Basics
of
Interactive Visual Analysis

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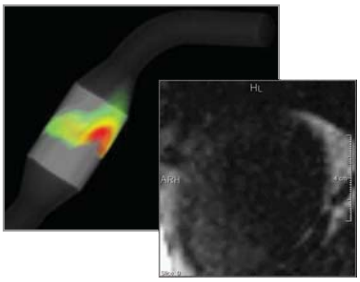
Interactive Visual Analysis

- 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**

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*
- **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**…



Target Data Model: "Scientific Data"

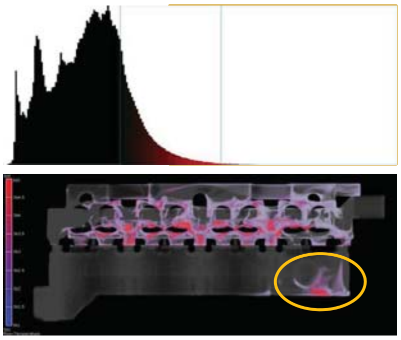
- **Characterized** by a combination of
  - **independent variables**, like **space** and/or **time** (cf. **domain**)
  - and **dependent variables**, like **pressure**, **temp**., etc. (cf. **range**)
- So we can think of this type of data as **given as $\mathbf{d}(\mathbf{x})$** with $\mathbf{x}$ ↔ **domain** and $\mathbf{d}$ ↔ **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**:
  - $\mathbf{d}$ is (at least to a certain degree) **continuous** wrt. $\mathbf{x}$

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

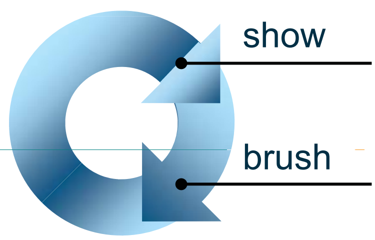
- Loop / bundling of *two complementary parts*:
  - **visualization** – show to the user!
    Something new, or something due to interaction.
  - **interaction** – tell the computer!
    What is interesting? What to show next?
- Basic example (**show – brush** – show – …), cooling jacket context:
  1.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

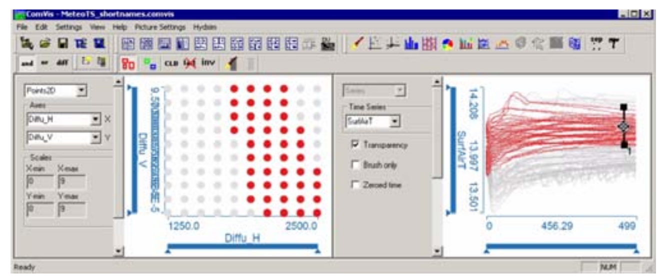
Show & Brush (IVA level 1)

- **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 (IVA level 1)

- **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 …*

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

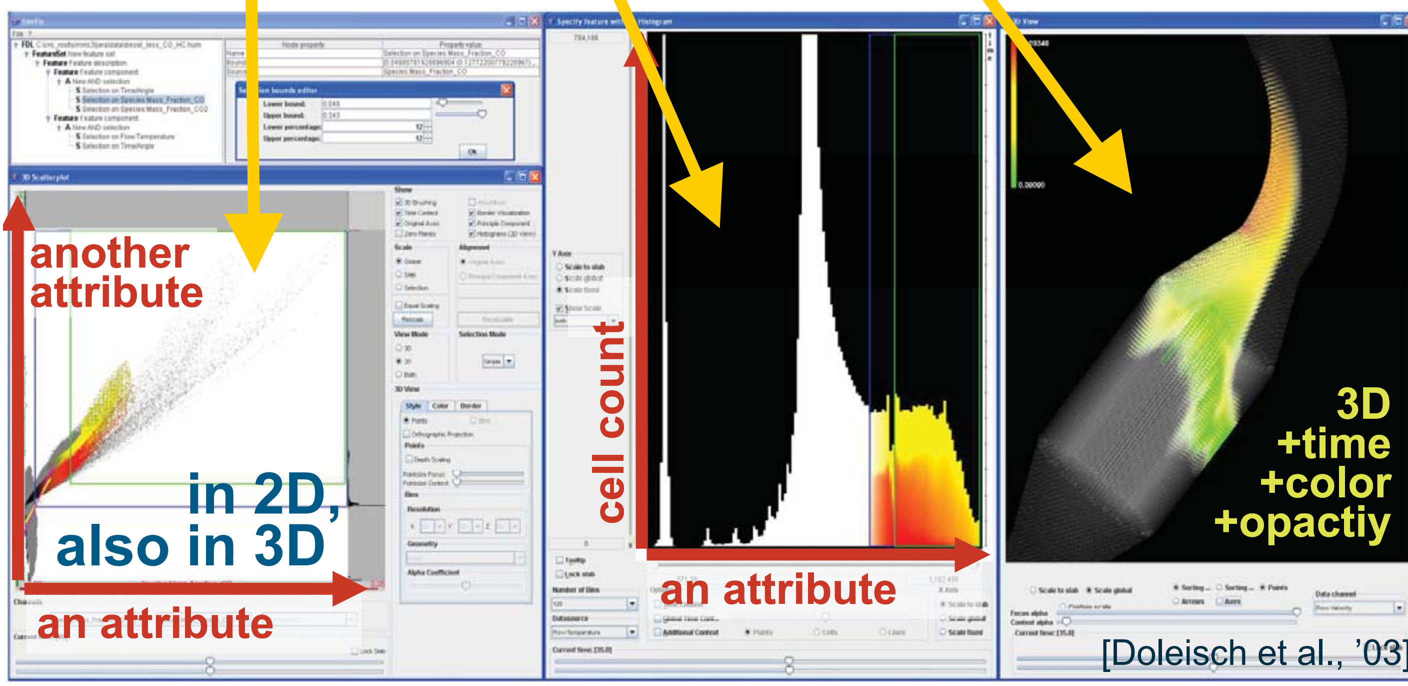
- bring up multiple views
  - at least one for **x**, *t*
  - at least one for d_i
- I see (something)!
- brush this "something"
- linked F+C visualization
- first insight!

