CSE528 Computer Graphics - Theories, Algorithms, and Applications

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Course Website

- http://www.cs.stonybrook.edu/~cse528 or
- http://www3.cs.stonybrook.edu/~qin/courses/graphics/graphics.html

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+)

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

- http://en.wikibooks.org/wiki/OpenGL_Programming

- Many online resources for OpenGL are available (for both reading materials and codes)

My Contact Information

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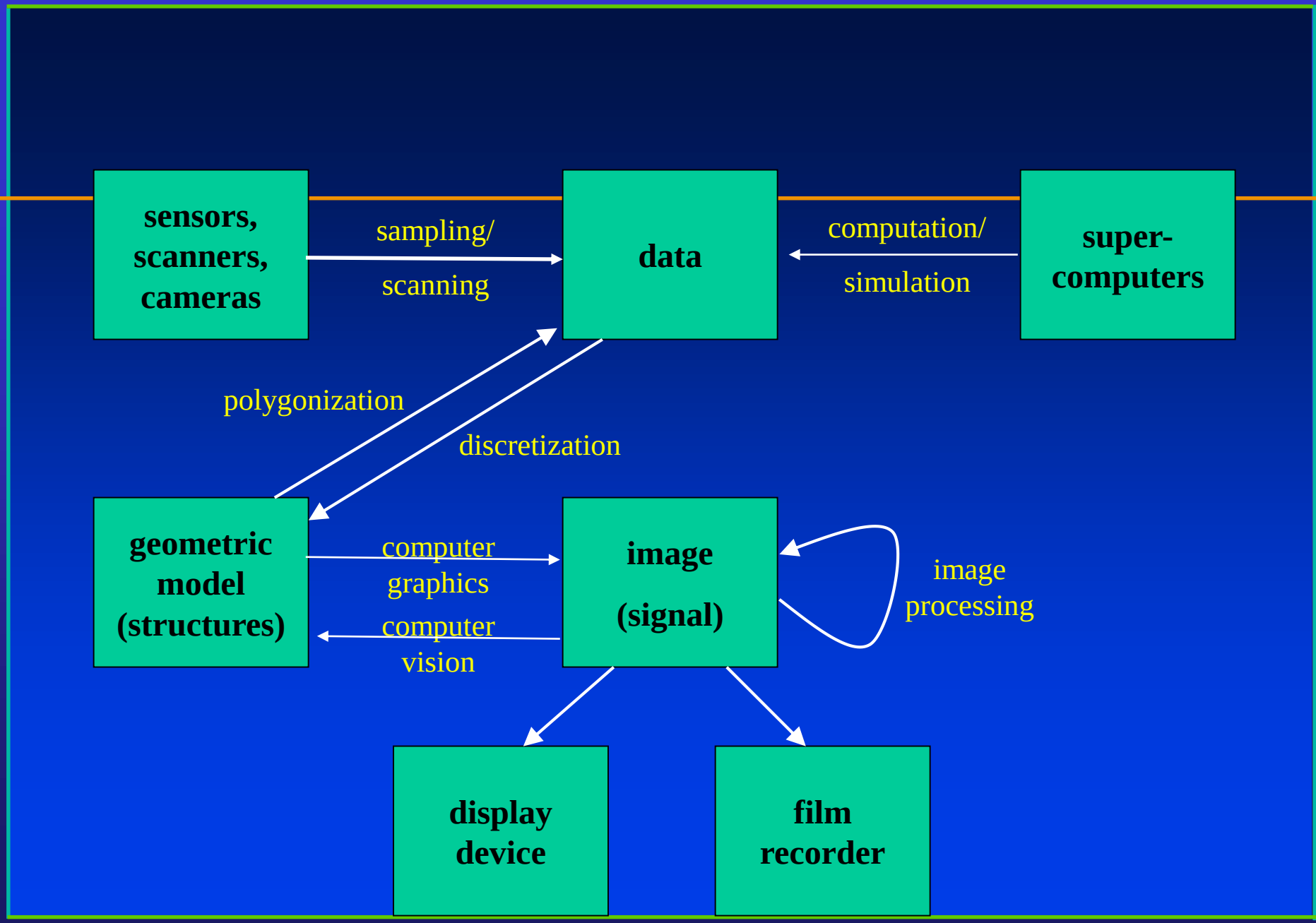
What is Computer Graphics

- *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
data
computation/ simulation
super-computers
polygonization
discretization
geometric model (structures)
computer graphics
computer vision
image (signal)
image processing
display device
film recorder

