Introduction to Computer Graphics (CS360A)

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Department of Computer Science and Engineering
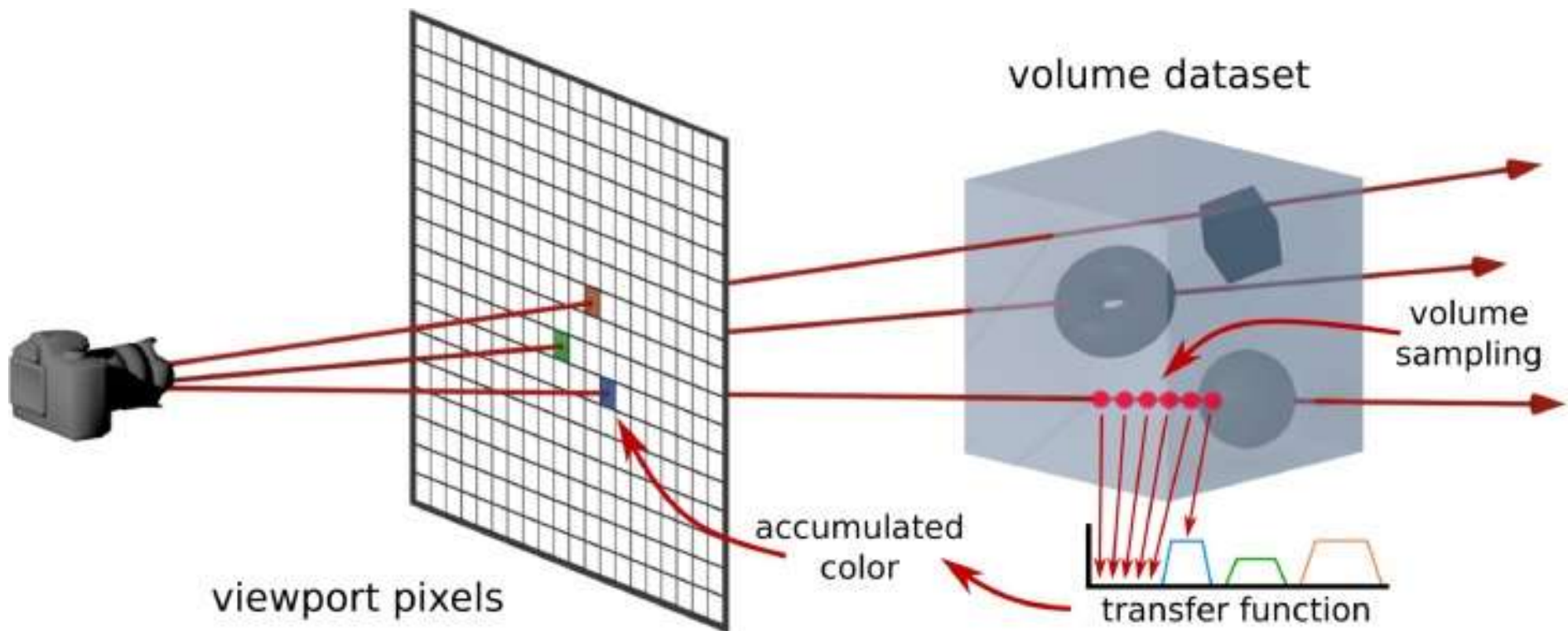
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Acknowledgements

- A subset of the slides that I will present throughout the course are adapted/inspired by excellent courses on Computer Graphics offered by Prof. Han-Wei Shen, Prof. Wojciech Matusik, Prof. Frédo Durand, Prof. Abe Davis, and Prof. Cem Yuksel, Prof. Klaus Mueller.
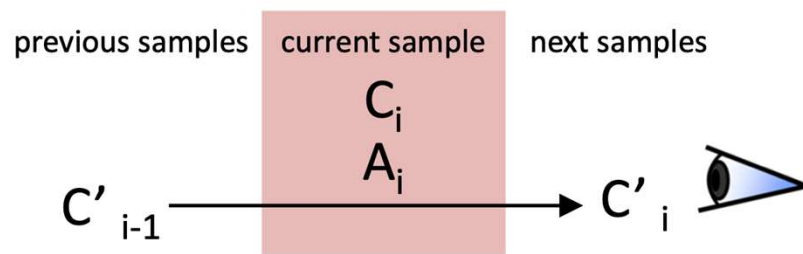
Ray Casting and Compositing

- Direct Volume Rendering

Opacity and Color Blending: Compositing

Back-to-front rendering

previous samples   current sample   next samples

C_i

A_i

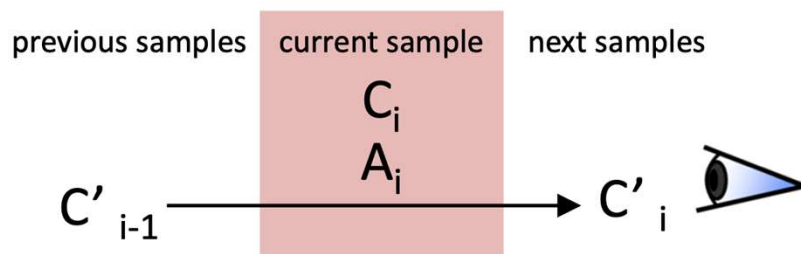C'_{i-1} C'_i

$$C'_i = C_i A_i + (1 - A_i) C'_{i-1}$$

A: Opacity = 1- Transparency = 1 - T

C: Color

Opacity and Color Blending: Compositing

Back-to-front rendering

previous samples | current sample | next samples

$$C_i$$
$$A_i$$

$$C'_{i-1} \longrightarrow C'_i$$

$$C_i' = C_i A_i + (1 - A_i) C_{i-1}'$$

Front-to-back rendering

next samples | current sample | previous samples

$$C_i$$
$$A_i$$
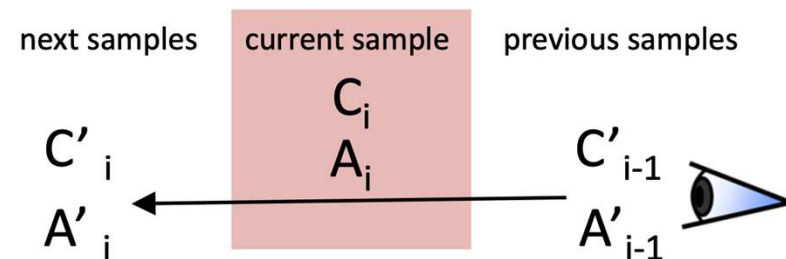
$$C'_i \longleftarrow C'_{i-1}$$
$$A'_i \qquad A'_{i-1}$$

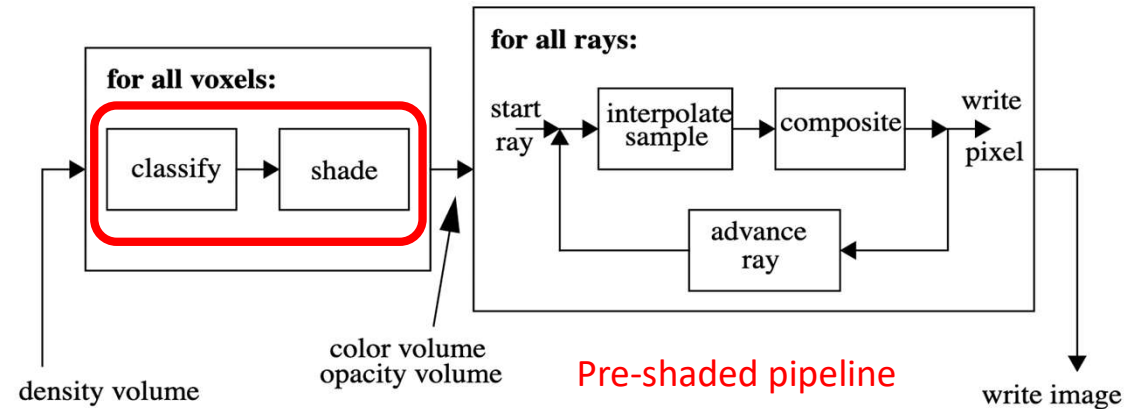$$C_i' = C_{i-1}' + (1 - A_{i-1}') C_i A_i$$

