

Integrating **Interactive** and **Computational** Analysis in **Visualization**

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Helwig Hauser? Visualization?



- **Background = computer science (CS)**
 - Studied CS at Vienna Univ. of Techn., Austria; PhD on flow visualization (also there)
 - Ass.-prof. at TU Wien; key res. at VRVis.at, later sci.-dir. there; prof. in visualization (CS Dept.) at UiB.no since 2007
- **What is visualization?**
 - many different interpretations available...
 - **here: computer-assisted means** (usually interactive) **to enable insight into data** (imaged phenomena)
 - many different **application areas**, including
 - **medicine** (3D imaging data, patient records, etc.)
 - **engineering** (data from physical/chemical models, etc.)
 - **business** (databases, etc.)

This Talk

- **Addressing a hot research topic** (visual analytics)
 - initiative started 2004 in the US (nat. security)
 - topic hot in Europe since 2005  **VisMaster**
Visual Analytics - Mastering the Information Age
- **Reporting from >1 decade of own research** (interactive visual analysis, IVA)
 - started in 2000 with the new VRVis.at
 - several PhD proj.: H. Doleisch, J. Kehrer, Z. Konyha, ...
 - >20 “IVA” papers, many talks, keynotes, etc.
- **Meeting HCI/CHI?** (human time constants, etc.?)
 - drawing some cautious links
 - awaiting interesting questions! :-)

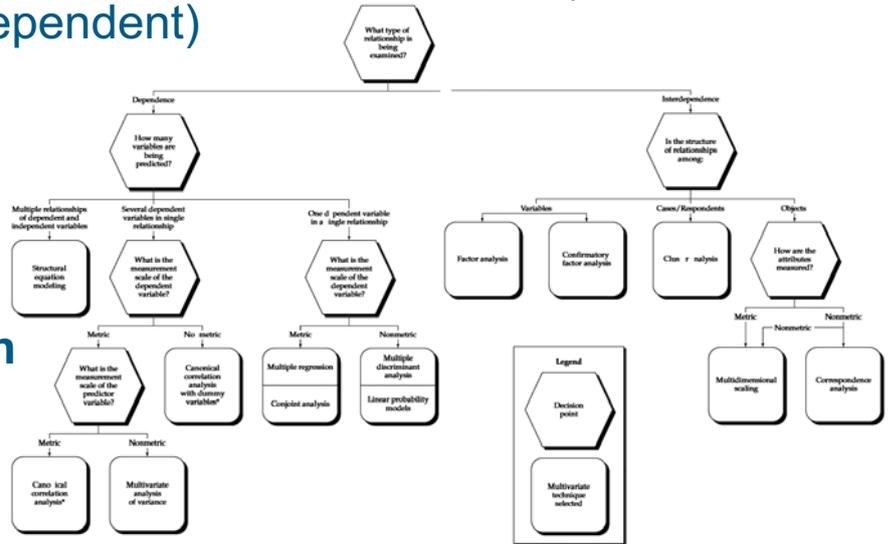
The Data Analysis Challenge

- **Today = emerging new information age**
 - enormous development of (computer) technology
 - fascinating opportunities for data acquisition, incl.
 - through measurements, e.g., imaging
 - through computational simulation
- **Increasing amount and complexity of data**
 - more and more data (GB→TB→PB→EB→...)
 - heterogeneous data (“big data”, etc.)
- **Big Data = a chance & a challenge!**
 - new opportunities (advancing knowledge, better ...)
 - difficult to master (getting more difficult quickly)

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



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

EuroVis Keynote

1. In the Beginning there were Mappings

Data values control the **visual variables** of points, lines, areas, surfaces, and volumes.

- Position
- Size
- Shape
- Value
- Color
- Orientation
- Texture
- Motion

J. Bertin, Semiology of Graphics: Diagrams, Networks, Maps. University of Wisconsin Press, Madison (1983).

EuroVis 2010, Bordeaux, France



- The should

- Matt

EuroVis Keynote

Dealing with Dimensions

- Many categorizations of dimension organization (see below paper for an early one)
- My categories:
 - **Subsetting** (e.g., SPLOMs, dense pixels)
 - **Reorganization** (e.g., parallel coords, glyphs)
 - **Embedding** (dimensional stacking, stacked bar charts, trellis displays)
 - **Reduction** (PCA, MDS, RadViz)

P. Wong and R. D. Bergeron, "30 years of multidimensional multivariate visualization." in Scientific Visualization: Overviews, Methodologies, and Techniques, edited by Nielson, Hagen, and Mueller (1994). pp. 3-33.

J. Bertin, Madison

EuroVis 2010, Bordeaux, France

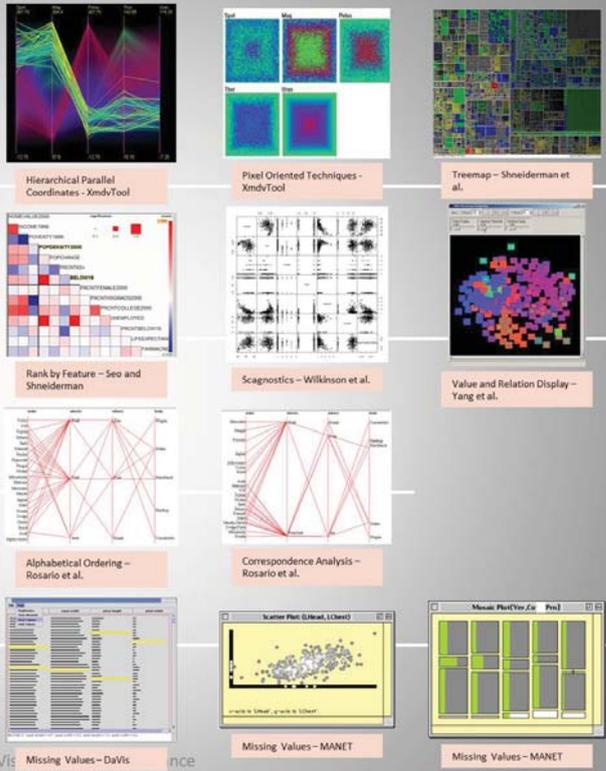
Also from Matt Ward's talk:

EuroVis 2010 Keynote

Other Challenges in Mappings

- Too many records
- Too many variables
- Non-numeric fields
- Missing values
- Streaming data

Many partial solutions; all have limitations.



Also from Matt Ward's talk:

EuroVis 2010 Keynote

Other Challenges in Mappings

- Too
- Too
- Non
- Missing values
- Streaming data

Many partial solutions; all have limitations.

And Then There are Relations

And What About Data Properties?

... 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! 😊

EuroVis 2010, Bordeaux, France

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*

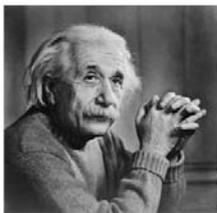
Yi, JS, Kang, YA, Stasko, J, Jacko, J, Toward a deeper understanding of the role of interaction in information visualization. IEEE Trans Vis Comput Graph. 2007 Nov-Dec; 13(6):1224-31.

EuroVis 2010, Bordeaux, France

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

Humans and Computers

*"Computers are incredibly fast, accurate, and stupid;
humans are incredibly slow, inaccurate, and brilliant;
together they are powerful beyond imagination."*



attributed to Albert Einstein

D. Keim, F. Mansmann | Dagstuhl Seminar 12081 | Information Visualization, Visual Data Mining and Machine Learning

7

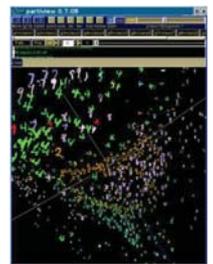
D. Keim, Dagstuhl Seminar Talk, 2012

- **Levels of integration:**

[Maniyar & Nabney;
MDM 2006]

L0: no integration – still the vast majority!

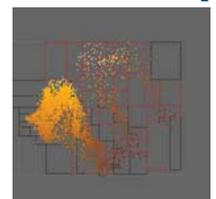
L1a: the **visualization of results** from some computational analysis (“for the report”, ...)



L1b: making **computational analysis** (partially) **interactive**

[Williams & Munzner;
InfoVis 2004]

L2: **tight integration** – extremely rare, still!



- Several in visual analytics / IVA / ... aim currently at conquering L2!

Integrating Interaction & Computation



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

HH, Dagstuhl Seminar, 2012

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.

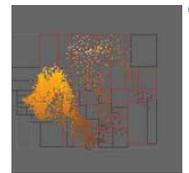
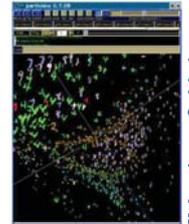
er,

,
etc.

[Sun..., 2010]

S

ve



[19002, 'faynuj & jafnuj'] [Williams & Munzner, 2004]

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

Integrating Interaction & Computation

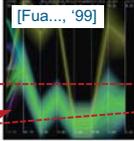


- Goal: to combine the *best of two worlds*

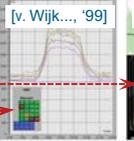
HH, Dagstuhl Seminar, 2012

Some Examples

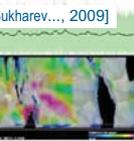
- Integration of clustering



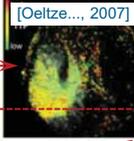
[Fua..., '99]



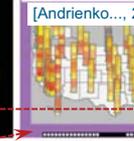
[v. Wijk..., '99]



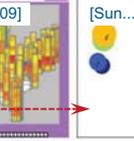
[Sukharev..., 2009]
- Integration of projection/embedding



[Oelze..., 2007]



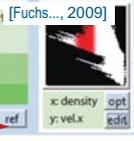
[Andrienko..., 2009]



[Sun..., 2010]
- Integration of classification/learning



[v. d. Elzen..., '11]
sex = male



[Fuchs..., 2009]
x: density opt
y: velx Edt

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

[19002, 'faynuj & jafnuj'] [Williams & Munzner, 2004]

Interactive Visual Analysis

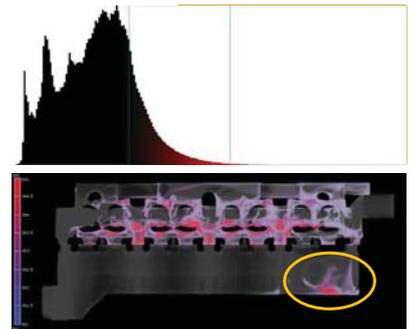
- Given data – *too much* and/or *too complex* to be shown all at once:
- IVA is an **interactive visualization methodology** to facilitate
 - the **exploration** and/or **analysis** of data (not necessarily the presentation of data), including
 - **hypothesis generation & evaluation, sense making,**
 - **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**

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 ($>90^{\circ}[\pm 2^{\circ}]$)
3. show focus+context vis. in 3D
4. locate relevant feature(s)



- **KISS-principle IVA:**

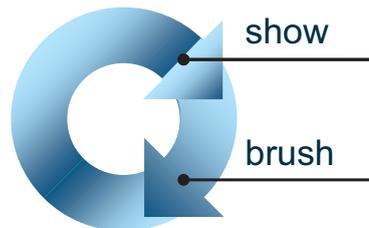
- linking & brushing, focus+context visualization, ...

