Interactive Visual Exploration and Analysis of Multi-Faceted Scientific Data

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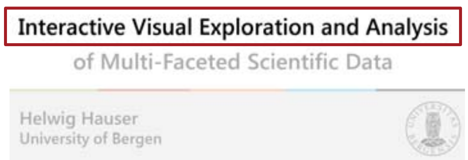
One page synopsis



- **Interactive Visual Analysis (IVA)**
  - **particular exploration/analysis methodology** (interactive, iterative, computationally supported, etc.)
  - **conceptual framework** with **levels of complexity** (from show&brush to visual computing)

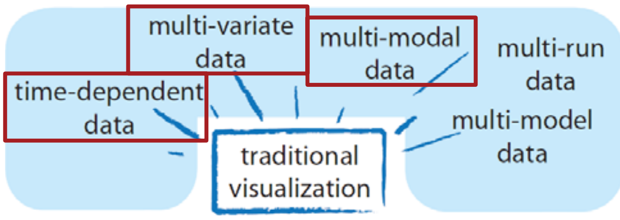
- **Problem context**: **scientific data** & **related tasks**
  - **computed, measured, or modeled data** (fields) (multi-faceted: time-dep., multivariate, multimodal, *etc.*)
  - mostly from the domain of **natural sciences** (physics, biology, climatology, etc., but also medicine)

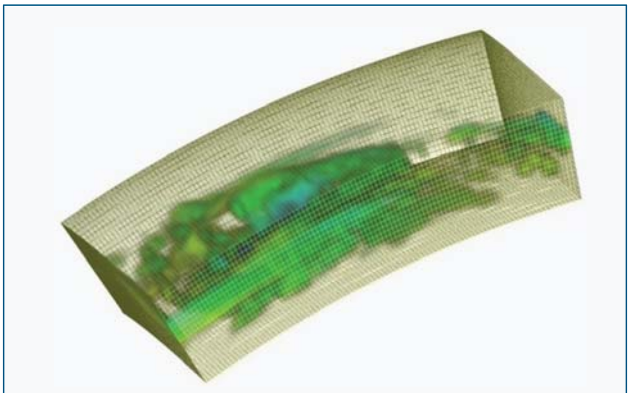
Multi-faceted Scientific Data

- Time-dependent scenarios
  (consider multiple time steps)

- Multi-variate data
  (multiple data variates, e.g., temperature, precipitation)

- Multi-modal data
  (simulation, satellite imagery, weather stations, etc.)

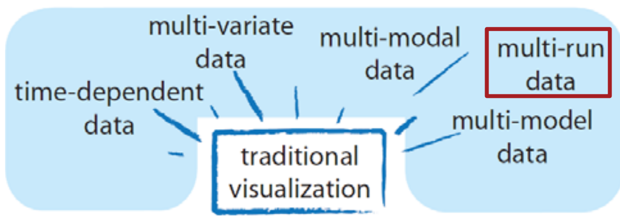


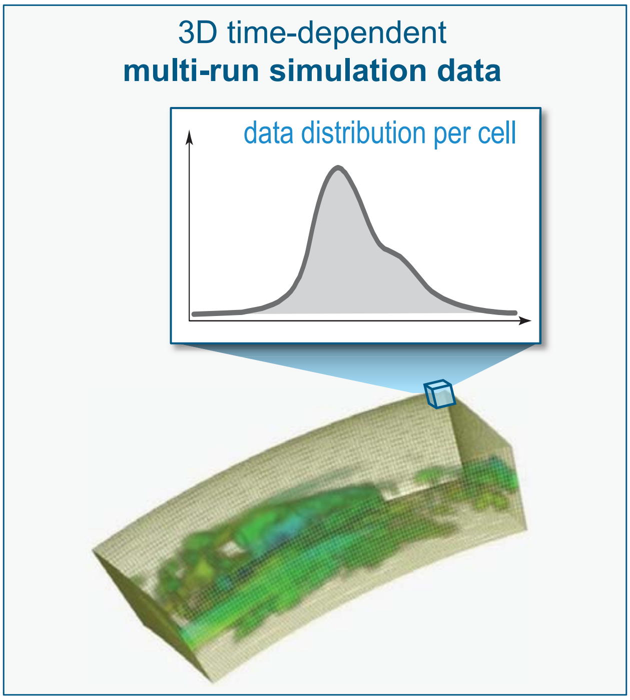


time-dependent 3D data

Multi-faceted Scientific Data

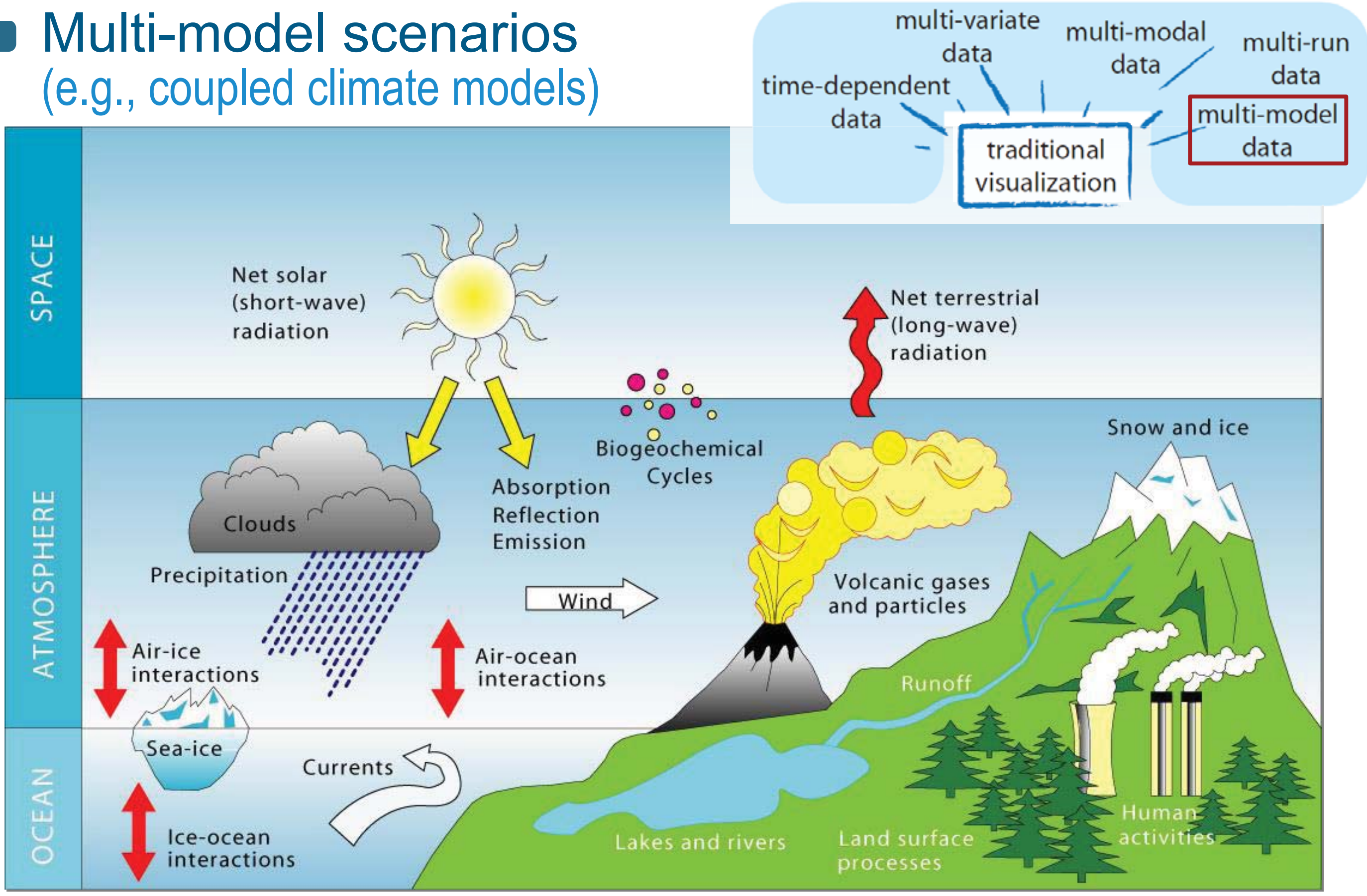
- Multi-run simulations
  (simulation repeated with varied model parameters)





Multi-faceted Scientific Data

- Multi-model scenarios
  (e.g., coupled climate models)



[Böttinger, ClimaVis08]

Target Model of "Scientific Data"

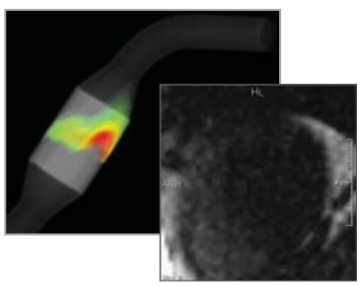
- **Characterized** by a combination of
  - **independent variables**, like **space** and/or **time** (cf. **domain**)
  - and **dependent variables**, like **pressure**, **temp.**, etc. (cf. **range**)
- So we can think of this type of data as **given as d(x)** with **x** ↔ **domain** and **d** ↔ **range** – examples:
  - **CT data** $d(\mathbf{x})$ with $\mathbf{x}\in R^3$ and $d\in R$
  - **unstead 2D flow** $\mathbf{v}(\mathbf{x},t)$ with $\mathbf{x}\in R^2$, $t\in R$, and $\mathbf{v}\in R^2$
  - **num. sim. result** $\mathbf{d}(\mathbf{x},t)$ with $\mathbf{x}\in R^3$, $t\in R$, and $\mathbf{d}\in R^n$
  - **system sim.** $\mathbf{q}(\mathbf{p})$ with $\mathbf{p}\in R^n$ and $\mathbf{q}\in R^m$
- **Common property**:
  - **d** is (at least to a certain degree) **continuous** wrt. **x**

Interactive Visual Analysis (IVA)

- Given multi-faceted scientific data:
- IVA is an **interactive visualization approach** to facilitate
  - the **exploration** and/or the **analysis** of data (not necessarily the presentation of data), including
    - **hypothesis generation & evaluation,**
    - **sense making**, **knowledge crystallization**, *etc.*
  - according to the **user's interest/task**, *for ex.*, by interactive feature extraction,
  - navigating between **overview** and **details**, *e.g.*, to enable interactive information drill-down [Shneiderman]
- through an **iterative & interactive visual dialog**

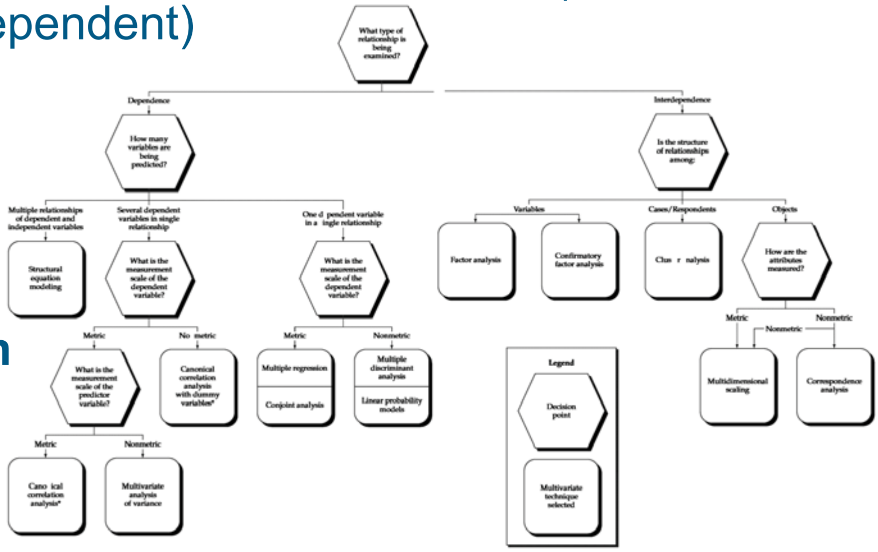
Interactive Visual Analysis ↔ Visual Analytics

- **IVA** ("interactive visual analysis") **since 2000**
- **Tightly related** to **visual analytics**, of course, *e.g.*, *integrating computational & interactive data analysis*
- A **particular methodology** with specific components (*CMV*, *linking & brushing*, *F+C vis.*, *etc.*)
- General enough to work in **many application fields**, but not primarily the VA fields (national security, *etc.*), in particular "**scientific data**" **fields**…



The "Technical" Approach(es)

- **Machine Learning, Statistics, Data Mining, …**
  - **main idea**: exploit ***computational means*** to **extract information** (knowledge) **from data**
  - **lots of approaches** available, incl.
    - advanced **data summaries** (e.g., statistics)
    - advanced **feature extraction methods** (often application-dependent)
    - advanced **embeddings** (dimension reduction)
    - **clustering**
    - **classification**
    - etc.



- Not *really* my field…

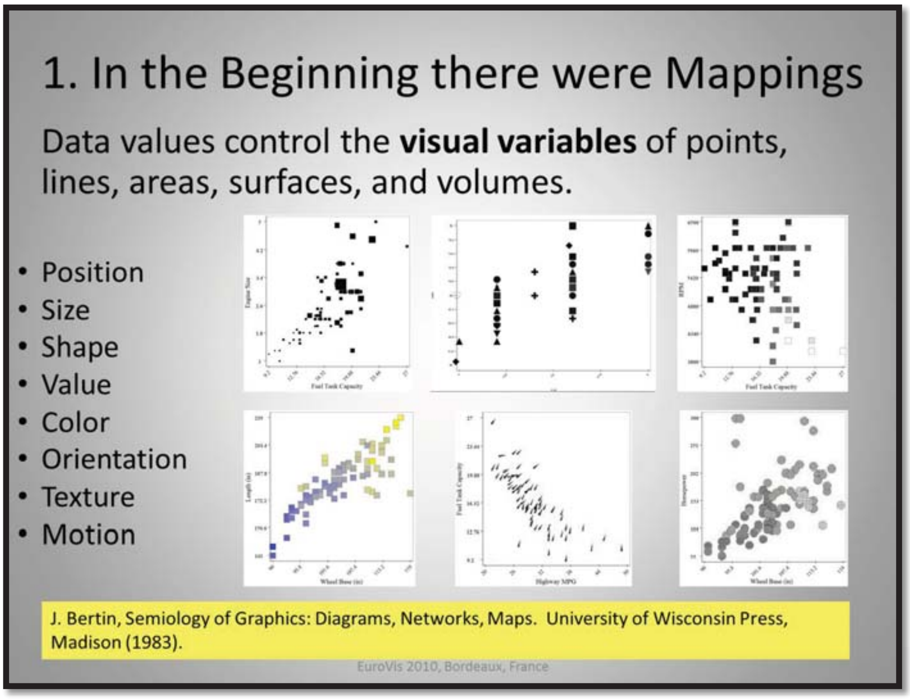
The "Human" Approach

- **Interactive visualization, visual analytics, IVA, …**
  - **main idea**: utilize ***perception & cognition*** to **extract information** (knowledge) **from data**
  - **visualization = show the data** to the user (seeing = understanding)
  - **interaction** allows for **step-by-step analysis**, incl.
    - classical information drill-down (from overview to detail) – cf. Shneiderman '91
    - iterative analysis (show features one-by-one)
    - comparative analysis (work out relations)
    - etc.

  - our **visual sense = data highway to the brain**!
  - a picture says more than 100 words

Matt Ward on Visualization (1/2)

- The **perceptual** and **cognitive power** of users should not be left unutilized!
- Matt Ward, 2010:



EuroVis Keynote

Matt Ward on Visualization (1/2)

- The
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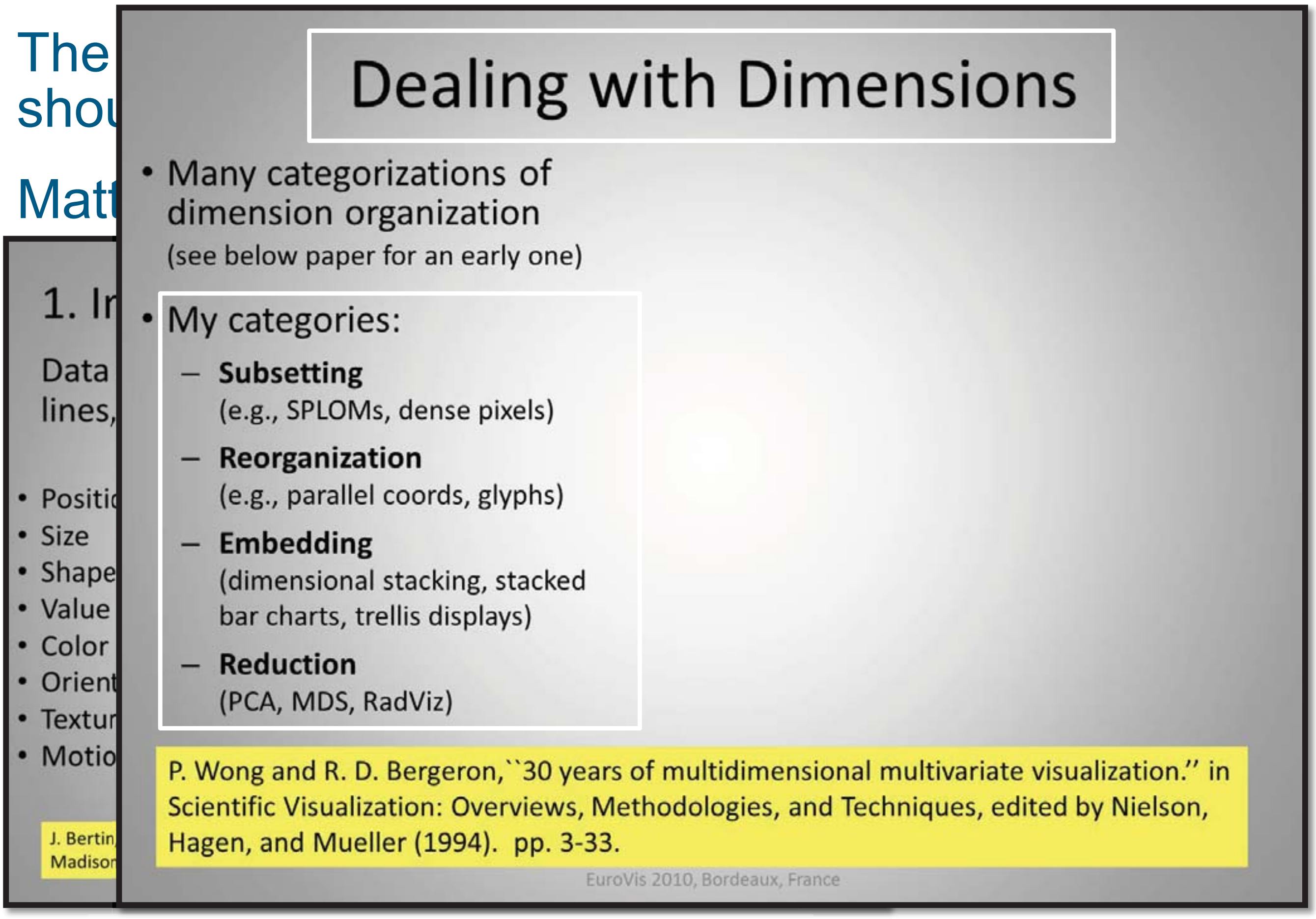
- Matt

