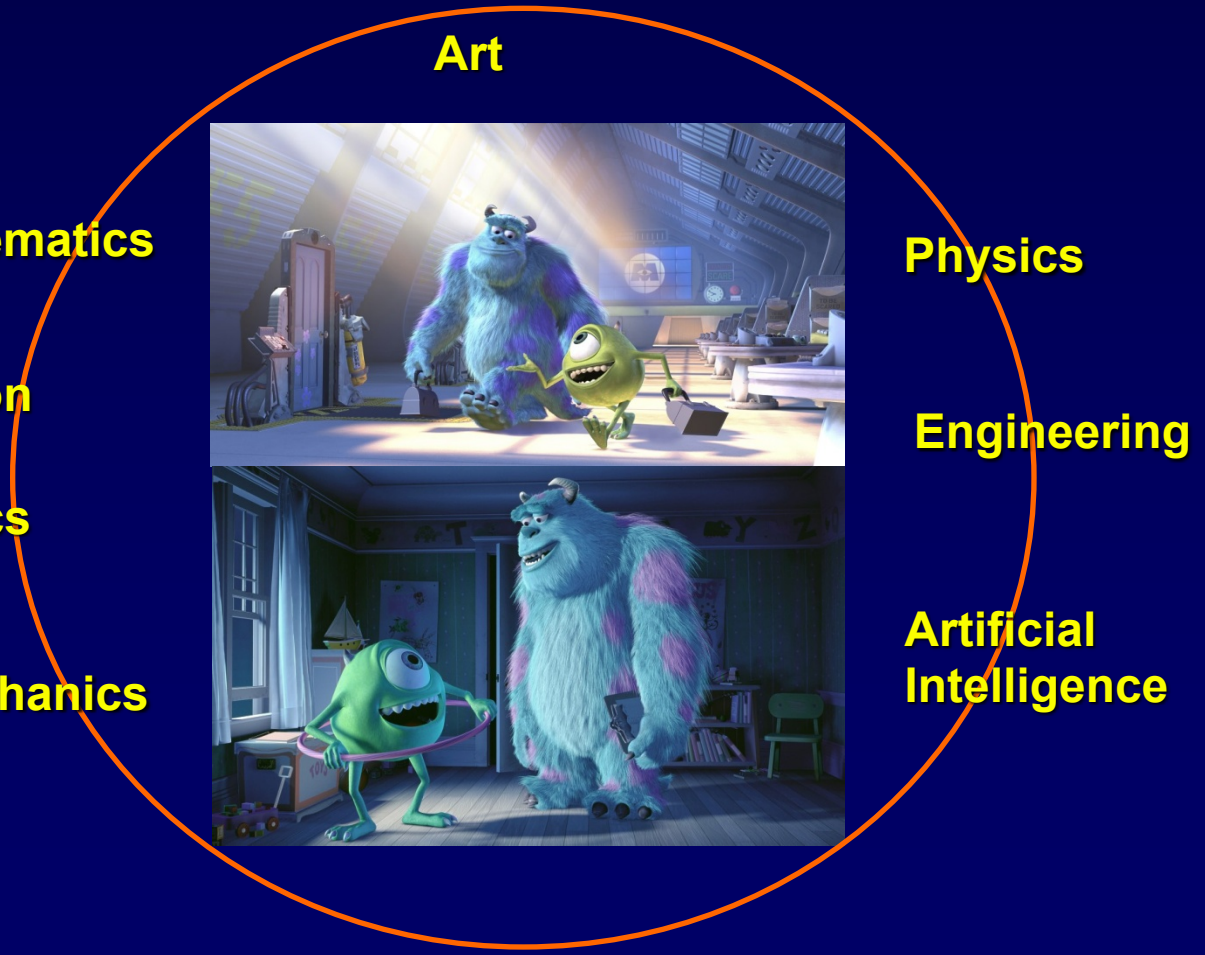
Dr. M. Alex O. Vasilescu

TAs: Ruining Cao, Arjun Lashmipathy, Garett Ridge

CS 174A – Fall 2017
Introduction to Computer Graphics

Computer Graphics

The Art and Science of creating imagery by computer



Applications of CG

Entertainment

- Films
- Computer Games
- Virtual reality

Visualization

- Scientific visualization
- Medical visualization
- Flight simulation
- Architecture

Education, etc.

History

- 2000 B.C.
  - *orthographic projection*
- 1400s
  - *Perspective: Italian Renaissance*
- 1600s
  - *coordinate systems: Descartes*
  - *optics: Huygens*
  - *optics, calculus, physics: Newton*

History

- 1897 oscilloscope: Braun
- 1950-1970
  - *computers with vector displays*
- 1966
  - *first true raster display*
- 1993
  - *1200x1200, 500k triangles/sec, 36-bit color, stereo, texture mapping… all at 60Hz*
- 1995
  - *feature-length CG films*
- Today…still rapidly evolving

Genesis of Computer Graphics and Interactive Techniques

A PhD project at MIT in the early 1960s

- Ivan E. Sutherland, 1963
  - *"Sketchpad, a man-machine graphical communication system"*

Sketchpad Demo

Quiz

https://design.osu.edu/carlson/history/timeline.html

When was the term “Computer Graphics” first stated?

William Fetter of Boeing coins the term "computer graphics" for his human factors cockpit drawings 1960.

1. When was the Graphical User Interface developed?

   GUI developed by Xerox (Alan Kay) 1969

2. When was Tron released?

   Disney contracts Abel, III, MAGI and DE to create computer graphics for the movie Tron released in 1981.

Quiz

4. Which is the first **animated** movie to employ CG?

   "The Great Mouse Detective" (1986) was the first animated film to be aided by CG.

5. When was the game "Doom" released?

   1993

6. Which is the best selling game of all time?

   http://en.wikipedia.org/wiki/List_of_best-selling_video_games

Tetris	*(495M copies)*
Minecraft	*(122M copies)*
Wii Sports	*(83M copies)*
Grand Theft Auto V	*(75M copies)*
Super Mario Bros.	*(40M copies)*

   …

Quiz

7. Which is the newest CG animated movie?

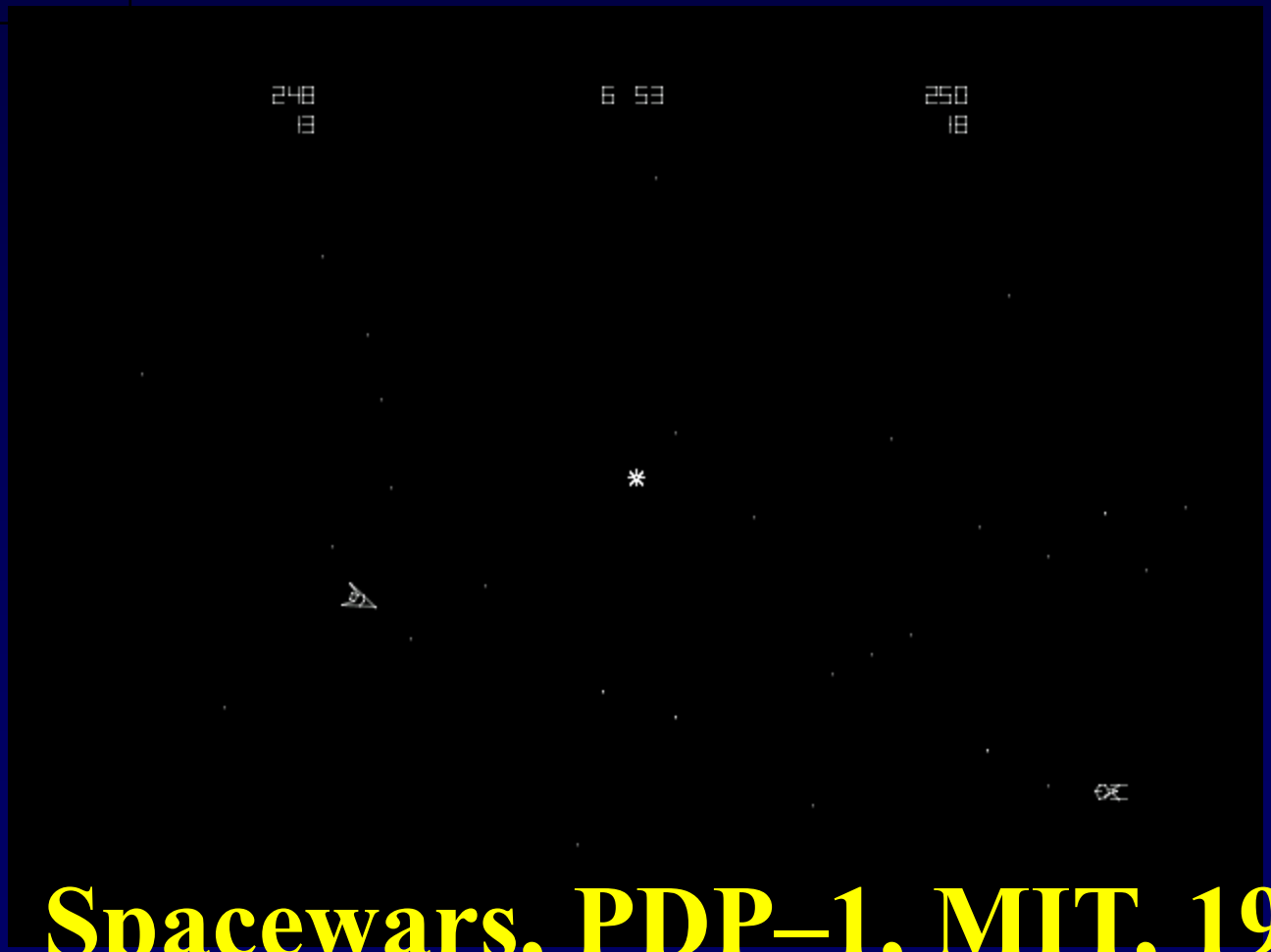
   ?? (trick question)

8. Which is bigger in terms of gross revenue, the game industry or the (Hollywood) movie industry?

   The game industry

9. Which is your favorite animated movie?

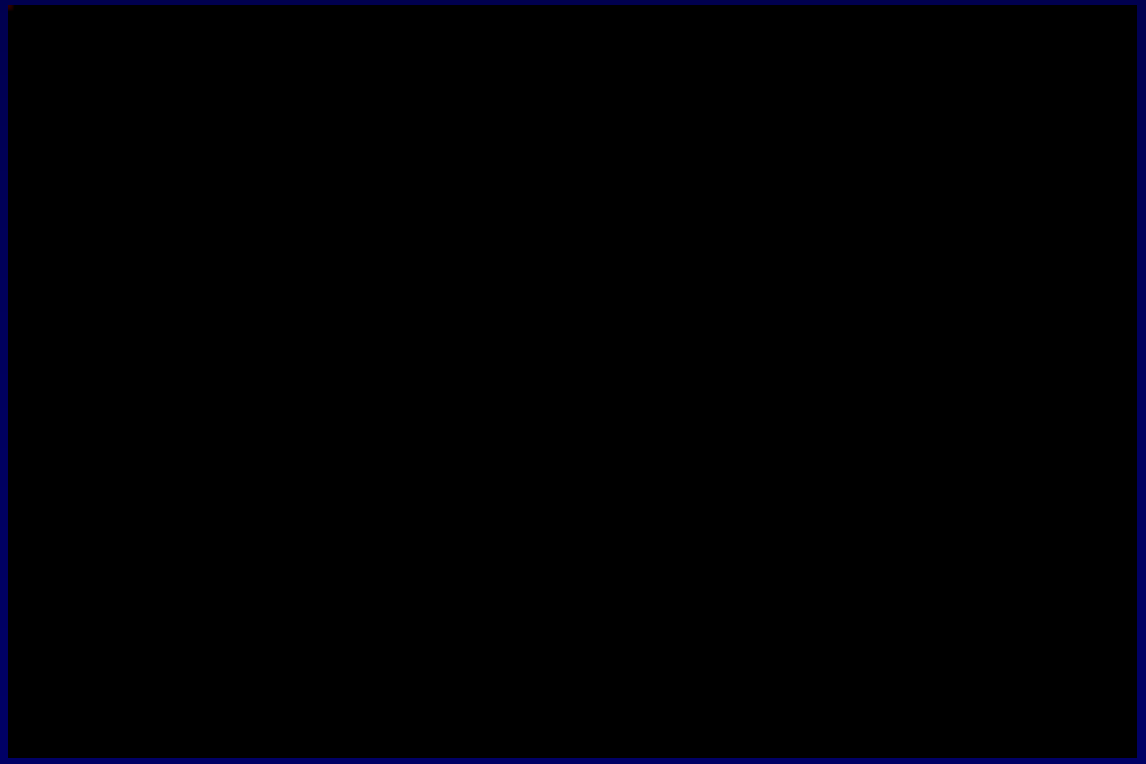
The First Computer Game?



Spacewars, PDP–1, MIT, 1961

The First "Computer" Game – 1958 !!

"Tennis for Two"



Far Cry

Metal Gear Solid 4

- *Watch your character from multiple points of view*
- *Renders everything on the fly. In the past, scenes were canned movies that were pre-rendered.*

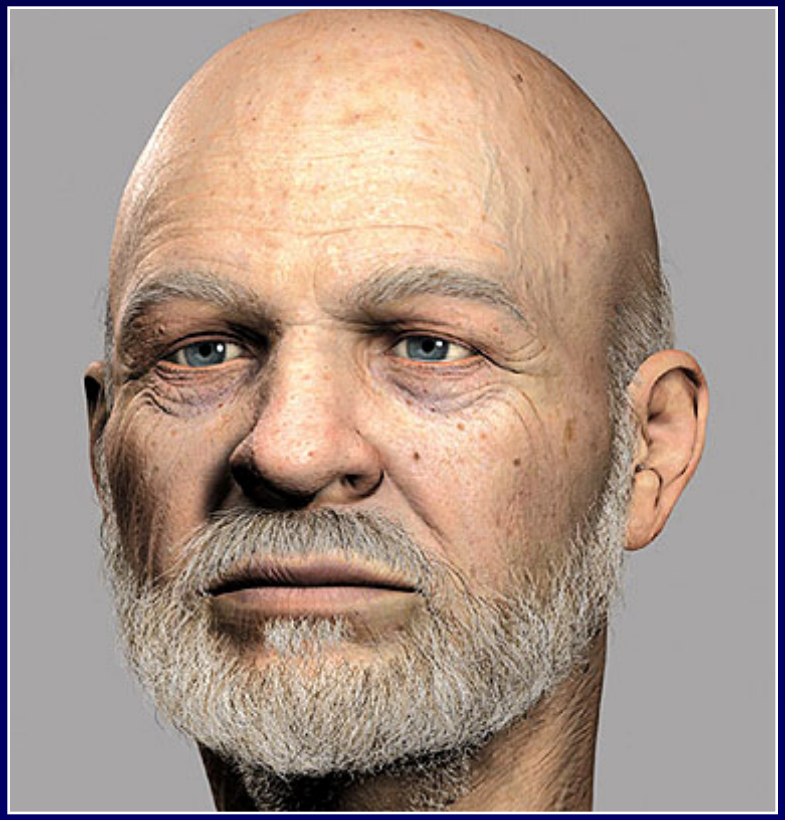
Games

Focus on interactivity

Games

Movies

To reality and beyond !