Show & Brush

(basic IVA)

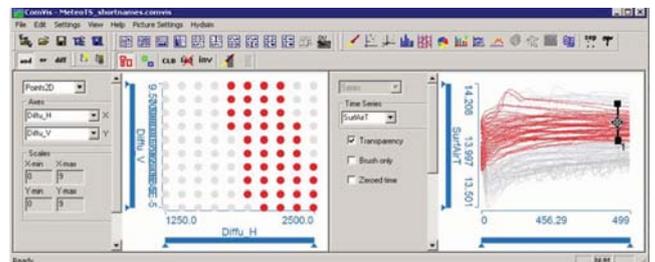


- **Tightest IVA loop**
 - **show data** (explicitly represented information)
 - **one brush** (on one view, can work on >1 dims.)



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

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- bring up multiple views
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... leads to ...

degree of interest

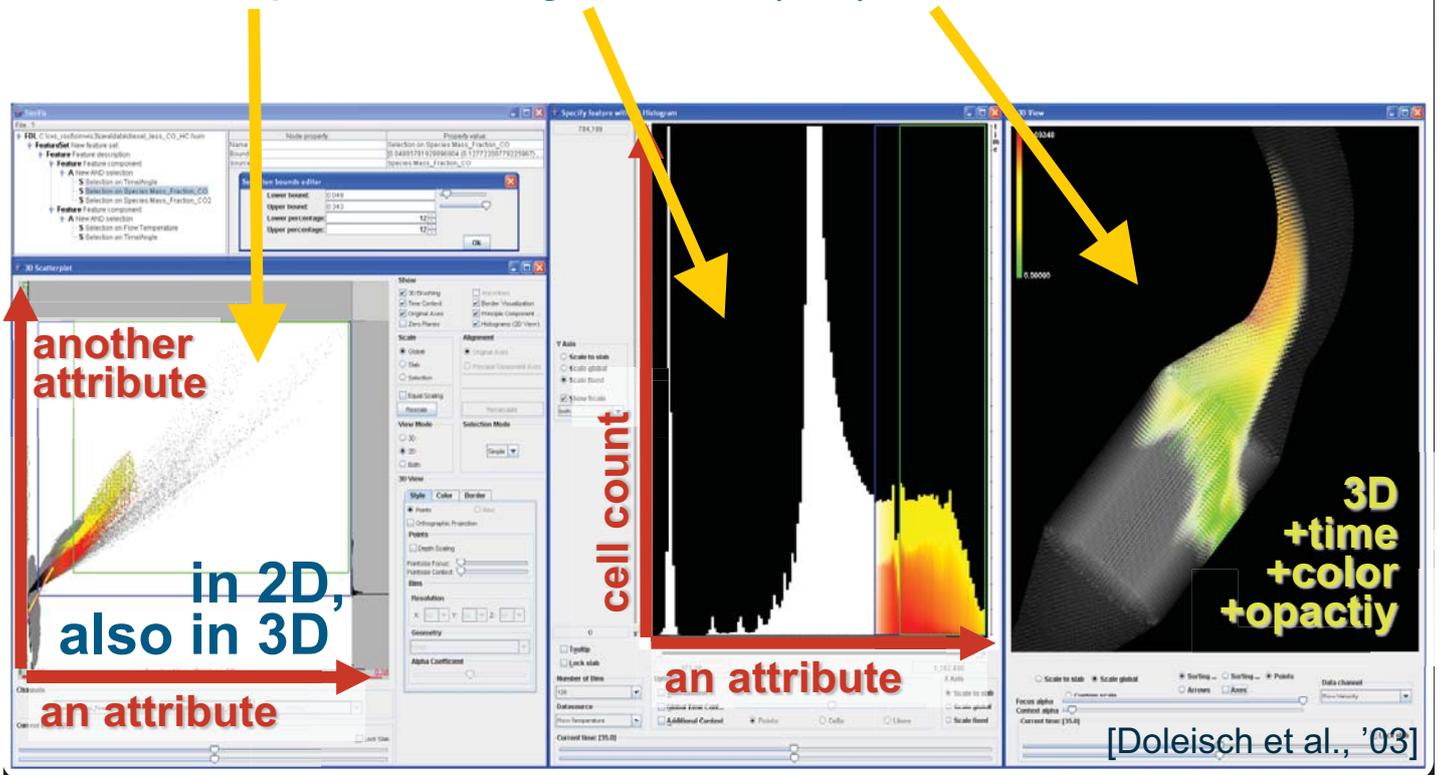
... requires ...

... is realized via ...

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

IVA: Multiple Views

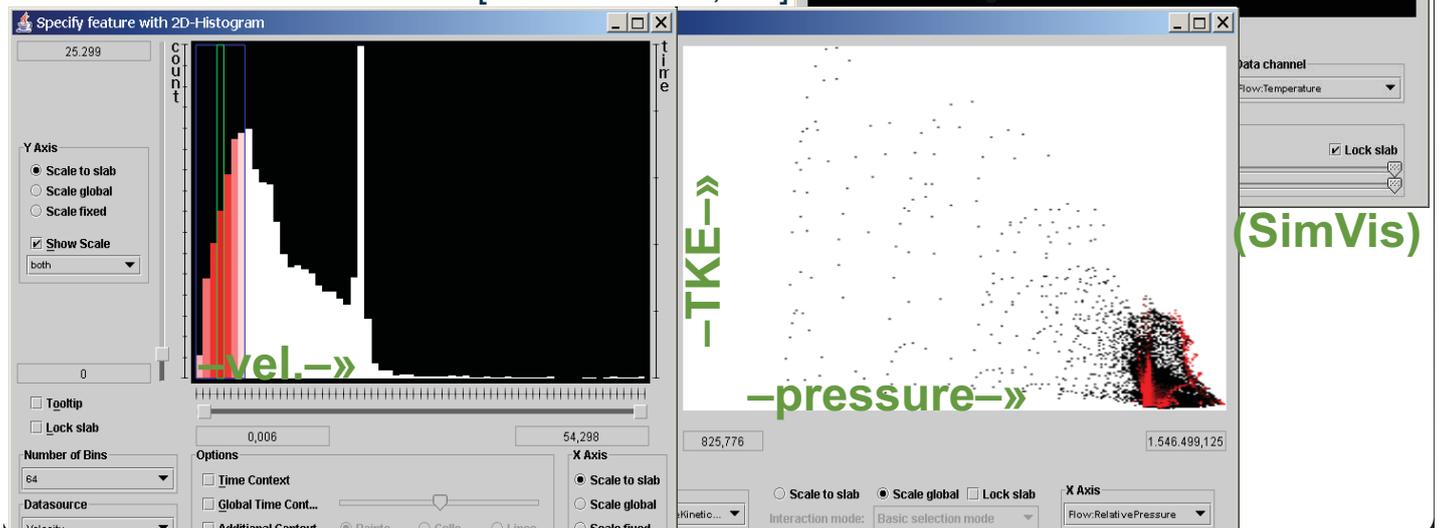
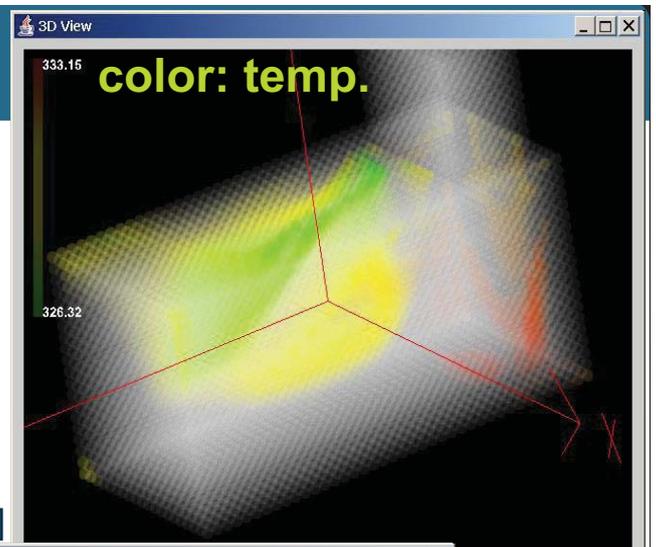
- One dataset, but multiple views
- Scatterplots, histogram, 3D(4D) view, etc.



