Interactive Visual Analysis of Rich Scientific Data

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HH, ii.UiB.no/vis

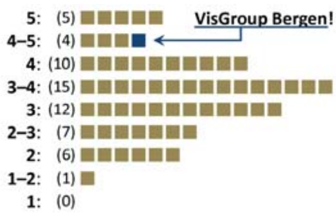
HH: prof. in visualization (vis)
@ Dept. of Informatics (ii)
@ Univ. of Bergen (UiB)

UiB VisGroup

- 2007: group of 3: 
- 2009: larger projects start
- 2011: EuroVis in Bergen

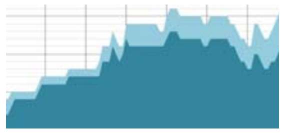
- 2013: new prof.: 

SemSeg
ILLUSTRASOUND
GEO ILLUSTRATOR
PHYSIO ILLUSTRATION



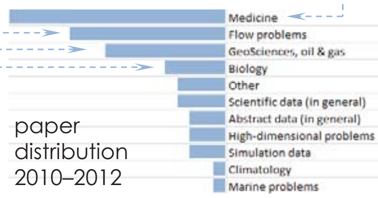
[ranking from NFR's 10-year evaluation in 2011/2012]

ii.UiB.no/vis Research



➢Application-oriented basic research in visualization:

1. Researched visualization methodology (how to visualize)
   - ➢ **Interactive Visual Analysis, *n*D data** (H. Hauser *et al.*)
   - ➢ **Visual Knowledge Discovery, 3D data** (St. Bruckner *et al.*)
   - ➢ **Illustrative Visualization** (I. Viola *et al.*)
2. Applications at which this research is oriented (for whom)
   - ➢ **Medical Visualization** (partner in MedViz Bergen, *etc.*)
   - ➢ **GeoSciences / Oil & Gas** (*e.g.*, financed by Statoil's Akademiaavtale)
   - ➢ **Biology / Bioinformatics** (with CBU@ii *et al.*)
   - ➢ **Fluid Dynamics** (in collab. with FFI.no, for ex.)
   - ➢ **Engineering** (visual analysis of simulation data)



ii.UiB.no/vis PhDs (11 so far)

Daniel Patel (Oct. 2009):
Expressive Vis. & Rapid Interpr. of Seismic Volumes

Jean-Paul Balabanian (Jan. 2010):
Multi-Aspect Vis.: from Linked to Integrated Views

Johannes Kehrer (May 2011):
IVA of Multi-faceted Scientific Data

Ove Daae Lampe (Nov. 2011):
IVA of Process Data

Armin Pobitzer (June 2012):
IVA of Time-dependent Flows

Paolo Angelelli (June 2012):
Visual Expl. of Human Physiology

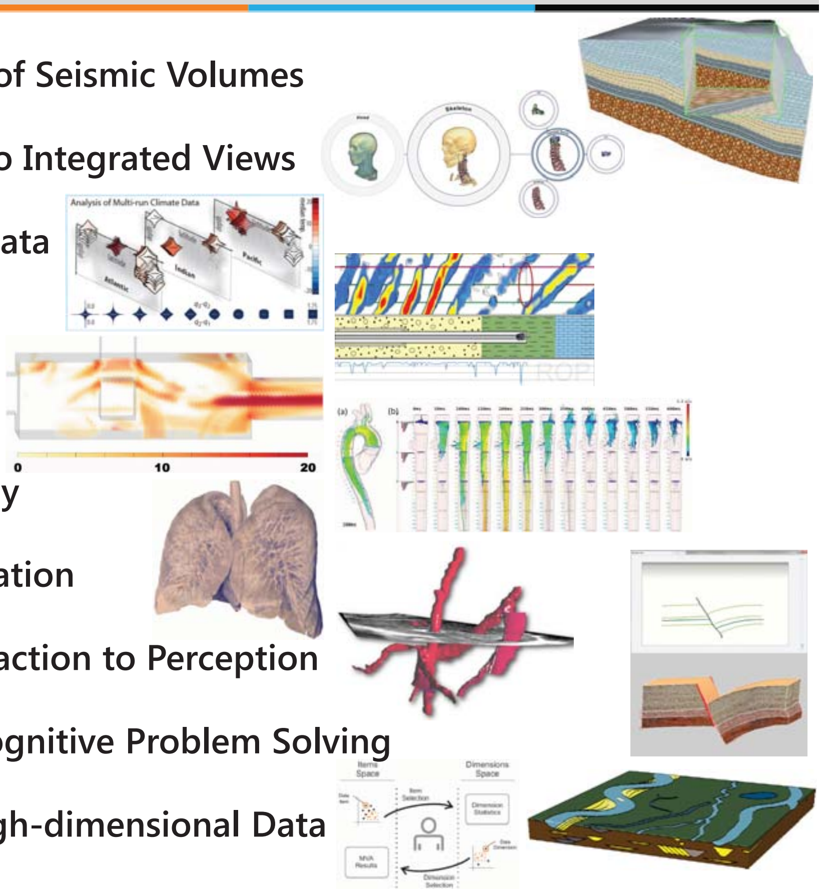
Veronika Šoltészová (Oct. 2012):
Perception-Augmenting Illumination

Åsmund Birkeland (May 2013):
Ultrasonic Vessel Vis.: From Extraction to Perception

Endre Lidal (May 2013):
Sketch-based Storytelling for Cognitive Problem Solving

Çağatay Turkay (Nov. 2013):
Interactive Visual Analysis of High-dimensional Data

Mattia Natali (Sept. 2014):
Sketch-based Mod. & Conceptual Vis. of Geomorphological Processes for …



Interactive Visual Analysis

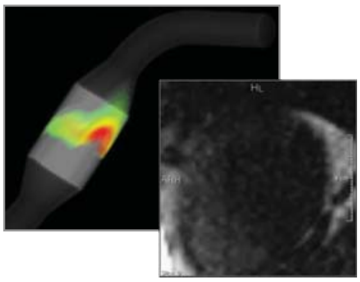
Helwig Hauser
University of Bergen

Interactive Visual Analysis (IVA)

- Given data –
  too much and/or *too complex* to be shown at once:
- 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**

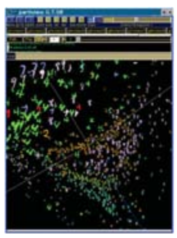
Interactive Visual Analysis ↔ Visual Analytics

- **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**…

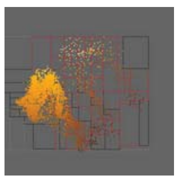


Integrating Interaction & Computation

- **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**:
  - **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]

Target Data Model: "Scientific Data"

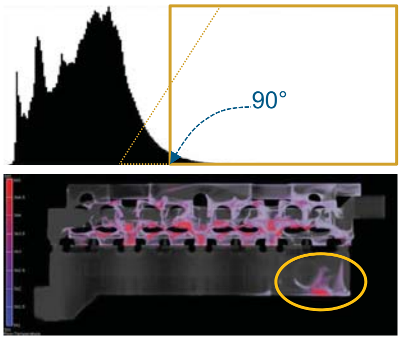
- **Characterized** by a combination of
  - **independent variables**, like **space** and/or **time** (cf. **domain**)
  - and **dependent variables**, like **pressure**, **temp.**, etc. (cf. **range**)
- So we can think of this type of data as **given as d(x)** with **x** ↔ **domain** and **d** ↔ **range** – 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 of Scientific Data

- **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**
- 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.*

The Iterative Process of IVA

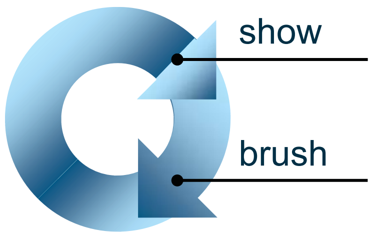
- Loop / bundling of *two complementary parts*:
  - **visualization** – show to the user!
    Something new, or something due to interaction.
  - **interaction** – tell the computer!
    What is interesting? What to show next?
- Basic example (**show – brush** – show – …), cooling jacket context:
  1. 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, …

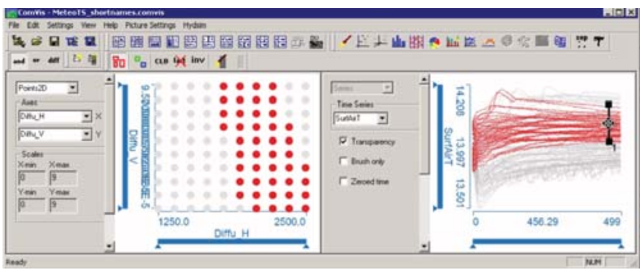
Show & Brush (basic IVA)

