Transfer Functions for Direct Volume Rendering

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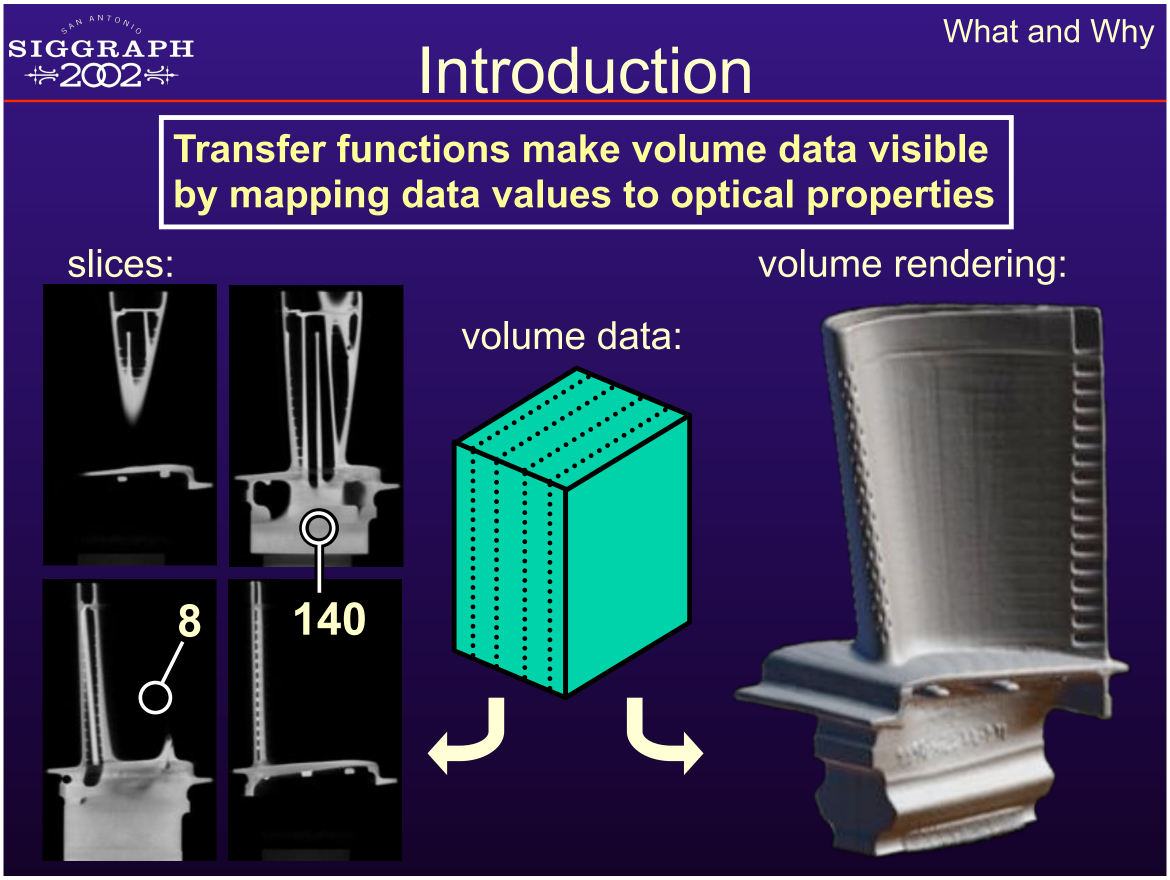
Contributions:
Many, as noted

Outline

1. Transfer Functions: what and why

2. Review of current methods

3. Ideas for future work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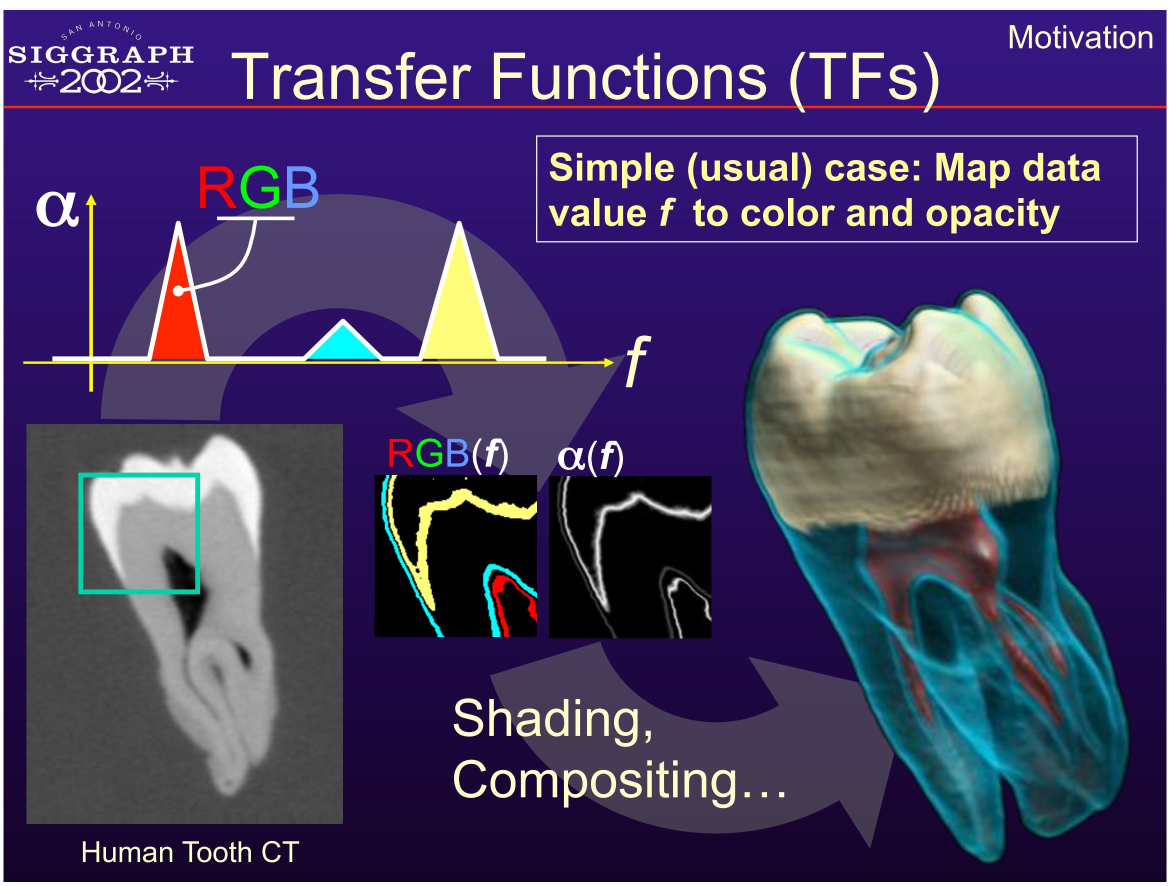
What and Why
Introduction
Transfer functions make volume data visible by mapping data values to optical properties
slices:
volume rendering:
volume data:
8
140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Motivation
Transfer Functions (TFs)
Simple (usual) case: Map data value f to color and opacity
RGB
α
f
RGB(f)
α(f)
Shading,
Compositing…
Human Tooth CT

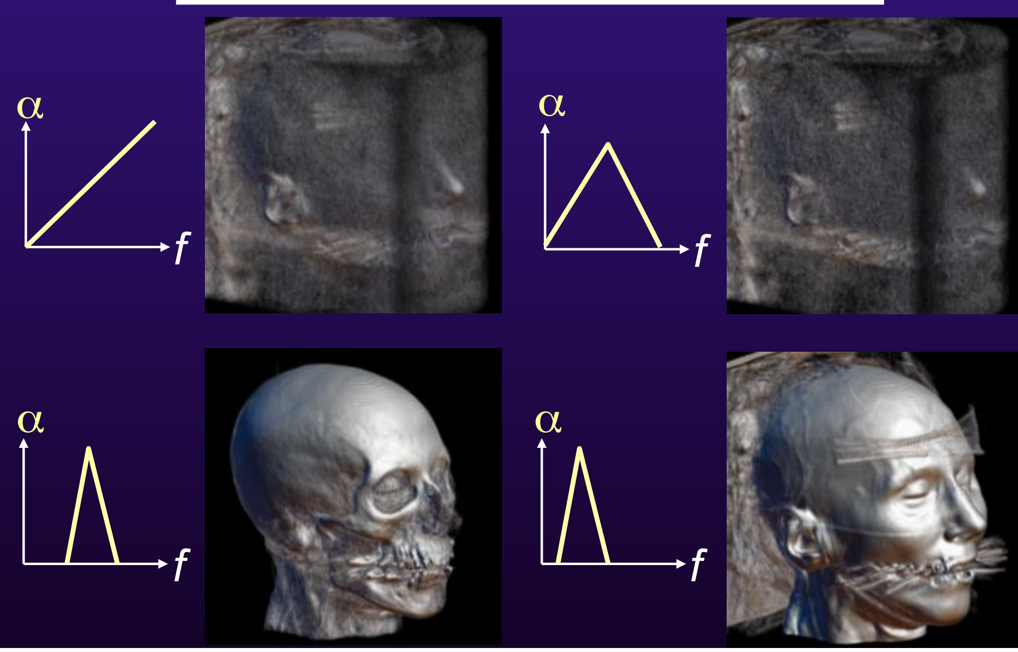
Optical Properties

Anything that can be composited with a standard graphics operator ("over")

- Opacity: "opacity functions"
  - Most important
- Color
  - Can help distinguish features
- Emittance
  - Why don't we use this more often?
- Phong parameters (k_a, k_d, k_s)
- Index of refraction

