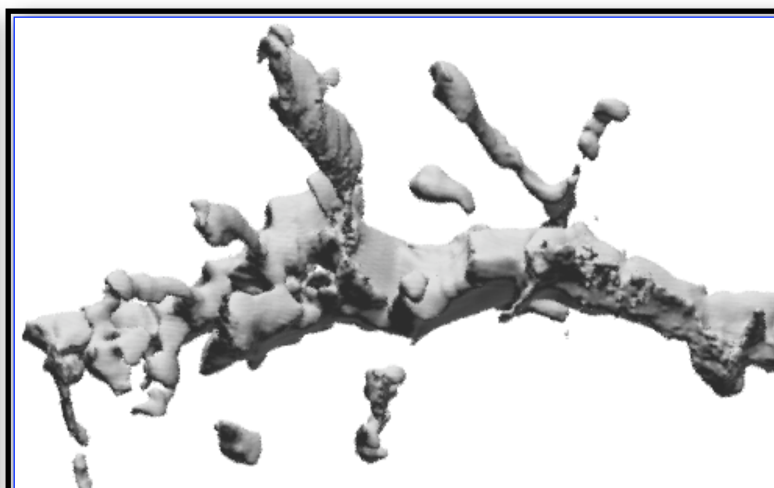
CS 5630/6630
Scientific Visualization

Volume Rendering I: Overview

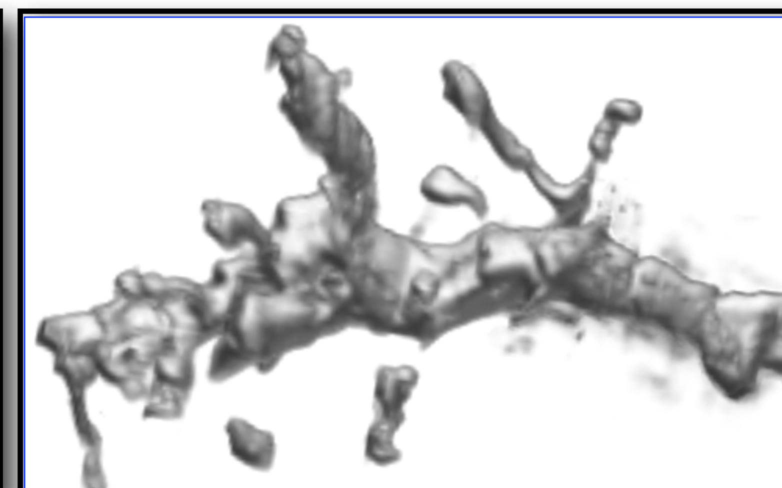
Motivation

- Isosurfacing is limited
  - It is “binary”
  - A hard, distinct boundary is not always appropriate

Slice



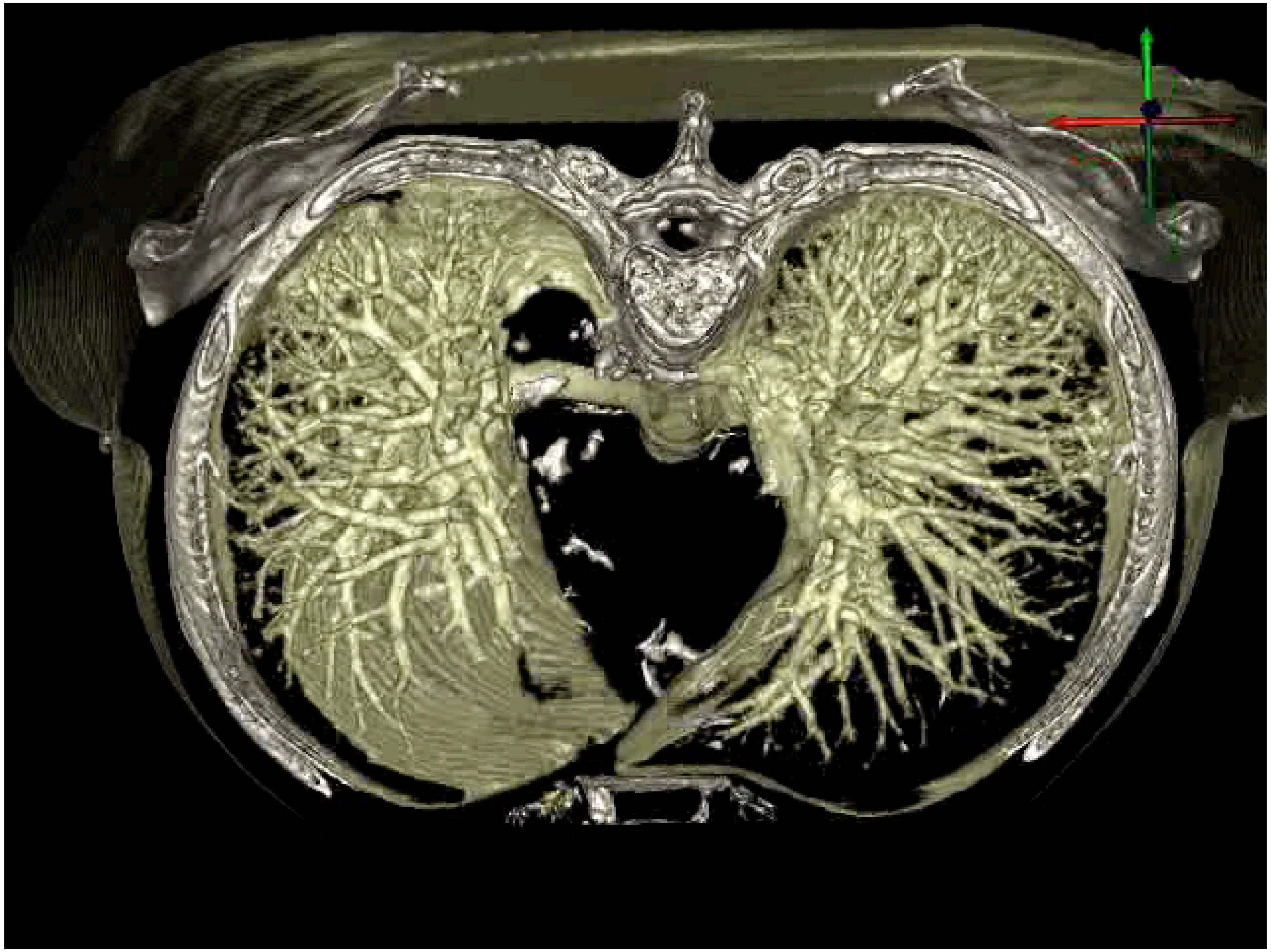
Isosurface



Volume Rendering

Motivation

- Volume rendering is good for...
  - Measured, "real-world" data with noise



Radiation treatment planning [Chen et al.]

