Medical Visualization

Uncertainty Visualization in Medical Volume Rendering Using Probabilistic Animation
Uncertainty-Aware Guided Volume Segmentation

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Visualization in clinical work

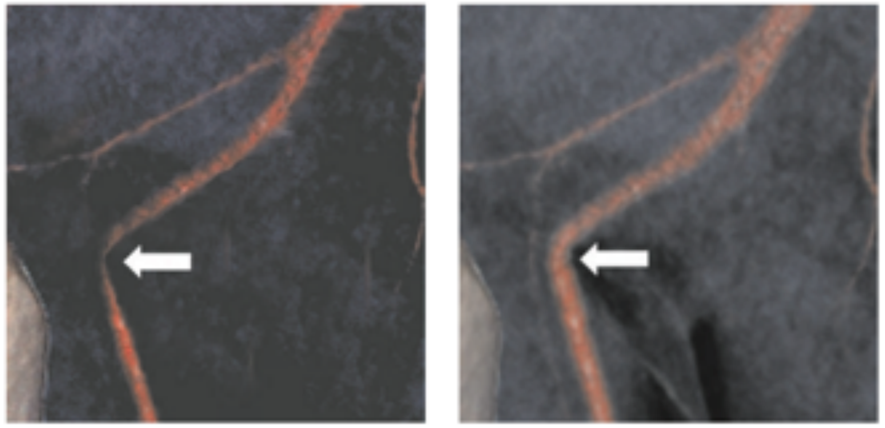
- Modern techniques like Direct Volume Rendering (DVR) are routinely used in the clinical work
- Still challenges where existing approaches are insufficient

Visualization in clinical work

Simplest approach for Direct Volume Rendering (DVR):

- Using static, pre-defined Transfer Functions (presets)
  —> common in actual clinical usage

- Issue: Individual variations between patients and diagnostic tasks



a b

Fig. 1
Misleading preset TF
a) shows stenosis
b) changed parameters —> no stenosis!

Visualization in clinical work

Radiologists employ manual TF (Transfer Function) adjustments to study several possible outcomes

Problems:

- Time-consuming
- Not performed in a controlled manner —> not all relevant parameters can be explored
- No ideal unbiased exploration of all possibilities

Discussed Papers

Uncertainty Visualization in Medical Volume Rendering Using Probabilistic Animation

Clas Lundström, Patrick Ljung, Anders Persson, Anders Ynnerman,
IEEE Transaction on Visualization and Computer Graphics 13, 6 (2007)

Uncertainty-Aware Guided Volume Segmentation

Jörg-Stefan Praßni and Timo Ropinski and Klaus Hinrichs
IEEE TVCG, vol. 16, no. 6, pp. 1358-1365, 2010.

Discussed Papers

1 Uncertainty Visualization in Medical Volume Rendering Using Probabilistic Animation

"In this paper uncertainty visualization methods are proposed that aim to increase the accuracy and efficiency of DVR as a diagnostic tool."

Uncertainties in visualization

- Uncertainties are inherent in TF (Transfer Function) classification
- Highly relevant to explore these uncertainties
- Need to separate the classification and the rendering appearance control of the TF
- Here: a number of animation schemes are defined to convey relevant uncertainty

