Tools & Techniques for Direct Volume Interaction

4. Guided Navigation and Exploration

Guidance & Navigation

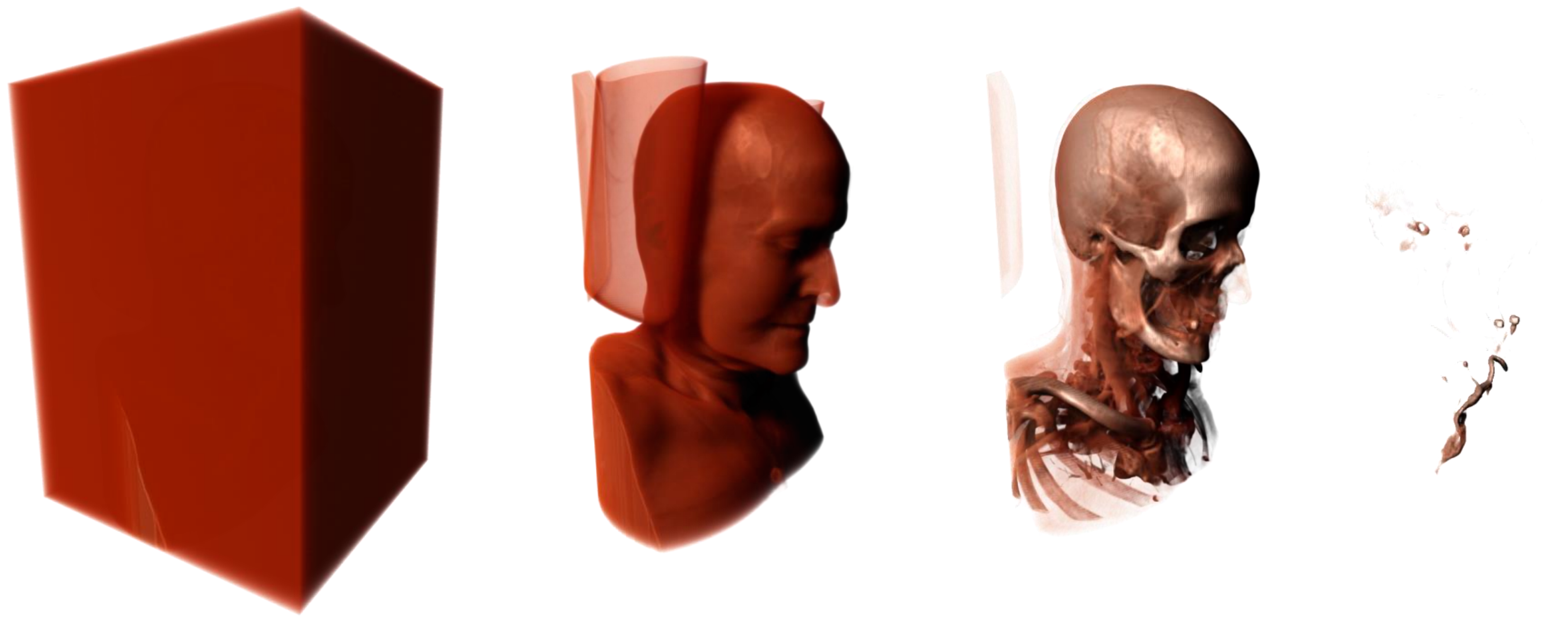
- Goal: simplify the specification of visualization parameters (particularly for non-expert users)
- Exploit knowledge about data, domain, and user tasks to reduce search space
- Constrain interaction facilities in order to reduce complexity/enhance efficiency
- Often: non-invasively enhance existing workflows or applications

Overview

- Strategies for guidance in the specification of common parameters
  - Isovalue/transfer function
  - Viewpoint/camera settings
  - Region of interest/clipping
  - Visualization technique
- Important challenges
  - Identification of relevant values/ranges
  - Adjustment/tuning of values
  - Presentation and interaction

Transfer Functions (1)

- Non-trivial mapping of data values to visible structures



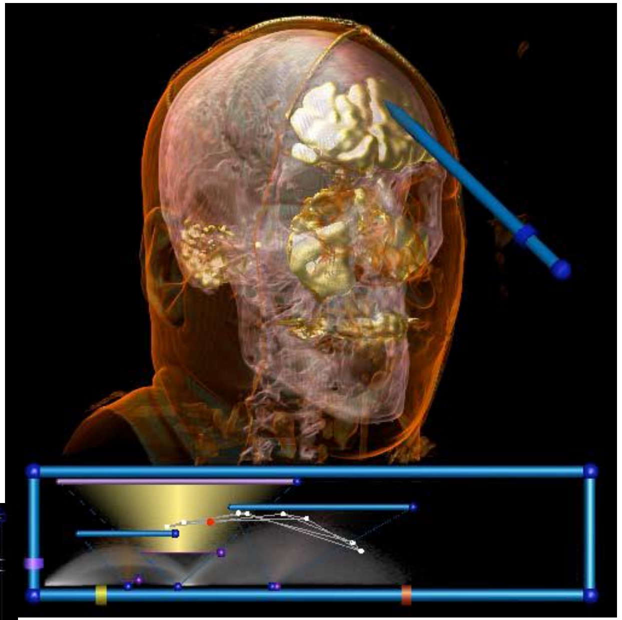
Transfer Functions (2)

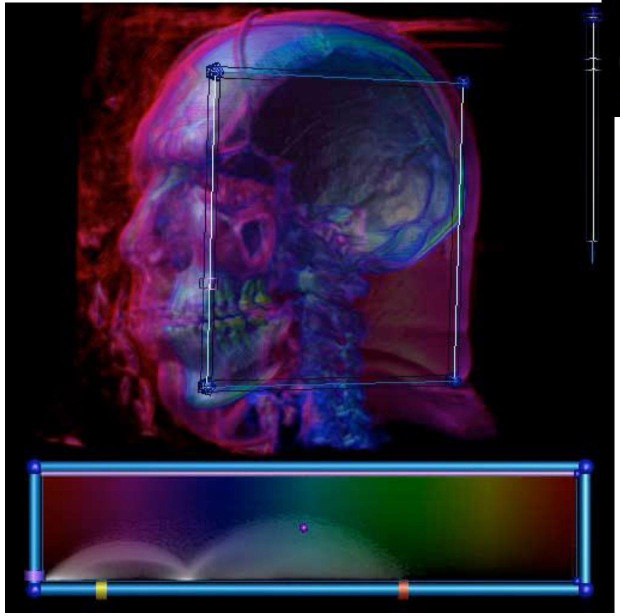
- Presets
- 2D Interfaces
- 3D Interfaces

- **Data-based Guidance**
- **Image-based Search**

Transfer Functions: 3D Interfaces

- Limitations
  - 3D Interaction can be complex
  - No overview of what is there



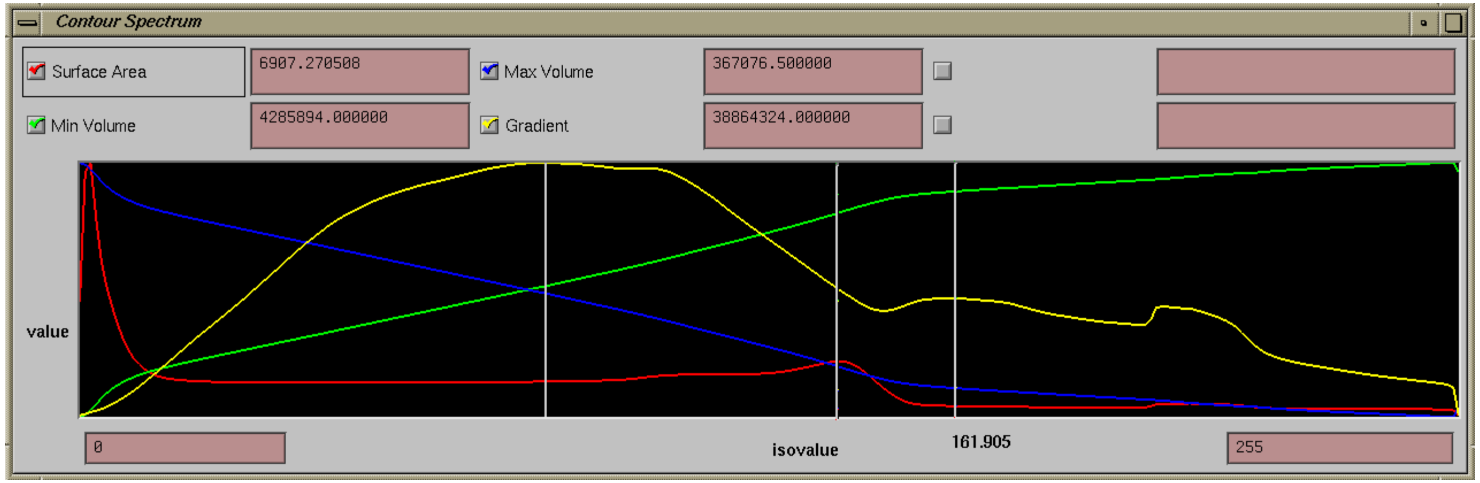


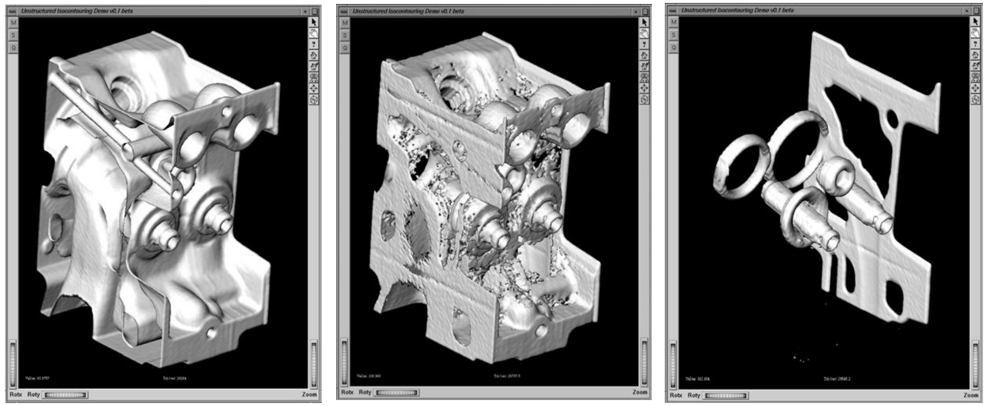
Transfer Functions: Data-based Guidance

- Extract additional derived information from the data
  - Contour Spectrum
  - 3D Histograms
  - Statistical Signatures
  - Isosurface Similarity
- Determine …
- Display for guidance or extract

Contour Spectrum [Bajaj et al. 1997]

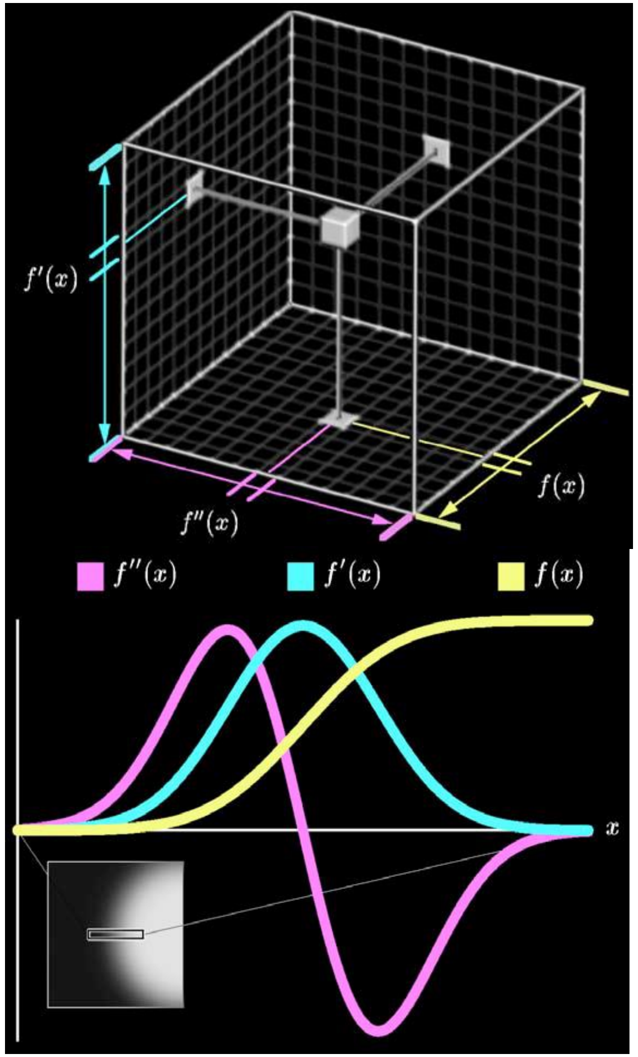
- Compute and plot descriptive properties for for each isovalue to guide the selection process
  - Surface Area
  - Enclosed Volume
  - etc.



