CSE528 Computer Graphics: Theory, Algorithms, and Applications

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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, have BASIC knowledge on graphics and/or visualization, or talk to the instructor
- You do NOT need to take CSE328 prior to this course
- However, you need to have taken CSE328, or CSE332, or equivalent courses elsewhere
- One required textbook, several suggested references
- Lecture notes are important!!! Class attendance in critical!!!
Course Facts

• **Students are expected to**
  
  – Read papers (four research papers in total) and finish one technical review report that summarizes all the papers that you have read during this semester
  
  – Present two papers selected from the aforementioned four papers in the class (in the middle of the semester)
  
  – Complete one course project, present your project in the class, and submit the final report on your course project
  
  – Complete your take-home written exam
  
  – Extra, Bonus points: extra paper reading assignments, additional functionalities on your final project (the total will be 10% extra for bonus points)

• **What projects are appropriate?**
  
  – Talk to the instructor and suggest possible topics of interest
  
  – Projects also available from the instructor
Course Prerequisites

• Mathematical skills: fundamental knowledge on calculus, linear algebra, analytic geometry, etc. (basic mathematical training at the undergraduate level), you should feel very comfortable with matrix algebra and calculus.

• Computer science background: data structure, algorithm design, basic programming skills, basic graphics/visualization courses or knowledge at the undergraduate level.

• Essentially, you need to have an undergraduate education in computer science or engineering with basic knowledge on graphics/visualization, you have to write programs.

• You need to speak to the instructor if you are not sure about your background knowledge and course prerequisites.
Course Prerequisites

• I expect that you are having the ability to learn a programming library on your own (OpenGL)!!!

• Please note that, this is an entry-level graduate course!!!
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.
My Goals for this Course

- My bottomline is that everybody in this class will learn something by the end of this semester, so that people are NOT wasting their time here.
- My strategy: breadth (I will make the slides available to everybody) + depth (I will pay attention to several important topics).
- In order to realize these goals, I would like to get everybody involved, and I very much encourage INTERACTION!
- Students must finish their assignments (paper reading, technical report on paper review, project proposal, various check points, final project report, final software demo) and course projects and they should give presentations to the entire class.
- Success in graduate education: a good idea (research project) + technical writing (putting together technical reports) that will lead papers in conferences and journals + communication skills (oral presentations at conferences).
OpenGL Tutorials

- Tutorials for Modern OpenGL (3.3+)

  - http://www.opengl-tutorial.org/

OpenGL Help for CSE528

- My TAs in previous years have also collected many examples:
- TA Website (for openGL tutorials):
Questionnaire

1. List your background courses/knowledge/education related to graphics/visualization, your current education level
2. What is the main goal/purpose for you to take this course (e.g., learn the knowledge, pursue a career in this area)
3. How does this course help your future professional career
4. Your expectations on the course
5. Your studying plan
6. Other important issues that you can think of about the course
My Contact Information

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Grading Requirements

• Meet with the instructor for (at least) 30 minutes to decide your study plan for this course, review your research experiences in the past, and plan for the future, and this should be done during the next three weeks.

• Upon the individual meeting with the instructor, select four research papers and start to read them immediately.

• Write and submit a one-page technical proposal on what you are planning to do for the rest of the paper (i.e., your course project during the next 2-3 months, programming-driven research projects, re-implementation of at least one paper, etc.).
Grading Requirements

• Submit your technical report on paper review (3-4 pages, single/double columns, single space)
• Give an oral presentation on two papers to the entire class (20 minutes)
• Finish all the course requirements for all check points
• Give a final presentation in class (10-15 minutes) based on your final technical report on your project (4-6 pages, single/double columns, single space)
My Expectations

• Your works should be your OWN!
• NEVER share code with your fellow student or debug code together
• Reference examples from the web is an effective way to learn and you are encouraged to do so
• When using open sources, you should explicitly point them out
• NOT a course about graphic/game design, NOT using graphics packages like PhotoShop / Maya
How to Get a “A”? 

