Visualization and Virtual Reality in Medicine

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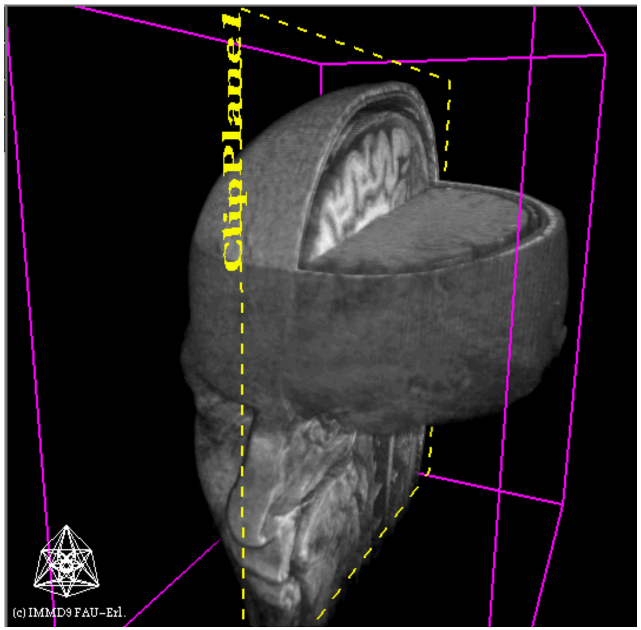
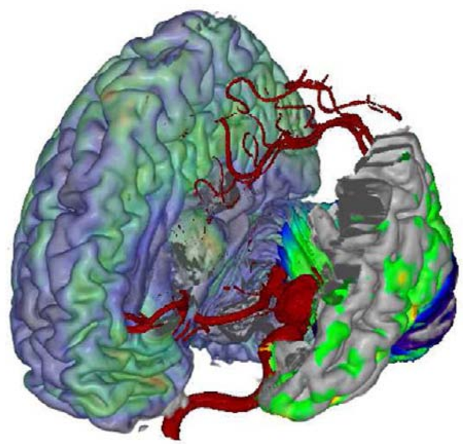
Tutorial Syllabus

Surface Visualization - Marching Cubes and its improvements - Smoothing of surface visualizations	(40 min.)
3D Vessel Visualization	(30 min.)
Labeling Medical Visualizations	(20 min.)
Break	(15 min.)
Direct Volume Visualization - Ray casting and texture-based approaches - Projection methods	(40 min.)
Multifield Medical Visualization	(30 min.)
Virtual Endoscopy	(20 min.)

Multifield Medical Visualization





Outline

- Introduction: Motivation and major applications
- Strategies for multimodal rendering
- Multifield volume rendering
- Surface-Based multimodal rendering
- Exploration techniques and transfer function design
- Illustrative Multimodal Visualization

Introduction

- Diagnosis, treatment planning and follow up often requires to integrate information from different sources
  - Multiple points in time (longitudinal data)
  - Multimodal data (PET/CT, PET/MRI or CT and MRI)
  - Pre- and intraoperative data
- Important subfield of medical visualization with seminal papers in the 1990s ([Valentino, 1991], [Cai, 1999], [Hastreiter, 1998], [Stokking, 1997])

Introduction: Visualization Goals

- **Integrate** the information to reveal interesting portions of both source data, e.g. metabolism from PET and anatomical structure from CT or MRI
  - High-uptake regions in PET reveal tumor but also organs such as gallbladder, liver, kidney
- **Compare** structures visible in both sources, e.g., tumor delineation in CT and MRI or in two MRI sequences
  - Indicate similarities and differences
- Data from sources with different resolution and quality is integrated → Uncertainty-awareness is desirable

Introduction: Technical Requirements

To integrate and compare data, it needs to be

- **Aligned** with each other (image registration)
- **Normalized** with respect to intensity values
- Fused with a multifield visualization technique

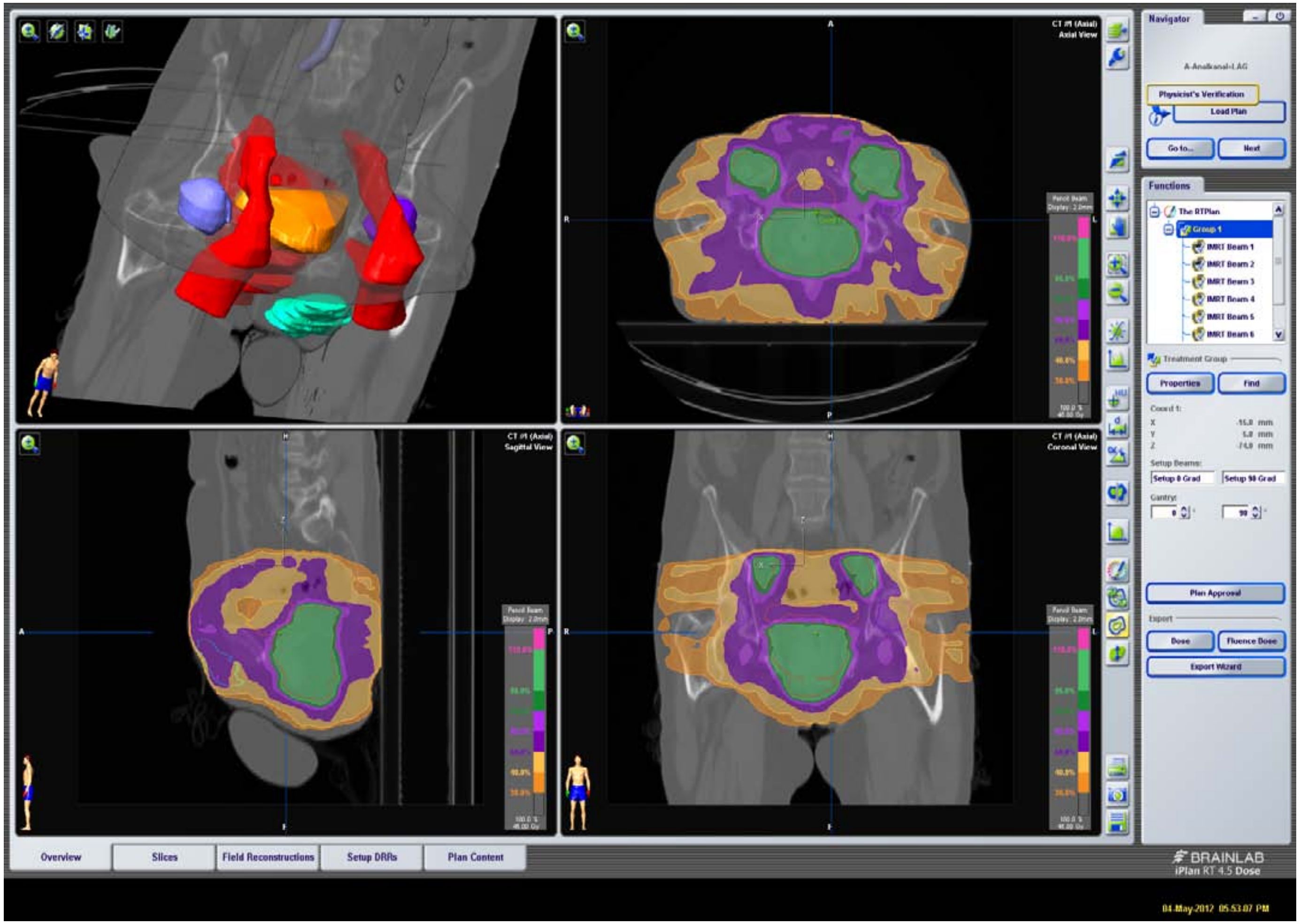
Thus, multimodal visualization is enabled by hybrid imaging devices (PET/CT, PET/MRI, SPECT/CT) and by powerful registration algorithms.

Some authors argue that only integrated data should be visualized in a fused manner since otherwise small registration errors hamper the interpretation.

Introduction: Major Applications

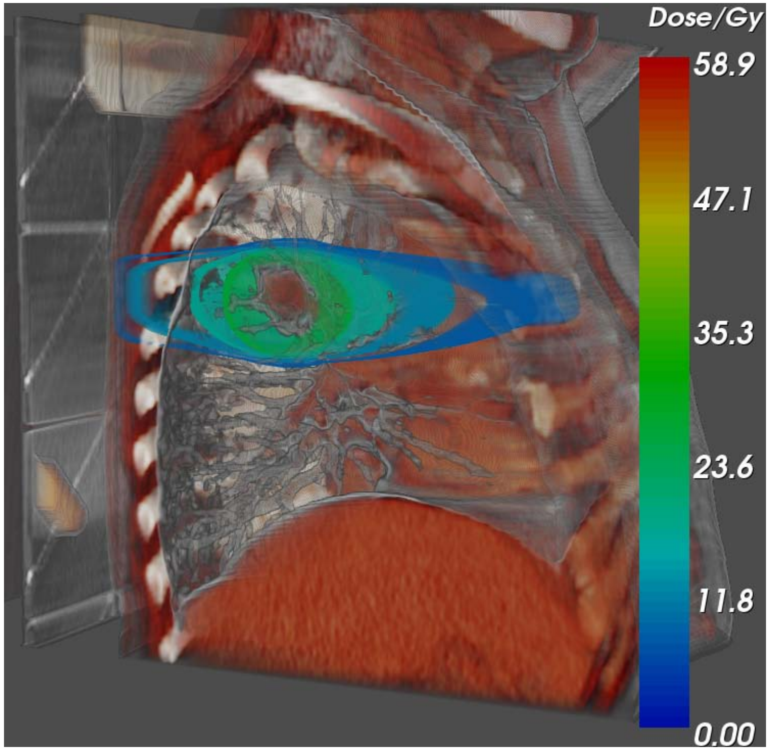
- Radiation treatment planning
- Hybrid imaging (nuclear medicine, radiology)
- Functional imaging in neuroscience and neuroradiology
- Dual-energy CTs
- Follow-up studies

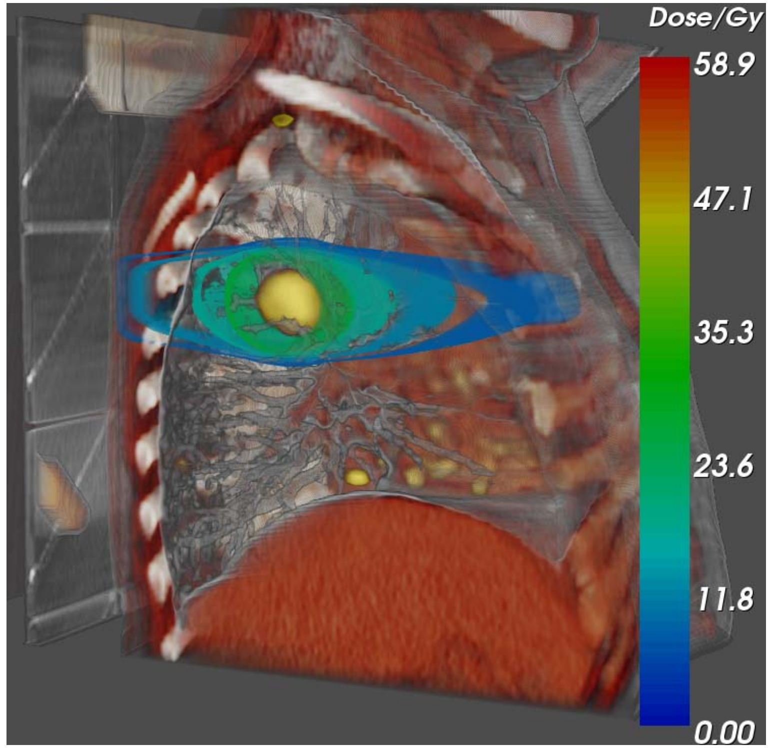
Major Applications: RT Planning



Planning CT and simulated dose distribution are overlaid (in 2D and 3D). Dose distribution is often displayed as isolines (Screenshot from BrainLab iPlan).

