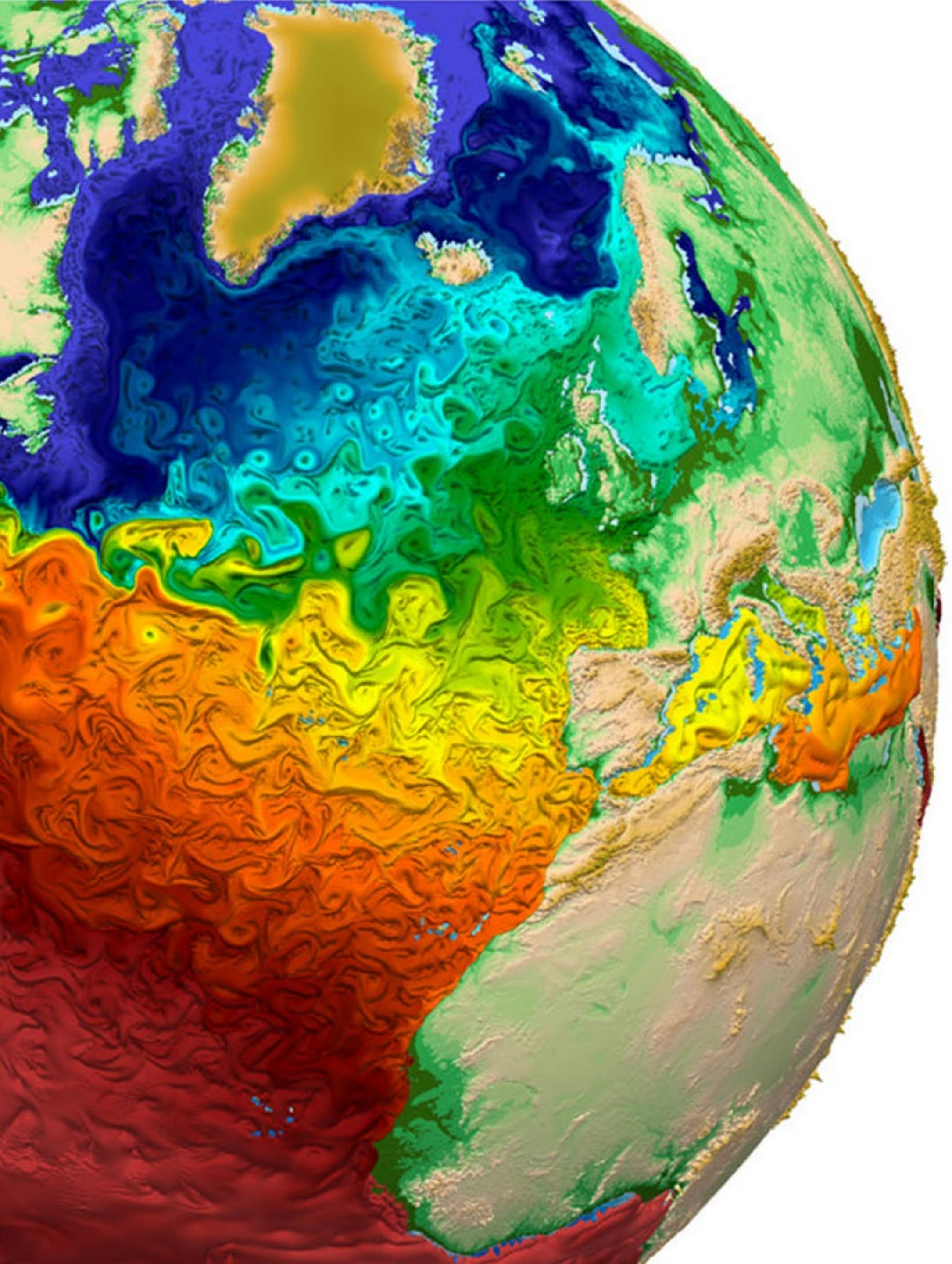


Classification

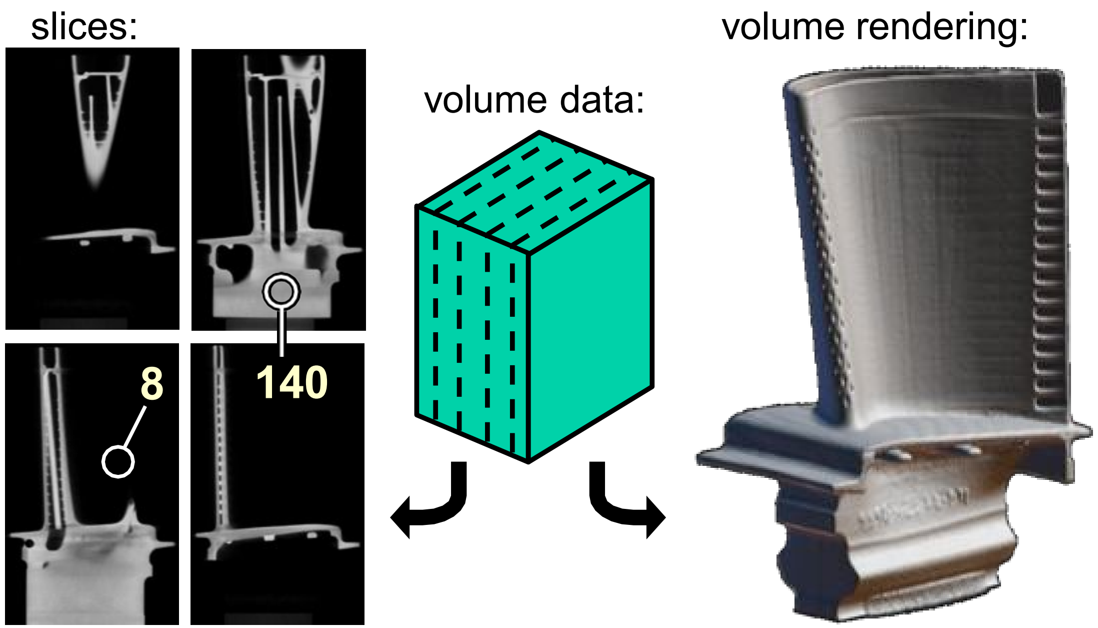
Transfer Functions

Professor Eric Shaffer

ILLINOIS

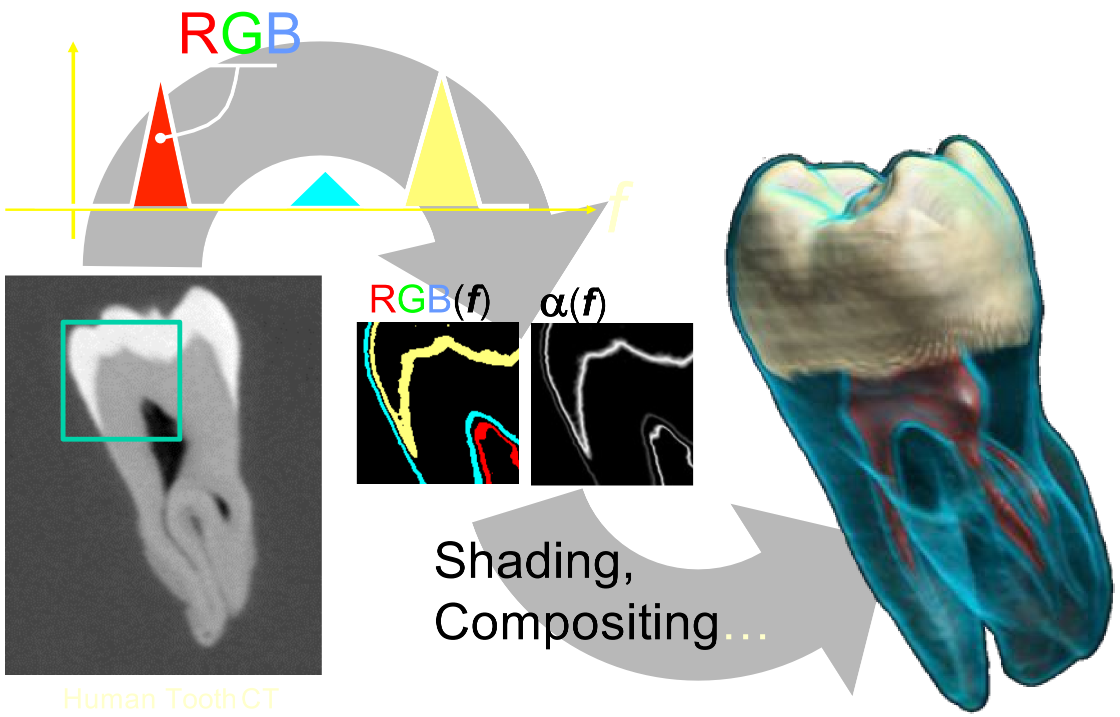
What are Transfer Functions?

Transfer functions make volume data visible by mapping data values to optical properties



Transfer Functions

Simple and usual case: Function maps data value to color and opacity



Optical Properties

Anything that can be composited with the standard graphics operator ″over“

- Opacity: ″opacity functions″
  - Most important
- Color
  - Can help distinguish features