- **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

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

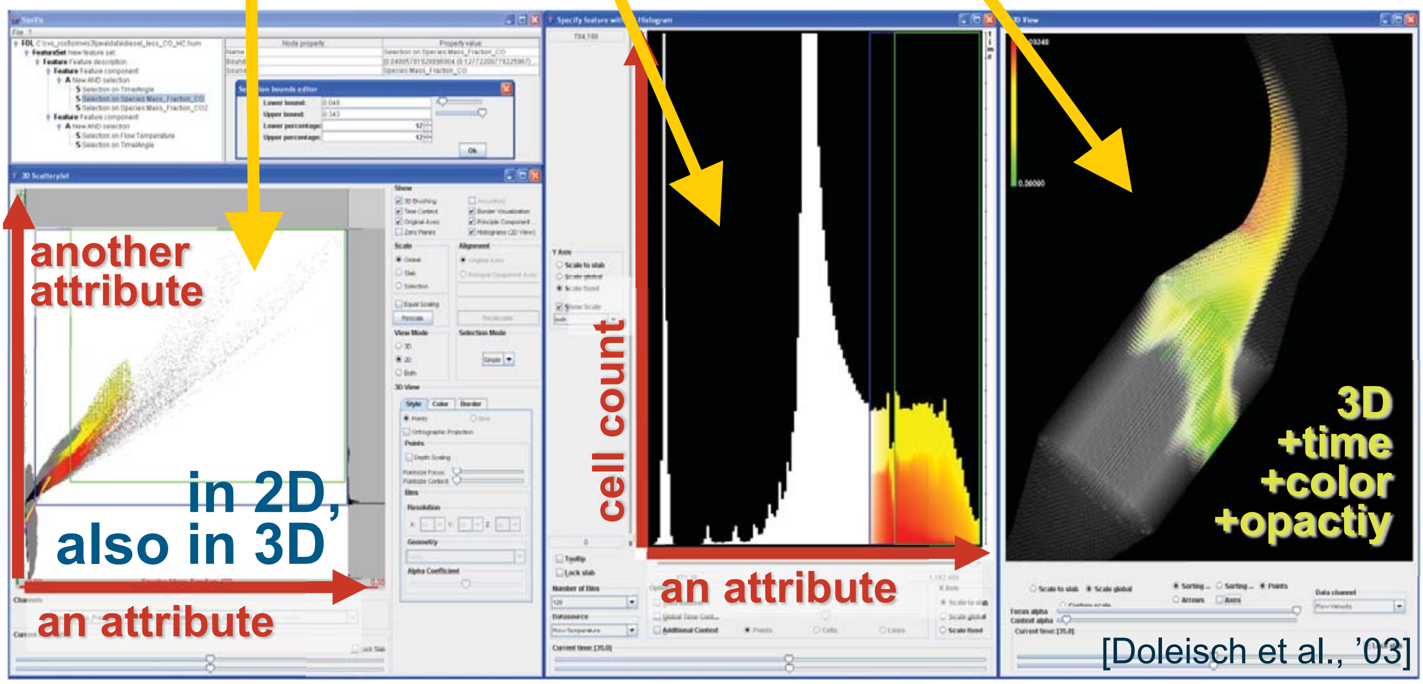
- Allows for **different IVA patterns** (wrt. domain & range)

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!

IVA: Multiple Views

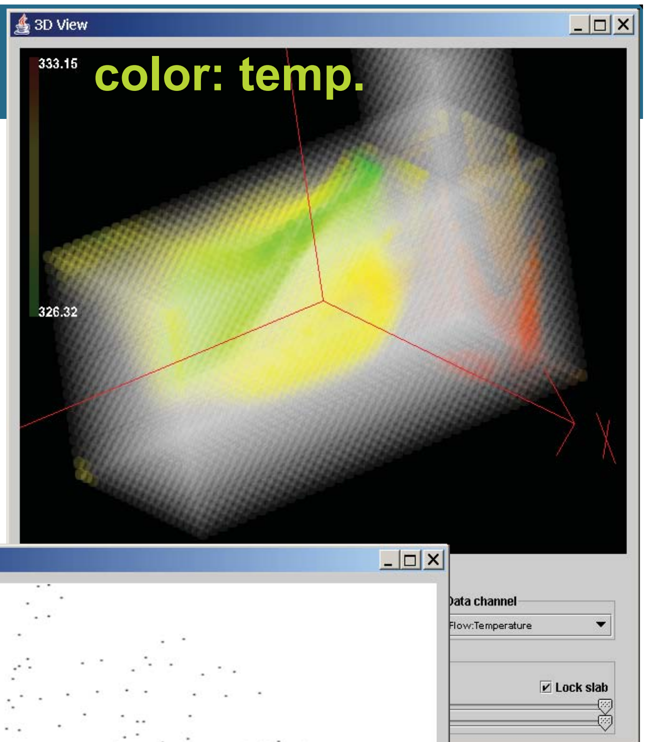
- One dataset, but multiple views
- Scatterplots, histogram, 3D(4D) view, etc.



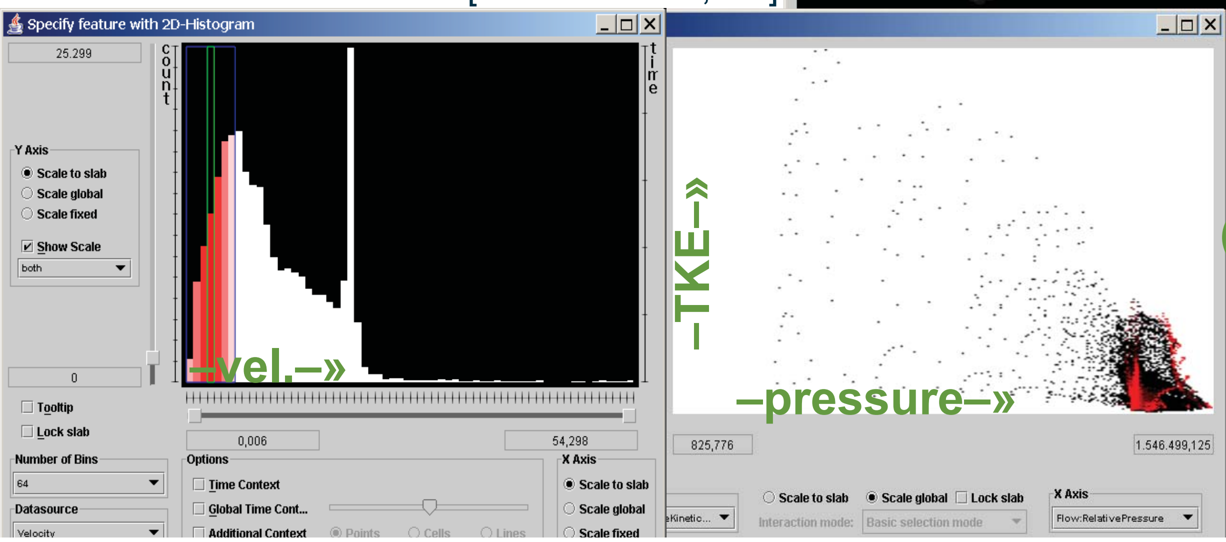
[Doleisch et al., '03]

Interactive Brushing

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



[Doleisch et al., '03]

