CSE328 Fundamentals of Computer Graphics: Concepts, Theory, Algorithms, Techniques, & Applications

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Course Website

- http://www.cs.stonybrook.edu/~cse328

Lecture Information

- WHEN: MW 2:40-4pm
- WHERE: HYBRID for Spring 2021; NCS 115
- OFFICE HOURS: MW 4 – 5:30pm, or by appointment!
- Teaching Assistant(s): Xi HAN (Hong's senior PhD student), xihan1@cs.stonybrook.edu
- TA office hours: Thursday 10am – 12pm, or by appointment!!!

Xi's Web Link

- http://www.cs.stonybrook.edu/~cse328
- At the bottom of that page, please click on TA Help Page (via link)
- You should be able to access them from the course website easily!

OpenGL Tutorials

- Tutorials for Modern OpenGL (3.3+)

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

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

- http://www.opengl.org
- Many other online resources are also available
- My TA will also have a designated website on OpenGL

Course Prerequisites

- Mathematical skills: fundamental knowledge on calculus, linear algebra, analytic geometry, etc. (basic mathematical training at the undergraduate level, Appendix A Mathematics for Computer Graphics is a good starting point to refresh our memory)
- Computer science background: programming skills at the basic undergraduate level (C/C++, OpenGL (graphics library))

Course Prerequisites

- You need to speak to the instructor if you are not sure about your background knowledge and course prerequisites
- Essentially, you need to have an undergraduate education in computer science or engineering with basic knowledge on computer programming

My Expectations

- Time and efforts dedicated to this course, you have to spend time on reading the textbooks/books (most of the references are available online), reviewing notes, attending my lectures, working on your assignments and homework, and taking exams (all midterm and final exams for Spring 2022).
- Problem-solving skills: what are the right and most effect approaches, taking advantages of online resources, etc.
- Interaction with the instructor, TA, and your fellow students, etc.

Expectations to Learn NEW THINGS

- Your works should be your OWN!
- NEVER share code with your fellow student or debug code together
- Reference examples from the internet is an effective way to learn (take advantage of the web)
- When using open sources, you should explicitly point them out
- NOT a course about graphic/game design, NOT using graphics packages like PhotoShop / Maya

Computer Graphics Course

Not about!

Paint and Imaging packages (Adobe Photoshop)

Cad packages (AutoCAD)

Rendering packages (Lightscape)

Modeling packages (3D Studio MAX)

Animation packages (Digimation)

Not about!

Game programming and/or Graphic design courses!!!

Grading Schemes (SPRING 2022)

- Three exams (two midterm exams + one final exam): 30%
- Class attendance: 10%
- Homework (non-programming): 15%
- Assignments (programming): 45%
- Total bonus: up to 15%

NOTE THAT, there is a final project option (to be discussed in my lecture)! Up to 30%!

The Course Objectives

- Provide our undergraduate students a comprehensive knowledge on fundamentals of computer graphics, including basic concepts, theory, algorithms, techniques, and applications for modeling, simulation, rendering, animation, human-computer interactions, and other key elements of graphics-driven 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

The Course Load and Learning Strategies

- Reading our textbook/book(s) (we will be covering about 70-90% contents of this book during this semester) and learn knowledge about background, theory, algorithms, techniques, system components and architecture, software and hardware elements, applications, etc.
- Practice on exercises documented at the end of each chapters (two types of exercises: problem-solving questions, and graphics programming examples)
- Many online resources are available (including reading materials and codes)

The Course Load and Learning Strategies

- All concepts, theories, algorithms, techniques, system matters, software and hardware elements, and applications relevant to computer graphics are well within the boundary of our textbook, so please DO read the book and practice on exercises
- At the same time, many programming examples throughout this book (in C and with the help of OpenGL, graphics library), so practice on those programming examples as well

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, 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 the primary concentration on our unique course mission
- Comprehensive lectures (focusing on geometric and physical 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

Course Facts

- This is a undergraduate course for both CSE and ISE students!!!
- Can I take this course? YES, if YOU
  - are a undergraduate student with CS background, have basic mathematical skills in calculus, linear algebra, and analytic geometry, have BASIC knowledge on computer programming, or talk to the instructor
- One required textbook, several suggested references
- Lecture notes are important! Class attendance is a must!

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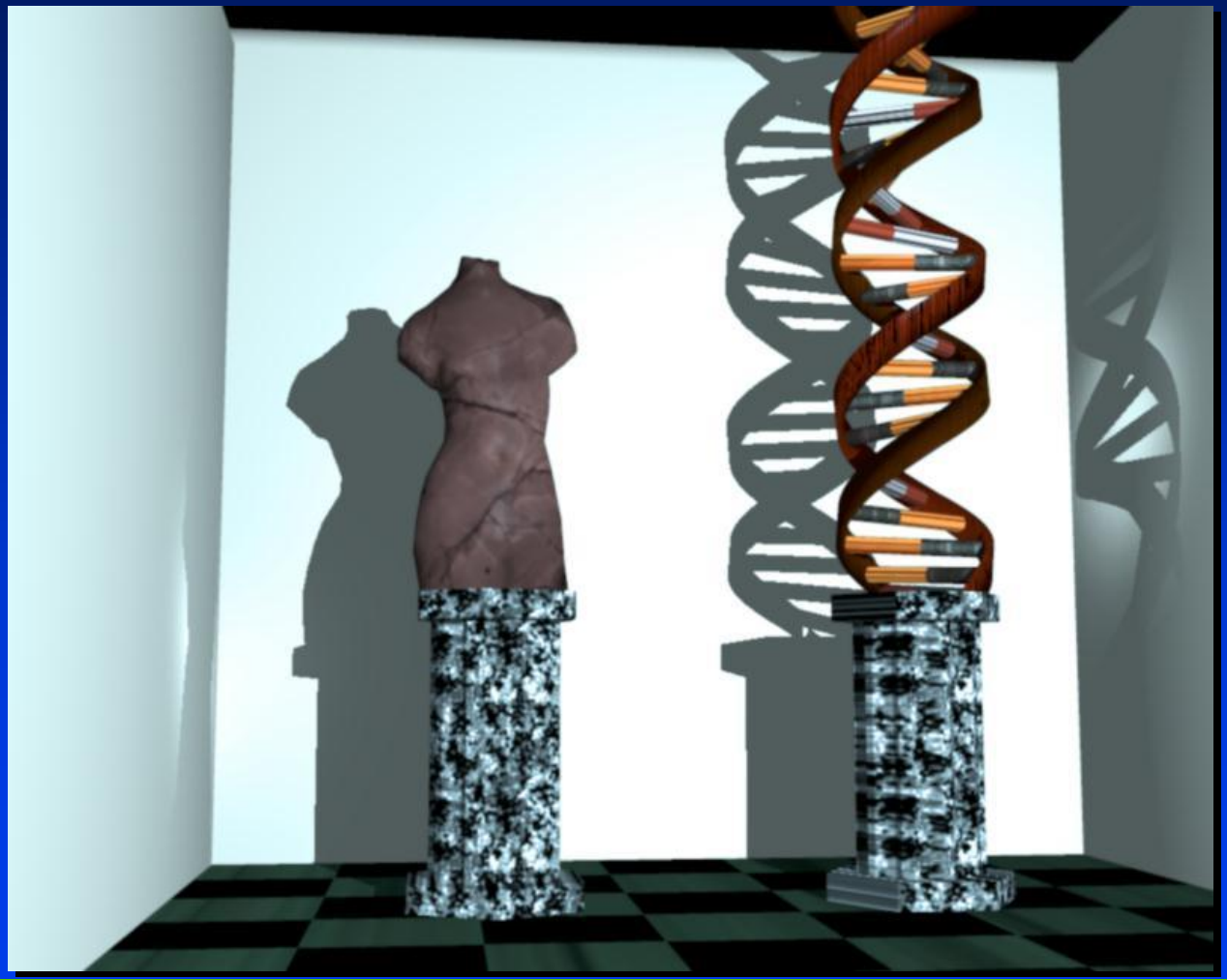
Computer Graphics Components



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

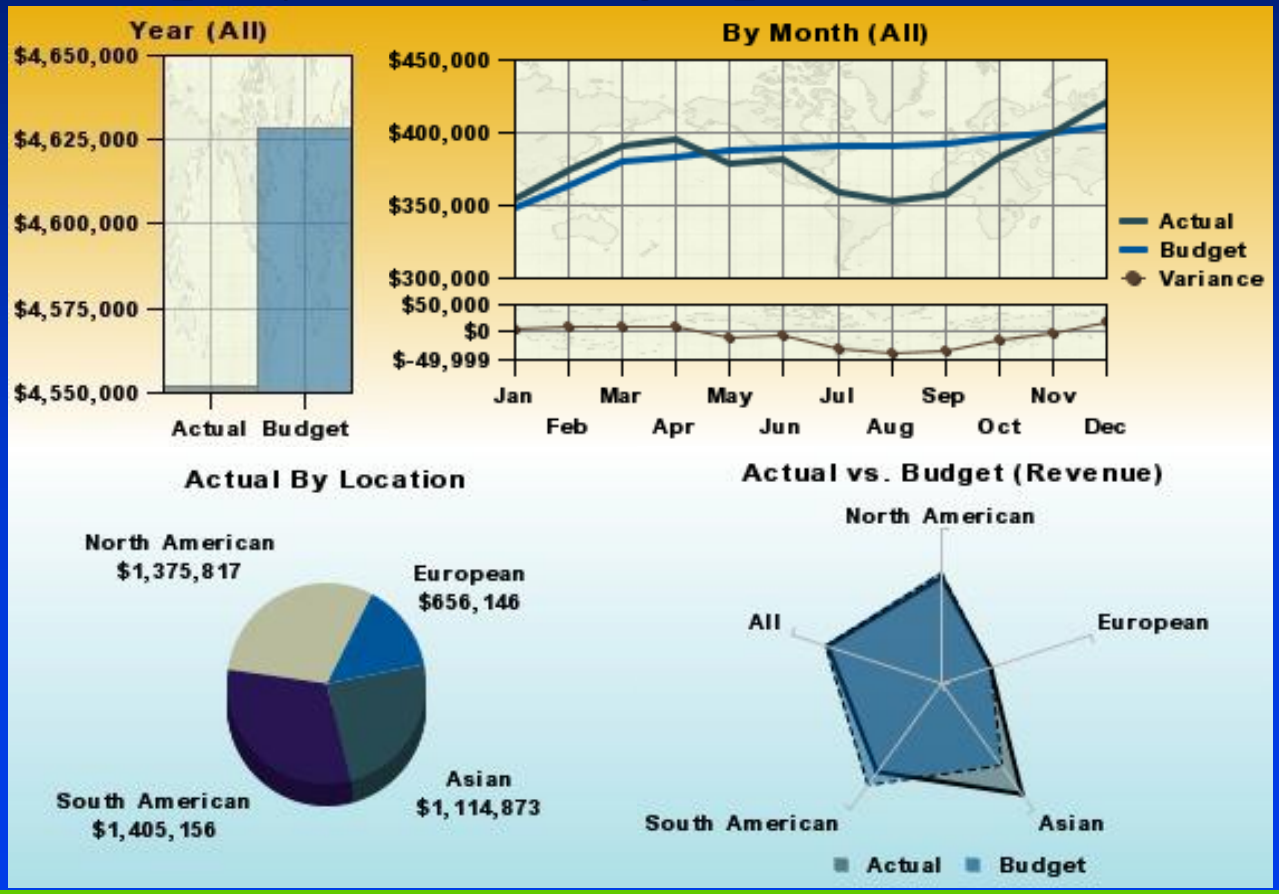
- (Realistic) pictorial synthesis of real and/or imaginary objects from their computer-based models (datasets)
- It typically includes modeling, rendering (graphics pipeline), and human-computer interaction
- So, we are focusing on computer graphics hardware, software, and mathematical foundations
- 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.

