CSE528 Computer Graphics: Theory, Algorithms, and Applications

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Key Components

- Introduction
  – Overview, definition
  – Various application examples and areas
  – Graphics history
  – Graphics software and hardware systems
  – Graphics programming
  – User-computer interface, special input/output devices

Key Components

- Geometry and Mathematics
  - Curves, and surfaces
  - Solid geometry and volumetric models for datasets
  - 3D geometric transformation
  - Data structures

Key Components

- Geometric Modeling
  - Curves
  - Surfaces
  - Shape modeling, matching, analysis
  - Shape parameterization
  - Solid modeling

Key Components

- Rendering
  - Object hierarchies
  - Ray tracing
  - Object and image order rendering
  - Graphics rendering pipeline
  - Color perception and color models
  - Basic optics
  - Visibility

Key Components

- Image-based techniques
  - Sampling
  - Filtering
  - Anti-aliasing
  - Image analysis and manipulation

Key Components

- Advanced Topics
  - Animation
  - Transparency and shadows
  - Texture mapping
  - Image-based rendering and modeling
  - Advanced modeling techniques
  - Case studies
  - Software packages
  - ……………

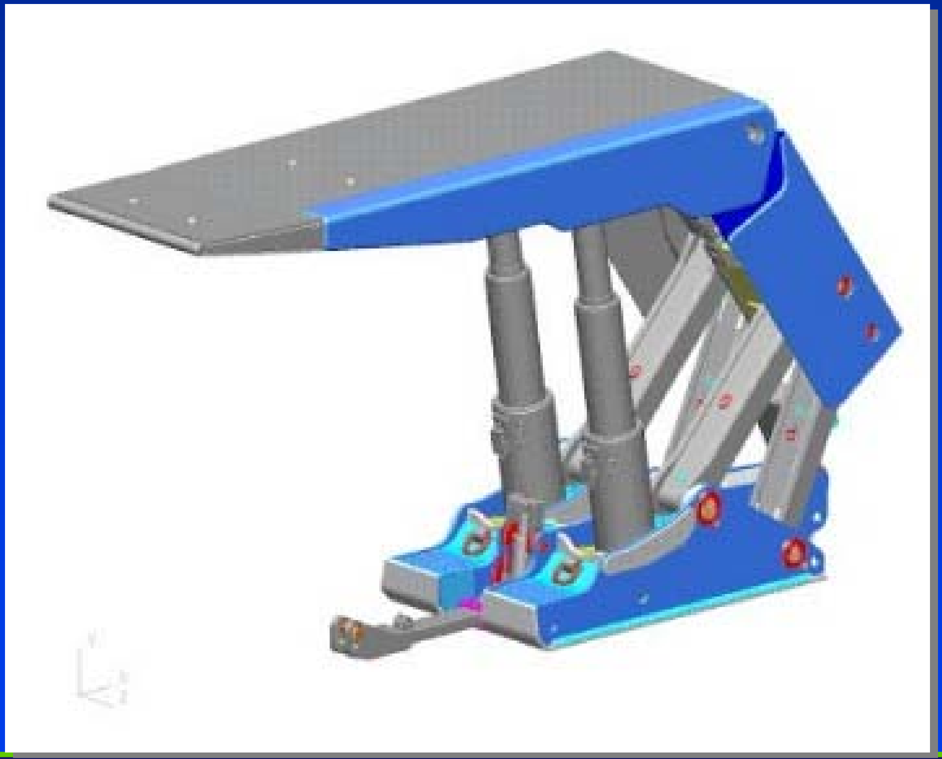
Computer Graphics Pipeline

What is Computer Graphics?

- Computational process of generating images from models and/or datasets using computers
- This is called *rendering (computer graphics was traditionally considered as a rendering method)*
- A rendering algorithm converts a geometric model and/or dataset into a picture

What is Computer Graphics?

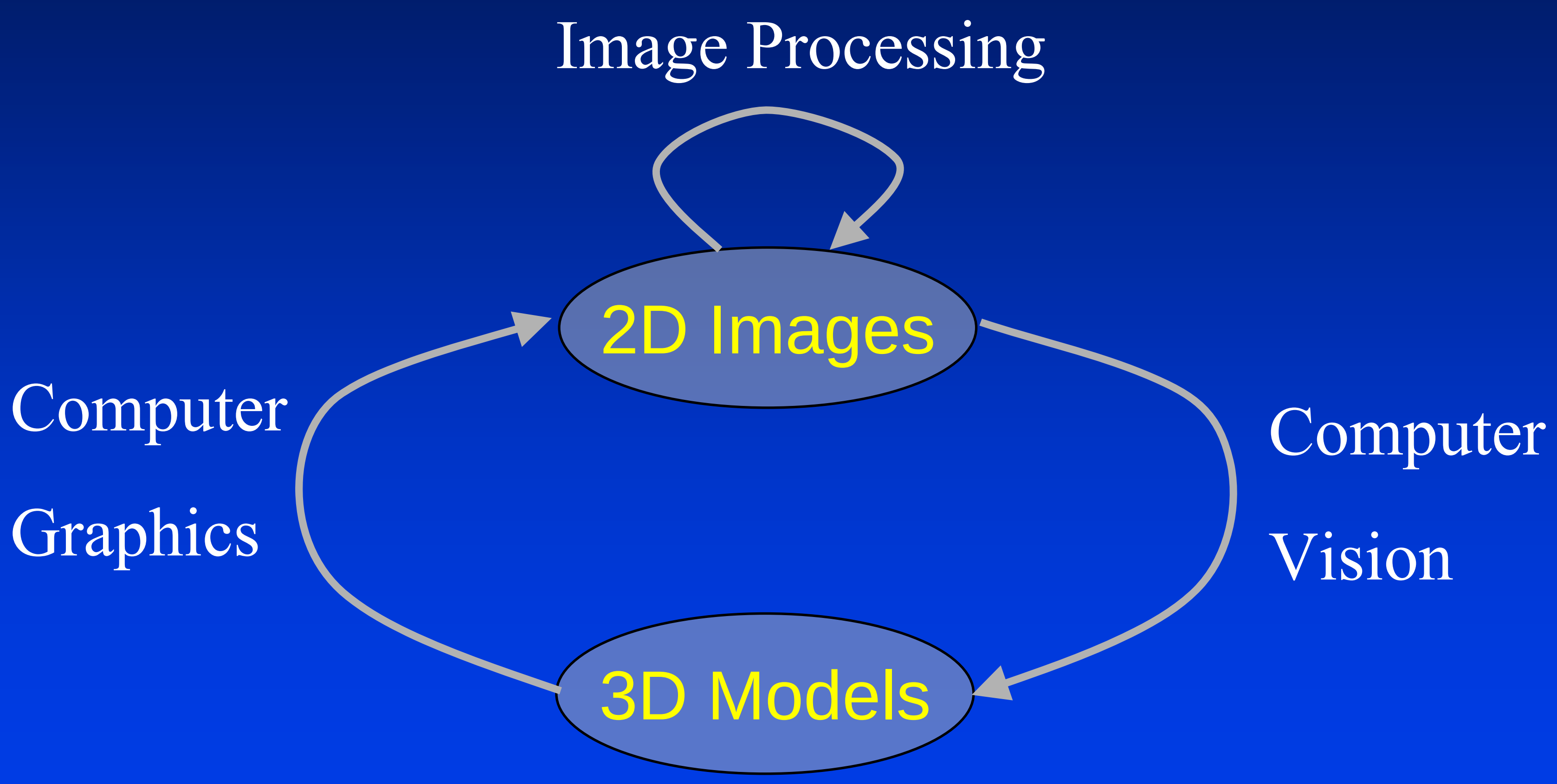
This process is also called *scan conversion* or *rasterization*



Computer Graphics

- Computer graphics consists of :
  1. Modeling (representations)
  2. Rendering (display)
  3. Interaction (user interfaces)
  4. Animation (combination of 1-3)
- Usually "computer graphics" refers to rendering