Major Applications: RT Planning

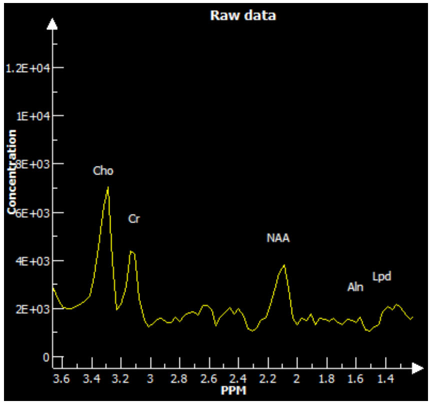


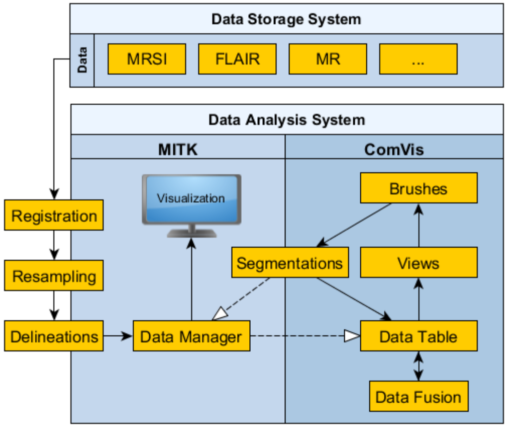


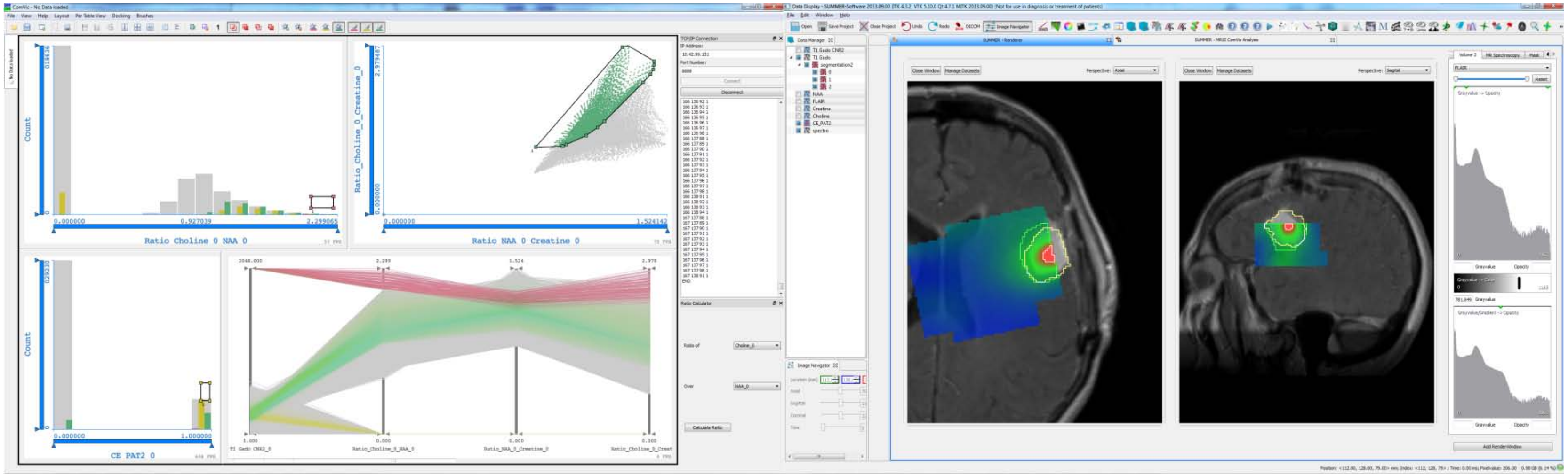
Left: Fusion of the planning CT and four iso-dose surfaces.

Right: Additional fusion of PET (From: Schlachter, 2014)

Major Applications: RT Planning

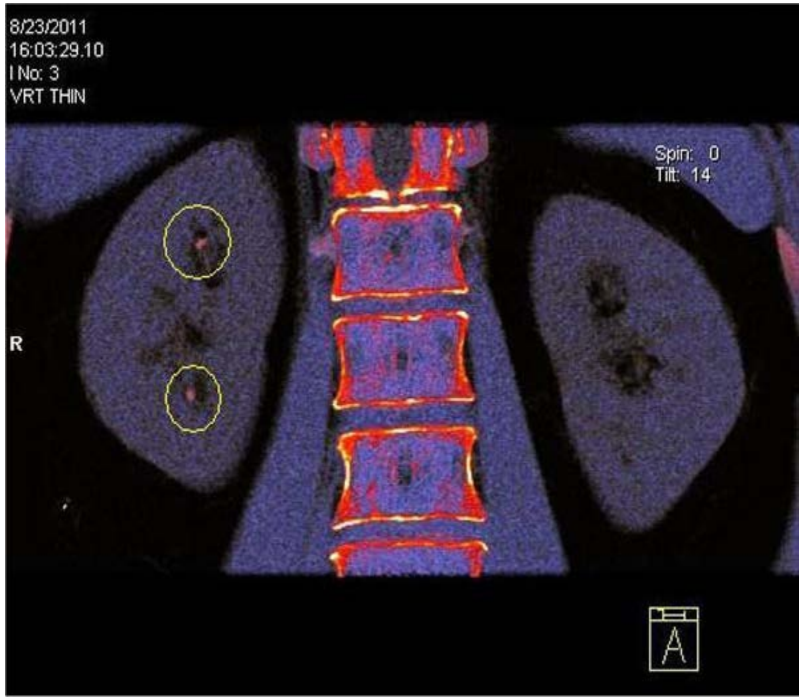






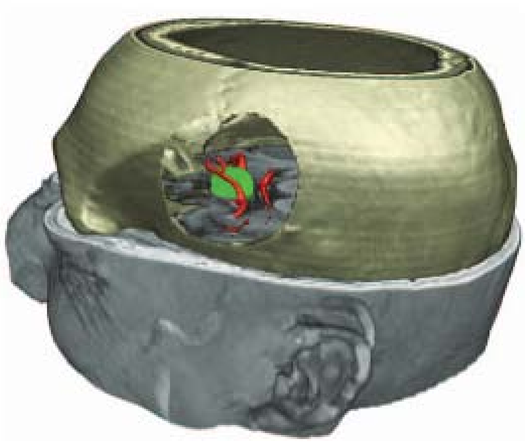
MR Spectroscopy (left) is combined with other MRI data to define a planning volume for radiation treatment. The lower left view is used to select properties from spectroscopy data to be highlighted in the other views (From: Nunes, 2014)

Major Applications: Dual Energy CT



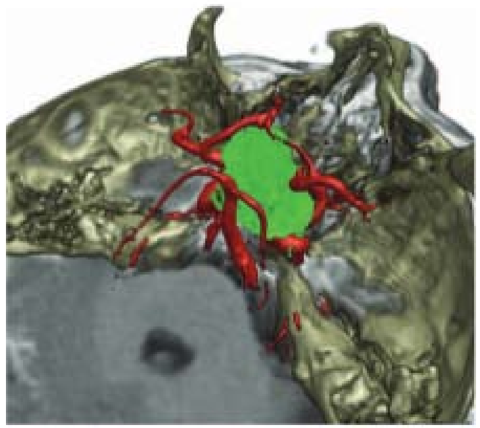
CT-Data in two energy levels are overlaid (one serves a background image).

Major Applications: Neurosurgery Planning



Left: Multi-volume rendering (green: tumor - MR, red: vessels - MRA, brown: skull - CT).

Right: Multi-volume blending (black/white: brain - MR, red: metabolic active
part of tumor - PET, yellow: brain areas active during speech - fMR)



Left: CT data (skull) and MRI data (brain) for visualization of electrodes for epilepsy surgery.

Right: CT, MRI and MRA data for tumor resection planning.

Target structures were segmented (From: [Beyer, 2007])

Medical Image Data

- Anatomical data (CT, CTA, MRI, MRA, …)
  - High spatial resolution
- Functional data (fMRI, PET, SPECT)
  - Represent functional processes
  - Low resolution
- Radiation isodose distribution
- Segmented data
- Diffusion Tensor Data

Medical Image Data

- Different anatomical data have a similar resoultion and a high overlap in information (information redundancy)
  - Fused visualization, e.g. to assess differences in tumor volume
- Functional and anatomical data are complementary
- Functional data are registered to anatomical data (not vice versa) to avoid distortions of the anatomical data

Strategies for Multimodal Rendering

2D Visualization

- Slice-based visualization
  - Side-by-side views, synchronization with respect to the selected slice and synchronized cursor (Linked Feature Display) (Levin, 1989)

- Integrated slice-based visualization
  - Overlay of both source datasets.
  - For each pixel,
    - data from only one source dataset is used or
    - data from both datasets are blended (semitransparently)

Strategies for Multimodal Rendering

3D Visualization

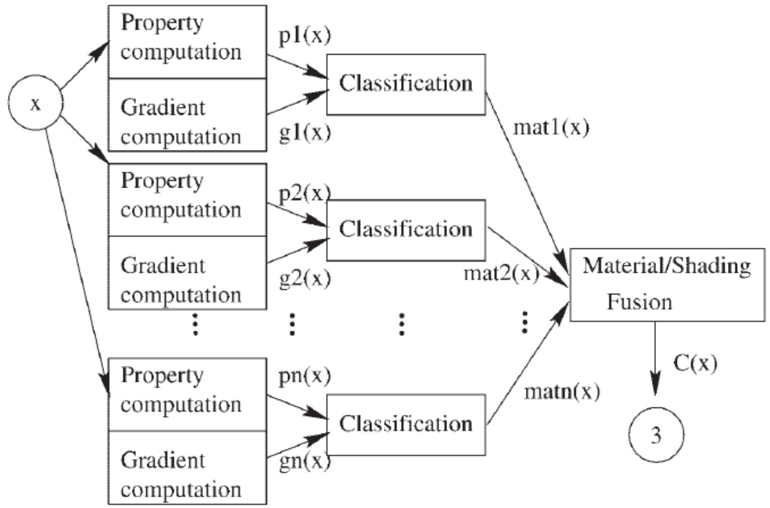
- Occlusion is aggravated for 3D multified data
- Key is to ensure visibility of essential information.

- Multifield volume rendering.
  - A combination of **geometric properties** and **data properties** is used to restrict the visible portions of the source data
- Surface-based rendering
  - A reference surface is extracted from one dataset.
  - Information from another dataset is projected and combined along the reference surface.

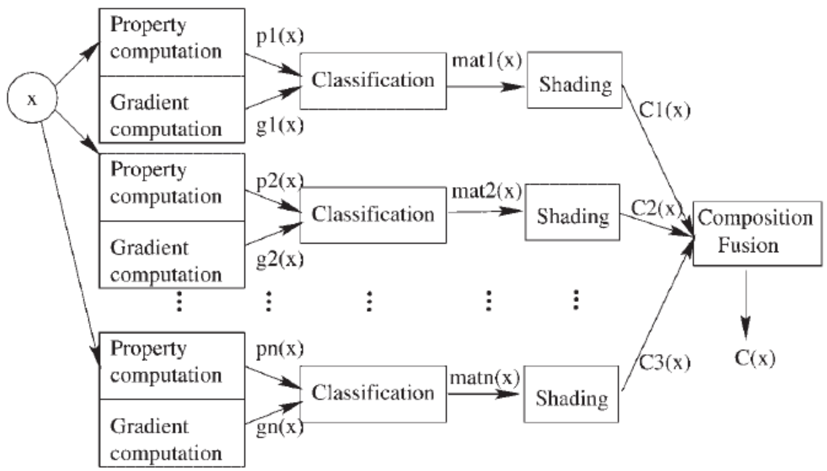
Strategies for Multifield Volume Rendering

Stages of Mixing Data ([Cai, Sakas 1999],[Ferre, 2004]):

- Accumulation level (material fusion)



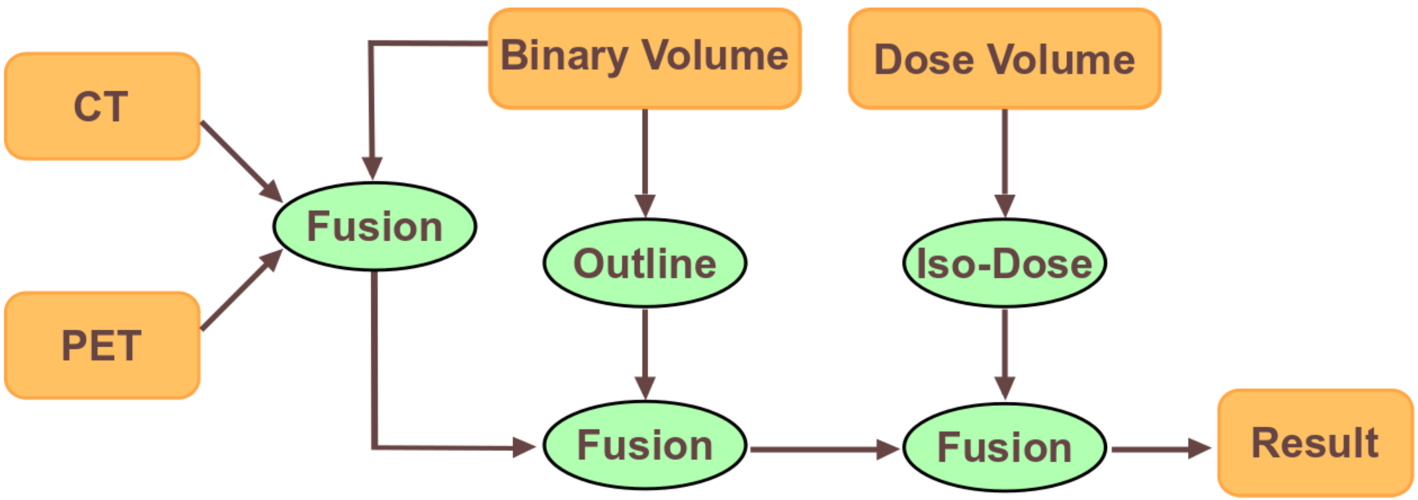
- Illumination level (shading fusion)



- Pixel level (fusion of two rendered images)

(From: [Ferre, 2004])

Strategies for Multifield Volume Rendering



(From: Schlachter, 2014)

Fusion pipeline for multimodal visualization for radiation treatment planning. Besides PET and CT, segmented risk structures and tumor (binary volume) and the dose simulation need to be integrated.

