Introduction to Volume Rendering

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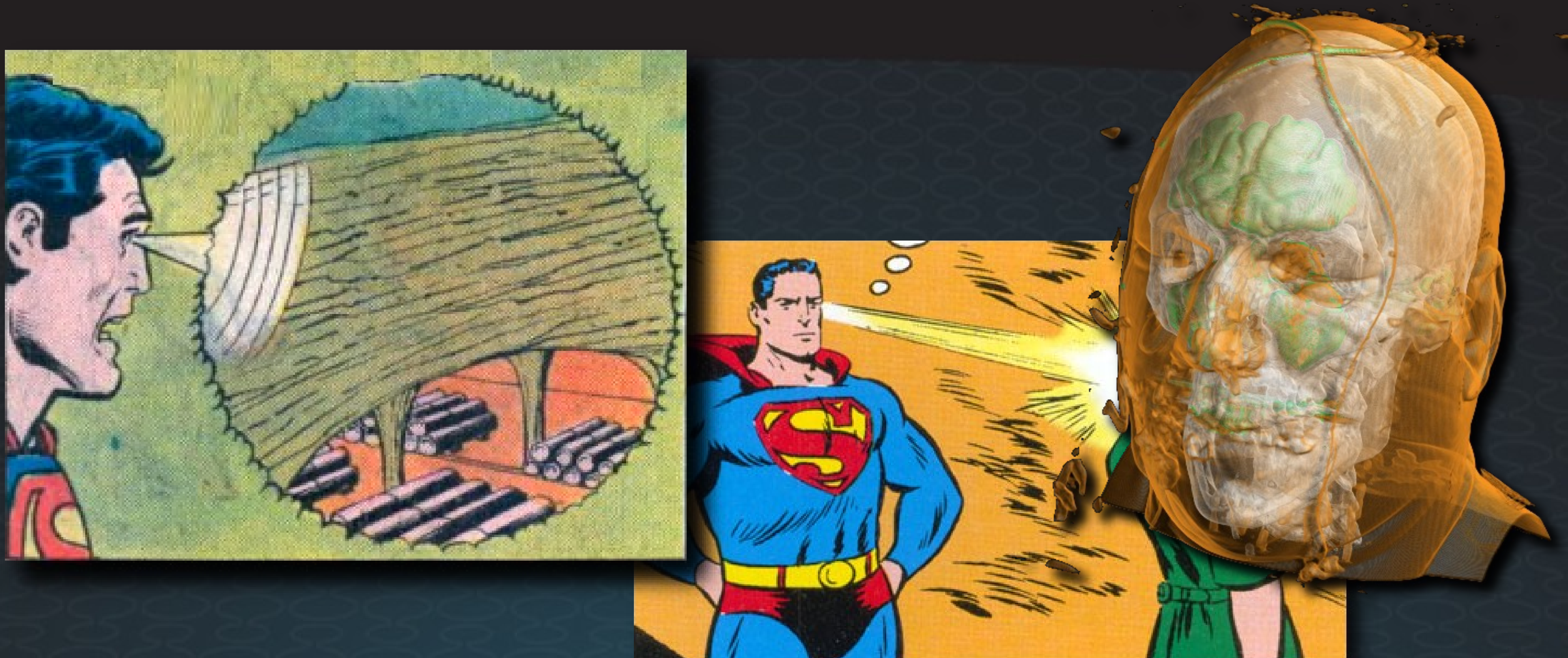
Slides adapted from presentations by C. Hansen

Overview

- Scalar Field Volume Rendering:
  - Intuitive problem formulation;
  - Applicative motivations;
  - Limitations of Iso-surface based rendering;
  - Direct Volume Rendering:
    - **Volume Ray Casting;**
    - Splatting;
    - Shear Warp;
    - Texture Mapping, etc.

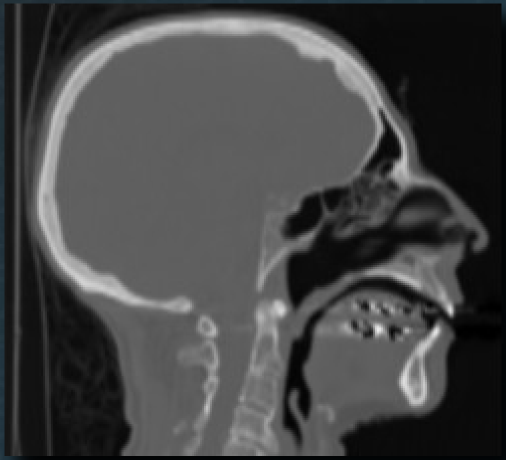
Intuitive Problem Formulation

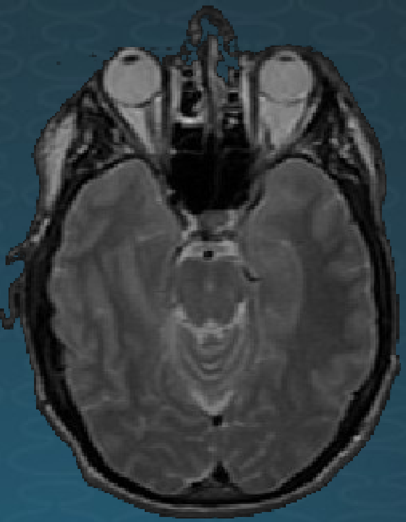


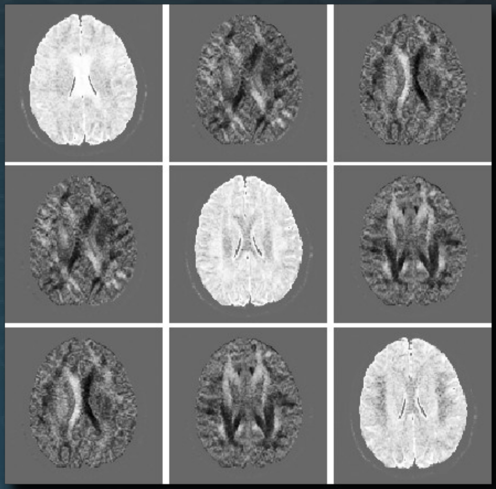
- Mimic Superman's SuperVision:
  - Represent in an intelligible manner the *interior* of a scalar volume.

Applicative Motivations

- Visualization of Measured 3D Data:
  - Computed Tomography;
  - Magnetic Resonance Field;
  - Ultrasound, etc.

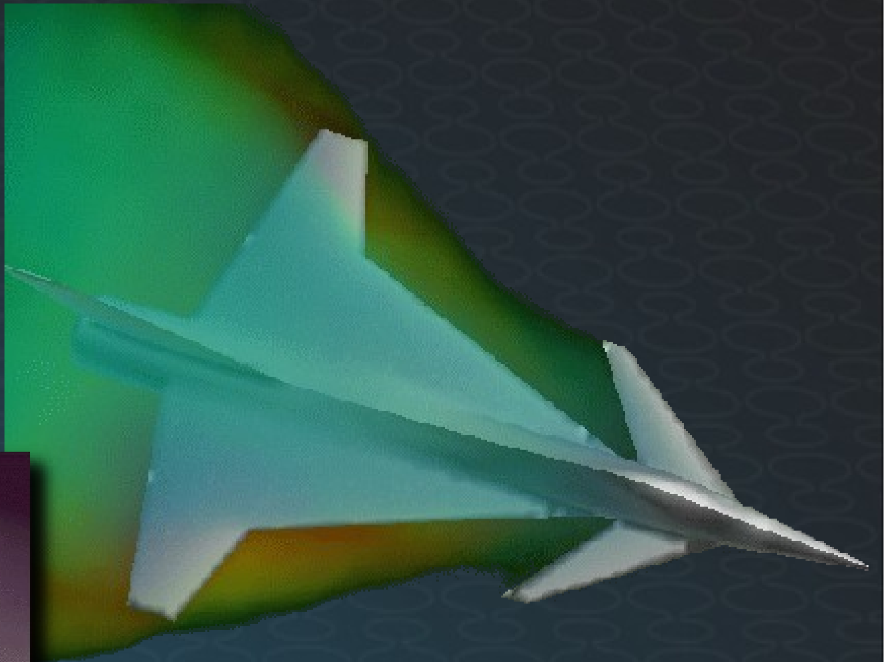


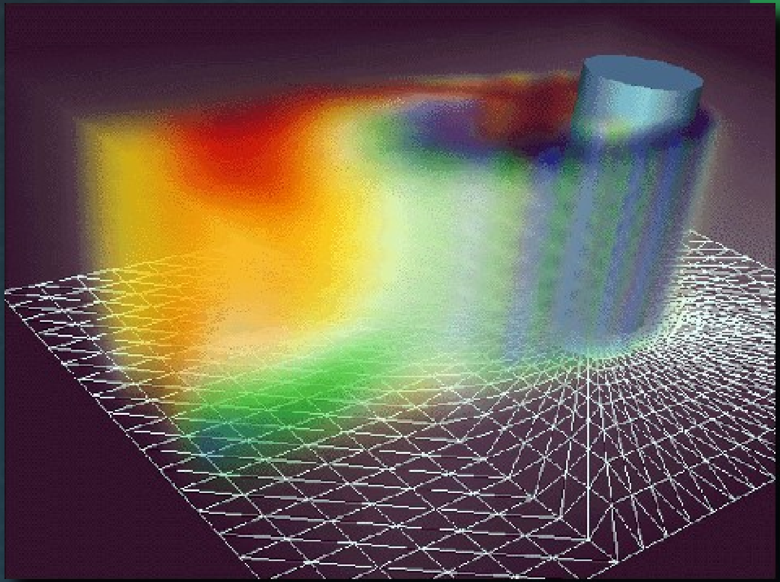




Applicative Motivations

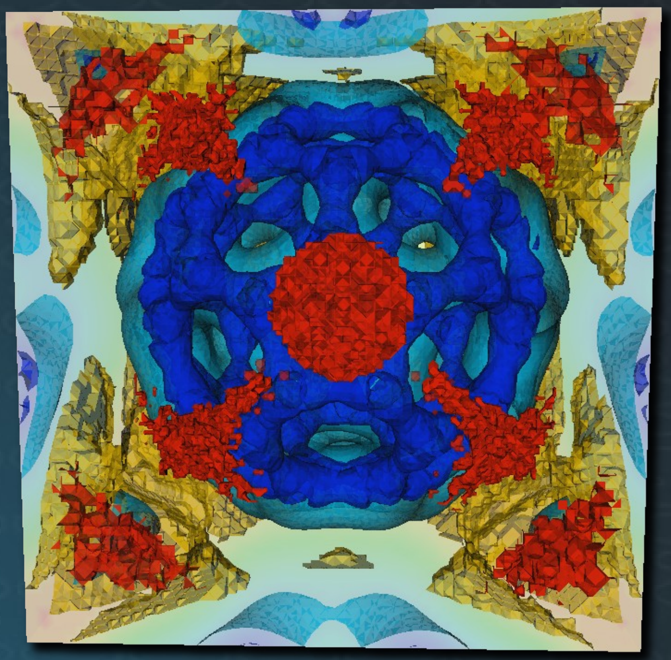
- Visualization of Simulated 3D Data:
  - Fluid dynamics;
  - Pressure;
  - Porosity;
  - etc.





Isosurface Based Rendering

- Level set:
  - $L(w) = \{ p \in \mathbb{M}, f(p) = w \}$
  - 2D: isocurves
  - 3D: isosurfaces
- Seed sets + marching;
- Specific blendings.

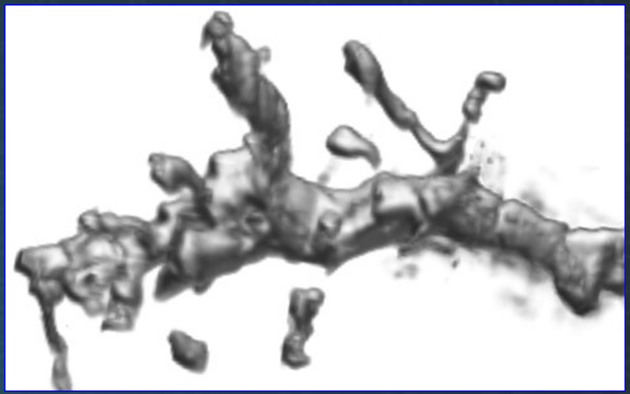


Isosurface limitations

- No view-dependency;
- Boundary representations only:
  - May be suited for particular data-sets (CT scans);
  - But not always appropriate (ex: fire simulation).

