Introduction

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School of Data and Computer Science

Exciting cartoons

Exciting cartoons

- Thinking:

Which graphics technologies are included in the cartoon product?

Exciting cartoons

- Hair Modeling

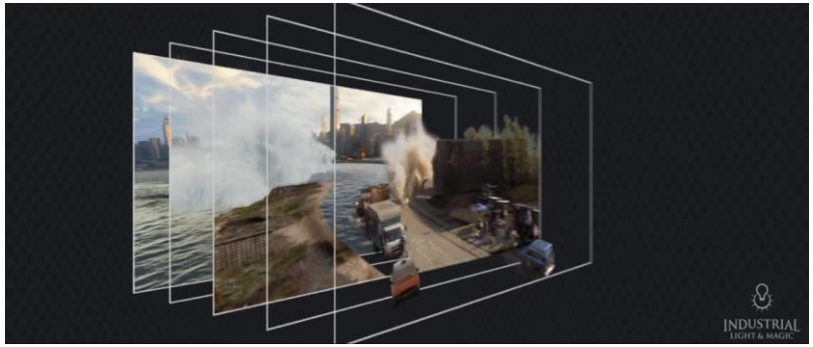
- Fluid simulation & illumination

Exciting movies

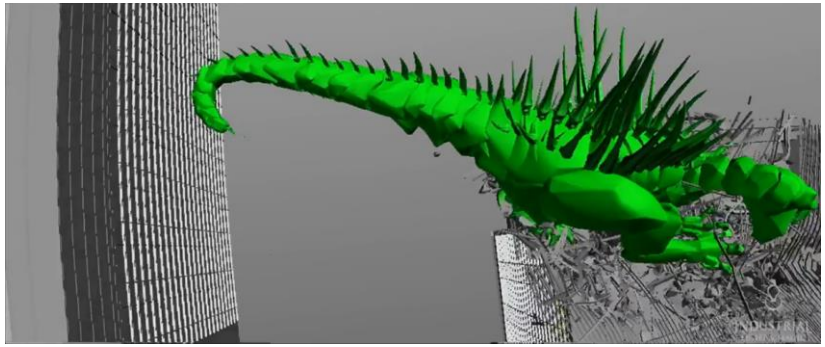
Exciting movies

Exciting movies

- Scene modeling



- Object modeling



Exiting games

What is Computer Graphics?

- The science and technology of modeling, processing and displaying objects in the world in a computer.
- Such models come from diverse and expanding set of fields including physical, biological, mathematical, artistic, and conceptual/abstract structures

Frame from animation by William Latham, shown at **SIGGRAPH 1992**. Latham creates his artwork using rules that govern patterns of natural forms.

What is Interactive Computer Graphics?

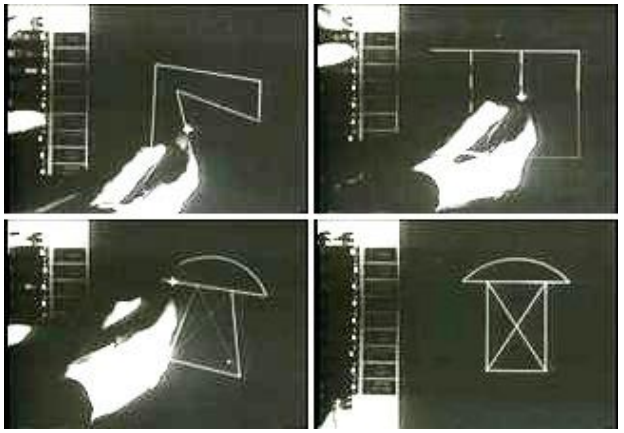
- User controls content, structure, and appearance of objects and their displayed images via rapid visual feedback
- Basic components of an interactive graphics system
  - input (e.g., mouse, stylus, multi-touch, in-air fingers…)
  - processing (and storage of the underlying representation/model)
  - display/output (e.g., screen, paper-based printer, video recorder…)

- First truly interactive graphics system, **Sketchpad**, pioneered by Ivan Sutherland 1963 Ph.D. thesis *Sketchpad, A Man-Machine Graphical Communication System*
- Used TX-2 transistorized "mainframe" at MIT Lincoln Lab

What is Interactive Computer Graphics?

- Almost all key elements of interactive graphics system are expressed in first paragraph of Sutherland's 1963 Ph.D. thesis.

The Sketchpad system uses drawing as a novel communication medium for a computer. The system contains input, output, and computation programs which enable it to interpret information drawn directly on a computer display. Sketchpad has shown the most usefulness as an aid to the understanding of processes, such as the motion of linkages, which can be described with pictures. Sketchpad also makes it easy to draw highly repetitive or highly accurate drawings and to change drawings previously drawn with it…



What is Interactive Computer Graphics?

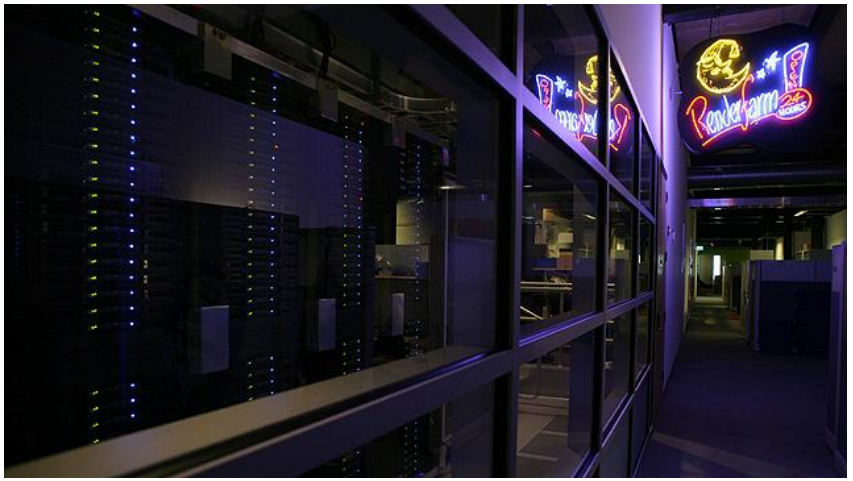
What is Interactive Computer Graphics?

- Autodesk 3Ds Max 2016 - Overview

What is Batch Computer Graphics?

- Today, still use non-interactive batch mode for final production-quality video and film (special effects – FX). Rendering a single frame of Monsters University (a 24 fps movie) averaged 29 hours on a 24,000-core render farm!

Still from Monsters University



Render farm

What is Batch Computer Graphics?

- Exposure the cloud rendering technology in “Little Door Gods (小门神, 2016)”

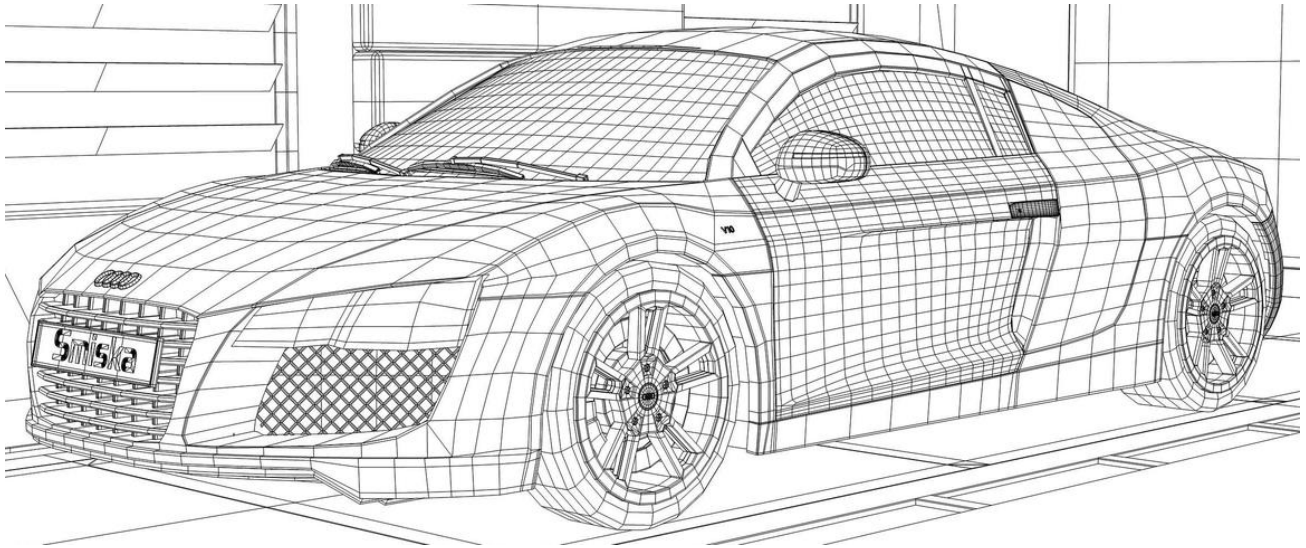
The Basic Content of Computer Graphics

- Modeling (shape): **creating** and **representing** the geometry of objects in the 3D world.
- Rendering (displaying): is a term inherited from art and deals with the **creation** of 2D shaded images from 3D computer models.
- Animation (simulating): describing how objects **change in time**.

Modeling

How do we represent objects/environments?

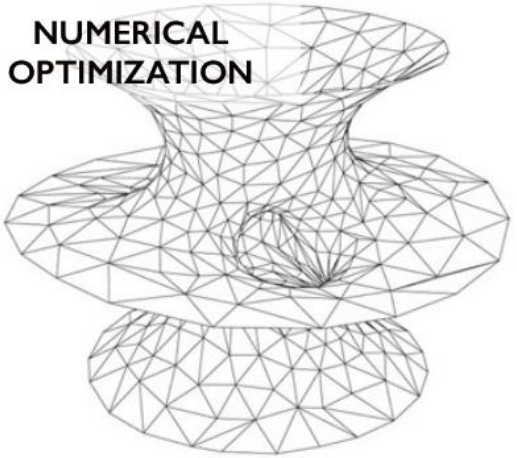
- shape — the geometry of the object
- appearance — emission, reflection, and transmission of light



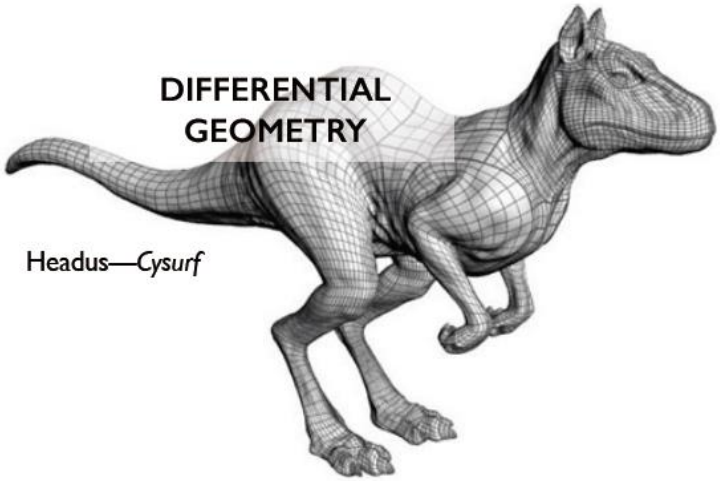
Modeling

How do we construct these models?