Multifield Volume Rendering

Select data properties:

- Define a **fusion transfer function** (FTF) that assigns color and opacity depending on the intensity (and gradient) of v_1 and v_2.

Select geometric properties:

- Use predefined segmentations, clipping planes, clipping boxes or deformable clipping planes (Konrad, 2004) to restrict the visualization of one source dataset.
- **Example**: A segmented tumor along with a safety margin defines a volume of interest.

Geometric and data properties may be combined, e.g., with distance-based transfer functions.

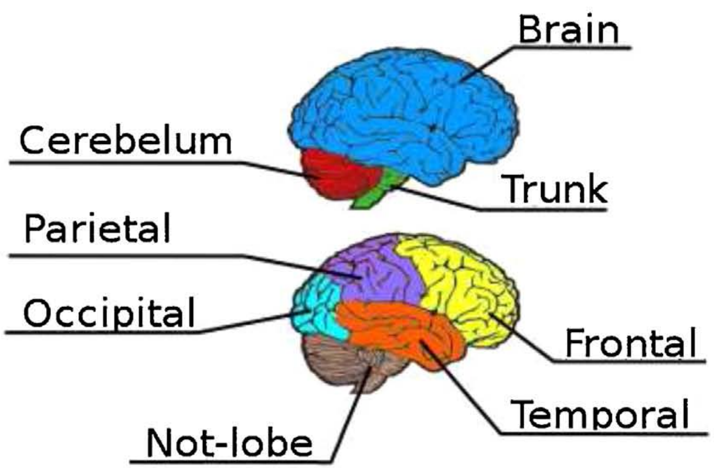
(see [Manssour, 2002] for a discussion)

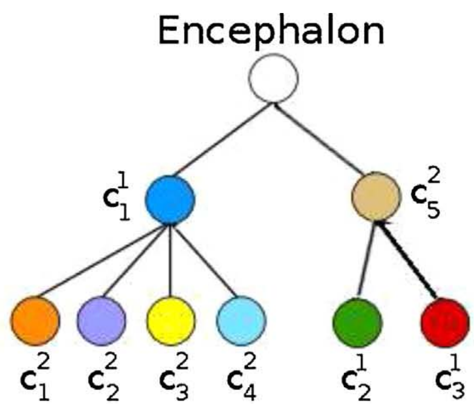
Multifield Volume Rendering

Fusion modes (Abellan, 2013):

- Global fusion transfer function
- Segmentation-Based (Local) FTF
- Interactively Manipulated (Local) FTF

Often, local FTF override the global FTF.

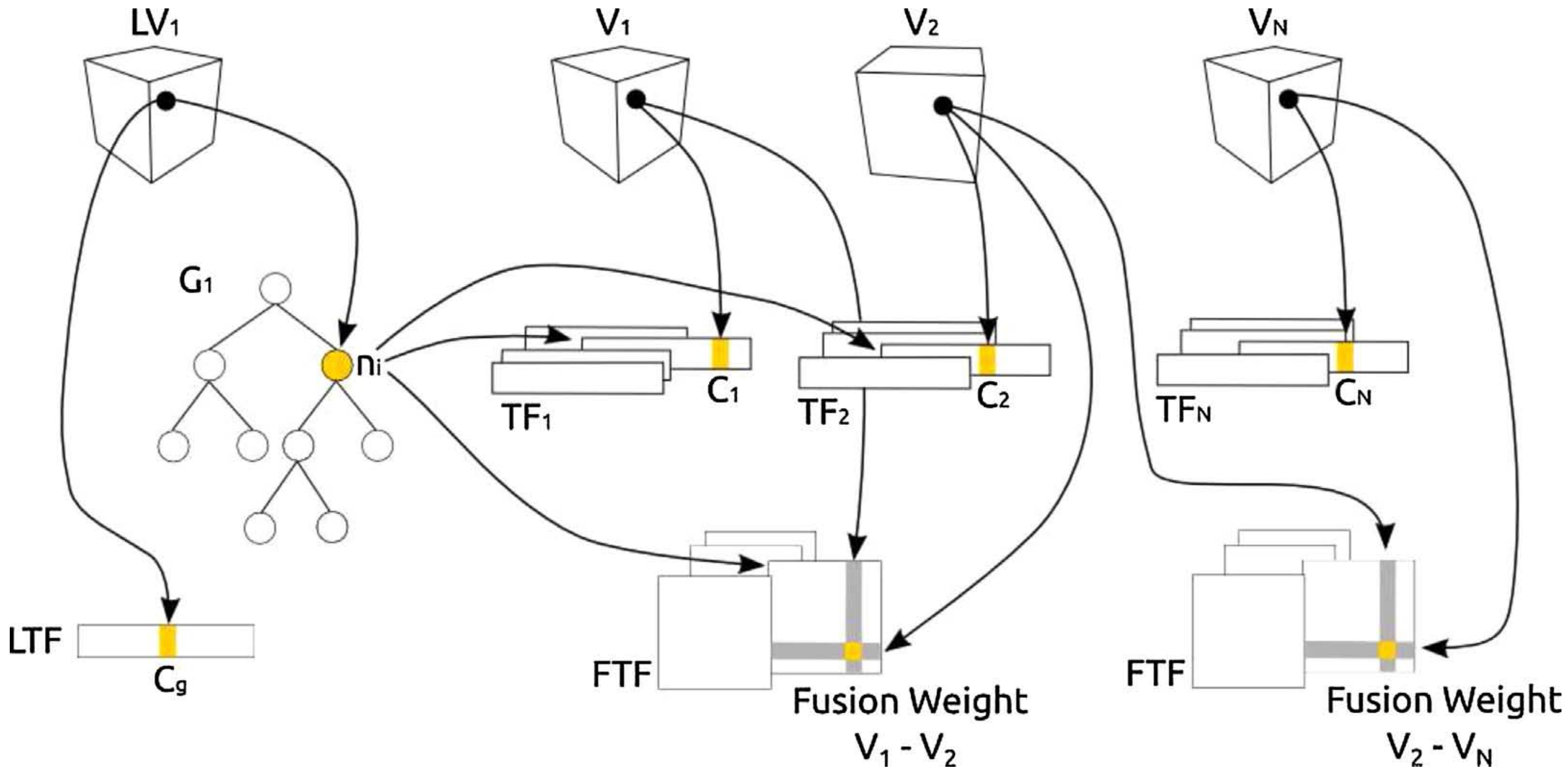




Segmentation – region graph construction

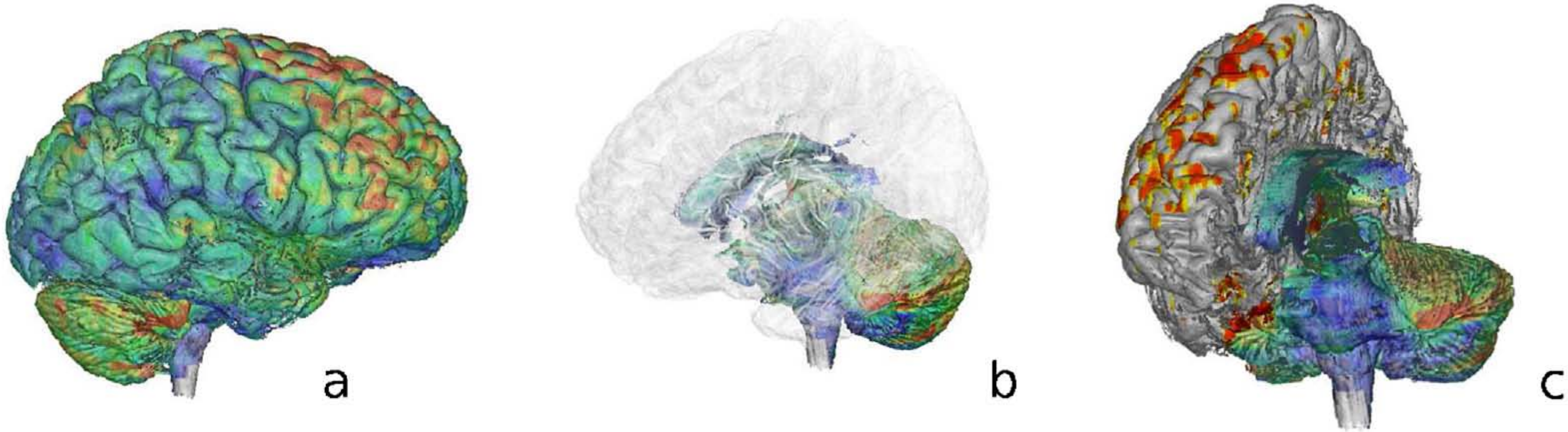
(From: Abellan, 2013)

Multifield Volume Rendering



Local Transfer Functions (LTF) control the fusion for the respective area in two (or more) datasets (From: Abellan, 2013)

Multifield Volume Rendering



(From: Abellan, 2013)

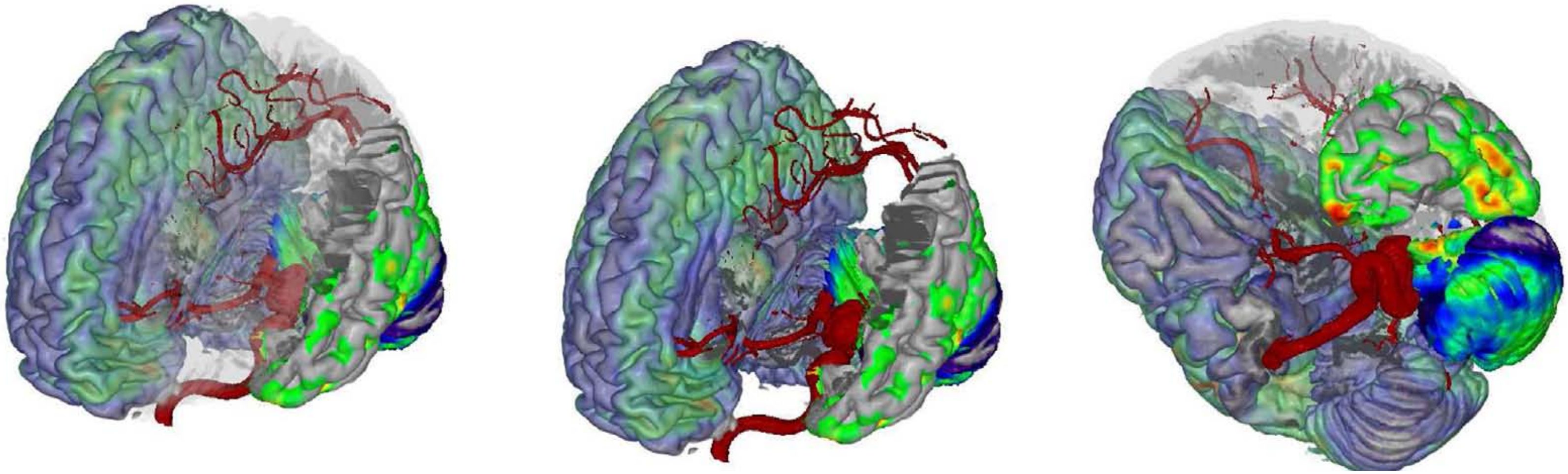
Combination of PET and MRI:

(a) global fusion of PET on the brain surface;

(b) rendering of the ROI (middle brain and cerebellum); and color ghosting for the context;

(c) high activity in the left part of the brain

Multifield Volume Rendering

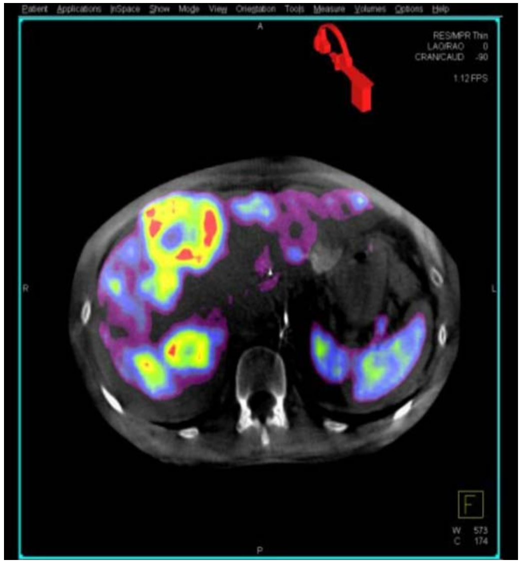


(From: Abellan, 2013)

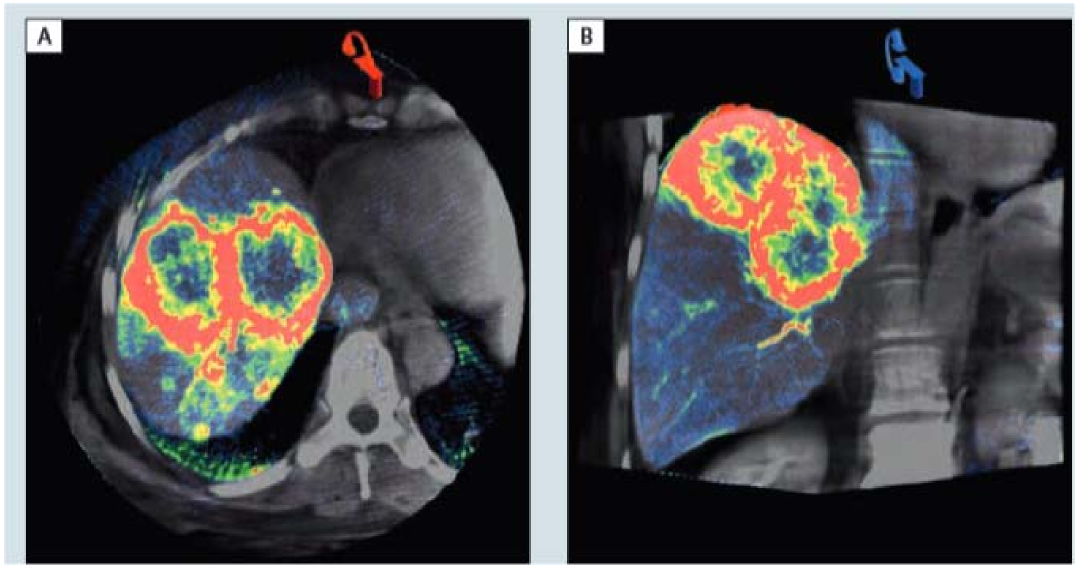
Combination of PET activity, MR (brain) and MRA (blood vessels).

