CSC 544
Data Visualization

Direct Volume Rendering

Slides courtesy of Joshua Levine
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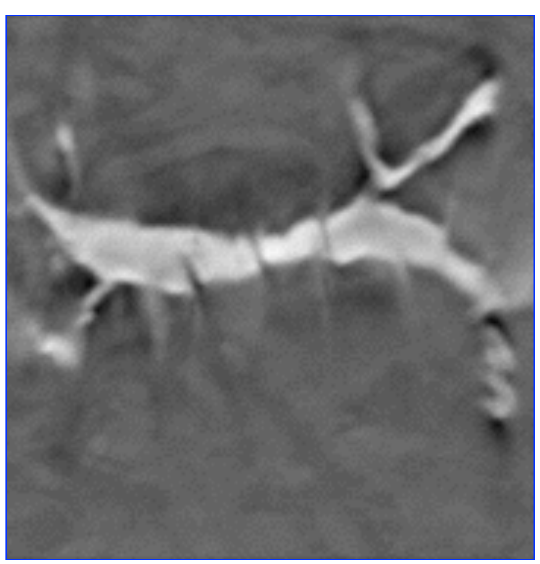
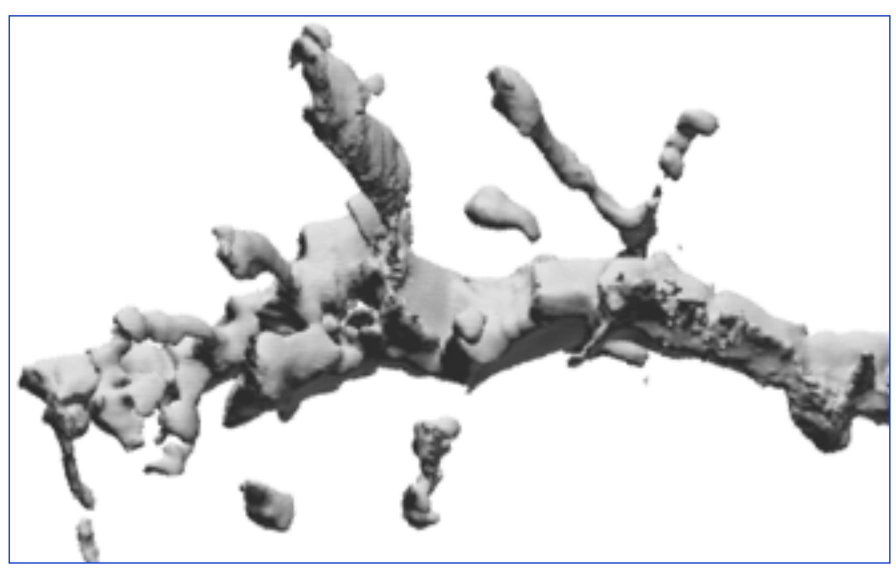
Limitations of Isosurfaces

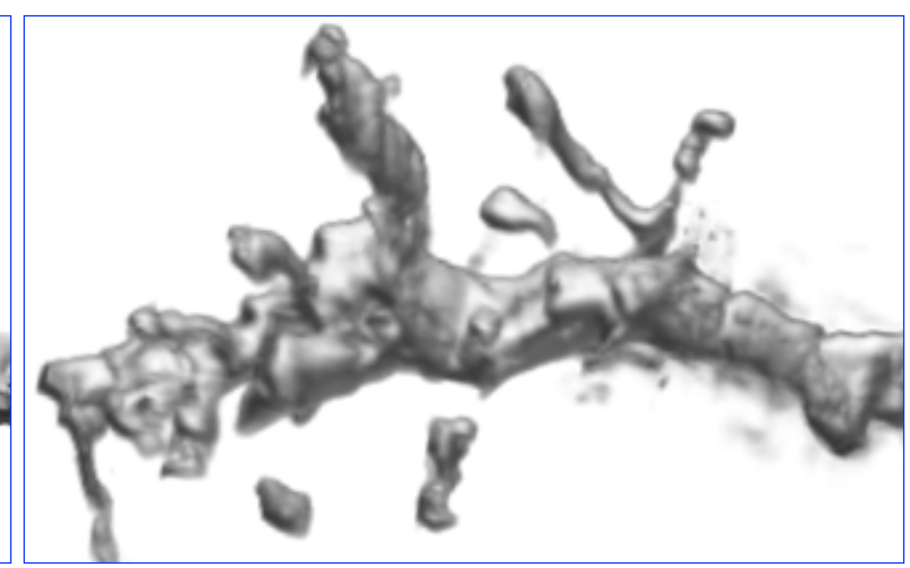
- Isosurfacing is "binary"
  - What about points inside isosurface?
  - How does each voxel contributes to image?
- Is a hard, distinct boundary necessarily appropriate for the visualization task?



Slice

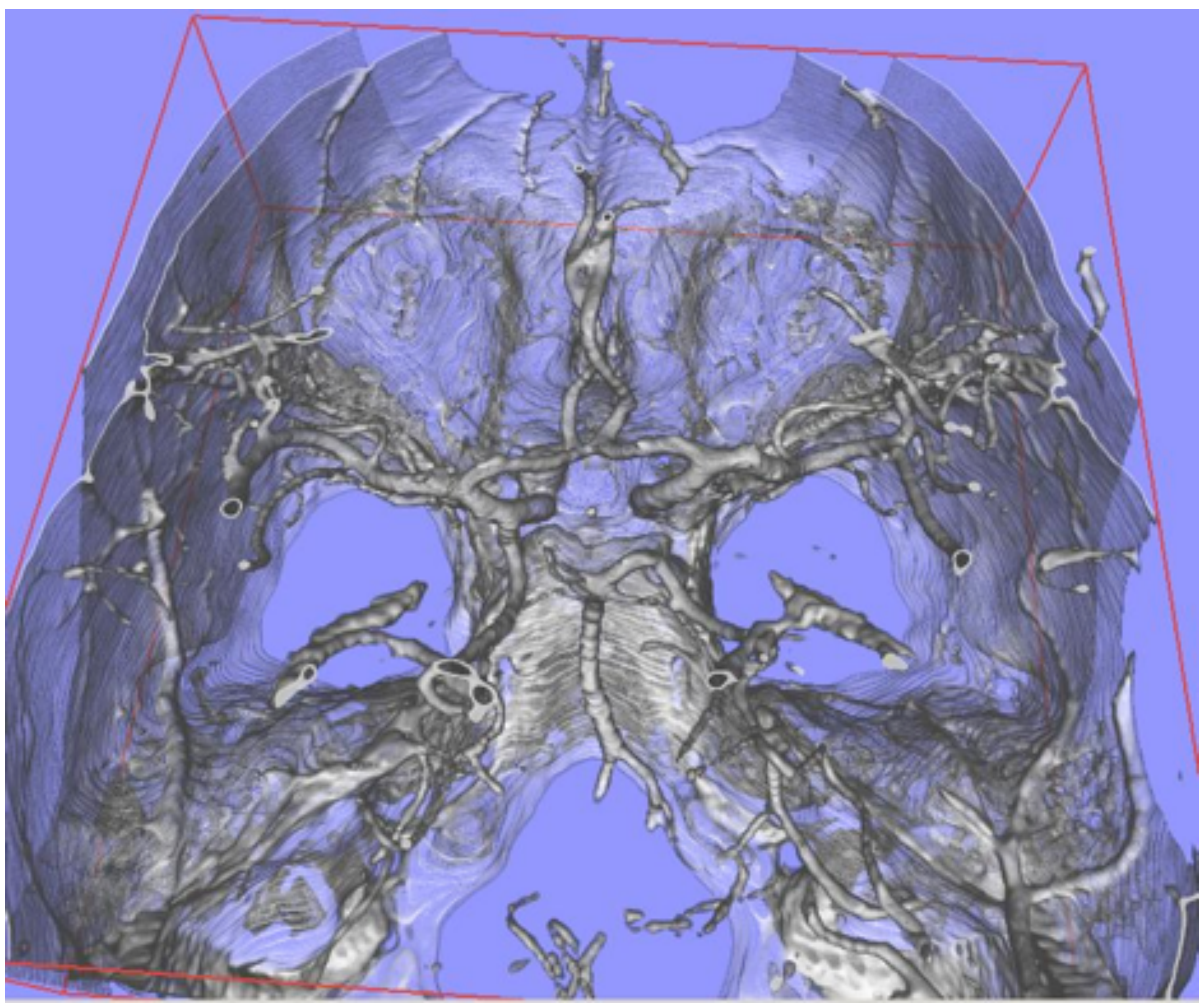


Isosurface

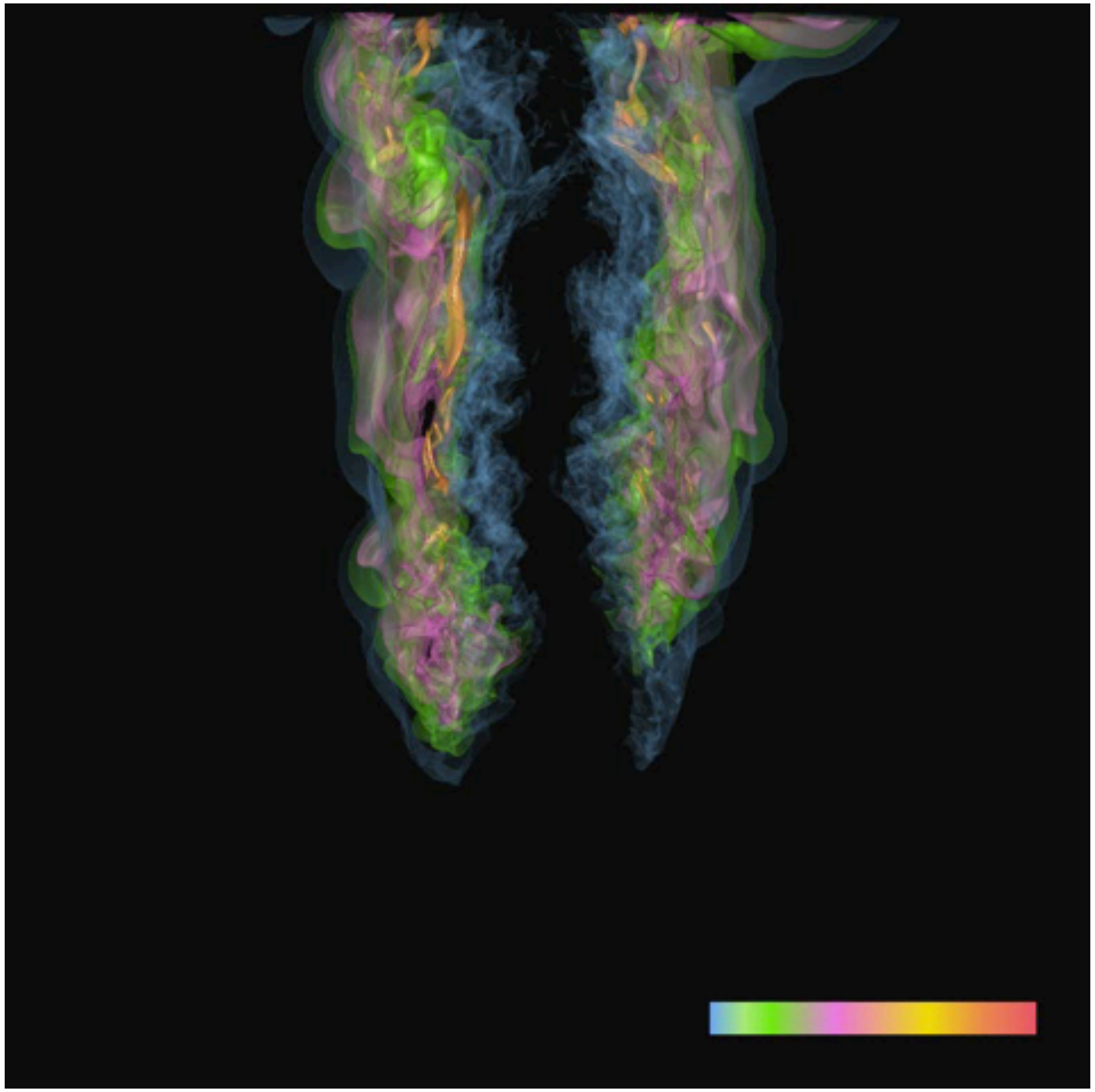


Volume Rendering

- Isosurfacing is poor for ...
  - Measured, "real-world" (noisy) data
  - Amorphous, "soft" objects