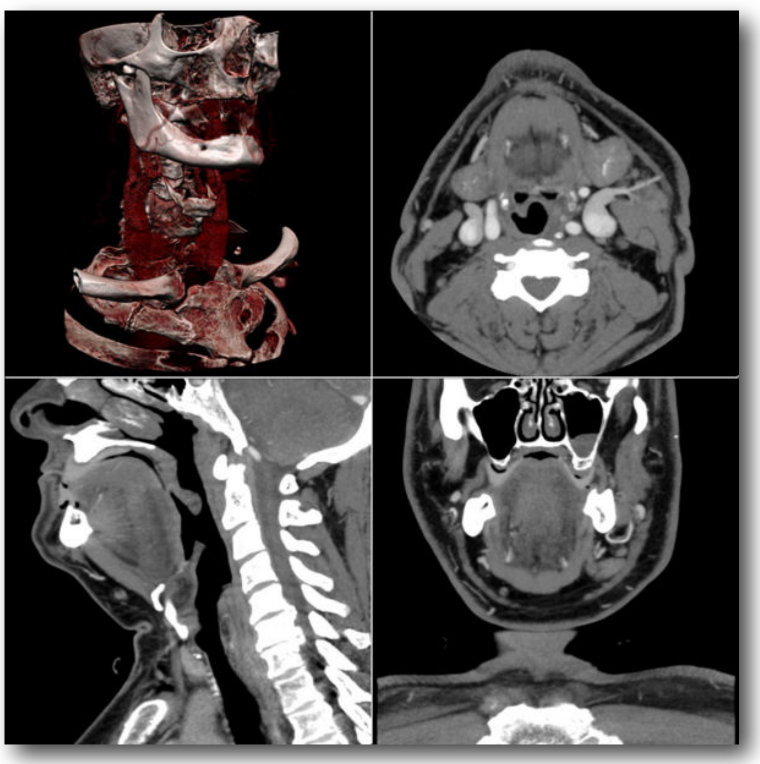
Motivation

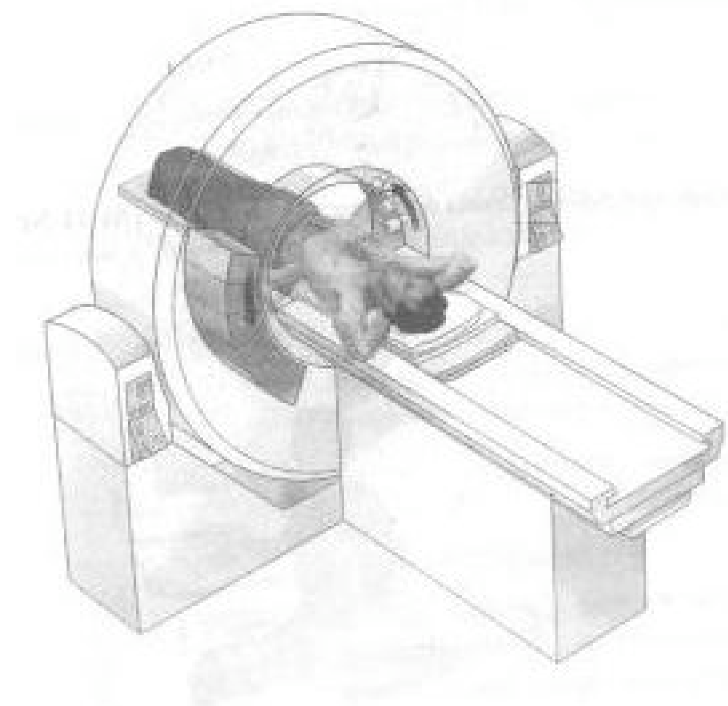
- Volume rendering is good for...
  - Amorphous, “soft” objects

C-Safe: Simulating acccidental fires and explosions [Smith et al.]

Acquisition - Structured Grids

- Computed Tomography (CT)
  - A series of 2D X-Rays acquired by rotating an emitter/detector around the object to be scanned
  - Each slice is then composed into a 3D volume





[Hounsfield 67]

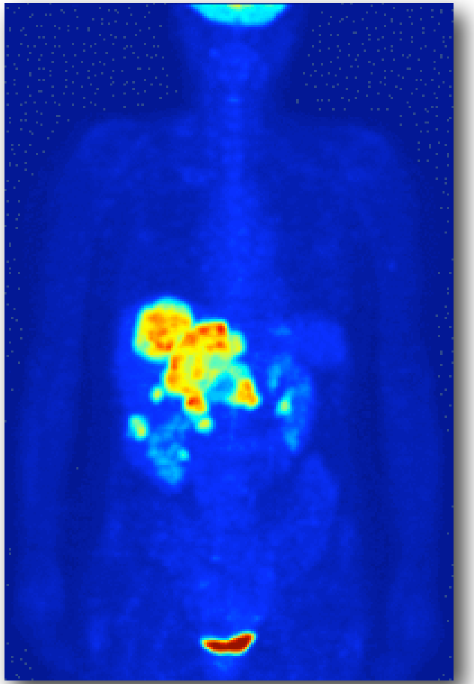
Acquisition - Structured Grids

- Magnetic Resonance Imaging (MRI)
  - A large magnetic field is applied to the object, which aligns hydrogen nuclei
  - The field pulses and time of relaxation to alignment is measured
    - T1 - 33% restored, T2 - 66% restored
  - Determines water content in tissue

[Lauterbur 73]

Acquisition - Structured Grids

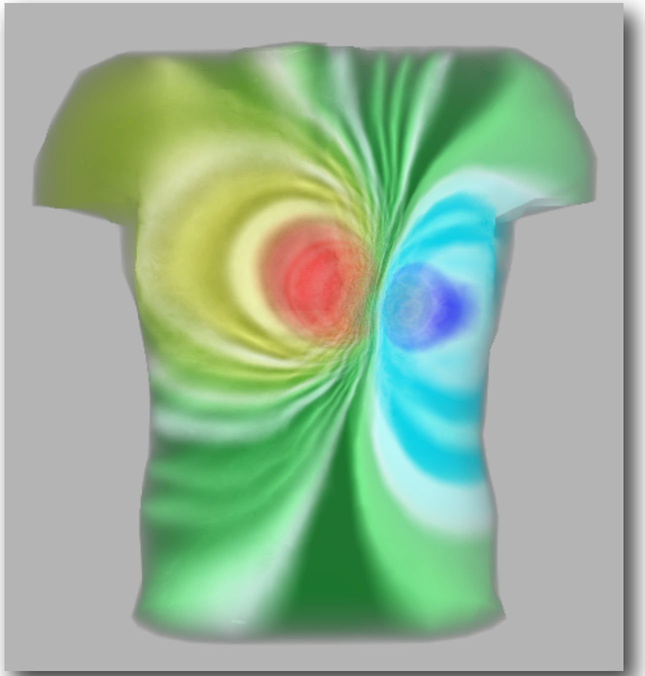
- Positron Emission Tomography (PET)
  - A radioactive isotope is inserted into a sugar and injected into the body
  - Positron emission from decay interacts with electrons to create gamma rays
  - Gamma rays are detected to find position of isotopes in body



