Computer Graphics

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

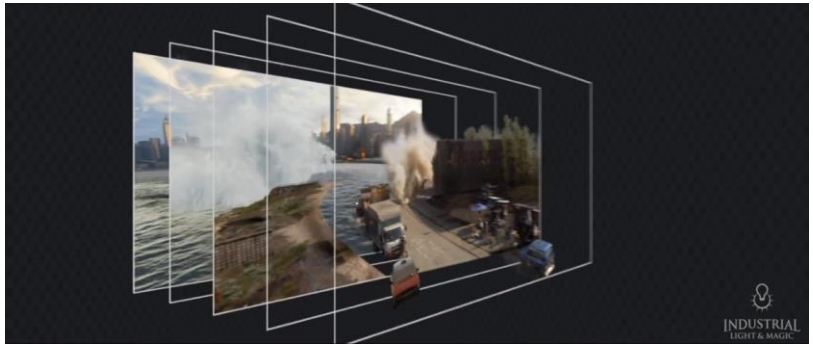
- Fluid simulation & illumination

Exciting movies

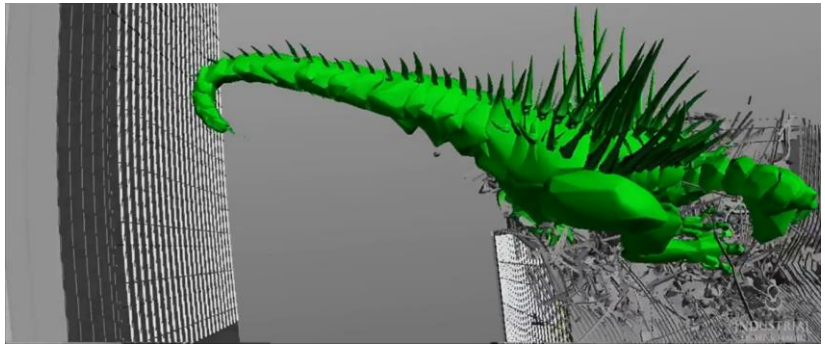
Exciting movies

Exciting movies

- Scene modeling



- Object modeling



What is CG used for?

- Movies
  - animation
  - special effects

What is CG used for?

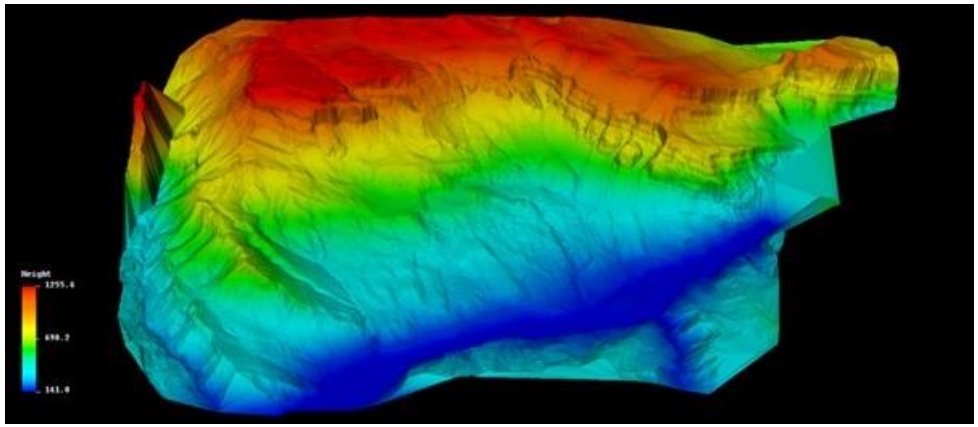
- Movies
  - performance capture

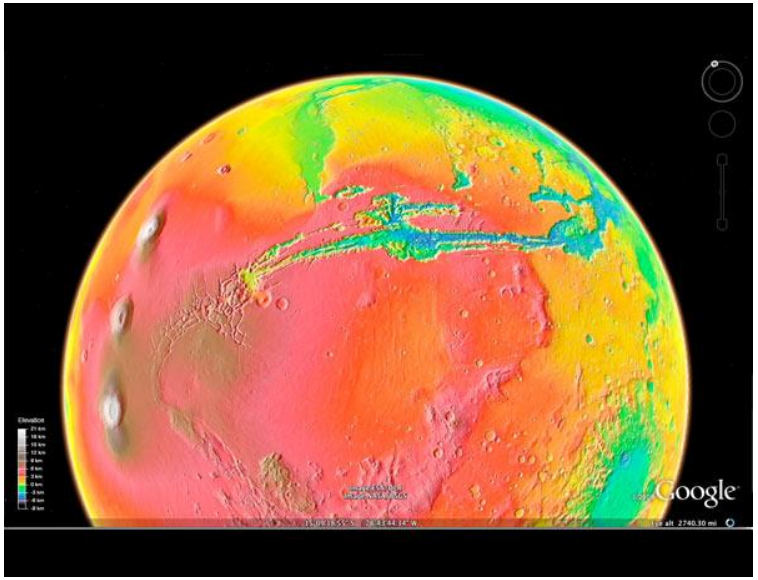
What is CG used for?

- Computer games

What is CG used for?

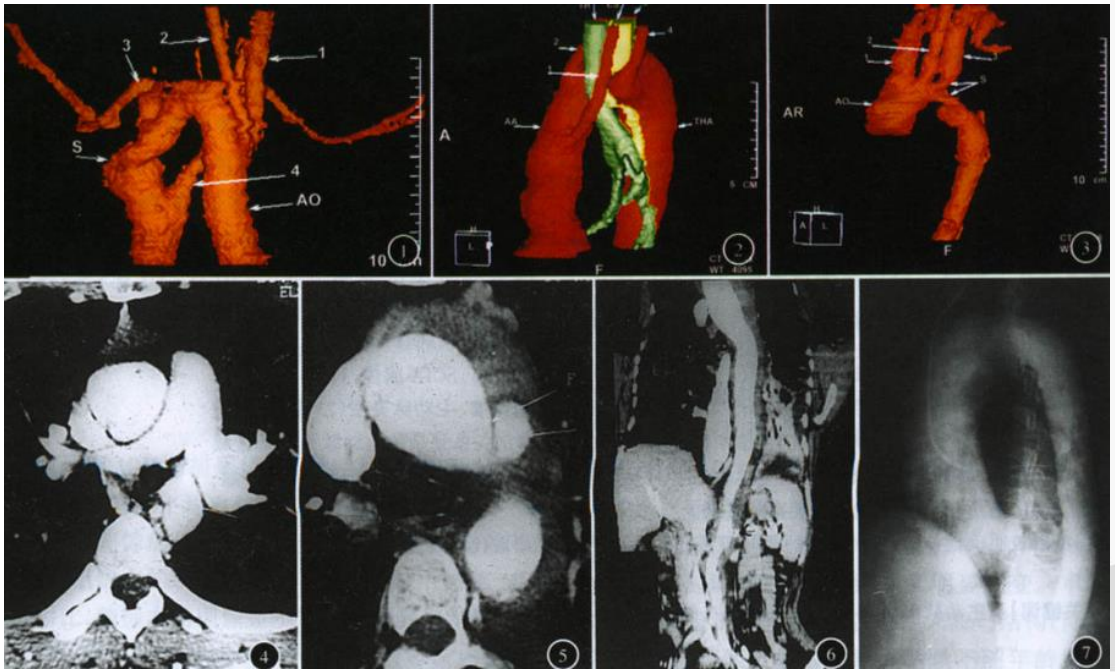
- Visualization
  - Geography
    - Geometric Registration Technique / Digital Earth & Digital City

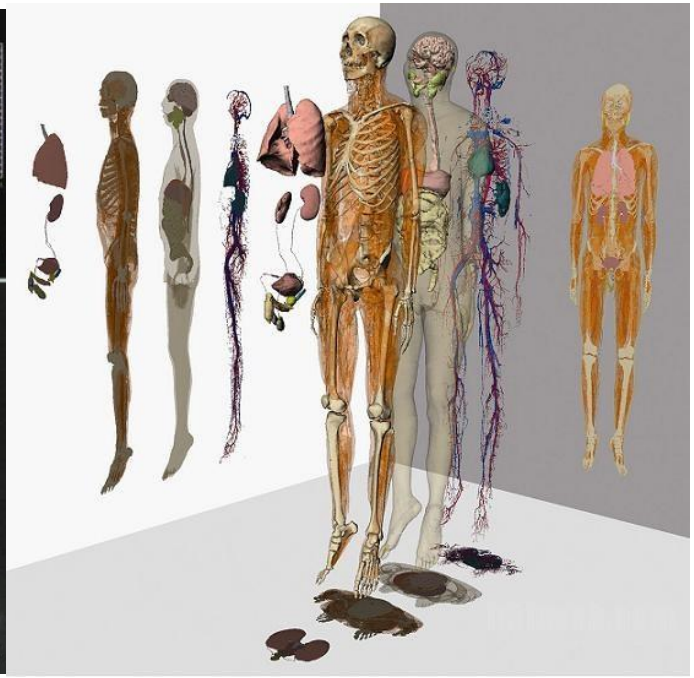




What is CG used for?

- Visualization
  - Medical Imaging





What is CG used for?

- Training & simulation

Army Research Lab—IES

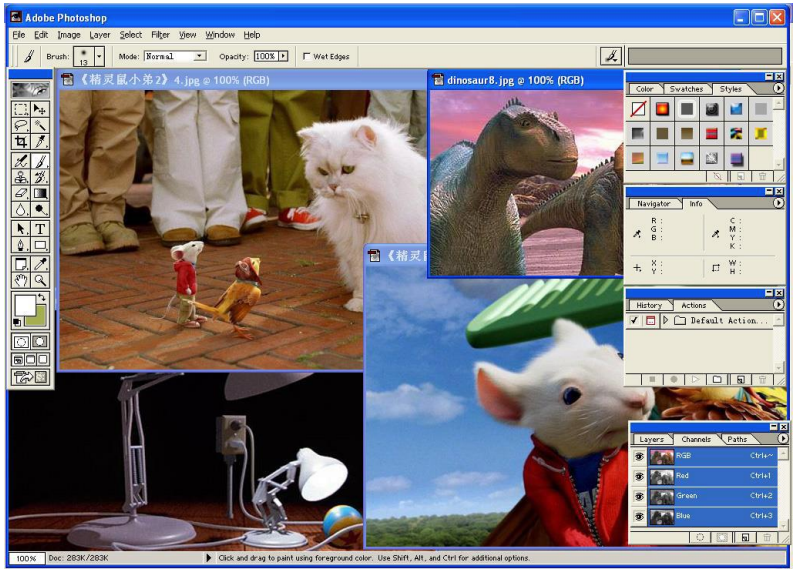
NASA/Ames—ACFS

What is CG used for?

- advertising
- design
- art

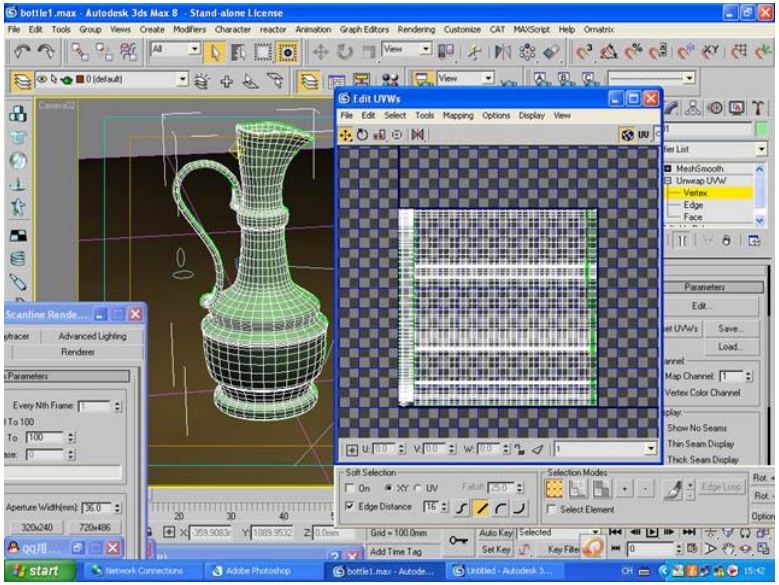
What is CG used for?

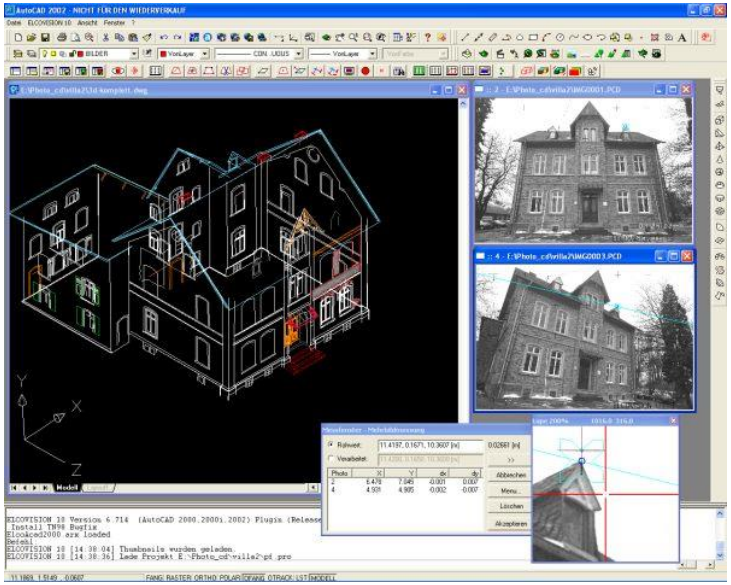
- UI Design

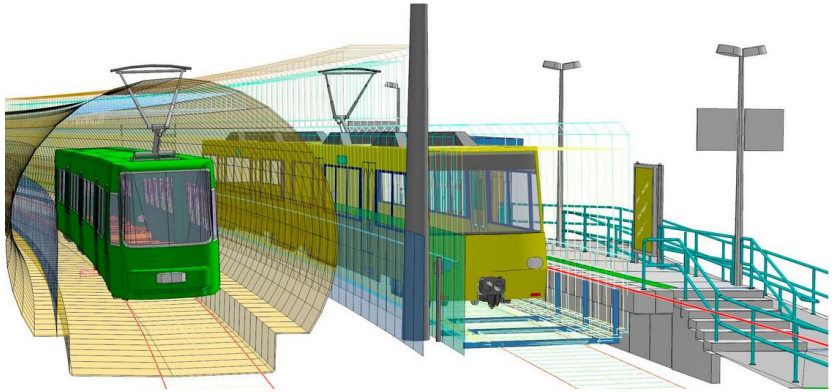


What is CG used for?