Slice

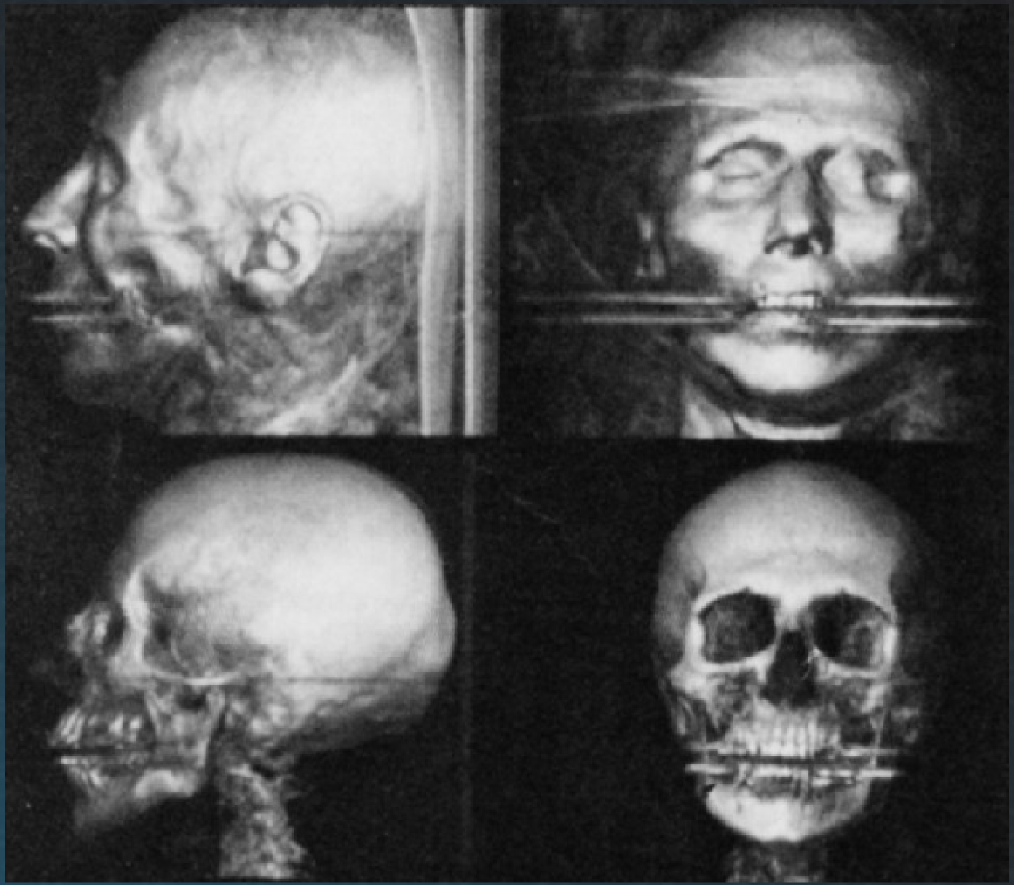
Isosurface



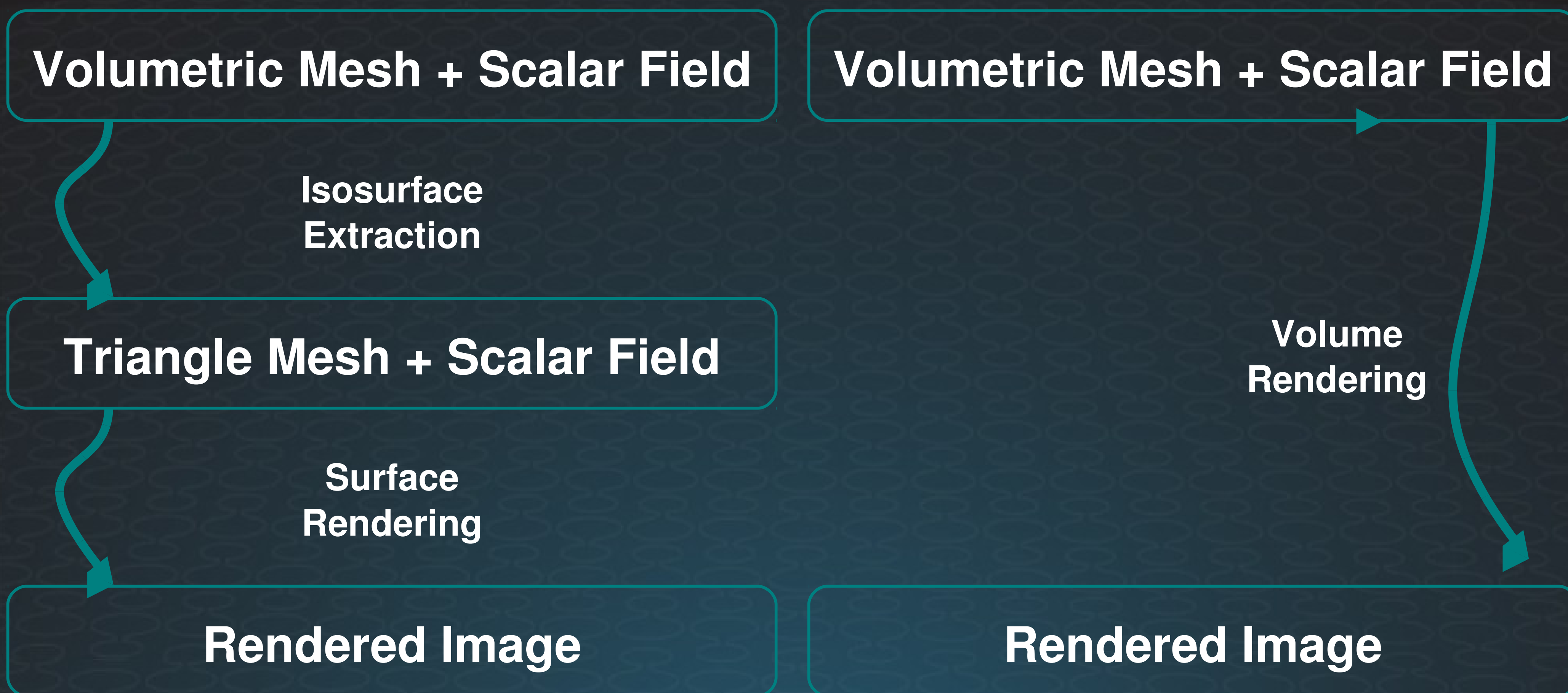
Volume Rendering

Key Idea of Volume Rendering

- Every voxel should contribute to the image;
- Greater flexibility;
- Integrate blending.



Pipelines: Isosurfaces VS Vol. Rend.



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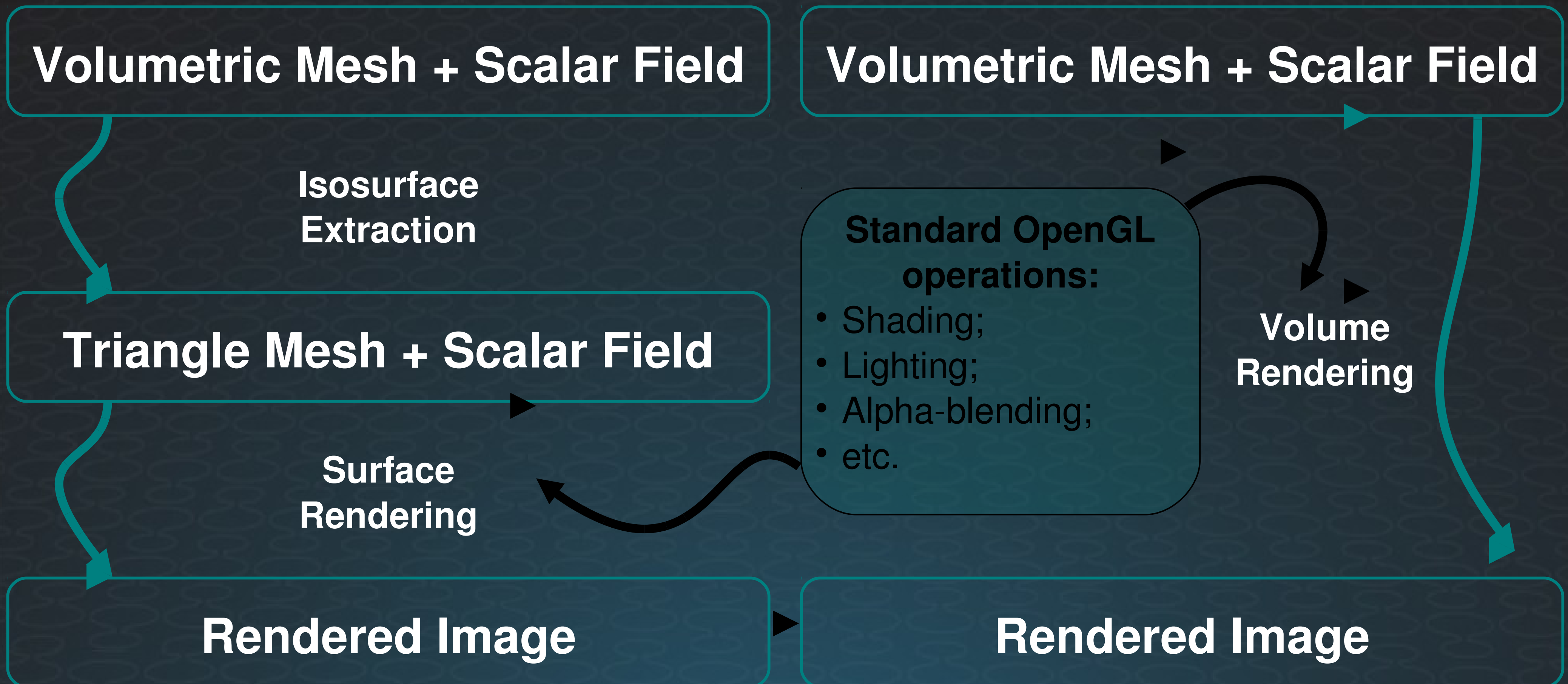


What does *Volume Rendering* refer to?

- Any rendering process which:
  - Maps from a volume data-set;
  - To a rendered image;
  - Without intermediary geometry (no isosurface).

- How does it work?
  1) Define “rules” for color and opacity;
  2) Accumulation process depending on the view point.

Direct Volume Rendering

- Consider the 3D data as:
  - A semi-transparent medium;
  - Light-emitting medium.
- Approaches based on physical models of light (cf. Computer Graphics Illumination);
- The 3D data is represented as a whole:
  - View “all” of the inside!

Direct Volume Rendering: Overview

1) Transfer Function Design:
   - Allows the user to specify “rules” for color and opacity.

1) Accumulation process:
   - **Volume Ray Casting;**
   - Splatting;
   - Shear warp, Texture Mapping, etc...

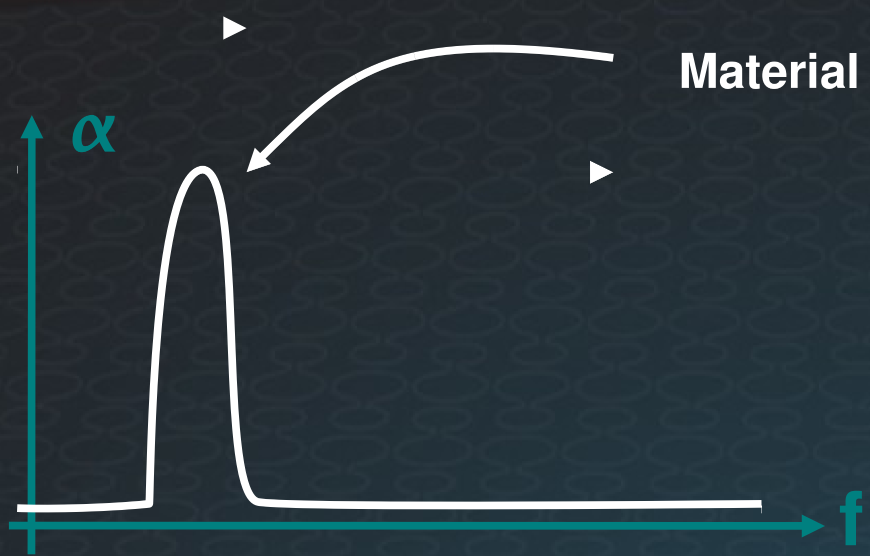
Transfer Functions

- Given a Volumetric Mesh and a Scalar Field:
  - Provide an intuitive way to define:
    - The color of a region;
    - Its level of opacity.
  - Process dependent on the Scalar Field (**feature space**):
    - For a given isovalue:
      - Its color;
      - Its opacity.