$$A_i' = A_{i-1}' + (1 - A_{i-1}') A_i$$

A: Opacity = 1- Transparency = 1 - T
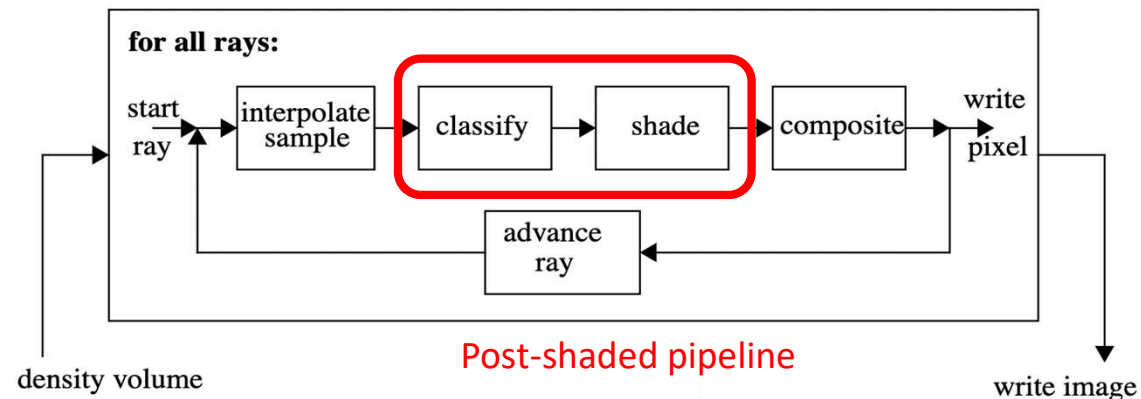
C: Color

Types of Volume Rendering Pipelines

- Pre-shaded pipeline
  - Classify and shade the data first and then perform ray casting and compositing
  - Color and opacity values are interpolated

Pre-shaded pipeline

Types of Volume Rendering Pipelines

- Pre-shaded pipeline
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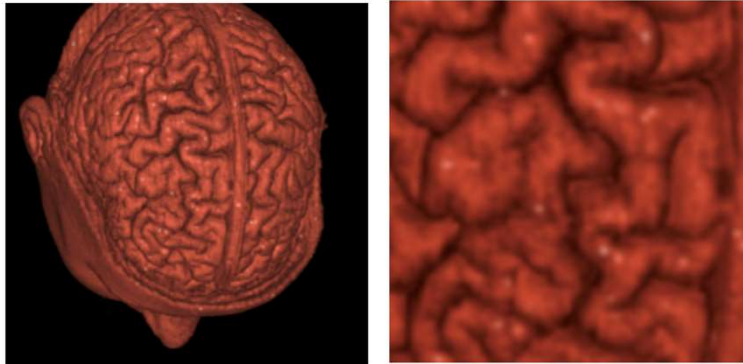 - Color and opacity values are interpolated
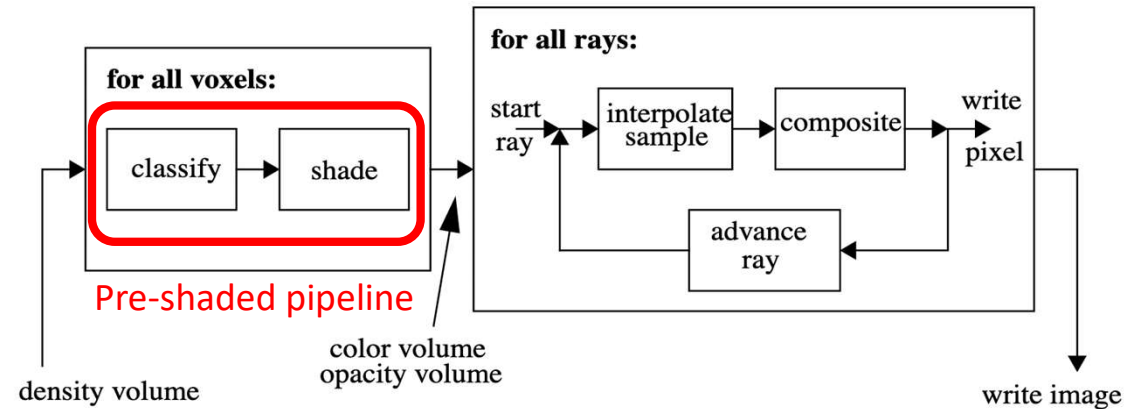
- Post-shaded pipeline
  - Directly ray cast into the data, get data values at query location and use transfer function to shade and then composite
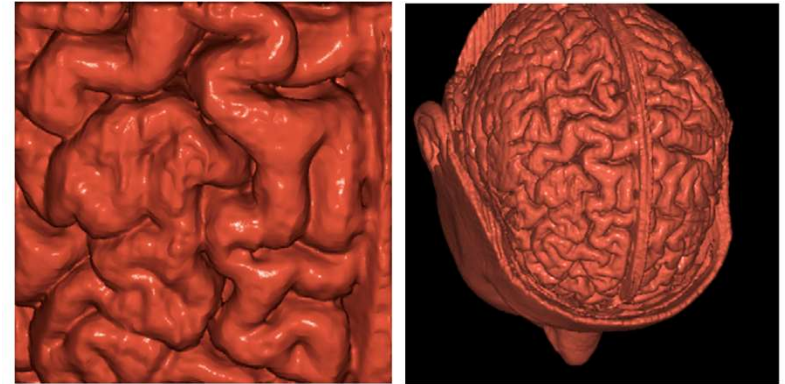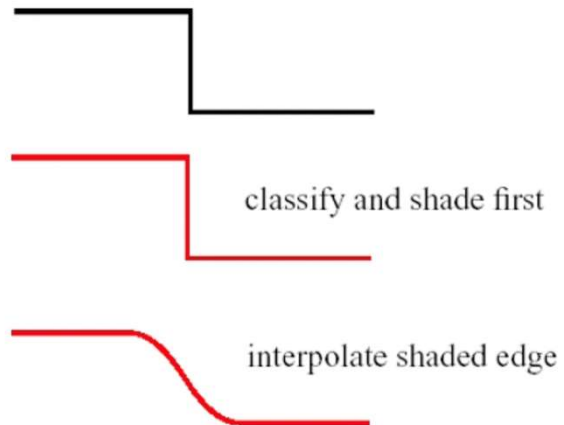 - Data value are interpolated

Pre-shaded pipeline

Post-shaded pipeline
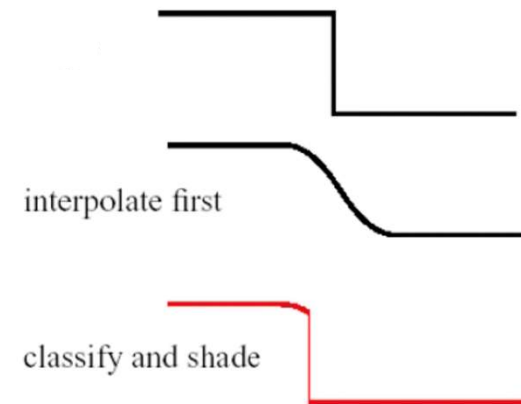
# Pre-shaded vs Post-shaded Volume Rendering

Blurry edge

Pre-shaded pipeline

classify and shade first

interpolate shaded edge

Sharp edge

Post-shaded pipeline

interpolate first

classify and shade
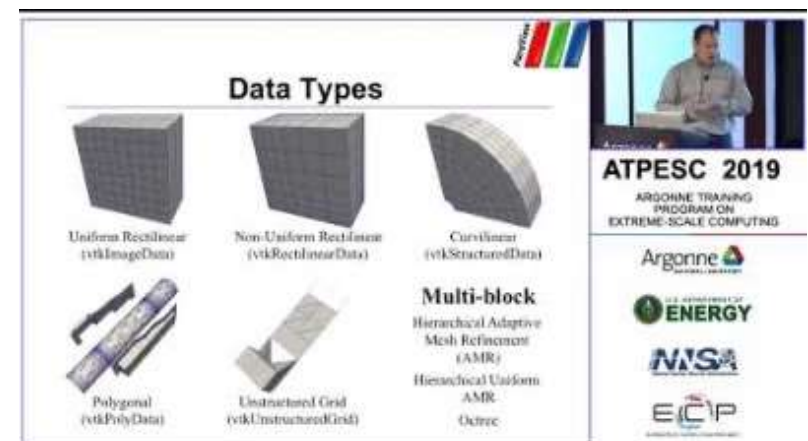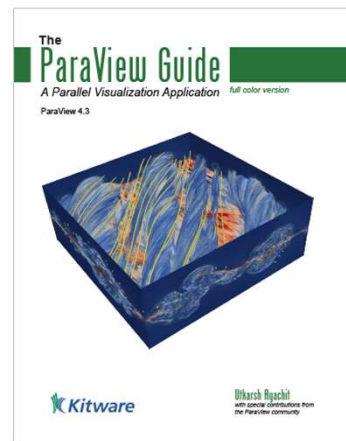
Transfer Function

