Visualization and Visual Analysis of Multi-faceted Scientific Data: A Survey

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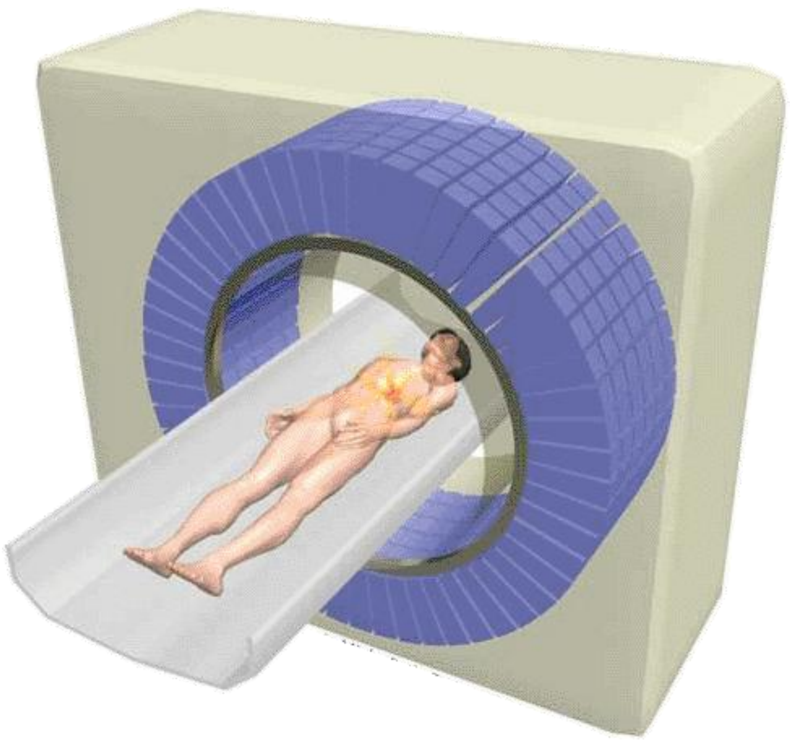
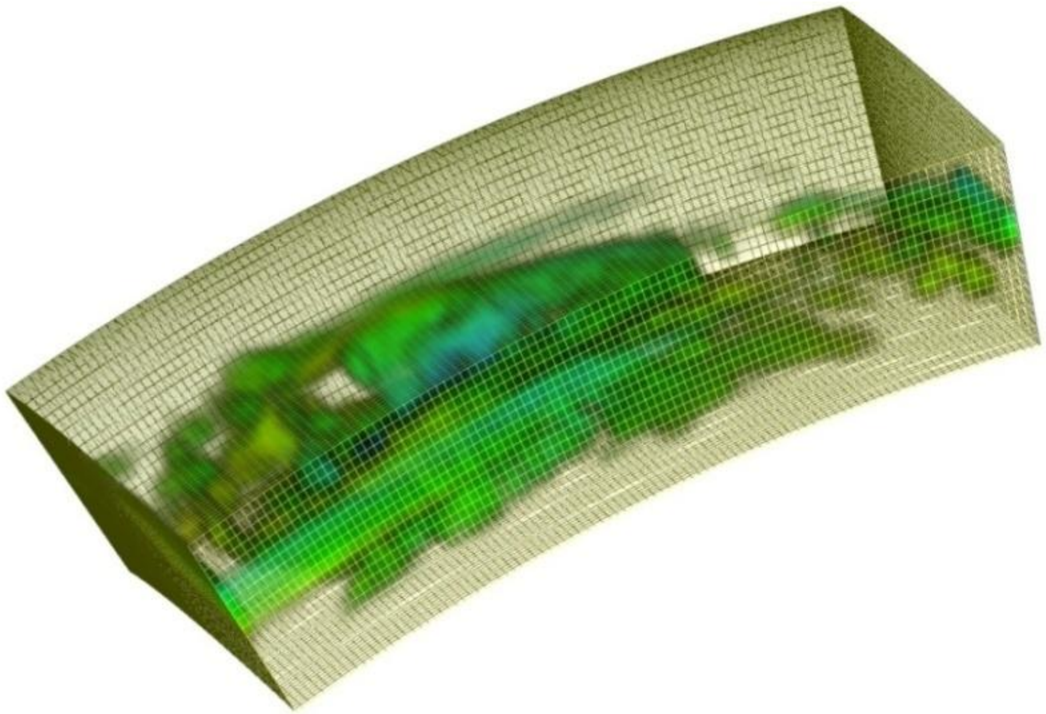
Motivation

Increasing amounts of scientific data



medical scanner

computational simulation

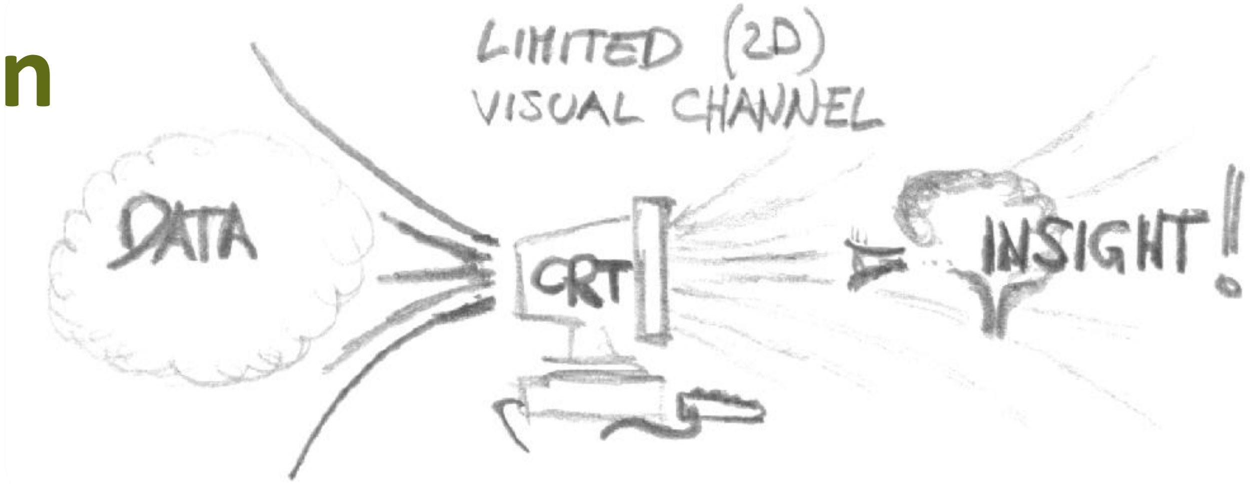


time-dependent
3D data

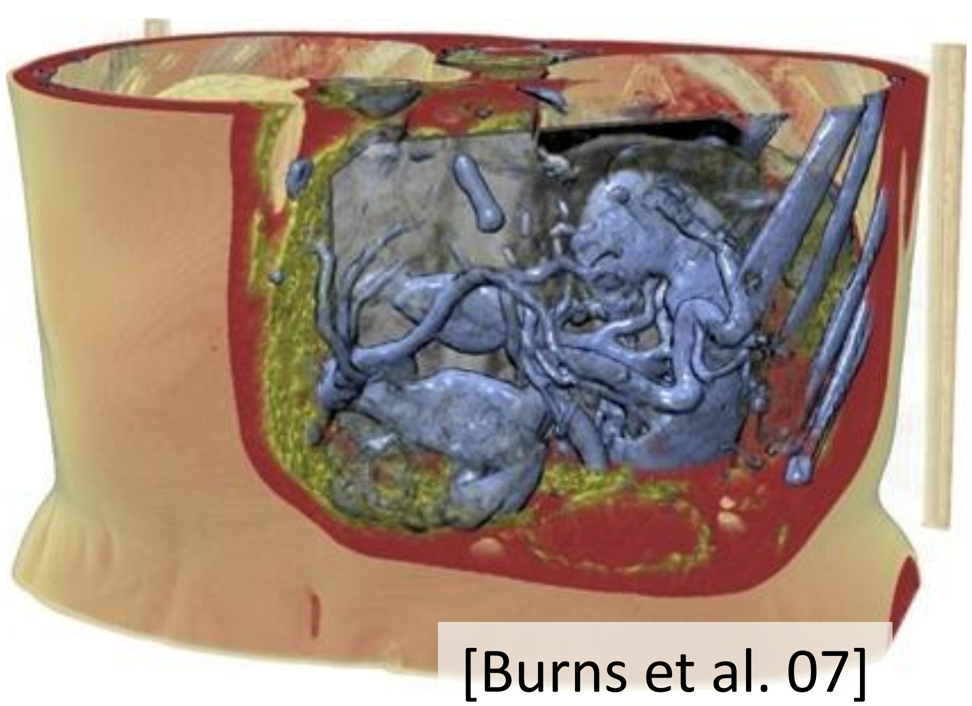
Hard to analyze and understand

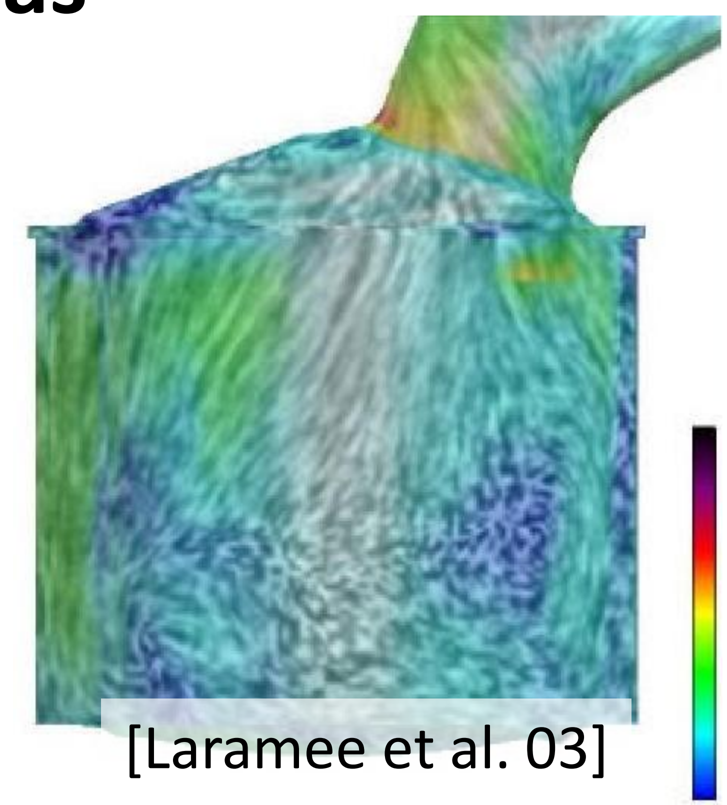
Visualization

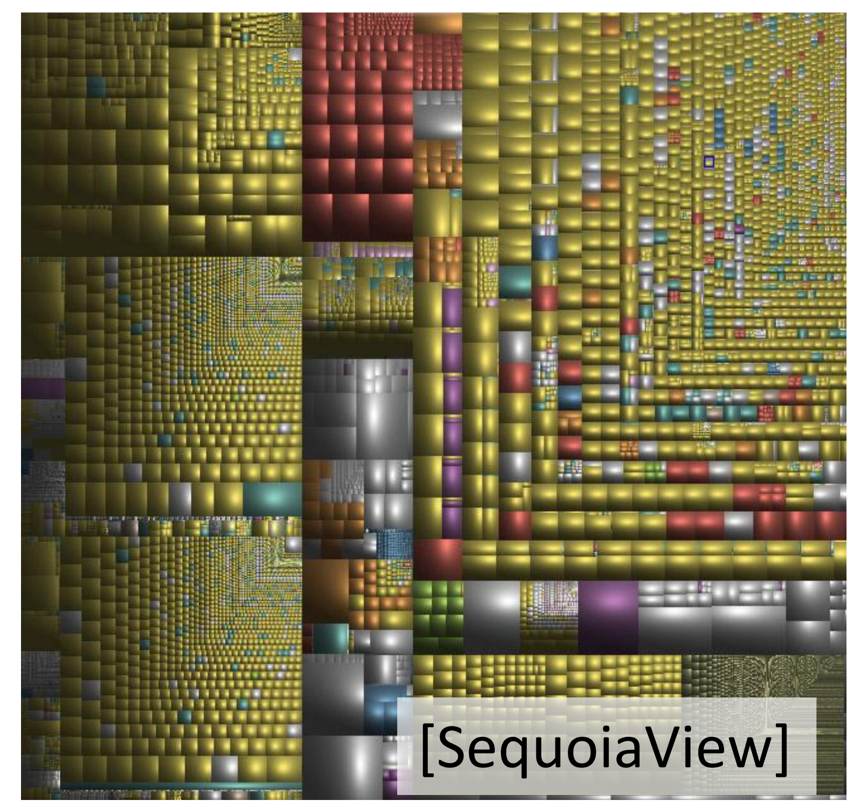
"The purpose of visualization is insight, not pictures"
[Shneiderman '99]



Different application areas


[Burns et al. 07]

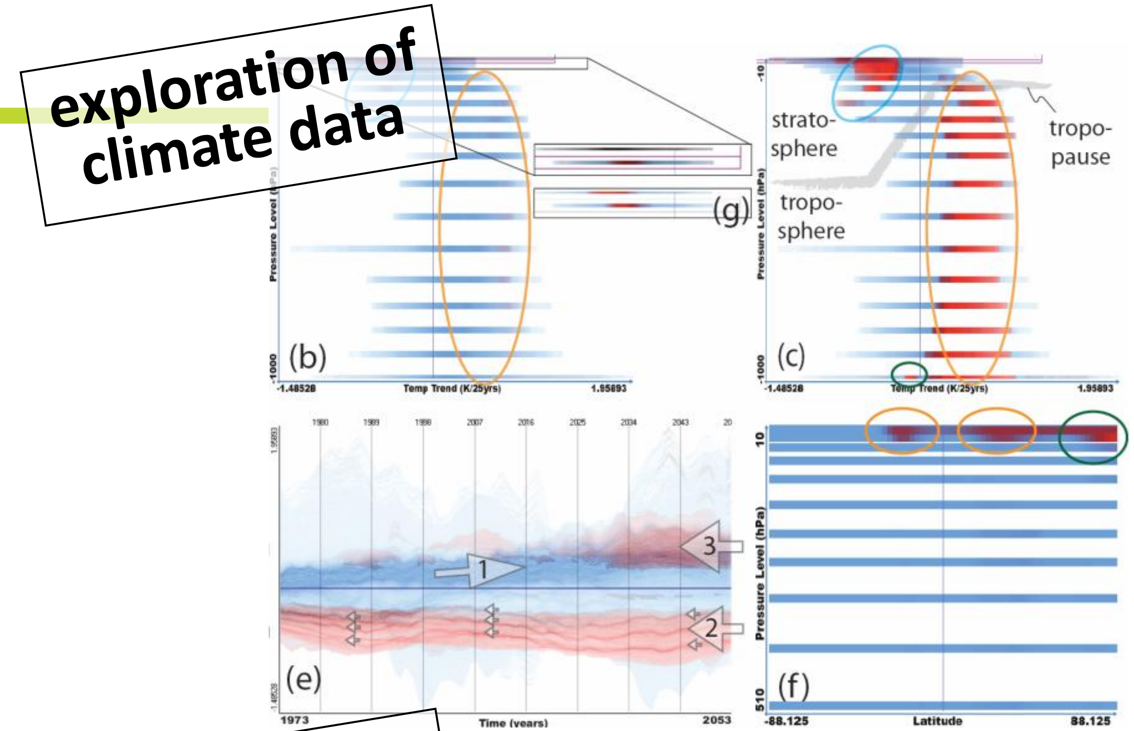

[Laramee et al. 03]

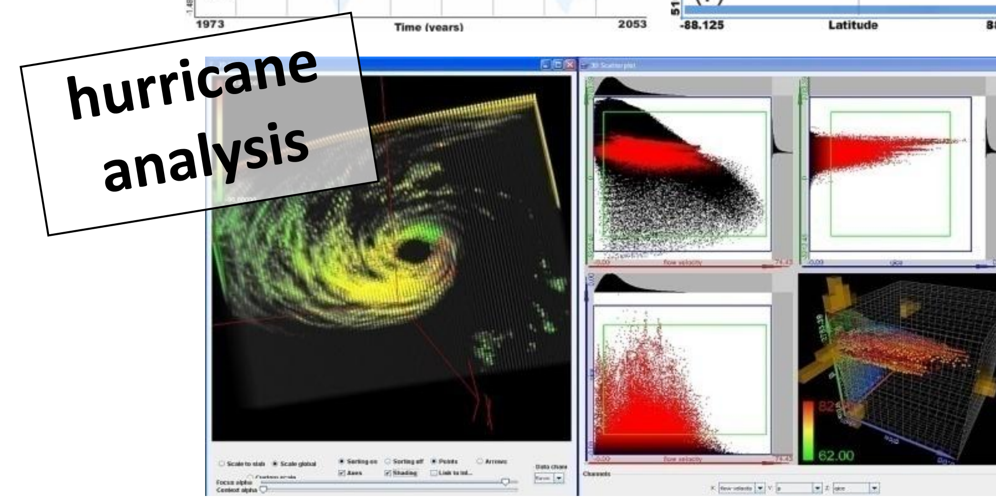

[SequoiaView]