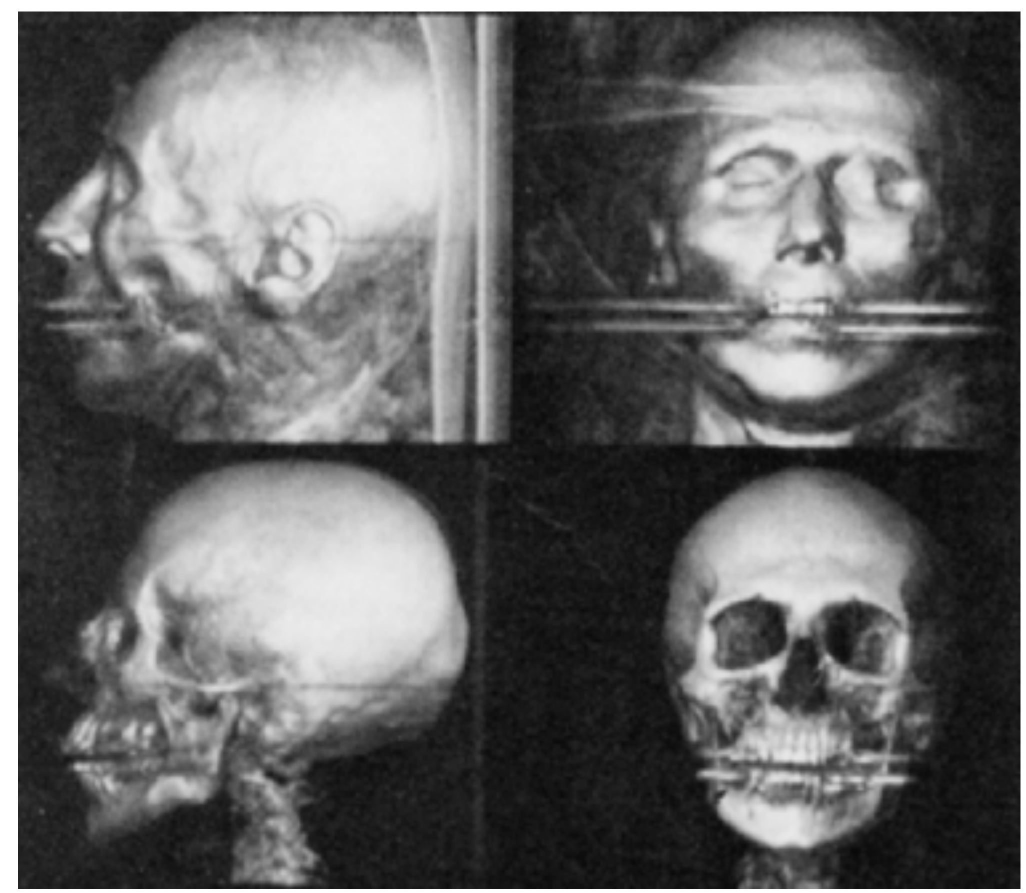
http://www.cg.informatik.uni-siegen.de/



http://vis.cs.ucdavis.edu/gallery/Yu/combustion/

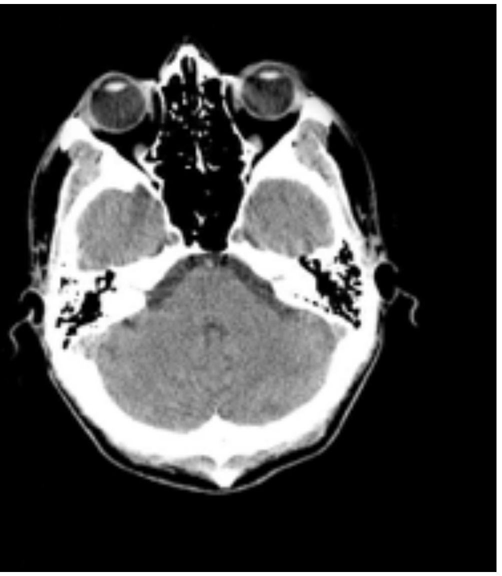
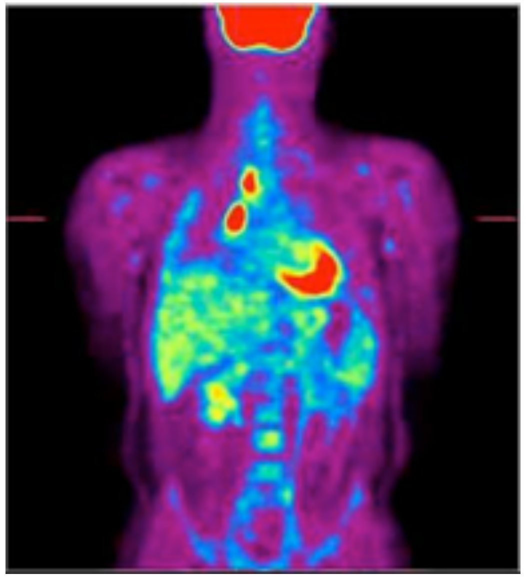
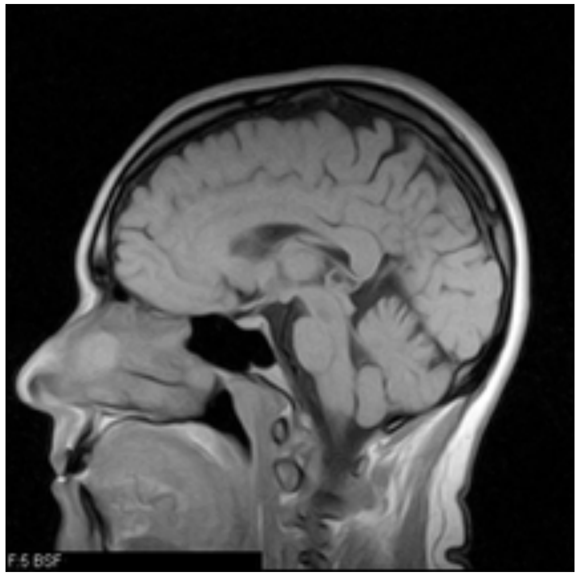
Why Volume Rendering?

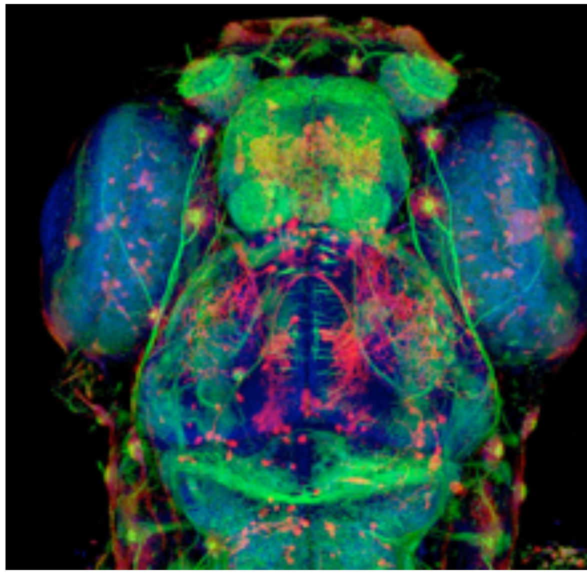
- Allows every voxel to contribute to image
- Provides greater flexibility



Marc Levoy, Display of Surfaces from Volume Data, 1988

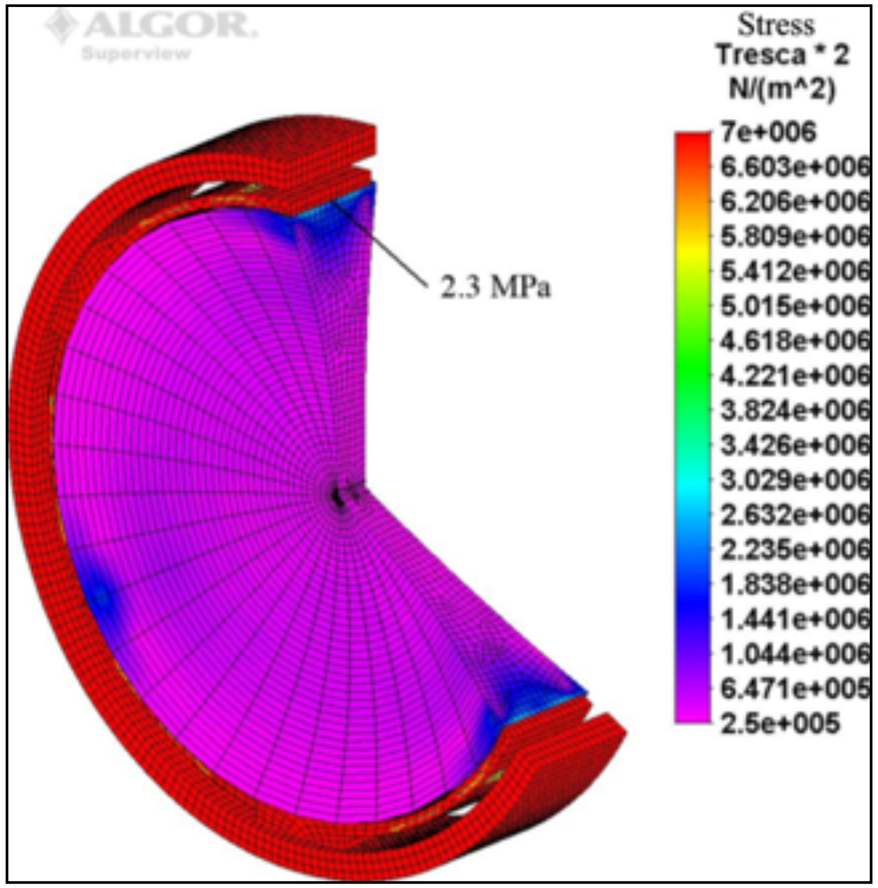
- Measured sources of volume data
  - CT (computed tomography)
  - PET (positron emission tomography)
  - MRI (magnetic resonance imaging)
  - Ultrasound
  - Confocal Microscopy