Semantic regions were defined to adjust fusion parameters locally.

Transparent Overlays

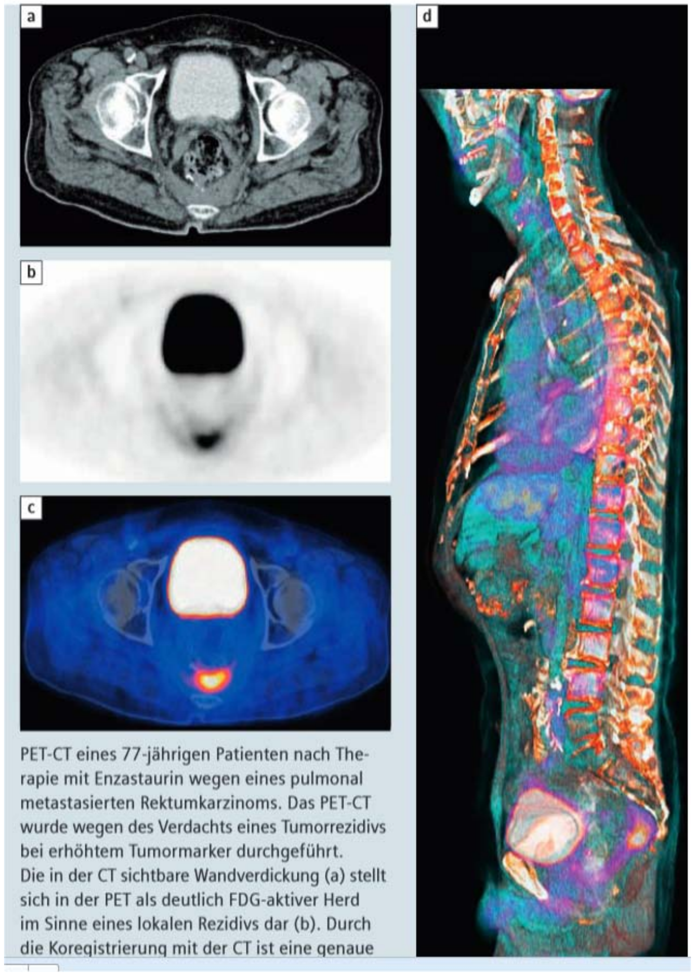


SPECT/CT
(From: Siemens.healthcare.com)



Dyna CT combined with perfusion imaging reveals two lesions of hepatocelluler carcinoma
(From: inside:health Mai, 2013, pp. 30)

Transparent Overlays



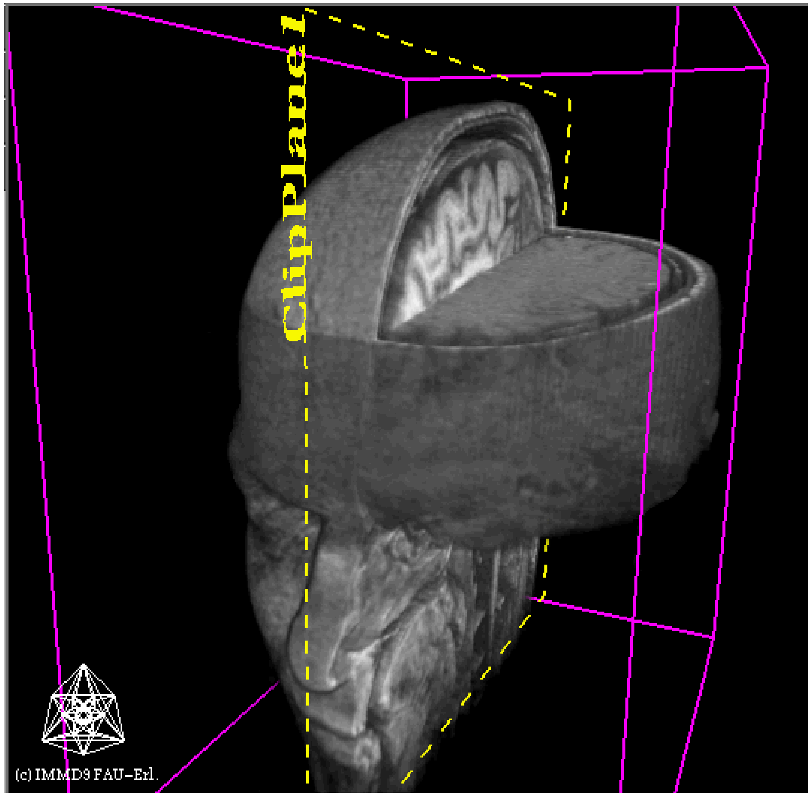
Clinical routine: three synchronized slice-based views:

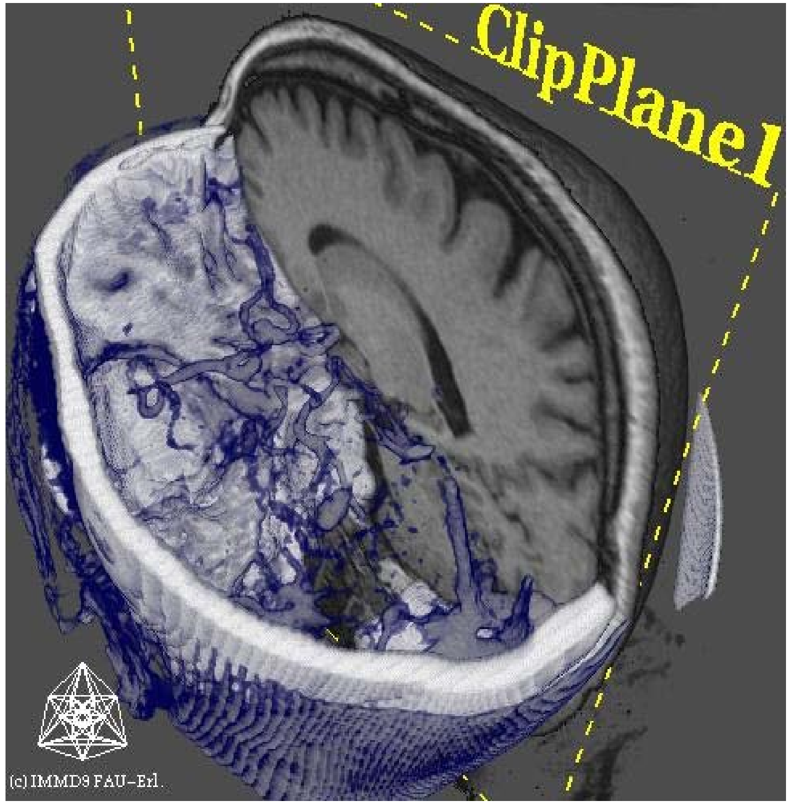
Dataset$_1$, fused view, Dataset$_2$

A slider controls opacity ofthe overlaid dataset.

Source: Inside Health, SIEMENS

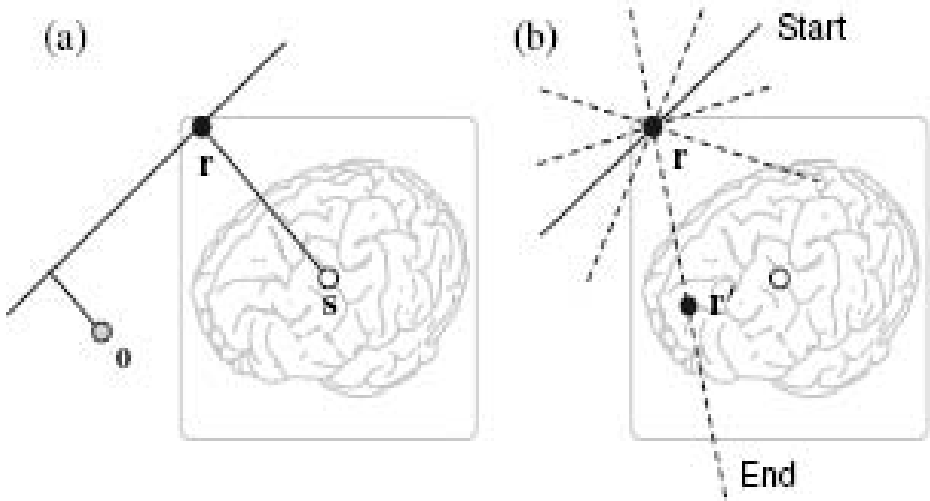
Exploration Techniques: Clipping Planes





Clipping planes to adjust the visible portion of the two source (CT and MRI brain) datasets (From: Hastreiter, 1998).

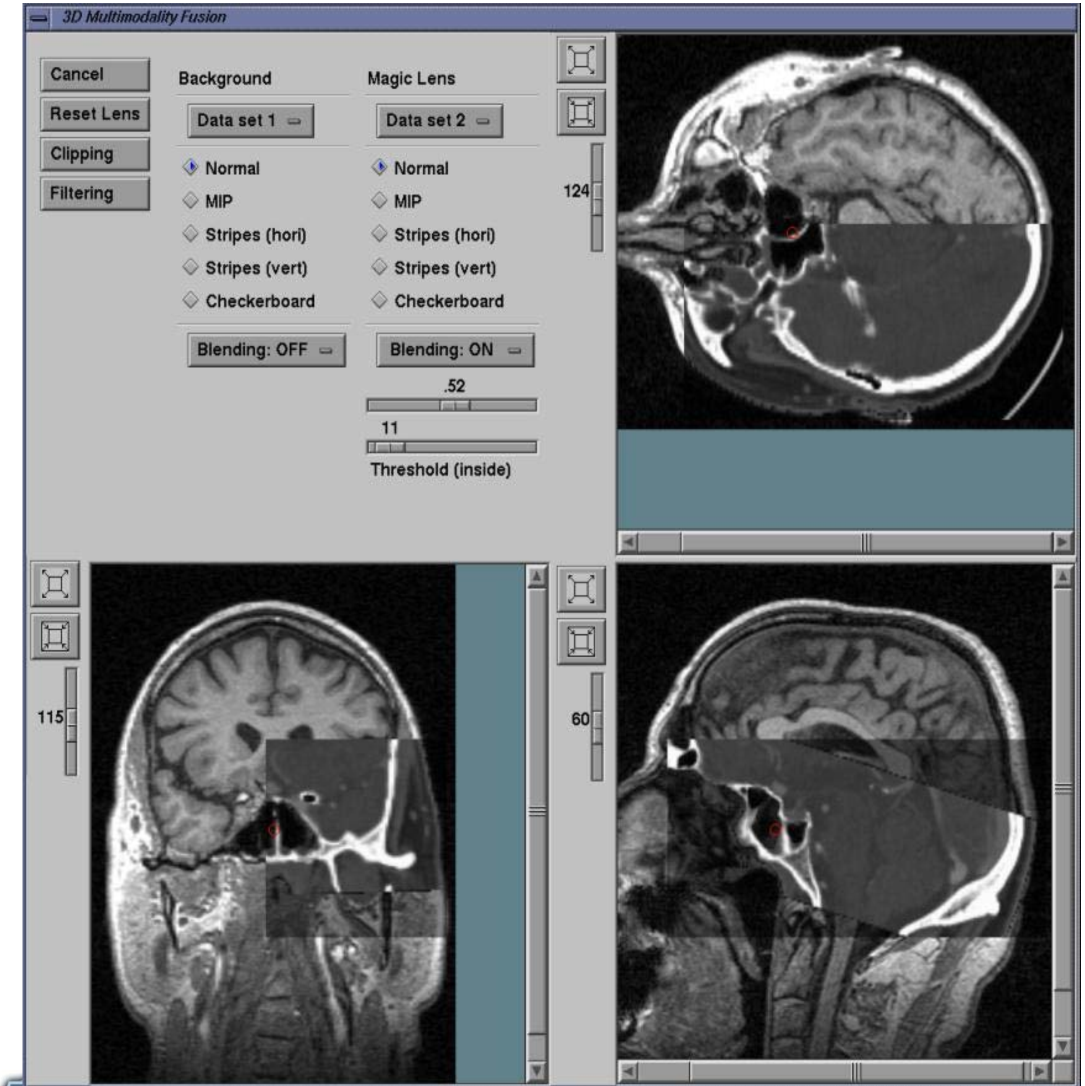
Exploration Techniques: Clipping Planes



Rotation of clipping planes along the world coordinate orign (o) is not intuitive. A reference point (r) that corresponds to the „middle“ of the clipping plane is more appropriate (Jainek, 2008).