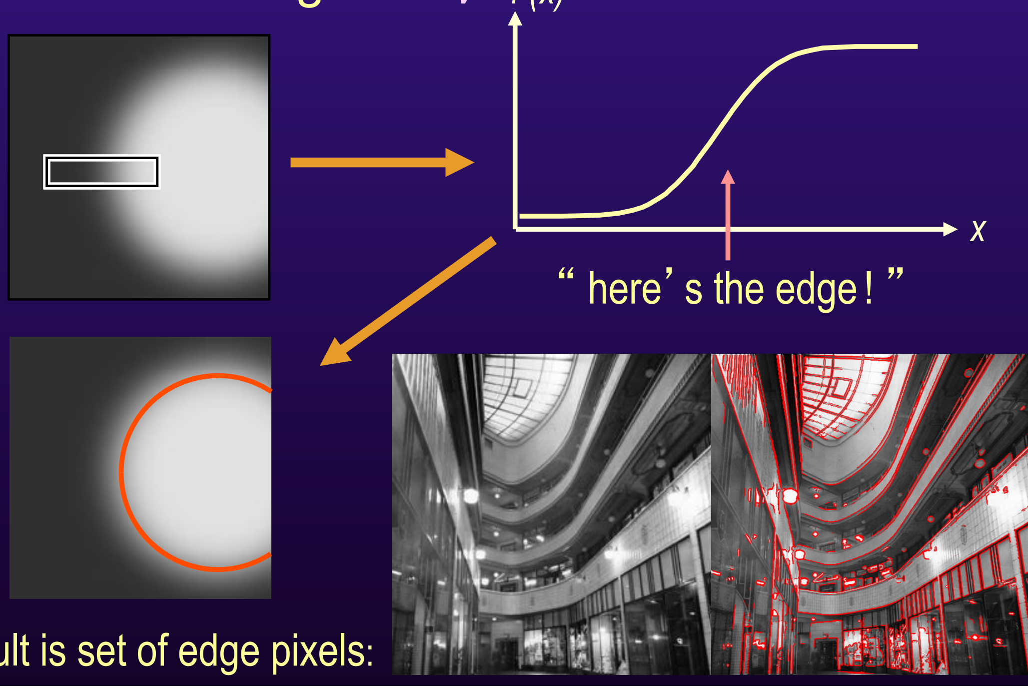
Alas…

Setting transfer functions is difficult, unintuitive, and slow



TFs as feature detection

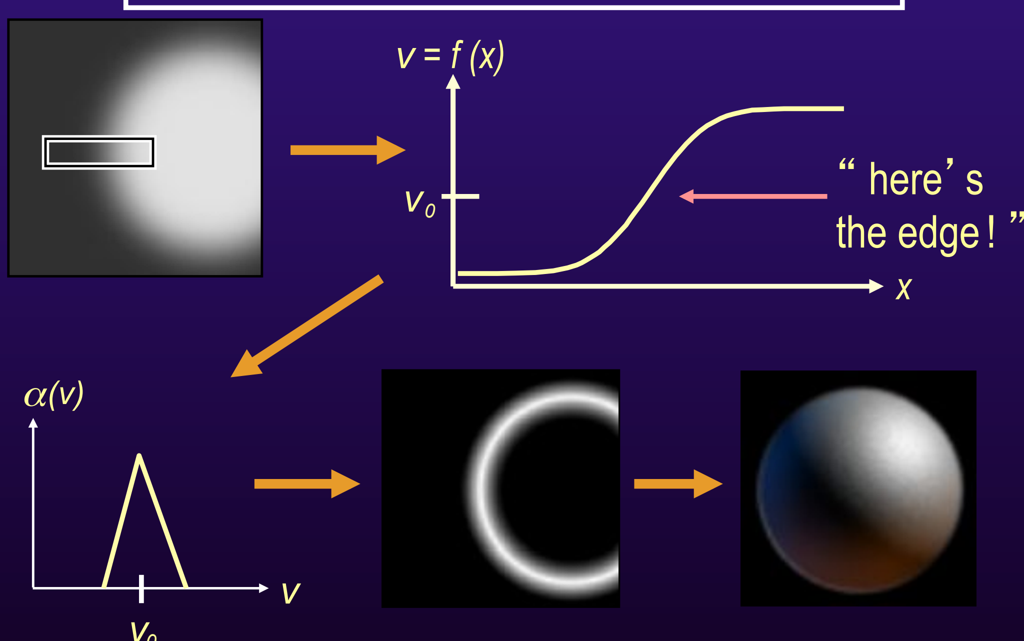
Where's the edge?



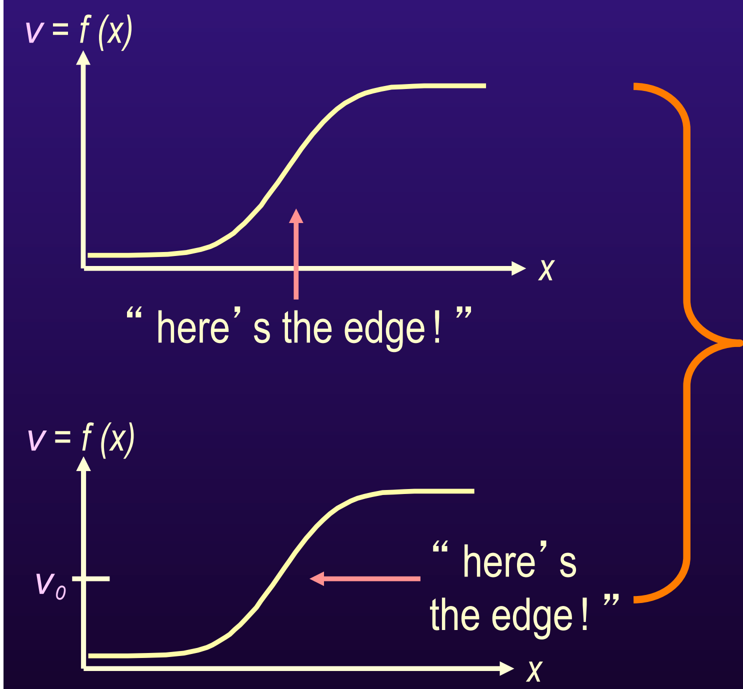
Result is set of edge pixels:

TFs as feature detection

We are looking in the data value domain, not the spatial domain



TFs as feature detection



Domain of the transfer function does not include position

Goals

- Make good renderings easier to come by
- Make space of TFs less confusing
- Remove excess "flexibility"
- Provide one or more of:
  - Information
  - Guidance
  - Semi-automation
  - Automation

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Outline

1. Transfer Functions: what and why

2. **Review of current methods**

3. Ideas for future work

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Organization

1. **Trial and Error (manual)**
2. Spatial Feature Detection
3. Image-Centric
4. Data-Centric
5. Others

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1. Trial and Error

1. Manually edit graph of transfer function
2. Enforces learning by experience
3. Get better with practice
4. Can make terrific images

William Schroeder, Lisa Sobierajski Avila, and Ken Martin; Transfer Function Bake-off Vis ’00

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Organization

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Current Methods

2. Spatial Feature Detection

Transform TF specification to feature detection in the spatial domain

- extremely flexible
- different parameter space
- not exactly transfer functions …

1. Fang, Biddlecome, Tuceryan (Vis '98) "Image-based Transfer Function Design…"
2. Rheingans, Ebert (Vis '00, TVCG July '01) "Volume Illustration: Non-photorealistic…"
3. Hladuvka, Gröller (VisSym '01) "Salient Representation of Volume Data"

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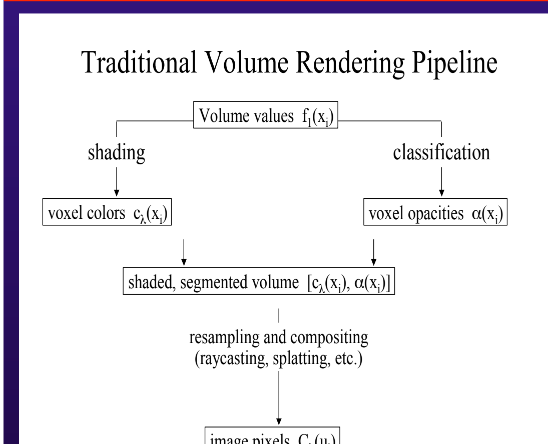
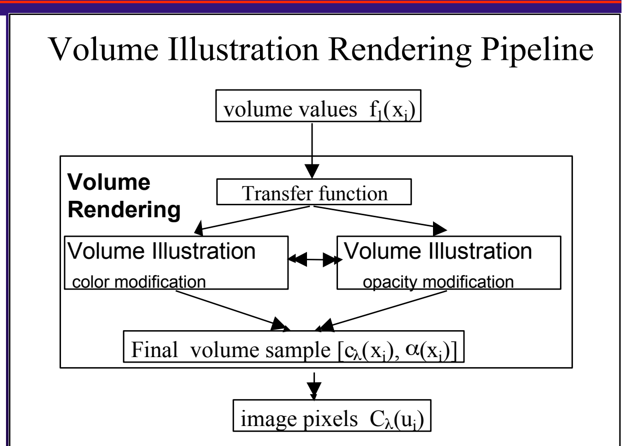
3. Spatial Features

Volume Illustration





Thanks to Penny Rheingans and David Ebert

Feature Enhancement

- Boundary, silhouette enhancement

Depth and Orientation Cues

- Halos, depth cueing

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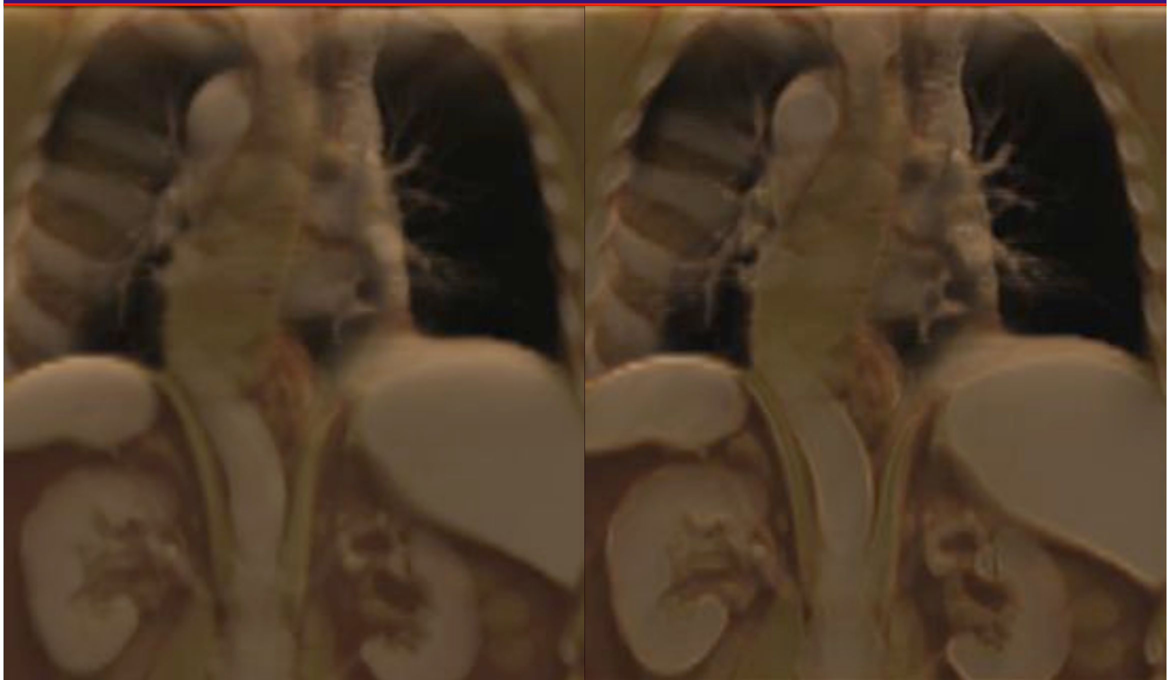
3. Spatial Features