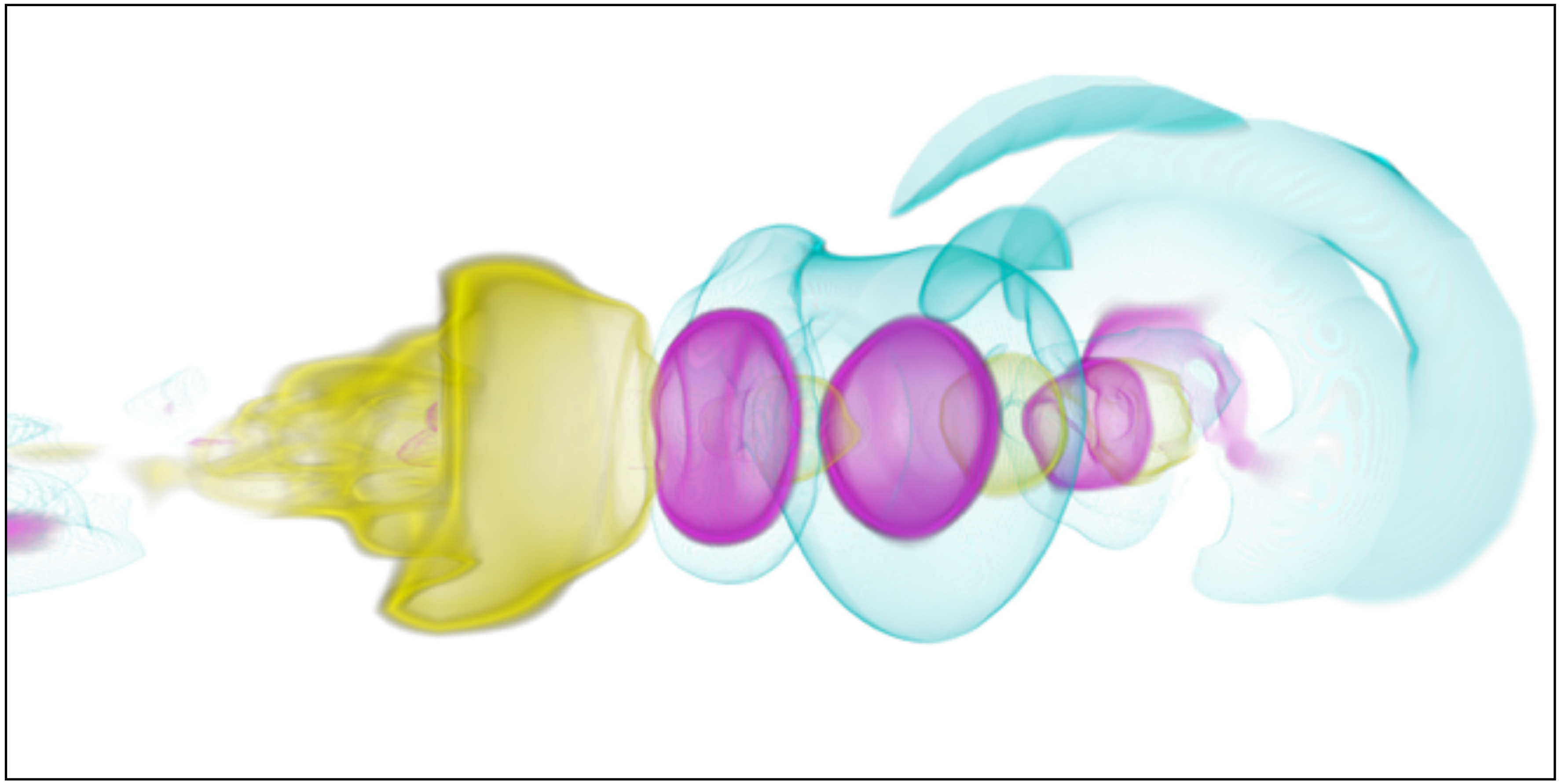






- Synthetic sources of volume data
  - CFD (computational fluid dynamics)
  - Voxelization of discrete geometry

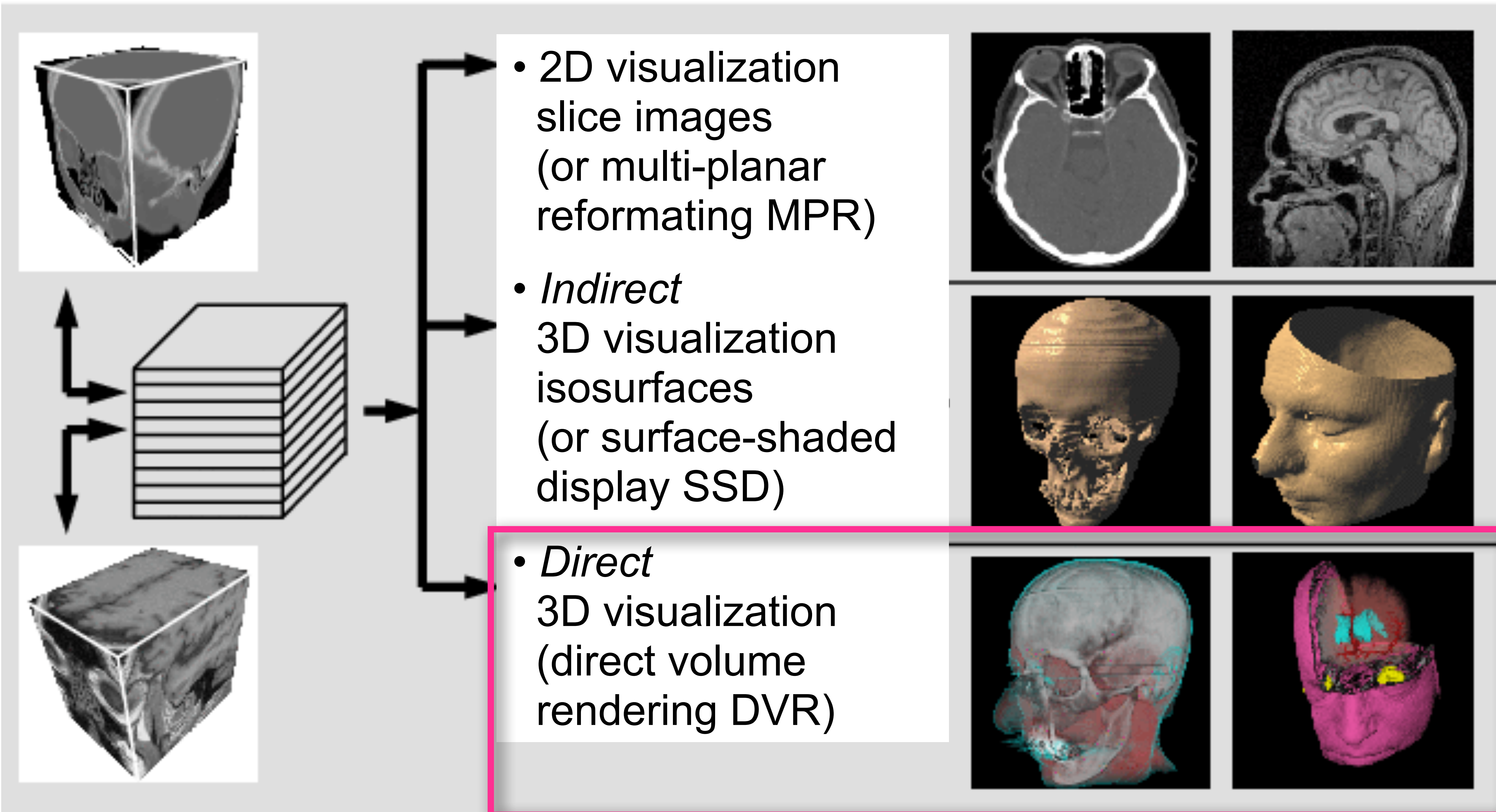
http://www.cs.utah.edu/~bnelson/publications.html



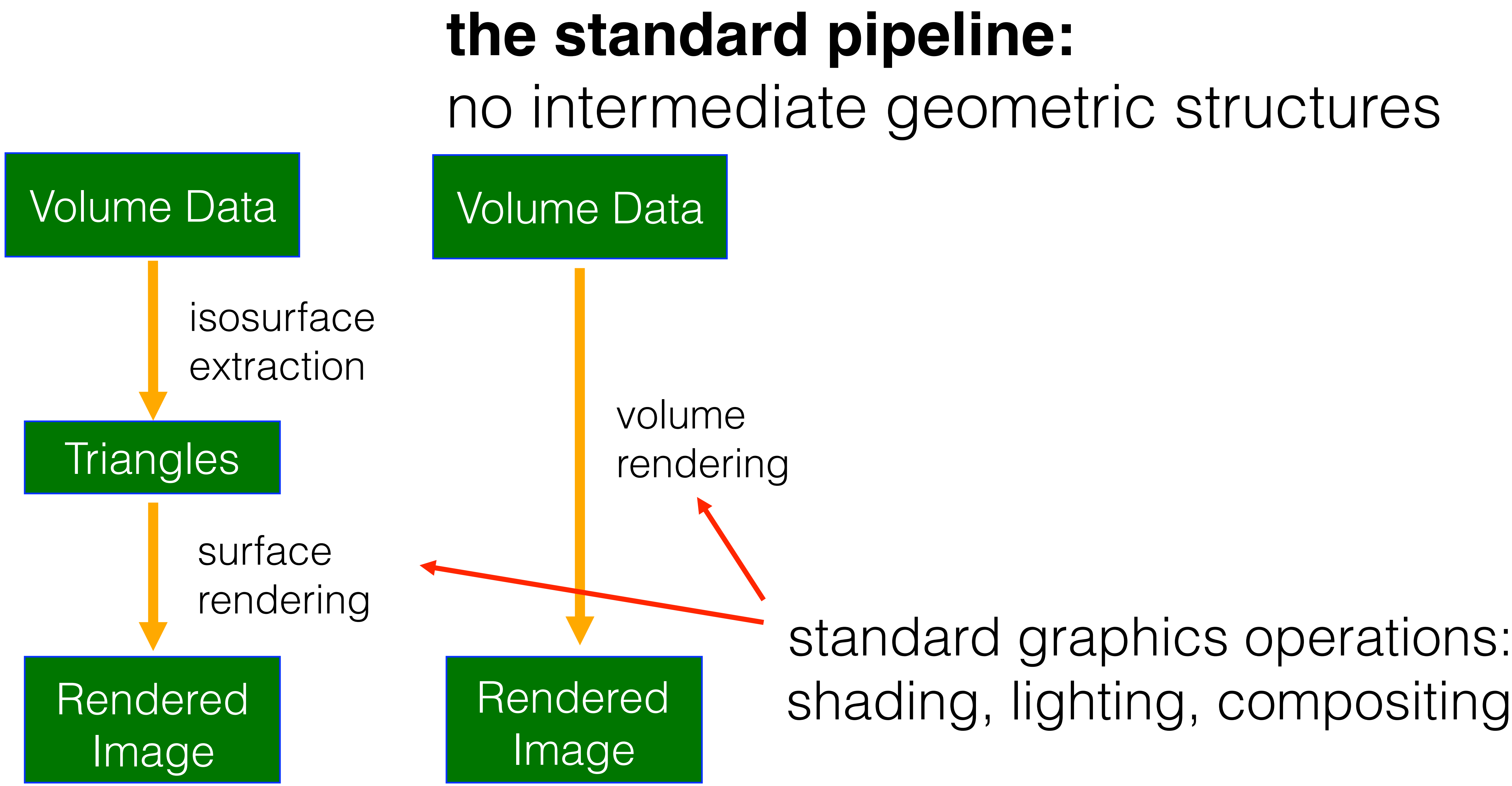


http://opticalengineering.spiedigitallibrary.org/article.aspx?articleid=1088924

Volume Rendering


• 2D visualization
slice images
(or multi-planar
reformating MPR)
• *Indirect*
3D visualization
isosurfaces
(or surface-shaded
display SSD)
• *Direct*
3D visualization
(direct volume
rendering DVR)

