INTERACTION IN VISUALIZATION

Petra Isenberg

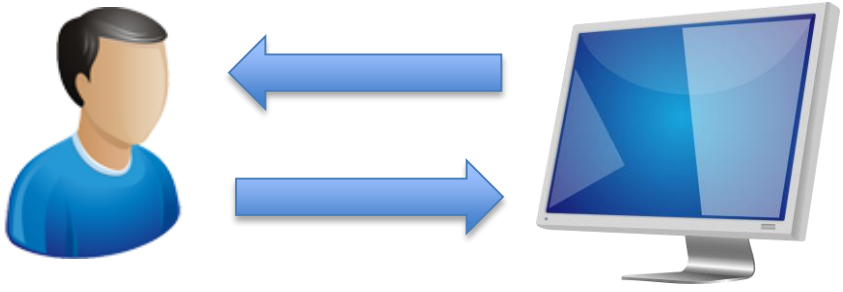
informatics mathematics
Inria

RECAP

- Interaction is fundamental to the definition of visual exploration
- You have already seen examples
  - for graphs
  - for multi-dimensional data

RECAP

- Visual exploration is more than just looking



- So far we focused mostly on output
  - but we have already used limited input earlier in the course
- Today: input for steering visual output

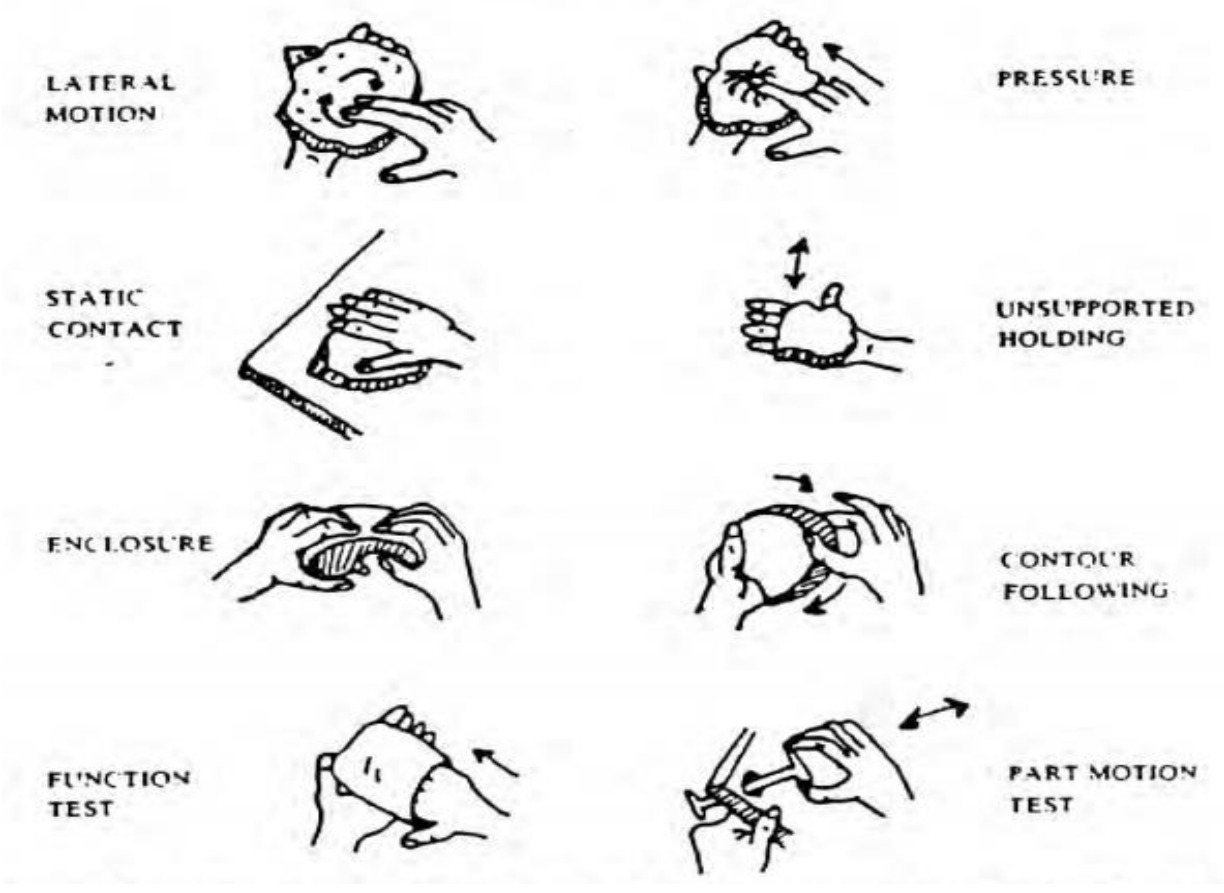
WHY INTERACT?

DEFINITION OF INTERACTION

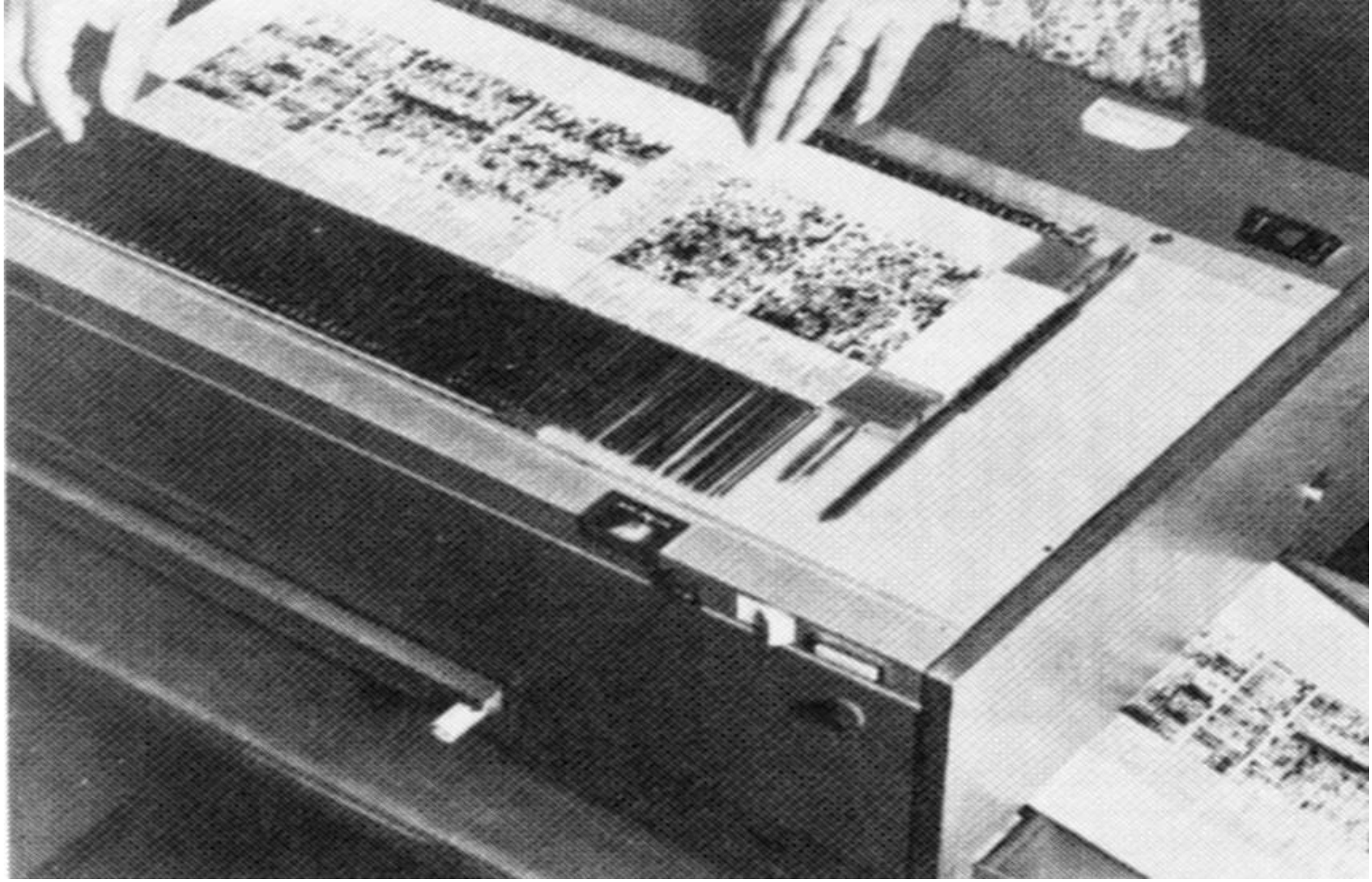
- Static content
  - many infographics

- Dynamic content
  - Animated content
    Changes independently from the user
  - Interactive content
    Changes as a result of user actions

PERCEPTION



LEDERMAN AND KLATZKY, 1987



THERE IS TOO MUCH
DATA TO SHOW

THERE ARE MANY WAYS
TO SHOW IT

LET THE USER DYNAMICALLY CONTROL WHAT TO SHOW AND HOW

NOT TOO LONG AGO...

1970s

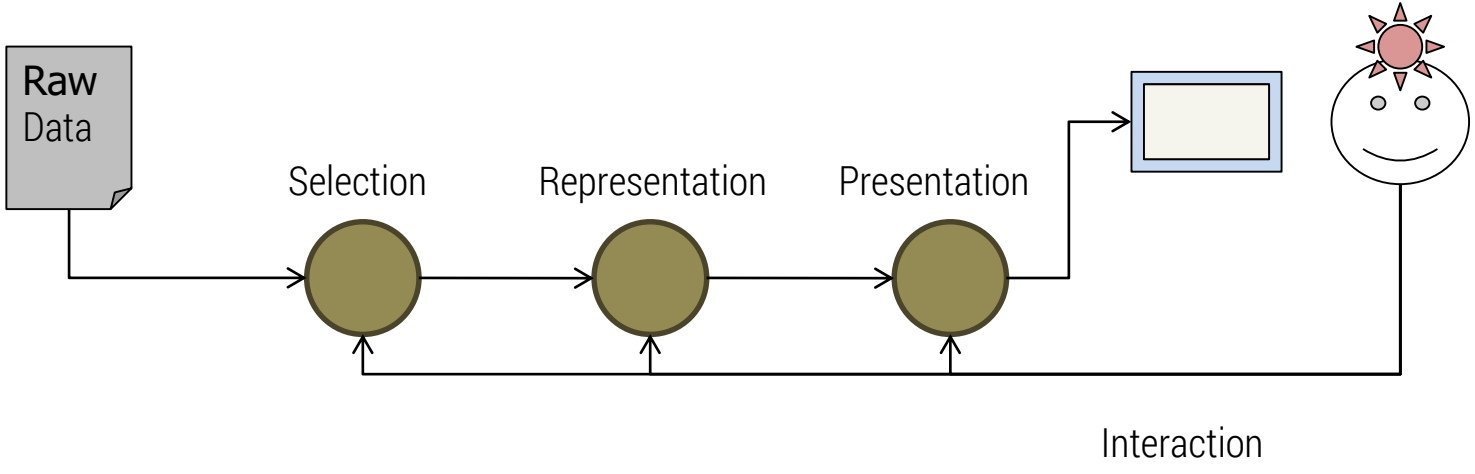
http://www.catb.org/esr/writings/taouu/html/ch02s02.htm
l

TAXONOMIES OF INTERACTION

- What?
  - What is the user doing?
- Why?
  - Why is the user doing it?
- How?
  - How is the user doing it?

THE VISUALIZATION PIPELINE

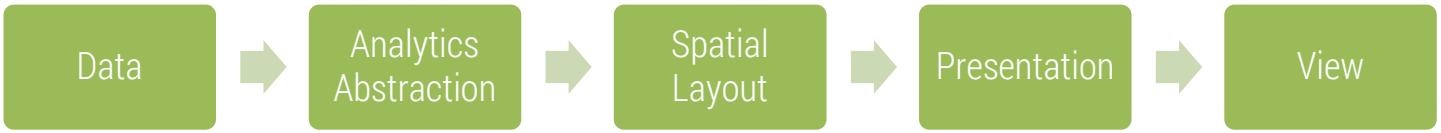
THE VISUALIZATION PIPELINE



The Visualization Pipeline

From [Spence, 2000]

THE VISUALIZATION PIPELINE



Data Transformation

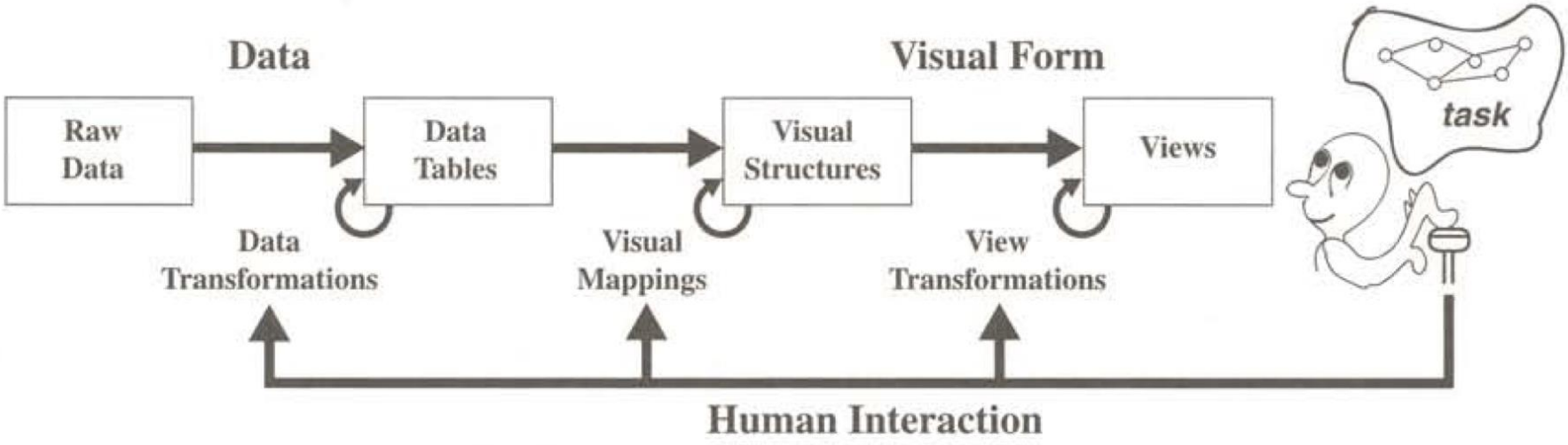
Spatial Mapping Transformation

Presentation Transformation

View Transformation

From [Card et al., Readings in Information Visualization]

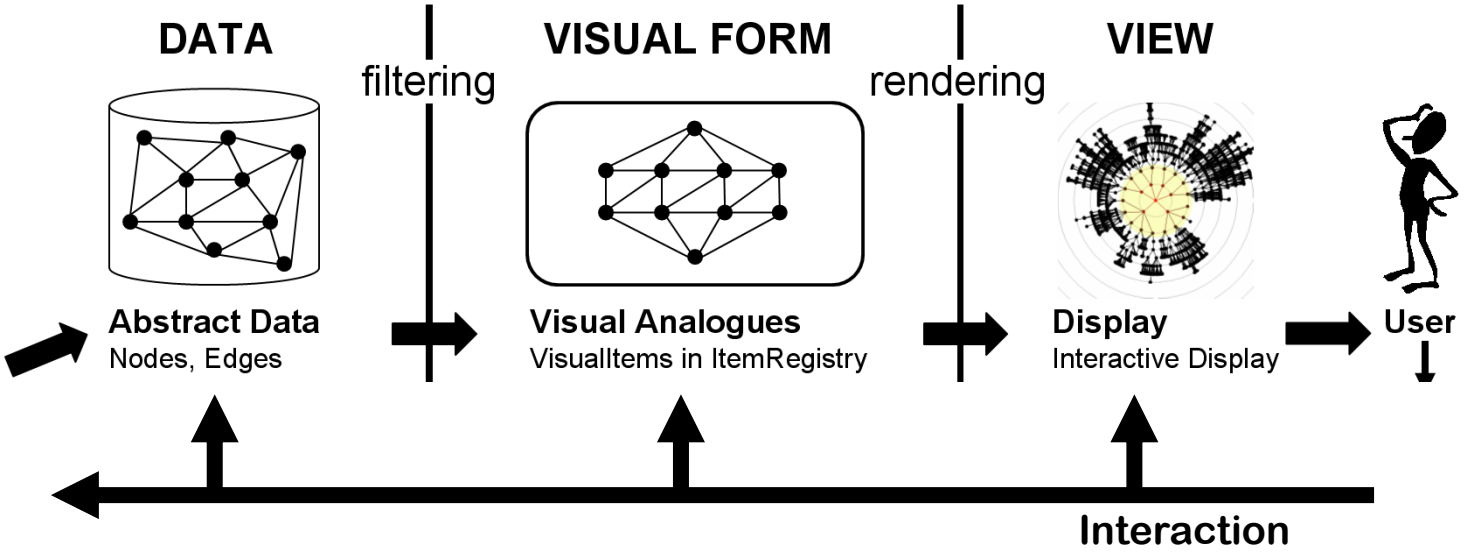
THE VISUALIZATION PIPELINE



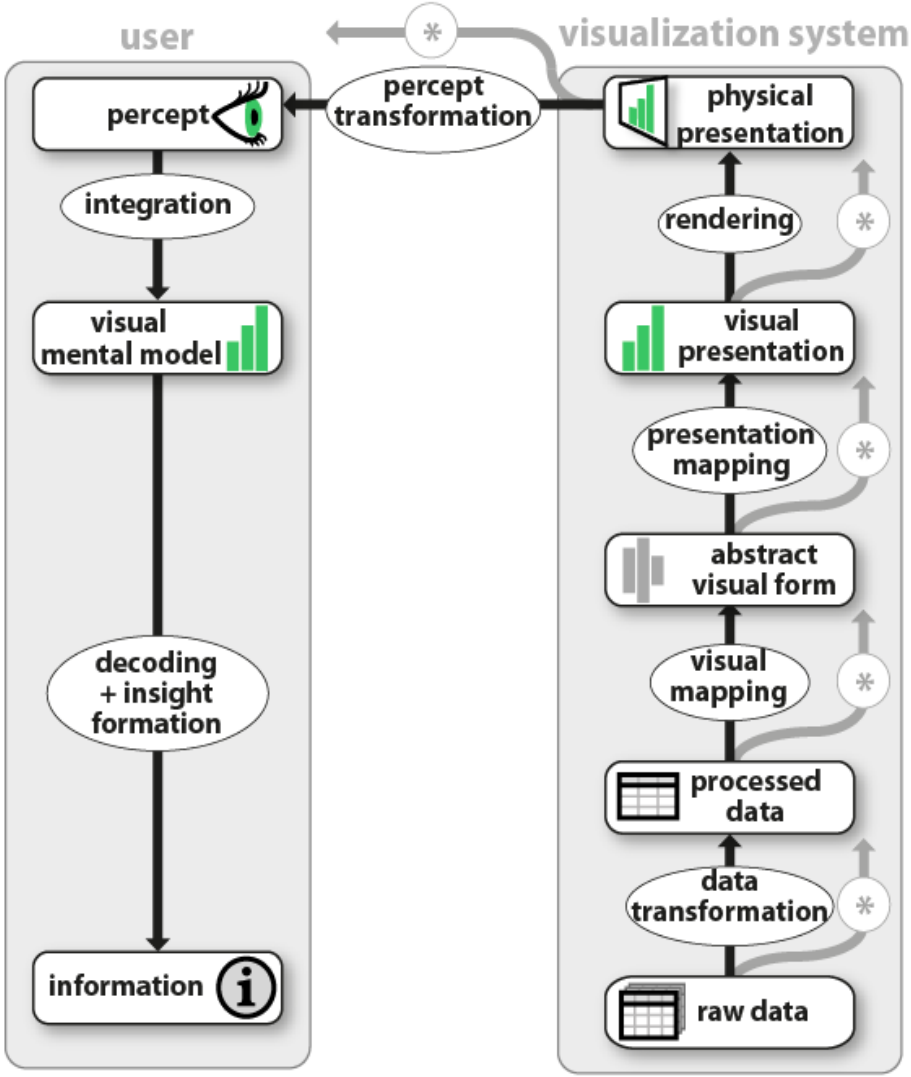
Raw Data: idiosyncratic formats
Data Tables: relations (cases by variables) + metadata
Visual Structures: spatial substrates + marks + graphical properties
Views: graphical parameters (position, scaling, clipping, . . .)

[Card, Mackinlay, Shneiderman, Readings in Information Visualization: Using Vision to Think, 1999]

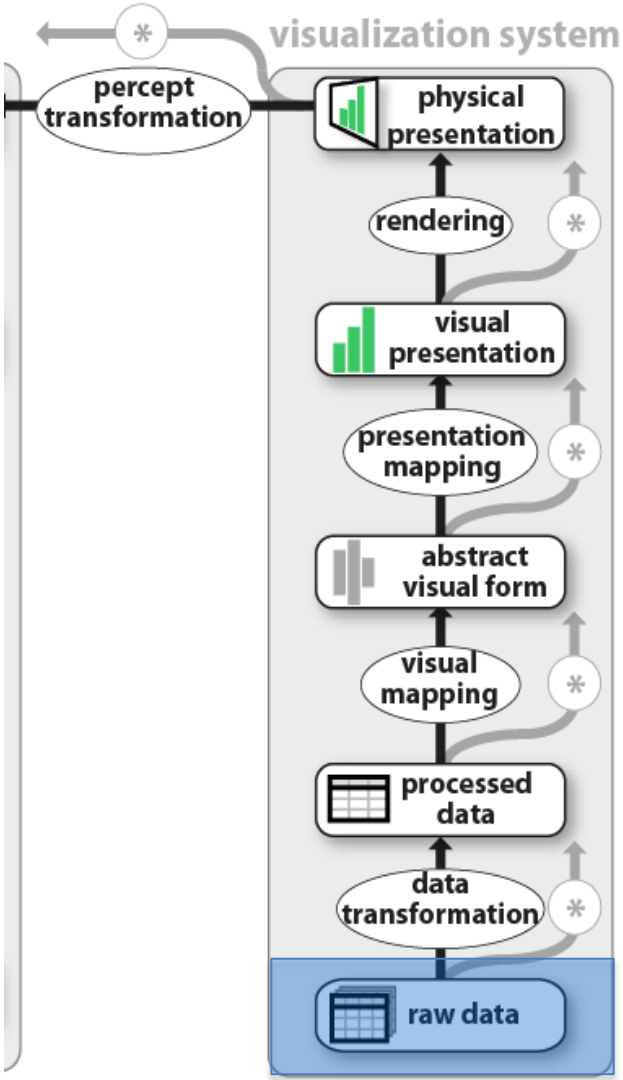
THE VISUALIZATION PIPELINE



From Ed CHI
Illustration by J. Heer



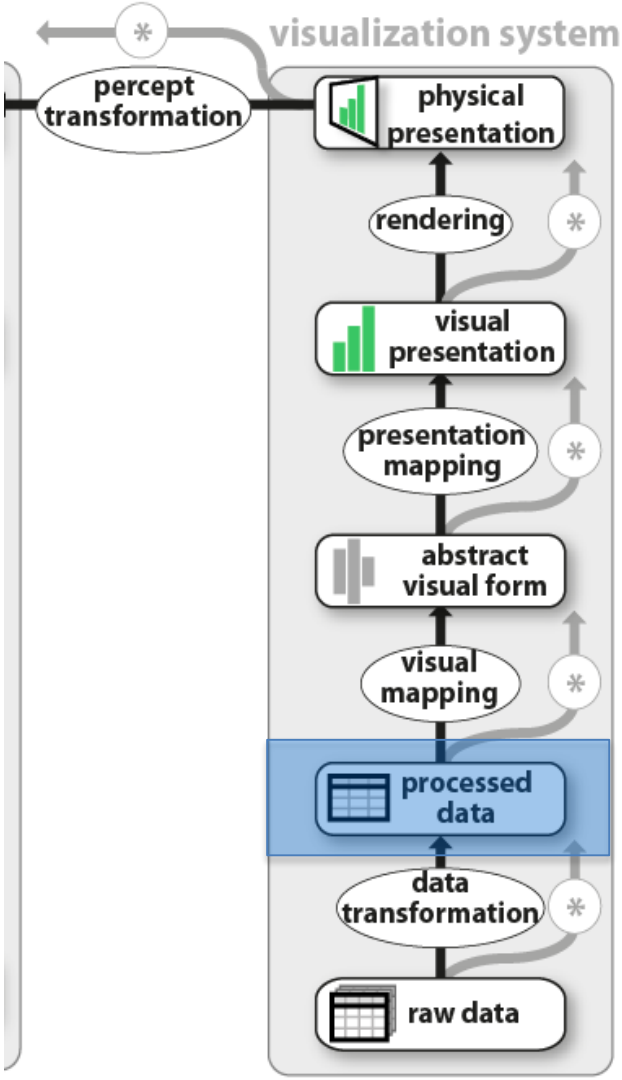
Jansen and Dragicevic 2013 (www.aviz.fr/beyond)



GAPMINDER for a fact-based world view

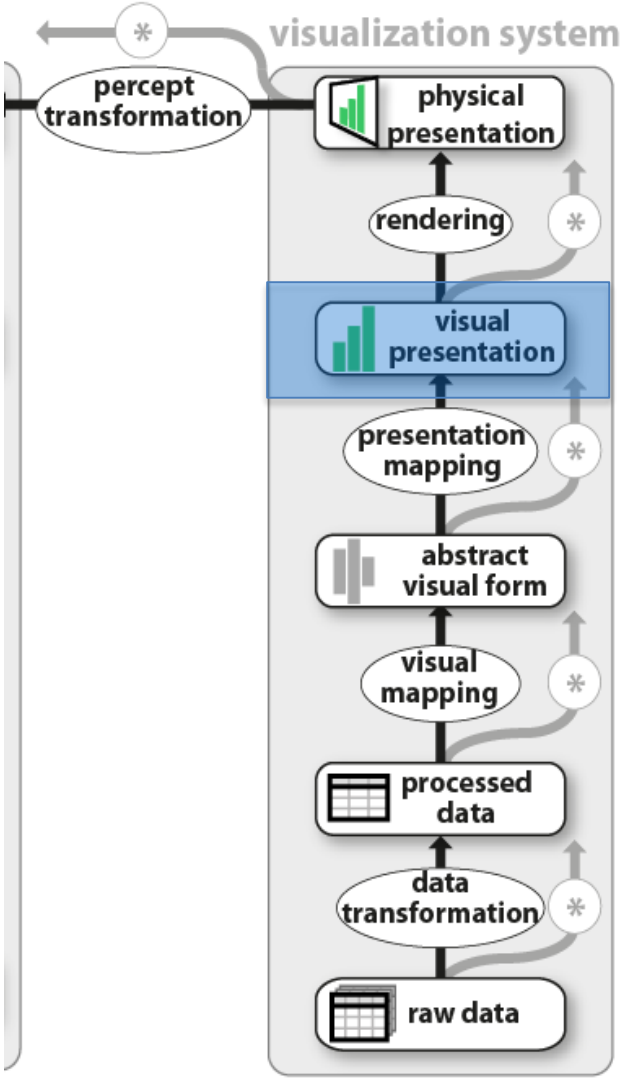
	A	B	C	D	E	F	G	H	I	J	K
1	Education aid (% of total aid)	1967	1968	1969	1970	1971	1972	1973	1974	1975	197
2	Australia					4.75	33.2	19.7	23.7	26.3	30.
3	Austria					24.7	42.3	13.5	2.52	15.9	4.8
4	Belgium					84.5	83.7	11	11.4	15.9	18.
5	Canada					33.7	38.6	18	25.3	8.41	5.1
6	Denmark					100	100	13.7	19	5.6	15.
7	Finland							29.6	13.5	14.1	20.
8	France					62.9	63.7	46.8	33.4	38.2	38.
9	Germany					54.6	54.8	21.7	18.8	23.6	18.
10	Greece										
11	Ireland										
12	Italy					20.1	95.8			39.5	
13	Japan					12.6	12.3	2.92	1.08	2.15	2.5
14	Luxembourg										
15	Netherlands						42	32.6	12.4	15	1
16	New Zealand							19.5	20.9	5.15	8.8
17	Norway					54.7	48.8	32.4	9.71	5.74	7.0
18	Portugal										
19	Spain										
20	Sweden					32.6	23.4	15	13.7	20.7	18.
21	Switzerland					47	46	12	15	8.7	11.
22	United Kingdom					49.8	32.4	15.9	16.2	0.91	0.
23	United States					69.3	64	9.97		7.76	6.1
24											

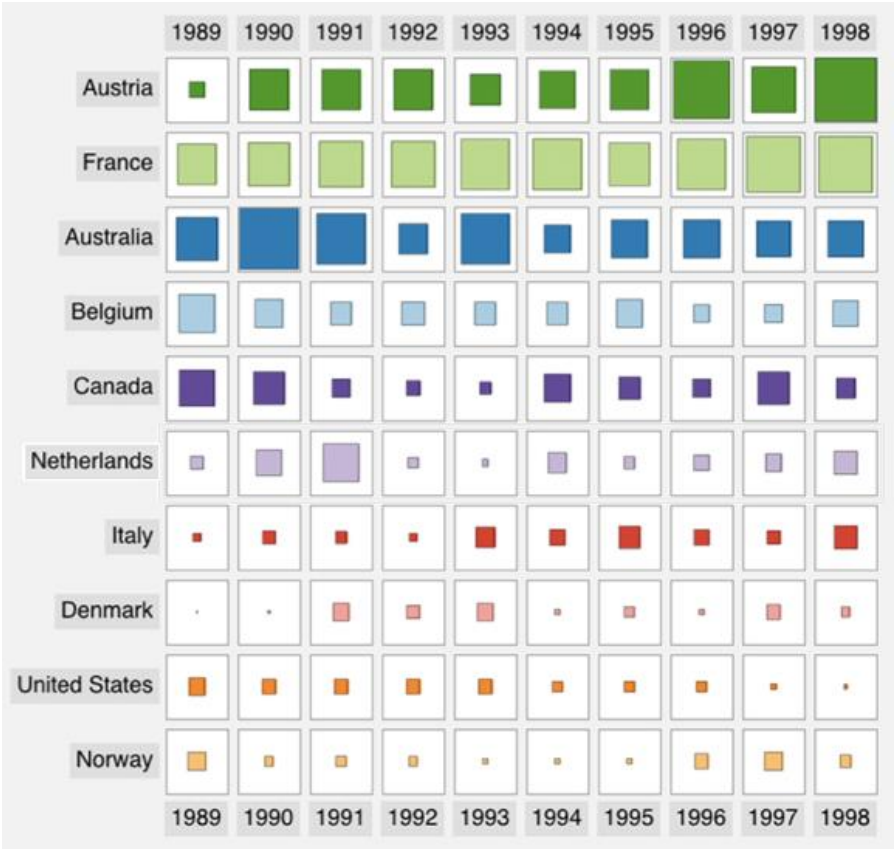
Jansen and Dragicevic 2013 (www.aviz.fr/beyond)