A Classical Classification

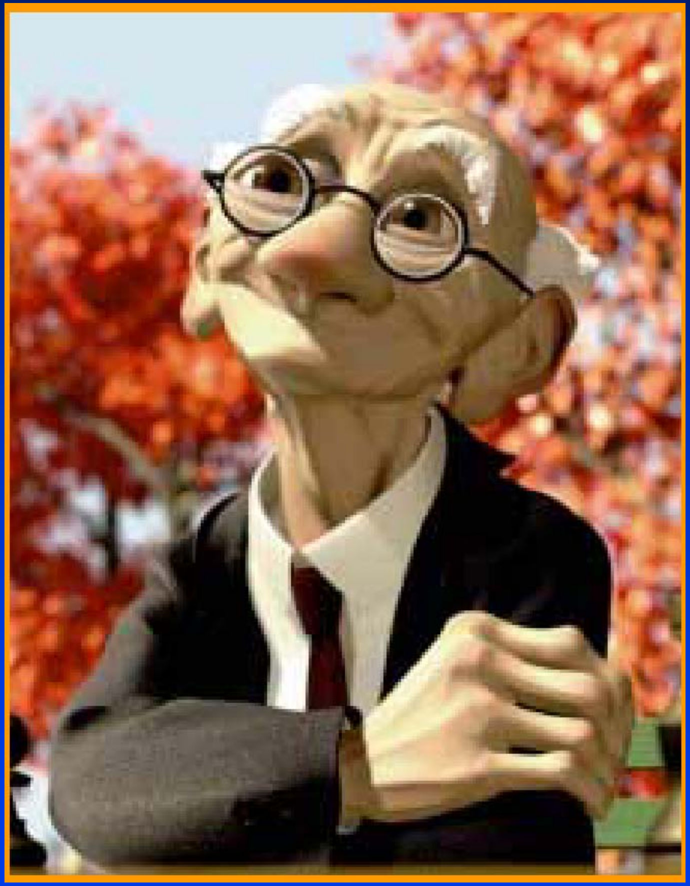


Surface Graphics

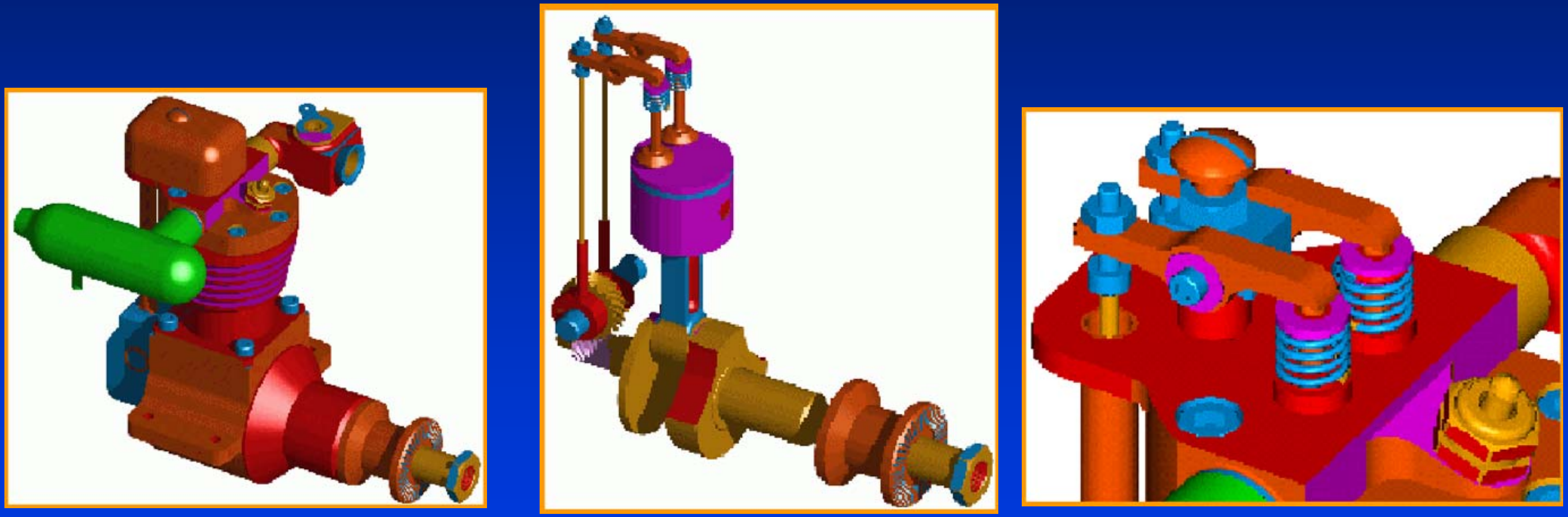
- Surface representations are good and sufficient for objects that have *homogeneous* material distributions and/or are not *translucent* or *transparent*
- Such representations are good only when object boundaries are important (in fact, only boundary geometric information is available)
- Examples: furniture, mechanical objects, plant life
- Applications: video games, virtual reality, computer-aided design

Applications

Computer Animation



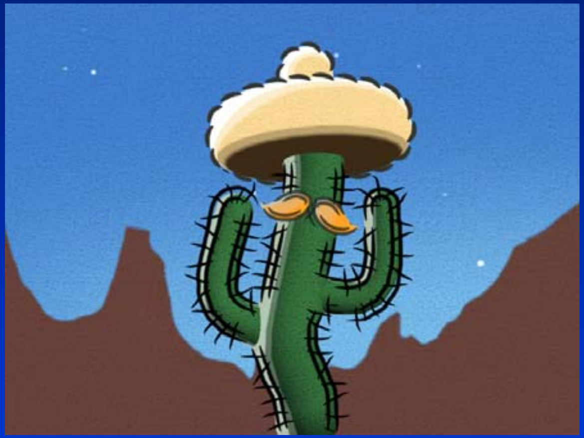
Computer Aided Design (CAD)

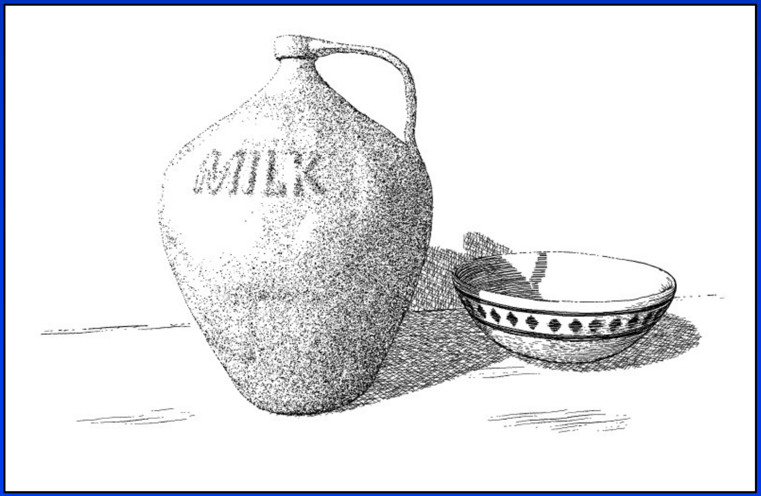


Architecture

Video Games

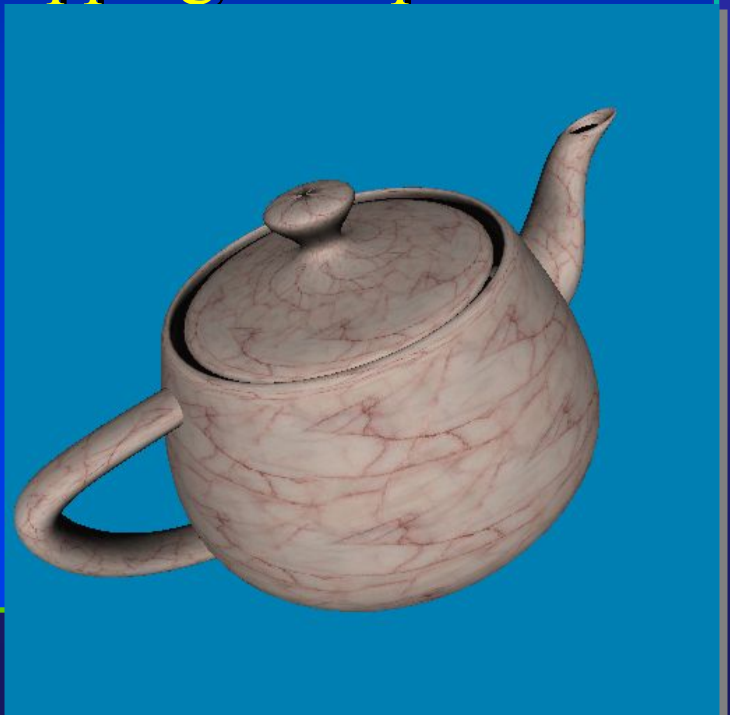
Digital Art





Surface Graphics – Pros and Cons

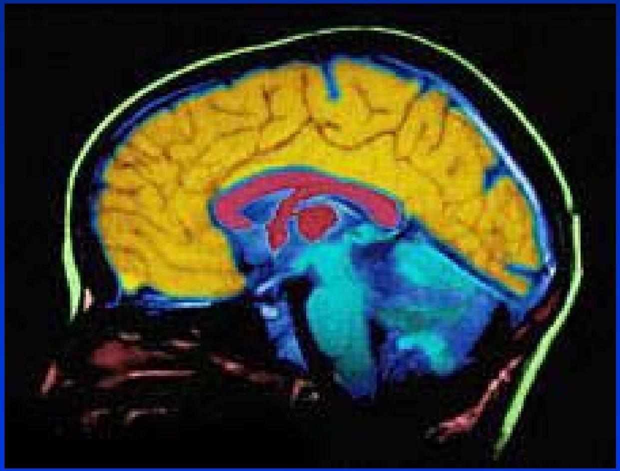
- Good: explicit distinction between inside and outside makes rendering calculations easy and efficient
- Good: hardware implementations are inexpensive
- Good: can use tricks like texture mapping to improve realism
- Bad: an approximation of reality
- Bad: does not let users peer into and thrsee ough objects

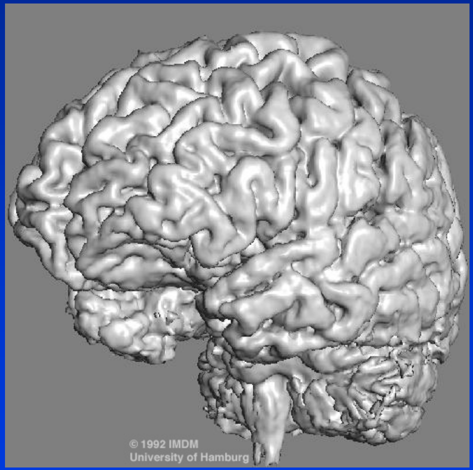


Volume Graphics

- Surface graphics doesn't work so well for clouds, fog, gas, water, smoke and other *amorphous phenomena*
- "amorphous" = "without shape"
- Surface graphics won't help users if we want to explore objects with very complex internal structures
- Volume graphics provides a good technical solution to these shortcomings of surface graphics
- Volume graphics includes *volume modeling (representations)* and *volume rendering* algorithms to display such representations