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

(next slide)

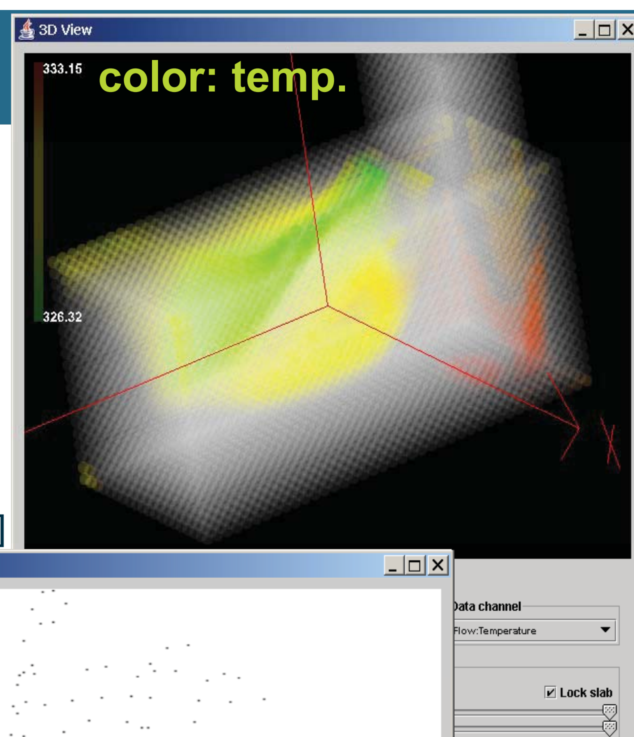
IVA: Multiple Views

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

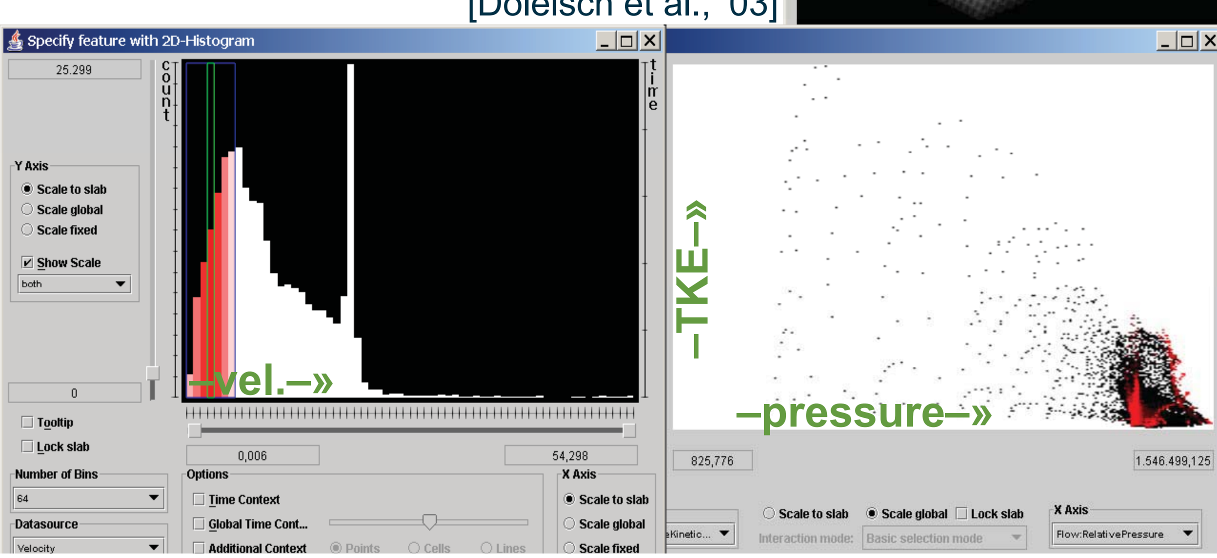


IVA: Interactive Brushing

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



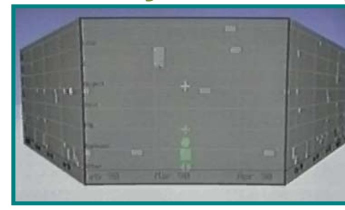
[Doleisch et al., '03]



IVA: Focus+Context Visualization

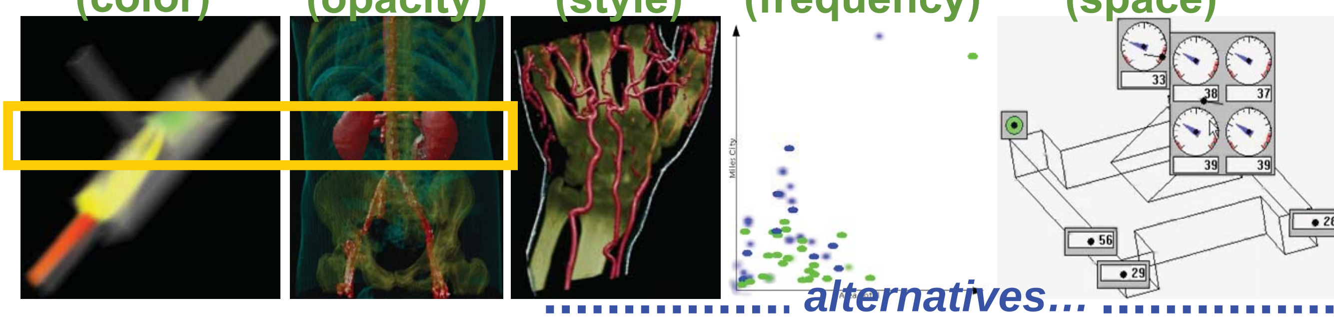
- Traditionally space distortion
  - more space for data of interest
  - rest as context for orientation
- Generalized F+C visualization
  - emphasize data in focus (color,opacity, …)
  - differentiated use of visualization resources

[Mackinlay et al. 1991]



[Hauser… 2001, 2003]

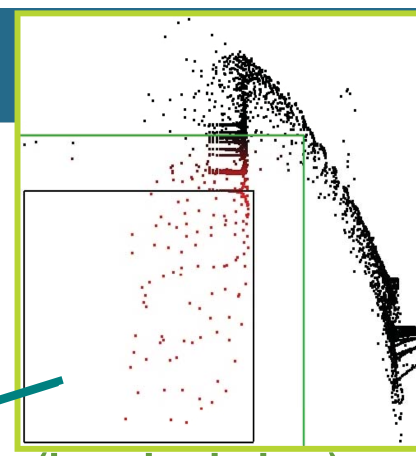
(color) (opacity) (style) (frequency) (space)