Transfer Function Design

- **Key Idea:**
  - Associate distinct *materials* (function ranges) to distinct properties

Transfer Function Design



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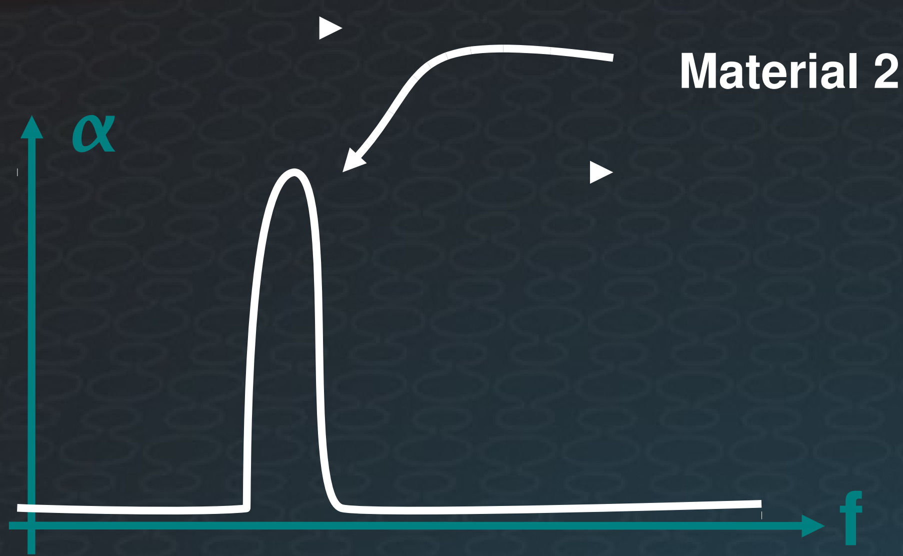
Transfer Function Design



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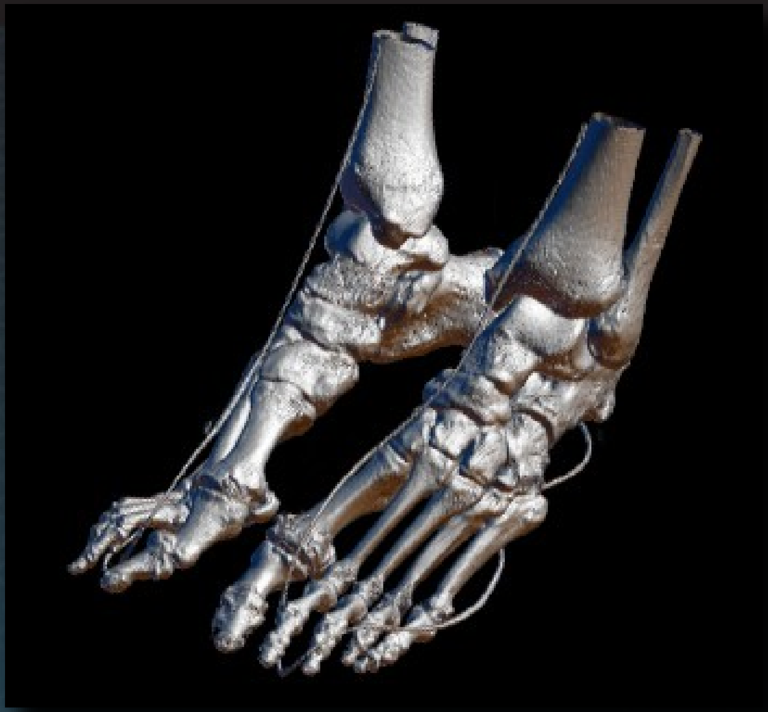

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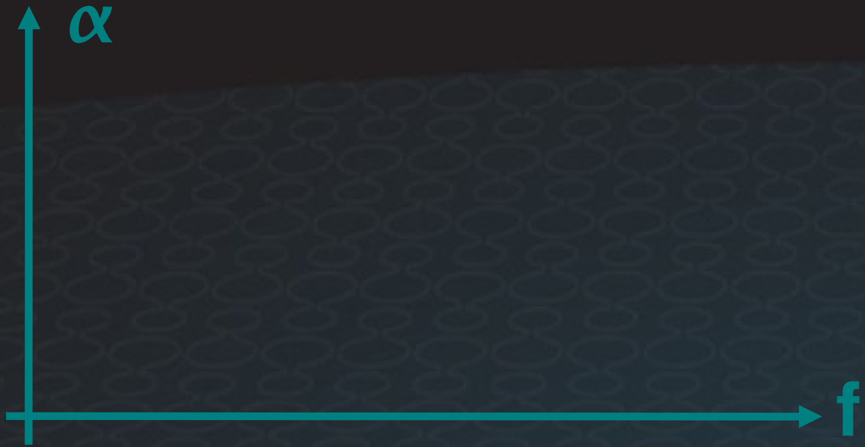
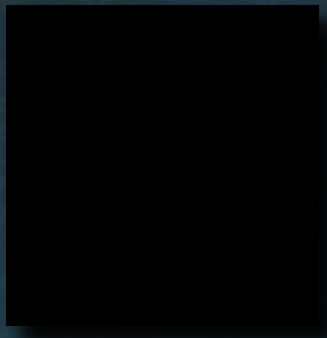
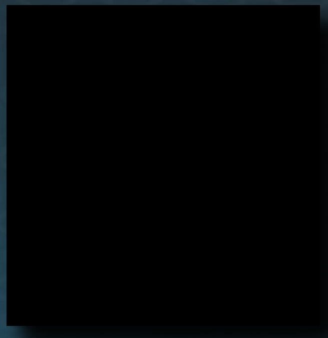
Transfer Function Examples



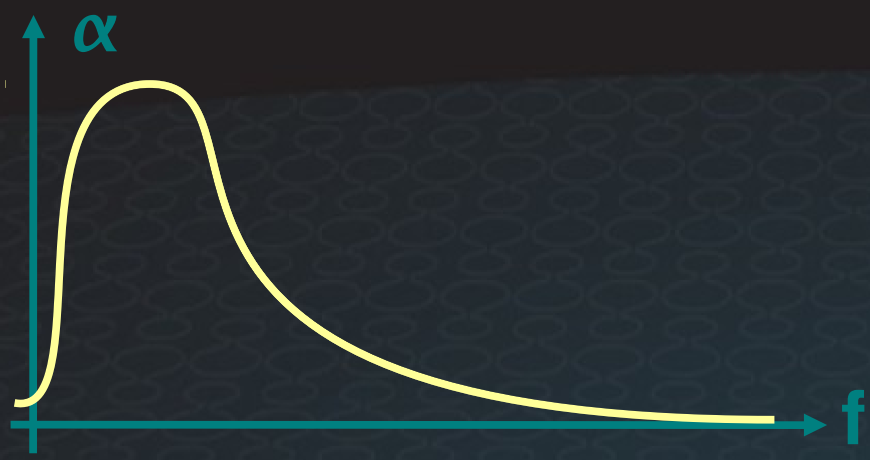


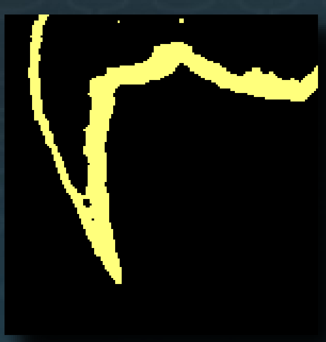
Color



Opacity

Transfer Function Examples





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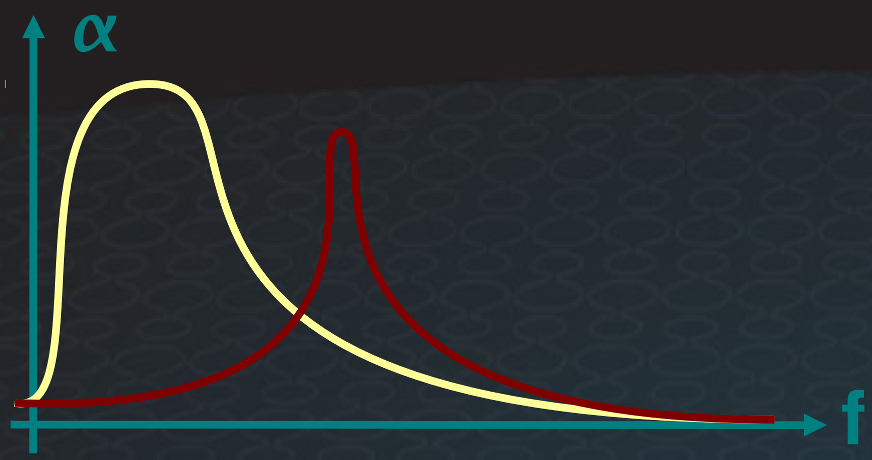

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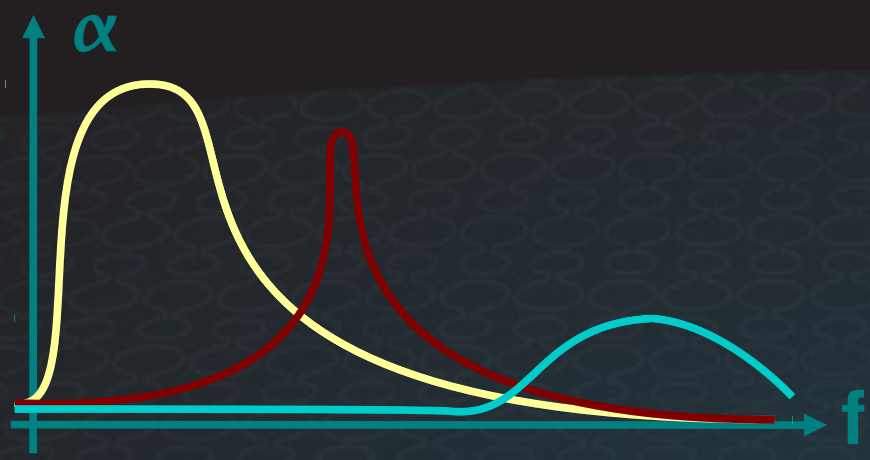

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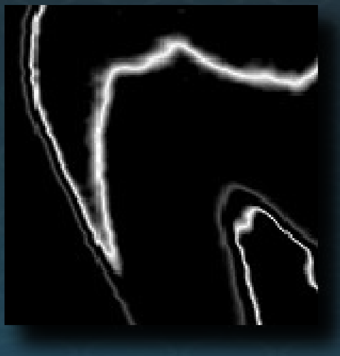

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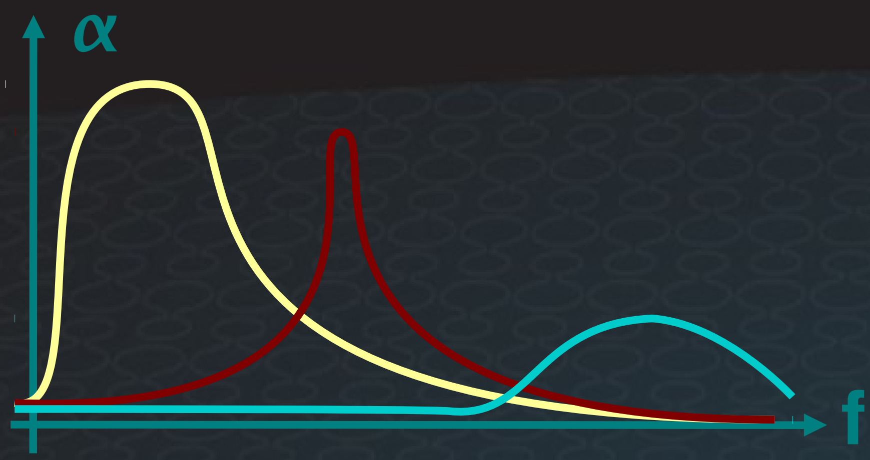