Interactive Brushing

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

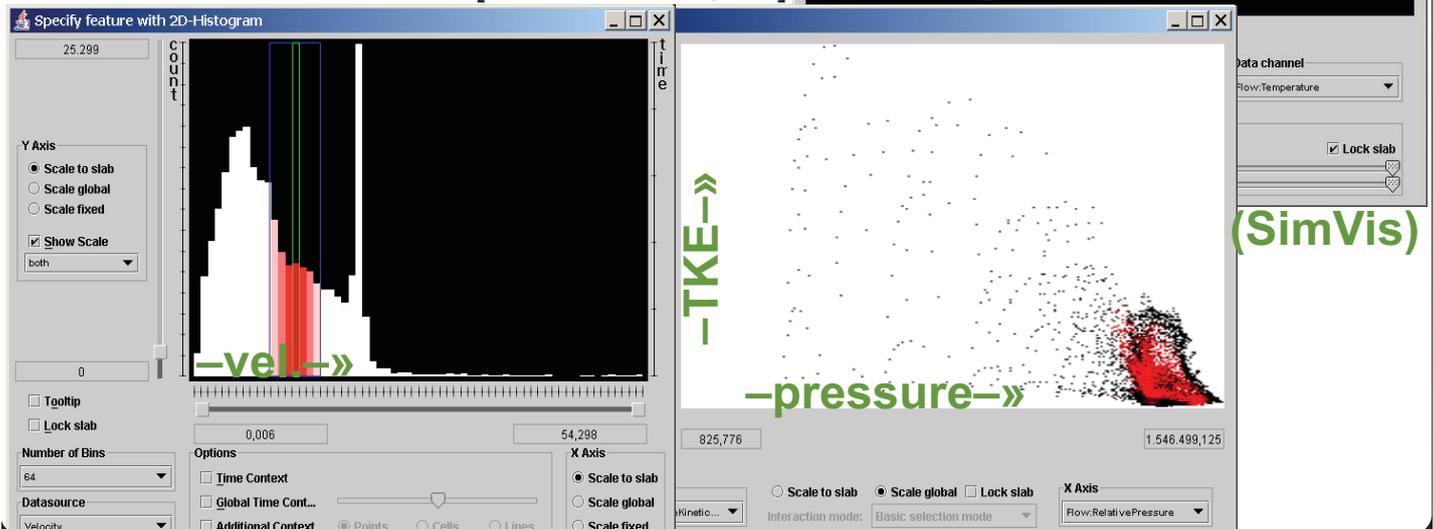
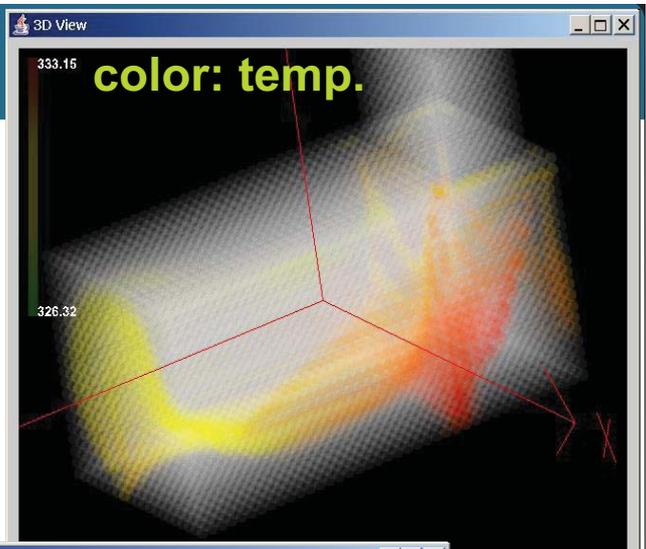
[Doleisch et al., '03]



Interactive Brushing

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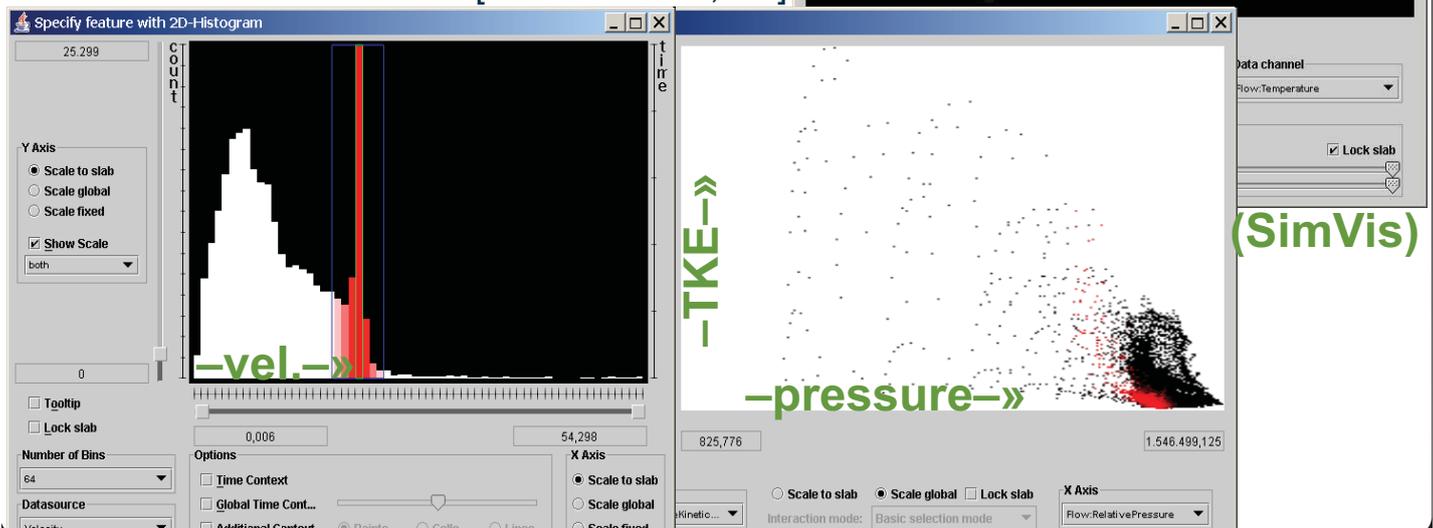
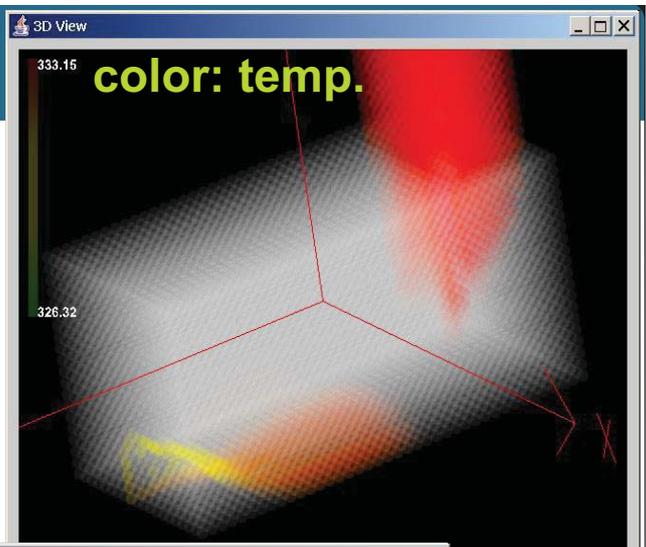
[Doleisch et al., '03]



Interactive Brushing

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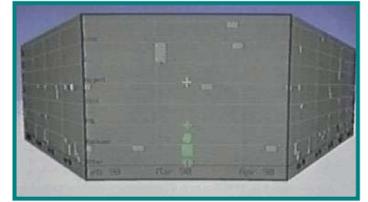
[Doleisch et al., '03]



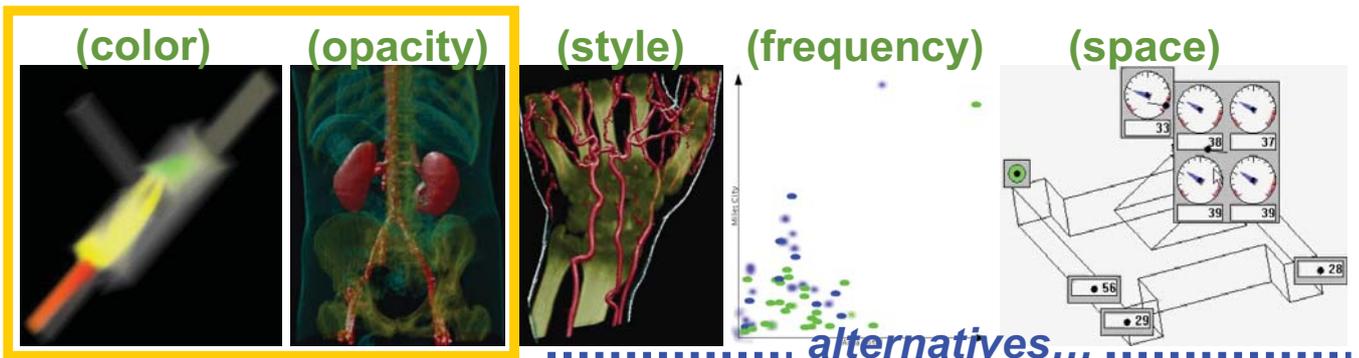
IVA: Focus+Context Visualization

- 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]



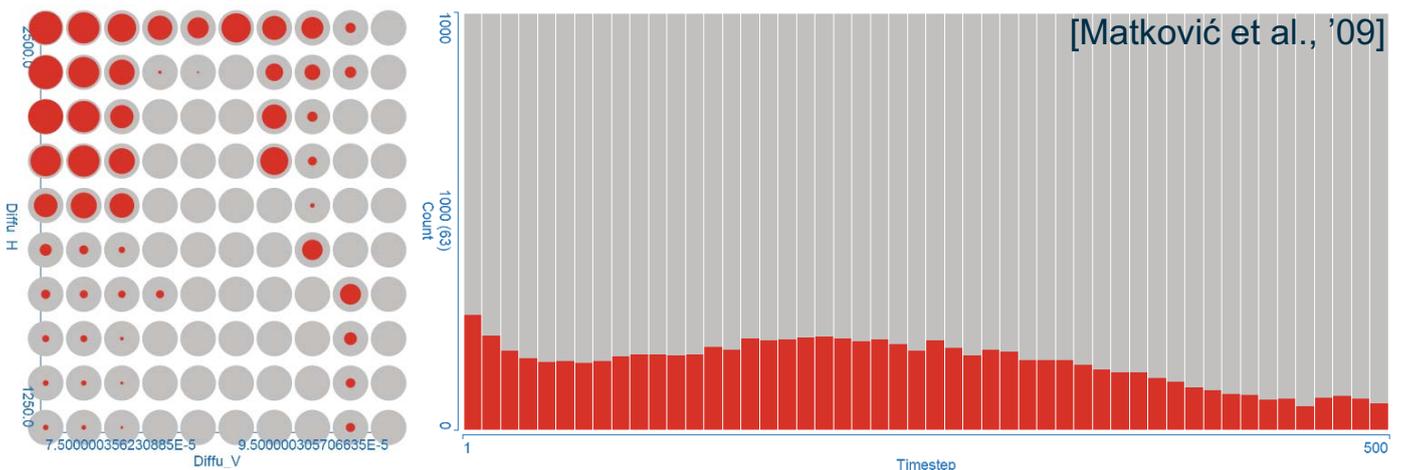
[Hauser... 2001, 2003]