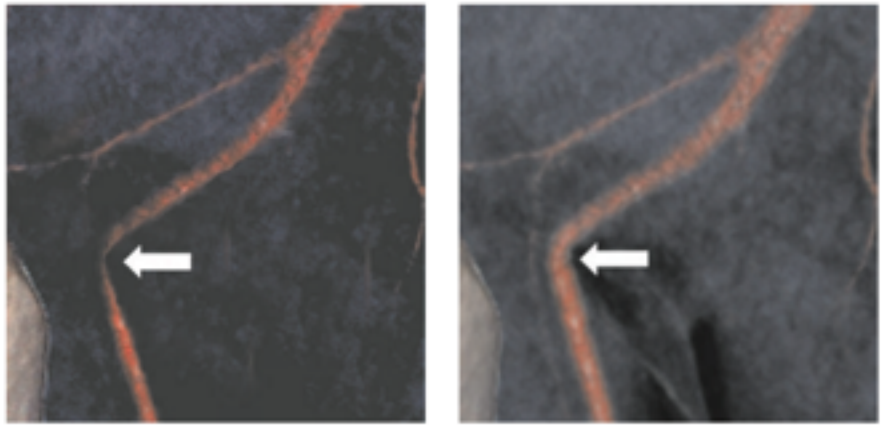


Fig. 1
uncertainties in classification

Probabilistic Animation

- Image regions corresponding to confident tissue classification —> will be static
- Uncertain parts will change over time
- For each sample, the probability of a material is reflected by the nr. of frames in the animation cycle

Choosing the right Transfer Function

Two main views on Transfer Functions (TF)

1. Implicit probabilistic view

TF is seen as a direct mapping from sample value to a color

- Currently dominating approach
- Fuzzy classification is typically achieved by connecting material probability and opacity level

Choosing the right Transfer Function

Two main views on Transfer Functions (TF)

2. Explicit probabilistic view

Application of a TF is a two-step approach

A. The sample value is mapped to a set of material probabilities

B. These material probabilities are used to combine the individual material colors, which results in the sample color

Choosing the right Transfer Function

Explicit probabilistic TF

Each material to be visualized is connected to an individual TF component consisting of two parts:

1. Material appearance (here: static)
2. Classifying function, that maps intensity to material likelihood

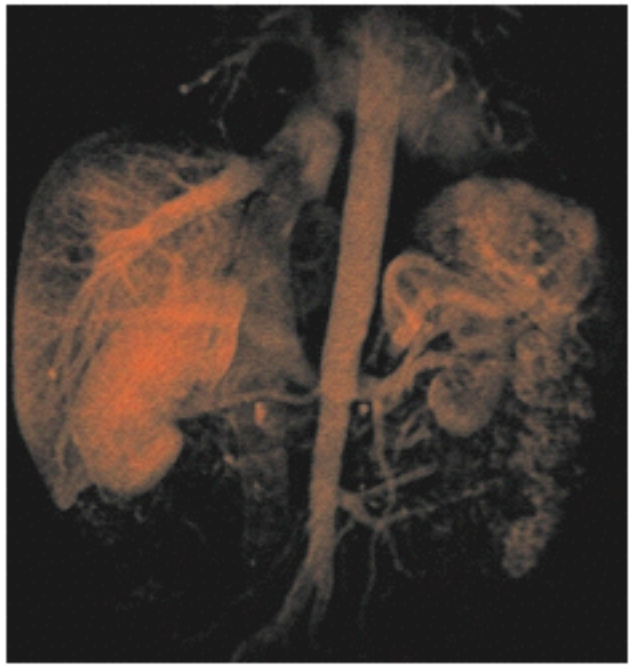
Having a separate probability component enables possibilities also for non-animated renderings