- Determines what color & opacity a sample value should have
  - Input: an interpolated data value
  - Output: a color and opacity (RGBA)

Transfer Function

1.059: 0.151

Scalar data value color scale
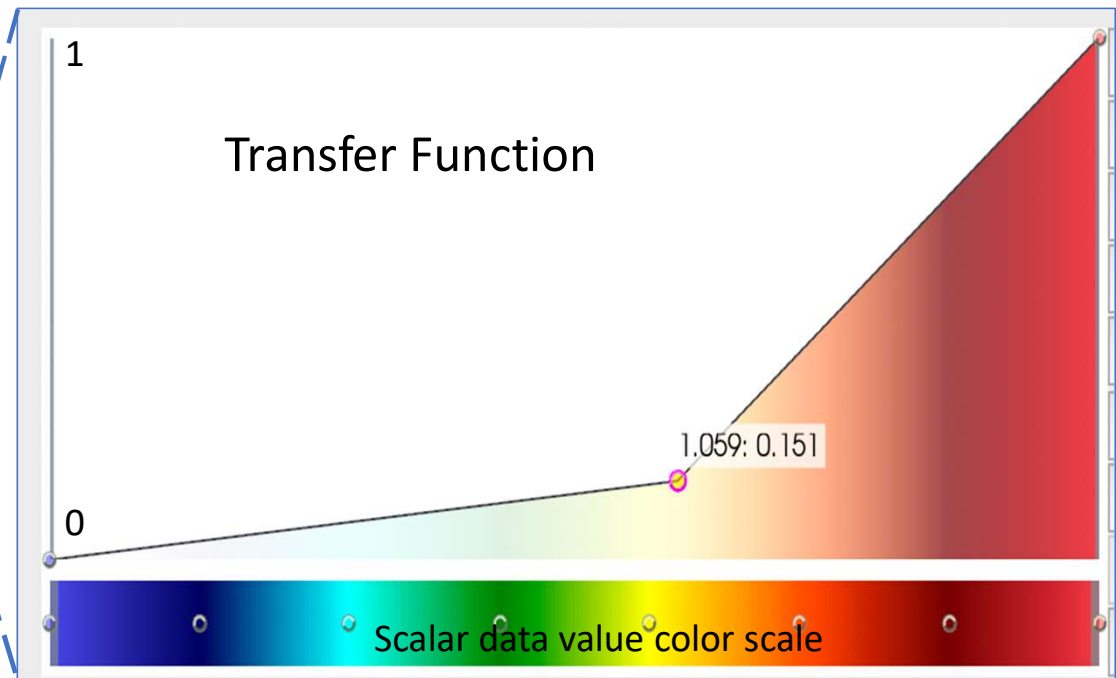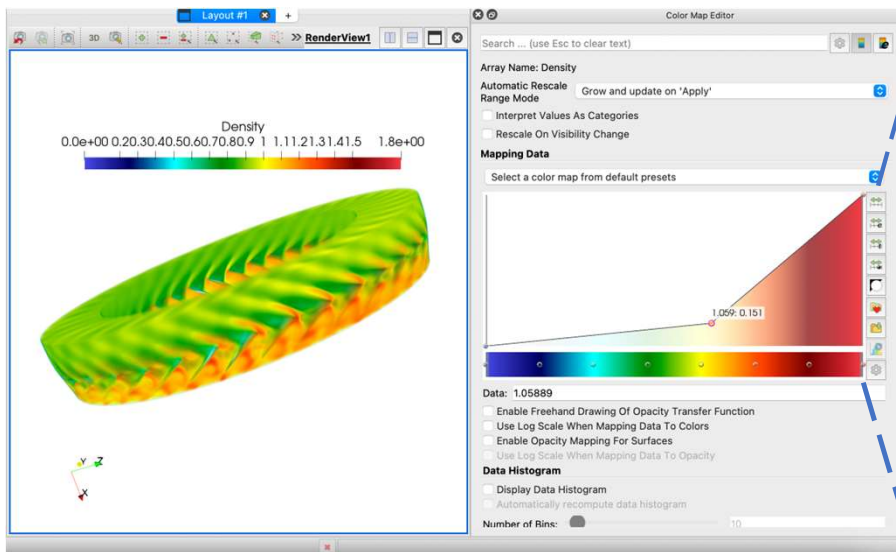
Transfer Function Demo
Using ParaView
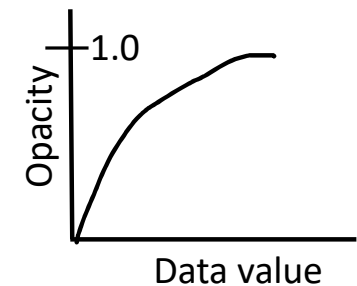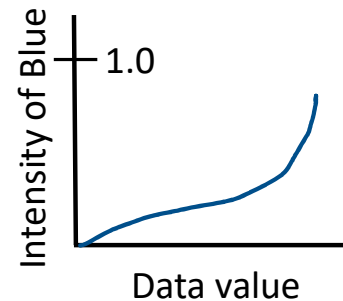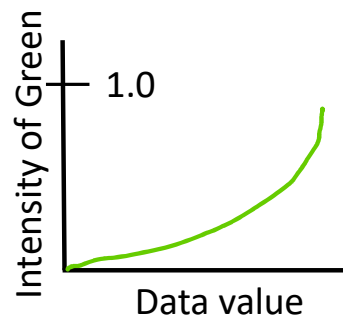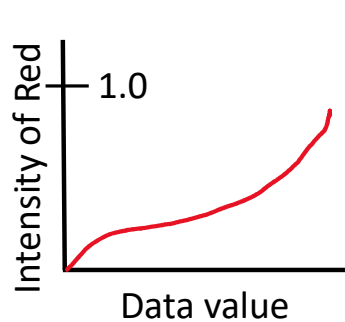
More Information about ParaView

- Getting Started
- *The ParaView Tutorials*
- *The ParaView Guide*
  - *aka The Book*
- The ParaView web page
  - www.paraview.org
- ParaView discussion forum
  - https://discourse.paraview.org/

Video Tutorial

Transfer Function

- At the simplest form, we can think of four 1D transfer functions
  - Red, Green, Blue, Alpha (opacity)

Transfer Function

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  - Red, Green, Blue, Alpha (opacity)

- Can you design an opacity transfer function for showing an Isosurface?
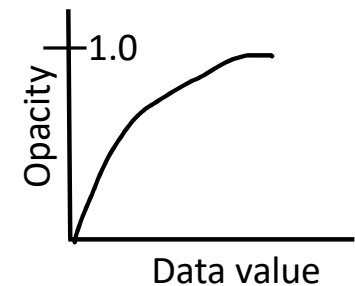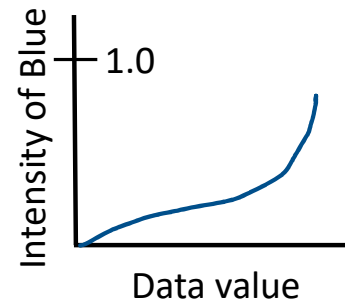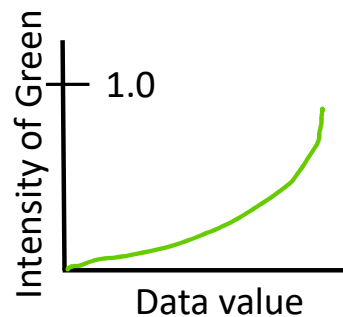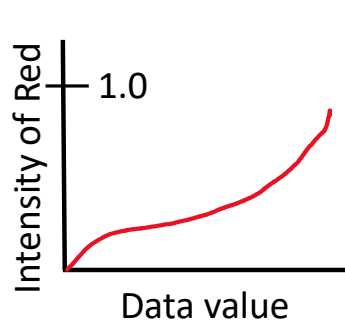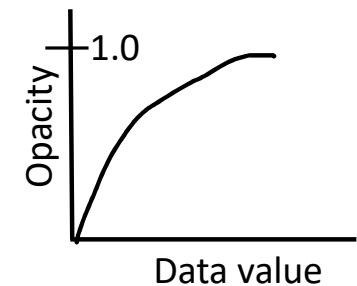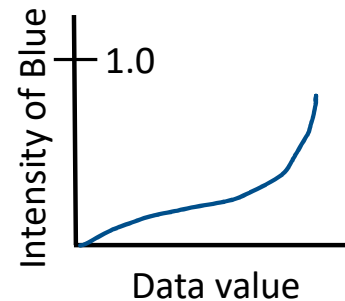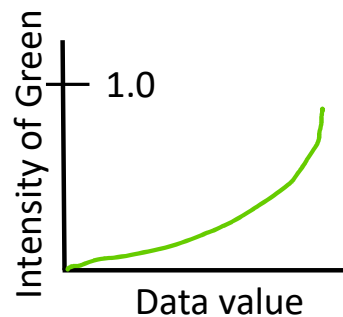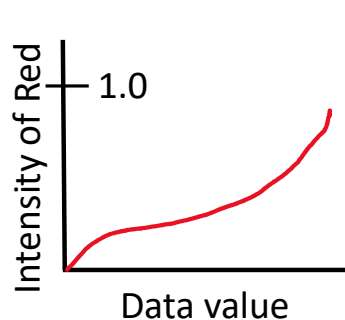
Transfer Function

