CSE528 Computer Graphics - Theories, Algorithms, and Applications

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Course Website

- [http://www.cs.stonybrook.edu/~cse528](http://www.cs.stonybrook.edu/~cse528) or
CSE528 TA

- Mr. Xi HAN (Hong’s senior PhD student)
- xihan1@cs.stonybrook.edu
- Office hours: WF 3-4pm, or by appointments
- TA help page (OpenGL resources and submission instructions, directly managed by Xi):
  https://www3.cs.stonybrook.edu/~xihan1/courses/cse528/ta_help_page.html
- 2-3 OpenGL tutorials during this semester, or depending on the actual demands from students
Course Lectures and Office Hours

• **Lecture time:** TuTh 1:15-2:35pm

• **Location:** OLD Computer Science Building Rm.2120

• **Office hours:** TuTh 2:35-4:05pm, or by appointment
Grading Schemes

- Three exams (two midterm exams + one final exam): 30% (10% each)
- Class attendance: 10%
- Homework (non-programming): 15%
- Programming assignments: 45%
- Bonus: up to 15%
- (Optional, one course project, details to be discussed in class)
Late Submission Penalty

• **25% per day!!!**
The Course Objectives

- Provide graduate students a comprehensive knowledge on computer graphics concepts, theory, algorithms, techniques, and applications for modeling, simulation, rendering, animation, human-computer interactions, and other key elements of visual computing.

- Demonstrate the significance of these mathematical and computational tools and graphics algorithms in visual computing and relevant areas.

- Emphasize a "hands-on" approach to both the better understanding of graphics concept/theory/algorithms and the effective use of graphics techniques in various applications.
Course Facts

• This is an entry-level graduate course for both MS and PhD students (a quals course for PhD students)!!!

• Can I take this course? YES, if YOU
  – are a graduate student with CS background, have skills in calculus and linear algebra, or talk to the instructor

• You do NOT need to take CSE328 prior to this course

• However, if you had taken CSE328, or CSE332, or equivalent courses elsewhere, it would definitely help!

• One suggested (BUT NOT required) textbook, several suggested references

• Lecture notes are important!!! Class attendance is critical!!!
Basic Requirements for Graphics Programming Assignments

- Interactive interface (graphics-based)
- Intuitive and easy to understand
- Efficient (fast, high-performance)
- Basic functionalities
- Examples
- Flexible and easy to generalize
OpenGL Tutorials

- **Tutorials for Modern OpenGL (3.3+)**
  - Many online resources for OpenGL are available (for both reading materials and codes)
My Contact Information

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What is Computer Graphics

- **Computer Graphics**: The pictorial synthesis of real or imaginary objects from their computer-generated-models.
- Computer graphics is the production of (usually) images where none existed before.
sensors, scanners, cameras

sampling/scanning

polygonization
discretization

computers

geometric model (structures)

computer graphics

computer vision

image (signal)

image processing

display device

film recorder

sampling/scanning

computation/simulation
Related Terminologies

- **Image Processing**: Analysis or reconstruction of objects from image data. Basically, this is the inverse of computer graphics in that it starts with the image and works from there.

- **Computer Vision**

- **Computer Generated Imagery (CGI)**: Production of imagery using computers. Includes both computer graphics and image processing.
Key Components

• Computer graphics pipeline, basic concepts, theory, algorithms, and techniques
• Modeling: representation choices of different models
• Rendering: simulating light and shadow, camera control, visibility, discretization of models
• HCI (human-computer interface): specialized I/O devices, graphical user interfaces
• Animation: lifelike characters, natural phenomena, surrounding virtual environments
• Advanced topics
Key Components

• Possible advanced topics, including (but not just limited to)
  – Image processing techniques,
  – Data modeling techniques,
  – Image-based modeling and rendering,
  – Radiosity, Photo mapping/tracing,
  – Non-photorealistic rendering,
  – Image vectorization, etc.

• You are welcome to suggest new topics!
Main Concentrations

- Mathematical concepts, modeling and rendering theory, and computational tools
- Fundamental algorithms in representation, modeling, simulation, rendering, animation, etc.
- Geometric (and graphical and visual) modeling and simulation techniques, and geometric processing and analysis tools
- A large variety of applications in graphics and visualization as well as other visual computing areas
- Several advanced topics and they are all research-oriented, representing the most sophisticated ones
Our Course

• A subset of key concepts, theory, algorithms, techniques, and applications

• Extensive topics with a main focus on our unique course mission

• Comprehensive lectures (focusing on geometric intuition, good ideas, and application needs)

• Numerous slides, figures, images, and videos for easy understanding (after all, this is the nature of graphics and visualization)

• Active students’ involvements
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

