixels
2. Embed multi-dim data
3. Parallelize queries (GPU)

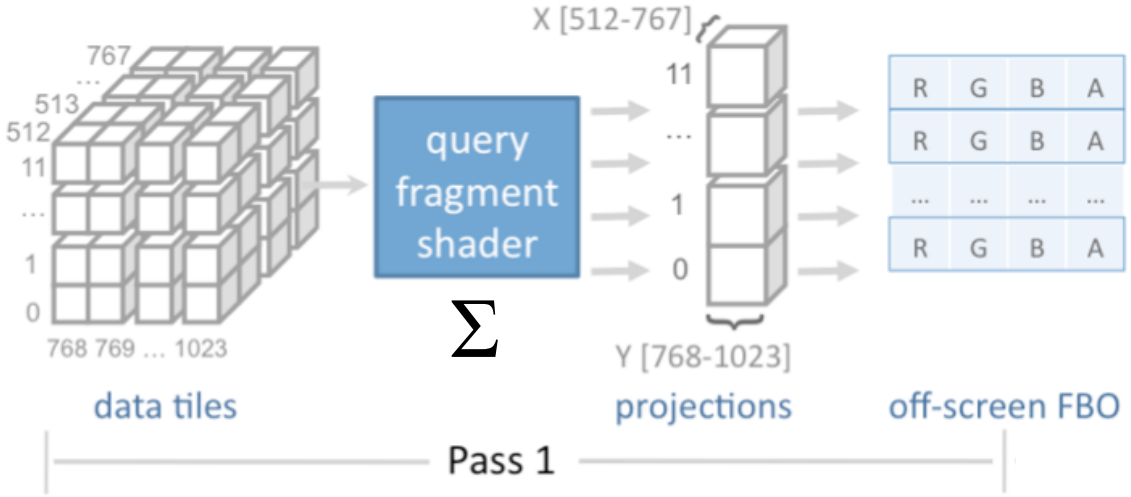
Query & Render on GPU (WebGL)



Pre-compute tiles & send from server.

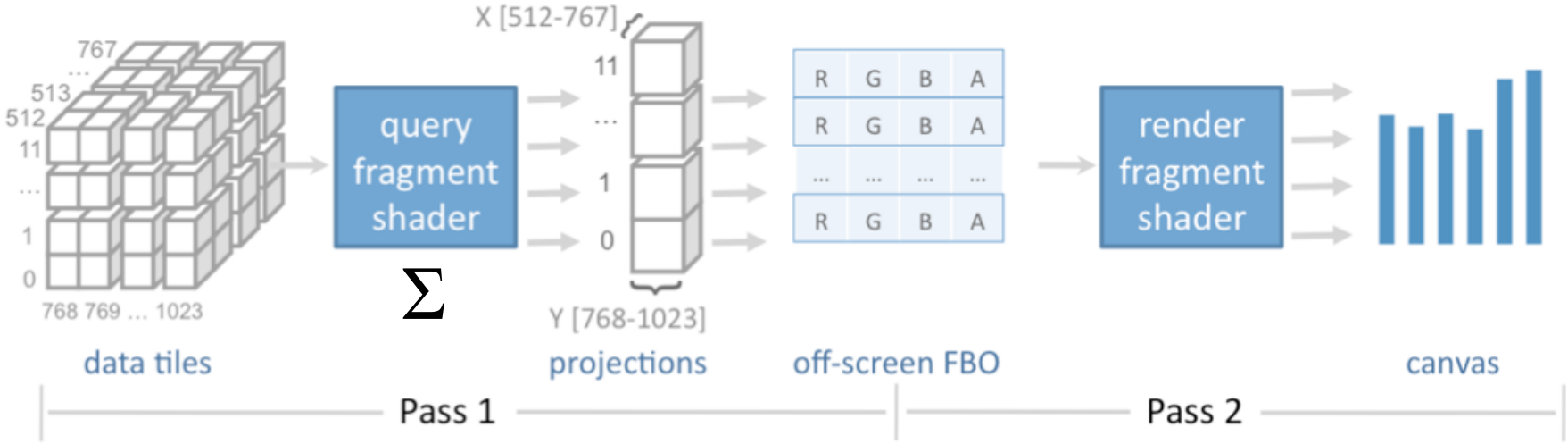
Bind data tiles as image textures.

