Visualization. Multiple Views

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Outline

- Multiple Views
- Data and encoding
- Coordinated views
- Data Reduction Techniques
- Dimensionality Reduction

Outline

- **Multiple Views**
- Data and encoding
- Coordinated views
- Data Reduction Techniques
- Dimensionality Reduction

Multiple Views

- Often information too complex for a single view
  - Show multiple views side by side
    - Different views of the data
  - Not merely isolated separate views
    - Mighty tools which show **data relationships**

- **Single view:** combination of a set of data together with specifications on how to display this data

Multiple Views

- Advantages:
  - **Eyes Beat Memory**: two simultaneous views have lower cognitive load than remembering previous view
  - Facilitate data understanding
    - Comparison
    - Show details
  - Facilitate data exploration
    - Show focus + context
    - Different data + same encoding

Multiple Views

- Challenges:
  - Real-estate trade-off: popup view vs. static side-by-side
  - Alternative: Single view that is changed through interaction (filtering, aggregation, navigation)
  - Choosing the most adequate implementation:
    - Visual representation selection
    - Data reduction
    - Design adequate interaction methods

Multiple Views

- Coordinated views
  - Further step that adds linked interactions
  - Boosts expressivity
  - Increases exploration possibilities

Multiple Views

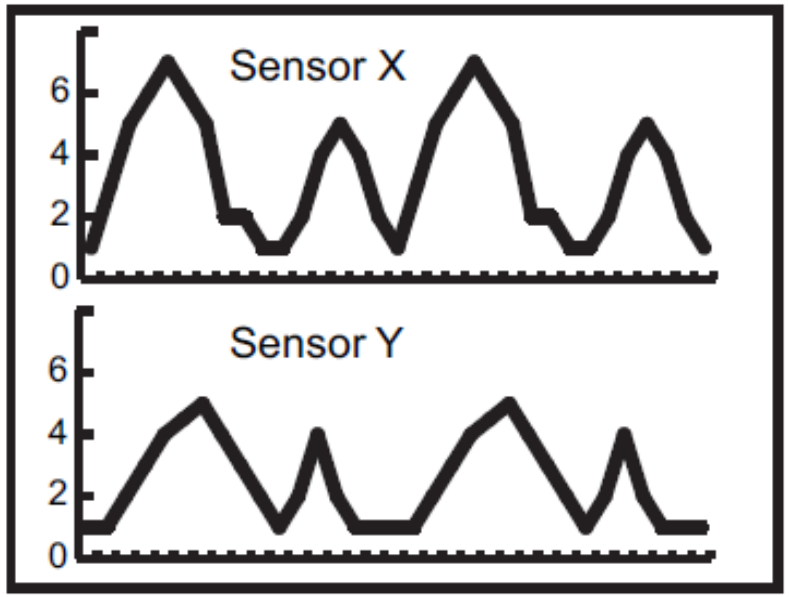
- Visual representation selection. Decisions:
  - Is all the data shared in both representations?
  - Which representation for each view?
  - How do we partition data?
- Answers linked to each other

- Multiple views approaches: Juxtaposition, superposition, and explicit encoding

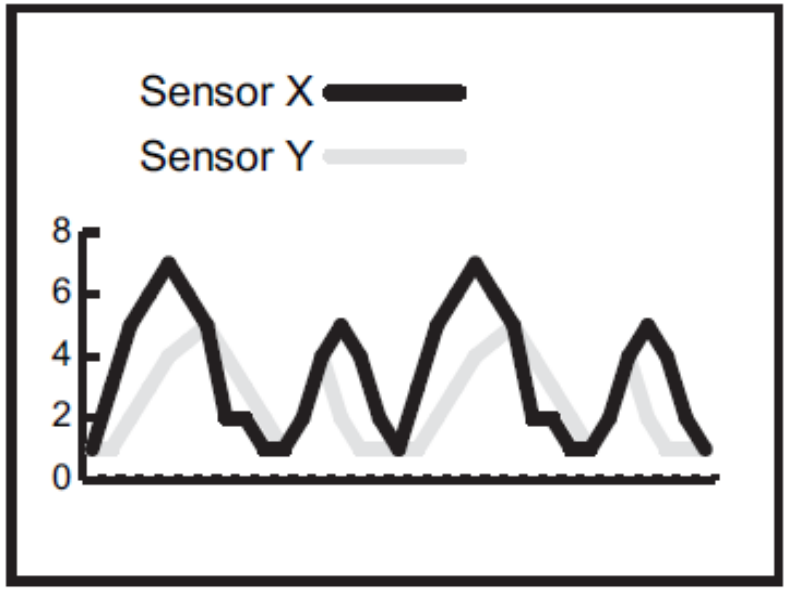
Multiple Views

- Multiple views layouts (aka ***facet***, ***multiform***):

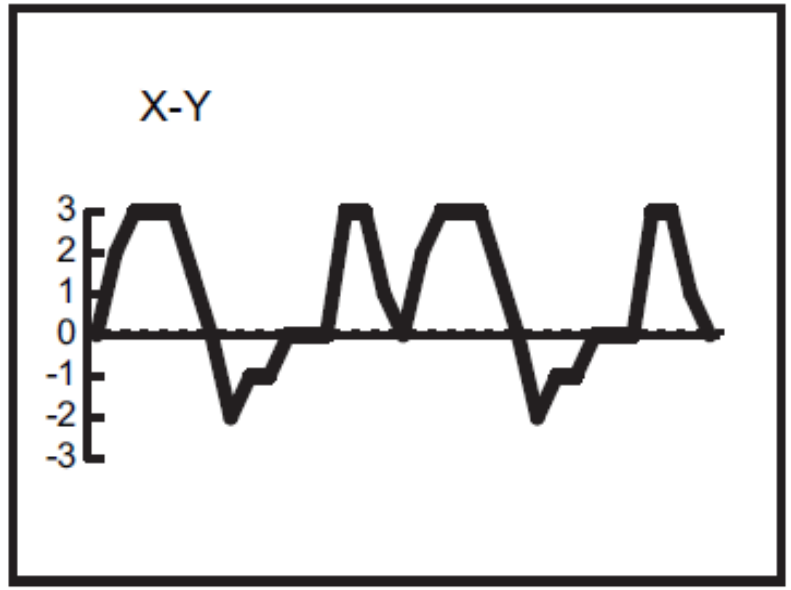
Juxtaposition



Superposition



Explicit encoding: difference



Multiple Views

- Juxtaposition. Why?
  - Comparing two views that are simultaneously visible is relatively easy
    - Move our eyes back and forth
  - Alternative: change over time: comparing current state to its previous state requires users to consult their working memory

Multiple Views

- Juxtaposition. Design choices
  - Which channels are shared
  - How much of the data is shared
  - How/if the navigation is synchronized
  - … but also when to show them, how to arrange, which attributes used to split the data, how many regions…

Multiple Views

- Juxtaposition. How?
  - Uniform design: Same representation, different data
  - Multiform design: Different encoding, same data
    - Can support more tasks
    - Need coordinating views with linked highlighting
    - Rationale behind multiform: a single monolithic view has strong limits on the number of attributes that can be shown simultaneously without introducing too much visual clutter

Multiple Views

- Juxtaposition. Shortcomings:
  - Larger display area required (e.g. 2x)
  - Trade-off between display area and working memory
    - Typically can encode more layers than superimposing

Multiple Views

- Superposition:
  - Use of multiple layers over the same space
- Layer: set of objects spread out over a region
  - Spatially intermixed with objects that are not part of the visual layer
  - Each set of objects in each layer visually distinguishable from objects in other layers at a perceptual level

Multiple Views

- Superposition. Why?
  - Does not require more space
  - Can use the whole view
  - May reduce eye movement required to compare

Multiple Views

- Superposition. Design choices
  - How many layers?
    - More limited than when using juxtaposition
  - How are layers perceptually distinguished?
  - How to partition items into layers?
  - Are layers static? Or are they constructed dynamically in response to user interaction?

Multiple Views

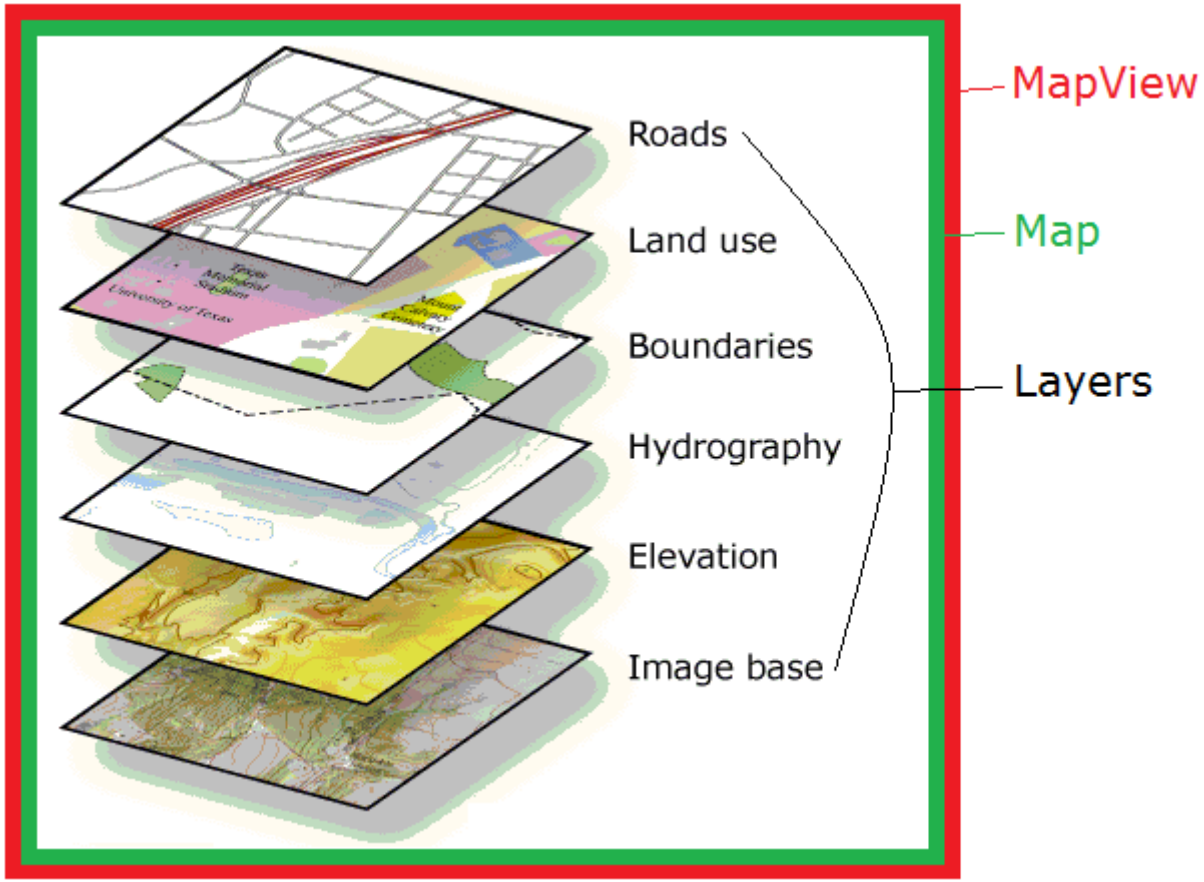
- Superposition. How?
  - Make different and non overlapping range of the visual channels active in the encoding
    - E.g. foreground and background
  - Number of distinguishable layers limited if they contain a substantial number of area marks
    - Two layers is achievable, three with careful design
    - Multiple layers only if few marks in each

Multiple Views

- Superposition. Static layers
  - All layers displayed simultaneously
  - Requires selective direction of visual attention

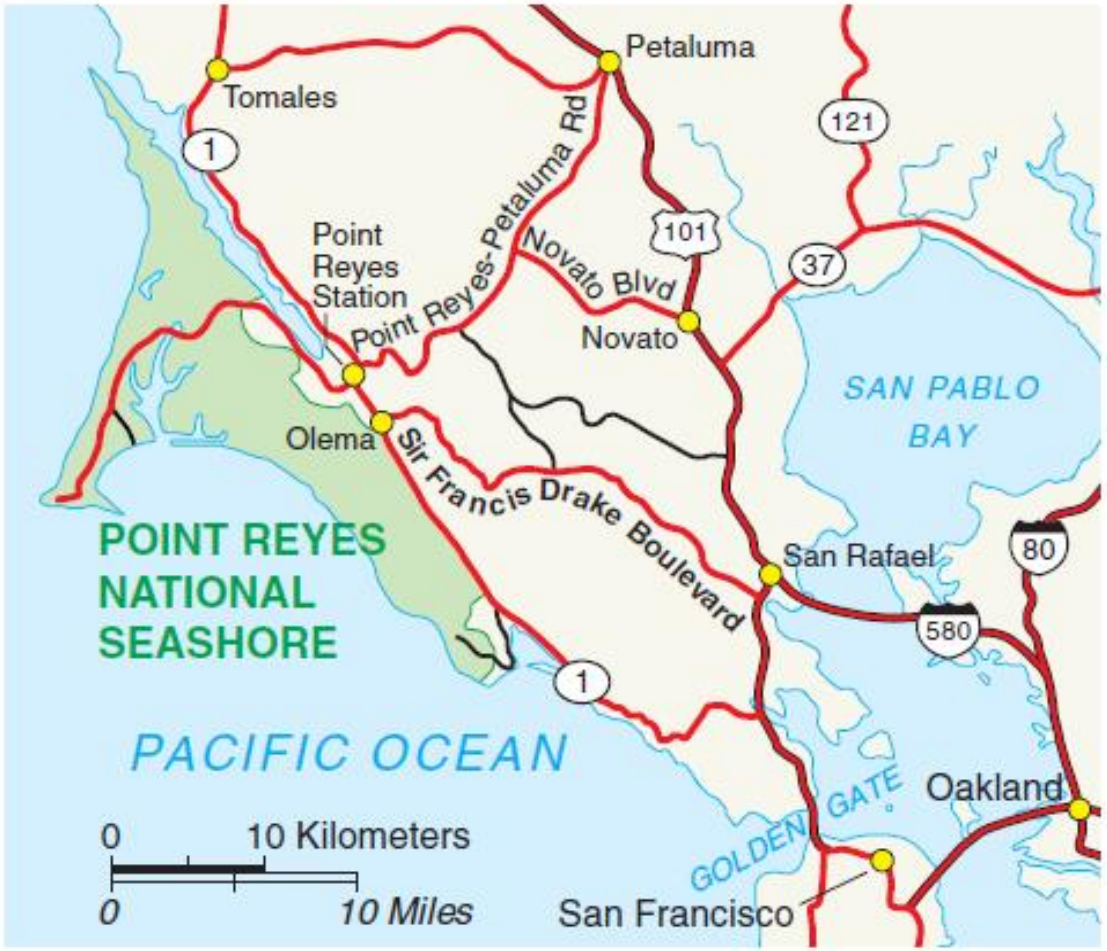
Multiple Views

- Superposition. Static layers



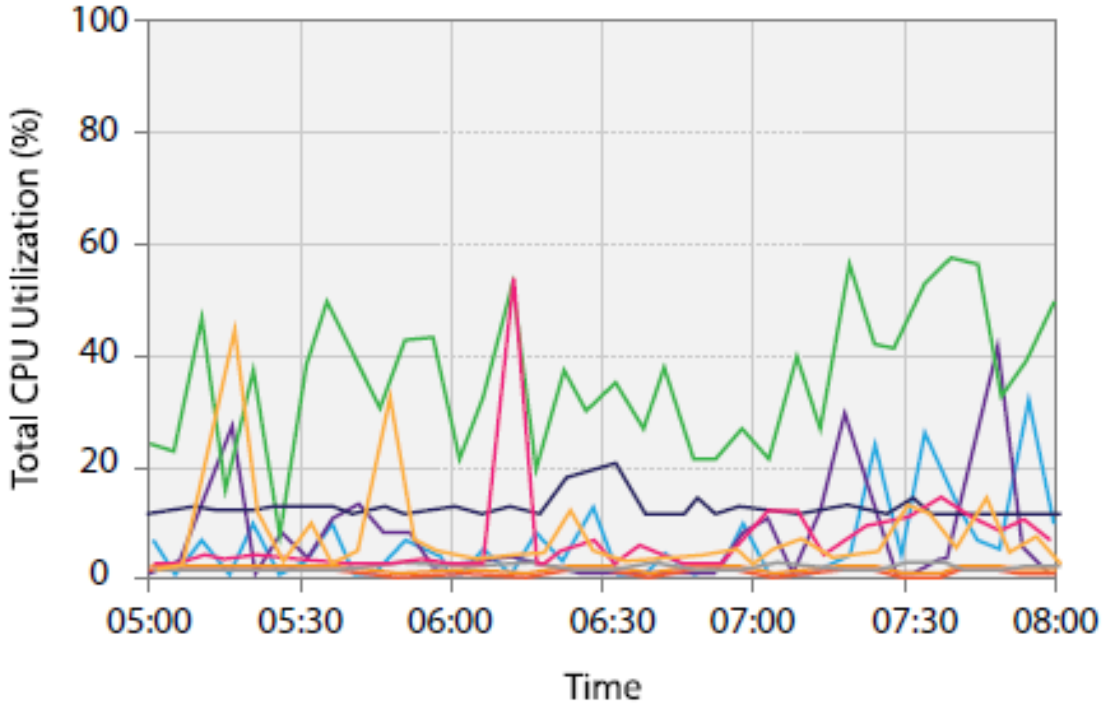
Multiple Views

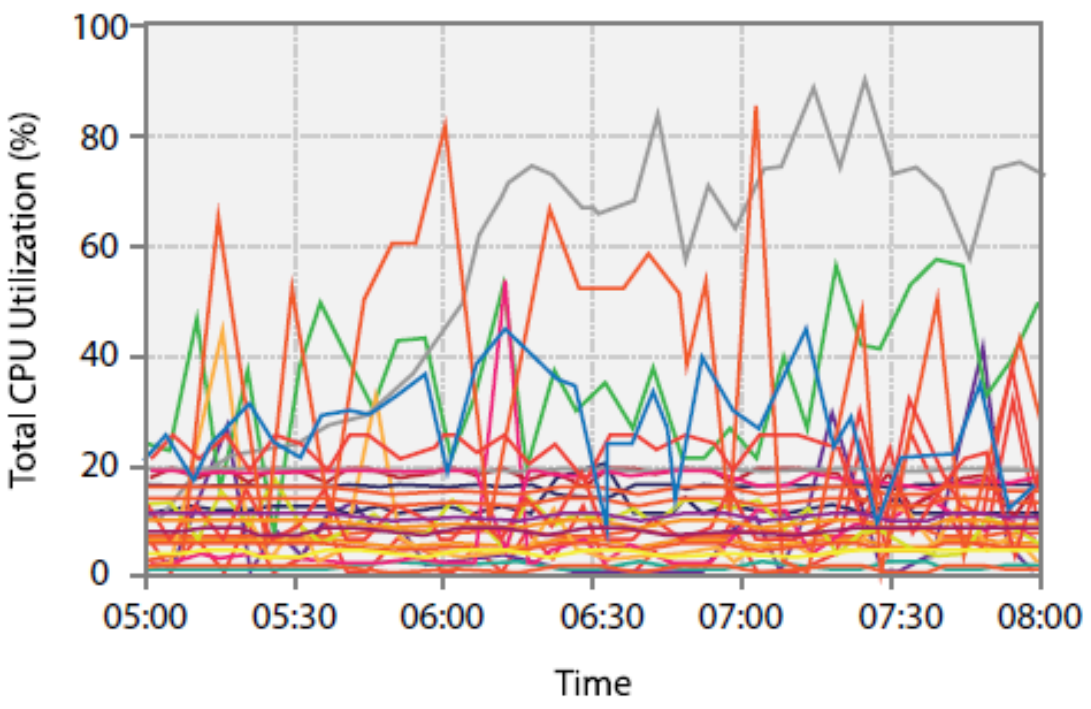
- Superposition. Static layers



Multiple Views

- Superposition. Static layers.
  - Line charts: up to a dozen lines



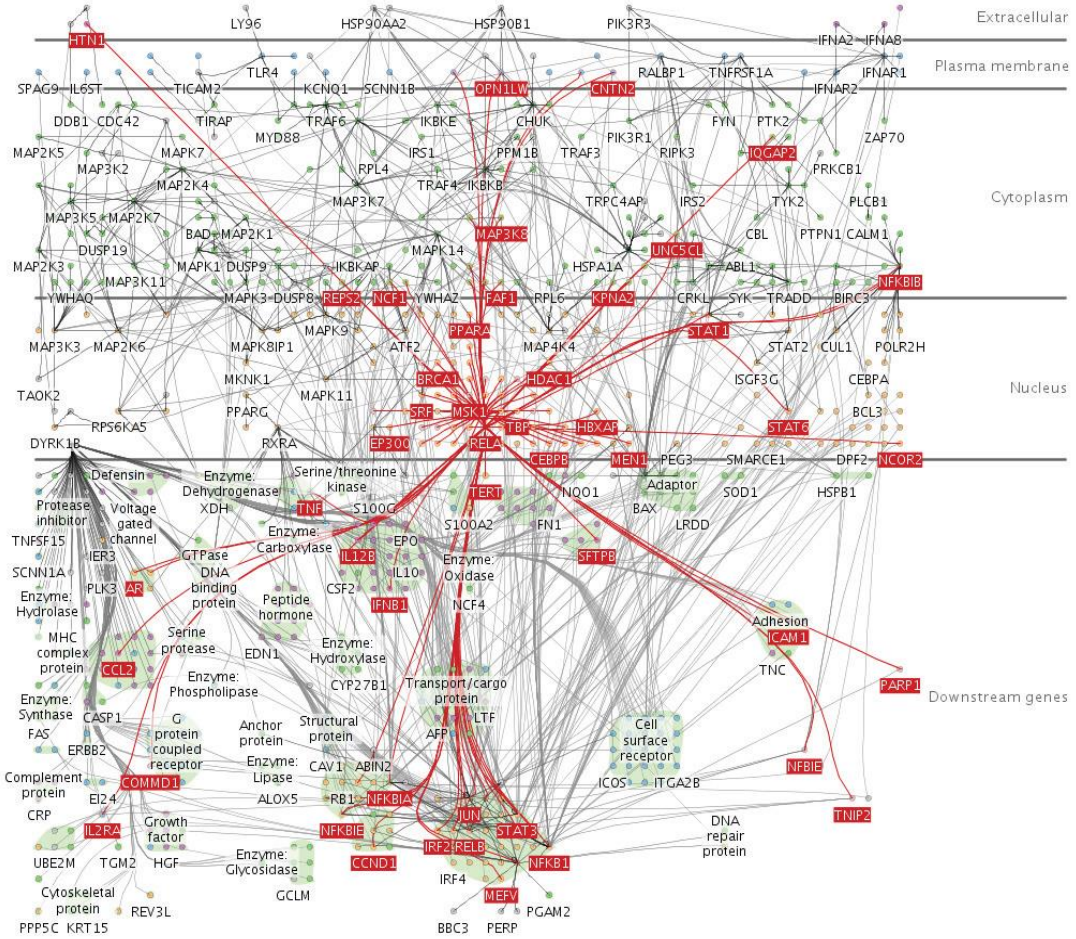


Multiple Views

- Superposition. Dynamic layers:
  - A layer with different salience is constructed interactively
    - Typically in response to user interaction
  - Can have a huge number of different layers
    - Not displayed simultaneously
    - Built on the fly