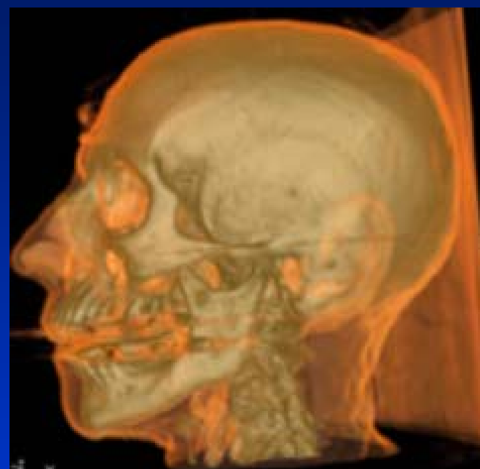
Scientific Visualization

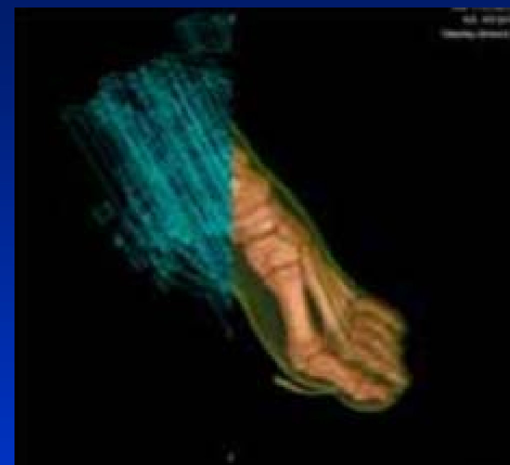


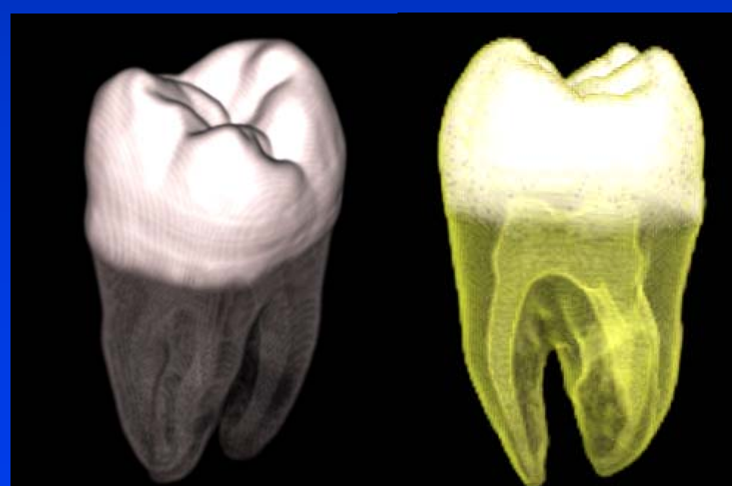


Visualization (Isosurfaces)

Visualization (Volume Rendering)