- manual description (e.g., write down a formula)
- interactive manipulation
- procedurally — write a generating program (e.g., fractals)
- scan a real object (laser scanners, computer vision, …)

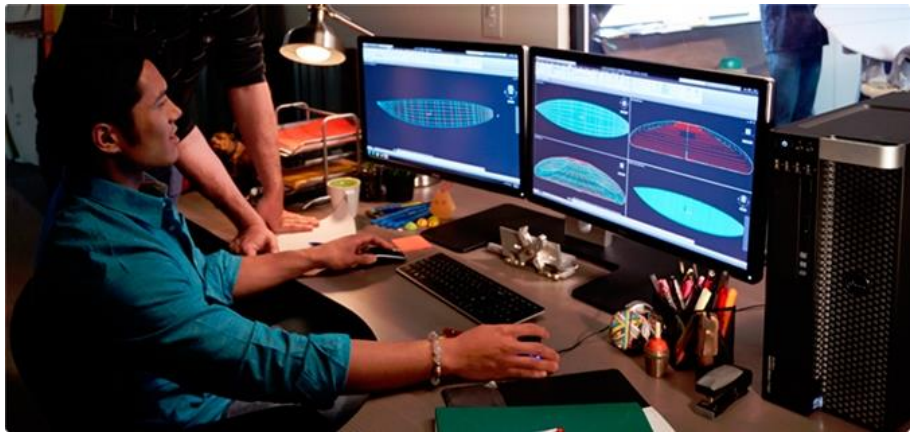


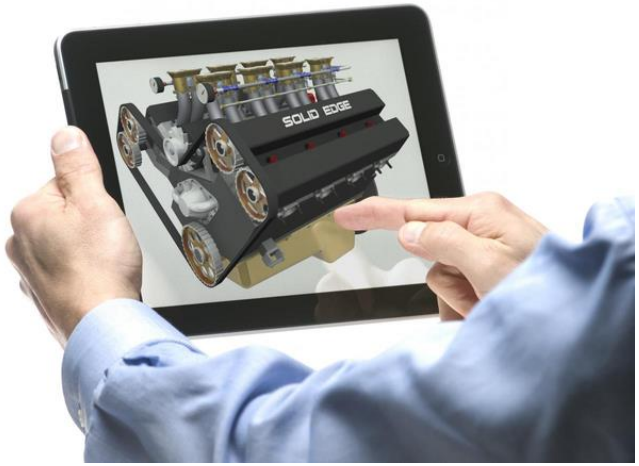
[Hoppe et al. 1993]



Modeling

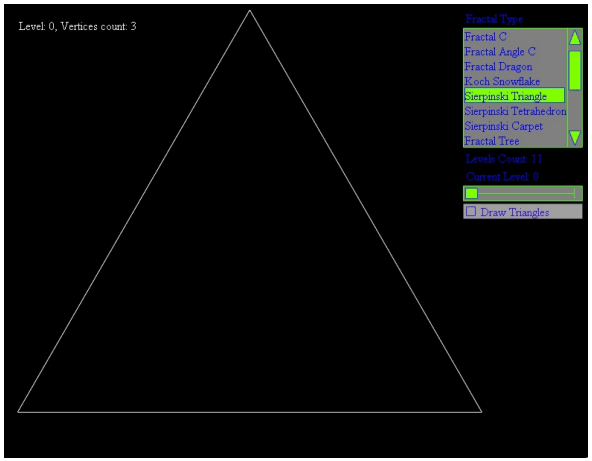
- Interactive manipulation

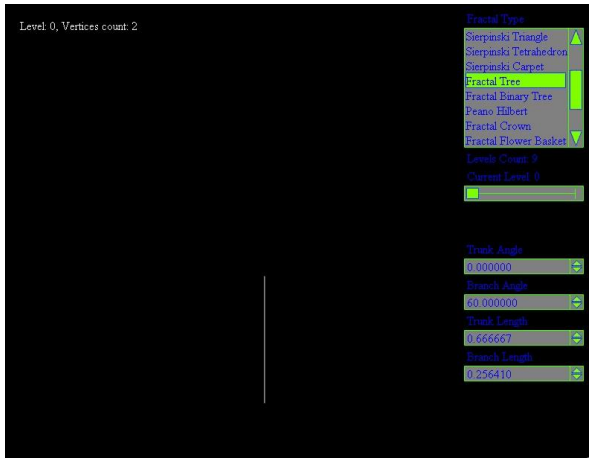


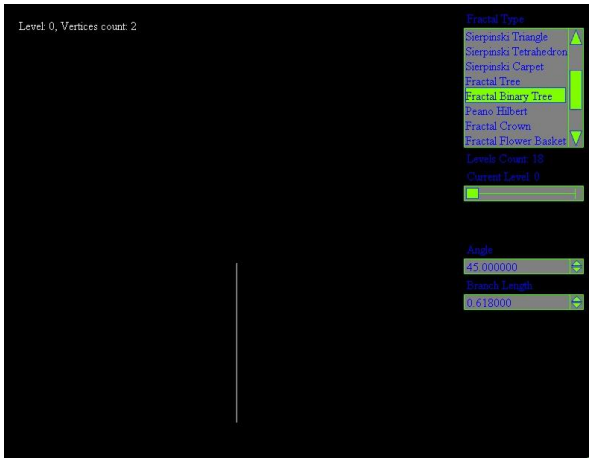


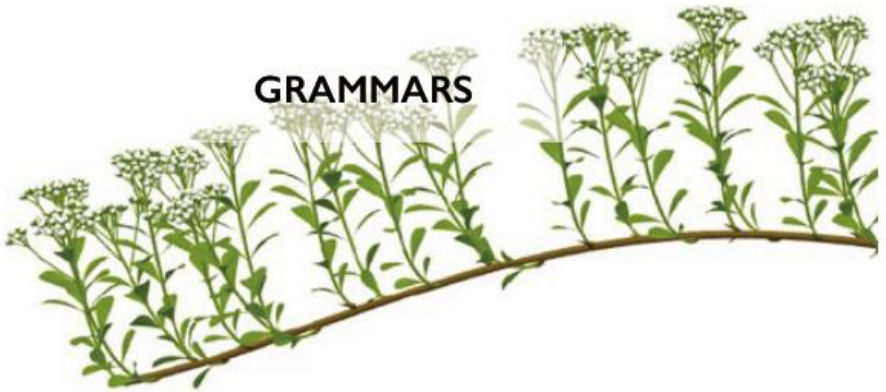
Modeling

- Procedurally generation





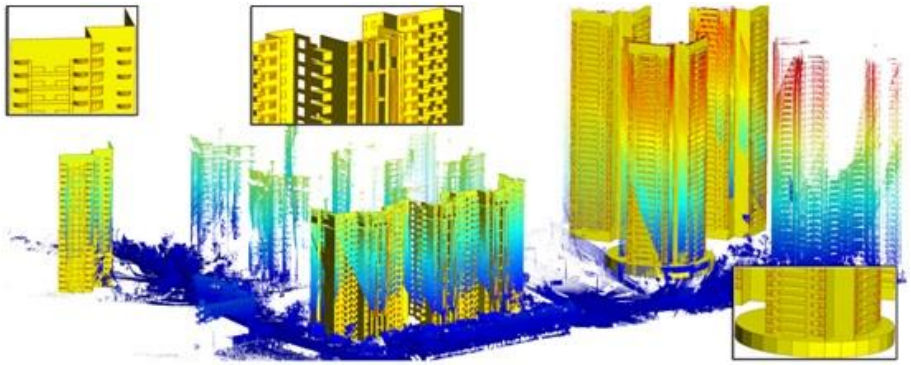




[Prusinkeiwicz et al. 2001]

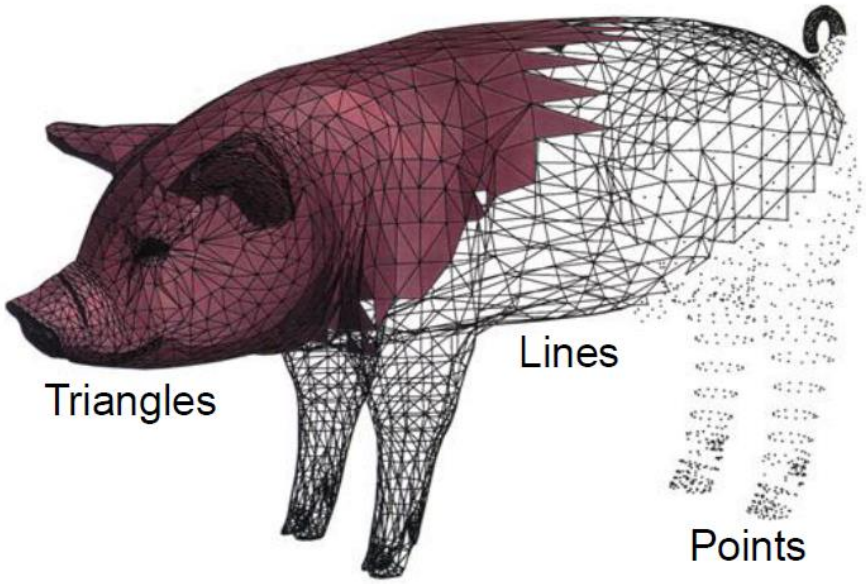
Modeling

- Scan a real object



Discrete Geometry: Points & Meshes

- Digitized 3D objects
  - Computerized modeling of 3D geometry
- Triangular meshes
  - Piecewise linear approximation to surfaces

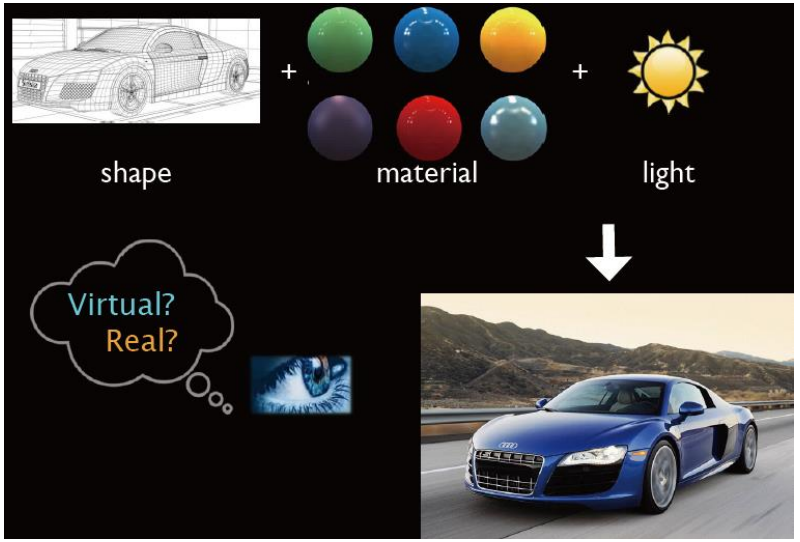


Rendering

- Generation of 2D images from a 3D Models.
  - I/O of Computer Graphics
    - Input : graphics : object (shape, material,...)
    - Output : image : array of pixels (RGB)