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

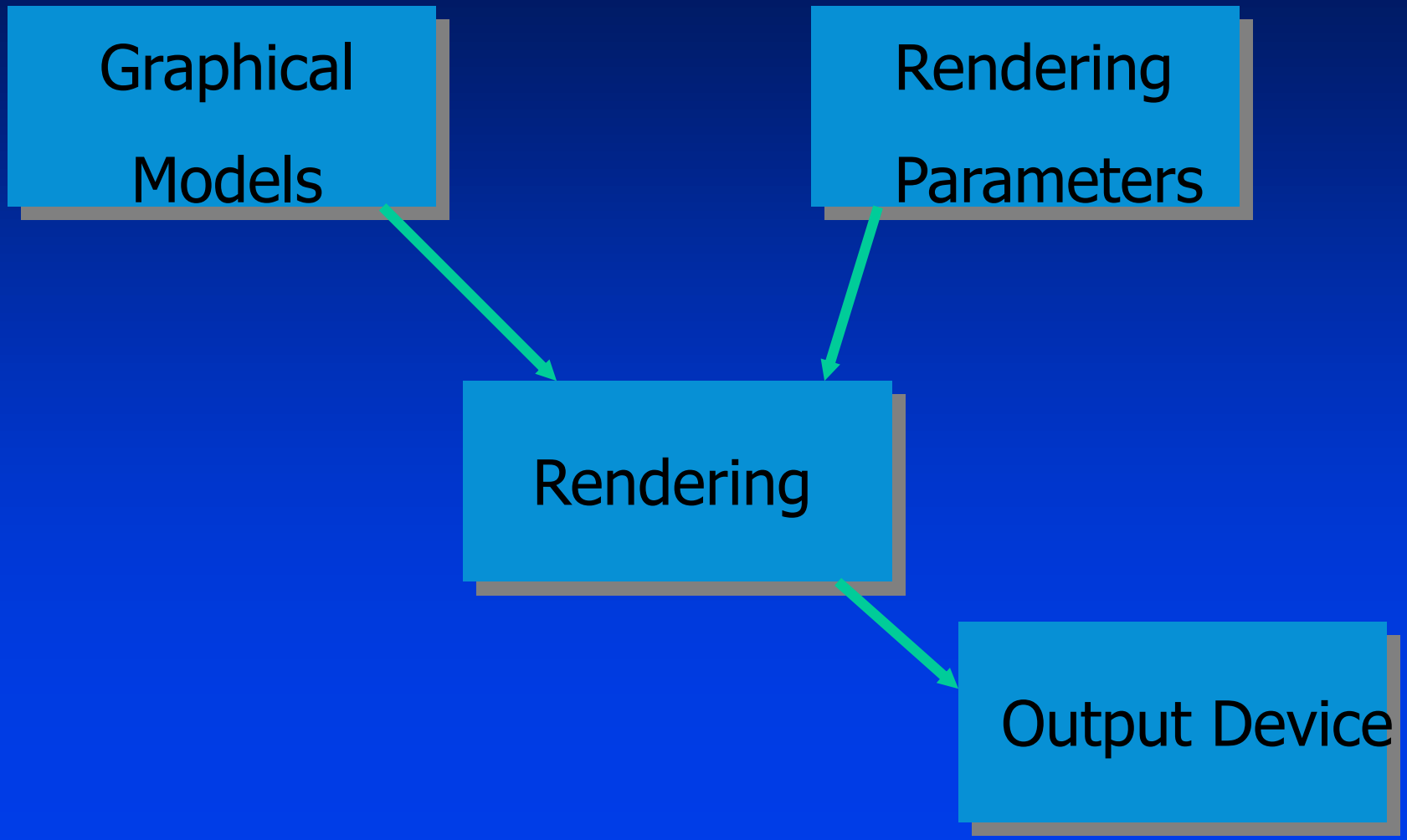
A picture is worth a thousand words

- 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



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

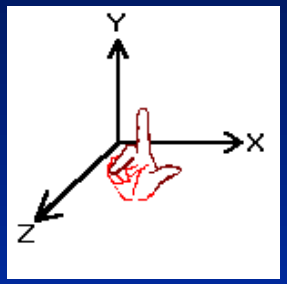
- Camera parameters
  - Location
  - Orientation
  - Focal length

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

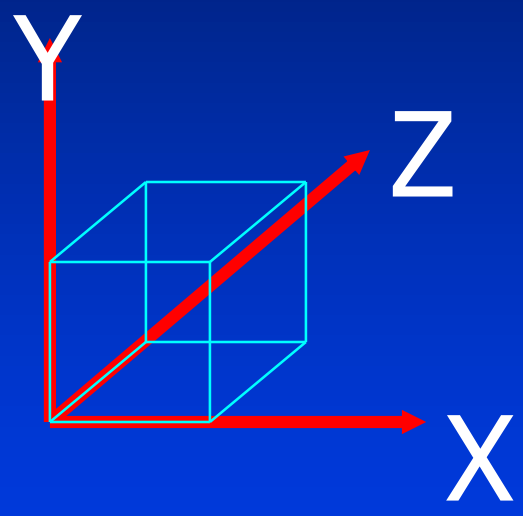
- Rendering is typically the conversion of 3D to 2D

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

- Computer Graphics with OpenGL, Fourth Edition, Donald Hearn, M. Pauline Baker, and Warren R. Carithers, Prentice Hall, 2011.
- A recommended textbook (BUT NOT REQUIRED)!

