Advanced Visual Medicine: Techniques, Applications and Software

Visual Analysis of Perfusion Data

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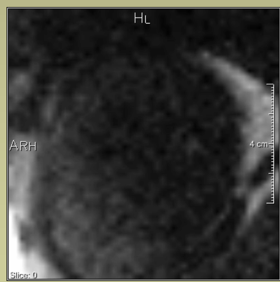


Outline

Introduction

- Intraoperative Navigation and Medical Mixed Reality
- Integration of Simulation and Visualization for Surgical Planning
- Diffusion Tensor Imaging Visualization Techniques and Applications
- **Visual Analysis of Perfusion Data**
- Surface-based Vessel Visualization
- Fast Tagged Multi-resolution Volume Rendering

Questions and Answers

Structure

Motivation of Perfusion Imaging

Data Acquisition and Pre-processing

Visual Analysis of Perfusion Data

- Basic Techniques
- Advanced Techniques

Case Study: Coronary Artery Disease

Literature

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 Artery Disease (CAD) Diagnosis
  - Localization of less-perfused myocardial regions for functional analysis and correlation with supplying coronaries to support stenosis evaluation

Data Acquisition

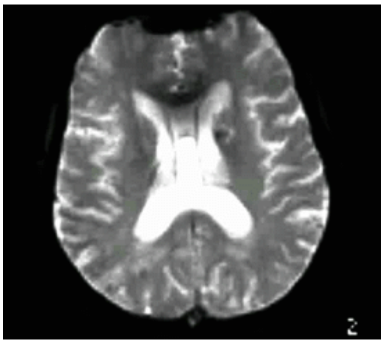
Magnetic resonance (MR) perfusion diagnosis

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:

- 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 Artery Disease
  (T1, 128 x 128 x 4 x 40, 20-40sec)



Pre-Processing

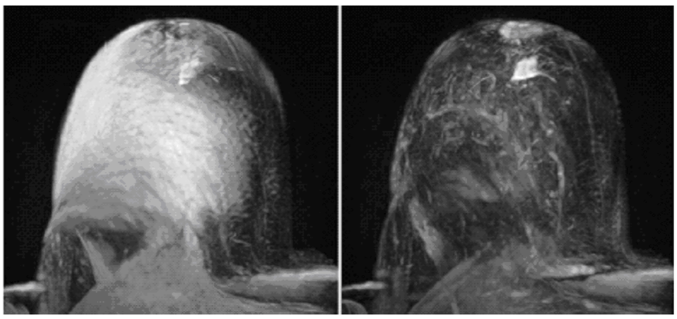
Low signal-to-noise (S/N)-ratio requires smoothing

- 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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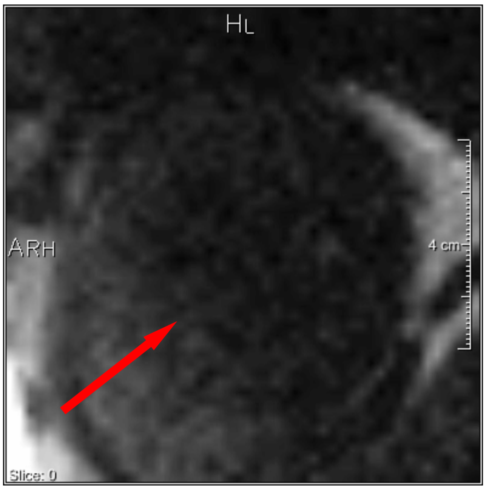
Basic Visual Analysis Techniques – Cine-Movies

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

Prevailing method in tight schedule of clinical routine

Problems:

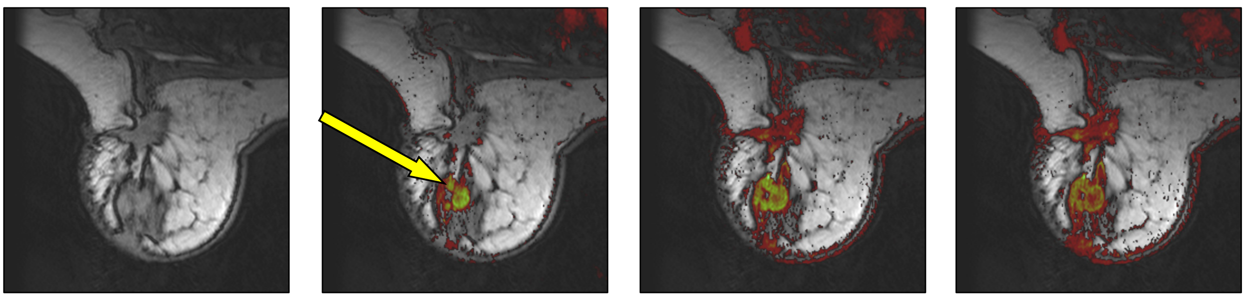
- user-dependent,
- no quantitative results,
- small perfusion defects remain undetected



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

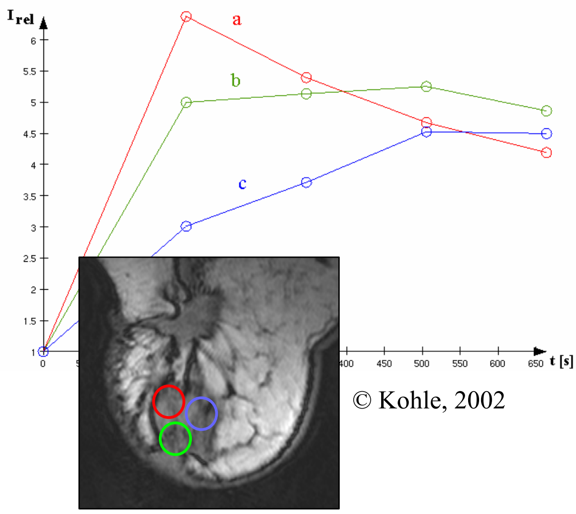


t_0 t_1 t_2 t_3

Basic Visual Analysis Techniques – ROI-Selection

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

Semi-quantitative analysis based on perfusion parameters



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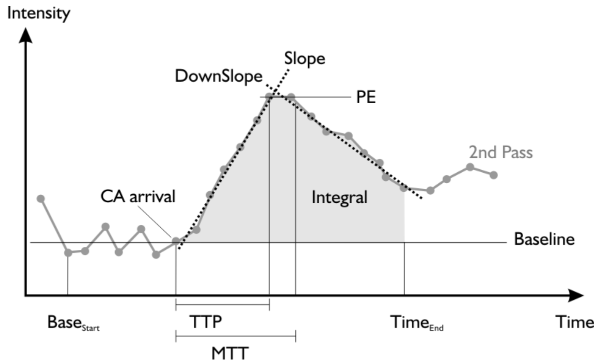
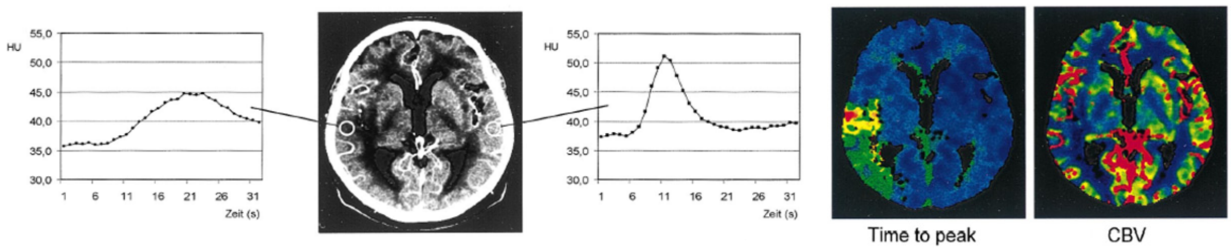