Movies

Special effects

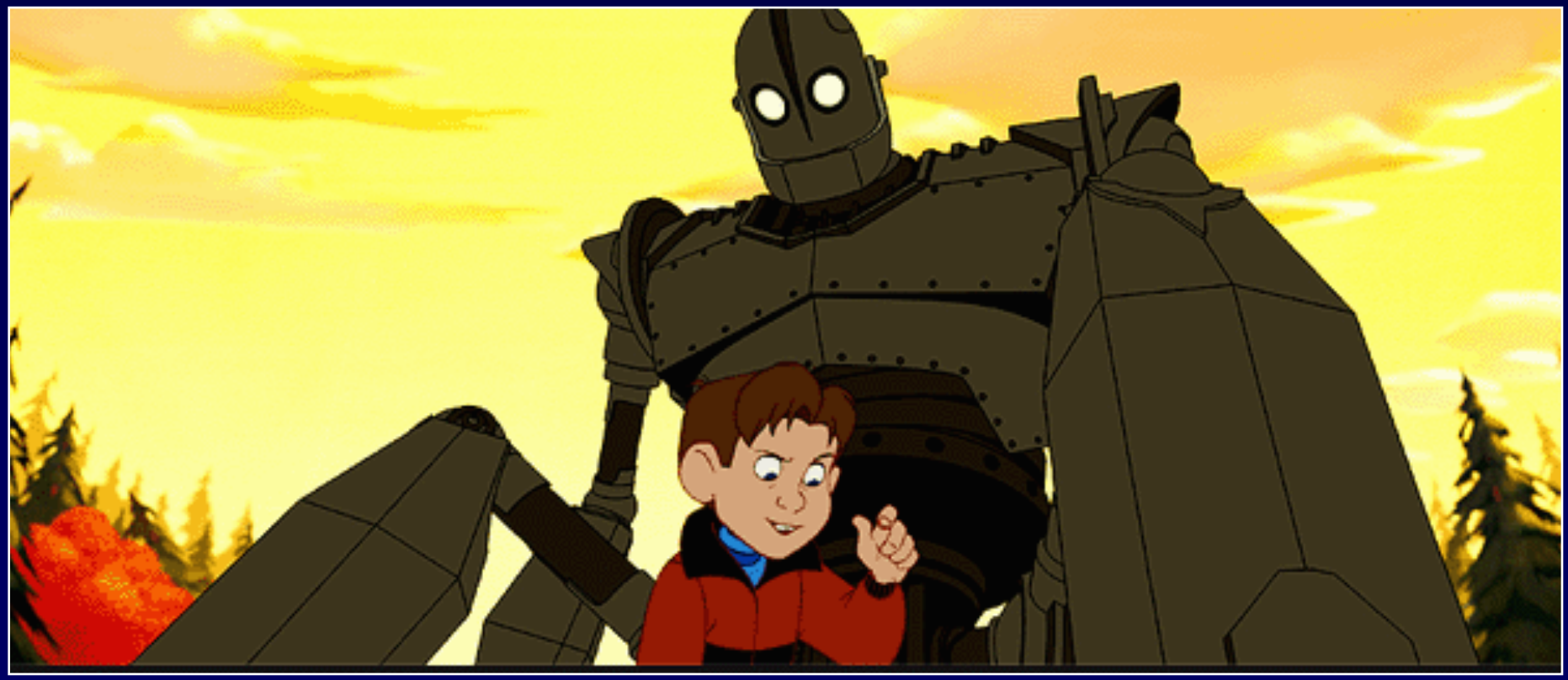
Movies

Digital Compositing


CG Axe
Base Color

Digital Compositing

Cartoons



Computer-Aided Design

Precision modeling

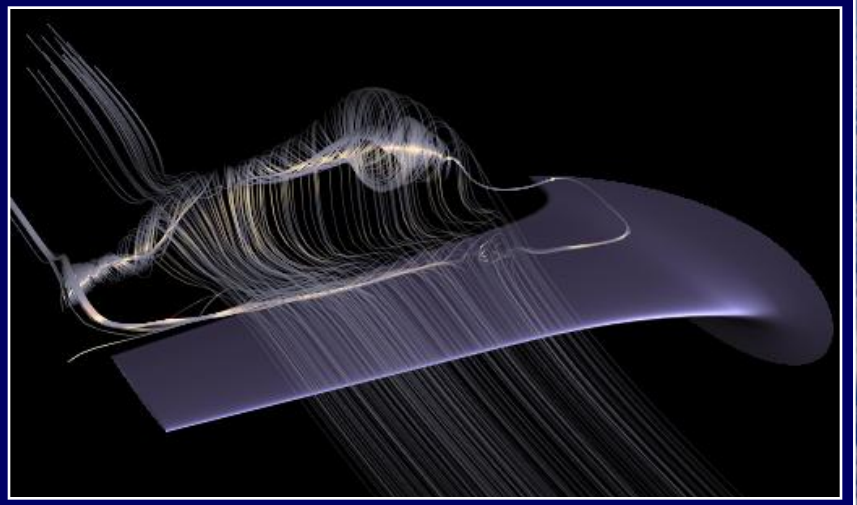
Engineering visualization

Modeling Clay

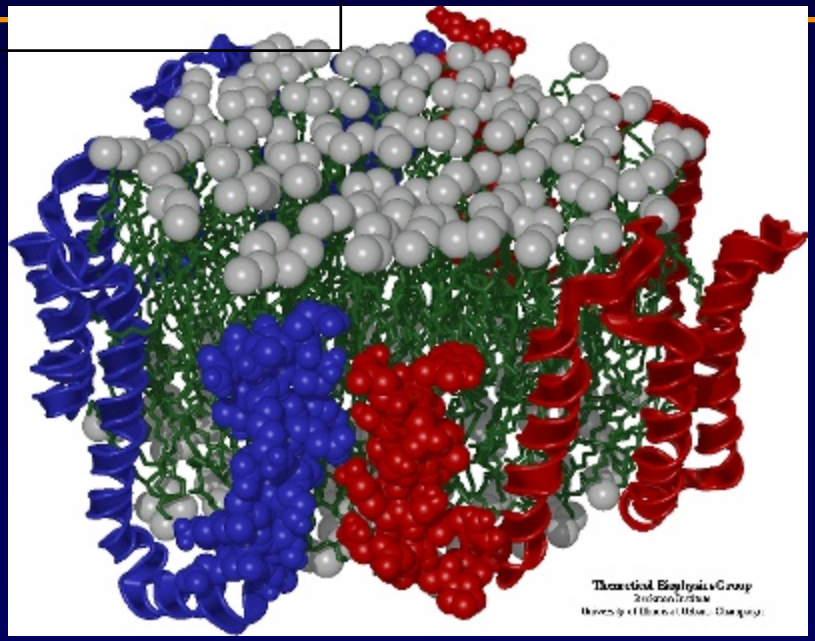
Computer-Aided Design

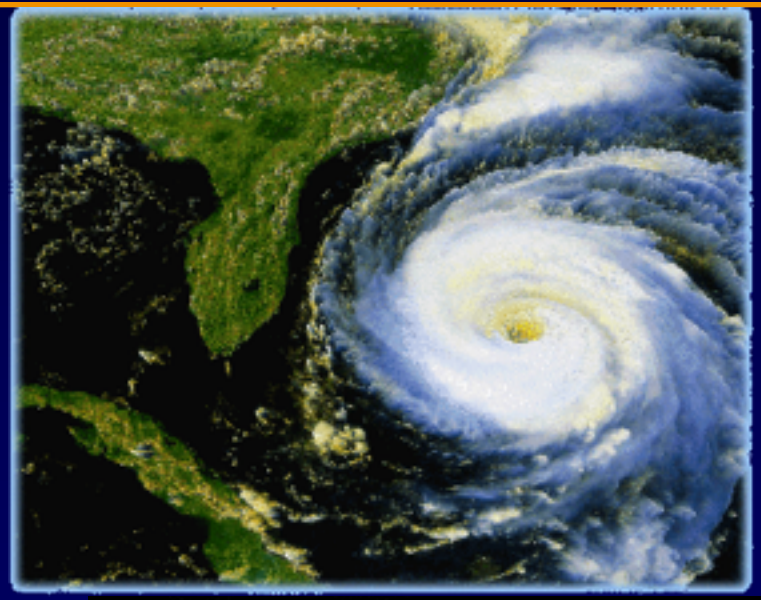
It's not just about visualization

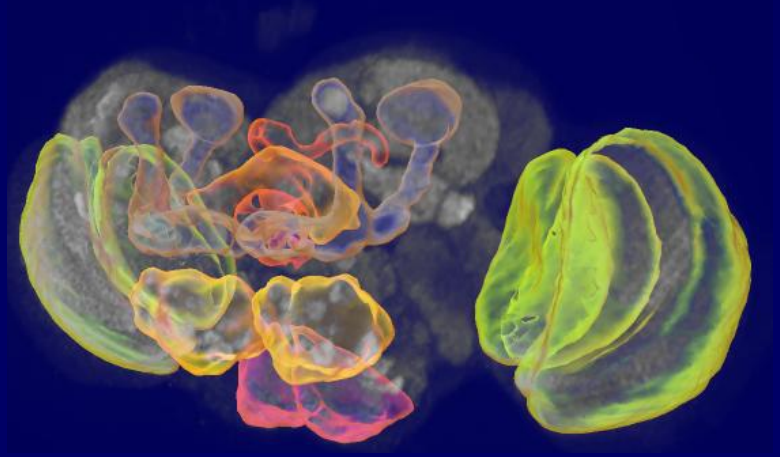
- Simulation is also useful

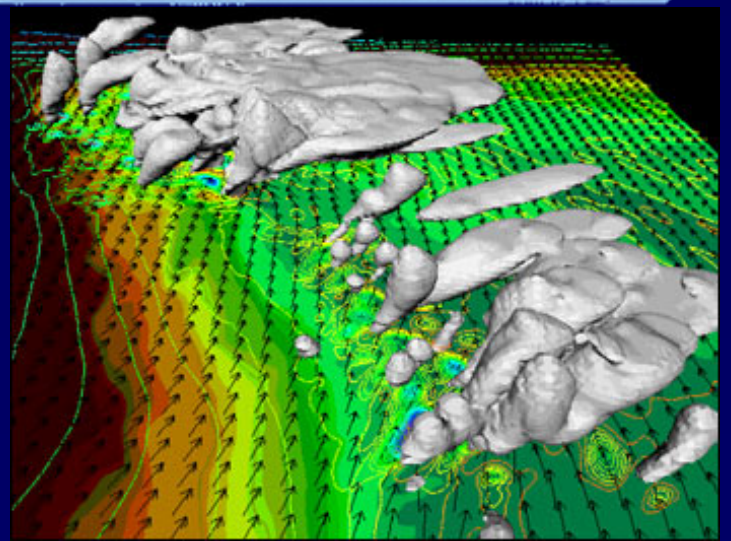


Visualization: Scientific

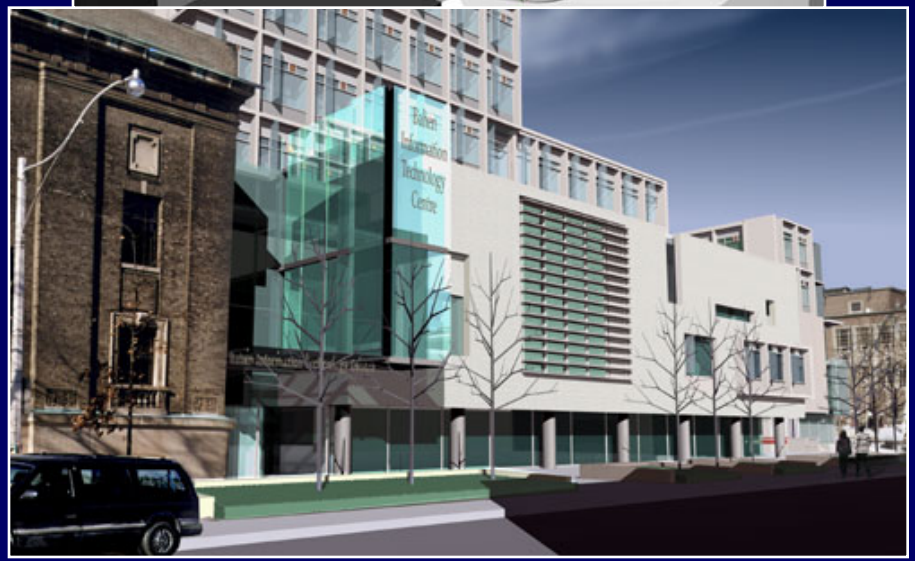


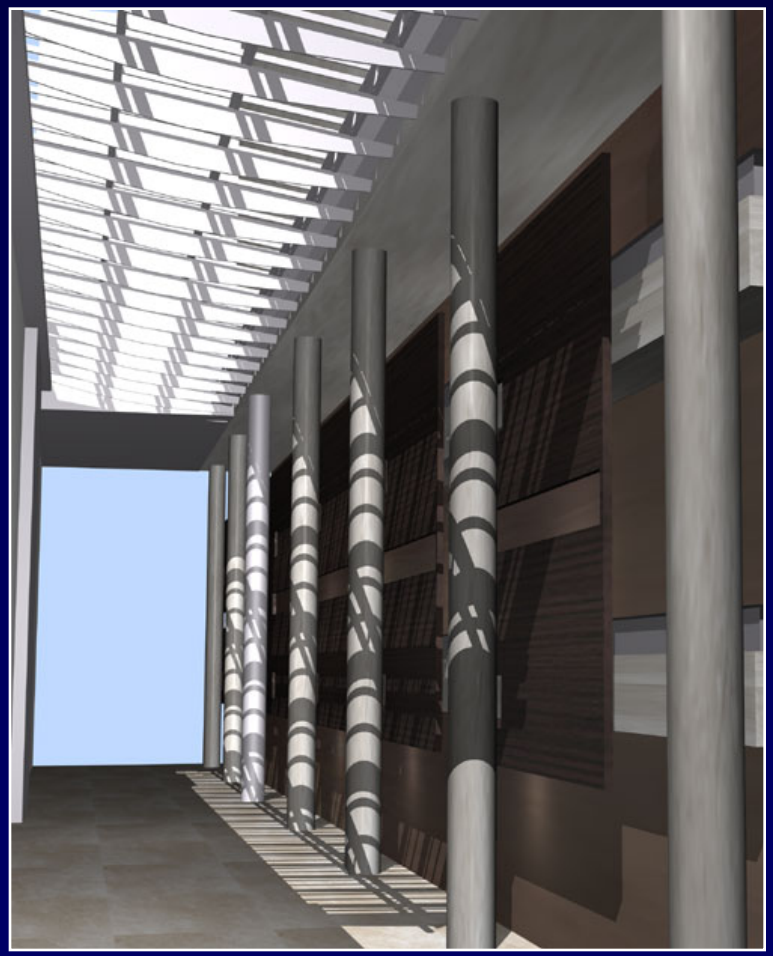






Visualization: Architectural

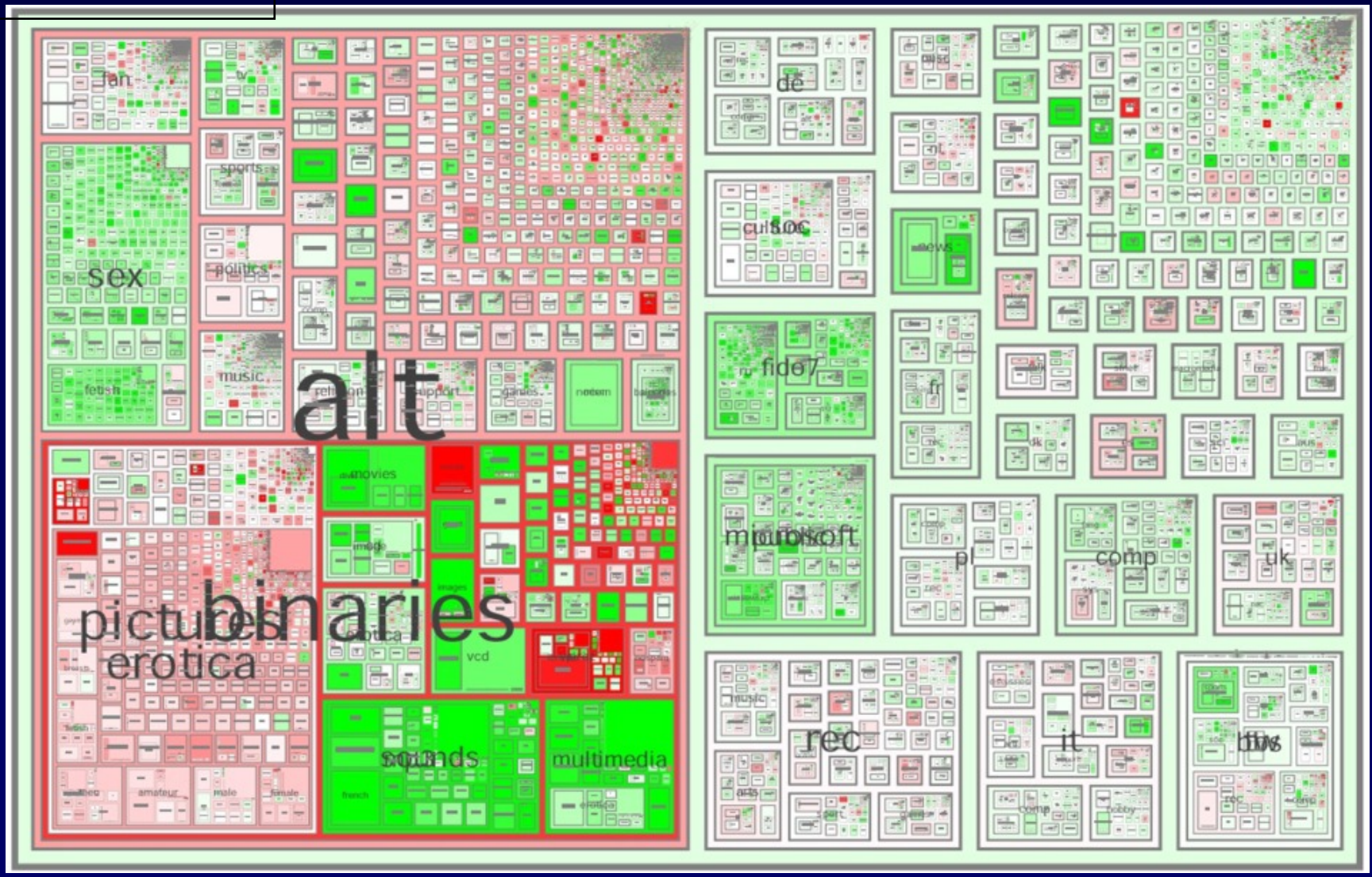




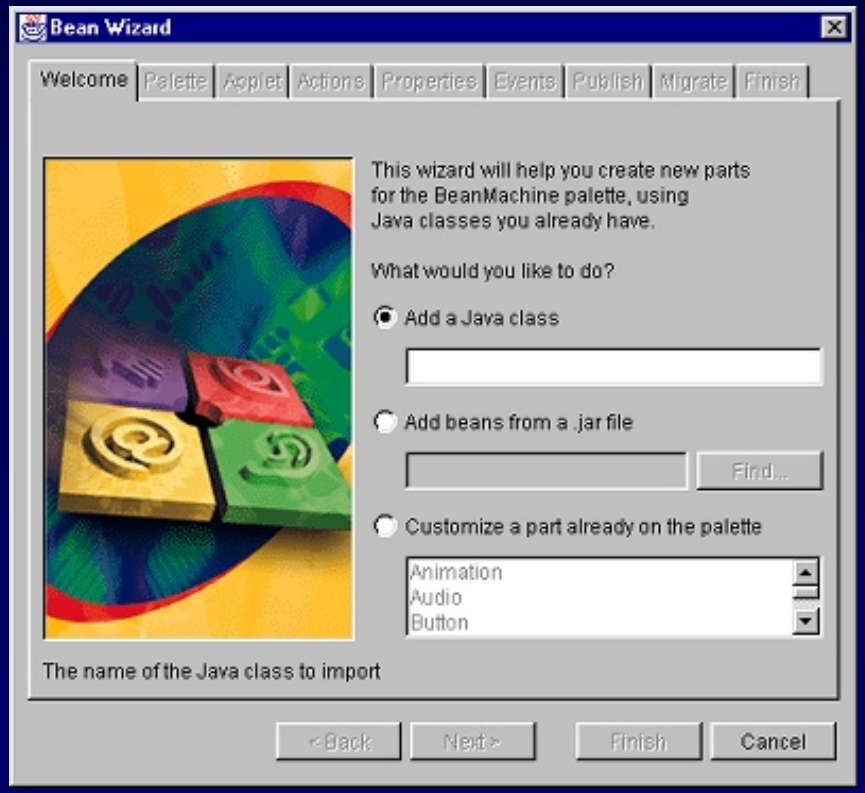
http://www.diamondschmitt.com/

Visualization: Info

Smith and Fiore



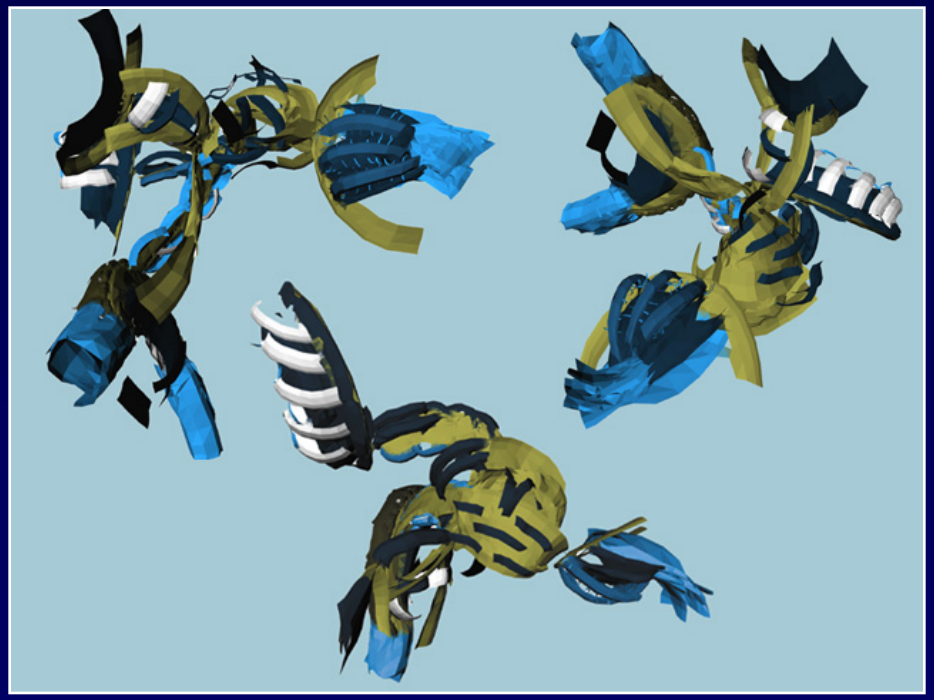
Graphical User Interfaces



WIMP

Steven Schkolne

Art

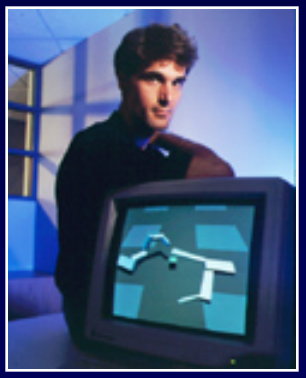


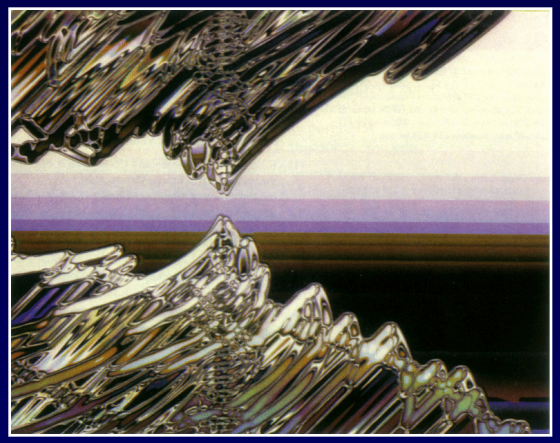
Steven Schkolne

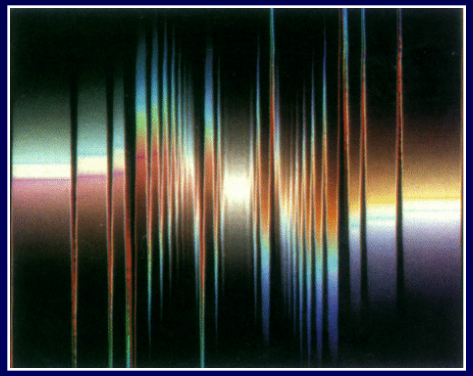
Digital Art

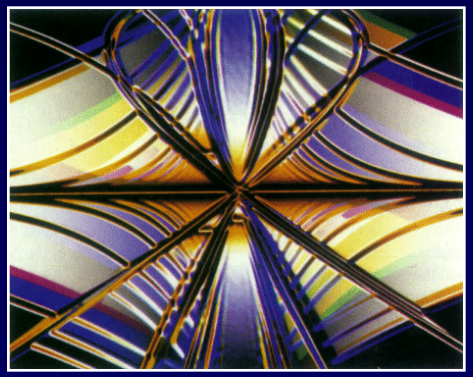
Genetically evolved

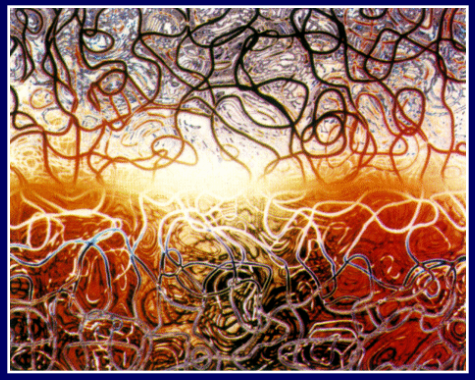
Carl Sims