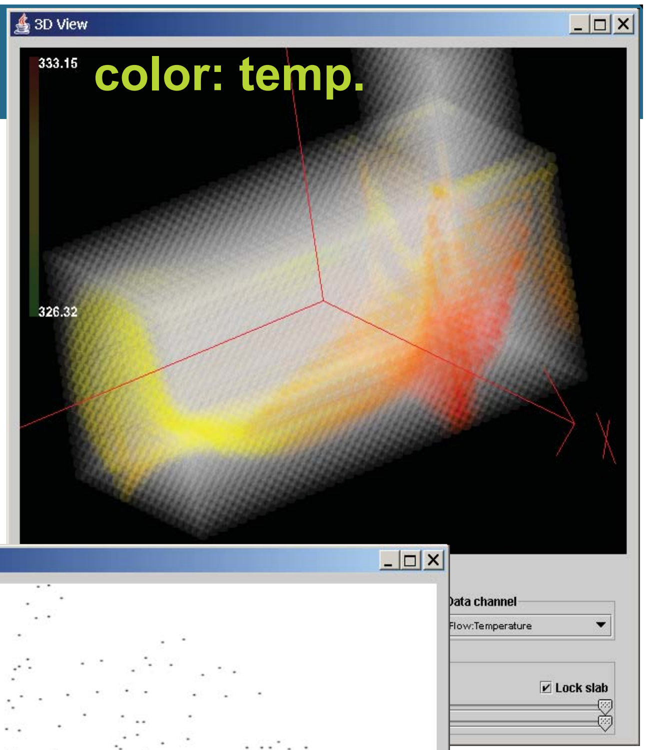


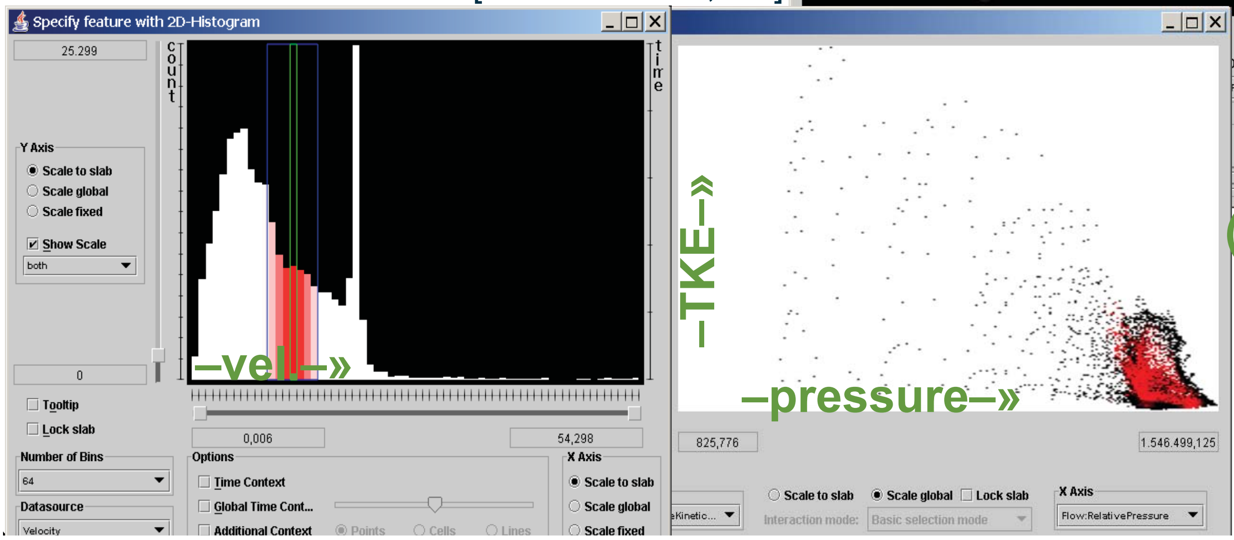
(SimVis)

Interactive Brushing

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

[Doleisch et al., '03]

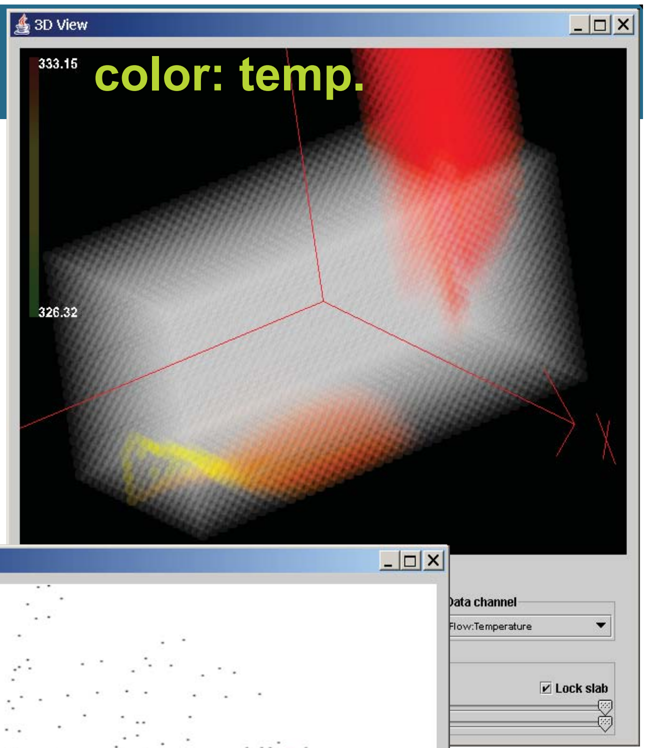


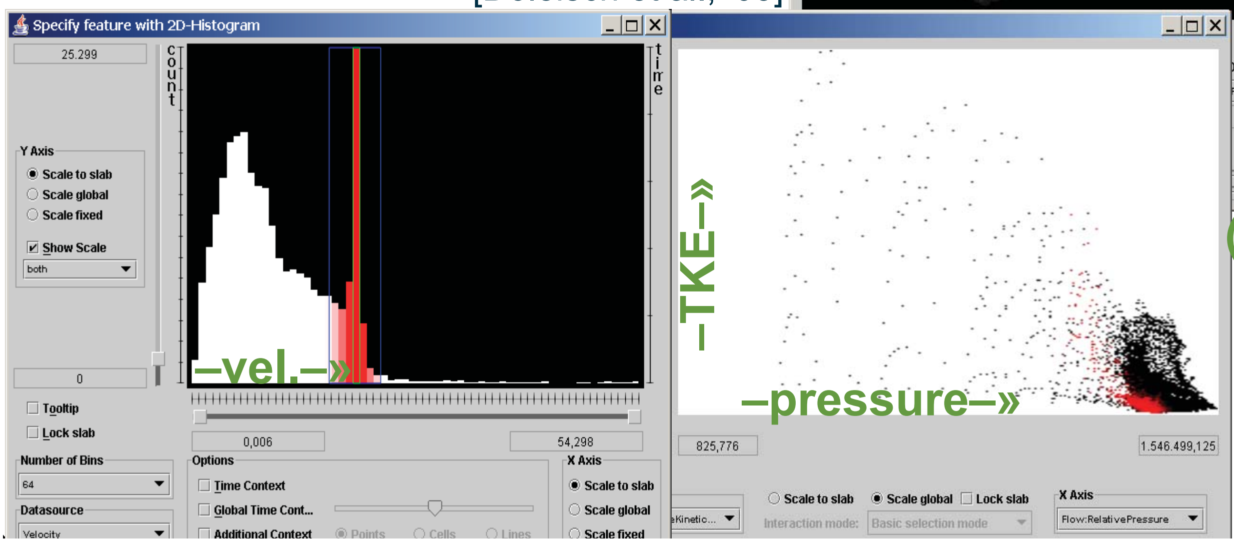


Interactive Brushing

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

[Doleisch et al., '03]



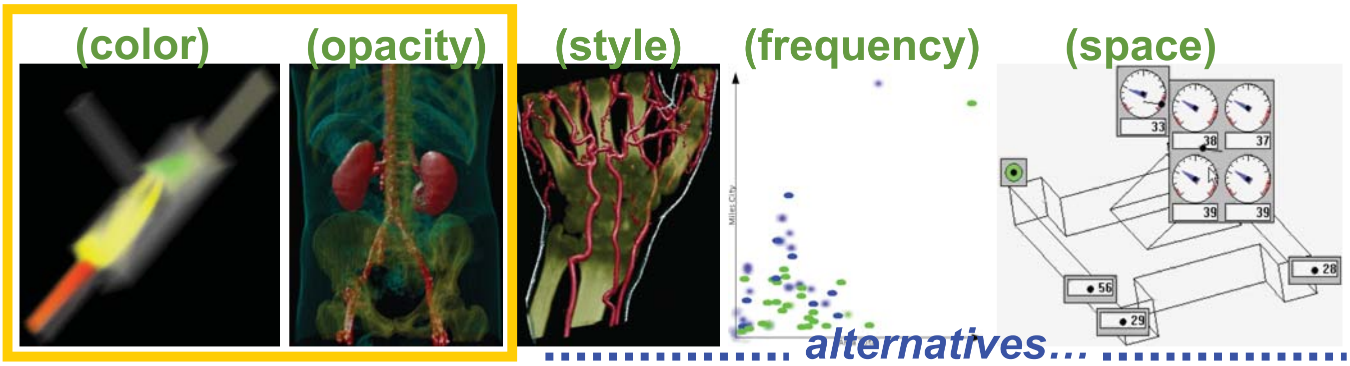


IVA: Focus+Context Visualization

- 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]

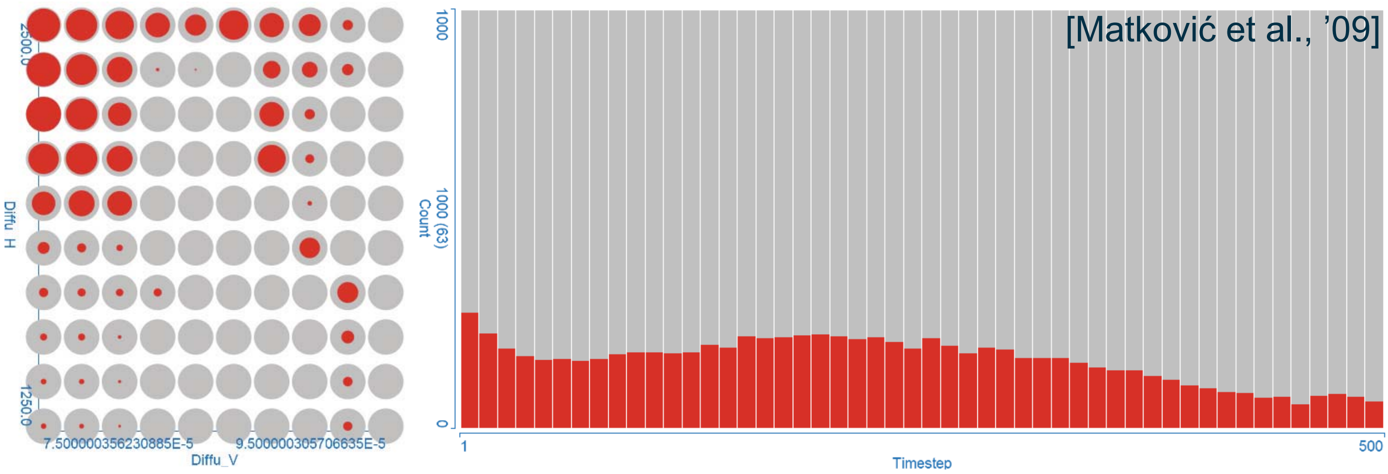
[Hauser… 2001, 2003]