Multiple Views

- Superposition. Dynamic layers



Multiple Views

- Difference encoding:
  - Two or more layers with different layers of information combined
    - Only the difference: Different visual encoding
    - Original + difference: Original encoding for the data to compare and another visual cue for the difference
  - Many encoding variants

Multiple Views

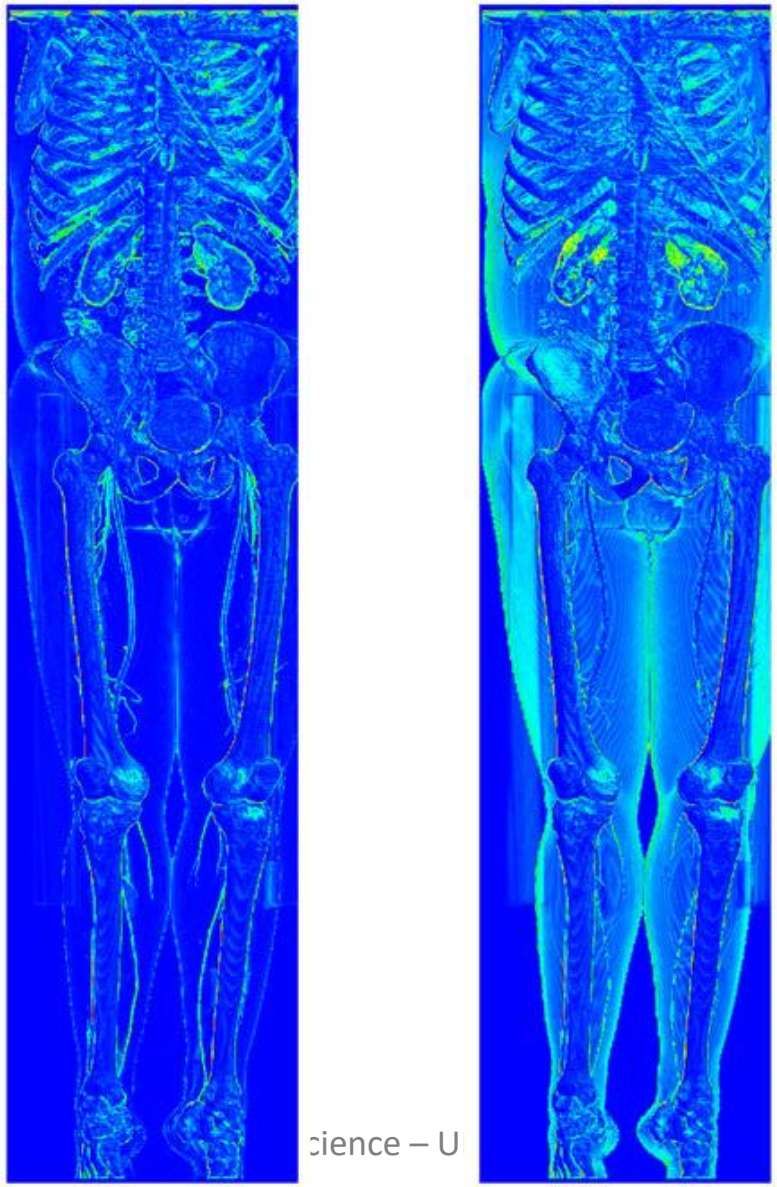
Original

Algorithm 1

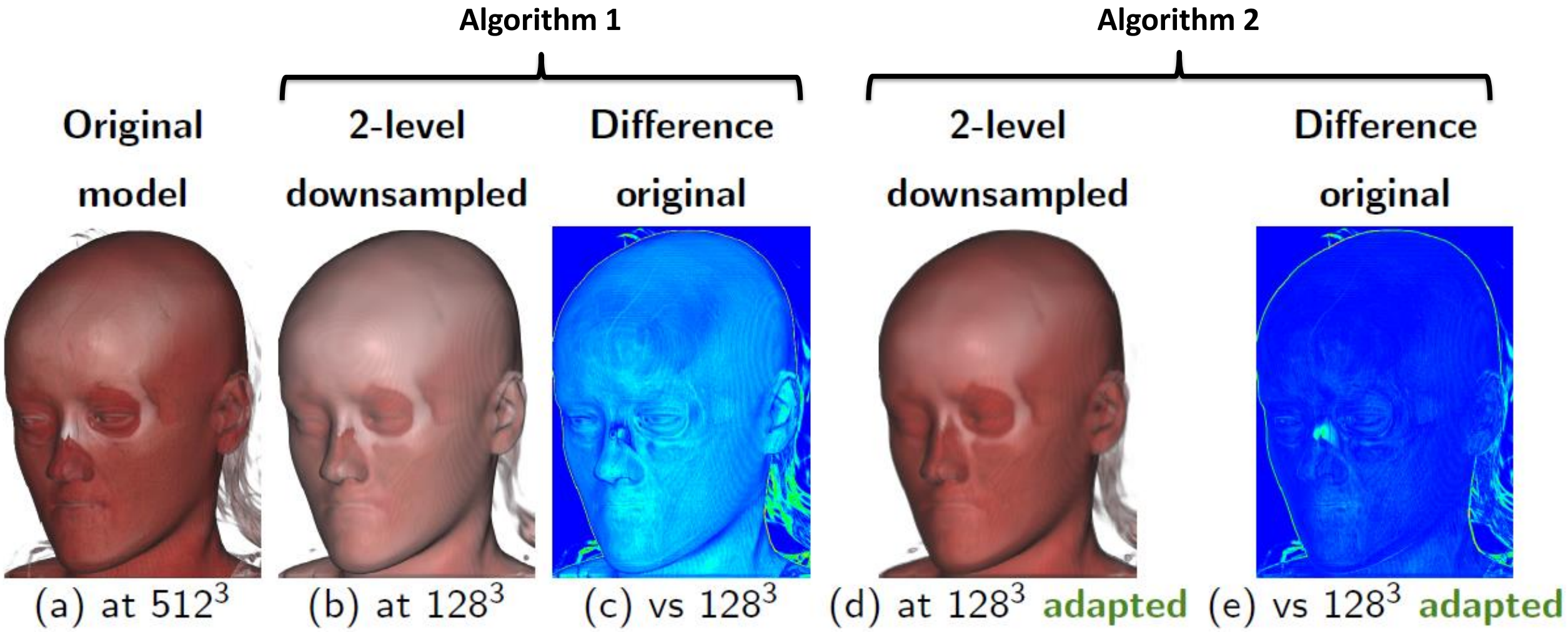
Algorithm 2

Multiple Views

- Difference images:
  - Different encoding
    - Similar regions: cold color (blue)
    - Different regions: warmer colors
      - Warmer → larger difference

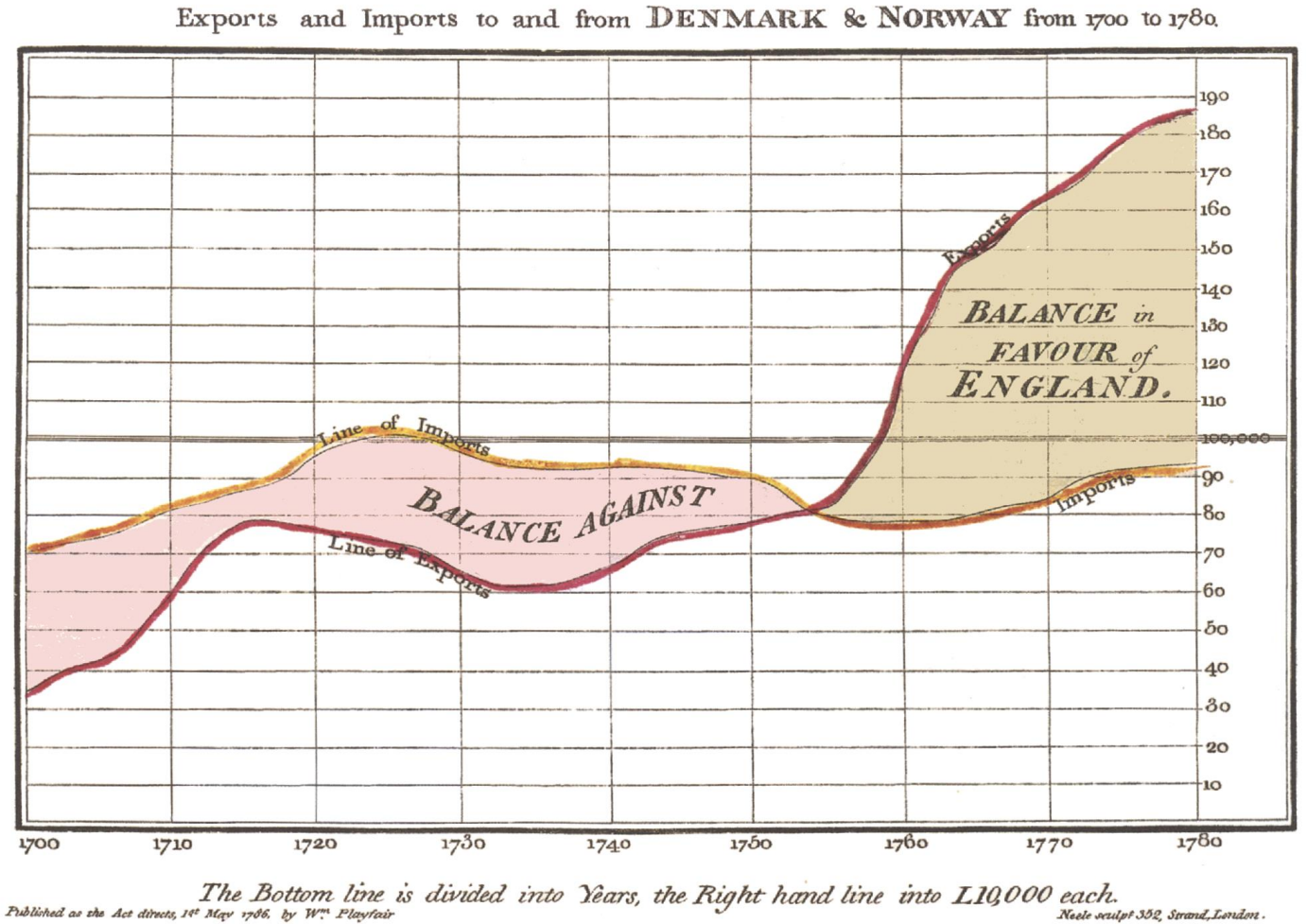


Multiple Views



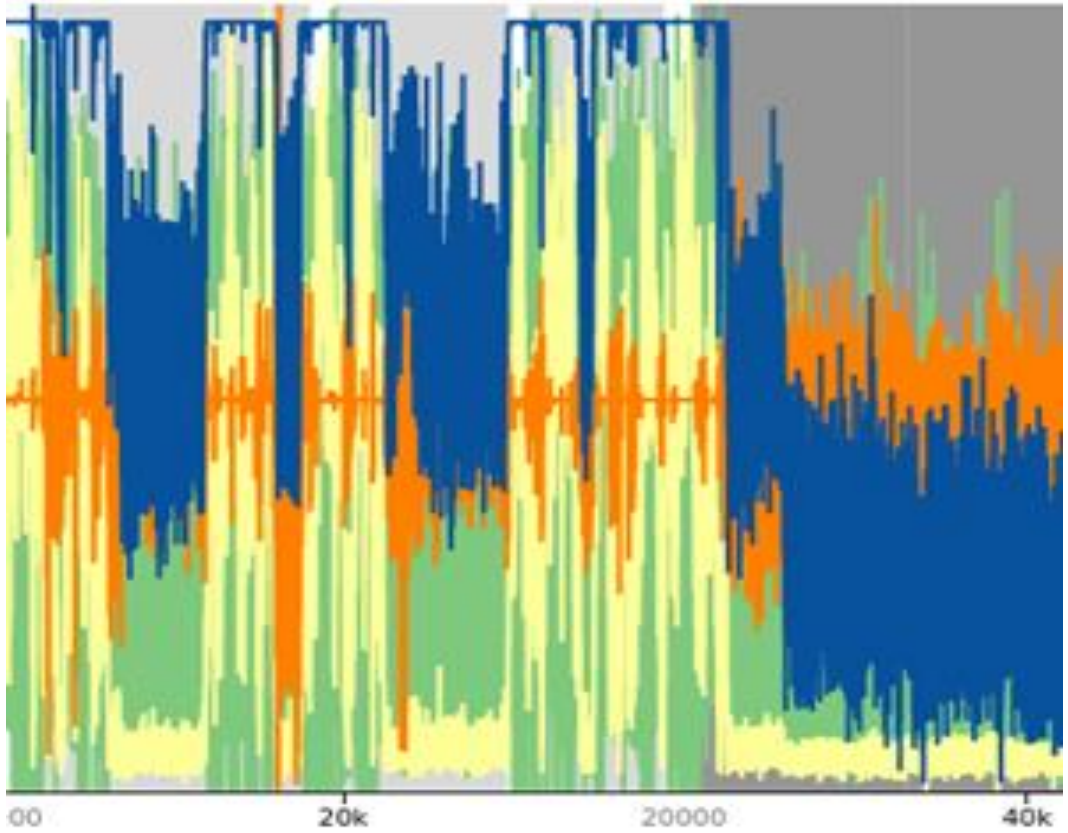
Multiple Views

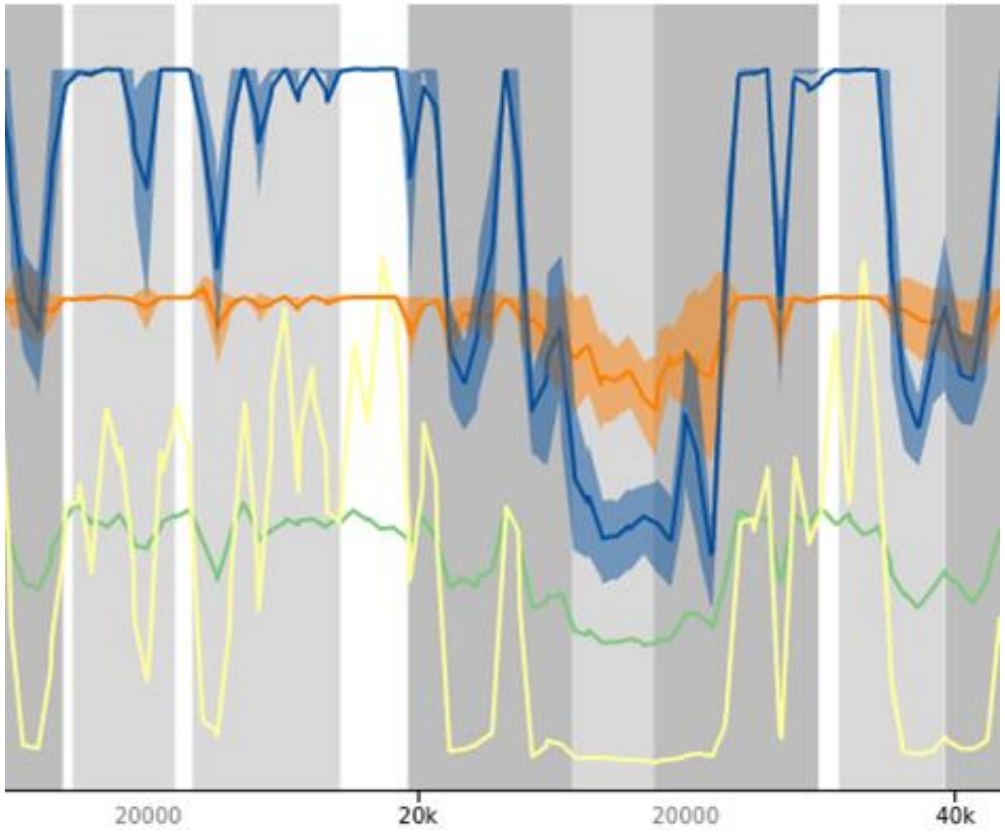
- Difference encoding: original + difference



Multiple Views

- Difference encoding: only differences (+ average)





Outline

- *Multiple Views*
- **Data and encoding**
- Coordinated views
- Data Reduction Techniques
- Dimensionality Reduction

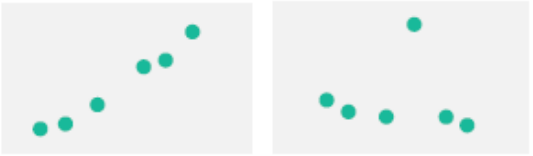
Data and encoding

- Data sharing possibilities:
  - All data is shared in both views
  - A subset of the data in each view
  - No data is shared

Data and encoding

- Share encoding:
  - All channels are handled the same way for an identical visual encoding
- Multiform views:
  - Different encodings for the different views
    - Some, but not necessarily all, aspects of the visual encoding differ

Data and encoding

		Data		
		All	Subset	None
Encoding	Same	Redundant	 Overview/ Detail	 Small Multiples
	Different	 Multiform	 Multiform, Overview/ Detail	No Linkage

Data and encoding

- Dual view systems:
  - Overview & detail
  - Focus + context
  - World in miniature
  - Difference views
  - Master/slave representations
  - Small-multiples

Data and encoding

- Techniques. Overview & detail:
  - One view shows a subset of what is in the other
  - Commonly two views (e.g. navigation in maps)
    - Overview provides the context
    - Detail usually a larger view (zooming on the details)
    - Navigation is synchronized

Data and encoding

- Techniques. Overview & detail

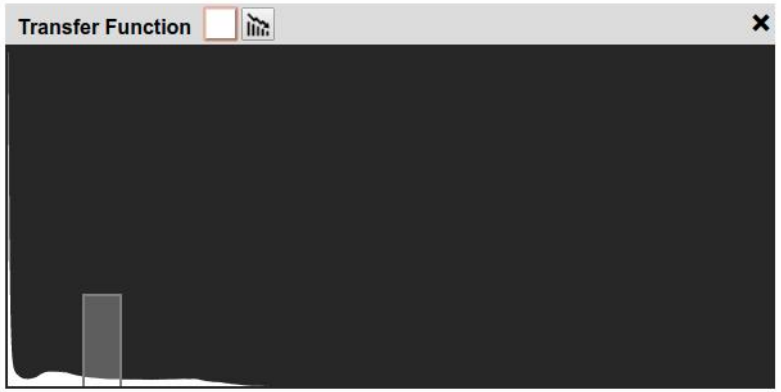
Data and encoding

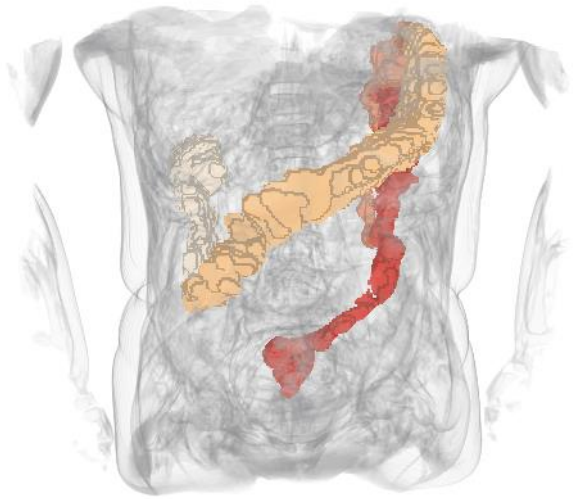
- Techniques. Overview & detail:
  - Details on demand is typically another example
    - Commonly multiform (different representation for the details, e.g. tables)