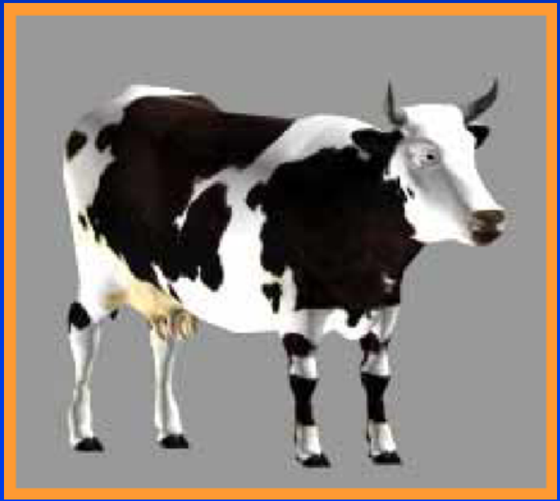




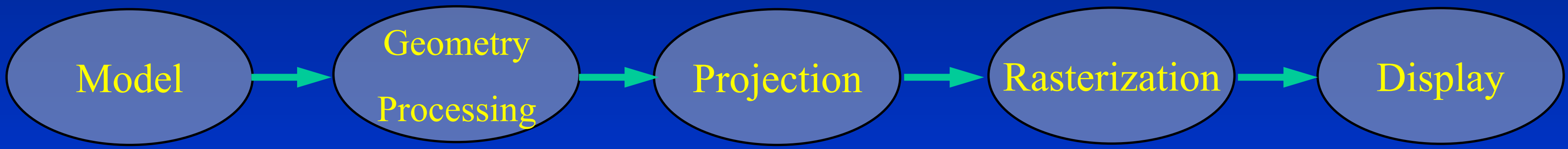
Computer Simulation

Graphics Pipeline

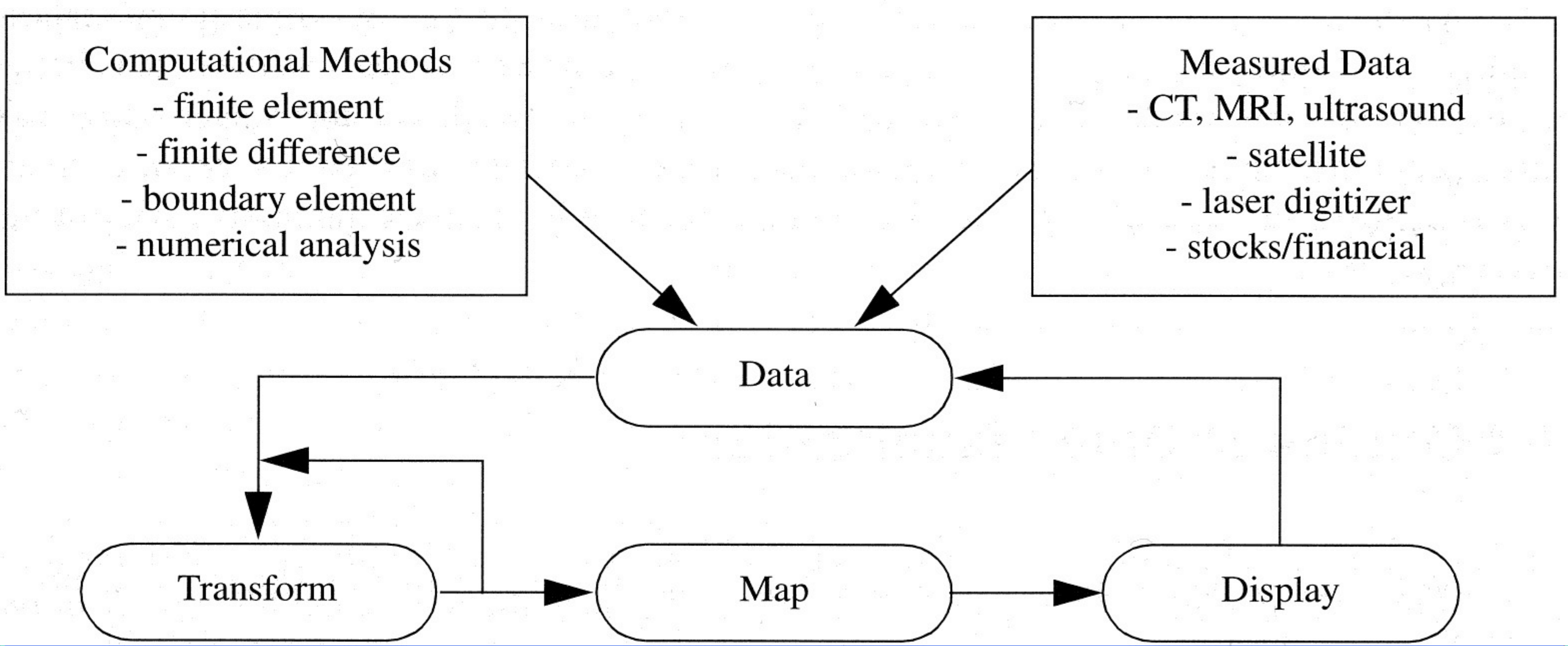
Modeling → Rendering



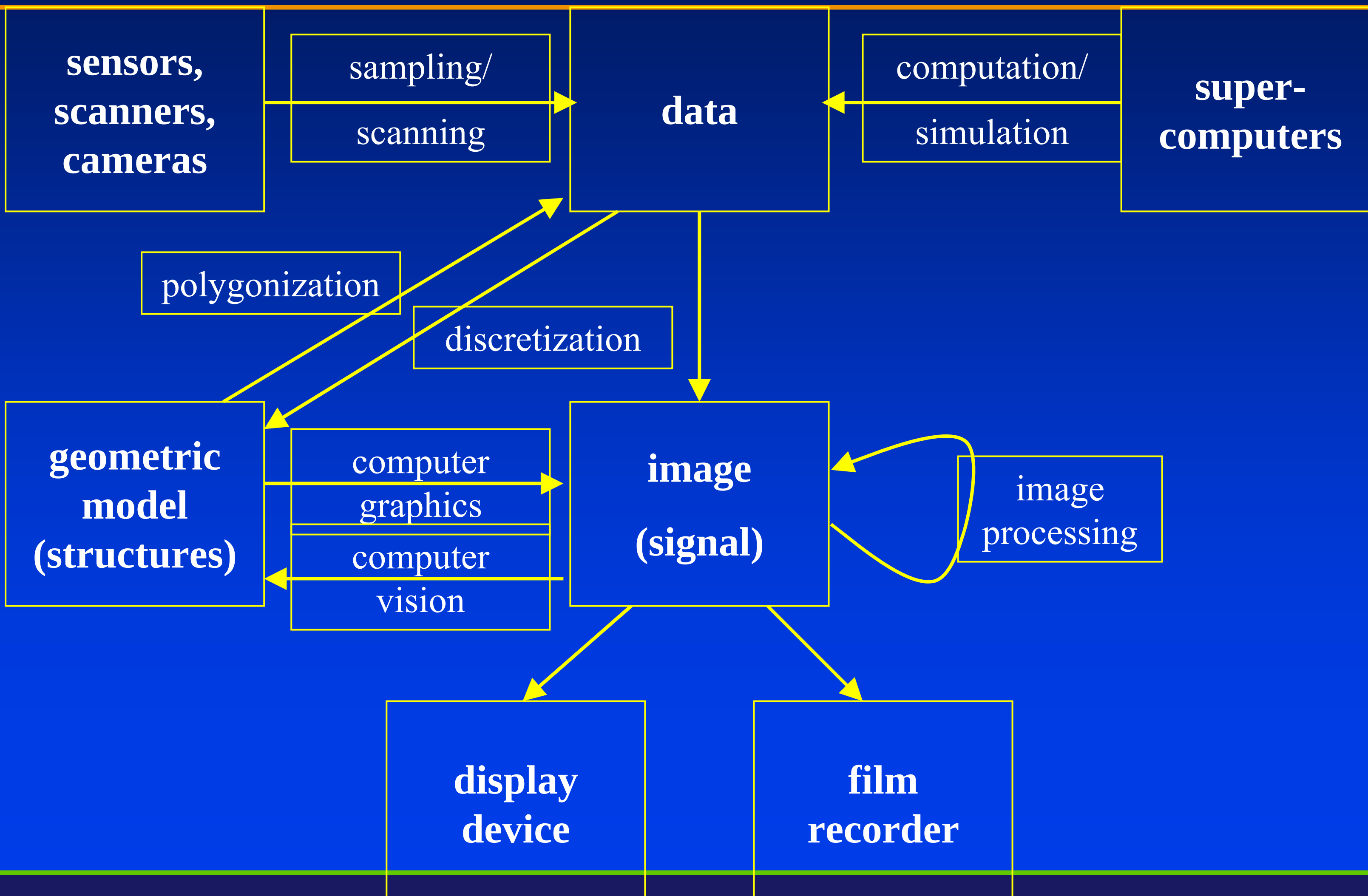
Computer Graphics Pipeline



Visualization Pipeline



Relevant Disciplines



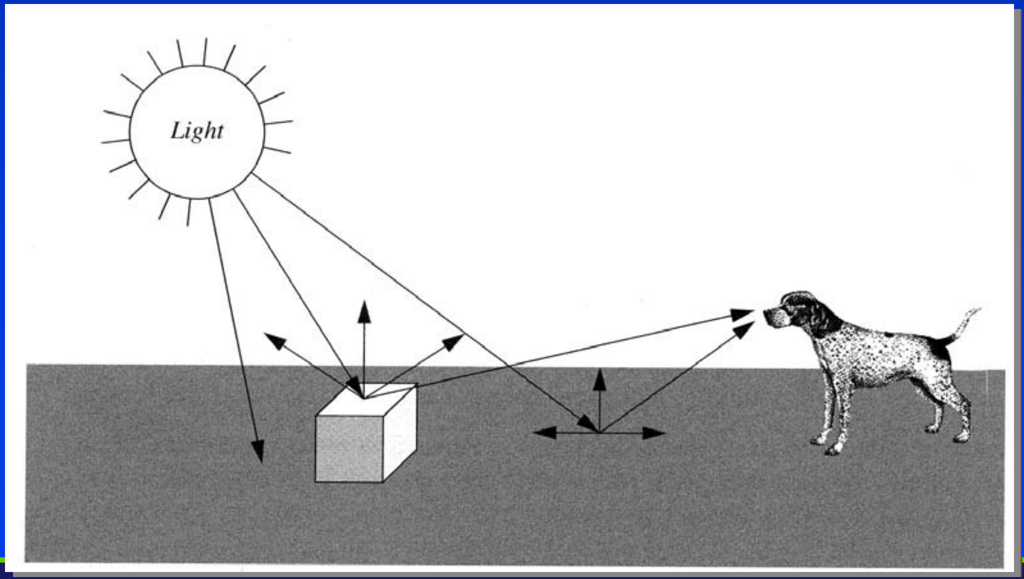
Lights, Cameras and Objects

- In reality, how are we able to see things in the real world?
- What's the computational process that occurs?
- Let us start this process:
  1. Open eyes
  2. Photons from light source strike object
  3. Bounce off object and enter eye
  4. Brain interprets image you see

We will have to simulate this process computationally!

Lights, Cameras and Objects

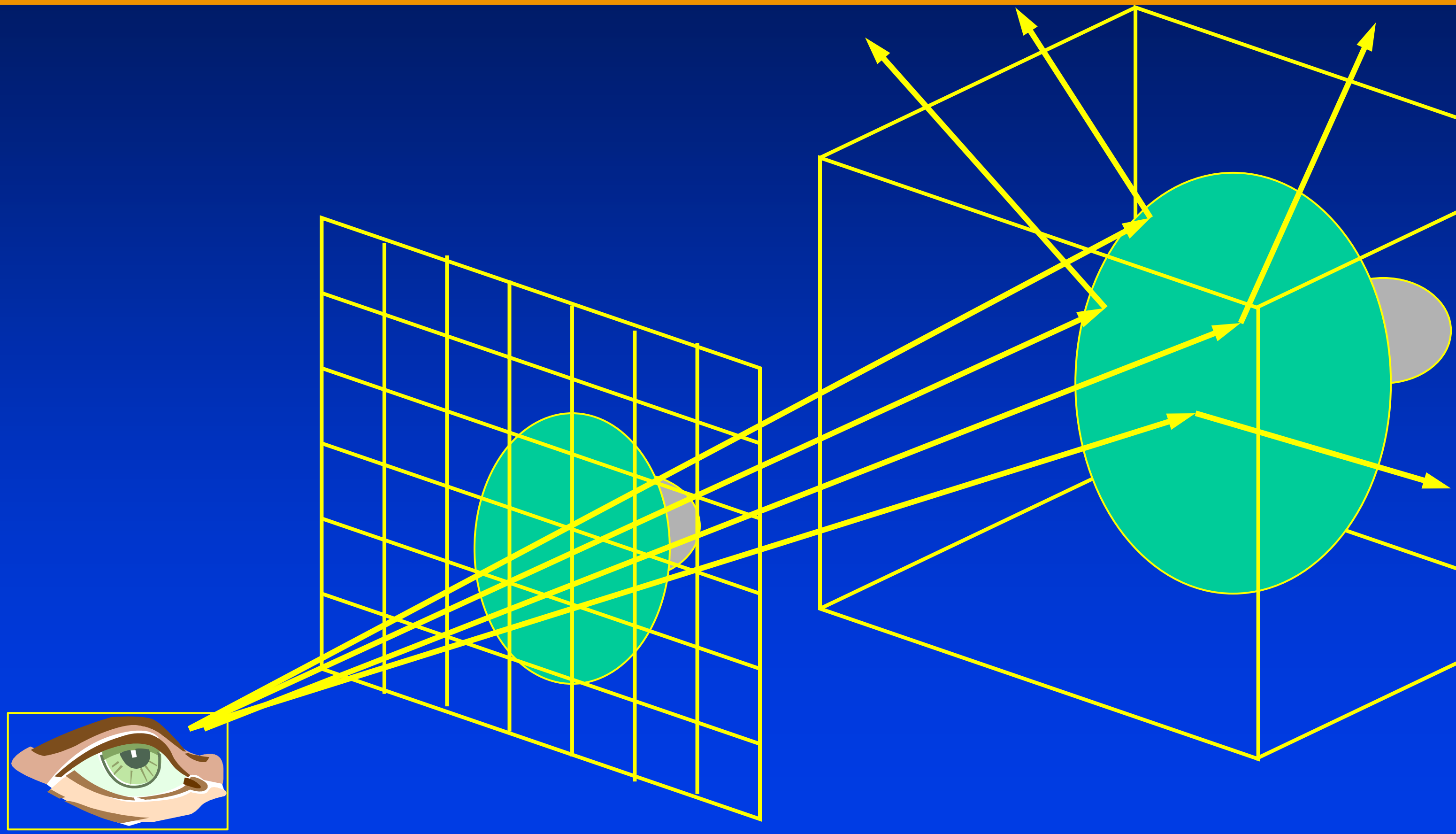
- Rays of light emitted by light source
- Some light strikes object we are viewing
  - Some light absorbed
  - Rest is reflected
  - Some reflected light enters our eyes



Lights, Cameras and Objects

- How do we simulate light transport in a computer?
- Several ways
- *Ray-tracing* is one
- Start at eye and trace rays the scene
- If ray strikes object, bounces, hits light source → we see something at that pixel
- Most computer applications don't use it. Why?
- With many objects very computationally expensive

Surface Ray-Tracing



Rendering Processes: Image-Order and Object-Order

- Ray-tracing is an *image-order* process: operates on *per-pixel basis*
- Determine for each ray which objects and light sources ray intersects
- Stop when all pixels processed
- Once all rays are processed, final image is complete
- *Object-order* rendering algorithm determines for each object in scene how that object affects final image
- Stop when all objects processed

Rendering Processes: Image-Order and Object-Order

- Image-order approach: start at upper left corner of picture and draw a dot of appropriate color
- Repeat for all *pixels* in a left-to-right, top-to-bottom manner
- Object-order approach: paint the sky, ground, trees, barn, etc. back-to-front order, or front-to-back
- Image-order: very strict order in which we place pigment
- Object-order: we jump around from one part of the regions to another