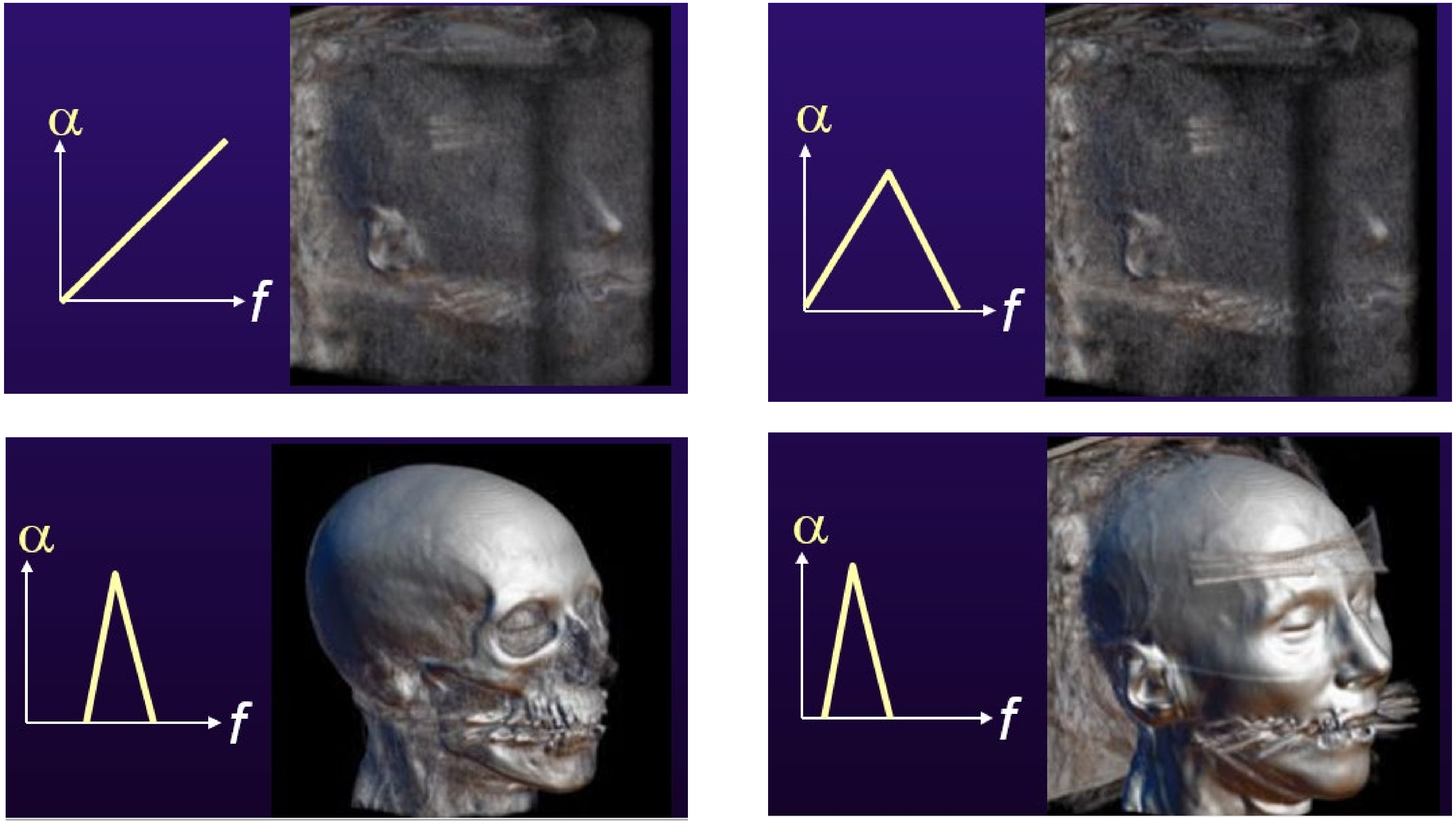
- Emittance
- Phong parameters (k_a, k_d, k_s)
- Index of refraction

$$\mathbf{I} = \sum_{i=1}^{n} \mathrm{C}_i \alpha_i \prod_{j=1}^{i-1} (1 - \alpha_j)$$

$$\mathbf{C}'_{i+1} = \mathbf{C}'_i + (1 - \alpha'_i)\mathbf{C}_i \alpha_i$$
$$\alpha'_{i+1} = \alpha'_i + (1 - \alpha'_i)\alpha_i$$