- At the simplest form, we can think of four 1D transfer functions
  - Red, Green, Blue, Alpha (opacity)

- Can you design an opacity transfer function for showing an Isosurface?
  - <u>A step function at the isovalue</u>
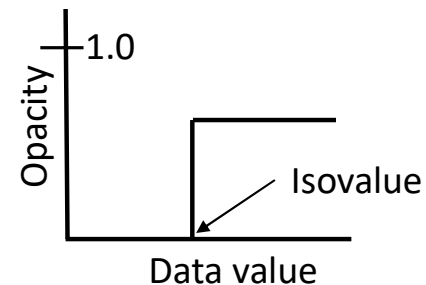
Classification and Shading

- We have already seen that <u>shading</u> is the process of assigning color values to data points considering parameters of the rendering system

- <u>Classification</u>: Mapping data values to opacities
  - Region of interest → High Opacity so that clearly seen
  - Unimportant regions → Full or semi transparent
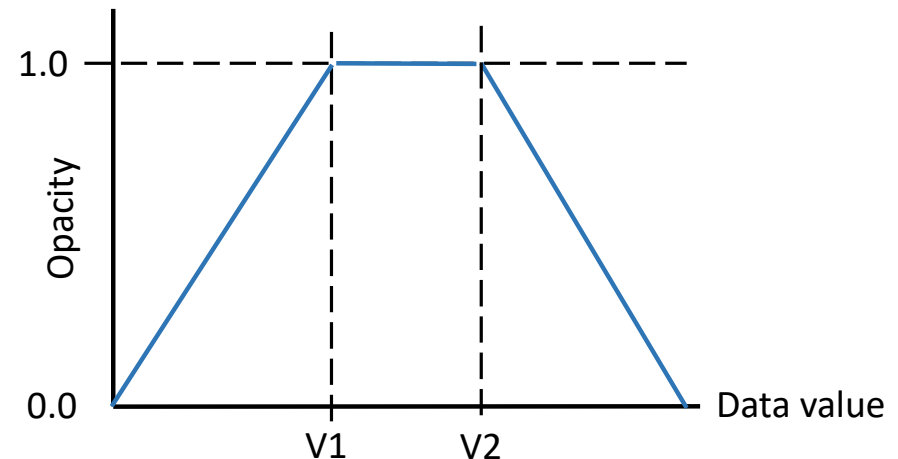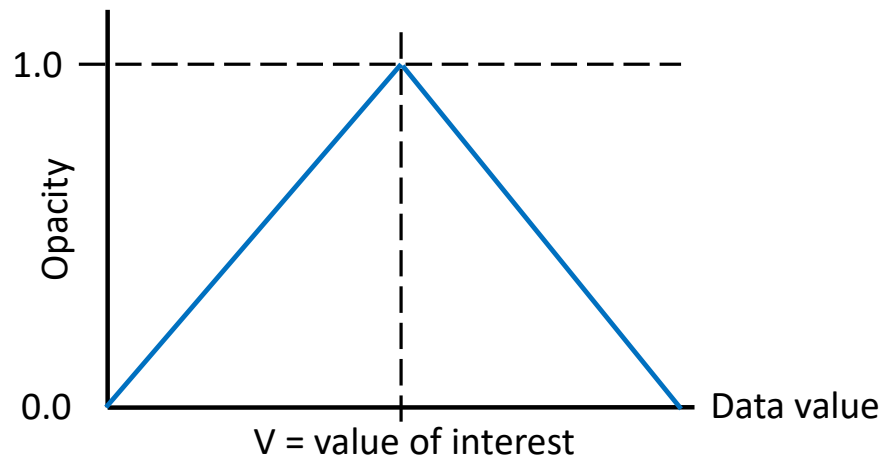
Classification: Color + Opacity Transfer Function

- Distinguish between different materials or features in the data
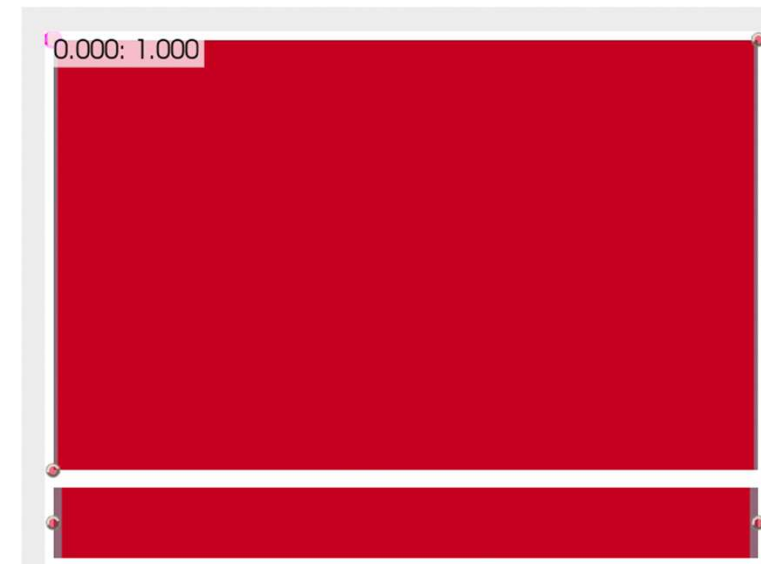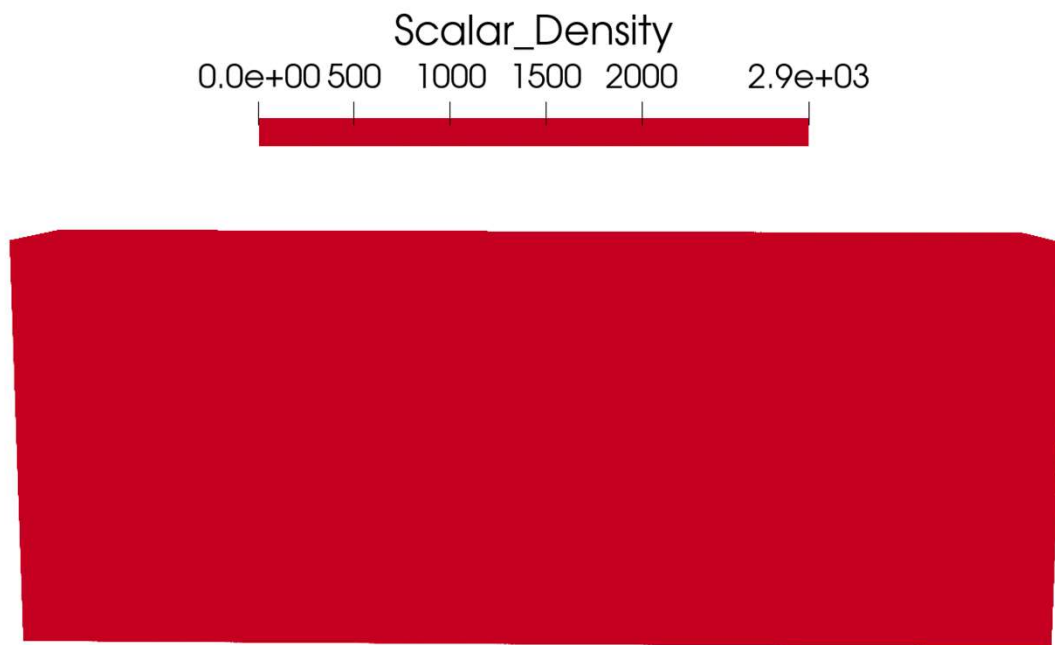
Single color for all data values and all data values have opacity = 1.0