F+C Visualization in IVA Views

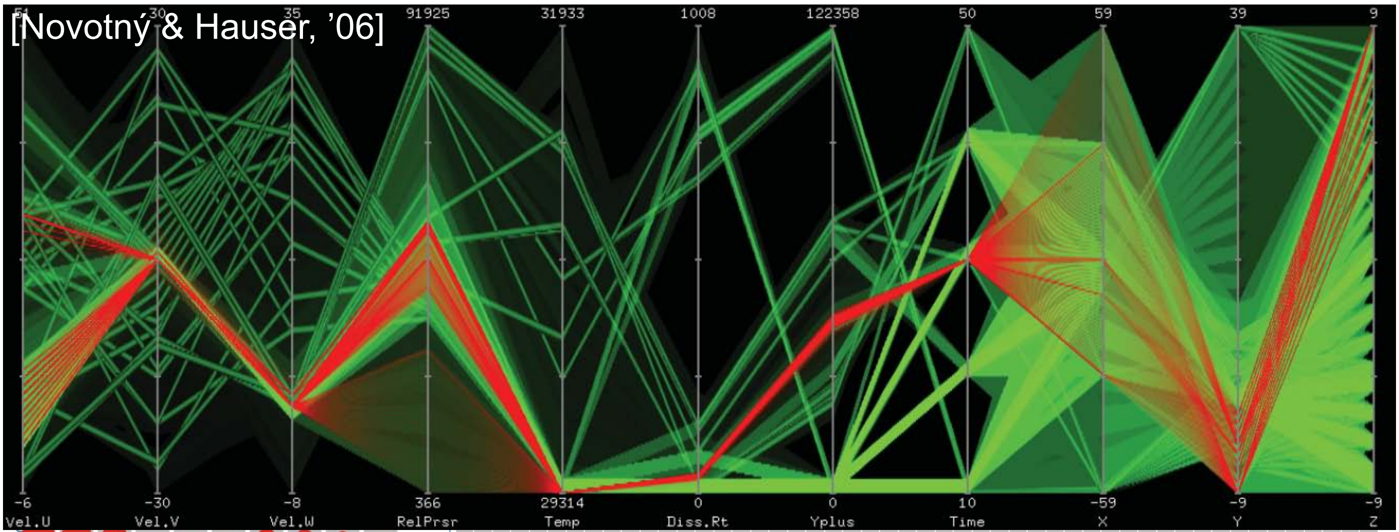
- Colored vs. gray-scale visualization
- Opaque vs. semi-transparent visualization

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

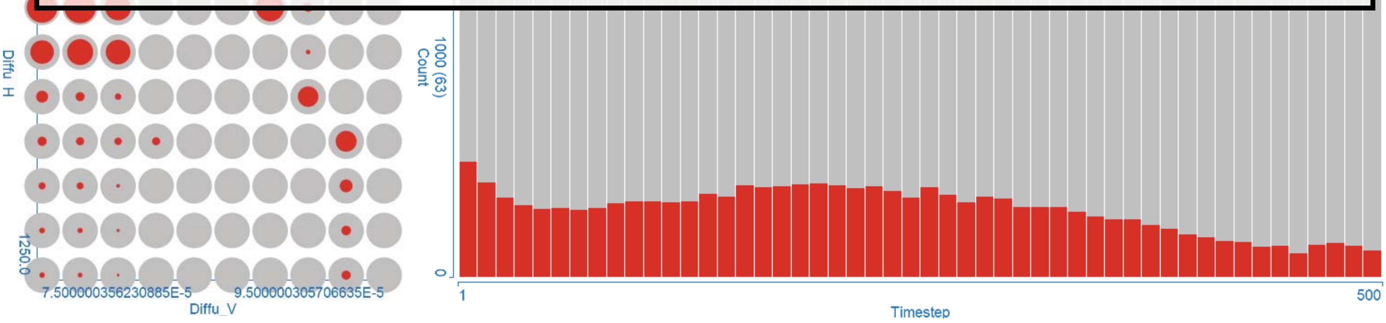


F+C Visualization in IVA Views

[Novotný & Hauser, '06]

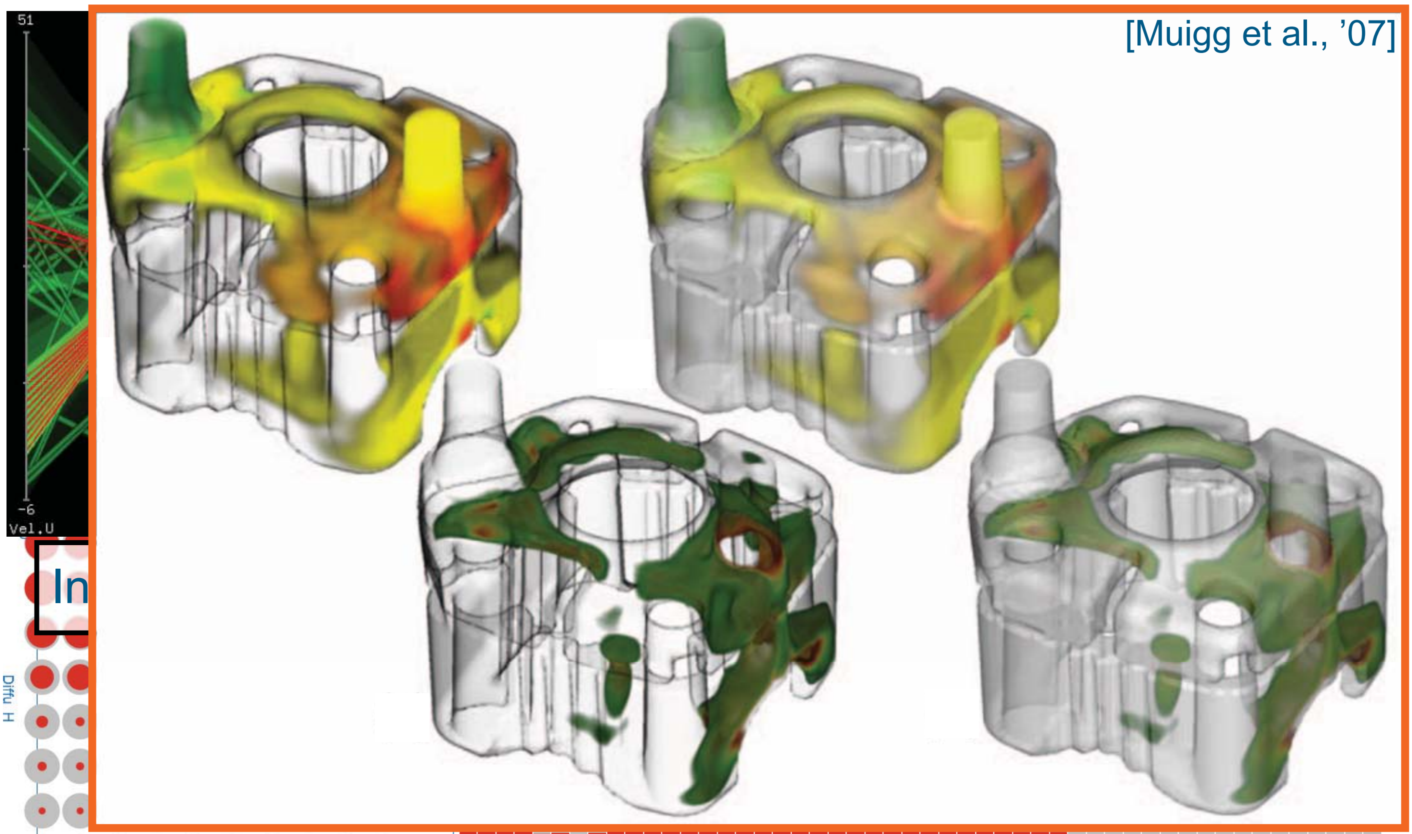


In parallel coordinates (above): brushed data in red & over …



F+C Visualization in IVA Views

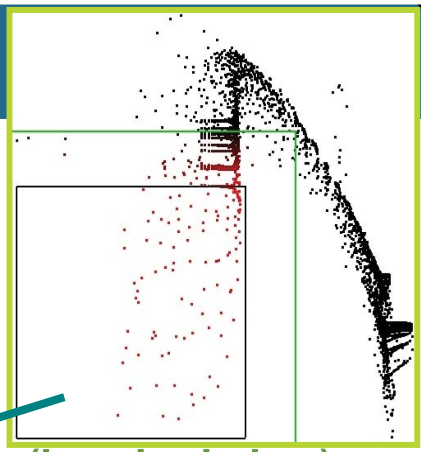
[Muigg et al., '07]