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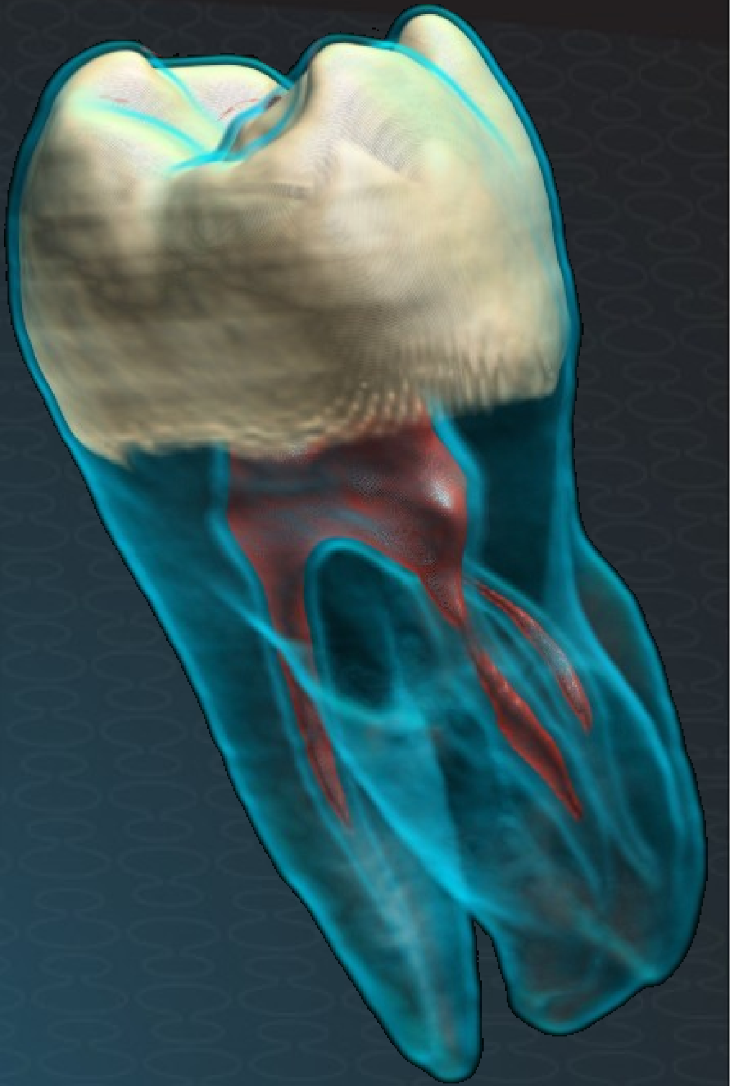
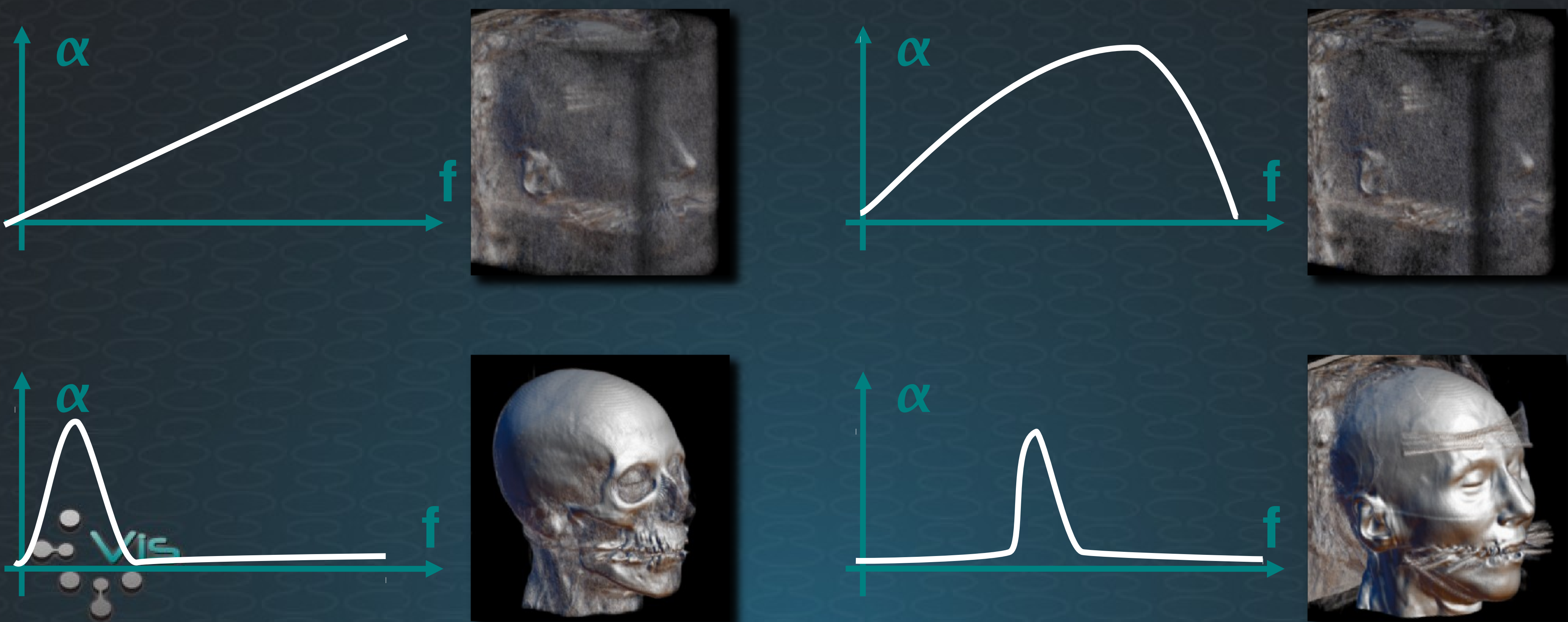
Opacity



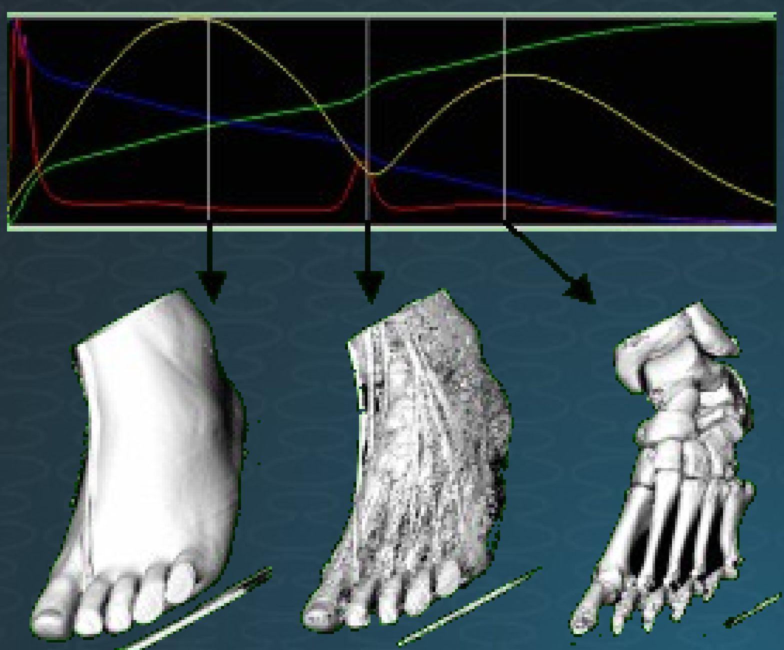
From A User Perspective

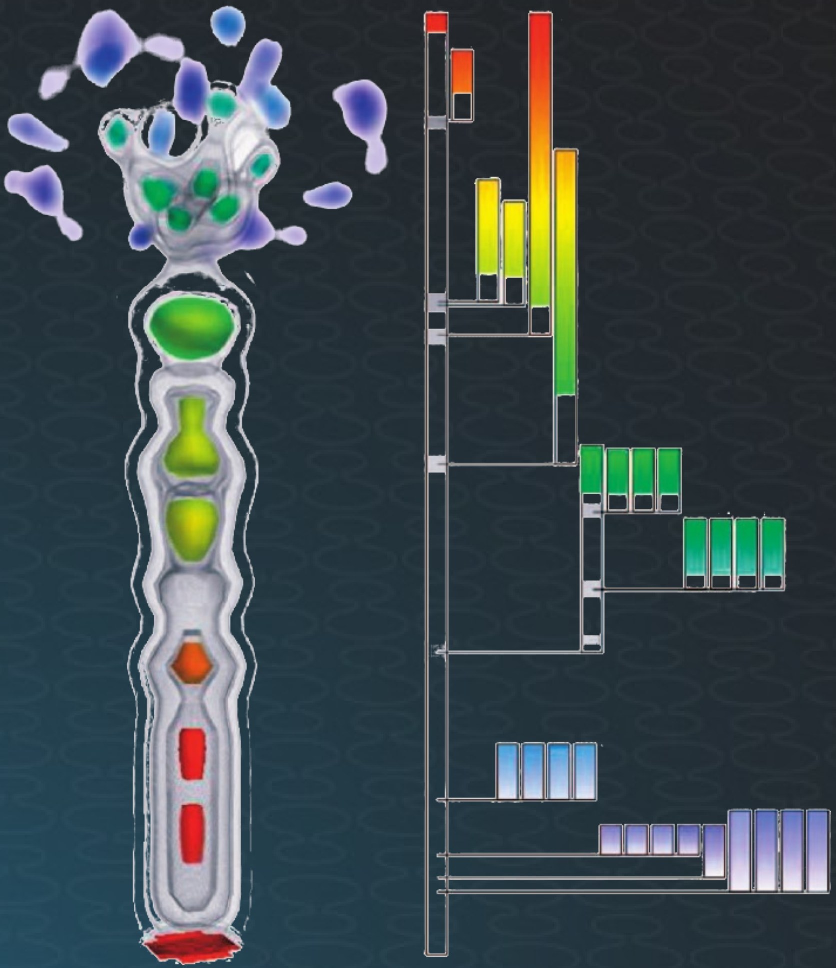
- Finding the “right” transfer function can be hard:
  - Experienced users;
  - A priori knowledge about the data-set (value isolation).