Choosing the right Transfer Function

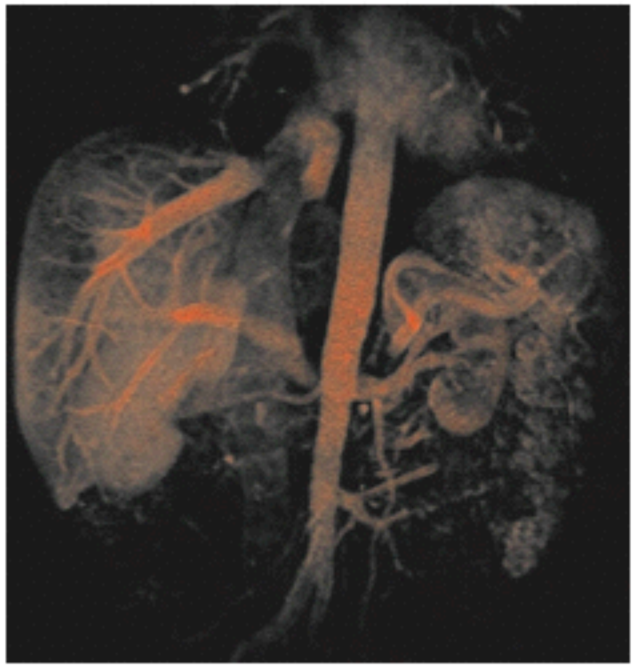
<u>Explicit probabilistic TF</u>

Separate probability component

- enables e.g to connect uncertainty to color desaturation



a



b

Fig. 2
a. Traditional rendering
b. Desaturating uncertain regions

Probabilistic Animation II

Probabilistic TF model resulting in a set of material probability values $p_0(s),\dots,p_m(s)$ for each intensity value s

<u>Key part of the animated rendering:</u>

Derivation of the sample color $c(s)$ from the material probabilities

Probabilistic Animation II

<u>Traditional rendering:</u>

Mix the materials' colors, weighted by the probabilities

<u>With animation:</u>

Colors of materials with high probabilities are displayed in high number of frames

Intensity values corresponding to uncertain material classification —> varying color mapping in the rendering

Probabilistic Animation II

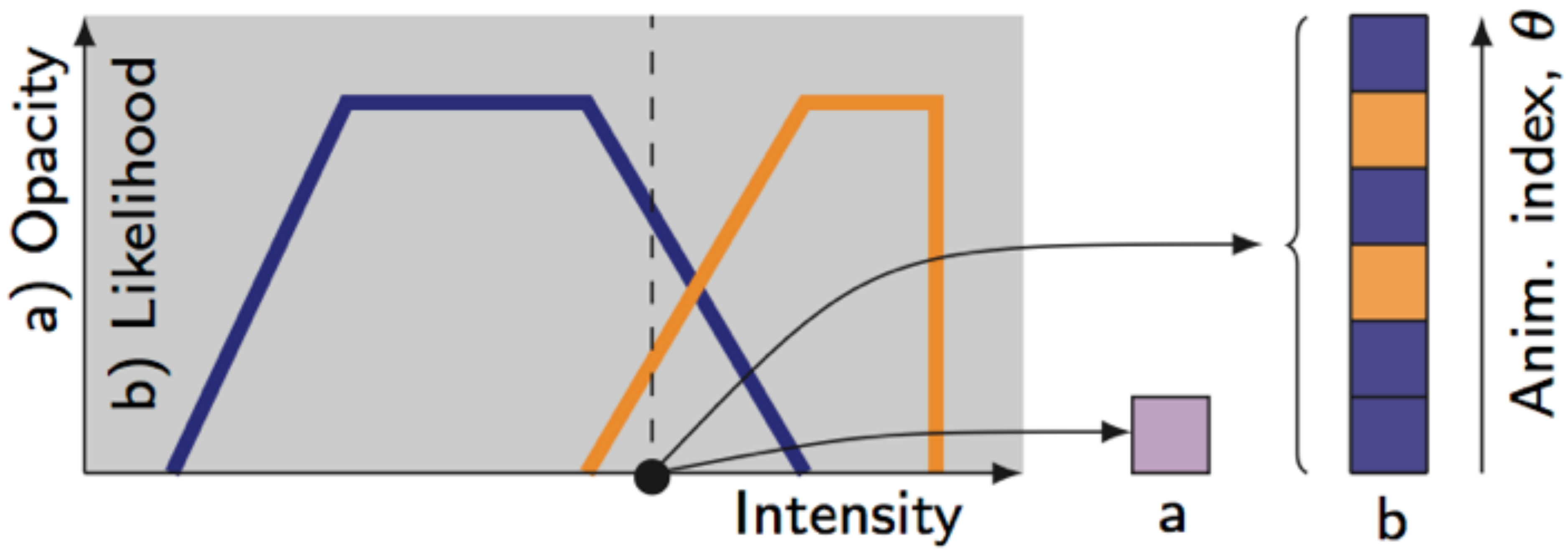


Fig. 3

Traditional DVR vs. probabilistic animation

- Traditionally, TF maps intensity value to a single color
- Probabilistic animation maps an intensity value to an array of pure material colors

