Introduction to Computer Graphics: Geometric Processing and Modeling

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Lectures: Mon: 10:10 – 11:50am @海韵教学楼 207

Labs: Wed: 2:30 – 5:25pm @海韵实验楼 305
Course Synopsis

What is this course about?

- Concepts, algorithms, programming in 3D Graphics and Geometric Modeling
  - About representing, rendering, analyzing, and manipulating 3D shapes and scenes

Topics:

- Basic Computer Graphics pipeline
- Basic OpenGL programming for 3D Graphics
- Basic Geometric Computing for 3D Computer Graphics
- Modeling (representing + analyzing) 3D Shapes and their applications
Workload

- **Reading**
  - No required textbook
  - Please follow the lecture and course slides closely
  - Learn OpenGL following the online tutorial
  - Do necessary research and online search to solve problems in your homework implementation

- **Programming**
  - 4 programming homework projects
  - You are expected to finish the homework by every Wednesday
Grading

- Homework (100%)
  - Homework 1 (20%)
  - Homework 2 (20%)
  - Homework 3 (30%)
  - Homework 4 (30%)
Prerequisites and Requirements

- Basic linear algebra, calculus
- C/C++ programming background
  - Some starter codes will be provided in C++ for homework projects

- Self-learning:
  - Objective Oriented Programming in C/C++ (to understand homework starter codes)
  - OpenGL Programming
Be comfortable in read/writing C++ codes such as the following:

```cpp
class TriangleMesh {
    public:
        struct Point { double x, y, z; }
        struct Face { int pt_ids[3]; }

        TriangleMesh(void) {}  // Constructor
        ~TriangleMesh(void) {} // Destructor

        void loadMesh(char *filename);

        Point * vertexList;
        Face * faceList;
};
```

Codes often written in Object-Oriented Programming style.
Be comfortable in read/writing C++ codes such as the following:

```cpp
#include <vector>
class TriangleMesh{
public:
    struct Point { double x, y, z;};
    struct Face { int pt_ids[3];};

    TriangleMesh (void)
    ~ TriangleMesh (void)

    void loadMesh(char *filename);

    std::vector<Point> vertexList;
    std::vector<Face> faceList;
};
```

Sometimes you will see codes written using Standard Template Library (STL)
What is Computer Graphics?

The creation of, manipulation of, analysis of, and interaction with pictorial representations of objects and data using computers.

-- Dictionary of Computing

A picture is worth a thousand words.

It looks like a swirl. There are smaller swirls at the edges. It has different shades of red at the outside, and is mostly green at the inside. The smaller swirls have purple highlights. The green has also different shades. Each small swirl is composed of even smaller ones. The swirls go clockwise. Inside the object, there are also red highlights. Those have different shades of red also. The green shades vary in a fan, while the purple ones are more uni-color. The green shades get darker towards the outside of the fan...
Why Computer Graphics?

CG techniques utilized in various scientific, engineering, and entertainment tasks:

- **CAD/CAGD/CAM**: to digitize the world + simulate the scientific phenomena and engineering manufacturing

- **Visualization**: CG has become the dominant form of computer output → help better display/analyse scientific phenomena/discoveries

- **3D Computer Vision and AI**: teach computer to understand captured images/videos better

- And many more…
Movies

- CG has been changing Special Effects in the Movie Industry (Billions of dollars spent)
- Physically based animation makes them realistic
Video Games

- Important driving force
- Realistic rendering + interactive animations
- Try to avoid heavy computation and use various CG tricks
Somatosensory Video Games

Microsoft XBox360 Kinect games
Computer Aided Design/Manufacturing

Significant impacts on the design process:

- Mechanical, electronic design (executed entirely on computer environments)
- Architectural & product design (being migrated to computer environments)

- Interactive design/visualization → assist modeling
- Simulating their behavior in the virtual environment
Scientific Simulation for Education
Scientific Visualization for Discovery

- Scientific data representation
- Picture vs. stream of numbers
- CG Techniques for visualization → contour plots, color encoding, constant value surface rendering, custom shapes...

Display of a 2D slice through the total electron density of C-60; Created by Cary Sandvig of SGI

Predicted molecular structures

Social Media Visualization
Computer-assisted Medicine

- Aid in clinical analysis/diagnosis
- Virtual medical training and educations
Computer-assisted Medicine

3D Body Scanning and Posture/Motion Analysis

Real-time Human Body Scan
Reconstructed Digital Model

Scanning system developed by LSU GVC group and used in Baton Rouge Pennington Biomedical Research Center. Digital body shape measurement for diabetes disease monitoring and analysis.
Navigation, Urban Security…

Google Earth
Simulate/visualize/predict the propagation of airborne contaminants in virtual Manhattan
Virtual/Mixed Reality

- Computer-aided Virtual Environment (CAVE)
Virtual/Mixed Reality

- CAVE, Interactive modeling
- Virtual walkthroughs (training pilots, surgeons...)