Classification: Color + Opacity Transfer Function

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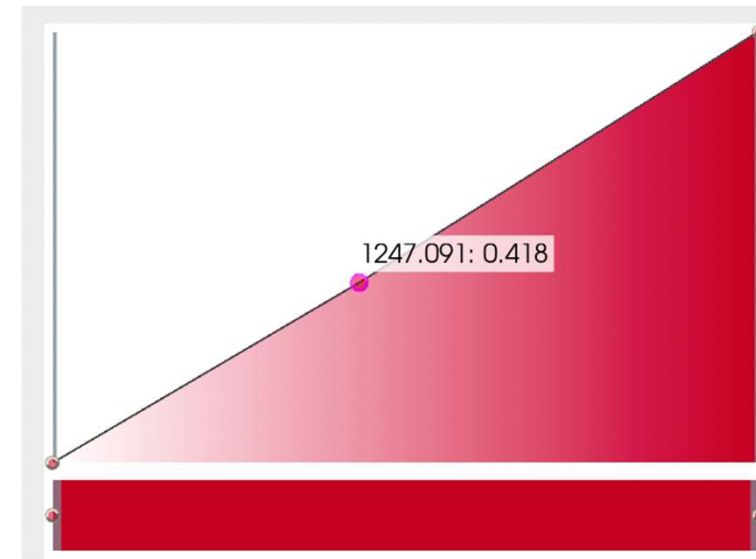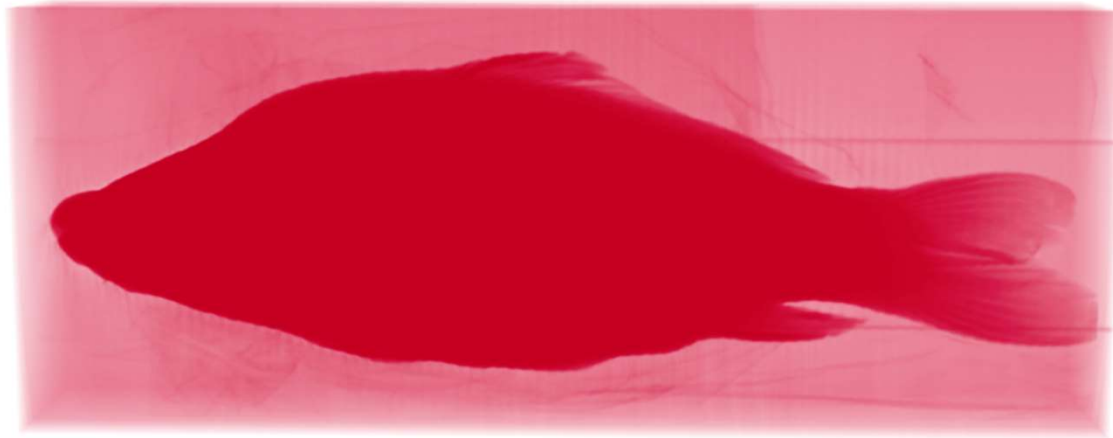
Set opacity function as a ramp function, shows some structure inside

Classification: Color + Opacity Transfer Function

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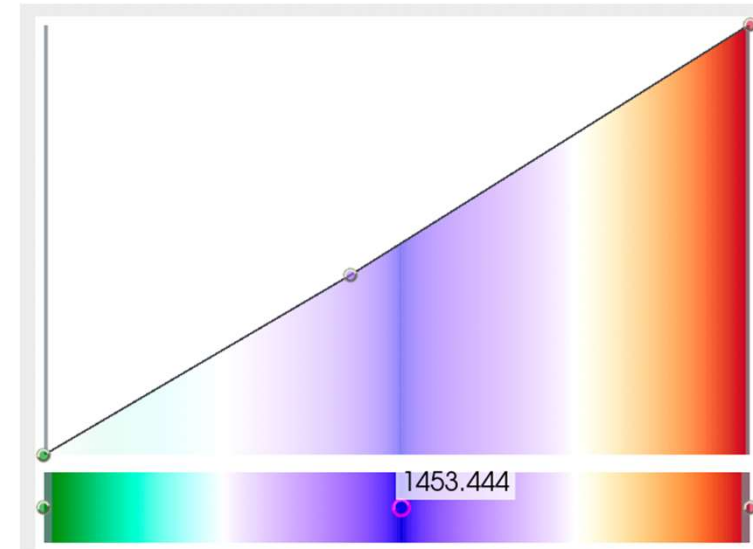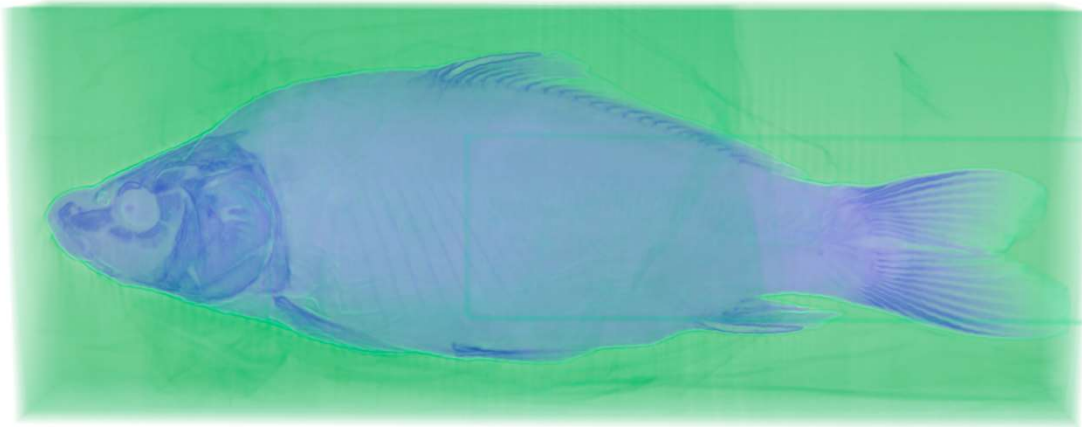
Add two more colors in the color transfer function, fish is blue, background is green

Classification: Color + Opacity Transfer Function

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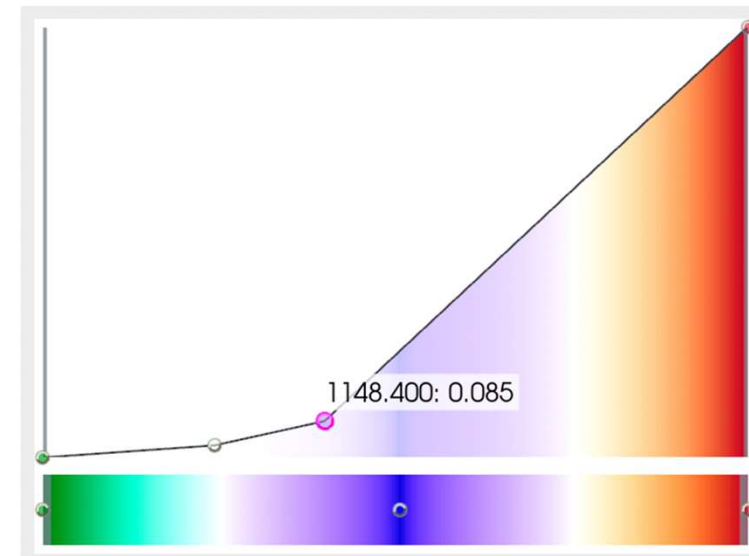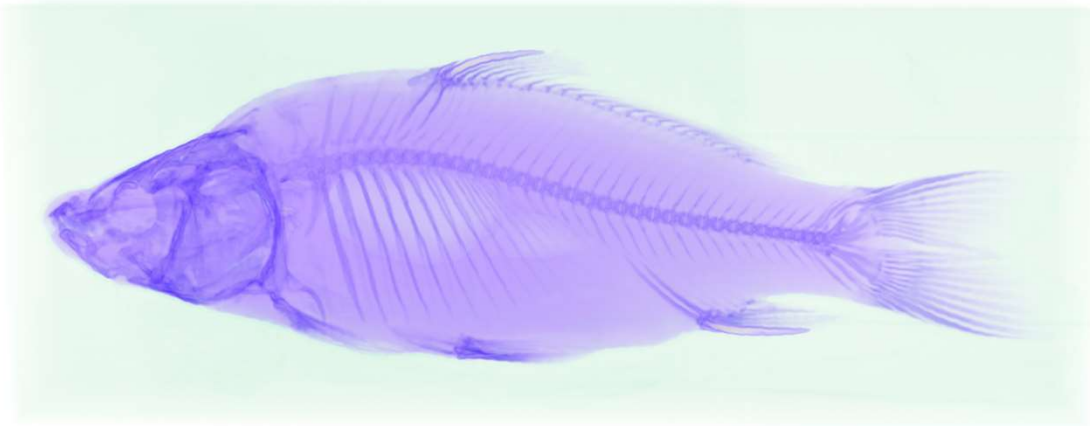
Modified opacity transfer function to remove some of the background