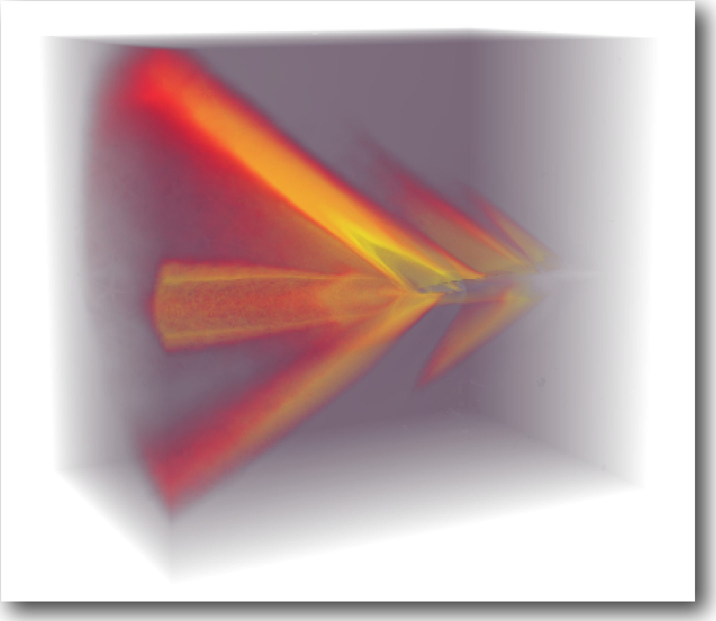
[Kuhl and Edwards 59]

Acquisition - Unstructured Grids

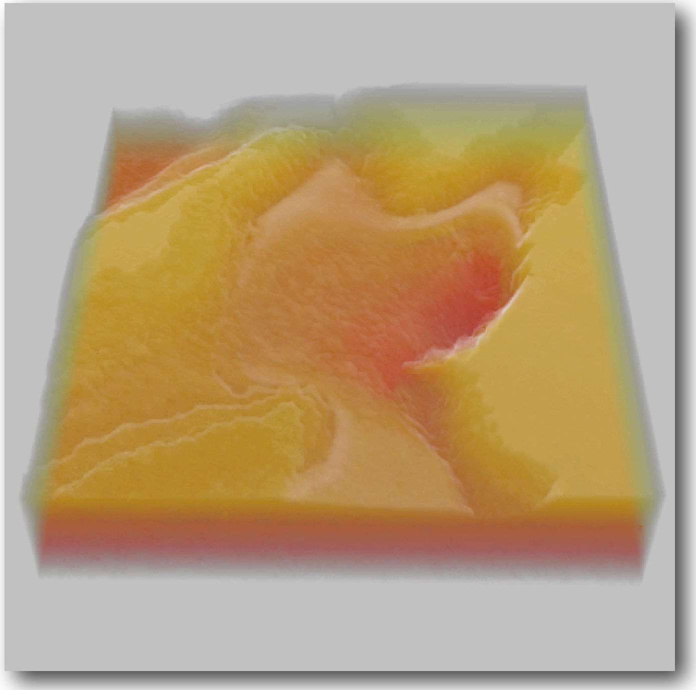
- Computational Fluid Dynamics
- Structural Mechanics



Electric Potentials in Torso
[MacLeod et al 94]



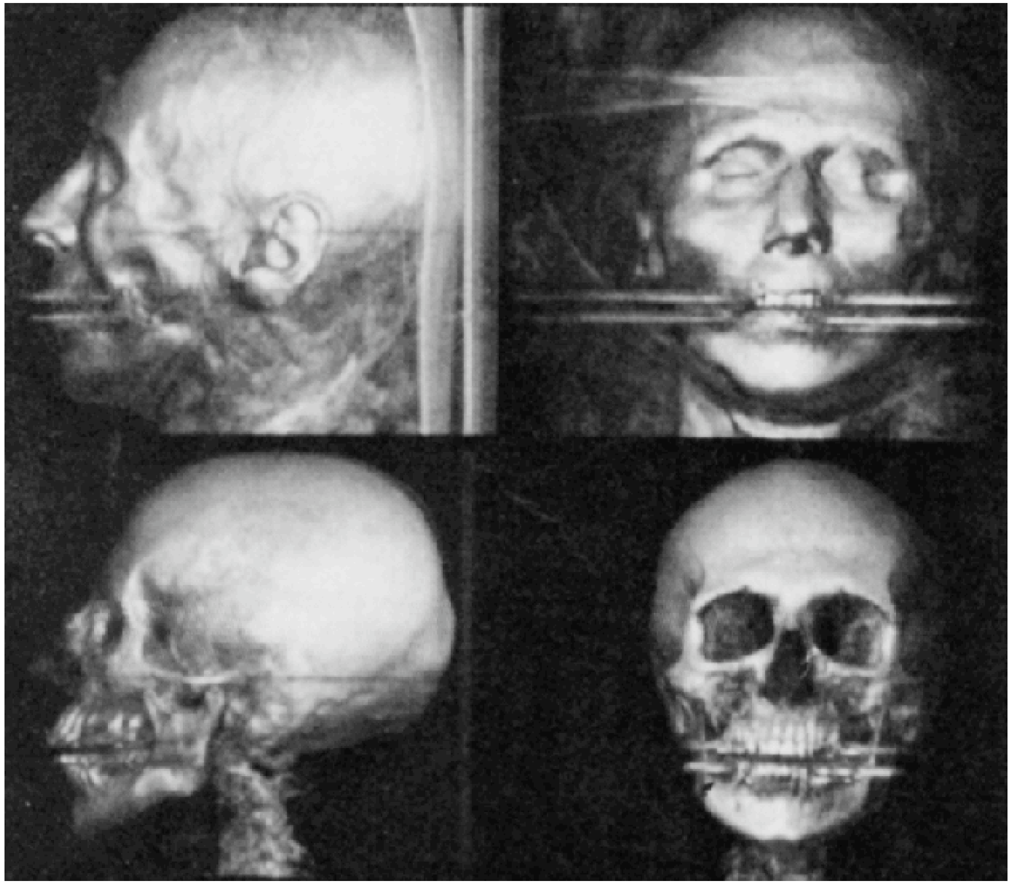
Turbulence around fighter jet
[Neely and Batina 92]



San Fernando
Earthquake Simulation
[O'Hallaron and Shewchuk 96]