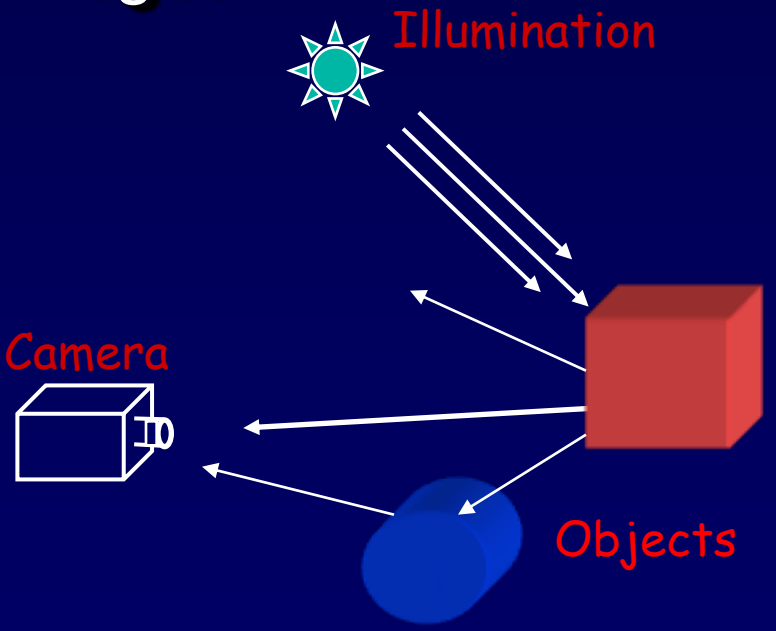


Digital Art


By Jason Salavon
The Top-Grossing Film of All Time
“Titanic”
^2nd

What is an Image / Video?

- Array of pixels (one or more numbers)
- A video is a time sequence of images
- How they are formed:
  - *Objects in the world (static or dynamic)*
  - *Illumination (light sources)*
  - *Imaging device (eye, camera)*
- We want to synthesize images/videos



Basic sub-areas of computer graphics

Modeling

Animation

Rendering

Interaction

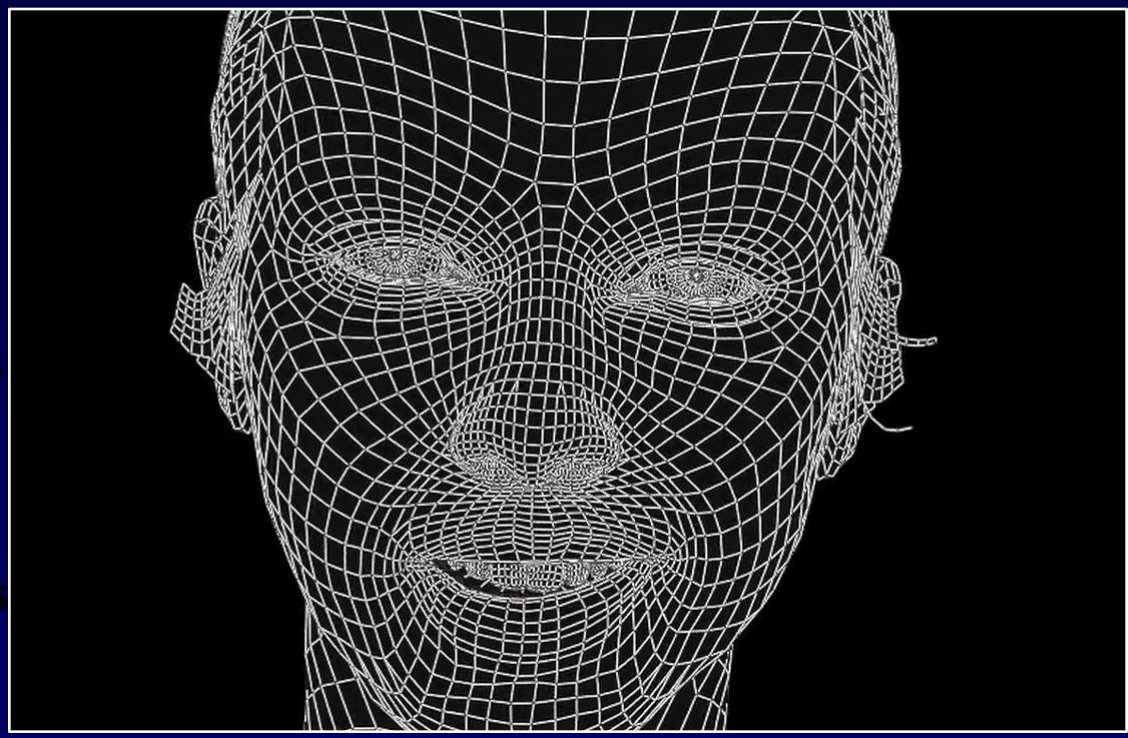
Basic sub-areas of computer graphics

- Modeling
  - *How do we model (mathematically represent) objects?*
  - *How do we construct models of specific objects?*
- Animation
  - *How do we represent the motions of objects?*
  - *How do we give animators control of this motion?*
- Rendering
  - *How do we simulate the real-world behavior of light?*
  - *How do we simulate the formation of images?*
- Interaction
  - *How do we enable humans and computers to interact?*
  - *How do we design human-computer interfaces?*

Modeling

Primitives

- 3D points
- 3D lines and curves
- Surfaces (BREPs): polygons, patches
- Volumetric representations
- Image-based representations