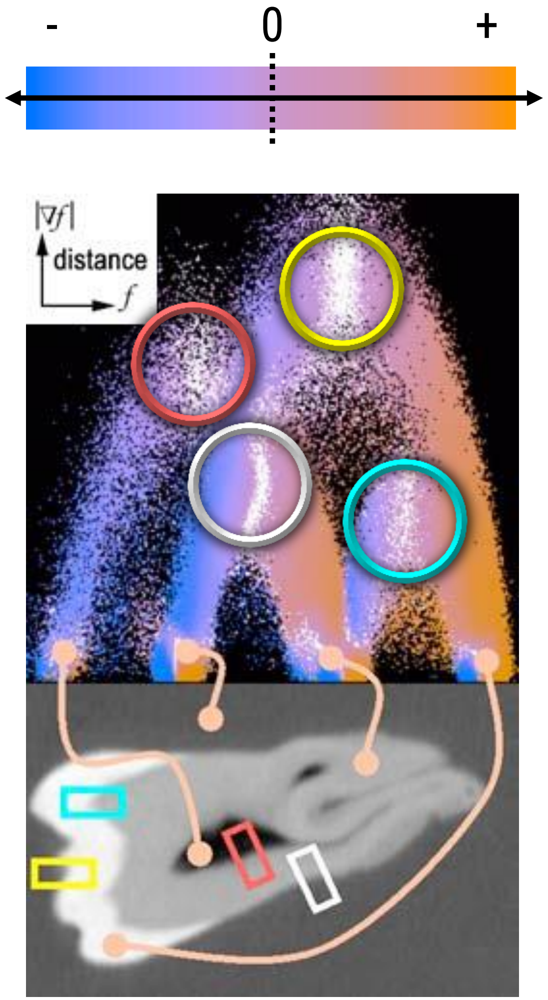


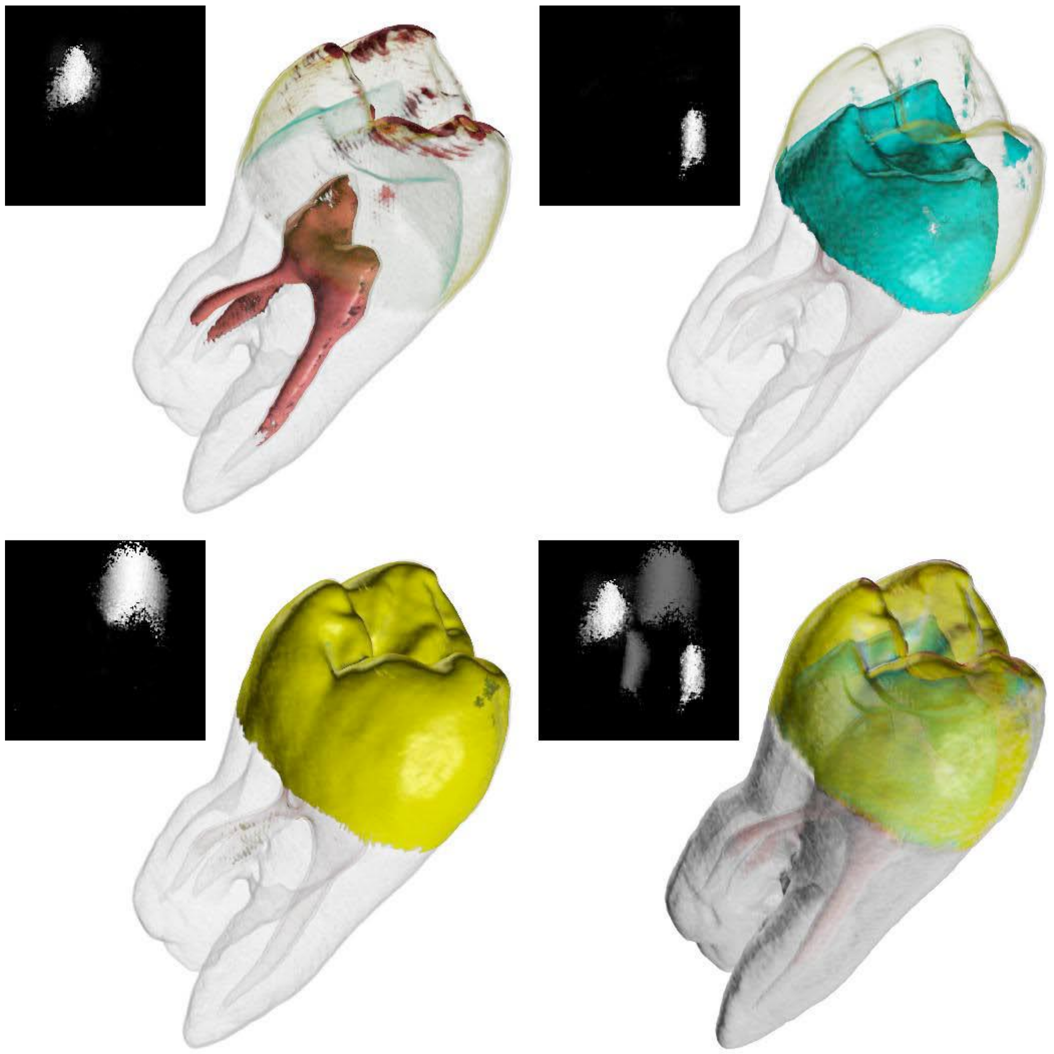
3D Histograms (1) [Kindlmann & Durkin 1998]

- Generate 3D histogram of data value, 1st derivative and 2nd derivative
- Boundaries: edges as maximum of 1st derivative, zero crossing of 2nd
- Distance function derived from histogram volume mapped to opacity function



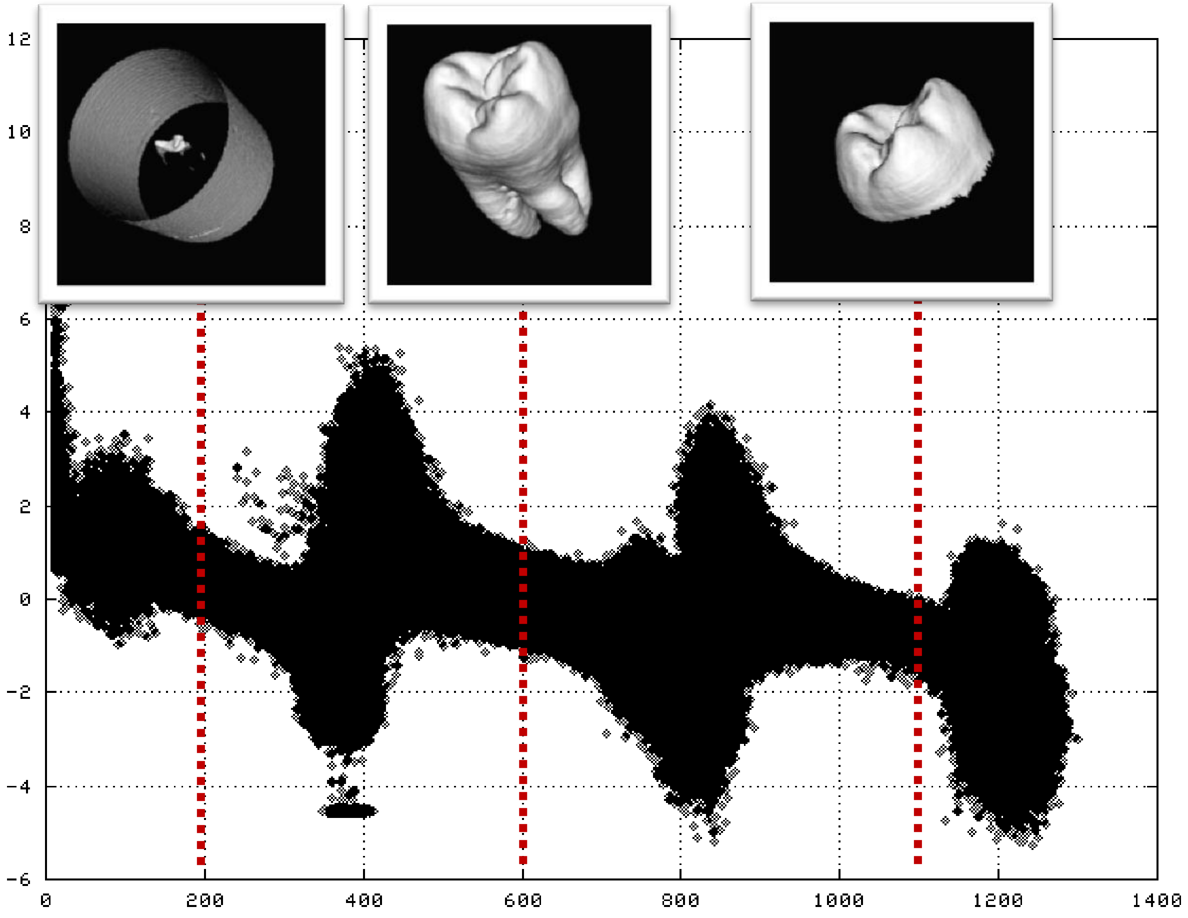
3D Histograms (2) [Kindlmann & Durkin 1998]





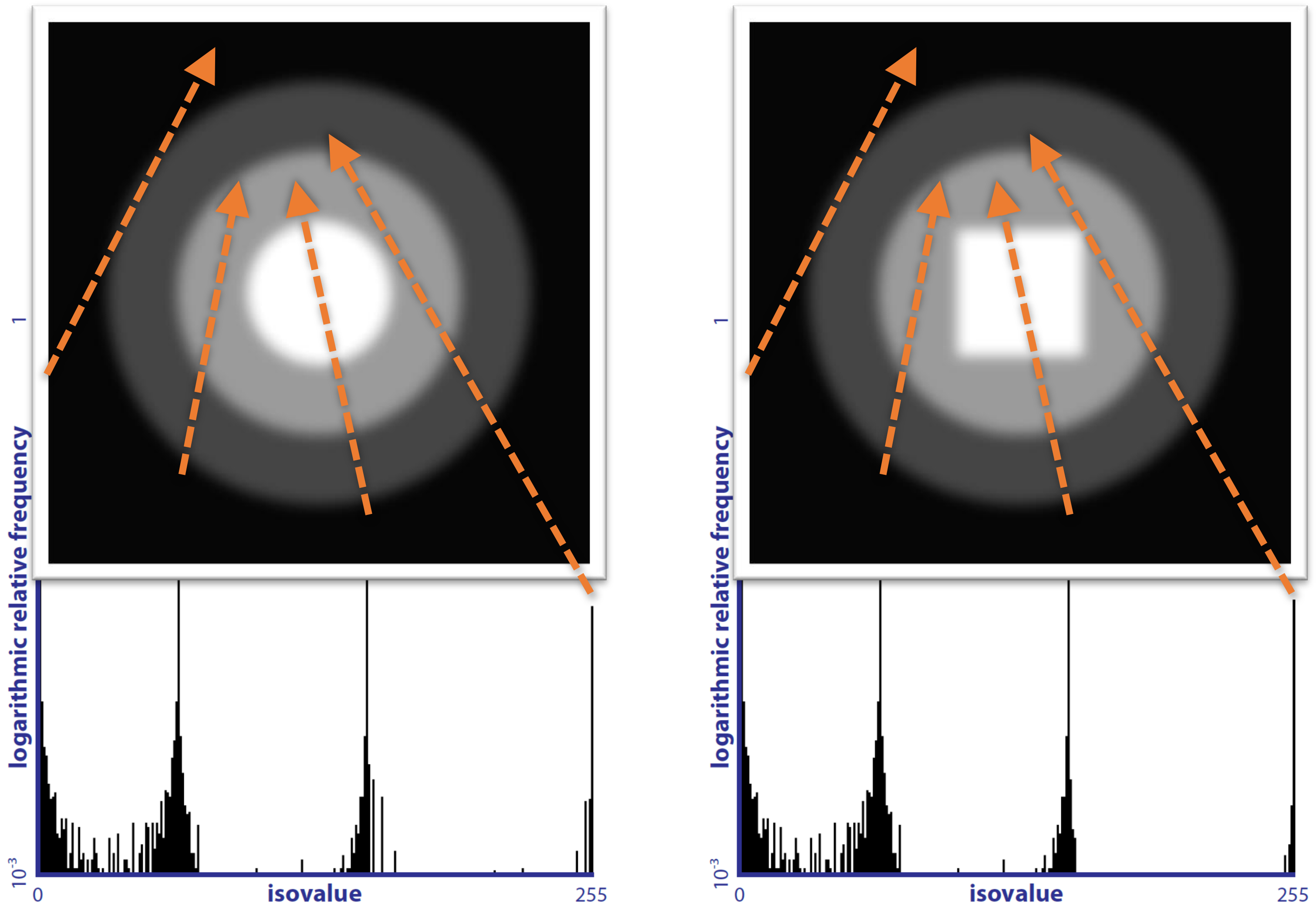
Statistical Signatures [Tenginaki et al. 2001]

- Localized k-order central moments
  - Mean over local window
  - Local higher order moment
- On-boundary region
  - 2^{nd} order moment locally max.
  - 3^{rd} order moment locally zero
  - 4^{th} order moment locally min.
  - Skew has zero crossing
  - Kurtosis const. min. of -2



skew vs. data value

Isovalue Similarity: Motivation [Bruckner & Möller 2010]



Isosurface Similarity: Approach [Bruckner & Möller 2010]

- **Treat isosurfaces as a whole**
  instead of individual voxels

- **Characterize the shape**
  of every isosurface

- **Quantify their similarity**
  by comparing all isosurface shapes

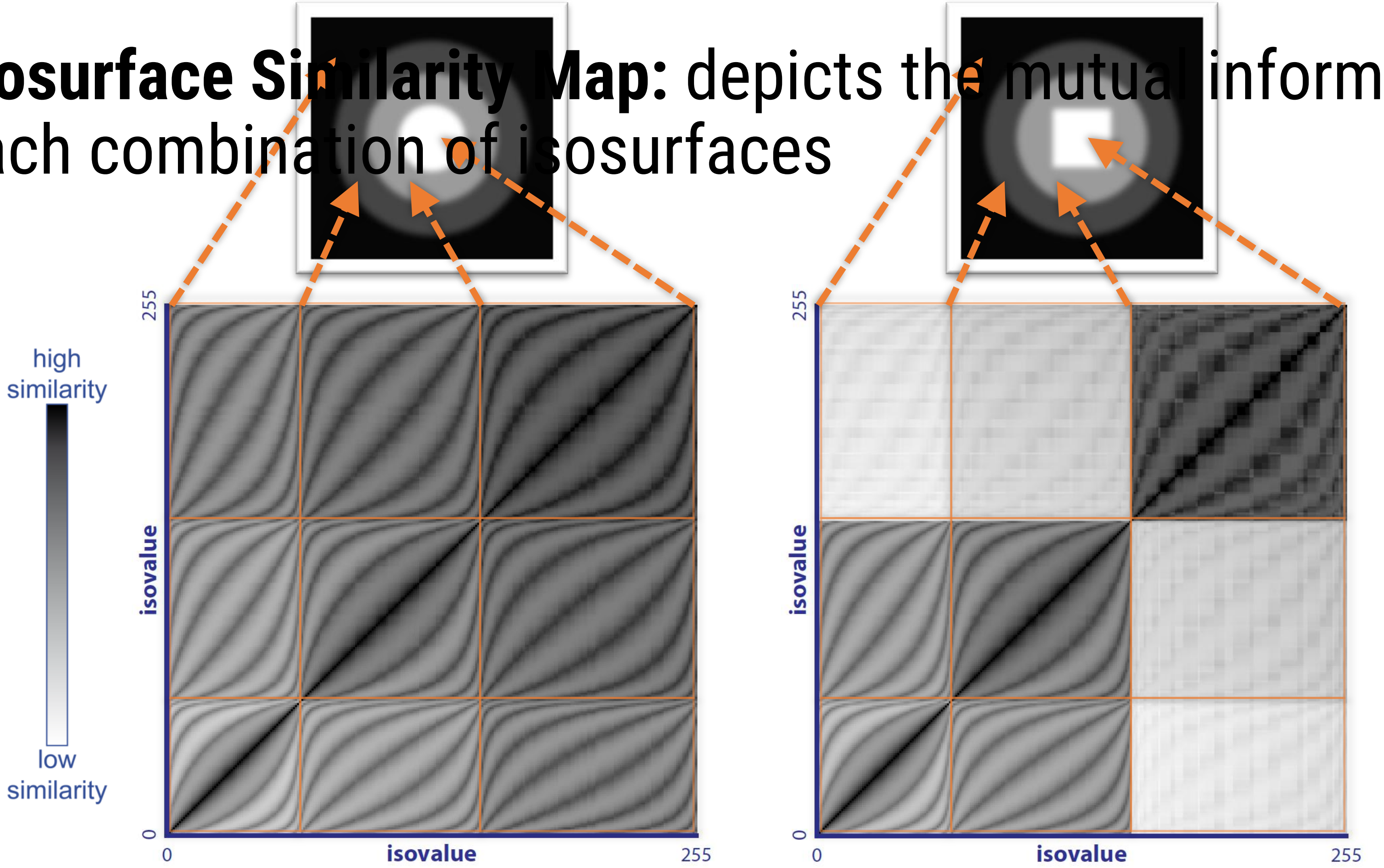
Isosurface Similarity: Measure [Bruckner & Möller 2010]

- Regard the distances to a pair of isosurfaces as **random variables** X, Y
  - Characterize the amount of information they share to evaluate similarity

- **Mutual Information:** Commonly used information-theoretic measure
  - Measures how much knowing one variable reduces the uncertainty about the other