Data and encoding

Inspector

Transfer Function



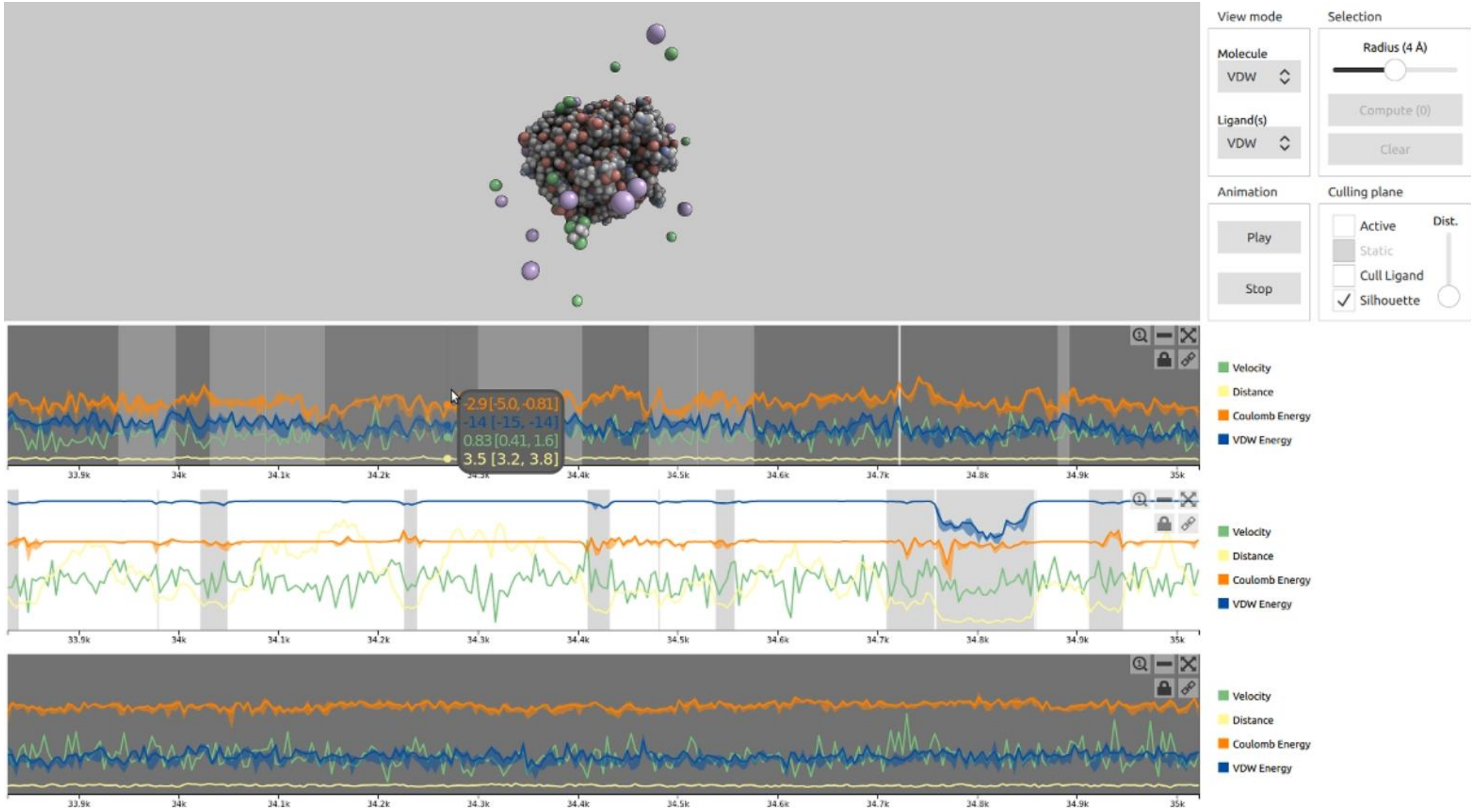


/	solid volume	gas volume	longitude	perimiter	area	min radius	max radius
Left	67.9	31.8	202	138	709	6.67	23.9
Transverse	285	47.4	378	224	1512	9.32	36
Right	105	17.6	195	328	1503	6.11	44.2
Pelvic	119	85.8	/	/	/	/	/
Ileum terminal	/	/	119	92.2	327	6.55	14.1

Patient id: CORACHAN_001

09:50:00 14/03/2015

Data and encoding

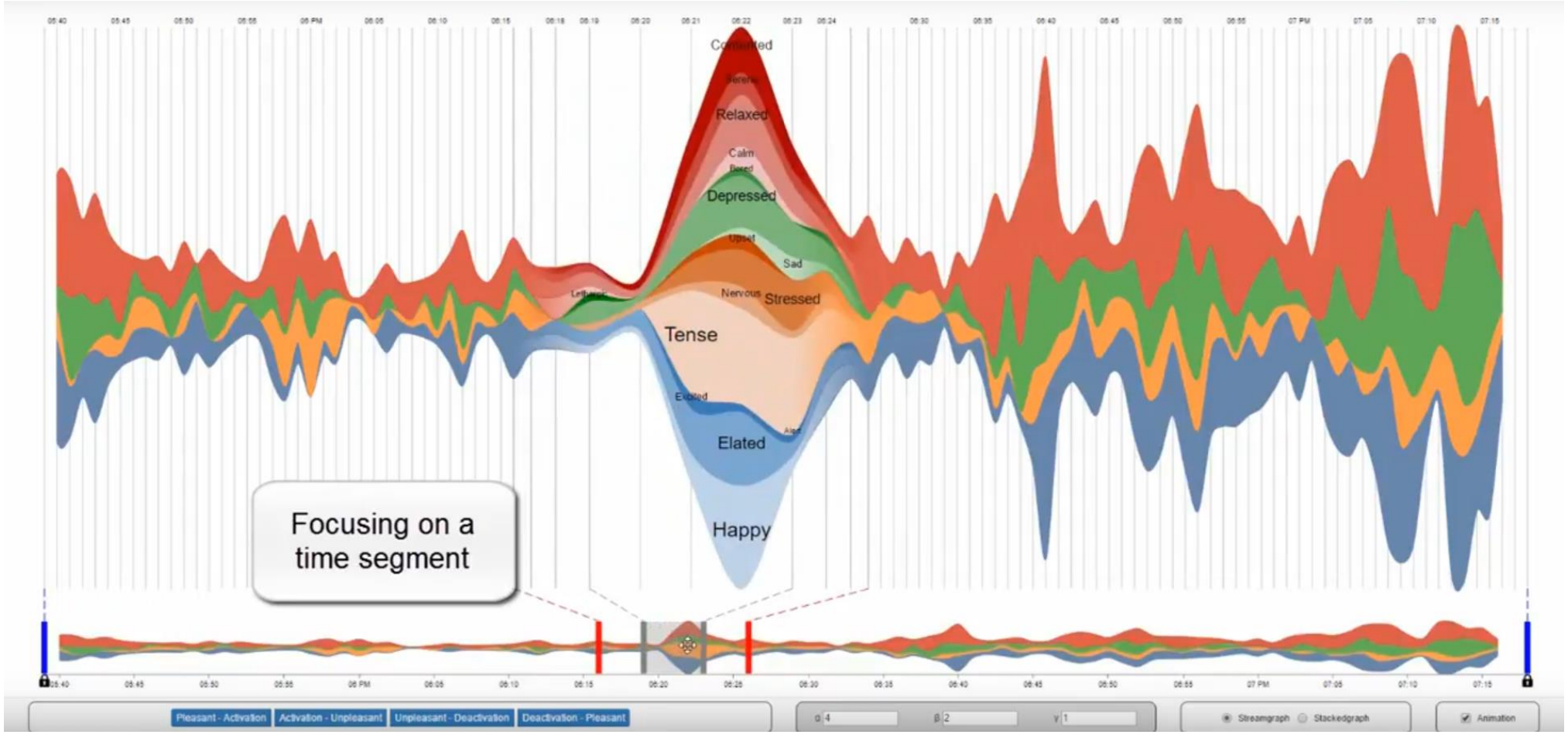


Data and encoding

- Techniques. Focus + context:
  - Stresses the detail over the context
  - Context typically does not show as much information as an overview
  - Commonly combines other techniques for the focus, e.g. fish-eye lens, distortion, magnification…

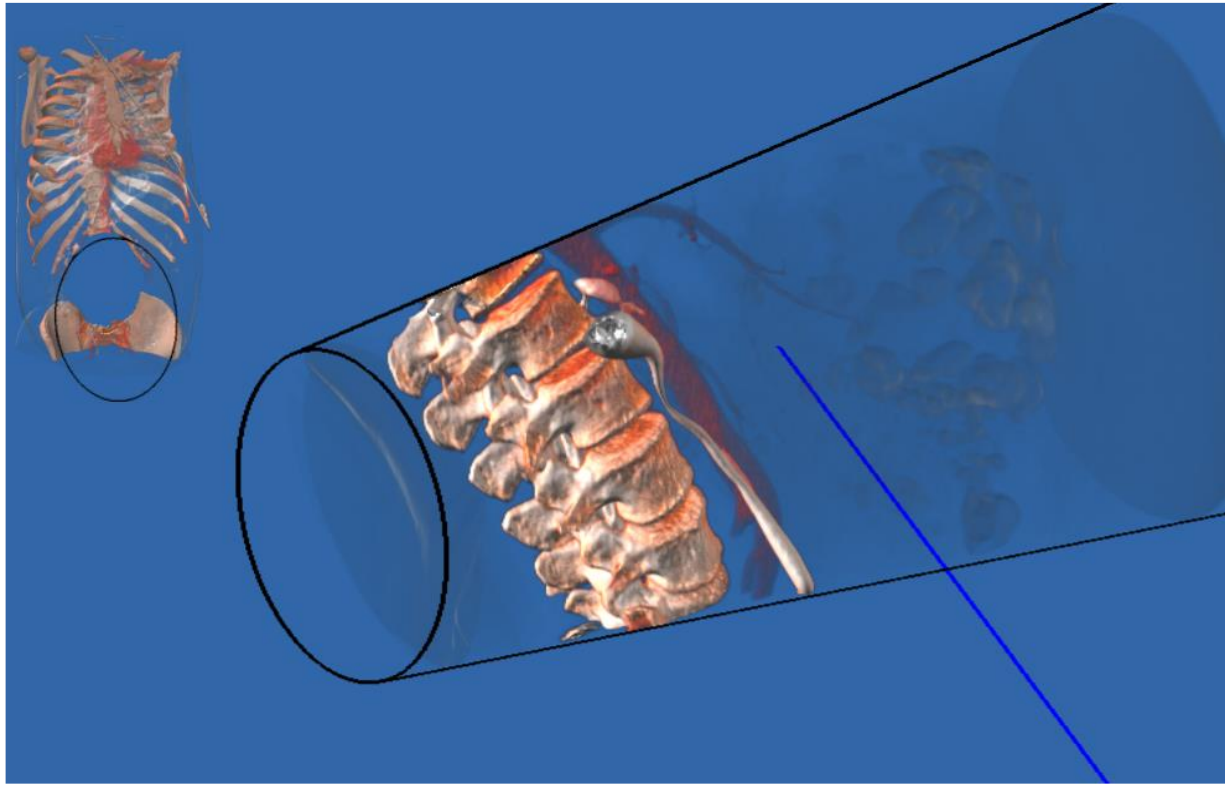
Data and encoding

- Techniques. Focus + context



Data and encoding

- Techniques. Focus + context



Data and encoding

- Techniques. World in miniature:
  - Similar to focus + context
  - Context shown as a miniature model
    - Typically does not use distortion

Data and encoding

- Techniques. World in miniature

Data and encoding

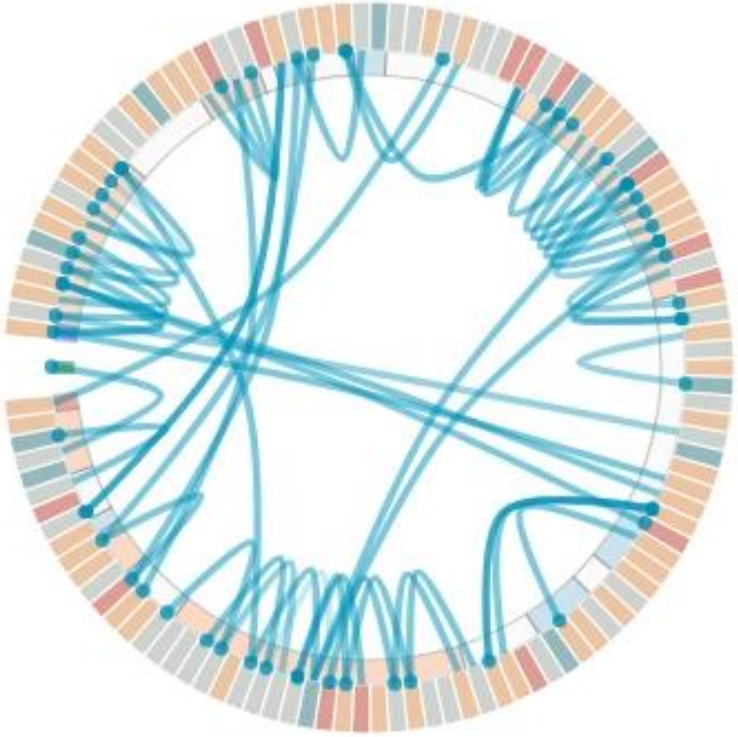
- Techniques. Master-slave views:
  - One view controls the other
  - More a kind of relationship between views
    - Can be applied to multiple facet types
  - Not very common
    - Flexibility is typically provided

Data and encoding

- Techniques. Difference views:
  - Merge two or more views together to show the difference
  - Focus on highlighting such difference
    - Color encoding the difference is a popular choice
    - Can build different geometry/visual encoding to show the difference

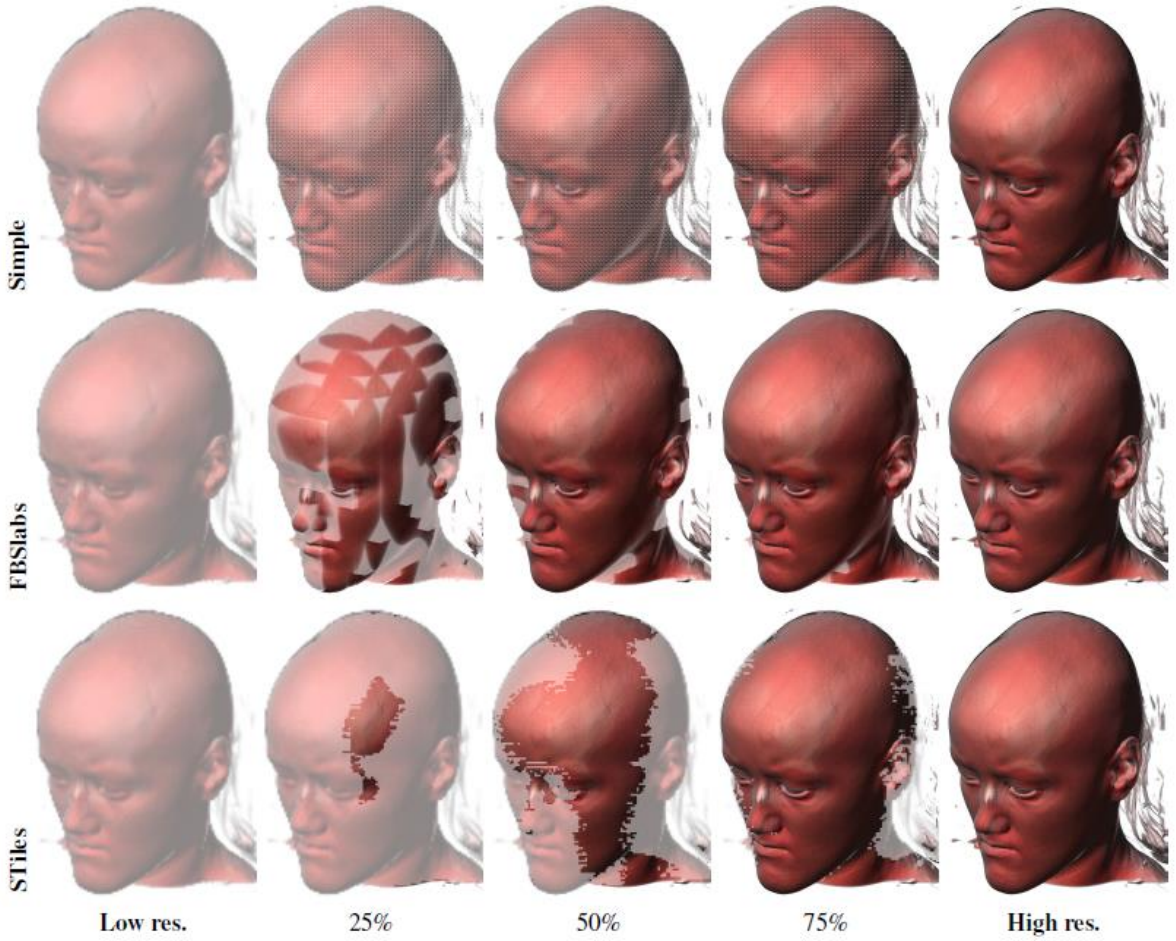
Data and encoding

- Difference across **many steps**: current step + difference information



Data and encoding

- Difference encoding: current step + de-emphasized previous



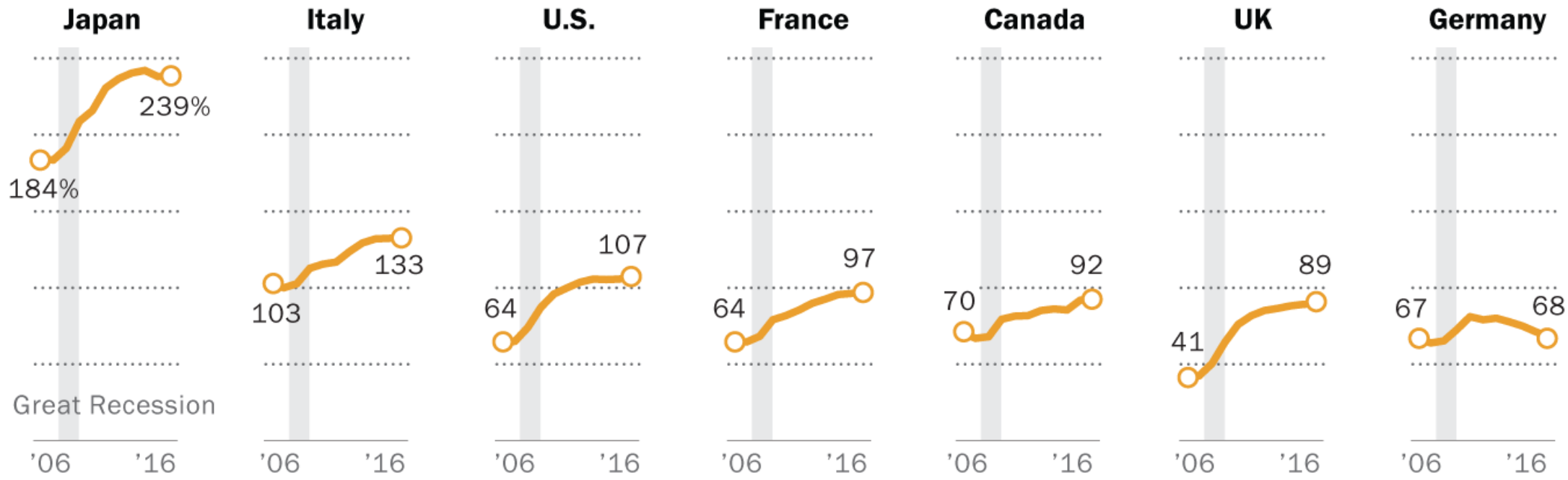
Data and encoding

- Techniques. Small multiples:
  - Matrix of small visualizations laid side-by-side
    - Can be glyphs
  - Different partitions of the data into disjoint pieces
    - Typically with the same visual encoding
  - Often aligned to support visual comparison
  - Require high amount of real-state
    - A few dozen views with several hundred elements in each view
  - Alternative to animation (requires massive memory load)

Data and encoding

- Techniques. Small multiples

Total gross debt as a share of GDP in the Group of Seven nations



https://medium.com/pew-research-center-decoded/how-pew-research-center-uses-small-multiple-charts-2531bfc06419

Data and encoding

- Small Multiples. Discussion:
  - Use appropriate charts for your data
  - Use comparable scales and comparable encodings
  - Arrange the individual charts logically
  - Use equal size for all charts & choose appropriate size

Data and encoding

- Partitioning data
  - Separate data into groups
    - Can use categorical variables, items, attributes…
  - Selection of attributes, as well as order, has an important impact on the result
    - Shall influence on the patterns that are visible

Data and encoding

- Partitioning data. Design choices
  - How to divide the data
  - How many splits to carry out
  - Order in which attributes are used to split things up
  - How many views to choose