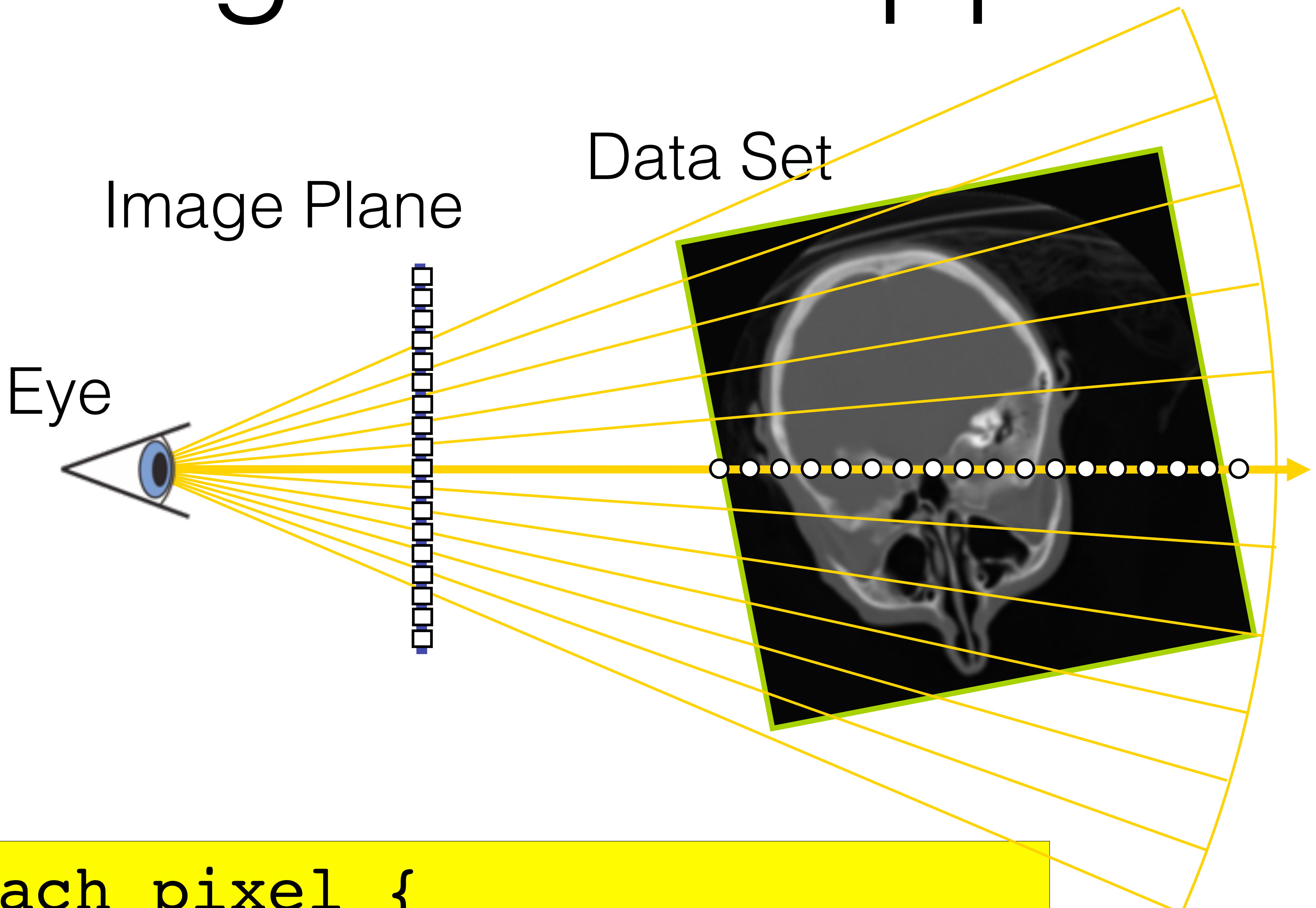
Pipelines: Isosurfacing vs. Volume Rendering



- DVR: Render volume **without extracting any surfaces**
- Map scalar values to **optical properties** (color, opacity)
- Needs an **optical model**
- Solve **volume rendering integral** for viewing rays into the volume

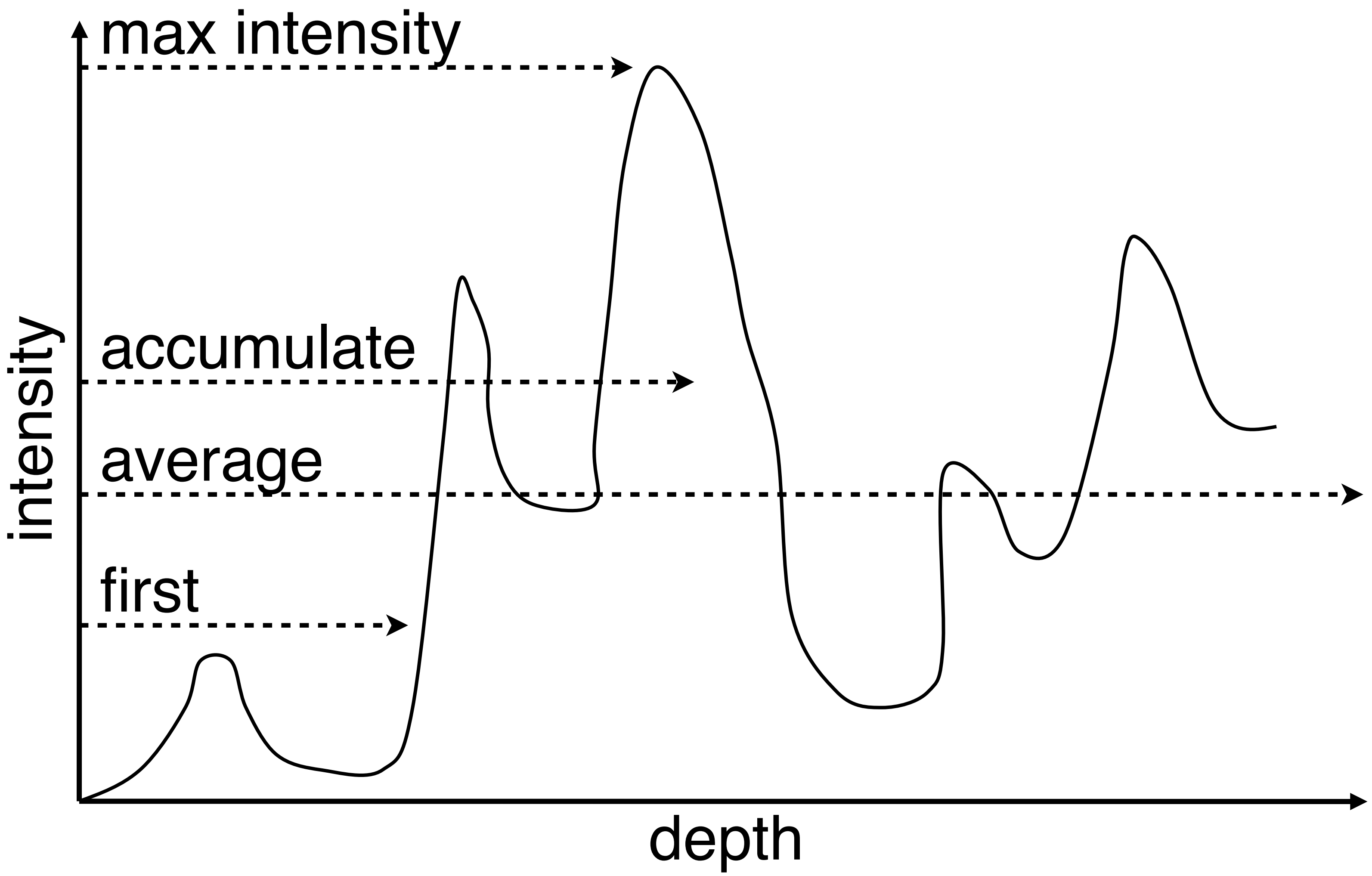
Volume Ray Casting

Image order approach

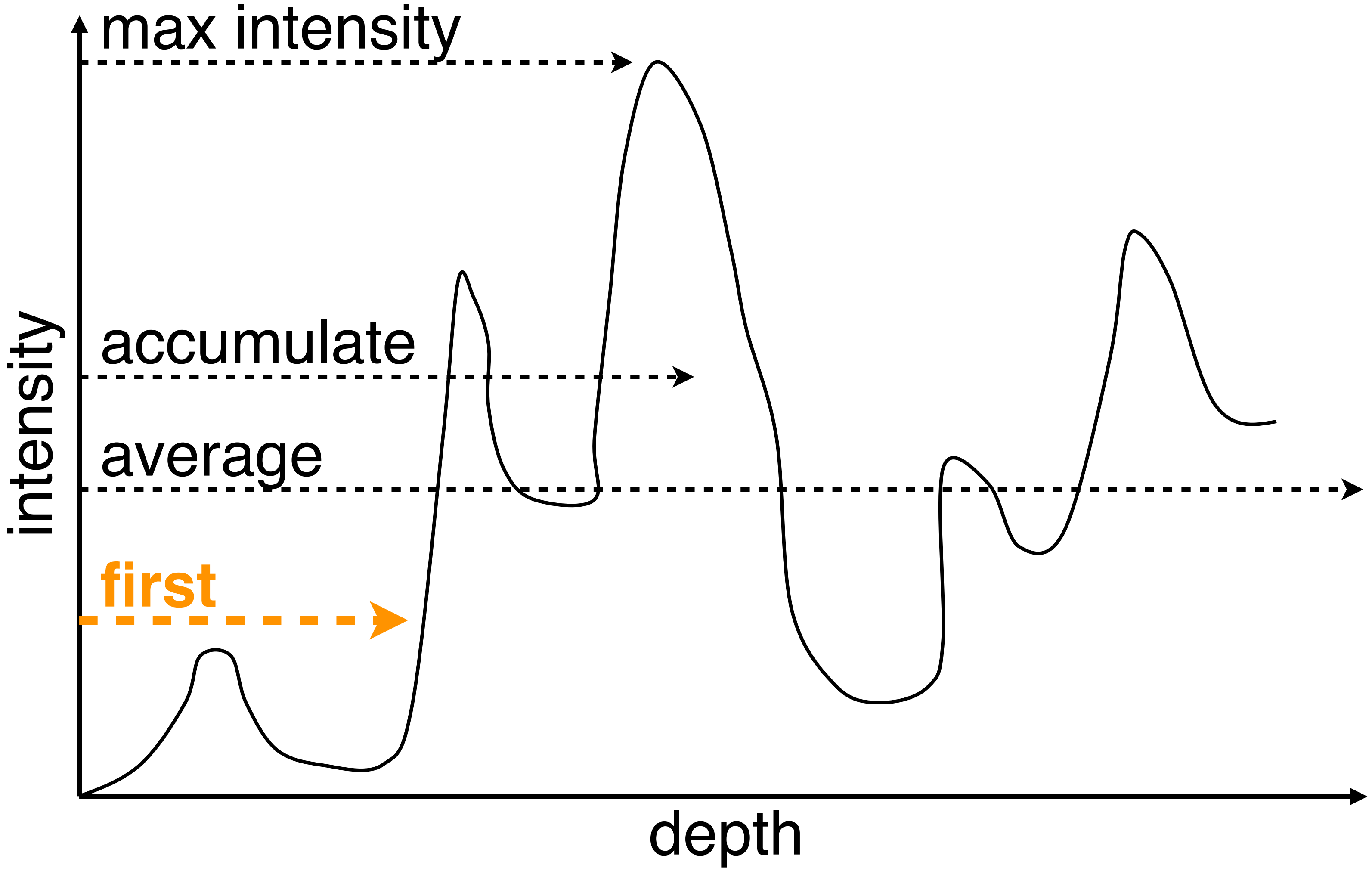



```
For each pixel {
   calculate color of the pixel
}
```