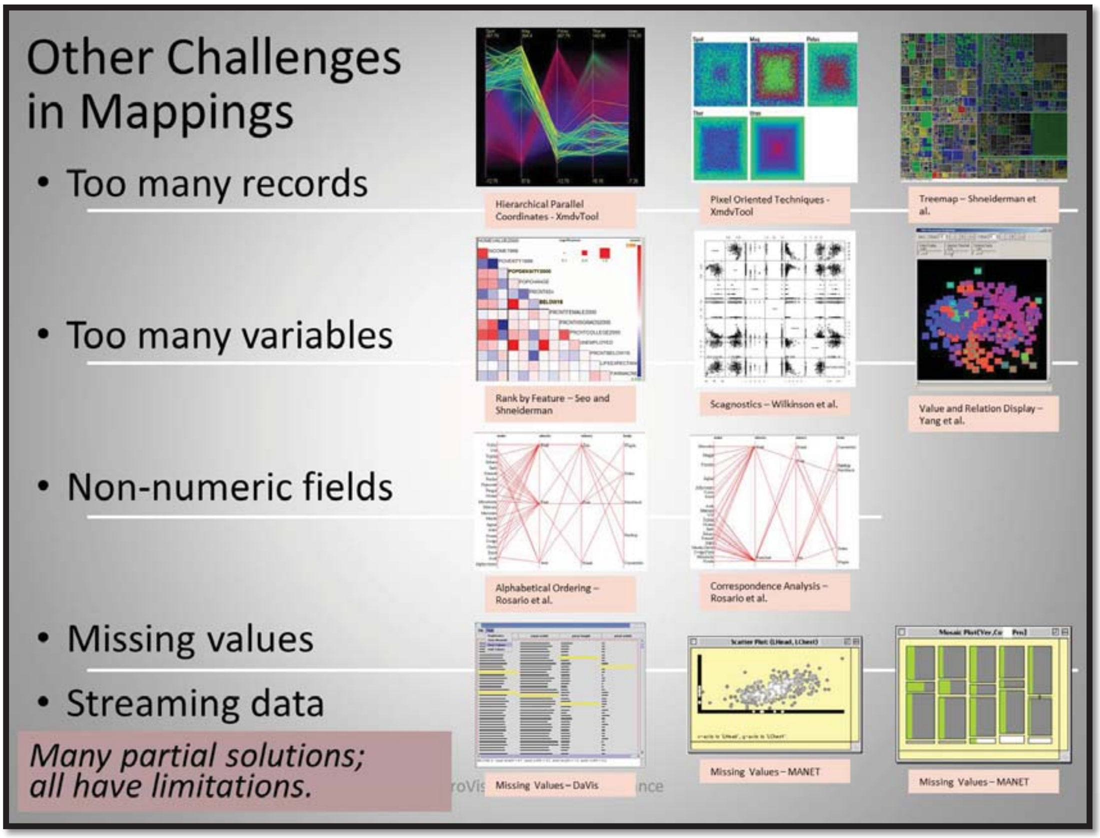


EuroVis Keynote

Matt Ward on Visualization (2/2)

- Also from Matt Ward's talk:

EuroVis 2010 Keynote



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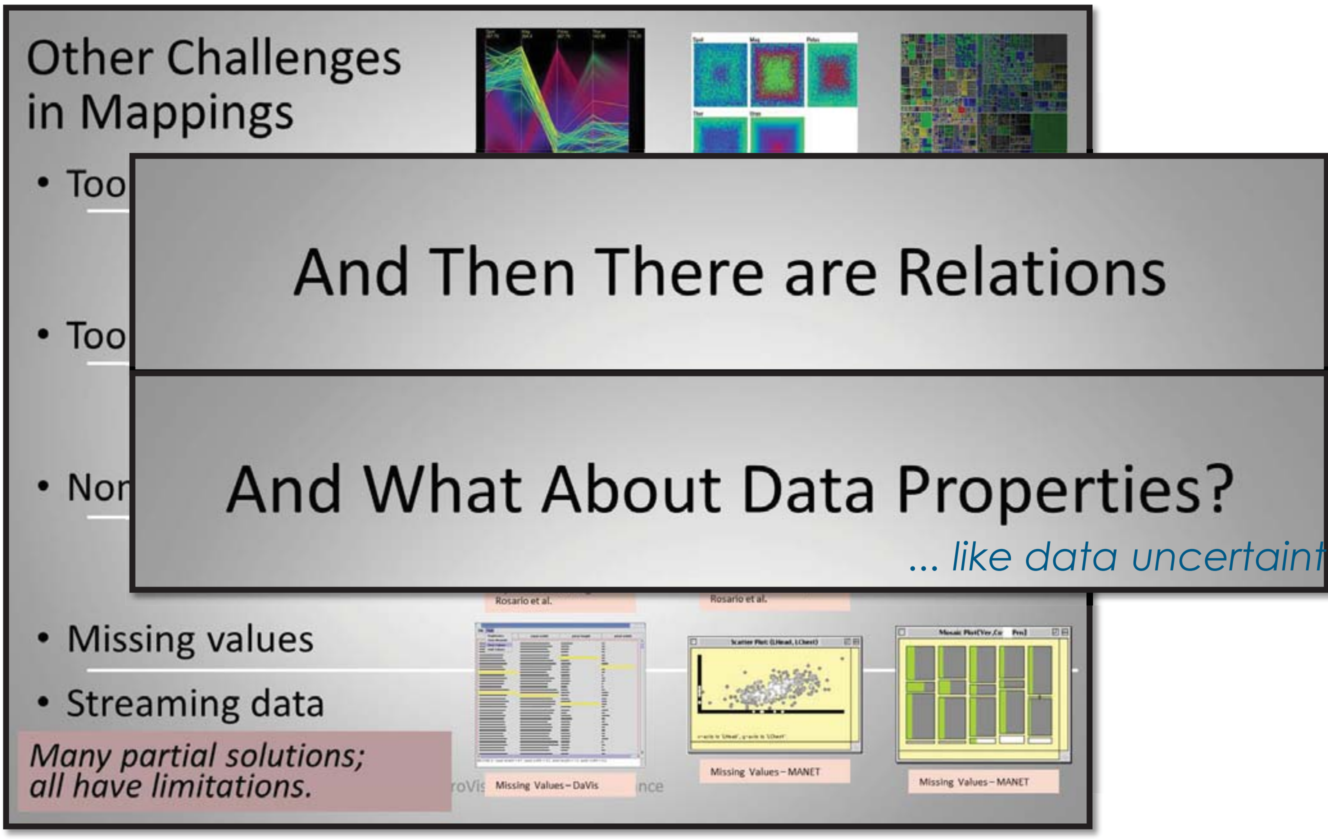


... like data uncertainty

After Mapping Comes Interaction

Visualization without interaction
is like a sports car with no engine!

Nice to look at,
but not good for much! ☺

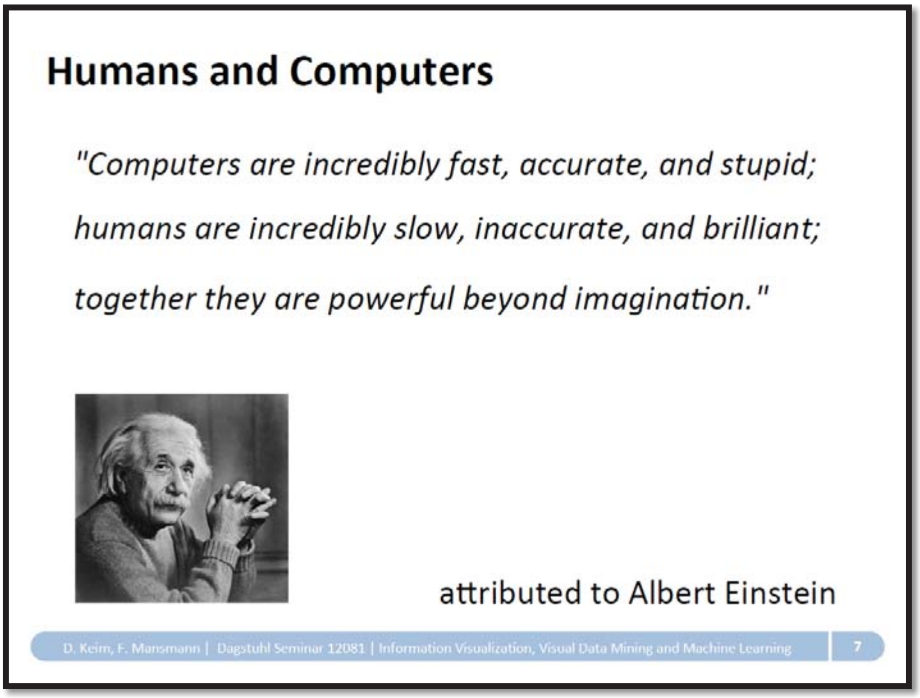
Categories of Interactions

- *Select: mark something as interesting*
- *Explore: show me something else*
- *Reconfigure: show me a different arrangement*
- *Encode: show me a different representation*
- *Abstract/Elaborate: show me more or less detail*
- *Filter: show me something conditionally*
- *Connect: show me related items*

Yi, JS, Kang, YA, Stasko, J, Jacko, J, Toward a deeper understanding of the role of interaction in information visualization. IEEE Trans Vis Comput Graph. 2007 Nov-Dec; 13(6):1224-31.

The Vision of Integration (1/2)

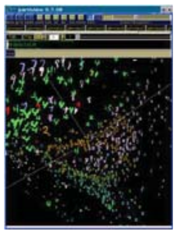
- (I)VA is about the **integration** of **interactive visual** analysis means **and computational analysis**



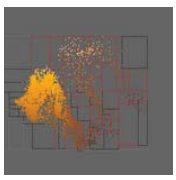
D. Keim, Dagstuhl Seminar Talk, 2012

Integrating Interaction & Computation

- **Goal**: to combine the *best of two worlds* [Keim et al.]:
  - data **exploration**/analysis by the **user**, based on **interactive visualization**
  - and **data analysis** by the **computer**, based on **statistics**, **machine learning**, *etc.*
- State of the art / **levels of integration** [Sun..., 2010]
  - **mostly no integration**, still
  - some **vis. of results** of computations
  - also: making **comp. semi-interactive** (here called "**inner integration**")
  - **rare: tight integration**
- **Outer integration** (here!): bundling **interaction & computation in a loop**



[Maniyar & Nabney, 2006]



[Williams & Munzner, 2004]

HH, Dagstuhl Seminar, 2012

Integrating Interaction & Computation

- **Goal**: to combine the *best of two worlds* [Keim et al.]:

Integrated Methods

- Clustering
  - k-means
  - hierarchical clustering methods
  - etc.
- Projections (embeddings), e.g., for dimension reduction
  - PCA
  - MDS
  - etc.
- Classification, regression
  - decision trees
  - SVM
  - etc.
- Etc.

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etc.
n: [Sun..., 2010]
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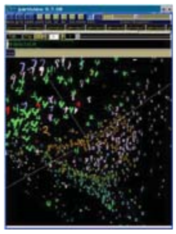
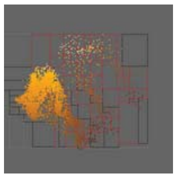

[Maniyar & Nabney, 2006]


[Williams & Munzner, 2004]

- **Outer integration** (here!):
bundling **interaction & computation in a loop**

Integrating Interaction & Computation

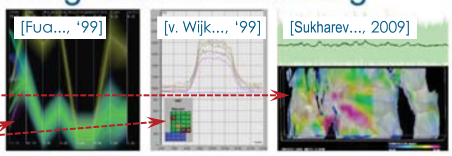
- **Goal**: to combine th…

Integrated Methods

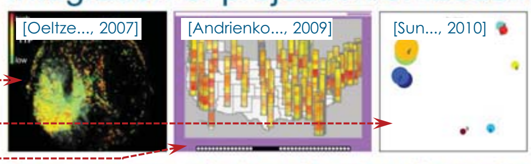
- Clustering
  - k-means
  - hierarchical clustering me…
  - etc.
- Projections (embeddings), e.g.,
  - PCA
  - MDS
  - etc. (SOM)
- Classification, regression
  - decision trees
  - SVM
  - etc. (gen. alg.)
- Etc.

Some Examples

- Integration of clustering



- Integration of projection/embedding



- Integration of classifcation/learning

[Williams & Munzner, 2004]

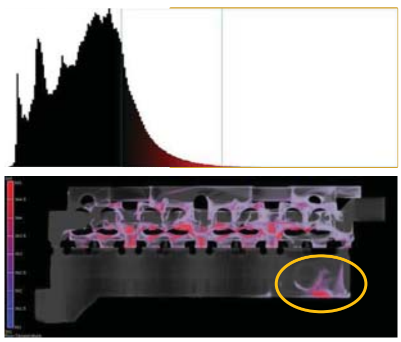
- **Outer integration** (here!):
bundling **interaction & computation in a loop**

Interactive Visual Analysis of Scientific Data

- When used to study scientific data, **IVA employs**
  - methods from **scientific visualization** (vol. rend., …)
  - methods from **statistical graphics** (scatterplots, …), **information visualization** (parallel coords., *etc.*)
  - **computational tools** (statistics, machine learning, …)
- Applications include
  - **engineering**, **medicine**, **meteorology/climatology**, **biology**, *etc.*
- **Interactive visual analysis** (as exemplified in this tutorial) **works really well with scientific data**, *e.g.*,
  - results from **numerical simulation** (spatiotemporal)
  - imaging / **measurements** (in particular multivariate)
  - sampled **models**

The Iterative Process of IVA

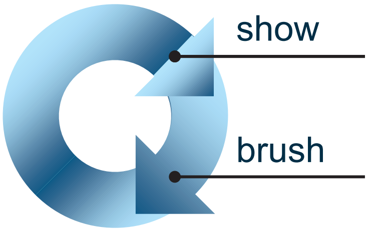
- Loop / bundling of *two complementary parts*:
  - **visualization** – show to the user!
    Something new, or something due to interaction.
  - **interaction** – tell the computer!
    What is interesting? What to show next?
- Basic example (**show – brush** – show – …), cooling jacket context:
  1. show a histogram of temperatures
  2. brush high temperatures (>90°[±2°])
  3. show focus+context vis. in 3D
  4. locate relevant feature(s)



- **KISS-principle IVA**:
  - linking & brushing, focus+context visualization, …

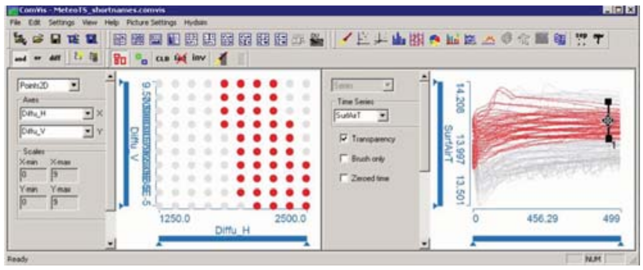
Show & Brush (basic IVA)

- **Tightest IVA loop**
  - **show data** (explicitly represented information)
  - **one brush** (on one view, can work on >1 dims.)



A typical (start into an) **IVA session** of this kind:

- bring up multiple views
  - at least one for **x**, t
  - at least one for d_i
- I see (something)!
- brush this "something"
- linked F+C visualization
- first insight!



Show & Brush (basic IVA)

- **Tightest IVA loop**
  - **show data** (explicitly represented information)
  - **one brush** (on one view, can work on >1 dims.)
- **Requires**:
  - multiple views (≥2)
  - interactive brushing capabilities on views (brushes should be editable)
  - focus+context visualization
  - linking between views
- Allows for **different IVA patterns** (wrt. domain & range)

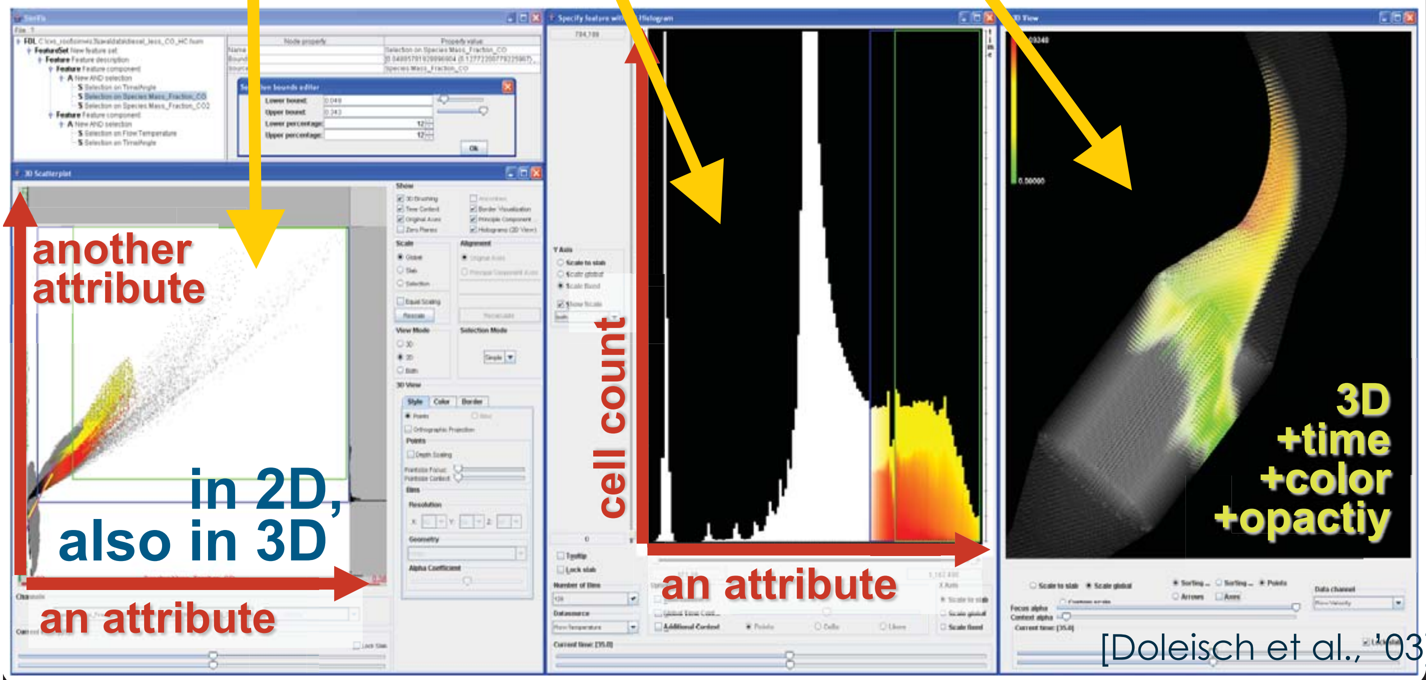
A typical (start into an) **IVA session** of this kind:

- bring up multiple views
  - at least one for **x**, t
  - at least one for d_i
- I see (something)!
- brush this "something"
- linked F+C visualization
- first insight!

… leads to… degree of interest *… requires…* *… is realized via …*

IVA: Multiple Views

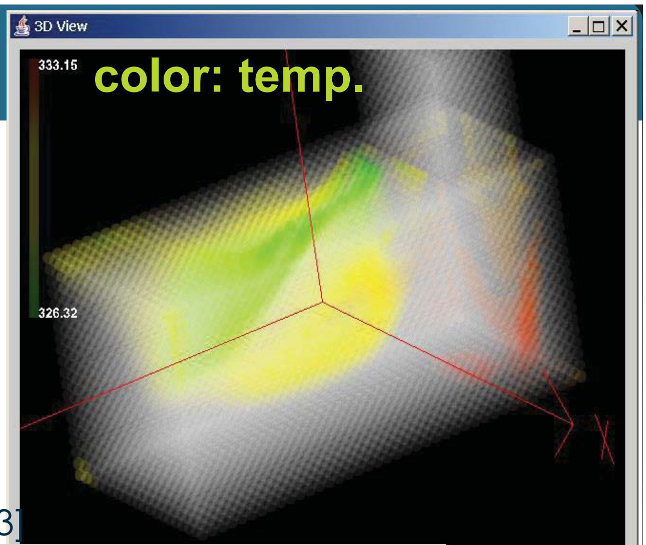
- One dataset, but multiple views
- Scatterplots, histogram, 3D(4D) view, etc.