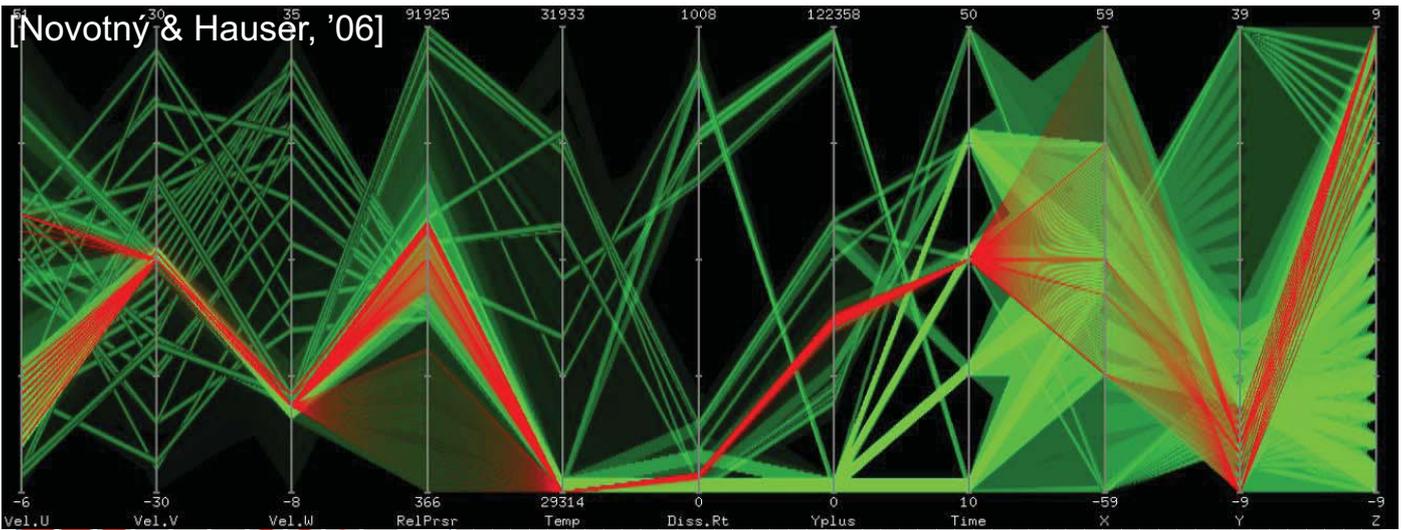
F+C Visualization in IVA Views

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

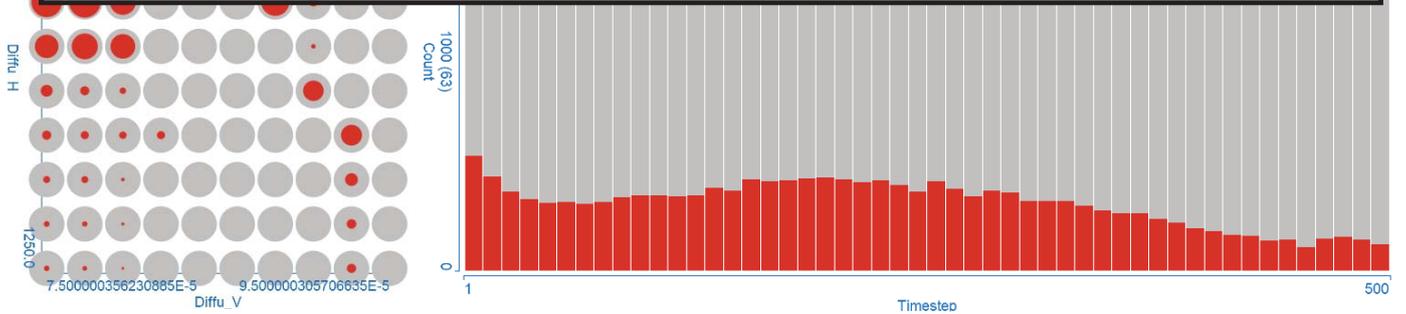
In a scatterplot (left) or histogram (right): brushed data in red...



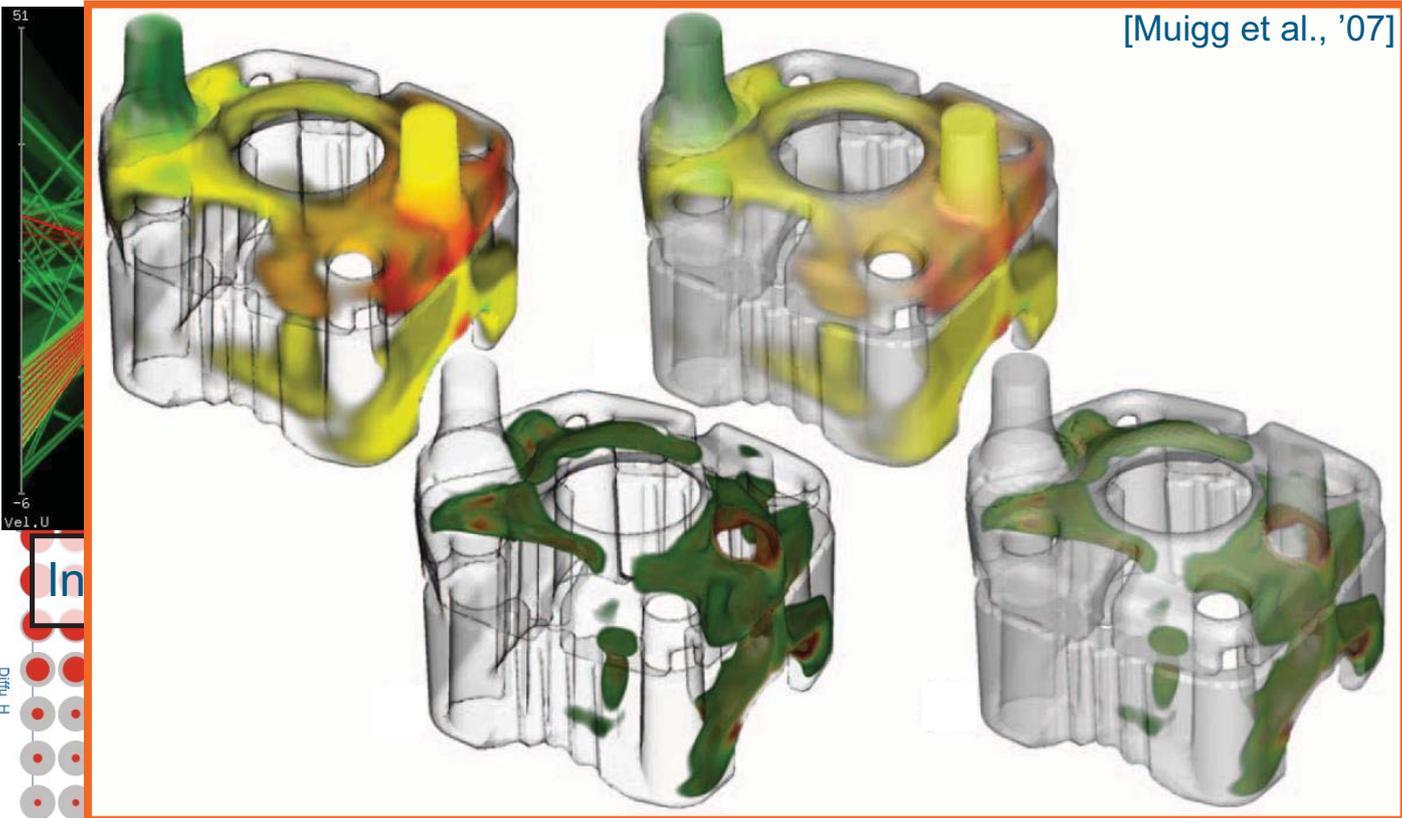
F+C Visualization in IVA Views



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



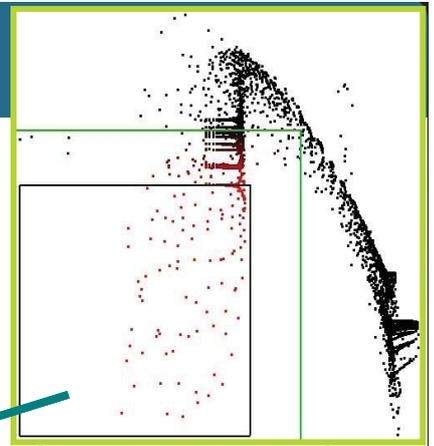
F+C Visualization in IVA Views



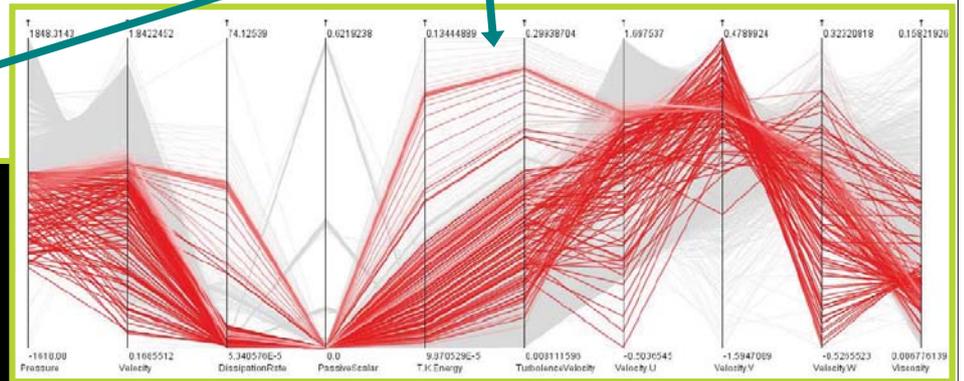
In 3D (above): less transp. & colored, in illustrative context ...