Basic Elements of Computer Graphics

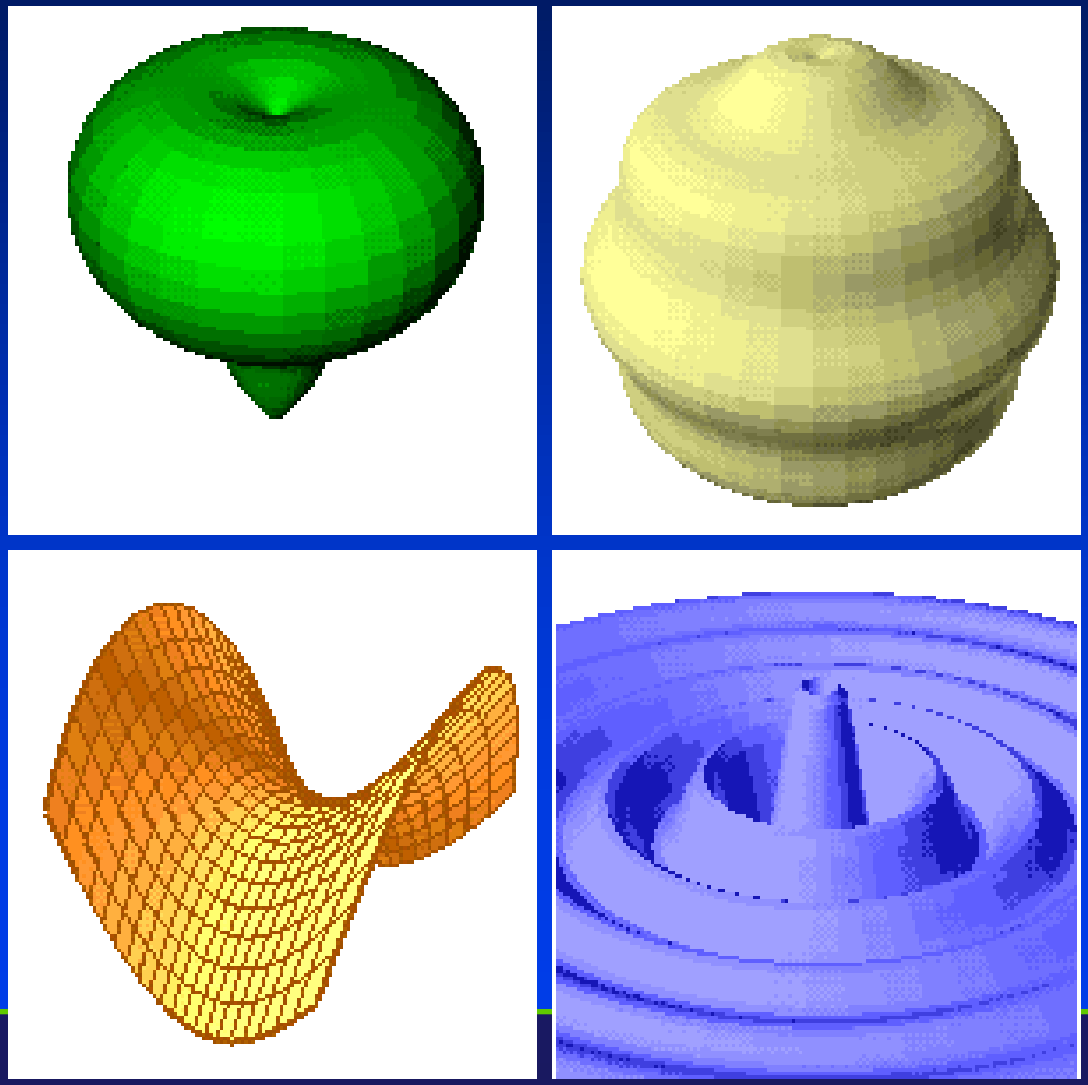
- Graphics modeling: representation choices
- Graphics rendering: geometric transformation, visibility, discretization, simulation of light, etc.
- Graphics interaction: input/output devices, tools
- Animation: lifelike characters, their interactions, surrounding virtual environments

Earlier Days of Computer Graphics

- Visual display of data (graphs and charts)



Mathematical Function Plots



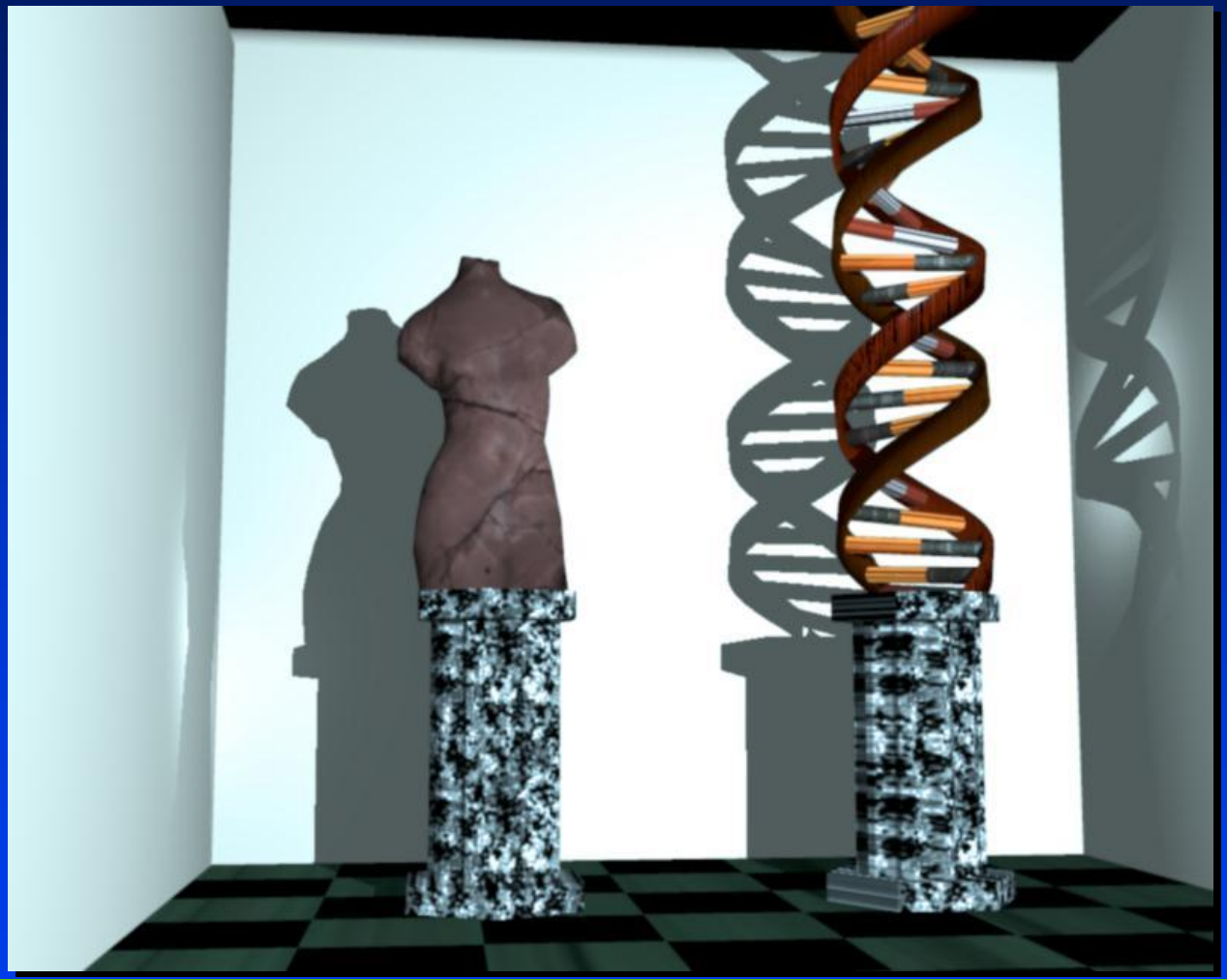
Mathematical Background

- 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

Computer Graphics Components



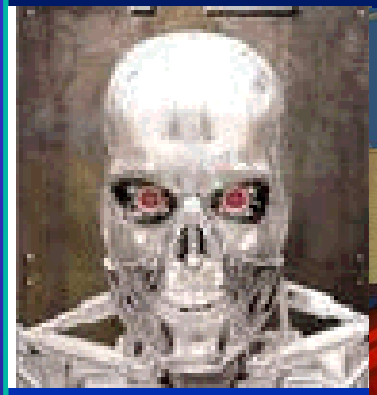
A Very Good Textbook for General Issues in Computer Graphics

- Computer Graphics with OpenGL, 4th Edition, Donald Hearn, M. Pauline Baker, and Warren R. Carithers, Prentice Hall, 2011.
- Strongly recommended, but NOT REQUIRED!!!