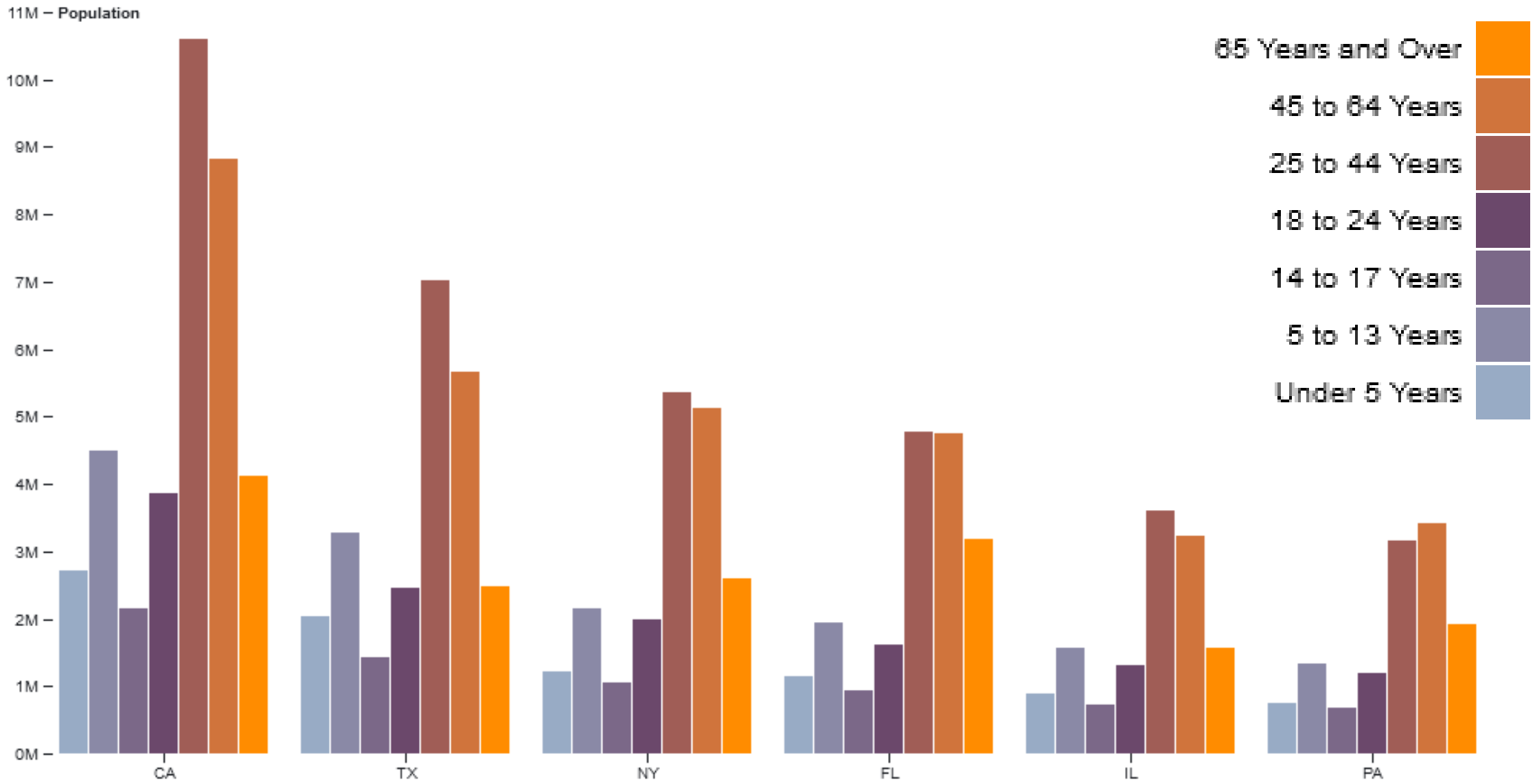
Data and encoding

- Partitioning data. Other choices
  - How to arrange the regions
    - Aligning, ordering, nesting…
  - The complexity of what the partition encodes
    - May fall into a continuum
    - May be a complex portion of information
      - Might be coded with a glyph

Data and encoding

- Partitioning data. Grouping
  - Can help compare between attributes
    - E.g. grouped bar charts
      - Individual attributes same category
      - Across categories, only up to a certain level

Data and encoding

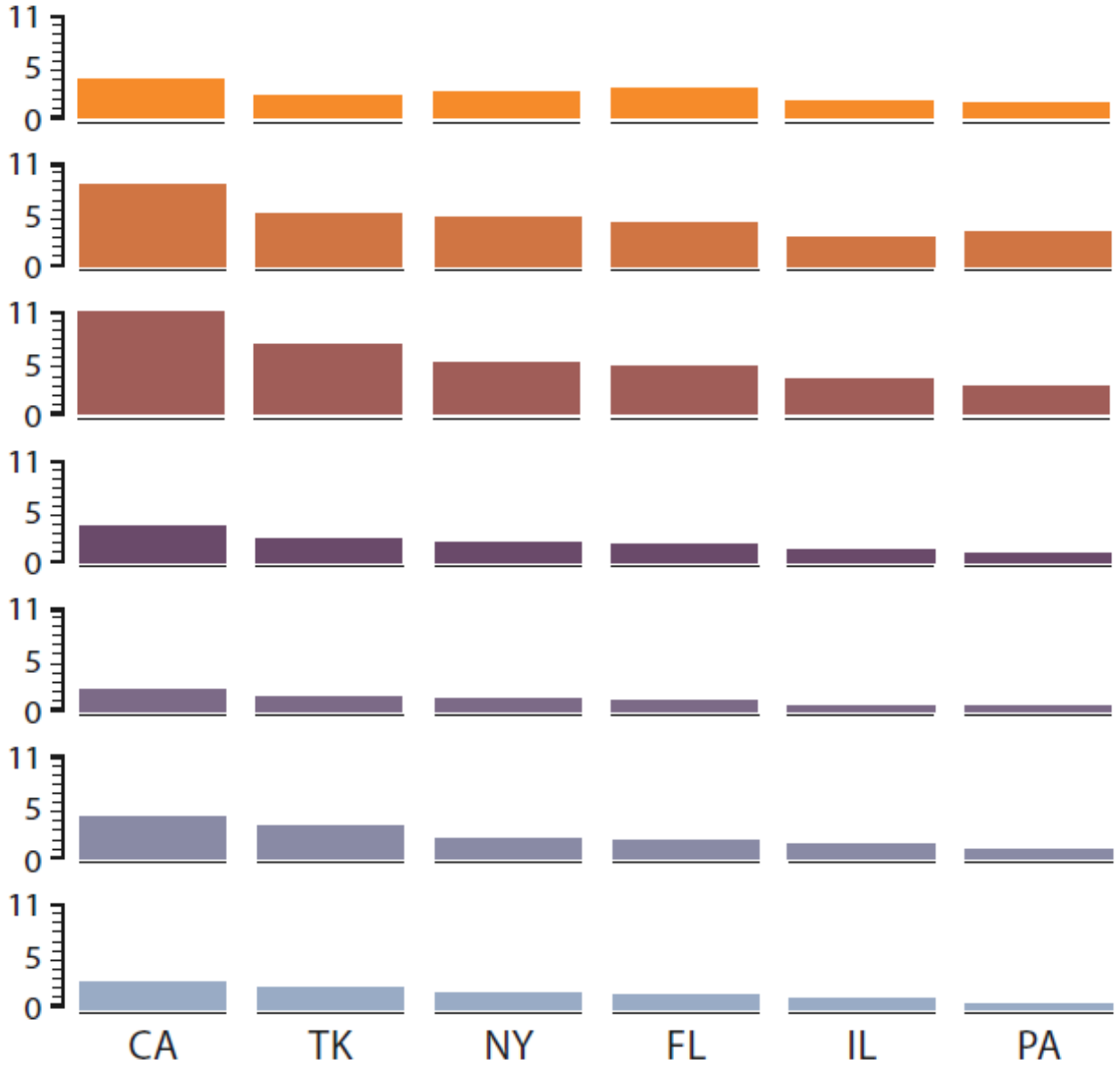


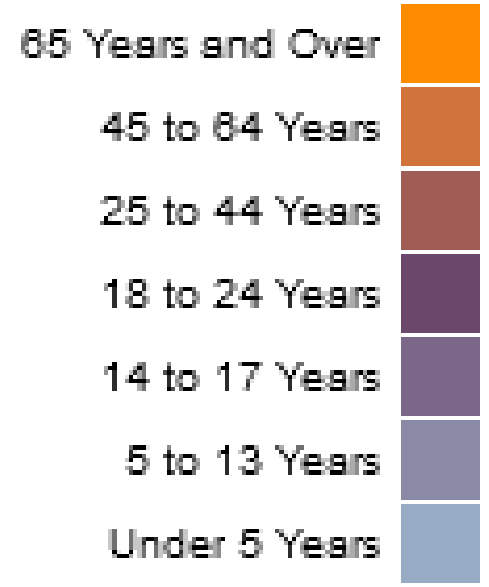
Munzner, T. Visualization Analysis & Design

Data and encoding

- Partitioning data. Separating
  - Can help compare individual attributes
    - Individual attributes

Data and encoding





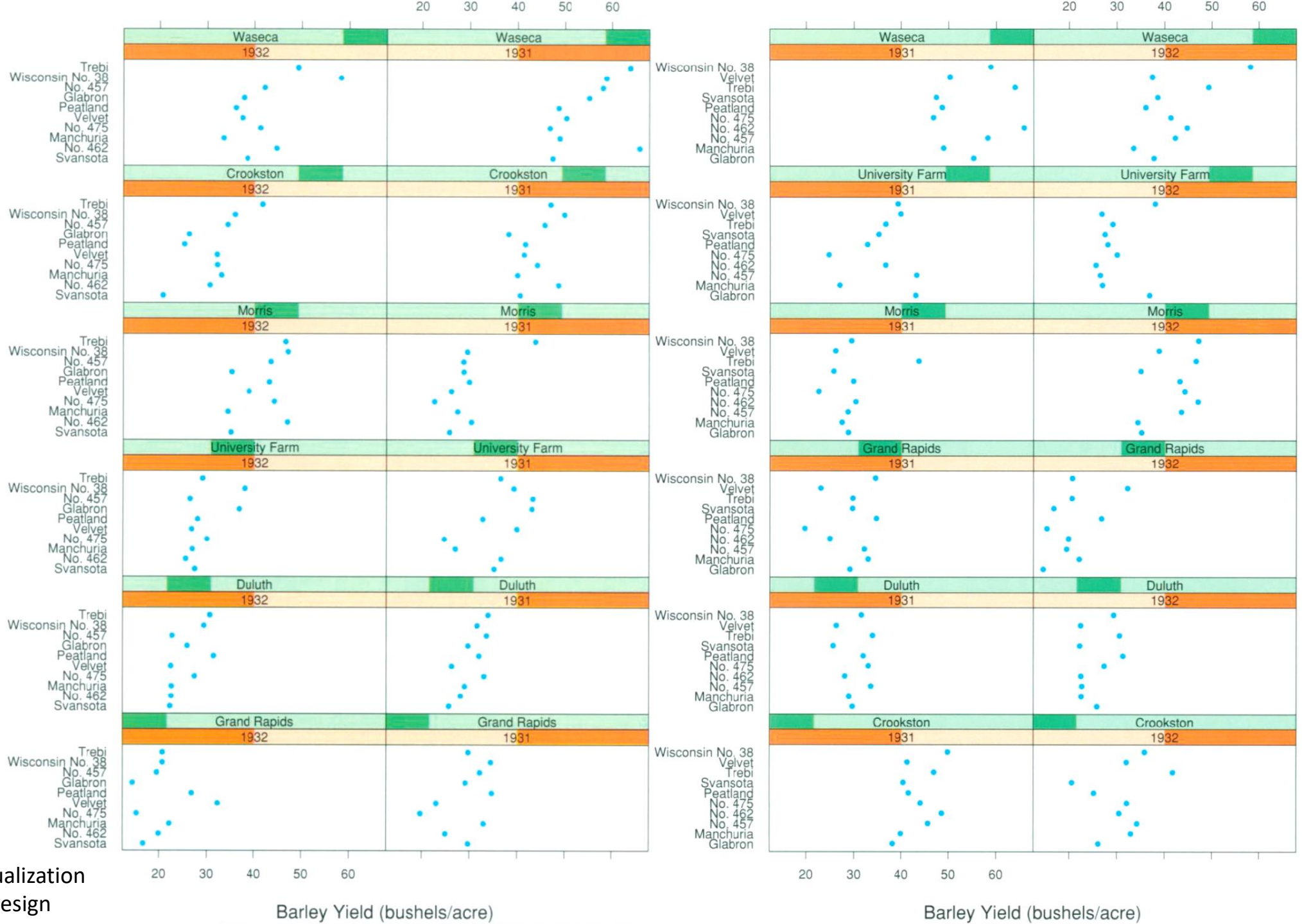
Munzner, T. Visualization Analysis & Design

Data and encoding

- Partitioning data. Trellis
  - Partitioning a multi attribute dataset into multiple views
    - Ordered within a 2D matrix
  - Can help find anomalies
    - Proper ordering required

Data and encoding

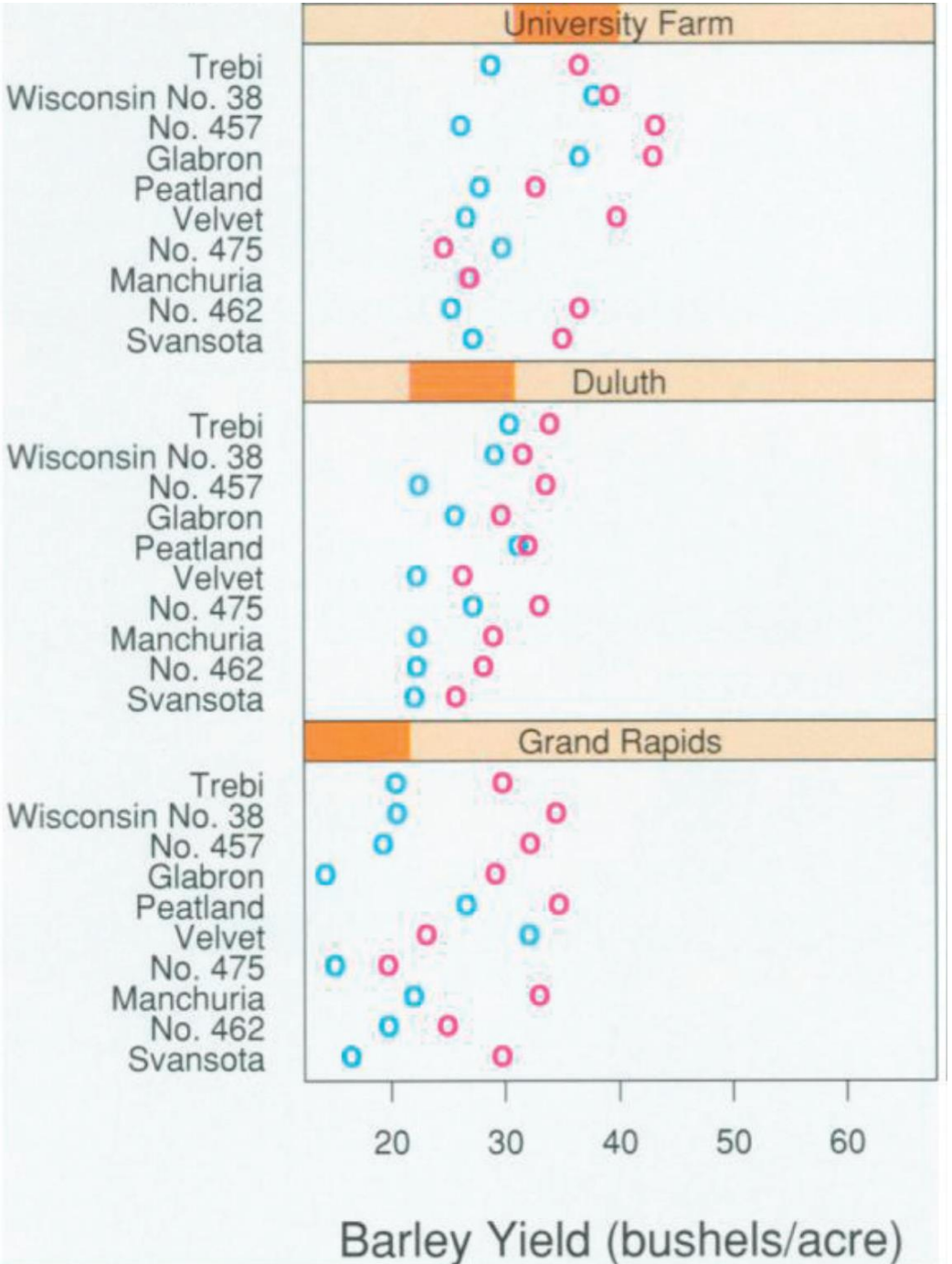
- Partitioning data. Trellis
  - E.g. Barley dataset:
    - 3 categorical keys: site (6 levels), variety (10 levels), year (2 levels)
    - Quantitative value: yield
  - Partitioning: Columns: Per year & Rows: Site
  - Individual plot: X: yield & Y: variety
  - Left: ordered by median for the site, and rows ordered by medians for the variety
    - Shows outliers



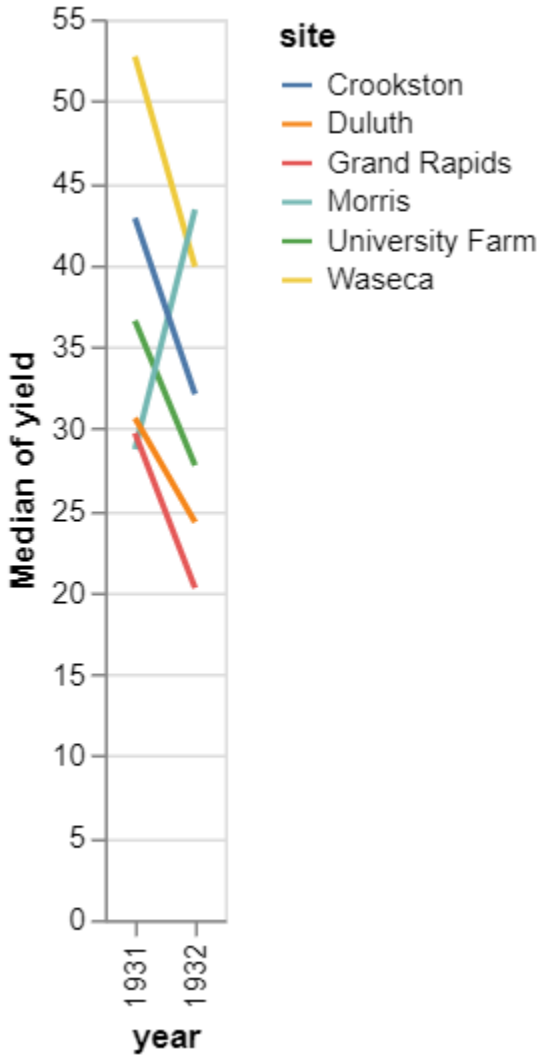
Munzner, T. Visualization Analysis & Design


1932
1931
Waseca
Crookston
Morris
Trebi
Wisconsin No. 38
No. 457
Glabron
Peatland
Velvet
No. 475
Manchuria
No. 462
Svansota

