Visualisierung Medizinischer Daten 2
6. Vorlesung
Interaction Techniques

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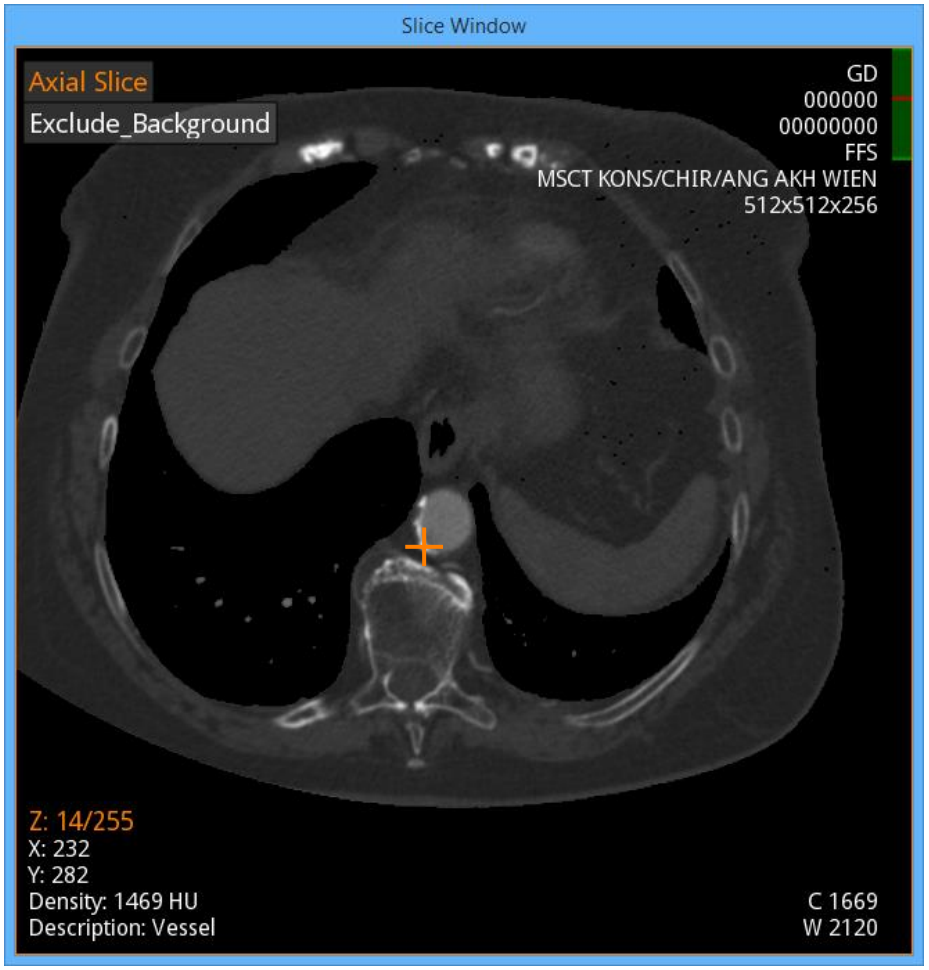
Exploration of Data

- Scrolling through slices
- Changing brightness and contrast (windowing)
- Flexible definition of arbitrary / oblique slices
- Cine mode for impression of animation

Exploration of Data

- Display additional image information
  - Patient information (name, birth date, ...)
  - Image information (modality, voxel size, acquisition date and time, ...)
  - Selected voxel (coordinate, density value)
  - More or less detailed information
- Usually displayed in the image corners
- Anonymization

Exploration of Data



Additional information displayed in the image corners (patient, image, meta info)

Information hidden

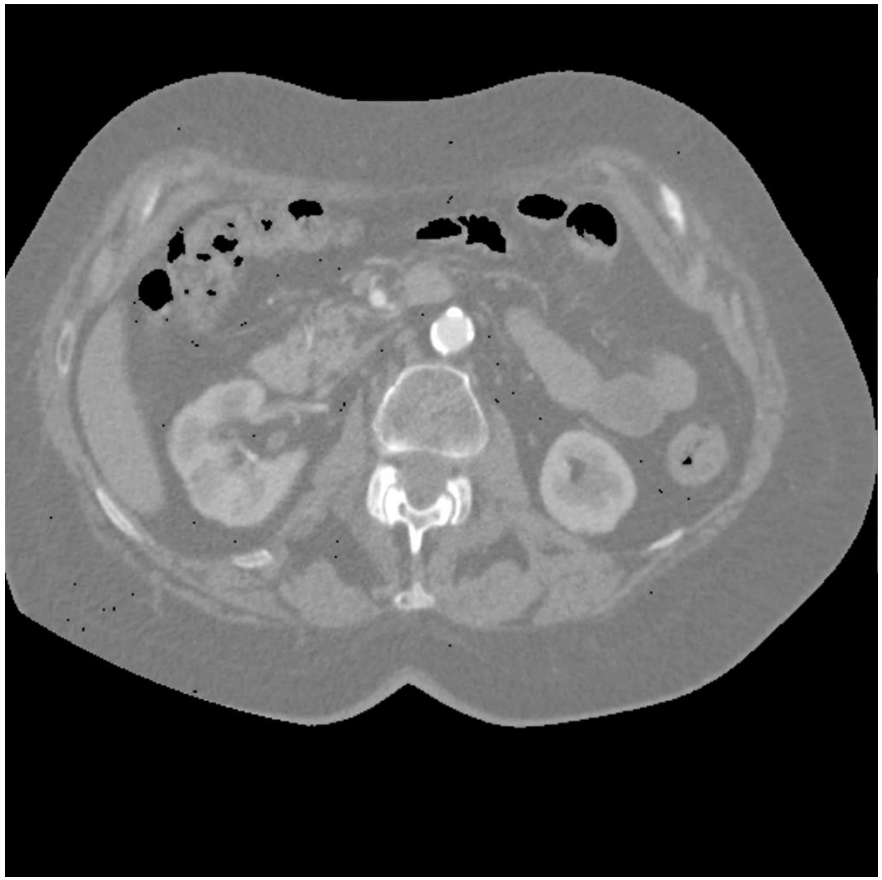
Exploration of Data

- Simultaneous display of multiple data sets
  - Example: CT data set of a liver with and without contrast agent side-by-side
  - Same windowing applied to both data sets

- Selection of the slice direction
  - Coronal, sagittal, axial
  - Oblique

Exploration of Data

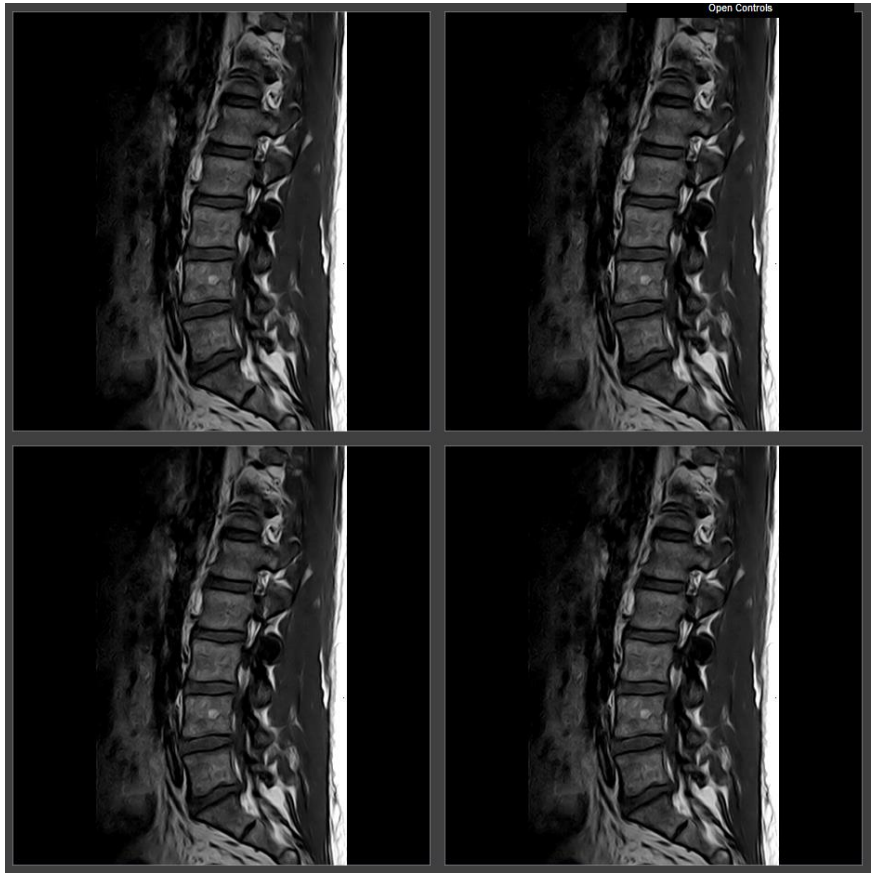
- Windowing function



Exploration of Data

- Simultaneous display of multiple slices

2x1 matrix view



2x2 matrix view

Reduction of Data

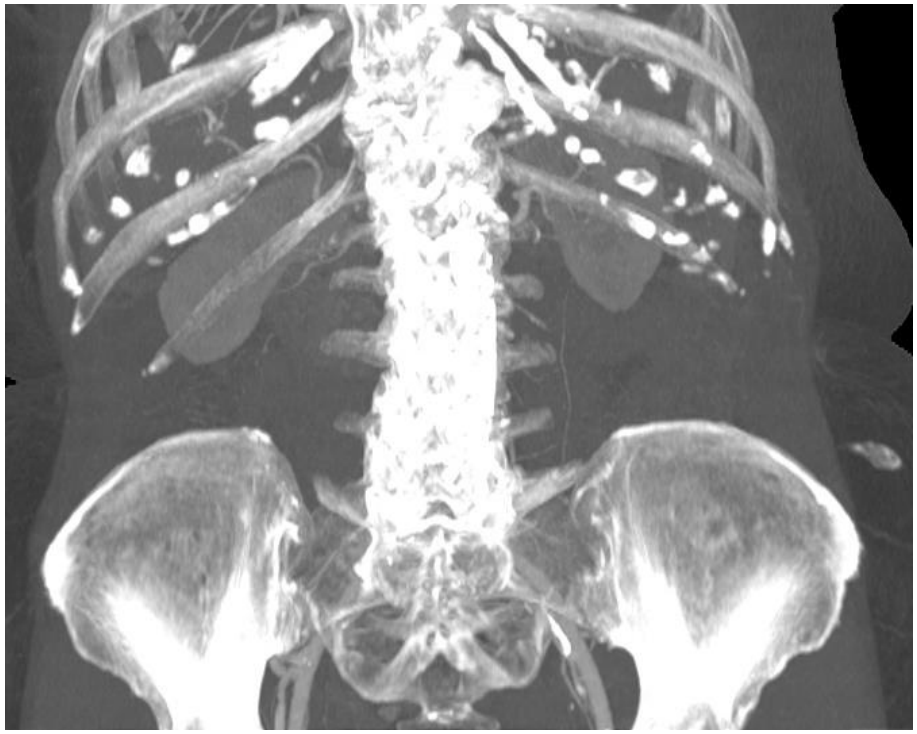
- Why?
  - Focus on specific regions with the data
  - Reduction/removal of noise
  - Certain constraints (memory, rendering, time)

- How?
  - Selection of a data interval (iso-surface)
  - Definition of a region/volume-of-interest
  - Downsampling
  - Data aggregation (e.g., MIP, CFA)

Reduction of Data

- Depict maximum/minimum along viewing ray

Vast number of axial slices



MIP

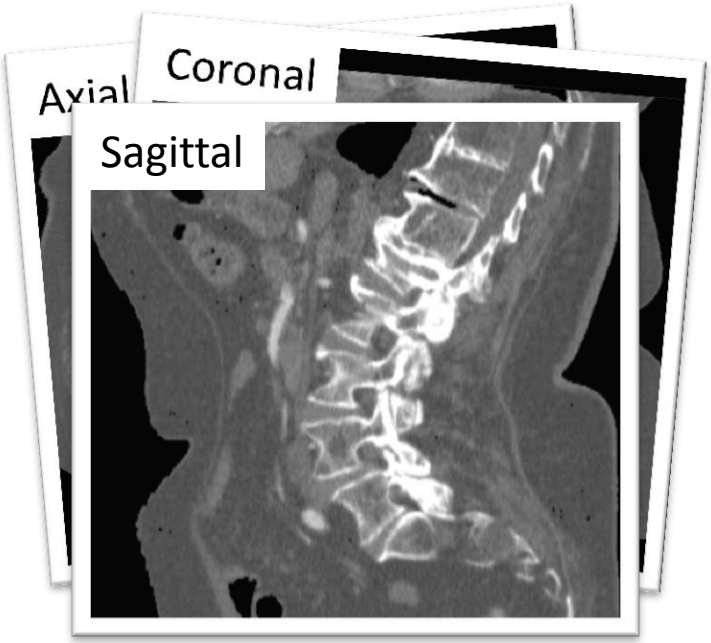
Sparse Interaction

- Motivation
  - Hide irrelevant data
  - Show only relevant data
  - Show only suitable visualization techniques

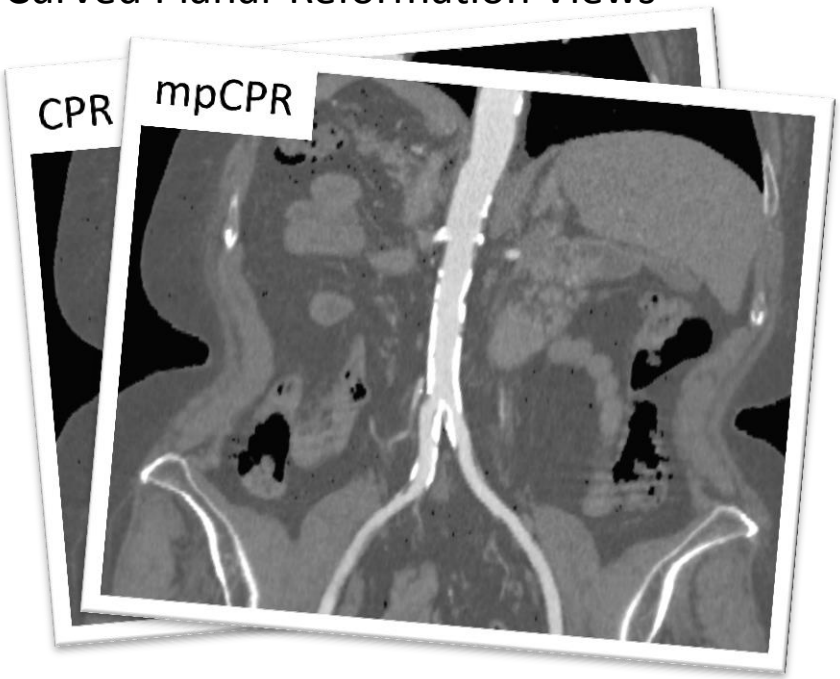
- Solution
  - Smart Super Views
  - Sparse user interaction
  - Domain knowledge externalized