IVA: Linked Views

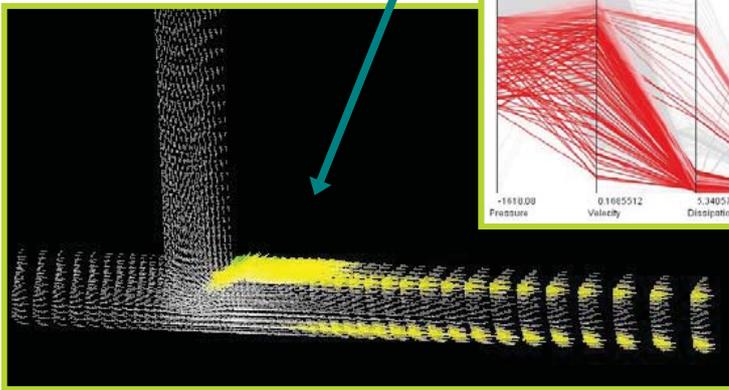
- Brushing: mark data subset as especially interesting
- Linking: enhance brushed data in linked views consistently (F+C)



(brushed view)



(linked views)



[Doleisch & Hauser, '02]

IVA: Degree of Interest (DOI)

- $doi(.)$: data items tr_i (table rows) \rightarrow 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)

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

Specification

- explicit, e.g., through direct selection
- implicit, e.g., through a range slider



Fractional DOI values: $0 \leq doi(tr_i) \leq 1$

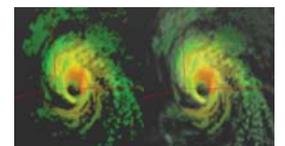
- several levels (0, low, med., ...)
- a continuous measure of interest
- a probabilistic definition of interest

(cont'd on next slide)

IVA: Smooth Brushing \rightarrow Fractional DOI

- Fractional DOI values** esp. useful wrt. **scientific data**: (quasi-)continuous nature of data \leftrightarrow smooth borders

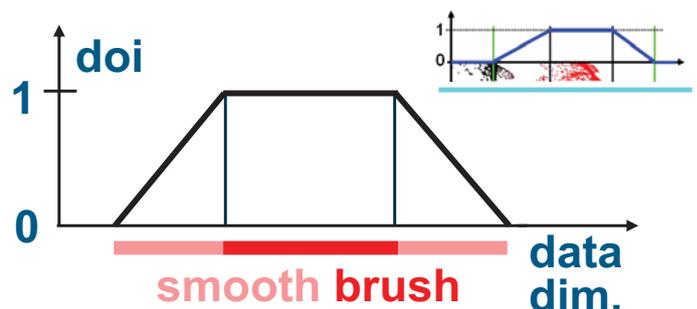
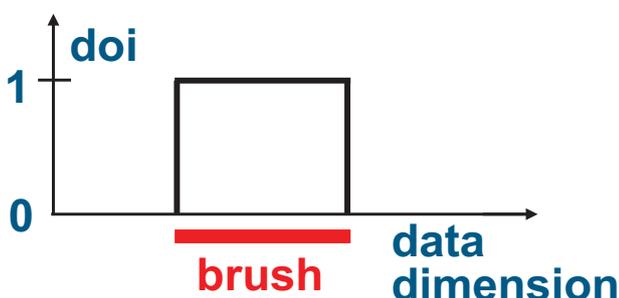
- Goes well with gradual focus+context vis. techniques (coloring, semitransparency)

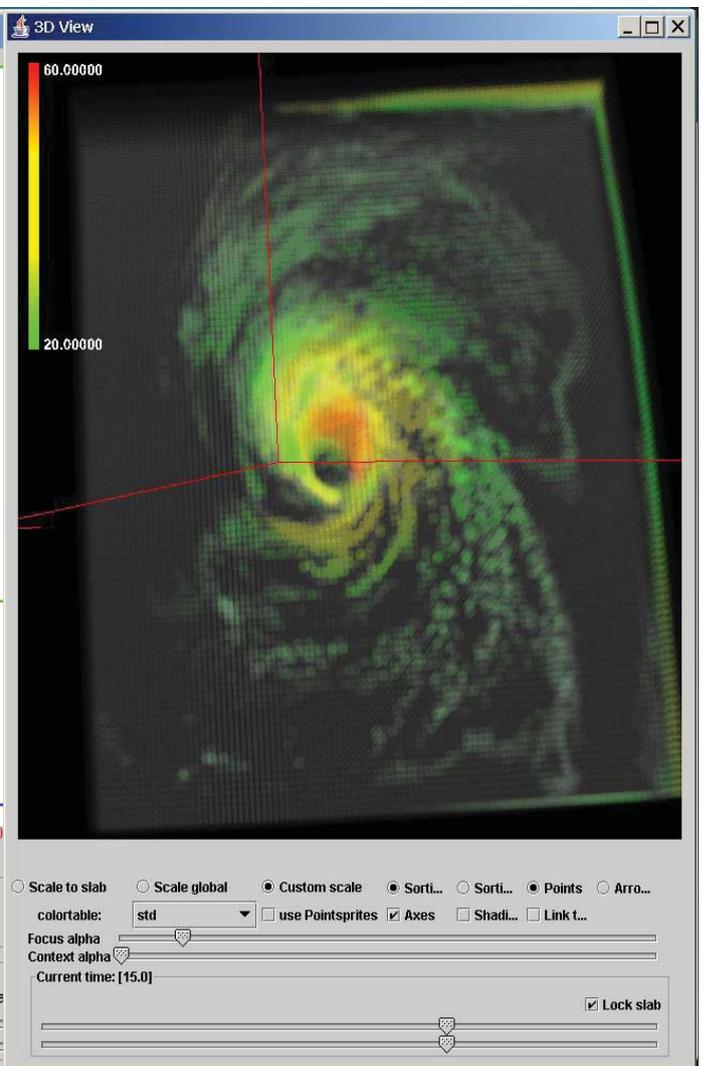
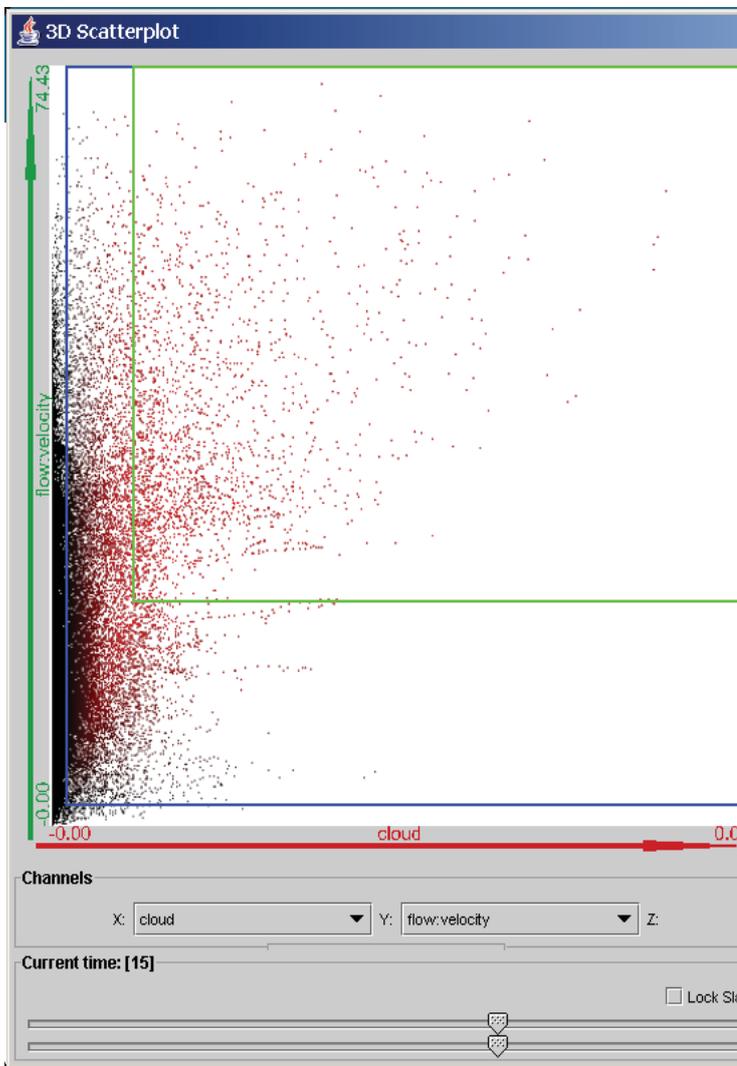
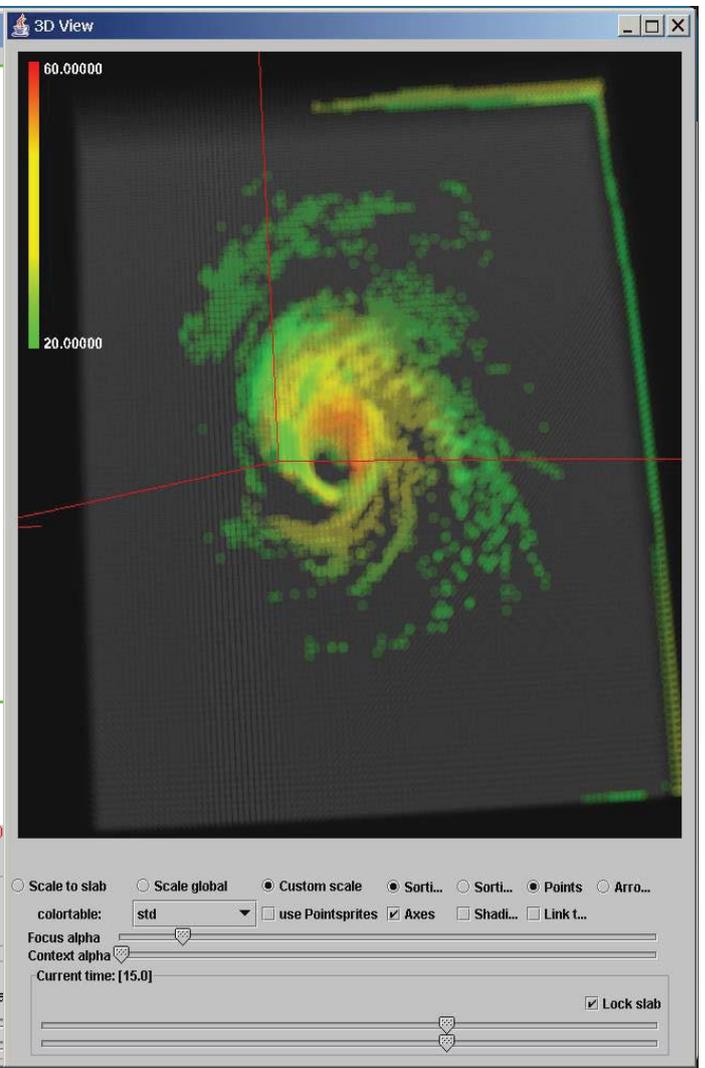
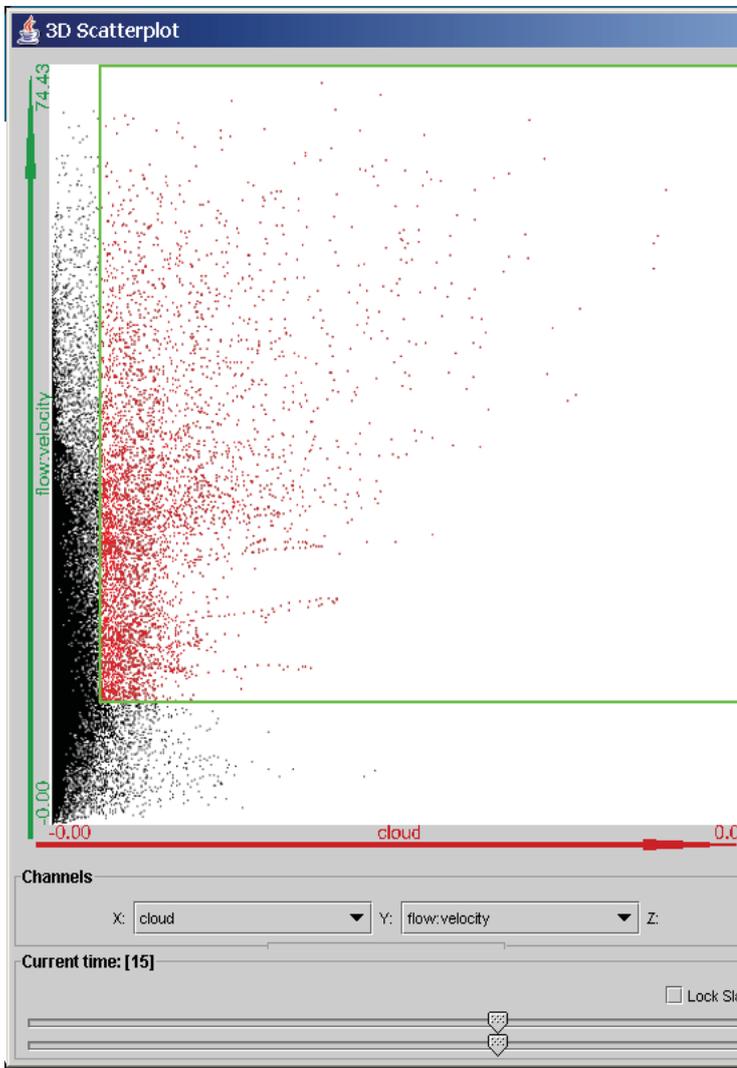