Volume Rendering Overview

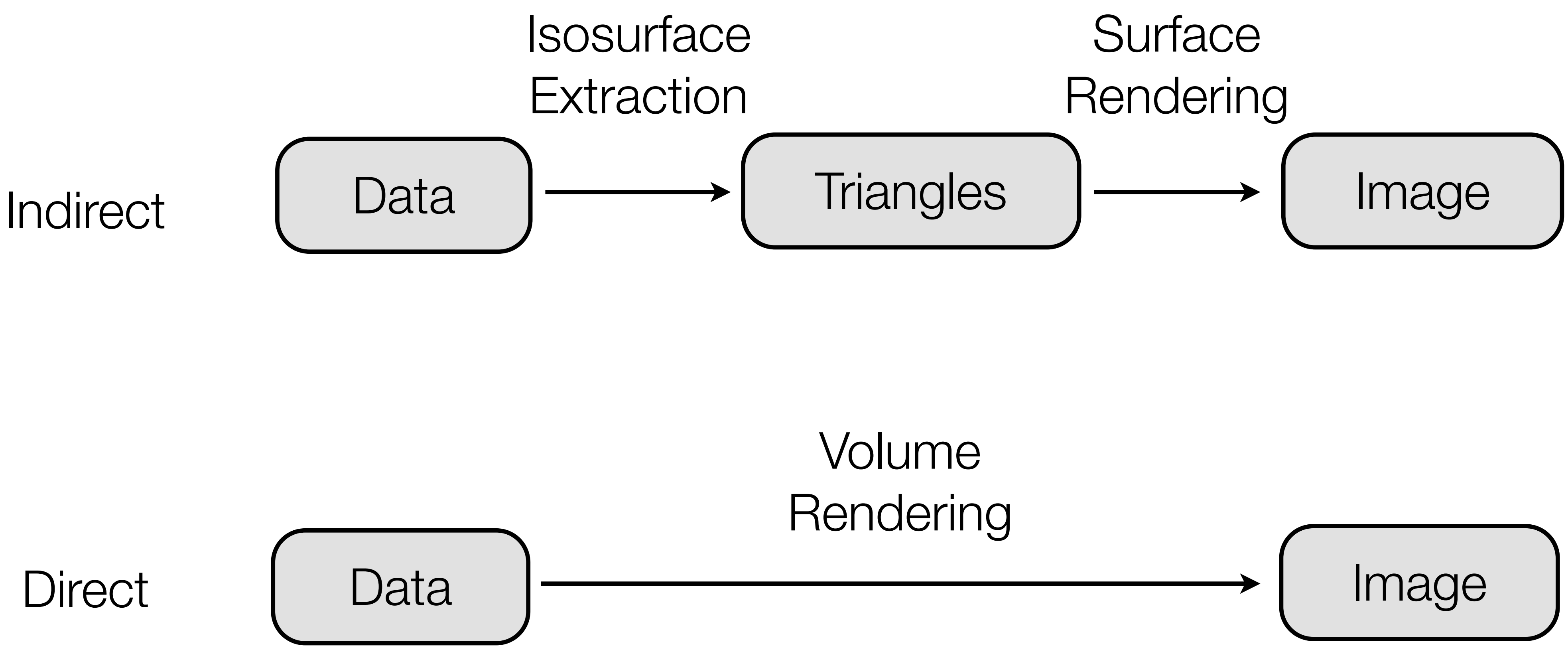
- Every voxel contributes to the image



[Levoy 88]

Volume Rendering Overview

- No intermediate geometric structures or binary distinctions

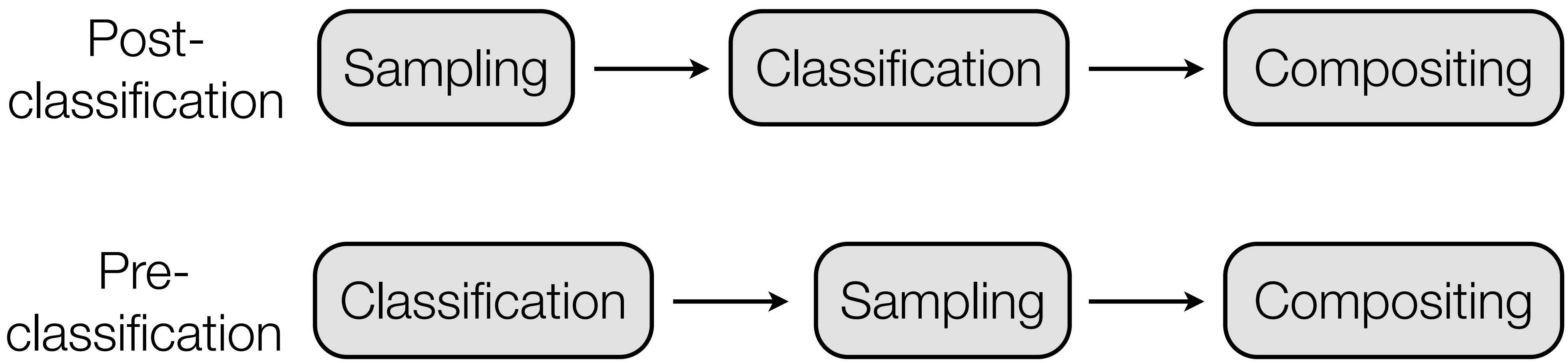


Volume Rendering Overview

- Direct Volume Rendering
  - The data is considered to represent a semi-transparent, light-emitting medium
  - Based on laws of physics
  - Volume data is used as a whole
  - Color and opacity are used to distinguish materials within the volume