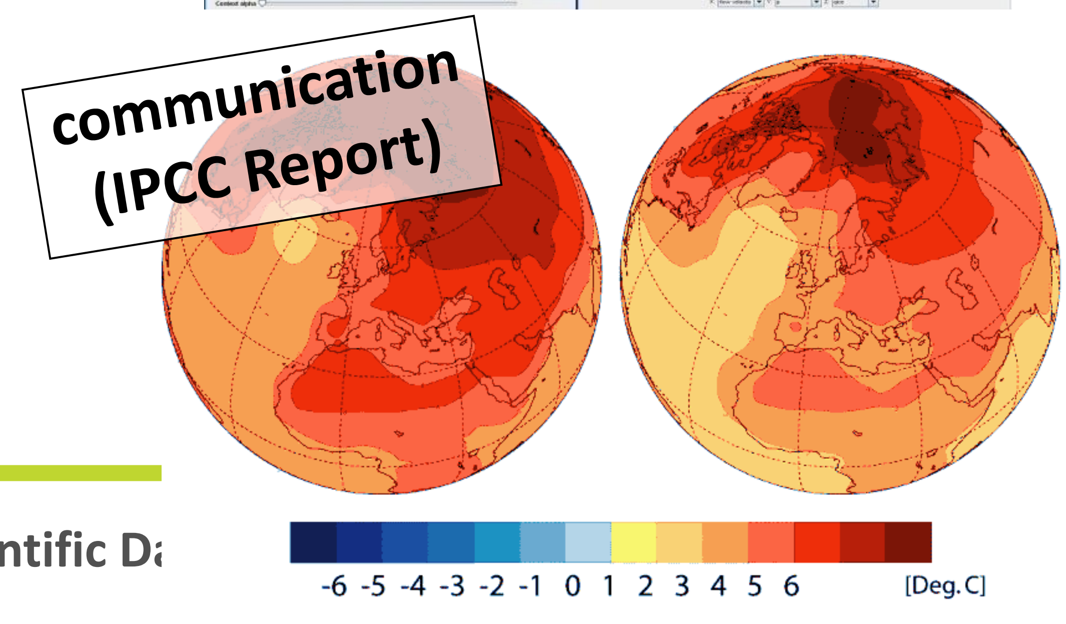
Typical Visualization Tasks

Visualization is good for

- **visual exploration**
  - find unknown/unexpected
  - generate new hypothesis
- **visual analysis** (confirmative vis.)
  - verify or reject hypotheses
  - information drill-down
- **presentation**
  - show/communicate results

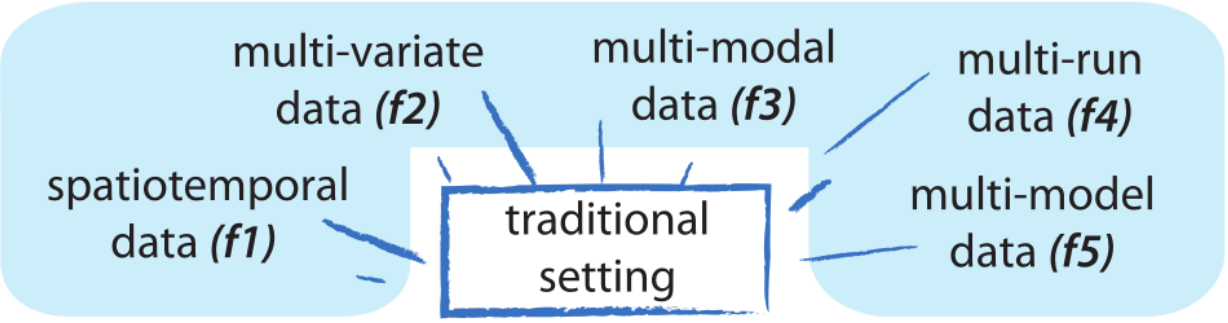


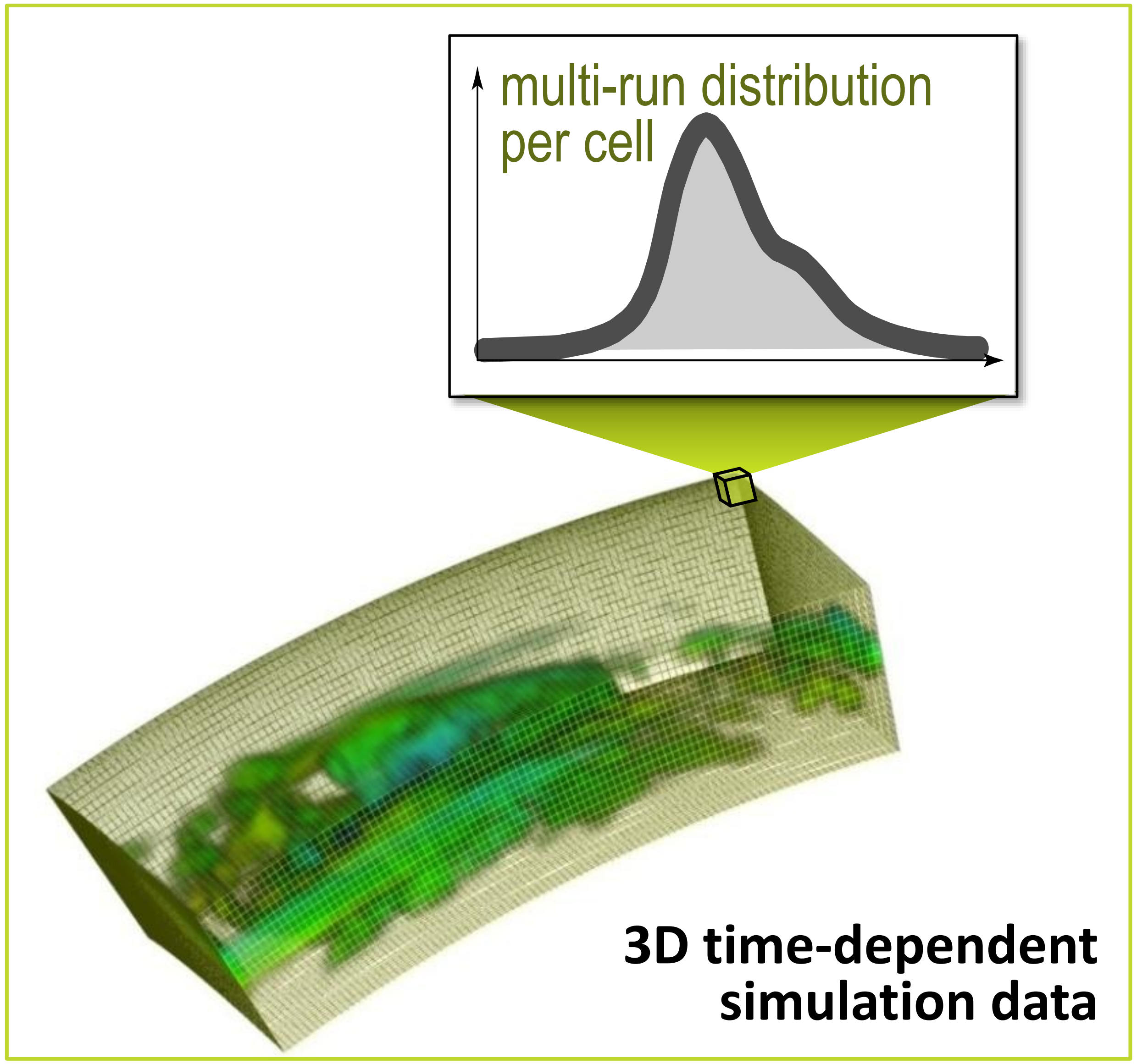




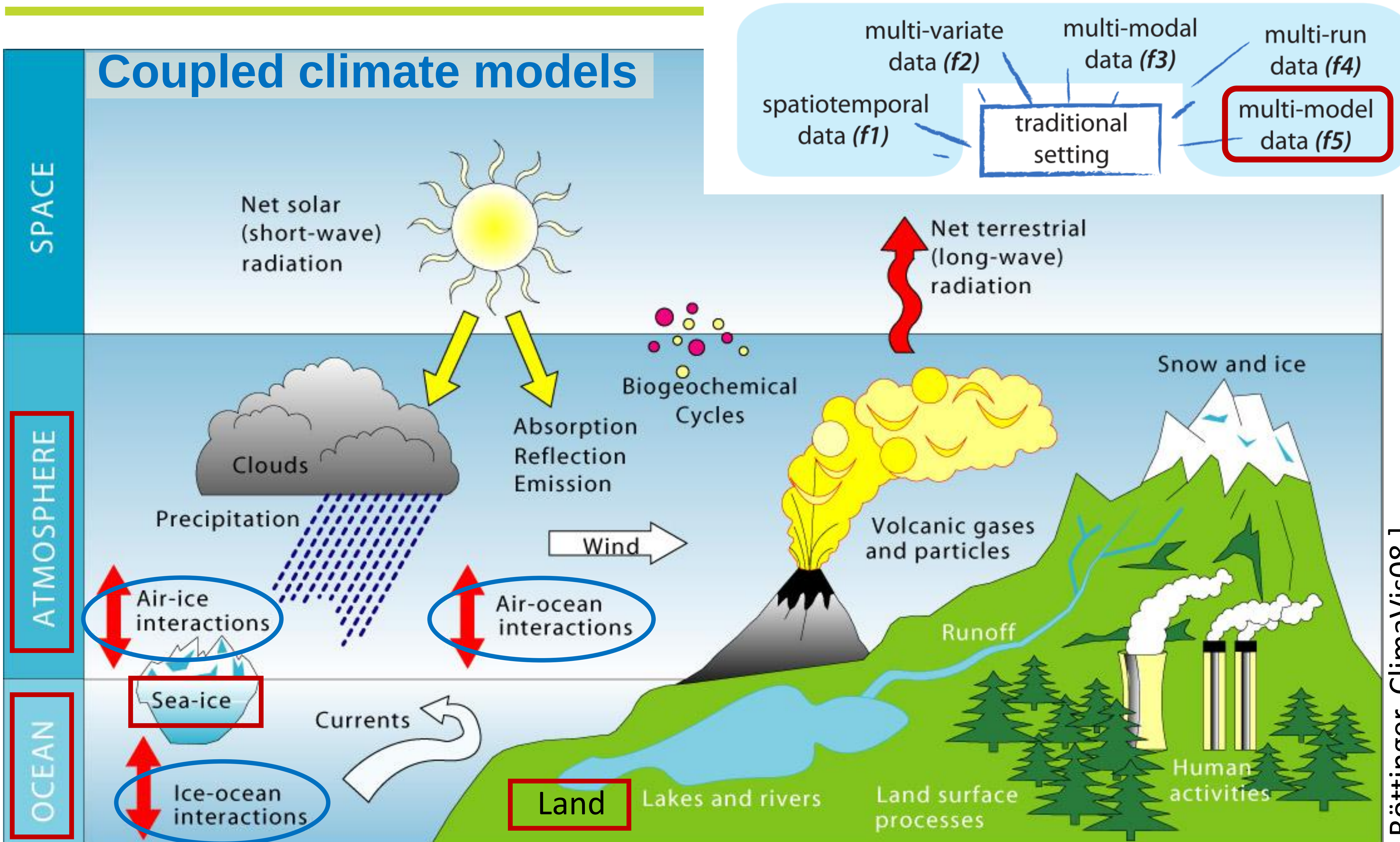
Multi-faceted Scientific Data

- **Spatiotemporal data**
- **Multi-variate/multi-field data** (multiple data attributes, e.g., temperature or pressure)
- **Multi-modal data** (CT, MRI, large-scale measurements, simulations, etc.)
- **Multi-run/ensemble simulations** (repeated with varied parameter settings)
- **Multi-model scenarios** (e.g., coupled climate model)



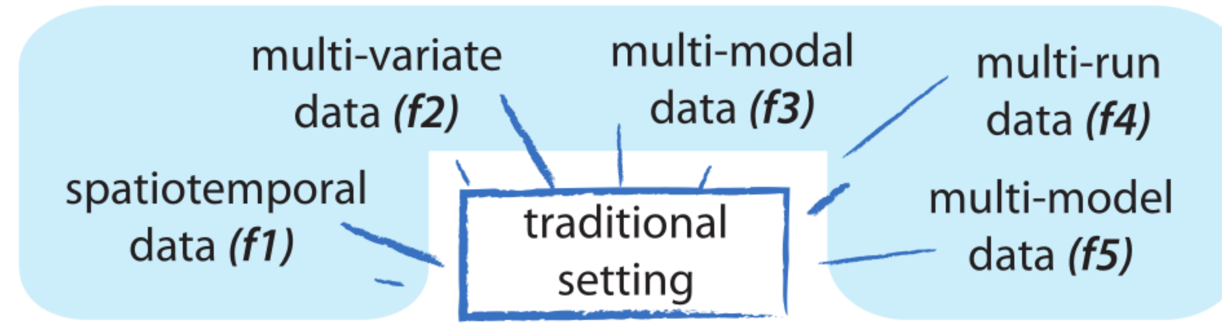


Multi-faceted Scientific Data

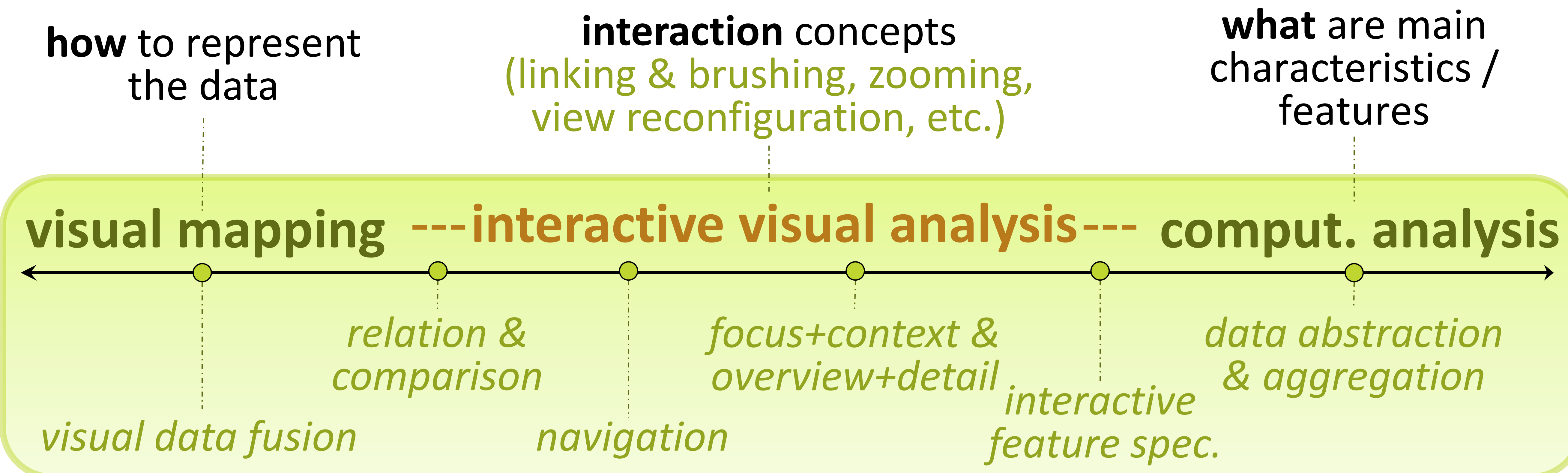


[Böttinger, ClimaVis08]

Categorization



- **Literature review of 200+ papers on scientific data**
- **How are vis., interaction, and comput. analysis combined?**



[compare to Keim et al. 09; Bertine & Lalanne 09]