Computer Graphics is also called Image Synthesis

A picture is worth a thousand words

- Chinese Proverb
Computer Graphics

• (Realistic) pictorial synthesis of real and/or imaginary objects from their computer-based models (datasets)
• It typically includes modeling, rendering (graphics pipeline), and human-computer interaction
• So, we are focusing on computer graphics hardware, software, and mathematical foundations
• Computer Graphics is computation
  – A new method of visual computing
• Why is Computer Graphics useful and important?
• Course challenges: more mathematics oriented, programming requirements, application-driven, inter-disciplinary in nature, etc.
Computer Graphics Systems

Graphical Models

Rendering Parameters

Rendering

Output Device
Output Devices

• **Vector Devices**
  – Lasers (for example)

• **Raster Devices**
  – CRT, LCD, bitmaps, etc.

– Most output devices are 2D
– Can you name any 3D output devices?
Graphical Models

- **2D and 3D objects**
  - Triangles, quadrilaterals, polygons
  - Spheres, cones, boxes

- **Surface characteristics**
  - Color, reaction to light
  - Texture, material properties

- **Composite objects**
  - Other objects and their relationships to each other

- **Lighting, fog, etc.**

- **Much, much more…**
Rendering

• Conversion of 3D model to 2D image
  – Determine where the surfaces “project” to.
  – Determine what every screen pixel might see.
  – Determine the color of each surface
Rendering Parameters

• Camera parameters
  – Location
  – Orientation
  – Focal length
3D Graphics vs. 2D Graphics

• **2D**
  - X, Y - 2 dimensions only
  - We won’t spend time on 2D graphics in this course

• **3D**
  - X, Y, and Z
  - Space

• Rendering is typically the conversion of 3D to 2D
3D Coordinate Systems

Right-Hand Coordinate System

OpenGL uses this!
Left-Hand Coordinate System

Direct3D uses this!
Mathematical Background

- **Computer Graphics has a strong 2D/3D geometry component**
- **Basic linear algebra is also helpful** – matrices, vectors, dot products, cross products, etc.
- **More continuous math (vs. discrete math)** than in other typical computer science courses
- **Function plots, curves, and surfaces**
Primary Topics

• Overview, applications
• Basic components, history development
• Hardware, system architecture, raster-scan graphics
• Line drawing, scan conversion
• 2D transformation and viewing
• 3D transformation and viewing
• Hierarchical modeling
• Interface
• Geometric models
• Color representations
• Hidden object removal
• Illumination models
• Advanced topics
Primary Topics

- Local Illumination and Graphics Rendering
- Texture Mapping Techniques
- Procedural Modeling Fundamentals and Various Techniques
- Radial Basis Functions and Applications
- Ray Tracing
- Geometry-driven Deformation and FFD
- Computer Animation
- Hidden Surface Removal
- Differential Geometry
A Very Good Textbook for General Issues in Computer Graphics


• *A recommended textbook (BUT NOT REQUIRED)*!
OpenGL Reference Books

1. OpenGL Programming Guide,
2. OpenGL Reference Manual,
3. OpenGL Superbible
4. http://www.opengl.org and many online resources (for reading materials and codes)
Why Graphics and Visualization

- A Chinese proverb: “a picture is worth a thousand words.”

- “A picture is worth more than a thousand words.” – ancient proverb
What is Visualization

Visualization is a method of extracting meaningful information from complex or voluminous datasets through the use of interactive graphics and imaging.
Why Graphics and Visualization

- Enable scientists (also engineers, physicians, general users) to observe their simulation and computation
- Enable them to describe, explore, and summarize their datasets (models) and gain insights
- Offer a method of SEEING the UNSEEN
- Reason about quantitative information
- Enrich the discovery process and facilitate new inventions
Why Graphics and Visualization

• Analyze and communicate information
• Revolutionize the way scientists/engineers/physicians conduct research and advance technologies
• About 50% of the brain neurons are associated with vision
• The gigabit bandwidth of human eye/visual system permits much faster perception of visual information and identify their spatial relationships than any other modes
  – Computerized human face recognition
Entertainment
Graphics Examples
More Examples

Images

Points

Volumes
Medicine and Health-care
More Examples
Terrain Modeling and Rendering
What Are Our Ultimate Goals?

• A large variety of datasets (acquired via scanning devices, super-computer simulation, mathematical descriptions, etc.)

• A pipeline of data processing that consists of data modeling (reconstruction), representation, manipulation (rigid transformation or deformation), classification (segmentation), feature extraction, simulation, analysis, visual display, conversion, storage, etc.

• Visual information processing in the intelligent way (Intelligent Information Processing)
What Are Our Ultimate Goals?

- Datasets that are huge, multi-dimensional, time-evolving, unstructured, multi-attributes (geometric info. + material distributions), scattered (both temporal and spatial)...