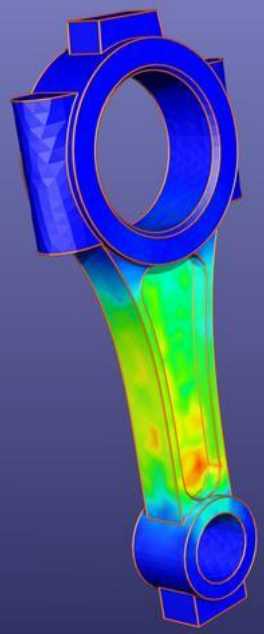
OpenGL Reference Books

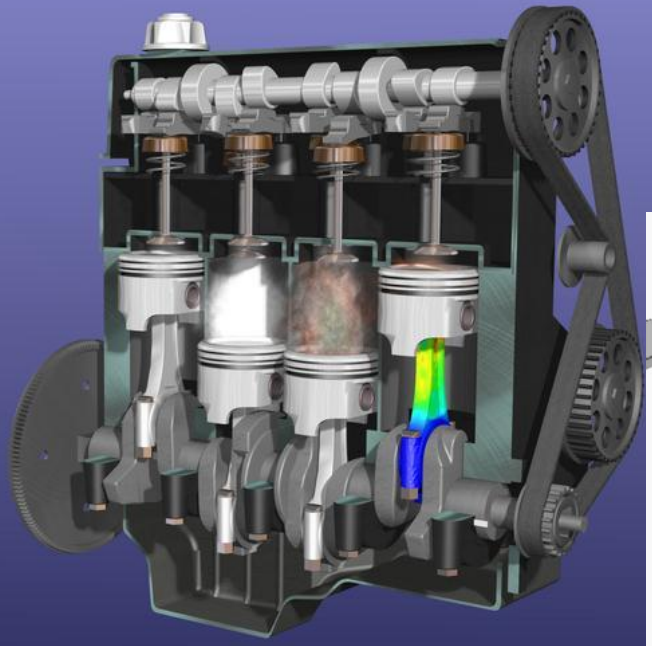
1. OpenGL Programming Guide
2. OpenGL Reference Manual
3. OpenGL Superbible
4. These are for your references only
5. Many online resources, please take advantage of them by searching for online materials (both reading materials and codes)