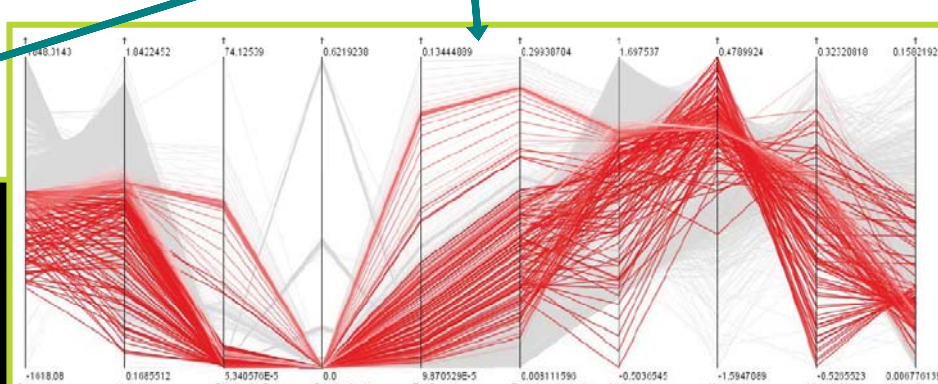
alternatives…

IVA: Linked Views

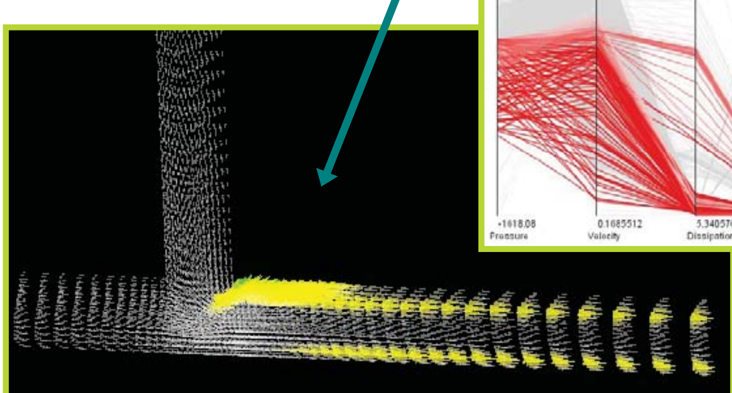
- Brushing: mark data subset as especially intersting
- Linking: enhance brushed data in linked views consistently (F+C)



(brushed view)



(linked views)



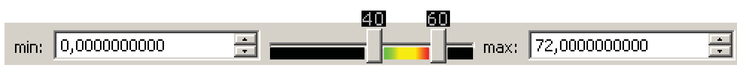
[Doleisch & Hauser, '02]

IVA: Degree of Interest (DOI)

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

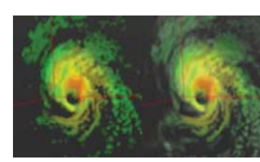


- Fractional DOI values: $0 \leq doi(tr_i) \leq 1$
  - several levels (0, low, med., …)
  - a continuous measure of interest
  - a probabilistic definition of interest

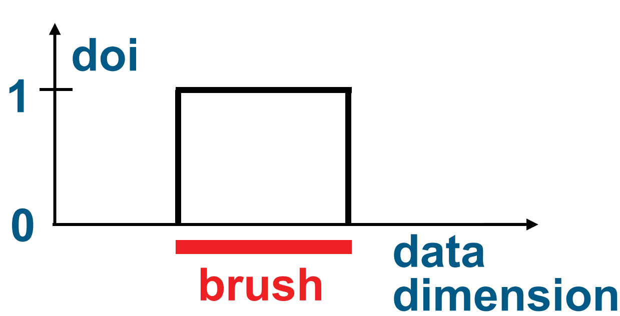
(cont'd on next slide)

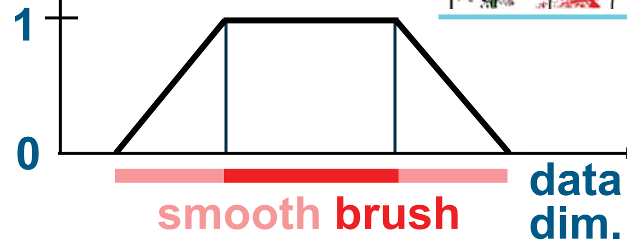
IVA: Smooth Brushing → Fractional DOI

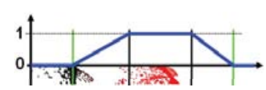
- **Fractional DOI values** esp. useful wrt. **scientific data**: (quasi-)continuous nature of data ↔ smooth borders
- Goes well with gradual focus+context vis. techniques (coloring, semitransparency)



- 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)



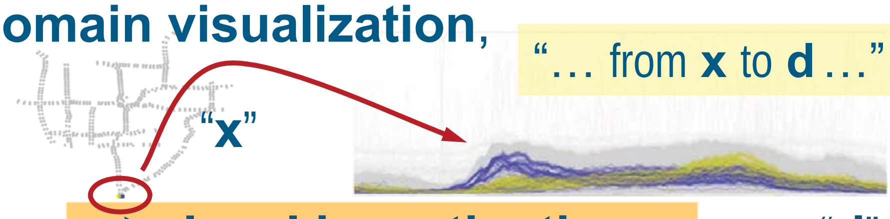




Three Patterns of SciData IVA

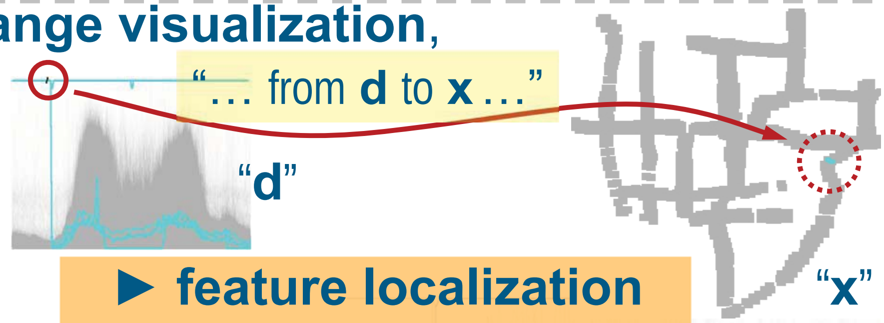
- Preliminary: domain **x** & range **d** visualized (≥2 views)