OpenGL Reference Books

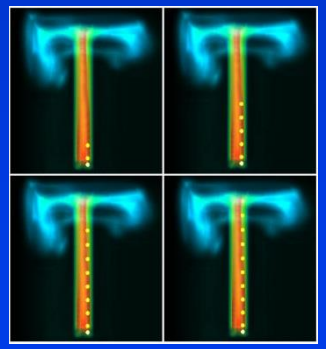
1. OpenGL Programming Guide,
2. OpenGL Reference Manual,
3. OpenGL Superbible
4. http://www.opengl.org and many online resources (for reading materials and codes)

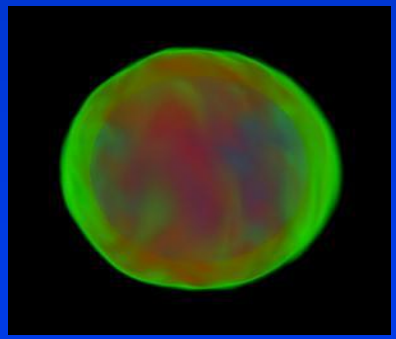
Why Graphics and Visualization

- 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



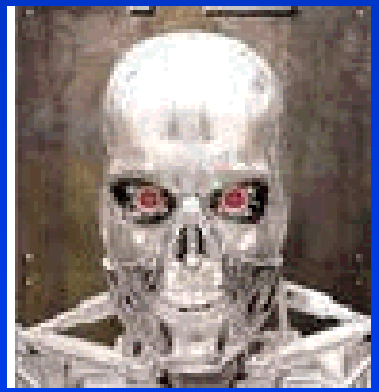
Why Graphics and Visualization

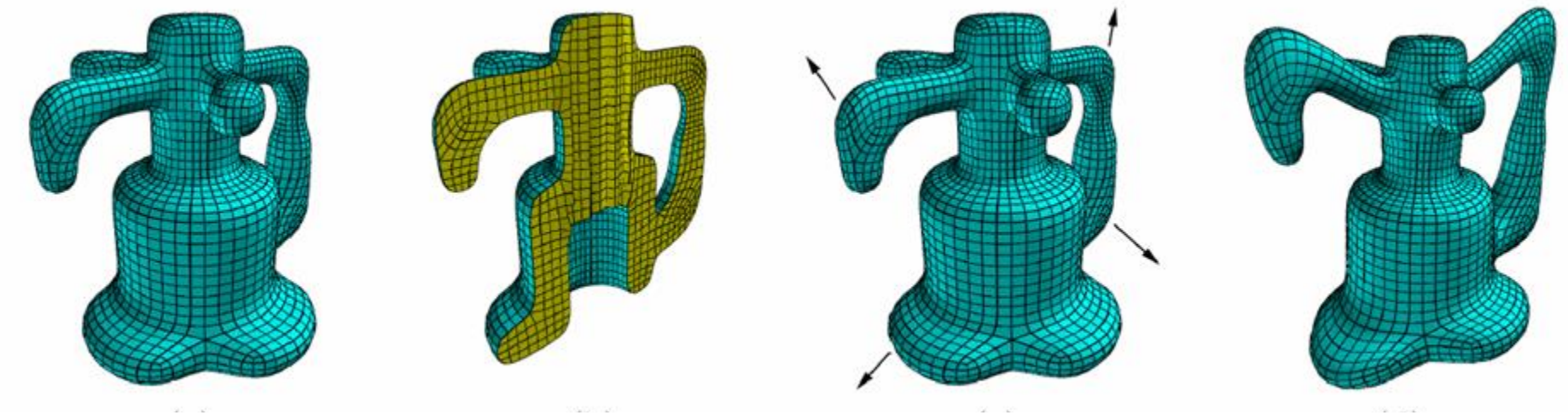
- Enable scientists (also engineers, physicians, general users) to observe their simulation and computation
- Enable them to describe, explore, and summarize their datasets (models) and gain insights
- Offer a method of SEEING the UNSEEN
- Reason about quantitative information
- Enrich the discovery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

