Visual Medicine: Part Two – Advanced Topics in Visual Medicine

Visual Analysis of Perfusion Data

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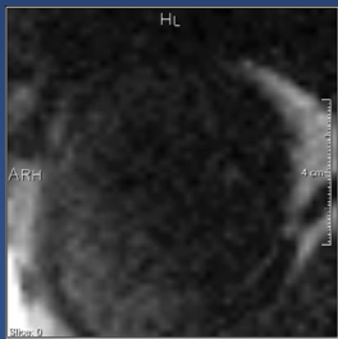


Outline

Advanced Topics in Visual Medicine

- **Visual Analysis of Perfusion Data**
- Intraoperative Navigation and Medical Mixed Reality
- Diffusion Tensor Imaging
- Visualization of Vasculature
- Fast Tagged Multi-resolution Volume Rendering
- GPU-aided Computed Tomography
- Soft-Tissue-Simulation

Questions and Answers

Structure

- Motivation
- Image Data and Preprocessing
- Visual Analysis of Perfusion Data
  - Basic Techniques
  - Advanced Techniques
- Case Study: Coronary Artery Disease
- Conclusion and Future Work

Motivation

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

Selected diagnostic application areas:

- Ischemic stroke
  - Fast localization of tissue at risk after an ischemic stroke
- Breast cancer
  - Evaluation of the dignity (malignant or benign) of breast tumors and radiation therapy monitoring
- Coronary Artery Disease
  - Localization of less-perfused myocardial regions for functional analysis and correlation with supplying coronaries to support detection of stenosis and assessment of its relevance

Image Data

Magnetic resonance (MR), Computed tomography (CT) perfusion diagnosis

Application of a contrast agent (CA) bolus

Repeated acquisition of subsequent images covering the volume of interest

CA wash-in provides signal changes in MR/CT ➔ tracer of blood

Typical dataset characteristics:

- Ischemic stroke (T2-weighted, 128 x 128 x 20 x 40, 40sec)
- Breast cancer (T1-weighted, 512 x 512 x 80 x 6, 1min)
- Coronary Artery Disease (T1-weighted, 128 x 128 x 4 x 40, 20sec)

Preprocessing

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

Tissue boundaries must be maintained

Perfusion analysis requires inter-pixel correspondence over time

Motion correction is essential prerequisite

Crucial in MR mammography and myocardial perfusion due to:

- Respiration artifacts
- (and heart motion)

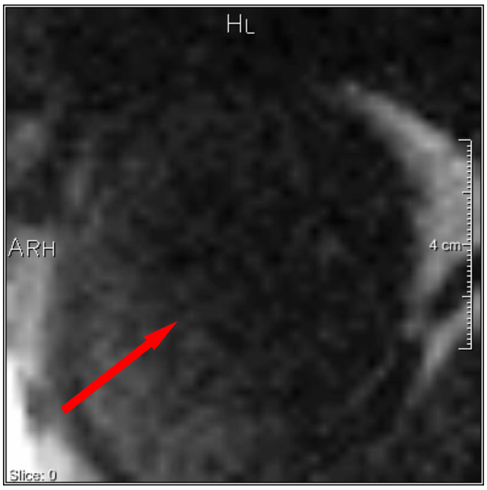
➔Motion correction, e.g. by combining rigid and elastic registration based on mutual information and gradient descent method for optimization [Rueckert, 1999]

Basic Visual Analysis Techniques – Cine-Movies

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

Problems:

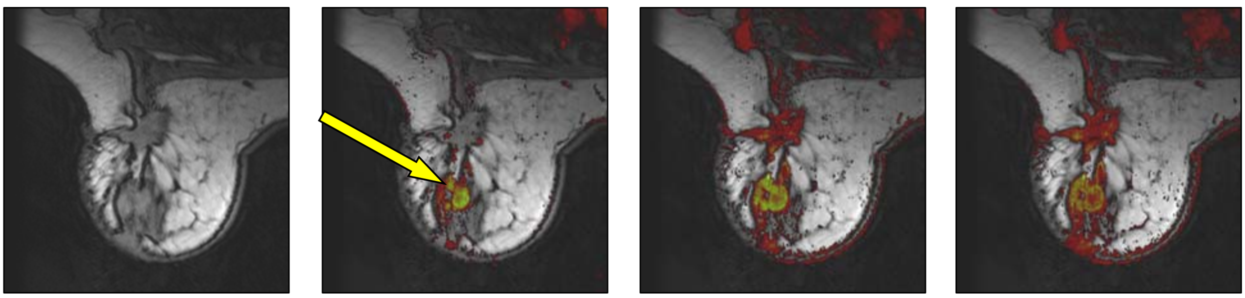
- user-dependent,
- no quantitative results,
- small perfusion defects remain undetected