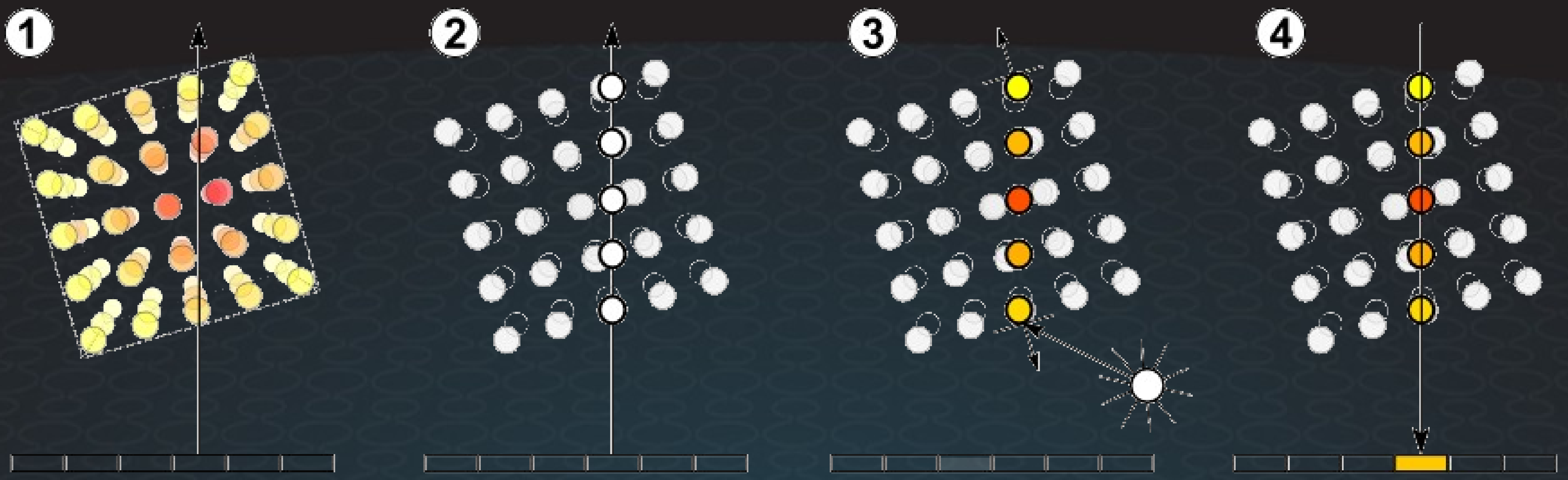
From A User Perspective

- Semi-Automatic technique:
  - [BPS97];
- Semi-Automatic technique:
  - [WDCPH07];





Ray Casting Overview

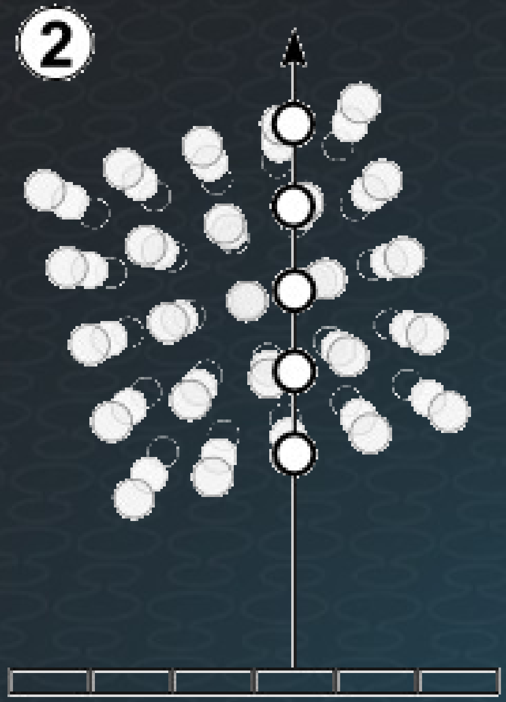


1) Ray Casting;
2) Sampling;
3) Shading;
4) Compositing.

Ray Casting

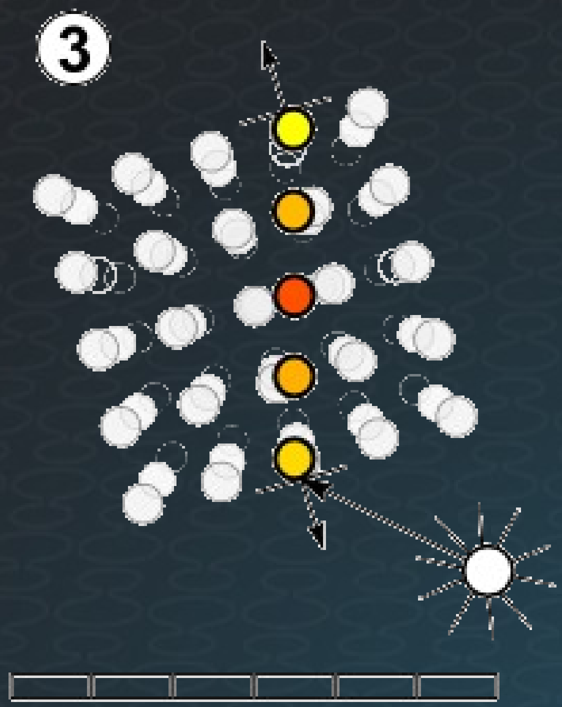
- For each pixel of the screen space:
  - Cast a ray;
  - Direction of observation;
  - Intersection problem:
    - Octrees.

Sampling



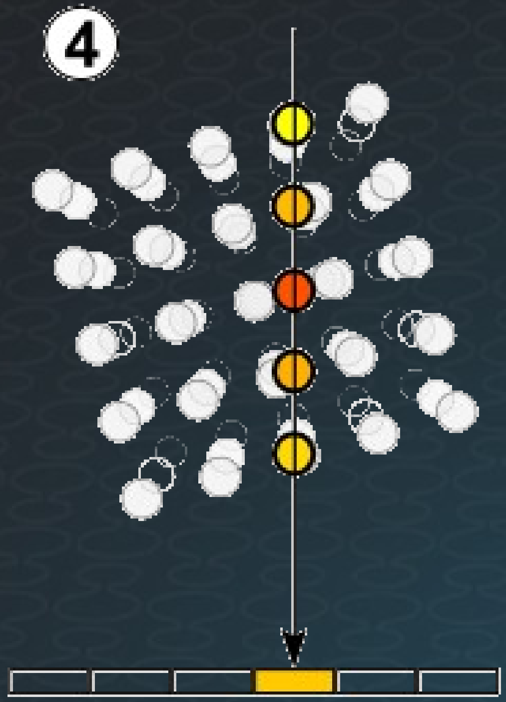
- Along each ray:
  - Sample the data along the ray;
    - Intersection with edges;
  - Compute the function value on samples
    - Apply the appropriate interpolant;

Shading



- For each sample:
  - Retrieve the corresponding color;
  - Compute the gradient of the field:
    - Normal of the corresponding isosurface;
  - Shade the sample accordingly, given:
    - The normal (gradient);
    - The color;
    - The view direction and the lights.

Compositing



- Integrate all the contributions;
- Along each ray:
  - Go from the back to the front;
  - At each sample:
    - Retrieve the opacity value;
- Composite all along.

Alpha-blending

- OpenGL facility to blend color contributions;
- The order matters!
  - $C_a = (0,0,0)$, $\alpha_a = 1$;
  - $C_b = (0,1,0)$, $\alpha_b = 0.5$;
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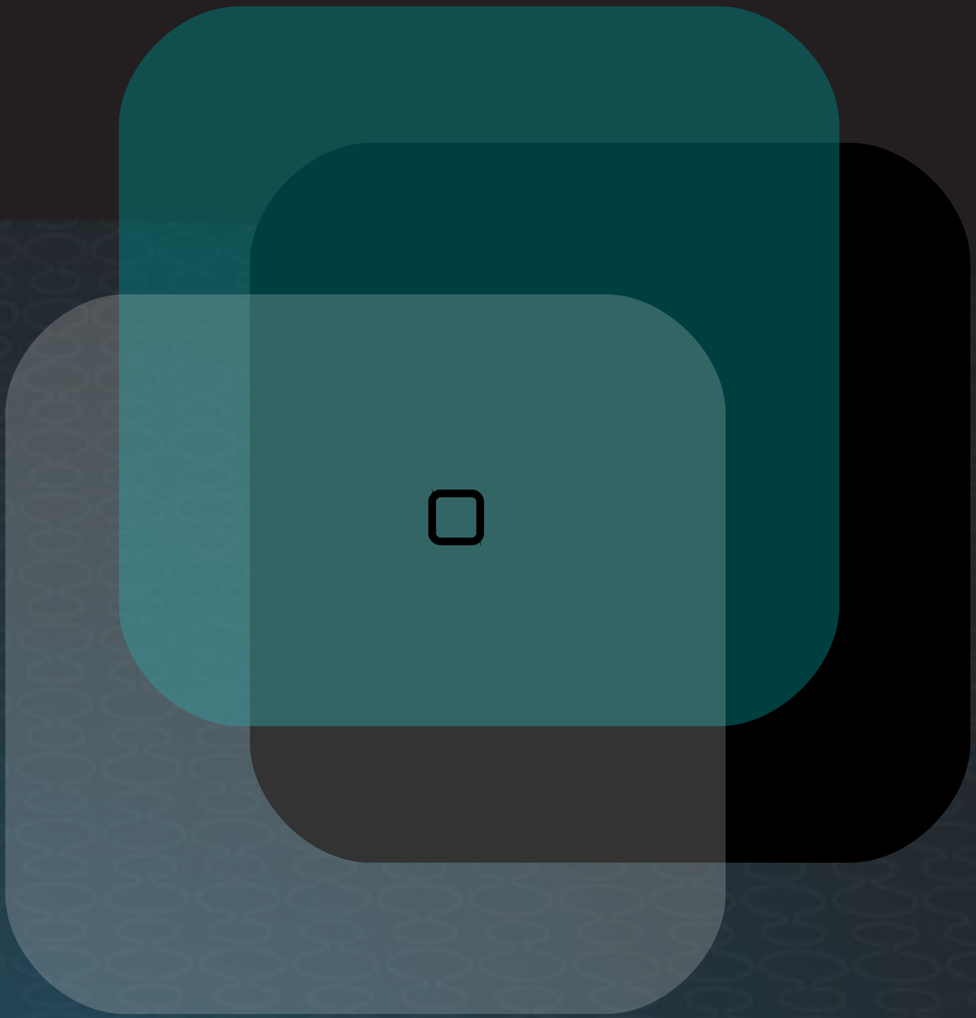

