DATA VISUALIZATION

Interaction

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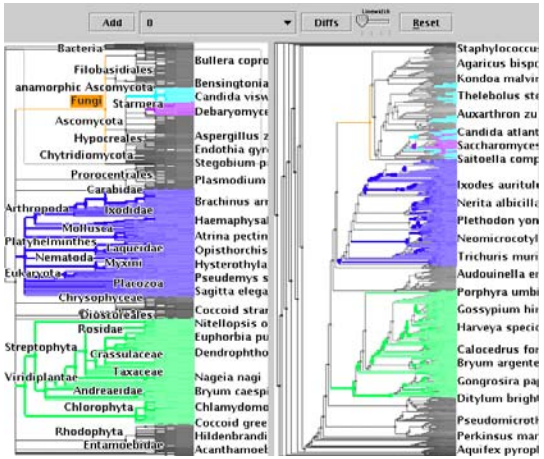
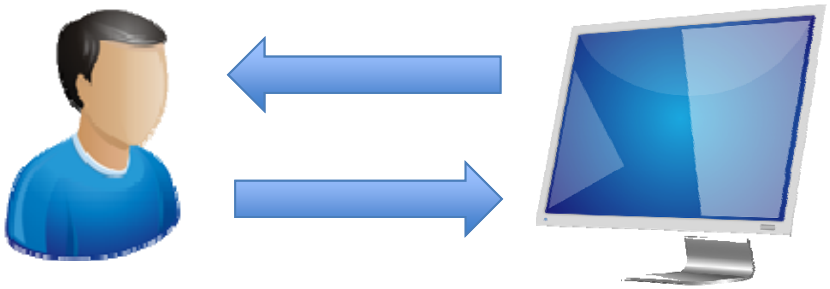
RECAP

- interaction is fundamental to the definition of visual exploration
- you have already seen examples
  - for graphs
  - for multi-dimensional data
  - for time-dependent data



RECAP

- visual exploration is more than just looking



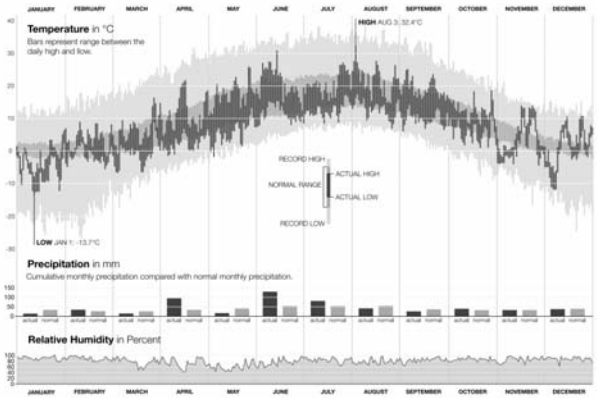
- so far we focused mostly on output; but we have already used limited input earlier in the class
- today: input for steering visual output

WHY INTERACT?

DEFINITION OF INTERACTION

STATIC CONTENT

– many infographics

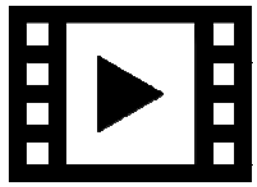


New York Times, 1980.
Cited in Tufte, 1983

DYNAMIC CONTENT

– **animated content**
changes independently from the user

– **interactive content**
changes as a result of user actions

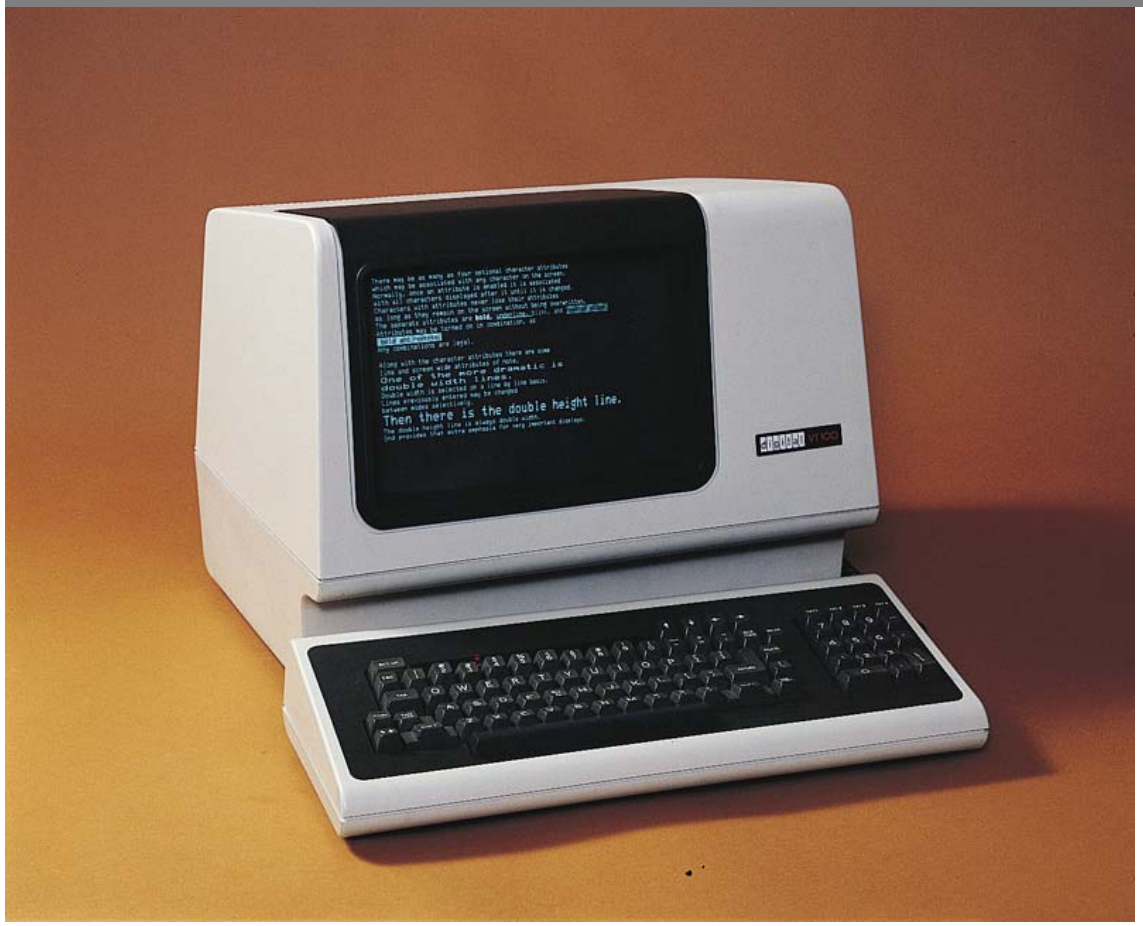


THERE IS TOO MUCH
DATA TO SHOW

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.html

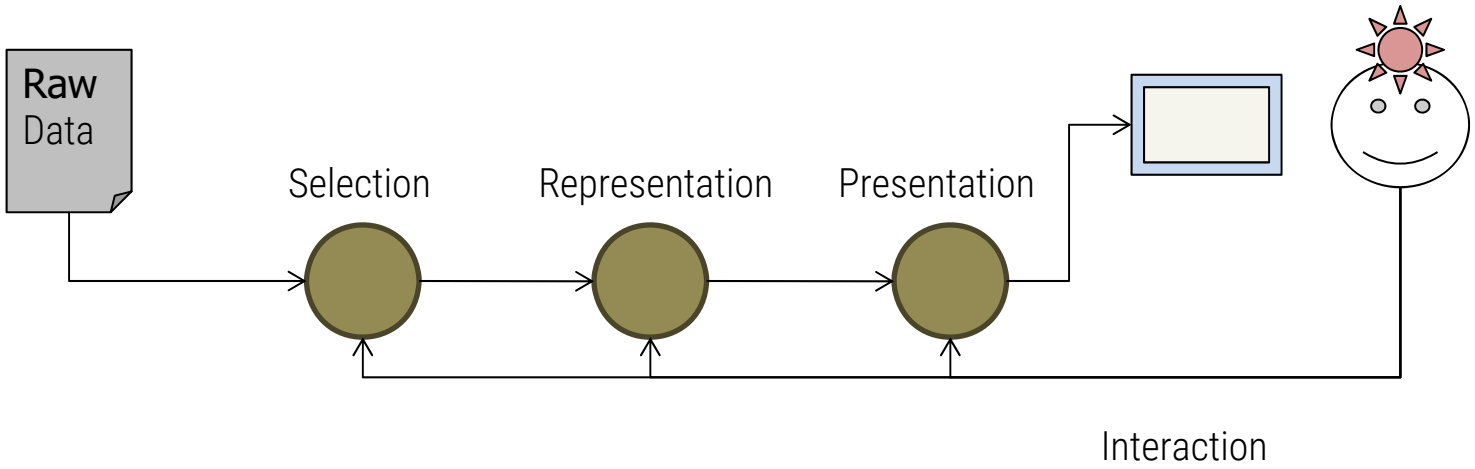
TODAY

Büschel et al. 2021

TAXONOMIES OF INTERACTION

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

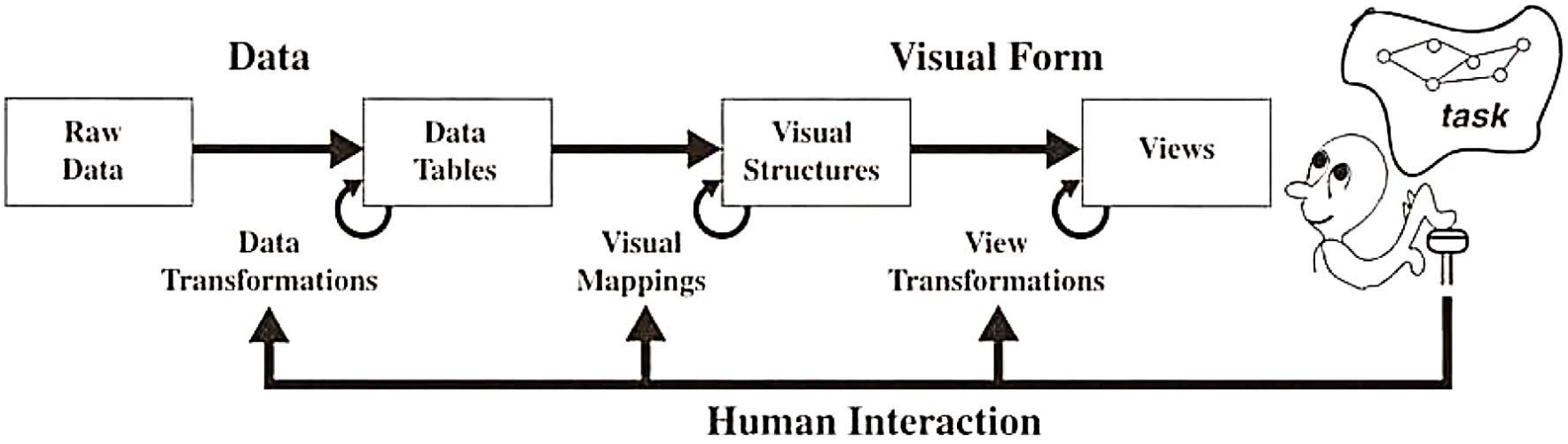
THE VISUALIZATION PIPELINE



The Visualization Pipeline

from [Spence, 2000]

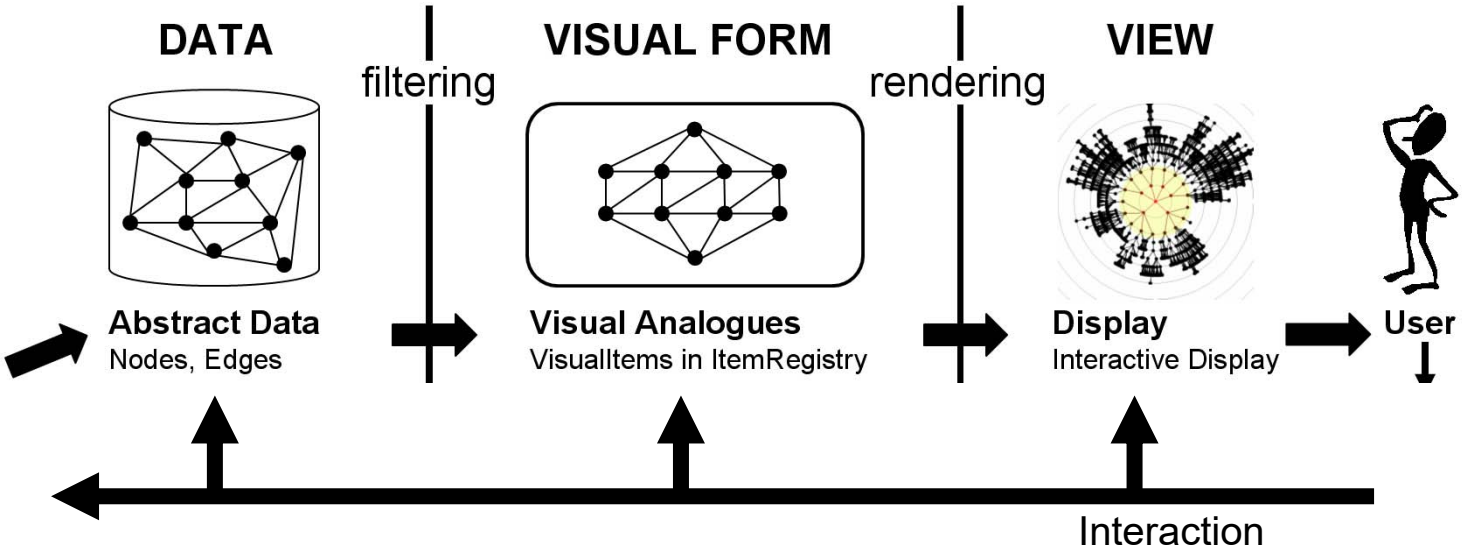
THE VISUALIZATION PIPELINE



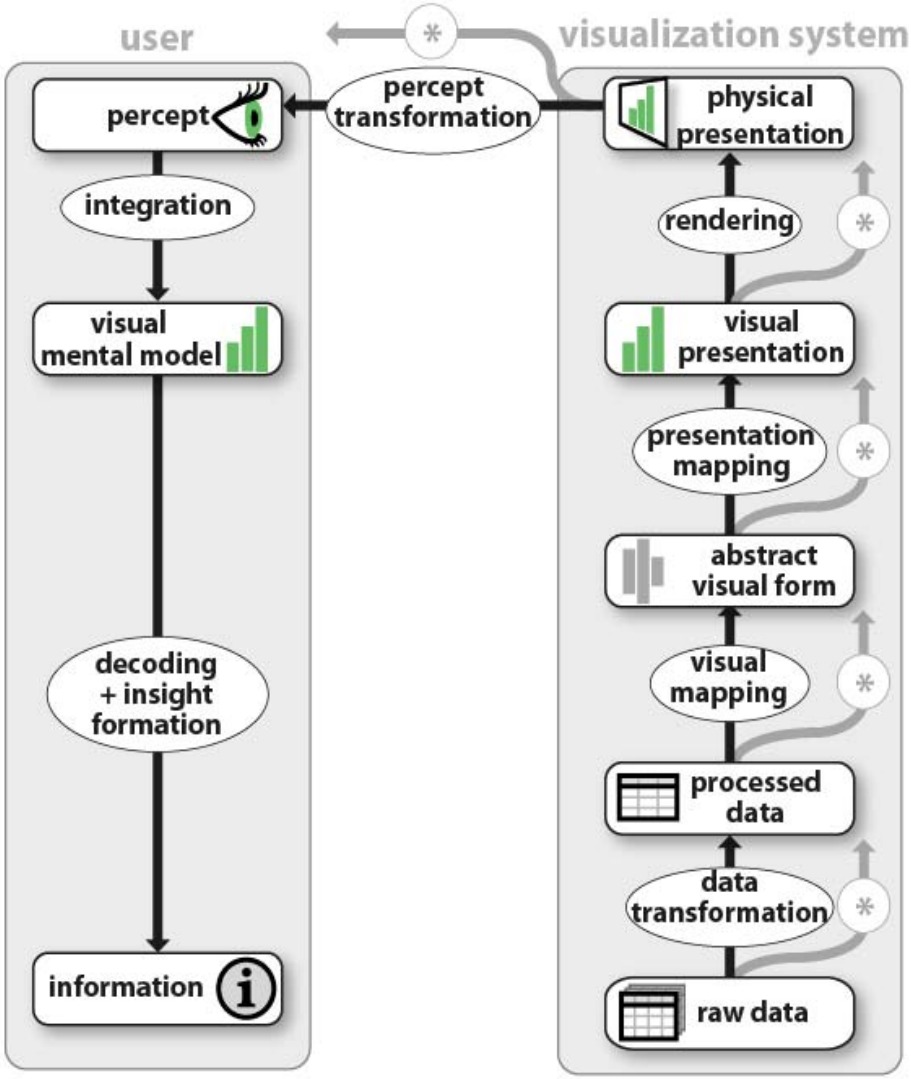
Raw Data: idiosyncratic formats
Data Tables: relations (cases by variables) + metadata
Visual Structures: spatial substrates + marks + graphical properties
Views: graphical parameters (position, scaling, clipping, . . .)

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

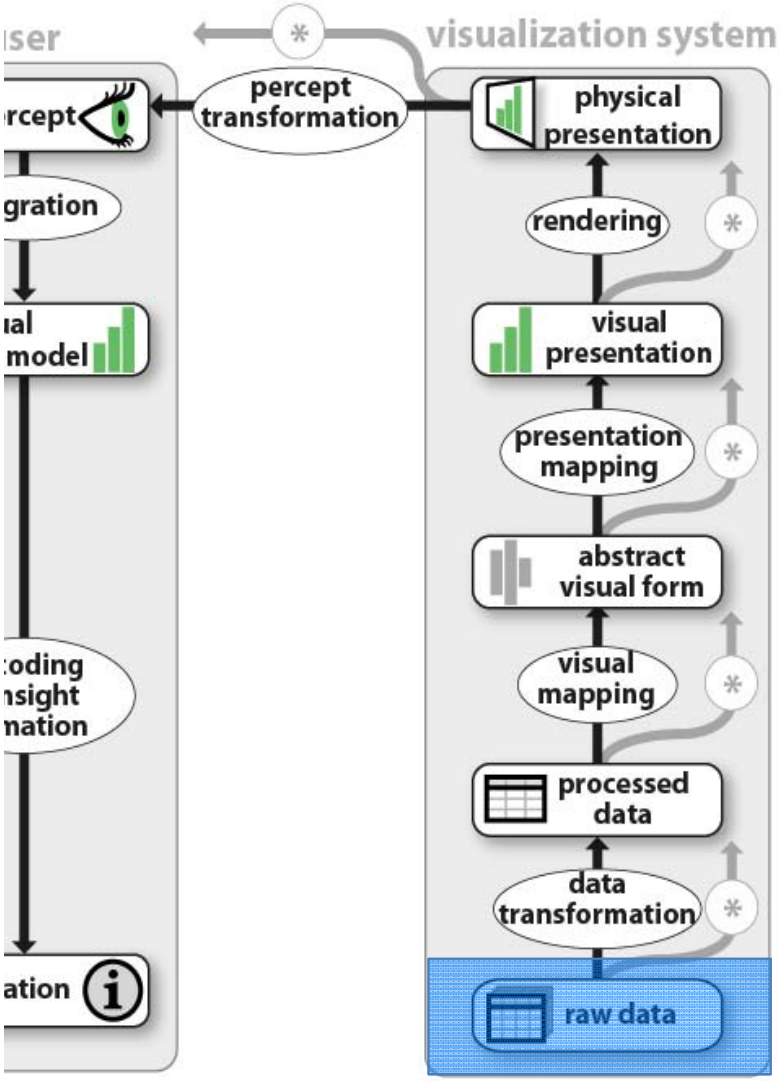
THE VISUALIZATION PIPELINE



from Ed Chi,
illustration by J. Heer



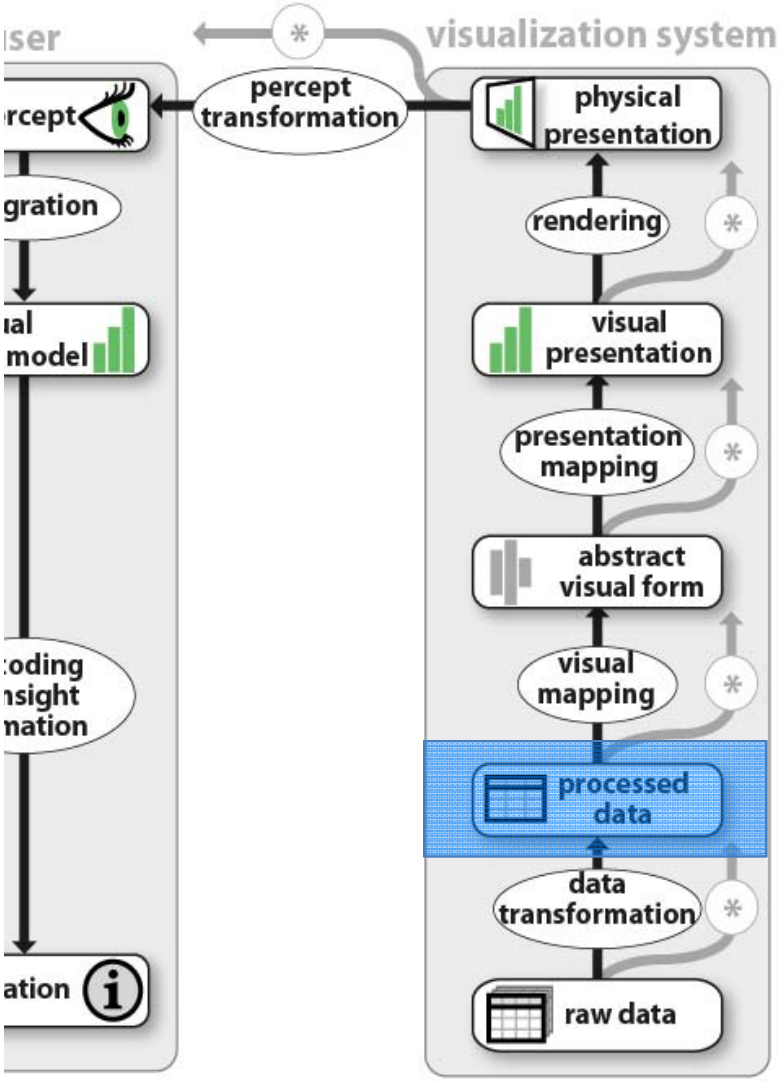
Jansen and Dragicevic 2013 (www.aviz.fr/beyond)



GAPMINDER for a fact-based world view

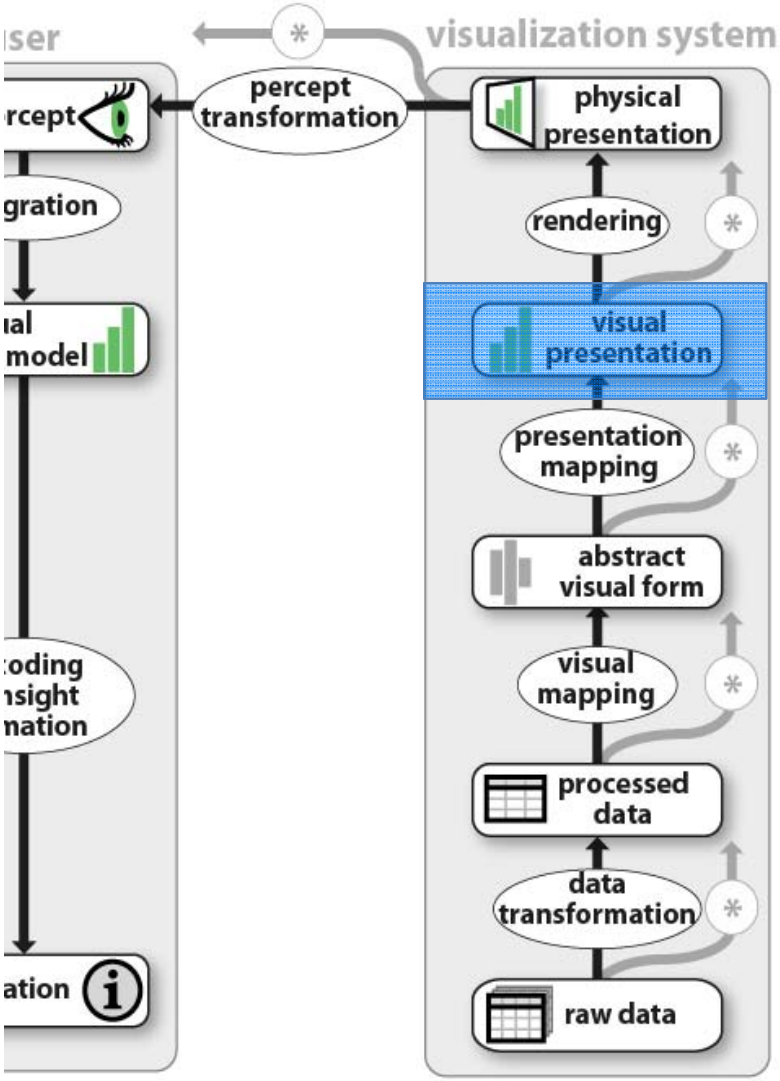
	A	B	C	D	E	F	G	H	I	J	K
1	Education aid (% of total aid)	1967	1968	1969	1970	1971	1972	1973	1974	1975	197
2	Australia					4.75	33.2	19.7	23.7	26.3	30.
3	Austria					24.7	42.3	13.5	2.52	15.9	4.8
4	Belgium					84.5	83.7	11	11.4	15.9	18.
5	Canada					33.7	38.6	18	25.3	8.41	5.1
6	Denmark					100	100	13.7	19	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											

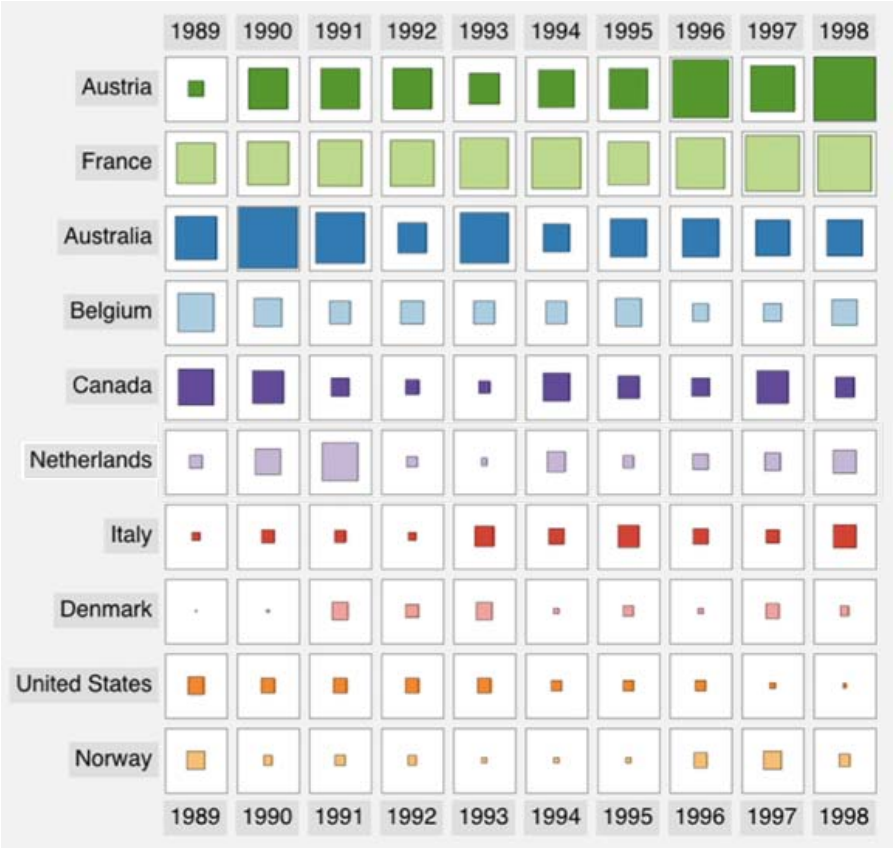
Jansen and Dragicevic 2013 (www.aviz.fr/beyond)



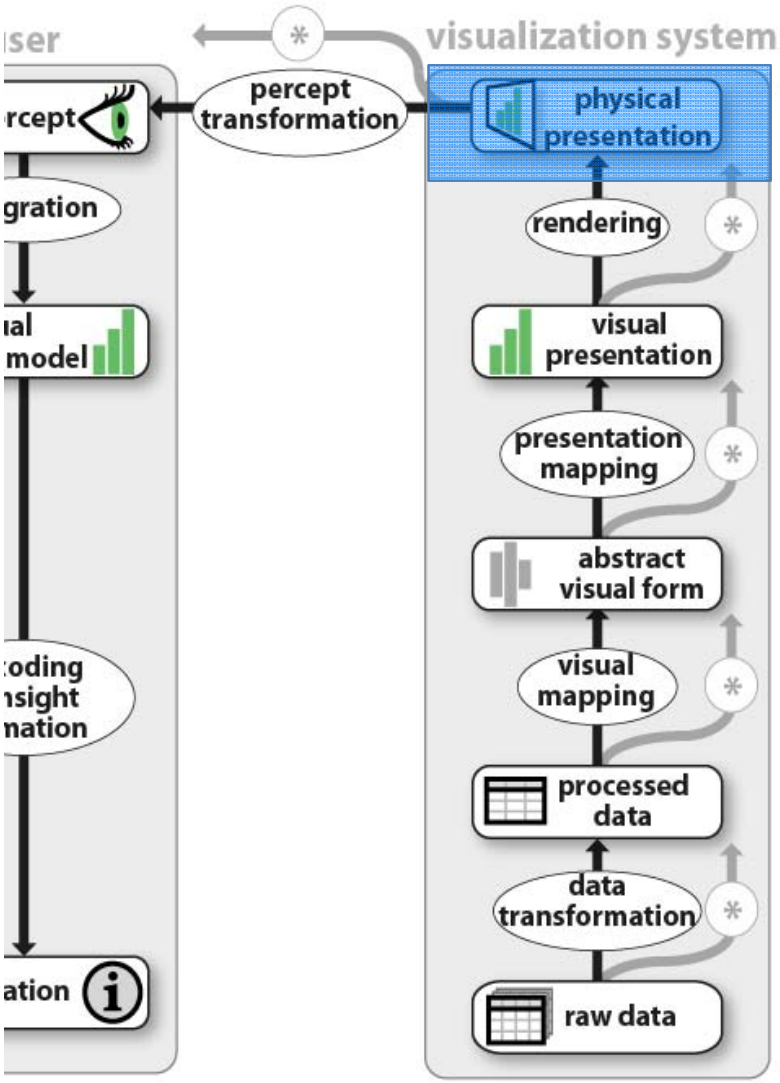
	A	B	C	D	E	F	G	H	I	J	K
1		1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
2	Austria	12.23	31.86	31.07	31.57	24.02	28.61	30.52	44.99	35.41	48.95
3	France	31.87	34.18	35.95	36.06	38.78	40.18	32.68	39.26	43.15	43.9
4	Australia	33.57	46.93	39.24	23.18	38.94	21.38	29.1	29.43	27.97	28.32
5	Belgium	29.93	22.13	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

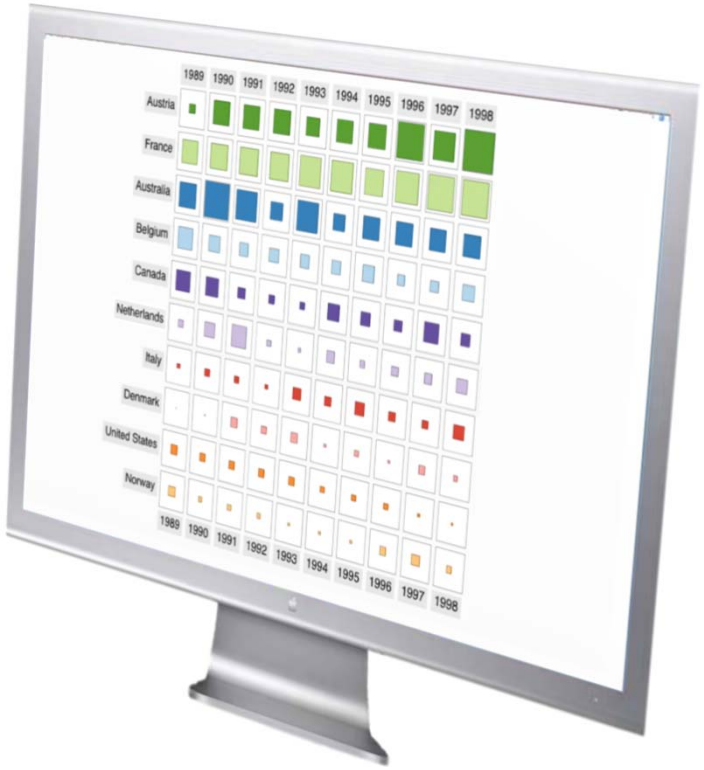
Jansen and Dragicevic 2013 (www.aviz.fr/beyond)



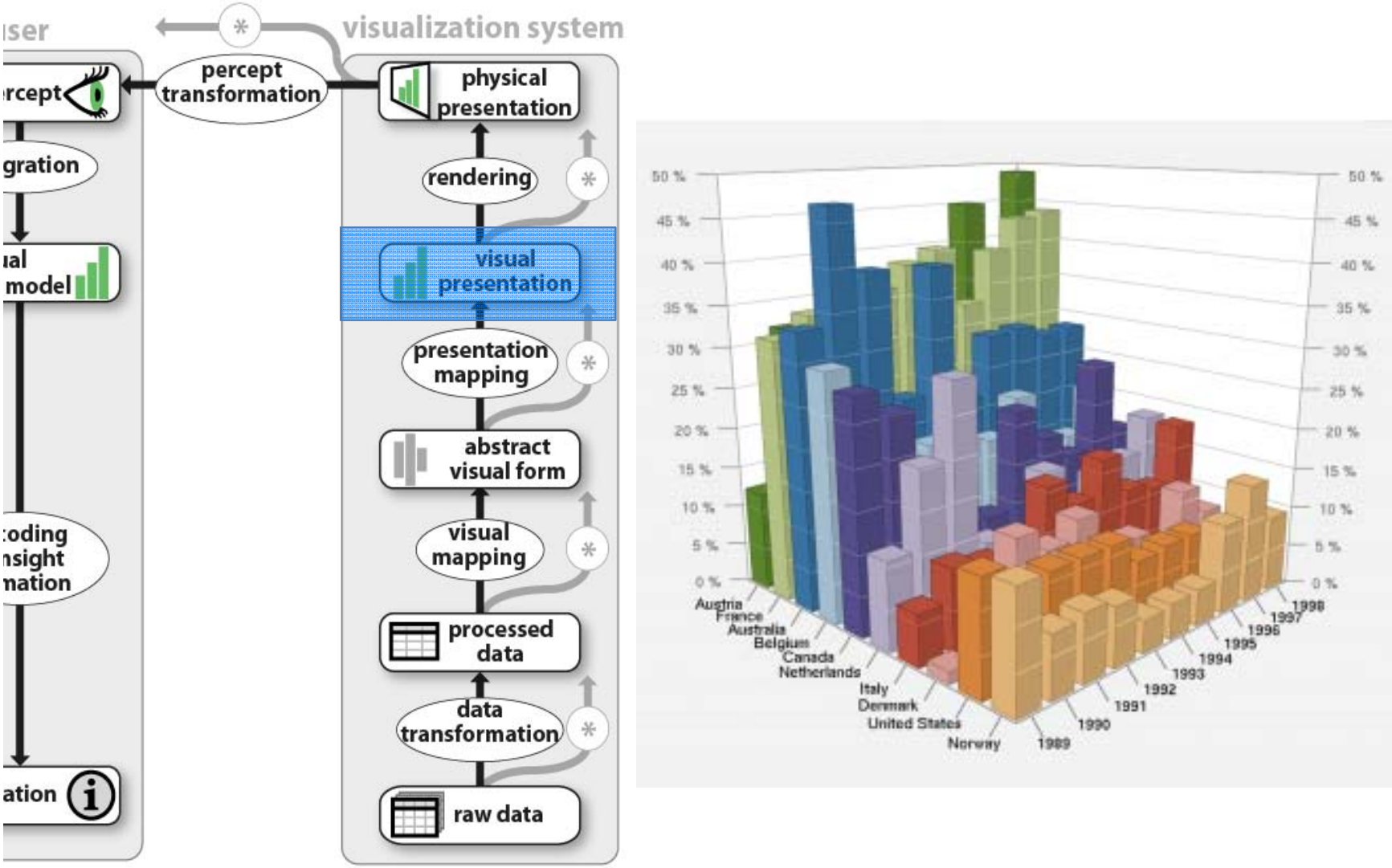


Jansen and Dragicevic 2013 (www.aviz.fr/beyond)

