

CSC 544

Data Visualization

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Lecture 20

Transfer Function Design

March 29, 2023

Today's Agenda

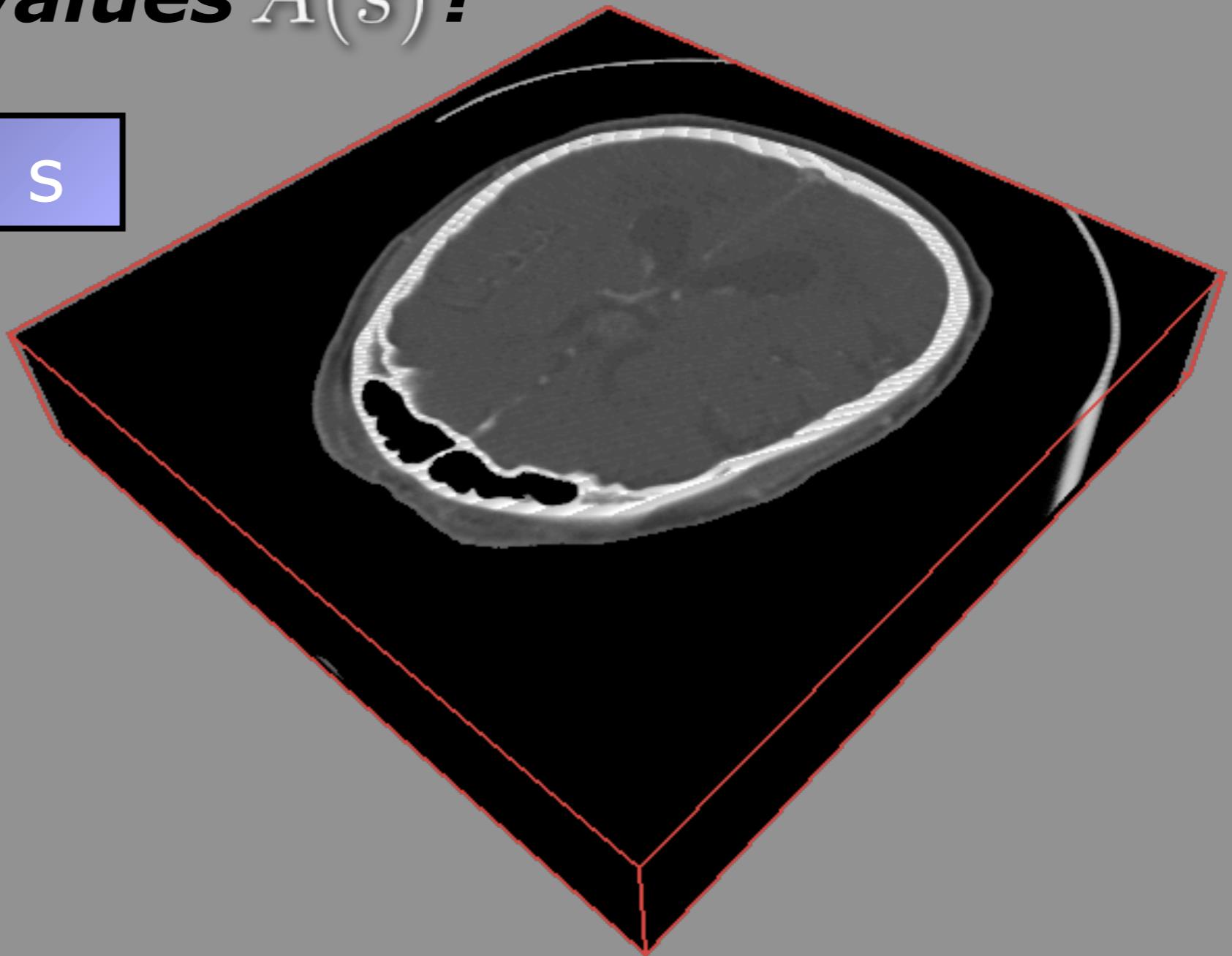
- Reminders:
 - A05 questions? (due Apr. 10)
 - P02 DUE!, P03 posted (due Apr. 26), P04 (due May 3)
- Goals for today: Discuss designing transfer functions for volume rendering

Transfer Functions

Classification

***How do I obtain the emission values $q(s)$ and
Absorption values $A(s)$?***

scalar value s



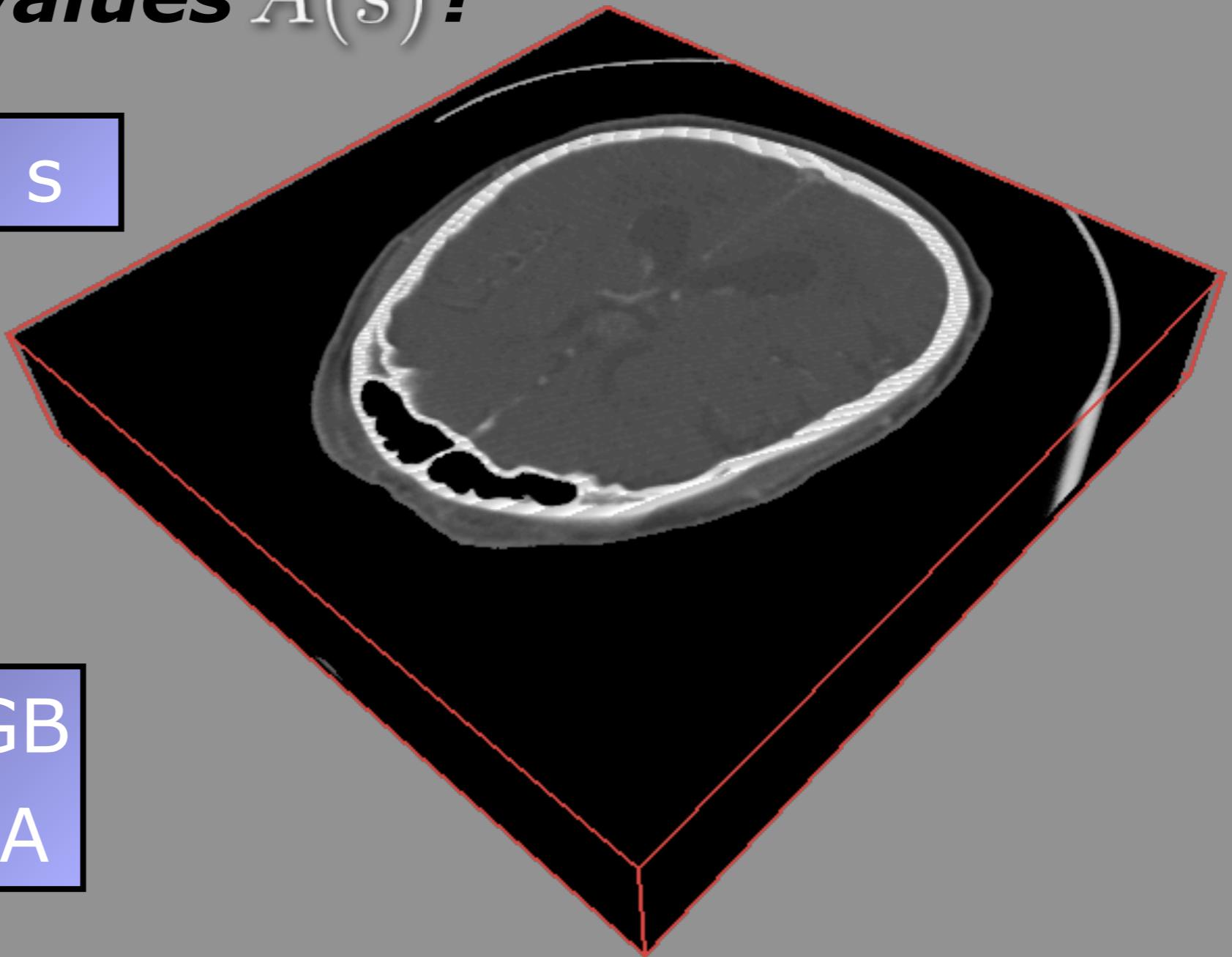
Classification

***How do I obtain the emission values $q(s)$ and
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$T(s)$

emission RGB
absorption A



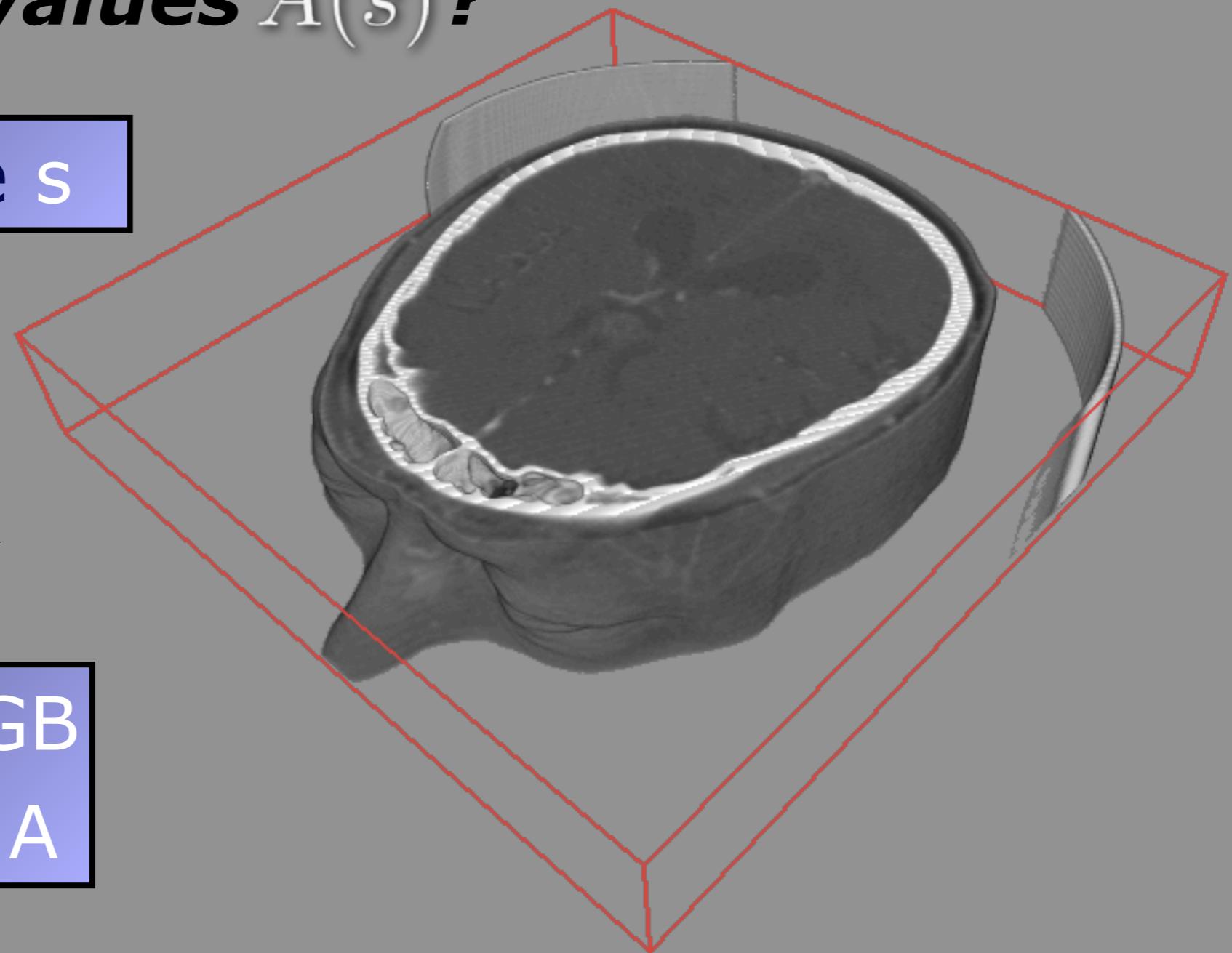
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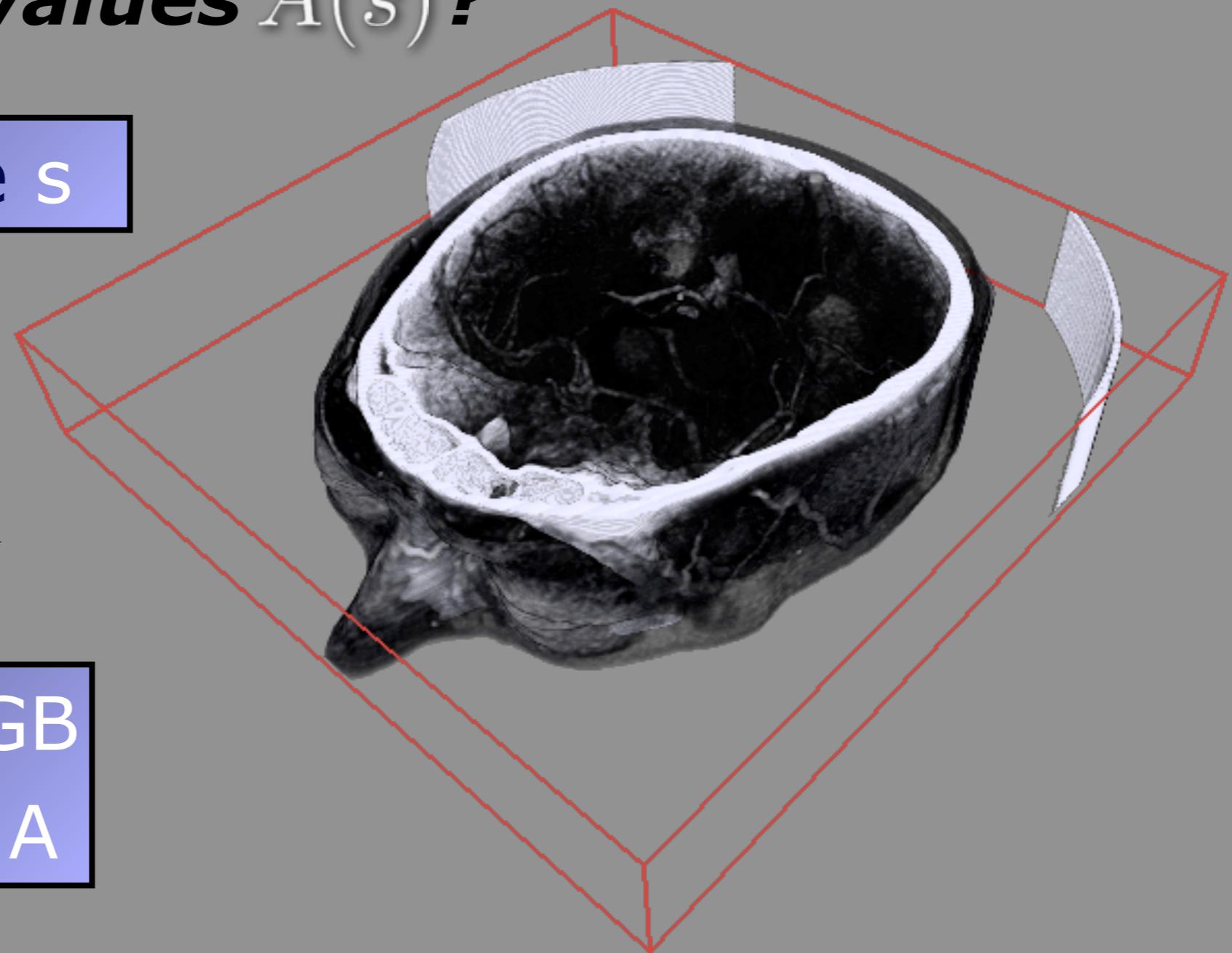
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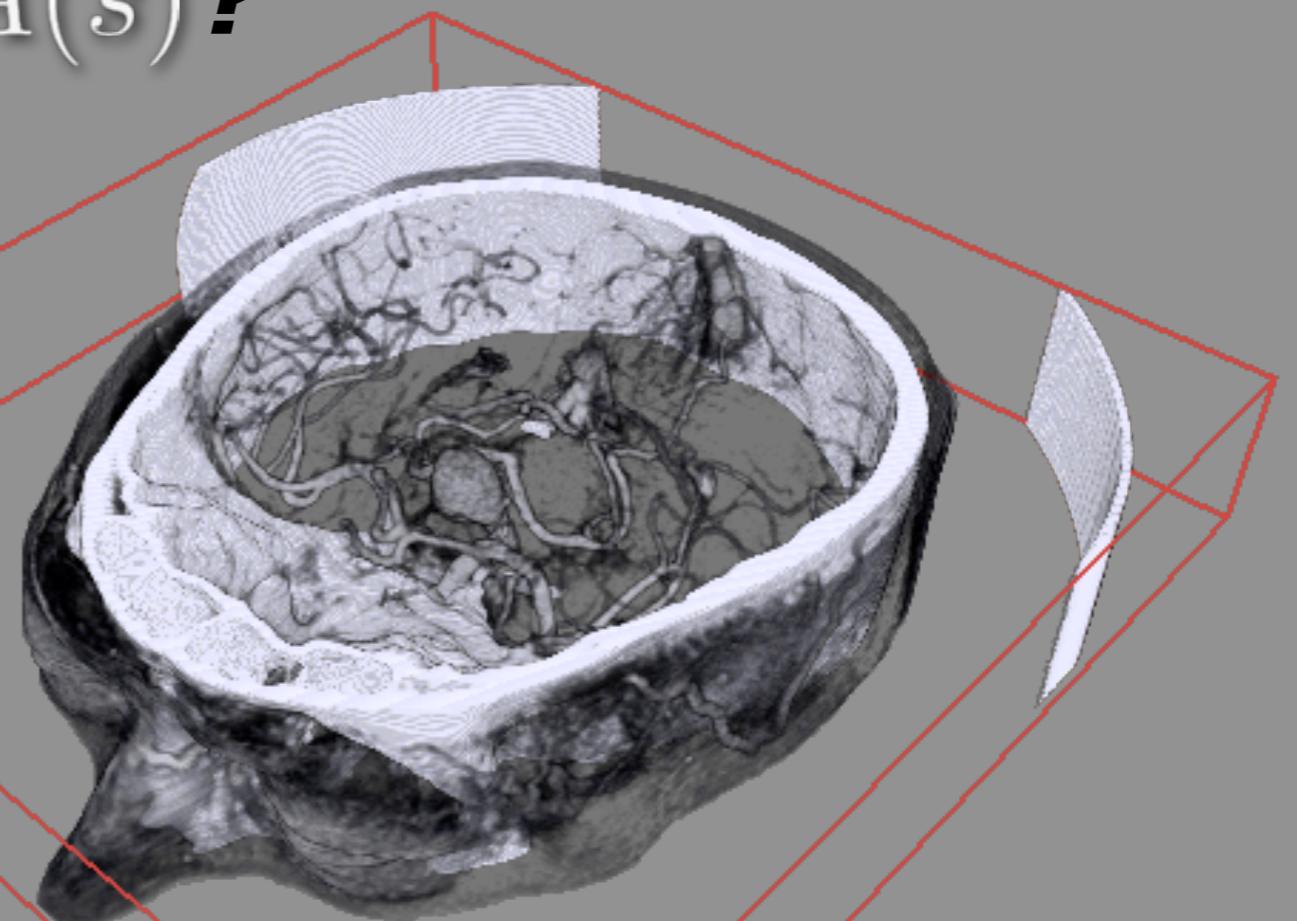
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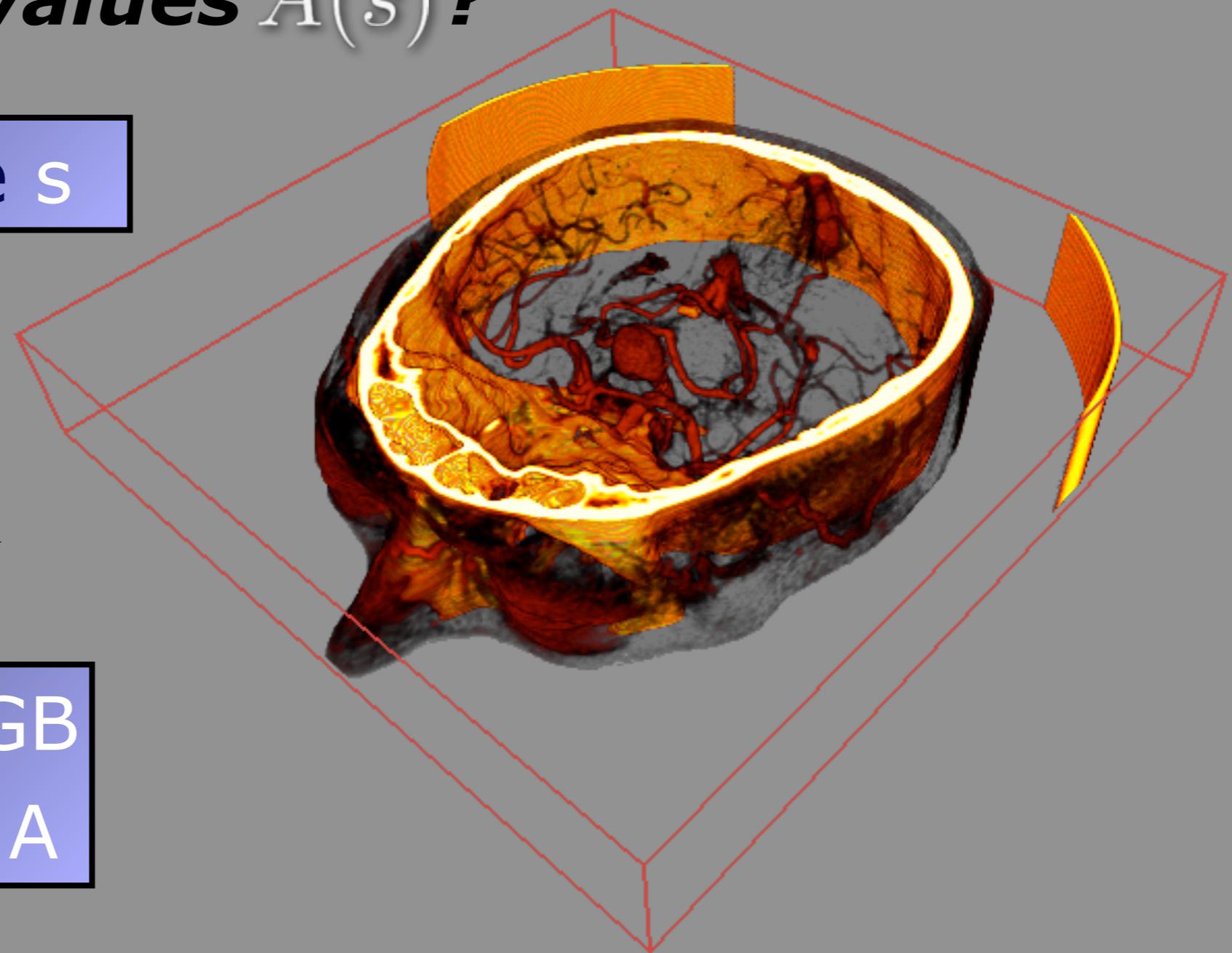
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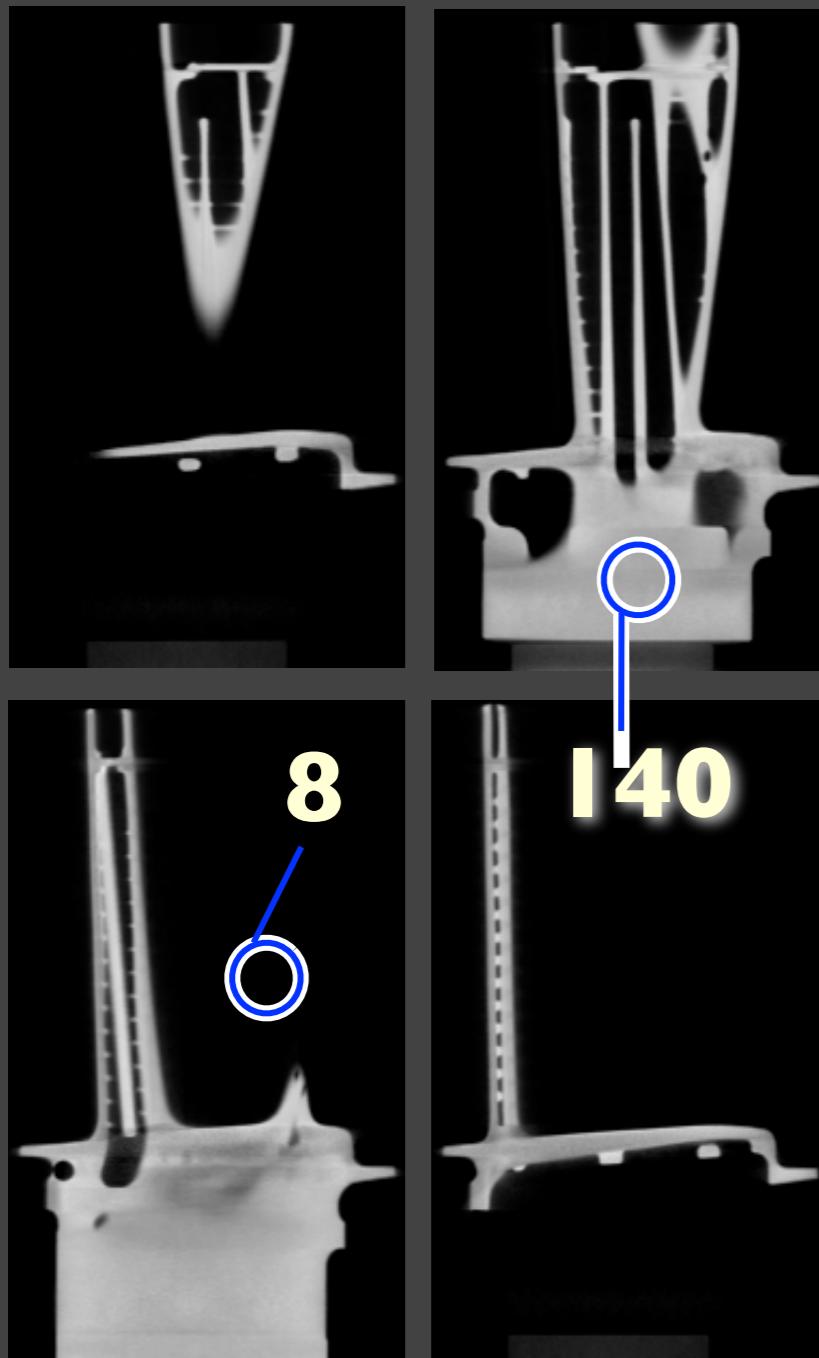
emission RGB
absorption A



Introduction

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

slices:



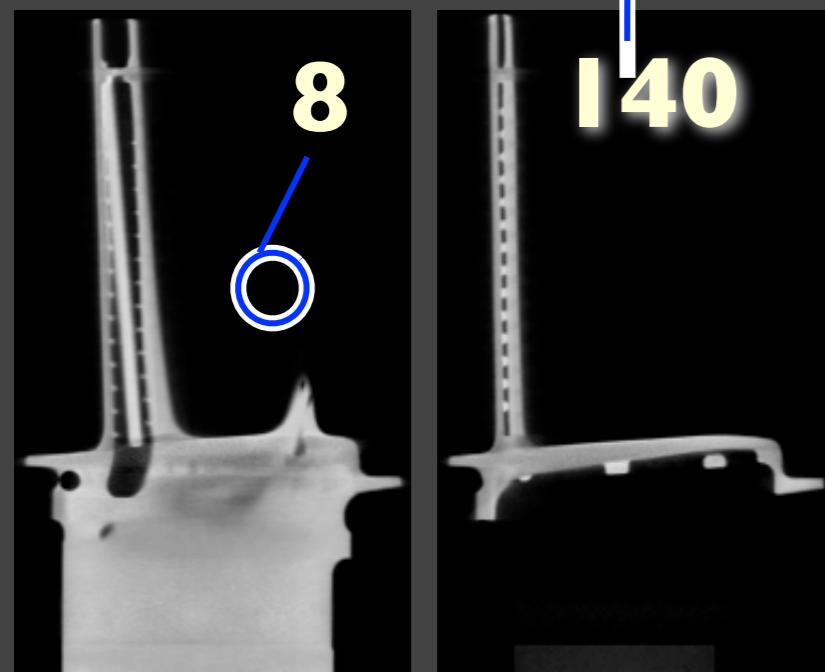
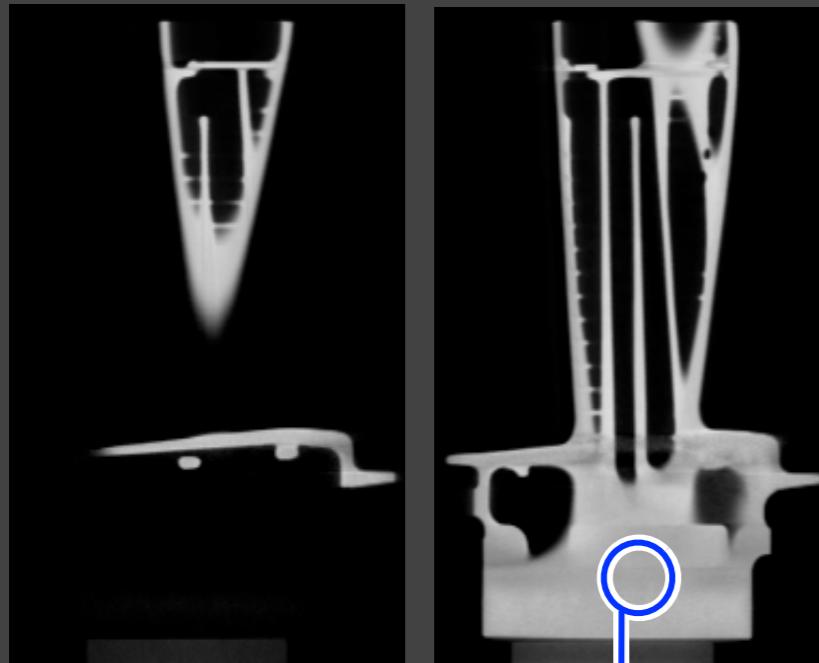
volume data:



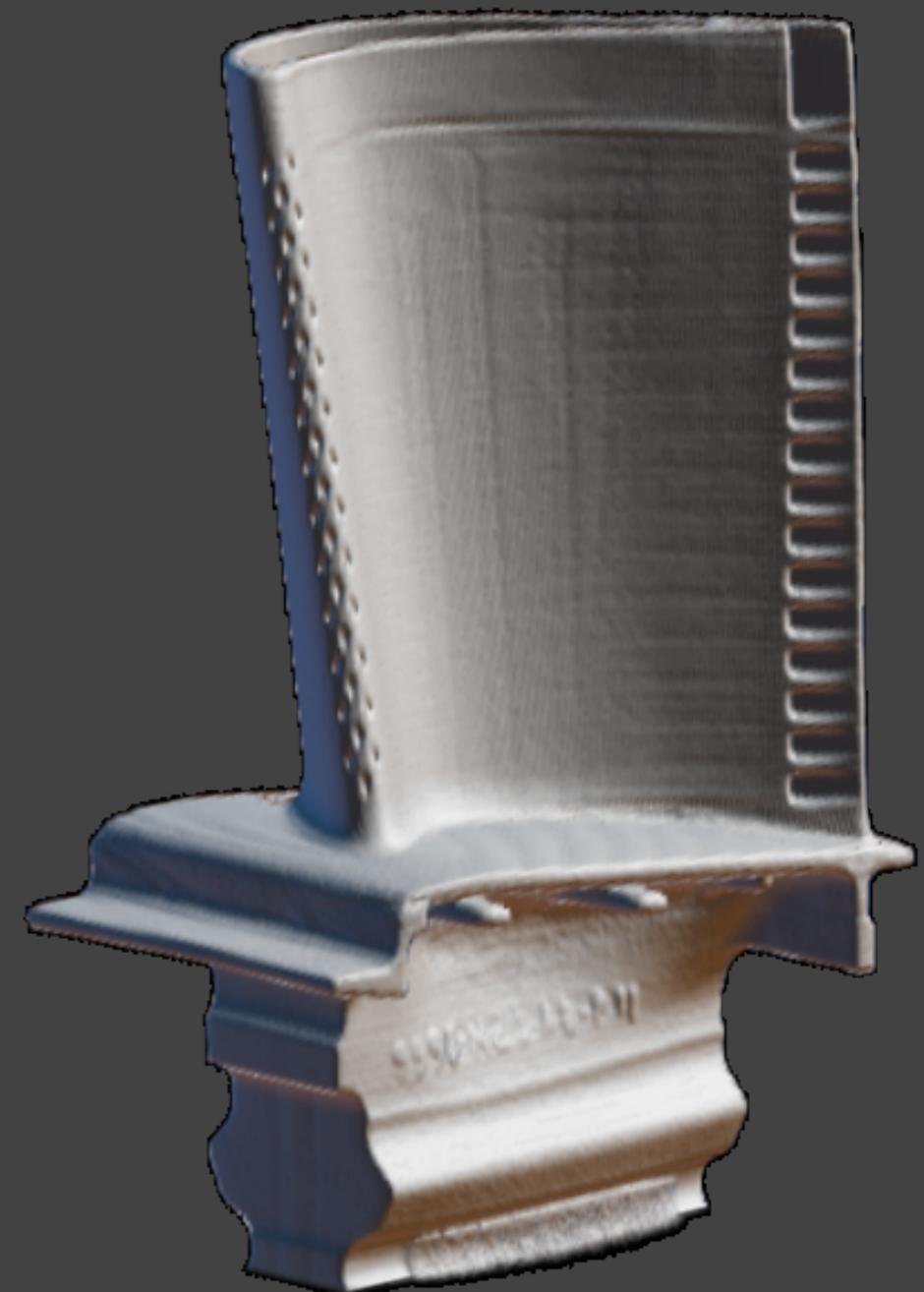
Introduction

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

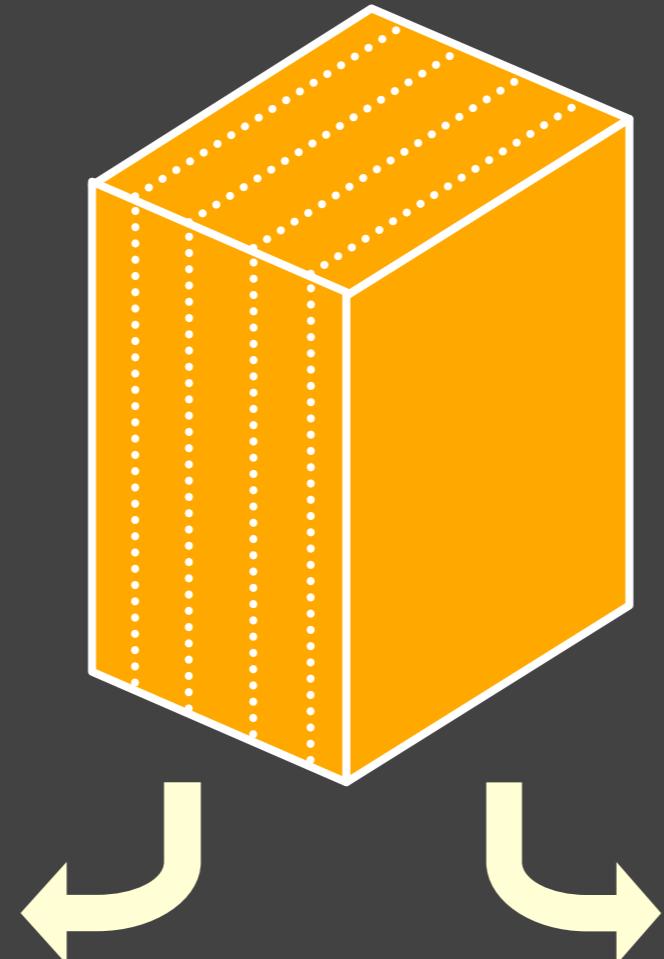
slices:



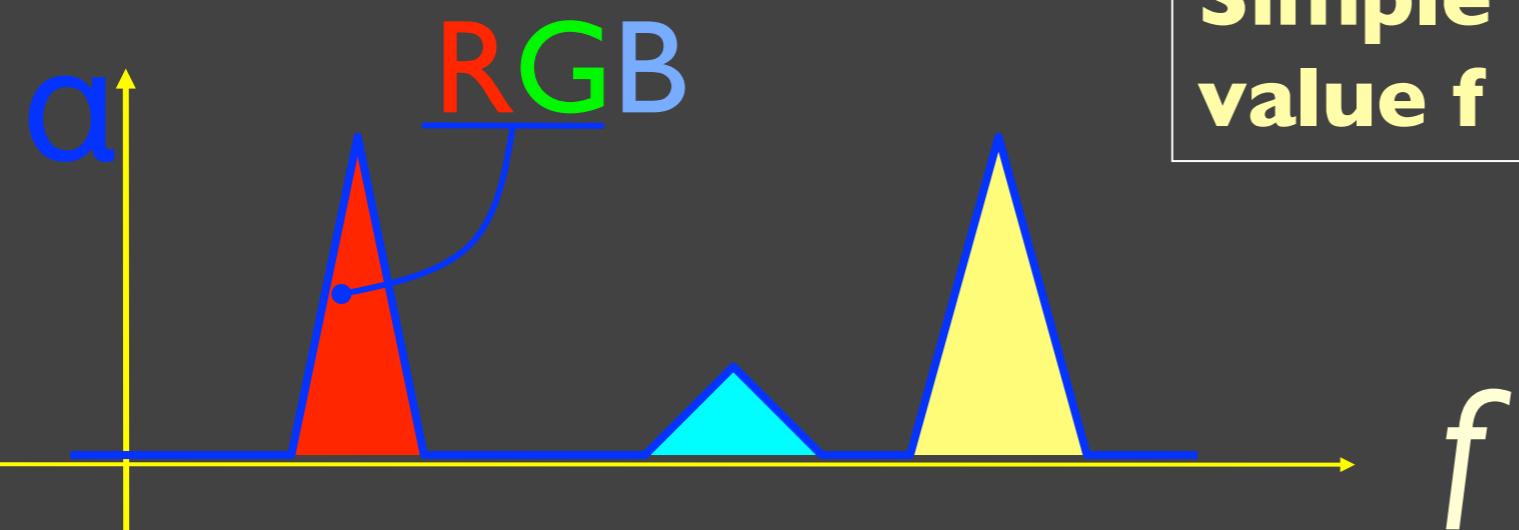
volume rendering:



volume data:

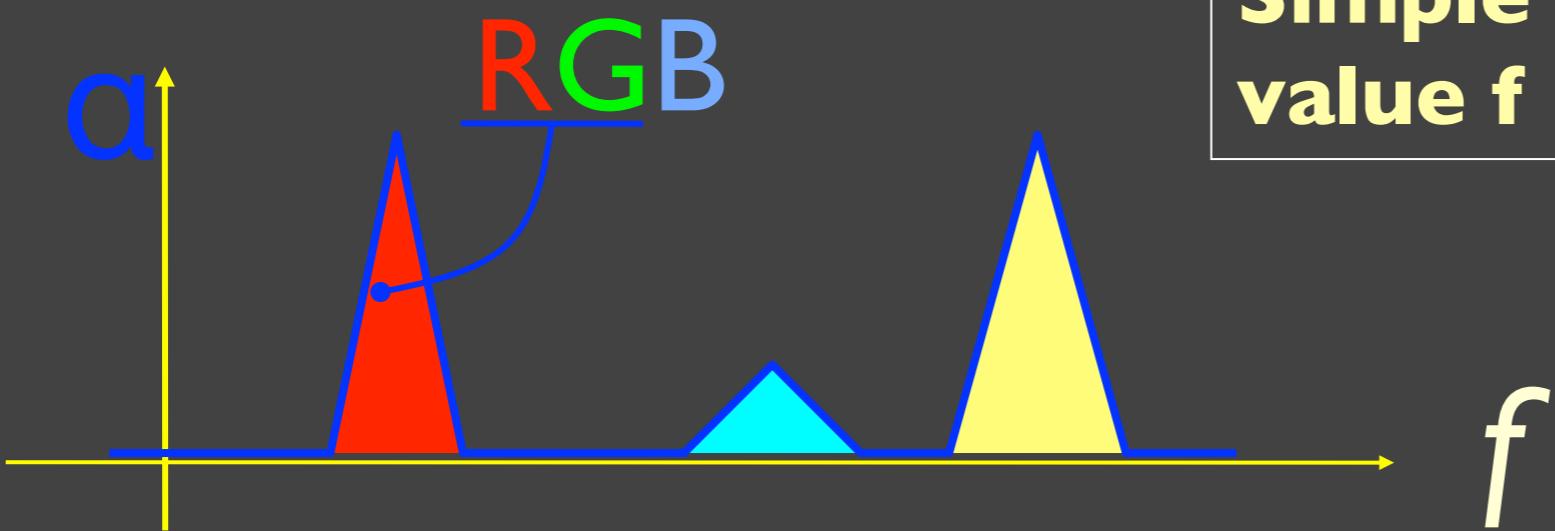


Transfer Functions (TFs)

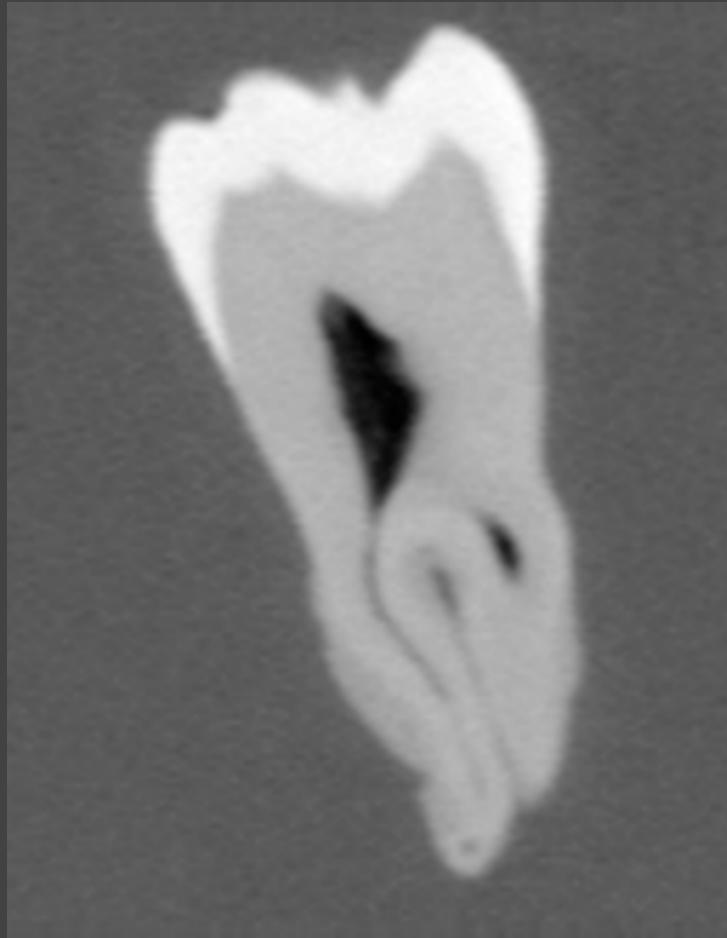


Simple (usual) case: Map data value f to color and opacity

Transfer Functions (TFs)

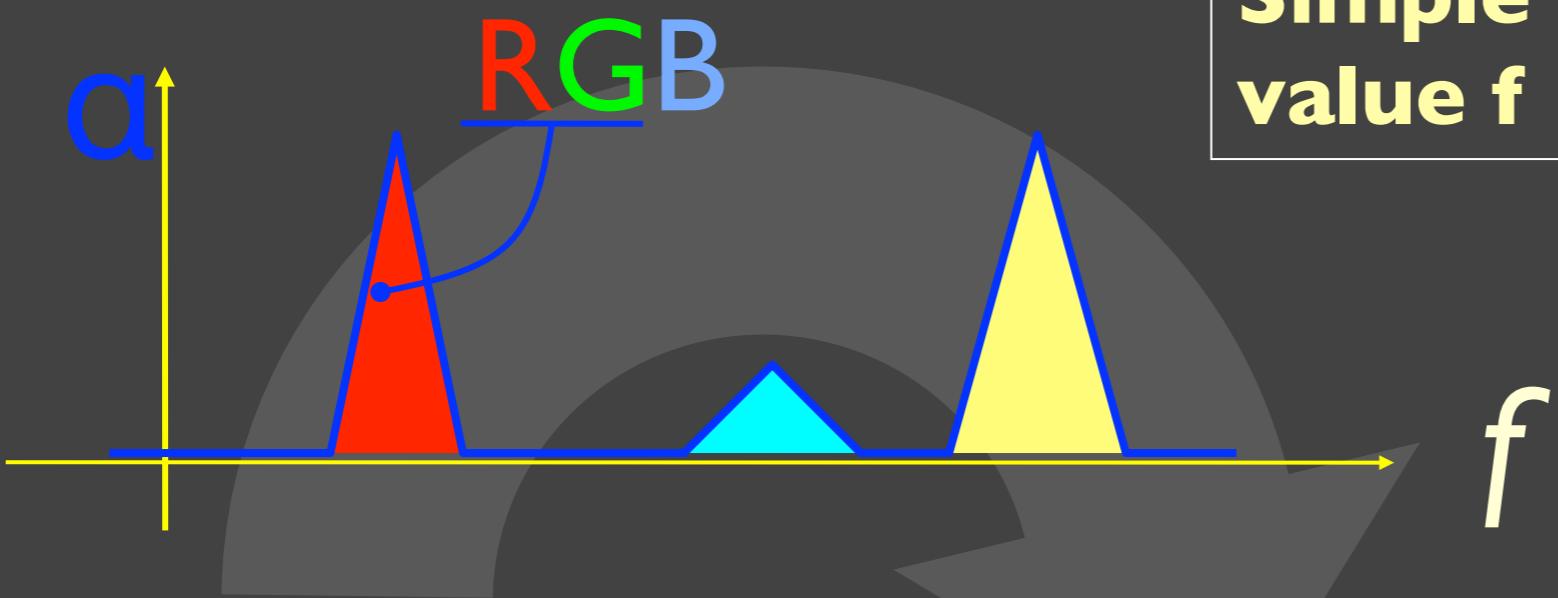


Simple (usual) case: Map data value f to color and opacity

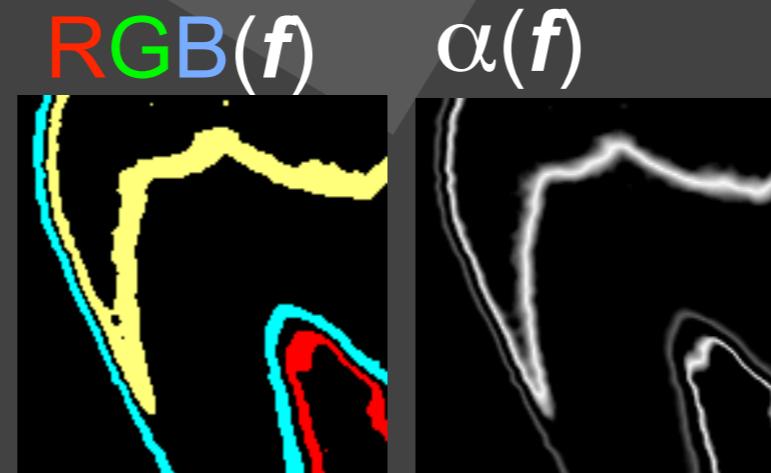
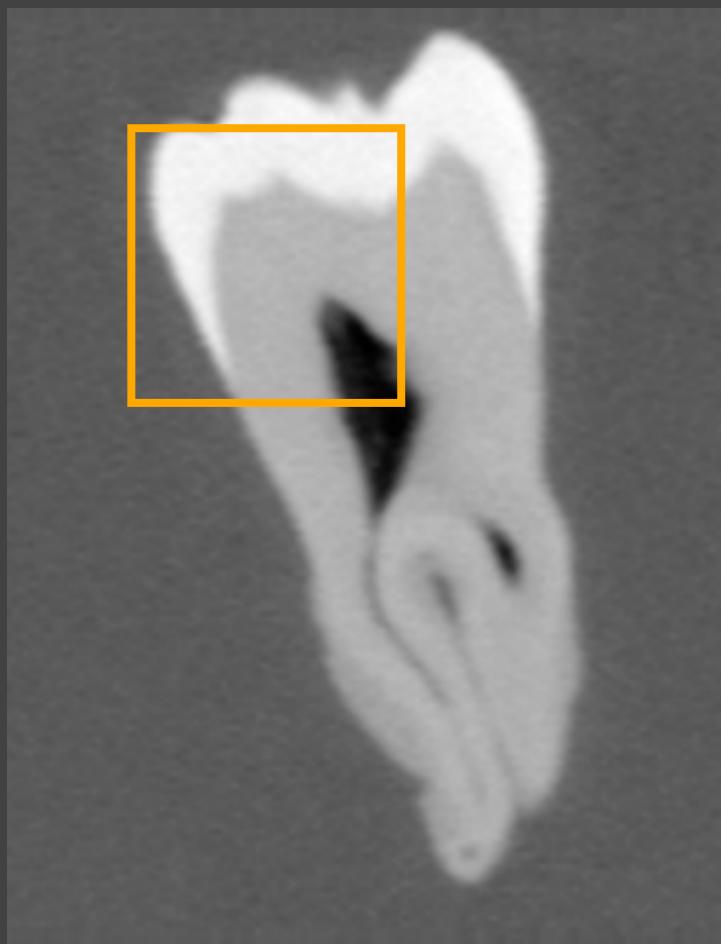


