Advanced Visual Medicine: Techniques for Visual Exploration & Analysis

Visual Analysis of Perfusion Data

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Structure

Motivation of Perfusion Imaging

Data Acquisition and Pre-processing

Visual Analysis of Perfusion Data

- Basic Techniques
- Advanced Techniques
- Interactive Visual Analysis

Case Study: Coronary Heart Disease

- Medical Background
- Visual Exploration Techniques
- Glyph-Based Visualization of Perfusion, Contractility and Viability
- Integration of Perfusion and Morphologic Data

Motivation of Perfusion Imaging

Examination of blood flow in vasculature below the common spatial resolution of static image data

Selected diagnostic application areas:

- Ischemic Stroke Diagnosis
  - Fast localization of “tissue at risk”
- Breast Tumor Diagnosis
  - Evaluation of the dignity (malignant or benign) of breast tumors and radiation therapy monitoring
- Coronary Heart Disease (CHD) Diagnosis
  - Localization of less-perfused myocardial regions for functional analysis and correlation with supplying coronaries to support stenosis evaluation

Data Acquisition

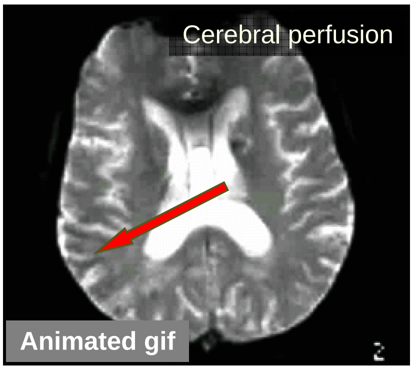
Focus Magnetic Resonance (MR) perfusion diagnosis

Application of a contrast agent (CA)

- Very fast injection to form a bolus
- Repeated acquisition of subsequent images
- CA wash-in provides signal changes ➔ tracer of blood

Typical dataset characteristics in MRI:

- Ischemic stroke diagnosis (T2, 128 x 128 x 20 x 40, 40sec)
- Breast tumor diagnosis (T1, 512 x 512 x 80 x 6, 10min)
- Diagnosis of Coronary Heart Disease (T1, 128 x 128 x 4 x 40, 20-40sec)



Data Pre-Processing

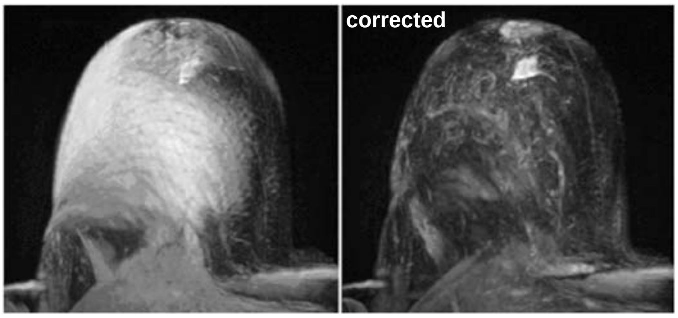
Low signal-to-noise (S/N)-ratio requires smoothing

- Tissue boundaries must be maintained

Analysis requires inter-pixel correspondence over time

- Crucial in breast tumor and CAD diagnosis due to respiration, muscle relaxation, (and heart motion)

➔Motion correction, e.g., by combining rigid and elastic registration based on mutual information and a gradient descent method for optimization [Rueckert, 1999]



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Basic Visual Analysis Techniques *Cine Movies*

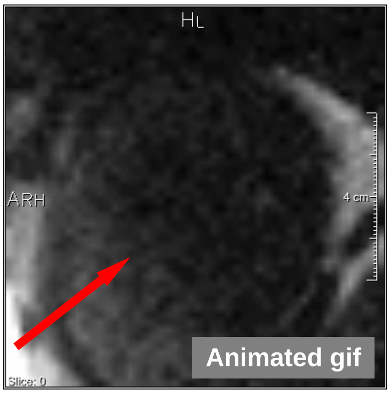
Comprehensive overviews on analysis and visualization of perfusion data can be found in [Preim and Bartz 2007] and [Preim, 2008/09]

Cine-movies, which step through all points in time for a selected slice

Prevailing method in tight schedule of clinical routine

Problems:

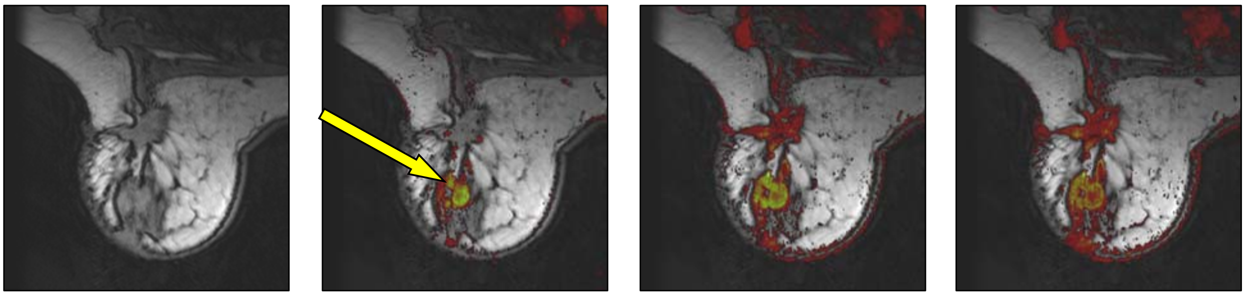
- user-dependent,
- no quantitative results,
- small perfusion defects remain undetected



Basic Visual Analysis Techniques
Subtraction Images

Subtraction images, which depict the intensity difference between two selected points in time

Differences are color-coded, gray-scale reference image serves as context information



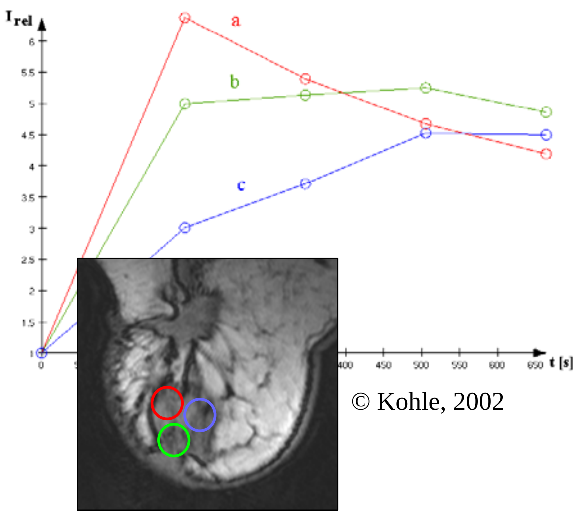
t_0 t_1 t_2 t_3

-- Insertion --
Perfusion Parameters

ROI-selection, Analysis of time-intensity curves (TIC)

Physicians are trained to infer tissue characteristics from TIC shape

Semi-quantitative analysis based on perfusion parameters



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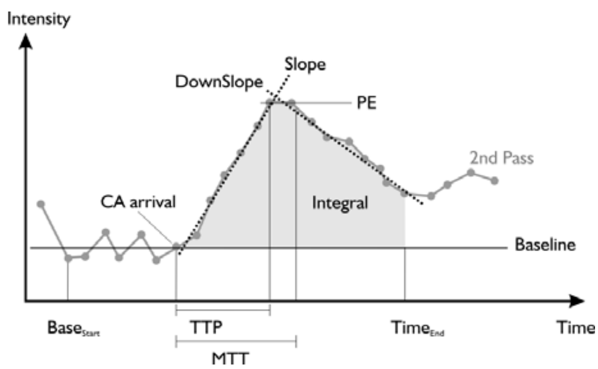

TTP = Time to Peak
MTT = Mean Transit Time
PE = Peak Enhancement

Aux. Variables: $Base_{Start}$, CA arrival, $Time_{End}$

Basic Visual Analysis Techniques
Color-Coded Parameter Maps

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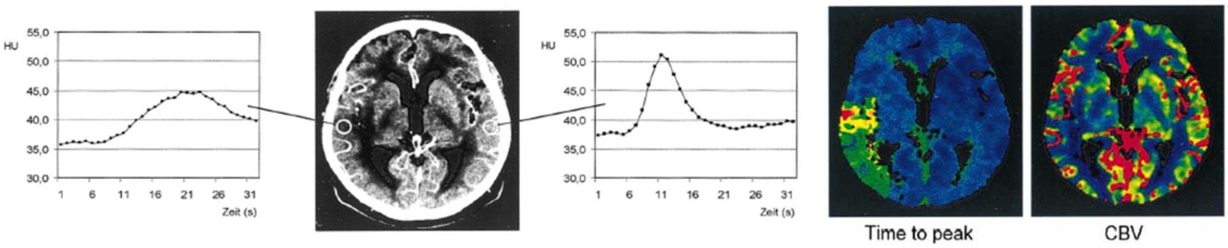
Color-coded parameter maps for a selected slice



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Diagnosis often requires examination of several parameters

Tiled visualization requires mental integration

➔ Strategy for designing multiparameter visualizations:
- Utilizing other visualization attributes besides color
- Adaptation and parameterization of the visualization
- Integration of exploration facilities

Advanced Visual Analysis Techniques
Multiparameter Vis [Oeltze, 2005/06/08]