Volume Illustration



Original TF | Boundaries (gradient)

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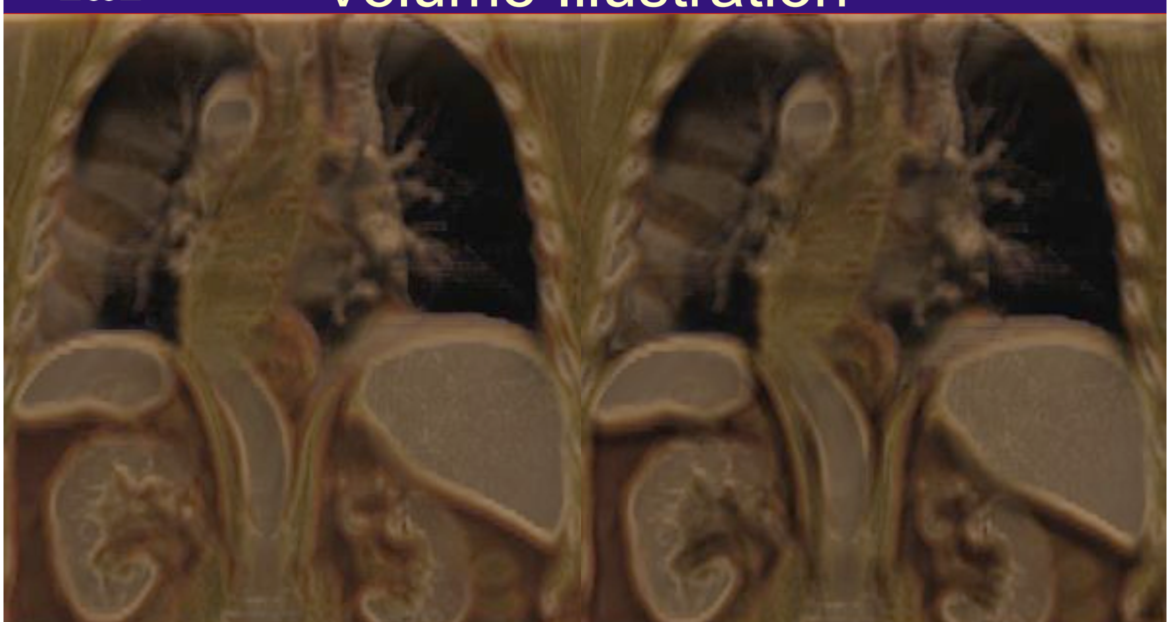
3. Spatial Features

Volume Illustration



Silhouettes | Halos

Blurs distinction between transfer functions and feature detection

Organization

1. Trial and Error (manual)
2. Spatial Feature Detection
3. Image-Centric
4. Data-Centric
5. Others

3. Image-centric

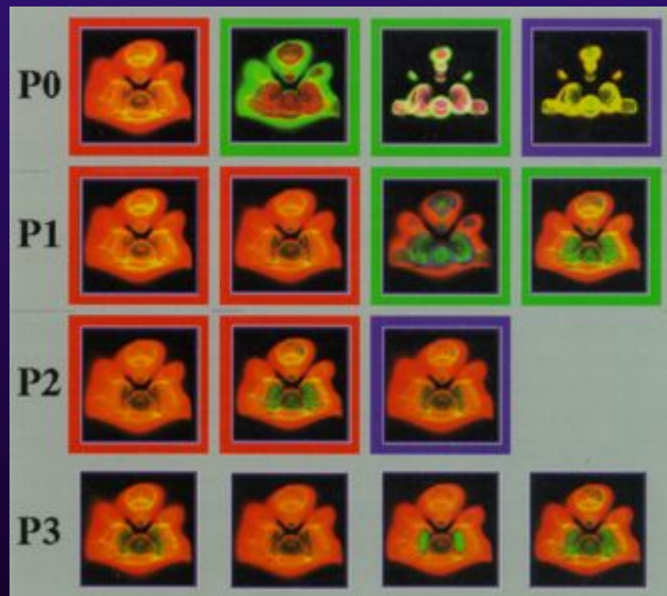
Specify TFs via the resulting renderings

- Genetic Algorithms ("Generation of Transfer Functions with Stochastic Search Techniques", He, Hong, *et al.*: Vis '96)
- Design Galleries (Marks, Andalman, Beardsley, *et al.*: SIGGRAPH '97; Pfister: Transfer Function Bake-off Vis '00)
- Thumbnail Graphs + Spreadsheets ("A Graph Based Interface…", Patten, Ma: Graphics Interface '98; "Image Graphs…", Ma: Vis '99; Spreadsheets for Vis: Vis '00, TVCG July '01)
- Thumbnail Parameterization ("Mastering Transfer Function Specification Using VolumePro Technology", König, Gröller: Spring Conference on Computer Graphics '01)

Genetic Algorithms

Initial stochastic search; refinement can be user driven or automated (“fitness functions”)

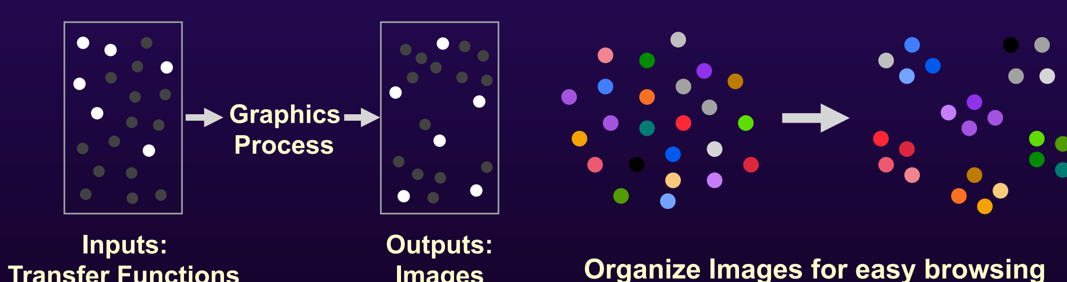
“Generation of Transfer Functions with Stochastic Search Techniques”, He, Hong, *et al.*: Vis ’96



Design Galleries

Effective method for general class of “parameter tweaking” problems

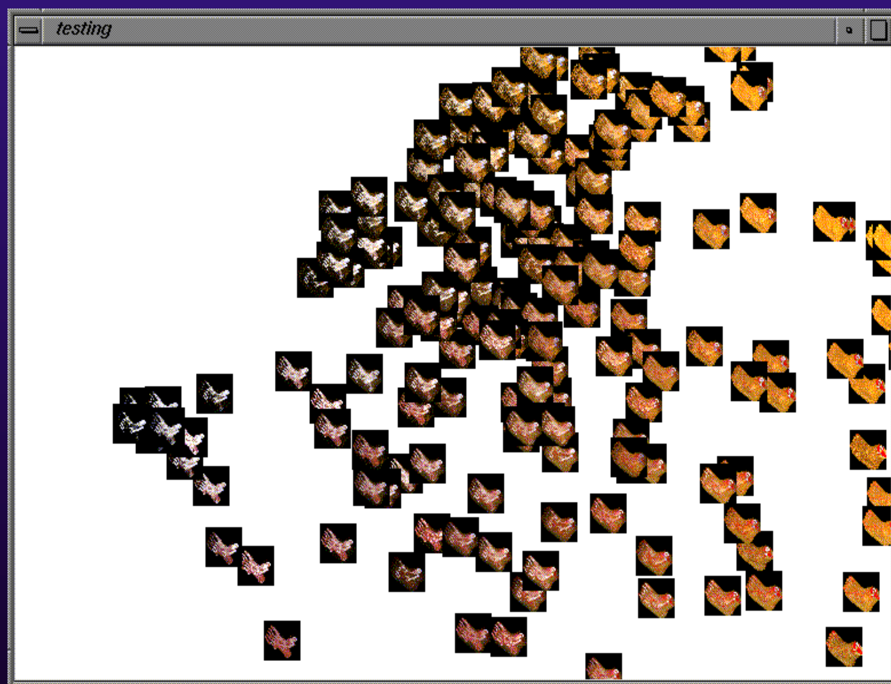
- Provide convenient GUI to whole parameter space (“what’s possible?”)
- Sampling parameter space: dispersion
- Organize output images: arrangement



Design Galleries

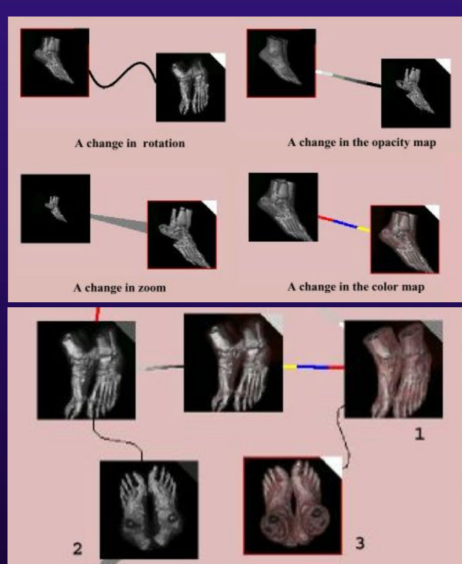
VolDG
(software available)