Human Tooth CT

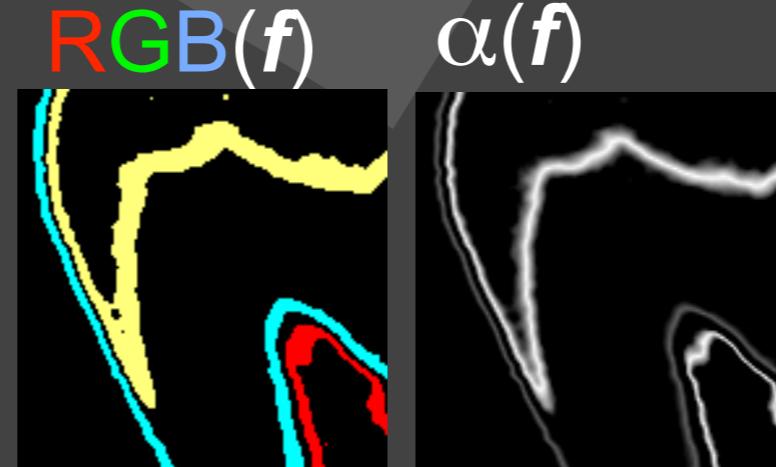
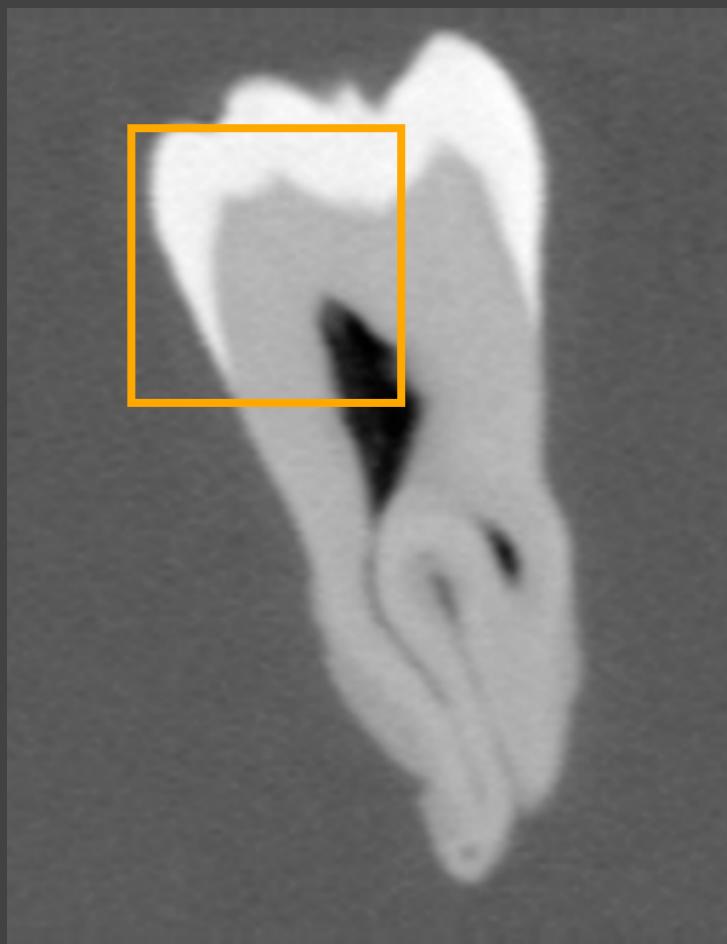
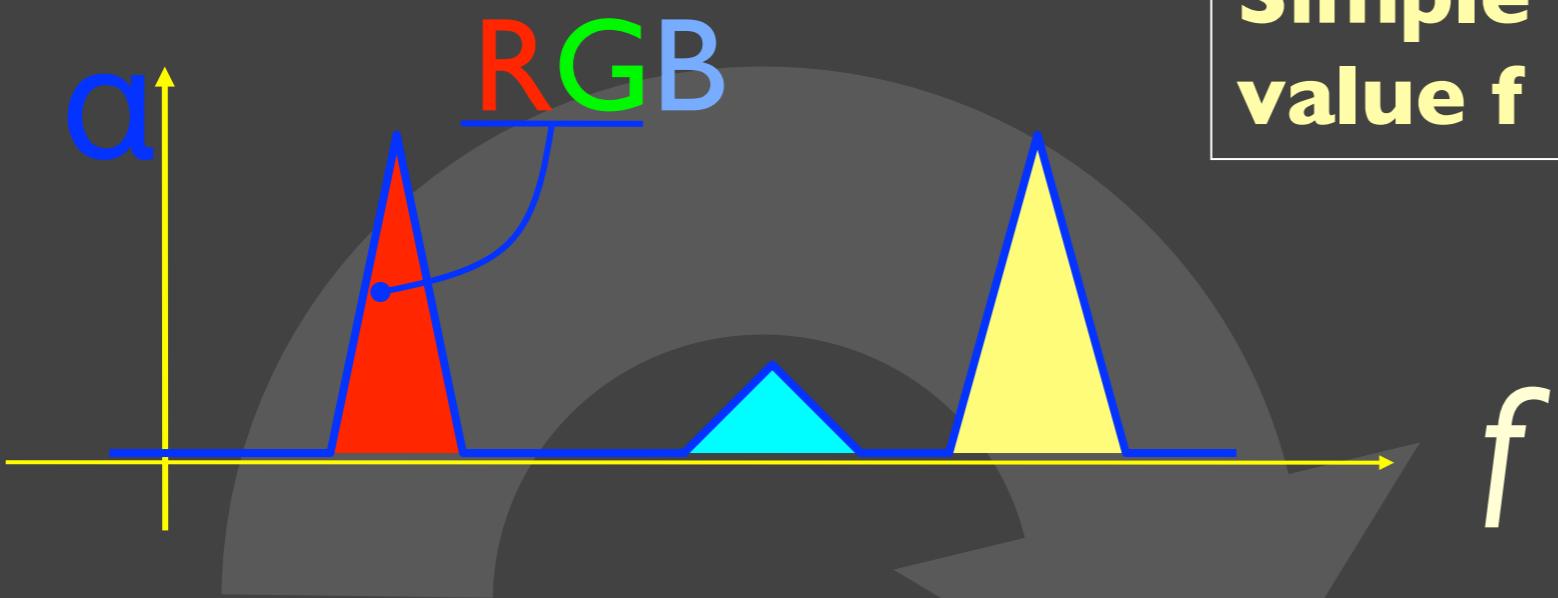
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Simple (usual) case: Map data value f to color and opacity



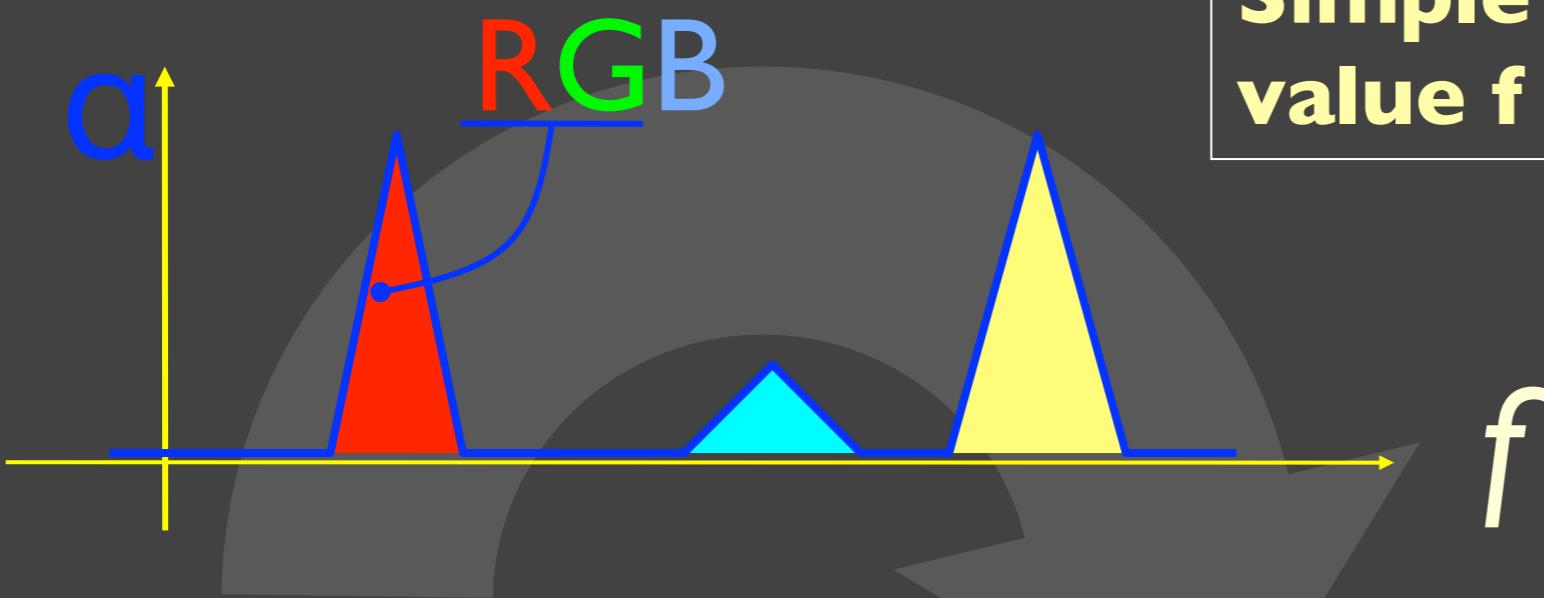
Transfer Functions (TFs)



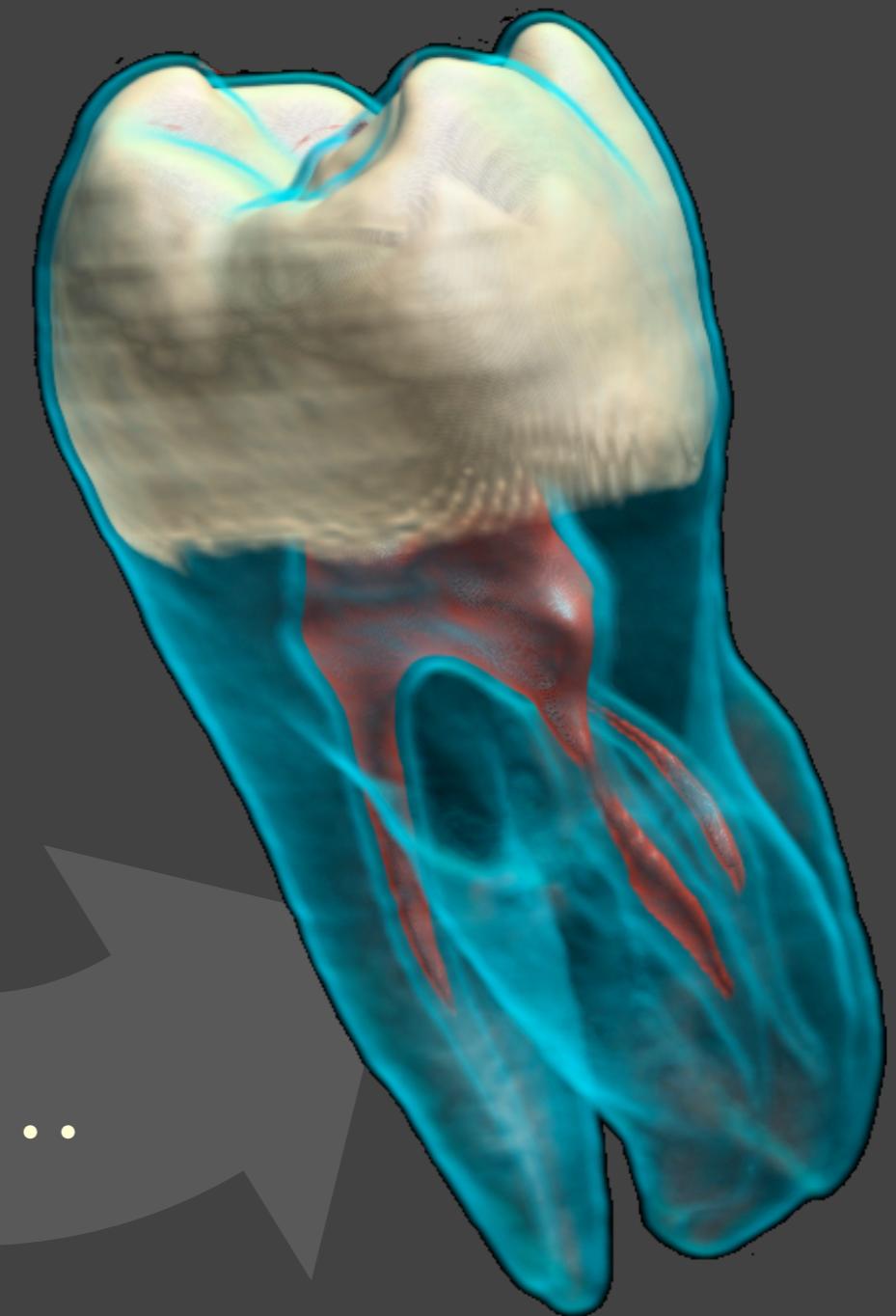
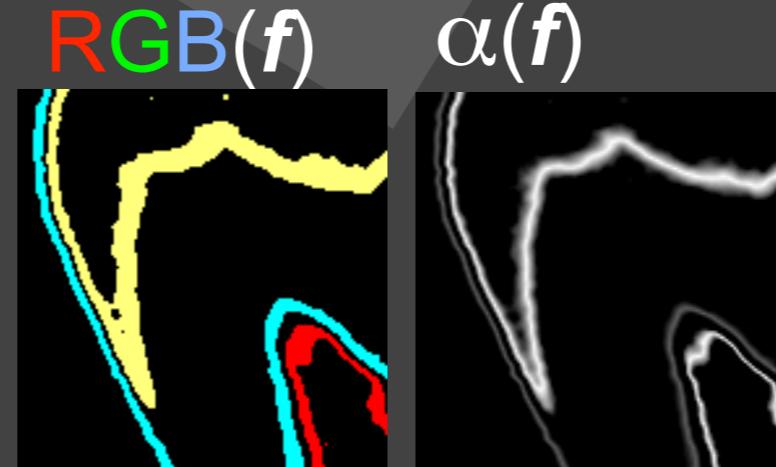
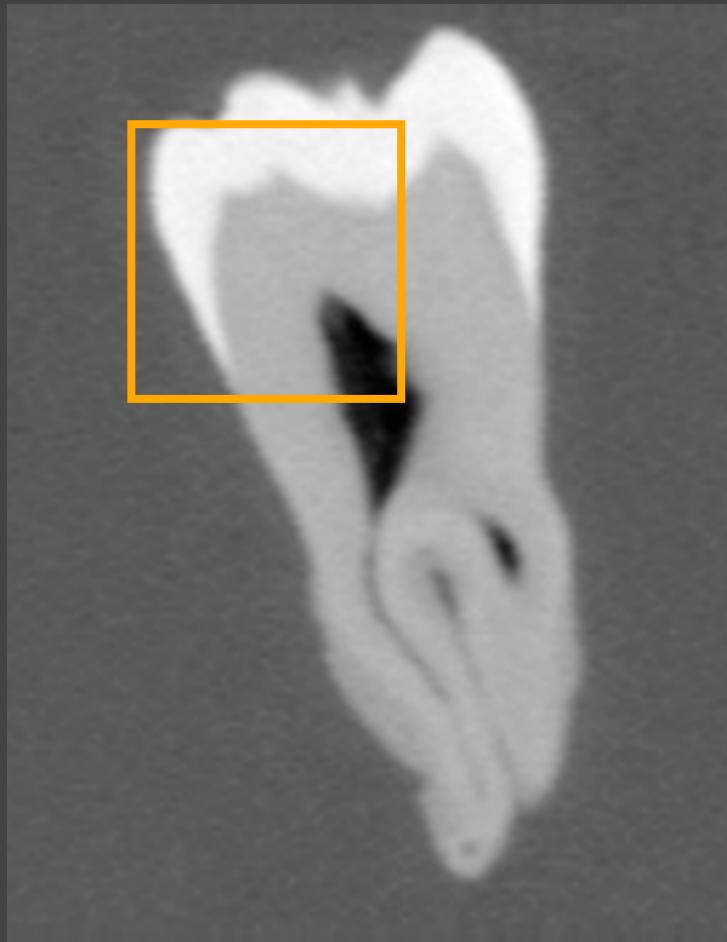
Shading,
Compositing...

Human Tooth CT

Transfer Functions (TFs)



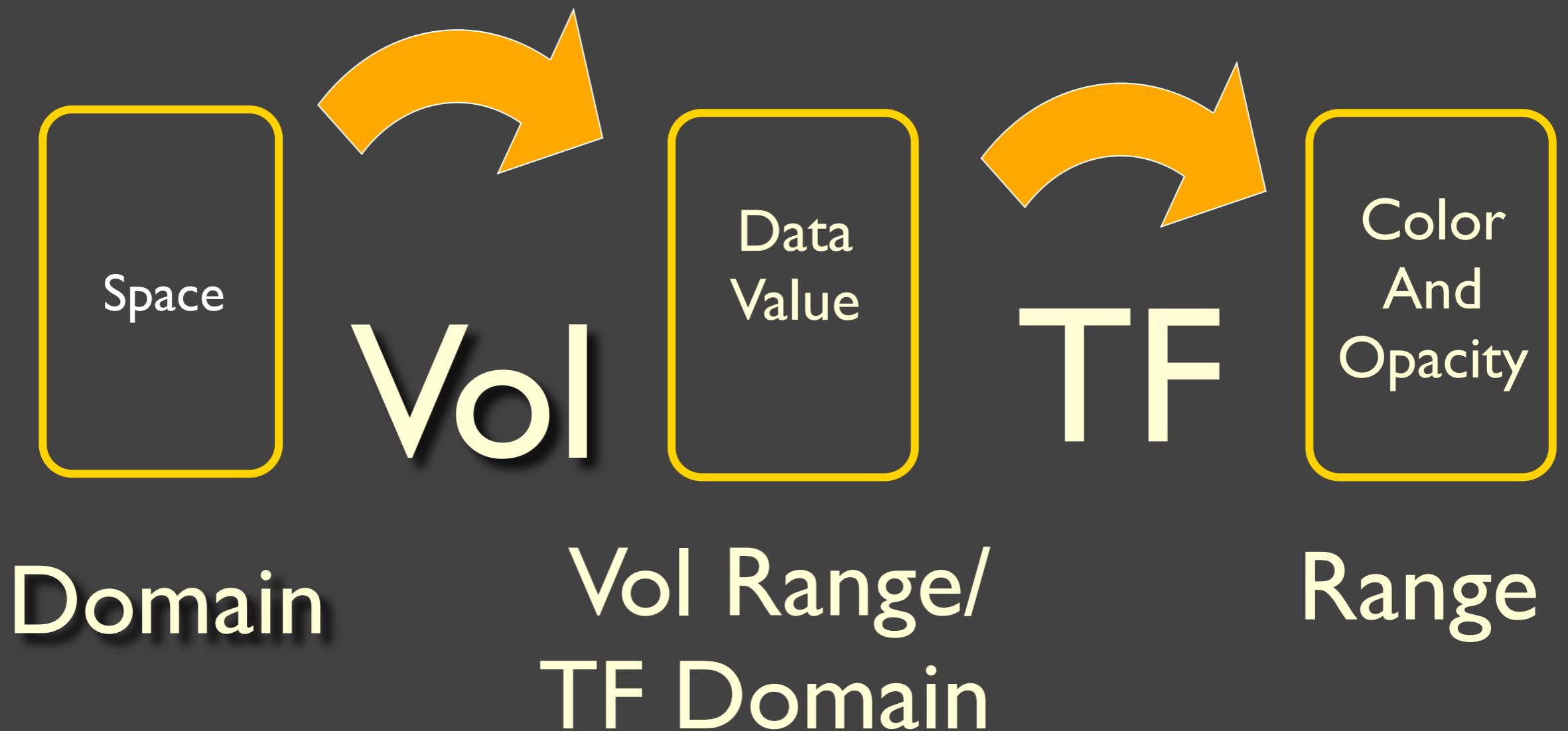
Simple (usual) case: Map data value f to color and opacity



Shading,
Compositing...

Human Tooth CT

Basic Transfer Functions:

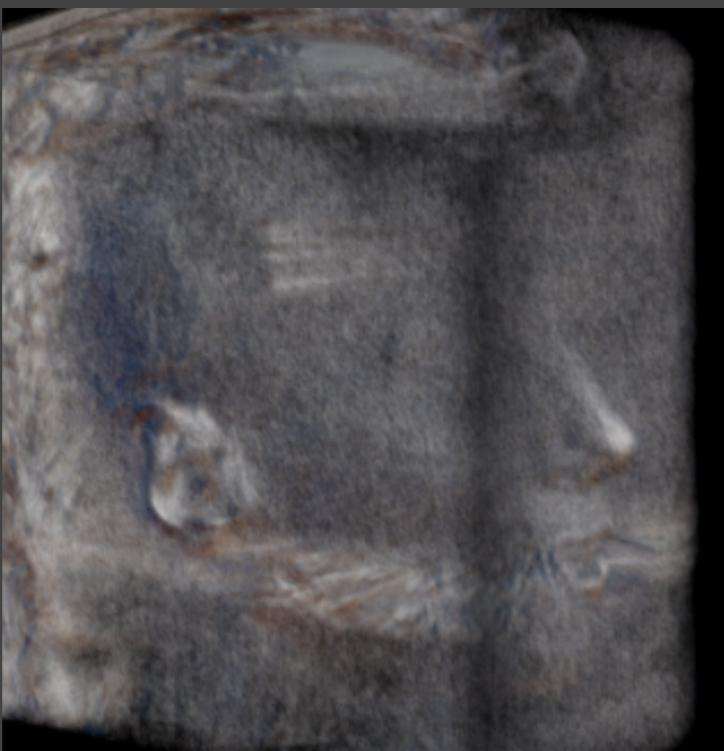
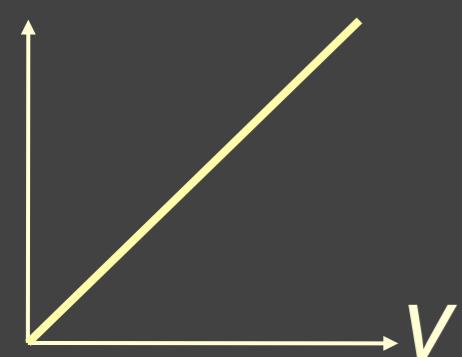


What Can Be Controlled by the Transfer Function?

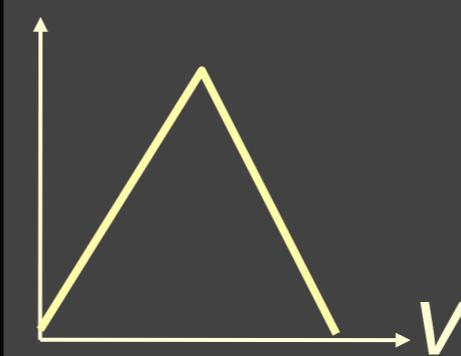
- Optical Properties: Anything that can be composited with a standard graphics operator (“over”)
 - Opacity: “opacity functions”
 - Color: Can help distinguish features
 - Phong parameters (ka , kd , ks)
 - Index of refraction

Setting Transfer Function: Hard

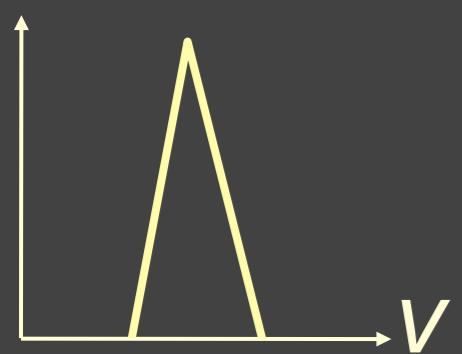
α



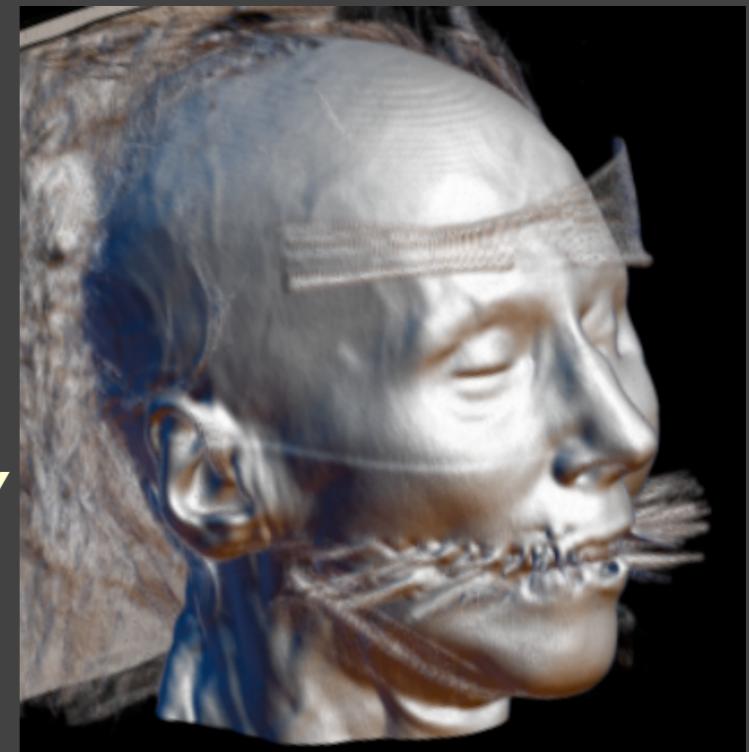
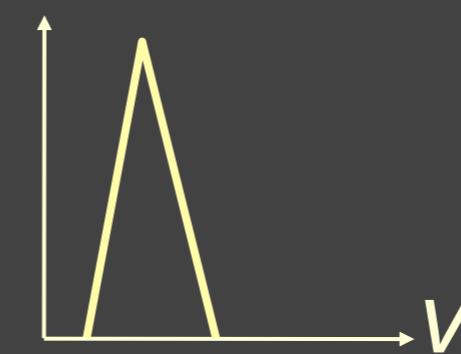
α



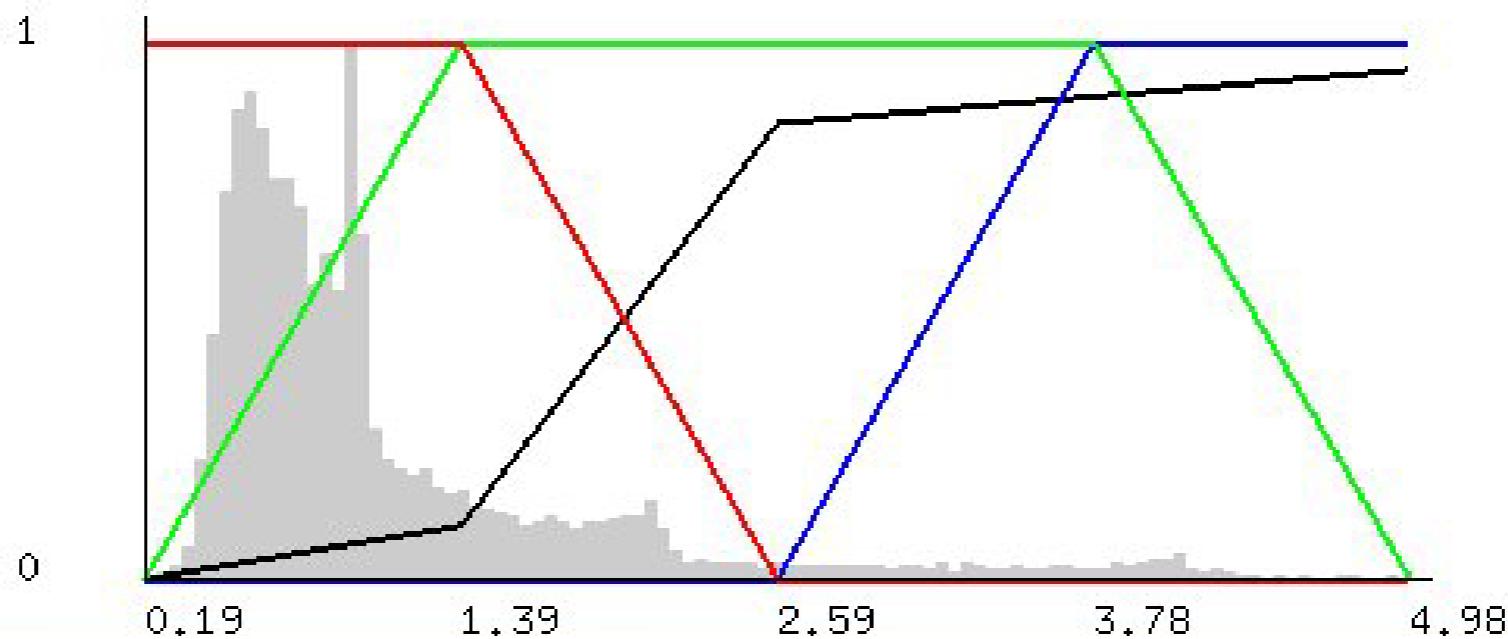
α



α

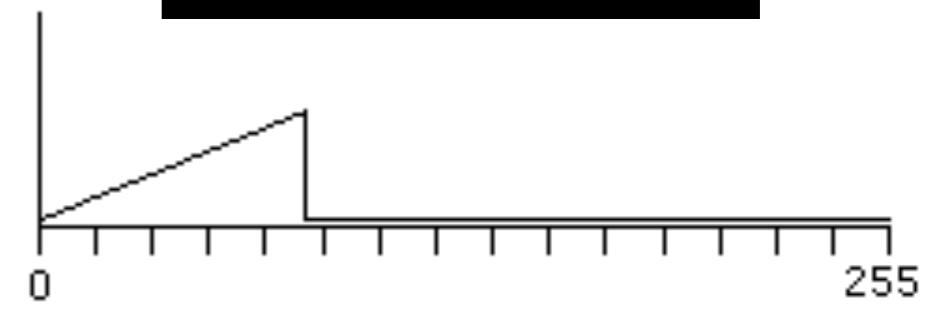
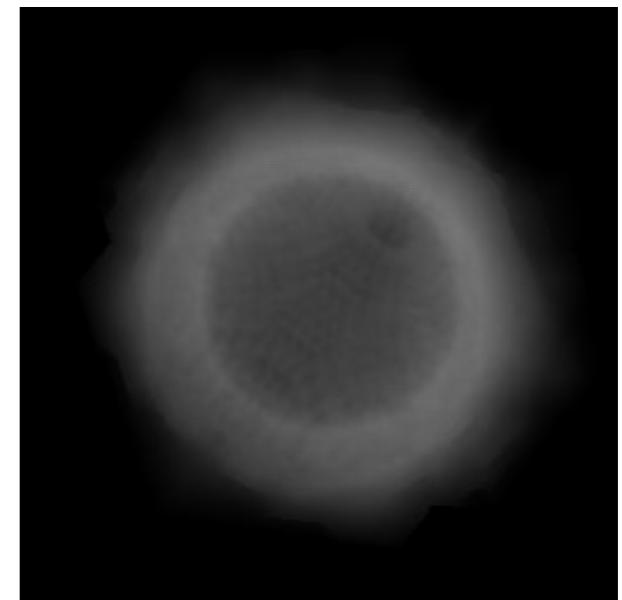
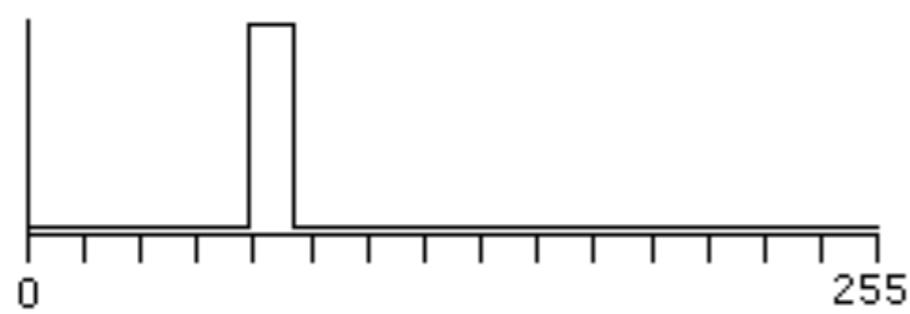
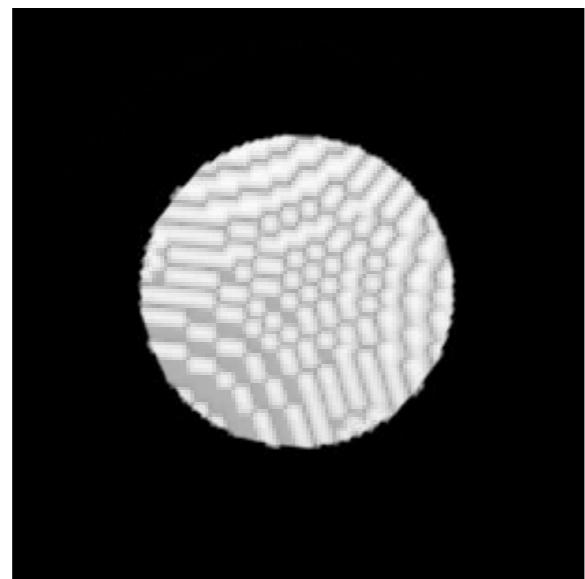


Transfer Function

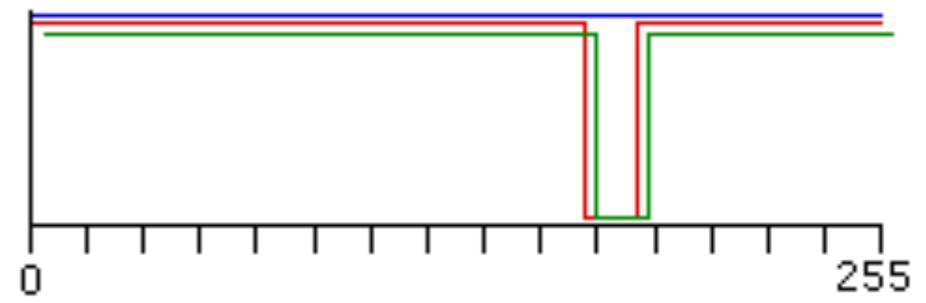
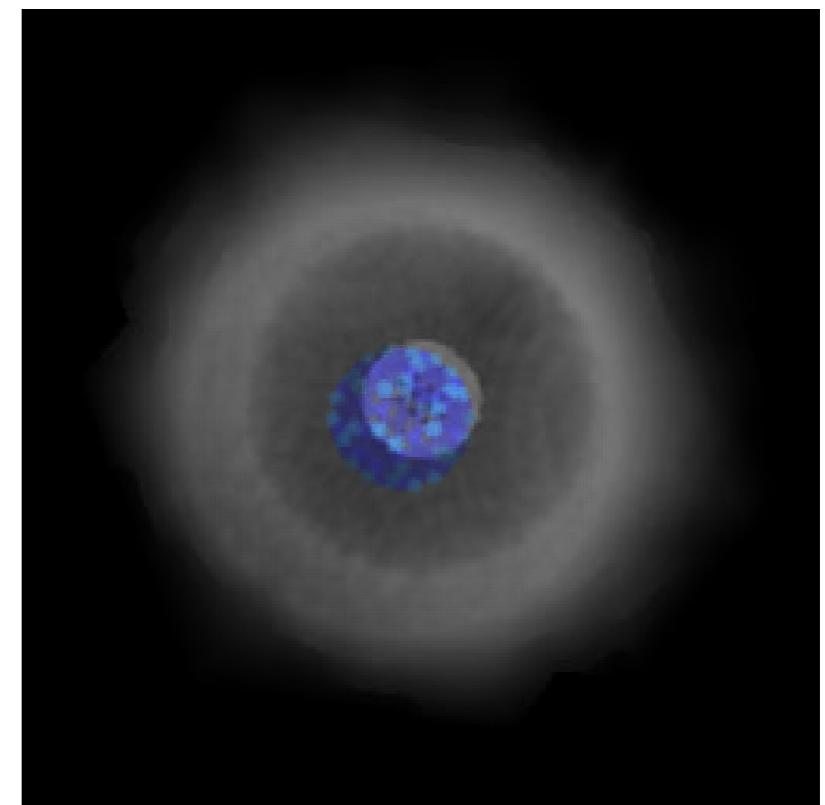
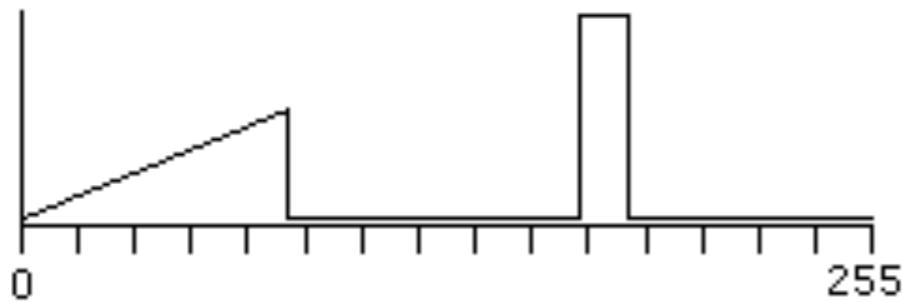
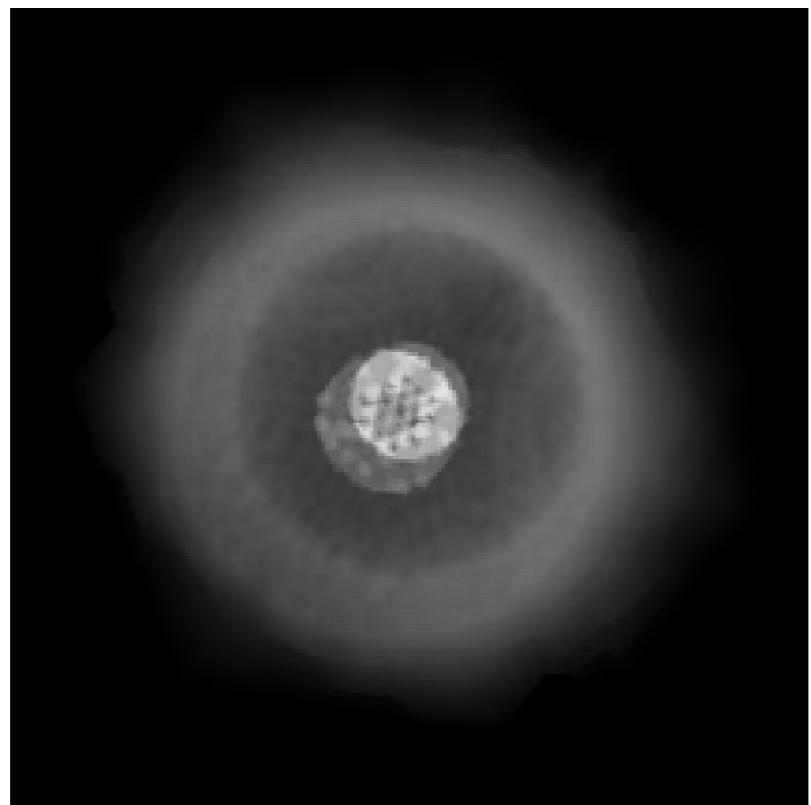


- » RGB components
- » Opacity

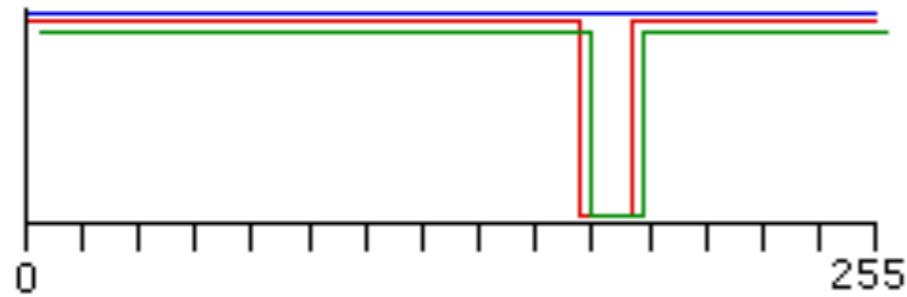
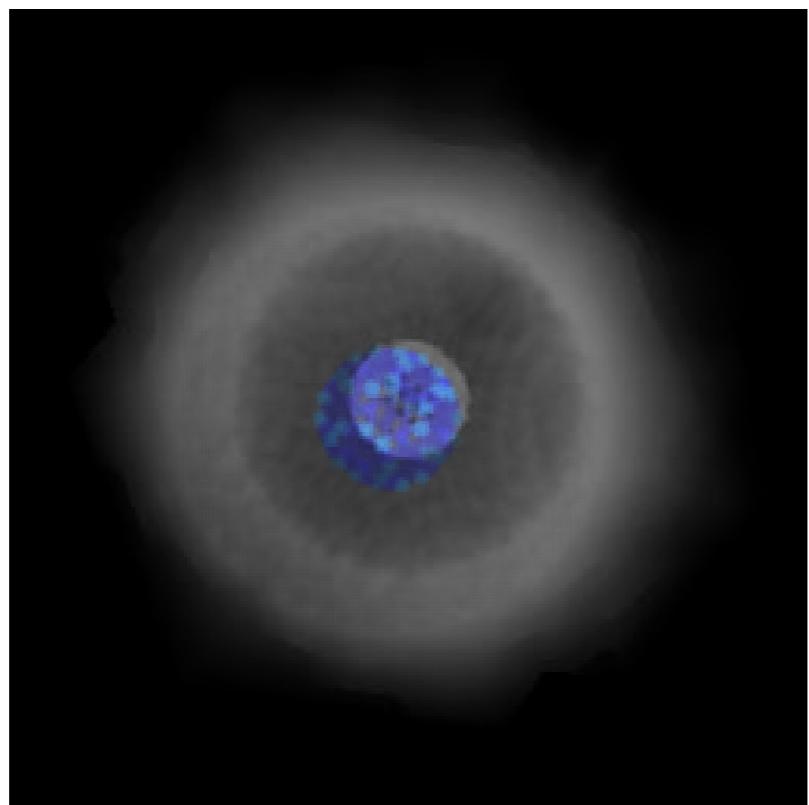
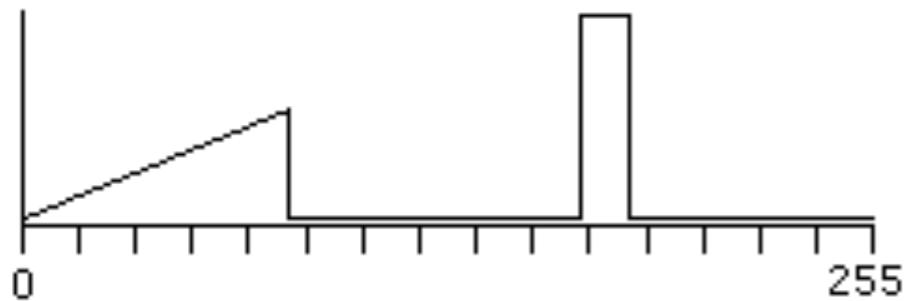
Transfer Function



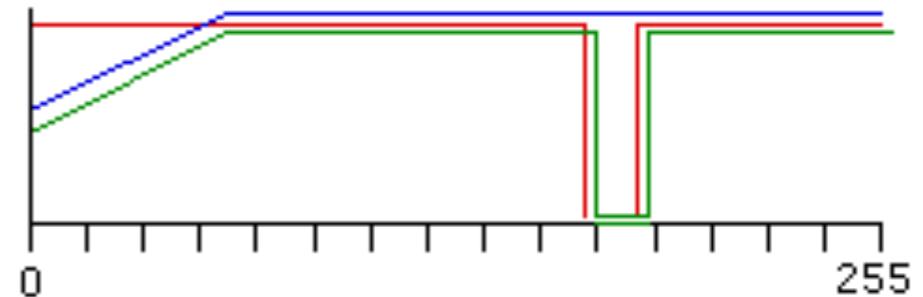
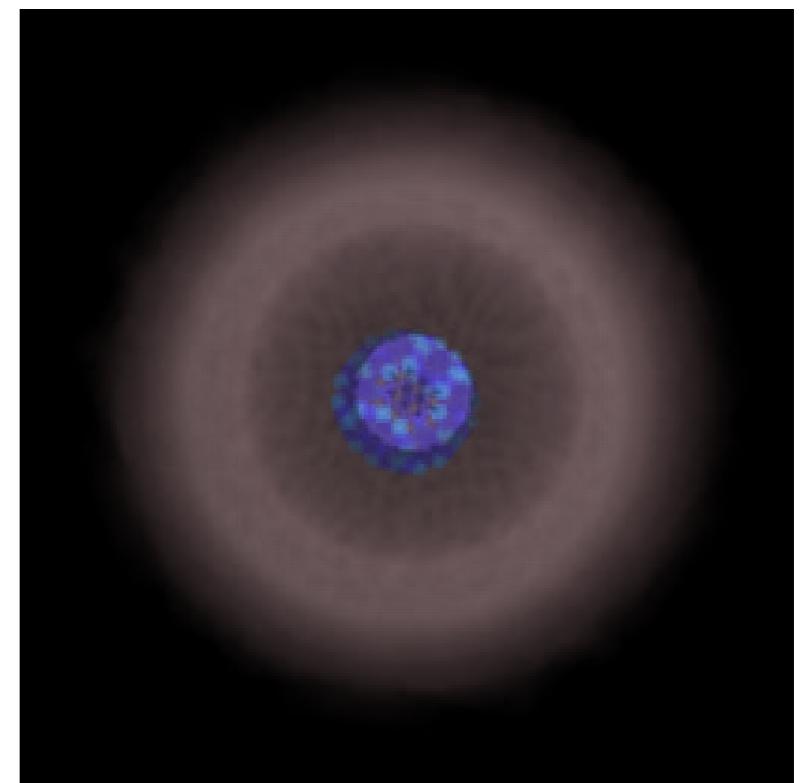
Transfer Function



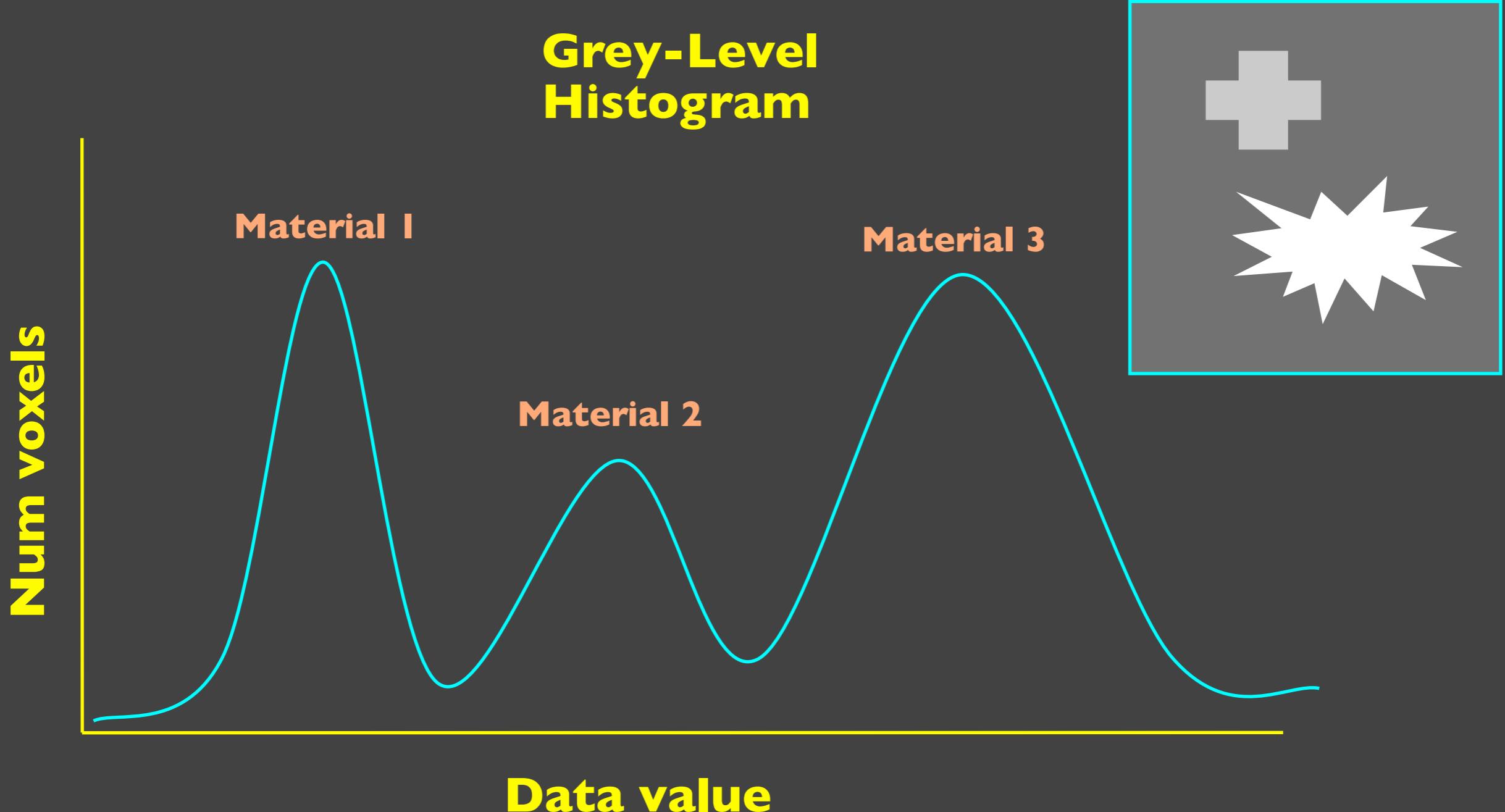
Transfer Function



Different colors, same opacity

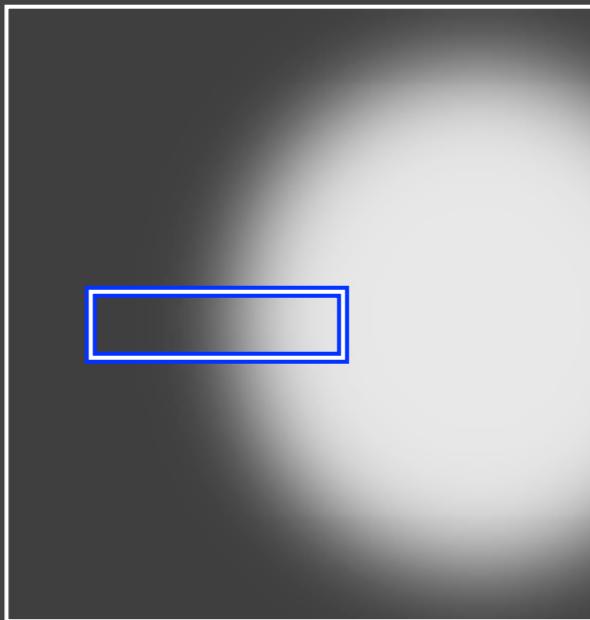


Volumes as Consisting of Materials

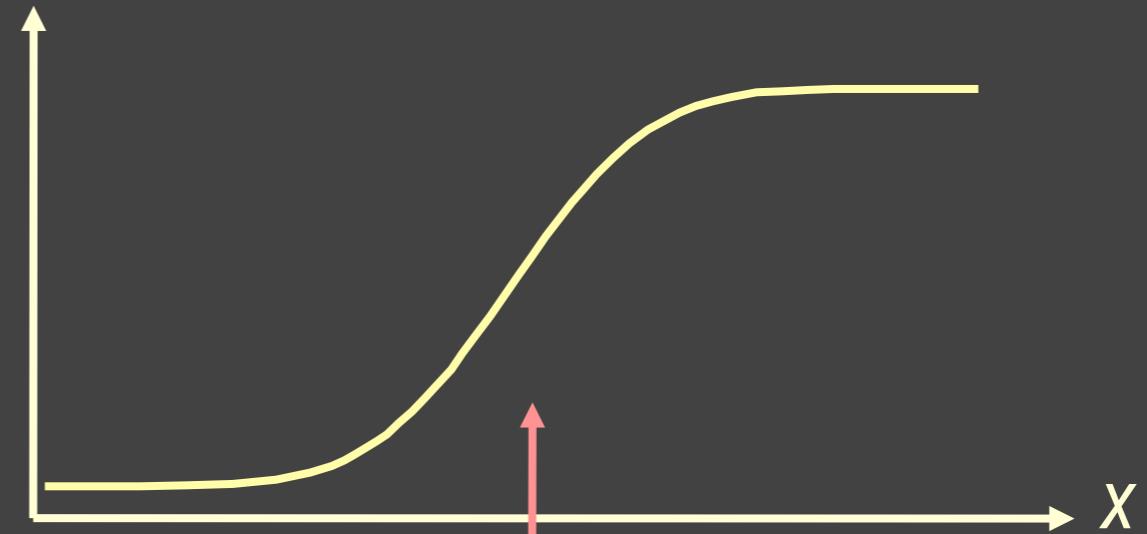


Finding edges: easy

“Where’s the edge?”