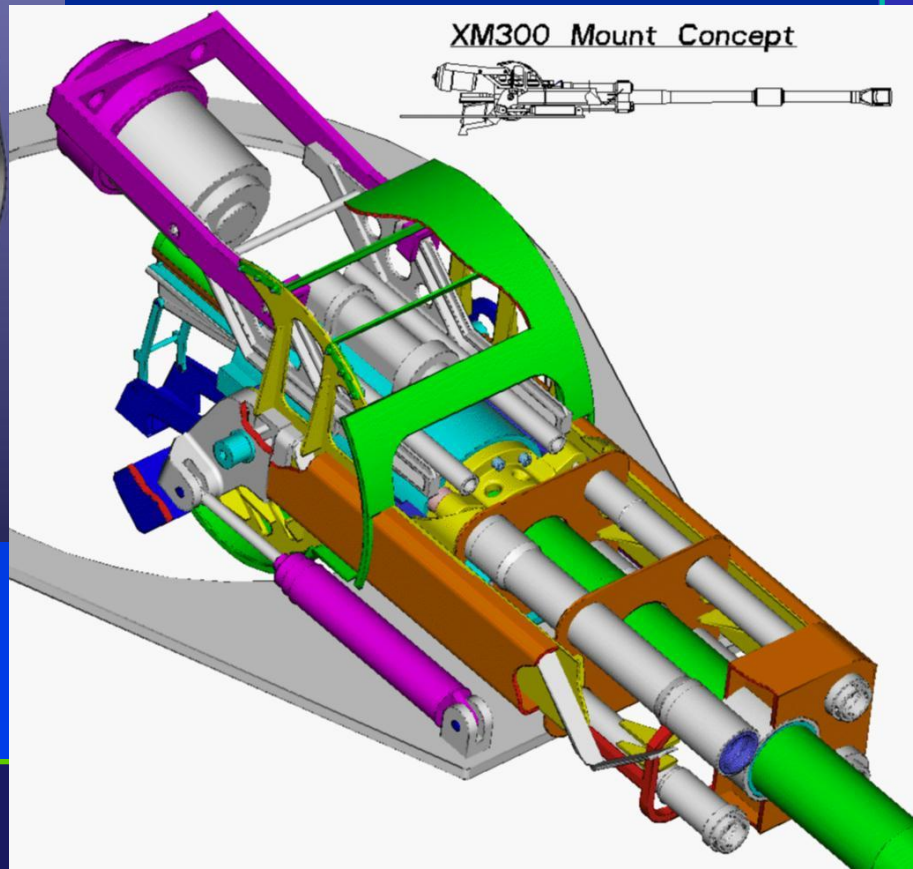
Digital Entertainment

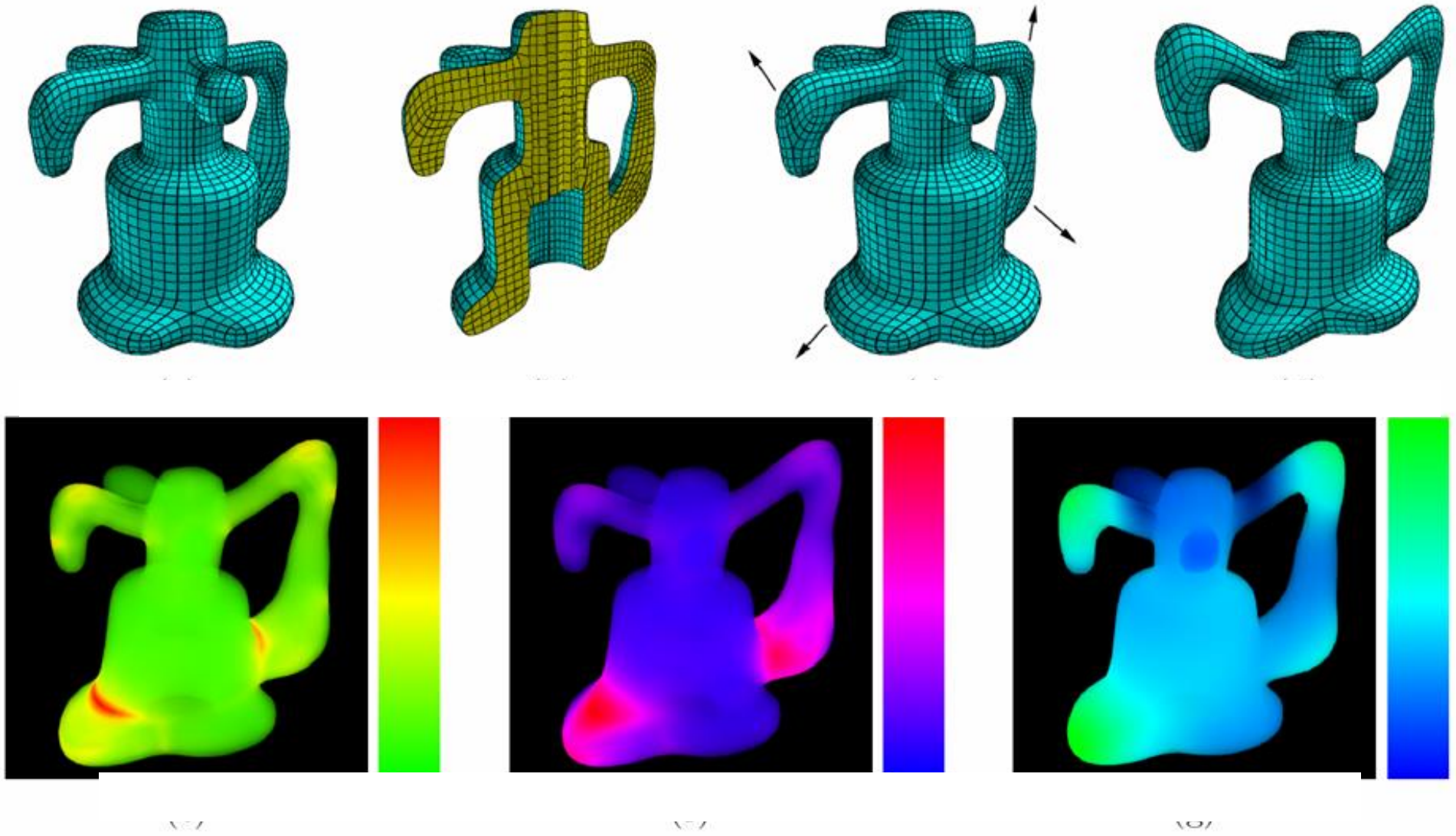


Computer-Aided Design



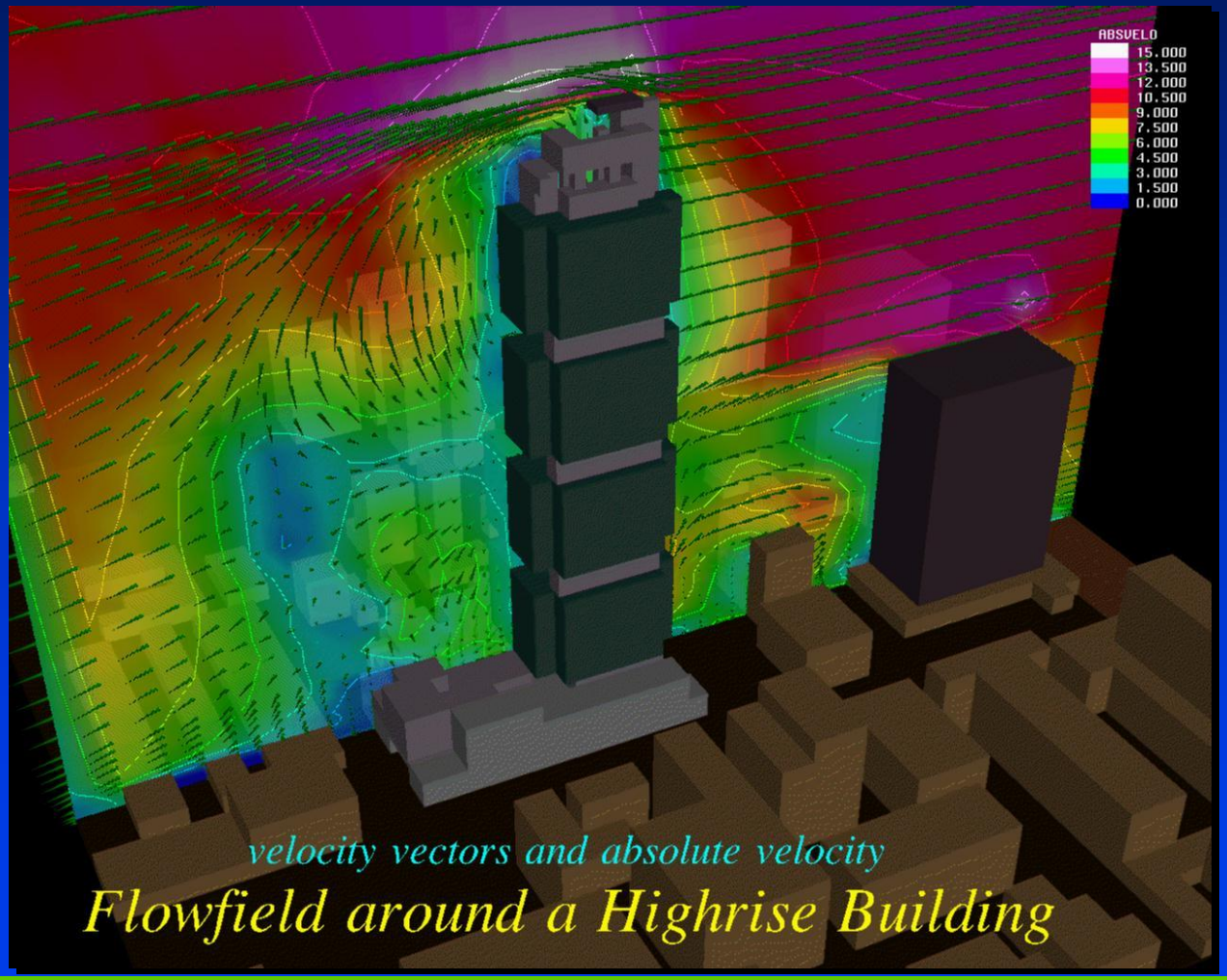






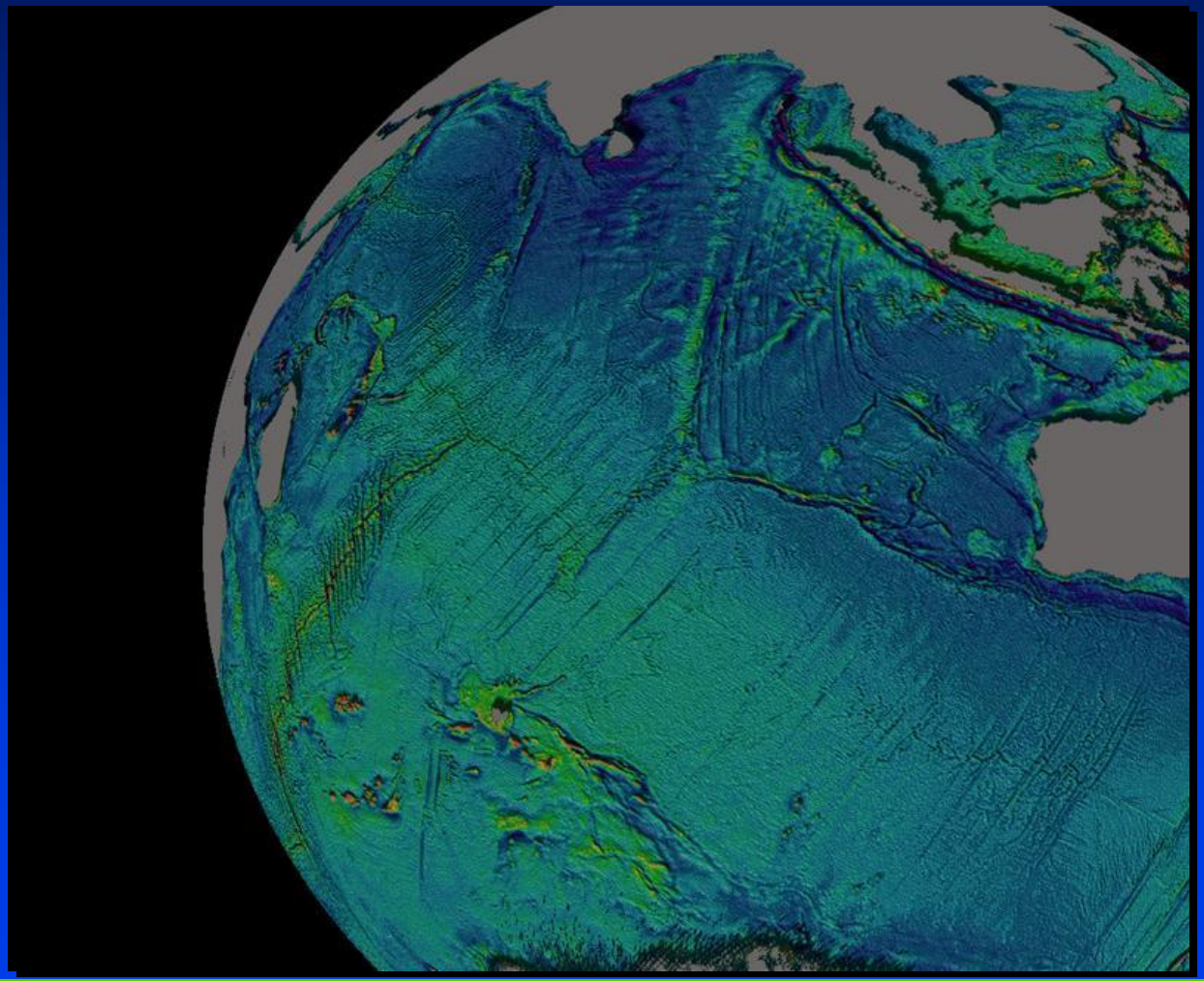
Architectural Engineering

Scientific Visualization/Simulation

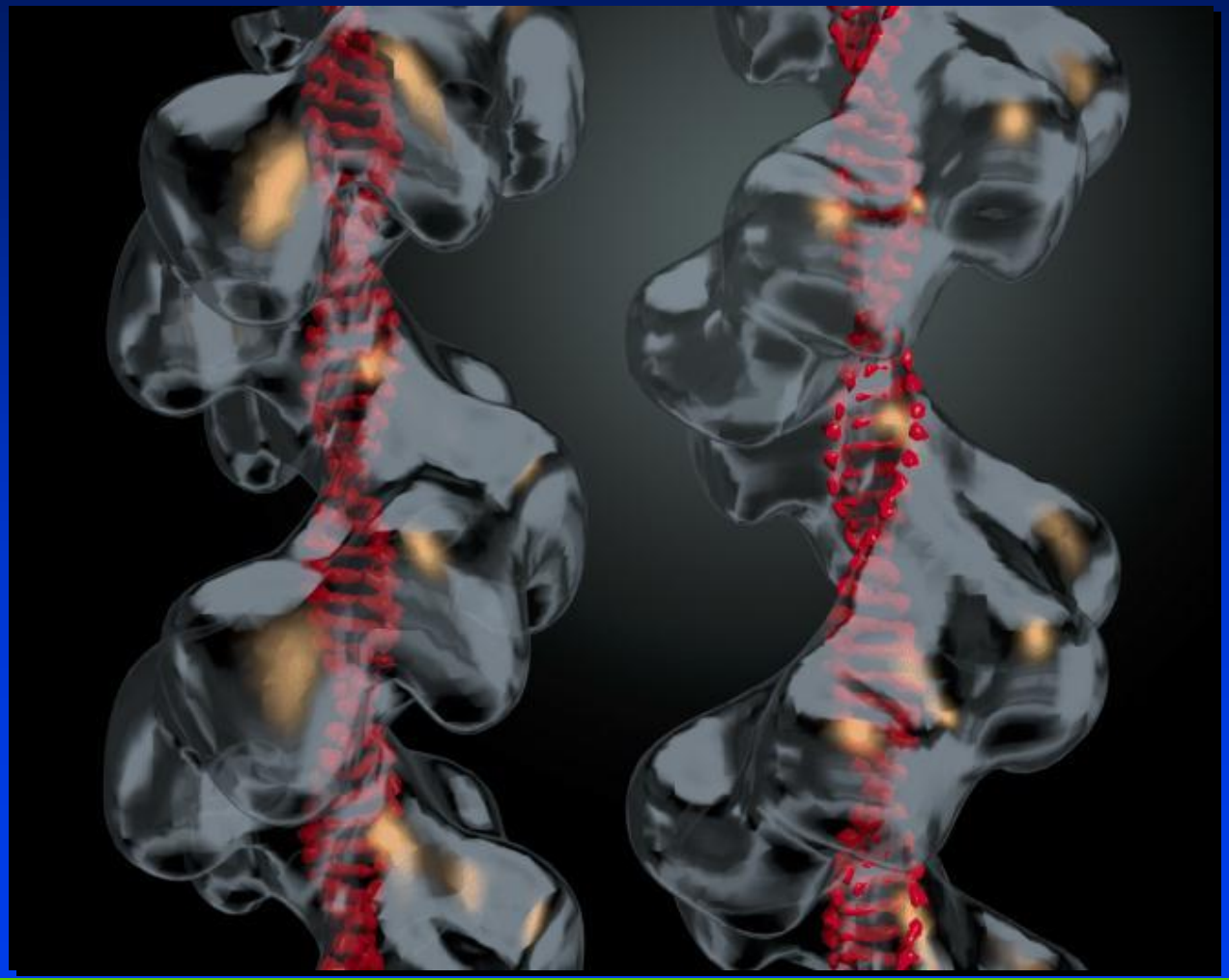


Digital Ocean

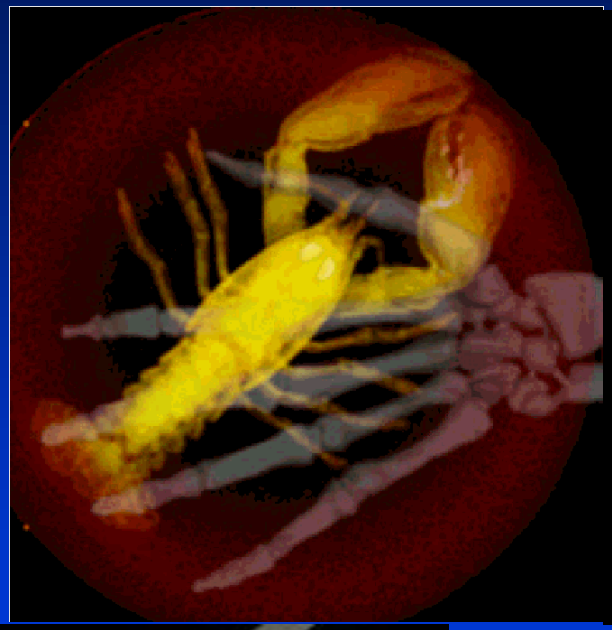
Geosciences/GIS

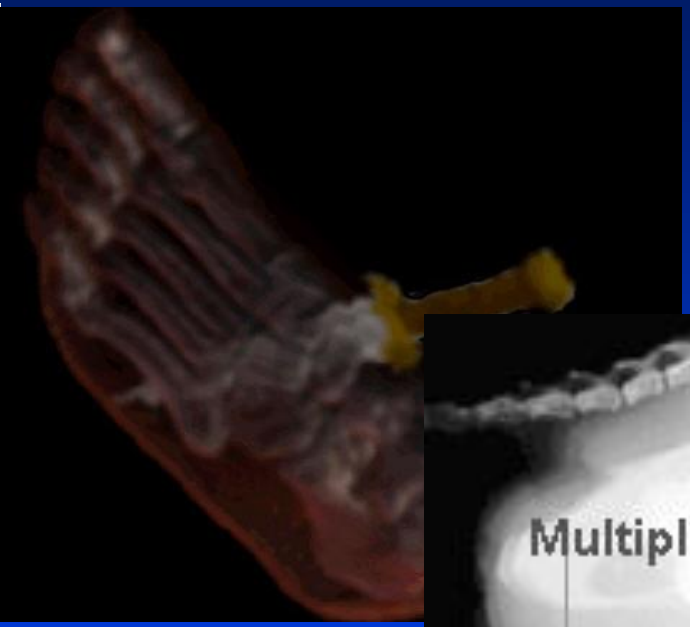