Rendering Processes: Image-Order and Object-Order

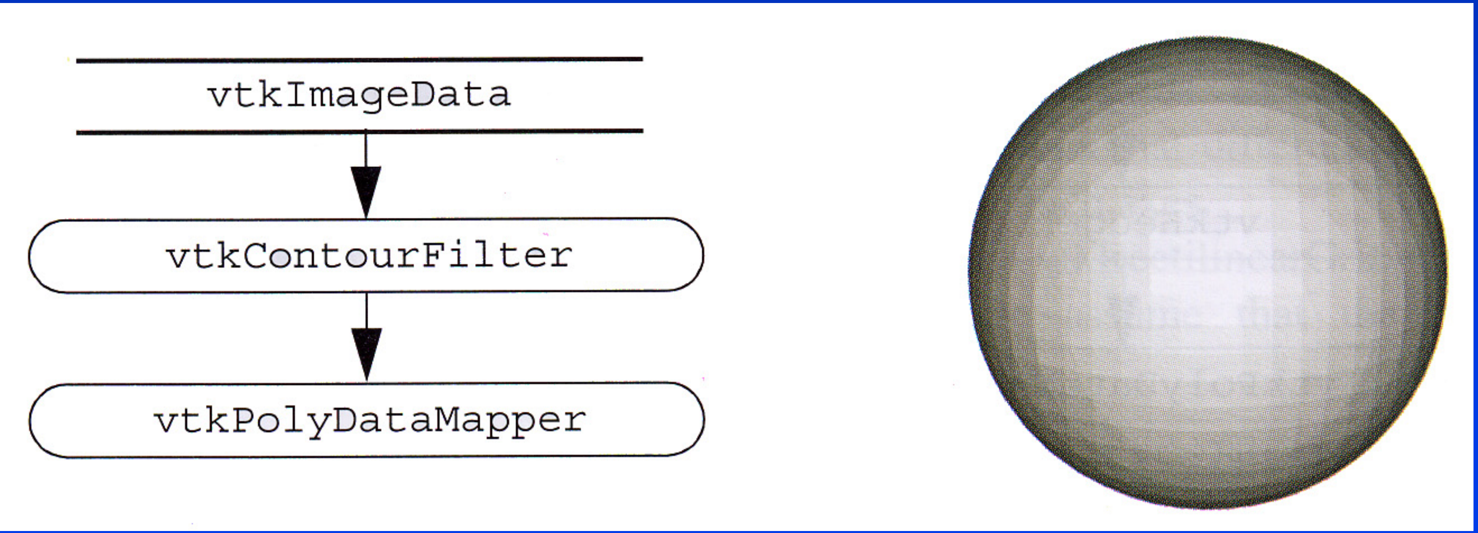
- Advantages and disadvantages of each
- Ray-tracing can produce very realistic looking images, but is very computationally expensive
- Object-order algorithms more popular because hardware implementations of them exist
- Not as realistic as ray-tracing

Surface Rendering

- We have considered interaction between light rays and object boundaries
- This is called *surface rendering* and is part of *surface graphics*
- Computations take place on boundaries of objects
- Surface graphics employs *surface rendering* to generate images of *surface' mathematical and geometric representations*

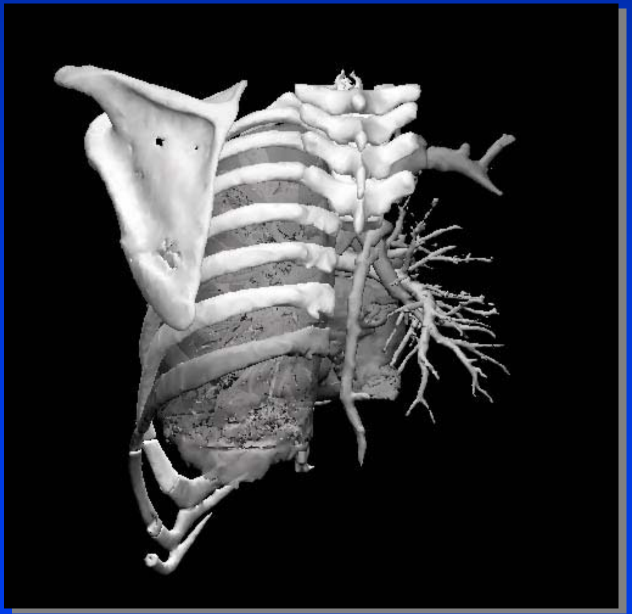
Mathematical Surfaces (Sphere)

- Equation of a sphere: $x^2 + y^2 + z^2 = r^2$
- How thick is the surface?
- Are there objects in real world thickness zero?



Surface Graphics

- Can you think of objects or phenomena for which this approach to rendering will fail?
- When is a surface representation not good enough?
- Would a surface representation suffice to represent the internal structure of the human body?



From Surface Graphics to Volume Visualization

- Visualization: transformation of data into graphical form
- Object-oriented-based approach: data are the objects, transformations are the methods

Data Visualization Example

- Usually we **evaluate** the equation of a sphere for a particular radius, r: $x^2 + y^2 + z^2 = r^2$
- Suppose we evaluate it for different values of r?
- We get a solid sphere
- Now imagine we evaluate it for any value of *x*, *y*, *z* and *r* $F(x, y, z) = x^2 + y^2 + z^2 - r^2$
- We get what's called a **field function**
- You plug in some values for *x*, *y*, *z*, *r* and get some number. That number is "located" at position (*x*, *y*, *z*)

Data/Model Visualization Example

- A **quadric** is a special function with maximum

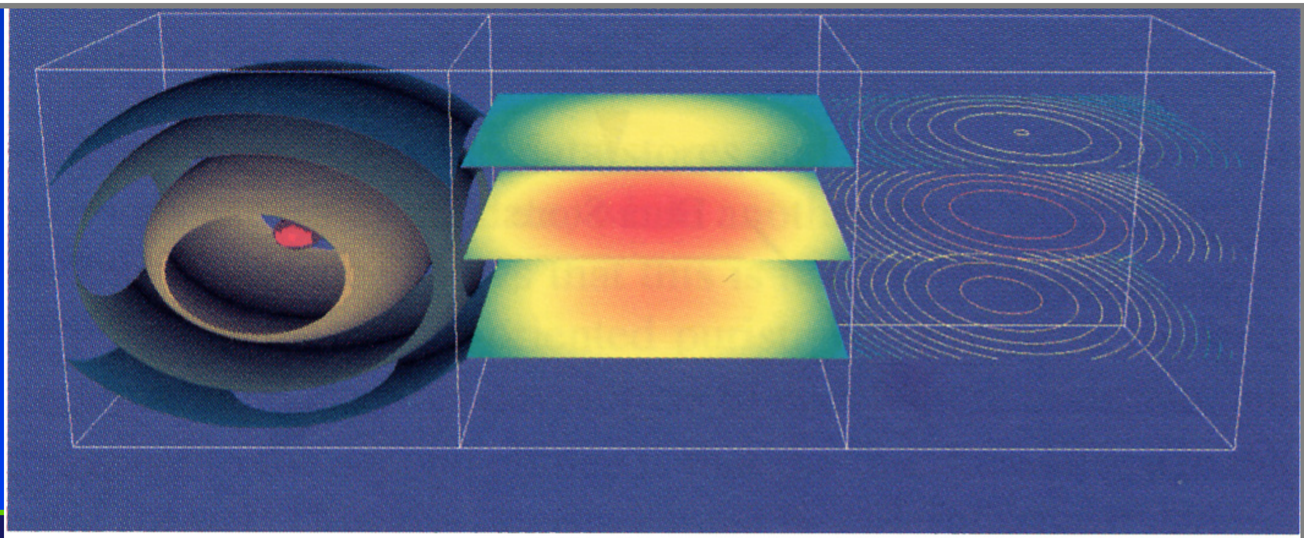
$$F(x, y, z) = a_0x^2 + a_1y^2 + a_2z^2 + a_3xy + a_4yz + a_5xz + a_6x + a_7y + a_8z + a_9$$

- A **solid** sphere is an example of a quadric with a_3, a_4, a_5, a_6, a_7, and a_8 all equal to zero
- If those values aren't zero, we get some pretty strange shapes
- Imagine squishing a **solid** rubber ball (i.e., not a hollow ball, like a tennis ball)

Data Visualization Example

- If we plug in x, y, z, r for any quadric, we can get some very strange-looking **field functions**. Here's an example:

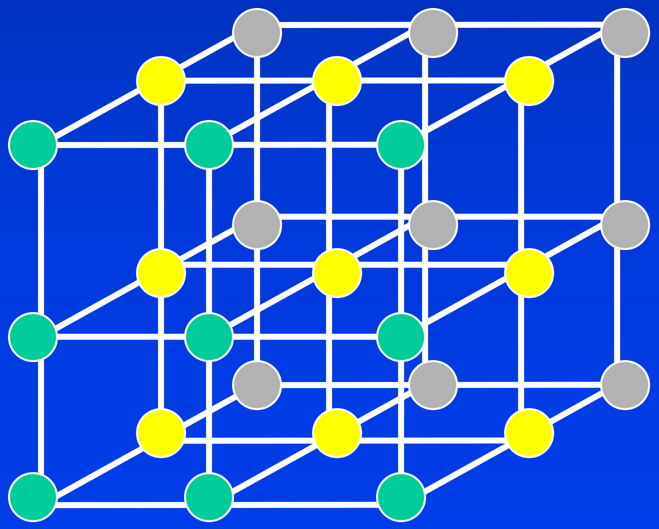
$$F(x, y, z) = a_0x^2 + a_1y^2 + a_2z^2 + a_3xy + a_4yz + a_5xz + a_6x + a_7y + a_8z + a_9$$



(a) Quadric visualization (`Sample.cxx`)