[Doleisch et al., '03]

Interactive Brushing

- Move/alter/extend brush interactively
- Interactively explore/ analyze multiple variates



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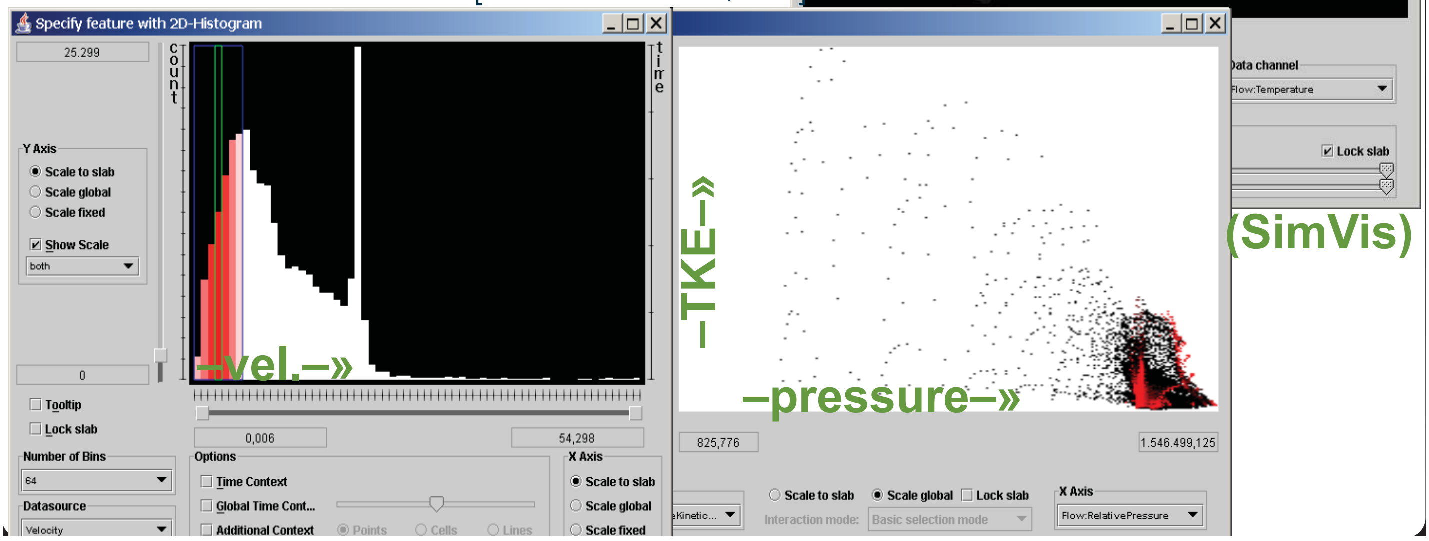

(SimVis)

Interactive Brushing

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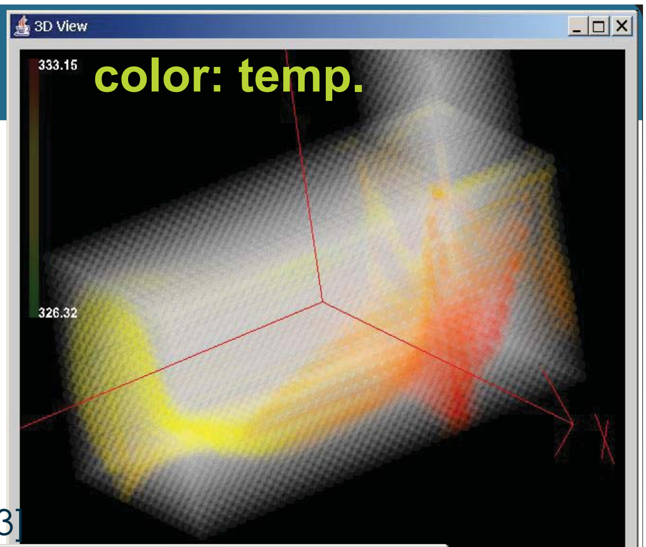

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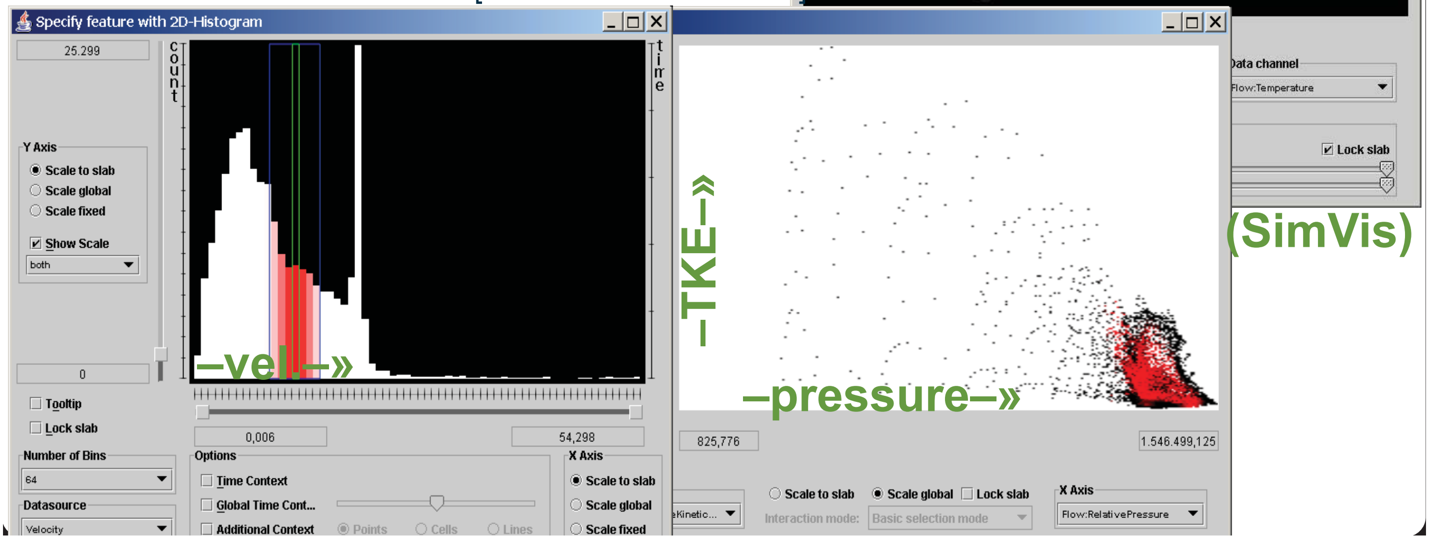

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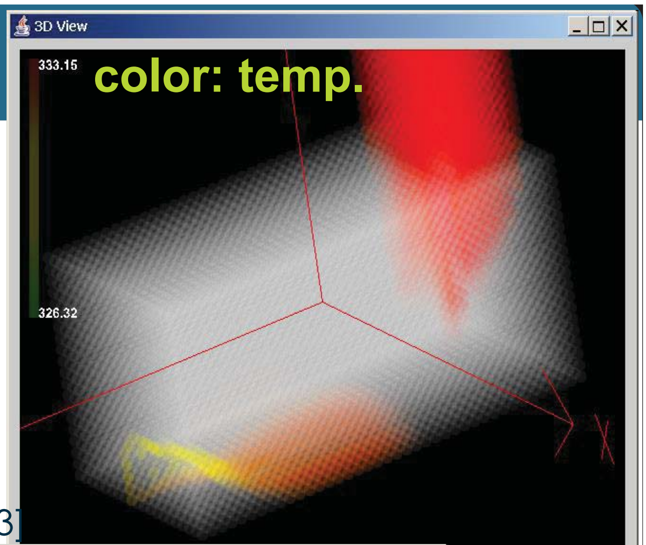

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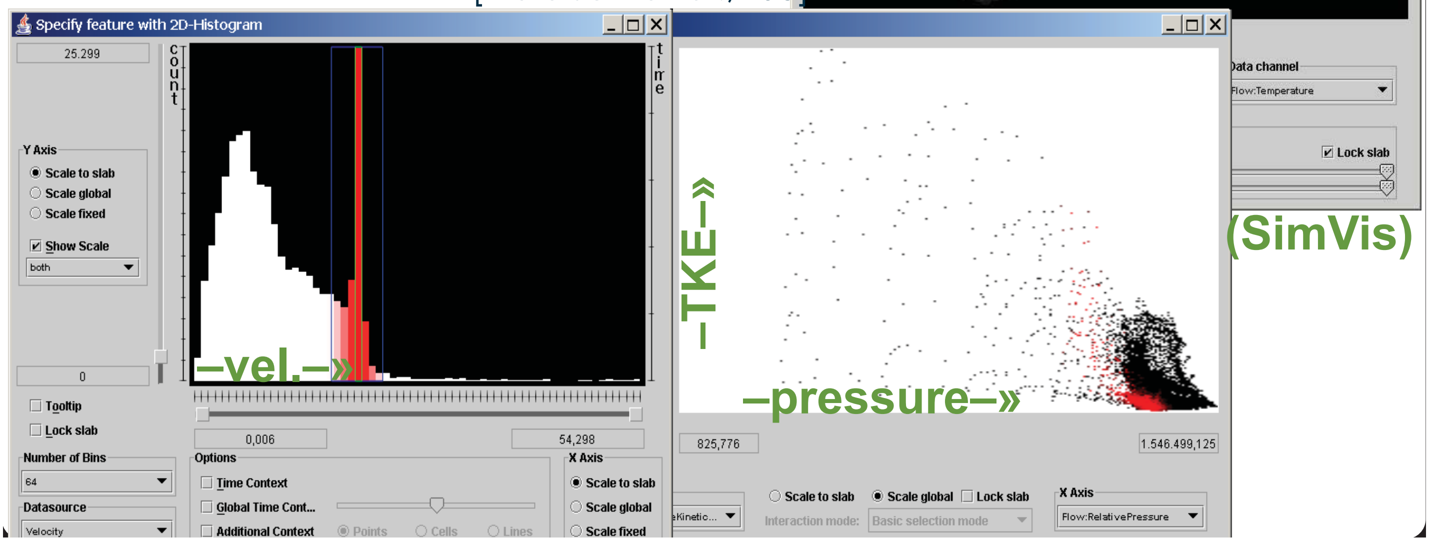
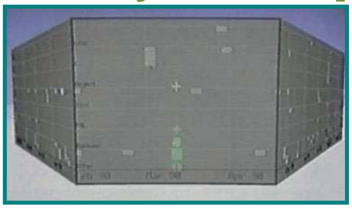


IVA: Focus+Context Visualization

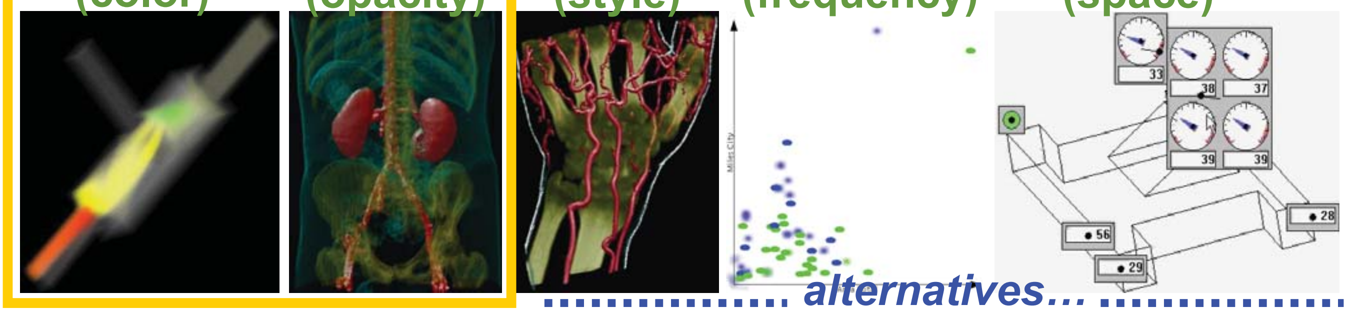
- Traditionally space distortion
  - more space for data of interest
  - rest as context for orientation
- Generalized F+C visualization
  - emphasize data in focus (color,opacity, …)
  - differentiated use of visualization resources

[Mackinlay et al. 1991]



[Hauser… 2001, 2003]

(color) (opacity) (style) (frequency) (space)



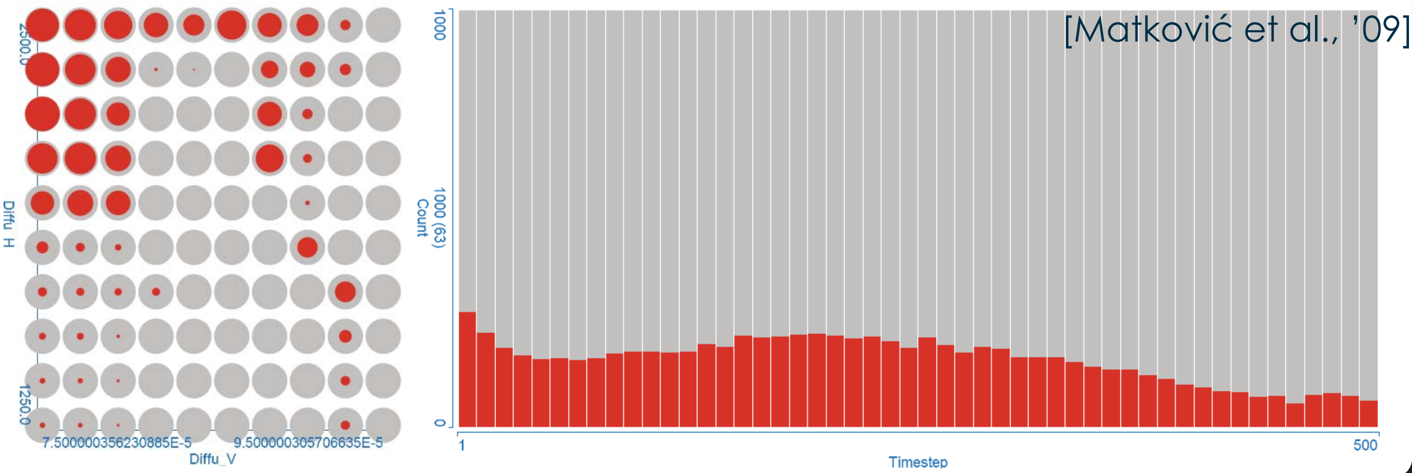
alternatives…

F+C Visualization in IVA Views

- Colored vs. gray-scale visualization
- Opaque vs. semi-transparent visualization

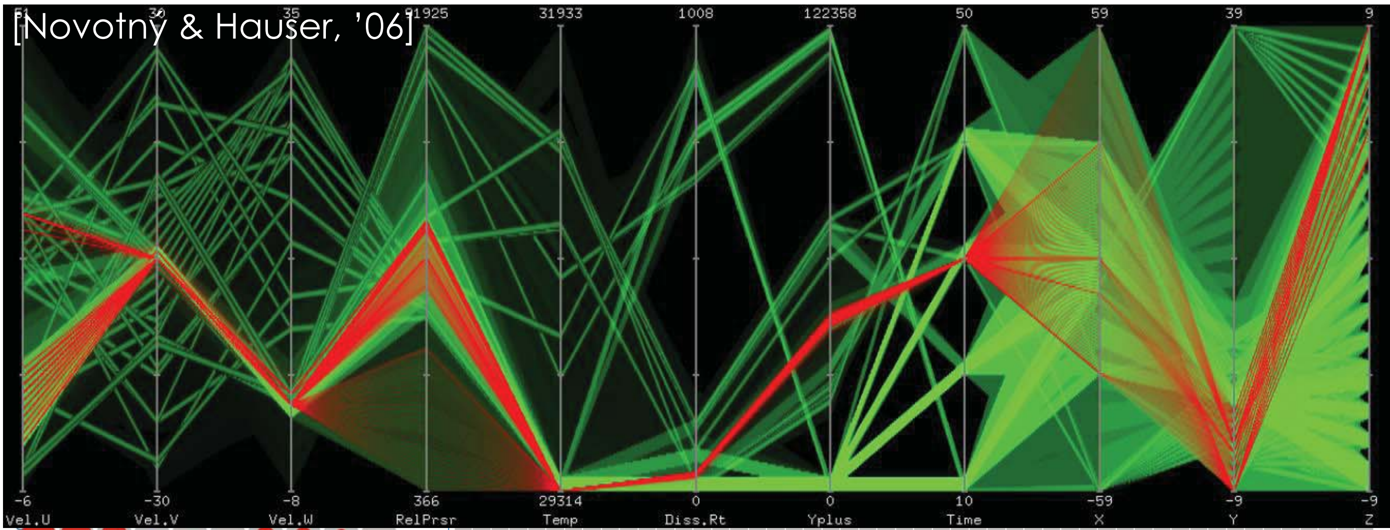
In a scatterplot (left) or histogram (right): brushed data in rec

[Matković et al., '09]

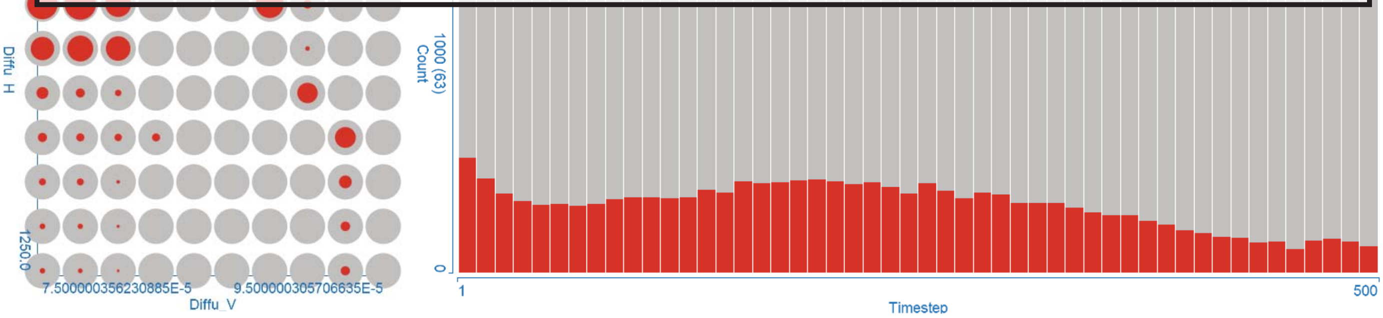


F+C Visualization in IVA Views

[Novotný & Hauser, '06]