Basic Visual Analysis Techniques – Subtraction Images

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

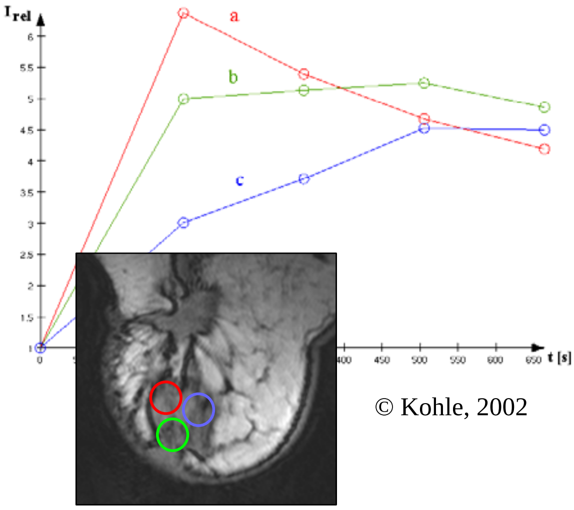
Differences are color-coded, gray-scale reference image serves as context information



t_0 t_1 t_2 t_3

Basic Visual Analysis Techniques – ROI-Selection

ROI-selection, Analysis of time-intensity curves



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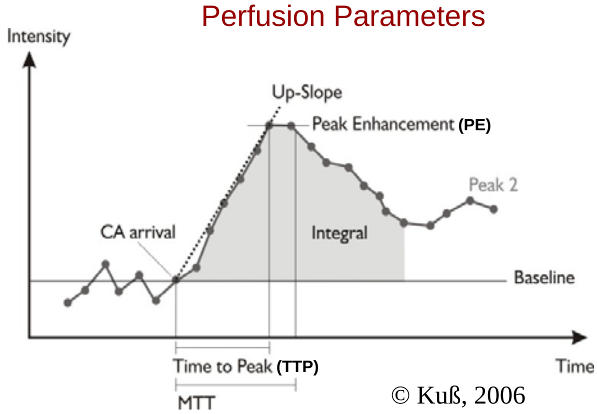
Perfusion Parameters



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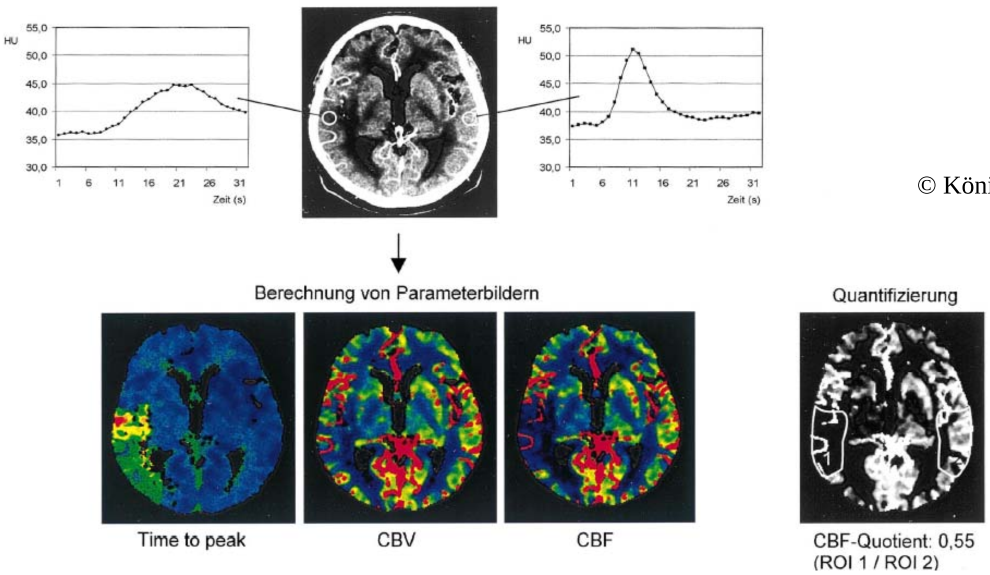
Basic Visual Analysis Techniques – Color-Coded Parameter Maps

Color-coded parameter maps for a selected slice



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Advanced Visual Analysis Techniques – Multiparameter Visualizations (1)

Perfusion diagnosis often requires examination of several parameters

Single parameter maps need to be integrated mentally

➔ Integrated visualization of several parameters [Oeltze, 2005]

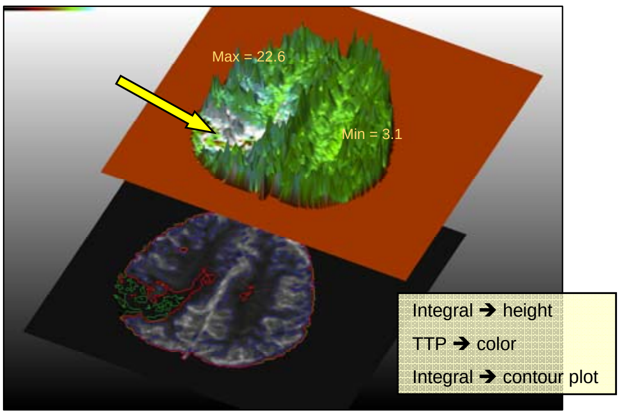
Strategies for multiparameter visualization:

1) Utilizing other visualization attributes besides color.
2) Adaptation and parameterization of the visualization.
3) Integration of exploration facilities.
4) Automatic detection of striking regions.