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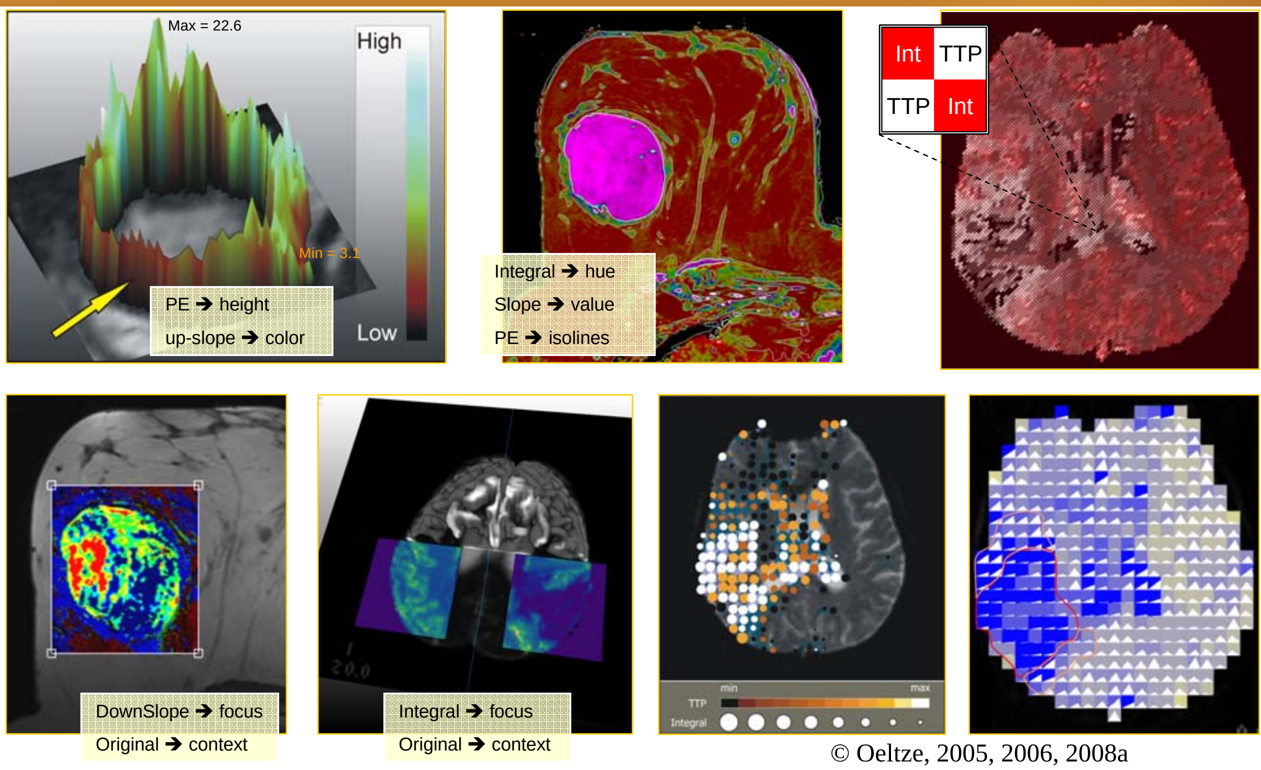
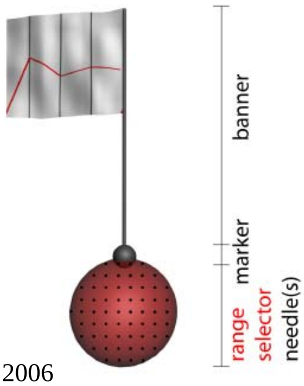


© Oeltze, 2005, 2006, 2008a

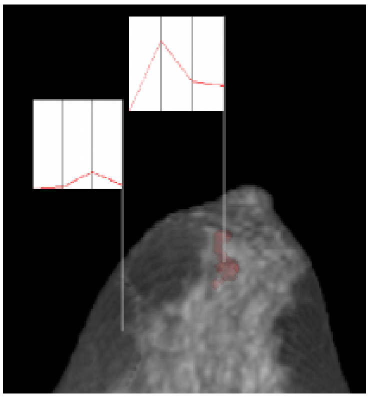
Advanced Visual Analysis Techniques
Probing and Annotating

Profile Flags [Mlejnek, 2005]:

- 3D glyph for probing and annotating volumetric data
- Adaptation to breast cancer diagnosis [Mlejnek, 2006]
- Automatic positioning of flags according to tissue classification
- Banner shows corresponding time-intensity curve
- Flags may be dragged to inspect the neighborhood



© Mlejnek, 2006



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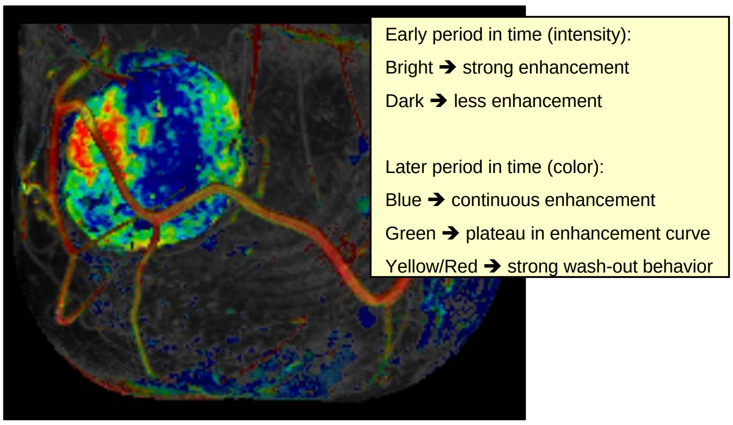
Advanced Visual Analysis Techniques
Projection Methods

Maximum **I**ntensity and **C**losest **V**essel **P**rojection [Kohle, 2002]:

- Gray-scale MIP of subtraction volume serves as context
- CVP with color mapping depending on the dynamical behavior of the voxels time-intensity curve
- Color is only assigned if projected intensity exceeds a threshold



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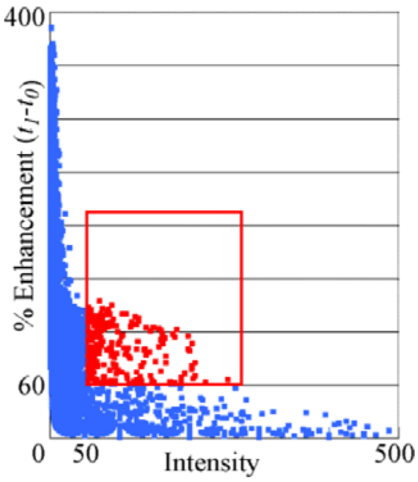
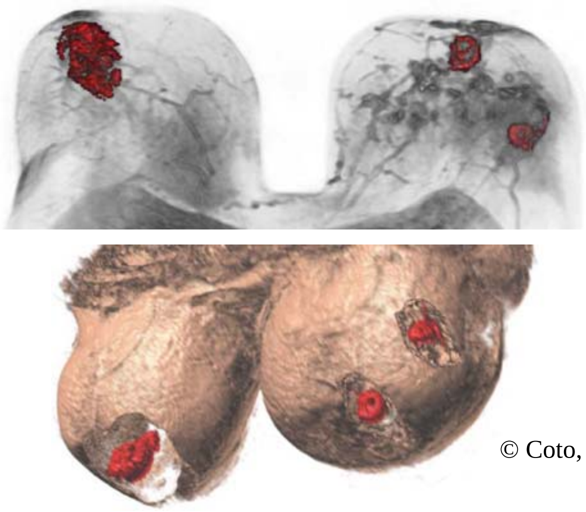
MammoExplorer [Coto, 2005]:

- Support of breast cancer diagnosis combing InfoVis and MedVis
- Integration of scatterplots, brushing and linking, Two-level and Importance-driven volume rendering





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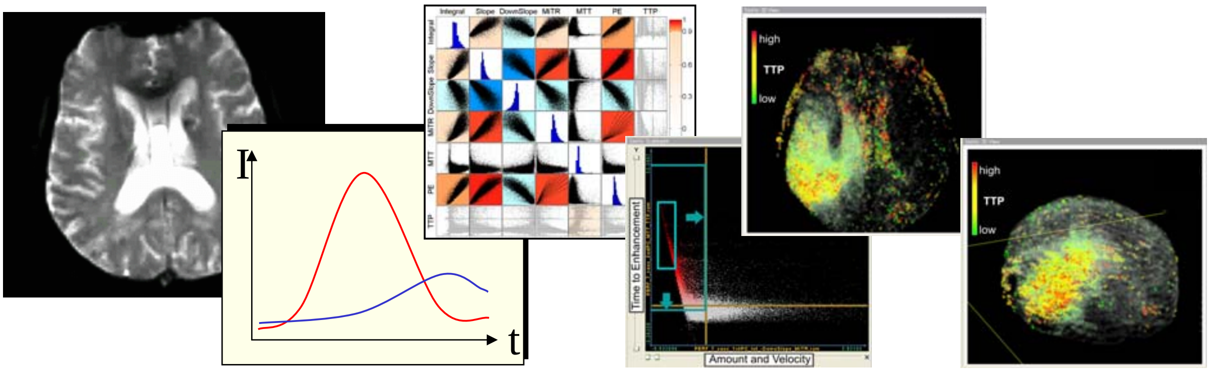
Interactive Visual Analysis of Perfusion Data

Interactive Visual Analysis

Presented at last years IEEE Vis [Oeltze, 2007]

Combination of statistical analysis (correlation analysis, PCA, …) with visualization and exploration techniques (brushing&linking, …)

Support of researchers in the field of perfusion imaging, in particular, in perfusion sequence and contrast agent design



Interactive Visual Analysis
Clinical Research Questions

- How do the perfusion parameters depend on each other?
- How many parameters are relevant for a particular application?
- What is the relationship between imaging details (CA amount, acquisition timing, temporal resolution) and the expressiveness and correlation of the perfusion parameters?
- How strong do the answers to (1),(2),(3) differ from patient to patient?

➔ Correlation analysis explains inter-parameter relations

➔ Principal Component Analysis (PCA) allows a dimension reduction of the parameter space and the detection of trends in the data

➔ Visual Analysis concludes the visualization of analysis results and the interactive exploration considering these results

Interactive Visual Analysis
Analysis Framework

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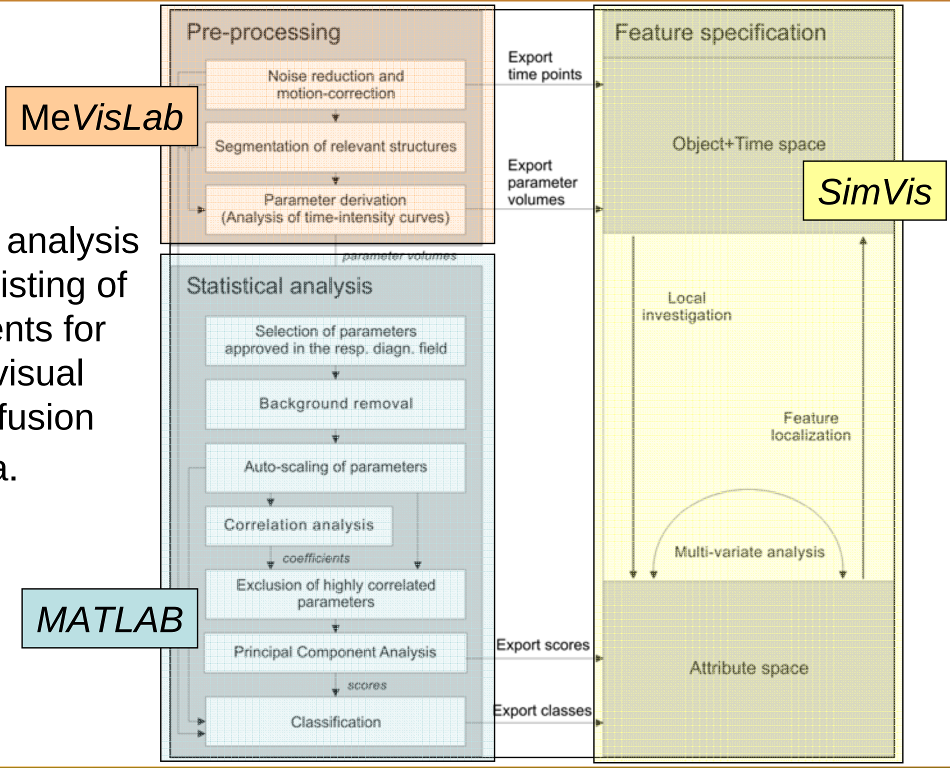

Perfusion data analysis approach consisting of three components for a streamlined visual analysis of perfusion parameter data.