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Textile/Cosmetics Industry

- Virtual fashion design
- Real-time cloth animation
- Web-based virtual try-on applications
Computer Art

- Digital Painting
- Digital Sculpting
- Digital Calligraphy
And more ...
3D Graphics Pipeline

3D Model Acquisition

Reconstruction from Images, Range images, or Point clouds

Geometric Modeling and Processing

Digital geom. processing
Surface and solid modeling
...

Animation, Rendering, Visualization

Ray tracing
Texture synthesis
Physics-based simulation
...
Graphics and Visual Computing

3D Display:
http://www.youtube.com/watch?v=G10bzatpuFc&feature=related
Acquiring 3D Digital Models

- Manual Design
  - interactive design and editing (AutoCad, 3DMax)
  - sketch-based modeling
- Mathematical Description
- Scanning

\[ S(u, v) = \sum_{i=0}^{8} \sum_{j=0}^{m} R_{i,2j+4}(u, v)P_{j,i} \]
Acquiring 3D Digital Models

- Manual Design
- Mathematical Description
- Scanning
  - By camera: image based reconstruction
  - By laser scanner: with depth
Representation of 3D Objects

A brief overview of common 3D representation techniques

- Polygonal Representation
- Space Subdivision Technique
- Spline Function
- Implicit Function Representation
- M-Representation (Medial Axis)
- Other Methods
  - Constructive Solid Geometry (CSG) Representation
  - GC (Generalized Cones, Generalized Cylinders)
  - Spatial Decomposition (Spherical harmonics, Zernike…)
  - Overlapping Spheres
  - …
Representation of 3D Objects

A brief overview of representation techniques we will go over this semester

- Polygonal Representation
- Space Subdivision Technique
- Spline Function
- Implicit Function
- M-Representation
- Other Methods:
  - Constructive Solid Geometry (CSG)
  - GC (Generalized Cones, Generalized Cylinders)
  - Spatial Decomposition (Spherical harmonics, Zernike…)
  - Overlapping Spheres
  - …

How do we choose a suitable representation?

- the nature of the object
- the particular geometric computation we need to apply
- the application

→ will explain later with details through each individual representation scheme and its suitable applications
Polygonal (Triangular) Mesh

- Objects $\leftarrow$ a mesh of planar triangular (polygonal) facets
  - can represent an object to different accuracy levels

- Pro: A ubiquitous representation in Computer Graphics
  - Easy to generate and process
  - With effective algorithm for rendering (machine-oriented rep.)
  - Other rep. (CSG, splines, voxels…) $\rightarrow$ mesh for rendering

- Con: accuracy, often unstructural
  - Faceted rep. VS curved surfaces: different continuity condition
  - Constructing methods matter $\rightarrow$ mesh quality
Triangular Mesh

• Surface shapes can be triangulated

Polygonal approximation of surfaces:

2D shape or 3D surface can be approximated with locally linear polygons. To improve accuracy (visual or numerical approximation quality), we only need to increase the number of edges.
Tetrahedral Mesh

- Solid shapes can be tetrahedralized

Polyhedra approximation of solid geometric data

3D volumetric data (3-manifold) can be approximated with locally linear polyhedra. To improve accuracy (visual or numerical approximation quality), we only need to increase the number of edges.
Polygonal Mesh

- Quad-Mesh
- Triangle Mesh
- A Mesh = \{\text{Vertex Positions, Connectivity, Additional Attributes}\}
Polygonal Mesh

- Quad-Mesh
- Triangle Mesh

A Mesh = \{\text{Vertex Positions, Connectivity, Additional Attributes}\}

Vertex Normal, Edge length, face area, any scalar/vector fields…
CSG Representation

- Polygonal Mesh → machine-oriented representation
- CSG → user-oriented representation
  - store the “logic of the shape”
- A CSG modeling system
  = \{building blocks, Boolean operations\}
  \{union, subtract, intersect\}

Widely used in 3DMax, Maya… as their modeling scheme:
- Support user-intervention
- Good for simple shapes
Space Subdivision Representation

- Not explicitly represents the geometric object
- But consider the space the object occupy

an octree rep.
= a hierarchical tree built by sequential subdivision of occupied cells

- Widely used for complicated scenes that need faster processing and lower accuracy
e.g. Collision detection in realtime simulation or animation
Implicit Representation

- Usually Compact

- Good for modeling shapes with closed-form expression

- Good for processing with topological changes
  - Simulation
  - Reconstruction (Hole-filling)
  - …
Spline

- Exact analytical rep.
- Support interactive shape editing
- Compact rep.

- Major modeling techniques in CAD
M-Representation

- Popular for animation, used in Maya, 3DMax
- Models
  - may still be represented as triangle meshes,
  - but their movement driven by M-rep
- Consider vertices on the boundary surface (skin), their deformations are induced by the deformation of skeleton

- A skeleton is a 1-D graph, each node represents a joint
- The deformation of the skeleton $\rightarrow$ the transformation of joints
Resources

Reference books (optional) :

1. OpenGL Programming Guide (the Red Book)  

2. 3D Computer Graphics  
   by Alan Watt. Addison-Wesley.

   by James Foley, Andries van Dam, Steven Feiner, John Hughes. Addison-Wesley.

To do research in CG:  

What math is important for Computer Graphics? (by Greg Turk)