Perfusion Parameters

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

Basic Visual Analysis Techniques – Color-Coded Parameter Maps

Color-coded parameter maps for a selected slice



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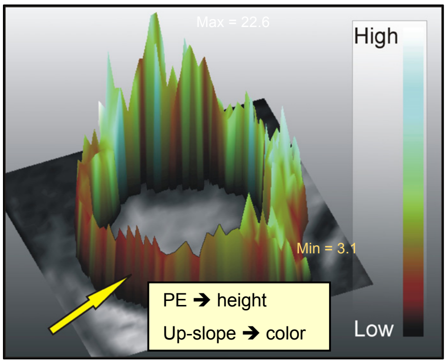
Diagnosis often requires examination of several parameters

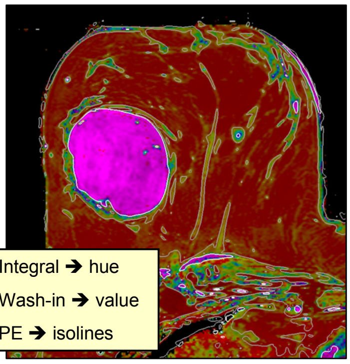
Tiled visualization requires mental integration

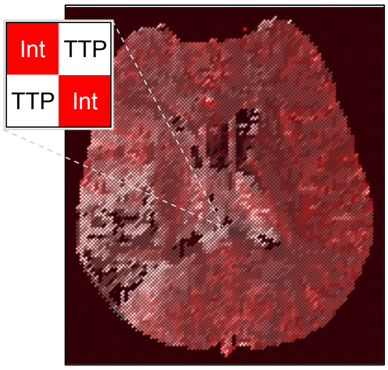
➔ Strategy for designing multiparameter visualizations:

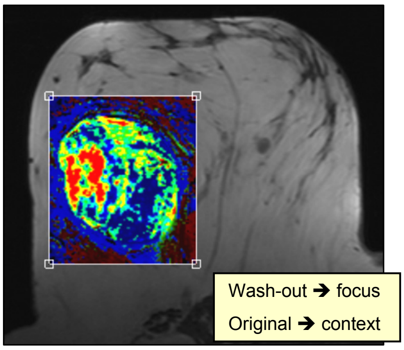
- Utilizing other visualization attributes besides color
- Adaptation and parameterization of the visualization
- Integration of exploration facilities

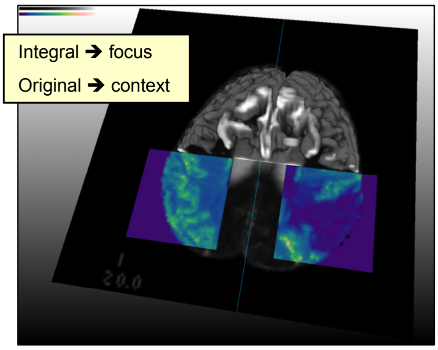
Advanced Visual Analysis Techniques – Multiparameter Vis [Oeltze, 2005/06]

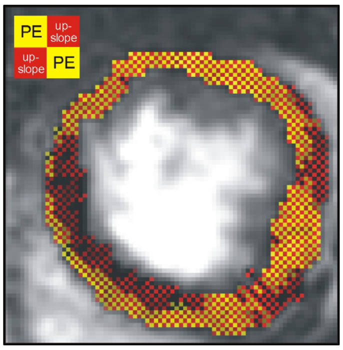








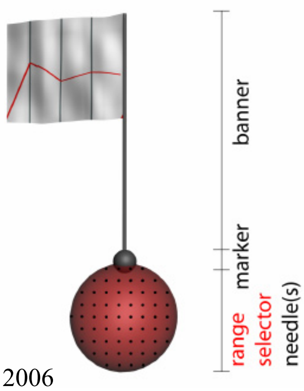




Advanced Visual Analysis Techniques – Probing and Annotating

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



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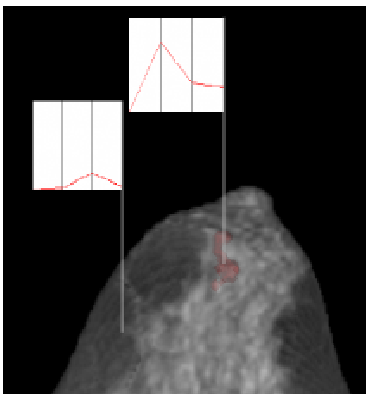

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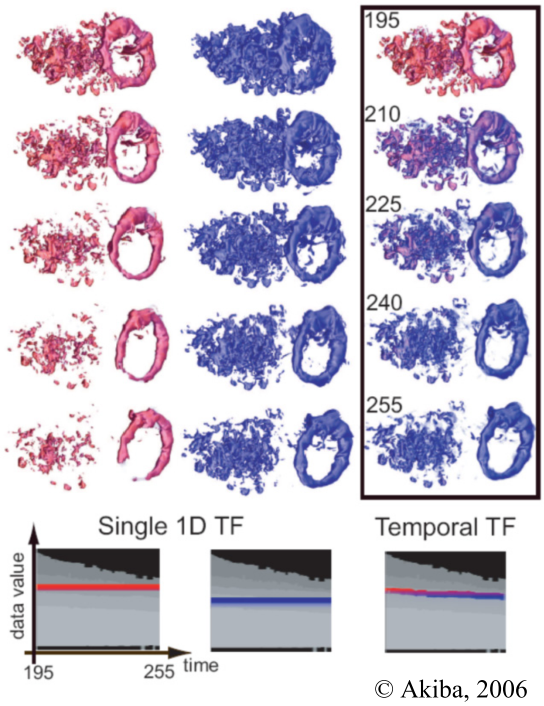
Advanced Visual Analysis Techniques – Direct Volume Rendering

Suitable for data with high spatial resolution, e.g. from breast tumor or ischemic stroke diagnosis

Performance issues due to large amount of data (4d!) ➔ Exploitation of temporal coherence [Liao, 2003]

Tracking of important features, e.g. a tumor, over time ➔ Temporal transfer functions [Akiba, 2006]



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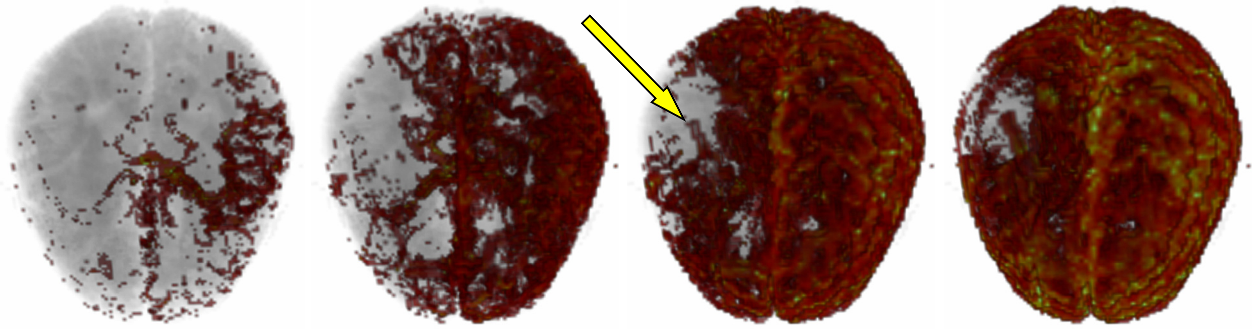
Advanced Visual Analysis Techniques – Extending Subtraction Images