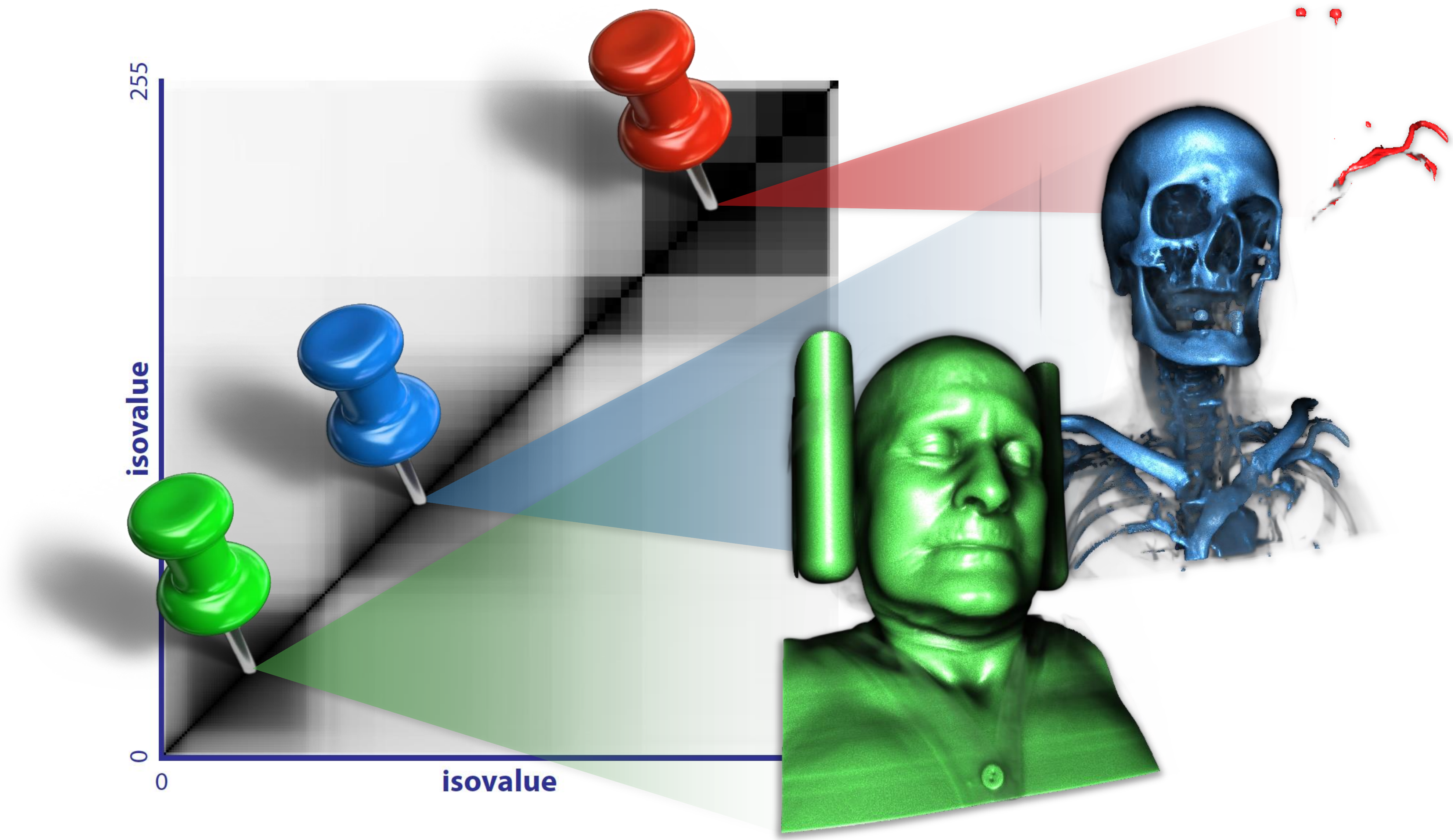
Isosurface Similarity: Example [Bruckner & Möller 2010]

- **Isosurface Similarity Map:** depicts the mutual information of each combination of isosurfaces



Isosurface Similarity: Detection [Bruckner & Möller 2010]

- Find “good” isovalues for a given data set without requiring parameter tuning
  - **Representative:** Each isovalues exhibits high similarity to many other isovalues
  - **Distinct:** The individual chosen isovalues have low mutual similarity
- Reorder all isovalues according to these criteria by recursively evaluating the similarity distribution


255
isovalue
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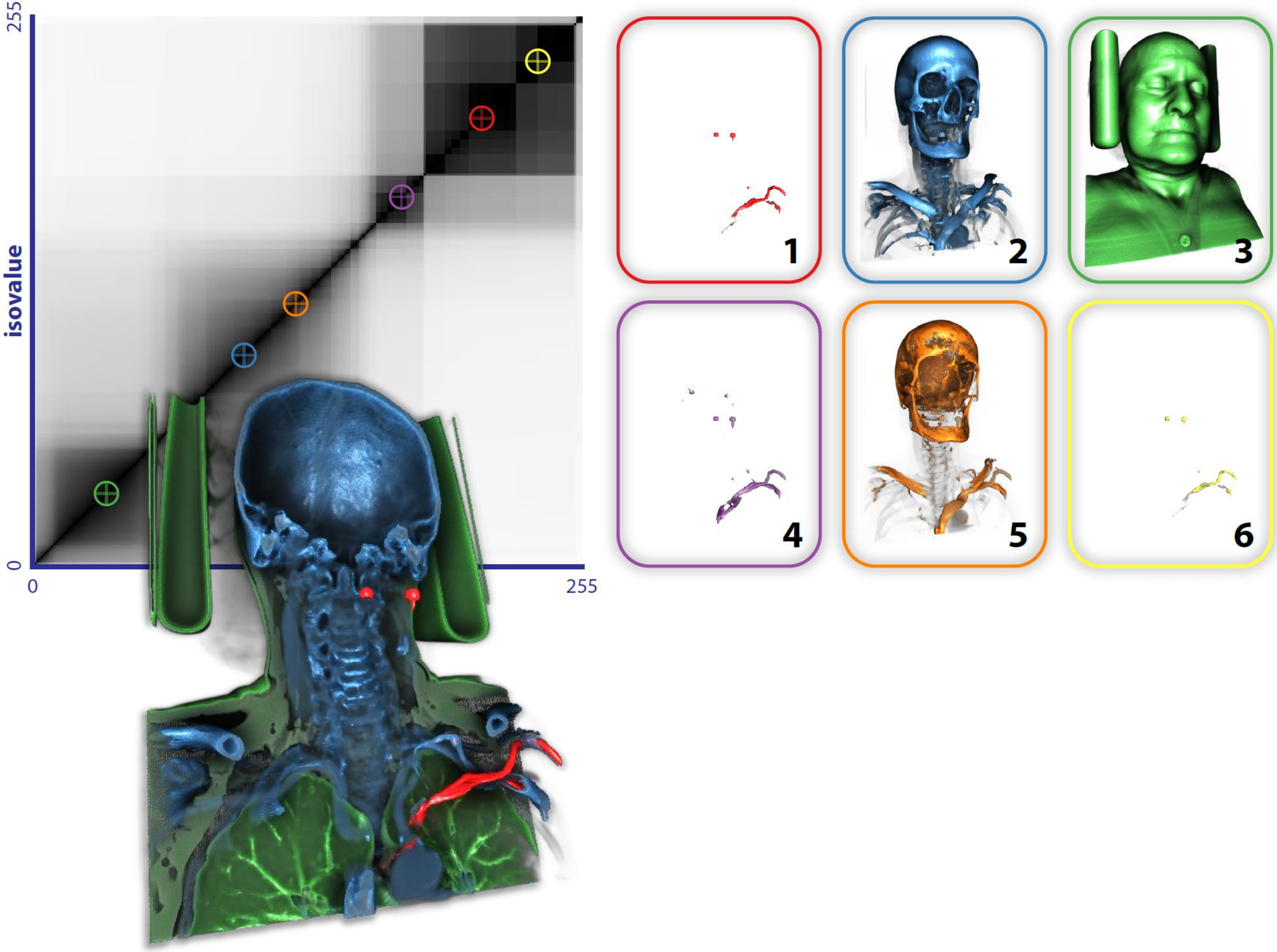

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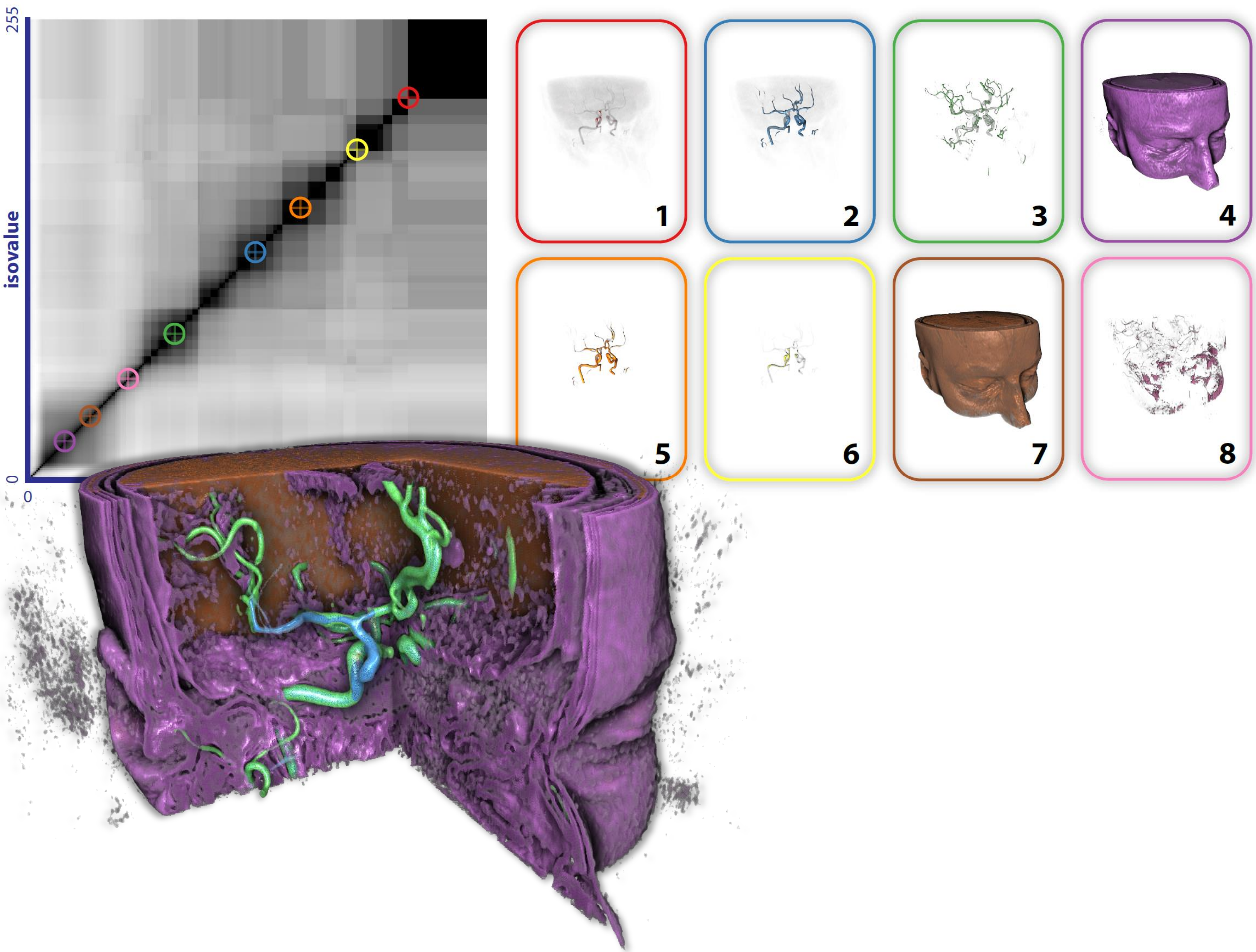
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8

Transfer Functions: Image-based Search

Design Galleries [Marks et al. 1996]

- General method of parameter specification problems
- Provide overview of the whole parameter space
  - Sampling the parameter space: dispersion
  - Organize the output images: arrangement

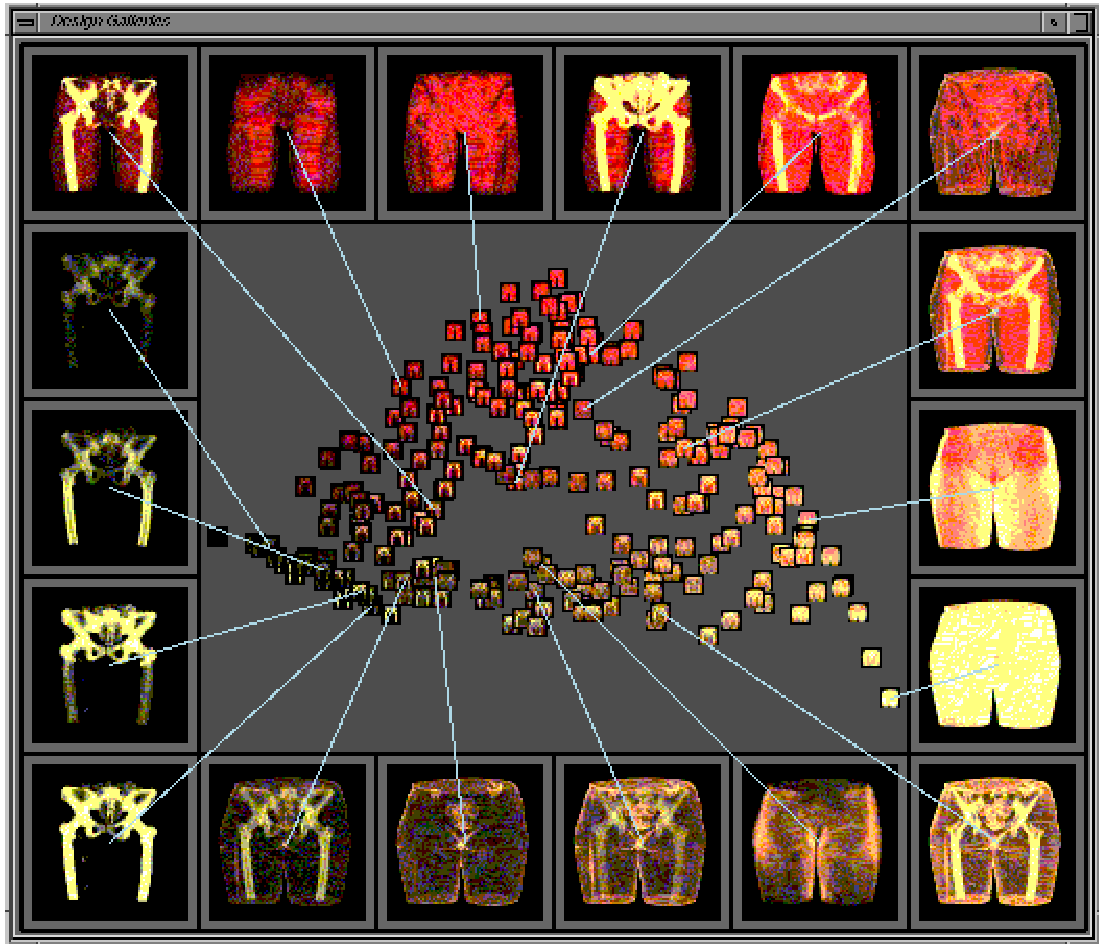
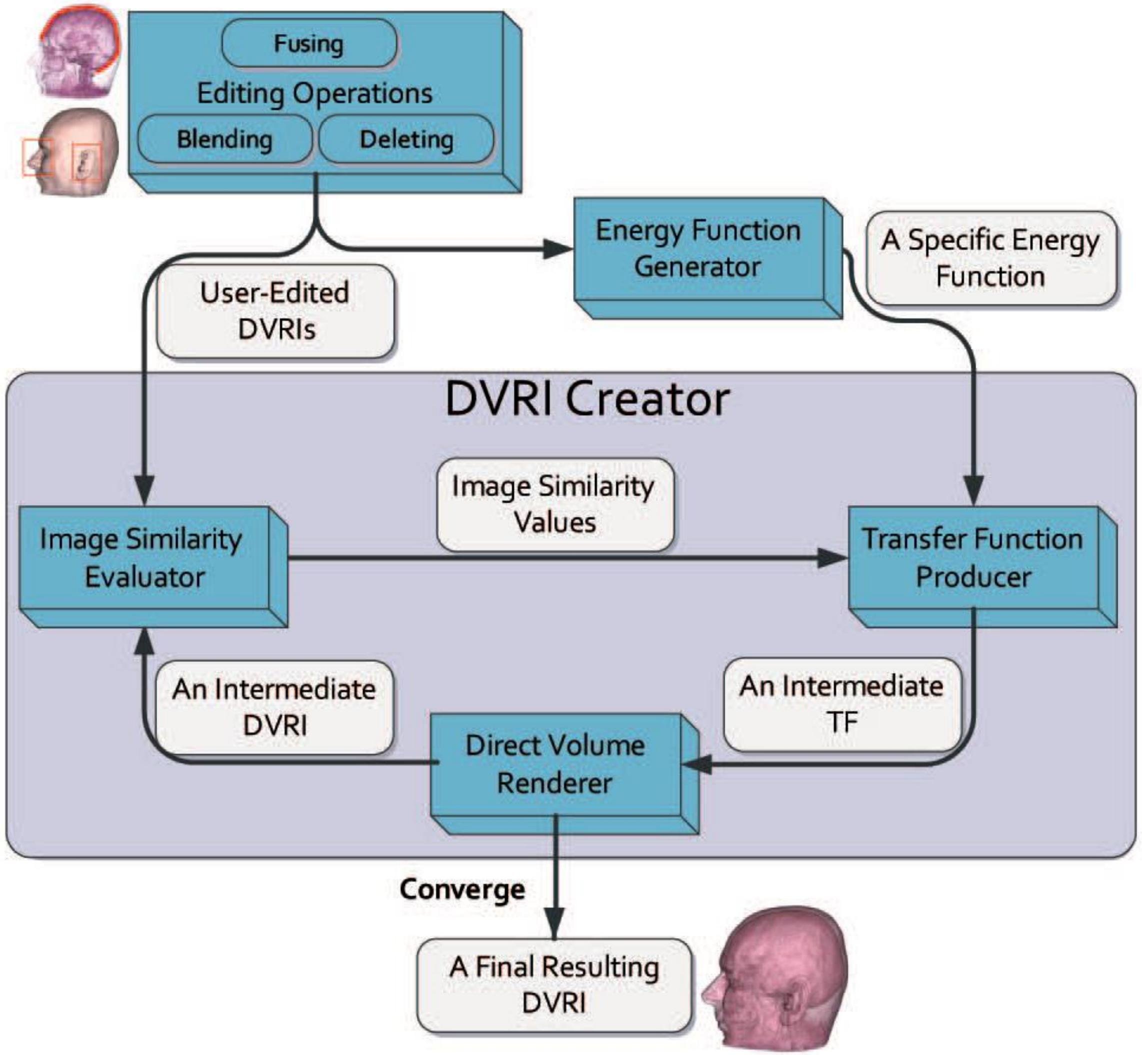