Interactive Visual Analysis
Correlation Analysis

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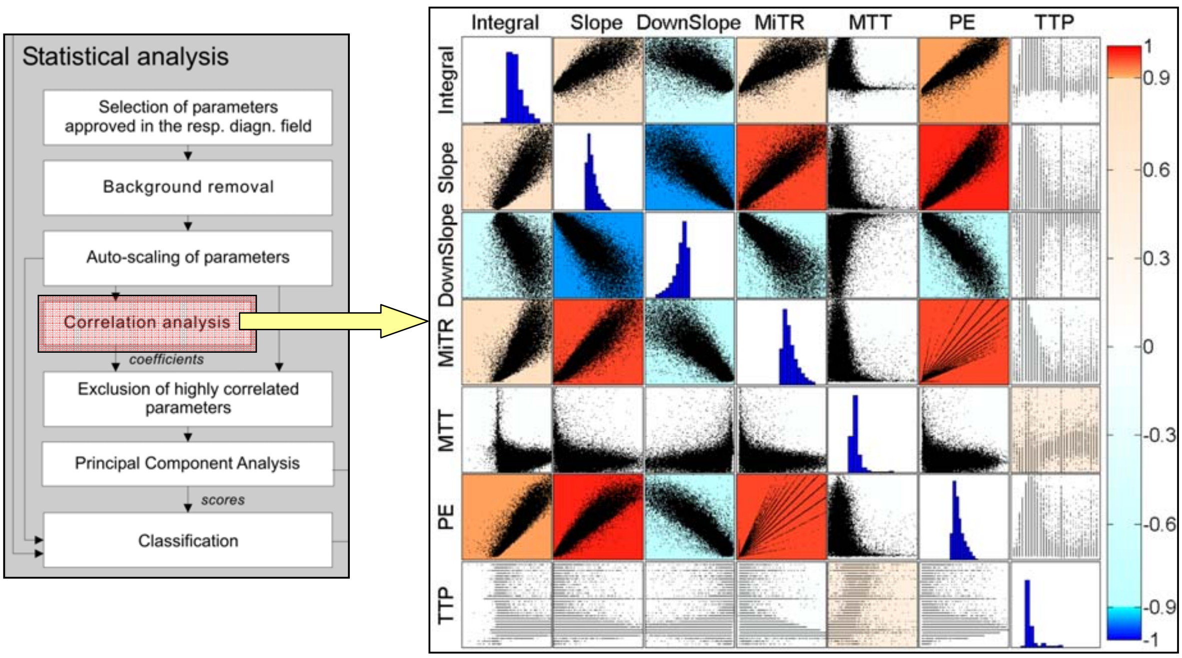
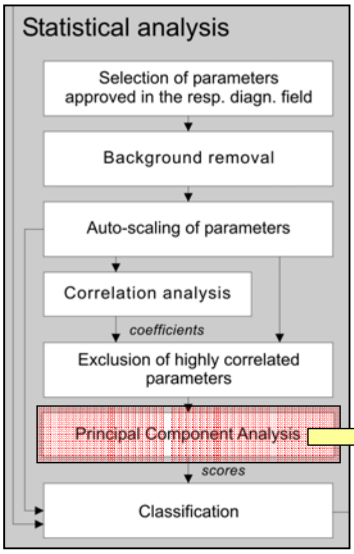
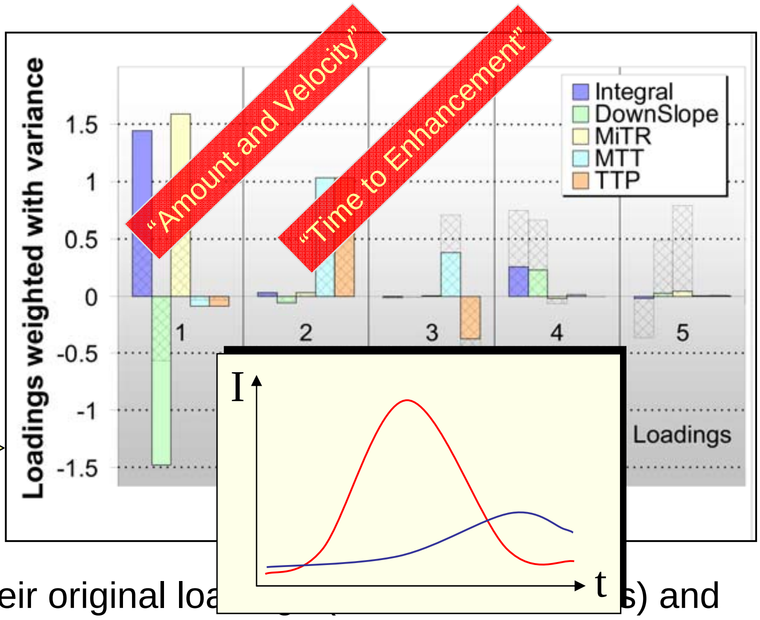


Scatterplot-matrix of perfusion parameters. Strong positive and negative correlation coefficients are emphasized.

Interactive Visual Analysis
Principal Component Analysis

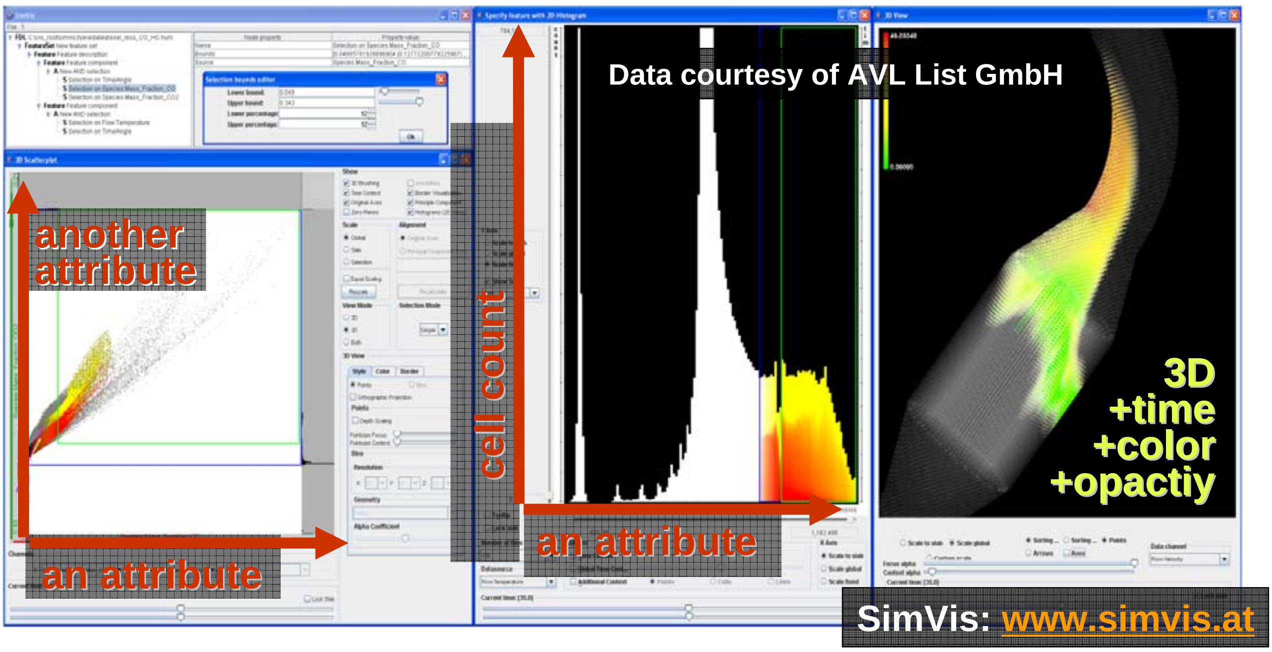




Principal components, their original loa… s) and the significance weighted loadings (filled bars). Each pc represents a trend in the data. The loadings indicate how the different variables correlate with these trends. They disclose inter-parameter relations.

Interactive Visual Analysis
SimVis for Feature Specification

Multiple, linked views, such as scatterplots, histograms, 3D(4D) views, etc.



Interactive Visual Analysis
Case Study: Ischemic Stroke

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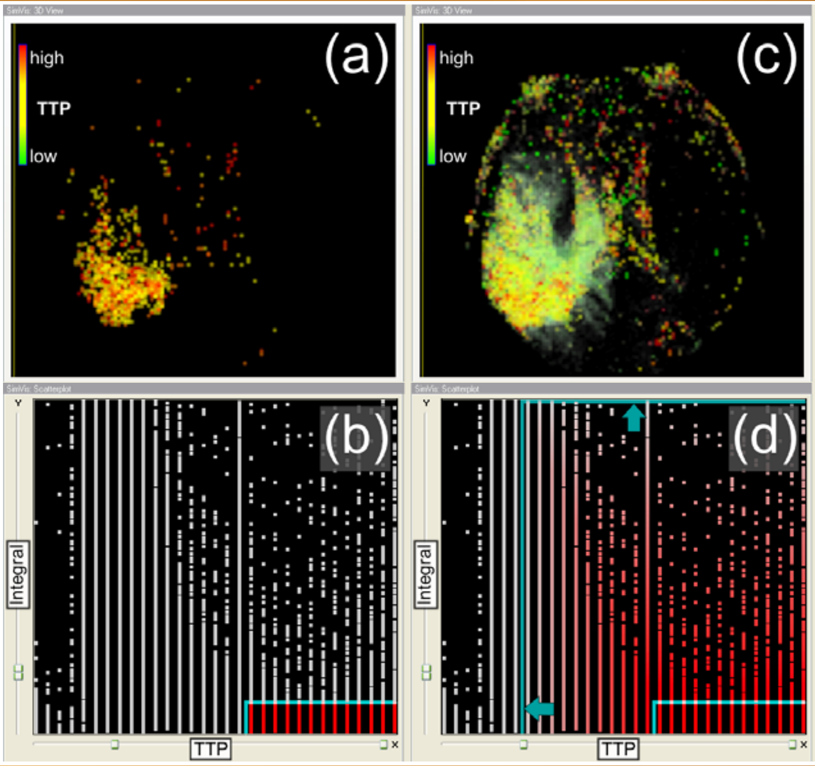
Brushing for interactive feature localization in (b) reveals the infarction core (a)