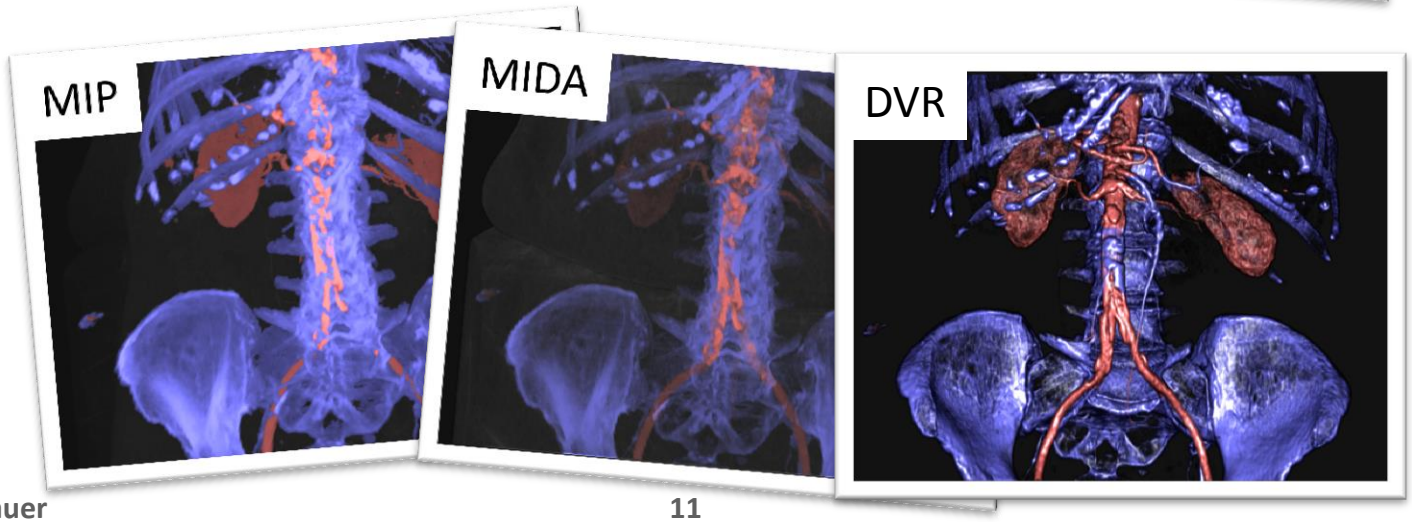
Smart Super Views – Motivation

Slice Views

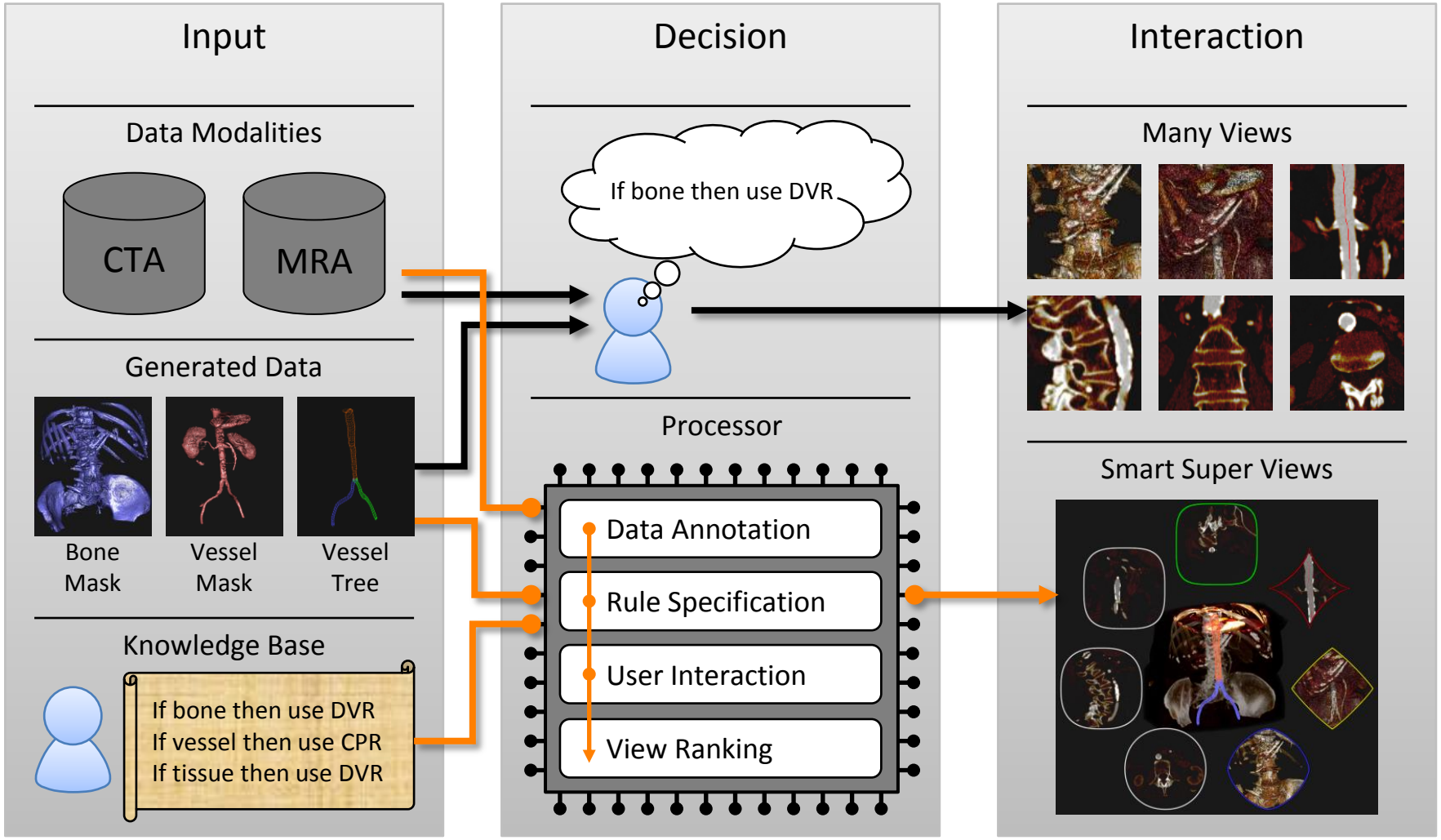


Curved Planar Reformation Views



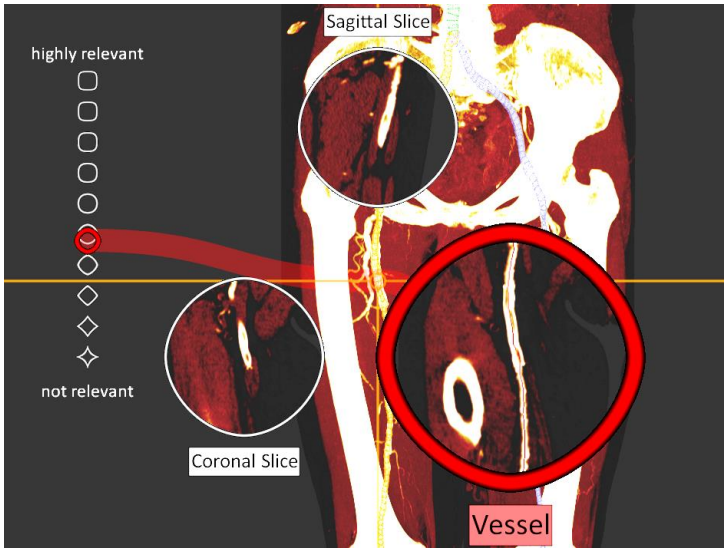


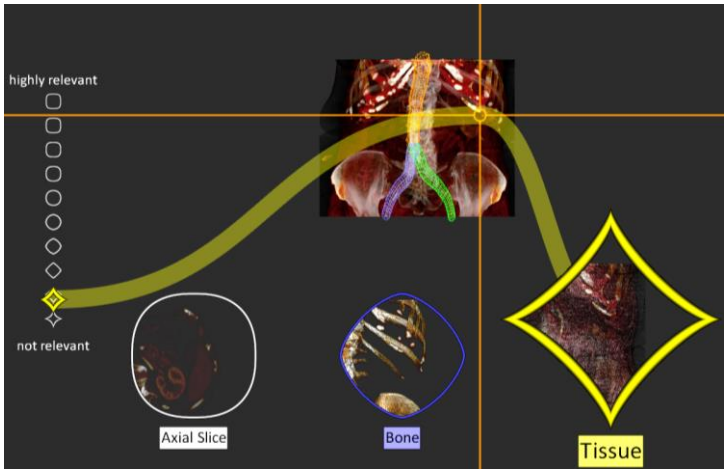
Smart Super Views

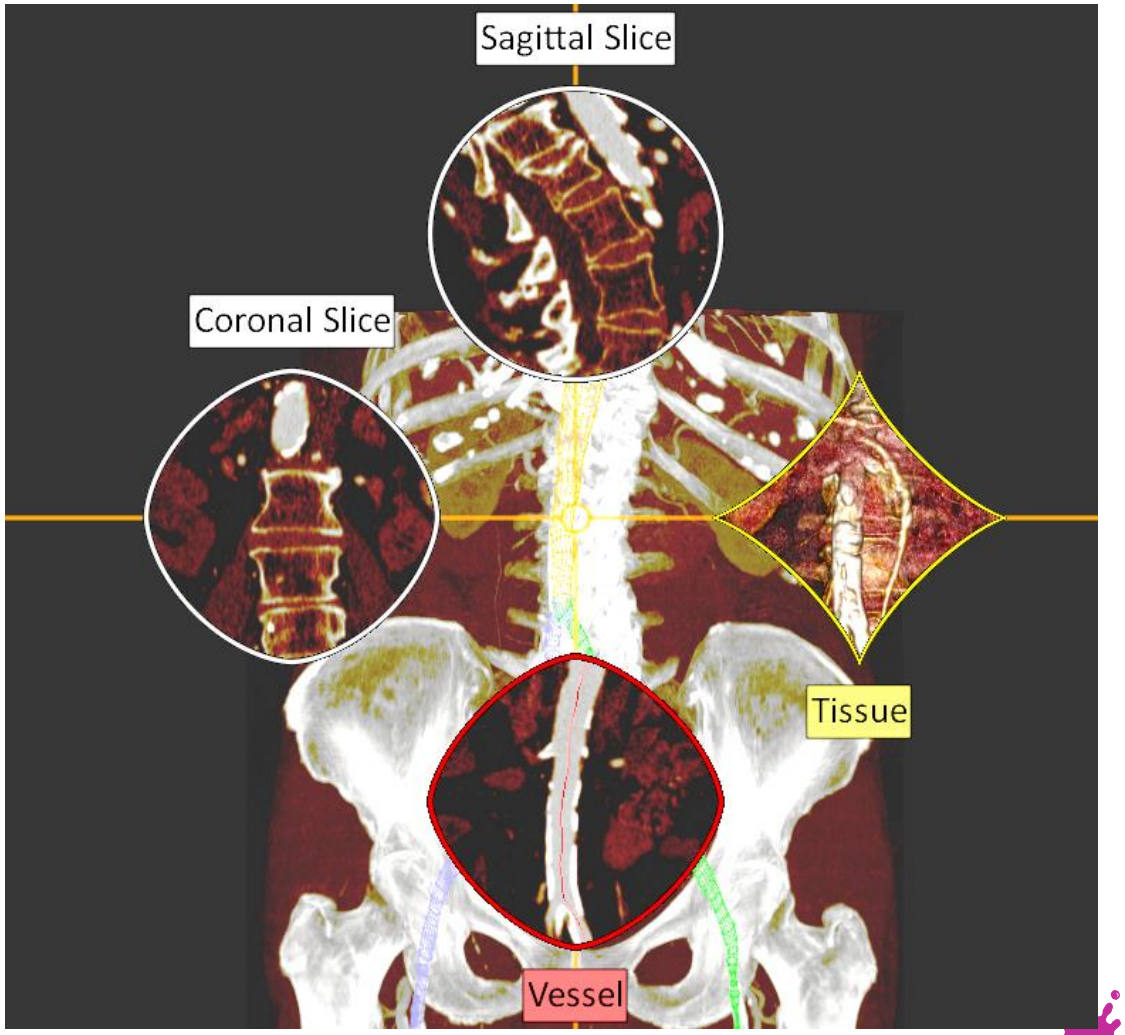


Smart Super Views

- Liner / radial layout of views around the ROI







Transfer Functions

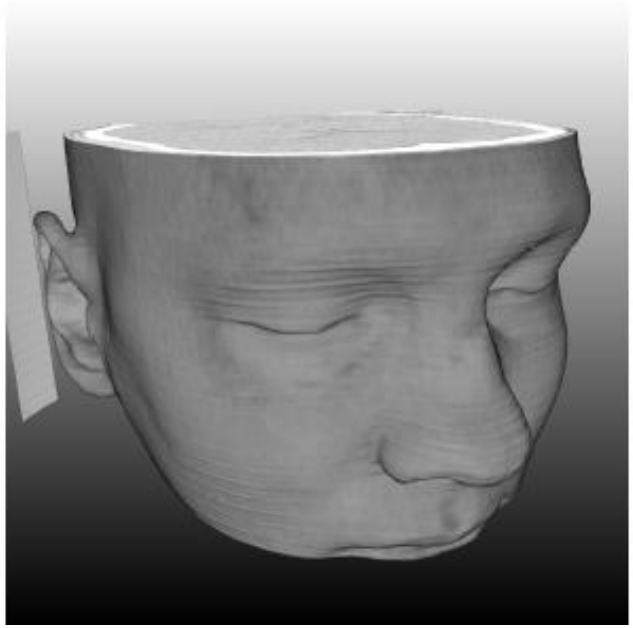
- Mapping of data values to *renderable quantities* (e.g., colors, grayvalues, transparency, ...)
- Defines the visibility of structures within a volume
- Flexible parametrization important for interaction

- **Challenge:**
  - Specification not always trivial (requires substantial experience and knowledge)
  - Exploration of data sets with unknown objects

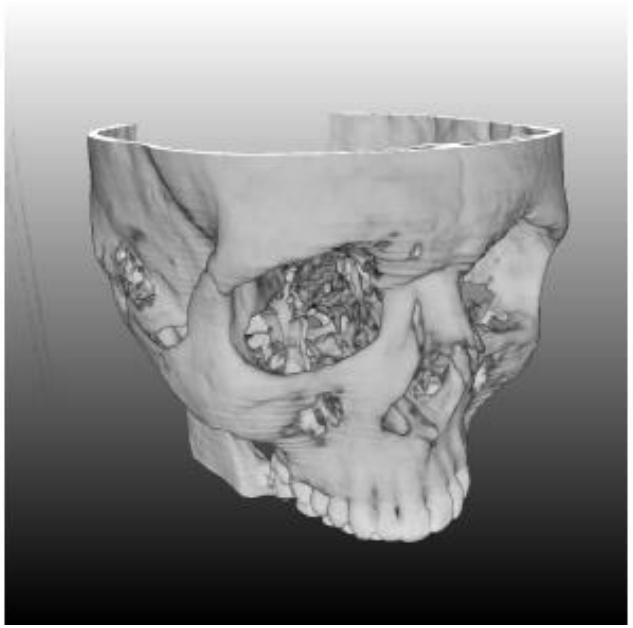
Transfer Functions

- Applied during volume rendering (e.g., DVR)
- Example with three different opacity TFs

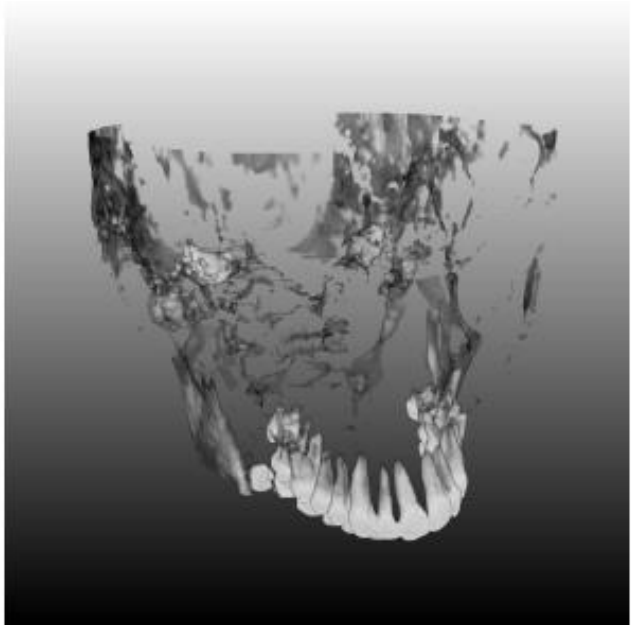
[Source: Bernhard Preim]



skin



bone



teeth

Transfer Functions

- **Requirements:**
  - Selection of predefined transfer functions (e.g., for liver or lung in CT data sets)
  - Intuitive possibility to search for suitable TFs
  - Perceivable relation between the TF parameters and the resulting visualization
  - Flexible TF specification
  - Fast preview of data with current TF

Transfer Functions

- Common transfer functions:
  - Windowing
  - Bi- or Trilevel windowing
  - Inverse windowing
  - Piece-wise linear function
  - Higher degree polynomials, e.g., splines

- **Problem:**
  - No intuitive visual relation of the TF properties with the resulting visualization

Transfer Functions

- Discrete representation in lookup tables
- Example: 4096 entries with 32 bit each (8 bits per RGBA channel)
- Hardware support (e.g., store lookup table in texture memory)
- During rendering, access lookup table

Transfer Functions

- Stochastic generation of transfer functions
  - Use can select from a predefined set of TFs
  - Iterative process
  - Presentation as thumbnails
    [He *et al*. 1996, König *et al*. 2001]

- Image-based specification of TFs
  [Fang *et al.* 1998]

Transfer Functions

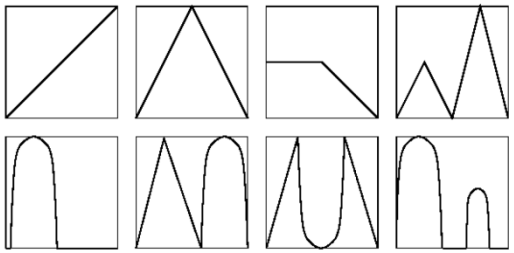
- Incorporate image processing filters into TFs (e.g., edge detection filter)

- Local TFs

- Multi-dimensional TFs
  - 2D, 3D ...
  - Display of derived data values
  - Gradients

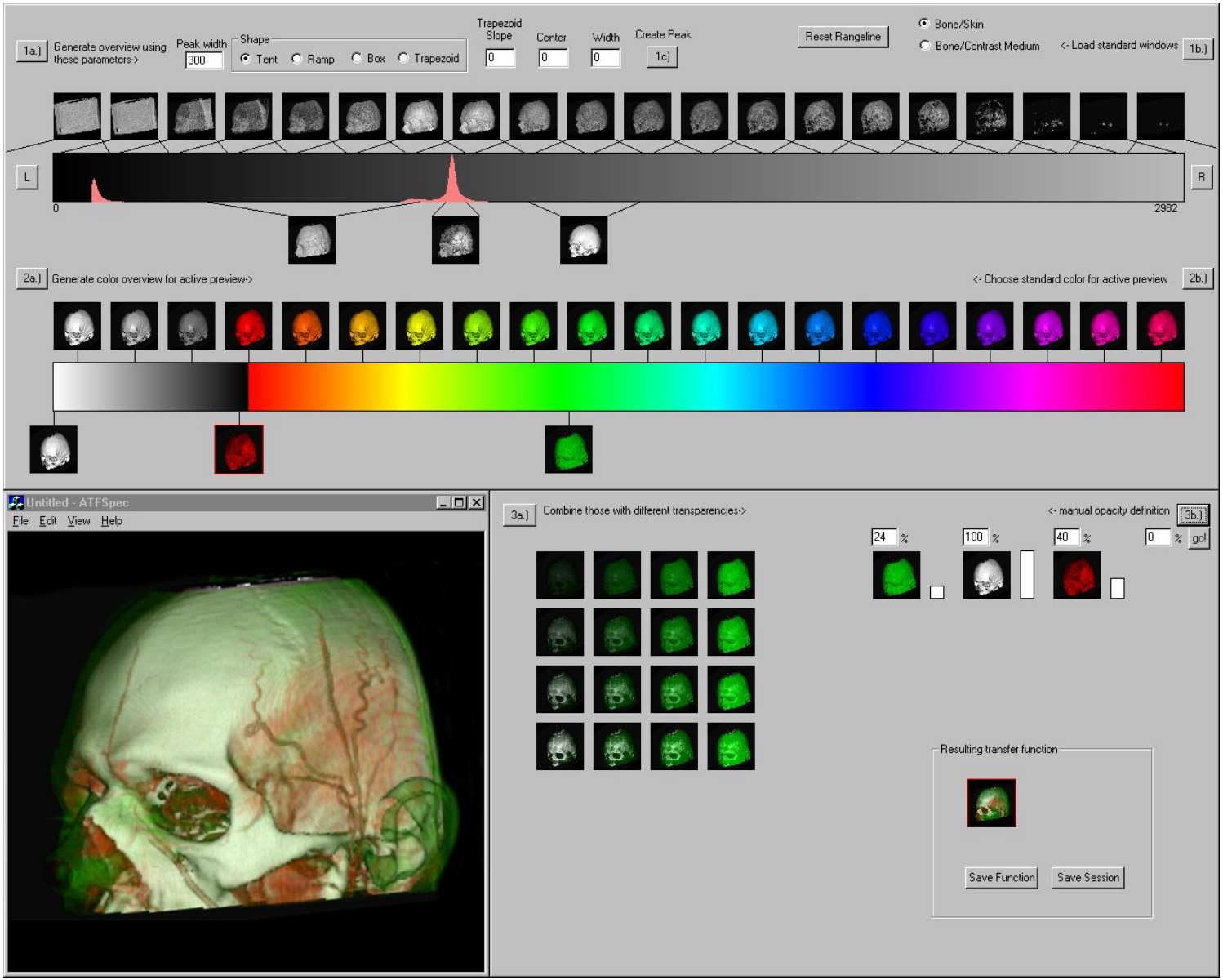
Stochastic Generation of TFs

- Iterative process [He *et al.* 1996]
- **1.** Library of initial TFs



- **2.** „Mutation“ of the fuction with a genetic algorithm (25 generations)
- **3.** Direct Volume Rendering (DVR)
- **4.** Subjective evaluation of the result by the user

