Surface Graphics

- Objects are explicitly defined by a surface or boundary representation (explicit inside vs outside)
- This boundary representation can be given by:
  - a mesh of polygons:

  200 polys 1,000 polys 15,000 polys

  - a mesh of spline patches:

  an “empty” foot
Surface Graphics - Pros and Cons

• Pros:
  - fast rendering algorithms are available
  - acceleration in special hardware is relatively easy and cheap (many $200 game boards)
  - use OpenGL to specify rendering parameters
  - surface realism can be added via texture mapping

• Cons:
  - discards the interior of the object and just maintains the object’s shell
  - does not facilitate real-world operations such cutting, slicing, dissection
  - does not enable artificial viewing modes such as semi-transparencies, X-ray
  - surface-less phenomena such as clouds, fog, gas are hard to model and represent
Volume Graphics

- Maintains a representation that is close to the underlying fully-3D object (but discrete)
- Models the object as a magic gel that can change its properties at any time:

Volumetric human head acquired by CT scanning and viewed using volume rendering

- Different aspects of the dataset can be emphasized via changes in the functions that translate raw densities into colors and transparencies
- Volume rendering is a formidable technique for the exploration of datasets, since when the nature of the data is not known, it is difficult to create the right polygonal mesh
Volume Graphics - Pros and Cons

- **Pros:**
  - maintains a representation that is close to the underlying fully-3D object (but discrete)
  - can achieve a level of realism (and ‘hyper-realism’) that is unmatched by surface graphics:
    - allows easy and natural exploration of volumetric datasets

- **Cons:**
  - has high rendering complexity
  - hardware acceleration is complex and expensive (a commodity board costs over $3,000)
Volume Graphics - Definitions

- A volume is sometimes called a 3D image
  - it is a 3D array of point samples, called voxels (volume elements)
  - the point samples are located at the grid points
  - the process of generating a 2D image from the 3D volume is called volume rendering

Sampling:
MRI, CT, Ultrasound

Numerical simulations:
Computational Fluid Dynamics
Finite Element Method

Discretization:
voxelization

volume
volume rendering
image
Volume Grid Types

cubic
anisotropic rectilinear
rectilinear
curvilinear
unstructured

shown in 2D, for ease of drawing
Volume Rendering Modes

- For each pixel in the image, a ray is cast into the volume:

- Four main volume rendering modes exist:

  **X-ray:**
  rays sum volume contributions along their linear paths

  **Iso-surface:**
  rays look for the object surfaces, defined by a certain volume value

  **Maximum Intensity Projection (MIP):**
  a pixel value stores the largest volume value along its ray

  **Full volume rendering:**
  rays composite volume contributions along their linear paths
The Volume Rendering Pipeline

Original CT Data

Original raw density data

Segmentation

Classification

Gradient computation

Shading

Resampling

Compositing

Final Image
Volume Rendering Applications - Medical Imaging

- Classic application for volume rendering since datasets are inherently volumetric
- Modalities are: CT, MRI, PET, SPECT, Ultrasound (more on these later)
- Doctors use volume rendering to visualize organs, structures, and tissue of interest
  - can render unimportant structures (semi-)transparent and emphasize important ones
  - for example: render a brain tumor opaque and the surrounding brain tissue as a faint hull
- The medical check-up of the future:
  - get a full body scan with CT and MRI
  - specialist doctors use volume visualization to investigate the state of the discretized patient:
    - a cardiologist checks coronary arteries for arteriosclerotic plaque
    - a radiologist/proctologist flies through the virtual colon and checks for cancerous polyps
  - simulate and plan a surgery or procedure on the digital patient if necessary
  - keep the scan as a digital record of the patient for future reference and statistics
Paleontology and Archaeology

- Volumetric scanning (CT, MRI) and subsequent volume rendering provide a means for non-destructive exploration of
  - prehistoric artifacts (dinosaur eggs, fossils in a chunk of soil)
  - artifacts from ancient cultures (mummies, the ‘frozen man’)

non-destructive procedure:

old procedure:
destructive unwrapping of the mummie

- CT scan
- CT slice reconstruction
- volume rendering
- artistic sketch based on volume rendering
Computational Fluid Dynamics

- Fluid flow is governed by the Navier-Stokes system of simultaneous differential equations
- These systems are solved using iterative methods on discrete grids
- The results are visualized with volume visualization
- Examples:
  - Flow around an airplane wing
  - Spiral flow
  - Shockwave
Modeling and Display of Natural Phenomena

- Modeling of precipitation, ocean turbulence, ozon layer, acid rain, typhoons, hurricanes,...
- Visualization of data from satellites and sensors

global wind and weather modeling
Oil and Gas Exploration

- Visualize seismic, temperature, pressure, permeability in a combined display
  - locate most promising locations to drill

well-paths in oil zones (based on seismic data)

interactive display wall for collaborative visualization
Education

- The LBNL ‘Virtual Frog’ project

- The National Library of Medicine ‘Visible Man’ and ‘Visible Woman’
  - full-body CT and MRI scans were obtained of a dead man and a dead woman
  - the bodies were then crysectioned (1/3 mm) and each exposed section was photographed
  - the volumetric data have been used for educational purposes in many applications

cryosections

volume rendered anatomical atlas
Industrial and Security Applications

- Industrial CT
  - reverse engineering
  - inspection for structural failures

- Security
  - airport luggage CT
  - drug detection

engine

rendered bag
Virtual Reality and Games

• Surgery planning and training uses volume rendering for visual feedback of the simulation
  - haptic feedback devices are employed in conjunction with virtual scalpels, drills

• Next generation computer games with realistic volumetric effects
  - spilled guts, ripped organs, and other pleasant visuals

• Special effects for movies