Marks, Andalman, Beardsley, *et al.*: SIGGRAPH ’97; Pfister: Transfer Function Bake-off Vis ’00

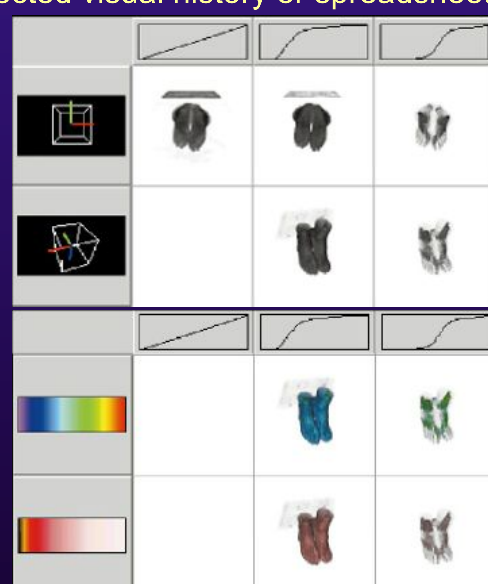


Thumbnail Graphs, Spreadsheets

Exploration guided by logically connected visual history or spreadsheet



“A Graph Based Interface for Representing Volume Visualization Results”, Patten, Ma: Graphics Interface ‘98



“Visualization Exploration and Encapsulation via a Spreadsheet-Like Interface”, Jankun-Kelly, Ma: TVCG July 2001

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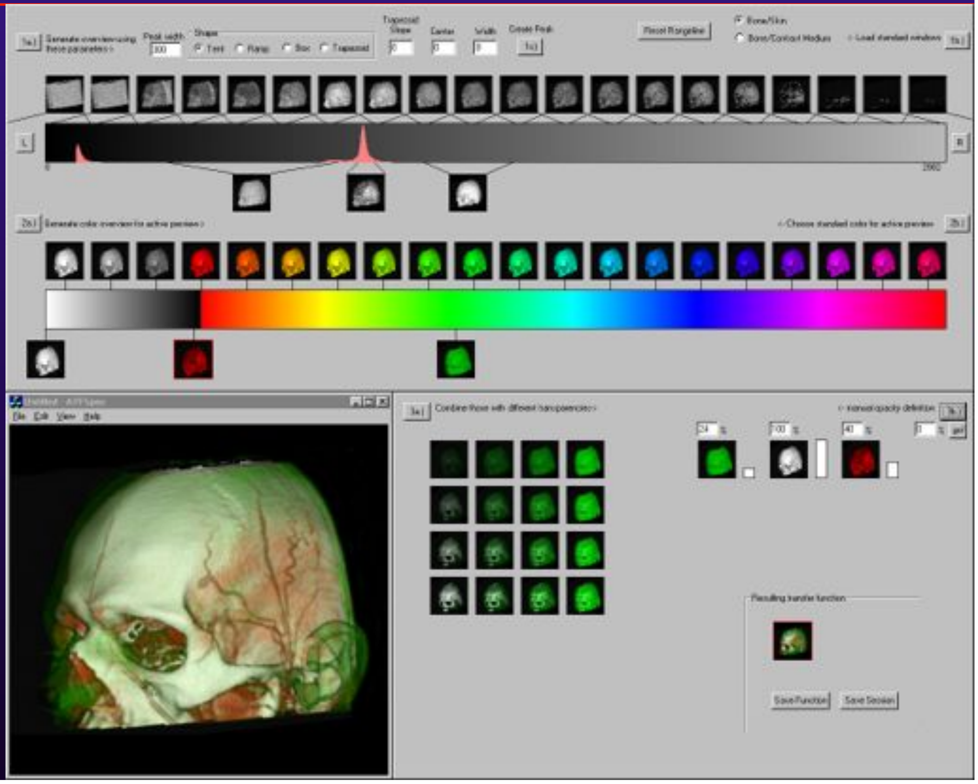
3. Image-Centric

Thumbnail Parameterization

“Mastering Transfer Function Specification Using VolumePro Technology”, König, Gröller: Spring Conference on Computer Graphics ’01



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Current Methods

Organization

1. Trial and Error (manual)
2. Spatial Feature Detection
3. Image-Centric
4. Data-Centric
5. Others

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4. Data-centric

Specify TF by analyzing volume data itself

1. Salient Isovalues:
   - Contour Spectrum (Bajaj, Pascucci, Schikore: Vis '97)
   - Statistical Signatures ("Salient Iso-Surface Detection Through Model-Independent Statistical Signatures", Tenginaki, Lee, Machiraju: Vis '01)
   - Other computational methods ("Fast Detection of Meaningful Isosurfaces for Volume Data Visualization", Pekar, Wiemker, Hempel: Vis '01)

2. "Semi-Automatic Generation of Transfer Functions for Direct Volume Rendering" (Kindlmann, Durkin: VolVis '98; Kindlmann MS Thesis '99; Transfer Function Bake-Off Panel: Vis '00)

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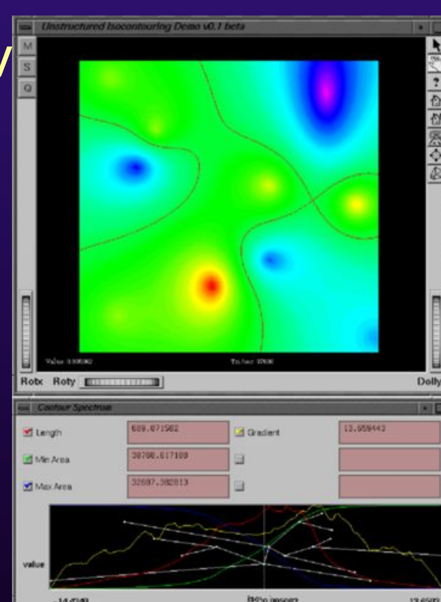
Salient Isovalues

What are the "best" isovalues for extracting the main structures in a v

- Contour Spectrum (Bajaj, Pascucci, Schikore: Vis '97; Transfer Function Bake-Off: Vis '00)
- Efficient computation of isosurface metrics
  - Area, enclosed volume, gradient surface integral, etc.
- Efficient connected-component topological analysis
- Interface itself concisely summarizes data



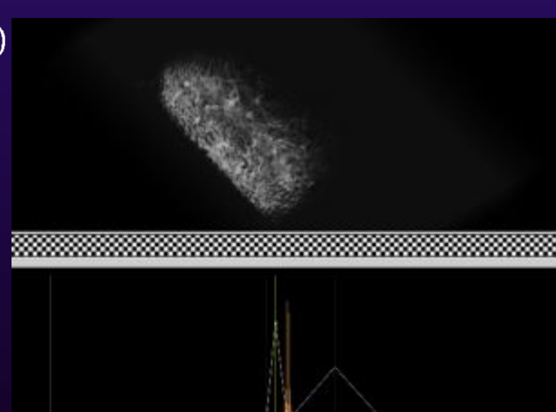
Contour Spectrum

Statistical Signatures

- Localized *k*-order central moments
- At each position *P* in volume, compute …
  - *LM* : mean over local window W
  - m_k: local higher order moment (LHOM)

$$m_k = \frac{1}{w^2} \sum (x - LM)^k \quad ,(\forall x \in W)$$

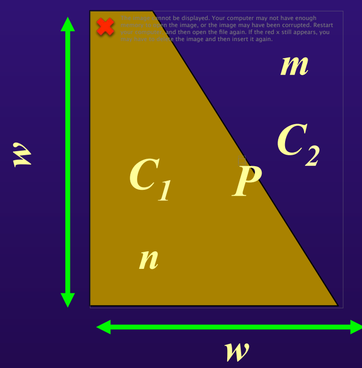
Example: m_3



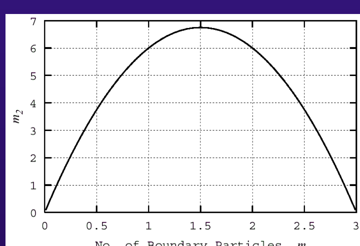
(Thanks to Shiva Tenginaki, Jinho Lee, Raghu Machiraju)

Boundary Model

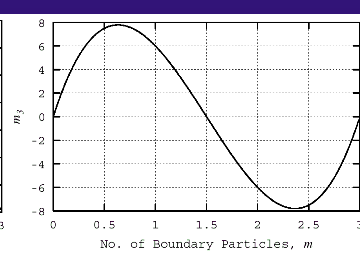
- Small window
- Boundary if $|C_1 - C_2| > 0$
- Binomial distribution of materials
- Extrema and zero-crossings of moments and cummulants are influenced by presence of boundaries