Pixel Compositing Schemes

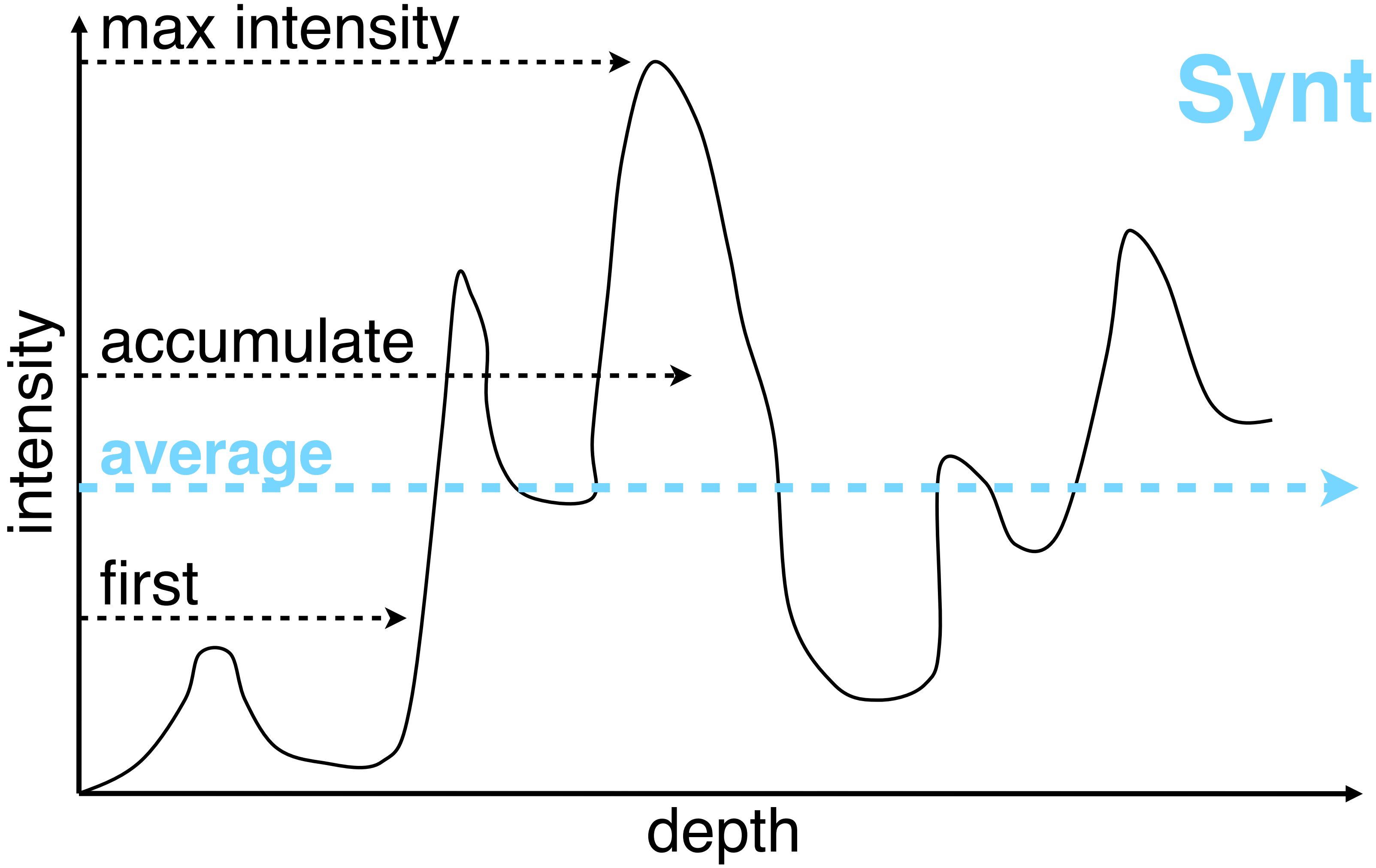


Pixel Compositing Schemes

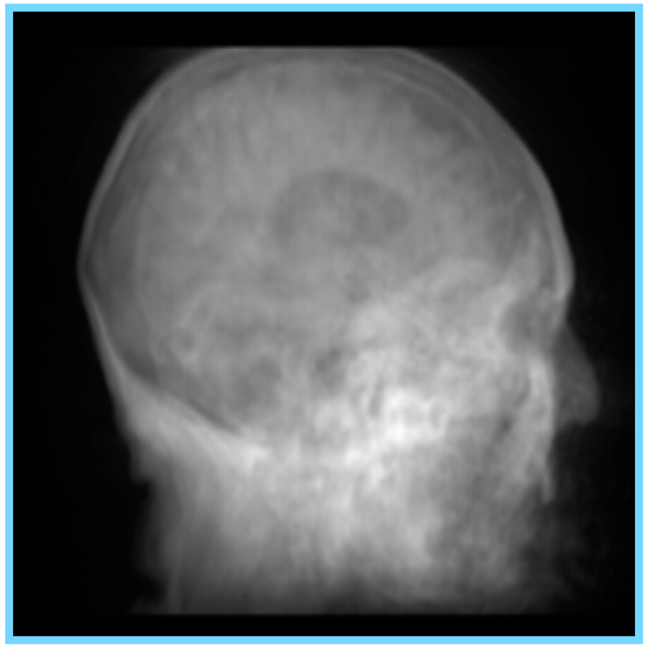


Exact Isosurface

Pixel Compositing Schemes



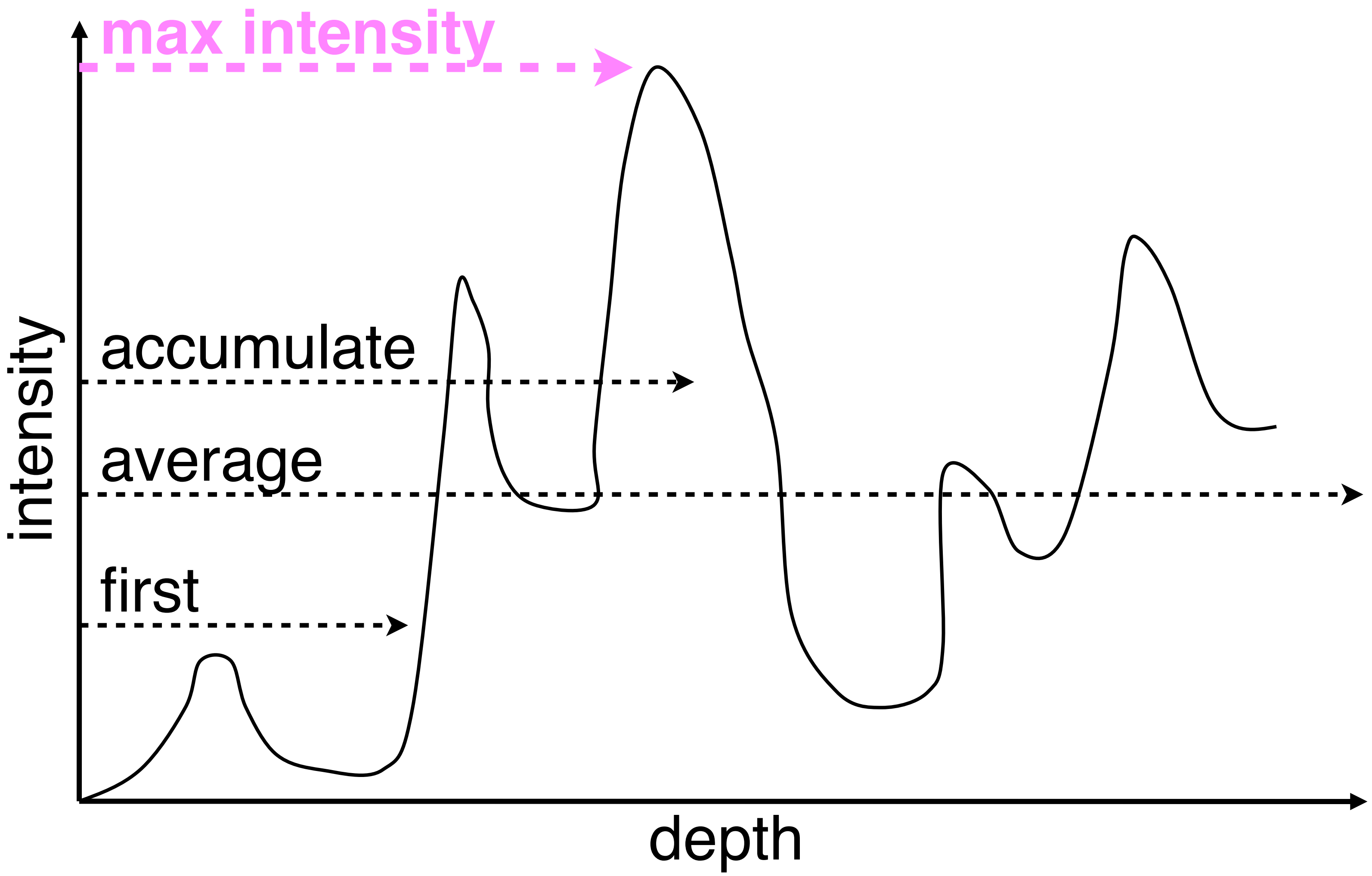
Synthetic Reprojection

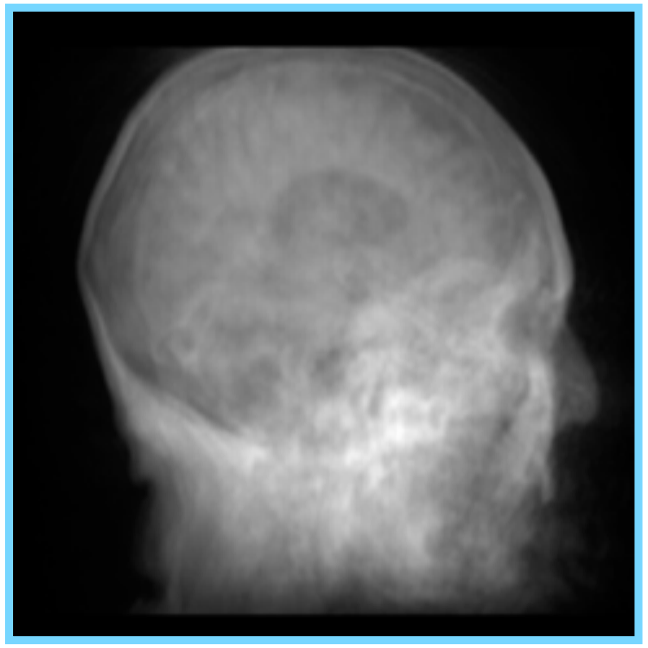


Similar to X-rays

maximum intensity projection (MIP)