Smooth brushing (d) indicates “tissue at risk” surrounding the core (c)



Interactive Visual Analysis
Case Study: Ischemic Stroke

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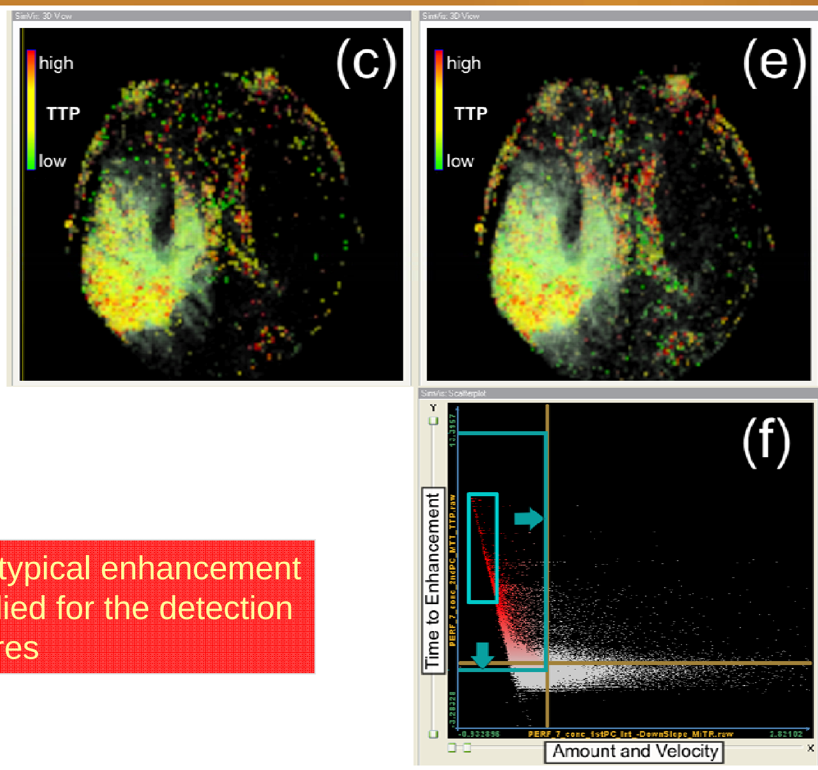
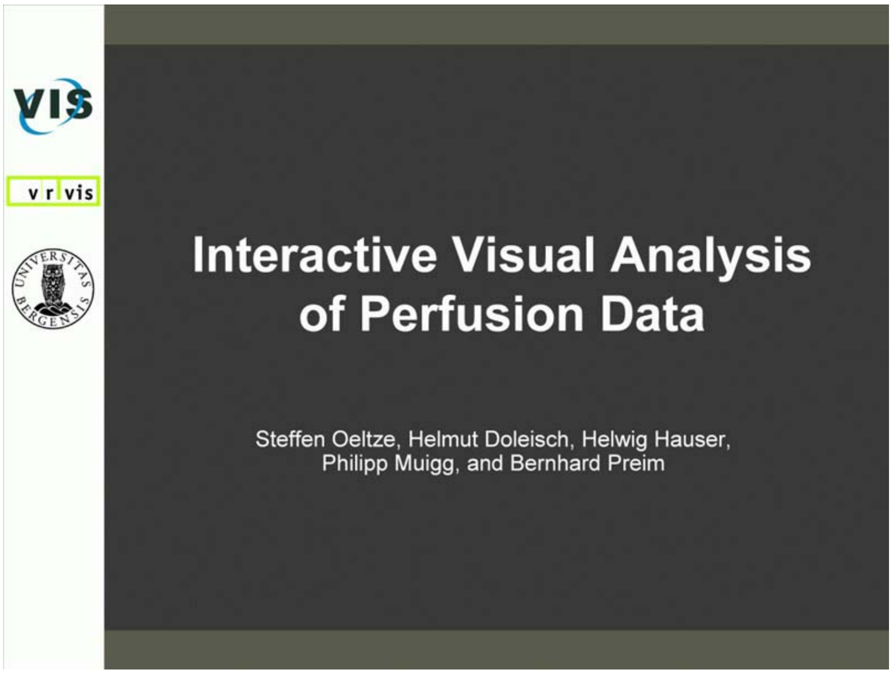
Smooth brushing of pc1 (Amount and Velocity) and pc2 (Time to Enhancement) in (f) yields a very similar result (e) compared to the selection in (c)



➔ Trends representing typical enhancement patterns may be applied for the detection of suspicious structures

Interactive Visual Analysis
Video: Breast Tumor Diagnosis



Supplemental website: http://wwwisg.cs.uni-magdeburg.de/cv/VAoPD/

Interactive Visual Analysis
Function Graph Visualization

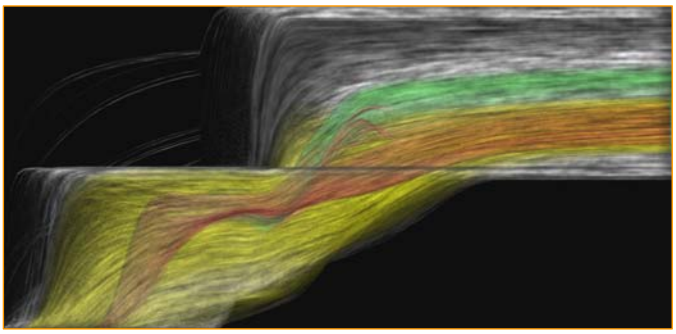
Based on recent work published at EuroVis 2008 [Muigg, 2008]

Remember: Physicians are trained to infer tissue characteristics from TIC shape. “*They know which shapes they are looking for*.”

➔ Exploitation of this knowledge for feature specification

Function Graph Visualization

- Large number of graphs (time-intensity curves)
- Overdrawing/cluttering
- Provide insight into unprocessed perfusion data



© Muigg, 2008

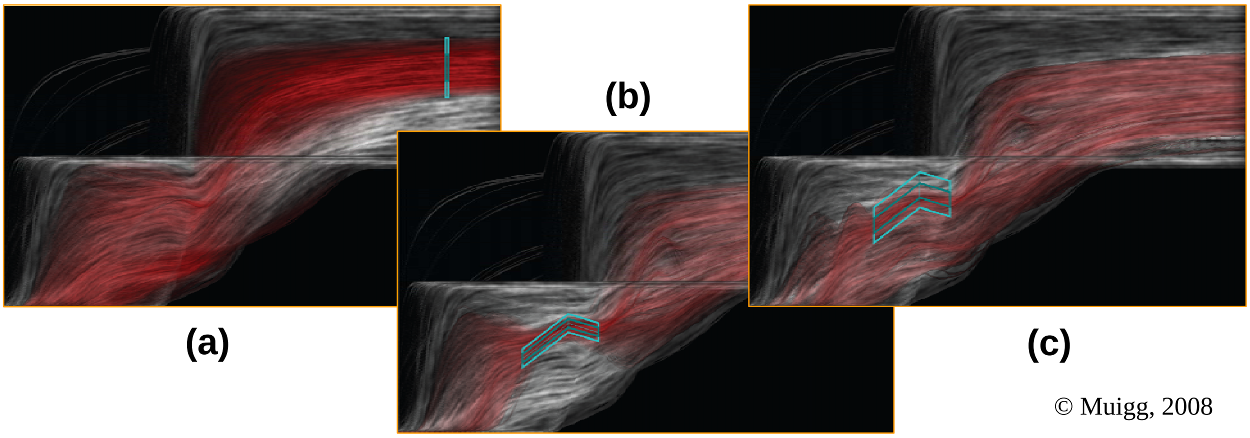
Interactive Visual Analysis
Function Graph Selection

Time step brushing **(a)**

- Interval selection based on single time step

Similarity brushing based on

- average distance between data and selection poly-line or on **(b)**
- derived graphs/selection poly-line (invariant to vert. translation) **(c)**



(a) **(b)** **(c)**

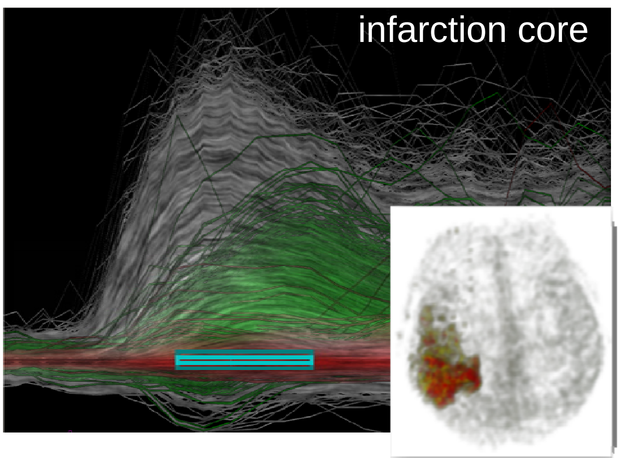
Interactive Visual Analysis
Case Study: Ischemic Stroke

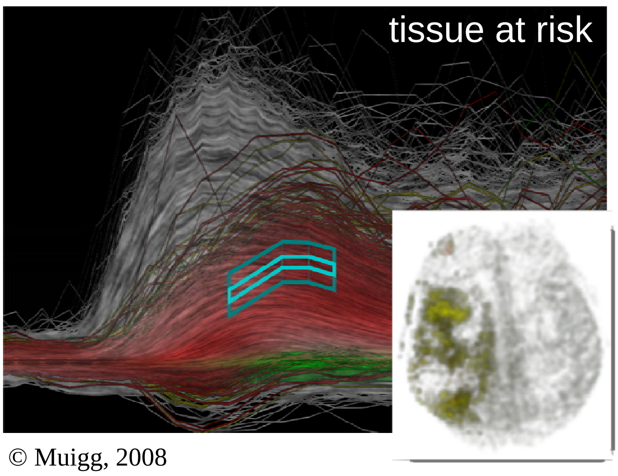
Similarity brushing used to select

- regions with barely any enhancement
- regions with late enhancement

3D view used to locate selected features

40 time steps
~200,000 function graphs





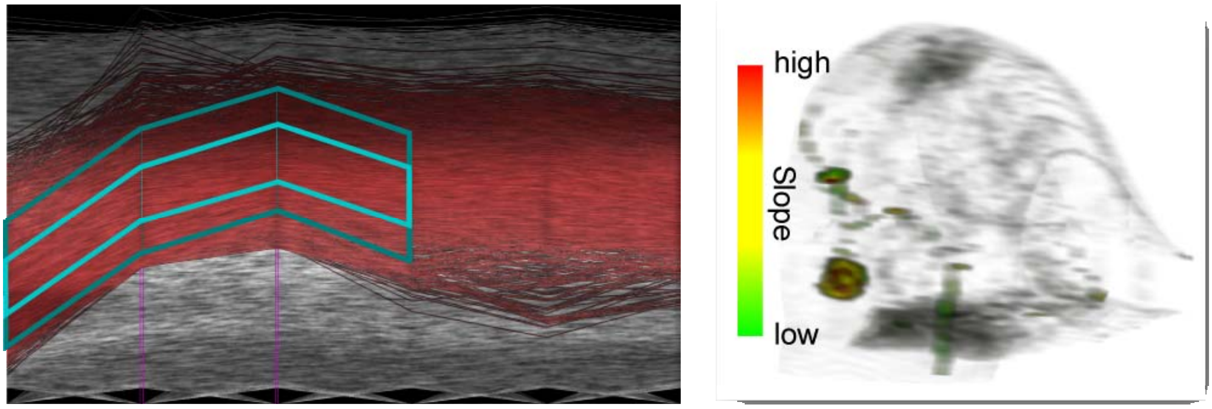
Interactive Visual Analysis
Case Study: Breast Tumor Diagnosis