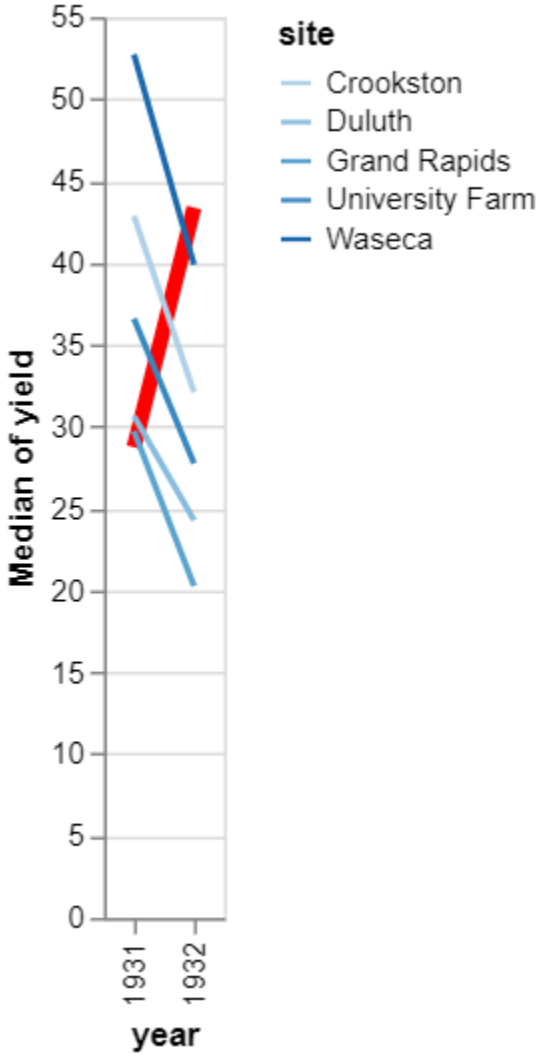
er


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

Data and encoding



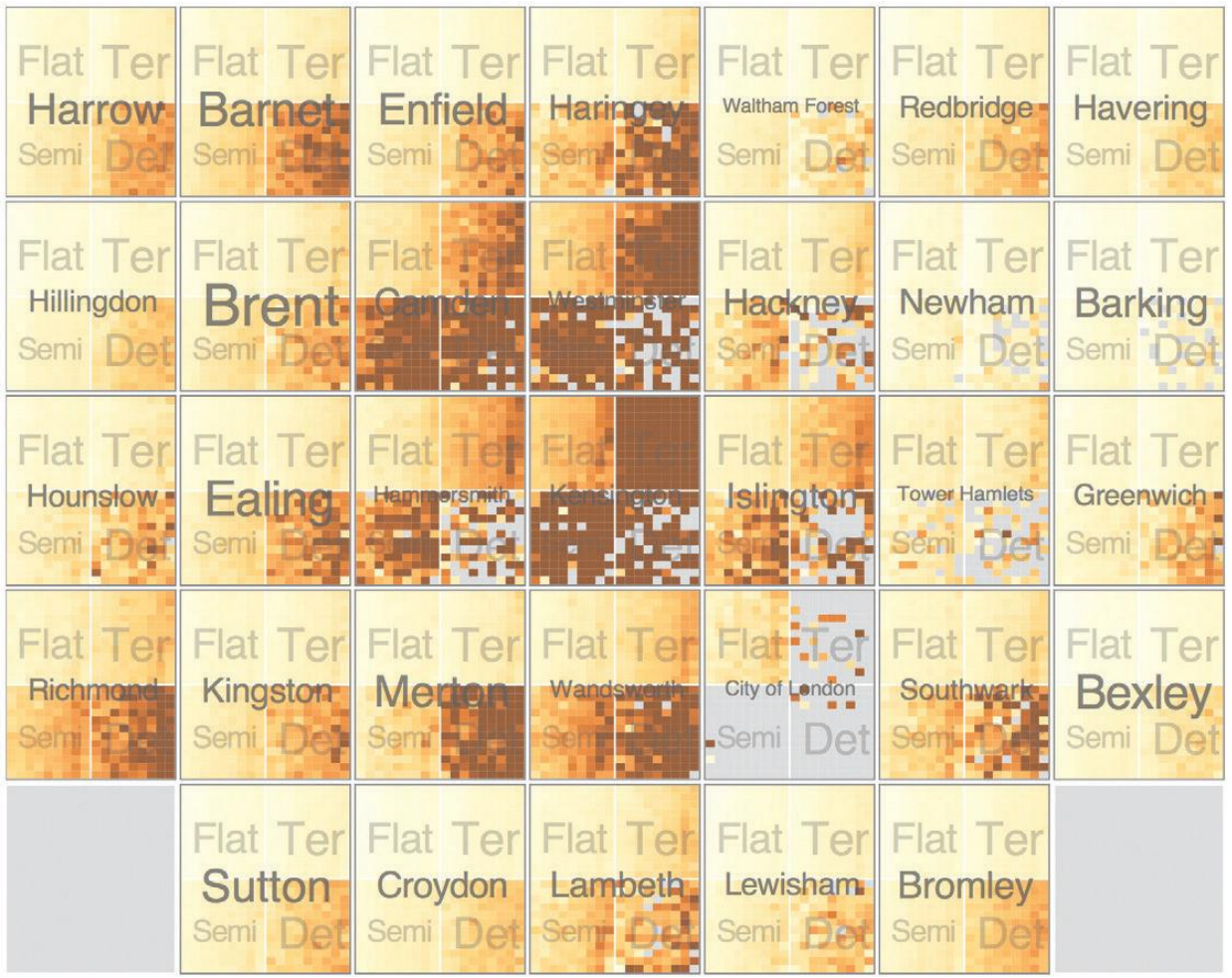
Data and encoding



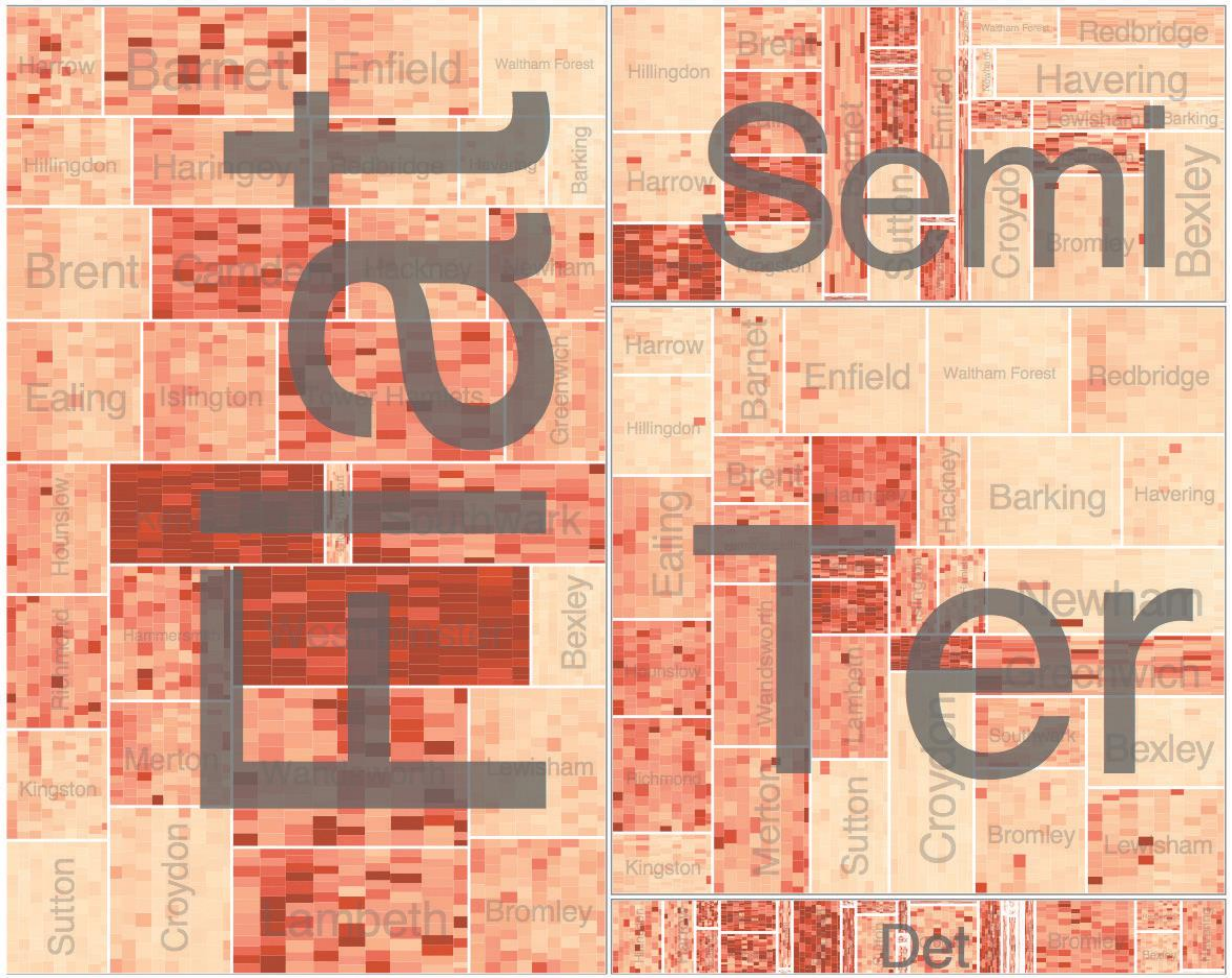
Data and encoding

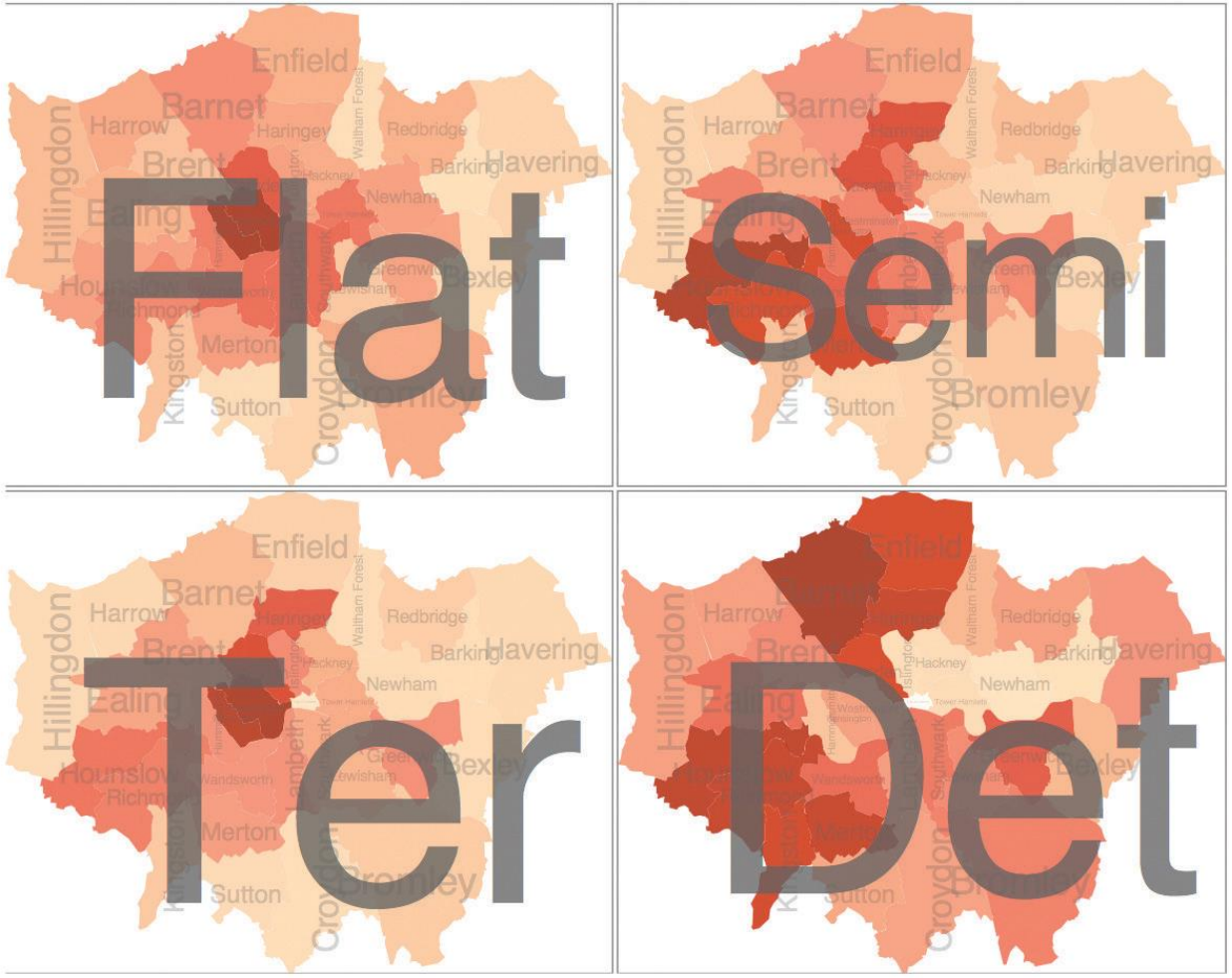
- Partitioning data. Recursive subdivision
  - Can be used in exploratory way
    - User reconfigure the display to see different choices of partitioning and encoding variables
  - HiVE: Hierarchical Visual Expression system:
    - Over 1M property transactions data
    - Categorical attribute *residence* with four levels: flats (Flat), attached terrace houses (Ter), semidetached houses (Semi) and fully detached houses (Det)
    - Price attribute is quantitative, time of sale is year+month, neighborhood can be treated as categorical or spatial…

Data and encoding



Data and encoding





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- **Coordinated views**
- Data Reduction Techniques
- Dimensionality Reduction

Coordinated Views

- Effective exploration comes from **coordinating/linking** views
  - Different names: *linked views*, *multiple views*, *coordinated views*, *coordinated multiple views*, and *coupled views*
- Linkage:
  - Actions in one view are somehow propagated to other views

Coordinated Views

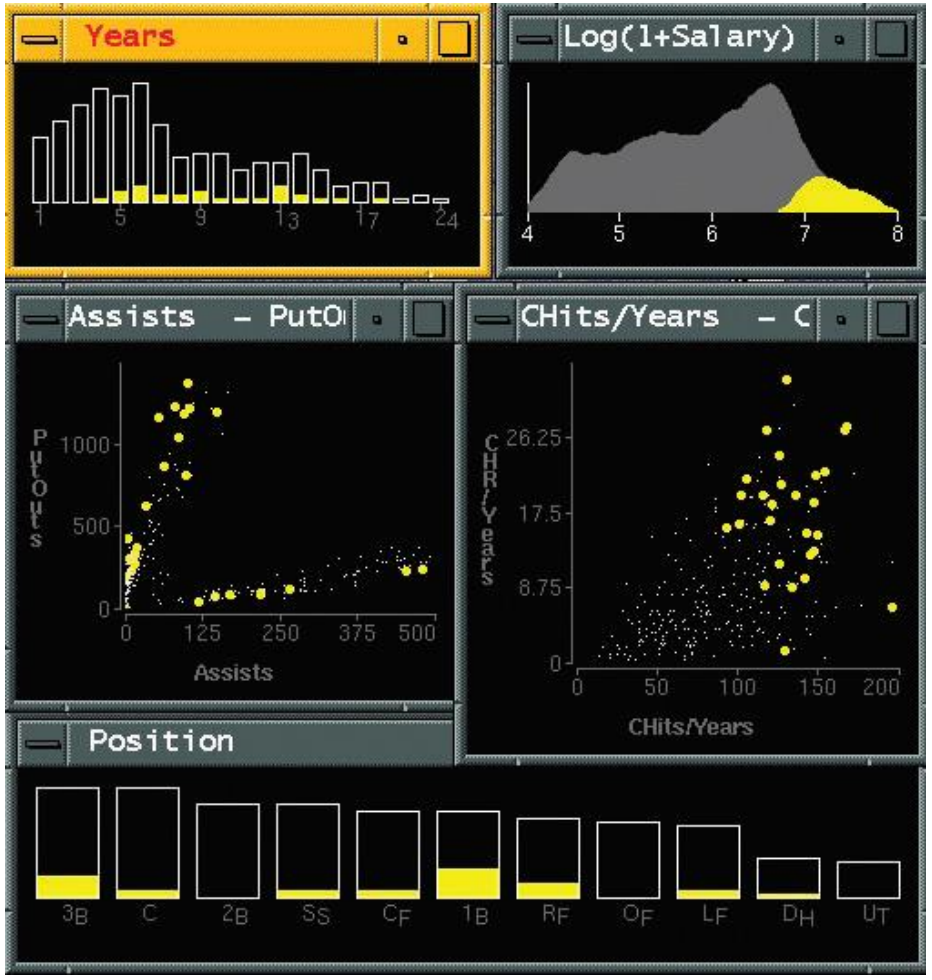
- Linking choices
  - Linked highlighting:
    - Highlighting / brushing – items selected in one view selected in all others
  - Linked navigation:
    - View parameters change through the interaction with other views

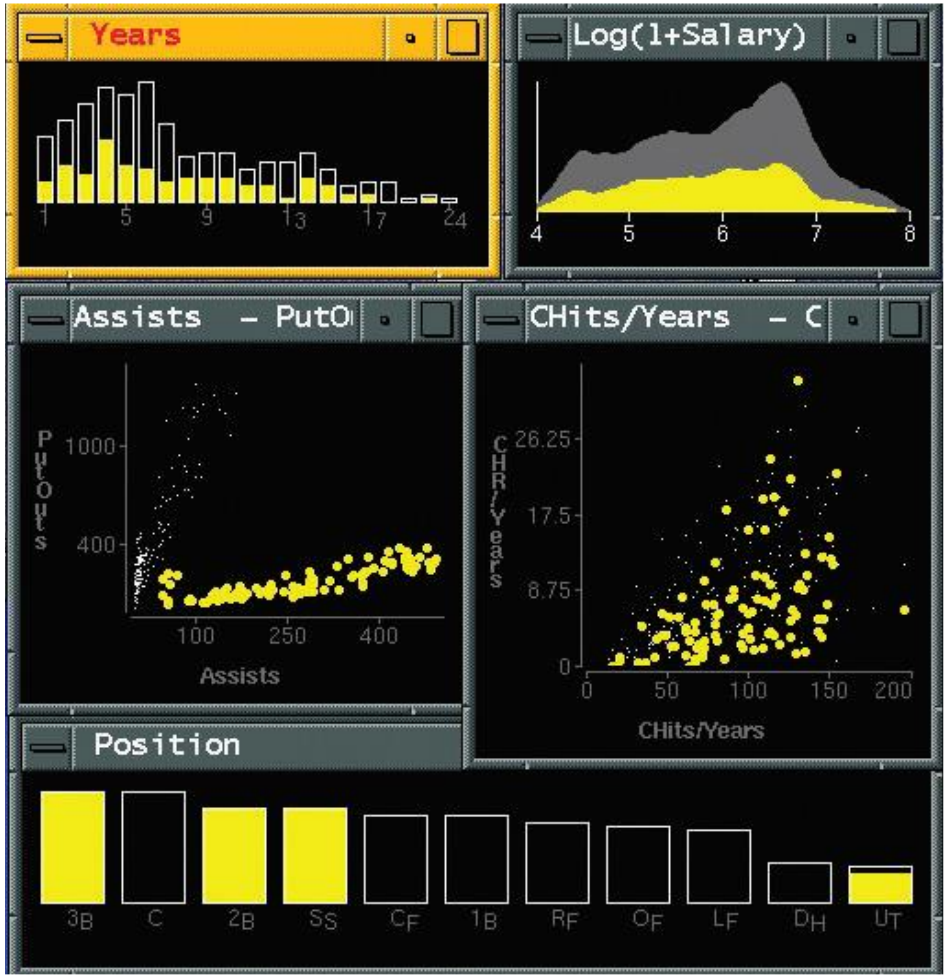
Coordinated Views

- Linked highlighting:
  - Unleashes the full power of linked views. One of the most common forms of linking
    - items that are interactively selected in one view are immediately highlighted in all other views using in the same highlight color
      - also called **brushing** or **cross-filtering**
  - Special case of a shared visual encoding in the color channel

Coordinated Views

- Linked highlighting





Coordinated Views

- Overview – detail:
  - Commonly two views (e.g. navigation in maps)
    - Overview provides the context
    - Detail usually a larger view (zooming on the details)
  - Special case of data sharing between views
- **Navigation is synchronized**

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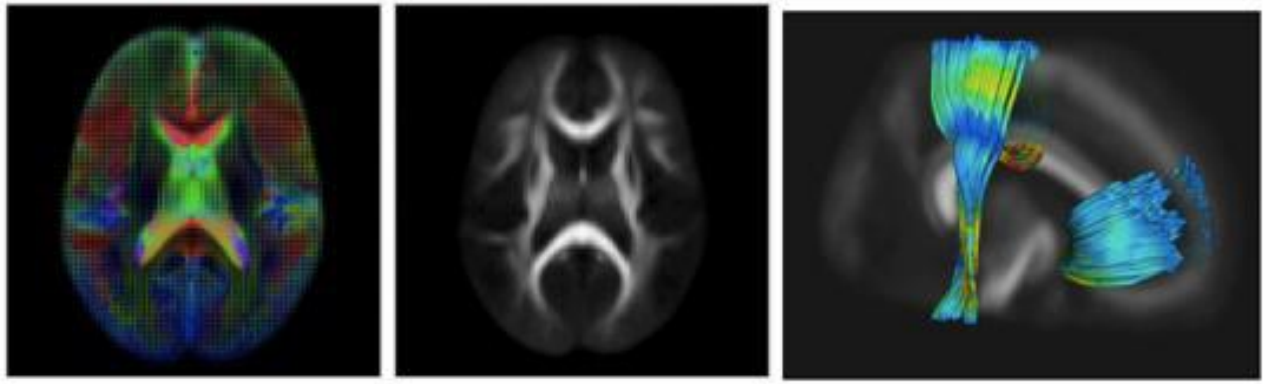
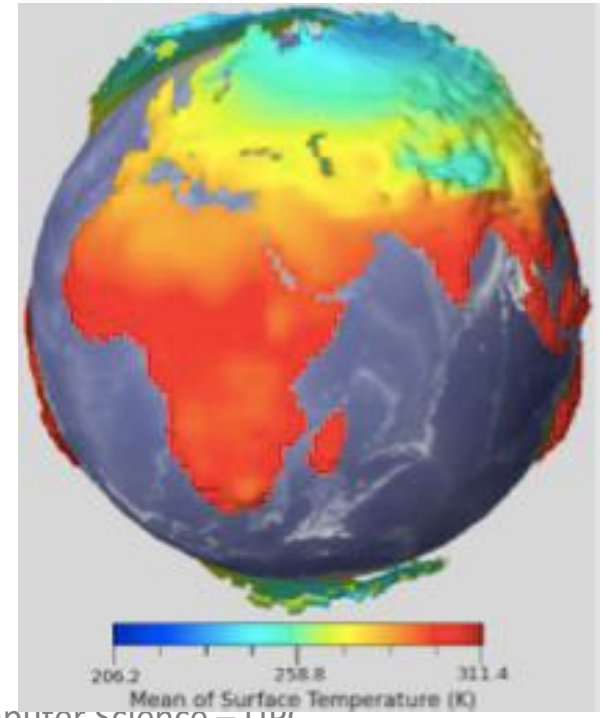
Data reduction

- Data: complex and large
- Reduce!
  - Derive new data to show within view
  - Change view over time
  - Reduce items/attributes within single view
  - Facet across multiple views





Data reduction

- Simple filtering
  - items
  - attributes
- Simple aggregation
  - items
  - attributes
- Attributes: dimensionality reduction
  - linear
  - non-linear

Data reduction

- Filtering
  - Leave some things out
- Aggregation
  - Merge things together
- Overviews
  - Temporal through navigation
  - Separate dedicated view
  - Focus + context
    - Selective filtering
    - Geometric distortion
    - Distortion costs/benefits

Data reduction

- Filtering
  - Spatial
  - Non-spatial

Data reduction

- Spatial filtering: Filter based on spatial position (aka **navigation**)
  - Unconstrained: camera can move anywhere
  - Constrained: limit on possible motion
- Panning | translating
- Rotating (in 3D)
- Zooming
  - Geometric: analogous to real-world
    - Appearance fixed, viewpoint changes sizes of objects
  - Semantic: representation adopts to screen space

Data reduction

- Non-spatial item filtering
  - Dynamic Queries:
    - Dynamically change the view, restrict items based on a query
  - Immediate visual feedback
  - Scented widgets can give an information about the impact of filtering

The New York Times

Tuesday, February 14, 2012 Last Update: 2:58 PM ET

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U.S. Seeks to Size Up China's Heir Apparent During Visit

By MARK LANDLER and EDWARD WONG 19 minutes ago

China's vice president, Xi Jinping, began a visit to the United States on Tuesday that amounts to a get-to-know-you exercise for the man who is widely seen as the next leader of China.

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Obama Keeps Up Pressure on G.O.P. Over Payroll Tax

By HELENE COOPER and JENNIFER STEINHAUER 12:22 PM ET

The president's remarks on Tuesday came a day after House Republicans said that they were ready to extend the payroll tax cut without offsetting it with other cuts.

TimesCast

Nicolas Asfouri/Agence France-Presse — Getty Images

TimesCast: Bombings in Bangkok

Explosions in Bangkok | Santorum ties Romney in latest New York Times/CBS News poll | Underage models at New York Fashion Week.

· TimesCast Archive

Blasts in Bangkok Add to Suspicions About Iran

By THOMAS FULLER 40 minutes ago

A series of explosions on Tuesday led to the capture of two men identified in Thai media reports as Iranians.

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Flaw Found in an Online Encryption Method

By JOHN MARKOFF 1 minute ago

Researchers have discovered an unexpected weakness in the

OPINION »

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Egan: A Widow's Wisdom
Same-sex marriage finds an unlikely G.O.P. champion.

Why Don't Americans Elect Scientists?
Scientists have never gotten a political foothold in the United States.