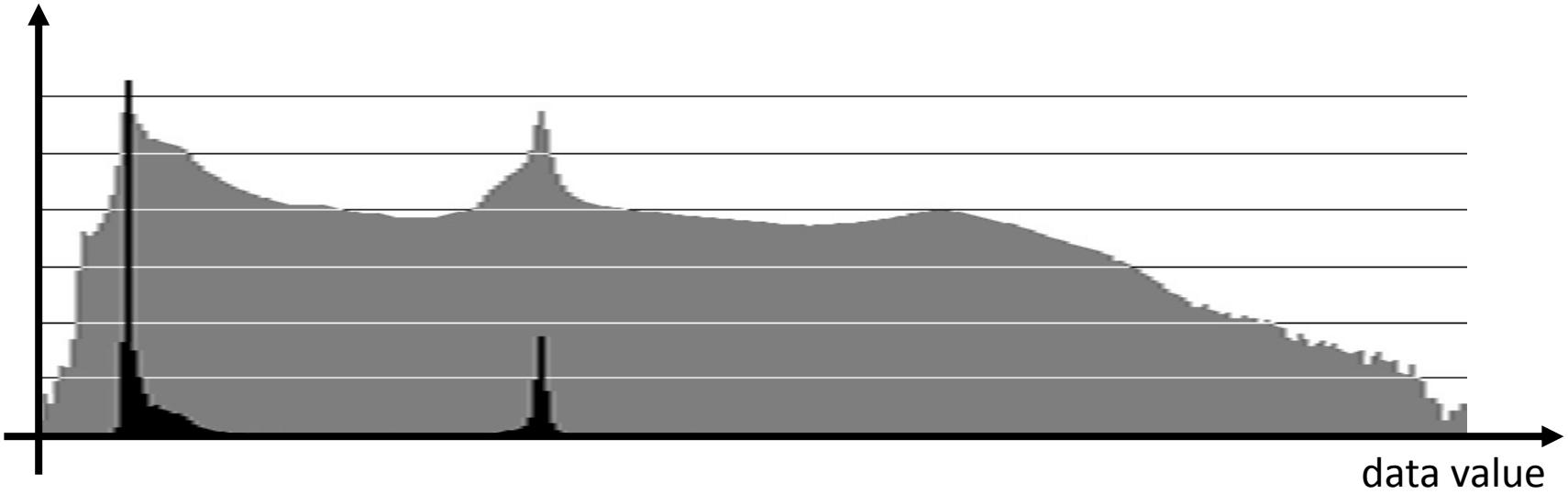
Stochastic Generation of TFs



[A. König, Dissertation, 2001]

Image-Based Specification of TFs

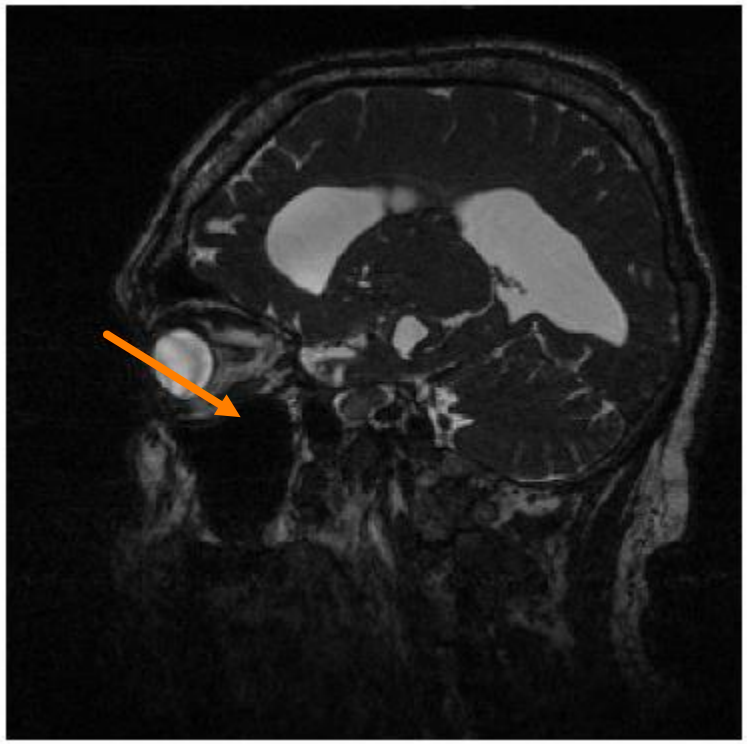
- Image information used for transfer function specification
  - Global histogram
  - Histogram of a slice
  - Histogram along a viewing ray



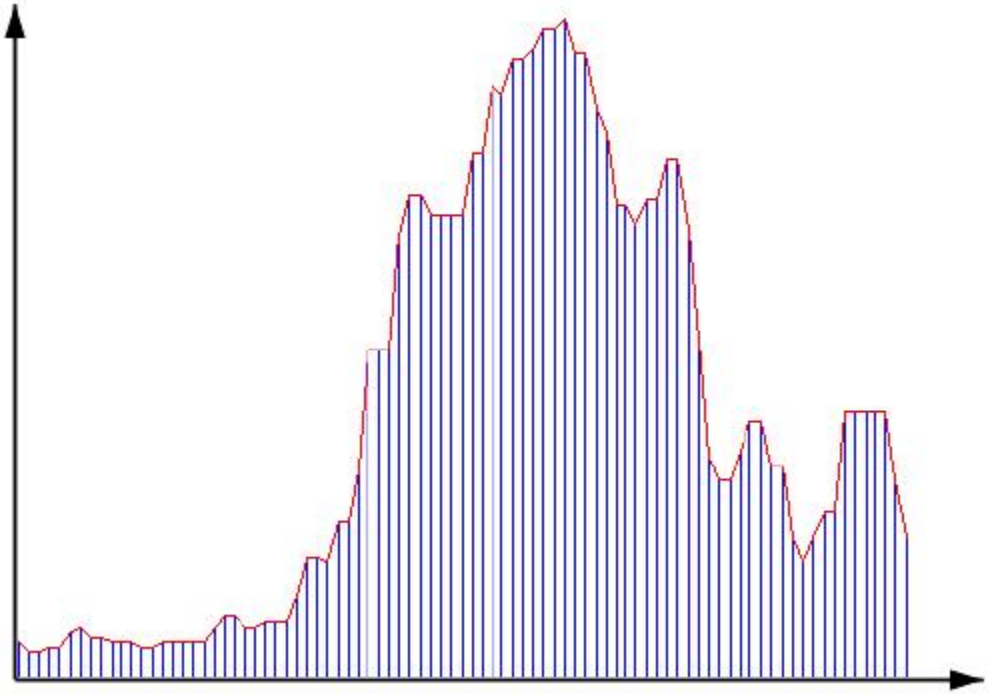
[Kniss et al. 2002]

Image-Based Specification of TFs

- Histogram along a viewing ray



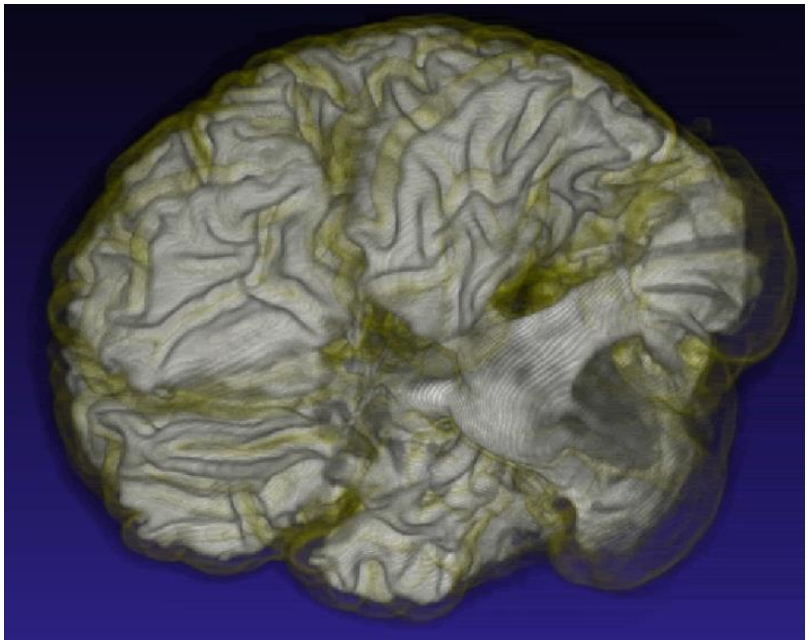
Bright: Eye-ball
Dark: muscles

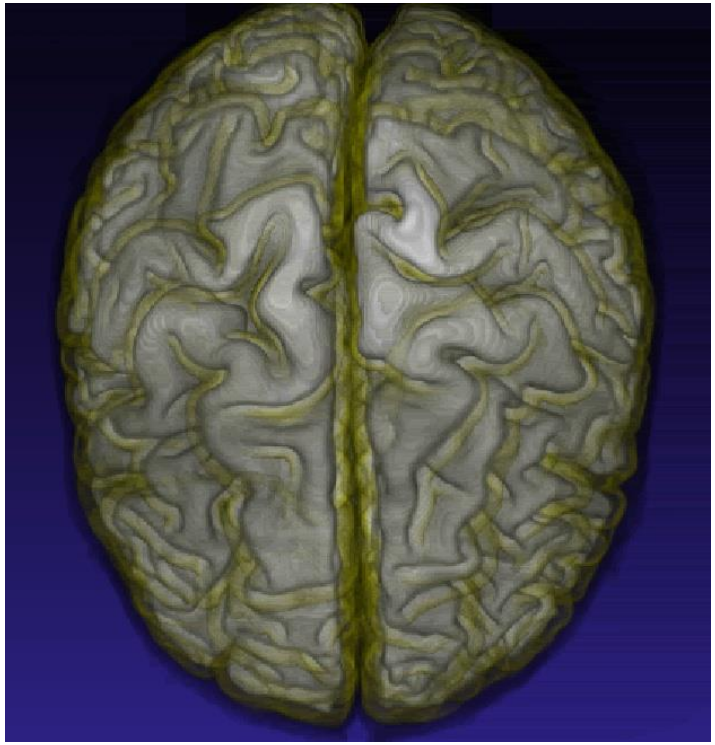


[Source: Bernhard Preim, Dirk Bartz]

Transfer Functions

- Implicit segmentation of the white brain matter with proper TFs
- Enhancement of the histogram area between the maxima of the gray and white brain matter

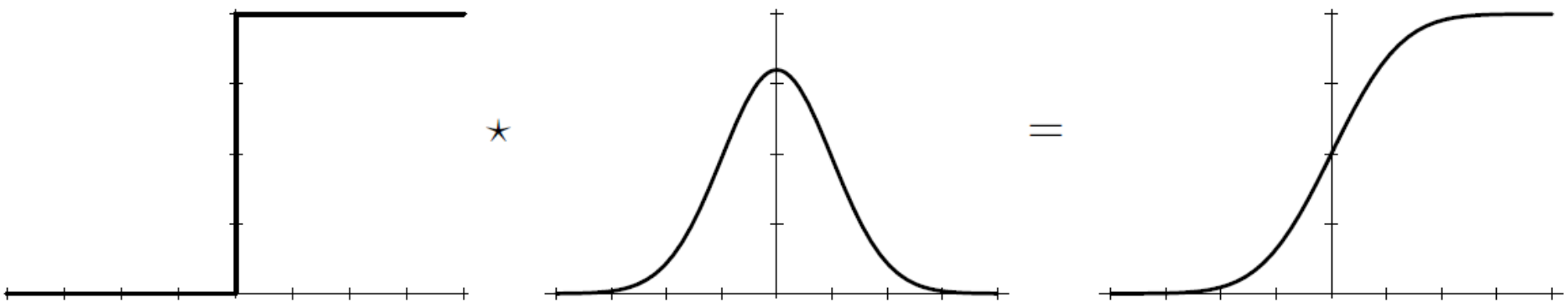




[Source: Bernhard Preim]

Data-Based Specification of TFs

- Edge emphasizing TFs
- Ideal edge is blurred due to an error function
- Assumption: Gaussian error function

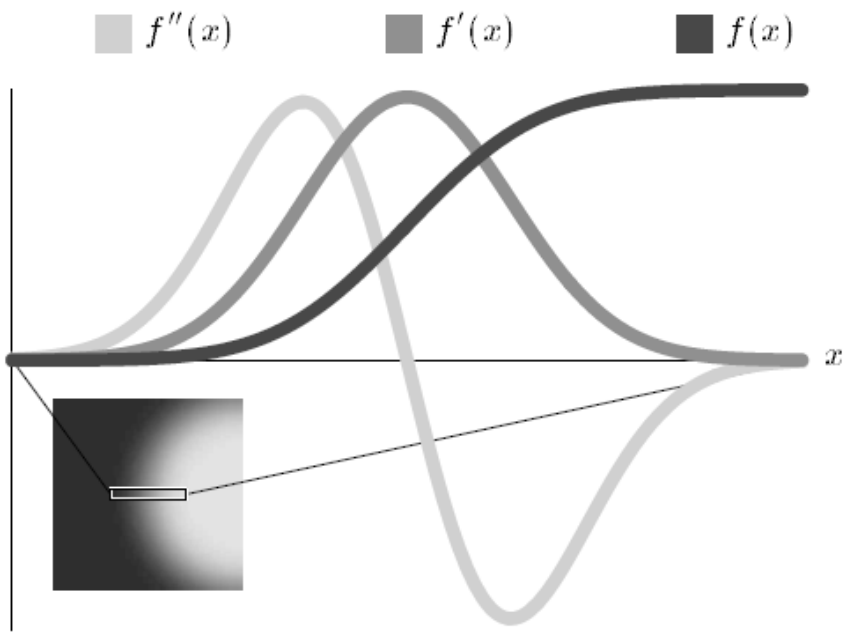


[Kindlman, Durkin 1998]

Data-Based Specification of TFs

- Edge characteristics:
  - High gradient g
  - Small second derivative h (zero-crossing)
- $g(v) = \frac{1}{\|P\|} \sum_{p \in P} \tilde{f}_p'(v)$
- $h(v) = \frac{1}{\|P\|} \sum_{p \in P} \tilde{f}_p''(v)$
- $p(v) = \frac{-h(v)}{g(v)}$

[Kindlman, Durkin 1998]



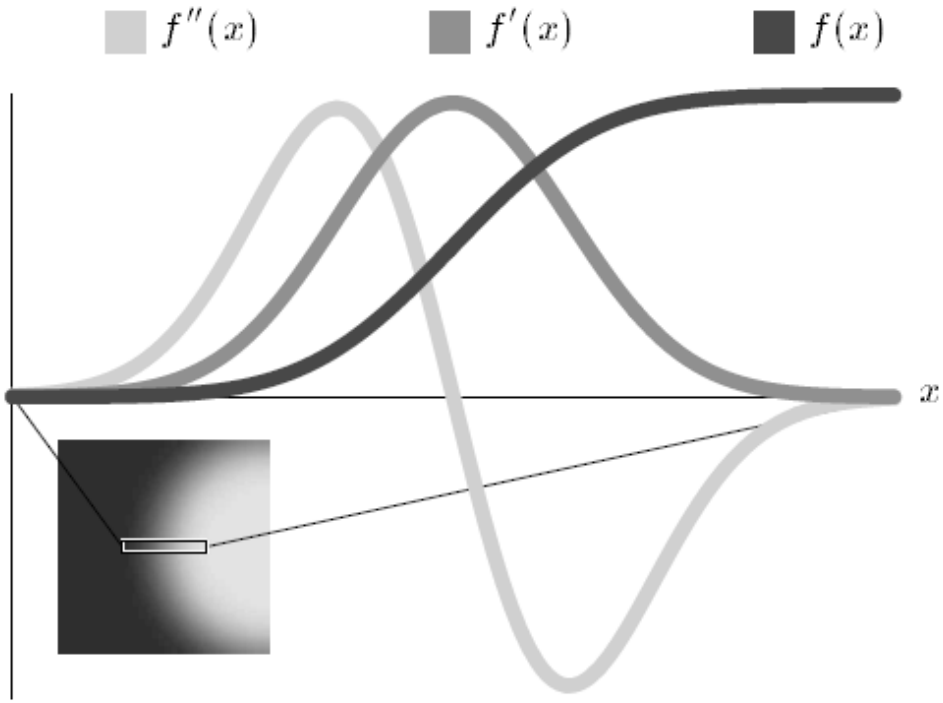
Data values along an edge with the first and second derivatives

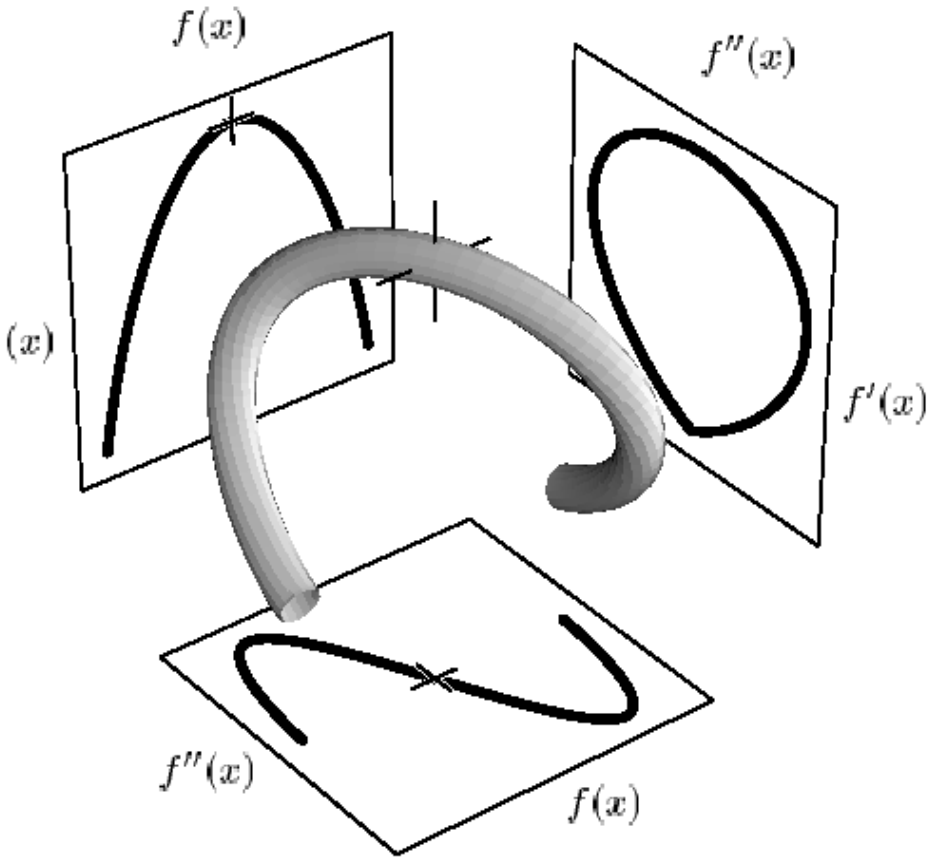
Data-Based Specification of TFs

- Determine $g(v)$ and $h(v)$ by averging of the first and second derivative of all voxels with value v
- **Internal representation:**
  - Histigram volume H
  - x-axis → $f(v)$, y-axis → $f''(v)$, z-axis → $f'(v)$
- **Algorithm:**
  - 1. Determine *min* & *max* values of $f''(v)$ and $f'(v)$ (*min* $f'(v) = 0$)
  - 2. Fill H, where *min* & *max* of $f''(v)$ and $f'(v)$ is mapped between 0 and 255