Attributes

- Color, texture maps
- Lighting properties

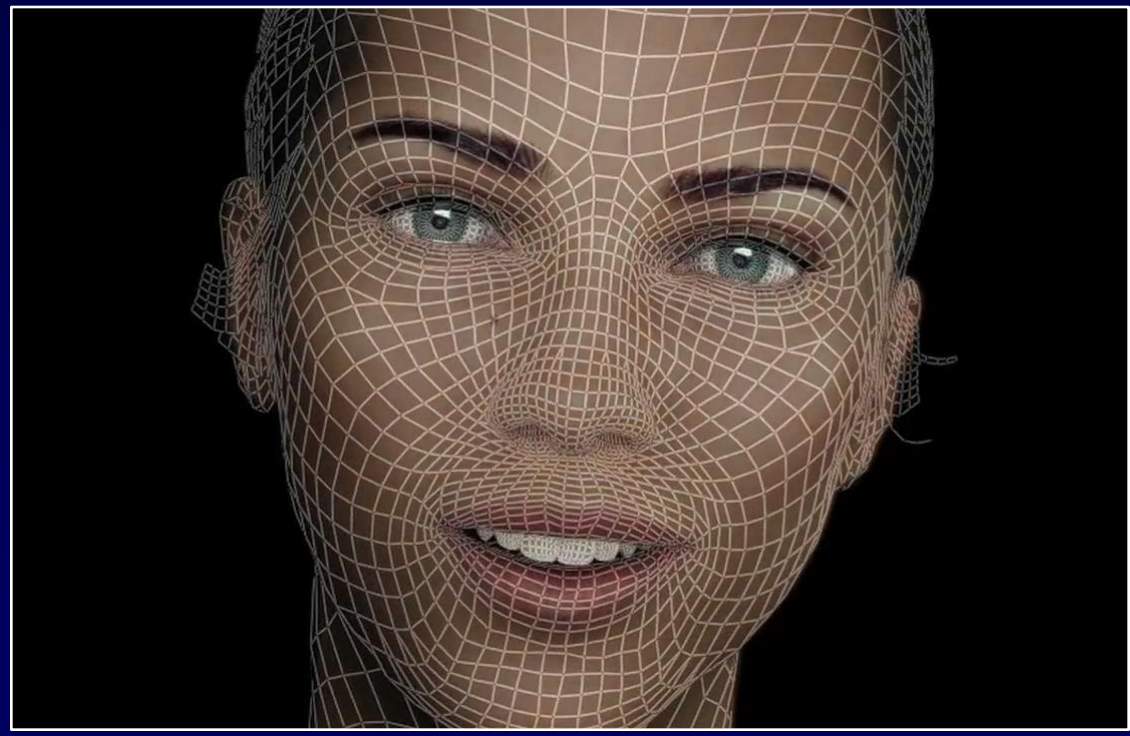
Geometric transformations

Rendering

Visibility

Simulating light propagation

- Reflection
- Asborption
- Scattering
- Emission
- Interference



Animation

Keyframe animation

Motion capture

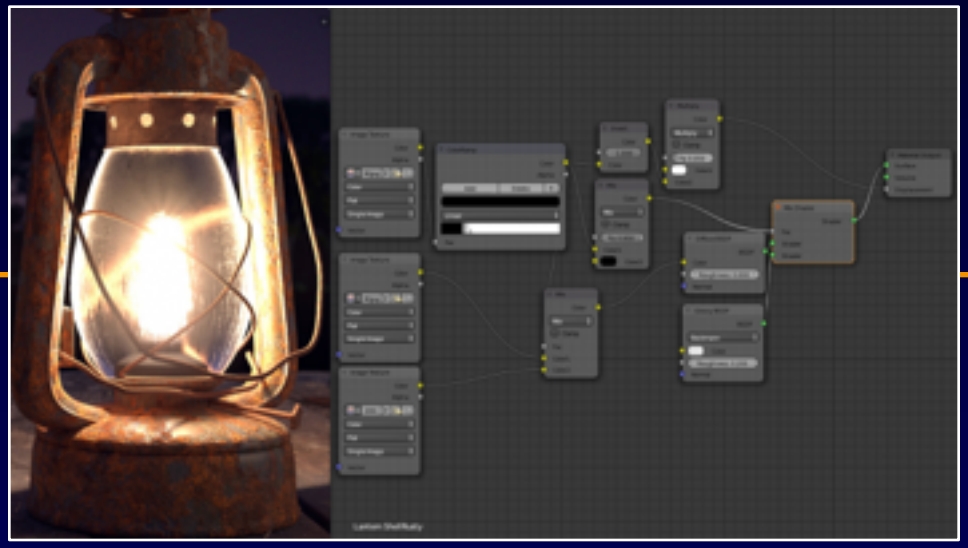
Procedural animation

- Physics-based animation
- Behavioral animation

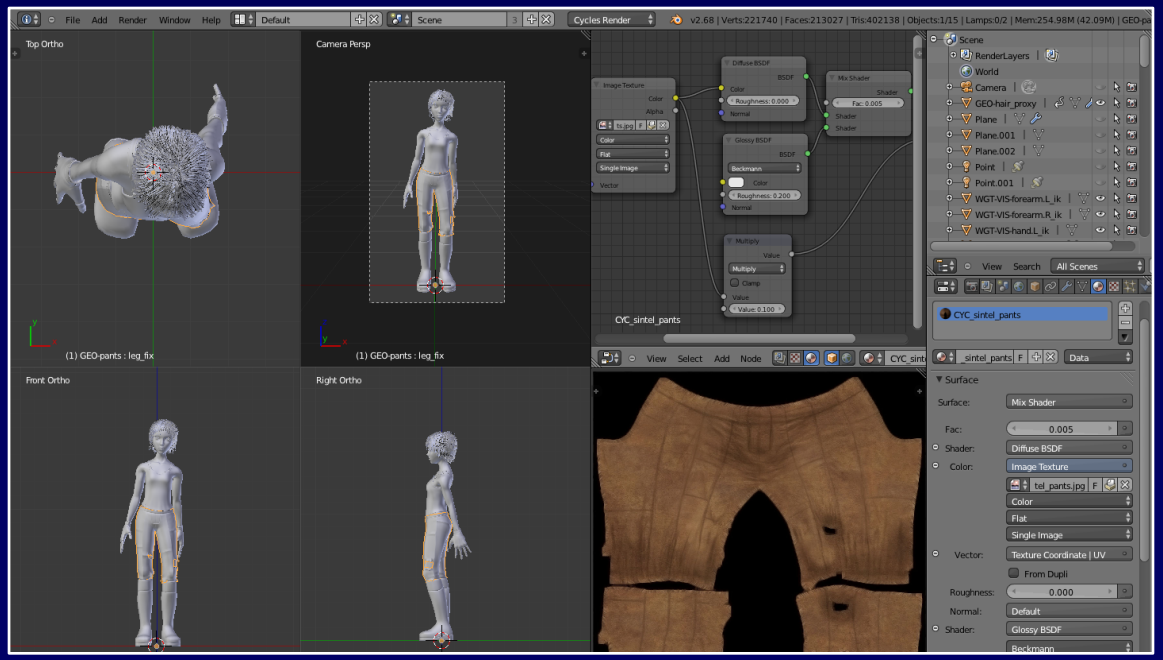
Interaction

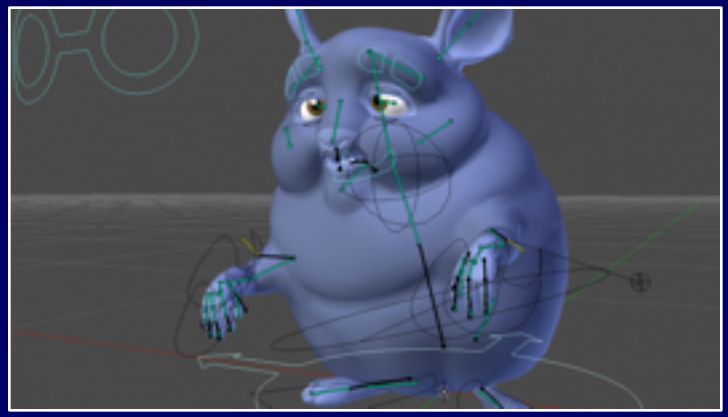
Input/Output Devices

Tools



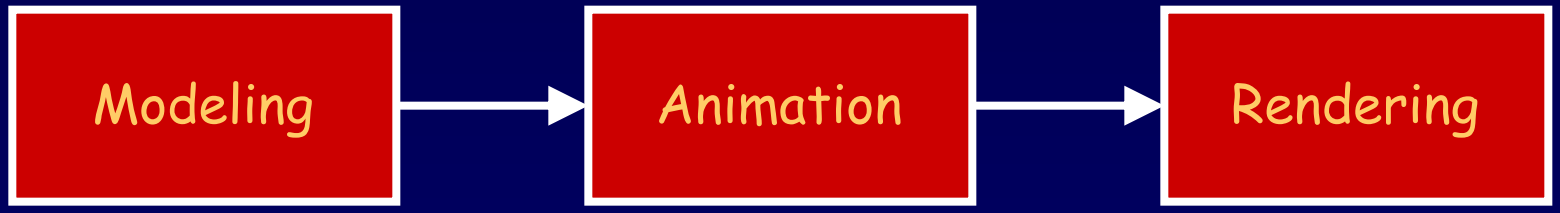
- Modeling, animation, and rendering





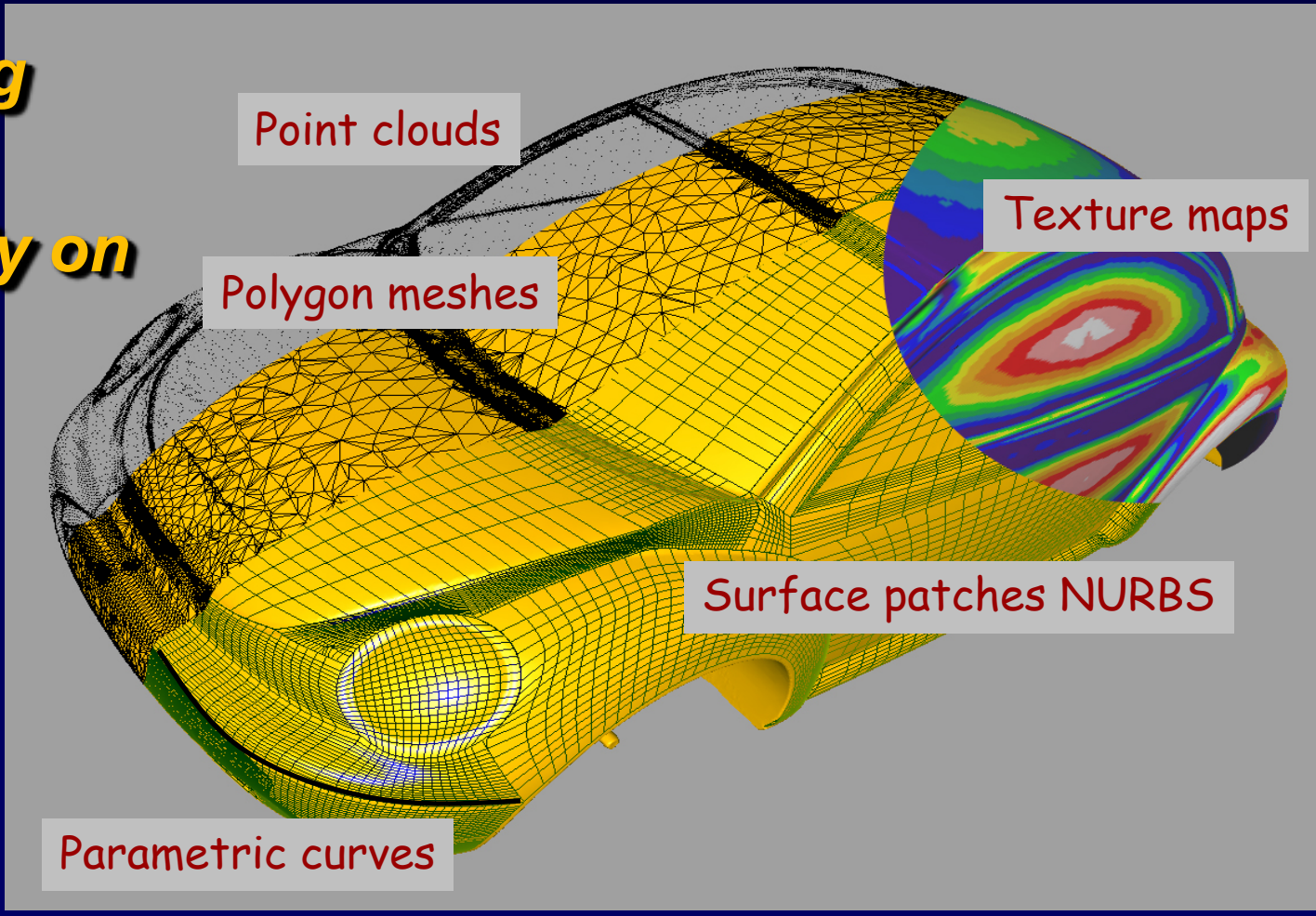
Elements of CG

The graphics pipeline



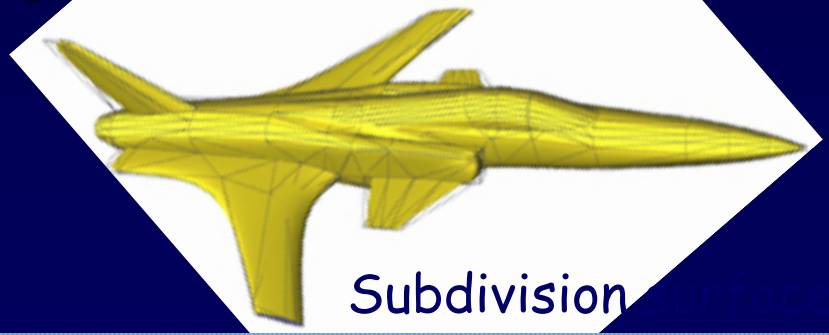
Modeling

Representing objects geometrically on a computer

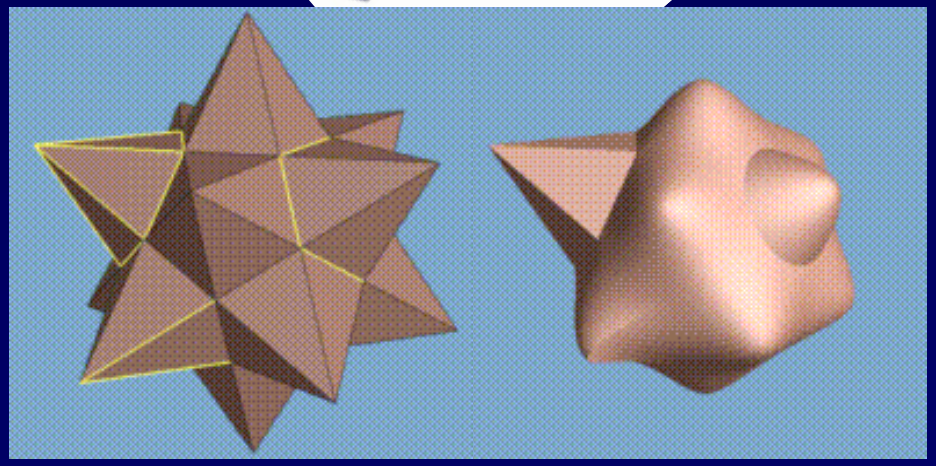


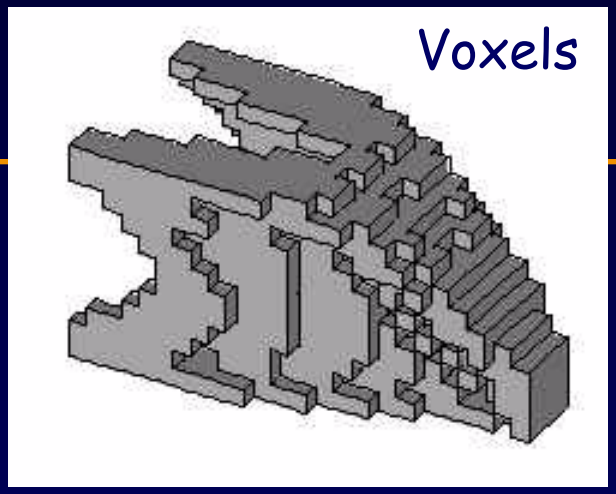
Modeling

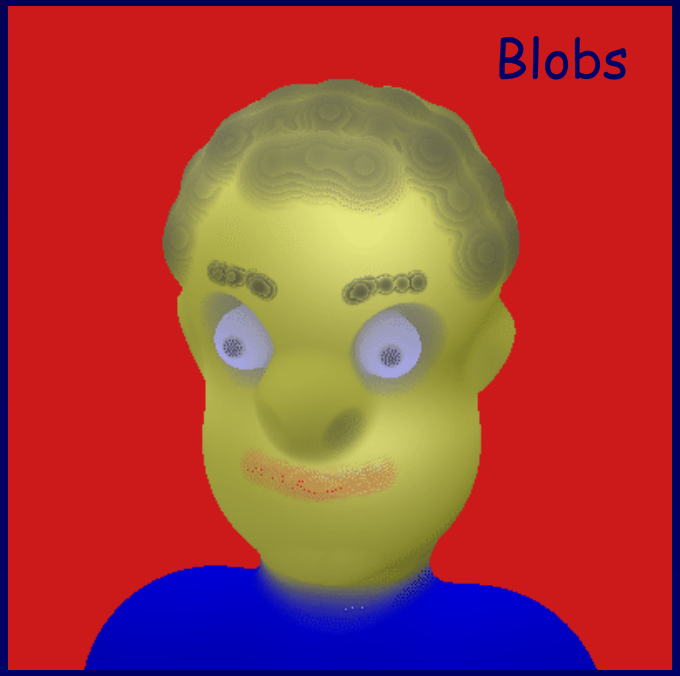
Alternative representations



Subdivision surfaces

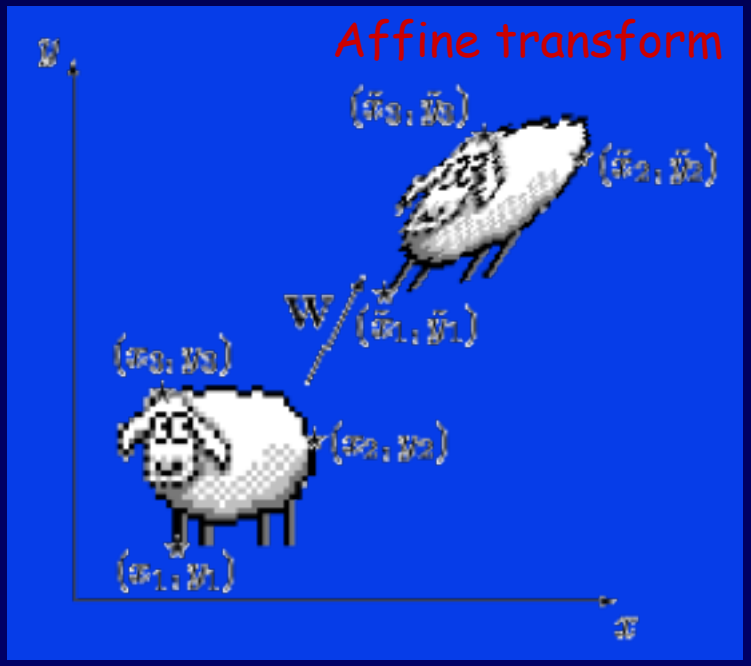


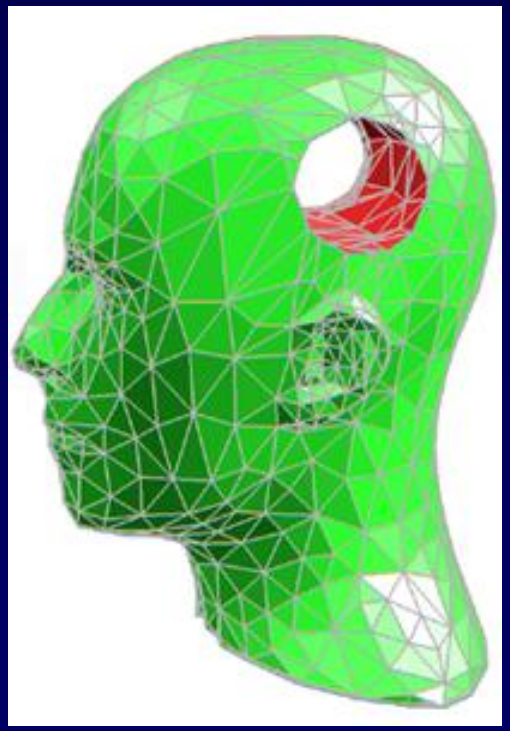




Modeling

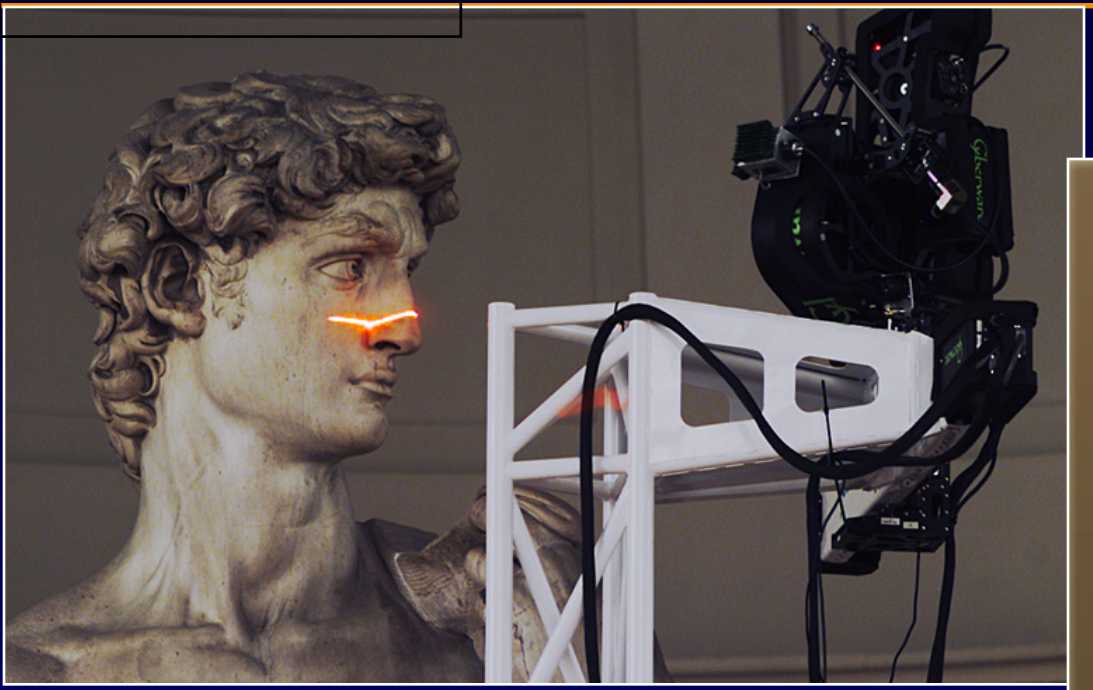
Altering geometric models





Ying, Kristjansson, Biermann, Zorin

Scanning Shapes



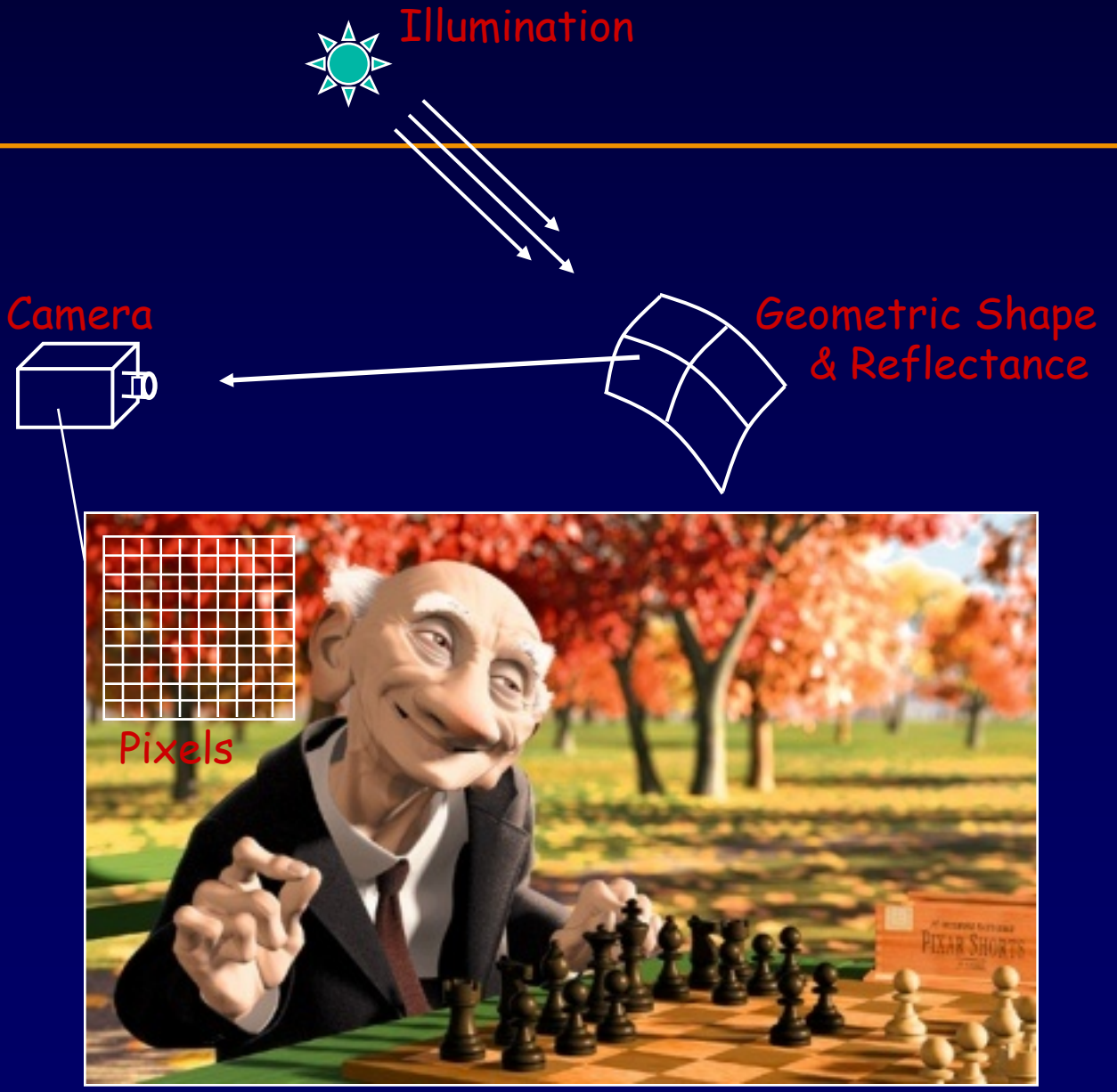
Digital Michaelangelo Project

Plant Modeling

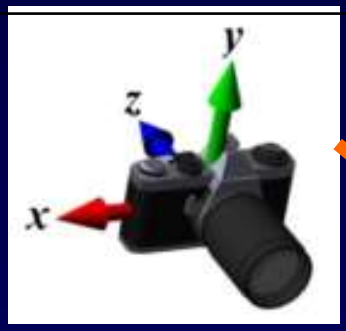
Plant Modeling

Rendering

Key elements

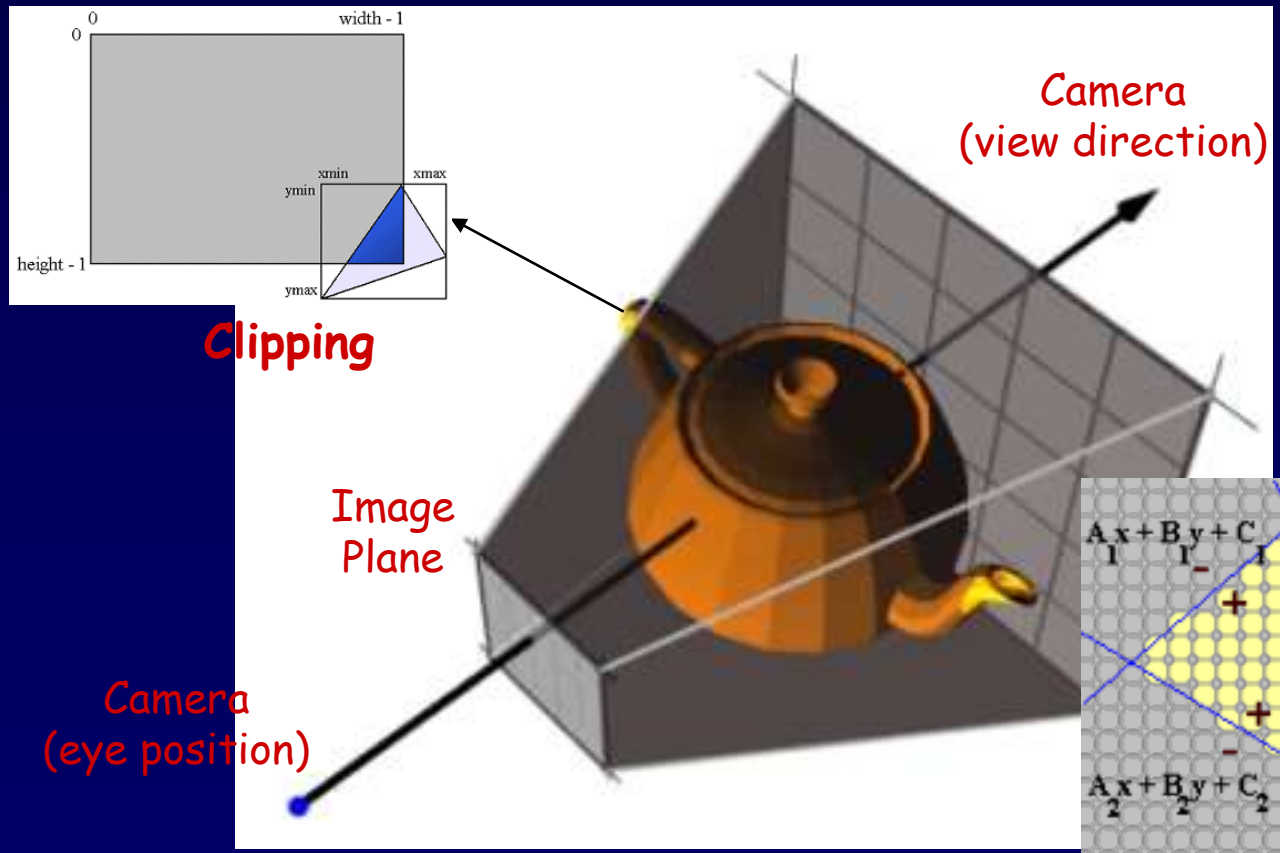


Camera Model



Rendering

Draw visible surfaces onto display



Reflectance Modeling

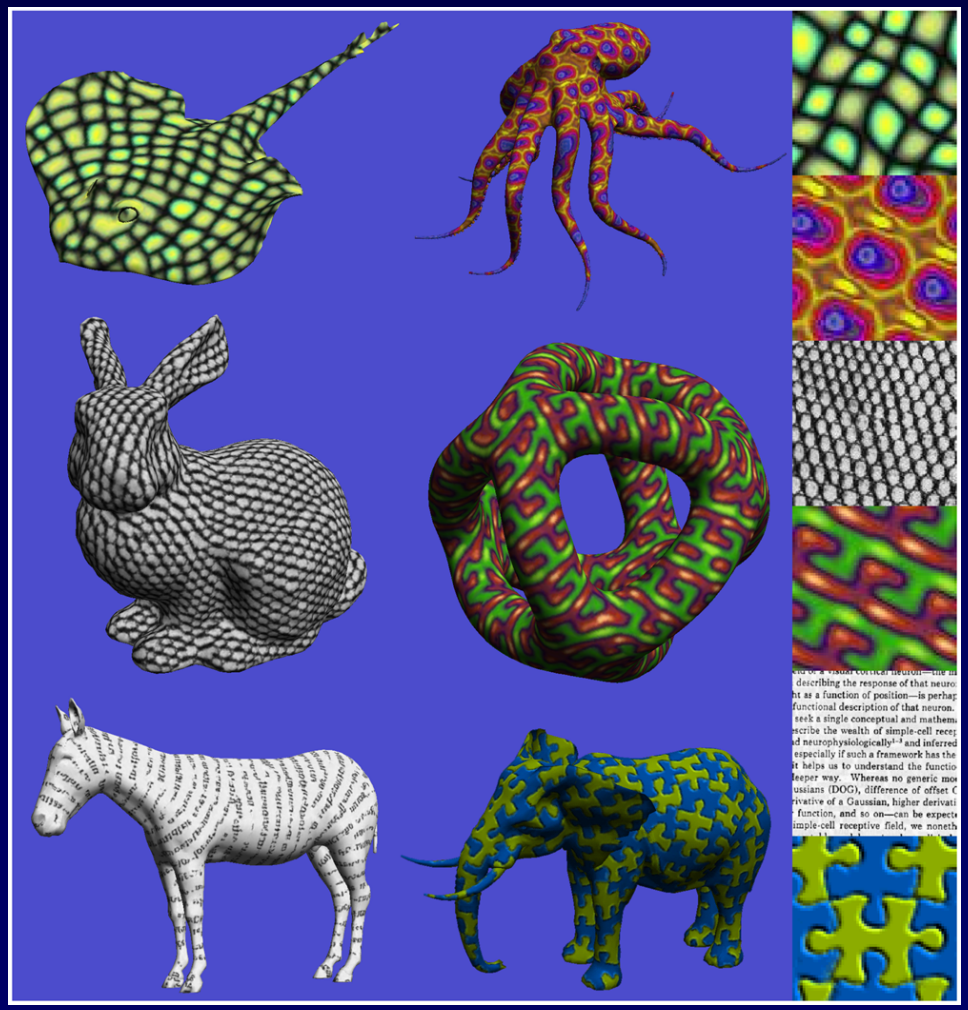
Complex Reflectance

Subsurface Scattering

Translucency and varied levels of light penetration can be created using subsurface scattering effects

Texture