3D object → Image

Display or Rendering



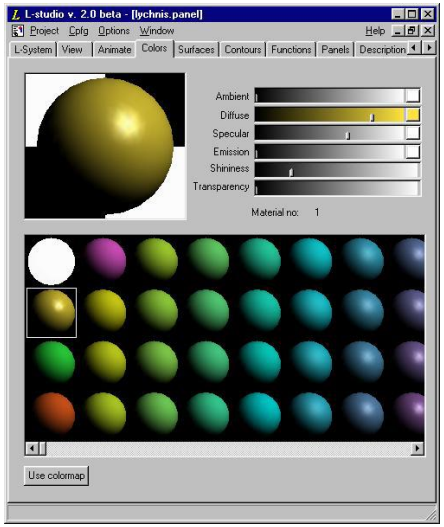
Rendering

- Different objectives
  - Photorealistic
  - Interactive
  - Artistic

Lights

Dark

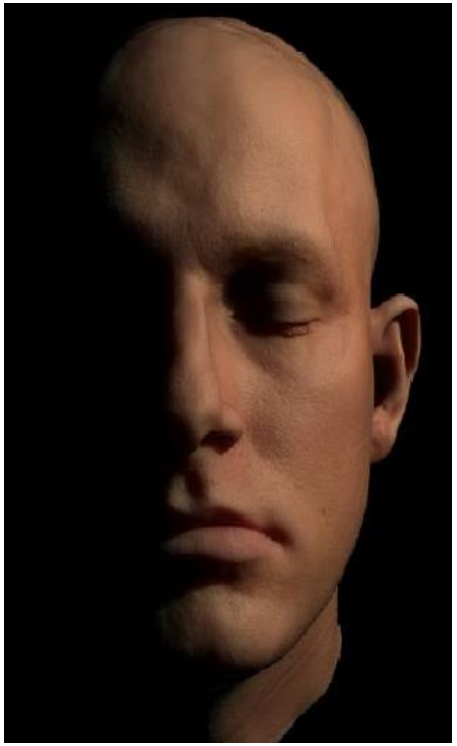
Materials



Bright

Photorealistic rendering

- Photorealistic rendering
  - Physically-based simulation of light, camera
  - Shadows, realistic illumination, multiple light bounces
  - Special effects, movies



Photorealistic rendering

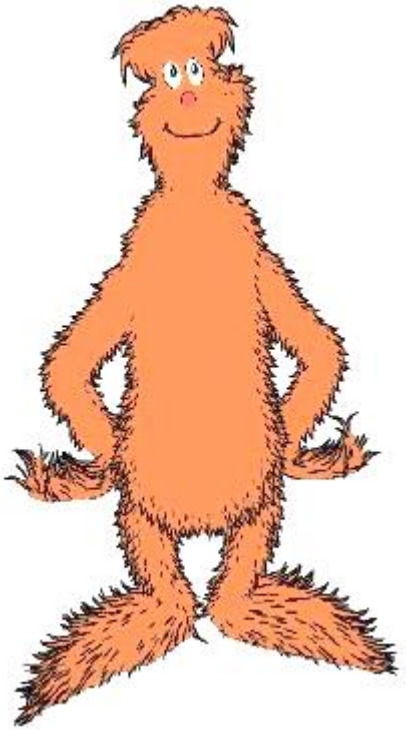
- GODZILLA - Visual Effects Breakdown

Interactive rendering

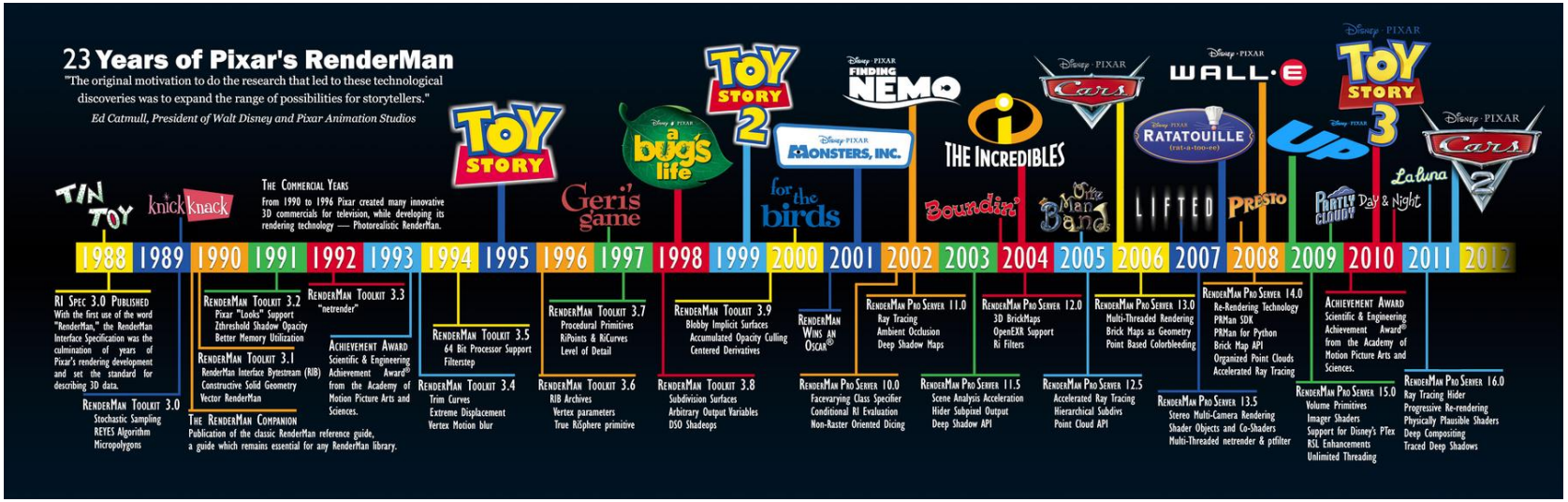
- Produce images within milliseconds
- Using specialized hardware, graphics processing units (GPUs)
- Standardized APIs (OpenGL, DirectX)
- Often “as photorealistic as possible”
- Hard shadows, fake soft shadows, only single bounce of light
- Games

Artistic rendering

- Stylized
- Artwork, illustrations



Pixar’s RenderMan



Pixar's RenderMan

Animation

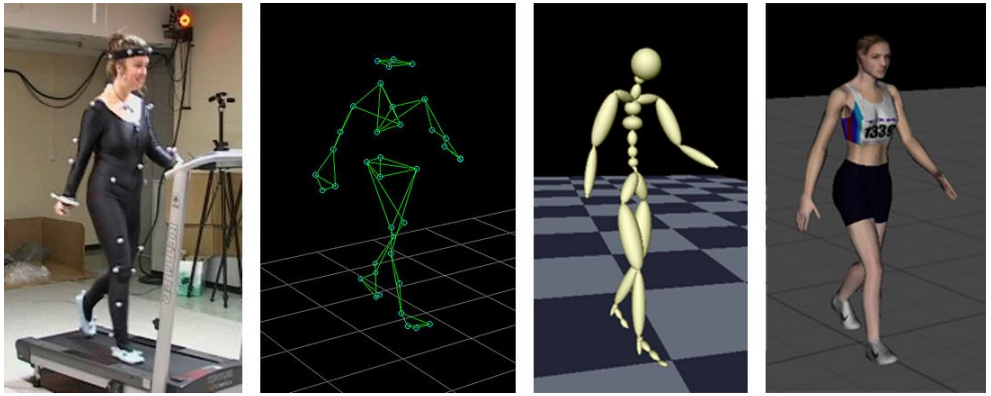
- Making geometric models move and deform

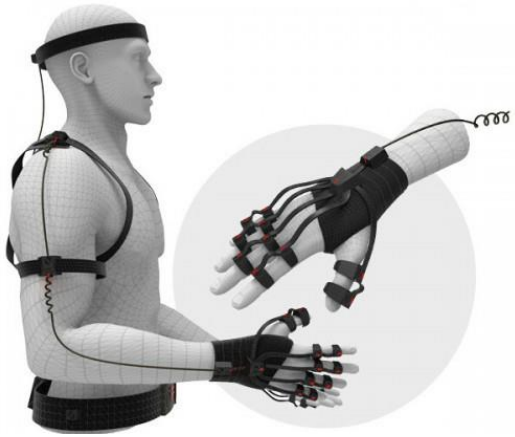
How do we represent the motion of objects?

- positions, angles, etc. as functions of time

How do we control/specify this motion?

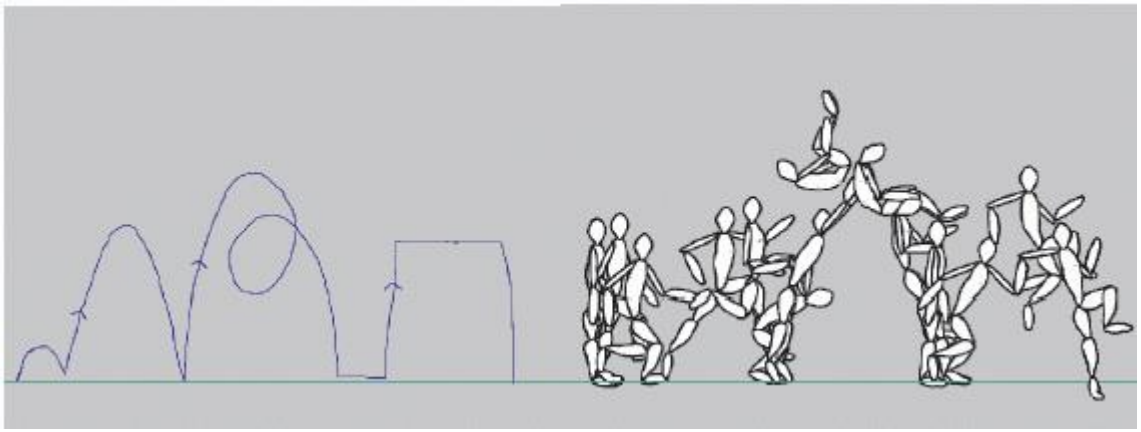
- generate poses by hand, fill in with keyframing
- behavioral simulation (program little “brains” for objects)
- physical simulation
- motion capture

