Connecting The Dots
Showing Relationships in Data and Beyond

Marc Streit[1], Hans-Jörg Schulz[2], Alexander Lex[3]

VisWeek Tutorial 2012

1. Johannes Kepler University Linz, Austria
2. University of Rostock, Germany
3. Harvard School of Engineering and Applied Sciences, Cambridge, MA, USA

Motivation

Common task in data analysis and many kinds of information intensive work:

> Compare, evaluate and interpret
> **related pieces of information**

LET‘S START WITH A LITTLE GAME…

Do you know this guy?

Wally 

Walter  

Waldo 

Holger 

…

http://www.classicmedia.tv/pr/whereswaldo/

http://www.findwaldo.com/fankit/graphics/

http://tomsvision.wordpress.com/tag/wheres-wally/

In case you wanna have a tattoo…

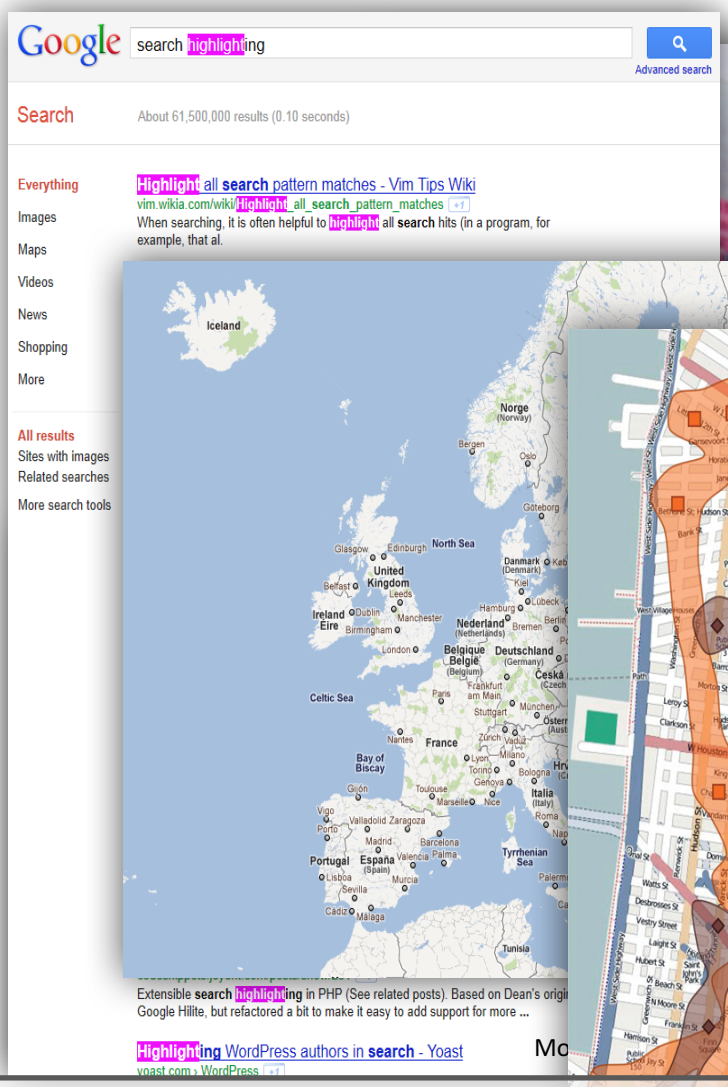
Spot the differences

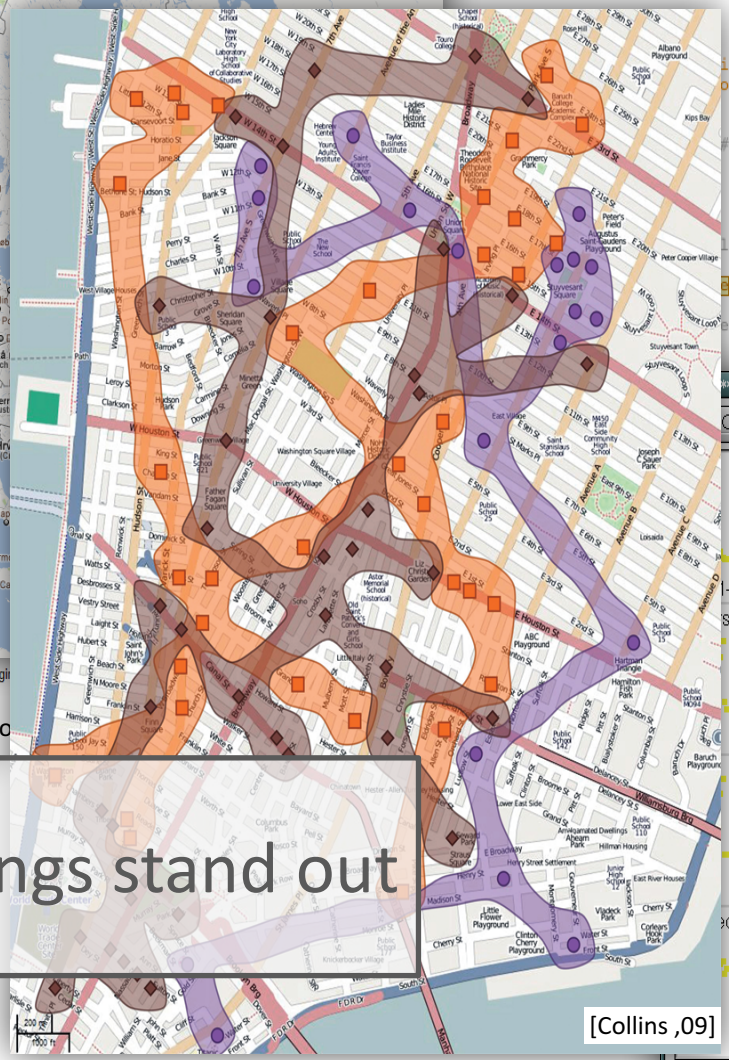
Comparison Task

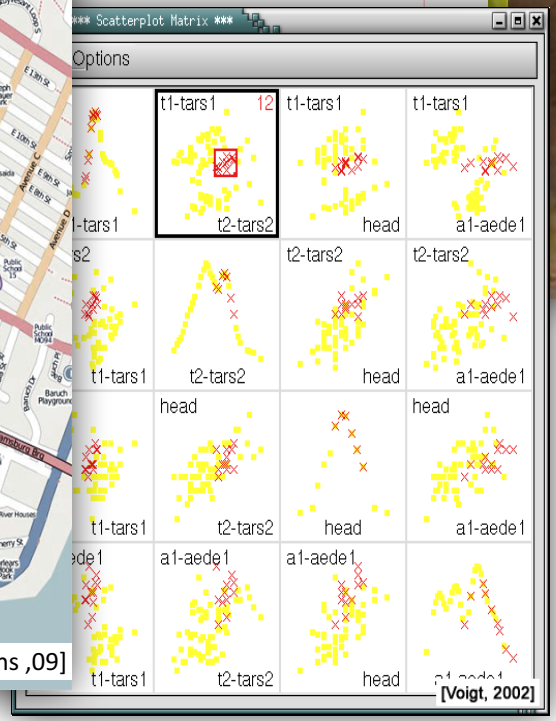
What‘s the Problem?

Finding, comparing and interpreting information is error-prone and tedious

→ Support human







Make things stand out

Overview

PART 1: What to link?

Defining Common Relations

PART 2: How to link?

Representing Relation on View Level

PART 3: When to link?

Cases in which Linking is Beneficial

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Part I: What to Link?

1. **Entities/Elements (what is linked?)**
   – data items, clusters, datasets…
2. **Cardinality (how many are linked?)**
   – binary or n-ary (n>2)
3. **Domain (where do the links stem from?)**
   – data, view, interaction

About Ourselves: Hans-Jörg Schulz

MSc+PhD in Rostock (Topic: Graph Visualization)

Currently researcher at the University of Rostock working on visualization of heterogeneous data (funded by the German Research Foundation DFG)

What he does when the DFG is not looking:

- tree visualization survey: http://treevis.net
- visualization design spaces
- visualization for the biological domain

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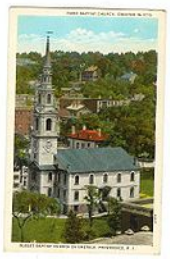
pedia.org/wiki/Providence,_Rhode_Island



First Baptist Church in America, founded 1638, present building occupied in 1776, is the oldest Baptist congregation in America

The area which is now Providence was first settled in June 1636 by Roger Williams, and was one of the original Thirteen Colonies of the United States.[10] Although the west bank of the Providence River was later claimed by both the English and the Dutch, the actual inhabitants and true masters of the region were the Pokanoket Tribe of the Wampanoag Nation led by Massasoit Ousamequin.[11] Williams secured permission to settle from the Pokanoket and gave the city its present name.[12] Williams' Providence soon became a refuge for persecuted religious dissenters, as he himself had been exiled from Massachusetts.[13] Providence's growth would be slow during the next quarter-century—the subsuming of its territory into surrounding towns, difficulty of farming the land, and differing of local traditions and land conflicts all slowed development.[13]

In the mid-1770s, the British government levied taxes that impeded Providence's maritime, fishing and agricultural industries, the mainstay of the city's economy. One example was the Sugar Act, which was a tax levied against Providence's distilleries that adversely affected its trade in rum and slaves. These taxes caused Providence to join the other colonies in renouncing allegiance to the British Crown. In response to enforcement of unpopular trade laws, Providence residents spilled the first blood of the American Revolution in the notorious Gaspée Affair of 1772.[13]

Providence in the mid-nineteenth century

Though during the Revolutionary War the city escaped enemy occupation, the capture of nearby Newport disrupted industry and kept the population on alert. Troops were quartered for various campaigns and Brown University's University Hall was used as a barracks and military hospital.[13]

NPS map of the W3R Route

After departing from Newport, French troops sent by King Louis XVI and commanded by the Comte de Rochambeau passed through Providence on their way to join the attack against British forces. The march from Newport to Providence was the beginning of a campaign led jointly by General George Washington in a decisive march that ended with the defeat of General Cornwallis in the Siege of Yorktown at Yorktown, Virginia and the Battle of the Chesapeake.

Following the war, Providence was the country's ninth-largest city.[b][13] with 7,614 people. The economy shifted from maritime endeavors to manufacturing, particularly machinery, tools, silverware, jewelry and textiles. By the turn of the twentieth century, Providence boasted some of the largest manufacturing plants in the country, including Brown & Sharpe

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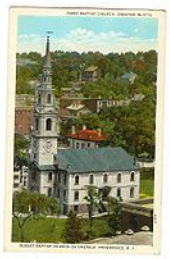

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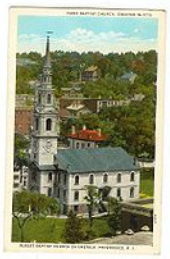

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Blinking

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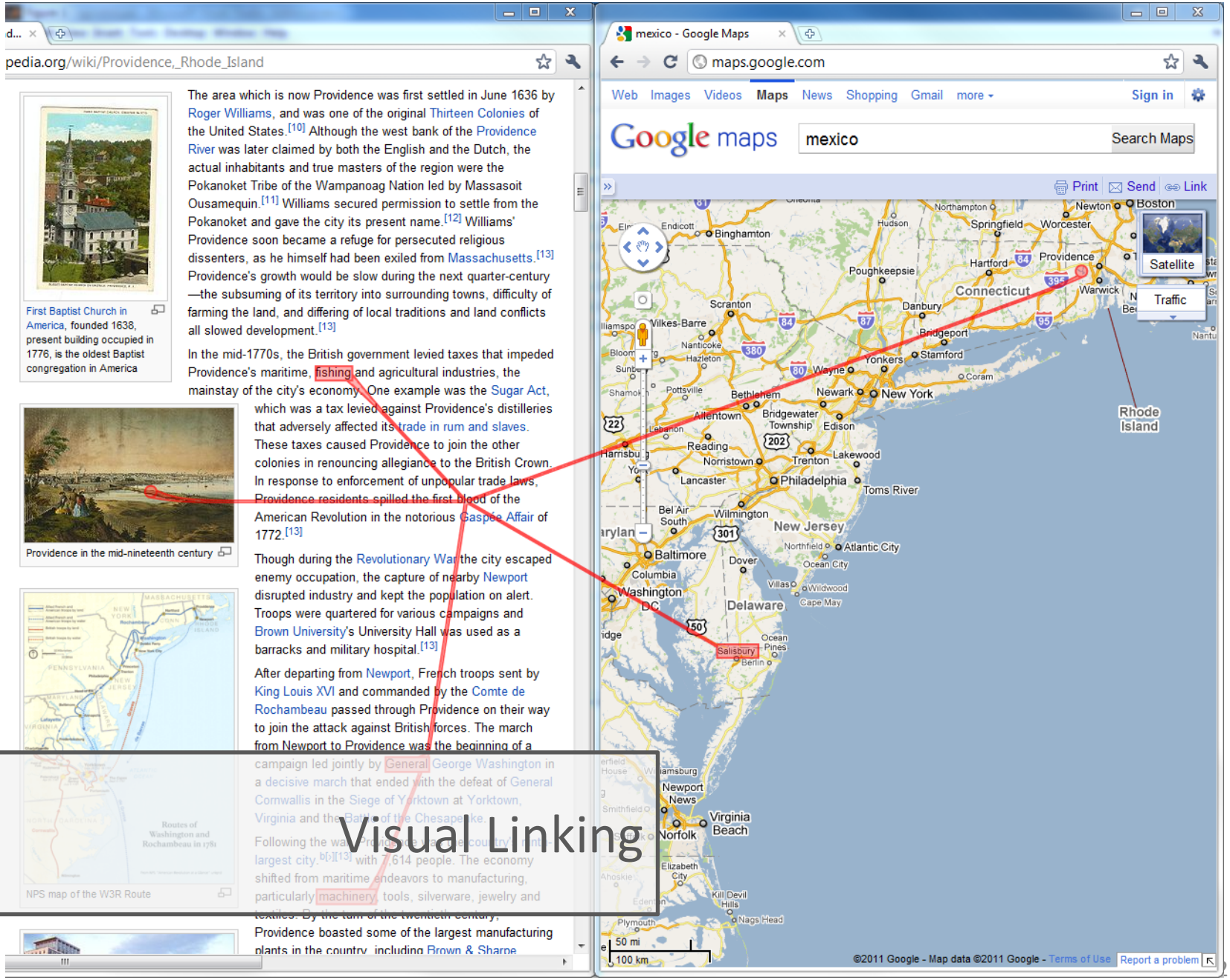
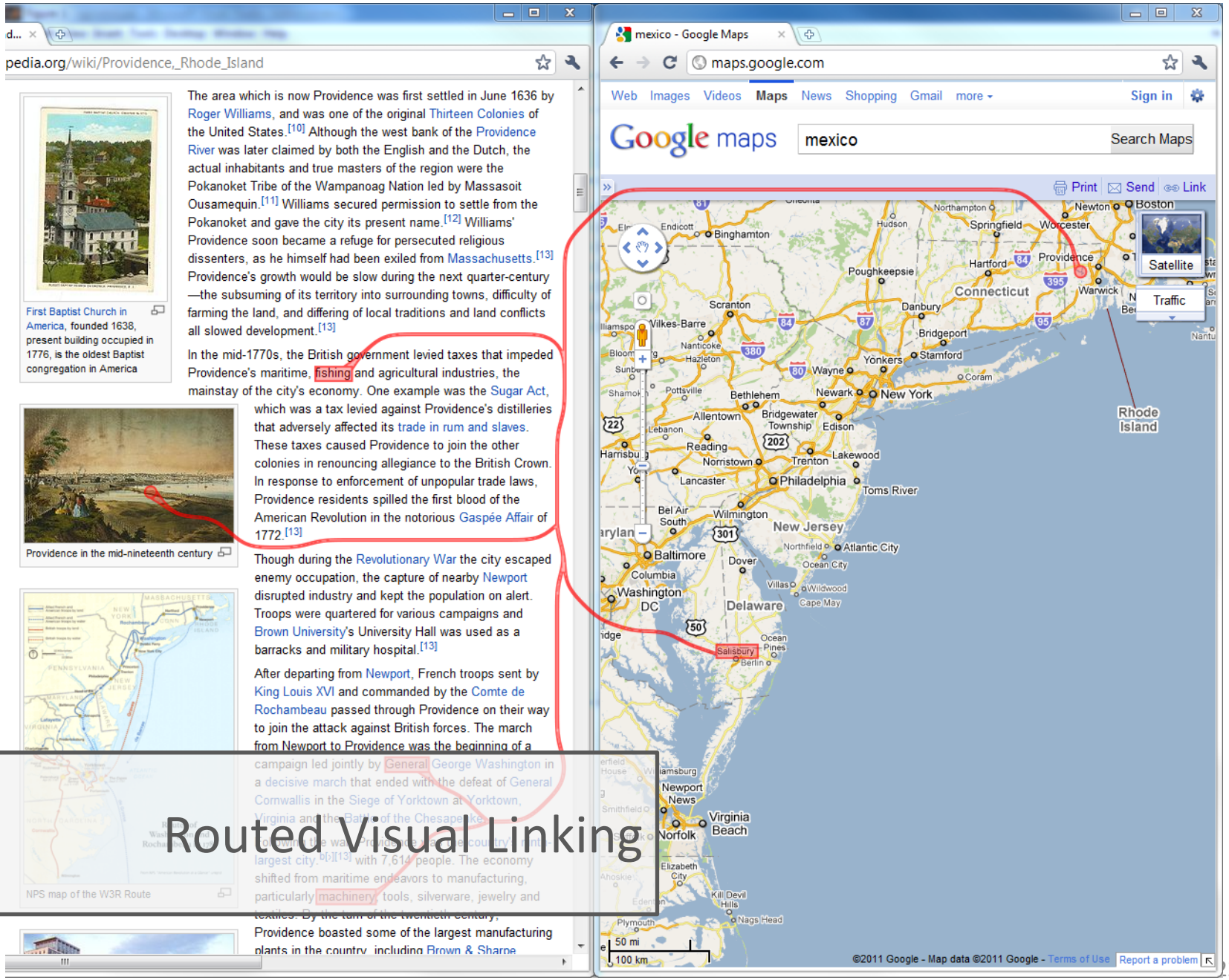


Visual Linking



Routed Visual Linking

Part II: How to Link?

1. Similarity (Gestalt principle, Wertheimer 1923)
2. Proximity (Gestalt principle, Wertheimer 1923)
3. Connectedness (Palmer&Rock 1994)

About Ourselves: Alex Lex

PhD from Graz University of Technology

Post-doctoral Researcher at VCG@Harvard

Research Topics:

- Visualizations with applications in molecular biology
- Visual linking

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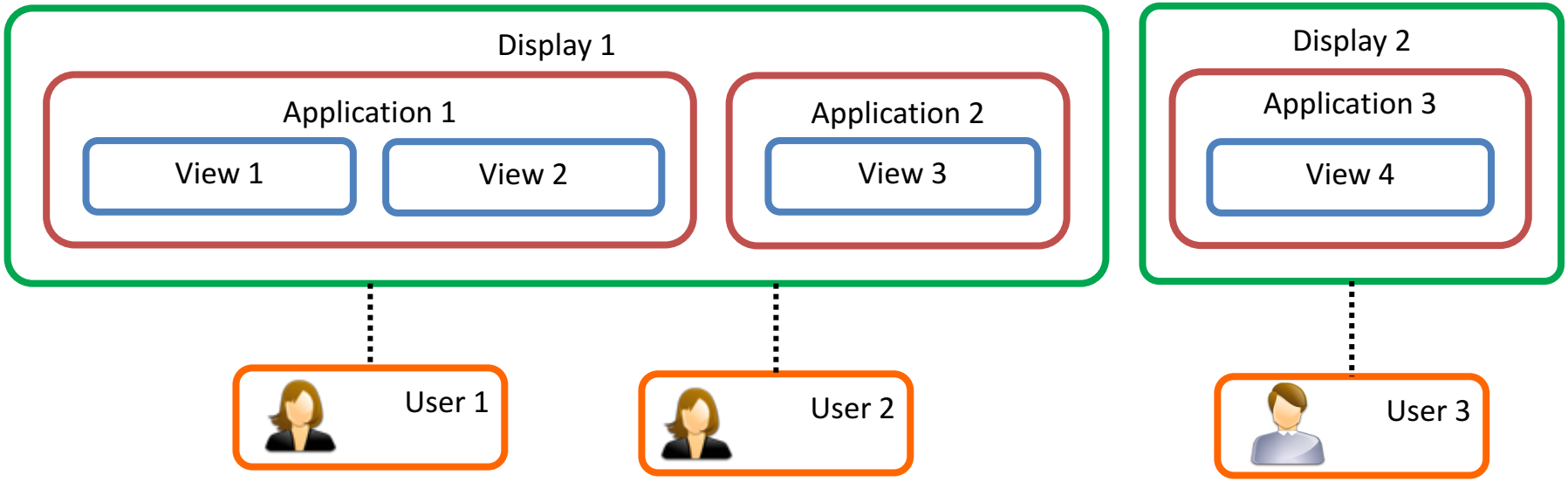
Cases in which Linking is Beneficial

Part III: When to link?



About Ourselves: Marc Streit

PhD from Graz University of Technology

Assistant Professor at Johannes Kepler University Linz

Visiting Researcher at Harvard Medical School

Research Topics:

- Visual Analysis of Heterogeneous Data
  Focus: Biomolecular Data
- Visual Linking
- Caleydo (www.caleydo.org)

Overview

PART 1: What to link?

Relations on Data, View, and Interaction Level

PART 2: How to link?

Representing Relation on View Level

PART 3: When to link?

Application Areas that Benefit from Linking

Schedule

2:15 – 3:15	Part I: What to Link?
3:15 – 3:40	Part II: How to Link?
3:40 – 4:15	Coffe break
4:15 – 4:50	Part II: How to Link?
4:50 – 5:50	Part III: When to link?

WHAT‘S YOUR BACKGROUND?

WHAT'S NEXT:
WHAT TO LINK BY HANSI

PART I:
WHAT TO LINK?

Speaker: Hans-Jörg Schulz

Linking What Belongs Together

Fulfilling the criterion of being expressive, we want to link "stuff" that it is

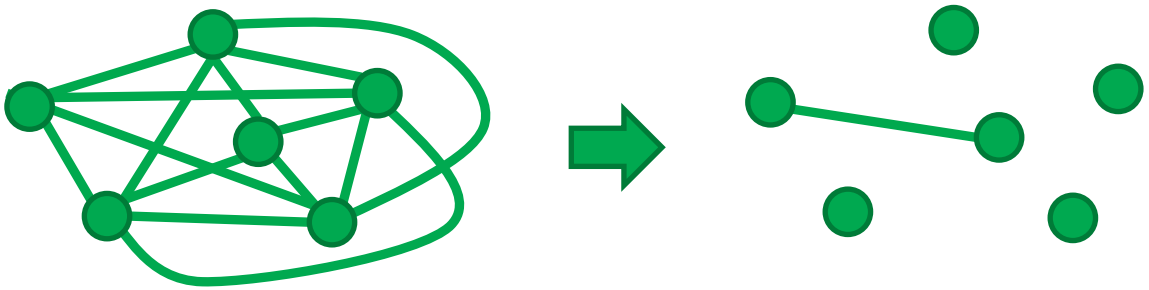
Related, Associated, Connected, Affiliated,…

"When two objects, qualities, classes, or attributes, viewed together by the mind, are seen under some connexion, that connexion is called a relation." —Augustus De Morgan (1858)

Linking What Belongs Together

Disclaimer: There appear to be cases in which the opposite is useful/done.

The EIRTEE*-Scenario



*Everything-Is-Related-To-Everything-Else

Relations

Definition:

Relations assign true/false to a *k*-tuple.

Aspects to consider:

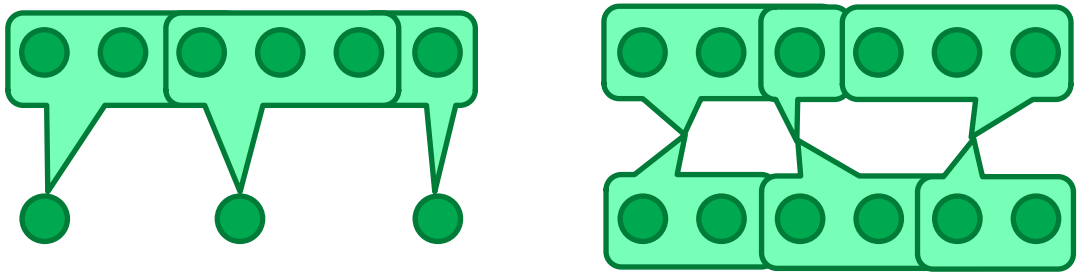
- the cardinality *k*
- the elements of the tuple
- the domain in which the relation is defined

Relations: Cardinality

Cases:

- *k=0*: tautology (TRUE) + contradiction (FALSE)
- *k=1*: unary (property)
- *k=2*: binary (is not necessarily a 1:1 relation!)

- *k>2*: n-ary with n>2



Relations: Elements

We define relations over (some part of) data.

We assume a simple hierarchical data model:

- $\{attrib_1,\ldots,attrib_i\}$ = data item
- $\{item_1,\ldots,item_j\}$ = data cluster
- $\{cluster_1,\ldots,cluster_k\}$ = data set
- $\{set_1,\ldots,set_l\}$ = data landscape

The tuple elements are drawn from these levels.

Relations: Elements

A set of elements is defined by a granularity and a scope.

While the granularity defines the level of detail of the relation, scope defines its extent.

For example, relations can be established between data clusters (granularity), which are drawn either from an individual data set or from multiple data sets of a data landscape (scope).

Relation Scope level > Relation Granularity

Relations: Domain

While the relation is defined over the data domain, it may stem from any of the following:

- Data Domain
- View Domain
- Interaction Domain

To identify the original Relationship Domain can sometimes be hard: Is data related because it is jointly interacted with, or is it jointly interacted with because it is related?

Relations put Together

- Cardinality
  - binary
  - n-ary with n>2
- Domain
  - Data
  - View
  - Interaction
- Elements = Granularity + Scope
  - Data attributes
  - Data items
  - Data clusters
  - Data sets
  - Data landscape

Relationships: Other Aspects

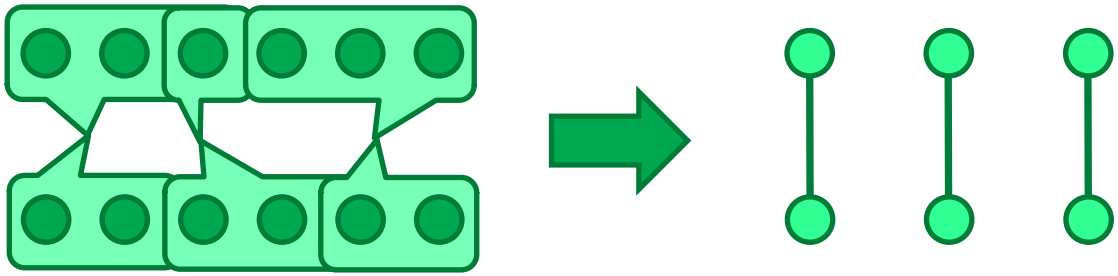
- Inherent vs. Derived
- Transitivity, Directionality, Strength
- Multiple relationships
  Example: coauthorship, citation, co-citation,…
- Running between different
  - Data tuples, Data tables, Data bases
  - Graphical objects, Views, Applications

Relationships: Interrelations

Under certain circumstances, it is possible to transform relationships. For example:

- n-ary relations on data item level
  → binary relations on data cluster level

(via the 1:n inclusion relation between items and cluster)



Relationships: Interrelations

Under certain circumstances, it is possible to transform relationships. For example:

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(via the 1:n inclusion relation between items and cluster)

- relations derived from interaction domain
  → relations from data domain, if interaction logs are considered as additional data set

Relationships: Examples

Example #	Description	Domain	Granularity	Scope	Cardinality
1	ARGOIs	Data	Attributes	Data set	binary
2	Graphs	Data	Items	Data set	binary
3	Hypergraphs	Data	Items	Data set	n-ary
4	Clustered Data	Data	Items	Data set	n-ary
5	Matchmaker /VisBricks	Data	Clusters	Data set	binary
6	StratomeX	Data	Clusters	Landscape	binary
7	StratomeX: DVI	Data	Data Sets	Landscape	binary
8	Spatial Treemaps	View	Attributes	Data set	binary
9	Stack‘n‘Flip	Interaction	Data sets	Landscape	binary

Example #1: ARGOIs

(Domain: Data, Elements: Attributes in Data Set, Cardinality: binary)

- Relationship: two attributes are related, iff they belong to the same data tuple
- Common visual representation: ParCoords

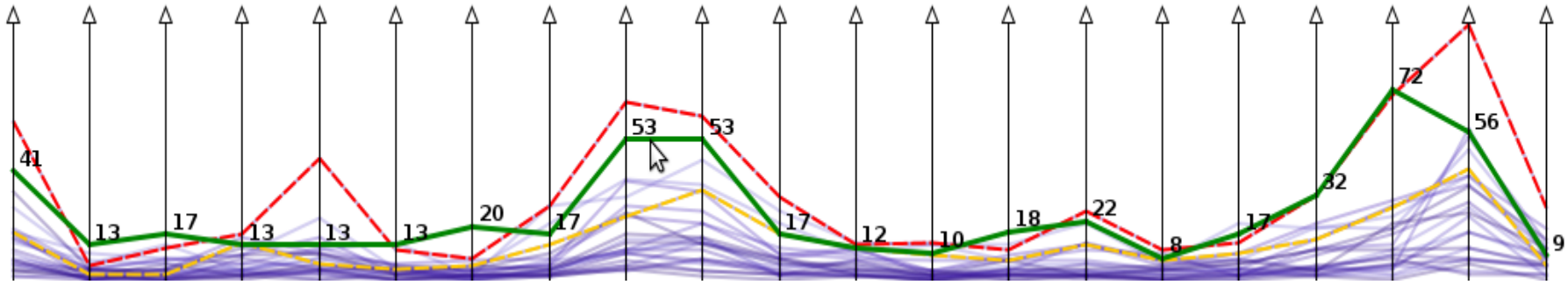
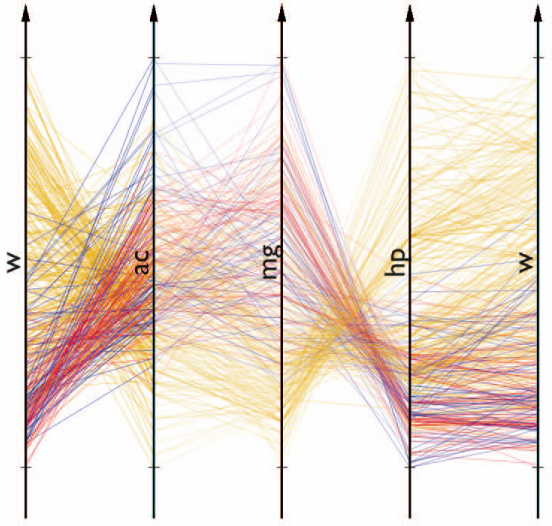


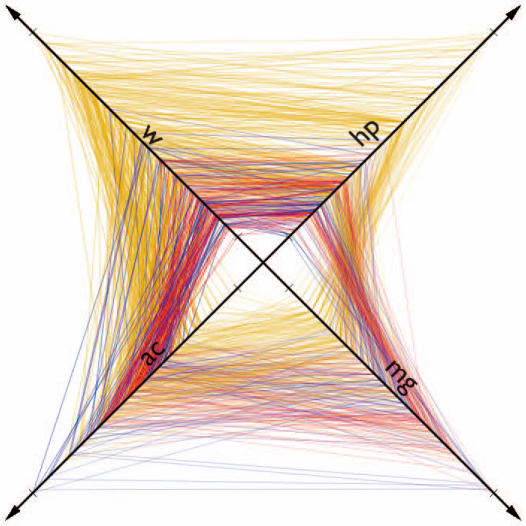
Image taken from Tominski+Schulz (2012)

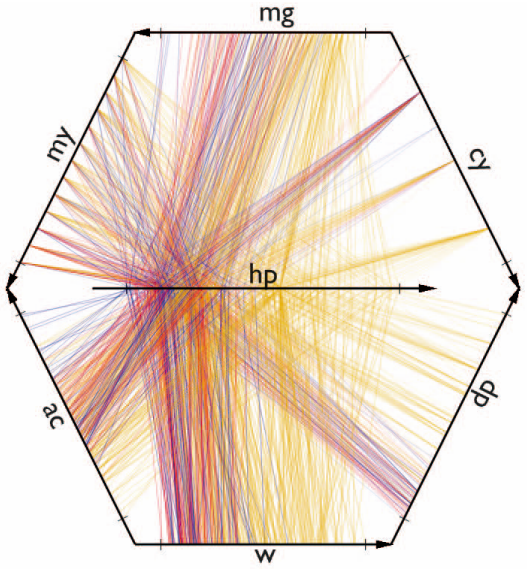
Example #1: ARGOIs

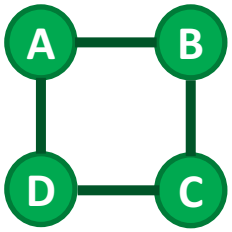
(Domain: Data, Elements: Attributes in Data Set, Cardinality: binary)

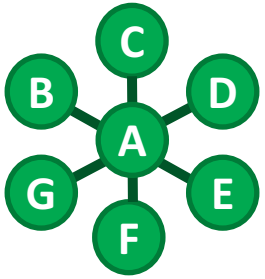
Generalization by Claessen+Wijk (2011):









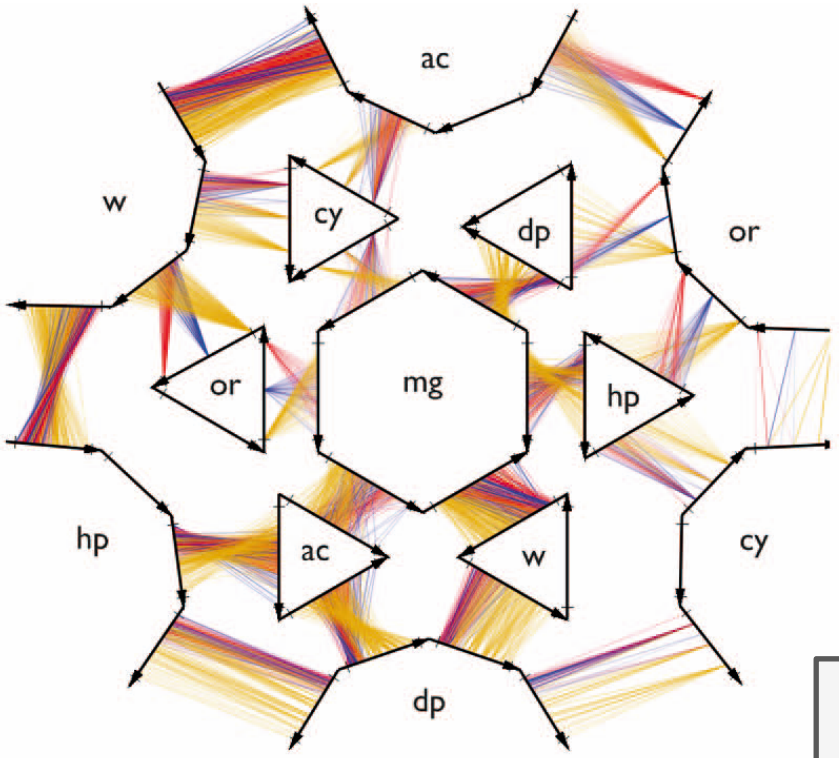


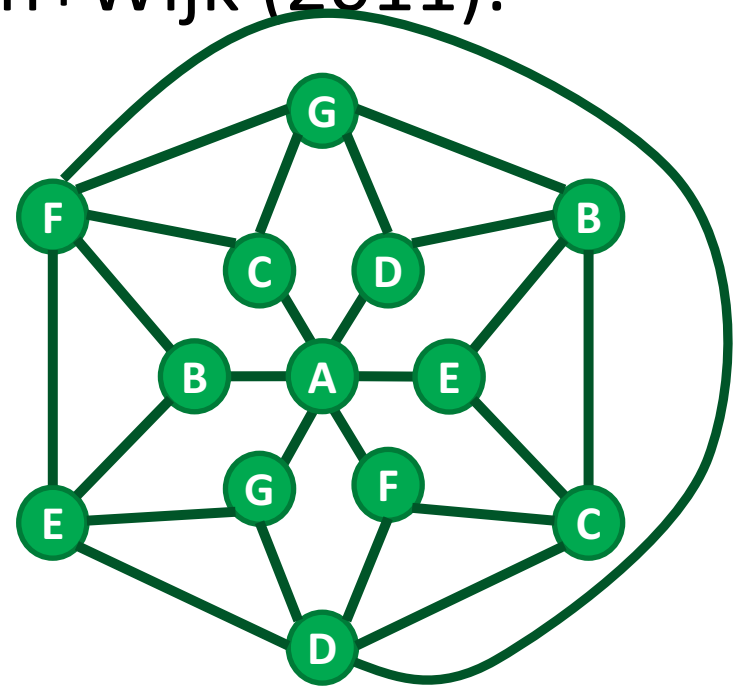
Attribute Relation Graphs of Interest ARGOIs

Example #1: ARGOIs

(Domain: Data, Elements: Attributes in Data Set, Cardinality: binary)

Generalization by Claessen+Wijk (2011):





Straight-line planarity required!

Example #2: Graphs

(Domain: Data, Elements: Items in Data Set, Cardinality: binary)

- Relationship: two items are related, iff there exists an edge between them
- Common visual representation: Node-Link-Diagram

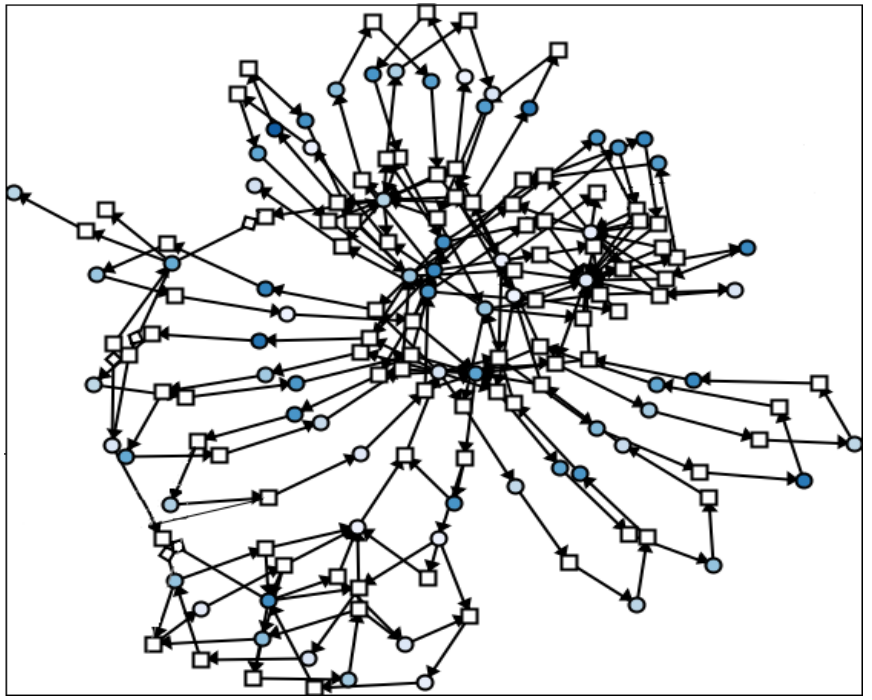


Image taken from
Hadlak, Schulz, Schumann (2011)

Example #3: Hypergraphs

(Domain: Data, Elements: Items in Data Set, Cardinality: n-ary)

- Relationship: a number of items are related, iff there exists a hyperedge between them
- Common visual representation: Euler-Diagram

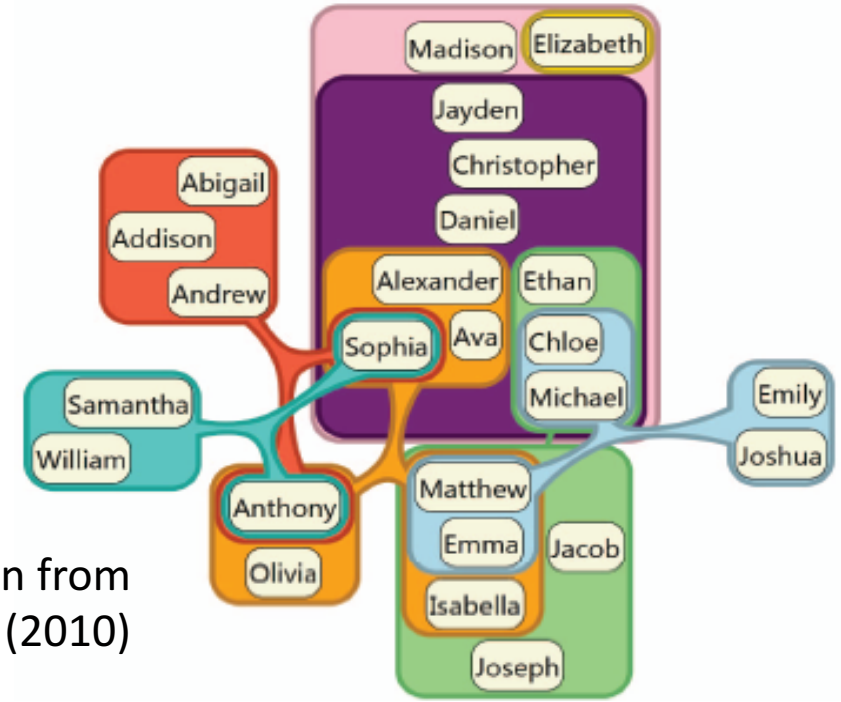
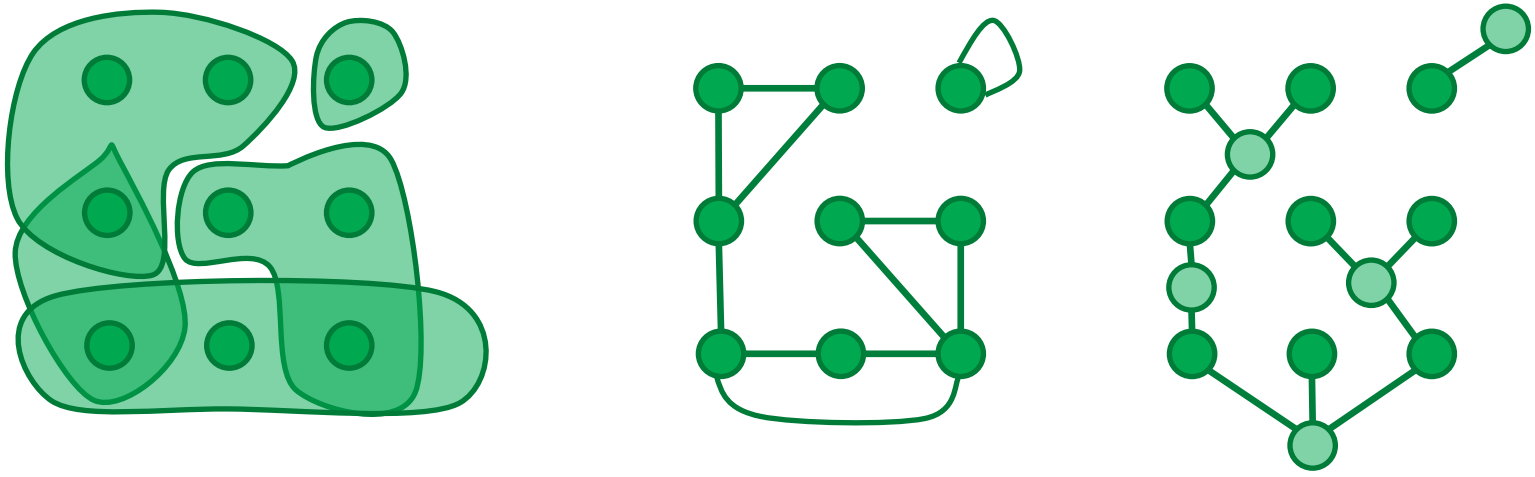


Image taken from Riche+Dwyer (2010)

Example #3: Hypergraphs

(Domain: Data, Elements: Items in Data Set, Cardinality: n-ary)

- Recall interrelationships
- Hypergraphs can be transformed into regular graphs



Example #4: Clustered Data

(Domain: Data, Elements: Items in Data Set, Cardinality: n-ary)

- Relationship: a number of items are related, iff they belong to the same cluster
- Common visual representation: Scatterplot

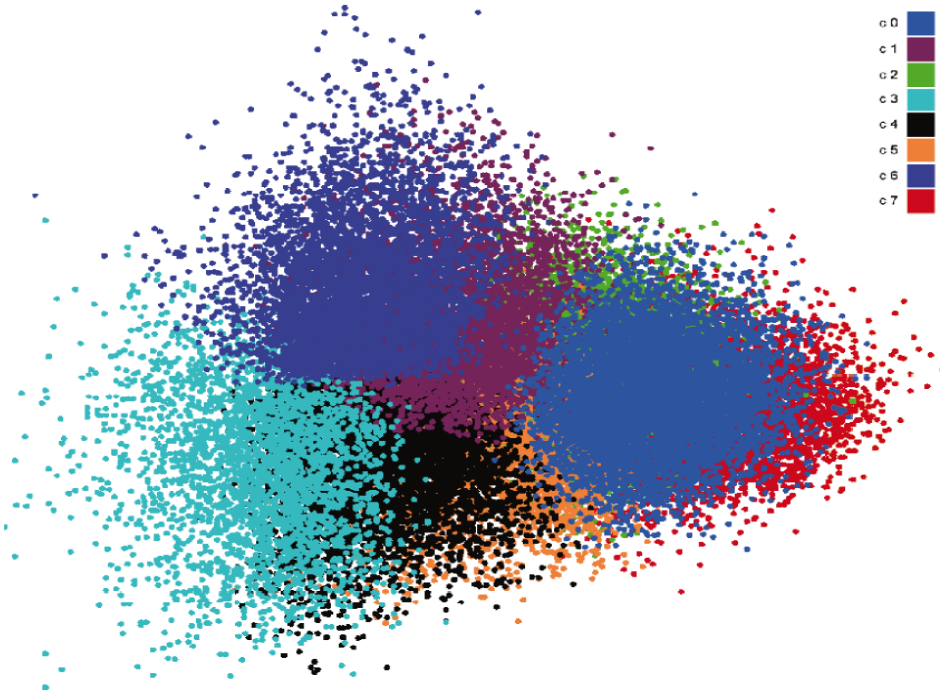


Image taken from Luboschik et al. (2010)

Example #4: Clustered Data

(Domain: Data, Elements: Items in Data Set, Cardinality: n-ary)

- *Clustering is the division of data into groups of similar objects.*
- **given:** a (dis-)similarity measure/matrix
  - n-dimensional, numerical data: Euclidean Distance
  - network data: Graph-theoretic Distance
  - strings of text: Edit Distance
- **sought:** a grouping of the data w.r.t. that measure

Example #4: Clustered Data

(Domain: Data, Elements: Items in Data Set, Cardinality: n-ary)

- What makes a good grouping?
  - **Compact:** elements in cluster are similar
  - **Separated:** clusters are different
  - **Balanced:** cluster membership is equally probable
  - **Parsimonious:** much fewer clusters than data objects

Source: Cosma Shalizi (2009)

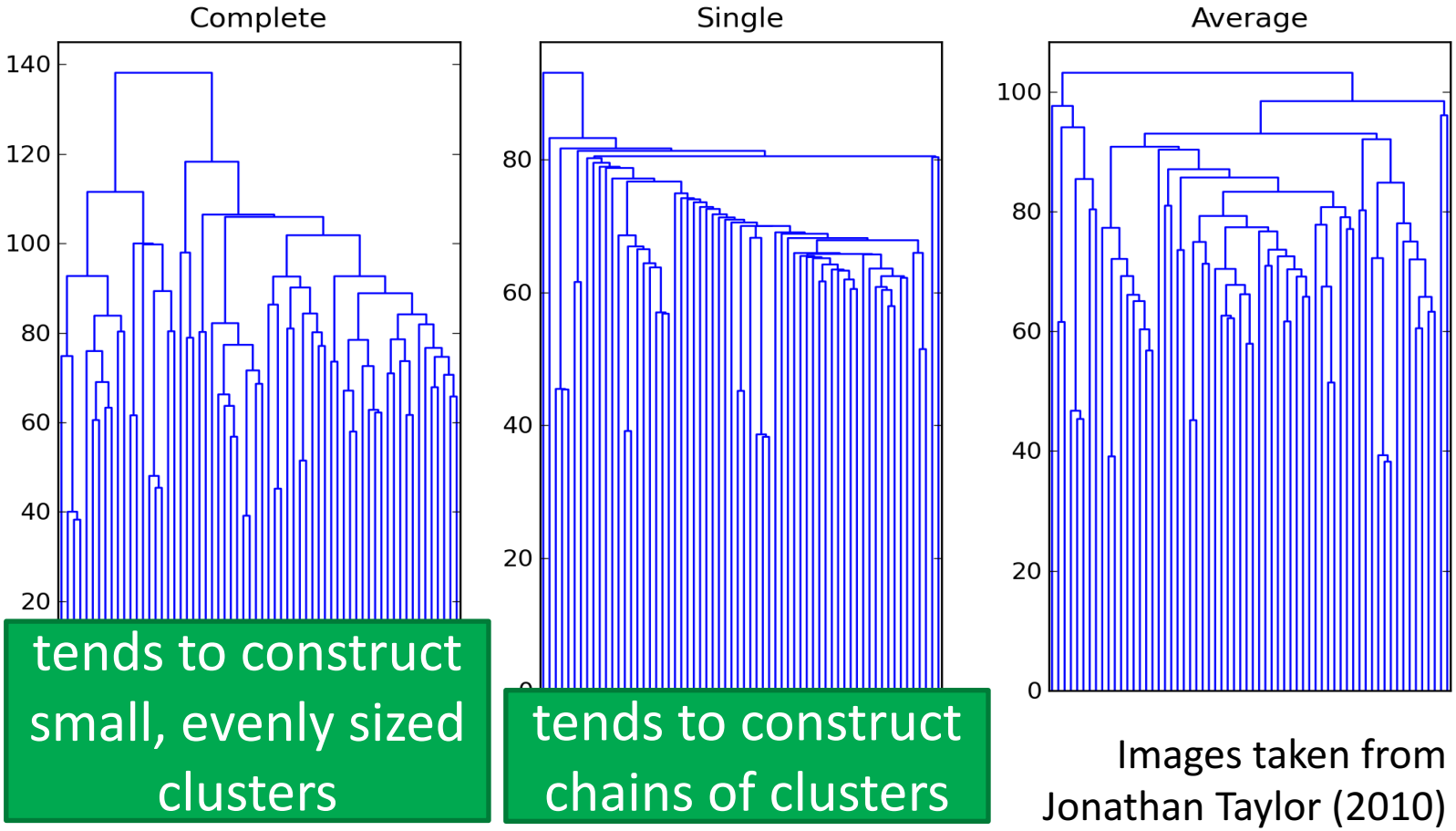
Example #4: Clustered Data

(Domain: Data, Elements: Items in Data Set, Cardinality: n-ary)

- Directionality of the clustering:
  - **Top-down:** divisive
  - **Bottom-up:** agglomerative
- Linkage metrics:
  - **Single Linkage:** nearest neighbor
  - **Complete Linkage:** farthest neighbor
  - **Average Linkage:** all neighbors

Example #4: Clustered Data

(Domain: Data, Elements: Items in Data Set, Cardinality: n-ary)



tends to construct small, evenly sized clusters

tends to construct chains of clusters

Images taken from Jonathan Taylor (2010)

Example #4: Clustered Data

(Domain: Data, Elements: Items in Data Set, Cardinality: n-ary)

- Consensus Clustering
  - NP complete
- Heuristics:
  - **Quantitative/metric-based: CSPA**
    Cluster-based Similarity Partitioning Algorithm
  - **Structural/graph-based: HGPA**
    Hyper-Graph Partitioning Algorithm

Example #5: Matchmaker/VisBricks

(Domain: Data, Elements: Clusters in Data Set, Cardinality: binary)

- Relationship: two clusters are related, iff they share data items
- Common visual representation: Ribbons

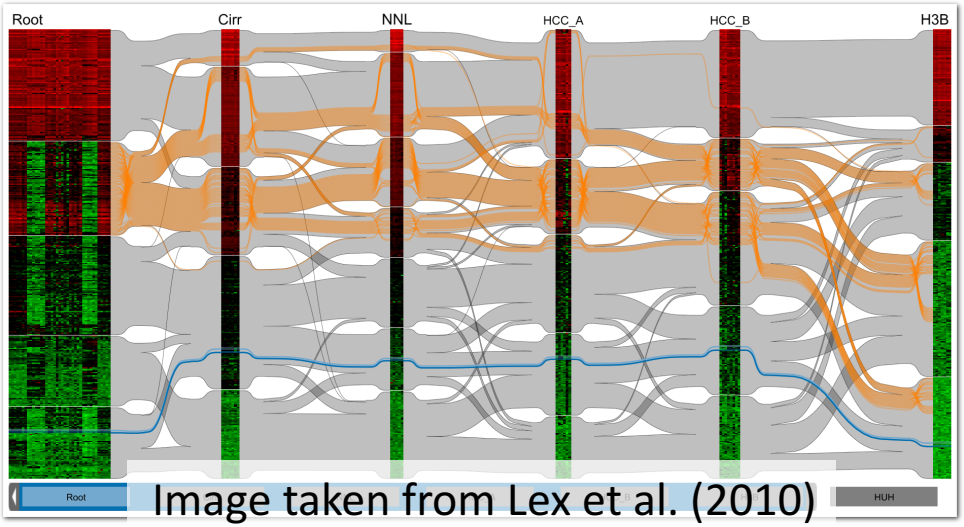


Image taken from Lex et al. (2010)

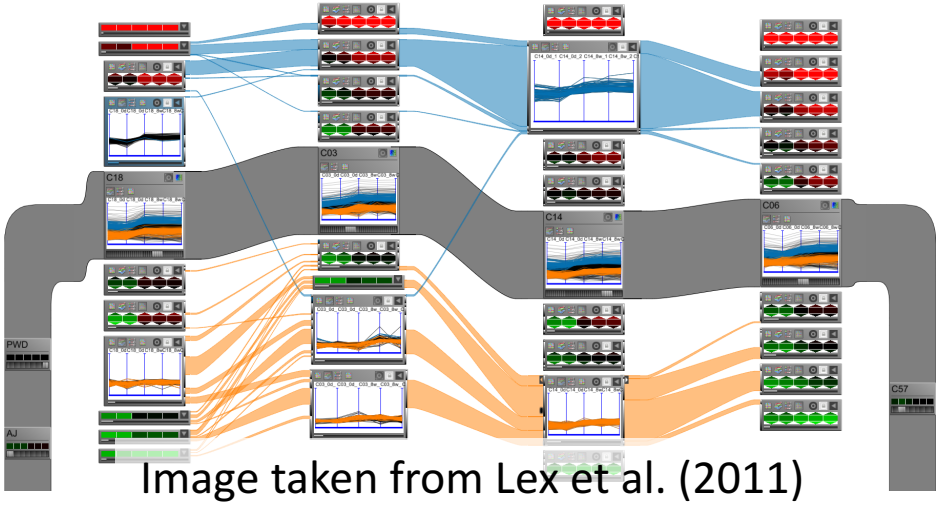


Image taken from Lex et al. (2011)

Example #5: Matchmaker/VisBricks

(Domain: Data, Elements: Clusters in Data Set, Cardinality: binary)

Matchmaker: Clusters of the whole data set

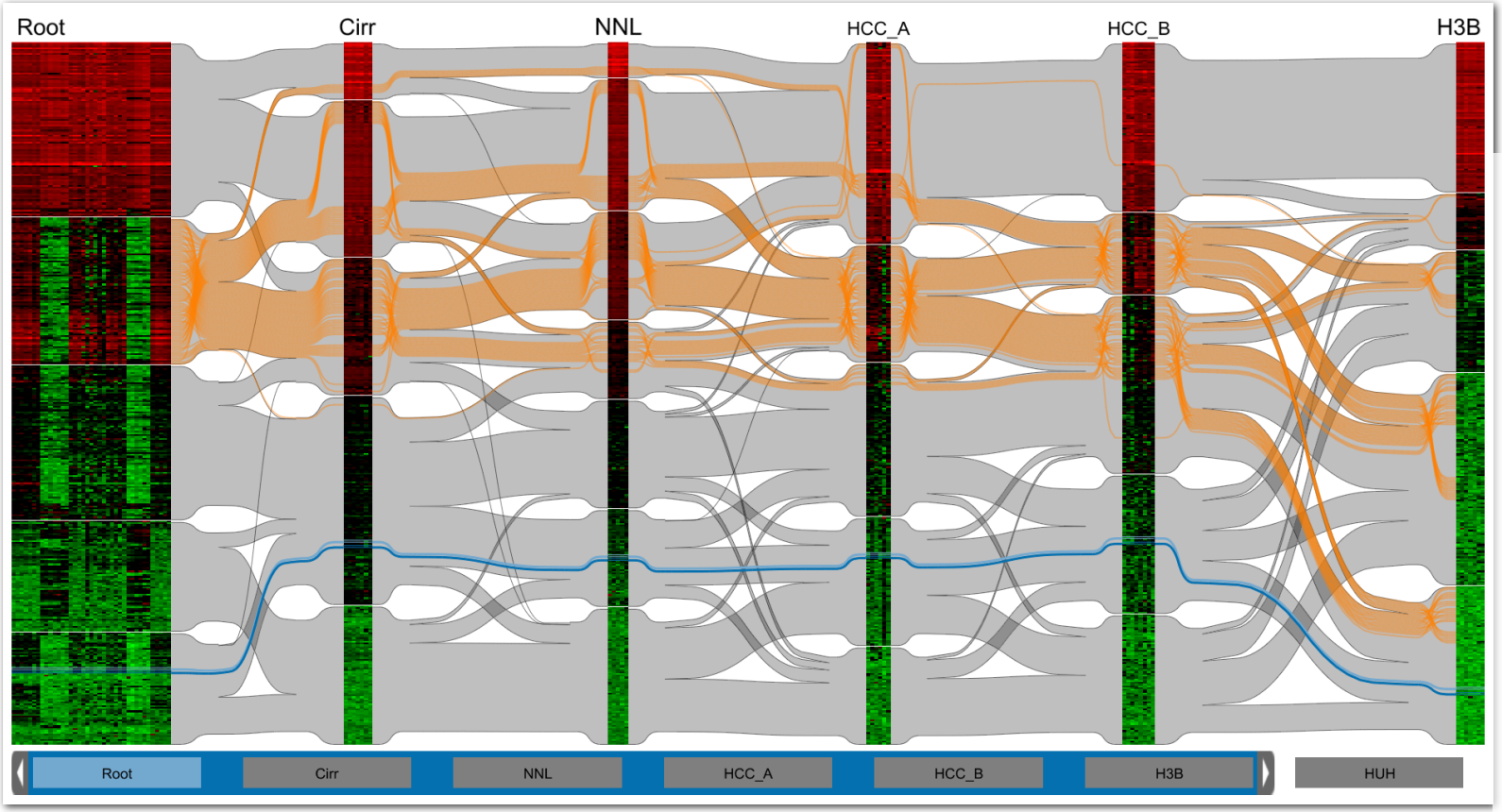


Image taken from Lex et al. (2010)