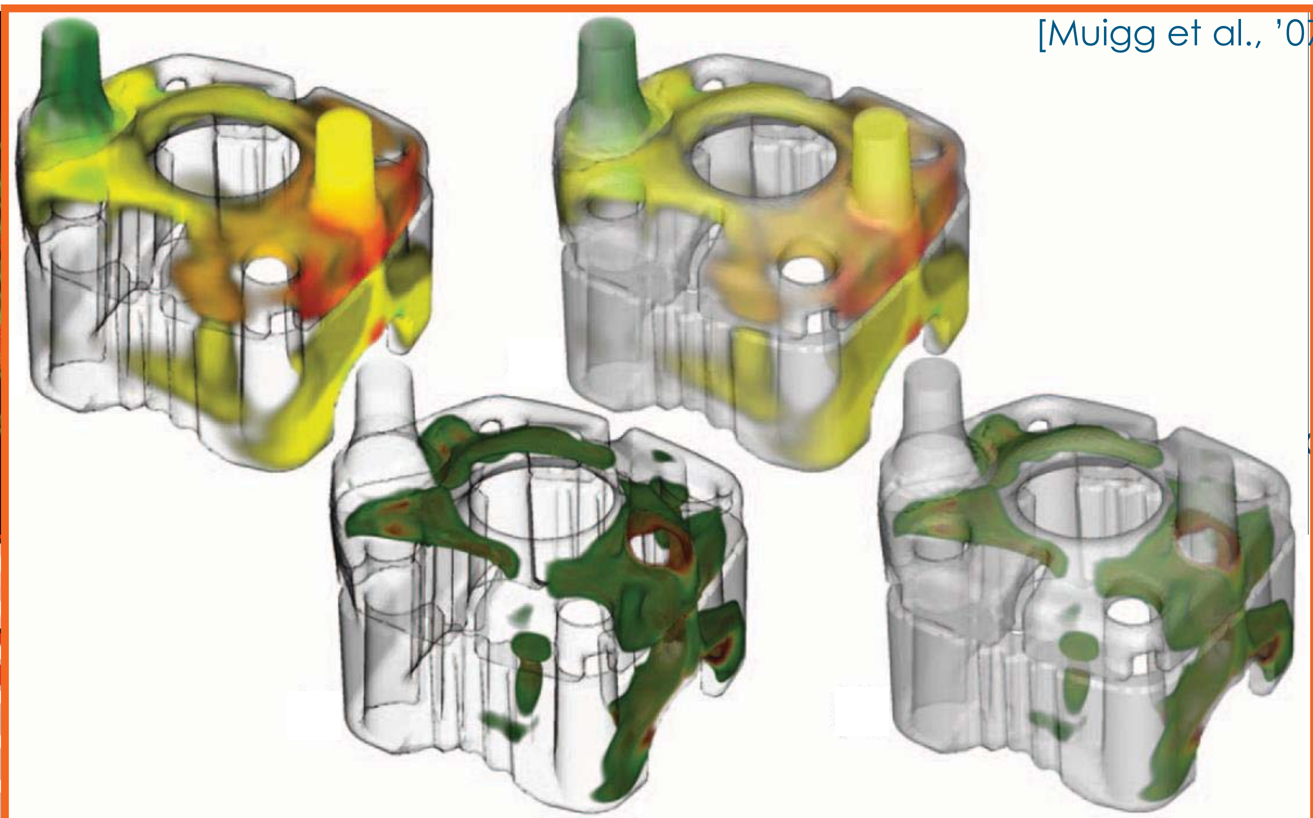


In parallel coordinates (above): brushed data in red & over



F+C Visualization in IVA Views

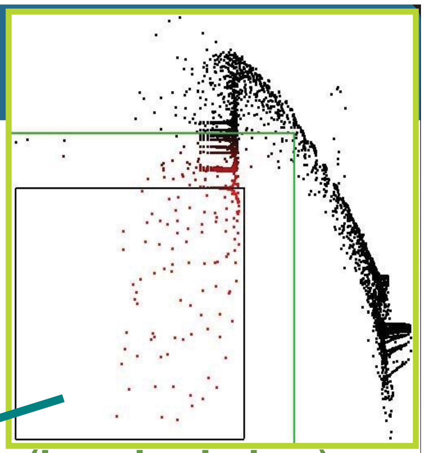
[Muigg et al., '07

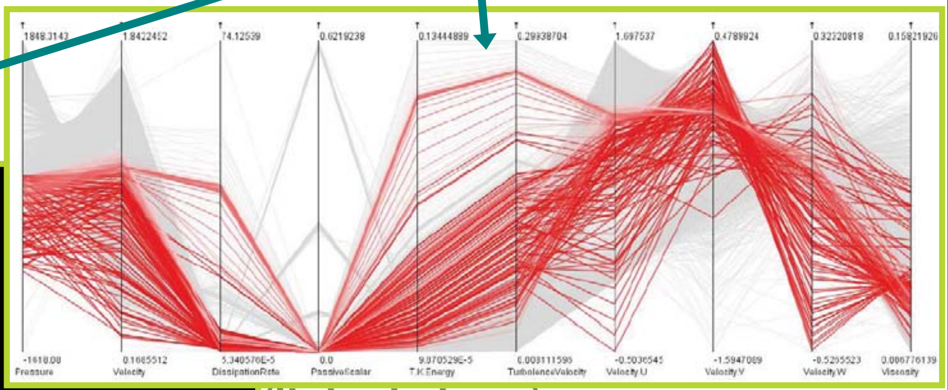


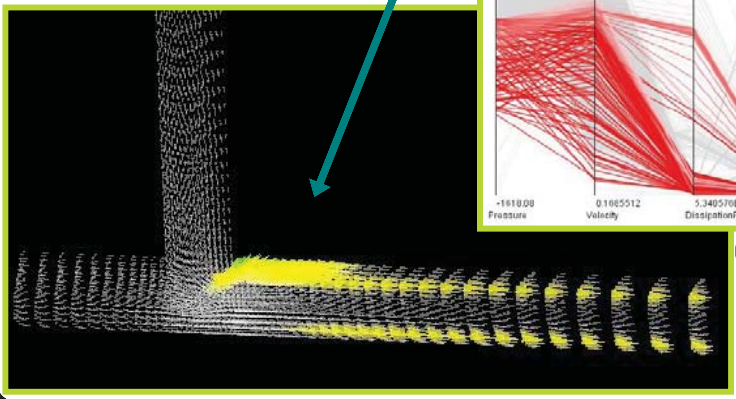
In 3D (above): less transp. & colored, in illustrative context

IVA: Linked Views

- Brushing: mark data subset as especially intersting
- Linking: enhance brushed data in linked views consistently (F+C)



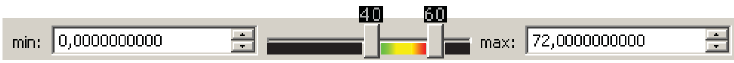




[Doleisch & Hauser, '02

IVA: Degree of Interest (DOI)

- *doi*(.): data items tr_i (table rows) → degree of interest $doi(tr_i) \in [0,1]$
  - $doi(tr_i) = 0 \Rightarrow tr_i$ not interesting ($tr_i \in$ context)
  - $doi(tr_i) = 1 \Rightarrow tr_i$ 100% interesting ($tr_i \in$ focus)
- Specification
  - explicit, e.g., through direct selection
  - implicit, e.g., through a range slider



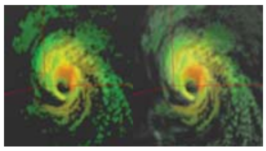
- Fractional DOI values: $0 \leq doi(tr_i) \leq 1$
  - several levels (0, low, med., …)
  - a continuous measure of interest
  - a probabilistic definition of interest

x	*y*	*d1*	*d2*	*doi*
0	0	17,20	-0,22	0,00
1	0	12,10	0,10	0,00
2	0	7,70	0,45	0,00
3	0	2,10	0,90	0,00
0	1	24,10	0,02	0,00
1	1	21,90	0,36	0,00
2	1	15,50	0,87	0,74
3	1	11,10	1,20	1,00
0	2	27,20	0,12	0,00
1	2	24,10	0,66	0,18
2	2	17,30	1,35	1,00
3	2	12,10	2,20	0,60
0	3	35,50	0,67	0,00
1	3	30,90	1,30	0,00
2	3	24,50	2,10	0,10
3	3	20,80	2,90	0,00

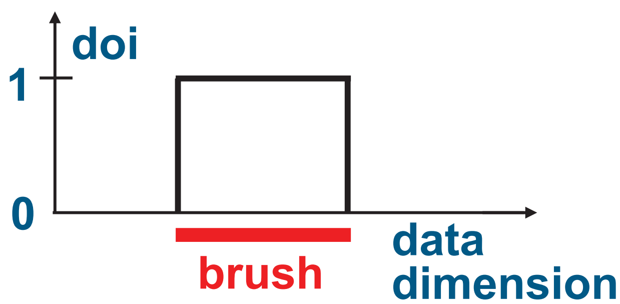
(cont'd on next slid

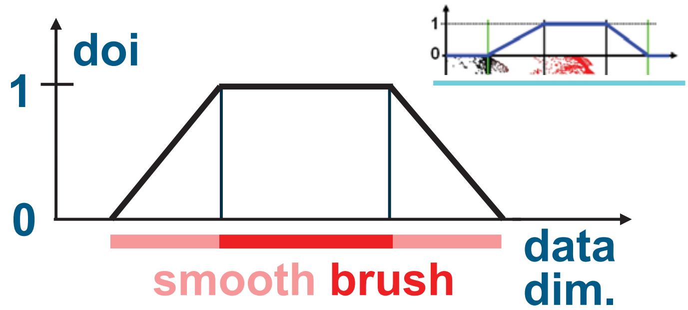
IVA: Smooth Brushing → Fractional DOI

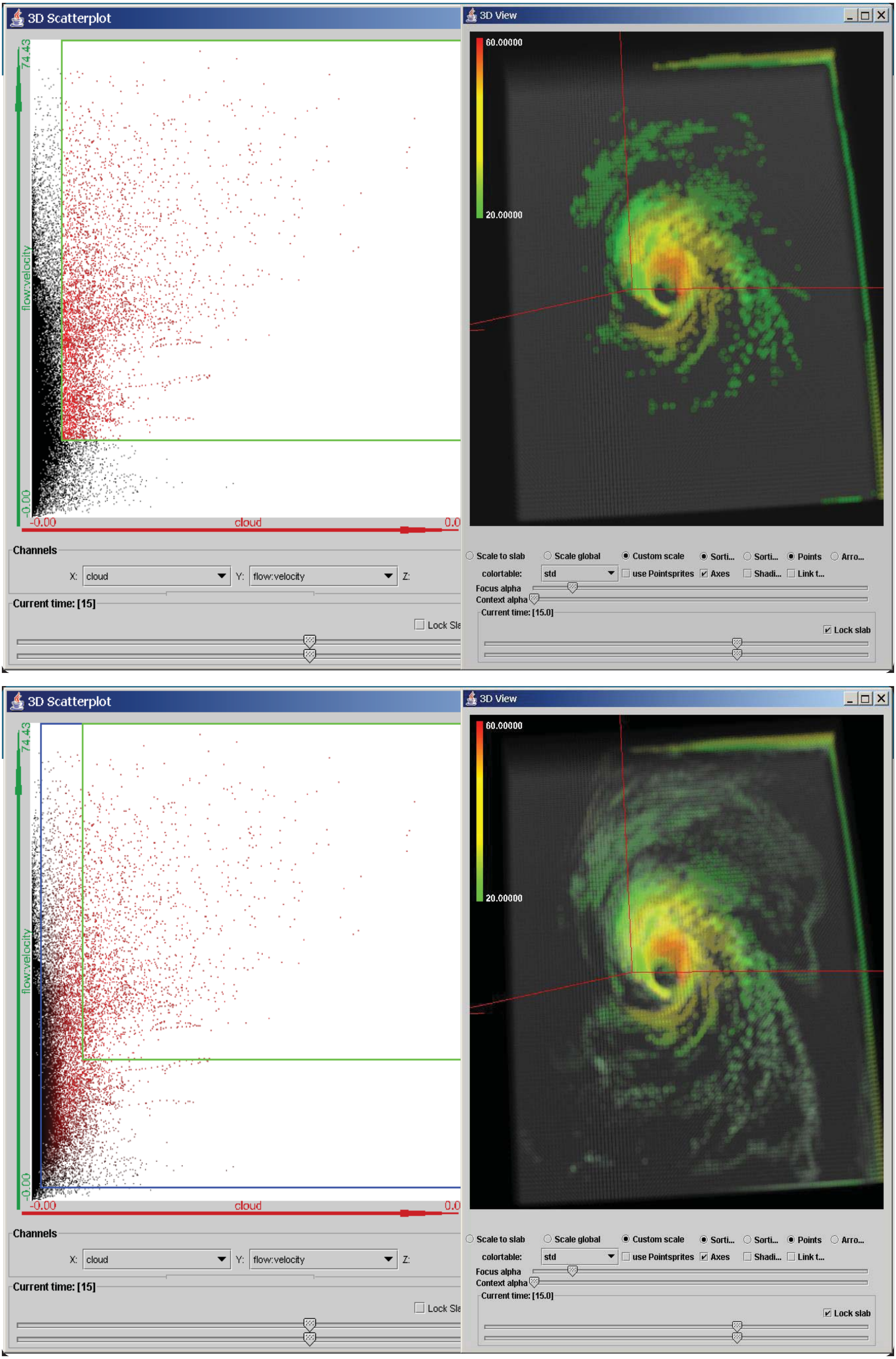
- **Fractional DOI values** esp. useful wrt. **scientific data**: (quasi-)continuous nature of data ↔ smooth borders
- Goes well with gradual focus+context vis. techniques (coloring, semitransparency)



- Specification: **smooth brushing** [Doleisch & Hauser, 2002]
  - "inner" range: all 100% interesting (DOI values of 1)
  - between "inner" & "outer" range: fractional DOI values
  - outside "outer" range: not interesting (DOI values of 0)






3D Scatterplot
74.43
flow:velocity
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X: cloud
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Current time: [15]
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use Pointsprites
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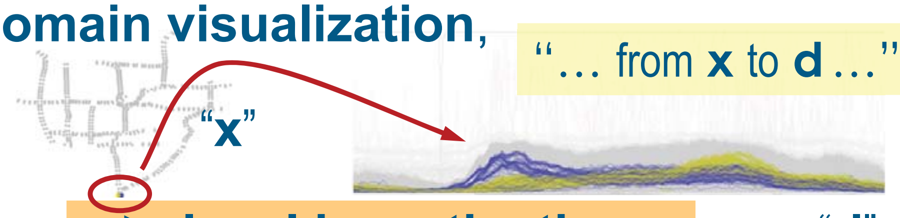
Shadi...
Link t...
Focus alpha
Context alpha
Current time: [15.0]
Lock slab

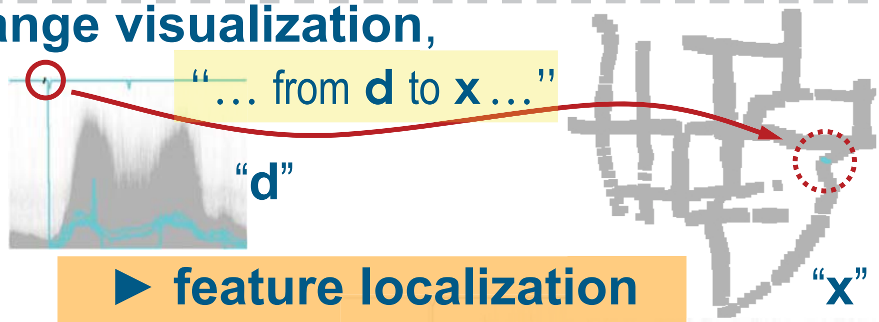
Three Patterns of SciData IVA

- Preliminary: domain **x** & range **d** visualized (≥2 views)
  - **brushing on domain visualization,** *e.g.*, brushing special locations in the map view



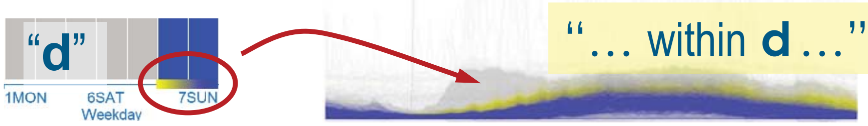
❶ ► **local investigation**

  - **brushing on range visualization,** *e.g.*, brushing outlier curves in a function graph view



❷ ► **feature localization**

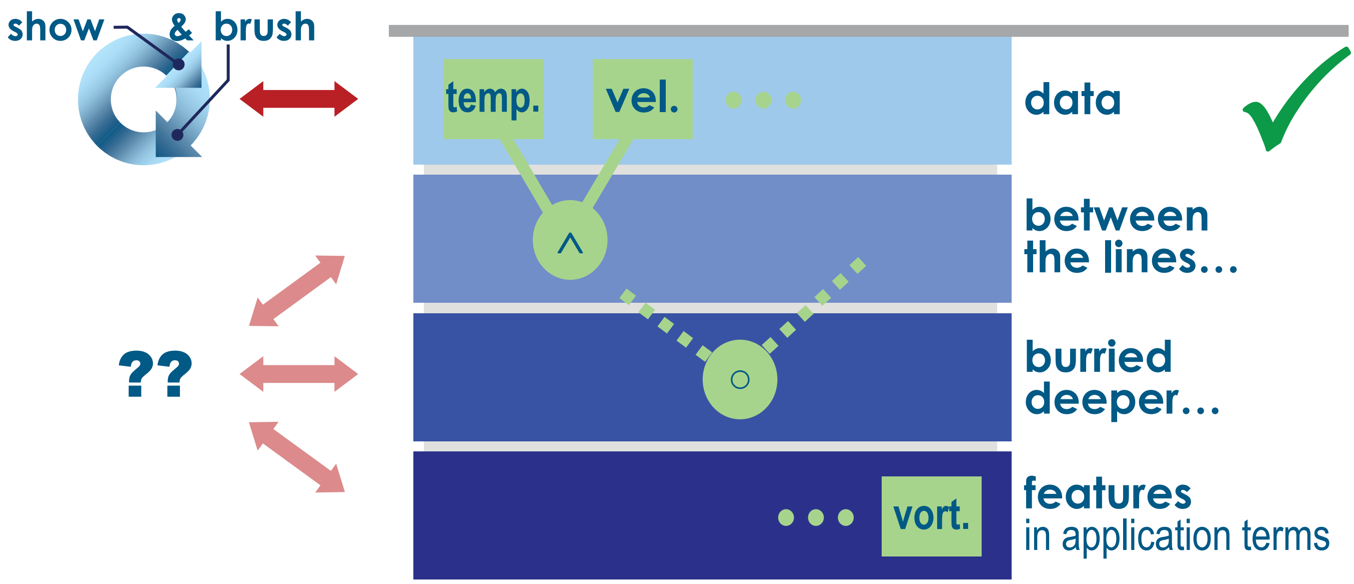
relating multiple range variates



❸ ► **multi-variate analysis**

IVA – Levels of Complexity (1/4)

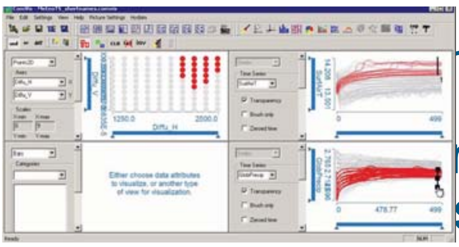
- A ***lot*** can be done with basic IVA, already! [pareto rule]
- We can consider a **layered information space**: from **explicitly** represented information (the **data**) to **implicitly** contained information, **features**, …



IVA – Levels of Complexity (2/4)