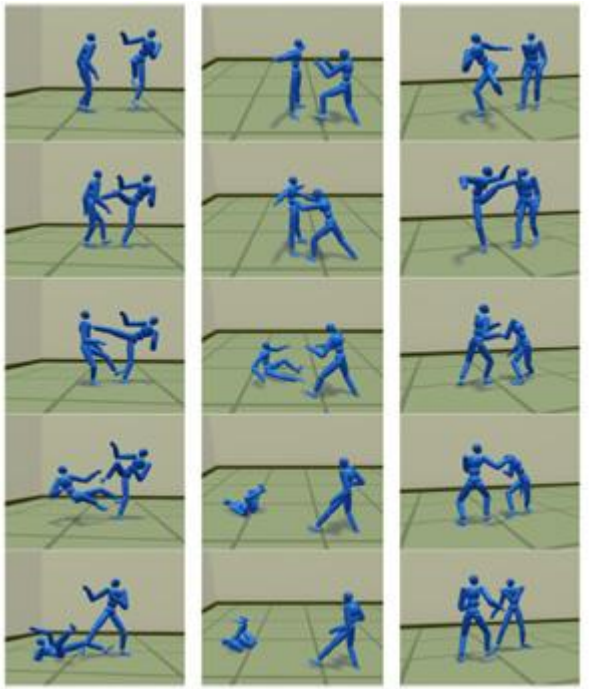




Animation

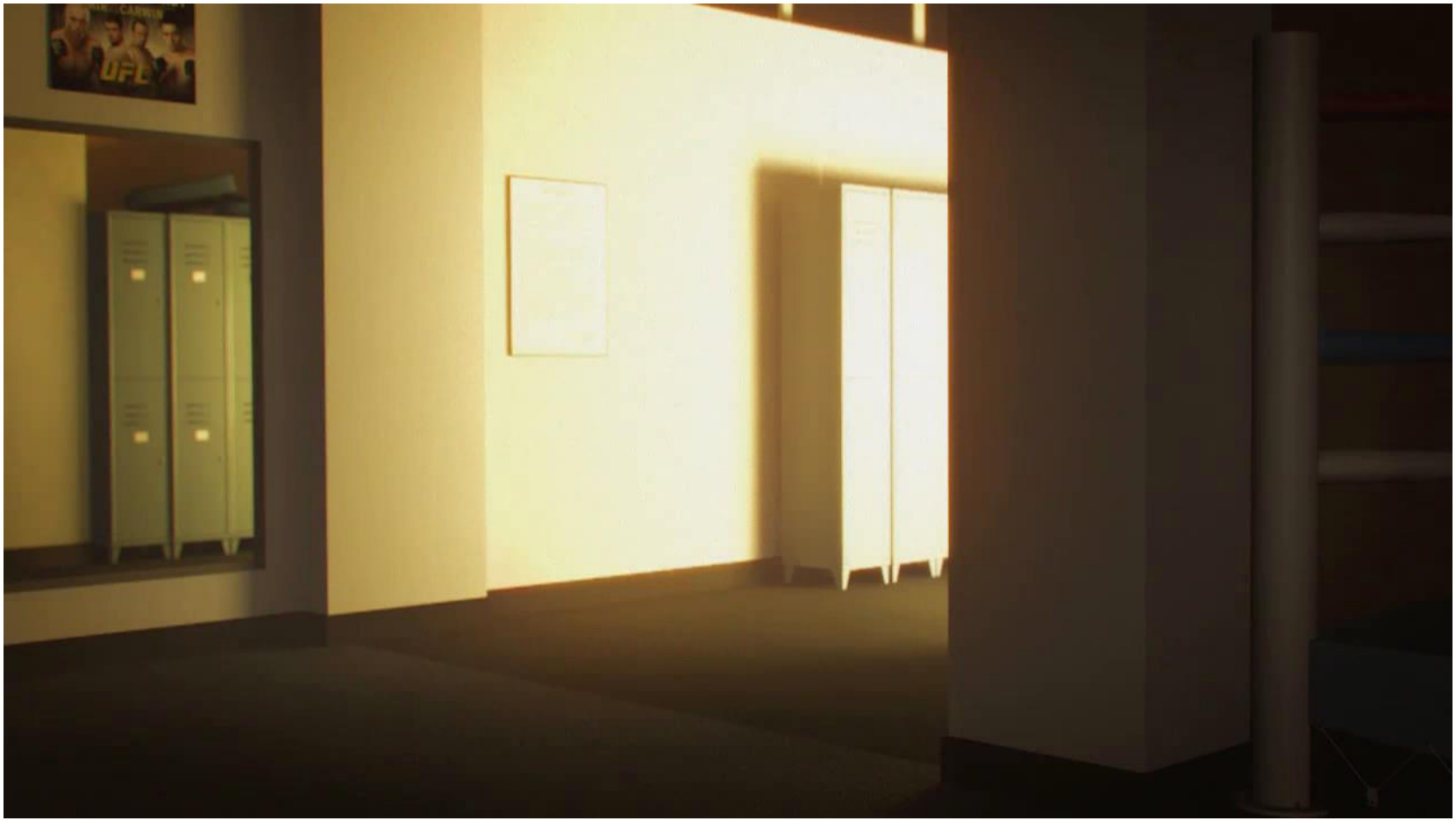
- **Generating motion**
  - interpolating between frames, states





Animation

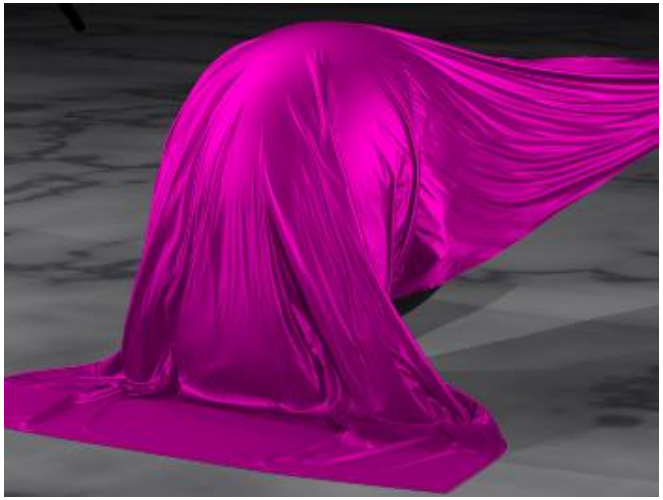
- A Warrior's Dream – from SIGGRAPH Asia 2014

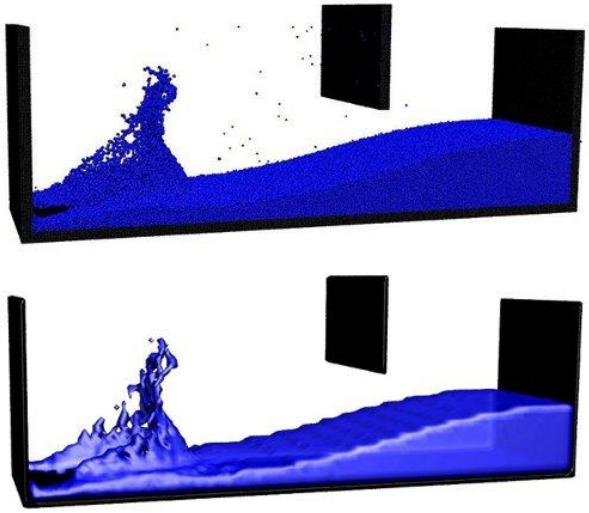


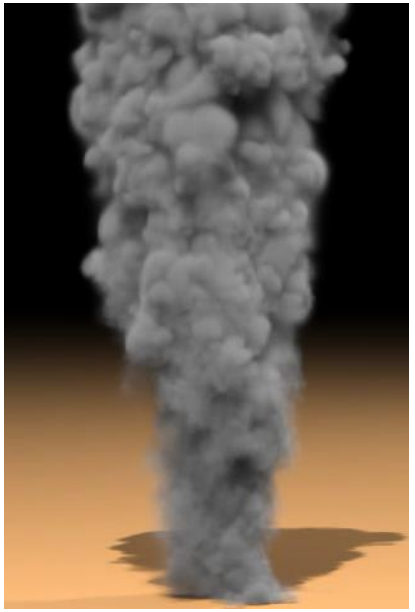
Animation

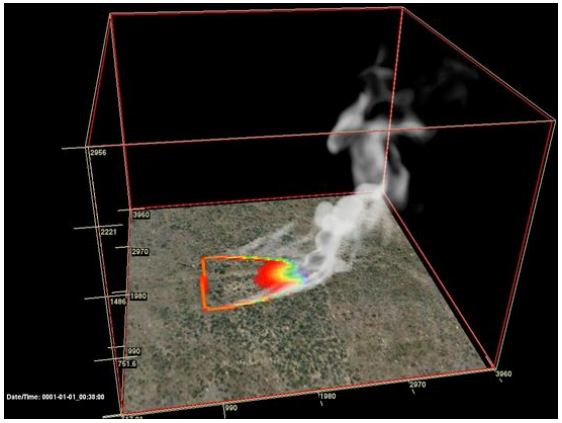
- Deforming or editing the geometry
- Change over time
- Faces, articulate characters, ……

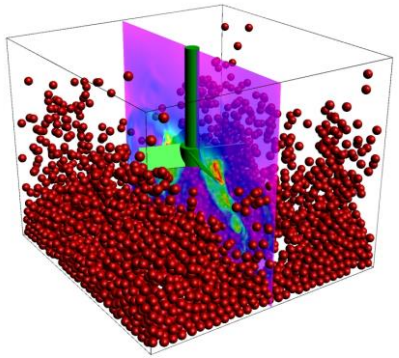
Physics simulation

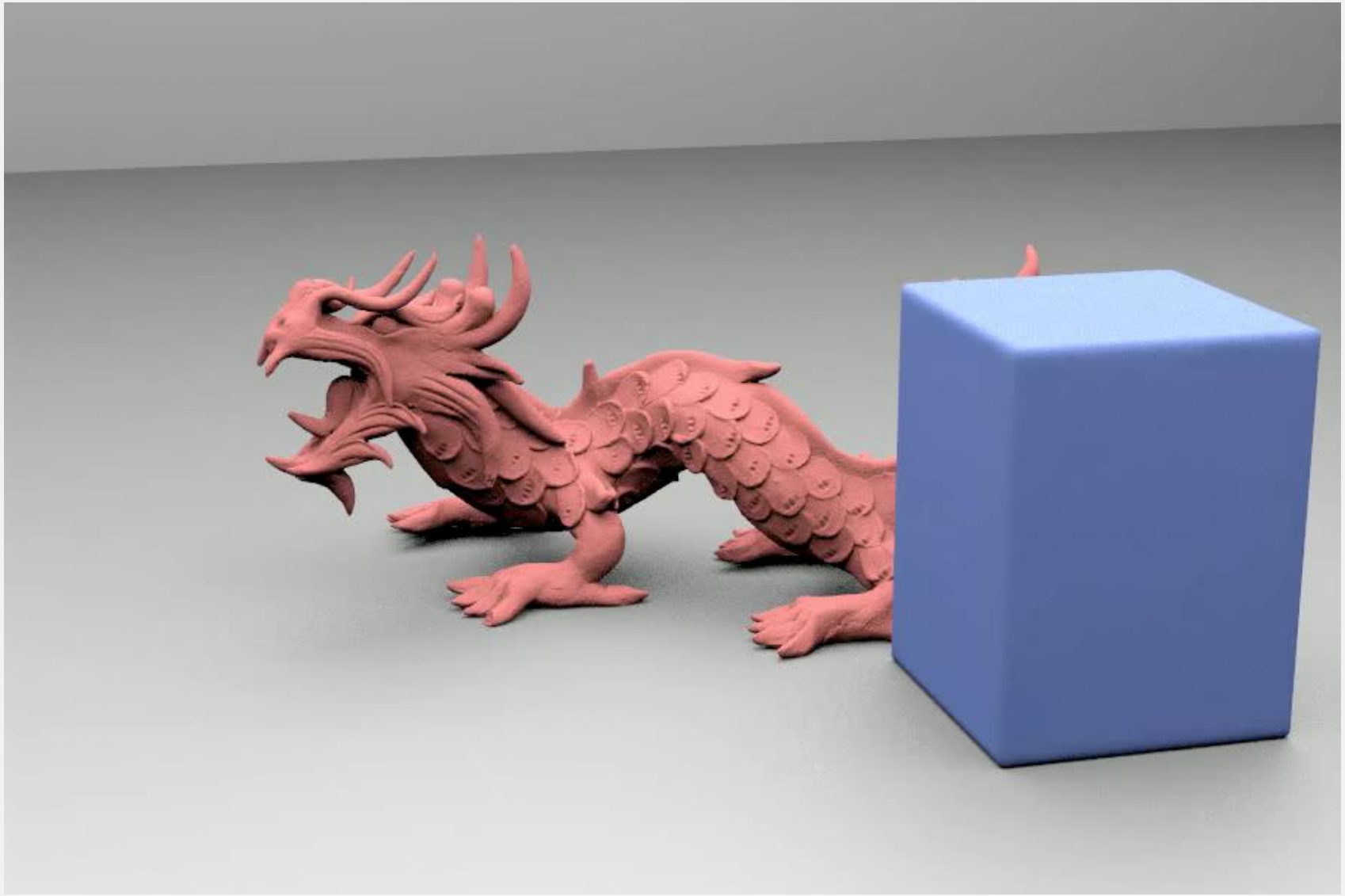












Physics simulation

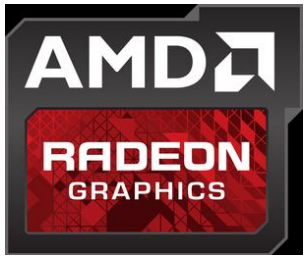
- Iron Man 3

Enabling Modern Computer Graphics

- Hardware revolution
  - **Moore's Law:** every 12-18 months, computer power improves by factor of 2 in price / performance as size shrinks
  - Newest CPUs are 64-bit with 2, 4, 6, 8, even up to 18 cores
  - Intel Skylake – consumer processor with 4 cores, 8 threads, and a fully featured graphics chip built in to the processor
  - Significant advances in commodity graphics chips every 6 months vs. several years for general purpose CPUs
    - NVIDIA GeForce GTX Titan X… 3072 cores, 12GB memory, and 7 teraflops of processing power in a single chip