Example #5: Matchmaker/VisBricks

(Domain: Data, Elements: Clusters in Data Set, Cardinality: binary)

VisBricks: Clusters of dimensional subsets

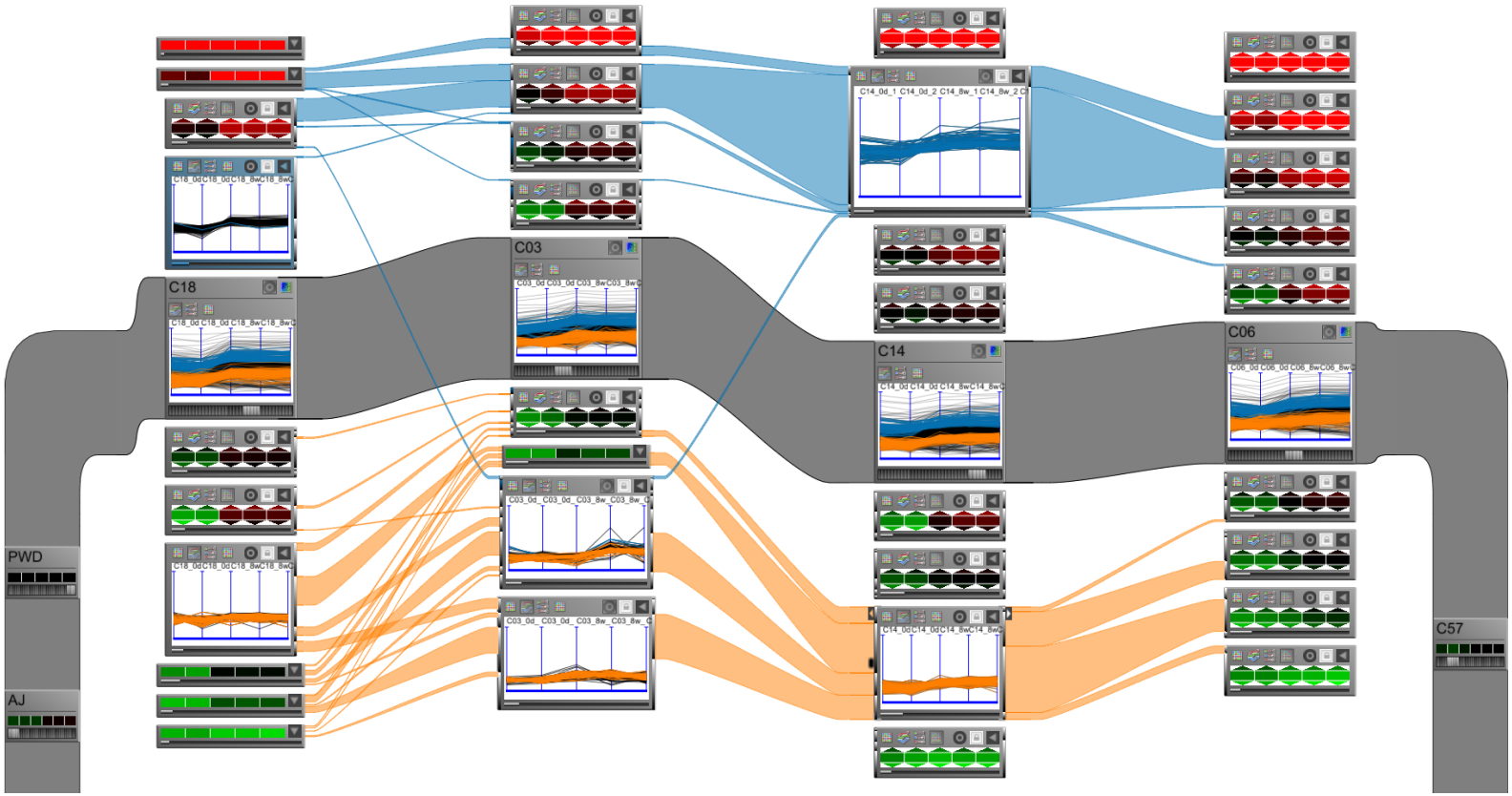


Image taken from Lex et al. (2011)

Example #6: StratomeX

(Domain: Data, Elements: Clusters in Landscape, Cardinality: binary)

- Relationship: two clusters are related, iff they contain data with the same keys (IDs)
- Common visual representation: Ribbons

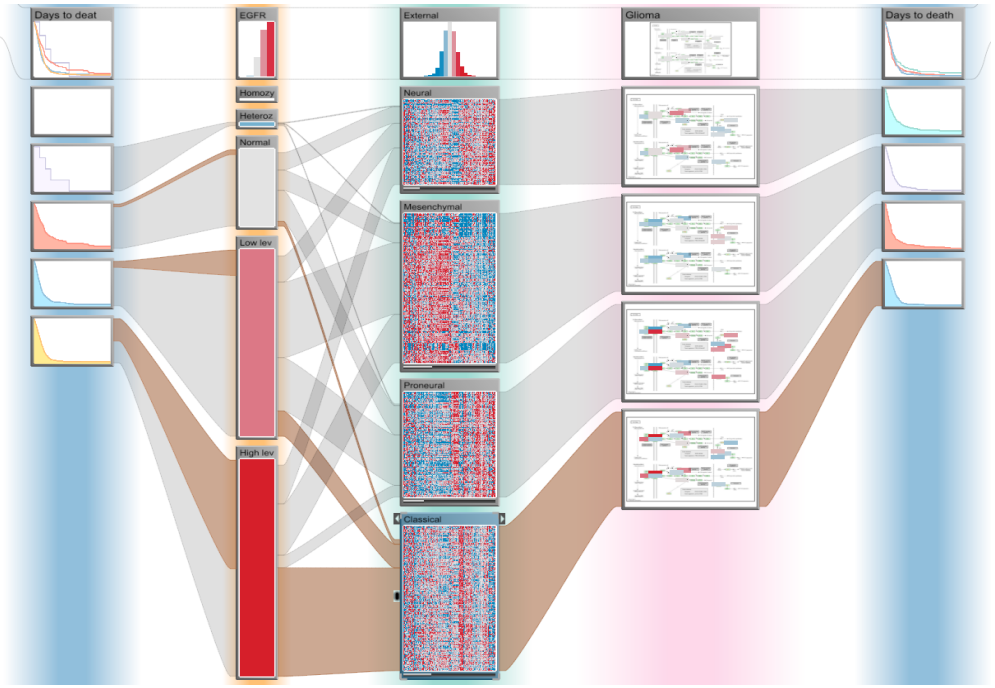


Image taken from Lex et al. (2012)

Example #6: StratomeX

(Domain: Data, Elements: Clusters in Landscape, Cardinality: binary)

- StratomeX: Clusters of different data sets

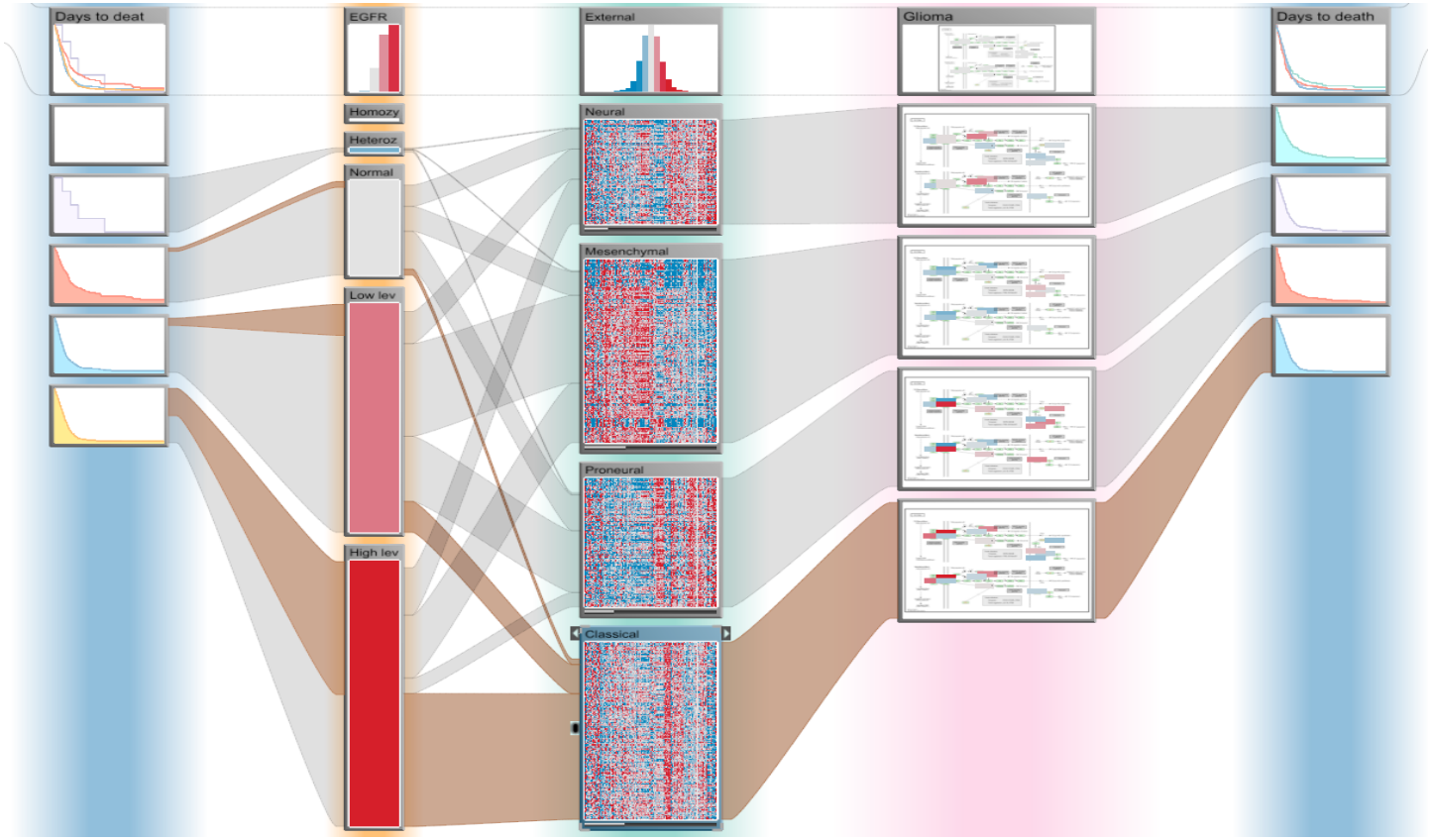


Image taken from Lex et al. (2012)

Example #7: StratomeX DVI

(Domain: Data, Elements: Data Sets in Landscape, Cardinality: binary)

- Relationship: two data sets are related, iff they contain data with the same keys (IDs)
- Common visual representation: Graph

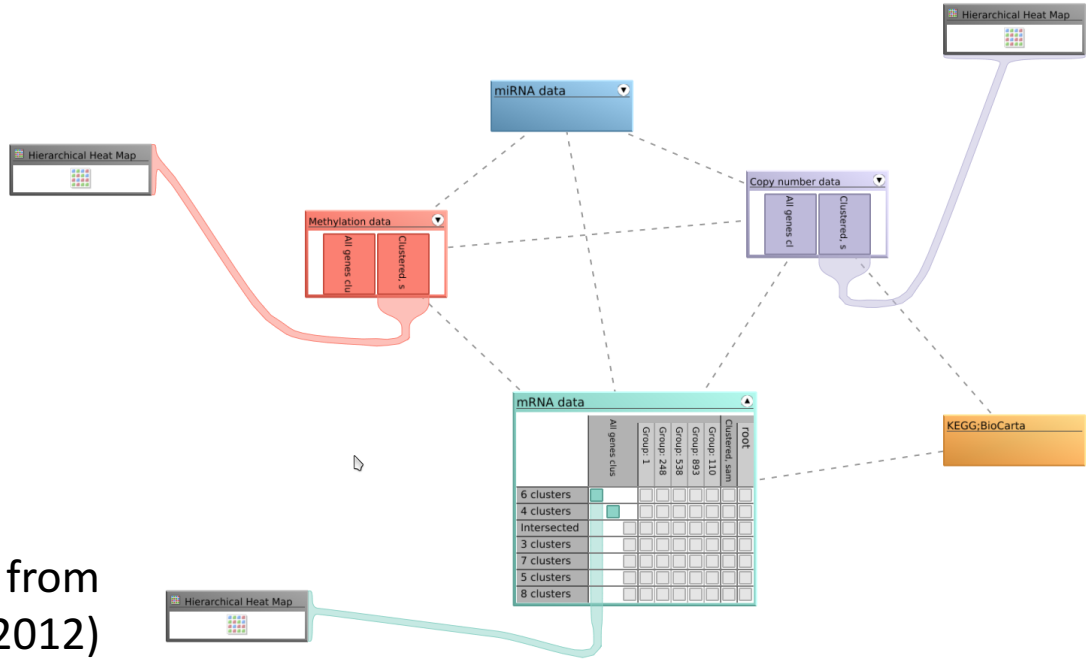
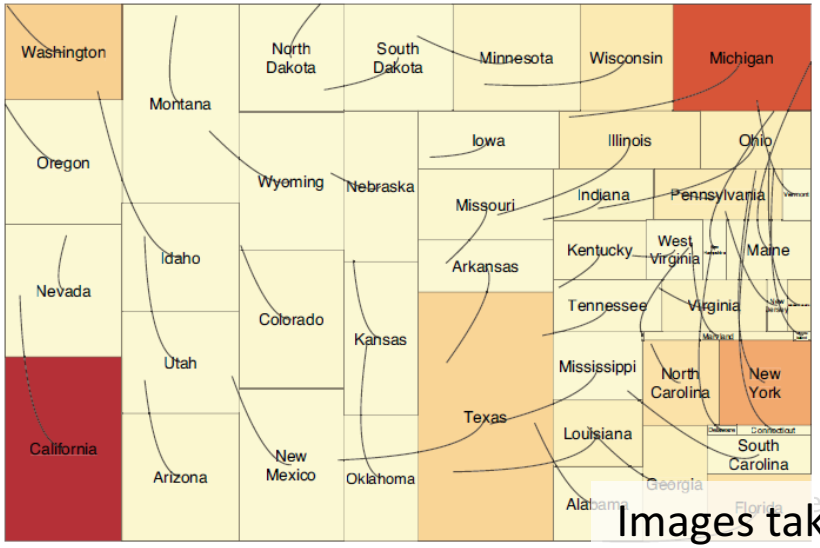


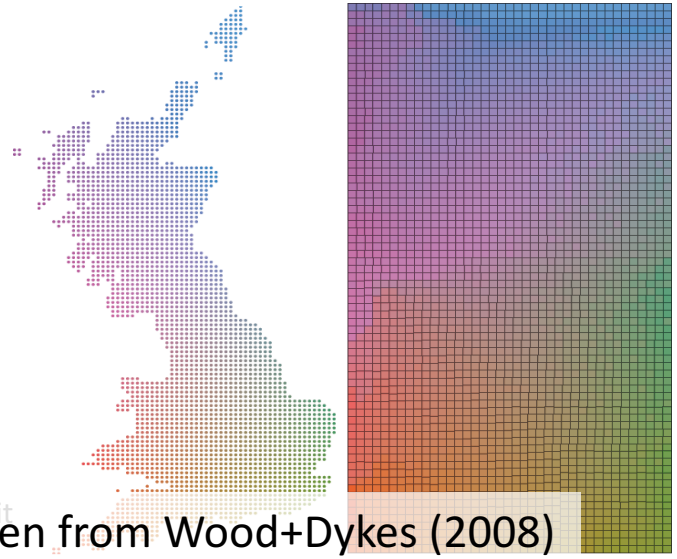
Image taken from Lex et al. (2012)

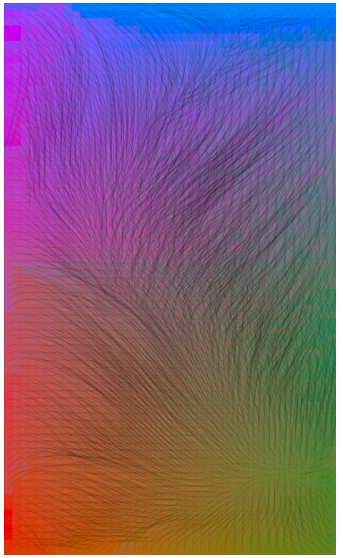
Example #8: Spatial Treemaps

(Domain: View, Elements: Attributes of Data Items, Cardinality: binary)

- Relationship: two spatial positions are related, iff they both belong to the same data item
- Common visual representation: Strokes and/or Color







Images taken from Wood+Dykes (2008)

Example #8: Spatial Treemaps

(Domain: View, Elements: Attributes of Data Items, Cardinality: binary)

Lines

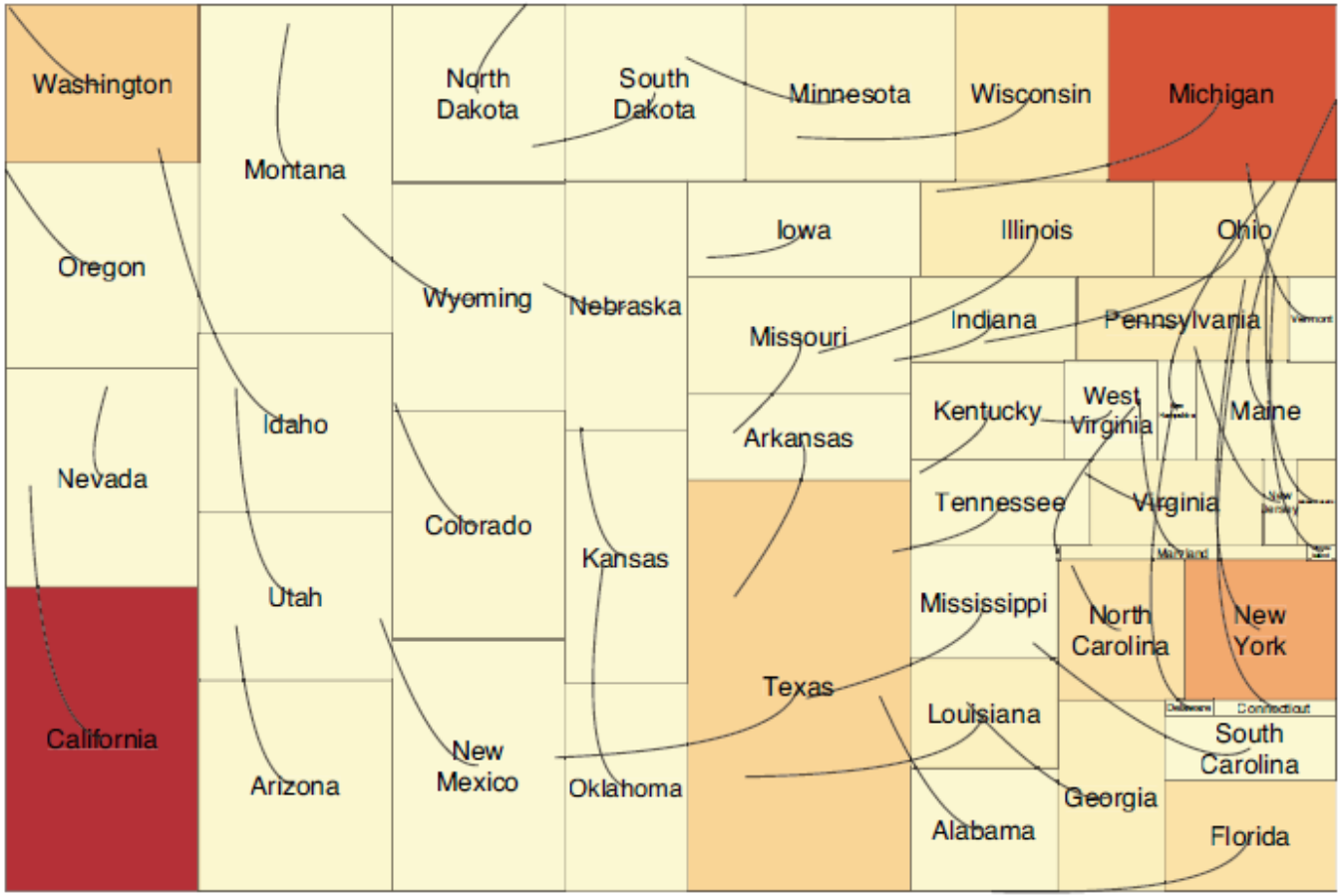
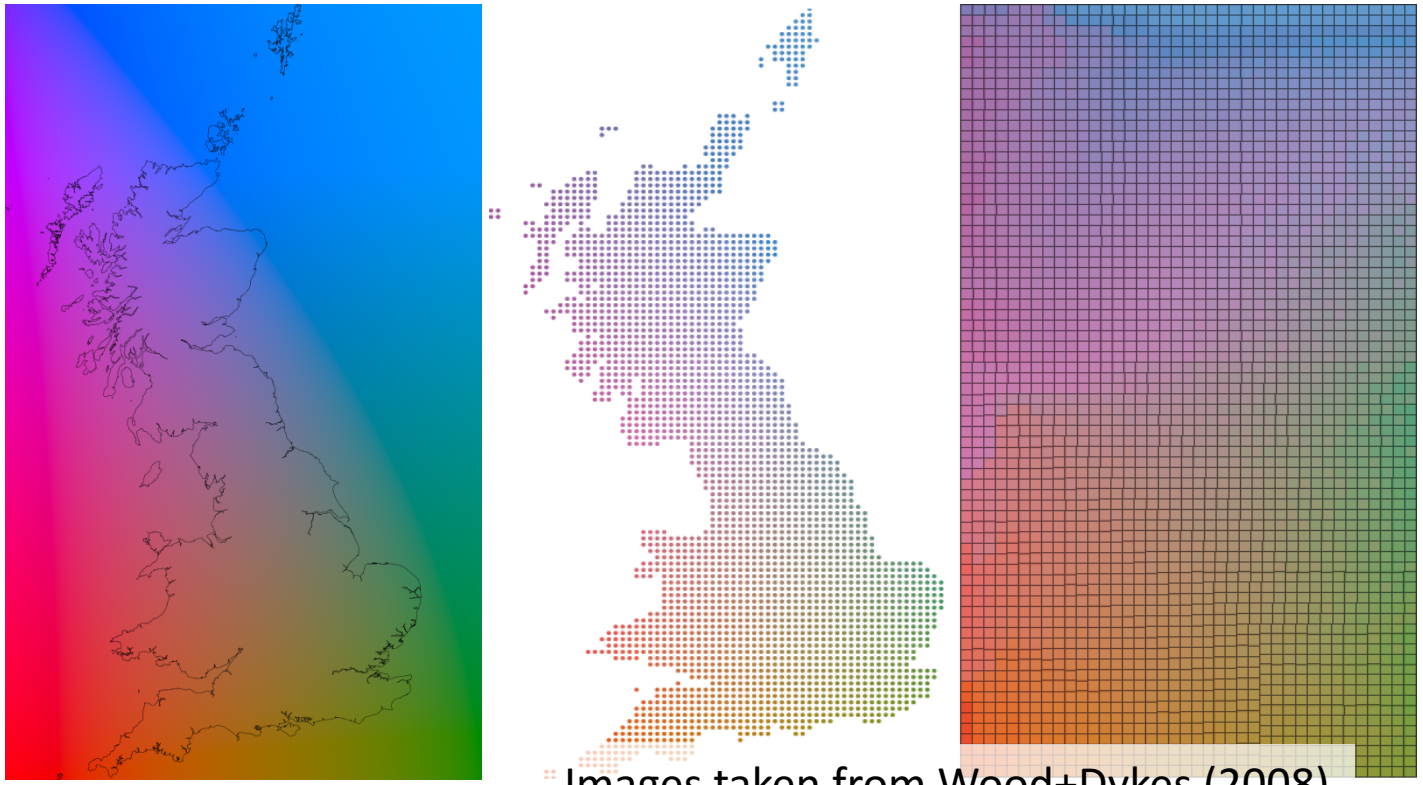


Image taken from Wood+Dykes (2008)

Example #8: Spatial Treemaps

(Domain: View, Elements: Attributes of Data Items, Cardinality: binary)

Color

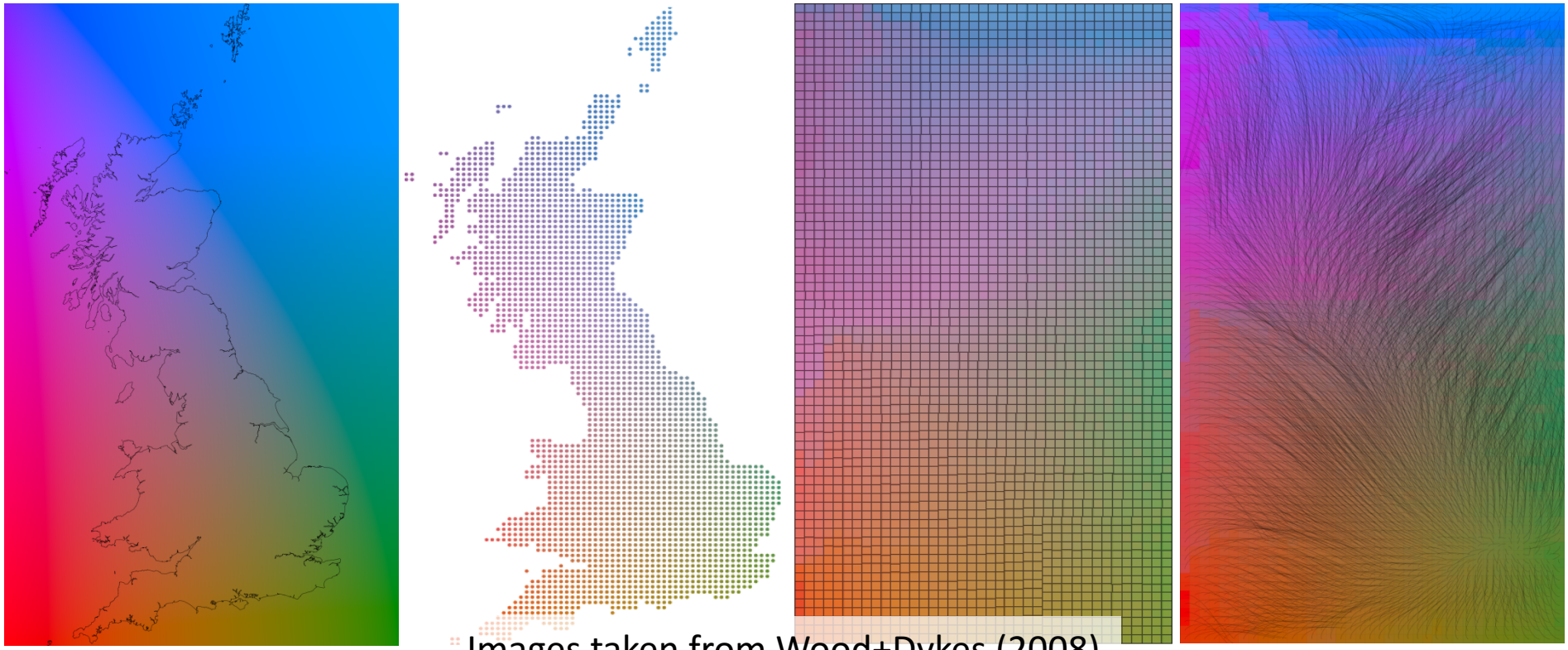


Images taken from Wood+Dykes (2008)

Example #8: Spatial Treemaps

(Domain: View, Elements: Attributes of Data Items, Cardinality: binary)

Color+Lines



Images taken from Wood+Dykes (2008)

Example #9: Stack'n'Flip

(Domain: Interaction, Elements: Data Sets in Landscape, Cardinality: binary)

- Relationship: two data sets are related, iff they are used in sequence
- Common visual representation: Graph

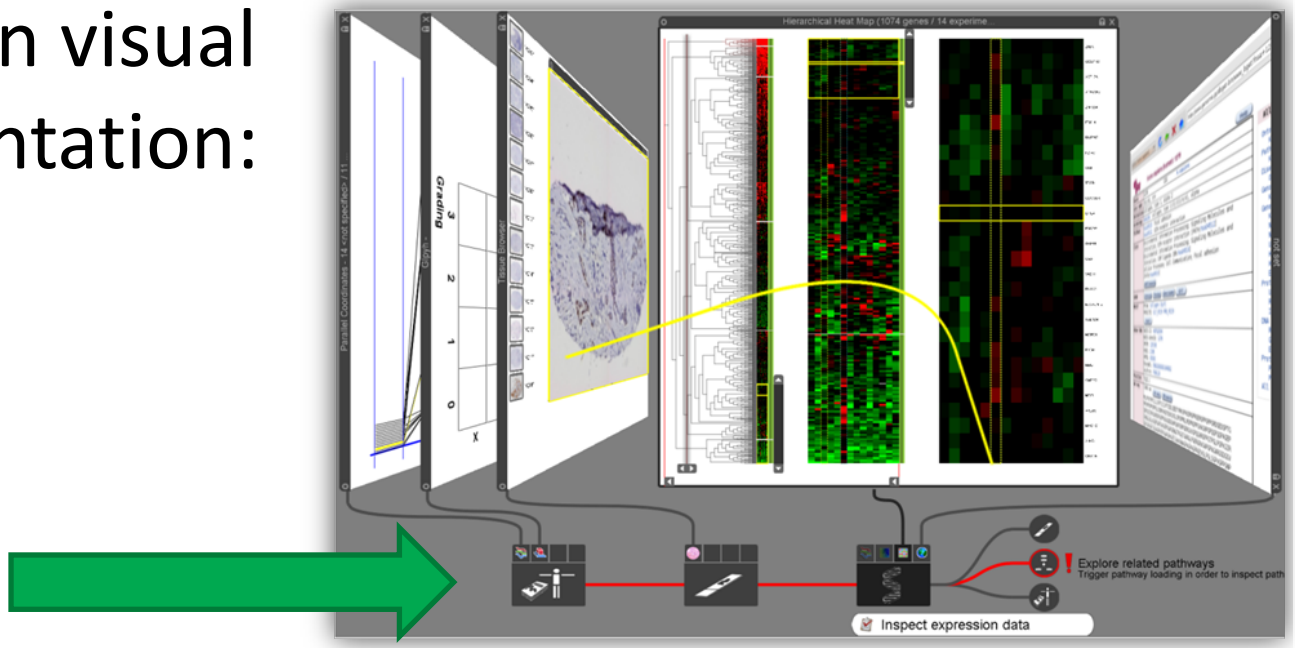
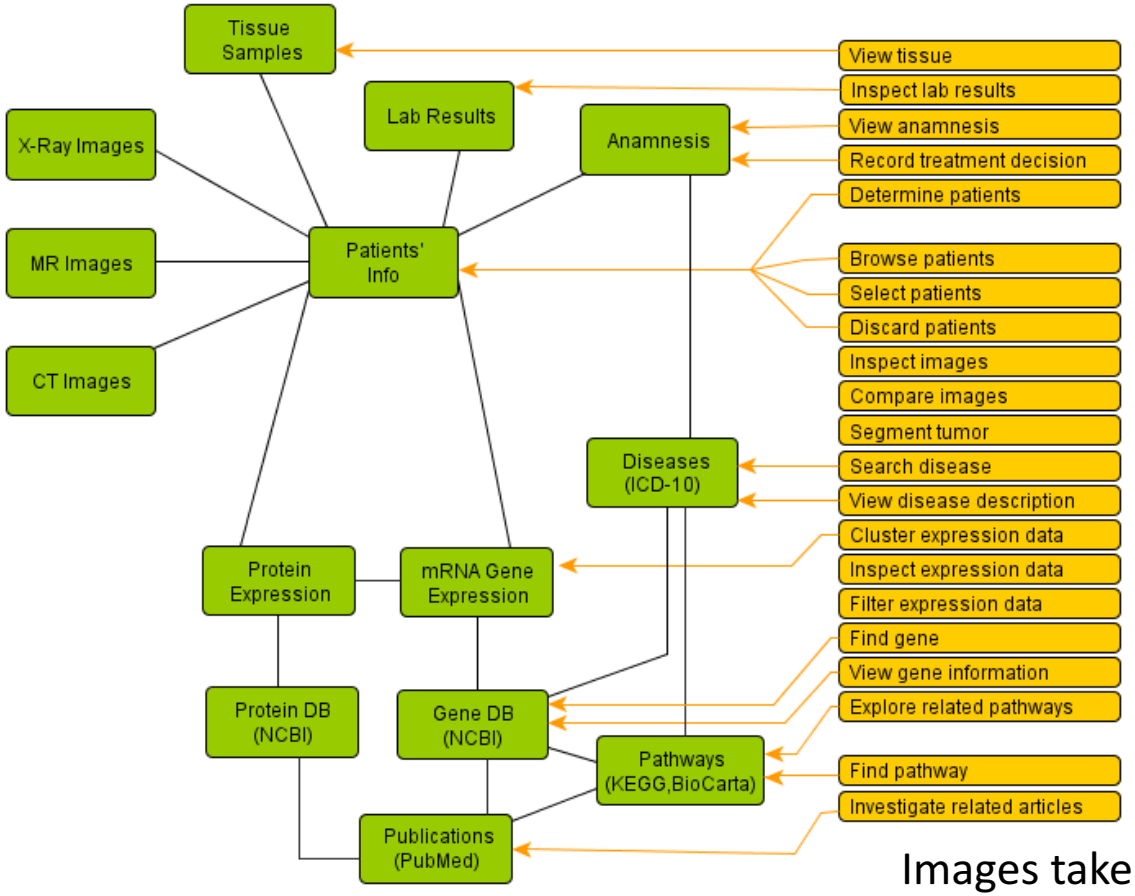
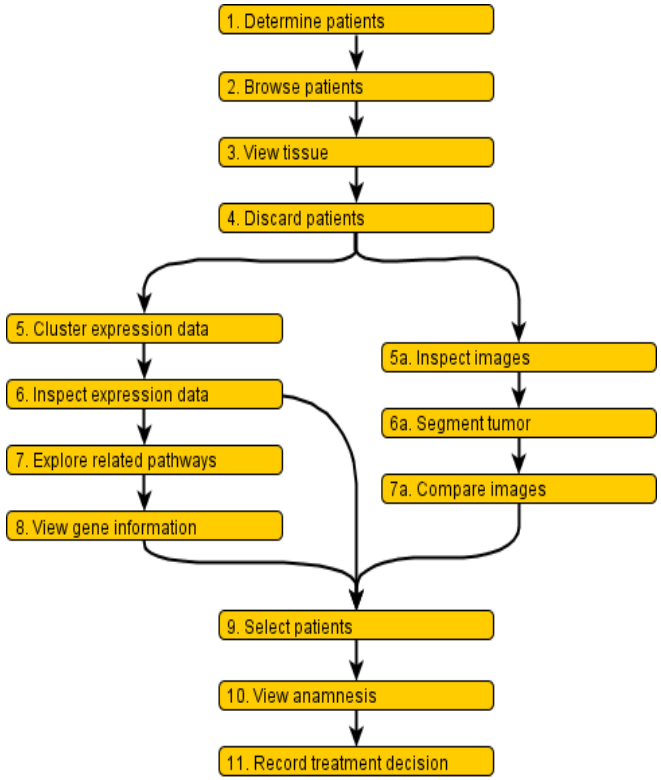


Image taken from Streit et al. (2012)

Example #9: Stack'n'Flip

(Domain: Interaction, Elements: Data Sets in Landscape, Cardinality: binary)





Images taken from Streit et al. (2012)

Example #9: Stack'n'Flip

(Domain: Interaction, Elements: Data Sets in Landscape, Cardinality: binary)

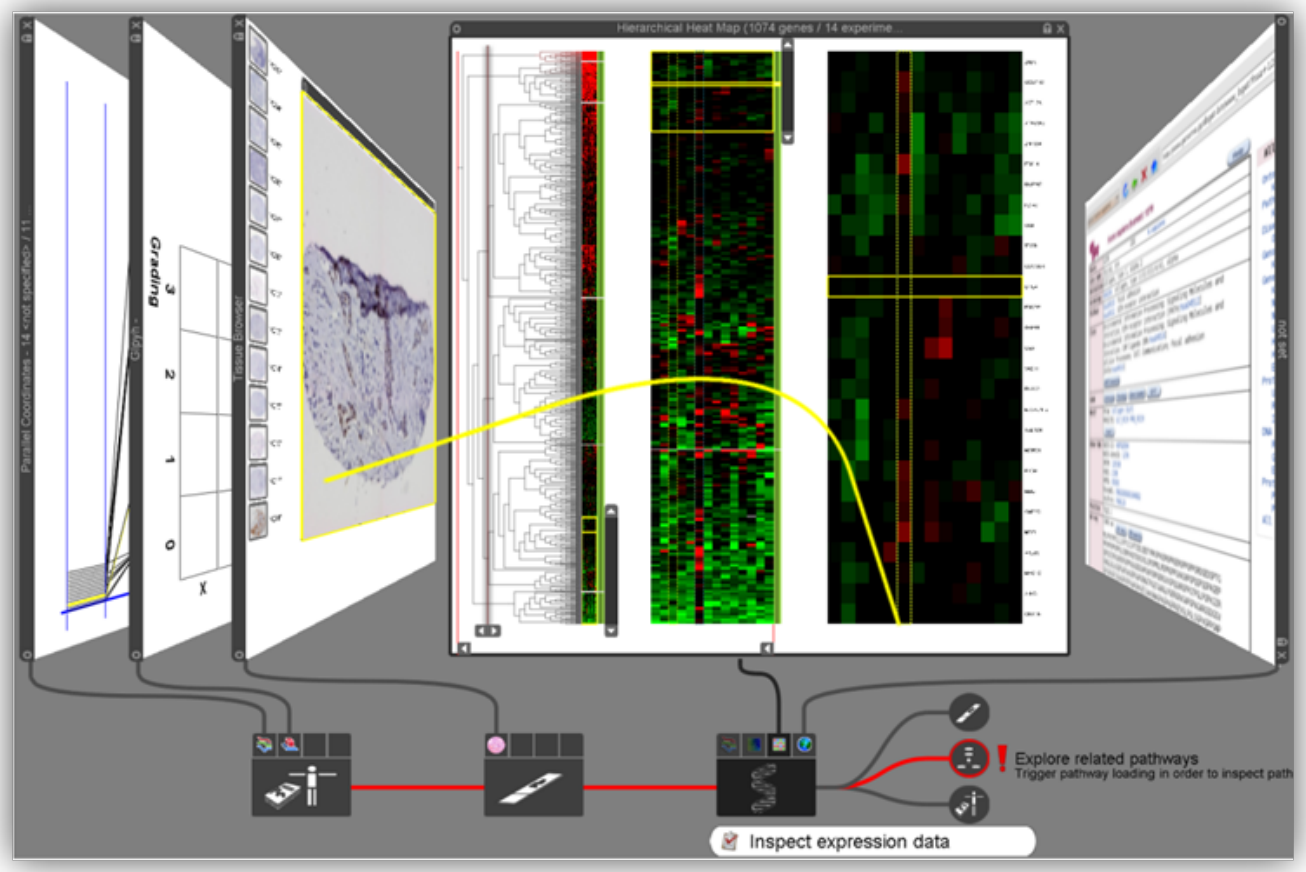


Image taken from Streit et al. (2012)

Edge-based Traveling

Using Relations for Interaction

Clicking an edge with one off-screen end leads automatically towards it

Tooltip indicates details about the off-screen node

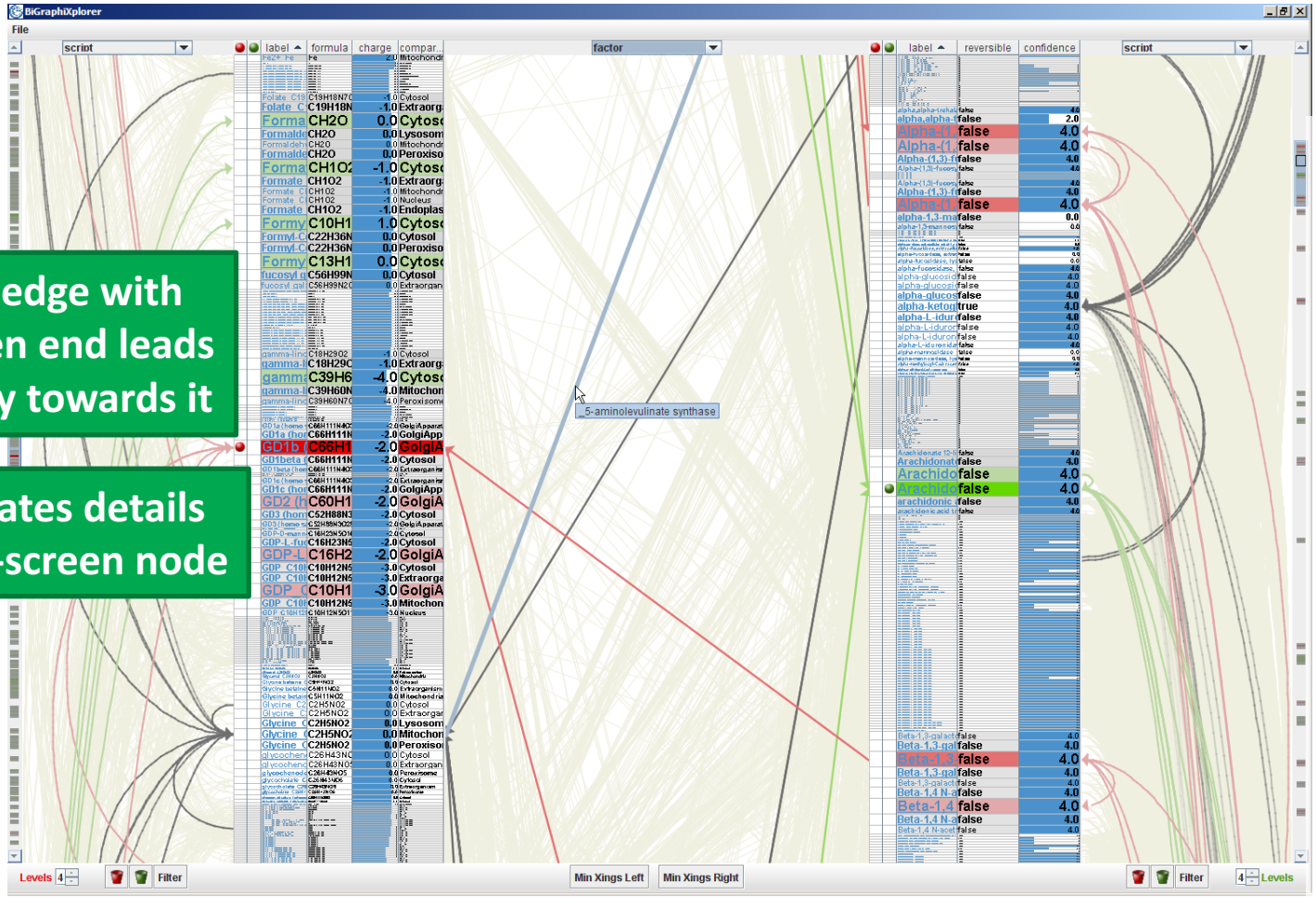


Image taken from Schulz et al. (2008)

What to do with a relation?

- Represent in data space:
  e.g., multidimensional data → graph
  → use standard graph visualization
- Represent in view space:

This is what “Part 2: How to Link” is all about!

PART II:
HOW TO LINK?

Speaker: Alexander Lex

Schedule

3:15 – 3:40	First half
3:40 – 4:15	Coffe break
4:15 – 4:50	Second half
4:50 – 5:50	When to link? By Marc Streit

Contents

1. Discussion of objectives, definitions
2. Establishing quality criteria
3. Brief introduction to most linking techniques
4. Detailed discussion of selected linking techniques
5. Details on techniques that employ connectedness

Linking Objective

Express a relationship between *n* entities, which is not obvious from the visual encoding.

Supplementary relationships, e.g., based on

- brushing
- clustering
- derived relationship

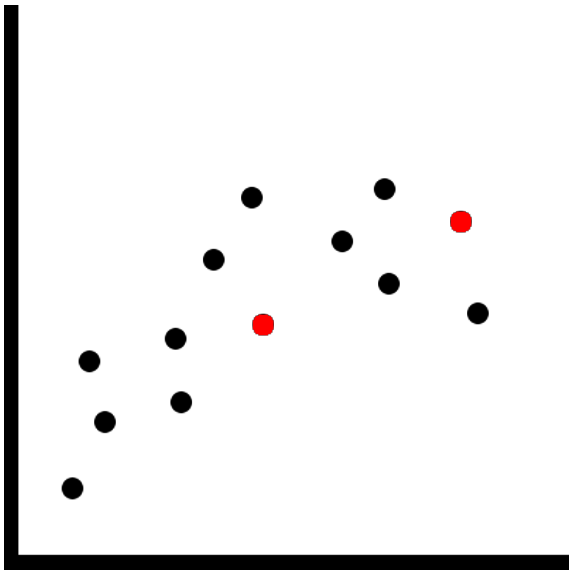
Consequence:

must work in supplement to the primary visual encoding, the base representation (BR).

Base Representation (BR)…

… is a visualization or an image which is meaningful by itself

… may be adapted to enable linking



Base Representation with supplemented links

How To Link?

Linking of information based on perceptual grouping principles.

- Gestalt principles [Wertheimer, 1923] and recent extensions

Good resource for grouping principles and other issues of perception:

http://www.csc.ncsu.edu/faculty/healey/PP/index.html

By Christopher G. Healey

Quality Attributes for Links (1/2)

Scalability for # items

- How many items can be linked for one relation?

Scalability for # relations

- How many relationships can be shown at the same time?

Perception issues

- Can the links be perceived easily or "preattentively"?
- Can all entities belonging to a relationship be easily identified?

Quality Attributes for Links (2/2)

Occlusion issues

- Is the base representation preserved?

Compatibility to base representation?

- Is the choice of visual encoding for a link suitable for the encoding of the base representation?

Practical/Implementation issues?

- Easy to implement?
- Efficient to implement?

Quality Attributes Online

http://connecting-the-dots.caleydo.org

Critique: Visual Encoding Conventions

Good, suitable, feature inherent!

Limiting, but good technique might address the problem.

Limiting, but may work under certain circumstances.

Severely limiting, no (known) solution.

Three Major Classes of Links

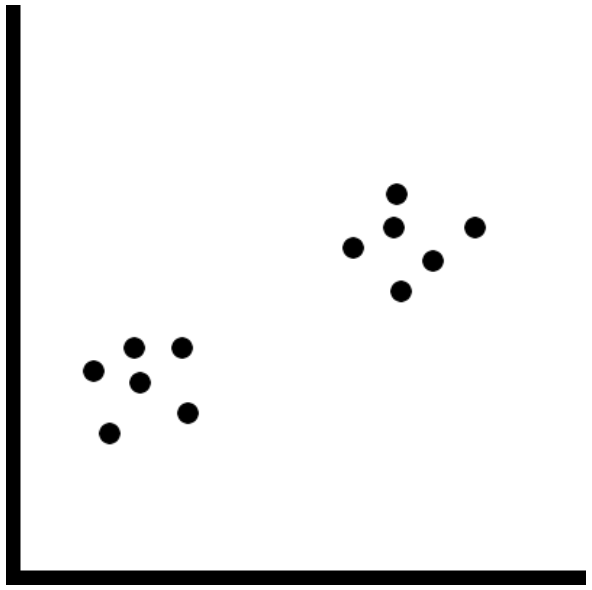
Proximity

Similarity

Connectedness

Proximity

Grouping/linking by placing entities in close proximity

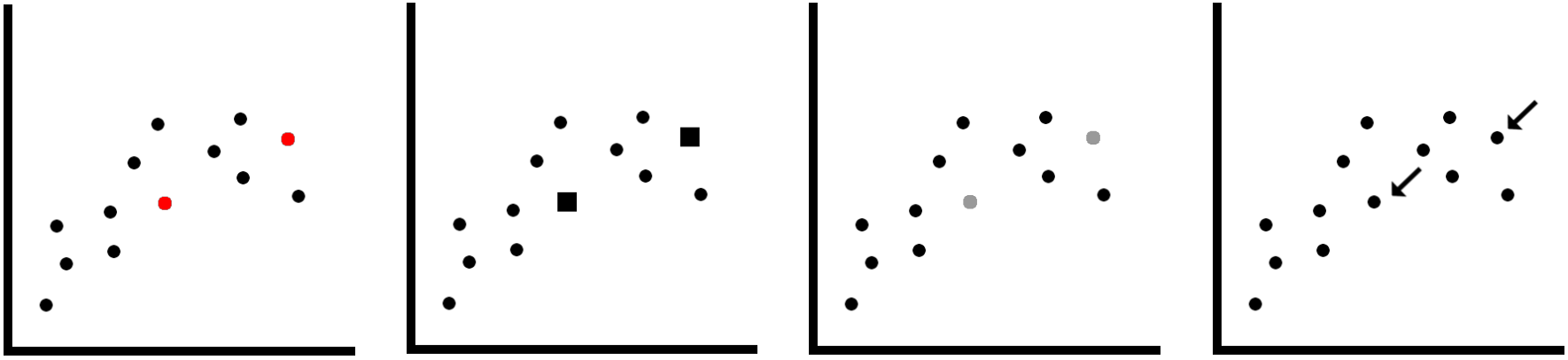


Similarity

Co-modulation of a visual-variable [Bertin 1974]

color, shape, size, value, orientation, texture, …

Adding a glyph, label, frame, background

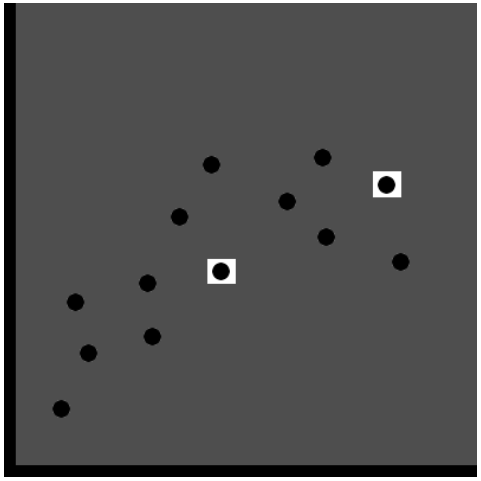


Similarity

Modulate everything else

Blurring, darkening, desaturating, etc.

Blur

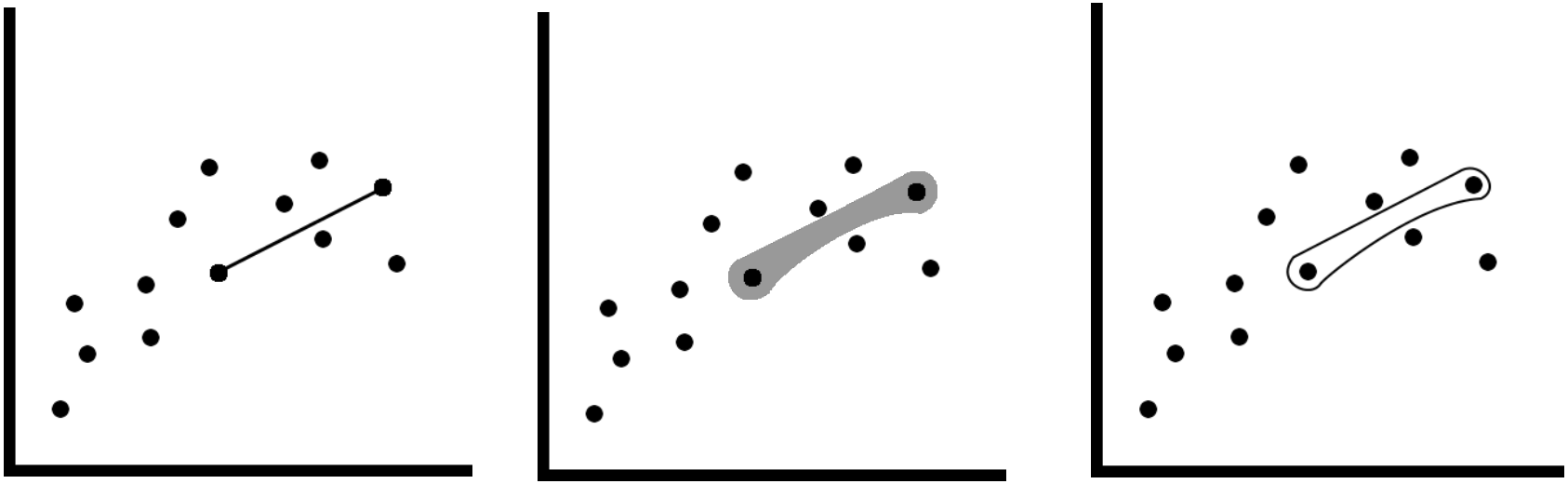


Darkening

Connectedness and Common Region

Connected items with a line or curve

Surround items with a outline, surface, volume



The “obscure” grouping principles

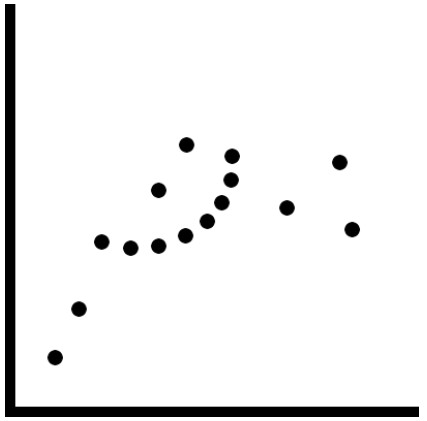
“Obscure” in terms of applicability for linking

Common fate

- motion in the same direction

Good Continuation

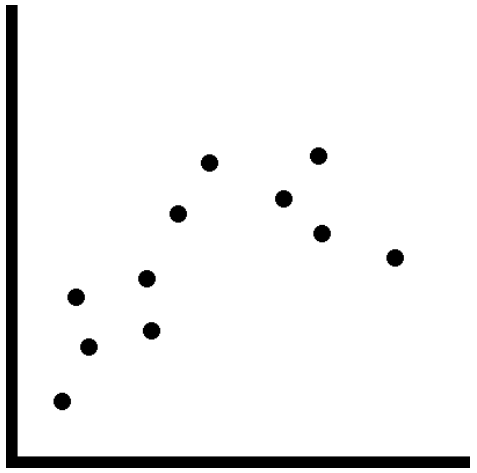
- arrange items on a line / curve
- in consequences similar to position but more limited



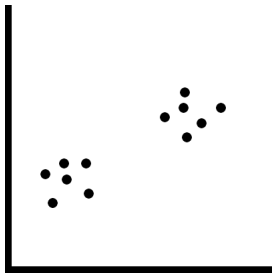
The “obscure” grouping principles

Flicker

- Works well for a few items
- Grabs your attention
- Often perceived annoying



PROXIMITY



Proximity

Scalability for # items: very good

Scalability for # relations: very good

Perception: very good

Occlusion issues: not really

Practical/implementation issues: not really

Proximity: Compatibility to BR

Problematic because:

position is „the best“ visual variable →
in very many cases used as a primary encoding

adding relationships (e.g. by brushing) triggers significant rearrangement

difficult to keep up mental map

Proximity Uses

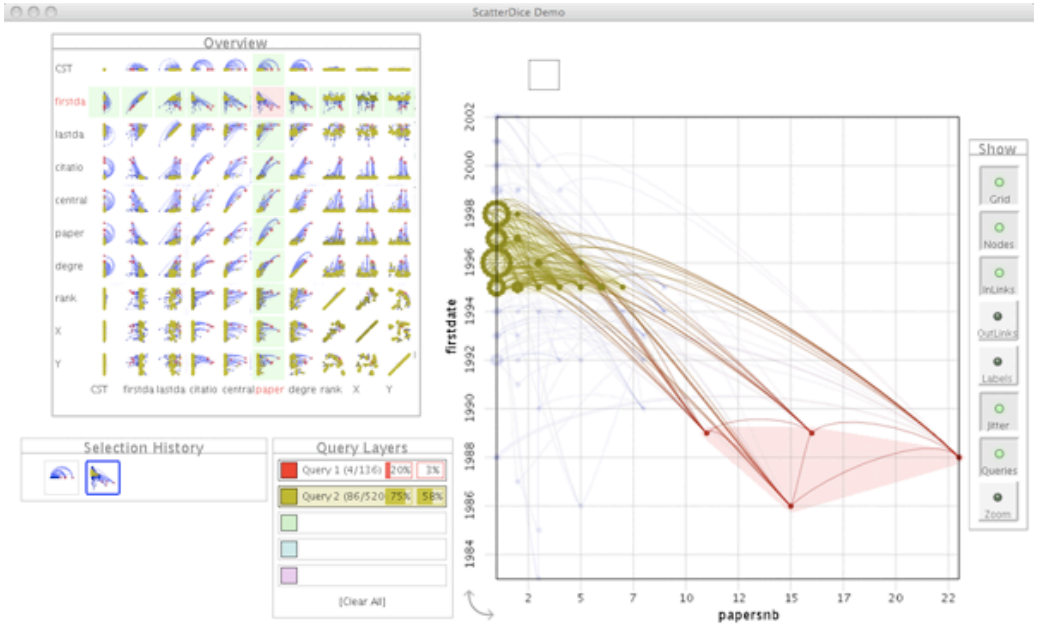
Is used only when position is variable

- e.g., in graphs using a node-link layout
- e.g., when using projection/MDS methods: to emphasize individual dimensions
- e.g., sorting in a table

Proximity in Graphs

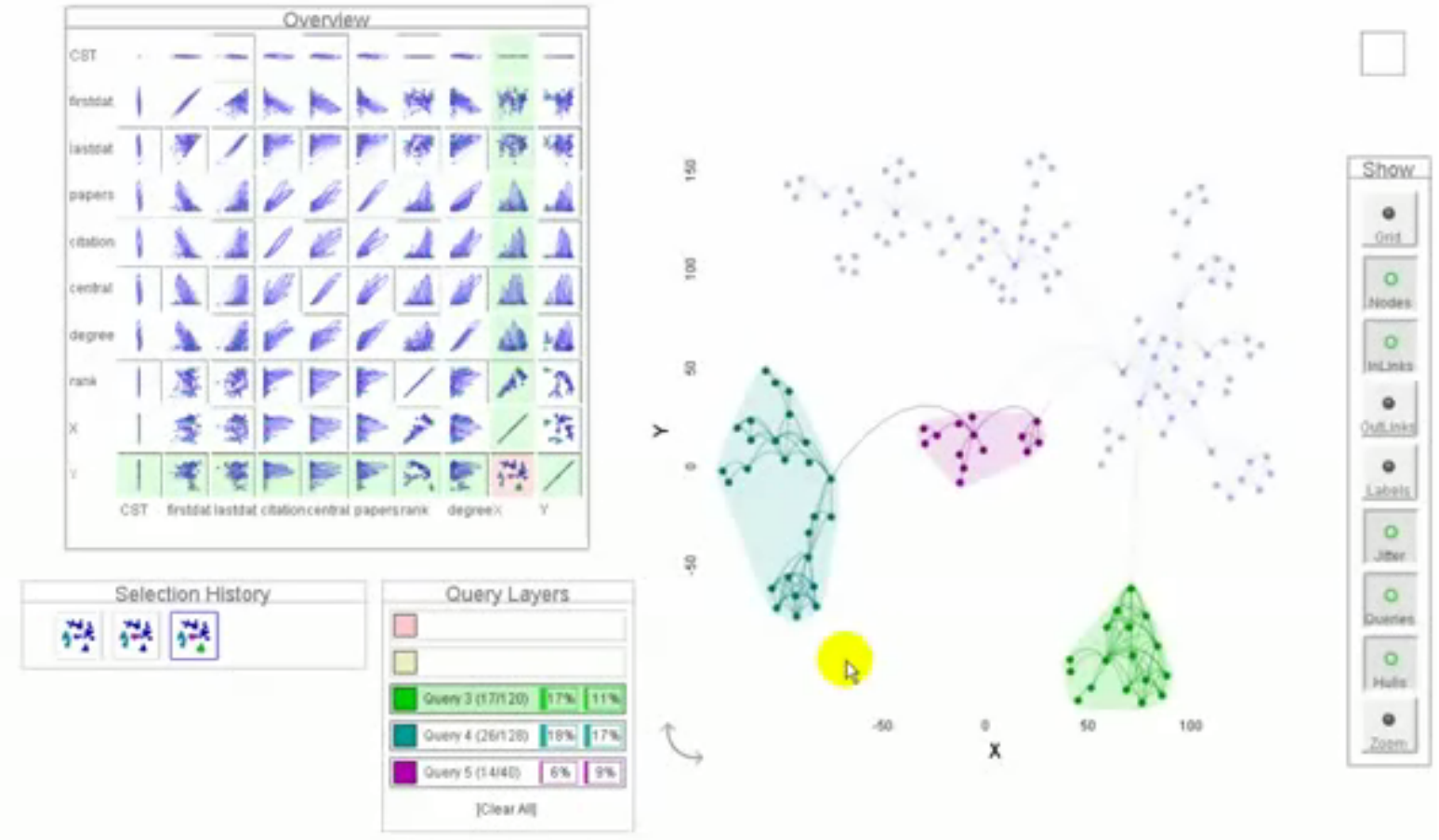
GraphDice

System to see relationships between large quantities of node attributes in graphs



[Brezerianos et al., 2010]

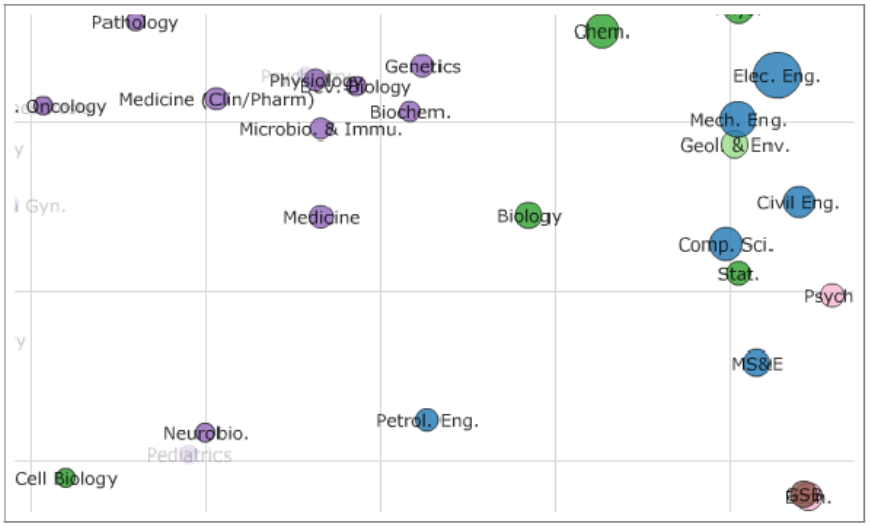
Proximity - Graph Dice



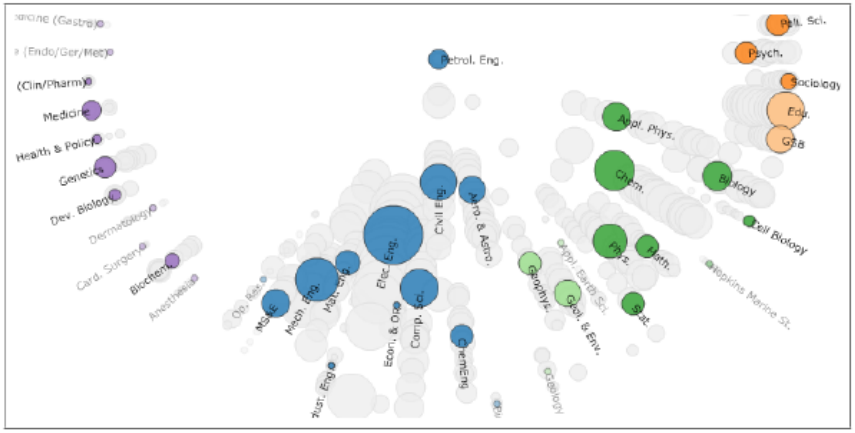
[Brezerianos et al., 2010]

Proximity - MDS

Topical distances between depratments in a 2D projection



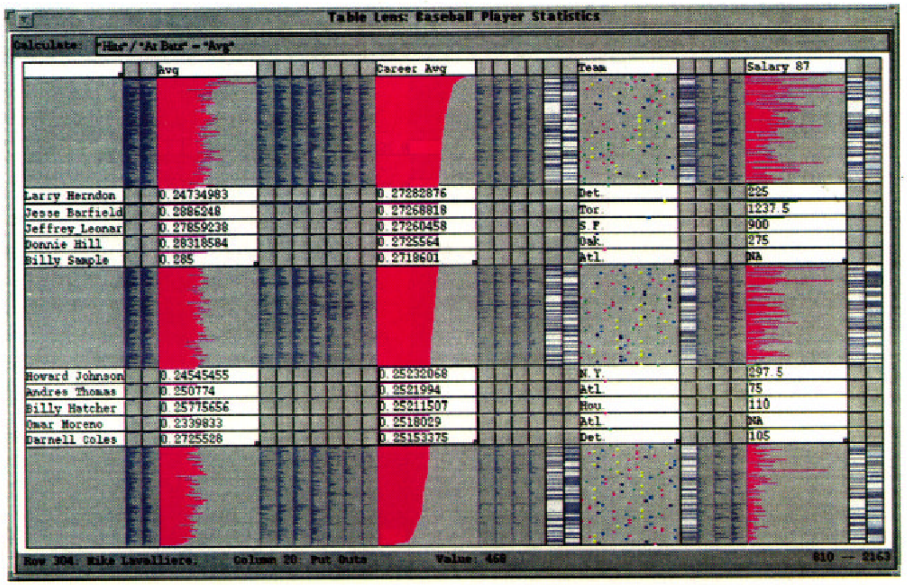
Topical distances between the selected Petroleum Engineering and the others.