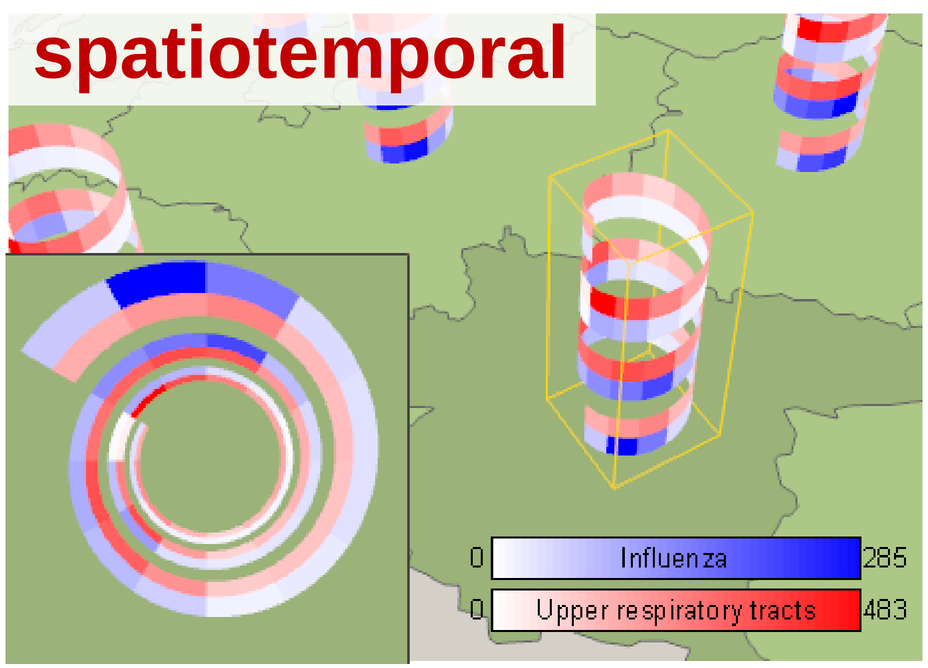
Visual vs. Computational Analysis

- **Interactive Visual Analysis**
  - \+ user-guided analysis possible
  - \+ detect interesting features without looking for them
  - \+ understand results in context
  - \+ uses power of human visual system
  - – human involvement not always possible or desirable (expensive!)
  - – limited dimensionality
  - – often only qualitative results
  - – (still) often unfamiliar

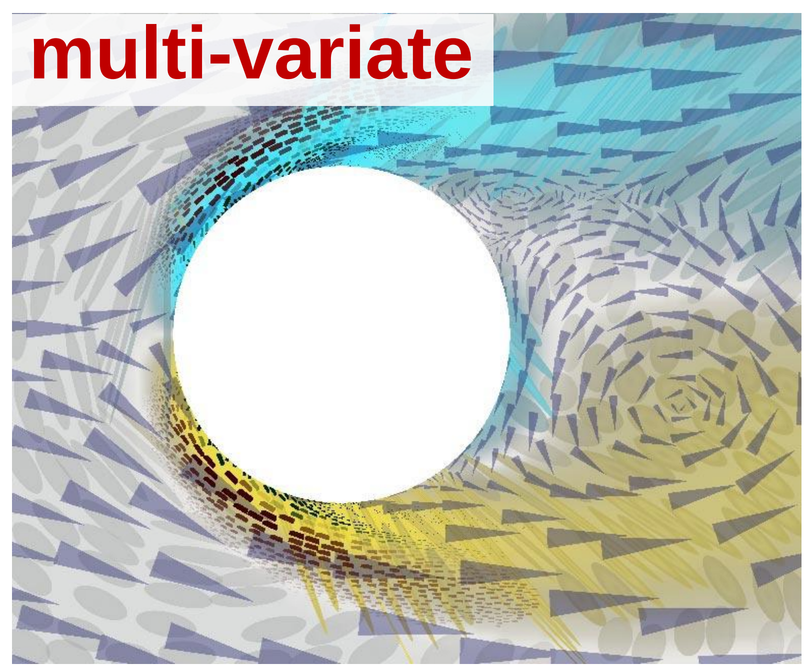
- **Automated Data Analysis**
  - \- needs precise definition of goals
  - \- limited tolerance of data artifacts
  - \- result without explanation
  - \- computationally expensive
  - \+ hardly any interaction required (after setup)
  - \+ scales better w.r.t. many dimensions
  - \+ precise results
  - \+ long history (mostly statistics)

Fusion within a single visualization

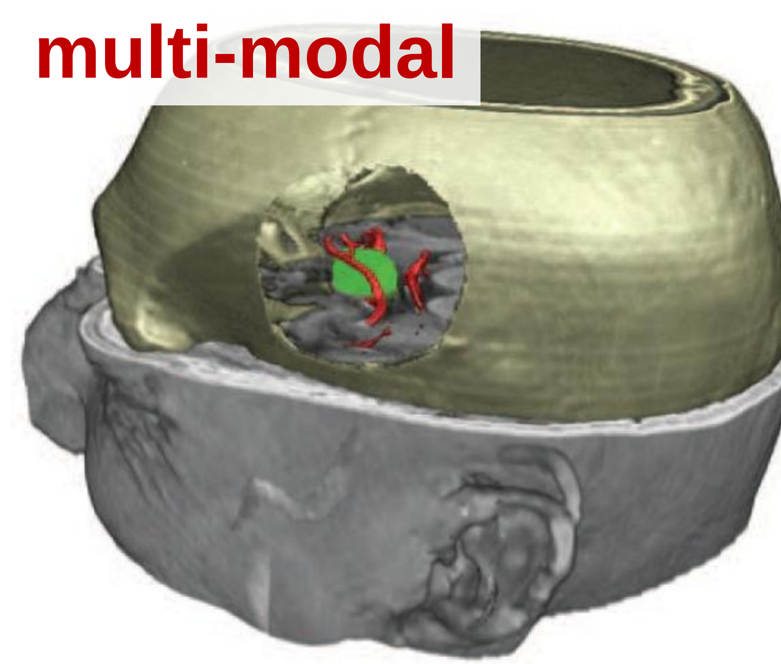
- common frame of reference
- layering techniques (e.g., glyphs, color, transparencey)
- multi-volume rendering (coregistration, segmentation)



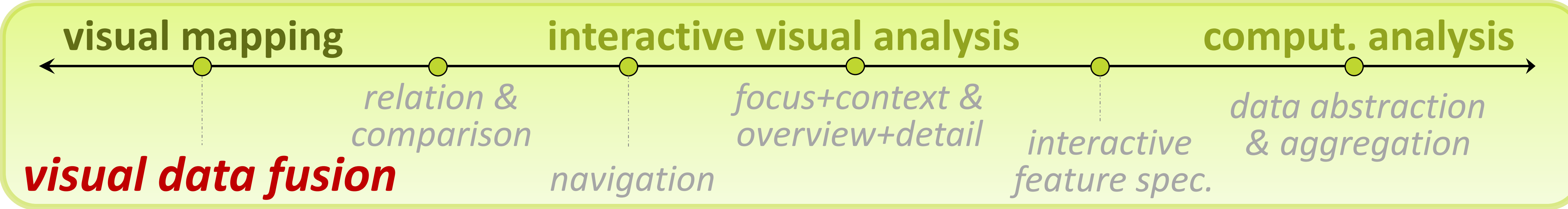
Helix glyphs [Tominski et al. 05]



Layering [Kirby et al. 99]

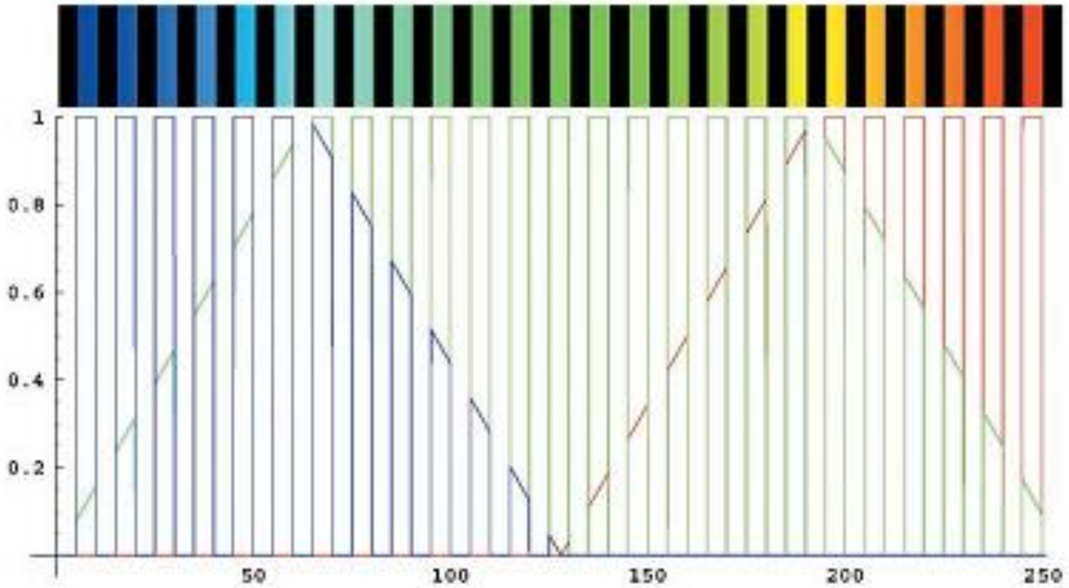


Multi-volume rendering [Beyer et al. 07]

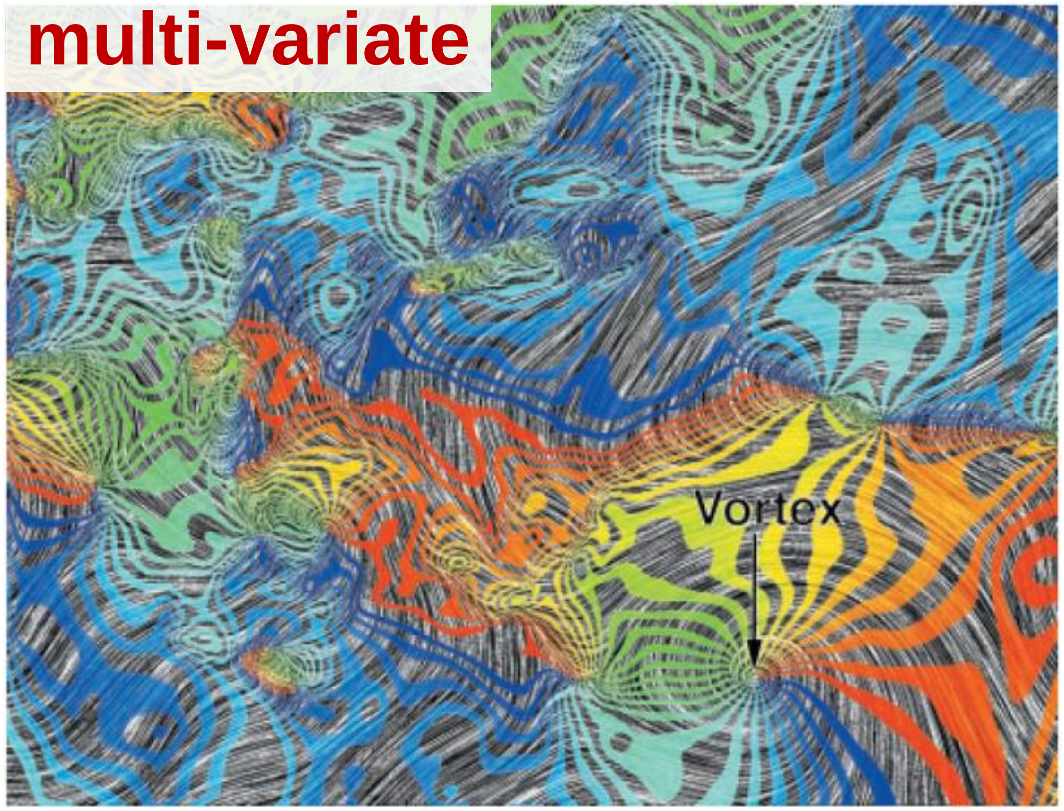


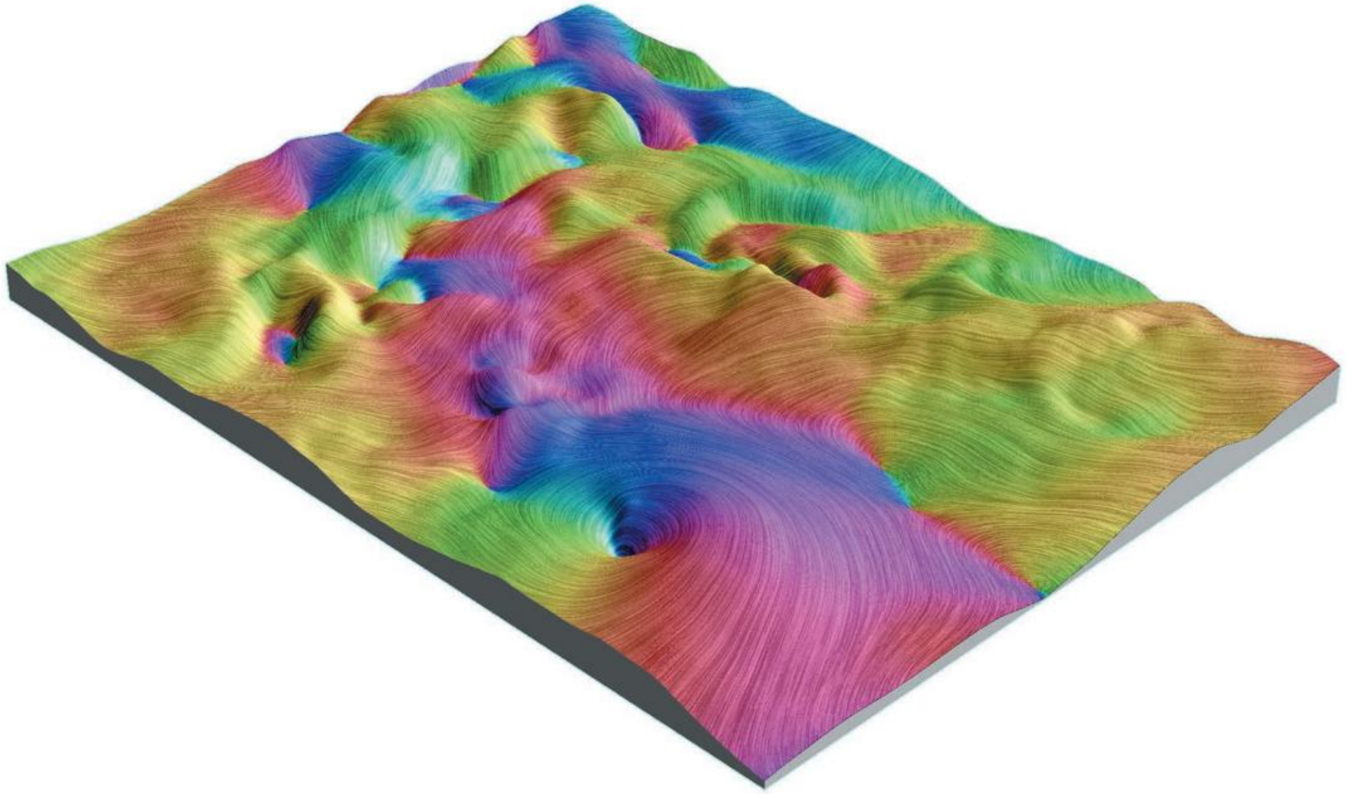
Layering techniques [Wong et al. 02]