Image Editing [Wu & Qu 2007]

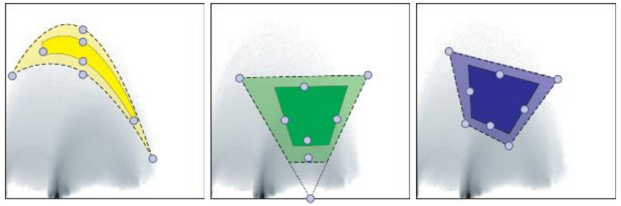
- Edit output images to indicate desired/undesired features
- Genetic algorithm to find transfer function which represents the image best



Transfer Functions: Feature-based

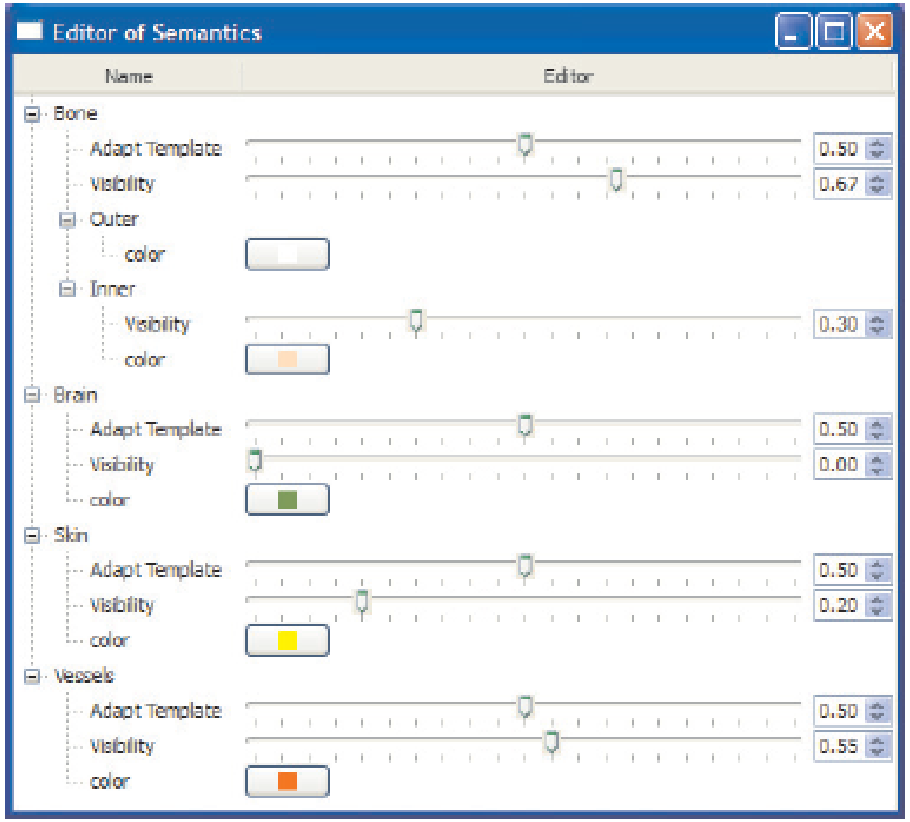
Transfer Functions: Semantics (1) [Resk Salama et al. 2006]

- General setup
  - Set of representative reference datasets
  - Set relevant entities (e.g. tissues: *bone*, *skin*, *brain,…*)
  - Transfer function template composed of primitives



- Transfer function template is adapted for each reference dataset → parameter vector p(i) for each dataset
- PCA on the parameter vectors to simplify the interaction space

Transfer Functions: Semantics (2) [Resk Salama et al. 2006]



Transfer Functions: Workflow Guidance

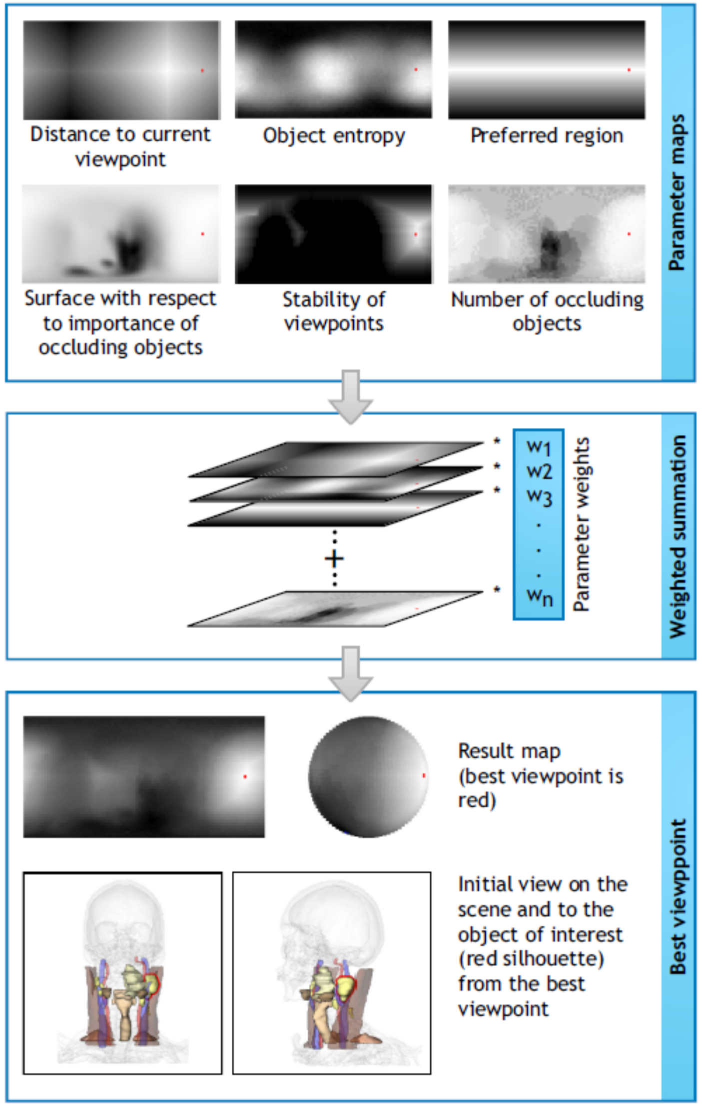
View Selection

View Selection: Unbiased [Bordoloi & Shen 2005]

- Generic set of criteria that describes the quality of a view
  - **View goodness:** voxel visibilities capture a user-specified importance function
  - **View likelihood:** number of other viewpoints which are similar to a given view
  - **View stability:** maximal change that can occur when the camera position is shifted within a small neighborhood
- Choice of importance function
  - Without additional information: opacity specified in the transfer function

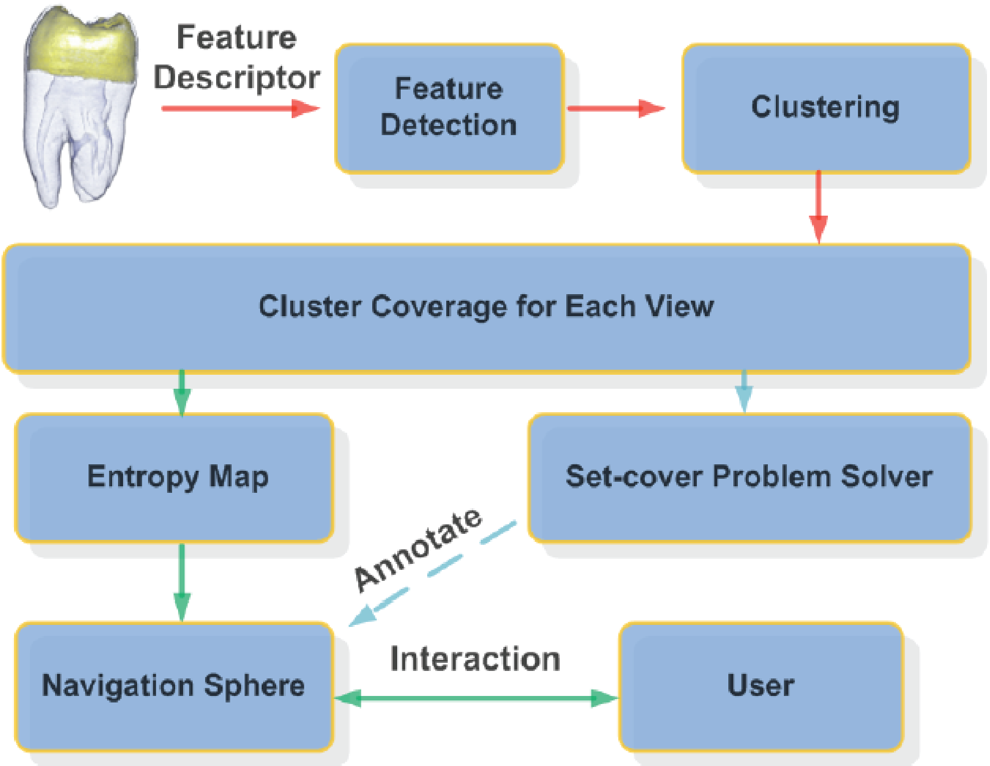
View Selection: Object-based [Mühler et al. 2007]

- Weighted parameter maps
  - Object entropy
  - Number of occluders
  - Importance of occluders
  - Size of unoccluded surface
  - Preferred region
  - Distance to current viewpoint
  - Viewpoint stability



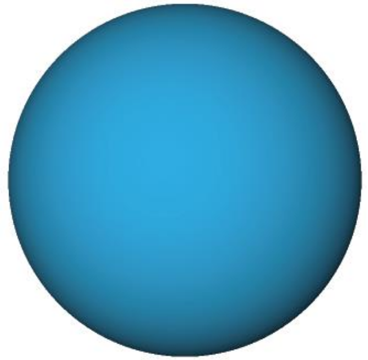
View Selection: Feature-based [Zheng et al. 2011]

- Multi-dimensional feature descriptor (transfer function independent)
  - Scalar value
  - Gradient magnitude
  - Voxel coordinate
- Clustering in feature space
- Fitting of 3D ellispoids

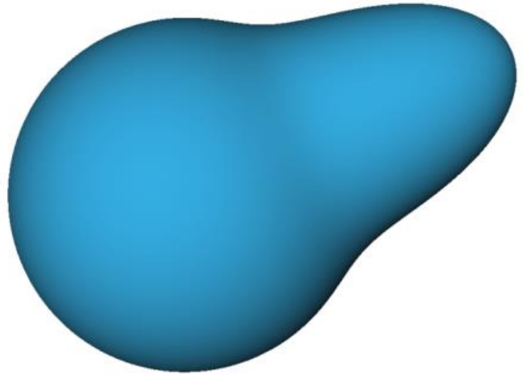


View Selection: Point-based [Kohlmann et al. 2008]

- Best 3D view for a picked point of interest, e.g. mouse location on a 2D slice (“LiveSync”)
- Good viewpoint is determined by several potentially conflicting criteria
- Criteria are represented as viewing spheres which encode view “goodness”