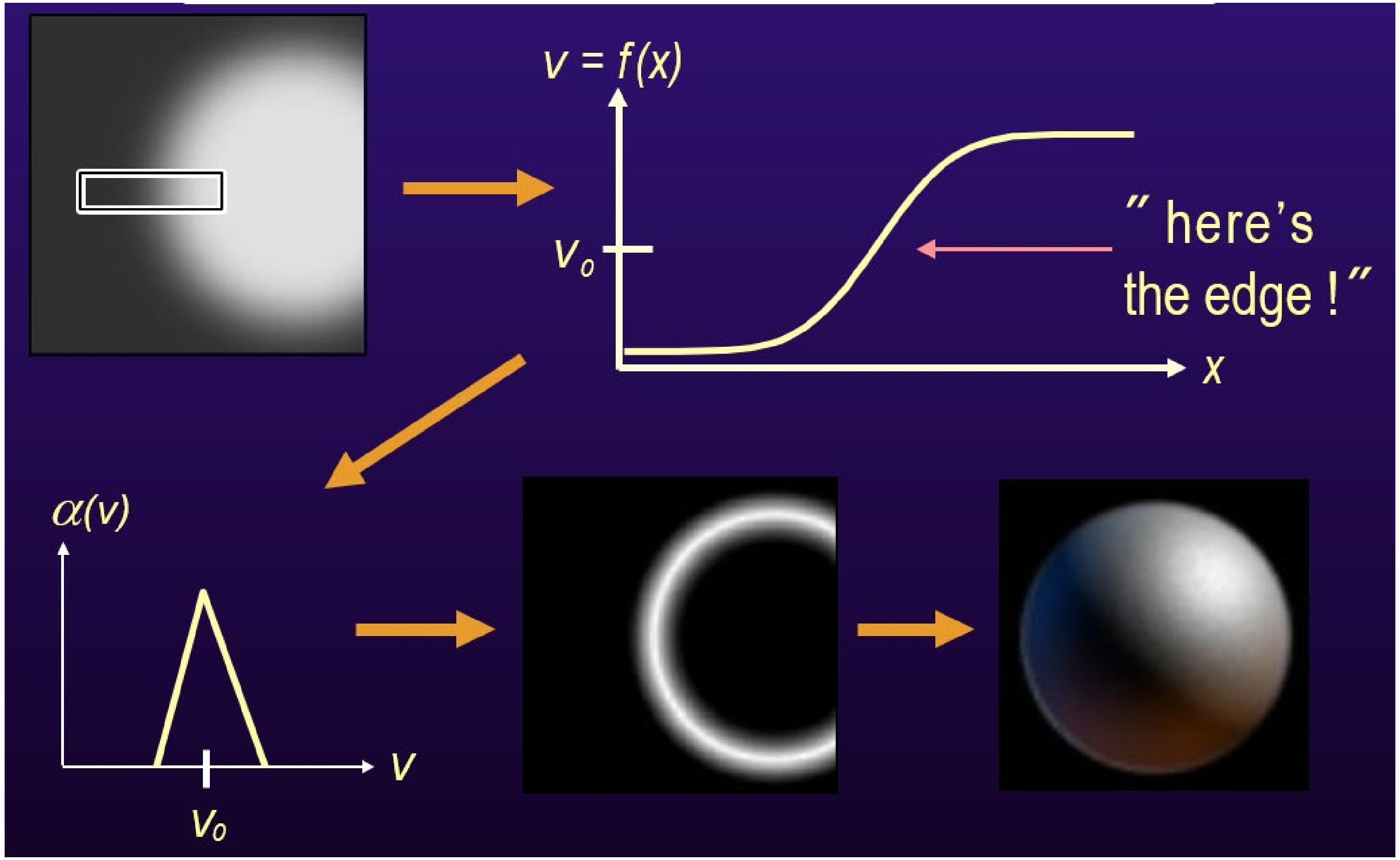
ILLINOIS

Setting Transfer Functions is difficult…unintuitive and slow

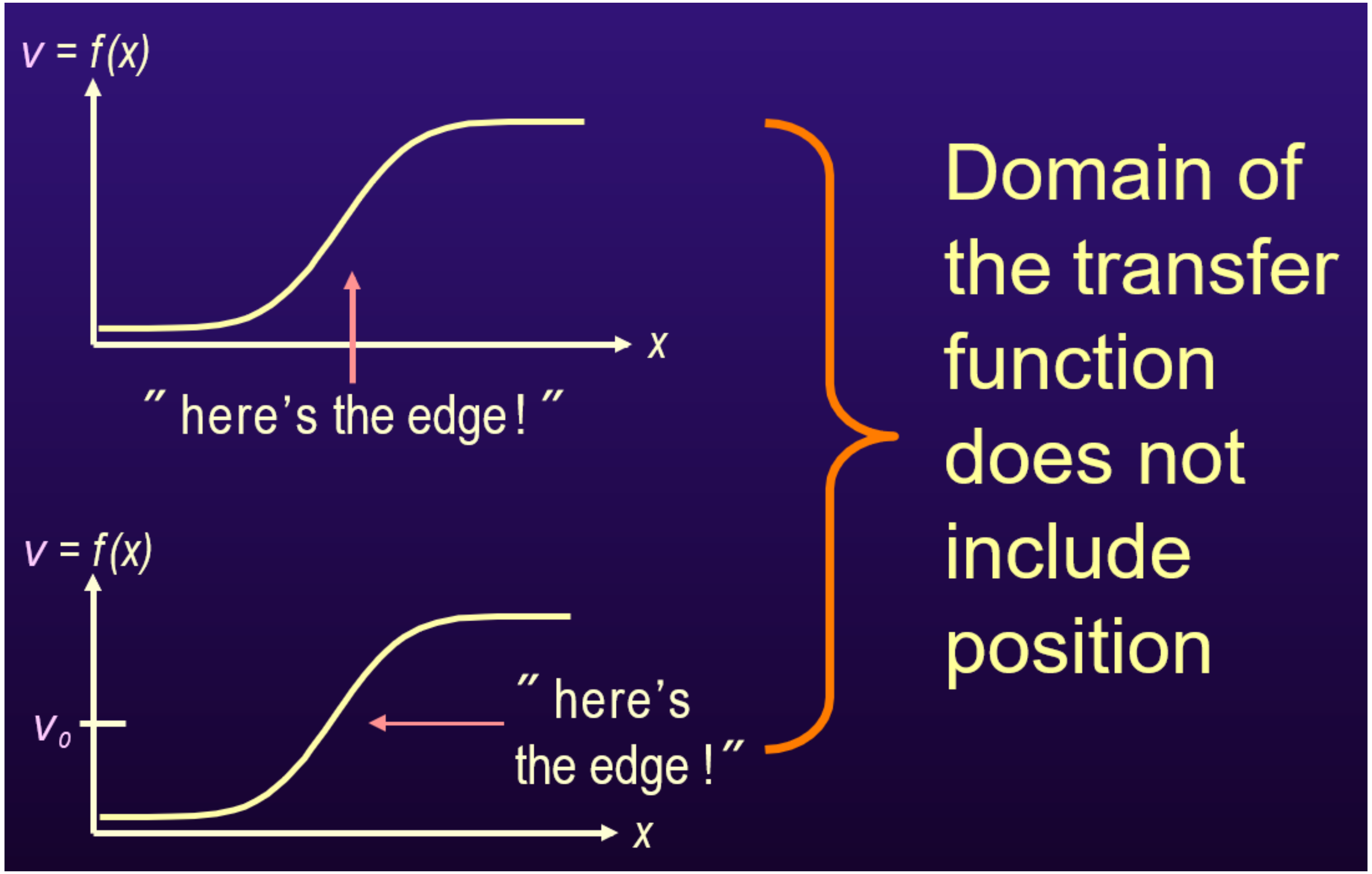


Transfer Functions as Feature Detection

Where's the edge or surface?



Why are Transfer Functions Difficult to Create?



Consider creating a function to segment multiple features

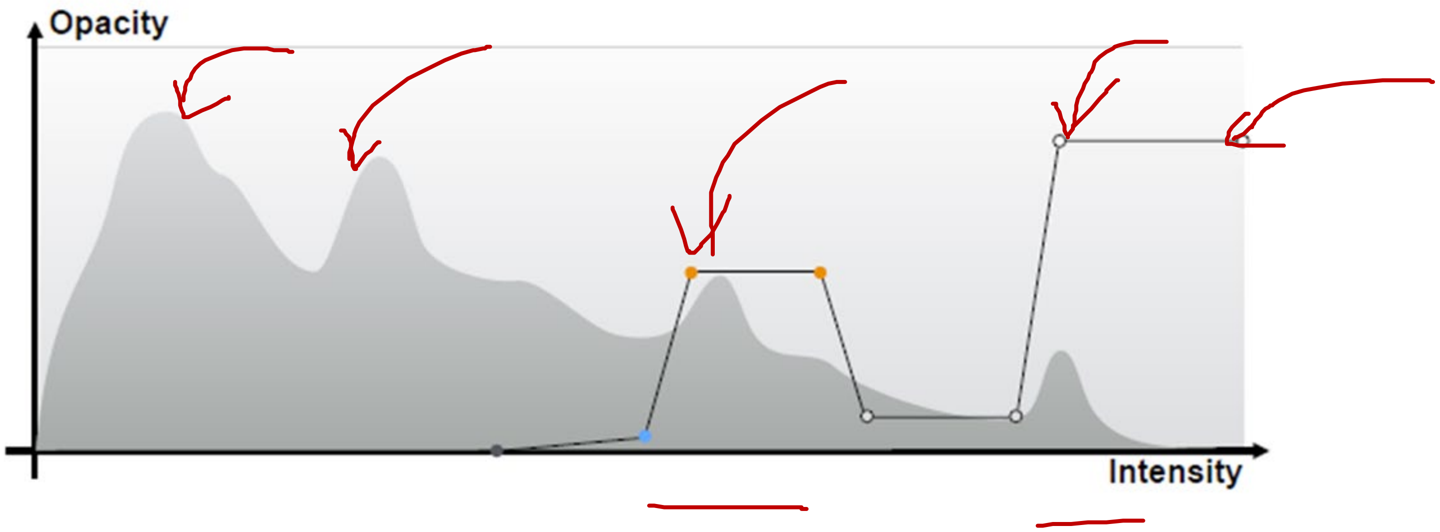
Consider having to create a multi-dimensional transfer function

Transfer Function Taxonomy

There are many ways to categorize transfer functions.

One common approach is data-centric.

What is the dimensionality of the data the function operates on?