- NO mid-term tests!
- NO final exams!
- PAPER READING/PRESENTATION, COURSE PROJECT, TECHNICAL REPORTS, and TAKE-HOME EXAM only, 100% on paper reading/presentation, course project, technical reports, and take-home exam!!!
- Bonus points (10%): extra work on paper reading and additional functionalities on your programming project!!!
Course Project (60%)

- One-page project proposal: 5%
- Mid-term software demo with preliminary results: 12%
- A working system + software codes: 35%
- Oral presentation and final demo in class: 5%
- Final course project report: 3%
Basic Requirements for Graphics Course Project

- Interactive interface (graphics-based)
- Intuitive and easy to understand
- Efficient (fast, high-performance)
- Basic functionalities
- Examples
- Flexible and easy to generalize
Projects, and Reading / Writing Assignments

• Course project: 60%
• Paper presentation on two papers (October 23-24, Monday & Tuesday): 10% (details to be announced later)
• Paper reading and technical report on literature review (four research papers in total, throughout the semester), your technical report on paper review will be due on November 20 Monday at 2:30pm: 10%
• Take-home written exam (November 27, Monday, at 8pm): 15%
• Class attendance and asking questions during office hours: 5%
• Extra, bonus points: 10% extra for additional paper reading and additional functionalities on your final project
Final Presentations (10-15 Minutes Each)

- Tentatively, December 8-10 (Friday-Sunday)
- Location: TBA
- Signup sheets will be available late in the semester!!!
Final Project Submission Schedule

- Technical Report + Software + ppt file for your final presentation: DUE December 8 (Friday) 8am
Late Submission Penalty

• 25% per day!!!
Lecture Information for CSE528

- **WHEN:** Monday & Wednesday 2:30pm - 3:50pm
- **WHERE:** OLD Computer Science Building, Rm. 2311
- **OFFICE HOURS:** Monday & Wednesday 12:50pm - 2:20pm, or by appointment, Rm. 151 (Hong’s office)
- **CREDITS:** 3
- **TA INFO:** CS PhD students, TBD!!!
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.
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.
sensors, scanners, cameras

sampling/scanning

data

computation/simulation

super-computers

genermic model (structures)

polygonization

discretization

image (signal)

computer graphics

computer vision

image processing

display device

film recorder

sampling/scanning

computation/simulation

super-computers

geometric model (structures)

polygonization

discretization

image (signal)

computer graphics

computer vision

image processing

display device

film recorder
Course Project (60%)

- One-page project proposal (September 27, Wednesday at 2:30pm): 5%
- Mid-term demo with preliminary results (November 1, Wednesday): 12%
- A working system + software codes (December 8, Friday at 8am): 35%
- Oral presentation and final demo in class (12/8-10, Fri-Sun): 5%
- Final course project technical report and final presentation ppt file (12/8 Friday at 8am): 3%
Paper Presentation (10%)

- Two research papers (including the paper that your course project is based on)
- Tentatively, October 23 (Monday), and special arrangement on October 24 (Tuesday)
- Specific timeslots: to be announced later!
- Paper presentation on two papers in class: 20 minutes per student
- All presentations are expected to be in our lecture room!!
- Please sign up on the sheet!!!
Technical Report on Literature Review (Four Papers in total)

- **November 20 Monday at 2:30pm**
- **Electronic submission (PDF format) to me and my TA before the deadline!!!**
- **Hardcopies submitted to either me at the lecture room or my office (NEW CS Building, Rm.151) before November 20 Monday at 2:30pm!!!**
Extra Lectures???

- Due to Hong’s travel schedule, I might need to add some extra lectures, details to be announced later.
- There might be some extra lectures on OpenGL to be held by my TA, details to be announced later.
Course Project and Final Presentation

- Technical report for your course project + a working software system + ppt file for your final presentation: Due 12/8 Friday 8am
- Email to CSE528 TA and Hong
- Final Presentation: (tentatively) from December 8 (Friday) to December 10 (Sunday)
- Final Presentation Time (10-15 minutes each student): specific timeslots to be announced!!!
- All Final Presentations: expected to be in our Seminar Room!!! Details to be announced later!!!
- Please sign up on the sheet!!!
Final Presentations (10-15 Minutes Each)

- Dec. 8 (Friday) to Dec. 10 (Sunday), details to be announced later!!!
- Please sign up later!!!
Final Submission Schedule