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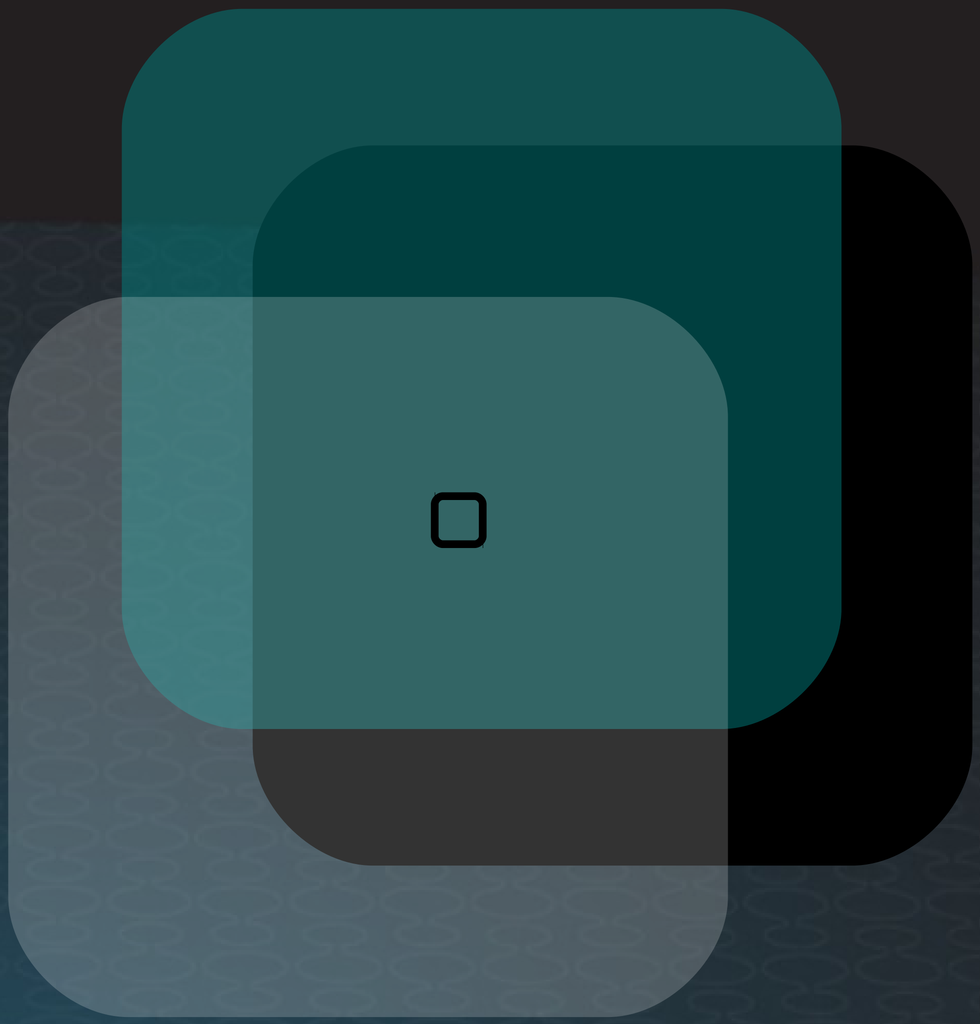
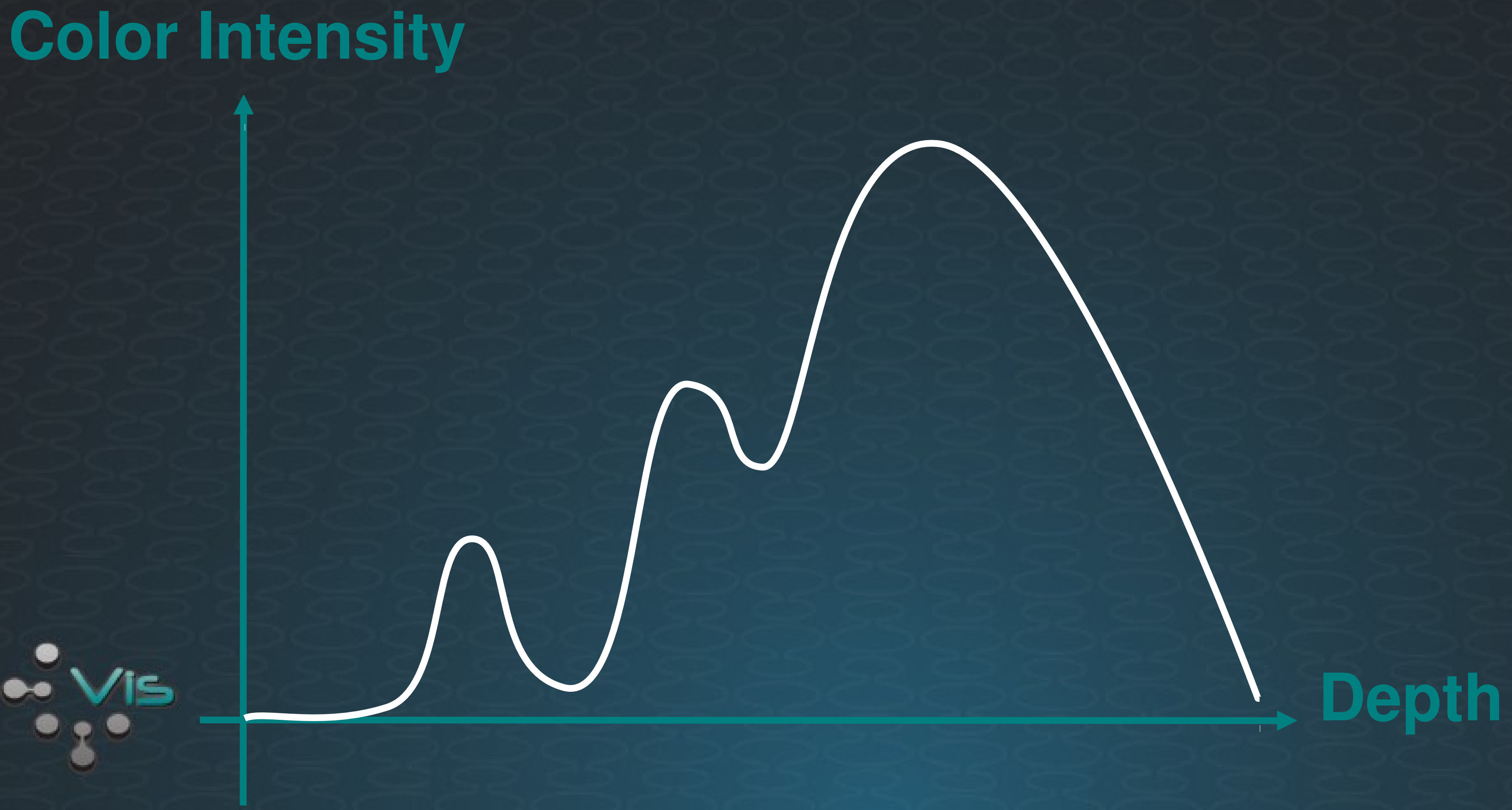


$$C'(i) = \alpha(i)*C(i) + (1 - \alpha(i))*\alpha(i-1)*C(i-1)$$

$$\alpha'(i) = \alpha(i) + (1 - \alpha(i))*\alpha(i-1)$$

Compositing Schemes

- Color intensity along the ray:



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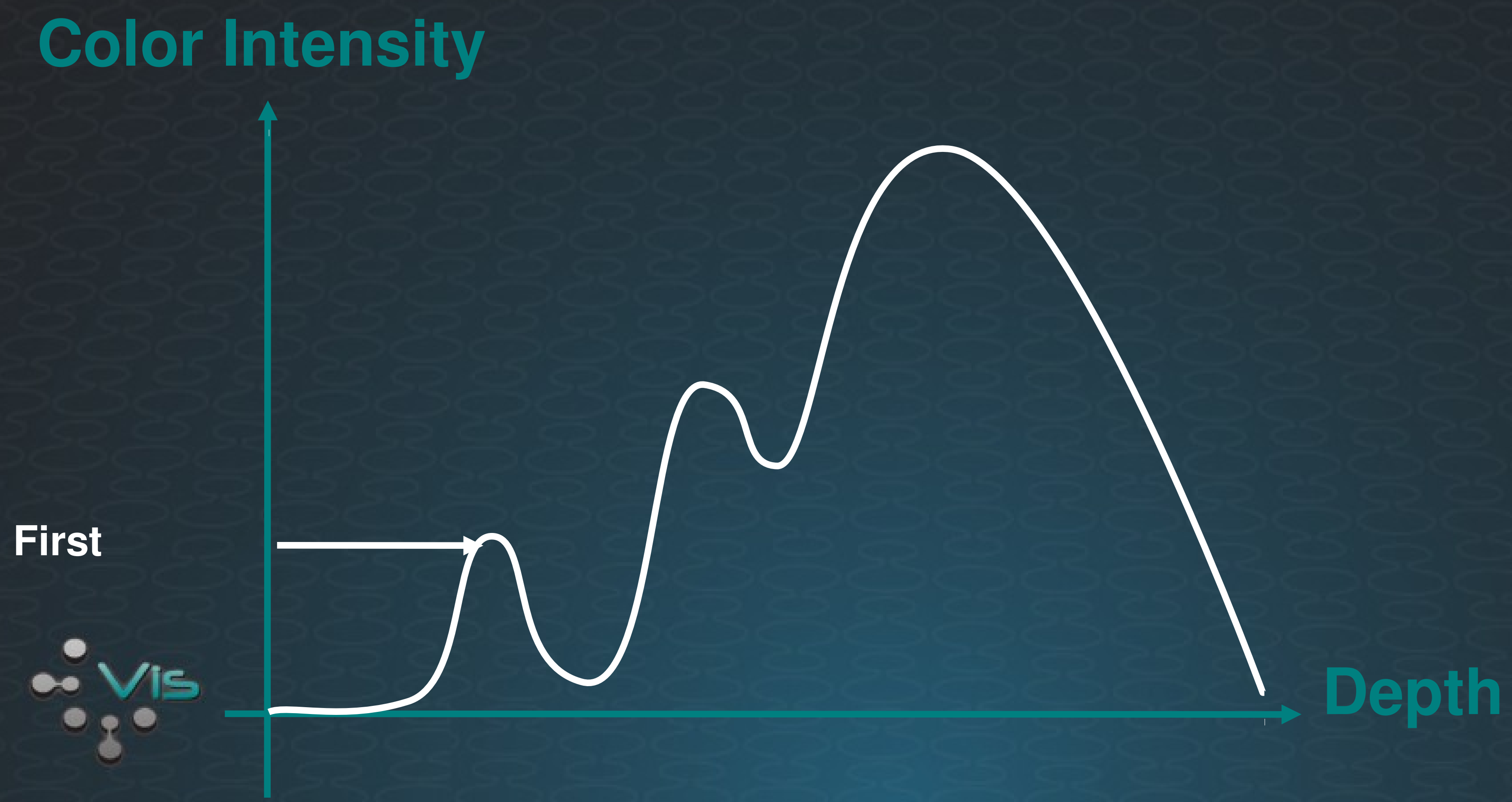

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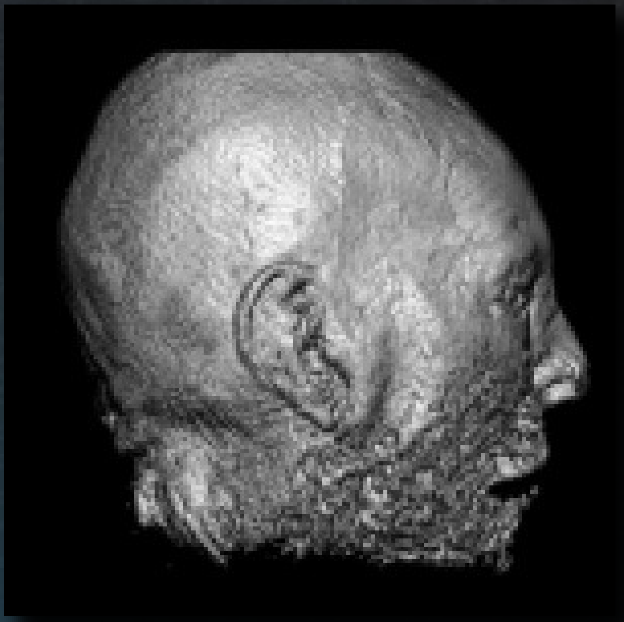