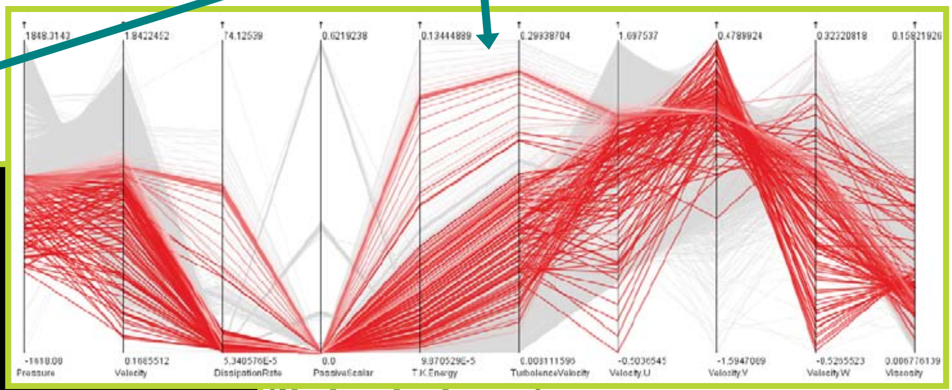
In 3D (above): less transp. & colored, in illustrative context …

IVA: Linked Views

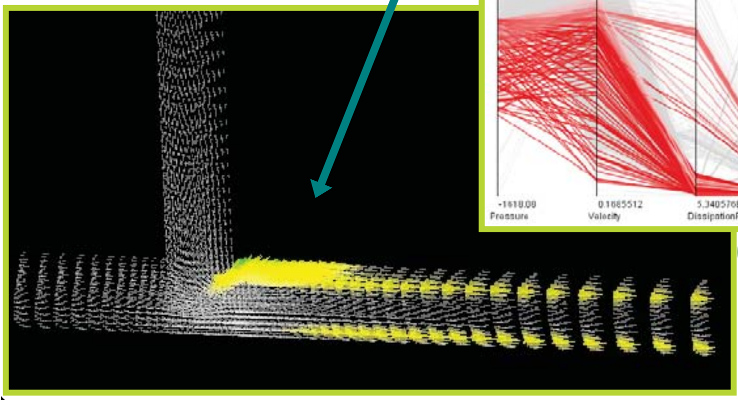
- Brushing: mark data subset as especially intersting
- Linking: enhance brushed data in linked views consistently (F+C)



(brushed view)



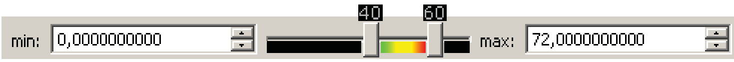
(linked views)



[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



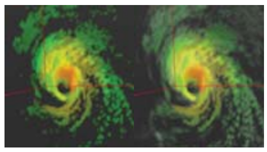
x	*y*	*d1*	*d2*	*doi*
0	0	17,20	-0,22	0,00
1	0	12,10	0,10	0,00
2	0	7,70	0,45	0,00
3	0	2,10	0,90	0,00
0	1	24,10	0,02	0,00
1	1	21,90	0,36	0,00
2	1	15,50	0,87	0,74
3	1	11,10	1,20	1,00
0	2	27,20	0,12	0,00
1	2	24,10	0,66	0,18
2	2	17,30	1,35	1,00
3	2	12,10	2,20	0,60
0	3	35,50	0,67	0,00
1	3	30,90	1,30	0,00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

- 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

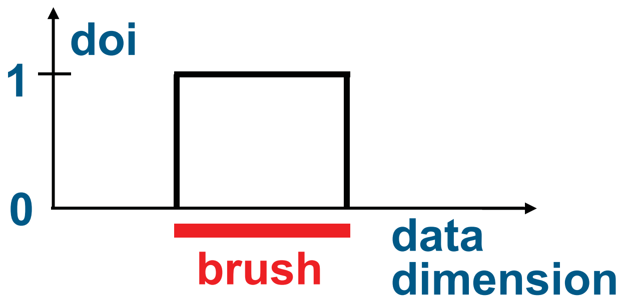
(cont'd on next slide)

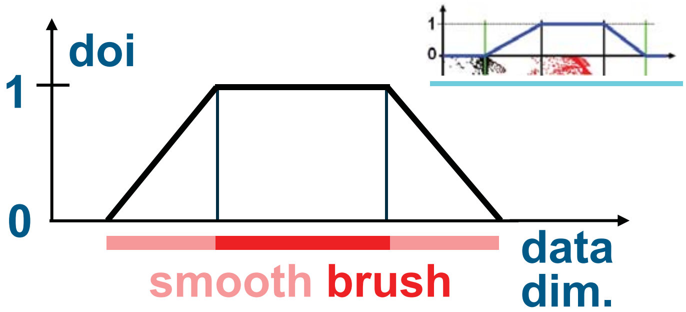
IVA: Smooth Brushing → Fractional DOI

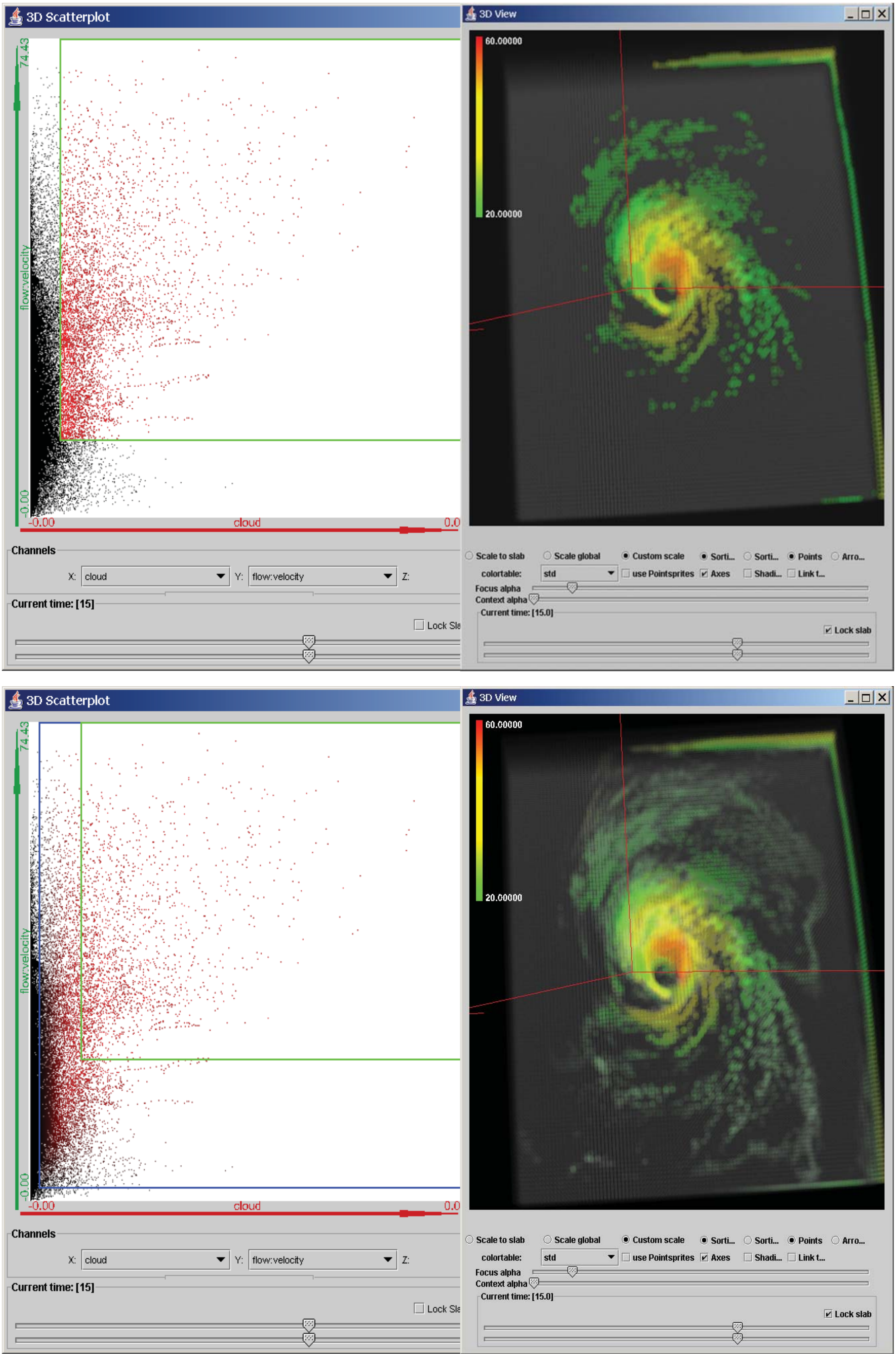
- **Fractional DOI values** esp. useful wrt. **scientific data**: (quasi-)continuous nature of data ↔ smooth borders
- Goes well with gradual focus+context vis. techniques (coloring, semitransparency)