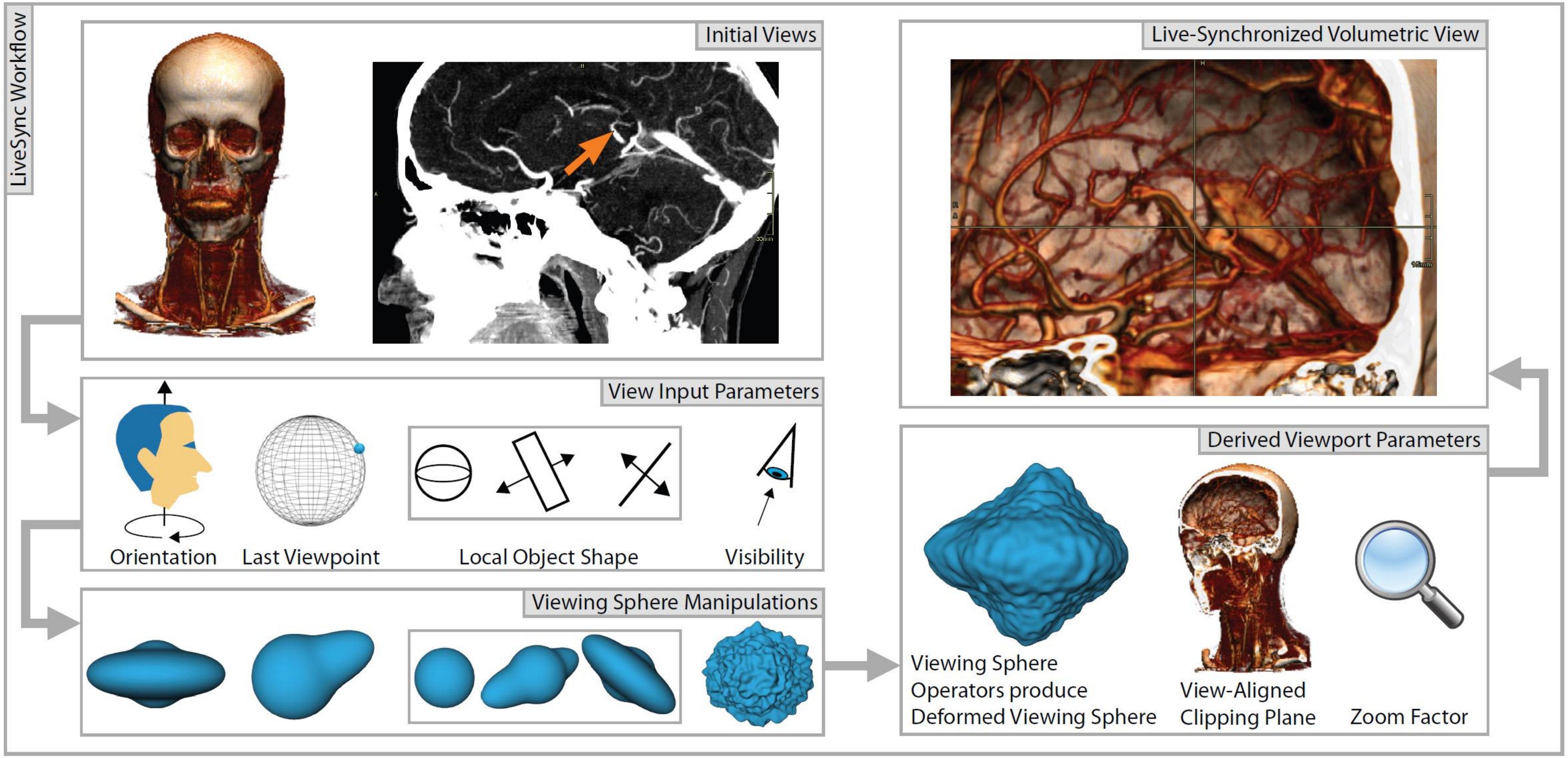


all viewpoints equally good



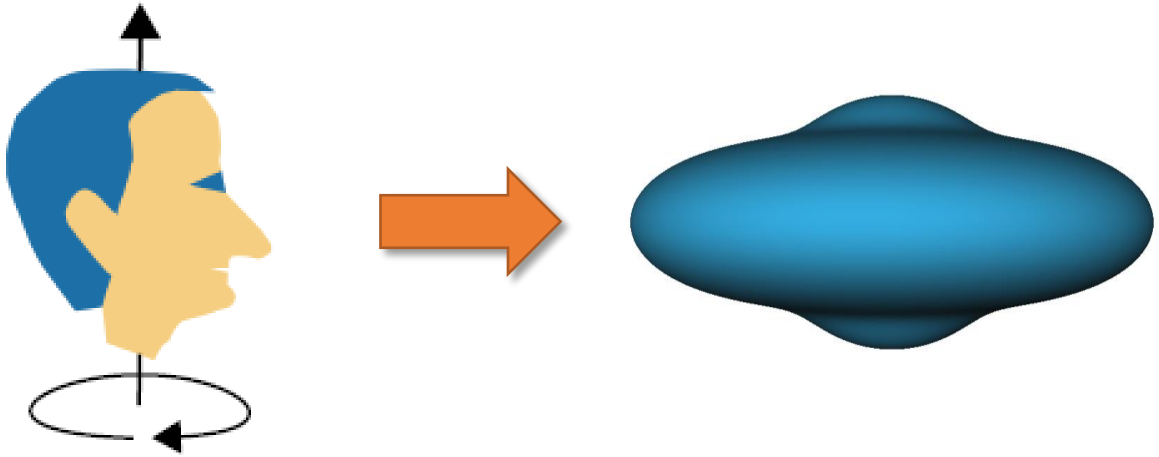
preferred viewing direction

LiveSync Workflow



Patient Orientation

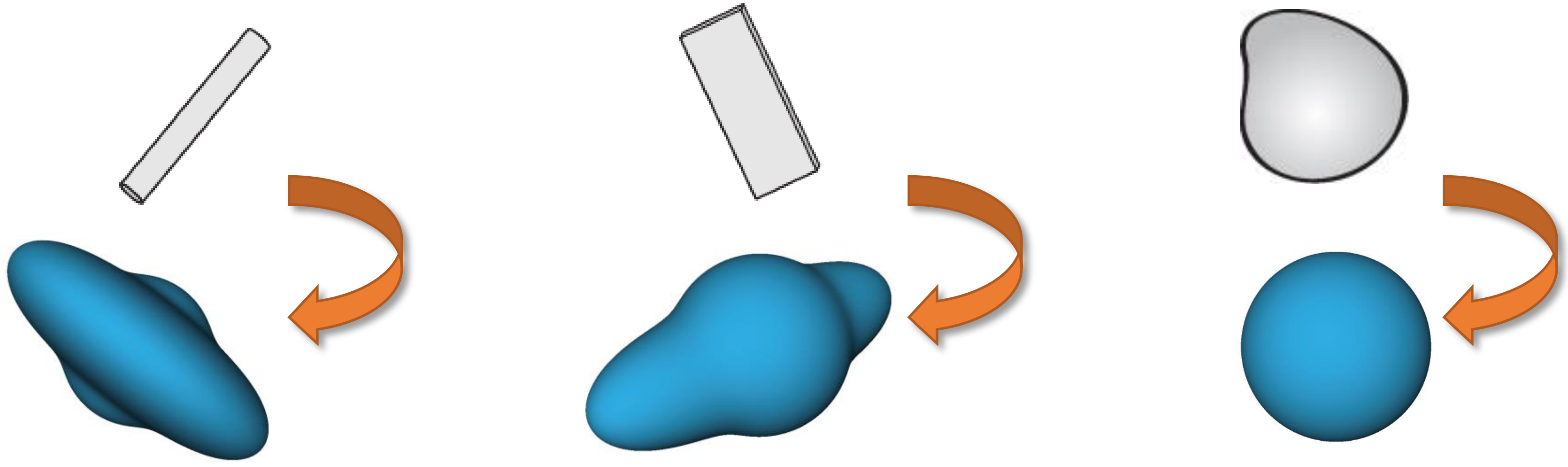
- Consider preferred viewing directions according to type of examination
- Head-feet axis serves as rough estimation to derive preferred viewpoints



Feature Shape

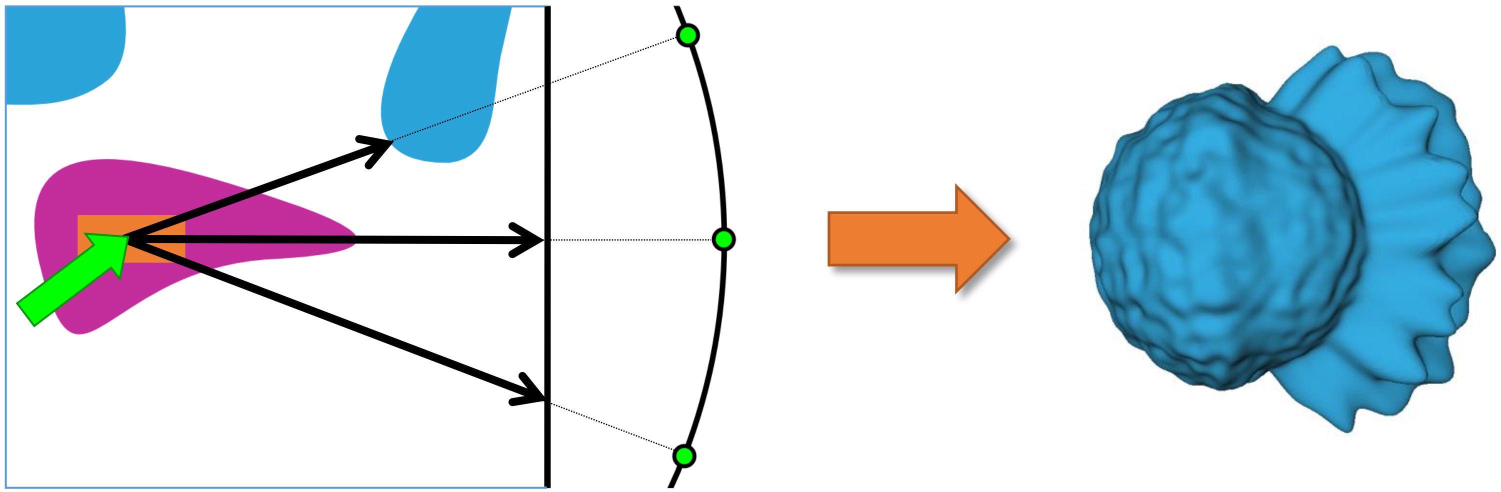
- Consider local shape of structure of interest
- Local region growing (picked point as seed)
- Principal component analysis on result

$\lambda_1 >> \lambda_2 \approx \lambda_3$ $\quad$ $\lambda_1 \approx \lambda_2 >> \lambda_3$ $\quad$ $\lambda_1 \approx \lambda_2 \approx \lambda_3$



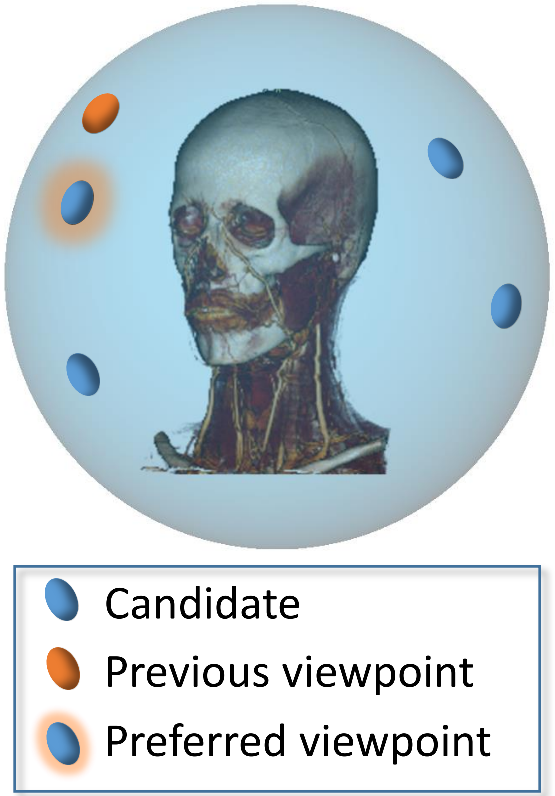
Feature Visibility

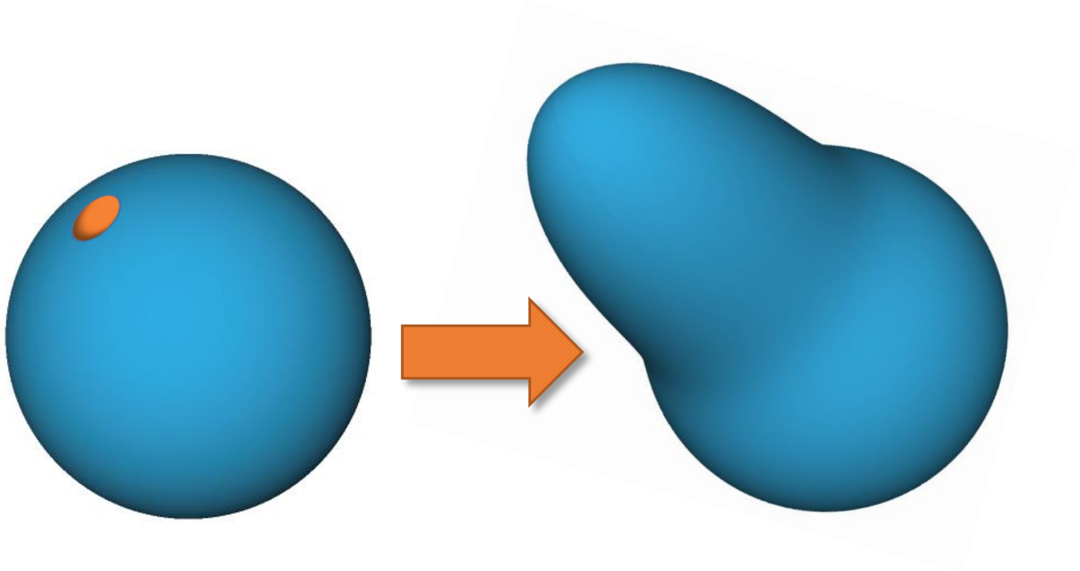
- Include information about occlusion
- Cast & analyze visibility rays
  - Exit of tissue of interest
  - Distance to occluding objects



Viewpoint History

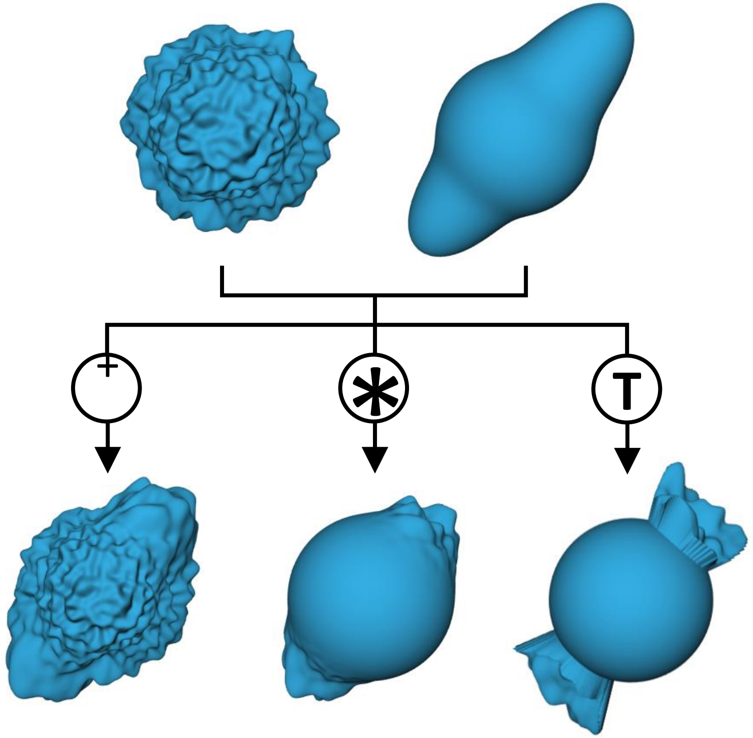
- Avoid big shifts for successive pickings
- Prefer viewpoints closer to the previous one





Combination

- Final viewpoint estimated based on combined viewing sphere for the different criteria



Summation

Intuitive approach

Good results

Multiplication

Emphasize characteristics

High impact of low values

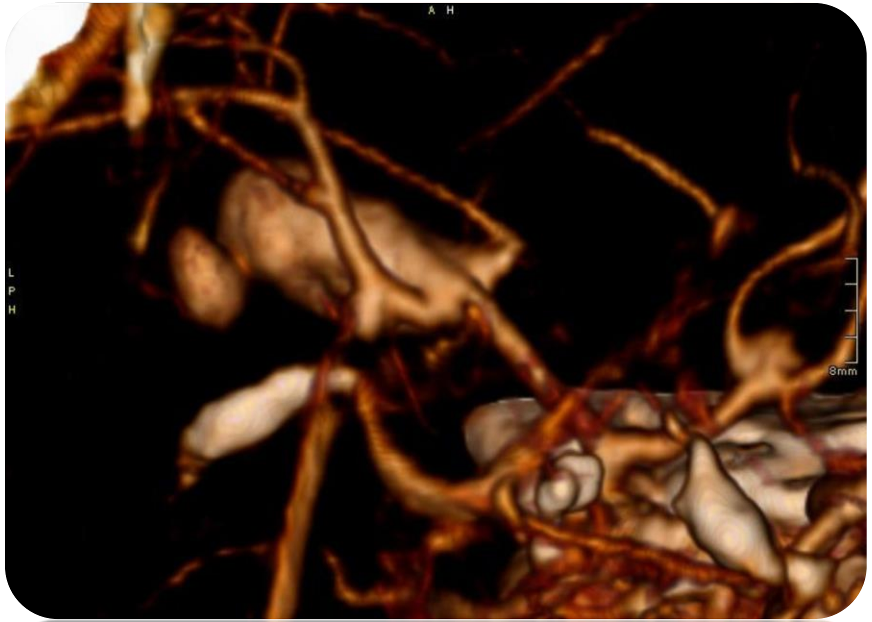
Thresholding

Preferred sphere

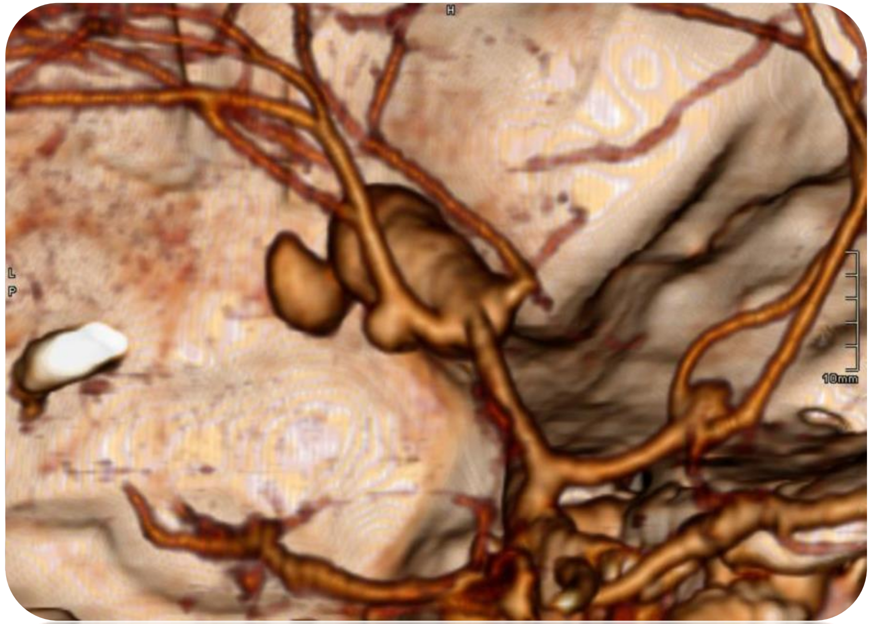
Definition of knock-out criteria

Results (3)