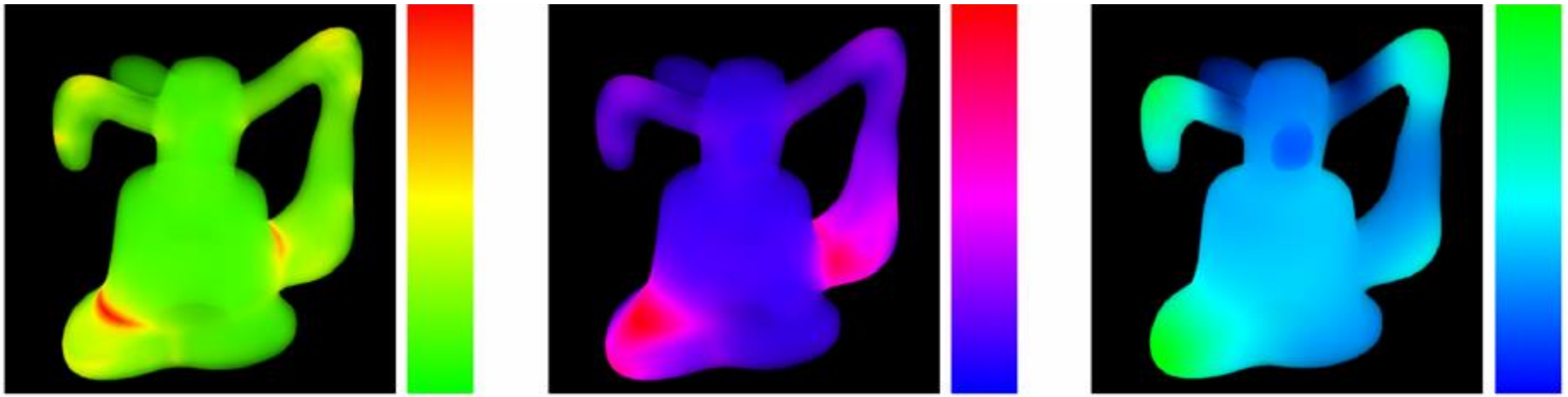
Why Graphics and Visualization

- 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

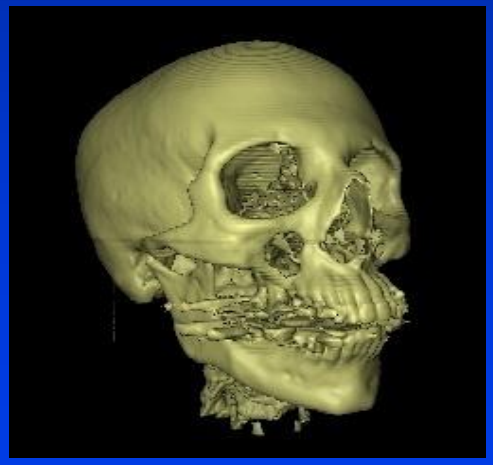
Entertainment







Graphics Examples



More Examples

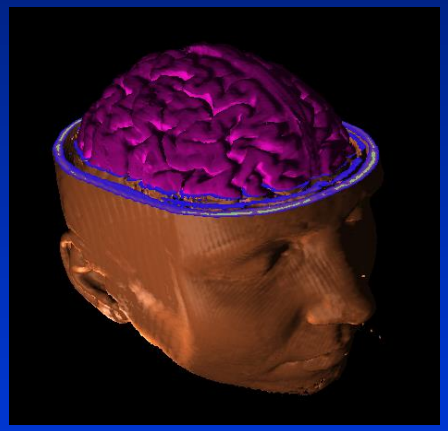
Images

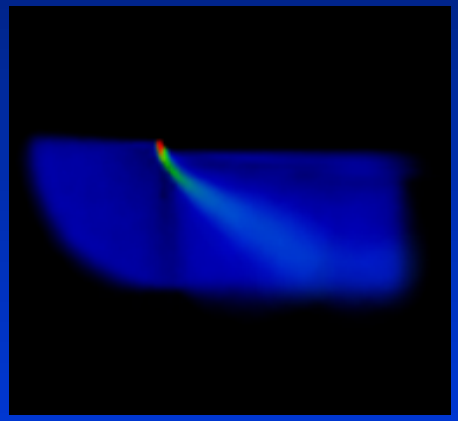
Points

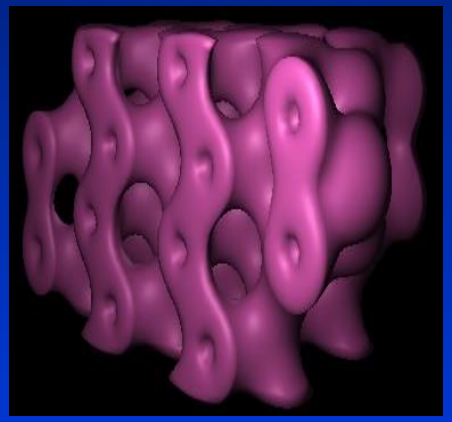
Volumes

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!!!