- CAD-CAM & Design







Great Ideas in Computer Graphics

- Computers(with suitable output devices) can draw geometric stuff, not just manipulate numbers.
- Computers can draw images of 3D worlds with realistic shapes and light and animate them as well.
- People can create 2D and 3D models.
- People can interact with them in 2D and 3D through innate visual and kinesthetic senses.
- Computers can make the virtual appear real(special effects).
- Computers can be fun(games).
- ……

What is Computer Graphics?

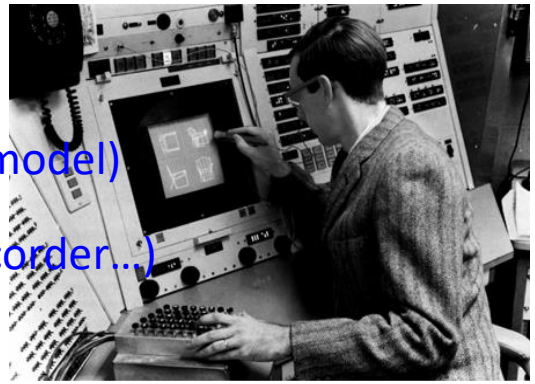
One of many different descriptions:

- The science and technology of imaging the world in pixels, such that it provides the real experience(looks real, sounds real, feels real)
- **Computer graphics** = synthesis of all visual content

  modeling + rendering + processing + animation

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…)

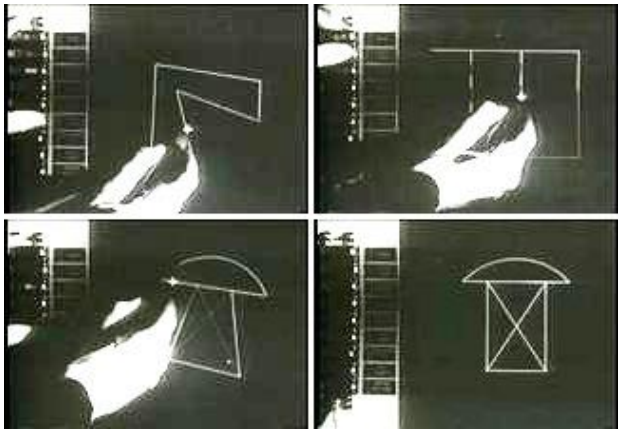


- First truly interactive graphics system, **Sketchpad**, pioneered by **Ivan Sutherland** 1963 Ph.D. thesis *Sketchpad, A Man-Machine Graphical Communication System*

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?

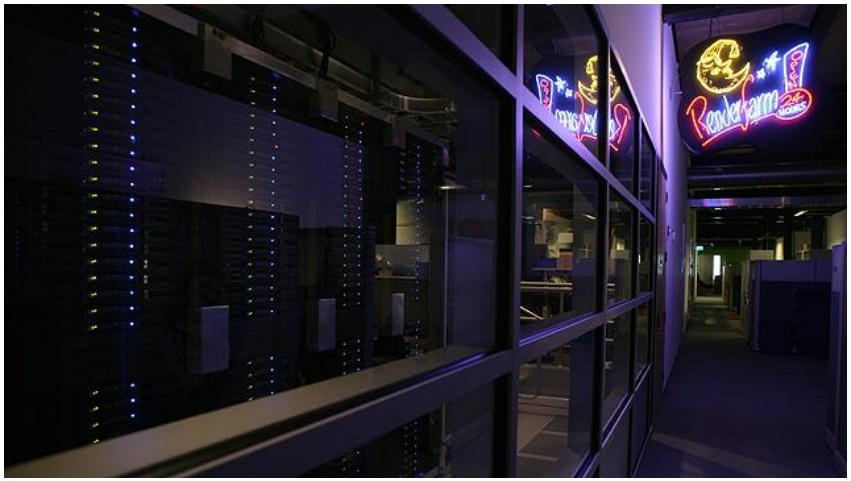
What is Interactive Computer Graphics?

- 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)”

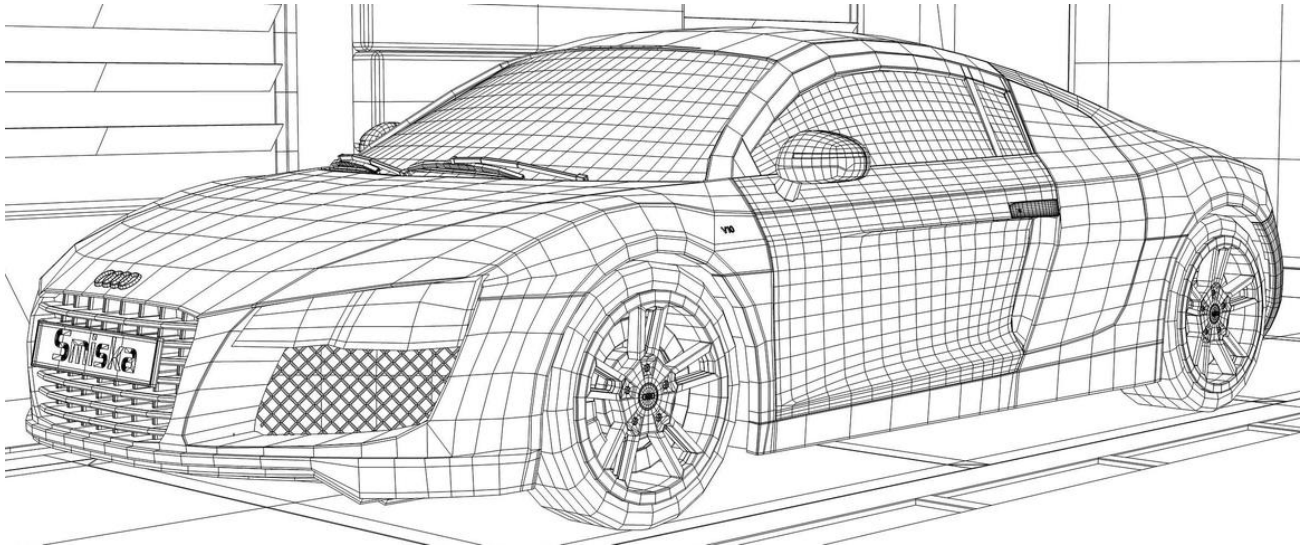
The Basic Content of Computer Graphics

- **Modeling** (shape & appearance): **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?

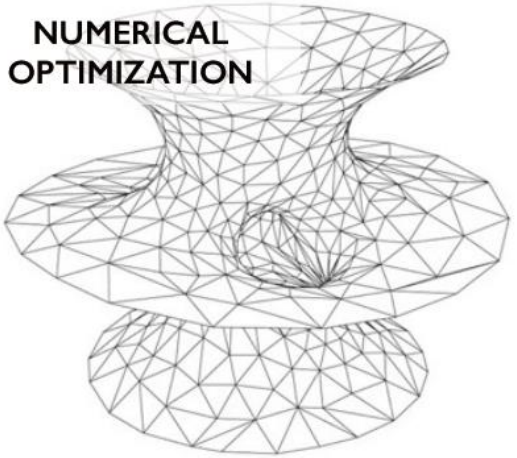
- shape — the geometry of the object
- appearance — emission, reflection, and transmission of light



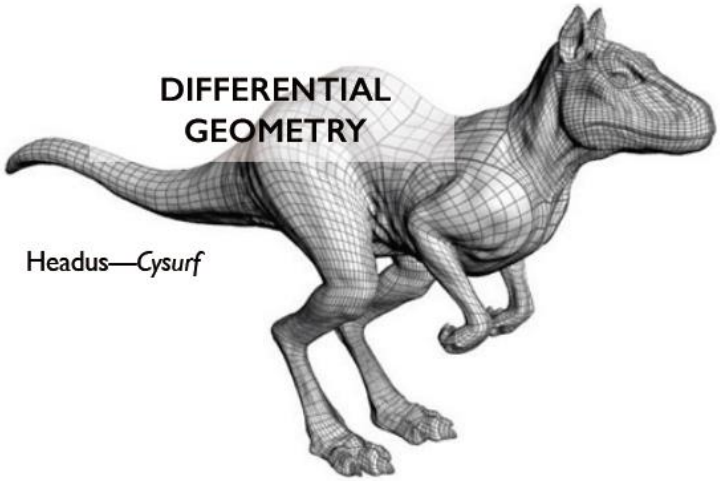
Modeling

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, …)

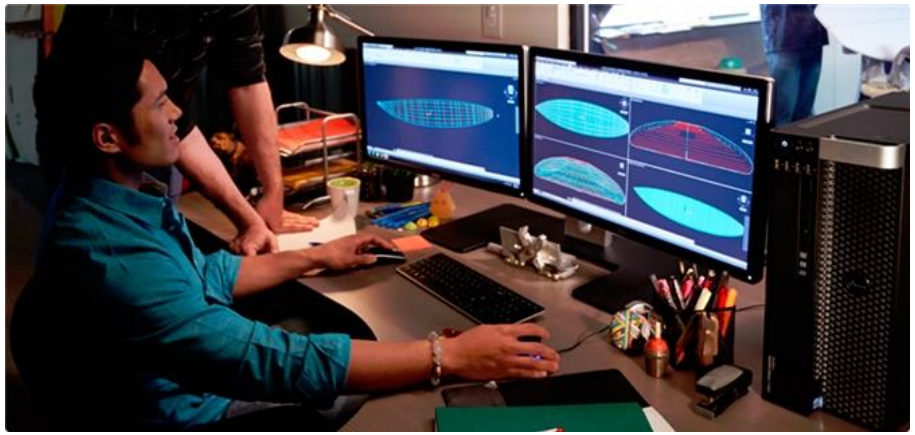


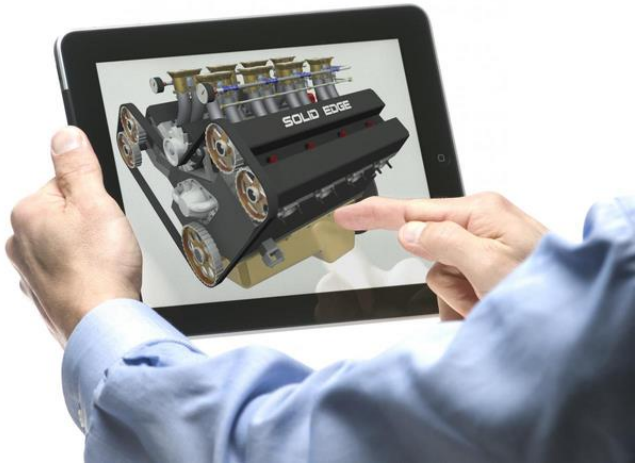
[Hoppe et al. 1993]