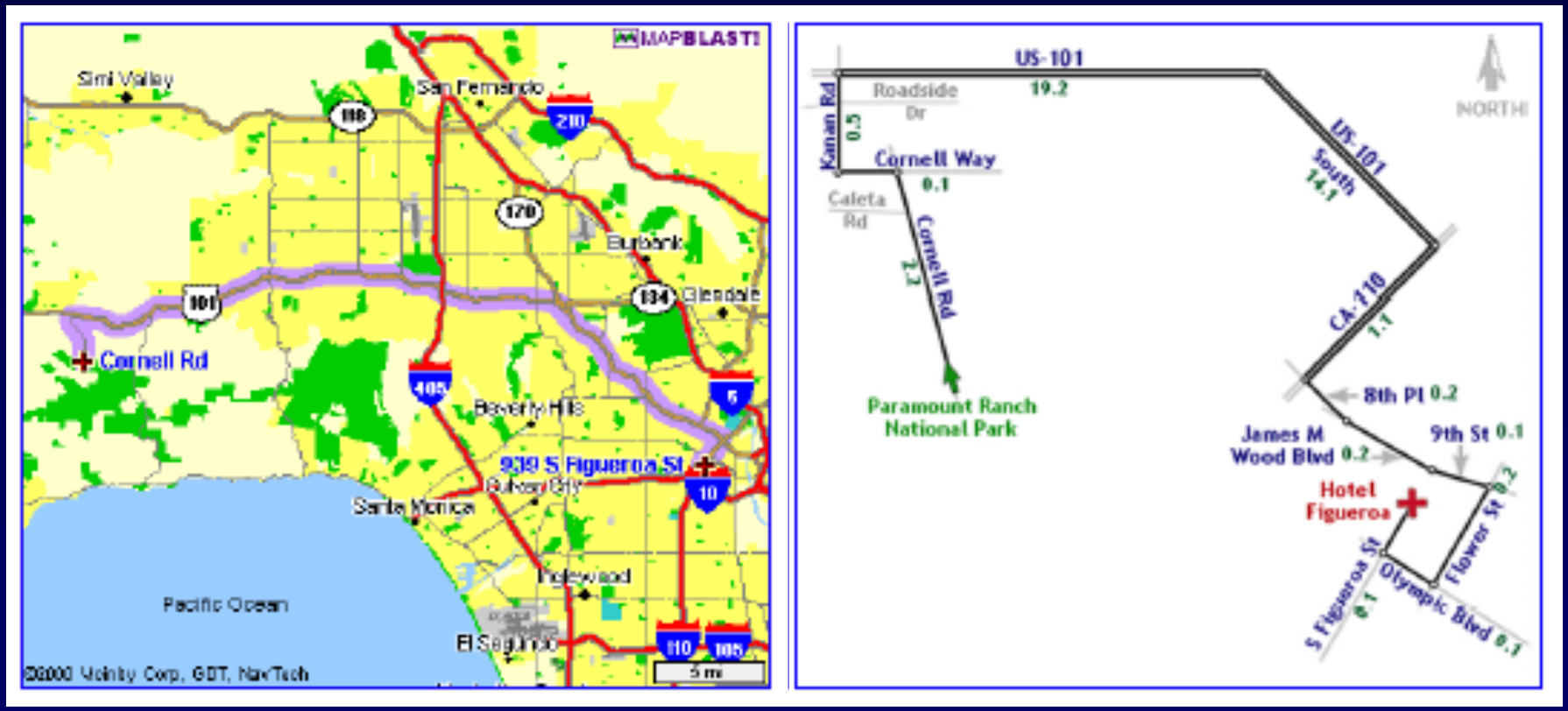
Multilevel texture synthesis



Non-Photorealistic Rendering

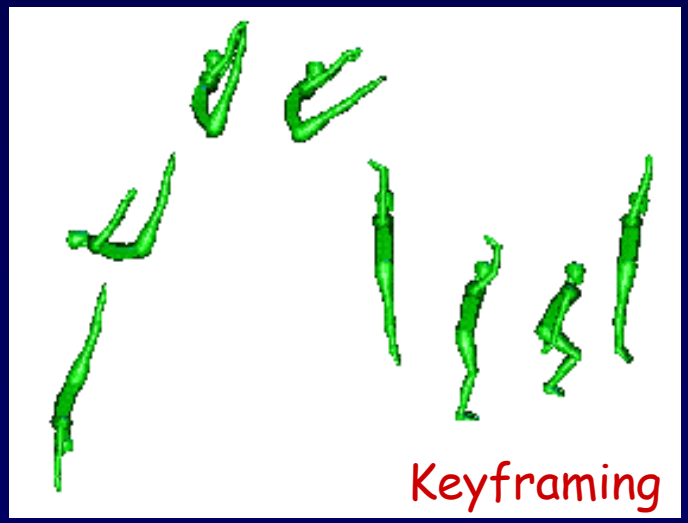
Aaron Hertzmann

Rendering: Information



Animation

Keyframe animation



Animation

Pixar: "Luxo Jr." (1986)

A baby lamp finds a ball to play with and it's all fun and games until the ball bursts. Just when the elder Luxo thinks his kid will settle down for a bit, Luxo Jr. finds another ball—ten times larger.

Luxo Jr. has a great dad in the larger lamp. Even though he is a bit unpredictable, the elder Luxo gives him room to grow and explore. And the tiny light has no problem with that.

When John Lasseter was learning how to make models, he chose the nearest, easiest subject: an architect's lamp sitting on his desk. He started moving it around in the animation system like it was alive and it eventually became another short film by Pixar that was nominated for an Academy Award®.

“Bingo”

Directed by Chris Landreth – Alias - 1998

Based on the play “Disregard this Play” by Greg Kotis

Animation

Motion capture

Animating Golem in LOTR

Animation

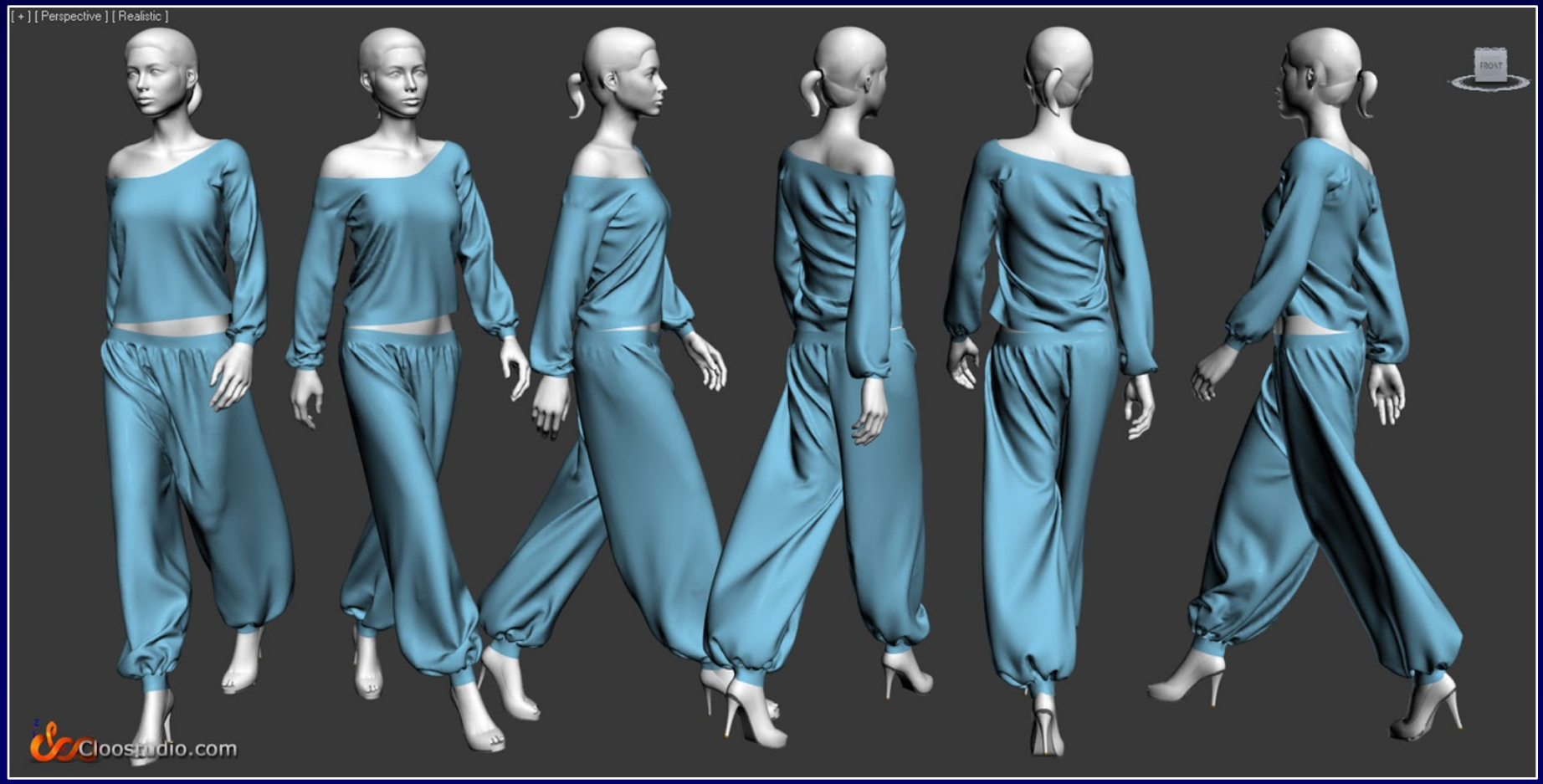
The Animatrix –

"Final Flight of the Osiris"

Animation

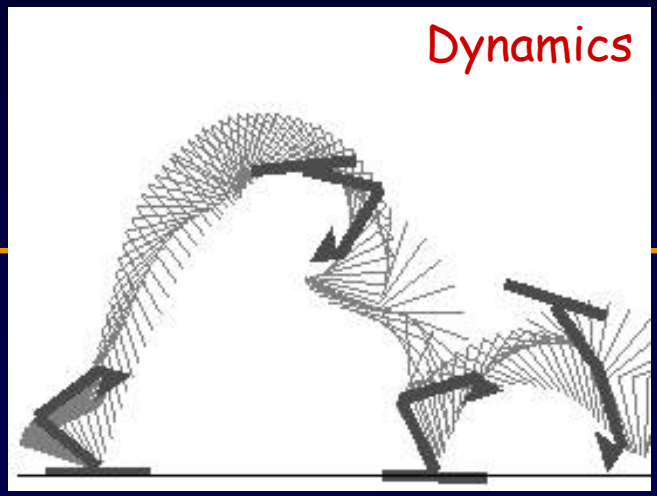
Example: "Geri's Game" - Pixar

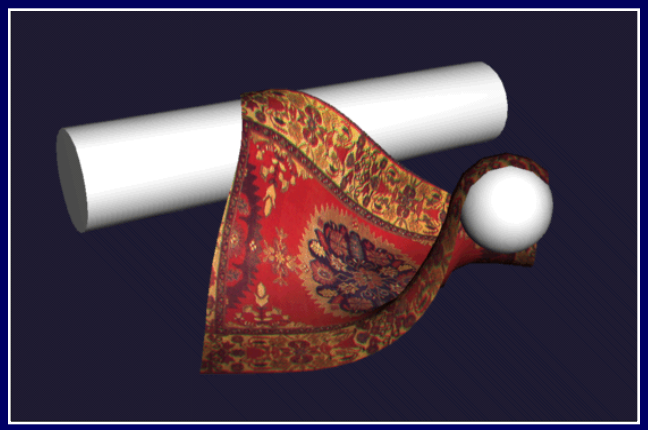
Cloth Simulation

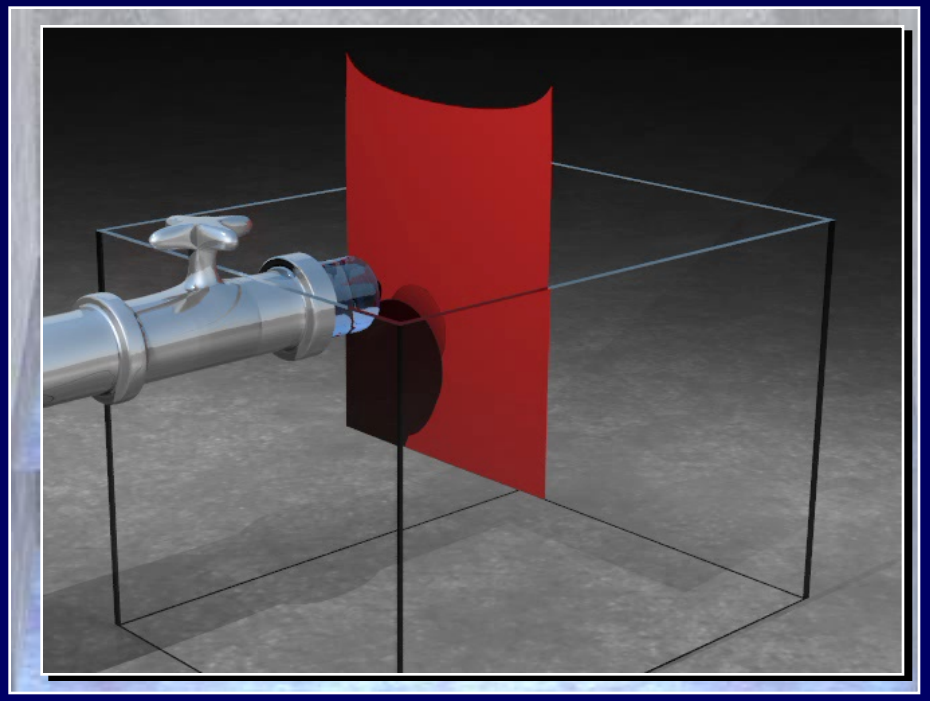


Animation

Physics-based animation







Fluid Simulation

Modeling

- Incompressibility
- Viscocity

Navier-Stokes Equations

$$\nabla \cdot \mathbf{u} = 0$$

$$\frac{\partial \mathbf{u}}{\partial t} = \nu \nabla \cdot (\nabla \mathbf{u}) - (\mathbf{u} \cdot \nabla)\mathbf{u} - \frac{1}{\rho}\nabla p + \mathbf{g}$$