- opacity modulation
- filigreed
- colormap enhancement
- 2D heightmap



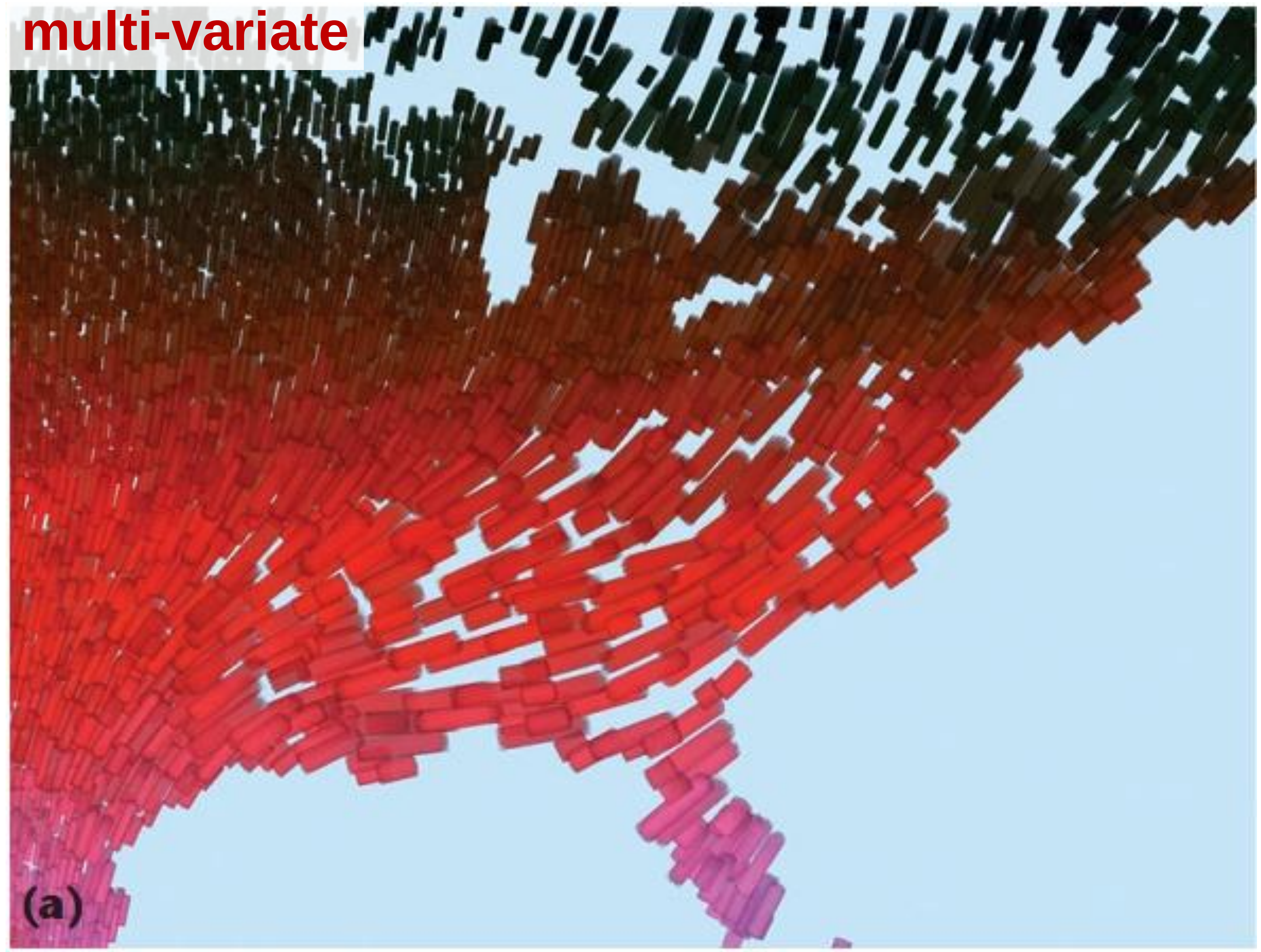
colormap + square wave modulation





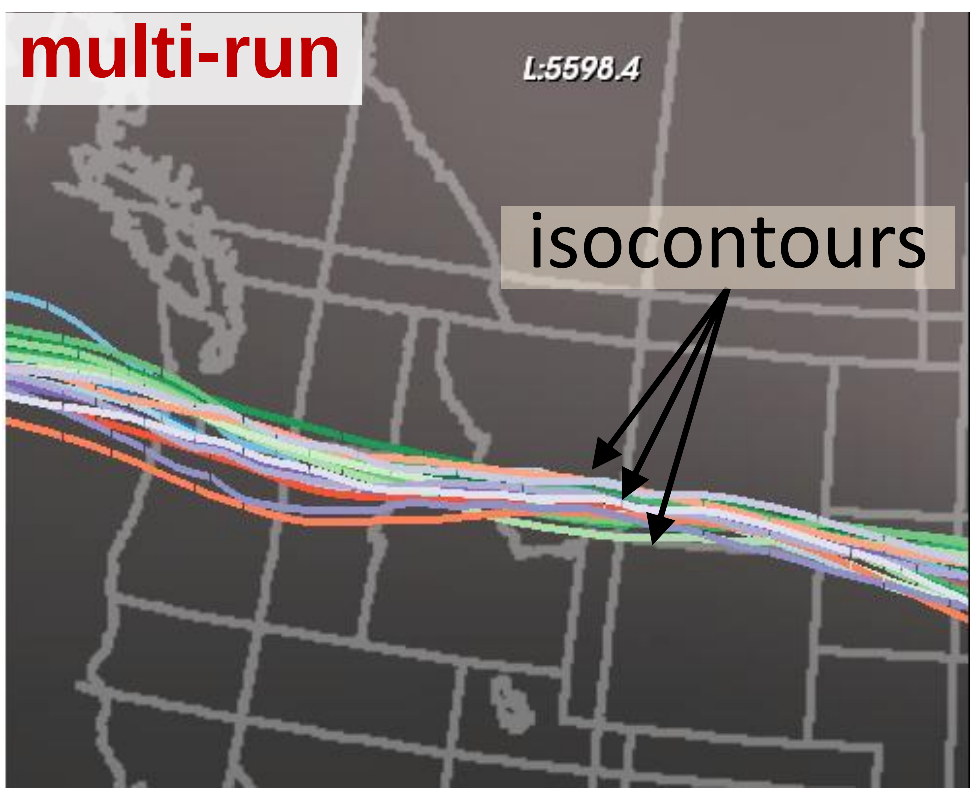
Preattentive Visual Features: Textures and Colors [Healey & Enns 02]

- temperature
  → color
- wind speed
  → coverage
- pressure
  → size
- precipitation
  → orientation

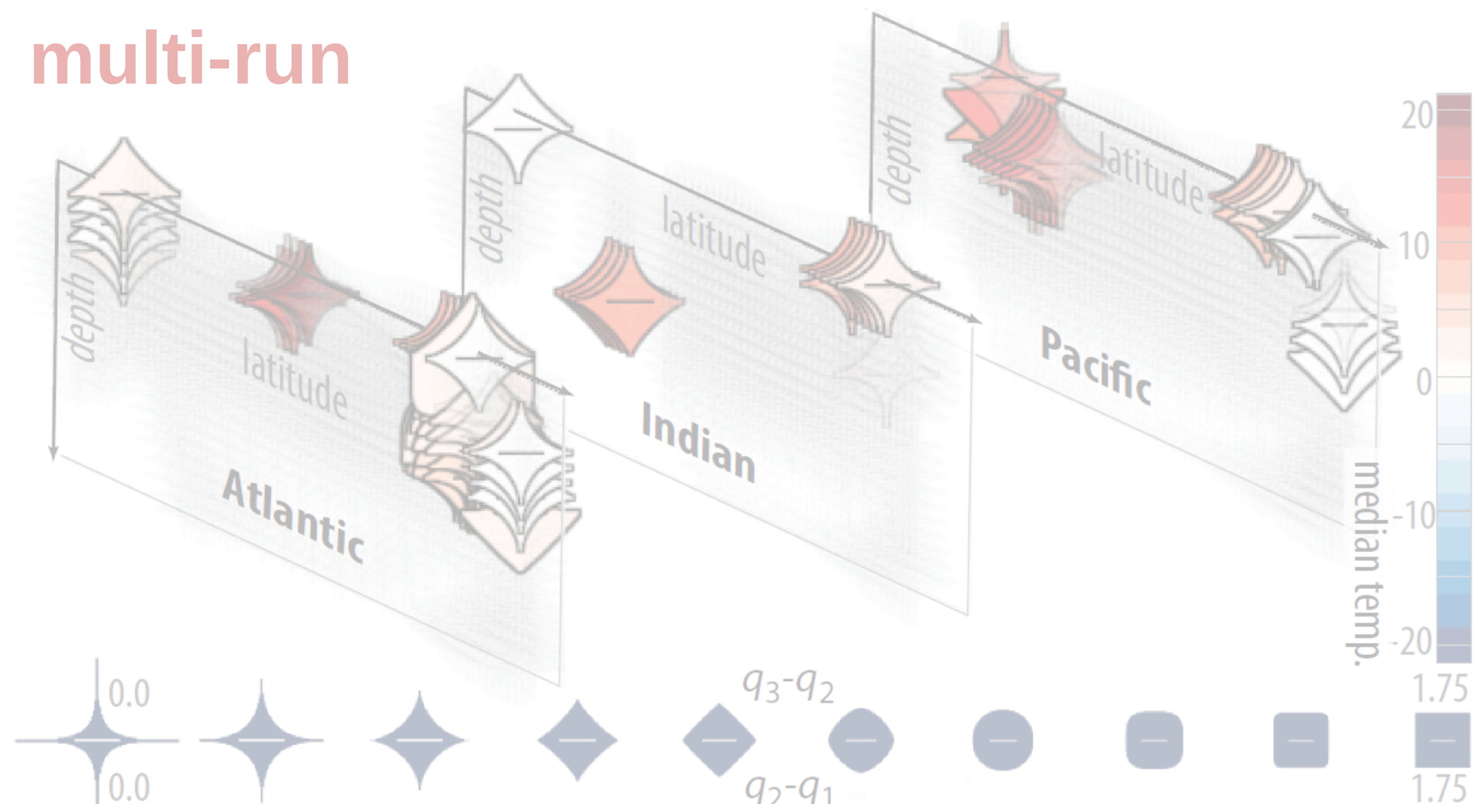


Fusion of multiple simulation runs

- spaghetti plots [Diggle et al. 02]
- summary statistics (box plots and glyphs)



EnsembleVis [Potter et al. 09]

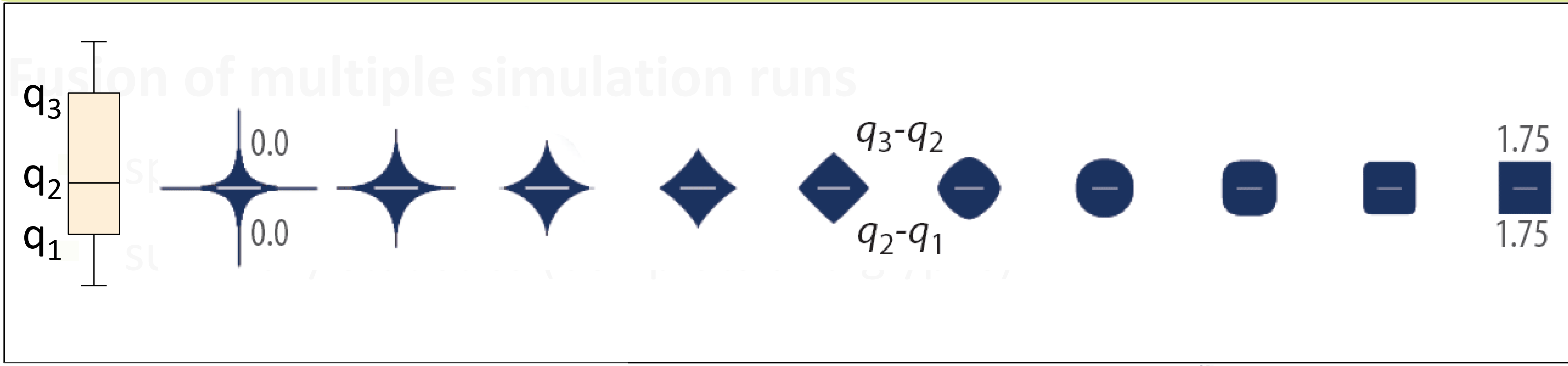


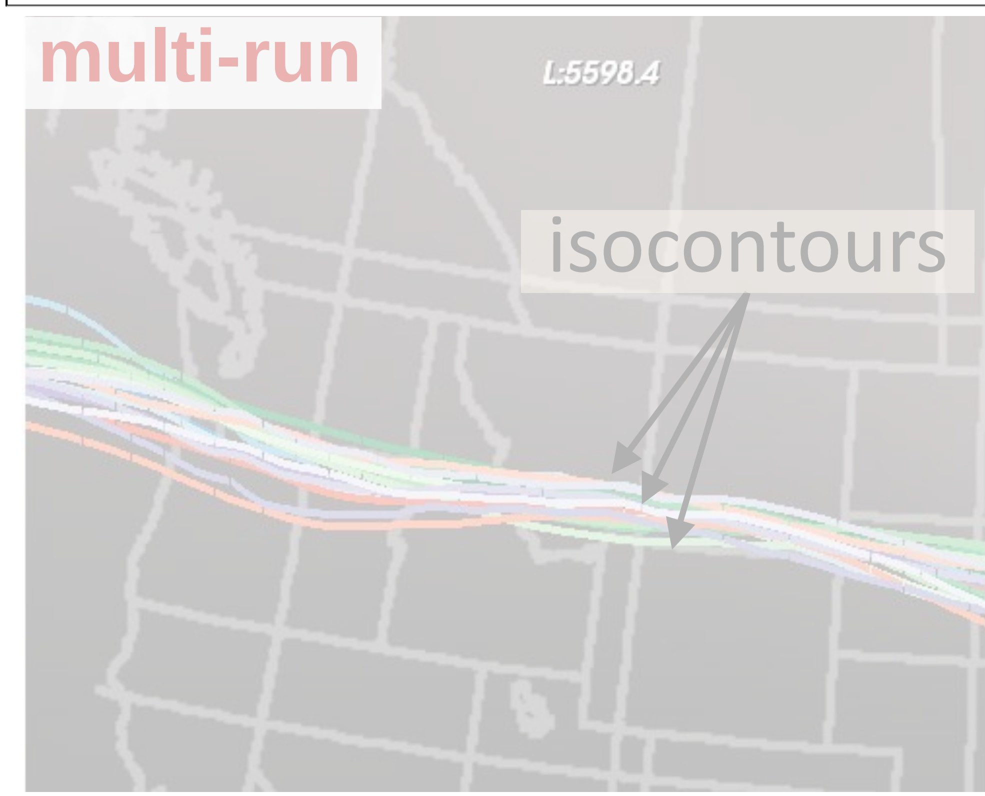
Glyph-based overview [Kehrer et al. 11]

visual mapping — interactive visual analysis — comput. analysis

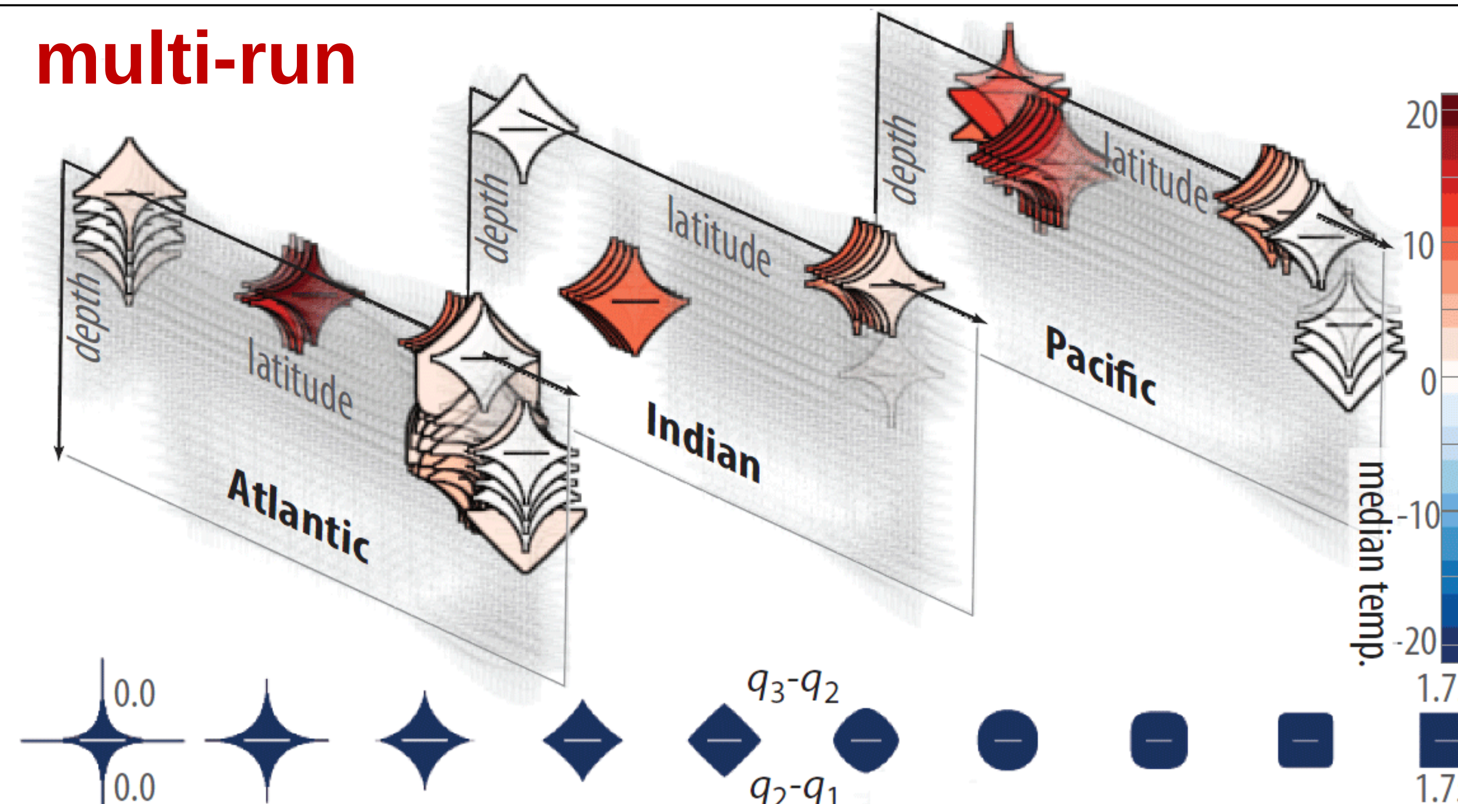
relation & comparison · navigation · focus+context & overview+detail · interactive feature spec. · data abstraction & aggregation

visual data fusion





EnsembleVis [Potter et al. 09]