• Technical Report + Software + ppt file for your final presentation: DUE December 8 (Friday) 8am
OpenGL Help for CSE528

- My TAs in previous years have collected many examples:
  - http://www3.cs.stonybrook.edu/~dozhang/cse528/
- TA Website (for openGL tutorials):
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
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, interdisciplinary 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!
Basic Elements of Computer Graphics

- Graphics modeling: representation choices
- Graphics rendering: geometric transformation, visibility, discretization, simulation of light, etc.
- Graphics interaction: input/output devices, tools
- Animation: lifelike characters, their interactions, surrounding virtual environments
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
• 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

OpenGL Reference Books


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
Graphics Examples

Department of Computer Science
Center for Visual Computing

CSE528 Lectures
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
More Examples

Images

Points

Volumes
Medicine and Health-care
More Examples
Terrain Modeling and Rendering
Virtual Environment
National Security
Tourism
Design and Manufacturing
What are Happening Now

• **Network Graphics**

  3D Advertisement

  Server → Virtual Museum → Client

  Live Sports Broadcast
What are Happening Now

• Wireless Graphics
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 and 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.
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!!!
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
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
Papers, Projects, and Take-home Exam

- Paper presentation on two papers (October 23-24, Monday and Tuesday): 10%
- Paper reading and your technical report on literature review (four research papers, throughout the semester), your technical report on paper review will be due on Monday November 20, 2016, due at 2:30pm: 10%
- Take-home written exam (November 27, Monday due at 8pm): 15%
- Class attendance and asking questions during office hours: 5%
- Course project: 60%
- Extra, bonus points: 10% extra for additional paper reading and additional functionalities on your final project

**Basic project requirements:**
- Interactive interface (graphics-based)
- Intuitive and easy to understand
- Efficient (fast, high-performance)
- Basic functionalities
- Examples
- Flexible and easy to generalize
If You are Serious about this Course

• Study my on-line, electronic course notes, and read the textbook
• Paper reading (four papers in total), write a technical report on literature review and survey that summarizes all four papers, and submit it before the due date (due Monday November 20, 2:30pm)
• Present two papers out of the aforementioned four papers in our class (additional papers are optional for bonus points) on October 23-24, Monday and Tuesday)
• Think about your course project right away, start to think about how to implement them (bonus points are possible with additional functionalities in your project)
If You are Serious about this Course

- Write a proposal on your project (one-page proposal) and start to work on it immediately
- Finish your project by the end of this semester and submit your final course project
- Try to submit a paper if your project is really really new (please note that, this is NOT required for this course)
- You are welcome to communicate with me via emails, call me, or come to meet with me during my office hours in my office!
- Feel free to make appointments with me!
Project Plan and Deadlines

- Submit your own one-page proposal on the course project (September 27 Wednesday is the deadline, due at 2:30pm)
- Implement basic functionalities and user interface before the mid-term check point (November 1 Wednesday), demo on 11/1 Wednesday
- Study a set of relevant papers (4 papers, throughout the semester) and submit your technical report for paper review on November 20 Monday 2:30pm
- Your technical report on literature review is due on November 20 Monday at 2:30pm!!!
Project Plan and Deadlines

• Paper presentation week (October 23-24, Monday and Tuesday)

• Class presentation & final project demonstration (at the end of the semester, tentatively on December 8-10, Friday to Sunday)

• Final technical report and software code on your course project (at the end of the semester, December 8 Friday 8am)

• Individual project is required!!!

• Office hours / individual meetings

• Penalty for late submission (25% each day)
Deadlines for CSE528

- **September 27** (Wednesday at 2:30pm): one-page proposal for the course project
- **October 23-24** (M&Tu): paper presentation week
- **November 1** (Wednesday): mid-term system demo
- **November 20**: technical report on paper review (on total 4 papers) due at 2:30pm on Monday
- **November 27** (Monday, 8pm): take-home written exam
- **December 8** (Friday, 8am): course project due
- **December 8-10**: final course project presentation
- **12/8 8am**: final project (report+software+ppt) due
How to Get a “A”?  

• Finish all the course requirements, and I will issue a “A” grade