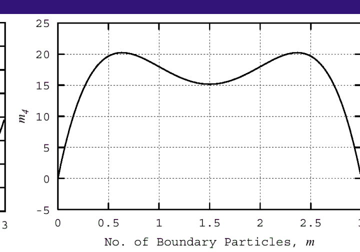
Moments + Cummulants



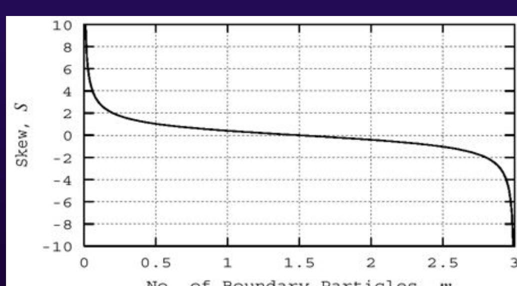
m_2



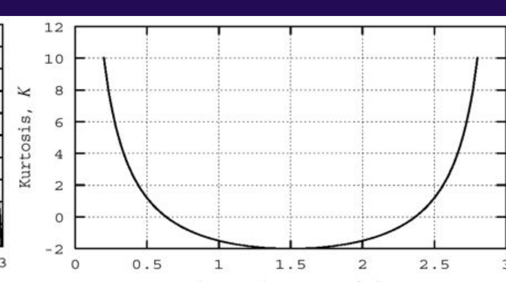
m_3



m_4

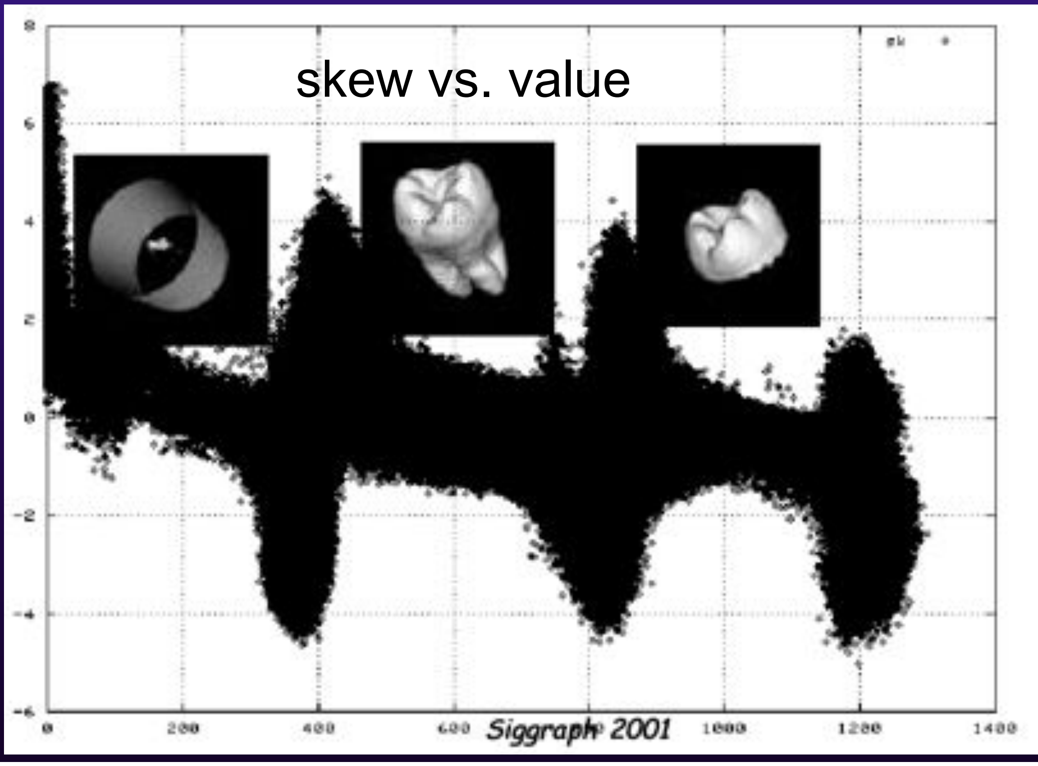


Skew



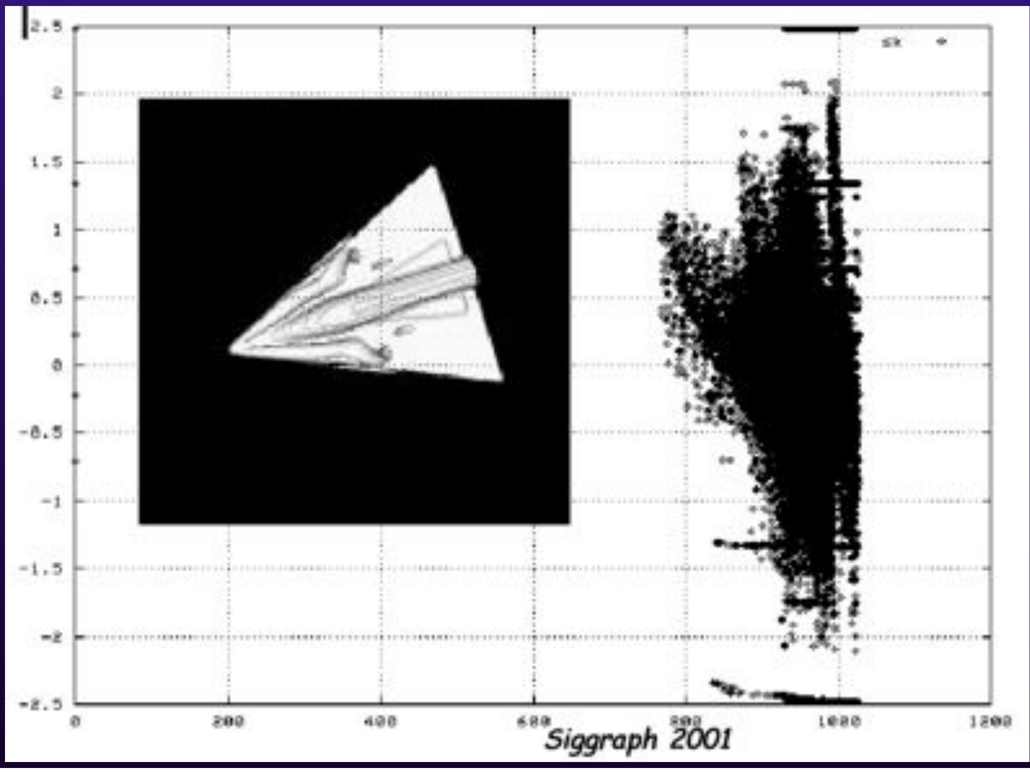
Kurtosis

Scatterplots

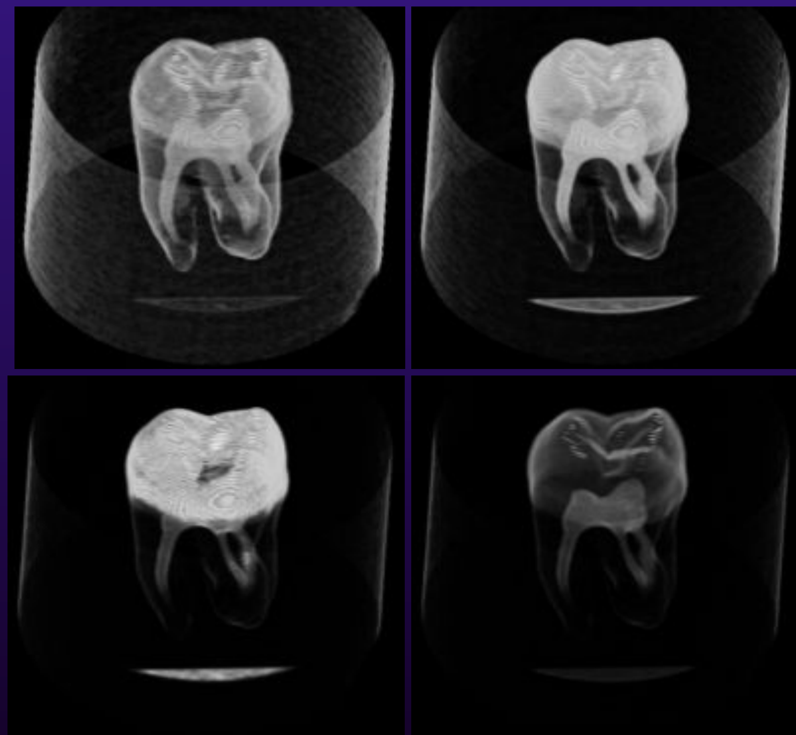


4. Data-Centric

Scatterplots



Tooth renderings



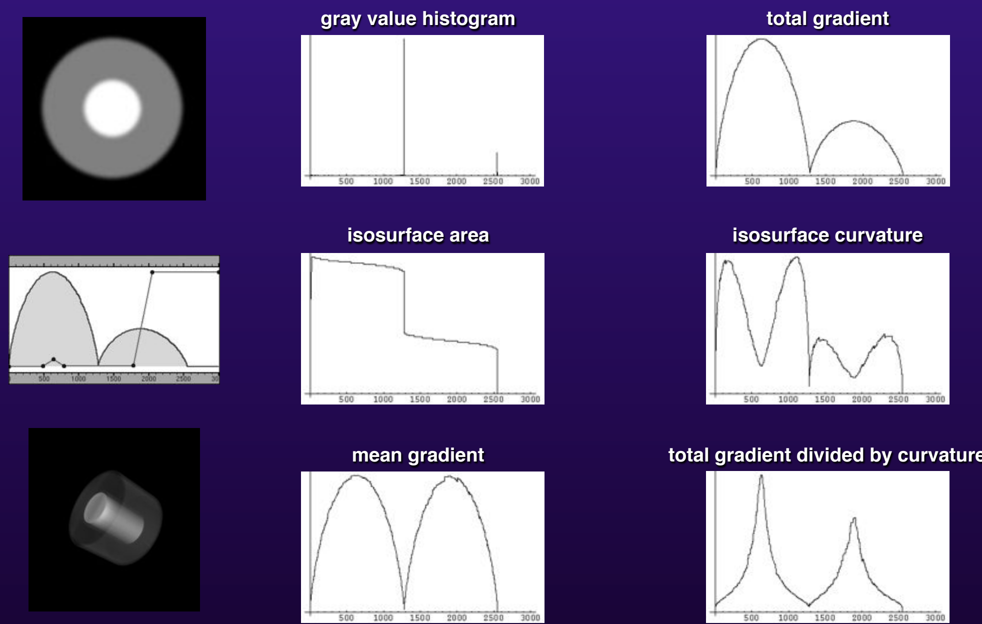
Other Computational Methods

"Fast Detection of Meaningful Isosurfaces for Volume Data Visualization", Pekar *et al.*: Vis '01