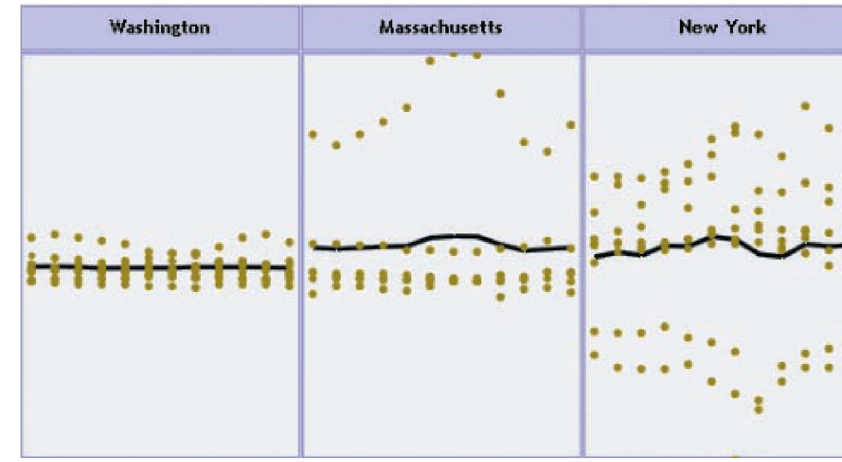
Glyph-based overview [Kehrer et al. 11]

visual mapping — interactive visual analysis — comput. analysis

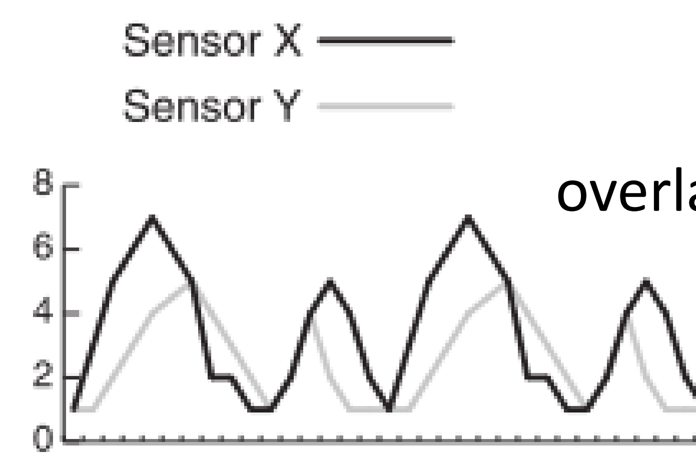
visual data fusion · **relation & comparison** · navigation · focus+context & overview+detail · interactive feature spec. · data abstraction & aggregation

Taxonomy [Gleicher et al. 11]

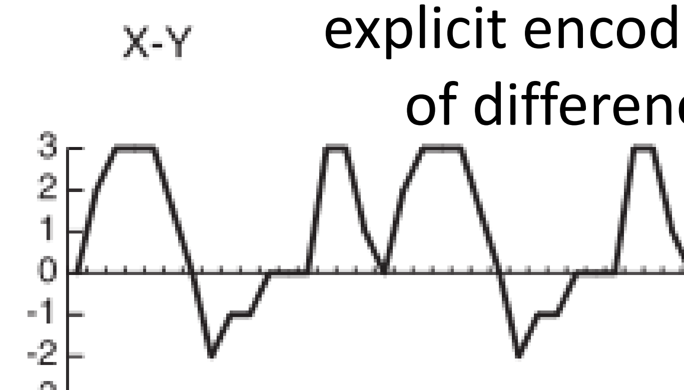
- side-by-side comparison
- overlay in same coordinate system
- explicit encoding of differences / correlations



side-by-side comp.

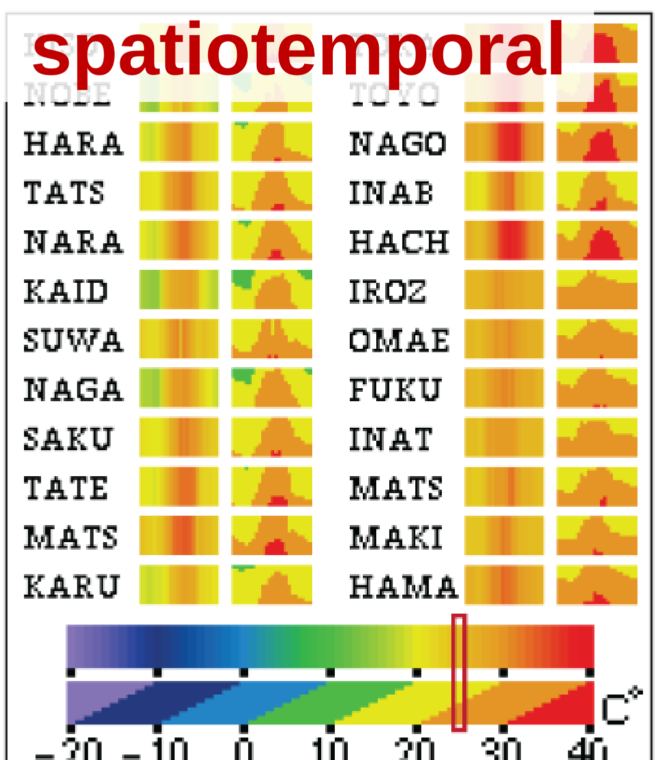


overlay



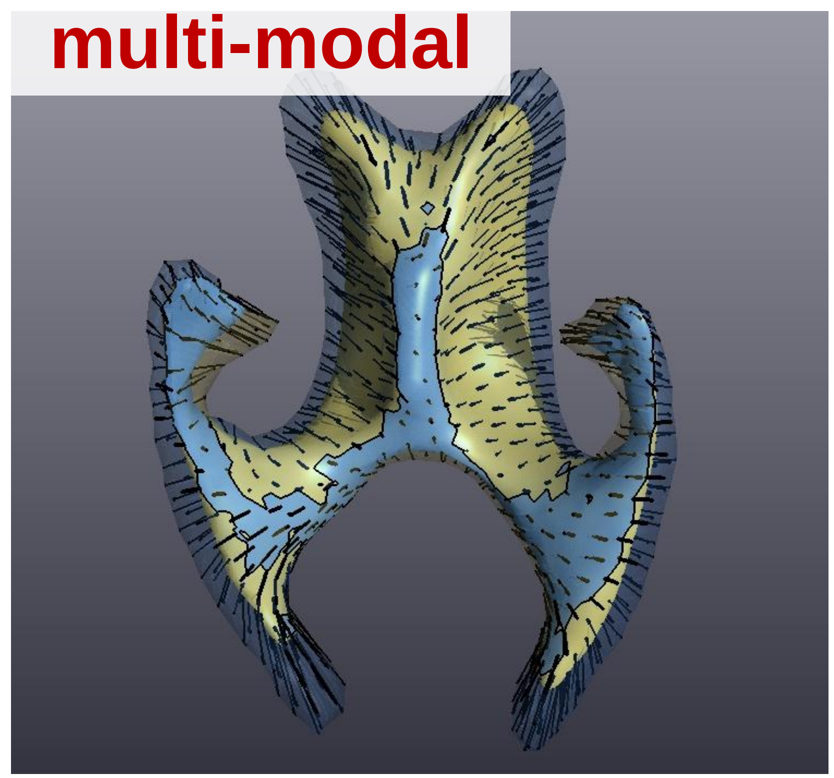
explicit encoding of differences

spatiotemporal



2-tone coloring [Saito et al. 05]

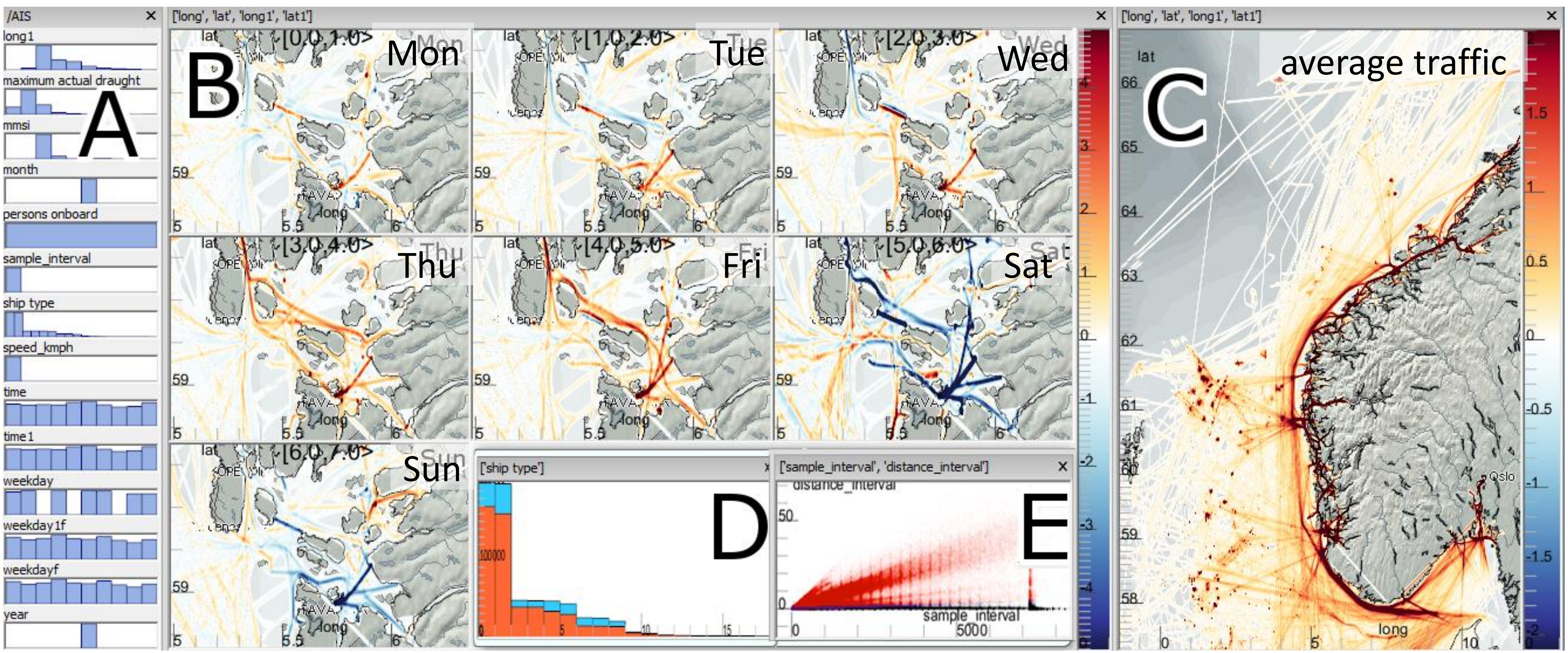
multi-modal



Nested surfaces [Buskin et al. 11]

Difference Views [Daae Lampe et al. 10]

spatiotemporal



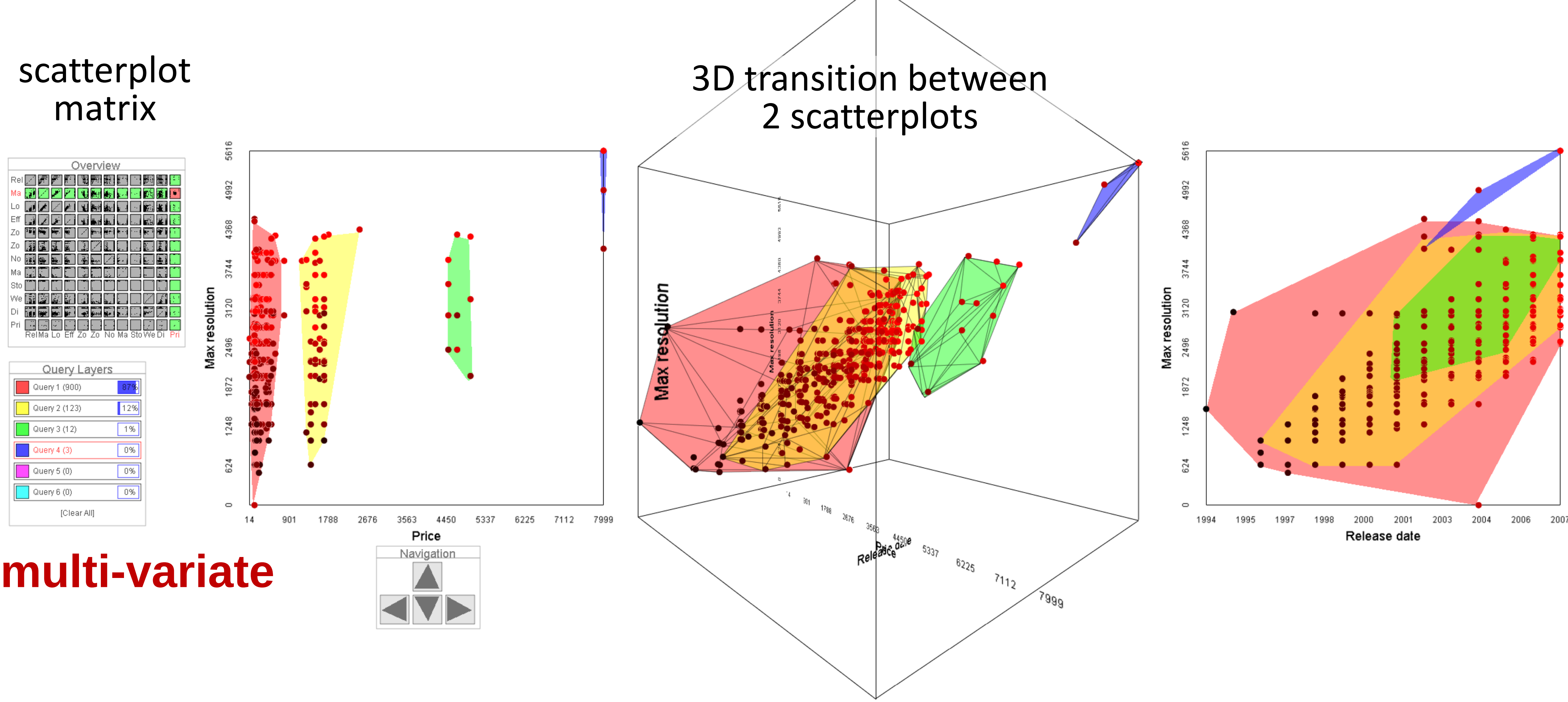
visual mapping — interactive visual analysis — comput. analysis

visual data fusion · *relation & comparison* · ***navigation*** · *focus+context & overview+detail* · *interactive feature spec.* · *data abstraction & aggregation*