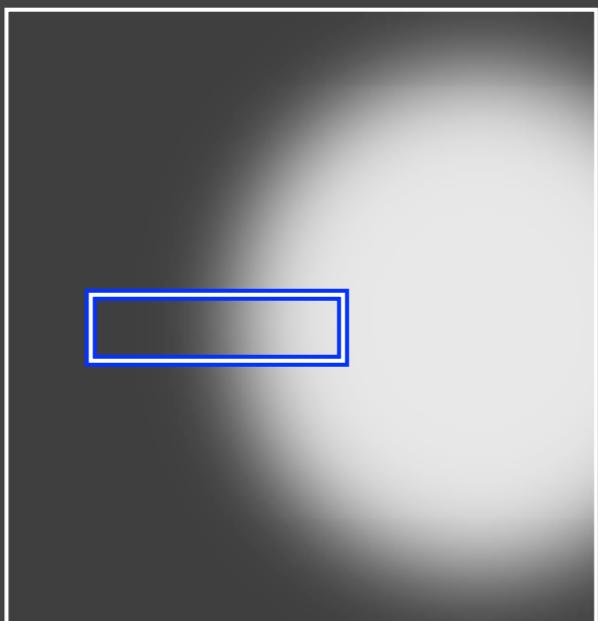
$$v = f(x)$$



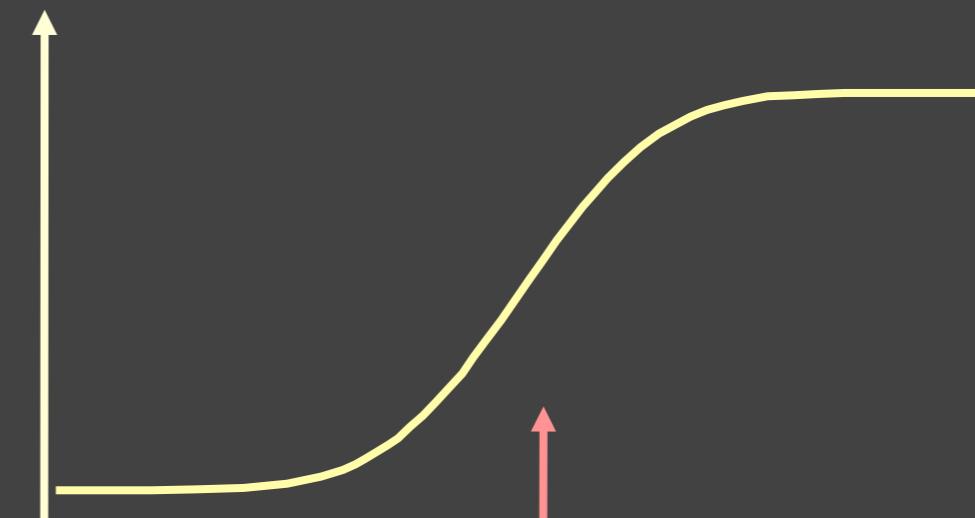
“ here’s the edge ”

Finding edges: easy

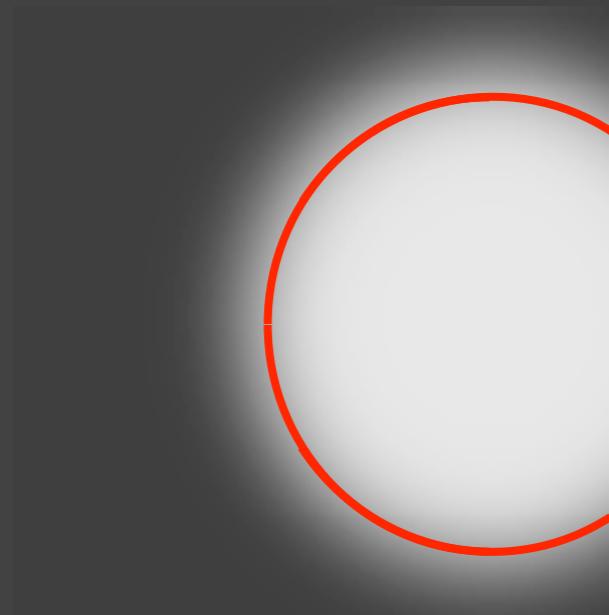
“Where’s the edge?”



$$v = f(x)$$



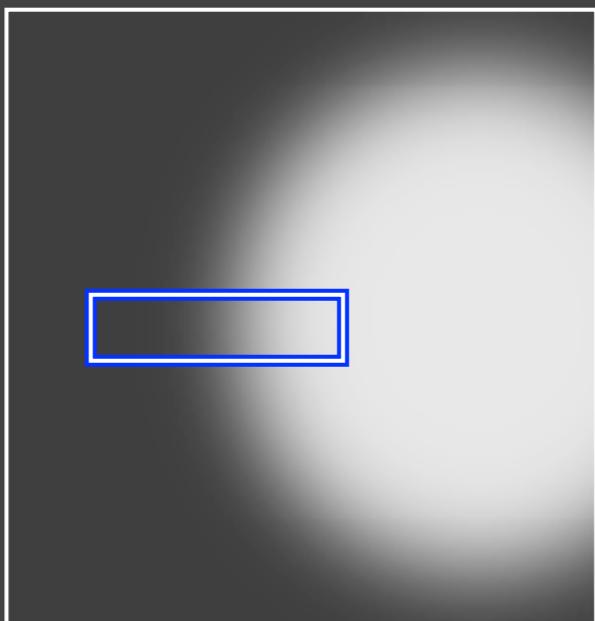
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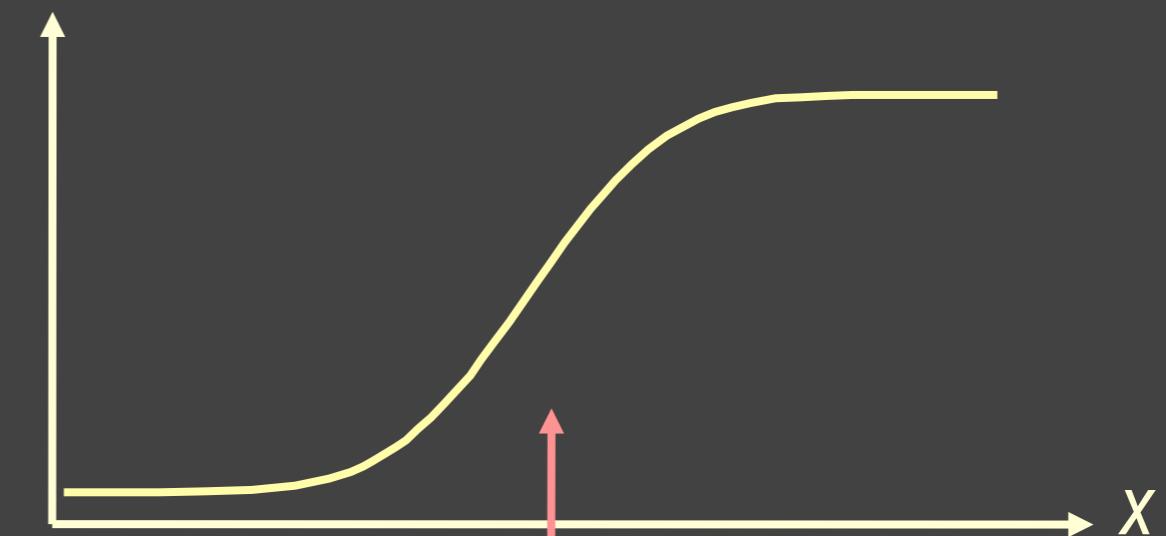
Result: edge pixels

Finding edges: easy

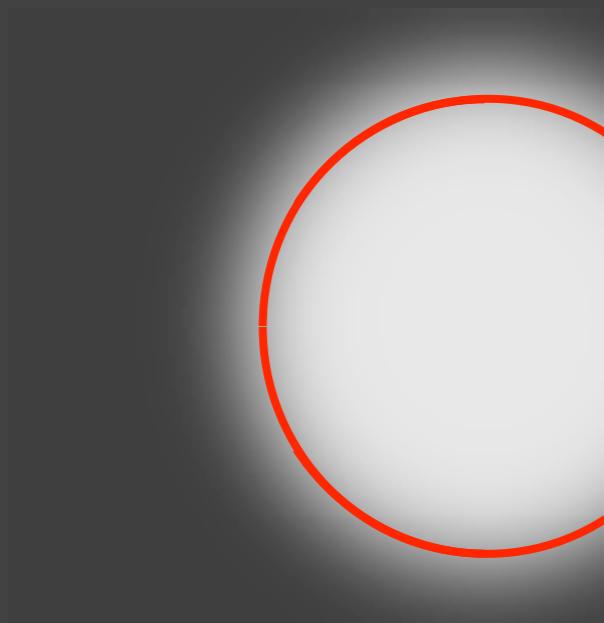
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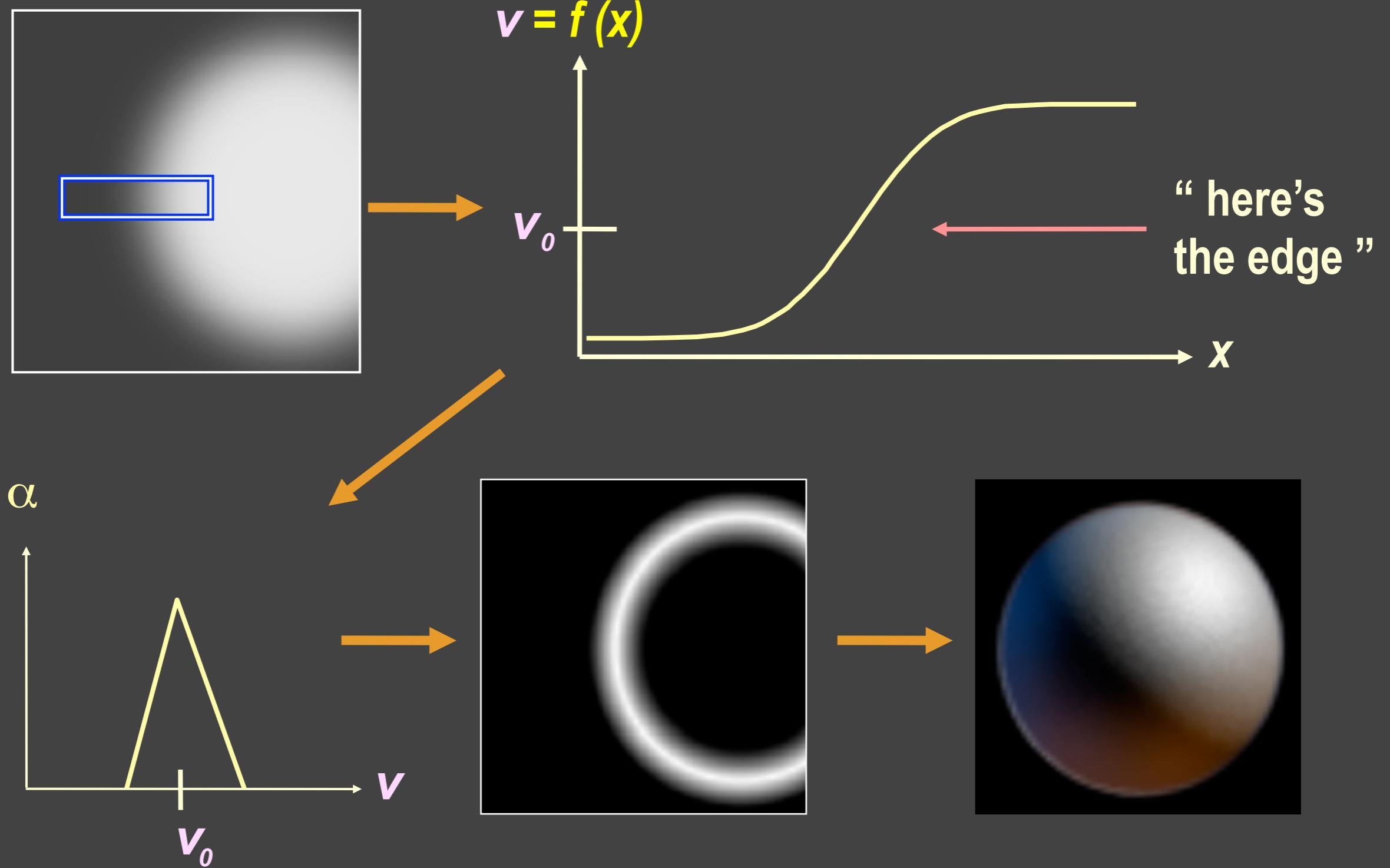
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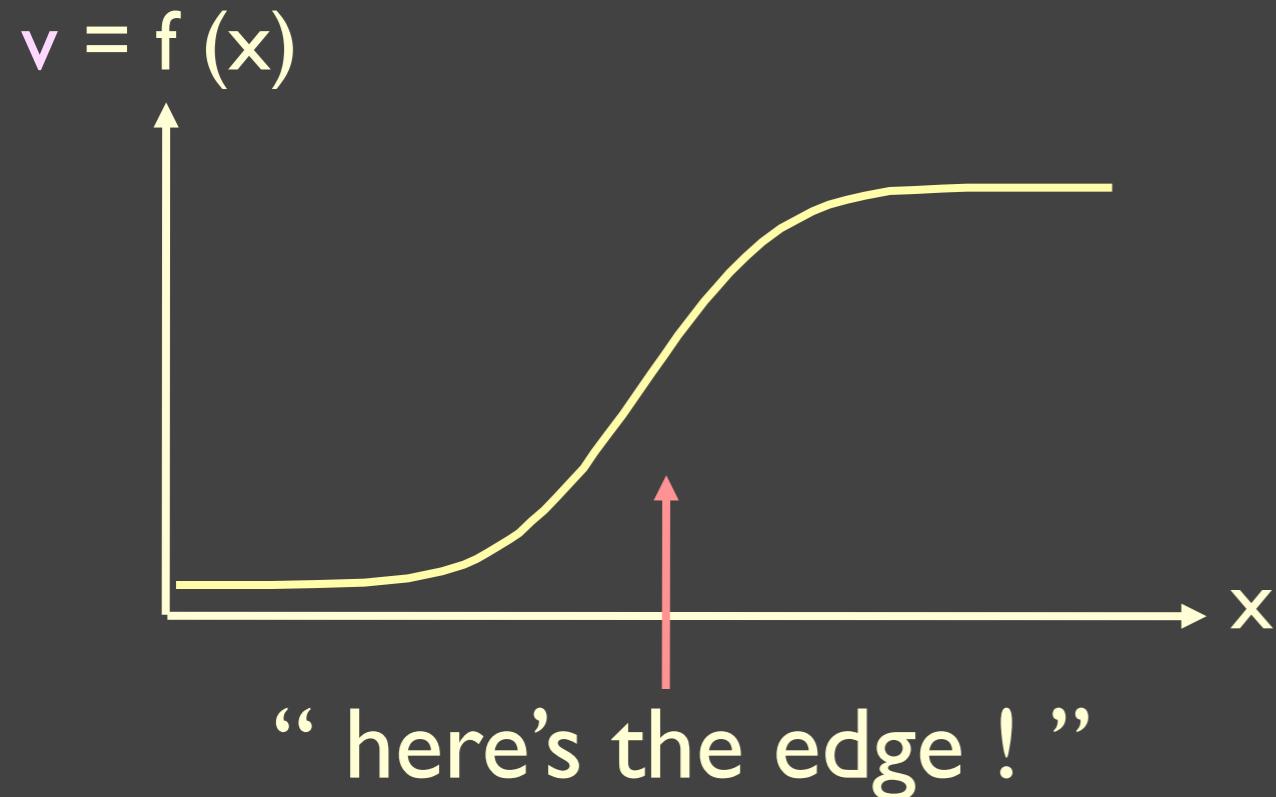
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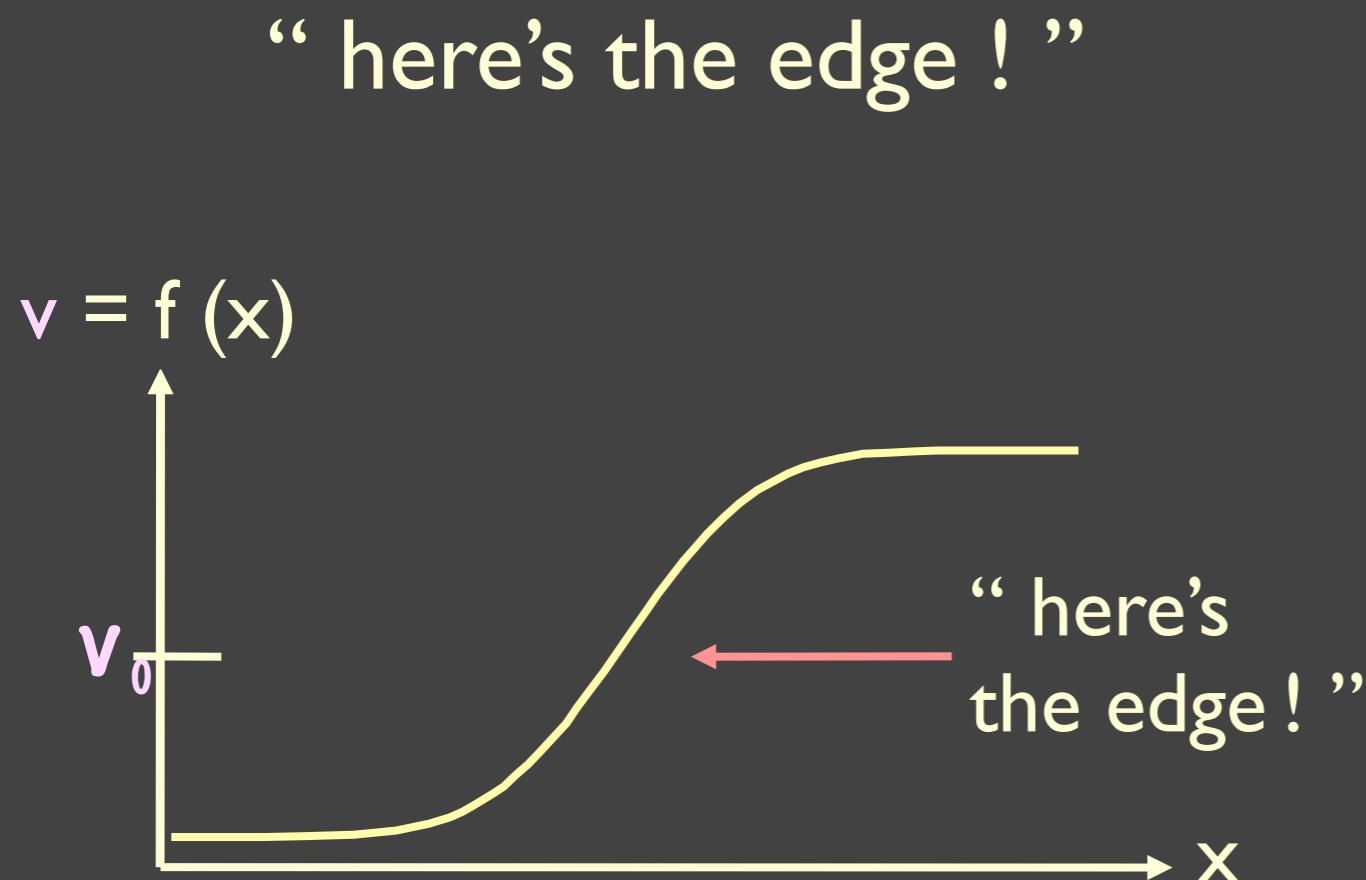
Transfer function Unintuitive



TFs as feature detection



Domain of the transfer function does not include position



Domain

What Makes Designing TF's Challenging?

1. Non-spatial: spatial isolation doesn't imply data value isolation
2. Many degrees of freedom
3. No constraints or guidance
4. Material uniformity assumption

Goals for TF Design

- 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

TF Techniques/Tools

- 1. Trial and Error**
- 2. Data-Centric Approach**
- 3. Image-Centric Approach**

I.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





TF Techniques/Tools

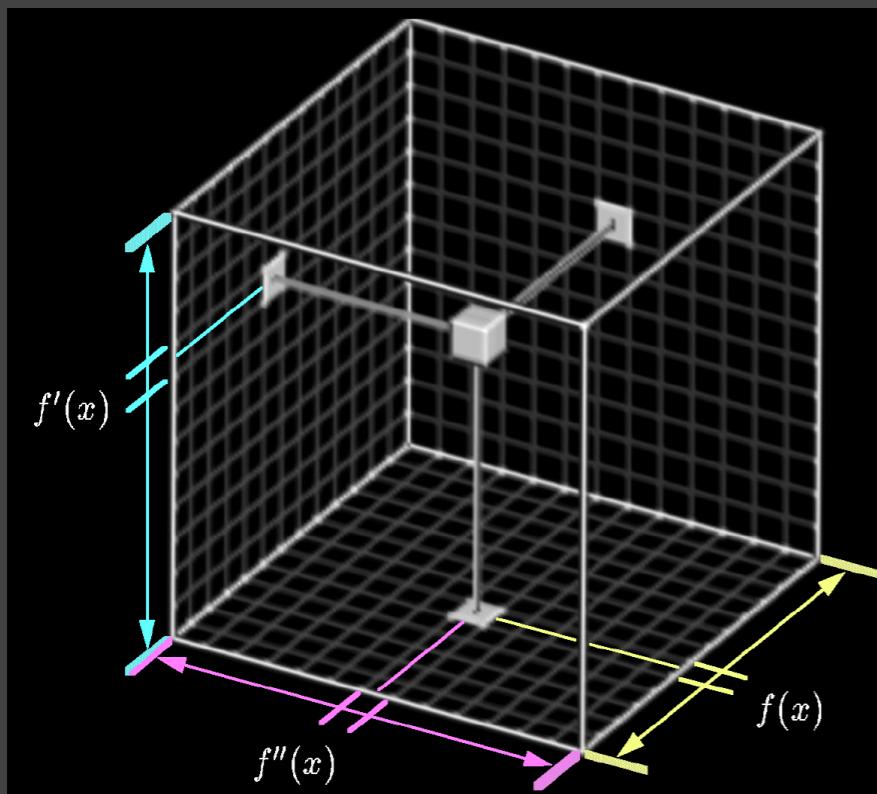
1. Trial and Error
2. **Data-Centric Approach**
3. Image-Centric Approach

Use derivatives

Reasoning:

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

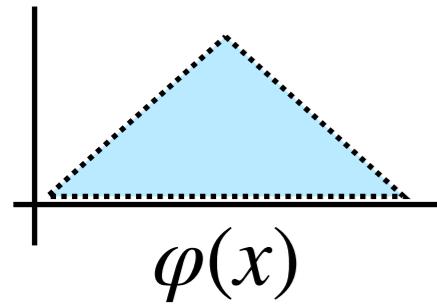
Make 3D histograms of value, 1st, 2nd deriv.



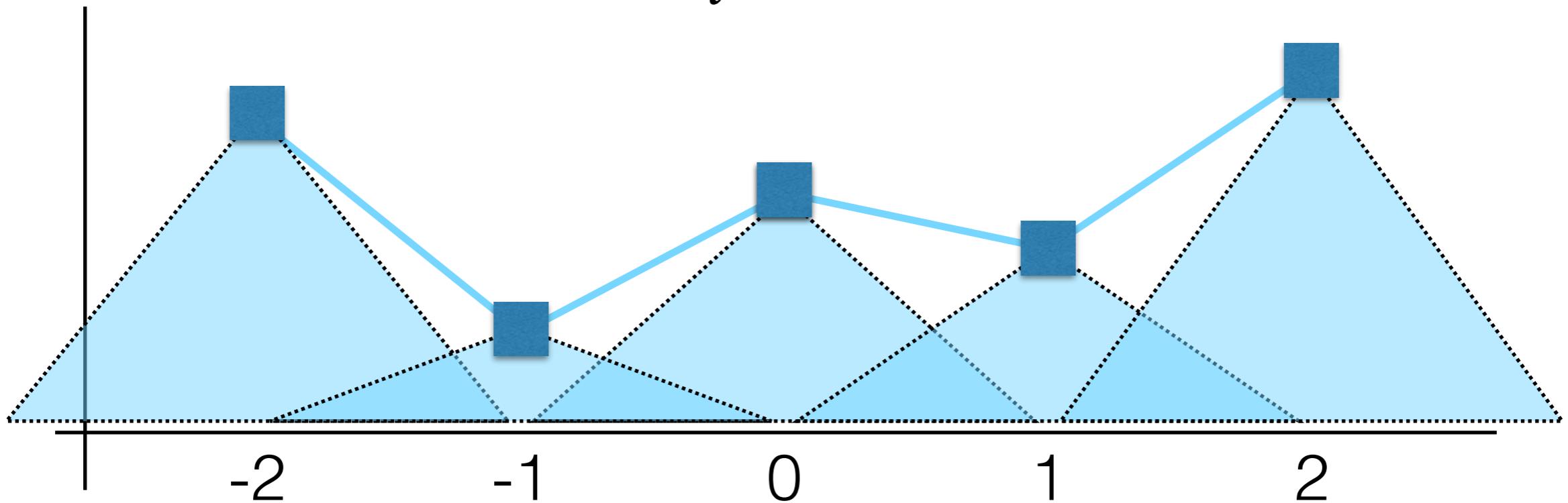
By (1) **inspecting** and
(2) **algorithmically analyzing**
histogram volume, we can
create transfer functions

Some Background: Gradients

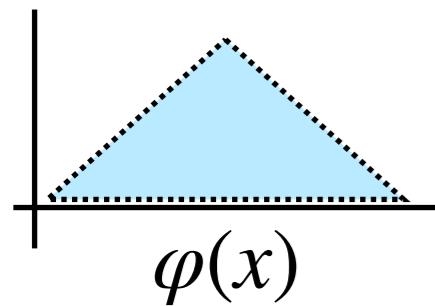
Recall: Finite-Dimensional Function Spaces



$$f(x) = \sum_i \varphi(x - i)c_i$$

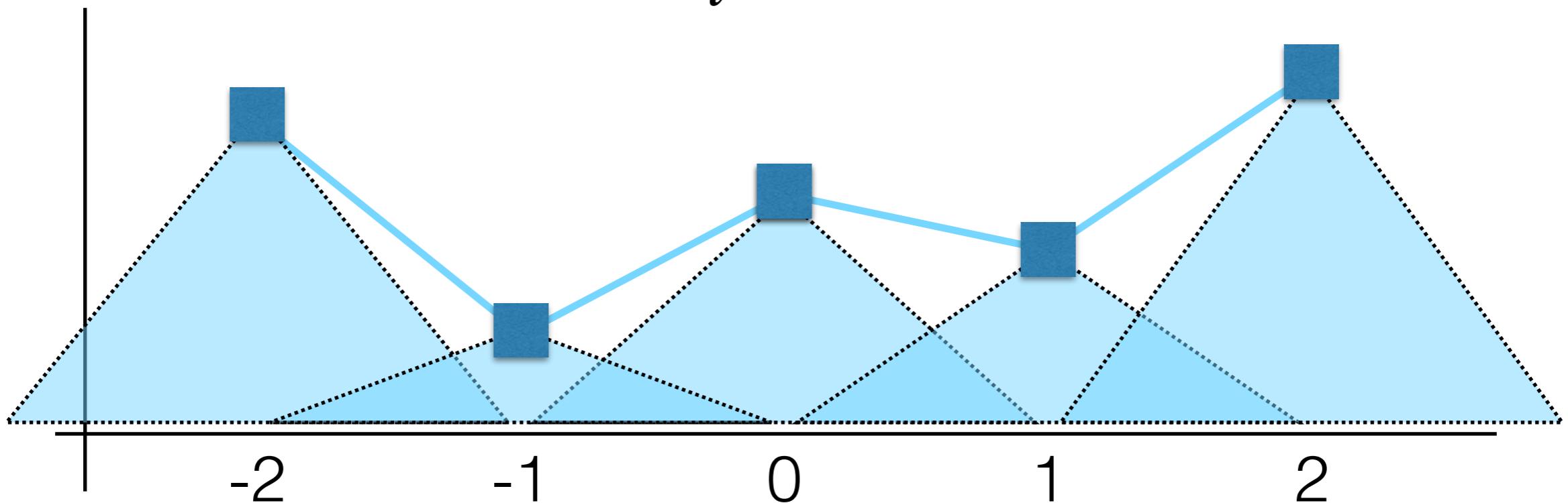


Recall: Finite-Dimensional Function Spaces



$$f(x) = \sum_i \varphi(x - i)c_i$$

Diagram illustrating the decomposition of a function $f(x)$ into a sum of shifted and scaled simple functions $\varphi(x - i)c_i$. The equation shows $f(x)$ as a sum (**sums**) of i terms, where each term is a **simple function** $\varphi(x - i)$ scaled by c_i and shifted by i (**shifts** and **scales**).



Derivatives of Finite-Dimensional Function Spaces

$$f(x) = \sum_i c_i \varphi(x - i)$$

$$\frac{df}{dx}(x) = \frac{d}{dx} \sum_i c_i \varphi(x - i)$$

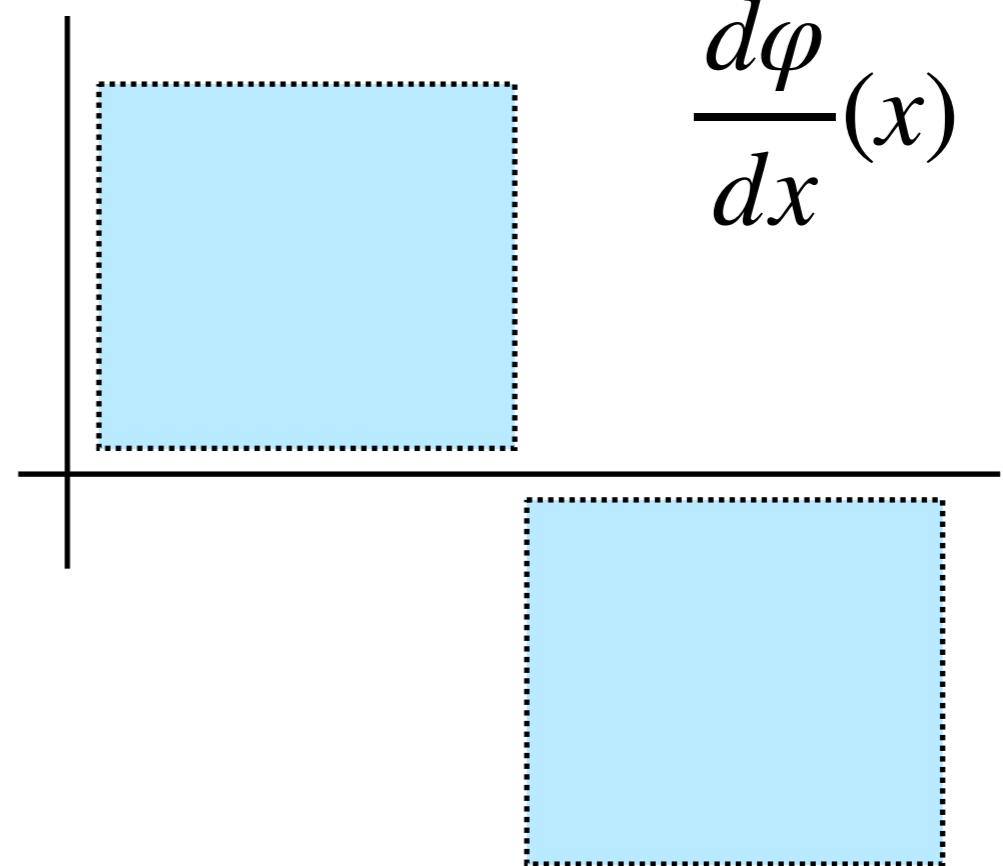
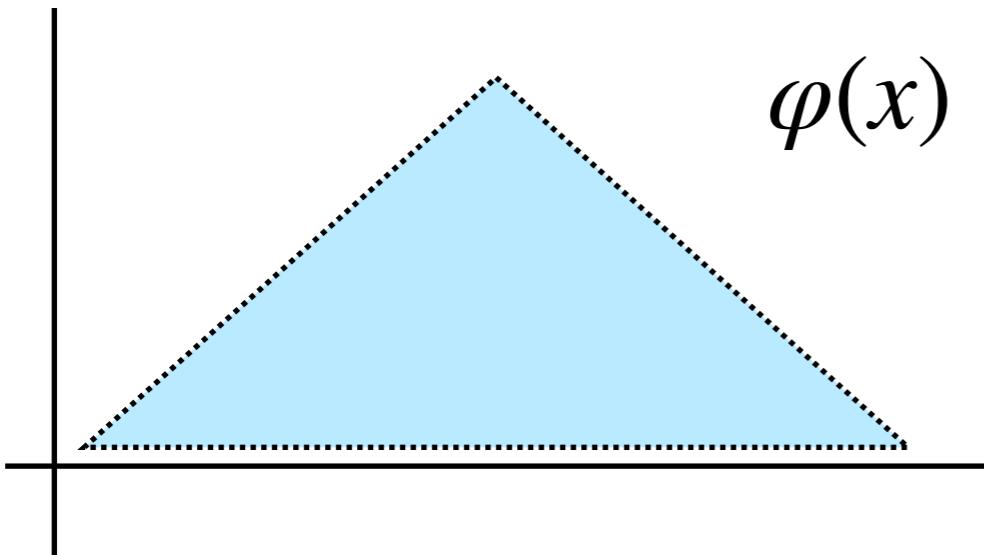
Derivatives of Finite-Dimensional Function Spaces

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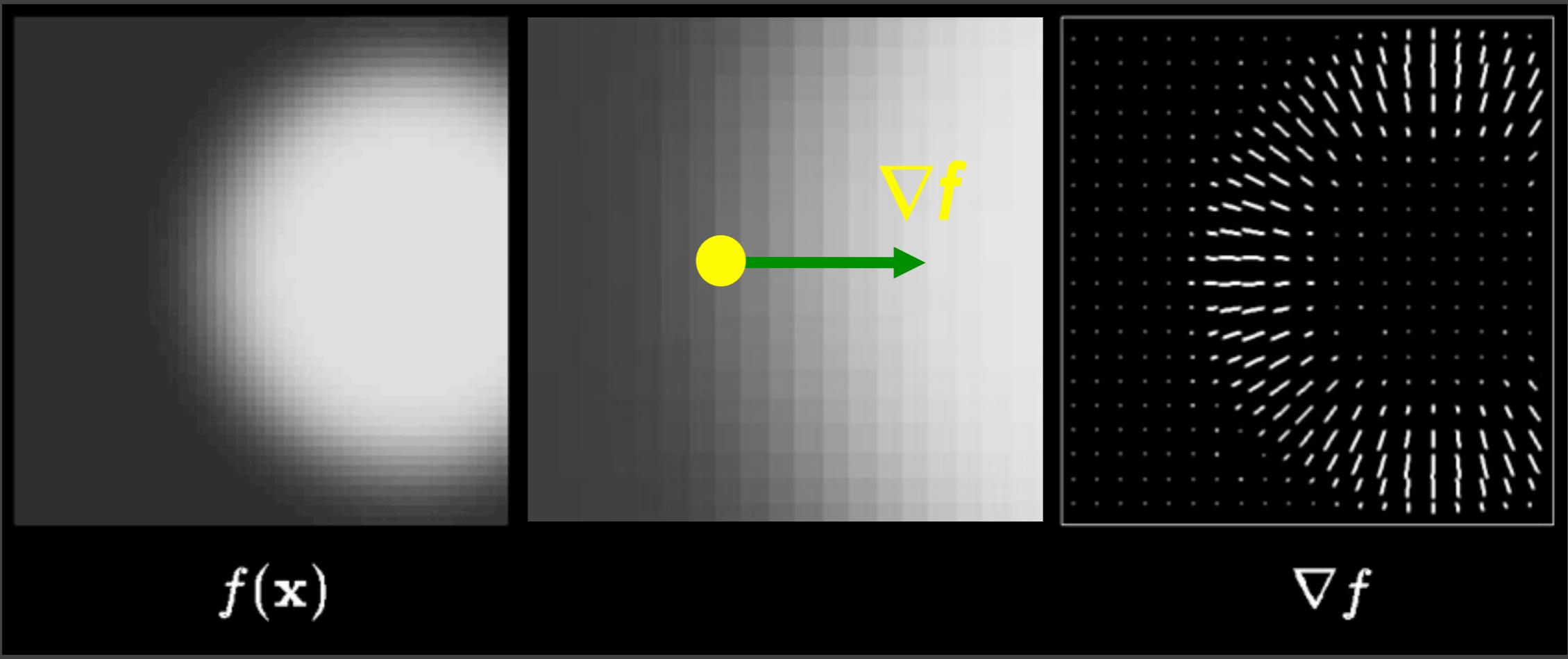
$$\frac{df}{dx}(x) = \sum_i c_i \frac{d\varphi}{dx}(x - i)$$

- Derivatives are just another type of function space where we change the “simple function”

Derivatives of Finite-Dimensional Function Spaces

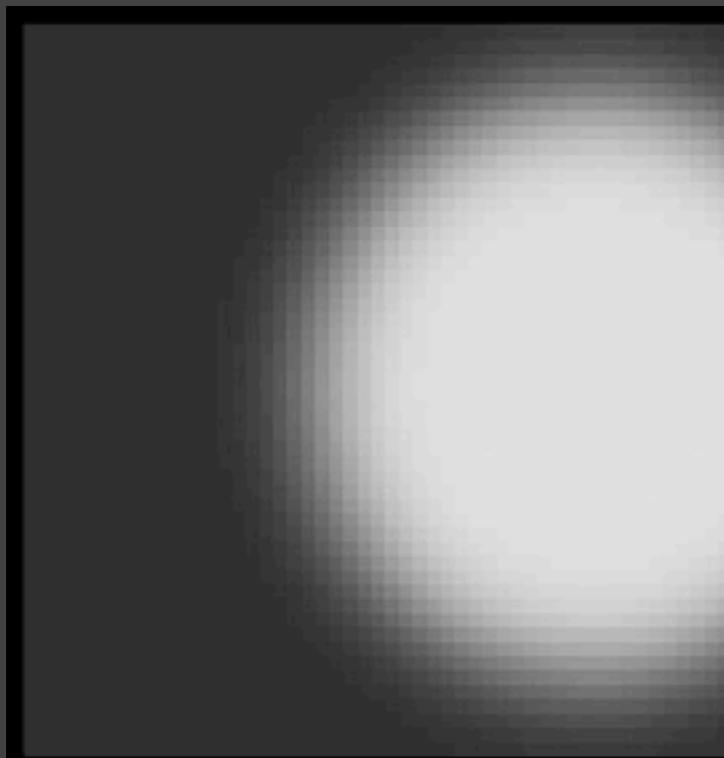


Gradient

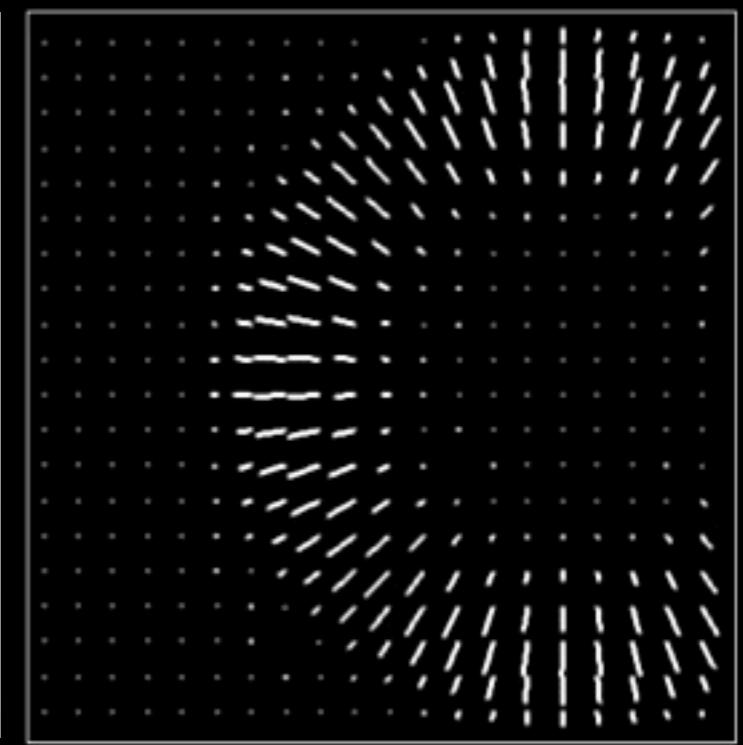
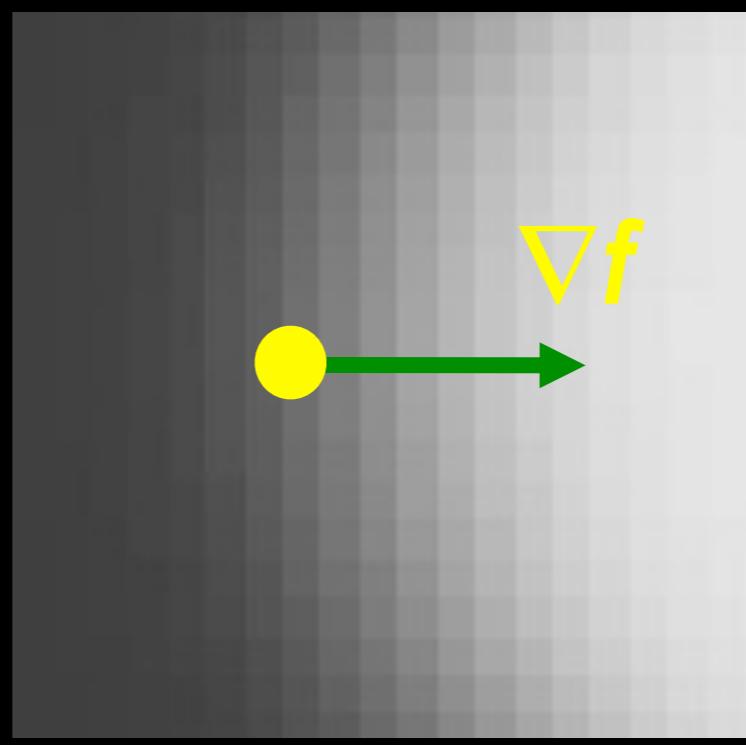