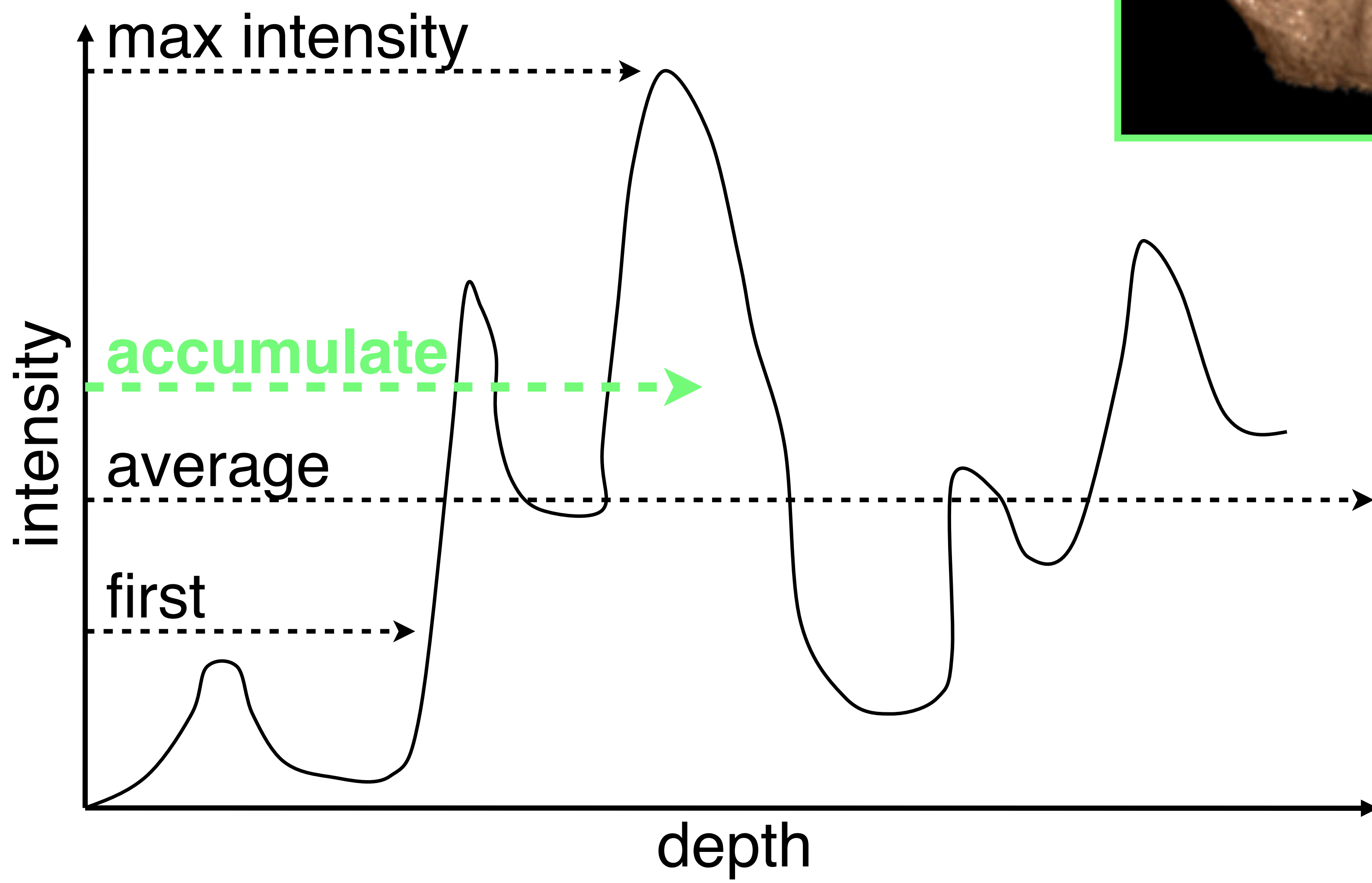
Pixel Compositing Schemes

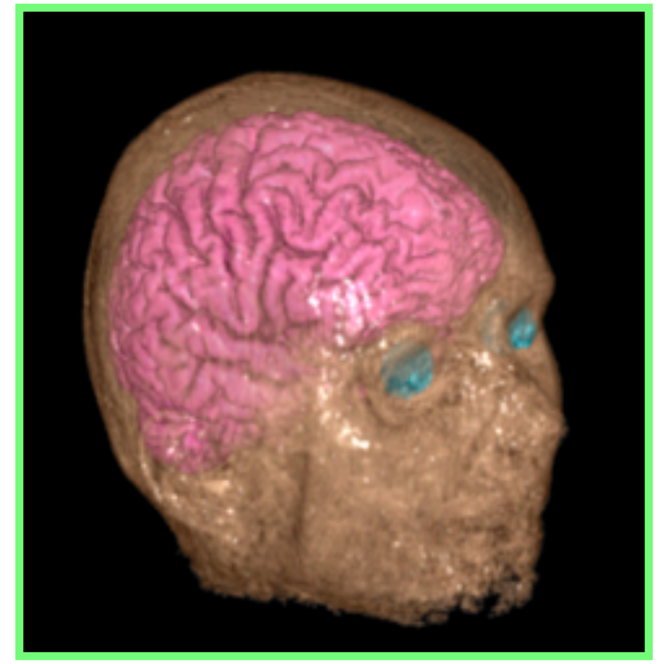


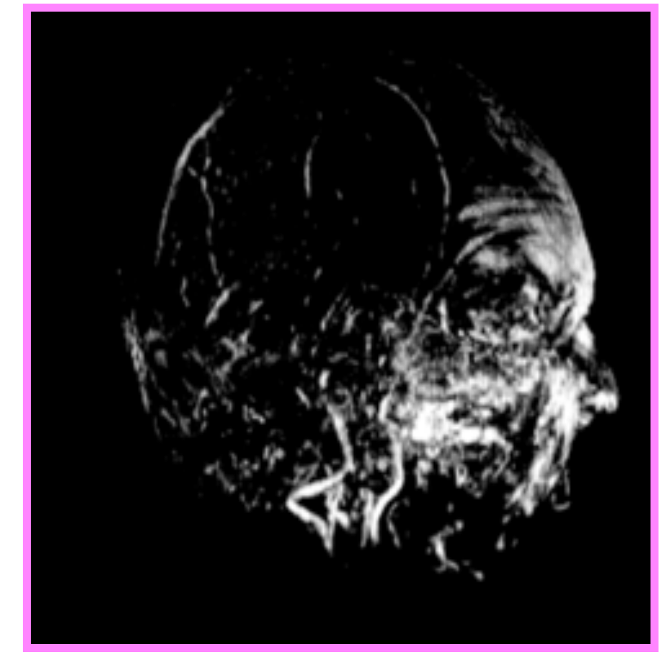


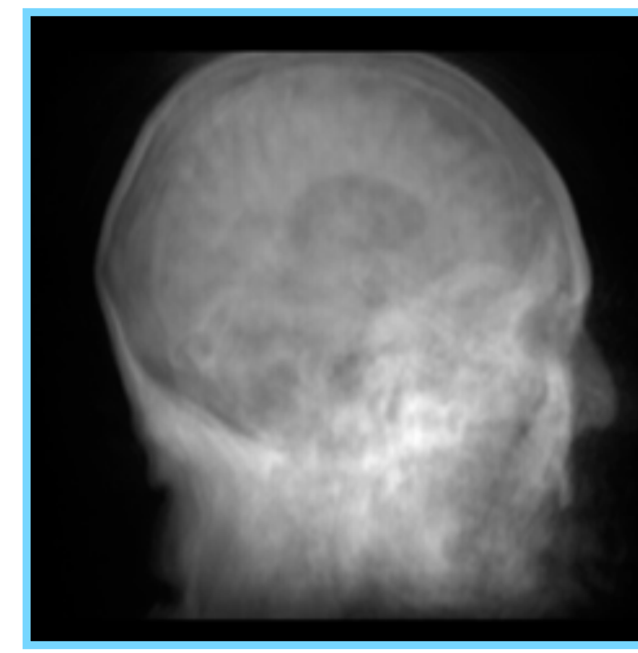
Used in PET and Magnetic Resonance Angiograms