Data-Based Specification of TFs

- Cross-hairs (right image) = middle of boundary

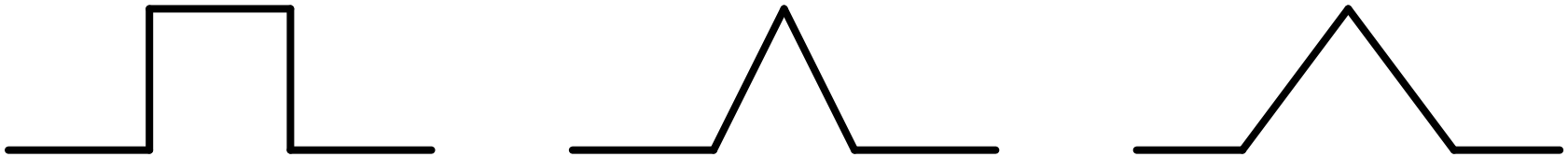




[Kindlman, Durkin 1998]

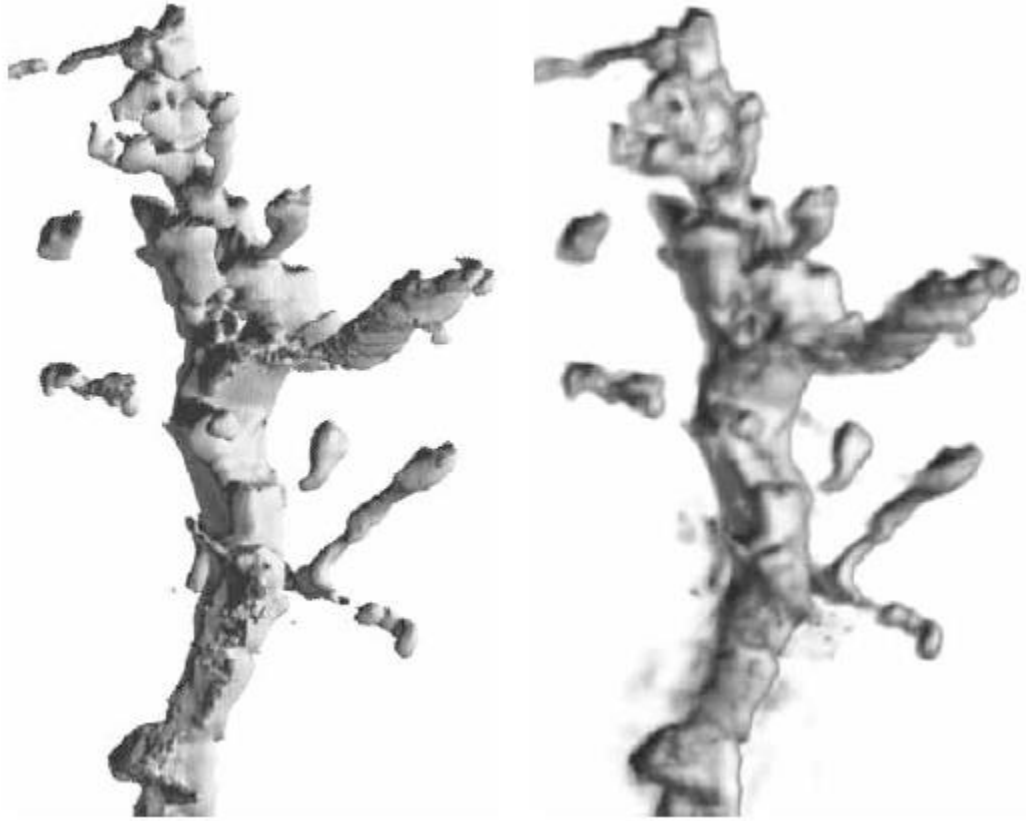
Data-Based Specification of TFs

- Histogram volume defines positions of edges in relation to the data
- User can
  - select the peaks to display
  - specify the shape of the displayed peaks with a boundary emphasis function
- Typical shapes of such functions



Data-Based Specification of TFs

- Comparison of edge emphasizing iso-surface rendering and direct volume rendering
- Spiny dendrite from a cortical pyramidal neuron:



[Kindlman, Durkin 1998]

Data-Based Specification of TFs

- **Requirements:**
  - Clear, sharp object boundaries
  - Homogeneous data
  - Low noise, no outliers
  - CT data in medicine (in case of contrast agent, uniform enhancement is required)

Data-Based Specification of TFs

- Reference TF specified only once
- **Goal:** Reuse empirically determined TF
- **Application:** Visualization of an object within a data set acquired by a certain modality (e.g., an aneurysm in MR data)

Data-Based Specification of TFs

- **Algorithm:**
  - Select a reference data set D_{ref} and a TF $T_{ref}(v)$
  - Use normalized histograms of data sets $H(D_{ref})$ and $H(D_{study})$
  - Nonlinear transformation t of intensity values of D_{study}, such that $H(D_{study}) \sim H(t(D_{ref}))$
  - → $T_{study}(v) = T_{ref}(v)$

Data-Based Specification of TFs

- How to determine histogram similarity
  - Minimize distances of histograms

$$D_t(H_1, H_2) = \sum_v |H_1(v) - H_2(t(v))|$$

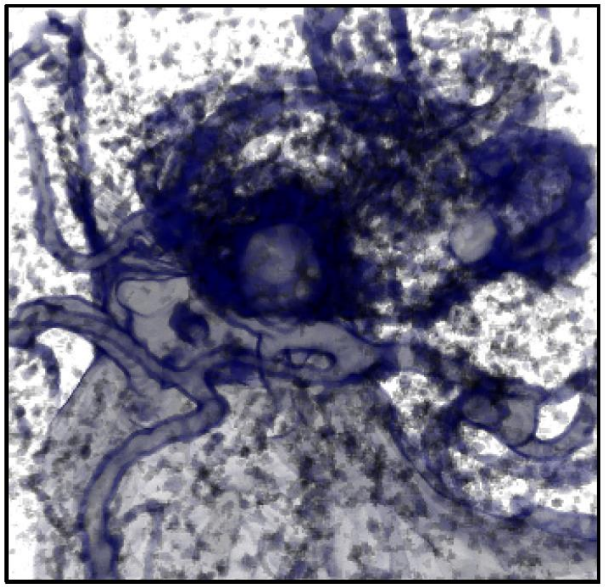
  - Use p-function of Kindlmann (takes $f'(v)$ and $f''(v)$ into account)
  - p-values are more discriminative for comparable data sets

[Rezk-Salama et al., VMV 2000]

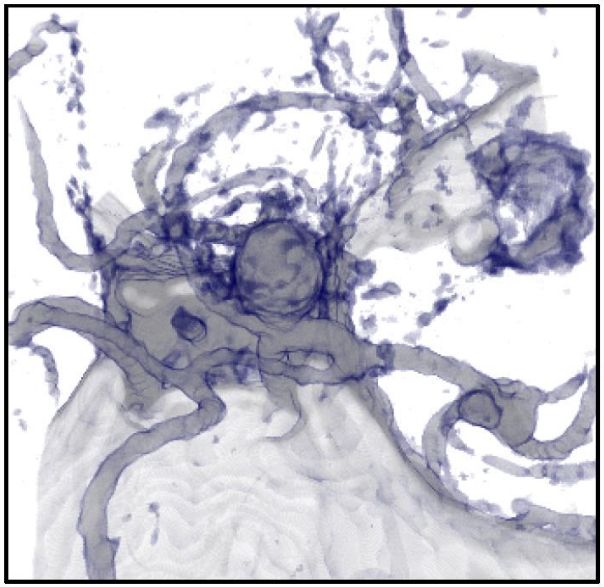
Data-Based Specification of TFs

- Visualization of cerebral vessels

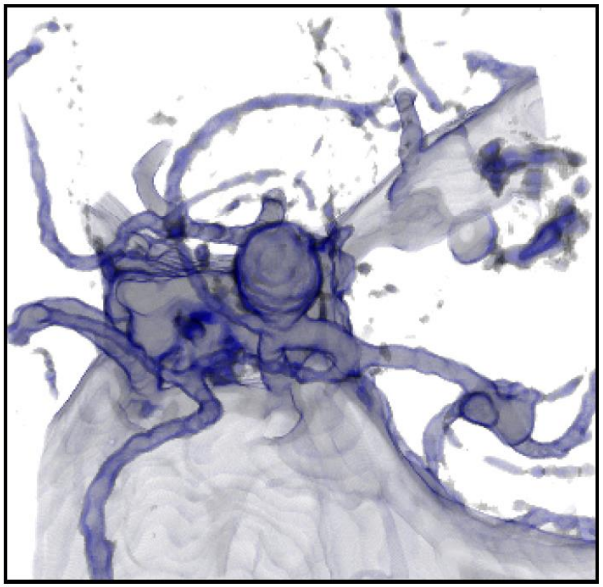
[Rezk-Salama et al., VMV 2000]



Without adjustment



Adjustment of histogram



Adjustment of position function

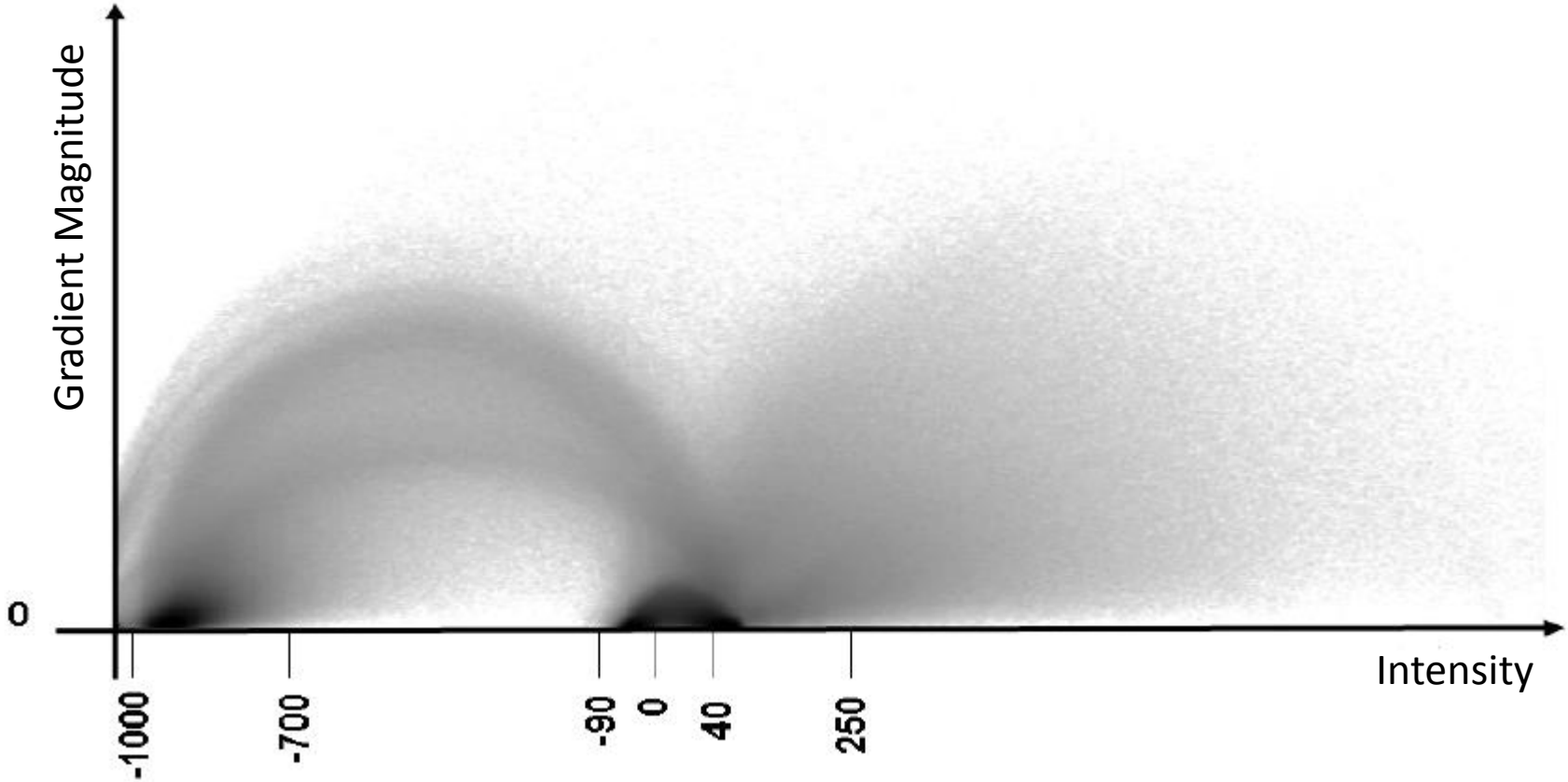
Multi-Dimensional Transfer Functions

- **1D-TFs:** Map data values to color and opacity
- **Multi-dimensional TFs:** Use additional information such as the gradient magnitude or the second derivative
- **Typical example:** Adjust opacity according to gradient magnitude → enhancement of tissue transitions
- **Pros:** Additional degrees of freedom → high quality visualizations
- **Cons:** Requires high degree of interaction

Multi-Dimensional Transfer Functions

- 1. derivative → vector
- 2. derivative → matrix
- Hessian Matrix $H = \begin{pmatrix} I_{xx} & I_{xy} & I_{xz} \\ I_{yx} & I_{yy} & I_{yz} \\ I_{zx} & I_{zy} & I_{zz} \end{pmatrix}$
- Scalar value of the 2. derivative: Largest eigenvalue of the Hessian Matrix
- Gradient usually computed by central differences

- Gradient Intensity Histograms

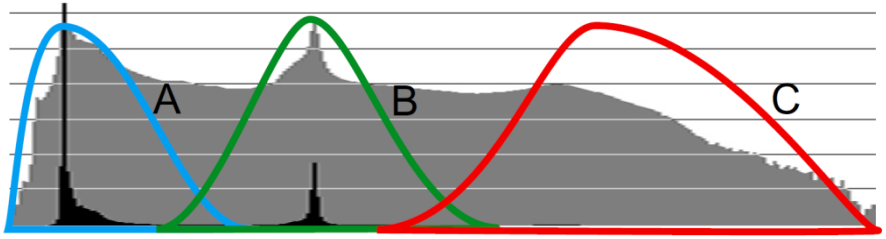


[Source: Bernhard Preim]

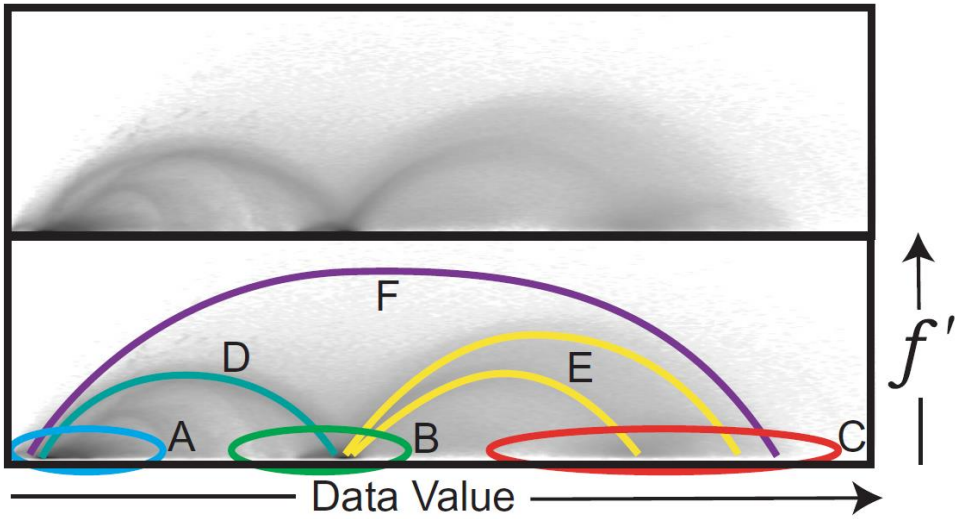
Multi-Dimensional Transfer Functions

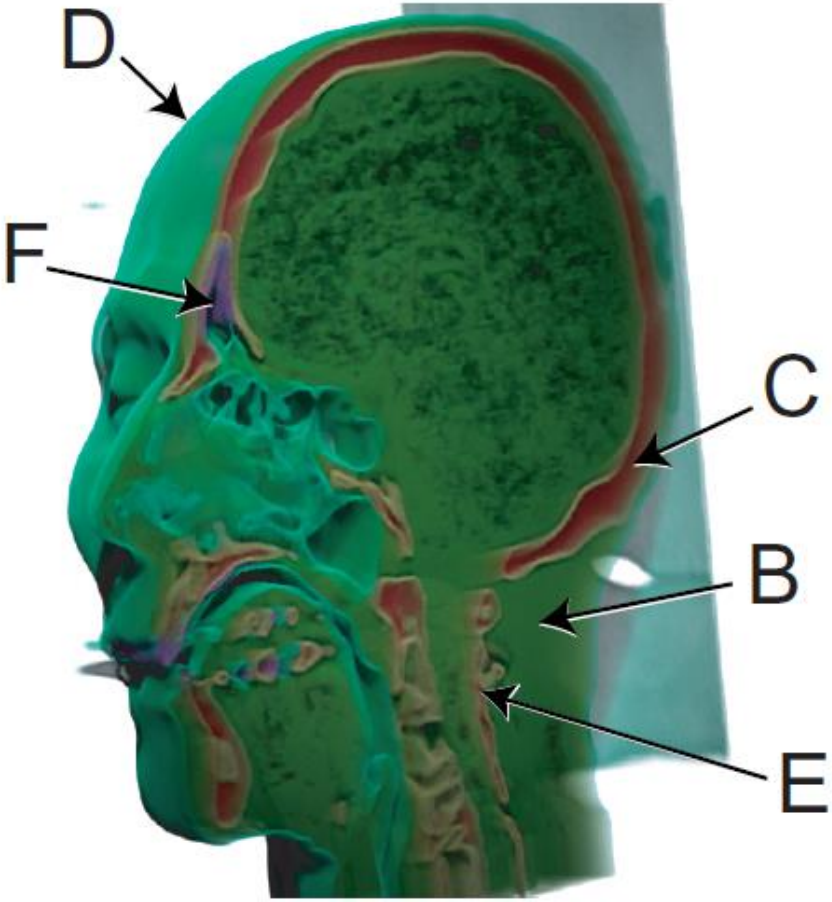
- Materials: A B C Material boundaries: D E F