Modeling

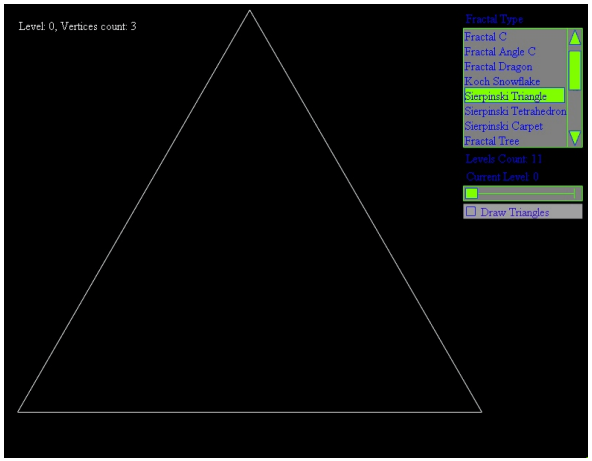
- Interactive manipulation

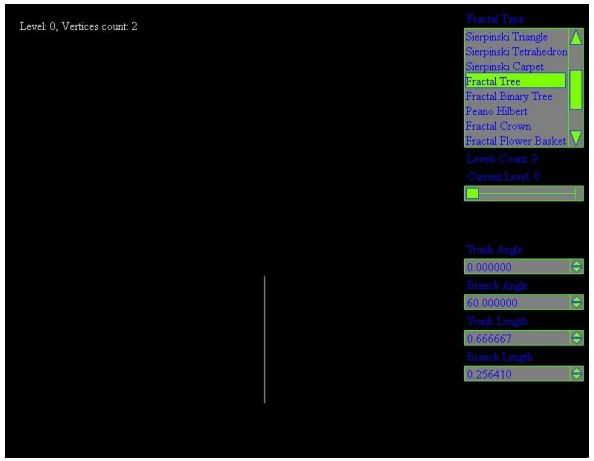


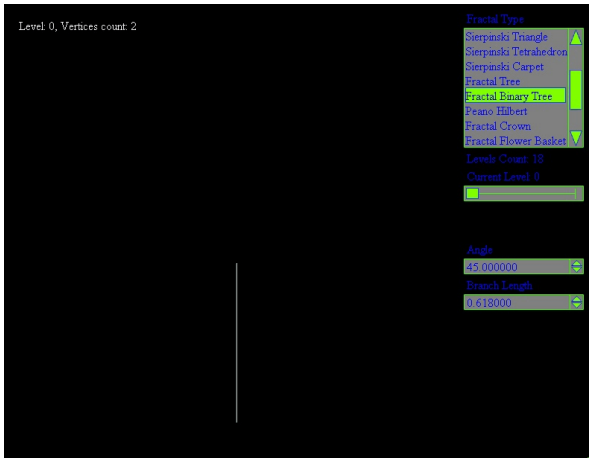


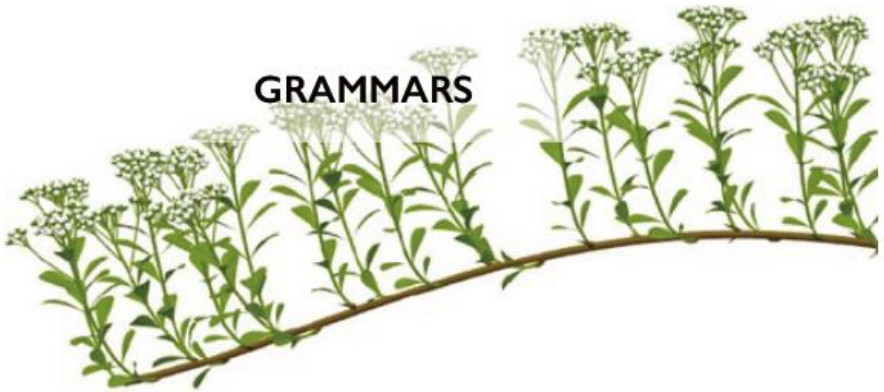
Modeling

- Procedurally generation





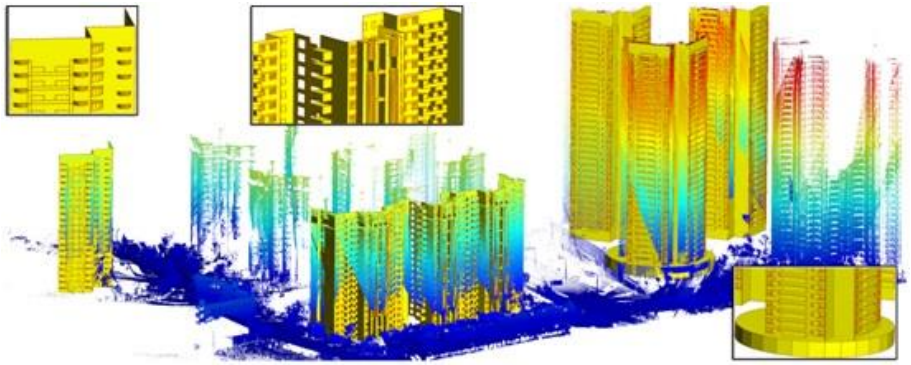




[Prusinkeiwicz et al. 2001]

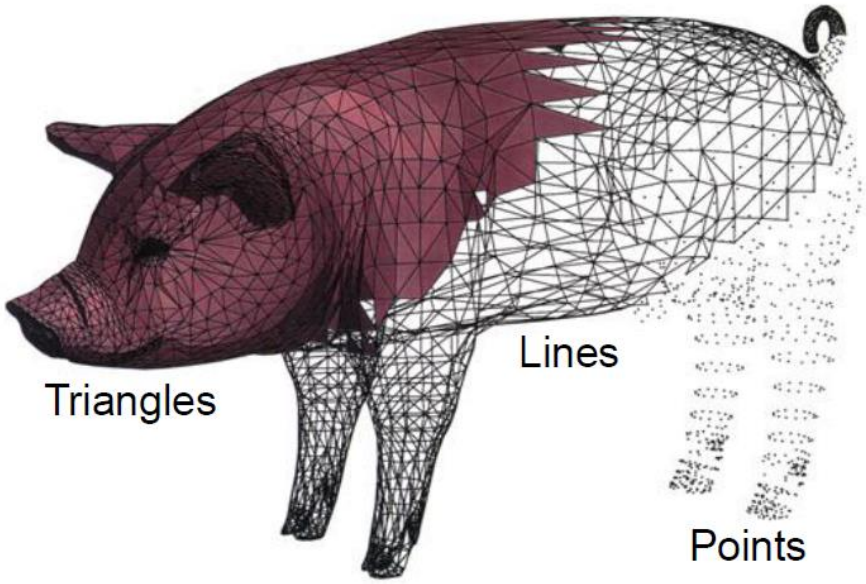
Modeling

- Scan a real object



Discrete Geometry: Points & Meshes

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



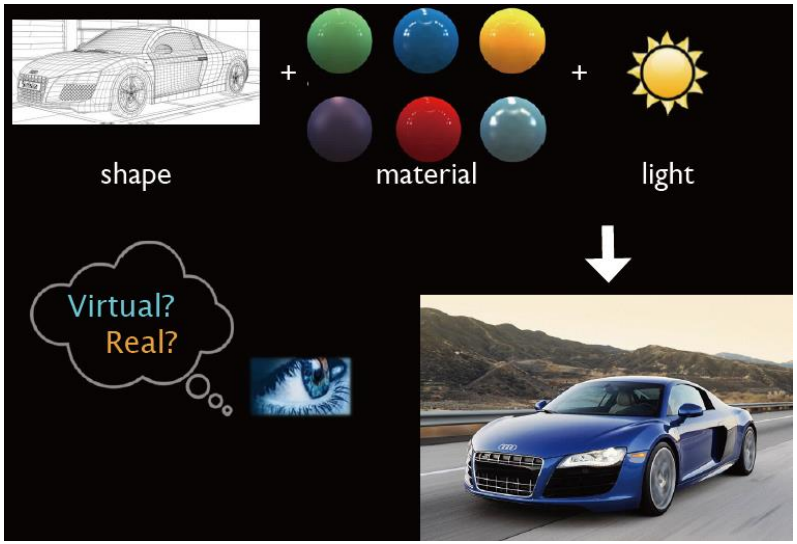
Rendering

- Generation of 2D images from a 3D Models.
  - Rendering converts a model into an image either by simulating light transport to get physically based photorealistic images, or by applying some kind of style as in non-photorealistic rendering

- I/O of Computer Graphics
  - Input : graphics : object (shape, material,...)
  - Output : image : array of pixels (RGB)

3D object → Image

Display or Rendering



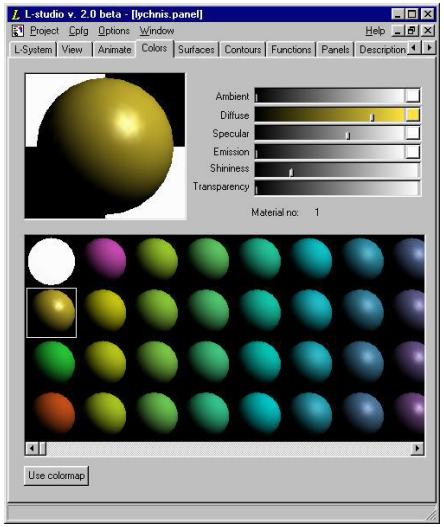
Rendering

- Different objectives
  - Photorealistic
  - Interactive
  - Artistic(non-photorealistic)

Lights

Dark

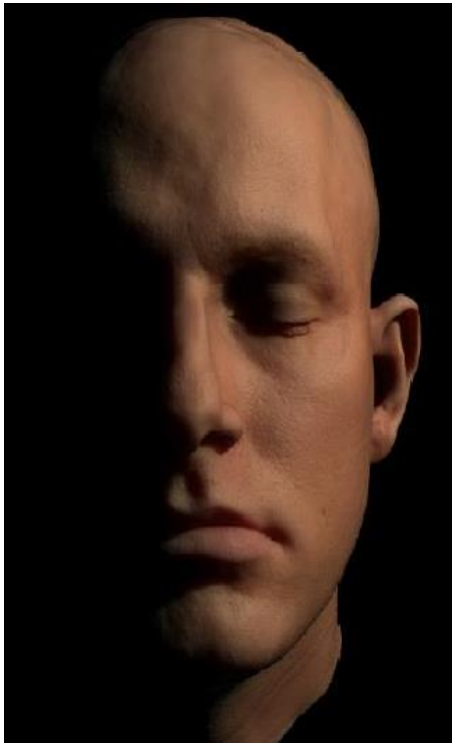
Materials



Bright

Photorealistic rendering

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



Photorealistic rendering

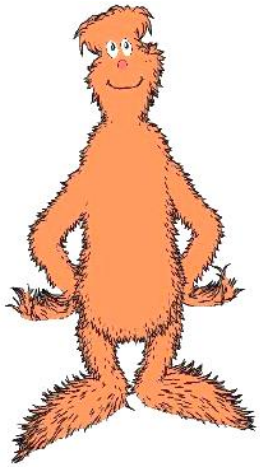
- GODZILLA - Visual Effects Breakdown

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(non-photorealistic rendering)

- Stylized
- Artwork, illustrations



1 Highlight effect in cel animation: Various highlights suggest different artistic meanings of objects in the scene.

Artistic rendering

Animation

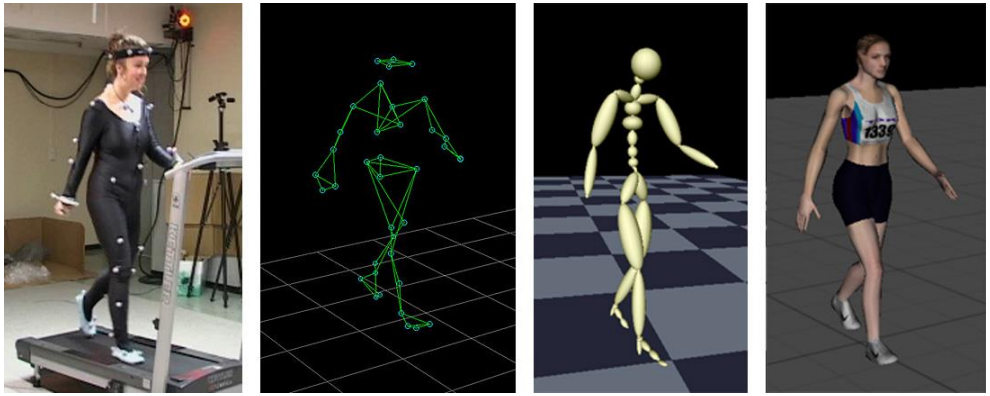
- Making geometric models move and deform

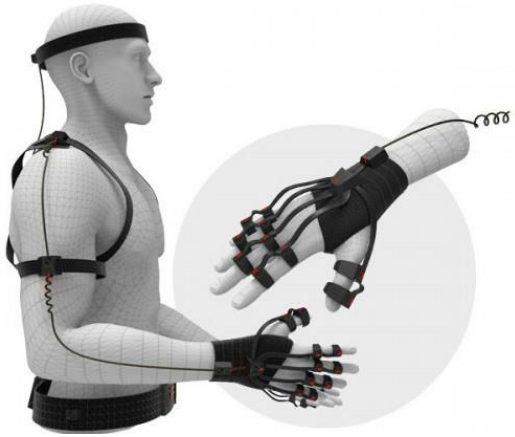
How do we represent the motion of objects?

- positions, angles, etc. as functions of time

How do we control/specify this motion?

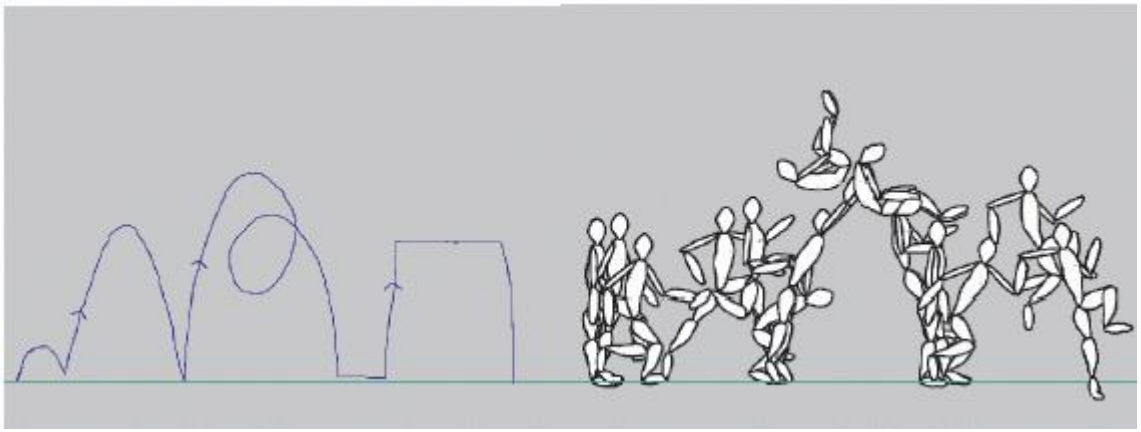
- generate poses by hand, fill in with keyframing
- behavioral simulation (program little “brains” for objects)
- physical simulation
- motion capture