Subtraction volumes:

- Depict intensity difference between two selected points in time
- Rendered by means of direct volume rendering
- Transfer functions code the magnitude of difference
- Gray-scale reference volume serves as context information

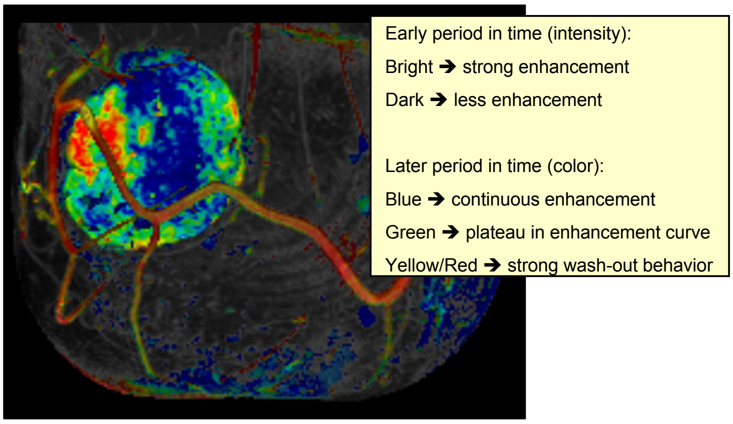


t_0 t_1 t_2 t_3

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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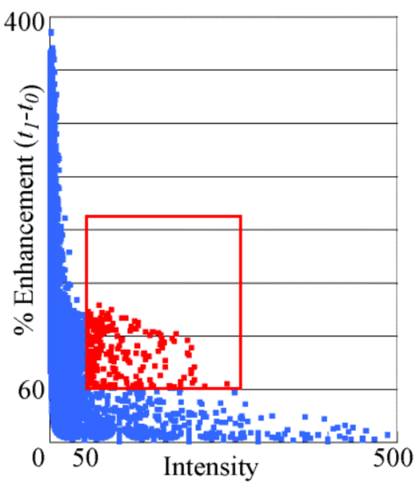
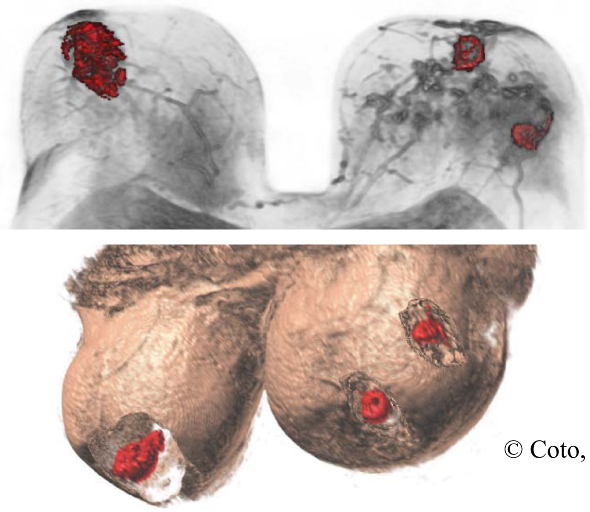
Advanced Visual Analysis Techniques – Combining InfoVis and MedVis

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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Visual Analysis Techniques – Conclusion

Perfusion data are semi-quantitatively analyzed (no standardized intensity values exist)

Normalization, e.g. comparison between healthy and suspicious region is required.

Basic visualization techniques allow to detect suspicious regions

Multiparameter techniques (colored heightfields, flexible lenses, glyphs,…), facilitate a more comprehensive analysis and may speed up the diagnosis

Profile flags for annotating perfusion data, e.g. to communicate diagnosis

Volume rendering is applied to explore data with high spatial resolution

Visual Analysis Techniques – Very Recent and Future Work

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

Will be presented here at IEEE Vis07: "Interactive Visual Analysis of Perfusion Data" [S.Oeltze, H.Doleisch, H.Hauser, P.Muigg, B.Preim]

Future Work

Evaluation of visual analysis techniques in clinical settings to examine:

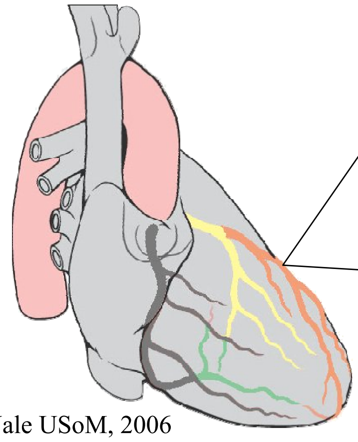
- Speed (compared to commercial systems)
- Diagnostic accuracy
- Which parameter combinations are suitable?
- How many parameter should be integrated?
- Which parameter is best mapped to which visual attribute?

Case Study: Coronary Artery Disease – Medical Background

Definition: severe stenosis of one or more coronary arteries

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

Angina pectoris, cardiac arrhythmia and heart attack may result



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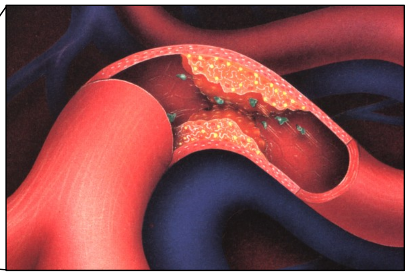

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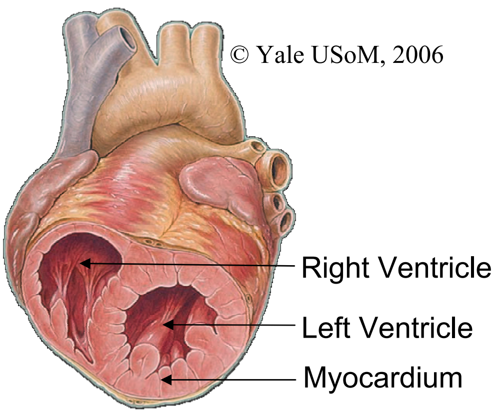
Left Circumflex Artery (LCX)
Left Anterior Descending Artery (LAD)
Right Coronary Artery (RCA)

Case Study: Coronary Artery Disease – Tasks and Data Acquisition

➔ Localization and quantification of the perfusion defect

➔ Exploiting anatomical knowledge about supplying coronary arteries to support stenosis detection and evaluation