Probabilistic Animation II

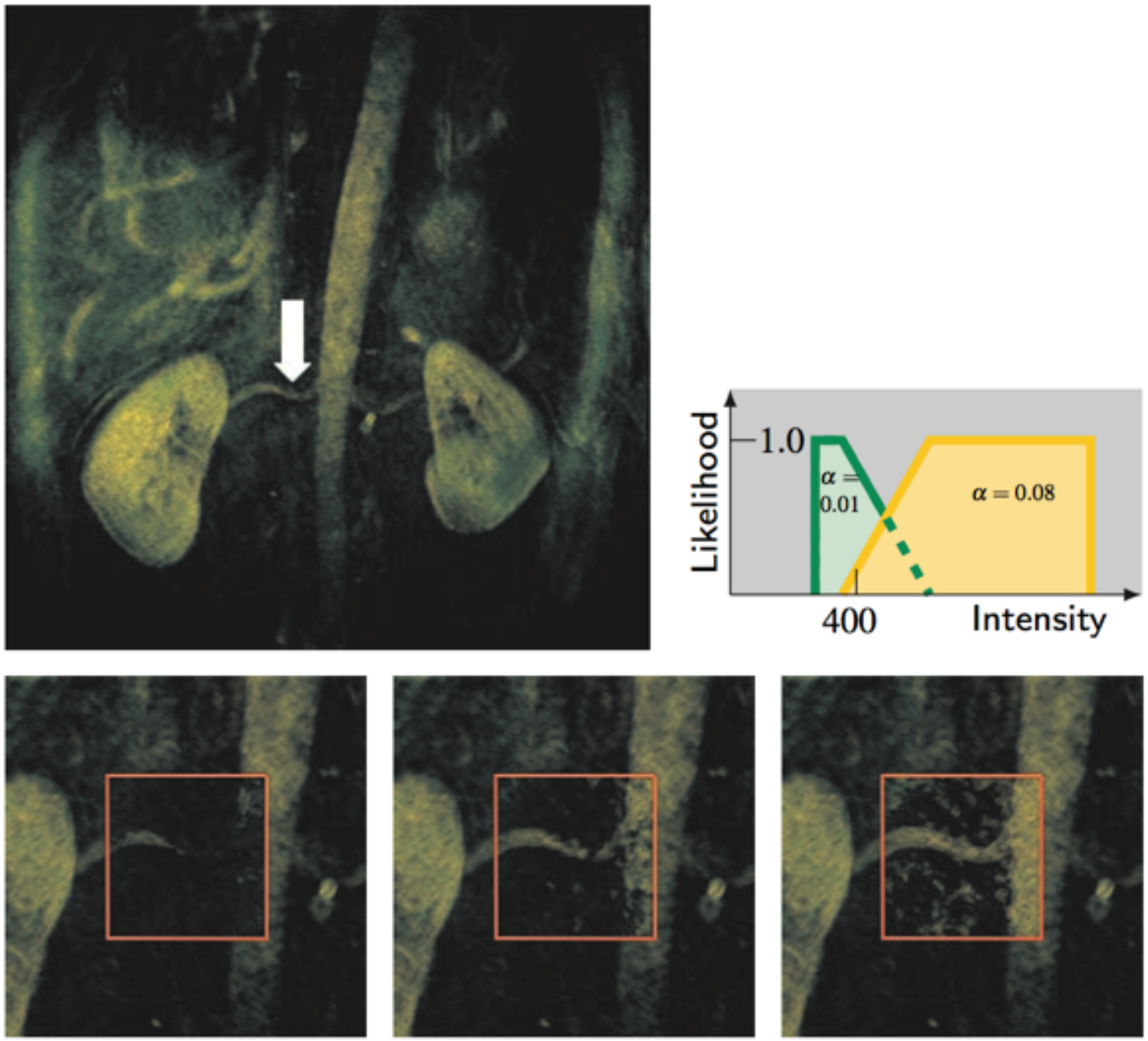


Fig. 4

Top left:
Traditional rendering (possible stenosis)

Top right:
Probabilistic TF

Bottom:
Animation of suspicious region

Discussed Papers

2 Uncertainty-Aware Guided Volume Segmentation

"In this paper we propose a guided probabilistic volume segmentation approach that focuses on the minimization of uncertainty."