Gradient

$$\nabla f = (dx, dy, dz)$$



$f(\mathbf{x})$

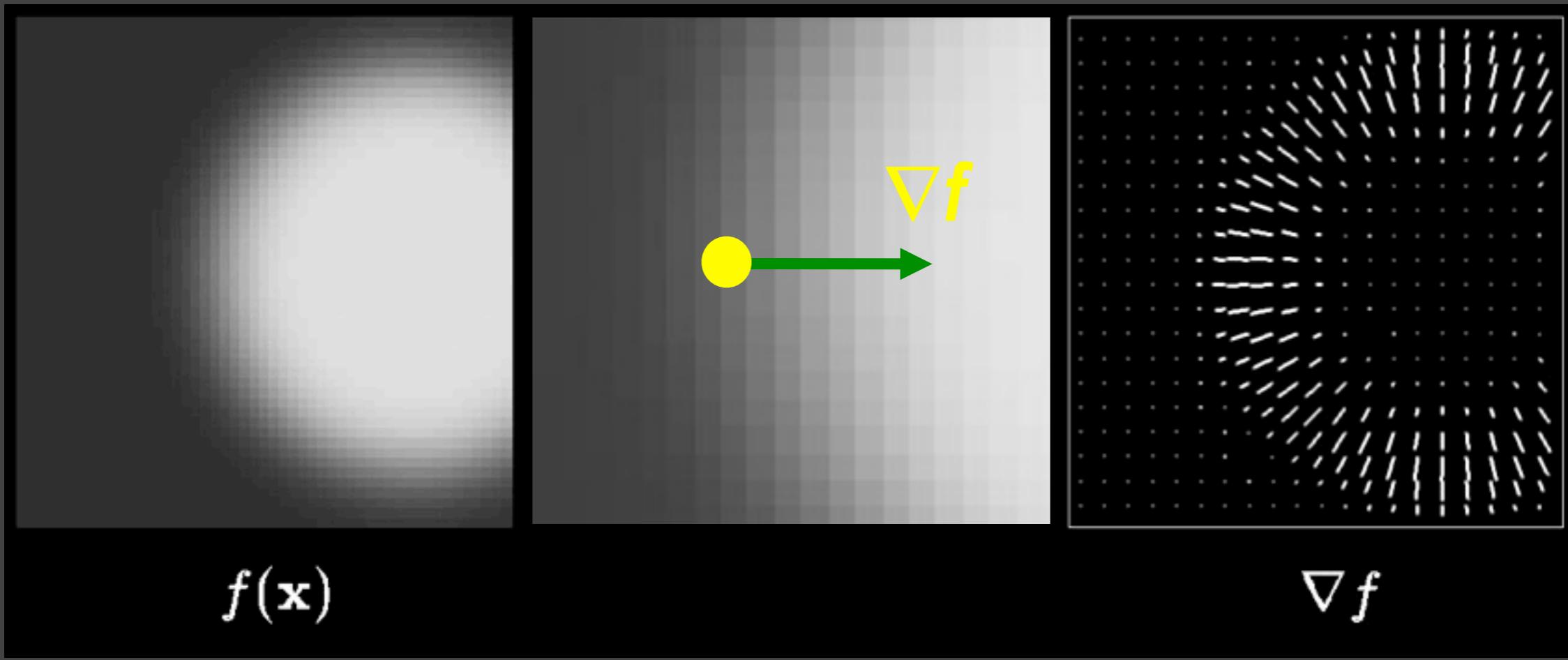


∇f



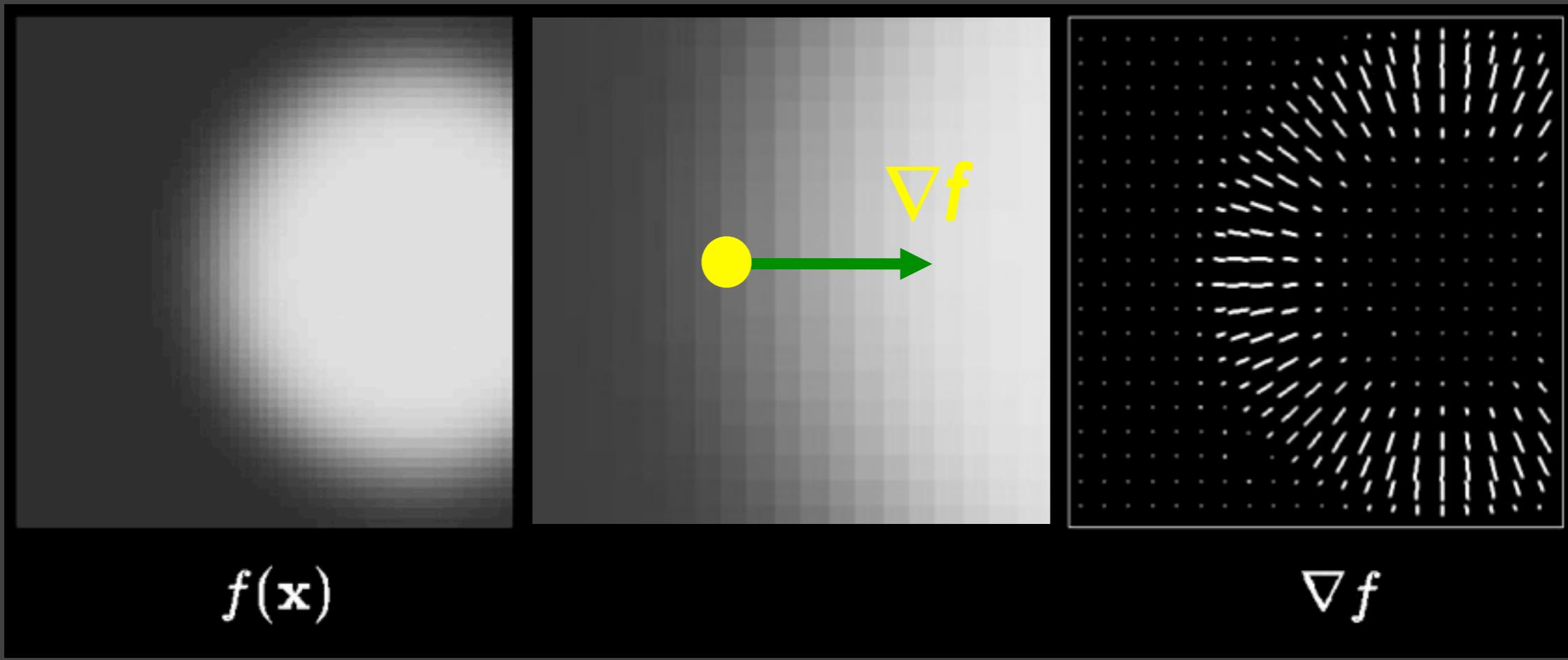
Gradient

$$\begin{aligned}\nabla f &= (dx, dy, dz) \\ &= ((f(1,0,0) - f(-1,0,0))/2,\end{aligned}$$



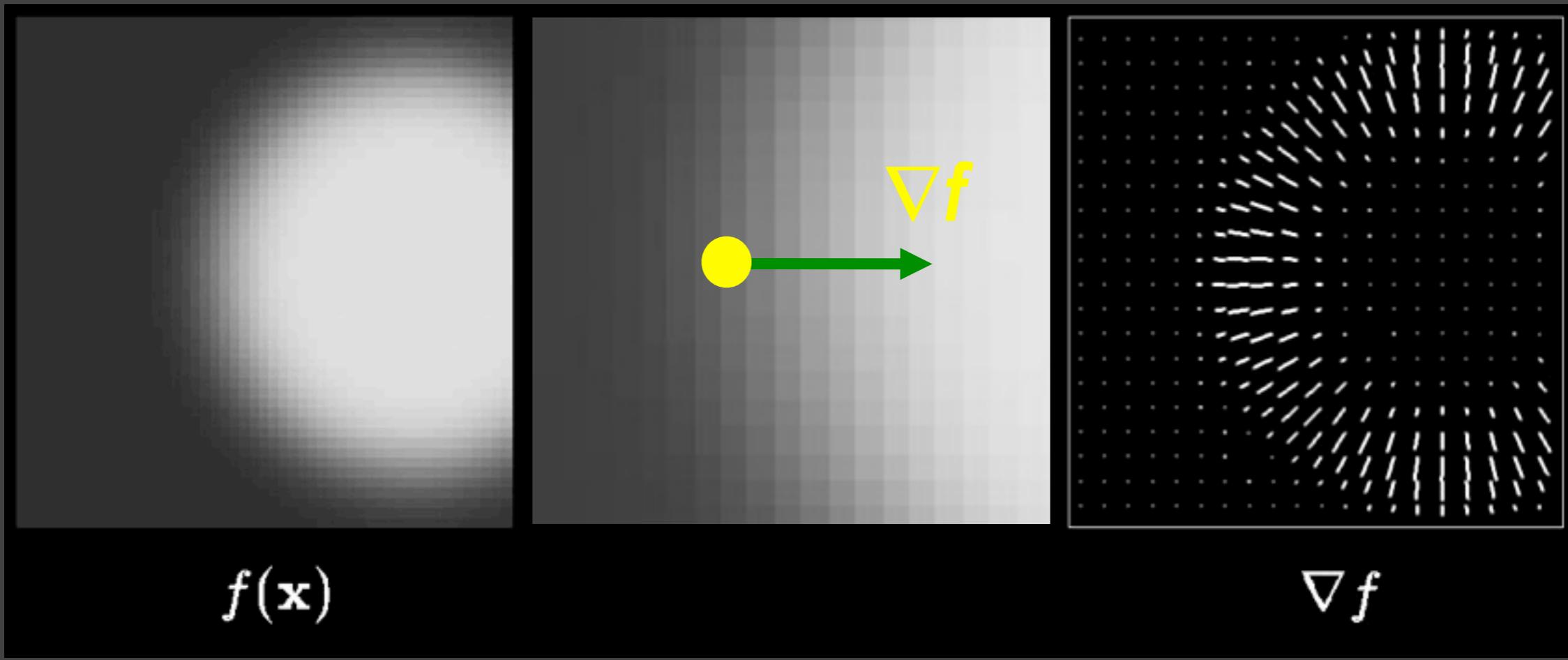
Gradient

$$\begin{aligned}\nabla f &= (dx, dy, dz) \\ &= ((f(1,0,0) - f(-1,0,0))/2, \\ &\quad (f(0,1,0) - f(0,-1,0))/2,\end{aligned}$$



Gradient

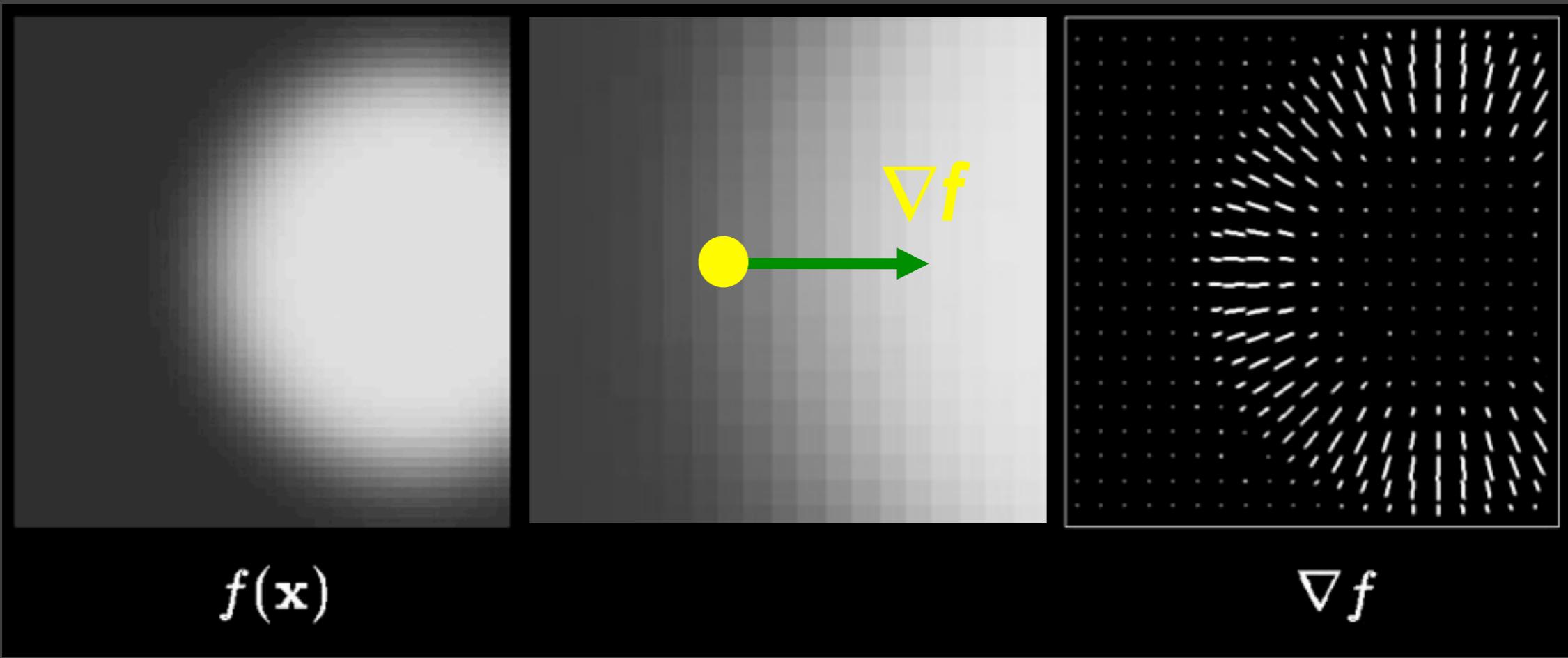
$$\begin{aligned}\nabla f &= (dx, dy, dz) \\ &= ((f(1,0,0) - f(-1,0,0))/2, \\ &\quad (f(0,1,0) - f(0,-1,0))/2, \\ &\quad (f(0,0,1) - f(0,0,-1))/2)\end{aligned}$$



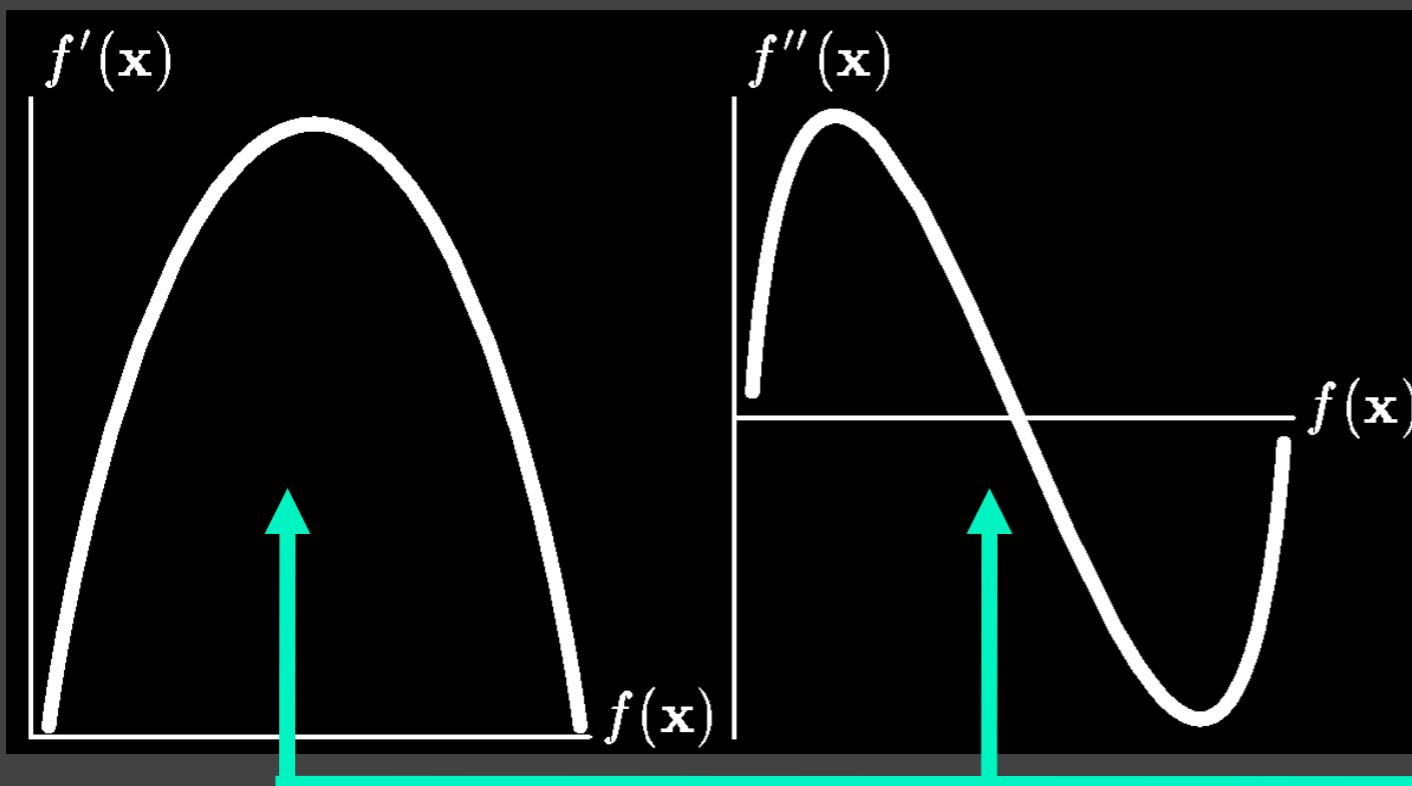
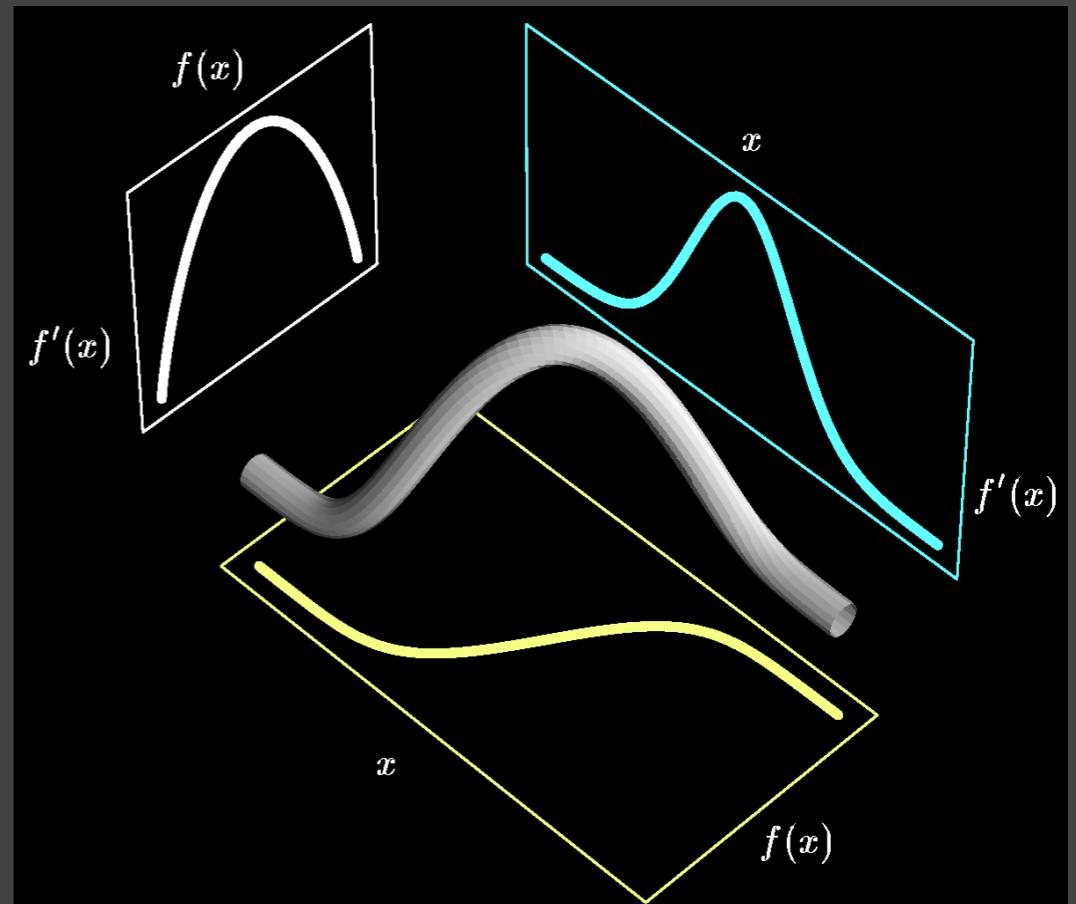
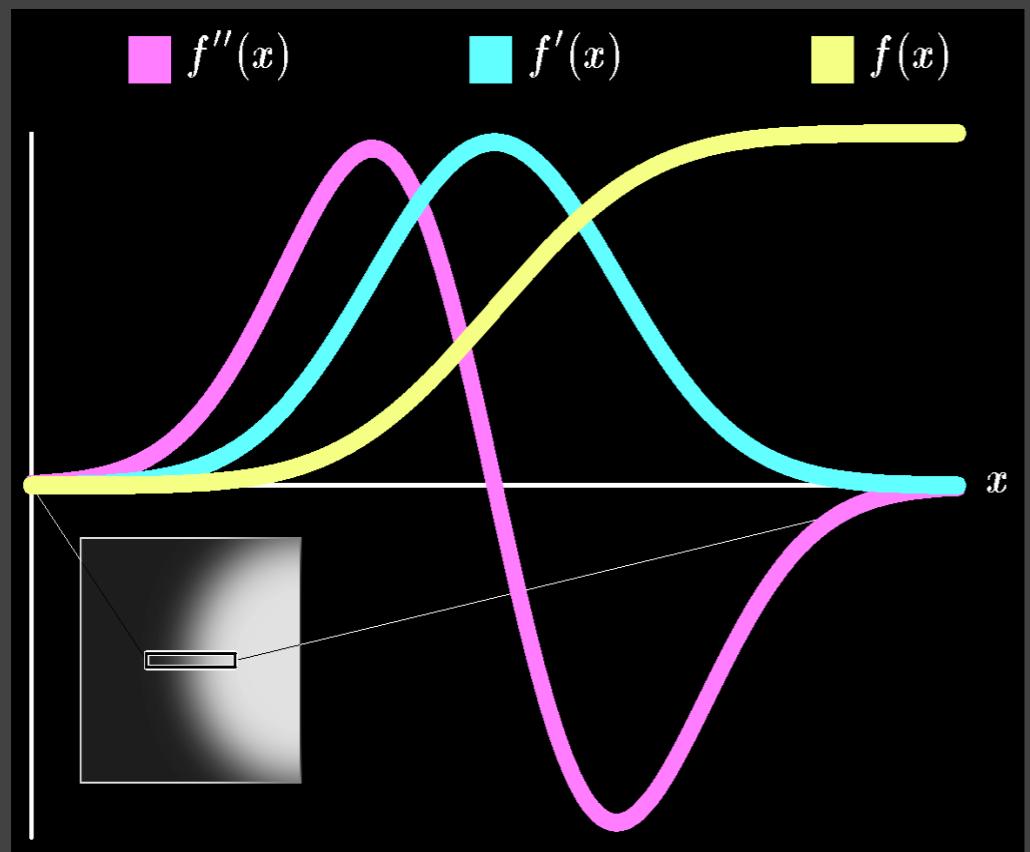
Gradient

$$\begin{aligned}\nabla f &= (dx, dy, dz) \\ &= ((f(1,0,0) - f(-1,0,0))/2, \\ &\quad (f(0,1,0) - f(0,-1,0))/2, \\ &\quad (f(0,0,1) - f(0,0,-1))/2)\end{aligned}$$

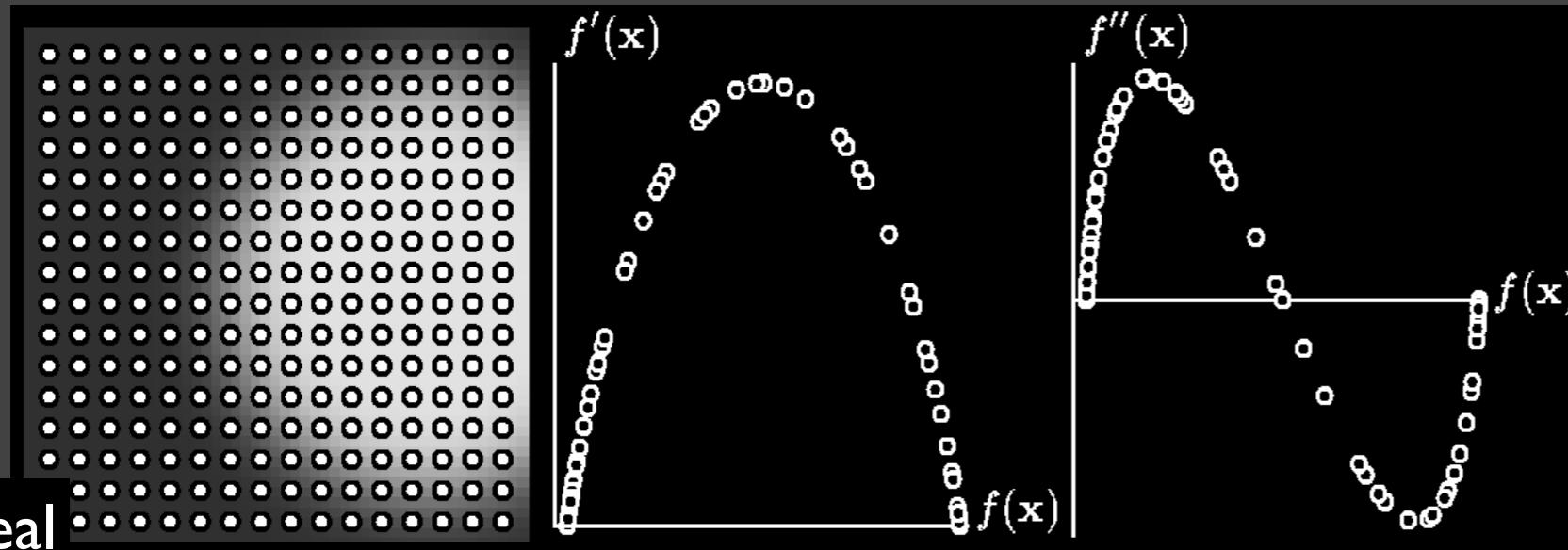
- Approximates "surface normal" (of isosurface)



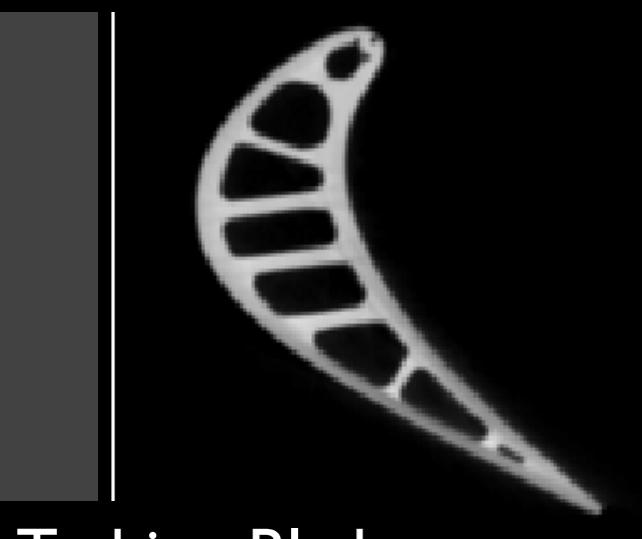
Derivative relationships



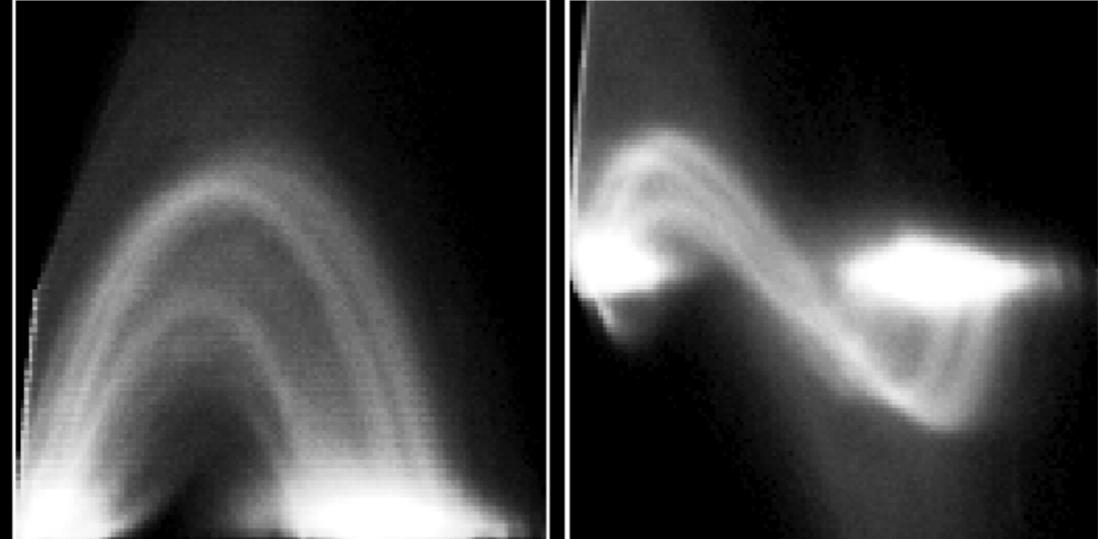
Edges at maximum
of 1st derivative or
zero-crossing of 2nd



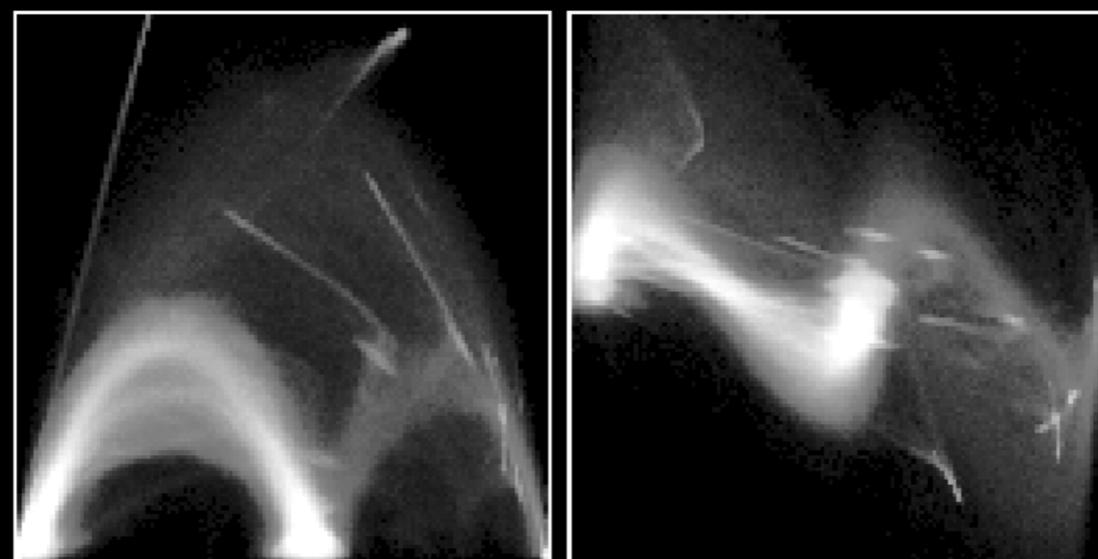
Ideal



Turbine Blade



Engine Block

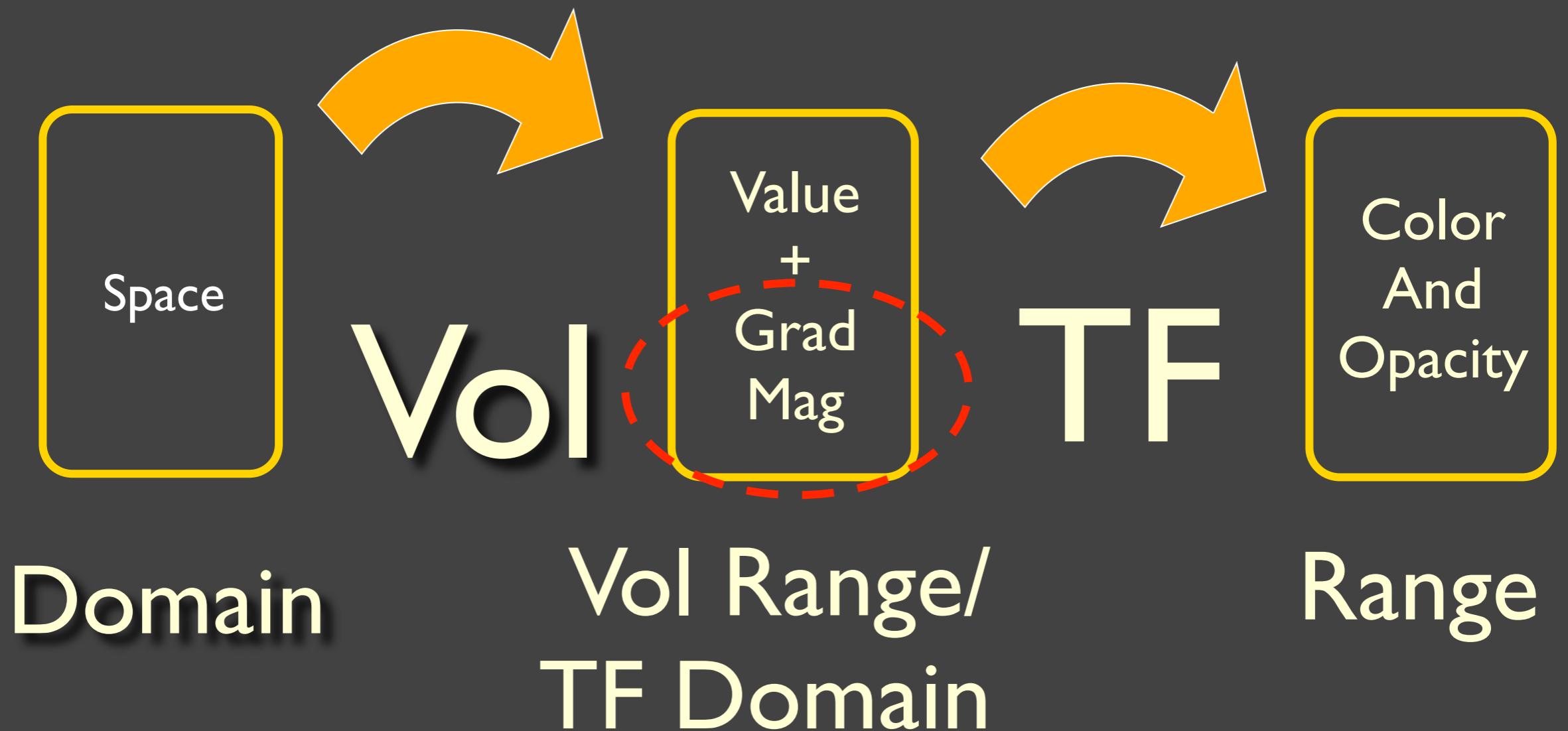


Project histogram volume to 2D scatterplots

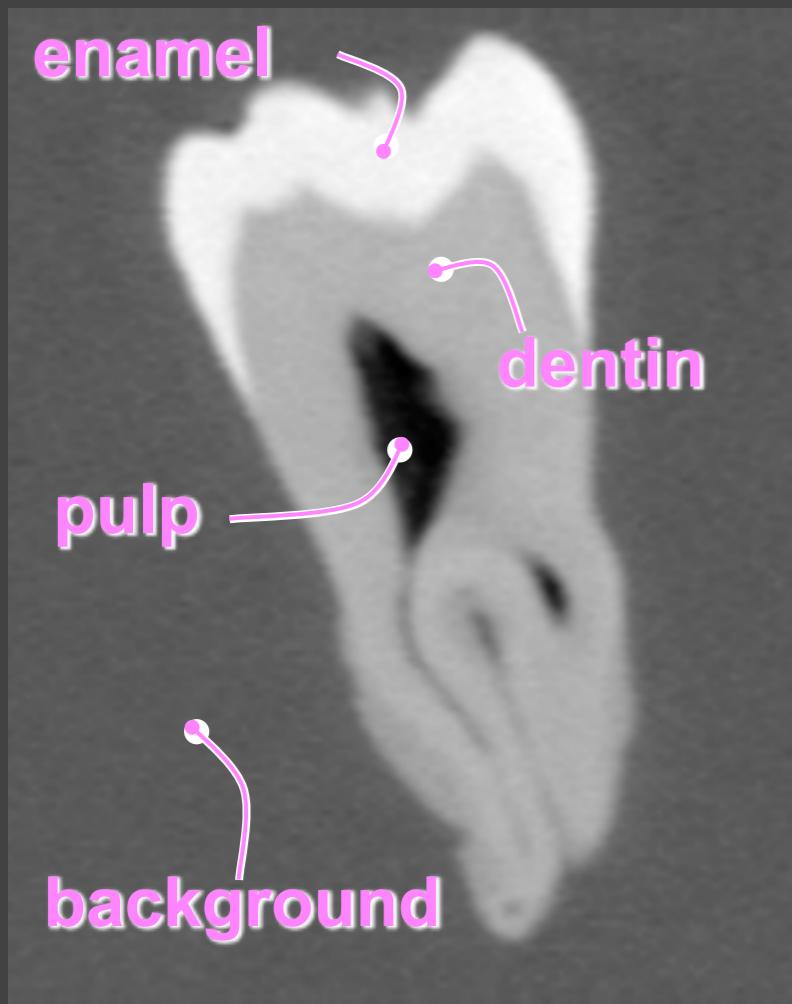
- Visual summary
- Interpreted for TF guidance
- No reliance on boundary model at this stage

Higher-Dimensional Transfer Functions

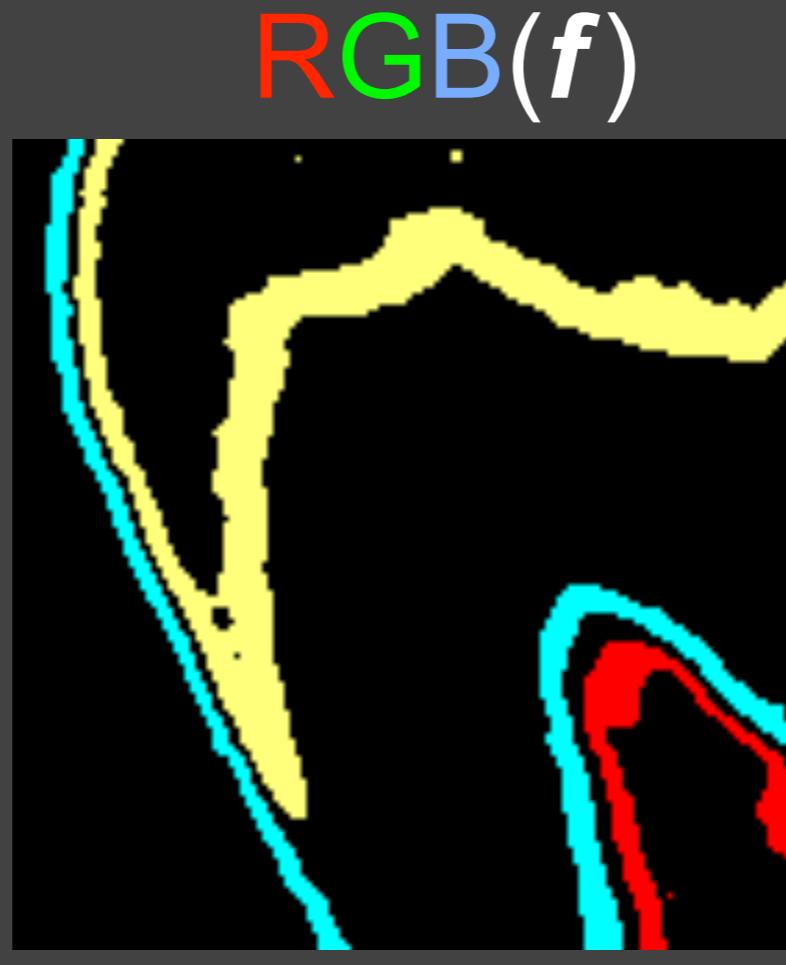
Basic Transfer Functions:



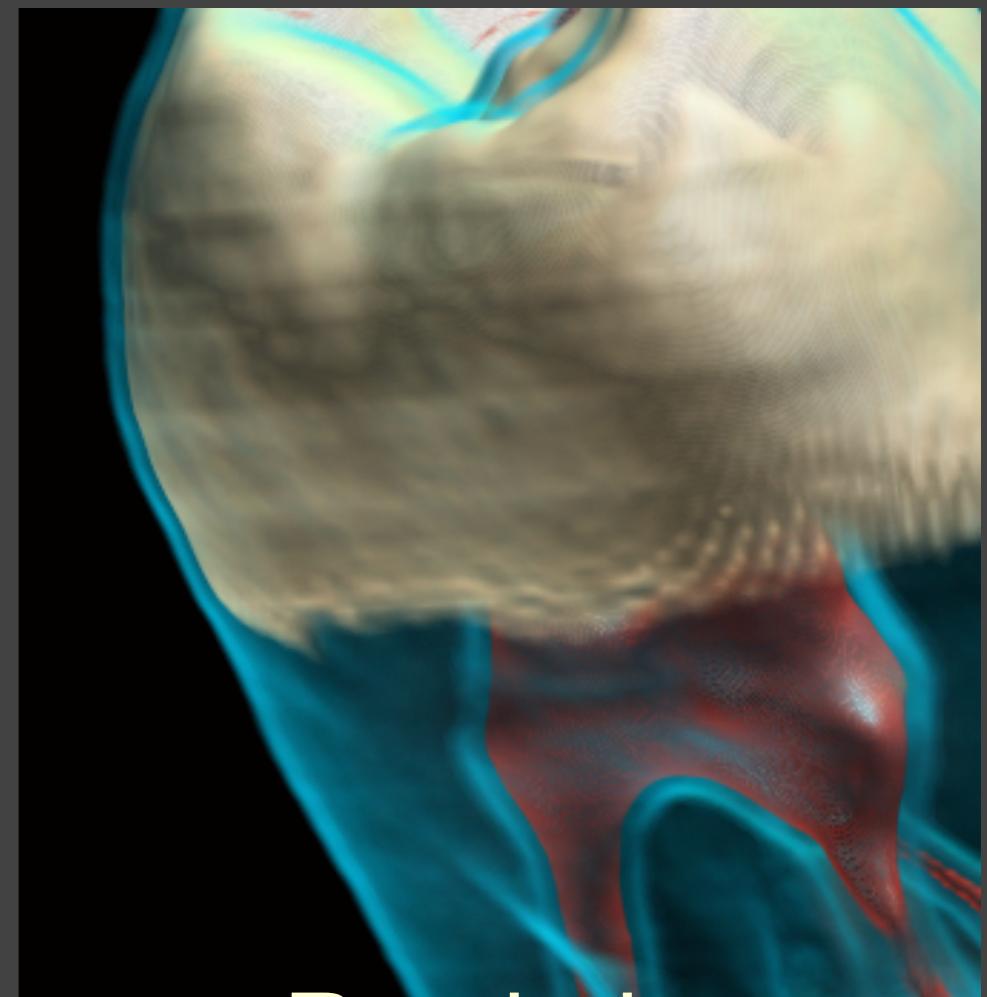
ID TFs: limitation



Slice



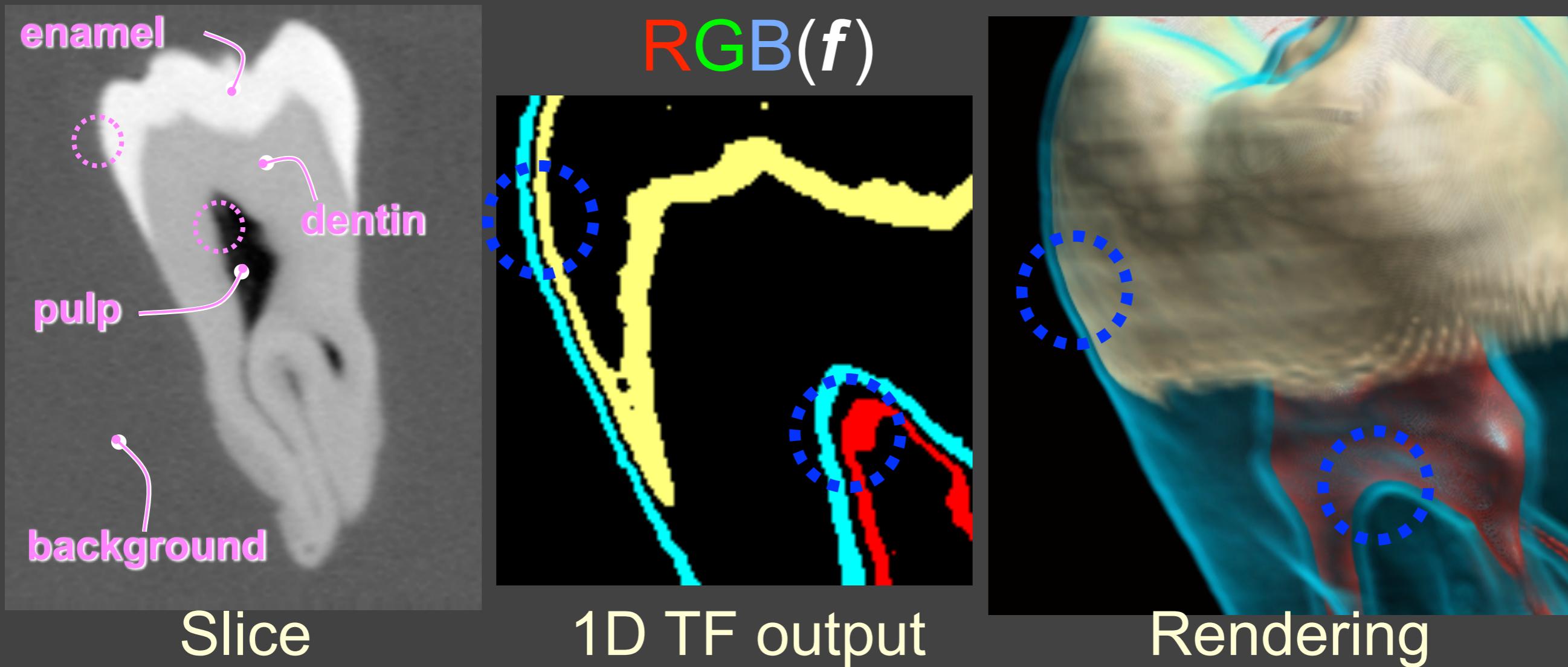
1D TF output



Rendering

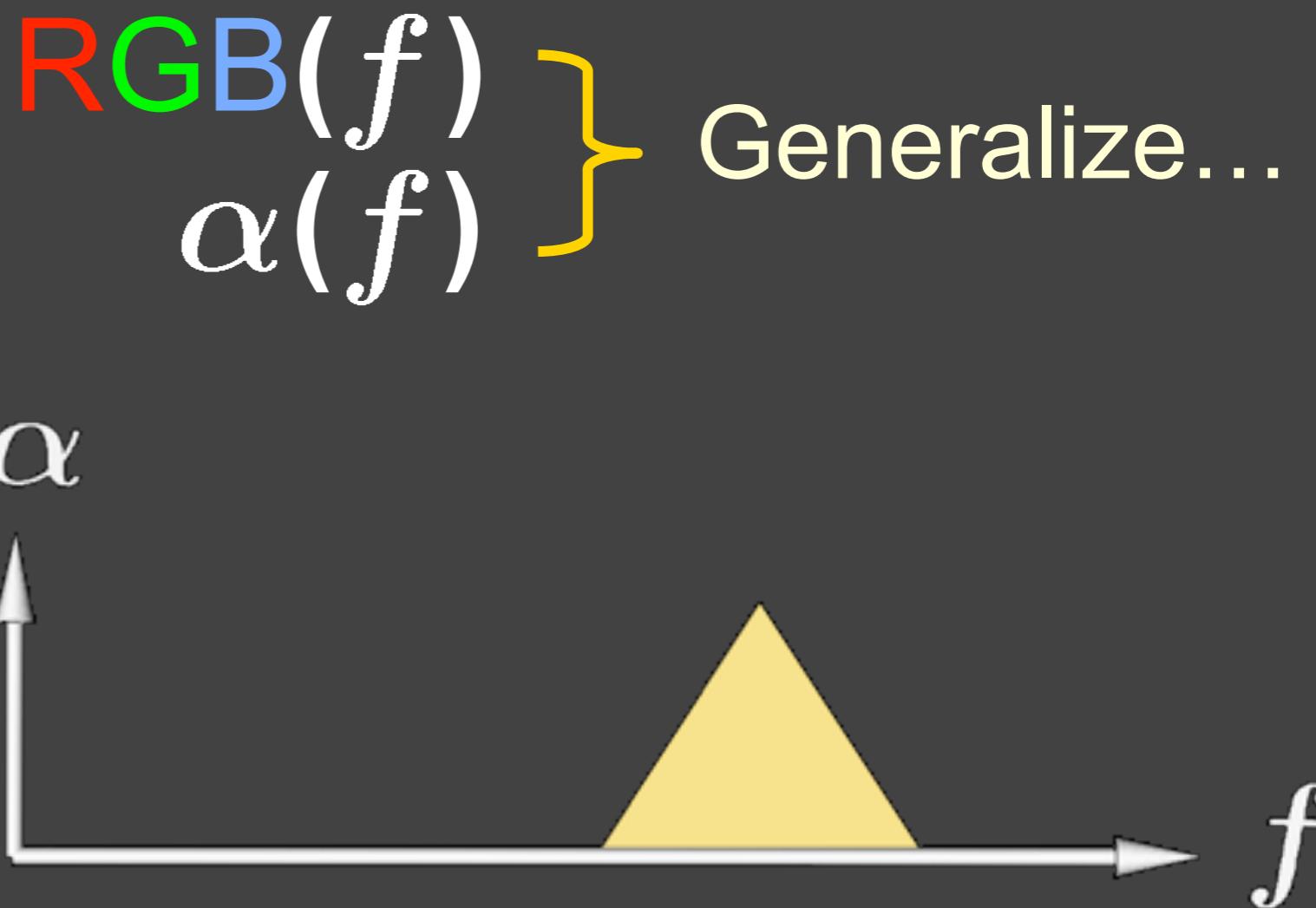
1D transfer functions can not accurately capture all material boundaries