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



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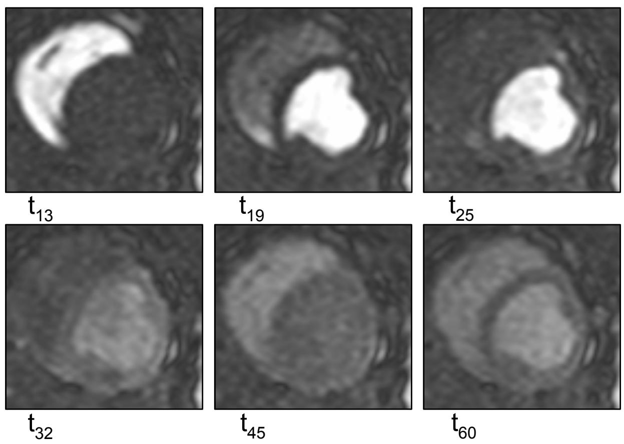
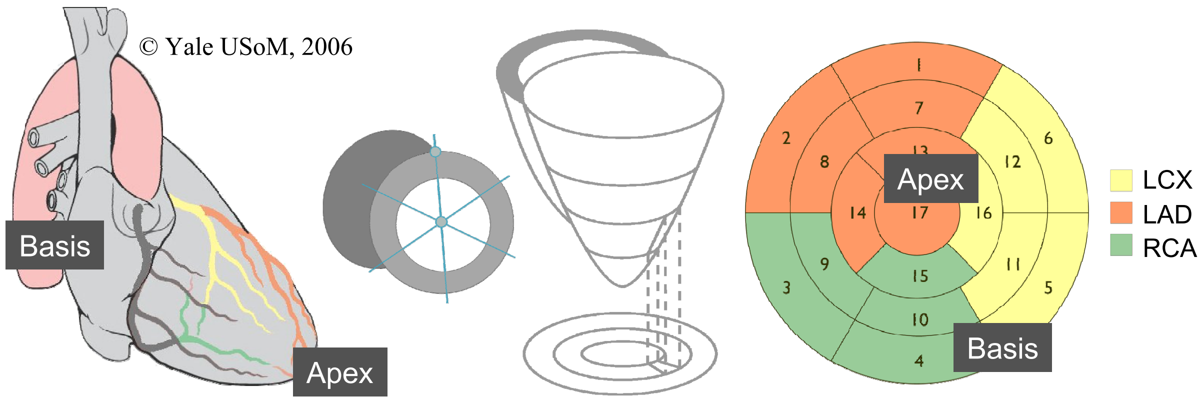


Case Study: Coronary Artery Disease – 17 Segment Model and Bull's Eye Plot

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 coronaries [Cerqueira, 2002]



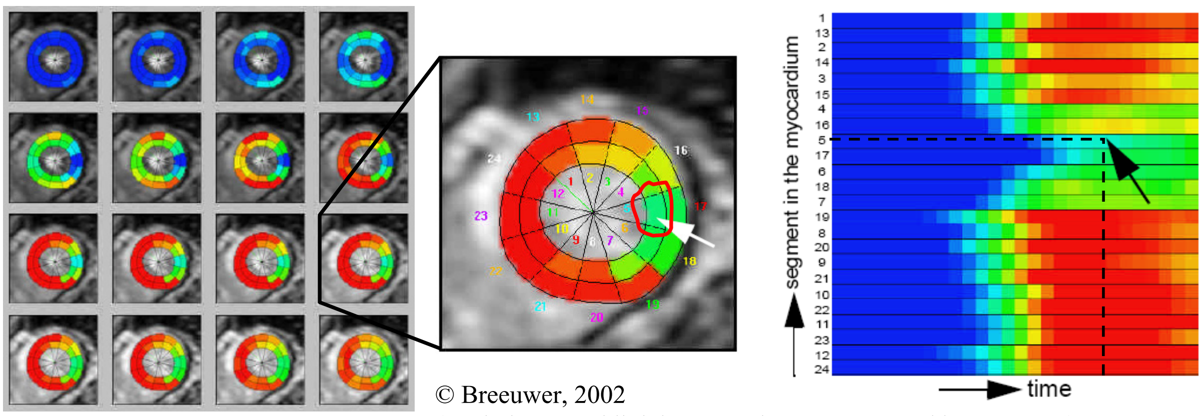
Case Study: Coronary Artery Disease – Uptake Movie and Perfusogram

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

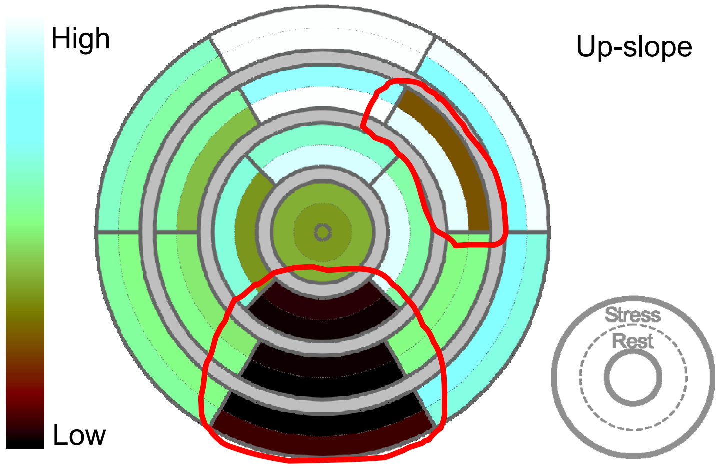


© Breeuwer, 2002
(Techniques and link between them are patented by PHILIPS)

Case Study: Coronary Artery Disease – Bivariate Bull's Eye Plot

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

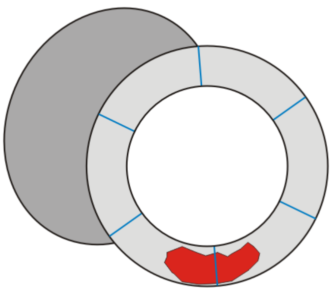
- Integrated visualization of two different parameters
- Rest/Stress-comparison of one parameter
- Identification of areas where perfusion defects first appear or become worse with stress

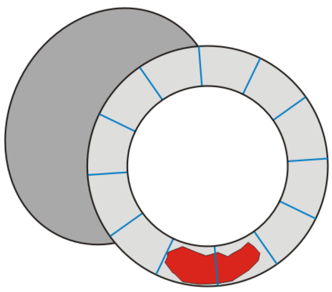


Case Study: Coronary Artery Disease – Segment-Based vs. Pixel-Wise

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

Problem: Segments with ischemic and non-ischemic tissue



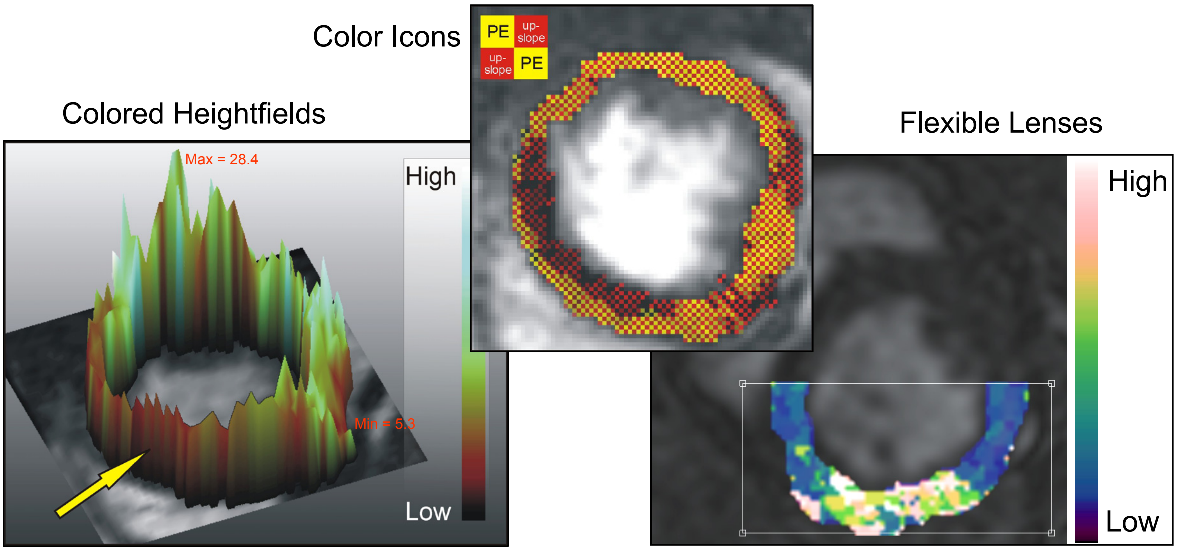


➔Advances in image acquisition and motion correction algorithms allow pixel-wise analysis by means of parameter-maps [Panting, 2001]