Similarity brushing used to select suspicious regions

3D view shows

- selected features
- context visualization of the breast

6 time steps
~1,000K function graphs



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Interactive Visual Analysis
Conclusion

Integration of pre-processing techniques, statistical methods, and interactive feature specification

Assessment of the reliability of specific perfusion parameters and of inter-parameter correlations

Detection of trends, representing two types of enhancement patterns:

- Typical ➔ applied for detecting suspicious structures
- Atypical ➔ may indicate pre-processing failures

Similarity brushing in function graph representations exploits knowledge of physicians about expected time-intensity curve shape

Compared to pure visual exploration, interactive visual analysis enables a more reproducible evaluation supported by statistical results

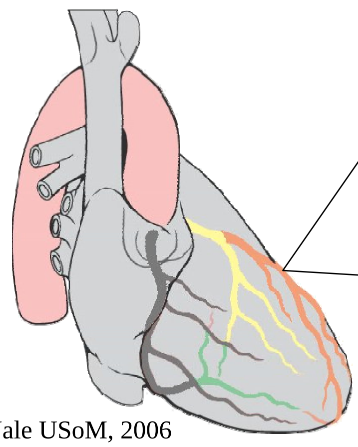
Case Study: Diagnosis of Coronary Heart Disease

Case Study
Coronary Heart Disease

<u>Definition:</u> severe stenosis of one or more coronary arteries

Early stage CHD characterized by perfusion defect of the myocardium (heart muscle)

Angina pectoris, cardiac arrhythmia and heart attack may result



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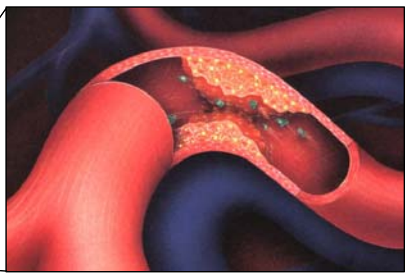


© www.cardio-bielefeld.de, 2006

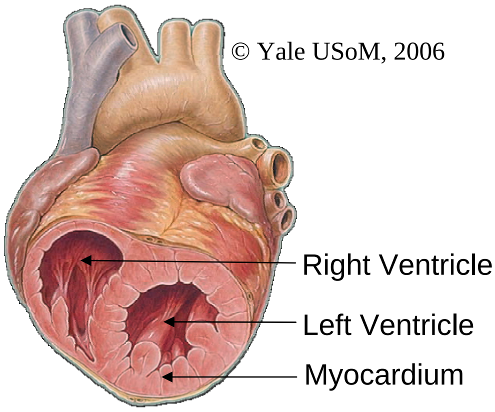
Left Circumflex Artery (LCX)
Left Anterior Descending Artery (LAD)
Right Coronary Artery (RCA)

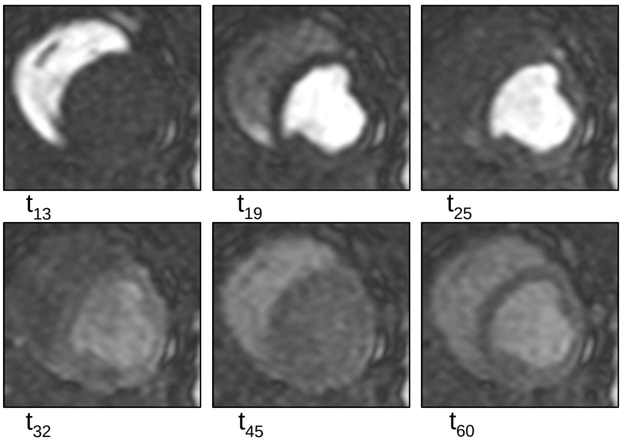
Coronary Heart Disease
Data Acquisition

➔ Localization and quantification of the perfusion defect

➔ Exploiting anatomical knowledge about supplying coronary arteries to detect stenosis

ECG-triggered data acquisition during breath-hold at rest (and under stress) in 3-4 cardiac short axis planes

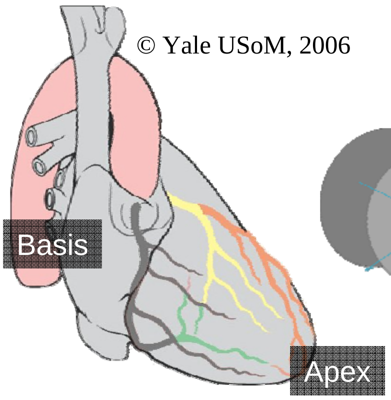


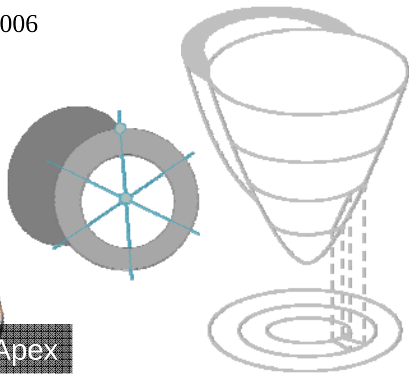


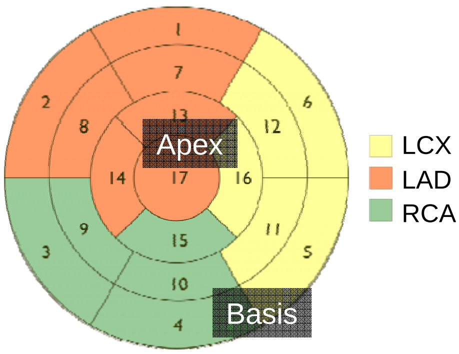
Coronary Heart Disease
Segment-wise Analysis

Plotting of perfusion parameters in Bull's Eye Plot (BEP) by means of polar coordinates

American Heart Association (AHA) – 17 segment model specifies relation between myocardial regions and supplying coronary arteries [Cerqueira, 2002]







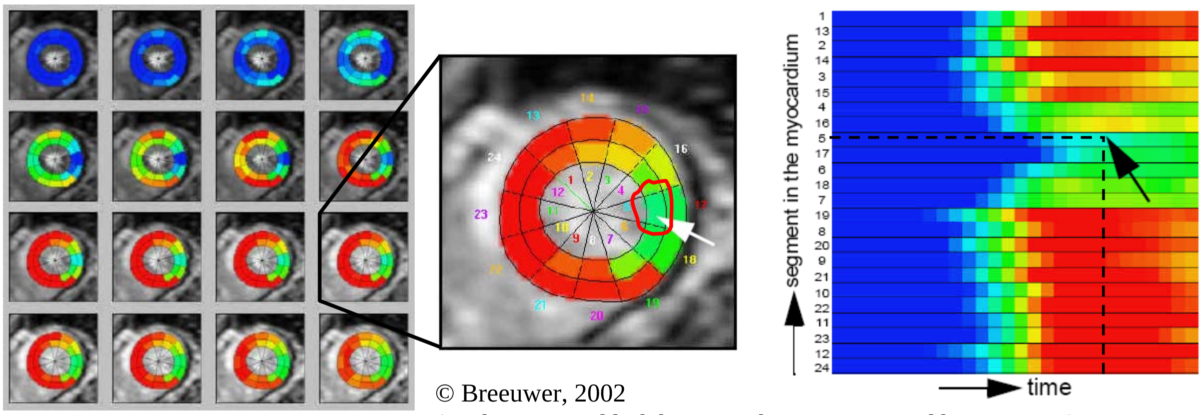
Coronary Heart Disease
Uptake Movie and Perfusogram

Uptake Movie [Breeuwer, 2002]:

- (Repeated) display of the perfusion images series as a movie
- Intensity values of points or segments are color-coded

Perfusogram [Breeuwer, 2002]:

- Color-coded intensity values as a function of time and place

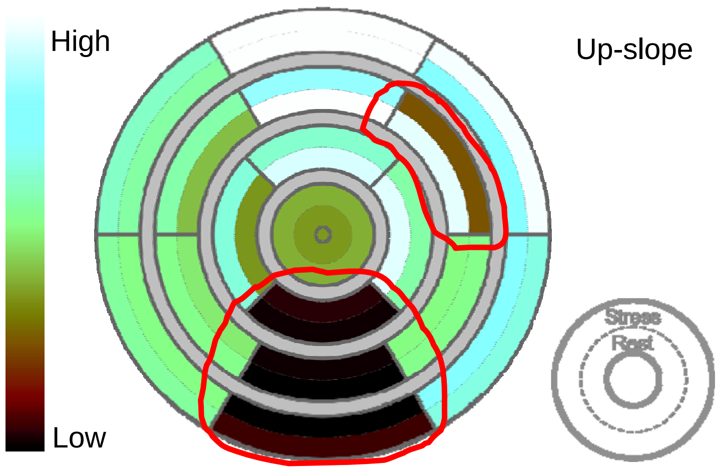


© Breeuwer, 2002
(Techniques and link between them are patented by PHILIPS)

Coronary Heart Disease
Bivariate Bull's Eye Plot

Refined Bull's Eye Plot (BiBEP) [Oeltze, 2006]:

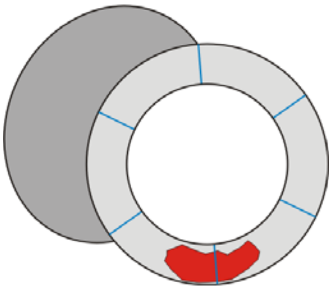
- Integrated visualization of two different parameters
- Rest/Stress-comparison of one parameter
- Identification of areas where perfusion defects first appear or become worse with stress

