CS 5630/6630
Scientific Visualization

Volume Rendering I: Overview
Motivation

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

- Volume rendering is good for...
  - Measured, “real-world” data with noise
Motivation

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

C-Safe: Simulating accidental 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
    \[ f(x) = \mathbb{R} \rightarrow \mathbb{R}^4, \ s \rightarrow (r, g, b, \alpha) \]

- Lookup table
  - Use linear interpolation
Classification - Transfer Functions

- VisTrails example
Classification - Optical Models

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

$\max f(x)$
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 $\Delta s$
  - volume $E \Delta s$
  - particles per unit $\rho$
  - 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 $s = D$

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

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

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

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

[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

\[ n = \nabla f \mid \nabla f \mid \]

\[ P_L(a) = \left(\frac{8}{3\pi}\right)(\sin \theta + (\pi - \theta)\cos \theta) \]

[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