➔Integrated visualization of several parameters [Oeltze, 2006]

Case Study: Coronary Artery Disease – Multiparameter Visualizations

Integrated visualization of several parameters [Oeltze, 2006]



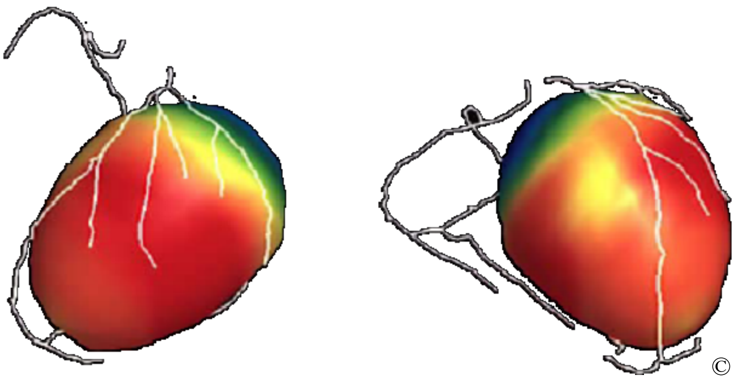
Case Study: Coronary Artery Disease – Integrating Perfusion & Morphology

Perfusion defect has been localized

➔Correlating affected regions and supplying coronaries to detect stenosis

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

Fusion of SPECT and CT data [Nakajo, 2005]



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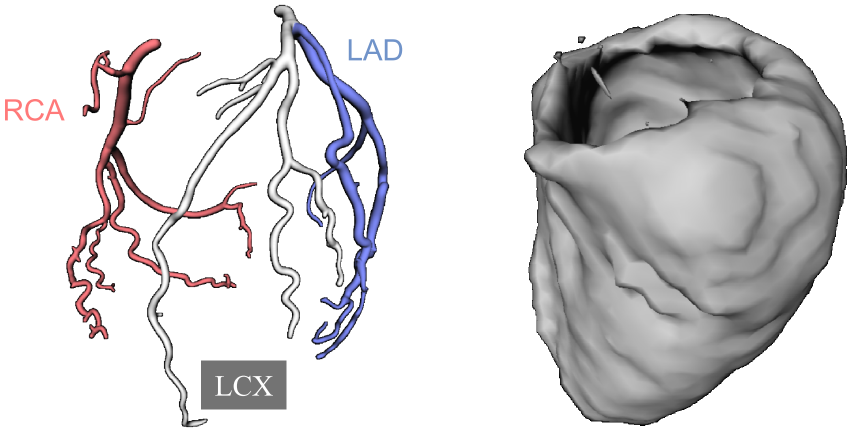
Case Study: Coronary Artery Disease – Preprocessing of CT-morphologic Data

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],

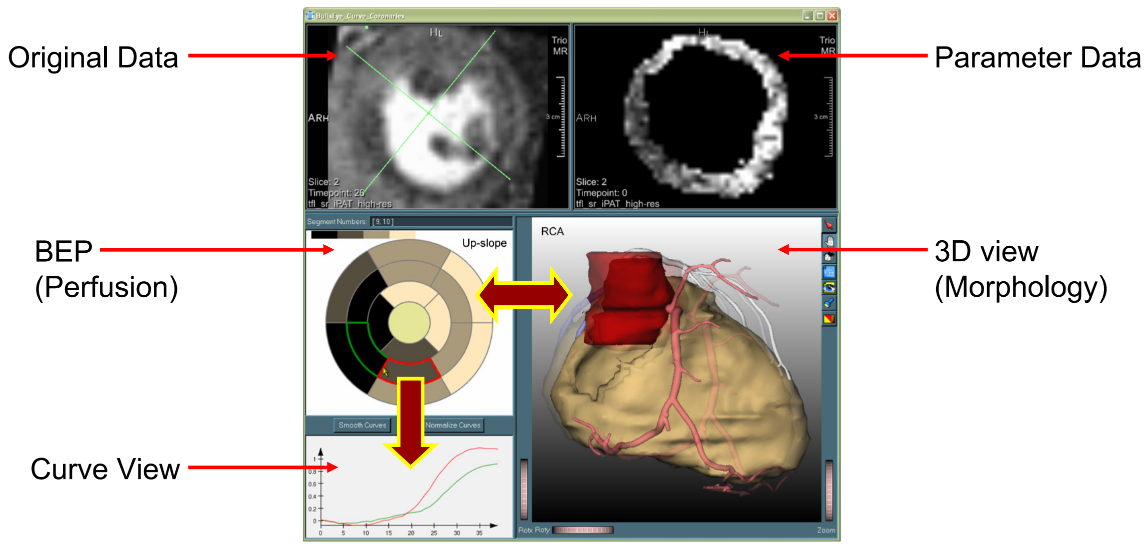
Manual labeling of coronary branches (LCX, LAD, RCA)



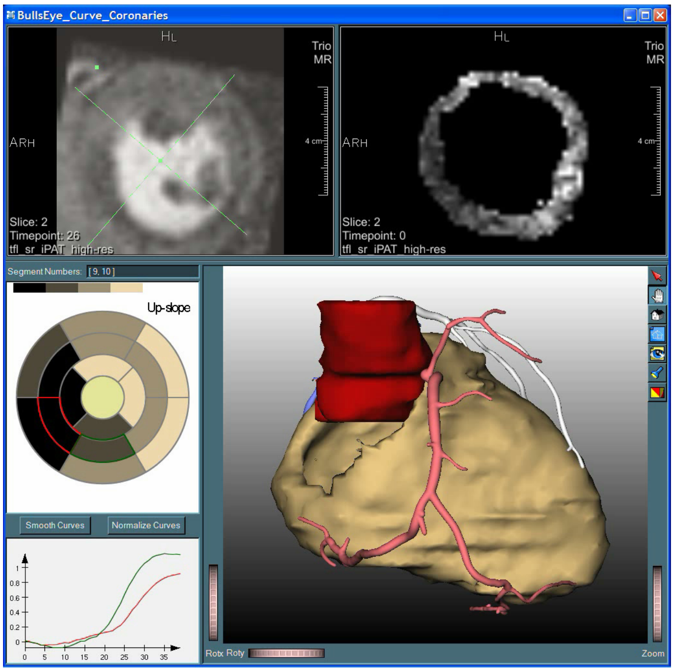
Case Study: Coronary Artery Disease – Linked Views

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



Case Study: Coronary Artery Disease – Identifying Supplying Branch (Video)