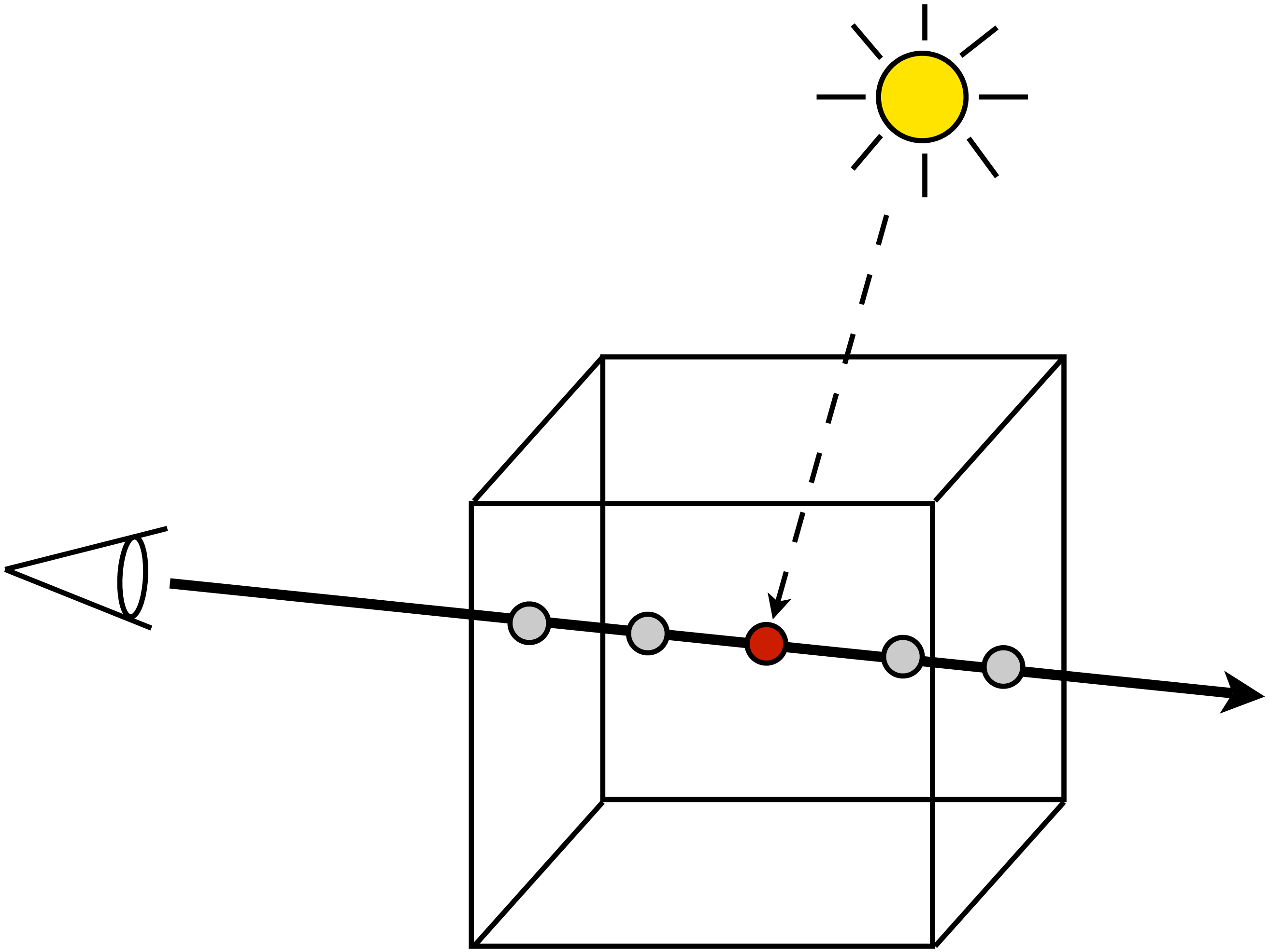
Volume Rendering Overview

- Three stages of volume rendering
  - Sampling: Selecting the steps through the volume
  - Classification: Computing a color and opacity for a step
  - Compositing: Blending together classified steps into a final image



Sampling

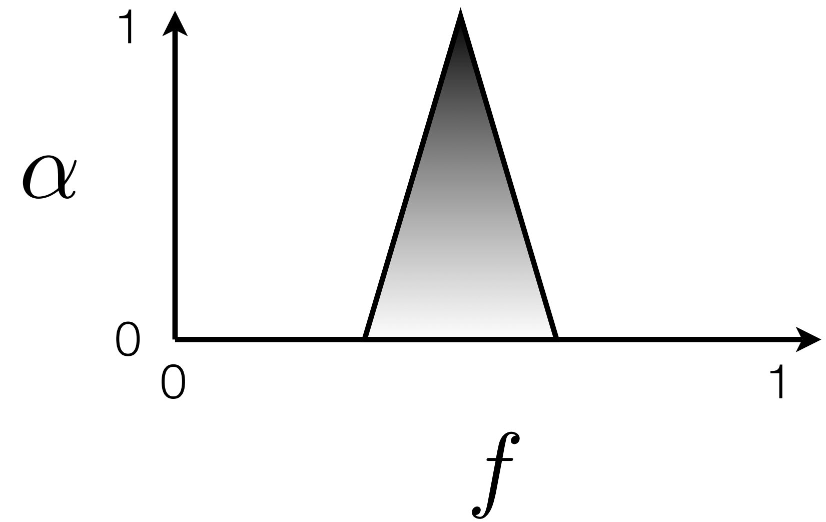
- Sample at discrete steps within the volume



Classification - Transfer Functions

- Transfer Functions
  - Maps a data value to color and opacity

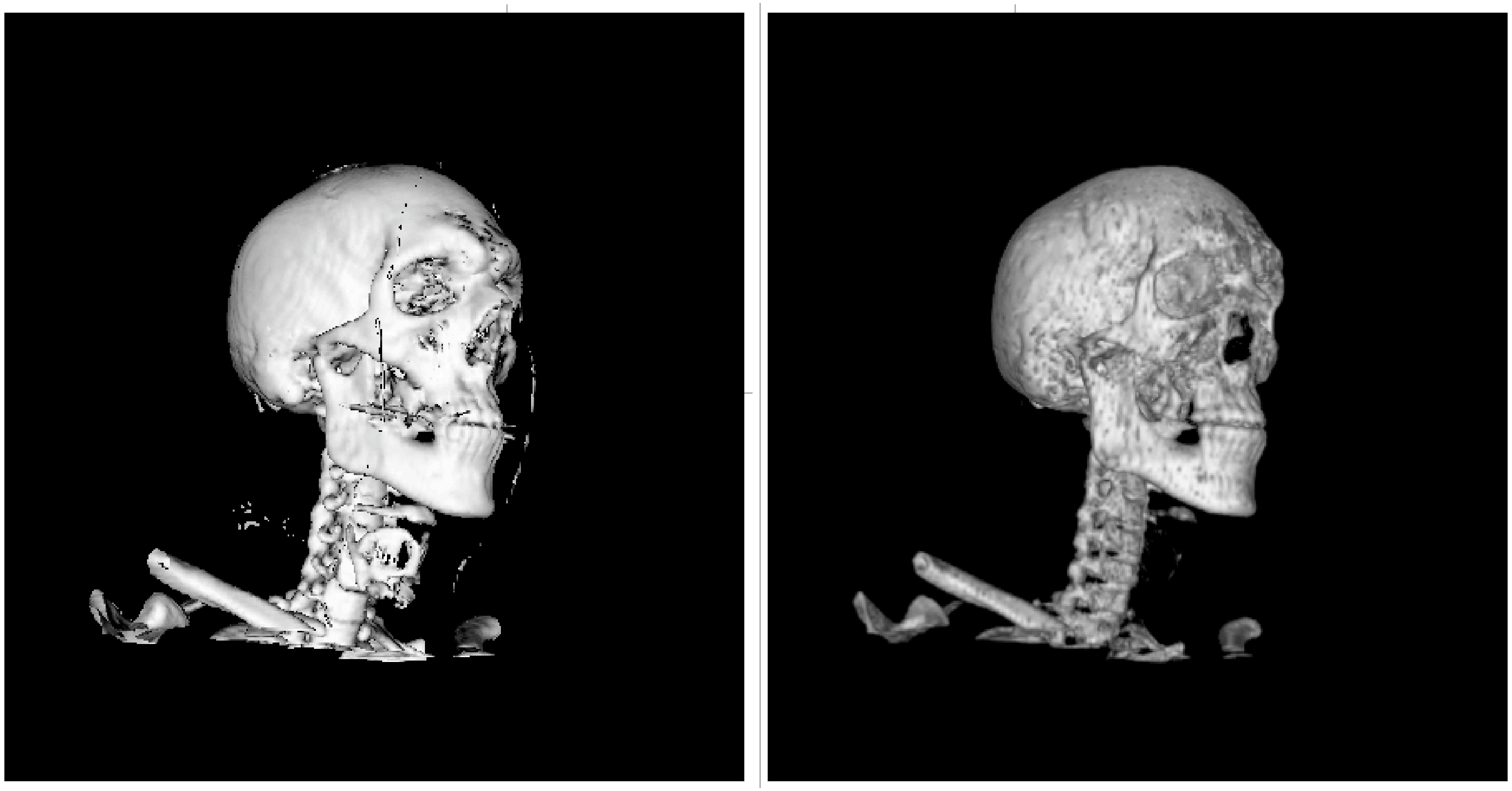
$$f(x) = \mathbf{R} \rightarrow \mathbf{R}^4, s \rightarrow (r, g, b, \alpha)$$