- **brushing on domain visualization**, *e.g.*, brushing special locations in the map view



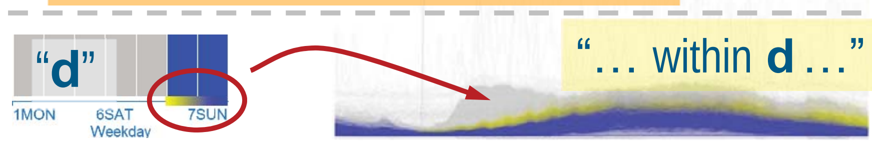
❶ ▶ **local investigation**

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



❷ ▶ **feature localization**

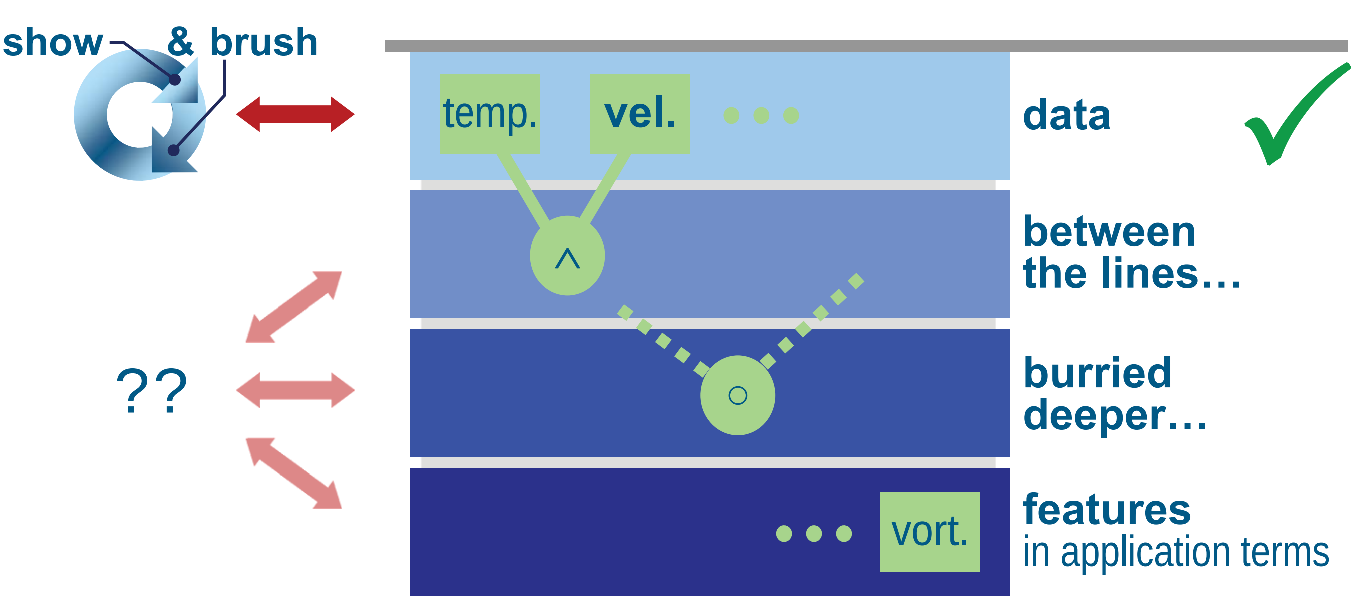
relating multiple range variates



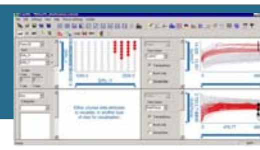
❸ ▶ **multi-variate analysis**

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**, …

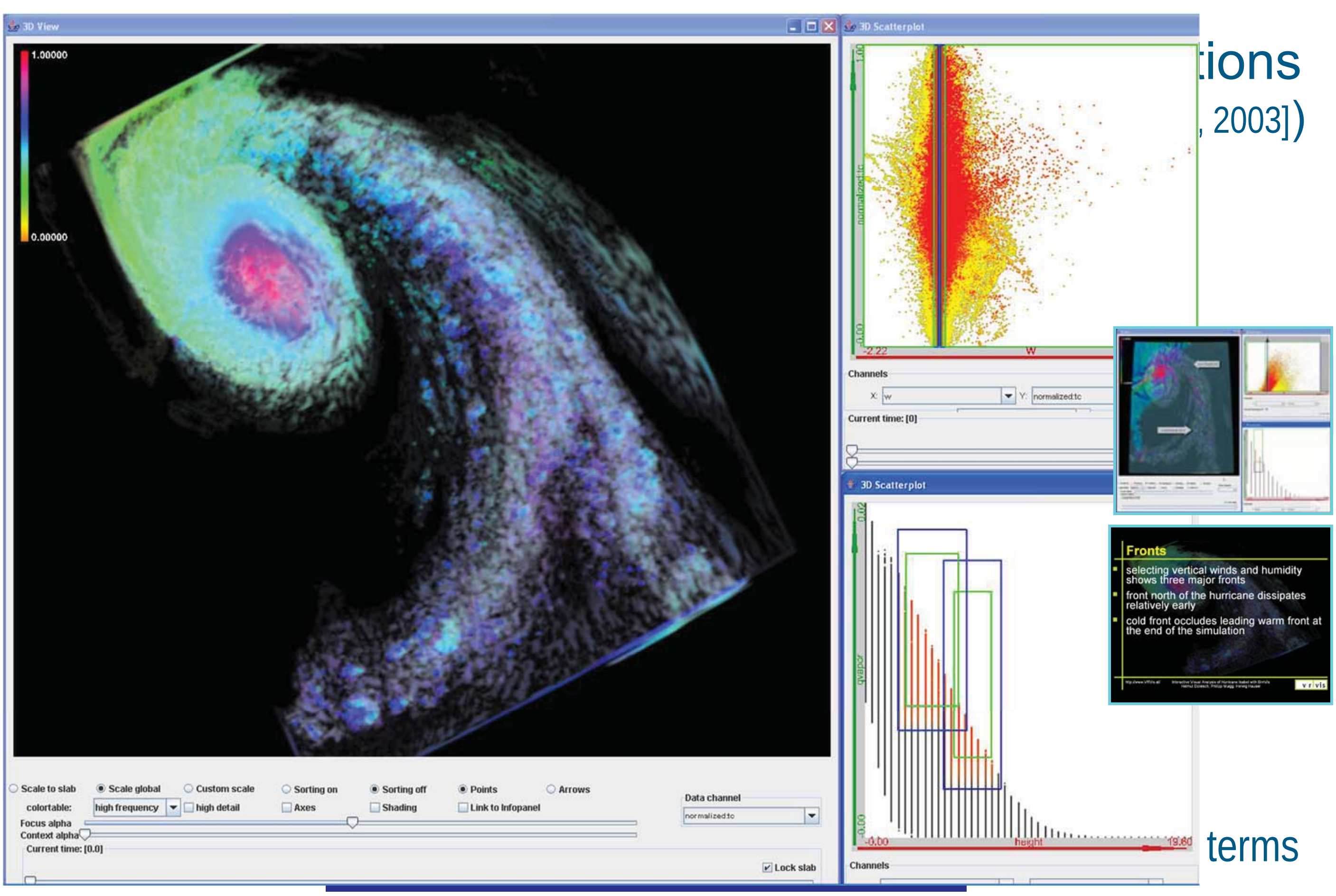


IVA – Levels of Complexity (2/4)



- A lot can be done with KISS-principle IVA! [pareto 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 (level 2) Example



tions
, 2003])

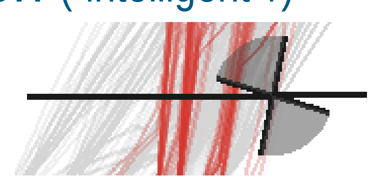
terms

IVA – Levels of Complexity (3/4)

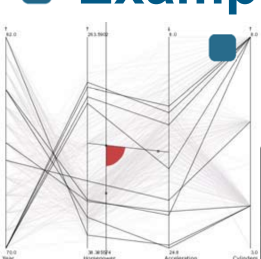