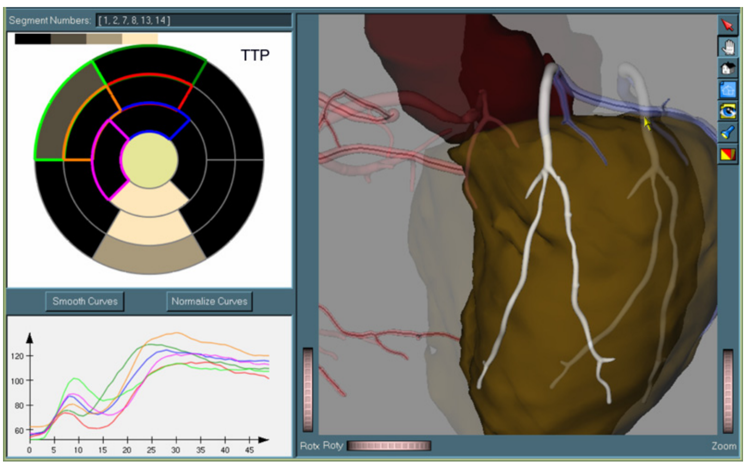


Case Study: Coronary Artery Disease – Identifying Supplied Segments

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

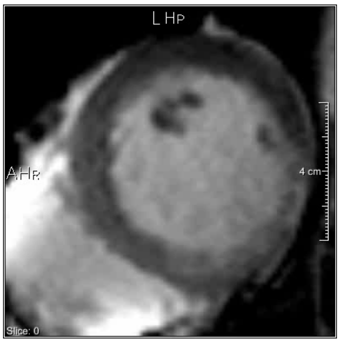
User is guided through scene by animations [Mühler, 2006]

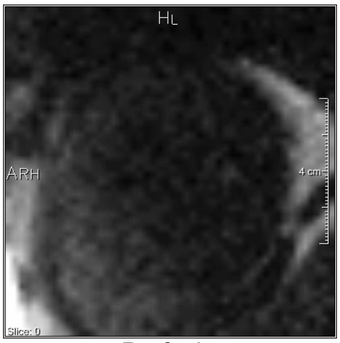
Semi-automatic definition of appropriate viewpoint for each artery

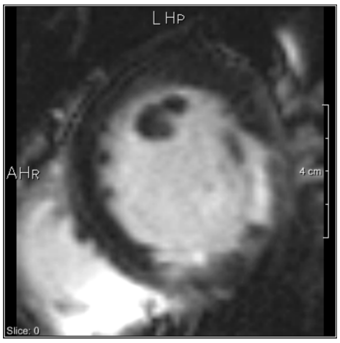


Case Study: Coronary Artery Disease – Integrating Function, Perfusion & Viability

- 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)

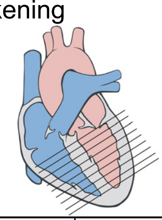

Function


Perfusion

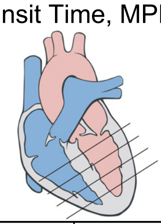

Viability
(*Late Enhancement*)

Case Study: Coronary Artery Disease – Integrating Function, Perfusion & Viability

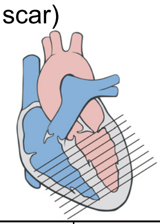
Functional parameters:
Wall thickness
(systole, diastole)
Wall thickening



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



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



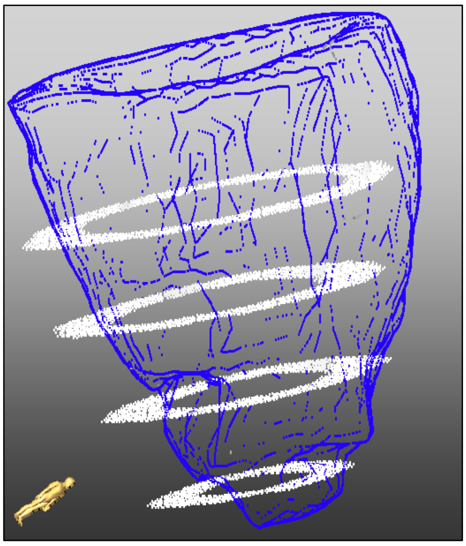
Integration is tricky due to differences in slice orientation, slice distance, slice thickness, in-plane resolution, contrast, acquired region of interest, motion artifacts

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

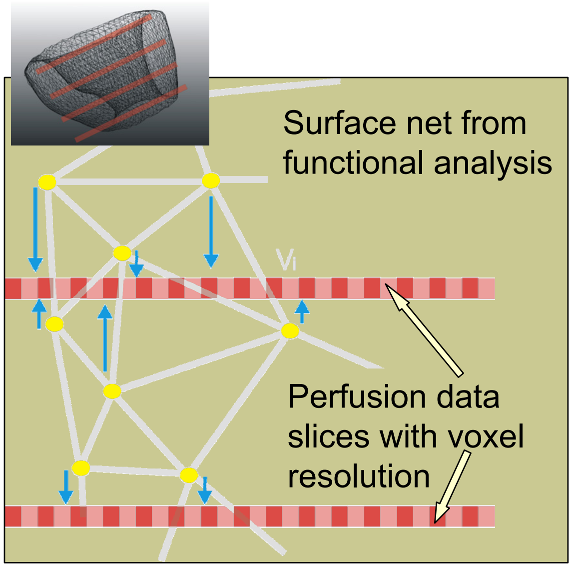
Glyph-based integrated visualization
[Paasche 2007]

Case Study: Coronary Artery Disease – Glyph Placement (1/2)

Glyph placement based on slice location of perfusion data and surface visualization of left ventricle (from LE-data)



Combination of functional and perfusion parameters (different number of slices)



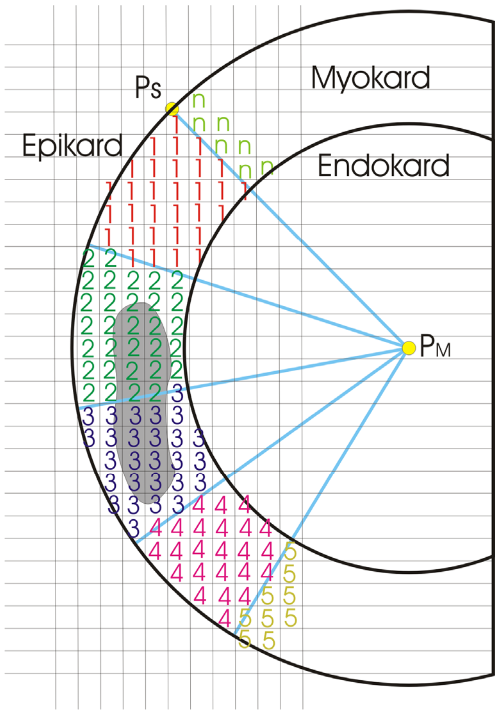
Case Study: Coronary Artery Disease – Glyph Placement (2/2)

Segment-based glyph placement

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

Voxel-wise glyph placement

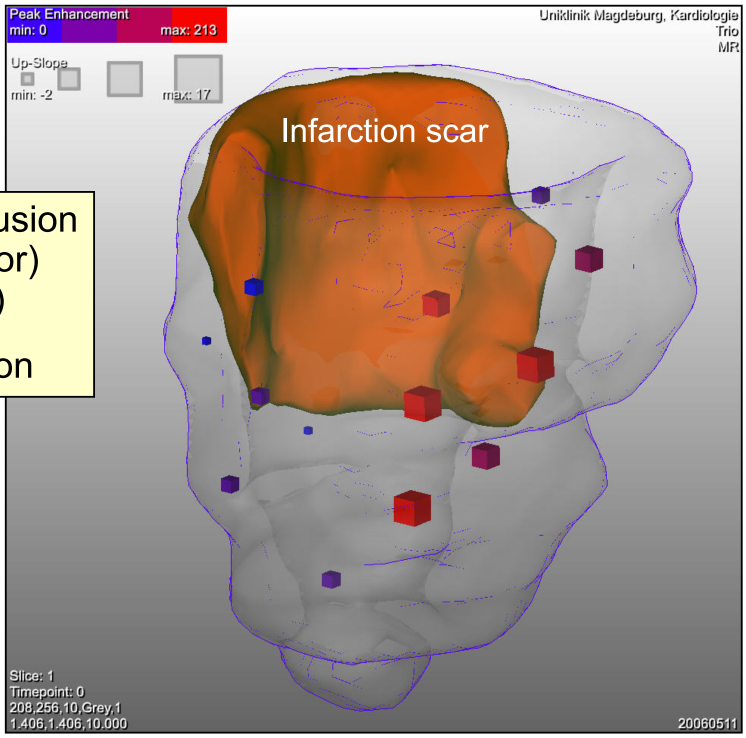
- 250-500 glyphs per slice



Case Study: Coronary Artery Disease – Examples (1/8)