Integral of gradient magnitude over isosurface

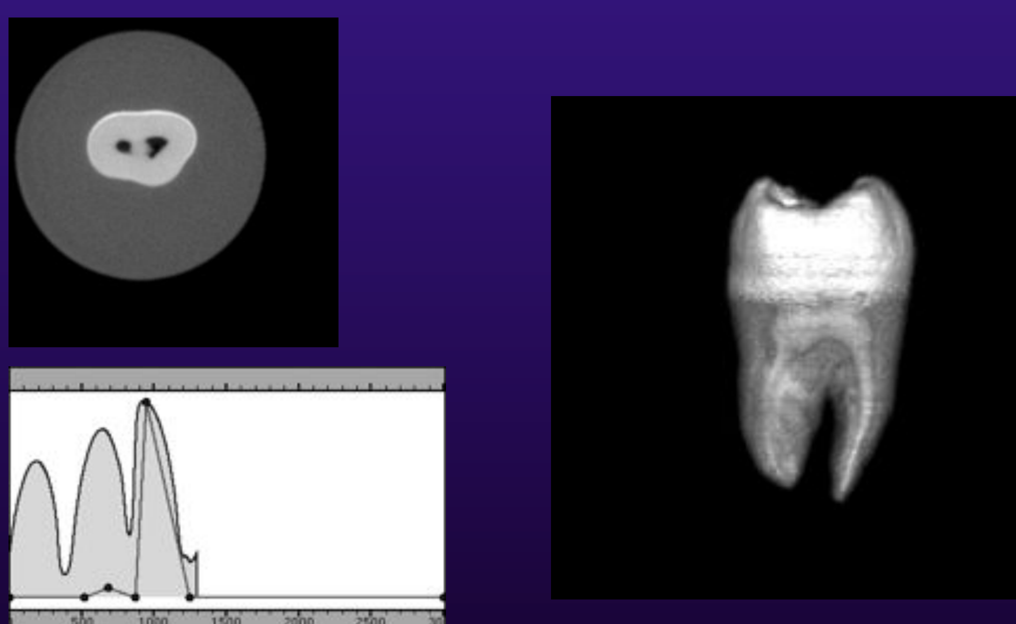
- High for isovalues of strong boundaries
- Can be computed with divergence theorem:
  Integral of vector field over surface is same as integral of divergence in the interior
- Application of classical vector calc
- Rapid computation with Laplacian-weighted histograms

Other Computational Methods



Pekar et al. "Fast Detection of Meaningful Isosurfaces for Volume Data Visualization", Vis '01

Other Computational Methods



MEAN gradient combined with the opacity transfer function

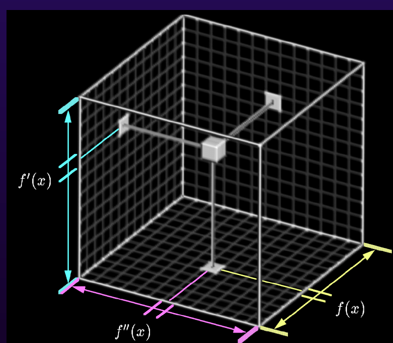
Pekar et al. "Fast Detection of Meaningful Isosurfaces for Volume Data Visualization", Vis '01

"Semi-Automatic …"

Reasoning:

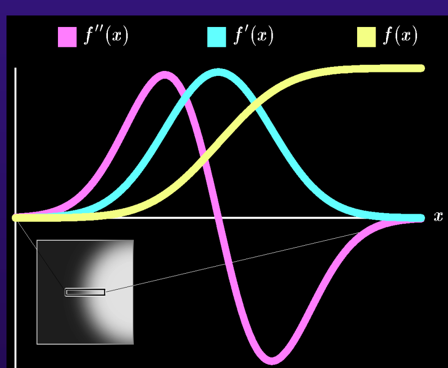
- TFs are volume-position invariant
- Histograms "project out" position
- Interested in boundaries between materials
- Boundaries characterized by derivatives

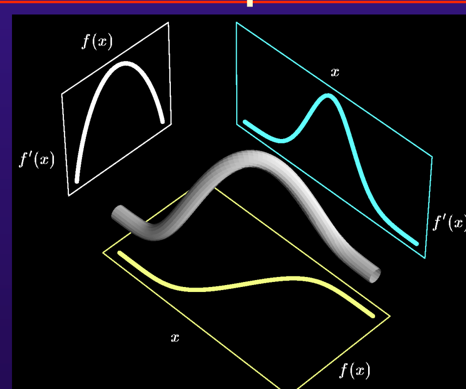
➔ Make 3D histograms of value, 1st, 2nd deriv.

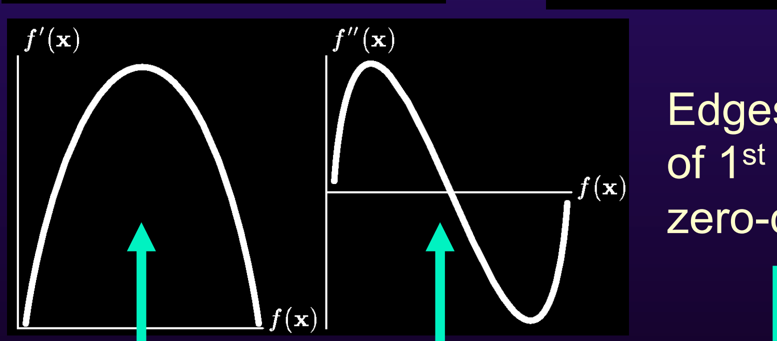


By (1) inspecting and (2) algorithmically analyzing histogram volume, we can create transfer functions

Derivative relationships

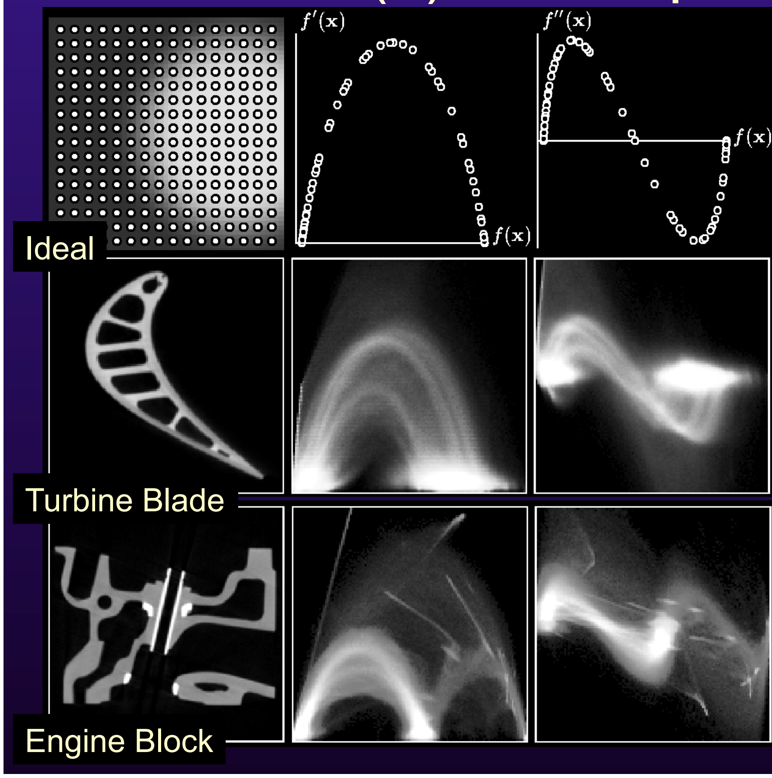






Edges at maximum of 1st derivative or zero-crossing of 2nd

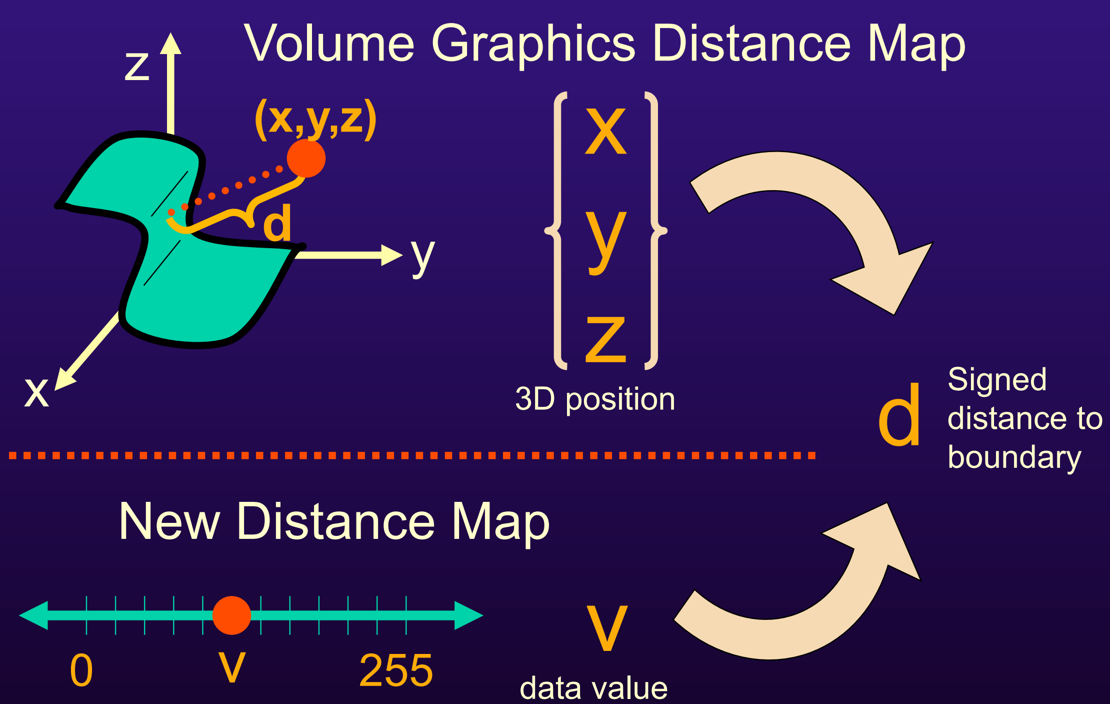
(1) Scatterplots



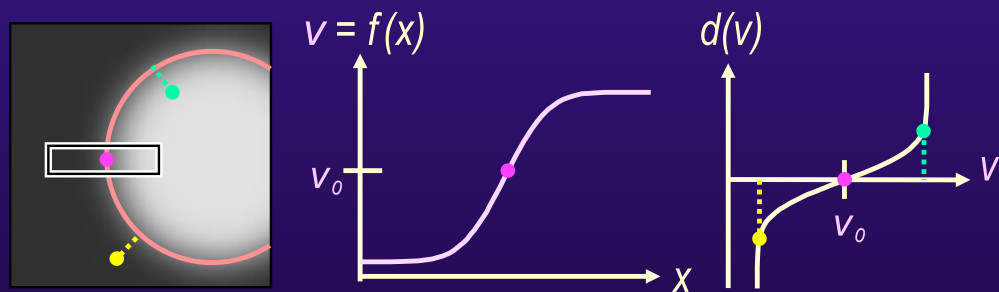
Project histogram volume to 2D scatterplots

- Visual summary
- Interpreted for TF guidance
- No reliance on boundary model at this stage