[Chuang et al., 2012]

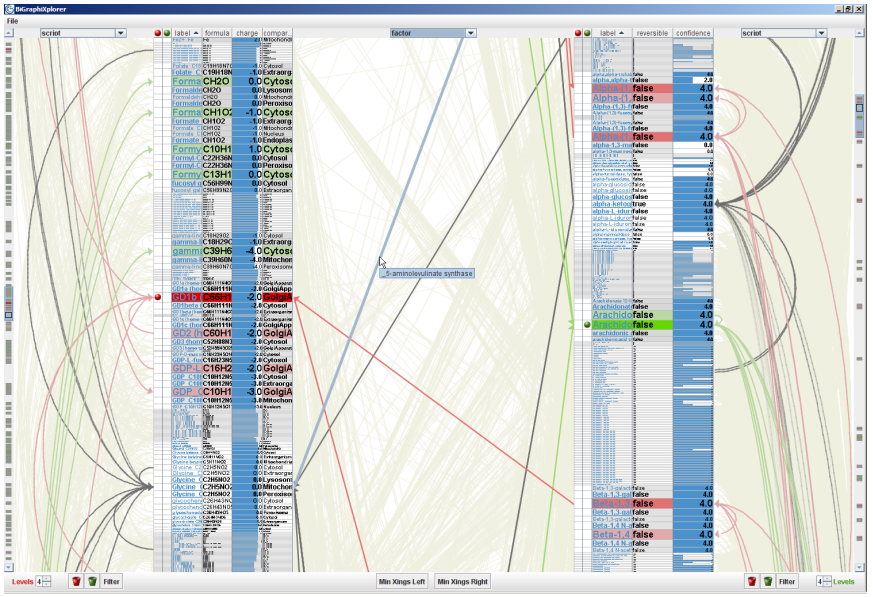
Proximity - Sorting

Table-Lens sorted according to one dimension.



[Rao and Card, 1994]

Bi-partite graph with tabular display for node attributes.



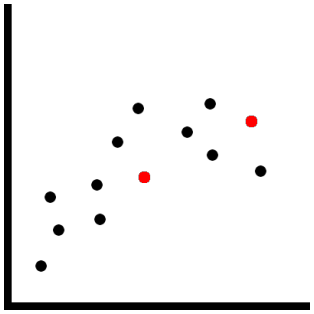
[Schulz et al., 2008]

Proximity Reccomendation

Use proximity if your primary visual encoding doesn‘t use position.

Proximity is also often combined with other visual encodings for links.

SIMILARITY



Similarity - Color

Scalability for # items: very good

Scalability for # relations: limited (7-8 colors can be easily distinguished)

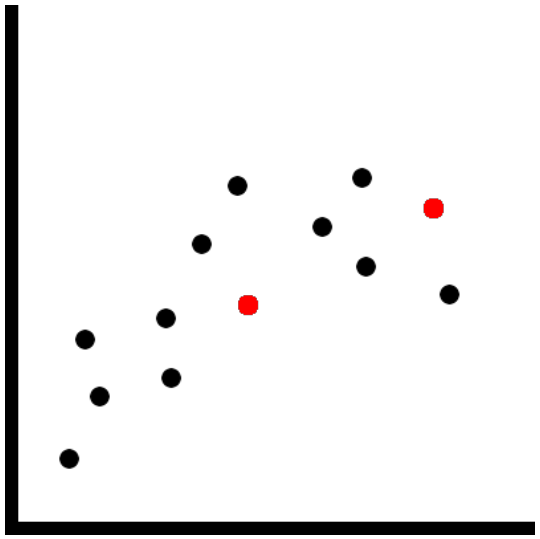
Occlusion issues: not really

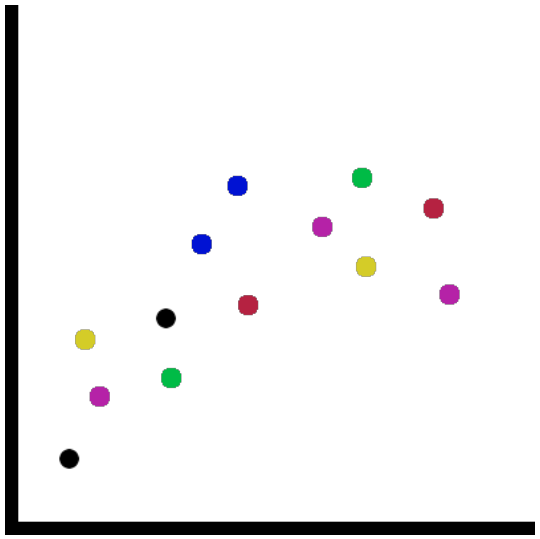
Compatibility to BR: good if color is „free“

Practical/implementation issues: not really

Color – Perception Issues (1/2)

Preattentive properties: Very good for 1-2 simultaneous, serial search for more

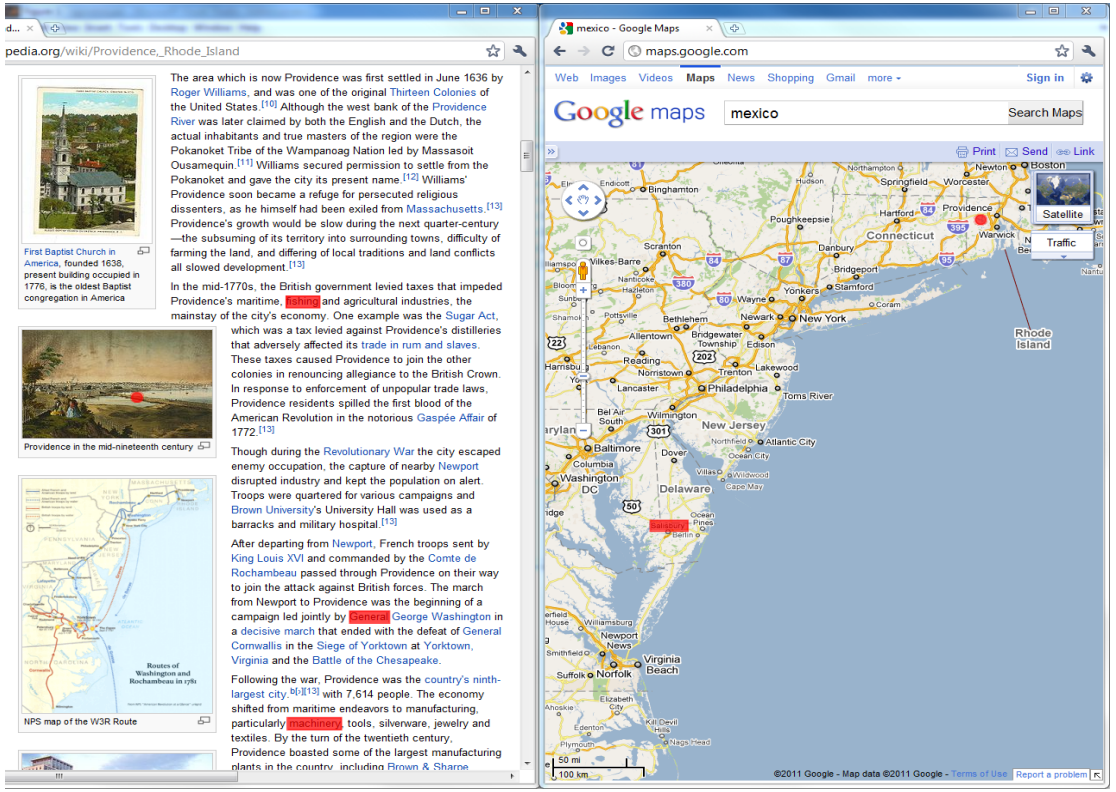




Color – Perception Issues (2/2)

Slower in a cluttered environment

Size of colored object relevant.



Color Reccomendation

Use color if

- position is already used
- you expect large numbers of elements
- you expect a limited number of simultaneous relationships

Be careful if

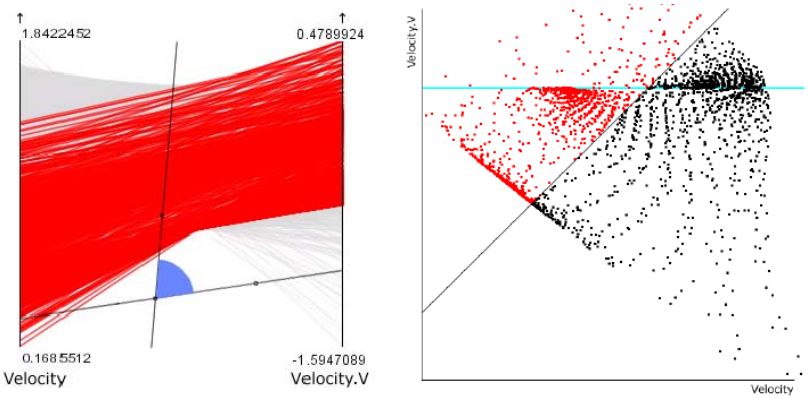
- the BR is cluttered
- its important that no entity is overlooked

Value / Saturation / Transparency

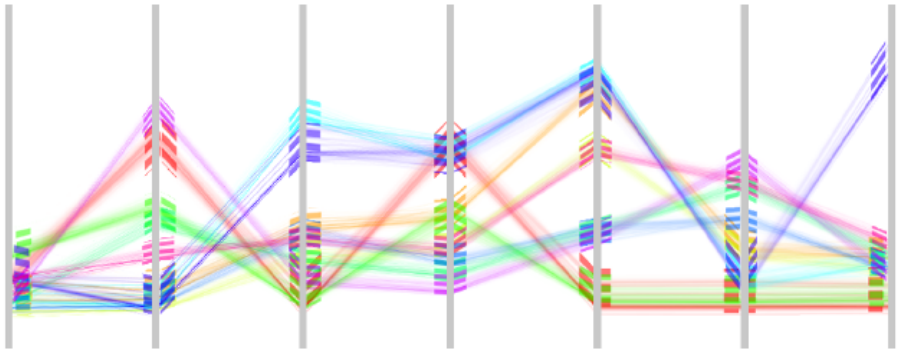
Value / Saturation / Transparency

- Similar to color
- Lower # of relations
- Influences visibility
- Often used for binary selections/filters

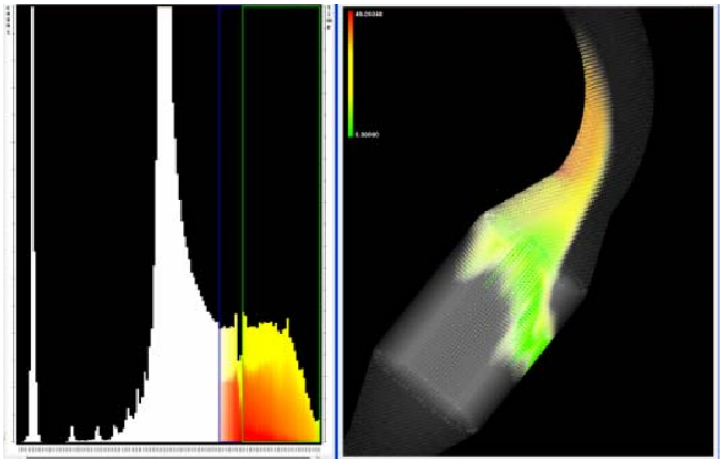
Color/Value Modulation Examples



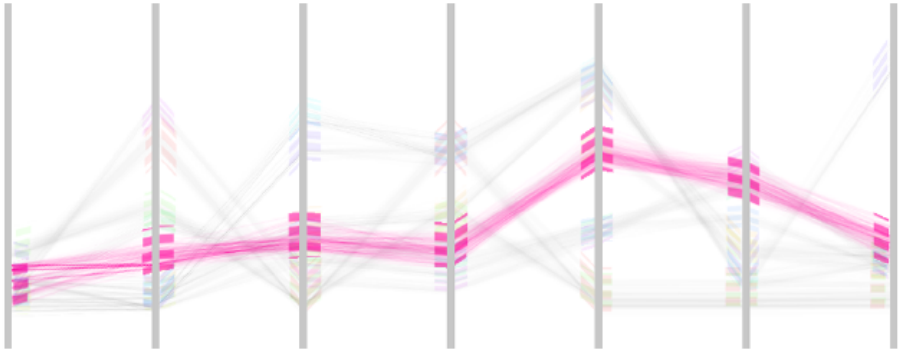
[Hauser et al., 2002]



(a)



[Doleisch , 2007]



(b)

[Johansson et al. , 2007]

Other Modulation-Based Similarity

Shape

- Less easily perceived than color.
- Better for larger # of relations, but doesn't work preattentively.
- Less flexible – requires a scatterplot-like setup
  - e.g.: exchange symbol used in a scatterplot
- Requires a minimum size of a mark

Size

- Problematic for larger # of relations.
- May lead to occlusions.
- e.g.: make line in PC plot thicker

Other Modulation-Based Similarity

Orientation

- Special requirements on the mark and on the BR
- -> limitations of shape apply

Texture

- Special requirements on the mark
- Minimum size of mark

Similarity based on Supplementation

Glyph, label

- Same problems as for shape
- Scalability for # relations: very good
- Scalability for # items: bad, introduces additional clutter

Frame & background

- Often combined with color to counter-balance small/thin features of mark
  otherwise binary only

Similarity based on Modulating Everything Else

Blurring, darkening the surrounding

Perception: good

Scalability # items: very good

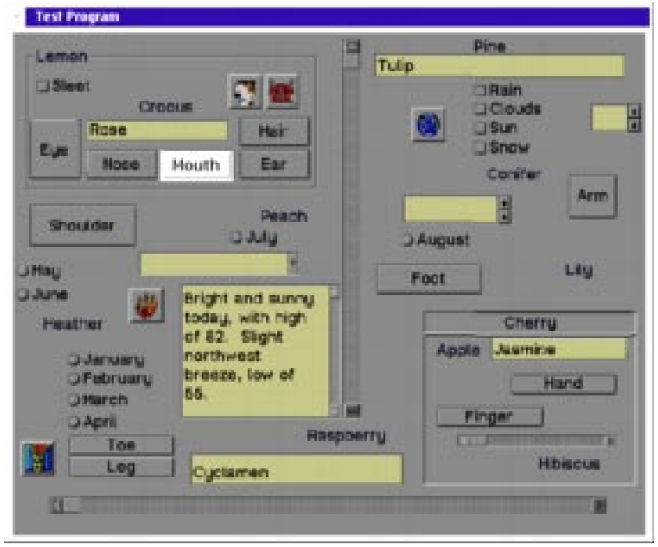
Scalability # relations: practically only 1 possible

Compatibility to BR: BR may become hard/impossible to read

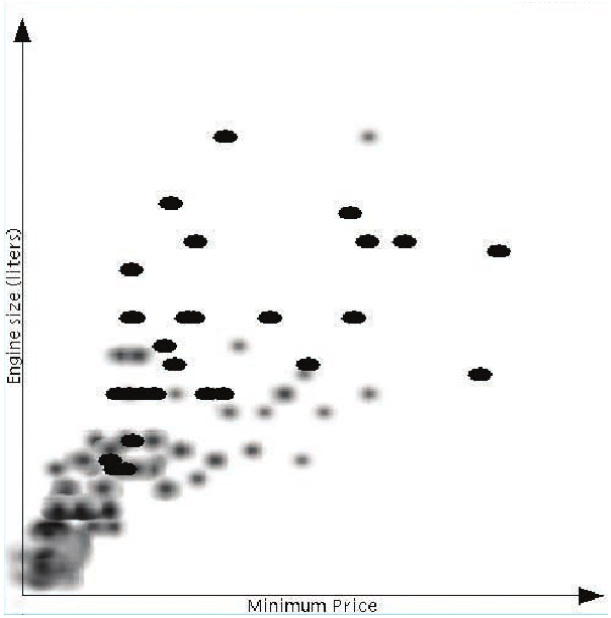
Practical issues: blur sometimes difficult to implement

Modulating Everything Else: Reccomendation, Example

Don‘t use unless the sole objective is to guide attention toward one (set of) items



[Zhai et al., 1997]



[Kosara et al., 2002]

CONNECTEDNESS AND COMMON REGION

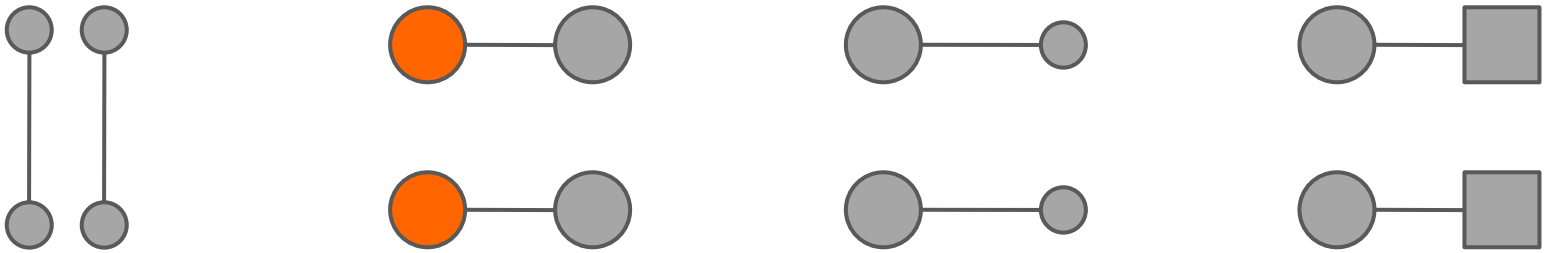
Connectedness

Scalability for # items: ok, special measures for many

Scalability for # relations: difficult if # items is non-trivial

Occlusion issues: problematic if no special measures are taken

A Little Experiment…



Proximity Color Size Shape

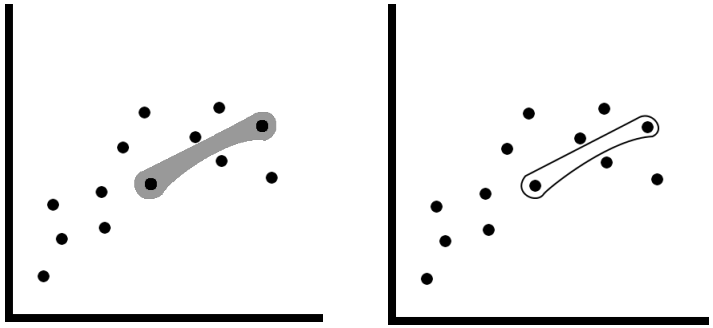
Connectedness

Perception issues:

- Connections can be perceived preattentively
- Very strong grouping principle
- Good at pointing at outliers

Practical Issues:

- Basic implementation trivial & fast
- Counter-balancing for the mentioned issues comes at a cost



Common Region

Very similar to Connectedness

- At what point is a line an area?

More „ink“ necessary

- Reduces possible # items and # relations
- Increases saliency
- Alternative if edges already used

Can be used with transparency to preserve BR

Connectedness Varieties

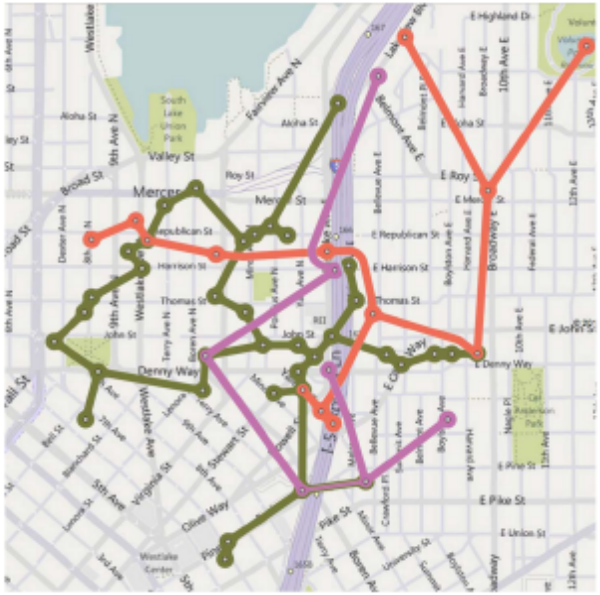
Bubble Sets

Image by [Dinkla et al., 2011]
Technique by [Collins et al.,2009]

Line Sets

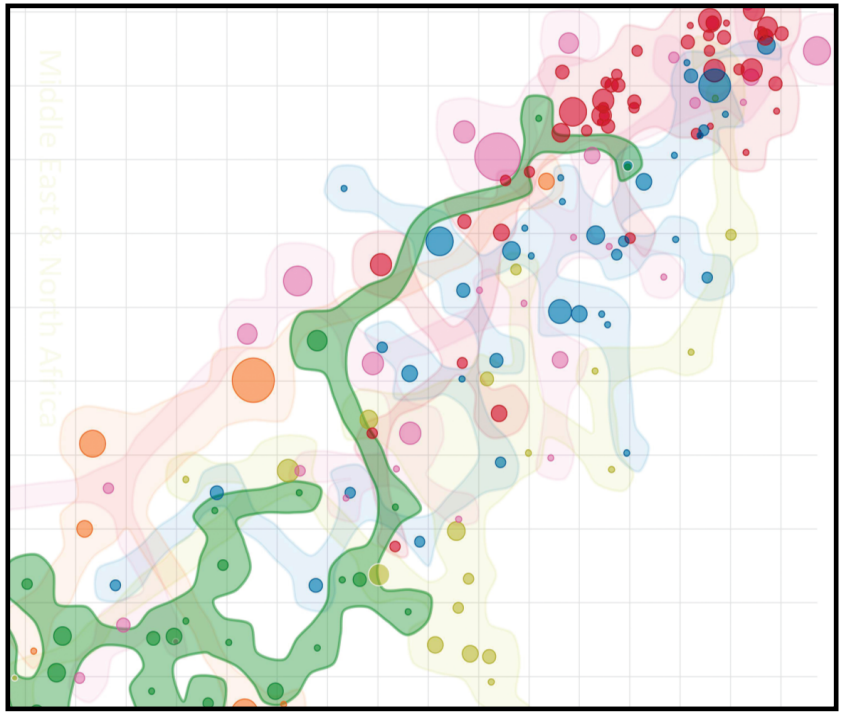
[Alper et al., 2011]

Kelp Diagrams

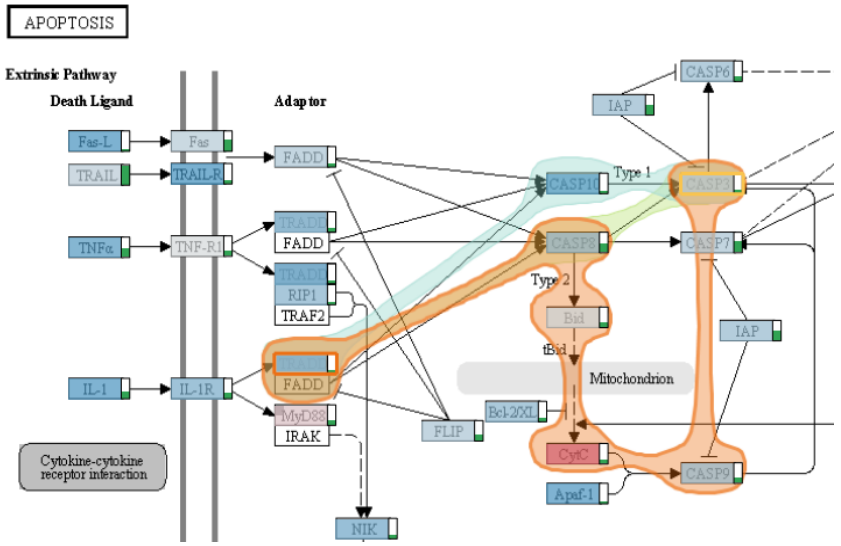


[Dinkla et al., 2012]

Bubble Sets



[Collins et al., 2009]

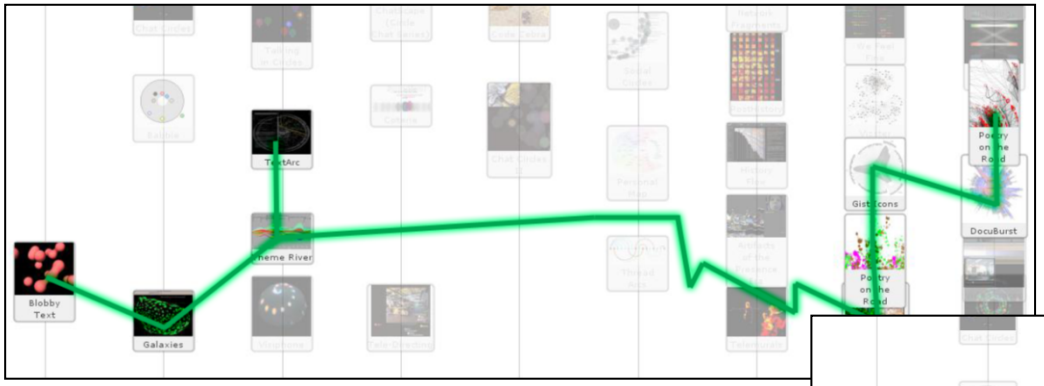


[Partl et al., 2012]

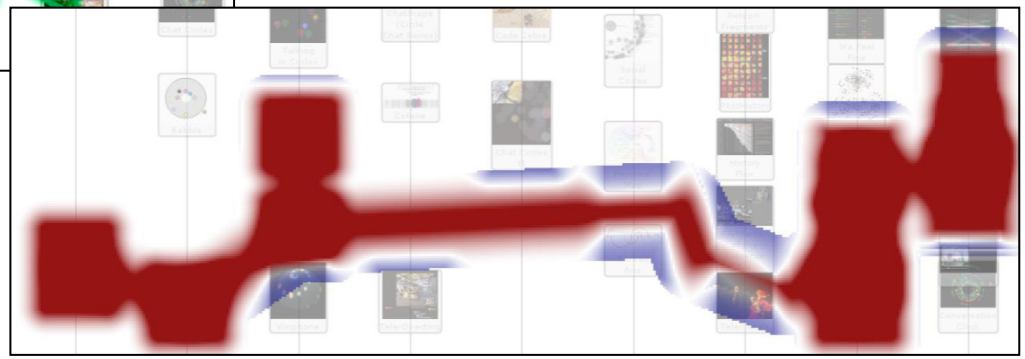
Bubble Sets

How it works:

Approach: connect nodes through virtual edges (route around obstacles) and compute a contour from this initial polyline



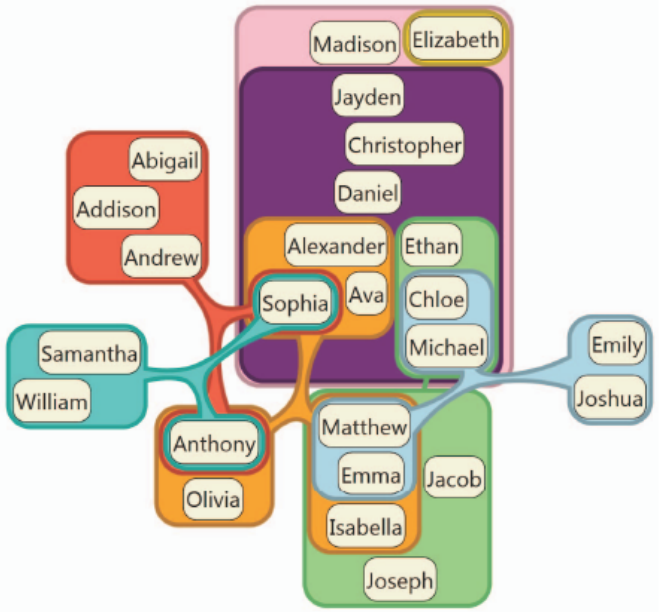
[Collins et al., 2009]



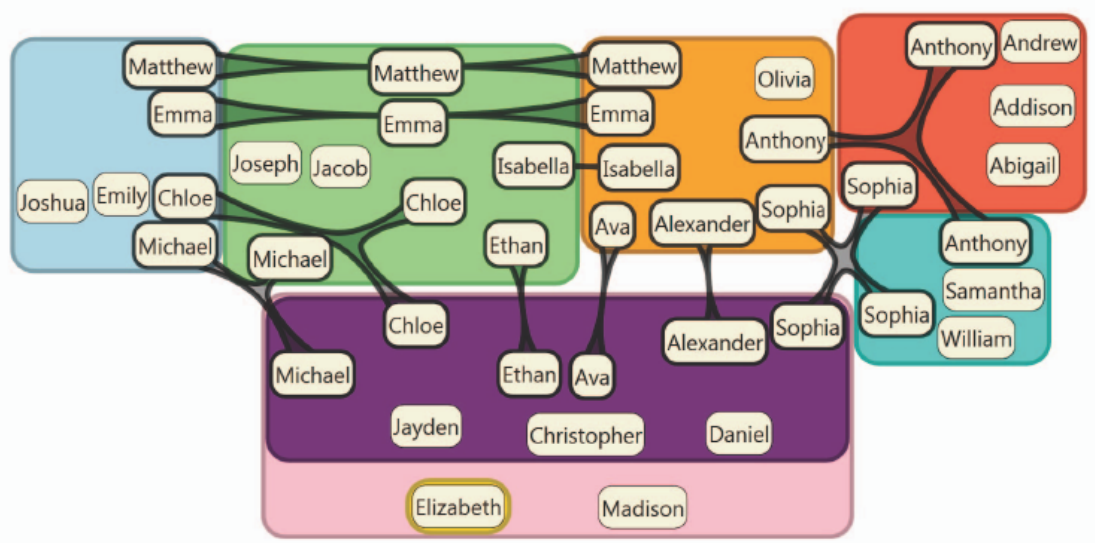
Positive (red) and negative (blue) energy fields, which guide the construction of the contour

“Advanced” Euler Diagrams

Compact Rectangular Euler Diagrams



Euler Diagrams with Duplicates

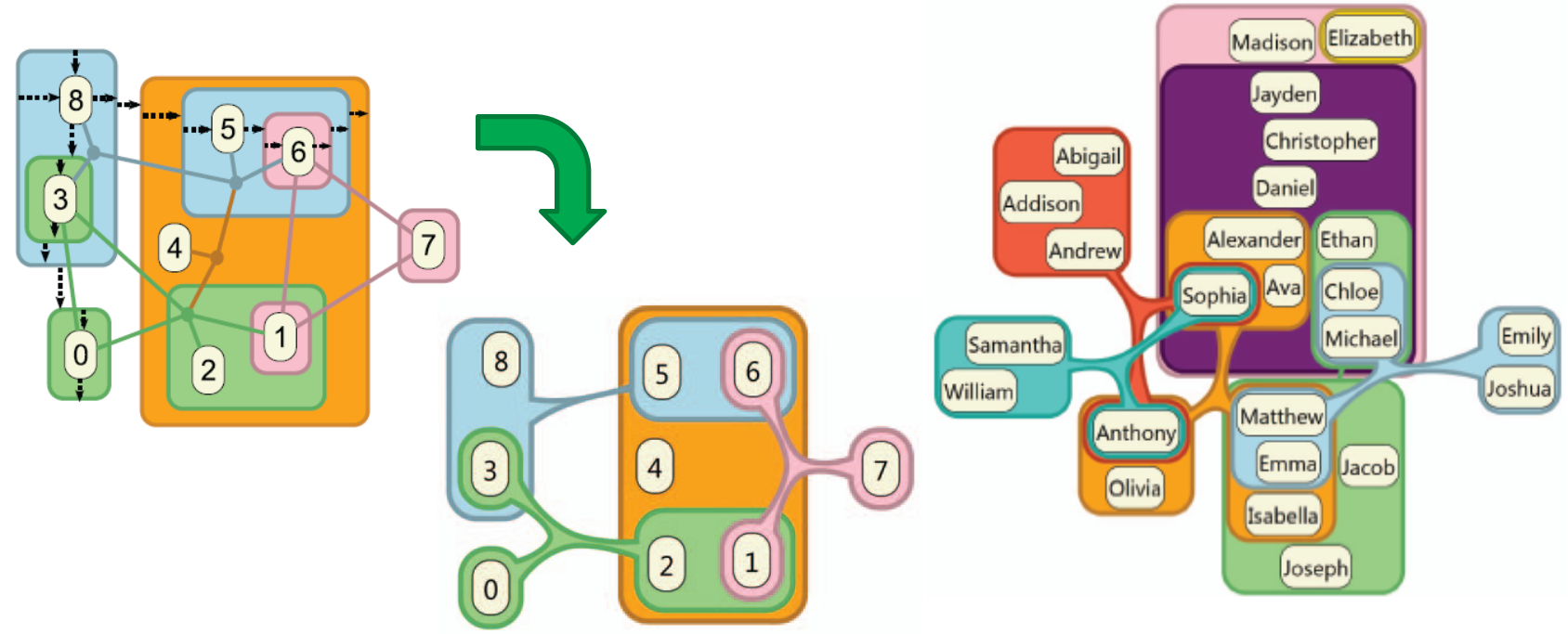


[Riche & Dwyer, 2010]

Compact Rectangular Euler Diagrams

How it works:

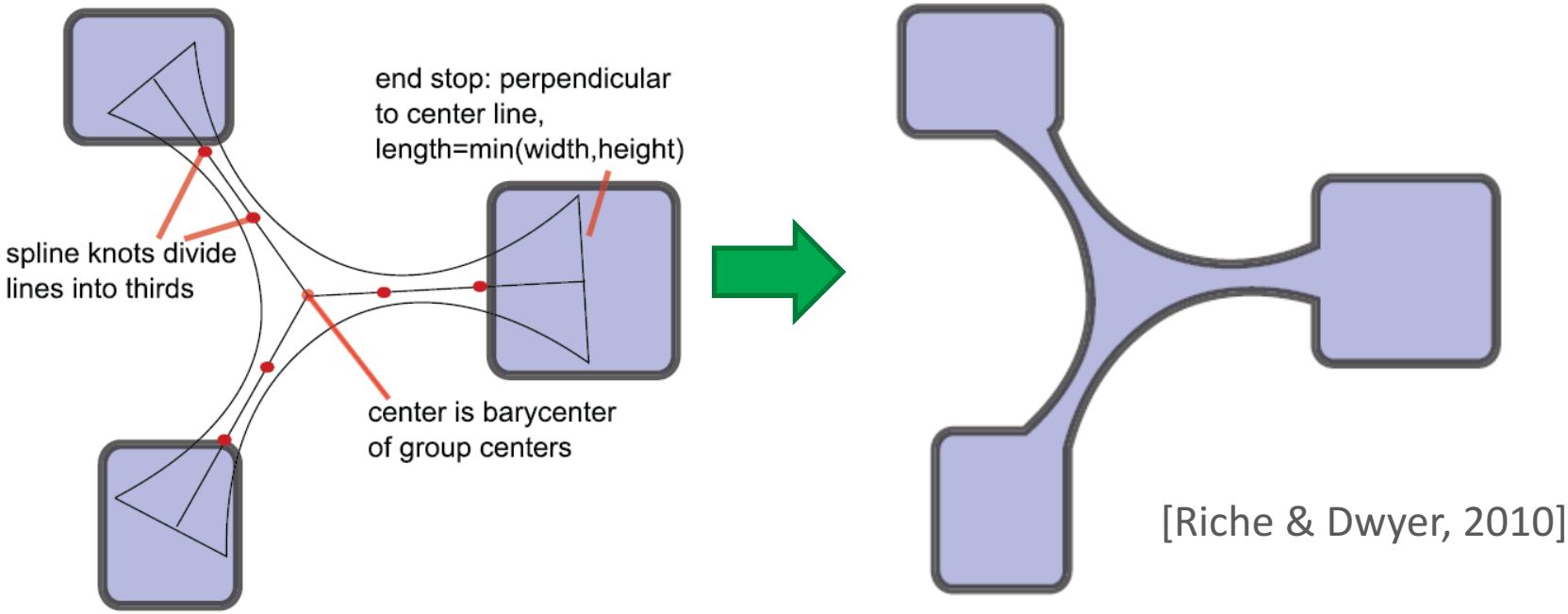
start with an edge representation, use a force directed layout and transform from edges to shapes



[Riche & Dwyer, 2010]

Compact Rectangular Euler Diagrams

How it works:



[Riche & Dwyer, 2010]

Addressing Scalability, Occlusion Issues

Scalability:

- Using abstraction
- Bundling

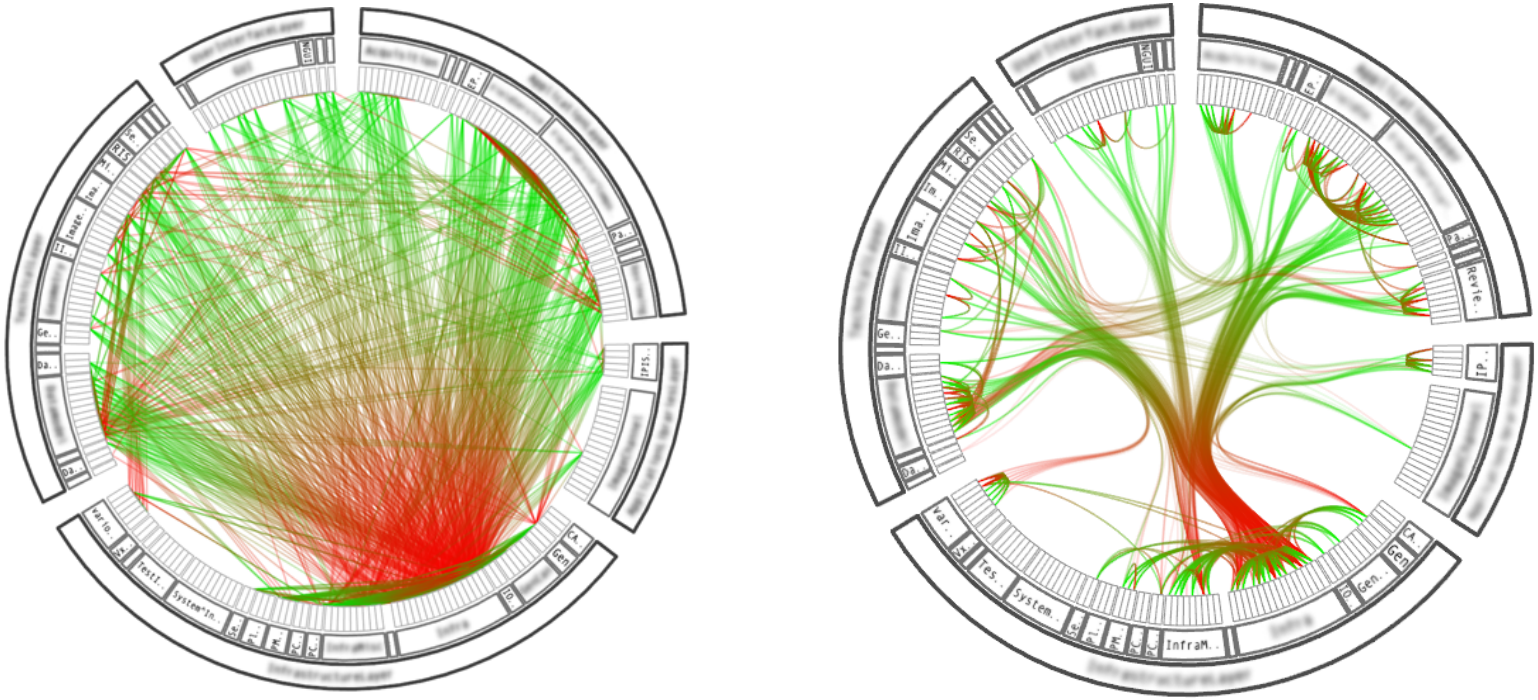
Occlusion

- Modifying the BR
- Routing

Bundling - HEB

Hierarchical Edge Bundling (HEB)

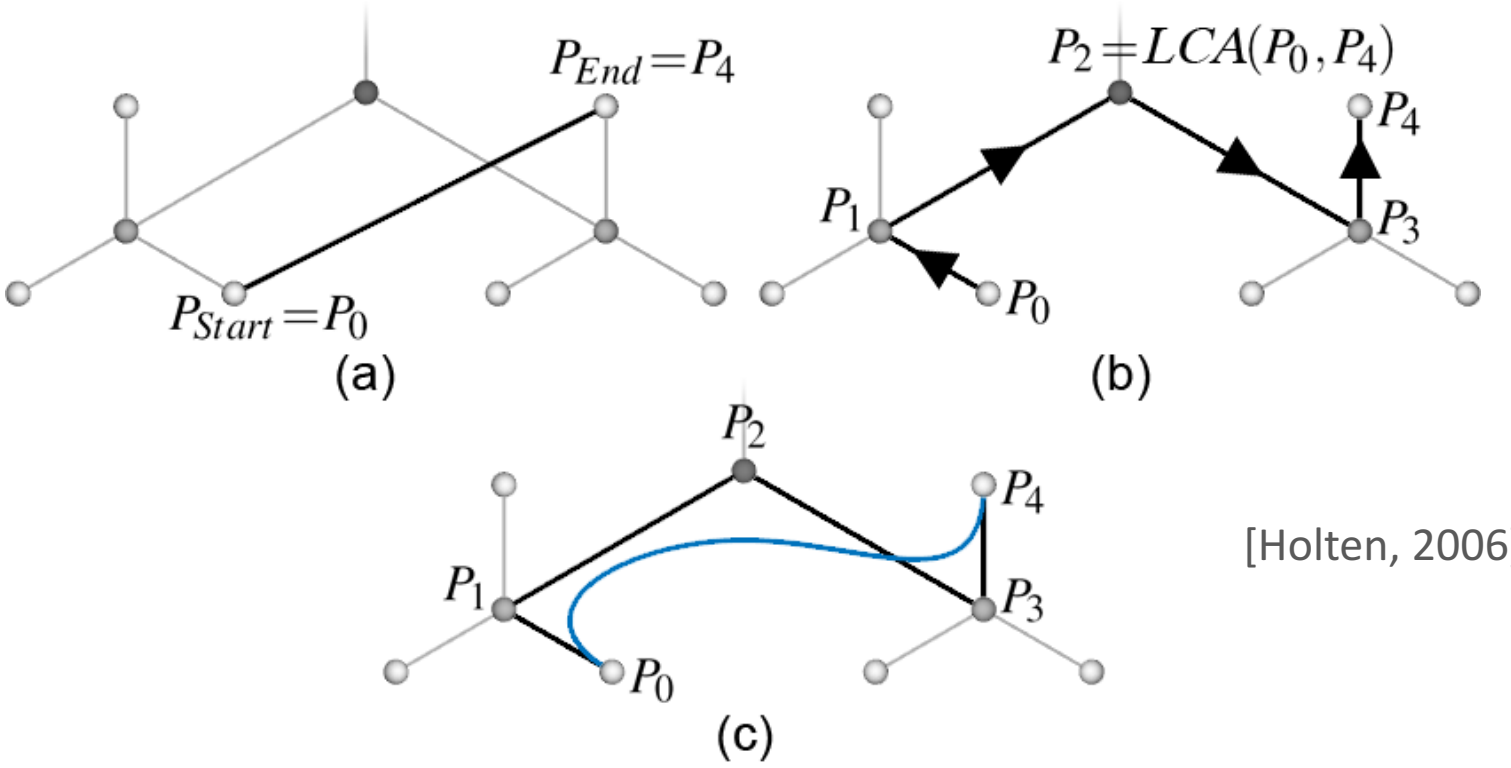
Can be used for links within a tree.



[Holten, 2006]

Bundling - HEB

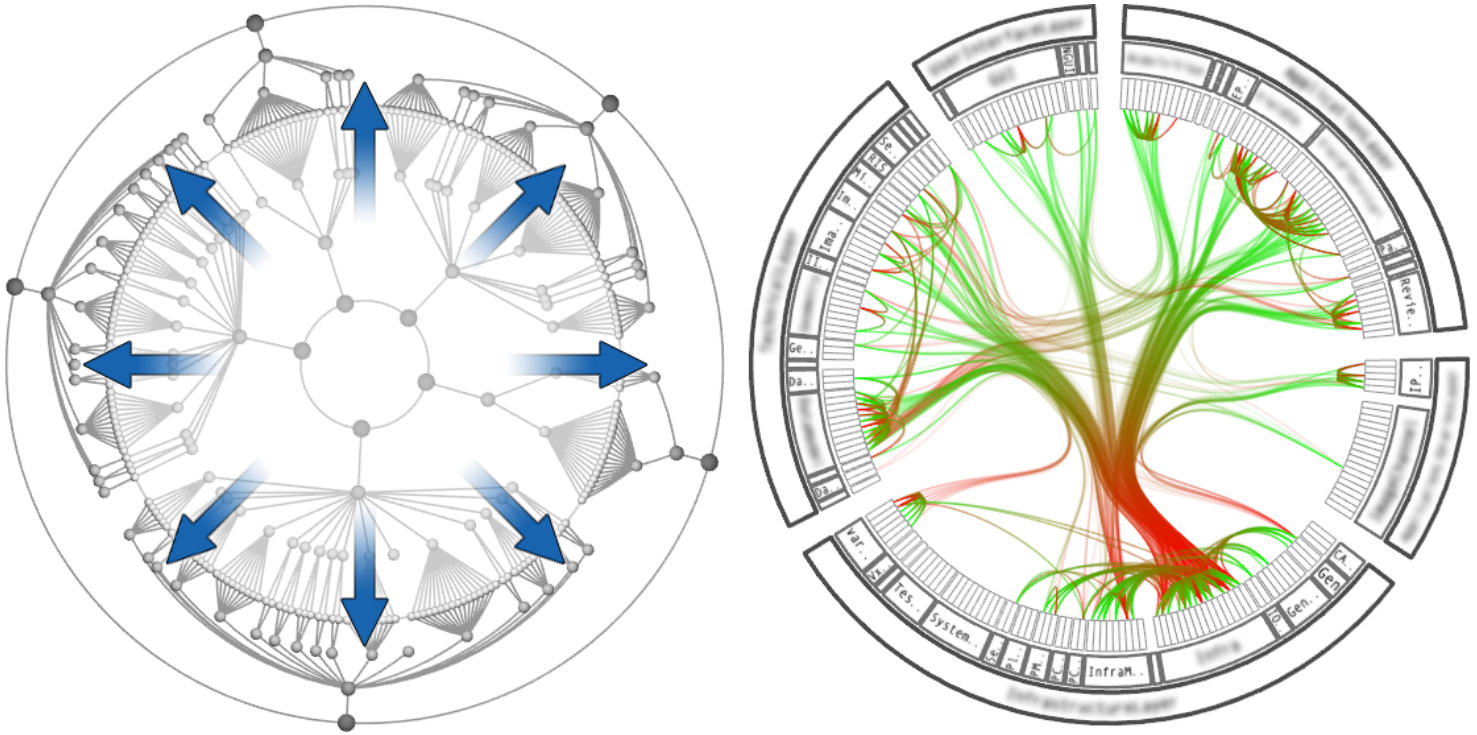
How it works:



[Holten, 2006]

Bundling - HEB

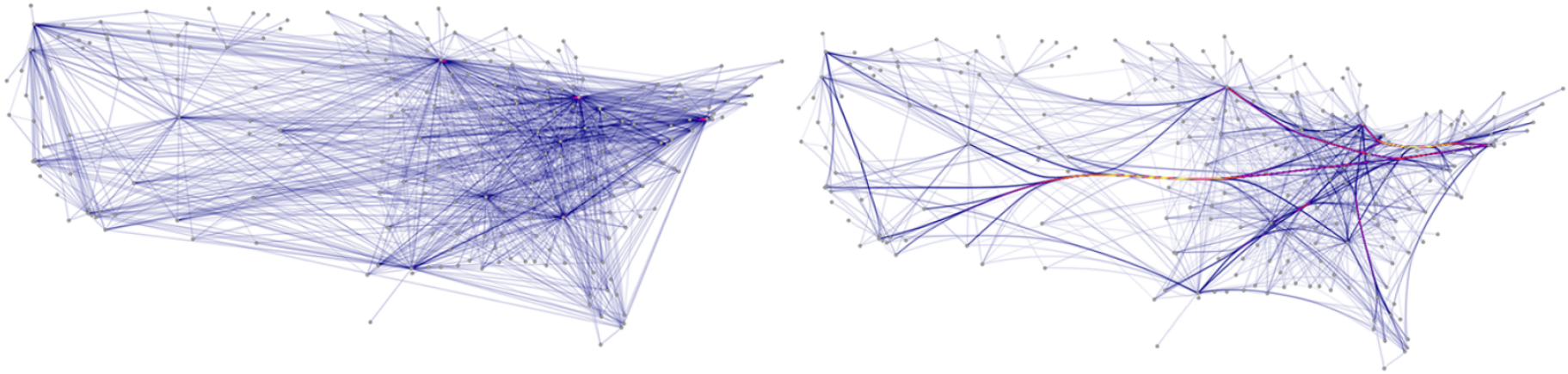
The underlying structure



[Holten, 2006]

Bundling - FEB

Force-Directed Edge Bundling

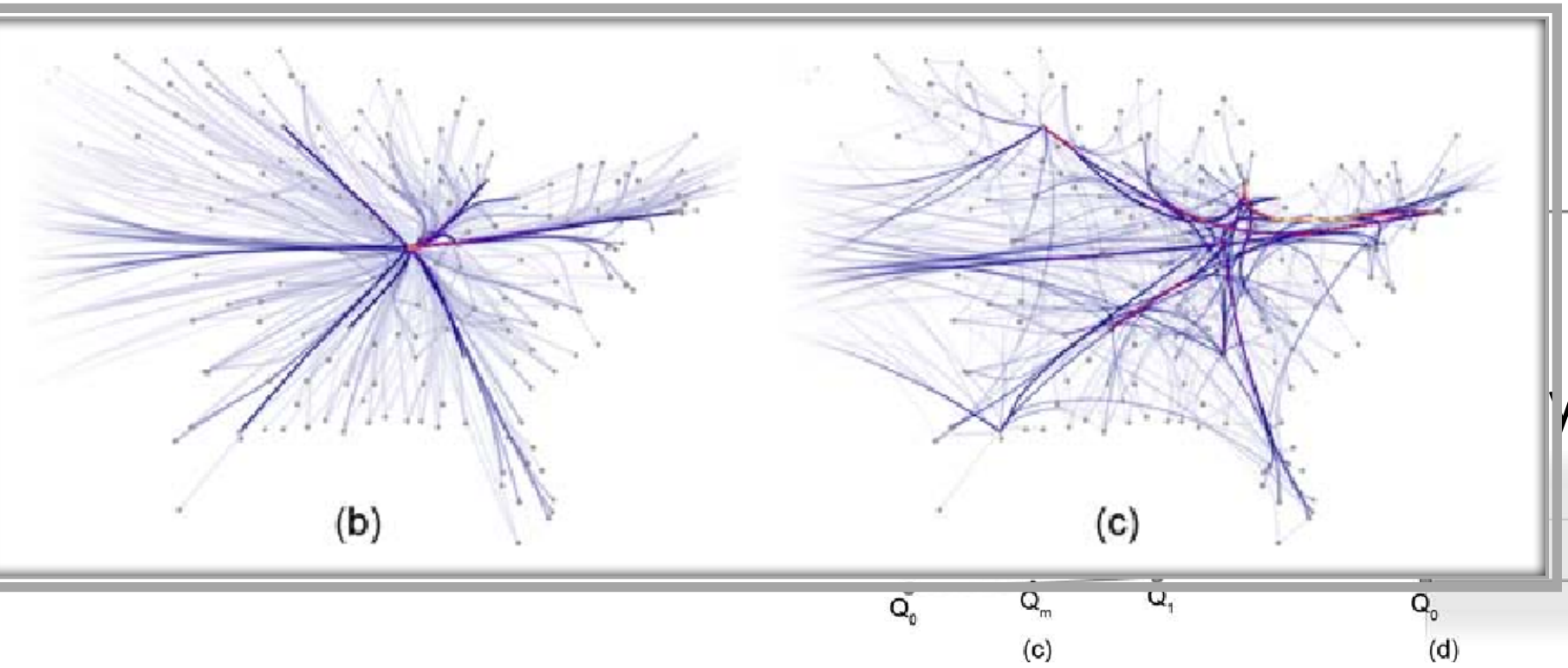


[Holten & van Wijk, 2009]

Bundling - FEB

How it works:

Edge Comaptibility

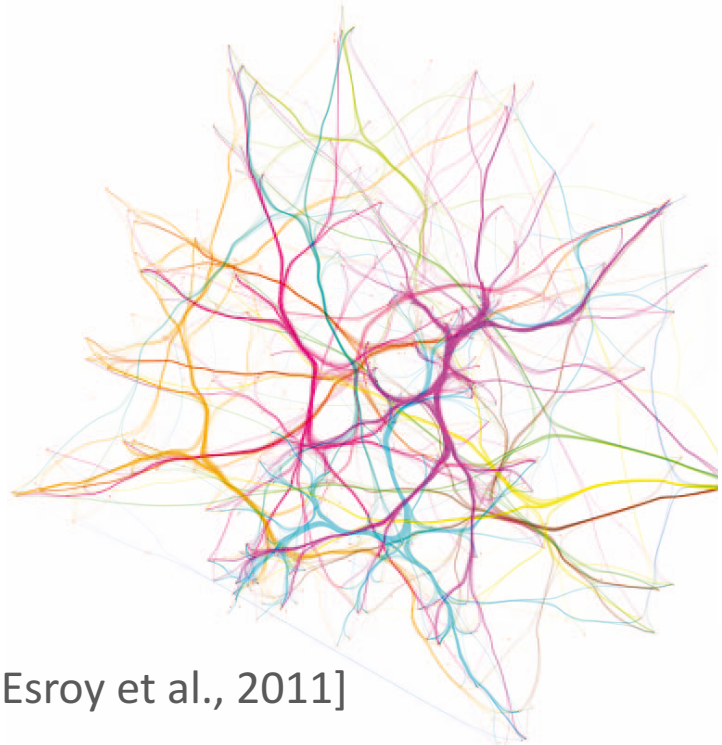


[Holten & van Wijk, 2009]

Other Bundling Approaches

Skeleton-based edge bundling

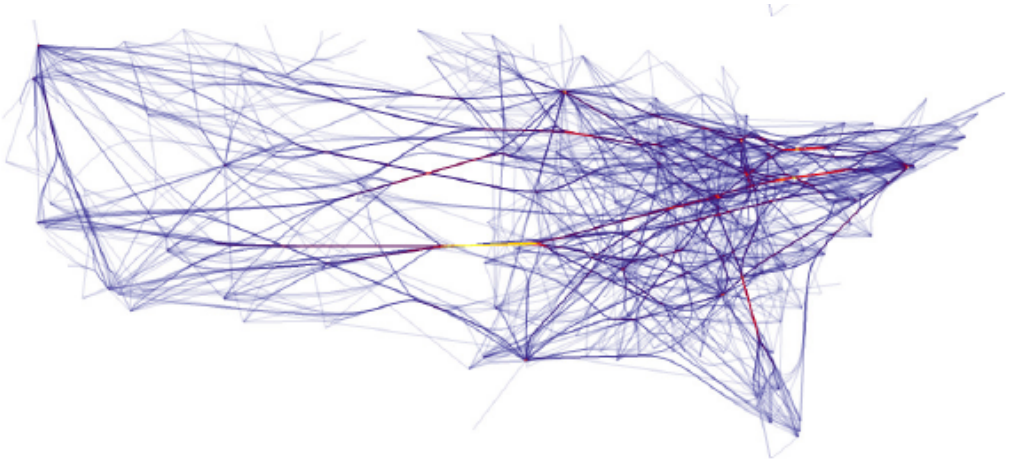
based on Clustering



[Esroy et al., 2011]

Agglomerative bundling

minimizing ink (collapsing edges in proximity)



[Gansner et al., 2011]

Case Study Context-Preserving Visual Links

ROUTING

Material based on InfoVis 2011 Talk by Markus Steinberger

Again a little experiment ;) …

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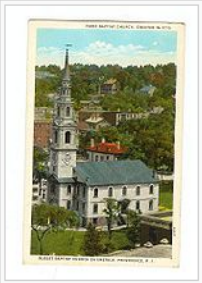

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In the mid-1770s, the British government levied taxes that impeded Providence's maritime, fishing and agricultural industries, the mainstay of the city's economy. One example was the Sugar Act, which was a tax levied against Providence's distilleries that adversely affected its trade in rum and slaves. These taxes caused Providence to join the other colonies in renouncing allegiance to the British Crown. In response to enforcement of unpopular trade laws, Providence residents spilled the first blood of the American Revolution in the notorious Gaspée Affair of 1772.[13]

Providence in the mid-nineteenth century

NPS map of the W3R Route

Though during the Revolutionary War the city escaped enemy occupation, the capture of nearby Newport disrupted industry and kept the population on alert. Troops were quartered for various campaigns and Brown University's University Hall was used as a barracks and military hospital.[13]

After departing from Newport, French troops sent by King Louis XVI and commanded by the Comte de Rochambeau passed through Providence on their way to join the attack against British forces. The march from Newport to Providence was the beginning of a campaign led jointly by General George Washington in a decisive march that ended with the defeat of General Cornwallis in the Siege of Yorktown at Yorktown, Virginia and the Battle of the Chesapeake.