Direct Volume Rendering

Issues:

- Design of effective transfer functions that map data values to optical properties (classification)
- Lack of reliability. DVR suffers from occlusion —> requires masking —> risk of unintentionally masking out parts of interest

—> important to visualize uncertainty in classification and segmentation

Guided Segmentation Approach

Guided Approach

- Focus on uncertainty
- Interplay between user and system

User:

- Strong in visual pattern recognition

System:

- Vast processing power
- Supports expensive computations and rough analysis

System Design

Provide efficient workflow

- Selection of appropriate segmentation algorithm crucial
- Random Walker Algorithm

Random Walker Algorithm

- Needs initial set of seed points (foreground and background)
- Views the volume as weighted graph —> nodes correspond to the voxels
- Determines probability for each voxel for random walker to reach a seed
- Probability for choosing a neighbor voxel —> defined by edge weights (derived from intensity differences)

Random Walker Algorithm

Issue:

- Expensive computation —> here solved by providing an OpenCL implementation

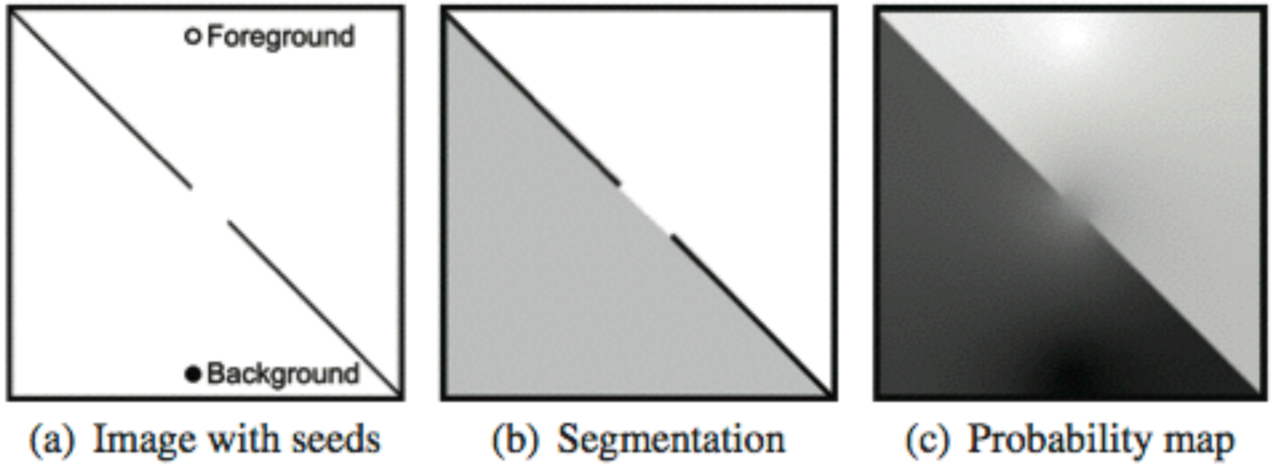


Fig. 5
Segmentation and probability map with random walker algorithm

Guided Volume Segmentation

- Uncertainty Information present in the segmentation generated by the algorithm —> exploiting to the user non-trivial
- in 3D visualization combining data set and probabilities is hardly practical
- in a slice-wise examination —> exploration cumbersome and poses risk of missing critical misclassifications

Guided Volume Segmentation

- Adoption of commonly used medical data model:
- Assumes: volume is composed of homogenous regions, intermixing at borders with smooth transitions
- Uncertainty expected to only exhibit thin margins at the boundaries
- Large areas of ambiguous probabilities —> indicators for potential misclassification