- Brooks: Materialist Fallacy
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- The Loyal Opposition: The Sant

MARKETS »

As 3:08 PM ET

S.&P. 500	Dow	Nasdaq
1,344.75	12,822.91	2,918.59
−7.02	−51.13	−12.80
−0.52%	−0.40%	−0.44%

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Cast Your Votes
Who will take home an Oscar this year? Start your ballot below with the Best Picture category.

Nominees...

'70s Sex Star Fascinates a New Era

"Lovelace" depicts the life of Linda Lovelace, the star of a 1972

Data reduction

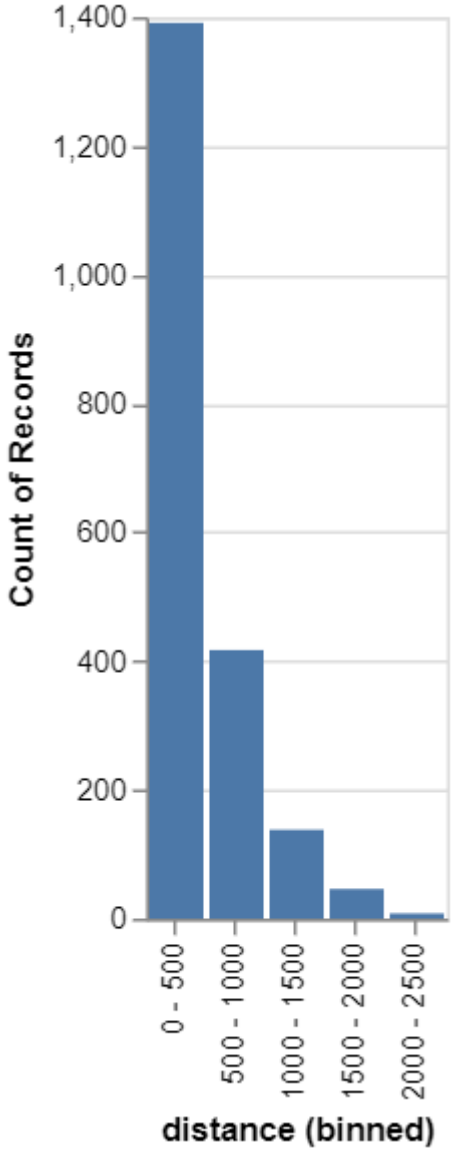
- Aggregation
  - Combine items (vs. eliminate with filtering)
  - Derived attributes
    - Min, max, avg, sum…
- Challenge: avoid averaging out signal

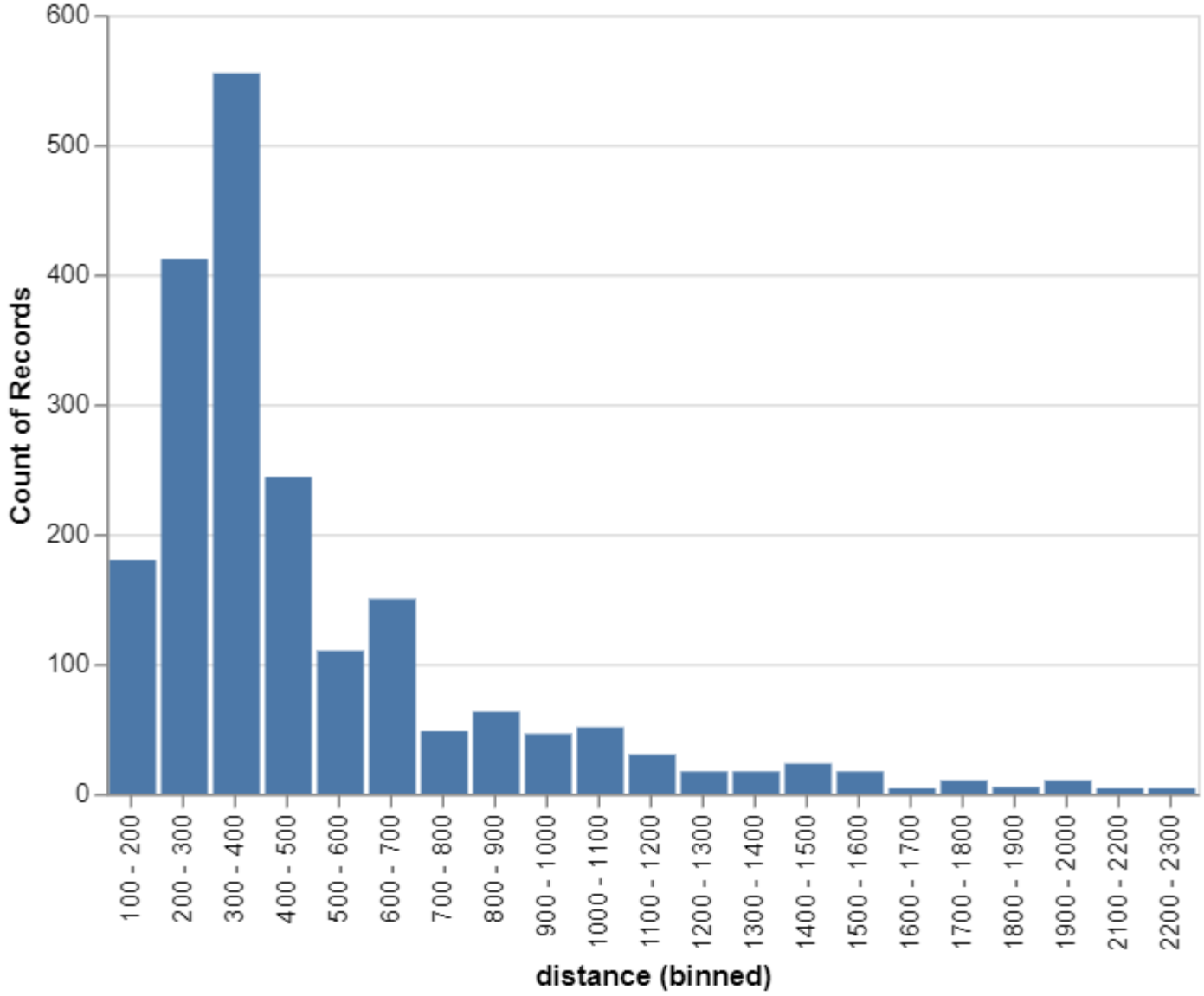
- Can be used in conjunction with filtering

Data reduction

- Aggregation. Histograms
  - Partition the range of original attribute into bins
    - Number of bins can be chosen
  - Compute the number of items that fall into each bin and derive it as an ordered attribute
  - Choice of the bin size is crucial
    - May make the appearance completely different
      - Could compute the bins based on data characteristics
      - Or provide interaction tools to show how the histogram varies

Data reduction





Data reduction

- Aggregation. Histograms. Visual representation
  - Bars encode the quantity of each range in length
    - Similar to bar charts but more concise

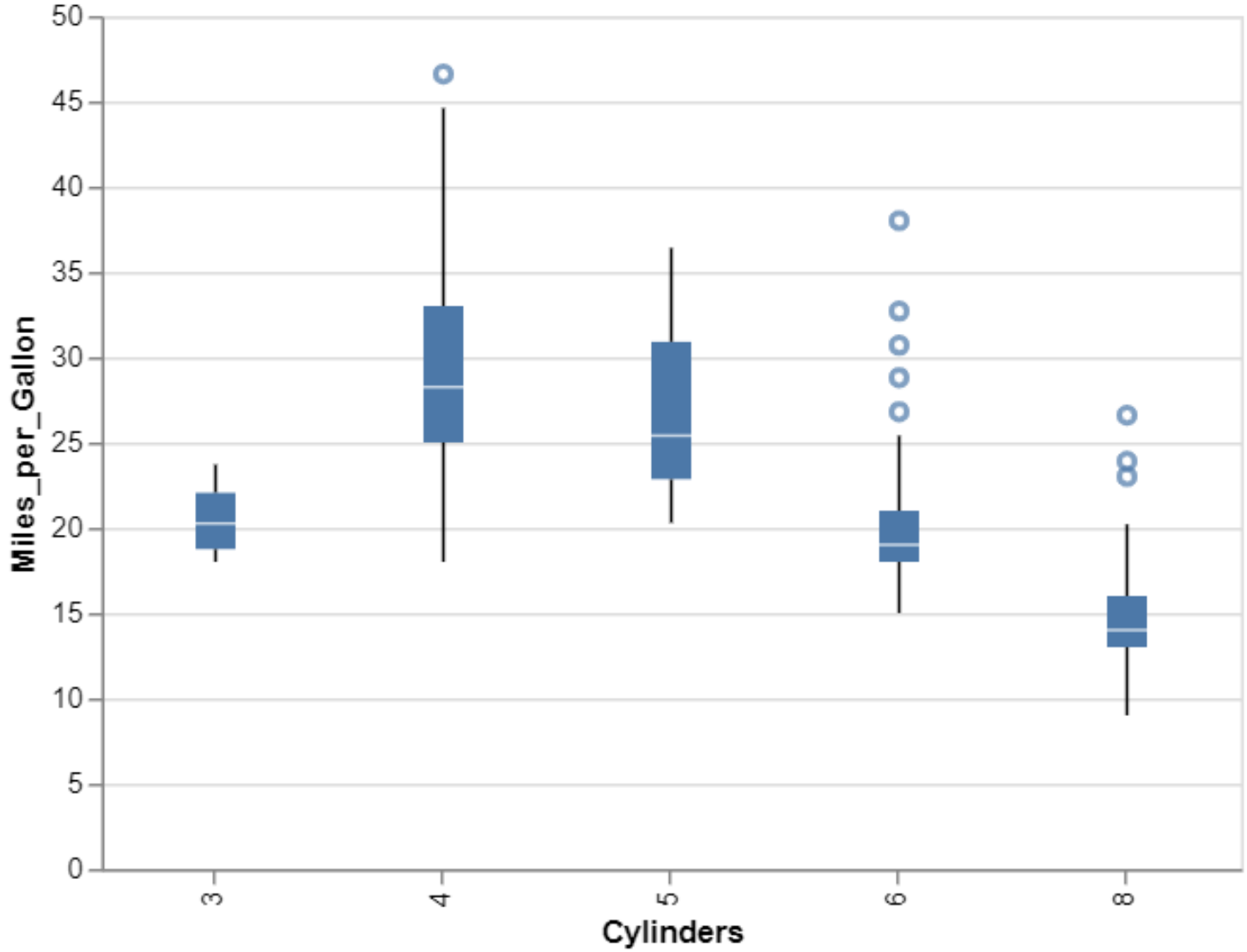
Data reduction

- Aggregation. Boxplots
  - Statistical summary of all the values that occur within the distribution of a single quantitative attribute.
  - Uses five derived variables carefully chosen to provide information about the attribute's distribution:
    - median (50% point), lower and upper quartiles (25% and 75% points), and the upper and lower fences (chosen values near the extremes, beyond which points should be counted as outliers)

Data reduction

- Aggregation. Boxplots. Visual representation
  - Box that stretches between the lower and upper quartiles and has a horizontal line at the median
  - Whiskers are vertical lines that extend from the core box to the fences marked with horizontal lines
  - Outliers beyond the range of the chosen fence cutoff are shown explicitly as discrete dots
  - Also known as *box-and-whisker* diagrams

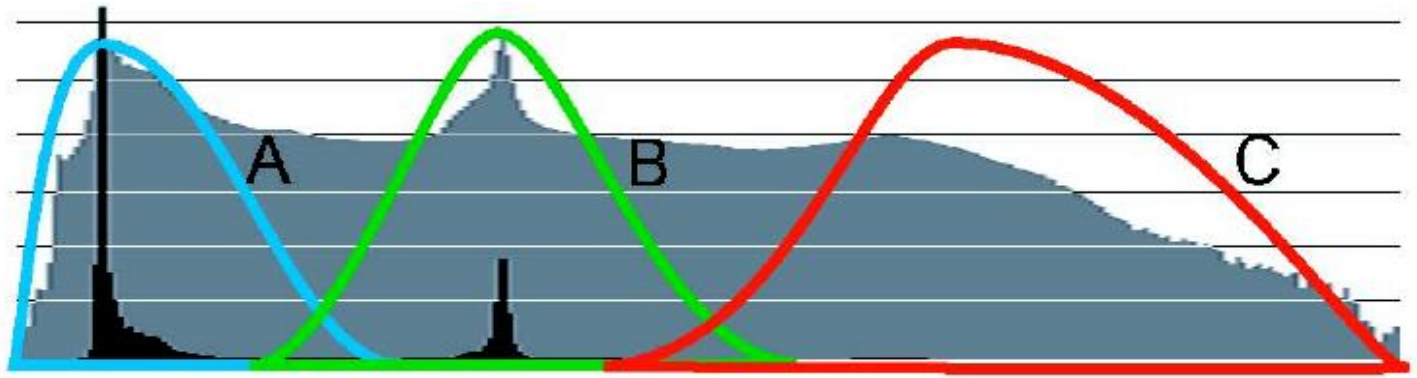
Data reduction

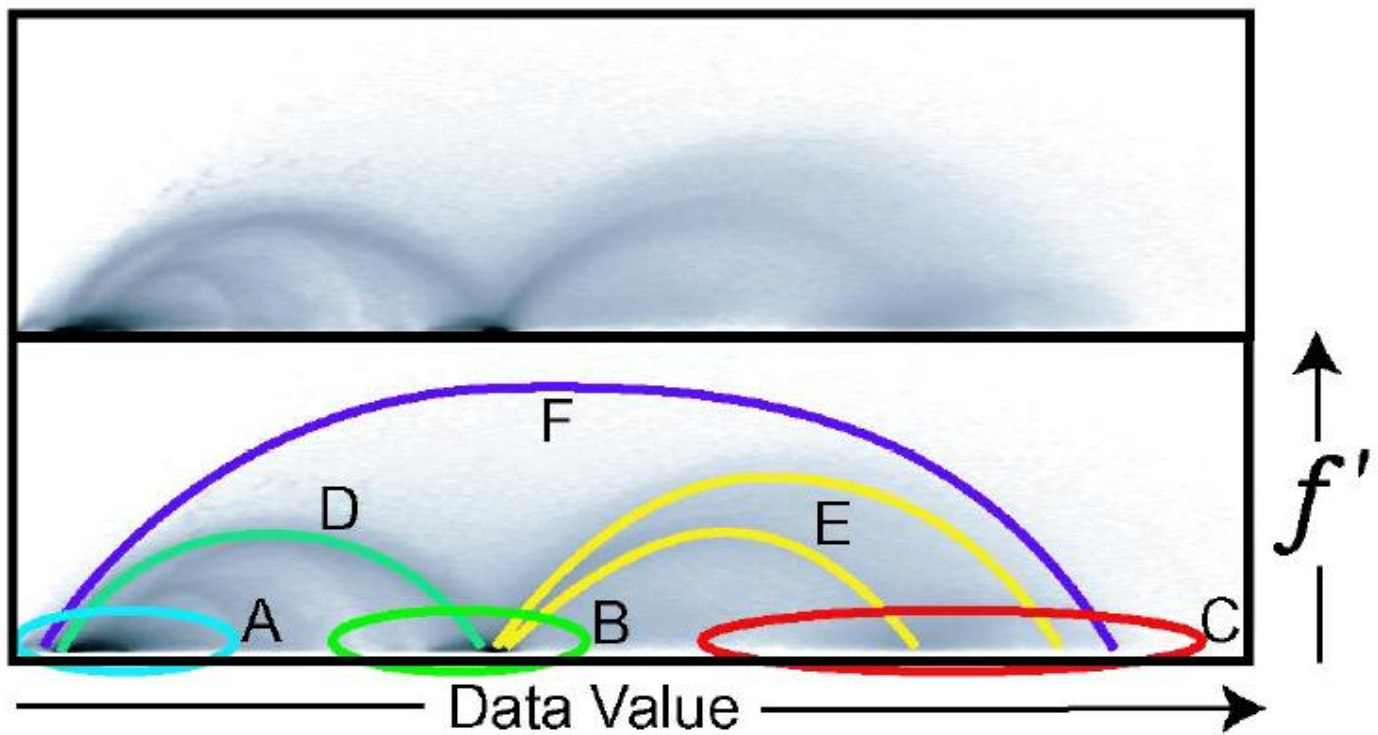


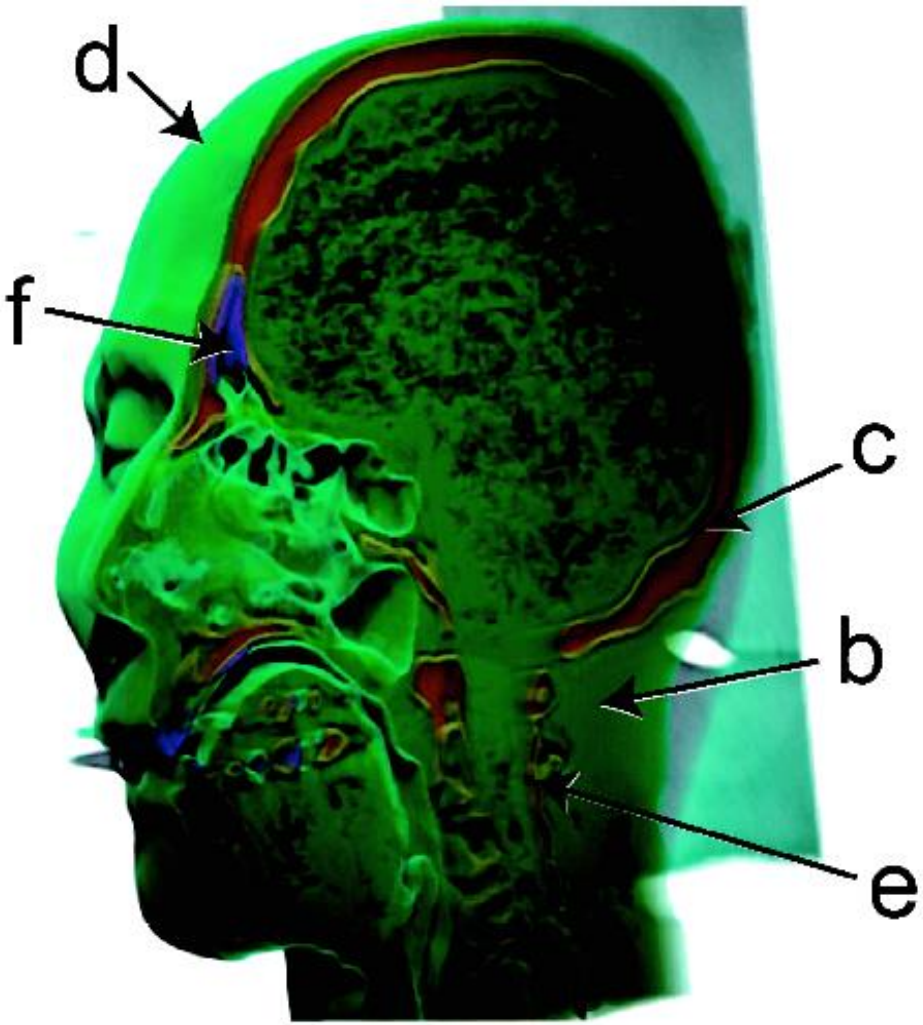
Data reduction

- Examples of techniques:
  - Classification
  - Dimensionality reduction
  - Overviews & aggregation
  - Filtering & navigation
  - Focus + context
  - Levels of detail

Data Reduction. Classification

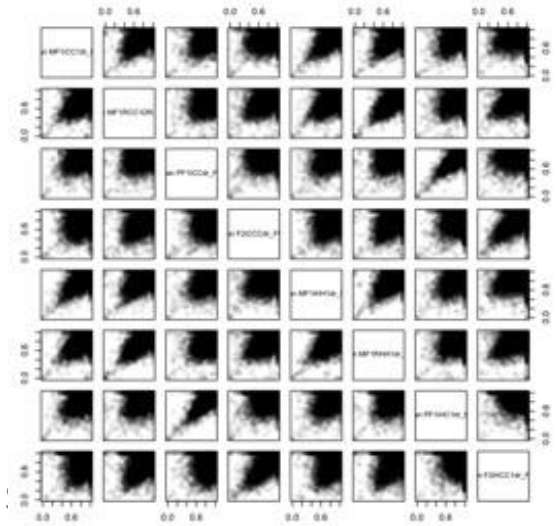


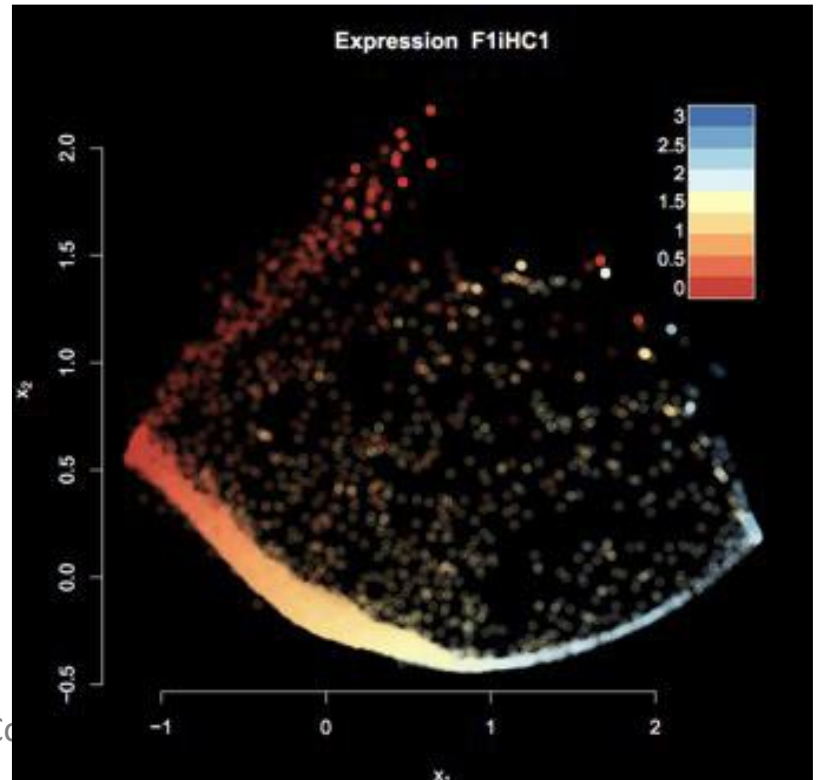




Data reduction. Dimensionality reduction

- Reduce m-dimensional data set Y to n-dimensional representation X
  - Preserve *information* in Y in reduced space X
  - Geometry (distances, angles, ...)
  - Statistics (density, entropy, ...)