Specification: **smooth brushing**

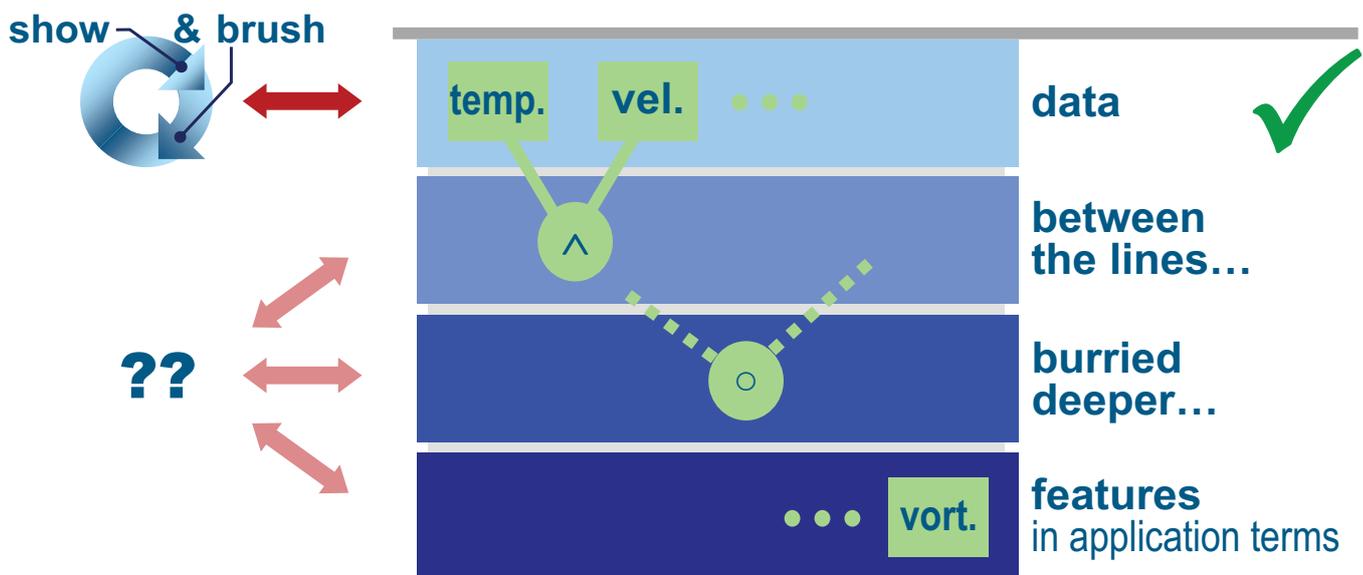
[Doleisch & Hauser, 2002]

- “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)

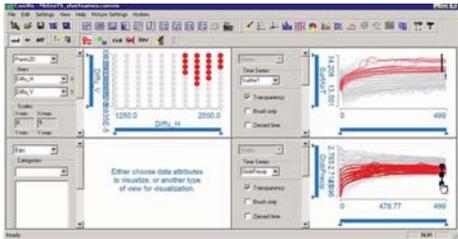




- A *lot* can be done with basic IVA, already! [pareto rule]
- We can consider a **layered information space**: from **explicitly** represented information (the **data**) to **implicitly** contained information, **features**, ...



- A *lot* can be done with basic IVA, already! ✓ [pareto rule] 
- For more advanced exploration/analysis tasks, we extend it (in several 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** (((b₀ op₁ b₁) op₂ b₂) op₃ b₃) ...)

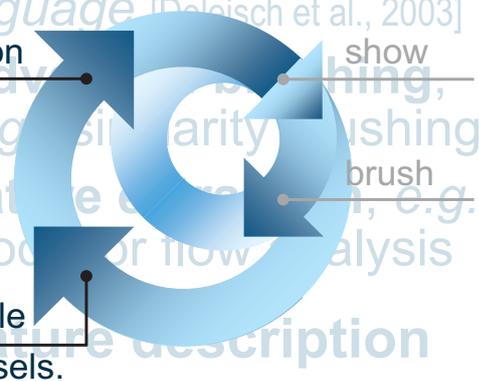


one with basic IVA, already! ✓ [parent rule]

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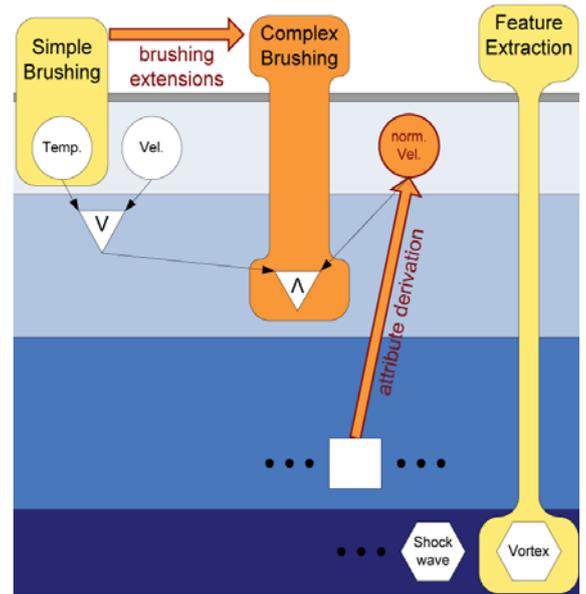
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- IVA, level 2: **logical combinations of brushes**, e.g., utilizing the *feature definition language* [Deleisch et al., 2003]
 - IVA, l. 3: **attribute derivation**; **advanced brushing**, with interactive formula editor; e.g., similarity brushing
 - IVA, l4: **application-specific feature extraction**, e.g., based on vortex extraction methods for flow analysis
- Level 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



- A *lot* can be done with basic I
- For more advanced explorat we extend it (in several steps):
 - IVA, level 2: **logical combin** utilizing the *feature definitio*
 - IVA, l. 3: **attribute derivatio** with interactive formula editc
 - IVA, l4: **application-specific** based on vortex extraction n



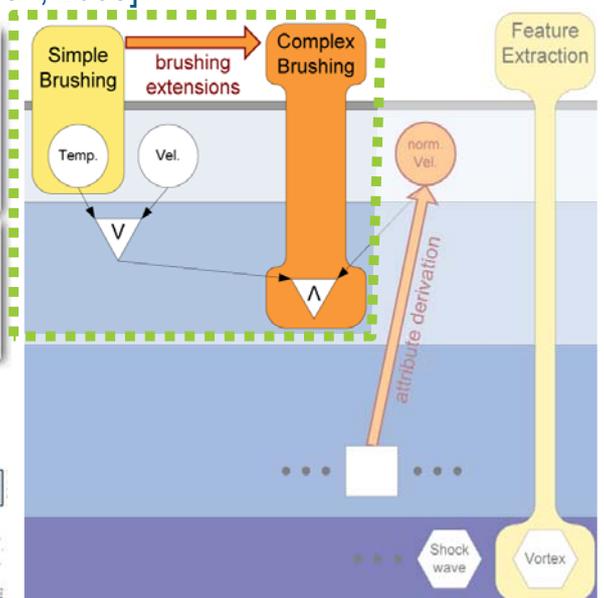
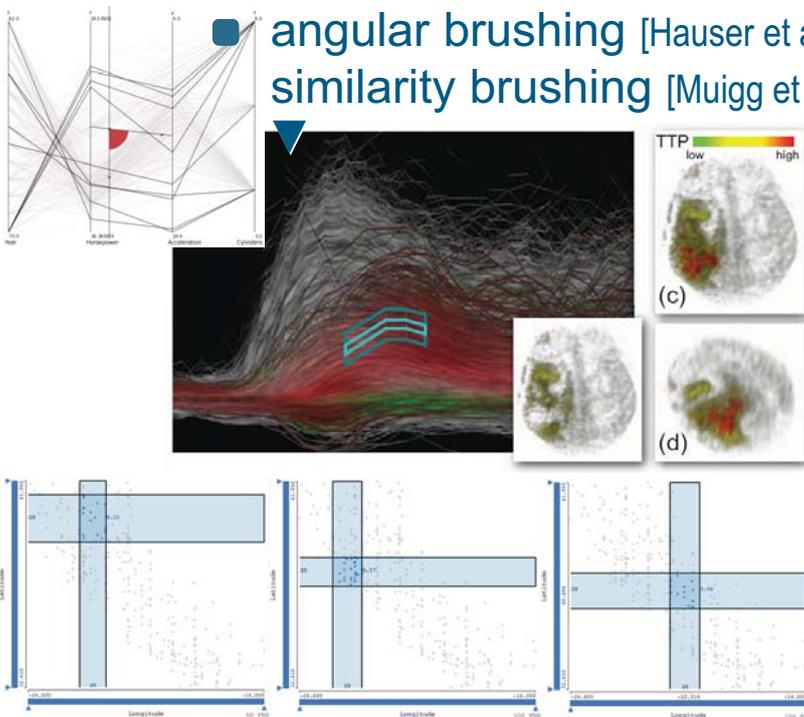
- Level 3: using **general info extraction** mechanisms, two (partially complementary) approaches:
 1. **derive additional attribute(s)**, then show & brush
 2. use an **advanced brush** to select “hidden” relations