A standard user interface for 1D TF settings. Color and opacity are assigned to data ranges using piecewise linear TF widgets. The background represents the histogram of binned scalar attribute data.

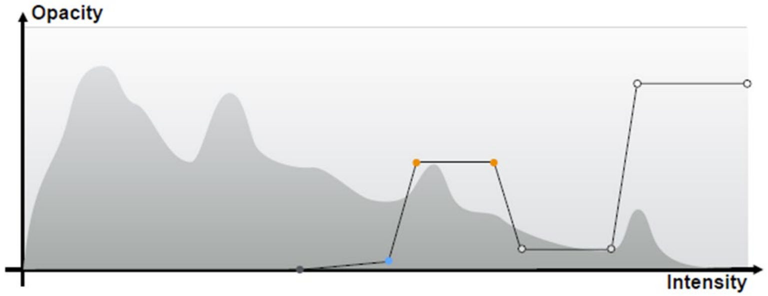
ILLINOIS

1D Transfer Functions

1D TFs map a scalar value to a visual representation…usually color and opacity

Some suitable applications for 1D TFS include:

- Industrial CT scan: density data with few overlapping intensity ranges
- Simulation data which is typically low-noise or noise-free



For most medical image data, 1D TF is inadequate:

- tissues have significant overlap in the intensity range, as described
- medical data is measured and relatively noisy

These characteristics negatively impact ability of 1D TFs to correctly classify tissue types.