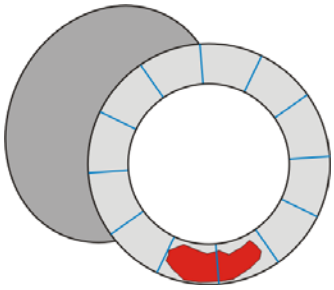


Coronary Heart Disease
Segment-wise vs. Voxel-wise

Segment-based analysis compensates artifacts due to low S/N-ratio, heart motion and respiration

Problem: Segments with ischemic and non-ischemic tissue





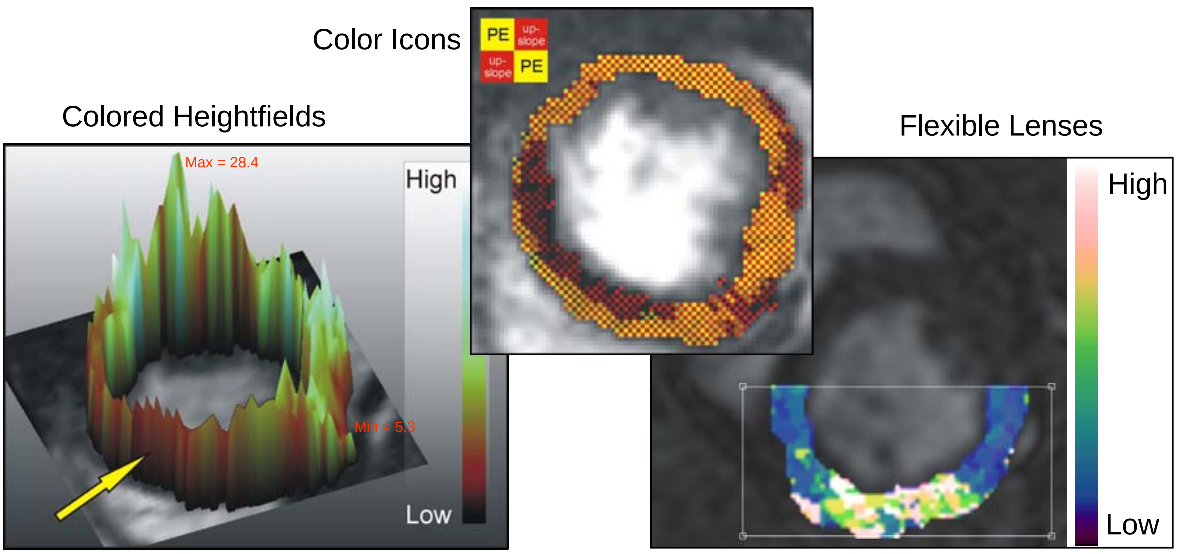
© Kuß, 2006

Advances in image acquisition and motion correction algorithms allow pixel-wise analysis by means of parameter-maps [Panting, 2001]

Integrated visualization of several parameters [Oeltze, 2006]

Coronary Heart Disease
Multiparameter Visualizations

Integrated visualization of several parameters [Oeltze, 2006]



Glyph-Based Visualization of Myocardial Perfusion Data and Enhancement with Contractility and Viability Information

Coronary Heart Disease
Glyph-based Visualization

Based on [Paasche, 2007] and [Oeltze, 2008b]

Glyph definition: graphic primitive whose visual attributes (shape, orientation, size, color, …) encode dimensions of a given datapoint or set of datapoints

Glyph-placement and design are non-trivial tasks [Ropinski, 2008]

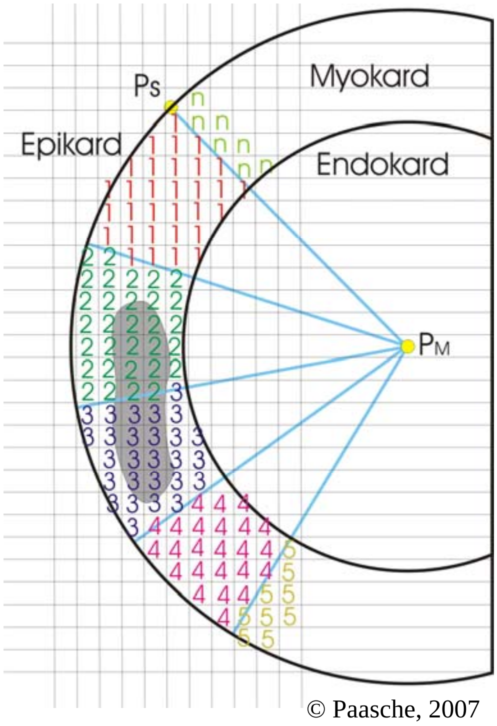
- Voxel-wise vs. segment wise placement
- 2D vs. 3D positioning
- Simple vs. advanced primitives
- Which attribute should reflect which data dimension?
- How many attributes should be used at all?
- …

Segment-wise

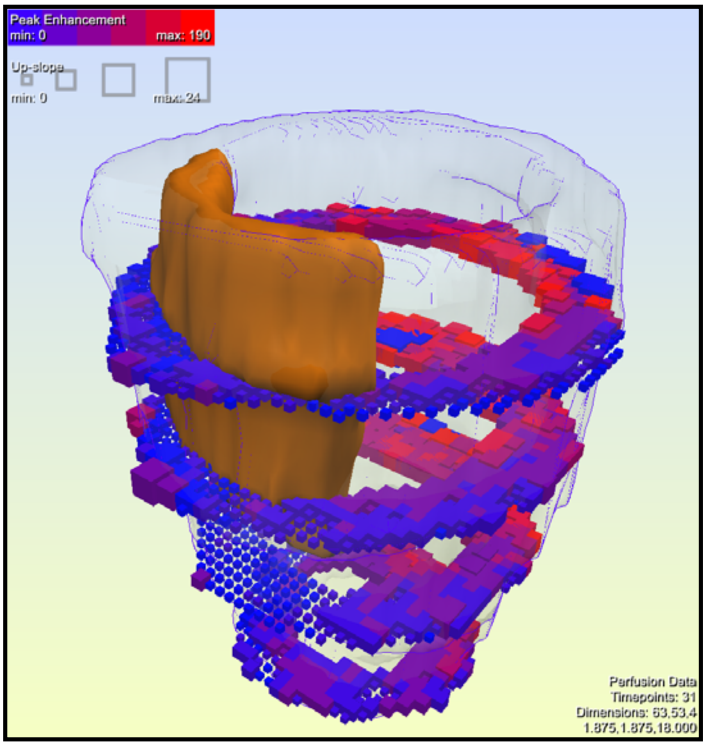
- AHA-conform division of the myocardium (17 segments)
- User-defined division allows more subtle evaluation (x segments per slice)

Voxel-wise

- 250-500 glyphs per slice

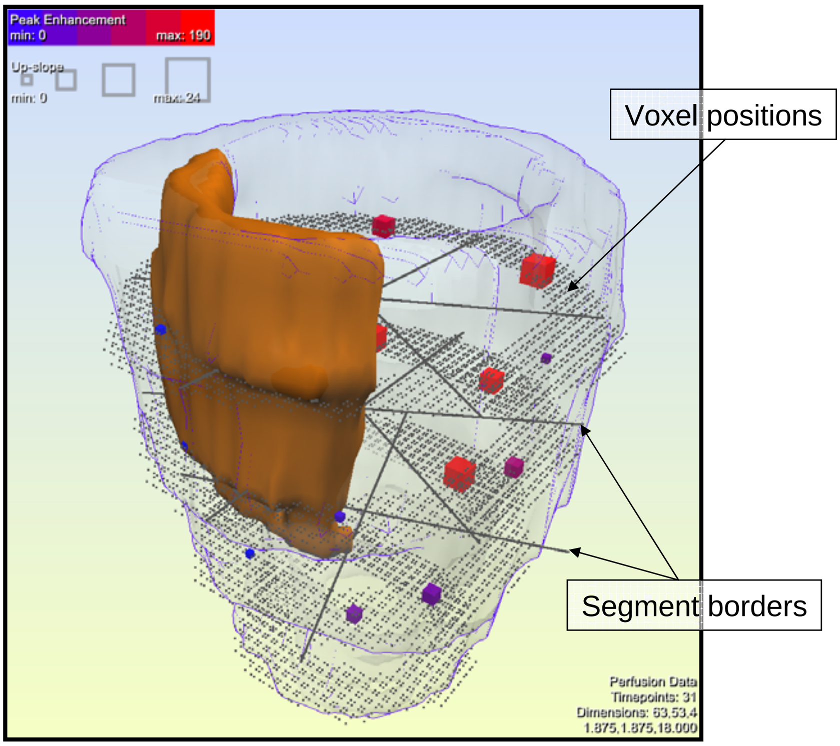


Cubes coding perfusion parameters PE (color) and Up-Slope (size)



Segment-wise AHA Glyph Placement

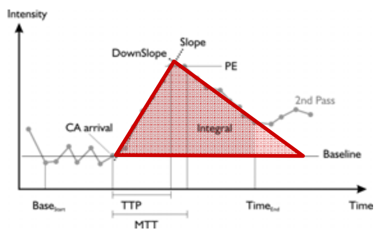
Cubes coding perfusion parameters PE (color) and Up-Slope (size)

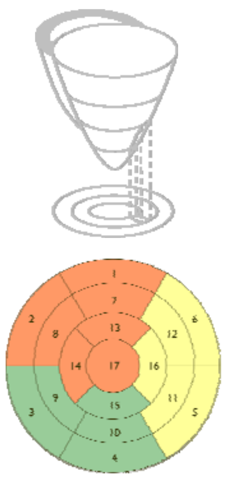


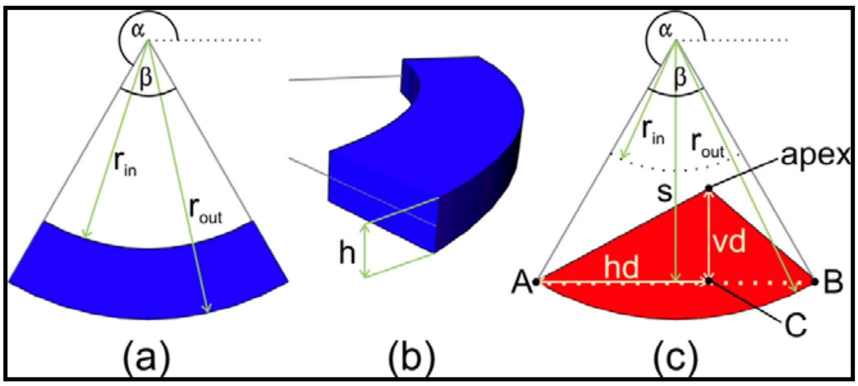
Glyph Design

Advanced Glyph Shapes:

- 3D Bull's Eye Plot Segments (a-b)
- 3D Time-intensity Curves (c)

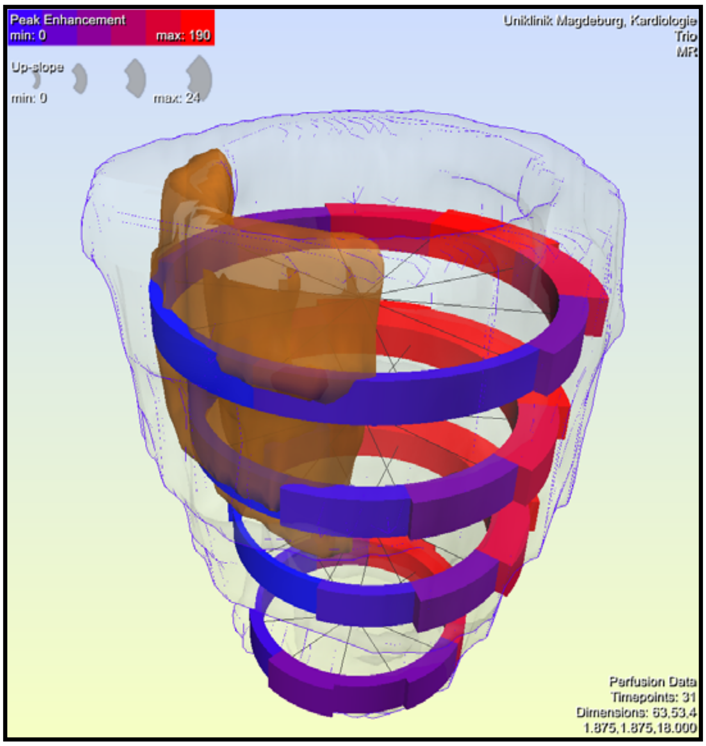






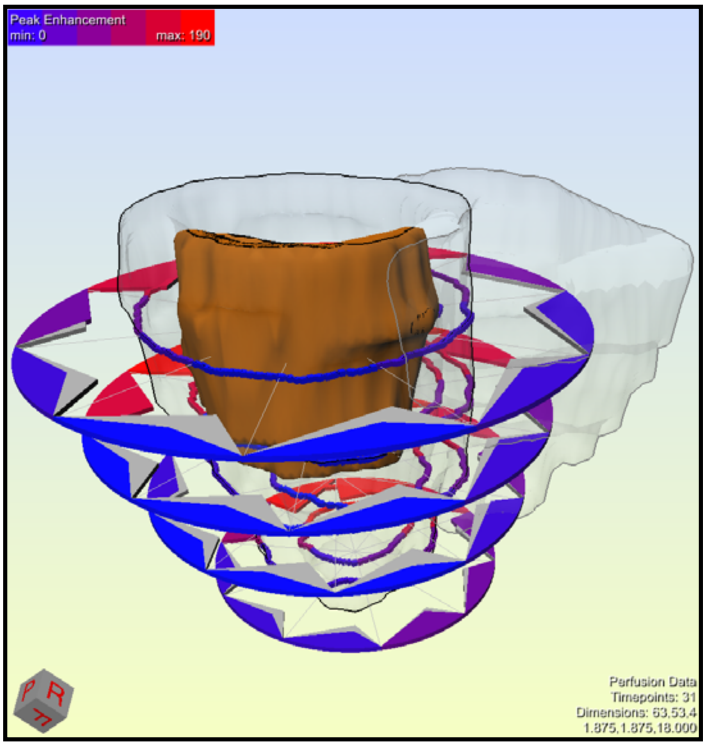
Coronary Heart Disease
3D Bull's Eye Plot Segments

- **3D BEP segments coding perfusion parameters PE (color) and Up-Slope (size)**
- **User-defined myocardial division**



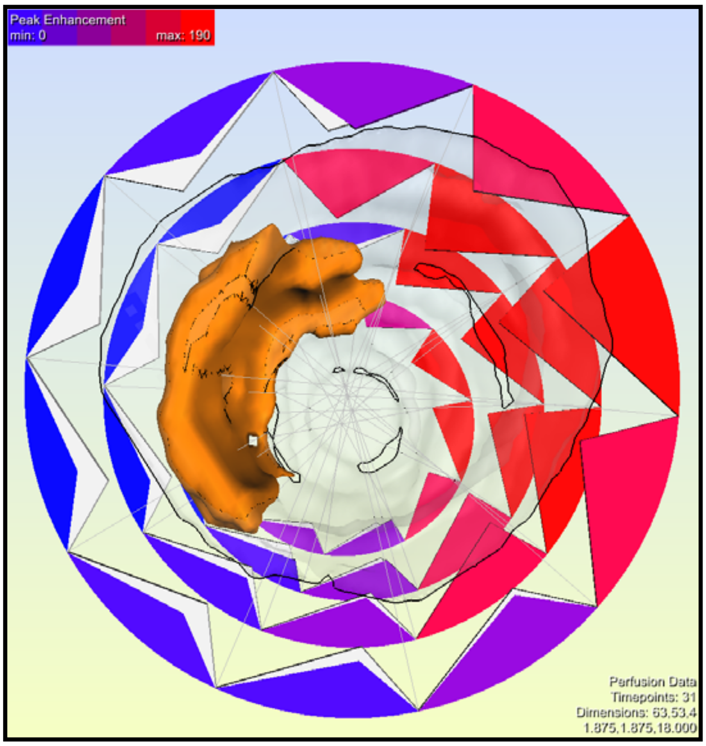
Coronary Heart Disease
3D Time-intensity Curves

- **3D TICs colored according to parameter PE**
- **Right ventricle serves as context information**
- **Emphasized ventricular wall supports spatial orientation**



Coronary Heart Disease
3D Time-intensity Curves

View along the long-axis of the ventricle provides a good overview presentation (default setting)



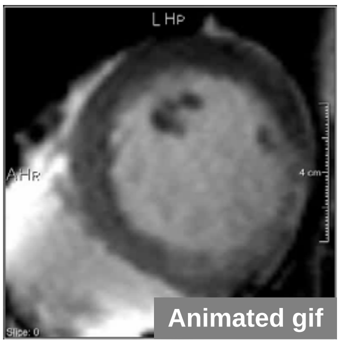
Coronary Heart Disease
Fusing Perfusion, Function & Viability

MR scanning protocol involves in addition to perfusion, the measurement of functional parameters and viability

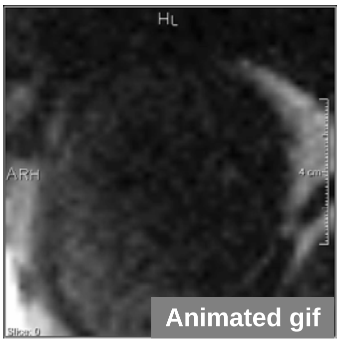
Integration for diagnosis of cardiac ischemia and infarction

➔ Differentiation of ischemic and healthy tissue

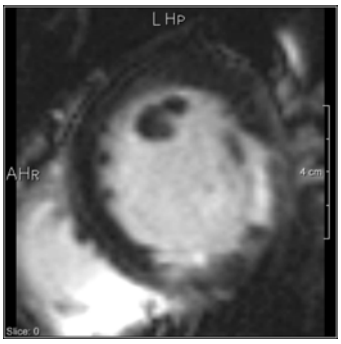
➔ Differentiation of scarred tissue and temporarily inactive but viable myocardium (stunned vs. hibernating)



Function



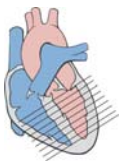
Perfusion



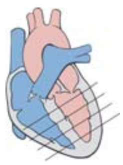
Viability
(*Late Enhancement*)

Coronary Heart Disease
Fusing Perfusion, Function & Viability

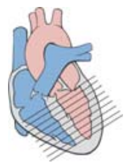
Functional parameters:
Wall thickness
(end-systole, end-diastole)
Wall thickening



Perfusion Parameters:
Peak Enh., Time to Peak, Up-slope, Integral, Mean Transit Time, MPRI



Viability (LE):
Transmurality
(Extension of the infarction scar)



Integration is tricky due to differences in slice orientation, slice distance, slice thickness, in-plane resolution, contrast, acquired region of interest, motion artifacts

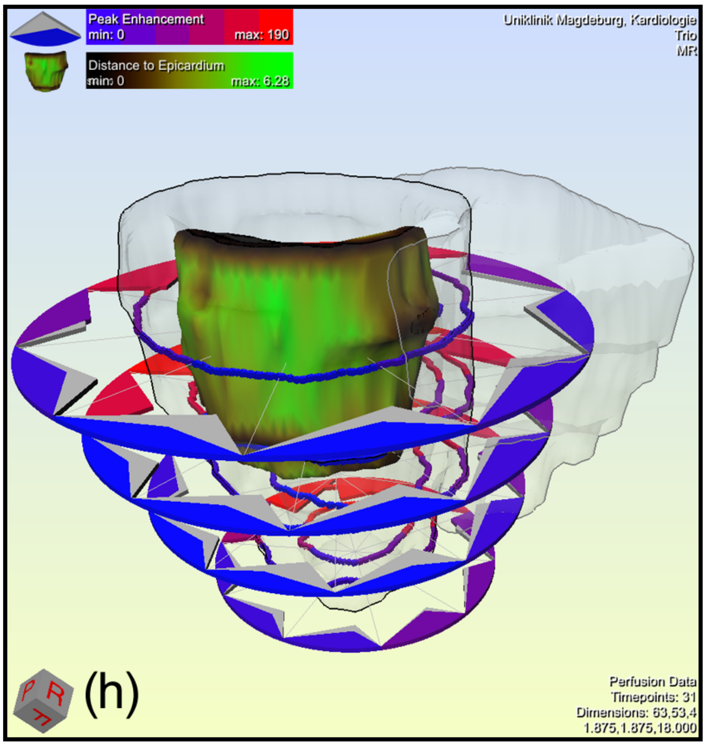
Pre-Processing
(Motion-correction, segmentation, registration, parameter derivation, AHA-conform division of the myocardium)