- A lot can be done with KISS-principle IVA! [pareto rule]
- **For more advanced** exploration/analysis **tasks**, we extend it (in seveal steps):
  - IVA, level 2: **logical combinations of brushes**, *e.g.*, utilizing the *feature definition language* [Doleisch et al., 200…]
  - IVA, l. 3: **attribute derivation**; **advanced brushing**, with interactive formula editor; *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

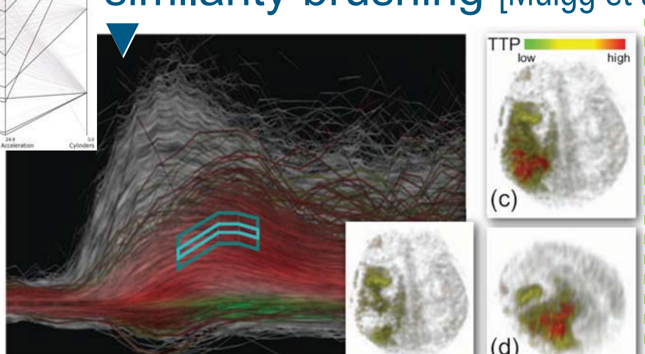
IVA (level 3): Advanced Brushing

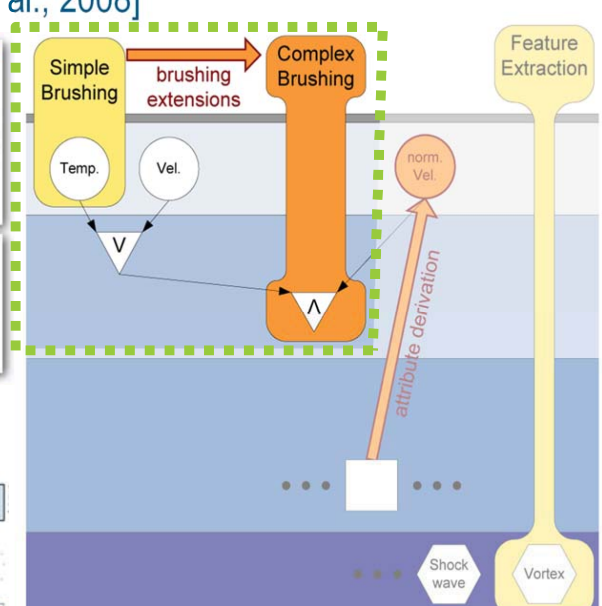
- **Std. brush**: brush 1:1 what you see
  Adv. brush: executes additional function ("intelligent"?)
- **Examples**:



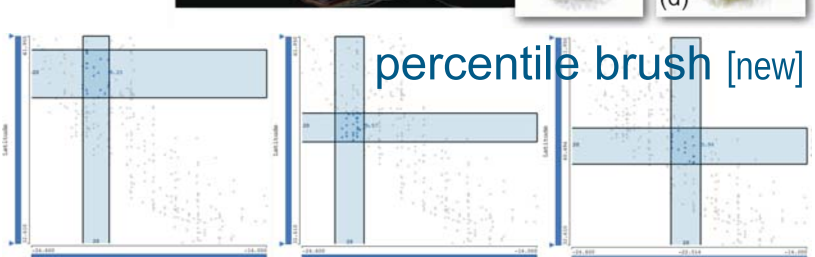
  - angular brushing [Hauser et al., 2002]
  - similarity brushing [Muigg et al., 2008]