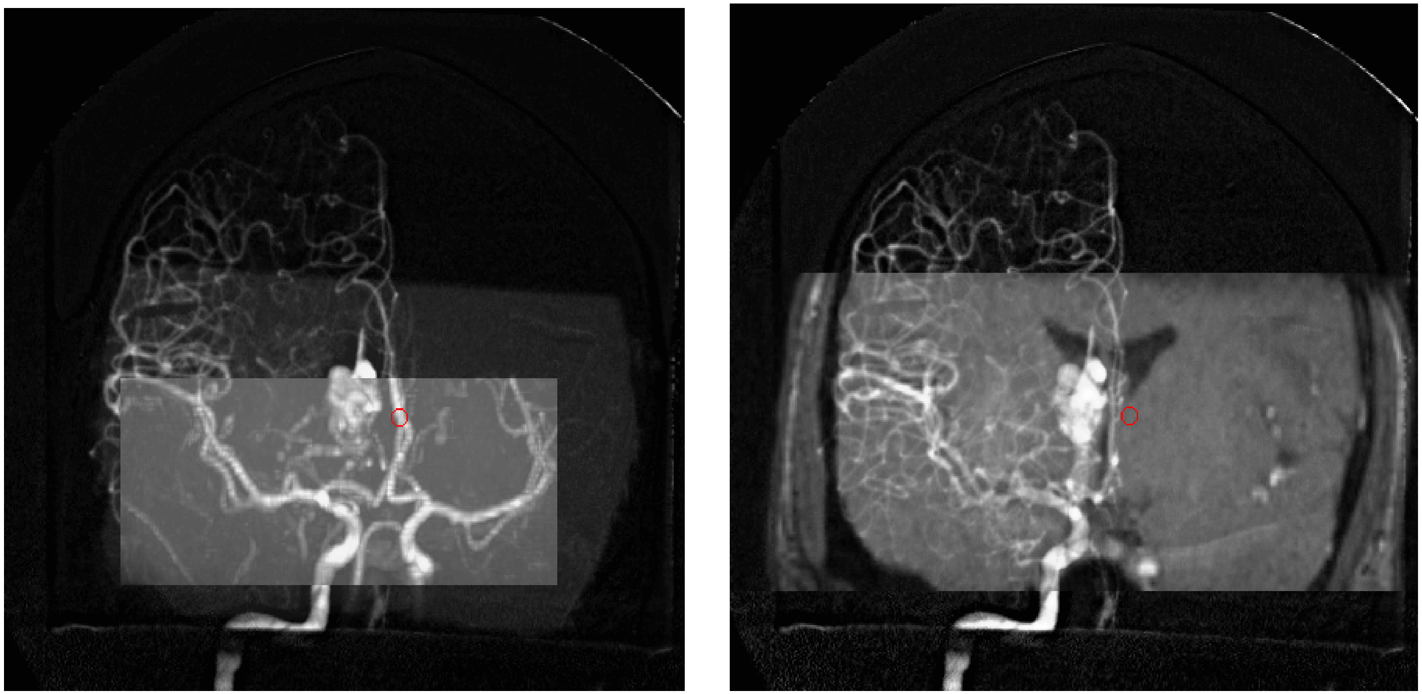
Today: Multitouch gestures may improve clip plane handling.

Exploration Techniques: Lens-based Interaction



Lens-based interaction with slice views. In the lens region CT data is visible (semitransparent overlay) (From: Hastreiter, 1998)

Exploration Techniques: Lens-based Interaction



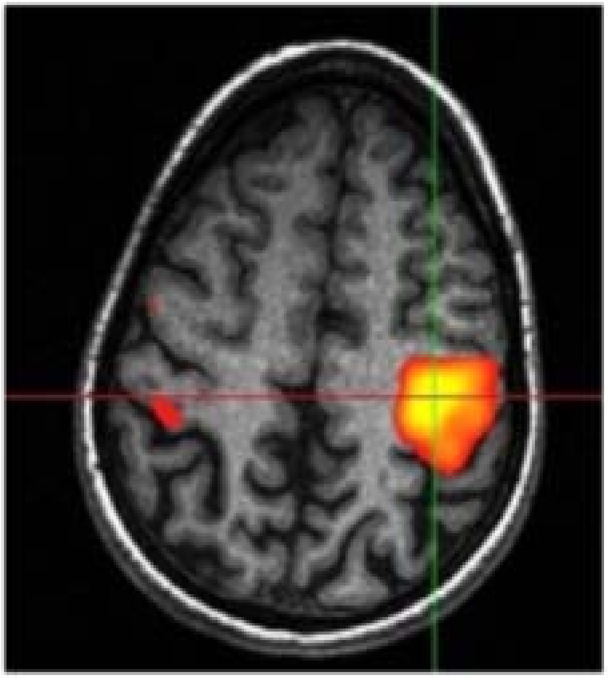
The concept of a lens may be transferred to a 3D volume lens

(From: Hastreiter, 1998)

Transfer Function Design

- Intensity of one dataset mapped to color (metabolism in PET data, activation in fMRI)
- Color should be used sparsely → map the same data to high transparency values (focus on regions with high metabolism or activation)
- Information-theoretic approach (Haidacher, 2008)
  - Evaluate the joint histogram of the two source data and determine for each (discrete) bin the probability that a combination of values occurs
  - Assign opacity such that rare combinations are preferred

Transfer Function Design

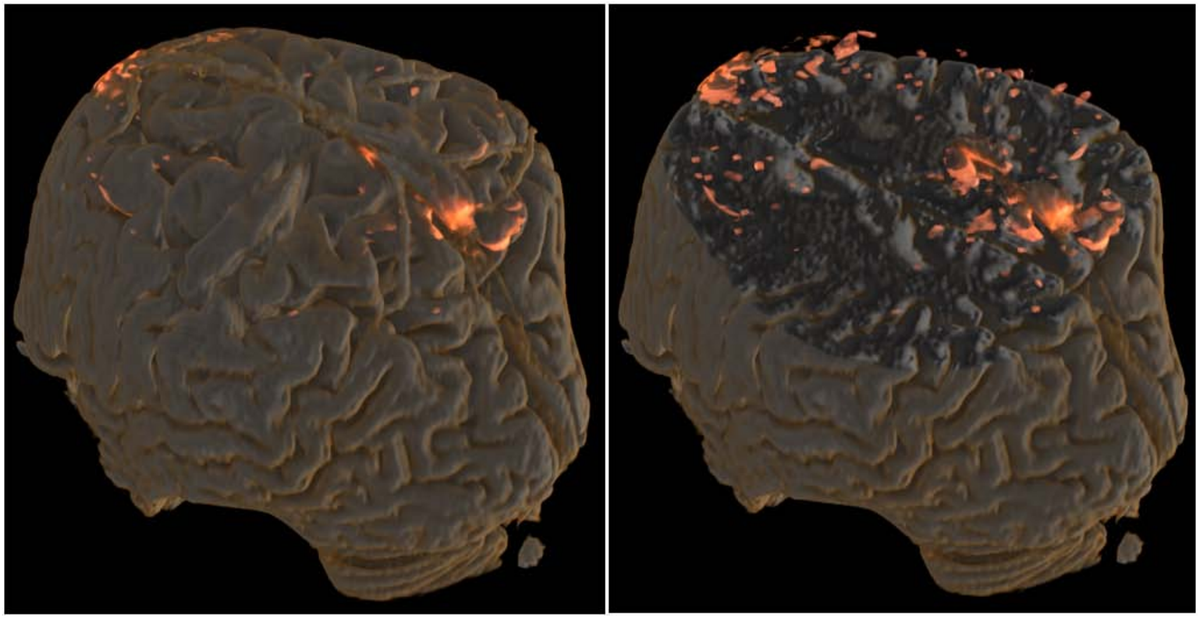


(From: [Rieder, 2008])

Combination of MRI data and functional MRI. Activity data are thresholded. Only for high activity it is mapped to color and overlaid on anatomical data. Limited Occlusion (slice view).

Color (as often) is only used for one dataset.

Transfer Function Design



Right image: voxels without fMRI activity have their opacity reduced by a factor of λ_{min} = 0.02 → interior signals are more visible (From: Nguyen, 2010)

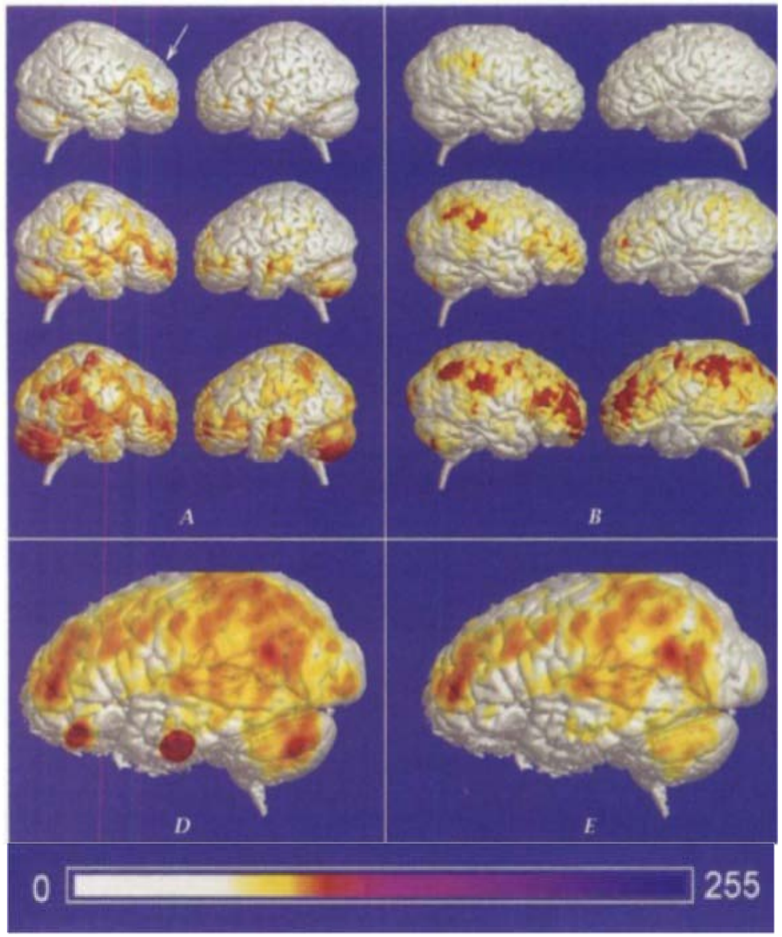
Surface-Based Visualization

Map functional values on the surface of a reference structure (heart, brain, …).

Functional values are integrated along the surface normal (**normal-based fusion**).

Common choice: maximize over these values.

Combination of MRI and SPECT data. Brain extracted from MRI. SPECT activity values mapped on the surface visualization of the brain.



(From: [Stokking, 1997])

Surface-Based Visualization

- Color-coding is essential.
- Stokking suggests
  - a color-scheme based on the HSV color space, and
  - Manipulation facilities to adjust the components (HSV primarily as a color space where goal-directed manipulation is enabled).

Illustrative Multimodal Visualization

Illustrative techniques (silhouettes and other feature lines) may serve as sparse representation of anatomical context.

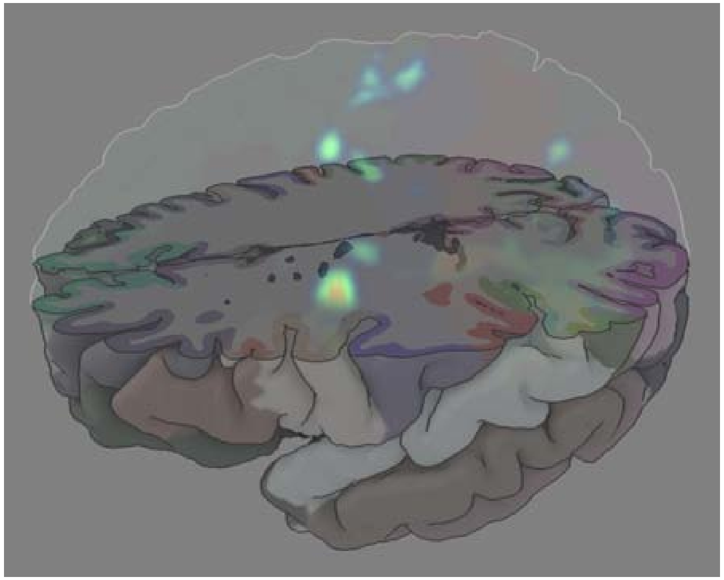
Examples: hull structures, such as skin, organs (brain, heart).