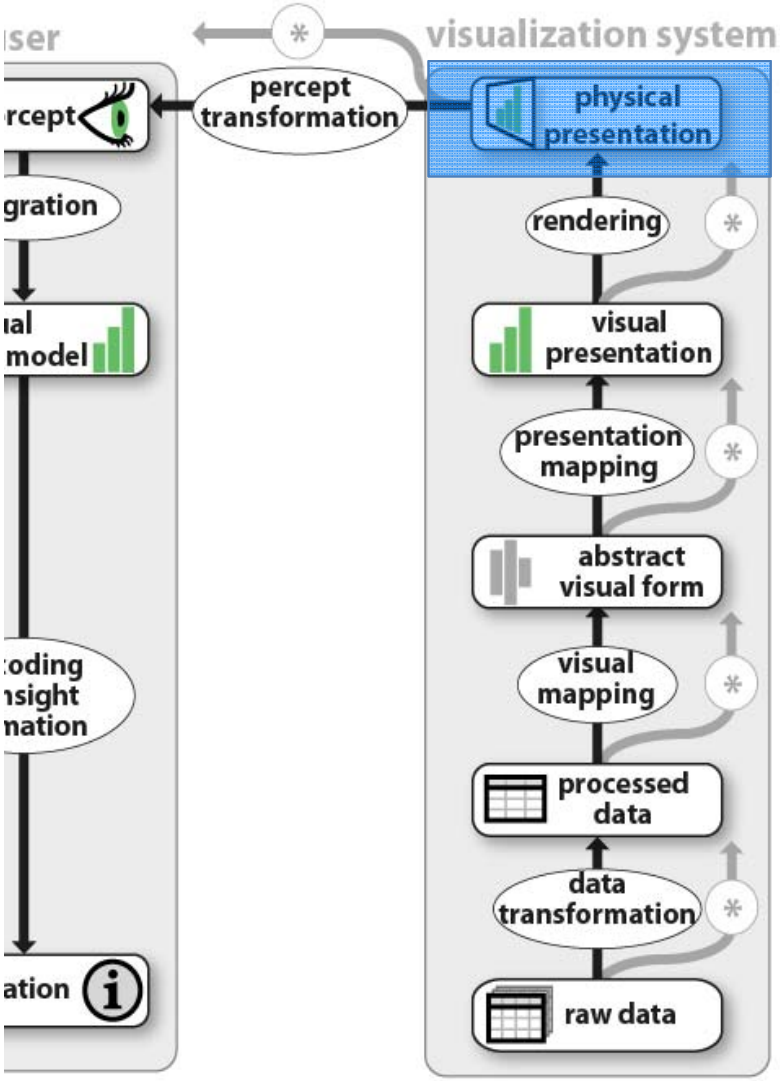




Jansen and Dragicevic 2013 (www.aviz.fr/beyond)



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



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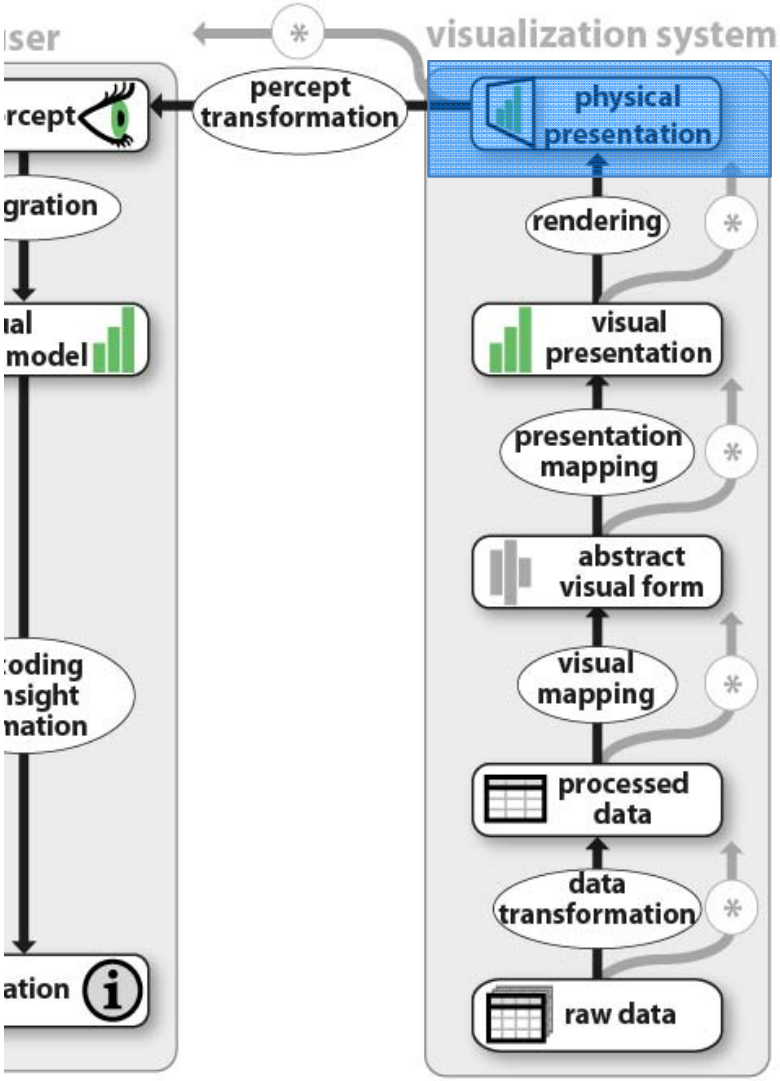

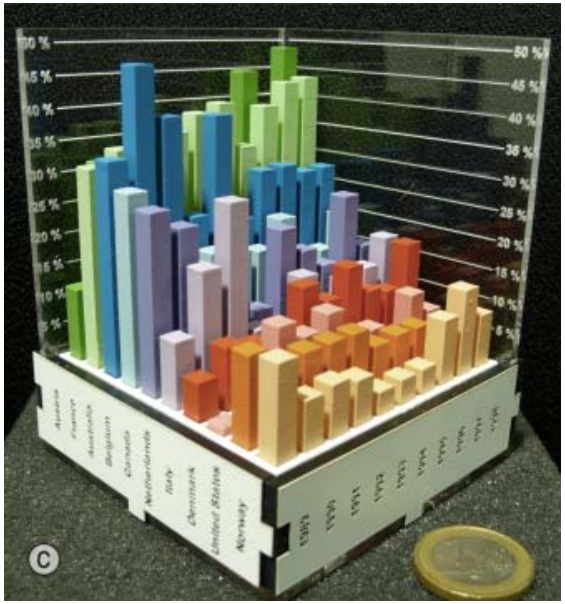

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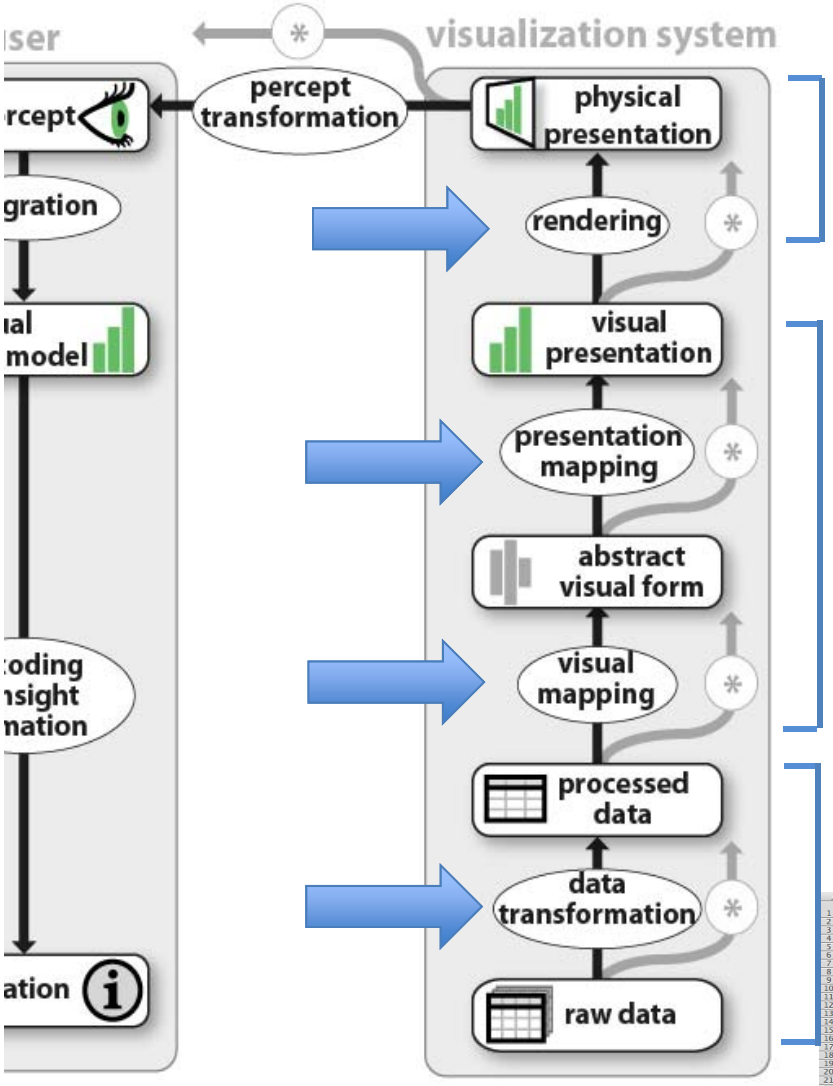
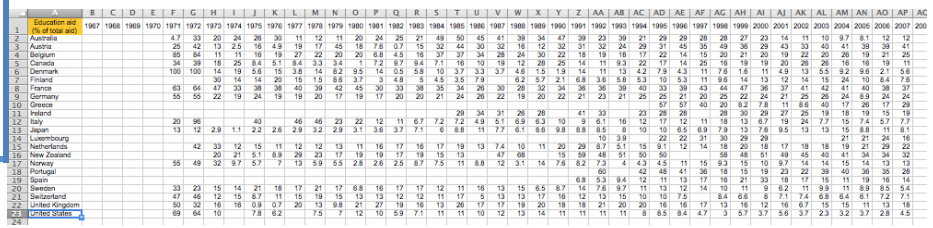




Jansen and Dragicevic 2013 (www.aviz.fr/beyond)

TAXONOMIES OF INTERACTION

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

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

ANALYTIC TASKS

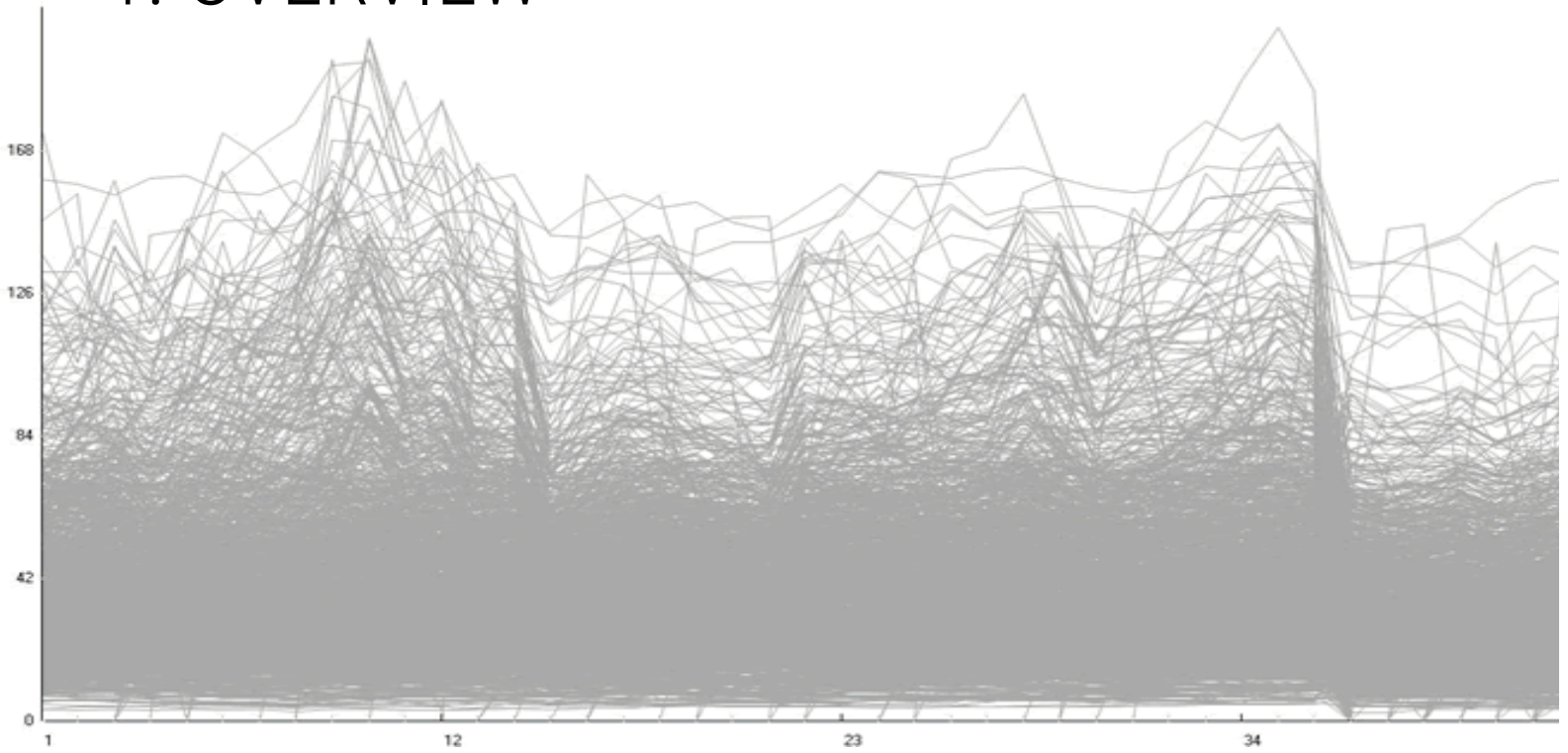
BEN SHNEIDERMAN 1996

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
6. HISTORY: KEEP
AND
7. EXTRACT: ALL
AND

Shneiderman's
visual information seeking
Mantra

ANALYTICAL

1. OVERVIEW

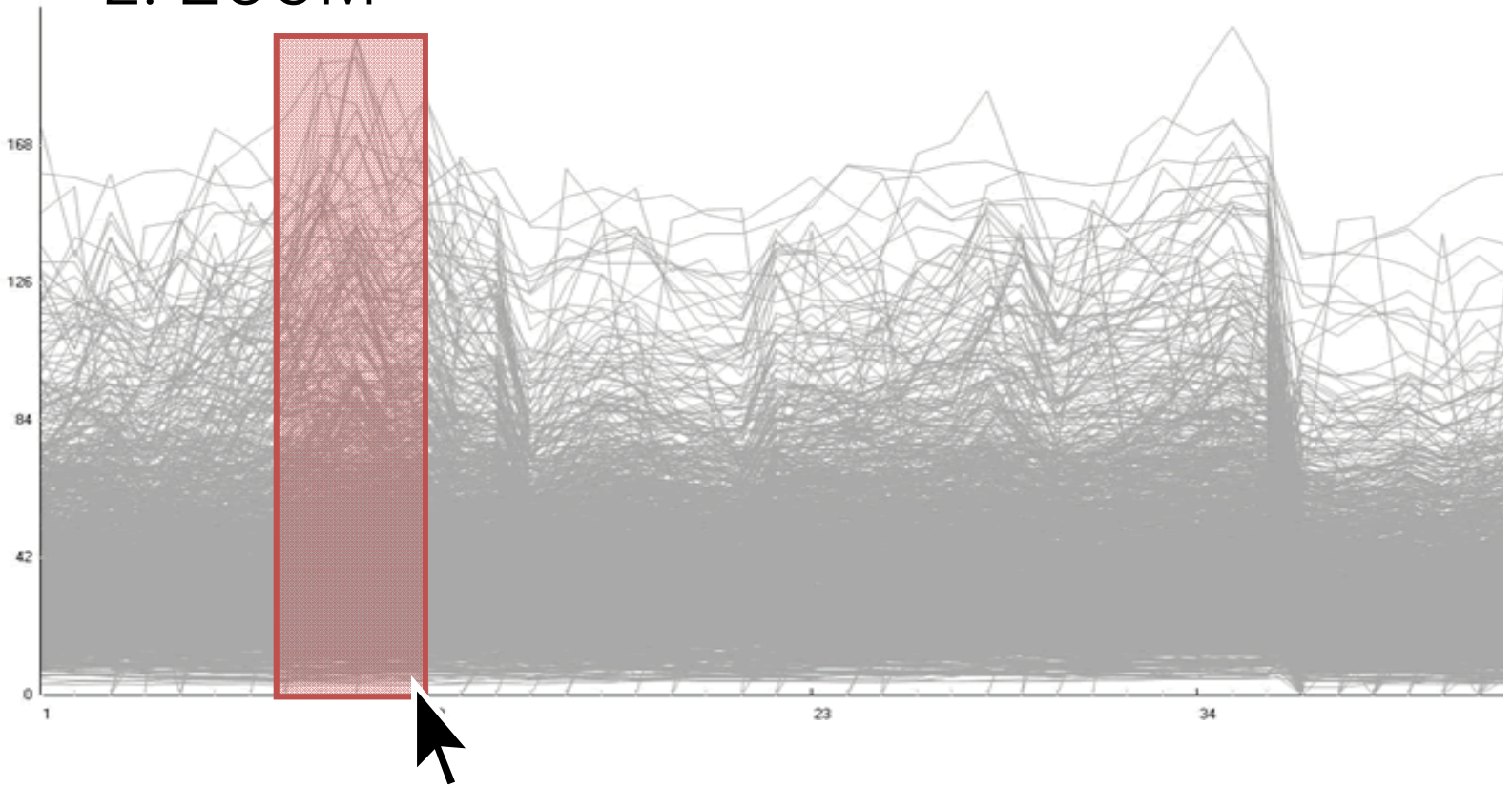


STEPHEN FEW, 2006 (LINK)

SOFTWARE: TIMESEARCHER 2

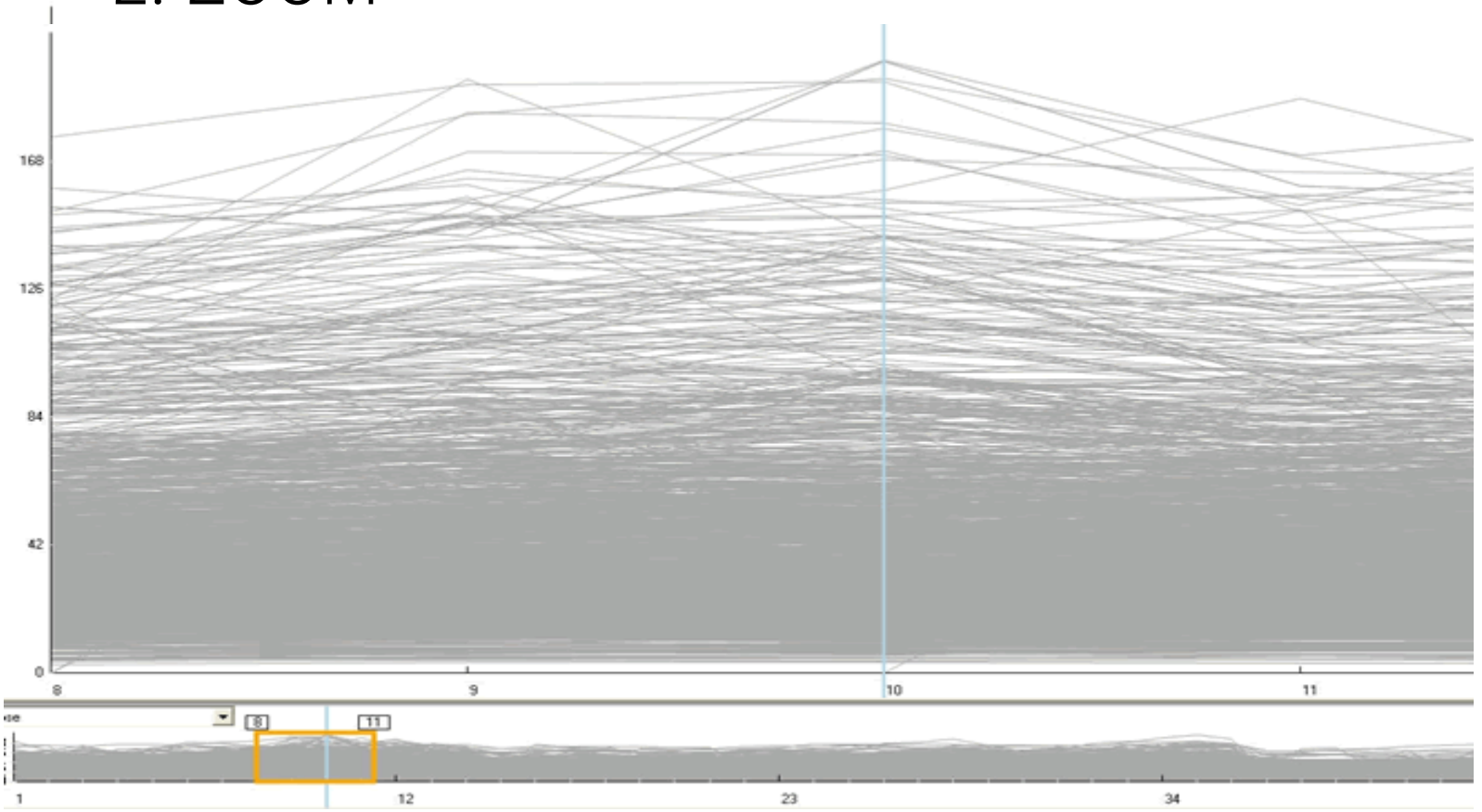
ANALYTICAL

2. ZOOM



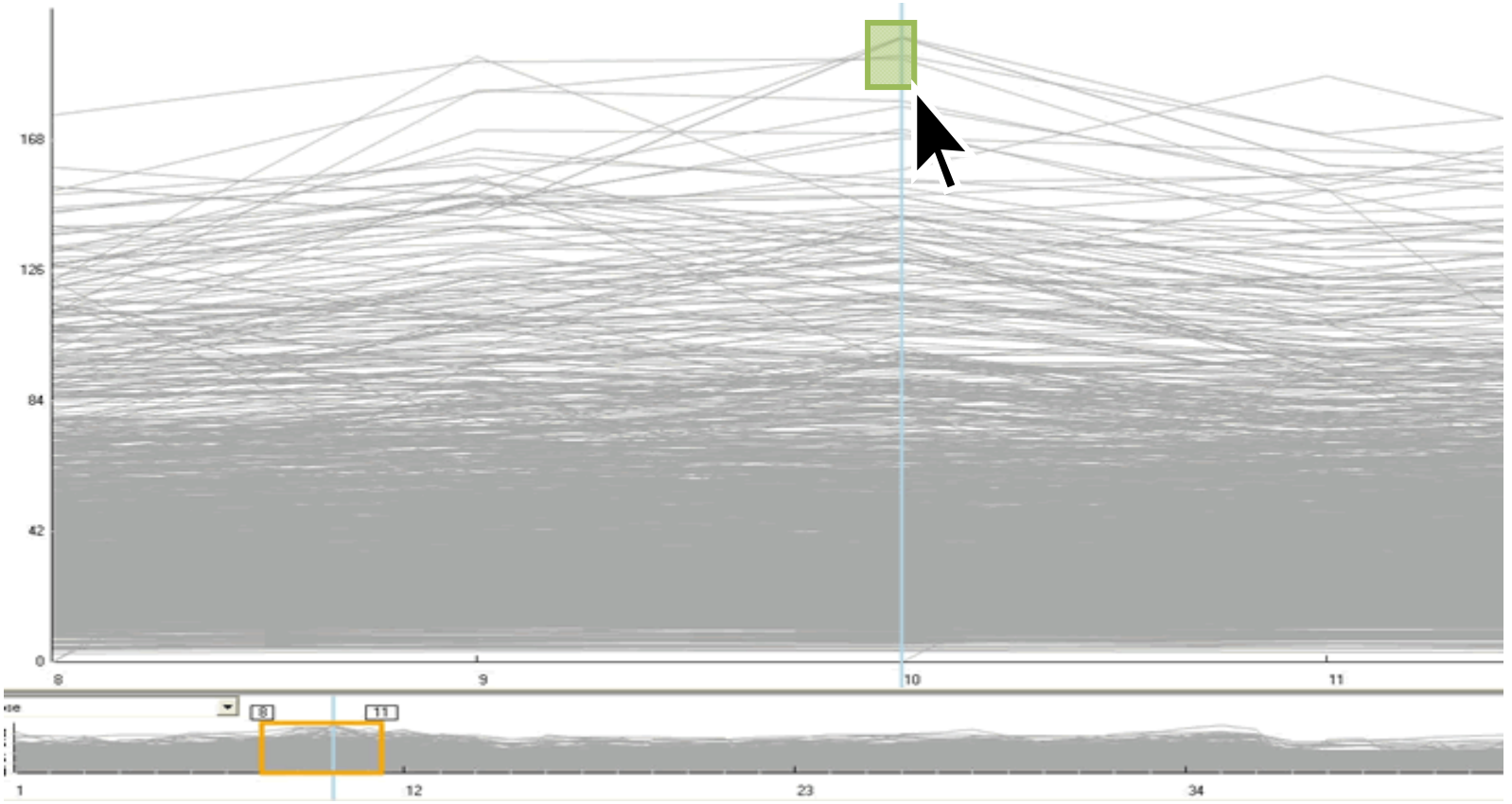
ANALYTICAL

2. ZOOM



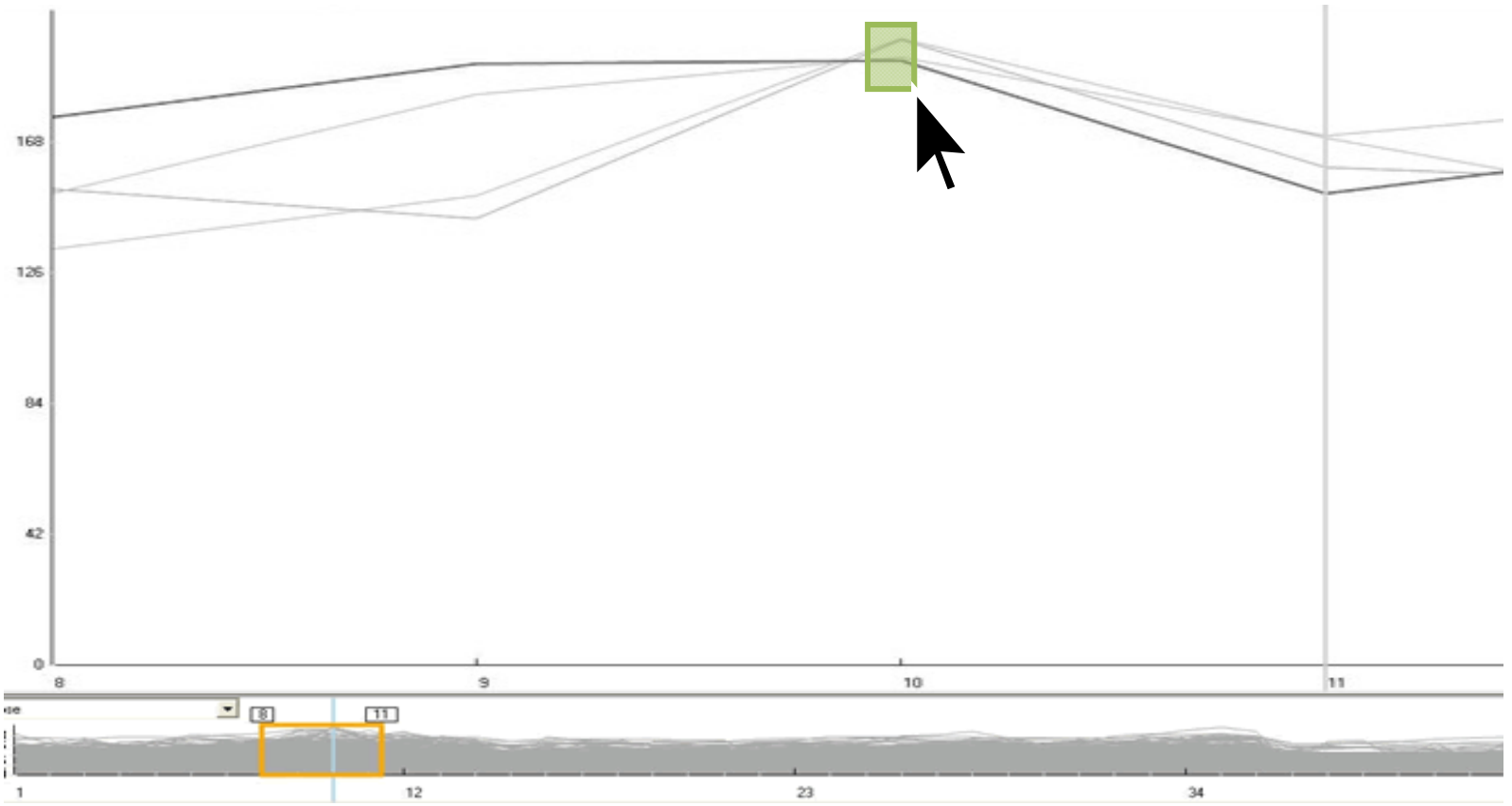
ANALYTICAL

3. FILTER



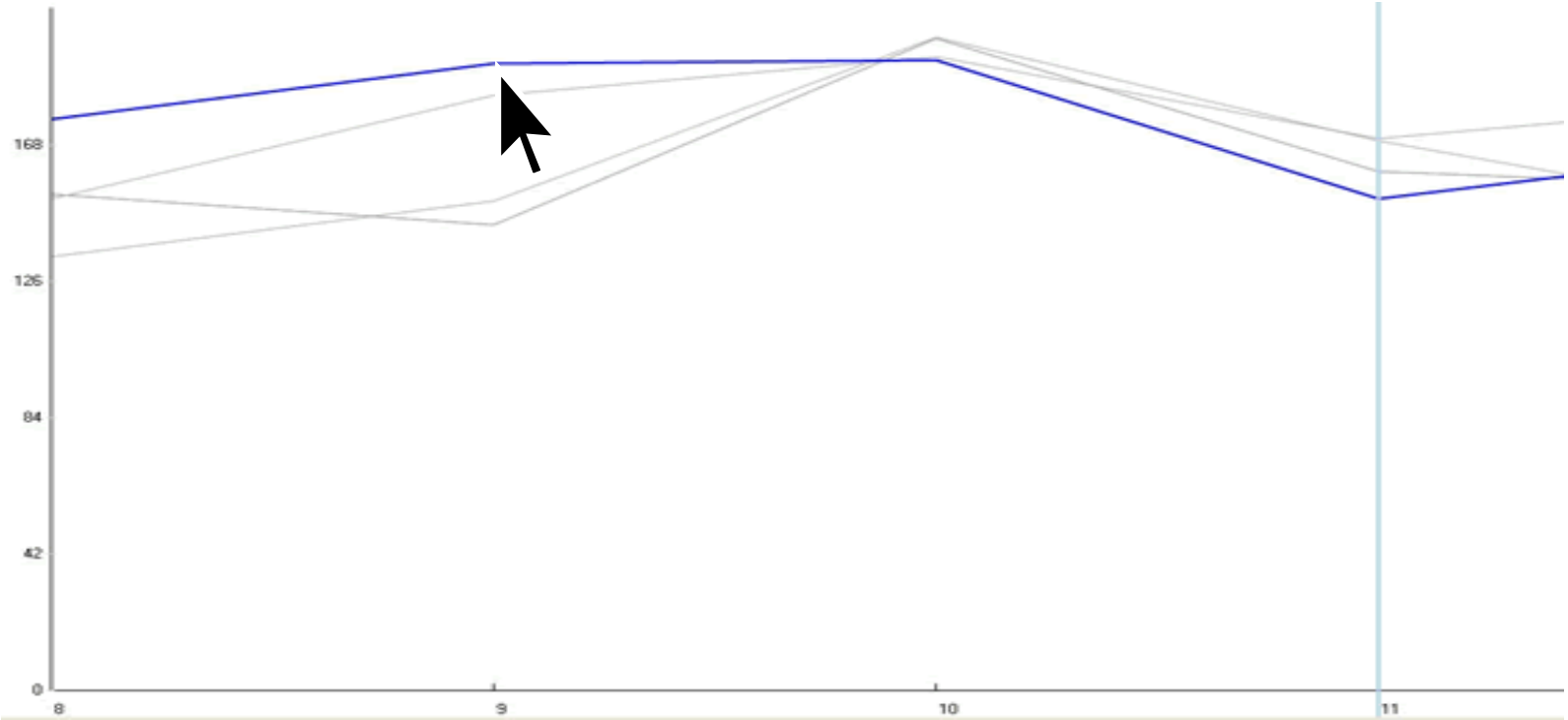
ANALYTICAL

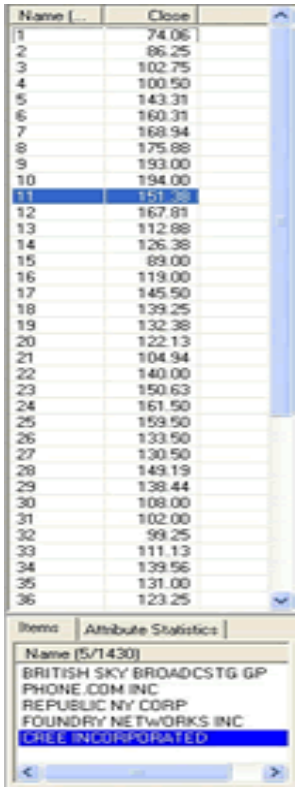
3. FILTER



ANALYTICAL

4. DETAILS ON DEMAND





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
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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