- A ***lot*** can be done with basic IVA, already! ✓ [pare rule
- **For more advanced** exploration/analysis **tasks**, we extend it (in seveal steps):
  - IVA, level 2: **logical combinations of brushes**, *e.g.*, utilizing the *feature definition language* [Doleisch et al., 2003]
  - IVA, l. 3: **attribute derivation**; **advanced brushing**, with interactive formula editor; *e.g.*, similarity brushing
  - IVA, l4: **application-specific feature extraction**, *e.g.*, based on vortex extraction methods for flow analysis
- Level 2: like **advanced verbal feature description**
  - ex.: "**hot** flow, also **slow**, near **boundary**" (cooling j.)
  - brushes comb. with **logical operators** (AND, OR, SUB)
  - in a **tree**, or **iteratively** $((((b_0\ op_1\ b_1)\ op_2\ b_2)\ op_3\ b_3)\ \ldots)$

IVA – Levels of Complexity (2/4)



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- ...nced exploration/analysis tasks, ...seveal steps):
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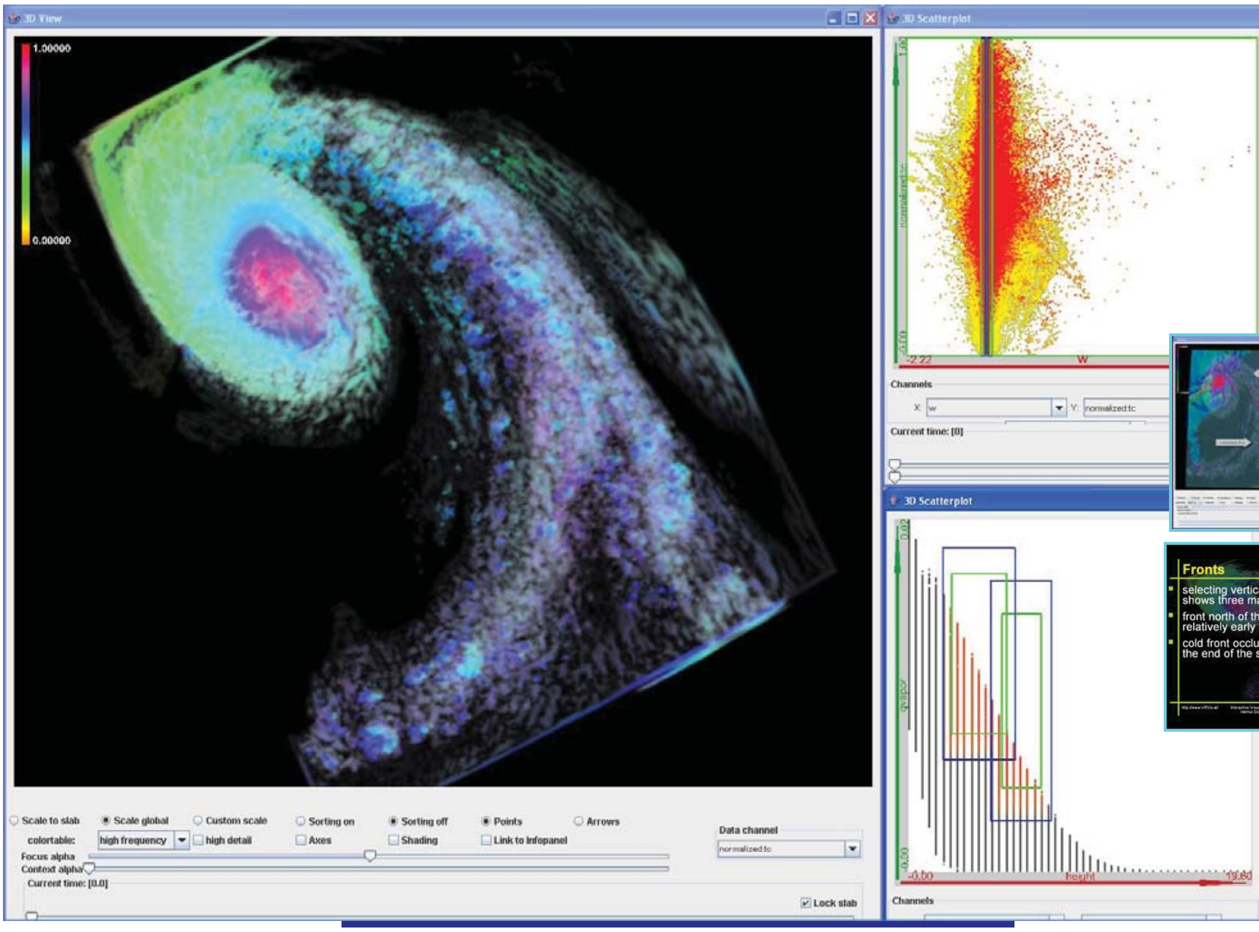
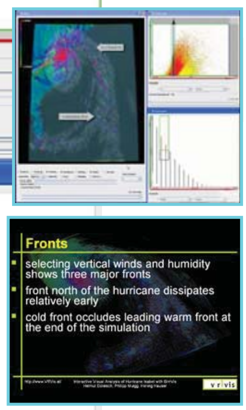
IVA (level 2) Example

tions

, 2003])





terms

IVA – Levels of Complexity (3/4)

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  - IVA, level 2: **logical combinations of brushes**, *e.g.*, utilizing the *feature definition language* [Doleisch et al. 2003]
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- Level 3: using **general info extraction** mechanisms, two (partially complementary) approaches:
  1. **derive additional attribute**(s), then show & brush
  2. use an **advanced brush** to select “hidden” relations

IVA – Levels of Complexity (3/4)

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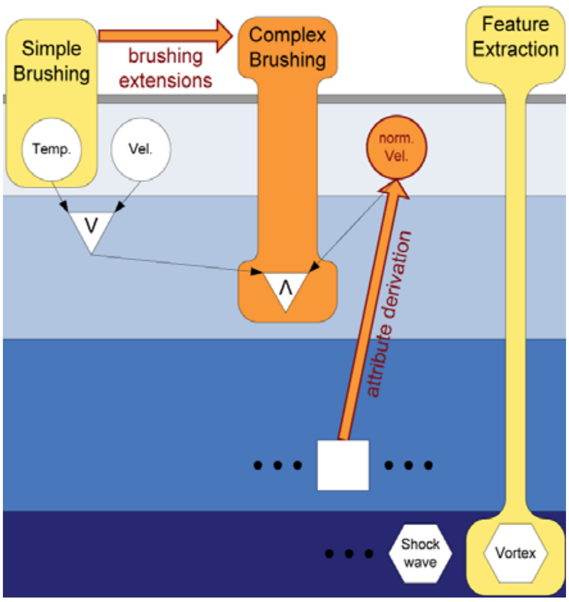
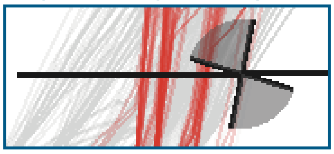
  based on vortex extraction n



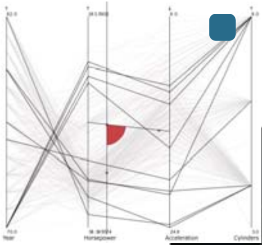
- Level 3: using **general info extraction** mechanisms, two (partially complementary) approaches:
  1. **derive additional attribute**(s), then show & brush
  2. use an **advanced brush** to select “hidden” relations

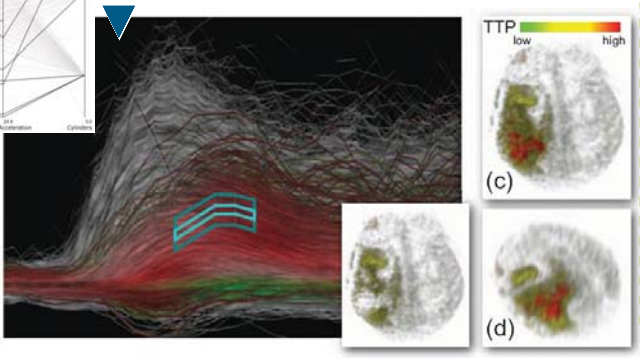
IVA (level 3): Advanced Brushing

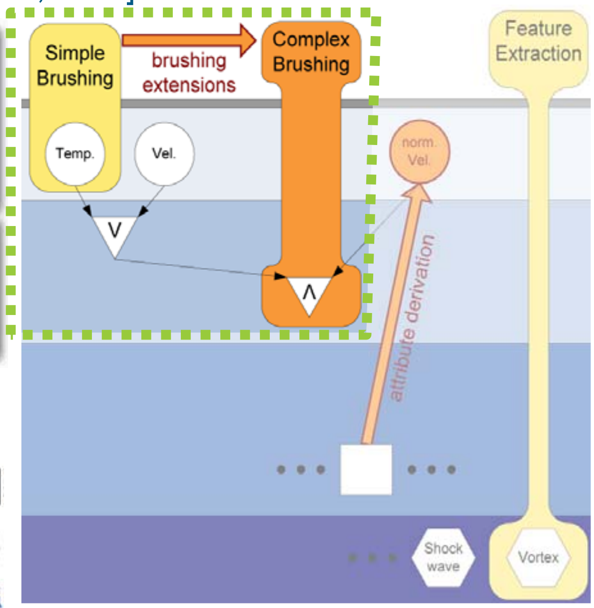
- **Std. brush**: brush 1:1 what you see
  Adv. brush: executes additional function ("intelligent"?)

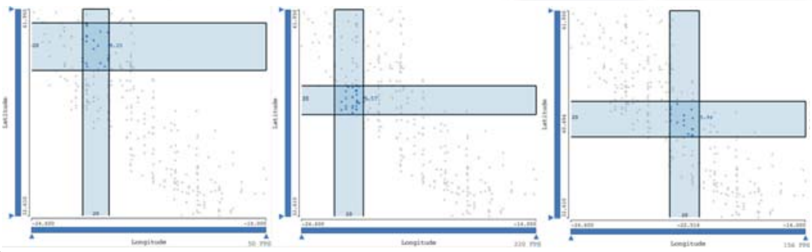


- **Examples**:
  - angular brushing [Hauser et al., 2002]
    similarity brushing [Muigg et al., 2008]



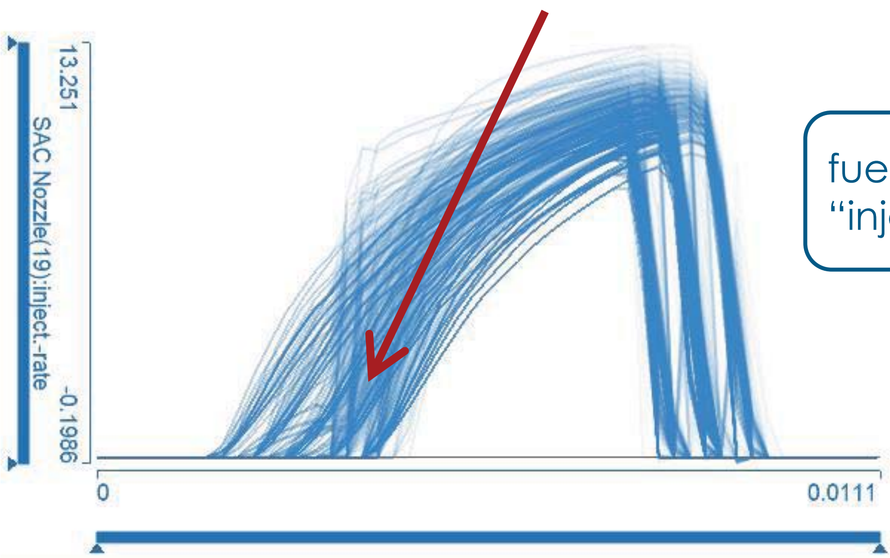






3rd level IVA, adv. brushing example

- Considering a visualization of a family of function graphs:
  - select the steeply rising graphs

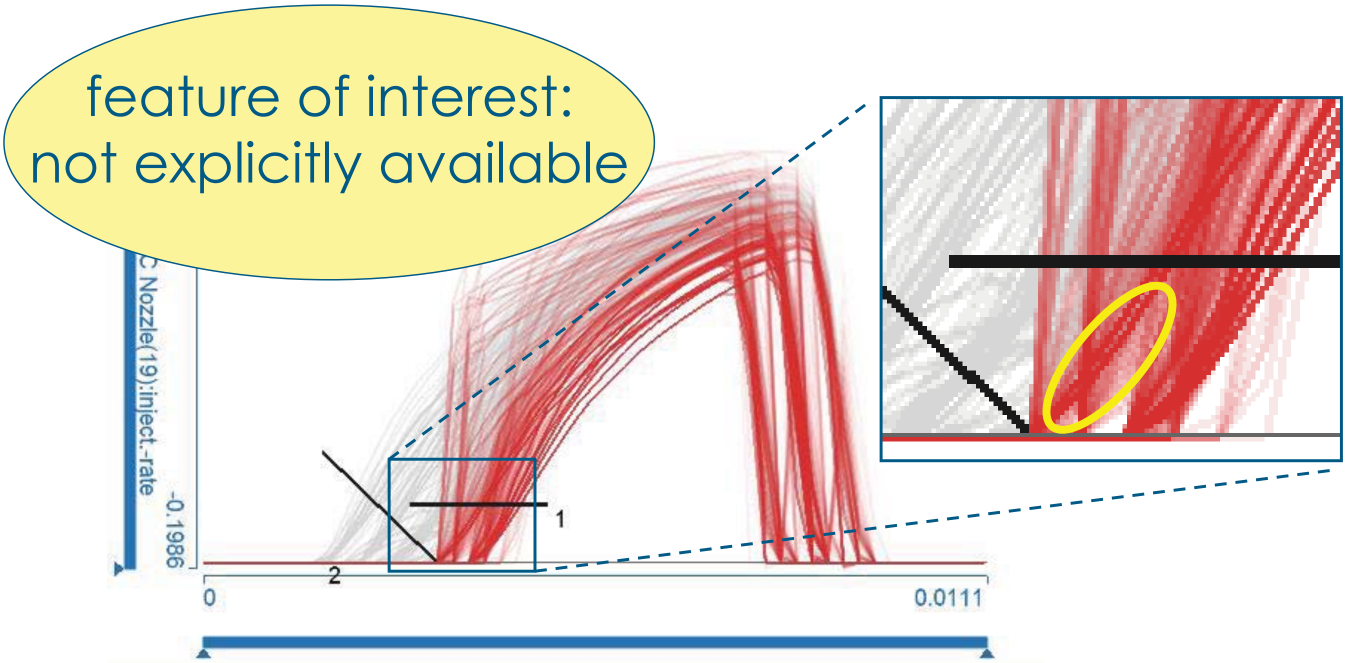


fuel injection simulation
"injection rate"

example prepared by Konyha, Zolt

3rd level IVA, adv. brushing example

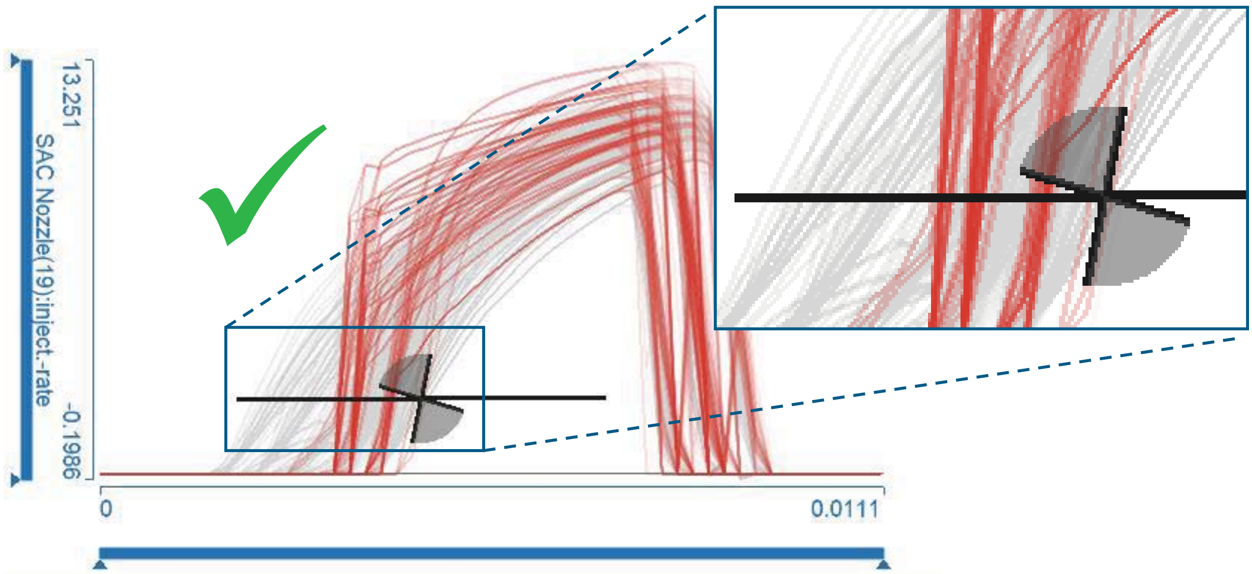
- A simple line brush is not enough
- Combining line brushes does not work, either



example prepared by Konyha, Zolt

3rd level IVA, adv. brushing example

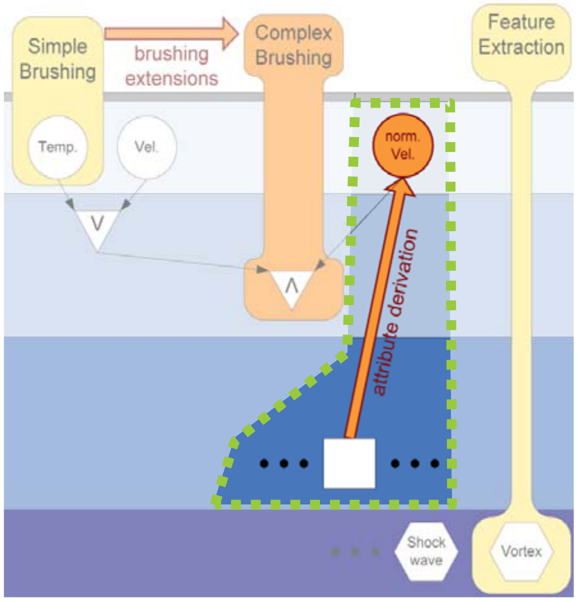
- The *angular line brush* (a specialized brush) selects the intended function graphs
  - that it intersects, and
  - the angle is in a given threshold



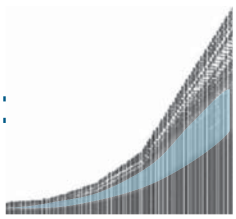
example prepared by Konyha, Zolt

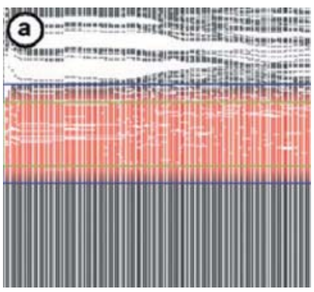
IVA (level 3): Attribute Derivation

- **Principle** (in the context of iterative IVA):
  - **see** some data feature Φ of interest in a visualization
  - **identify** a **mechanism** T **to describe** Φ
  - **execute** (interactively!) an **attribute derivation** step to represent Φ explicitly (as new, synthetic attribute[s] d_φ)
  - **brush** d_φ to get Φ
- **Tools** T to describe Φ from:
  - **numerical mathematics**
  - **statistics**, **data mining**
  - *etc.*
  - ➢ **scientific computing**
- **IVA** w/ **T ↔ visual computing**

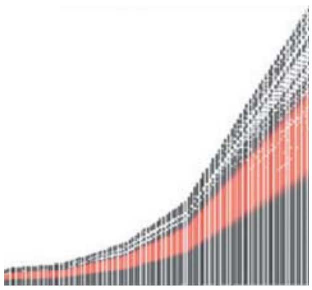


Attribute Derivation ↔ User Task / example

- The tools T, available in an IVA system, must reflect/match the **analytical steps of the user**:
- **Example**:
  - **first vis.**:  ↔ user wishes to select the “band” in the middle
  - **so?** an advanced brush? a lasso maybe?
  - **ah!** → let’s normalize *y* and then brush (a)



  - **leading to the wished selection**:



What user wishes to reflect?