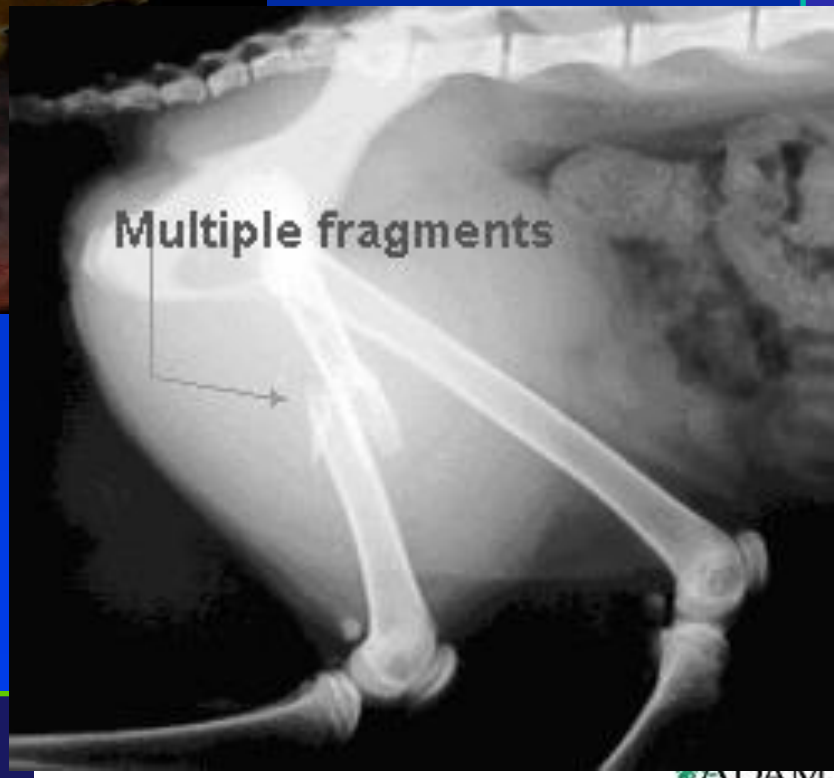
Biology (Protein on DNA)



Medicine and Healthcare

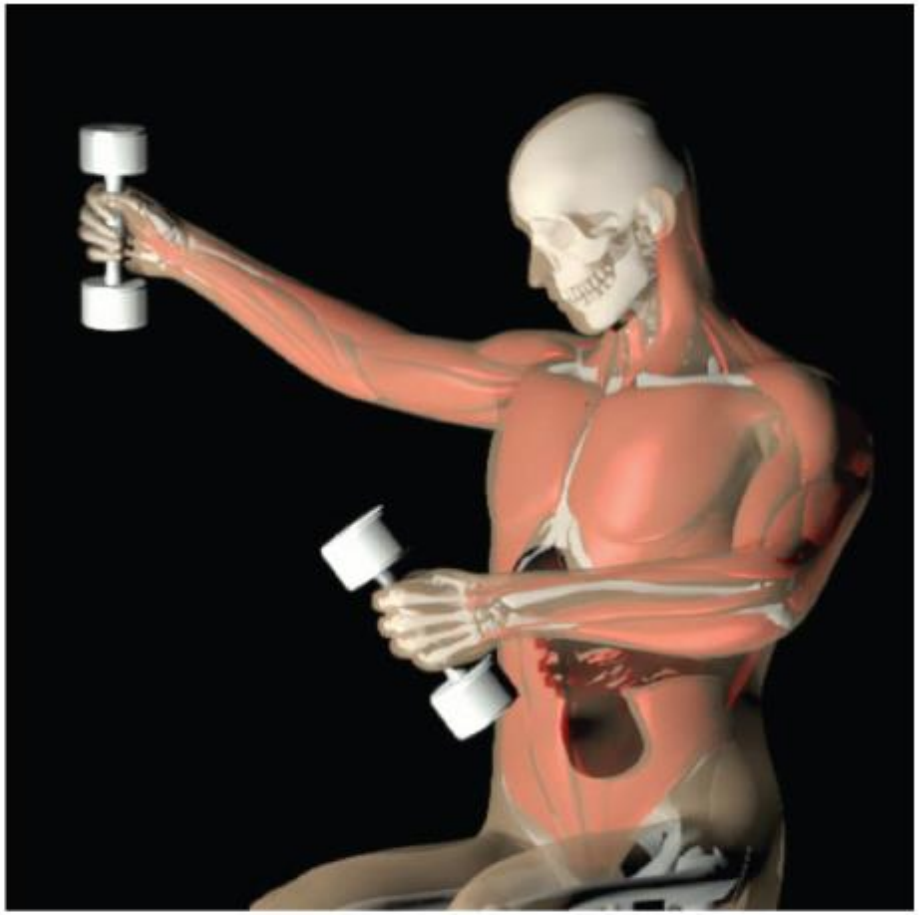






Biomechanical Modeling of Human

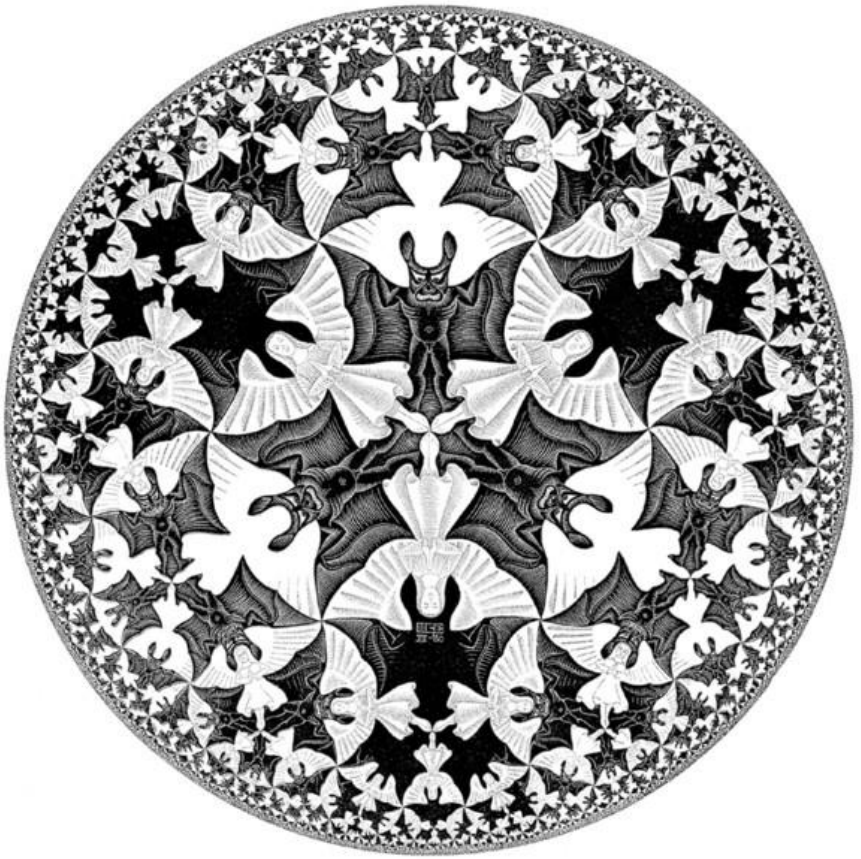
(a)



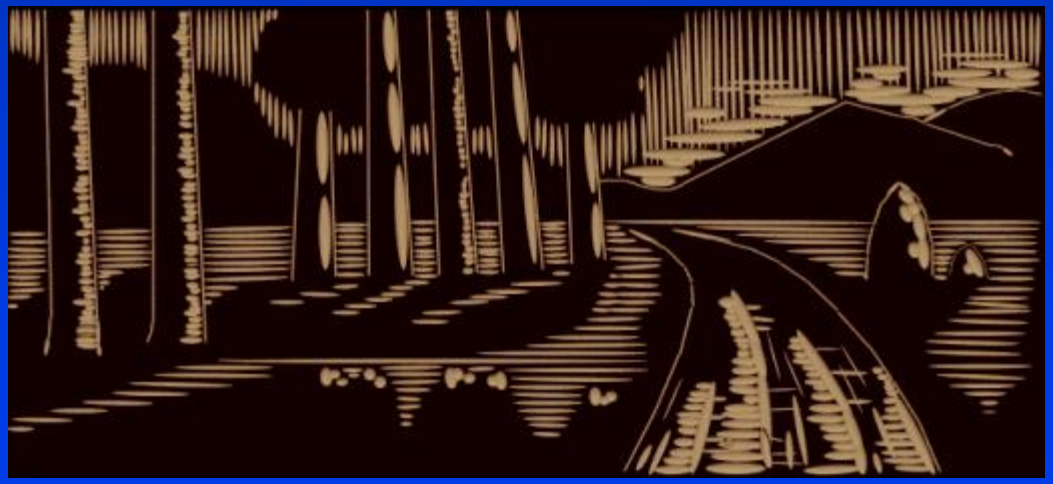
(b)

Fig. 13. The soft tissue simulator produces realistic deformations of (a) the visualization geometry, and (b) embedded volumetric muscles.