Following the war, Providence was the country's ninth-largest city.[b][13] with 7,614 people. The economy shifted from maritime endeavors to manufacturing, particularly machinery, tools, silverware, jewelry and textiles. By the turn of the twentieth century, Providence boasted some of the largest manufacturing plants in the country, including Brown & Sharpe

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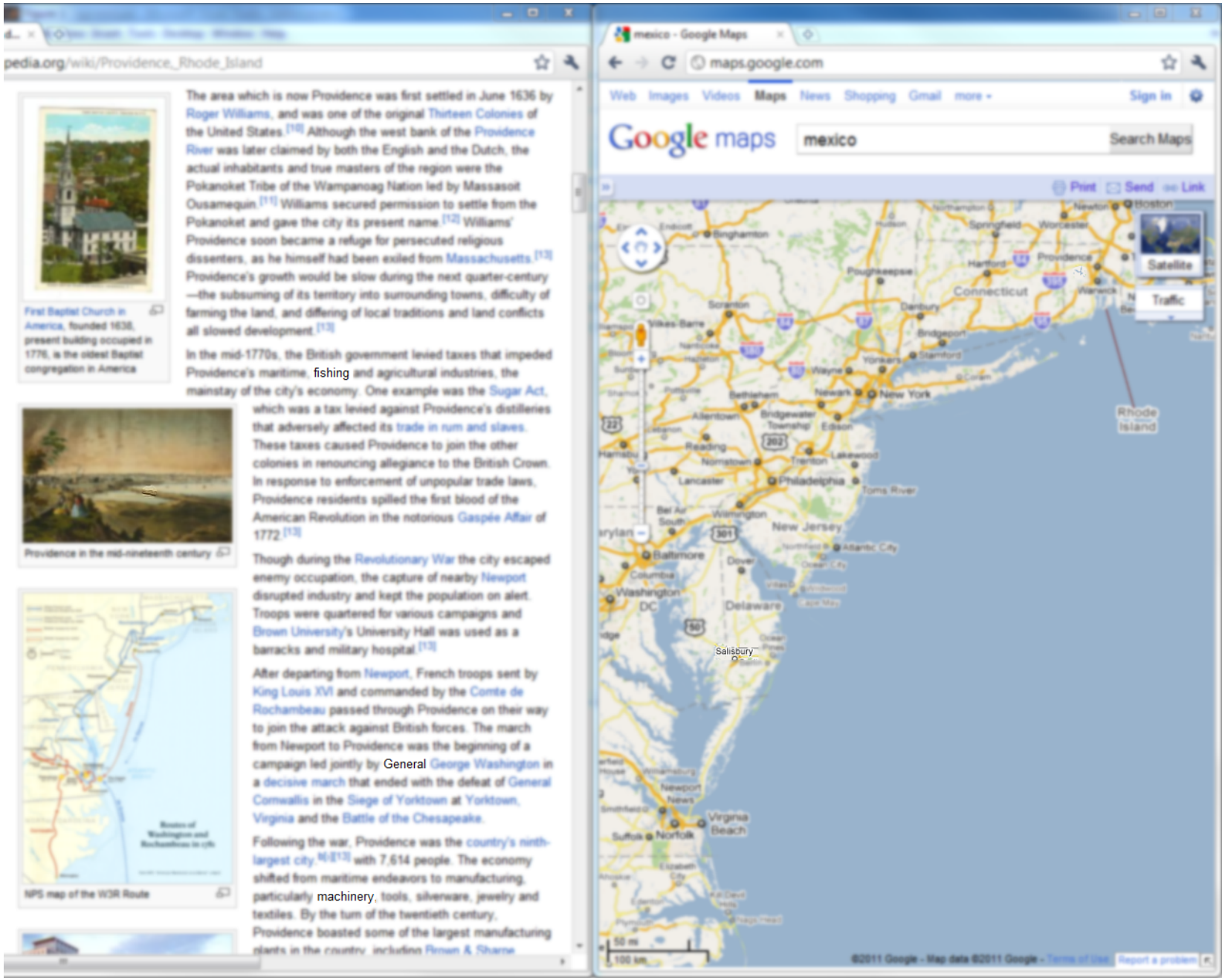
pedia.org/wiki/Providence,_Rhode_Island
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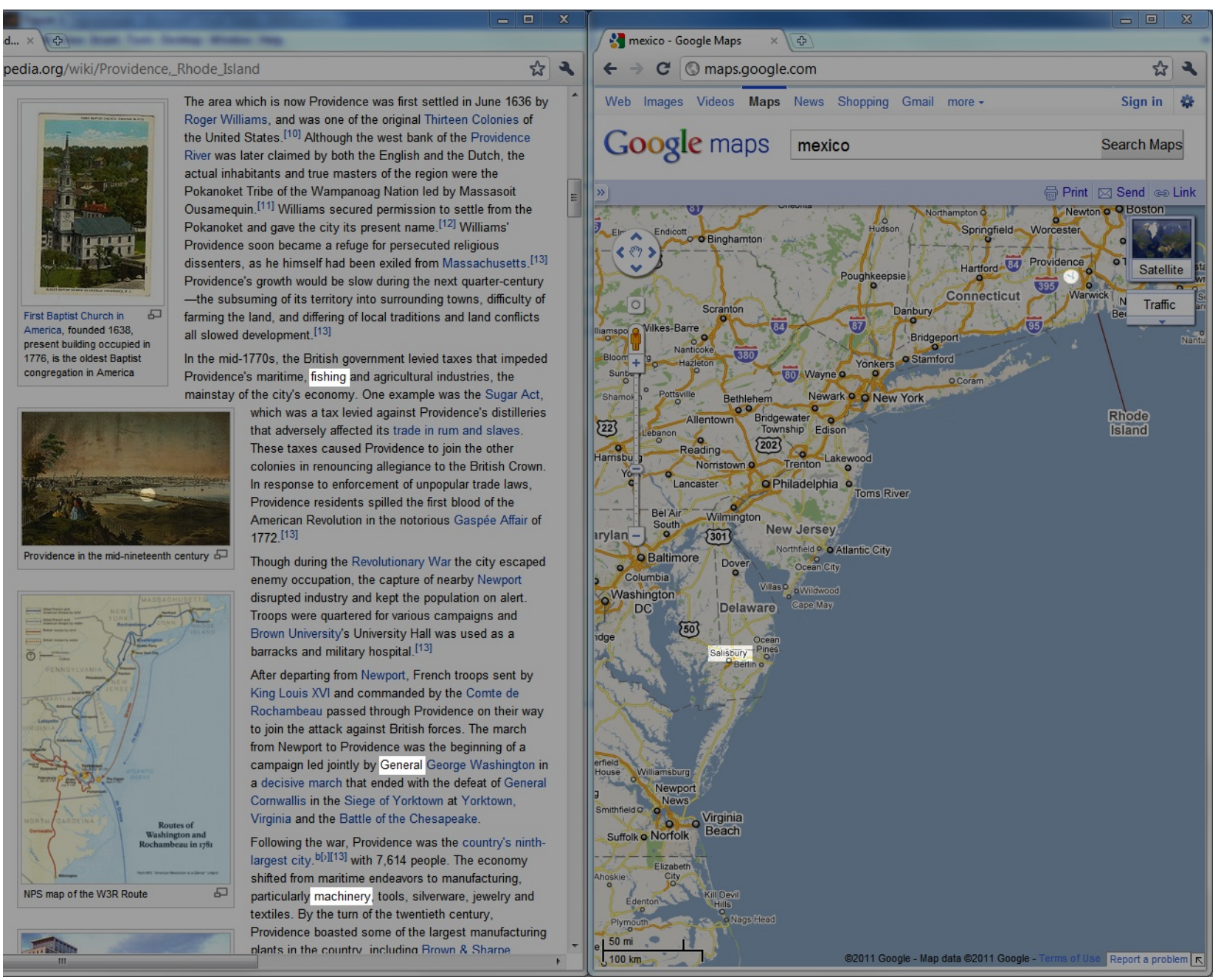
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Routes of Washington and Rochambeau in 1781
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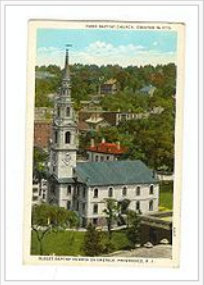

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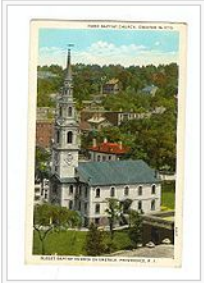

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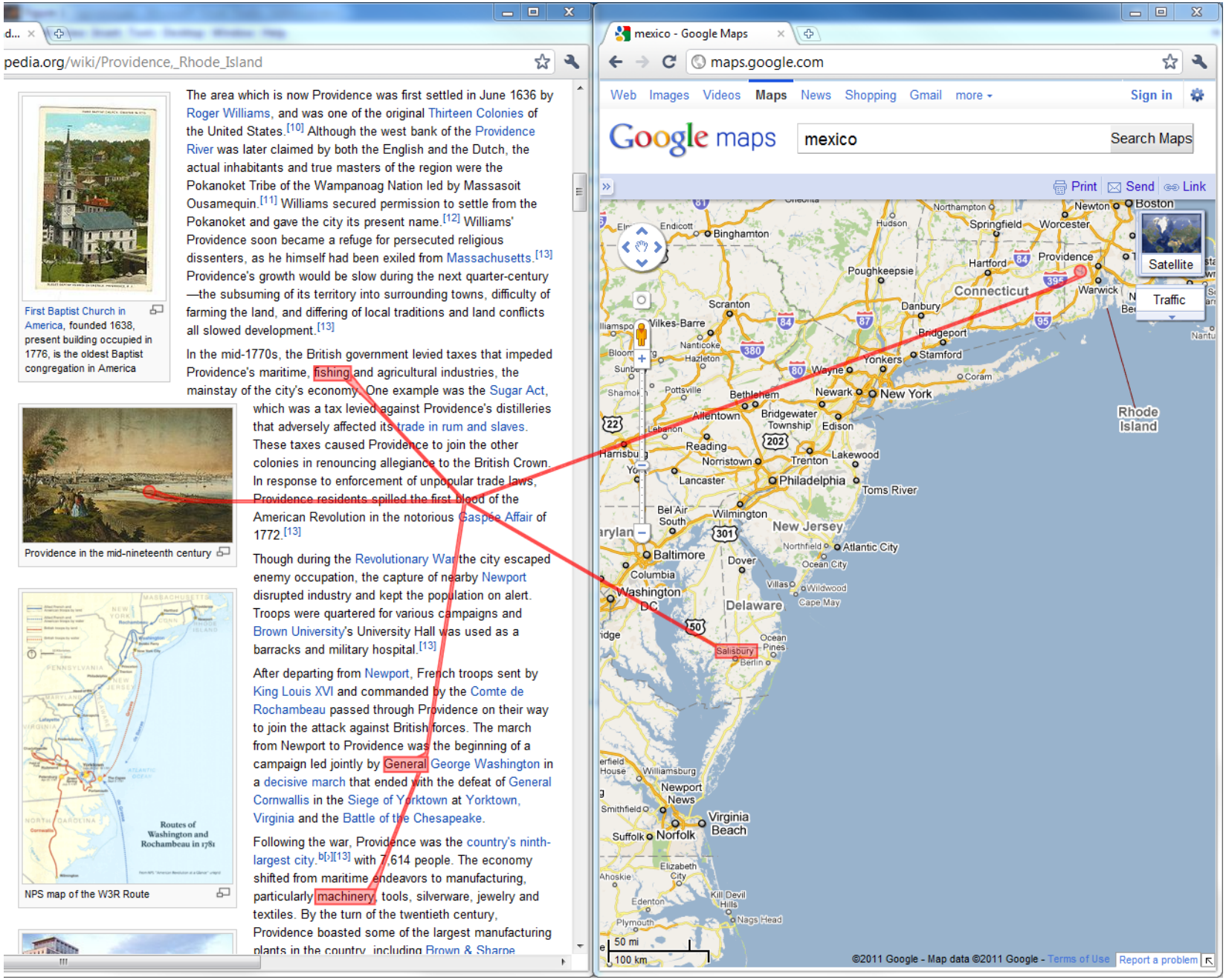
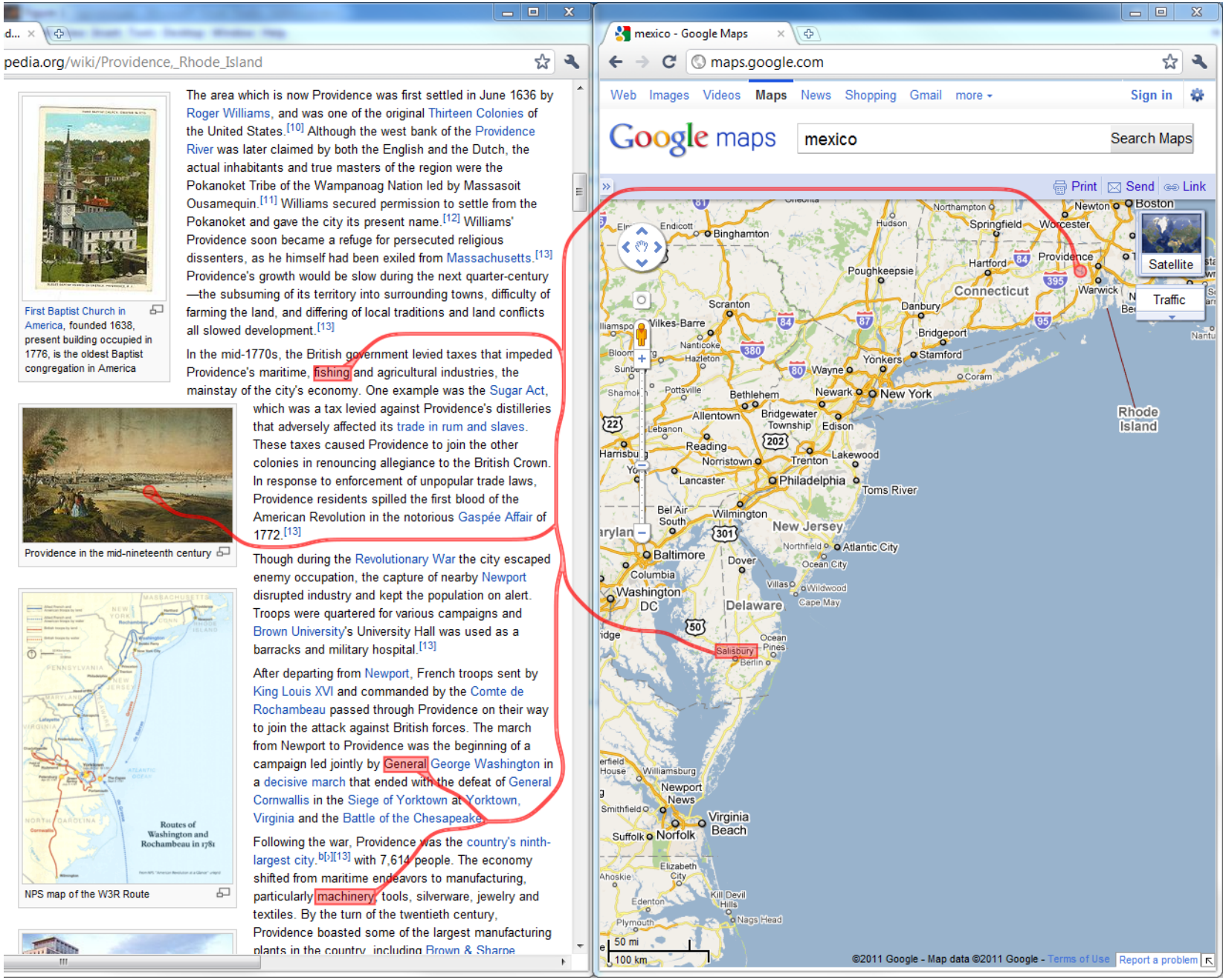


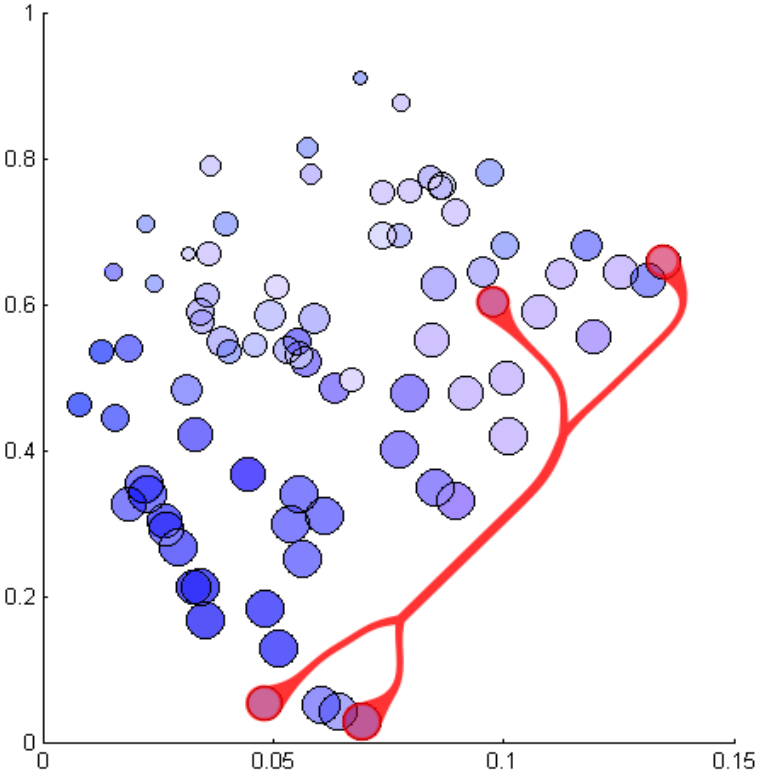
What is the problem?



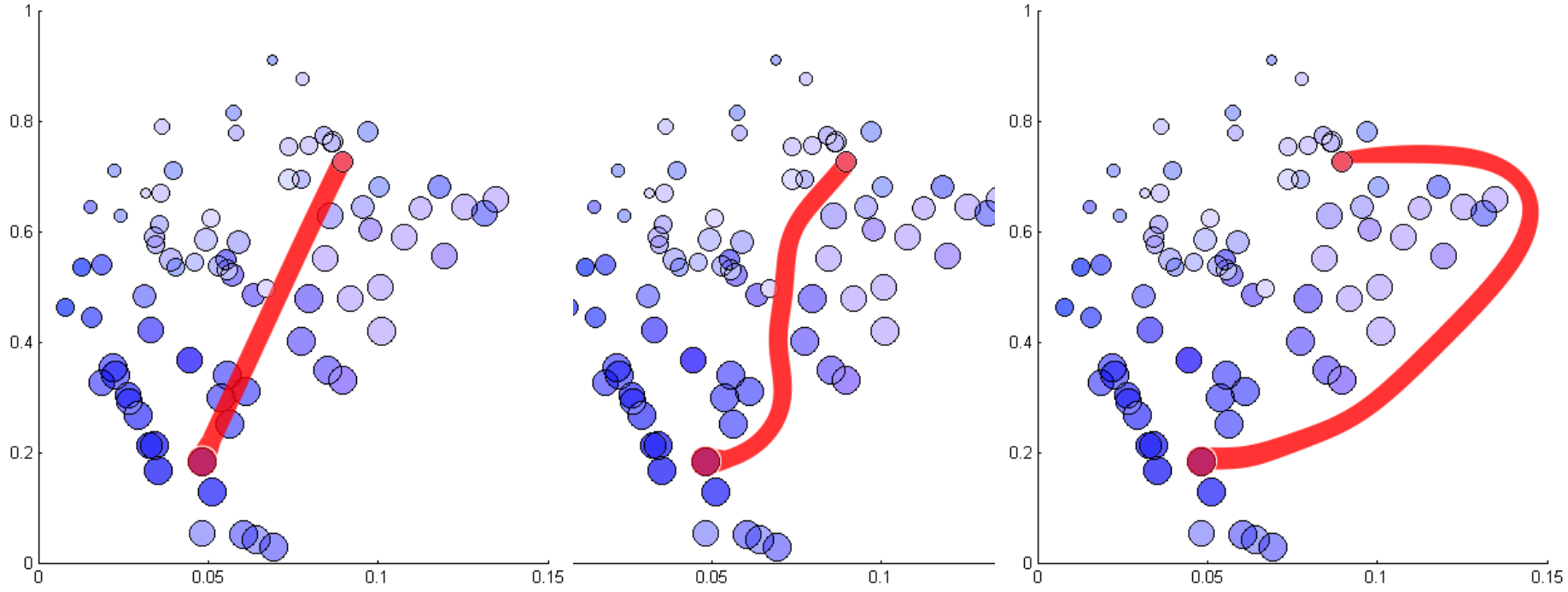
Context-Preserving Visual Links

Design Goals: Optimal link routes…

1. minimal length
2. minimal occluded information
3. visually distinguishable
4. unnecessary link-segments are avoided (bundling)



Tradeoff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System Overview

Important Content

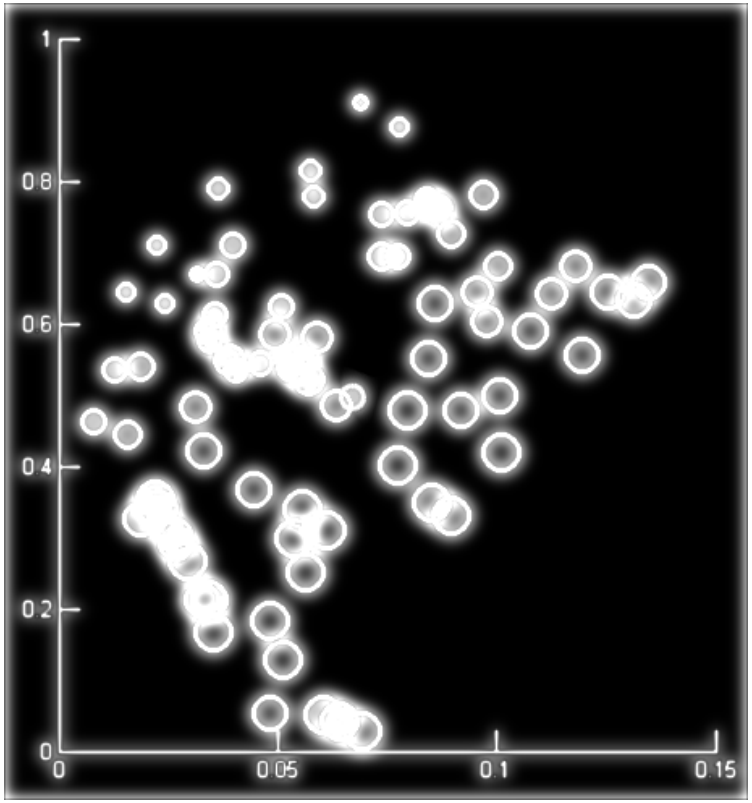
Bottom-Up Visual Saliency

[Itti 98]

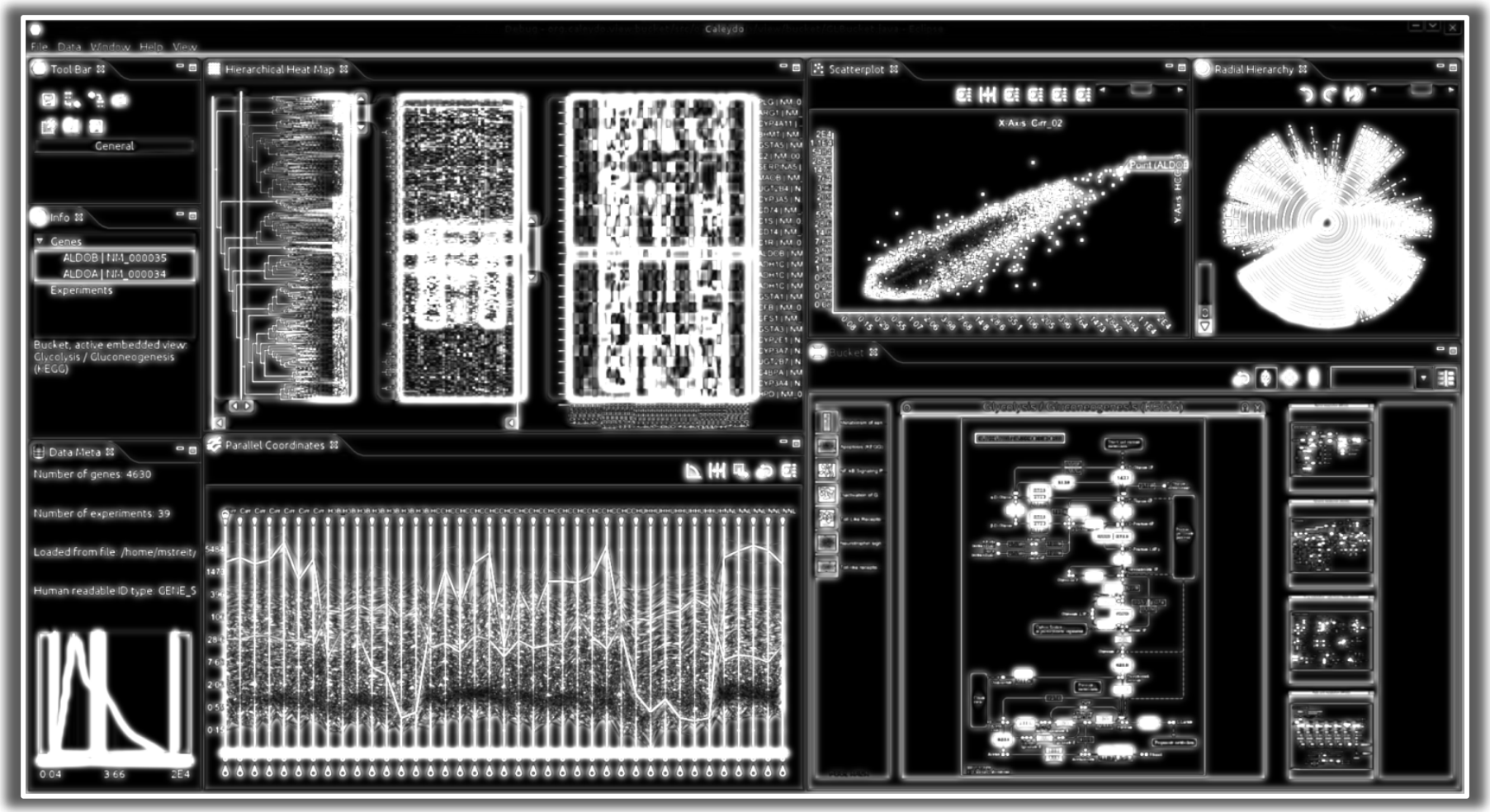
Based on human visual system

What stands out in images

Ignores high-level cognitive system



Saliency for a complex scene

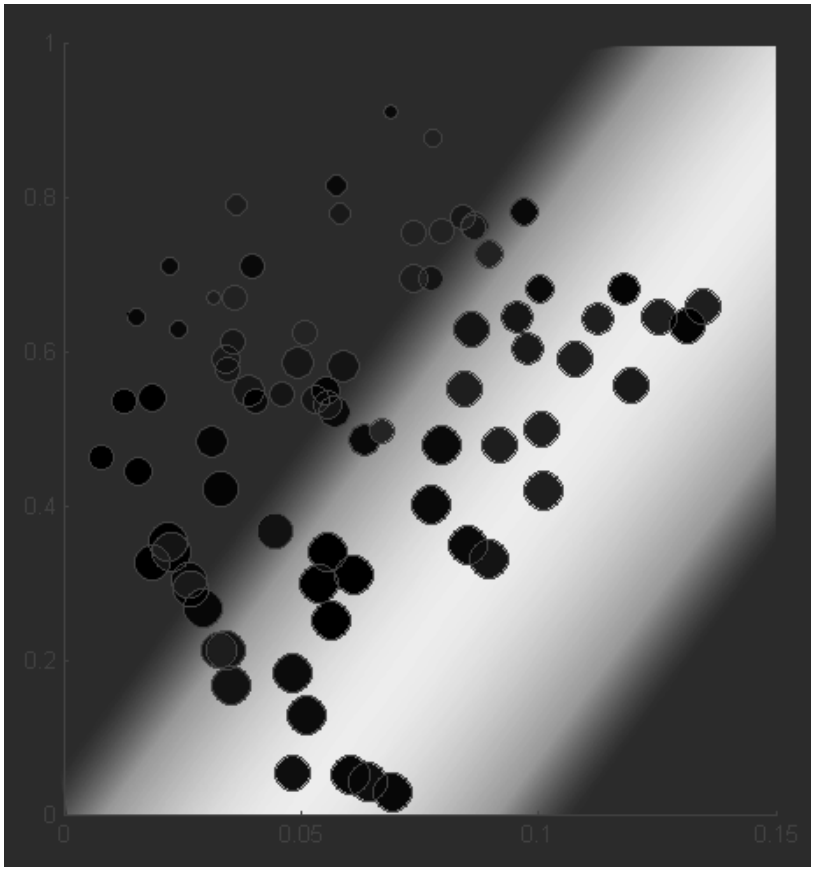


Color Similarity

Non-fixed link color:
choose distinguishable color

Otherwise: compute color similarity for every region

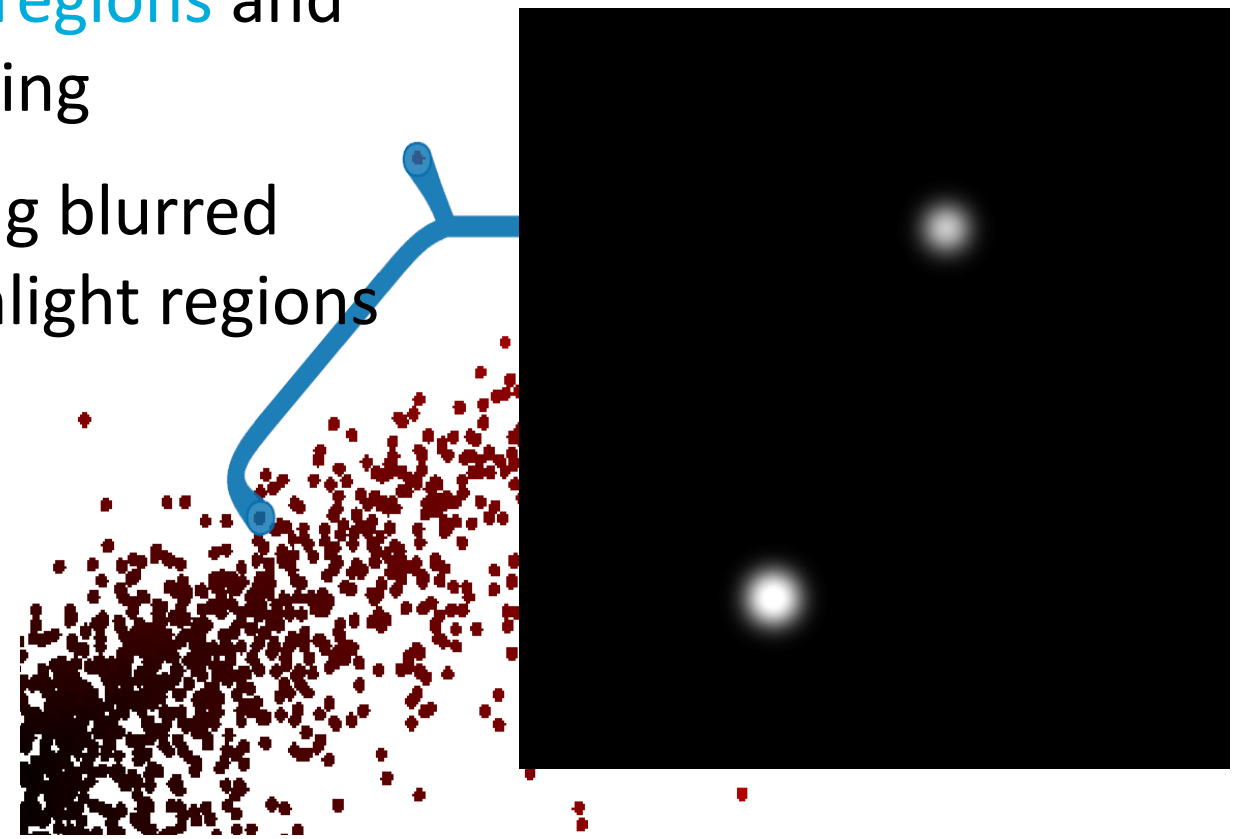
Requires base representation as image



Highlight Regions

Avoid highlight regions and their surrounding

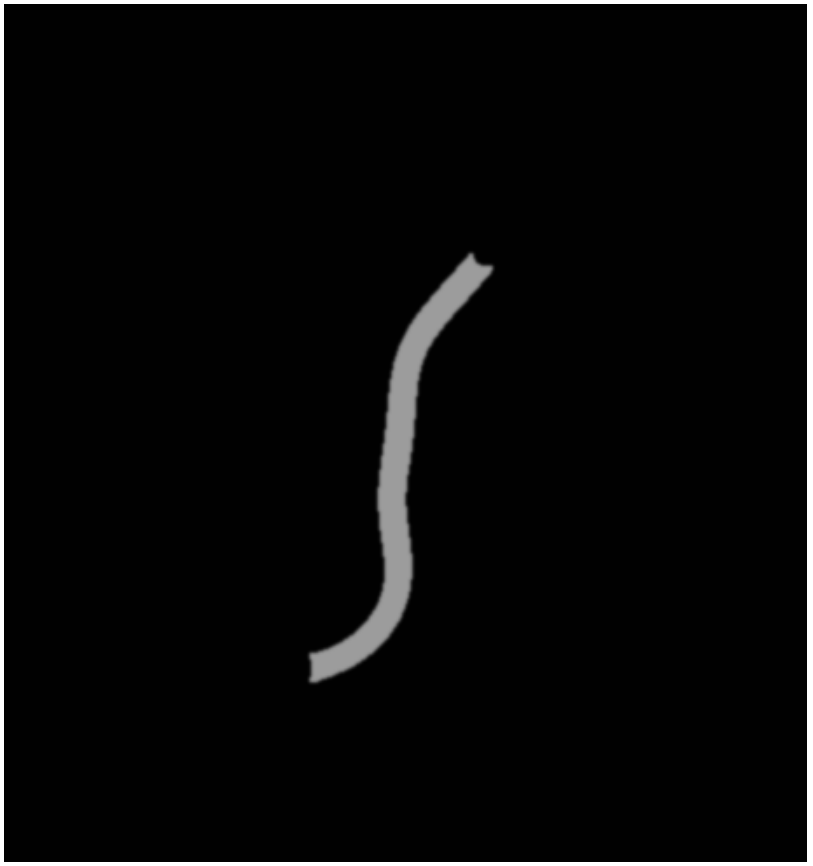
Realized by using blurred version of highlight regions



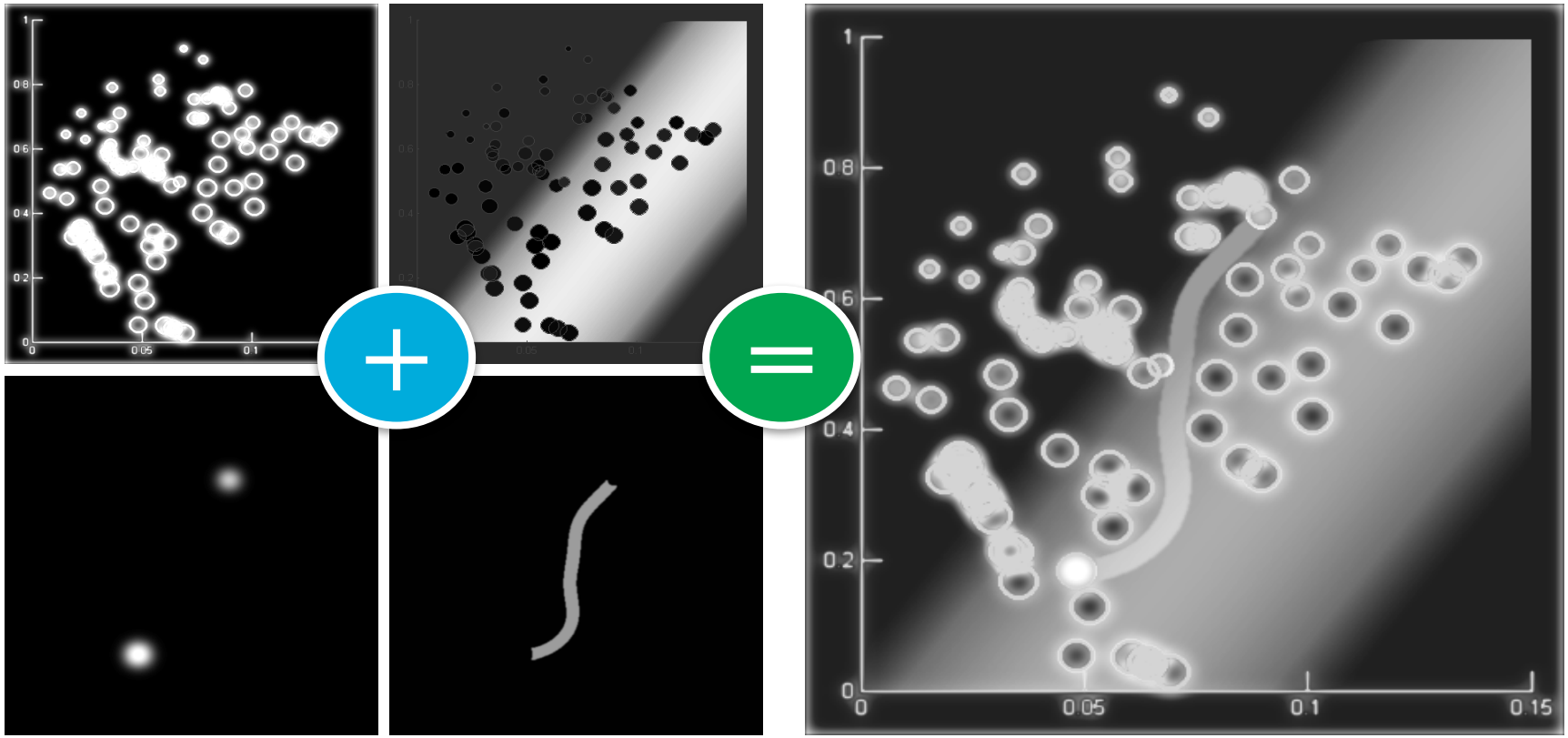
Other Link Sets

To support multiple linksets, we require a fixed priority among the linksets

Add high priority links as regions to avoid



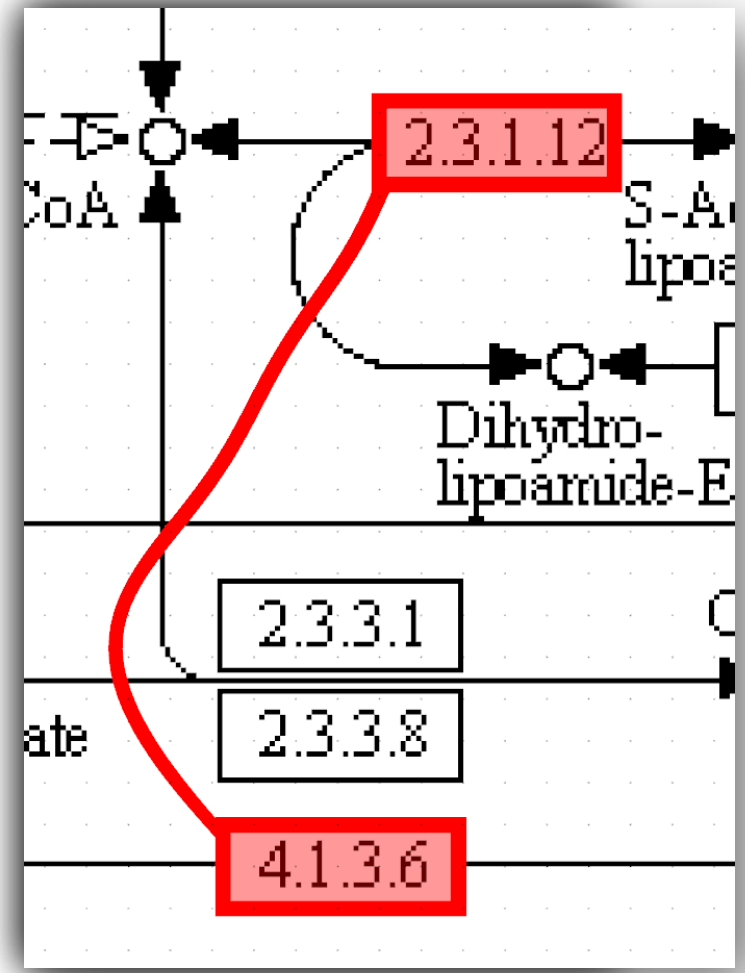
Combined Penalties



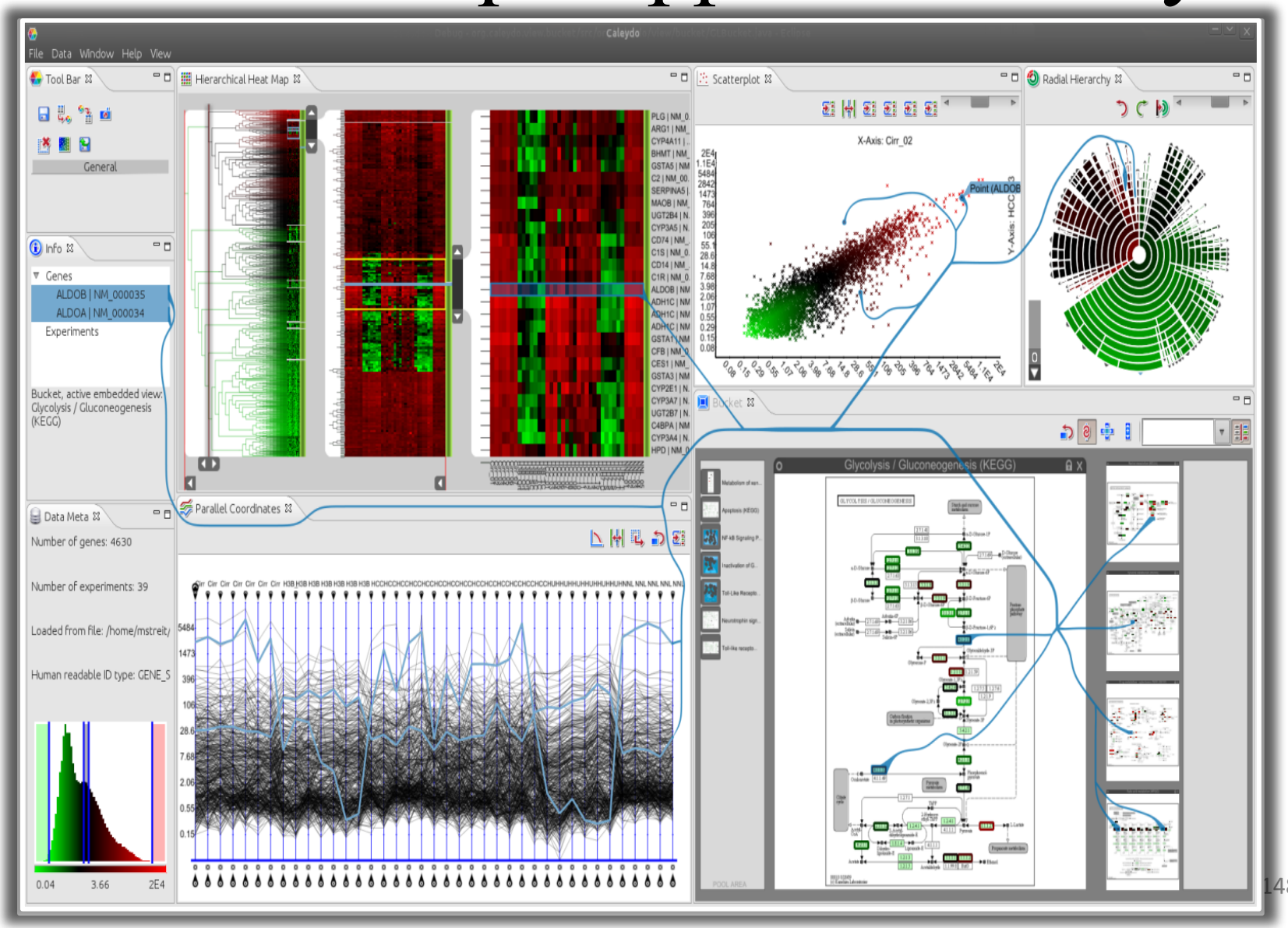
System Overview

Routing

- Multiple source shortest path problem
- Penalty map for crossing different regions
- Discretized version
- Modified version of Dijkstra‘s Algorithm



Technique applied to Caleydo



Evaluation: Hypothesis

Visual links lead to a better performance than conventional highlights.

Context-preserving visual links do not have a negative impact on performance.

Context-preserving visual links have a positive impact on user satisfaction.

Task: Visual Search

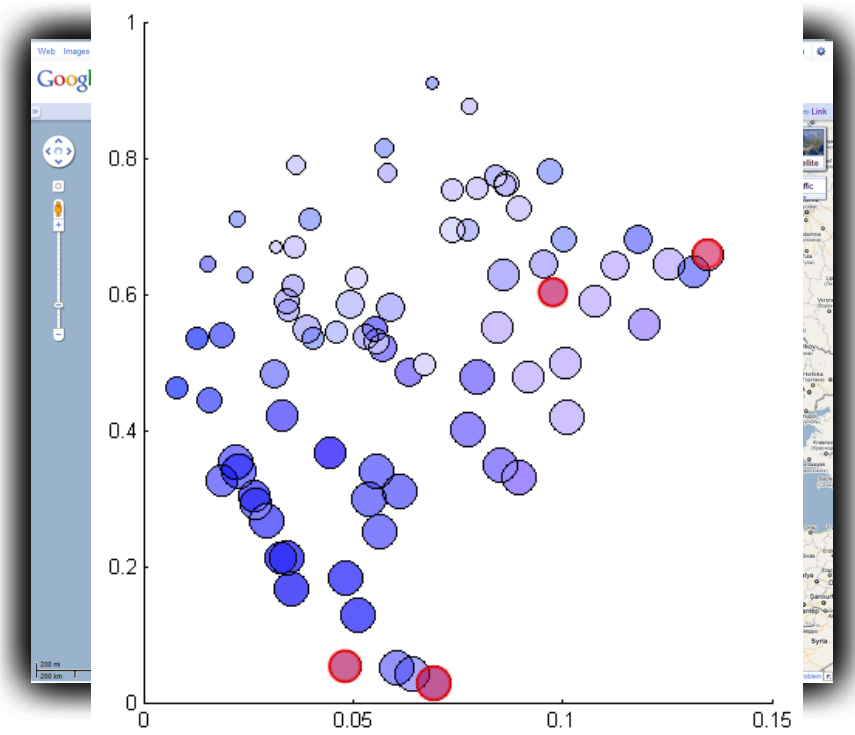
Count number of highlight regions (5 to 12)

Correctness and speed

Variety of visualizations

Eye-Tracker

Context information not required for task

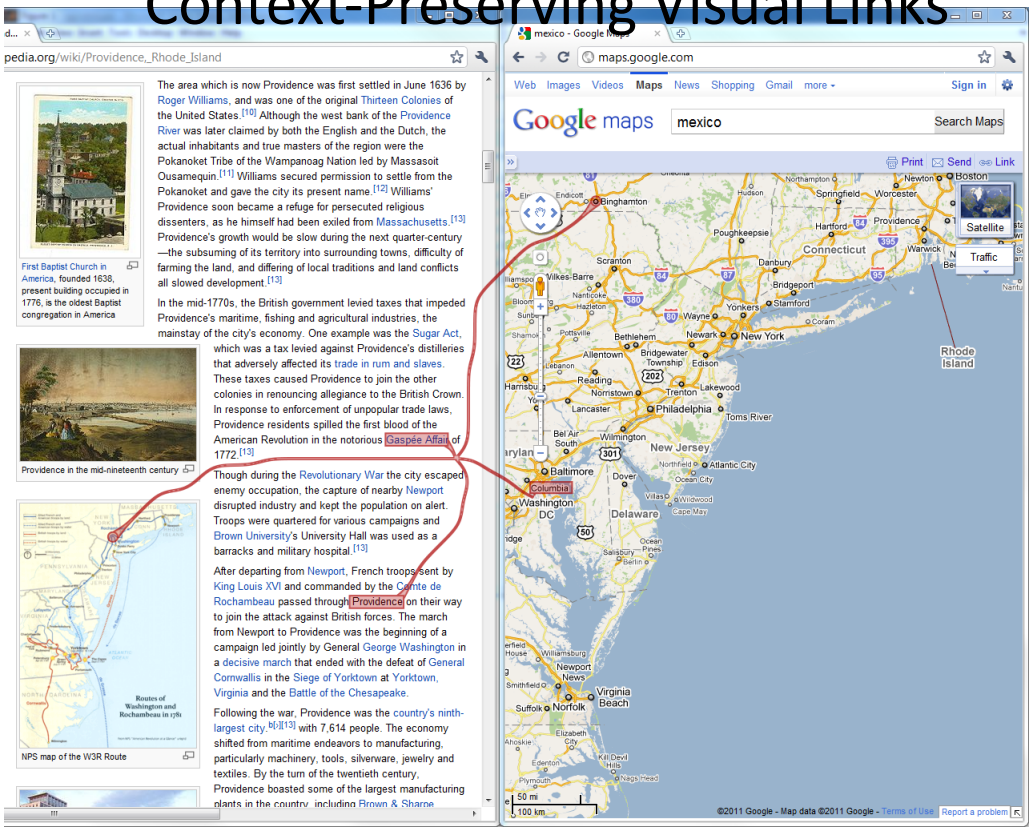


Three Techniques

Frame/color based highlighting

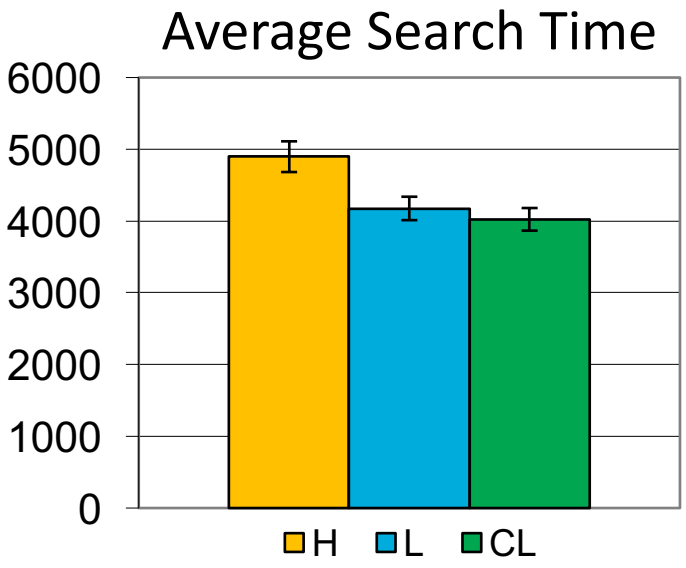
Straight Visual Links

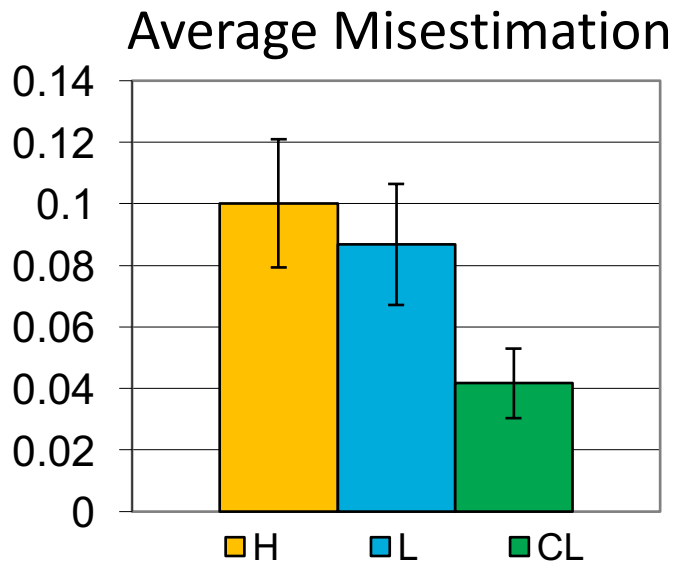
Context-Preserving Visual Links



Results

- Visual links lead to a better performance than negative impact on performance.

