CSC 317/2504: Computer Graphics

Course web site (includes all course information):
https://github.com/karansher/computer-graphics-csc317

Lectures: Monday 11:00-13:00 UC140 15:00-17:00 AH400
Slides and many lecture topics videos will be posted.

Prof. Karan Singh
karan@dgp.toronto.edu
Office hours Mondays 13:00-15:00 in BA 5258 or by appointment.

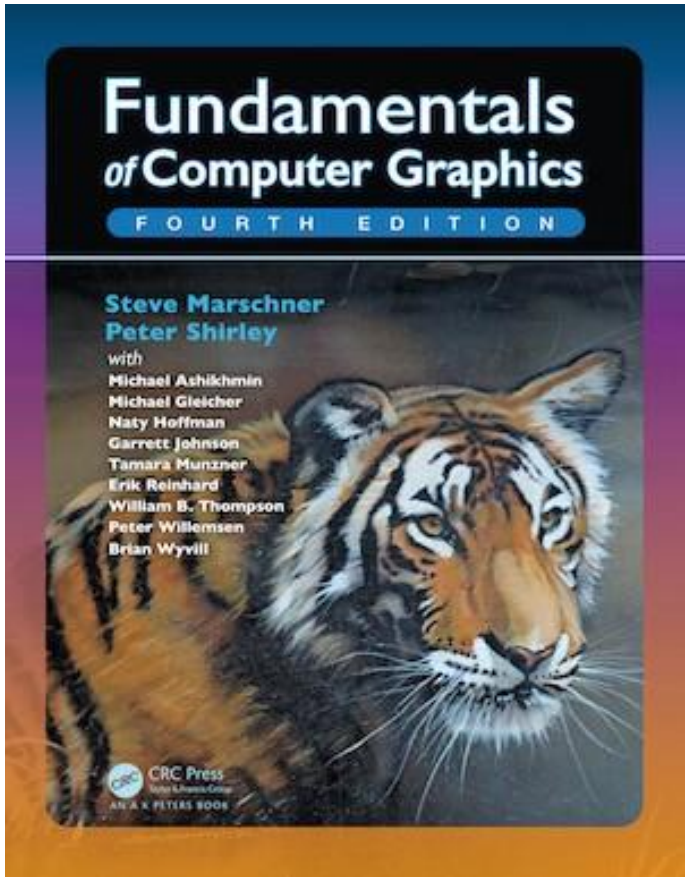
Tutorials: Wednesday 11:00-12:00 UC140, 16:00-17:00 AH400

Questions:
on Assignments: Github issues pages
on Administrative stuff: Quercus

Textbooks: Fundamentals of Computer Graphics
OpenGL Programming Guide & Reference

You will need:

- A computer to install and program the assignments.
- An internet connection for online material and to join occasional zoom meetings.
- Availability during class and tutorial times.
- The textbook for required readings



Marking Scheme

%	Item
9%	Assignment 1
9%	Assignment 2
9%	Assignment 3
9%	Assignment 4
9%	Assignment 5
9%	Assignment 6
9%	Assignment 7
9%	Assignment 8
8%	4 Quercus quizzes
10%	In class term test
10%	Take home term test

Academic Honesty Policy is on the webpage and is mandatory reading!