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

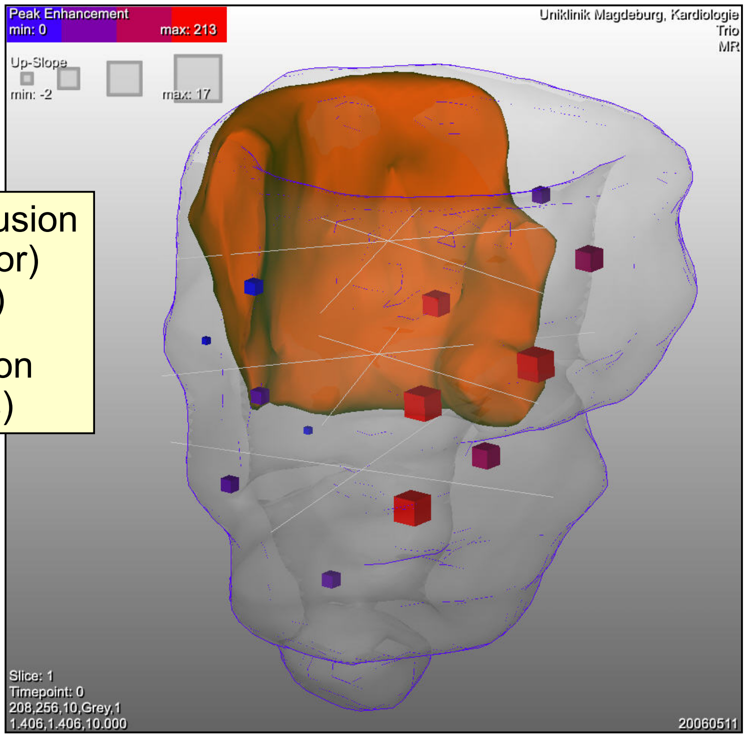
AHA-conform division



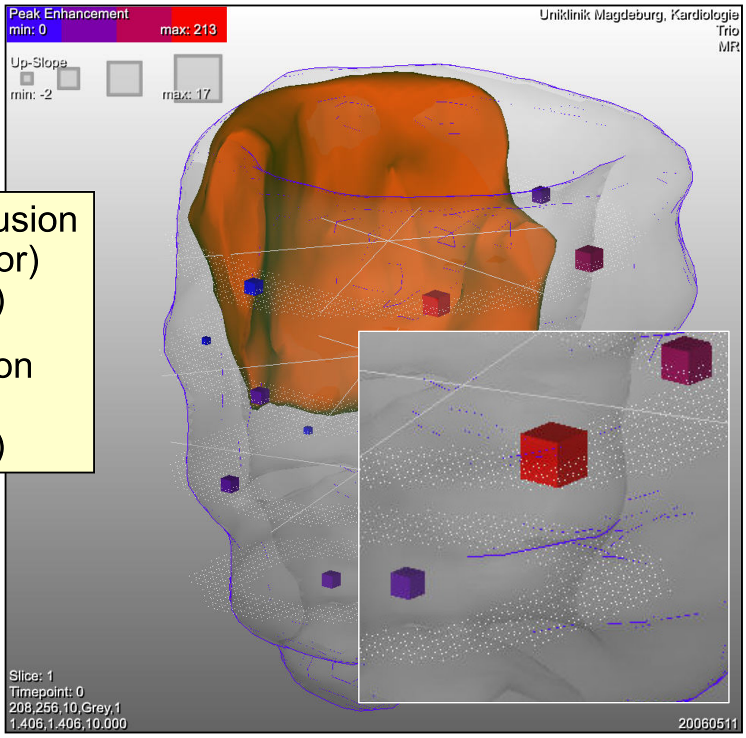
Case Study: Coronary Artery Disease – Examples (2/8)

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

AHA-conform division (+ segment-borders)



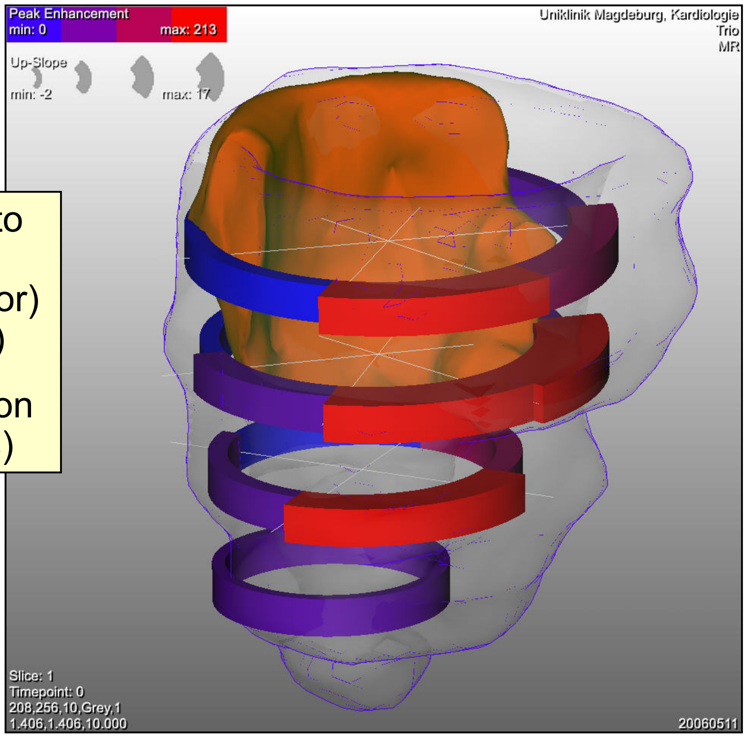
Case Study: Coronary Artery Disease – Examples (3/8)



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

AHA-conform division (+ segment-borders and voxel positions)

Case Study: Coronary Artery Disease – Examples (4/8)



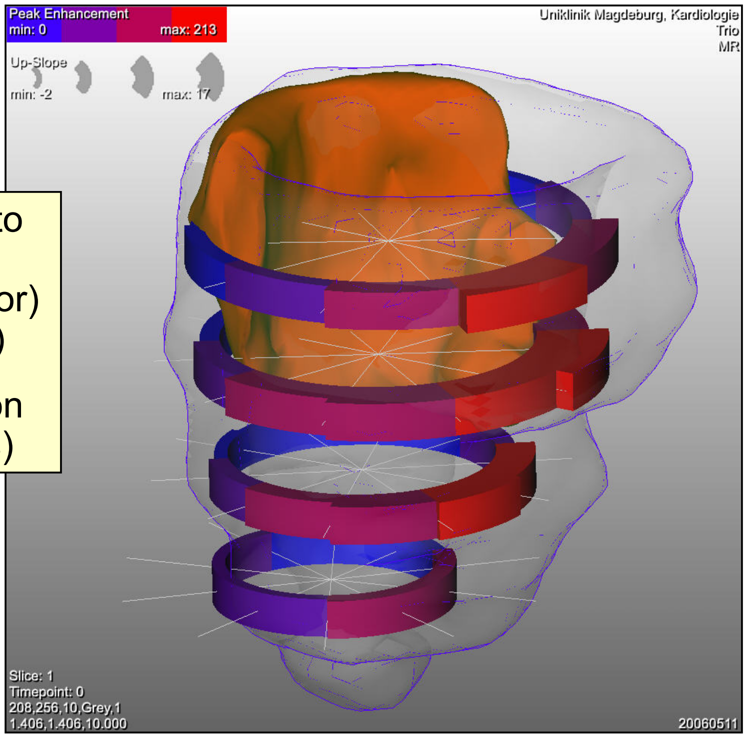
3D-BEP segments to code perfusion parameters PE (color) and Up-Slope (size)