Level Sets

$\mathbf{u}$: fluid velocity field

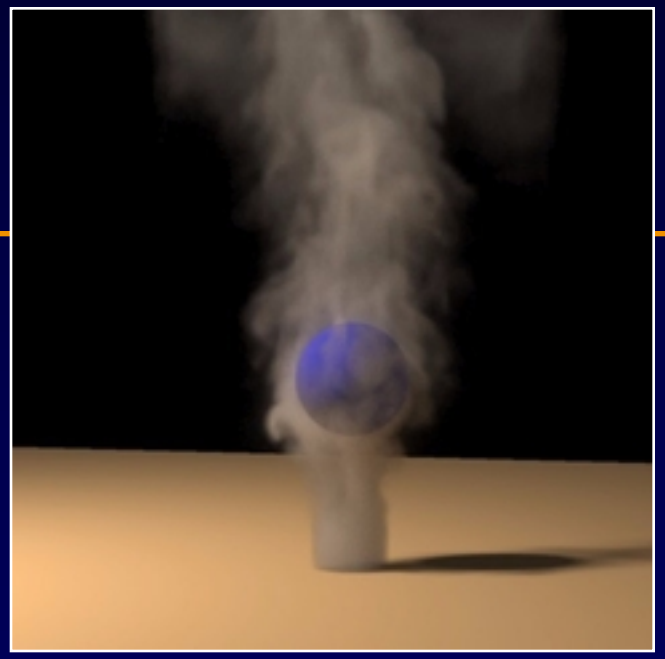
$\mathbf{g}$: gravity

p: pressure

ν: viscosity

ρ : density

Smoke Simulation



Assumptions

- No viscosity

Rendering

- Photon maps
- Multiple scattering

$$\nabla \cdot \mathbf{u} = 0$$

$$\frac{\partial \mathbf{u}}{\partial t} = (\mathbf{u} \cdot \nabla)\mathbf{u} - \frac{1}{\rho}\nabla p + \mathbf{f}$$

$\mathbf{u}$: smoke velocity field

$\mathbf{f}$: external forces

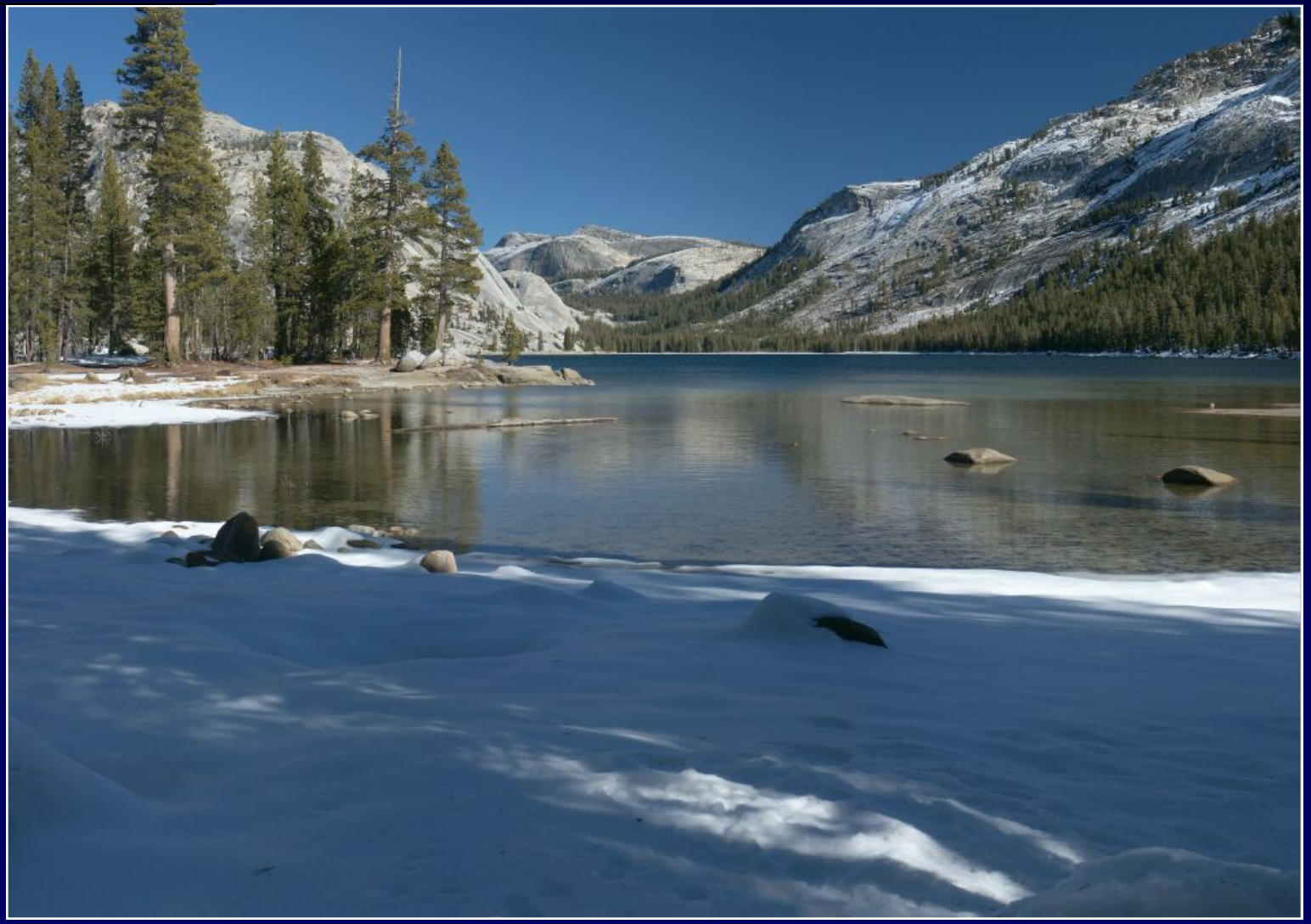
p: pressure

ρ : density

Animation

Behavioral animation

Reality is *Very* Complex



Reality is *Very* Complex

Reality is *Very* Complex

Great! But what are we going to do?

Learn the mathematical foundations of graphics

Apply them in 3 programming projects

Show that you understand the concepts in 2 exams

Summary of the Syllabus

+ Mathematics of computer graphics

+ Rendering

+ Modeling

+ Animation

- Interaction

- Hardware

Mathematics of Computer Graphics

Linear (vector/matrix) algebra

Coordinate systems

Geometry

- Points, lines, planes

Affine transformations

Projection transformations

More geometry

- Curves, surfaces

Typical Comments From Prior 174A Course Offerings

- Lots of math!
- A lot of material
- Fast pace
- A lot of programming
- Tough third project
- Challenging final exam

- Great animation shows at the start of each lecture!

- Please post copies of the lecture slides prior to each lecture?
  - *NO, I won't do that, because…*

Advice

- Attend lectures and discussion sessions!
  - *You will perform better on this course if you do (trust me)*
  - *The lecture slides are your "bible" for the exams*
- Start the assignments EARLY!!
  - *Get HELP from us with the assignments EARLY!*
- Do NOT do more on the assignments than you are required, unless you are done with the required part of the assignment
  - *You will NOT get more points for additional work*
- Refresh your knowledge of linear algebra and geometry, and keep up with the math

Important Issues to Remember

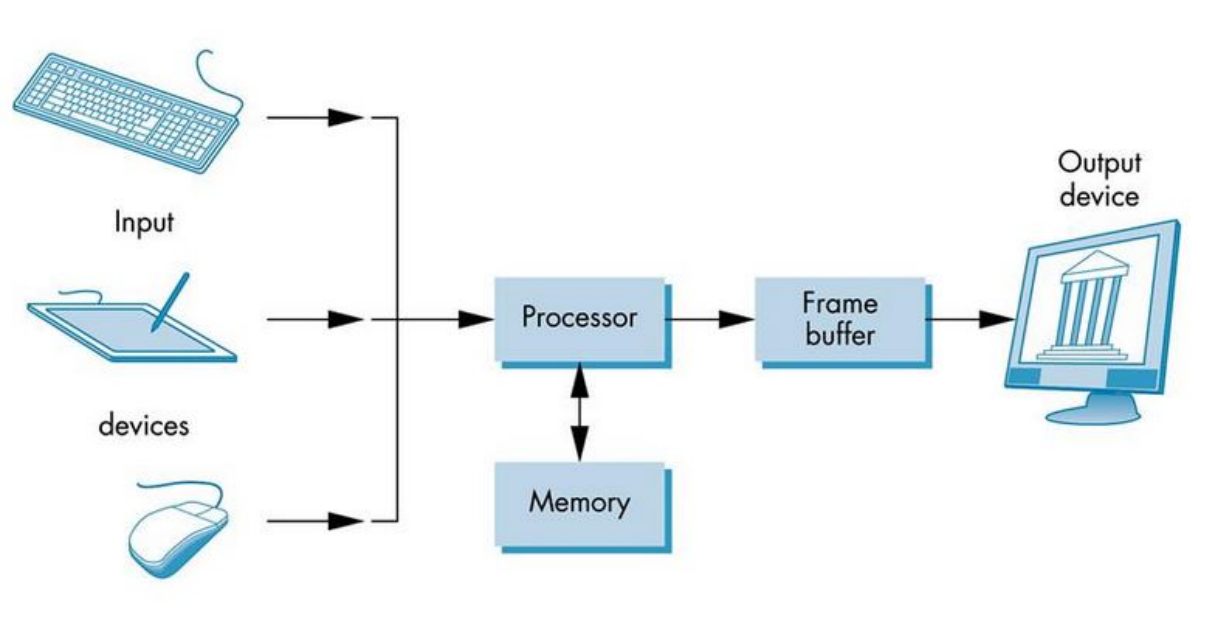
- Lectures normally begin at 5 min past the hour and run for 1.5 hrs non-stop
- Manage your course load
- Do individual work
- No plagiarism (of course)

A Basic Graphics System

Input devices

Output devices

Computing & rendering system



Input Devices

Keyboard

Mouse

Game controller

Tablet & Pen

Other sensors

- *Data glove*
- *Etc.*

Output Devices

Display

- LCD, Micromirror, Plasma, CRT
- VR headset

Printer

- 2D and 3D Printers

Standard Display Devices

LCD

(Liquid Crystal Display)

Plasma

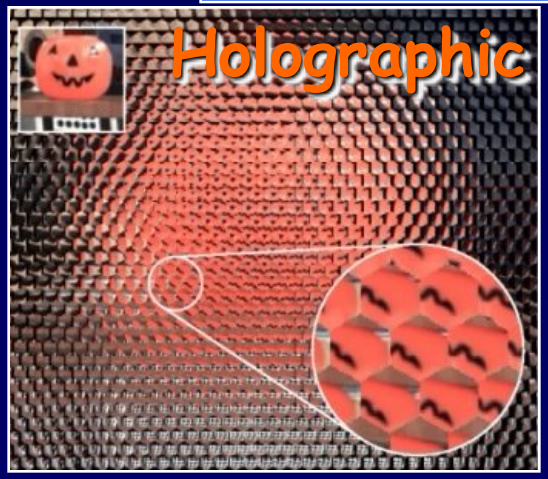
CRT

(Cathode Ray Tube)

Other display devices

- Passive Liquid Crystal (obsolete)
- Active Matrix (TFT) (transistors at grid points)
- Plasma Panel (neon bulbs)

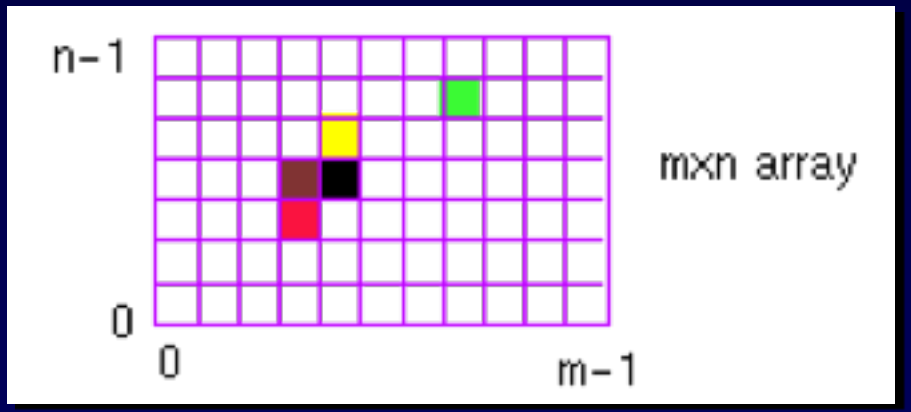
Exotic Display Devices



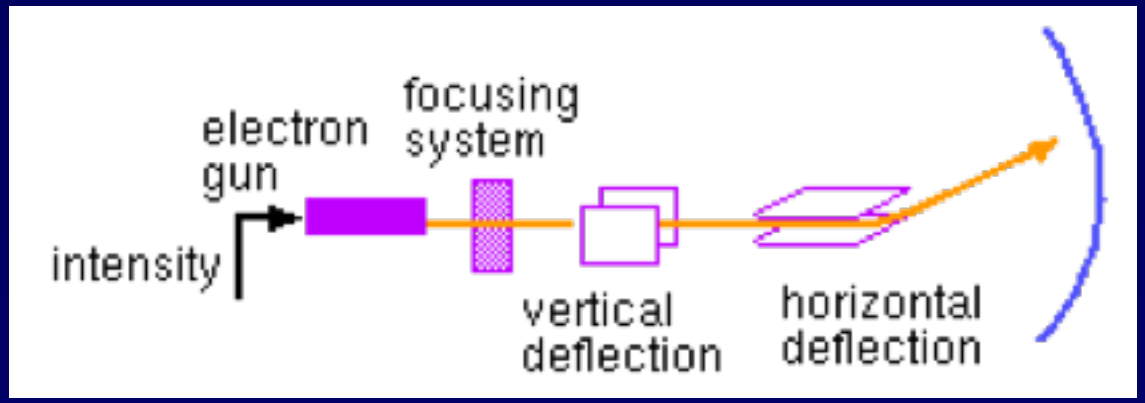
CRT Raster Graphics

Virtual raster device

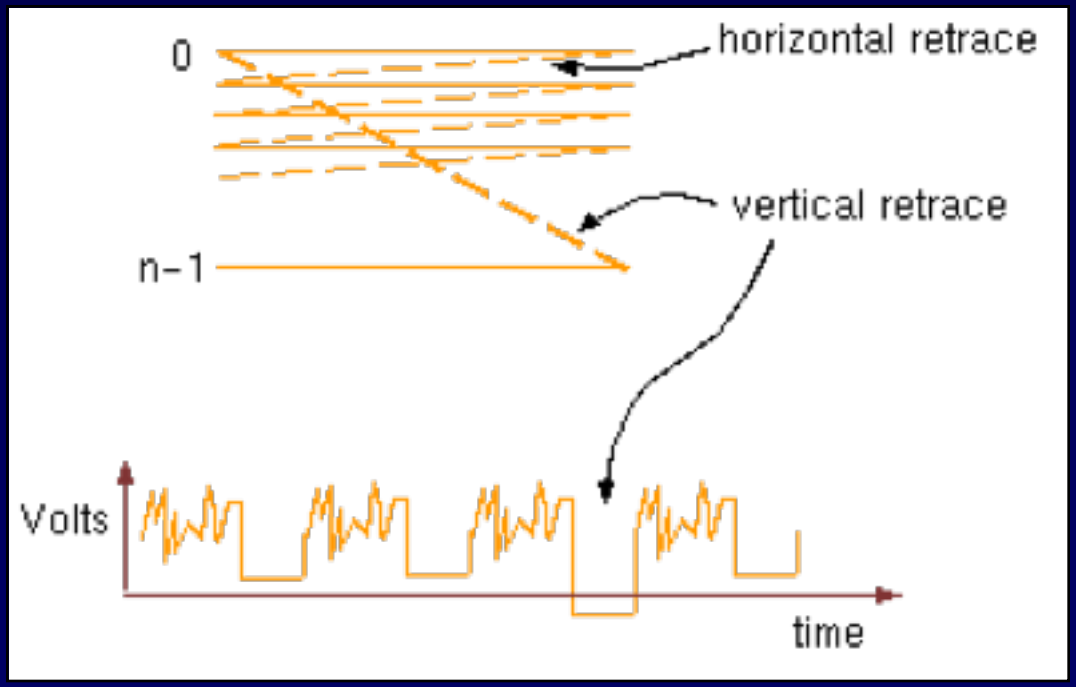
- Grid of m x n phosphors



Real raster device



Analog Video Signal Format



Displaying Intensities: Gamma Correction

Intensities

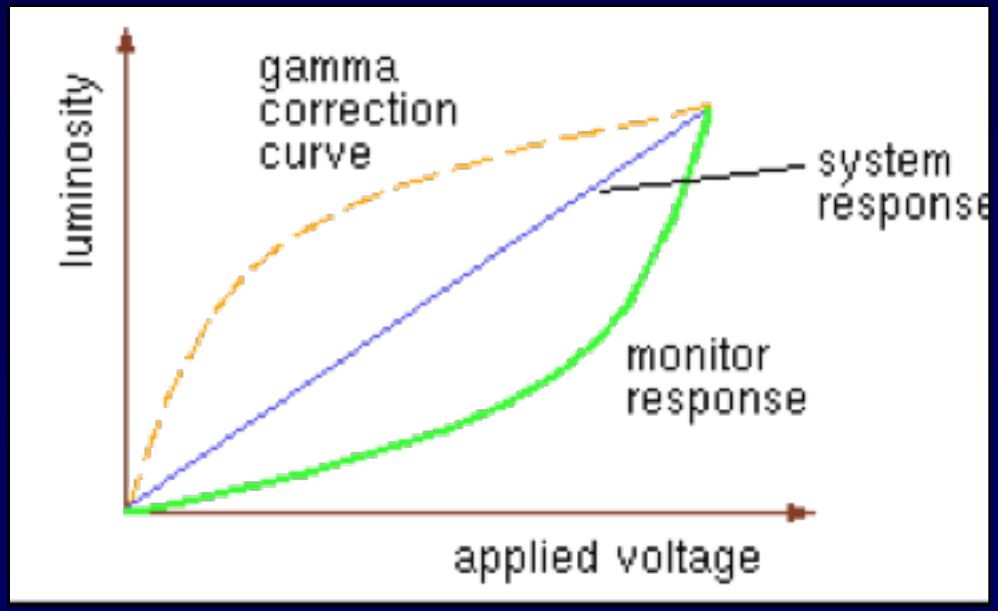
Phosphor emits intensity: $I = kN^{\gamma}$
where N is the number of electrons and γ is in (2.2, 2.5)

N is proportional to the control grid voltage which is proportional to the pixel value V

$I = KV^{\gamma}$ or $V = (I/K)^{1/\gamma}$

Displaying Intensities

Gamma Correction



Basic Analog Display Architecture

Pixels:

- Bitmap: 1bit/pixel
- Grey scale: 8 bits/pixel
- Color map: 8 bits/pixel, indirect
- True color: 24 bits/pixel
- True color + Alpha Channel: 32 bits/pixel

Selecting Intensities

Display 256 Intensities between 0 and 1

- Uniform is not good
- Eye is sensitive to ratios of intensities
- Intensities 0.10 and 0.11 differ as much as 0.5 and 0.55 for the human eye

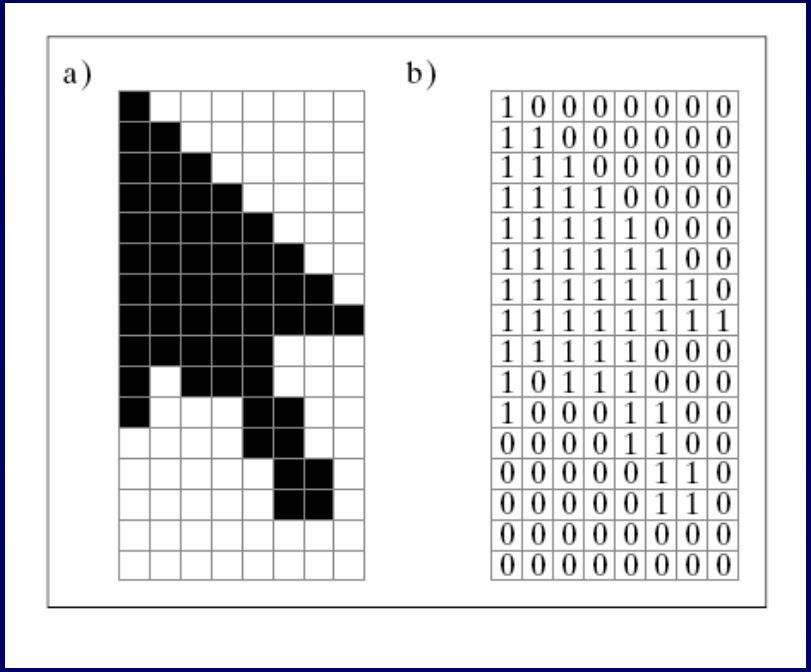
Definitions

- Pixel aspect ratio: width/height usually 1.
- Image aspect ratio: m/n: 4/3 for NTSC, 16/9 for HDTV.
- Refresh rate: most displays 60 or 72 Hz non-interlaced.
- Phosphorescence: light emitted after electron beam has passed.
- Monitor bandwidth: rate at which electron beam can turn on or off.
- Spot size: diameter of a single dot on the output device.
- Resolution: density of lines that can be resolved.