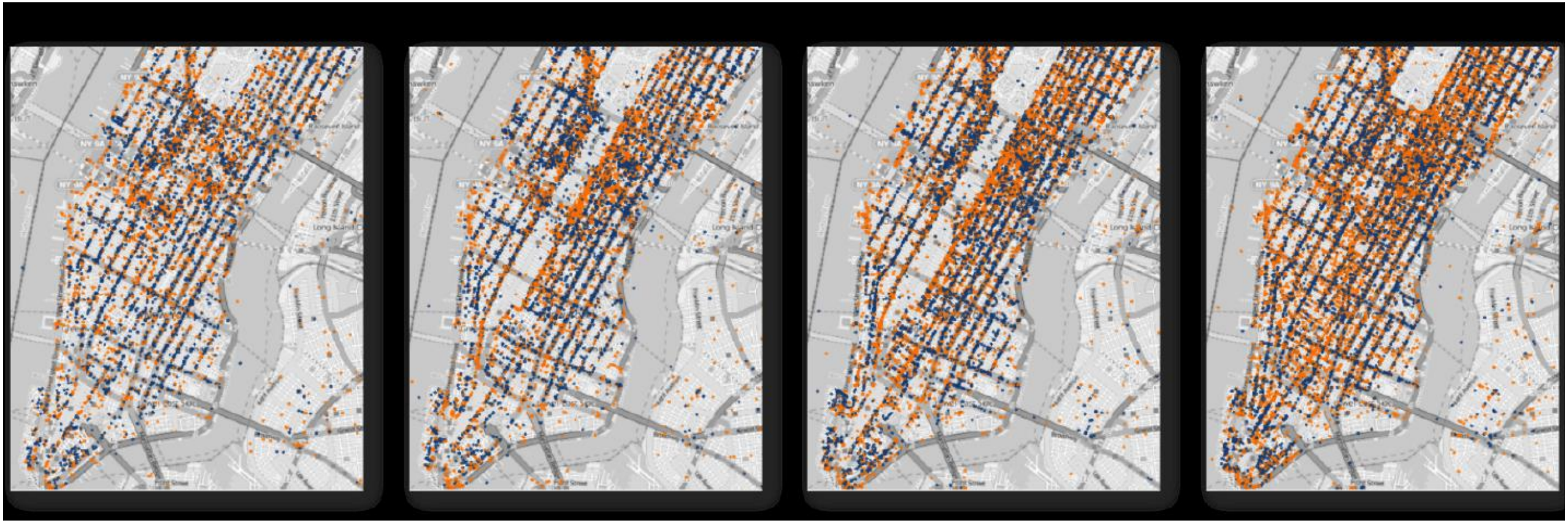
Data reduction. Dimensionality reduction

- Visualizing multiple dimensions
  - Start by visualizing individual dimensions
  - Avoid “over-encoding”
  - Use space and small multiples intelligently
  - Use interaction to generate *relevant* views
- There is rarely a single visualization that answers all questions. Instead, the ability to generate appropriate visualizations quickly is key.

Data reduction. Overviews & aggregation

- Explicit design of discrete levels of detail to yield overviews
  - Inherent multi-scale representation of dataset: Low LOD = overview
  - Represent many data items with single mark: aggregation / summarization
  - Cartographic generalization: Drawing maps at many scales, retaining important detail

Data reduction. Overviews & aggregation



Pickups (blue) and dropoffs (orange) in Manhattan on May 1st from 7am to 11am

Data reduction. Overviews & aggregation

- Cartographic generalization: Drawing maps at many scales, retaining important detail.

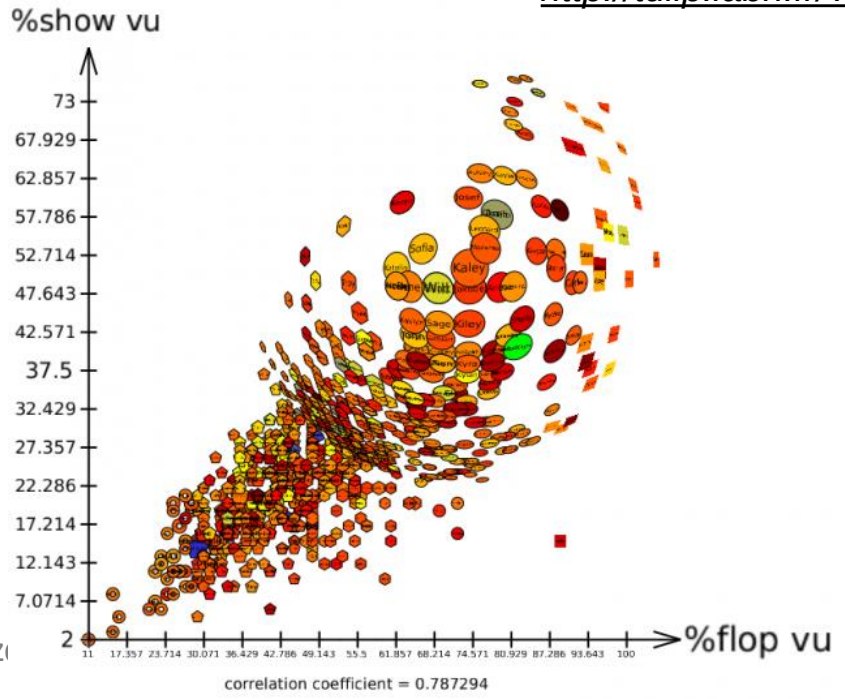
Data reduction. Filtering & Navigation

- User is interacting with system to process data, or to zoom more or less continuously (different from overviews)
  - Filter data to show subset:
    - Queries, such as selecting ranges of interest.
  - Navigation:
    - Geometric (correct) zooming
    - Semantic (abstract) zooming – drawn object scales non-linearly with number of pixels available to render it.

Data reduction. Focus+Context Visualization

- Different levels of detail integrated in the same view
  - Show area of interest (focus) in detail and its surroundings (context) in less detail
  - Distortion techniques

http://tulip.labri.fr/TulipDrupal/?q=node/371



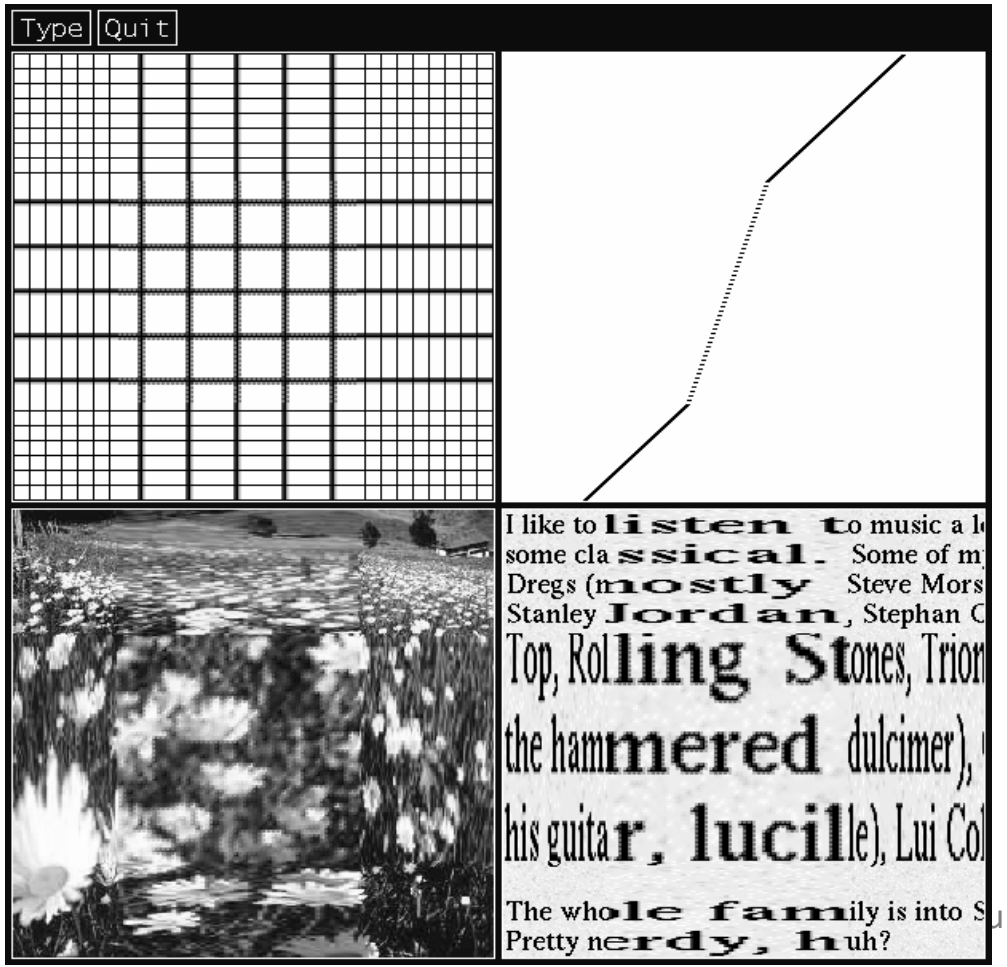
Data reduction. Focus+Context Visualization

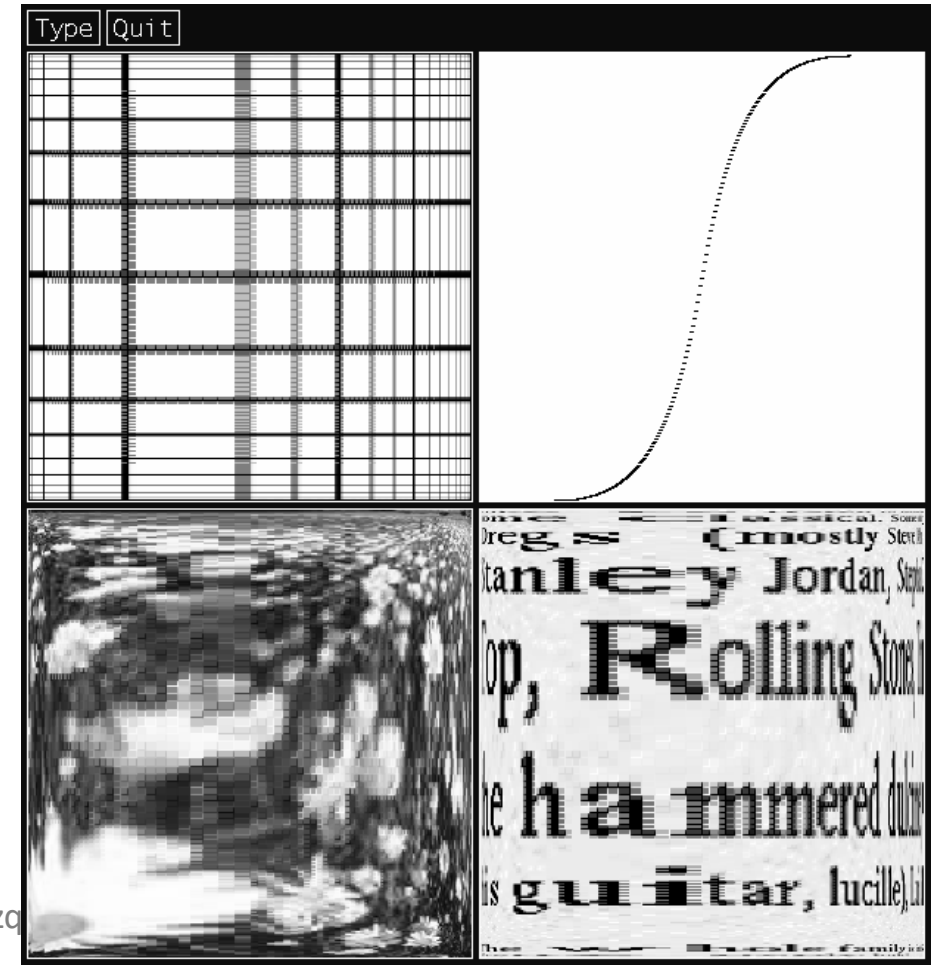
- Distortion techniques
  - Simple magnifying glass: Example of distortion technique.
  - UI: Magic Lens.
  - Bifocal distortion: X-Y, piecewise linear.
  - Fish-eye view: Radial, continuous.

See demos at http://flare.prefuse.org/demo - “distortions”

Data reduction. Focus+Context Visualization

- Simple magnifying glass.



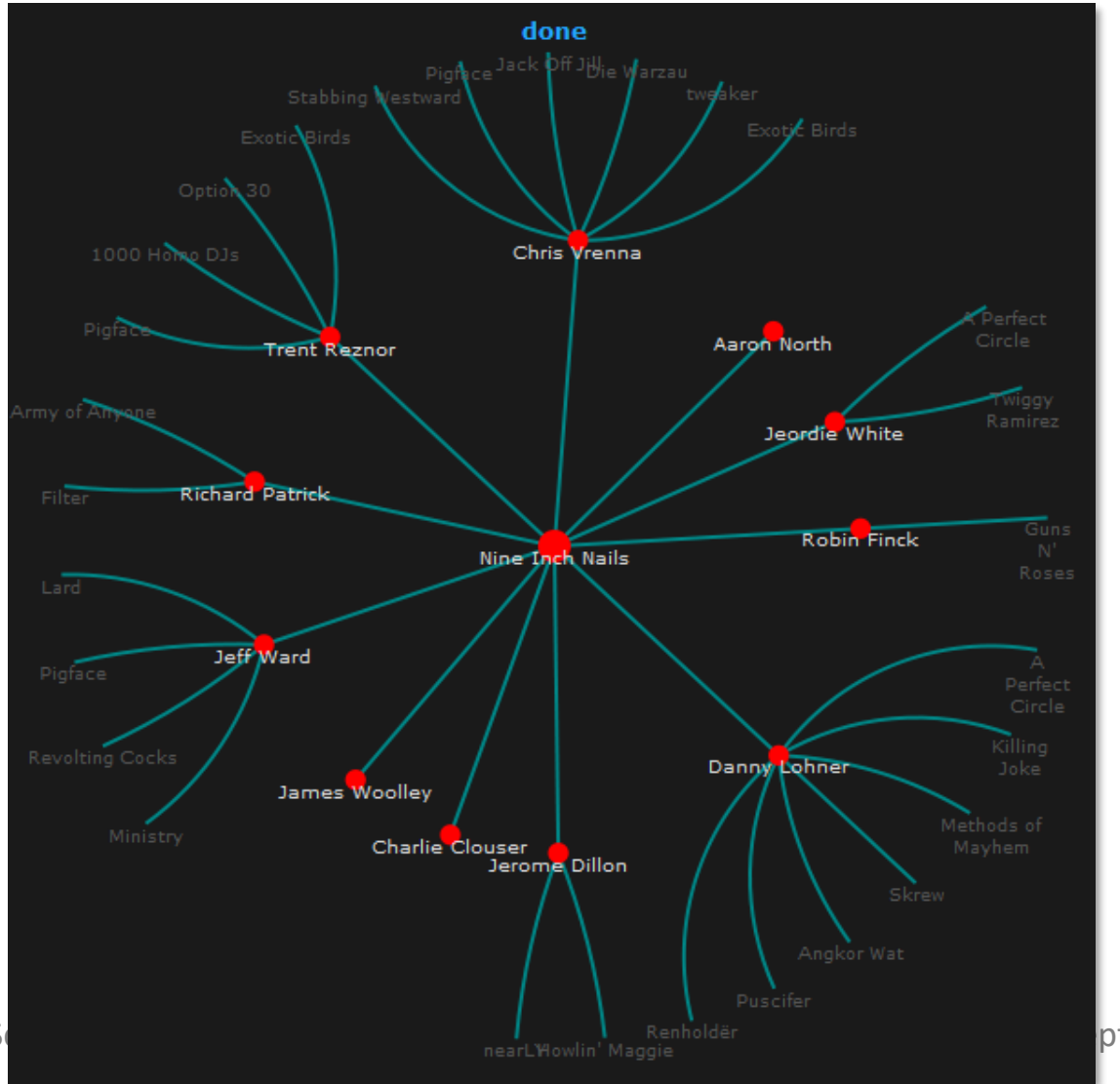


Data reduction. Focus+Context Visualization

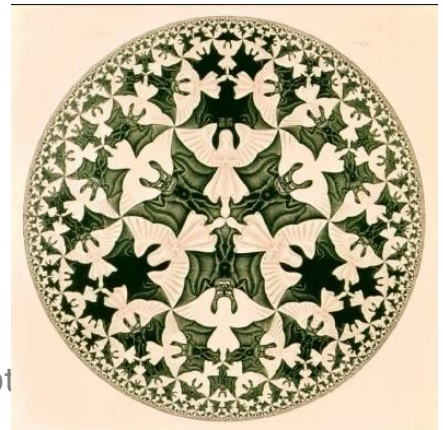
- Distortion: Hyperbolic trees
  - Layout hierarchy uniformly on hyperbolic plane, map plane onto circular display region [Lamping et al. 1995]
  - Smooth blending between focus (usually centre) and context.
  - Decrease in size outwards, exponential growing structure.
  - Thanks Escher!

Data reduction. Focus+Context Visualization

Example: http://thejit.org/static/v20/Jit/Examples/Hypertree/example1.html



http://thejit.org/static/v20/Jit/Examples/Hypertree/example1.html



Data reduction. Levels of detail

- Need more pixels:
  - Visualize at multiple levels of detail
  - Need contextual and detailed information
- Cockburn survey:
  - Overview+Detail: Spatial separation to partition
  - Zooming interfaces (ZUIs): Temporal separation
  - Focus+Context: No separation, single continuous view
  - Visual cues: Highlight, suppress or contextualize elements

Data reduction. Levels of detail

- Maps

Outline

- *Multiple Views*
- *Data and encoding*
- *Coordinated views*
- *Data Reduction Techniques*
- **Dimensionality Reduction**

Dimensionality Reduction

- Goals
  - Create smaller set of **new dimensions**
  - Set size is smaller than original, new dimensions
    - Completely synthetic
  - Includes some projections (but not all)
    - Usually also called projection/mapping

Dimensionality Reduction

- Only suitable if (almost) all information could be conveyed with fewer dimensions
  - How do you know?
    - Need to estimate true dimensionality to check if different than original
    - Very difficult task

Dimensionality Reduction

- Mapping multidimensional space into space of fewer dimensions
  - Typically 2D for clarity
  - 1D/3D may be possible
  - Keep/explain as much variance as possible
  - Show underlying dataset structure
- Motivation: true/intrinsic dimension of dataset is much lower than measured dimension
  - Linear vs. non-linear approaches

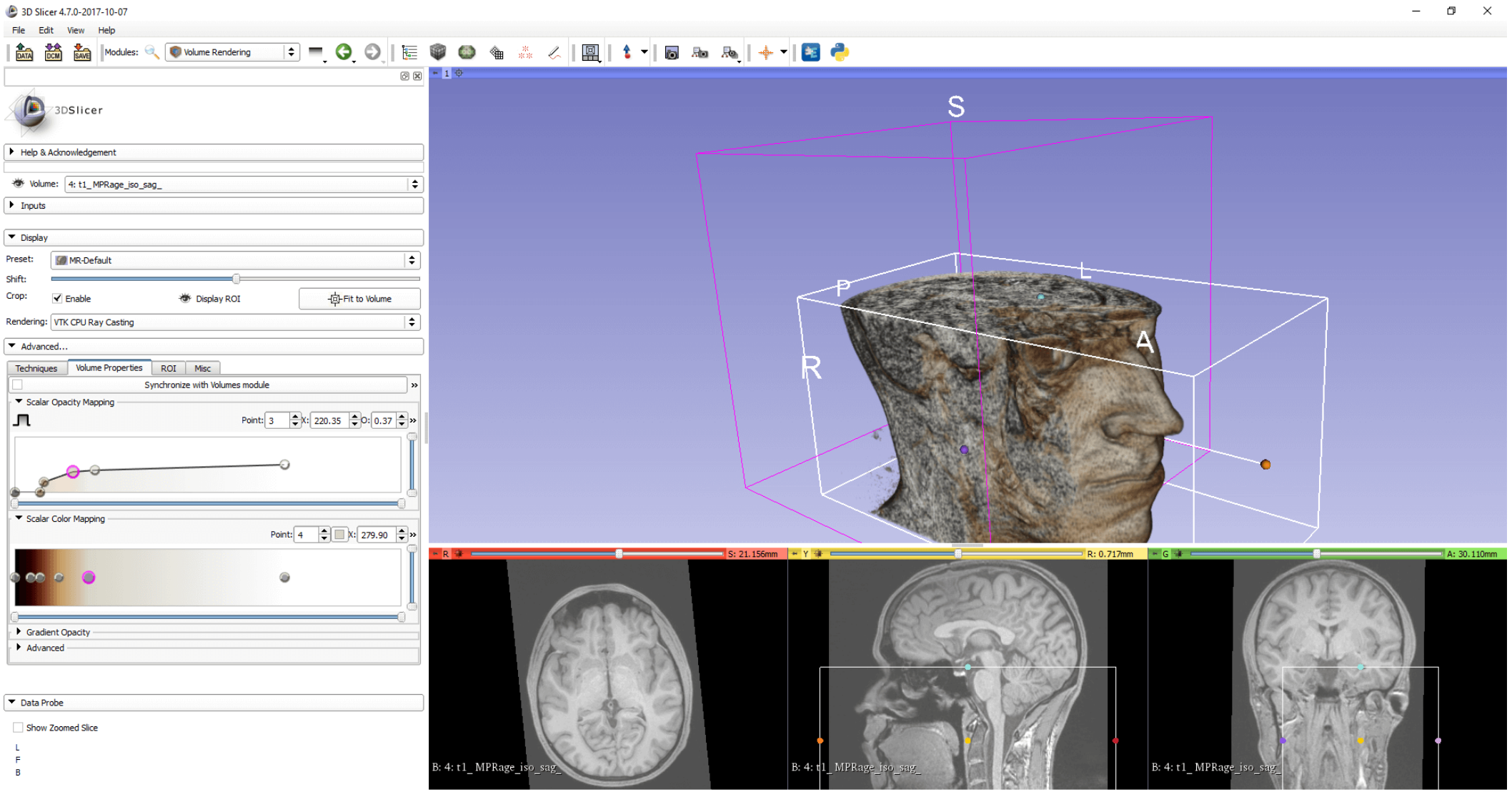
Dimensionality Reduction

- Error for low-dim projection vs high-dim original
  - No single correct answer; many metrics proposed
    - Cumulative variance that is not accounted for
    - Strain: match variations in distance (vs actual distance values)
    - Stress: difference between interpoint distances in high and low dimensions