- Aneurism



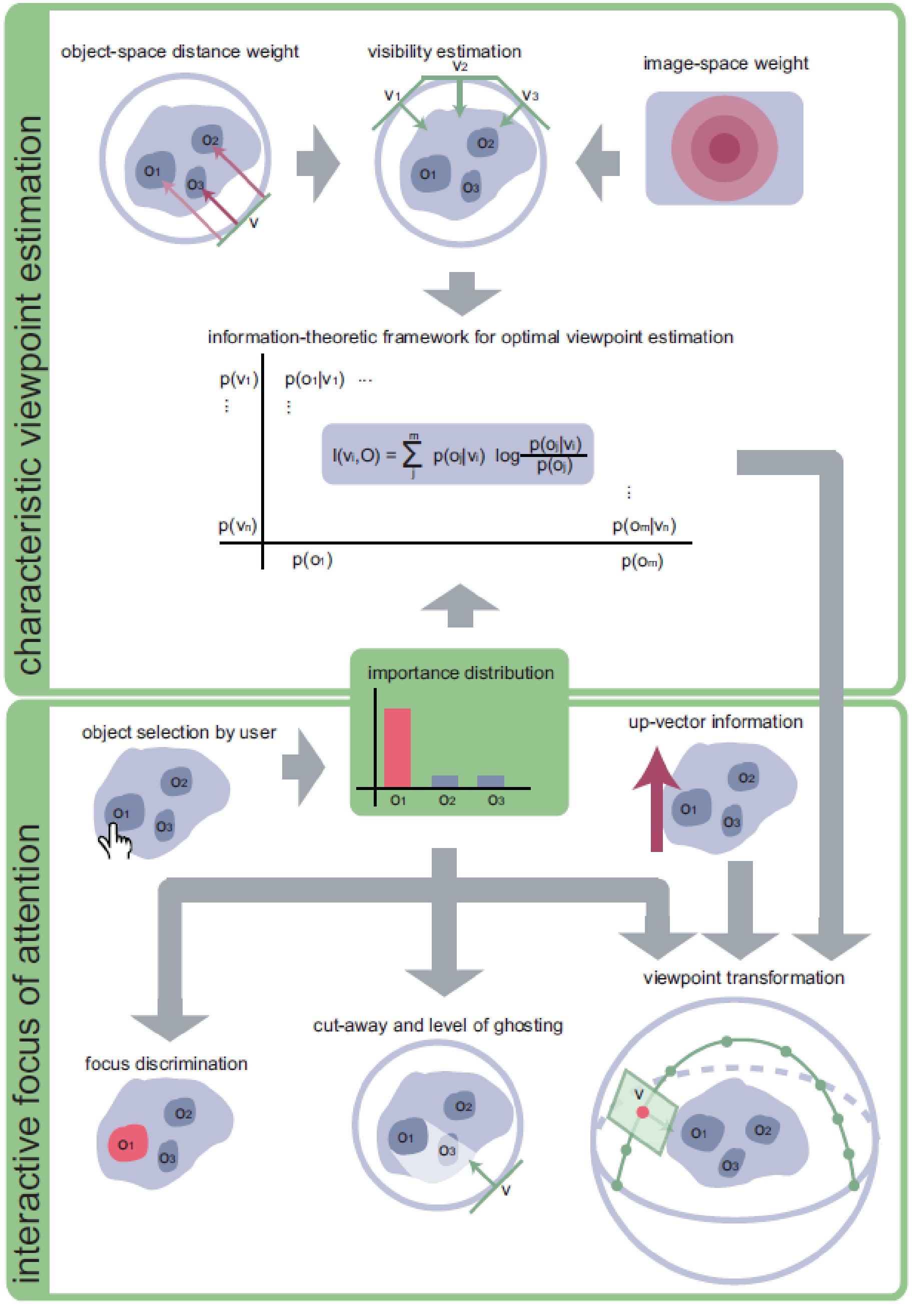
manual setup
(~ 1:50 min)



LiveSync
automatically generated
(< 1 sec)

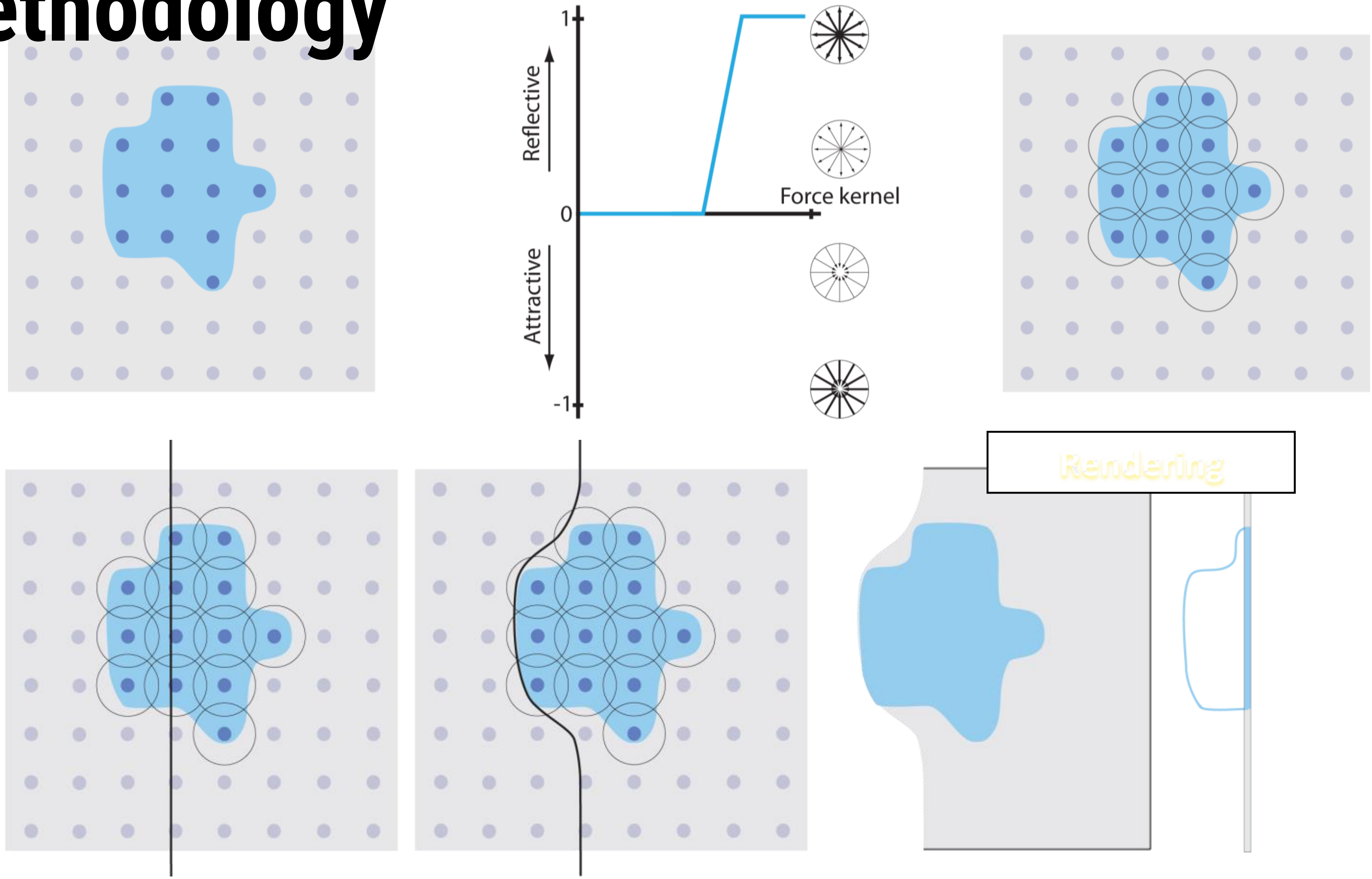
View Transitions [Viola et al. 2006]

- How to move from one view to another? (e.g., in a "guided tour" of the most important structures)



Clipping Structures

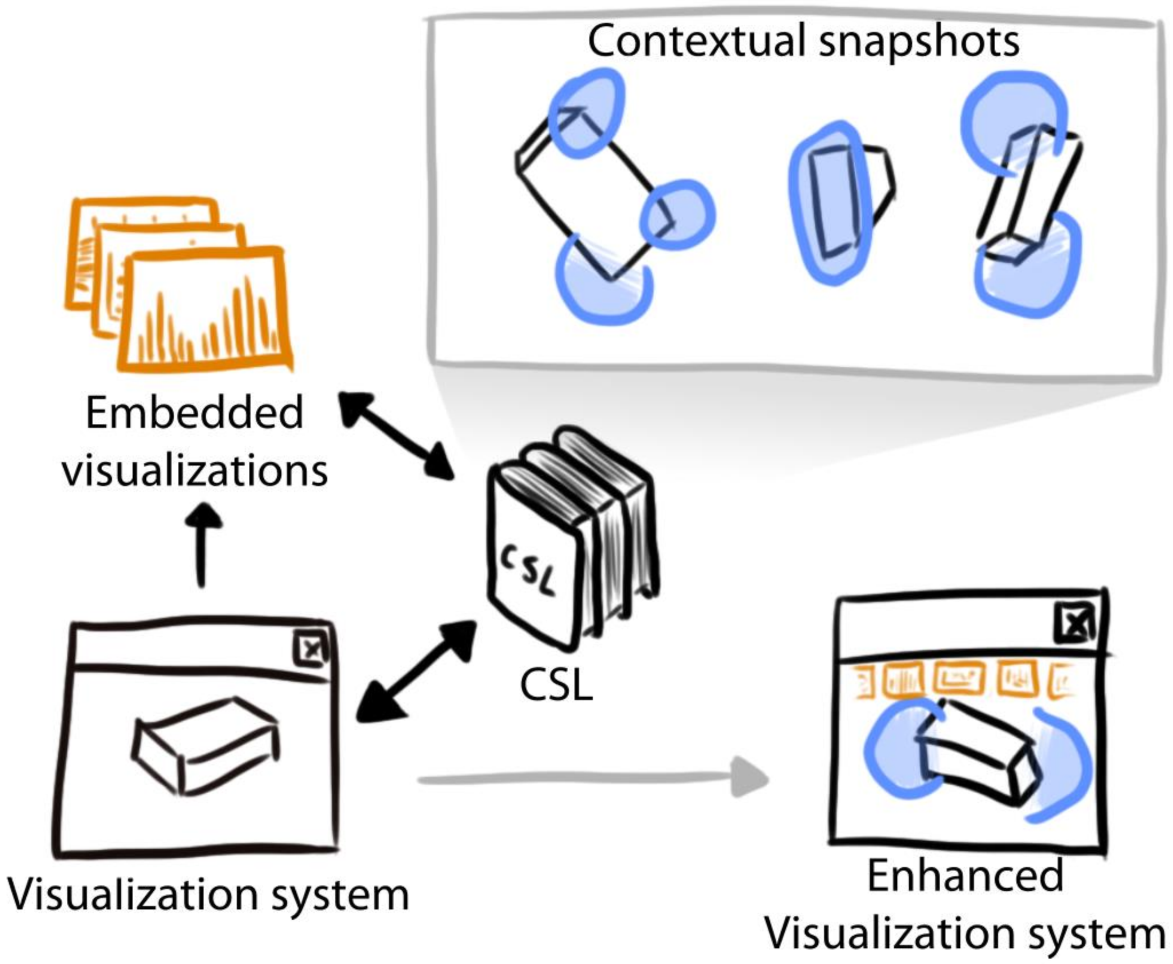
Methodology



Perceptually Linear Parameter Variation

Selection Management [Mindek et al. 2013]

- Spatial selections are tied to specified visualization parameters (you select what you see)
- Manage visualization parameters together with selections
- Generic API, not restricted to volume visualization http://www.cg.tuwien.ac.at/downloads/csl/



Perceptual Linearization [Lindow et al. 2012]

- Influence of changes in parameters is often highly non-linear with respect to changes in the image

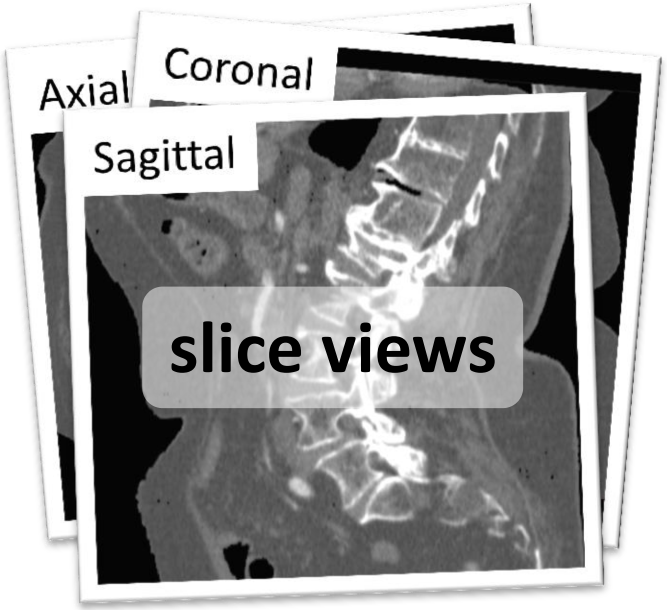
Similarity-based Linearization of (1)

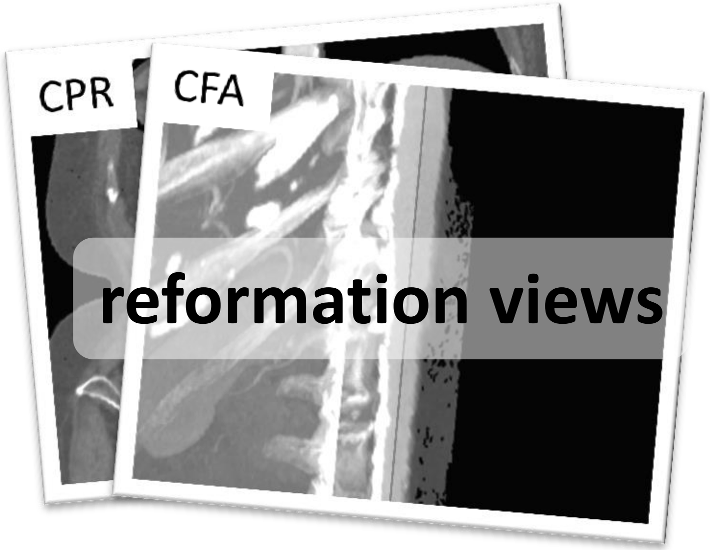
- Mapping between user interface and isovalue is typically linear
  - Examples are slider widgets, mouse movement, etc.
  - Data-dependent nonlinear visual response to user interaction
  - Makes it more difficult to investigate transitional value ranges
- Control derivative of the mapping function using the similarity between neighboring isovalues