(2) Analysis

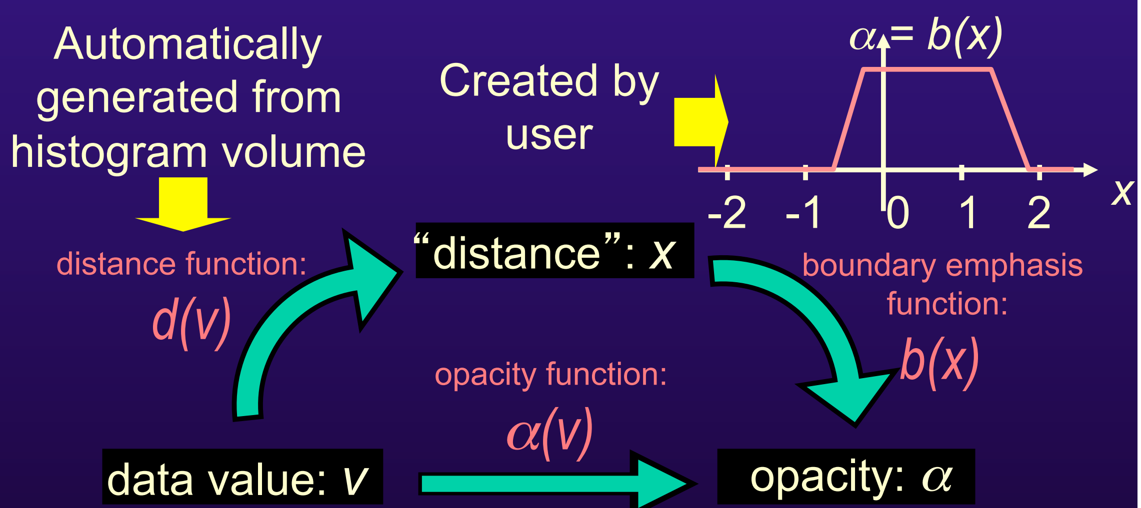


(2) New Distance Maps



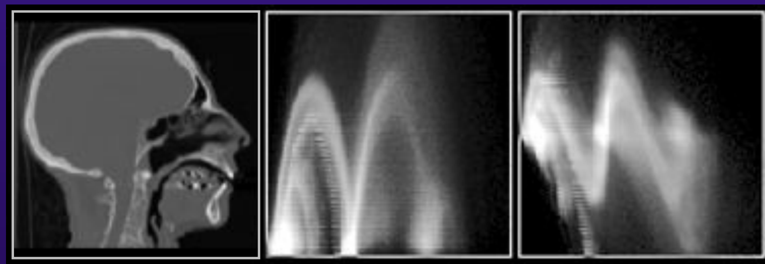
- Supports 2D distance map:
  d(v,g); g = gradient magnitude
- Produced automatically from histogram volume via boundary model

(2) Whole process

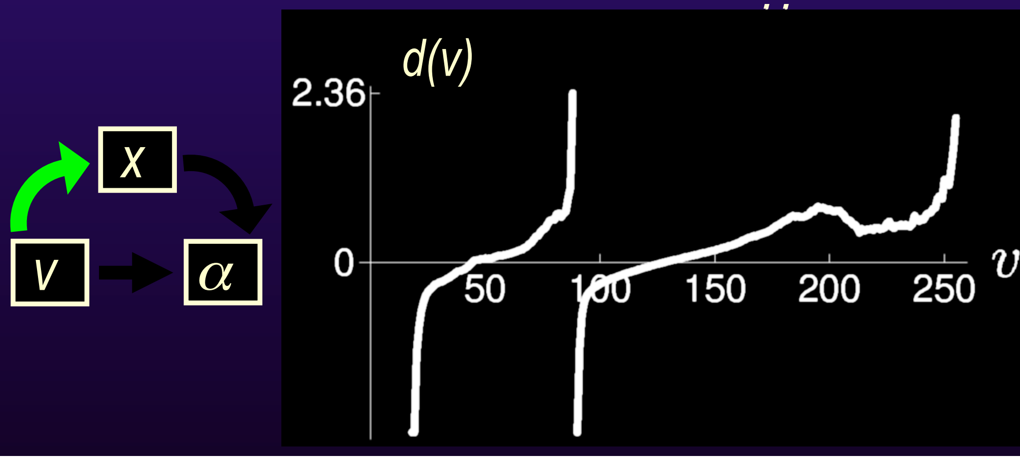


- Opacity function: $\alpha(v) = b(d(v))$
  $\alpha(v,g) = b(d(v,g))$

Results: CT Head

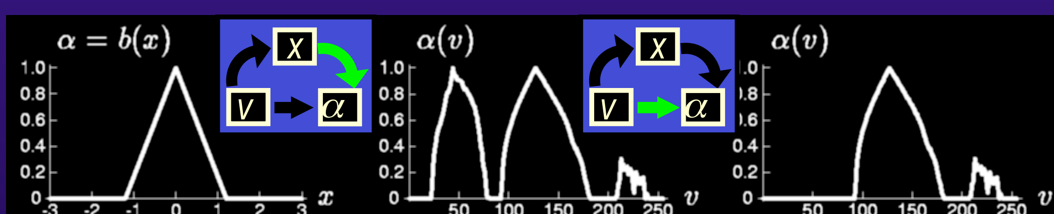


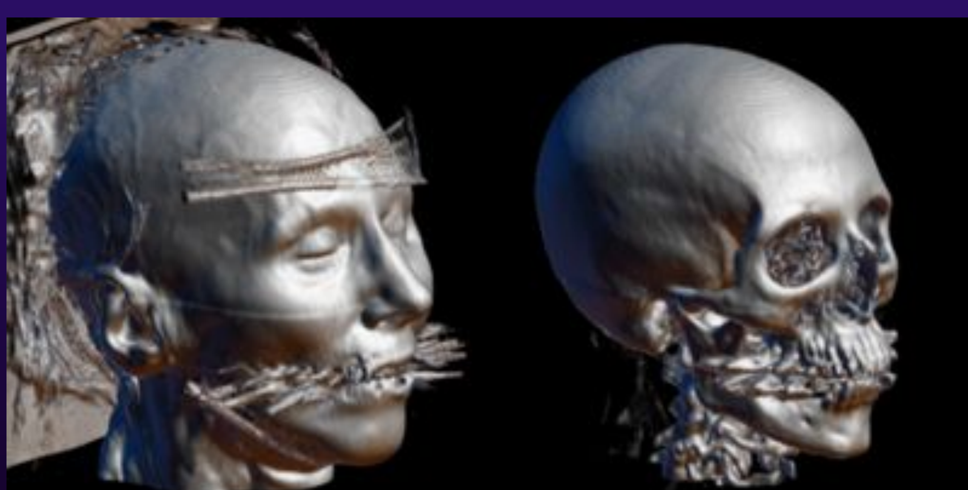
CT head slice — *f -- f '* — *f -- f ''*