Dimensionality Reduction

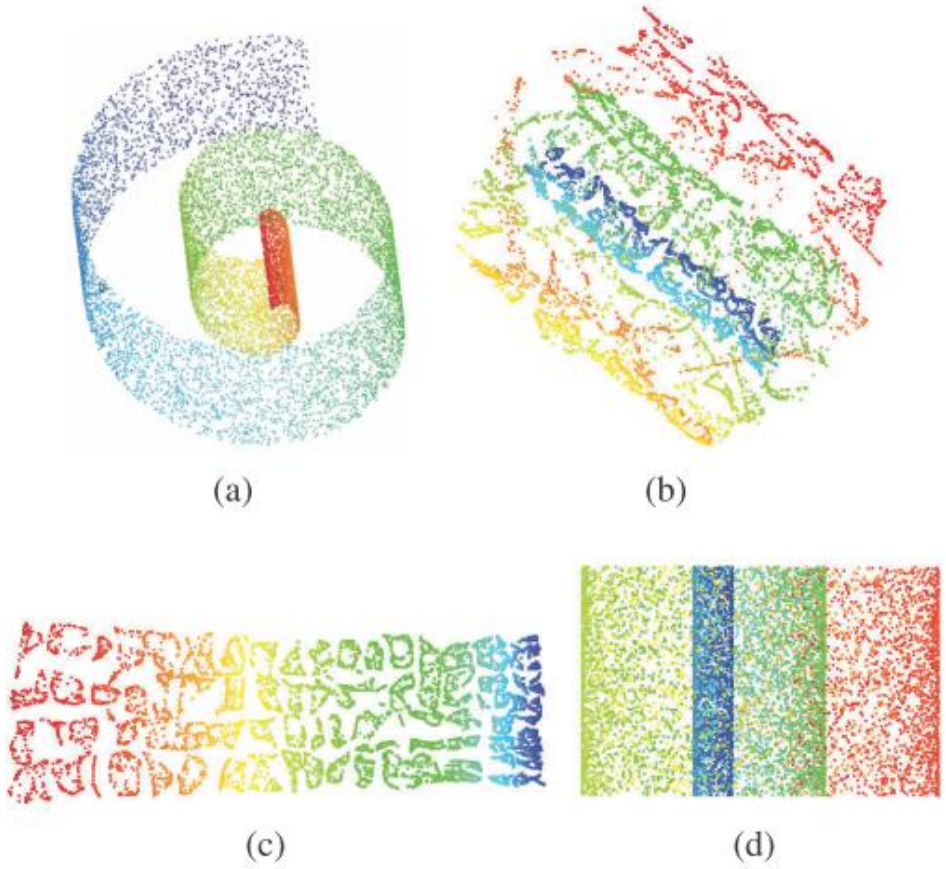
- Techniques:
  - Slicing
  - Projection
  - Transformation to subspace:
    - Principal component analysis
    - Multi-dimensional scaling
    - tSNE
    - UMAP

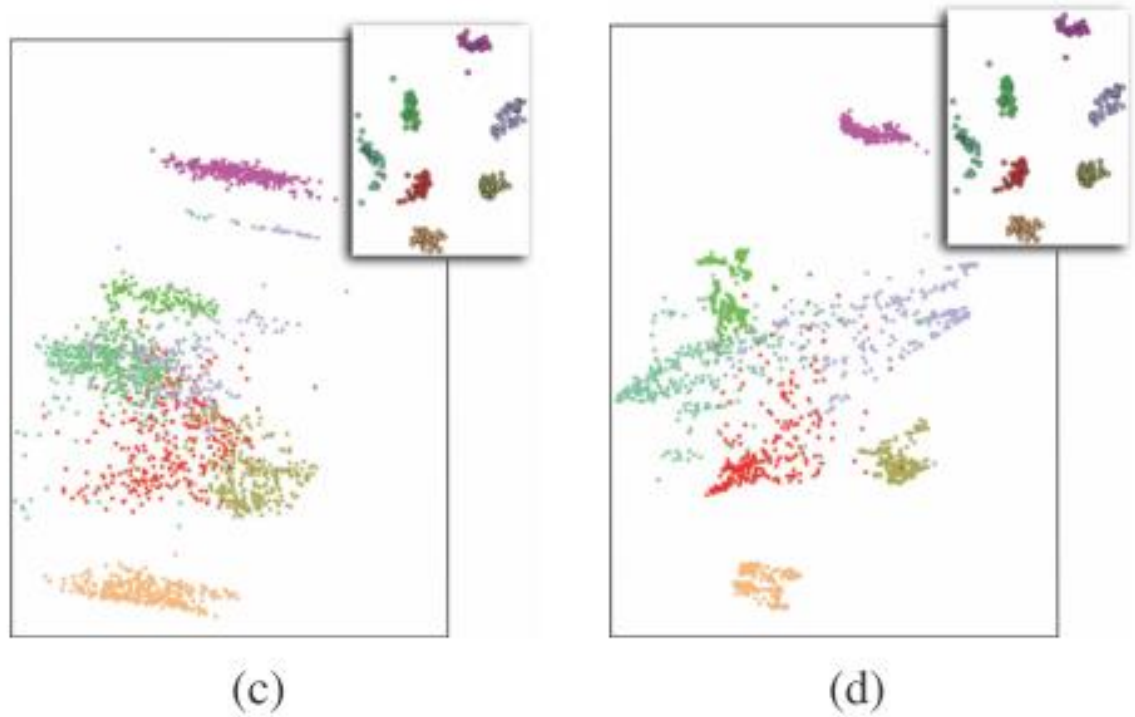
Dimensionality Reduction. Slicing



https://www.andreasjakl.com/visualizing-mri-ct-scans-mixed-reality-vr-ar-part-2-3d-volume-rendering/

Dimensionality Reduction. Multi-dimensional projections





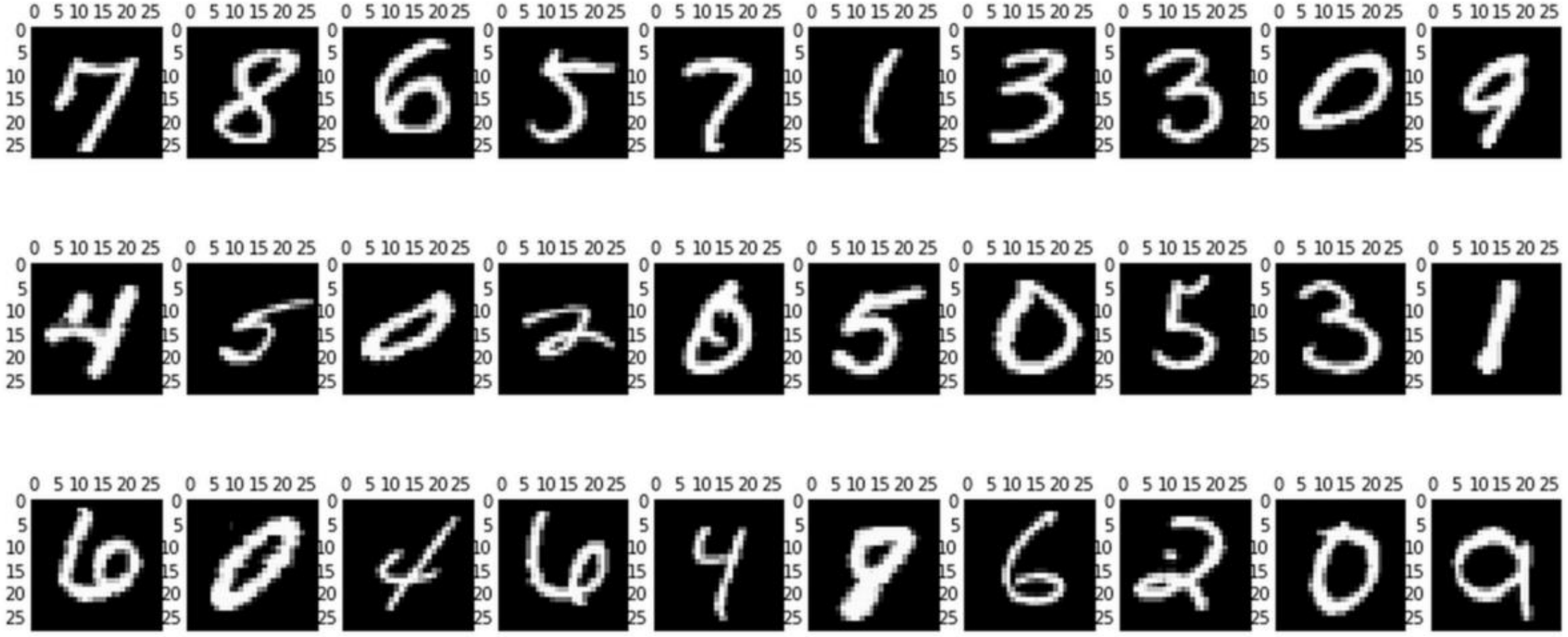
F. V. Paulovich, D. M. Eler, J. Poco, C. P. Botha, R. Minghim, and L. G. Nonato, "Piecewise Laplacian-based Projection for Interactive Data Exploration and Organization," *Computer Graphics Forum*, vol. 30, no. 3, pp. 1091-1100, Jun. 2011.

Dimensionality Reduction. Multi-dimensional projections

- PCA vs tSNE vs UMAP analysis of the MNIST dataset
  - 70000 handwritten numbers
  - Greyscale images of 28x28 pixels
    - → 784 dimensions

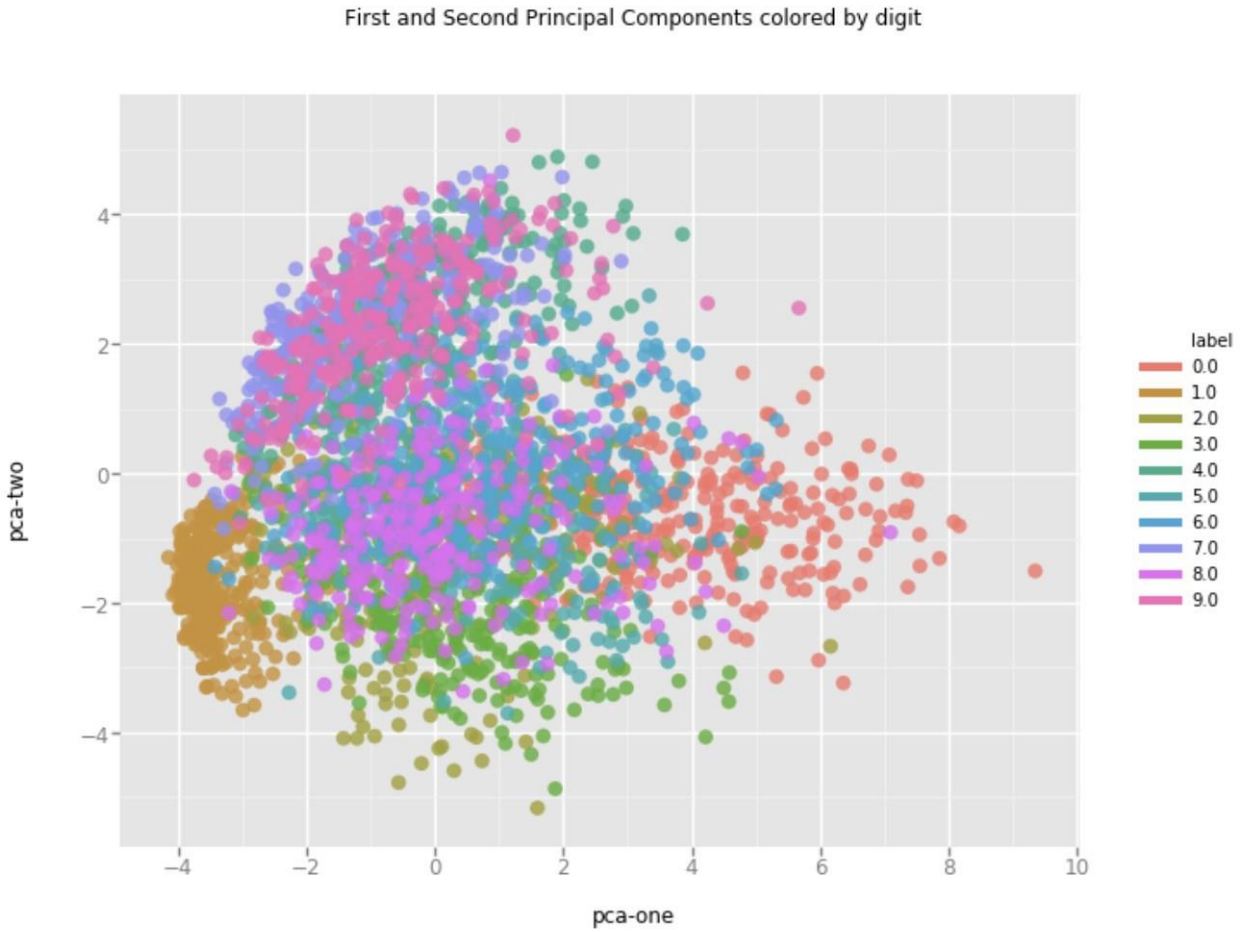
Dimensionality Reduction. Multi-dimensional projections

- MNIST dataset



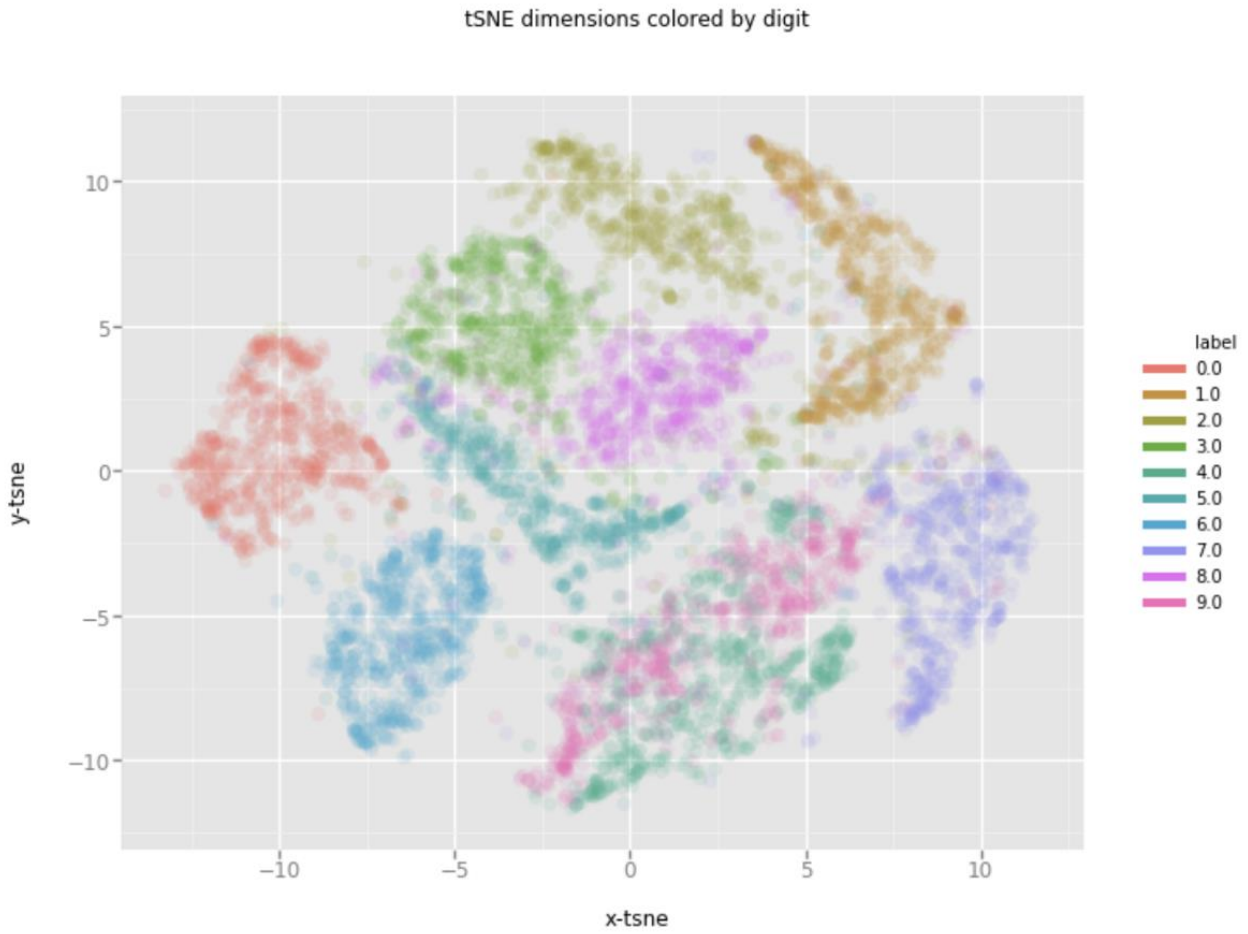
Dimensionality Reduction. Multi-dimensional projections

- Are we able to separate the images by number? → PCA



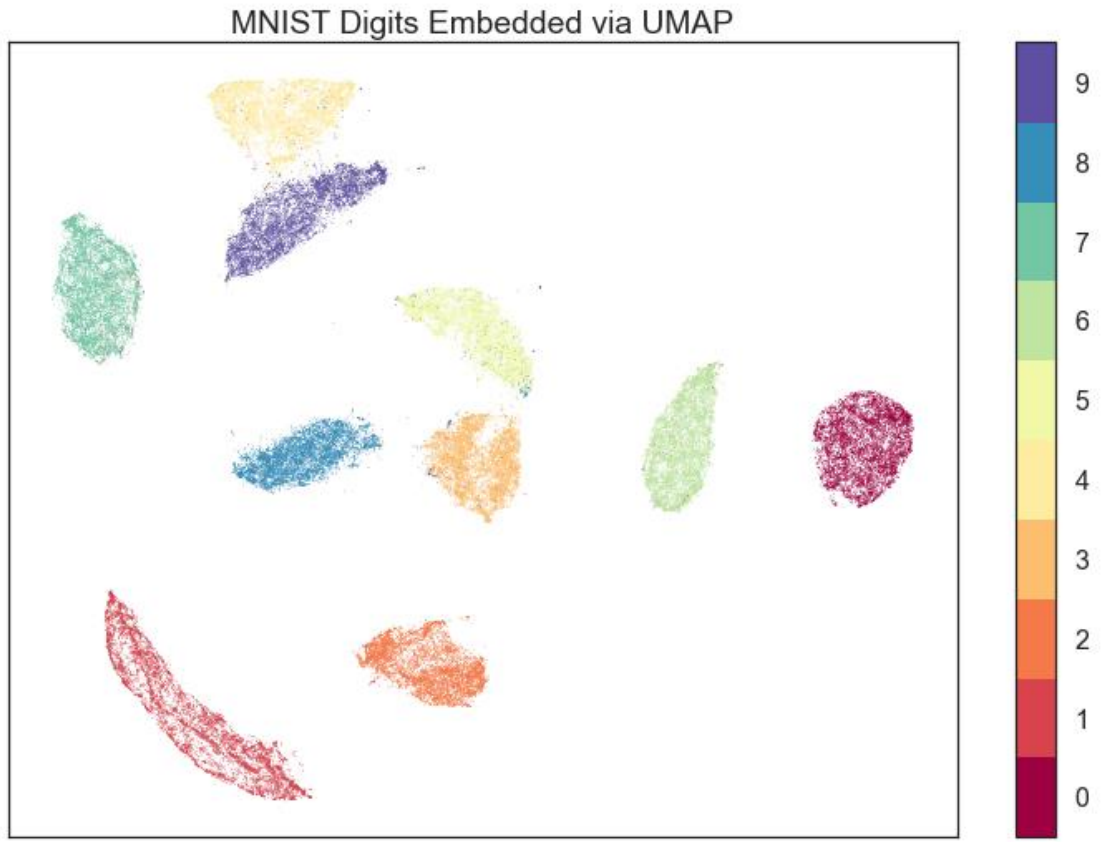
Dimensionality Reduction. Multi-dimensional projections

- Are we able to separate the images by number? → tSNE



Dimensionality Reduction. Multi-dimensional projections

- Are we able to separate the images by number? → UMAP



Sources of information

- Further reading:
  - [Roberts] State of the Art: Coordinated & Multiple Views in Exploratory Visualization,
  - [Scherr] Multiple and Coordinated Views in Information Visualization
  - [Munzner] Visualization Analysis and Design

Visualization. Multiple Views

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