Classification: Color + Opacity Transfer Function

- Distinguish between different materials or features in the data

Scalar_Density

385.791: 0.054
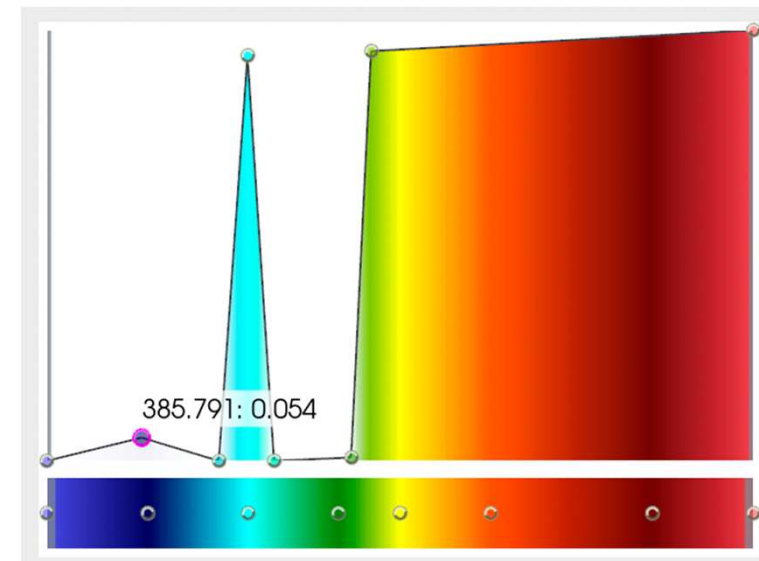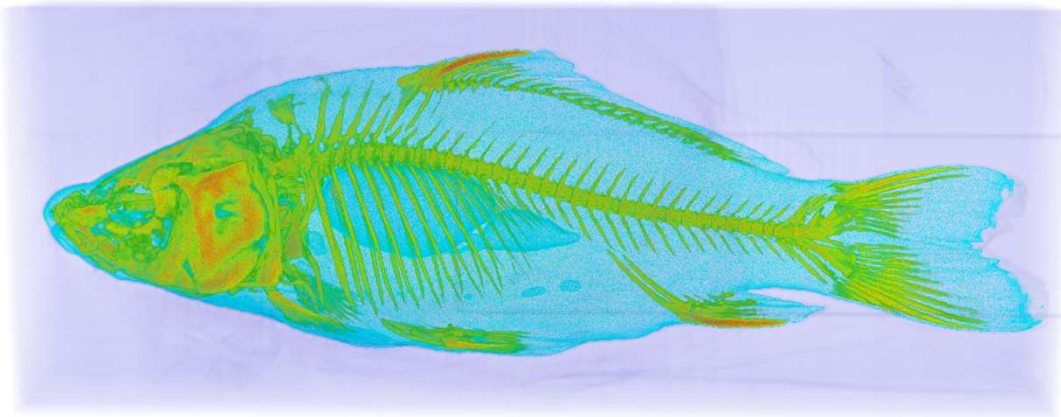
Use a different color transfer function and try to engineer a more effective opacity function

Classification: Color + Opacity Transfer Function

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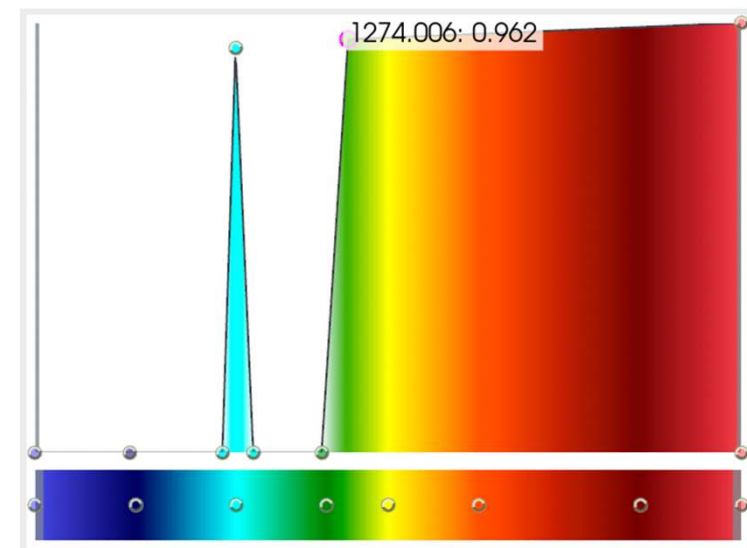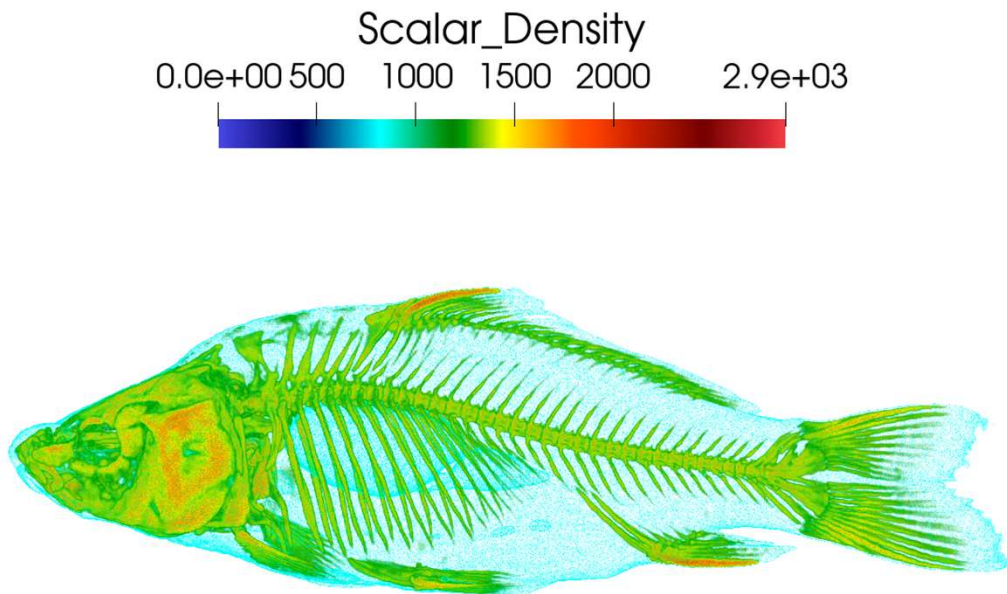
Change the opacity function to remove the background and the fish is seen clearly

Transfer Function Design

- Goal:
  - Use transfer functions to show salient features from the data set and deemphasize the unimportant data

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  - Without knowing what data values correspond to important data values, how do we design a good transfer function?
  - A small difference in transfer function can change the visualization drastically
  - Lots of manual tweaking might be required!

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- Need algorithms and strategies that can automatically analyze data design an effective transfer function given all possible transfer functions in the search space

Trail and Error + Domain Knowledge

- Manually control colors for scalar values and try different opacity functions to find an optimal one

- Use domain knowledge about the data set to guide the design process
  - E.g.: what range of values correspond to bone and skin?

- Can take significant amount of time!