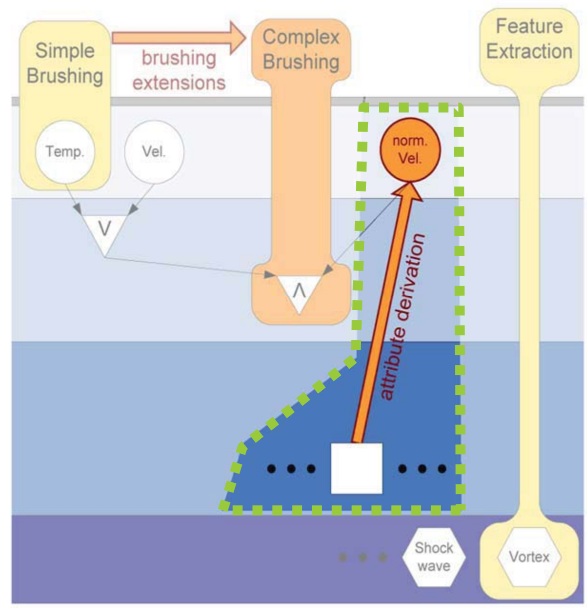


percentile brush [new]

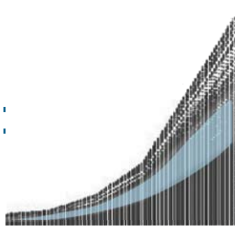


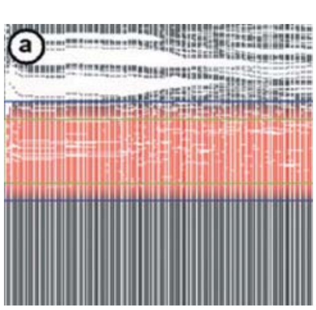
IVA (level 3): **Attribute Derivation**

- **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**

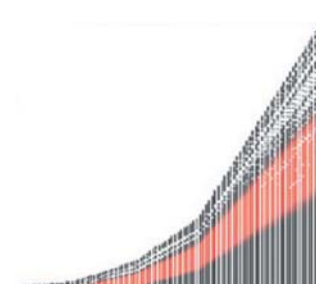


Attribute Derivation ↔ **User Task** / example

- 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!

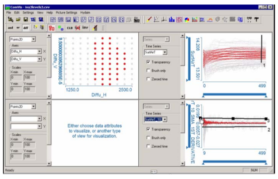
How to reflect these user wishes?

- 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.*)
  - **embedding** (project into a lower-dim. space, *e.g.*, with PCA for a subset of the attribs., *etc.*) ⇒ example ⇒ example
- **Important**: **executed on demand**, after prev. vis.

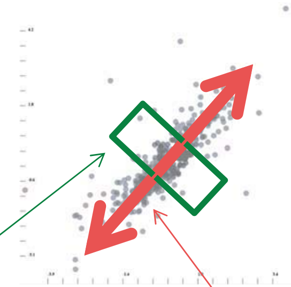
3rd-level IVA – Sample Iterations (1/2)

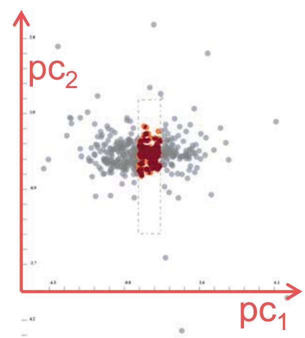


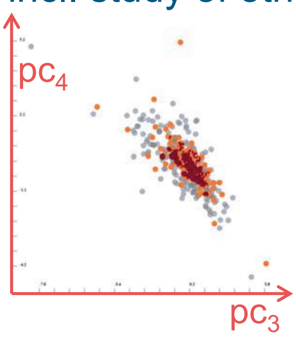
- The **Iterative Process of 3rd-level IVA**:
  - Example 1:
    - you look at some *temp. distribution over some region*
    - you are *interested raising temperatures*, ***but not temperature fluctuations***
    - you use a **temporal derivate estimator**, for ex., central differences $t_{change} = (t_{future} - t_{past})/\text{len}(\text{future}-\text{past})$
    - you plot t_{change}, e.g., in a **histogram** and **brush** what ever change you are interested in
    - maybe you see that 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

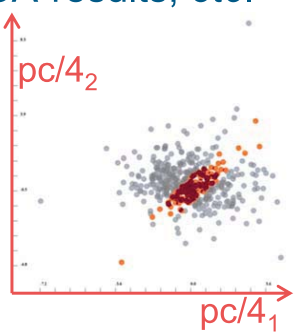
3rd-level IVA – Sample Iterations (2/2)

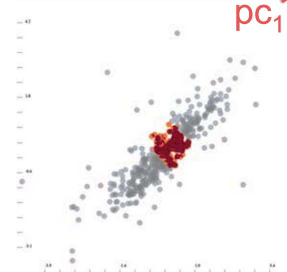
- The **Iterative Process of 3rd-level IVA**:
  - Example 2:
    - you bring up a scatterplot of d_1 vs. d_2: (from an ECG dataset [Frank, Asuncion; 2010])
    - obviously, d_1 and d_2 are correlated, our interest: the **data center** *wrt. the main trend*
    - we ask for a (local) **PCA** of d_1 and 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.*







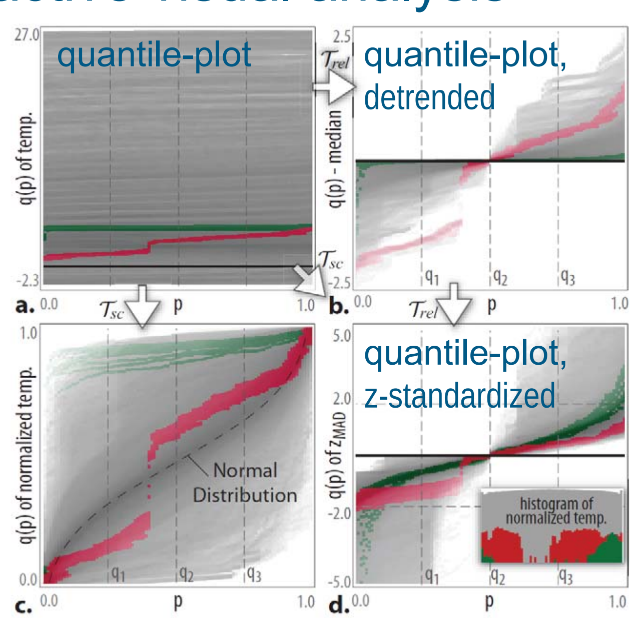


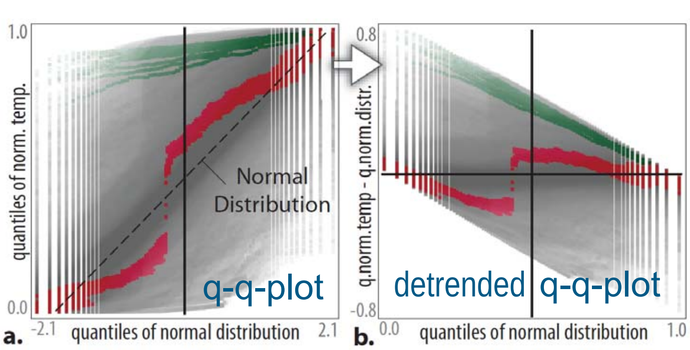


Visualizing / analyzing lots of statistics

[Kehrer et al., TVCG 2011]