Volumetric Representations

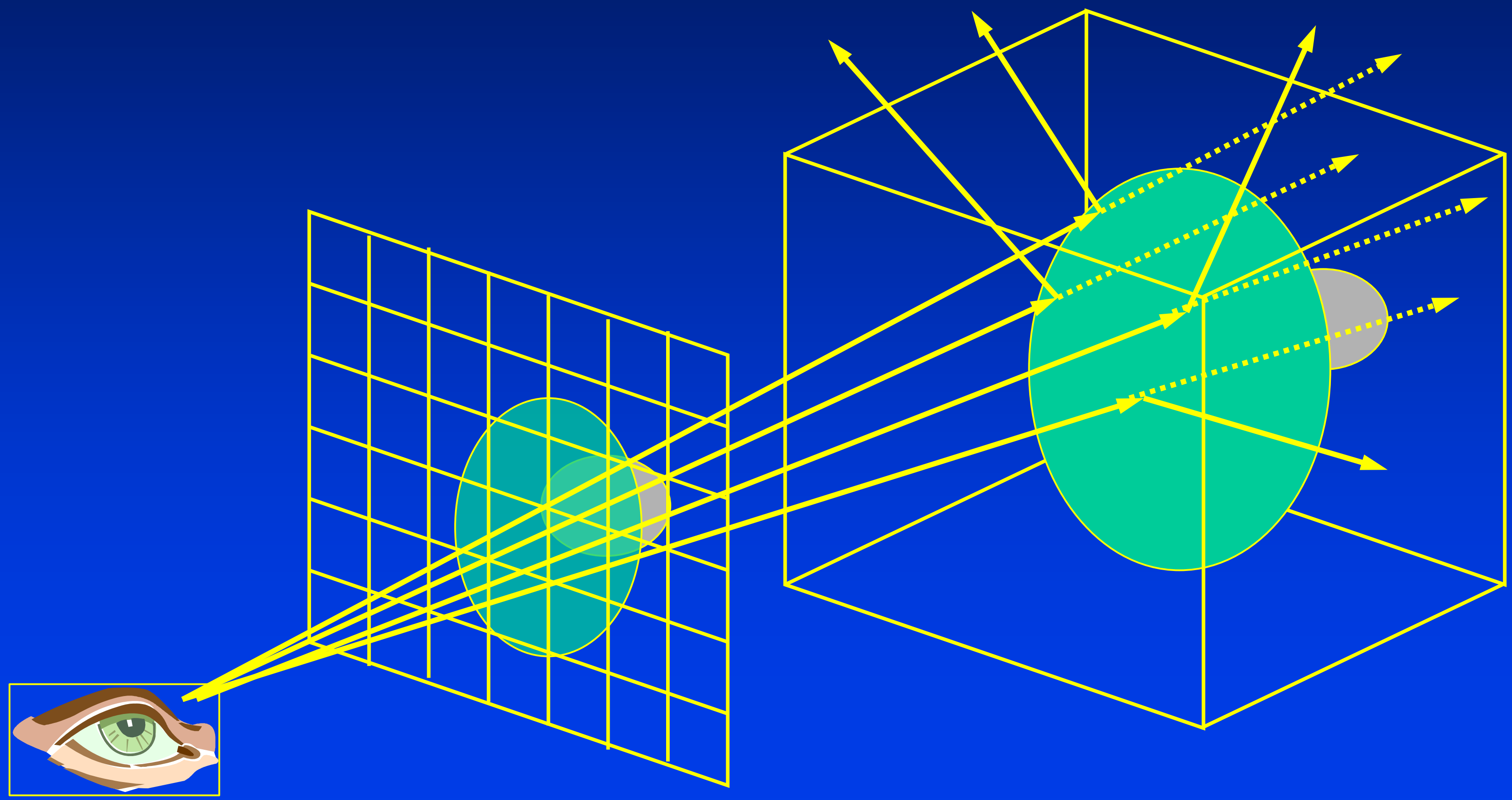
- A volumetric data-set is a 3D regular grid, or *3D raster*, of numbers that we map to a gray scale or gray level
- Where else have you heard the term *raster*?
- An 8-bit volume could represent 256 values [0, 255]
- Typically volumes are at least 200^3 in size, usually larger
- How much storage is needed for an 8-bit, 256^3 volume?



Volume Graphics

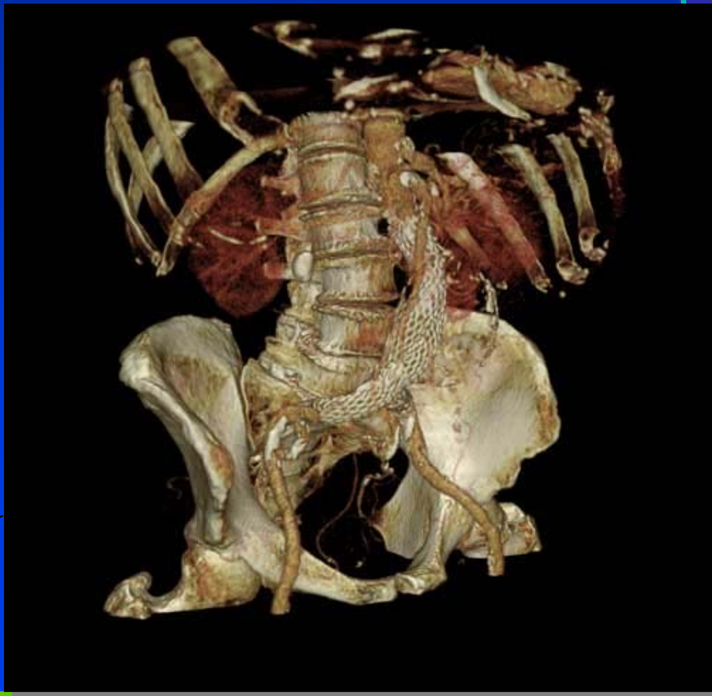
- Volumetric objects have interiors that are important to the rendering process (what does that mean?)
- Interior affects final image
- Imagine that our rays now don't merely bounce off objects, but now can penetrate and pass through
- This is known as *volumetric ray-casting* and works in a similar manner to surface ray-tracing

Volumetric Ray-Tracing



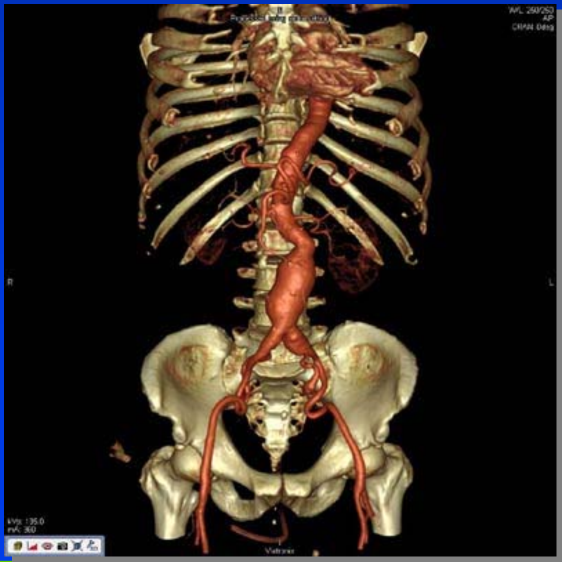
Volume Rendering

- In volume rendering, imaginary rays are passed through a 3D object that has been *discretized* (e.g., via CT or MRI)
- As these *viewing rays* travel through the data, they take into account of the *intensity* or *density* of each datum, and each ray keeps an accumulated value



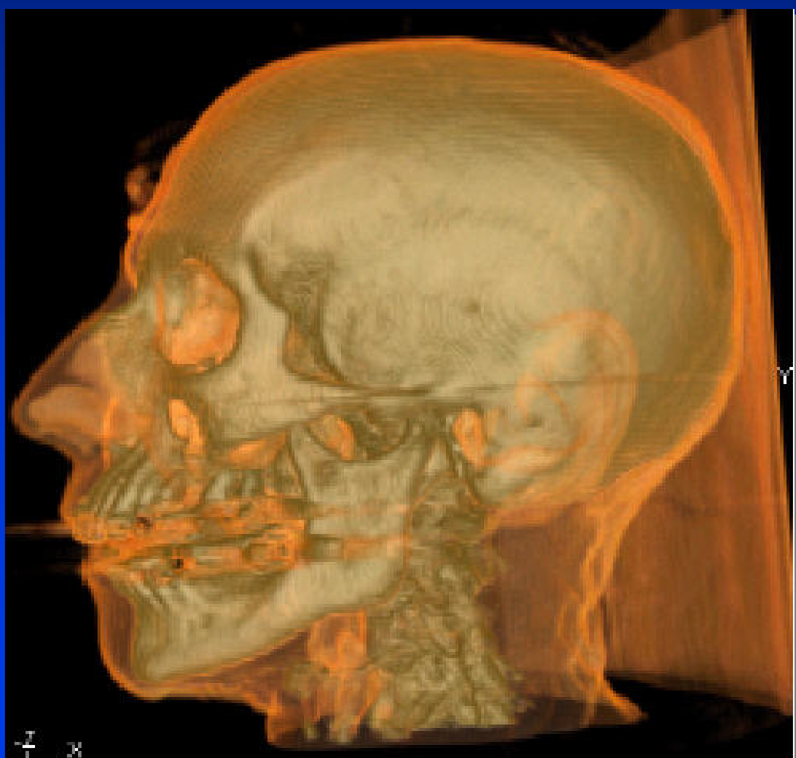
Volume Rendering

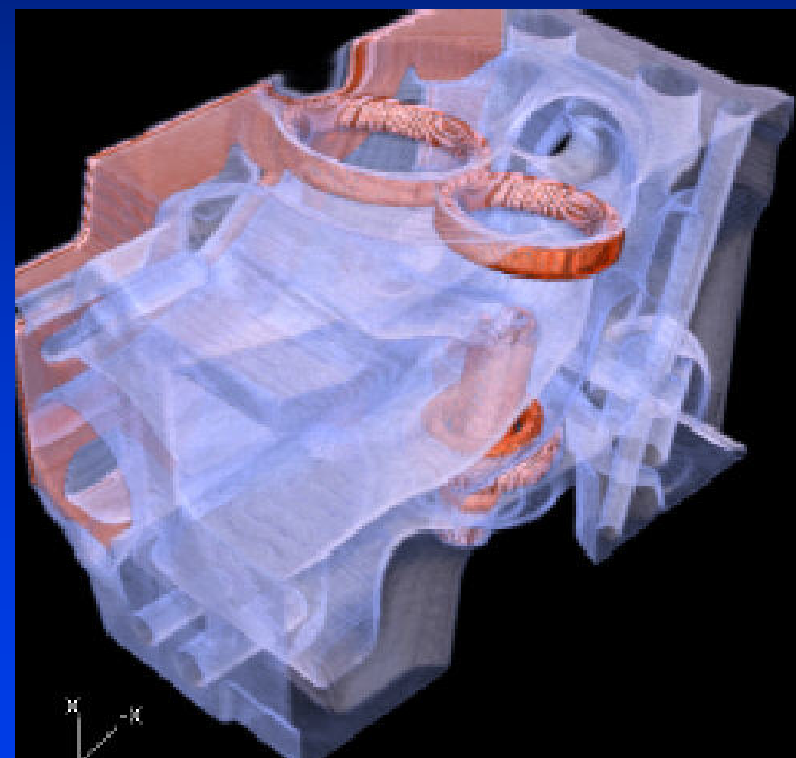
- As the rays leave the data, they comprise a sheet of accumulated values
- These values represent the volumetric data *projected* onto a two-dimensional image (the screen)
- Special mapping functions convert the grayscale values from the CT/MRI into color