Query & Render on GPU (WebGL)



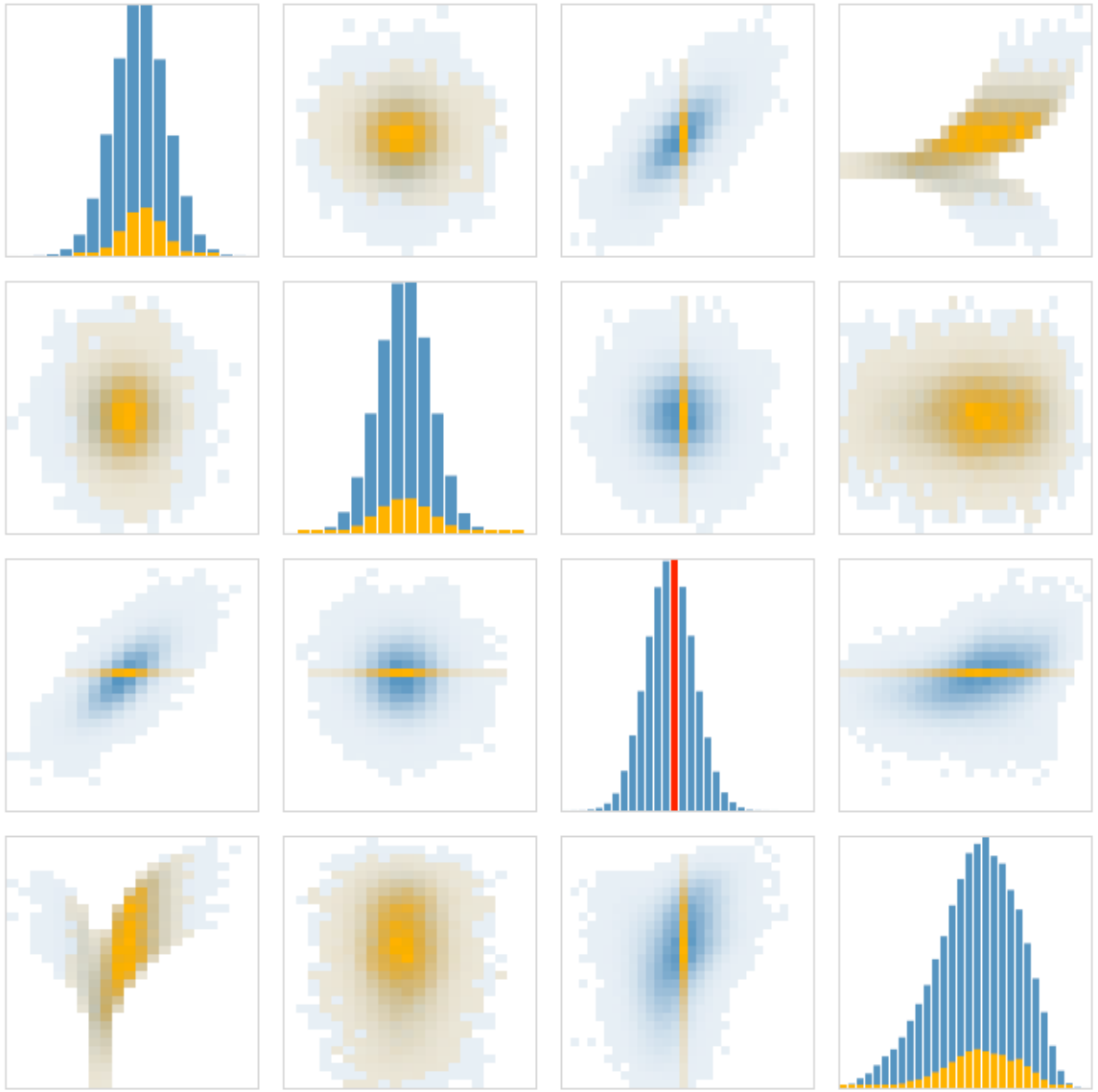
Compute aggregation for each output bin.
Executes in parallel on GPU.