1D TFs still often used in theses applications because higher dimensional work is so hard

MD Transfer Functions

TF operating on an input with more than one dimension is:

- a 2D TF (for a bi-variate input)
- An MD TF (for an input of multiple dimensions)

We can distinguish between TFs are that separable or are intrinsically high-dimensional.

A separable 2D TF is defined as:

two separate 1D functions that are combined only after both 1D functions have been applied separately

Separable 2D TF

$$\mathbf{q}_{\text{separable}}(d_1, d_2) = \mathbf{V}(\mathbf{M}(d_1), d_2)$$

M classifies material and V generates a visual mapping (e.g. rgba value)

Example:

Gradient-based opacity modulation in which the second dimension is used to improve visual appearance.

This suppresses interior homogeneous material regions and enhances boundaries.

Essentially, a 1D TF is applied first, followed by multiplying the opacity with a 1D function of gradient magnitude.

Non-Separable 2D TF

$$\mathbf{q}_{\text{non-separable}}(d_1, d_2) = \mathbf{V}(\mathbf{M}(d_1, d_2))$$

M classifies material and V generates a visual mapping (e.g. rgba value)

Example:

Simultaneous value and gradient magnitude mapping presented in

KNISS J., KINDLMANN G., HANSEN C.: Multidimensional transfer functions for interactive volume rendering. IEEE TVCG 8, 3 (July 2002)

9 Multi-Dimensional Transfer Functions for Volume Rendering

JOE KNISS, GORDON KINDLMANN, and CHARLES HANSEN
Scientific Computing and Imaging Institute
School of Computing, University of Utah

9.1 Introduction

Direct volume-rendering has proven to be an effective and flexible visualization method for 3D scalar fields. Transfer functions are fundamental to direct volume-rendering because their role is essentially to make the data visible: by assigning optical properties like color and opacity to the voxel data, the volume can be rendered with traditional computer graphics methods. Good transfer functions reveal the important structures in the data without obscuring them with unimportant regions. To date, transfer functions have generally been limited to 1D domains, meaning that the 1D space of scalar data value has been the only variable to which opacity and color are assigned. One aspect of direct volume-rendering that has received little attention is the use of multidimensional transfer functions.

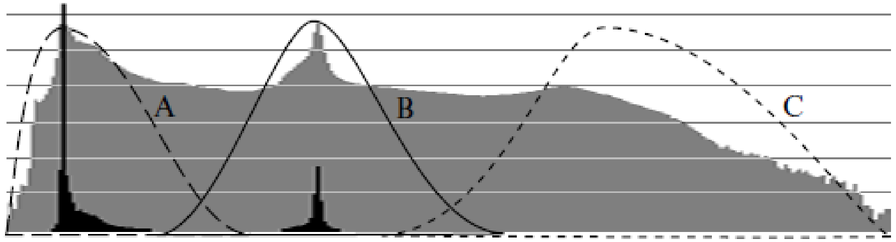
Often, there are features of interest in volume data that are difficult to extract and visualize with 1D transfer functions. Many medical datasets created from CT or MRI scans contain a complex combination of boundaries between multiple materials. This situation is problematic for 1D transfer functions because of the potential for overlap between the data-value intervals spanned by the different boundaries. When one data value is associated with multiple boundaries, a 1D transfer function is unable to render them in isolation. Another benefit of higher dimensional transfer functions is their ability to portray subtle variations in properties of a single boundary, such as thickness. When working with multivariate data, a similar difficulty arises with features that can be identified only by their unique combination of multiple data values. A 1D transfer function is simply not capable of capturing this relationship.

Unfortunately, using multidimensional transfer functions in volume rendering is complicated. Even when the transfer function is only 1D, finding an appropriate transfer function is generally accomplished by trial and error. This is one of the main challenges in making direct volume-rendering an effective visualization tool. Adding dimensions to the transfer-function domain only compounds the problem. While this is an ongoing research area, many of the proposed methods for transfer-function generation and manipulation are not easily extended to higher-dimensional transfer functions. In addition, fast volume-rendering algorithms that assume the transfer function can be implemented as a linear lookup table (LUT) can be difficult to adapt to multidimensional transfer functions due to the linear interpolation imposed on such LUTs. Q1