Images -- Monochrome

How many intensities are enough?

Black and White (Bitmaps)



Grayscale

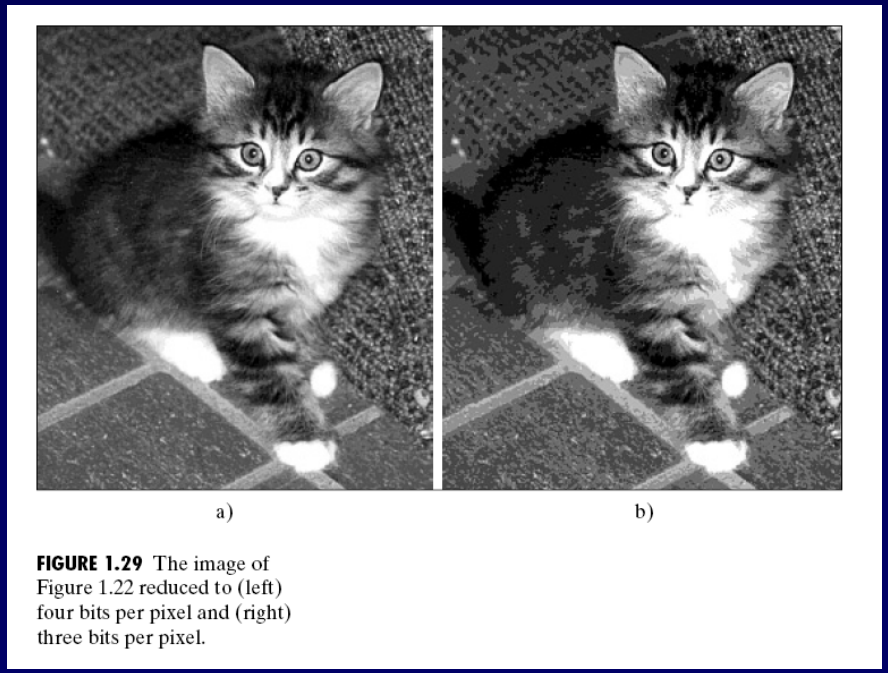
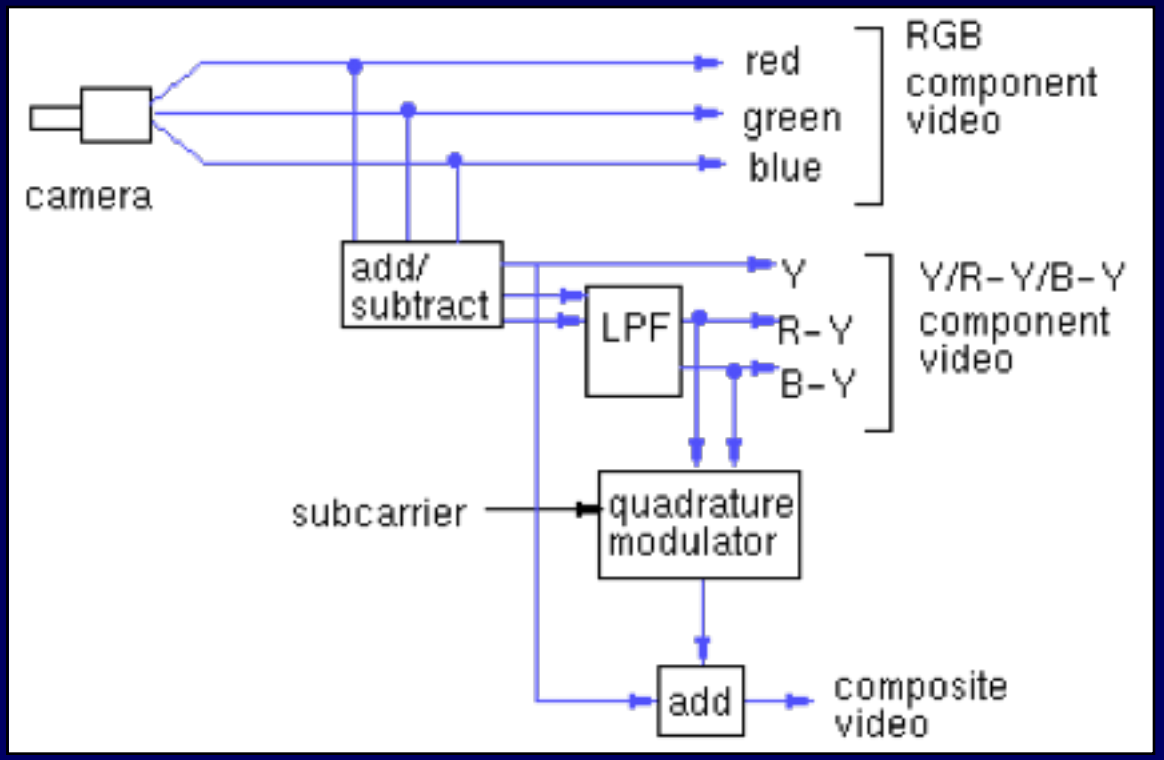


FIGURE 1.29 The image of Figure 1.22 reduced to (left) four bits per pixel and (right) three bits per pixel.

Color

Common format RGB (3x8 = 24 bits per pixel)

Video


camera
red
green
blue
RGB
component
video
add/
subtract
LPF
Y
R-Y
B-Y
Y/R-Y/B-Y
component
video
subcarrier
quadrature
modulator
add
composite
video

Standards

- **NTSC**
  - *North America & Japan*
  - *30 Hz, interlaced, 525 lines*
- **PAL**
  - *Britain and Western Europe*
  - *25 Hz, interlaced, 625 lines*
- **SECAM**
  - *France, Eastern Europe, Middle East*
  - *26 Hz, interlaced, 625 lines*
- **HDTV**
  - *16:9 aspect ratio, digital, interlaced or progressive*

Images

2D Arrays of color values (numbers)

- Monochrome
- Color

Rendering System

Software

- Interface
- Primitives
- Techniques

Hardware

- Graphics Pipeline

The Graphics Pipeline

NVIDIA GeForce GTX TITAN X (2015)

Why a pipeline?

- Well defined stages
- Parallelism
- Software and Hardware

ATI Radeon X800 (2004)

- 16 parallel rendering pipelines
- Floating point architecture
- Millions of triangles per second

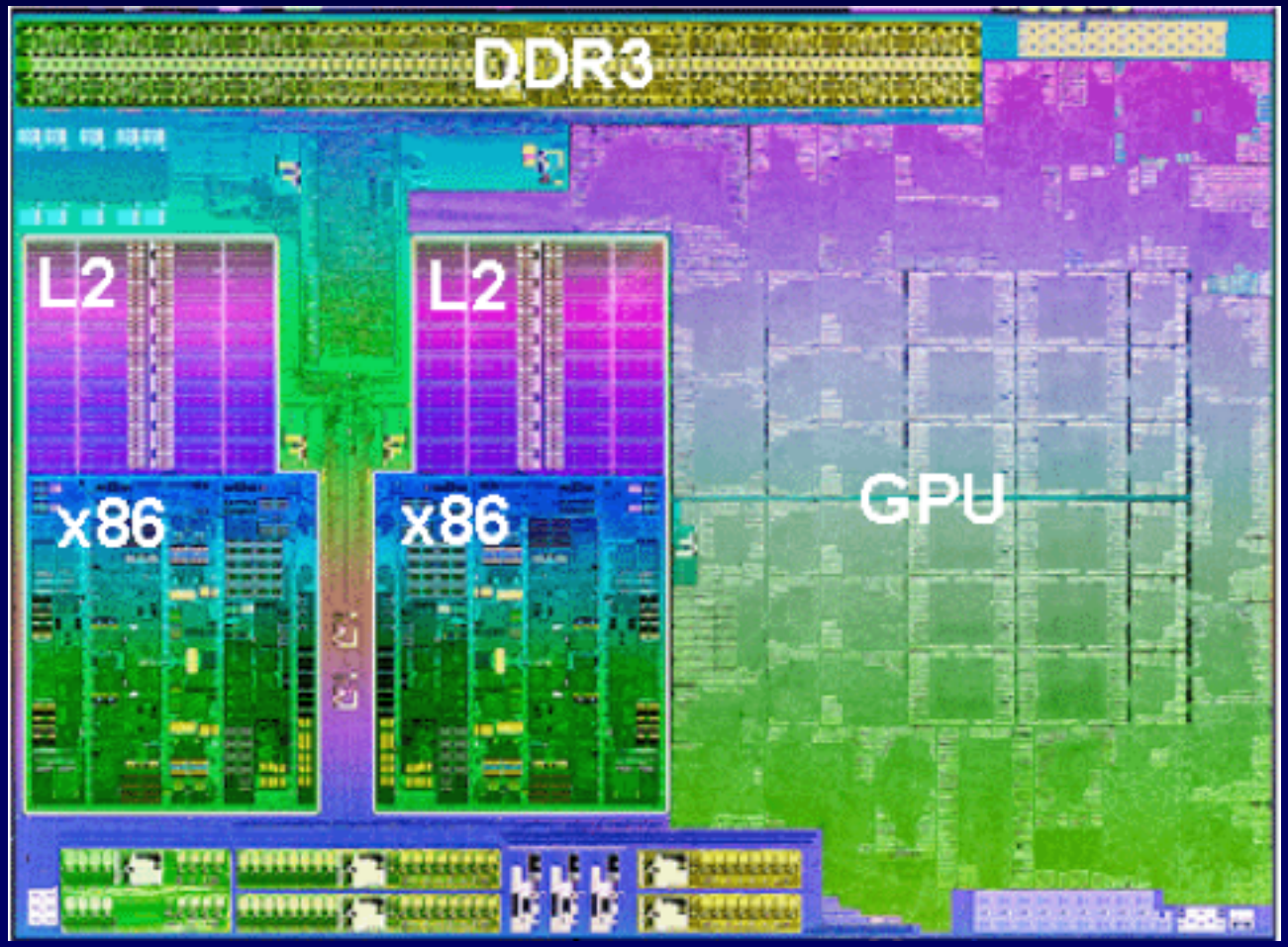
ATI Radeon 9700 (2002)

The “Latest” GPUs

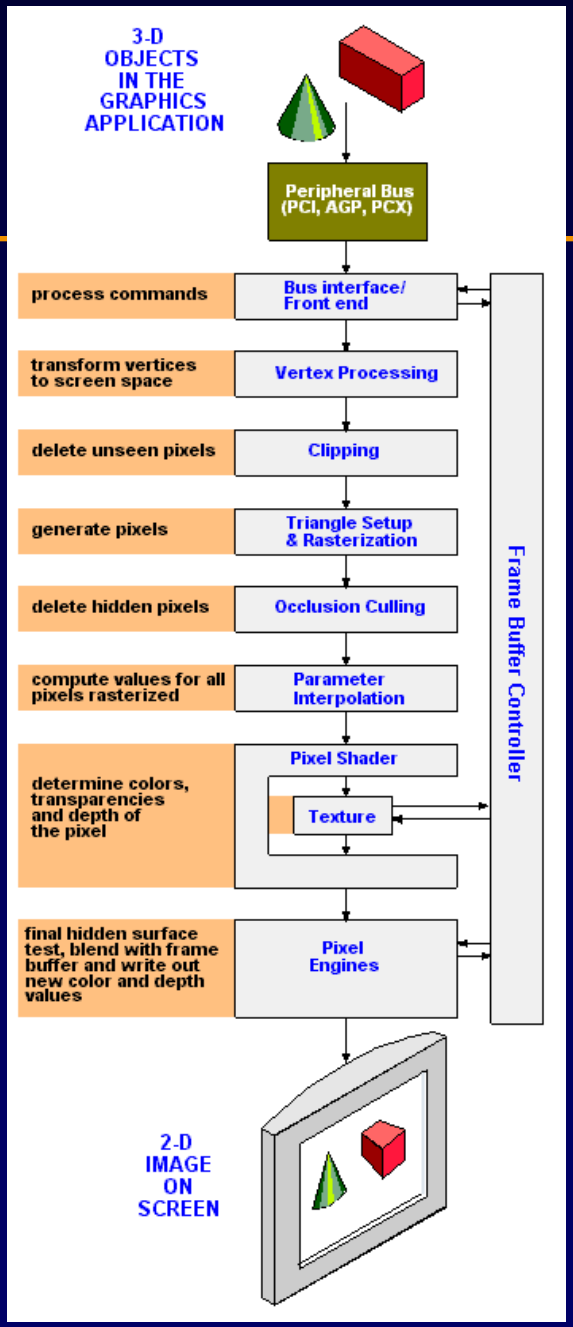
NVIDIA’s GTX 980 Ti

AMD's R9 Fury X

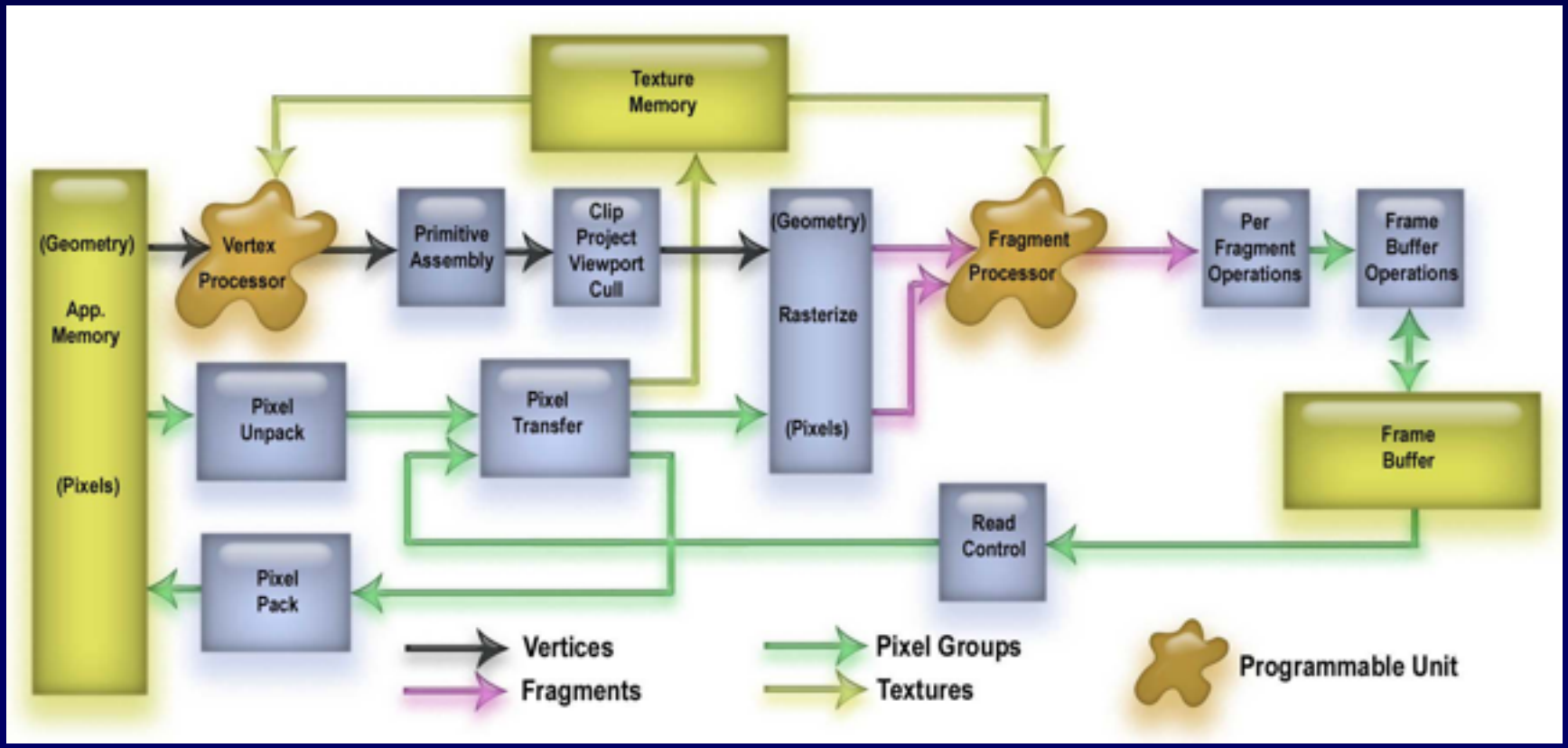
An Integrated GPU (AMD Trinity)



Stages in the Pipeline of a Modern GPU



Programmable OpenGL Pipeline



Per Vertex Operations and Per Pixel / Fragment Operations

Vertex Processor

- Vertex shaders

Fragment Processor

- Fragment shaders

Graphics Pipeline

Modeling

Illumination

Viewing (Projection)

Clipping

Visibility

Rasterization

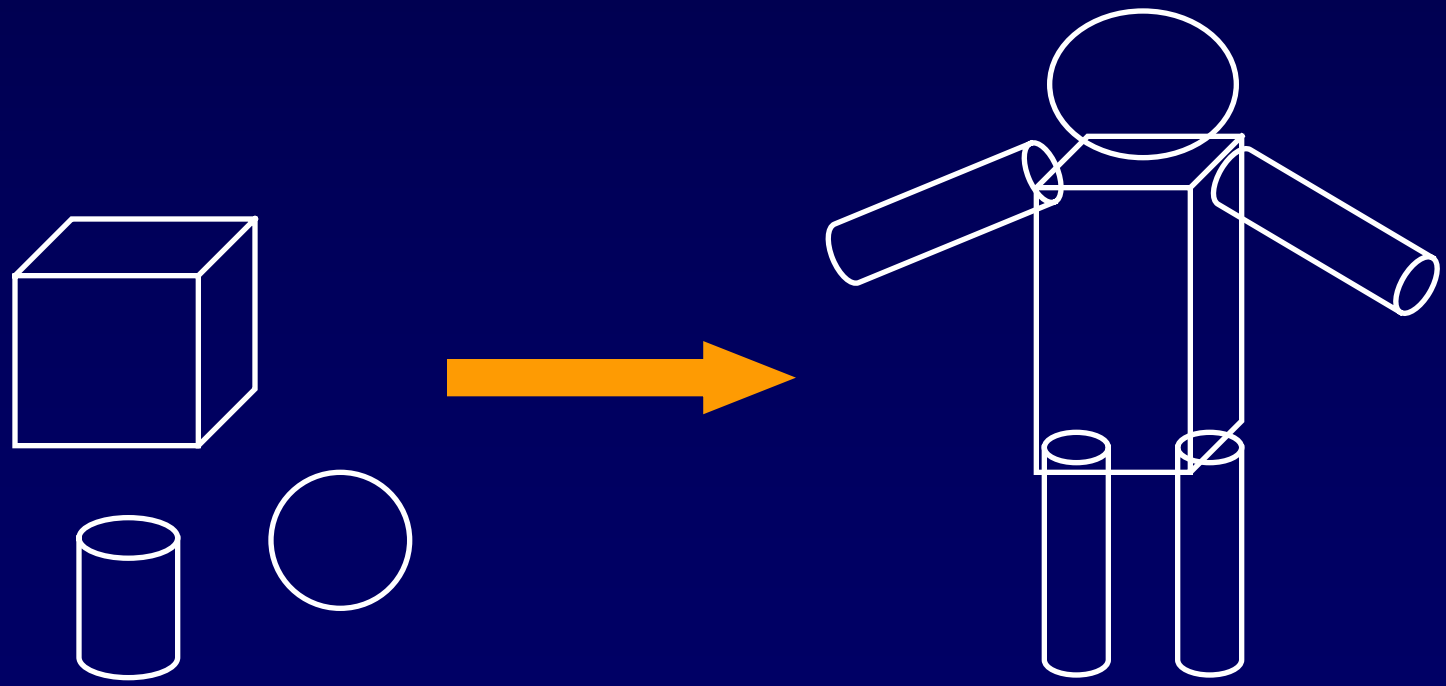
Modeling

Geometric Primitives

- Points
- Lines
- Planes
- Polygons
- Parametric surfaces
- Implicit surfaces
- Etc.