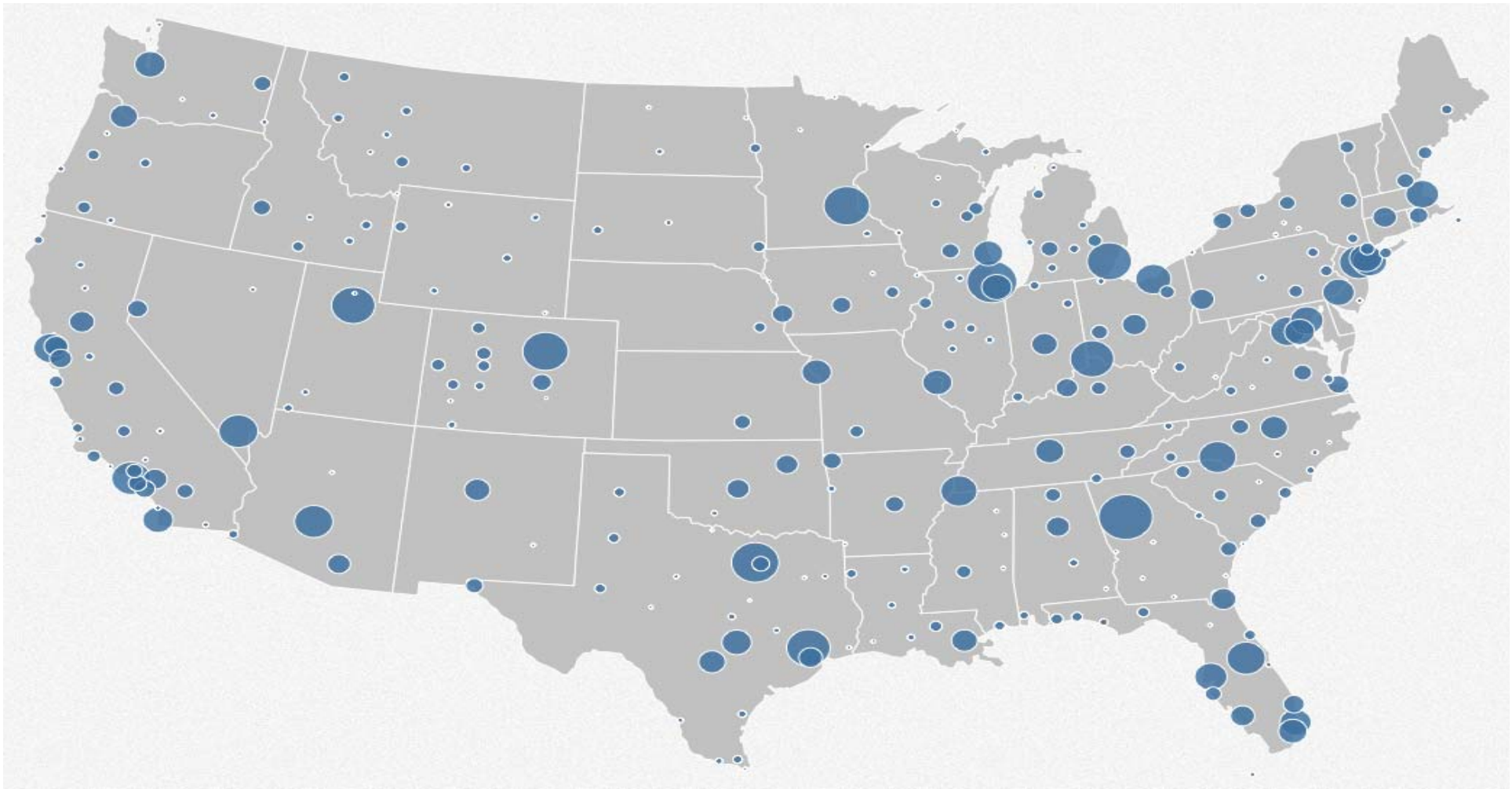
CONNECT

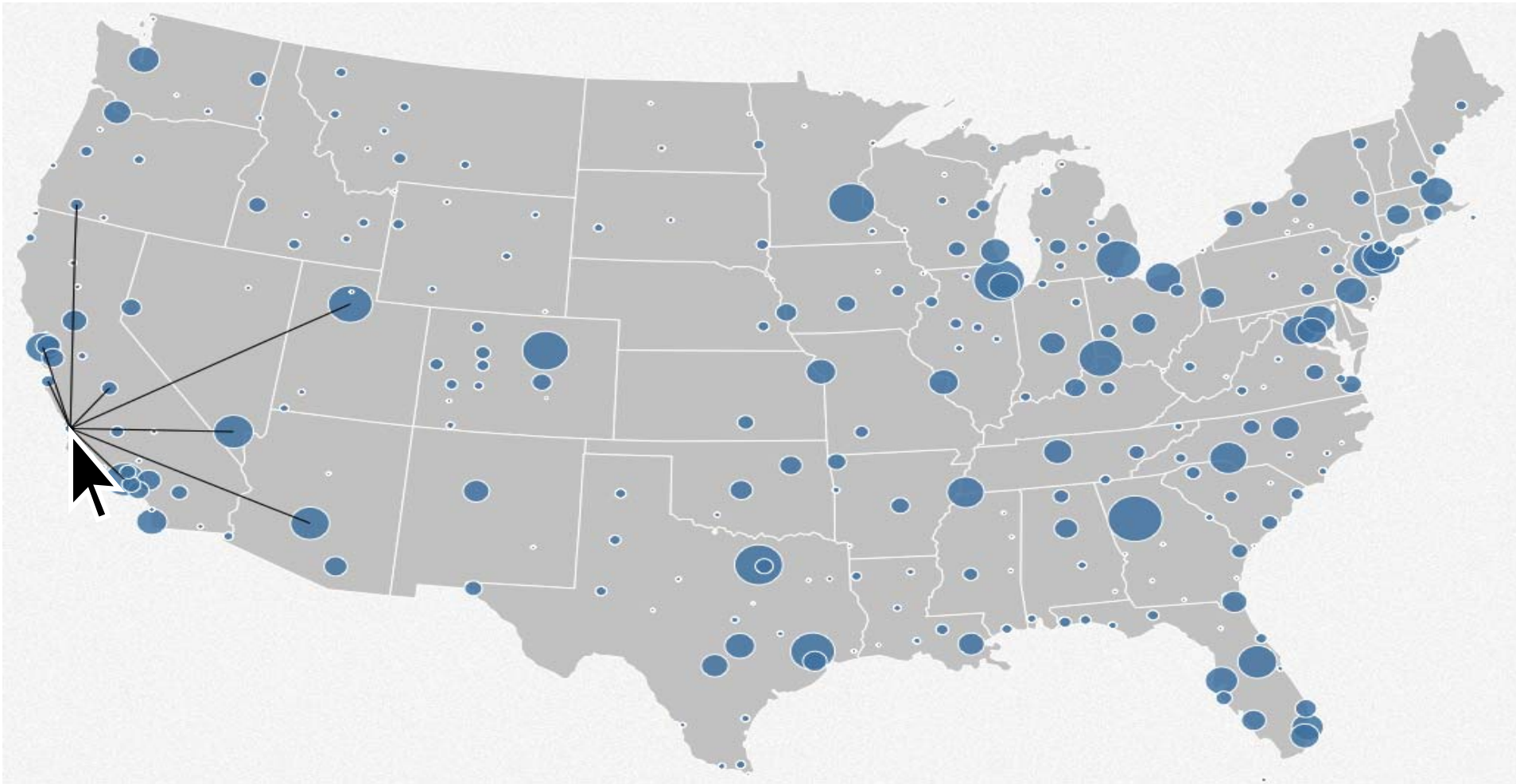
BASIC

Point Selection

Mouse Hover / Click

Touch / Tap





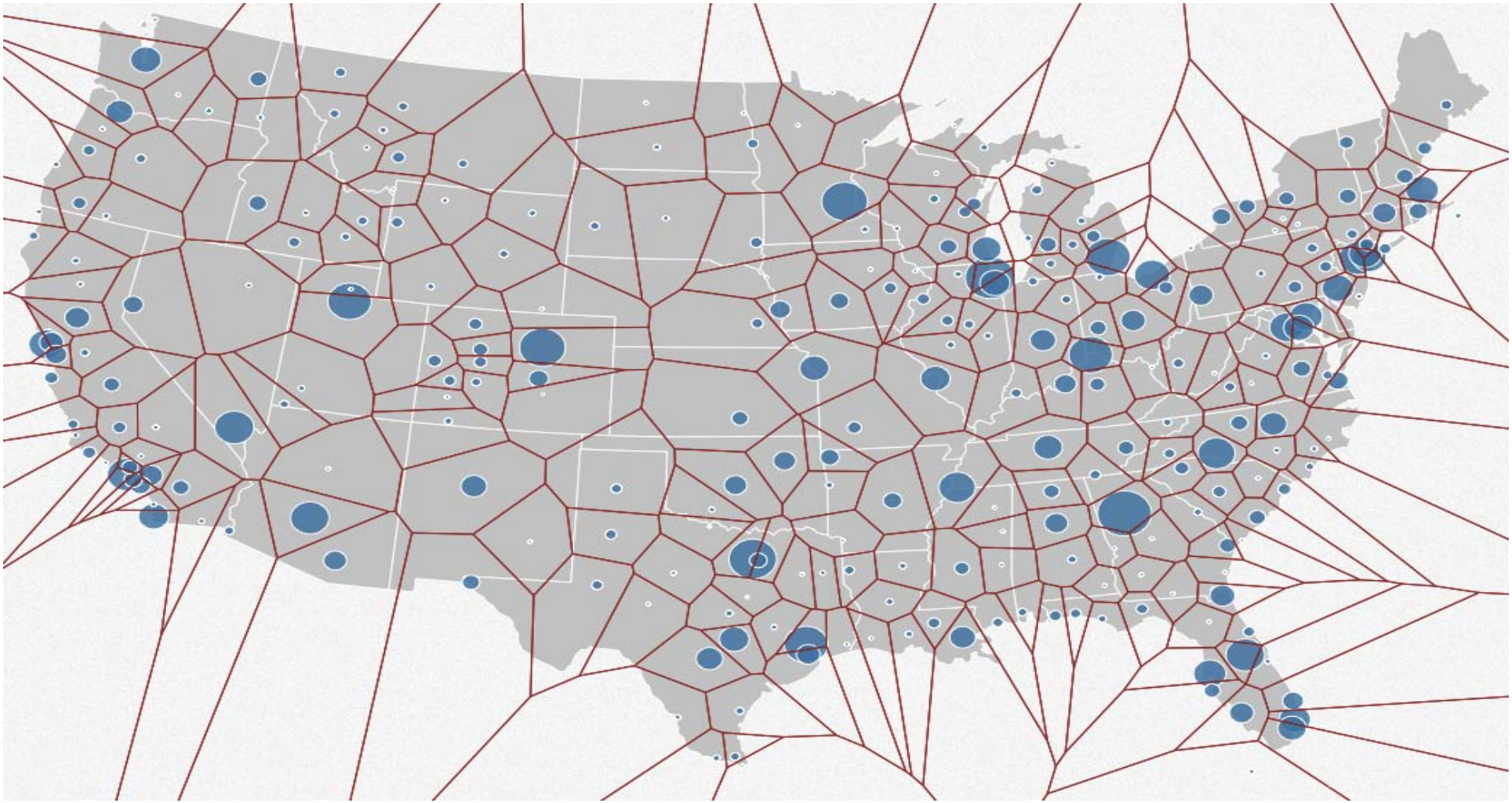
BASIC

Point Selection

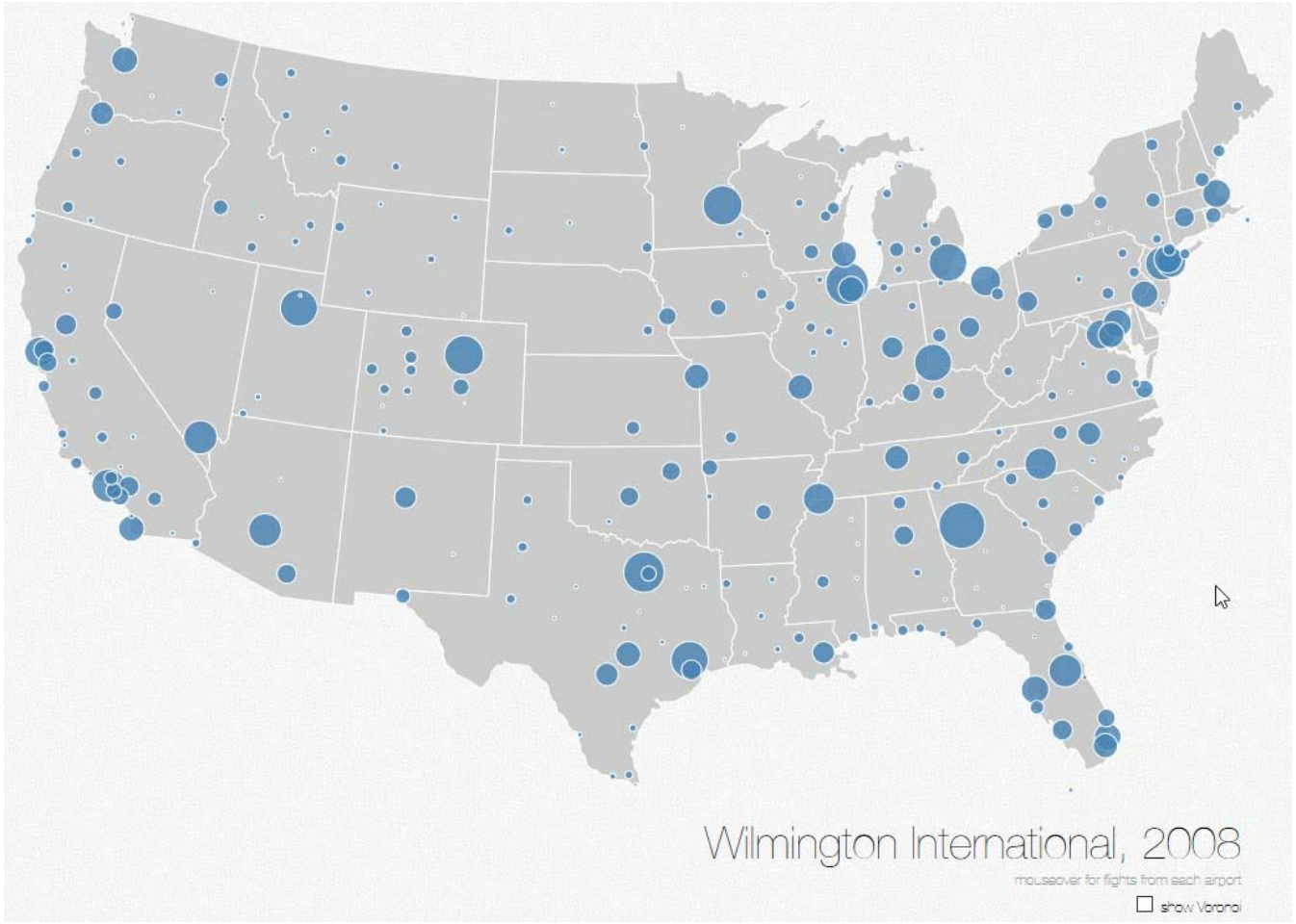
Mouse Hover / Click

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

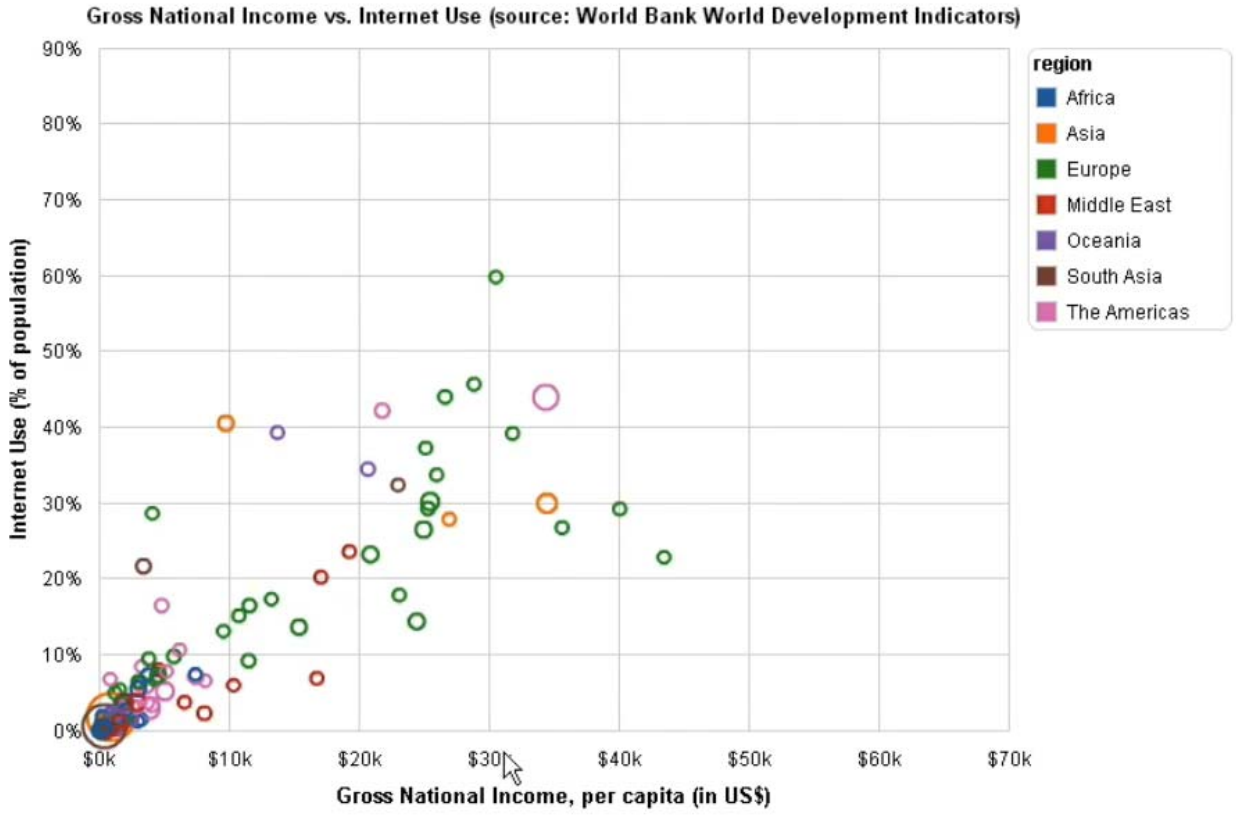
Point Selection

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

Region Selection

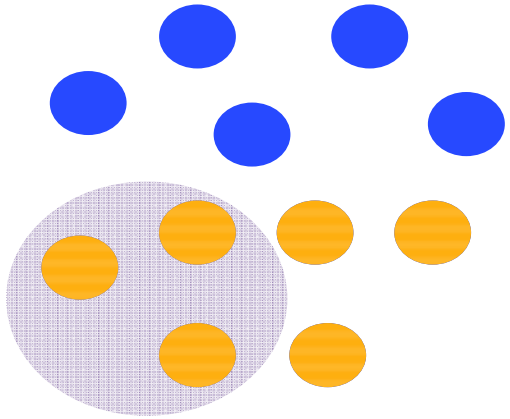
Rubber-band or Lasso
Area Cursors (“Brushes”)

RANGE

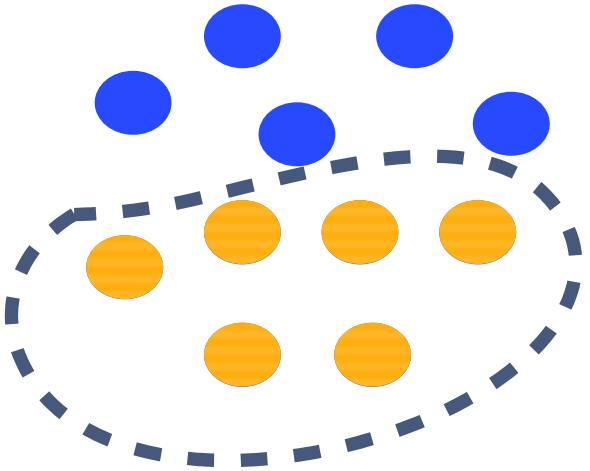


GENERALIZED SELECTION HEER ET AL. 2008

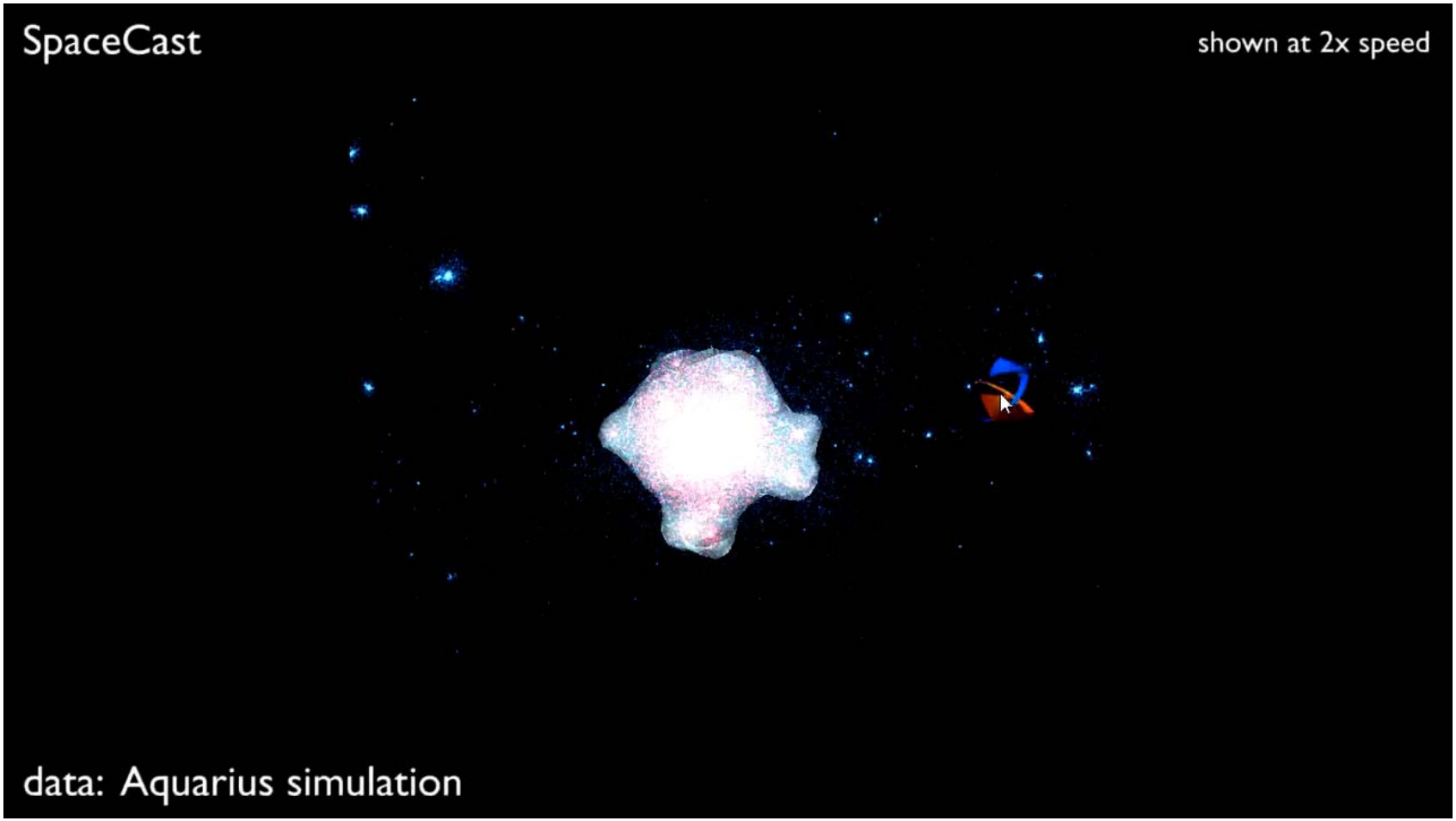
BRUSHES



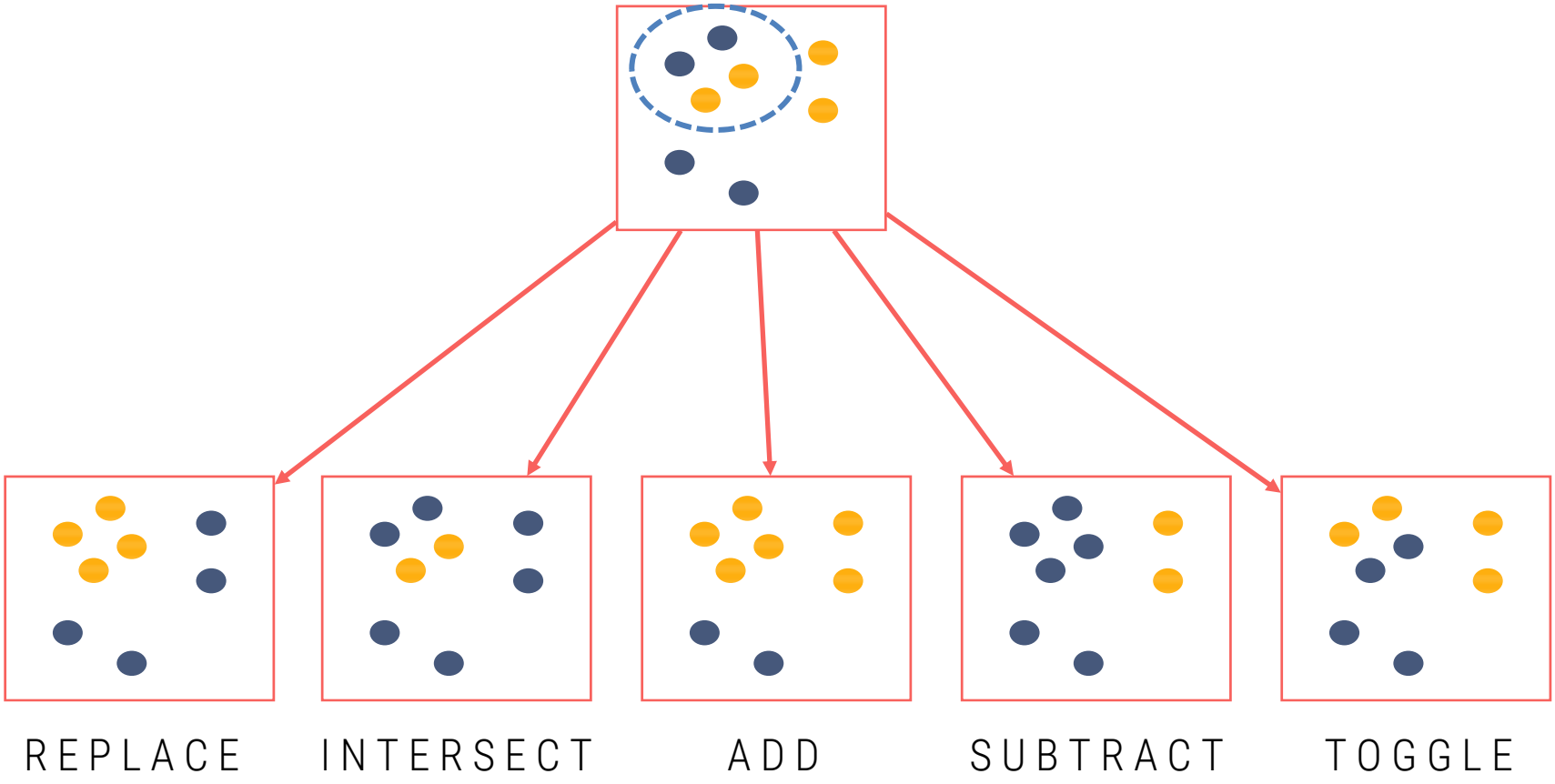
LASSOS



LASSO IN 3D

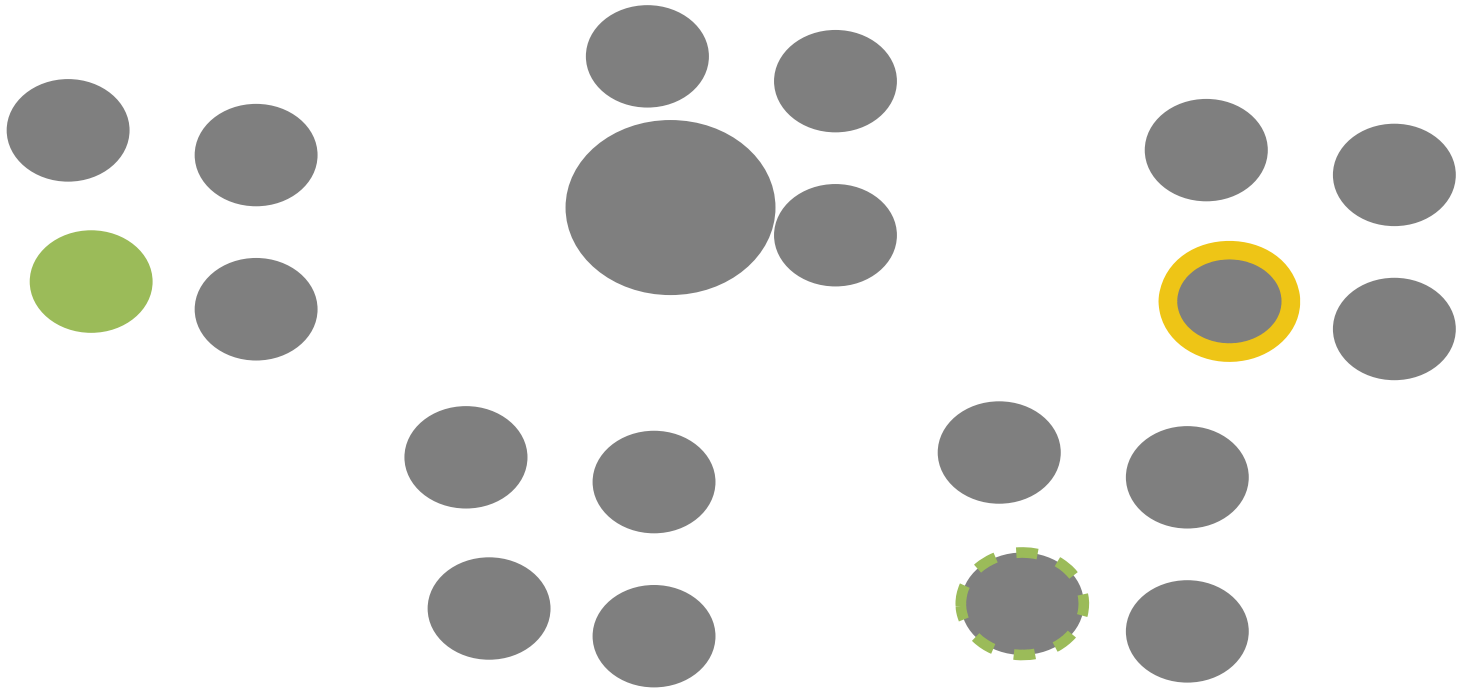


SELECTION OPERATIONS



HIGHLIGHTING

SELECTION + CHANGE IN APPEARANCE



SELECT

EXPLORE

SHOW ME SOMETHING ELSE

FILTER

RECONFIGURE

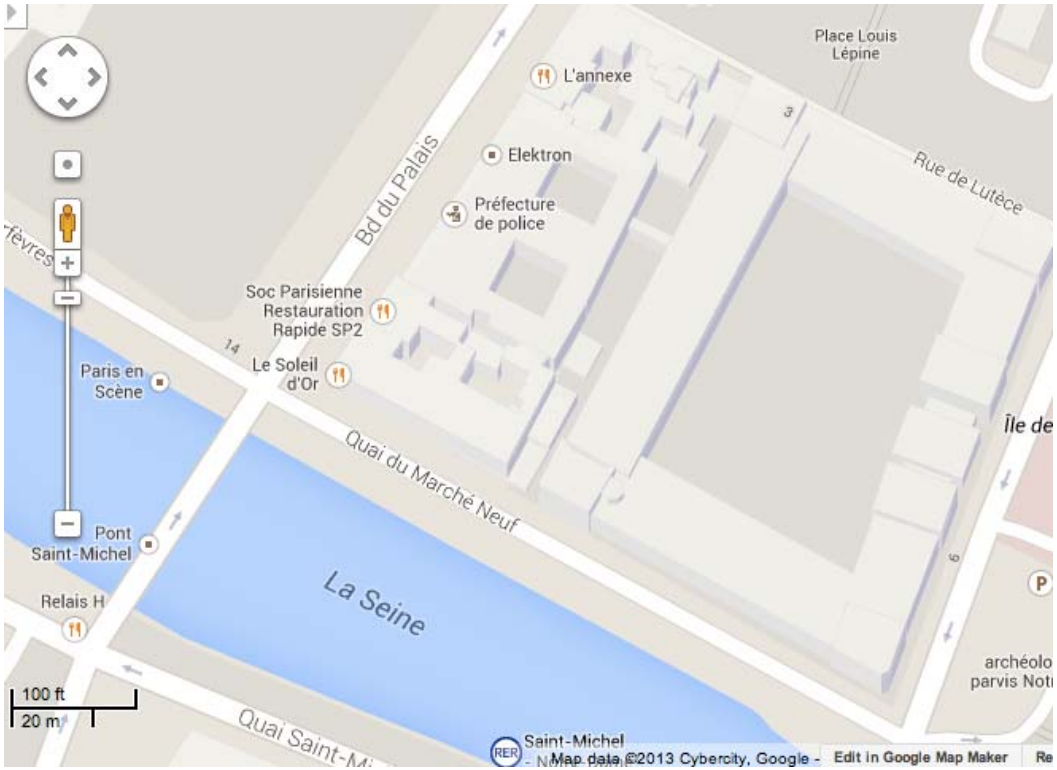
ENCODE

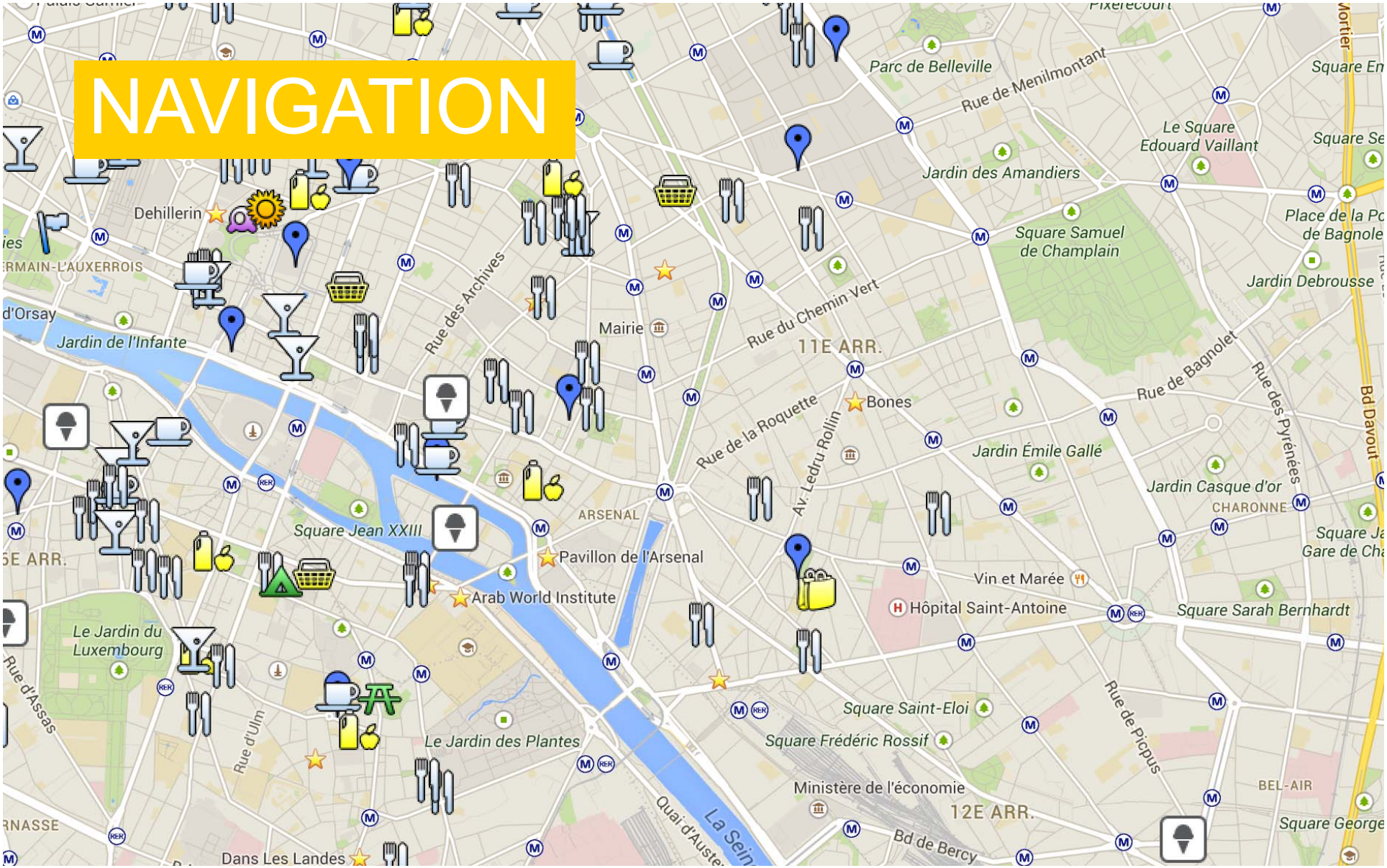
ABSTRACT/ELABORATE

CONNECT

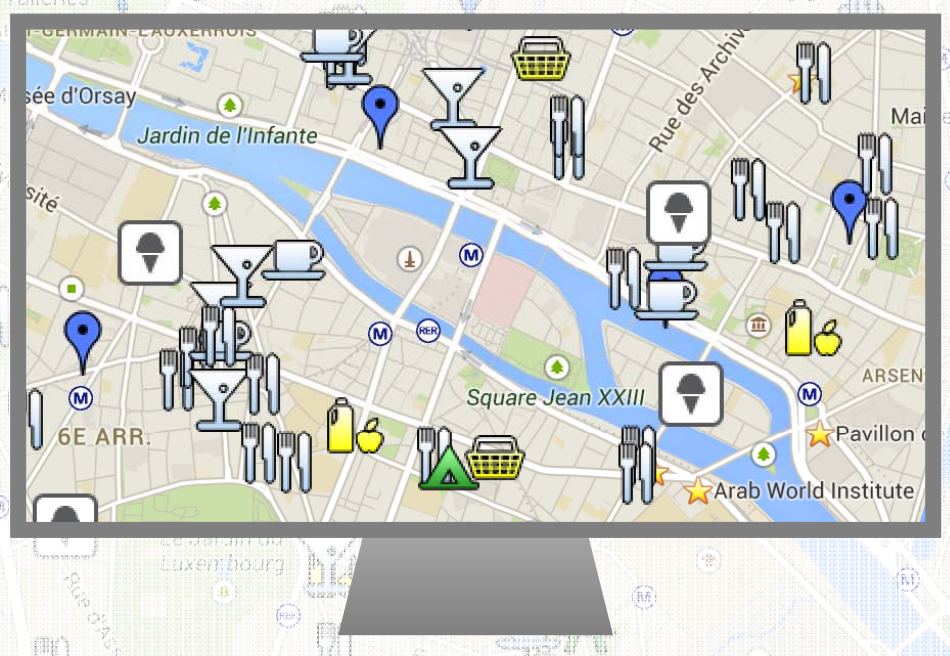
PROBLEM

Where am I?