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





[IEEE Vis, 2008]

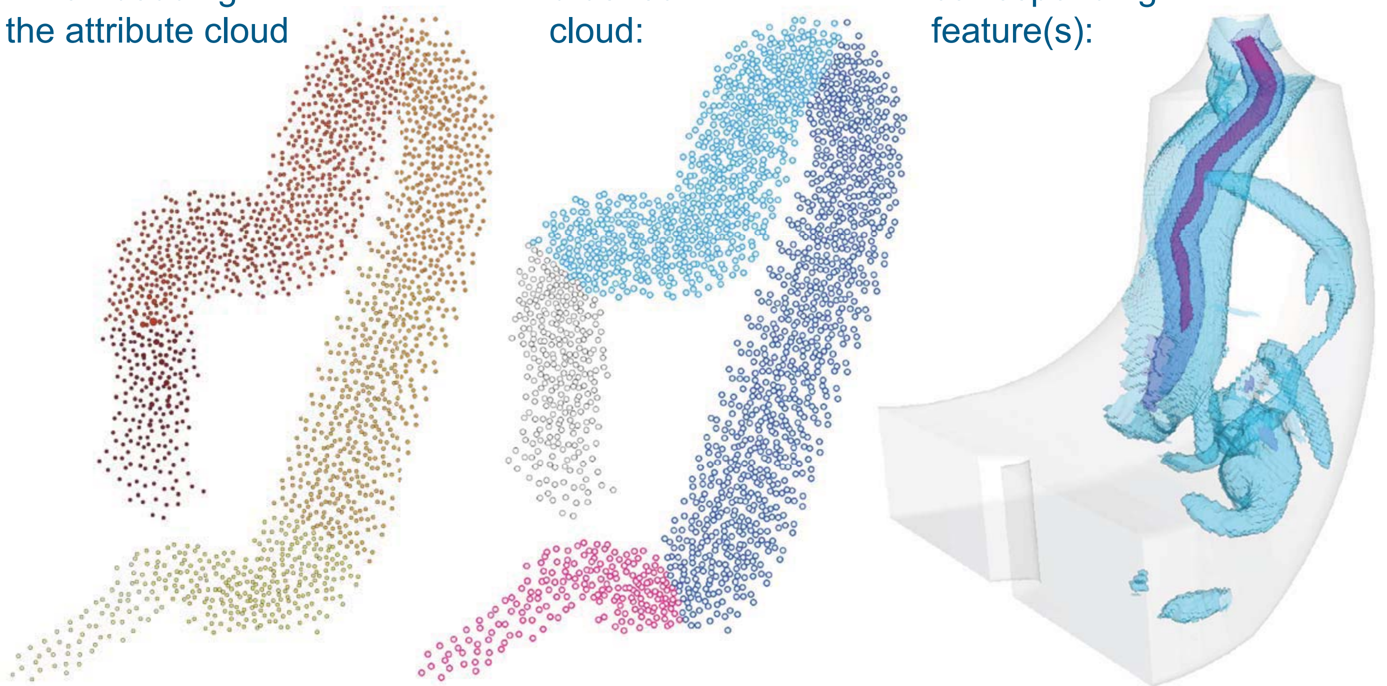
Brushing of Attribute Clouds for the Visualization of Multivariate Data

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

2D embedding: the attribute cloud

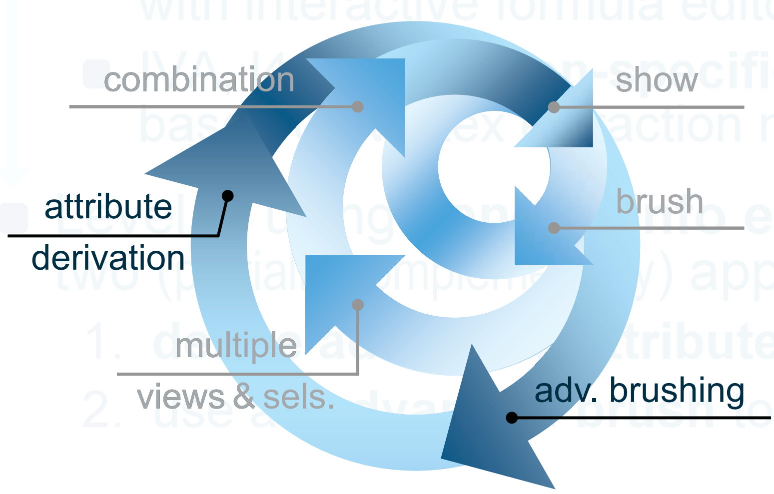
brushed cloud:

corresponding feature(s):



IVA – Levels of Complexity (4/4)

- A lot can be done with KISS-principle IVA! [pareto 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, l. 4: …n-specific **feature extraction**, *e.g.*, …based … extraction methods for flow analysis
- Level … **traction** mechanisms, two (partially complementary) approaches:
  1. … attribute(s), then show & brush
  2. use advanced brushing to select “hidden” relations



IVA – Levels of Complexity (4/4)