  - Lookup table
    - Use linear interpolation

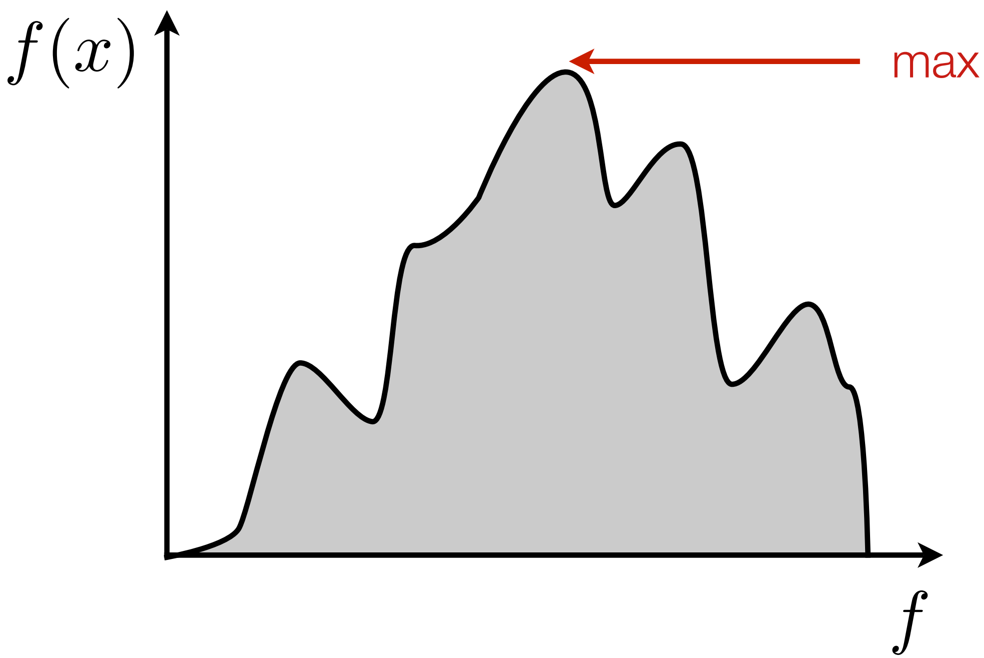
Classification - Transfer Functions

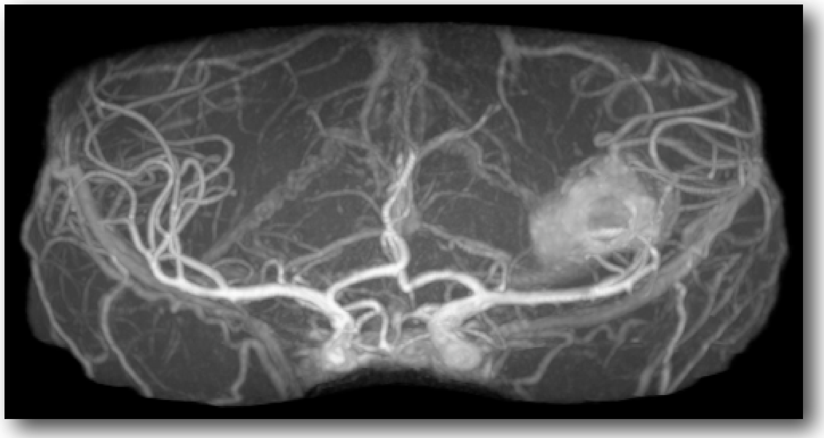
- VisTrails example



Classification - Optical Models

- Maximum Intensity Projection
  - The maximum intensity sample encountered for each pixel

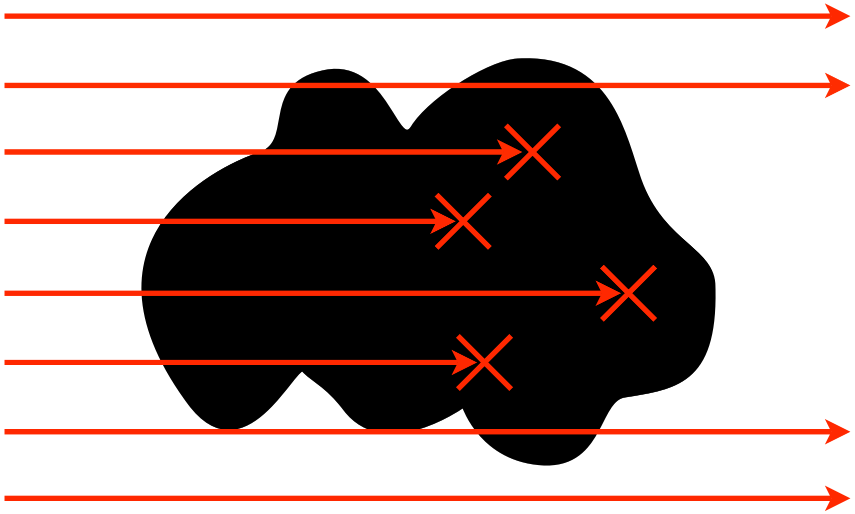


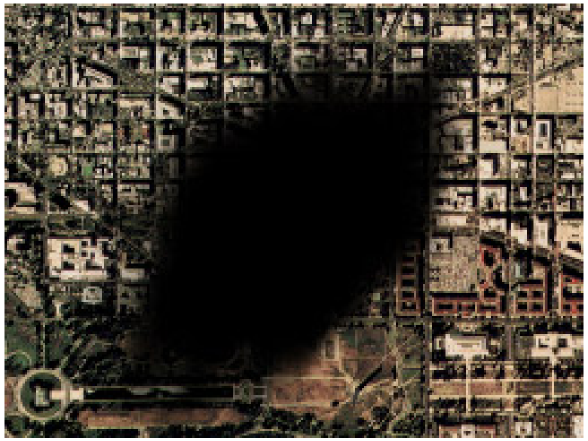


[Wallis and Miller 90]

Classification - Optical Models

- Absorption
  - Light is absorbed without emitting or scattering
  - Like a cloud of black smoke