Histogram

- <u>Histogram:</u> A histogram is an approximate representation of a statistical distribution. The area under a histogram can be normalized and used as a probability distribution function

$$H(s) = \sum_i \delta(x - x_i)$$

$$\delta(x) = \begin{cases} 1, & \text{if } x = 0 \\ 0, & \text{otherwise} \end{cases}$$
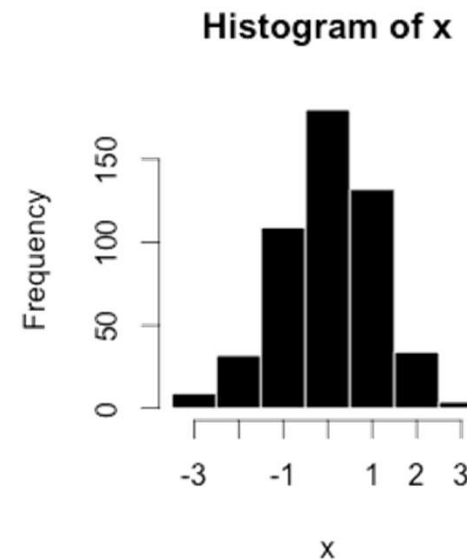
Histogram of x

Source: Wikipedia

1D Histogram Assisted Transfer Function Design
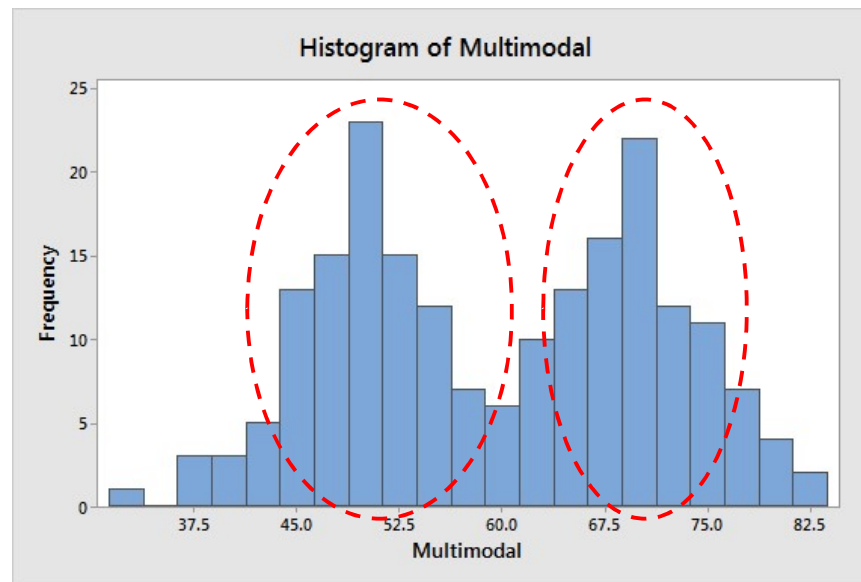
- Different features in data set can have different value ranges
- Value clusters can be seen from histogram plots
- Assign different colors for different clusters/histogram regions

Histogram of Multimodal

1D Histogram Assisted Transfer Function Design

- Different features in data set can have different value ranges
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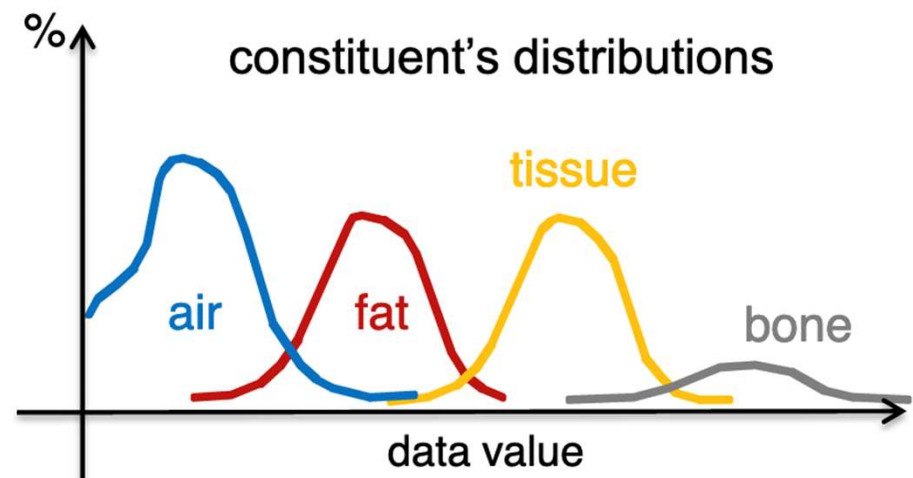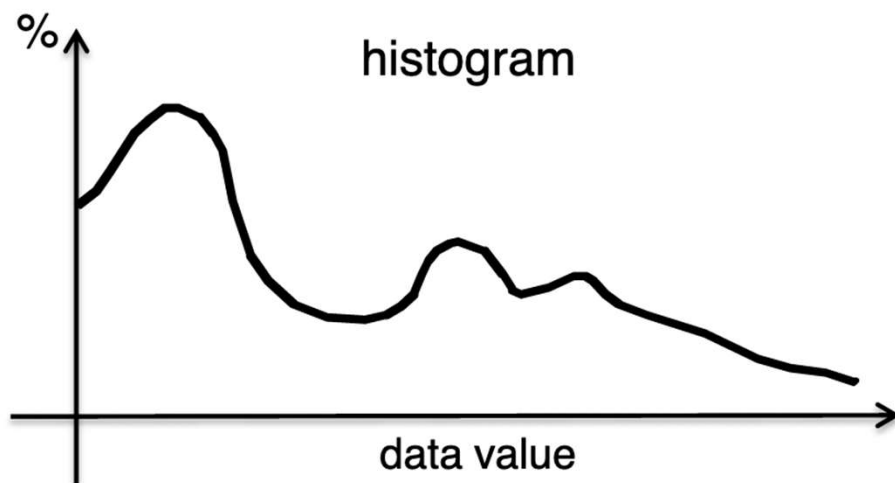- Assign different colors for different clusters/histogram regions
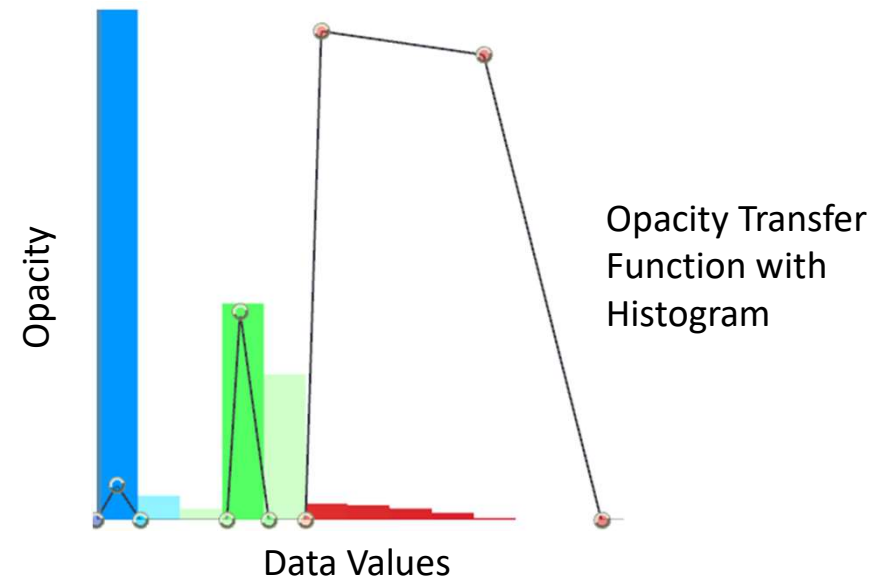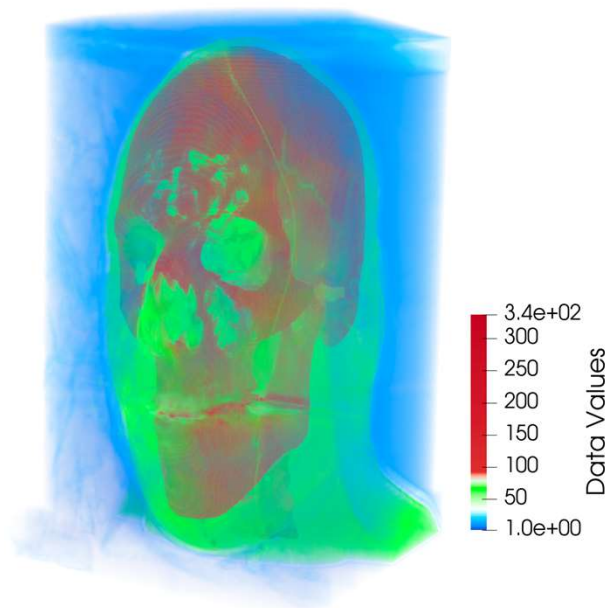
1D Histogram Assisted Transfer Function Design