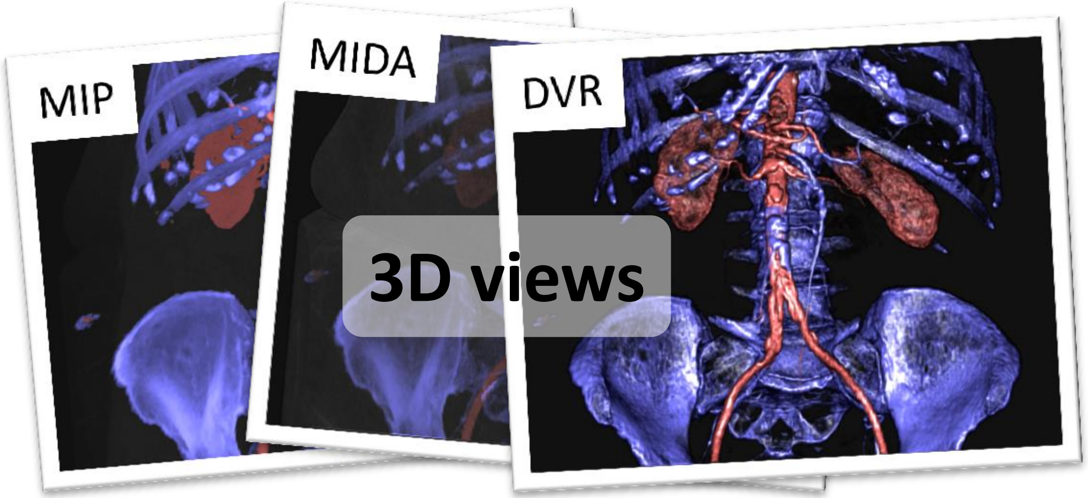
Similarity-based Remapping (2)

Medical Workstations

- Multiple high-resolution diagnostic monitors
- Many different views (identified by weird acronyms)
- Parameters, options, and settings gallore


Axial
Coronal
Sagittal
slice views

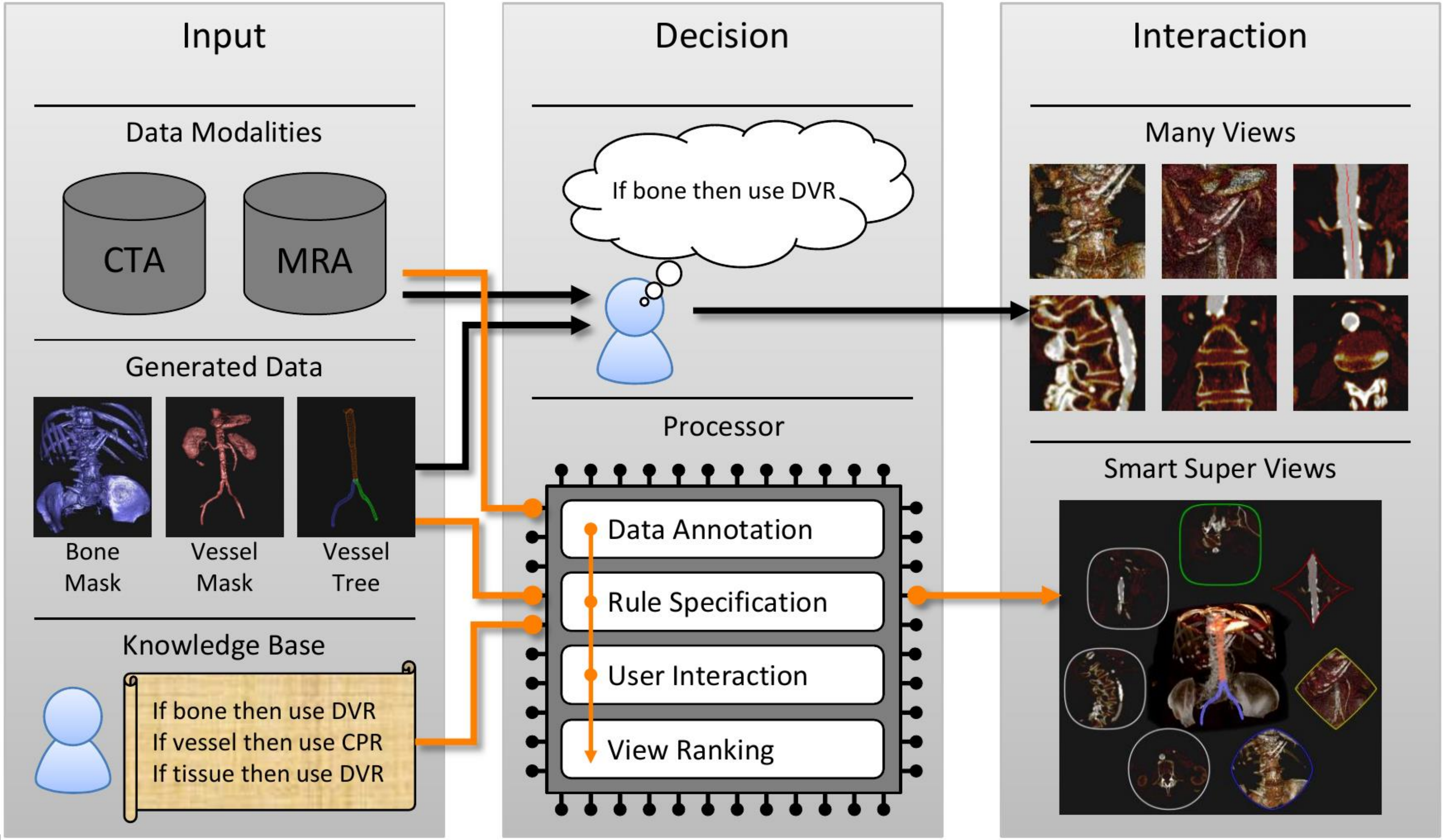

CPR
CFA
reformation views


MIP
MIDA
DVR
3D views

Smart View Concept

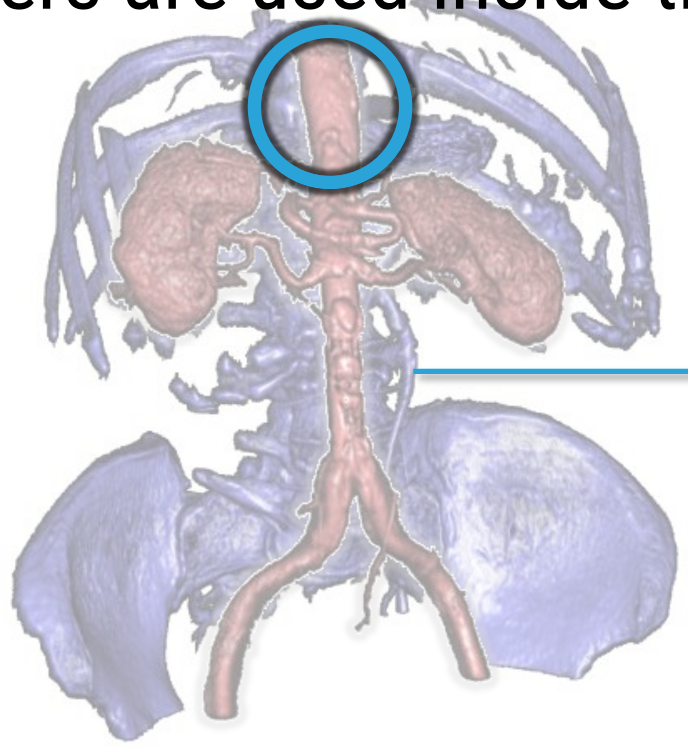
- Menus, panels, and toolbars are artificial and unfamilar constructs (a lightbox has no menu)
- Images should be central, radialogists know how to interpret them
- Usefulness of individual views depends on the context

Approach: avoid additional scaffolding – the image itself becomes the user interface


Input
Data Modalities
CTA
MRA
Generated Data
Bone Mask
Vessel Mask
Vessel Tree
Knowledge Base
If bone then use DVR
If vessel then use CPR
If tissue then use DVR
Decision
If bone then use DVR
Processor
Data Annotation
Rule Specification
User Interaction
View Ranking
Interaction
Many Views
Smart Super Views

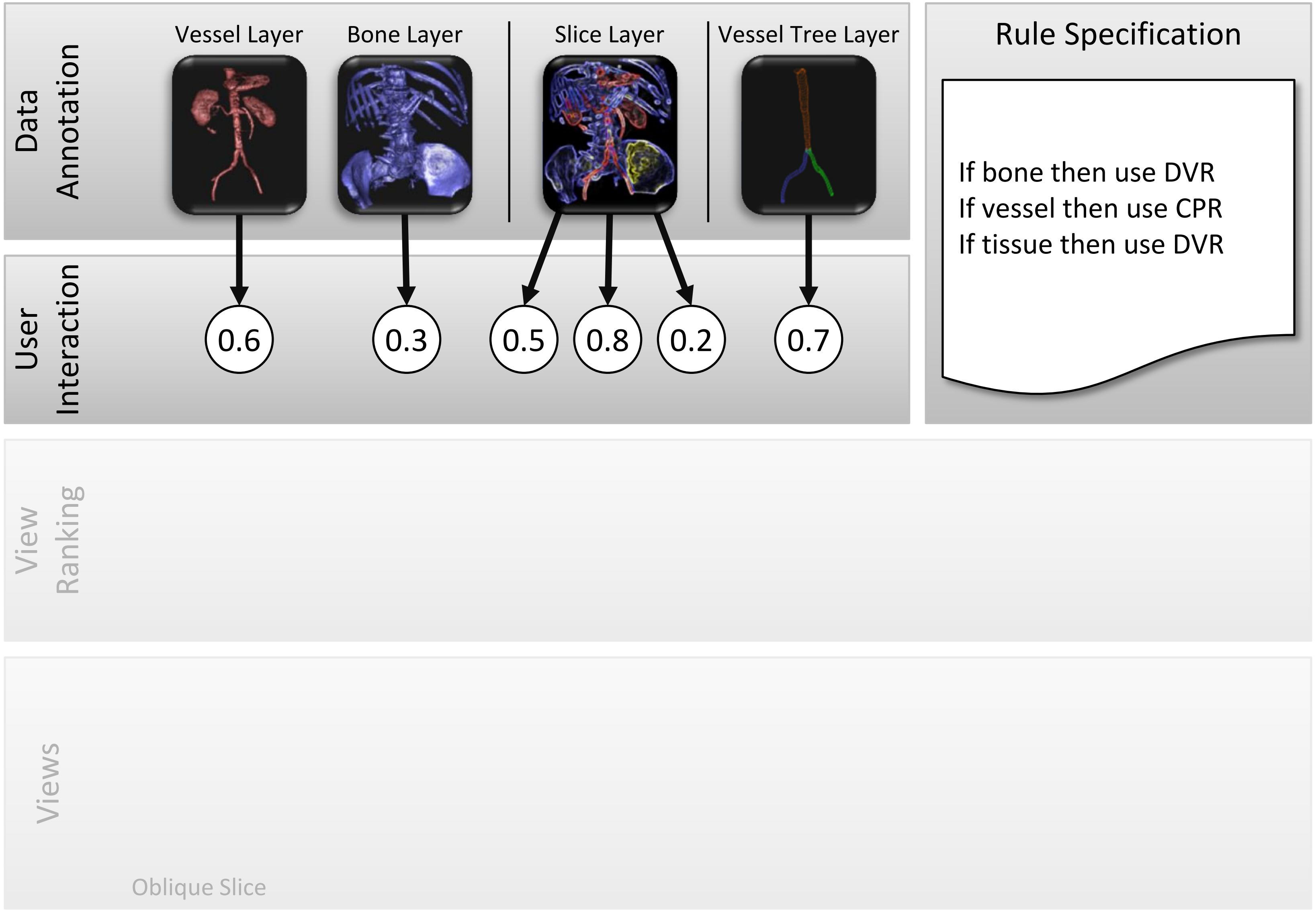
User Interaction

- User defines a ROI by moving the mouse
- Compute input values for all variables
- Layers are used inside the ROI



- One value for every input variable
- Sum over all pixels inside the ROI
- Pixels weighted with distance to center
- Specific layers for input variables

Smart Views (5)