- **Interactive search, zooming, and panning**
- **Scatterplot Matrix Navigation** [Elmqvist et al. 08]

scatterplot matrix

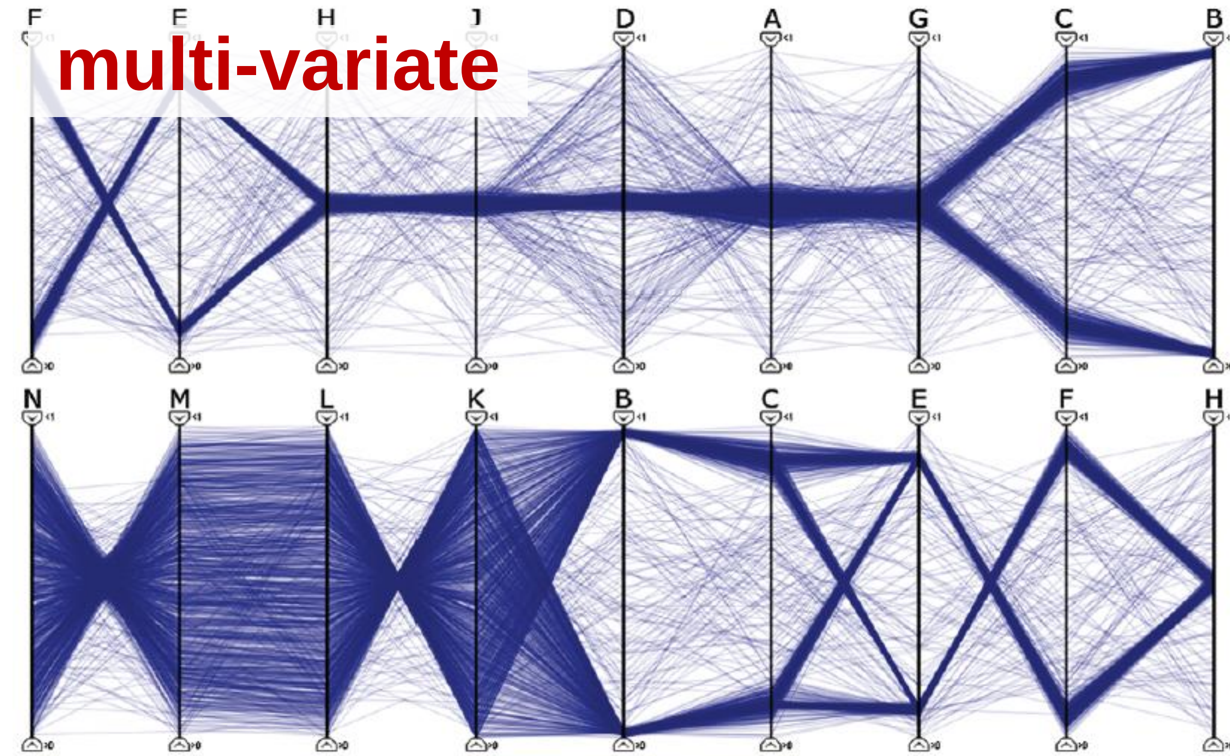
3D transition between 2 scatterplots



multi-variate

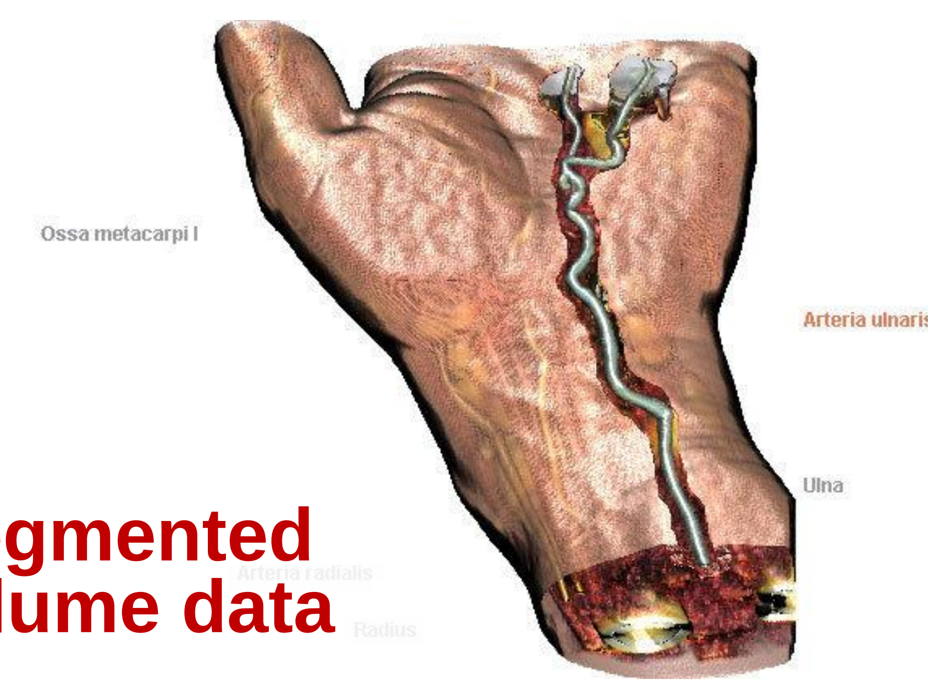
v r vis

- **Ranking/quality metrics**
  [Bertini et al. 2011]
  - clustering, correlations, outliers, image quality, etc.



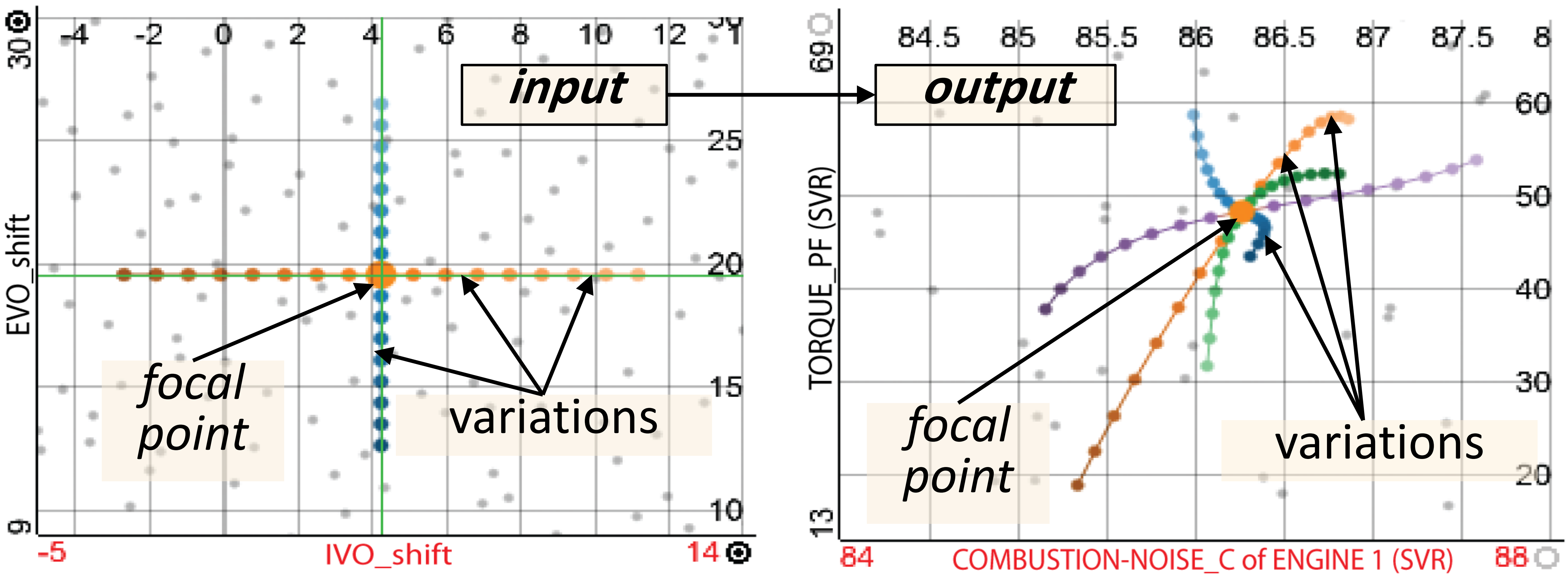
[Johansson & Johansson 09]

- **Automated viewpoint selection**
  - information-theoretic measures



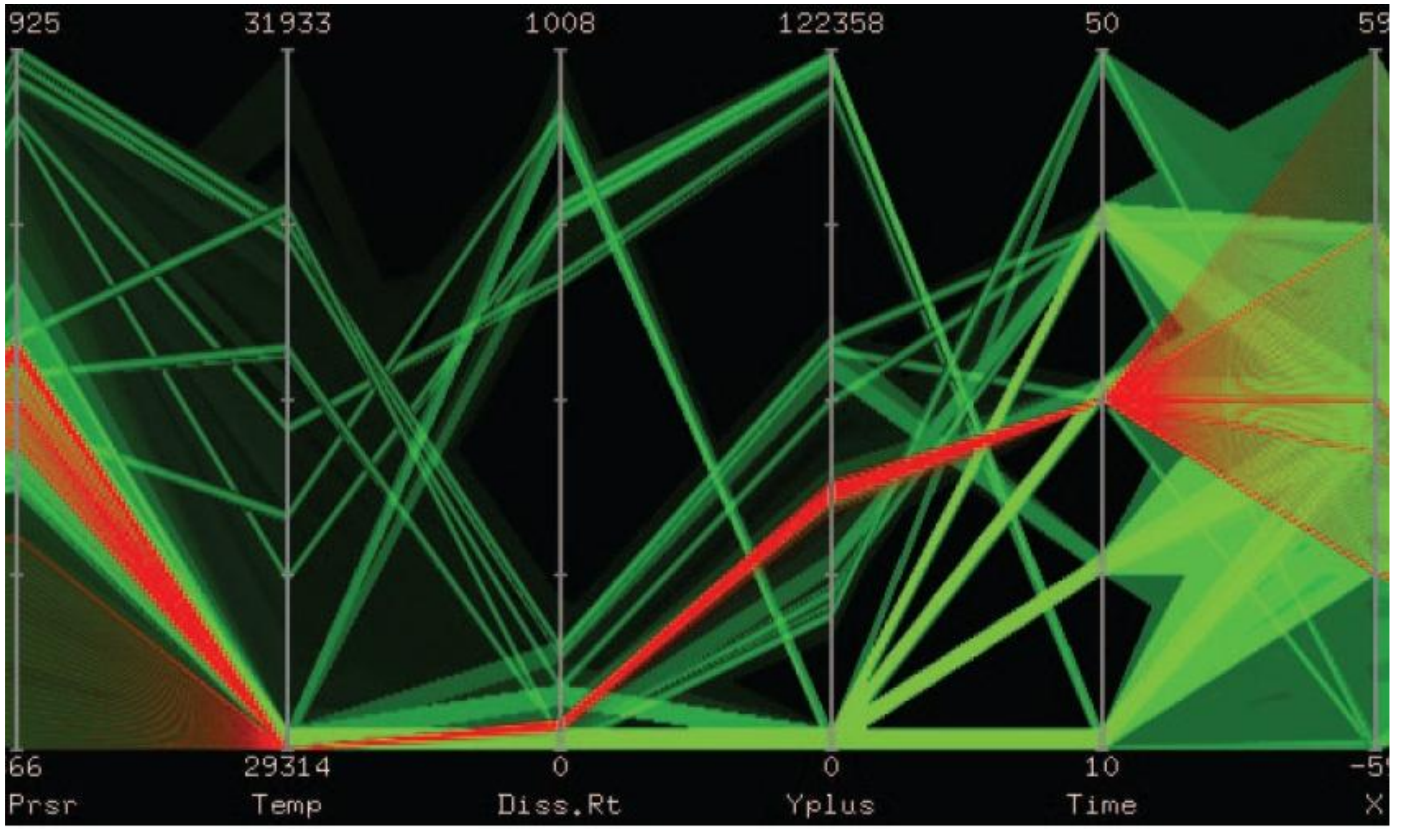
[Viola et al. 06]

Parameter space navigation (multi-run data)



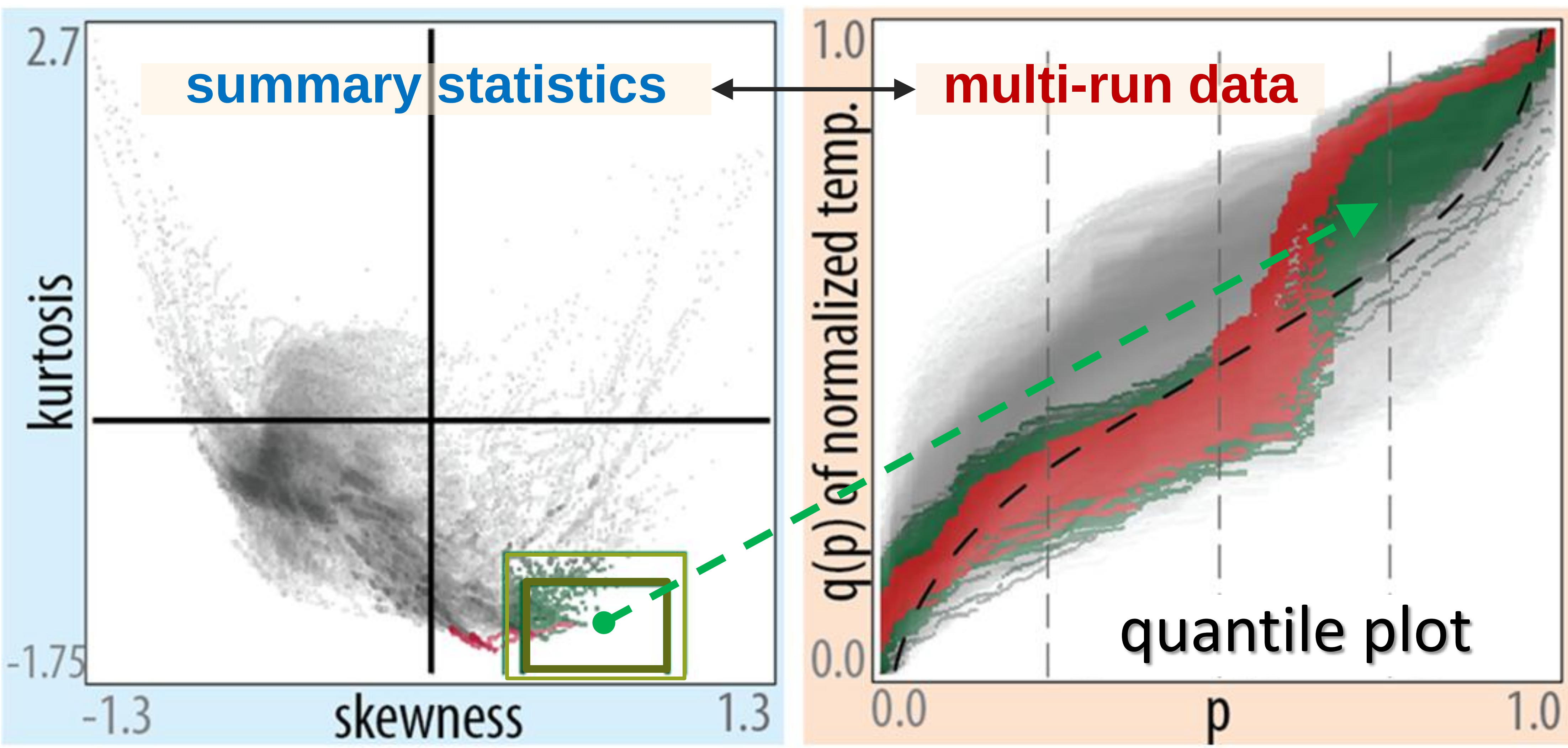
[Berger et al. 11]

- **Focus+context visualization**
  - different graphical resources (space, opacity, color, etc.)
  - focus specification (e.g., by pointing, brushing or querying)
- **Clustering & outlier preservation**