System Structure

- System supports user by analyzing probability field —> detect amb. regions —> direct user attention
- Interface is slice-based for input
- Slices used for seed point definition and displaying current segmentation result
- context information provided by a 3D view
- keep system simple —> only applicable for 2-way segmentation

Workflow

1. System generates intermediate rand. walker segmentation using defined seed points

2. System analyzes the prob. field to detect ambiguous regions

3. Overview: all detected regions in table and highlighted in 3D and slice view

4. User focuses on part. region and refines segmentation (defining new seed points)

5. Workflow is repeated

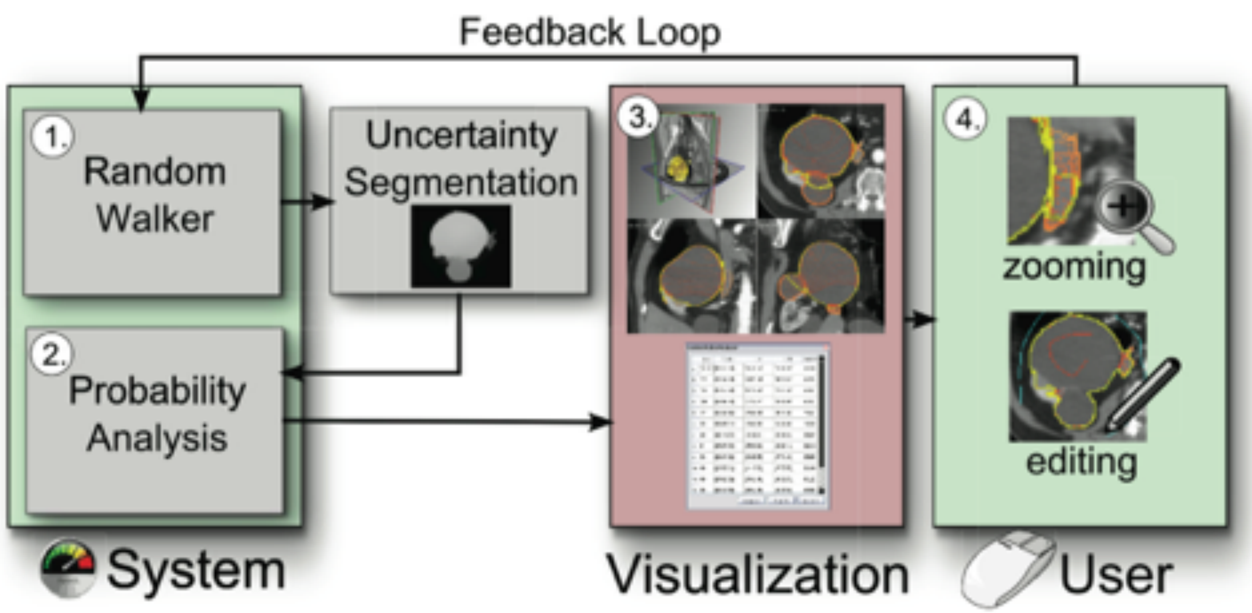


Fig. 6 Workflow

Uncertainty Detection

- Ability to detect uncertainty is crucial
- Obvious fore- and background parts can have non-clear probabilities
  Used thresholds: uncertain regions between 0.2-0.8
- To support user —> regions are sorted by importance
- Importance of uncertain region *R* is determined by the size and the probability distribution *p*

$$amb(R) := \sum_{v \in R} (1 - 2 \cdot |p(v) - 0.5|)$$

amb(R)	Ambiguity of Region *R*
v	Voxel
$1 - 2 \cdot |p(v) - 0.5|$	Uncertainty of voxel *v*

Uncertainty Visualization

- 3D view - provide an overview of the structure
- 2D views - well suited for precise inspections

<u>3D technique:</u>

- Opacity TF used —> constant hue, transparency modulated based on prob. values

Uncertainty Visualization

2D technique:

- Isolines are directly derived from the probability distribution
- To reduce cluttering regions outside range (0.2-0.8) are masked out, also edge detection is performed