1D TF (black = linear histogram, gray = log scale)



2D TF

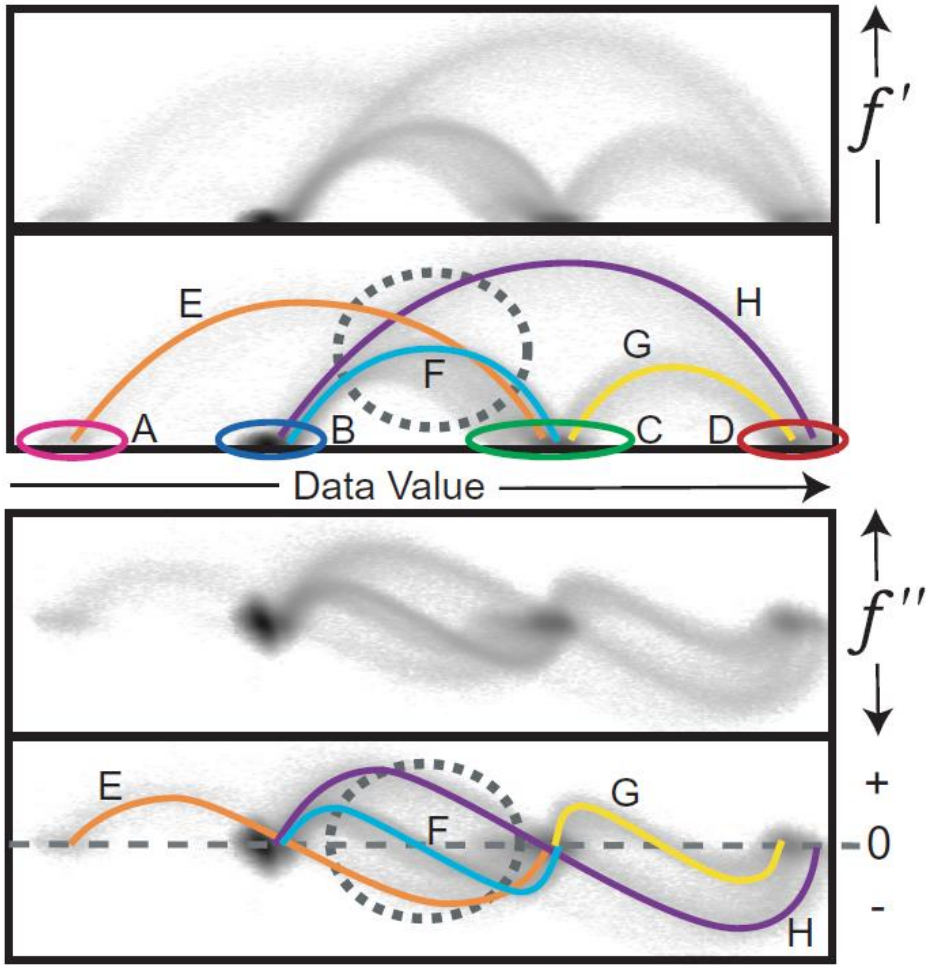


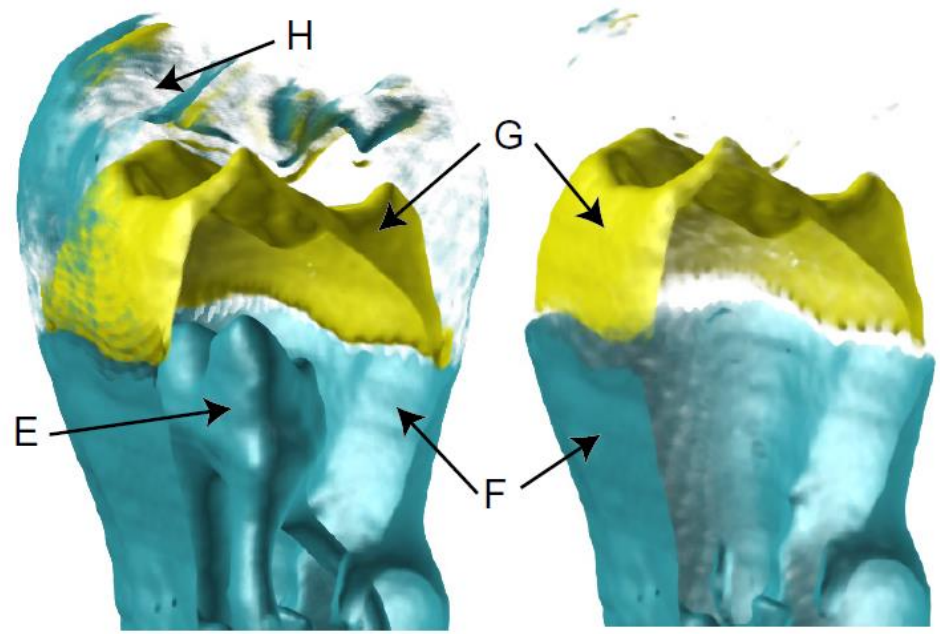


[Kniss et al. 2002]

Multi-Dimensional Transfer Functions

- 3D transfer functions using 2nd derivative





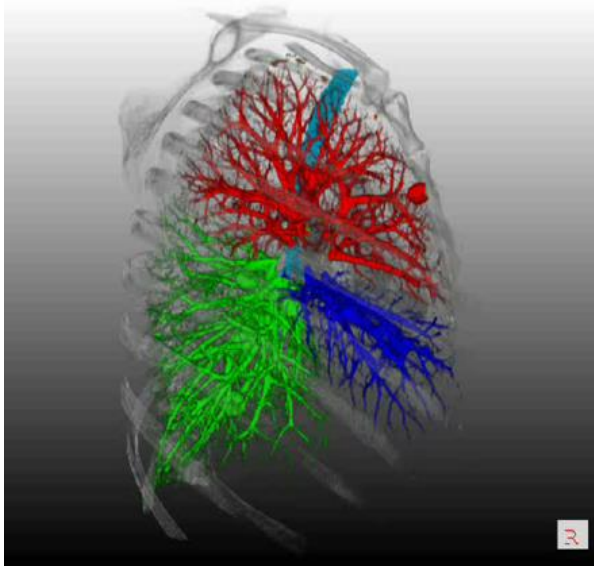
2D TF 3D TF

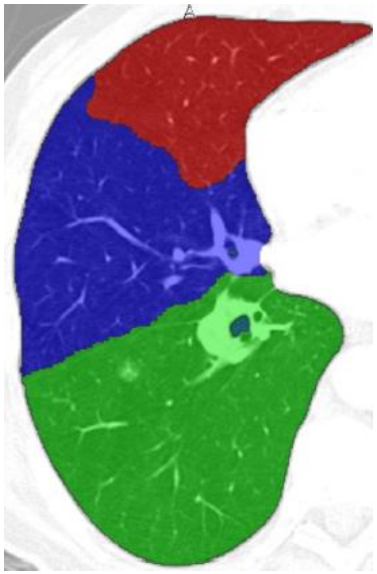
H ... dentin enamel
E ... dentin pulp
H + E should not be colored

[Kniss et al. 2002]

Local Transfer Functions

- Global TFs cannot differentiate well between different types of tissue
- Example: Split the TF lookup table into separate parts for different visualizations
- Interpolation over parts must be avoided





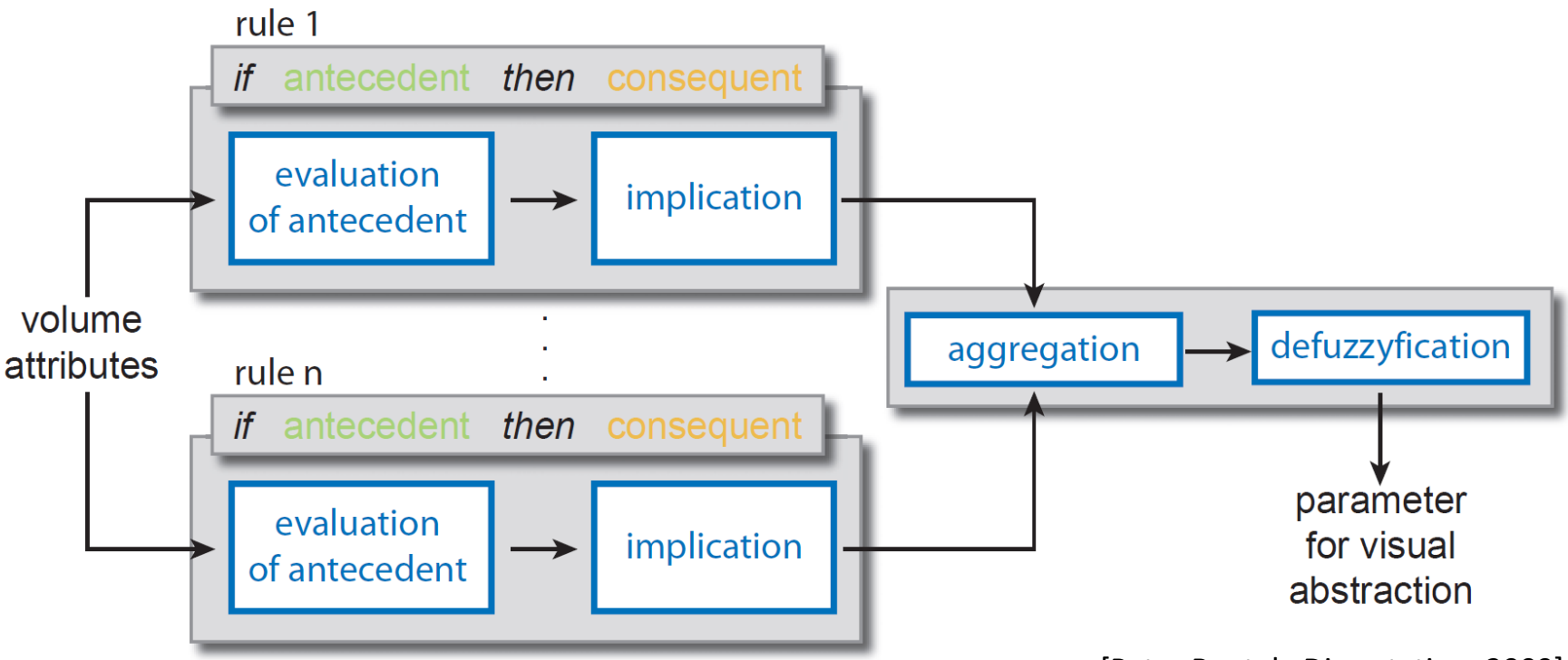
[Source: Bernhard Preim]

Semantic Visualization Mapping

- Maps semantics to different visualization styles
- Interaction-dependent semantics
  - Viewpoint
  - User focus
- Data semantics
  - Modality
  - Protocol
- Illustration semantics
  - Rendering technique
  - Style description (e.g., style transfer functions)

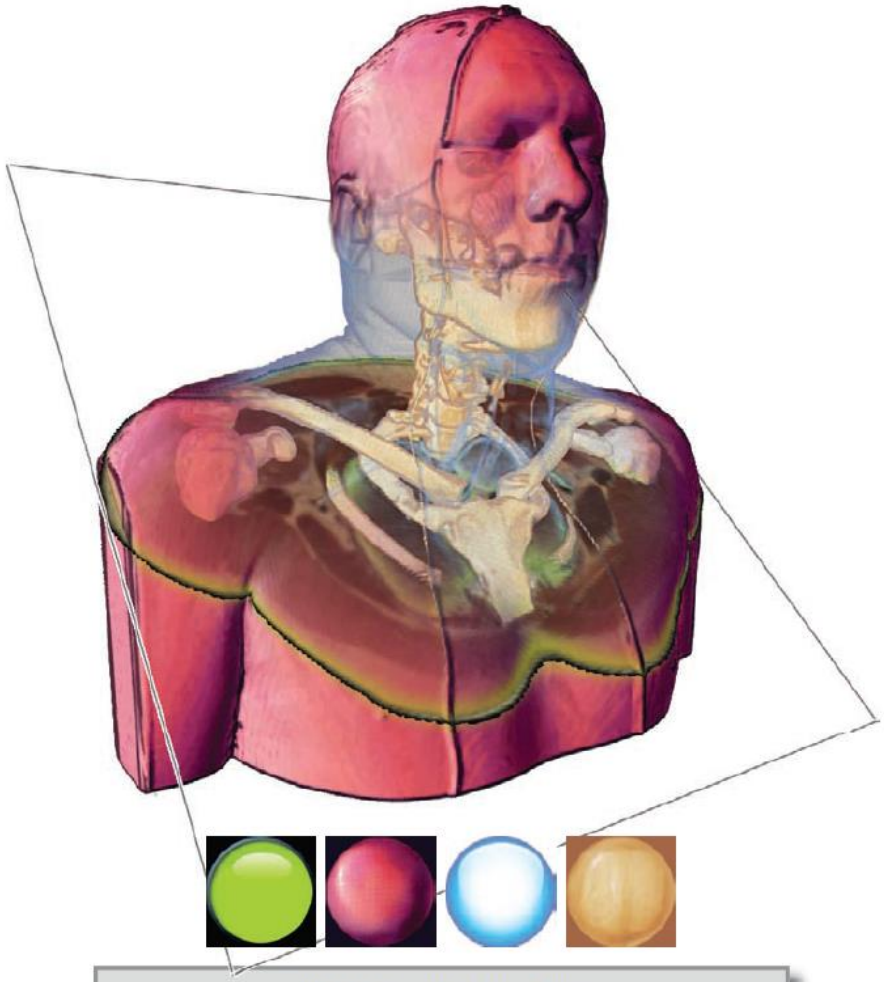
Semantic Visualization Mapping

- Various styles for different tissue types
- Visualization rules define mapping of volume attributes to visual attributes
- Fuzzy logic used to evaluated the rules



[Peter Rautek, Dissertation, 2009]

Semantic Visualization Mapping



if *distance to plane is low*
then *skin-style is transparent blueish* and *glossy green is low*

if *distance to plane is high*
then *skin-style is opaque* pink and *glossy green is transparent*

if *penetration depth is low* and *distance to focus is low*
then *skin-style is transparent white*

if *penetration depth is high* or *distance to focus is high*
then *skin-style is pink*

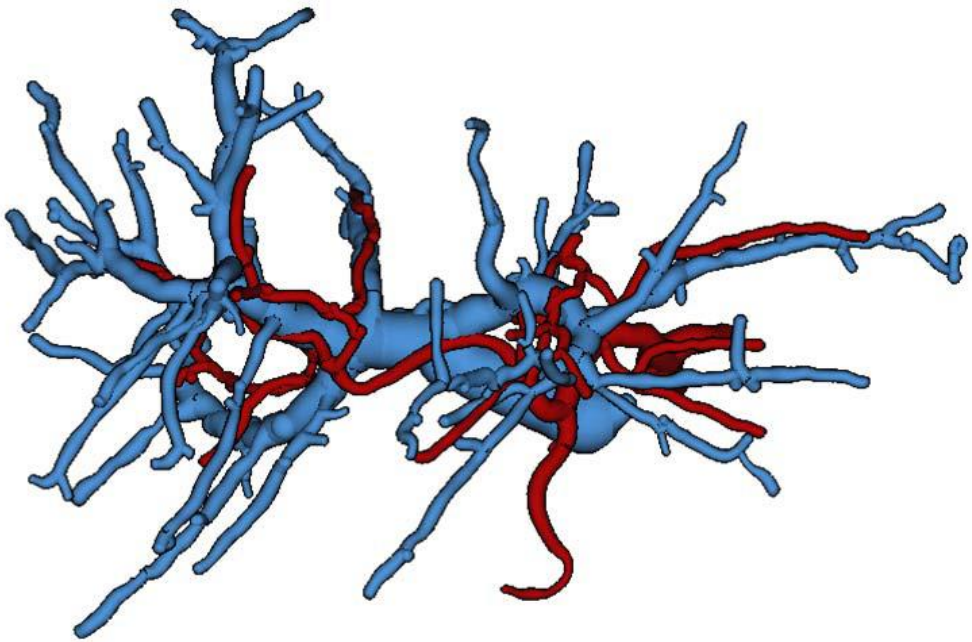
[Peter Rautek, Dissertation, 2009]

Volumetric Selection

- By specifying coordinates
- Picking within the volume visualization
  - Utilize multiple orthogonal views
  - Limit to a certain intensity range
  - Limit to segmented objects only
  - Limit to volume-of-interest

Volumetric Selection

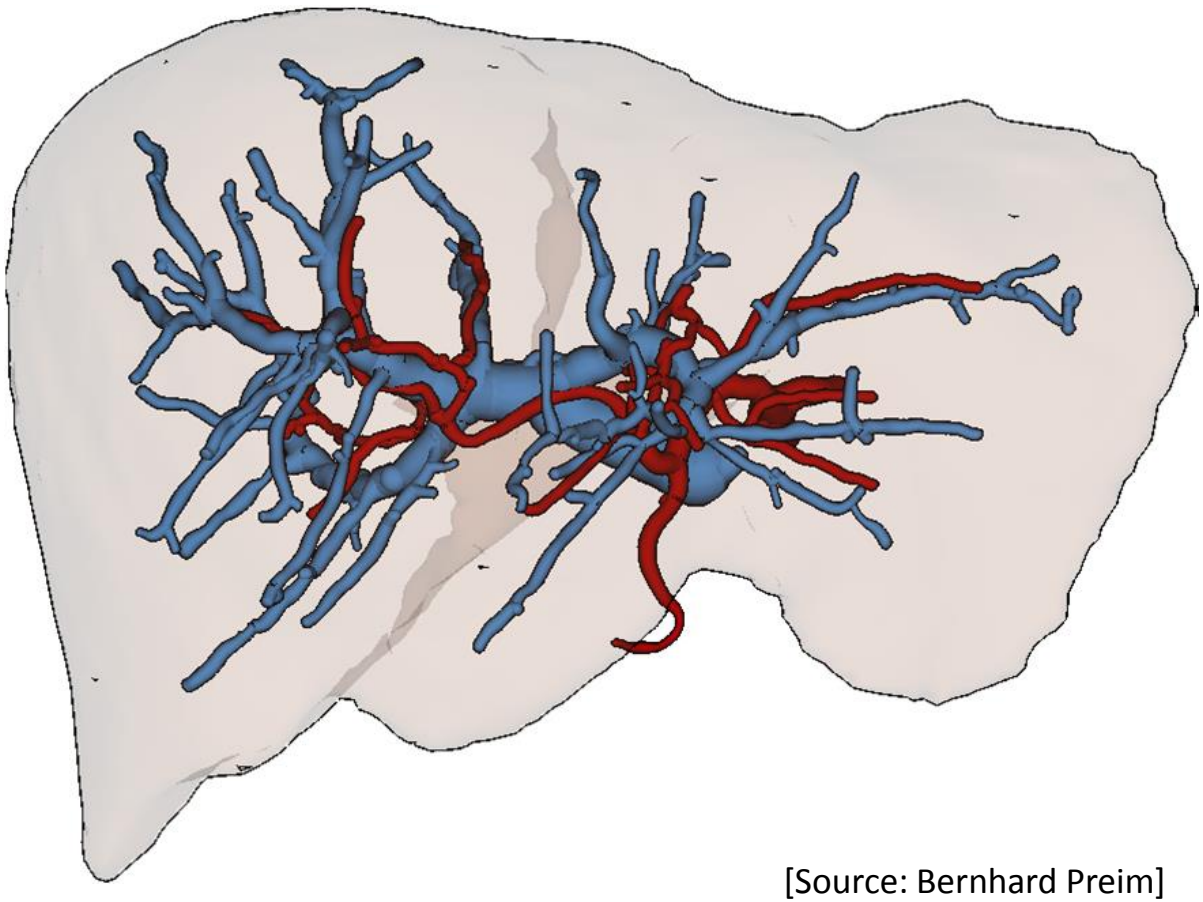
- Selection within a scene of multiple objects
- Object opaque → select first hit object (trivial)
- Possible implementation: Color picking



[Source: Bernhard Preim]

Volumetric Selection

- Semi-transparent objects
- Which object should be selected?