Query & Render on GPU (WebGL)



Accumulate results in offscreen buffer.
Render resulting plots in second pass.

Performance Benchmarks

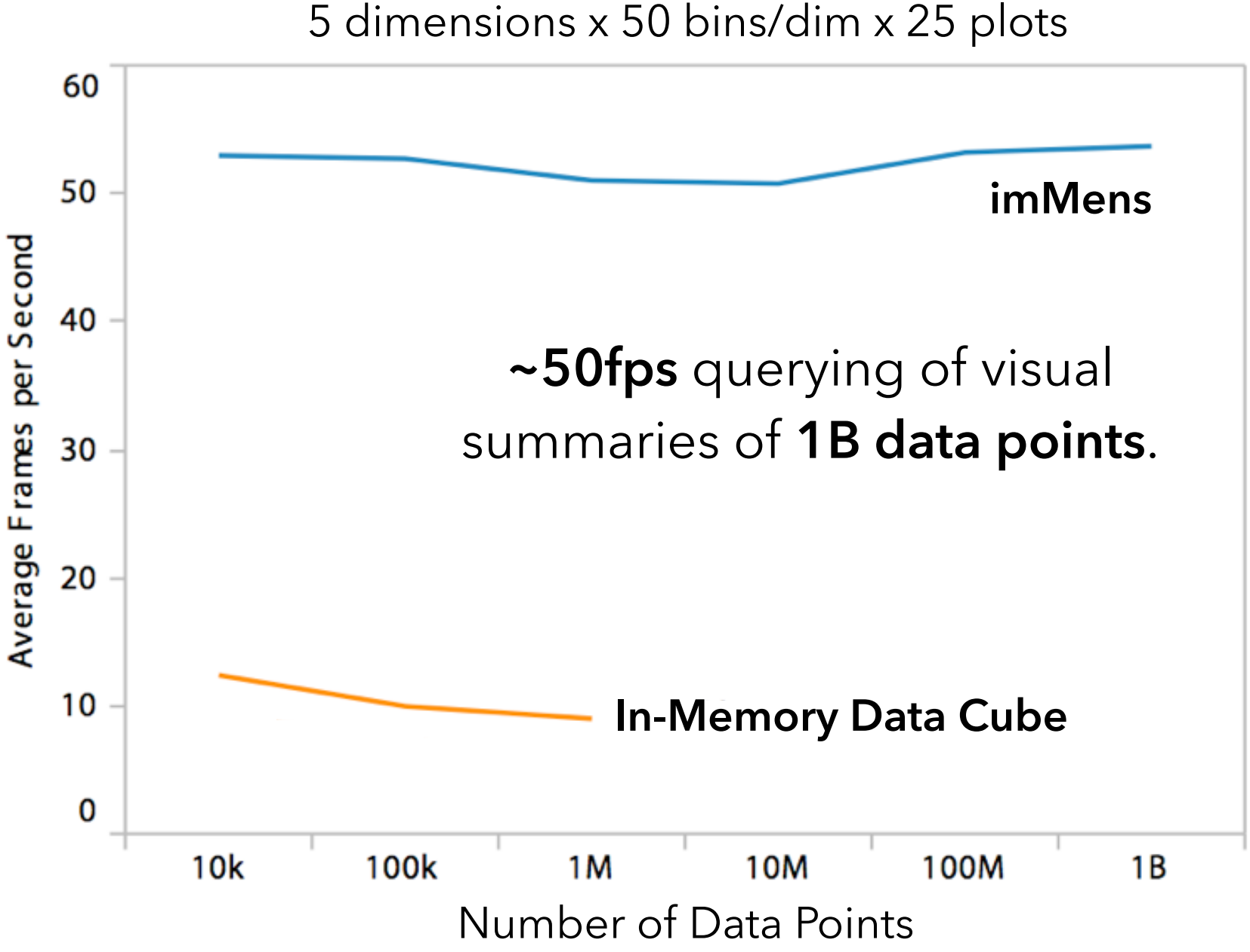


Simulate interaction:
brushing & linking
across binned plots.

- 4x4 and 5x5 plots
- 10 to 50 bins

Measure time from
selection to render.