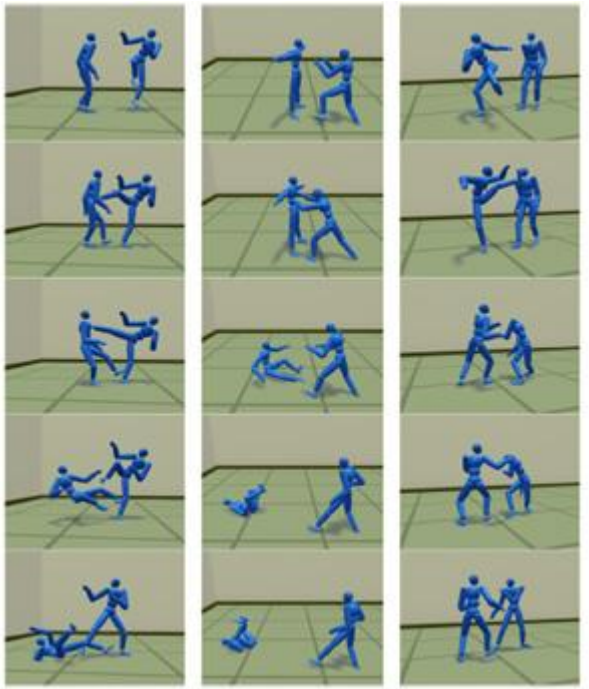




Animation

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

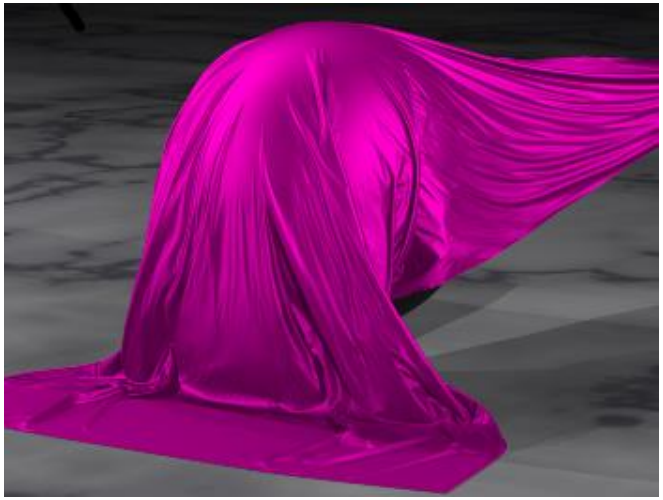


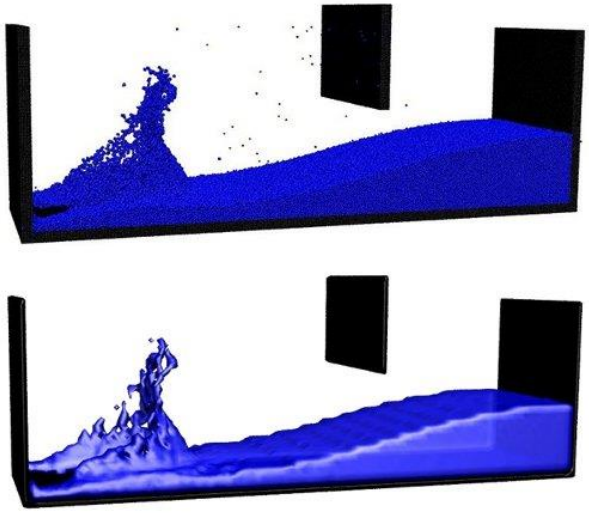


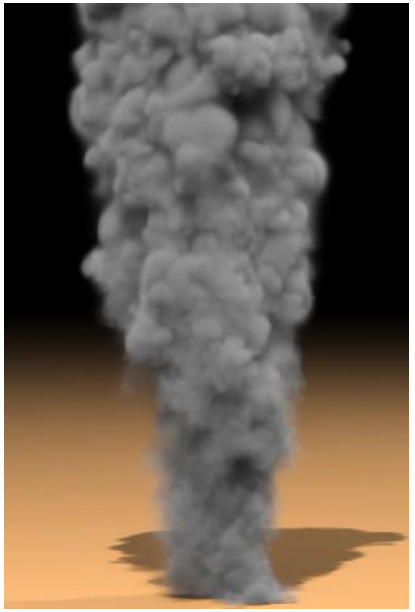
Animation

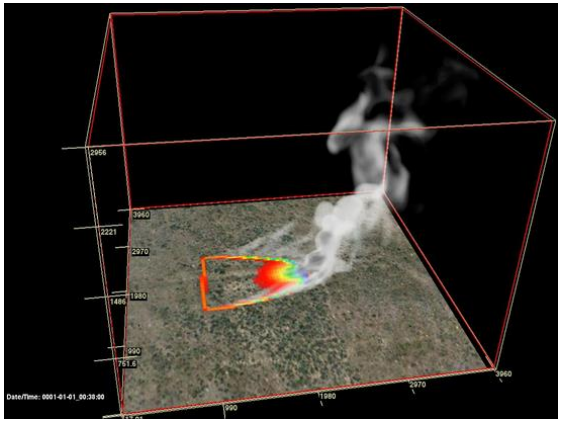
- Deforming or editing the geometry
- Change over time
- Faces, articulate characters, ……