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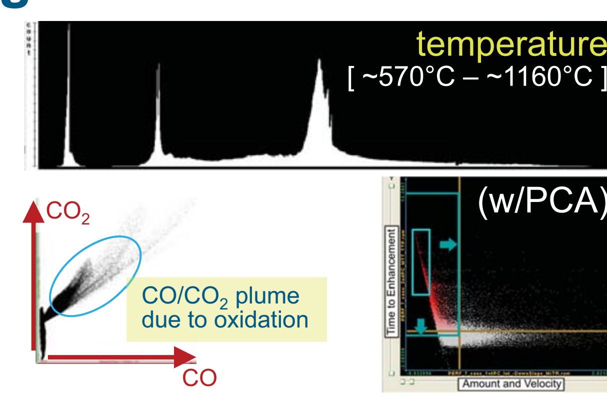
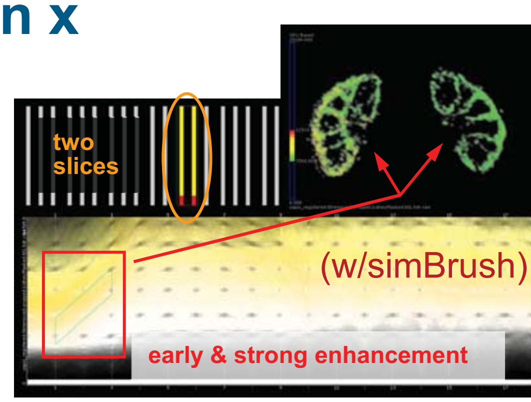
  - IVA, l. 3: **attribute derivation**; **advanced brushing**, with interactive formula editor; *e.g.*, similarity brushing
  - IVA, l4: **application-specific feature extraction**, *e.g.*, based on vortex extraction methods for flow analysis
- Level 4: **application-specific procedures**
  - tailored 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…

…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]: ≈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.

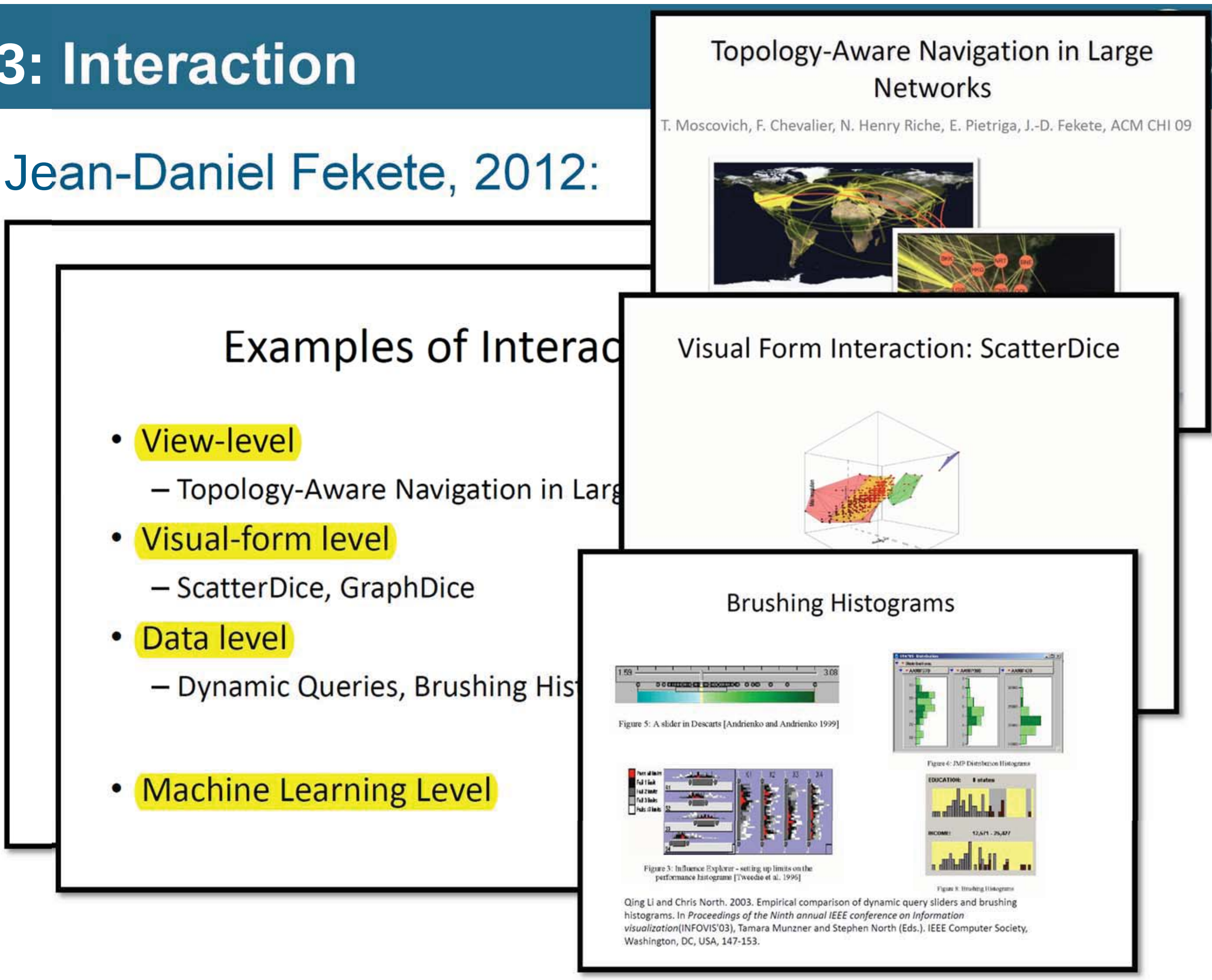
The immediate response time constant. A person can make an unprepared response to some stimulus within about a second [21]. If there is more than a second, then either the listening party makes a backchannel response to indicate that he his listening (e.g., "uh-huh") or the speaking party makes a response (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!

C3: Interaction

- Jean-Daniel Fekete, 2012:



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The Iterative Process of IVA…

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

Animated Transitions in Statistical Data Graphics
Jeffrey Heer
George G. Robertson
Microsoft Research

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

…lead to according **iteration frequencies**:

Optimizing Processes in Visual Analytics to Meet the Three Human Time Constants

- 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!**
- **Krešimir Matković** & **Giuseppe Santucci**!
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- All around SimVis and ComVis and …
- Funding partners (FFG, AVL, EU, UiB, …)