Advanced Visual Analysis Techniques – Multiparameter Visualizations (2)

Colored heightfields:

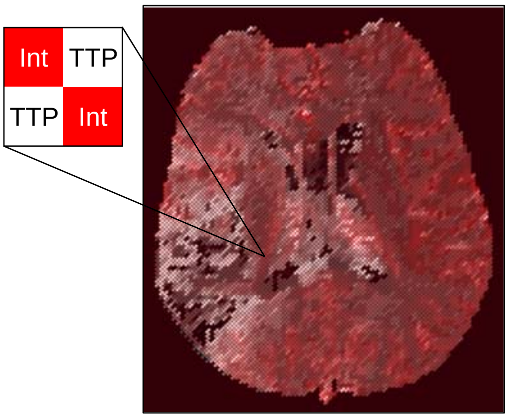
- Parameter 1 ➔ height, parameter 2 ➔ color
- Height is initially adapted to domain of the first parameter
- Contour plot: third parameter or parameter 1 (simplifies interpretation of regions occluded by strong elevations)
- Labelling of distinctive heights



Advanced Visual Analysis Techniques – Multiparameter Visualizations (3)

Color Icons [Levkowitz, 1991]:

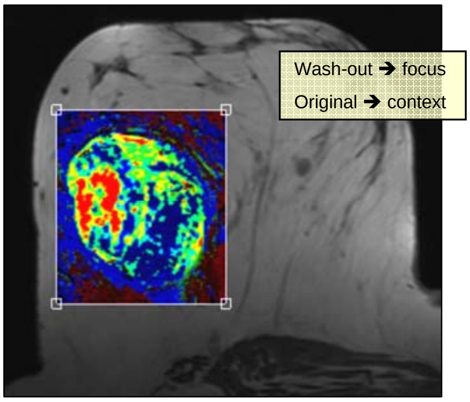
- Space-saving visualization of up to four parameters
- Each original pixel replaced by four quadratically arranged pixels
- Mapping to arbitrary color for each pixel of the icon
- Perception of resulting texture conveys global distribution of parameter combinations.

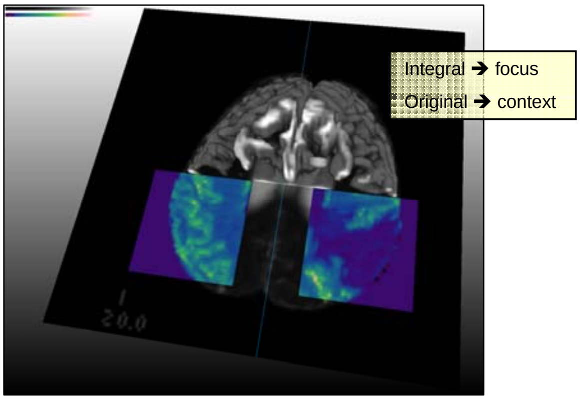


Advanced Visual Analysis Techniques – Multiparameter Visualizations (4)

Flexible synchronized lenses [Bier, 1993]:

- Focusing on one parameter in the context of the original data or another parameter
- Relocatable, resizable lens positioned by the user on context image
- Parameter image is projected through the lens
- Symmetric structures: Mirroring lens on line of symmetry

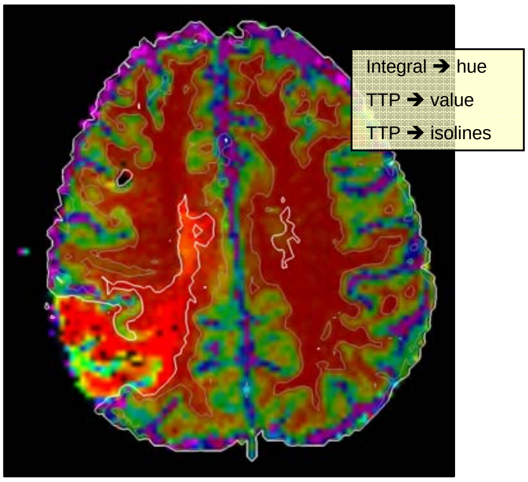


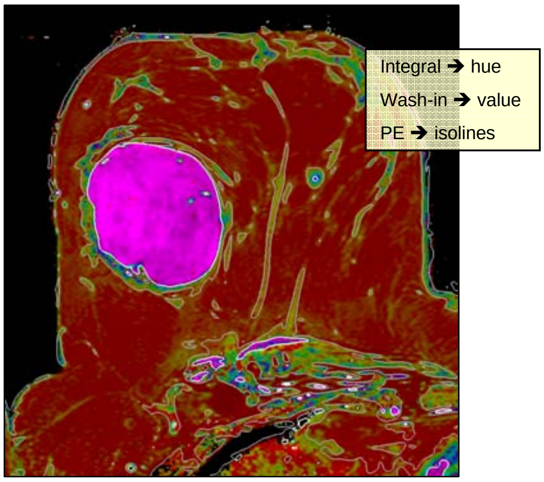


Advanced Visual Analysis Techniques – Multiparameter Visualizations (5)