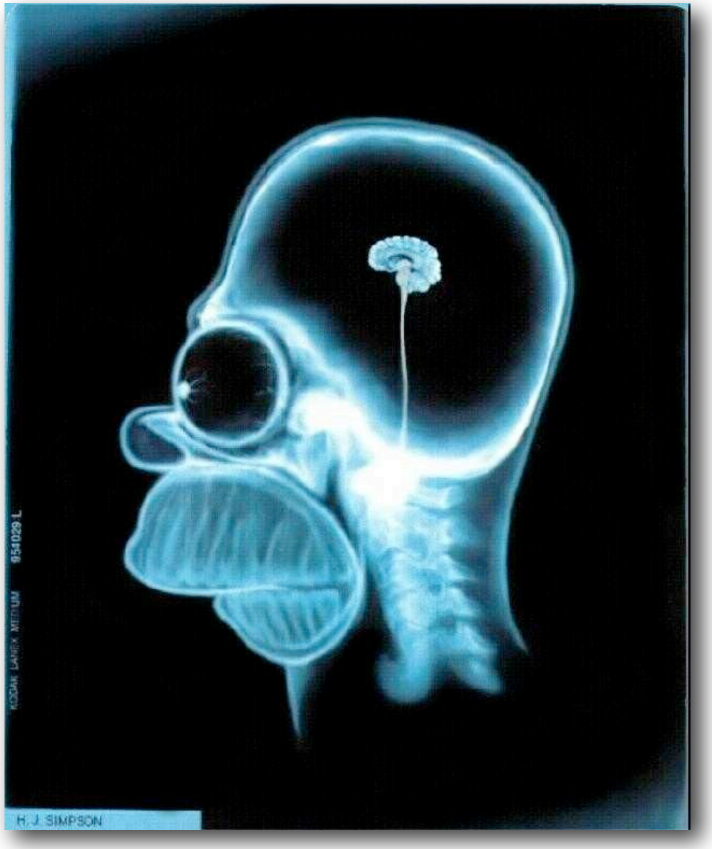




[Blinn 82]

Classification - Optical Models

- Absorption
  - X-Ray images



[Roentgen 1896]

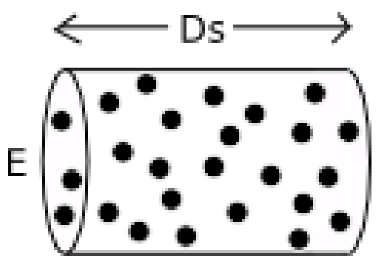
Classification - Optical Models

- Absorption
  - Cylinder in volume:
    - area E
    - thickness Δs
    - volume $E\Delta s$
    - particles per unit ρ
    - projected area of particles A
    - occluded area on base $\rho A E \Delta s$
    - intensity going through volume I

$$\frac{\delta I}{\delta s} = -\rho(s) A I(s)$$

$$I(s) = I_0 e^{\int_0^s \tau(t) dt}$$

$$\tau(s) = \rho(s) A$$

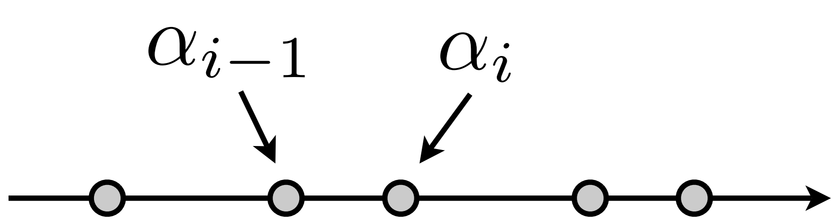


Compositing

- Absorption
  - Opacity is added over multiple steps

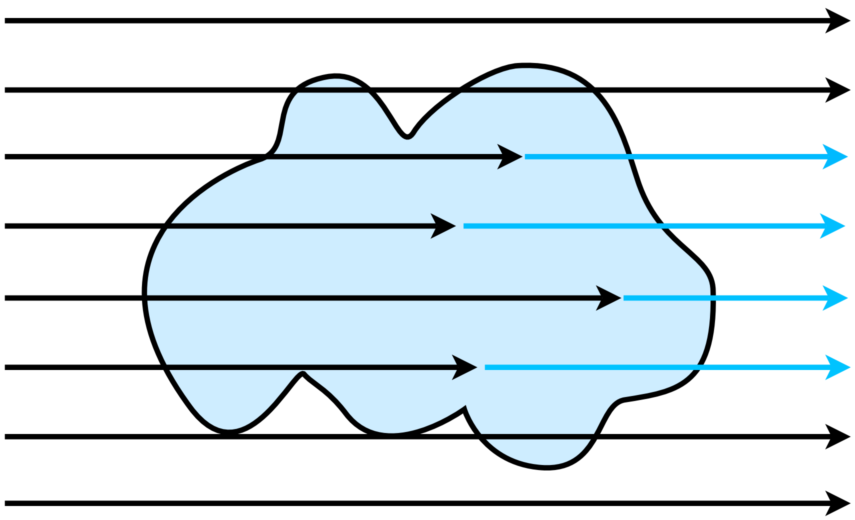
$$\alpha_i = \alpha_i + \alpha_{i-1}$$

  - This is commutative, thus the steps can be added in any order



Classification - Optical Models

- Emission
  - Light is increased as it goes through the volume
  - Like hot soot particles in a flame



Classification - Optical Models

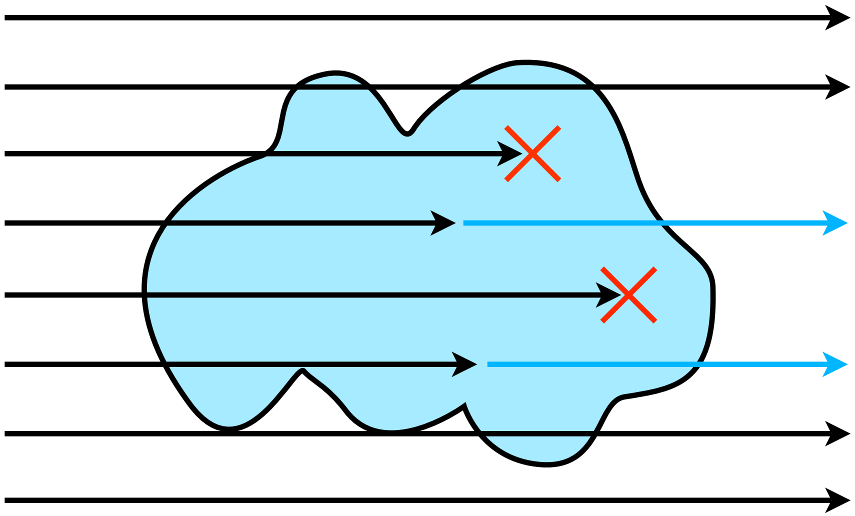
- Emission
  - glow per unit projected area C

$$\frac{\delta I}{\delta s} = C(s)\rho(s)A$$

$$I(s) = I_0 + \int_0^s C(s)\rho(s)A$$

Classification - Optical Models

- Absorption and emission
  - Occludes the light as well as adds to it
  - Like a real cloud



Classification - Optical Models

- Absorption and emission
  - edge $s = 0$
  - eye $s = D$

$$\frac{\delta I}{\delta s} = C(s)\rho(s)A - \rho(s)AI(s)$$

$$I(D) = I_0 e^{-\int_0^D \rho(t)A dt} + \int_0^D C(s)\rho(s)Ae^{-\int_s^D \rho(t)A dt} ds$$

$$I(D) \approx I_0 \prod_{i=1}^{n} t_i + \sum_{i=1}^{n} g_i \prod_{j=i+1}^{n} t_j$$

$$t_i = e^{-\rho(i\Delta x)A\Delta x} \qquad g_i = C(i\Delta x)\rho(i\Delta x)A$$