Volume Rendering

- *Semi-transparent rendering*





Volume Graphics

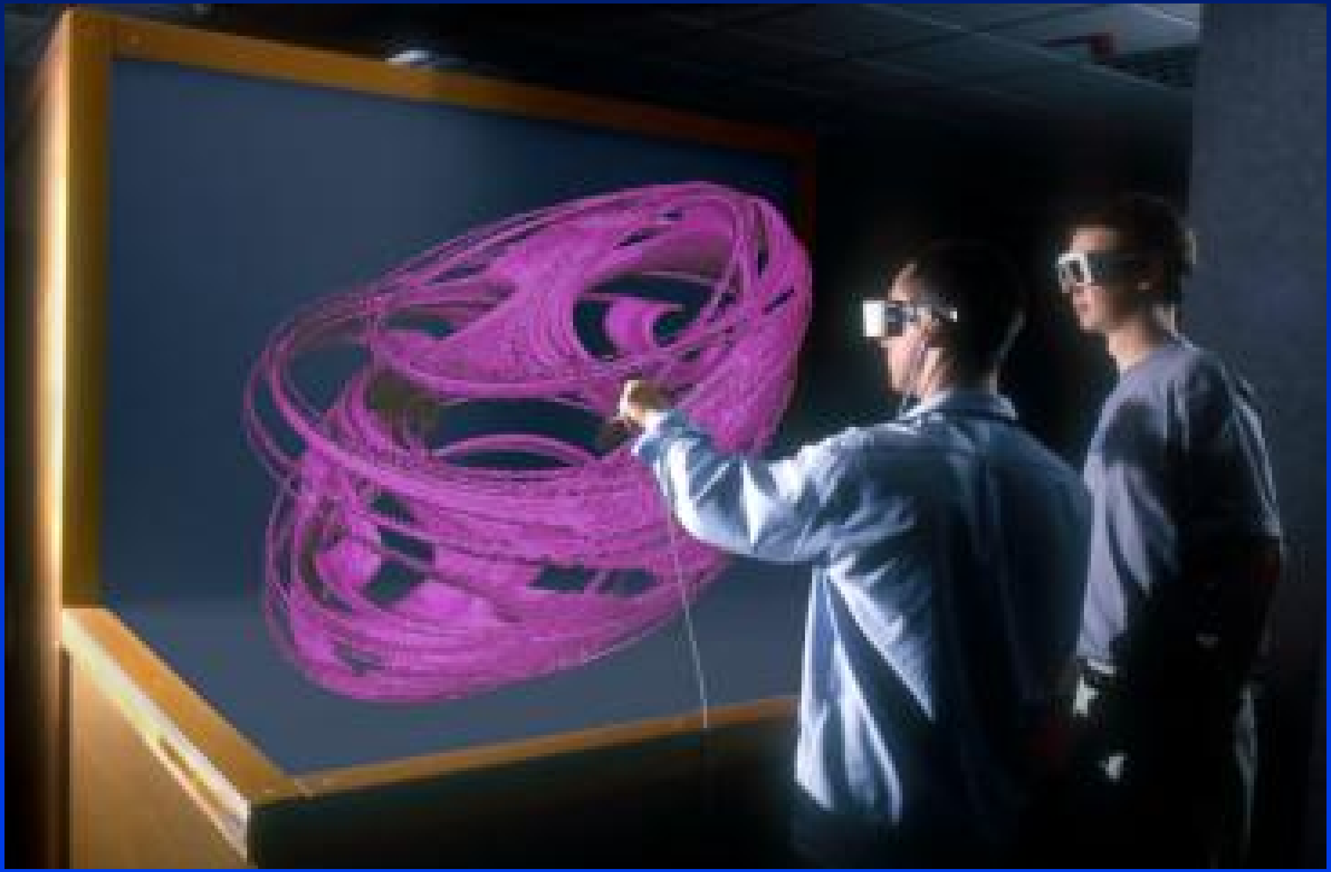
- Good: maintains a representation that is close to the underlying fully-3D object (but discrete)
- Good: can achieve a level of realism (and "hyper-realism") that is unmatched by surface graphics
- Good: allows easy and natural exploration of volumetric datasets
- Bad: extremely computationally expensive!
- Bad: hardware acceleration is very costly ($3000+ vs $200+ for surface rendering)

Surface Graphics vs. Volume Graphics

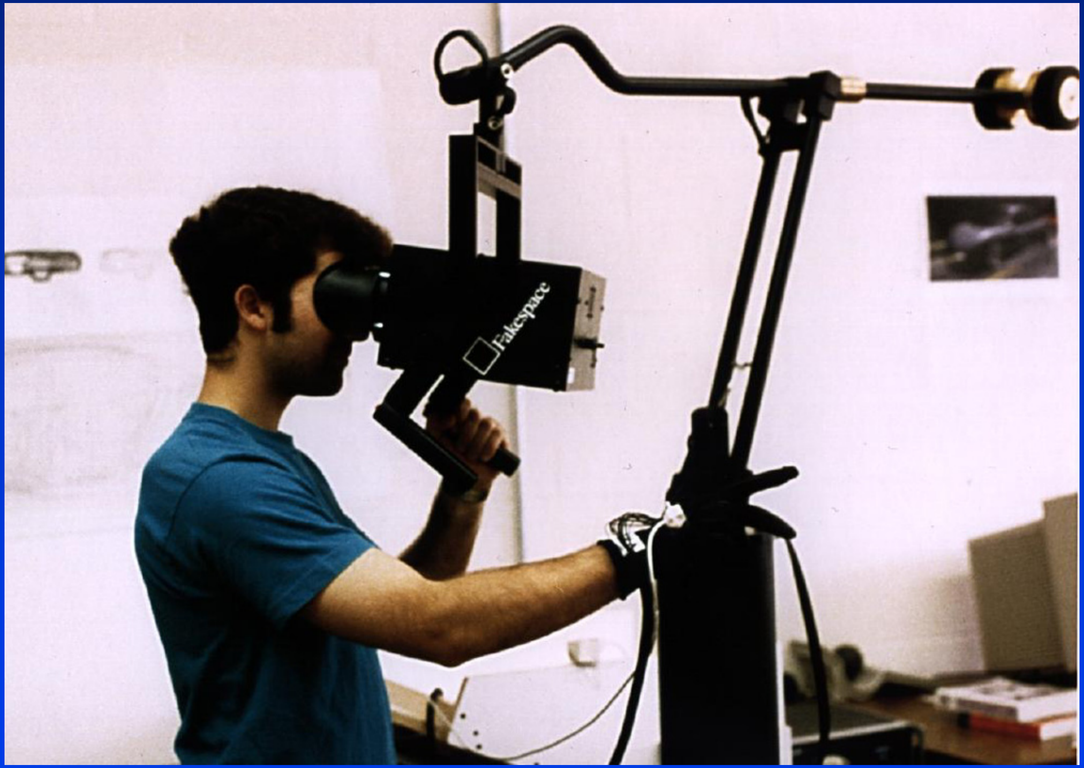
- Suppose we wish to animate a cartoon character on the screen
- Should we use surface rendering or volume rendering?
- Suppose we want to visualize the inside of a person’s body?
- Now what should approach we use? Why?
- Could we use the other approach as well? How?
- We could visualize body as collection of surfaces