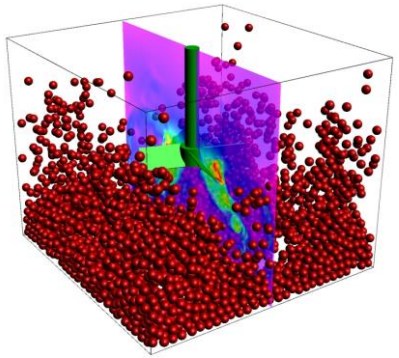
Physics simulation

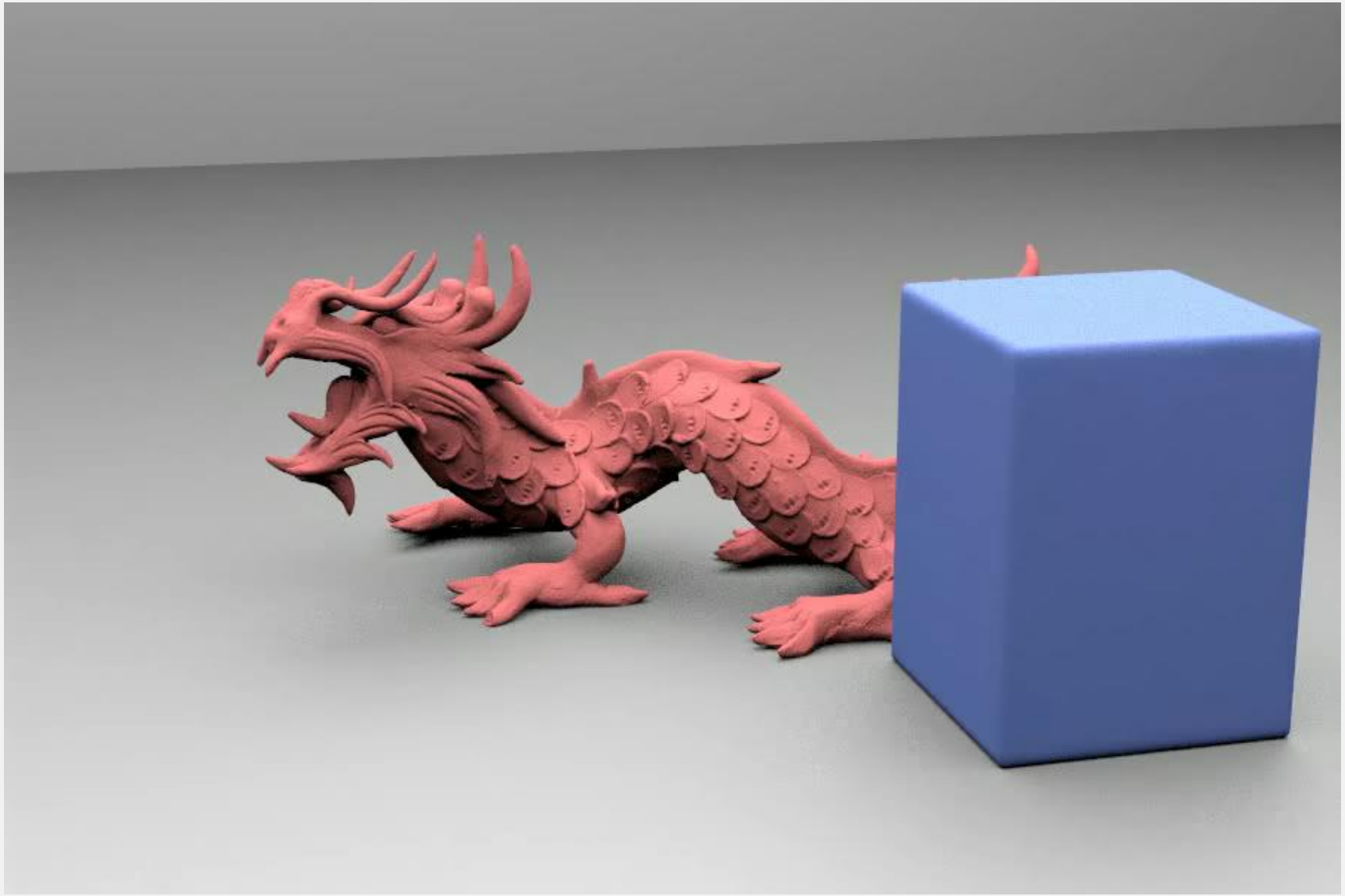






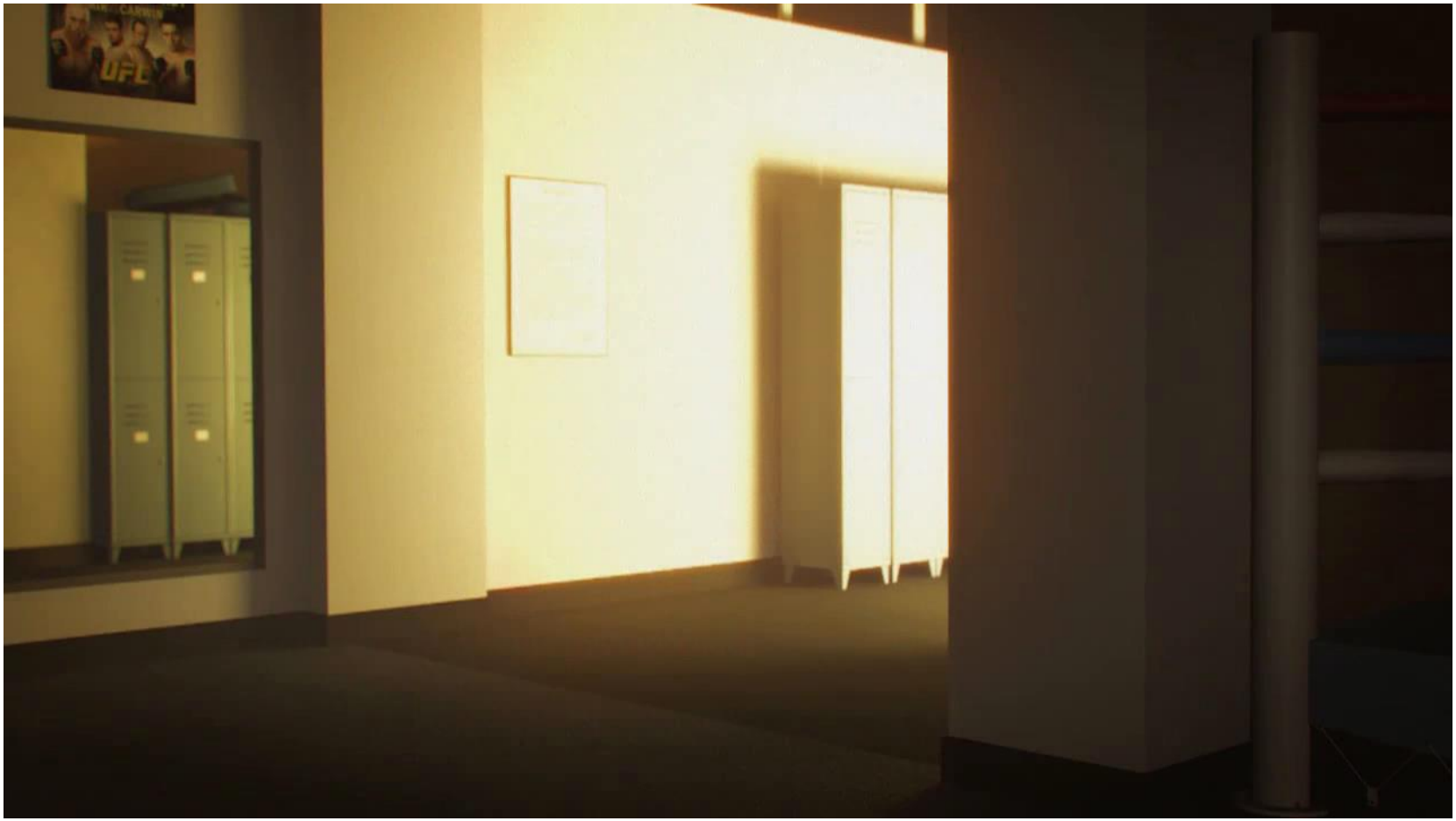




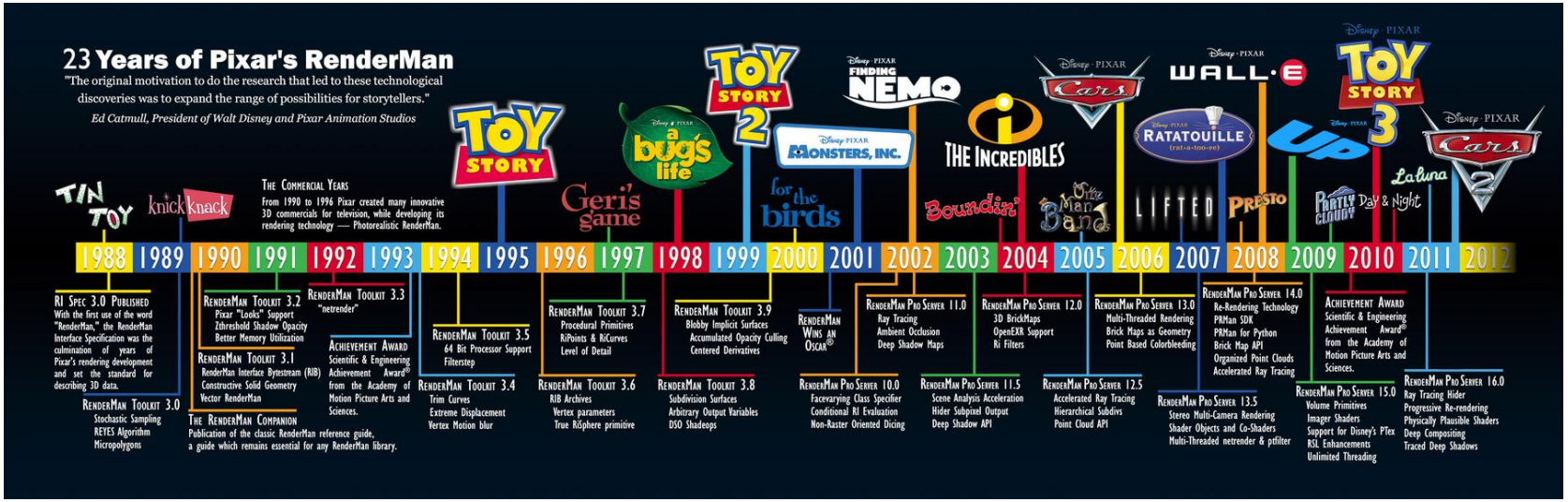


Animation

- A Warrior's Dream – from SIGGRAPH Asia 2014



Pixar’s RenderMan



Pixar's RenderMan

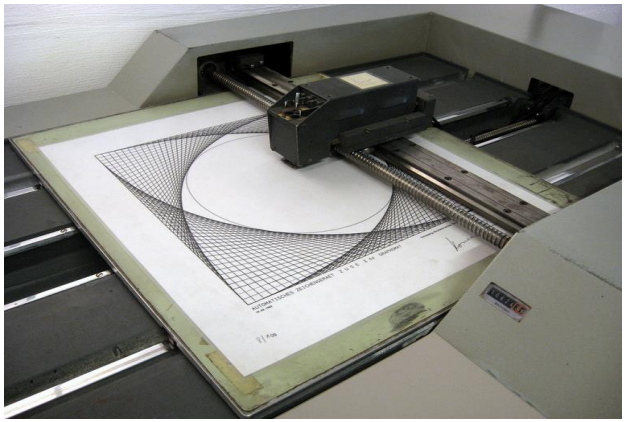
History of computer graphics

- 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

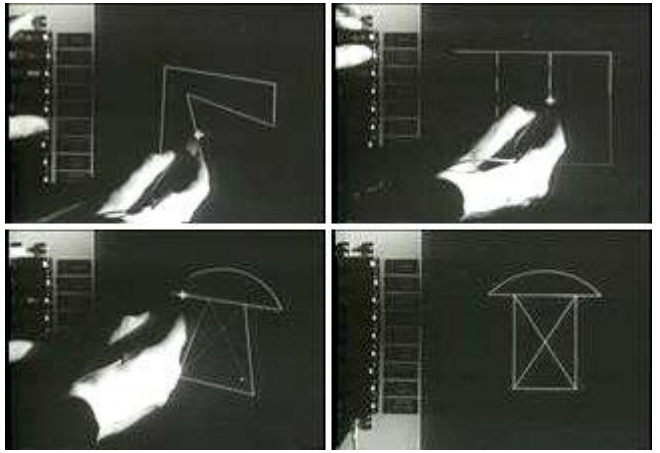
- The 1950's
  - In 1958, CalComp developed 565 drum plotter (滚筒绘图仪)

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



History of computer graphics

- The 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.

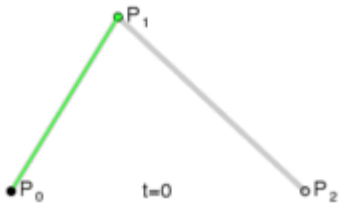


History of computer graphics

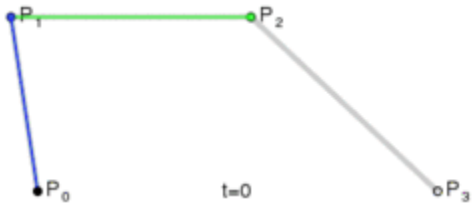
- The 1960's
  - Spacewar (太空大战) is one of the earliest digital computer video games. It is a two-player game, with each player taking control of a starship and attempting to destroy the other.
  - Steve Russell, MIT for PDP-1

History of computer graphics

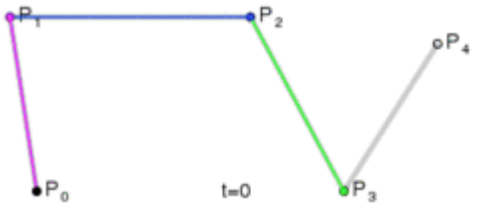
- The 1960's(CAD)
  - Professor Coons, the concept of "CAD" (Computer Aided Design) in 1958, Coons surface in 1964
  - In the late 1960's, a French engineer Pierre Bezier creates Bezier curves and Bezier surfaces that are now used in most CAD and computer graphics systems
  - UNISUR system for Car design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



Quadratic



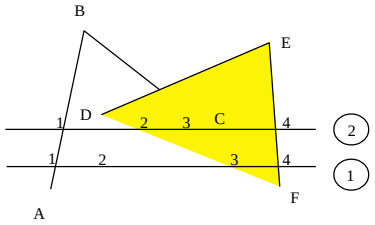
Cubic



Quartic

Bezier Curve

History of computer graphics

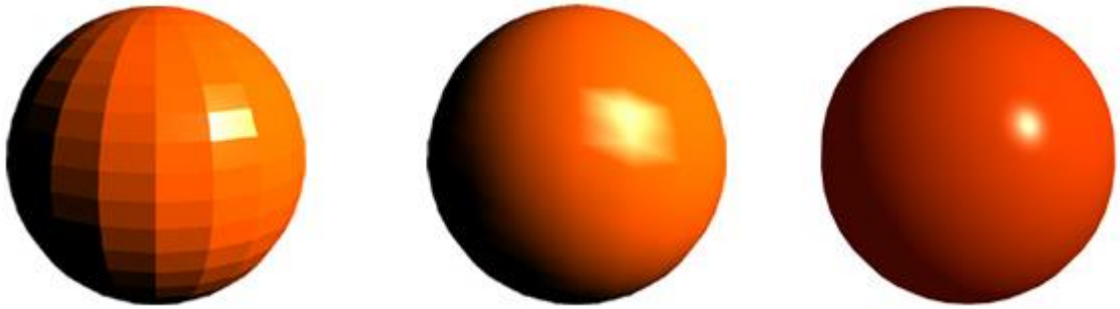


- The 1970's
- Fast development of Rasterizing Graphics
  - The concept of scan conversion(扫描转化), clipping (裁减) and surface hidden removal (消隐) and the corresponding algorithms.
- Standardization
  - In 1974, ACM SIGGRAPH formed the Graphics Standard Committee.
    - Core Graphics System (核心图形系统).
  - 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).

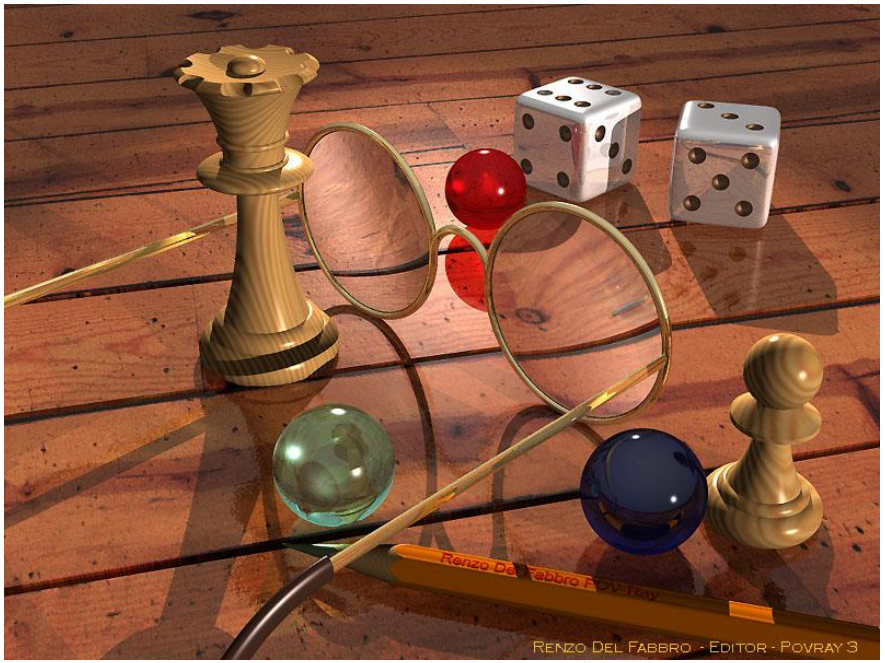


Flat shading Gourand shading Phong shading

History of computer graphics

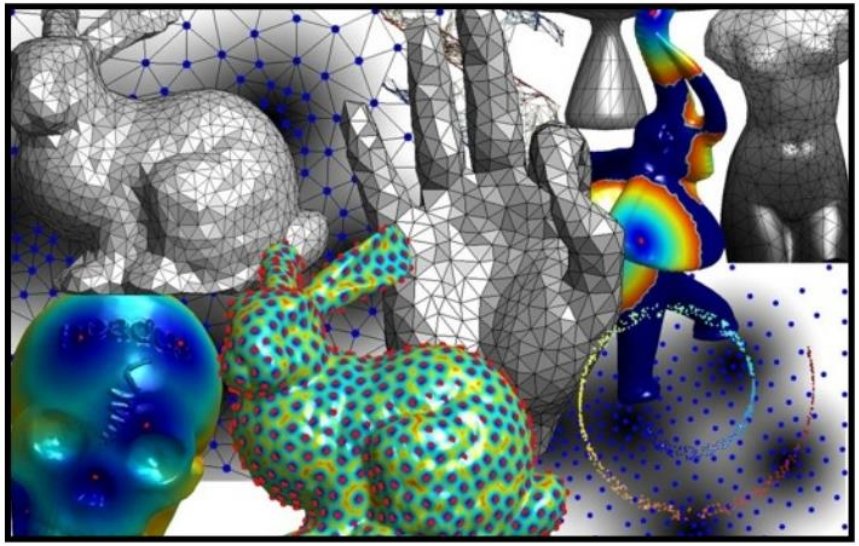
- The 1980's (Ray tracing 光线跟踪 and Radiosity 辐射度方法)
  - In 1980, Whitted proposed a ray tracing model, include light reflection (反射) and transmission (透射) effects.
  - A Milestone of CG.
  - Graphics Hardware

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



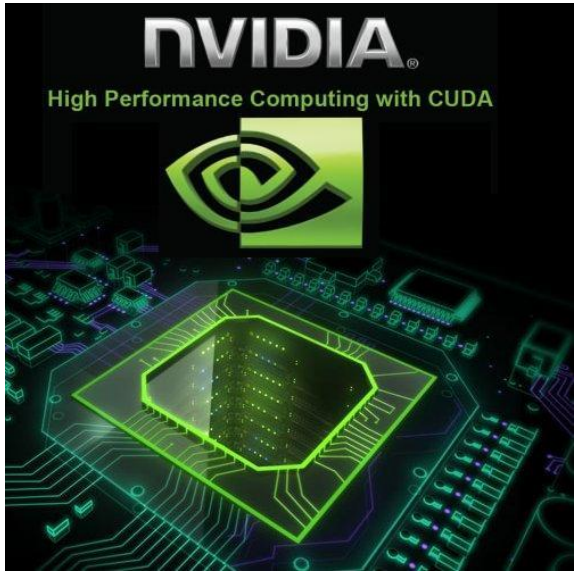
History of computer graphics

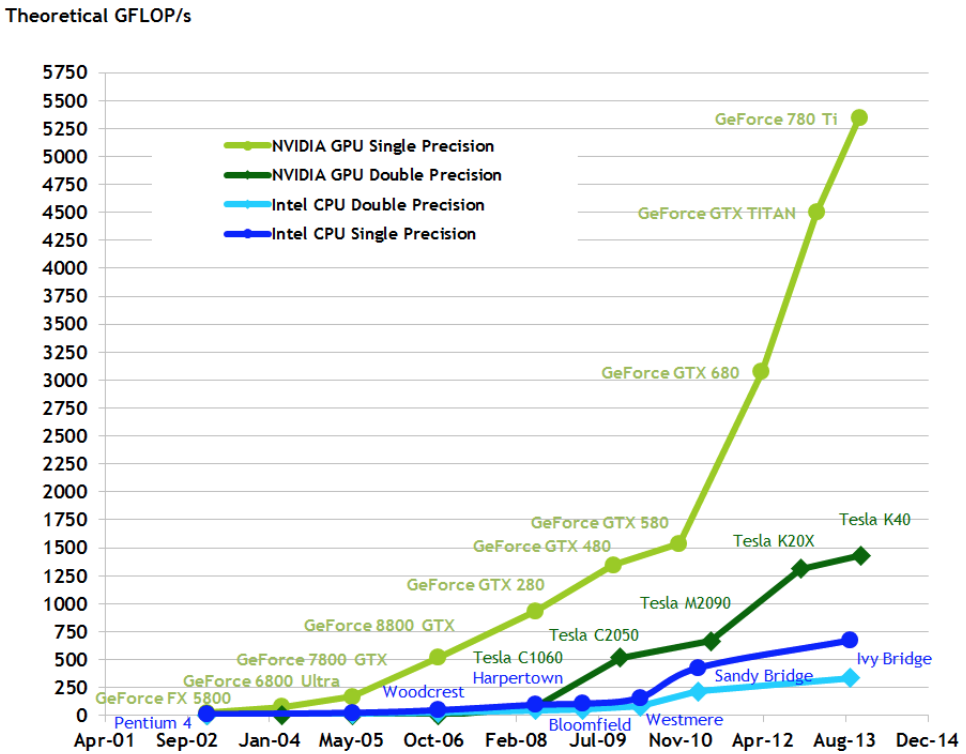
- The 1990's…
- Geometric Modeling:
  - Meshes,
  - Subdivision,
  - Implicit Surface,
  - Procedural,
  - Multi-resolution
- Rendering:
  - Volume Rendering,
  - Image-Based rendering,
  - Point-Based Rendering
- …