1D TFs: limitation

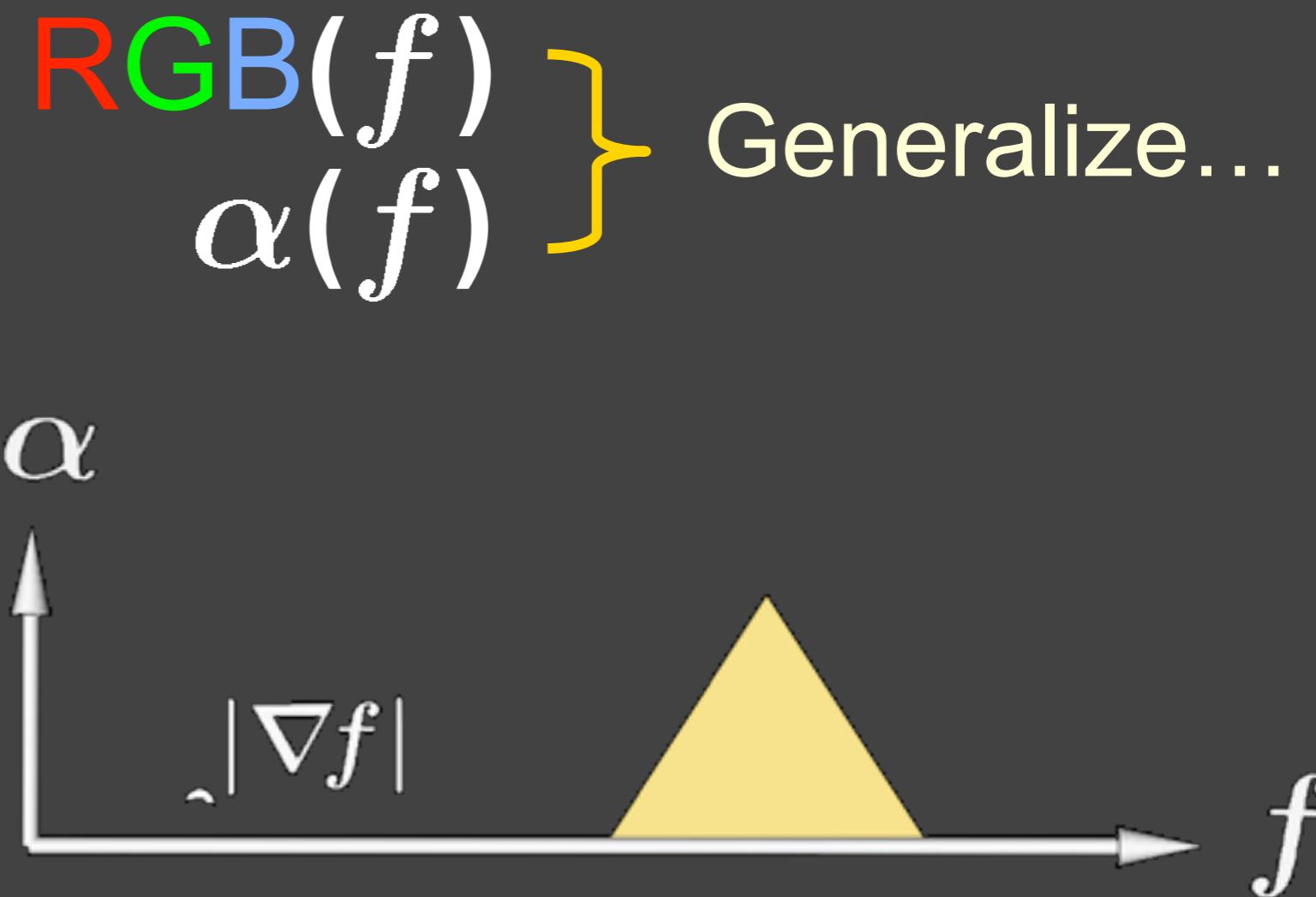


1D transfer functions can not accurately capture all material boundaries

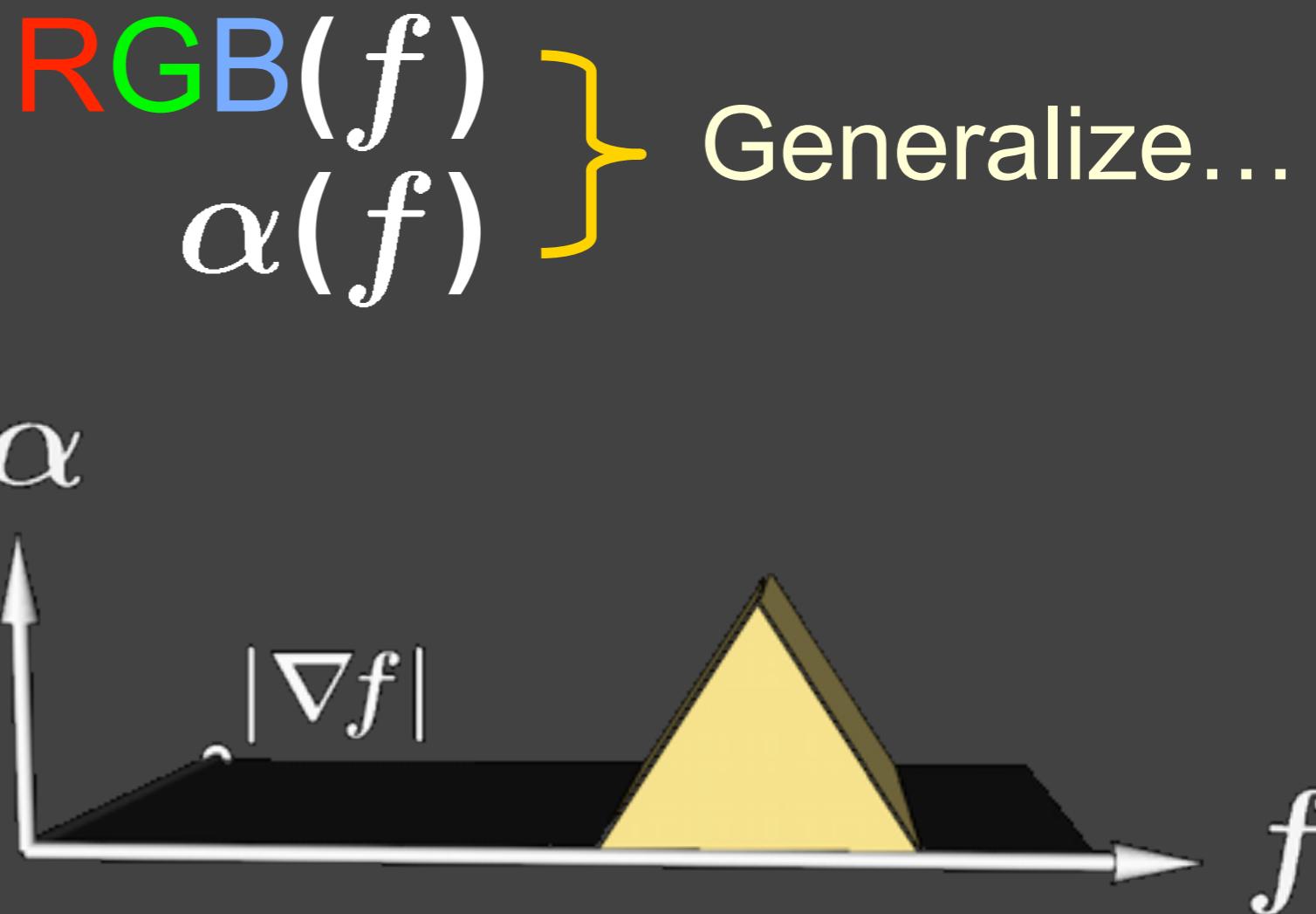
1D → 2D Transfer Function



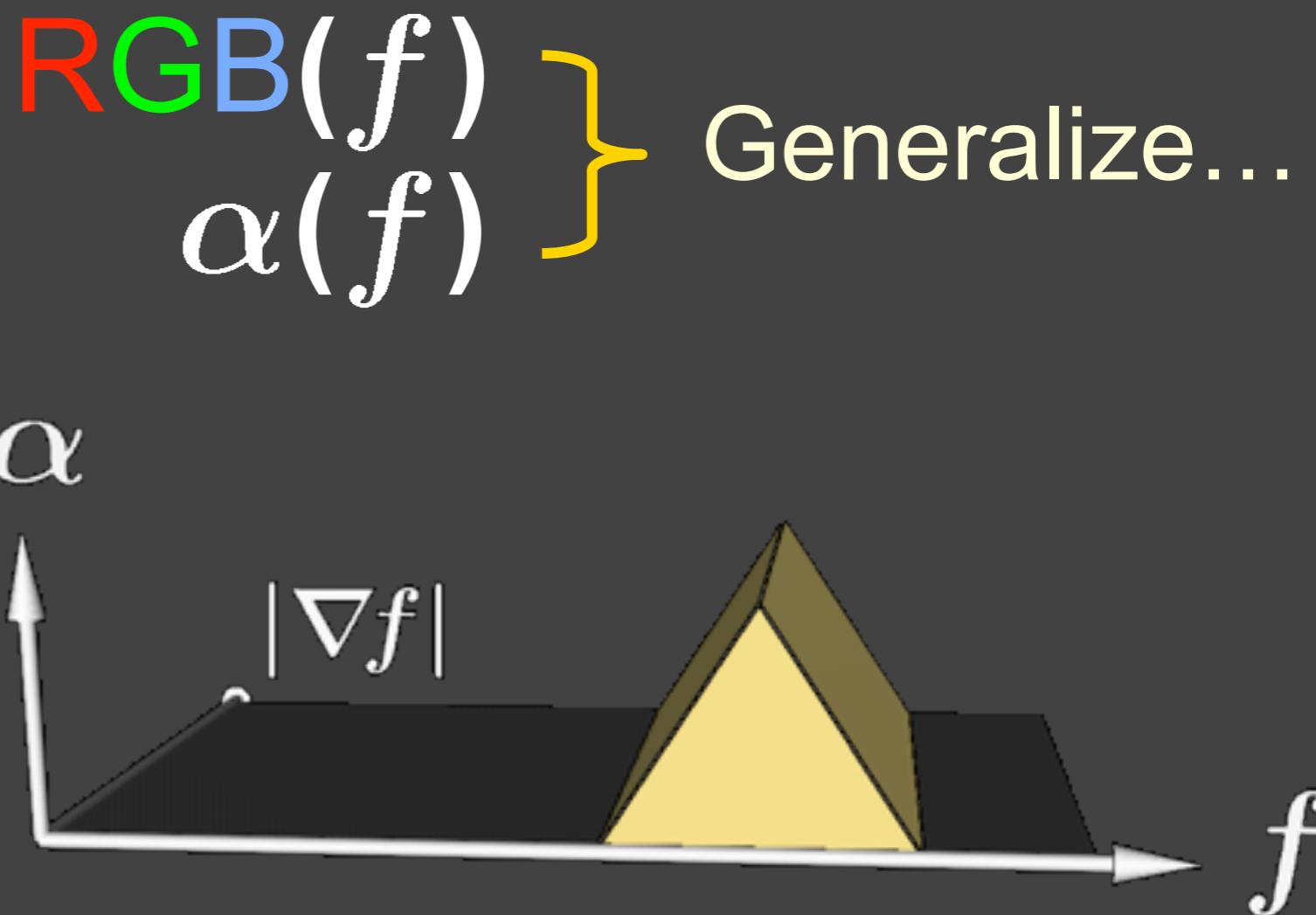
1D → 2D Transfer Function



1D → 2D Transfer Function



1D → 2D Transfer Function

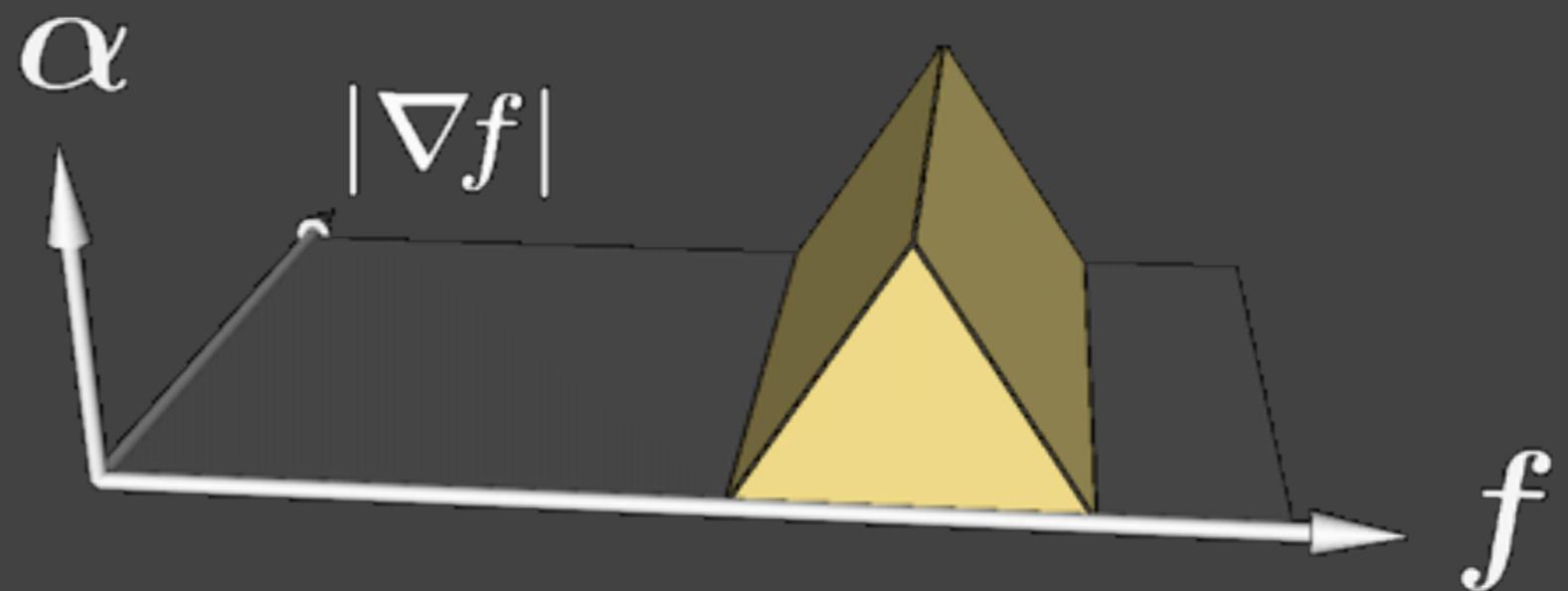


1D → 2D Transfer Function

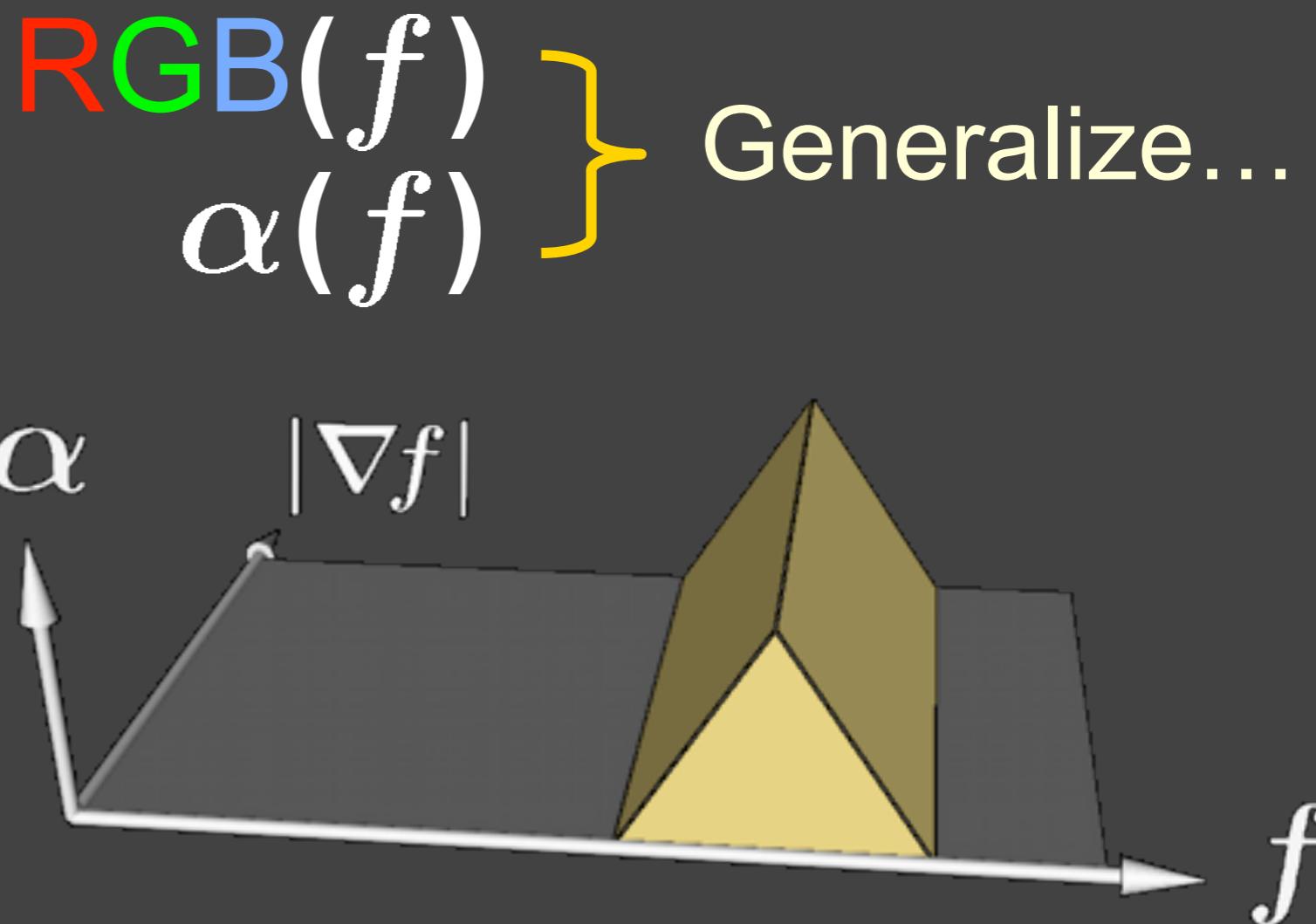


$\text{RGB}(f)$
 $\alpha(f)$

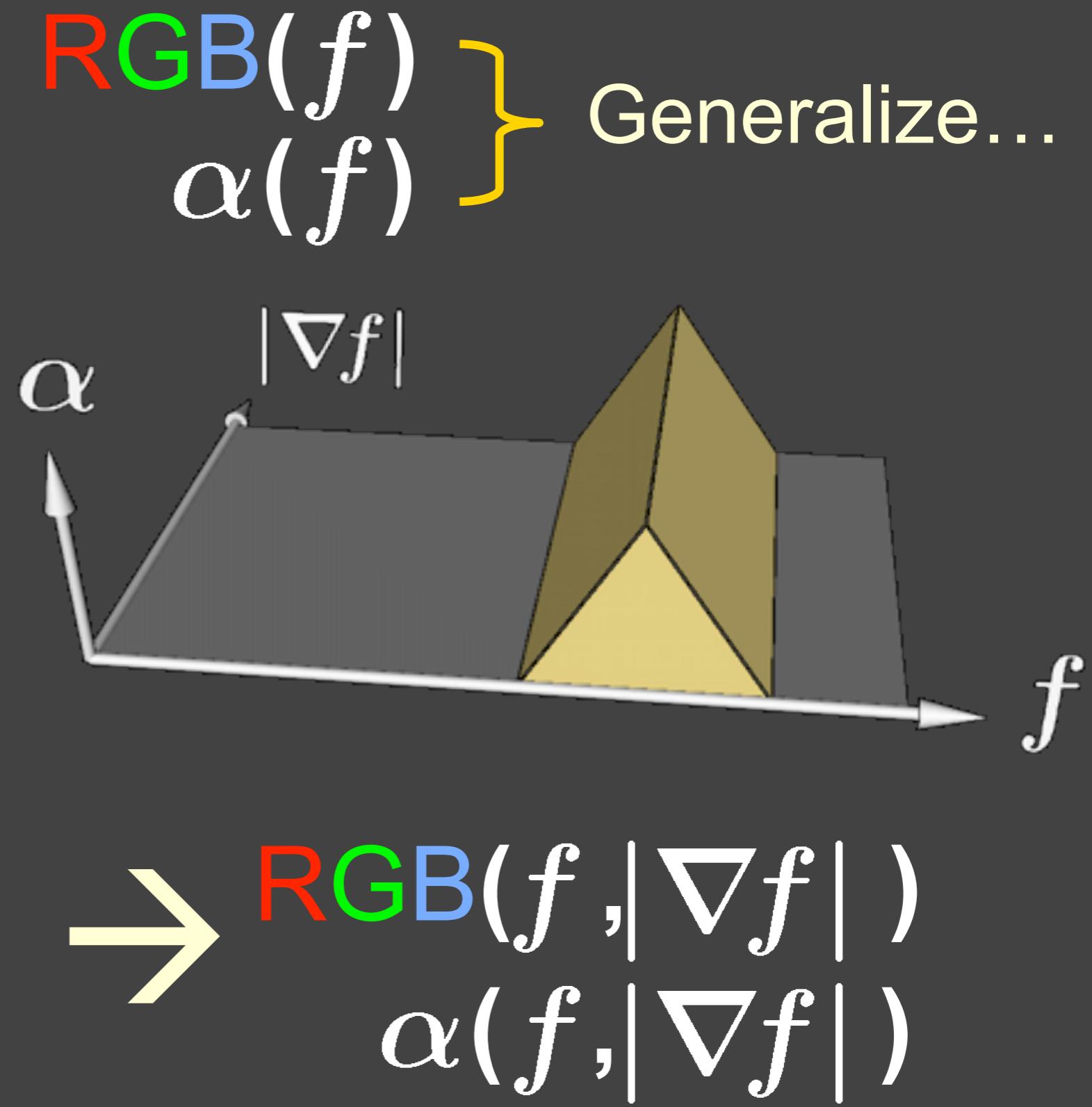
Generalize...



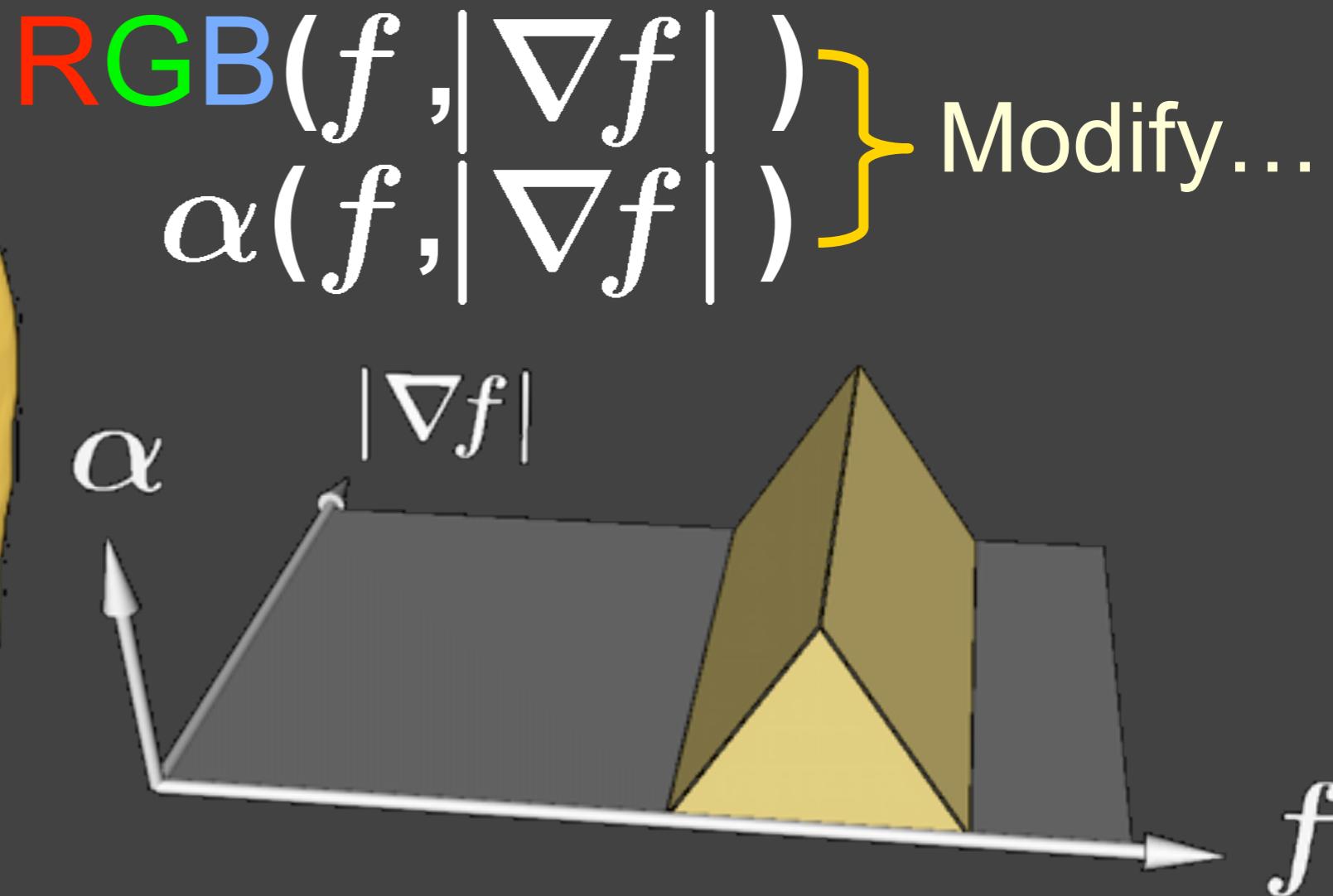
1D → 2D Transfer Function



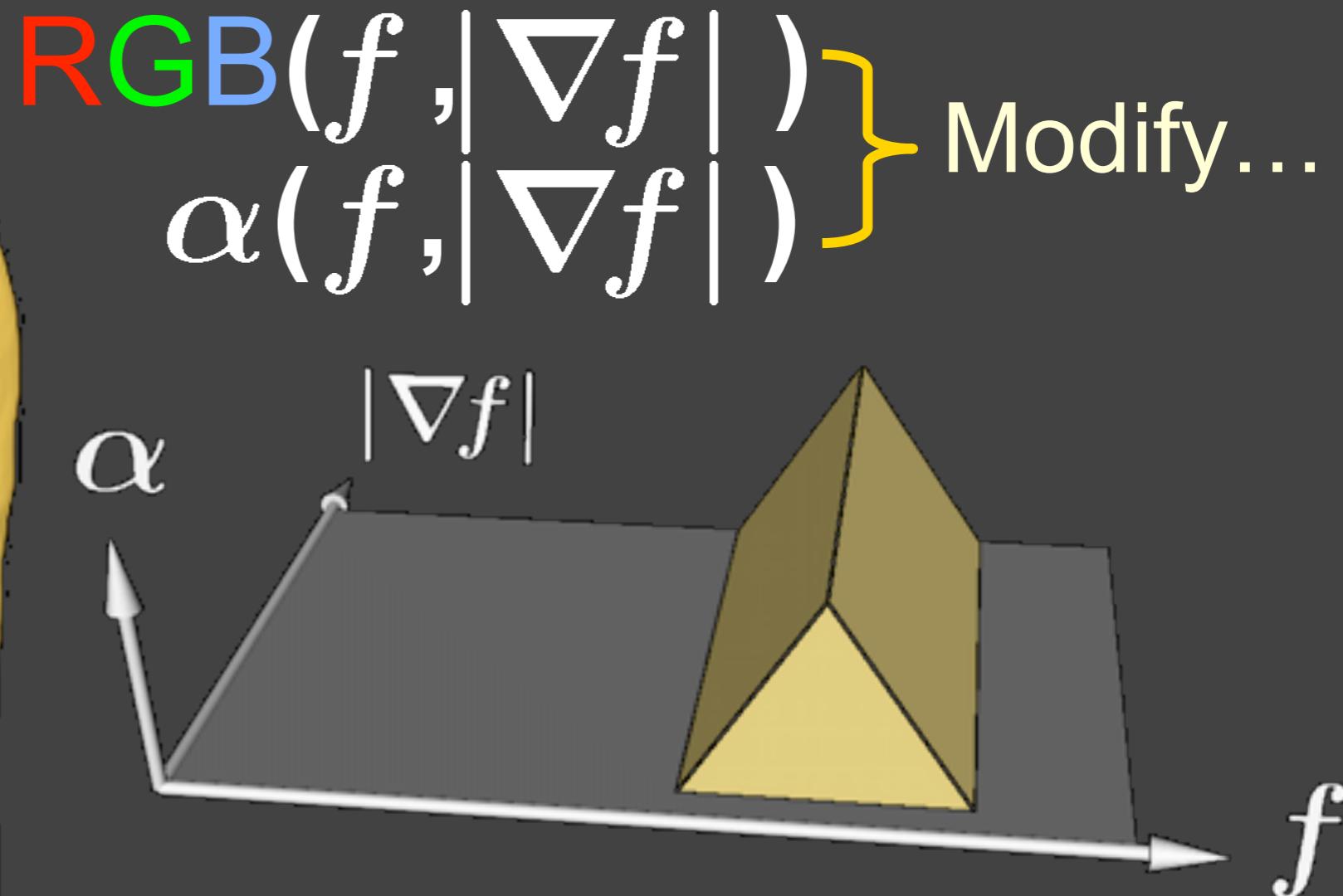
2D Transfer Function



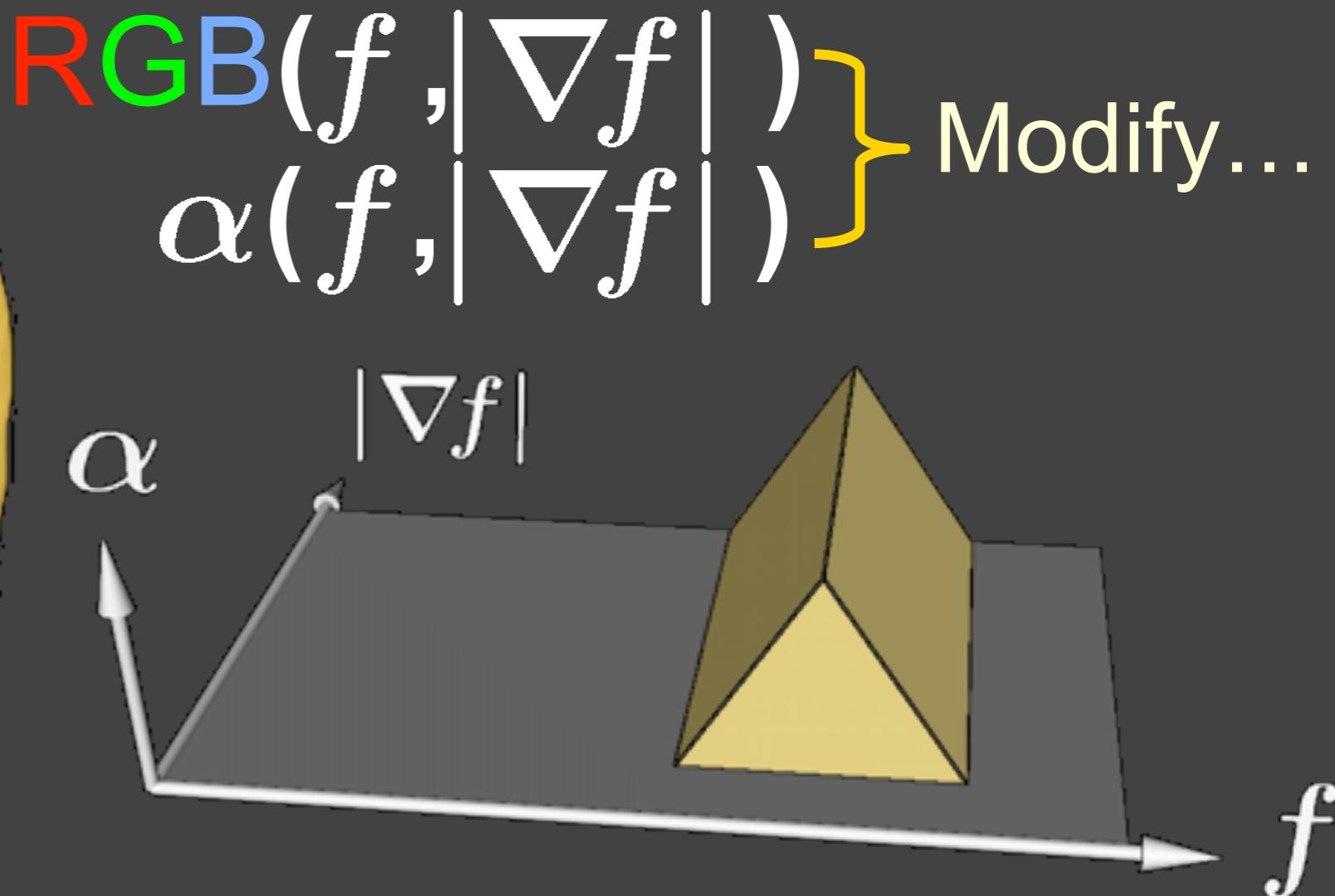
2D Transfer Function



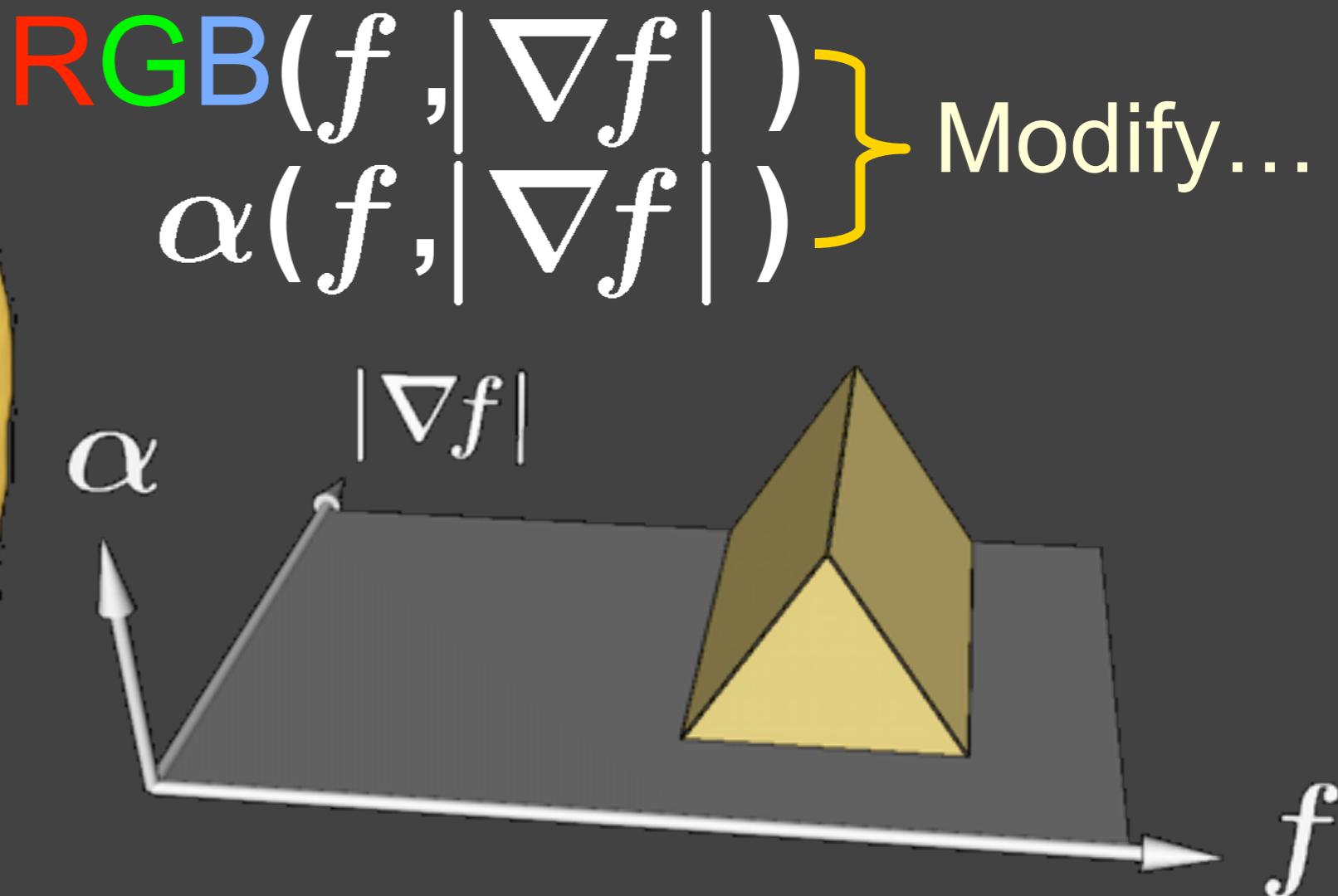
2D Transfer Function



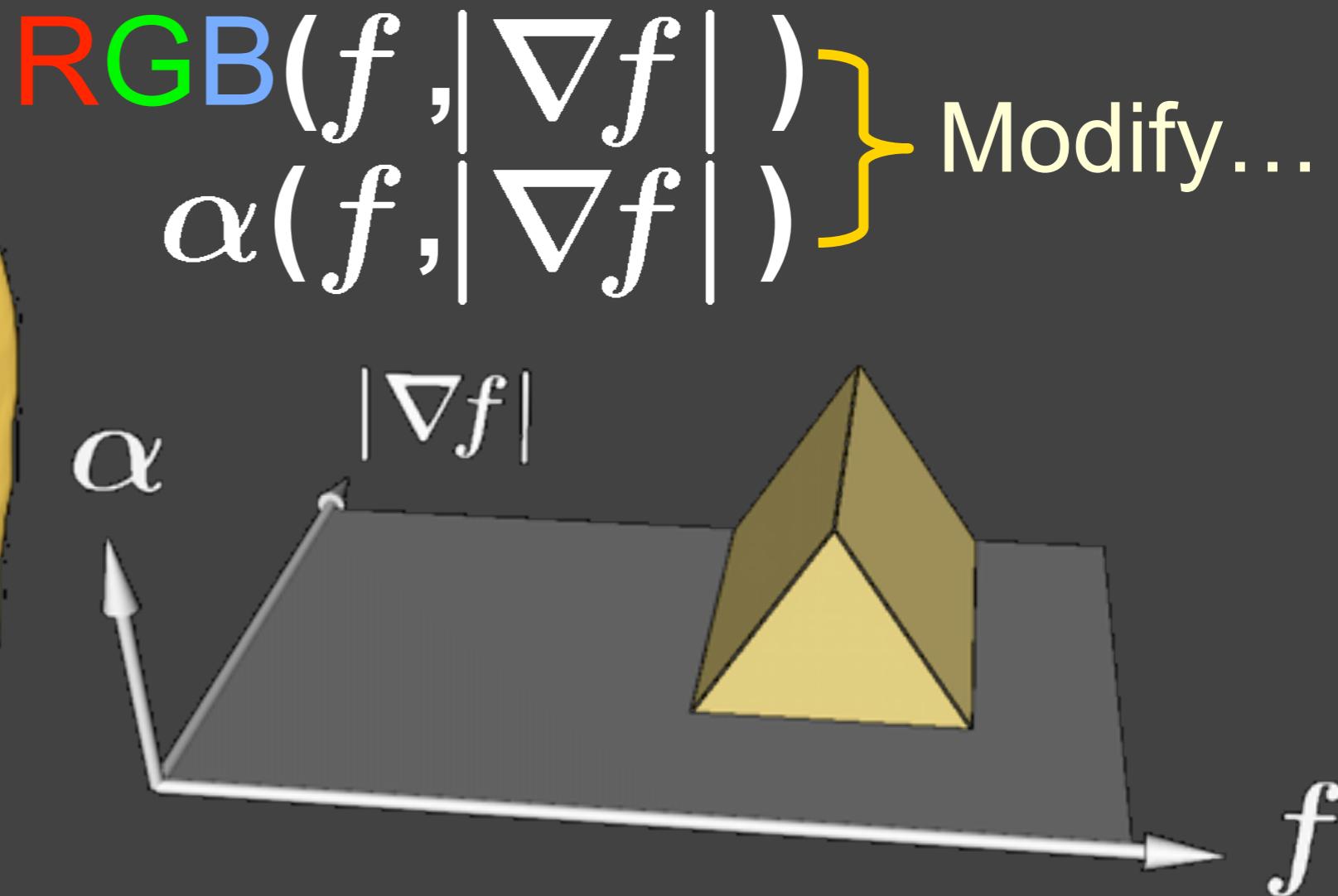
2D Transfer Function



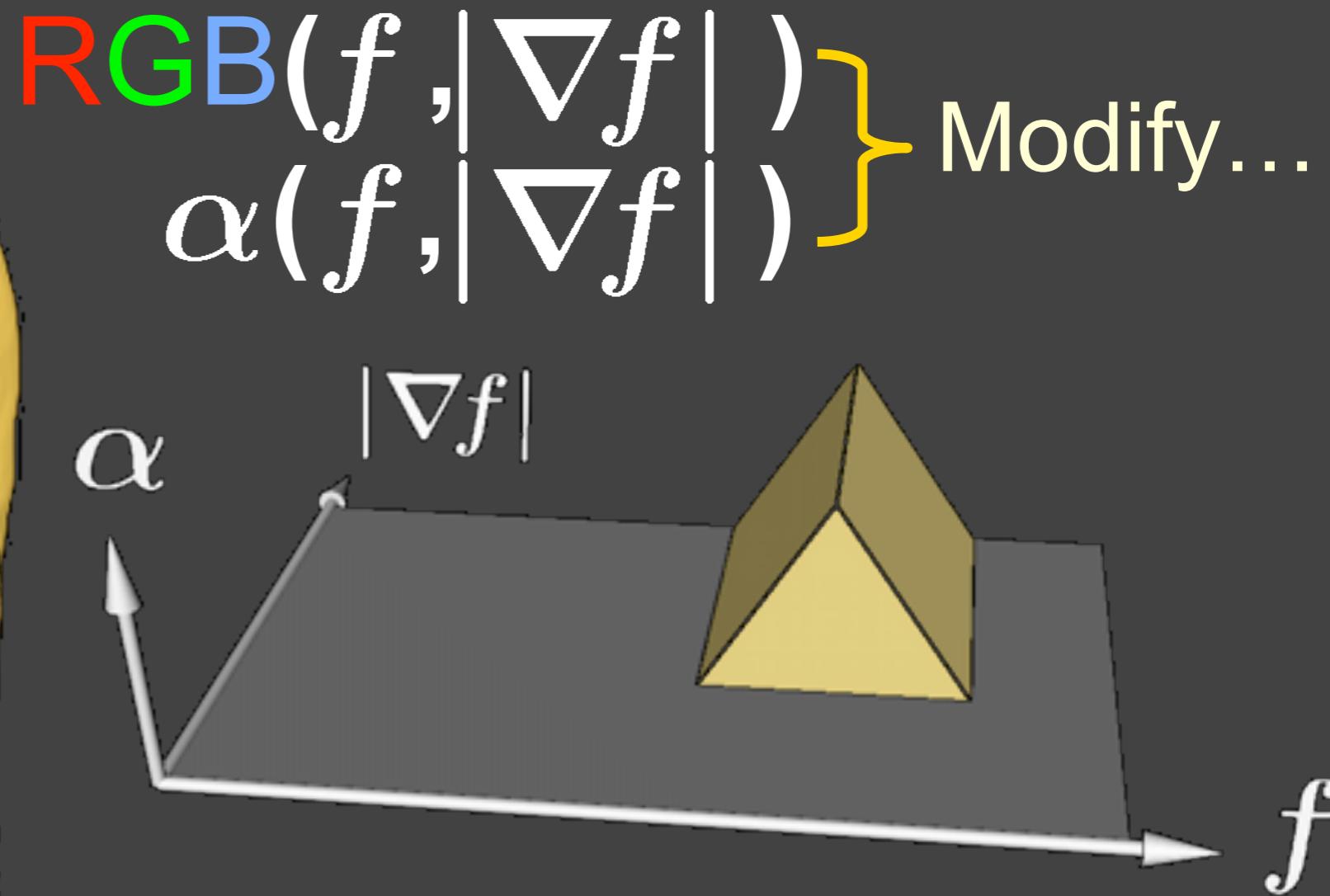
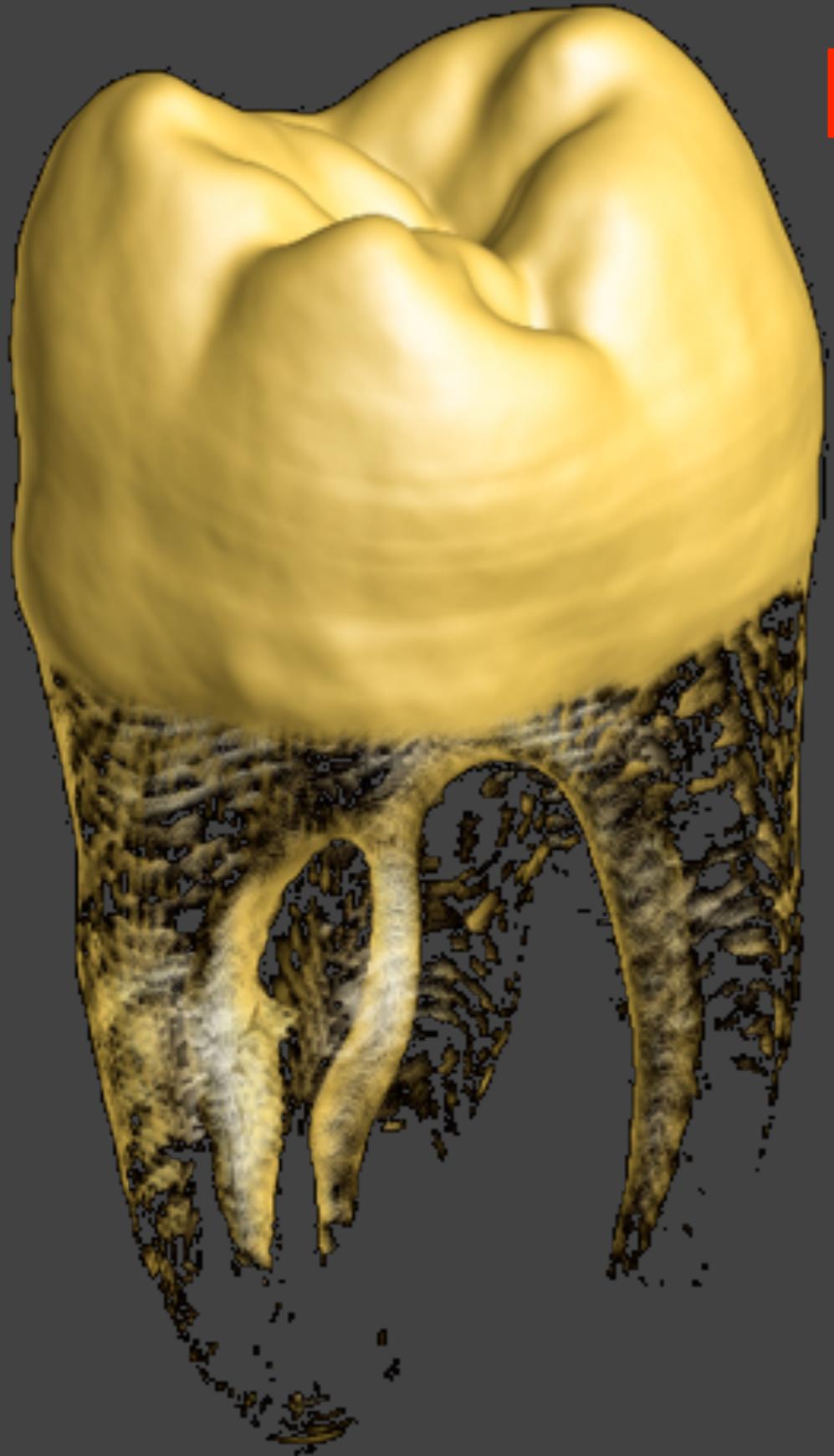
2D Transfer Function