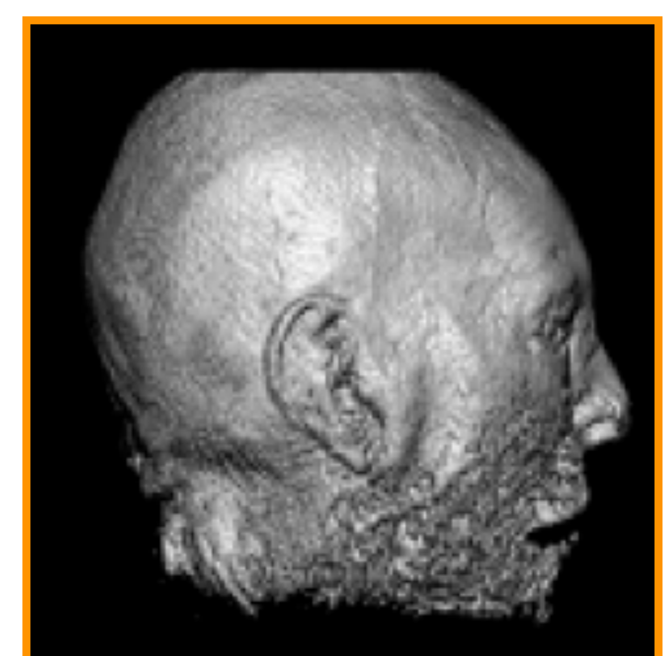
Pixel Compositing Schemes





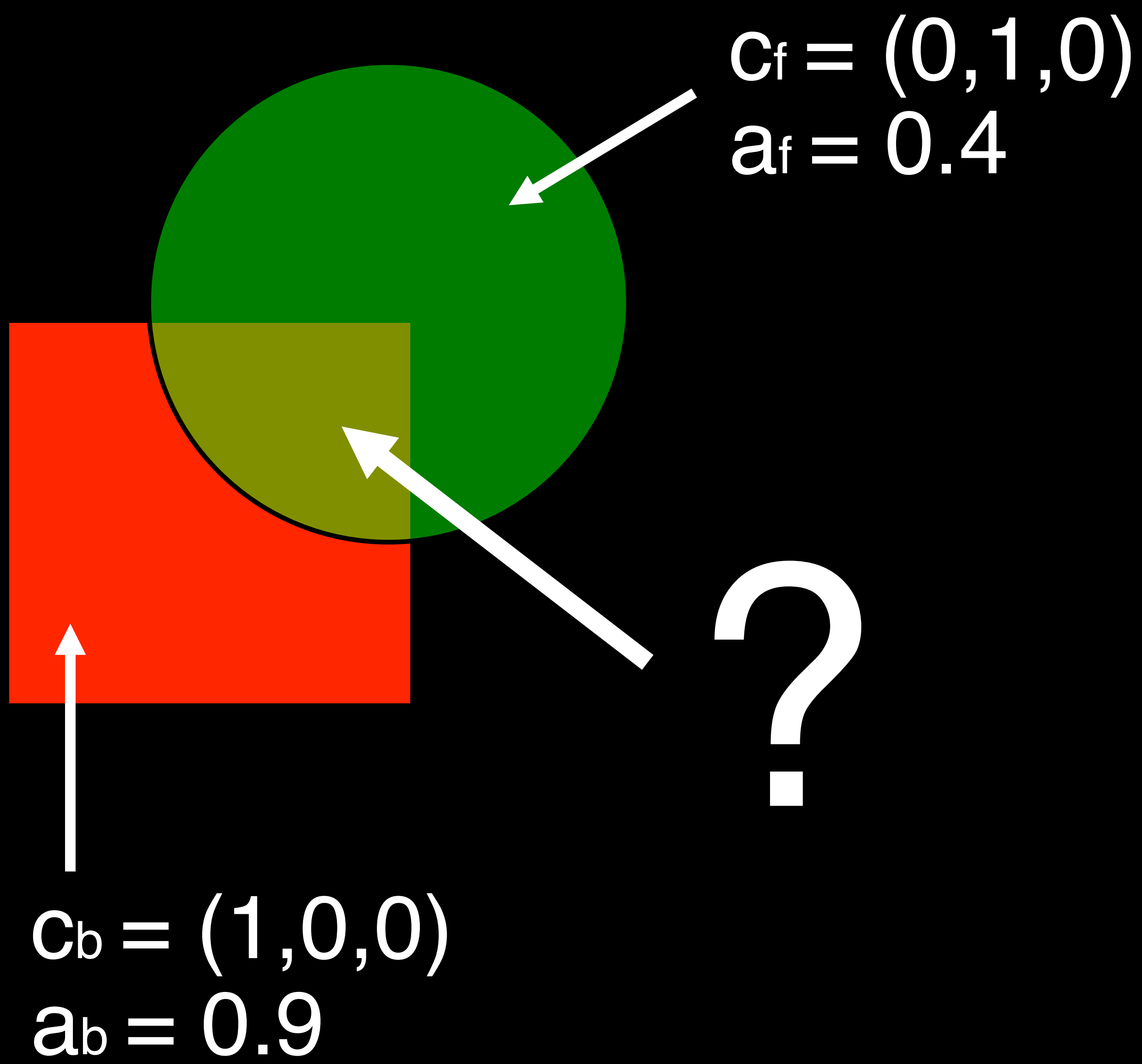






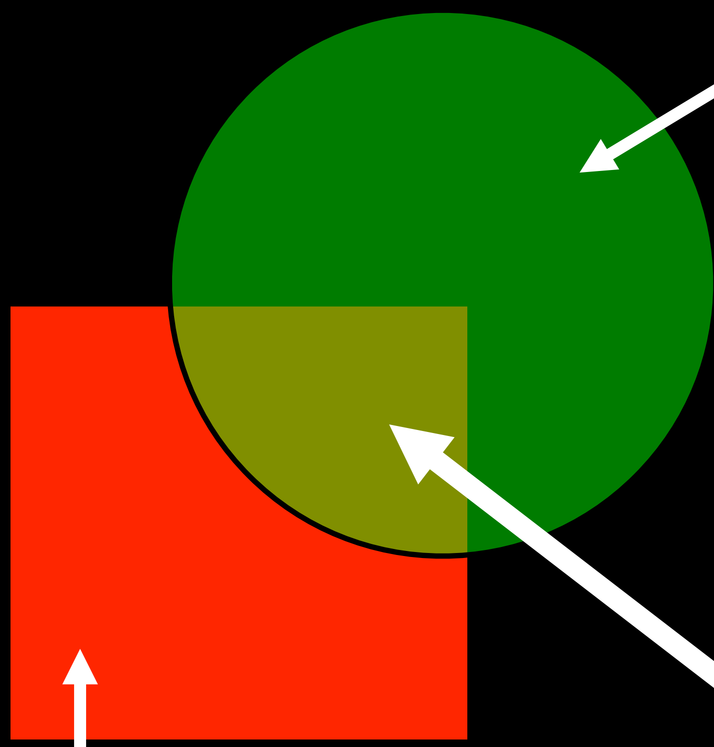
color to distinguish structures
opacity to show inside

Compositing



over operator

$$c = a_f * c_f + (1 - a_f) * a_b * c_b$$
$$a = a_f + (1 - a_f) * a_b$$



$c_f = (0,1,0)$
$a_f = 0.4$

$c_{red} = 0.4*0 + (1-0.4)*0.9*1 = 0.6*0.9 = 0.54$

$c_{green} = 0.4*1 + (1-0.4)*0.9*0 = 0.4$

$c_{blue} = 0.4*0 + (1-0.4)*0.9*0 = 0$

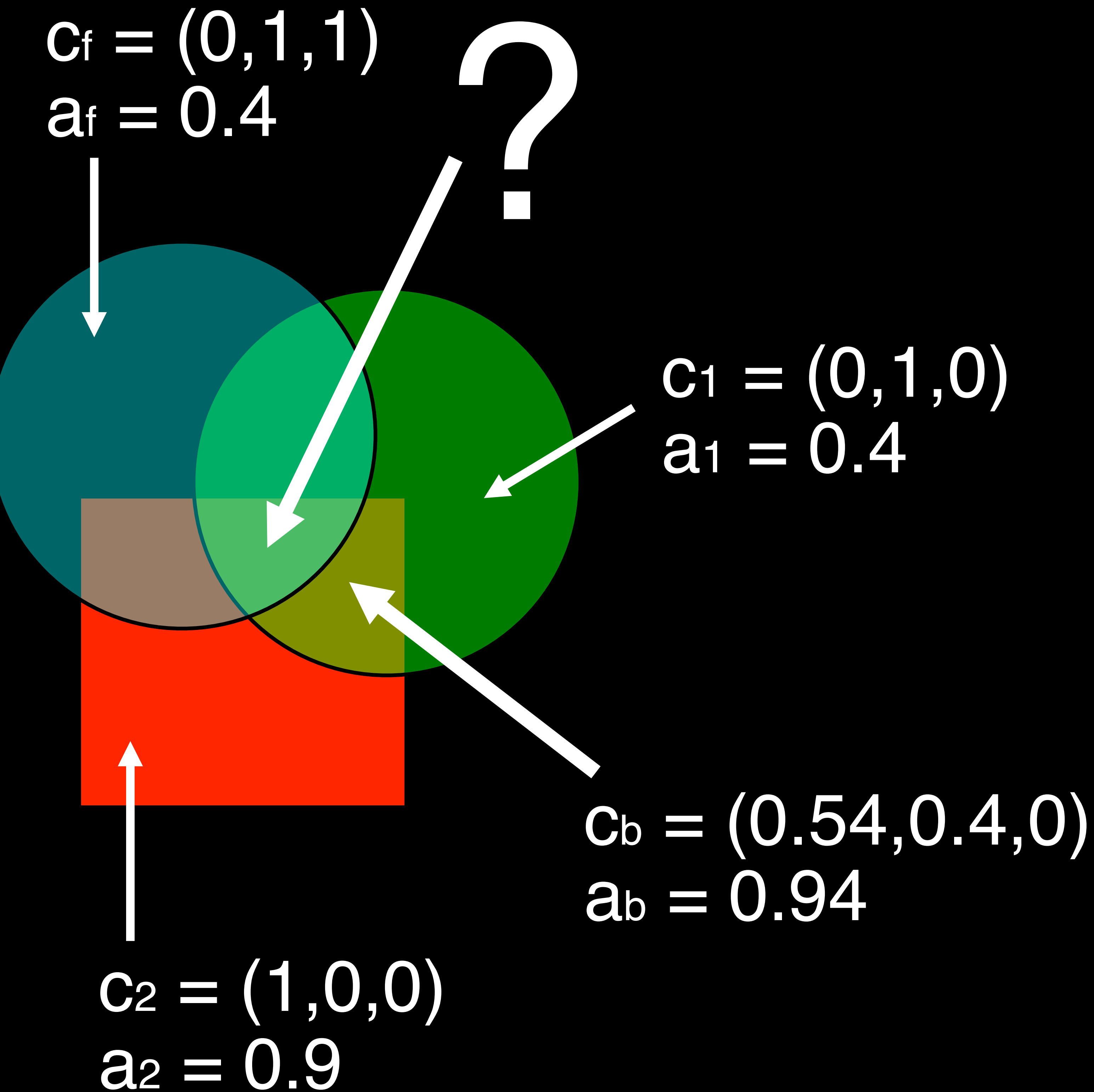
$a = 0.4 + (1 - 0.4)*(0.9) = 0.4 + 0.6*0.9)$