NAVIGATION
Parc de Belleville
Rue de Menilmontant
Le Square Edouard Vaillant
Jardin des Amandiers
Square Samuel de Champlain
Jardin Debrousse
Dehillerin
Rue des Archives
Mairie
Rue du Chemin Vert
11E ARR.
Jardin de l'Infante
Rue de la Roquette
Bones
Av. Ledru Rollin
Rue de Bagnolet
Rue des Pyrénées
Jardin Émile Gallé
Jardin Casque d'or
CHARONNE
ARSENAL
Square Jean XXIII
Pavillon de l'Arsenal
Arab World Institute
Vin et Marée
Hôpital Saint-Antoine
Square Sarah Bernhardt
Le Jardin du Luxembourg
Square Saint-Eloi
Square Frédéric Rossif
Rue de Picpus
Le Jardin des Plantes
Ministère de l'économie
12E ARR.
BEL-AIR
Bd de Bercy
Dans Les Landes
Rue d'Ulm
Rue d'Assas
Quai d'Austerlitz
Bd Davout

NAVIGATION



PANNING

ZOOMING

NAVIGATION

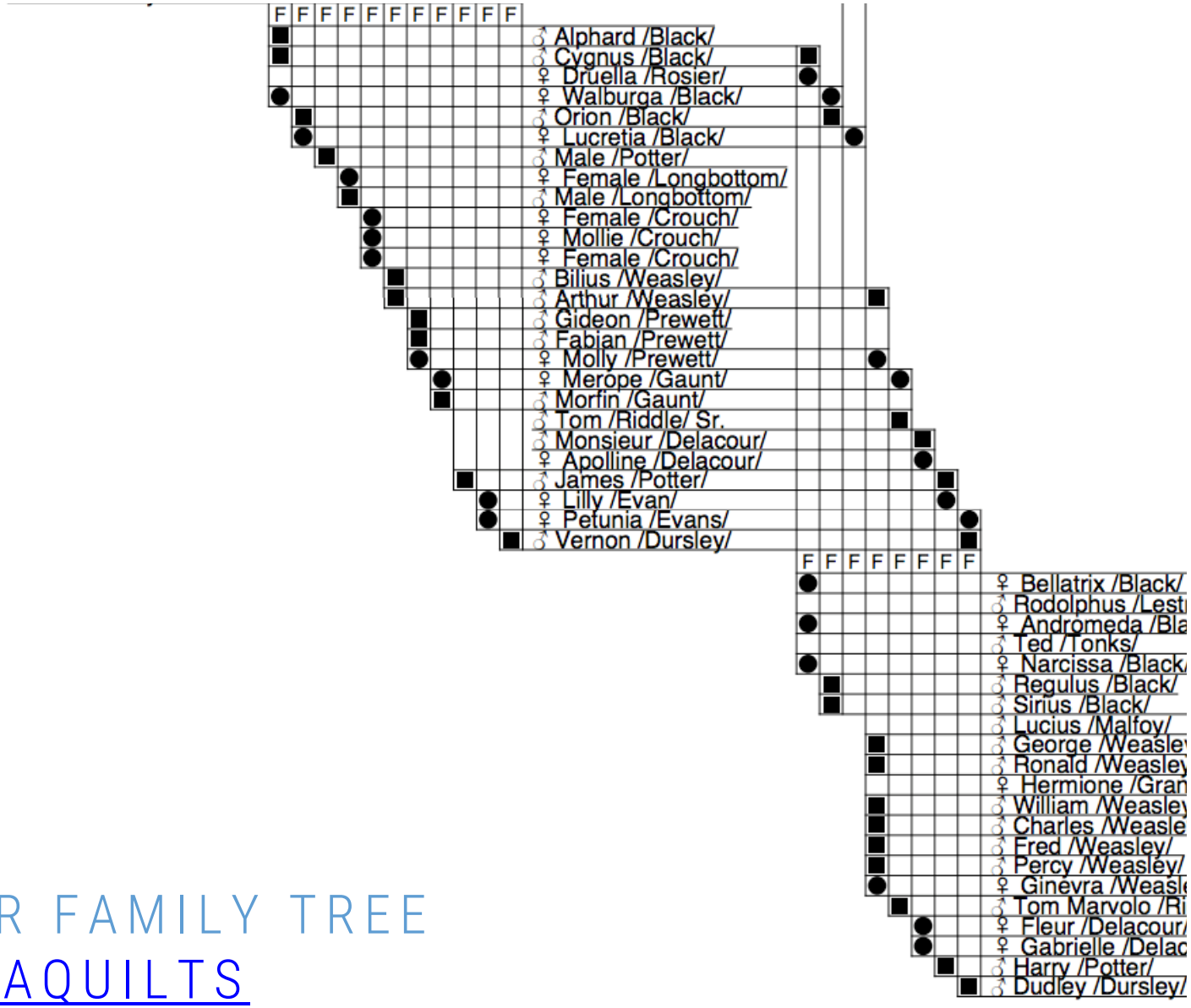
PANNING

ZOOMING

NAVIGATION

PANNING

ZOOMING



HARRY POTTER FAMILY TREE

AVIZ.FR/GENEAQUILTS

SELECT

EXPLORE

FILTER

SHOW ME SOMETHING CONDITIONALLY

RECONFIGURE

ENCODE

ABSTRACT/ELABORATE

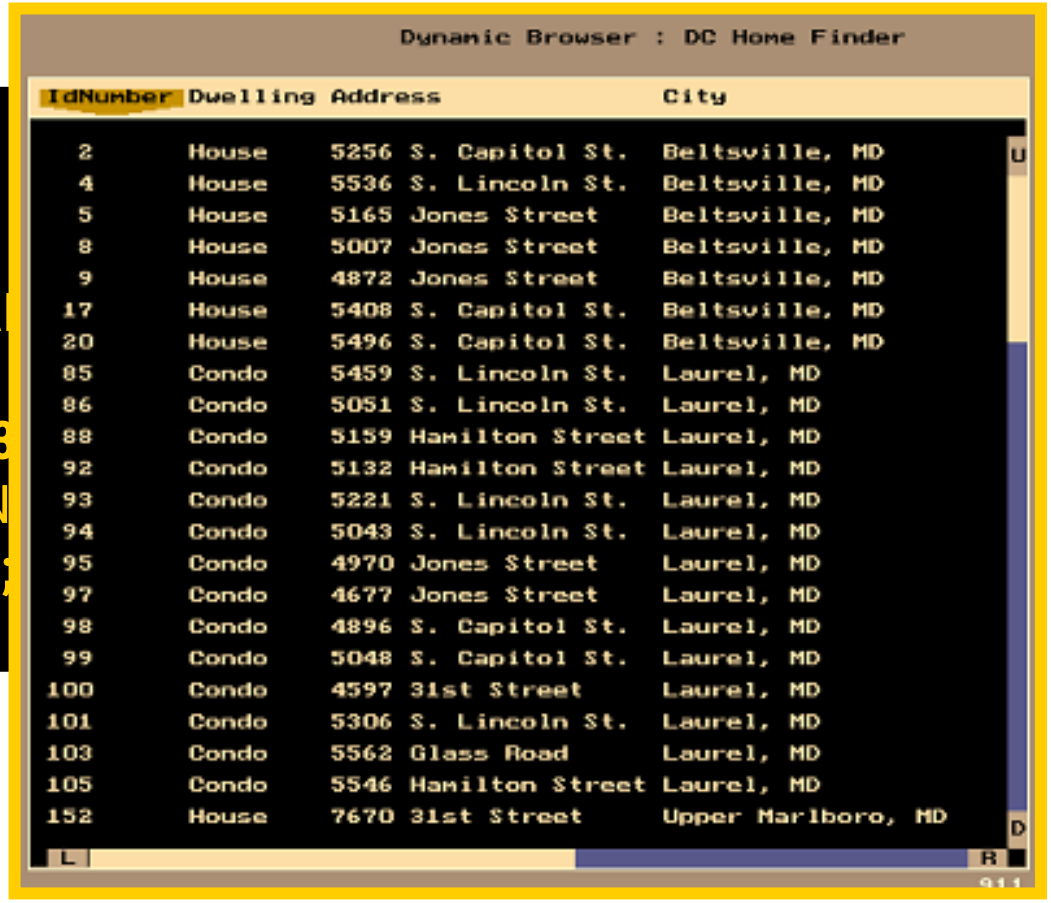
CONNECT

FILTERING

```
> SELECT house_address
  FROM realty_db
  WHERE price >= 200,000 AND
        price <= 400,000 AND
                 bathrooms >= 3 AND
                 garage == 2 AND
                 bedrooms >= 4;
```

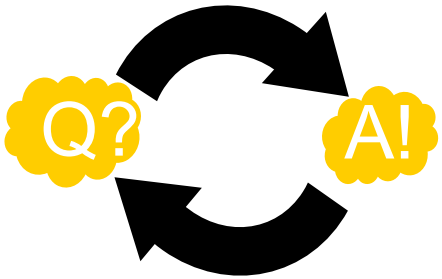
FILTERING

```
> SELECT house_address
  FROM realty_db
  WHERE price >= 200,000 A
        price <= 400,000 AND
                 bathrooms >= 3
                 garage == 2 AN
                 bedrooms >= 4;
```

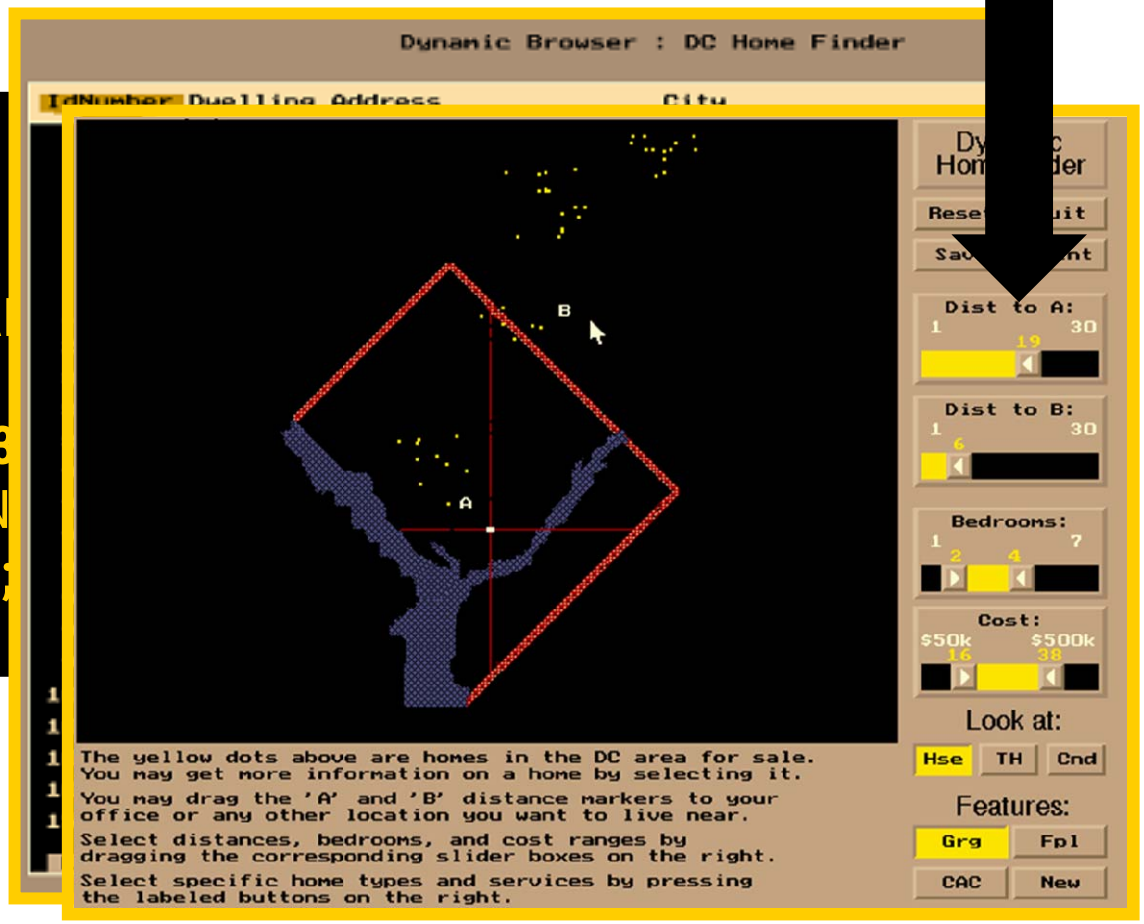


FILTERING

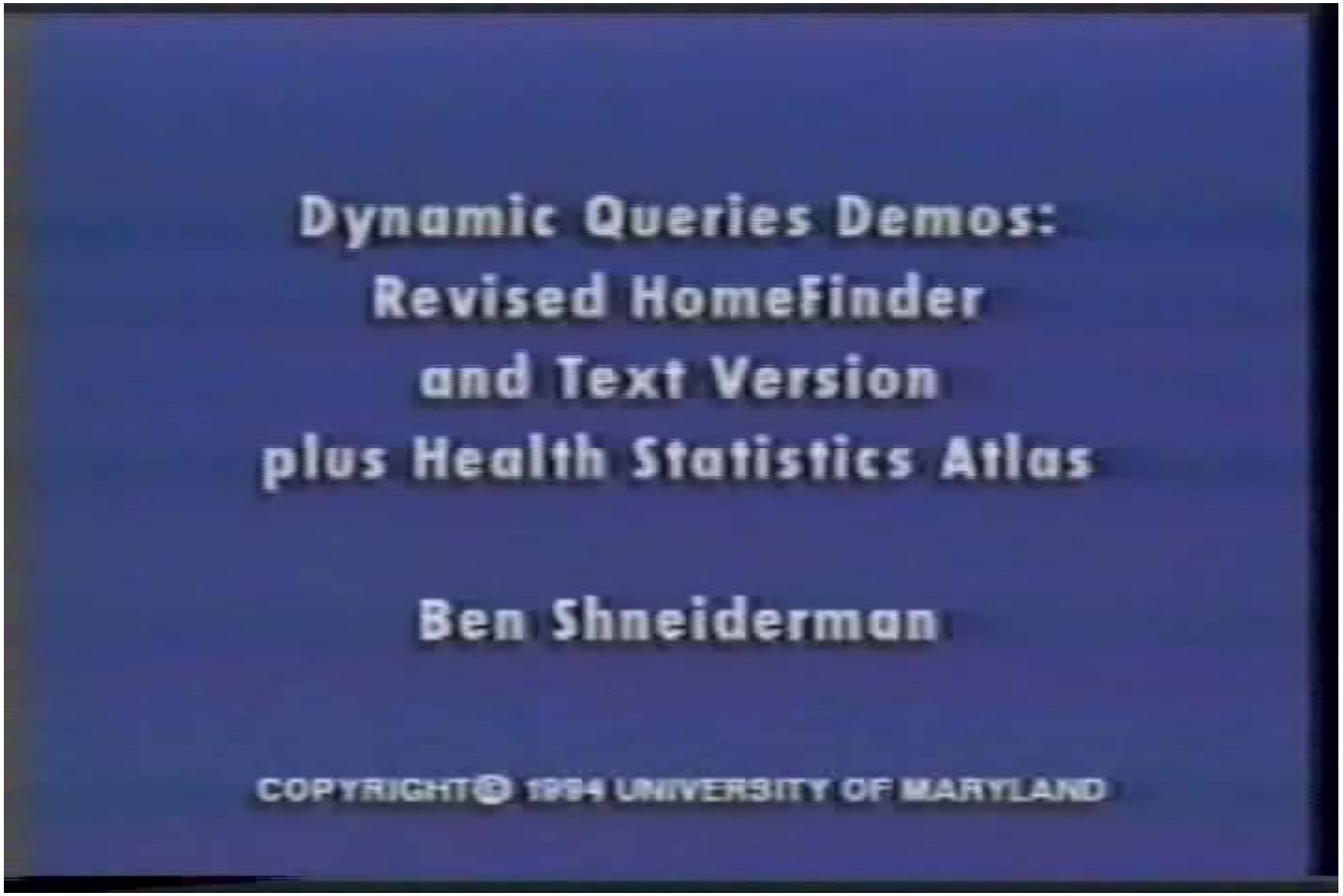
```
> SELECT house_address
  FROM realty_db
  WHERE price >= 200,000 A
        price <= 400,000 AND
                 bathrooms >= 3
                 garage == 2 AN
                 bedrooms >= 4;
```



REPLACING A QUERY WITH
"DYNAMIC QUERY WIDGETS"

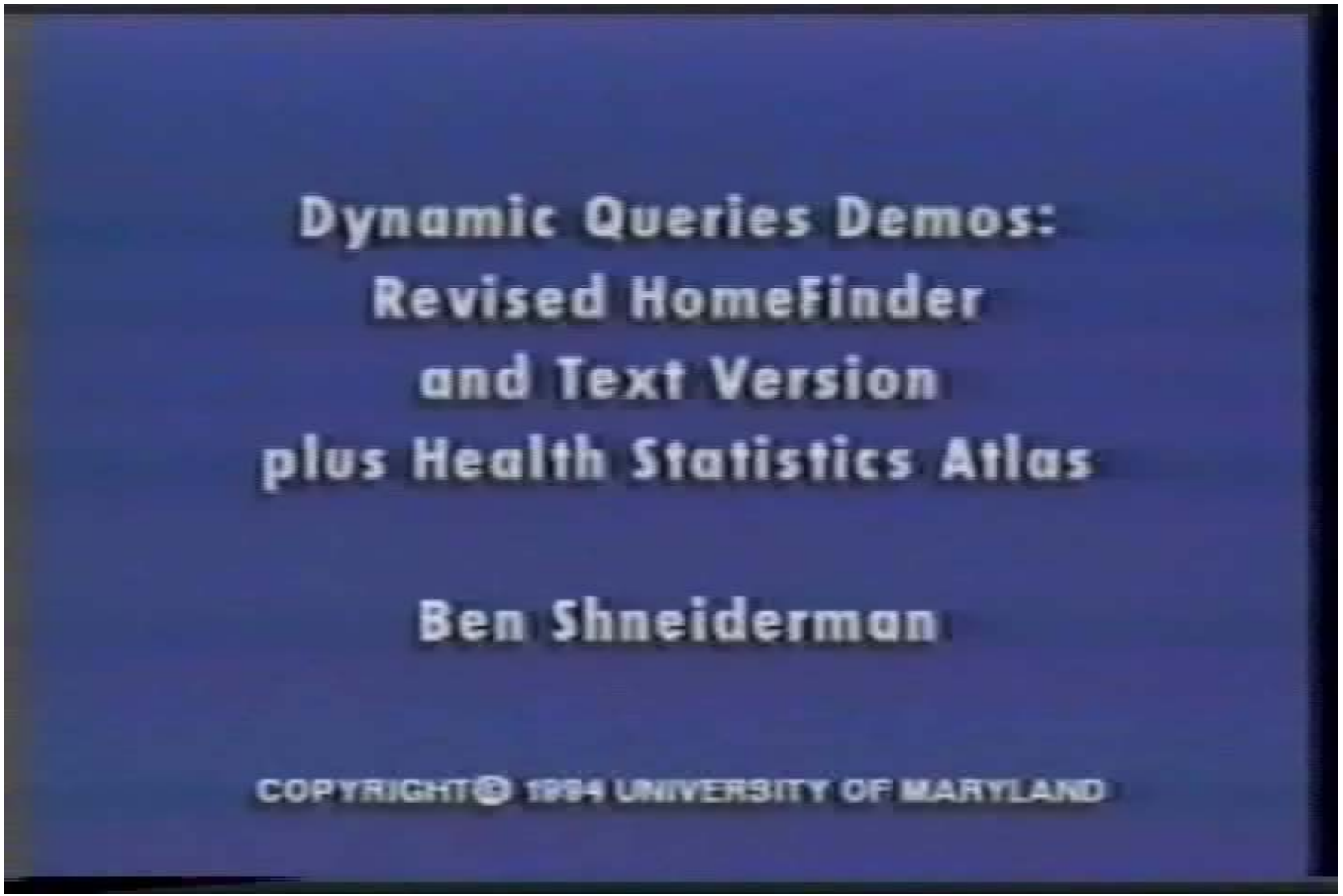


HOMEFINDER WILLIAMSON AND SCHNEIDERMAN 1992


Dynamic Queries Demos:
Revised HomeFinder
and Text Version
plus Health Statistics Atlas
Ben Shneiderman
COPYRIGHT© 1994 UNIVERSITY OF MARYLAND

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
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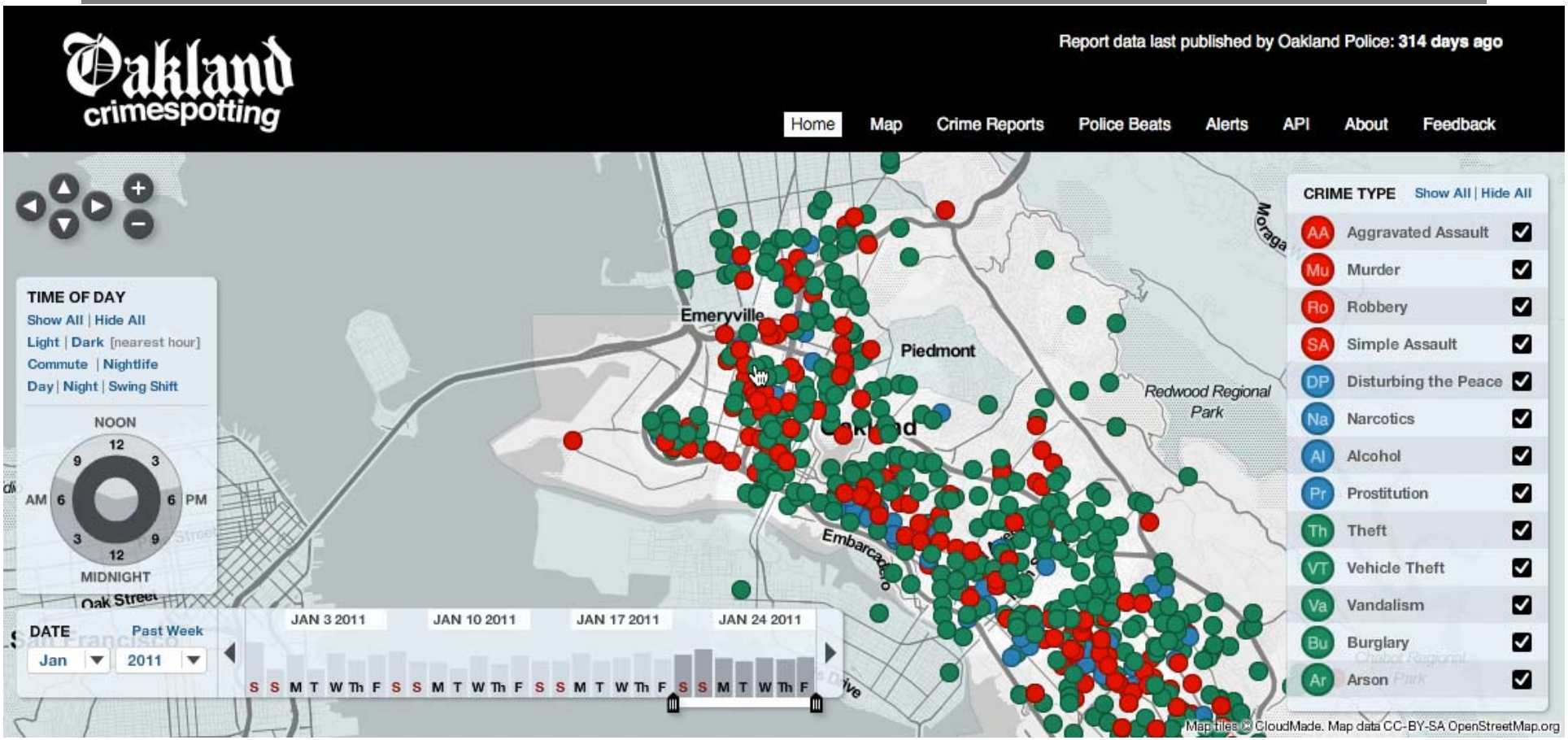
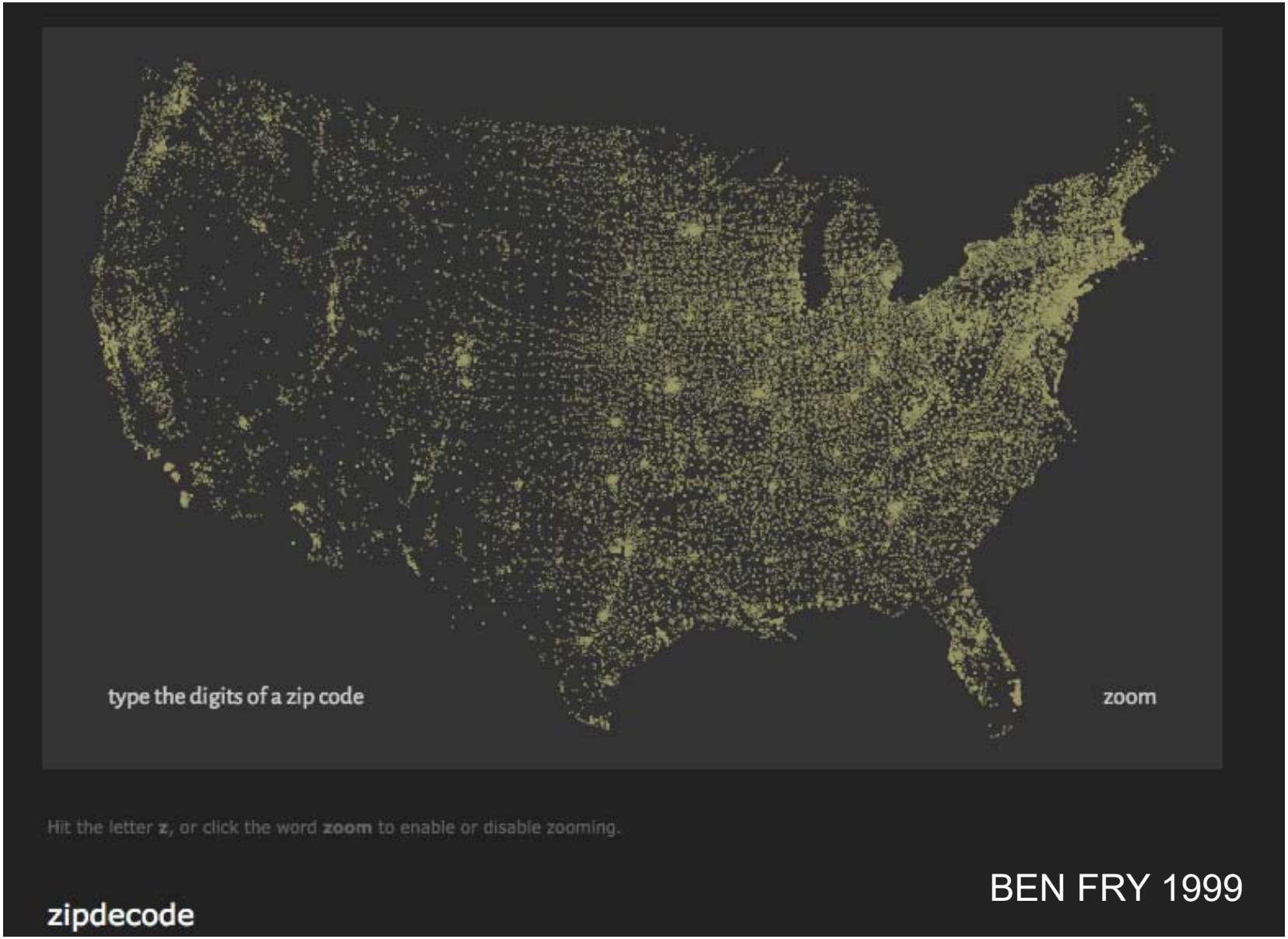
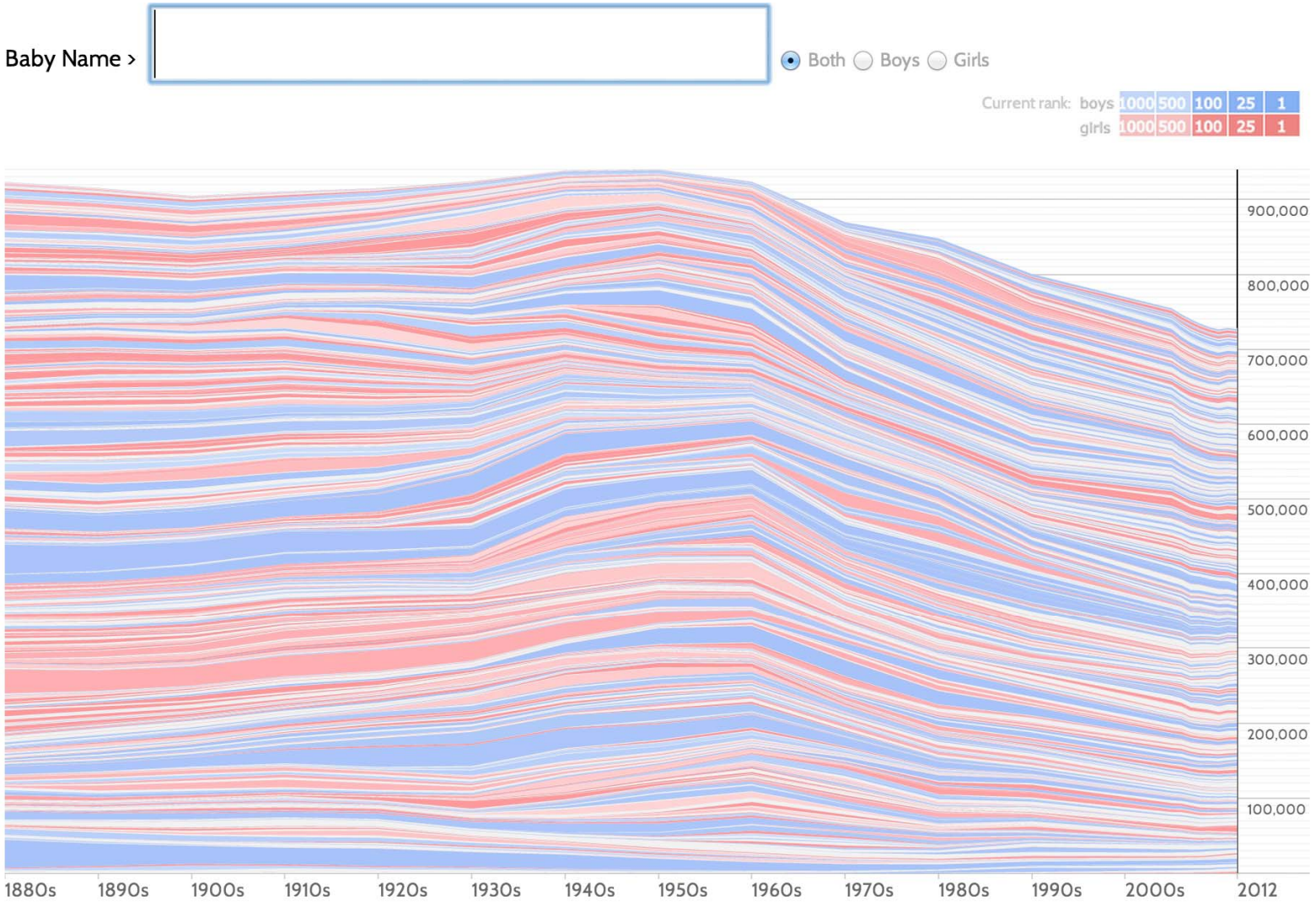
CRIMESPOTTING



STAMEN DESIGN


type the digits of a zip code
zoom
Hit the letter z, or click the word zoom to enable or disable zooming.
zipdecode
BEN FRY 1999