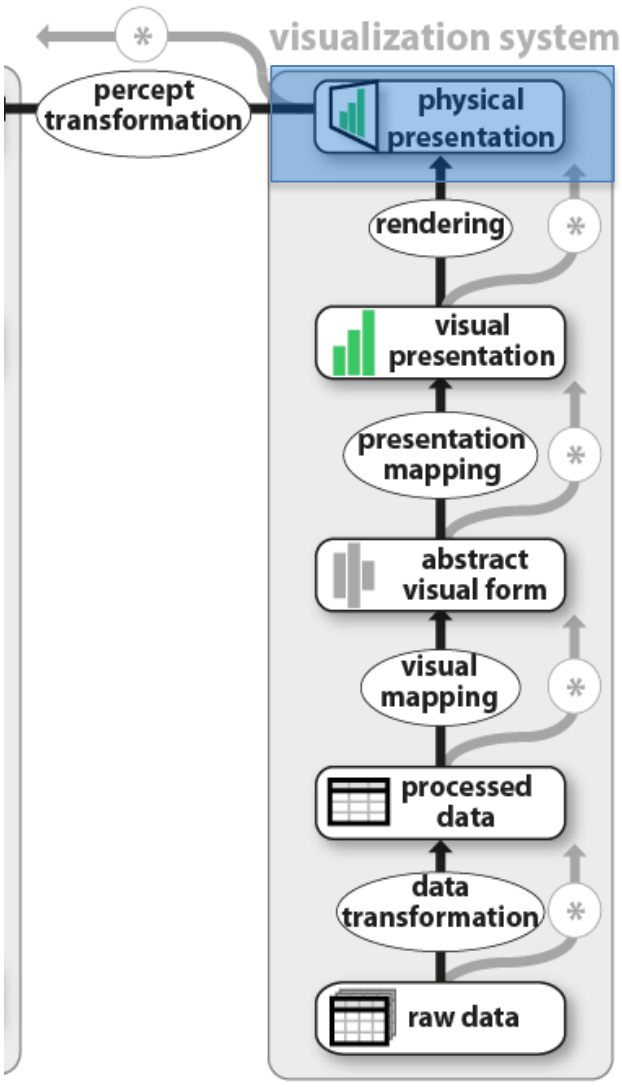
	A	B	C	D	E	F	G	H	I	J	K
1		1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
2	Austria	12.23	31.86	31.07	31.57	24.02	28.61	30.52	44.99	35.41	48.95
3	France	31.87	34.18	35.95	36.06	38.78	40.18	32.68	39.26	43.15	43.9
4	Australia	33.57	46.93	39.24	23.18	38.94	21.38	29.1	29.43	27.97	28.32
5	Belgium	29.93	22.13	17.64	18.52	17.72	17.13	21.77	13.63	14.69	20.38
6	Canada	28.11	25.09	14.35	11.19	9.291	21.67	17.33	13.98	25.19	15.66
7	Netherlands	10.78	20.12	29.08	8.702	5.085	15.12	9.117	12.48	13.75	18.17
8	Italy	6.278	9.992	9.04	6.076	15.66	12.26	16.75	11.75	10.75	17.98
9	Denmark	1.485	1.933	13.52	10.71	13.01	4.193	7.937	4.303	11.42	7.581
10	United States	13.69	11.25	11.22	11.22	11.22	7.992	8.465	8.409	4.702	3.038
11	Norway	14.25	7.561	8.219	7.255	3.967	4.307	4.476	10.99	14.62	9.296

Jansen and Dragicevic 2013 (www.aviz.fr/beyond)





Jansen and Dragicevic 2013 (www.aviz.fr/beyond)



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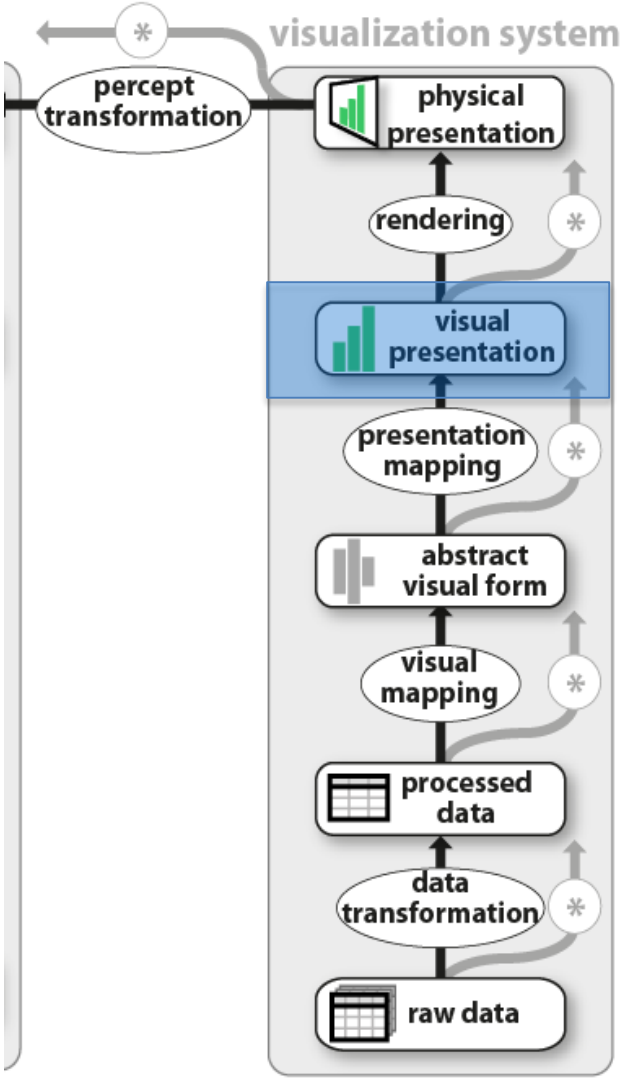
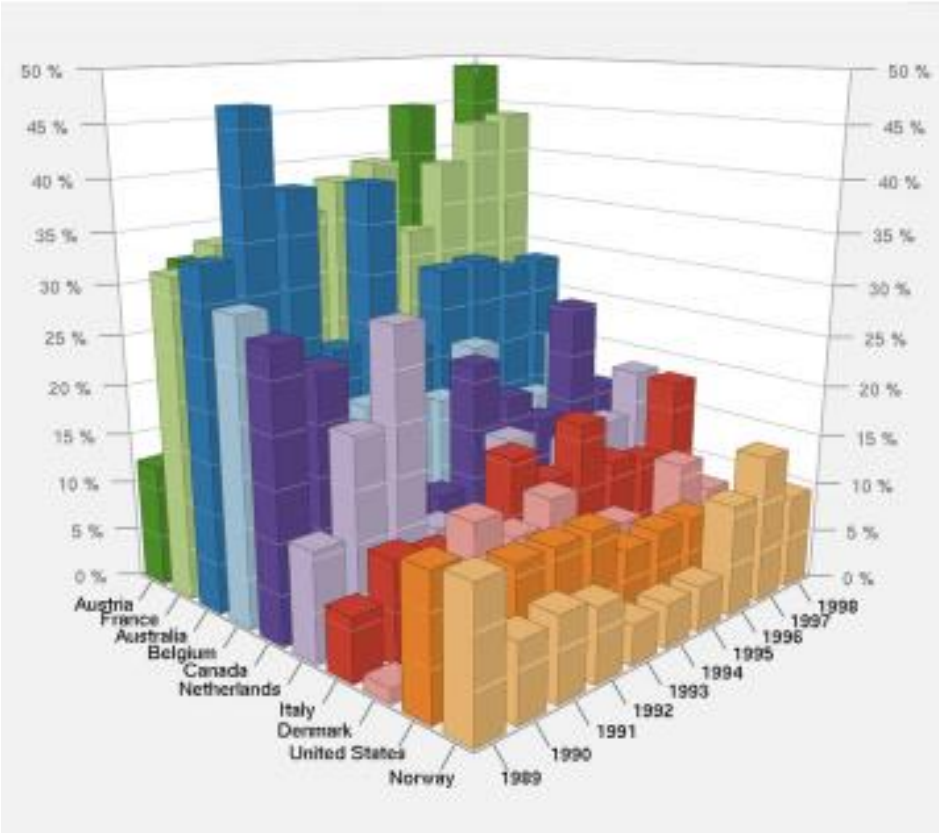
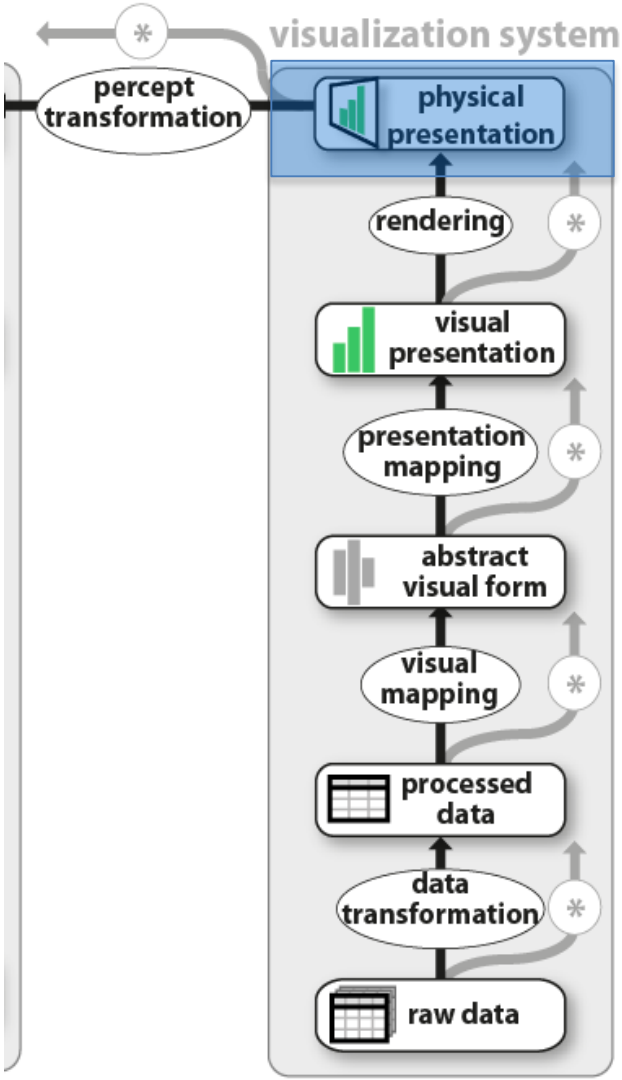
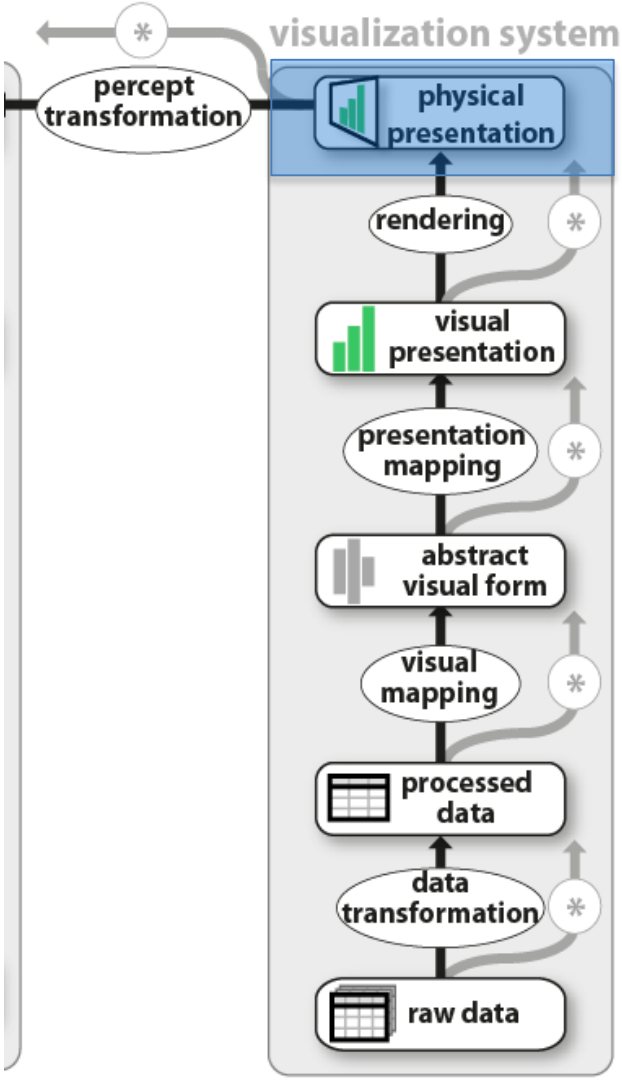


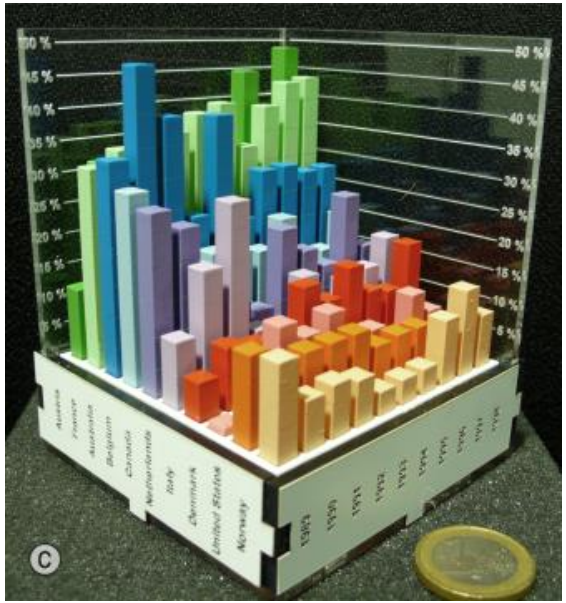


Jansen and Dragicevic 2013 (www.aviz.fr/beyond)



Jansen and Dragicevic 2013 (www.aviz.fr/beyond)





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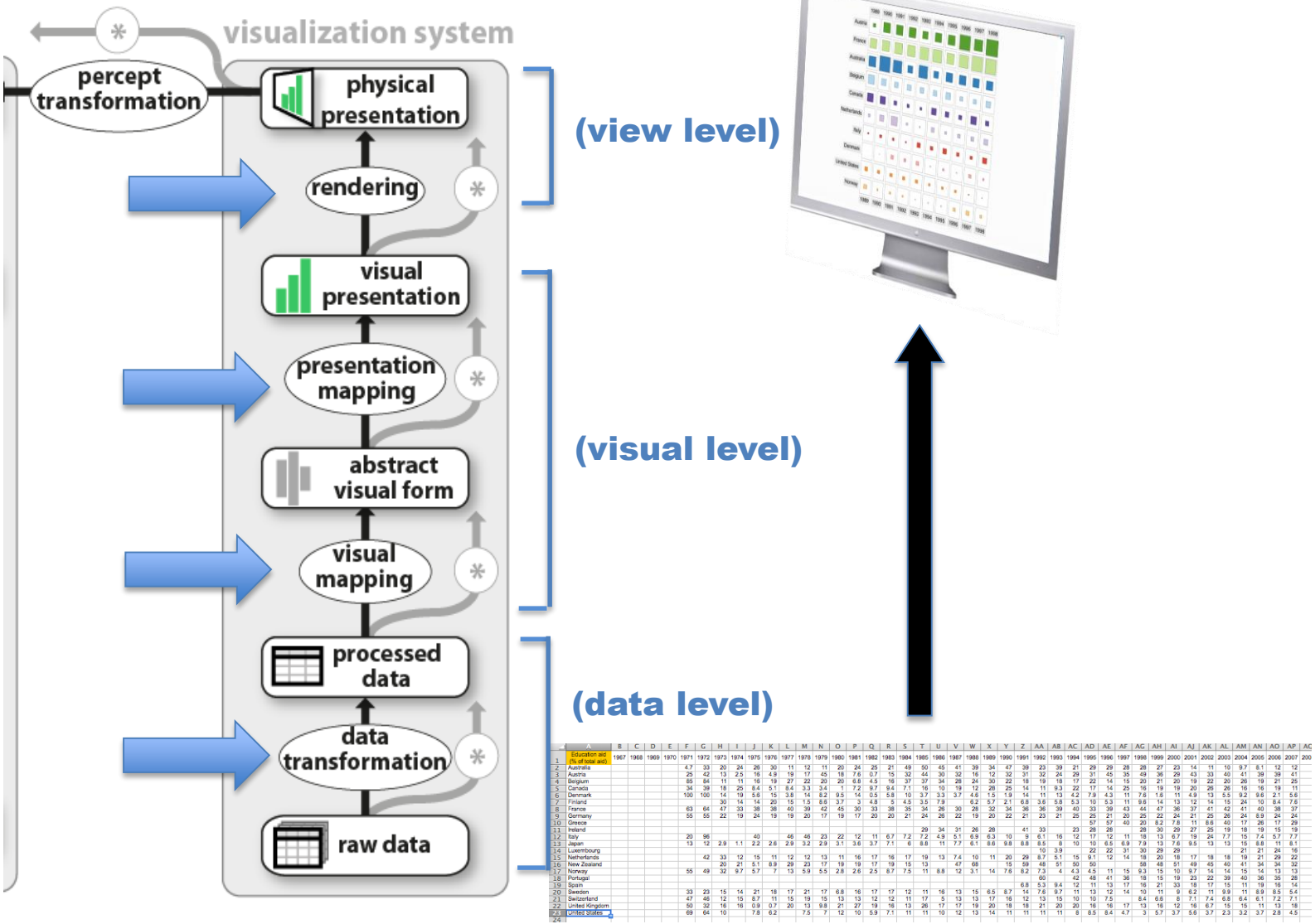


Jansen and Dragicevic 2013 (www.aviz.fr/beyond)

TAXONOMIES OF INTERACTION

- What?
  - What is the user doing?
- Why?
  - Why is the user doing it?

Tasks

- How?
  - How is the user doing it?

INTERACTION AS TASKS

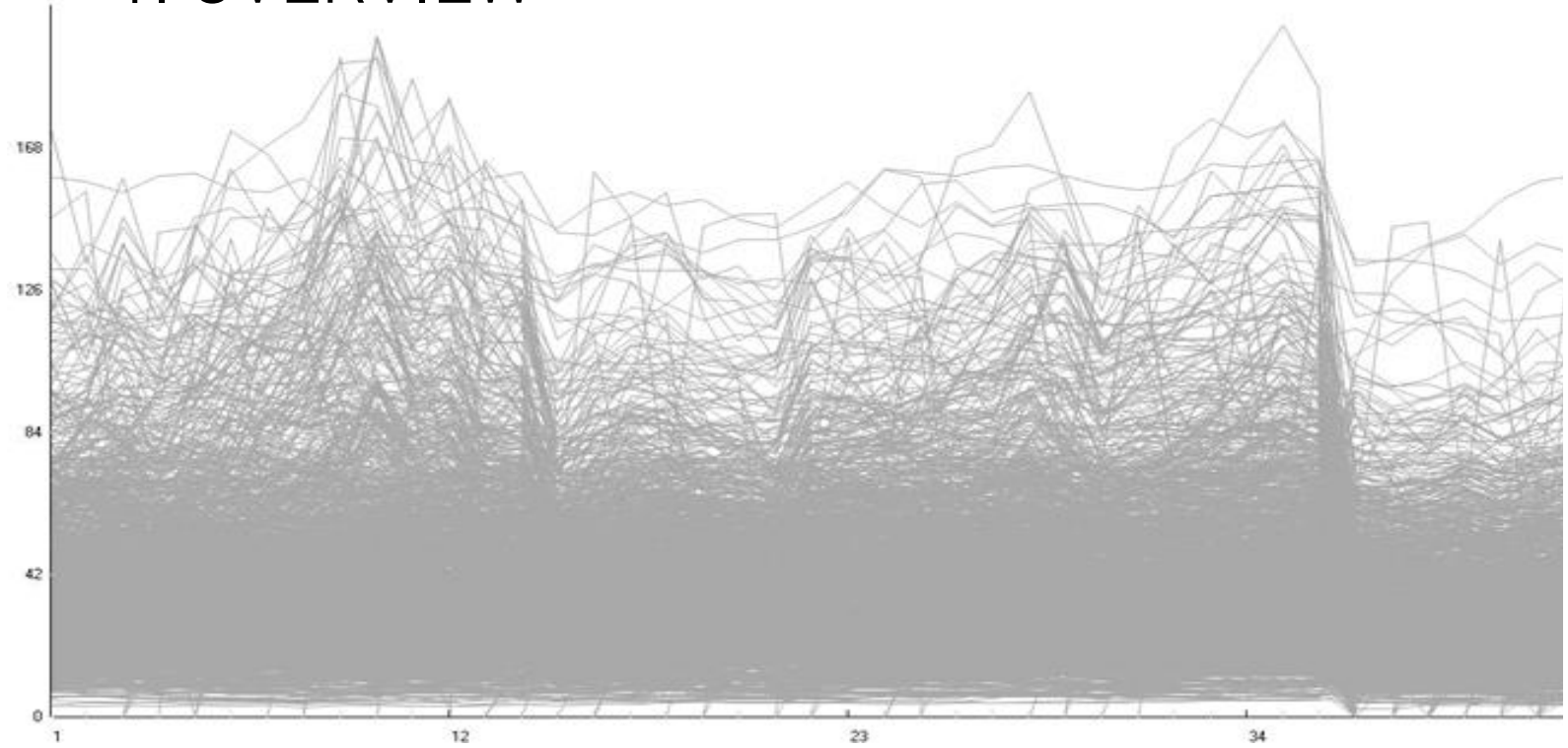
ANALYTIC TASKS

BEN SHNEIDERMAN 1996

1. OVERVIEW: GAIN AN OVERVIEW OF THE ENTIRE COLLECTION
2. ZOOM: ZOOM IN ON ITEMS OF INTEREST
3. FILTER: FILTER OUT UNINTERESTING ITEMS
4. DETAILS-ON-DEMAND: SELECT AN ITEM OR GROUP AND GET DETAILS WHEN NEEDED
5. RELATE: VIEW RELATIONSHIPS AMONG ITEMS
6. HISTORY: KEEP PAST ACTIONS FOR UNDO, REPLAY, AND PROGRESSIVE REFINEMENT
7. EXTRACT: ALLOW EXTRACTION OF SUB-COLLECTIONS AND QUERY PARAMETERS.

ANALYTICAL TASKS

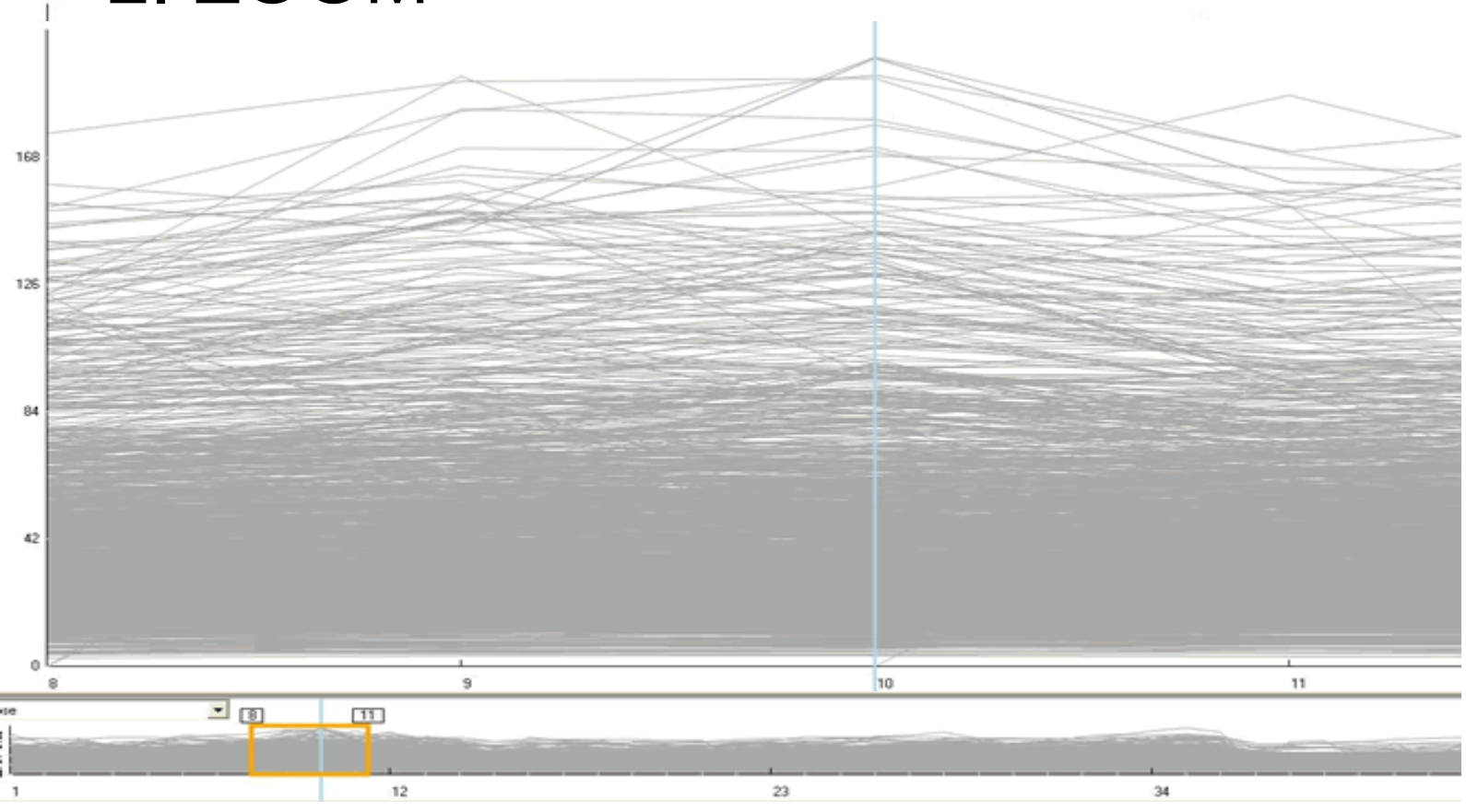
1. OVERVIEW



STEPHEN FEW, 2006 (LINK) SOFTWARE: TIMESEARCH

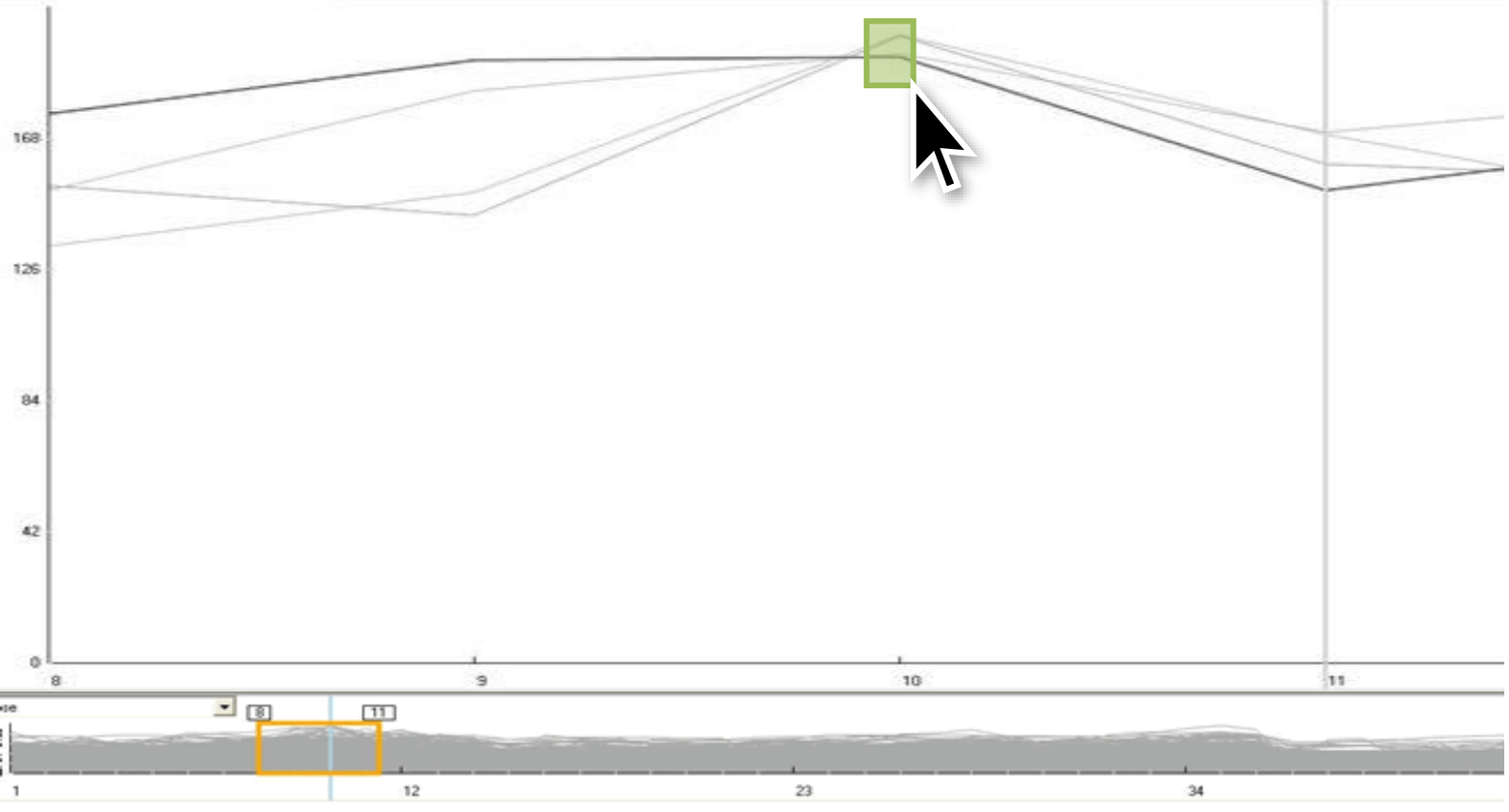
ANALYTICAL TASKS

2. ZOOM



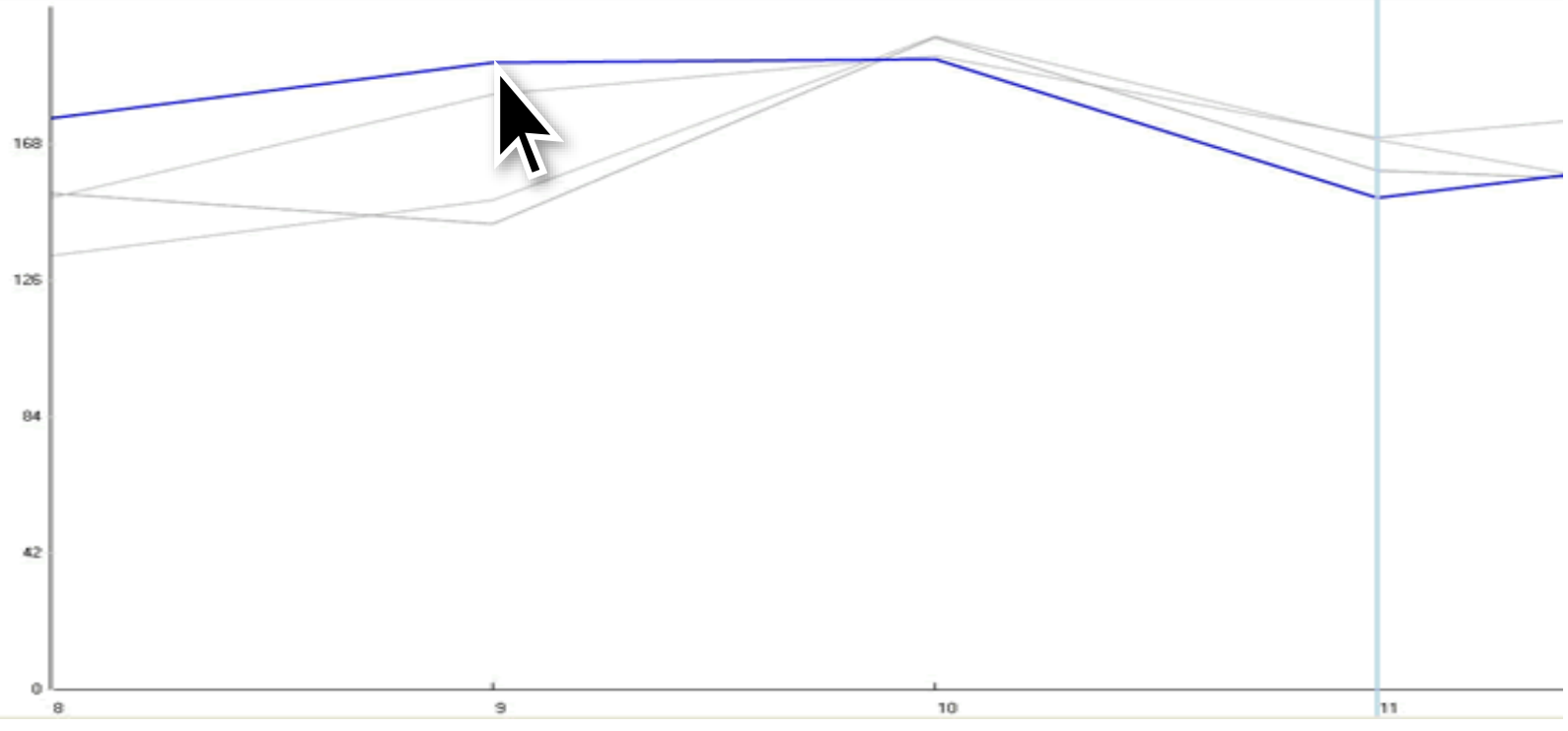
ANALYTICAL TASKS

3. FILTER



ANALYTICAL TASKS

4. DETAILS ON DEMAND



	Name [...	Close
1		74.06
2		86.25
3		102.75
4		100.50
5		143.31
6		160.31
7		168.94
8		175.88
9		193.00
10		194.00
11		151.38
12		167.81
13		112.88
14		126.38
15		89.00
16		119.00
17		145.50
18		139.25
19		132.38
20		122.13
21		104.94
22		140.00
23		150.63
24		161.50
25		159.50
26		133.50
27		130.50
28		149.19
29		138.44
30		108.00
31		102.00
32		99.25
33		111.13
34		139.56
35		131.00
36		123.25