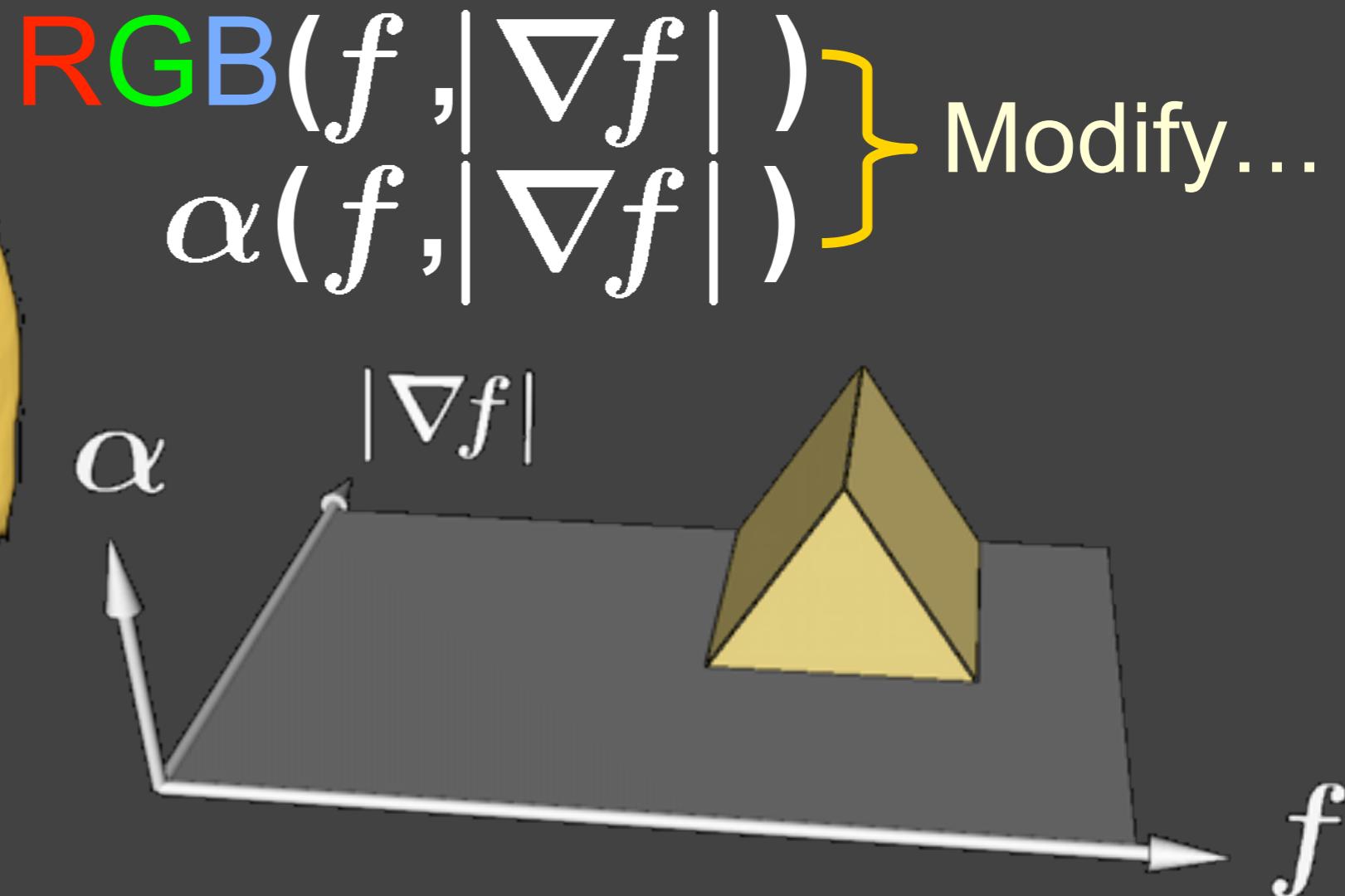
2D Transfer Function



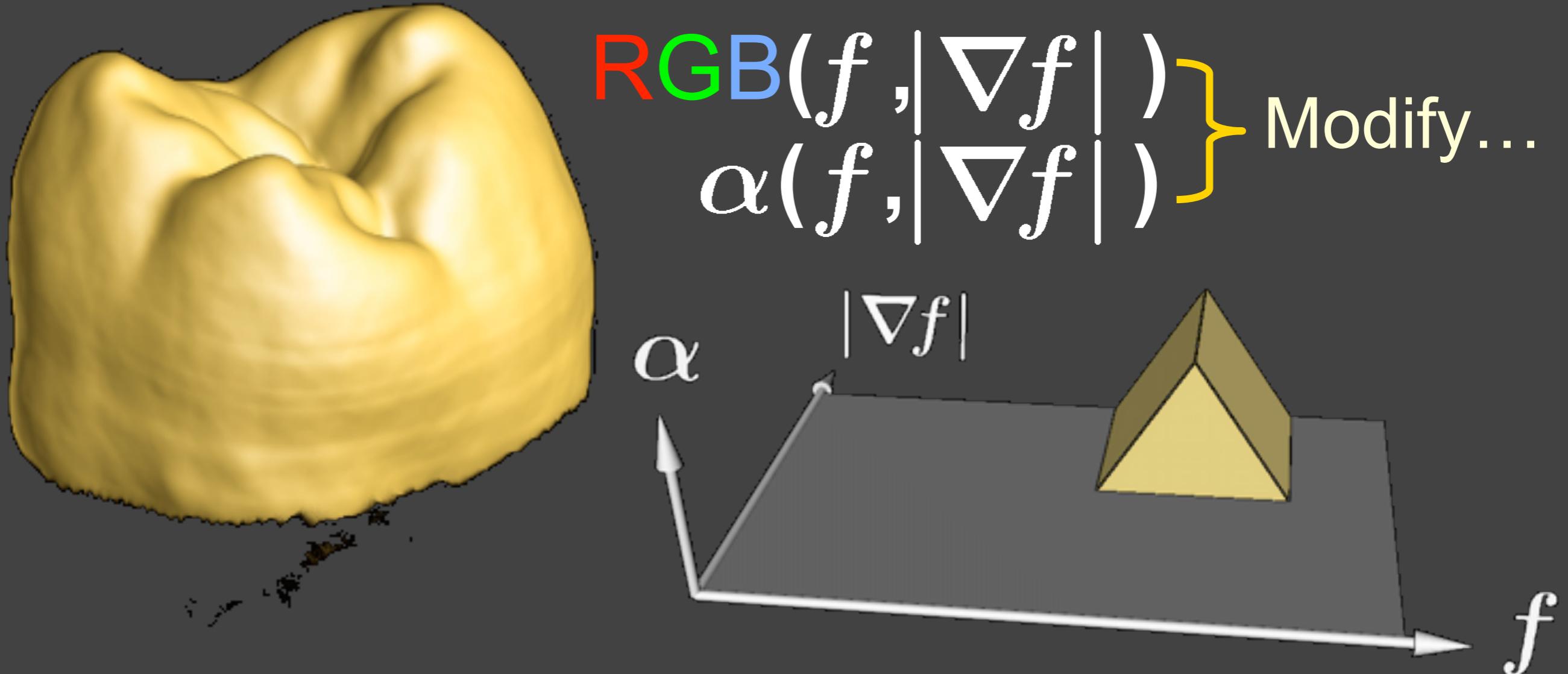
2D Transfer Function



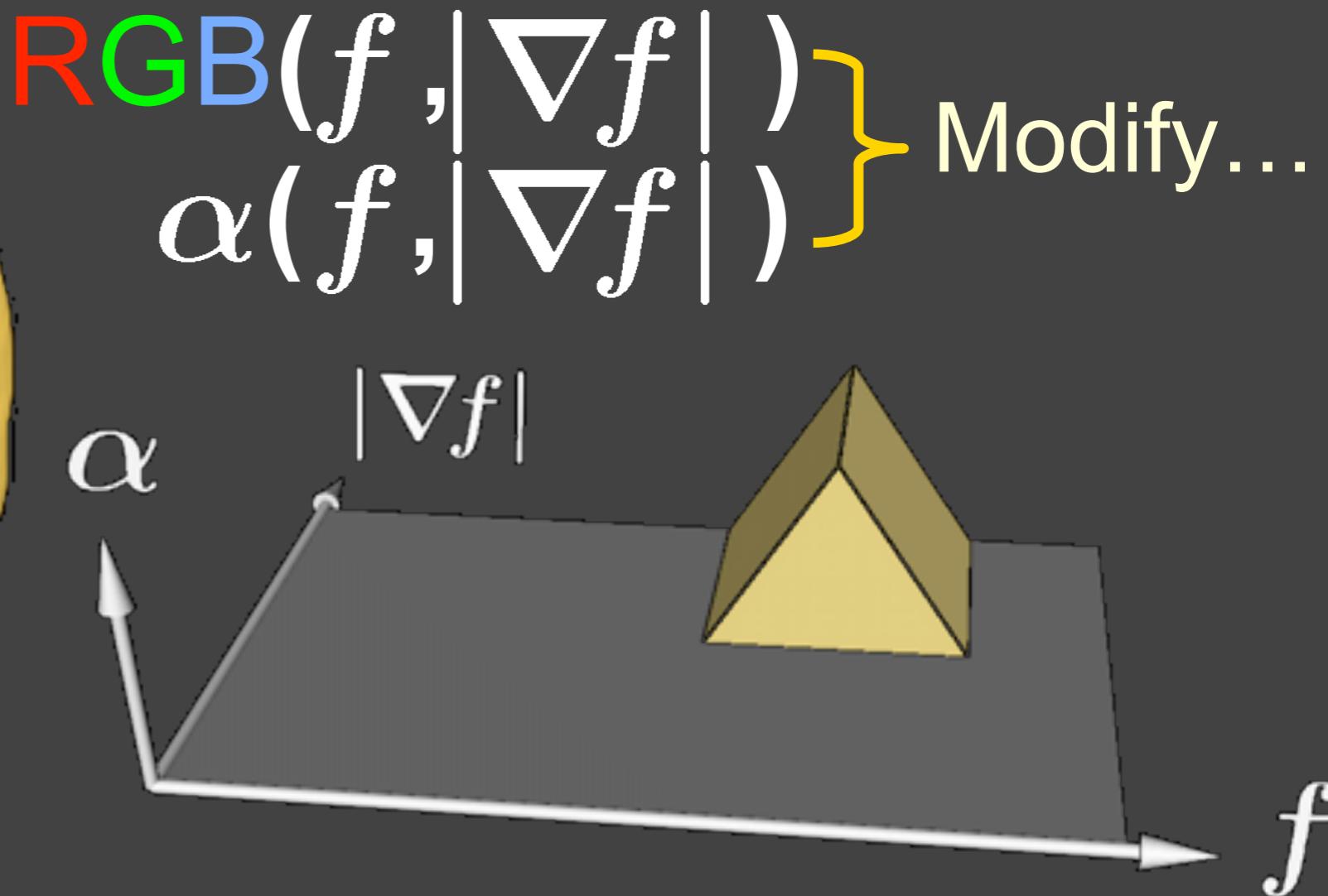
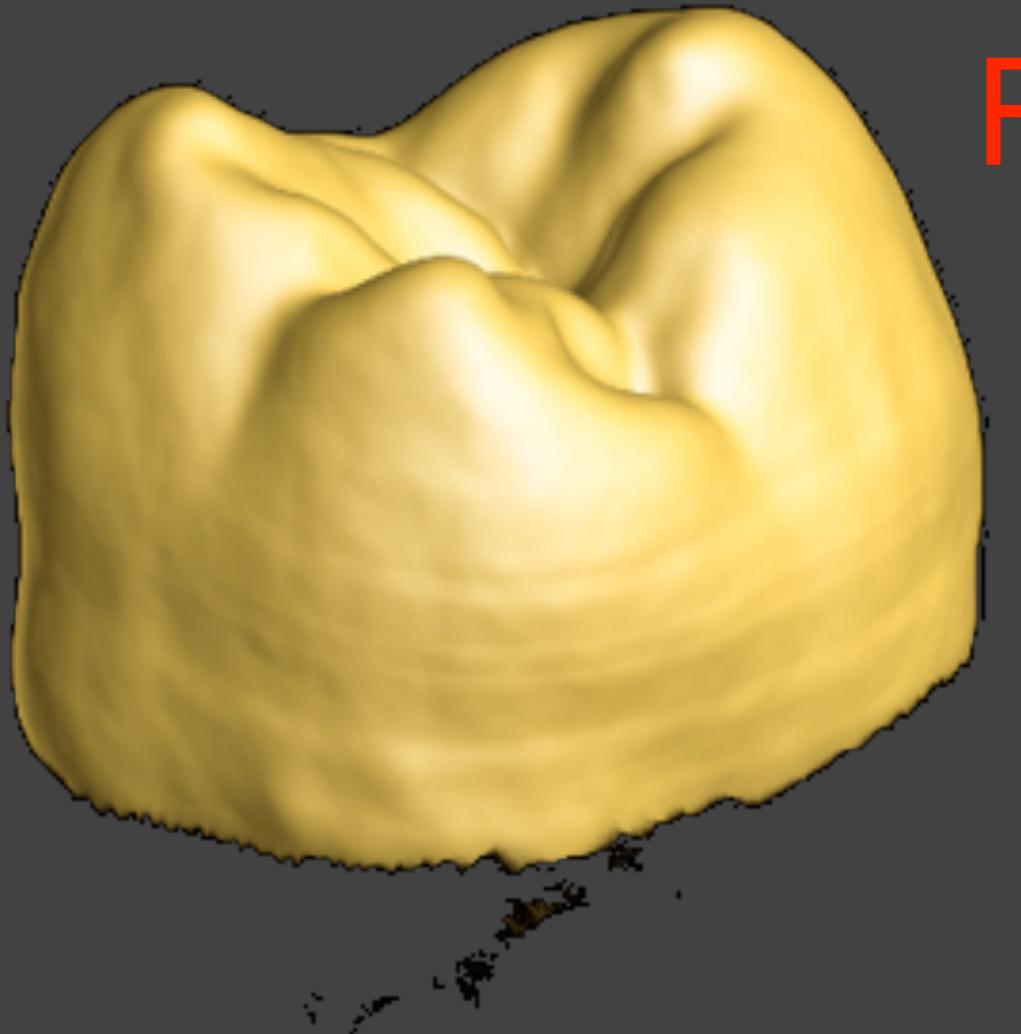
2D Transfer Function



2D Transfer Function



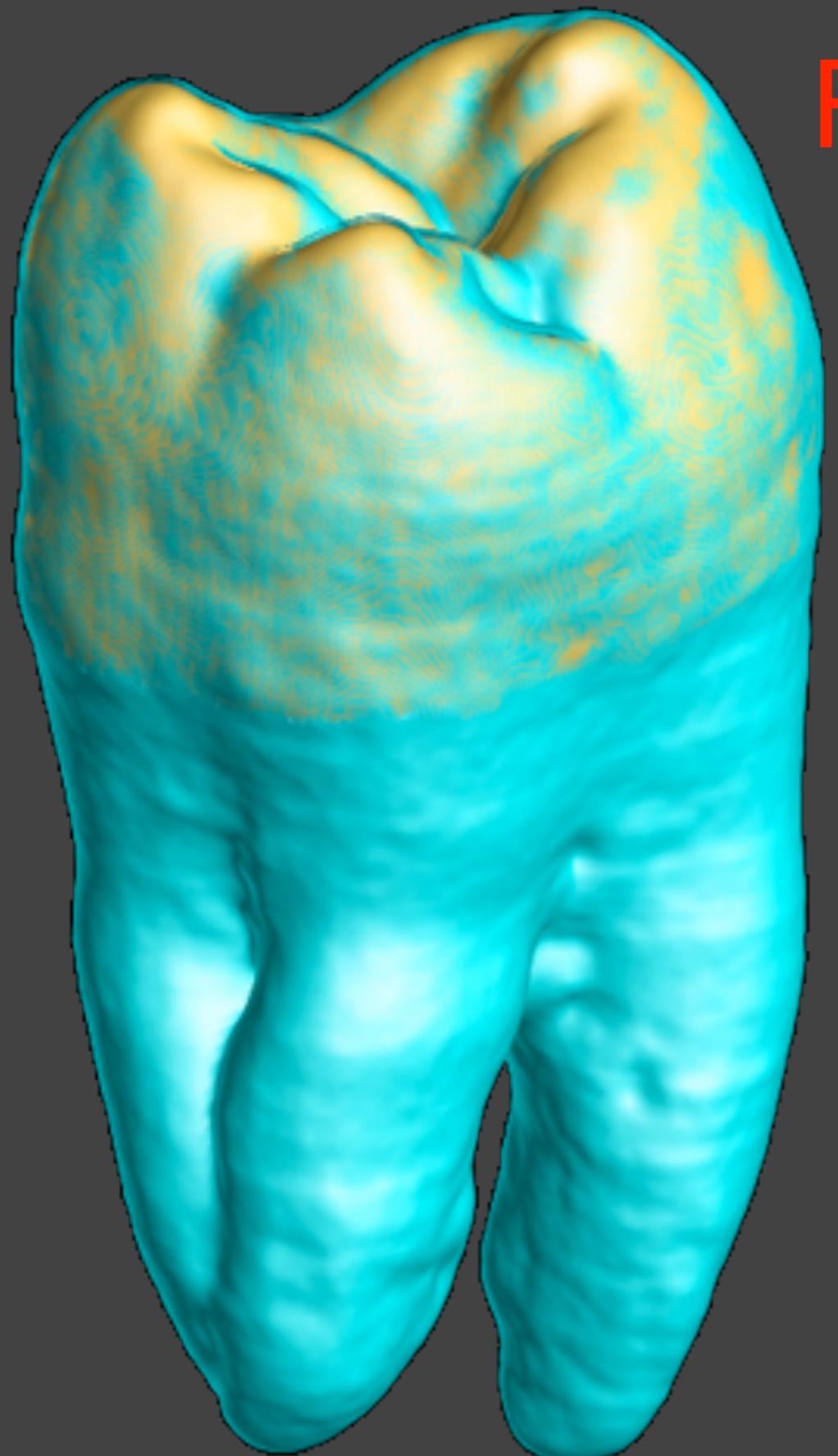
2D Transfer Function



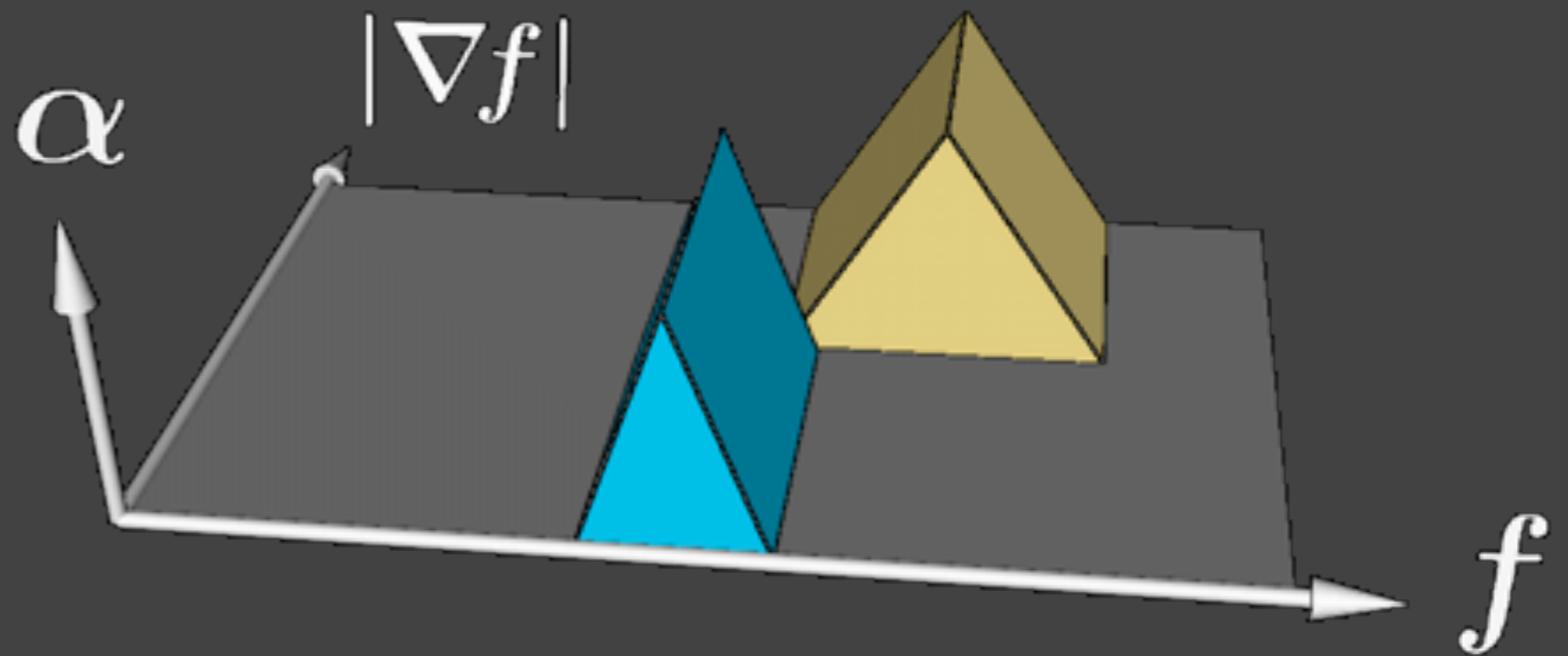
2D transfer functions give greater
flexibility in boundary visualization

Display of Surfaces from Volume Data, Levoy 1988

2D Transfer Function



$$\left. \begin{aligned} & \text{RGB}(f, |\nabla f|) \\ & \alpha(f, |\nabla f|) \end{aligned} \right\} \text{Modify...}$$



Trying to reintroduce
dentin / background
boundary ...



ImageVis

3D



ImageVis

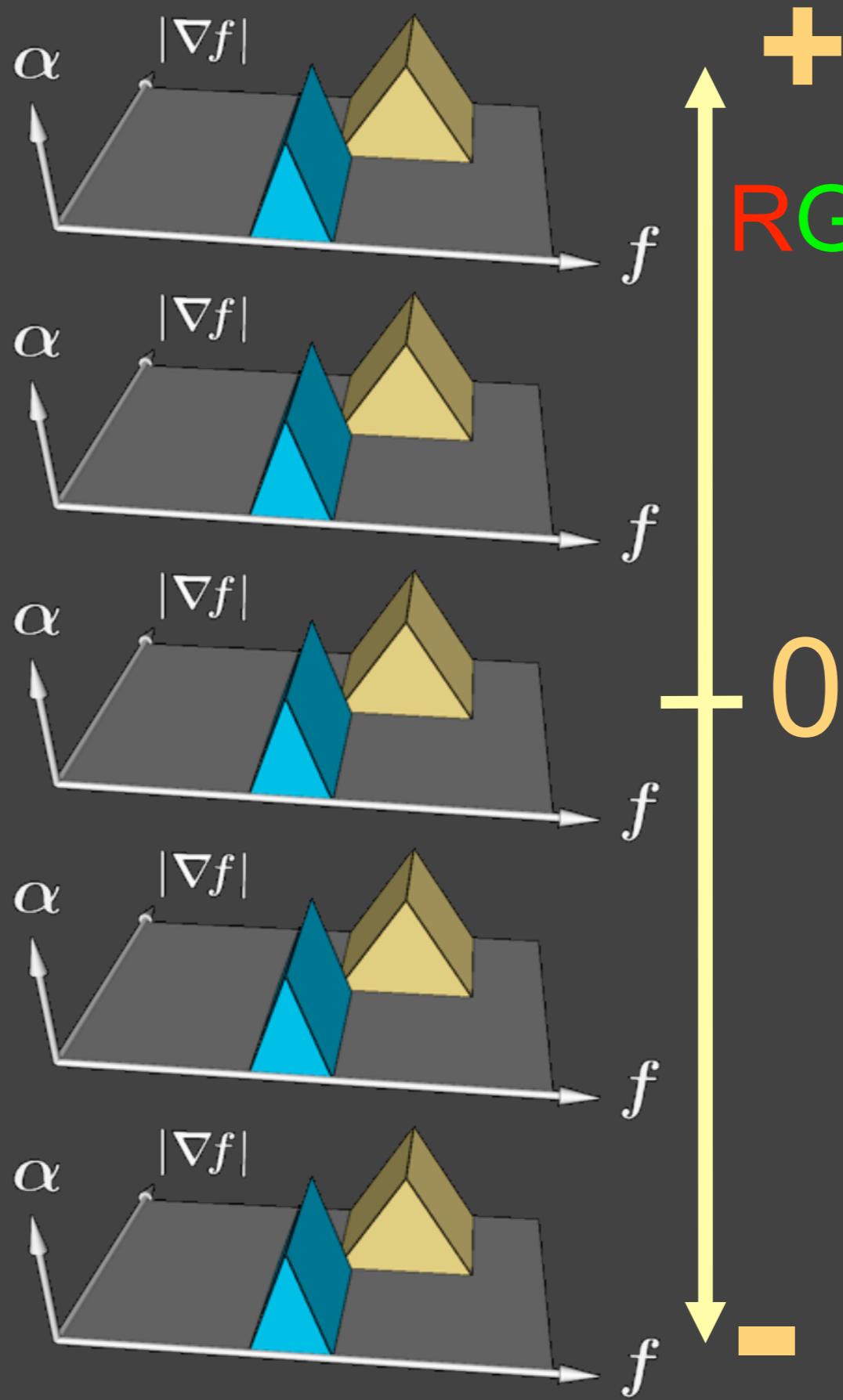
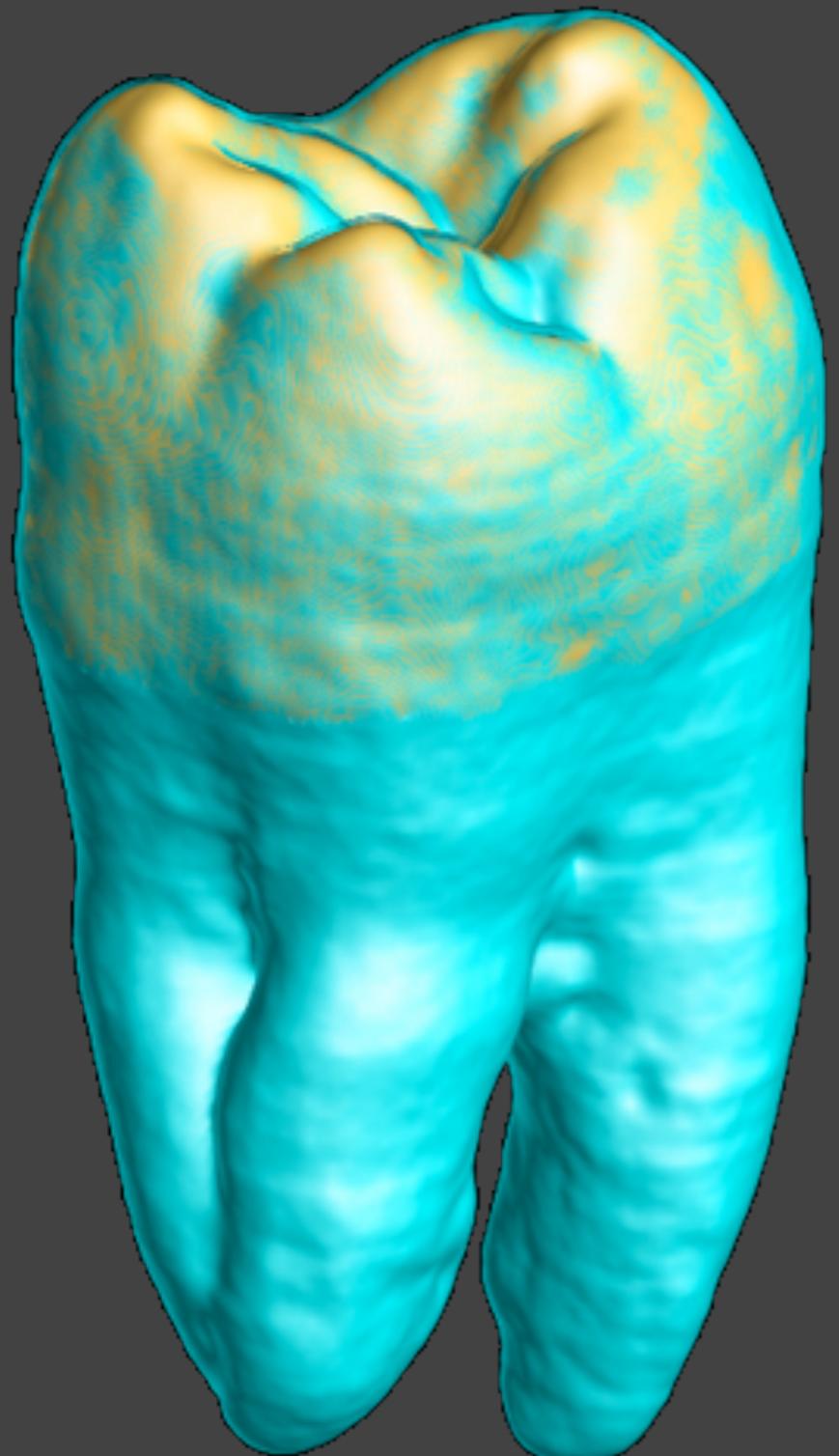
3D

2-Dimensional TFs

- Strengths:
 - Better flexibility, specificity
 - Higher quality visualizations
- Weaknesses:
 - Can be even harder to specify
 - Unintuitive relationship with boundaries
 - Greater demands on user interface

Other TF Methods

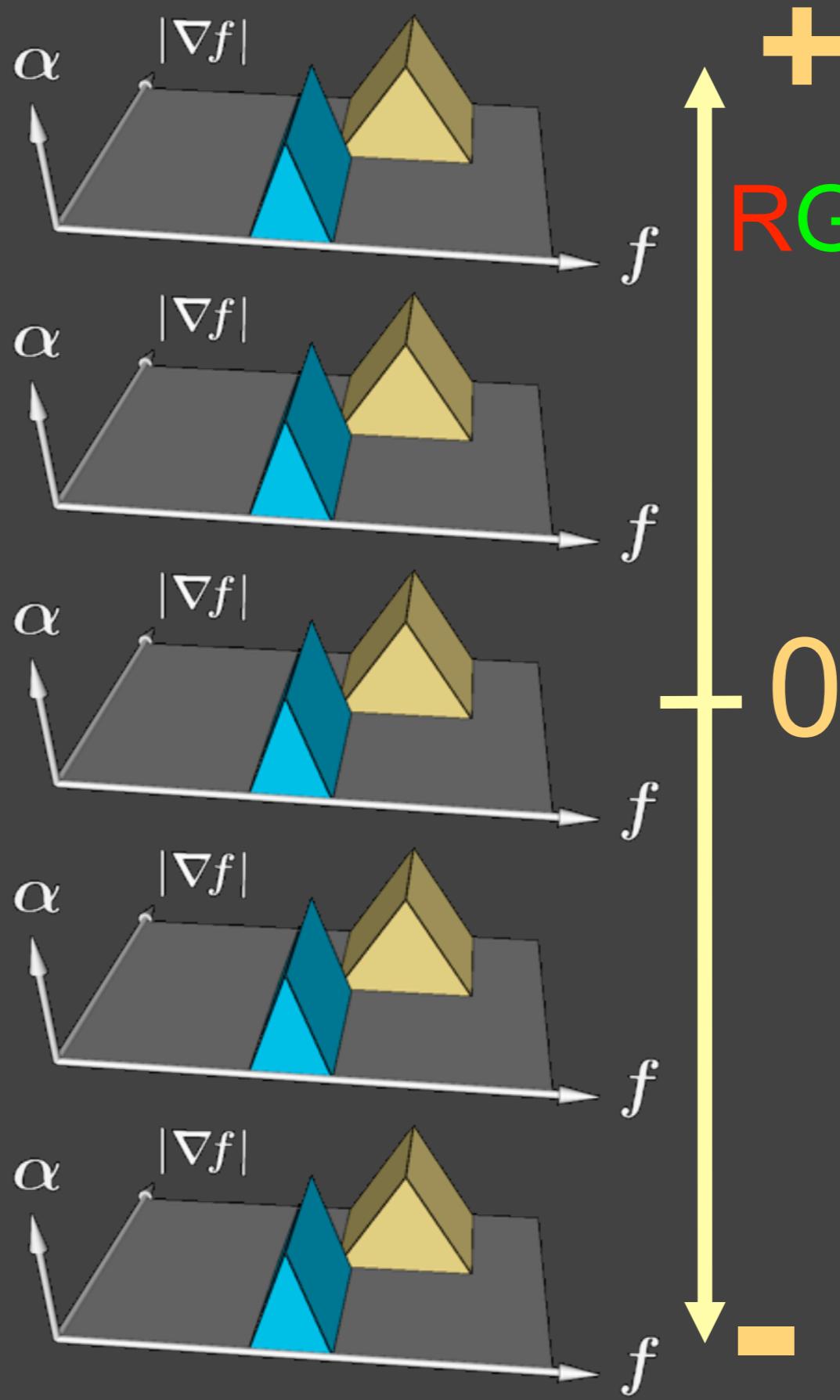
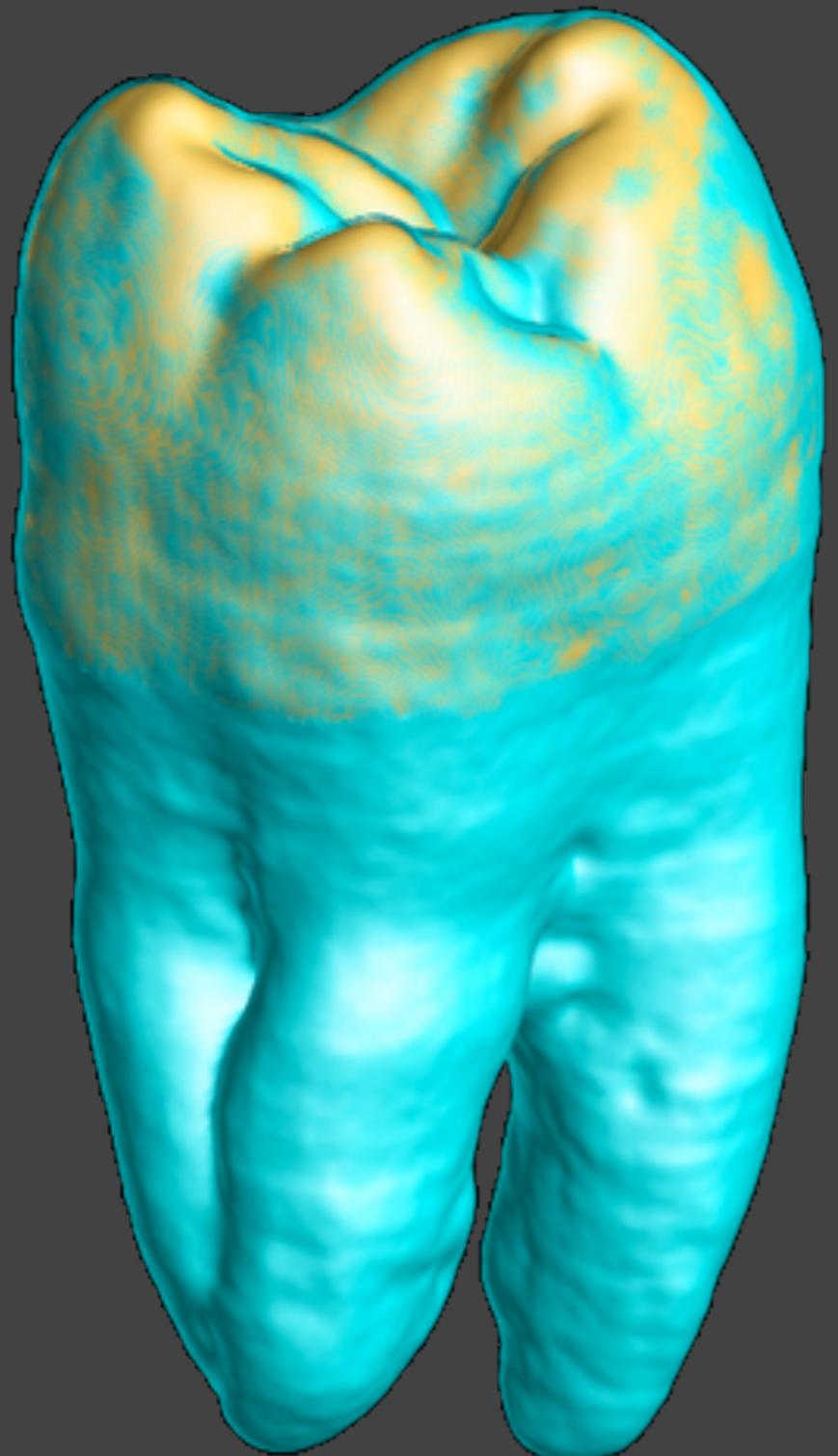
2D → 3D Transfer Function



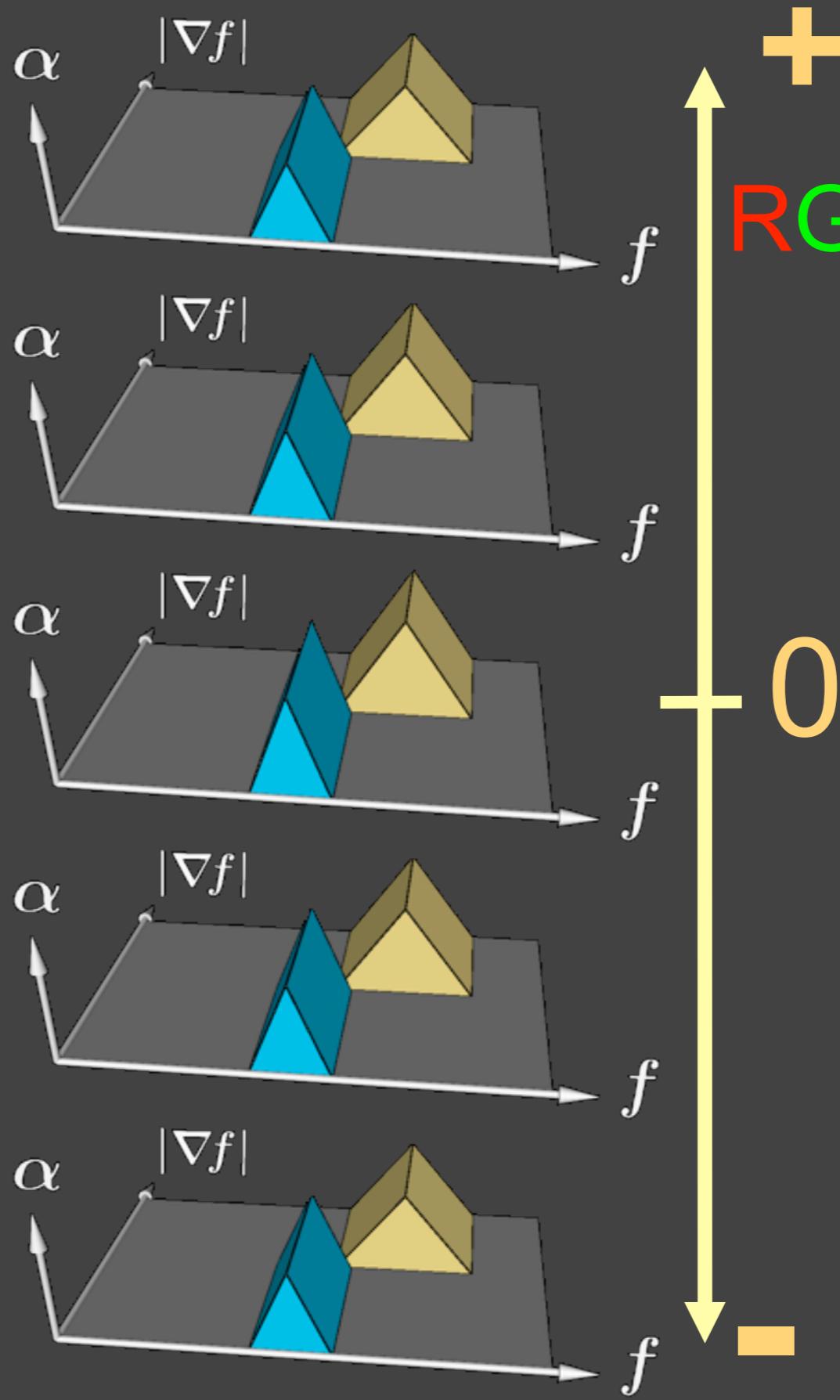
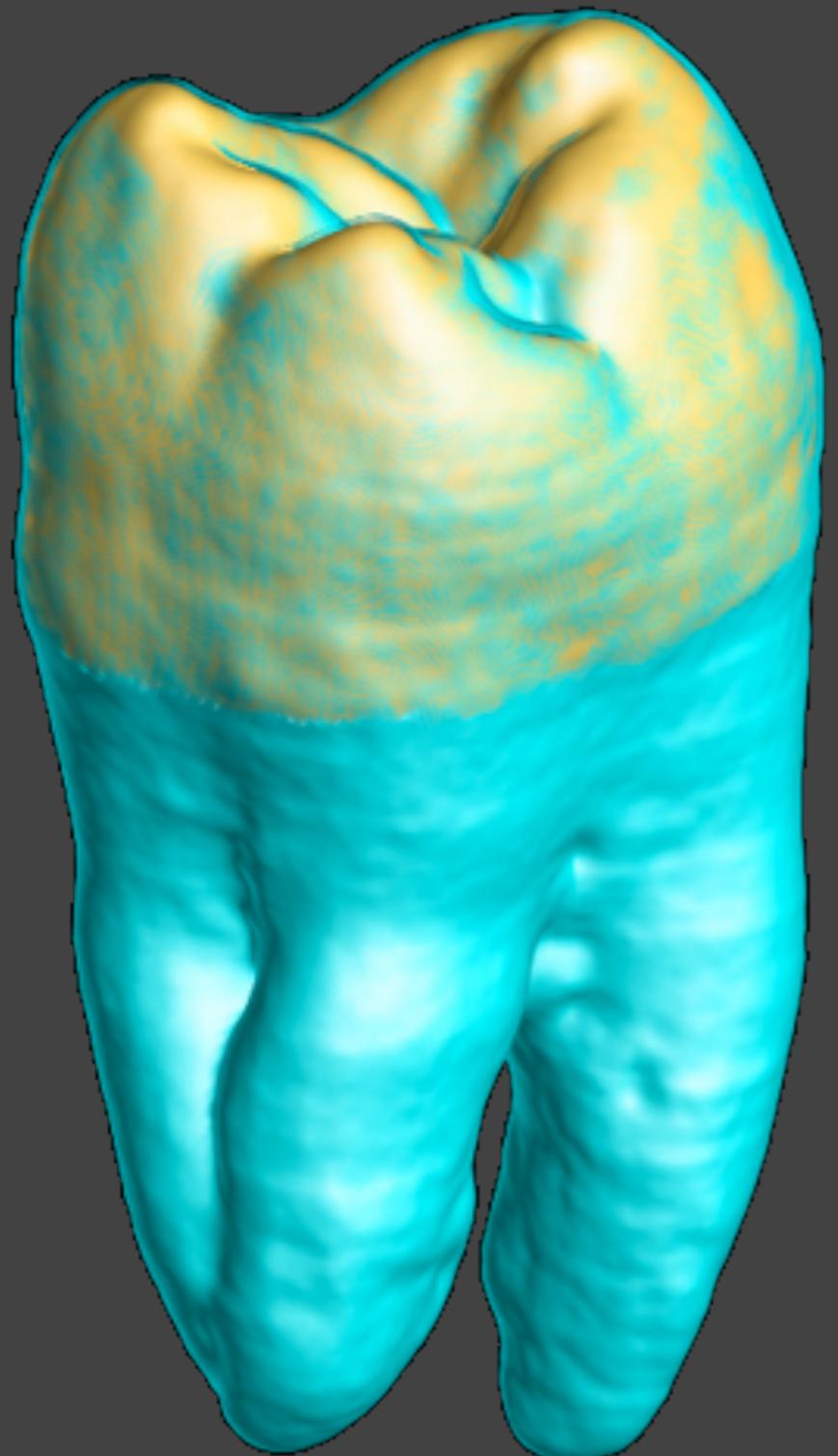
Second
directional
derivative

$D^2 \widehat{\nabla} f f$
measured with
Hessian

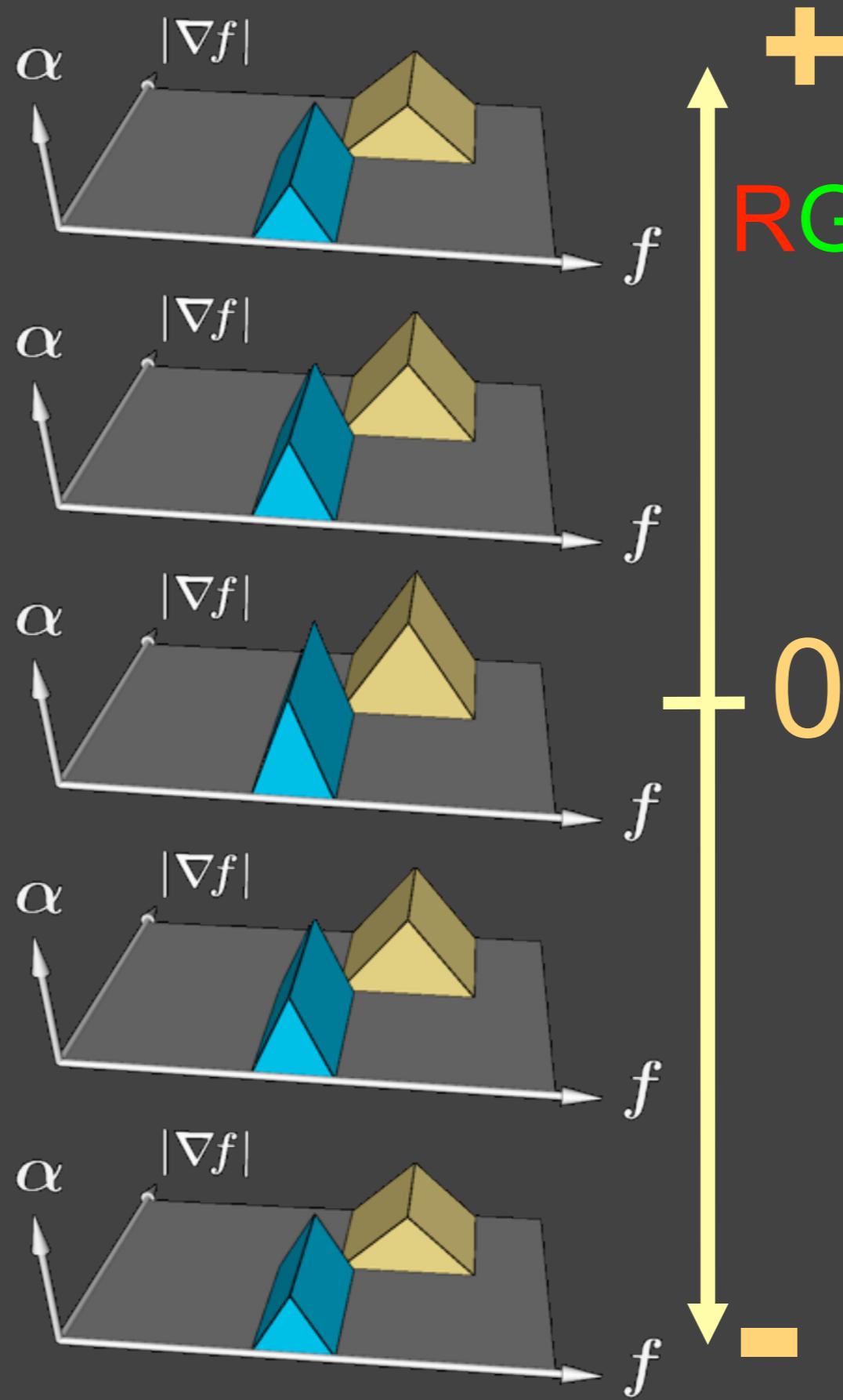
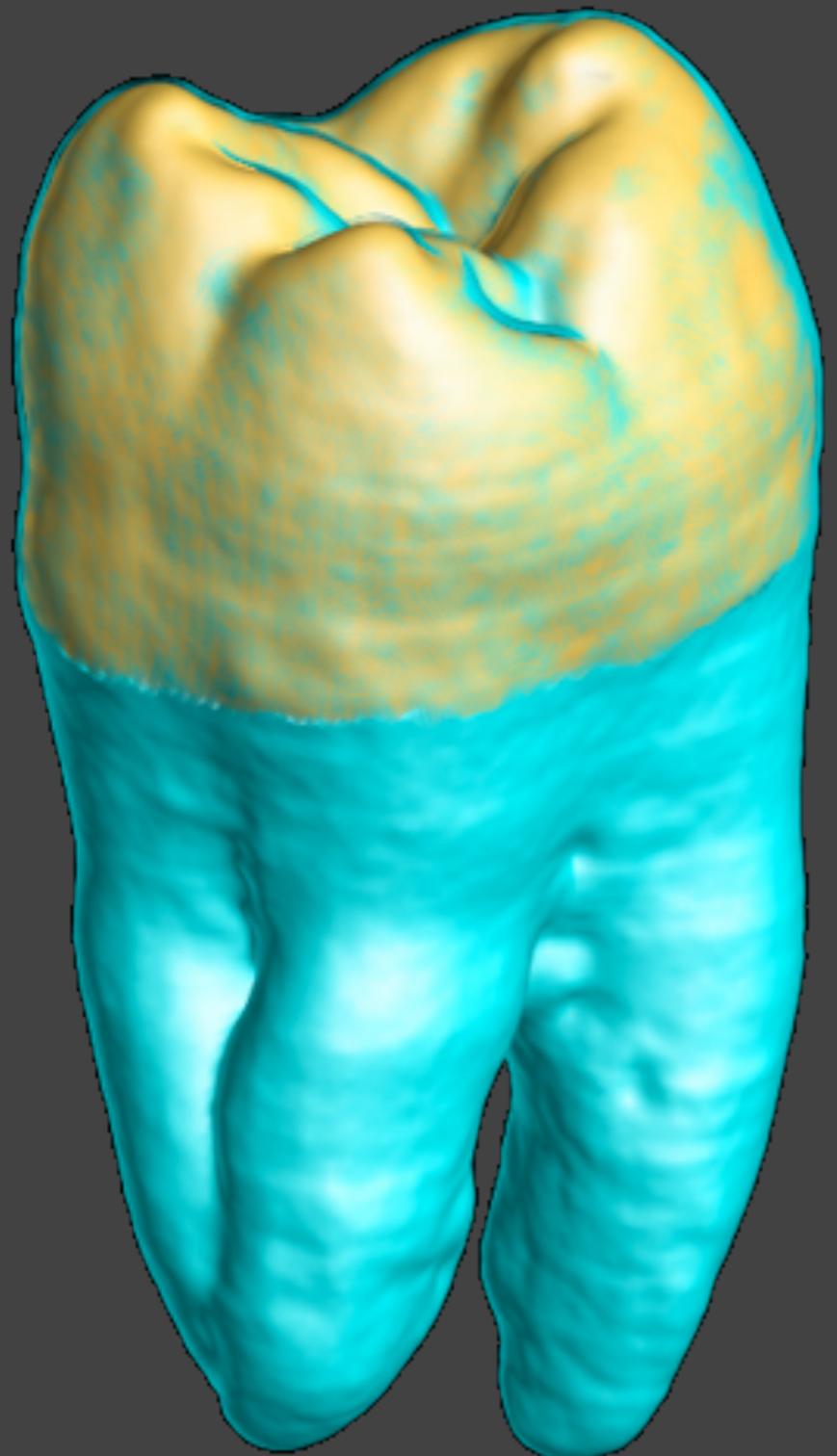
3D Transfer Function