IVA (level 3): Advanced Brushing

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

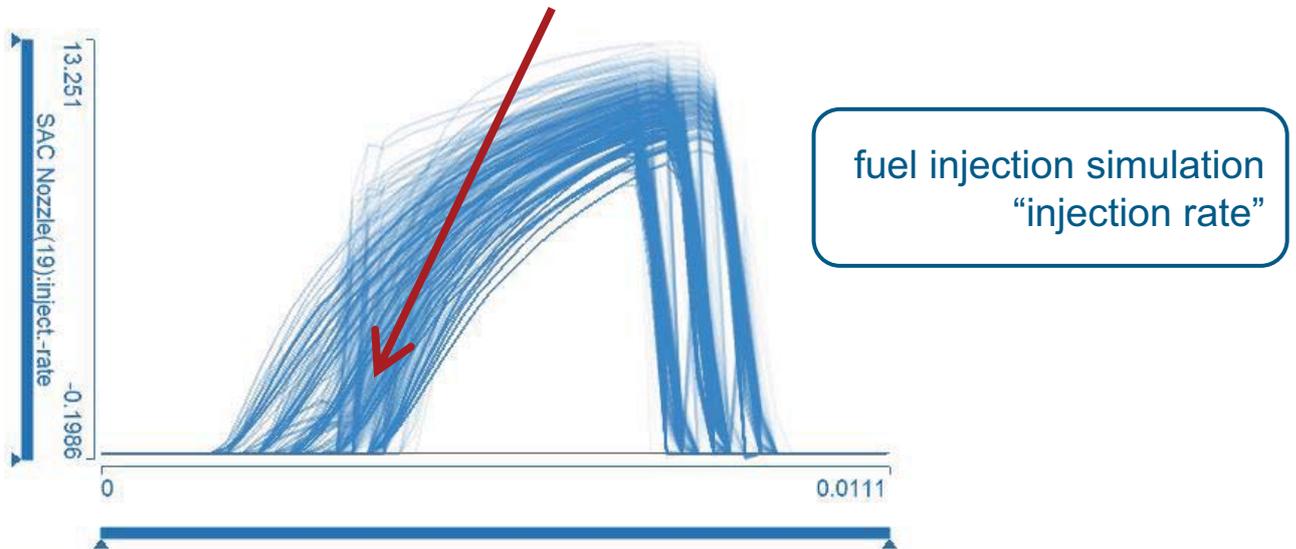
Examples:

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



3rd level IVA, adv. brushing example

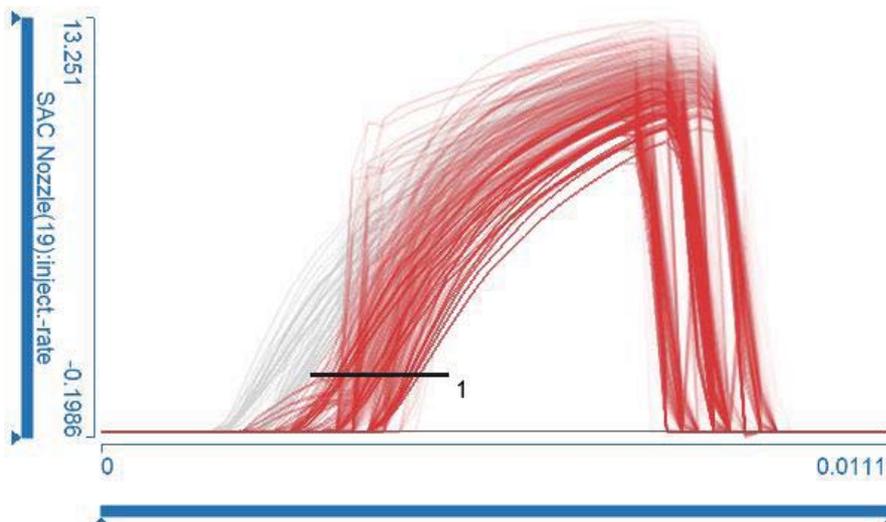
- Considering a visualization of a family of function graphs:
 - select the steeply rising graphs



example prepared by Konyha, Zoltan

3rd level IVA, adv. brushing example

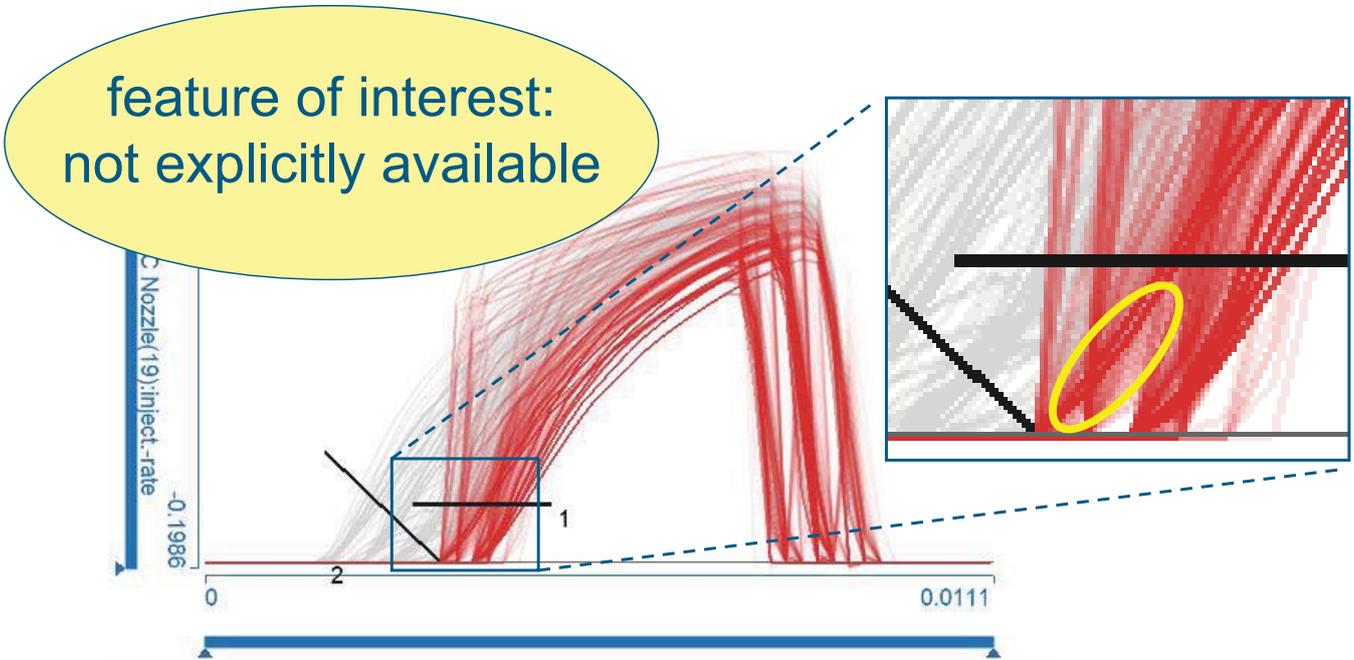
- A simple line brush is not enough



example prepared by Konyha, Zoltan

3rd level IVA, adv. brushing example

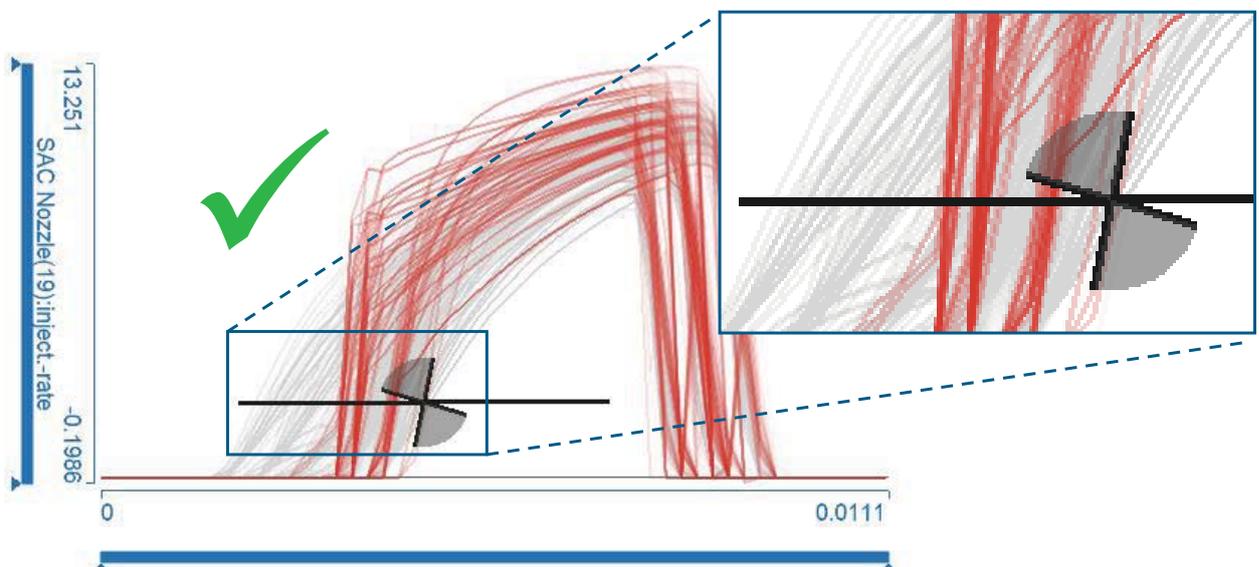
- A simple line brush is not enough
- Combining line brushes does not work, either



example prepared by Konyha, Zoltan

3rd level IVA, adv. brushing example

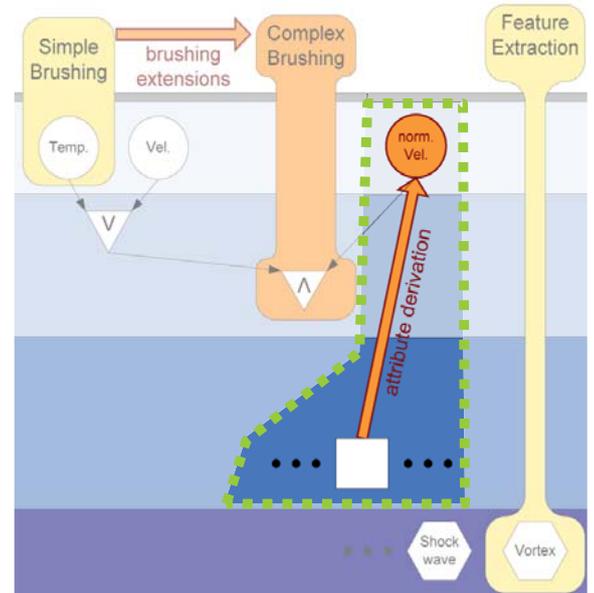
- The *angular line brush* (a specialized brush) selects the intended function graphs
 - that it intersects, and
 - the angle is in a given threshold



example prepared by Konyha, Zoltan

IVA (level 3): Attribute Derivation

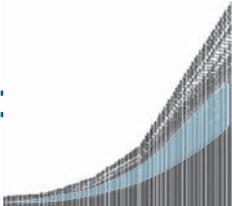
- **Principle** (in the context of iterative IVA):
 - see some data feature Φ of interest in a visualization
 - identify a **mechanism T** to describe Φ
 - **execute** (interactively!) an **attribute derivation step** to represent Φ explicitly (as new, synthetic attribute[s] d_ϕ)
 - brush d_ϕ to get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