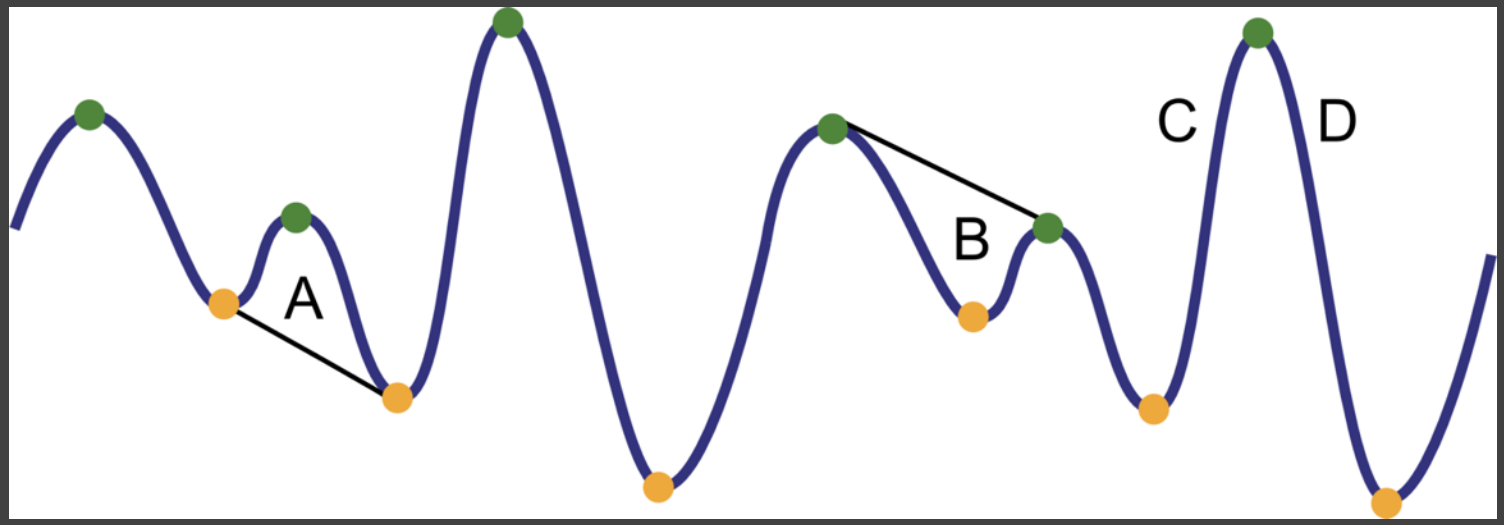
Test setup:
2.3 GHz MacBook Pro
NVIDIA GeForce GT 650M
Google Chrome v.23.0


5 dimensions x 50 bins/dim x 25 plots
60
50
40
30
20
10
0
Average Frames per Second
imMens
~50fps querying of visual summaries of 1B data points.
In-Memory Data Cube
10k
100k
1M
10M
100M
1B
Number of Data Points