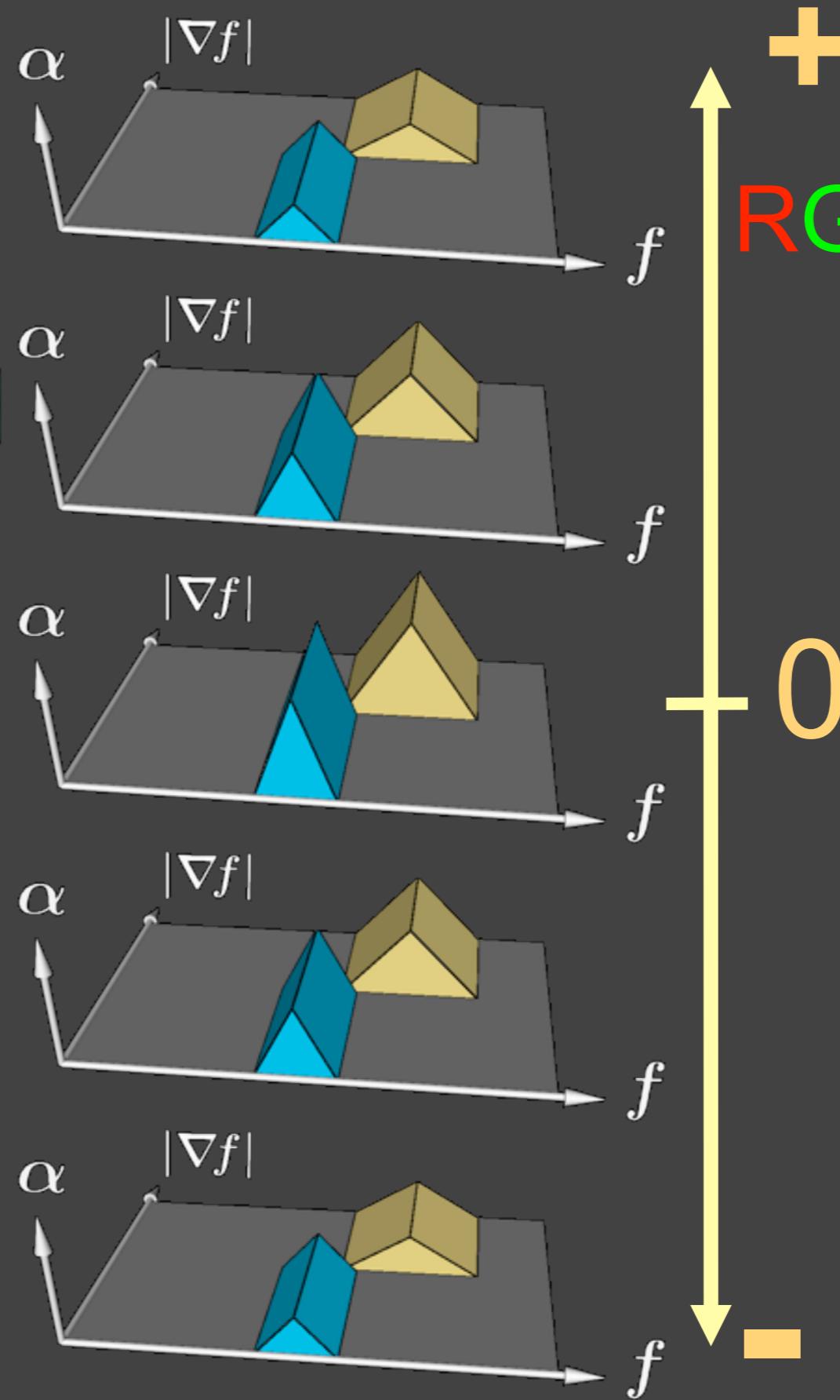
3D Transfer Function



3D Transfer Function



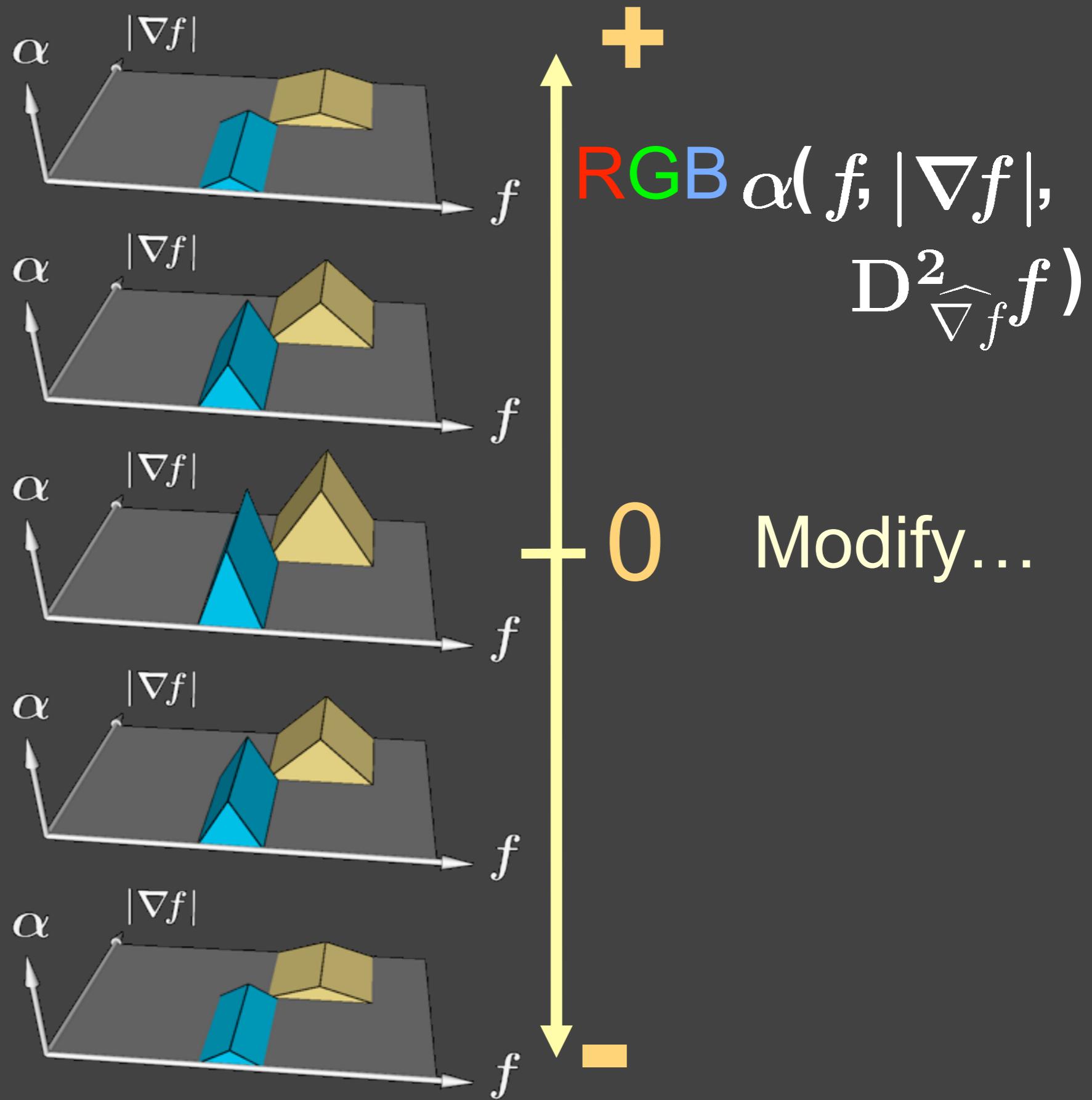
3D Transfer Function



$$+ \text{RGB} \alpha(f, |\nabla f|, D^2 \widehat{\nabla} f)$$

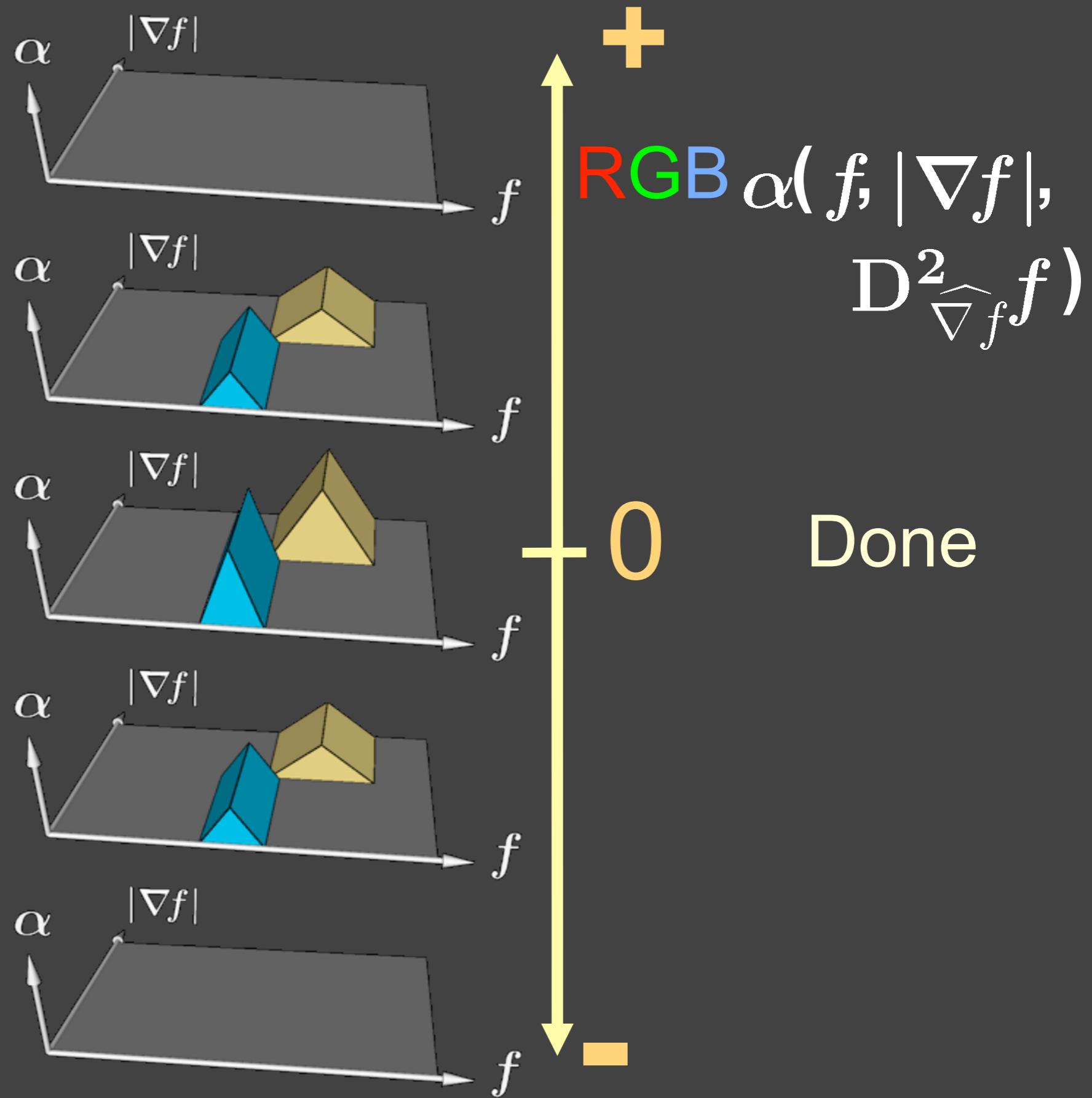
Modify...

3D Transfer Function

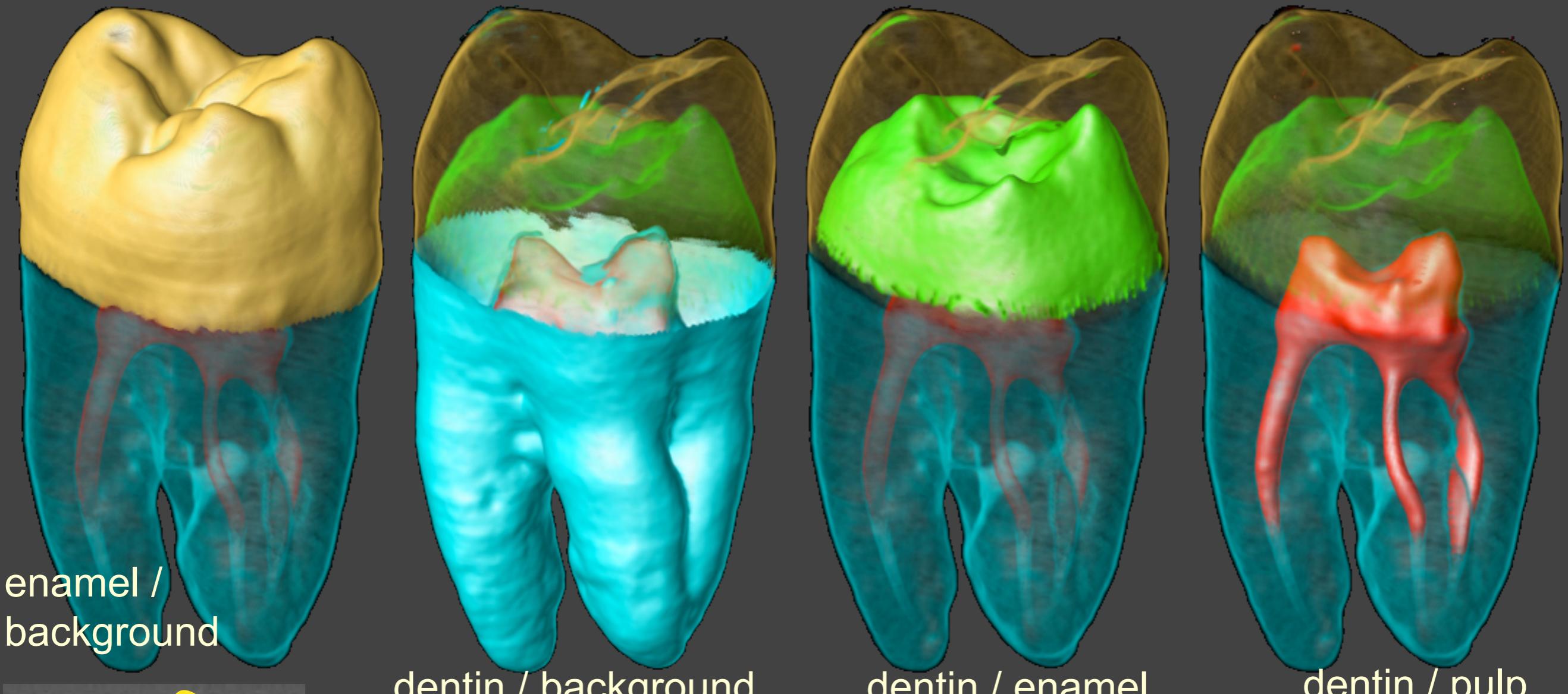


Modify...

3D Transfer Function



3D Transfer Function

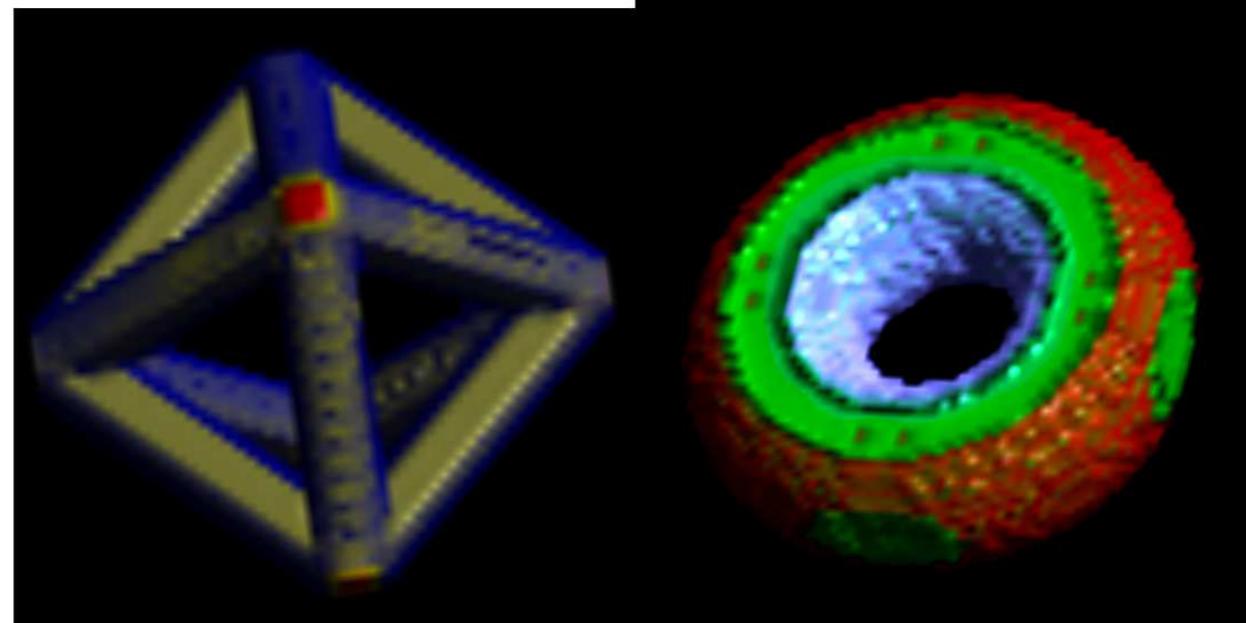
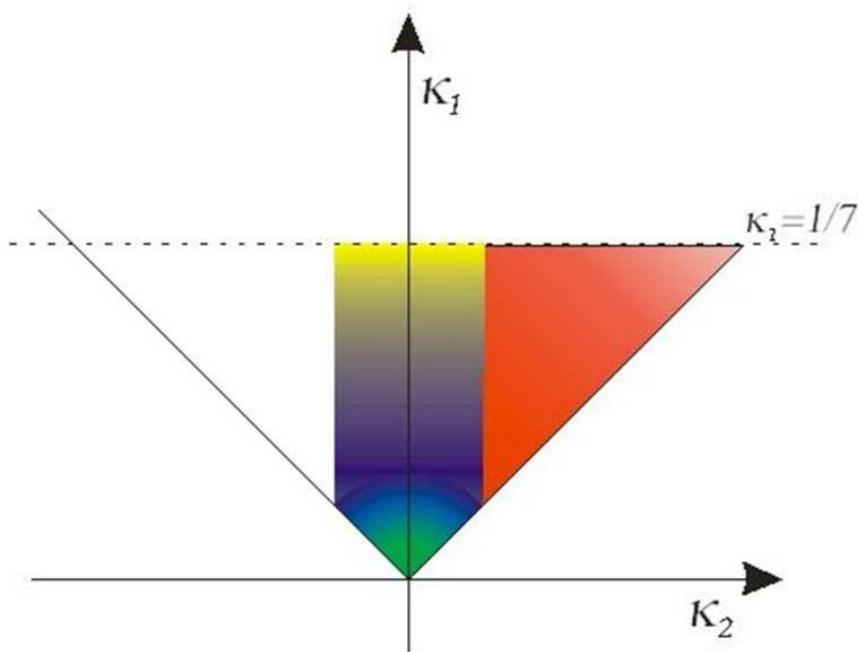
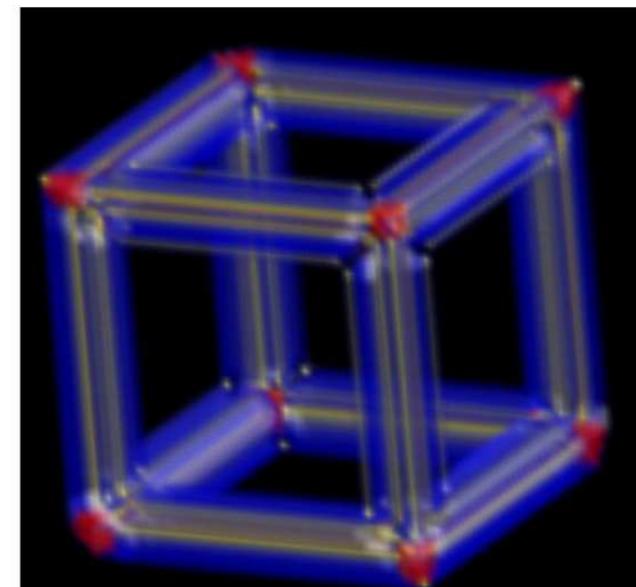


1D: not possible
2D: specificity not as good

Curvature

“Curvature-Based Transfer Functions for Direct Volume Rendering”, Hladuvka, König, Gröller: SCCG ’00

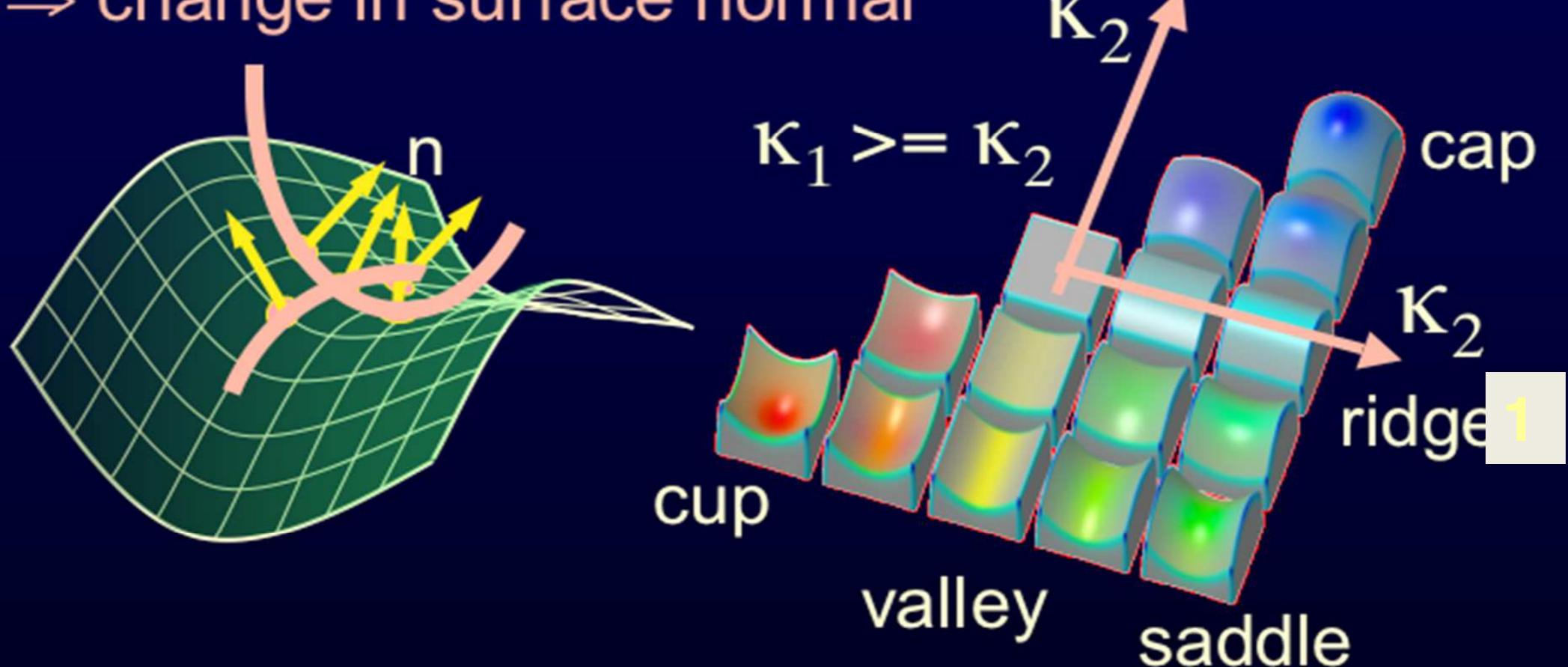
- Uses 2D space of K_1 and K_2 : principal curvatures of isosurface at a given point
- Graphically indicates aspects of local shape
- Specification is simple



Curvature

What is curvature

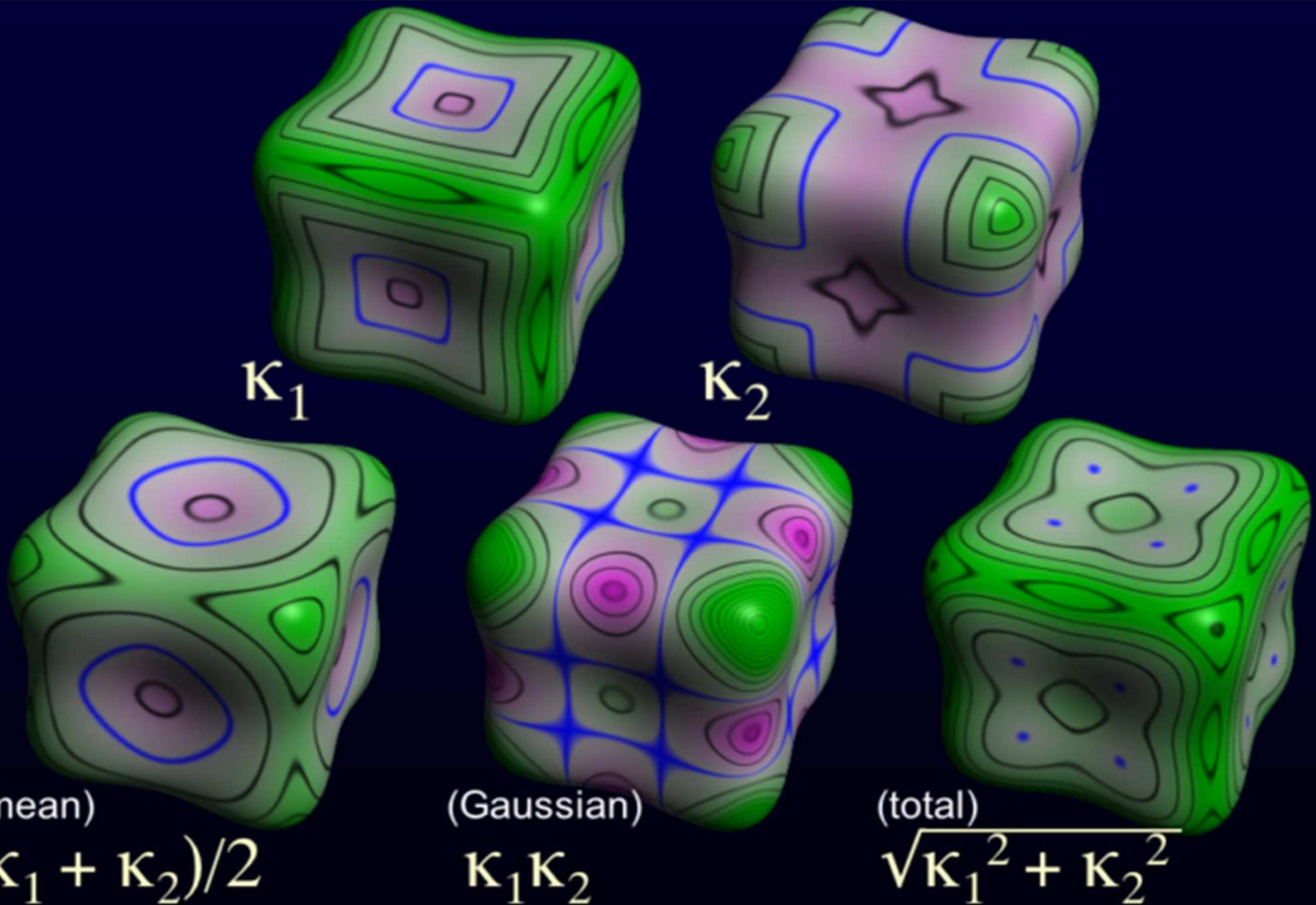
Small movements along the surface
⇒ change in surface normal



Principal curvature magnitudes

Principal curvature directions

Curvature measures



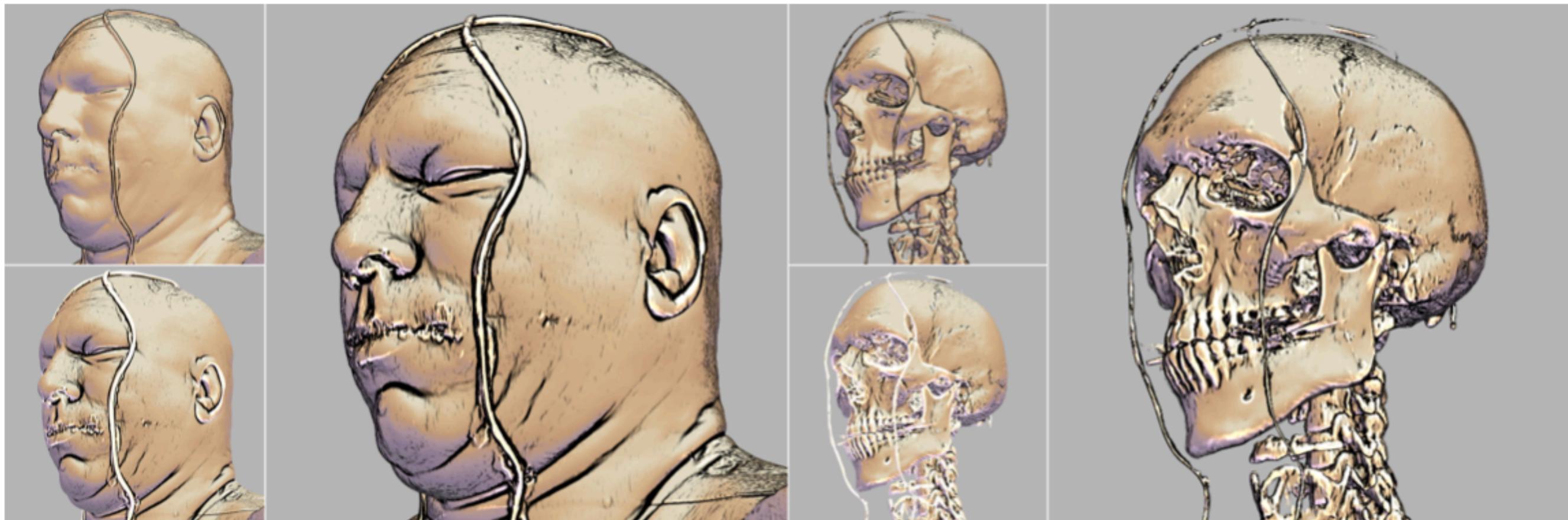


Figure 9: Curvature-based non-photorealistic volume rendering. The two small images depict the contribution of thickness-controlled contours (top) and ridge and valley emphasis (bottom). The large images show the combination of the two effects.

Curvature-Based Transfer Functions for Direct Volume Rendering: Methods and Applications

Gordon Kindlmann¹

Ross Whitaker¹

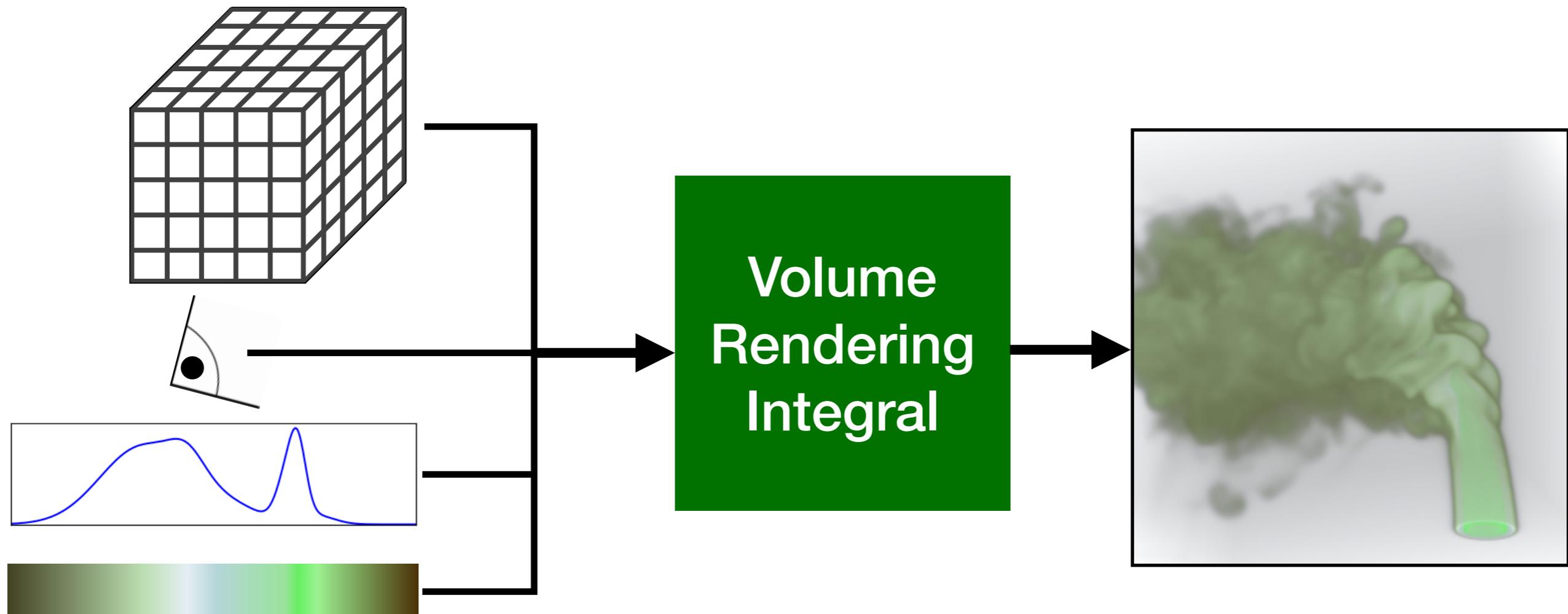
Tolga Tasdizen¹

Torsten Möller²

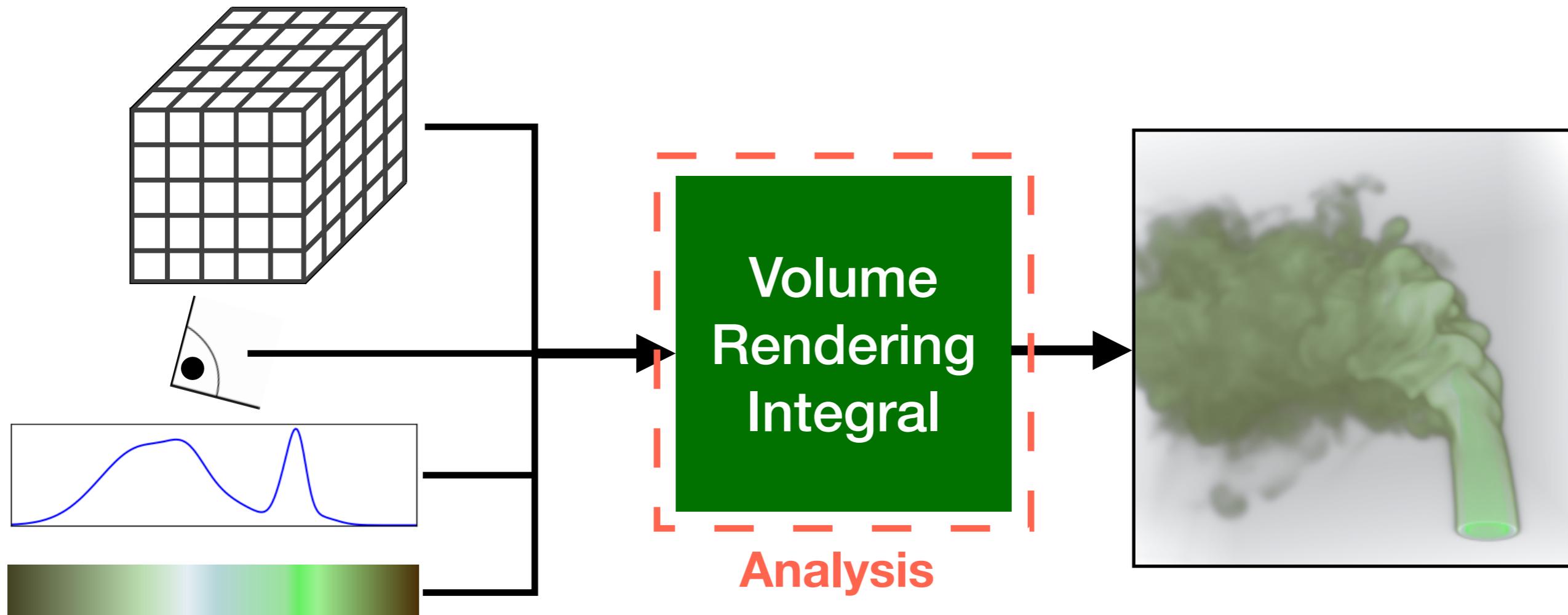
TF Techniques/Tools

- 1. Trial and Error**
- 2. Data-Centric Approach**
- 3. Image-Centric Approach**

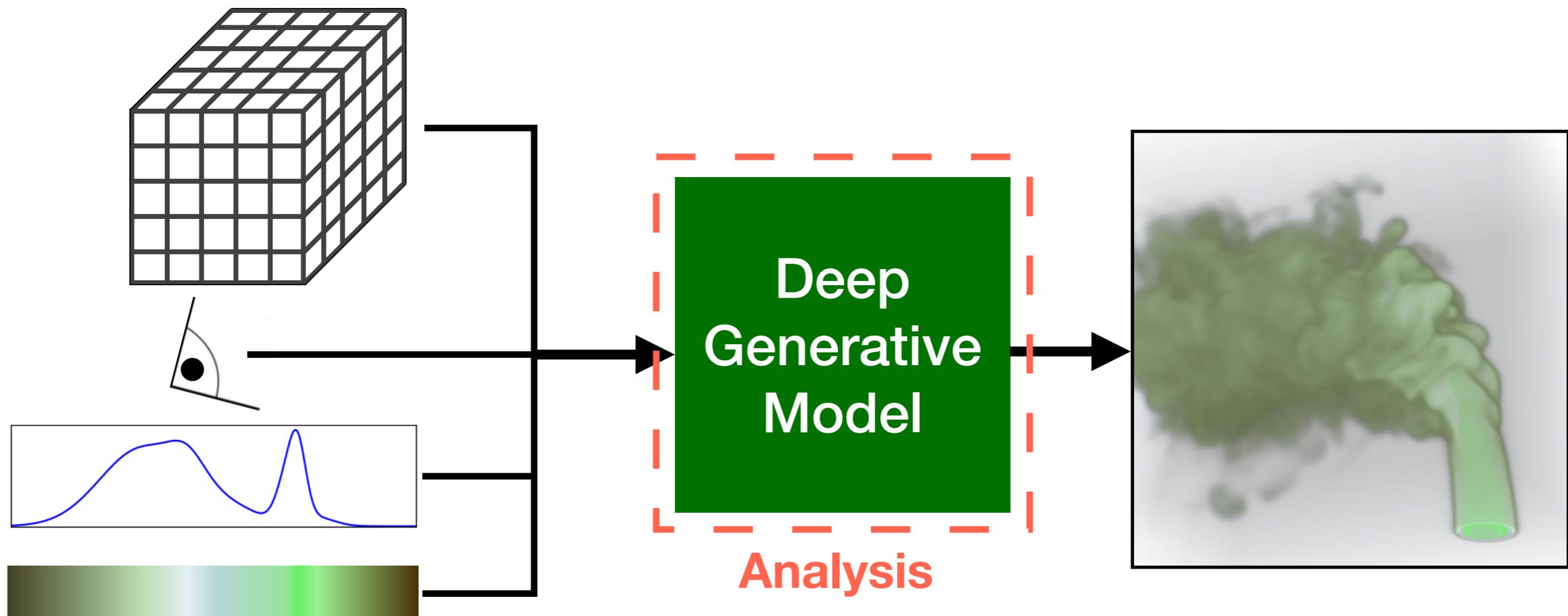
Process of Volume Rendering



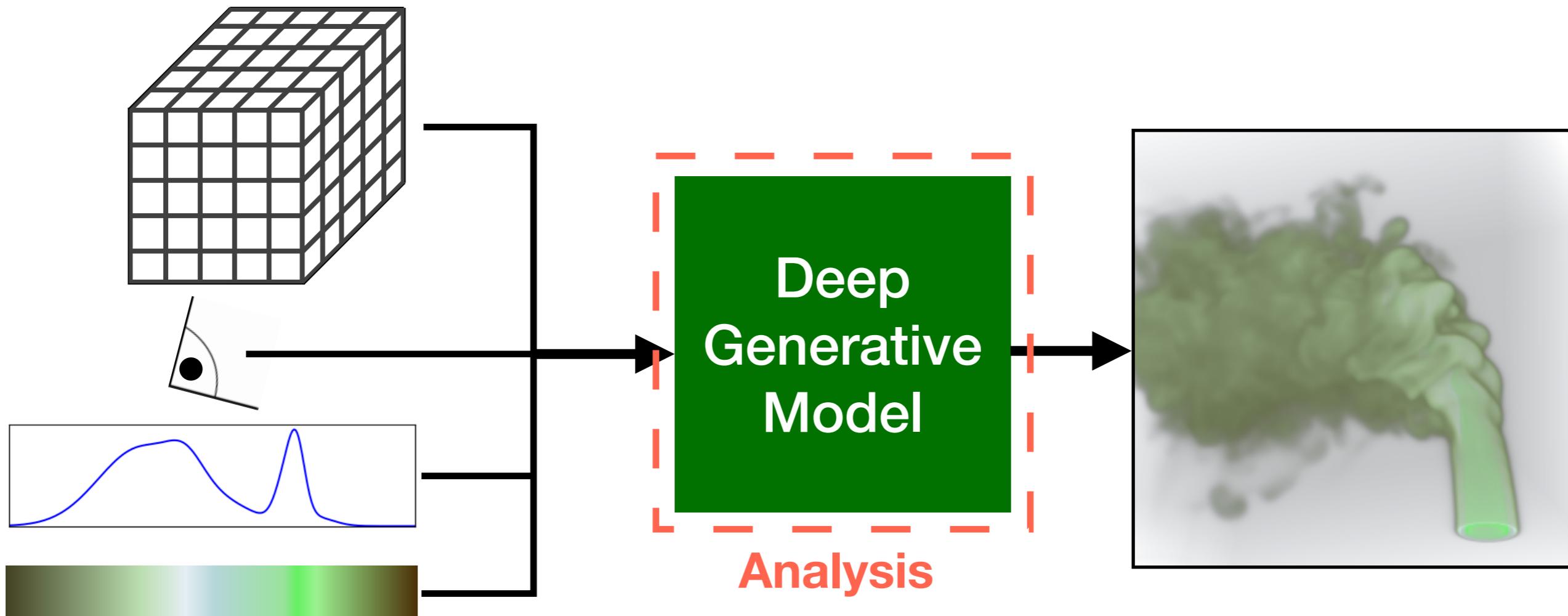
Process of Volume Rendering



Process of Volume Rendering



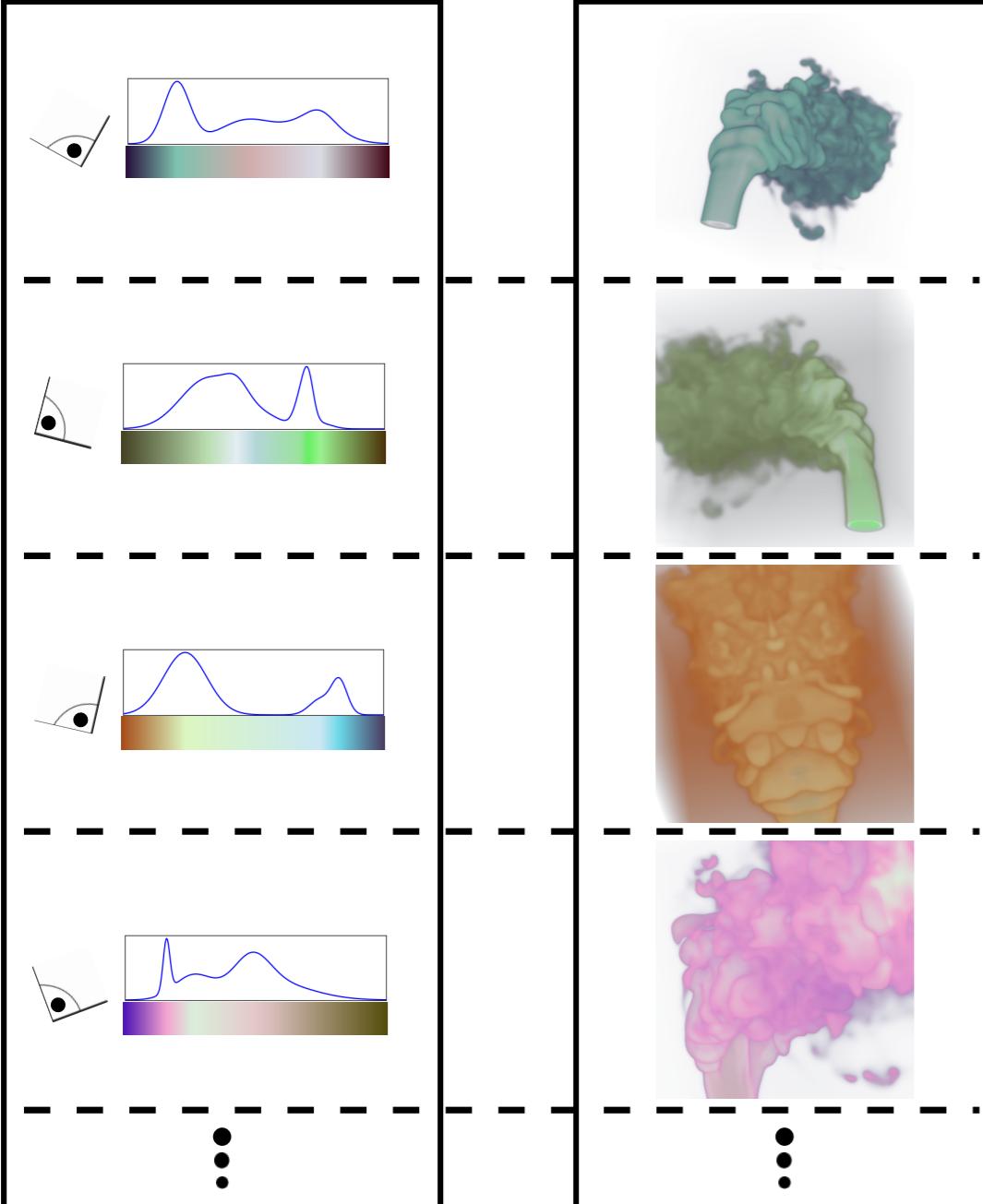
Process of Volume Rendering



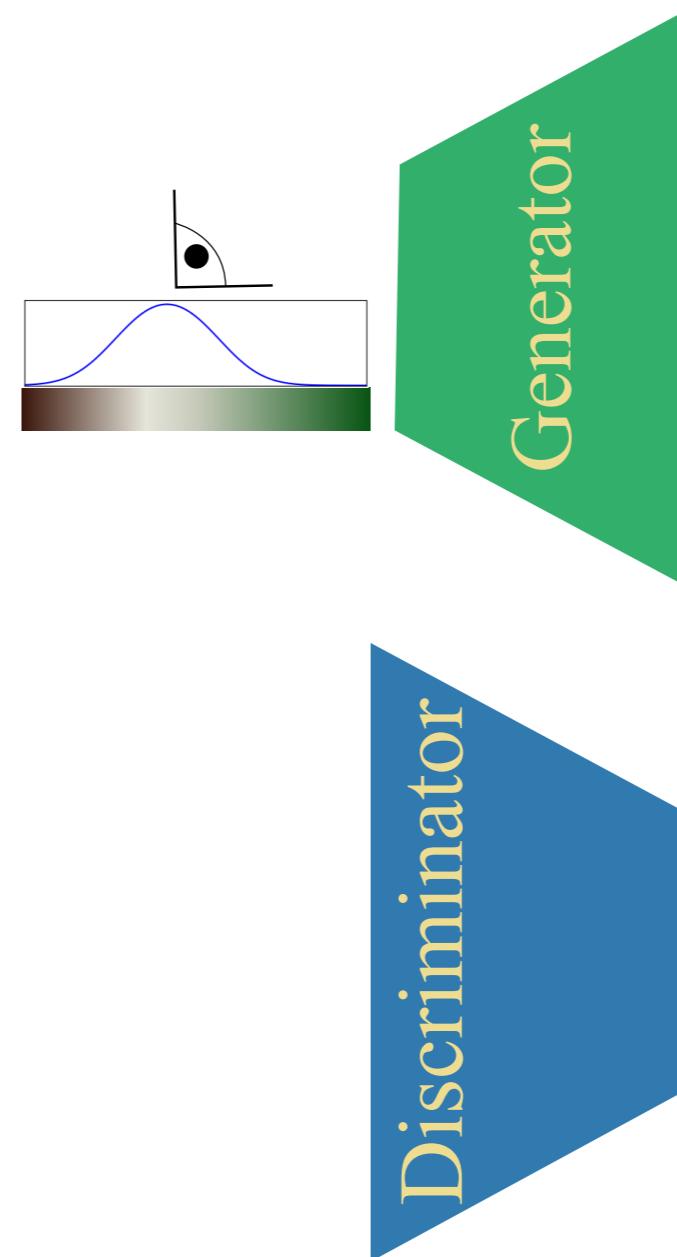
Can analysis on the volume rendering process give information to the user about the volume?