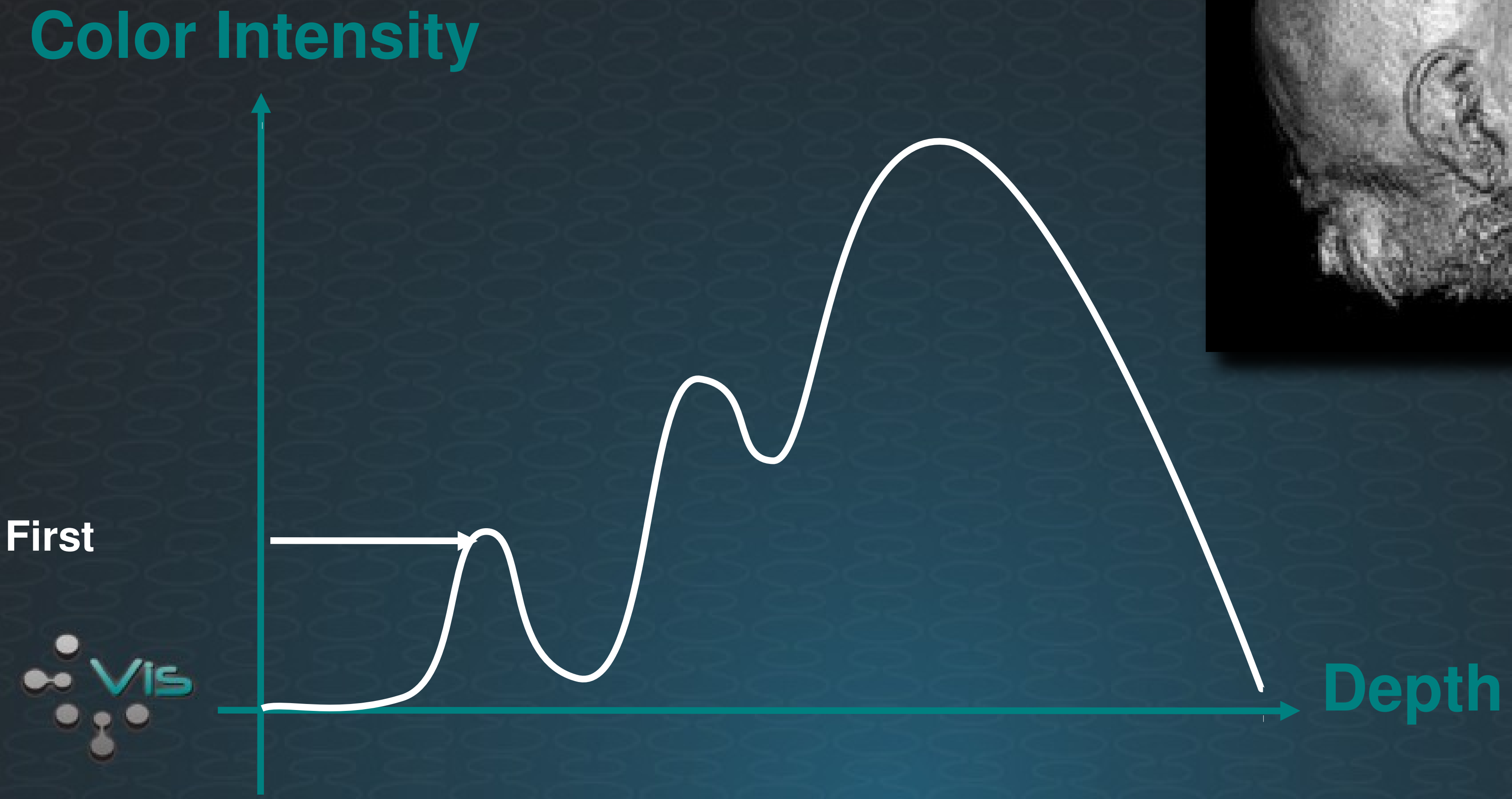

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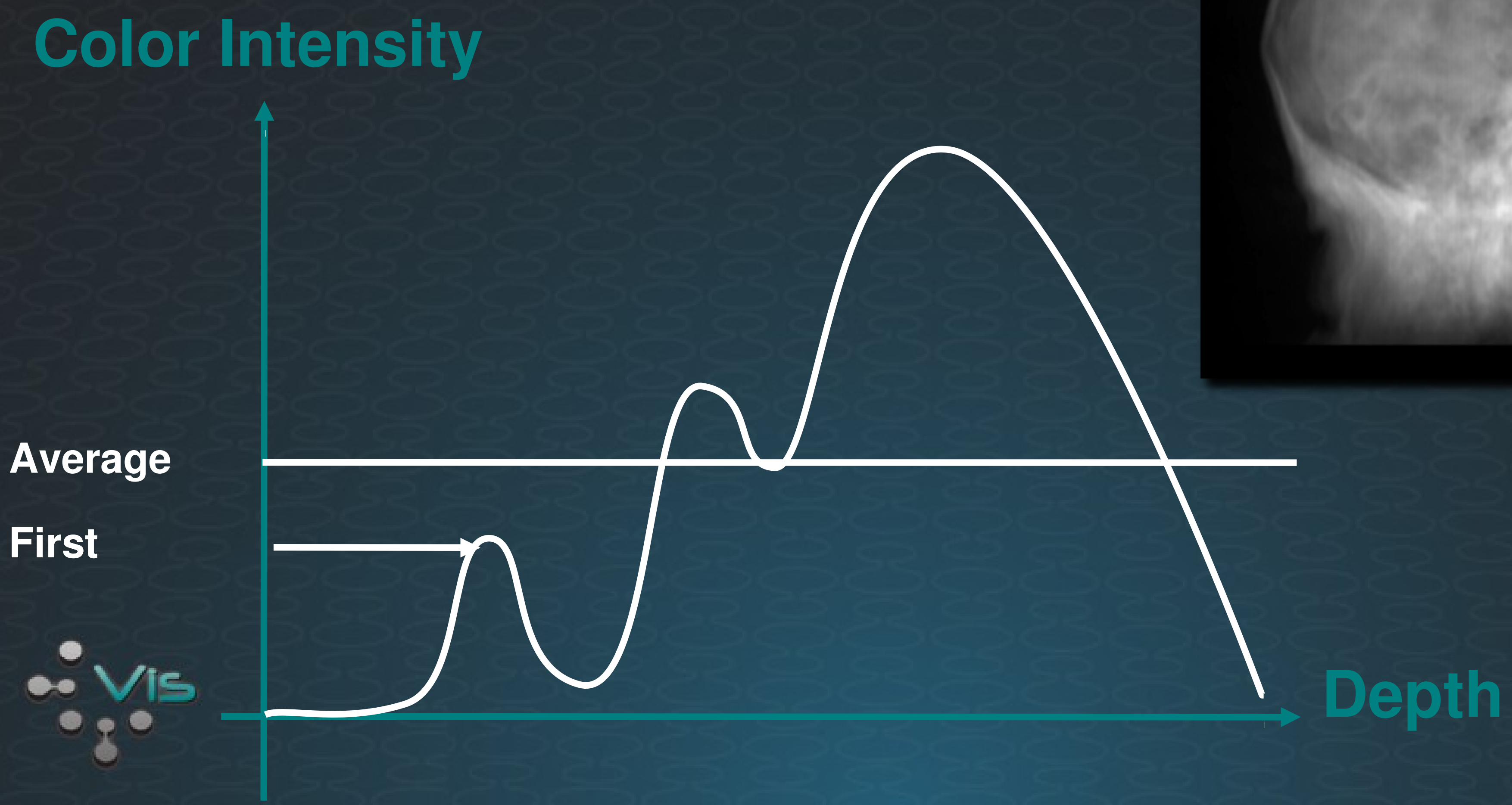

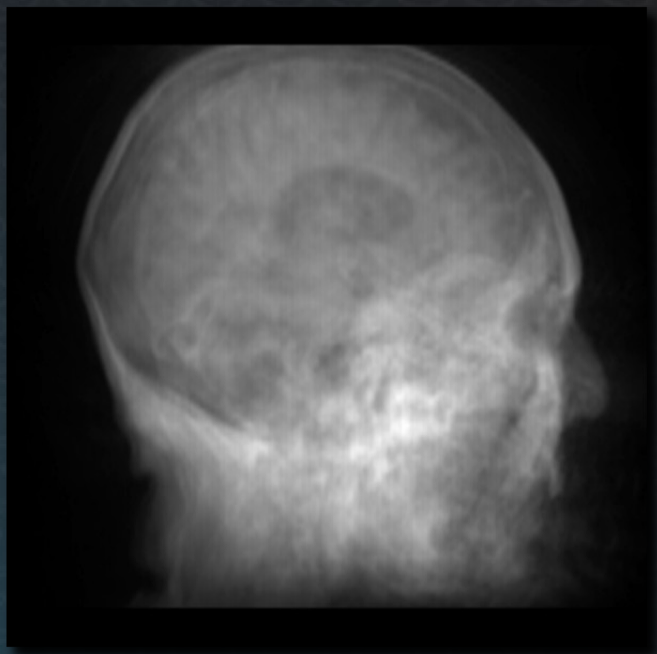

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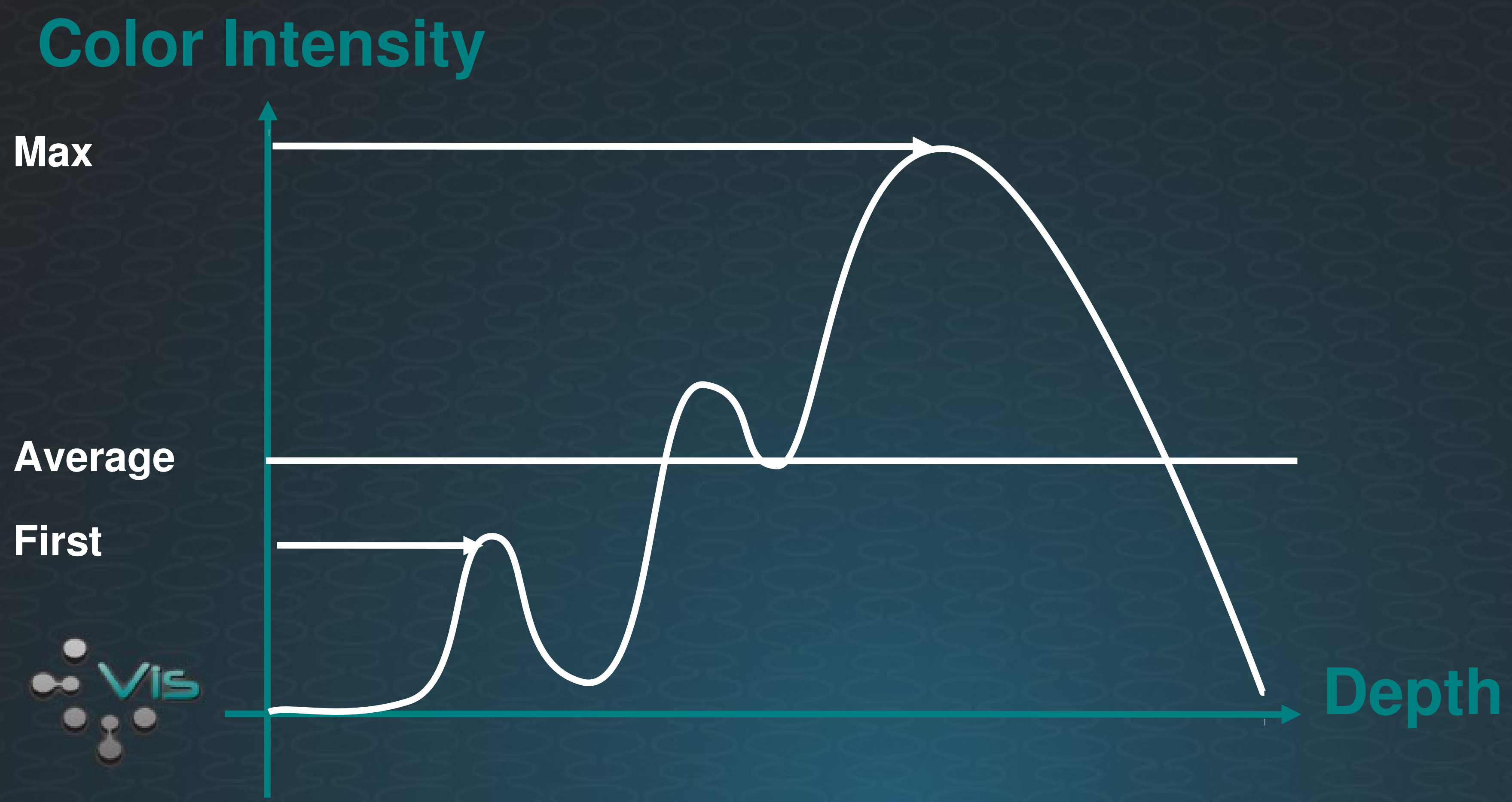