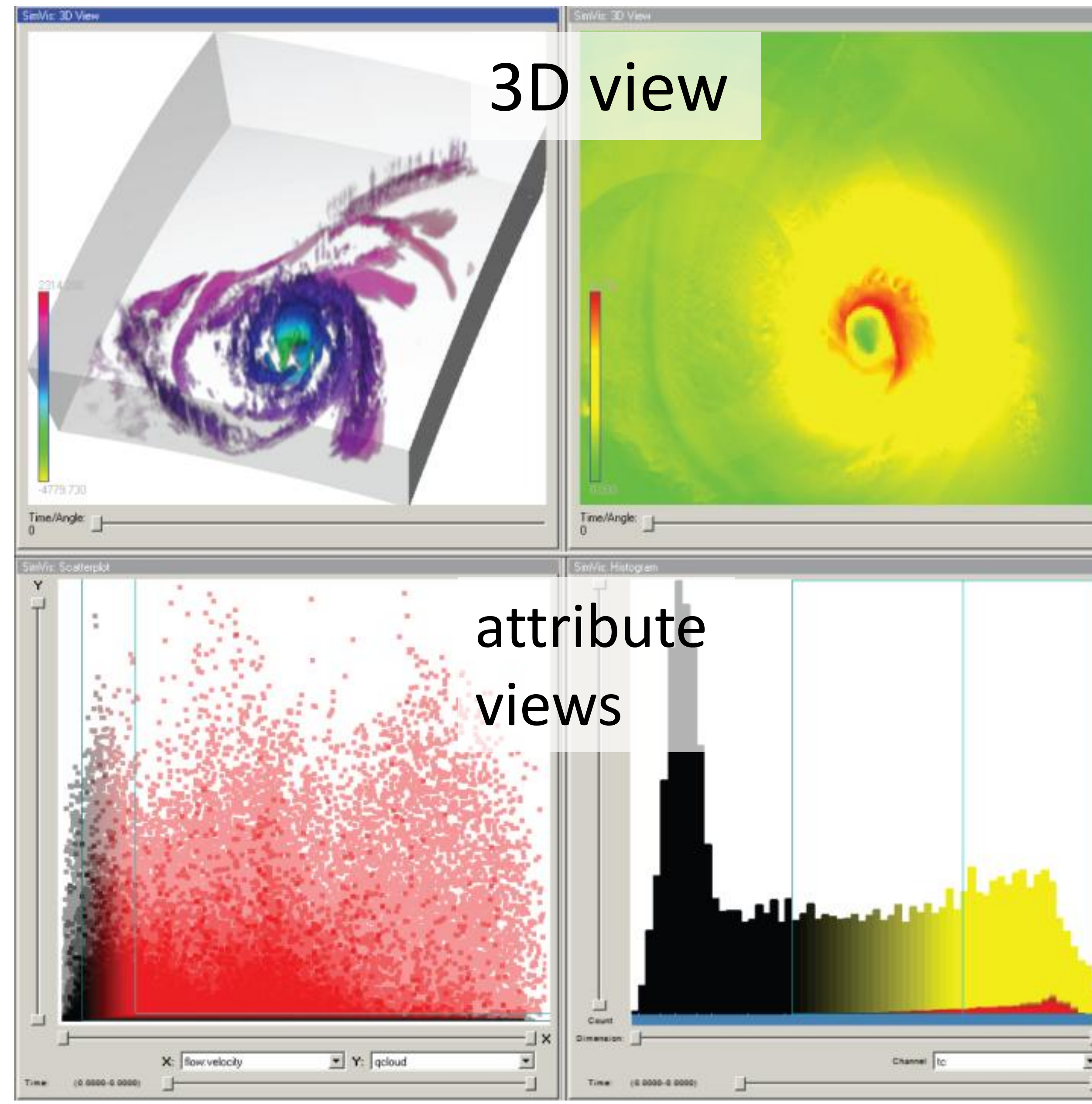
Outlier-preserving focus+context [Novontný & Hauser 06]

- **Overview+detail representation of multi-run data**



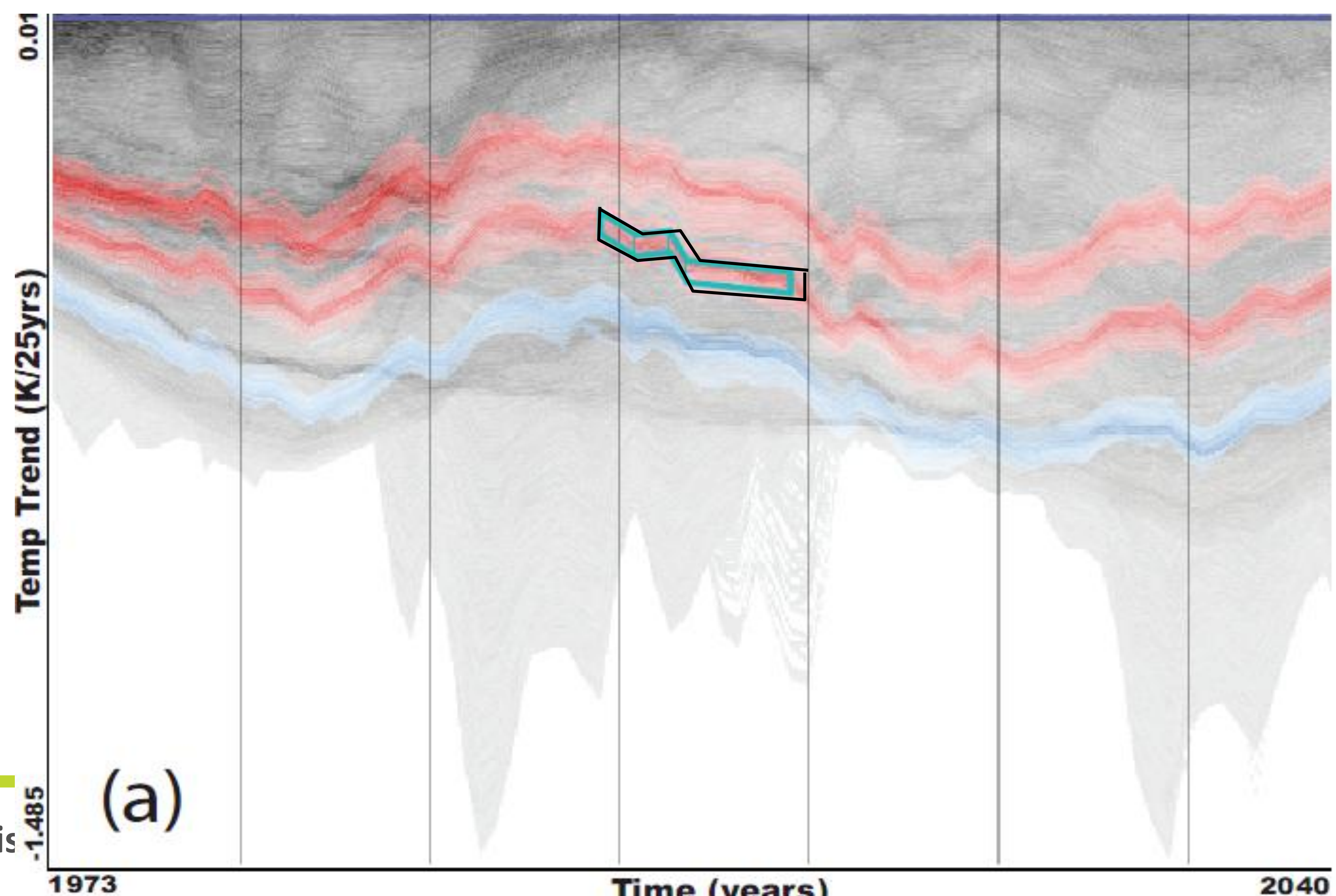
Brushing statistical moments [Kehrer et al. 10]

- **Brushing in multiple linked views**
- **SimVis [Doleisch et al. 03, 04]**



Select function graphs based on similarity [Muigg et al. 08]

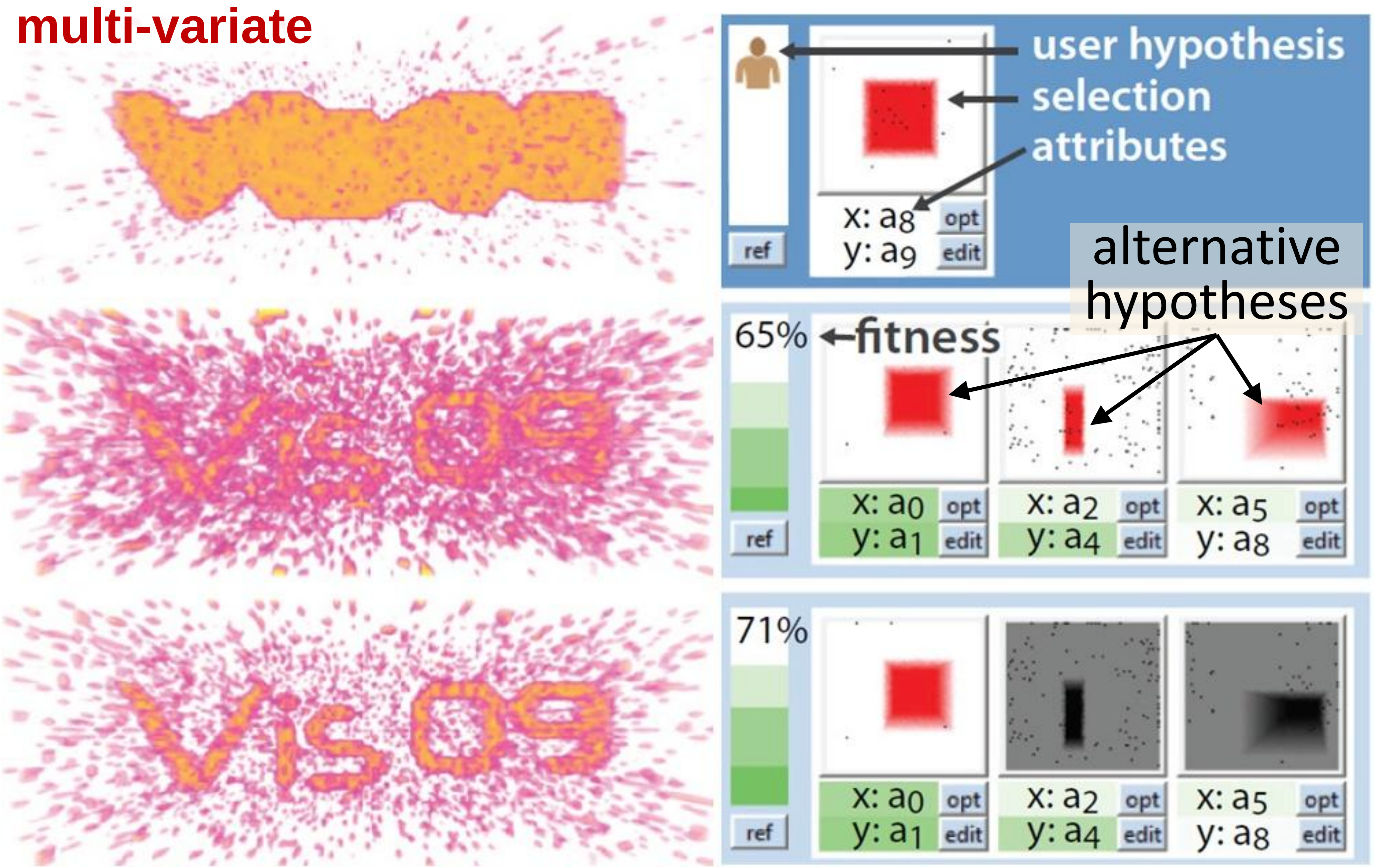
- pattern sketched by user
- similarity evaluated on gradients (1st derivative)



visual mapping — interactive visual analysis — comput. analysis

visual data fusion · relation & comparison · navigation · focus+context & overview+detail · **interactive feature spec.** · data abstraction & aggregation

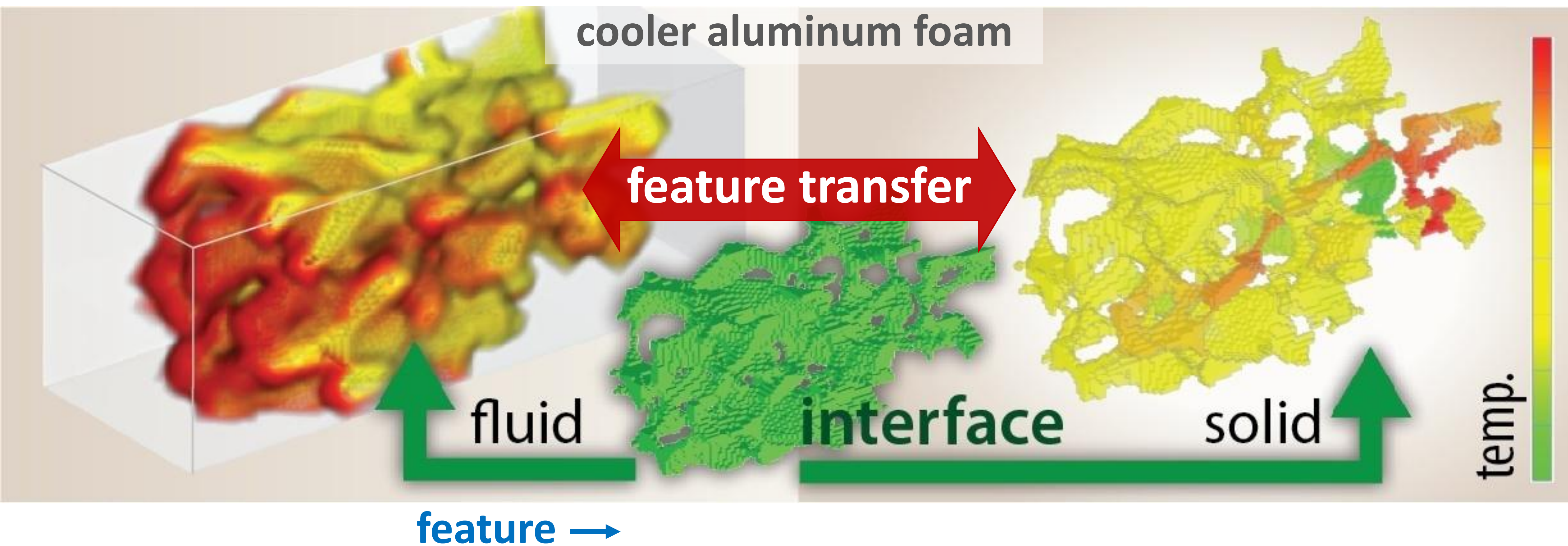
- **Tight integration with supervised machine learning**



Visual human+machine learning [Fuchs et al. 09]

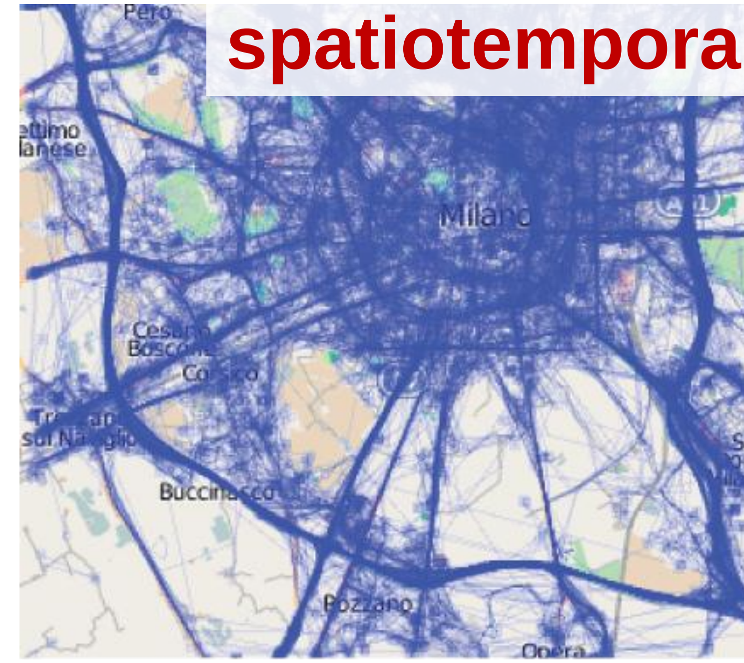
Fluid-structure interactions (multi-model data)