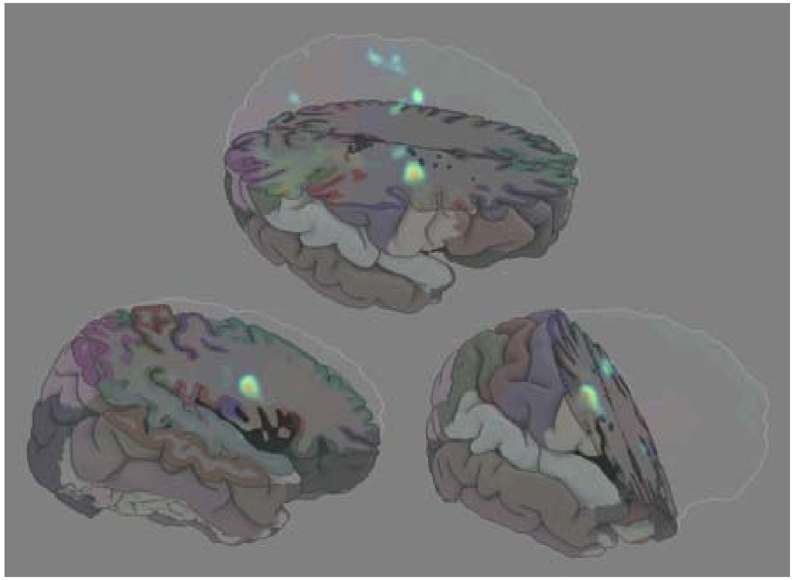
Use of illustrative techniques for multimodal visualization was first mentioned by [Wilson, 2002]

„To help differentiate the volumes, … can be achieved by varying color, lightning and rendering style.“

„The mixing of photorealistic and non-photorealistic rendering styles can be particularly effective in differentiating the two volumes, but also in drawing focus to features of interest.“

Illustrative Multimodal Visualization



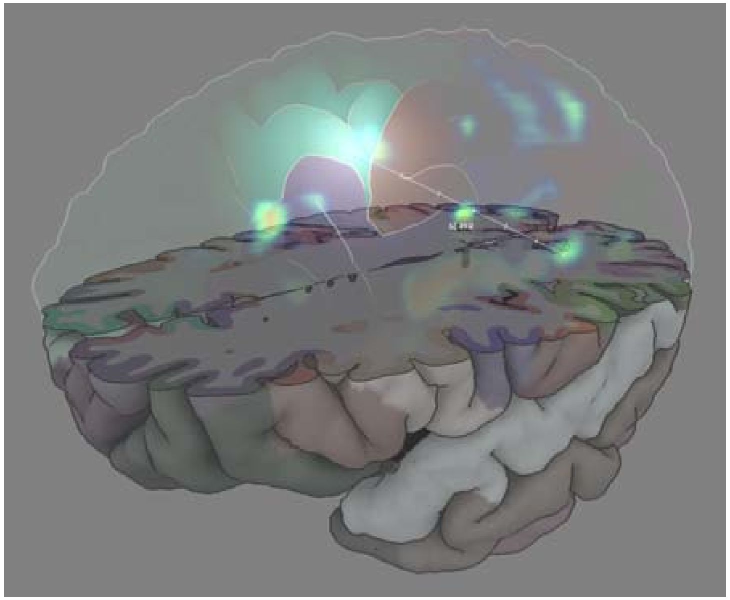


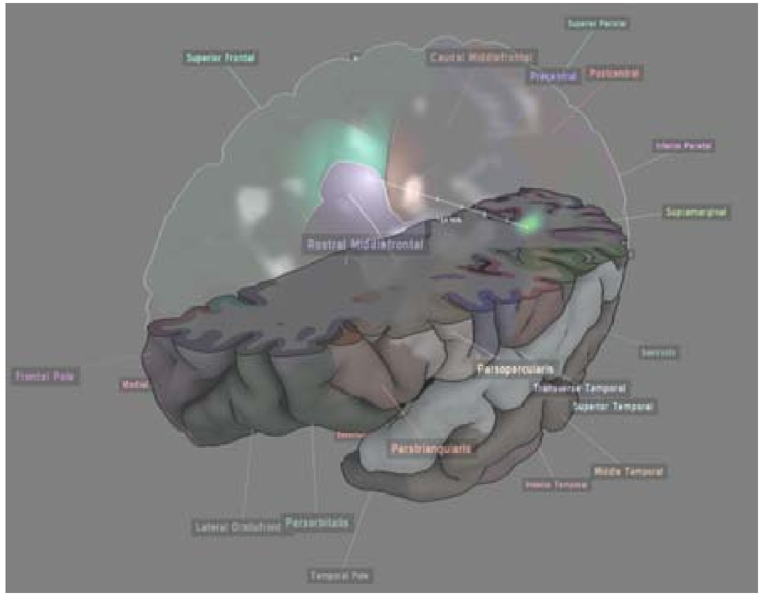
Location and extent of activation areas w. r. t. subcortical structures and the cortex surface should be shown. Brain, GM and WM are extracted from MRI data.

Activation areas from fMRI. Combination of clipping, (3D) silhouette rendering and (2D) edge detection.

Realized as hybrid surface and volume rendering (Jainek, 2008).

Illustrative Multimodal Visualization

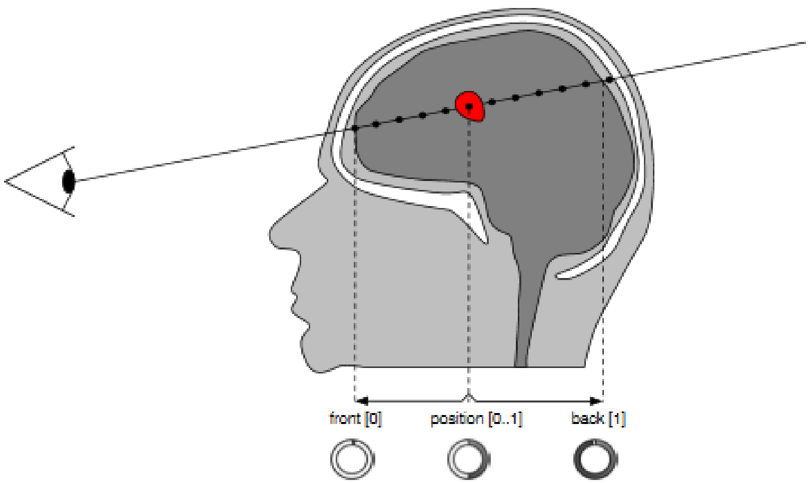


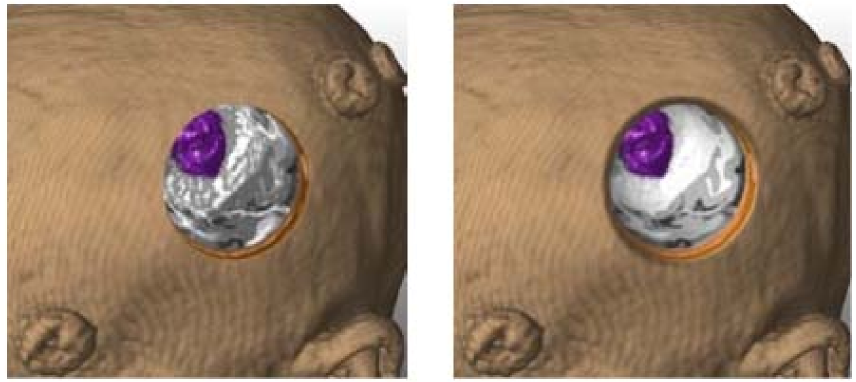


Multimodal visualization combined with distance measurements and (automatic) labeling (Jainek, 2008)

Illustrative Multimodal Visualization: Neurosurgery

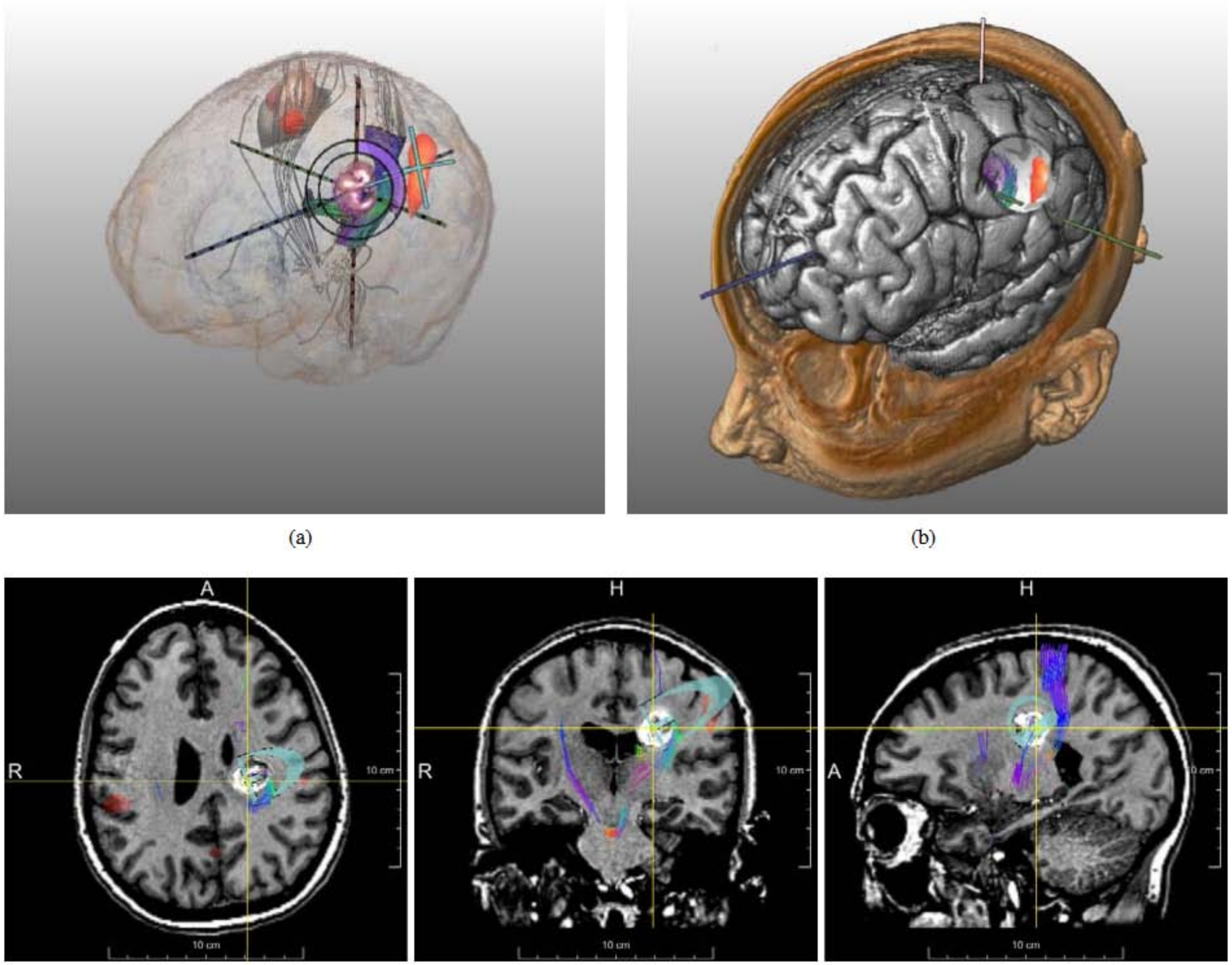
- Cut geometries are employed to reveal activation regions (fMRI) and fiber tracts (DTI) within MRI and CT data
- Internal and external 3D views are combined with slice views





The right image has an improved shading of the cut geometry (From: Rieder et al., 2008)

Illustrative Multimodal Visualization: Neurosurgery



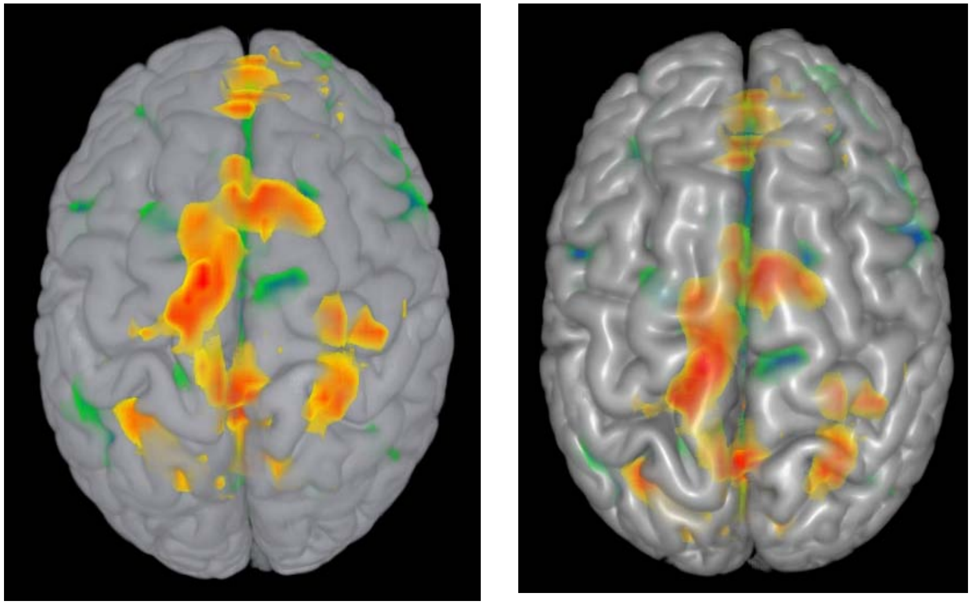
Internal view (brain structures), external view (skull, brain surface) and slice views (From: [Rieder, 2008])

Realization of Multimodal Rendering

- Like „standard“ volume rendering, (image-based) ray casting, splatting and texture-based approaches are used.
- GPU raycasting dominates (e.g. Beyer, 2007, Rößler, 2006, Schlachter, 2014)
- Hybrid (surface and volume rendering) with interleaving (Kreeger, 1999)
- Rendering is integrated in a single pass or two passes.