Graphic Arts



Computer Art with Physical Interface

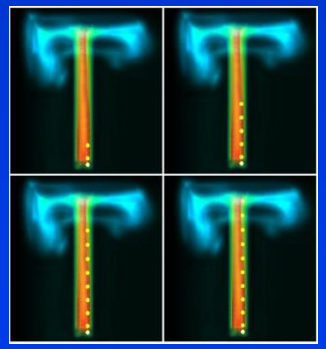


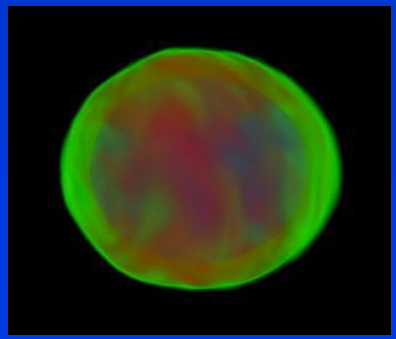
Why Graphics and Visualization

- 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

What is Visualization

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

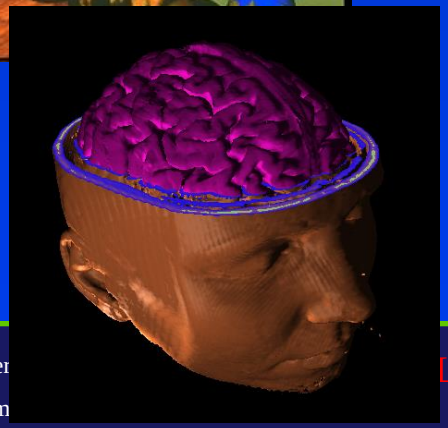



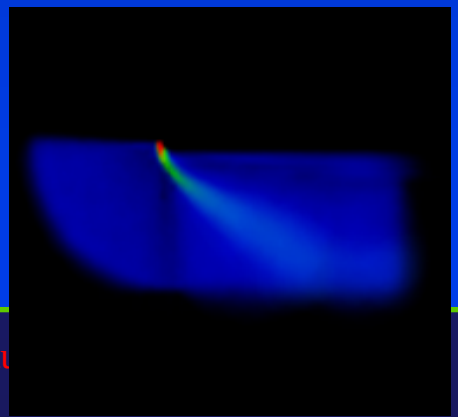


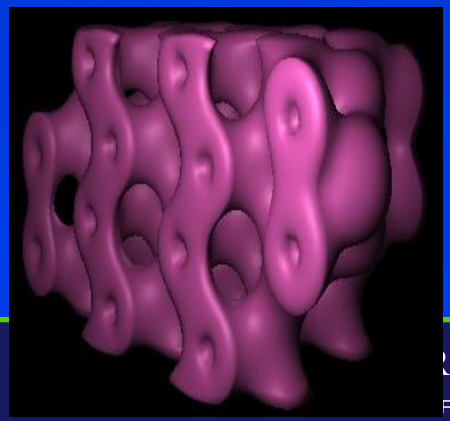
Why Graphics and Visualization

- 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

Graphics Examples







More Examples

Images

Points

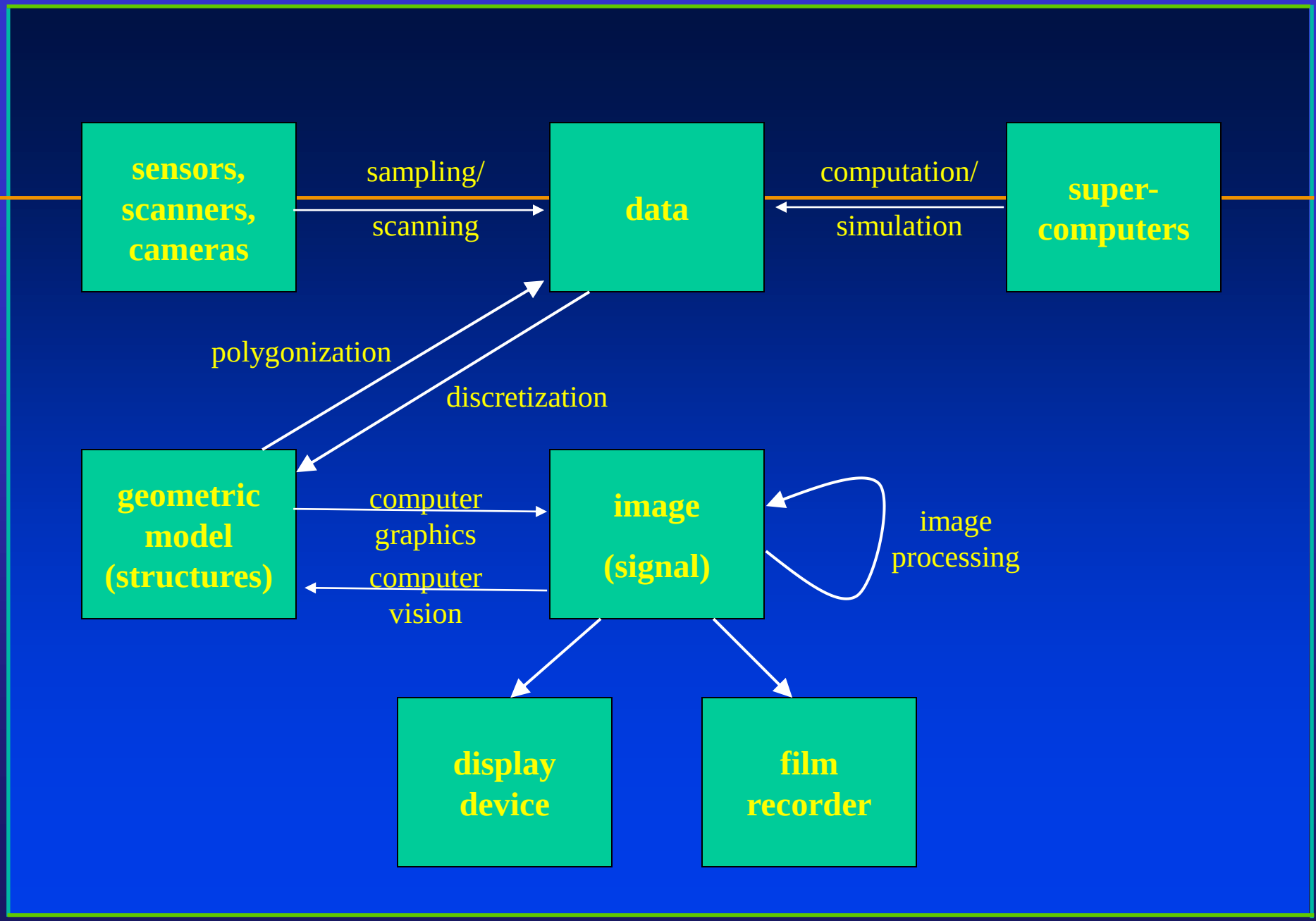
Volumes

Terrain Modeling and Rendering

Virtual Tourism

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


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

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

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

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)
- Environmental 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.