Items | Attribute Statistics

Name (5/1430)

BRITISH SKY BROADCSTG GP
PHONE.COM INC
REPUBLIC NY CORP
FOUNDRY NETWORKS INC
CREE INCORPORATED

VISUAL INFORMATION SEEKING MANTRA

OVERVIEW FIRST, ZOOM AND FILTER, THEN DETAILS ON DEMAND

OVERVIEW FIRST, ZOOM AND FILTER, THEN DETAILS ON DEMAND

OVERVIEW FIRST, ZOOM AND FILTER, THEN DETAILS ON DEMAND

OVERVIEW FIRST, ZOOM AND FILTER, THEN DETAILS ON DEMAND

OVERVIEW FIRST, ZOOM AND FILTER, THEN DETAILS ON DEMAND

OVERVIEW FIRST, ZOOM AND FILTER, THEN DETAILS ON DEMAND

OVERVIEW FIRST, ZOOM AND FILTER, THEN DETAILS ON DEMAND

OVERVIEW FIRST, ZOOM AND FILTER, THEN DETAILS ON DEMAND

OVERVIEW FIRST, ZOOM AND FILTER, THEN DETAILS ON DEMAND

OVERVIEW FIRST, ZOOM AND FILTER, THEN DETAILS ON DEMAND

INTERACTION AS INTENTS

SEVEN CATEGORIES OF INTERACTION BY INTENT

YI ET AL. 2007

SELECT

EXPLORE

FILTER

RECONFIGURE

ENCODE

ABSTRACT/ELABORATE

CONNECT

SELECT

MARK SOMETHING AS INTERESTING

EXPLORE

FILTER

RECONFIGURE

ENCODE

ABSTRACT/ELABORATE

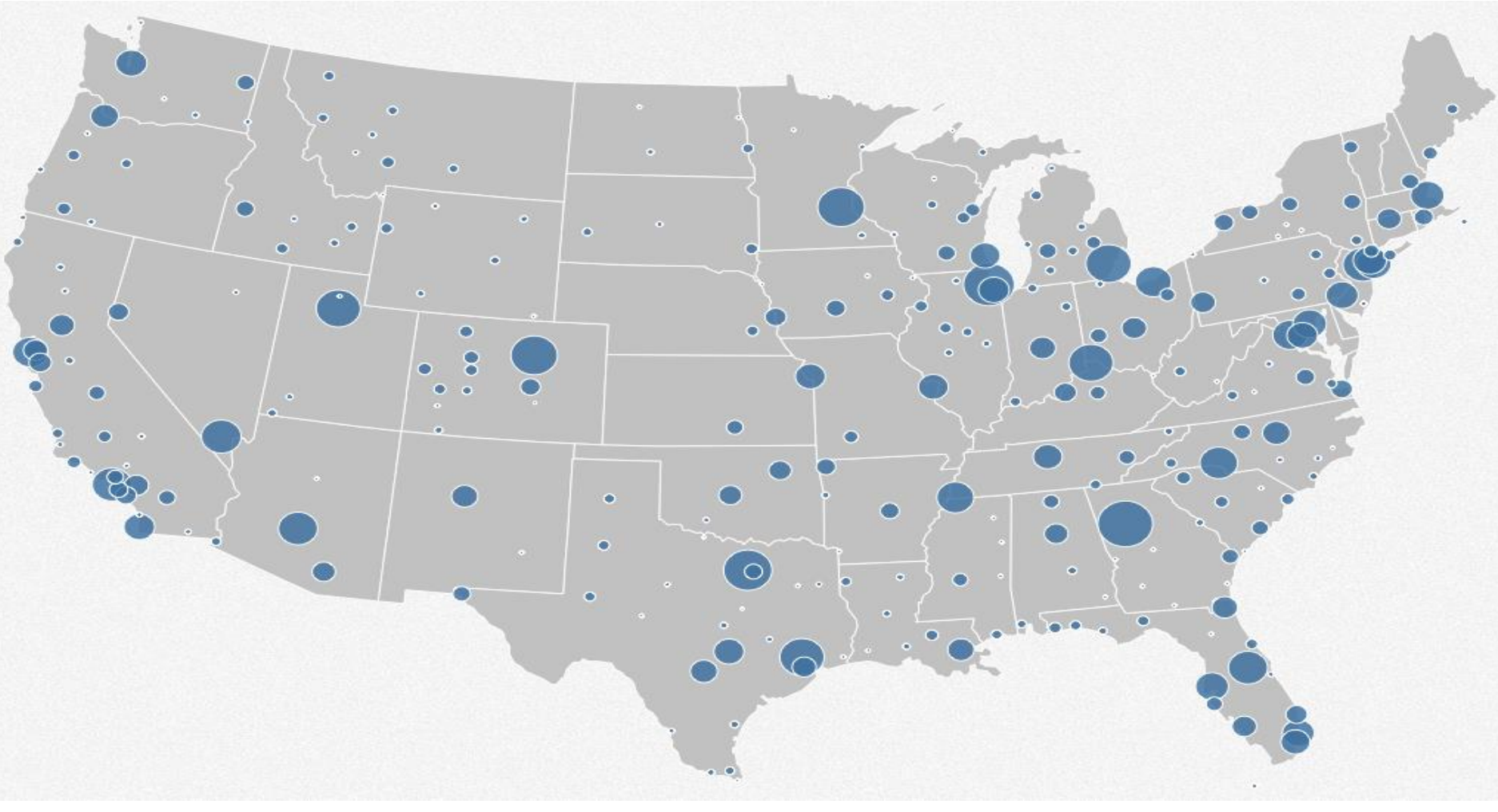
CONNECT

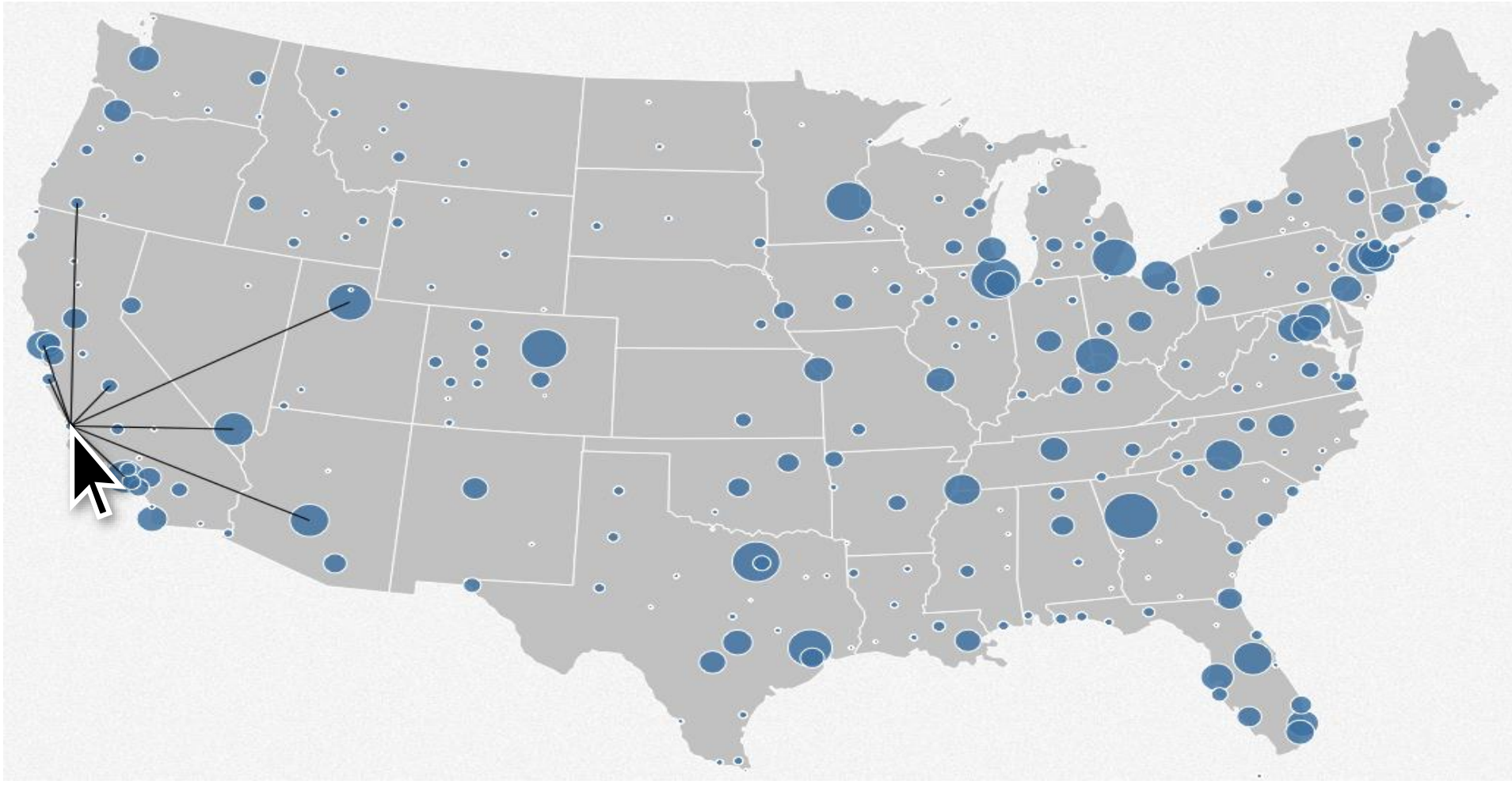
BASIC

Point Selection

Mouse Hover / Click

Touch / Tap





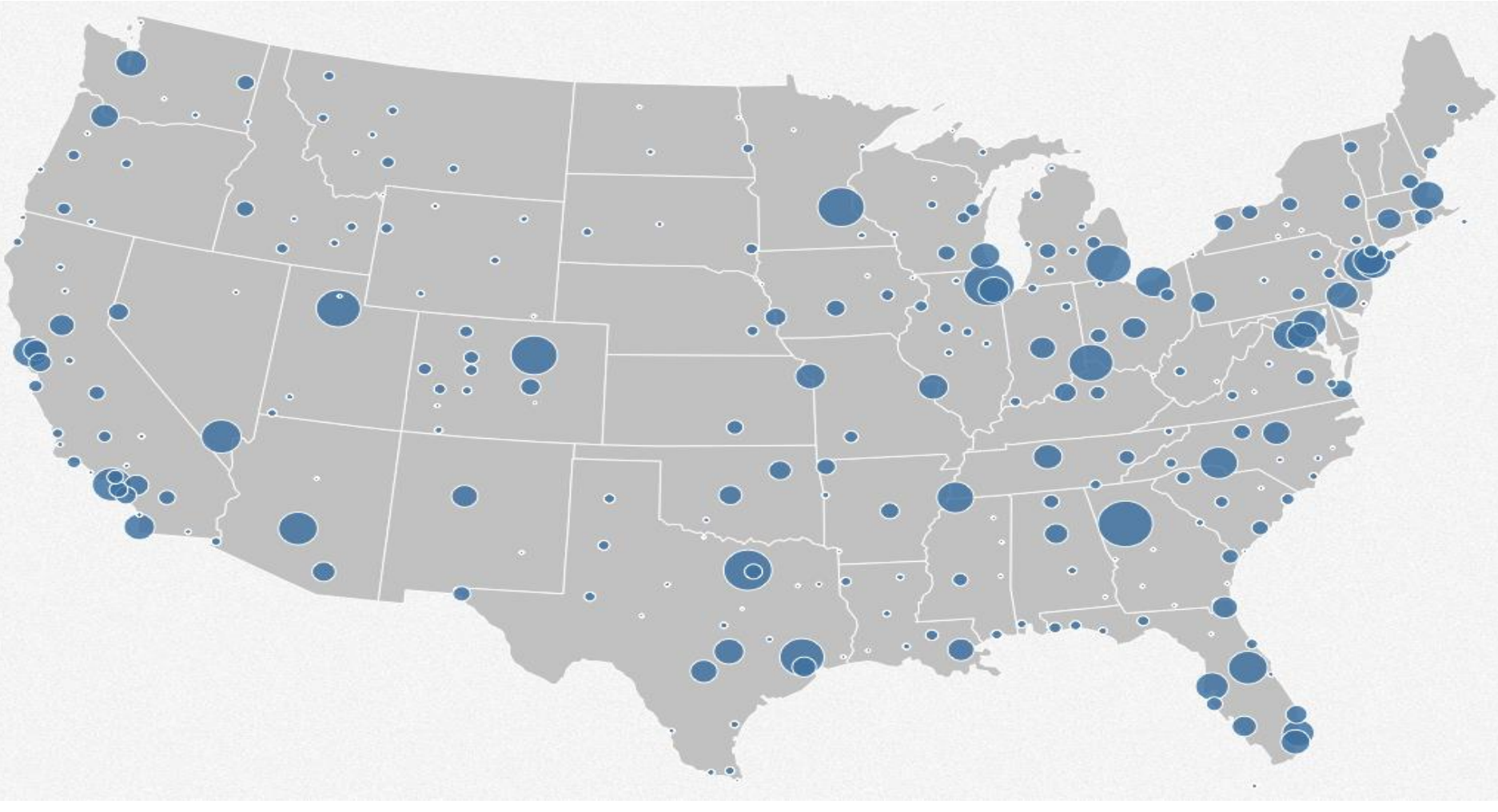
BASIC

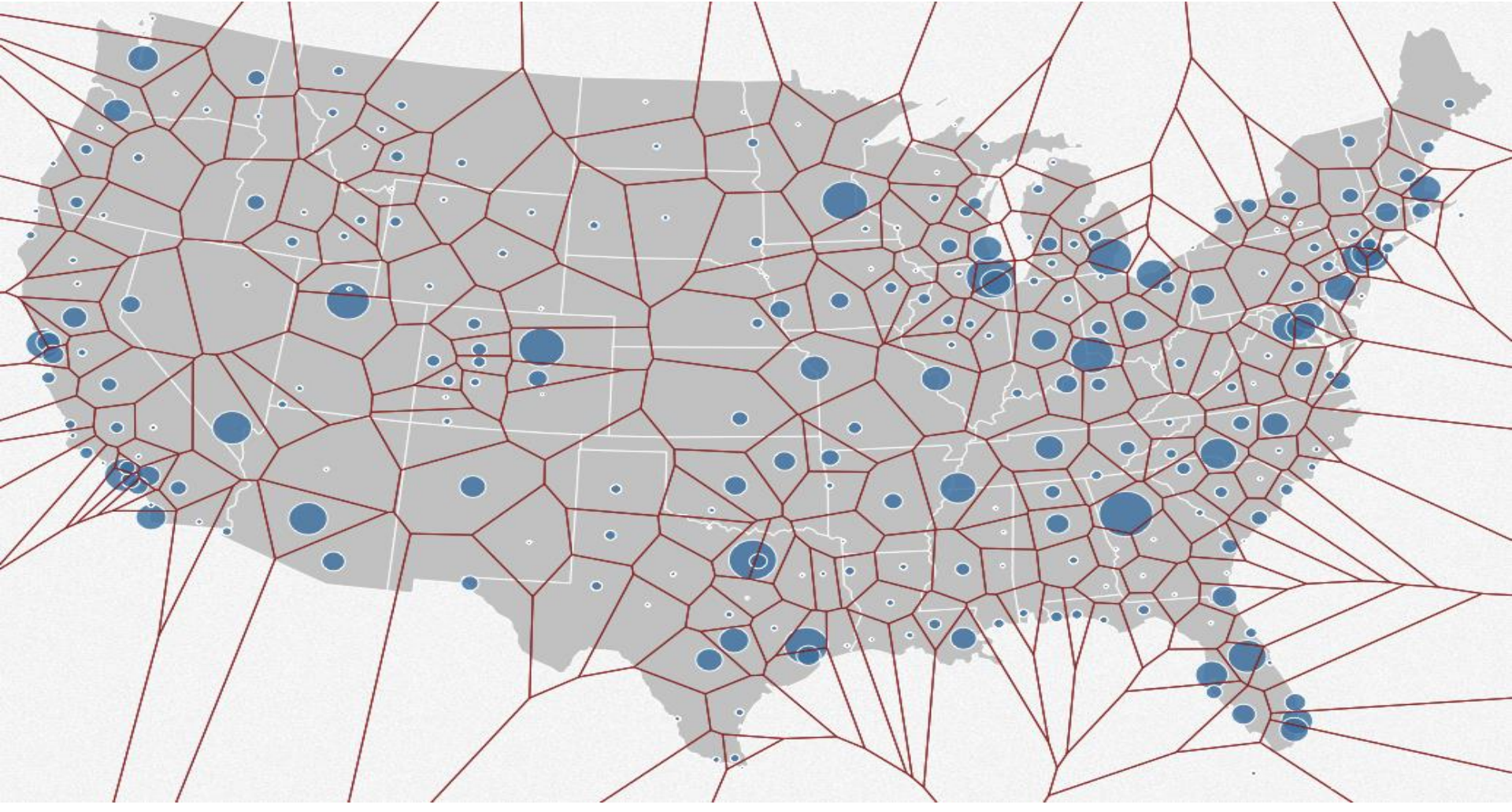
Point Selection

Mouse Hover / Click

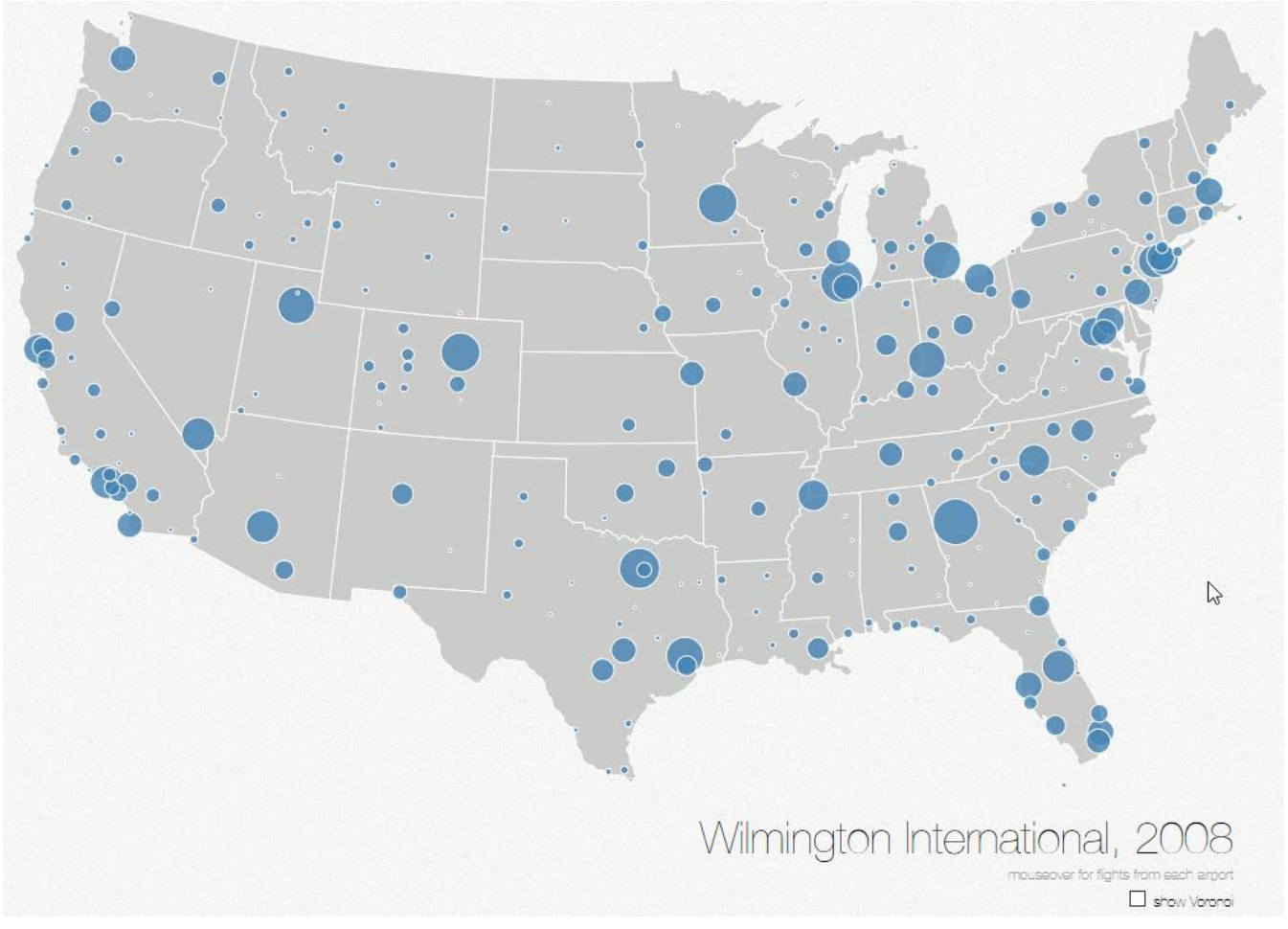
Touch / Tap

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





http://mbostock.github.io/d3/talk/20111018/#28


Wilmington International, 2008
mouseover for flights from each airport
show Voronoi

BASIC

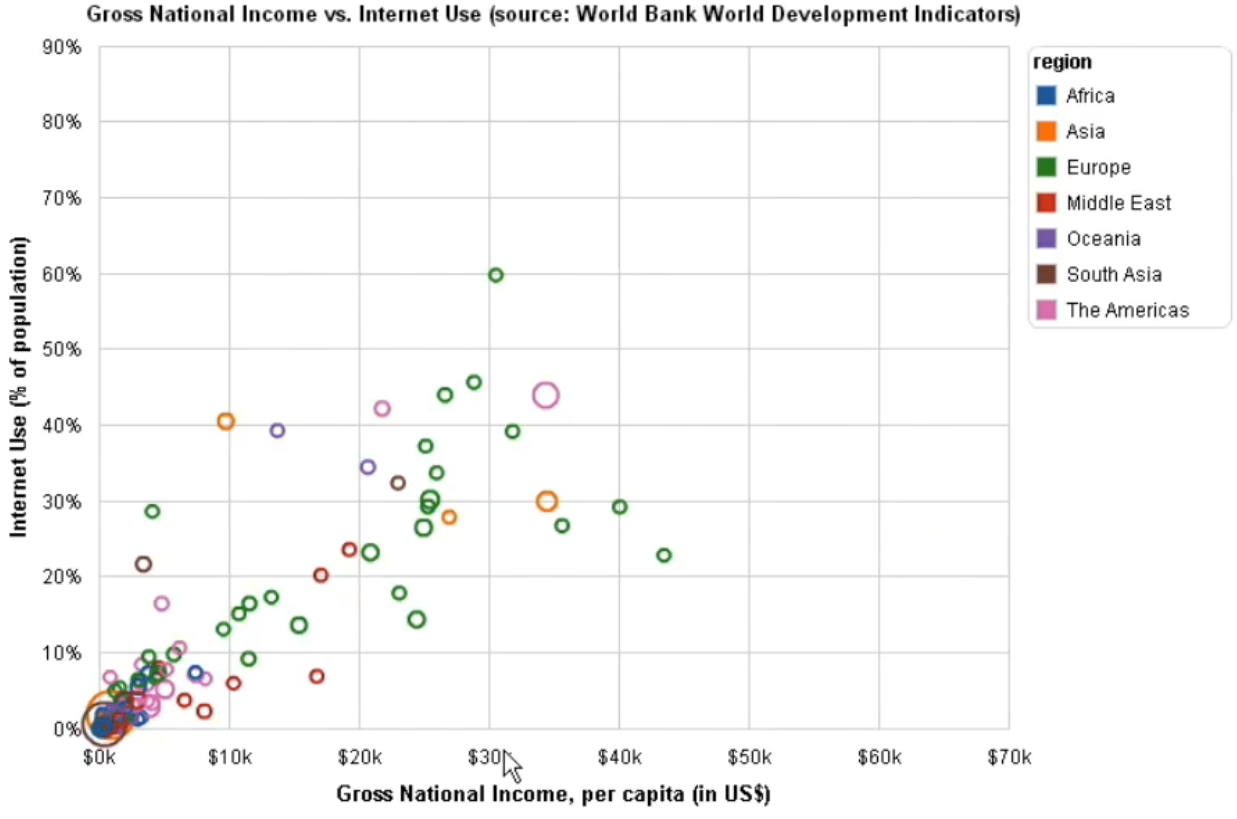
Point Selection

Mouse Hover / Click
Touch / Tap
Select Nearby Element (e.g., Bubble Cursor)

Region Selection

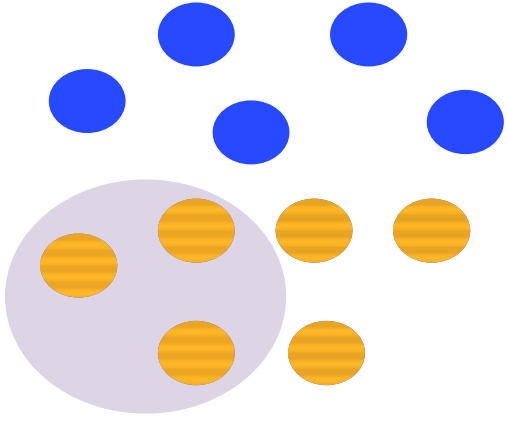
Rubber-band or Lasso
Area Cursors (“Brushes”)

RANGE SELECTION

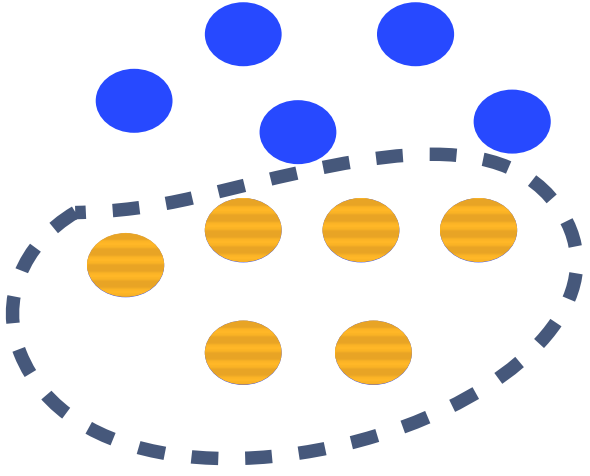


GENERALIZED SELECTION HEER ET AL. 2008

BRUSHES



LASSOS



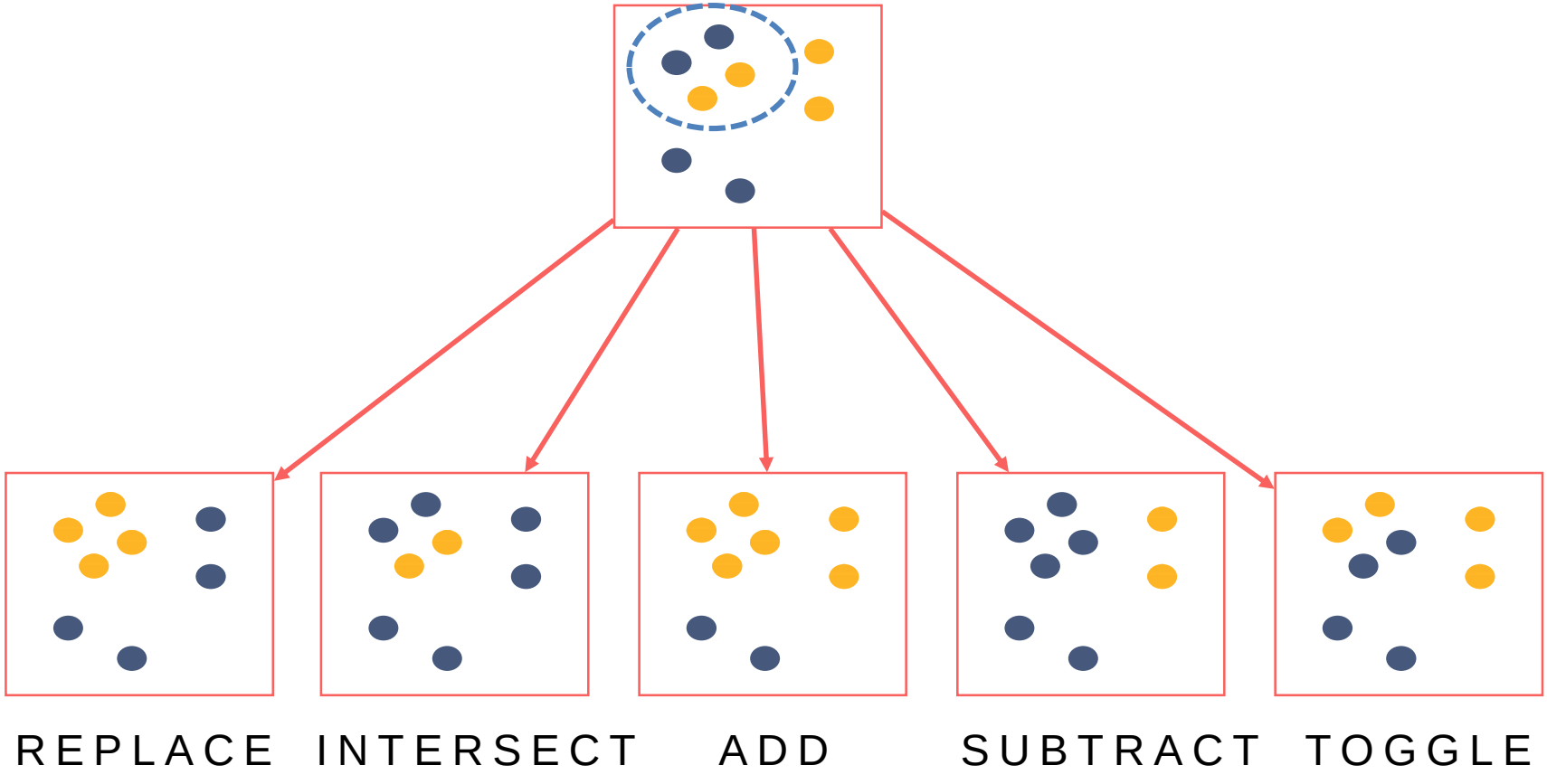
WILLS' SELECTION TAXONOMY:

WILLS' SELECTION TAXONOMY
SELECTION MEMORY

MEMORY	MEMORYLESS
25 < AGE < 35	25 < AGE < 35
COUNTRY = CANADA	COUNTRY = CANADA
EDU LEVEL = POSTSECONDARY	EDU LEVEL = POSTSECONDARY

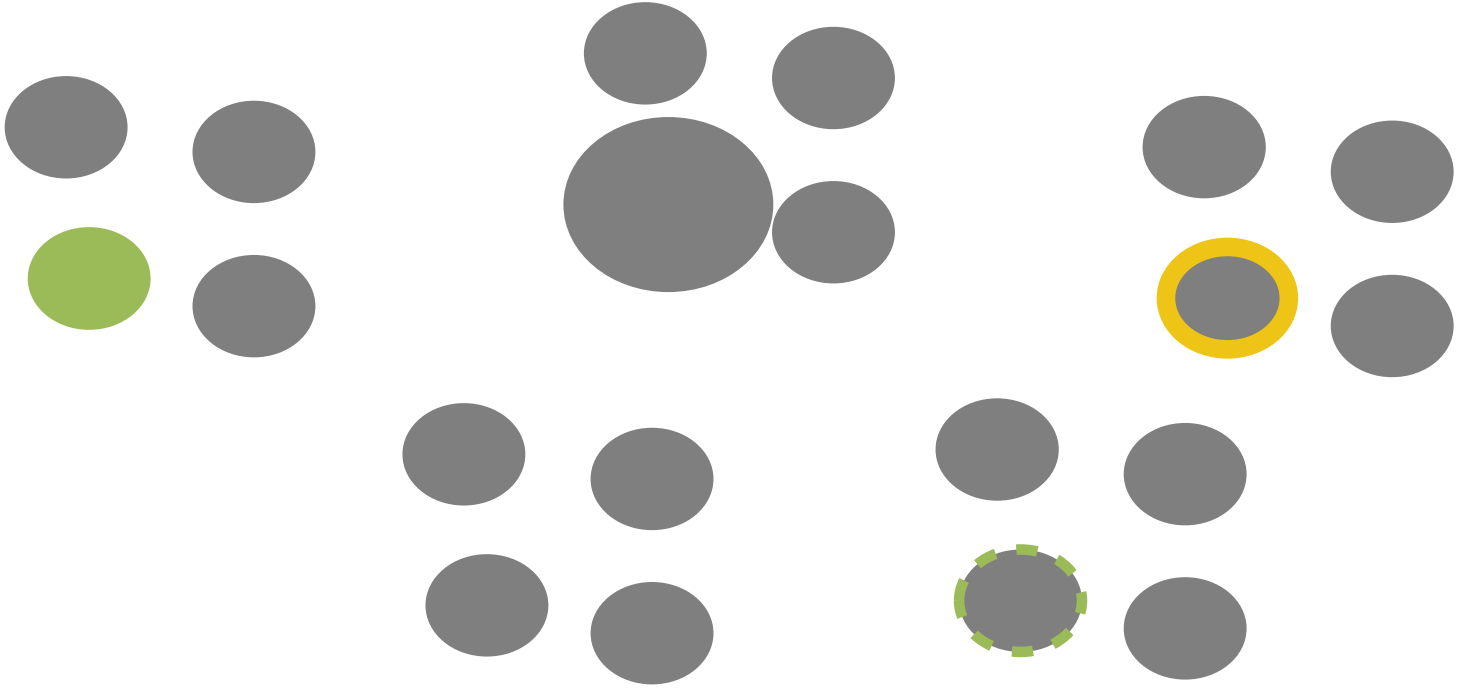
WILLS 2000

SELECTION OPERATIONS



HIGHLIGHTING

SELECTION + CHANGE IN APPEARANCE



SELECT

EXPLORE

SHOW ME SOMETHING ELSE

FILTER

RECONFIGURE

ENCODE

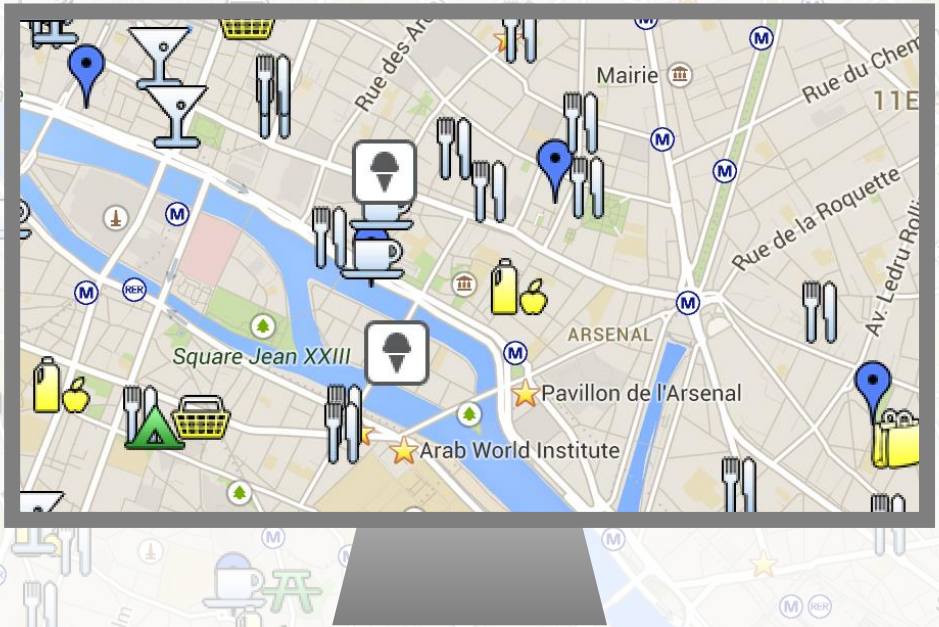
ABSTRACT/ELABORATE

CONNECT

PROBLEM

Where am I?

NAVIGATION



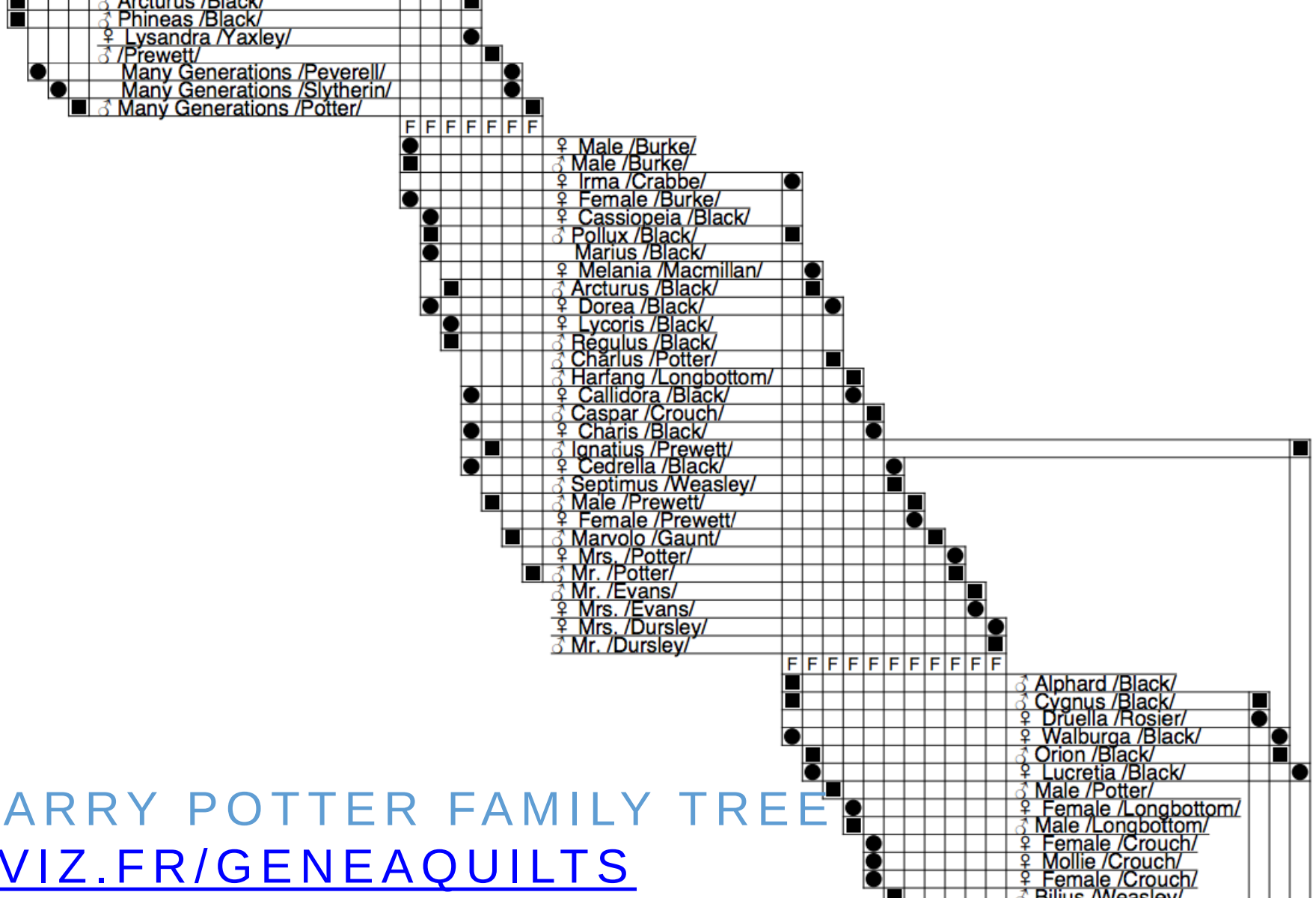
PANNING

ZOOMING

NAVIGATION

PANNING

ZOOMING



HARRY POTTER FAMILY TREE

AVIZ.FR/GENEAQUILTS

SELECT

EXPLORE

FILTER

SHOW ME SOMETHING CONDITIONALLY

RECONFIGURE

ENCODE

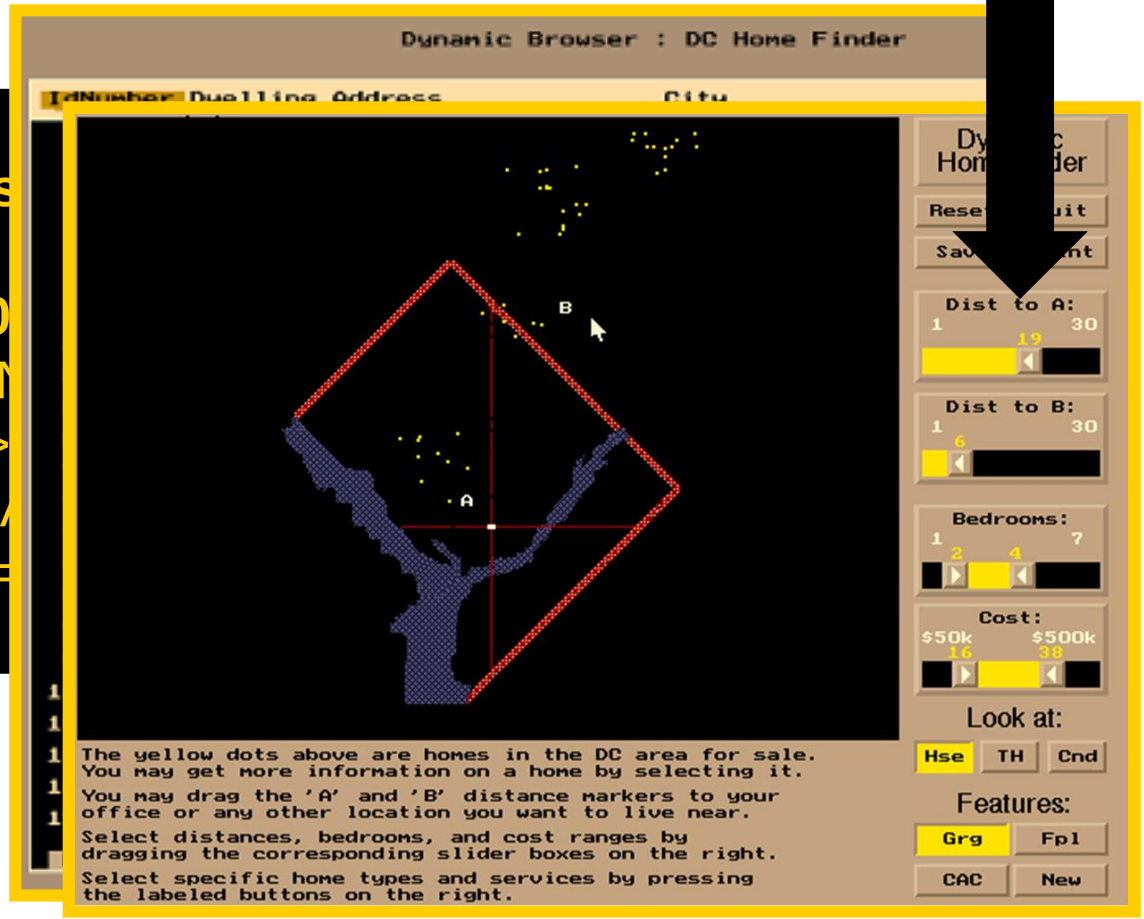
ABSTRACT/ELABORATE

CONNECT

FILTERING

```
> SELECT house-addres
    FROM realty-db
   WHERE price >= 200,0
         price <= 400,000 AN
                  bathrooms >
                  garage == 2 A
                  bedrooms >=
```

REPLACING A QUERY WITH "DYNAMIC QUERY WIDGETS"



HOMEFINDER WILLIAMSON AND SCHNEIDERMAN 1992

Dynamic Queries Demos: Revised HomeFinder and Text Version plus Health Statistics Atlas

Ben Shneiderman

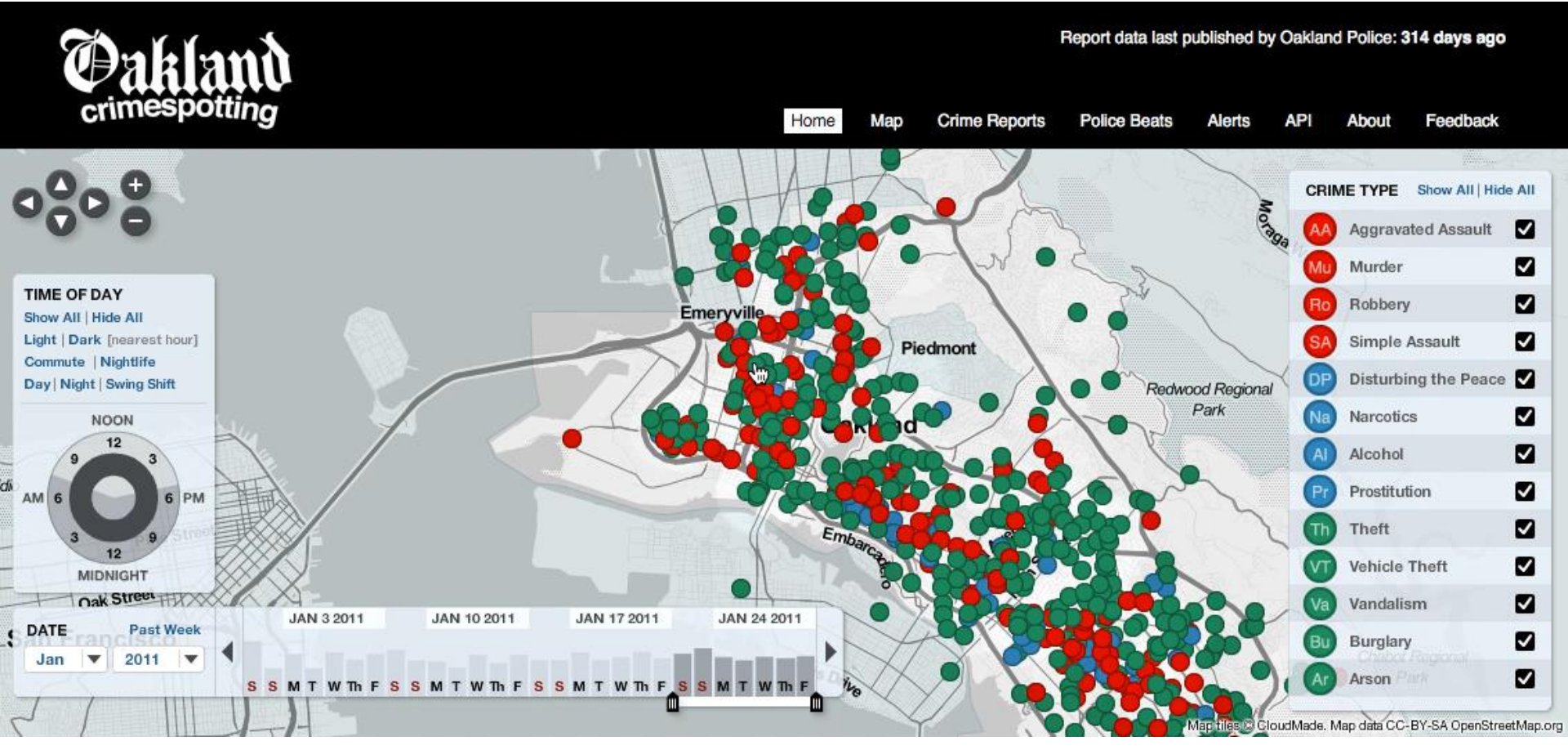
DIRECT MANIPULATION

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

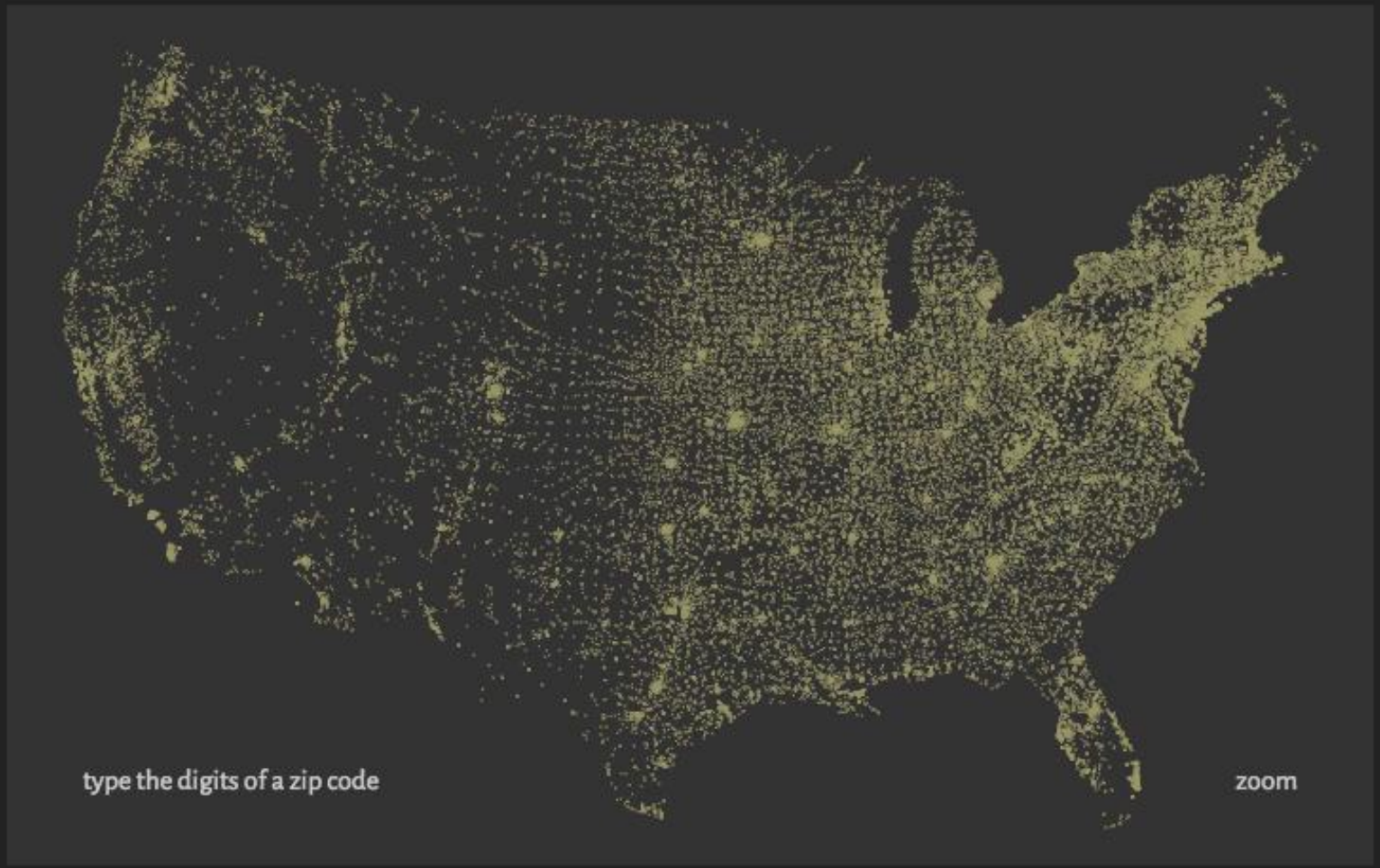
Dynamic Queries Demos: Revised HomeFinder and Text Version plus Health Statistics Atlas

Ben Shneiderman

CRIMESPOTTING



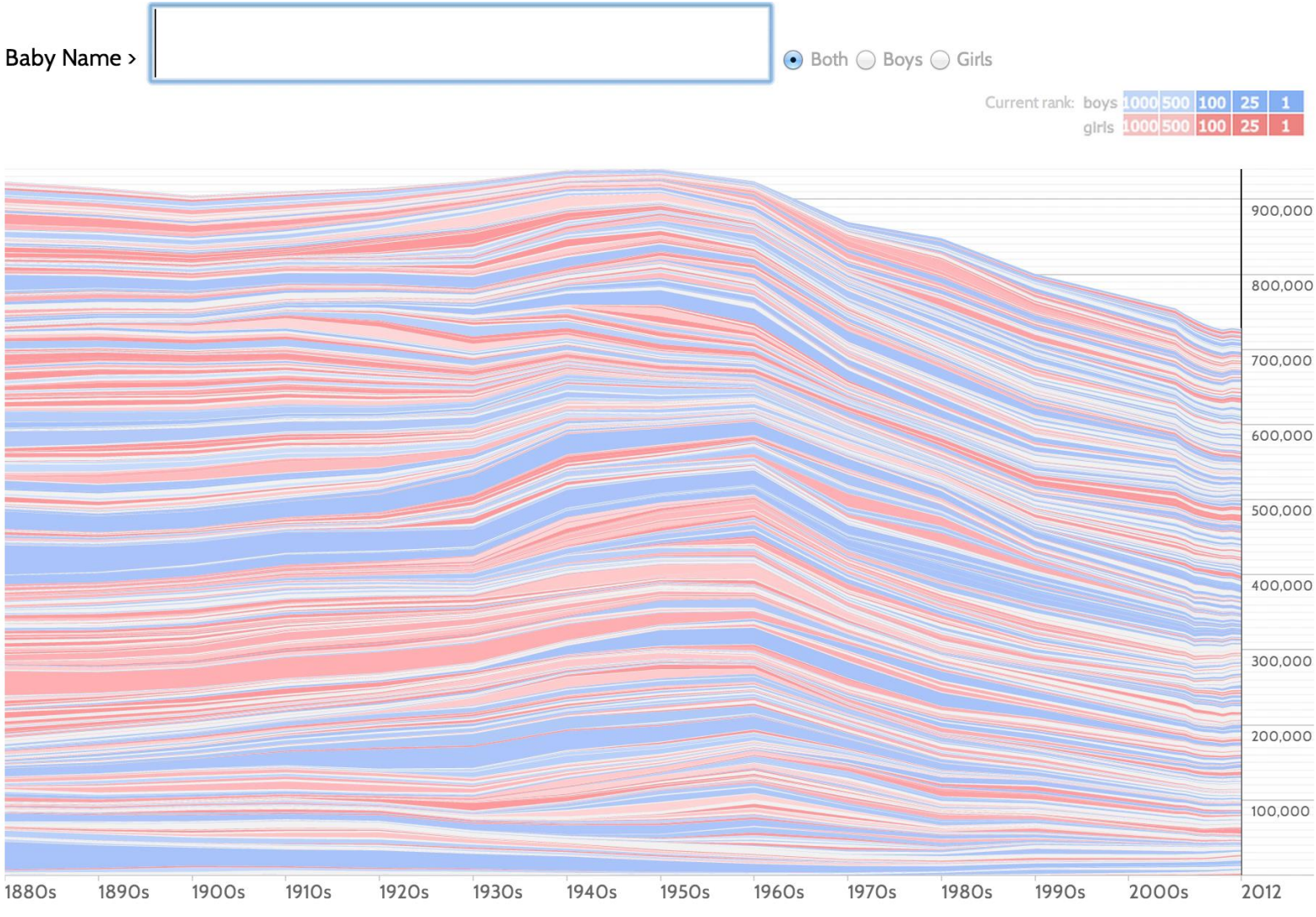
STAMEN DESIGN



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

zipdecode

BEN FRY 19



BABY NAME VOYAGER MARTIN WATTENBERG 2005

SELECT

EXPLORE

FILTER

SHOW ME A DIFFERENT ARRANGEMENT

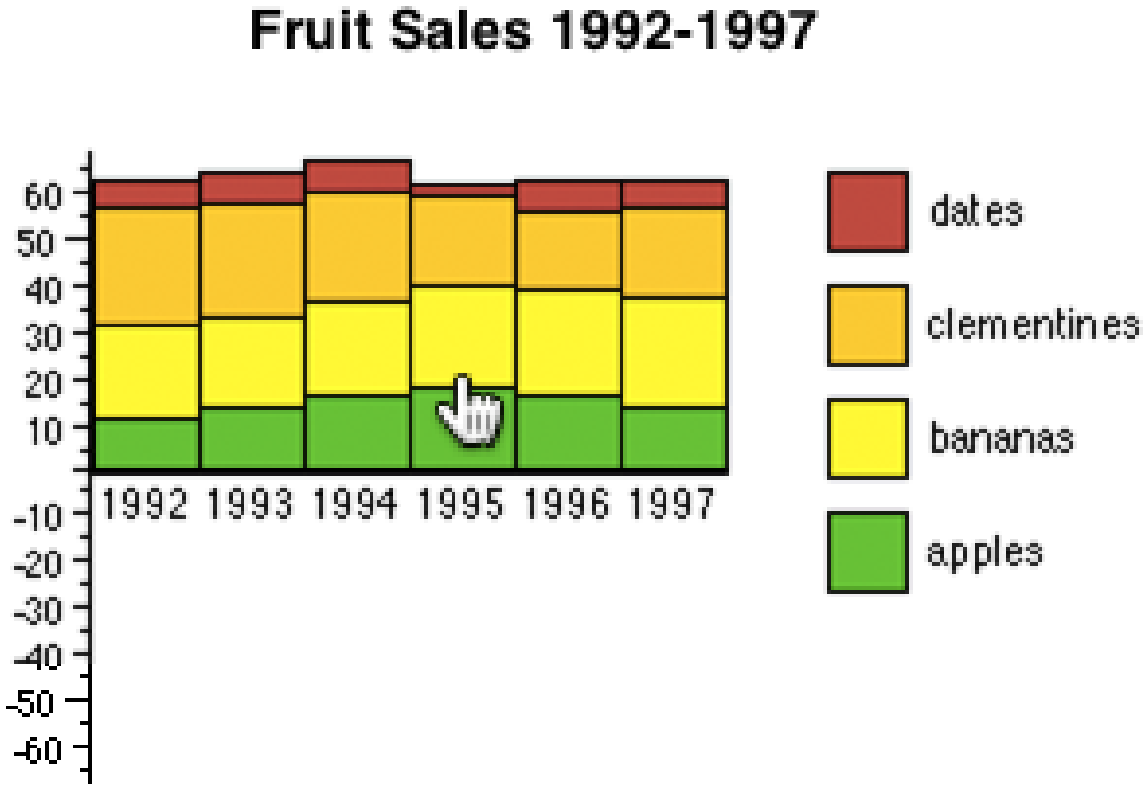
RECONFIGURE

ENCODE

ABSTRACT/ELABORATE

CONNECT

RE-ARRANGING DATA



INTERACTIVE STACKED HISTOGRAMS [DIX & ELLIS, 1998]

Graph Viewer

Graph Viewer

Roll-up by:

All

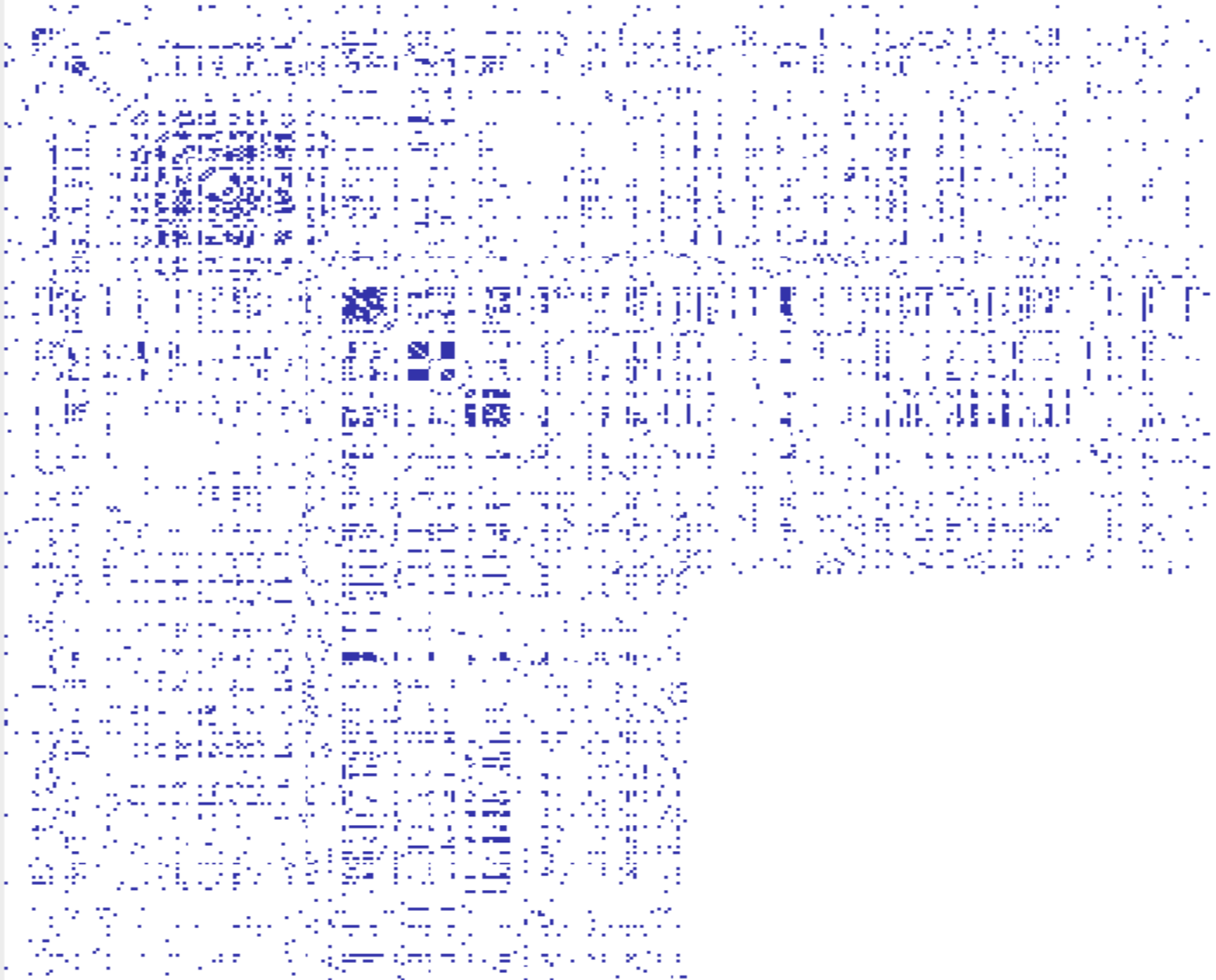
Visualization:

Matrix

Sort by:

None

Edge centrality filters:



Graph Viewer

Graph Viewer

Roll-up by:

All

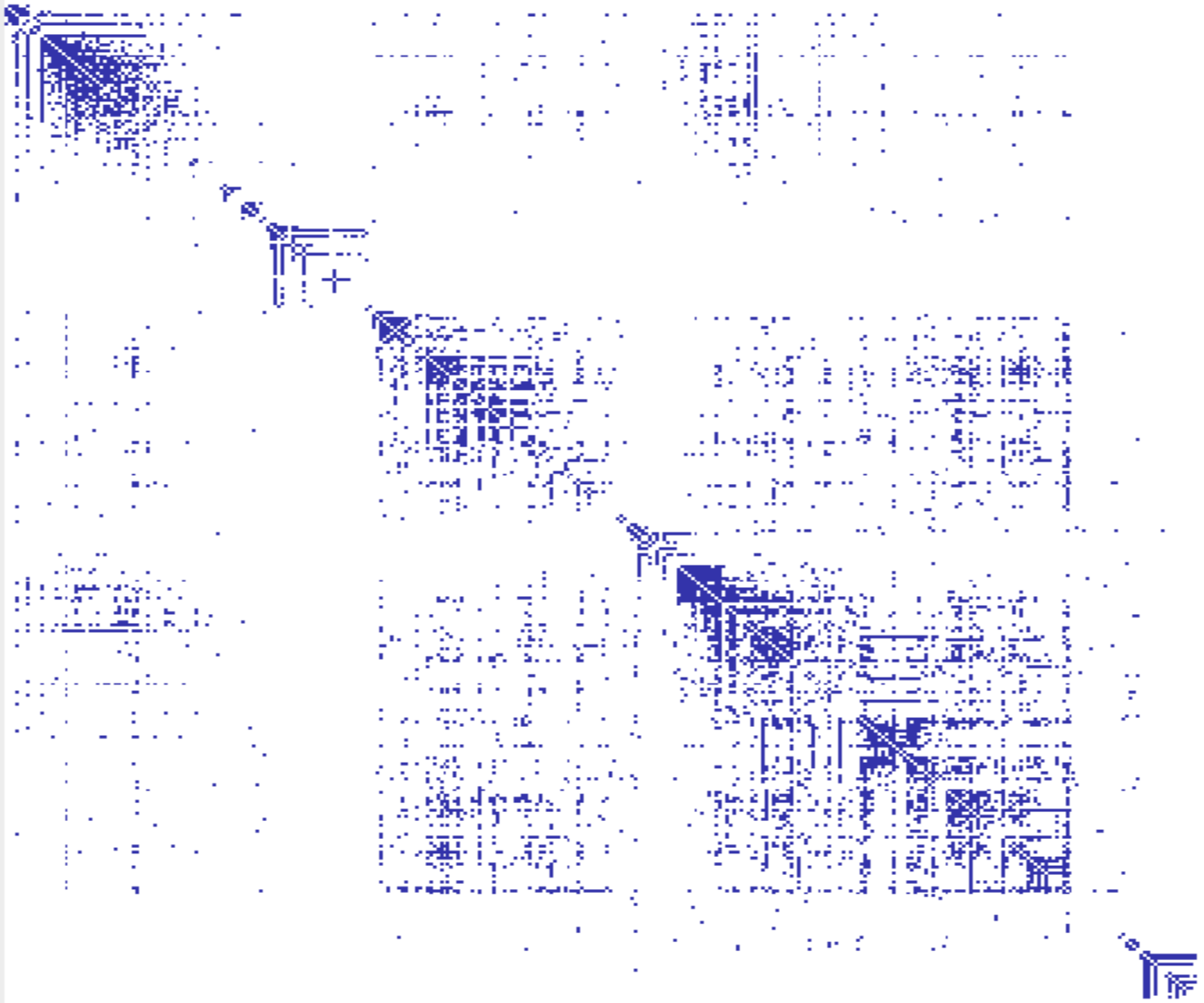
Visualization:

Matrix

Sort by:

Linkage

Edge centrality filters:



KINETICA [RZESZORTARKSI & KITTUR 2013]

SELECT

EXPLORE

FILTER

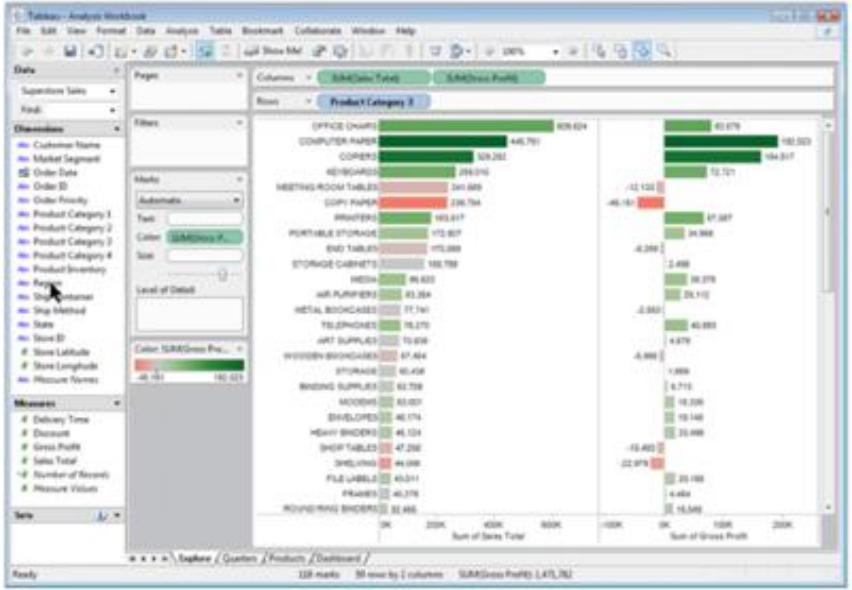
RECONFIGURE

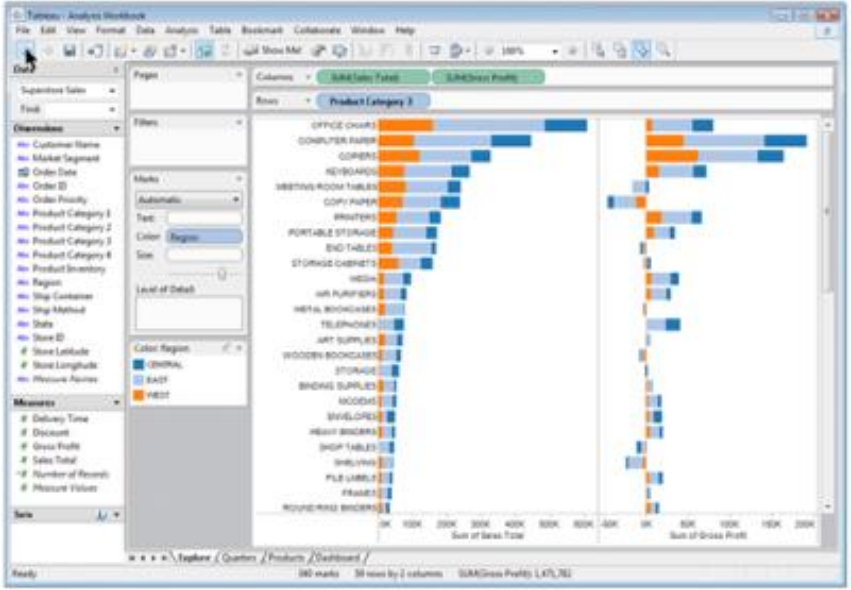
ENCODE

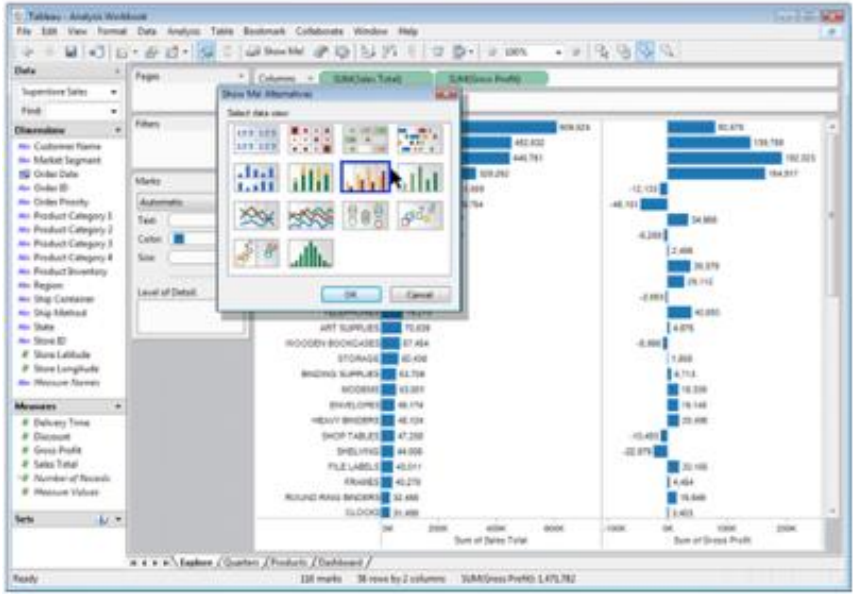
SHOW ME A DIFFERENT REPRESENTATION

ABSTRACT/ELABORATE

CONNECT







SELECT

EXPLORE

FILTER

RECONFIGURE

ENCODE

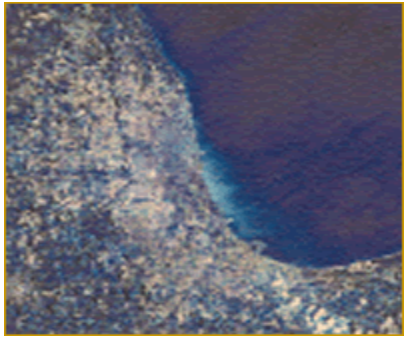
SHOW ME MORE
OR LESS DETAIL

ABSTRACT/ELABORATE

CONNECT

CHANGING LEVELS OF ABSTRACTION



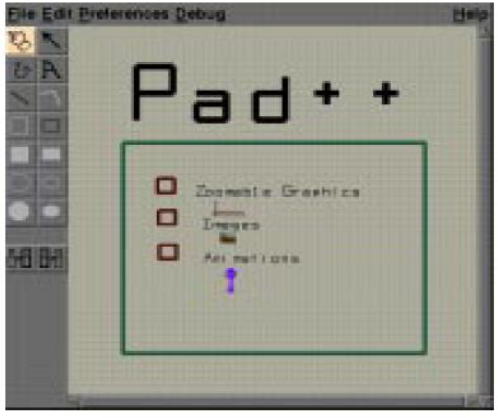


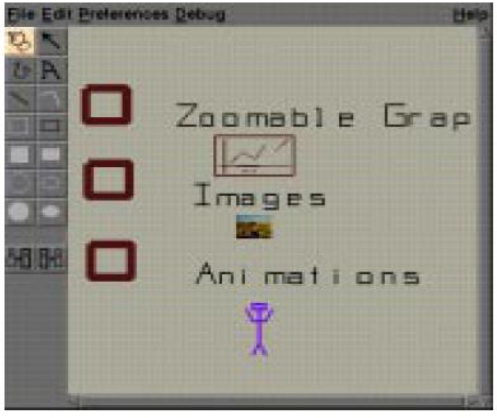


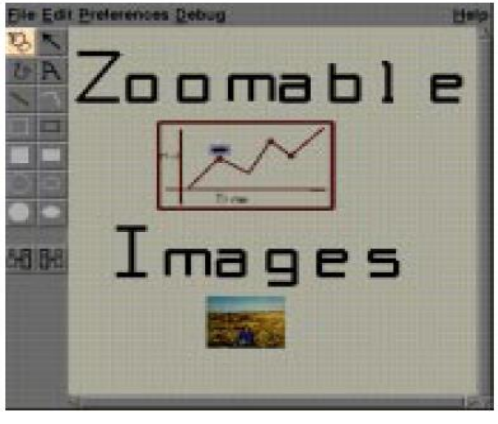

POWERS OF TEN RAY & CHARLES EAMES 1977

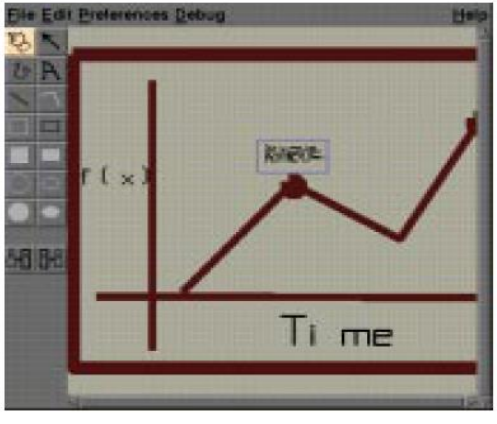

POWERS
OF TEN

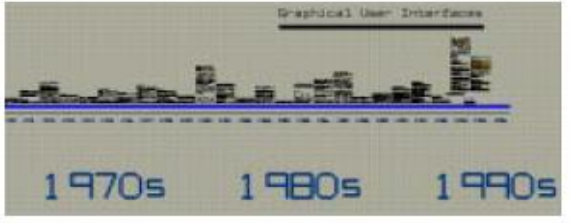
SEMANTIC ZOOMING

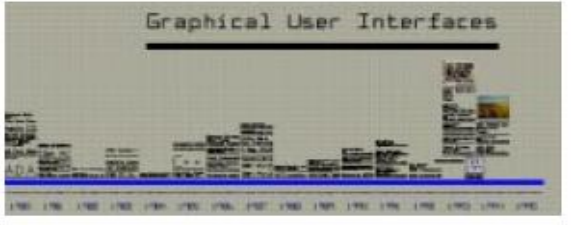










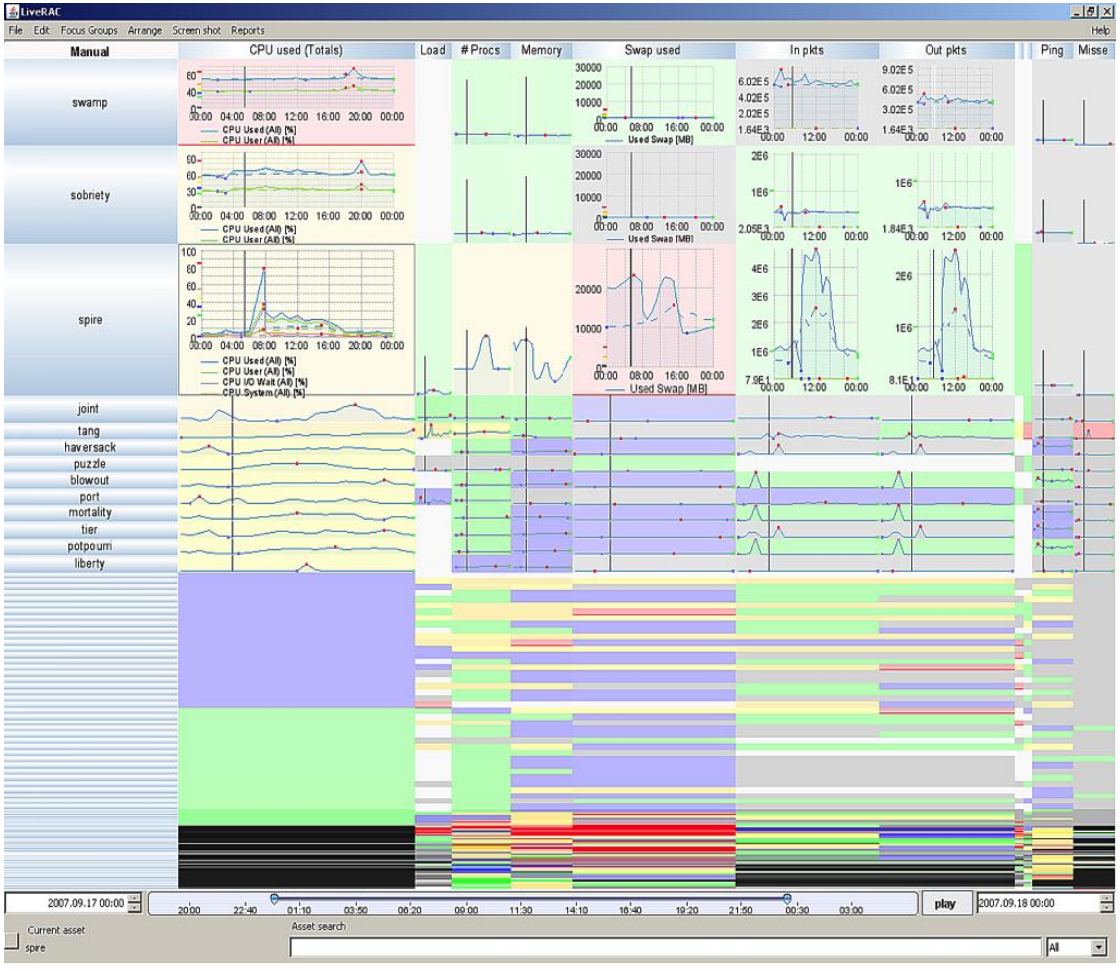


PAD++ BEDERSON AND HOLLAN 1994

LiveRAC

ENCODINGS CHANGE

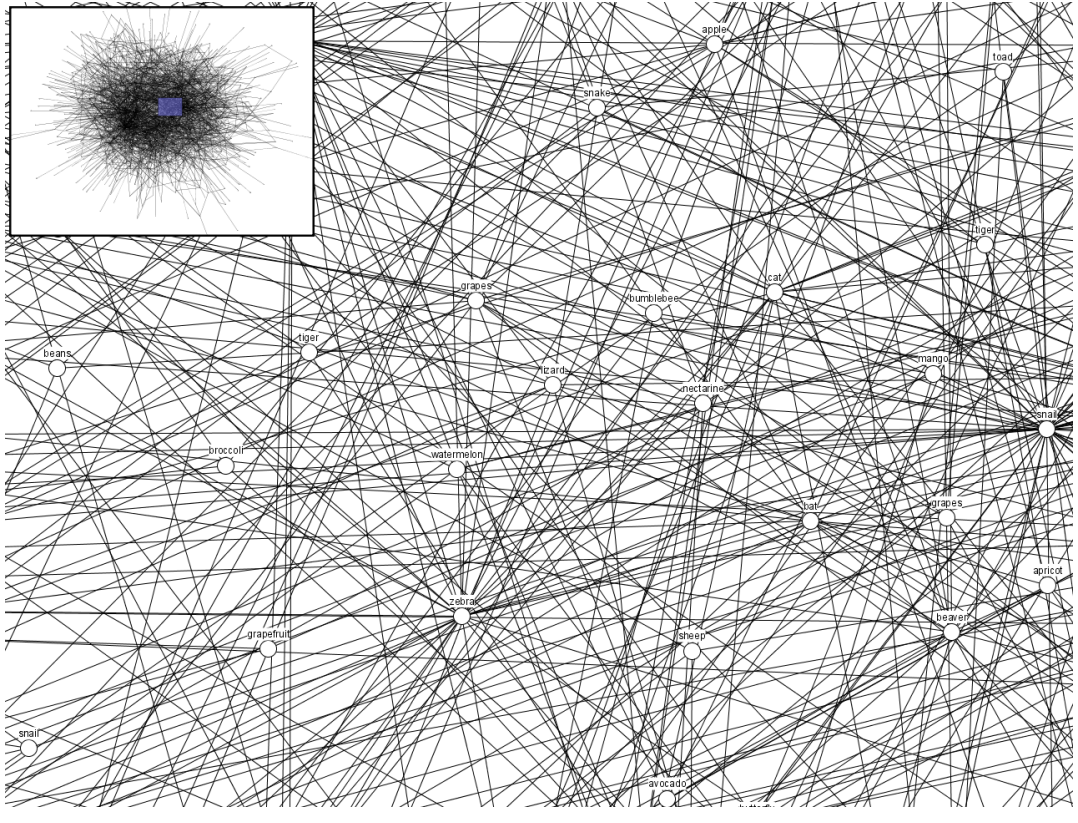
- –COLORED BOX
- –SPARKLINE
- –SIMPLE LINE CHART
- –FULL CHART: AXES AND TICKMARKS