Enabling Modern Computer Graphics

- Graphic subsystems
  - Offloads graphics processing from CPU to chip designed for doing graphics operations quickly
  - NVidia GeForce™, AMD Radeon™, and Intel HD and Iris Pro Graphics
  - GPUs originally designed to handle special-purpose graphics computations
  - Increasingly, GPUs used to parallelize other types of computation (known as **GPGPU**, or General-Purpose Computing on the Graphics Processing Unit)



Enabling Modern Computer Graphics

- High-end PCs with hot graphics cards (nVidia GeForce™, AMD Radeon™) have supplanted graphics workstations
- Such PCs are clustered together over high speed buses or LANs to provide “scalable graphics” to drive tiled PowerWalls, Caves, etc.
- Also build GPU-clusters as number crunchers, e.g., protein folding, weather prediction
- Now accessible to consumers via technologies like NVIDIA’s SLI (Scalable Link Interface) bridge

You can put multiple GPUs together in your computer using SLI.

Enabling Modern Computer Graphics

- Input Devices
  - Mouse, tablet & stylus, multi-touch, force feedback, and other game controllers (e.g., Wii), scanner, digital camera (images, computer vision), etc.
  - Body as interaction device (e.g. Kinect)

Xbox Kinect


Leap Motion


Nimble UX

Enabling Modern Computer Graphics

- Many form factors
  - Smartphones/laptops/desktops/tablets
  - Smart watches
  - Head-mounted displays (HMDs)
  - 3D immersive virtual reality spaces

Apple iPhone

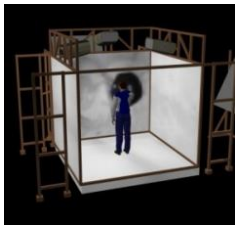
Android Phones

Tablets

Microsoft's first Surface

Apple Watch

Android Wear



Brown's old Cave

Microsoft Hololens

Oculus Rift

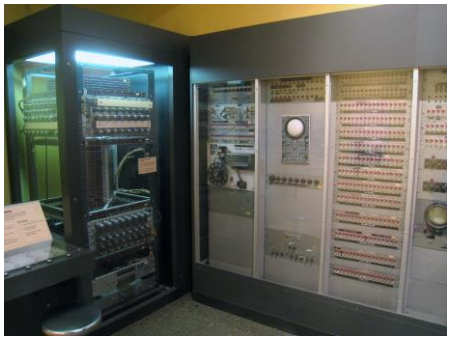
Google Cardboard

Enabling Modern Computer Graphics

- Software Improvements
  - Algorithms and data structures
    - Modeling of materials
    - Rendering of natural phenomena
    - “Acceleration data structures” for ray tracing and other renderers
  - Parallelization
    - Most operations are embarrassingly parallel: changing value of one pixel is often independent of other pixels
  - Distributed and Cloud computing
    - Send operations into ‘cloud’, get back results, don’t care how
    - Rendering even available as internet service!

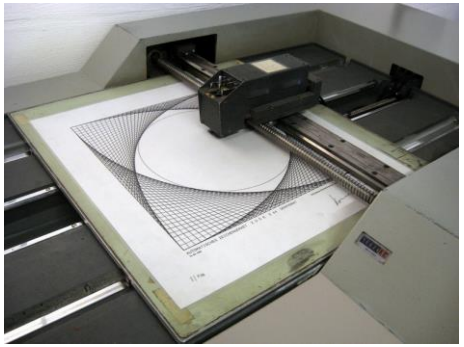
History of computer graphics

- The 1950's
  - In 1950, the first visual display unit is designed for MIT's Whirlwind I Computer（旋风一号）



  - In 1958, CalComp developed 565 drum plotter (滚筒绘图仪)

  - In 1958, Gerber Company developed the first flat plotter (平板绘图仪)



History of computer graphics

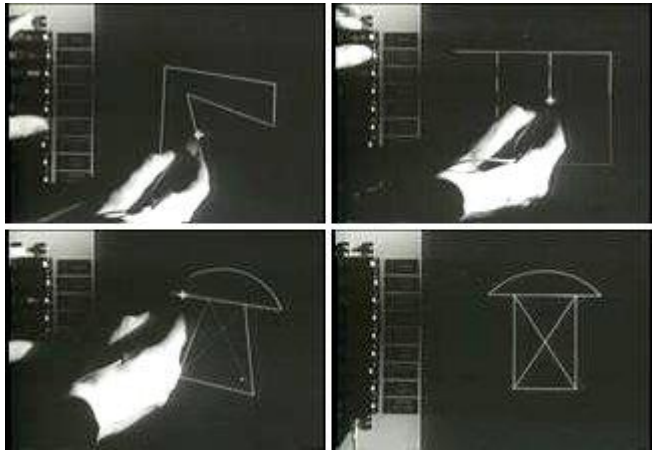
- The 1950's
  - In the late of 1950's, The whirlwind team became assimilated into the creation of SAGE air defense system (semiautomatic ground environment)
  - Emerge of interactive computer graphics

History of computer graphics

- The 1960’s
  - Spacewar (stylized "Spacewar! 星际飞行") is one of the earliest digital computer video games. It is a two-player game, with each player taking control of a starship and attempting to destroy the other.
  - Steve Russell, MIT for PDP-1

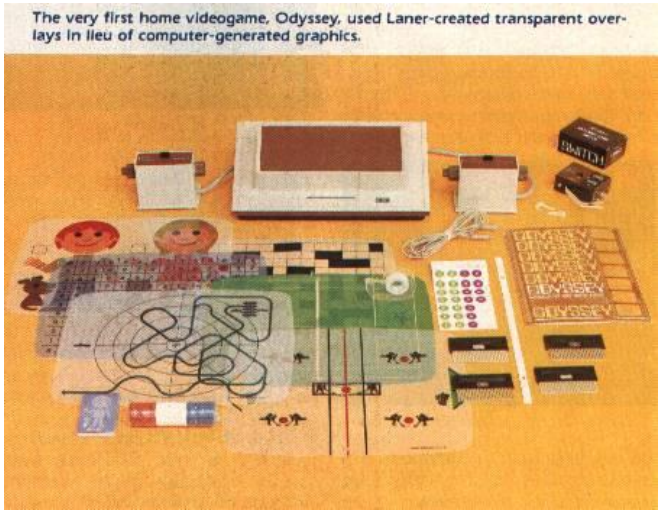
History of computer graphics

- The 1960's
  - Sketchpad (aka Robot Draftsman) was a revolutionary computer program written by Ivan Sutherland in 1963 in the course of his PhD thesis, for which he received the Turing Award in 1988.



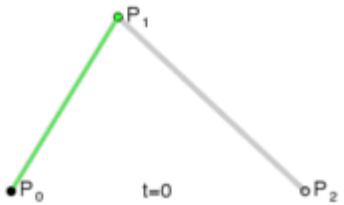
History of computer graphics

- The 1960’s
  - The Magnavox Odyssey (奥德赛) is the first commercial home video game console.
  - The Odyssey was designed by Ralph H. Baer, assisted by engineers William Harrison and William Rusch. They began around 1966 and had a working prototype finished by 1968.

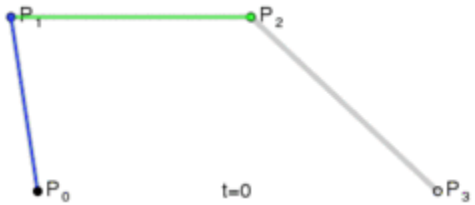


History of computer graphics

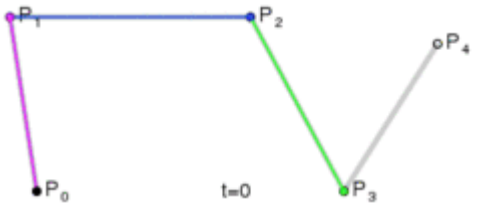
- The 1960's(CAD)
  - Professor Coons, the concept of "CAD" (Computer Aided Design) in 1958, Coons surface in 1964
  - In the late 1960's, a French engineer Pierre Bezier creates Bezier curves and Bezier surfaces that are now used in most CAD and computer graphics systems
  - UNISUR system for Car design in Renault
  - ACM Coons' award in 1985
  - Bezier and de Casteljau
  - Bezier and Forrest



Quadratic



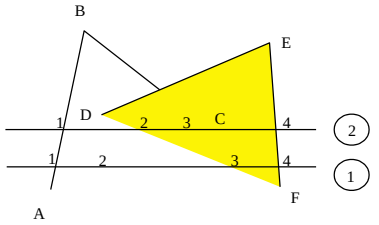
Cubic



Quartic

Bezier Curve

History of computer graphics

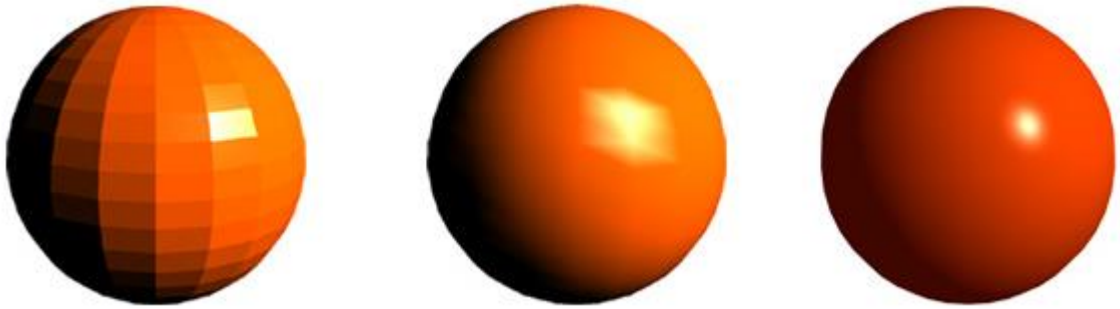


- The 1970's
- Fast development of Rasterizing Graphics
  - The concept of scan conversion(扫描转化), clipping (裁减) and surface hidden removal (消隐) and the corresponding algorithms.
- Standardization
  - In 1974, ACM SIGGRAPH formed the Graphics Standard Committee.
    - Core Graphics System (核心图形系统).
  - ISO published CGI (Computer Graphics Interface), CGM, (Computer Graphics Metafile), GKS(Graphics Kernel system), PHIGS (Programmer's Hierarchical Interactive Graphics Standard).