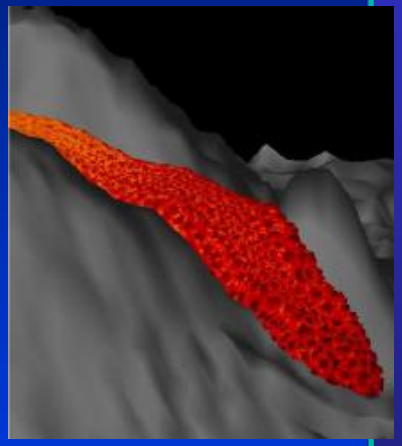
Key Components

- 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

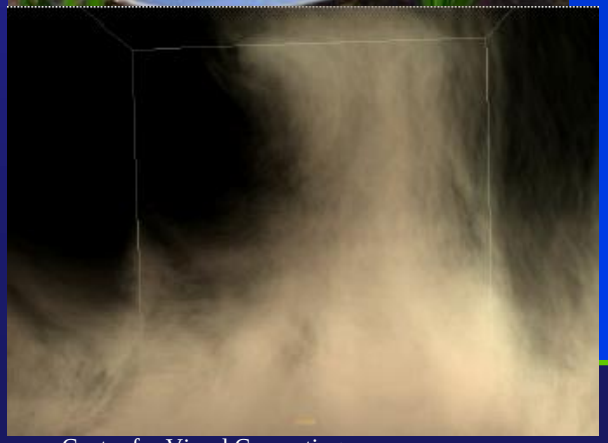
Natural Phenomena



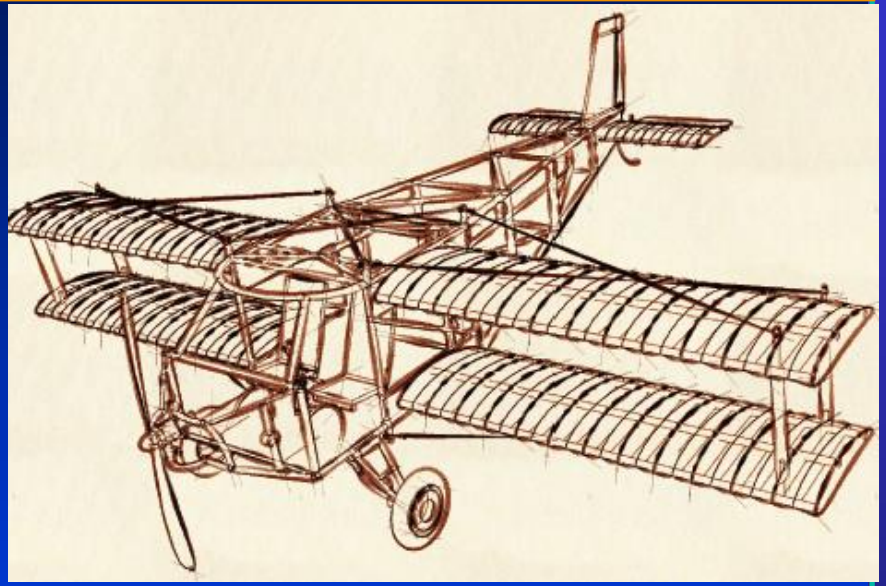


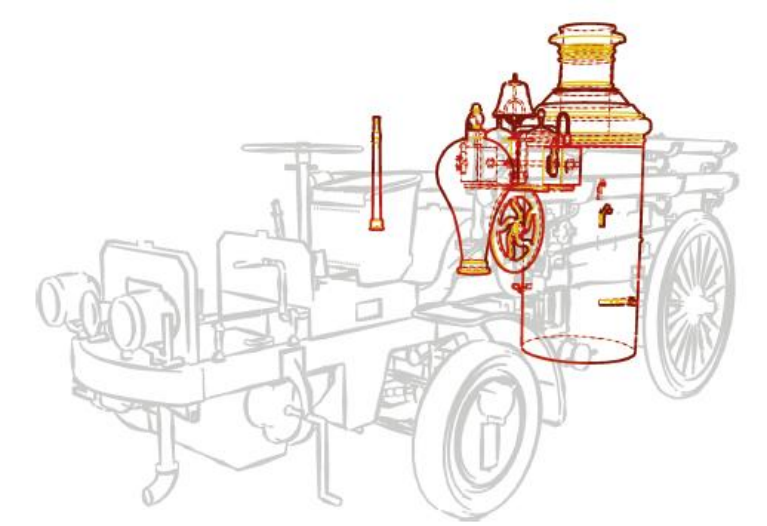




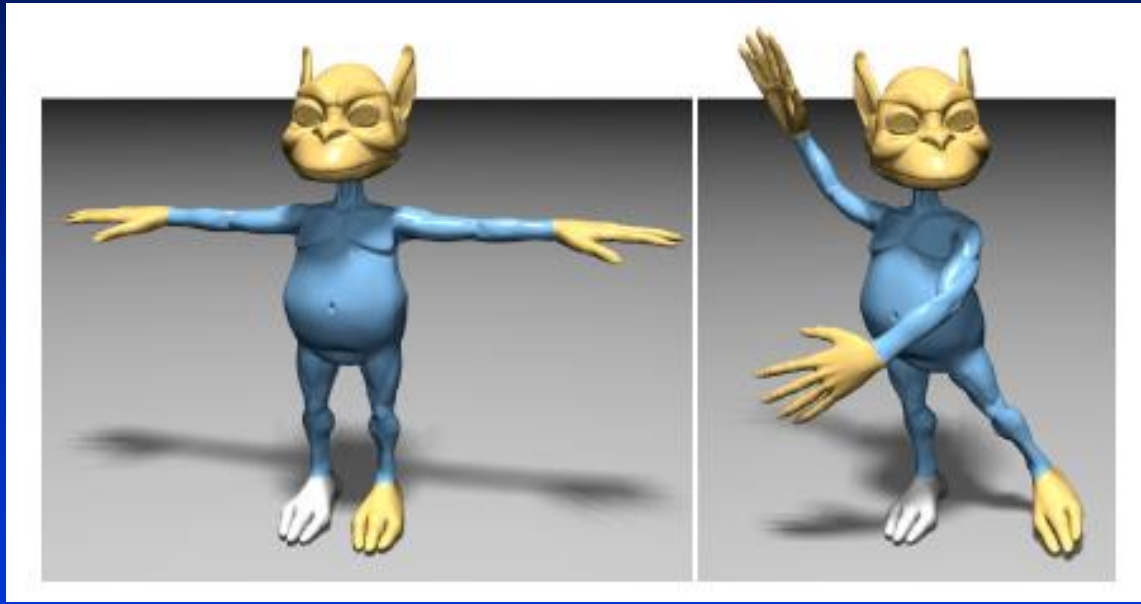



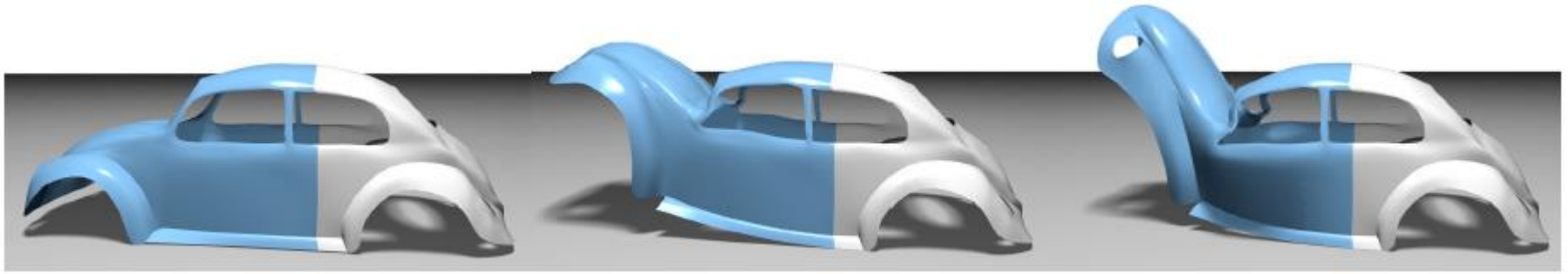

Non-Photorealistic Rendering



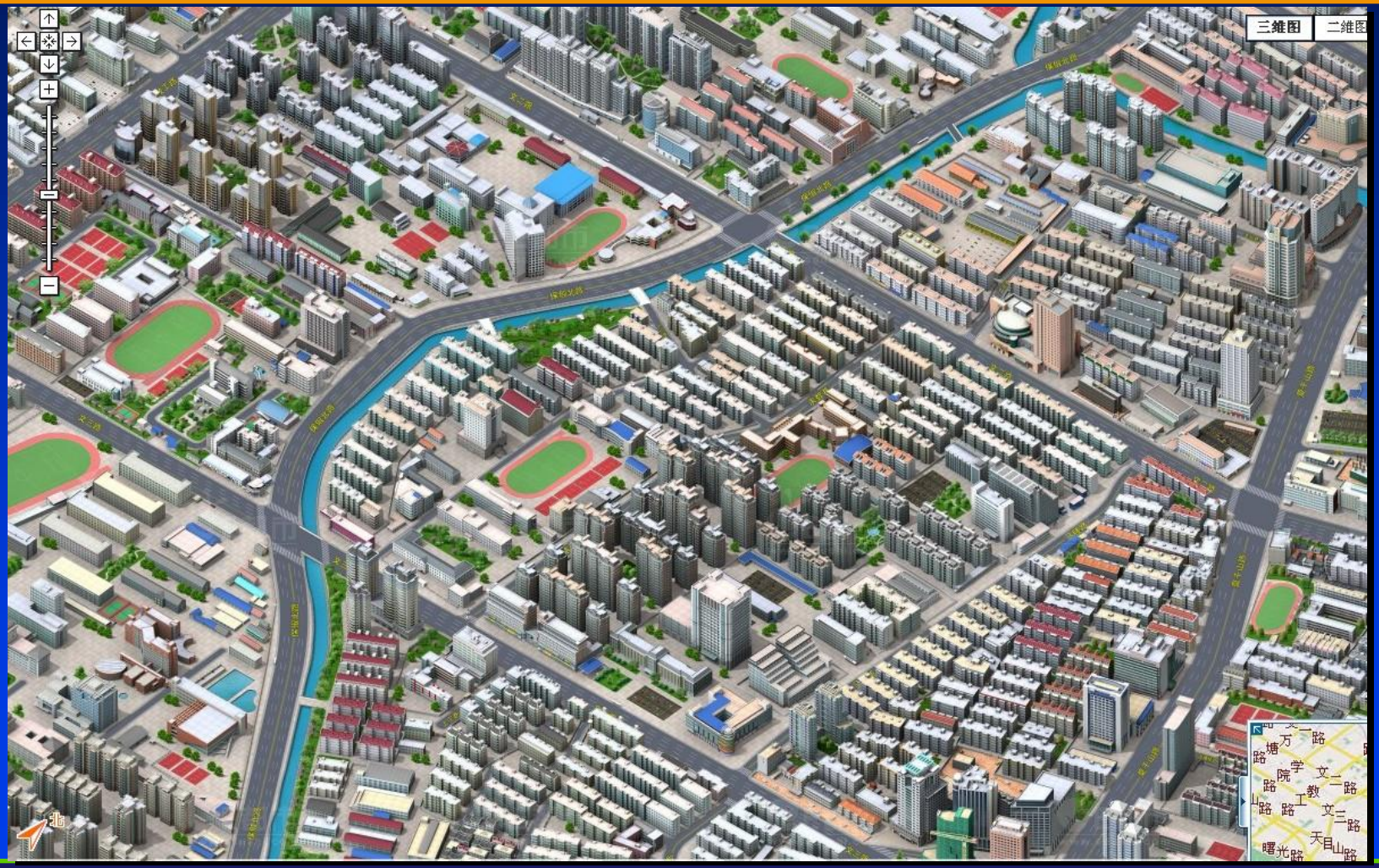


Shape Deformation

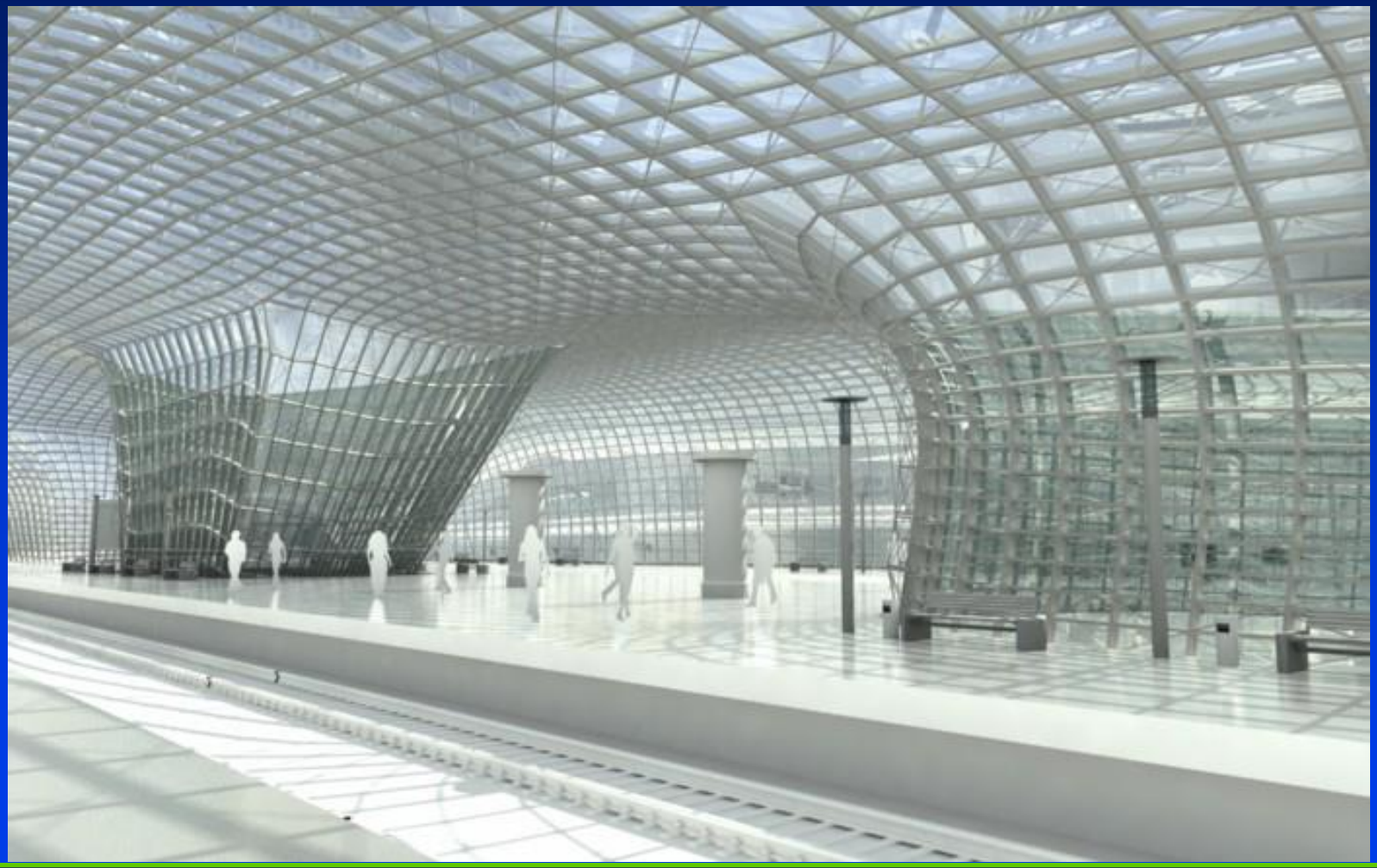




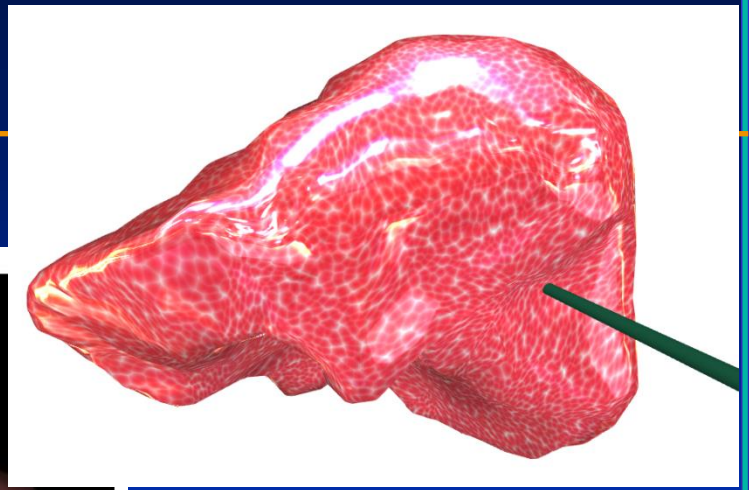
Urban Structure and Modeling

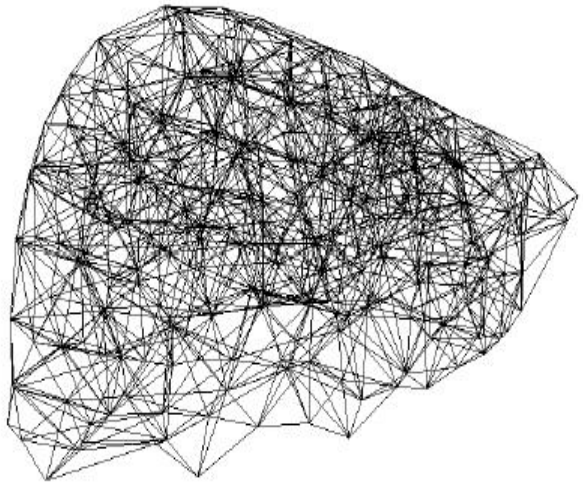


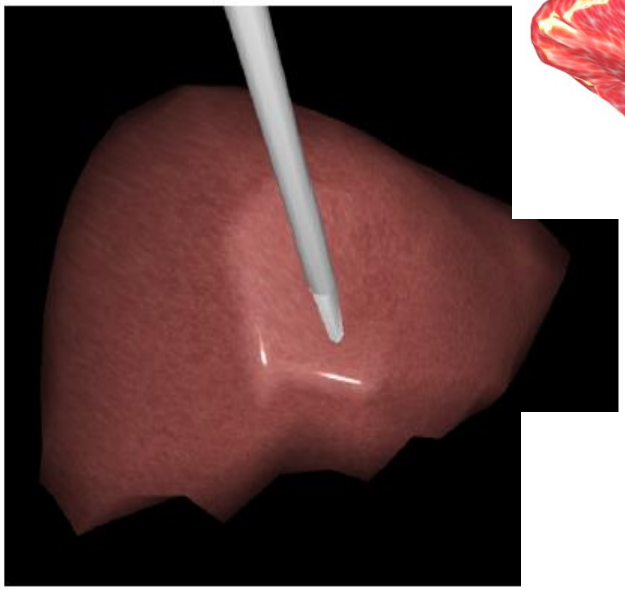