HSV-color coding and isolines [Preim, 2003]:

- Space-saving visualization of up to four parameters
- Mapping of three parameters on hue, saturation and value
- Representation of a fourth parameter by means of isolines

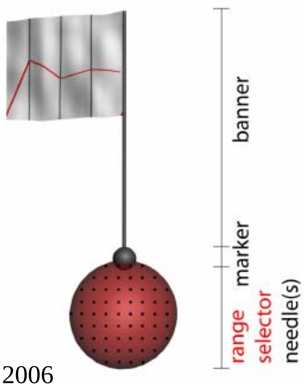




Advanced Visual Analysis Techniques – Probing and Annotating

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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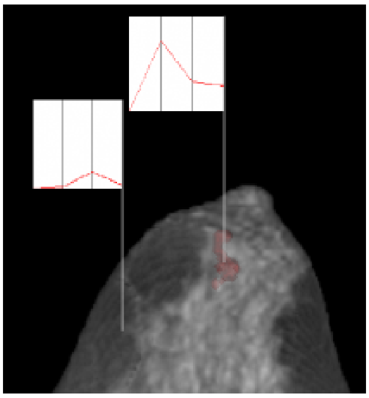

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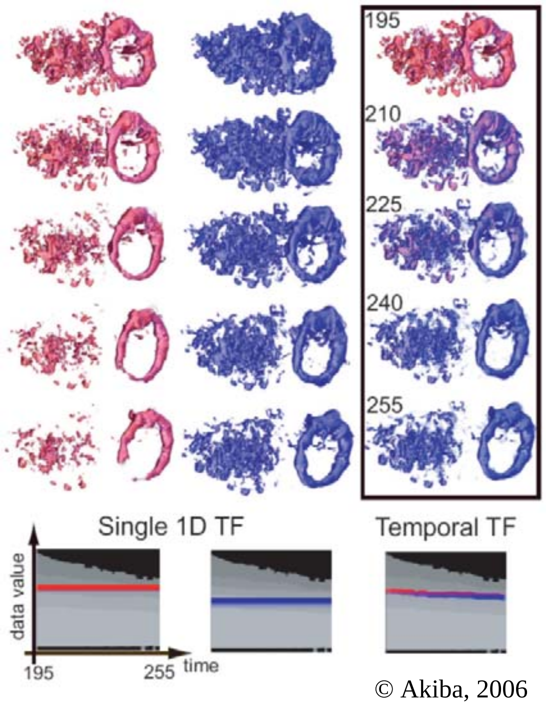
Advanced Visual Analysis Techniques – Direct Volume Rendering

Suitable for data with high spatial resolution, e.g. from breast cancer 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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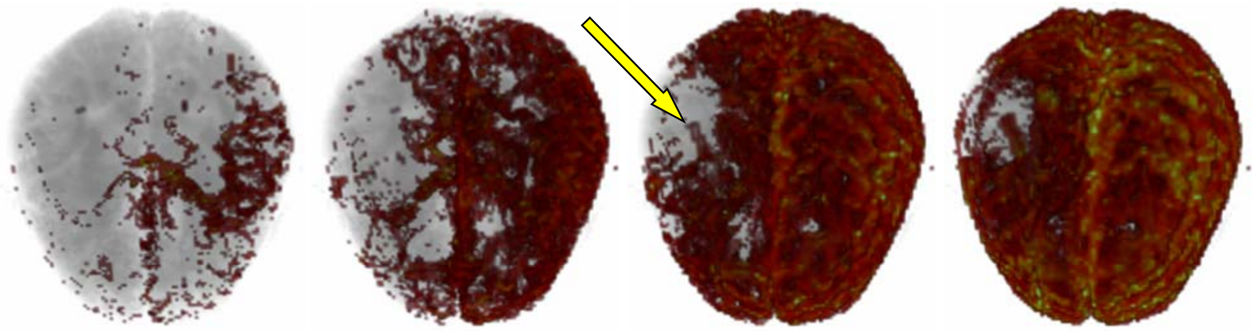
Advanced Visual Analysis Techniques – Extending Subtraction Images