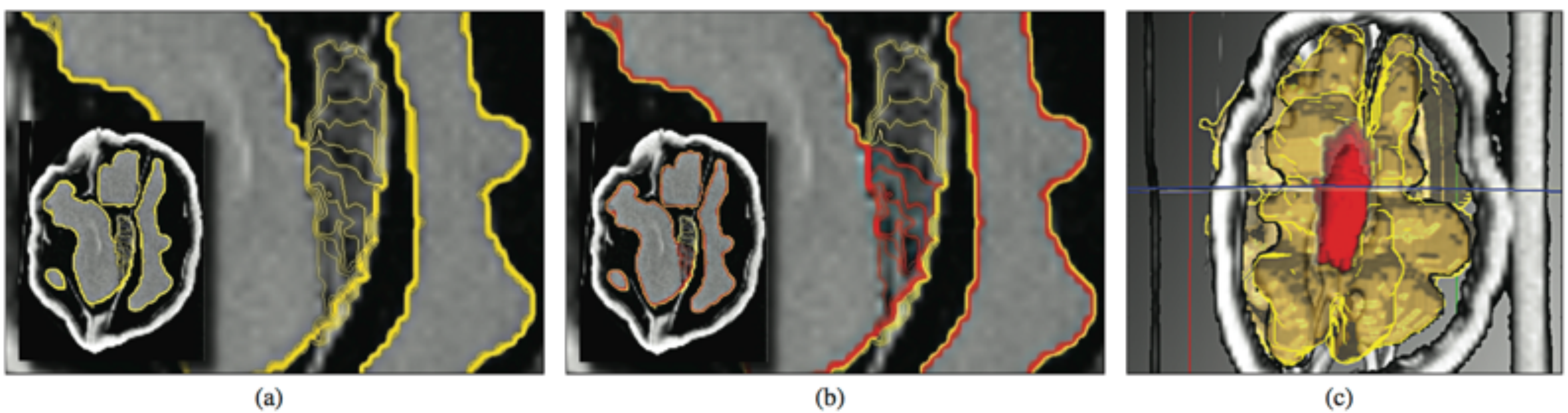


Fig. 7 Uncertainty Visualization
2D with isolines (a,b); 3D with opacity Transfer Function