BABY NAME VOYAGER MARTIN WATTENBERG 2005

SELECT

EXPLORE

FILTER

SHOW ME A DIFFERENT ARRANGEMENT

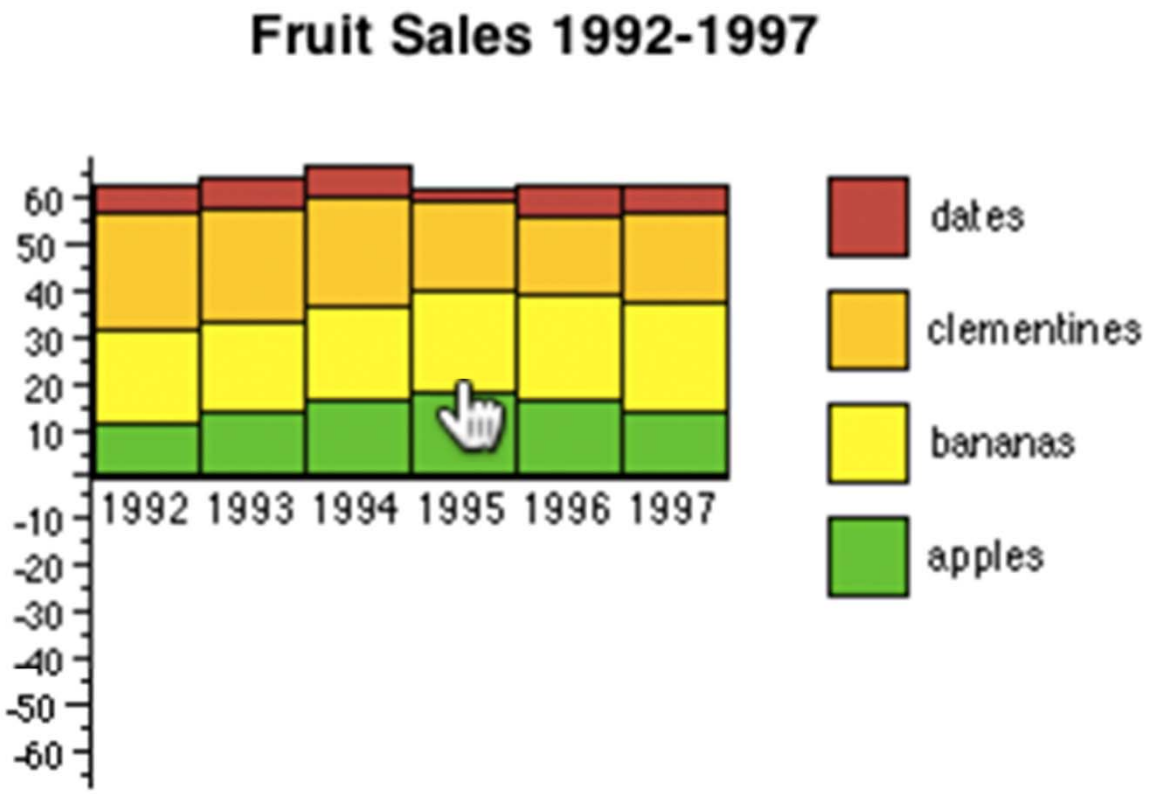
RECONFIGURE

ENCODE

ABSTRACT/ELABORATE

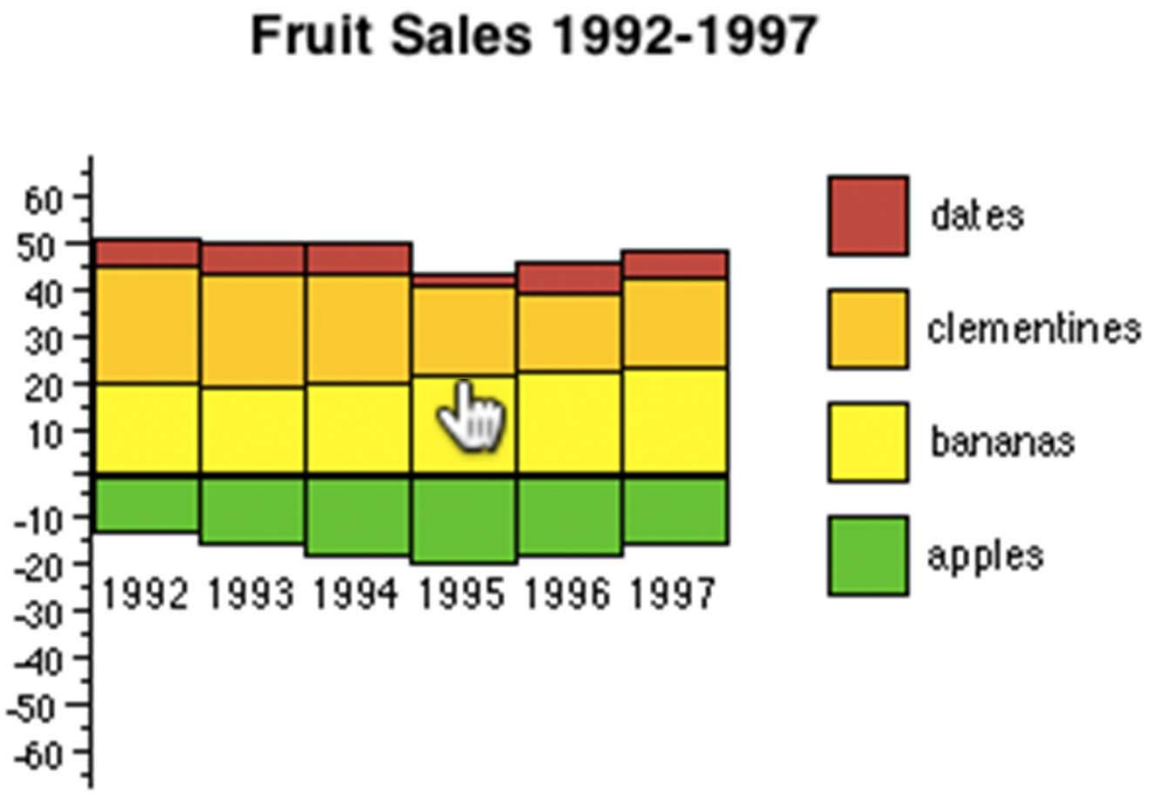
CONNECT

RE-ARRANGING DATA

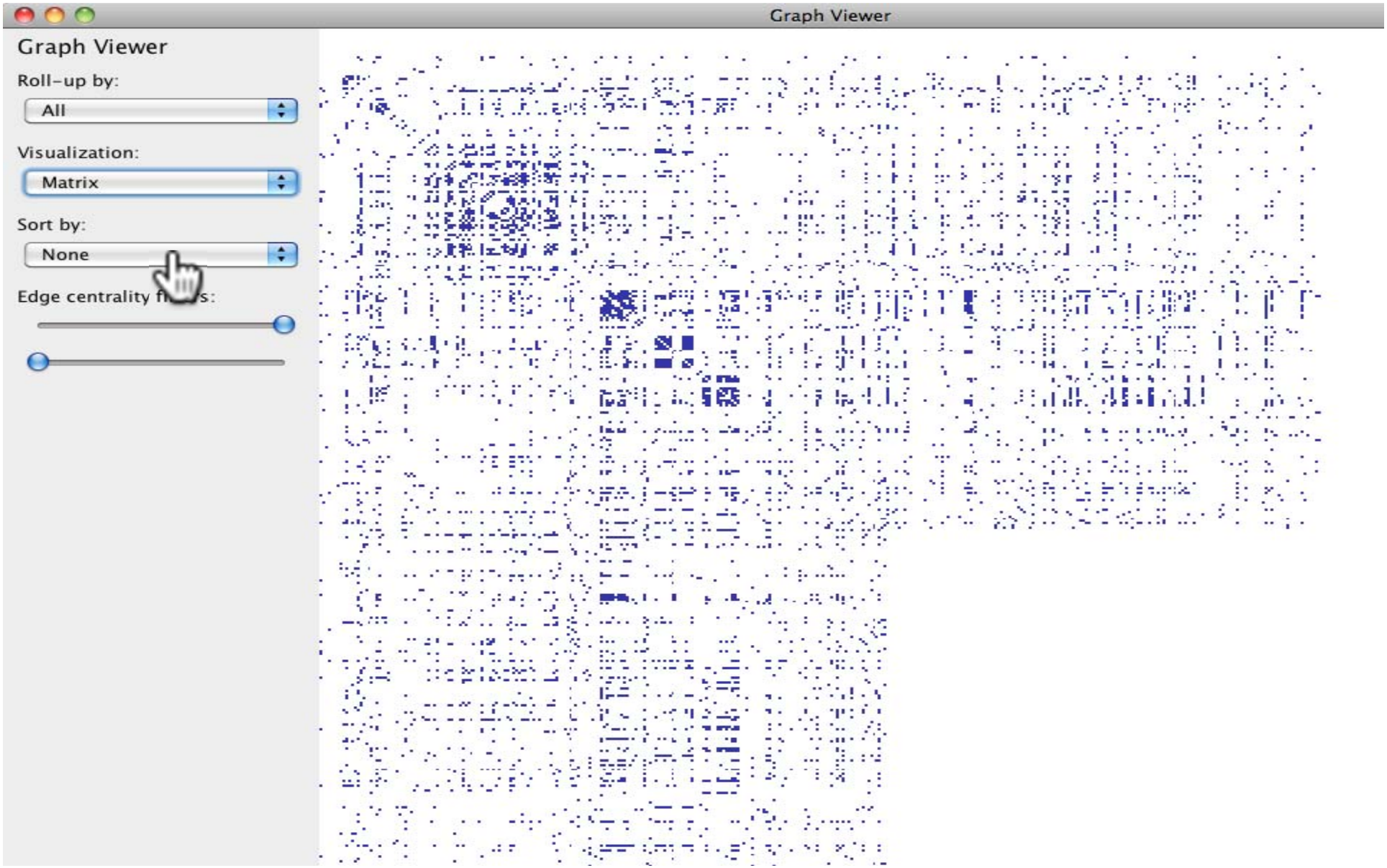


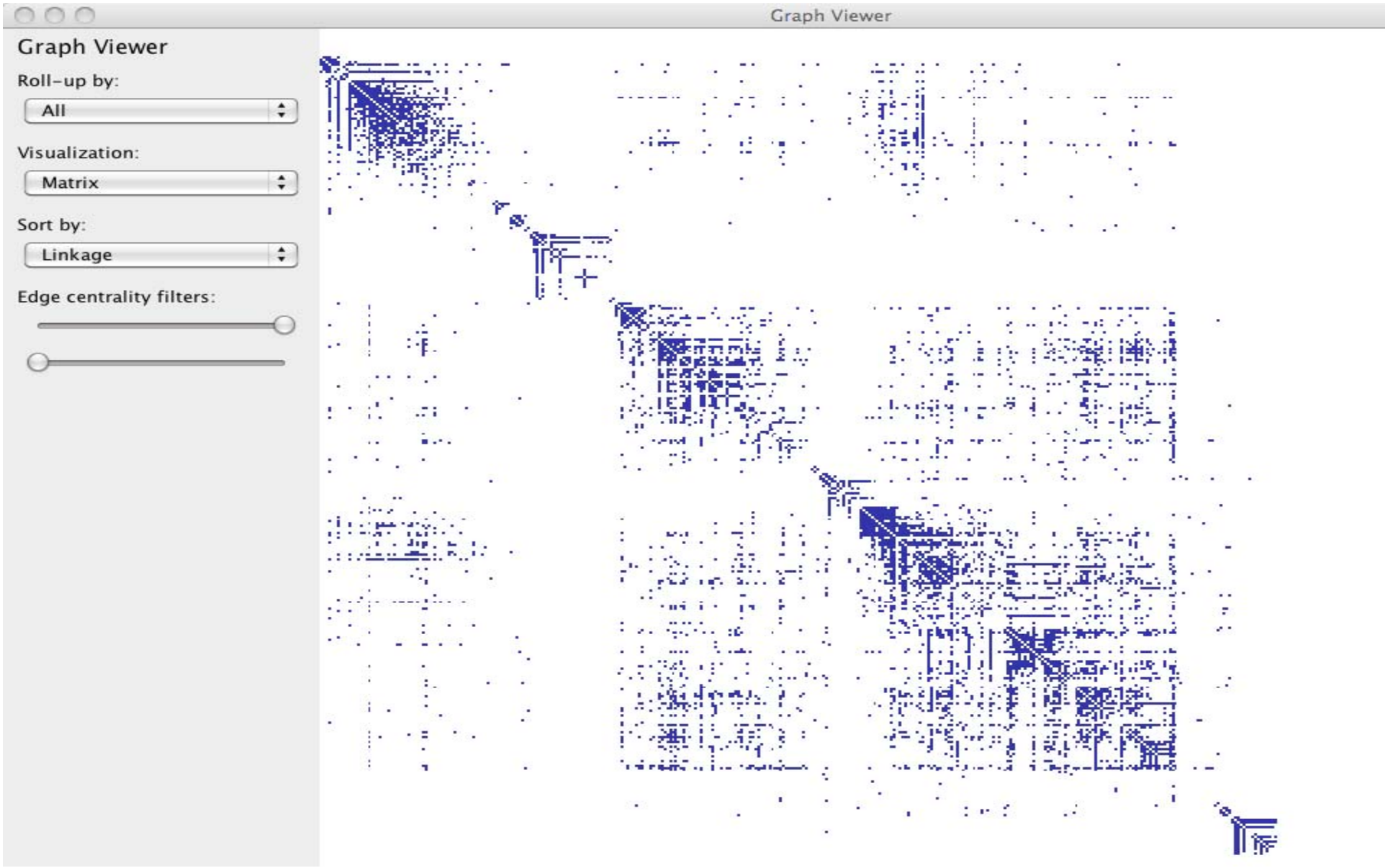
INTERACTIVE STACKED HISTOGRAMS [DIX & ELLIS, 1998]

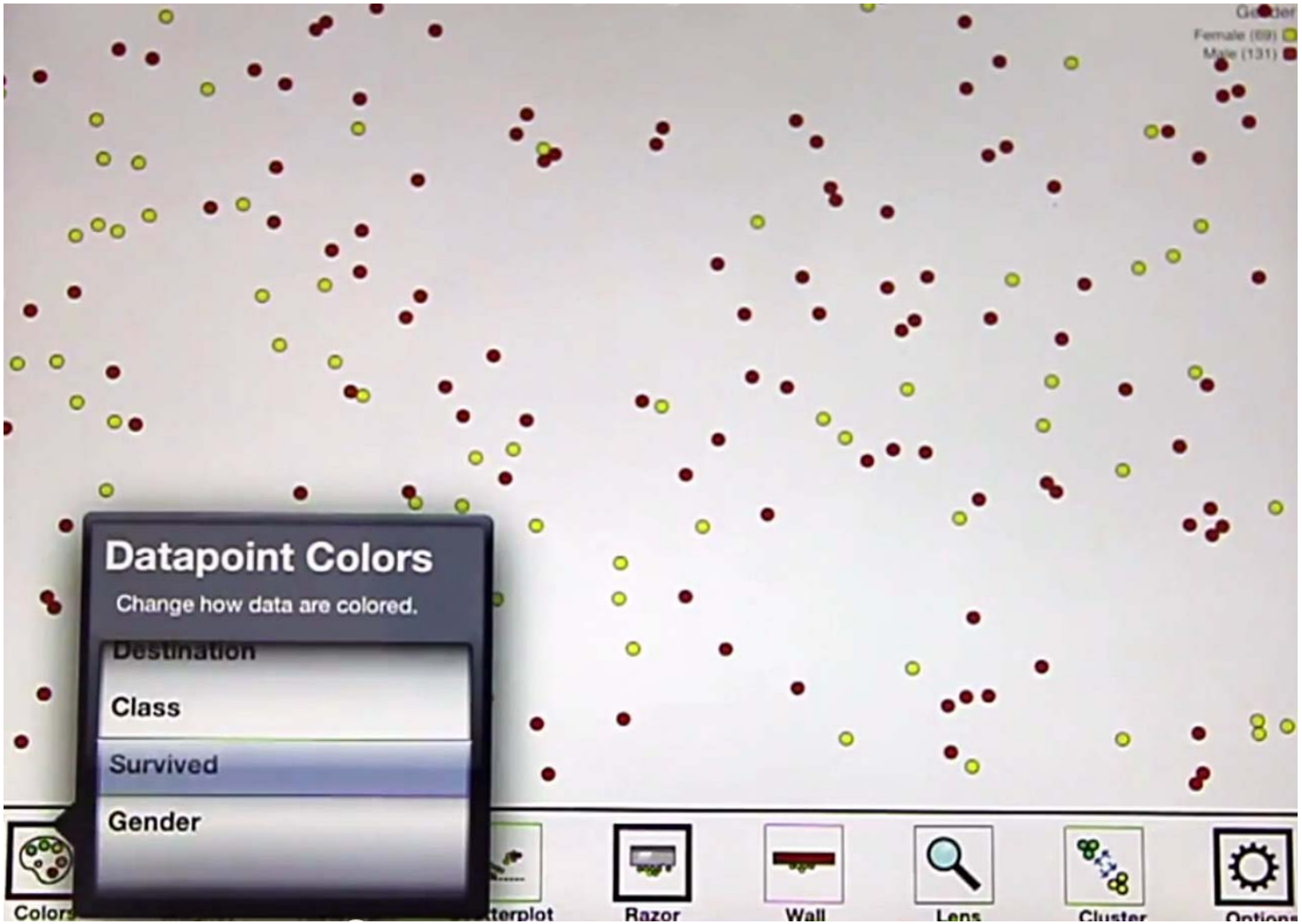
RE-ARRANGING DATA



INTERACTIVE STACKED HISTOGRAMS [DIX & ELLIS, 1998]


Graph Viewer
Graph Viewer
Roll-up by:
All
Visualization:
Matrix
Sort by:
None
Edge centrality f


Graph Viewer
Graph Viewer
Roll-up by:
All
Visualization:
Matrix
Sort by:
Linkage
Edge centrality filters:



KINETICA [RZESZORTARKSI & KITTUR 2013]

SELECT

EXPLORE

FILTER

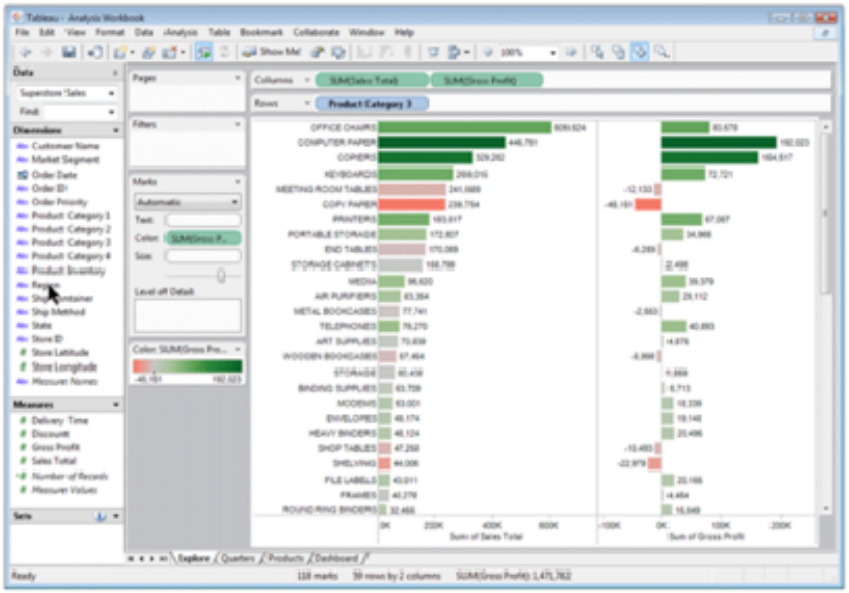
RECONFIGURE

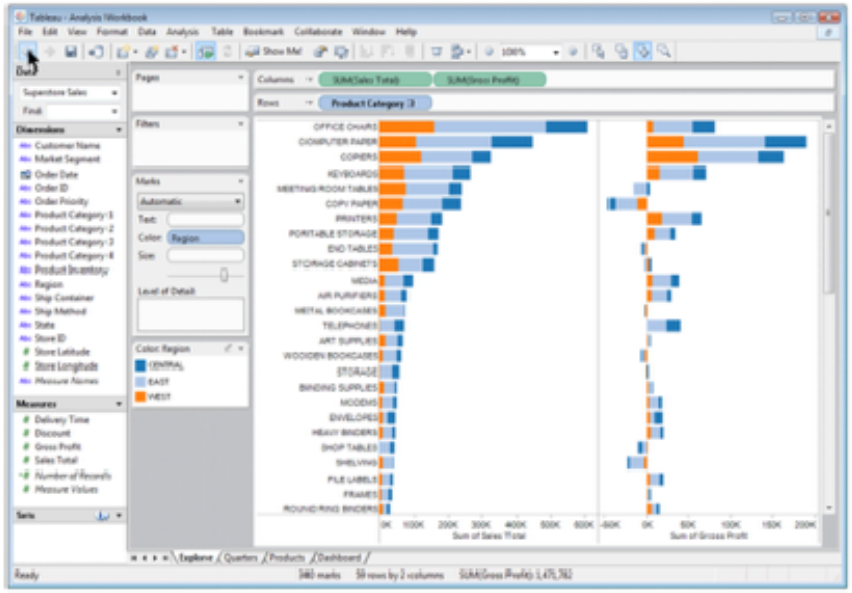
ENCODE

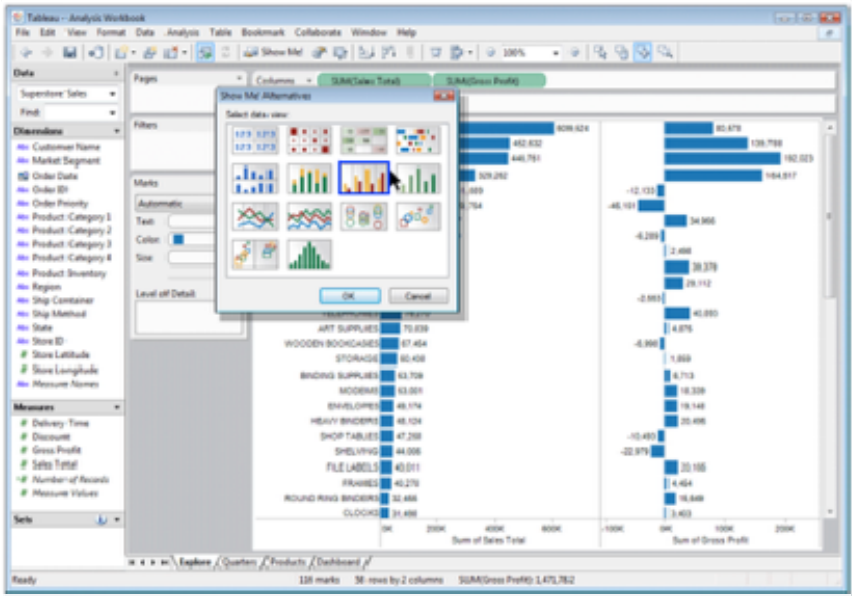
SHOW ME A DIFFERENT REPRESENTATION

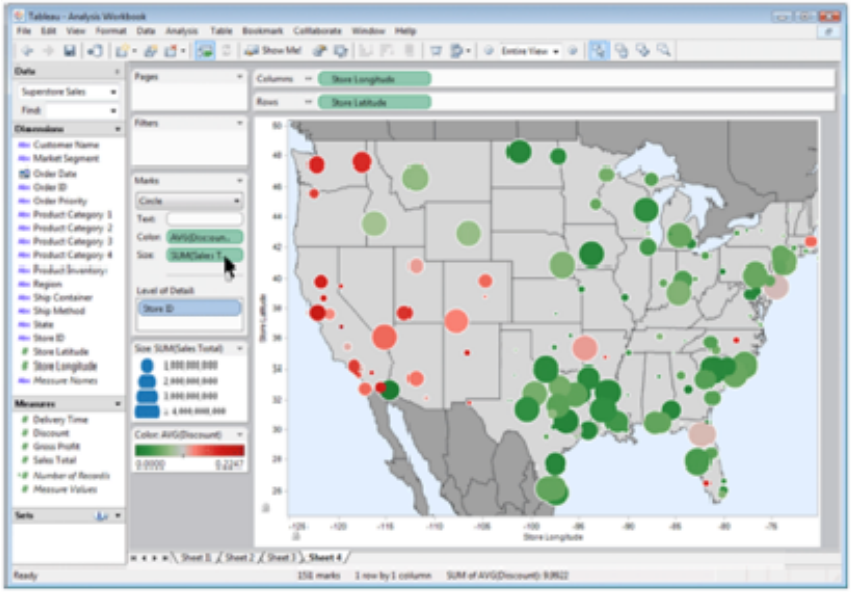
ABSTRACT/ELABORATE

CONNECT









SELECT

EXPLORE

FILTER

RECONFIGURE

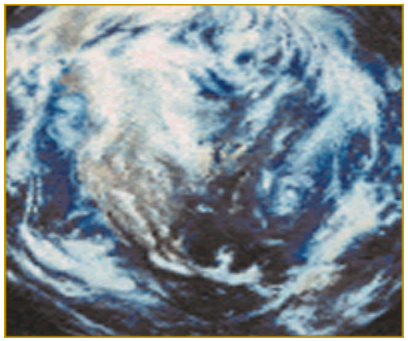
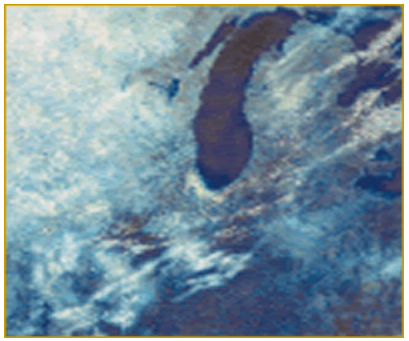
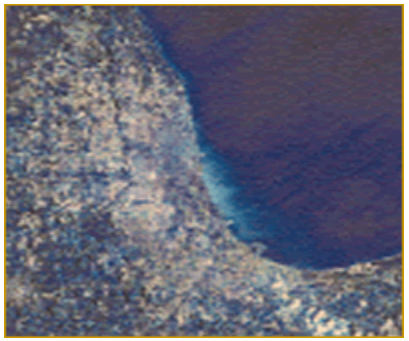
ENCODE

SHOW ME MORE
OR LESS DETAIL

ABSTRACT/ELABORATE

CONNECT

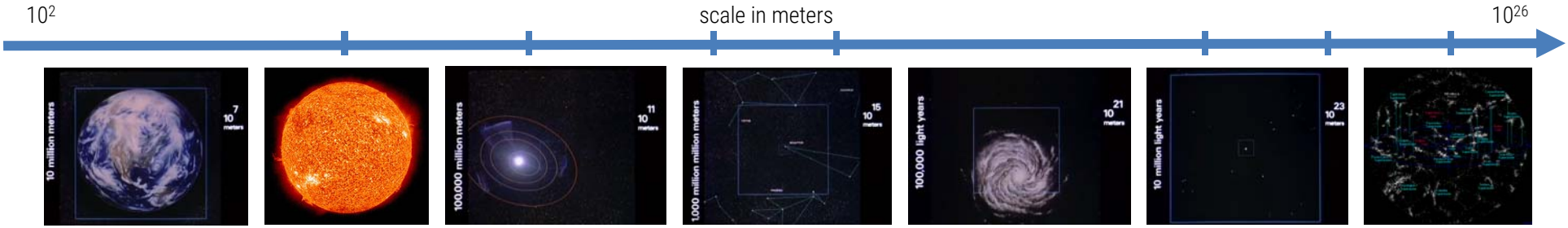
CHANGING LEVELS OF ABSTRACTION

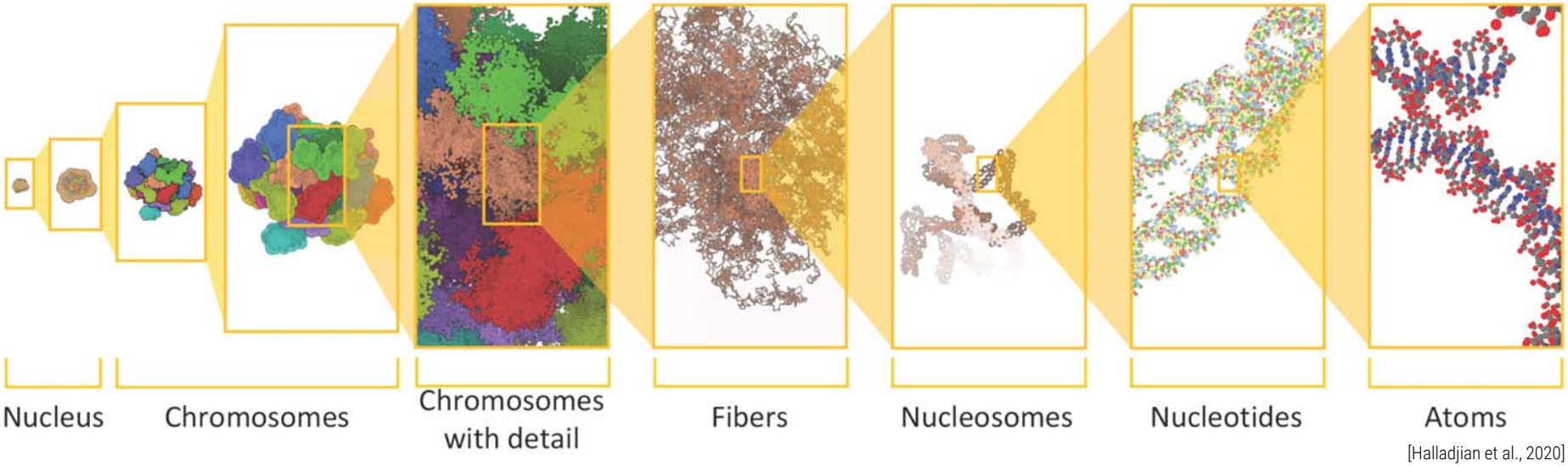
POWERS OF TEN RAY & CHARLES EAMES 1977

POWERS OF TEN RAY & CHARLES EAMES 1977

CHANGING LEVELS OF ABSTRACTION



[Powers of Ten]

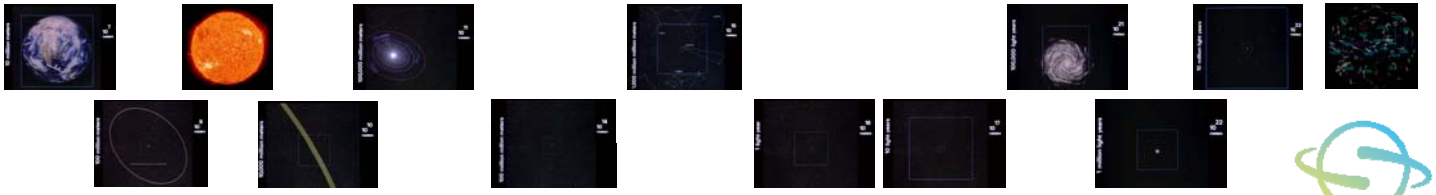


[Halladjian et al., 2020]

CHANGING LEVELS OF ABSTRACTION

[Pablo Carlos Budassi, CC BY_NC 4.0]

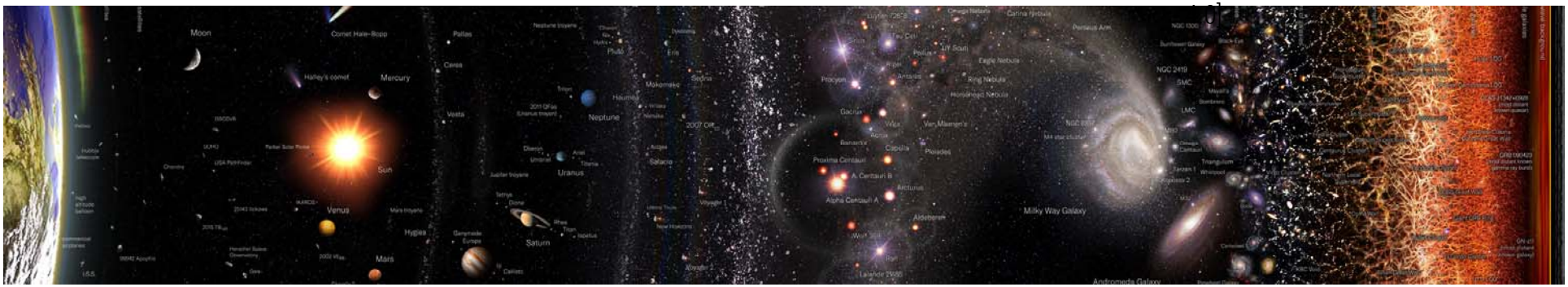
10^{-10} 10^{-5} 10^{2} scale in meters 10^{26}

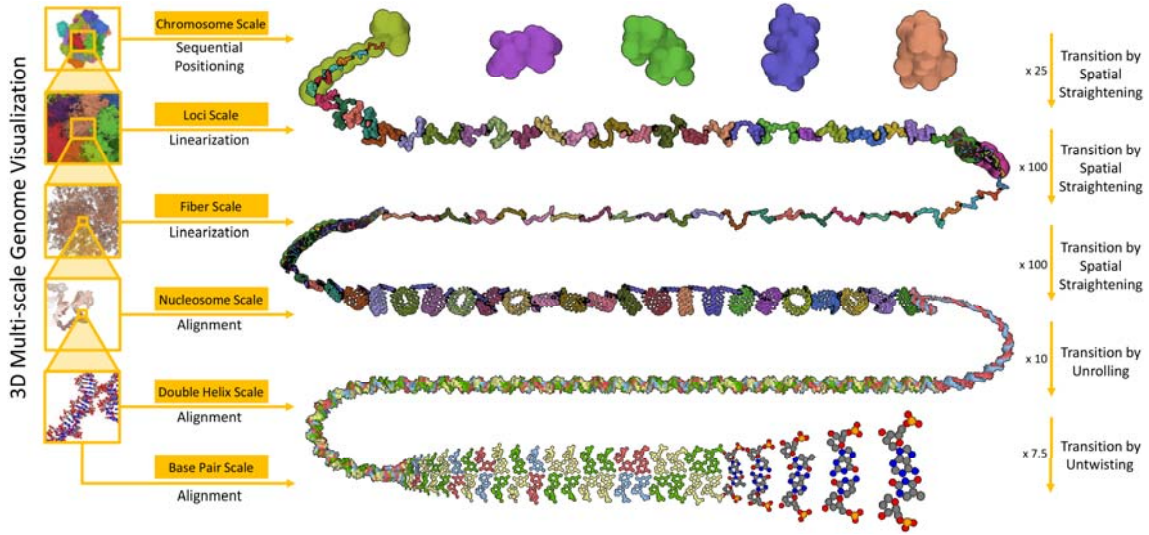


see OpenSpace

CHANGING LEVELS OF ABSTRACTION

[Pablo Carlos Budassi, CC BY_NC



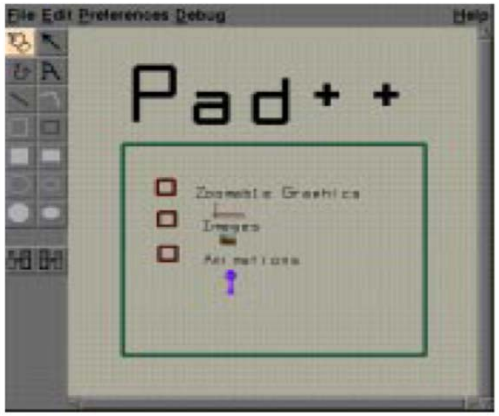


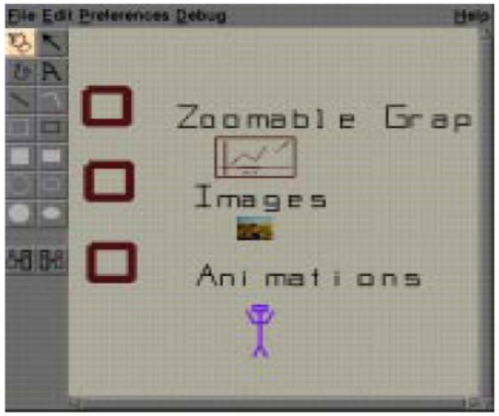
[Halladjian et al., 2022]

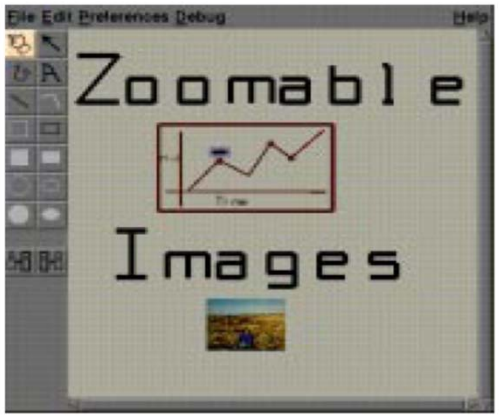
SEMANTIC ZOOMING

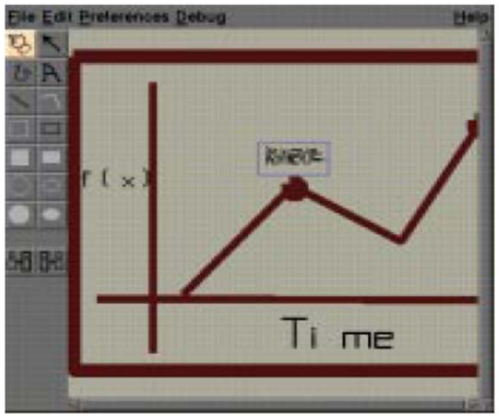
- “regular” zoom: like a photographic camera
  → all detail always shown,
  but “hidden in the pixels”
  → often limited scale levels available
- **semantic zooming**: additional information layers revealed/shown as the zoom level changes