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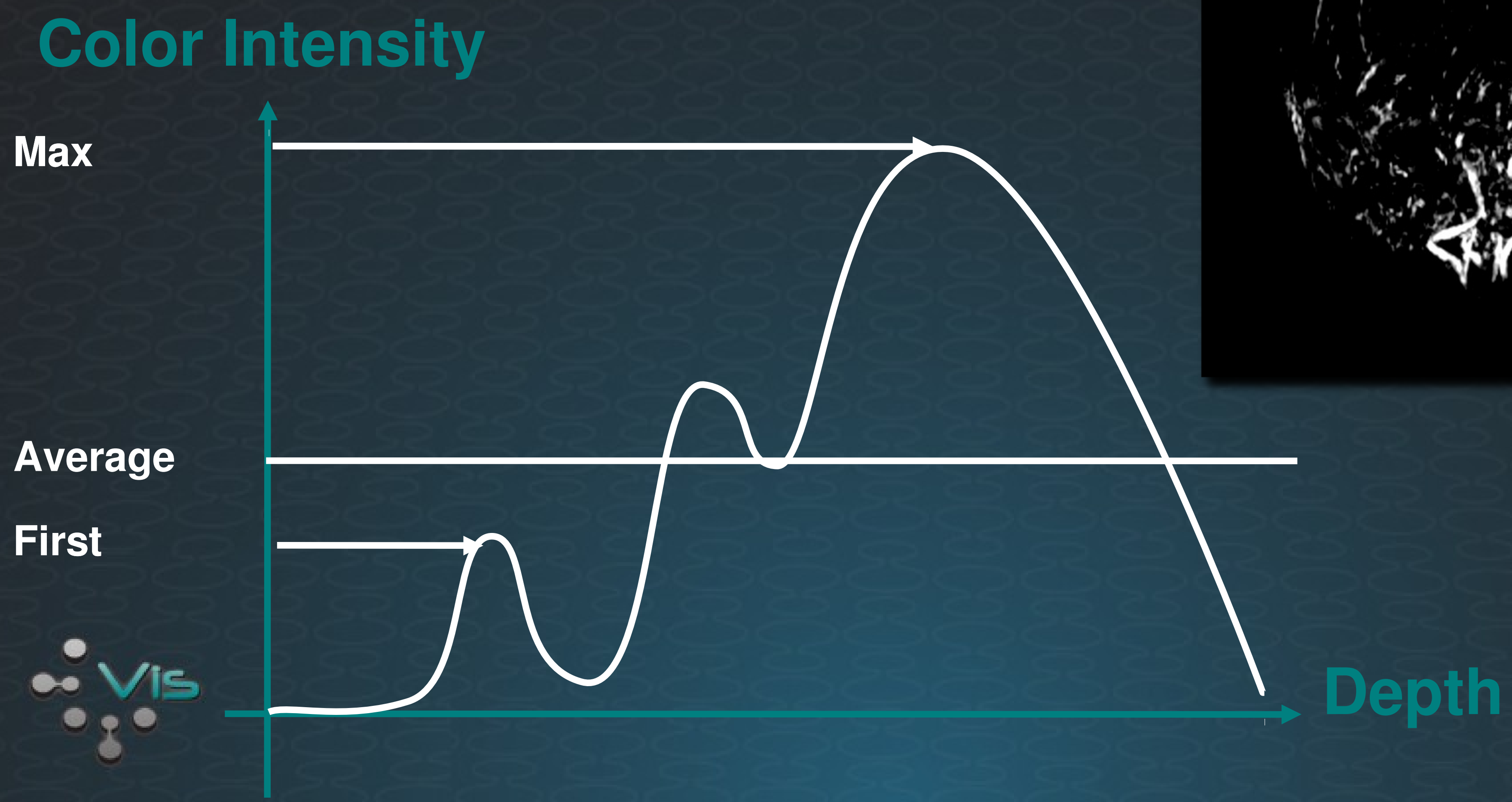

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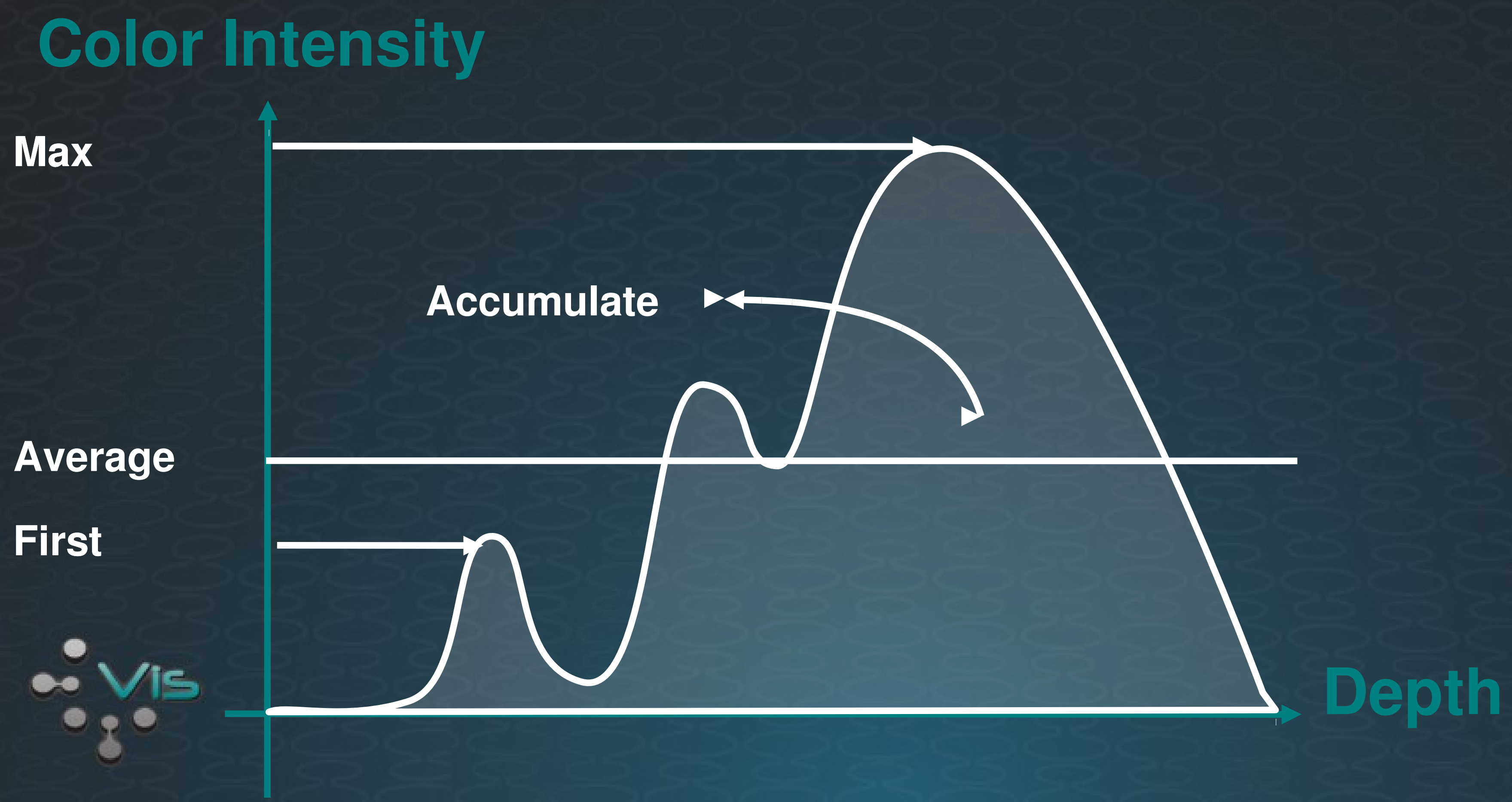

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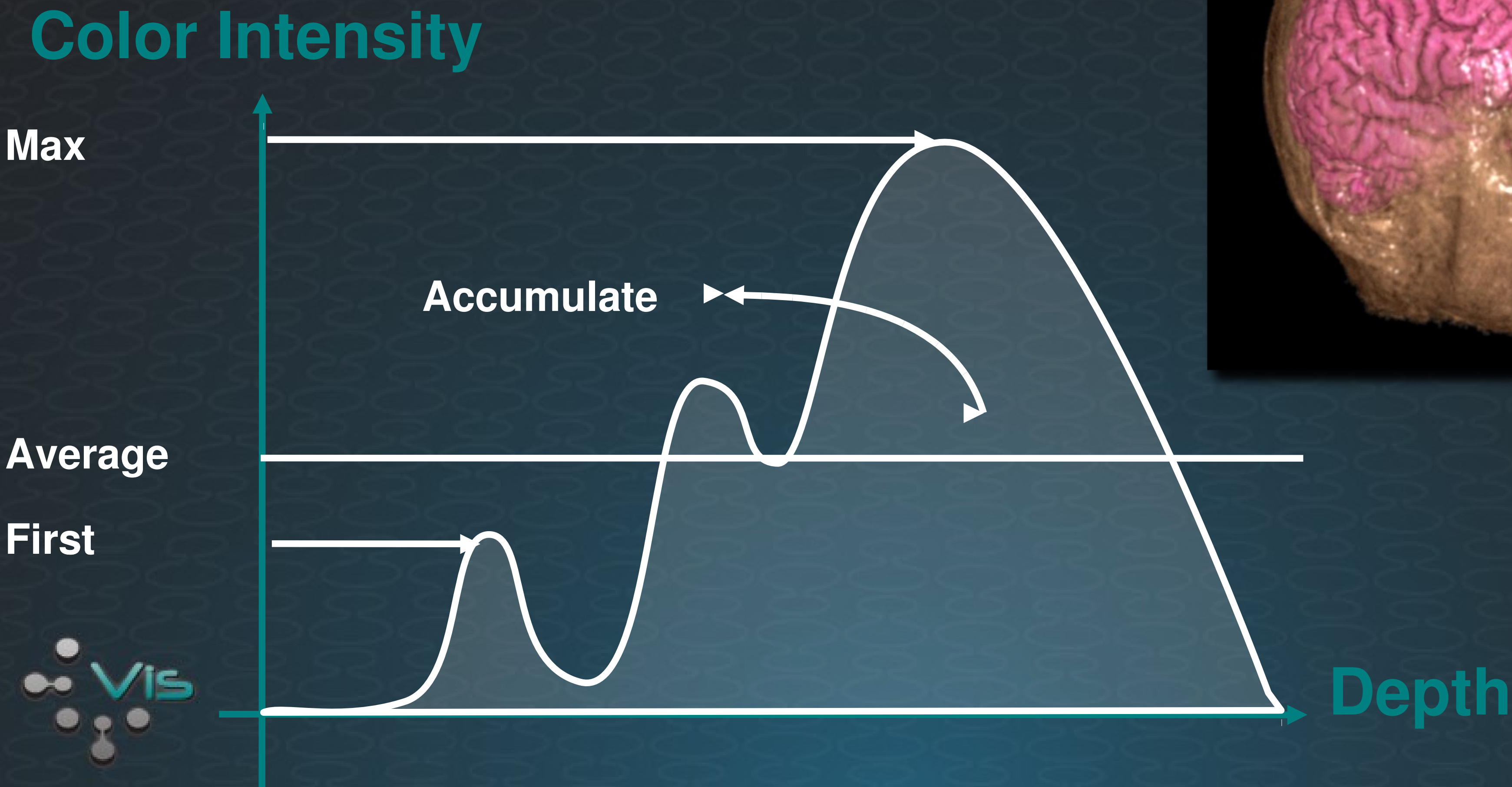

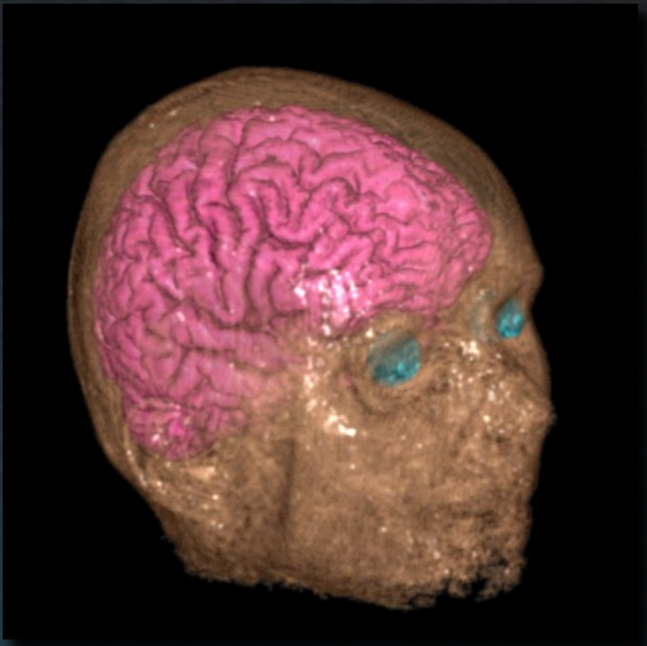

Compositing Along the Ray

- From Back to Front:

$$C'(i) = \alpha(i)*C(i) + (1 - \alpha(i))*\alpha(i-1)*C(i-1)$$

$$\alpha'(i) = \alpha(i) + (1 - \alpha(i))*\alpha(i-1)$$

Ray Casting: Discussion

- Avantages:
  - Simple algorithm;
  - Inherently parallel;
  - Can extend lighting model (diffraction);
  - High quality renderings.
- Drawbacks:
  - **SLOW!!!!**
    - Lots of rays;
    - Lots of samples;
  - Dense samples;
  - Not out-of-core...

Simple Optimizations

- Make the Ray Casting algorithm “Transfer Function Aware”:
  - No need to cast ray or sample in regions with no visual properties;
  - Segmentation of the feature space.

- Other advanced techniques...
  - On Thursday with Attila!