History of computer graphics

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



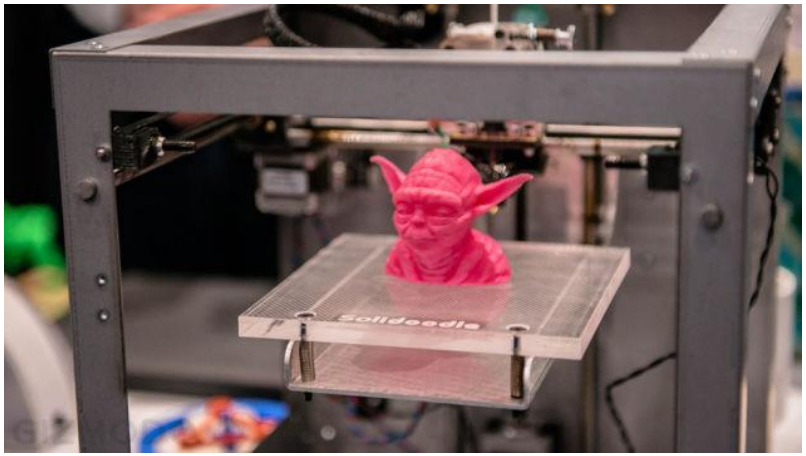


New trends

- Microsoft Kinects

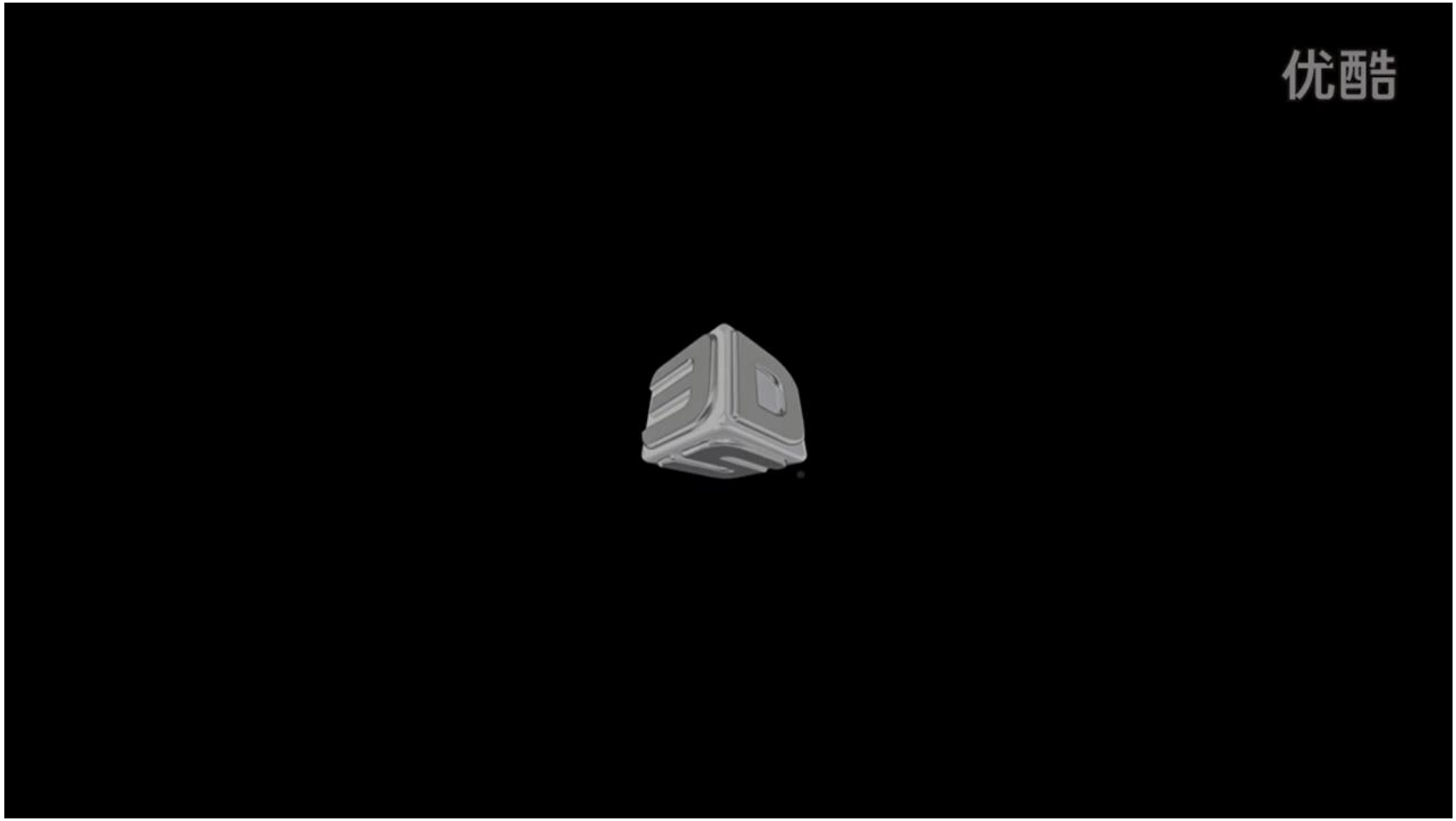
New trends

- 3D Printing



New trends

- 3D Printing



New trends

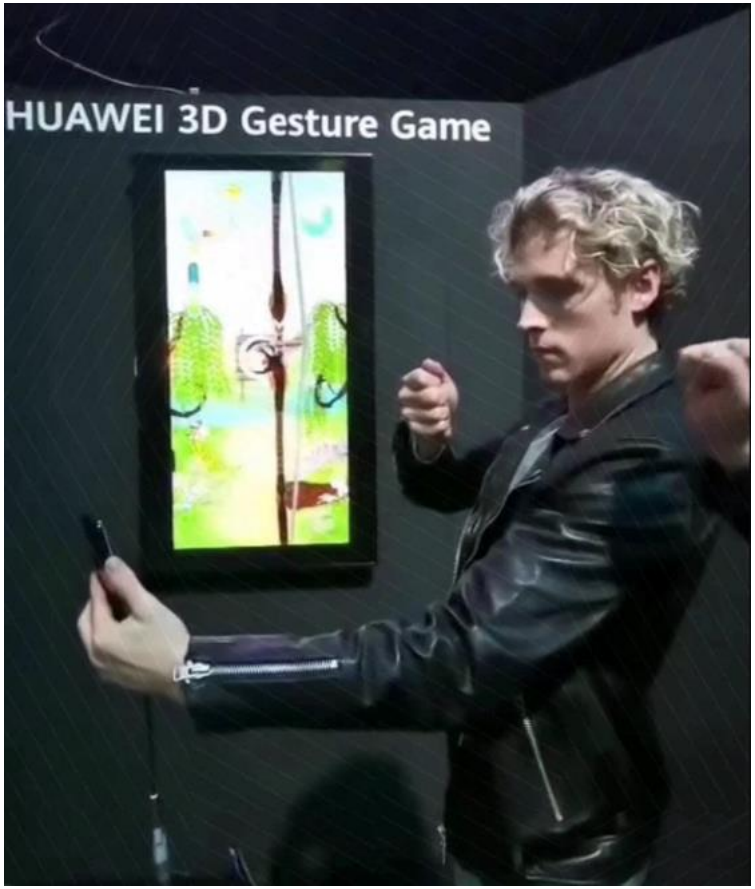
- Leap Motion

New trends

- Virtual Reality - Cyberith Virtualizer

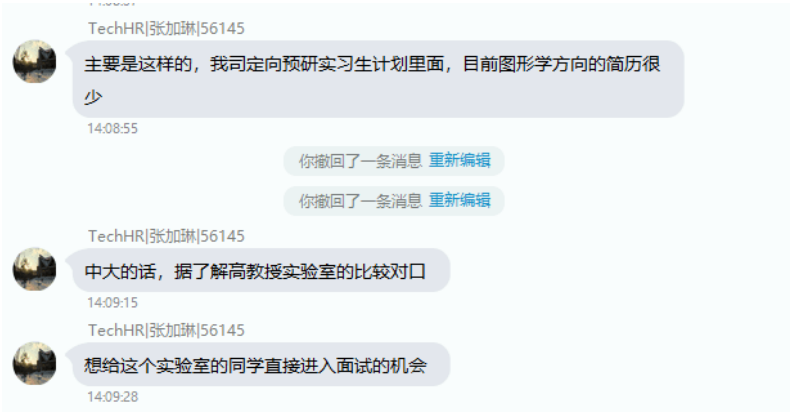
Deep Sensing Camera

- [华为Mate 20 Pro]



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

网易游戏 游戏热爱者 腾讯游戏 Tencent Games 盛大游戏 Microsoft game studios AUTODESK. 金山 KINGSOFT 西山居 游戏工作室

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

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

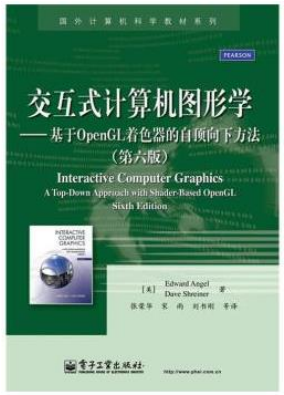
- **Good programming is very essential**
  - Good working knowledge of C++ is assumed.
  - The programming load is high.
- **Math**
  - Elementary geometry and linear algebra
  - Differential equation
  - The numerical method and calculated
  - Statistics

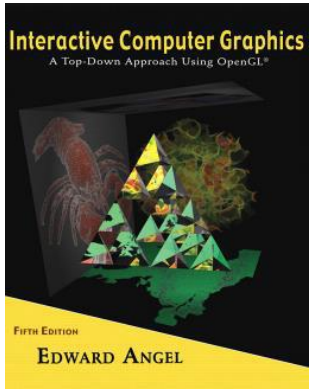
How much Math?

- 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
  - ……

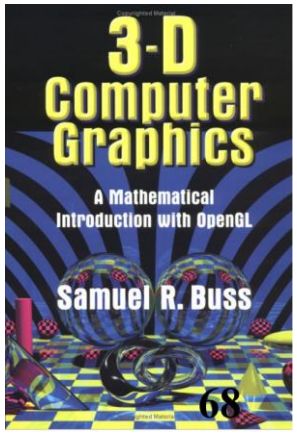
Optional Textbook

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

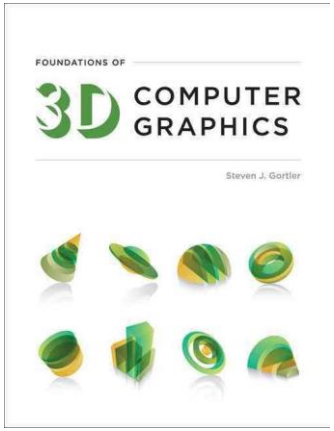


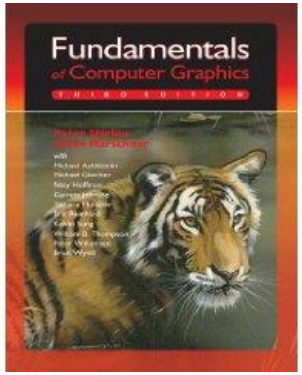


- 3D Computer Graphics: A Mathematical Introduction with OpenGL



Textbooks: Recommended Resources





- Foundations of 3D Computer Graphics
  - Steven Gortler, MIT Press
  - free online through UBC http://resolve.library.ubc.ca/cgi-bin/catsearch?bid=7005713
- Fundamentals of Computer Graphics
  - Peter Shirley, AK Peters
  - free online through UBC (2nd ed)http://resolve.library.ubc.ca/cgi-bin/catsearch?bid=7755681
- readings will be posted on schedule page
  - encouraged but not mandatory
  - pick whichever book suits your style

Course Assessment

- Project Assignments
  - Classroom participation (10%)： occasional tests(随堂测试)
  - Personal Project(70%): About 8 assignments.
  - Group Project(20%): Four people in a group. Find your teammates as soon as possible.

Course Mailbox

- Lecture Slides & Answer Questions
  - **QQ：475941616**
- Homework submission
  - **ftp://ras.sysu.edu.cn:6500/**

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
  - SIGGRAPH ASIA（2008）

Why Computer Graphics is hard?

- Graphics = synthesis
  - Graphics is about synthesis
  - Computer graphics = computer-assisted synthesis

- A forward problem(正问题):
  - Explicit model description  rendered image

Slide from Haozhang' lecture

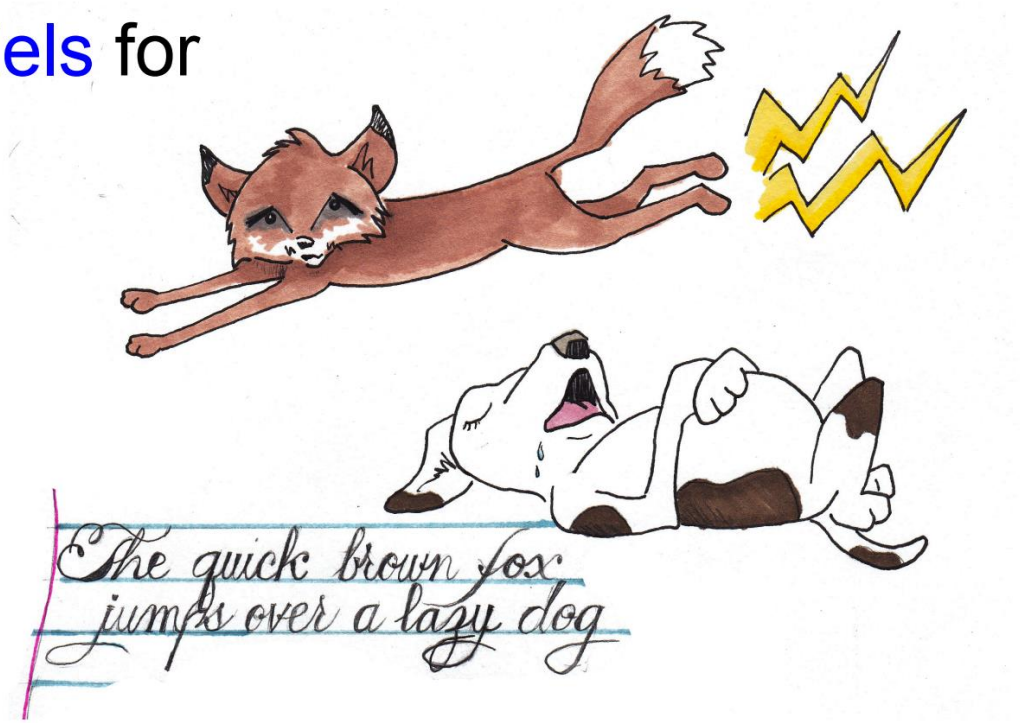
The “forward” problem

- “The quick brown fox jumps over a lazy dog.”
- Need explicit models for
  - A brown fox
  - A dog
  - Quick jump
  - Sleeping dog …

Slide from Haozhang’ lecture

The “forward” problem(正问题)

- “The quick brown fox jumps over a lazy dog.”
- Need explicit models for
  - A brown fox
  - A dog
  - Quick jump
  - Sleeping dog …



Slide from Haozhang’ lecture

What about Computer Vision?