ACMSIGGRAPH

History of computer graphics

- The 1970's (Rendering)
  - In 1970, Bouknight proposed the first lighting reflection model (**flat shading**)
  - In 1971, Gourand proposed "diffuse reflection + interpolation ", which is called as **Gourand shading**
  - In 1975, Phong proposed a local lighting model – **Phong shading**. (one of the most important and influential lighting model).

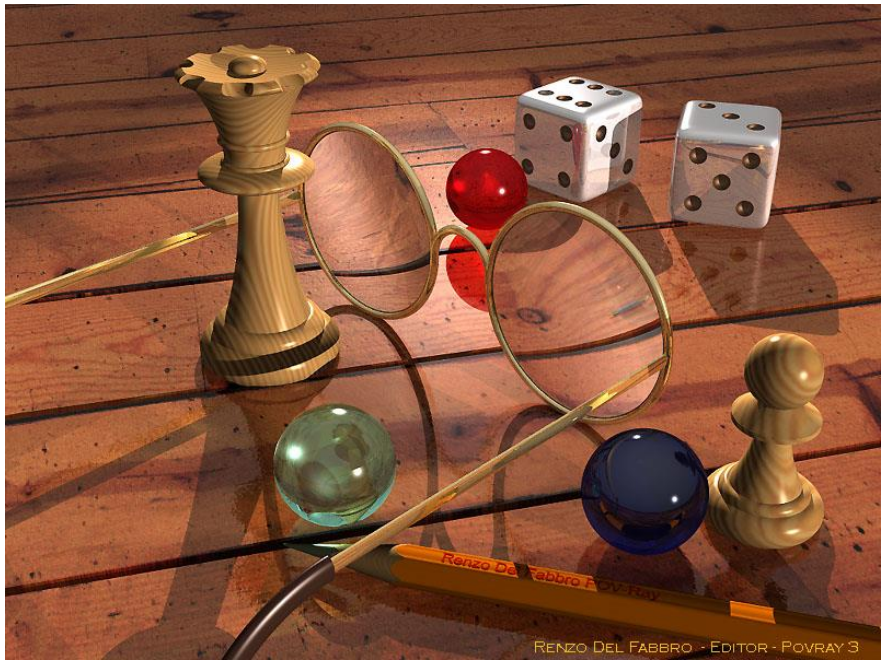


Flat shading Gourand shading Phong shading

History of computer graphics

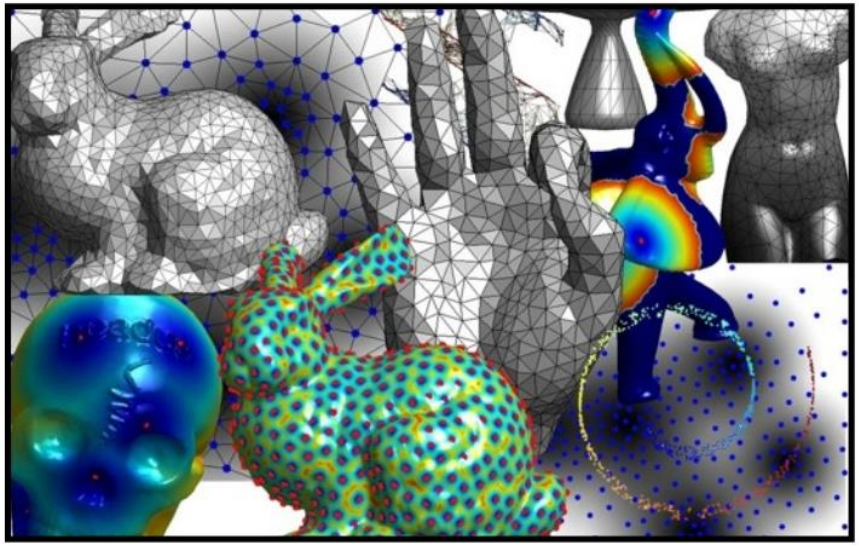
- The 1980's (Ray tracing 光线跟踪 and Radiosity 辐射度方法)
  - In 1980, Whitted proposed a ray tracing model, include light reflection (反射) and transmission (透射) effects.
  - A Milestone of CG.
  - Graphics Hardware

Graphics workstations such as these have been replaced with commodity hardware (CPU + GPU), e.g., MaxBuilts + Nvidia cards



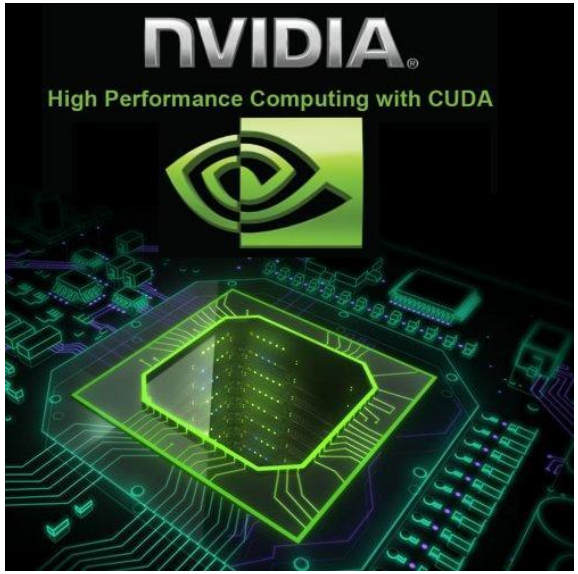
History of computer graphics

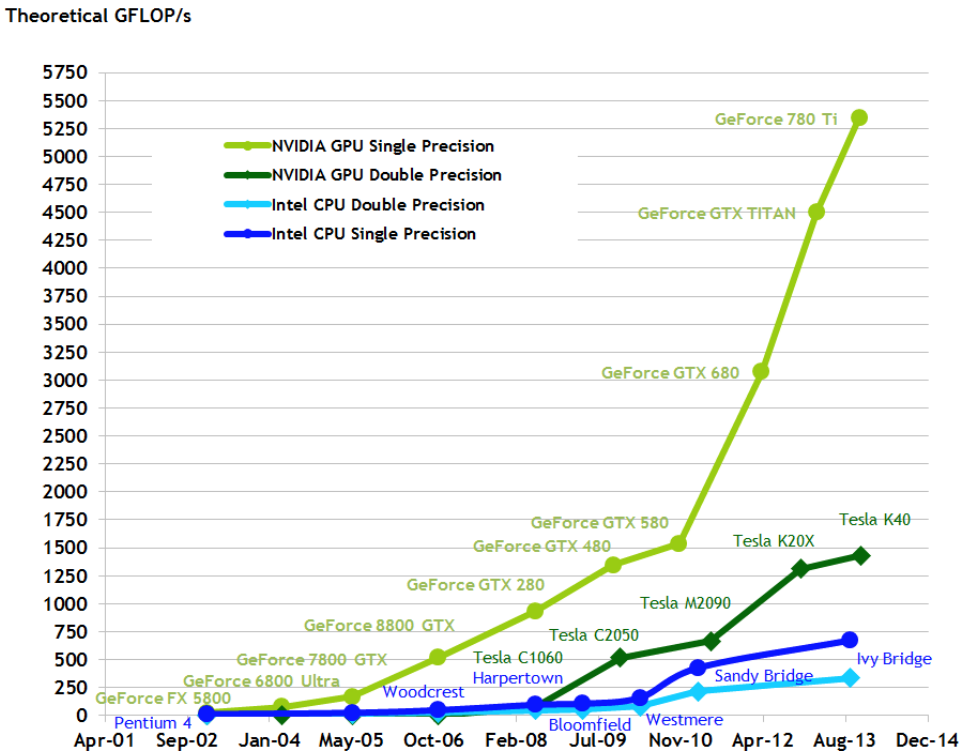
- The 1990's…
- Geometric Modeling:
  - Meshes,
  - Subdivision,
  - Implicit Surface,
  - Procedural,
  - Multi-resolution
- Rendering:
  - Volume Rendering,
  - Image-Based rendering,
  - Point-Based Rendering
- …



History of computer graphics

- The 2000's…
  - 3D Scan Technology
  - Graphics Hardware
  - GPU Parallel Computing