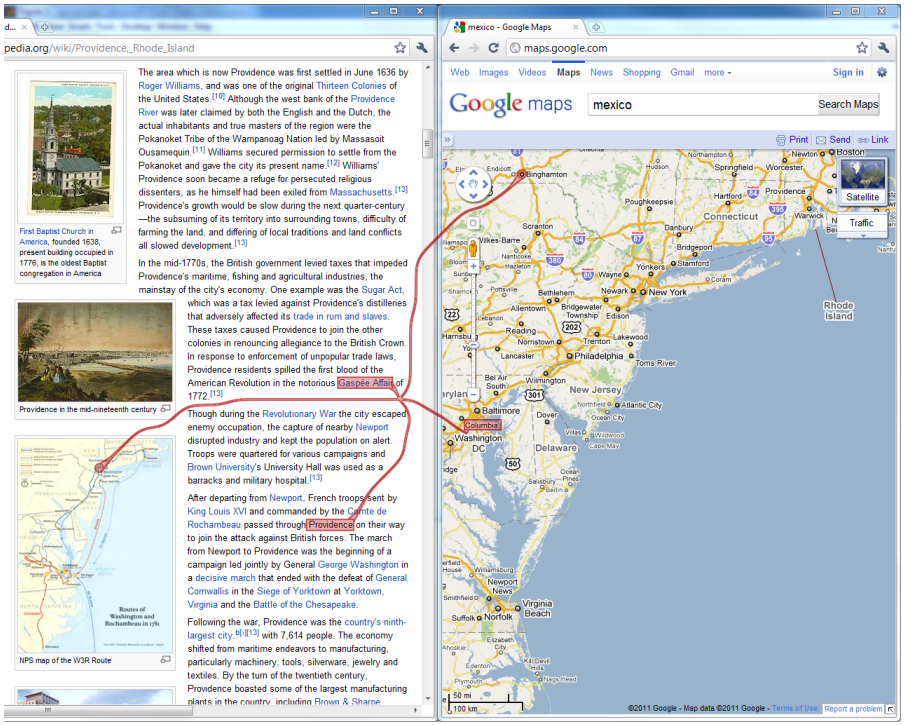


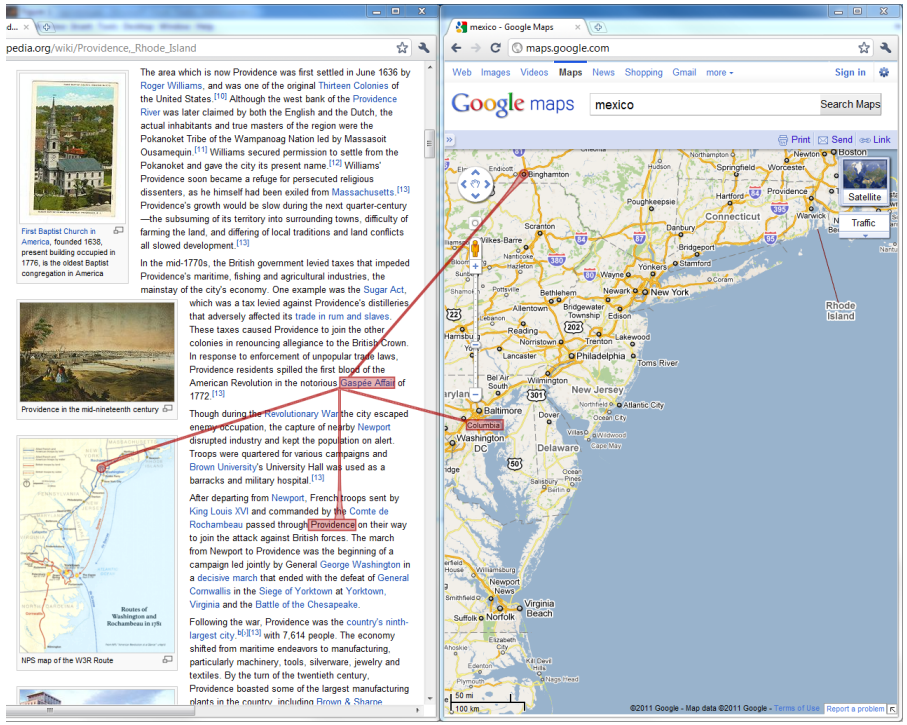


Gaze Plots

Context-Preserving Visual Links

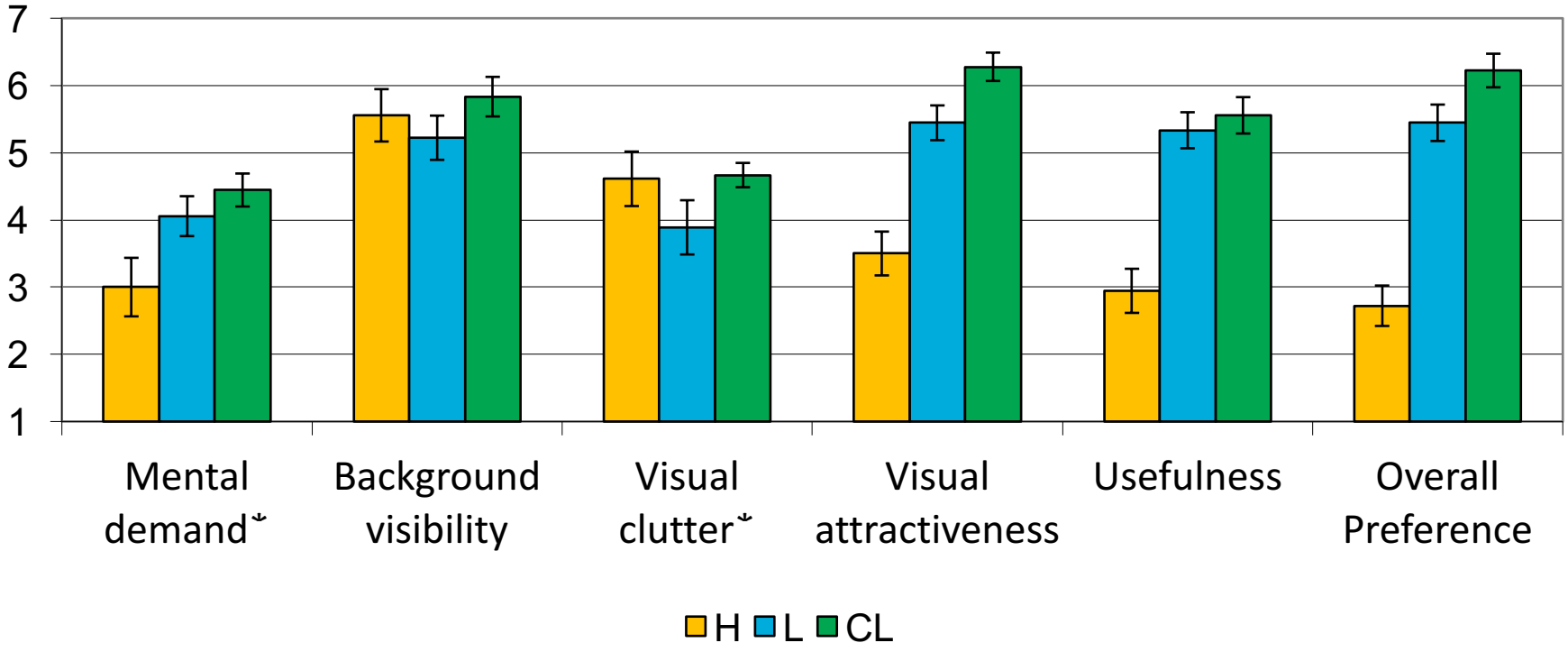
Straight Visual Links





Results

- Context-preserving visual links have a positive impact on user satisfaction.



Context-Preserving Visual Links Summary

Context-preserving visual links …

…avoid occlusion of important content in the BR

…can be adjusted to visually stand out from the BR

…do not harm performance when compared to non-routed visual links

Connectedness Reccomendation

Use connectedness if:

- You need the additional ink to make the links stand out from the BR
- You want to show many different relationships (e.g. as in a graph)
- You can not easily modulate the visual rep of the items
- You want to make sure that nothing is overlooked

Connectedness Reccomendation

Be careful if:

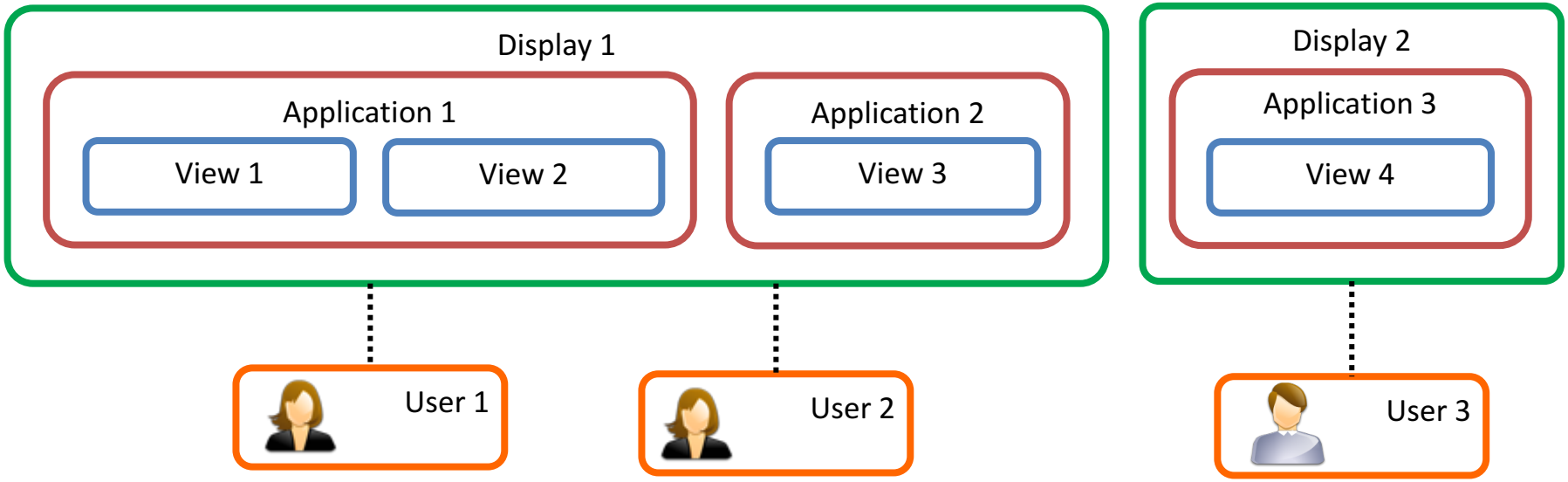
- You only have a handful of classes but a high # items
- You need a very fast implementation
  - Making connectedness run efficiently is often not trivial!

WHAT'S NEXT: WHEN TO LINK? BY MARC

PART III:
WHEN TO LINK?

Speaker: Marc Streit

Heterogeneity of Linking



Clarification

Part III orthogonal to Part I and II

Could be linking on data/view/interaction level

Could be any linking technique

View vs. Visualization

Visualization [Kosara 2008]

Visual representation that

is based on (non-visual) data

produces an image

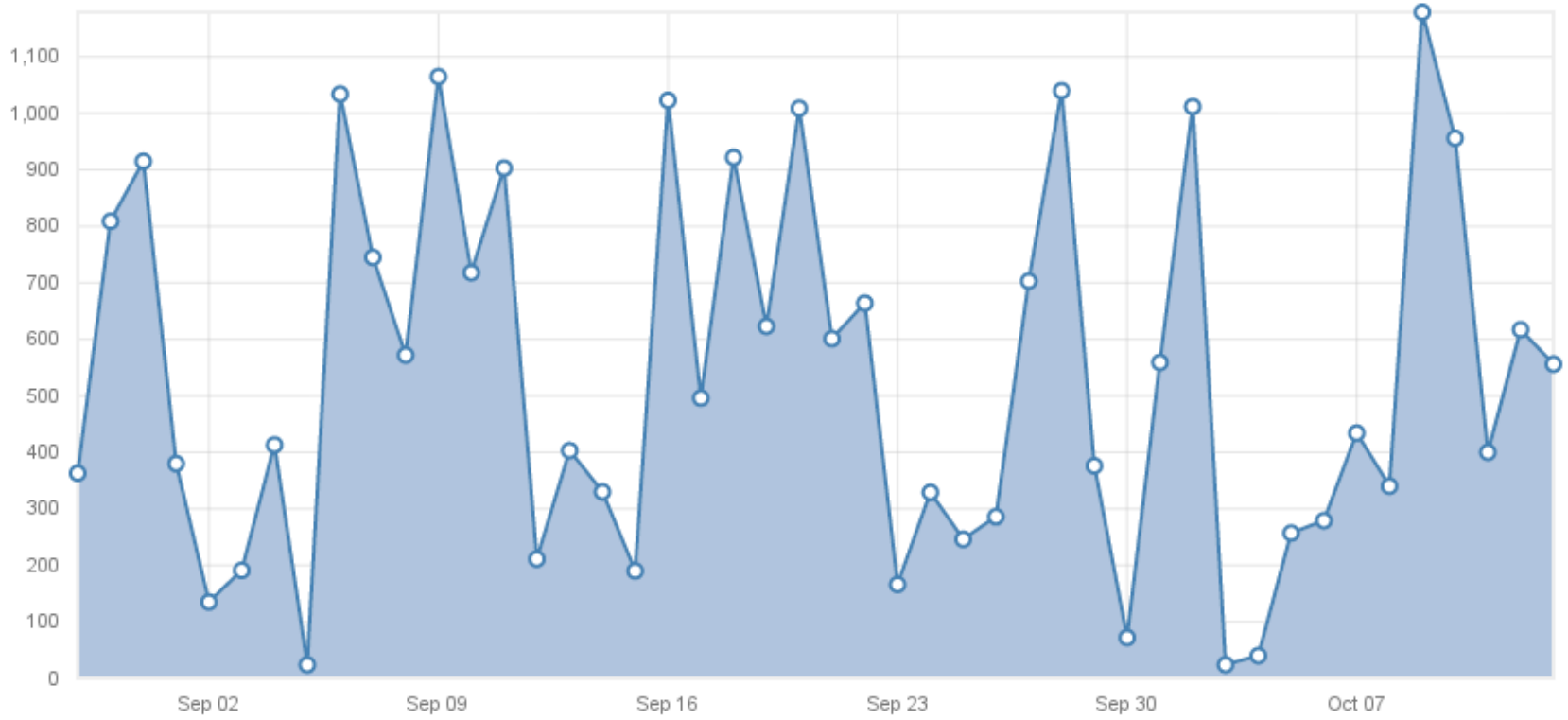
is readable and recognizable

View [Card, Mackinlay and Shneiderman 1999]

Physical display space (most often 2D) where a visual structure is rendered

Single Visualization

Showing a single relationship in the data

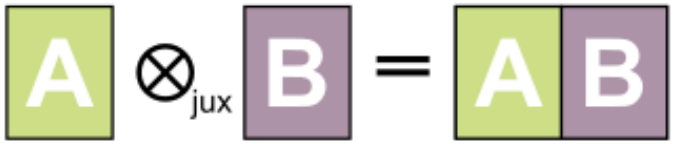


D3.js Line Chart Example

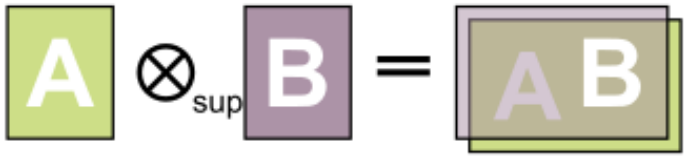
Composite Visualization Views (CVV)

[Javed and Elmqvist 2012]

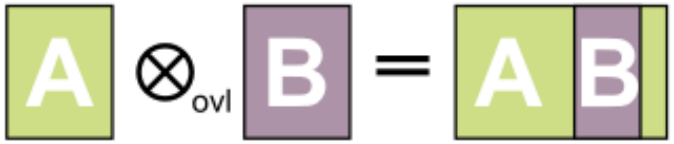
Create new visualizations by combining different visualizations



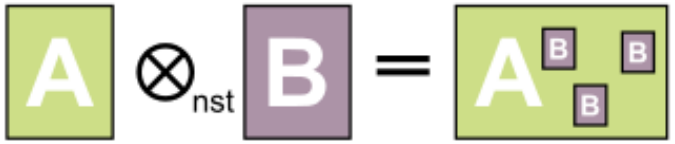
Juxtaposition
(Integrated Views)



Superimposition



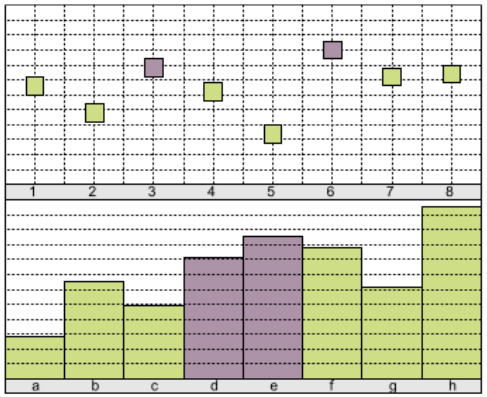
Overloading



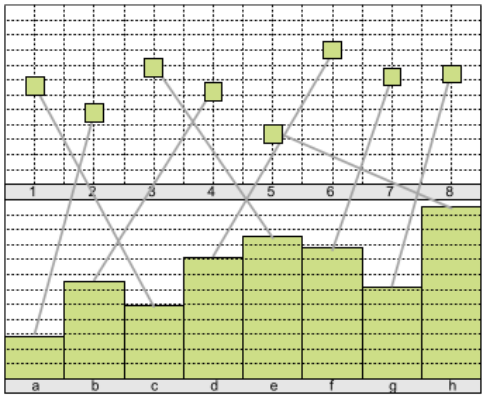
Nesting

Composite Visualization Views (CVV)

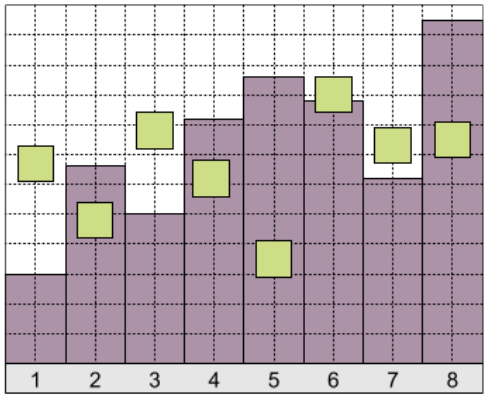
[Javed and Elmqvist 2012]



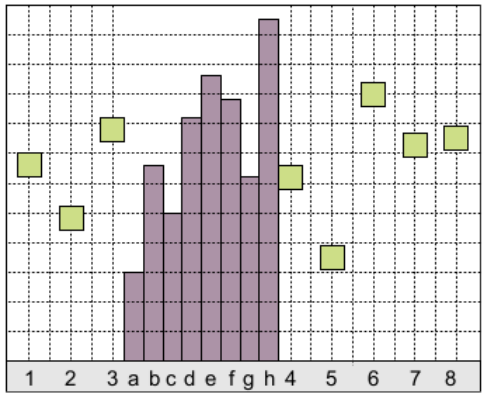
(a) Juxtaposed views.



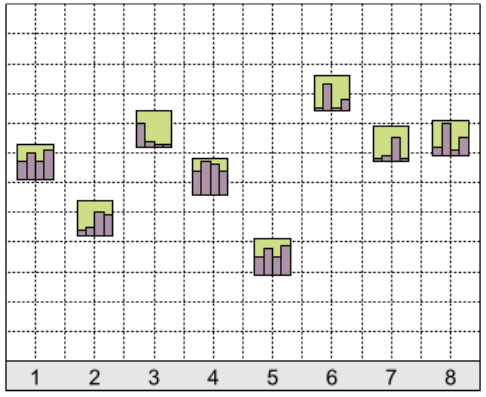
(b) Integrated views.



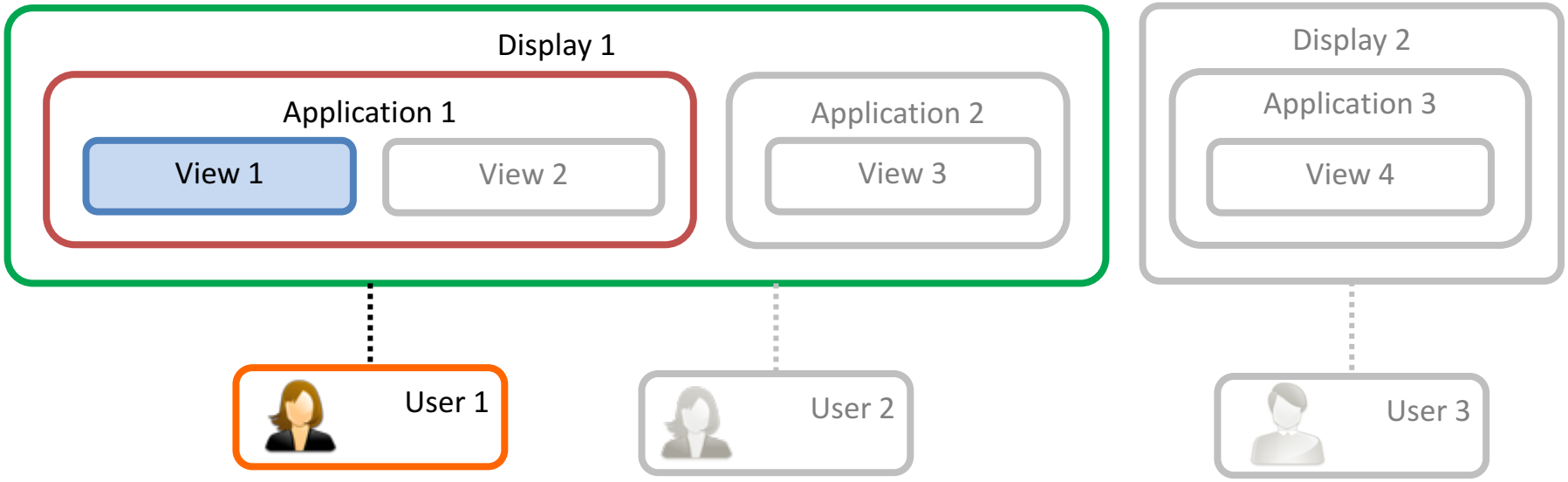
(c) Superimposed views.



(d) Overloaded views.



(e) Nested views.

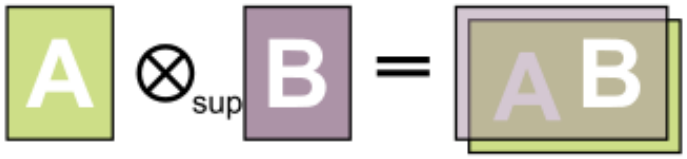


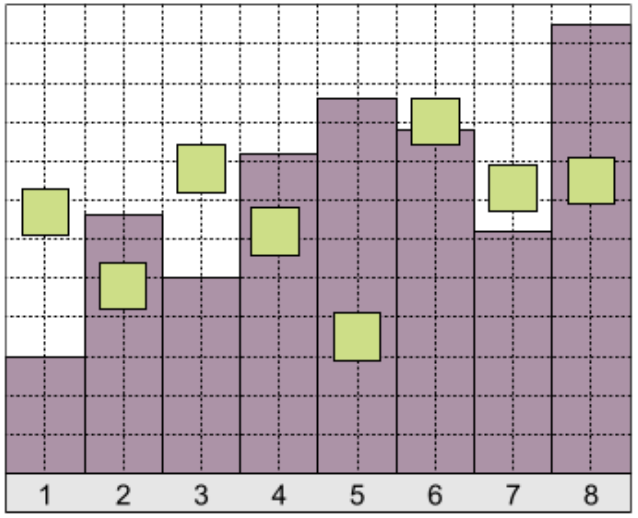
LINKING WITHIN A SINGLE VIEW

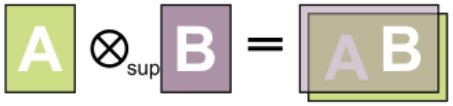
Composite Vis: Superimposition

Overlay of two or more visual spaces on top of each other

1:1 spatial linking



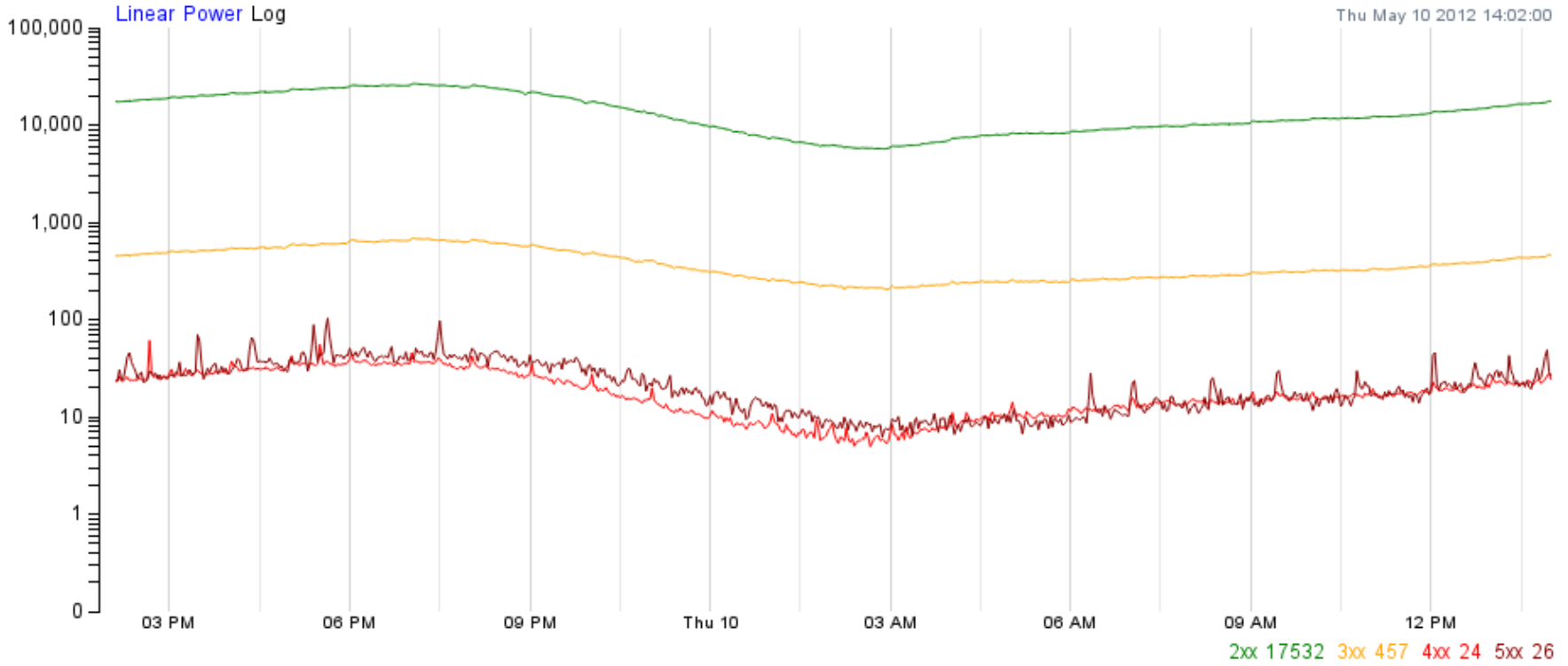




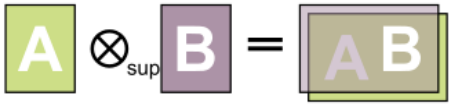
Superimposition

Superimposition Example

With several data series

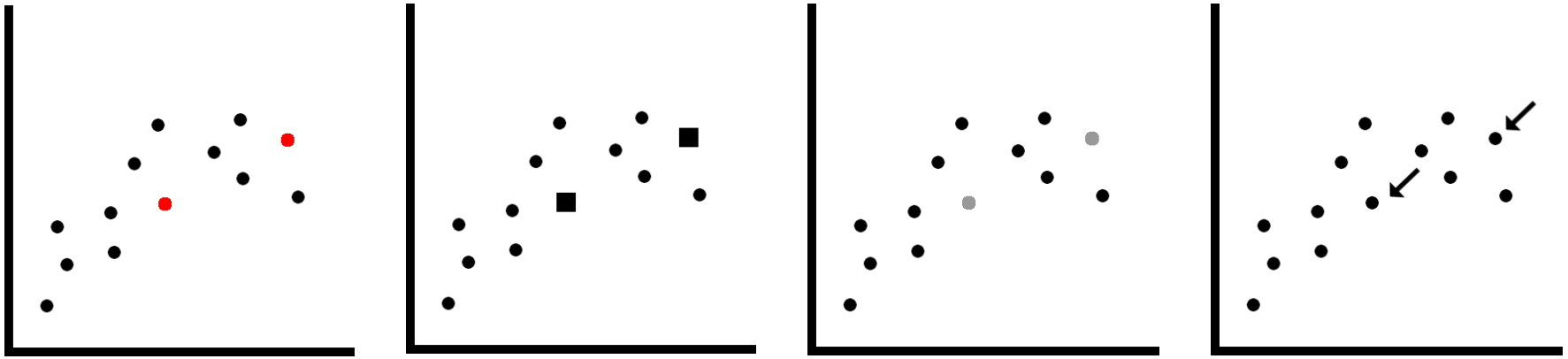


D3.js Interactive Line Graph Example

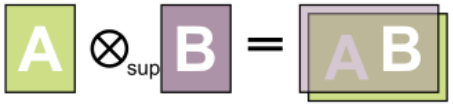


Superimposition

Base Representation with Supplemented Links



Color Shape Value Glyph



Superimposition

Example: Graphical Overlays

[Kong and Agrawala 2012]

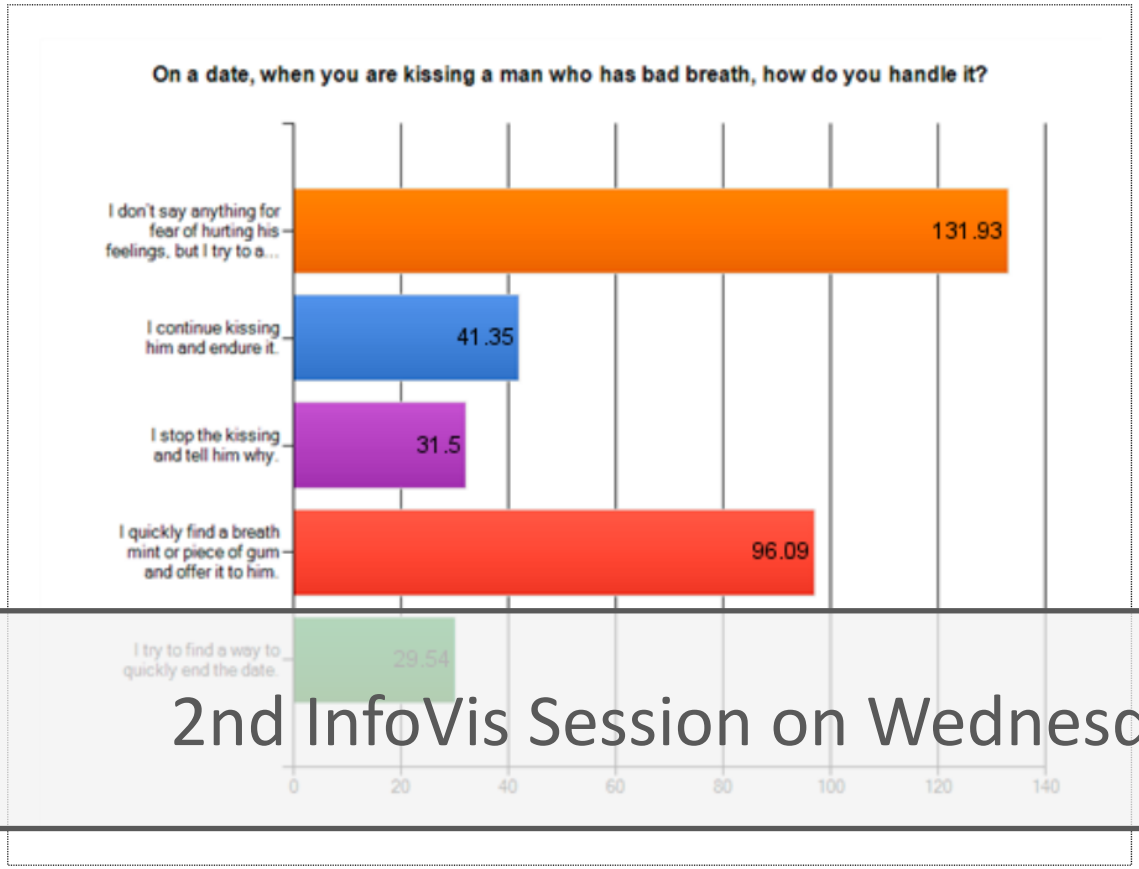


Chart type: Bar

Chart: 00193

Overlay type: Redundant encodings

- Data labels
- Line joining bars

Parameters

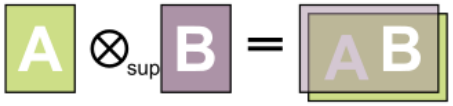
- Static / Interactive
- Inside / Outside

Font size: 8

Overlays data labels inside or outside each mark.

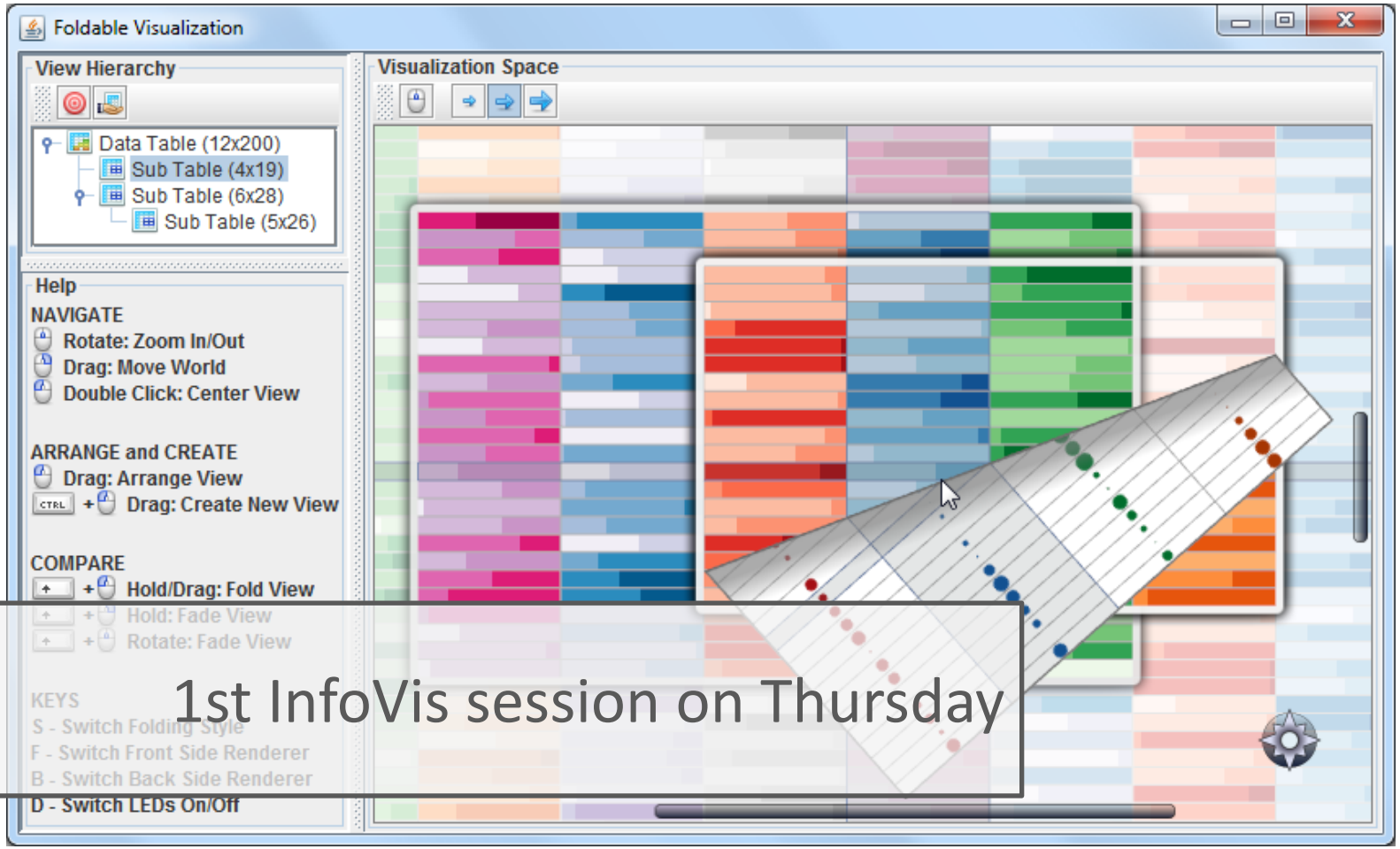
2nd InfoVis Session on Wednesday

More examples: http://vis.berkeley.edu/papers/grover



Superimposition

Visual Comparison Inspired by Natural Behavior



1st InfoVis session on Thursday

FoldableVis [Tominski et al. 2012]

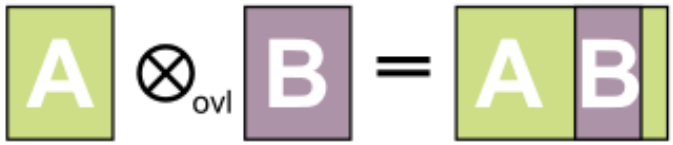
Composite Vis: Overloading

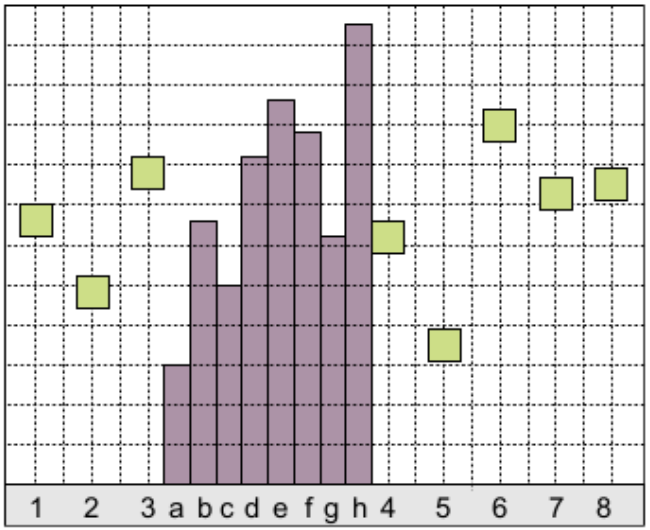
One visualization rendered inside another visualization

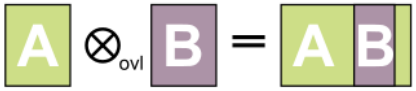
Host / client visualization

Same spatial mapping

No 1:1 spatial linkling

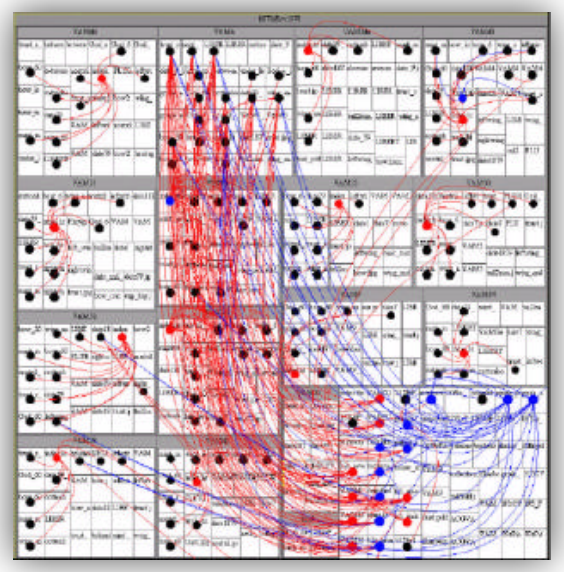




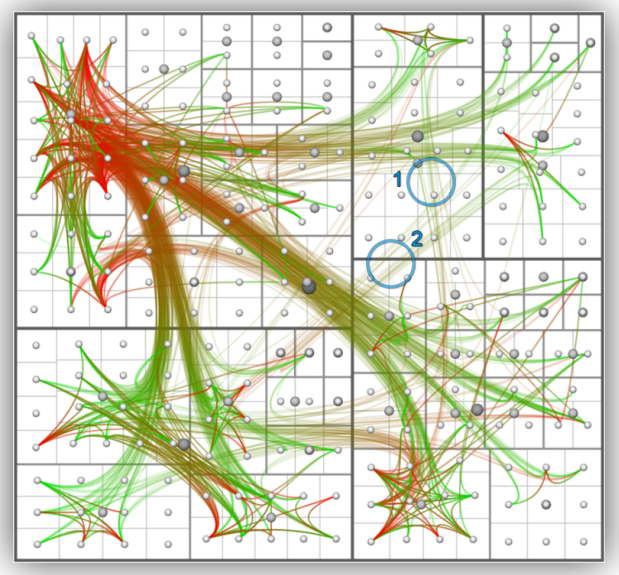


Overloading

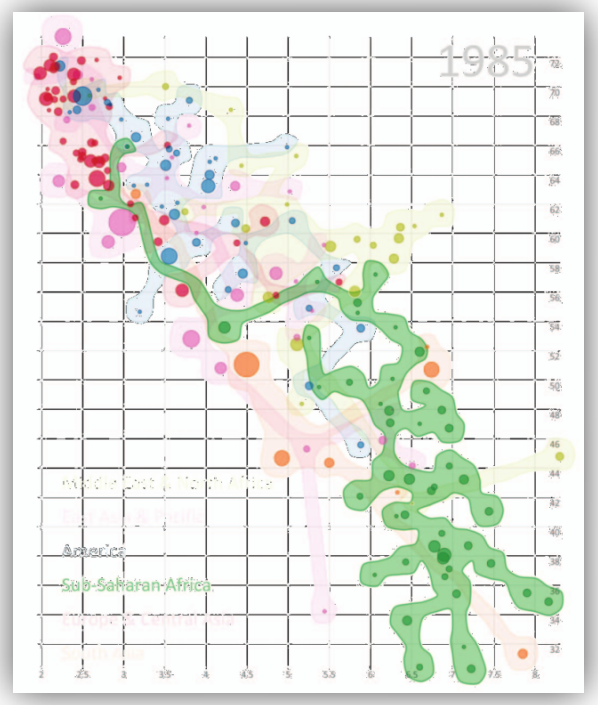
Overloading Examples



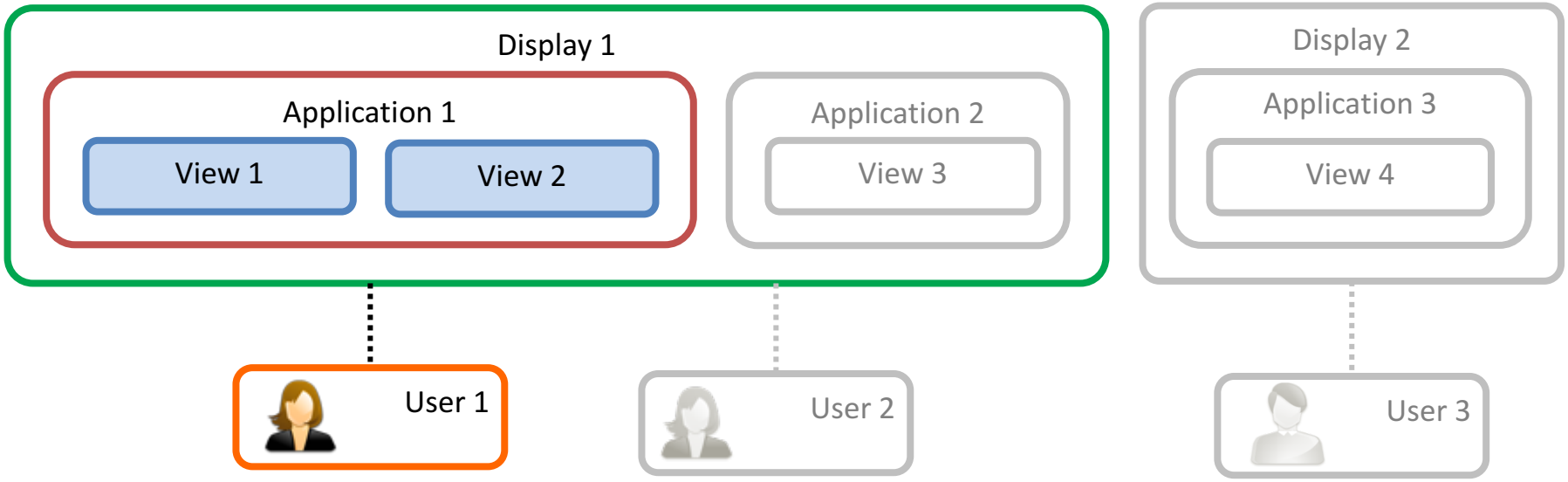
Treemap Overlay
[Fekete et al. 2003]



HEB [Holten et al. 2006]



[Collins et al. 2009]

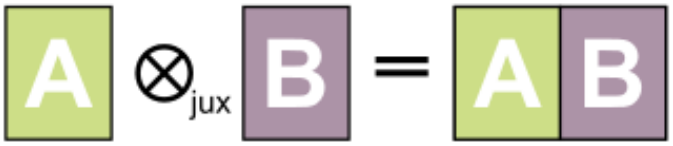


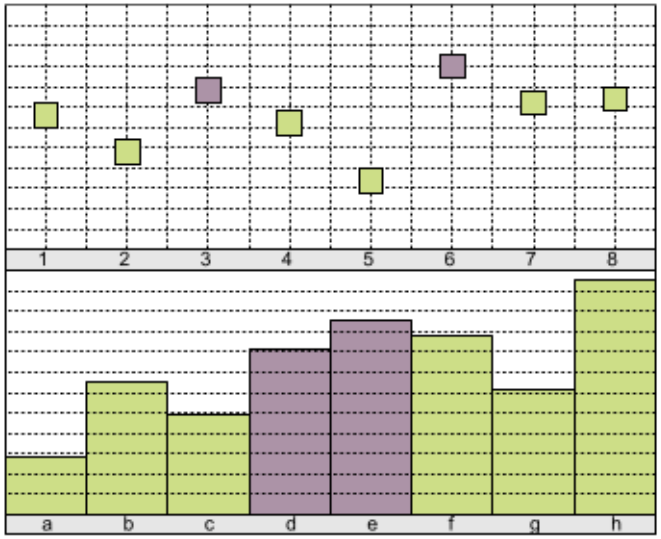
LINKING ACROSS MULTIPLE VIEWS

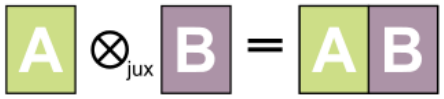
Composite Vis: Juxtaposition

Show visualizations in a side-by-side fashion

Very prominent paradigm



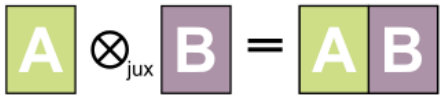




Juxtaposition

Manual Comparison

Cognitive work



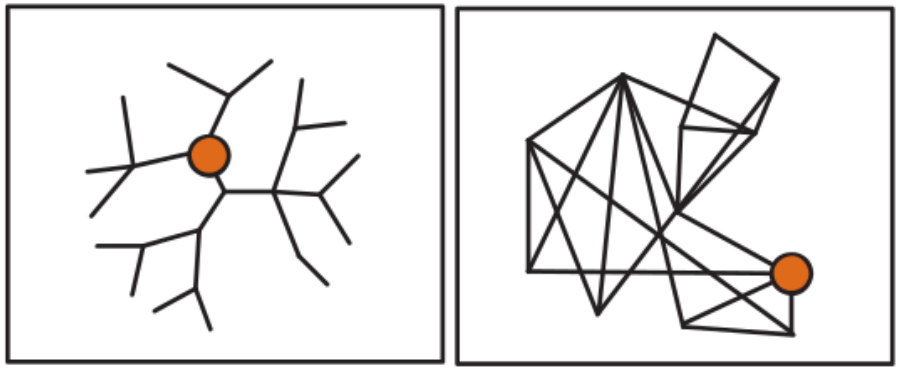
Juxtaposition

Multiple Coordinated Views

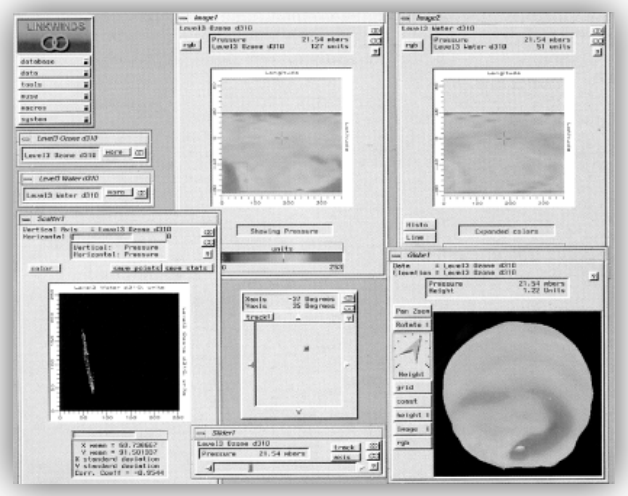
Actions in one view can be related to other view

Premise: *View and interact with data through different representations*

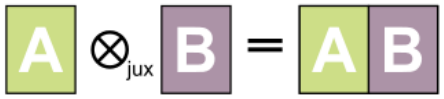
Coordination on diff. levels



[Colins and Carpendale 2007]



LinkWinds [Jacobson et al. 1994]



Juxtaposition

Linking & Brushing

Linking: Coordination between views

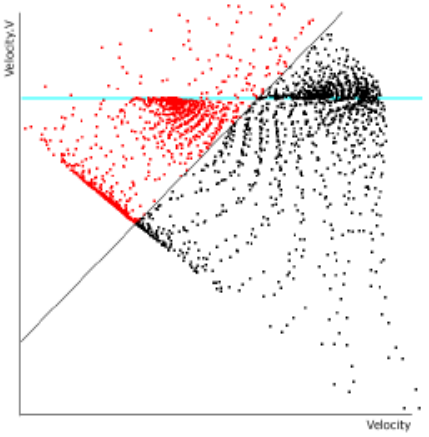
Brushing: Select groups of data points

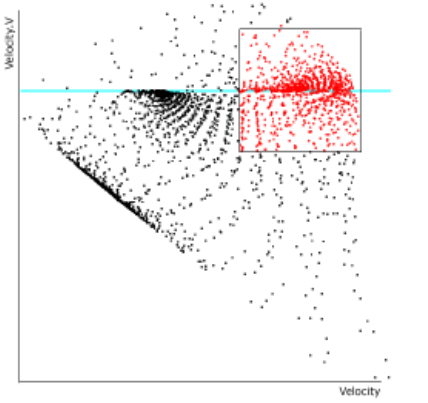
Geometric functions such as:

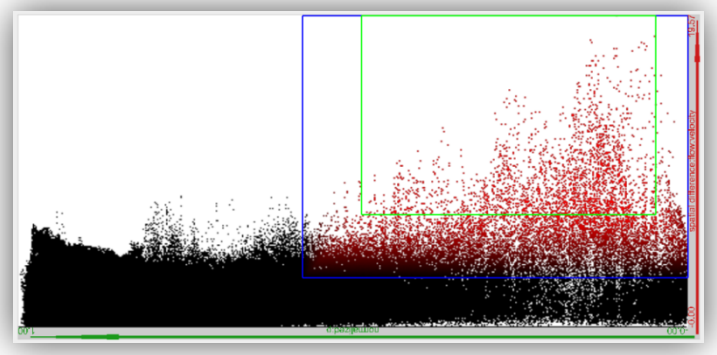
Rectangles, angles, free-form, lassos, etc.

Can be composite (AND, OR)

Can be continuous (smooth brush)

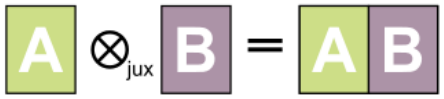






[Doleisch et al. 2004]

[Hauser et al. 2002]



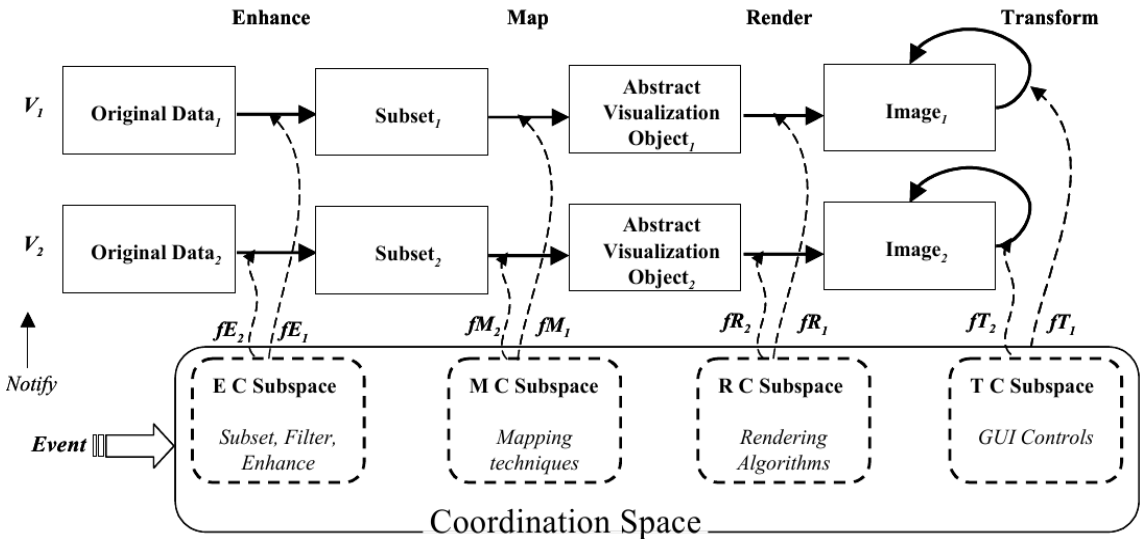
Juxtaposition

Coordination on Different Levels

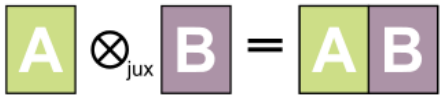
Most Common Types

- Brushing
- Navigational slaving (transformation, rotation)

Instead: coordinate on all levels of Vis Pipeline



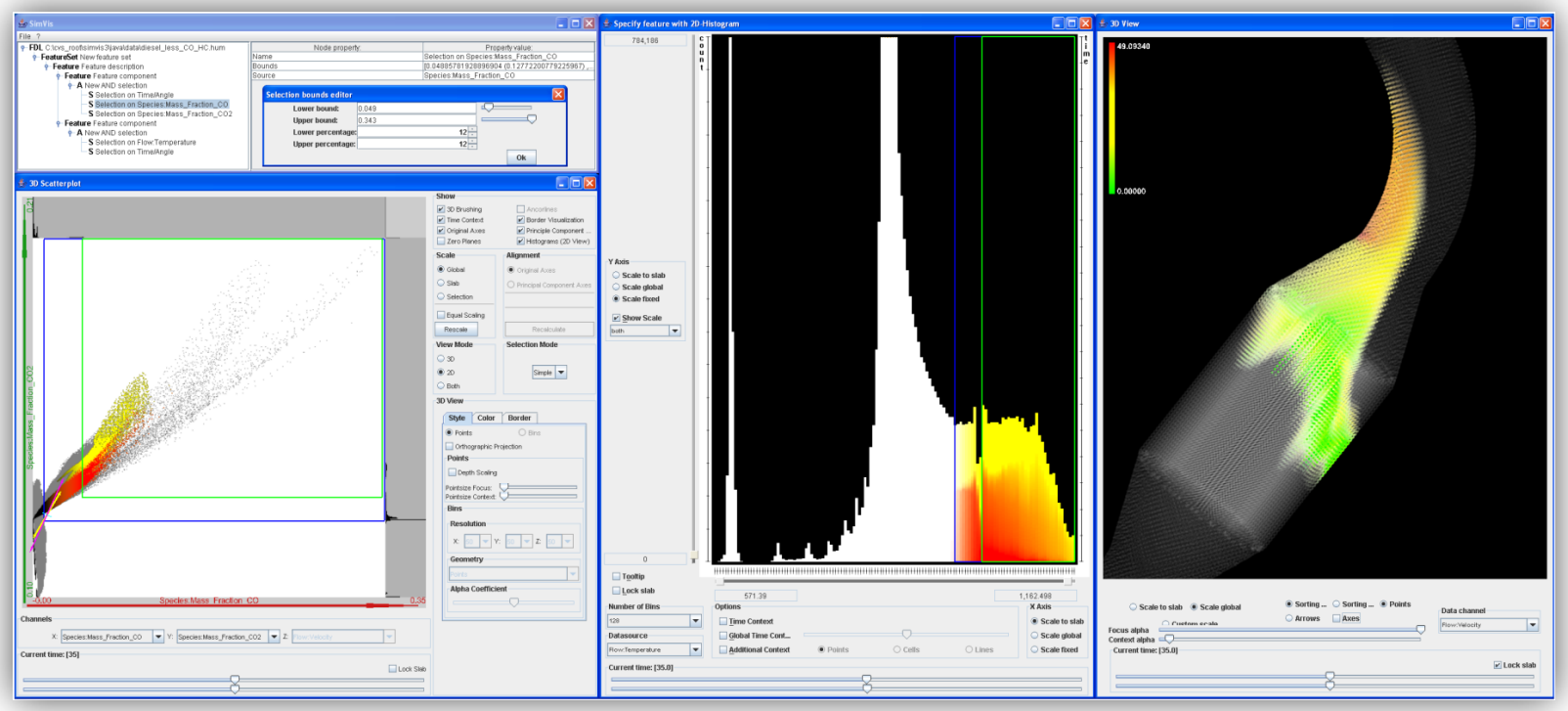
[Boukhelifa et al. 2003]



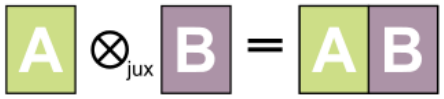
Juxtaposition

MCV Type 1

Different visualization techniques showing the same data



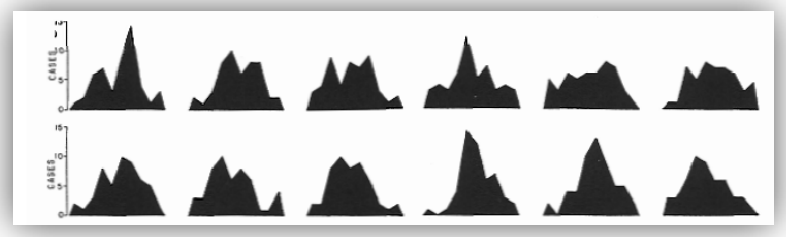
SimVis [Doleisch 2004]



Juxtaposition

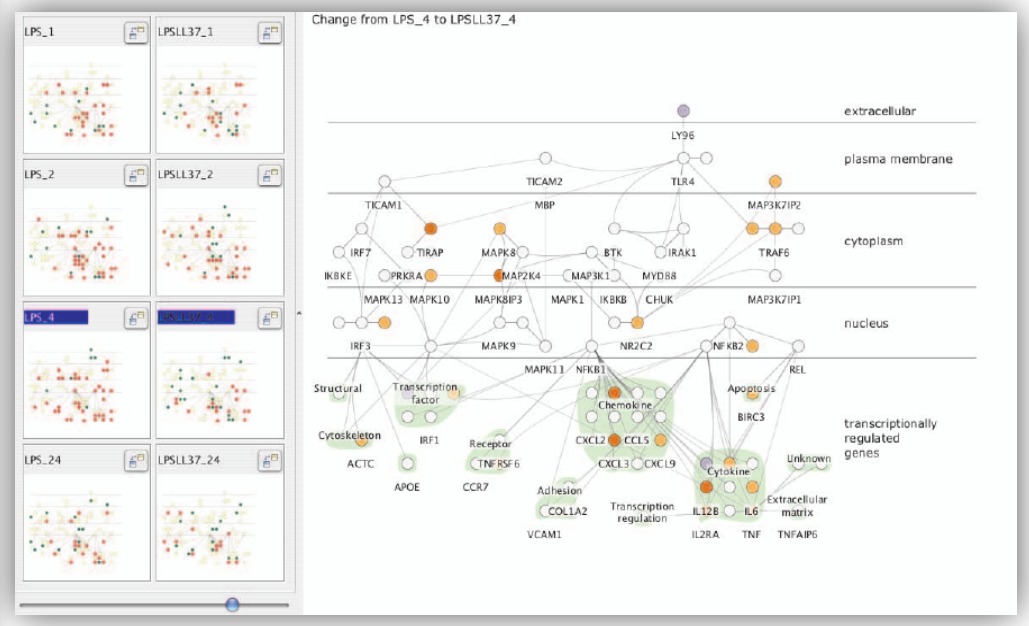
MCV Type 2: Small Multiples

Same visualization technique showing different data

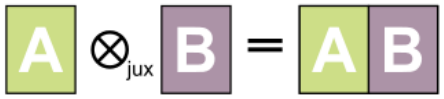


[Tufte 1993]

Rolling the Dice [Elmqvist et al. 2008]



Cerebral [Barsky et al. 2008]



Juxtaposition

Guidelines for Using MCV

Rules on how to use multiple views
→ see [Baldonado et al. 2000]