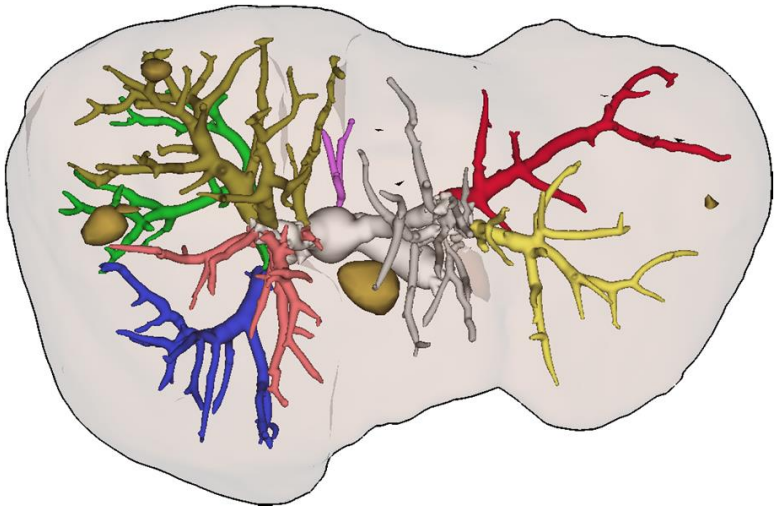


[Source: Bernhard Preim]

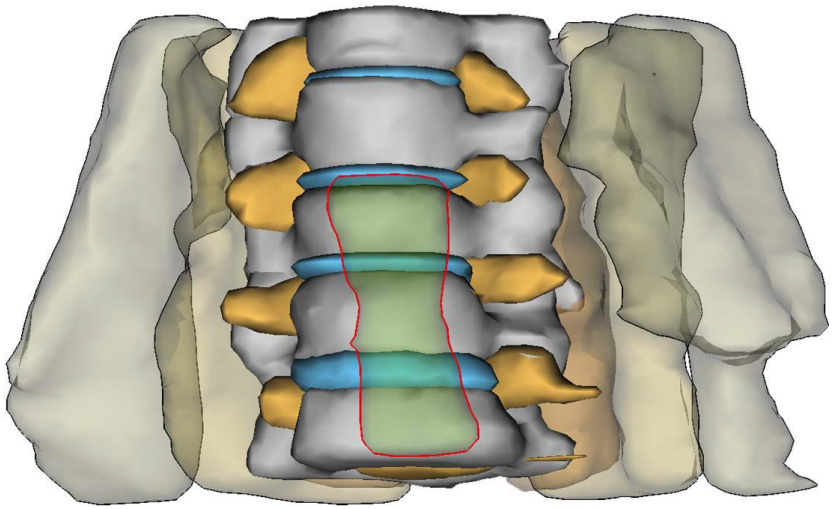
Volumetric Selection

- Attenuate ray according to
  - opacity and
  - size of objects hit
- Preferably selects smaller, opaque objects

[Sources: Bernhard Preim]



Opaque objects can be selected within the transparent liver



Semi-transparent objects in front of opaque objects with similar size still cannot be selcted

Volumetric Selection

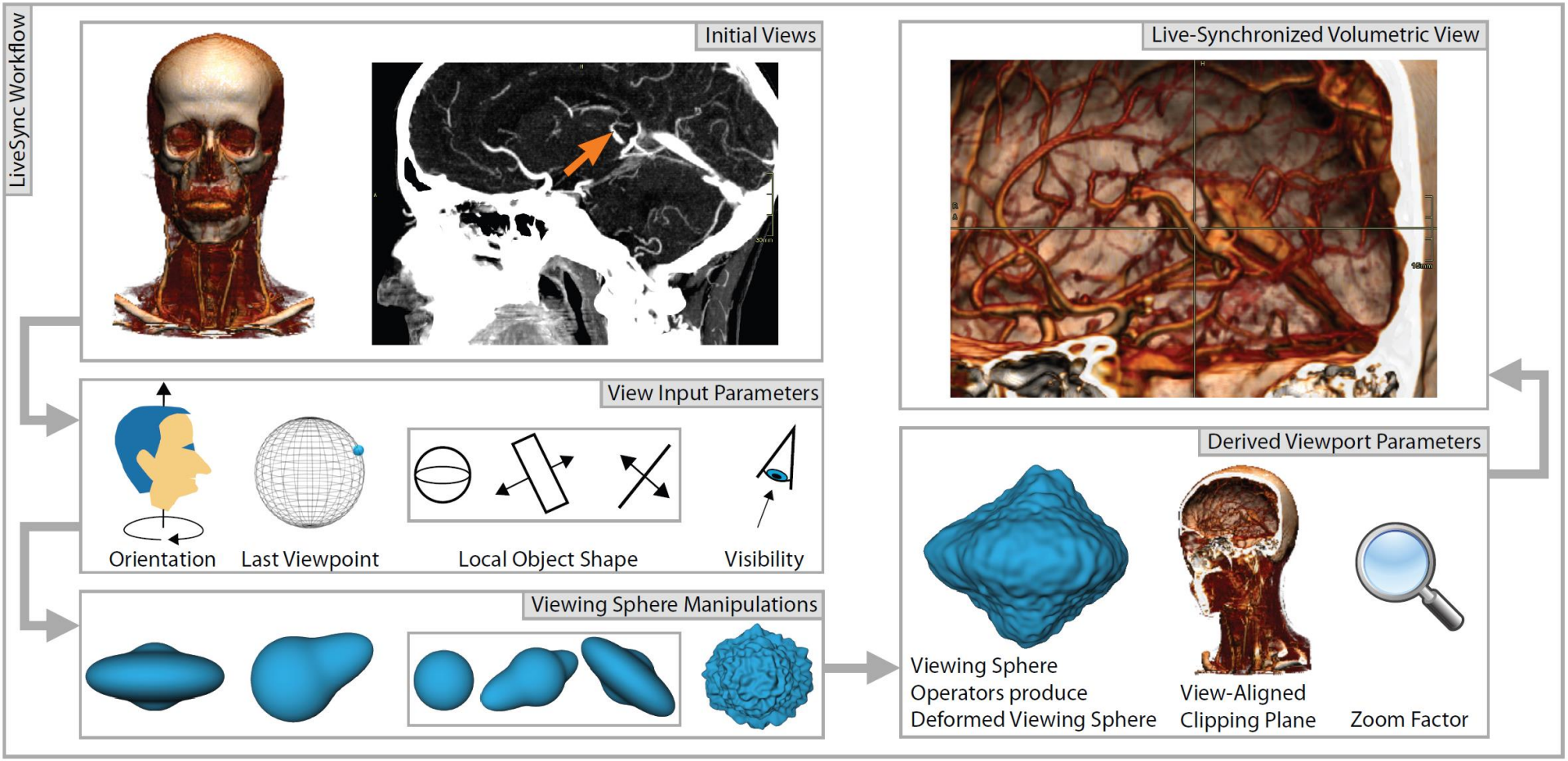
- **Solution:** List of selectable objects along the picking ray presented to the user
- User can scroll through the objects with the mouse wheel

LiveSync

- Two linked views:
  - 3D volumetric view
  - 2D slice view
- Picking in 2D slice view selects proper view in 3D
- Input parameters
  - Patient orientation
  - Viewpoint history
  - Local shape estimation (segmentation + PCA)
  - Visibility

LiveSync

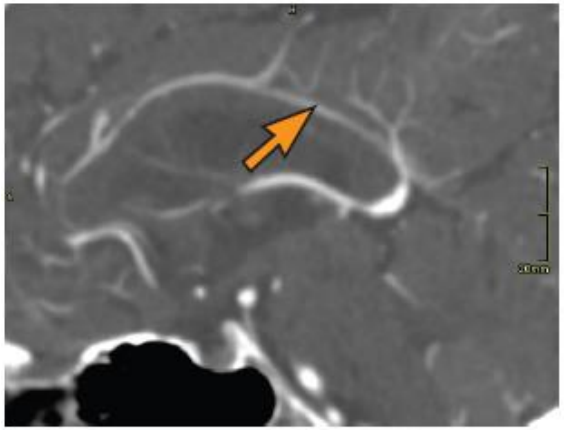
- Viewpoint estimated by deformation of viewing spheres → live synchronizaion of 2D and 3D views



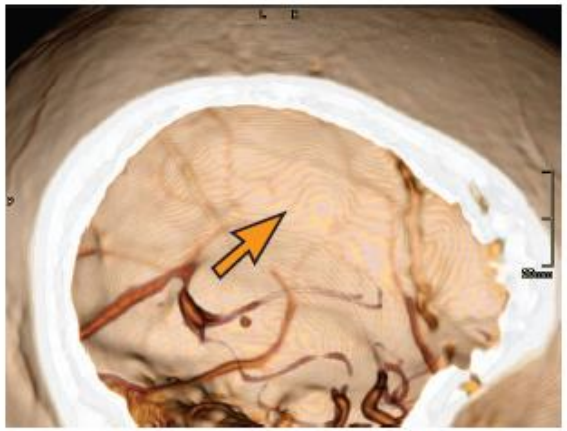
[Kohlmann et al. 2007]

LiveSync++

- TF automatically adjusted to present picked objects unoccluded
- Based on the distrubution of density values within a locel region around the picking position
- TF adjusted to mean and std-dev of the region



Picking



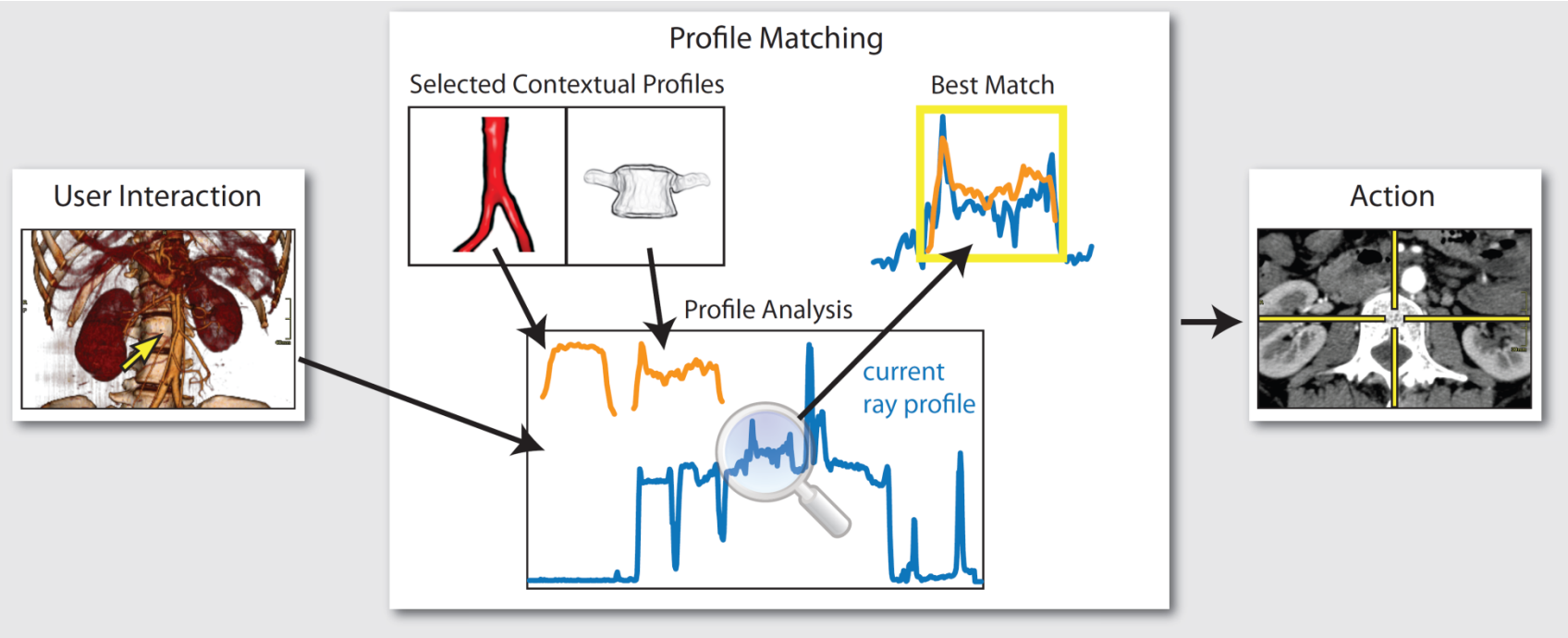
Not adjusted TF

Adjusted TF

[Kohlmann et al. 2008]

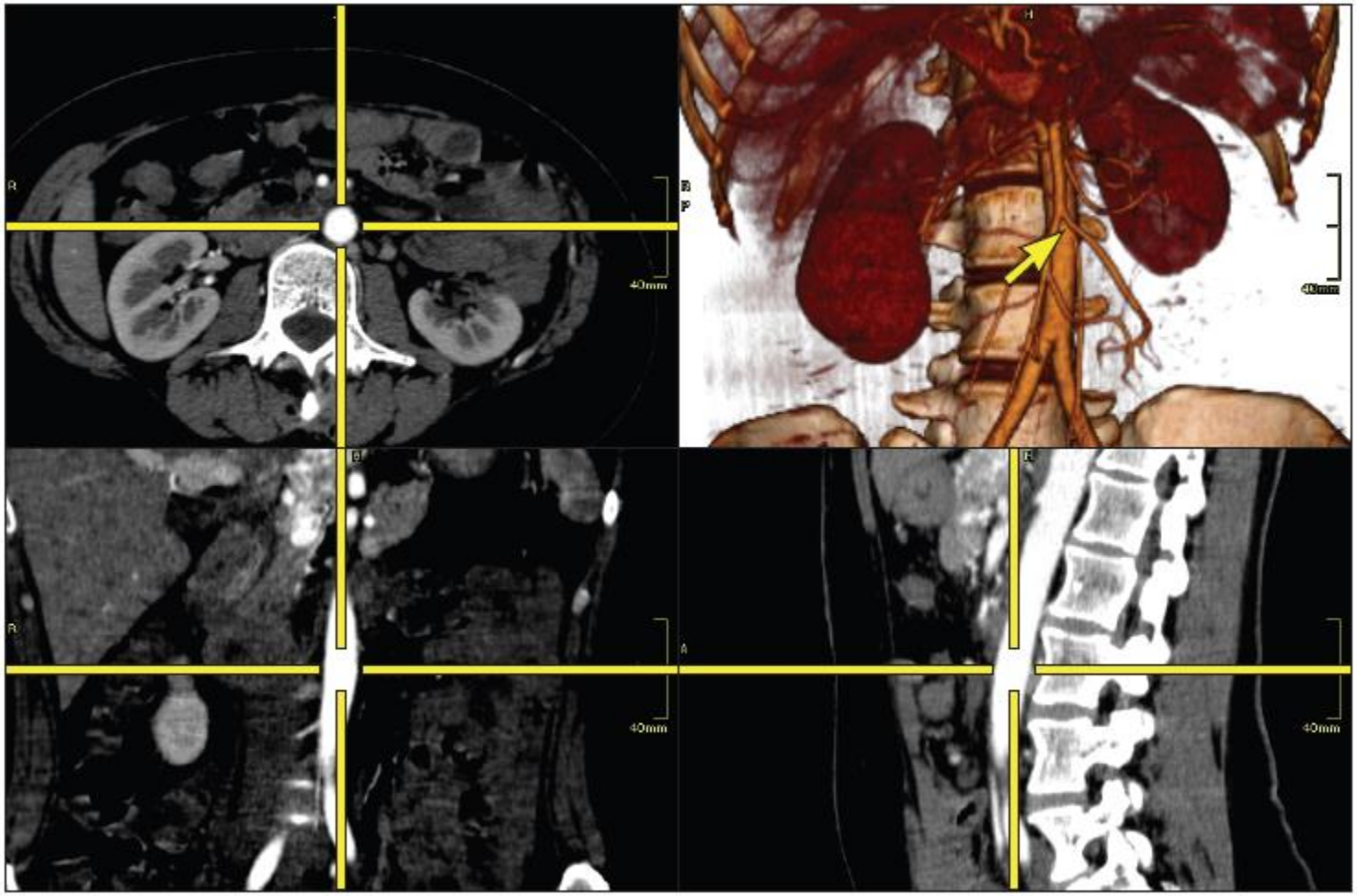
Contextual Picking

- Ray profile knowledge base of anatomical objects
- Picking within the 3D visualization
- Profile of picking ray analyzed to find best match
- Highlighting an interesting point in a 2D slice view



[Kohlmann et al. 2009]

Contextual Picking



[Kohlmann et al. 2009]