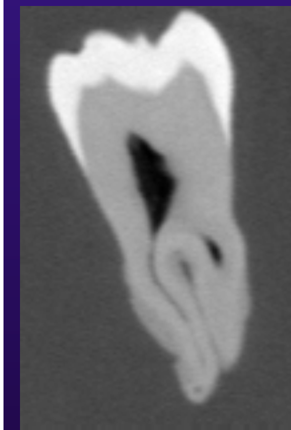
4. Data-Centric

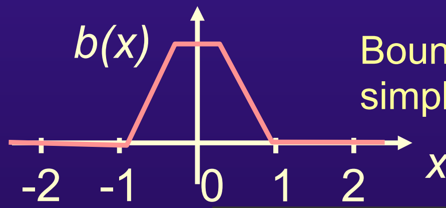
Results: CT Head





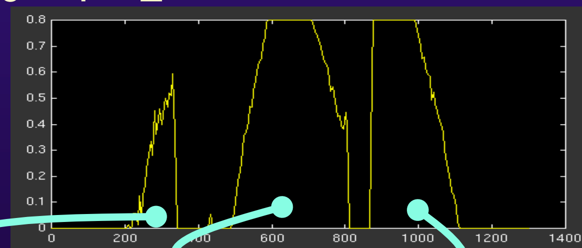
Results: Tooth

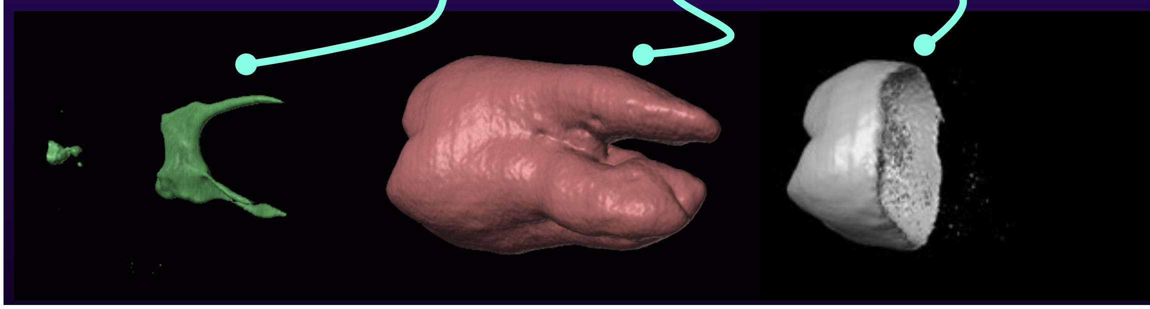




Boundary emphasis function simple to set

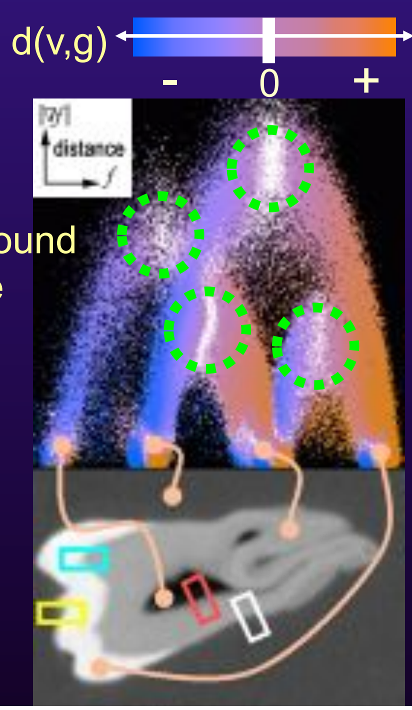
$\alpha(v) = b(d(v))$





Tooth: 2D transfer function

Detected **4** distinct boundaries between **4** materials



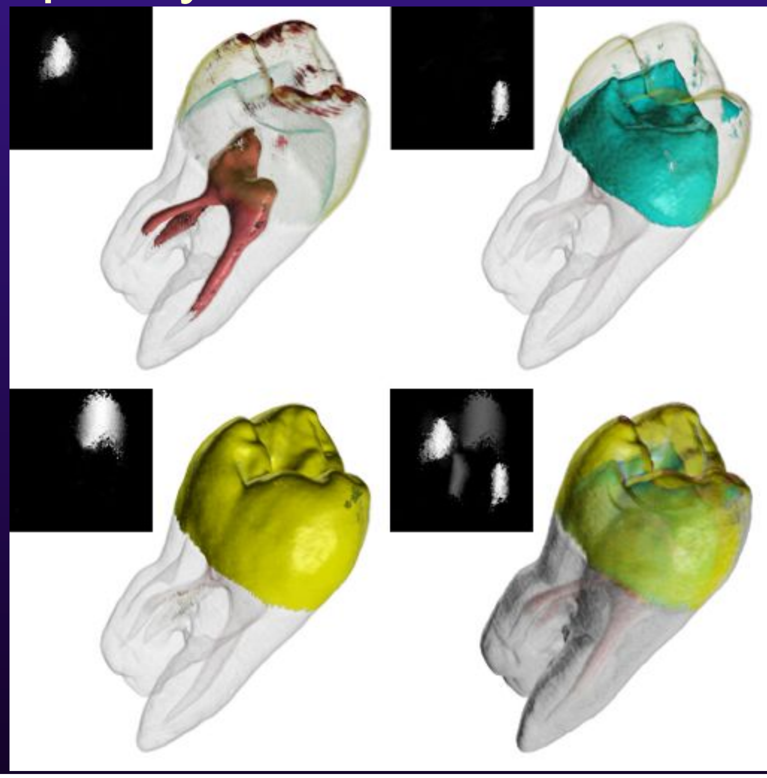
- Pulp
- Background
- Dentine
- Enamel

White regions in colormapped 2D distance function plot are boundary centers

Color transfer function

2D Opacity Functions

Mostly accurate isolation of all material boundaries



Organization

1. Trial and Error (manual)
2. Spatial Feature Detection
3. Image-Centric
4. Data-Centric
5. Others

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5. Other methods

- New domains: curvature
- New kinds of interaction

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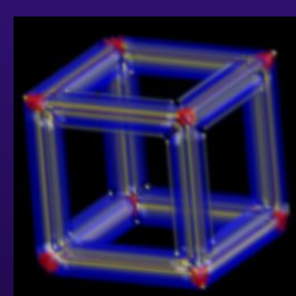
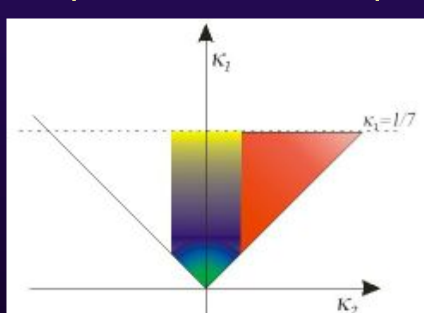
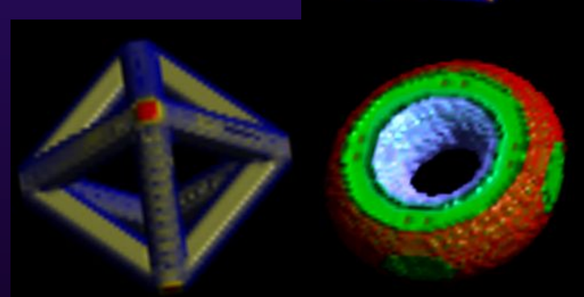
Curvature

"Curvature-Based Transfer Functions for Direct Volume Rendering", Hladůvka, König, Gröller: SCCG '00

- Uses 2D space of κ_1 and κ_2: principal curvatures of isosurface at a given point
- Graphically indicates aspects of local shape
- Specification is simple



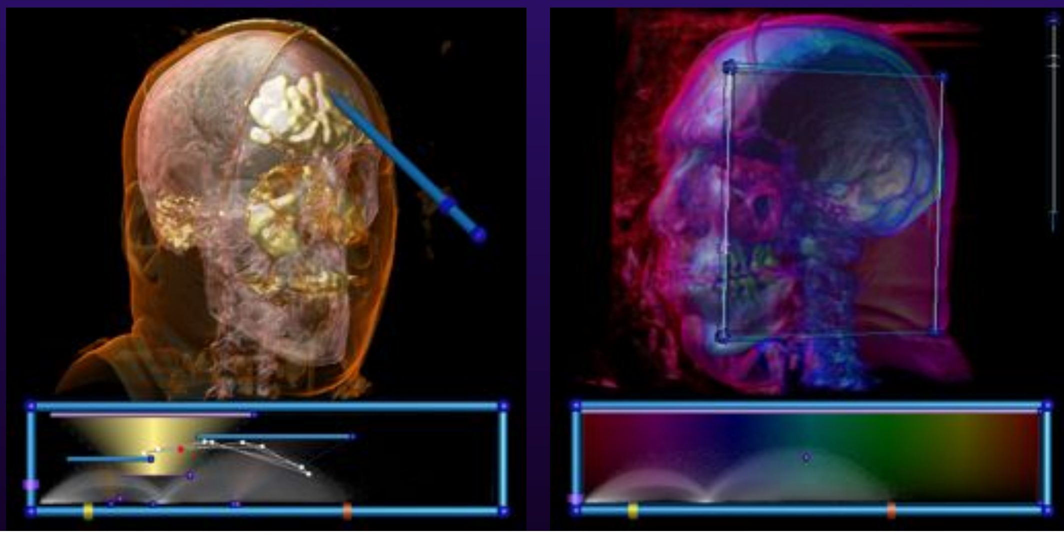




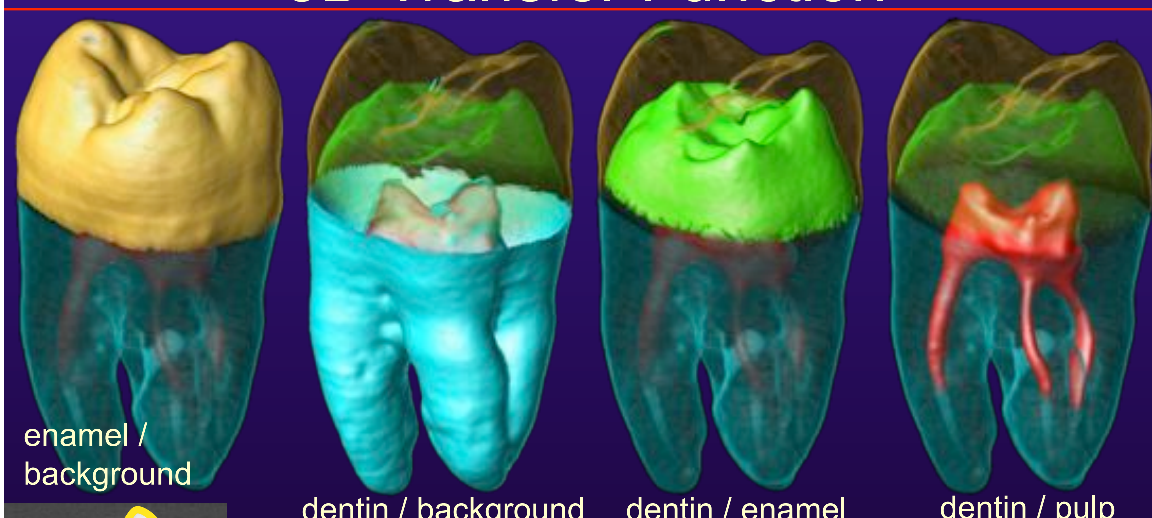
Different Interaction

"Interactive Volume Rendering Using Multi-Dimensional Transfer Functions and Direct Manipulation Widgets" Kniss, Kindlmann, Hansen: Vis '01

- Make things opaque by pointing at them
- Uses 3D transfer functions (value, 1st, 2nd derivative)
- "Paint" into the transfer function domain



3D Transfer Function



3D transfer functions allow
- easier boundary selection
- accurate boundary visualization

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Outline

1. Transfer Functions: what and why
2. Current Methods
3. Ideas for future work

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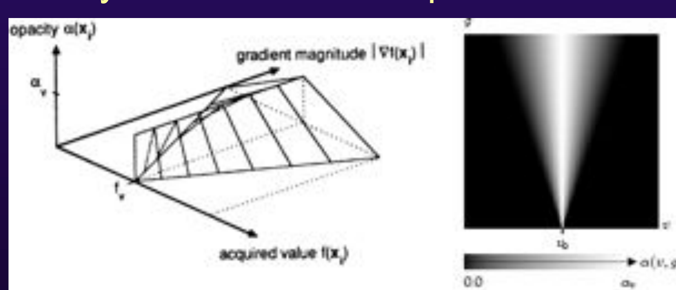
Different domains, ranges

- Time-varying data ("A Study of Transfer Function Generation for Time-Varying Volume Data", Jankun-Kelly, Ma: Volume Graphics '01)
- Multi-dimensional TFs expressive and powerful
  - Leverage current techniques for ease of use
- 2D opacity functions: let's use them!
  - Marc Levoy's 1988 CG+A Paper



Ranges: Emitance, textures, what else?

Other directions

- Variations on the histogram volume:
  - Different quantities, assumptions, models, analysis?
- Histograms/scatterplots entirely loose spatial information
  - Any way to keep some of it?
  - Can TFs have volume position in domain?

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Future Work

Other directions

- Image-centric methods have a certain appeal
  - Any way to steer and constrain them more effectively?
  - Image-space analysis of TF fitness?
- What kinds of tools do we really want?
  - Analytical vs. expressive; simplifying vs. honest?
  - What is the proper role for human experimentation?

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Questions?