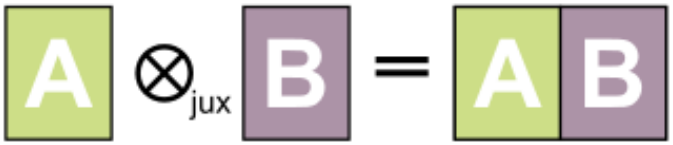
Cost-Benefit Tradeoffs

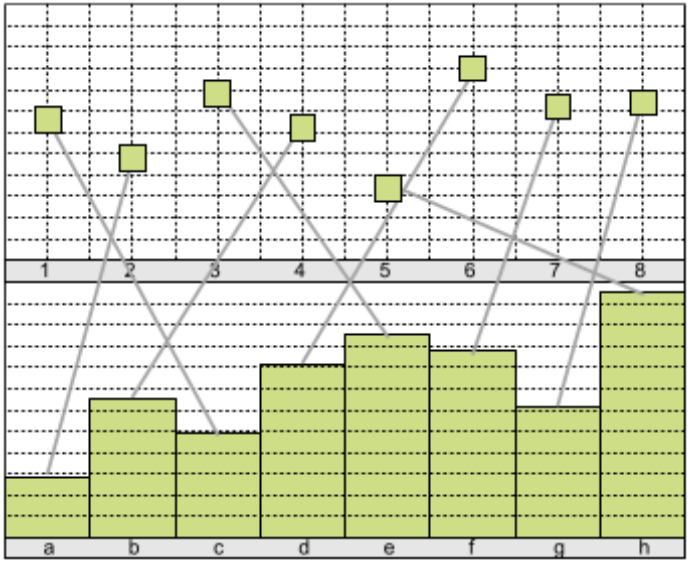
- Cognitive aspect
  - The time and effort required to learn the system
  - The load on the user's working memory
  - The effort required for comparison
  - The effort required for context switching
- System aspect
  - Computational requirements
  - Display space requirements

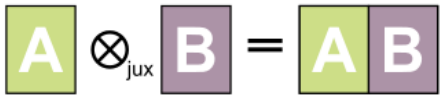
Composite Vis: Integrated Views

Visual composition is the same as for juxtaposition

Adds explicit visual links



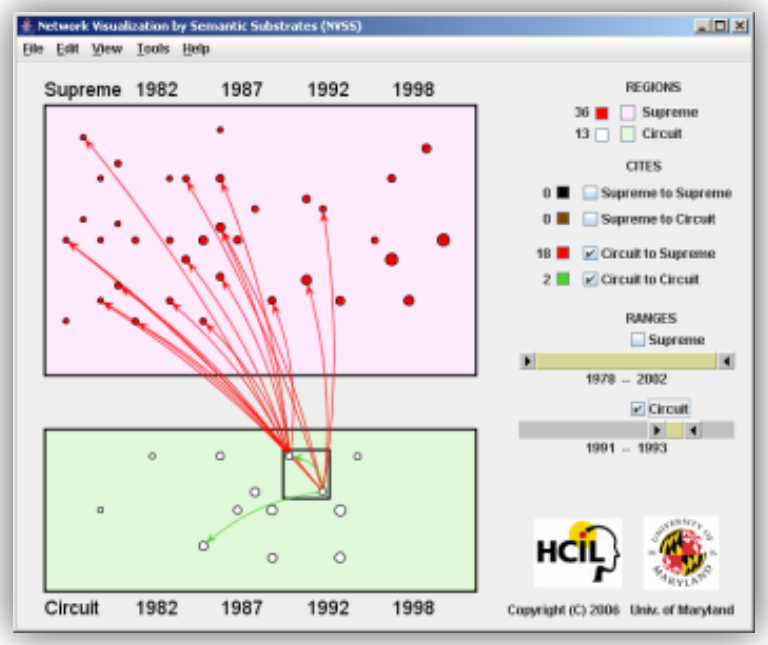




Integrated Views

Semantic Substrates

[Shneiderman and Aris, 2006]

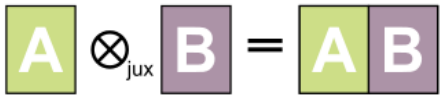


Graph results in a too complex visualization to interpret

User-defined semantic subsets

Visual links connecting identical items across visualizations

Single visualization
Single relationship



Integrated Views

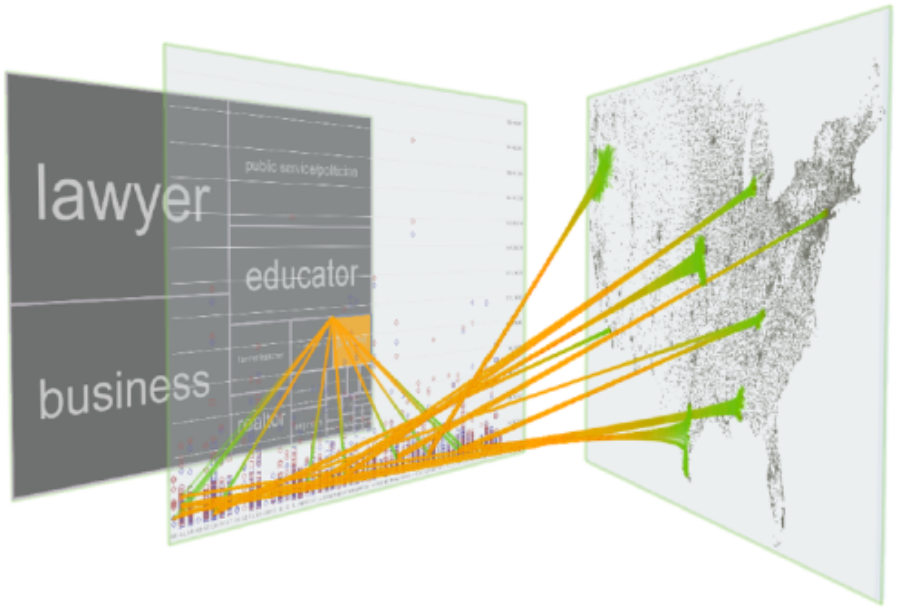
VisLink

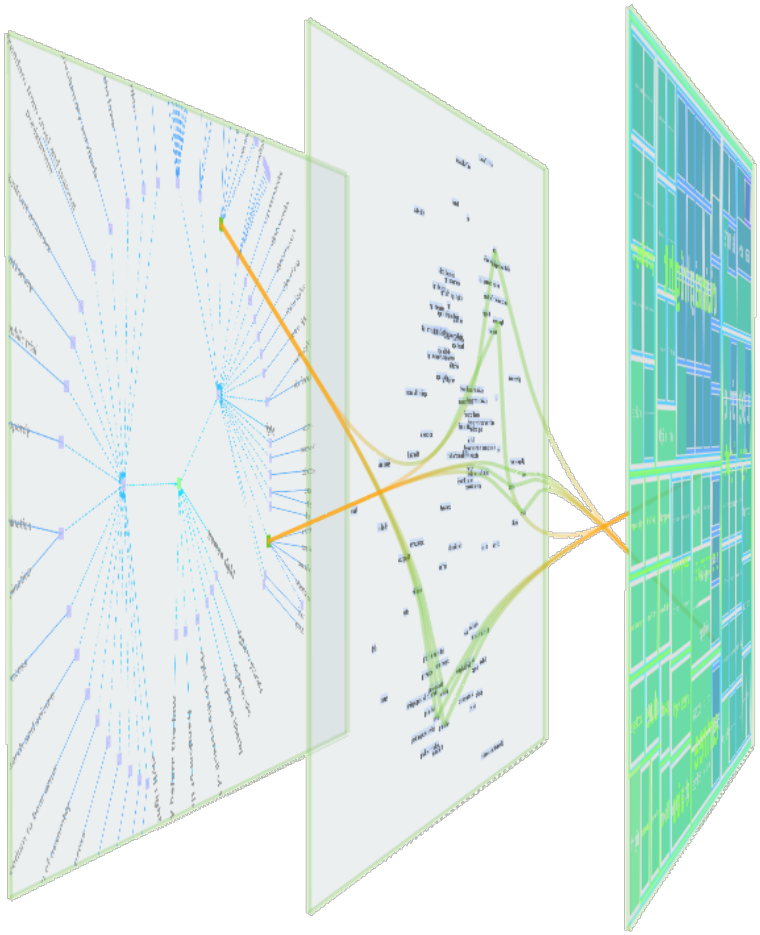
[Collins and Carpendale 2007]

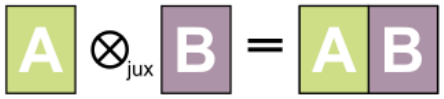
Multiple relationships / datasets

Multiple visualizations

Inter-plane edges



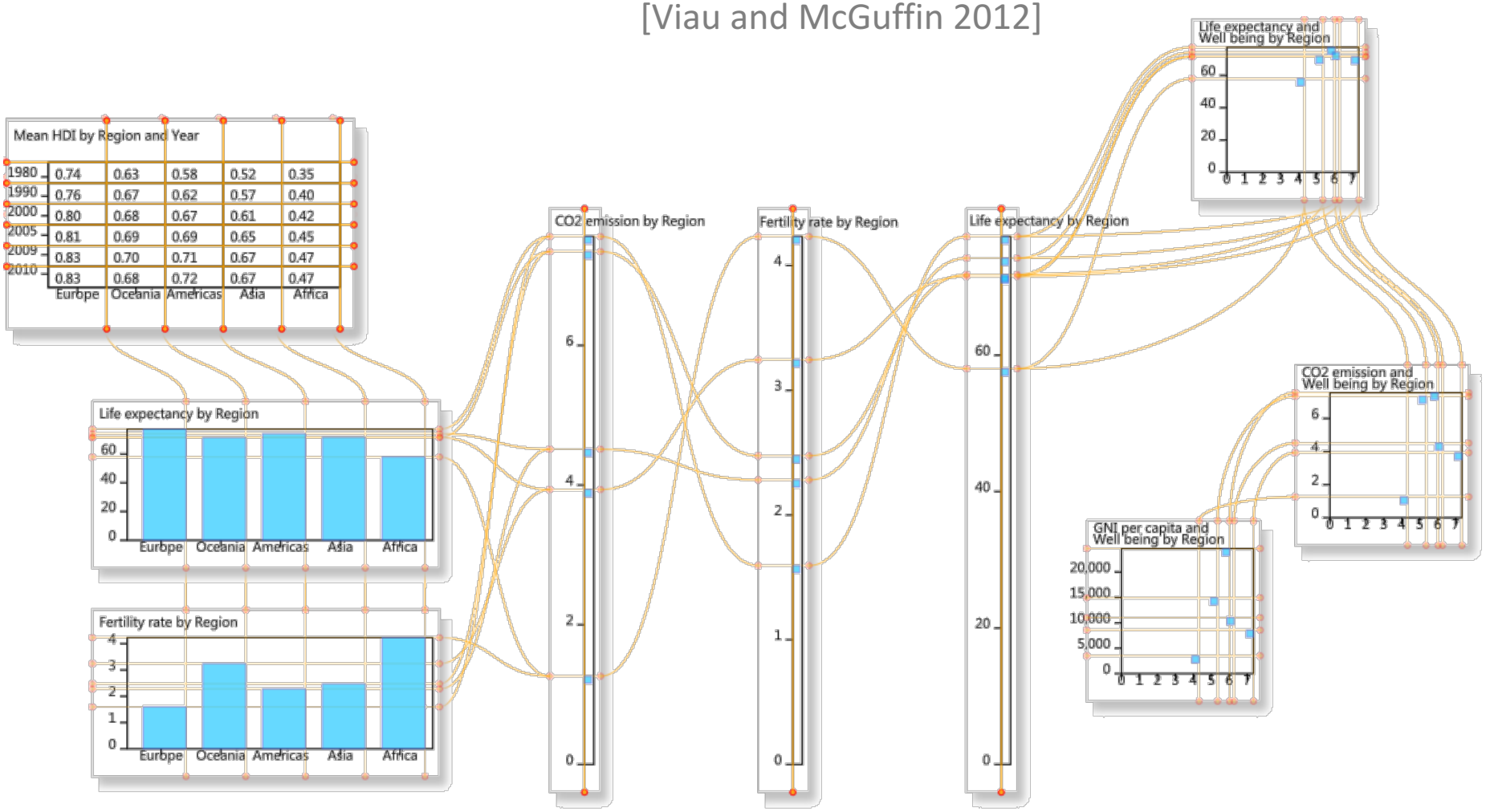


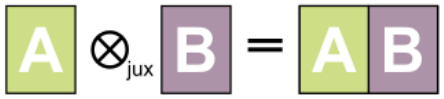


Integrated Views

Connected Charts

[Viau and McGuffin 2012]

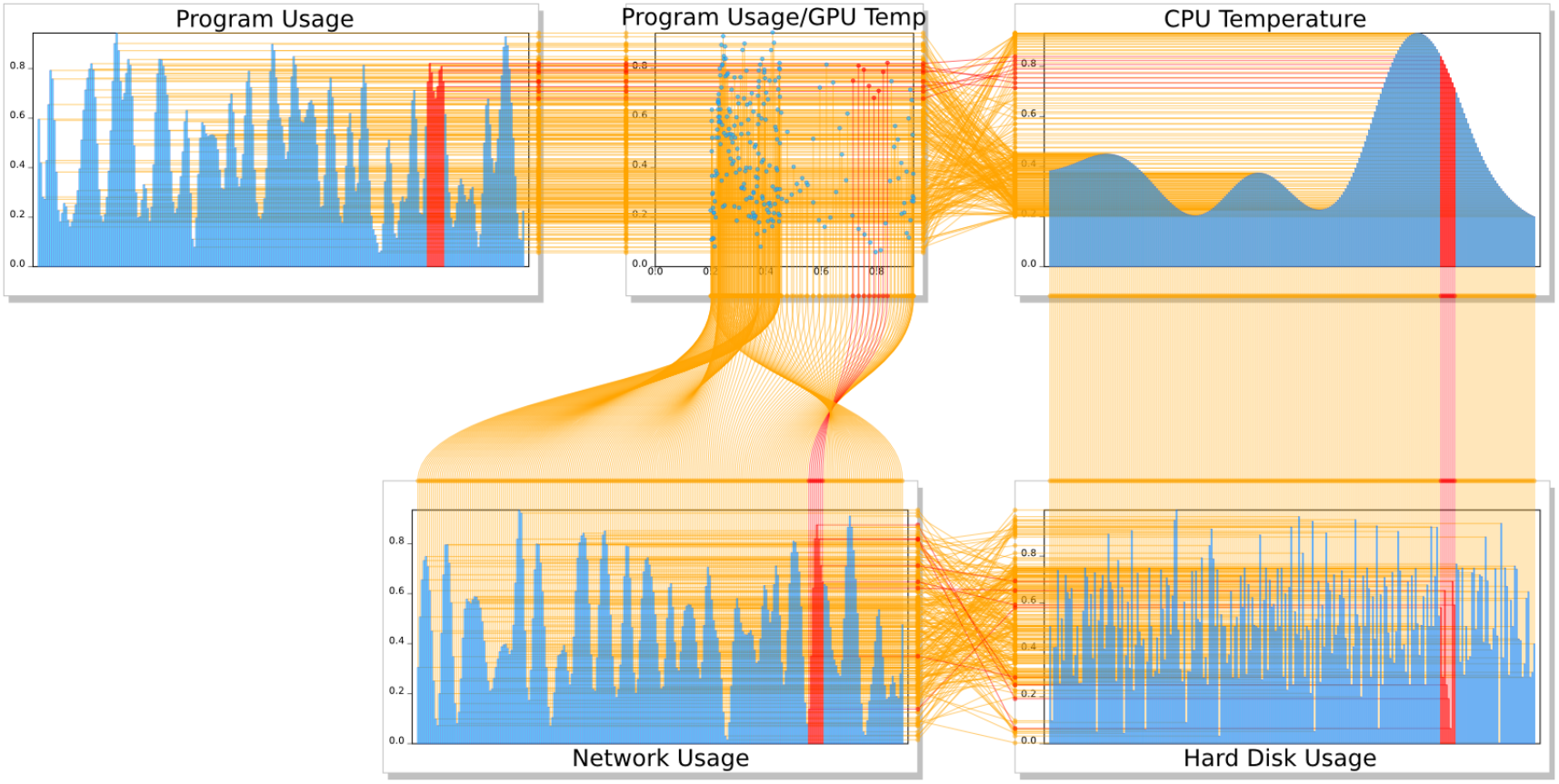




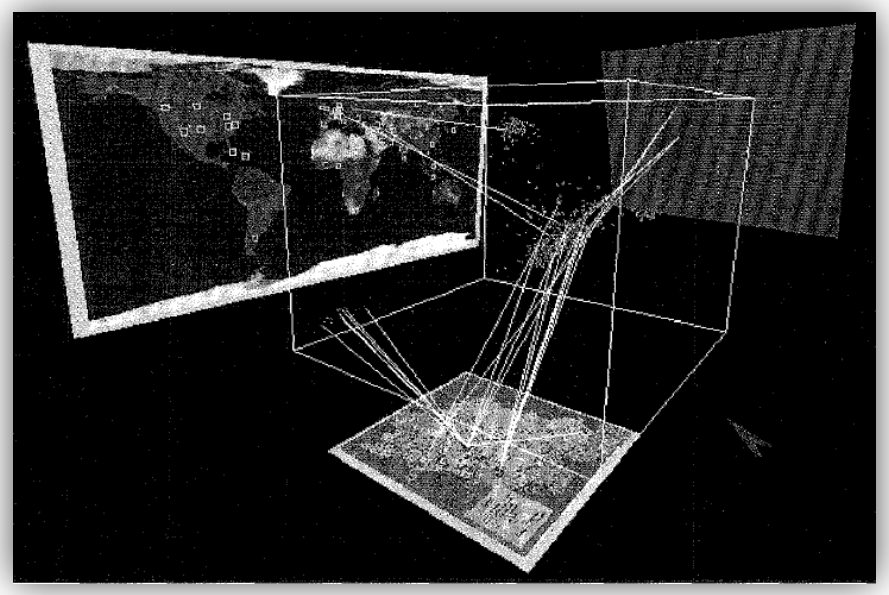
Integrated Views

Connected Charts

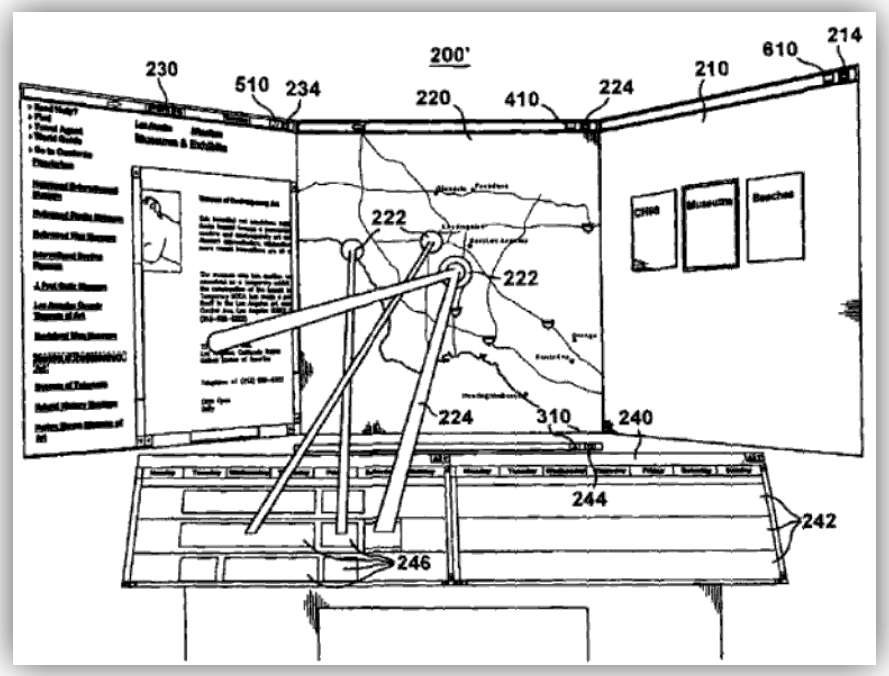
[Viau and McGuffin 2012]



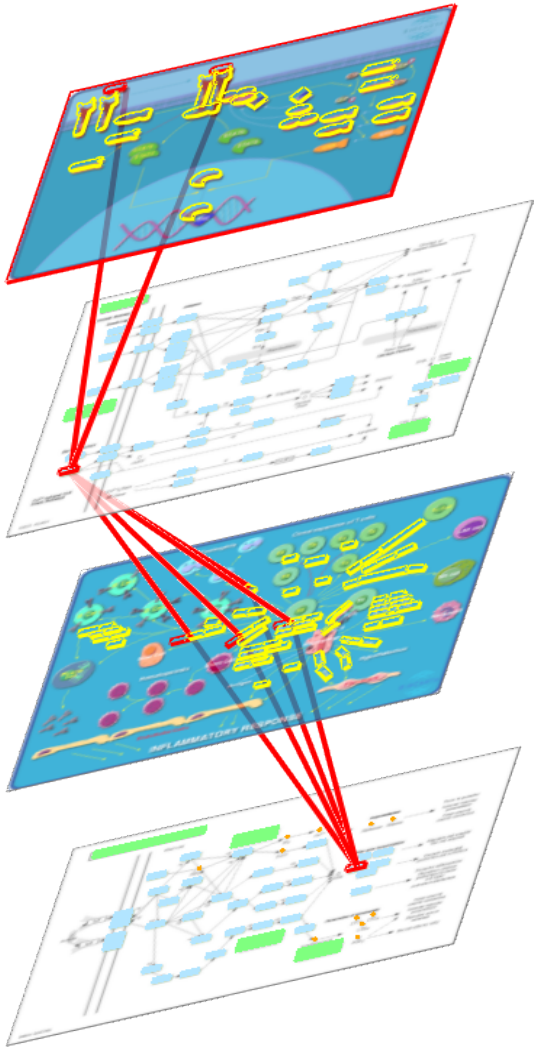
Further Integrated View Examples



[Risch et al. 1996]



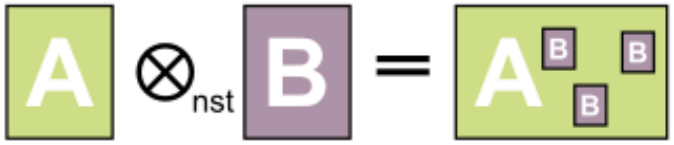
Microsoft patent [Höllerer et al. 2007]

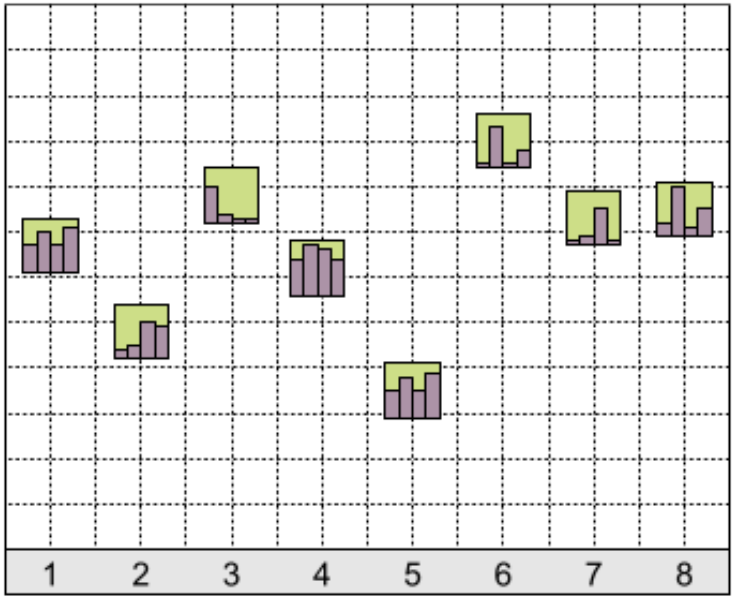


Interconnected Pathways [Streit et al. 2007]

Combined Vis: Nesting

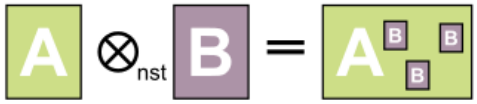
Client visualizations nested **inside** host visualization





Single or multi view?

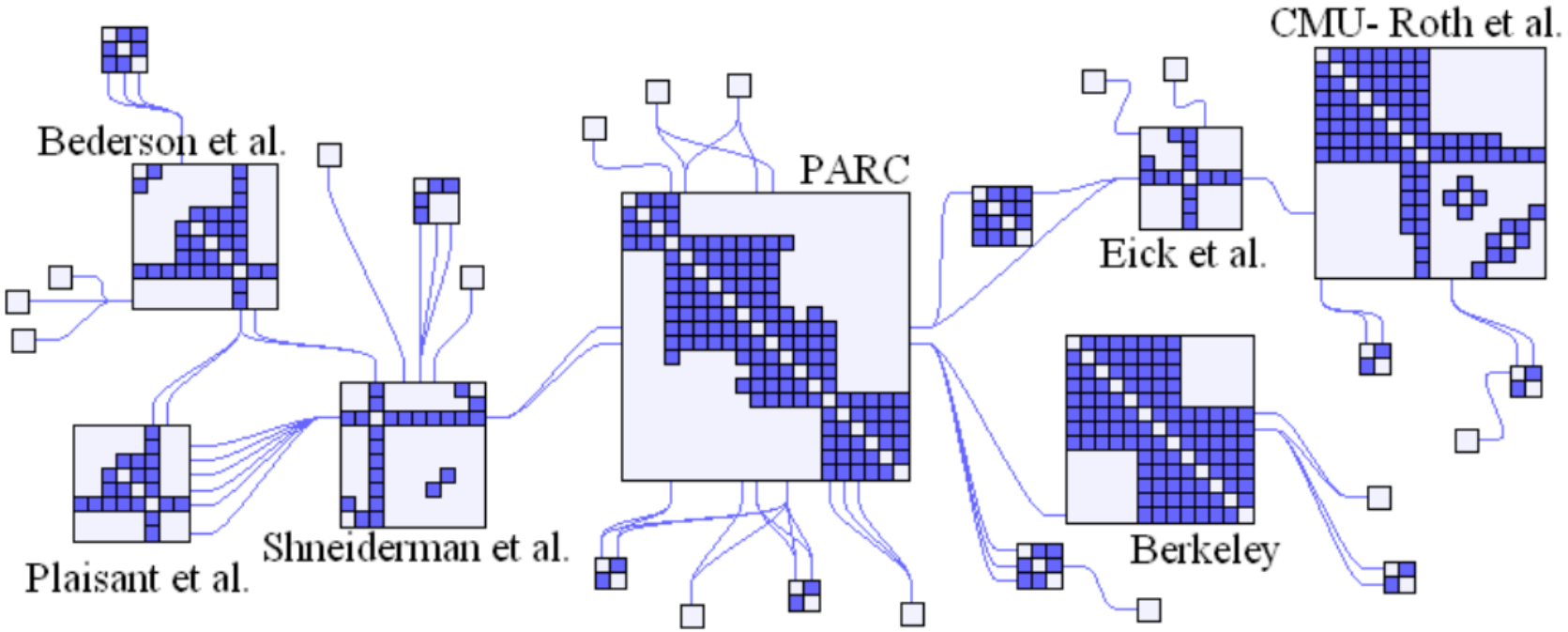
Depends on perspective



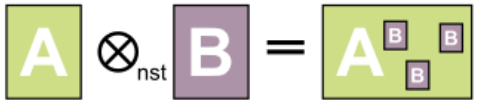
Nesting

Example 1: Nodetrix

[Henry et al. 2007]



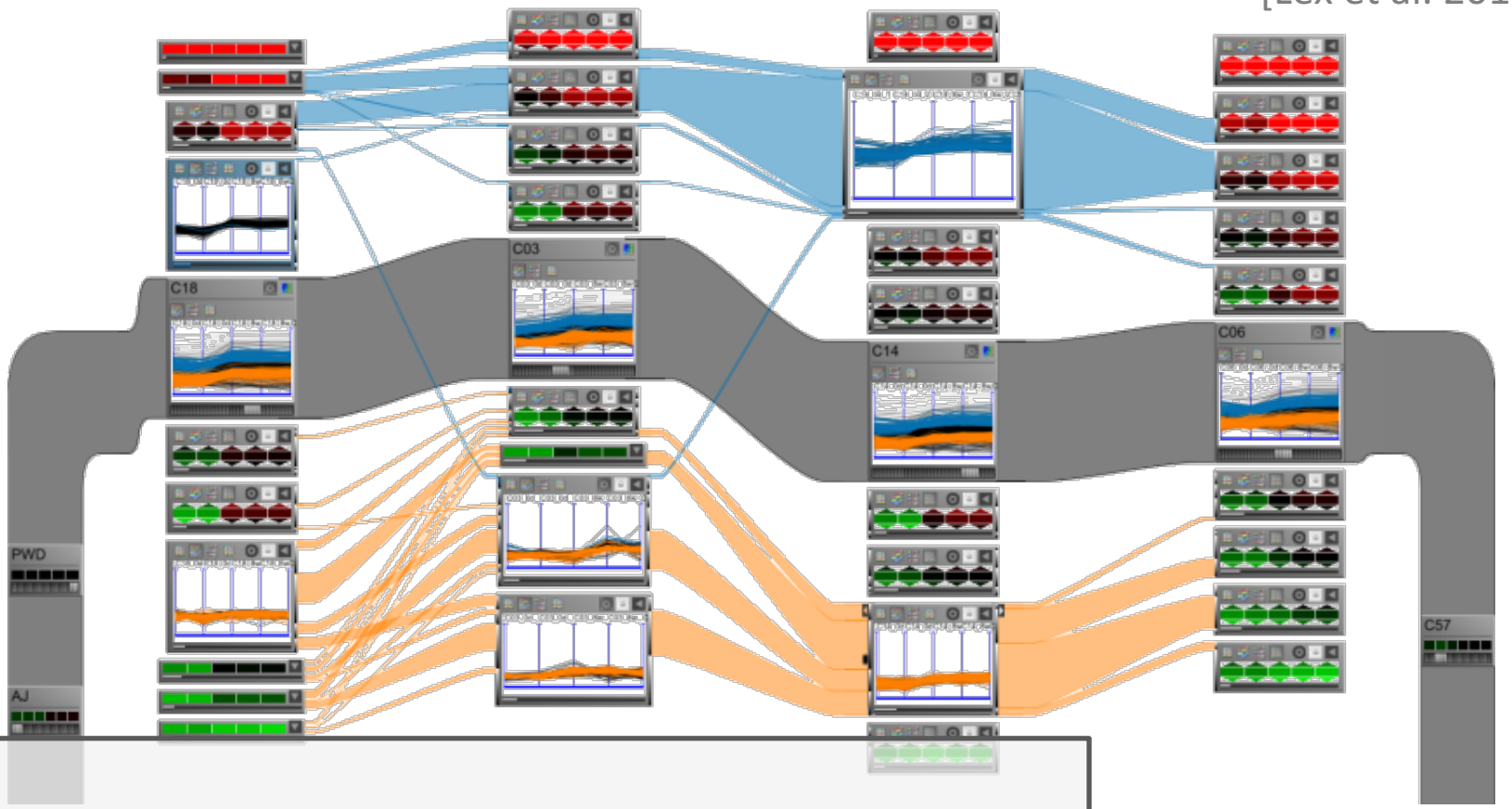
Single or composite visualization?



Nesting

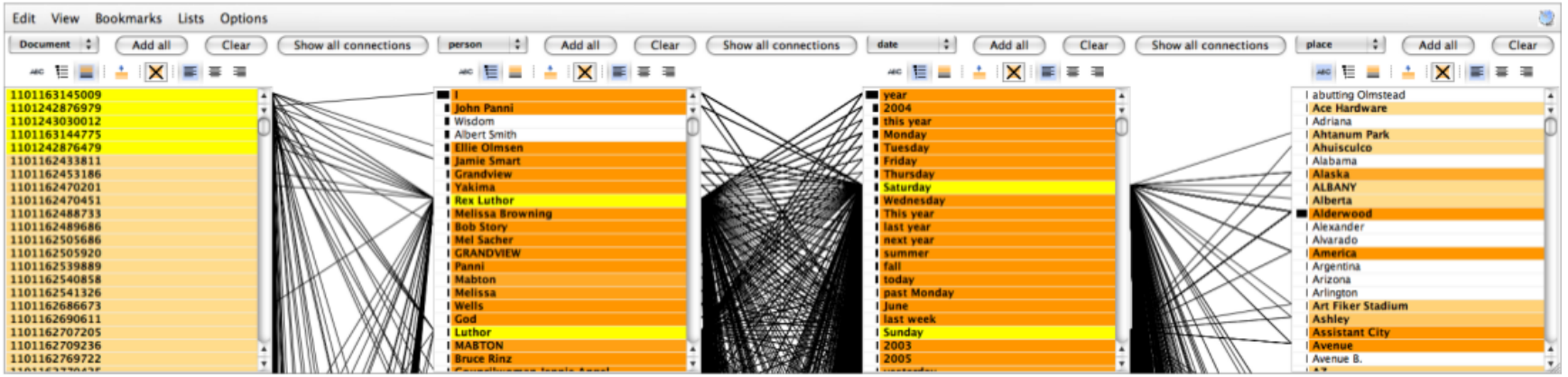
Example 2: VisBricks

[Lex et al. 2011]



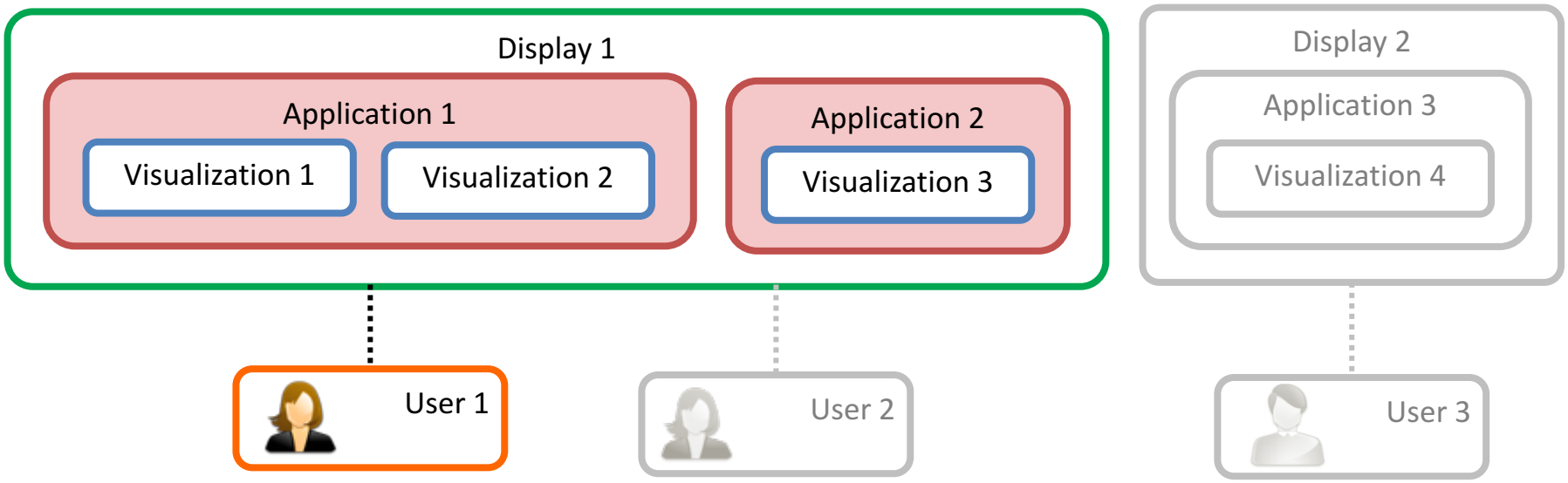
Single or composite visualization?

Example 3: Jigsaw List View

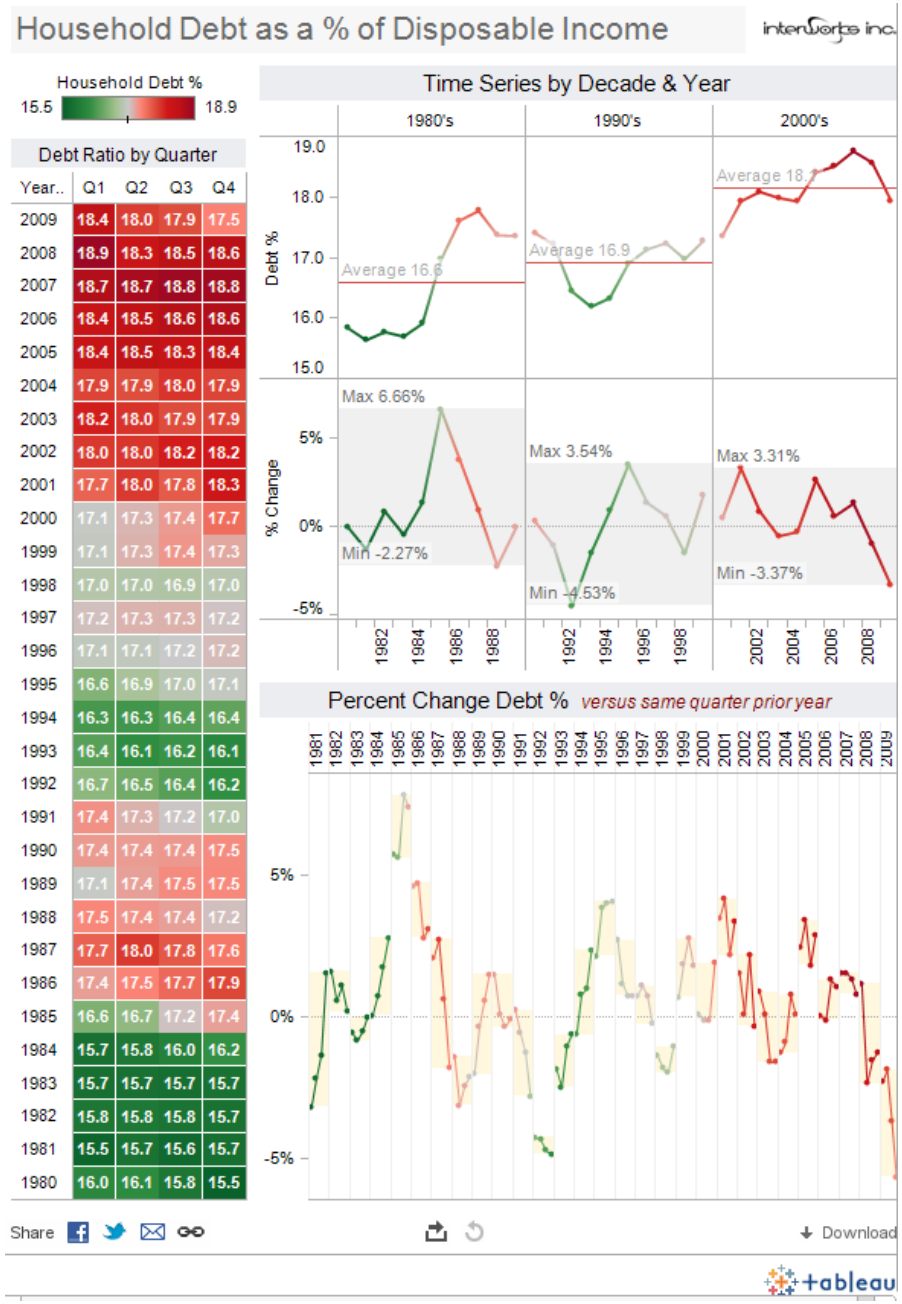


[Stasko et al. 2008]

Single or composite visualization?



LINKING ACROSS APPLICATIONS



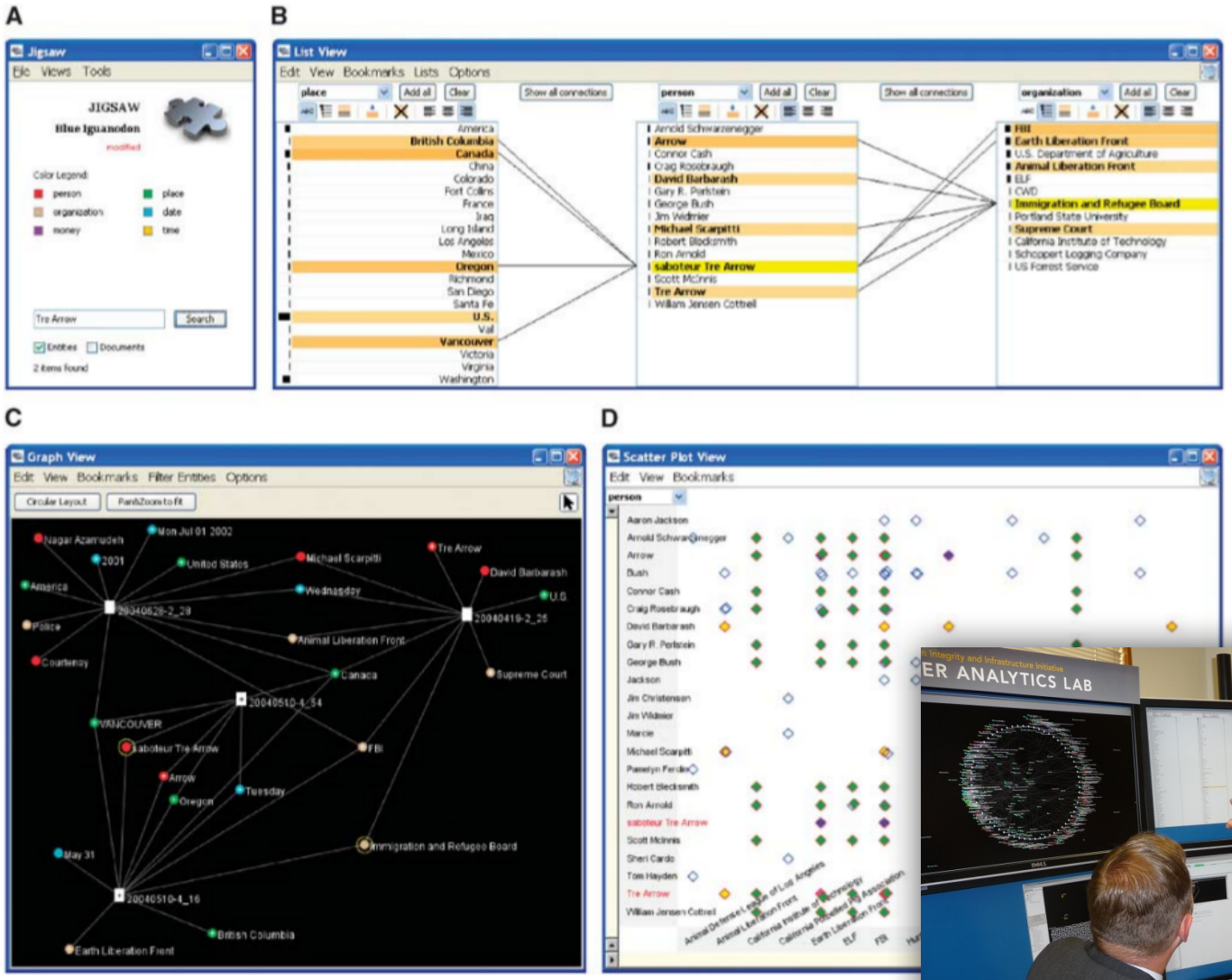
+ableau SOFTWARE

Domain specific specializations:

Banking, Consumer Packaged Goods, Education, Game Design, Government, Healthcare, Insurance, Manufacturing, Oil And Gas, Real Estate, Retail, Securities And Investments, Communications

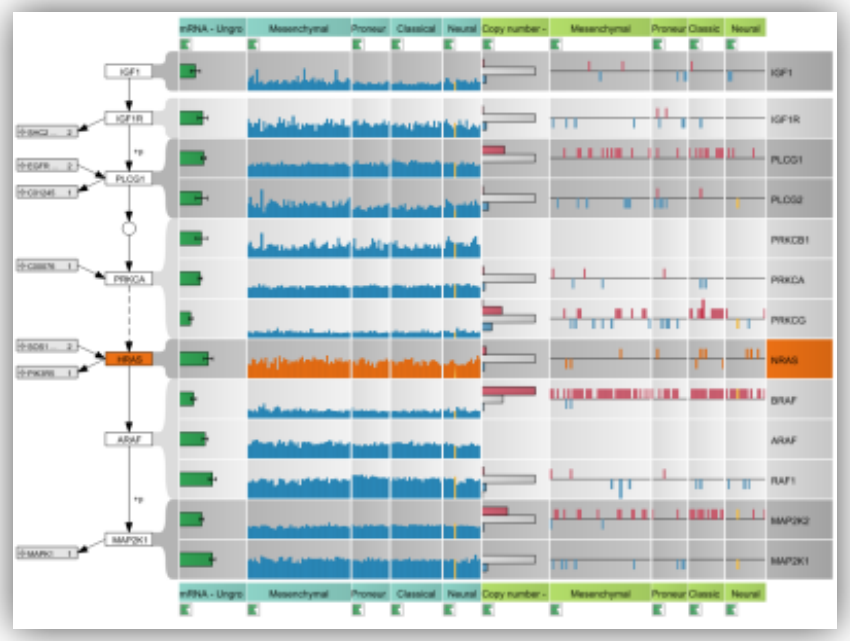
Jigsaw

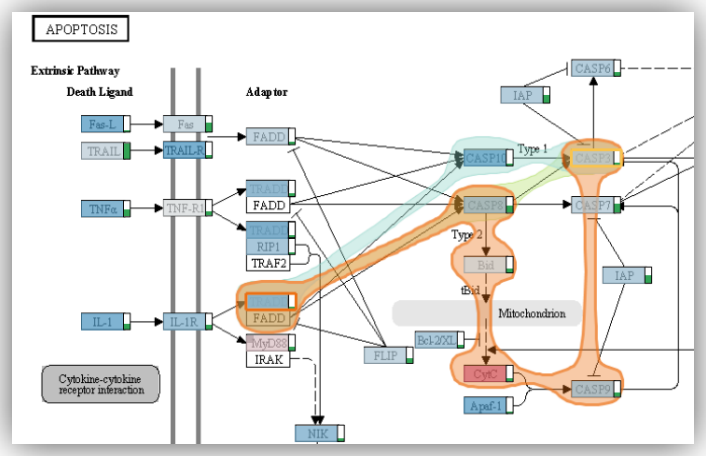
[Stasko et al. 2007]

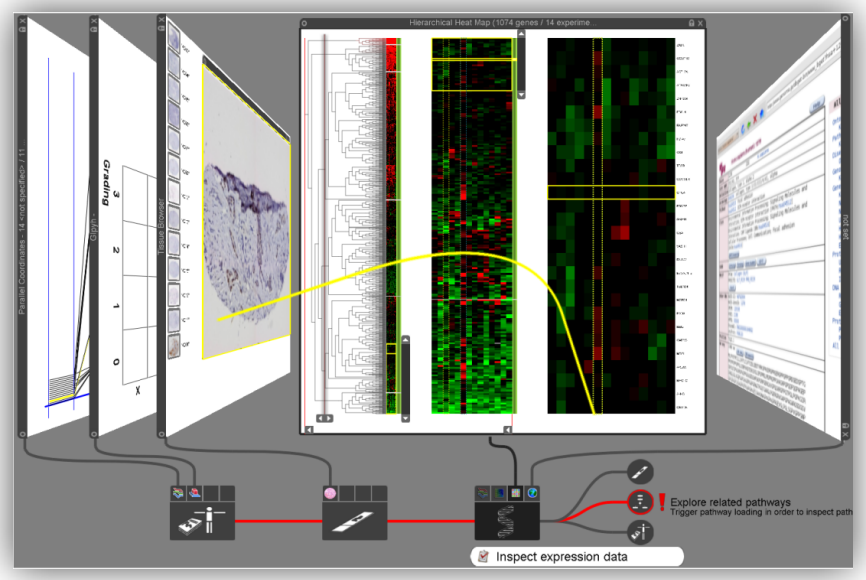


[Partl et al. 2012]

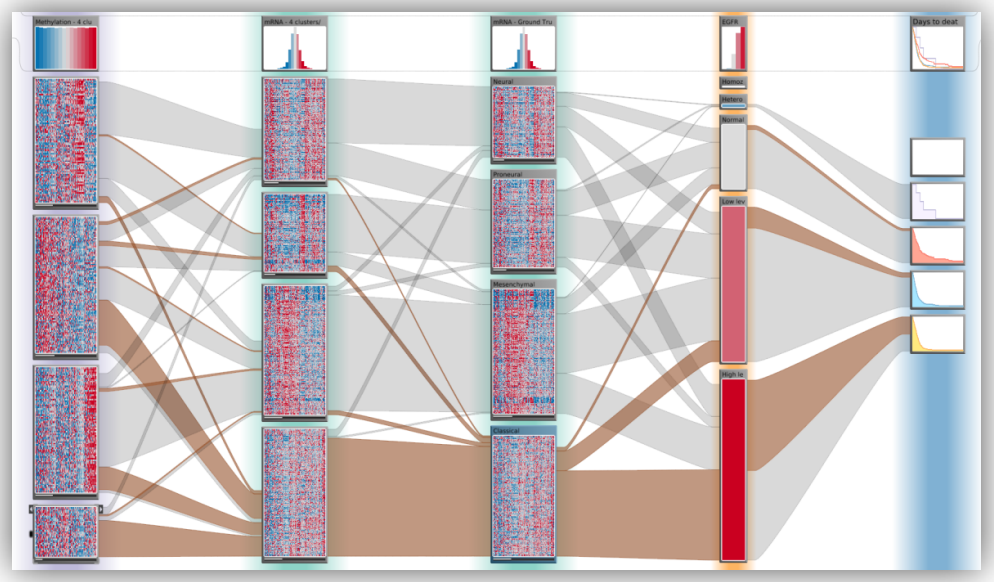
Caleydo







[Streit et al. 2012]



[Lex et al. 2012]

Super Application?

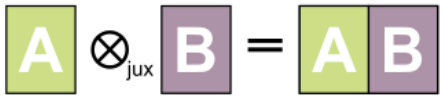
Super Application that can visualize everything

Not Feasible! Solution: use existing applications

Downsides:

- not integrated
- no highlighting, linking, etc.

Can we solve this?

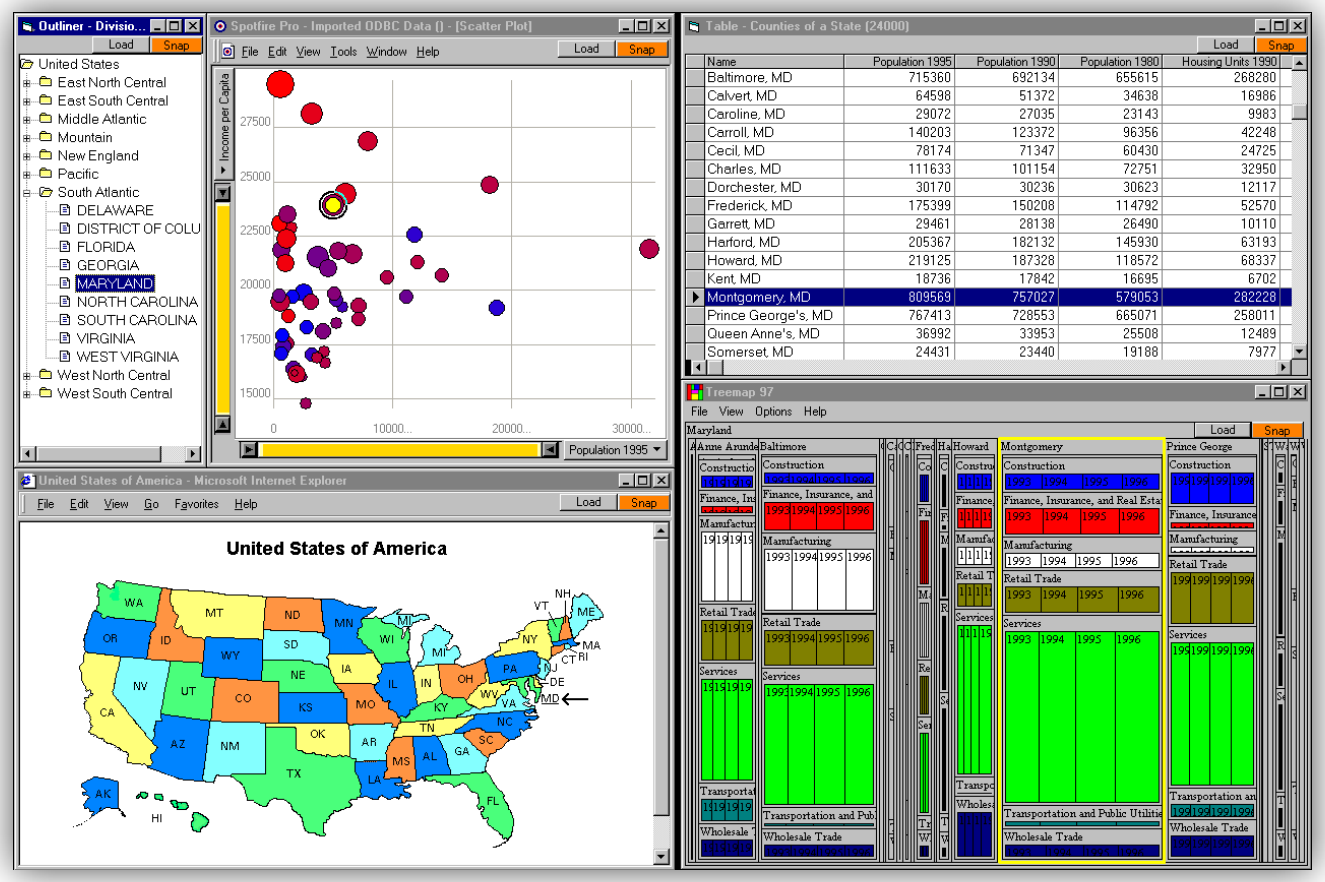


Juxtaposition

Snap-Together Visualizations

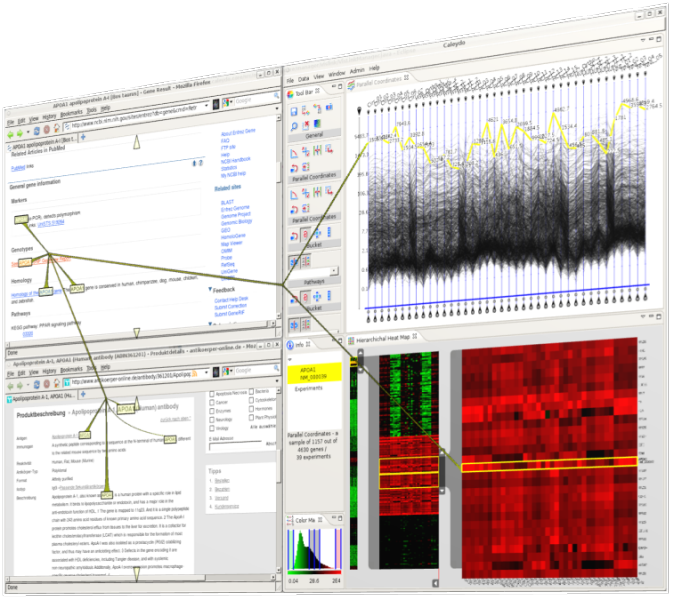
[North and Shneiderman 2000]

Linking & brushing across multiple applications



Manuela Waldner

[Waldner, GI 2010] – best paper award



VISUAL LINKING ACROSS APPLICATIONS

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GENERAL CONFERENCE INFORMATION

University of Ottawa

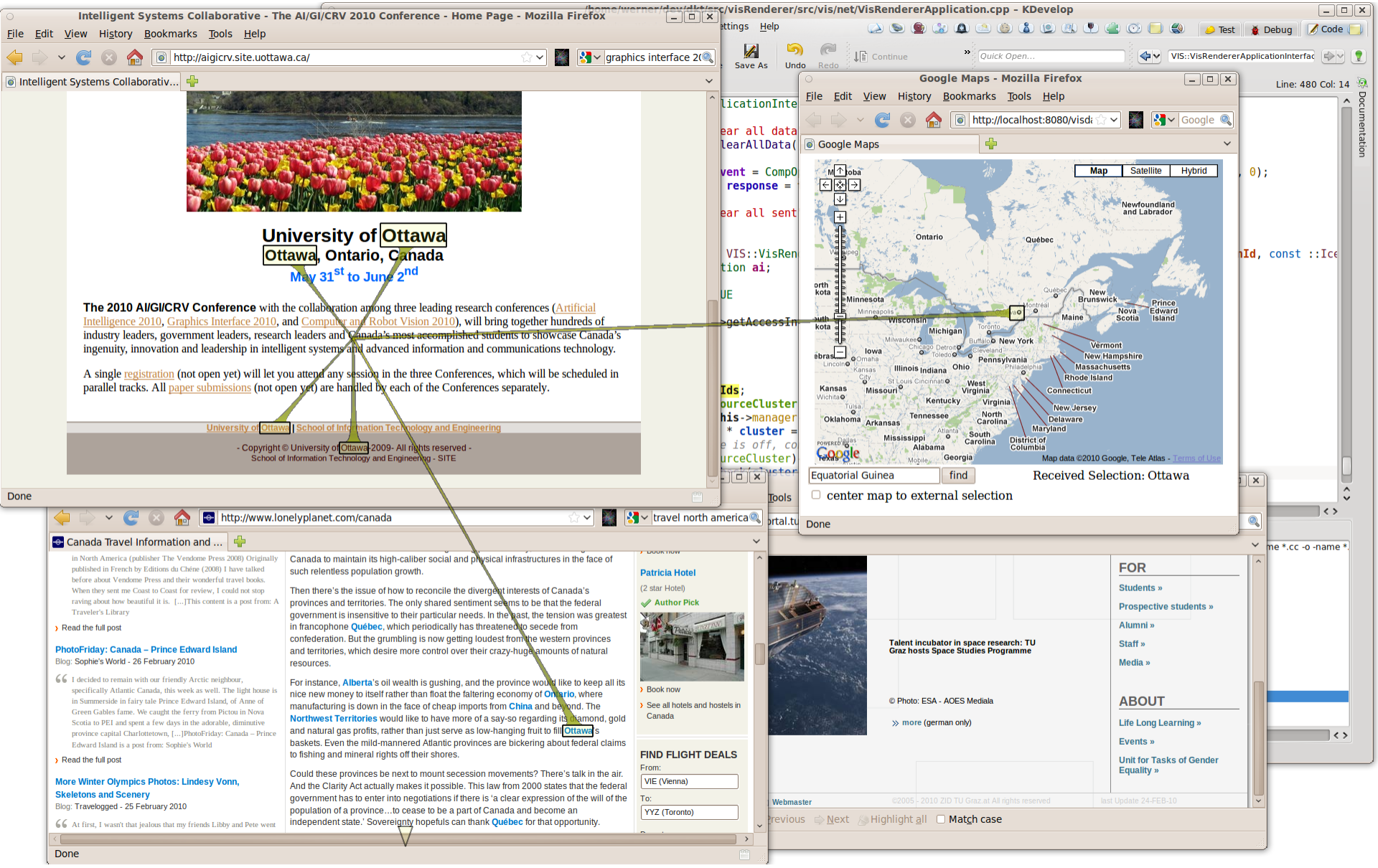
Ottawa, Ontario, Canada

May 31st to June 2nd

The 2010 AI/GI/CRV Conference with the collaboration among three leading research conferences (Artificial Intelligence 2010, Graphics Interface 2010, and Computer and Robot Vision 2010), will bring together hundreds of industry leaders, government leaders, research leaders and Canada's most accomplished students to showcase Canada's ingenuity, innovation and leadership in intelligent systems and advanced information and communications technology.