Implementation - Interface

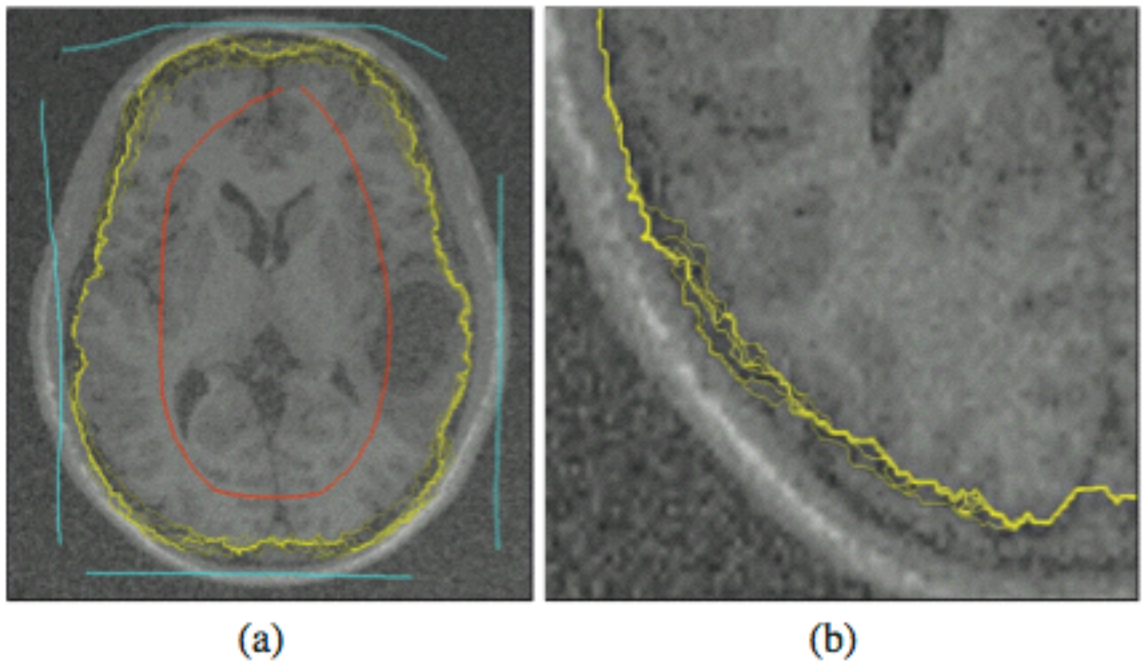


Fig. 8 Conducted Workflow
(a) Seed Placement (red fg, cyan bg)
(b) Detail view of uncertain region

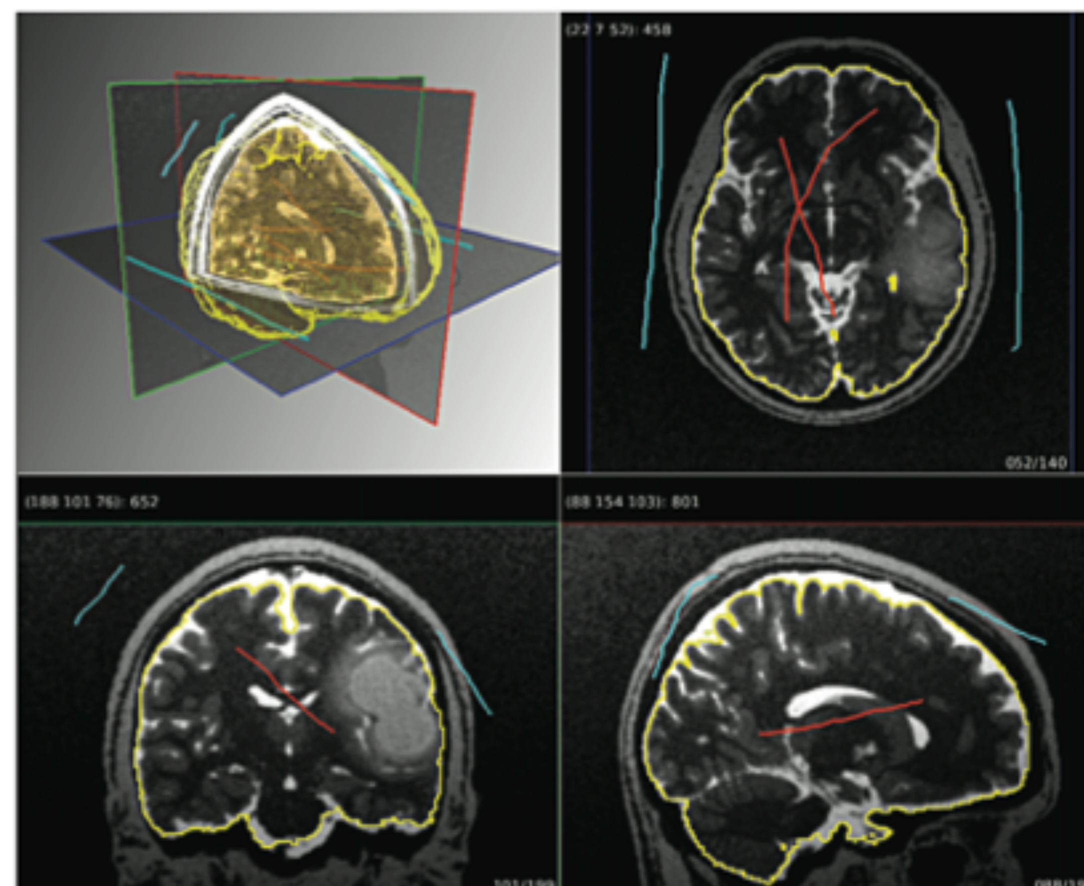


Fig. 9 Implementation view
Placing seeds shown in different views

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Fig. 1-4

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Fig. 5-9