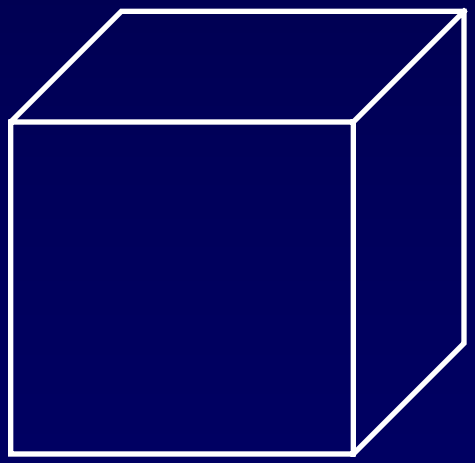
Modeling Transformations

Assembly

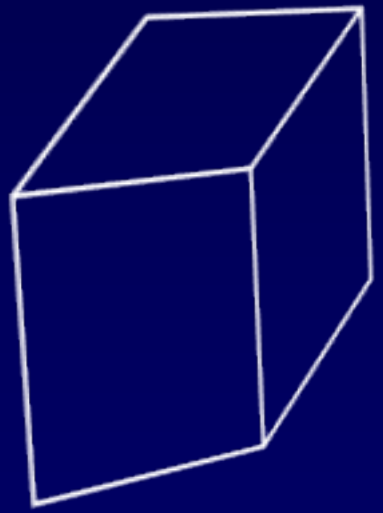


Viewing

Orthographic

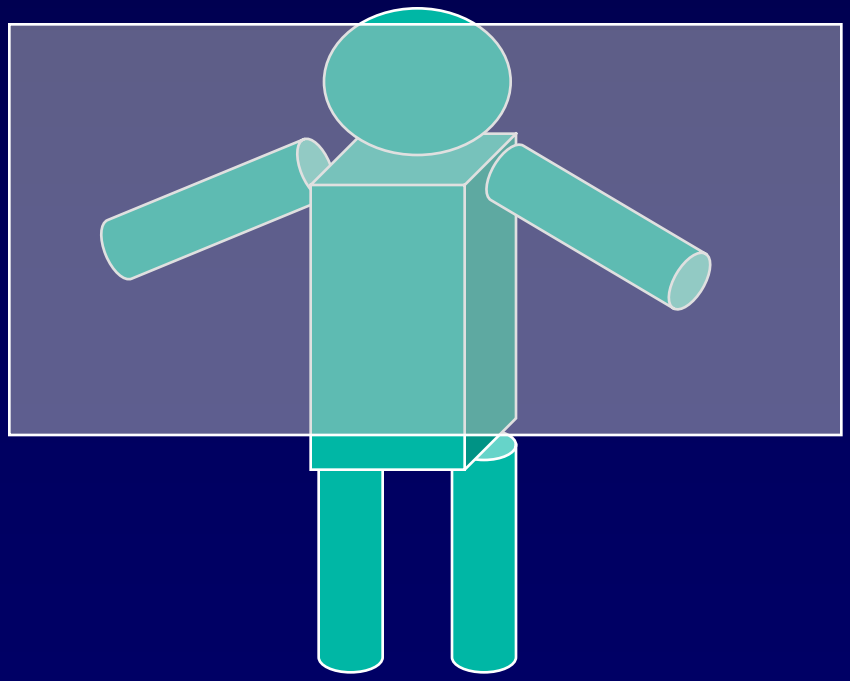


Perspective



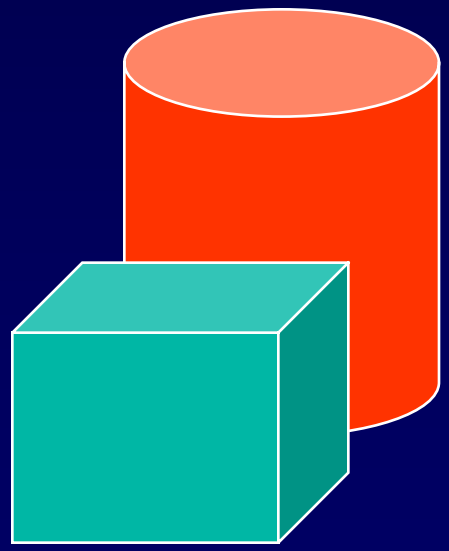
Clipping

Remove what is not visible



Visibility

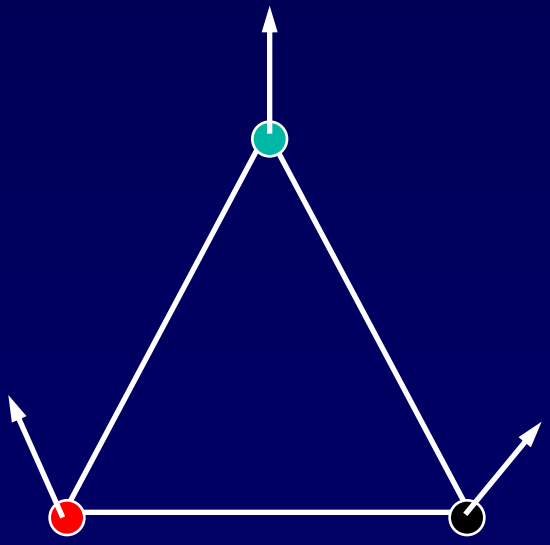
Resolve occlusions (efficiently)

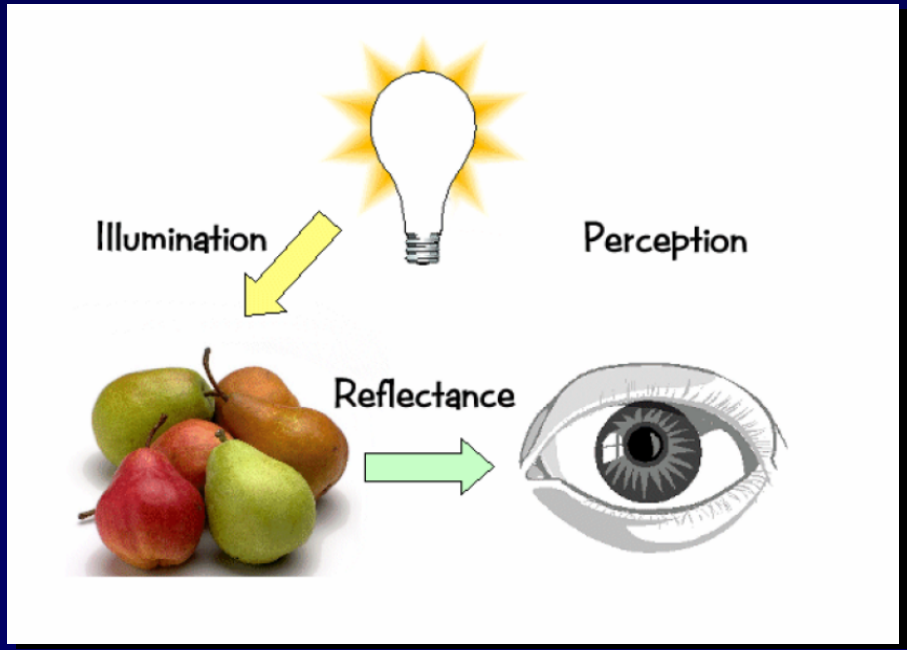


Illumination

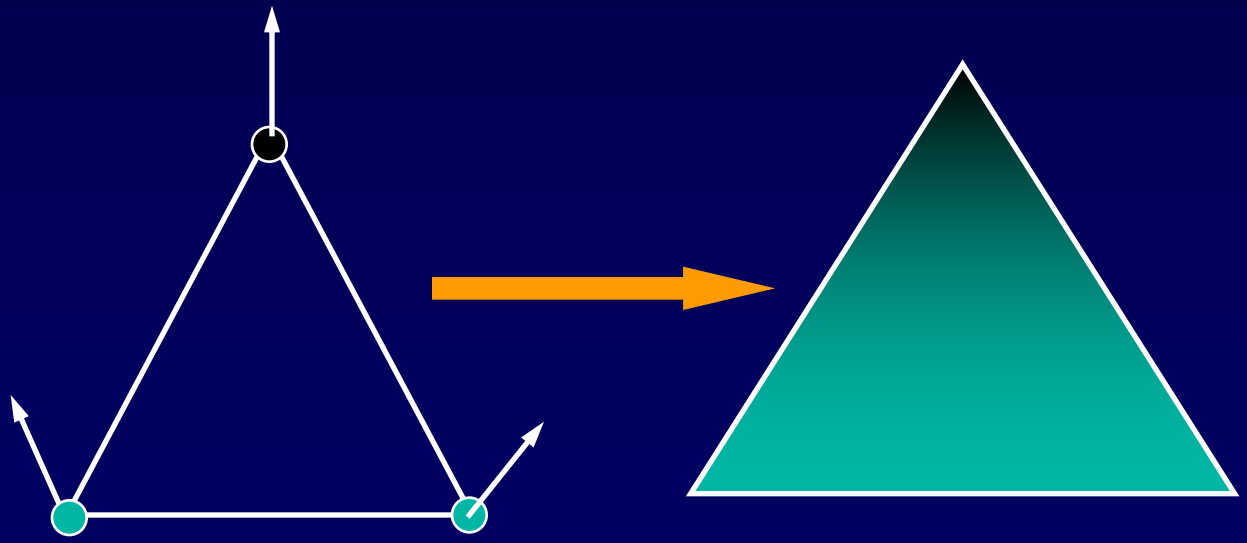
Compute normals and color at vertices

Per vertex operations



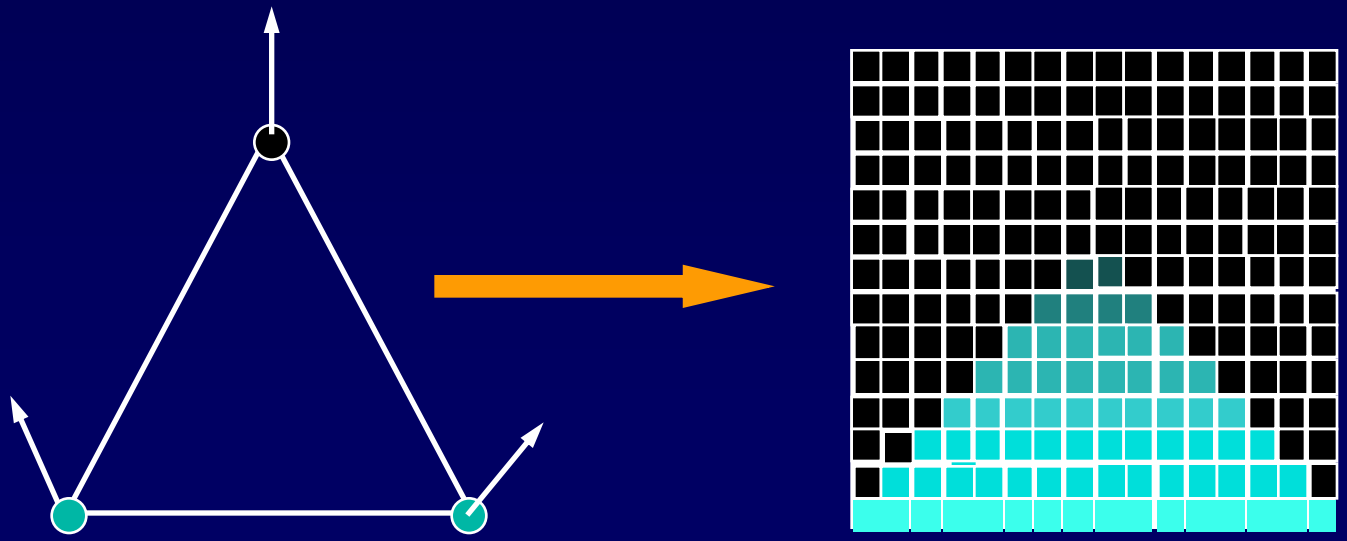


Shading

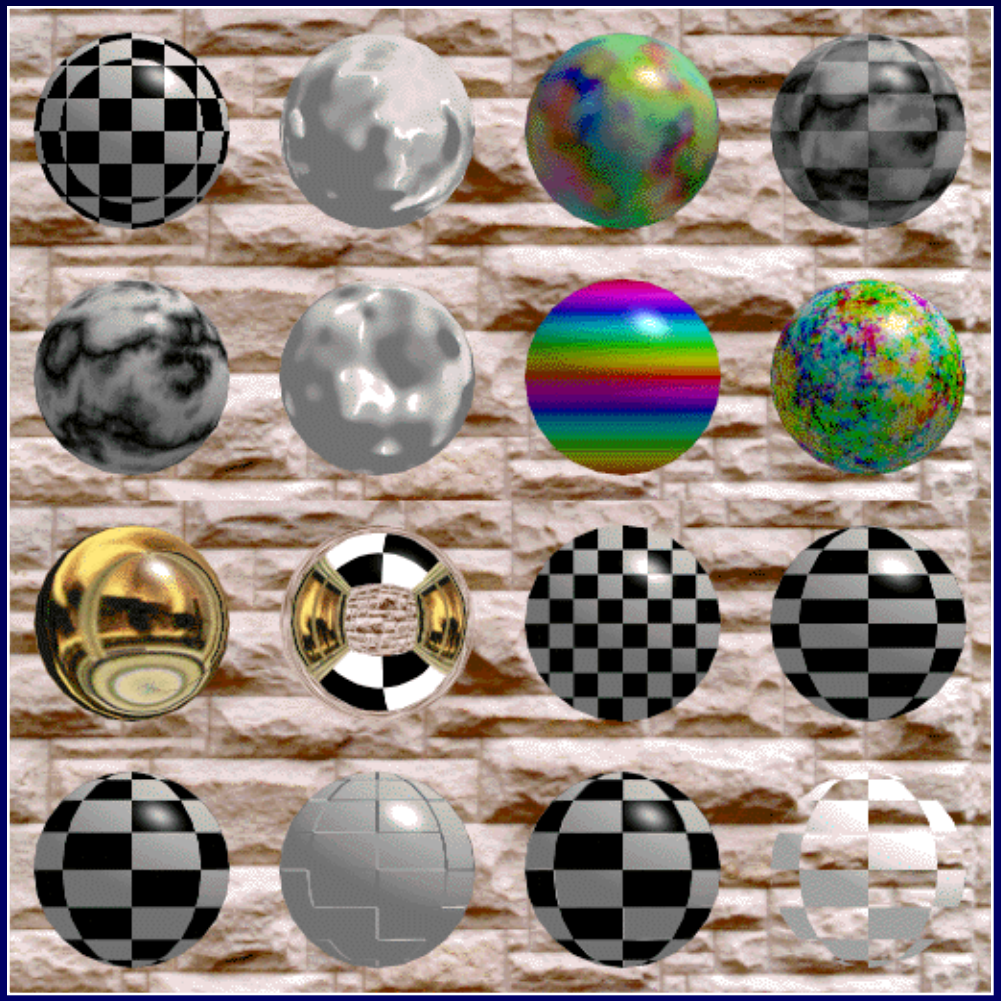


Rasterization

Convert to colored pixels



Texture Mapping



Other Issues

Shadows

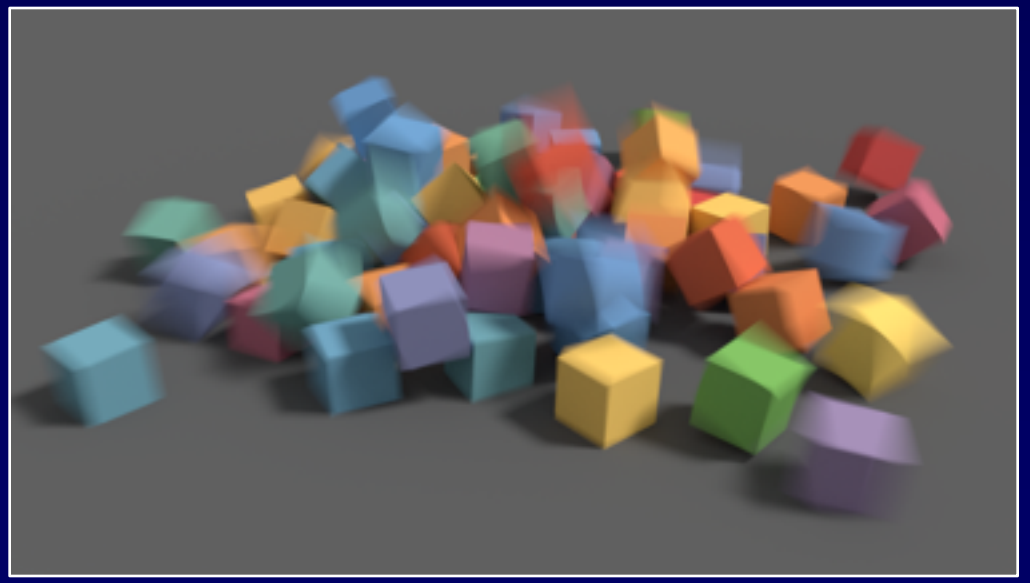
Participating media

Subsurface scattering

Motion blur

Camera models

Etc.



Final Result