Lightning for Multimodal Visualization

The improved spatial perception with proper shading enhances comprehension.

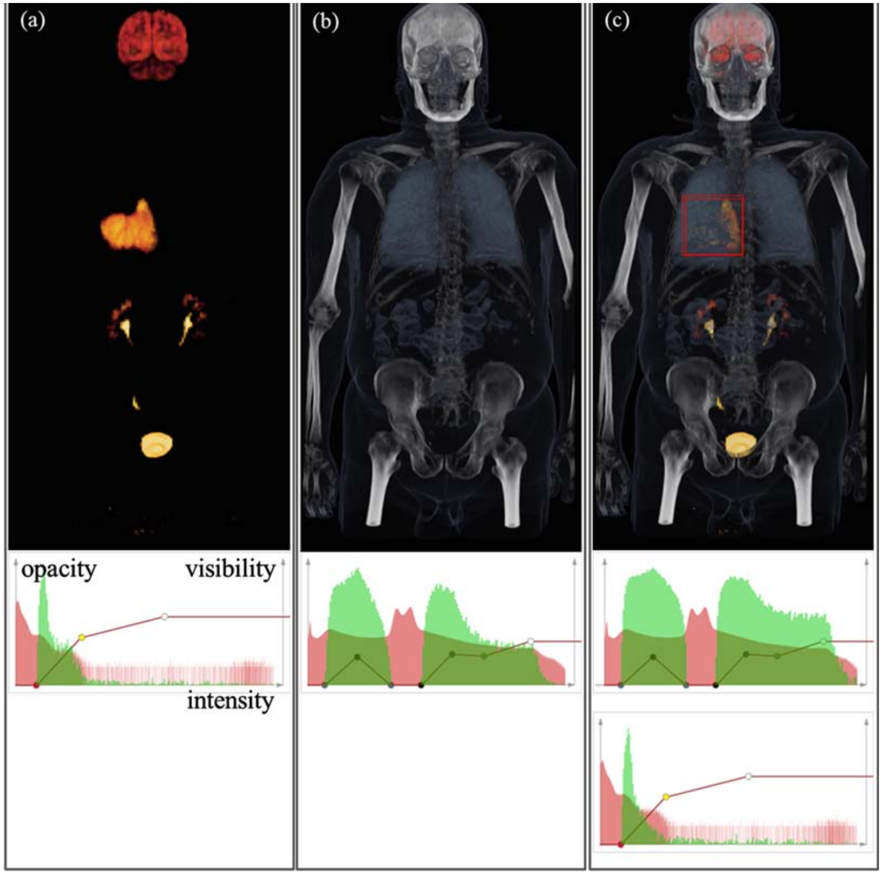


Integration of functional data and brain surface with and without lightning (From: Rößler, 2006)

Visibility-Based Fusion

- Visibility-driven transfer functions indicate how opacity mapping influences the relative visibility of each bin (**visibility histogramme**) (Correa, 2011)
- Individual transfer functions applied to each volume do not consider mutual influence on visibility
- **Joint visibility histogramme** enables a fusion transfer function optimized for visibility (Jung, 2013)
- Combination with automated preprocessing
  - High uptake values in PET are segmented (threshold-based, minimum region size)
  - Visibility of these regions as constraints for the manipulation of the CT-based opacity transfer function
- Visibility-based approaches are view-dependent → each rotation requires to recompute the histogramme (performance)

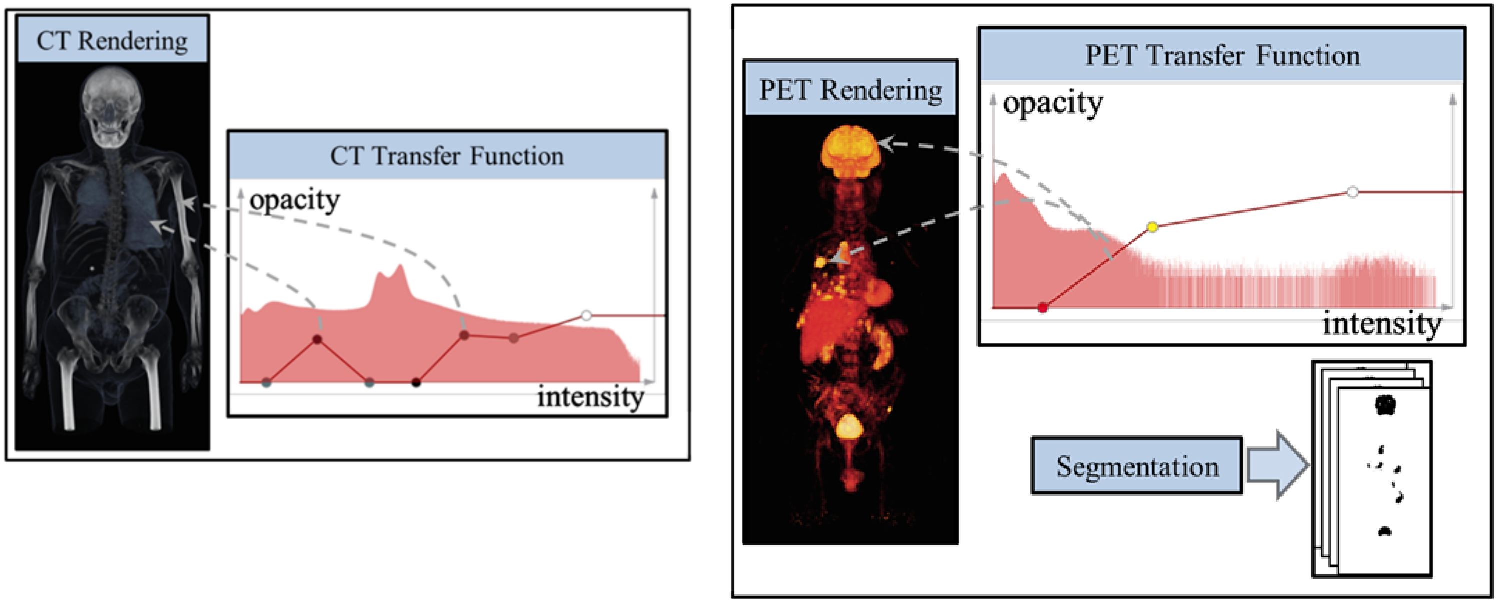
Visibility-Based Fusion



Visibility Histograms and opacity transfer functions (resulting visibility: green).

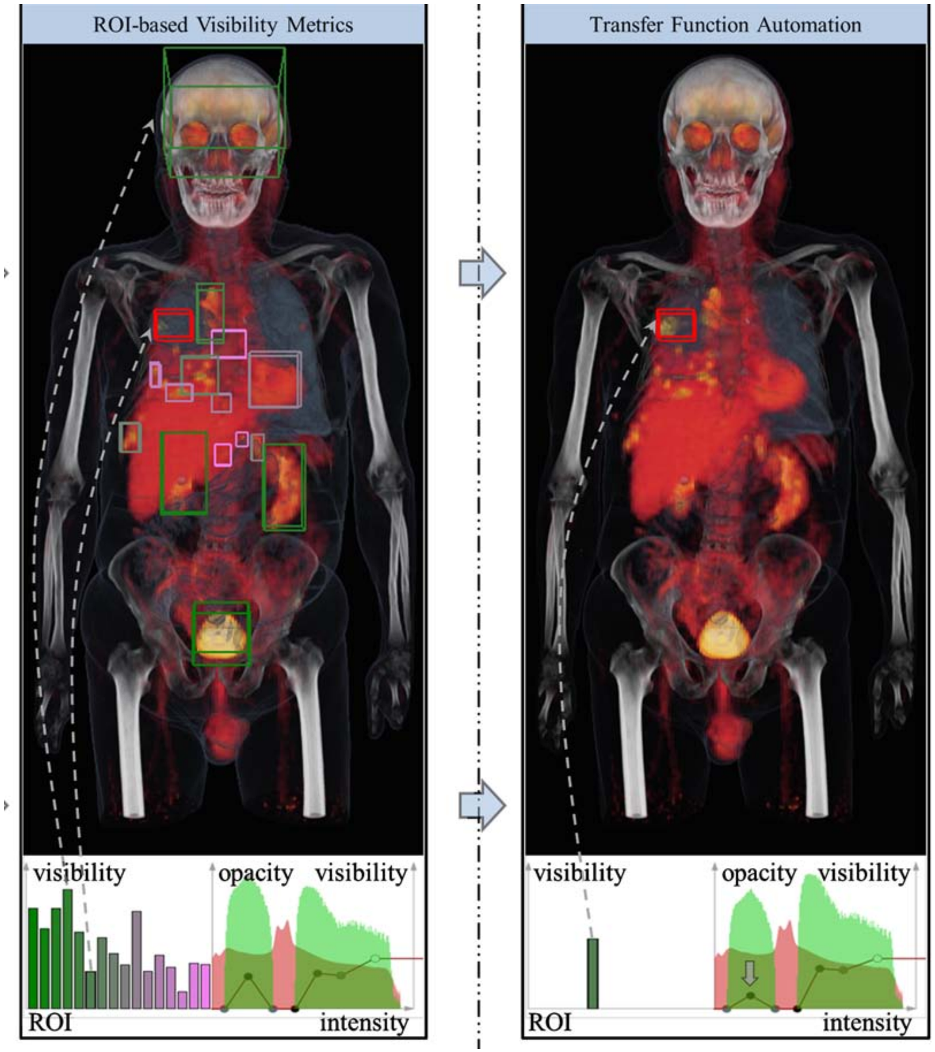
Left: PET only, **middle**: CT only; **right**: combined PET/CT.
(From: Jung, 2013)

Visibility-Based Fusion



Source volumes (CT and PET) with their histogramm and opacity transfer function. High uptake regions in PET are segmented.

Visibility-Based Fusion

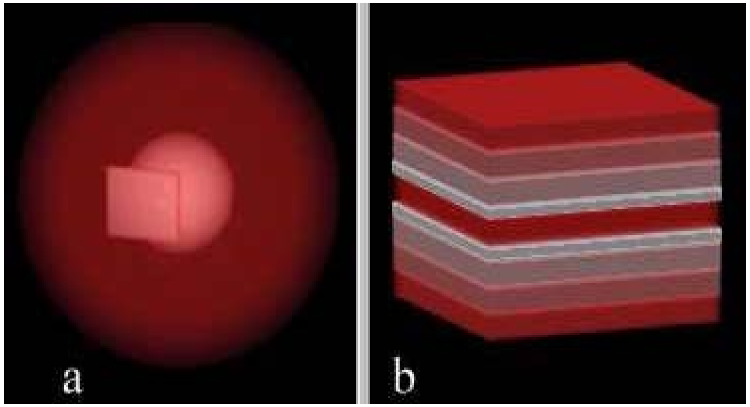


Fused volume rendering. The box-shaped ROIs (from PET) should be visible.