$c = (0.54,0.4,0)$
$a = 0.94$

$c_b = (1,0,0)$
$a_b = 0.9$

over operator

$$c = a_f*c_f + (1 - a_f)*a_b*c_b$$
$$a = a_f + (1 - a_f)*a_b$$



over operator

$$c = a_f * c_f + (1 - a_f) * a_b * c_b$$
$$a = a_f + (1 - a_f) * a_b$$

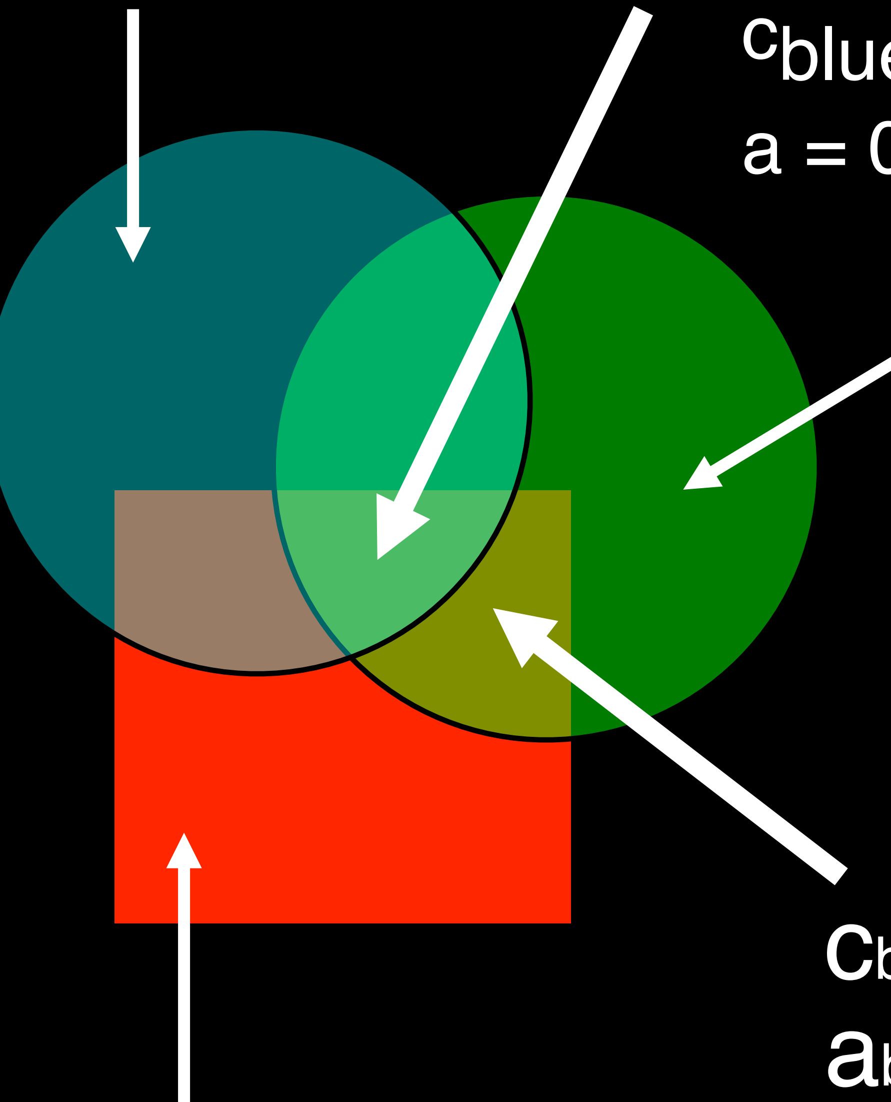
$c_f = (0,1,1)$
$a_f = 0.4$

$c_{red} = 0.4*0 + (1\text{-}0.4)*0.94*0.54 = 0.6*0.94*.54 = 0.30$

$c_{green} = 0.4*1 + (1\text{-}0.4)*0.94*0.4 = 0.6*0.94*.4 = 0.23$

$c_{blue} = 0.4*1 + (1\text{-}0.4)*0.94*0 = .4$

$a = 0.4 + (1 - 0.4)*(0.94) = 0.4 + 0.6*0.94) = .964$



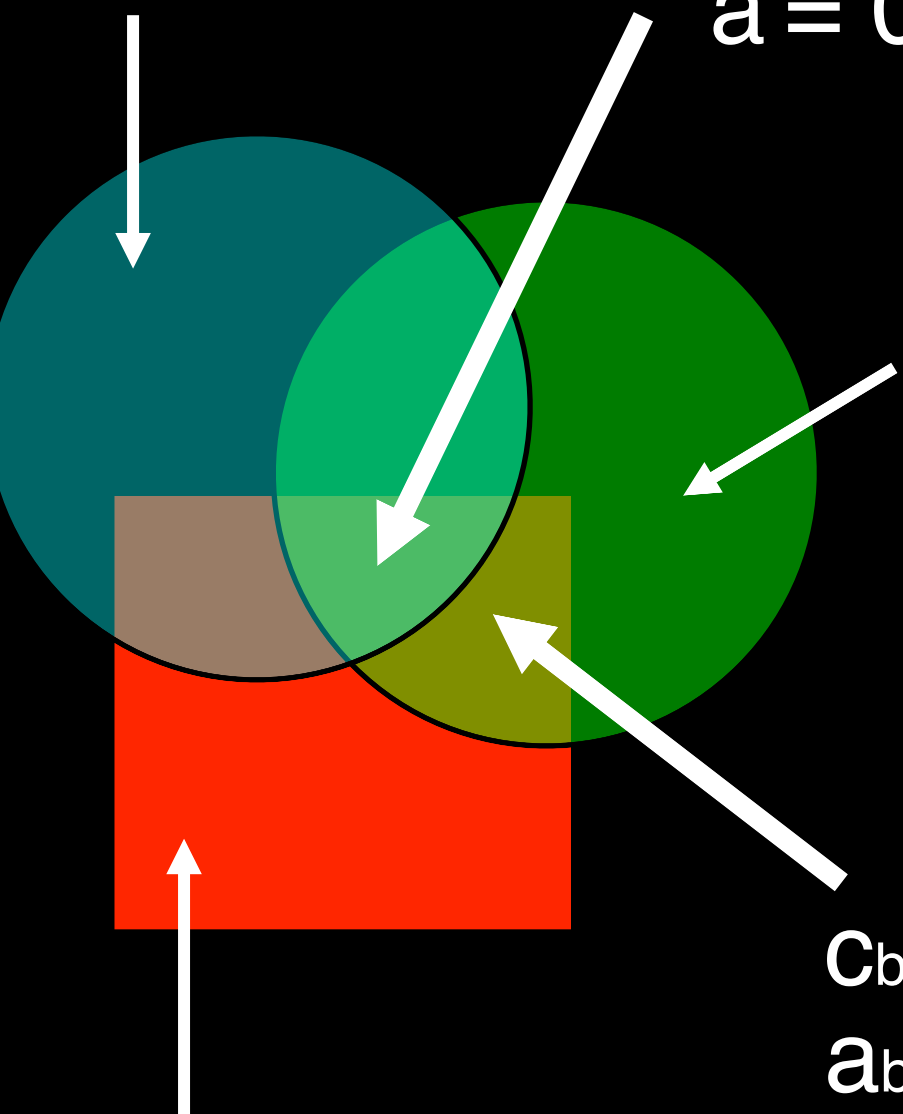
$c_1 = (0,1,0)$
$a_1 = 0.4$

$c_b = (0.54,0.4,0)$
$a_b = 0.94$

$c_2 = (1,0,0)$
$a_2 = 0.9$

over operator

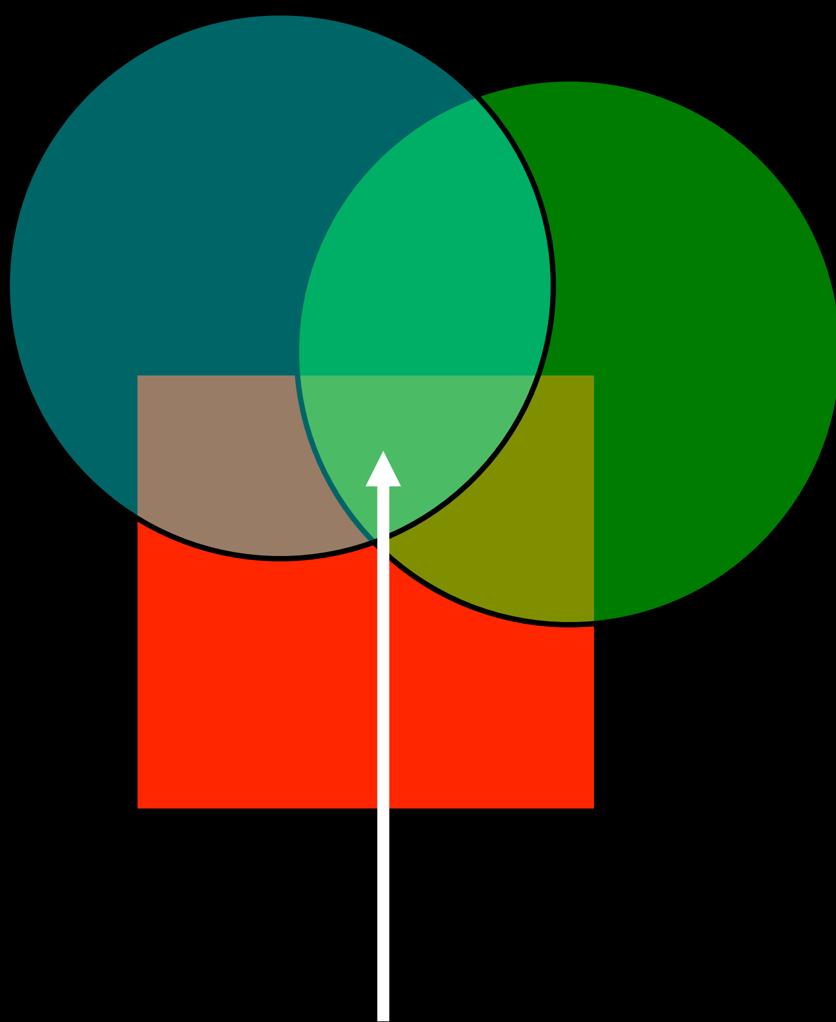
$$c = a_f*c_f + (1 - a_f)*a_b*c_b$$
$$a = a_f + (1 - a_f)*a_b$$



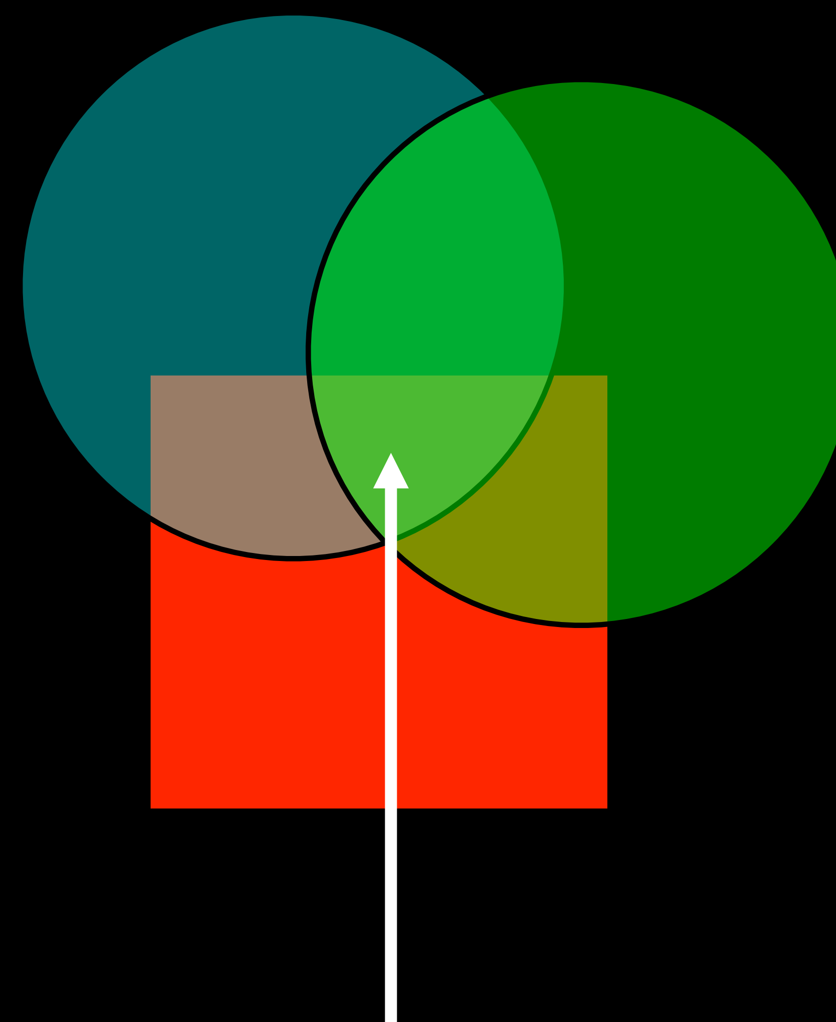
over operator

$$c = a_f * c_f + (1 - a_f) * a_b * c_b$$
$$a = a_f + (1 - a_f) * a_b$$

Order Matters!



c = (0.3,0.23,**<u>0.4</u>**)
a = 0.964



c = (0.3,0.23,**<u>0.23</u>**)
a = 0.964