- Lower level:
  - A factorization: given one view of a scene, determine he illumination and/or the scene's content (which a graphics system could produce the scene)
- High level: infer an understanding of what are:

An inverse problem:

From a rendered image to a model description

Slide from Haozhang' lecture

The inverse problem

- What are in the image and what is happening:

Slide from Haozhang' lecture

The inverse problem

- What are in the image and what is happening:
  - There is a fox
  - There is a dog
  - Fox jumps over dog
  - Fox is quick
  - Dog is Lazy…

Slide from Haozhang' lecture

Graphics vs. vision

- Classical view of graphics leads to challenges on:
  - Computational efficiency of rendering
  - Photo or physical realism of the rendered images under simplified models(need do it fast)
- Factorization: the inverse problem
  - Ill-posed problem: needs assumptions or more images
  - More difficult both conceptually and computationally

So then …

How can computer graphics be hard?

Slide from Haozhang' lecture

Reminder: DATA challenge

- What would be the one big difference between “data in graphics” and “data in computer vision”?

2D image data for computer vision

vs.

3D shape data for computer graphics

Slide from Haozhang’ lecture

3D data can make things hard

- Acquisition of 3D models is hard
- 3D shapes do not assume a canonical form（三维形状对象没有规范的形式）
- Spatial reasoning in 3D is hard
- 3D modeling, optimization, manipulation as well
- Interaction in 3D is hard – an HCI challenge

Slide from Haozhang' lecture

3D challenge: acquisition

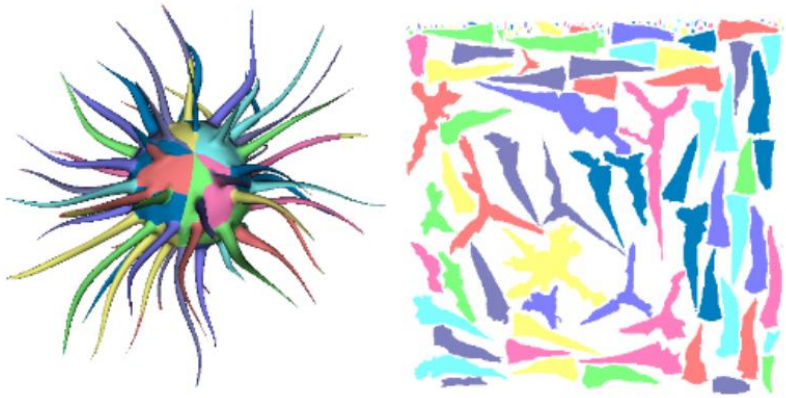
- Reconstruction or modeling from 3D scans
- Missing data + dynamic data + large scales

Scaling up from objects to scenes [Shao et al. *Siggraph Asia* 2012]

Slide from Haozhang' lecture

3D challenge: parameterization

- An arbitrary 3D shape is not a ready-made function
- Topologically complex and unorganized
  - Cannot apply classical math, e.g., FFT, like for images
  - But we know functions so well!
  - Need cutting into pieces and parameterizing: hard problem!

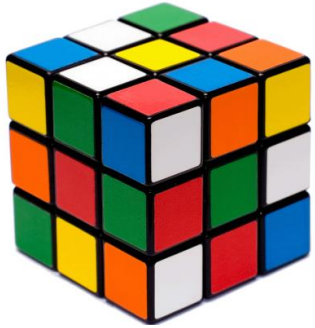


UVAtlas in Direct3D

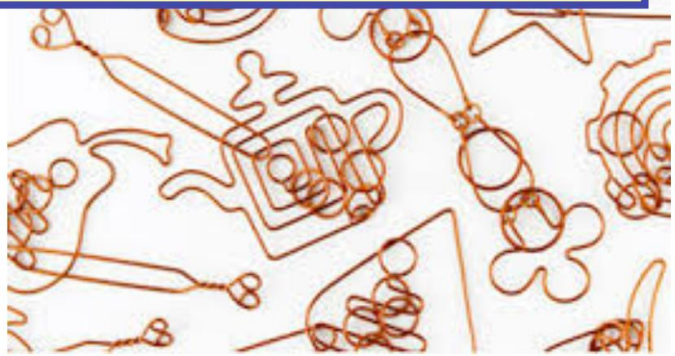
Slide from Haozhang' lecture

3D reasoning and manipulation are hard

- Humans very good at pattern recognition
- But not so good at 3D reasoning or manipulation



Length distortion, occlusion, memory load, etc.



Slide from Haozhang' lecture

The classical 3D challenge

- Images are much easier to acquire than 3D data
  - 3D shape or scene reconstruction quite challenging

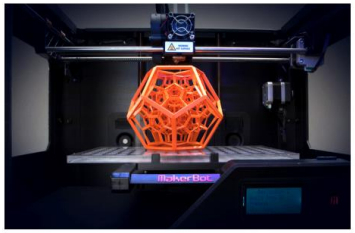
Computer graphics is hard by virtue of the fact that it inevitably has to work with 3D data.

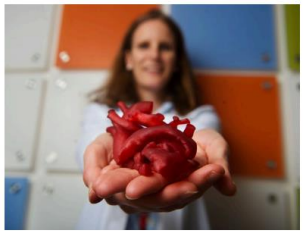
Many emerging 3D problems from design, manufacturing, and fabrication to be tapped into.

Slide from Haozhang' lecture

3D printing may be a blessing

- Graphics likes 3D to be wanted & used everywhere
- The internet has not made 3D data ubiquitous as promised: remember VRML around **26** years ago?
- 3D printing just might!



Slide from Haozhang' lecture

NOW change the classical view

- Keep doing synthesis, but focus on modeling
- Synthesis of all visual contents, not just images

Slide from Haozhang' lecture

New view: no explicit model

- Keep doing synthesis, but focus on modeling
- Synthesis of all visual contents, not just images

Model description is only abstract, hard to acquire, or unknown entirely

Slide from Haozhang' lecture

New view: novel content

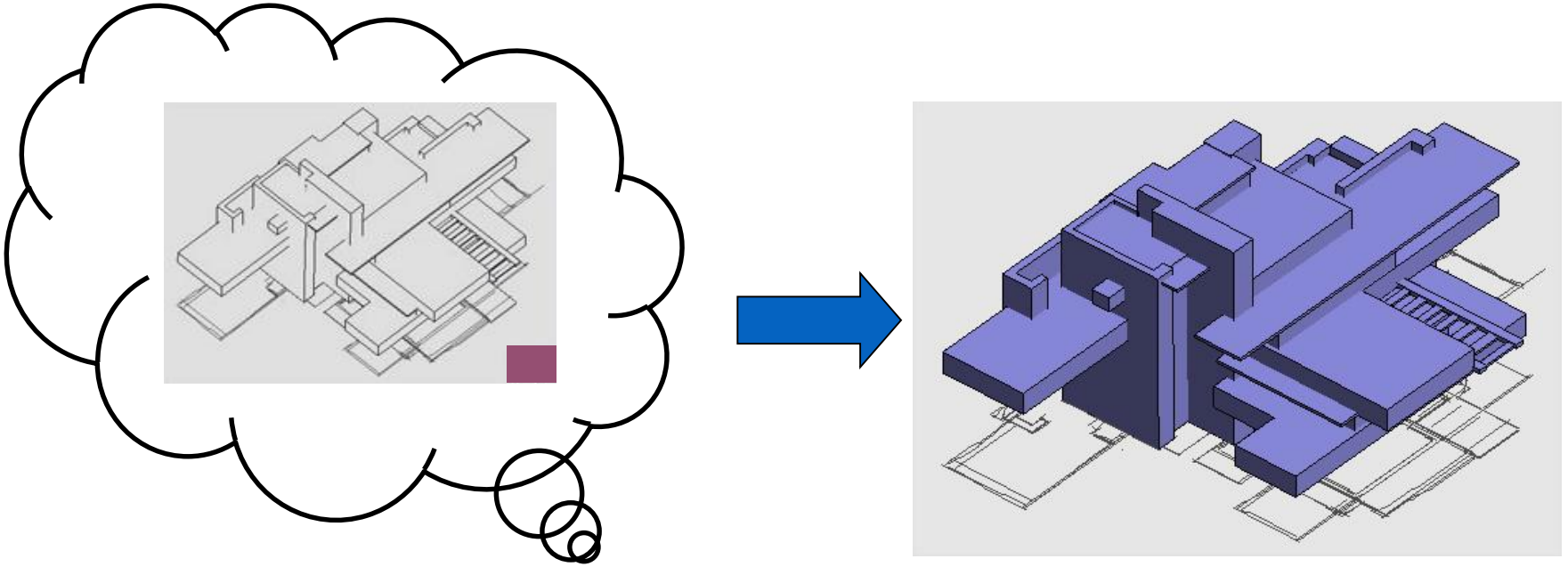
- Synthesis and manipulation of ~~images~~

novel + visual contents

abstract model, examples, etc. → novel content

Slide from Haozhang' lecture

Creation of 3D content is hard



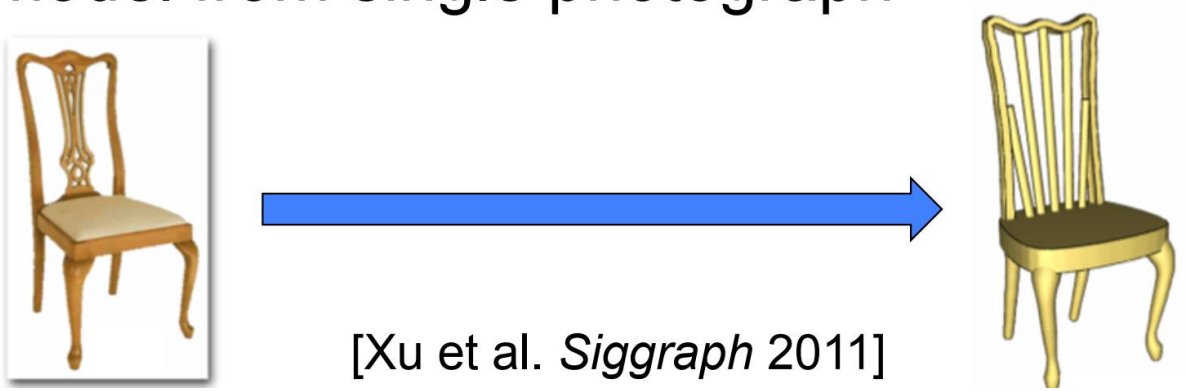
- From an inspiration, e.g., a sketch, to a 3D model or scene
- Quality content creation: job only for skilled artists

Example 1: from abstract model

- Sketch-to-scene

[Xu et al. *Siggraph* 2013]

- 3D model from single photograph



[Xu et al. *Siggraph* 2011]

Slide from Haozhang' lecture

Example 2: from examples

- Input: just a set of related examples
- Output: “more of the same” but really different!
- Need co-analysis: utilize a set = data-driven again
- Key: analysis = understanding a shape category
- To infer commonality and diversity in the set

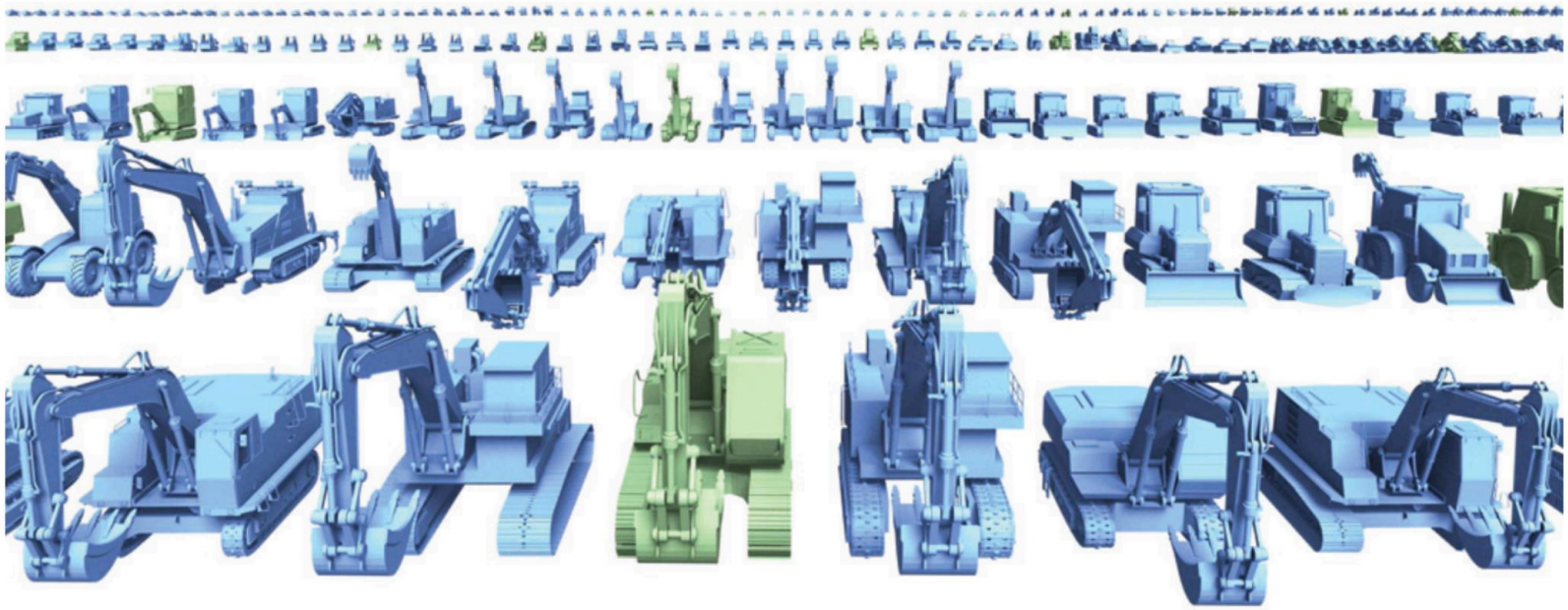
Slide from Haozhang’ lecture

Example 2: from examples

- Learn a probabilistic and generative model
- A new model is drawn from the prob. distribution
- Examples: a pre-segmented set of shapes
  - The shapes belong to the same object category

Slide from Haozhang' lecture

Example 2: from examples



Green models are from the training set; blue ones are synthesized results

[Kalogerakis et al. *SIGGRAPH* 2012]

Slide from Haozhang' lecture

Towards shape understanding

- Research in geometric modeling in computer graphics is keying on shape understanding
- Only when you understand a shape category (what is a “bicycle”?) can you recreate!