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

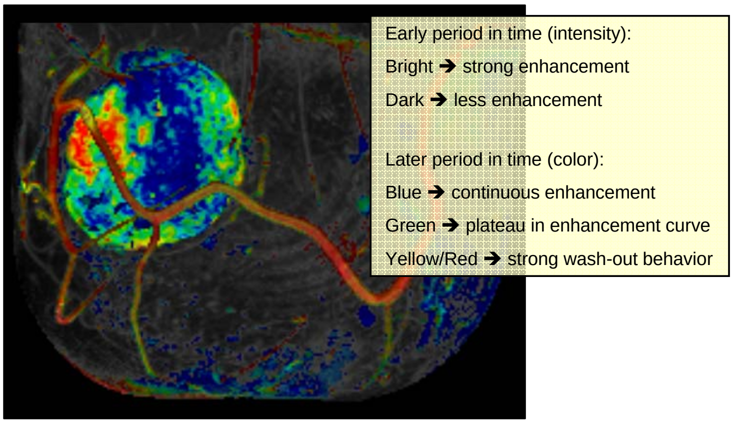


t_0 t_1 t_2 t_3

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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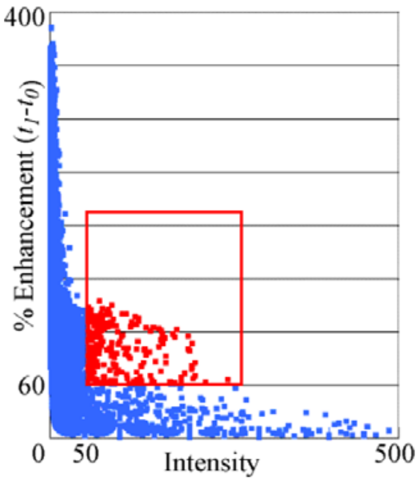
Advanced Visual Analysis Techniques – Combining InfoVis and MedVis

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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Case Study: Coronary Artery Disease – Medical Background

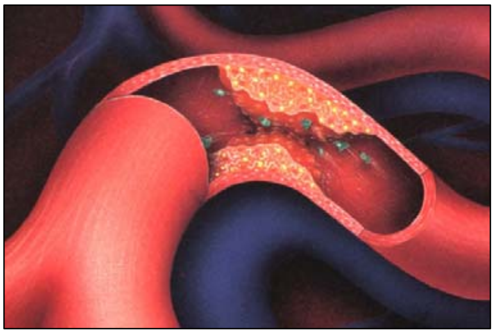
Coronary **A**rtery **D**isease: severe stenosis of one or more coronary arteries

Early stage CAD characterized by perfusion defect of the myocardium

Angina pectoris, cardiac arrhythmia and heart attack may result from restricted blood supply to the myocardium

➔ Localization and quantification of the perfusion defect

➔ Exploiting anat. knowledge about supplying coronaries to detect stenosis



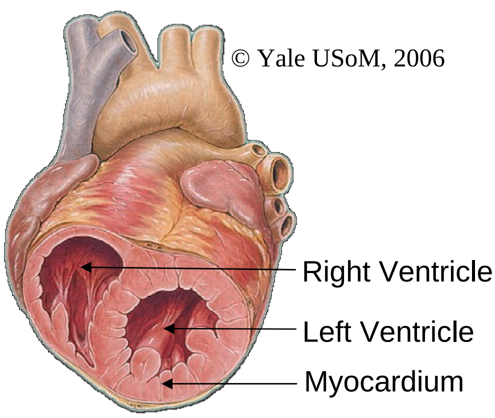
Stenosis caused by atherosclerosis.
© www.cardio-bielefeld.de, 2006

Case Study: Coronary Artery Disease – Image Acquisition

Magnetic resonance perfusion diagnosis

Very fast application of a contrast agent to form a bolus

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



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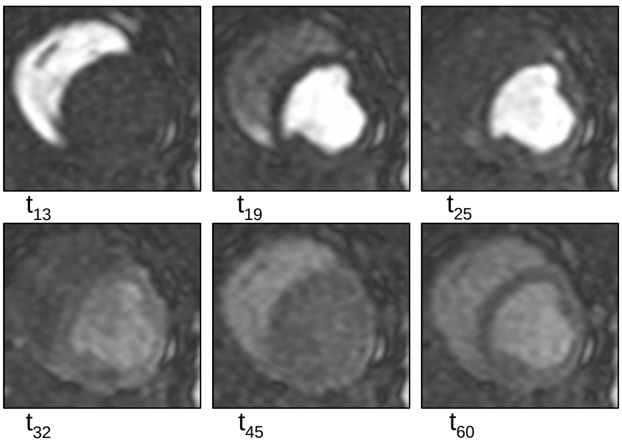
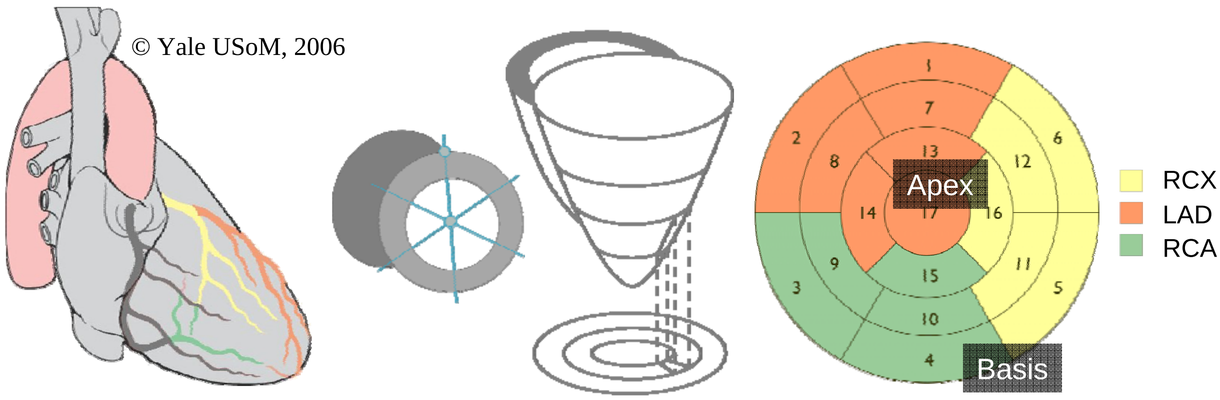