AHA-conform division (+ segment-borders)

Case Study: Coronary Artery Disease – Examples (5/8)

3D-BEP segments to code perfusion parameters PE (color) and Up-Slope (size)

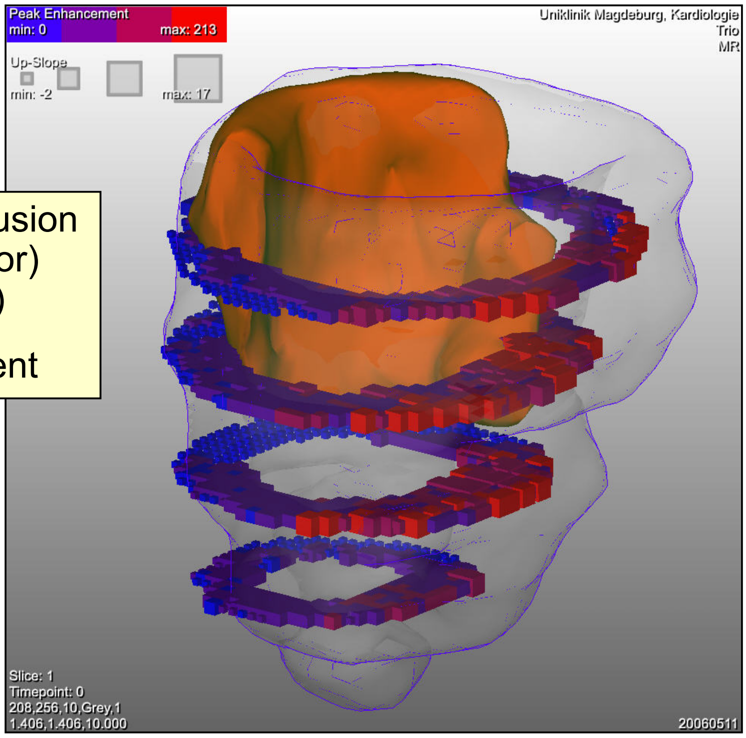
User-defined division (+ segment-borders)



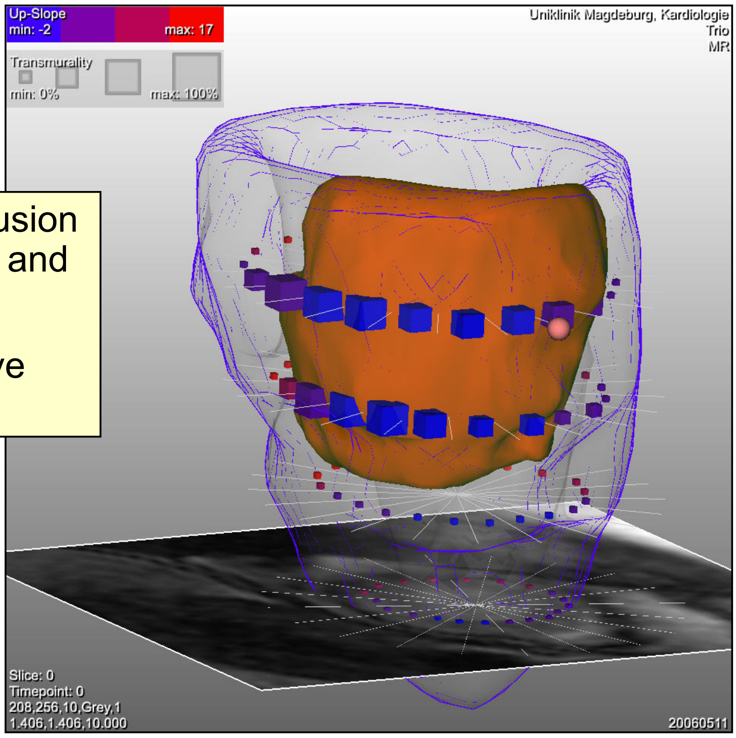
Case Study: Coronary Artery Disease – Examples (6/8)

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

Voxel-wise placement



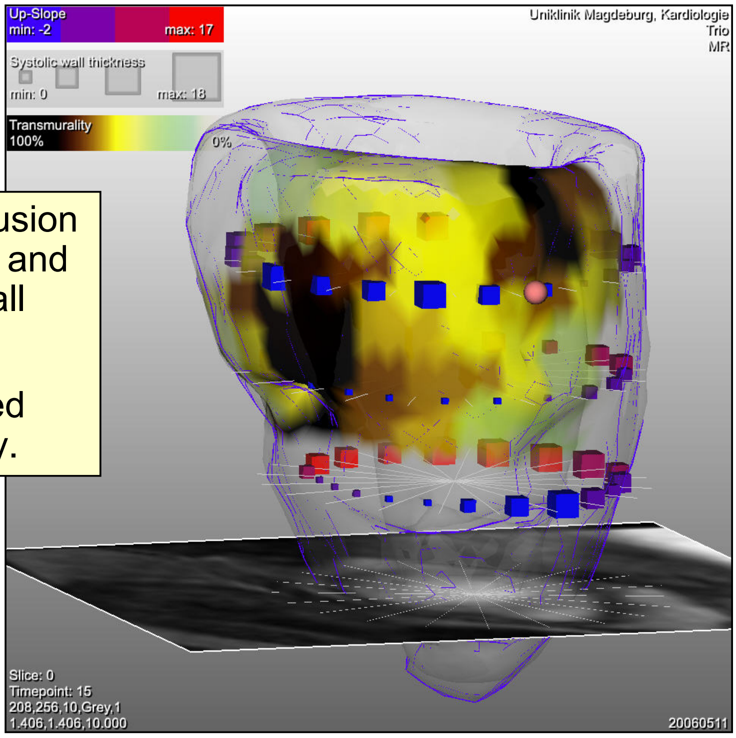
Case Study: Coronary Artery Disease – Examples (7/8)



Cubes to code perfusion (Up-Slope ➔ color) and transmurality (size).

Slice view to improve orientation in 3D.

Case Study: Coronary Artery Disease – Examples (8/8)



Cubes to code perfusion (Up-Slope ➔ color) and function (systolic wall thickness ➔ size).

Ventricle color-coded acc. to transmurality.

Case Study: Coronary Artery Disease – Conclusion and Future Work

Myocardial perfusion analysis to detect early stage Coronary Artery Disease

Multiparameter techniques provide alternative to segment-based analysis

Refined BEP allows rest/stress comparison of one parameter

Correlation of BEP and vasculature facilitates synchronized examination

3D-Glyph based visualizations are applied for an integrated analysis of myocardial function, perfusion and viability

Future Work:

Thorough evaluation of the diagnostic benefit in a clinical study

Integrated visualization of MR coronary angiographic data and MR cardiac functional, perfusion and late enhancement data

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MeVis RESEARCH

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