MCLACHLAN ET AL. 2008

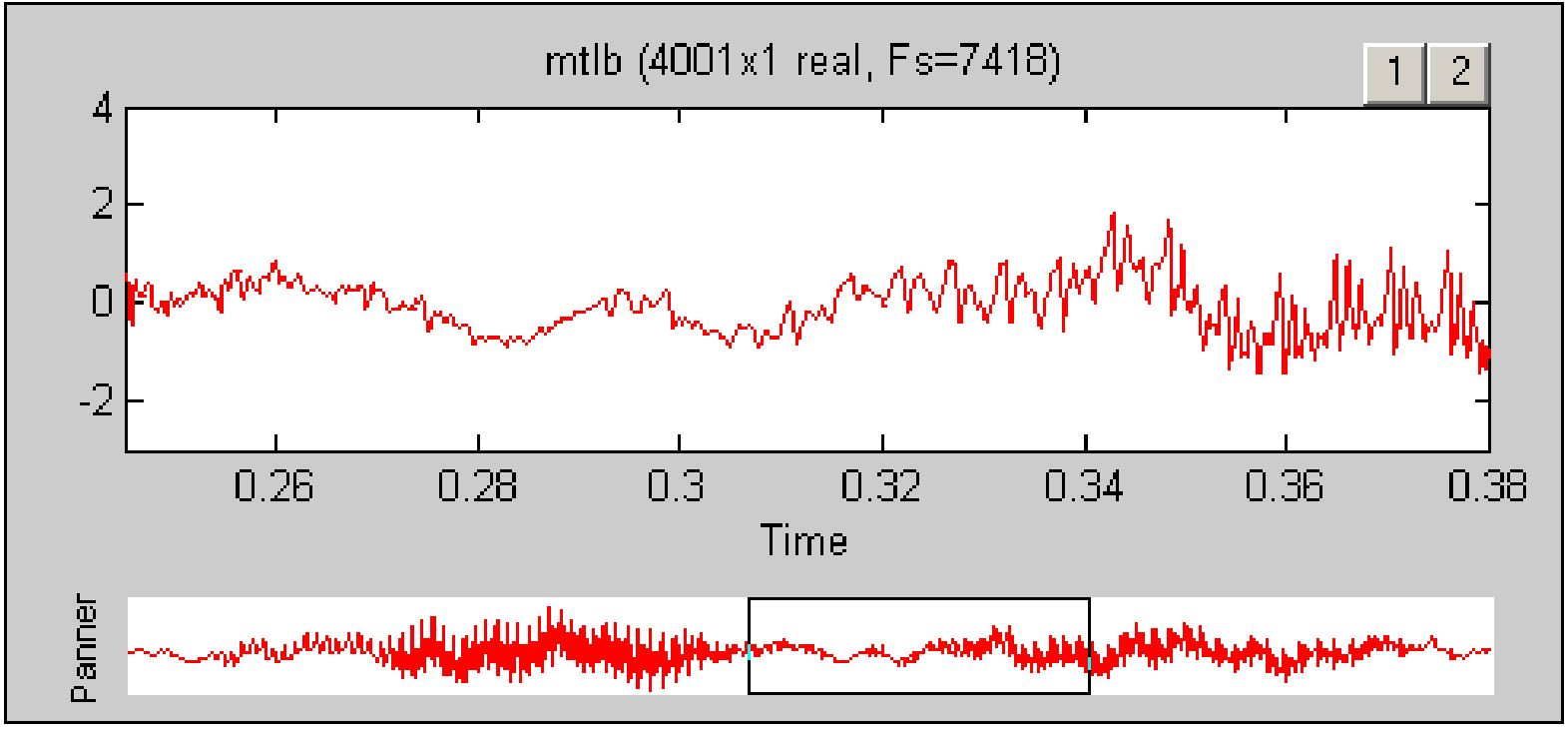
OVERVIEW + DETAIL

Panning a large graph



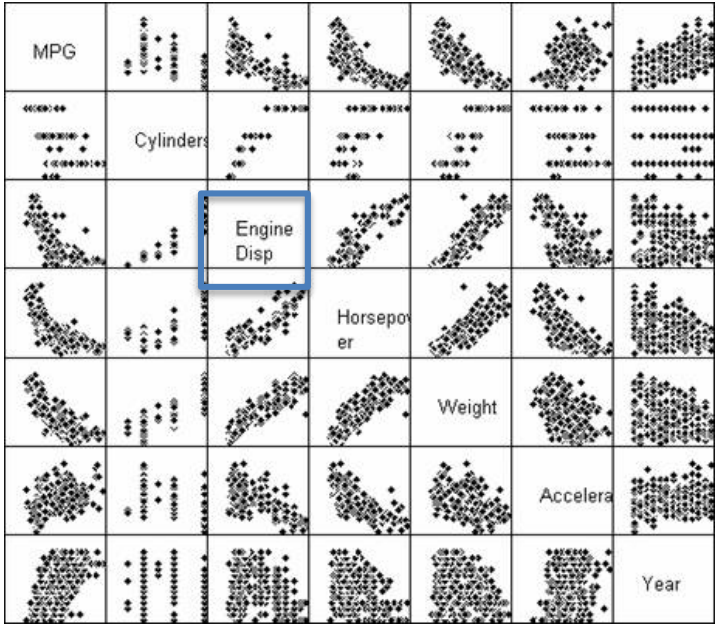
OVERVIEW + DETAIL

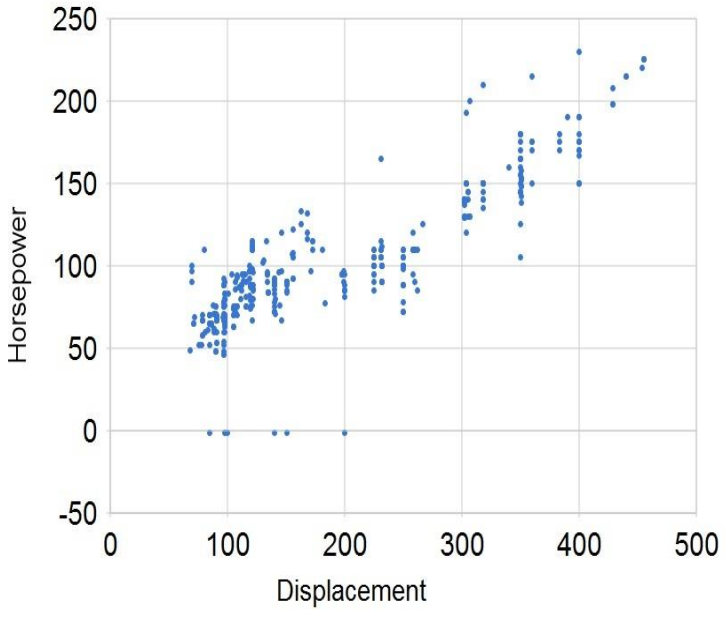
Panning a line chart



OVERVIEW + DETAIL

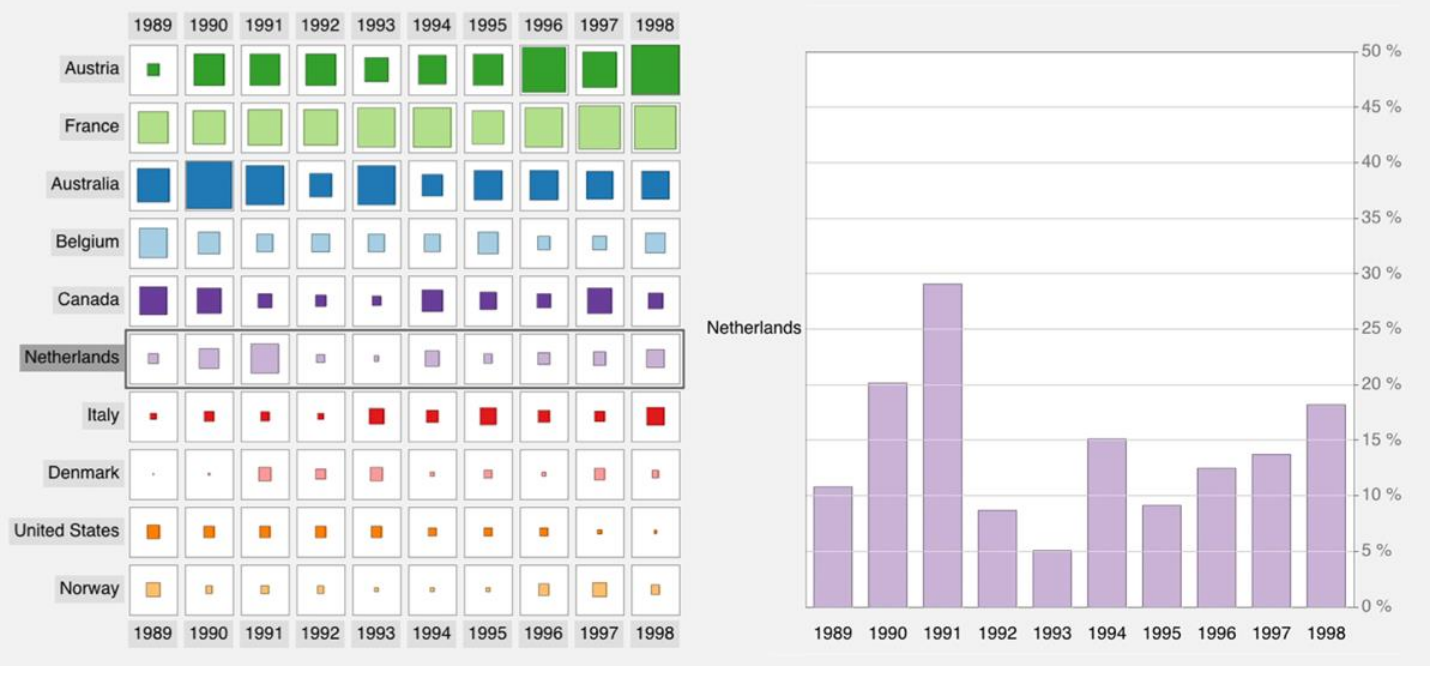
Browsing Multiple Views





OVERVIEW + DETAIL

Browsing Multiple Views

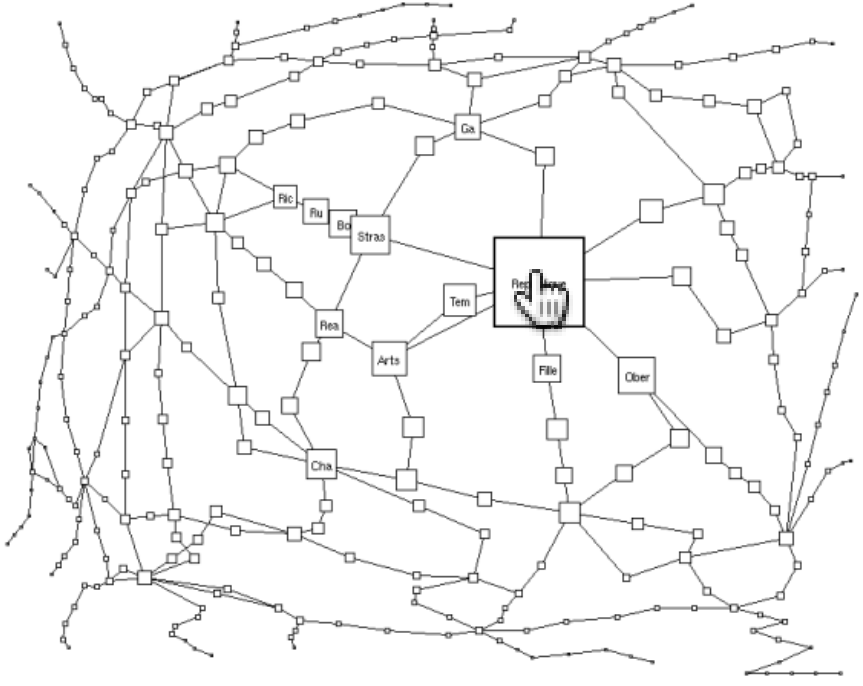


Jansen et al, 2013

FOCUS + CONTEXT

Space Distortion

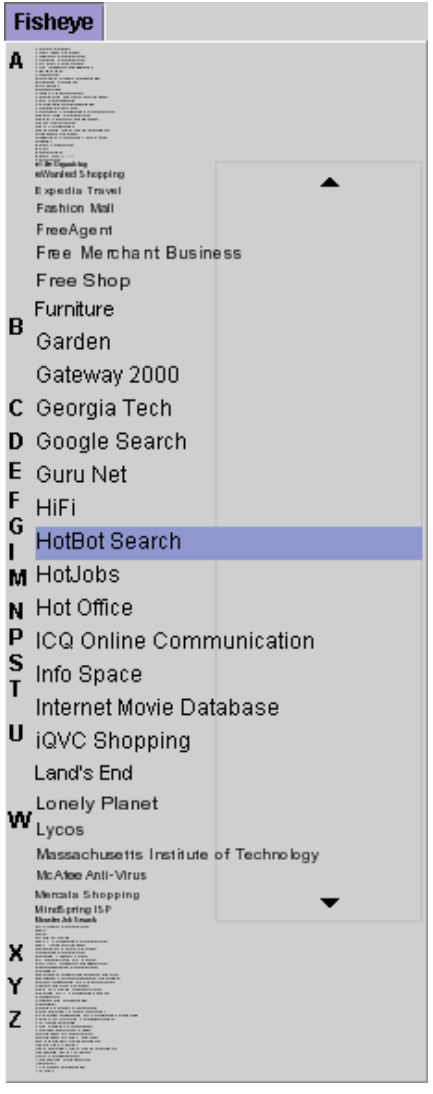
1) Fisheye Views of Graphs



Sarkar and Brown, 1992

FOCUS + CONTEXT

Space Distortion
2) Fisheye Menus

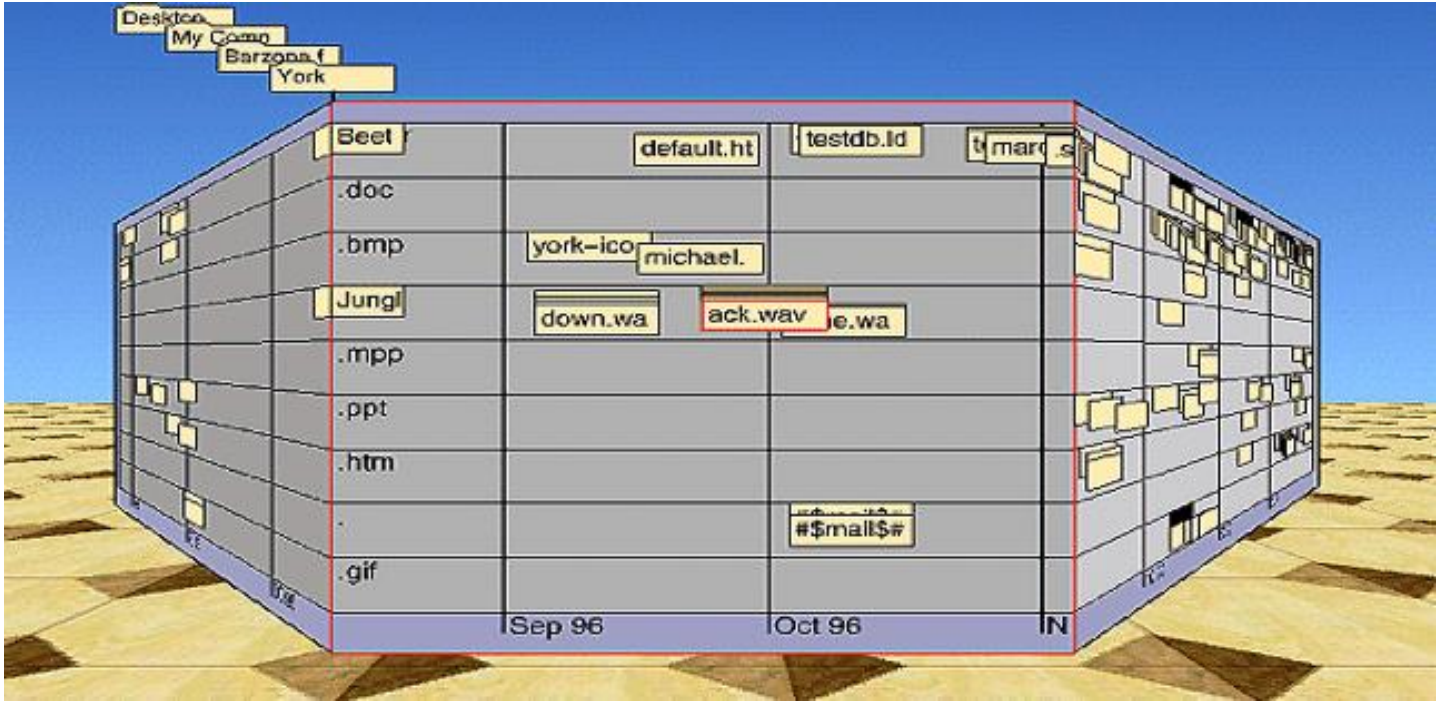


Bederson, 2000

FOCUS + CONTEXT

Space Distortion

3) Perspective Wall

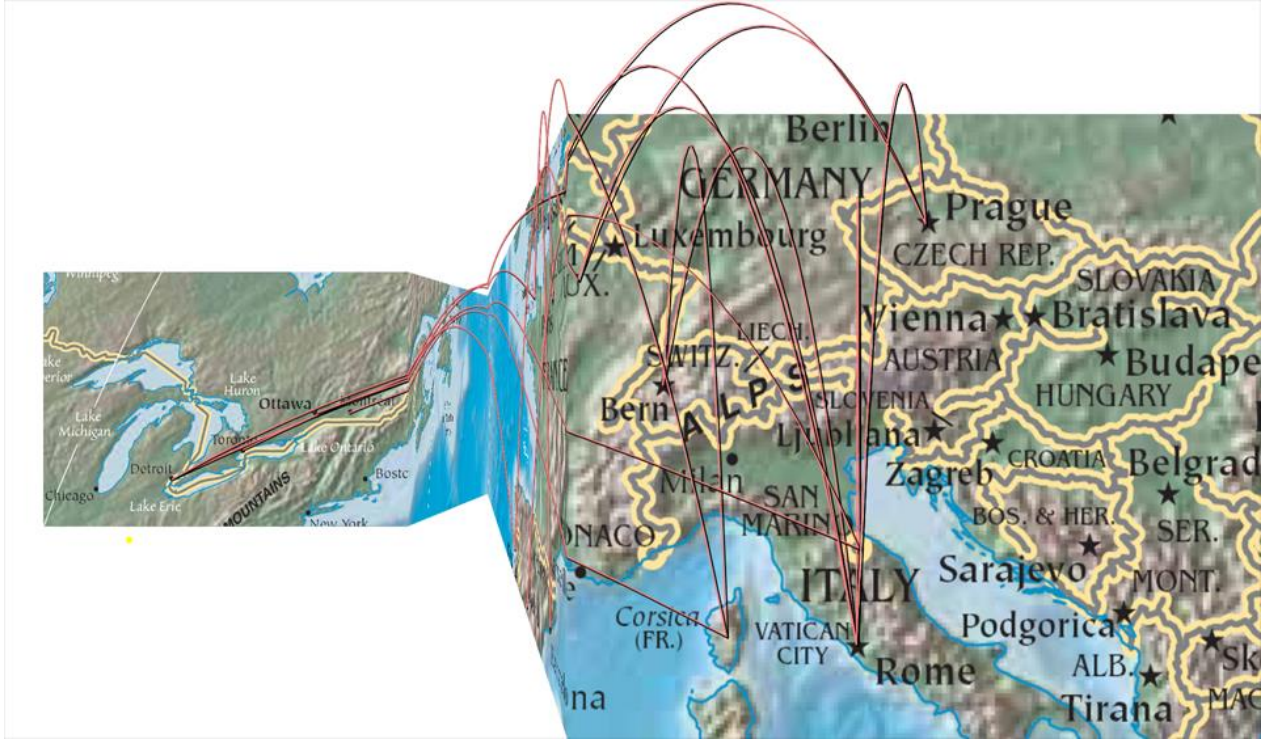


Mackinlay, Roberston and Card, 1991

FOCUS + CONTEXT

Space Distortion

4) Melange



Elmqvist et al, 2010

Mélange

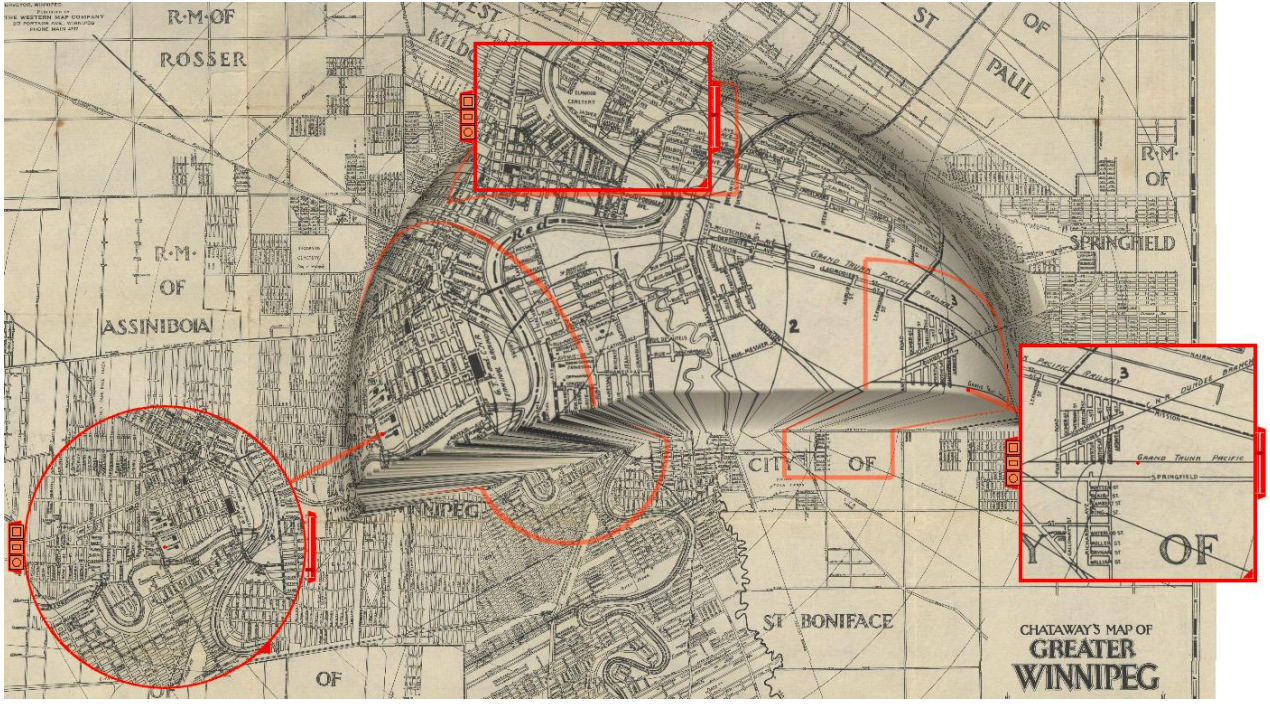
Space-Folding for Multi-Focus Interaction

Niklas Elmqvist [1], **Nathalie Henry** [1,2,3], **Yann Riche** [1,2,4] **and Jean-Daniel Fekete** [1]
[1] INRIA [2] LRI, Univ. Paris-Sud [3] University of Sydney [4] University of Queensland
{elm, nhenry, riche, fekete}@lri.fr

SIGCHI 2008 Conference

FOCUS + CONTEXT

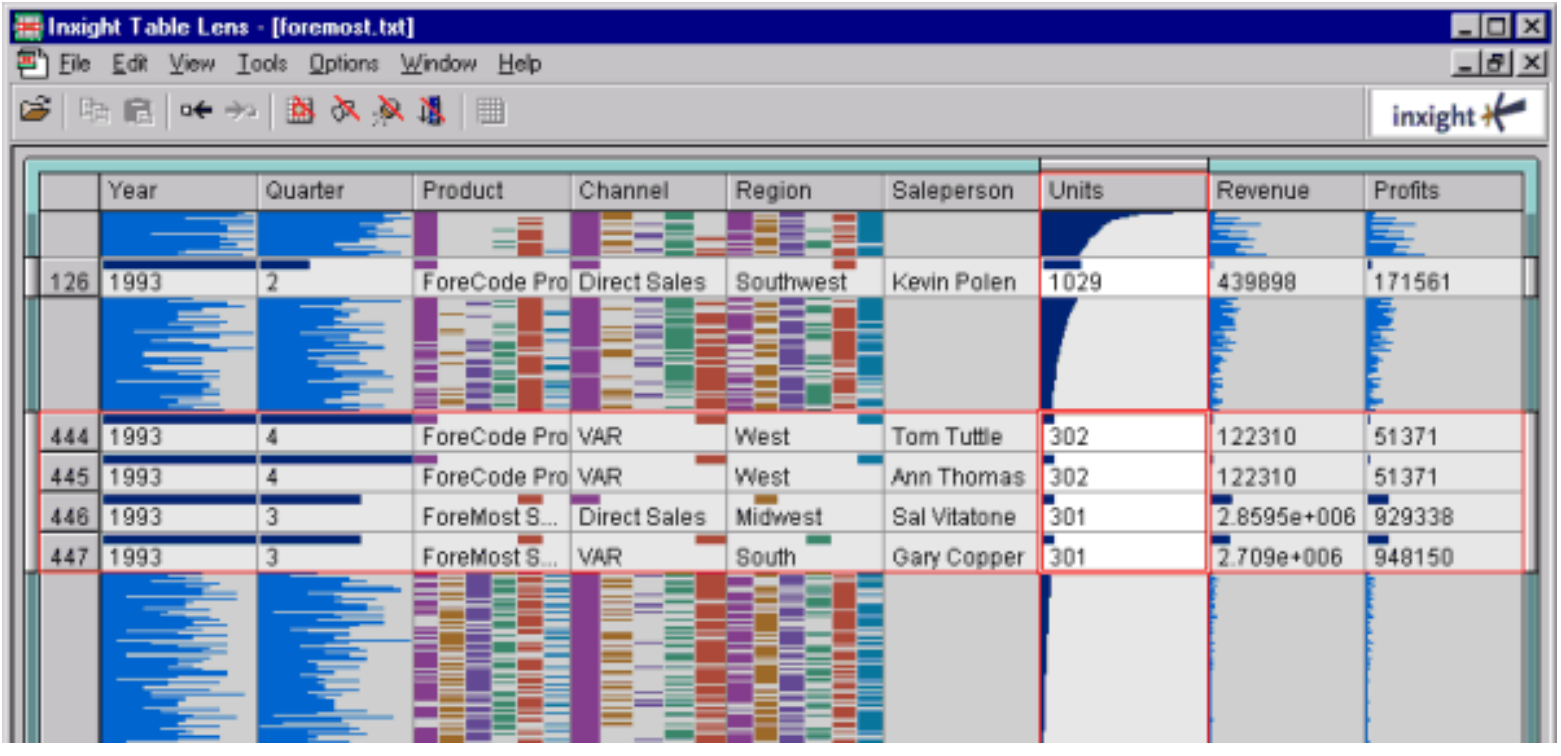
The Undistort Lens



Brosz, Carpendale and Nacenta, 2011

FOCUS + CONTEXT

Table Lens



Rao and Card, 1994

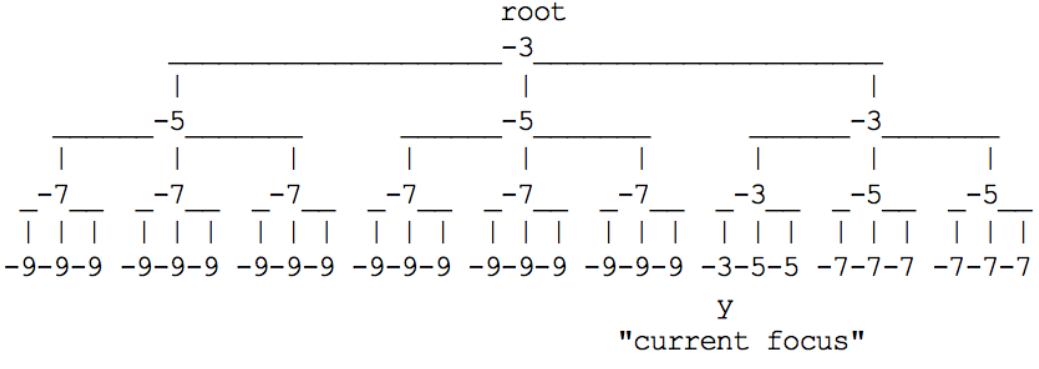
FOCUS + CONTEXT

Generalized Fisheye Views

(c) The Fisheye DOI:

$DOI_{fisheye(tree)}(x|.=y) = API(x) - D(x,y)$

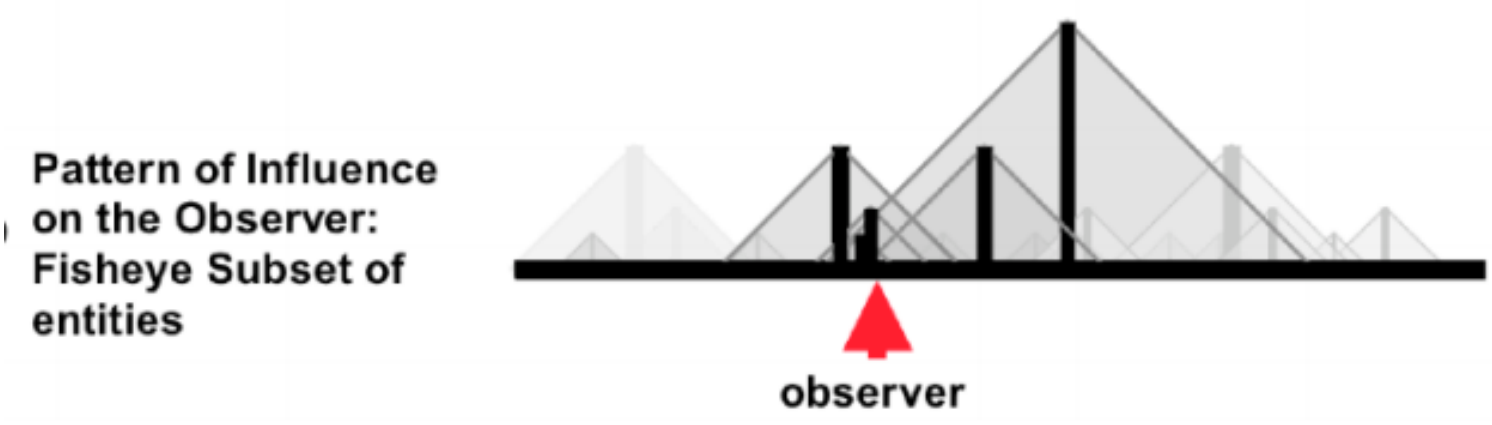
$= -(d_{tree}(x,y) + d_{tree}(x,root))$



Furnas, 1986
Generalized Fisheye Views

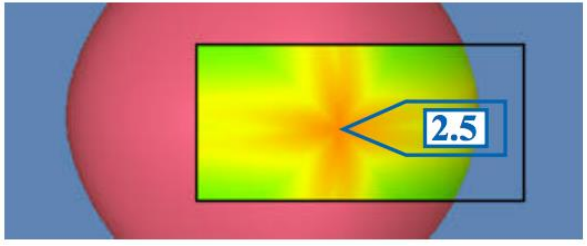
FOCUS + CONTEXT

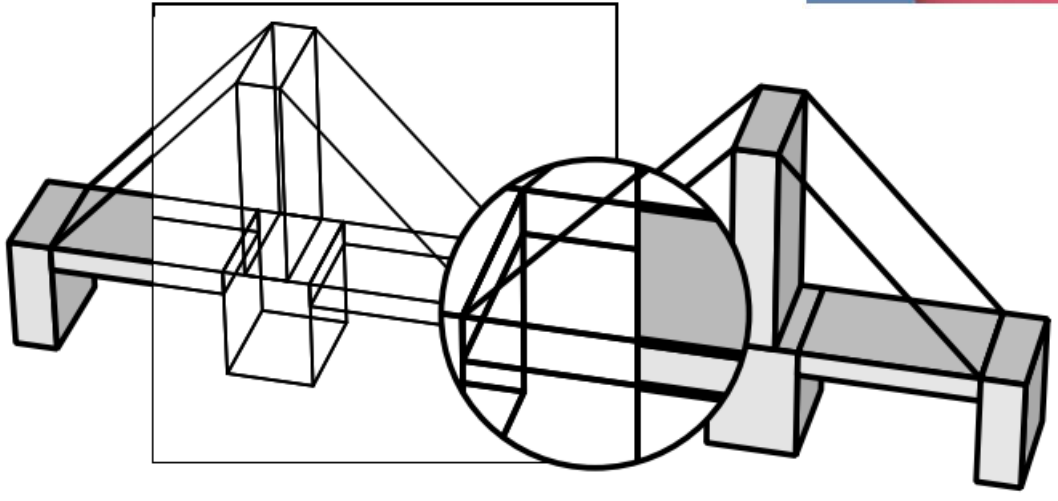
Generalized Fisheye Views



Furnas, 2010
A Fisheye Follow-Up: Further Reflections on Focus + Context

MAGIC LENSES

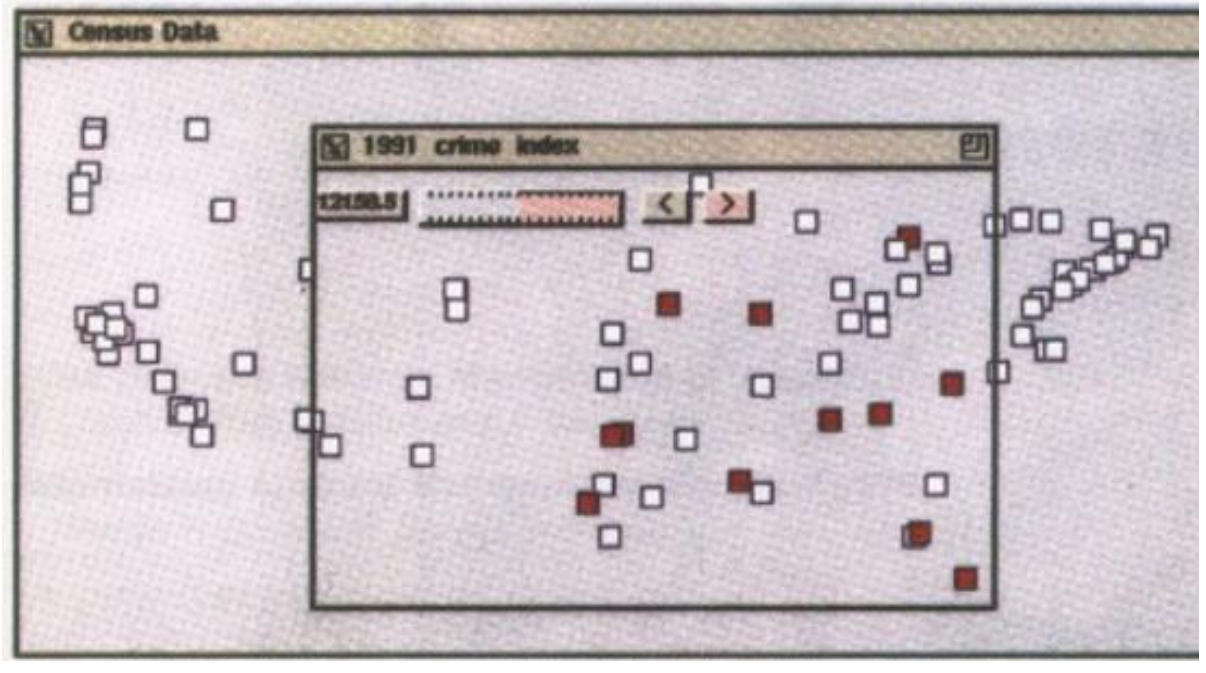




Bier et al, 1993

MAGIC LENSES

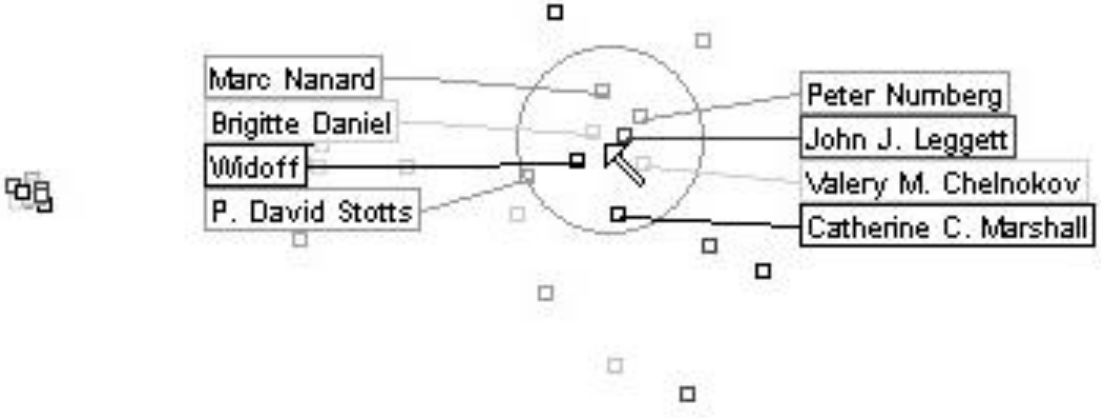
Movable filters for dynamic queries



Fishkin and Stone, 1995

MAGIC LENSES

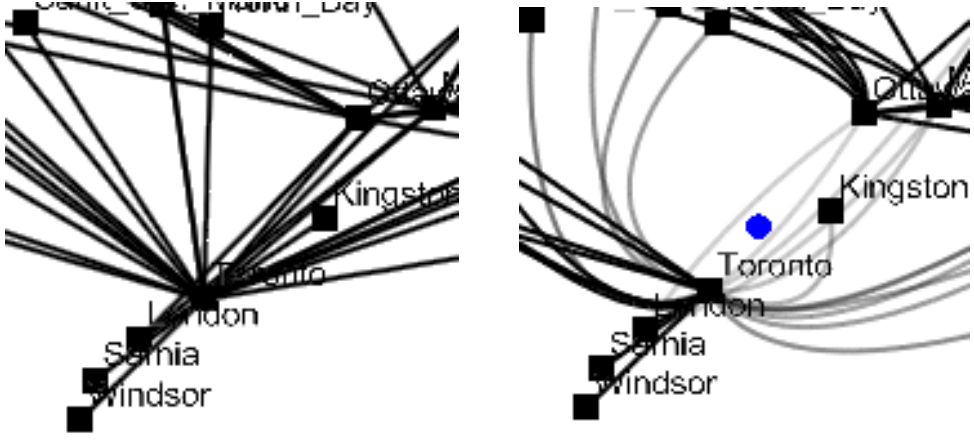
Exentric Labeling



Fekete and Plaisant, 1999

MAGIC LENSES

Edge lenses



Wong, Carpendale and Greenberg,

SELECT

EXPLORE

FILTER

RECONFIGURE

ENCODE

ABSTRACT/ELABORATE

CONNECT

SHOW ME RELATED ITEMS

BRUSHING AND LINKING

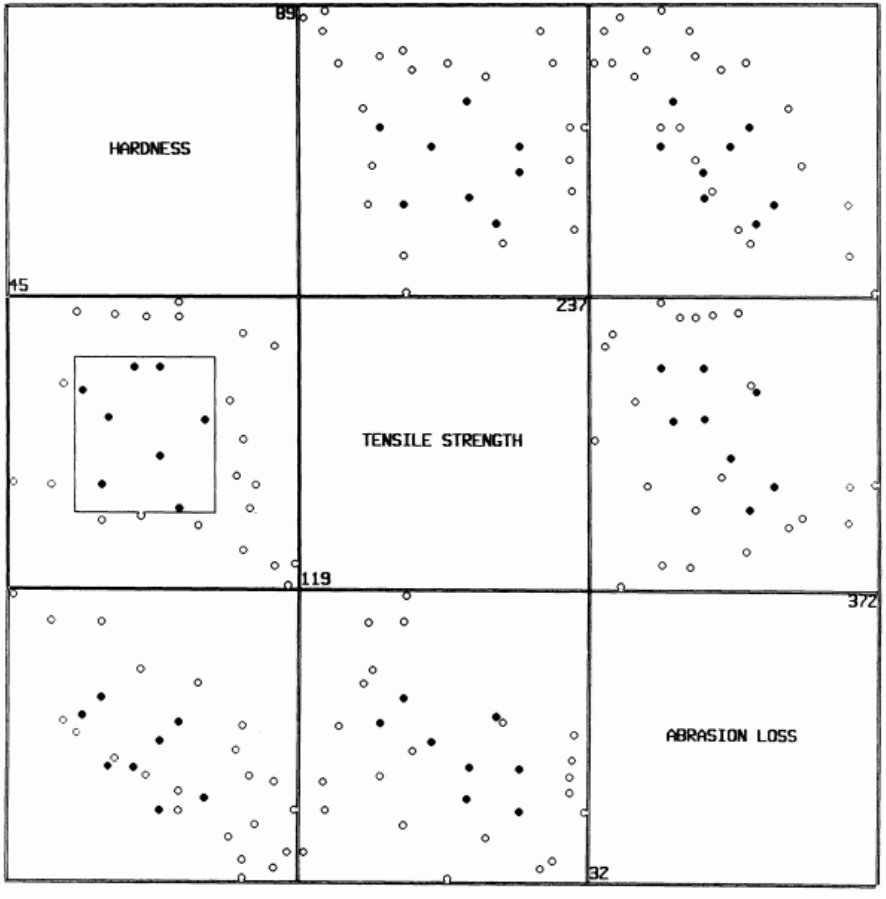
SELECT (“BRUSH”) A SUBSET OF DATA

SEE SELECTED DATA IN OTHER VIEWS

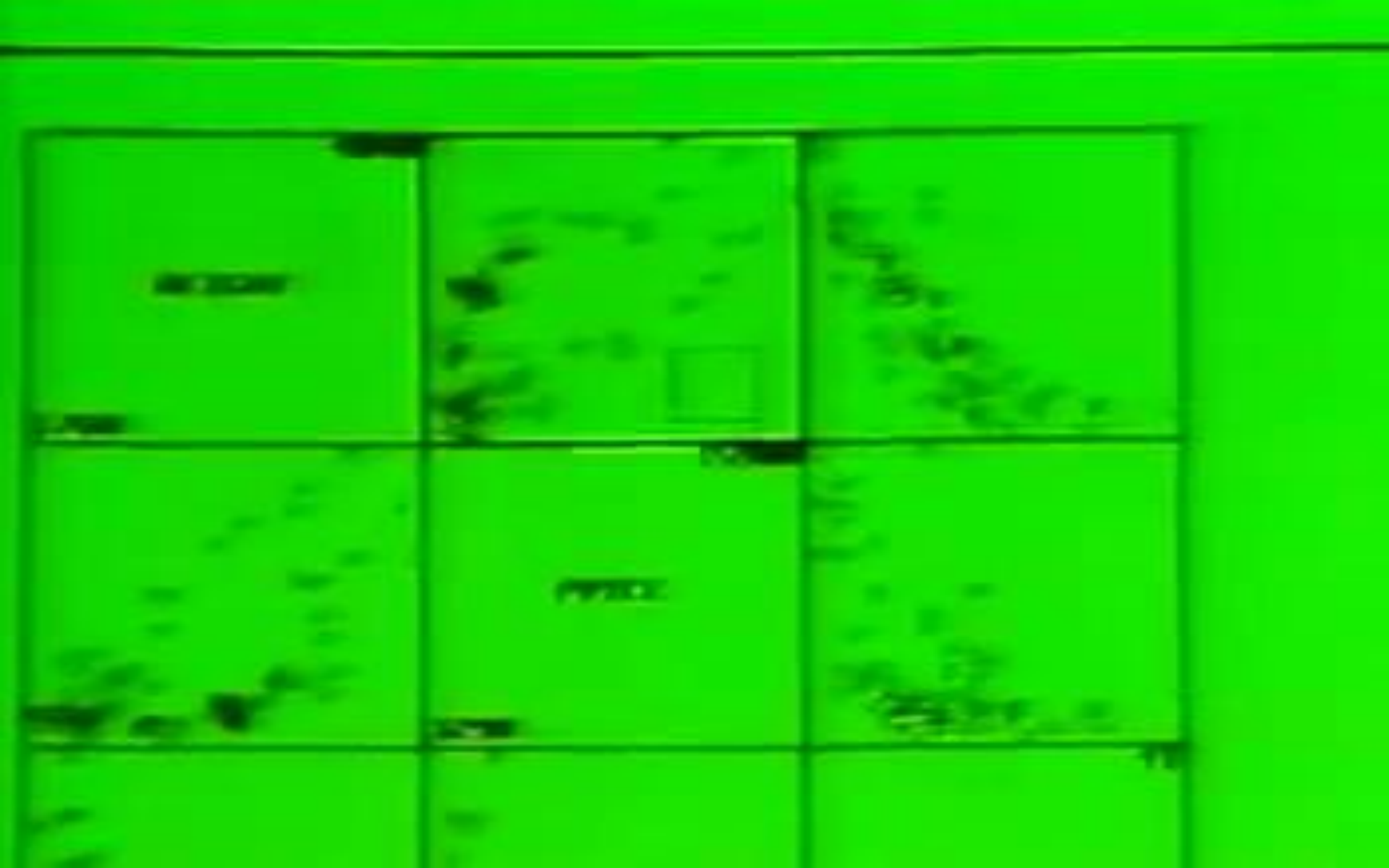
THE COMPONENTS MUST BE *LINKED*

- BY *TUPLE* (MATCHING DATA POINTS), OR
- BY *QUERY* (MATCHING RANGE OR VALUES)