[Max 94]

Compositing

- Absorption and emission
  - Opacity is blended over multiple steps
    - Back-to-front

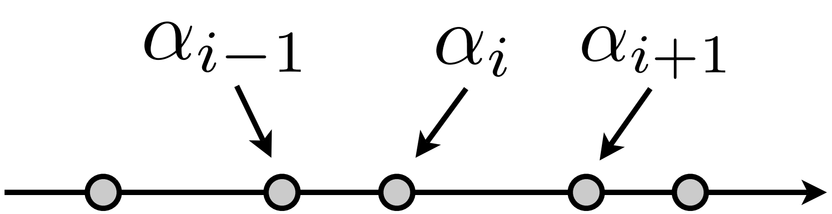
$$c_i = c_i \alpha_i + c_{i+1}(1 - \alpha_i)$$

    - Front-to-back

$$c_i = c_{i-1} + c_i \alpha_i (1 - \alpha_{i-1})$$

$$\alpha_i = \alpha_{i-1} + \alpha_i (1 - \alpha_{i-1})$$

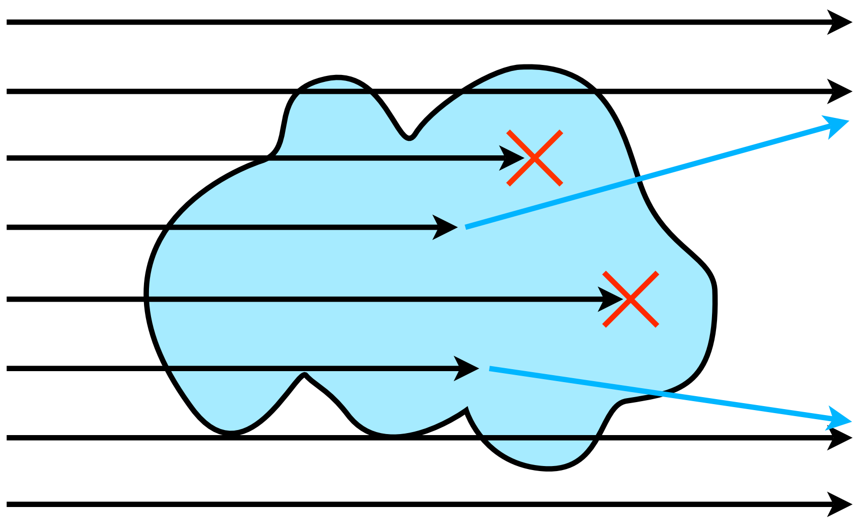
  - This is not commutative, thus the steps need to be in order



[Porter and Duff 84]

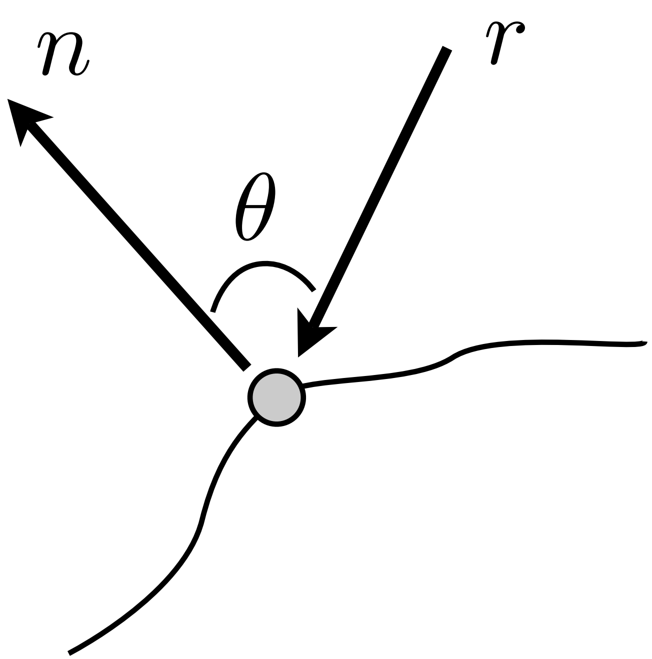
Classification - Optical Models

- Multiple Scattering
  - Light may collide with particles and change direction
  - Why is the sky blue?



Classification

- Shading



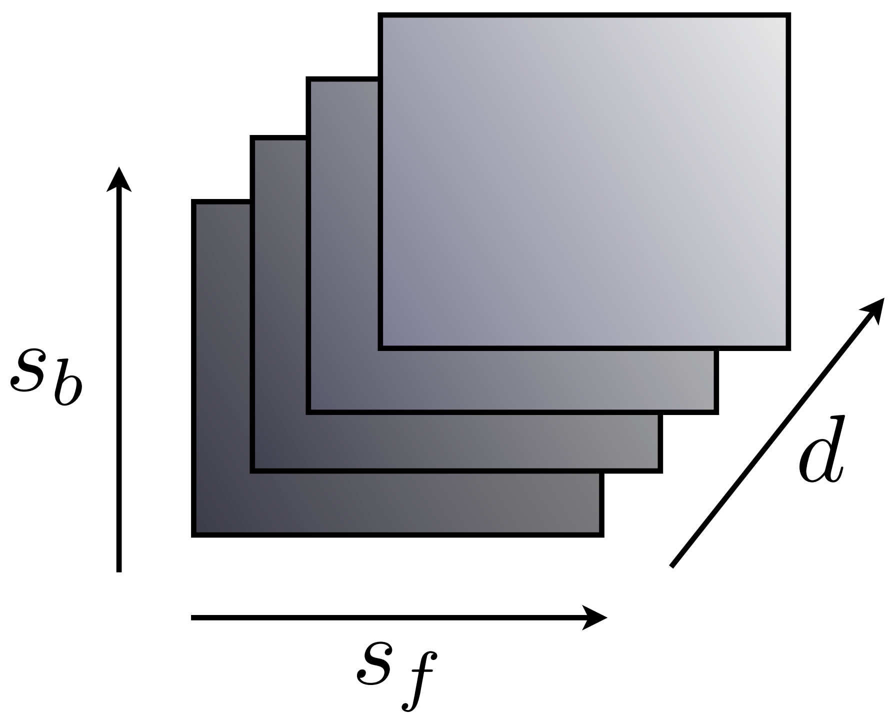
$$P_L(a) = (8/3\pi)(sin\theta + (\pi - \theta)cos\theta)$$

$$n = \bigtriangledown f \mid \bigtriangledown f \mid$$

[Blinn 82]

Classification

- Acceleration Techniques
  - Pre-integration
    - Use a 3D lookup table of colors and opacities (r,g,b,a)
    - Index by front scalar, back scalar, and the distance between samples



[Engel 01]

Classification

- Optical Models Example