- 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
-0.00
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cloud
0.0
Channels
X: cloud
Y: flow:velocity
Z:
Current time: [15]
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3D View
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Scale global
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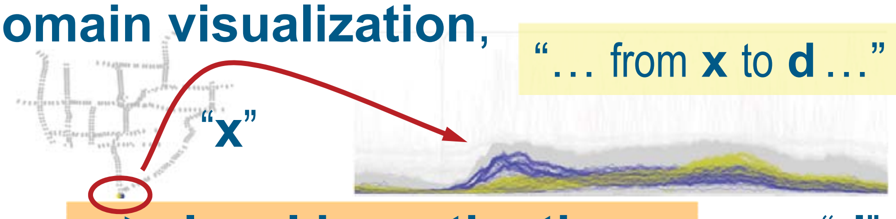
Current time: [15.0]
Lock slab

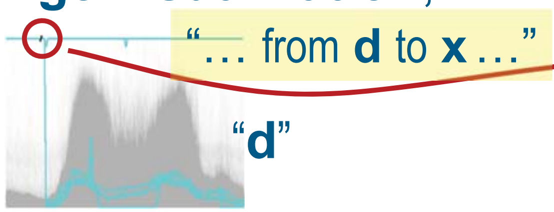
Three Patterns of SciData IVA

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



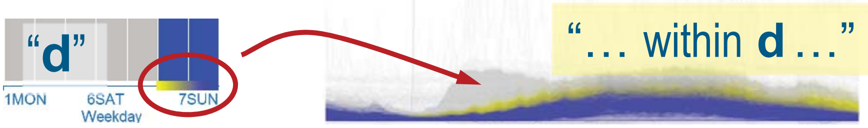
❶ ▶ **local investigation** “d”

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



❷ ▶ **feature localization** “x”

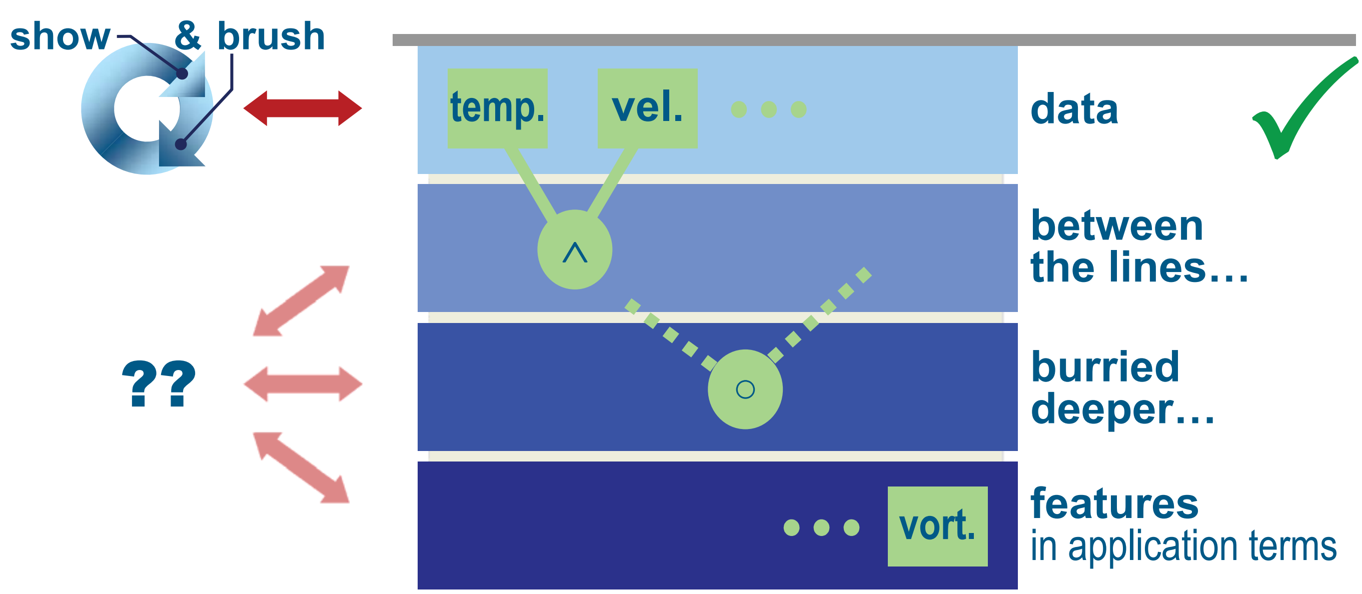
relating multiple range variates



❸ ▶ **multi-variate analysis** “d”

IVA – Levels of Complexity (1/4)

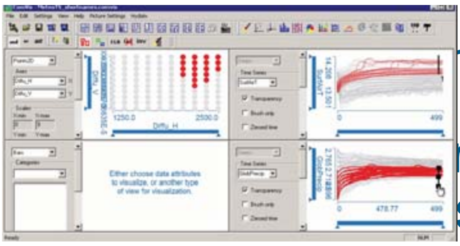
- A ***lot*** can be done with basic IVA, already! [pareto rule]
- We can consider a **layered information space**: from **explicitly** represented information (the **data**) to **implicitly** contained information, **features**, …



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$_3$) …)

IVA – Levels of Complexity (2/4)



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IVA – Levels of Complexity (3/4)

- 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 brushing
  - IVA, l4: **application-specific feature extraction**, *e.g.*, based on vortex extraction methods for flow analysis
- 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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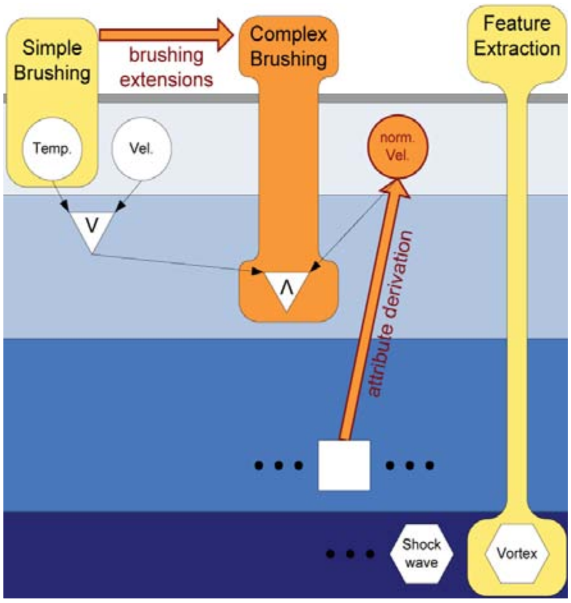
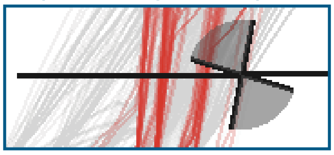


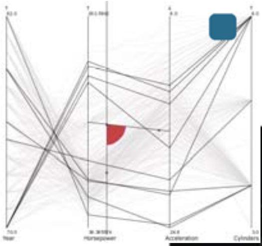
- Level 3: using **general info extraction** mechanisms, two (partially complementary) approaches:
  1. **derive additional attribute**(s), then show & brush
  2. use an **advanced brush** to select "hidden" relations

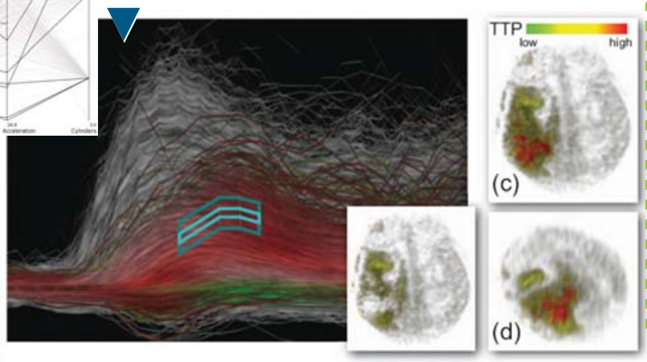
IVA (level 3): Advanced Brushing

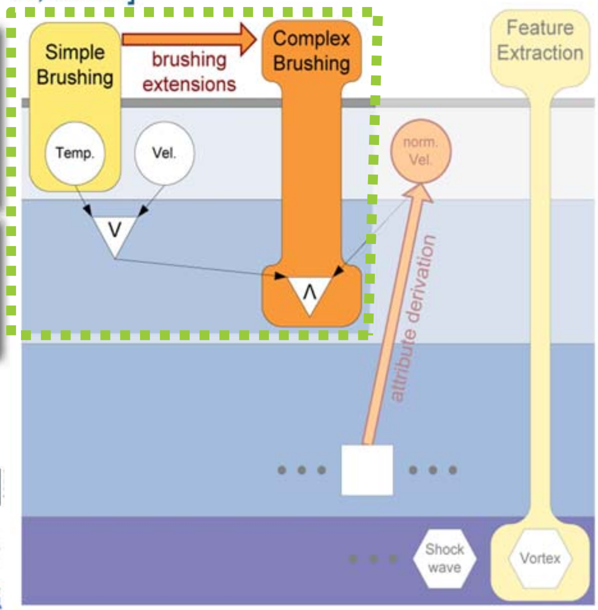
- **Std. brush**: brush 1:1 what you see
  Adv. brush: executes additional function ("intelligent"?)