- Many **generic wishes** – users interest in:
  - something **relative** (instead of some absolute values), example: show me the *top-15%*
  - **change** (instead of current values), ex.: show me *regions with increasing temperature*
  - some **non-local property**, ex.: show me regions with *high average temperature*
  - **statistical properties**, ex.: show me *outliers*
  - **ratios/differences**, ex.: show me population per area, difference from trend
  - *etc.*
- **Common characteristic** here:
  - **questions/tools generic**, not application-dependent!

How to reflect these user wishes?

- Many **generic wishes** – users interest in:
  - something **relative** (instead of some absolute values), example: show me the *top-15%* ⇒ ***use**, e.g., **normalization***
  - **change** (instead of current values), ex.: show me *regions with increasing temperature* ⇒ ***derivative estimation***
  - some **non-local property**, ex.: show me regions with *high average temperature* ⇒ ***numerical integration***
  - **statistical properties**, ex.: show me *outliers* ⇒ ***descriptive statistics***
  - **ratios/differences**, ex.: show me population per area, difference from trend ⇒ ***calculus***
  - *etc.* ⇒ ***data mining*** (fast enough?)
- **Common characteristic** here:
  - **questions/tools generic**, not application-dependent!

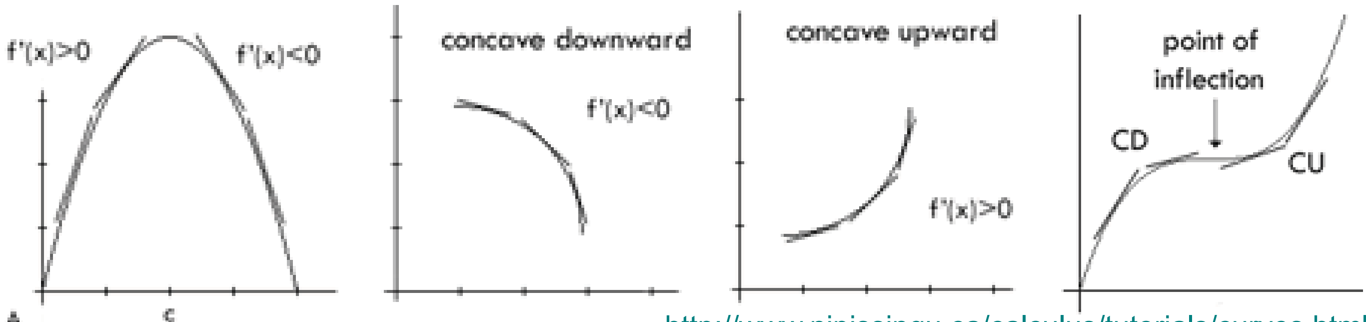
Some useful tools for 3rd-level IVA


(ex.)

- From **analysis**, **calculus**, **num. math**:
  - **linear filtering** (convolve the data with some linear filter on demand, e.g., to smooth, for derivative estimation, *etc.*)
  - **calculus** (use an interactive formula editor for computing simple relations between data attributes; +, −, ·, ⁄, *etc.*)
  - **gradient estimation**, **numerical integration** (*e.g.*, wrt. space and/or time) ⇒ example
  - **fitting/resampling** via **interpolation/approximation**
- From **statistics**, **data mining**: ⇒ example
  - **descriptive statistics** (compute the statistical moments, also robust, measures of outlyingness, detrending, *etc.*) ⇒ example
  - **embedding** (project into a lower-dim. space, *e.g.*, with PCA for a subset of the attribs., *etc.*) ⇒ example
- **Important**: **executed on demand**, after prev. vis.

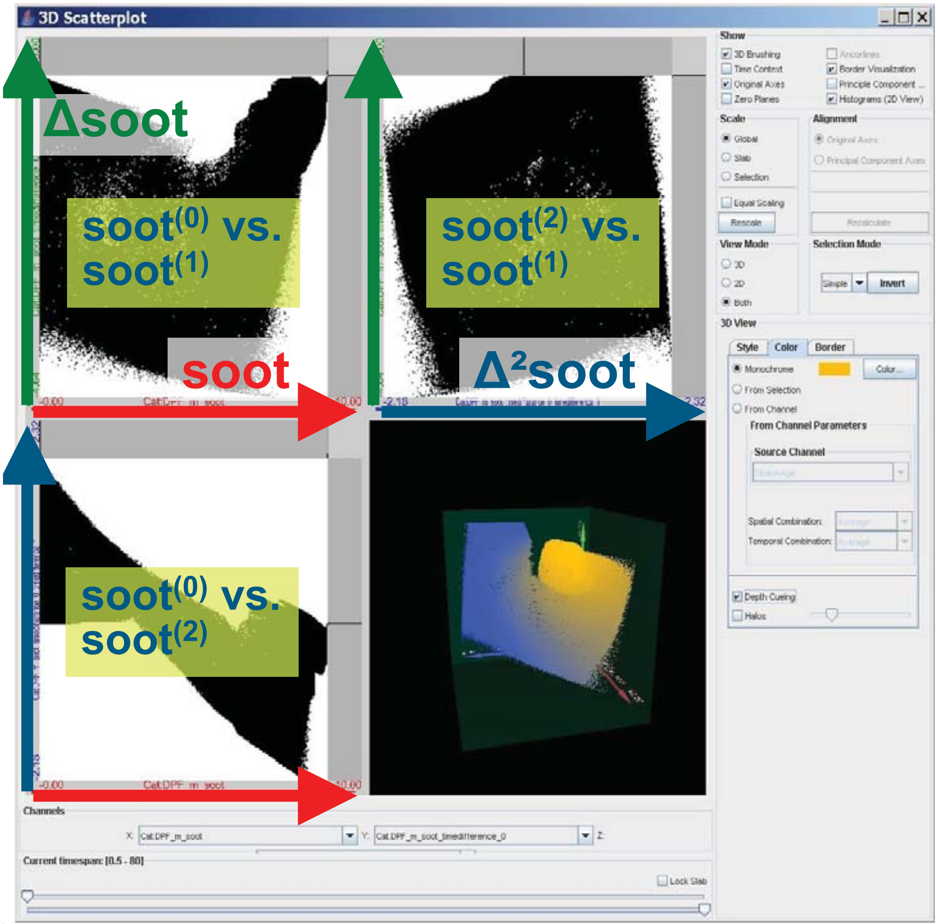
Curve Sketching

- Understanding function graphs:
  - special values of $f(x)$: zero, extremes, etc.
  - relative properties – positive/negative change $f'(x)$ local maxima/minima – $f'(x) = 0$
  - double-relative properties: the change of change e.g., local maxima ⇔ $f'(x) = 0$ & $f''(x) < 0$ inflection point – $f''(x) = 0$
- Remember your days in school:

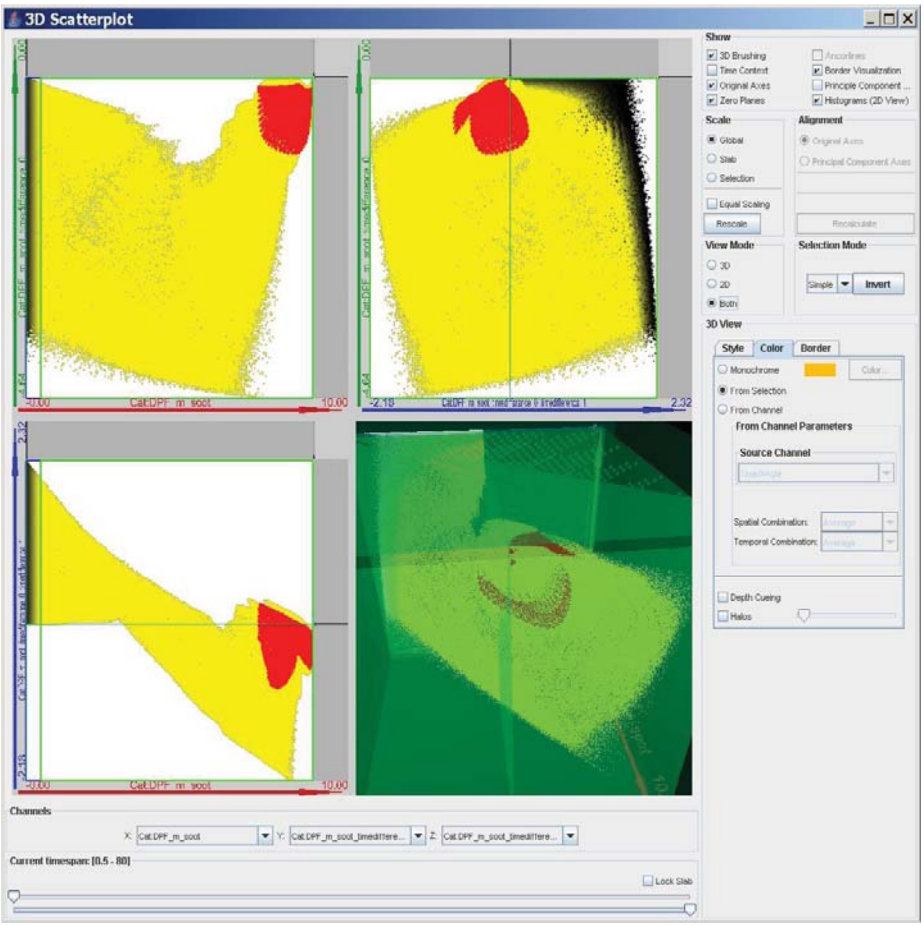


http://www.nipissingu.ca/calculus/tutorials/curves.html

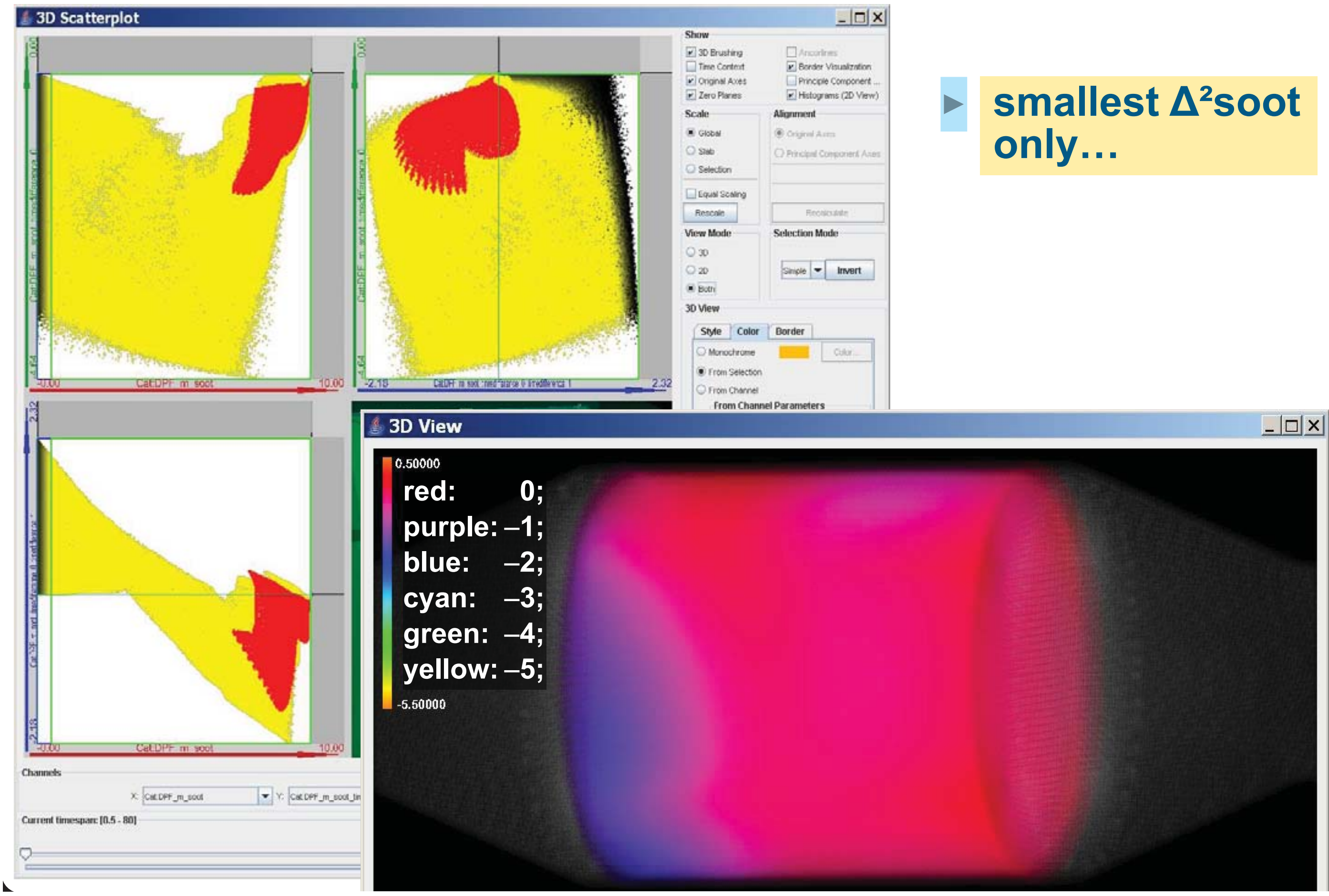
0-, 1st-, & 2nd-order Analysis



t=10s

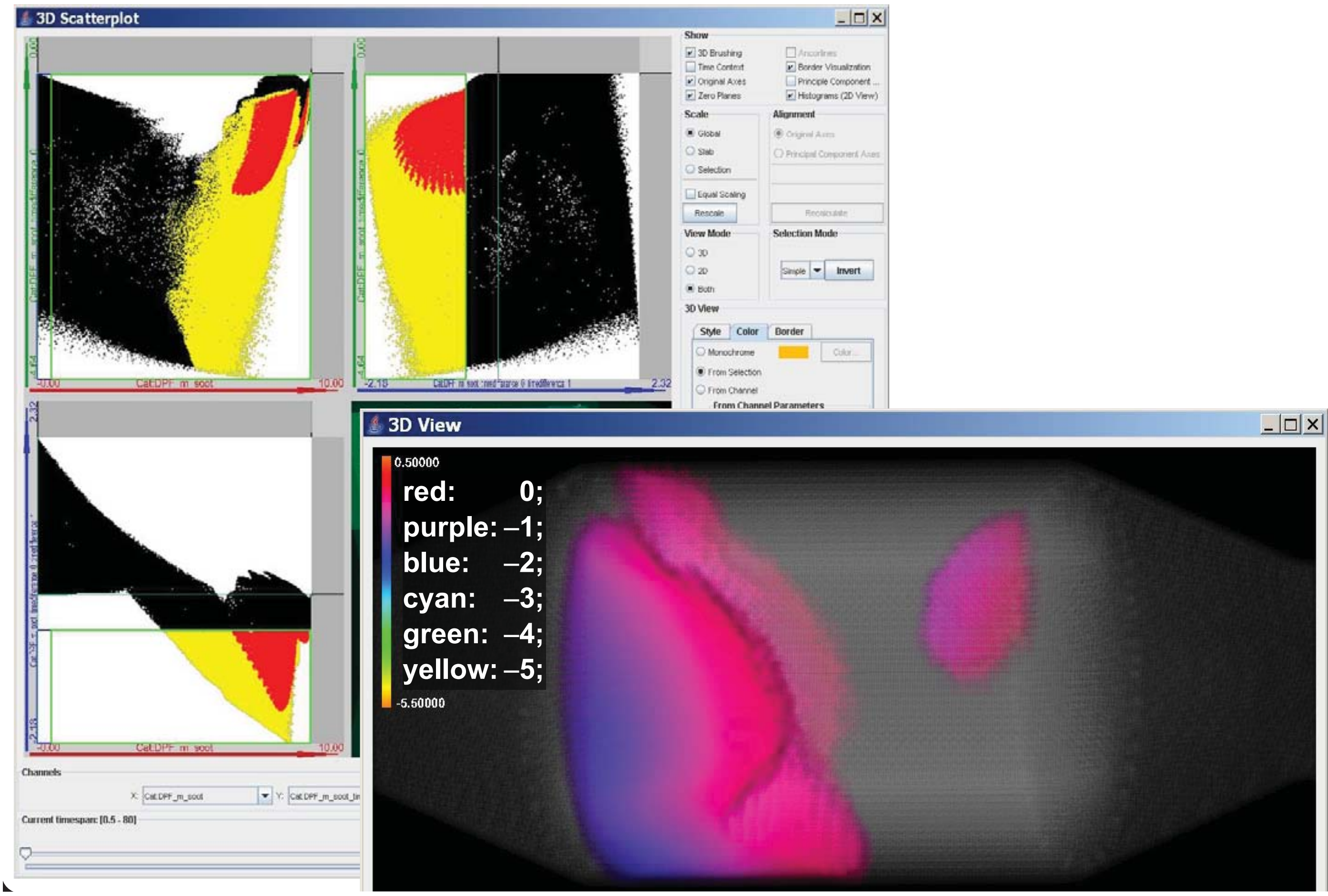


t=15s

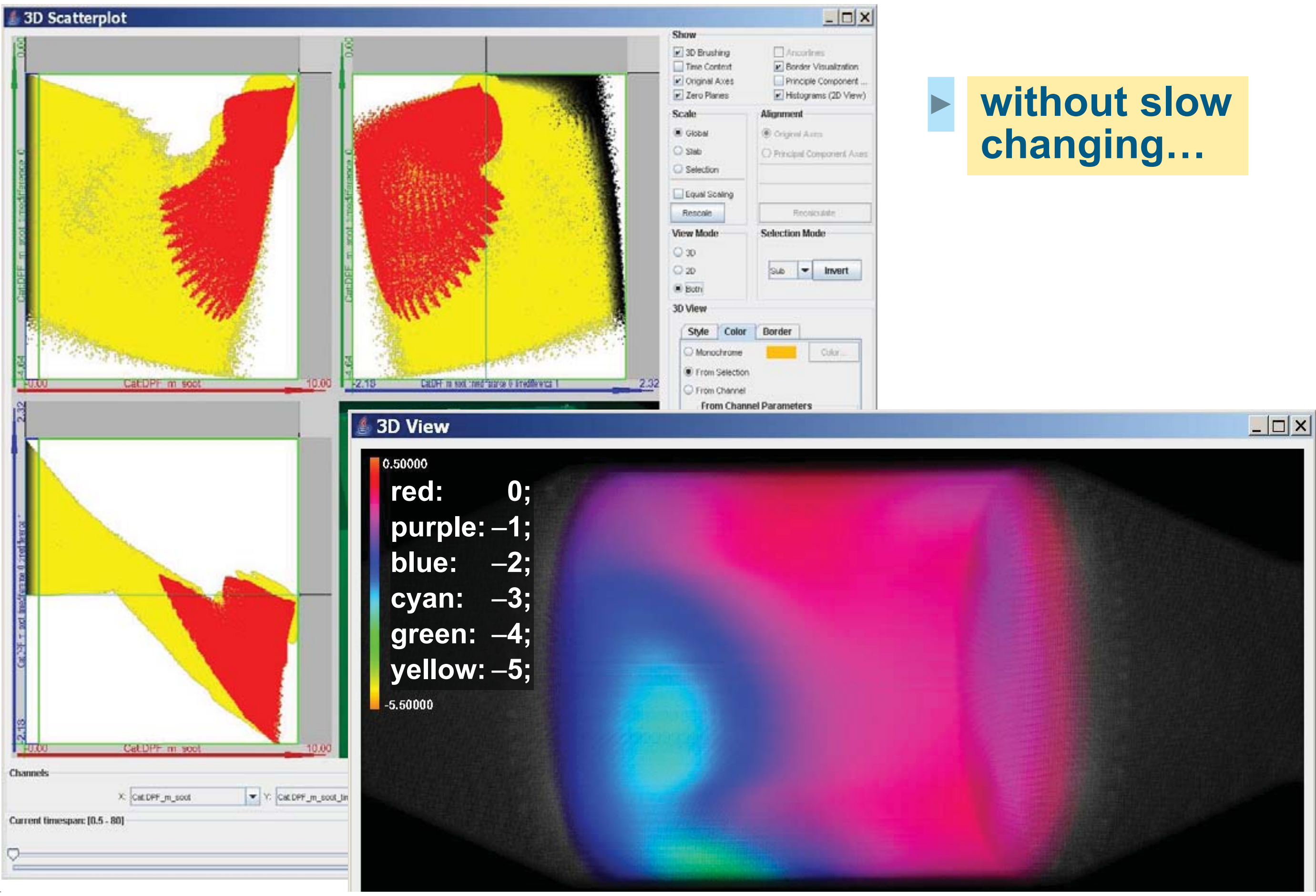


smallest Δ^2soot only…

t=15s, smallest Δ^2soot

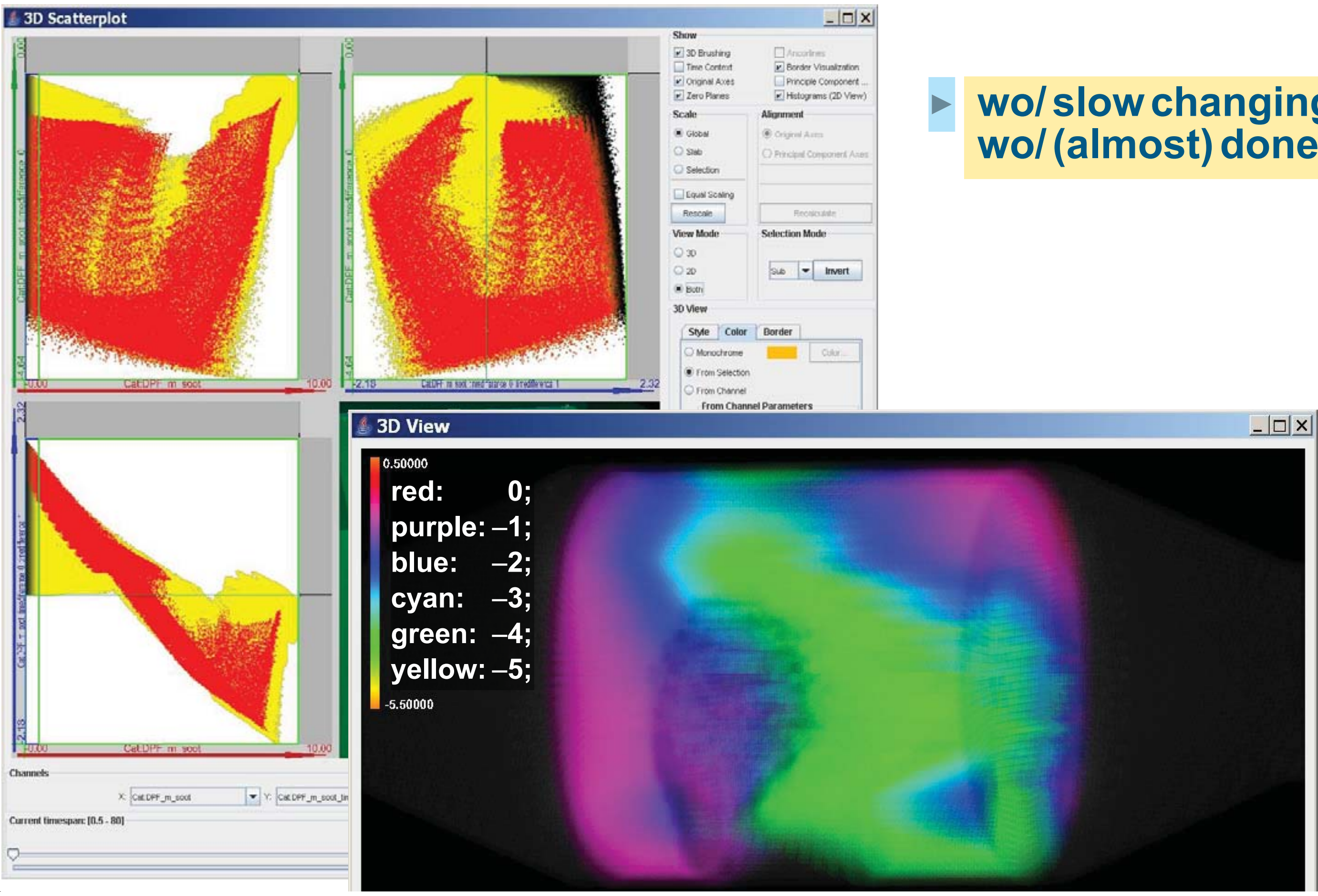


t=20s



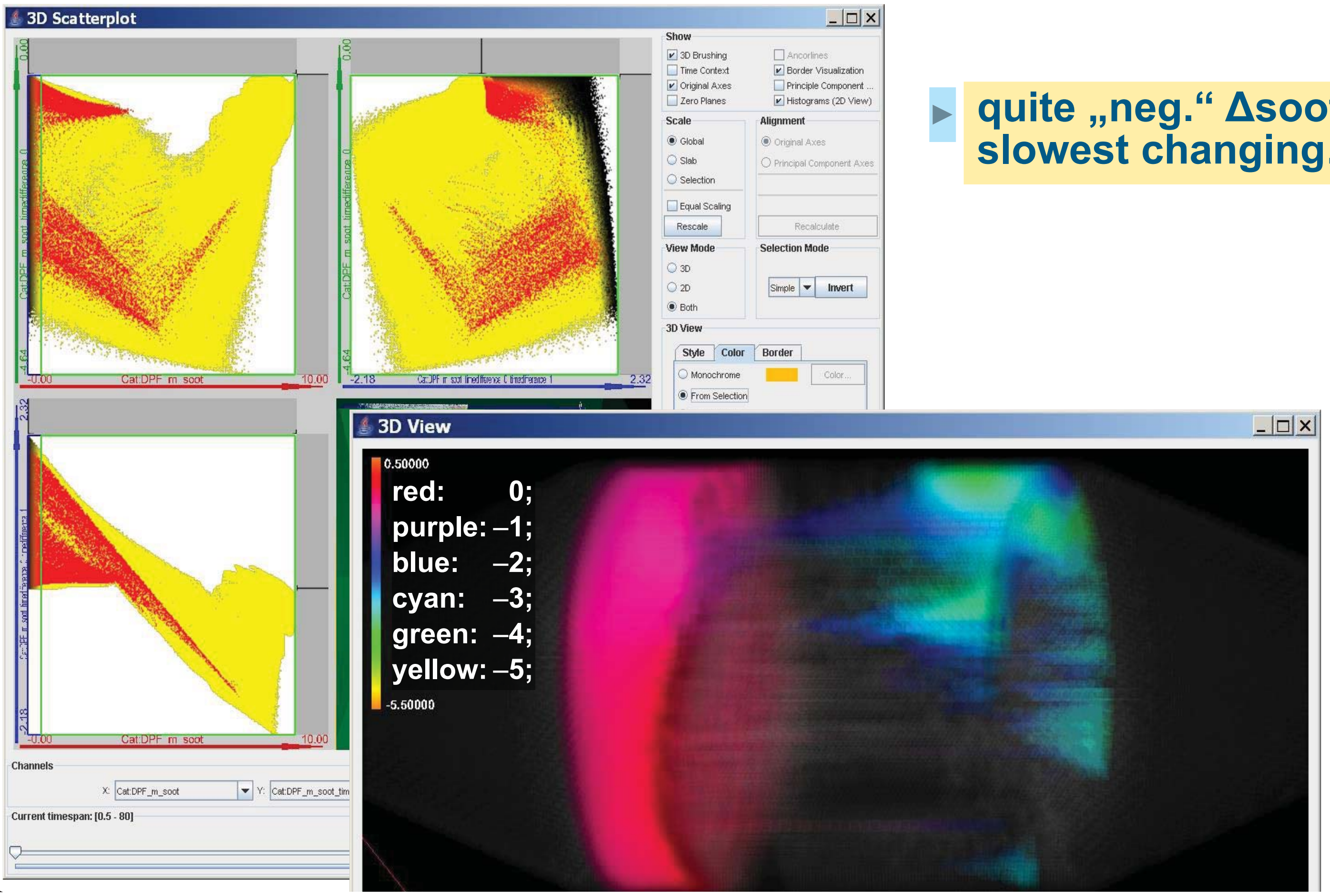
without slow changing…

t=30s



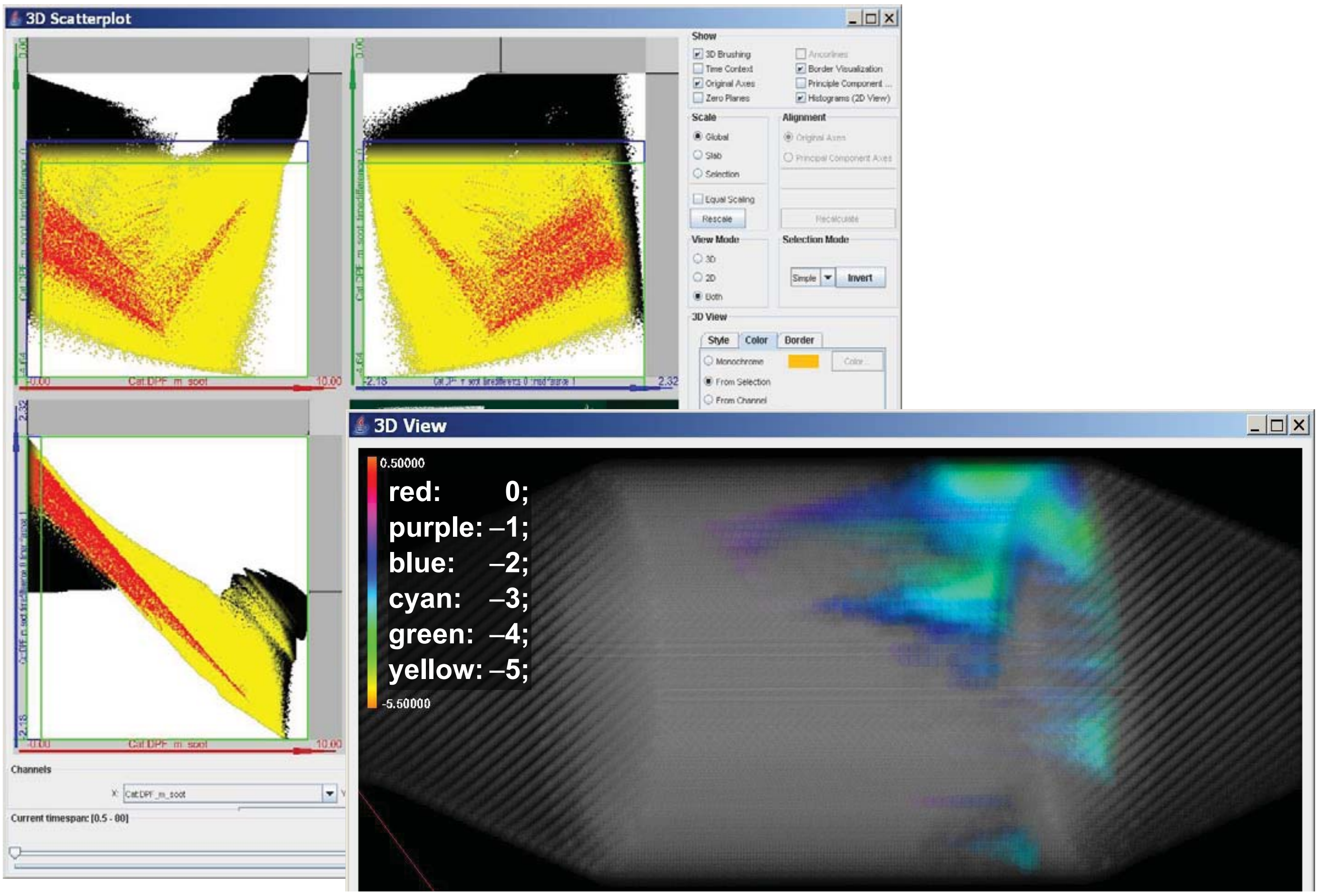
wo/ slow changing, wo/ (almost) done..

t=40s

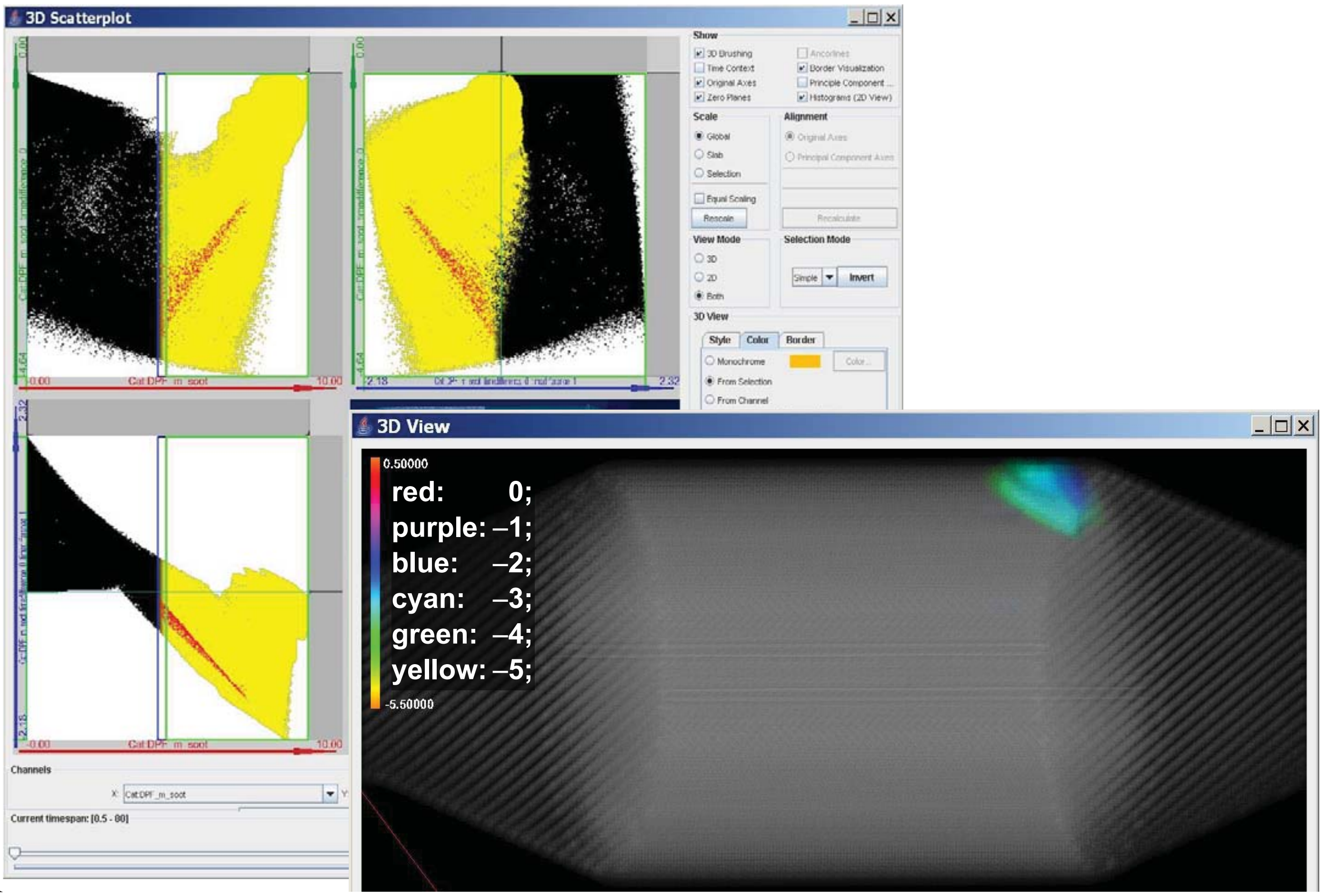


▶ quite „neg.“ Δsoot, slowest changing..