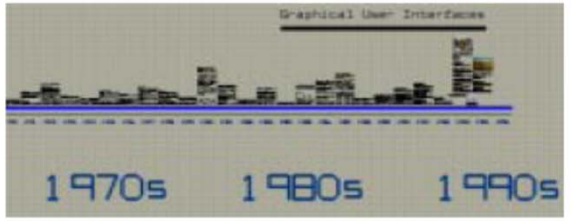
SEMANTIC ZOOMING

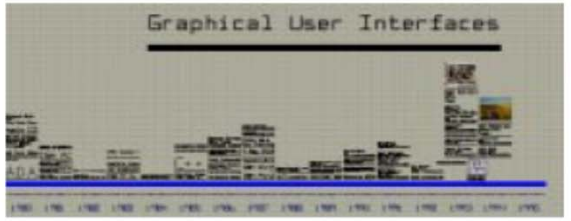


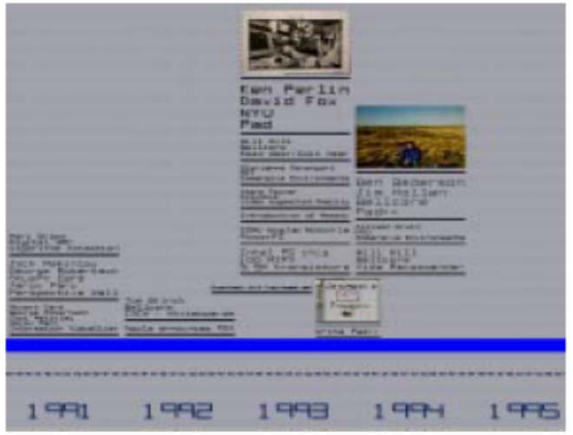






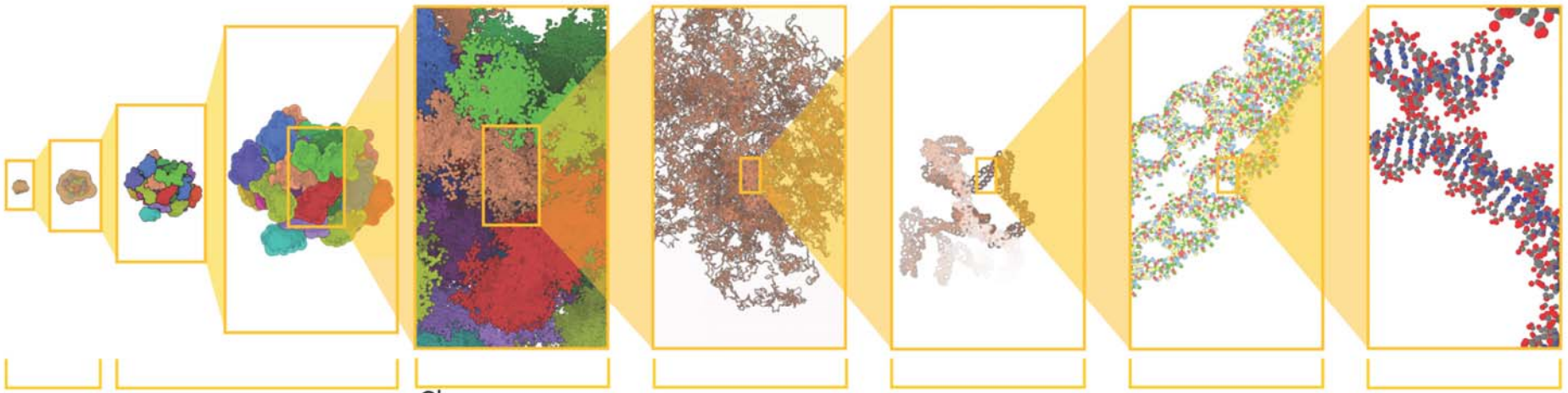






PAD++ BEDERSON AND HOLLAN 1994

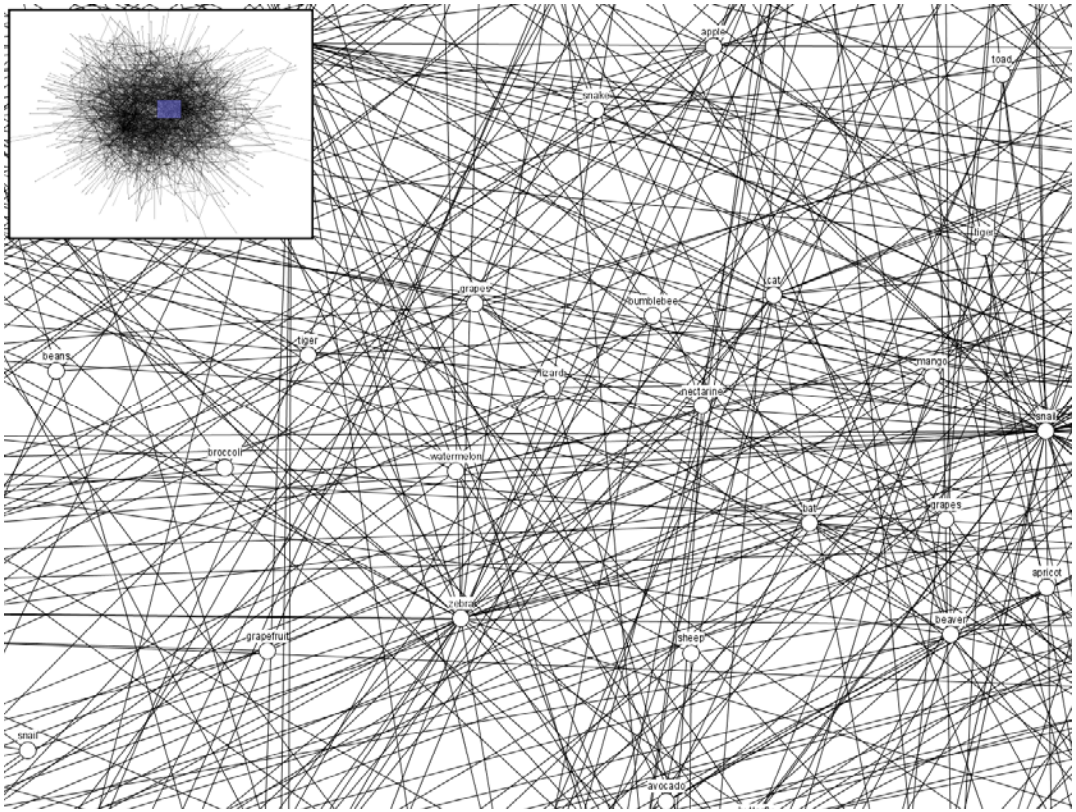
SEMANTIC ZOOMING



[Halladjian et al., 2020]

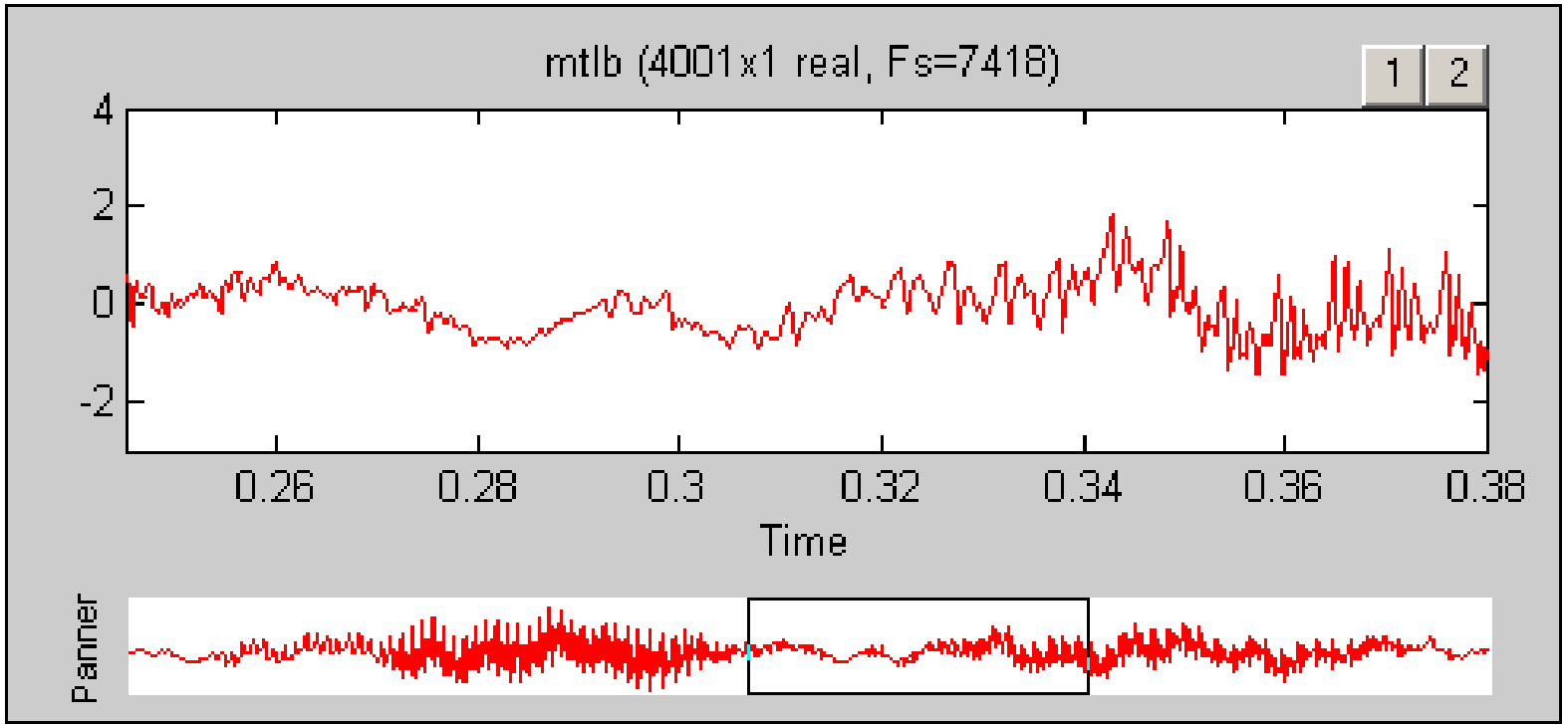
OVERVIEW + DETAIL

Panning a large graph



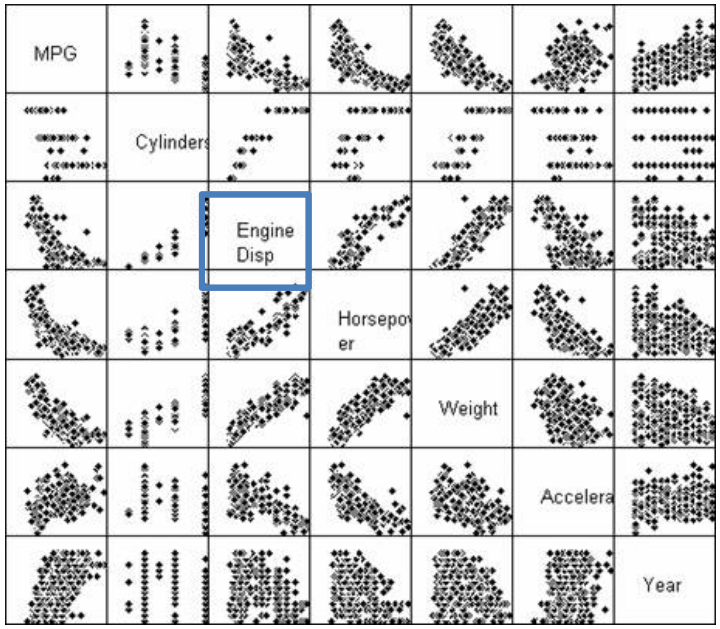
OVERVIEW + DETAIL

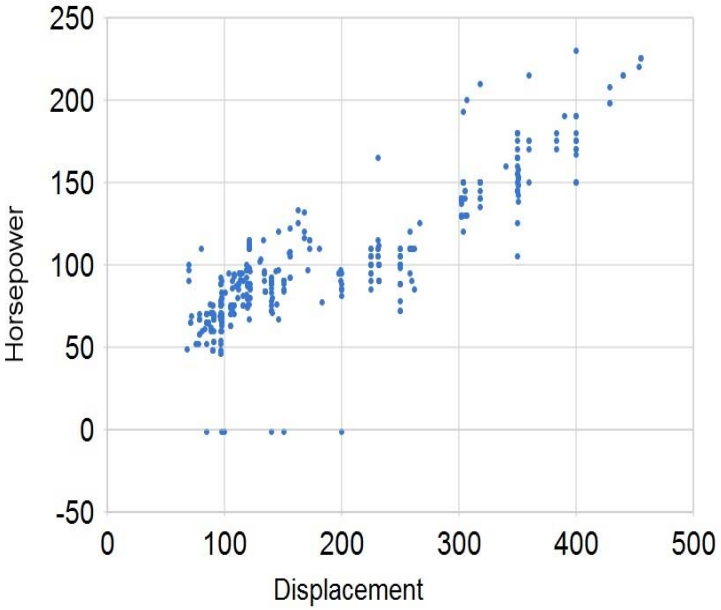
Panning a line chart



OVERVIEW + DETAIL

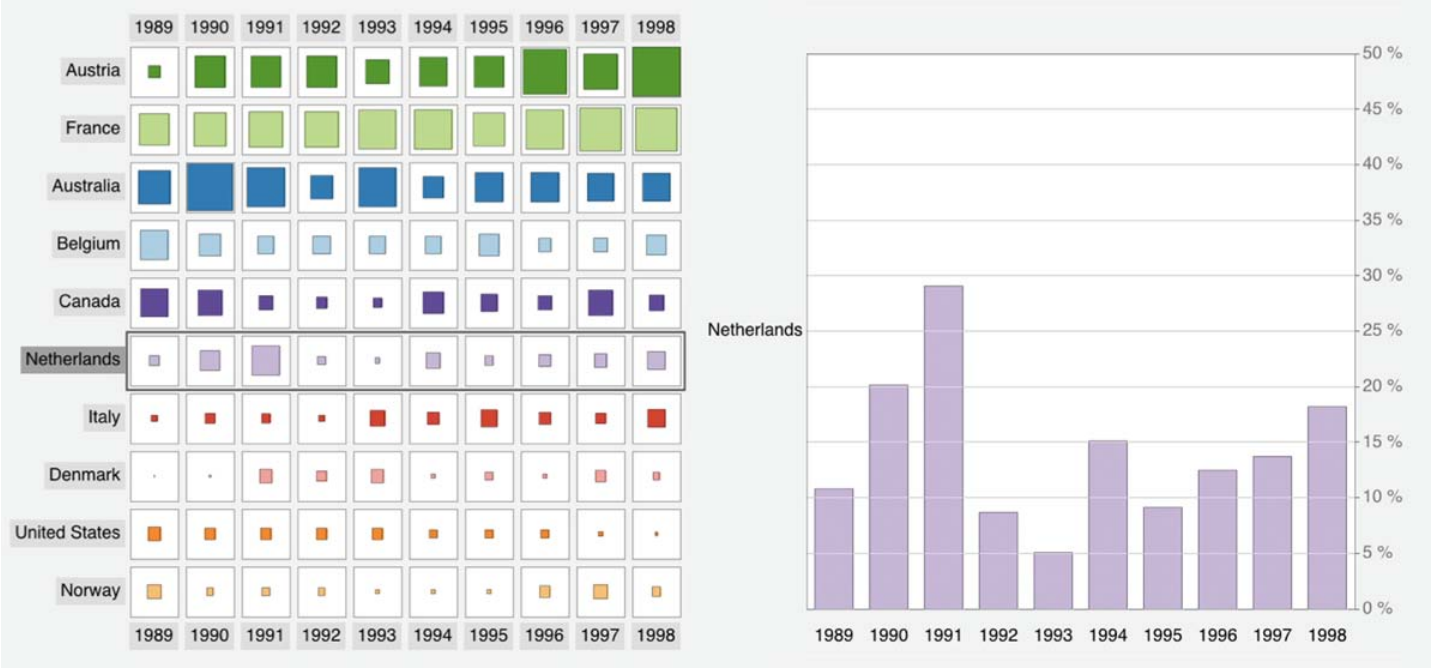
Browsing Multiple Views





OVERVIEW + DETAIL

Browsing Multiple Views

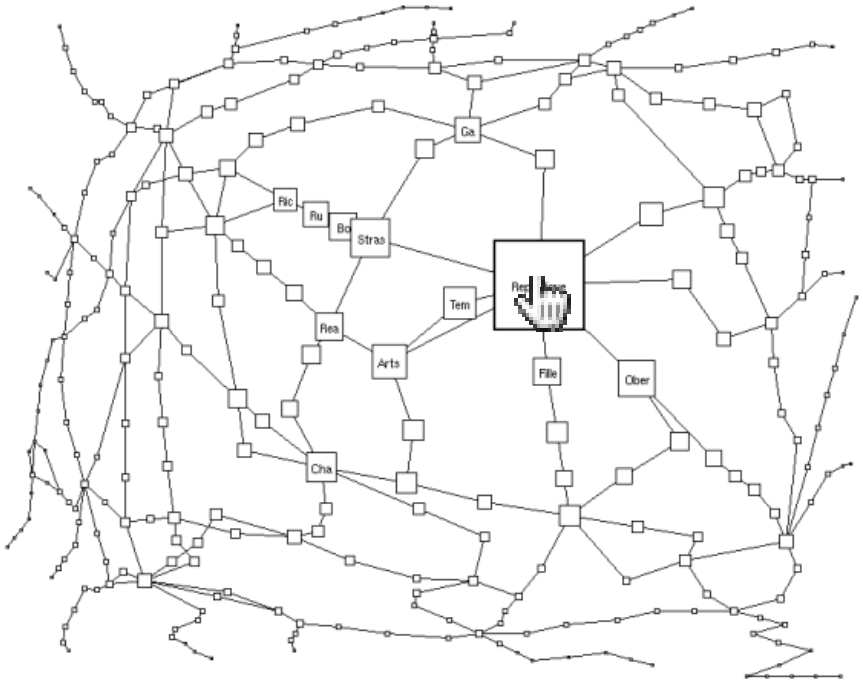


Jansen et al, 2013

FOCUS + CONTEXT

Space Distortion

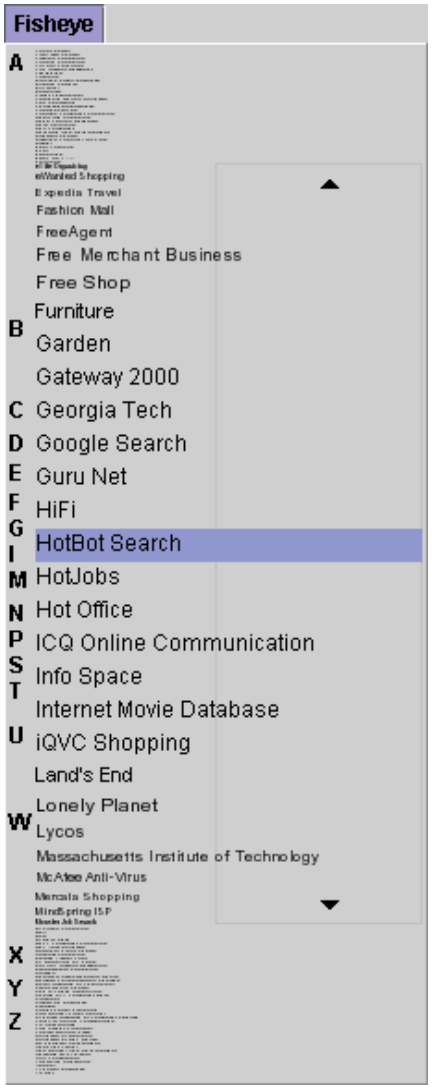
1) Fisheye Views of Graphs



Sarkar and Brown, 1992

FOCUS + CONTEXT

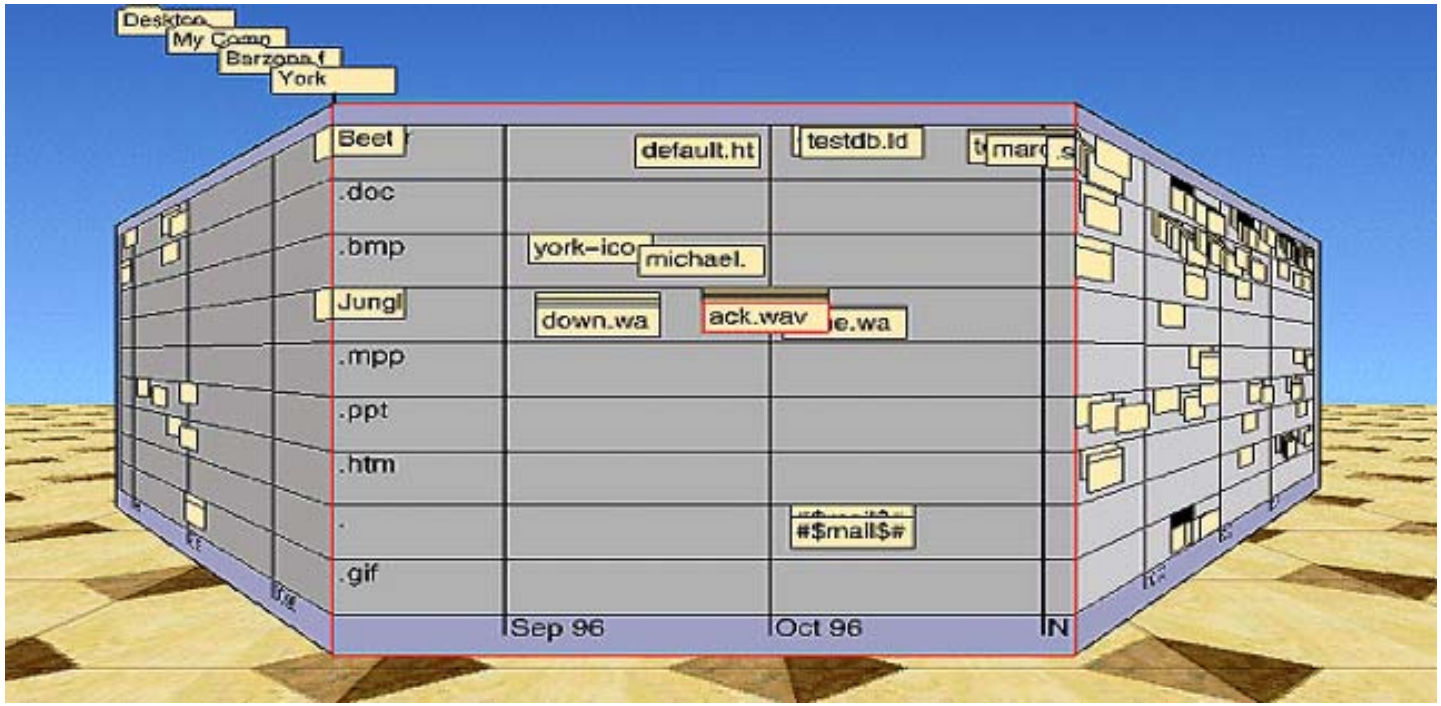
Space Distortion
2) Fisheye Menus



Bederson, 2000

FOCUS + CONTEXT

Space Distortion
3) Perspective Wall

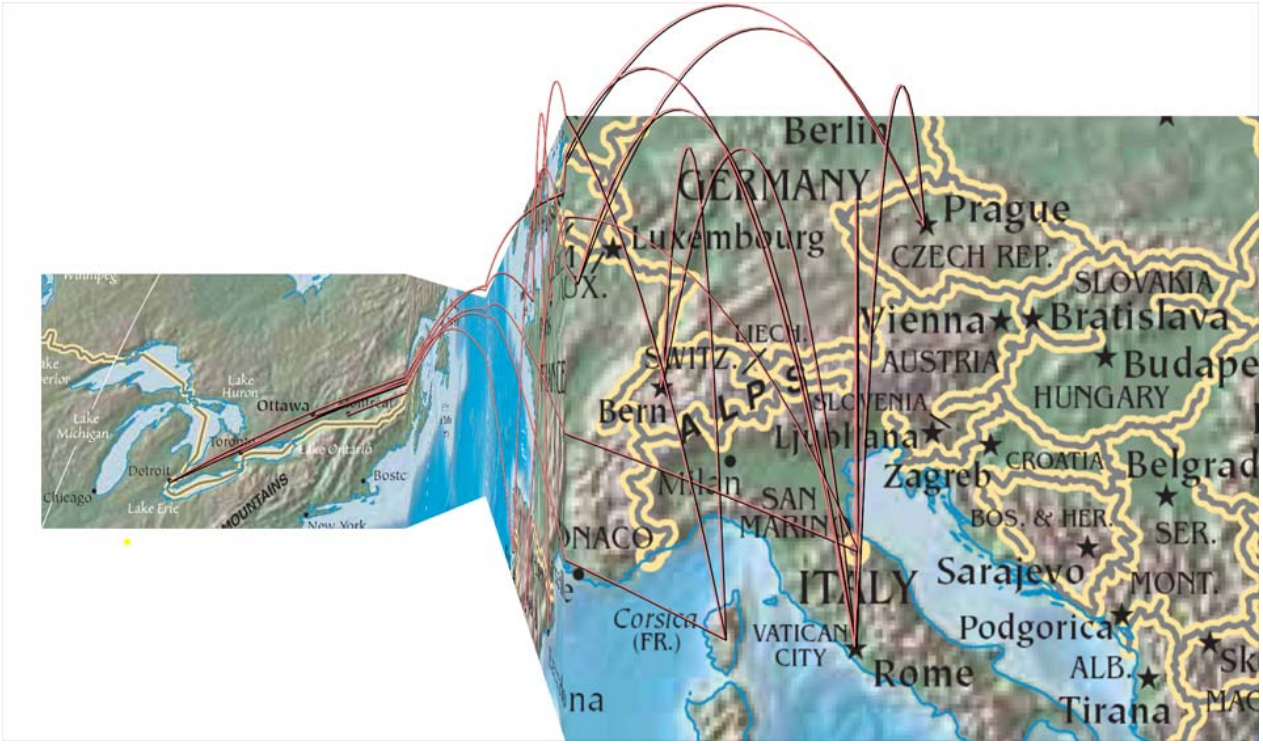


Mackinlay, Robertson and Card, 1991

FOCUS + CONTEXT

Space Distortion

4) Melange



Elmqvist et al, 2010

Mélange

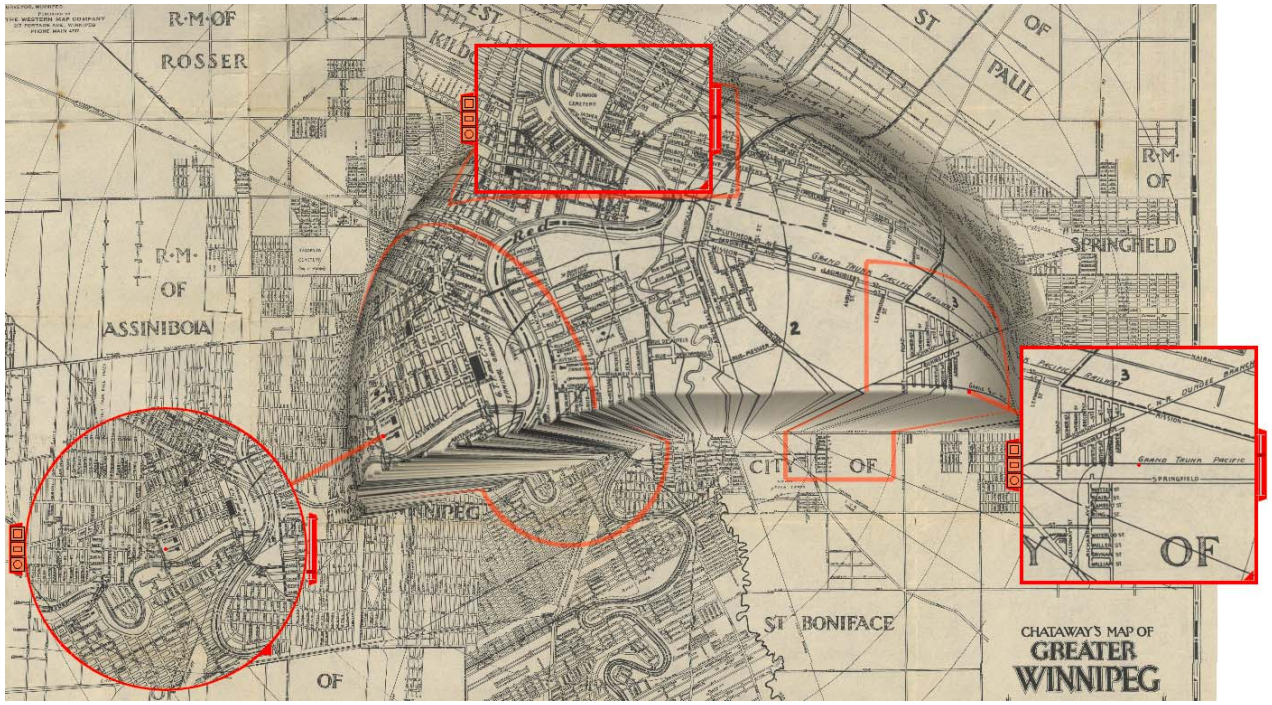
Space-Folding for Multi-Focus Interaction

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

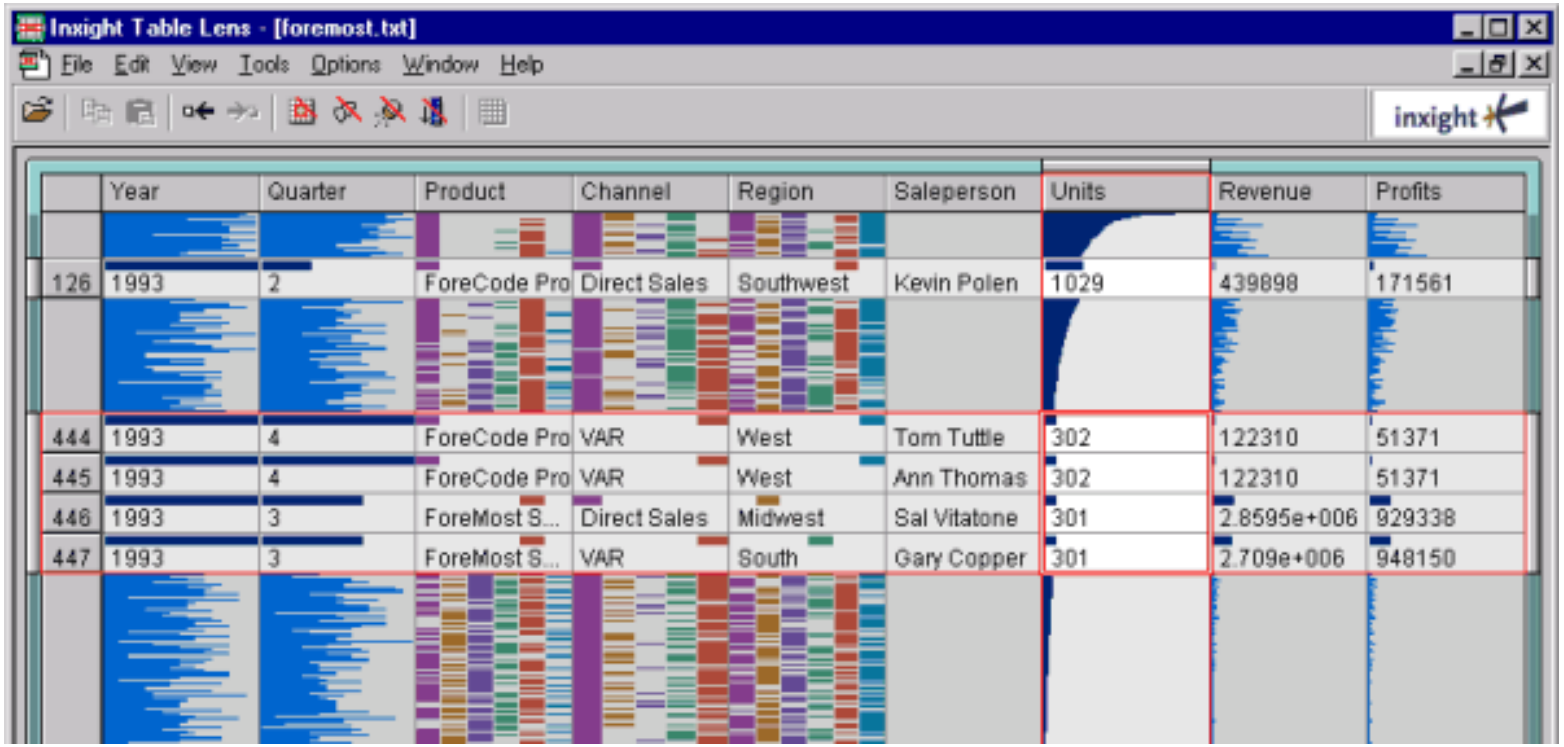
The Undistort Lens



Brosz, Carpendale and Nacenta, 2011

FOCUS + CONTEXT

Table Lens



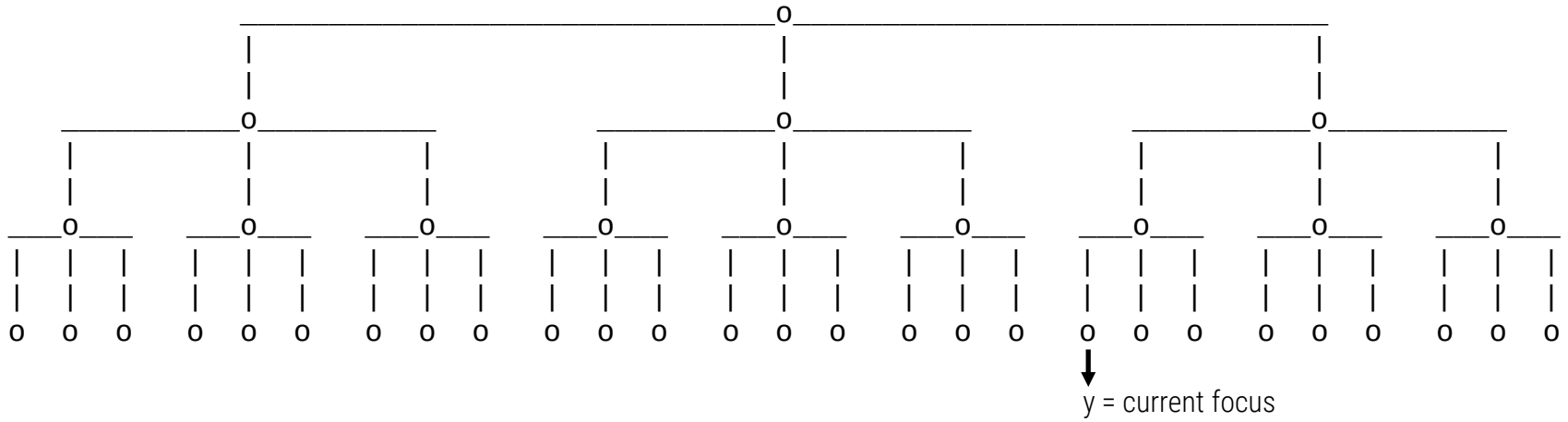
	Year	Quarter	Product	Channel	Region	Saleperson	Units	Revenue	Profits
126	1993	2	ForeCode Pro	Direct Sales	Southwest	Kevin Polen	1029	439898	171561
444	1993	4	ForeCode Pro	VAR	West	Tom Tuttle	302	122310	51371
445	1993	4	ForeCode Pro	VAR	West	Ann Thomas	302	122310	51371
446	1993	3	ForeMost S...	Direct Sales	Midwest	Sal Vitatone	301	2.8595e+006	929338
447	1993	3	ForeMost S...	VAR	South	Gary Copper	301	2.709e+006	948150

Rao and Card, 1994

FOCUS + CONTEXT

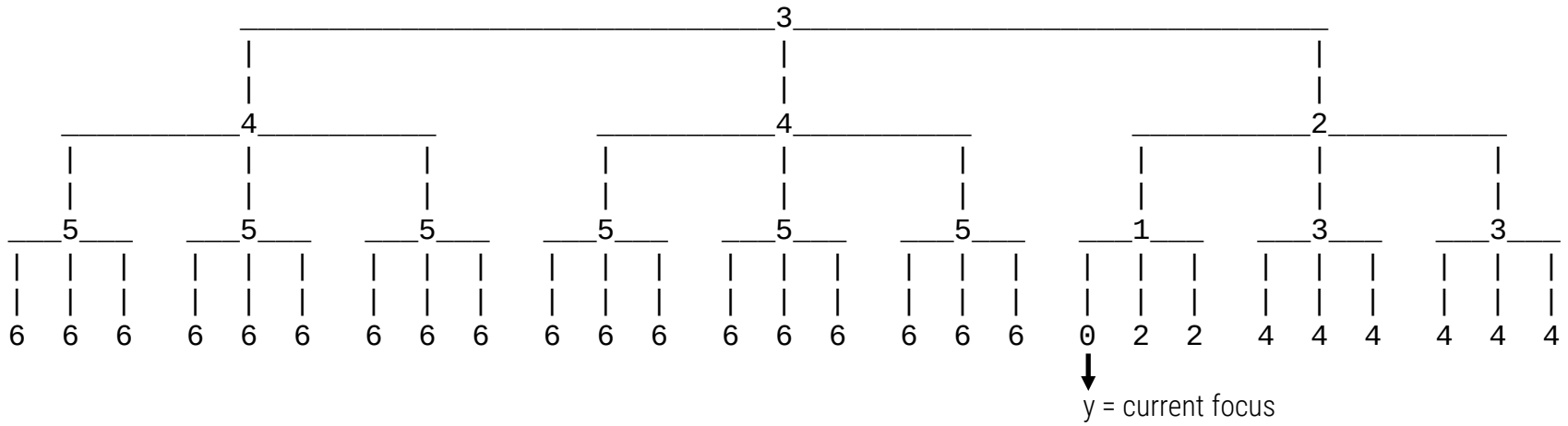
Generalized Fisheye Views [Furnaz, 1986]

- focus+context for non-linear representations
- for instance, how to zoom in trees?