Graphics Hardware

Virtual Reality Systems

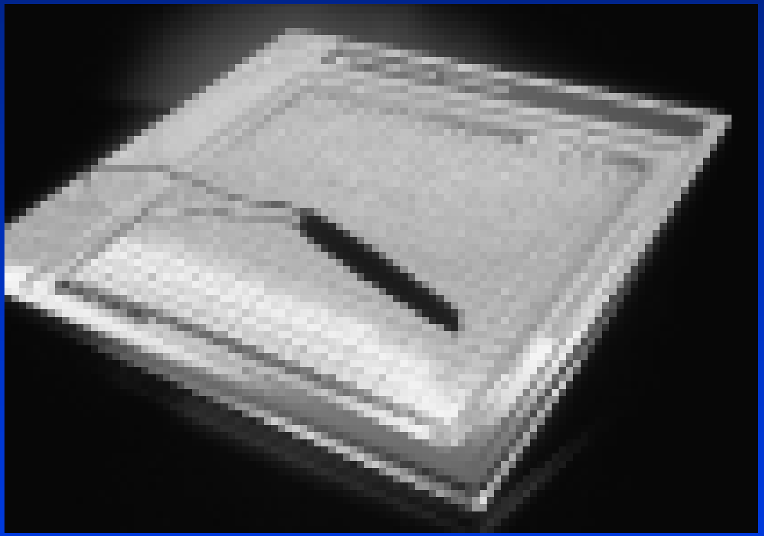


Virtual Reality Systems

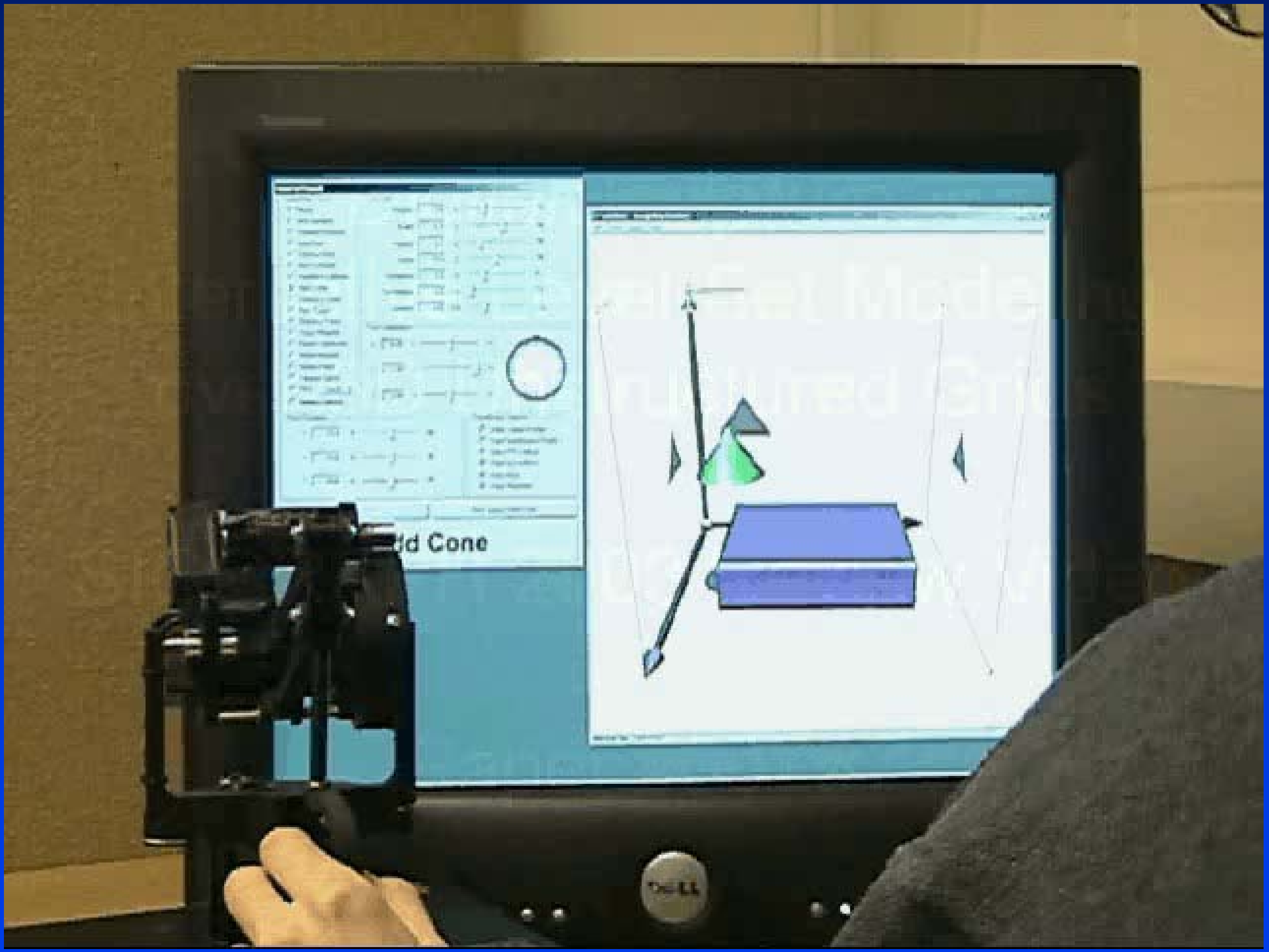


Virtual Reality Systems

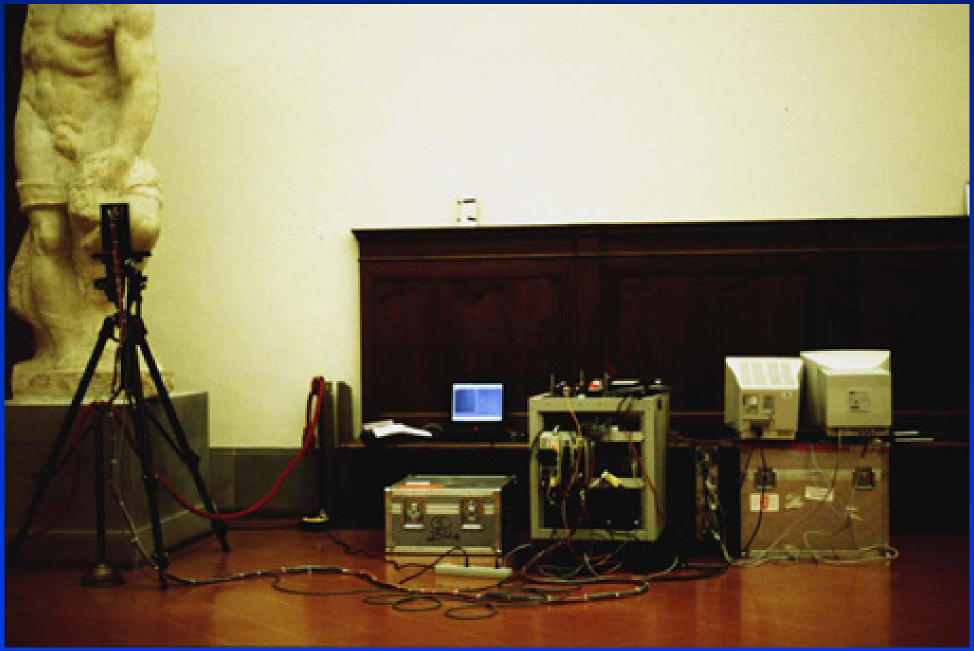
Trackball, Joystick, Touch Pad



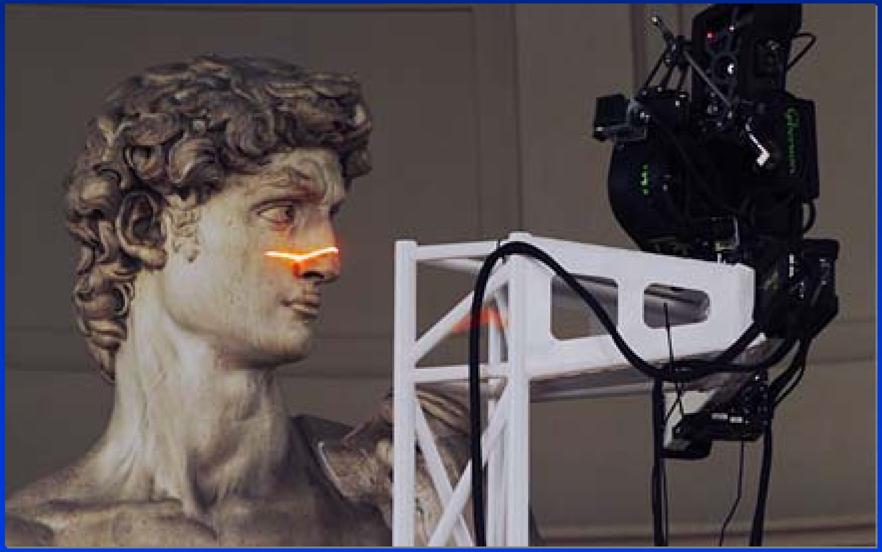
Haptics Device (Phantom 1.0)



3D Laser Range Scanner



3D Laser Range Scanner



3D Camera

Digital Fringe Projector

OpenGL

- Most widely used 3D graphics Application Program Interface (API).
- Truly open, independent of system platforms.
- Reliable, easy to use and well-documented.
- Default language is C/C++.

OpenGL

- The **GL** library is the core OpenGL system:
  - modeling, viewing, lighting, clipping
- The **GLU** library (GL Utility) simplifies common tasks:
  - creation of common objects (e.g. spheres, quadrics)
  - specification of standard views (e.g. perspective, orthographic)
- The **GLUT** library (GL Utility Toolkit) provides the interface with the window system.
  - window management, menus, mouse interaction

OpenGL

- To create a red polygon with 4 vertices:

```
glColor3f(1.0, 0.0, 0.0);
glBegin(GL_POLYGON);
    glVertex3f(0.0, 0.0, 3.0);
    glVertex3f(1.0, 0.0, 3.0);
    glVertex3f(1.0, 1.0, 3.0);
    glVertex3f(0.0, 1.0, 3.0);
glEnd();
```

- `glBegin` defines a geometric primitive:

  `GL_POINTS, GL_LINES, GL_LINE_LOOP, GL_TRIANGLES, GL_QUADS, GL_POLYGON…`

- All vertices are 3D and defined using `glVertex`

FLTK

- Fast Light Tool Kit (FLTK)
- www.fltk.org
- C++ oriented
  - A set of UI classes such as Window, box, etc.
- Can mix use with GLUT
- FLUID: fast light UI Designer
  - Fast creation of GUI
  - Automatically writes parts of GUI code from a graphical spec
  - Good for elaborate interfaces

Comments on Programming

- OpenGL, VTK, plus Glui
  - Simple, easy to program, limitations
- OpenGL, VTK, plus FLTK
  - Cross platform, more powerful
- OpenGL, VTK, plus Visual C++
  - Super!
  - Only run under windows system