BRUSHING AND LINKING



BRUSHING SCATTERPLOTS BECKER & CLEVELAND 1982

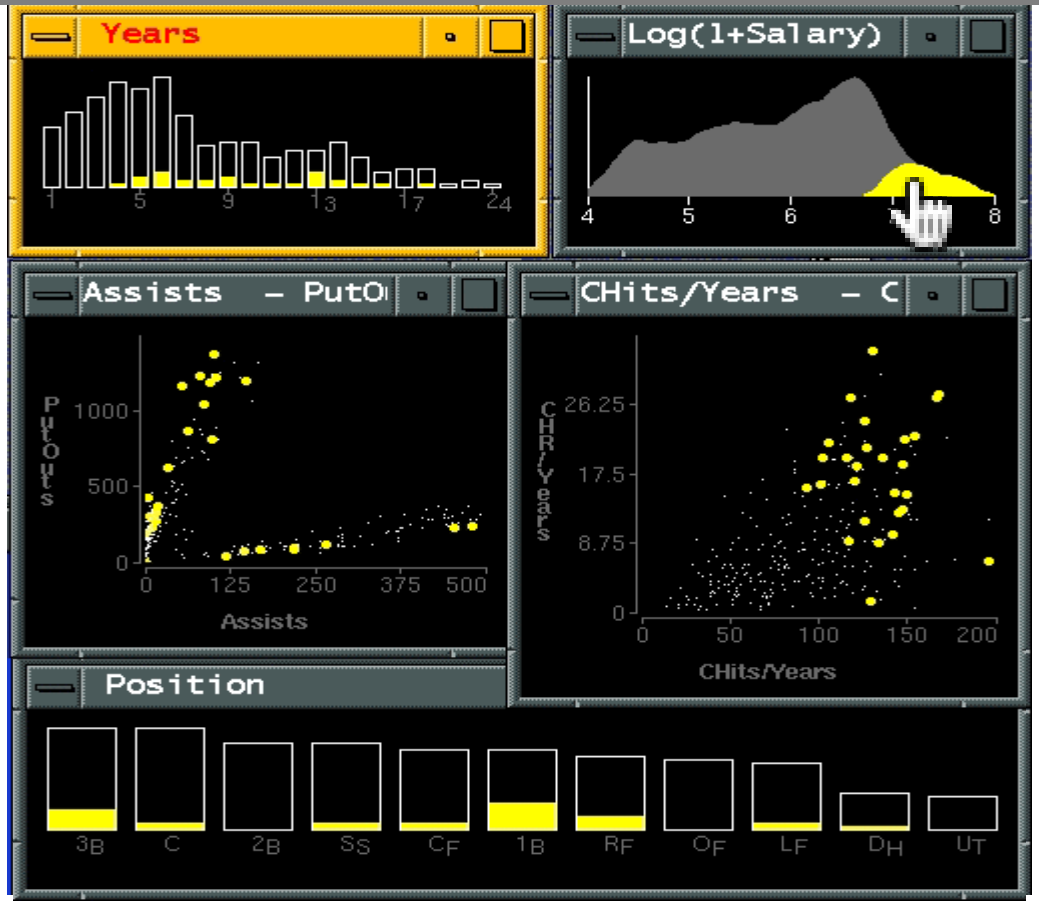


BRUSHING & LINKING

HOW LONG IN MAJORS

ASSISTS VS PUTOUTS (FIELDING ABILITY)

DISTRIBUTION OF POSITIONS PLAYED



SALARIES

HOME RUNS VS HITS (BATTING ABILITY)

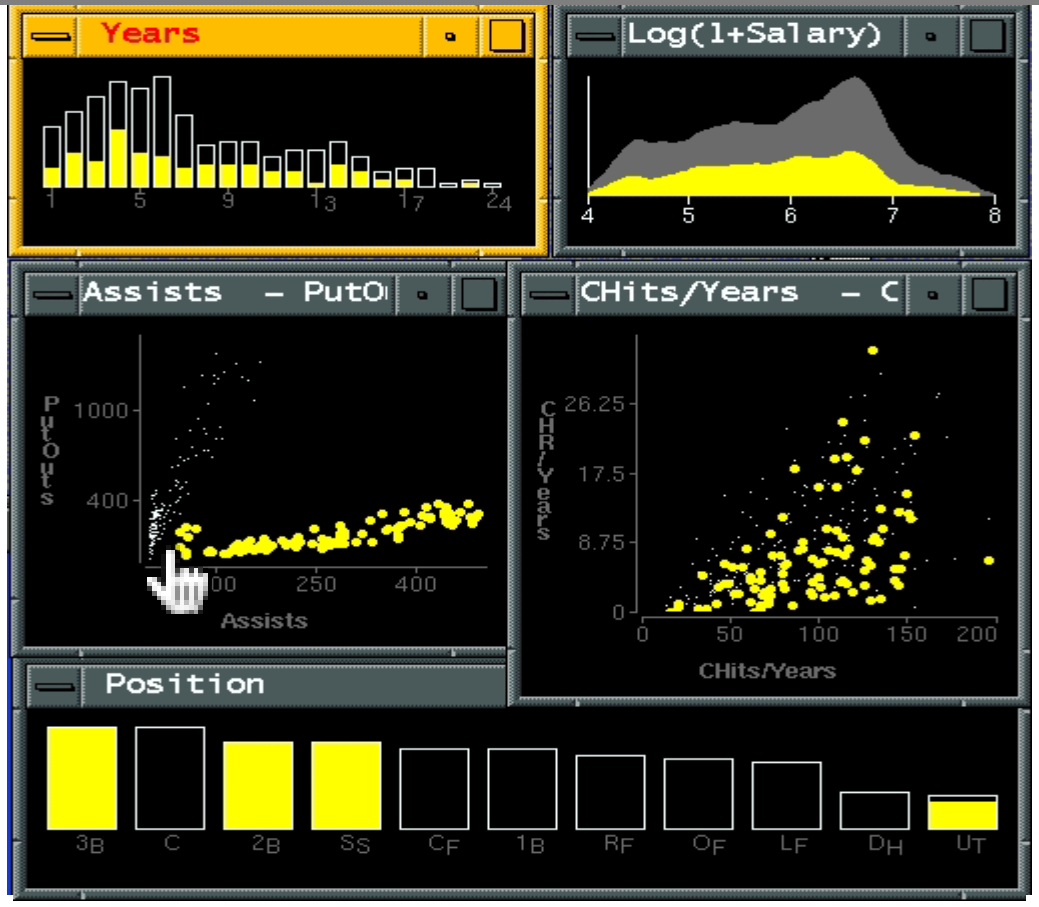
BASEBALL STATISTICS [FROM WILLS 95]

BRUSHING & LINKING

HOW LONG IN MAJORS

ASSISTS VS PUTOUTS (FIELDING ABILITY)

DISTRIBUTION OF POSITIONS PLAYED



SALARIES

HOME RUNS VS HITS (BATTING ABILITY)

BASEBALL STATISTICS [FROM WILLS 95]

Generalized Selection via Interactive Query Relaxation

Jeffrey Heer | Maneesh Agrawala | Wesley Willett
University of California, Berkeley

SEVEN CATEGORIES OF INTERACTION BY INTENT

YI ET AL. 2007

SELECT

EXPLORE

FILTER

RECONFIGURE

ENCODE

ABSTRACT/ELABORATE

CONNECT

TAXONOMIES OF INTERACTION

- What?
  - What is the user doing?
- Why?
  - Why is the user doing it?
- How?
  - How is the user doing it?

HOW?

INTERACTION TECHNIQUE

"An interaction technique is the fusion of **input and output**, consisting of all **software and hardware** elements, that provides a way for the user to accomplish a task"
(Tucker, 2004)

TYPES OF INTERACTION TECHNIQUES

Input: mouse, touch, keyboard, speech,...

Shneiderman: **Command-line interfaces vs. Direct manipulation interfaces**

HOW?

INTERACTION TECHNIQUE

"An interaction technique is the fusion of **input and output**, consisting of all **software and hardware** elements, that provides a way for the user to accomplish a task"
(Tucker, 2004)

TYPES OF INTERACTION TECHNIQUES

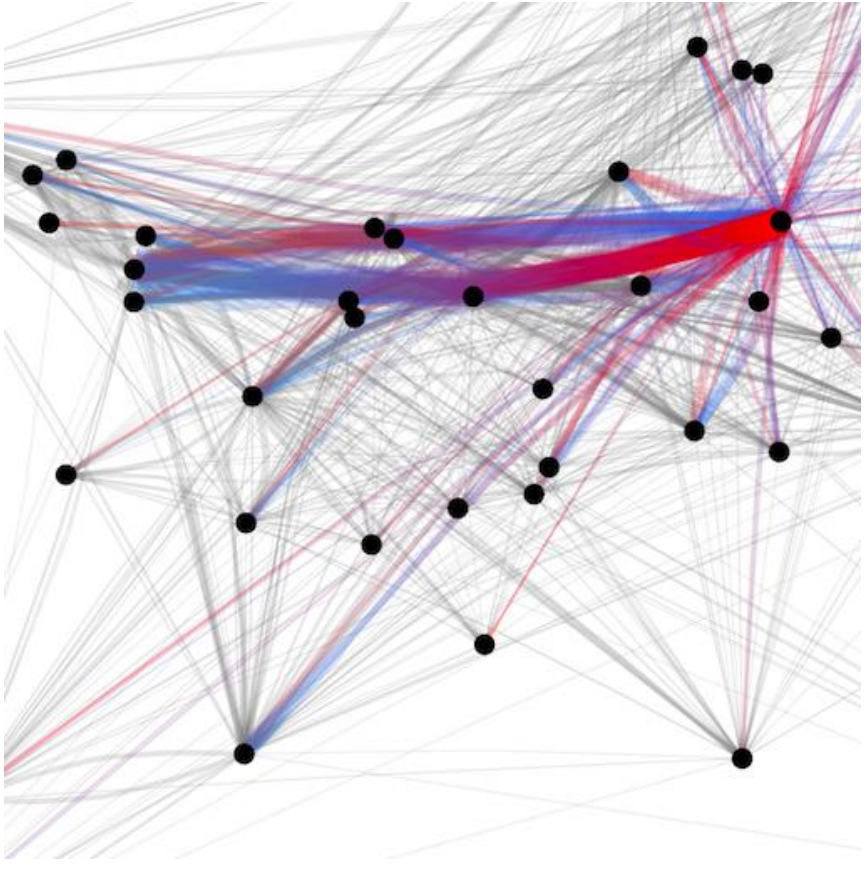
Input: mouse, touch, keyboard, speech,...

Shneiderman: **Command-line interfaces vs. Direct manipulation interfaces**

Beaudouin-Lafon: **Instruments** with different degrees of **directness**

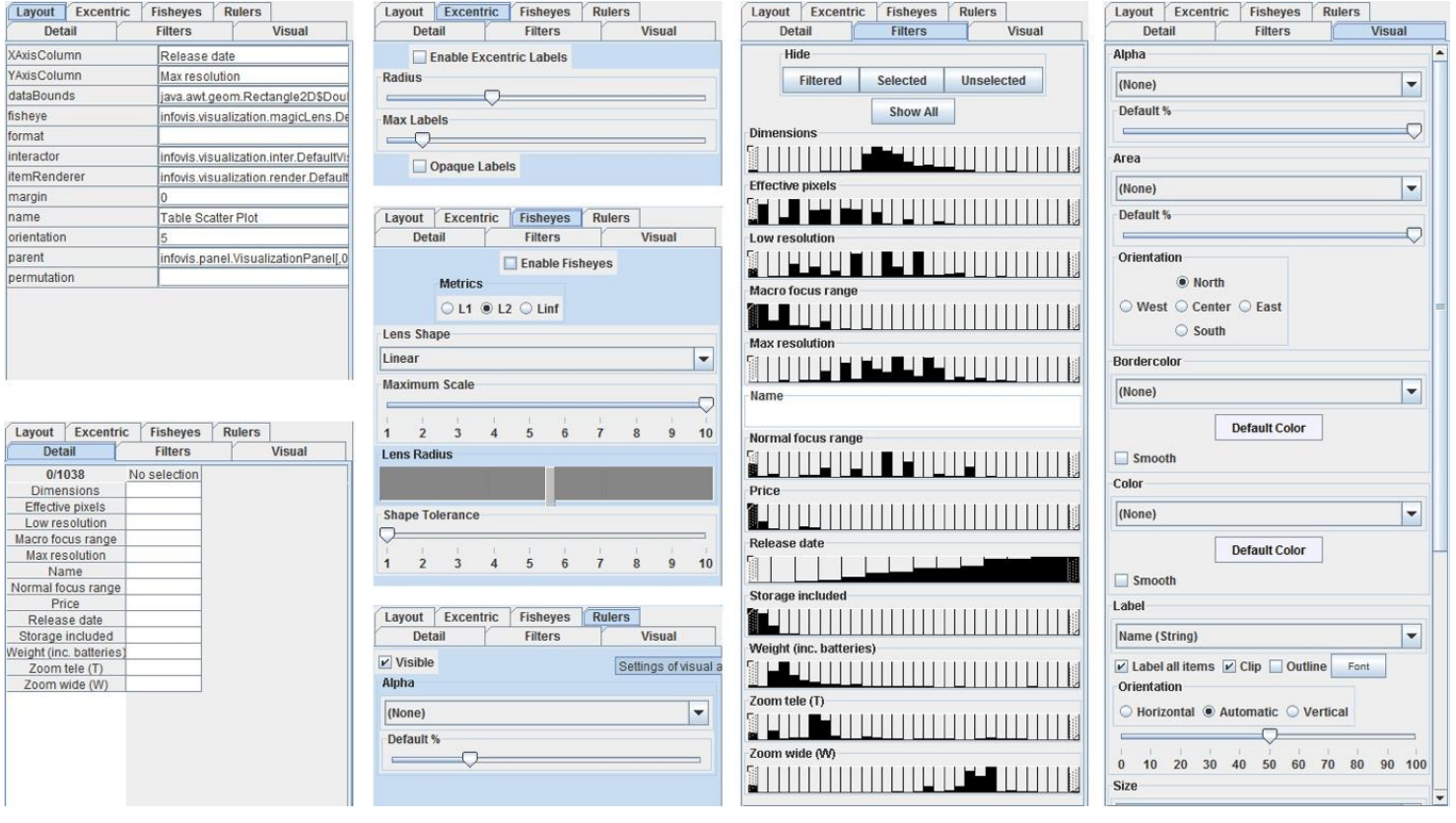
PITFALLS

#1 - Interaction has a cost



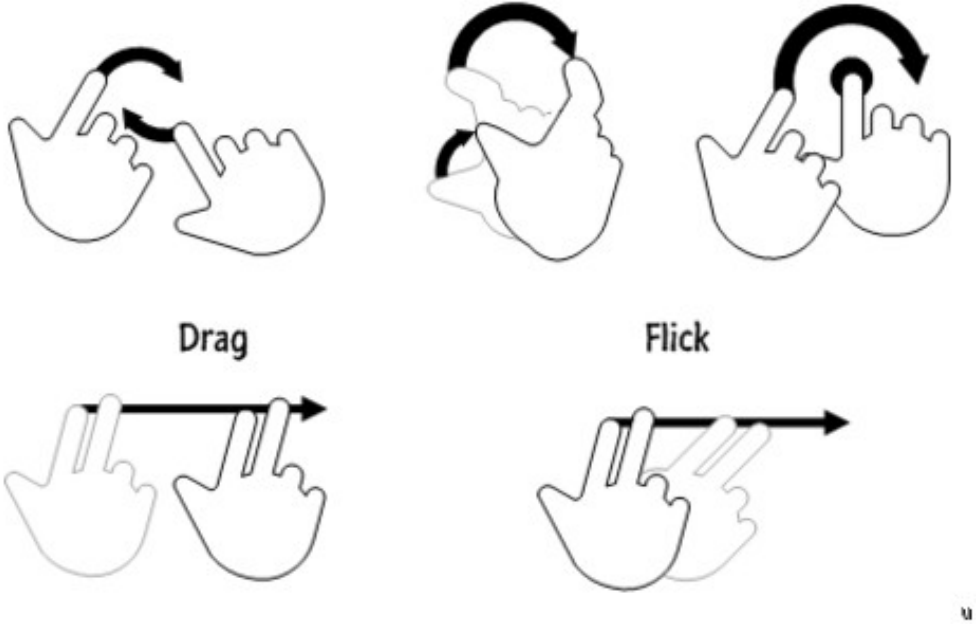
PITFALLS

#2 - Controls take screen real-estate



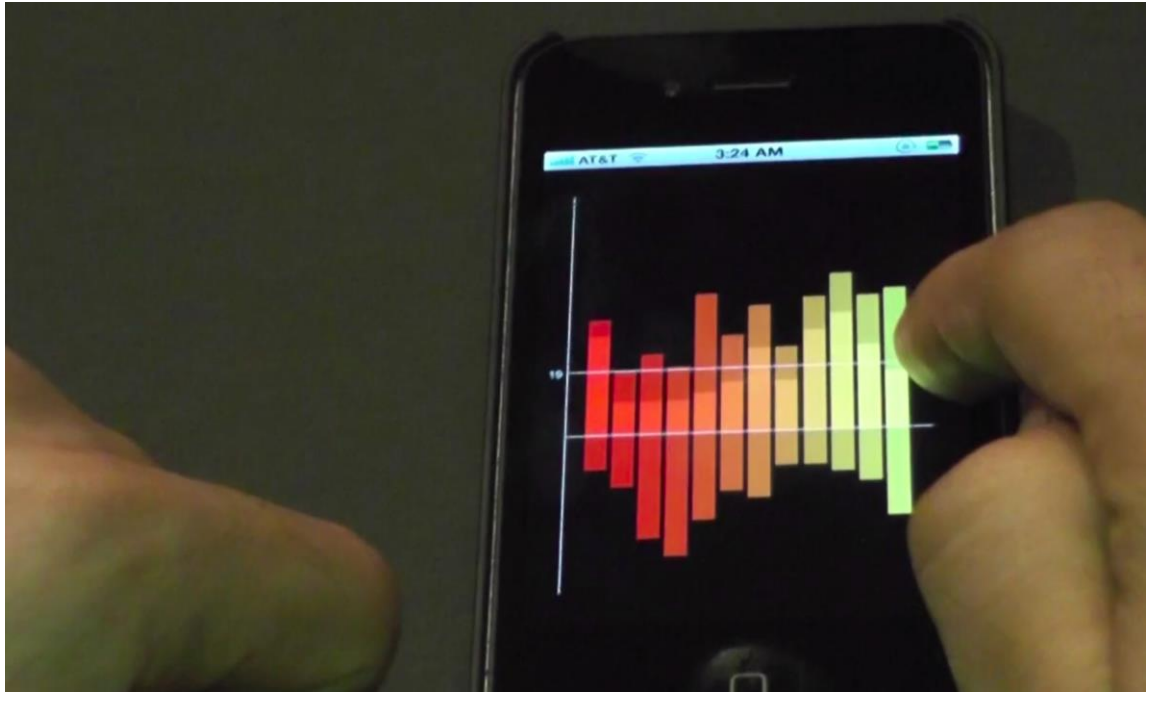
PITFALLS

#3 - Few techniques are self-explanatory



GOING BEYOND THE DESKTOP

TOUCH DEVICES

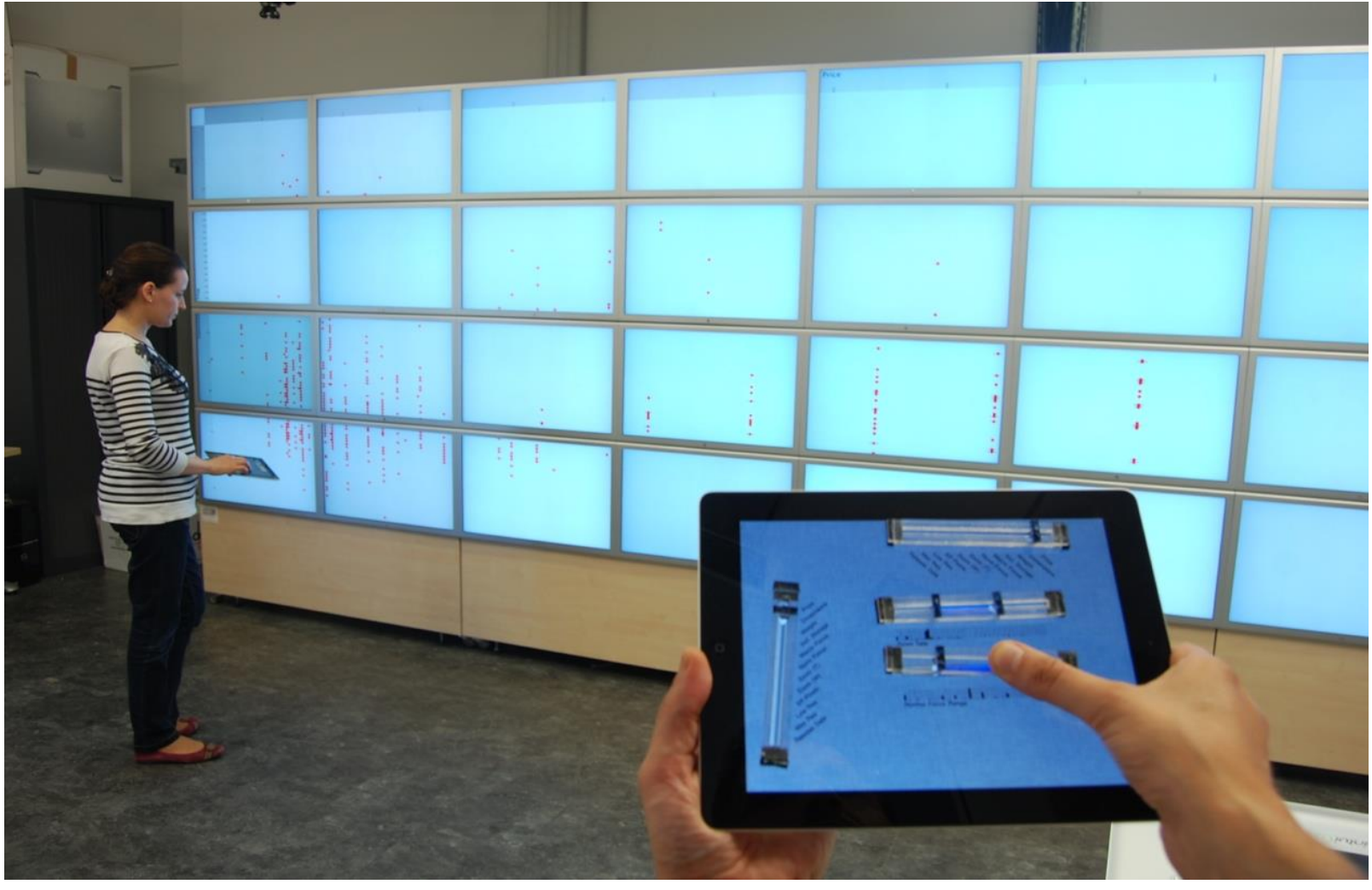


Sadana and Stasko, 2013

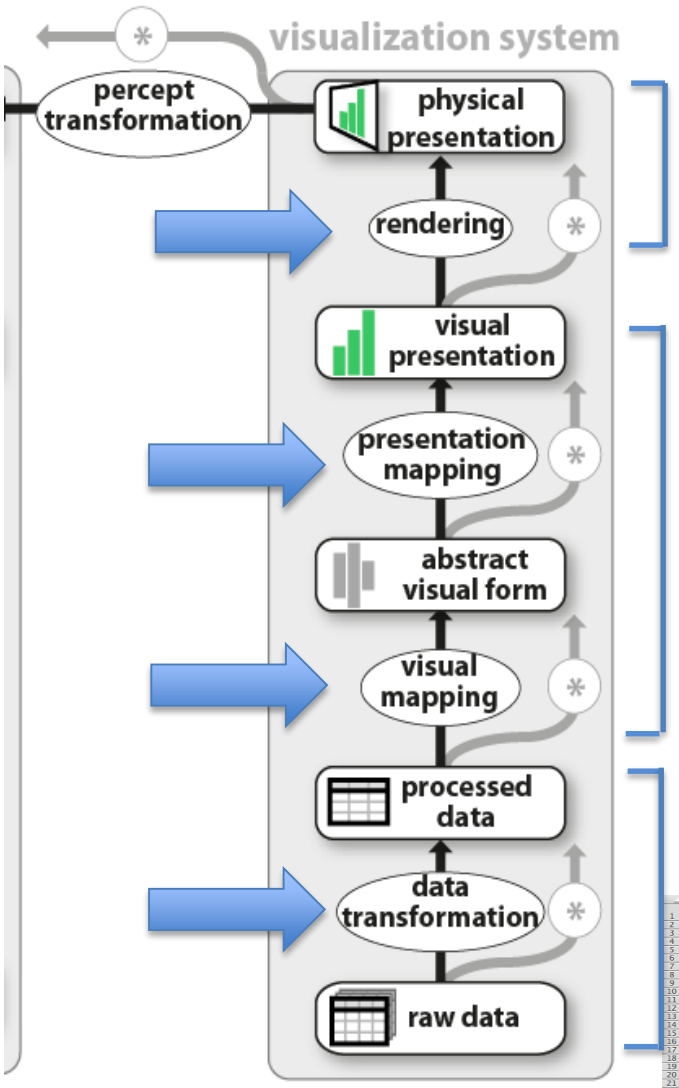
TABLETOP DEVICES

Isenberg and Carpendale, 2008

WALL-SIZED DISPLAYS



[Jansen et al., Tangible Remote Controller for Wall-sized Displays. CHI'12]



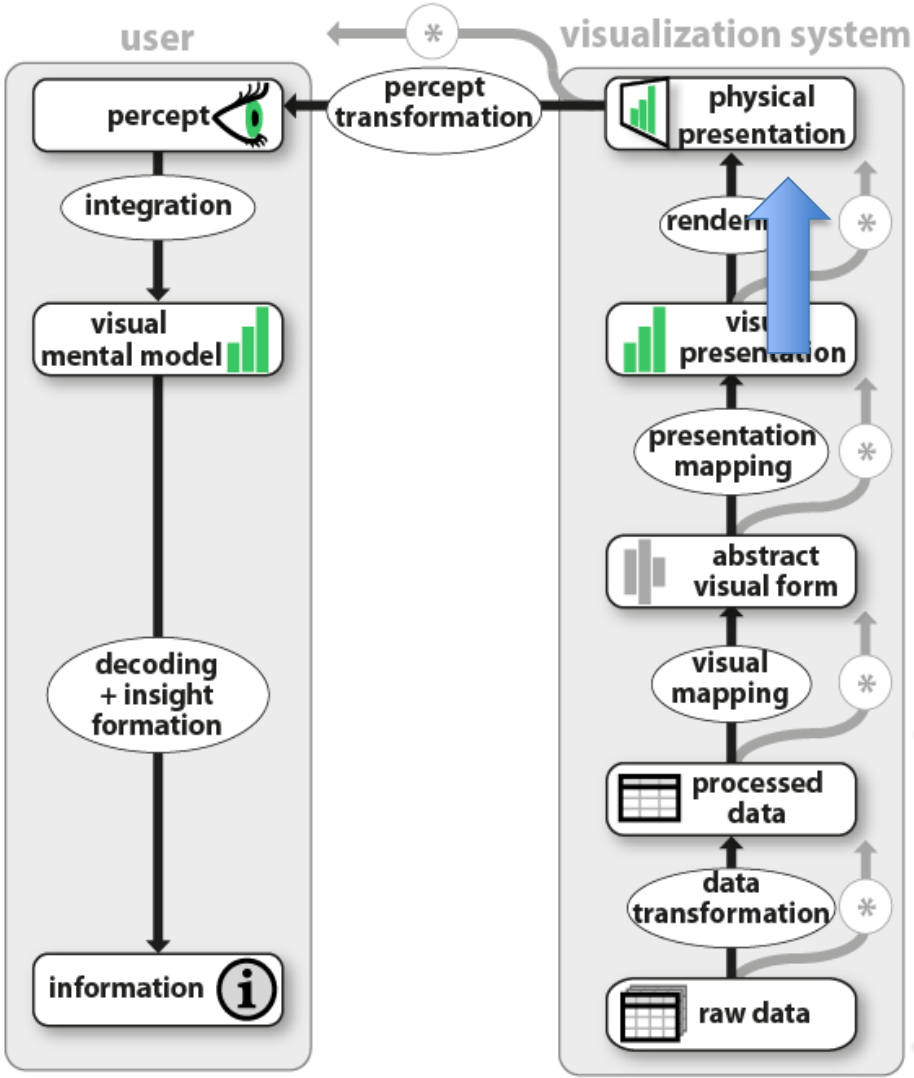
(view level)