Parting Thoughts

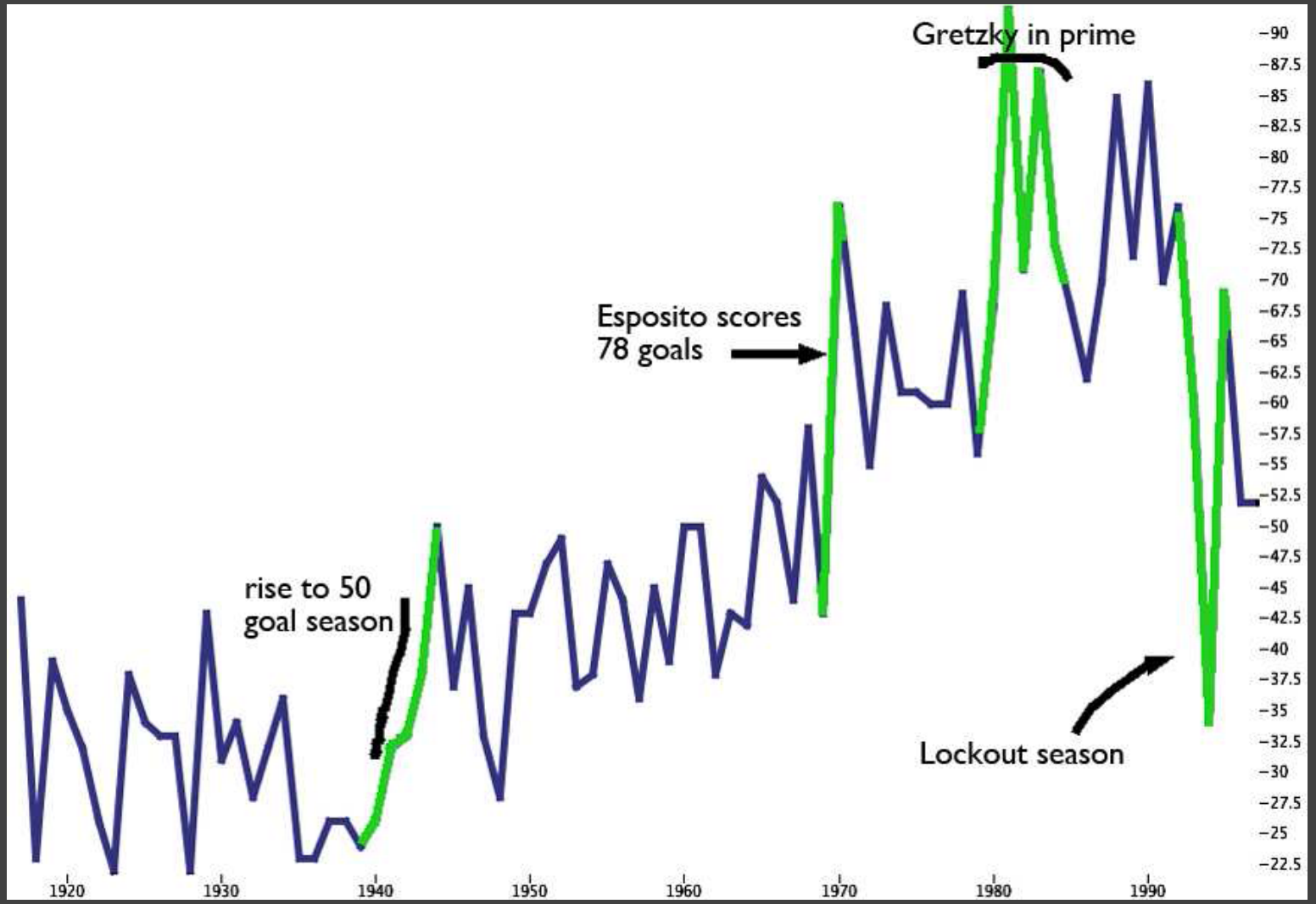
Consider how the structure and/or semantics of the data might be leveraged to aid analysis.

One idea: look beyond data features to incorporate perceptual features of the display.



Peaks, valleys, & slopes

Perceptual Annotation [Kong & agrawala 09]



NHL Goals per Year

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