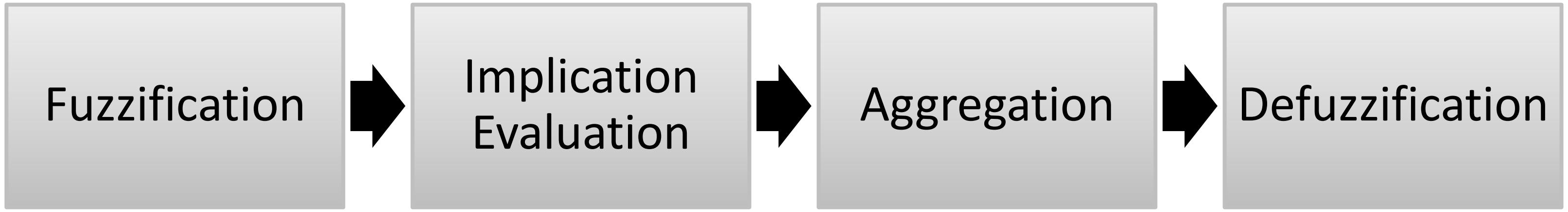


View Ranking

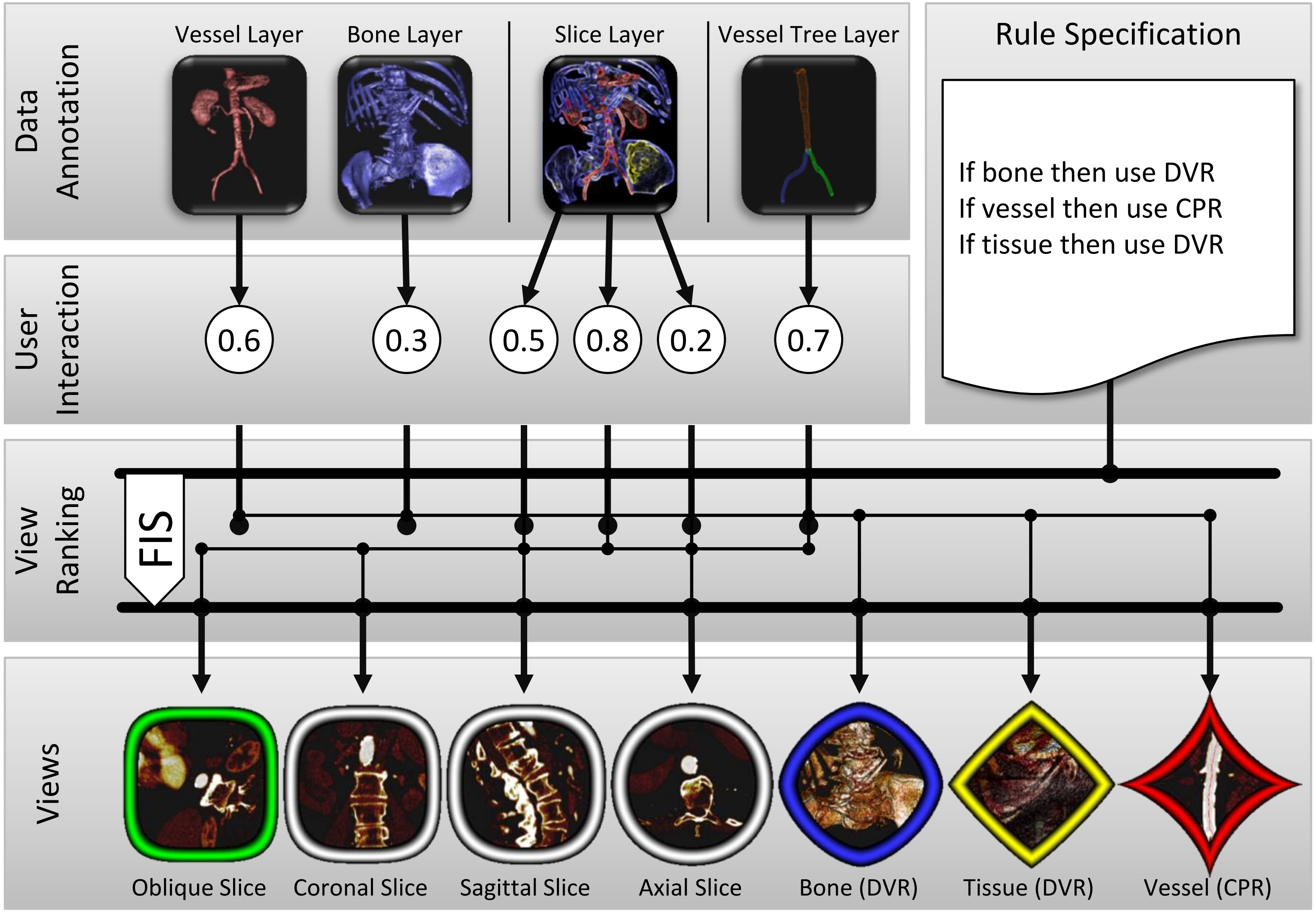
- Fuzzy logic for the inference system

⇒Fuzzy Inference System

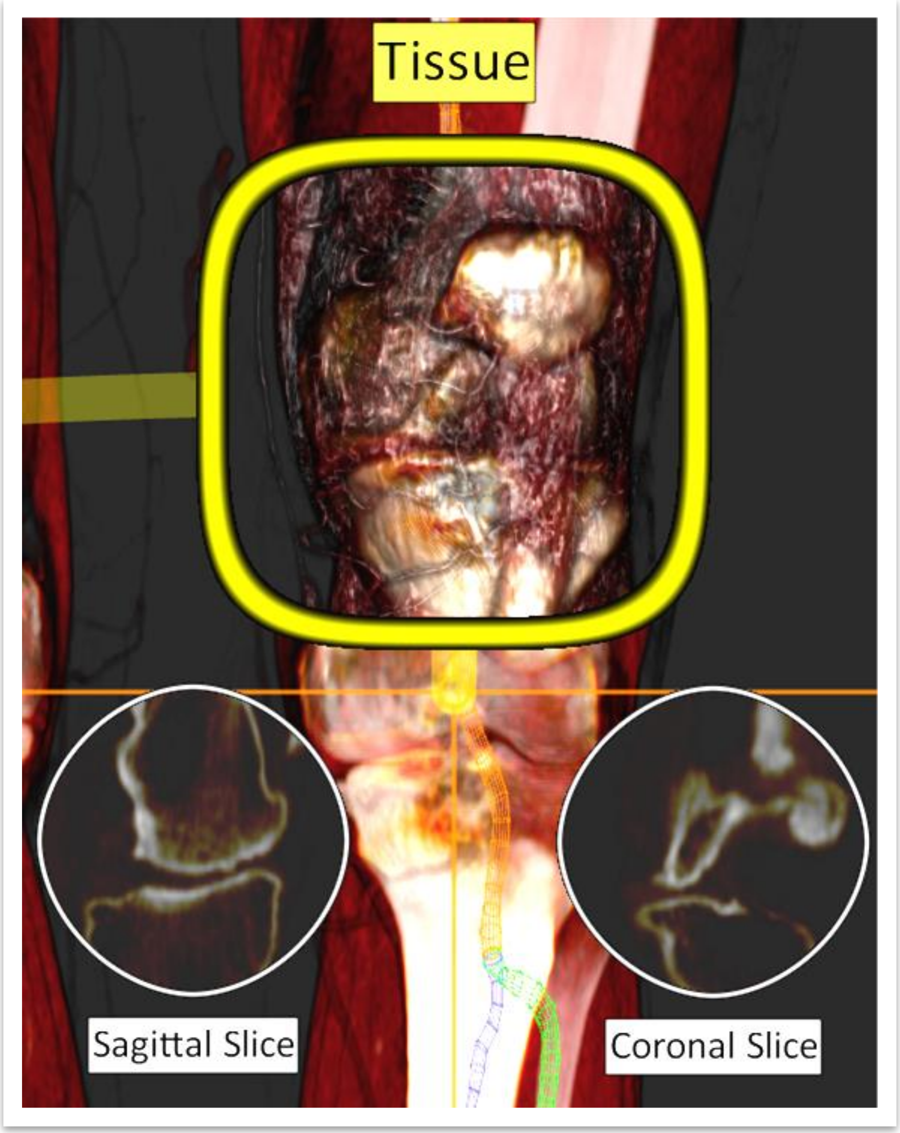
⇒Fuzzy rules specified by domain experts



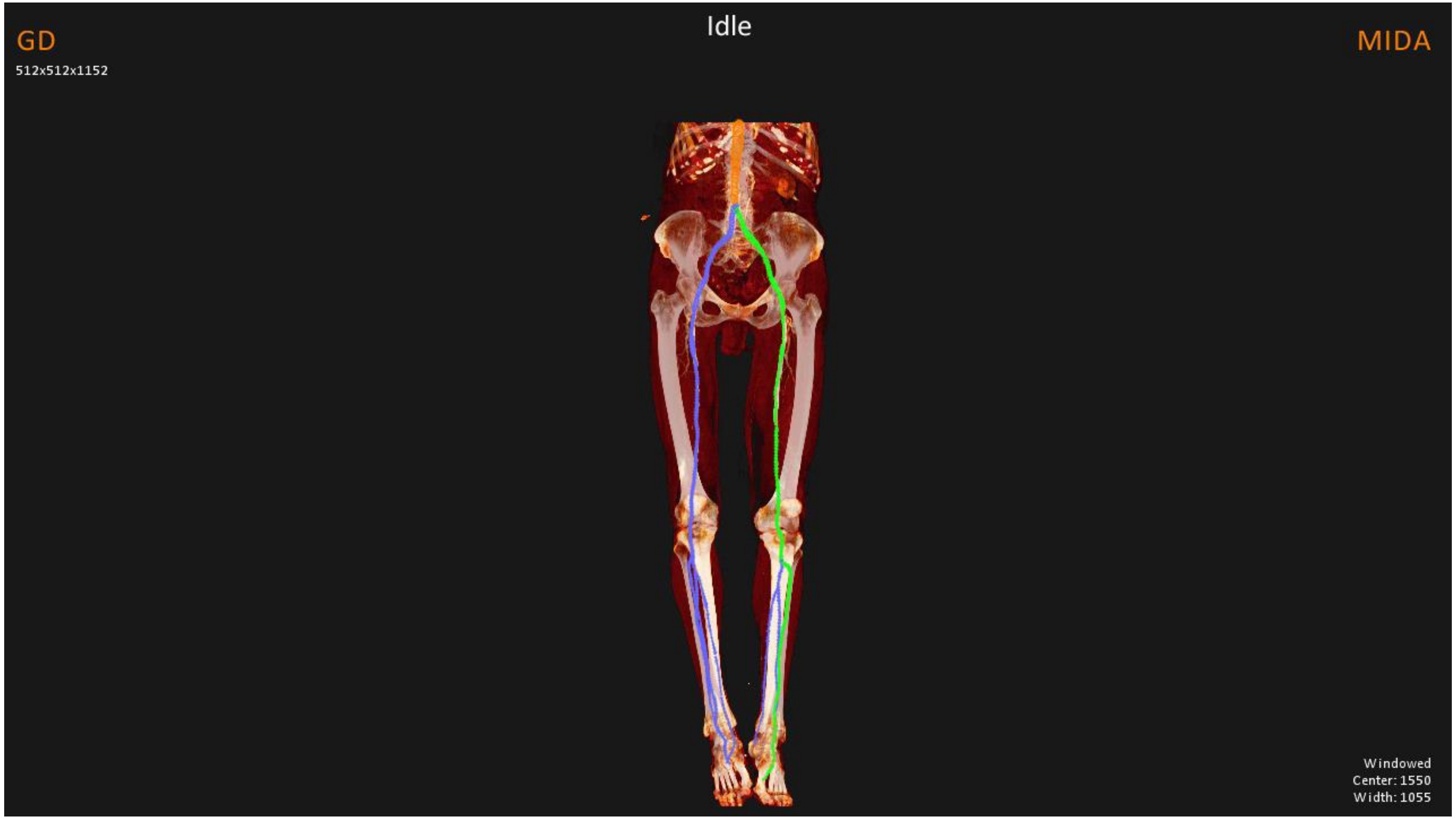
Smart Views (6)



Integrated Smart Views



Demonstration

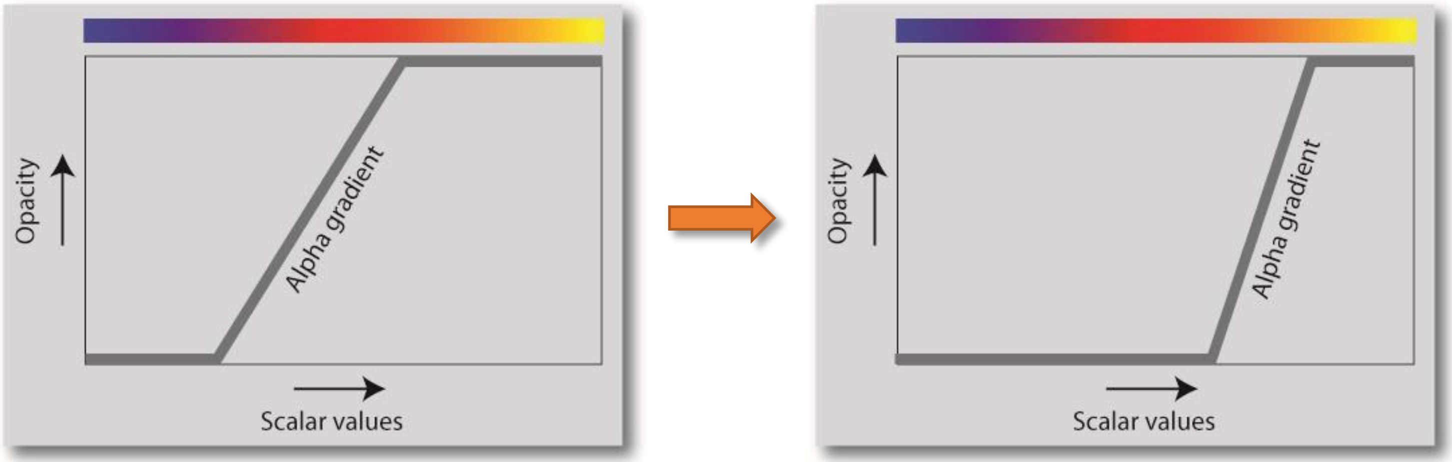


Transfer Function Adjustment (1)

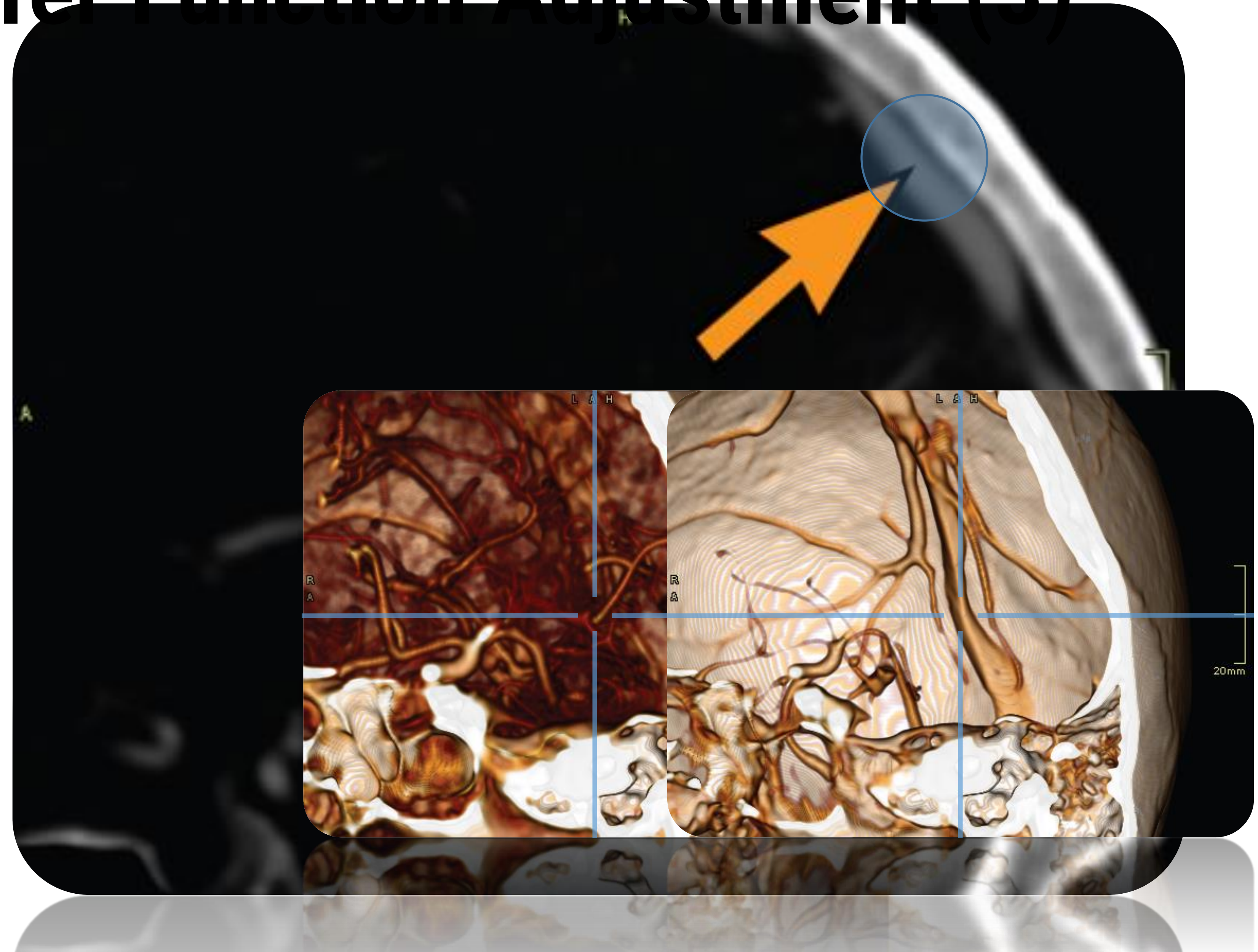
- DVR uses a transfer function to map data values to colors and transparencies
- Completely automatic transfer function setup is very difficult to achieve in practice
- At least ensure sharp depiction of picked structure
- Use mean value and standard deviation of growing region

Transfer Function Adjustment (2)

- Adjust opacity ramp for a predefined color table
- Center of ramp placed at mean value, slope set based on standard deviation



Transfer Function Adjustment (3)



Clipping Plane Specification

- Tissue intensities are not unique for many modalities
- Transfer function adjustment may result in occlusion of a picked structure
- Automatically place clipping plane to reveal occluded object
- Use visibility ray information obtained during viewpoint estimation