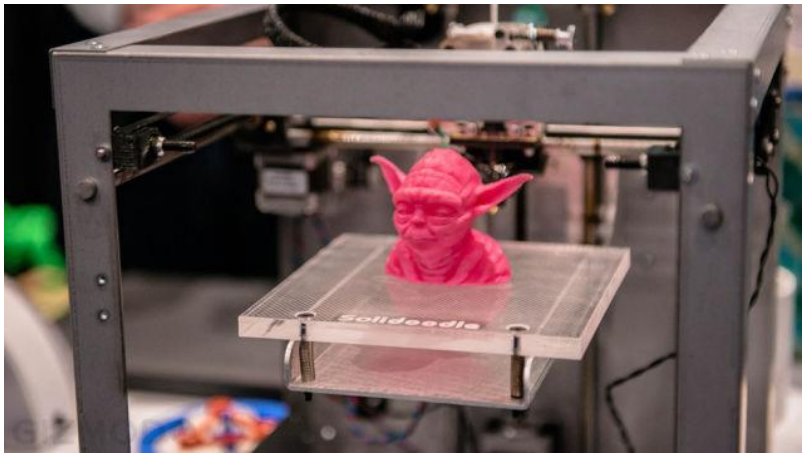


New trends

- Microsoft Kinects

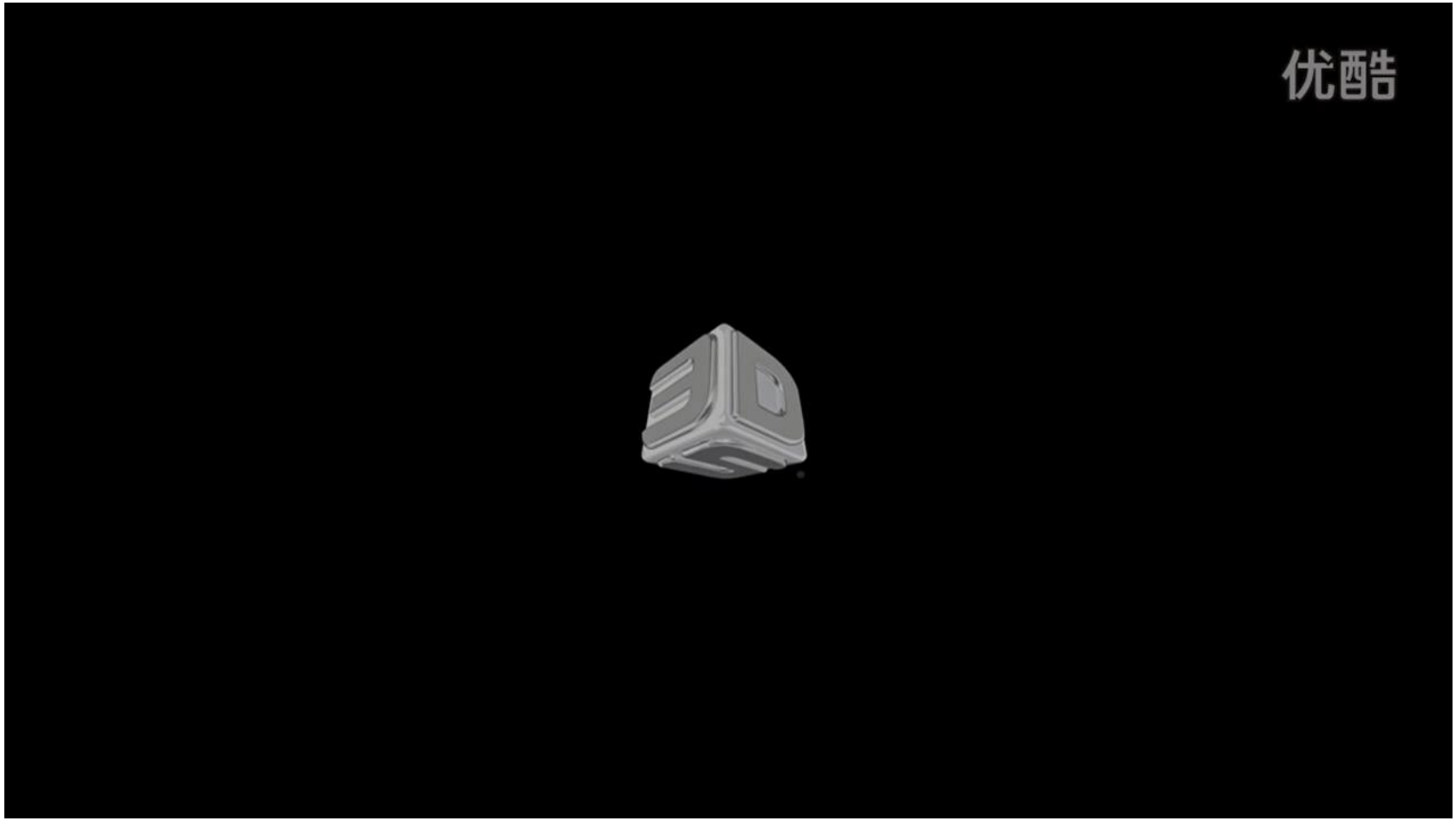
New trends

- 3D Printing



New trends

- 3D Printing



New trends

- Leap Motion

New trends

- Virtual Reality - Cyberith Virtualizer

What is CG used for?

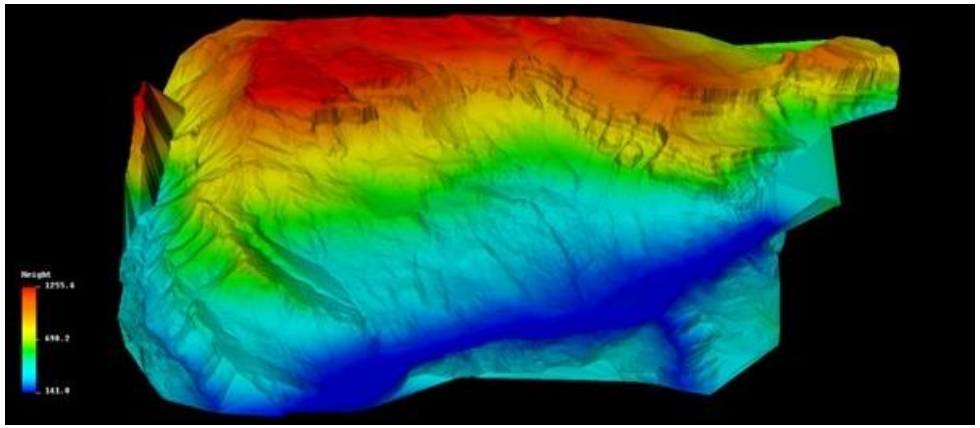
- Movies
  - animation
  - special effects

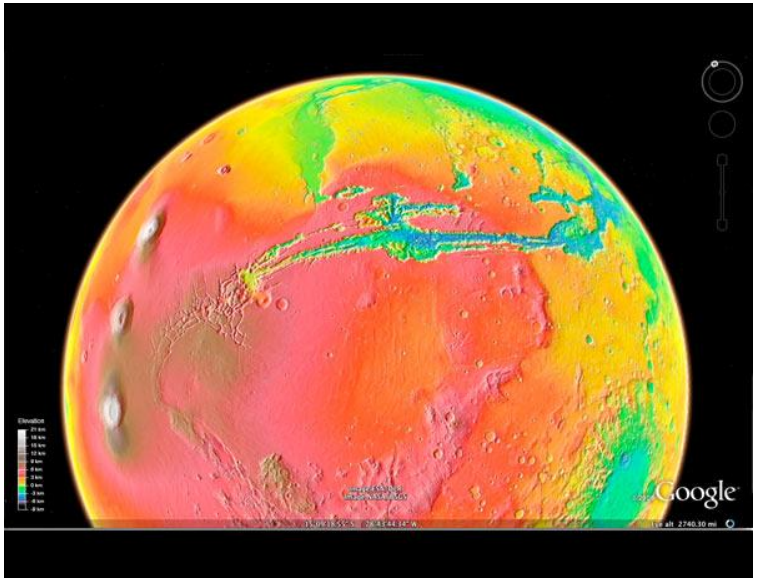
What is CG used for?

- Movies
  - performance capture

What is CG used for?

- Geography
  - Geometric Registration Technique / Digital Earth & Digital City





What is CG used for?

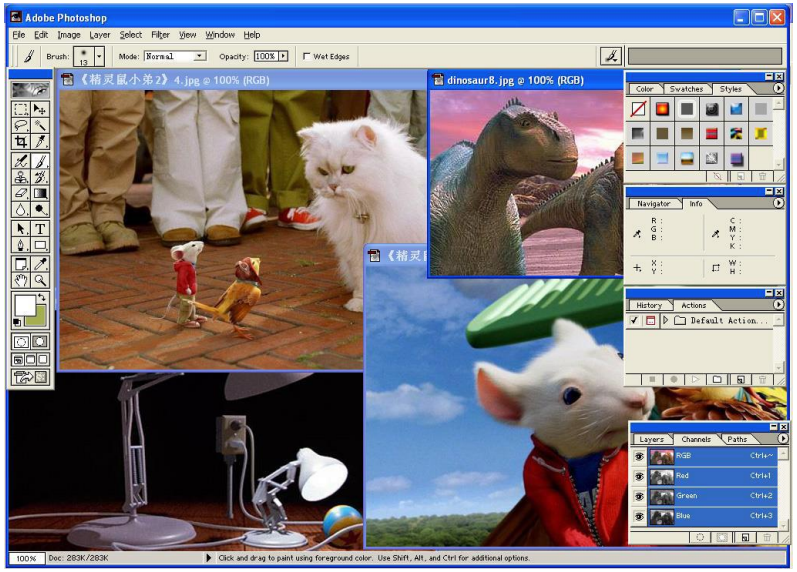
- Computer games

What is CG used for?

- images
  - advertising
  - design
  - art

What is CG used for?

- UI Design



What is CG used for?

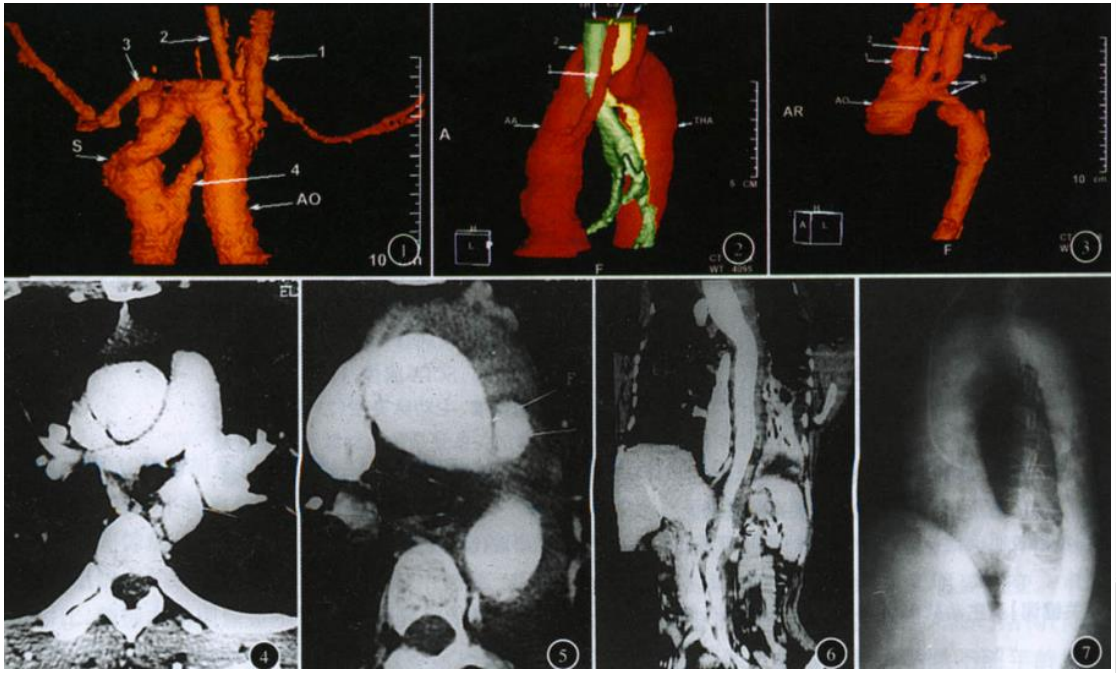
- Training & simulation

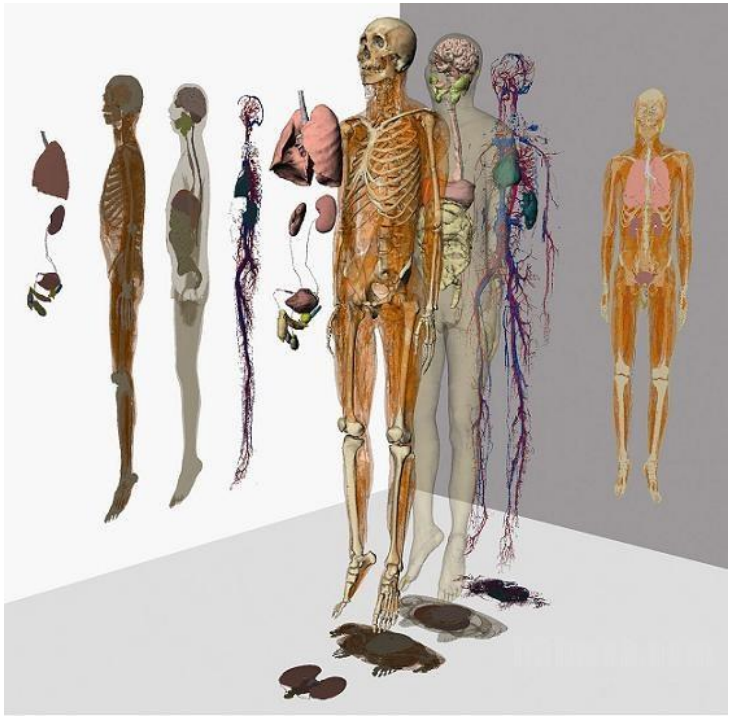
Army Research Lab—IES

NASA/Ames—ACFS

What is CG used for?