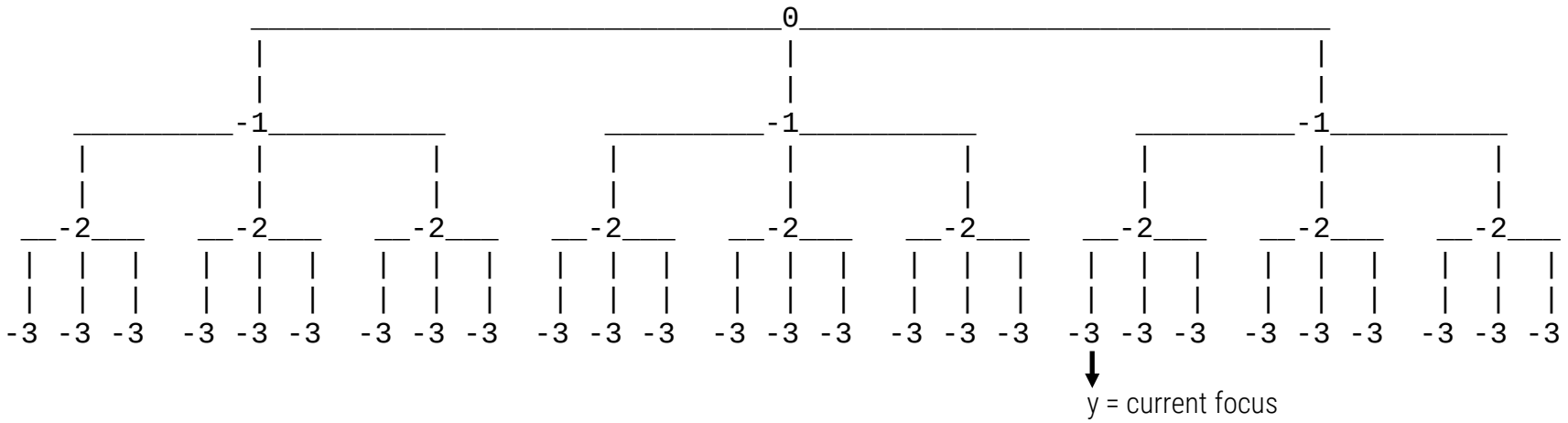
FOCUS + CONTEXT

- first notion of (un)importance:
  distance in tree from current focus $d_{tree}(x, y)$



FOCUS + CONTEXT

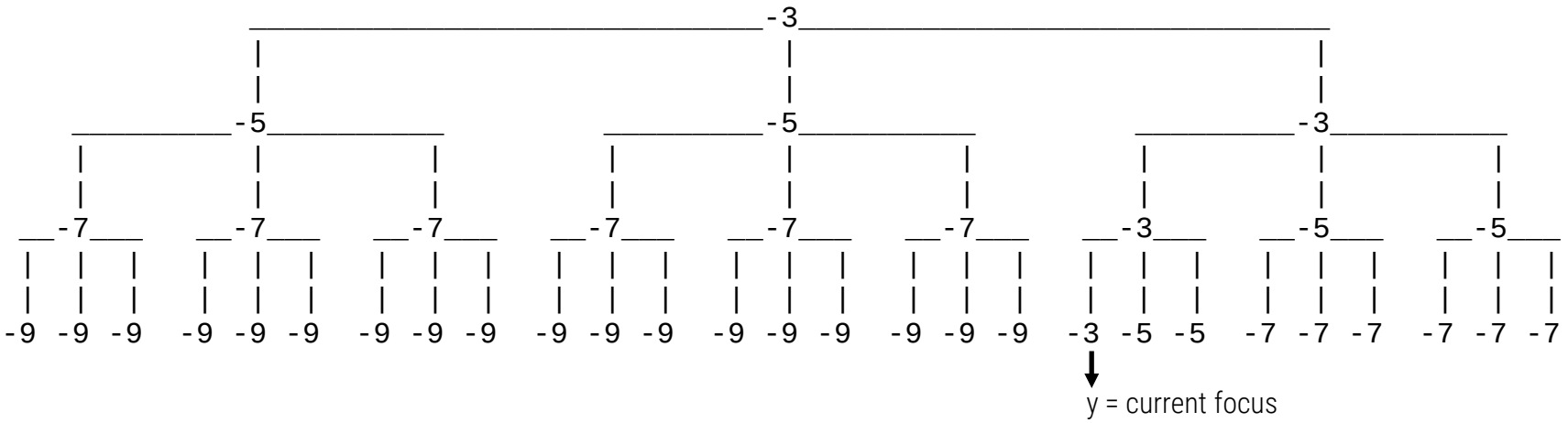
- second notion of importance:
  a priory importance
  $API(x) = -d_{tree}(x, root)$



FOCUS + CONTEXT

- fisheye degree of interest

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

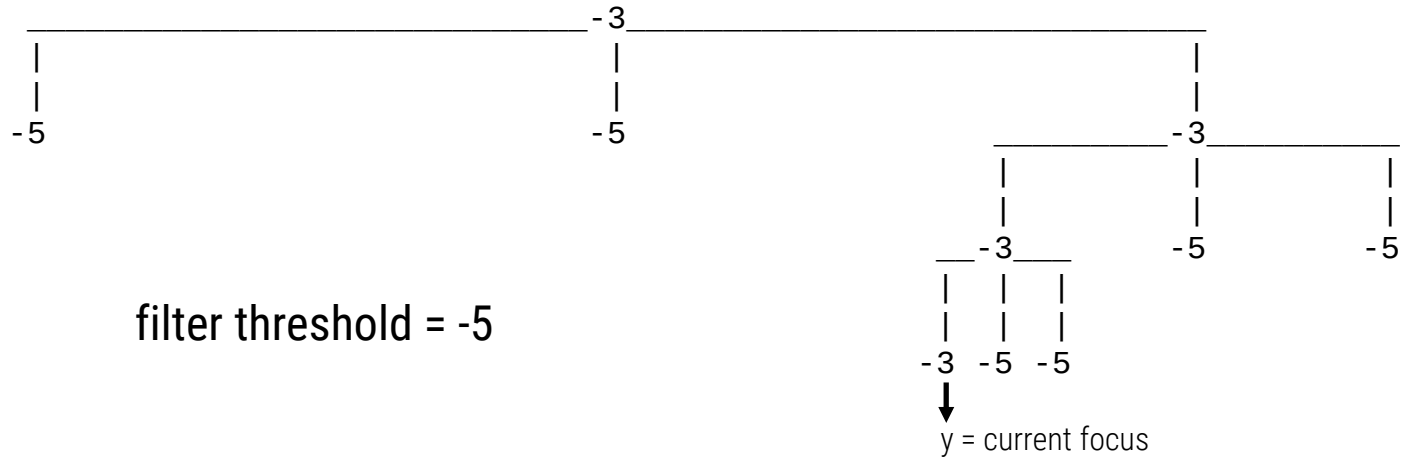


FOCUS + CONTEXT

- tree exploration based on $DOI_{fisheye(tree)}(x)$
  - focuses on local area and important distant points

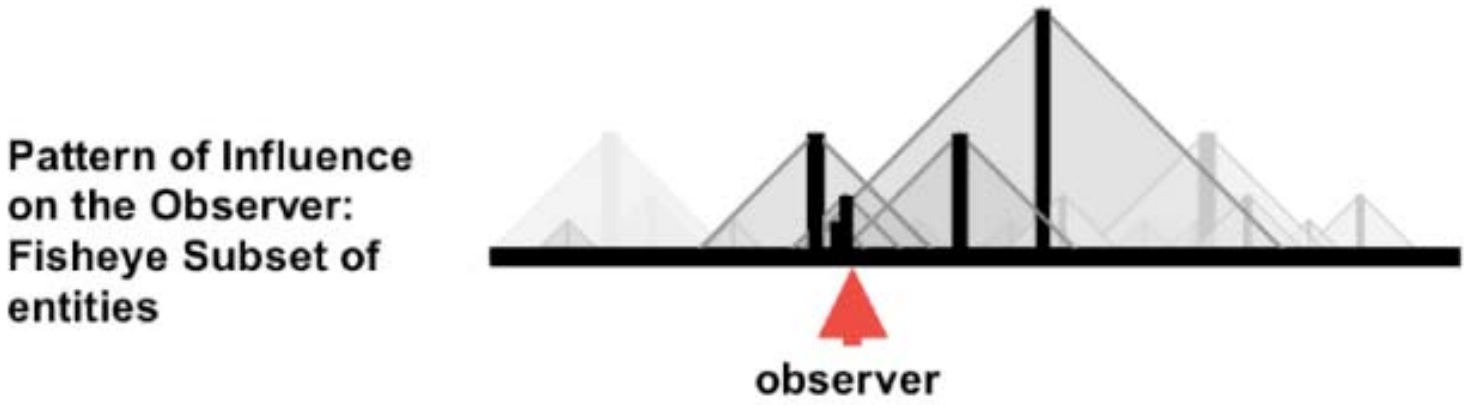
  → generalization of focus + context

  → other representations (graphs, etc.) similar



FOCUS + CONTEXT

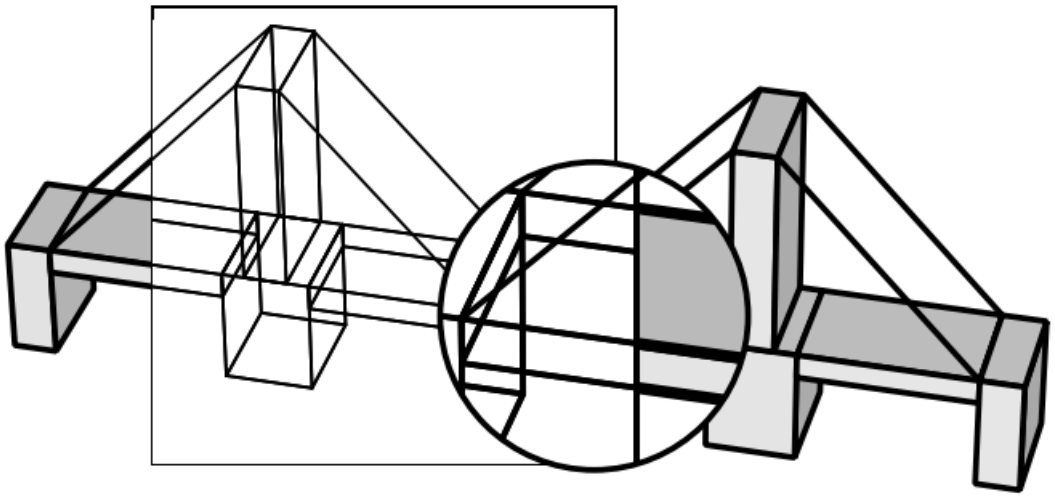
Generalized Fisheye Views

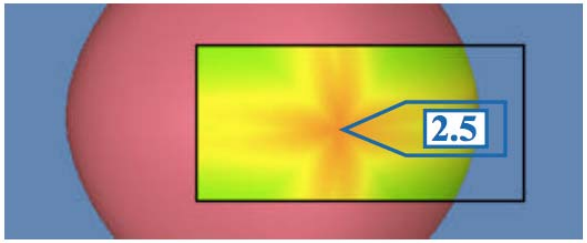


Furnas, 2010
A Fisheye Follow-Up: Further Reflections on Focus + Context

MAGIC LENSES

- reveal hidden information layers
- local control through movable and resizable lens

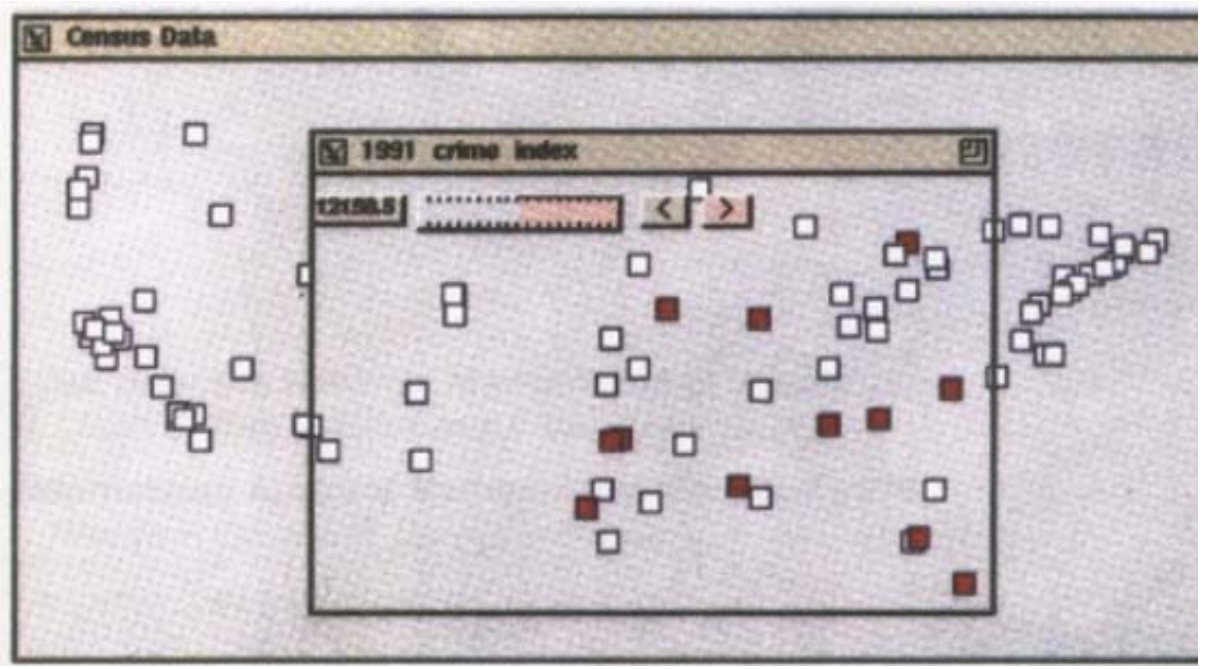




Bier et al, 1993

MAGIC LENSES

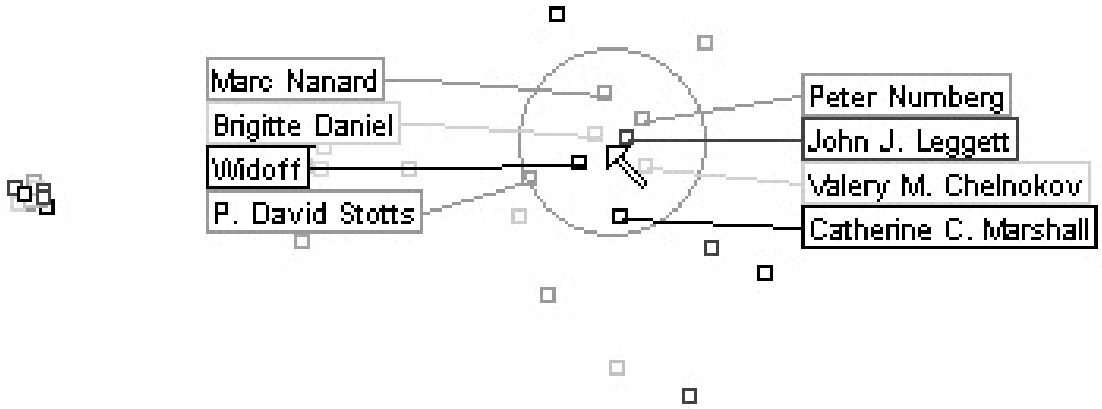
Movable filters for dynamic queries



Fishkin and Stone, 1995

MAGIC LENSES

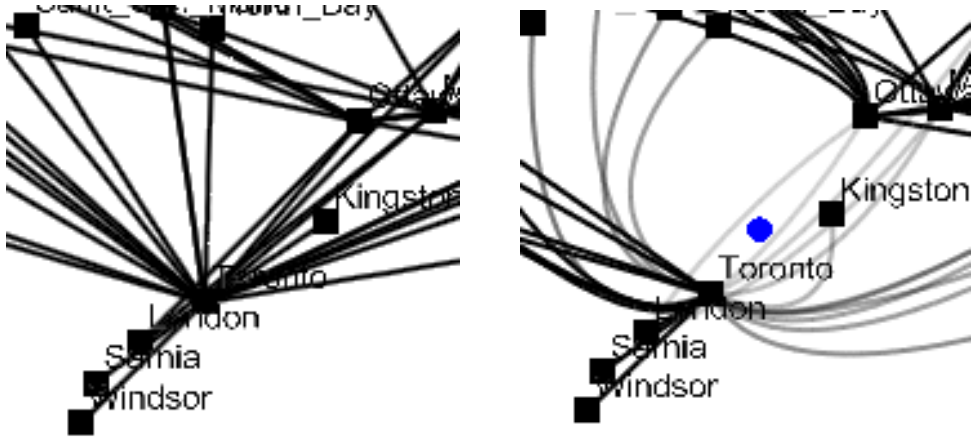
Exentric Labeling



 Fekete and Plaisant, 1999

MAGIC LENSES

Edge lenses



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

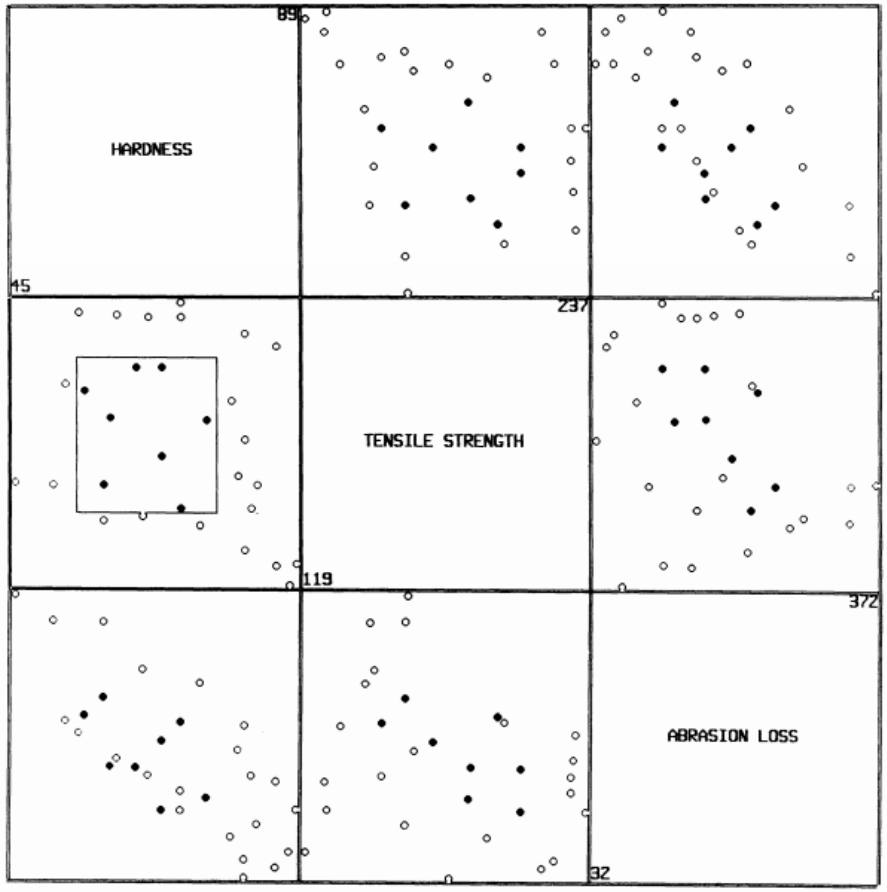
THE COMPONENTS MUST BE ***LINKED***

BY *TUPLE* (MATCHING DATA POINTS),

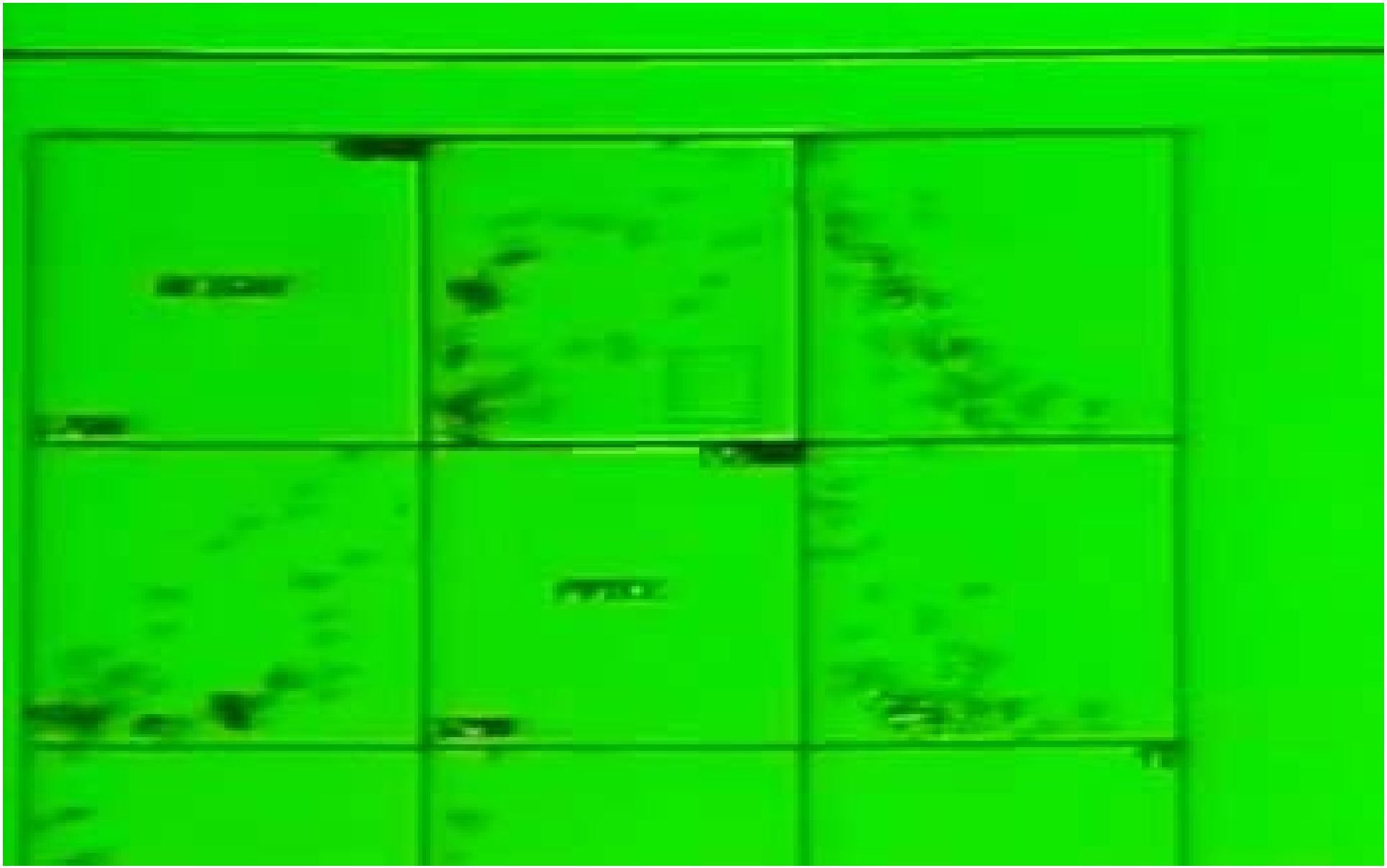
OR

BY *QUERY* (MATCHING RANGE OR VALUES)

BRUSHING AND LINKING



BRUSHING SCATTERPLOTS BECKER & CLEVELAND 1982

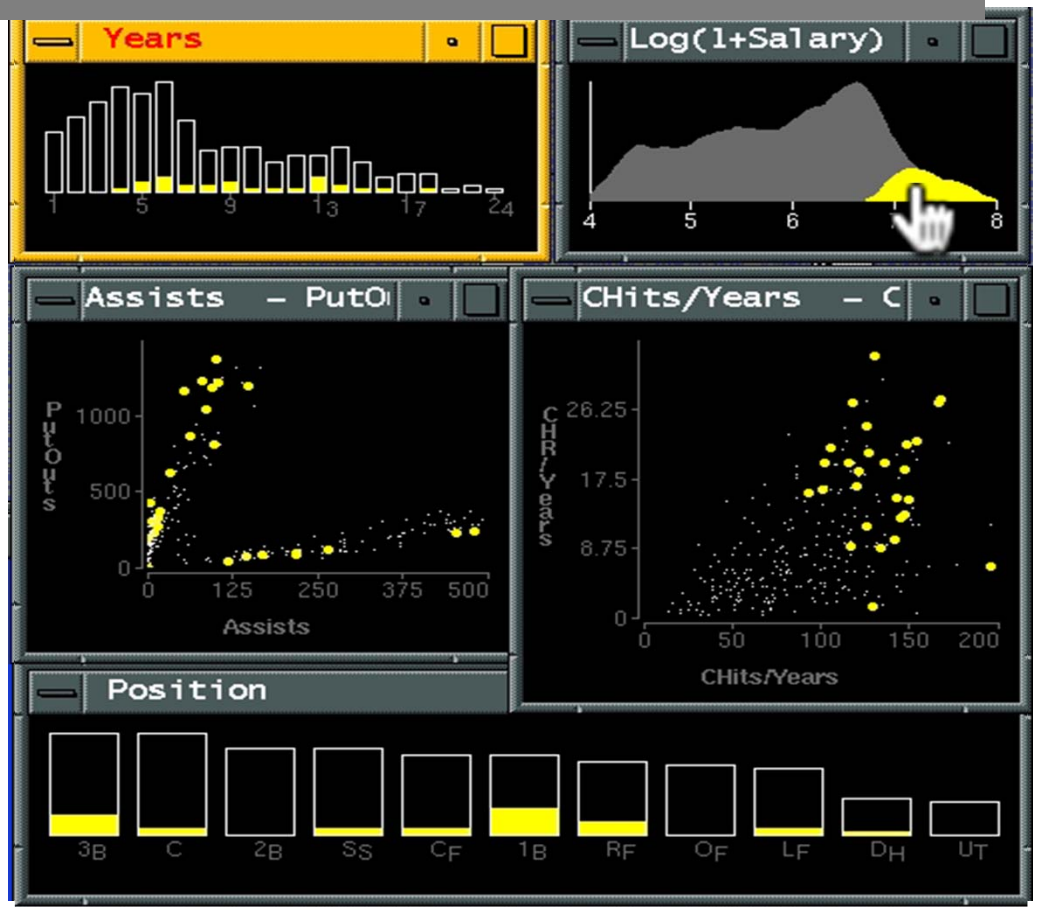


BRUSHING AND LINKING

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 AND LINKING

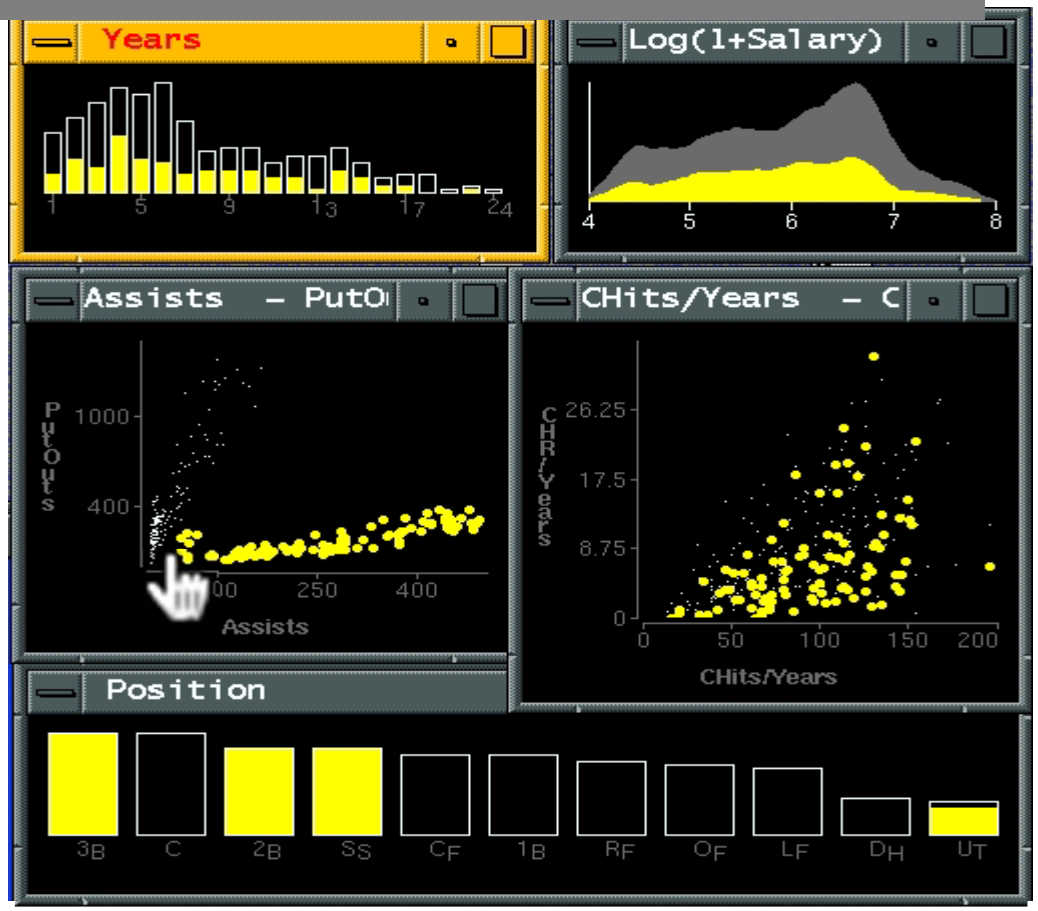
HOW LONG IN MAJORS

SALARIES

ASSISTS VS PUTOUTS (FIELDING ABILITY)

HOME RUNS VS HITS (BATTING ABILITY)

DISTRIBUTION OF POSITIONS PLAYED



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

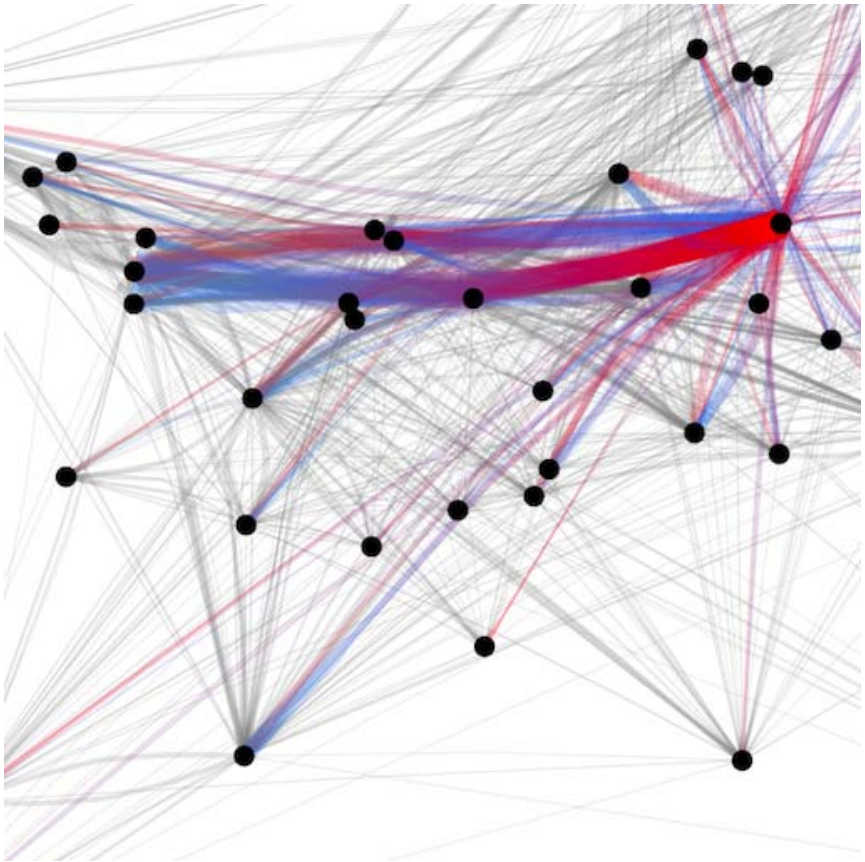
Input: mouse, touch, keyboard, speech,...