Case Study: Coronary Artery Disease – 17 Segment Model and Bull's Eye Plot

Plotting of time-intensity curve parameters in Bull's Eye Plot (BEP) by means of polar coordinates

American Heart Association – 17 segment model specifies relation between myocardial regions and supplying coronaries: left circumflex (RCX), left anterior descending (LAD), right coronary artery (RCA) [Cerqueira, 2002]



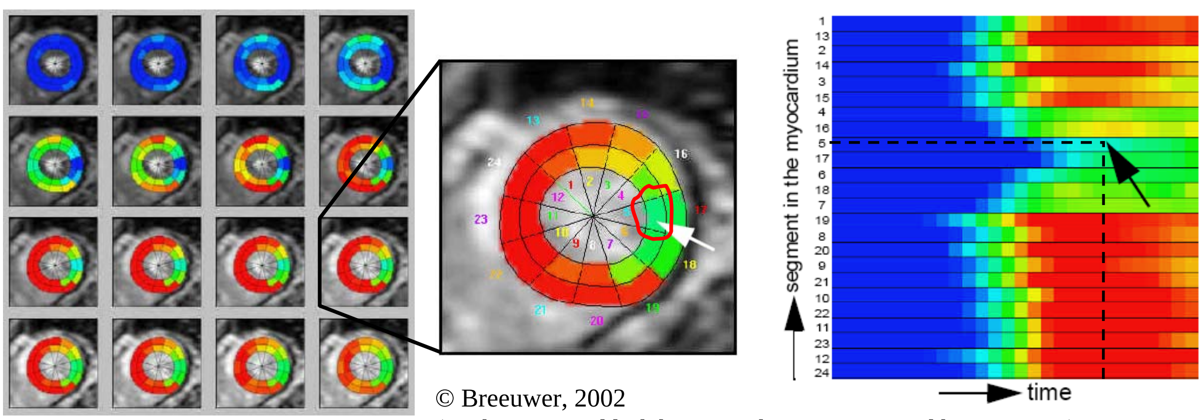
Case Study: Coronary Artery Disease – Uptake Movie and Perfusogram

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

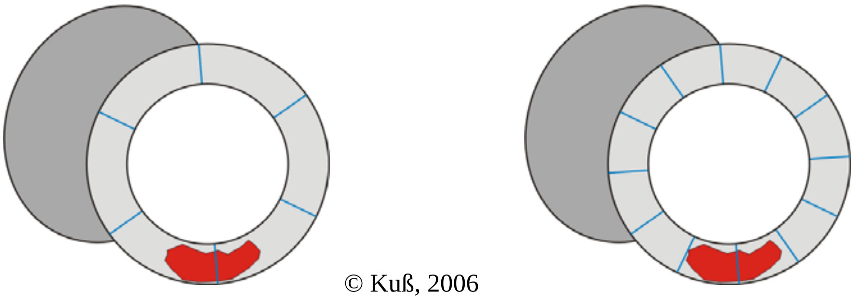


© Breeuwer, 2002
(Techniques and link between them are patented by PHILIPS)

Case Study: Coronary Artery Disease – 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



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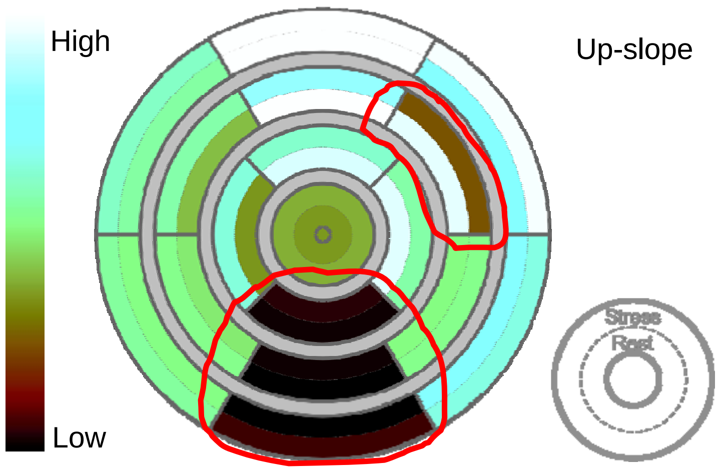
➔Advances in image acquisition and motion correction algorithms allow pixel-wise analysis by means of parameter-maps [Panting, 2001]

➔Integrated visualization of several parameters [Oeltze, 2006]

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

Refined Bull's Eye Plot (BiBEP):