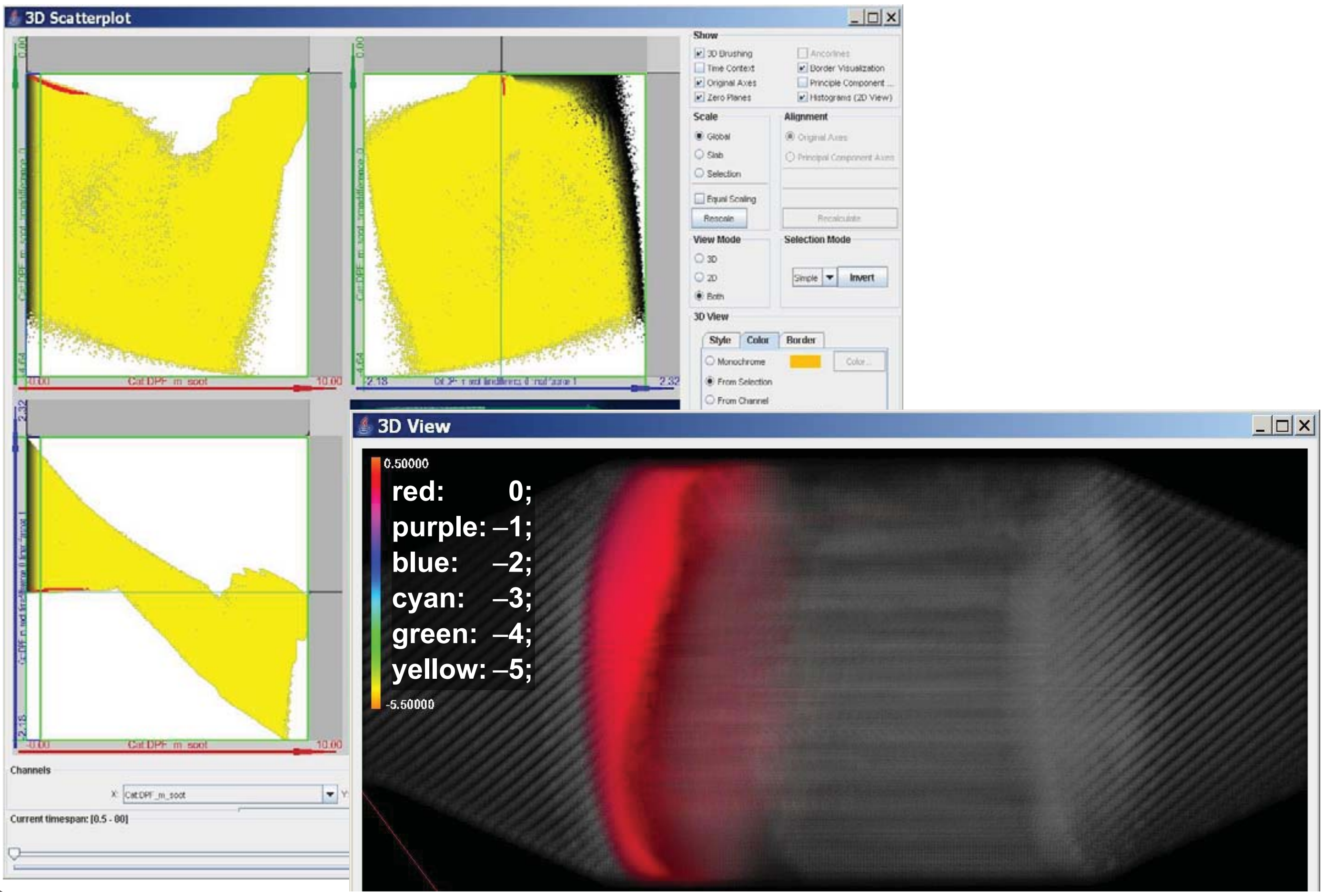
t=40s, “quite” negative Δsoot



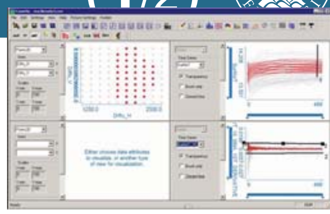
t=40s, slowest changing



t=60s



3rd-level IVA – Sample Iterations (1/2)

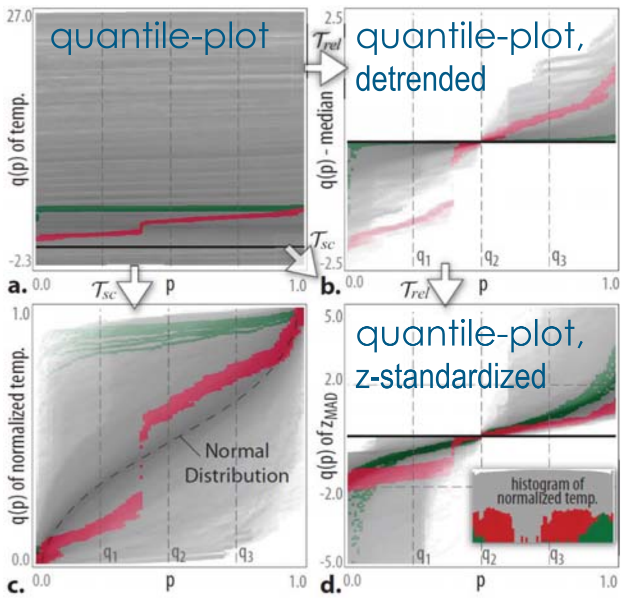


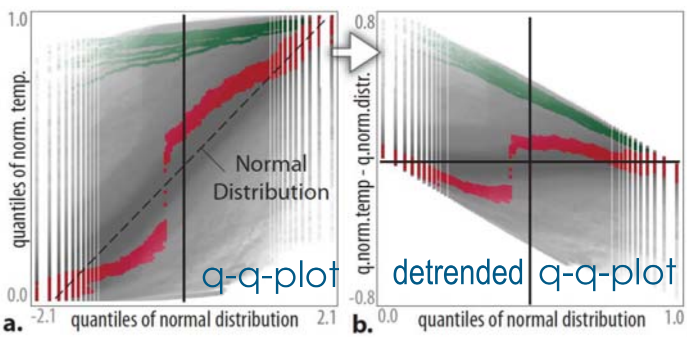
- The **Iterative Process of 3rd-level IVA**:
  - Example 1:
    - you look at some *temp. distribution over some region*
    - you are *interested in raising temperatures,* ***but not temperature fluctuations***
    - you use a **temporal derivate estimator**, *for ex.*, central differences $t_{change} = (t_{future} - t_{past})$ / len(future−past)
    - you plot t_{change}, *e.g.*, in a **histogram** and **brush** whatever change you are interested in
    - maybe you see some frequency amplification due to derivation, ***so you go back*** and
    - **use an appropriate smoothing filter** to *remove high frequencies from the temp. data*, leading to a derived new $\tau = t_{smooth}$ data attribute
    - selecting from a **histogram** of τ_{change} (computed like above) is then less sensitive to temperature fluctuations

Visualizing / analyzing *lots* of statistics

[Kehrer et al., TVCG 2011]

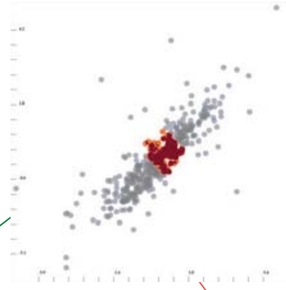
- Useful statistical measures include:
  - **moments** (μ, σ, …), **robust versions** (median, IQR, …)
  - **quartiles**, **octiles**, and **quantiles** $q(p)$
- Useful views lead to interactive visual analysis
  - **quantile-plot** $q(p)$ vs. p, *here for numerous* **x**
  - **detrending** (*e.g.*, $-q_2$), **normalization** (*e.g.*, z)

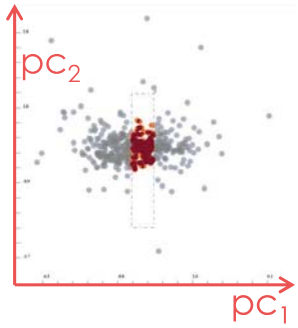


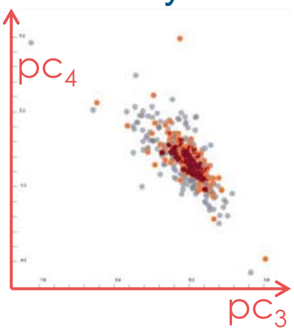


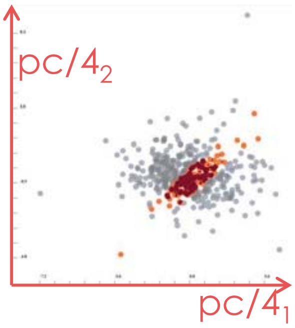
3rd-level IVA – Sample Iterations (2/2)

- The **Iterative Process of 3rd-level IVA**:
  - Example exploiting PCA:
    - you bring up a scatterplot of d_1 vs. d_2: (from an ECG dataset [Frank, Asuncion; 2010])
    - obviously, d_1 and d_2 are correlated, our interest: the **data center** *wrt. the main trend*
    - we ask for a (local) **PCA** of d_1 and d_2:
    - then we **brush the data center**
    - we get the wished selection
    - from here further steps are possible…, incl. study of other PCA-results, *etc.*









[IEEE Vis, 2008]

Brushing of Attribute Clouds for the Visualization of Multivariate Data

Heike Jänicke, Michael Böttinger, and Gerik Scheuermann, *Member, IEEE*

2D embedding: the attribute cloud

brushed cloud:

corresponding feature(s):

IVA – Levels of Complexity (4/4)

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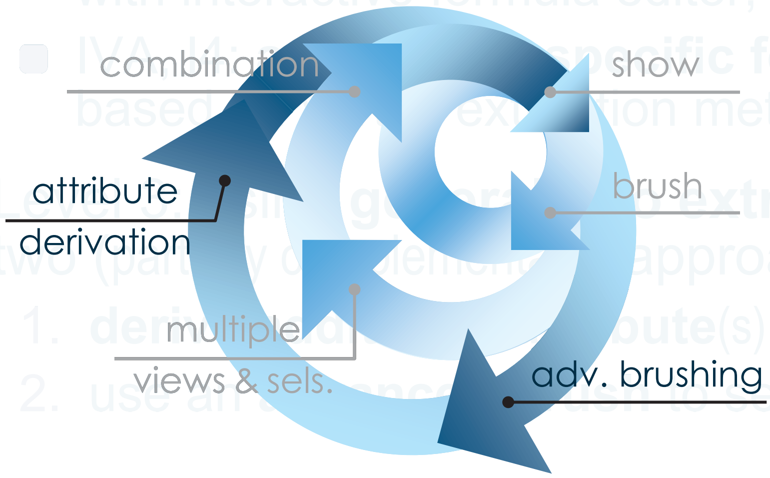
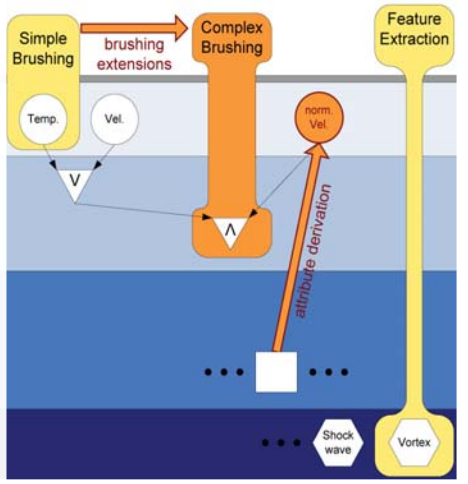
  - IVA, level 2: **logical combinations of brushes**, *e.g.*, utilizing the *feature definition language* [D leisch et al. 200] ✓
  - IVA, l. 3: **attribute derivation**; **advanced brushing**,



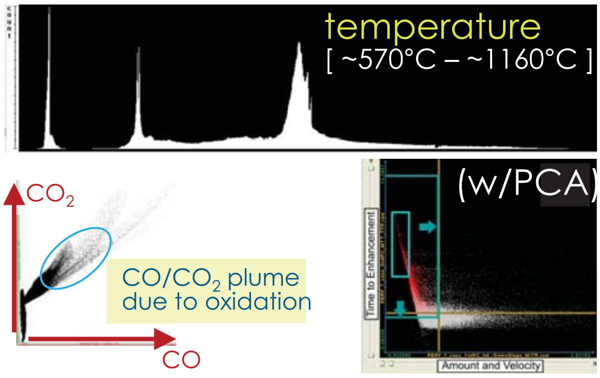


IVA – Levels of Complexity (4/4)

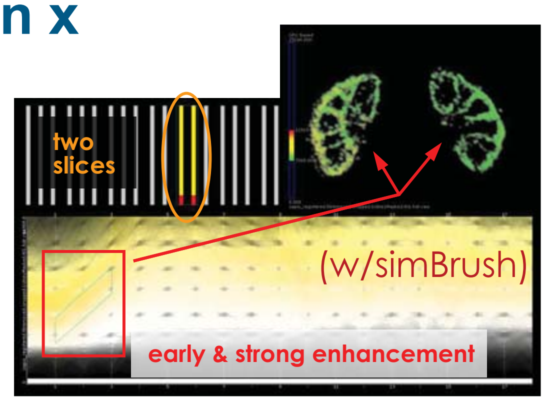
- A ***lot*** can be done with basic IVA, already! ✓ [pare rule
- **For more advanced** exploration/analysis **tasks**, we extend it (in seveal steps):
  - IVA, level 2: **logical combinations of brushes**, *e.g.*, utilizing the *feature definition language* [D leisch et al. 200] ✓
  - IVA, l. 3: **attribute derivation**; **advanced brushing**, with interactive formula editor; *e.g.*, similarity ✓
  - IVA, l4: **application-specific feature extrac**, based on vortex extraction methods for flow a
- Level 4: **application-specific procedures**
  - tailored solutions (for a specific problem)
  - “deep” information drill-down
  - *etc.*

Interactive Visual Analysis – delivery

- Understanding data **wrt. range d**
  - which distribution has data attribute $\mathbf{d}_i$?
  - how do $\mathbf{d}_i$ and $\mathbf{d}_j$ relate to each other? (**multivariate analysis**)
  - which $\mathbf{d}_k$ discriminate data features?



- Understanding data **wrt. domain x**
  - **where** are relevant features? (**feature localization**)
  - **which** values at specific **x**? (**local analysis**)
  - how are they **related to parameters**?



The Iterative Process of IVA…

…leads to an **interactive** & **iterative** workbench
for **visual data exploration & analysis**
(compare to **visual computing**, again)

- A really important question is:
  how fast is **one such loop**?
- Jean-Daniel Fekete, 2012:

Response Times

- 0.1 sec - animation, visual continuity, sliders
- 1 sec - system response, conversation break
- 10 sec - cognitive response

Stuart K. Card, George G. Robertson, Jock D. Mackinlay. The information visualizer, an information workspace. *Proc. CHI '91*, 181-186, 1991.

- Beyond 20 sec, users wait and loose attention
  - Forget their goals and plans
  - **Progress bar needed!**

TABLE 3. HUMAN TIME CONSTANTS FOR TUNING COGNITIVE CO-PROCESSOR

TIME CONSTANT	VALUE	REFERENCES
Perceptual processing	.1 s	[5]
Immediate response	1 s	[21]
Unit task	10 s	[5,21]

THE INFORMATION VISUALIZER, AN INFORMATION WORKSPACE

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CHI '91

Dagstuhl Seminar Talk

Categories of Interaction Pace

- **Separate ► unit task ► immediate ► continuous**
  - separate: offline processing
  - unit task [Card et al., '91]: ≈10s – before attention breaks!
  - immediate: ≈1s – maintains an interplay, a conversation
  - continuous: ≈0.1s – smooth in the eye (perception)

The unit task time constant. Finally, we seek to make it possible for the user to complete some elementary task act within 10 sec (say, 5~30 sec) [5,21], about the pacing of a point and click editor. Information agents may require considerable time to complete some complicated request, but the user, in this paradigm, always stays active. He or she can begin the next request as soon as sufficient information has developed from the last or even in parallel with it.

The immediate response time constant. A person can make an unprepared response to some stimulus within about a second [21]. If there is more than a second, then either the listening party makes a backchannel response to indicate that he his listening (e.g., "uh-huh") or the speaking party makes a response (e.g., "uh...") to indicate he is still thinking of the next speech. These serve to keep the parties of the interaction informed that they are still engaged in an interaction. In the Cognitive Co-processor, we attempt to have agents provide status feedback at intervals no longer than this constant. Immediate response animations (e.g., swinging the branches of a 3D tree into view) are designed to take about a second. If the time were much shorter, then the user would lose object constancy and would have to reorient himself. If they were much longer, then the user would get bored waiting for the response.

The perceptual processing time constant. The Cognitive Co-processor is based on a continuously-running scheduler loop and double-buffered graphics. In order to maintain the illusion of animation in the world, the screen must be repainted at least every .1 sec [5]. The Cognitive Co-processor therefore has a *Governor* mechanism that monitors the basic cycle time. When the cycle time becomes too high, cooperating rendering processes reduce the quality of rendering (e.g., leaving off most of the text during motion) so that the cycle speed is increased.

- Really important differences on the user side!

The Iterative Process of IVA…

…leads to an **interactive** & **iterative** workbench for **visual data exploration & analysis** (compare to **visual computing**, again)

- Different **levels of complexity** (show & brush, logical combinations, advanced brushing & attribute derivation, *etc.*)…

…lead to according **iteration frequencies**:

- on level 1: **smooth interactions, many fps,** for example during linking & brushing
- on level 2: **interleaved fast steps of brush ops.,** for example when choosing a logical op. to cont. with
- on level 3: **occasionally looking at a progress bar,** for example when computing some PCA, *etc*.

- These frequencies **limit the spectrum** of usable tools

➢ New res. work will help to **extend this spectrum**!

The Iterative Process of IVA…

…is a **very useful methodology** for **data exploration & analysis**

…is **very general** and can be (has already been) applied to **many different application fields** (in this talk the focus was on scientific data)

…**meets scientific computing** as a complementary methodology (with the **important difference** that in IVA the **user** with his/her **perception/cognition** is **in the loop** at **different frequencies**, also many fps)

…is **not yet fully implemented** (we've done something, e.g., in the context of **SimVis**, **ComVis**, *etc.*) – from here: different possible paths, incl. InteractiveVisualMatlab, IVR, *etc.*)

Acknowledgements

You!

We'd like to hire
- 1 PostDoc

Luis Gustavo *et al.*!

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UNIVERSITY OF BERGEN

Upcoming Job Opportunities in Visualization at the University of Bergen

The visualization research group at the University of Bergen's Department of Informatics, Norway (UiB), is preparing the announcement of two open positions. We invite all potentially interested applicants to contact us directly for further details.

- 1 PhD Fellowship (4 years):
  We are looking for a highly motivated individual with interest in the visualization of medical data. Suitable applicants should have a background in visualization, human-computer interaction, and/or computer graphics and very good programming skills. Since eligible candidates are required to have completed their Master's degree prior to the upcoming job announcement, we ask all interested candidates to contact us as soon as possible.
  Contact: Prof. Stefan Bruckner (stefan.bruckner@uib.no)
- 1 Postdoctoral Fellowship (4 years):
  We are looking for a promising scholar to fill a postdoctoral fellowship in visualization. This strategic position is not associated with a specific research project, but meant to strengthen the core visualization research activities in Bergen – considerable flexibility in terms of filling this appointment is envisioned. Applicants should have a completed PhD degree in visualization or a closely related subject, a strong publication record, a strong interest in high-quality research and also substantial interest in teaching of visualization and related topics.
  Contact: Prof. Helwig Hauser (helwig.hauser@uib.no)

The University of Bergen

The University of Bergen, Norway (UiB), has approximately 14,500 enrolled students and 3,200 faculty and staff. Six faculties cover most of the traditional university disciplines. Within the faculties there are 40 different specialized departments, multi-disciplinary research centers, and institutes. The University is engaged in the European Union's Framework programs for research and technological development and has been designated as a European Research Infrastructure and a Research Training Site in several scientific fields. Since 1997 more than 500 European researchers (professors, senior researchers, post docs and PhD candidates) have visited Bergen on EU grants, making UiB one of the most international universities, setting out to attract both established and junior scientists to contribute to research teams and work in multidisciplinary research groups. **Further information:** http://www.uib.no/en

The Visualization Group

The Department of Informatics at UiB is a dynamic international environment. The visualization research group was established in 2007 and focuses on new solutions for the effective and efficient visualization of large and complex data from measurements (e.g., from medical imaging or from seismic/sonar sensors), computational simulation (e.g., from computational fluid dynamics), or from analytic modeling (e.g., in the form of differential equations) for the purpose of data exploration, analysis, and presentation. Despite being a still relatively young group, the recent ten-year evaluation of all 62 informatics research groups in Norway conducted by an international evaluation panel on behalf of Norway's Research Council, found that the group's "(...) accomplishments made so far are excellent." and concluded with an overall assessment of "very good to excellent". **Further information:** http://www.ii.uib.no/vis

The City of Bergen

Bergen is Norway's second largest city with over 260,000 inhabitants and is located in the county of Hordaland on the south-western coast of Norway. Known as the "gateway to the fjords", Bergen is surrounded by spectacular scenery. As one of the offices of the Hanseatic League, Bergen was for several hundred years the center of prosperous trade between Norway and the rest of Europe. Today, Bergen is a lively and vibrant city with an international flair. Every semester the city with its university and colleges are proud and enthusiastic to welcome students from all over the world. Bergen is one of the most popular student cities in Scandinavia with 30,000 students in many different educational institutions. Its international atmosphere, together with the fact that Norway has been voted #1 in standard of living by the UNDP's Human Development Index for several years, make Bergen a very attractive place for life and study. **Further information:** http://www.visitbergen.com/en