- We are investigating mathematical tools and computational techniques for data modeling, reconstruction, manipulation, simulation, analysis, and display
Challenges

• TOO MUCH data
• The number of data sources keeps increasing
• Sensor quality and resolution are increasing
• Existing instruments are still available
• The speed of supercomputer is faster than ever
• We must do something (besides collecting and storing the datasets)
• We must deal with the huge datasets effectively
• Visual communication, improve our visual interaction with data
Challenges

• Data-driving, scientific computing to steer calculations
• Real-time interaction with computer and data experimentation
• Drive and gain insight into the scientific discovery process
Related Fields

- **Computer graphics (image synthesis)**
  - Generate images from complex multivariate datasets
- **Image processing, signal processing**
- **Image understanding (pattern recognition)**
  - Interpret image data
- **Computational vision**
- **Human-computer interaction**
  - Mechanisms to communicate, use, perceive visual information
- **Computer-aided design**
- **Neurological/physiological studies on human brain and our visual system**
Computer Graphics Pipeline

- Data acquisition and representation
- Modeling data and their (time-varying) behaviors (e.g., physical experiments or computational simulations)
- Graphics system and software environments for data rendering
- Image-based techniques
Data Sources

- Scanned, computed, modeled data
- The first process is data-gathering
- Large variety of data sources and attributes
- Extremely large-scale datasets
- Require real-time processing
Data Acquisition and Processing

- Pixels and voxels
- Regular & irregular grids
- Numerical simulations
- Surface or volumetric data
- Scalar, vector, tensor data with multiple attributes
- Higher-dimensional and/or time-varying data
- Popular techniques
  - Contouring, iso-surfaces, triangulation, marching cubes, slicing, segmentation, volume rendering, reconstruction
- Image-based processing techniques
  - Sampling, filtering, anti-aliasing, image analysis & manipulation
Information Domain

- **Sciences** (e.g., statistics, physics)
- **Engineering** (e.g., empirical observations for quality control)
- **Social events** (e.g., population census)
- **Economic activities** (e.g., stock trading)
- **Medicine** (e.g., computed tomograph (CT), magnetic resonance imaging (MRI), X-rays, ultrasound, various imaging modalities)
- **Geology**
Information Domain

- Biology (e.g., electronic microscopes, DNA sequences, molecular models, drug design)
- Computer-based simulations (e.g., computational fluid dynamics, differential equation solver, finite element analysis)
- Satellite data (e.g., earth resource, military intelligence, weather and atmospheric data)
- Spacecraft data (e.g., planetary data)
- Radio telescope, atmospheric radar, ocean sonar, etc.
- Instrumental devices recording geophysical and seismic activities (e.g., earthquake)
Graphics and Visualization

• Data acquisition, representation, and modeling
• Imaging processing
• Visualization (displaying) methods and algorithms
• More advanced research topics
Pathway to Success

• Highly-motivated
• Hard-working
• Start as soon as possible
• Communicate with the instructor on a regular basis
• Actively interact with your fellow students
• Visit libraries and internets frequently for papers and software system
• Read as many papers as possible
• Work on your course project
Computer Graphics

• “The purpose of scientific computing is insight, not numbers,” by Richard Hamming many years ago

• These fields are all within computer science and engineering, yet computer graphics spans multi-disciplines

• Computer Graphics (another definition)
  – Application of computers to the disciplines of sciences/engineering
Computer Graphics

• **Computer Graphics is application-driven, so what are its applications?**
Applications

- Simulation and training: flight, driving
- Scientific visualization: weather, natural phenomena, physical process, chemical reaction, nuclear process
- Science: Mathematics, physics (differential equations) biology (molecular dynamics, structural biology)
- Environments sciences
- Engineering (computational fluid dynamics)
- Computer-aided design/manufacturing (CAD/CAM): architecture, mechanical part, electrical design (VLSI)
Applications

- Art and Entertainment, animation, commercial advertising, movies, games, and video
- Education, and graphical presentation
- Medicine: 3D medical imaging and analysis
- Financial world
- Law
- WWW: graphical design and e-commerce
- Communications, interface, interaction
- Military
- Others: geographic information system, graphical user interfaces, image and geometric databases, virtual reality, etc.
Key Components

- **Modeling**: representation choices of different models
- **Rendering**: simulating light and shadow, camera control, visibility, discretization of models
- **HCI (human-computer interface)**: specialized I/O devices, graphical user interfaces
- **Animation**: lifelike characters, natural phenomena, surrounding virtual environments
Journals and Conferences

- Computer Graphics (proceedings of ACM SIGGRAPH)
- ACM Transactions on Graphics
- IEEE Transactions on Visualization and Computer Graphics
- IEEE Computer Graphics and Applications
- Computer-Aided Design
- Computer Aided Geometric Design
- Others!!!