A single registration (not open yet) will let you attend any session in the three Conferences, which will be scheduled in parallel tracks. All paper submissions (not open yet) are handled by each of the Conferences separately.

Done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Google Maps - Mozilla Firefox
http://localhost:8080/visd
Map Satellite Hybrid
Equatorial Guinea find
Received Selection: Ottawa
center map to external selection
Done
http://www.lonelyplanet.com/canada
Canada Travel Information and ...
Canada to maintain its high-caliber social and physical infrastructures in the face of such relentless population growth.
Then there's the issue of how to reconcile the divergent interests of Canada's provinces and territories. The only shared sentiment seems to be that the federal government is insensitive to their particular needs. In the past, the tension was greatest in francophone Québec, which periodically has threatened to secede from confederation. But the grumbling is now getting loudest from the western provinces and territories, which desire more control over their crazy-huge amounts of natural resources.
For instance, Alberta's oil wealth is gushing, and the province would like to keep all its nice new money to itself rather than float the faltering economy of Ontario, where manufacturing is down in the face of cheap imports from China and beyond. The Northwest Territories would like to have more of a say-so regarding its diamond, gold and natural gas profits, rather than just serve as low-hanging fruit to fill Ottawa's baskets. Even the mild-mannered Atlantic provinces are bickering about federal claims to fishing and mineral rights off their shores.
Could these provinces be next to mount secession movements? There's talk in the air. And the Clarity Act actually makes it possible. This law from 2000 states that the federal government has to enter into negotiations if there is 'a clear expression of the will of the population of a province…to cease to be a part of Canada and become an independent state.' Sovereignty hopefuls can thank Québec for that opportunity.
Patricia Hotel
(2 star Hotel)
Author Pick
Book now
See all hotels and hostels in Canada
FIND FLIGHT DEALS
From: VIE (Vienna)
To: YYZ (Toronto)
PhotoFriday: Canada – Prince Edward Island
More Winter Olympics Photos: Lindesy Vonn, Skeletons and Scenery
Talent incubator in space research: TU Graz hosts Space Studies Programme
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Students »
Prospective students »
Alumni »
Staff »
Media »
ABOUT
Life Long Learning »
Events »
Unit for Tasks of Gender Equality »
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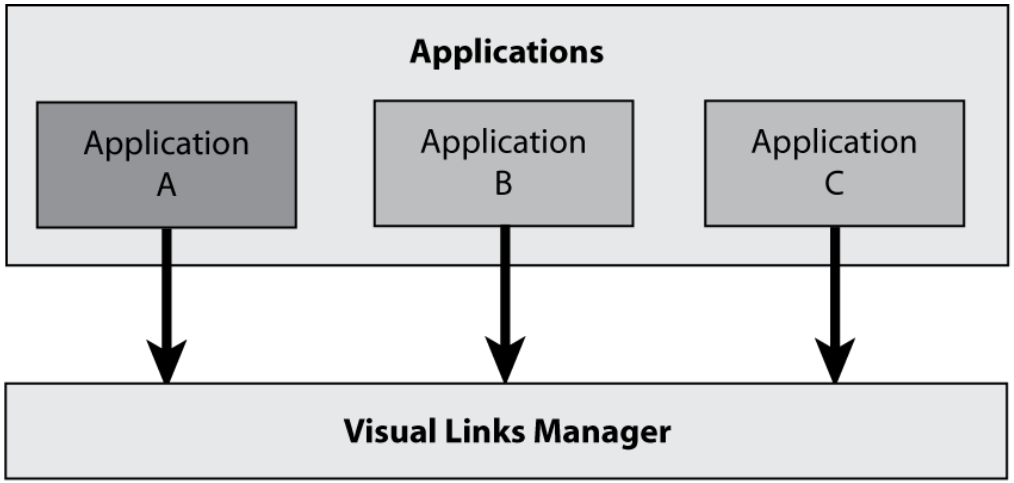
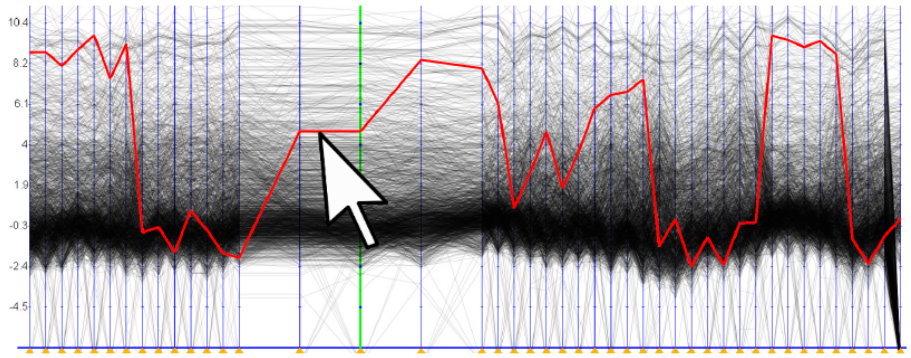
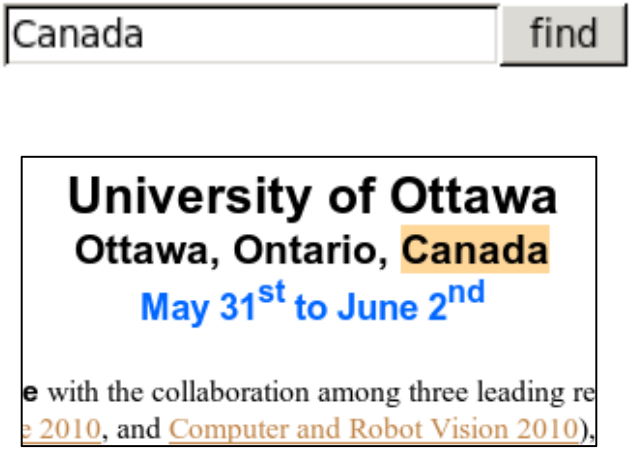
Visual Links Across Applications



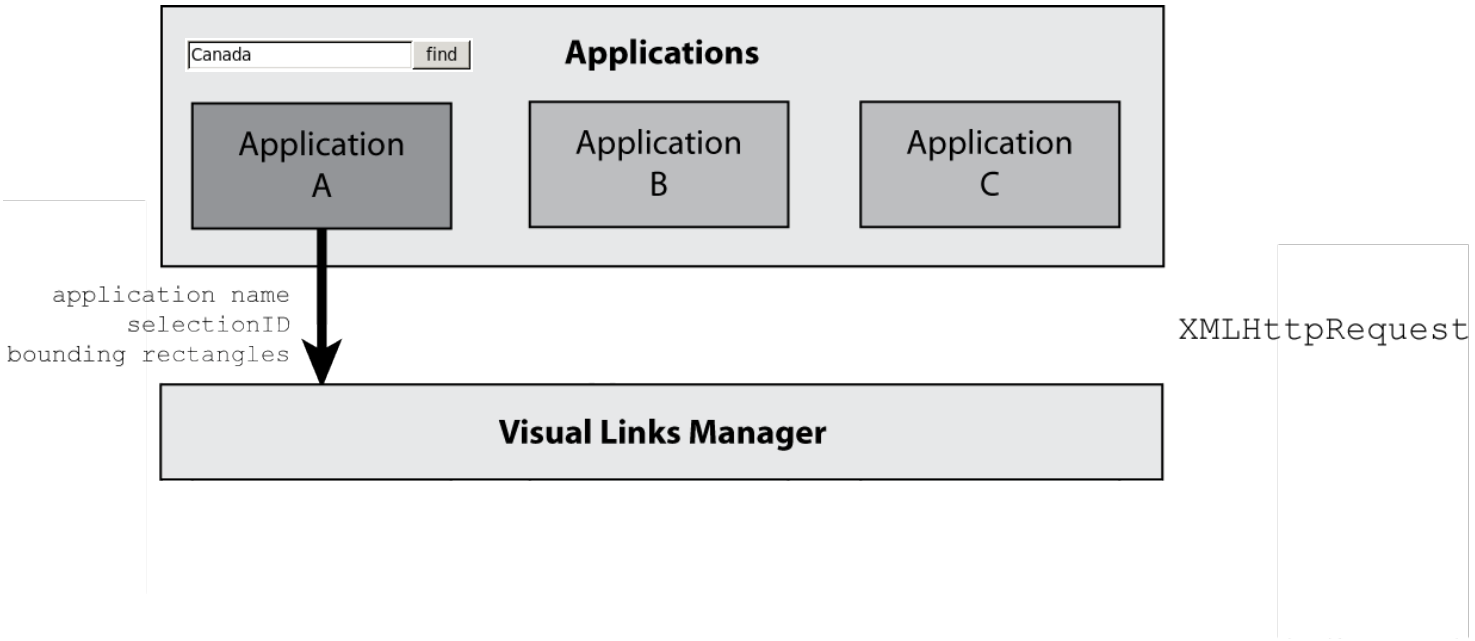
Triggering Selections

Determined by individual application

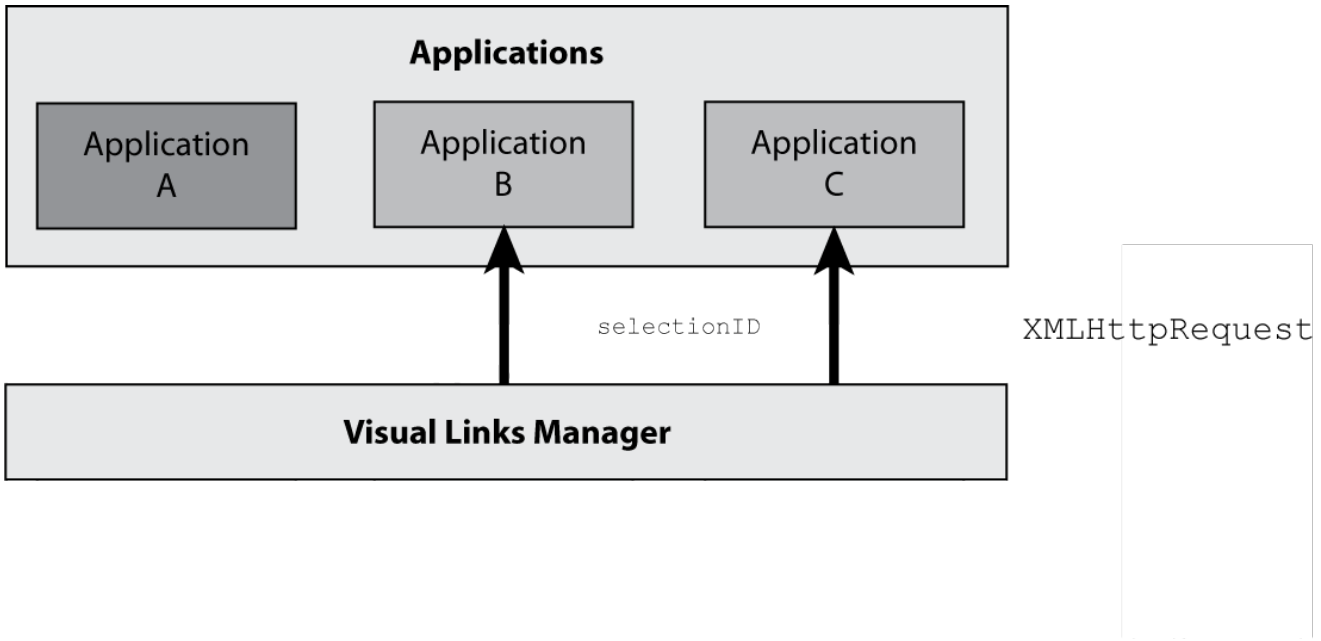




Visual Links Across Applications

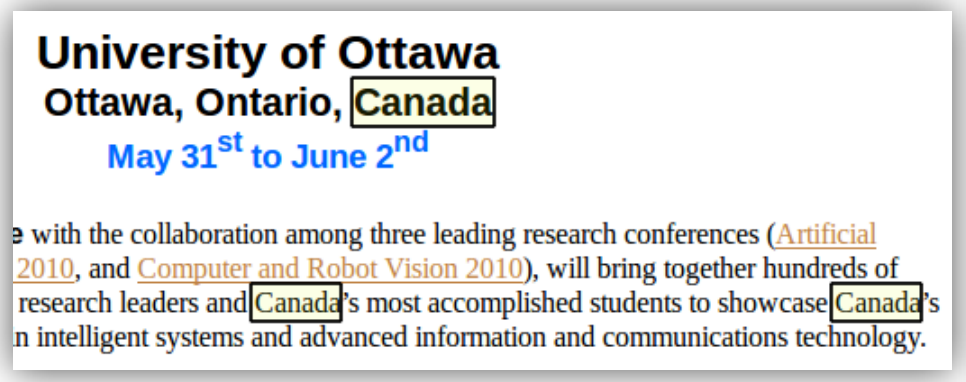


Visual Links Across Applications

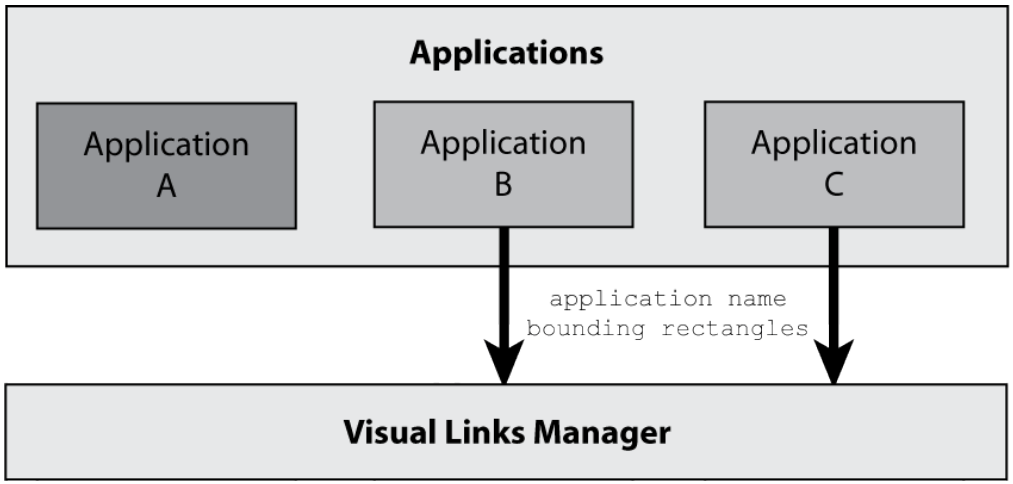


Selection Mapping

Applications evaluate incoming selection ID

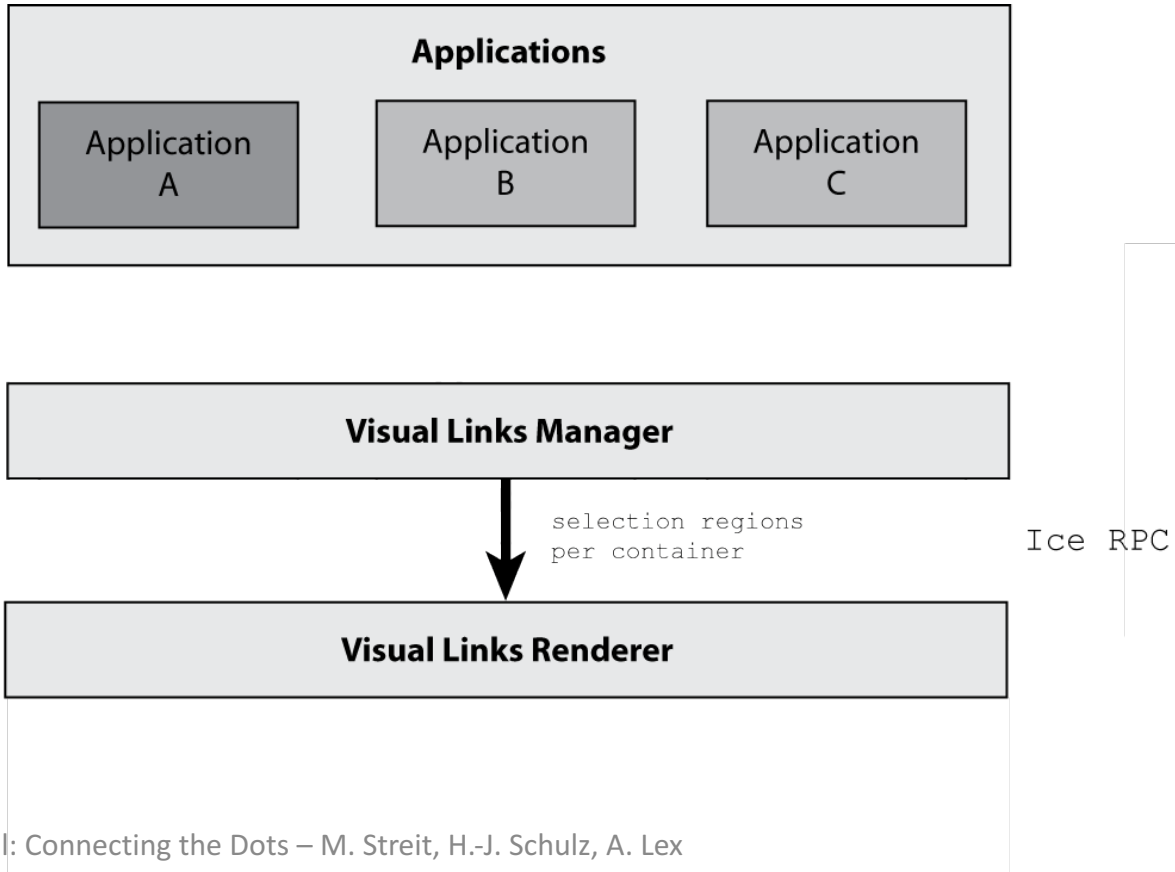


Visual Links Across Applications

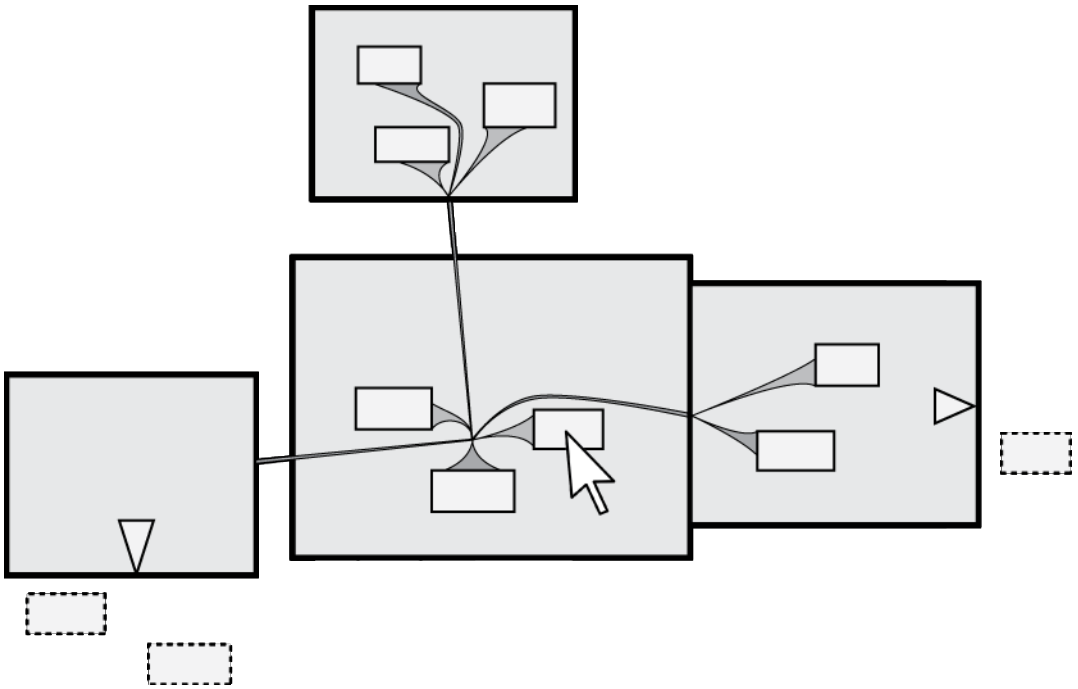


Visual Links Across Applications

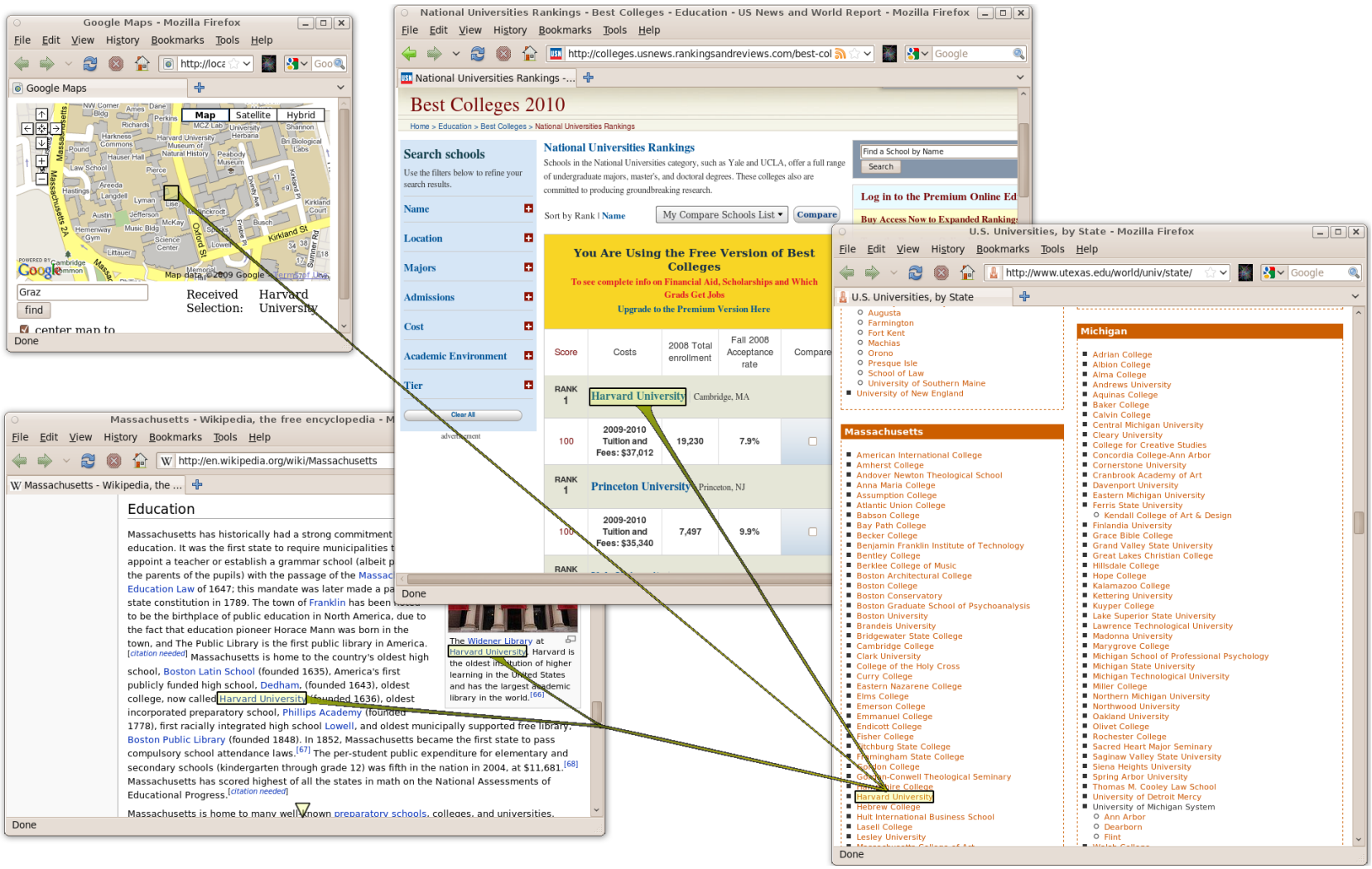
Selection regions are collected and sent to renderer



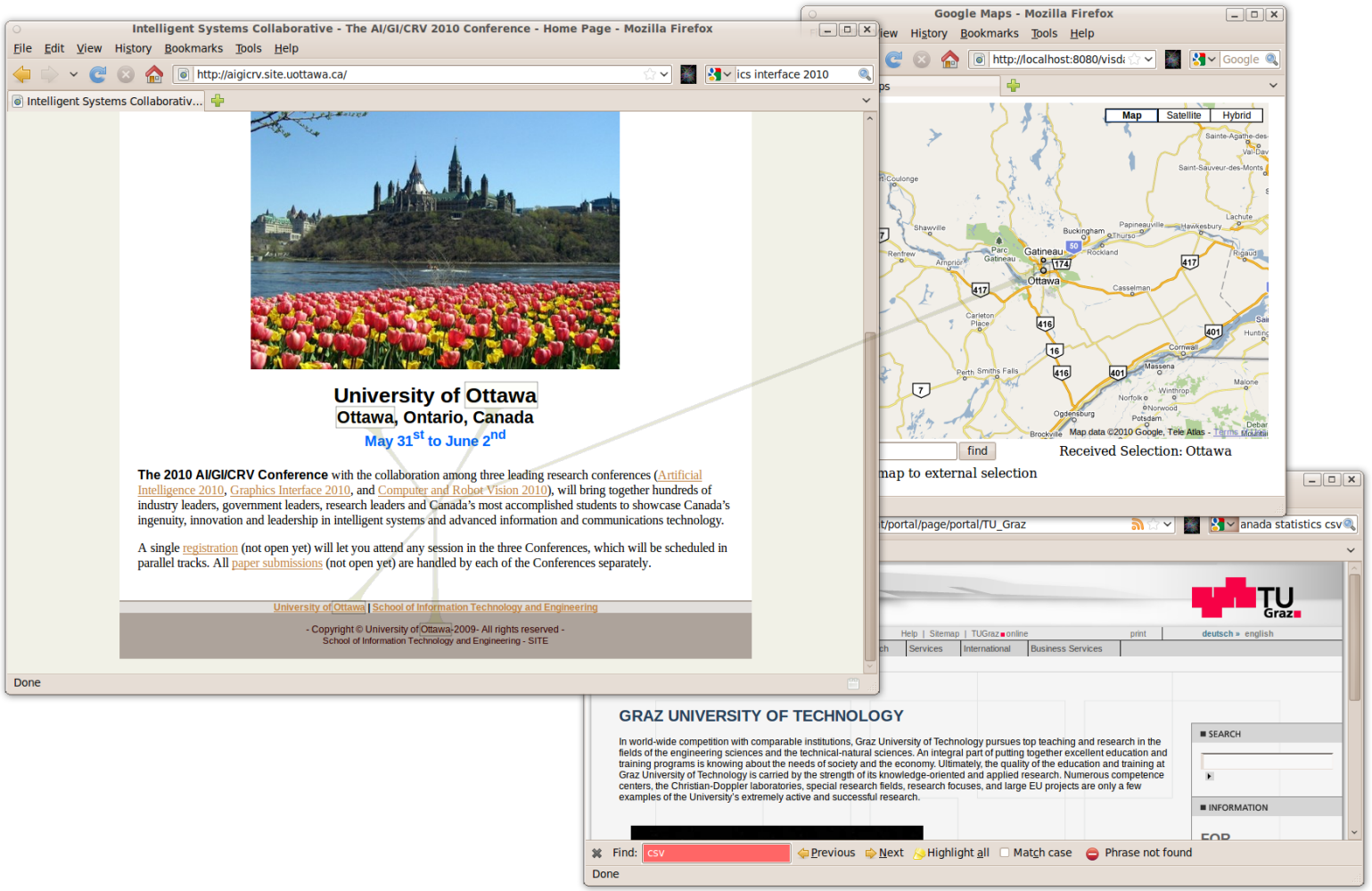
Design of Visual Links Across Apps



Design of Visual Links



Design of Visual Links



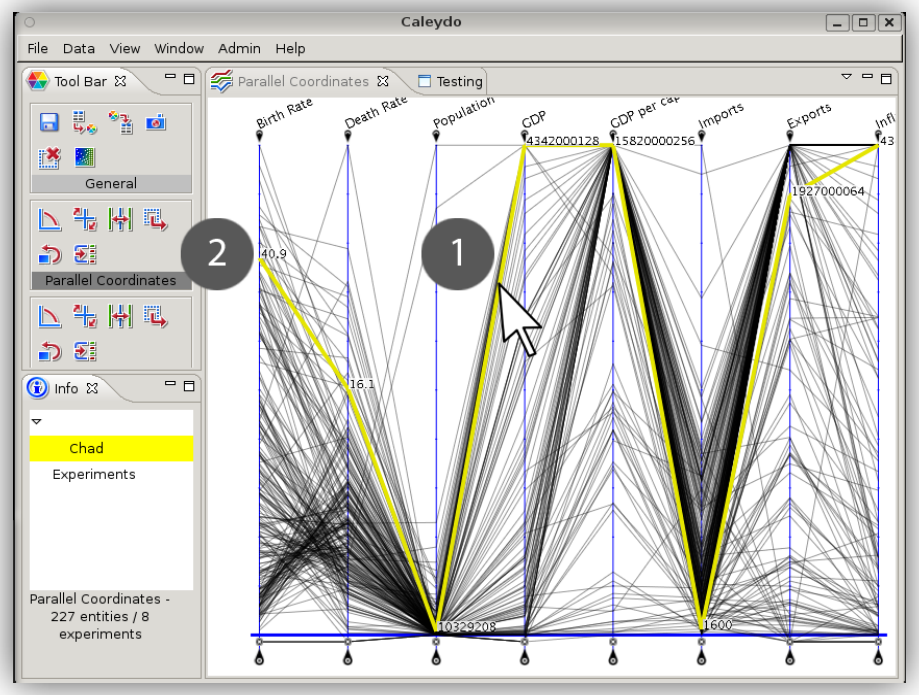
Application Integration

- Application support
  - Direct support
  - Software extensions (plug-ins)
  - Mashup application
  - OCR

Direct Application Support

Extending Caleydo visualization framework

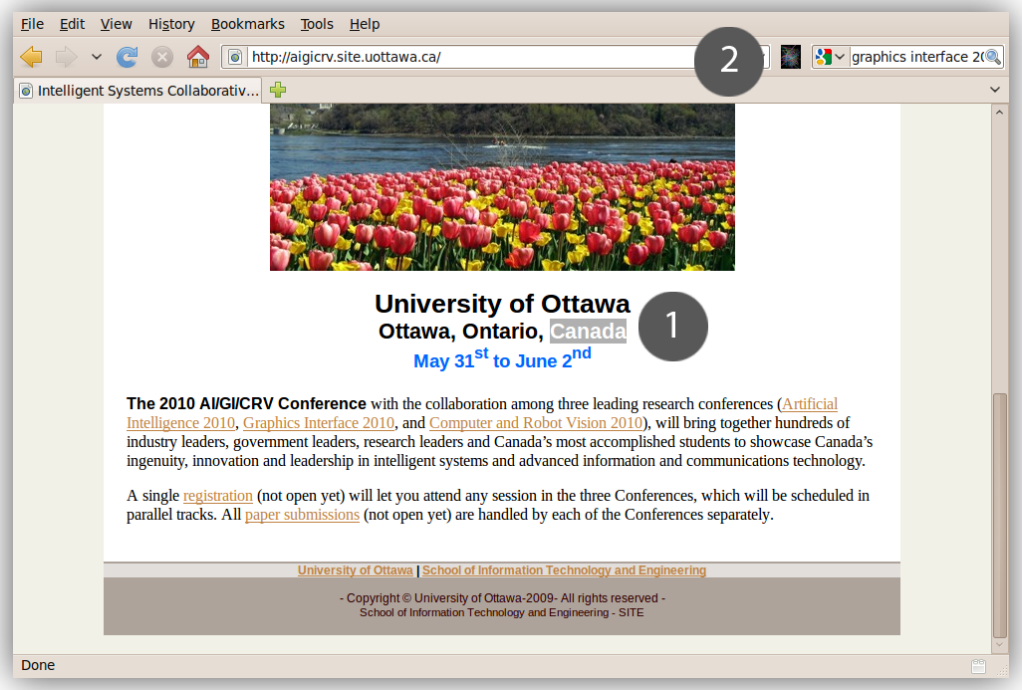
- Internal highlighting → coordinates are sent to manager



Software Extension

Mozilla Firefox web browser add-on

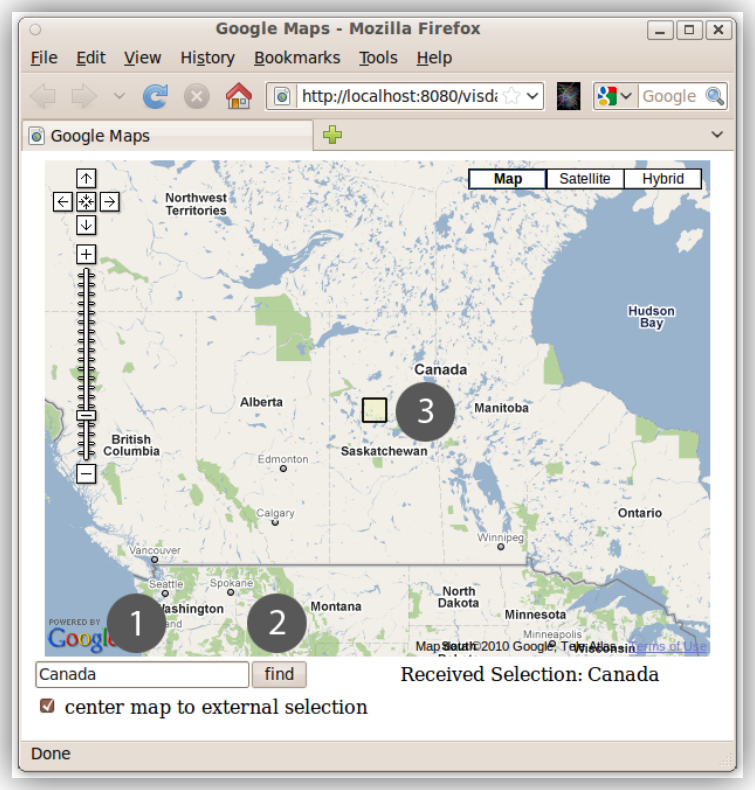
- Access to DOM of HTML-document
- Temporarily enclosing selection ID with -tag



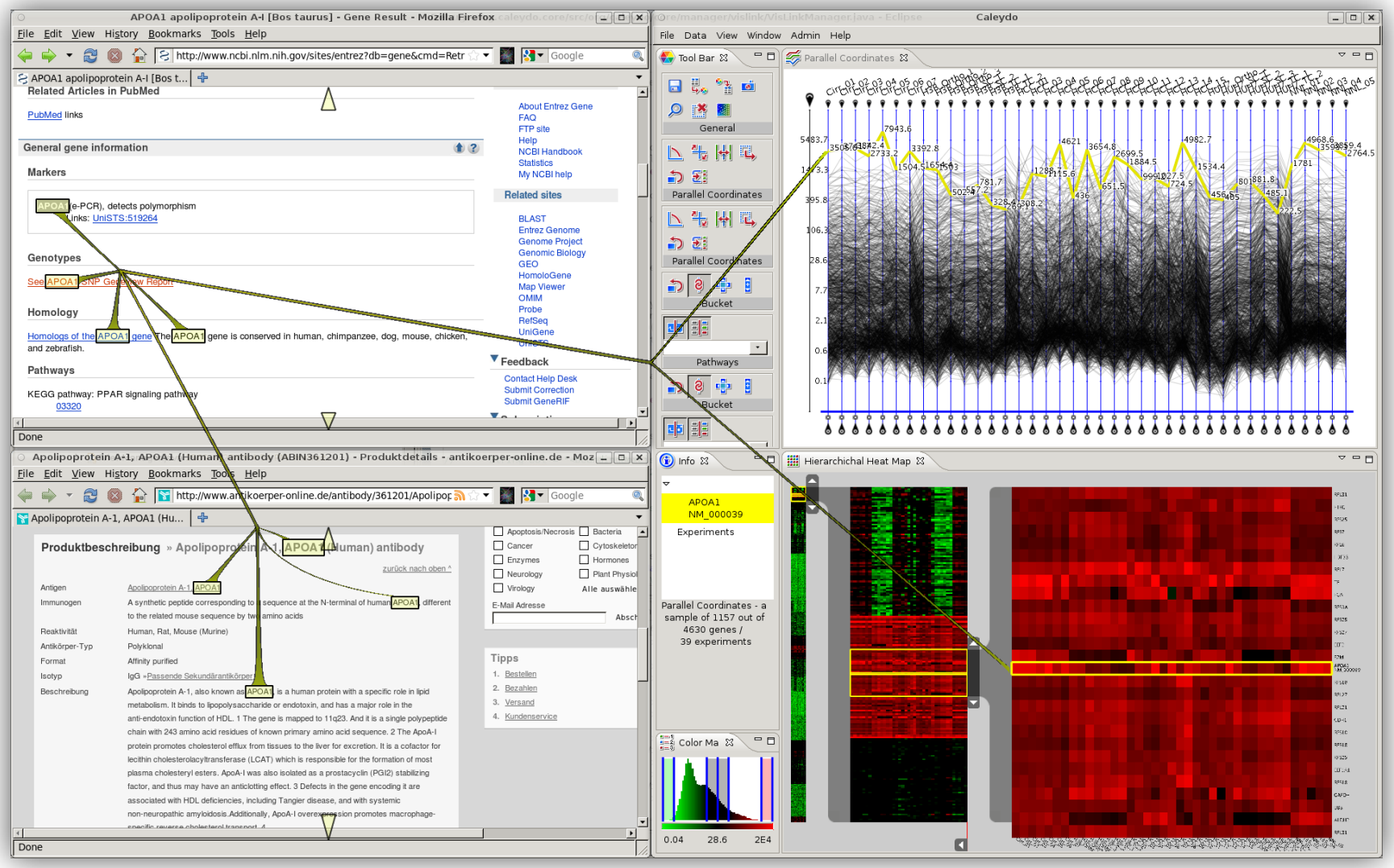
Mashup Application

HTML-page utilizing JavaScript and Google Maps API

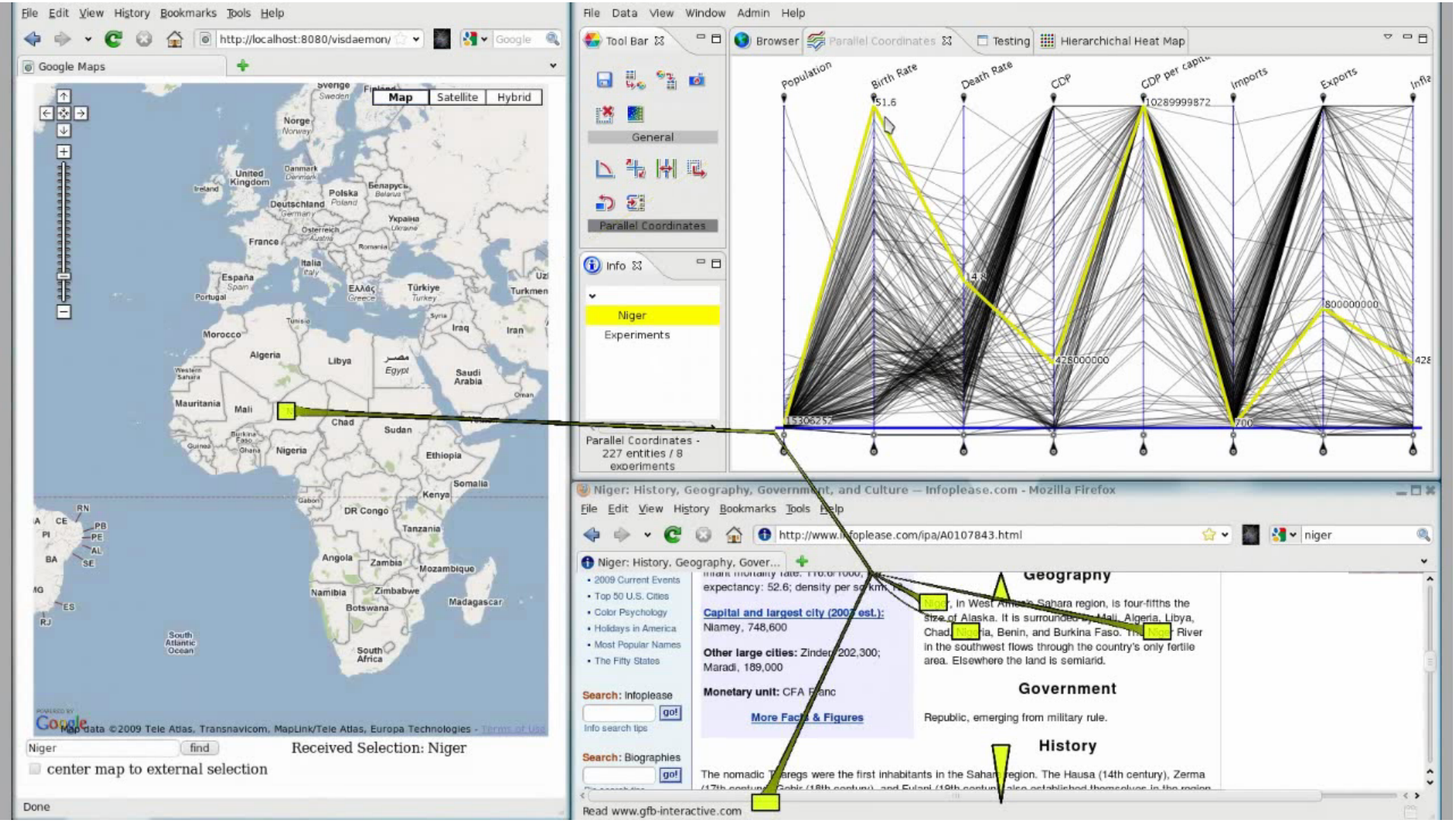
- Geographic location associated with selection ID
- Reports bounding rectangle around screen coordinates



Usage Scenario: Biomedical Analysis



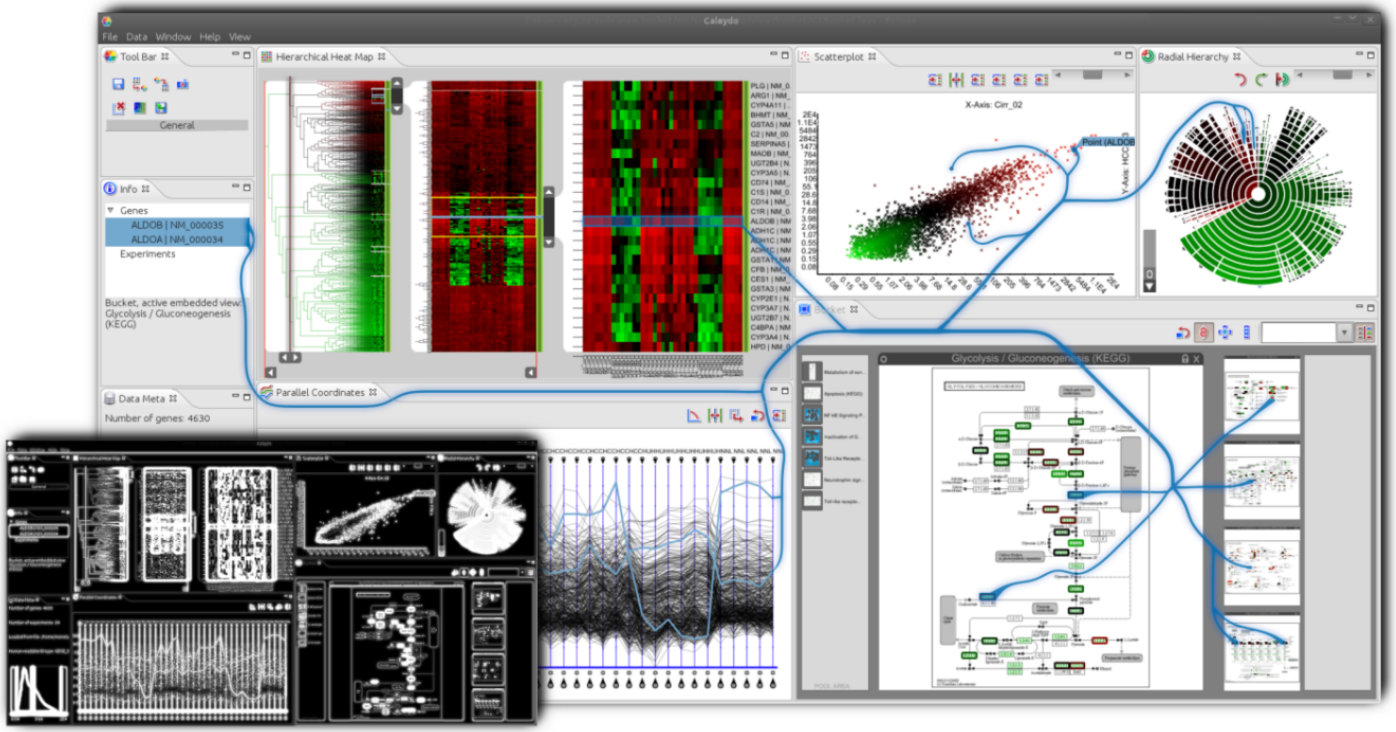
Usage Scenario: Economic Statistics



Soon Available: Routed Visual Links Across Apps

Light-weight app that renders on top of desktop

Real-time, OS-independent



What's missing: Linking beyond Strings

- Data
  - Abstractions
  - Selections
  - Intermediate processing results
- Meta-data
  - Groups (clusters)
- Interaction

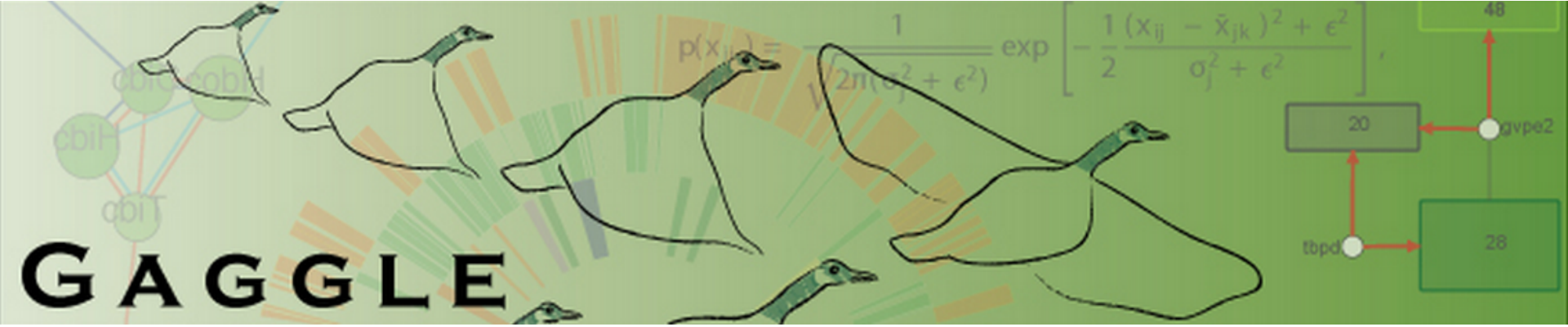
→ As discussed in Part I

Domain specific coordination project for systems biology

Broad Institute

http://www.genomespace.org

Allows to move data(sets) smoothly between applications

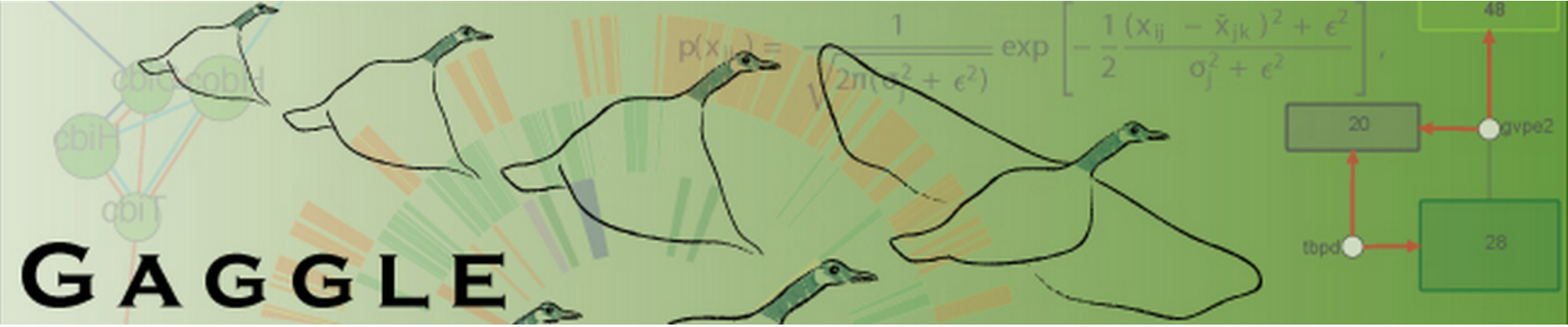


Domain specific coordination project for systems biology

Institute of Systems Biology

http://gaggle.systemsbiology.net/

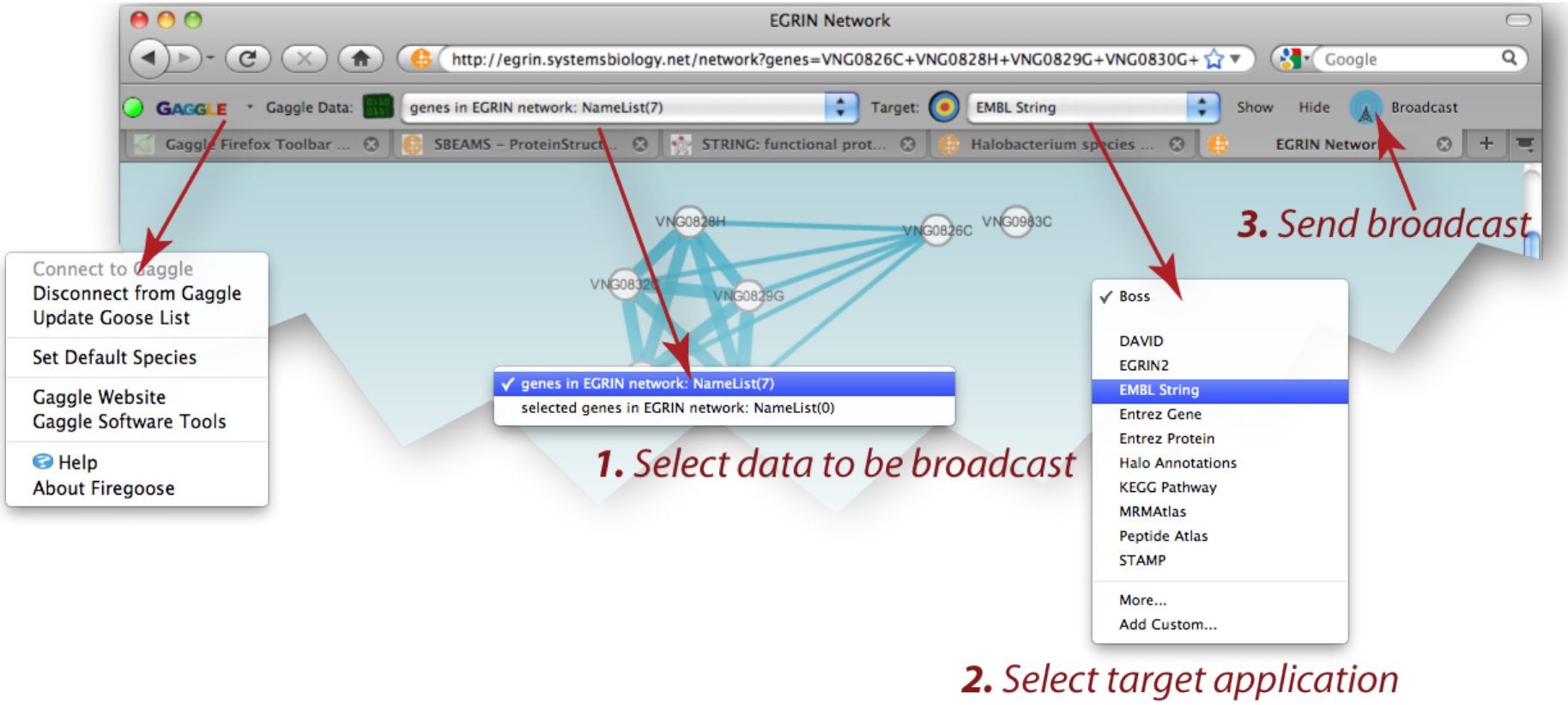
Also integrates analytical tools such as R



Allows to exchange:

- Name list
- Clusters/groups
- Tuple: a collection of name/value pairs
- Matrix (rows and columns)
- Network: a collection of nodes and edges

Firefox toolbar for the Gaggle



Obvious

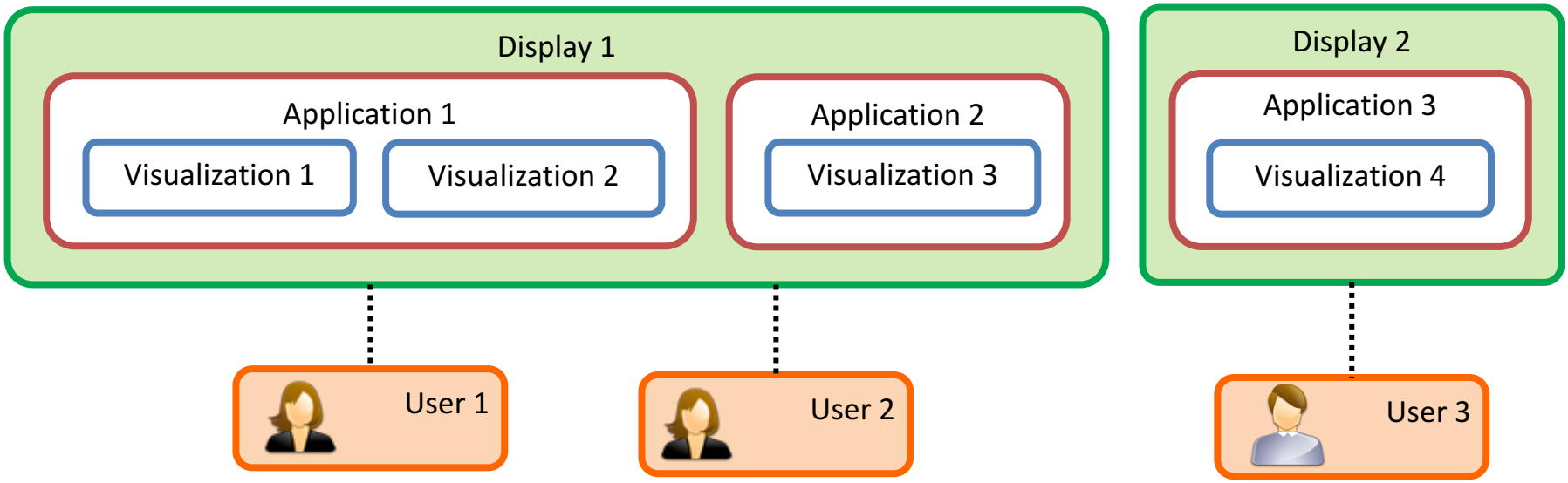
[Fekete et al. 2011]

Meta-Toolkit to Encapsulate Information Visualization Toolkits

http://code.google.com/p/obvious

Deep integration between frameworks

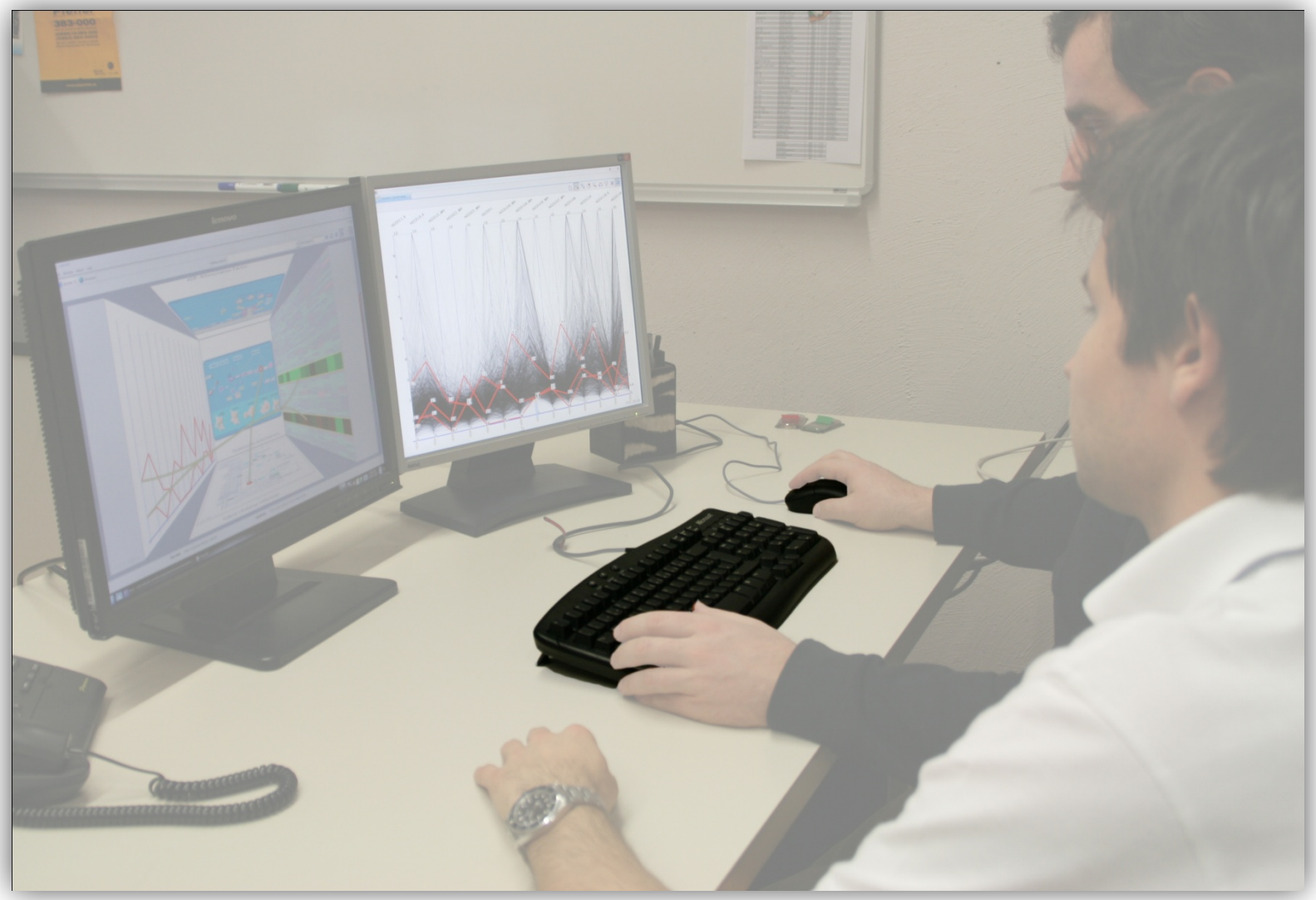
Unifies Prefuse, the InfoVis Toolkit, partly Improvise, JUNG and other data management libraries