Architectural Geometry

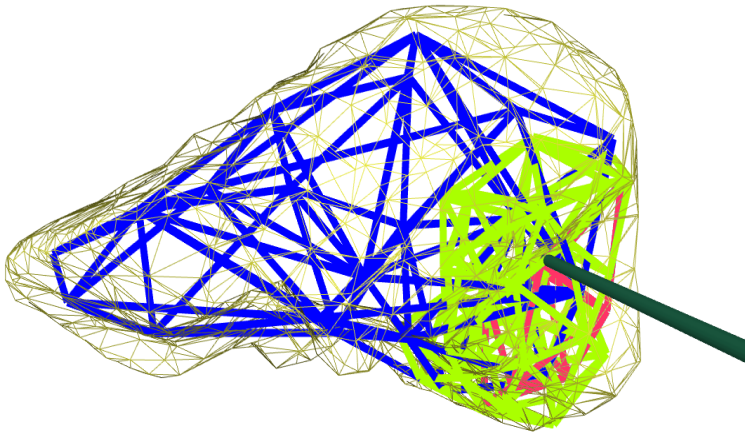


Organ Deformation

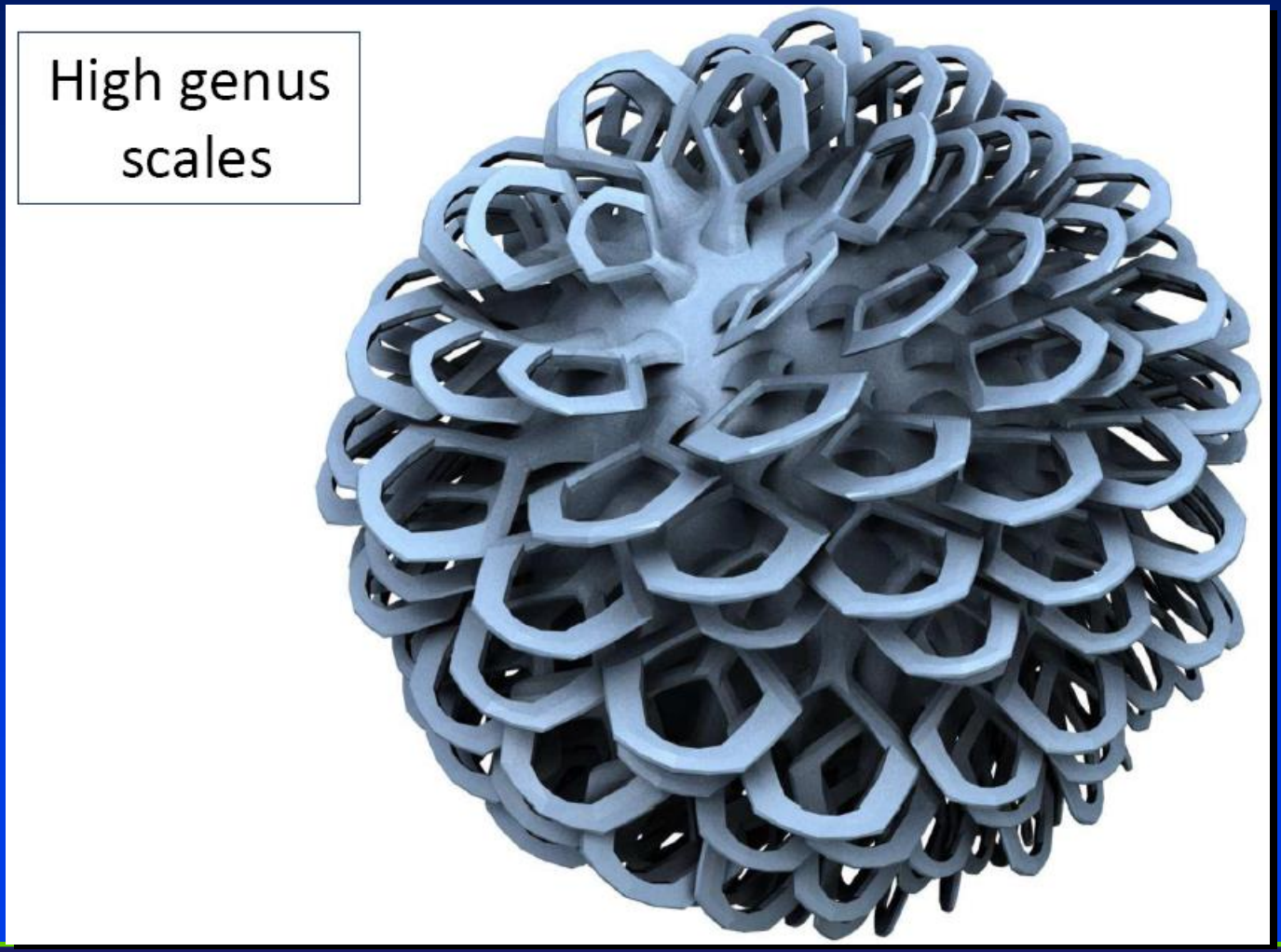








Geometry Texture Synthesis



PDE-driven Texture Synthesis

Journals and Conferences

- Siggraph (Siggraph Asia)
- Eurographics
- Pacific Graphics

- ACM Transactions on Graphics
- IEEE Transactions on Visualization and Computer Graphics
- Computer Graphics Forum

- Geometry-oriented journals and conferences (GMP, SPM, SMI, SGP, Computer-aided Design, CAGD, GMOD, Computers & Graphics)
- Computer Vision (CVPR, ICCV, ECCV)
- Image processing
- VR
- HCI

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