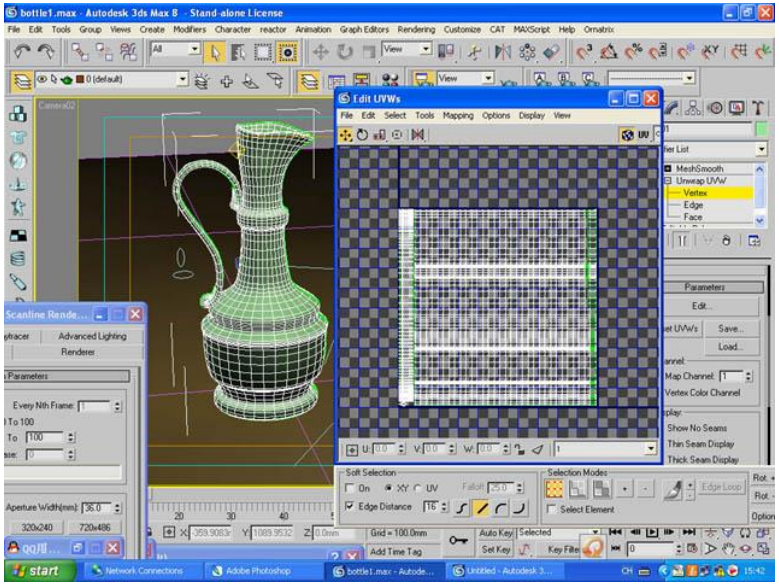
- Medical Imaging

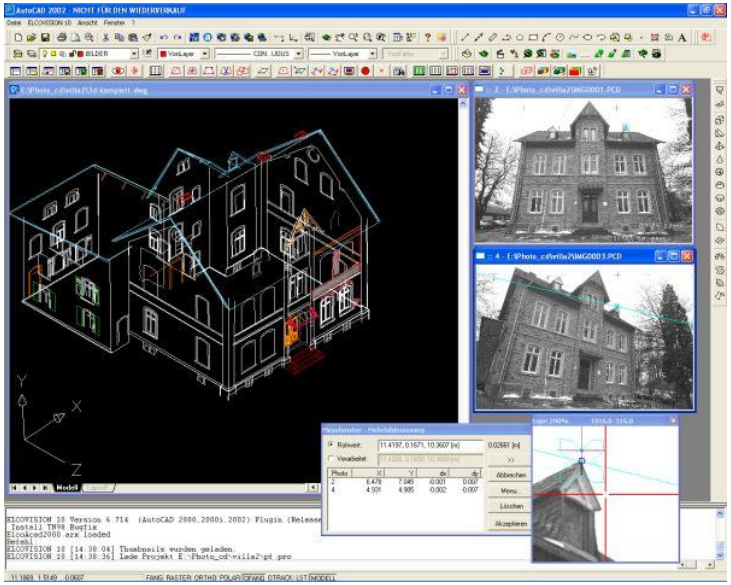


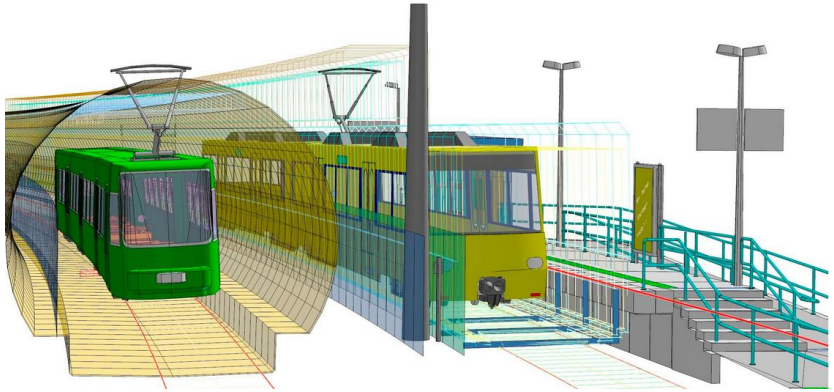


What is CG used for?

- CAD-CAM & Design







What is CG used for?

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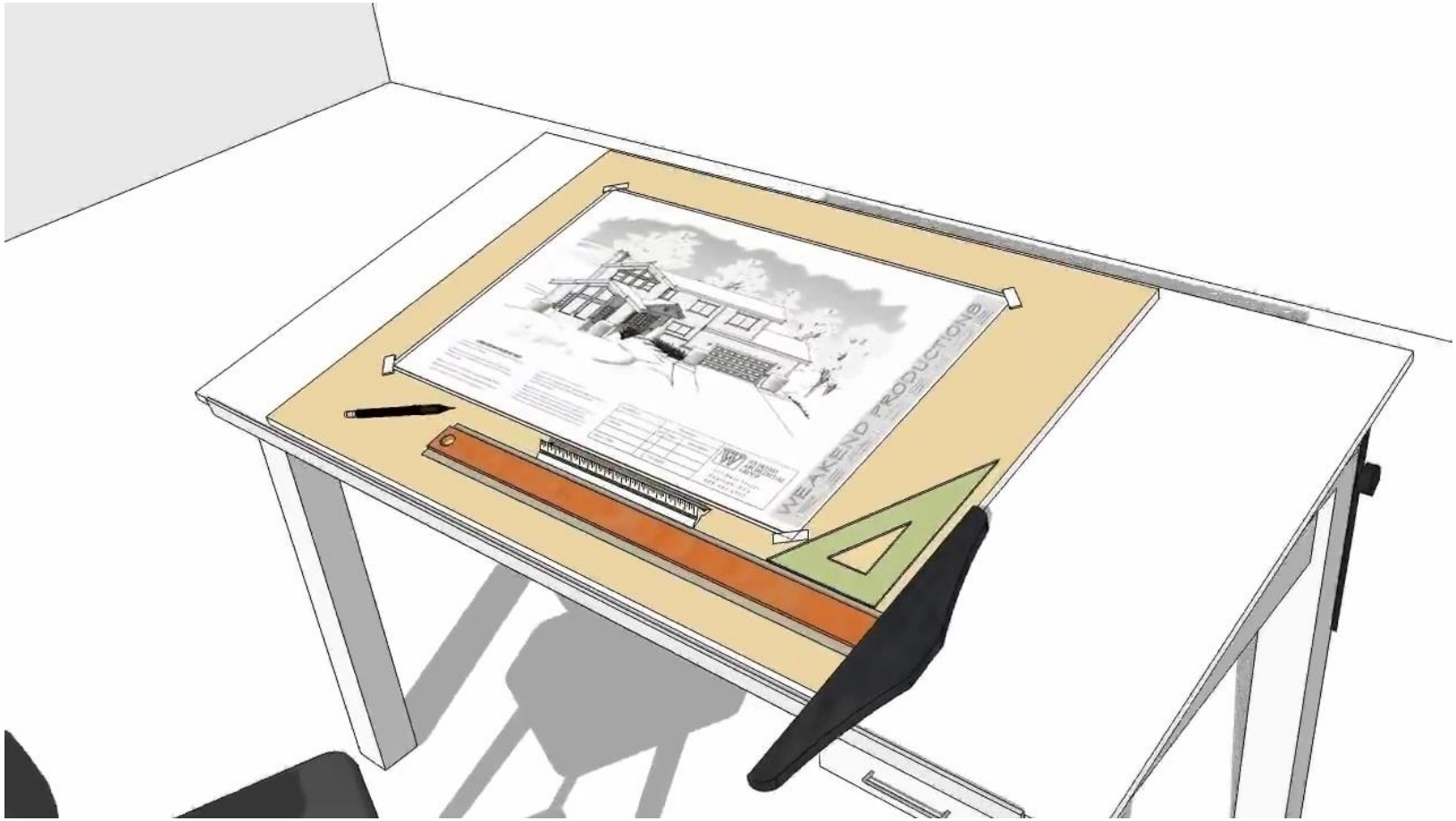


Why Study Computer Graphics?

- Wide Range of Applications
- Huge Market
  - Game
  - Movie
  - Education
- It is fun: create visually appealing results
- Fond of Science and Technology
- Opens doors to lots of job opportunities

Computer Graphics is Funny

- Interdisciplinary
  - mathematics, physics, computer, art…
- Understand the Law of Real World
  - illumination, motion
- You can ‘see’ what are your imaginary
- Virtual results may deceive your eyes
- Apply their knowledge to industry application

How to Study CG?

- Curiosity
  - Strong curiosity to unknown world
  - Desire and pursuit to technology
- Creative
  - Constantly thinking and trying
- Practice
  - Master kinds of technical ability during practice

What is the class about?

- Fundamental Algorithm of Computer Graphics
- 3D Geometry Processing
- Photorealistic Rendering
- OpenGL
- C++
- Hot Topic of Computer Graphics

- This is a programming class(OpenGL).
  - It is about algorithms that are created computer graphics images.
- Learning by doing!

We will **not** learn how to use animation or rendering **software** to create animations.

Our goal is to learn the basics that are necessary to develop such software.

Prerequisites

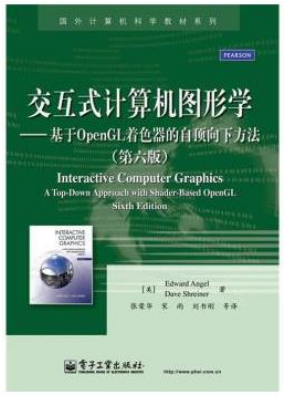
- **Good programming is very essential**
  - Good working knowledge of C++ is assumed.
  - The programming load is high.
- **Math**
  - Elementary geometry and linear algebra
  - Differential equation
  - The numerical method and calculated
  - Statistics

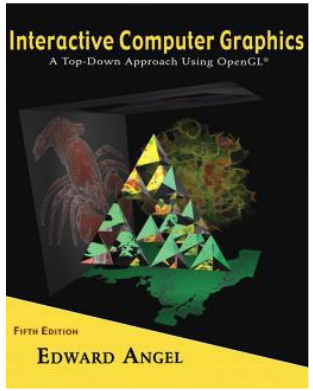
How much Math?

- Lots of simple linear algebra
  - Get it right, it will help you a lot!
- Some more advanced concepts
  - Homogeneous coordinates
  - Quaternions for interpolating rotations/orientations
  - Ordinary differential equations (ODEs) and their numerical solution
  - ……

Optional Textbook

- E. Angel, Interactive Computer Graphics — A top-down approach using OpenGL™, 6th ed., 2011. (国内有影印版)





计算机图形学（第4版）

“Computer Graphics with OpenGL, Fourth Edition”

OpenGL 编程指南 (原书第8版)

“OpenGL Programming Guide”

Course Assessment

- Project Assignments
  - Personal Project(55%)
  - Group Project(15%)
- Final Examination (30%)

Course Mailbox

- Lecture Slides & Answer Questions
  - **QQ：218024858**
- Homework submission
  - **sysucg2017@163.com**

Further Reading

- **Journals (International)**

  ACM Transactions on Graphics

  IEEE Transactions on Graphics and Visualization

  Computer Graphics Forum

  Computer Aided Geometric Design

  Computer-aided Design

  The Visual Computer

  Graphical Models

  Computer & Graphics

  Computer Graphics & Applications

- **Journals (Domestic)**

  软件学报

  计算机学报

  计算机辅助设计与图形学学报

  中国图象图形学报

- **Proceedings**

  Siggraph

  Siggraph Asia

  Eurographics

  Pacific Graphics

  Symposium on Geometry Processing

  Shape Modeling International

  Chinagraph

  ….

Lots of CG papers can be found here:

http://kesen.realtimerendering.com/

ACM SIGGRAPH

- Full: “the Special Interest Group on Computer Graphics and Interactive Techniques”
  - In 1967, professor van Dam at Brown Unversity and Sam Masta of IBM Corporation co-founded SIGGRAPH
  - In 1974, the first SIGGRAPH annual conference was held in University of Colorado (科罗拉多大学)
  - http://www.siggraph.org