Data, Knowledge, learning

play the key roles!

Slide from Haozhang’ lecture

Our new view of graphics

- Wikipedia was already catching up:
  - Something I hid: Computer graphics = methods for digitally synthesizing and manipulating visual content
- From image production to all (3D) visual content

Novelty

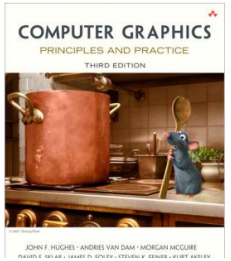
of the synthesized content is the BIG challenge!

Slide from Haozhang' lecture

Current graphics and computer vision

- Hughes, van Dam, et al.:
  - "Much of current research in graphics is in methods for creating geometric models, methods for representing surface reflectance, the animation of scenes …, and in recent years, an increasing integration of techniques from computer vision."

------ *page 2 of*



Slide from Haozhang' lecture

Not just “catching up”

- Shape understanding and inverse modeling are very much “vision-like” research problems
- So graphics is “catching up” ☺
- But could we do more?

Jim Kajiya (SIG’11): What human capacities do various CS disciplines attempt to supplement?

Slide from Haozhang’ lecture

How do CS assist/replace humans

- Numerics and algorithms: computation; inference
- DB and data mining: memory; knowledge discovery
- Artificial intelligence: human intelligence
- Computer vision: pattern detection and recognition

Human imagination!

Slide from Haozhang' lecture

Graphics and imagination

- Think of the various special effects we see in films
- Think of all the animated fantasy films
- Think of the virtual worlds CG has helped create

Computer graphics allows our imagination to be realized into (virtual) reality!

It allows a mental concept to turn into a digital representation, and now fabricated!

Slide from Haozhang' lecture

Still a long way to go

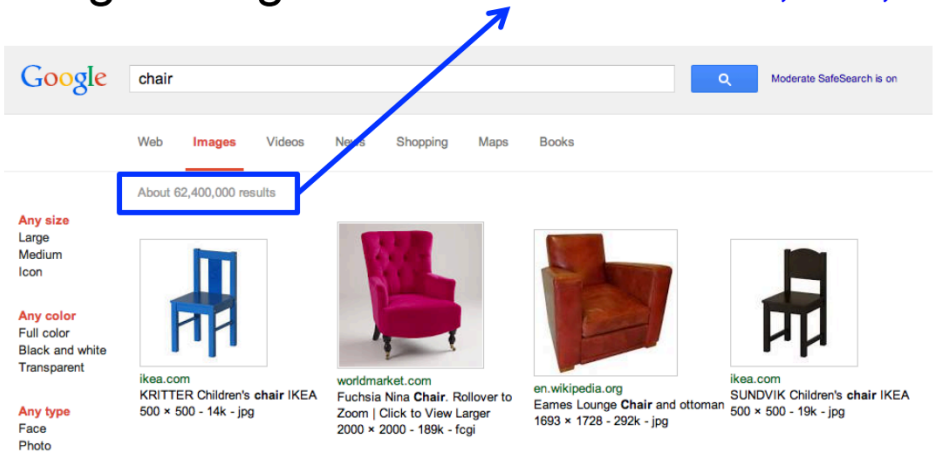
- Smart ideas: data-driven, data reuse, co-analysis, supervised learning, active learning, etc.
- Future of modeling in computer graphics

Data + knowledge + learning

Slide from Haozhang' lecture

A new 3D data challenge

Google image search for chair: 64,000,000 results

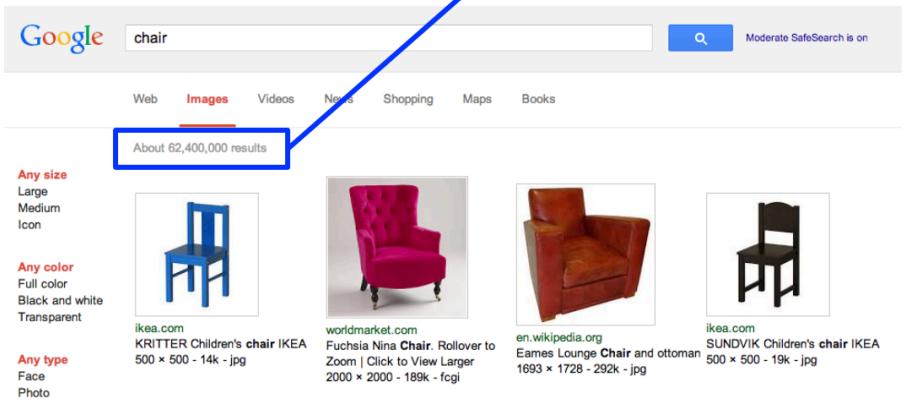


3D Warehouse: 24,951 results

Slide from Haozhang' lecture

No “Big 3D Data” yet

Google image search for chair: 64,000,000 results



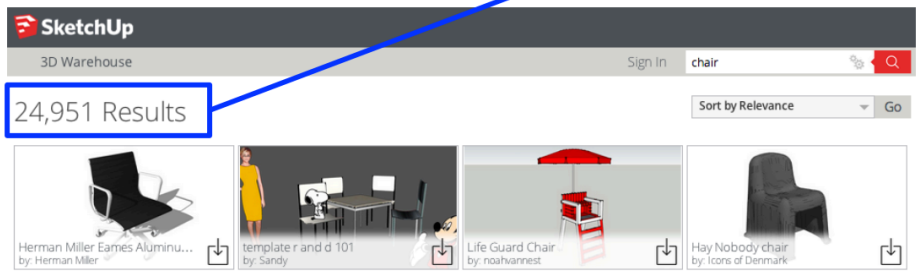
- Bicycles

29,900,000 vs. 1,225

- Strollers

5,070,000 vs. 36

3D Warehouse: 24,951 results



Slide from Haozhang’ lecture

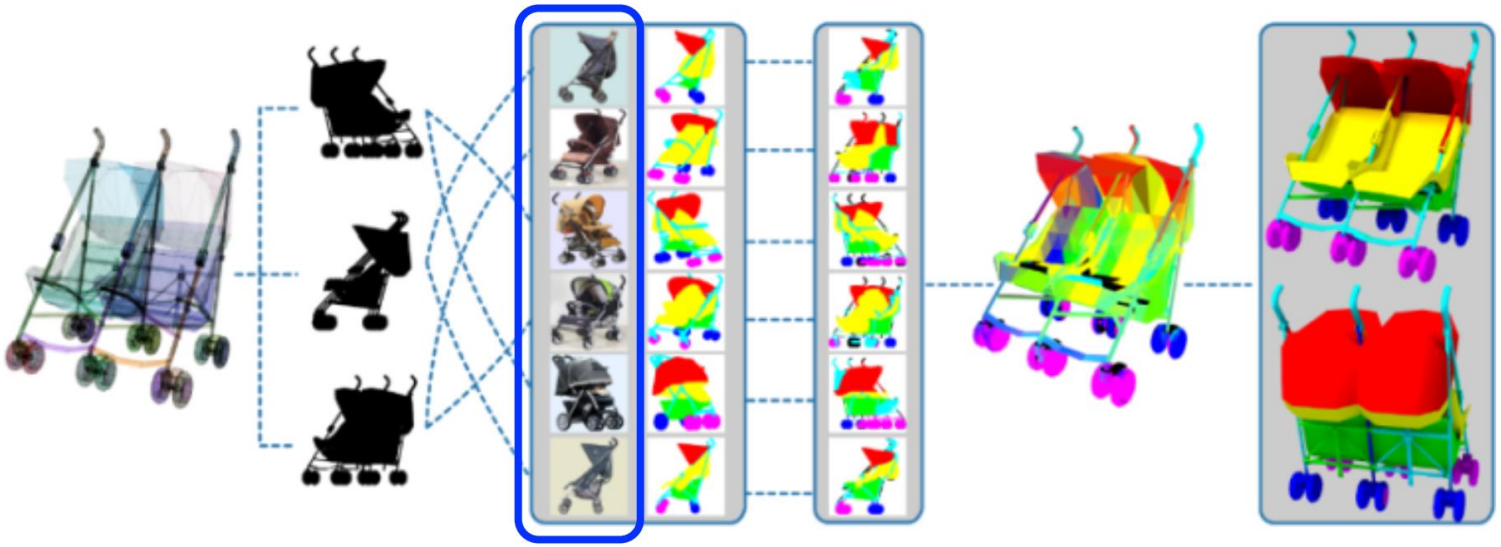
Problems with “small 3D data”?

- Lack of knowledge for learning-based 3D analyses
- Lack of examples for example-driven 3D syntheses
- One more reason why computer graphics is hard
- Small data is *the* detriment of

Data + knowledge + learning

Vast image data to help 3D analyses

- Projective shape analysis: train 3D segmentation by utilizing internet photos and their segmentations

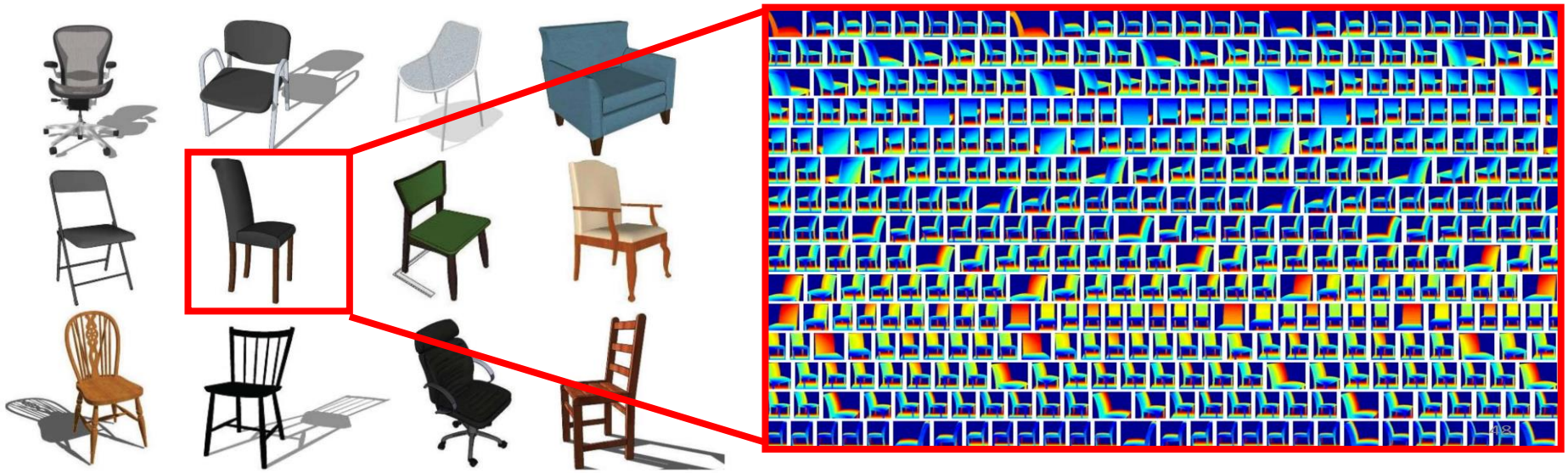


[Wang et al. *Siggraph Asia* 2013]

Slide from Haozhang' lecture

It goes the other way …

- Available 3D data help with computer vision tasks
- Train object detector by depth images of 3D models



"A picture is worth a thousand words."

"A 3D model is worth a thousand pictures ☺"

Slide from Haozhang' lecture

To fix “small 3D data” problem

- Need to synthesize more and more 3D models!
- Not just simple deformations [Xu et al. *SIGGRAPH Asia* 2010], [Zhang et al., *ECCV* 2014 oral]
- Much more variation and novelty

Novelty

of synthesized content enhances knowledge!

Slide from Haozhang’ lecture

Going further?

- Beyond realization of human imagination, can graphics enhance certain human capacity?
- One such capacity is human **creativity**
- Imagination and creativity are closely tied
- Can computer help humans become more creative?

Slide from Haozhang' lecture

Summary: why is graphics hard?

- 3D manipulation, reasoning, and design is hard
- Synthesis of 3D, esp. novel, 3D content, is hard
  - Model is abstract, hard to acquire, or unknown
  - Lack of Big 3D Data for data-driven approaches
- Realizing and enhancing human imagination and creativity is hard: need to define the right problem

Slide from Haozhang' lecture

A Possible Way to Deal with Some Difficulties in Computer Graphics

- The Combination and Application of Deep Learning in Computer Graphics
  - https://channel9.msdn.com/Shows/MicrosoftAI/DNN-application-Graphics