- 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

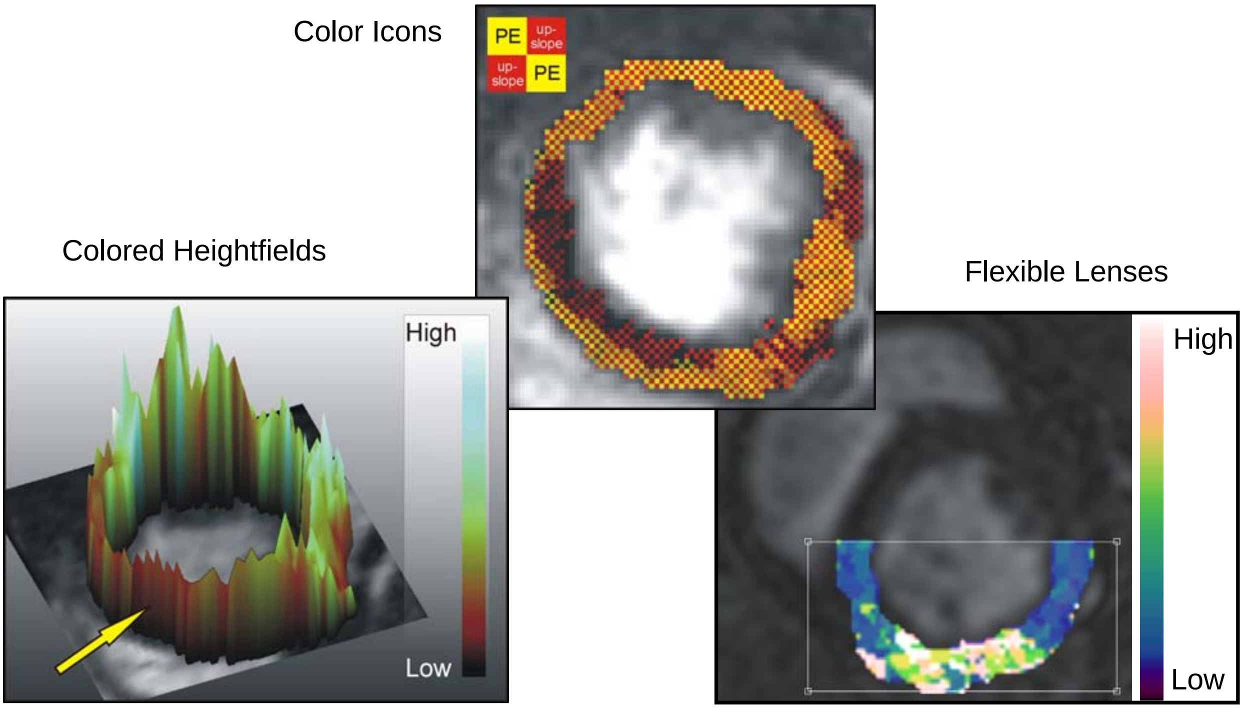


Case Study: Coronary Artery Disease – Multiparameter Visualizations

Color Icons

Colored Heightfields

Flexible Lenses



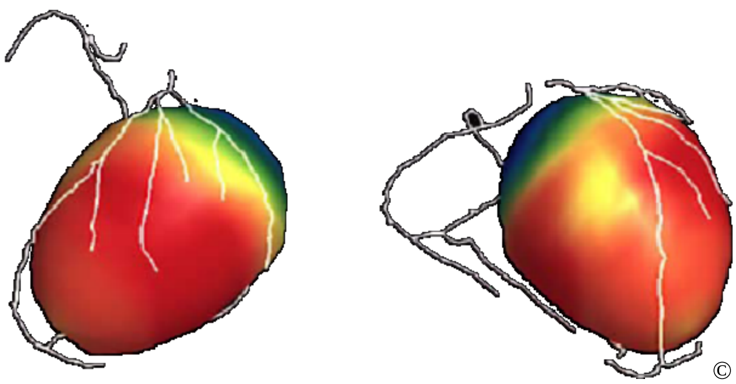
Case Study: Coronary Artery Disease – Integrating Perfusion & Morphology

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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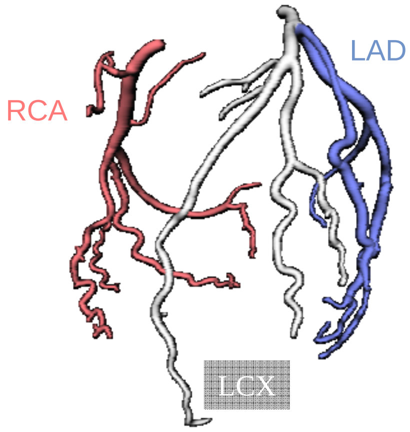
Case Study: Coronary Artery Disease – Preprocessing

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], segmentation of the left ventricle with live-wire