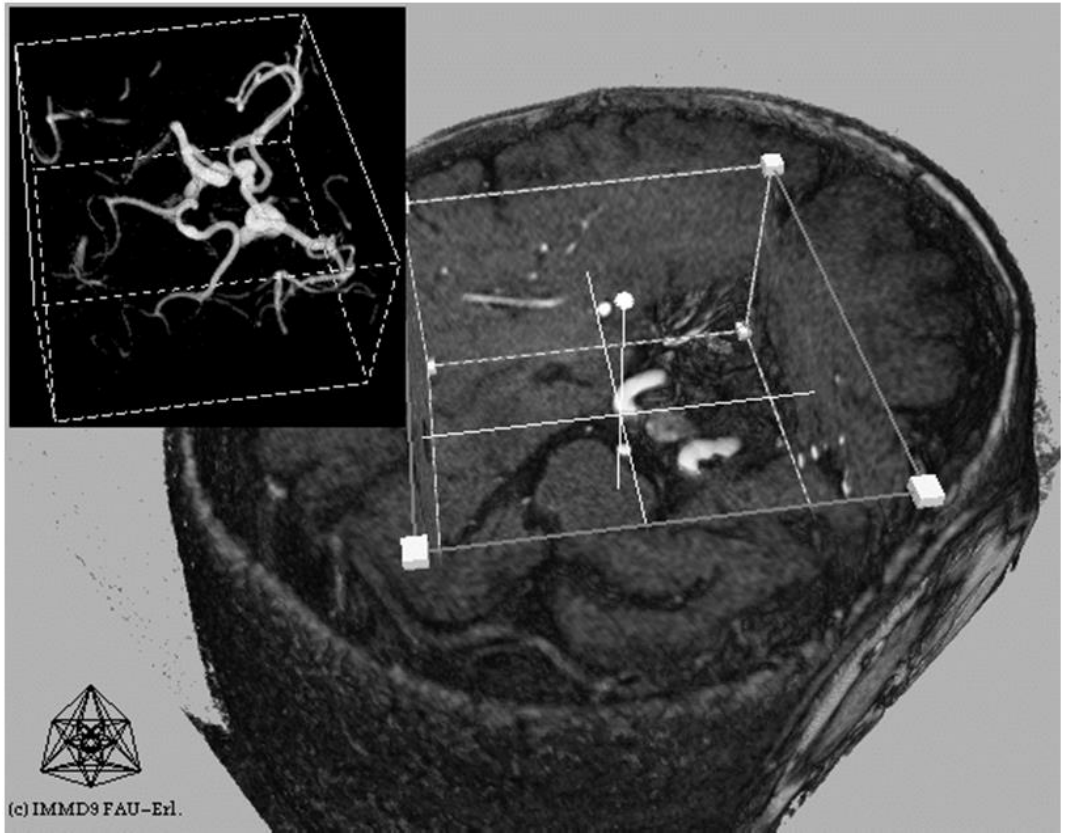
Volume Exploration

- Local volume rendering
  - More details if reducing the opacity and focusing on a smaller region (or subvolume)
  - Structure of tumors better judgable in 3D
  - Segmentation easier in smaller subvolumes

- Required Interaction
  - Specification of the local subvolume
  - Specification of a local transfer function

Volume Exploration

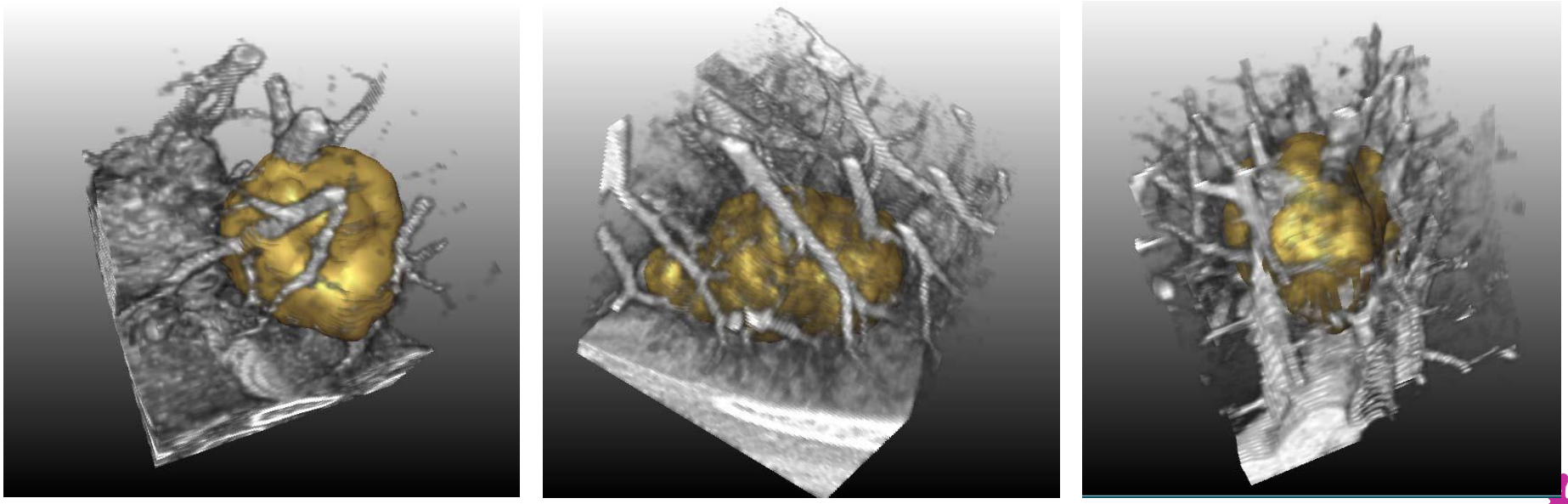
- Box clipping defines subvolume for detailed inspection of cervical vessels
- Local TFs applied in the subvolume



[Hastreiter et al. 1998]

Volume Exploration

- Local volume rendering to evaluate the surrounding of a tumor in CT thorax data
- Hybrid rendering
  - Tumor as iso-surface
  - Surrounding vascular structures with DVR



[Dicken et al. 2003]

Measurements

- Quantitative evaluation as addition to visual assessment
- Diagnosis (e.g., to assess vascular narrowings such as stenosis or occlusions)
- Rating of severity of diseases (tumor staging)
- Assessment of therapy progression
- Quality assurance
- Supporting decision process for therapy planning

Measurements – Example

- Average grayvalues within a region in CT data (e.g. severity of osteoporosis or lung malfunction)
- Angle: Assessment of possible malpositions, important for deciding on the necessity of an OP
- Distance: Tumor ↔ Vessels, criteria for application of thermo-ablation
- Vessel diameter: Criterium for reconstruction of clipped blood vessels
- Volumina of malicious objects (single or in total), criteria for therapy success

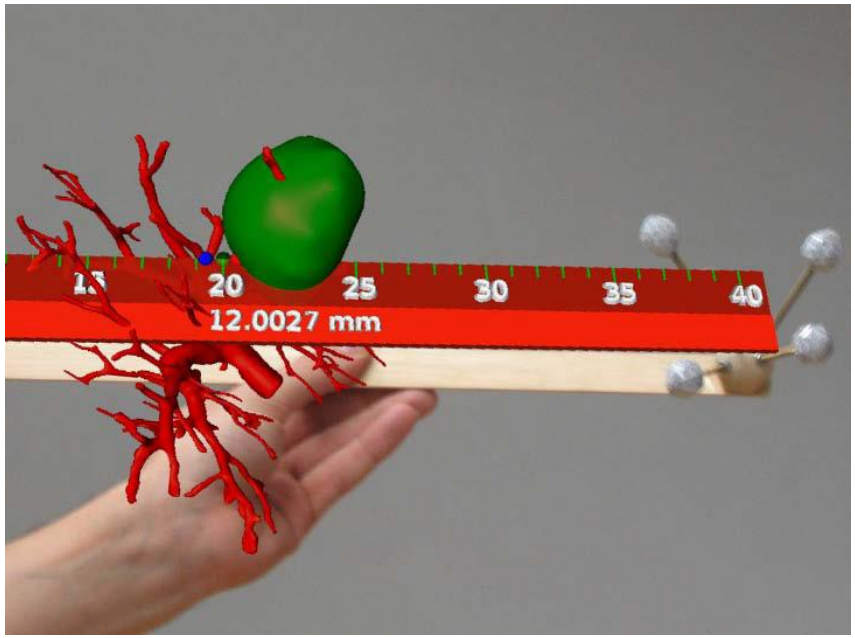
Measurements

- **2D:**
  - Exact and simple, every voxel is selectable
  - Angles between 3D objects cumbersome to approximate within 2D slices

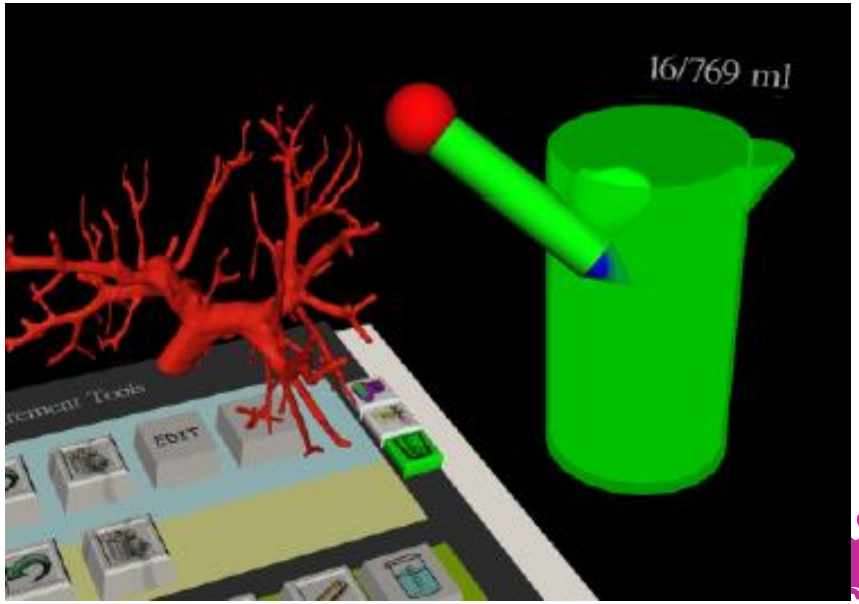
- Use segmentation results if existing
- Minimum distance between objects
- Extent of objects
- Angle between main axes of objects

Measurements

- Tracked ruler for distance measurements in an Augmented Reality (AR) environment



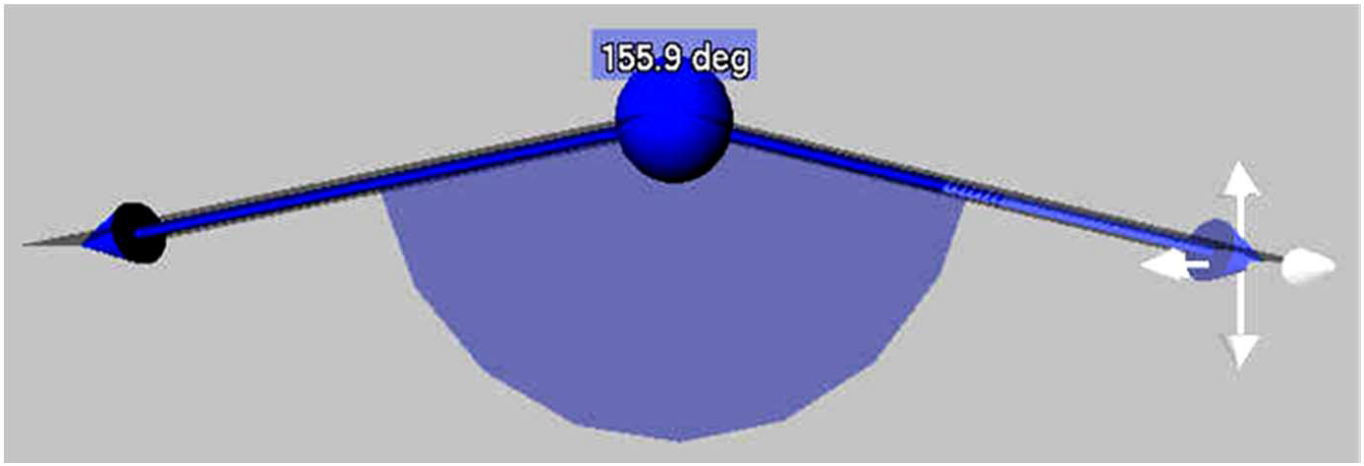
- Virtual cup to measure the volume

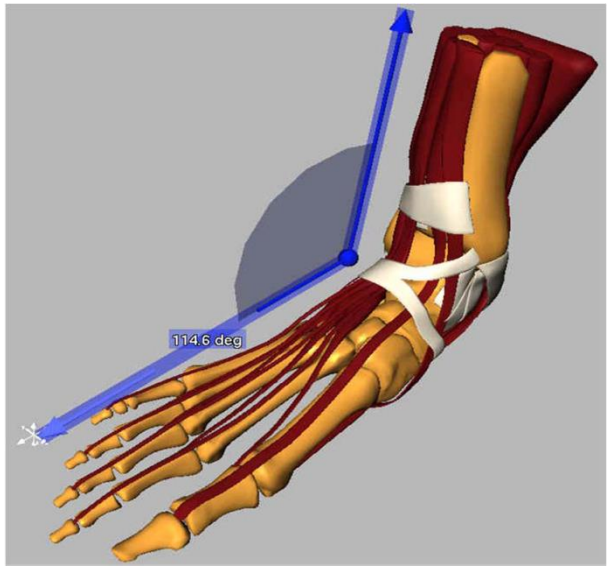


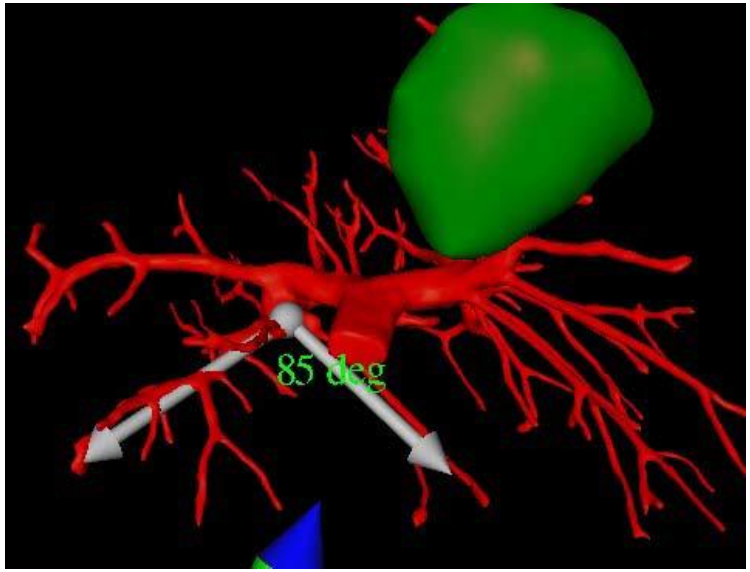
[Reitinger et al. 2006]

Measurements

- 3D widgets for angle measurements



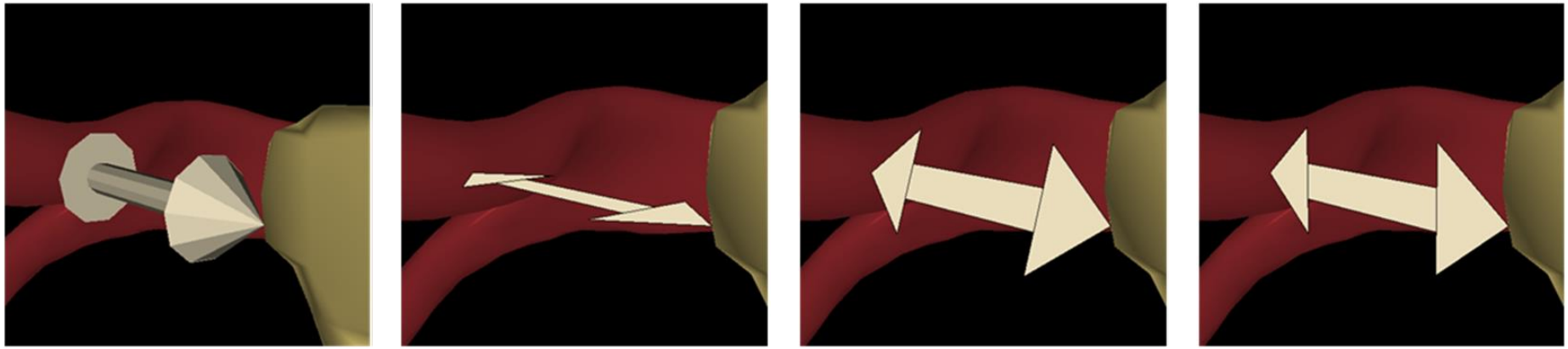




[Reitinger et al. 2006]

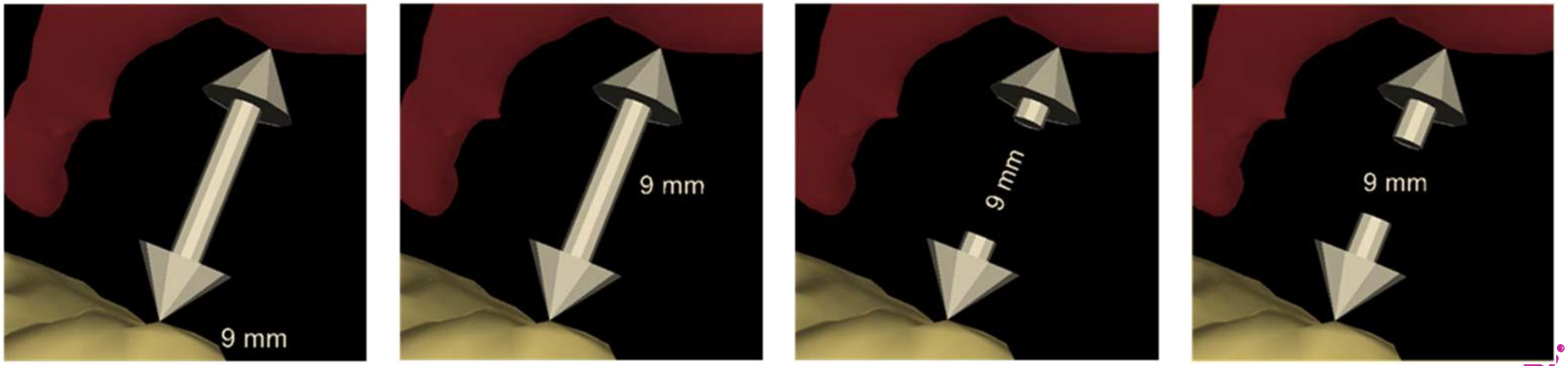
Measurements

- Design choices when rendering distance lines



view aligned

- Label placement possibilities



[Rössling et al. 2009]

Path Planning

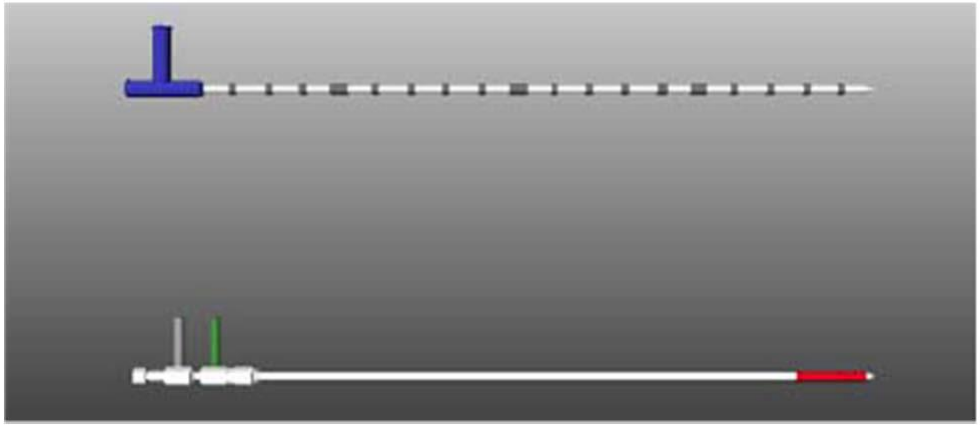
- Medical background
  - Treatment of non-operable tumor patients (e.g., if general health state is poor, tumor too close to blood vessels)
  - Tumors < 5 cm
  - Small number of tumors/metastases

Path Planning

- **Goal:**
  - Applicator placement to destroy the tumor
  - Account for surrounding structures (vessels)
- **Challenge:** Difficult visual assessment
- Determine entry and target points
- Overview planning in 3D, details in 2D slices
- User support
  - Histograms
  - Distance to vital structures, hit objects, ...