Using a Generative Model for Volume Rendering

Volume Rendered Images and Parameters



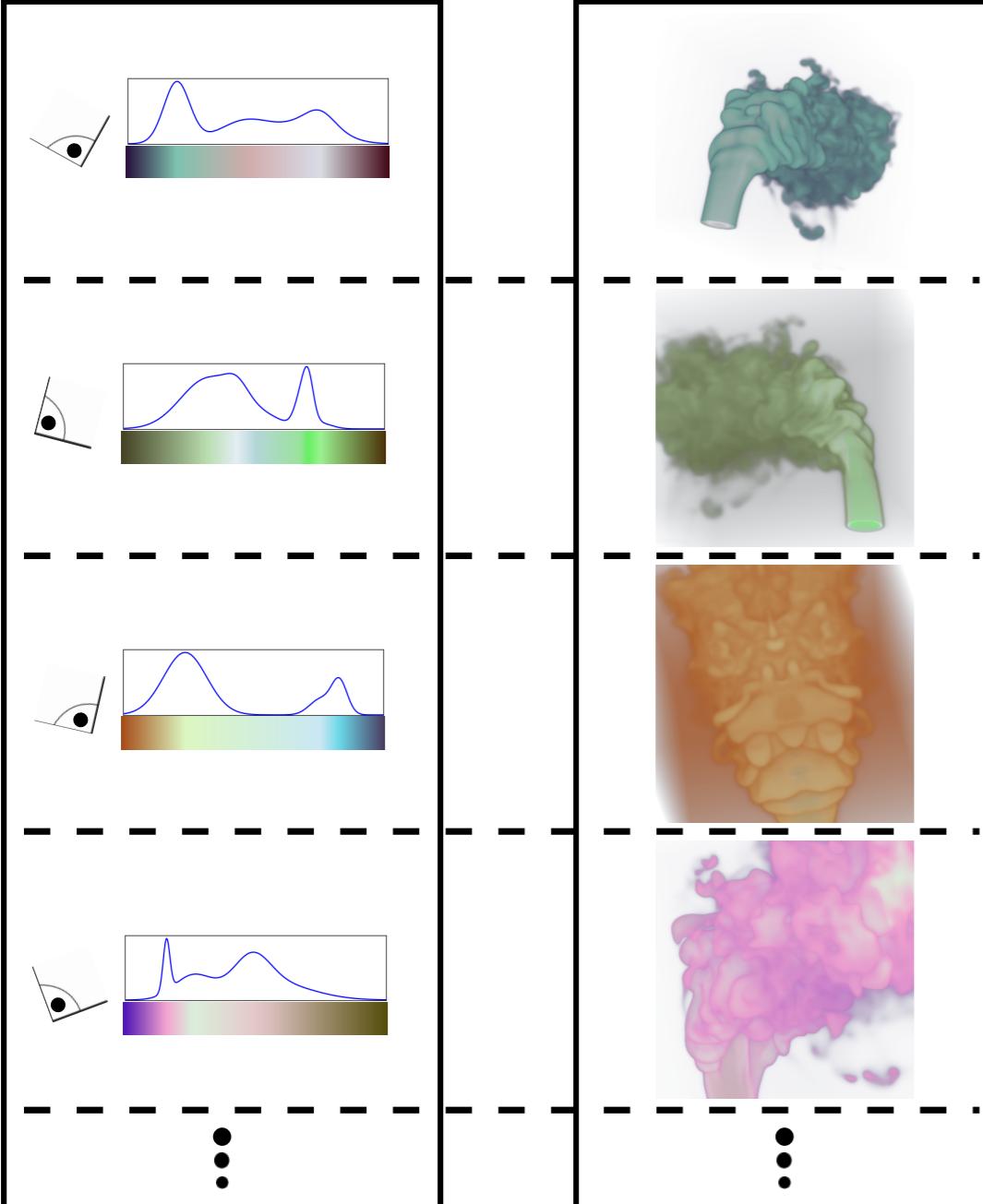
Generative Adversarial Network [Goodfellow et al. 2014]



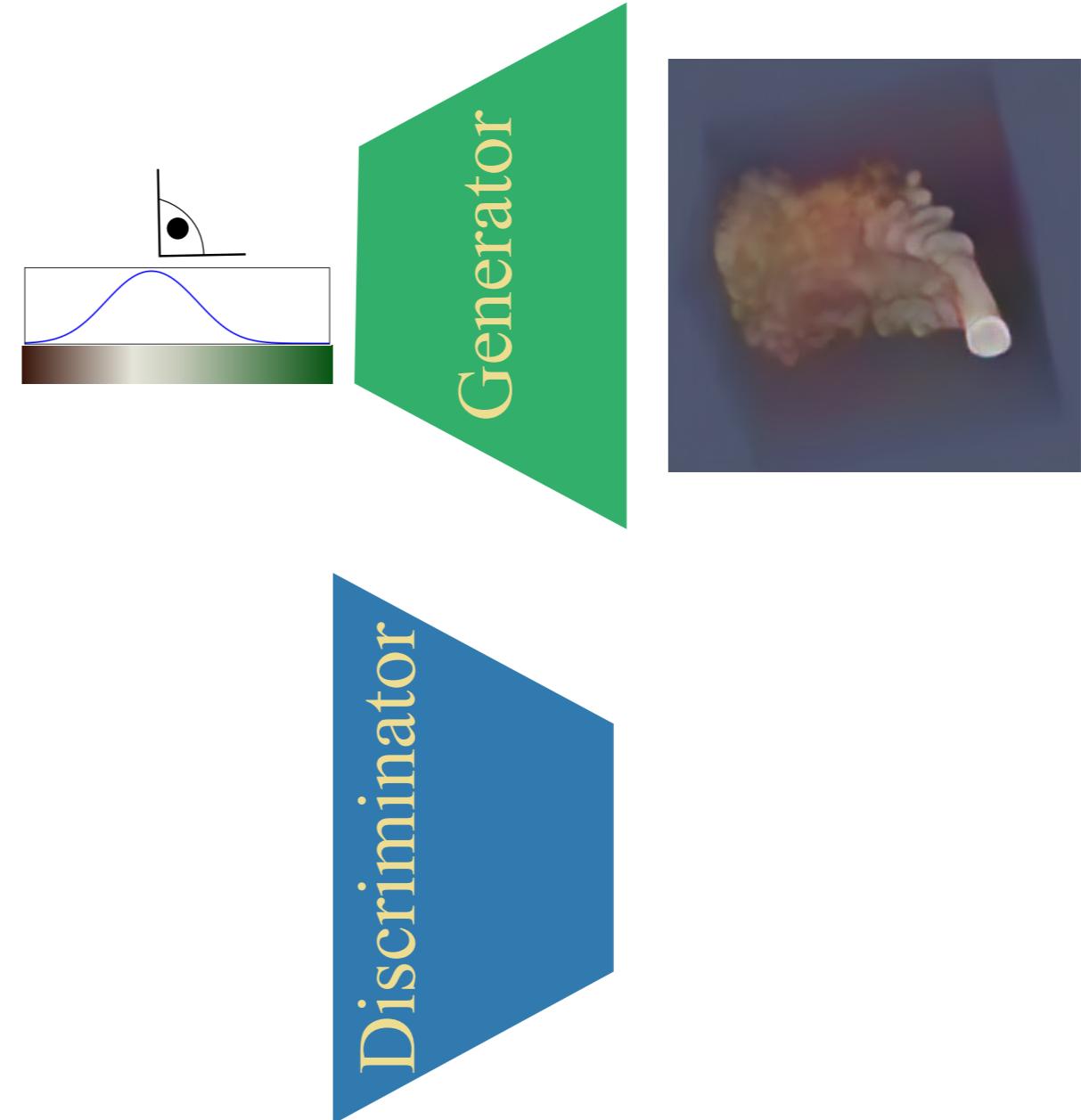
- Update generator until discriminator cannot determine real from fake

Using a Generative Model for Volume Rendering

Volume Rendered Images and Parameters



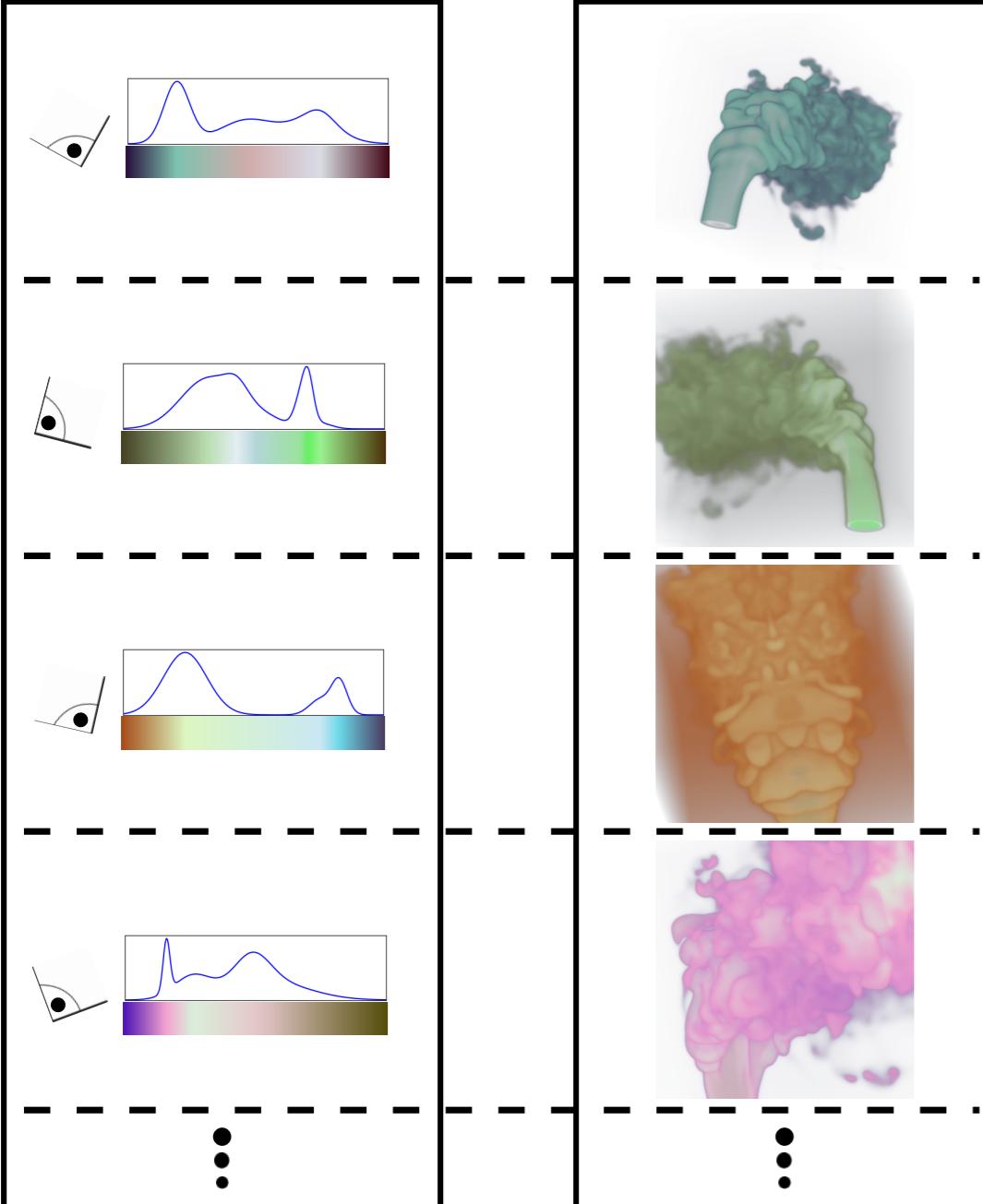
Generative Adversarial Network [Goodfellow et al. 2014]



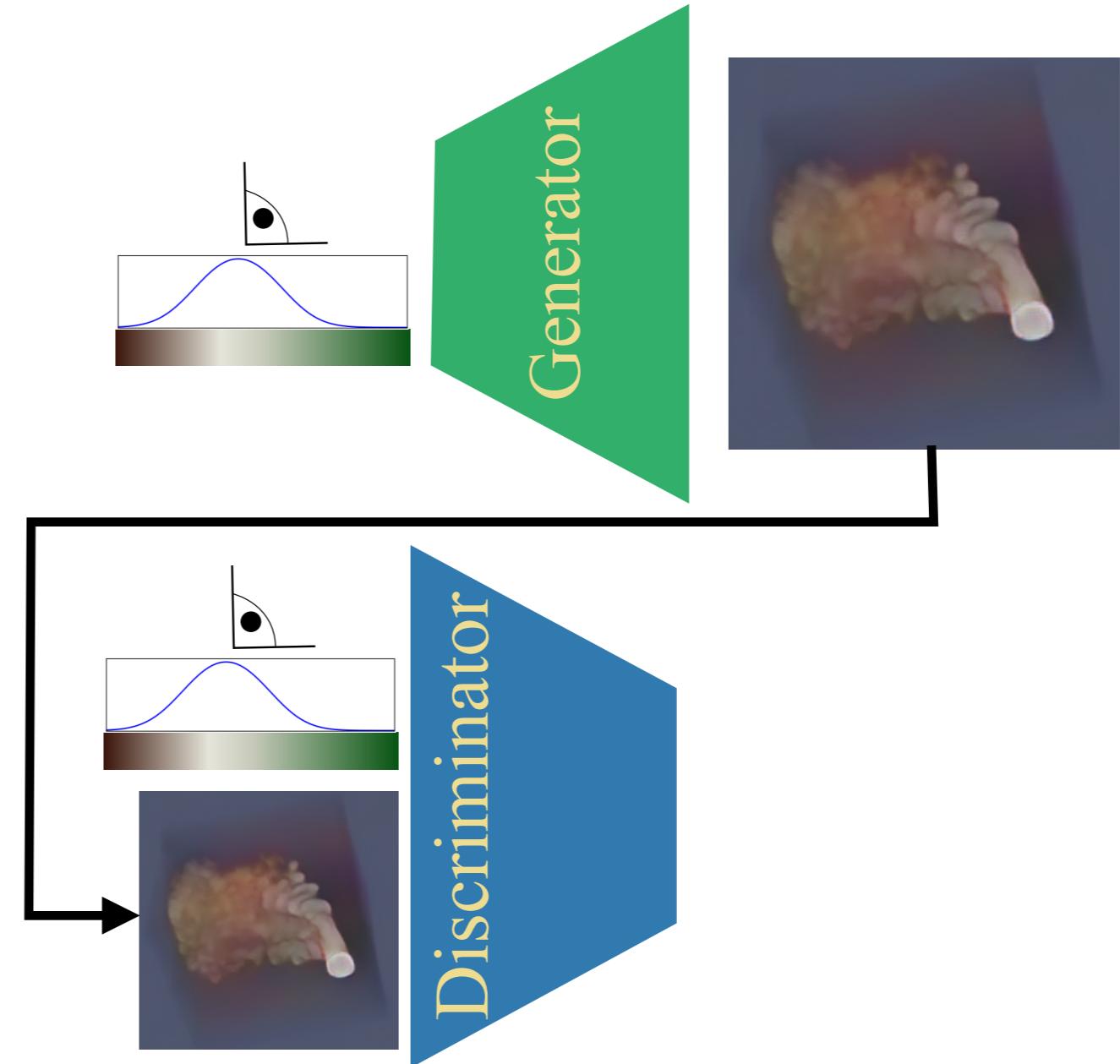
- Update generator until discriminator cannot determine real from fake

Using a Generative Model for Volume Rendering

Volume Rendered Images and Parameters



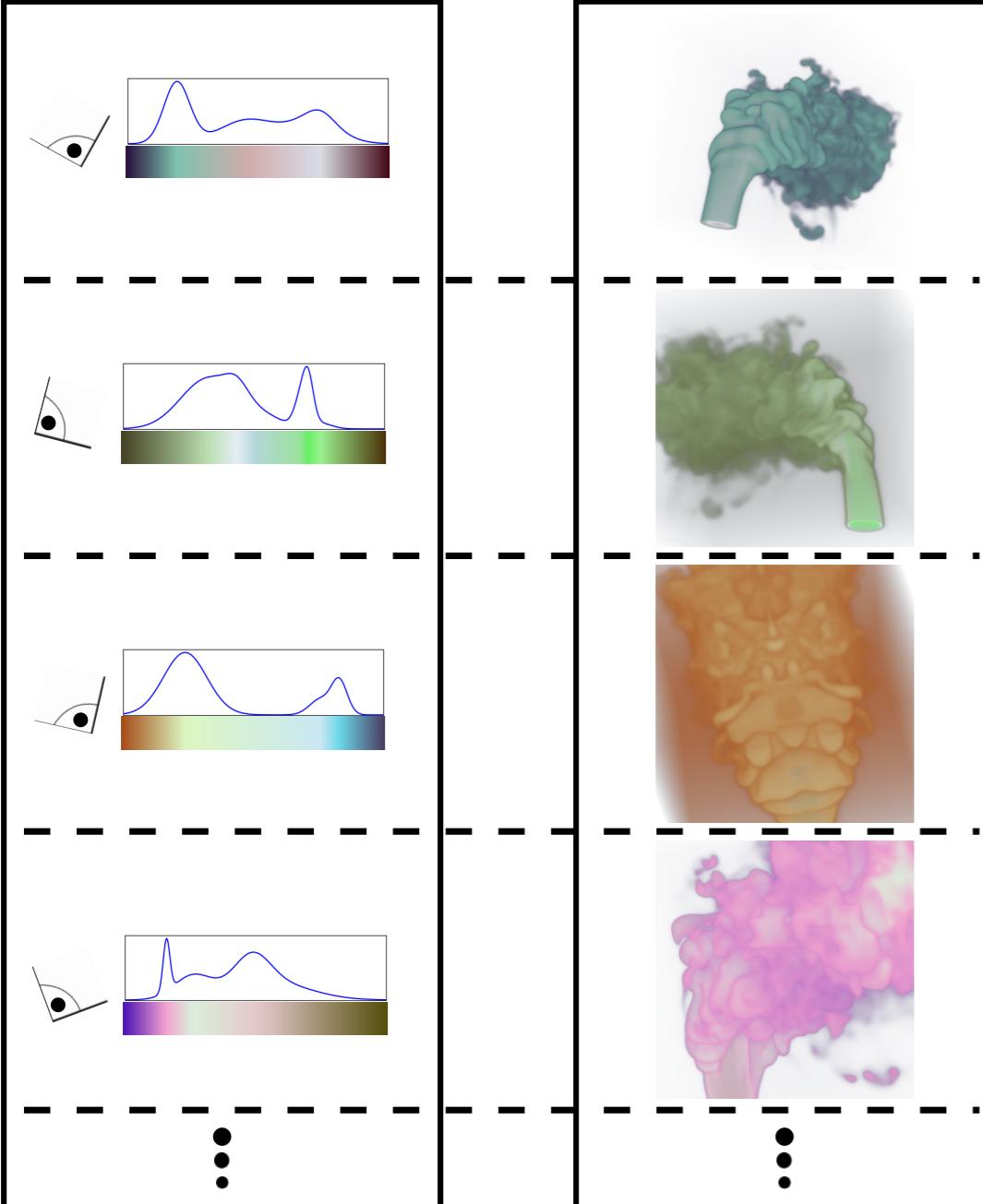
Generative Adversarial Network [Goodfellow et al. 2014]



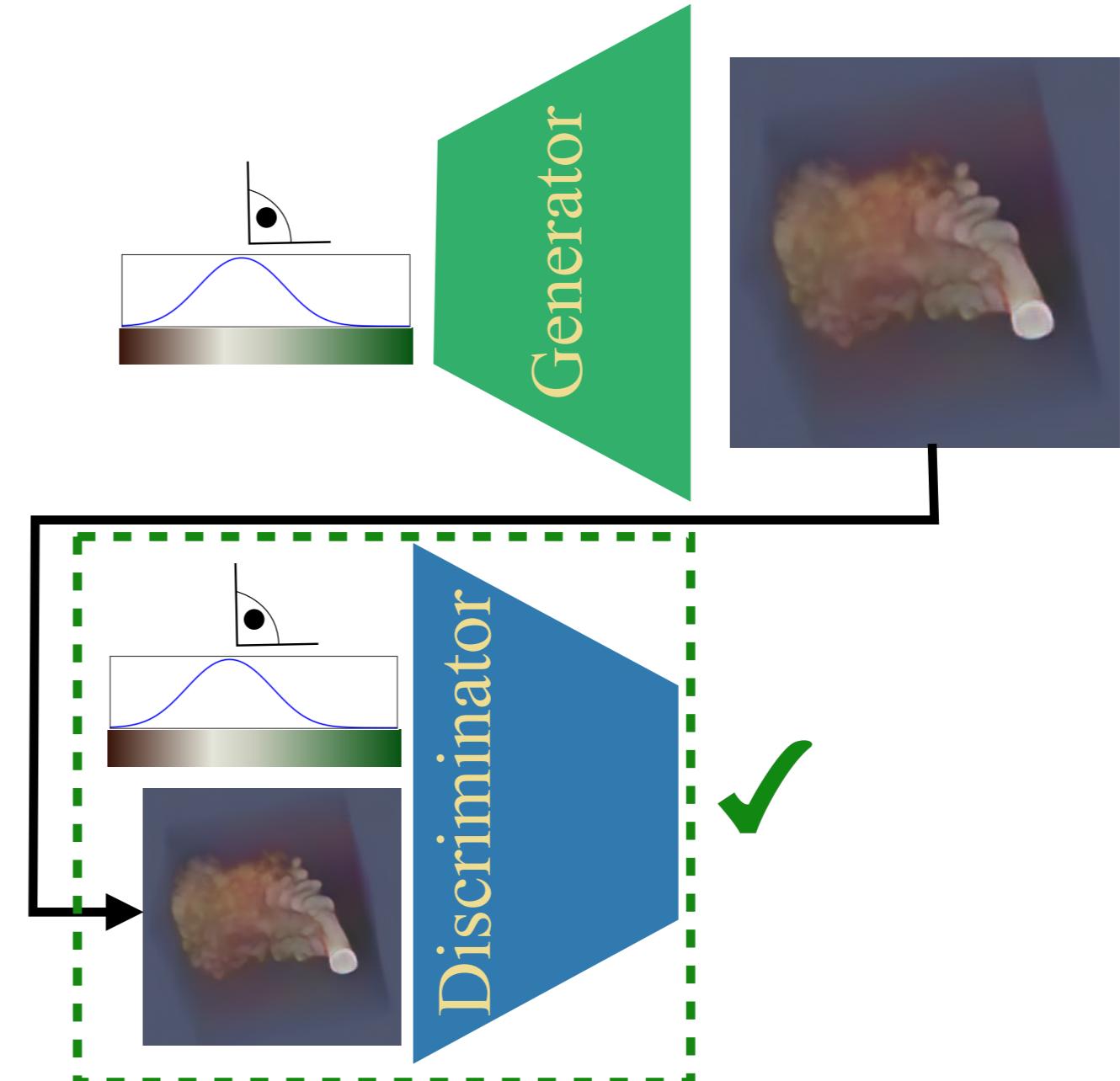
- Update generator until discriminator cannot determine real from fake

Using a Generative Model for Volume Rendering

Volume Rendered Images and Parameters



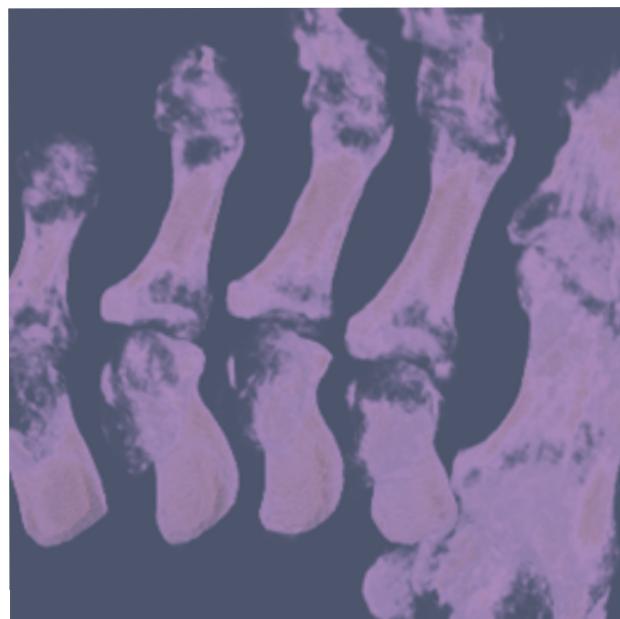
Generative Adversarial Network [Goodfellow et al. 2014]



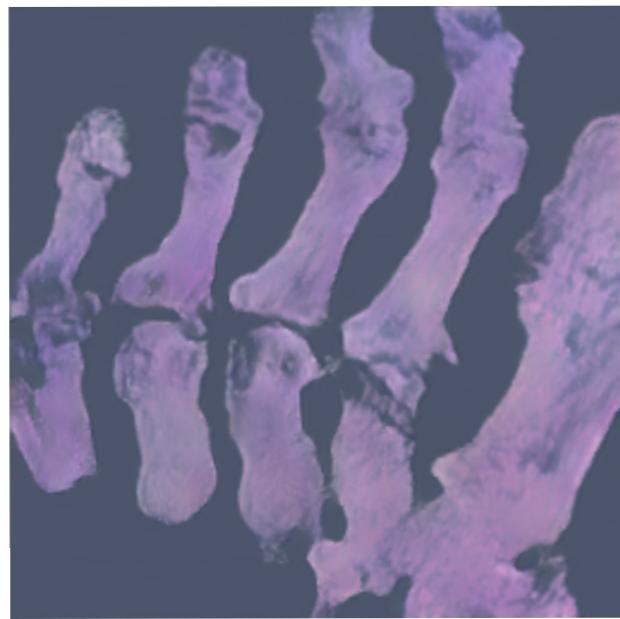
- Update generator until discriminator cannot determine real from fake

Qualitative Results

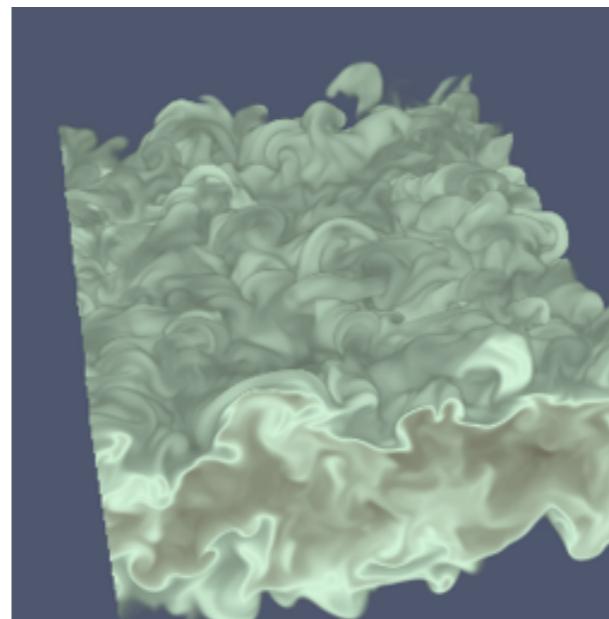
Ground Truth



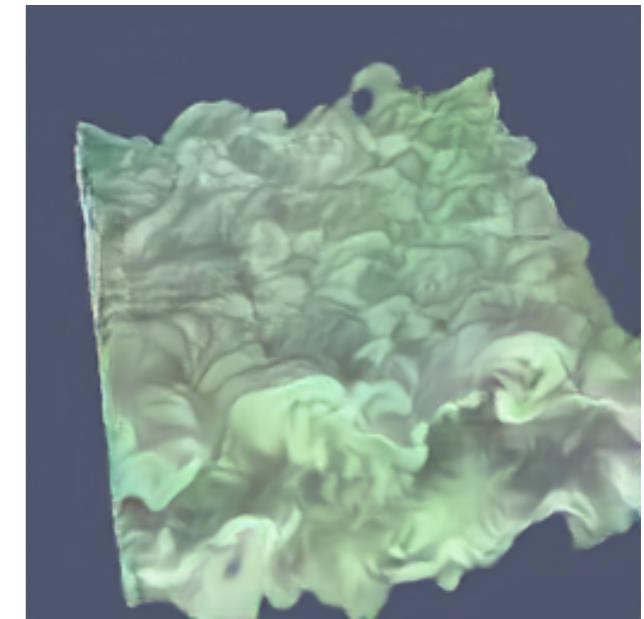
Synthesized



Ground Truth



Synthesized



Ground Truth



Synthesized



Ground Truth

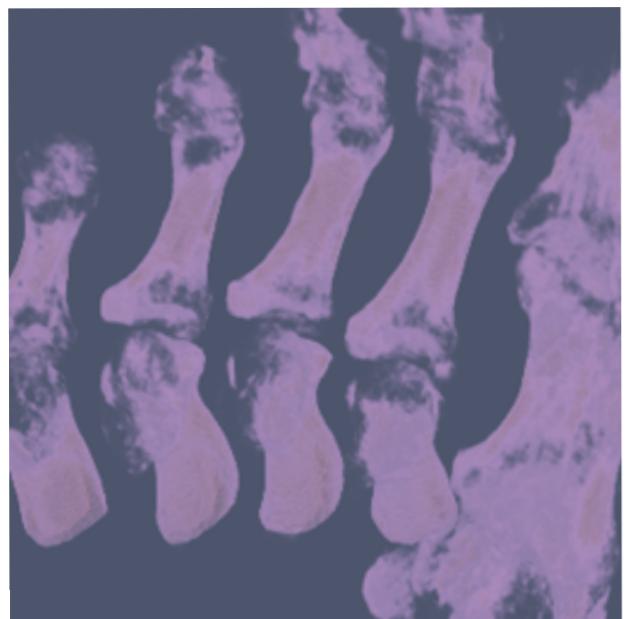


Synthesized

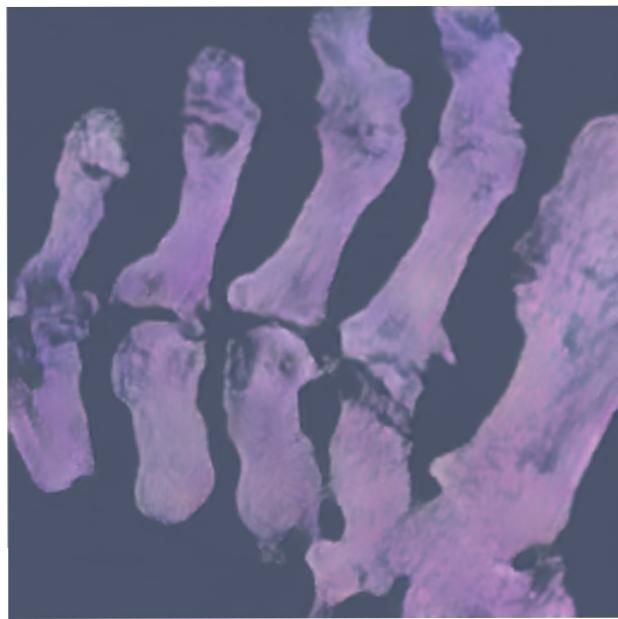


Qualitative Results

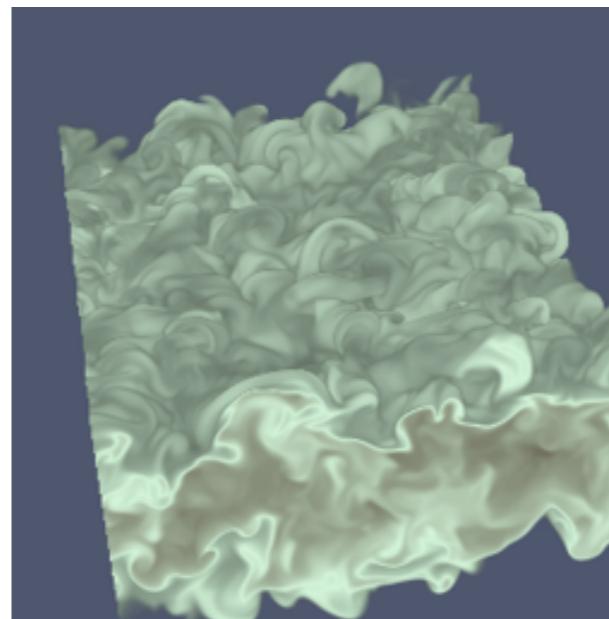
Ground Truth



Synthesized



Ground Truth



Synthesized



Ground Truth



Synthesized



Ground Truth

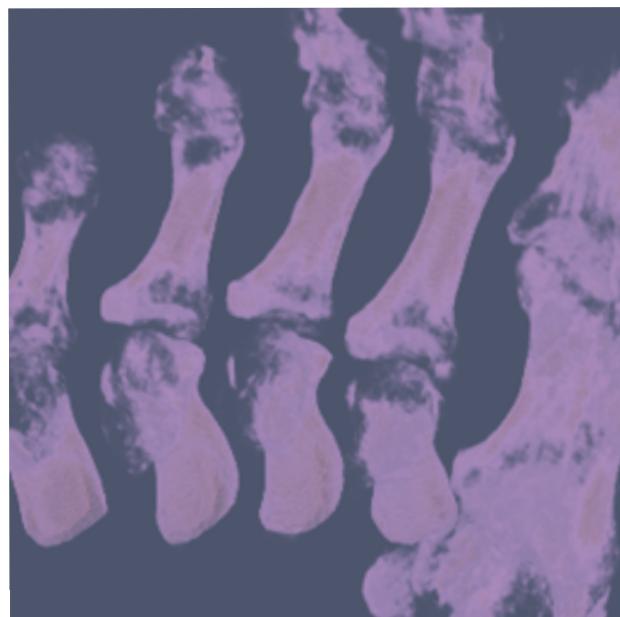


Synthesized

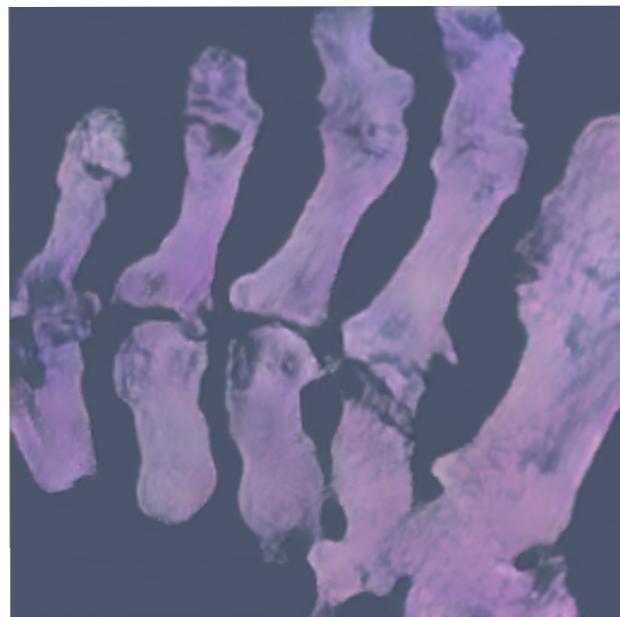


Qualitative Results

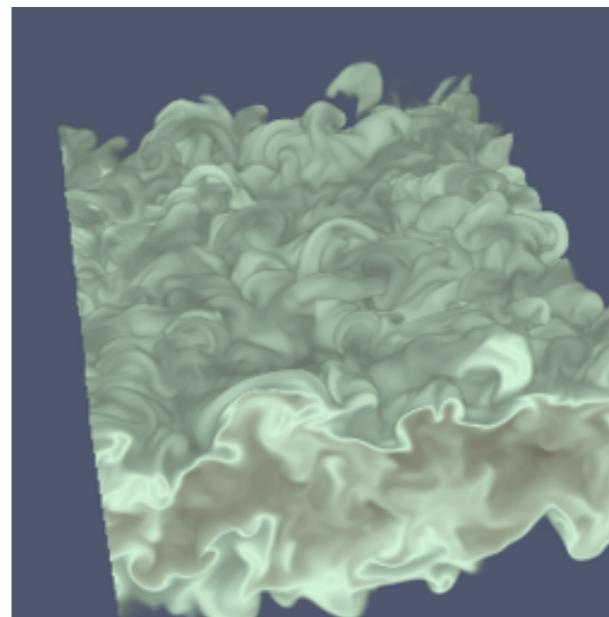
Ground Truth



Synthesized



Ground Truth



Synthesized



Ground Truth



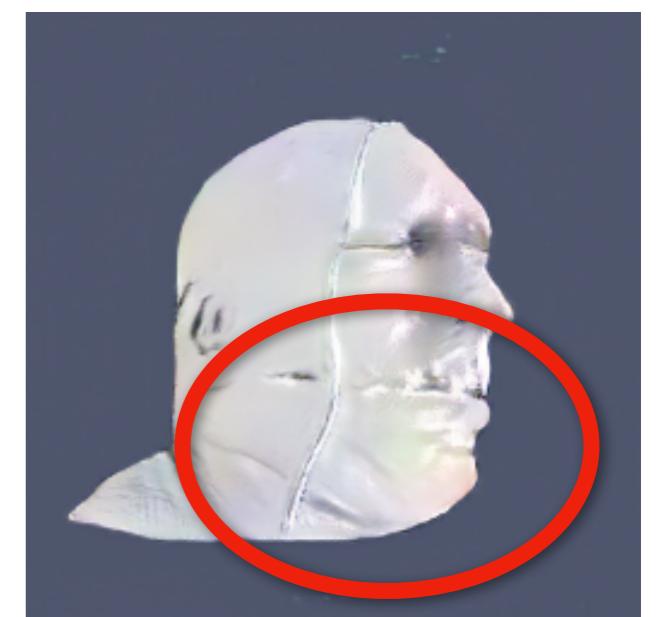
Synthesized



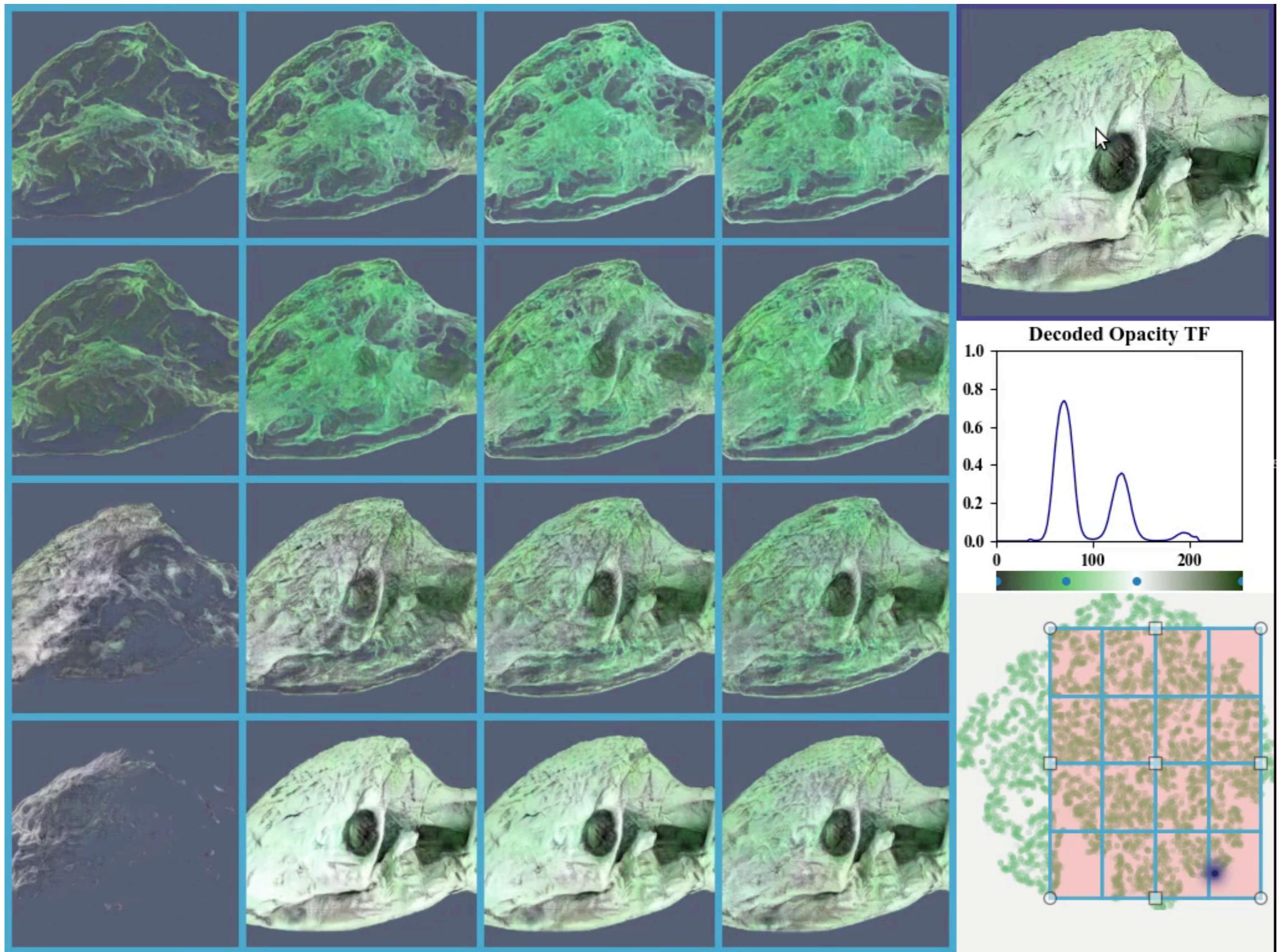
Ground Truth



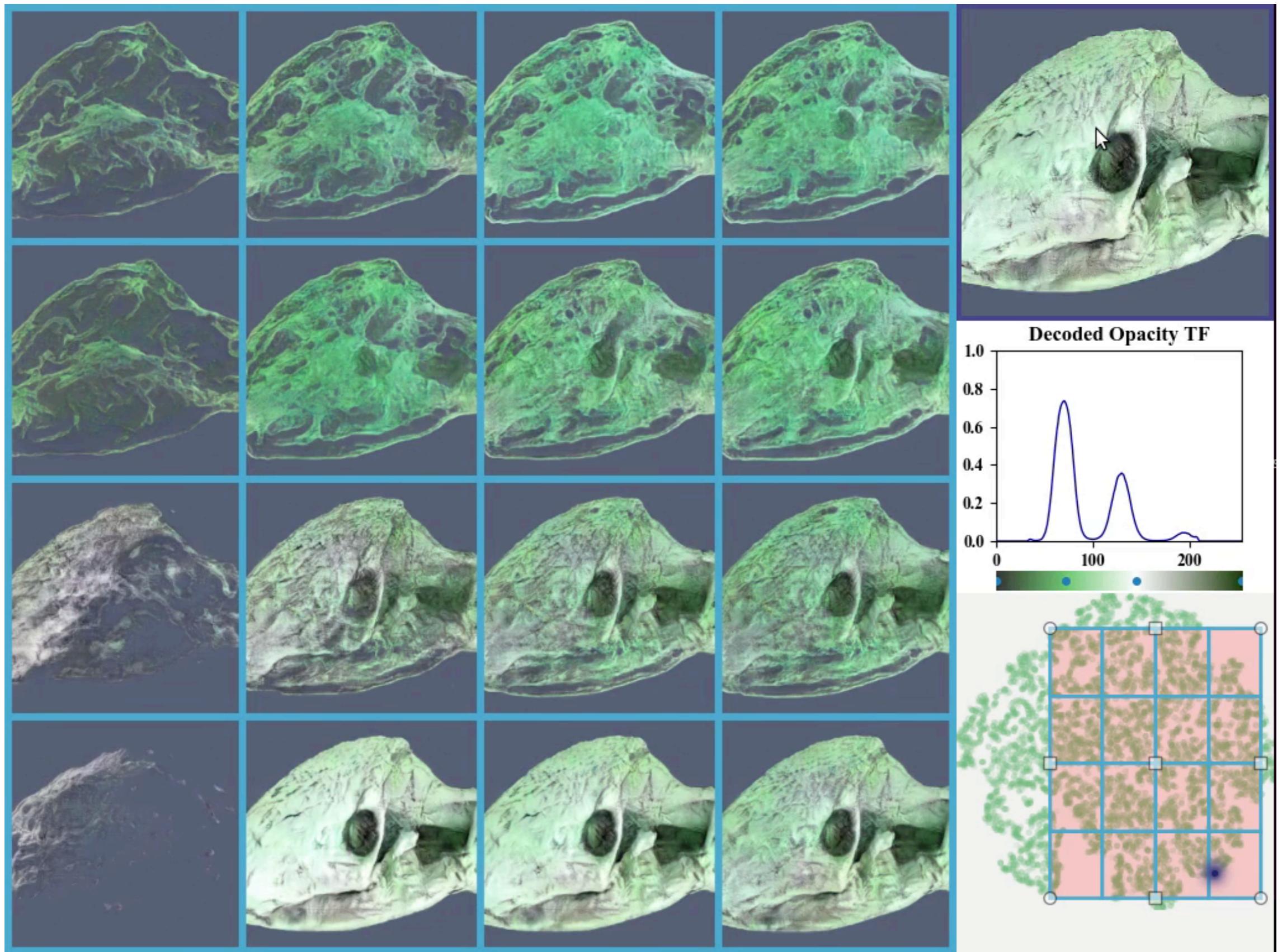
Synthesized



Volume Exploration w/ Latent Spaces



Volume Exploration w/ Latent Spaces



Lec21 Reading

- The contour spectrum. Chandrajit L. Bajaj, Valerio Pascucci, Daniel Schikore. IEEE Visualization 1997: 167-174

Reminder

Assignment 05

Assigned: Monday, March 27

Due: Monday, April 10, 4:59:59 pm

Project Milestones 03/04

Assigned: Wednesday, March 29

03 (Talk) Due: Wednesday, April 26, 4:59:59 pm

04 (Report) Due: Wednesday, May 3, 4:59:59 pm