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

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

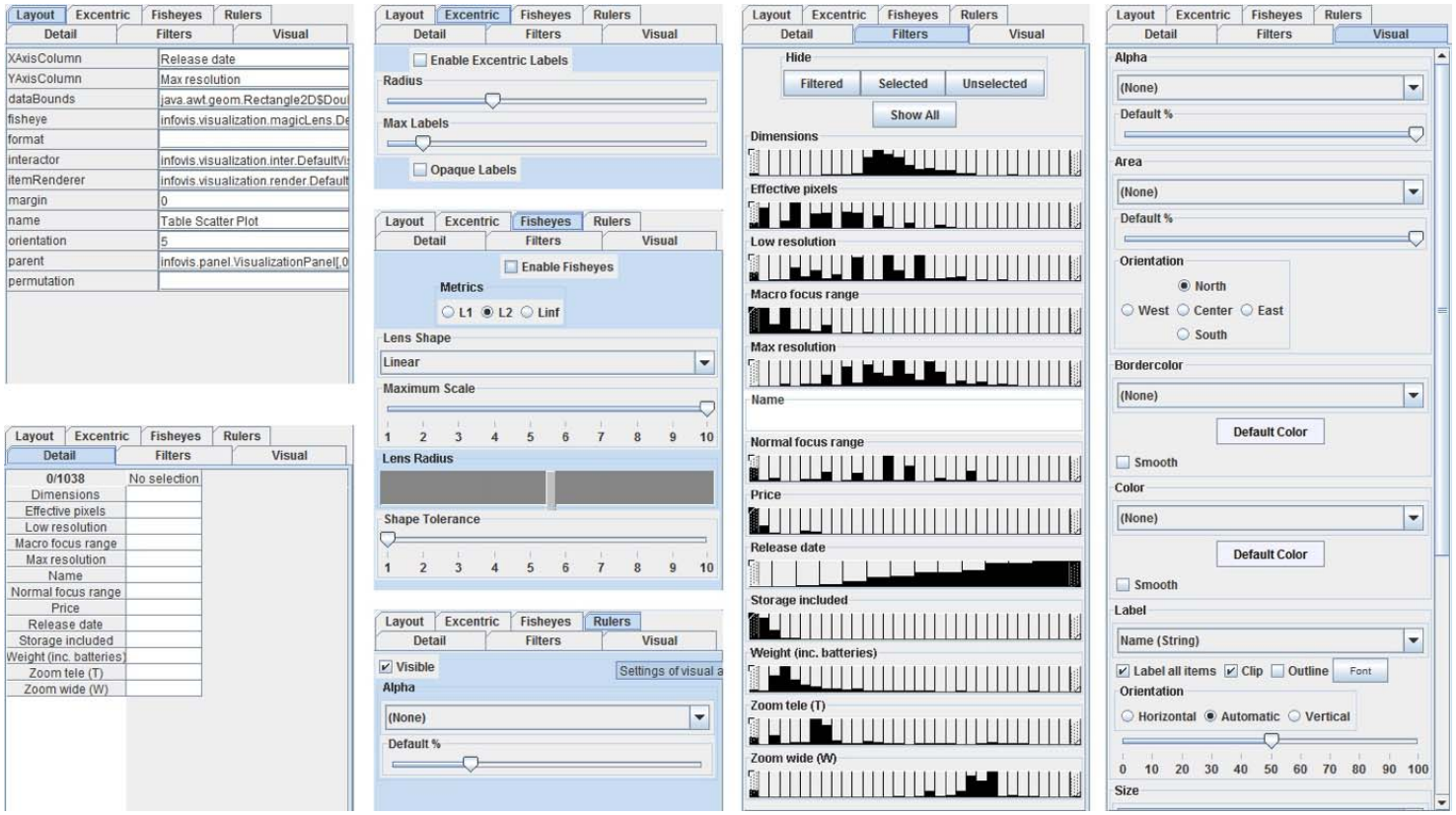
PITFALLS

#1 - Interaction has a cost



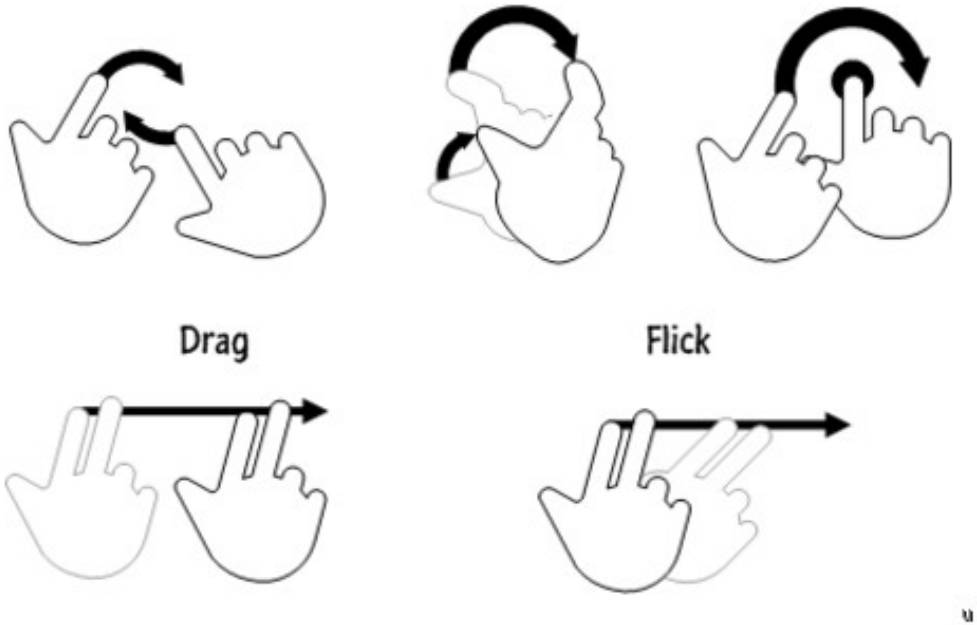
PITFALLS

#2 - Controls take screen real-estate



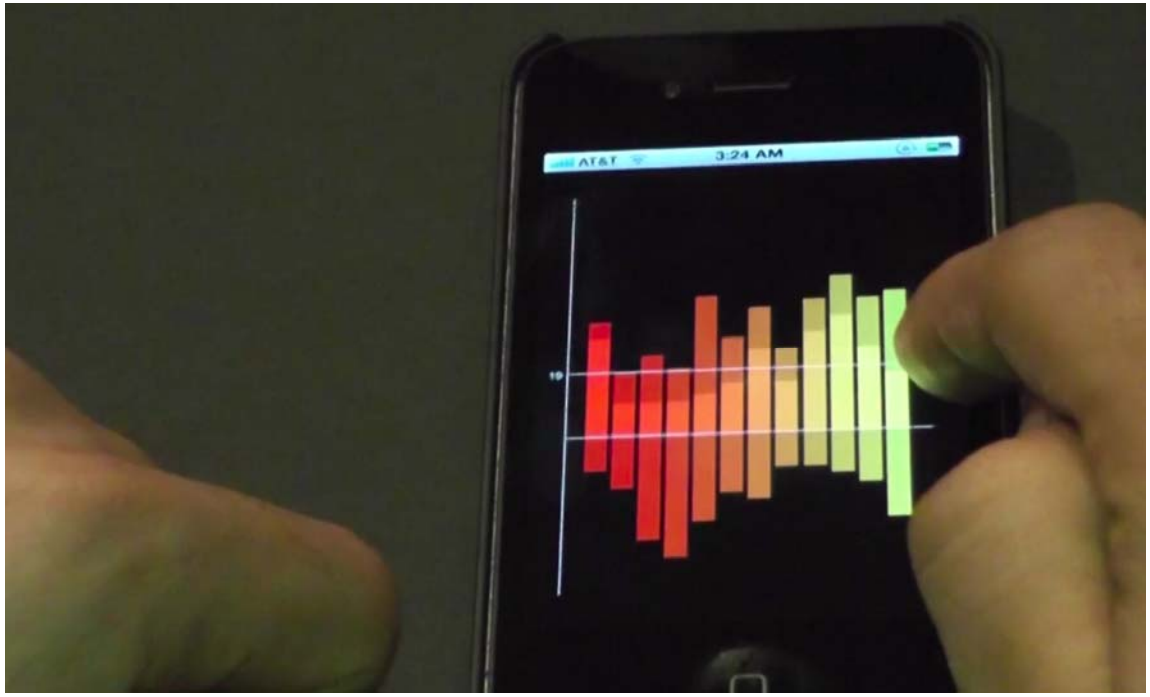
PITFALLS

#3 - Few techniques are self-explanatory



GOING BEYOND THE DESKTOP

TOUCH DEVICES



Sadana and Stasko, 2013

TABLETOP

Isenberg and Carpendale, 2008

WALL-SIZED DISPLAYS

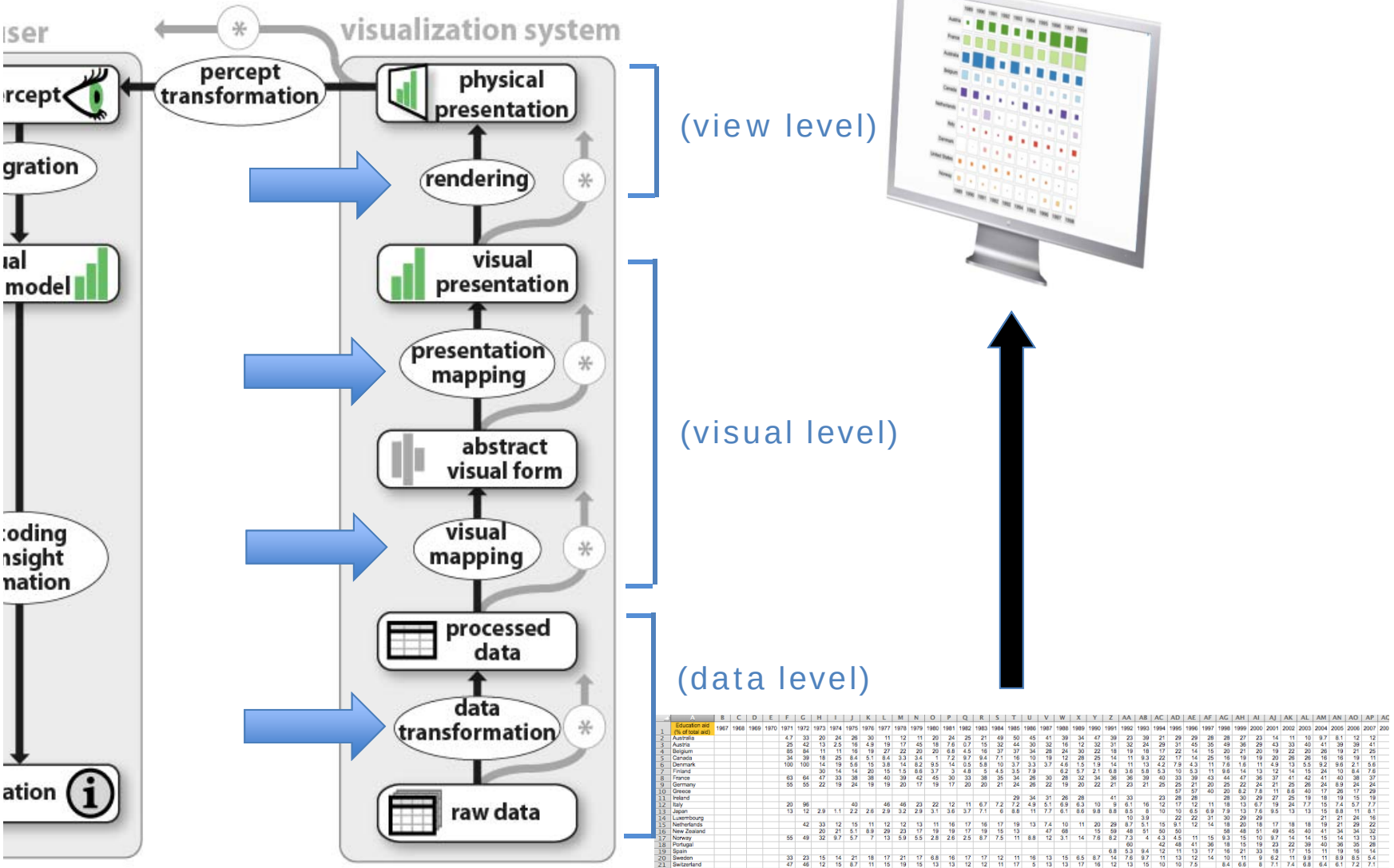
[Jansen et al., Tangible Remote Controller for Wall-sized Displays. CHI'12]

AR OR VR ENVIRONMENTS

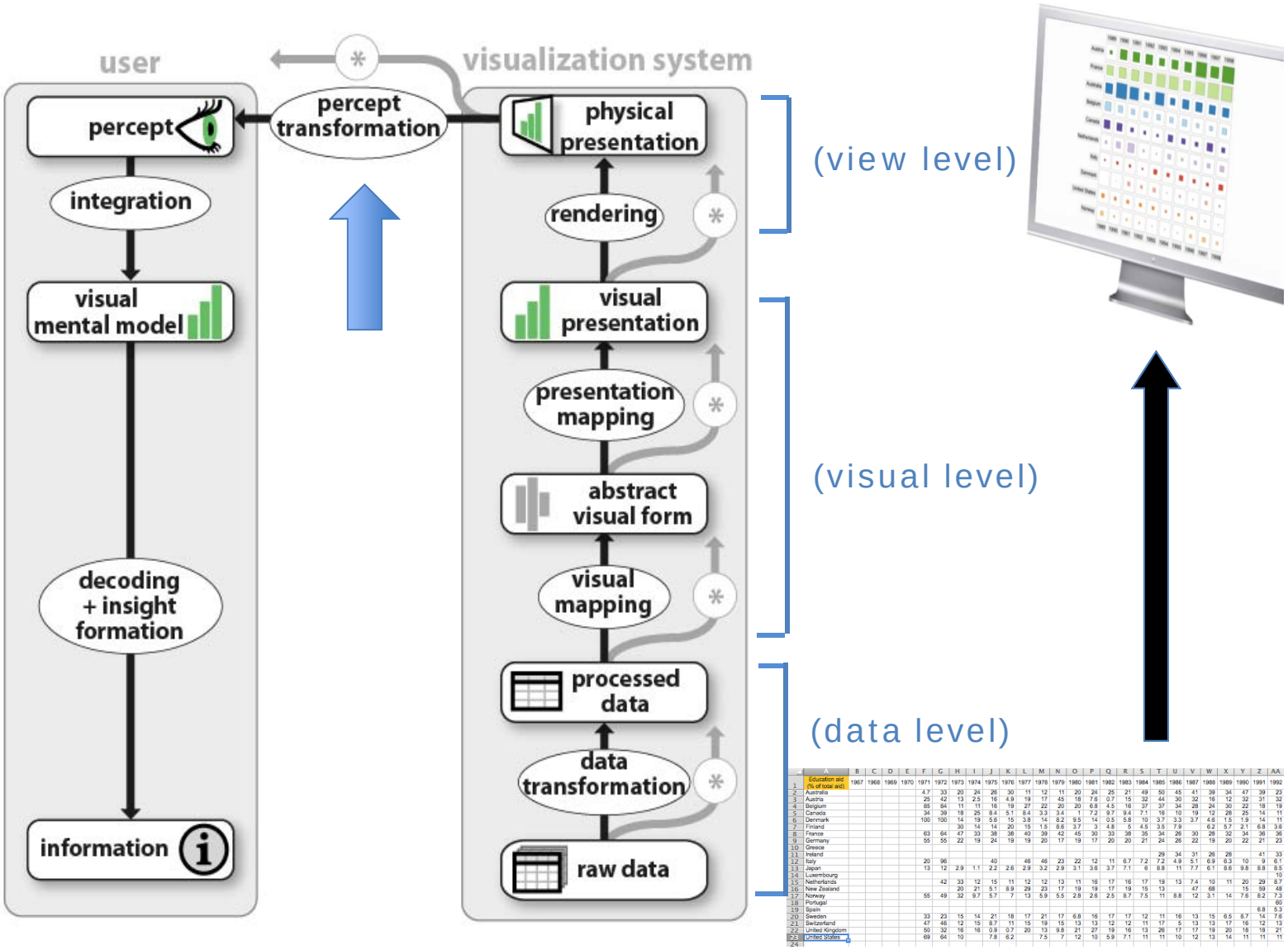
Büschel et al. 2021

DIFFERENCES TO DESKTOPS

- size of the display
  - perceptual differences (smaller, larger, perspective)
- input technique
  - touch vs. mouse; fat finger
  - 3d location input, proxemic interaction
  - large displays, AR: carried input when positioned distant from display (phone, tablet, special HW)

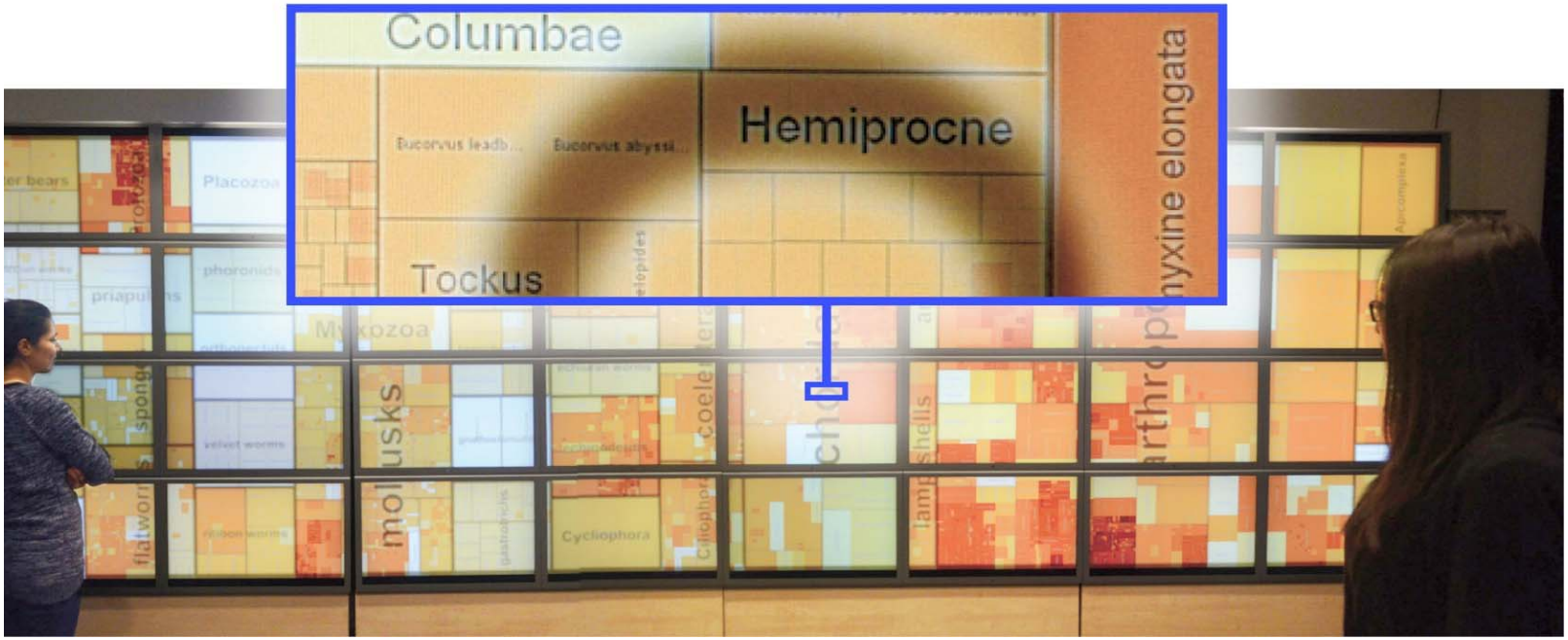


Jansen and Dragicevic 2013 (www.aviz.fr/beyond)

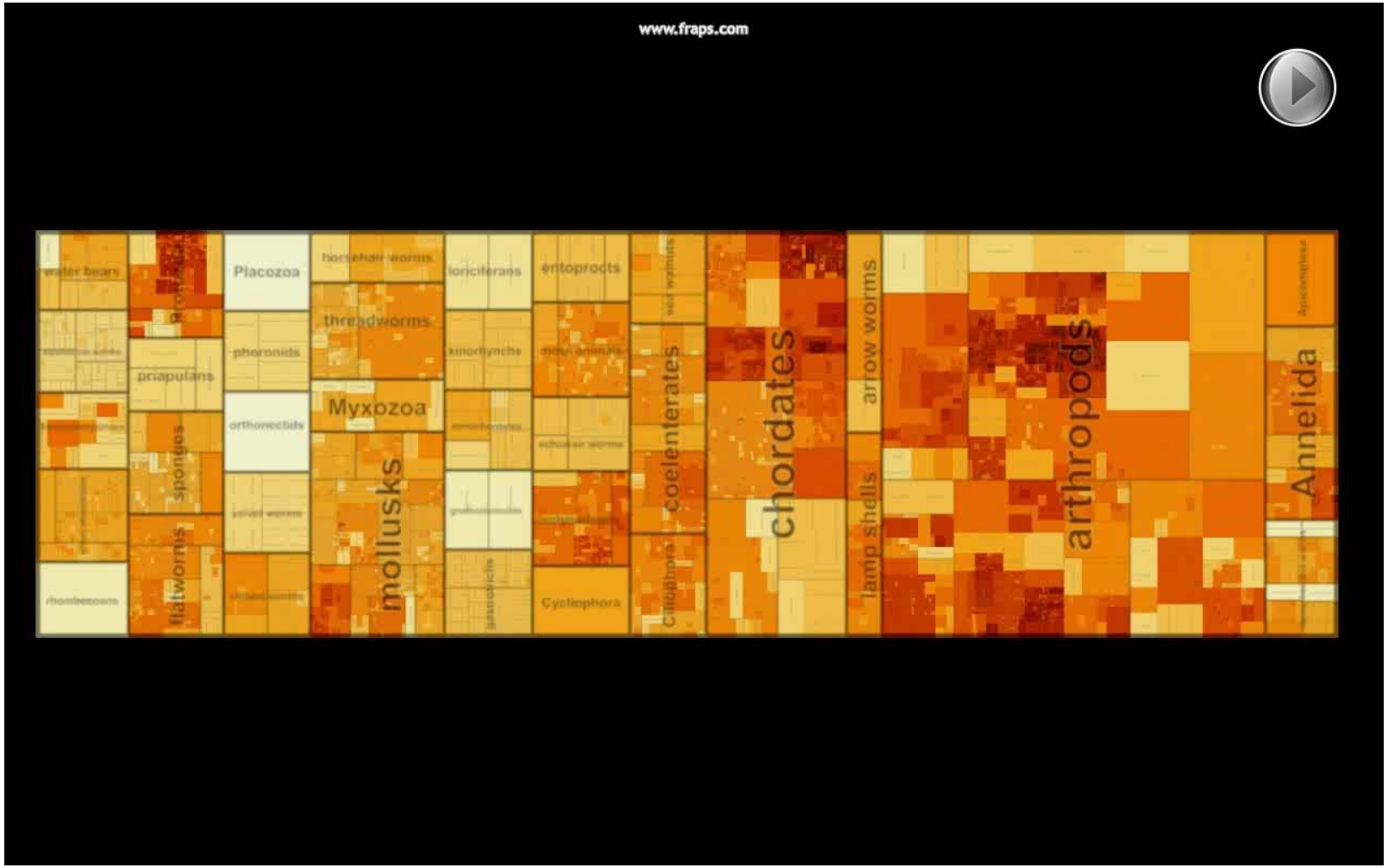


Jansen and Dragicevic 2013 (www.aviz.fr/beyond)

INTERACTION “W/O” INPUT

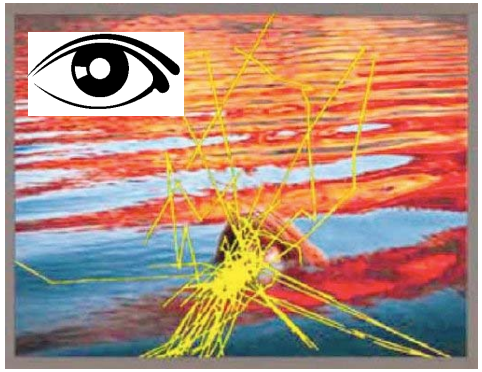


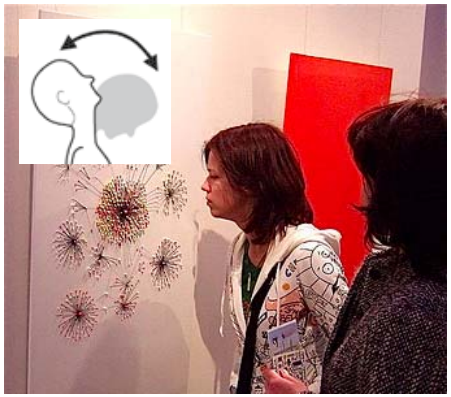
[Hybrid Images for Large Viewing Environments, InfoVis’13]



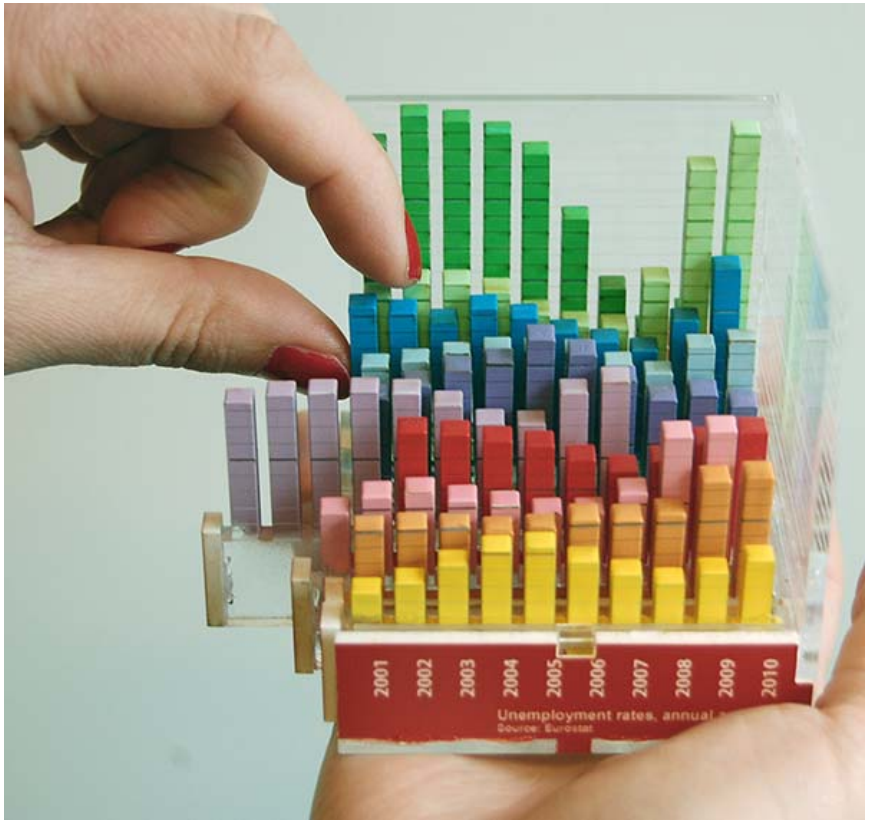
[Hybrid Images for Large Viewing Environments, InfoVis'13]

INTERACTION WITH THE PHYSICAL WORLD

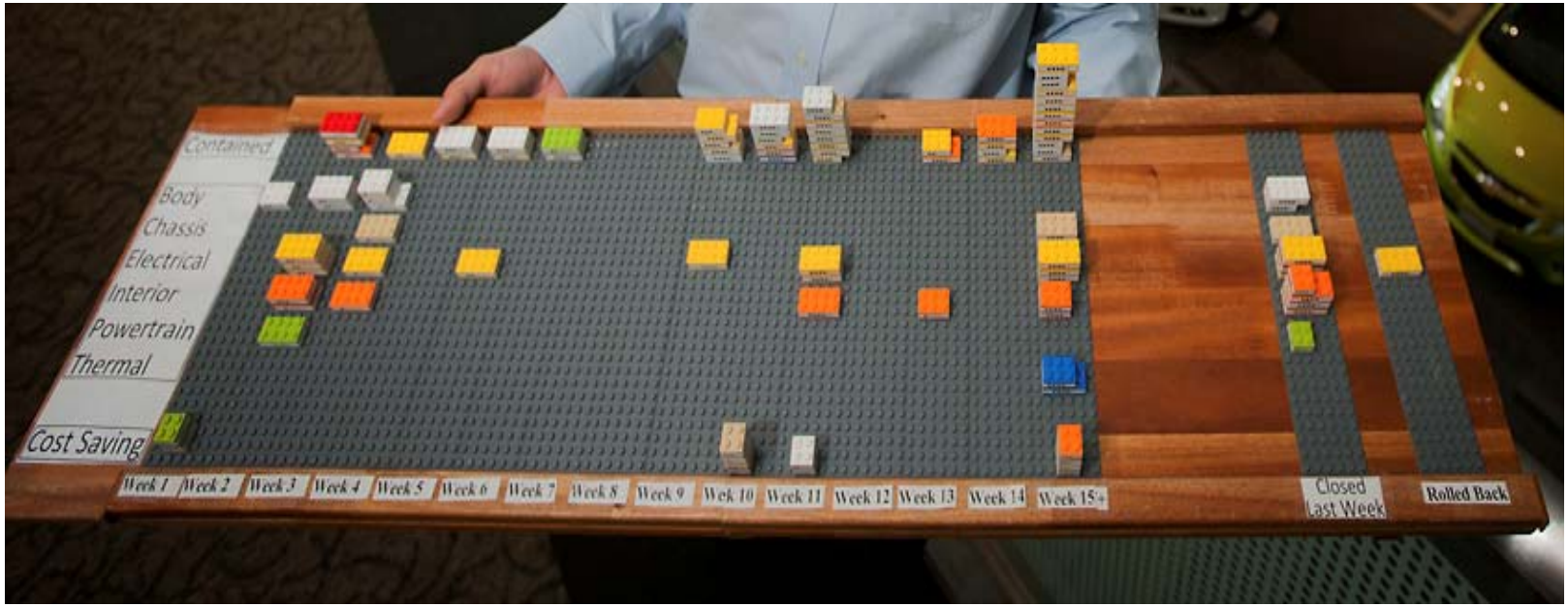




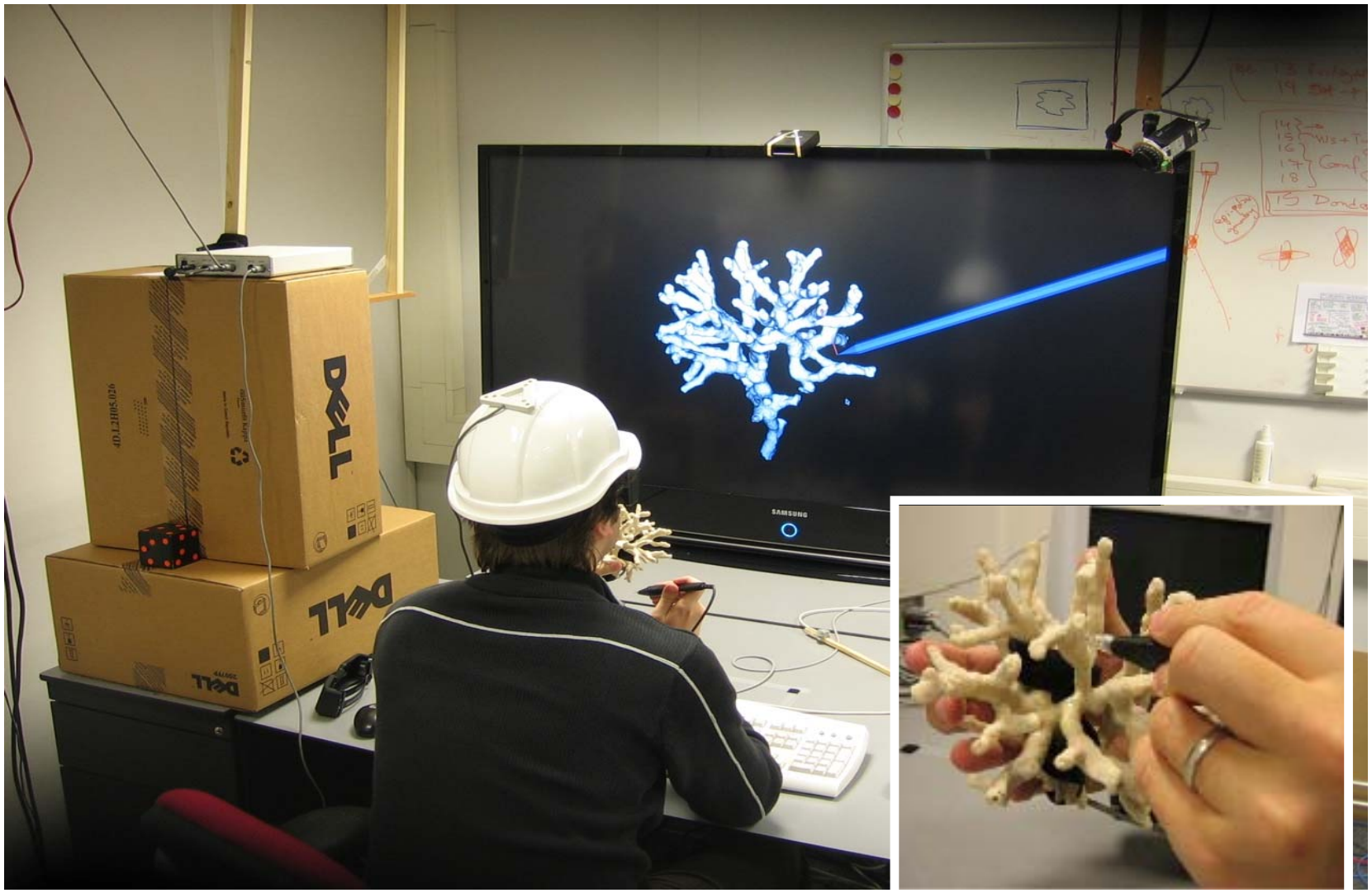
PHYSICAL VISUALIZATIONS



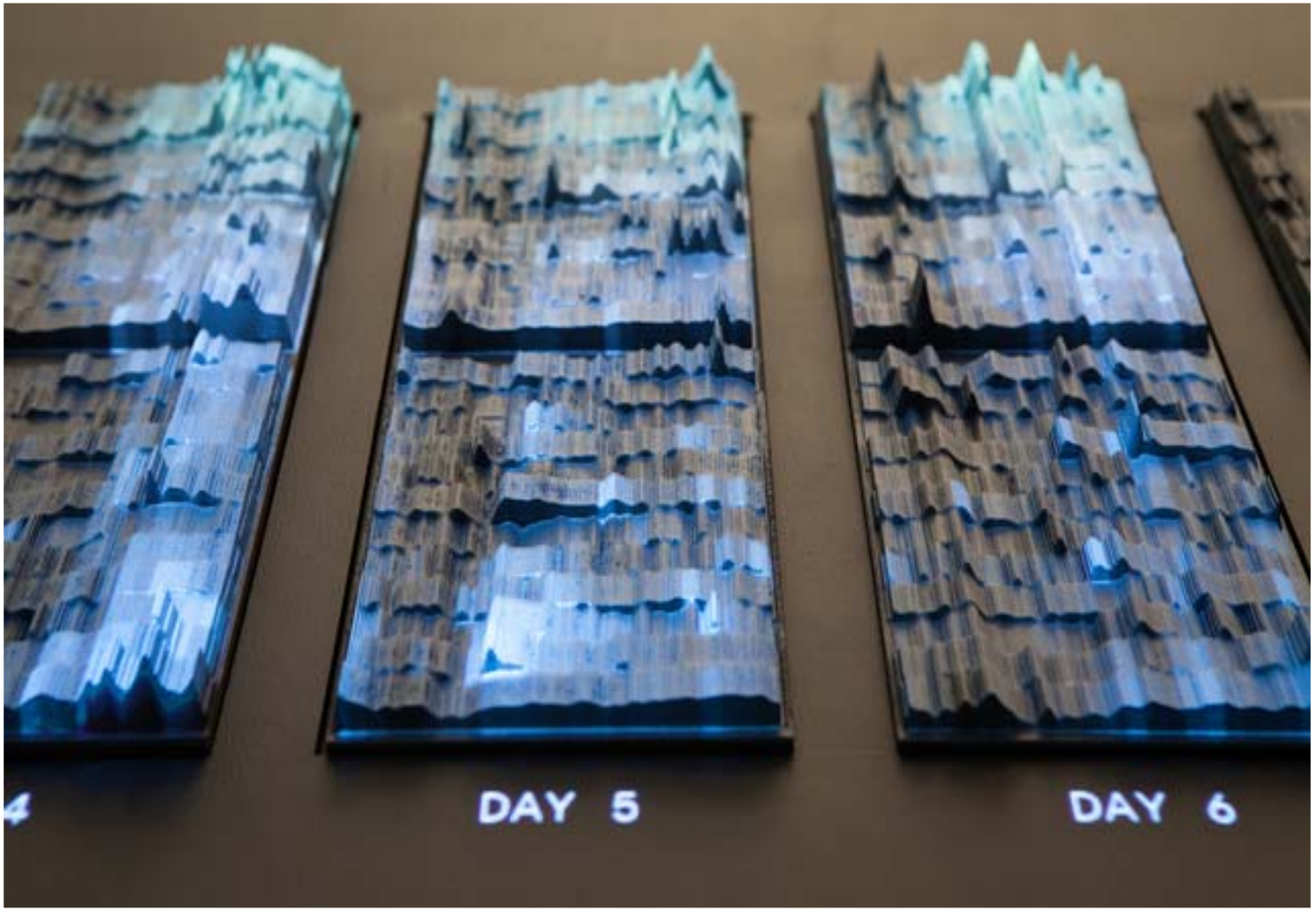
tinyurl.com/physvis



[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, https://nand.io/projects/emoto]

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

Relief (Leithinger et al, 2009)

SUMMARY

- interaction $\in$ visualization
- interaction can affect all parts of vis pipeline
- interaction taxonomies: What? Why? How?
- Shneiderman's mantra: overview, zoom, filter, details on demand
- interaction intents: select, explore, filter, reconfigure, encode, abstract/elaborate, connect

SUMMARY

- essential interaction concepts:
  - direct manipulation
  - semantic zooming
  - focus + context
  - brushing and linking
- interaction pitfalls
- interaction (& visualization) beyond the desktop