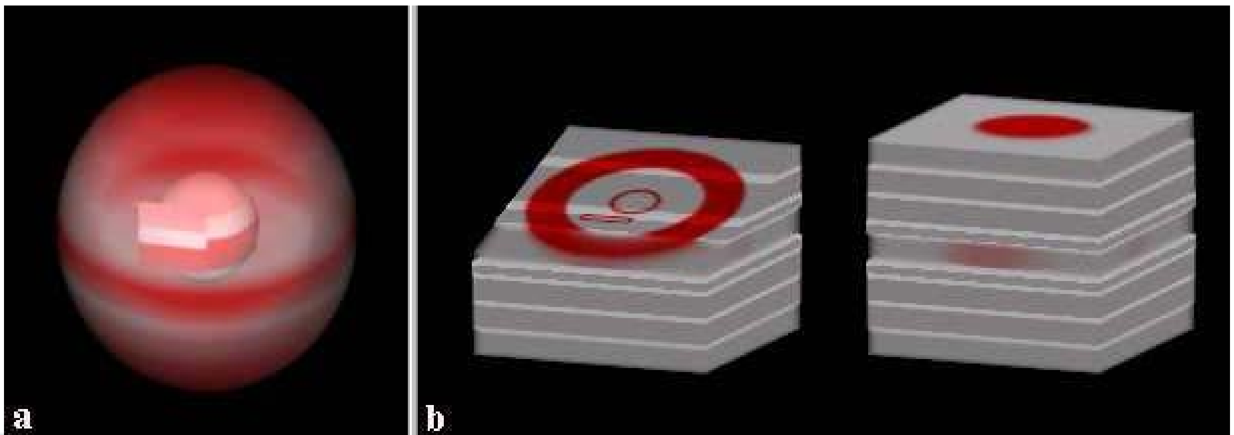
The right image shows the result after automation (From: Jung, 2013)

Prototyping of New Visualization Techniques

Before applying to real world data, use simple synthethic volumes (rasterize spheres with different layers, …) and

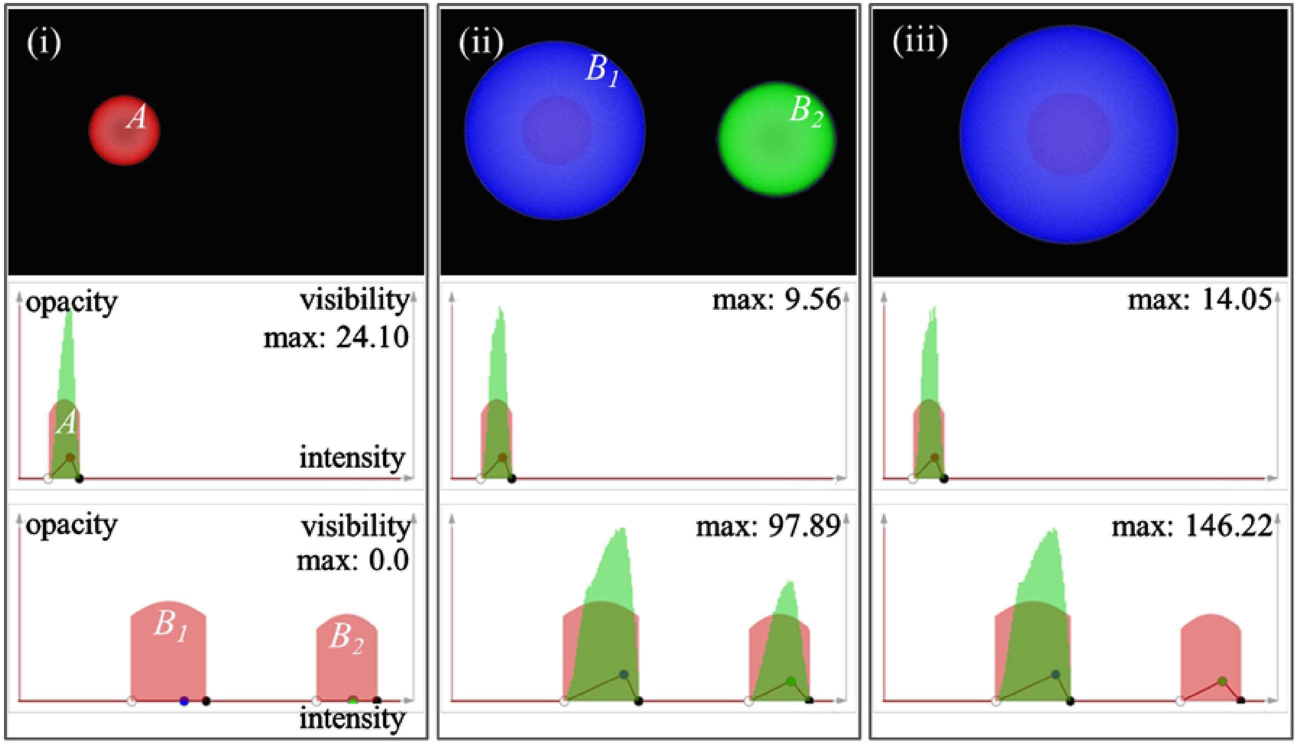


Combine them.



(From: [Manssour, 2002])

Prototyping of New Visualization Techniques

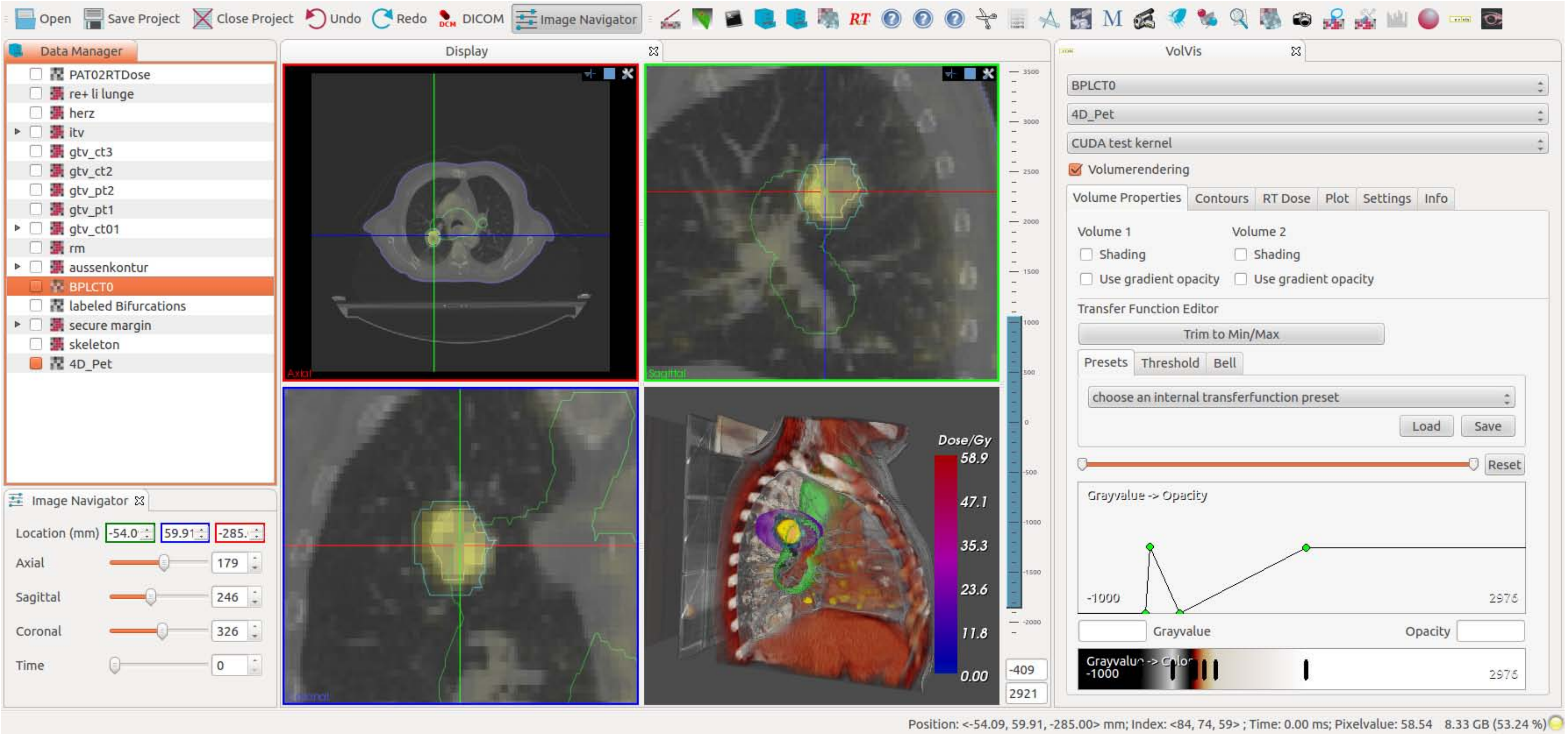


Synthetic volumes used for visibility-driven PET-CT visualization. One dataset with one and anothr with two spheres with different intensity values and added Gaussian noise were employed (From: Jung, 2013)

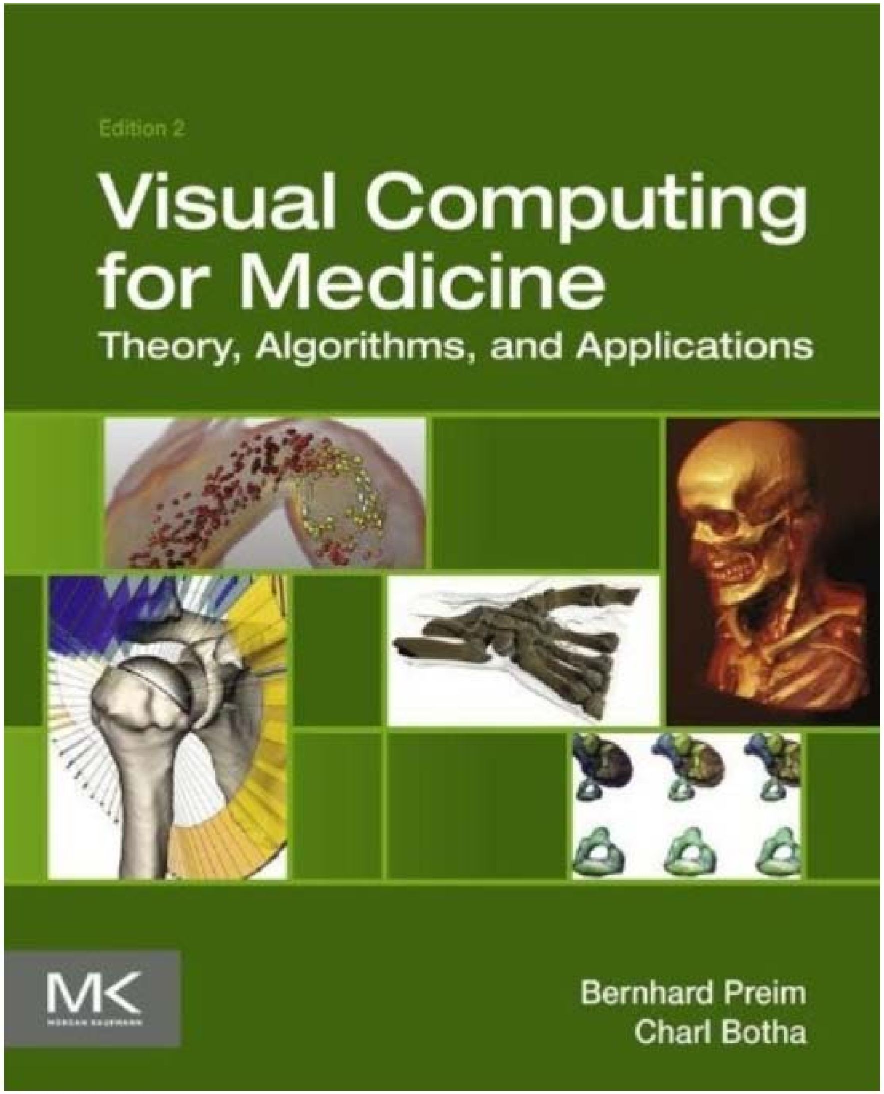
Summary

- Multimodal visualization incorporates advanced visualization techniques (illustrative rendering, smart visibility, ambient occlussion) and
- Advanced interaction techniques (control of cutting regions, fusion transfer functions)
- Besides general solutions (e.g. based on information theory) specific solutions exist, e.g. for mapping functional data on the brain.
- Combination of different views, in particular slice-based and 3D views is essential.

Summary



Different views and interaction facilities are combined for multimodal visualization for RT planning (From: Schlachter, 2014)


Edition 2
Visual Computing for Medicine
Theory, Algorithms, and Applications
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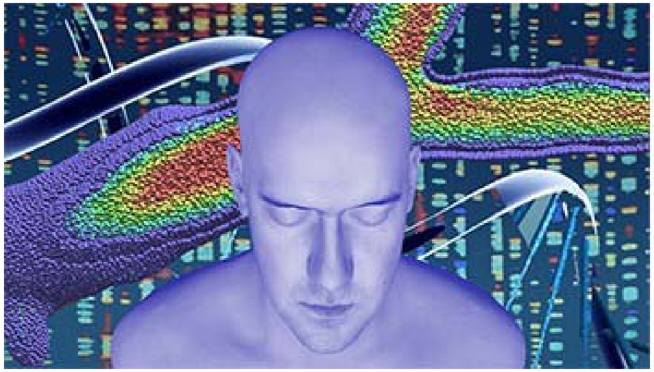
Bernhard Preim
Charl Botha

Upcoming Workshop



Eurographics
EUROPEAN ASSOCIATION FOR COMPUTER GRAPHICS

BANGOR UNIVERSITY
University of Chester

5th Eurographics Workshop on
Visual Computing for Biology and Medicine 2015
Monday 14th Sept 2015 and Tuesday 15th Sept 2015
To be hosted by Bangor and Chester Universities
Venue: Riverside Innovation Centre - University of Chester, UK

VCBM integrates medical image analysis and visualization.

Full paper (8 pages) are due on June 21

Careful and constructive review

Besides visualization topics, model-based segmentation, vessel analysis, landmark-based registration and applications in computer-assisted surgery were part of previous workshops

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