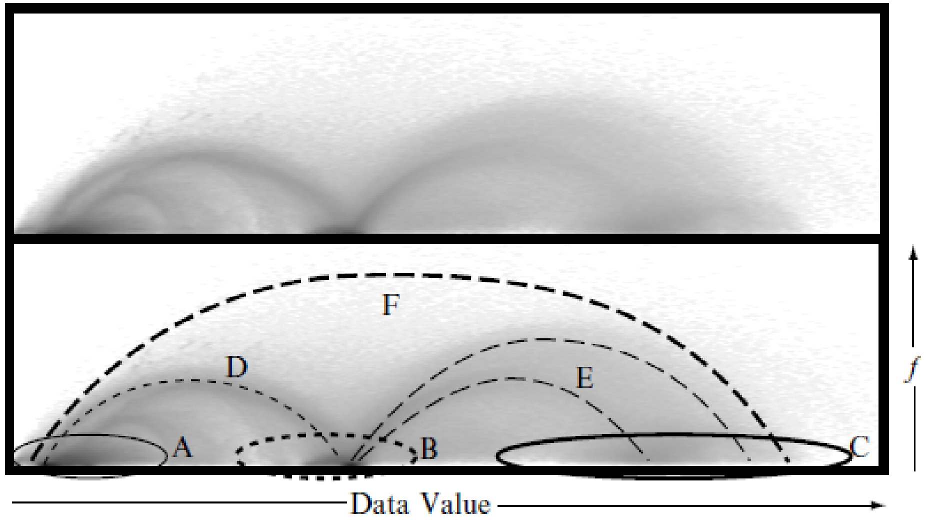
This chapter provides a detailed exposition of the multidimensional transfer function concept, a generalization of multidimensional transfer functions for both scalar and multivariate data, as well as a novel technique for the interactive generation of volumetric shadows. To resolve the potential complexities in a user interface for multidimensional transfer functions, we introduce a set of direct manipulation widgets

ILLINOIS

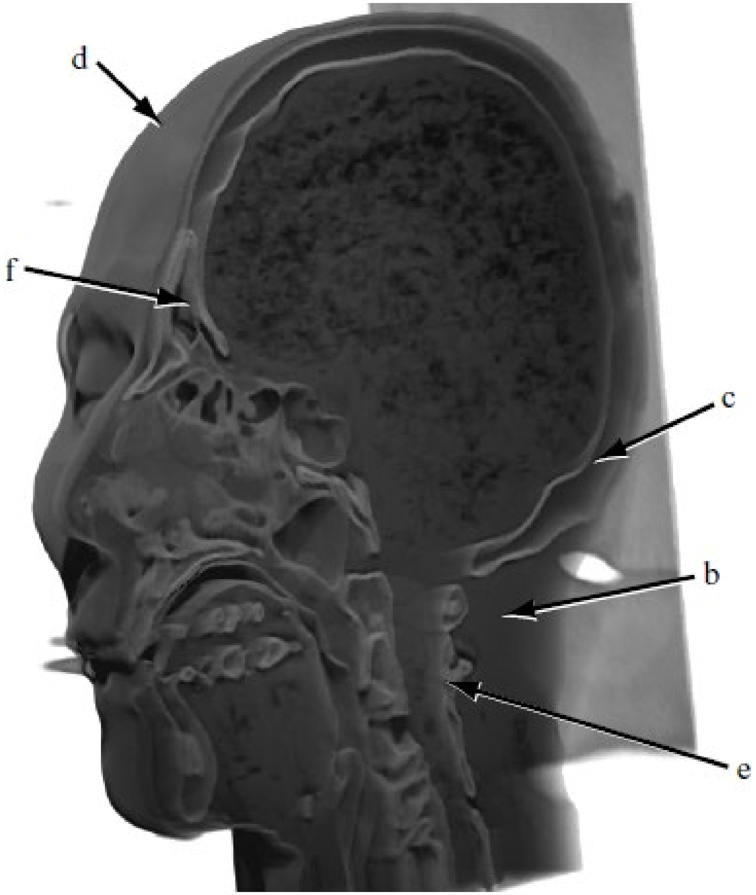
2D Transfer Function Example



(a) A ID histogram. The black region represents the number of data value occurrences on a linear scale; the grey is on a log scale. The colored regions (A,B,C) identify basic materials.