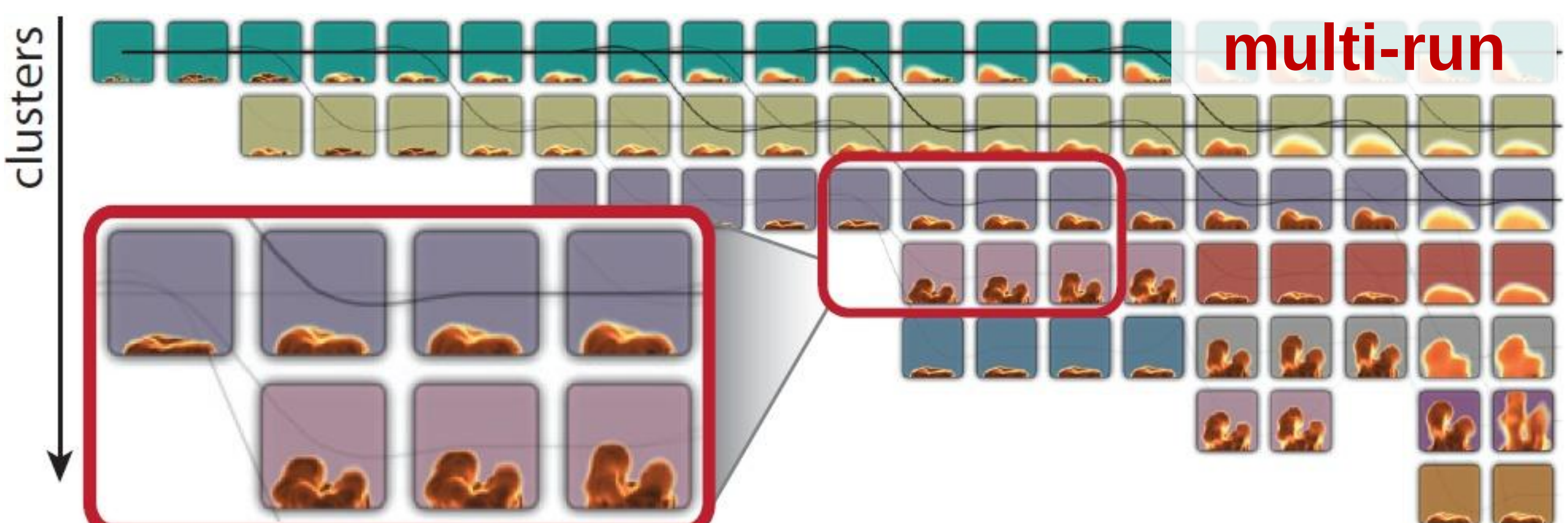
- heat exchange between fluid ⇔ structure
- feature specification/transfer across data parts [Kehrer et al. 11]



Algorithmically extract values & patterns

- dimensionality reduction (PCA, SOM, MDS)
- aggregation, summary statistics
- clustering, outliers, etc.





clustering of multi-run simulations [Bruckner & Möller 10]

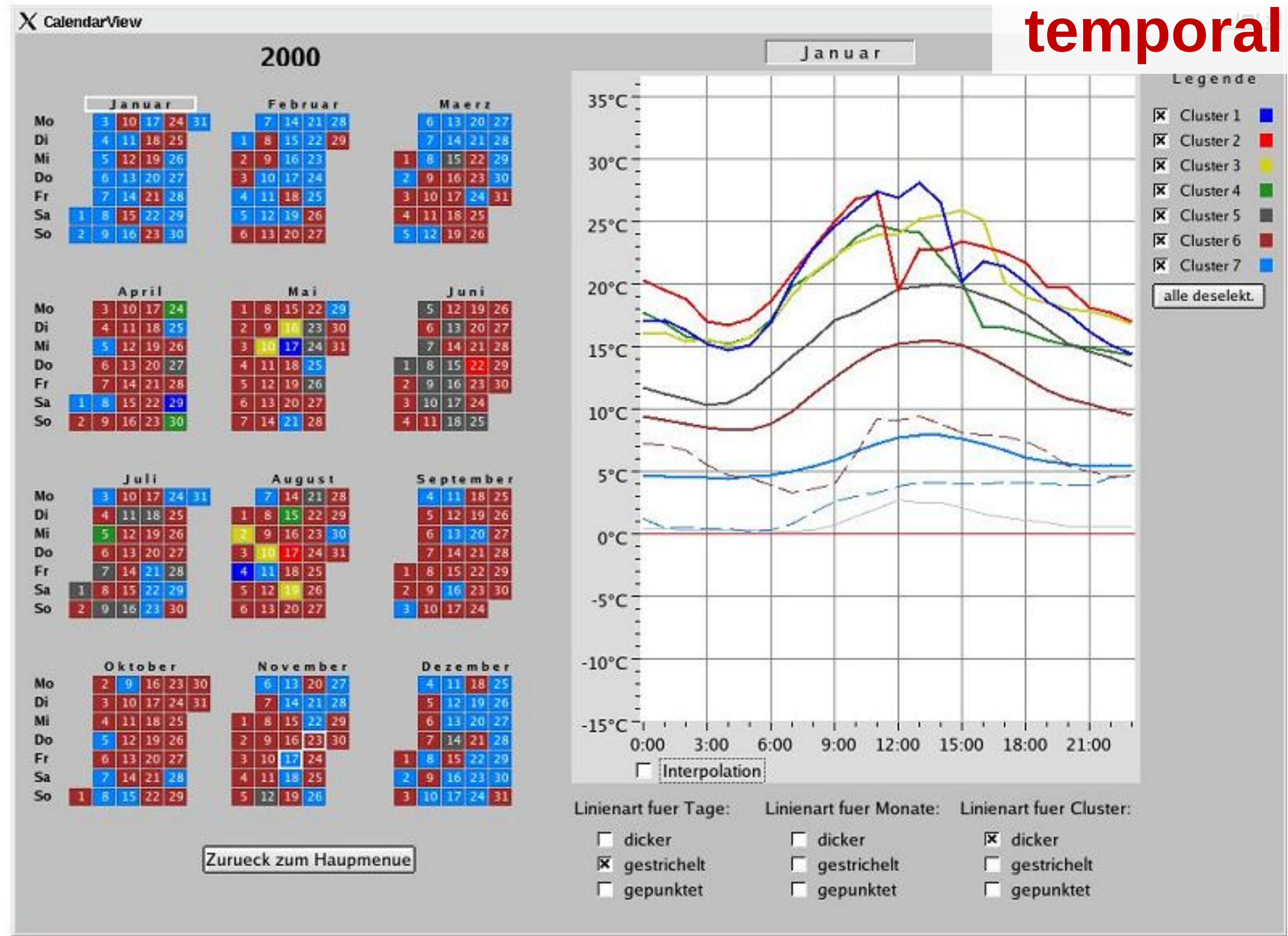
[Andrienko & Andrienko 11]

Cluster Calendar View

[vanWijk & van Selow '99]

- Time series clustered by similarity (K-means)

temporal

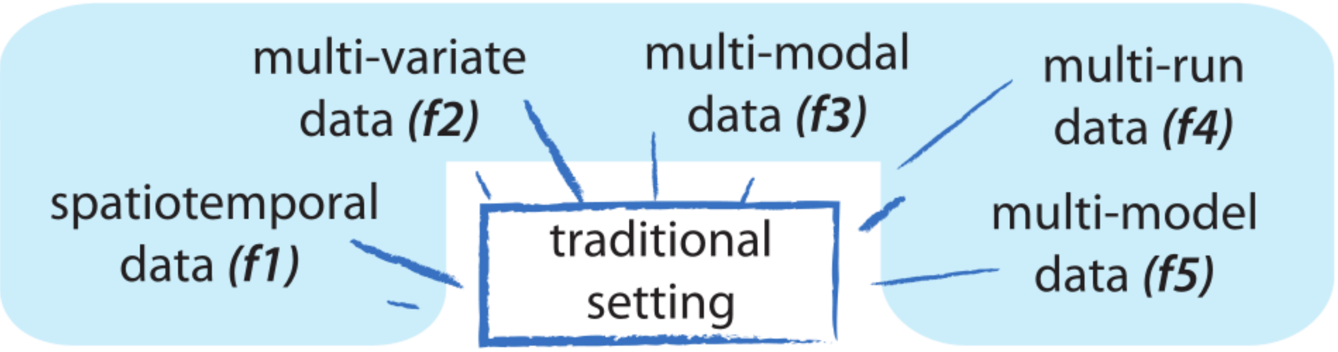


Categorization of approaches

	visual mapping: *visual data fusion*	interactive visual analysis: *relation & comparison*	interactive visual analysis: *navigation*	interactive visual analysis: *focus+context & overview+detail*	interactive visual analysis: *interactive feature specification*	computational analysis: *data abstraction & aggregation*
multi-dimensional	maps [13], [14], [92]; Helix glyphs [93]; flow maps [105]; function graphs [70], [71], [72]; Time Histograms [94], [110], [111]; chrono volumes [98]; illustrative techniques [99]; texture-based flow vis. [100]	2-tone coloring [20]; Helix glyphs [93]; juxtaposed views [19], [110]; difference views [107]	search, zooming and panning [40], [54]	2-tone coloring [20]; multi-level focus+con-text [71]; pixel-based multi-resolution techn. [104]	brushing [21], [70], [71], [95], [113]; transfer functions [110], [111]	aggregation [15], [103], [105]; trends [21]; flow features [82]; clustering [83], [84], [110]; PCA [17], [78], [85]; SOM [89], [90]; KDE [106], [107]; information theory [108]; wavelet analysis [109], [110]
multi-variate	attribute views [22], [50], [67]; color & texture [119]; layering [115], [124], [126]; 2-level volume rendering [127], [128]; glyphs [120], [121], [122], [123], [124], [125]	correlation fields [133]; operators [134]; multiple linked views [9], [26], [29], [73], [74], [76]	grand tour [47]; ScatterDice [46]; ranking & quality metrics [48], [130], [131], [132]	illustrative vis. [115], [116]; oulier-preserving methods [69]; smooth brushing [80]	brushing [9], [50], [74], [75], [112]; multi-dim. transfer func. [114], [115]; machine learning [91], [135], [136]	clustering [68], [130]; data binning [69]; PCA [78]; MDS [86], [87]; SOM [88], [89]; projections [47], [48], [130], [132]; point clouds [129]
multi-modal	resampling [138]; data model [142]; illumination model [143]; multi-volume rendering [128], [139], [143], [144], [145], [146]	difference views [107]; multi-image view [153]; nested surfaces [31], [154], [156]; features [44], [155]	viewpoint selection [49]	cutaway views [147], [139], [49]	transfer functions [143], [144]	registration [27]; mutual information [28]; comparison metrics [148], [151], [152], [133]
multi-run	glyphs & box plots [37], [43], [162], [163], [164]; shape descriptors [164]; families of surfaces [41]; spaghetti plots [35], [42], [165]	aggregated & multi-run data [36], [37], [41], [174]; HyperMoVal [51], [52]	aggregated & multi-run data [36], [37], [41]; parameter space nav. [51], [52]	aggregated & multi-run data [36], [37], [41]; simulation process vis. [173], [174]	trends & outliers [36], [37], [41]; visual steering [172]	overview statistics [31], [35], [36]; projections [41], [51], [170], [171]; operators [33]; PCA [169]; clustering [167], [168], [169]
multi-model	feature fusion across multiple data parts [37]	feature relation across data parts [37]	x	x	feature spec. across data parts [37]	x

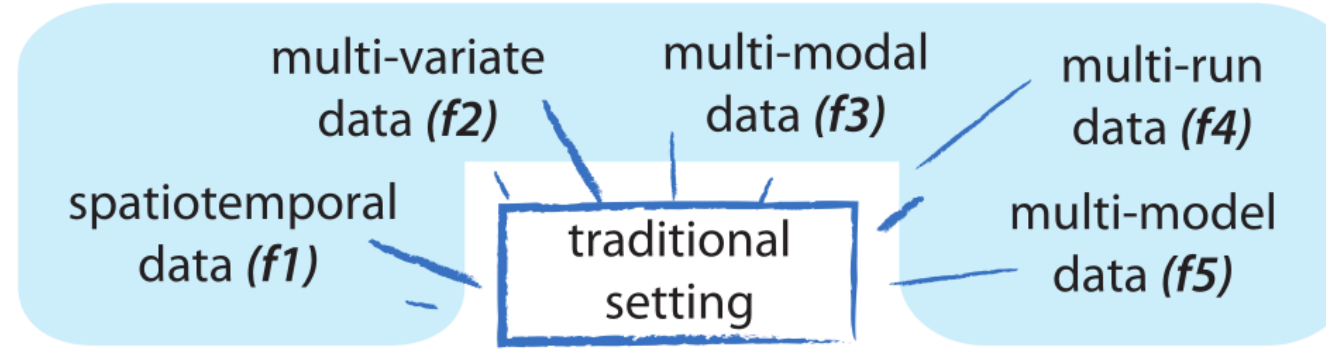
vrvis

Open Issues

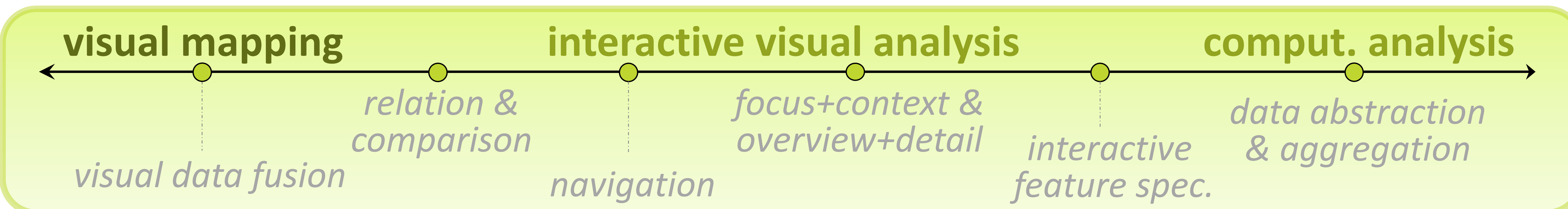


- **How to deal with data heterogeneity?**
  - most approaches only address one or two data facet
  - coordinated multiple views with linking & brushing
  - investigation of features across views, data facets, levels of abstraction, and data sets
  - fusion of heterogeneous data at feature/semantic level
- **Combination of vis., interaction, and comput. analysis**
  - analytical methods can controll steps in visualization pipeline (e.g., visualization mapping or quality metrics)
  - interactive feature specification + machine learning

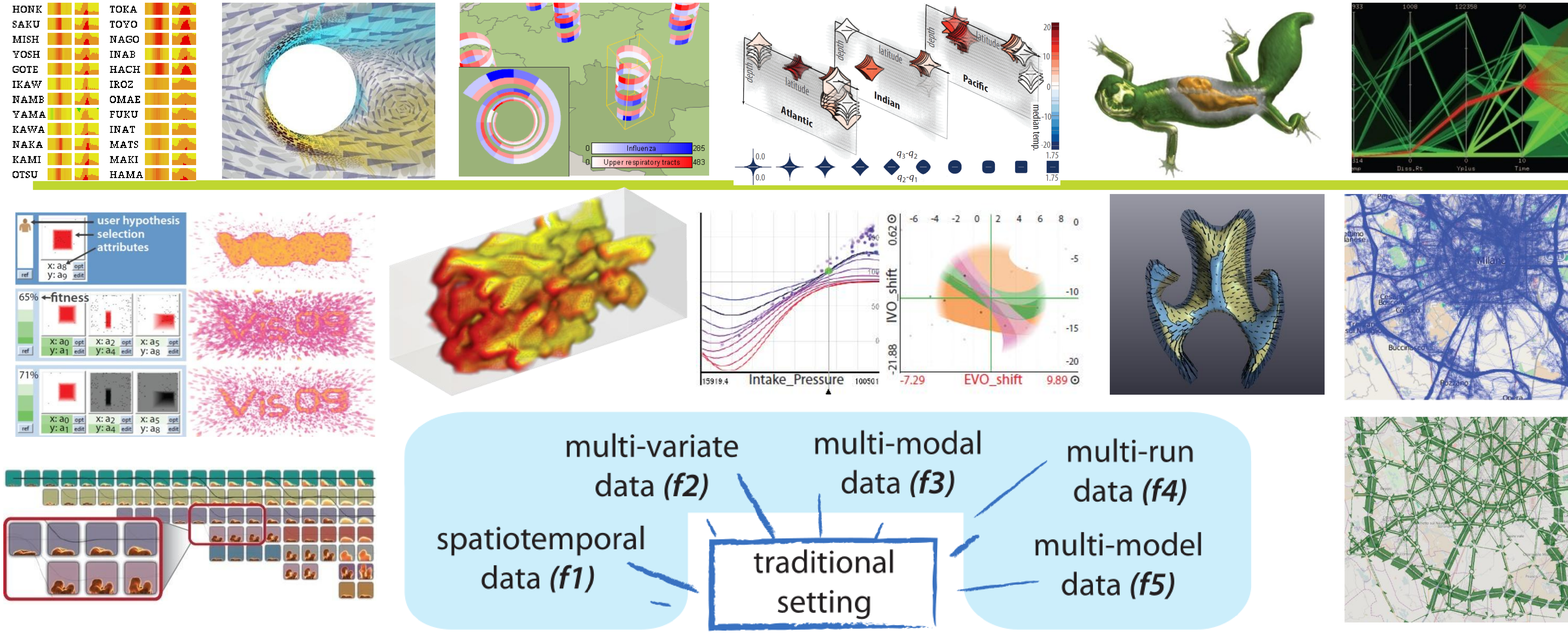
Conclusions



- **Scientific data are becomming multi-faceted**
- **Categorization based on common visualization, interaction, and comput. analysis methods**



- **Promising data facets, e.g., multi-run & multi-model data**



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