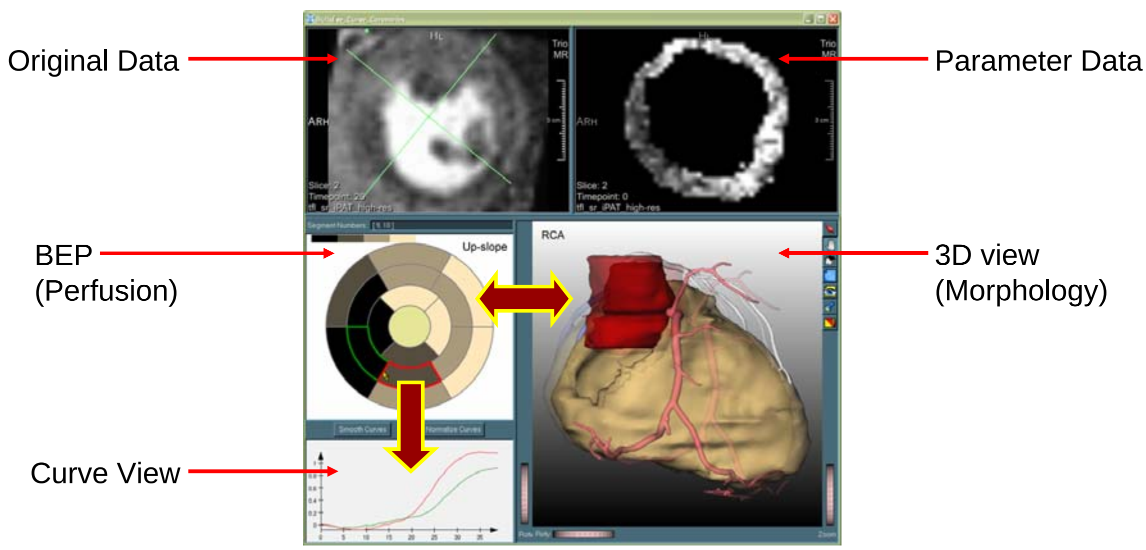
Manual labeling of coronary branches (RCX, LAD, RCA)



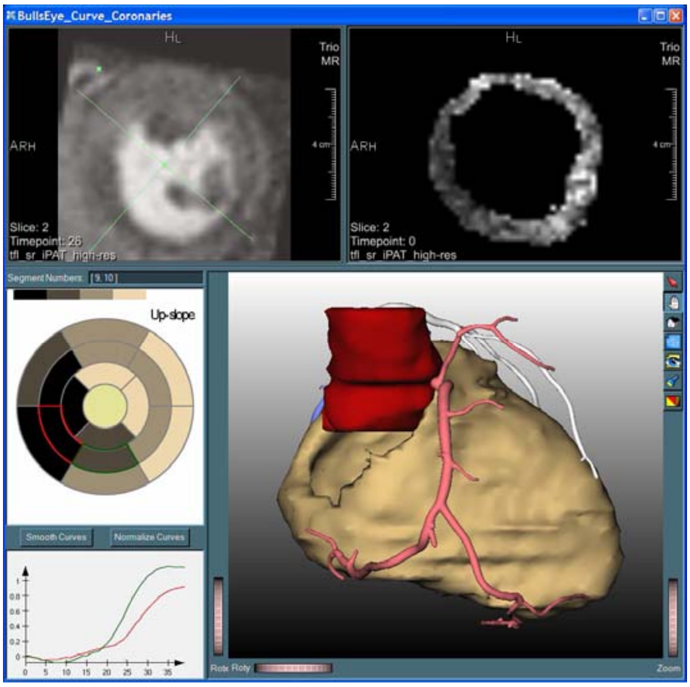
Case Study: Coronary Artery Disease – Linked Views

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

Focusing of supplying branch after picking segments in the BEP

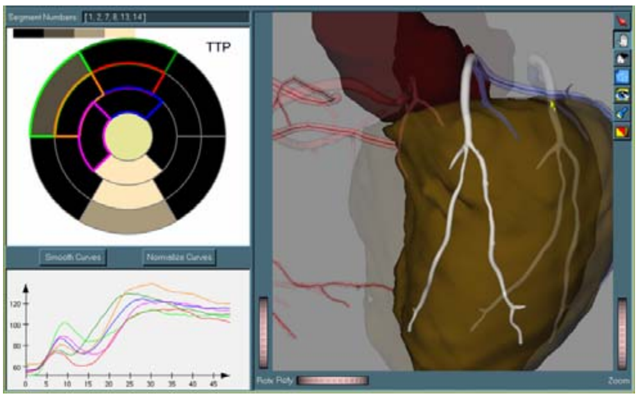


Case Study: Coronary Artery Disease – Identifying Supplying Branch



Case Study: Coronary Artery Disease – Identifying Supplied Segments

Accentuation of the supplied segments after picking a branch in the 3d-view



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

Semi-automatic definition of appropriate viewpoint for each coronary branch utilizing a script language

Conclusion and Future Work (1)

- Perfusion data are semi-quantitatively analyzed (no standardized intensity values)
- Normalization, e.g. comparison between healthy and suspicious region required.
- Basic visualization techniques allow to detect suspicious regions
- Multiparameter techniques, e.g. colored heightfields, color icons and flexible lenses, facilitate an in-depth and more comprehensive analysis
- Profile flags for annotating perfusion data, e.g. to communicate diagnosis
- Volume rendering is applied to explore data with high spatial resolution

Future Work:

- Combination of statistical analysis (PCA, …) with visualization
- Evaluation in clinical settings

Conclusion and Future Work (2)

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

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Siemens Medical Solutions

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