Integrated visualization based on glyphs, colored surfaces and isolines

Coronary Heart Disease
Integrating Perfusion and Viability

3D TICs colored according to parameter PE

Transmurality is color-coded on scar

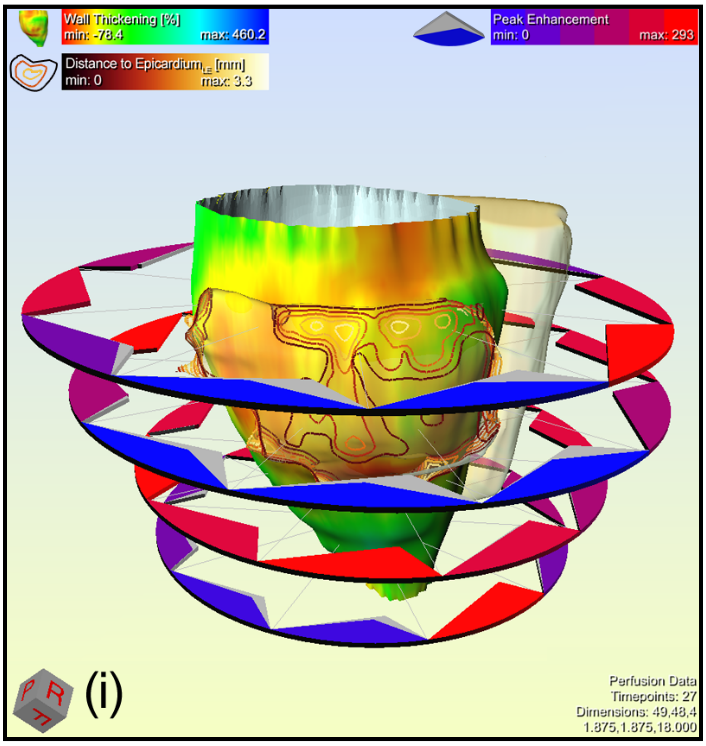


Coronary Heart Disease
Fusing Perfusion, Function & Viability

3D TICs colored according to parameter PE

Contractility is color-coded on endocardium

Isolines encode the scar's transmurality



Glyph-based Visualization
Conclusion

Simple glyph shapes (cube, sphere,…) may be applied in a voxel-wise analysis

Segment-wise analysis benefits from more advanced glyph shapes (3D Bull's Eye Plot Segments and 3D Time-intensity Curves)

Hypothesis: 3D Time-intensity Curves facilitate the most intuitive and easy to learn TIC shape coding ➔ Evaluation is pending

Glyphs can be combined with colored surfaces and isolines for an integrated analysis of perfusion, contractility and viability

Future Work: Integration of a visualization of the coronary arteries

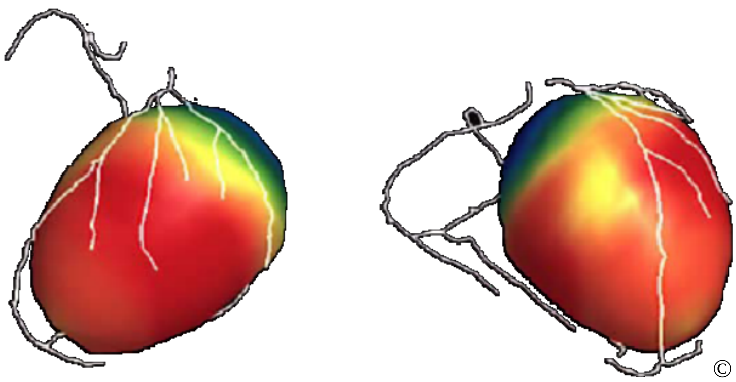
Integration of Perfusion and Morphologic Data

Coronary Heart Disease
Integrating Perfusion and Morphology

Correlation of myocardial territories and supplying coronary branches to detect stenosis or to evaluate severity of a known stenosis

Fusion of single photon emission computed tomography (SPECT) and X-ray coronary angiography [Schindler, 1999]

Fusion of SPECT and CT data [Nakajo, 2005]

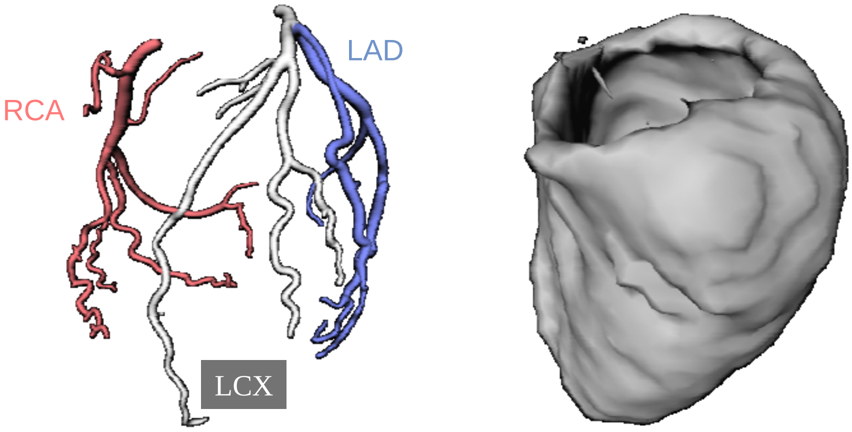


Coronary Heart Disease
MR-Perfusion and CT-Morphology

Integrated visualization of MR-perfusion and CT-morphologic data (coronary arteries, aorta ascendens, left ventricle) [Oeltze, 2006]

Segmentation of coronaries/aorta by advanced 3D region growing algorithm [Hennemuth, 2005]

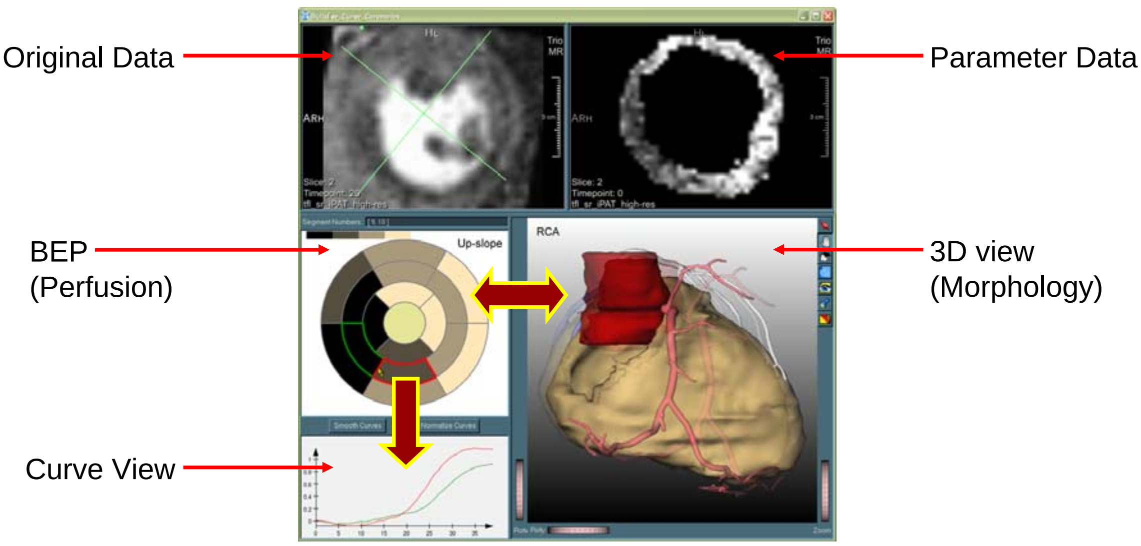
Manual labeling of coronary branches (LCX, LAD, RCA)



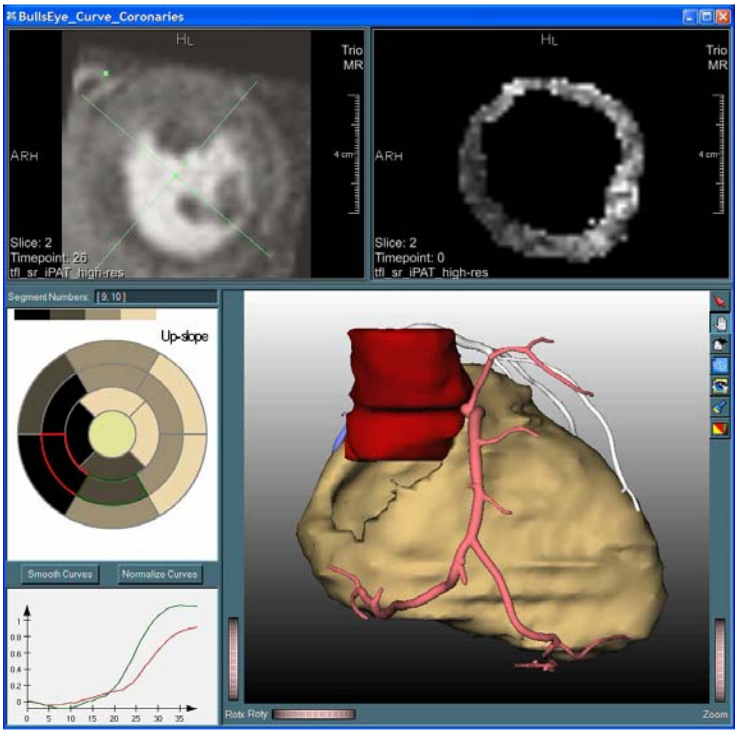
Coronary Heart Disease
Linked Views

Fusion of MR-perfusion and CT-data by establishing bidirectional link between BEP and 3D view

Focusing of supplying branch after picking segments in BEP



Coronary Heart Disease
Identifying Supplying Branch (Video)

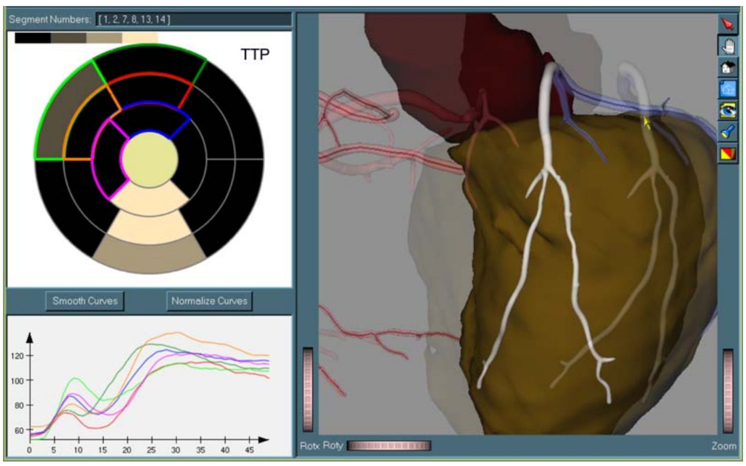


Coronary Heart Disease
Identifying Supplied Segments

Accentuation of supplied segments after picking an artery in the 3d-view

User is guided through scene by animations [Mühler, 2006]

Semi-automatic definition of appropriate viewpoint for each artery



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