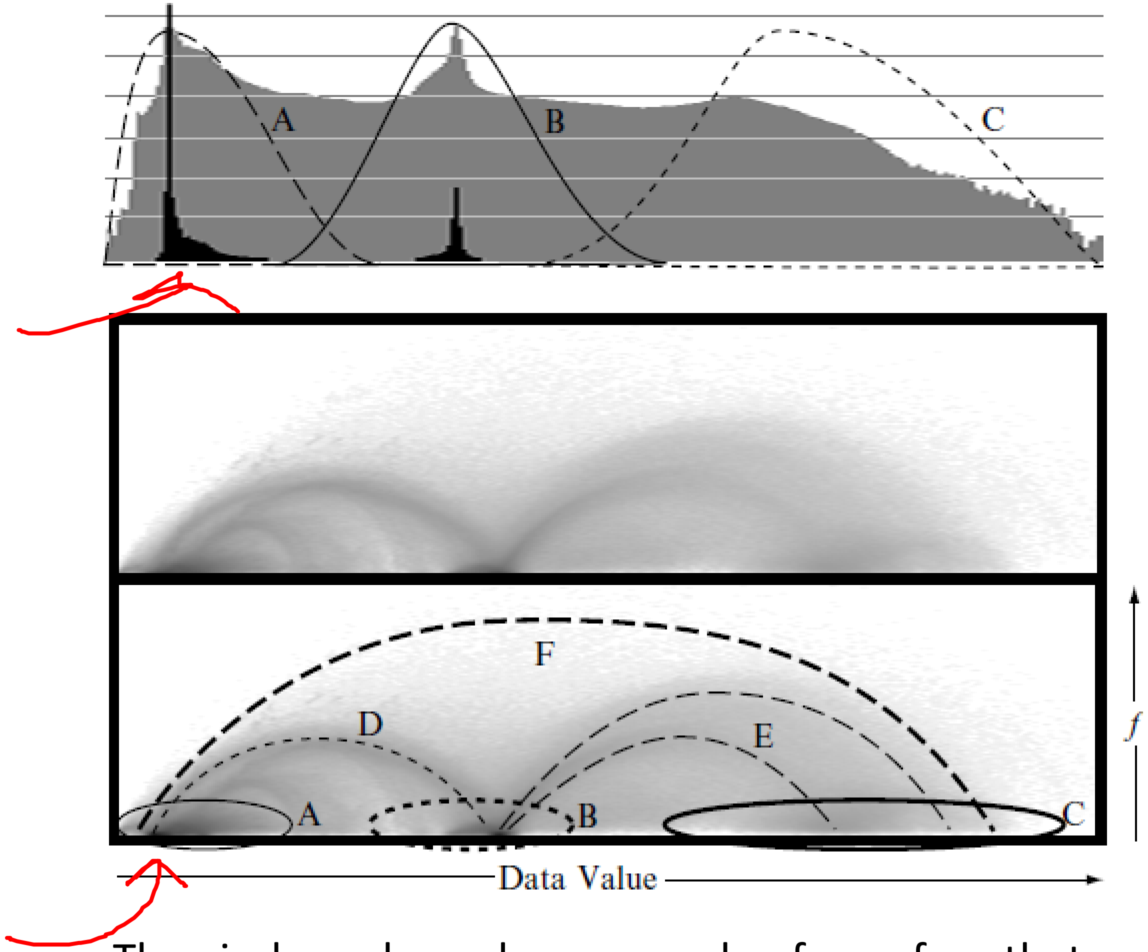
(b) A log-scale 2D joint histogram. The lower image shows the location of materials (A,B,C). and material boundaries (D,E,F).



(c) A volume-rendering showing all of the materials and boundaries identified above, except air (A), using a 2D transfer function.

ILLINOIS

Materials in CT Scan



A is air

B is soft tissue

C is bone

Density vs gradient magnitude plot

The boundaries between the materials are shown as the arches; air and soft tissue boundary (D), soft tissue and bone boundary (E), and air and bone boundary (F).

The air–bone boundary, example of a surface that cannot be isolated using a simple 1D transfer function.
This type of boundary appears in CT datasets as the sinuses and mastoid cells.

ILLINOIS

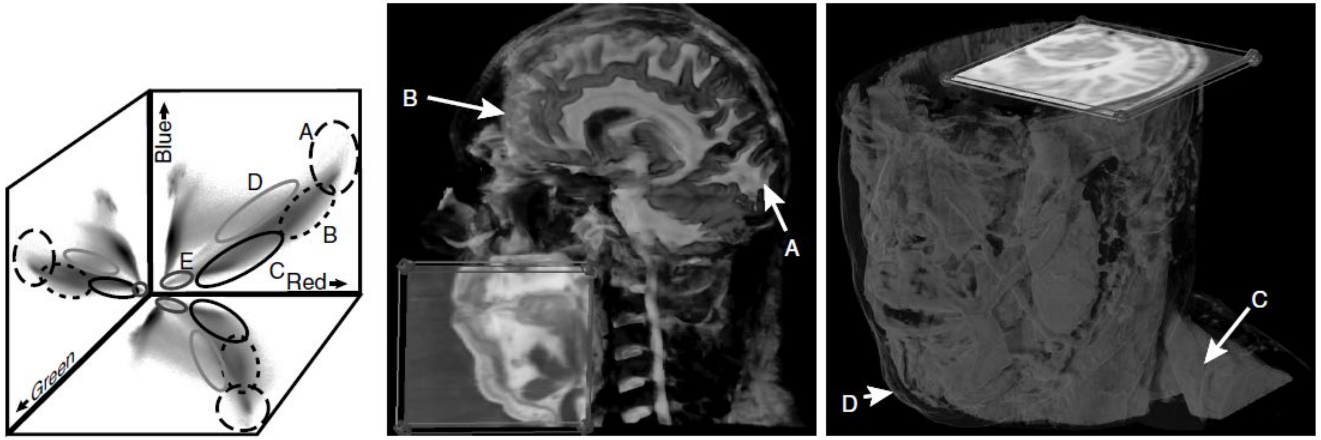
Multidimensional Transfer Functions

Moving beyond 2D TFs poses significant challenges in terms of user interfaces and cognitive comprehension.

Much research is, therefore, related to various forms of automation

Typical approaches include

- dimensional reduction,
- clustering and grouping
- machine learning,
- user interfaces such as parallel coordinates



(a) Histograms of the Visible Male RGB dataset

(b) The white (A) and gray (B) matter of the brain

(c) The muscle and connective tissues (C) of the head and neck, showing skin (D) for reference

Transfer Function Research

- 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