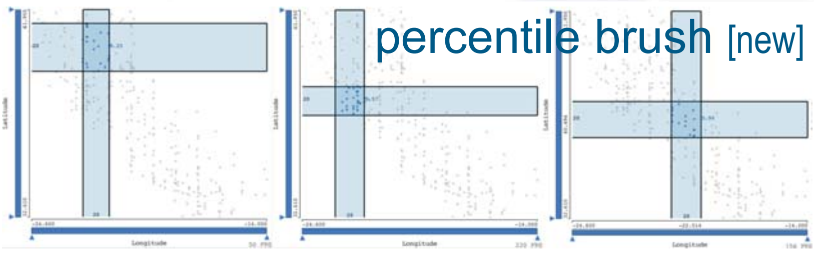
- **Examples**:
  - angular brushing [Hauser et al., 2002]
    similarity brushing [Muigg et al., 2008]





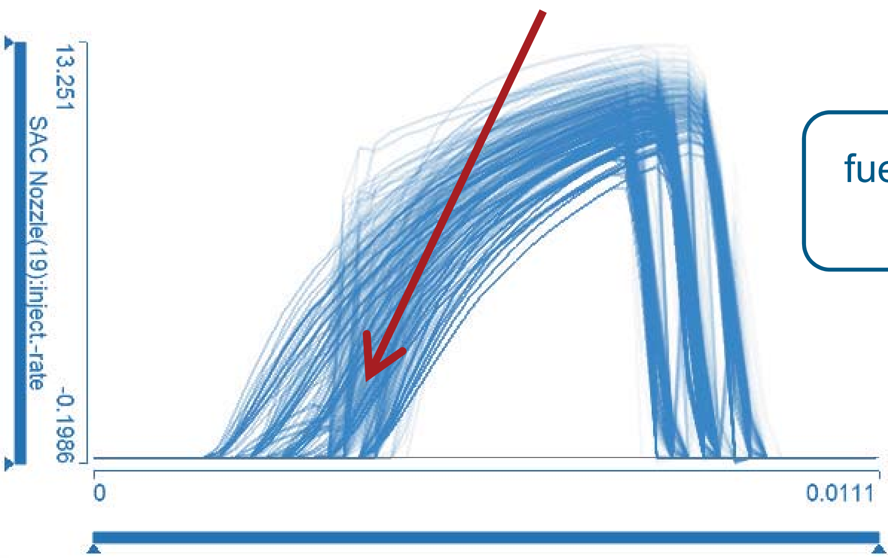


percentile brush [new]



3rd level IVA, adv. brushing example

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

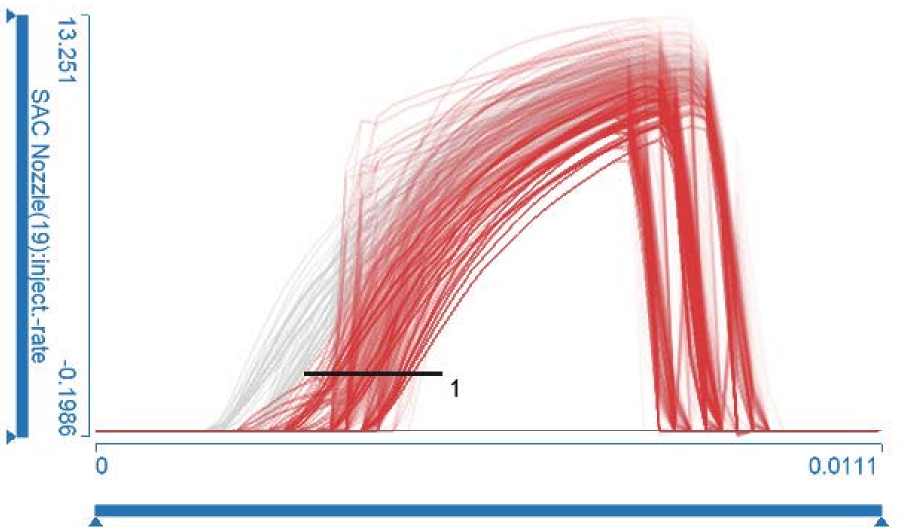


fuel injection simulation
"injection rate"

example prepared by Konyha, Zoltan

3rd level IVA, adv. brushing example

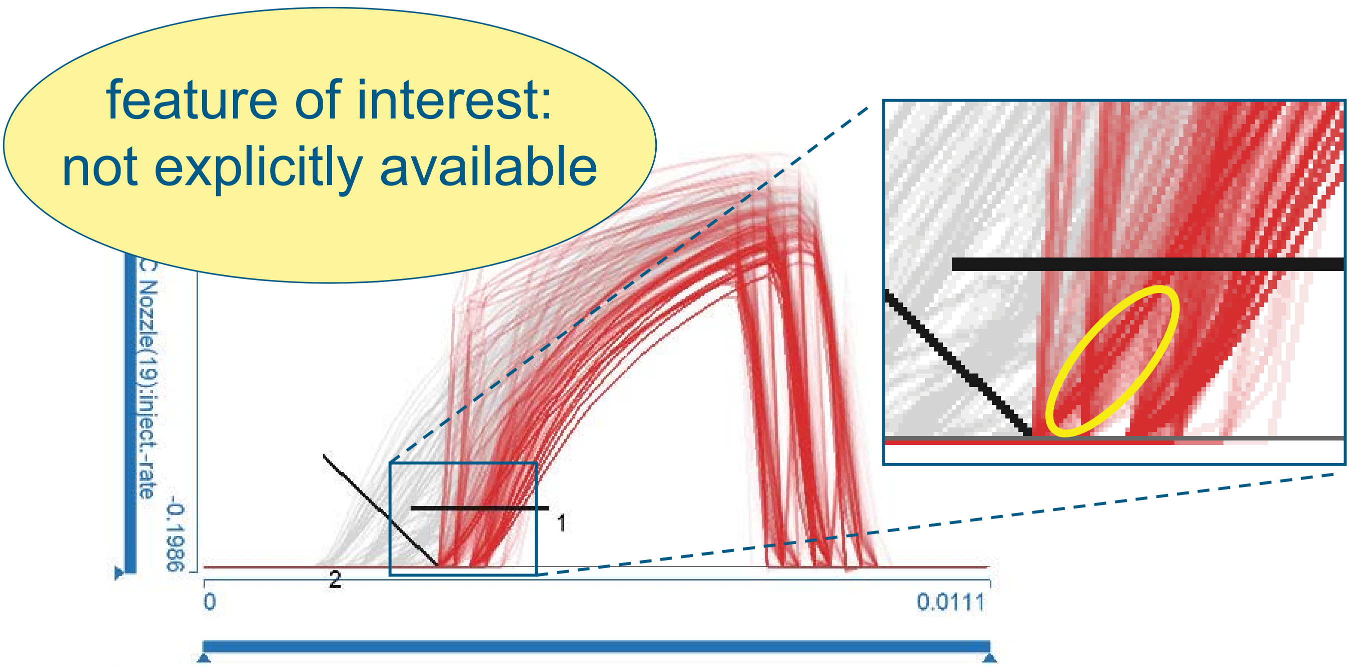
- A simple line brush is not enough



example prepared by Konyha, Zoltan

3rd level IVA, adv. brushing example

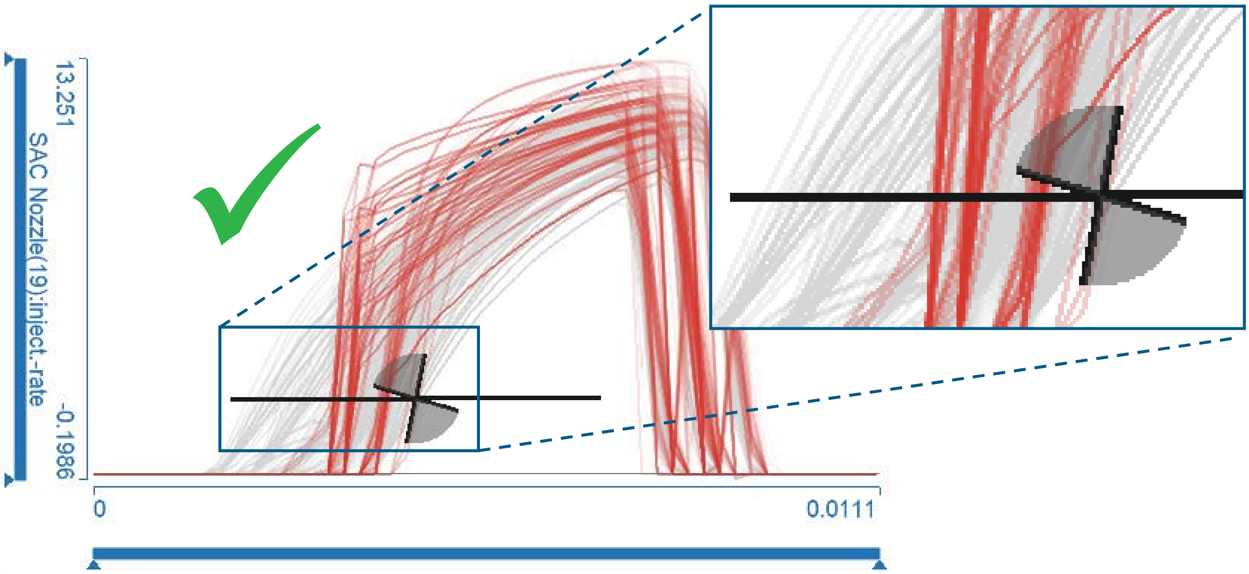
- A simple line brush is not enough
- Combining line brushes does not work, either