(visual level)

(data level)

Education aid (% of total aid)	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Australia					4.7	33	20	24	26	30	11	12	11	20	24	25	21	49	50	45	41	39	34	47	39	23	39	21	29	29	26	28	27	23	14	11	10	9.7	8.1	12	12			
Austria					25	42	13	2.5	16	4.9	19	17	45	18	7.6	0.7	15	32	44	30	32	16	12	32	31	32	24	29	31	45	35	49	36	29	43	33	40	41	39	39	41			
Belgium					85	84	11	11	16	19	27	22	20	20	6.8	4.5	16	37	37	34	28	24	30	22	18	19	18	17	22	14	15	20	21	20	19	22	20	26	19	21	25			
Canada					34	39	18	25	8.4	5.1	8.4	3.3	3.4	1	7.2	9.7	9.4	7.1	16	10	19	12	28	25	14	11	9.3	22	17	14	25	16	19	19	20	26	26	16	16	19	11			
Denmark					100	100	14	19	5.6	15	3.8	14	8.2	9.5	14	0.5	5.8	10	3.7	3.3	3.7	4.6	1.5	1.9	14	11	13	4.2	7.9	4.3	11	7.6	1.6	11	4.9	13	5.5	9.2	9.6	2.1	5.6			
Finland							30	14	14	20	15	1.5	8.6	3.7	3	4.8	5	4.5	3.5	7.9		6.2	5.7	2.1	6.8	3.6	5.8	5.3	10	5.3	11	9.6	14	13	12	14	15	24	10	8.4	7.8			
France			63	64	47	33	38	38	40	39	42	45	30	33	38	35	34	26	30	28	32	34	36	36	39	40	33	39	43	44	47	36	37	41	42	41	40	38	37			
Germany			55	55	22	19	24	19	19	20	17	19	17	20	20	21	24	26	22	19	20	22	21	23	21	25	25	21	20	25	22	24	21	25	26	24	8.9	24	24			
Greece																												57	57	40	20	8.2	7.8	11	8.6	40	17	26	17	29			
Ireland																			29	34	31	26	28		41	33		23	28	28		28	30	29	27	25	19	18	19	15	19			
Italy					20	96			40		46	46	23	22	12	11	6.7	7.2	7.2	4.9	5.1	6.9	6.3	10	9	6.1	16	12	17	12	11	18	13	6.7	19	24	7.7	15	7.4	5.7	7.7			
Japan					13	12	2.9	1.1	2.2	2.8	2.9	3.2	2.9	3.1	3.6	3.7	7.1	6	8.8	11	7.7	6.1	8.6	9.8	8.8	8.5	8	10	10	6.5	6.9	7.9	13	7.8	9.5	13	13	15	8.8	11	8.1			
Luxembourg																											10	3.9		22	22	31	30	29	29			21	21	24	16			
Netherlands						42	33	12	15	11	12	12	13	11	16	17	16	17	19	13	7.4	10	11	20	29	8.7	5.1	15	9.1	12	14	18	20	18	17	18	18	19	21	29	22			
New Zealand							20	21	5.1	8.9	29	23	17	19	19	17	19	15	13		47	68		15	59	48	51	50	50			58	48	51	49	45	40	41	34	34	32			
Norway			55	49	32	9.7	5.7	7	13	5.9	5.5	2.8	2.6	2.5	8.7	7.5	11	8.8	12	3.1	14	7.8	8.2	7.3	4	4.3	4.5	11	15	9.3	15	10	9.7	14	14	15	14	13	13			
Portugal																										60		42	48	41	36	18	15	19	23	22	39	40	36	35	28			
Spain																								6.8	5.3	9.4	12	11	13	17	16	21	33	18	17	15	11	19	16	14			
Sweden			33	23	15	14	21	18	17	21	17	6.8	16	17	17	12	11	16	13	15	6.5	8.7	14	7.6	9.7	11	13	12	14	10	11	9	6.2	11	9.9	11	8.9	8.5	5.4			
Switzerland			47	46	12	15	8.7	11	15	19	15	13	13	12	12	11	17	5	13	13	17	16	12	13	15	10	10	7.5		8.4	6.6	8	7.1	7.4	6.8	6.4	6.1	7.2	7.1			
United Kingdom			50	32	16	16	0.9	0.7	20	13	9.8	21	27	19	16	13	26	17	17	19	20	18	18	21	20	20	16	16	17	13	16	12	16	6.7	15	15	11	13	18			
United States			69	64	10		7.8	6.2			7.5	7	12	10	8.9	7.1	11	11	11	10	12	13	14	11	11	11	11	8	8.5	8.4	4.7	3	5.7	3.7	5.6	3.7	2.3	3.2	3.7	2.8	4.5			

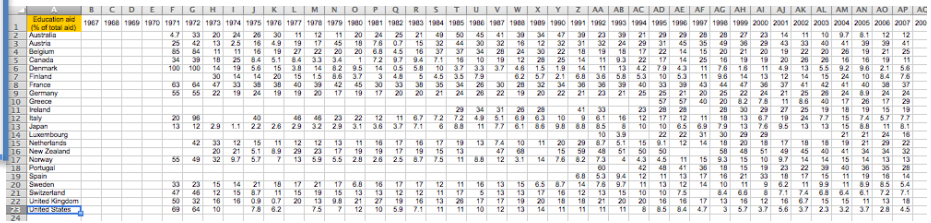
Jansen and Dragicevic 2013 (www.aviz.fr/beyond)



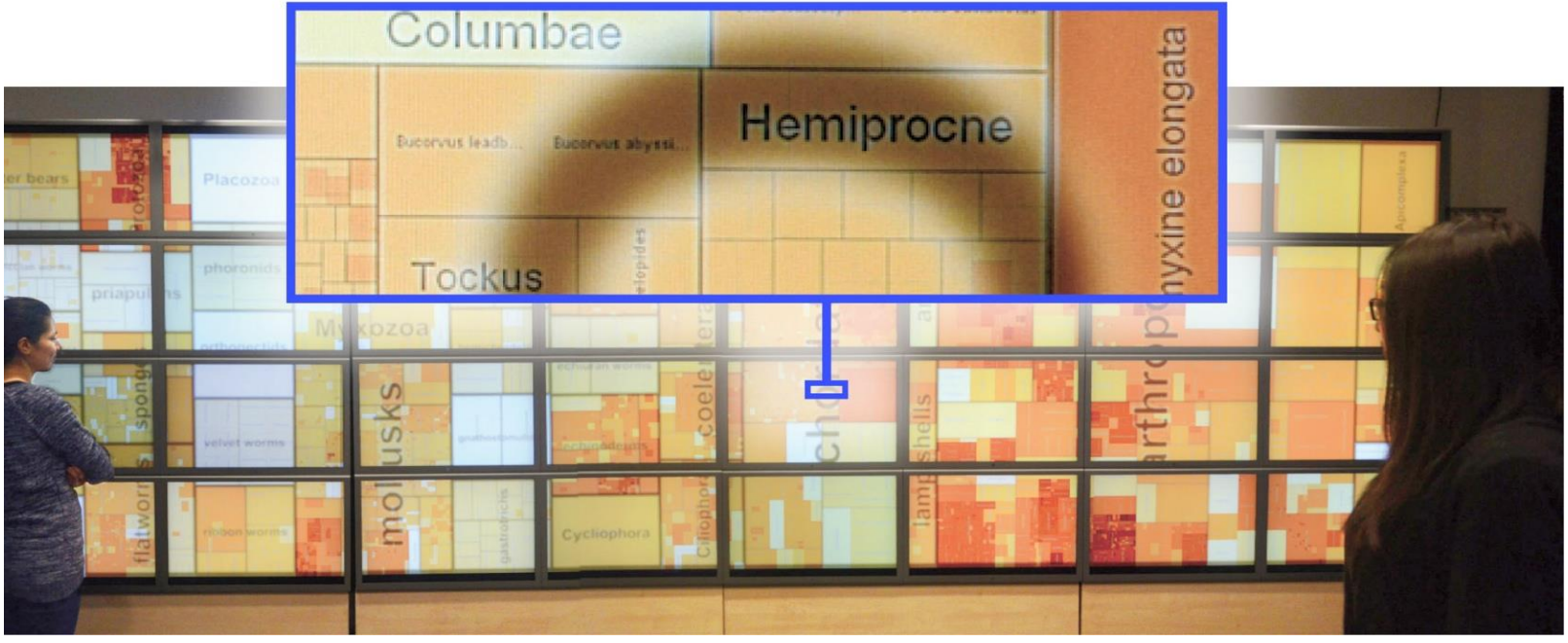
(view level)

(visual level)

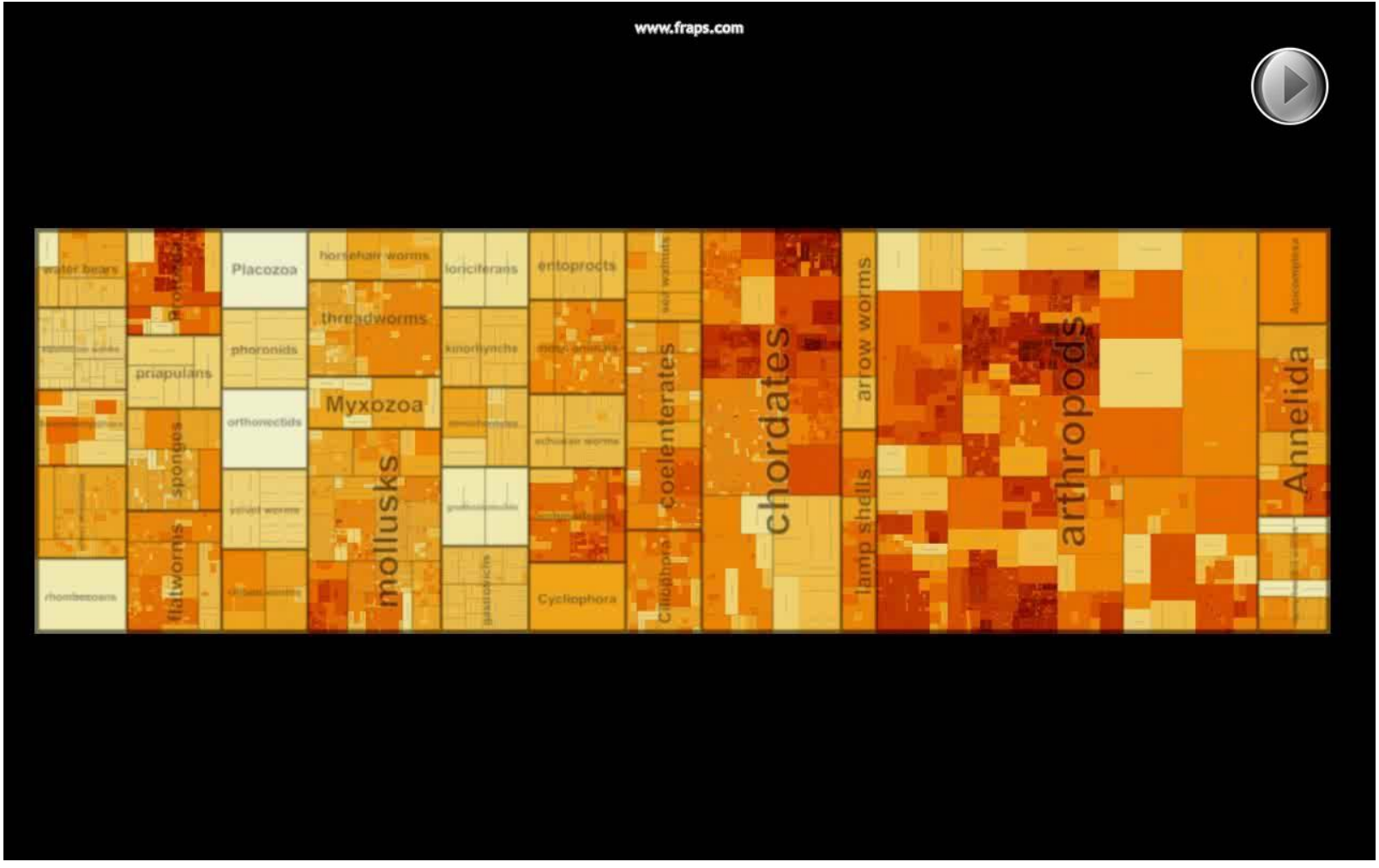
(data level)



Jansen and Dragicevic 2013 (www.aviz.fr/beyond)

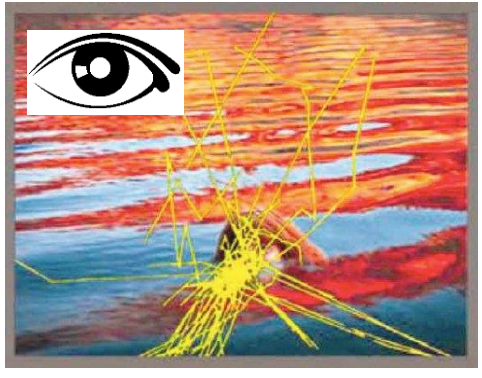


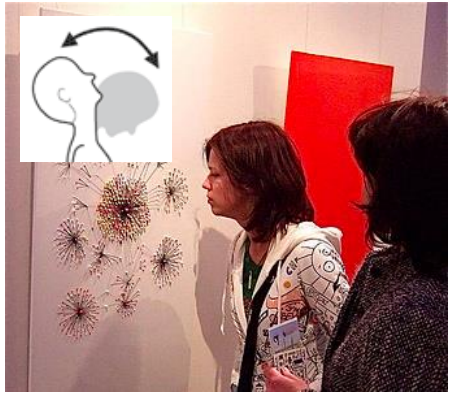
[Isenberg et al. , Hybrid Images for Large Viewing Environments, InfoVis'13]



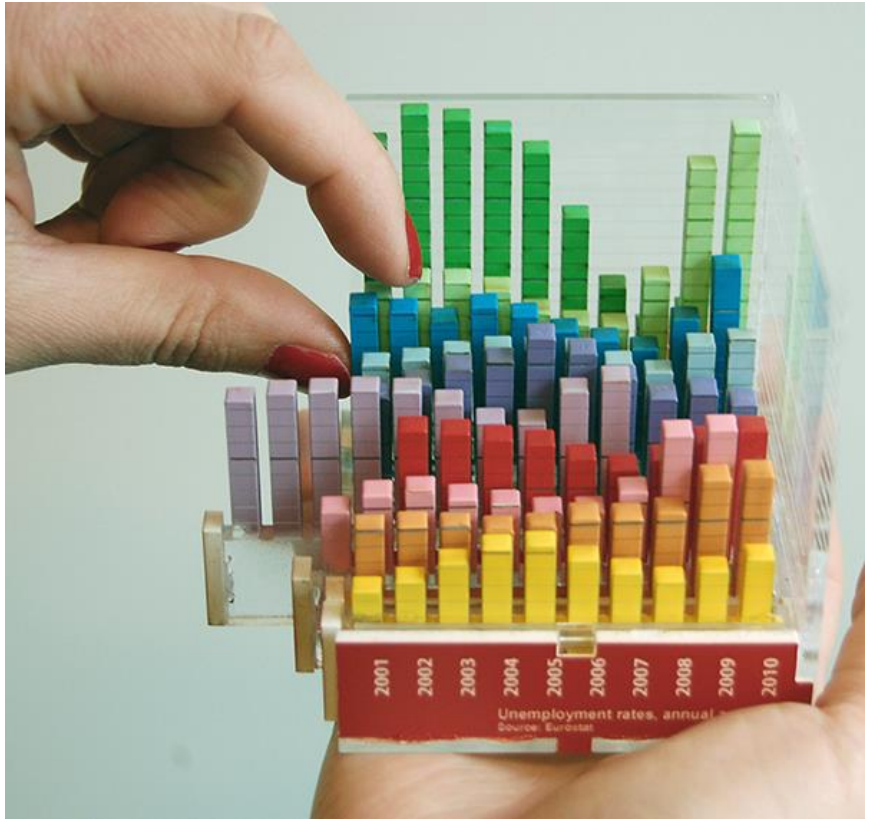
[Isenberg et al. , Hybrid Images for Large Viewing Environments, InfoVis'13]

INTERACTION WITH THE PHYSICAL WORLD

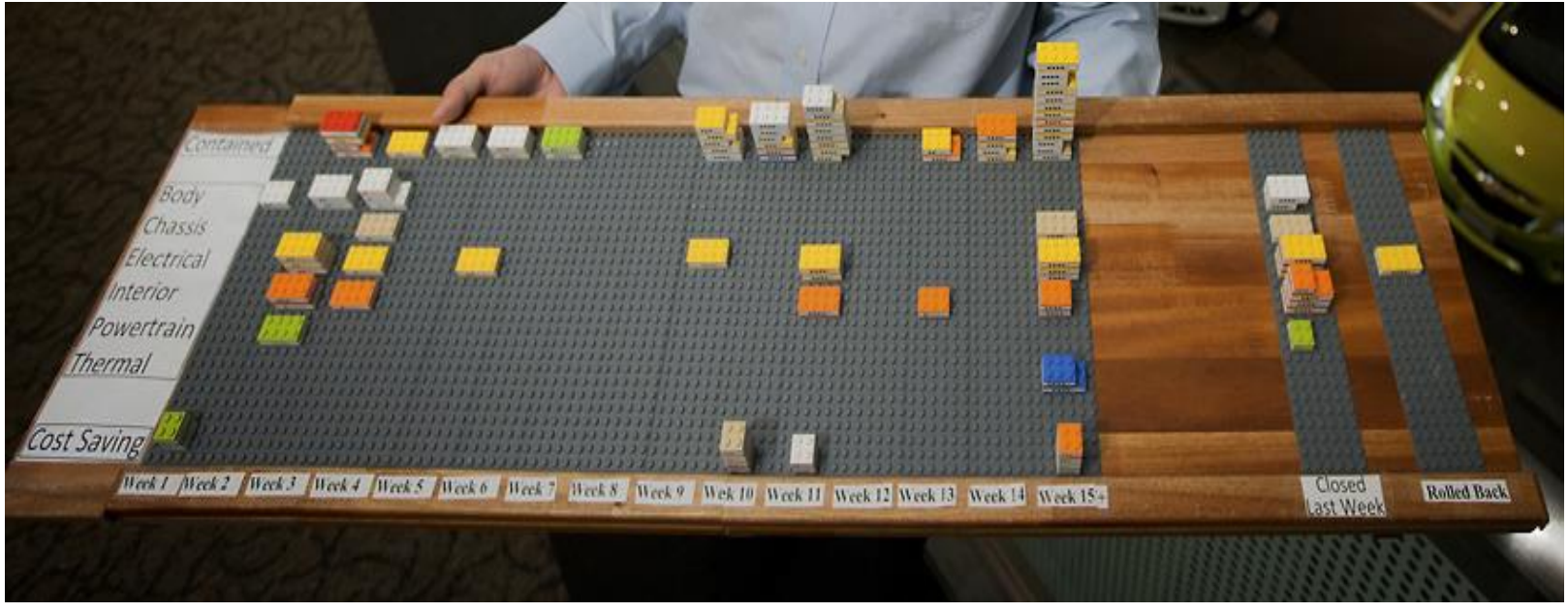




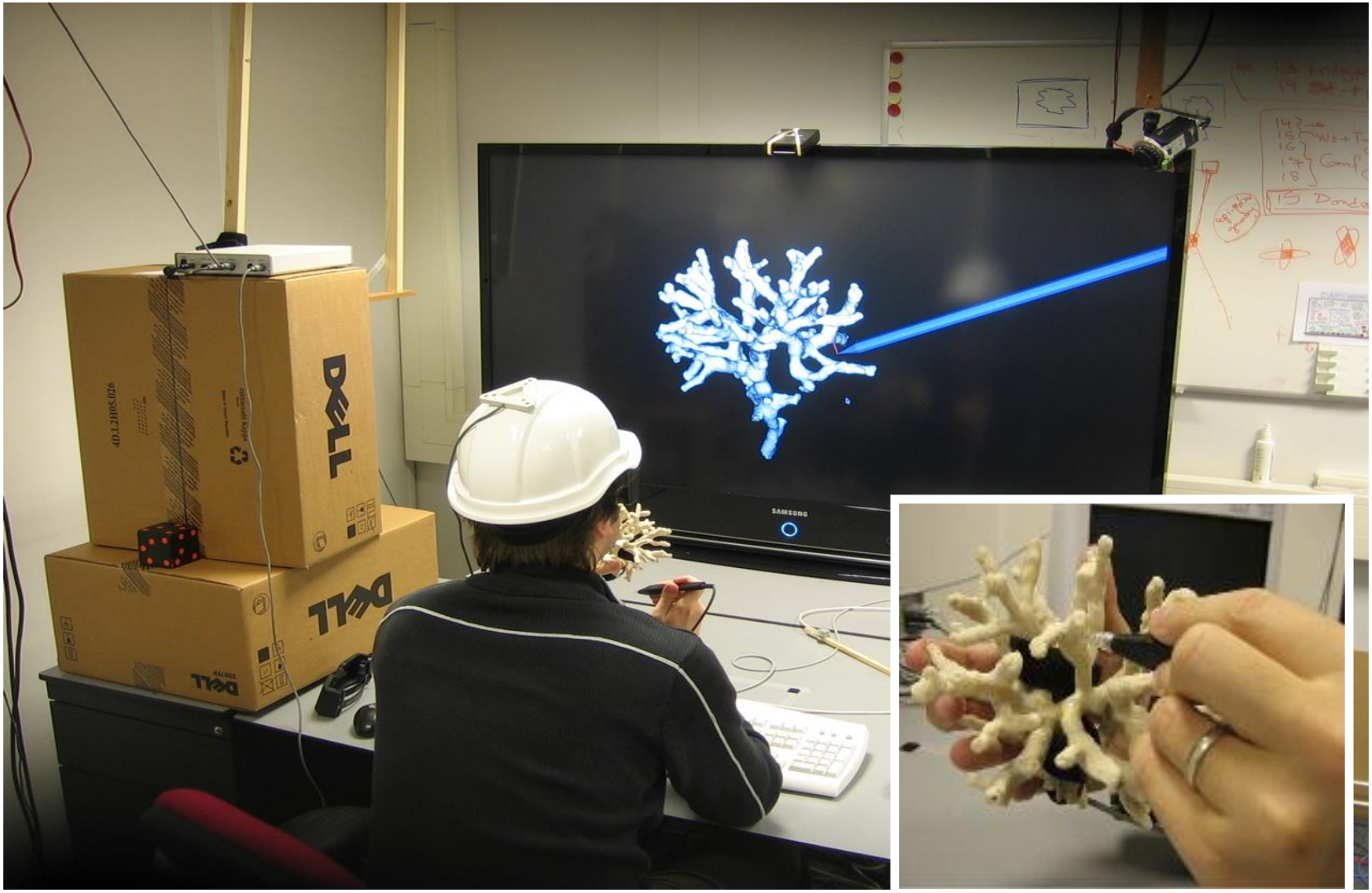
PHYSICAL VISUALIZATIONS



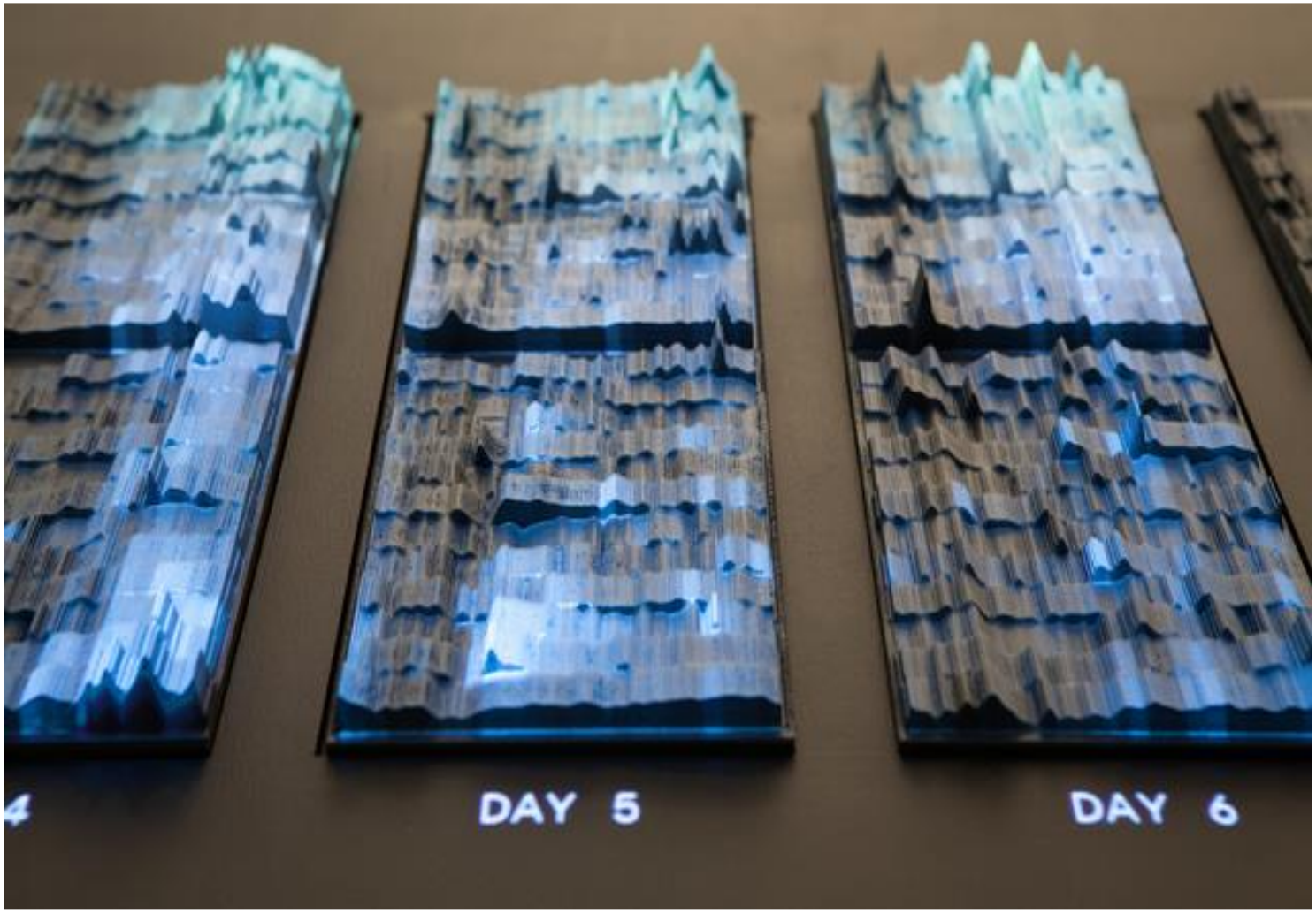
tinyurl.com/physvis



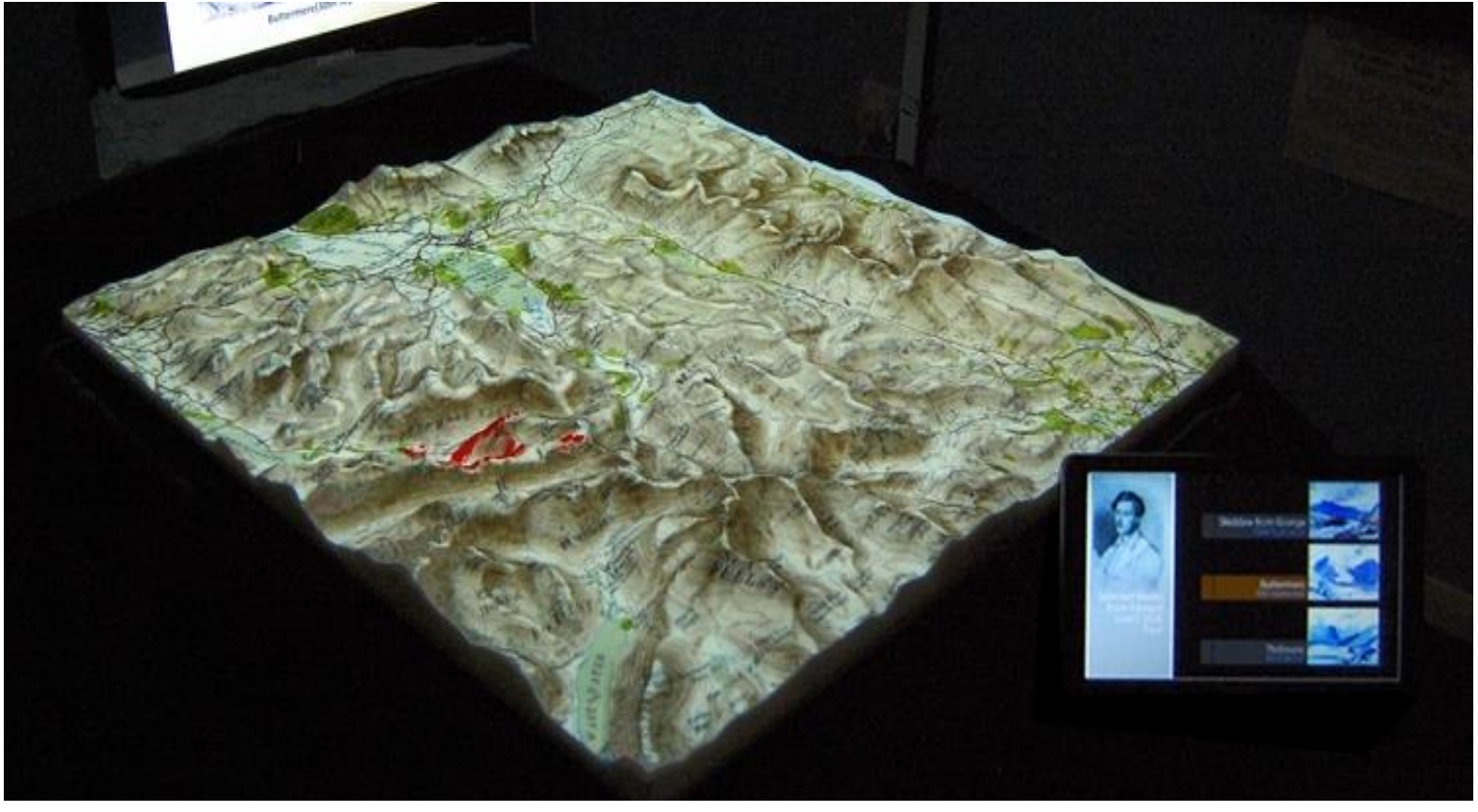
[Mark Wilson. How GM is saving cash using legos as a data viz tool. April 2012]



[Kruszynski & van Liere, Tangible Props for Scientific Visualization, Virtual Reality 13 (4) 2009]



[Stefaner & Hemmert, emoto data sculpture, http://www.nand.io/visualisation/emoto-installation]



[PARM: Projected Augmented Relief Models, University of Nottingham, 2012]

Relief (Leithinger et al, 2009)

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