- Different features in data set can have different value ranges
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- Assign different colors for different clusters/histogram regions

Opacity Transfer Function with Histogram

Multi-dimensional Transfer Function

- Use the gradient information of the data to design a better transfer function that can highlight boundaries clearly
  - Distinct features/materials have roughly constant data value
  - Data values transition smoothly from one material to the next

Gradient of f: $\quad \nabla f(p) = \begin{bmatrix} \dfrac{\partial f}{\partial x_1}(p) \\ \vdots \\ \dfrac{\partial f}{\partial x_n}(p) \end{bmatrix}$

Multi-dimensional Transfer Function

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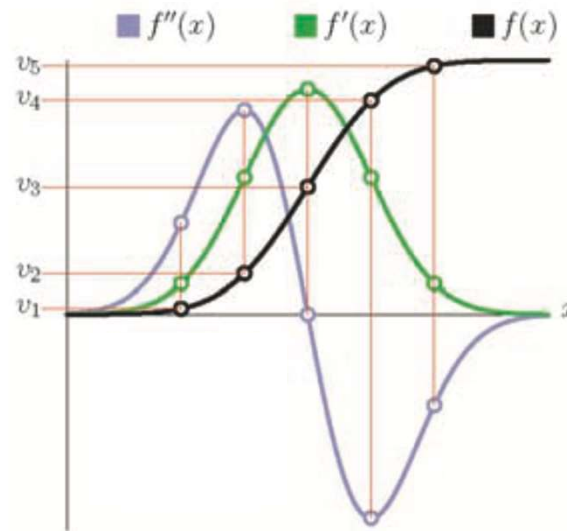 - Data values transition smoothly from one material to the next

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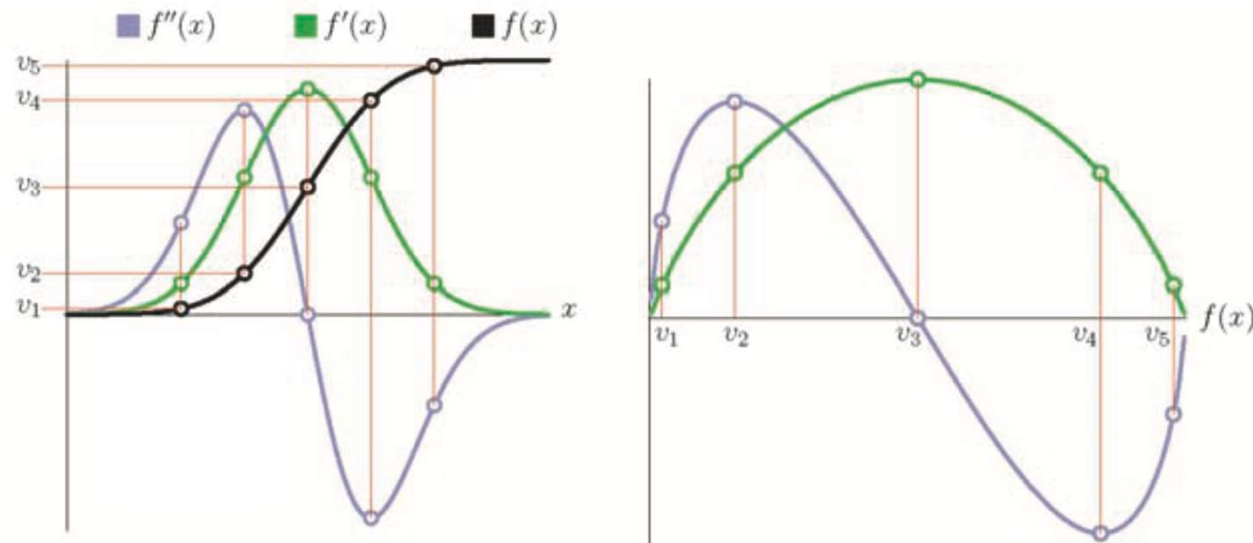

Relationships between f, f', f'' in an ideal boundary

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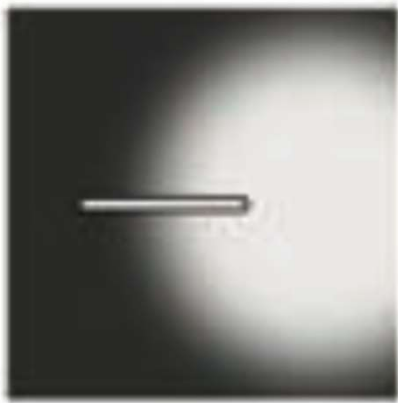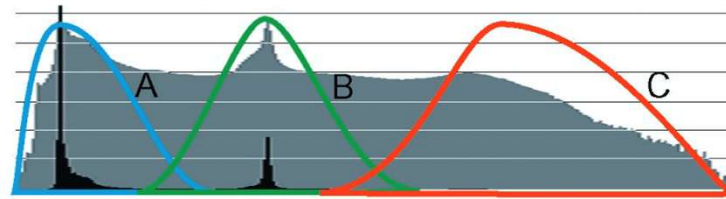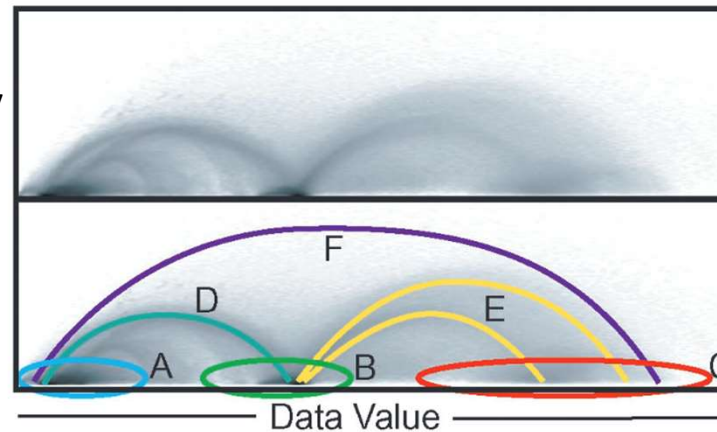

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Multi-dimensional Transfer Function
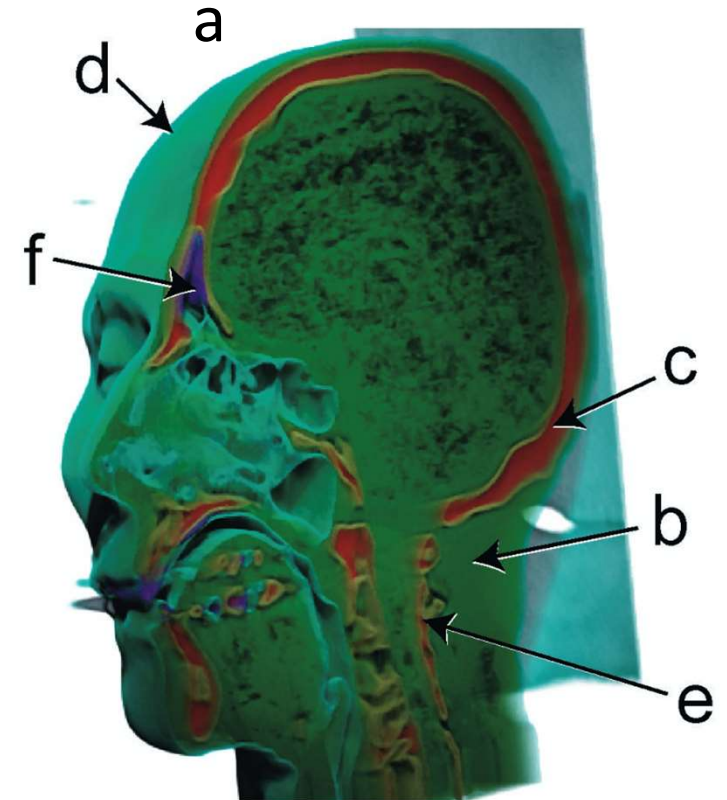
A: Air
B: Tissue
C: Bone

D: Air and tissue boundary
E: Tissue and bone boundary
F: Air and bone boundary

1D Transfer Function

2D Transfer Function
X-axis: Data Value, Y-axis: Gradient

References

- Multidimensional Transfer Functions for Interactive Volume Rendering, TVCG 2002

- State of the Art in Transfer Functions for Direct Volume Rendering, Ljung et al., EuroVis 2016