example prepared by Konyha, Zoltan

3rd level IVA, adv. brushing example

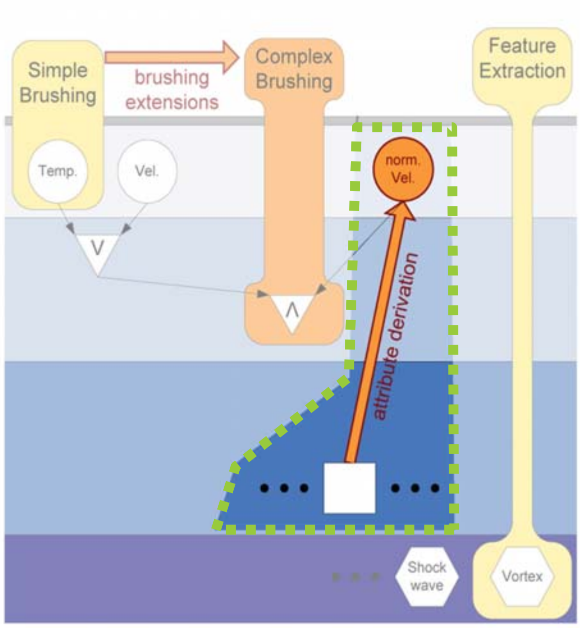
- The *angular line brush* (a specialized brush) selects the intended function graphs
  - that it intersects, and
  - the angle is in a given threshold



example prepared by Konyha, Zoltan

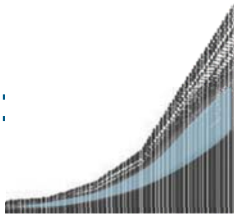
IVA (level 3): Attribute Derivation

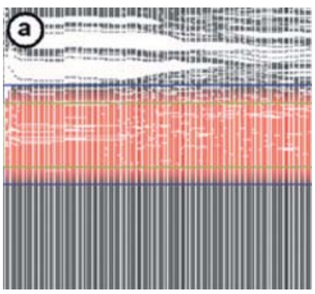
- **Principle** (in the context of iterative IVA):
  - **see** some data feature Φ of interest in a visualization
  - **identify** a **mechanism** T **to describe** Φ
  - **execute** (interactively!) an **attribute derivation** step to represent Φ explicitly (as new, synthetic attribute[s] d_φ)
  - **brush** d_φ to get Φ



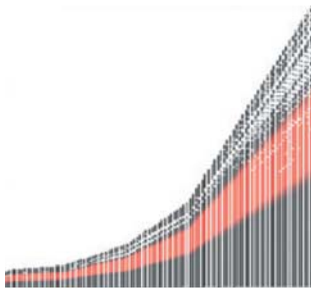
- **Tools** T to describe Φ from:
  - **numerical mathematics**
  - **statistics**, **data mining**
  - *etc.*
  - ➢ **scientific computing**
- **IVA** w/ **T** ↔ **visual computing**

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!

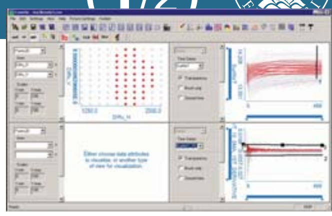
How to reflect these user wishes?

- 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

- 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.

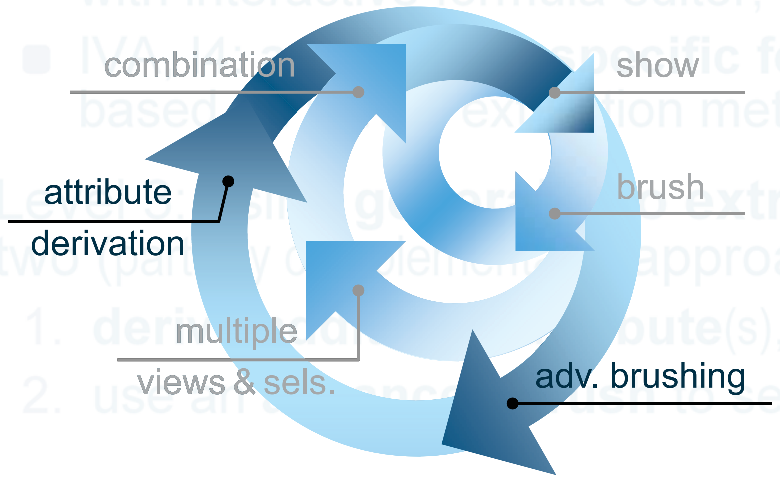
3rd-level IVA – Sample Iterations (1/2)

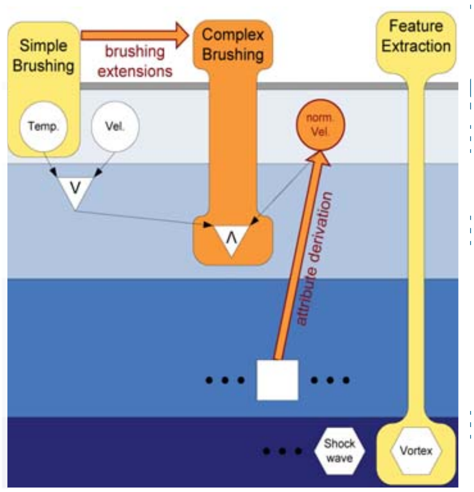


- The **Iterative Process of 3rd-level IVA**:
  - Example 1:
    - you look at some *temp. distribution over some region*
    - you are *interested in raising temperatures*, ***but not temperature fluctuations***
    - you use a **temporal derivate estimator**, *for ex.*, central differences $t_{change} = (t_{future} - t_{past})$ / 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

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* [Doleisch et al. 200
  - IVA, l. 3: **attribute derivation**; **advanced brushing**, with interactive formula editor;





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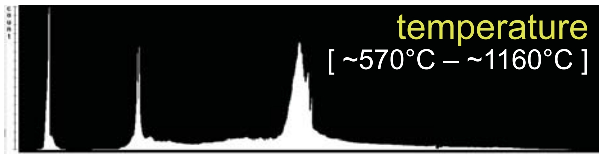
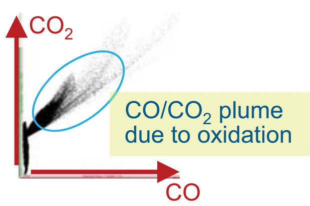
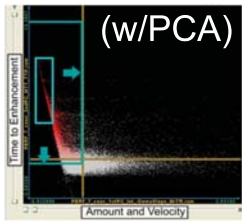
  - IVA, l. 3: **attribute derivation**; **advanced brushing**, with interactive formula editor; *e.g.*, similarity brushing
  - IVA, l4: **application-specific feature extraction**, *e.g.*, based on vortex extraction methods for flow analysis
- Level 4: **application-specific procedures**
  - tailored solutions (for a specific problem)
  - “deep” information drill-down
  - *etc.*

Interactive Visual Analysis – delivery

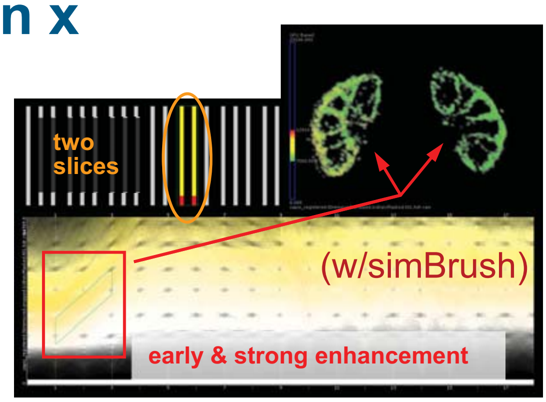
- Understanding data **wrt. range d**
  - which distribution has data attribute $\mathbf{d}_i$?
  - how do $\mathbf{d}_i$ and $\mathbf{d}_j$ relate to each other? (**multivariate analysis**)
  - which $\mathbf{d}_k$ discriminate data features?







- 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…

…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!

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