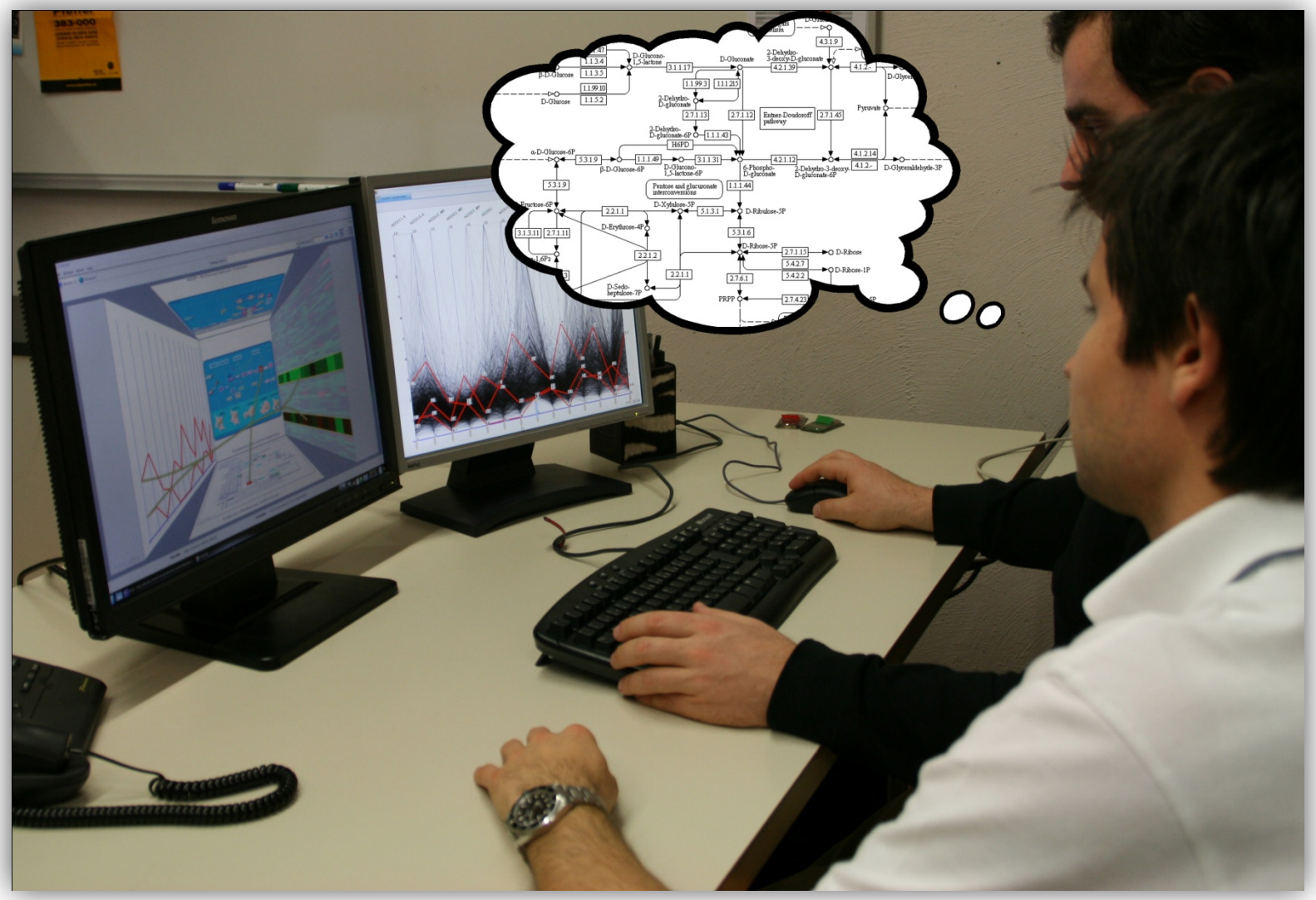
LINKING ACROSS DISPLAYS / USERS

Collaborative Information Analysis

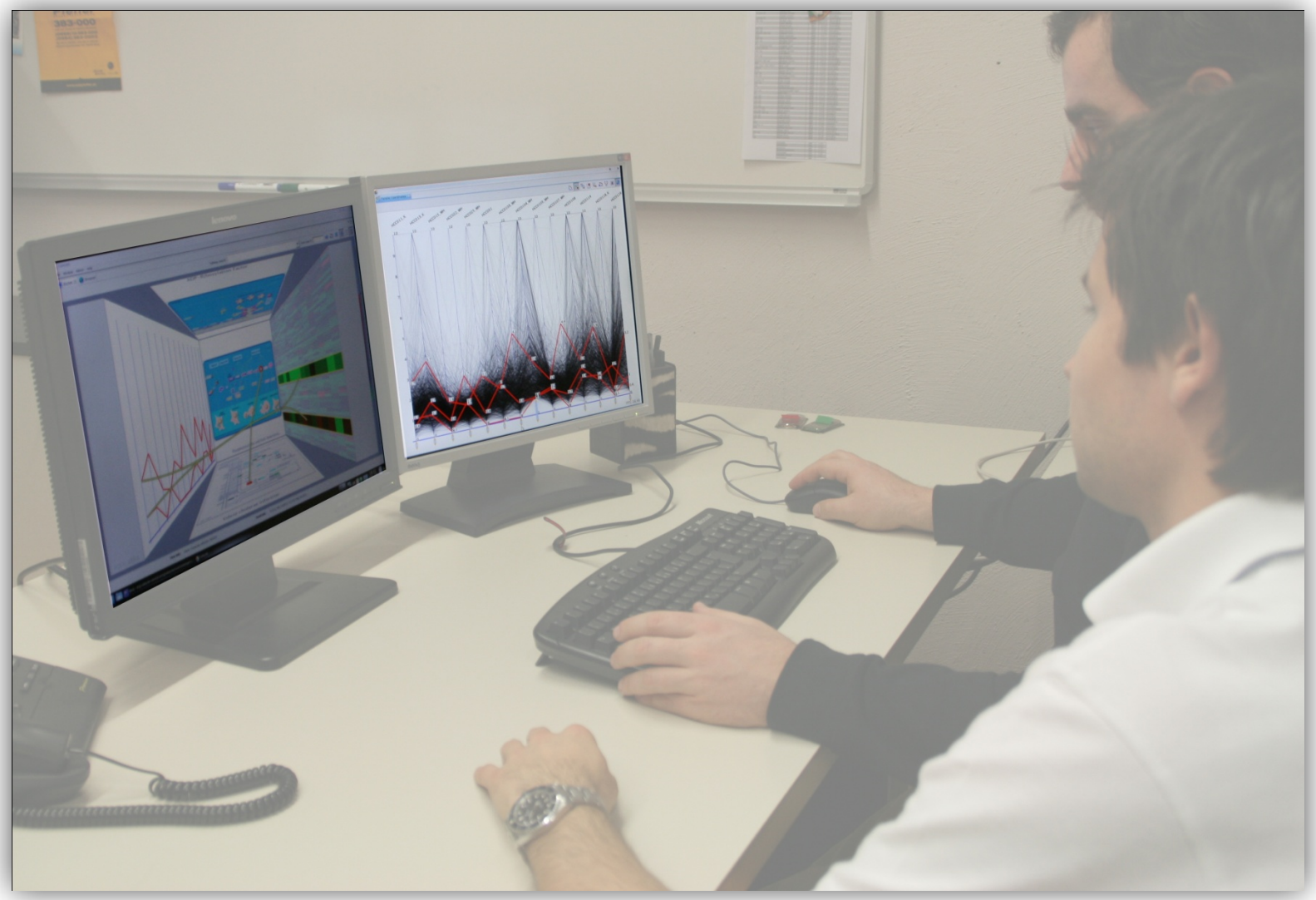
Collaborative Information Analysis



Collaborative Information Analysis



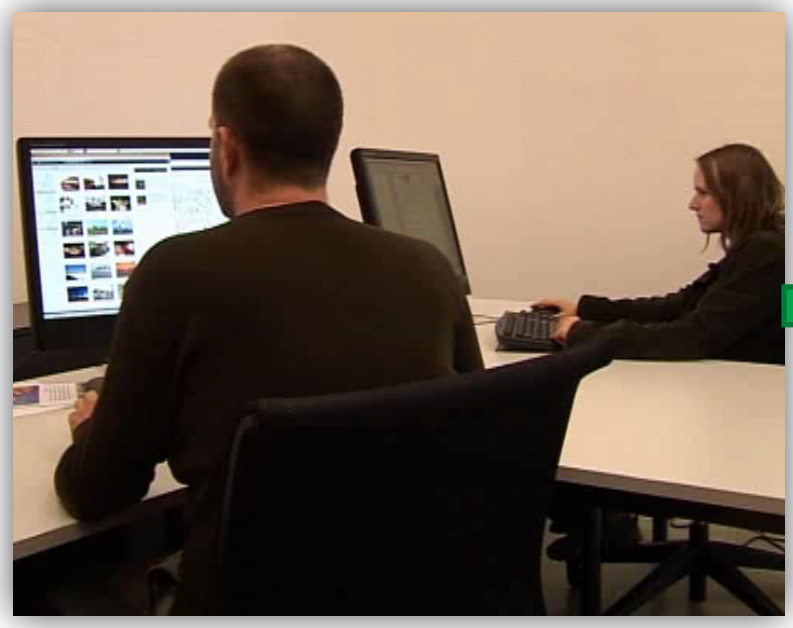
Collaborative Information Analysis



Collaborative Information Analysis

Separation

- Individual information extraction
- Discussion of individual contributions

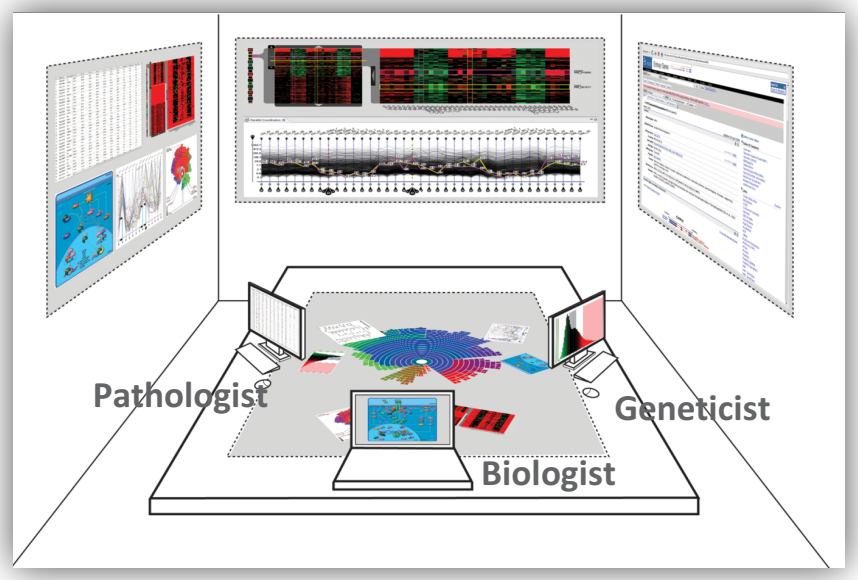


Collaborative Visual Analysis

Interdisciplinary analysis problems

Single domain expert may not be enough

→ Need for collaboration



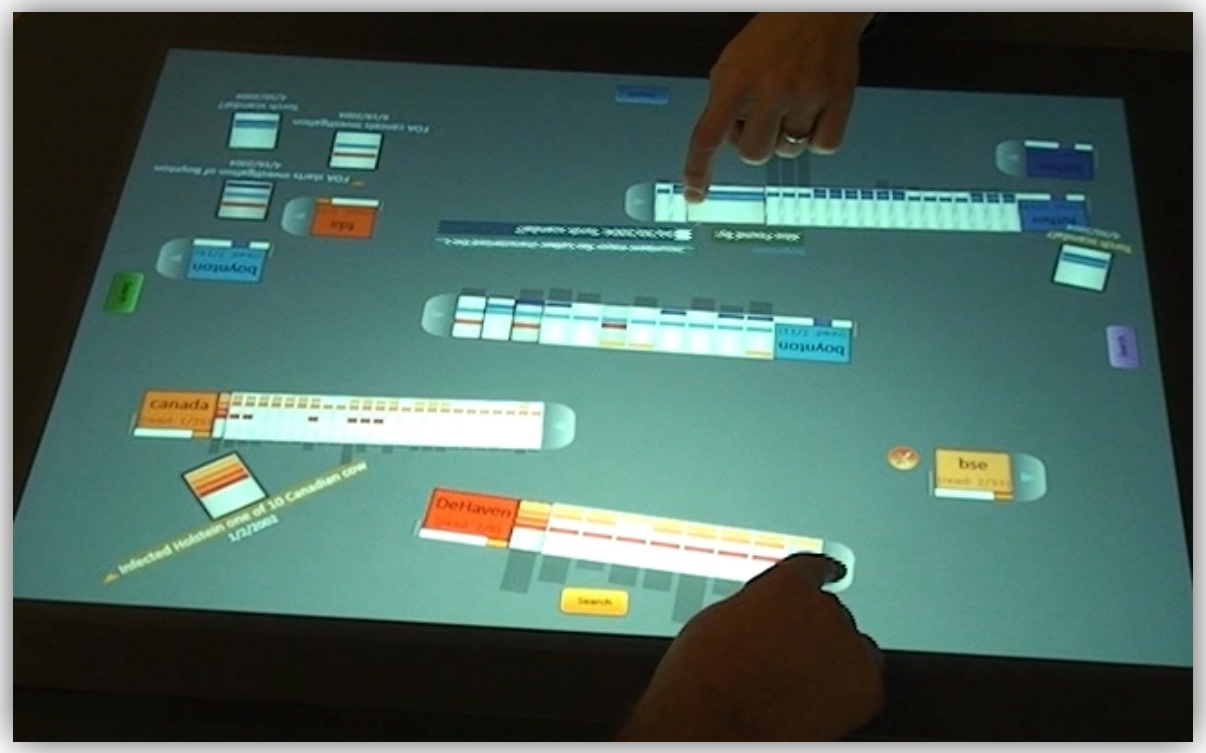
[Streit et al. 2009]

[Waldner et al. 2009]

Collaborative Brushing and Linking

[Isenberg and Fisher 2009]

Co-located Visual Analytics of Document Collections



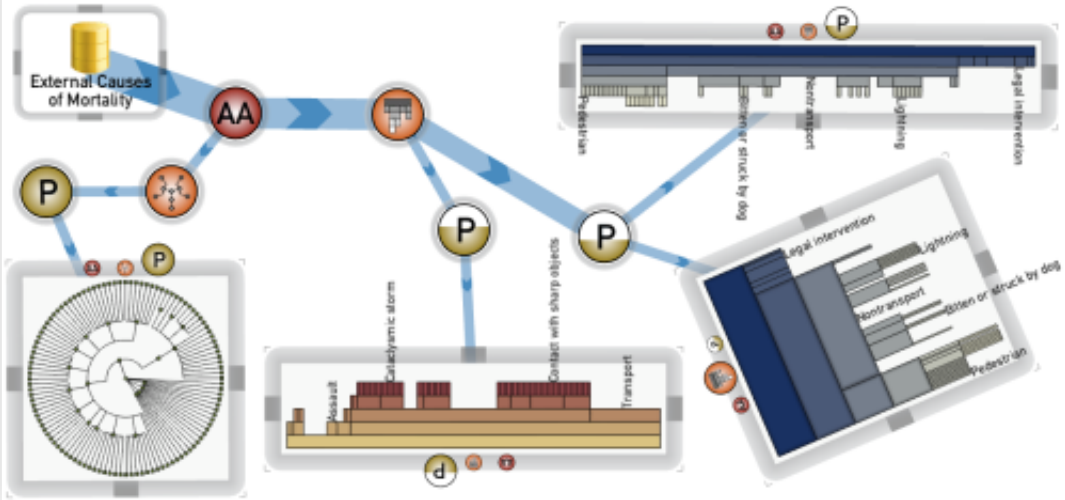
LARK: Coordinating Co-located Collaboration with InfoVis

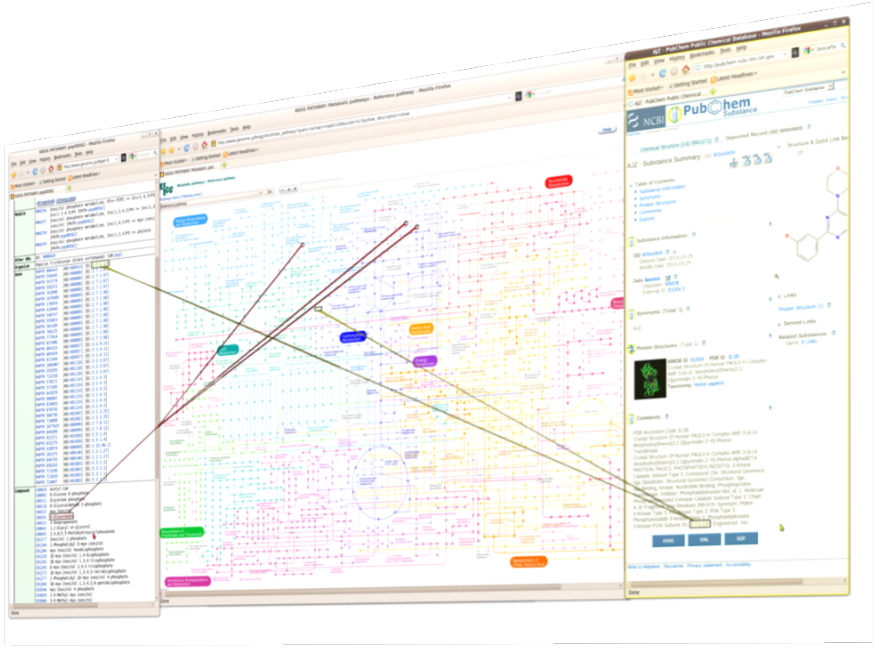
[Tobiasz et al. 2009]

MCV on large multi-touch displays

Explicitly indicating coordination points on

data, representation, presentation, and view level





[Waldner et al. 2011]

COLLABORATIVE INFO LINKING

Collaborative Info-Linking Approach

Collaborative environment that provides:

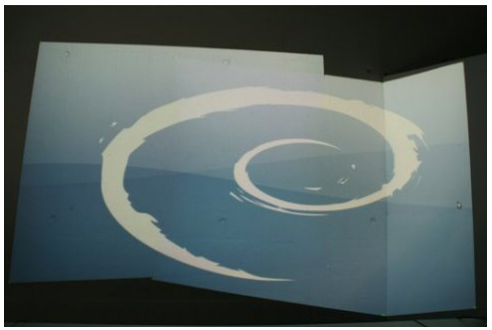
- Unmodified single-user application support
- Sufficient screen space
- Multi-pointer support
- User-specific visual links across applications
- Protecting workspaces
- Storing and sharing

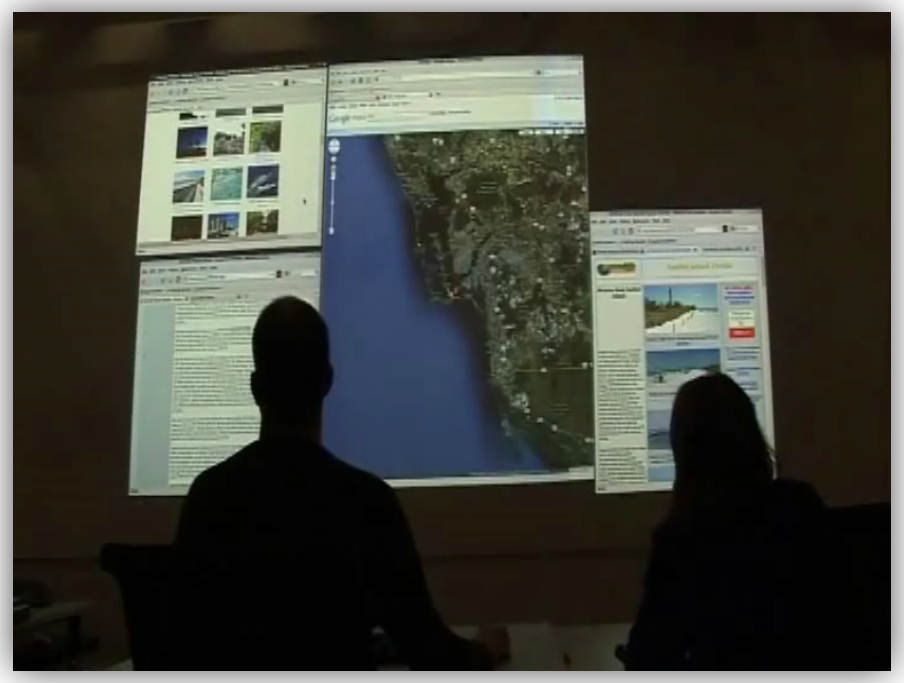
Large displays

Casually aligned multi-projector displays

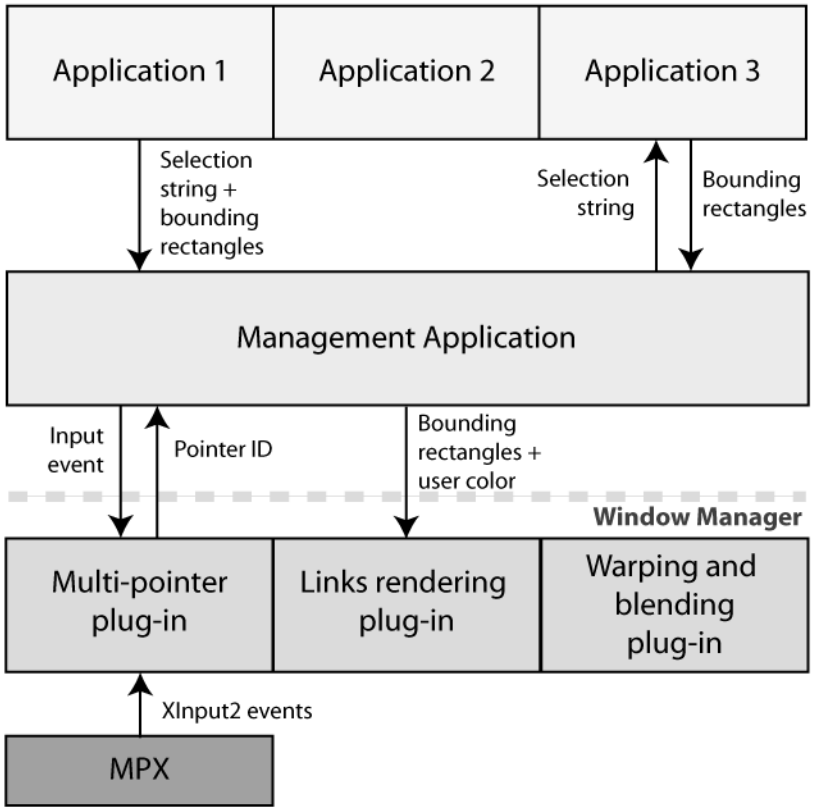
Compiz extension for tiled displays [Waldner et al., EDT/IPT 2008]

Warping and blending of overlapping projections in the window manager → application transparent

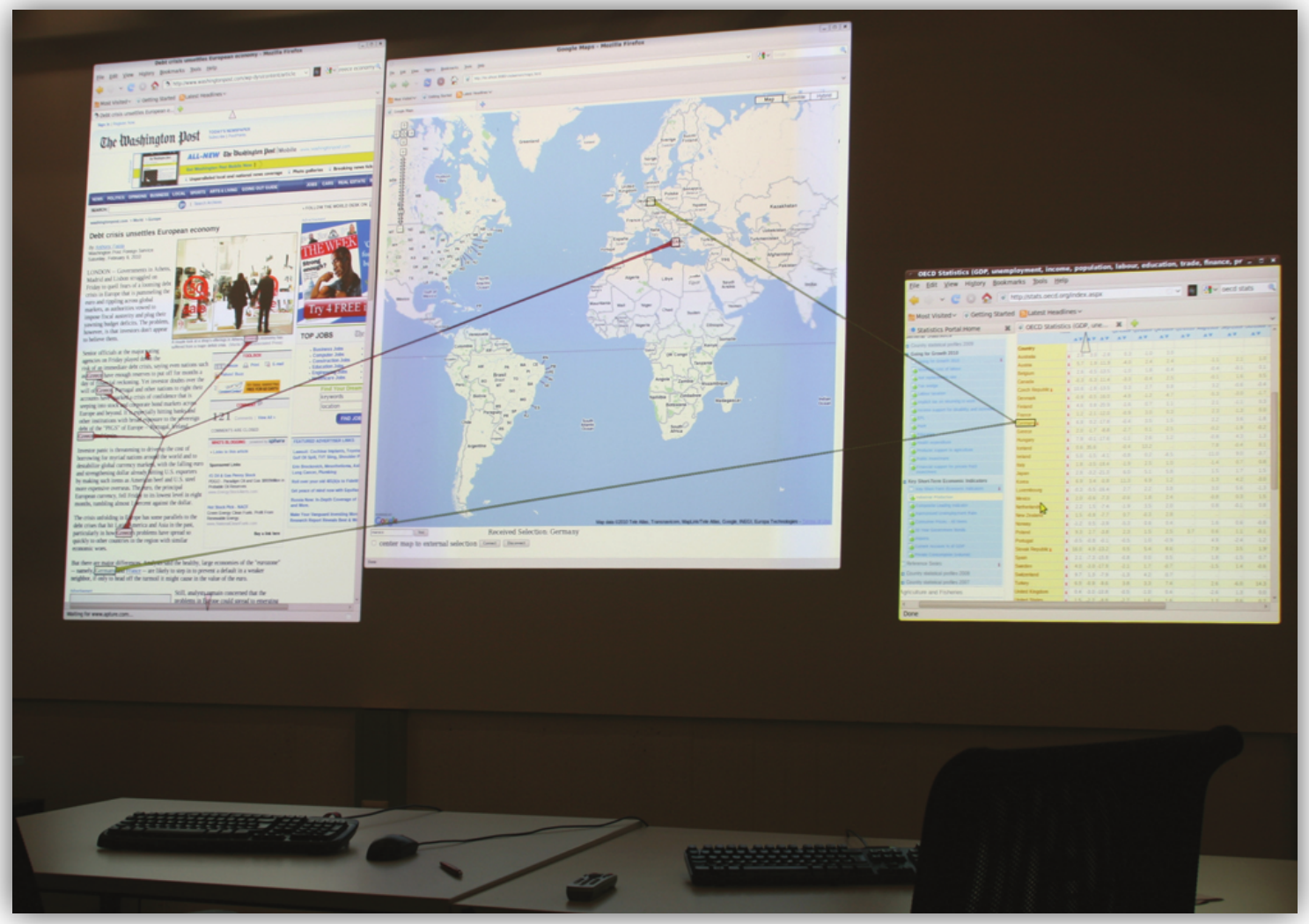




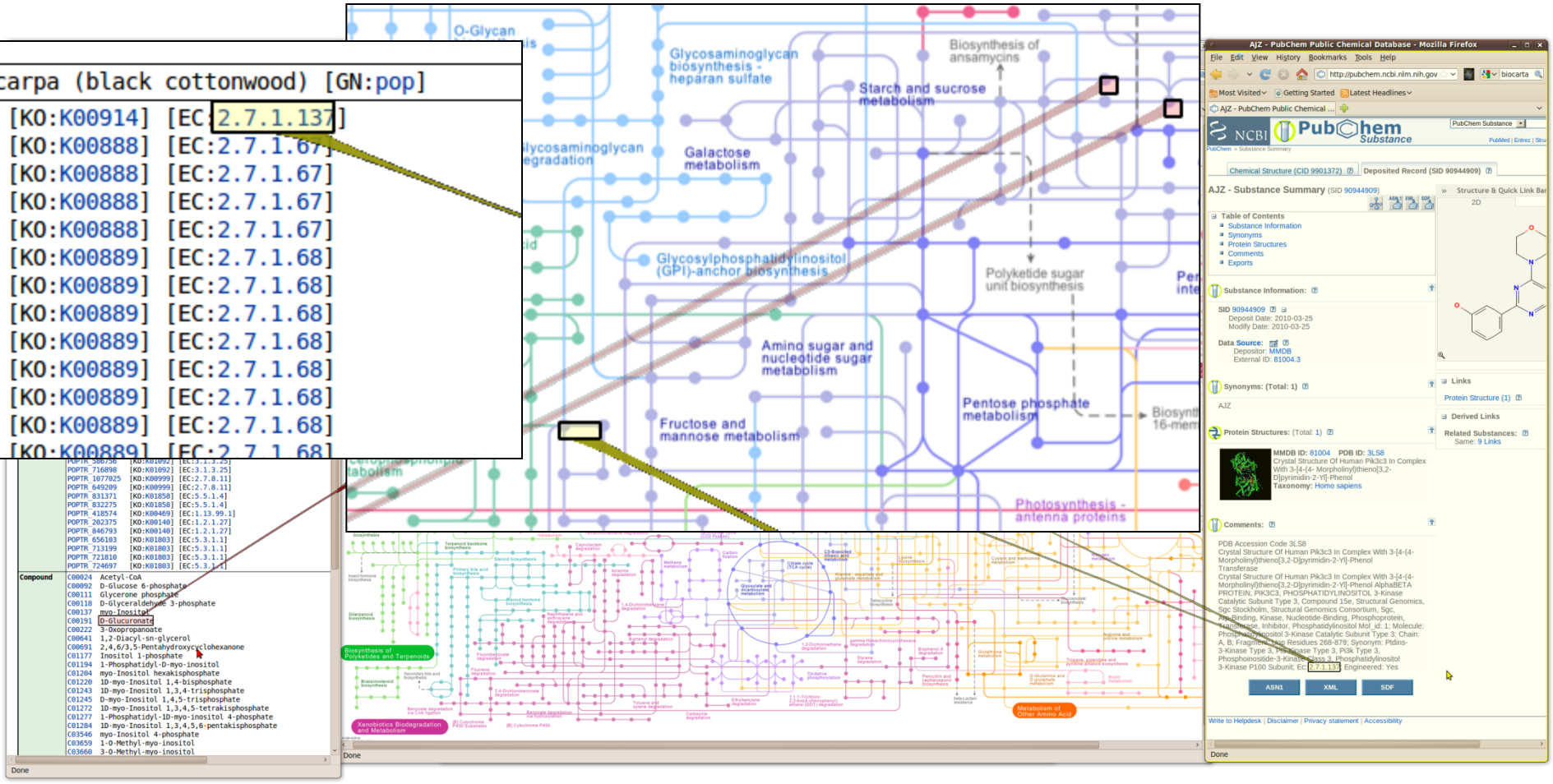
Linking Infrastructure



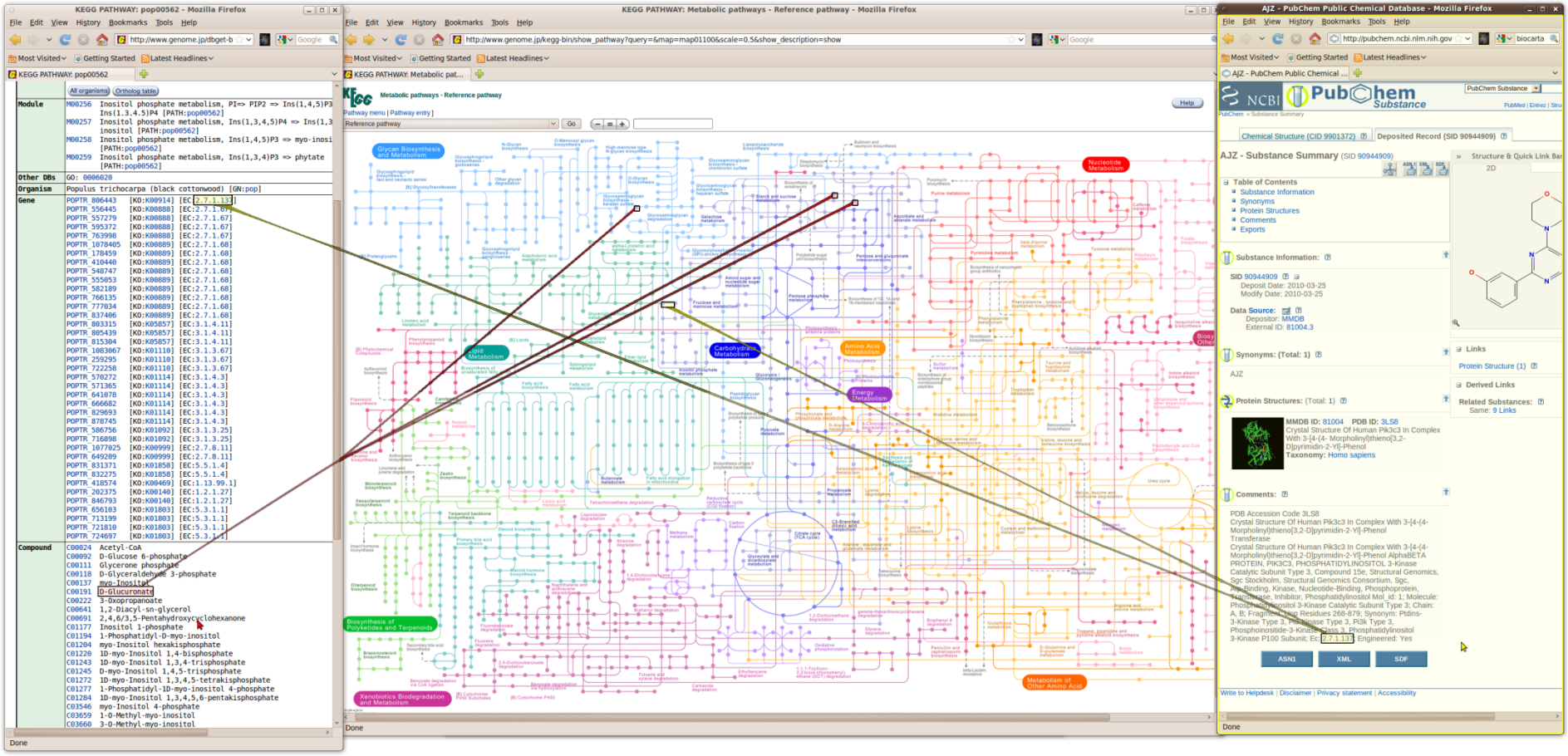
Collaborative Info Linking Video



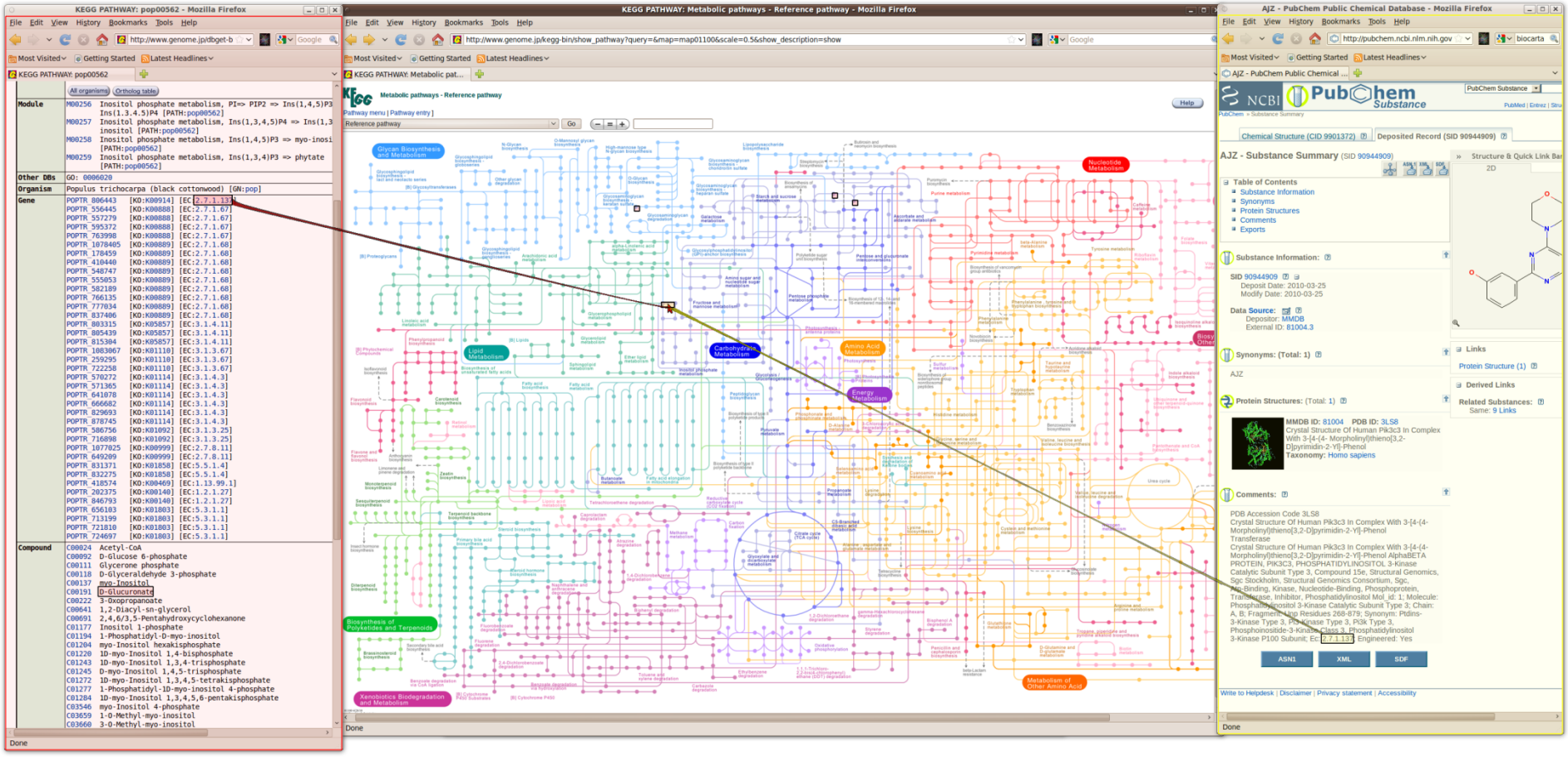
Collaborative Information Linking



Window Protection

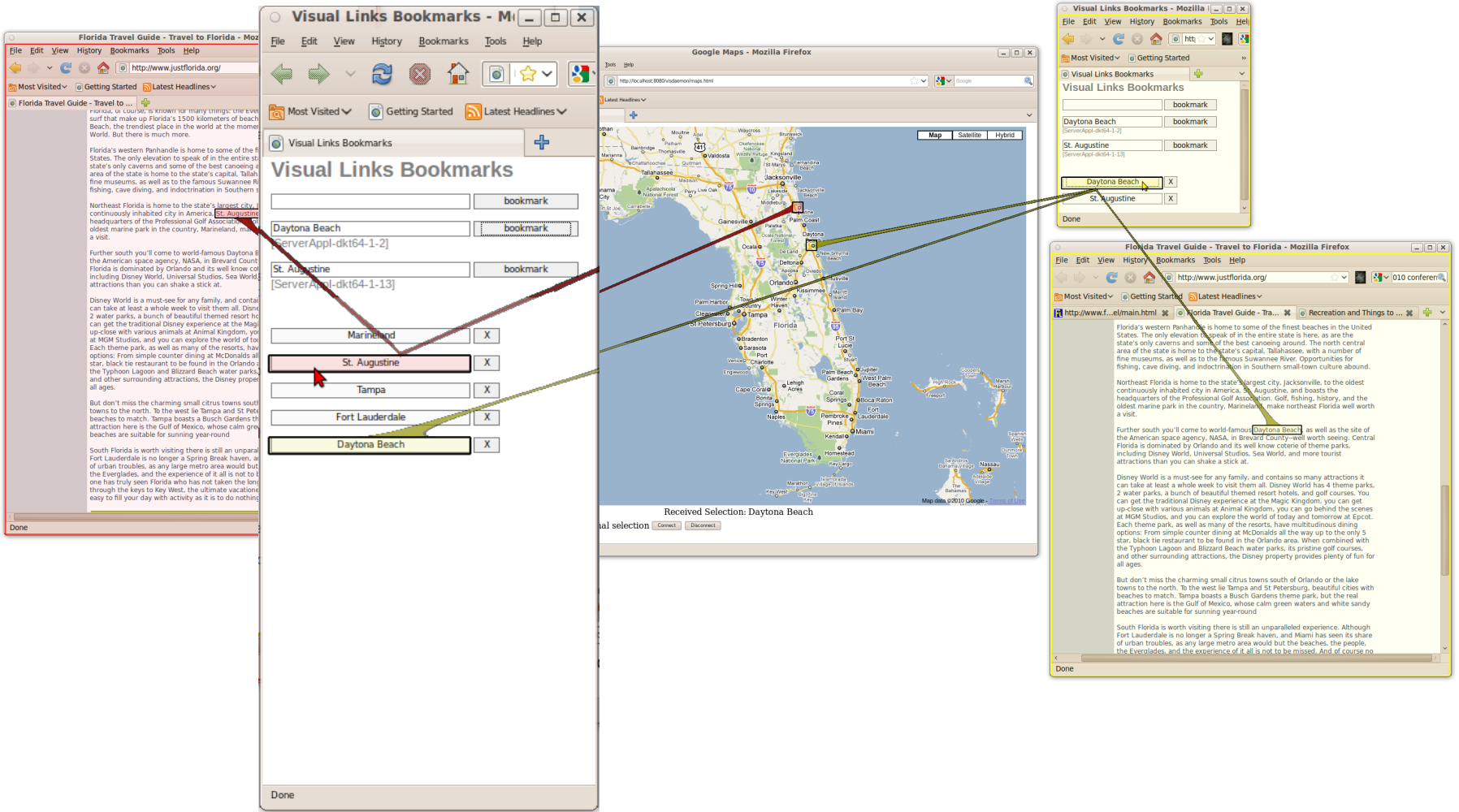


Selection „Hijacking“



Selection Storage and Management

Bookmark list as central storage and global



One-Shot Linking

Light-weight linking *from* unmodified applications

This image cannot currently be displayed.

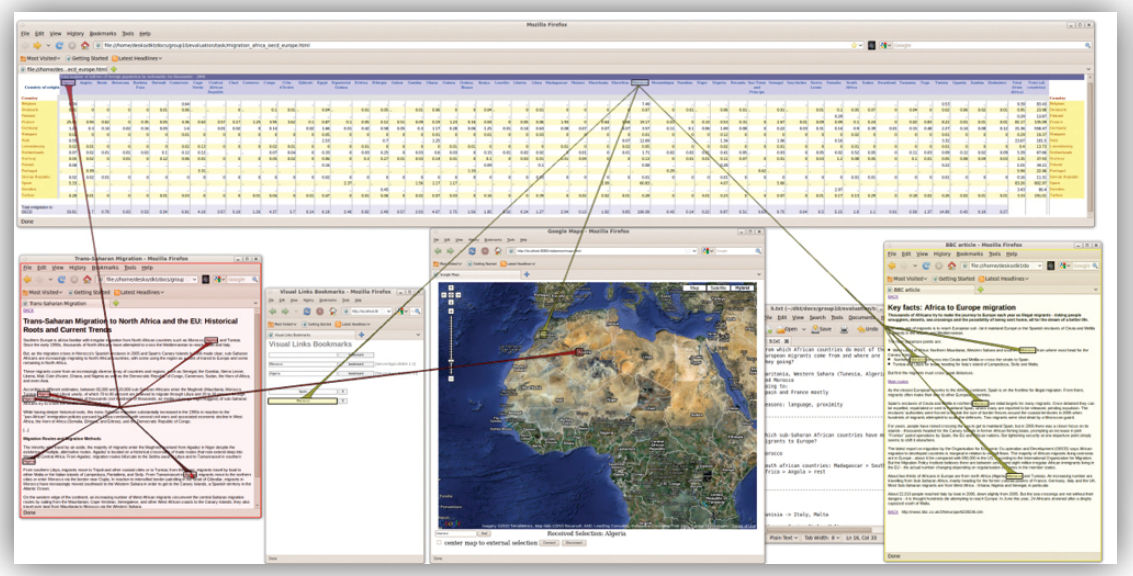
Text selection → keyboard shortcut → selection buffer

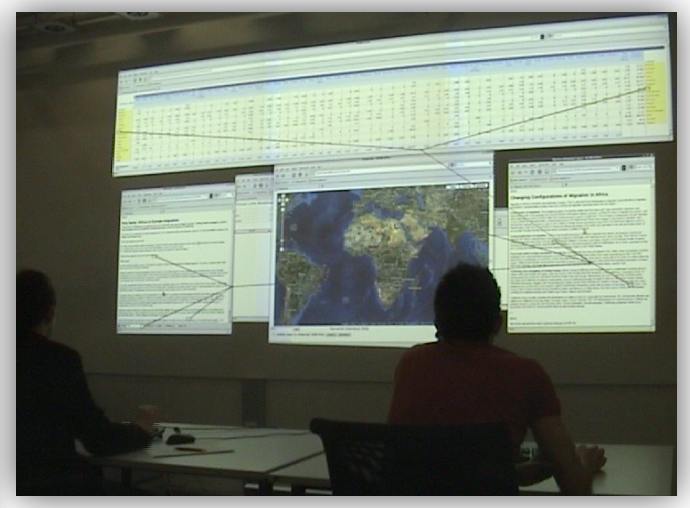
Observational Experiment

18 participants (16 males, 2 females) - pairs

Analysis of migration from Africa to Europe

Observations, video / audio recording, questionnaires, interview

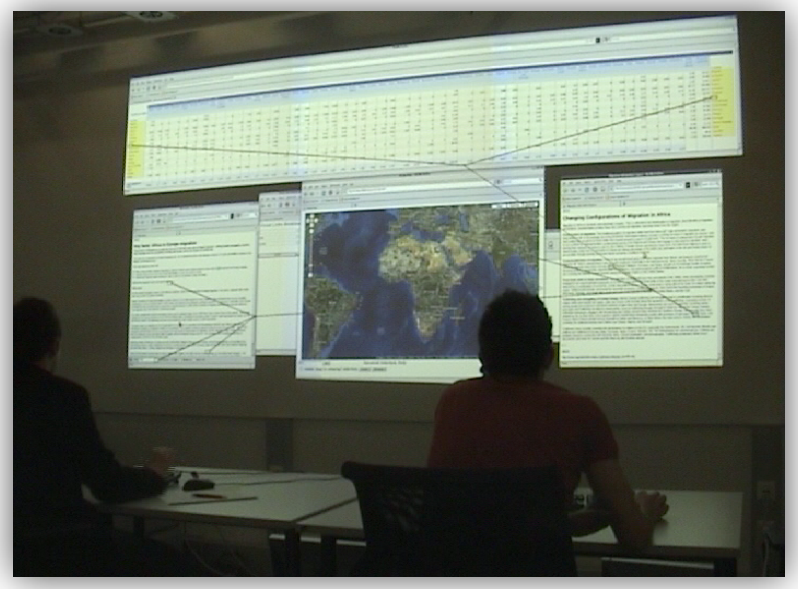


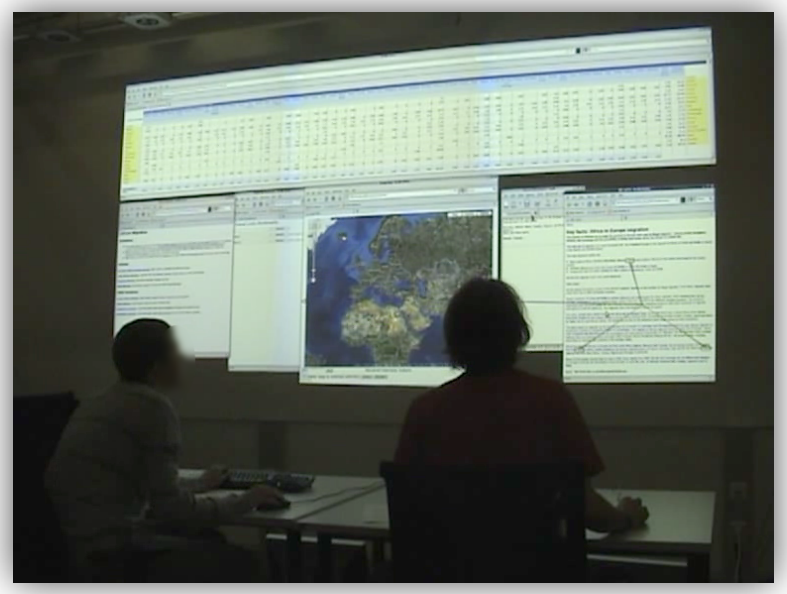


Results

Usage of information linking depends on work style

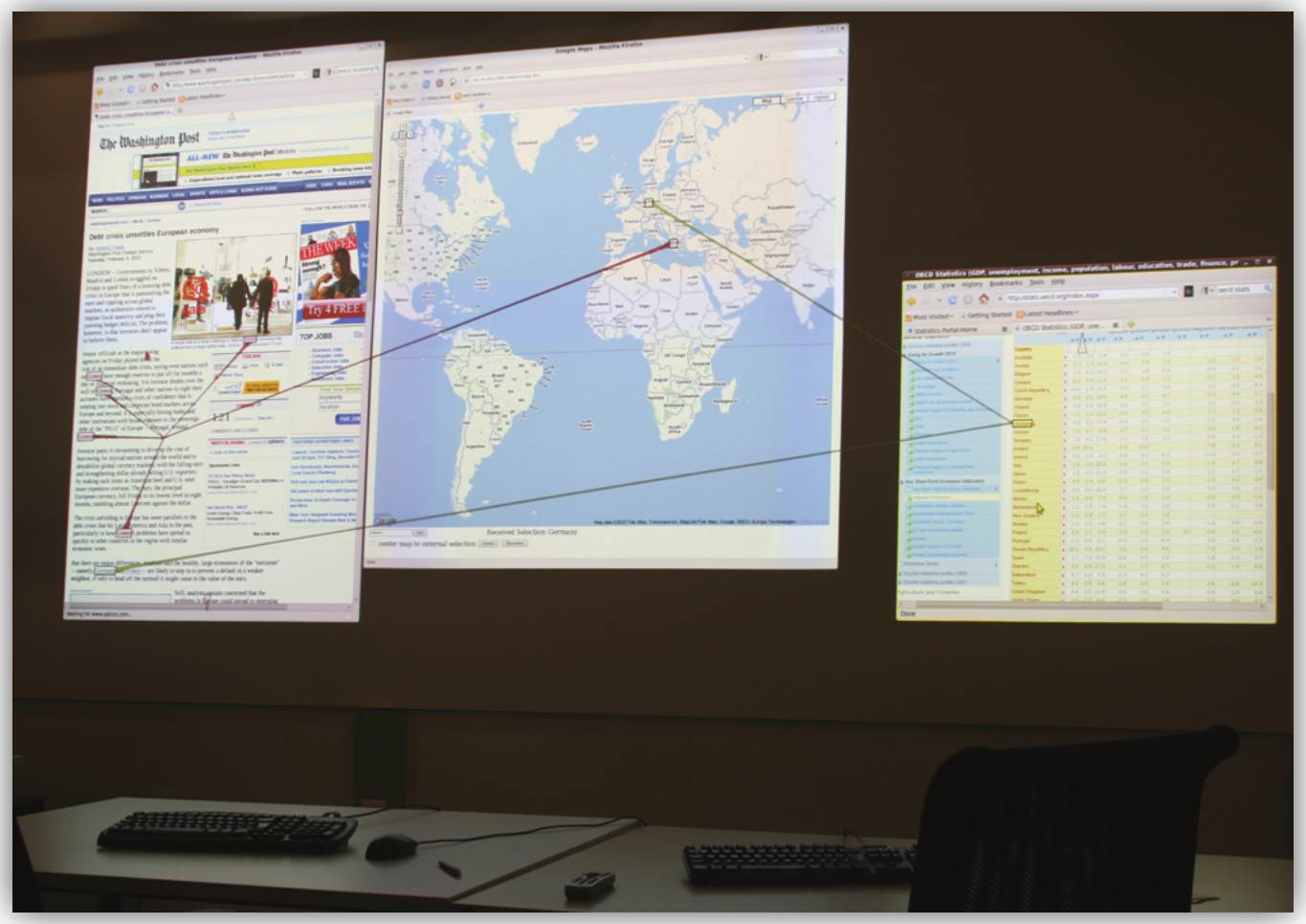
- Individual information retrieval → links to locate info
- Joint discussion → one set of links only
- Mixed-focus collaboration: most frequently





Results

- Distractions and conflicts
  - In general distraction was assessed as low
  - Input conflicts on shared windows, changes to window layout
  - Could be resolved by social protocols, but subjectively annoying
- Territoriality
  - Window ownership based on initial window layout
  - Movement of shared windows rare



Open Issues

What about visual clutter when more users are interacting?

How to handle discontinuous multi-display/projector setups?

Virtual Reality

Visual links in immersive environments

Biological Network Analysis in VR [Dickerson et al 2002]

TUTORIAL SUMMARY

Summary Part I – What to Link

Relations differ in their:

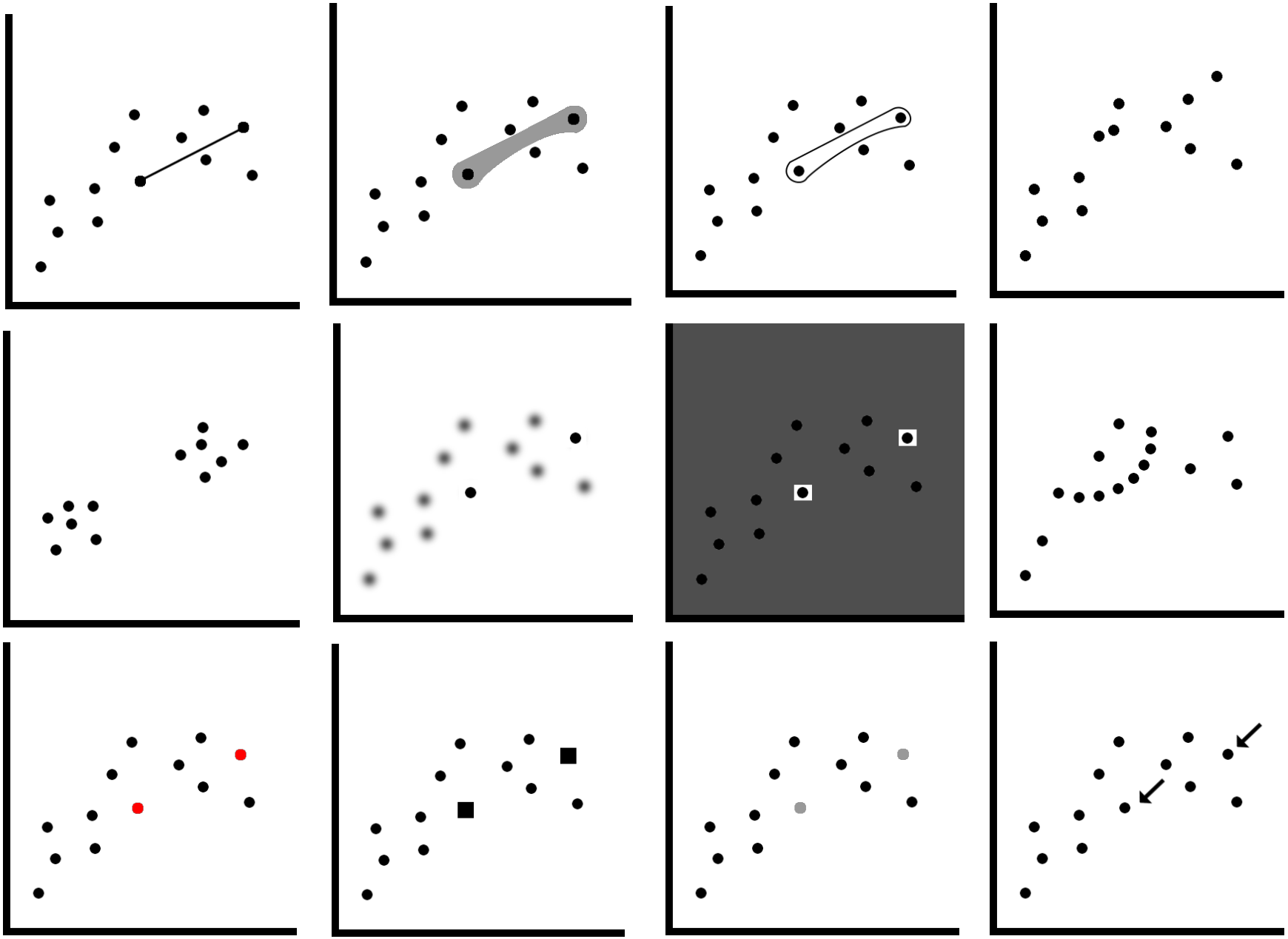
- Cardinality
- Elements (Granularity + Scope)
- Domain

Relations can be derived or inherent

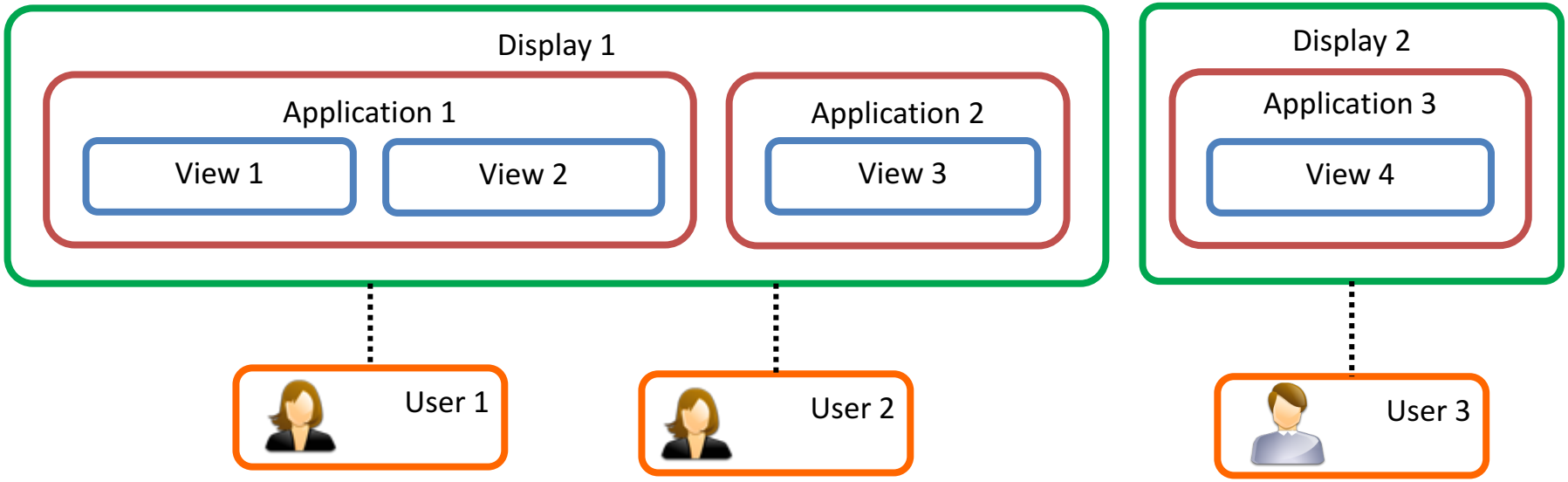
Examples given show what‘s already been done

– and what’s still left to explore!

Summary Part II – How to Link



Summary Part III – When to Link



Connecting The Dots

Showing Relationships in Data and Beyond

connecting-the-dots.caleydo.org

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