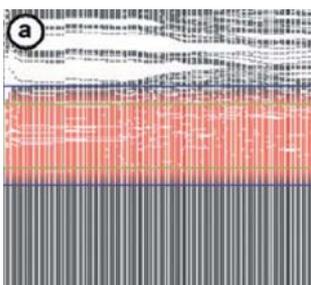


Attribute Derivation \leftrightarrow User Task / example

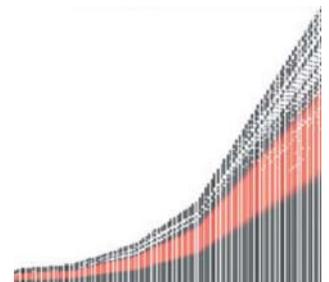
- The tools T, available in an IVA system, must reflect/match the **analytical steps of the user**:

■ Example:

- **first vis.:**  \leftrightarrow user wishes to select the "band" in the middle
- **so?** an advanced brush? a lasso maybe?
- **ah!** \rightarrow 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!

- 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**:
 - **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.

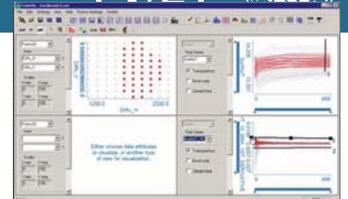
3rd-level IVA – Sample Iterations

(1/2)

■ The Iterative Process of 3rd-level IVA:

■ Example 1:

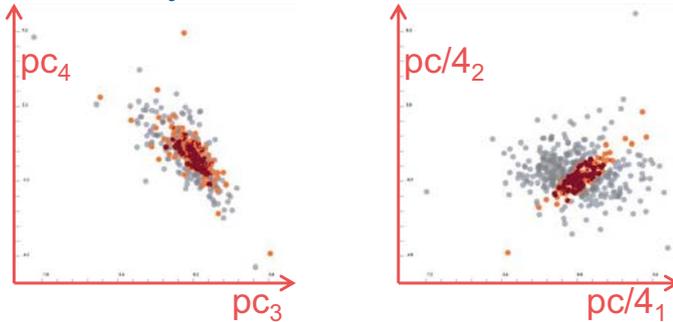
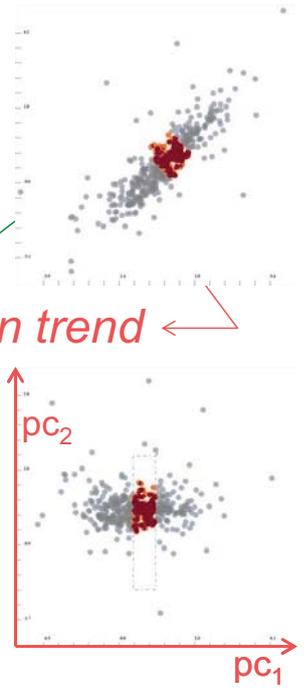
- you look at some *temp. distribution over some region*
- you are *interested in raising temperatures, but not temperature fluctuations*
- you use a **temporal derivate estimator**, for ex., central differences $t_{\text{change}} = (t_{\text{future}} - t_{\text{past}}) / \text{len}(\text{future-past})$
- 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 $\tau = t_{\text{smooth}}$ data attribute
- selecting from a **histogram** of τ_{change} (computed like above) is then less sensitive to temperature fluctuations



■ 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]

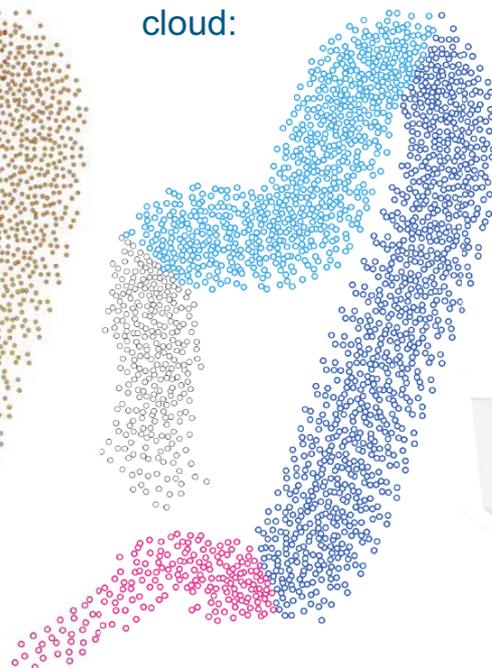
Brushing of Attribute Clouds for the Visualization of Multivariate Data

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

2D embedding:
the attribute cloud



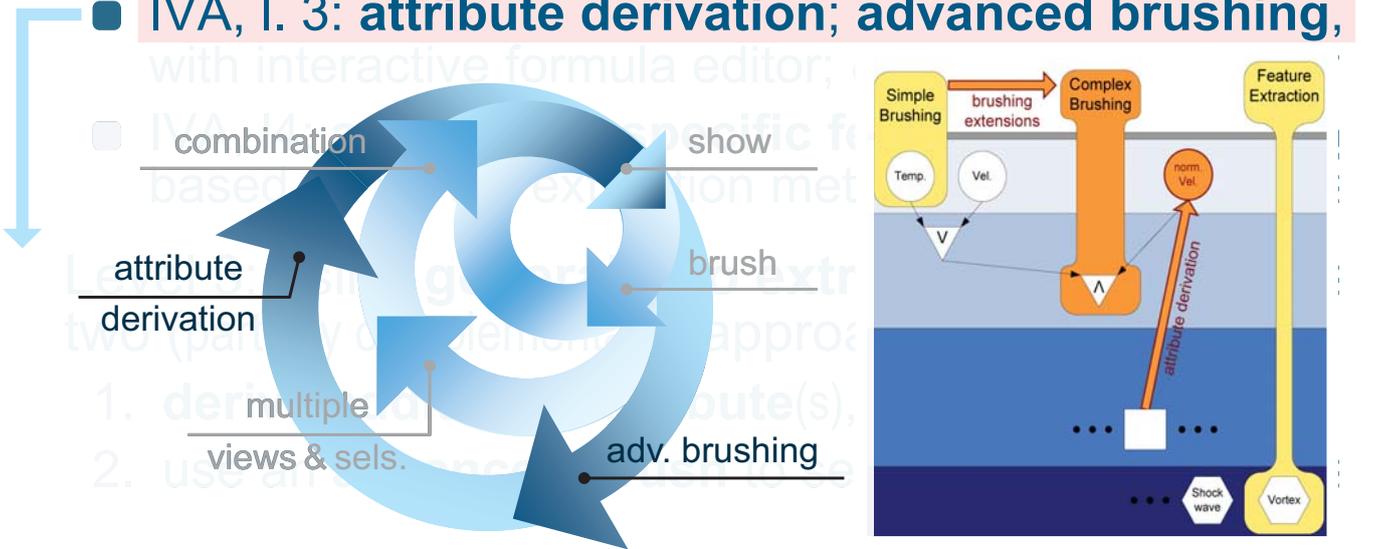
brushed
cloud:



corresponding
feature(s):



- A **lot** can be done with basic IVA, already! ✓ [parent rule]
- For more advanced exploration/analysis tasks, we extend it (in several steps):
 - IVA, level 2: **logical combinations of brushes** utilizing the *feature definition language* [Dreisch et al., 2005]
 - IVA, l. 3: **attribute derivation; advanced brushing**,

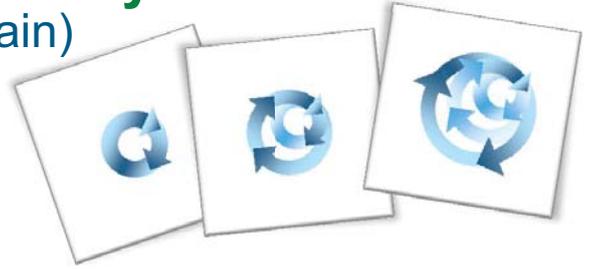


- A **lot** can be done with basic IVA, already! ✓ [parent rule]
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 - IVA, level 2: **logical combinations of brushes** utilizing the *feature definition language* [Dreisch et al., 2005]
 - IVA, l. 3: **attribute derivation; advanced brushing**, with interactive formula editor; e.g., similarity
 - IVA, l4: **application-specific feature extraction** based on vortex extraction methods for flow analysis

- Level 4: **application-specific procedures**
 - tailored solutions (for a specific problem)
 - “deep” information drill-down
 - *etc.*

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:

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

Stuart K. Card, George G. Robertson, Jock D. Mackinlay

Xerox Palo Alto Research Center
Palo Alto, California 94304
(415) 494-4362, Card.PARC@Xerox.COM

CHI '91

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!**

Dagstuhl Seminar Talk

Categories of Interaction Pace

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

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.**

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 is 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.

- 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.*)

- **You!**
- **Krešimir Matković & Giuseppe Santucci!**
- Helmut Doleisch, Raphael Fuchs, Johannes Kehrer, Çağatay Turkey, *et al.*!
- Collaboration partners (St. Oeltze, Fl. Ladstädter, G. Weber, *et al.*)
- All around SimVis and ComVis and ...
- Funding partners (FFG, AVL, EU, UiB, ...)