Path Planning

- Application areas:
  - Brain tumors
  - Liver metastases
- Applicators:
  - Radiofrequency therapy
  - Laser-induced interstitial thermo therapy

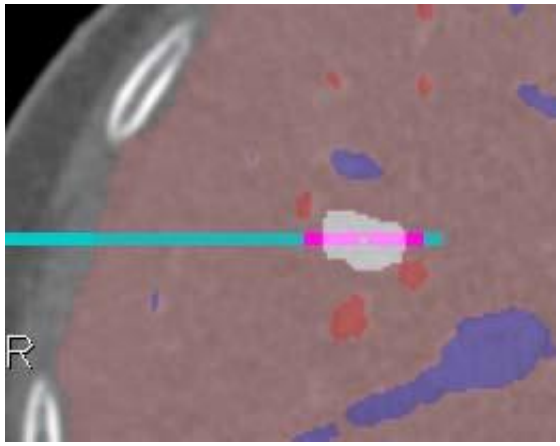


[Source: Bernhard Preim]

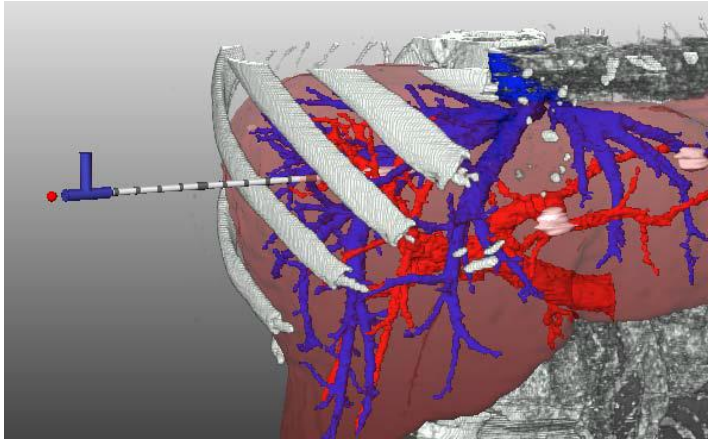
Path Planning

- **Problem:** Tumor within vascular system
- Path must avoid hitting a blood vessel

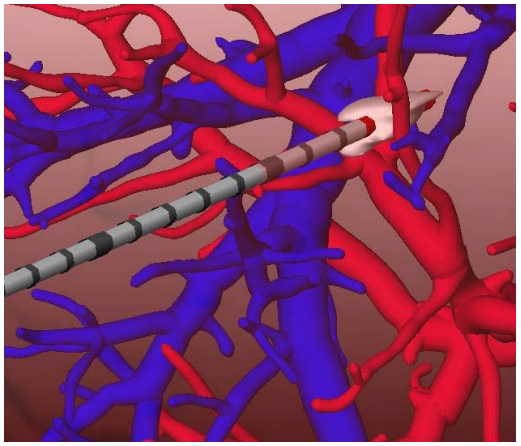
[Source: Bernhard Preim, Littmann et al. 2003]



2D



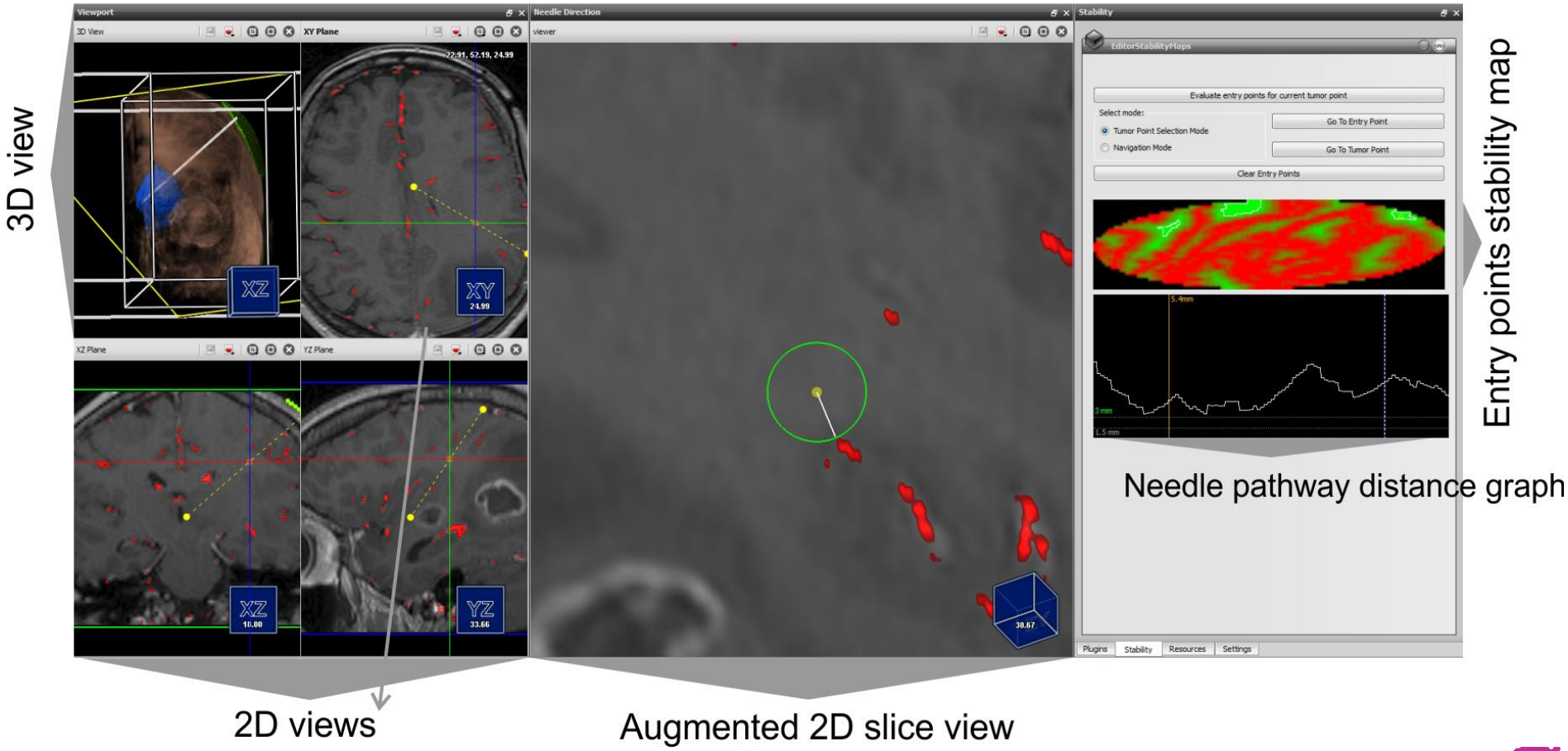
3D Overview



3D Detail

Biopsy Planner

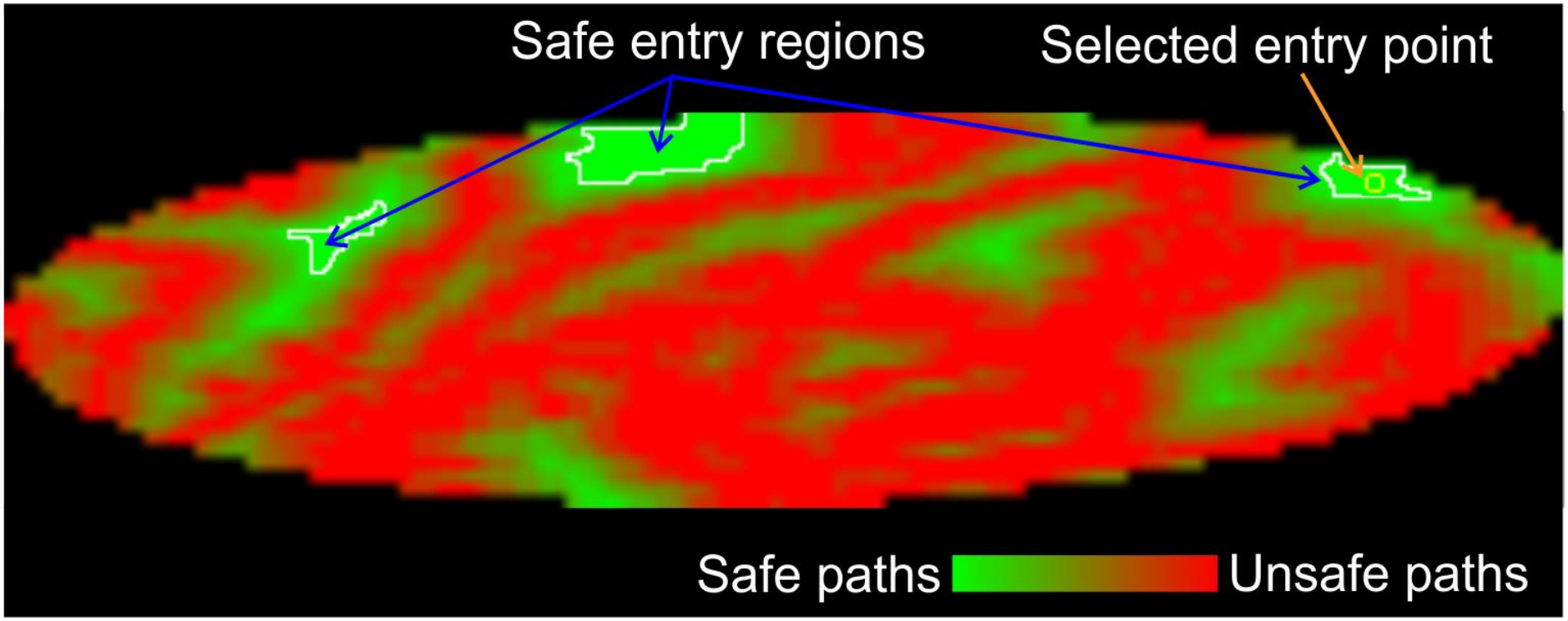
- Needle path plannning for brain tumors
- Supports the user with visual analysis



[Herghelegiu et al. 2012]

Biopsy Planner

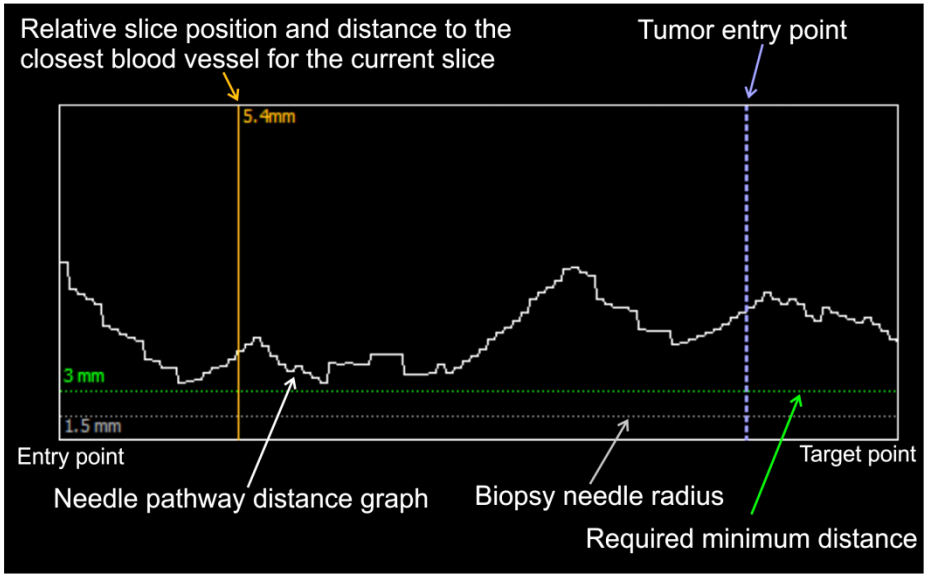
- Entry point stability map
- Red: Unsafe paths
- Green: Safe paths

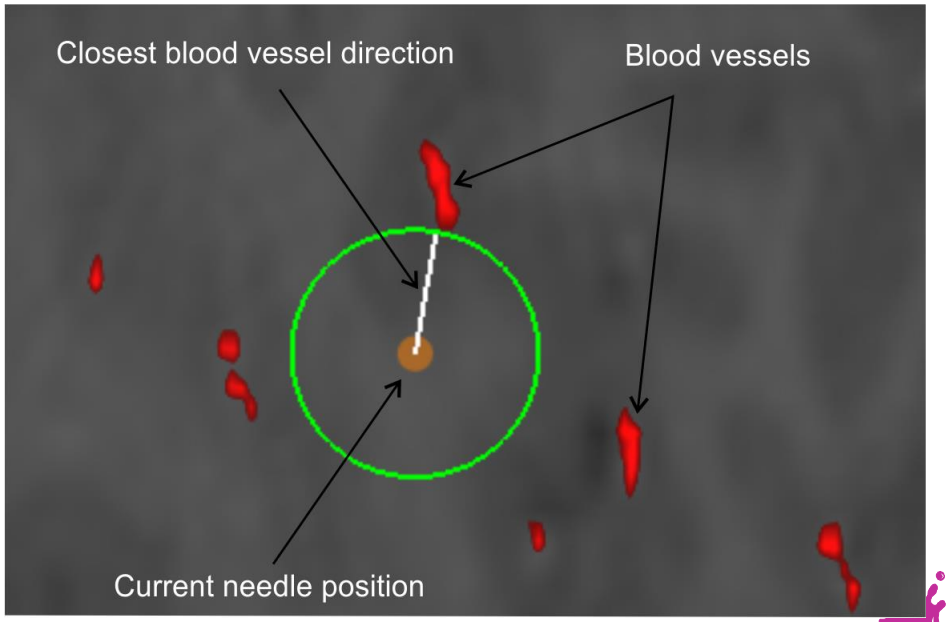


[Herghelegiu et al. 2012]

Biopsy Planner

- Needle path analysis
- Required minimum distance to blood vessels depends on needle radius
- Safety margin
- Tumor entry point
- Augmented 2D slice shows distance to closest blood vessel



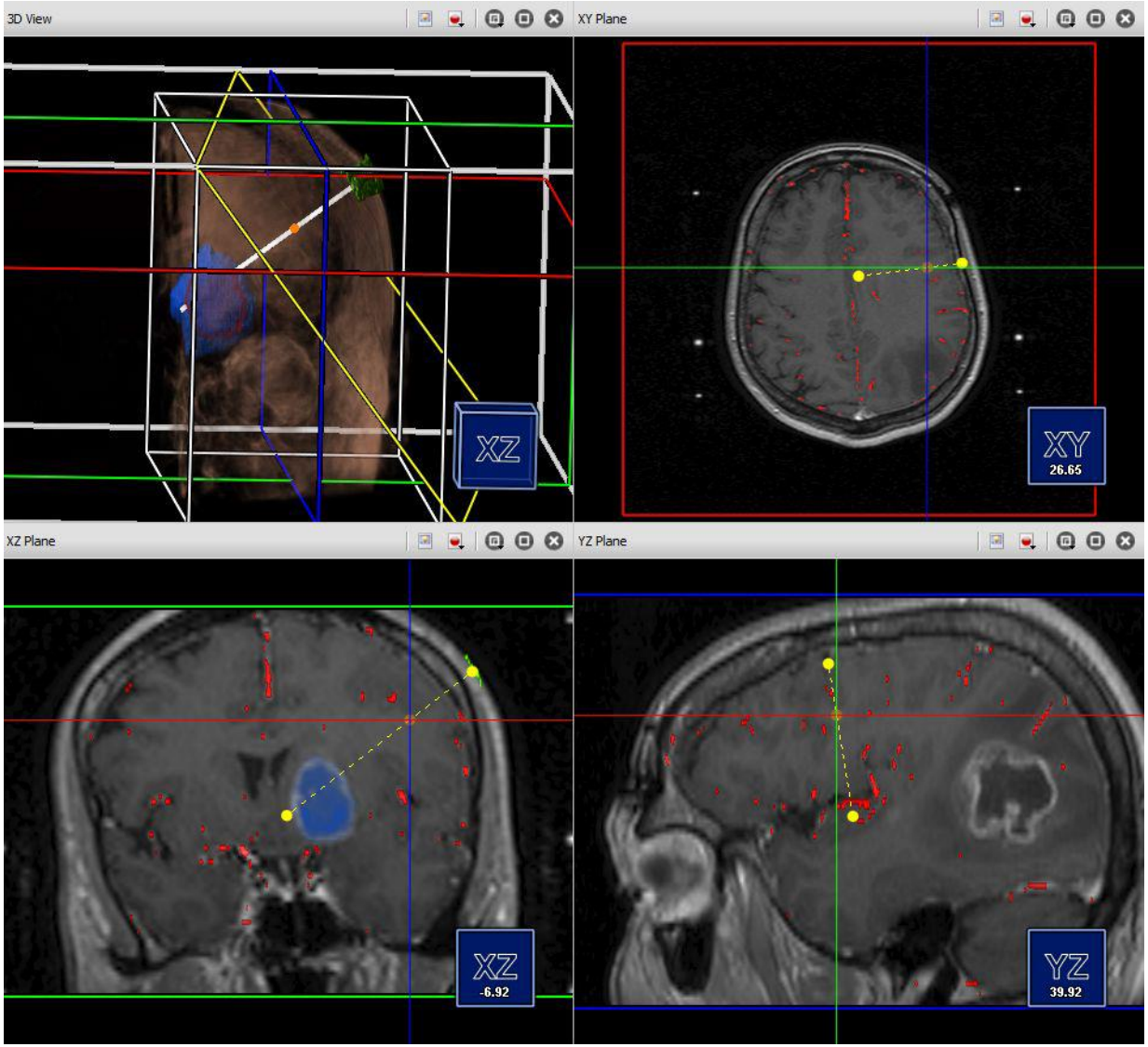


[Herghelegiu et al. 2012]

Biopsy Planner

- Linked views
- 3D view
- 3D slices

- Interactive visual path planning



[Herghelegiu et al. 2012]

Questions?

- Webpage: http://cg.tuwien.ac.at/courses/MedVis2/VU.html
- Abgabesystem: https://lva.cg.tuwien.ac.at/vismed2/

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- Meister Eduard Gröller