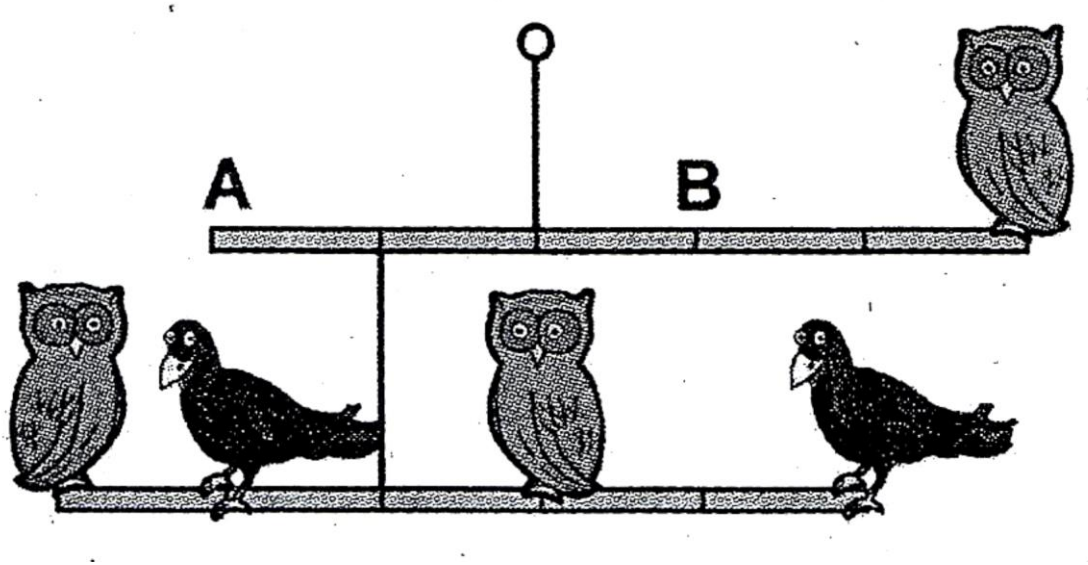
Tutorials sessions will be invaluable for the assignments.

Prerequisites (pre-test)

Background in math, CS and programming is required for this course.

A quick self-monitored pre-test (15-20 mins should be enough to do it)

1. Show you the mathematical background expected and your readiness for this course.
2. Show you what you need to brush up on. Questions about these math operations will not be answered by either Professors or TAs, we expect you to know this stuff.



Discrete Math

Q1: What is the intersection of the interval $\mathcal{A} = [-1, 3]$ and $\mathcal{B} = [0, 4]$? $\mathcal{A} \cap \mathcal{B} =$

Q2: In a balanced binary tree with n leaf nodes, how many internal nodes are there?

Q3: In a balanced binary tree with n leaf nodes, how deep is the tree?
(i.e., number of nodes on a shortest path from root to leaf)

Q4: What is 5! (five factorial)?

Q5: How many different ways are there to choose k items from a set of n items?

Linear Algebra

Q6: What size is the result of multiplying a 2×3 matrix and a 3×4 matrix?

Q7: What is the dot product between the vector $\mathbf{a} = [1, 2, 3]$ and $\mathbf{b} = [4, 5, 6]$? $\mathbf{a} \cdot \mathbf{b} =$

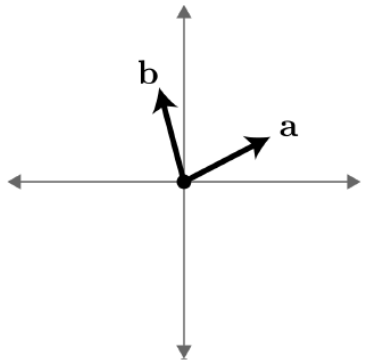
Q8: What is the cross product between the vector $\mathbf{a} = [4, 0, 0]$ and $\mathbf{b} = [0, 0, -2]$? $\mathbf{a} \times \mathbf{b} =$

Q9: What is the matrix product of the matrix $\mathbf{A} = \begin{pmatrix} 1 & 0 & 4 \\ 0 & 2 & 1 \\ 0 & -3 & 0 \end{pmatrix}$ and the vector $\mathbf{b} = \begin{pmatrix} -4 \\ 5 \\ 6 \end{pmatrix}$?

$\mathbf{A}\,\mathbf{b} =$

Q10: Using matrices, express the solution to the following system of equations:
$3x_1 + 2x_2 - 1x_3 = 10$, $2x_1 - 10x_3 = 0$, $-9x_1 + 9x_2 = -1$. (Form the system, but do not solve).

Q11: *Sketch* the results of $\mathbf{c} = \mathbf{a} + \mathbf{b}$ and $\mathbf{d} = \mathbf{b} - \mathbf{c}$ on the plot:



Mappings

Q12: Suppose we have a $f : \mathcal{A} \to \mathcal{B}$, what needs to be true to call f a *well-defined function*?

Q13: Is $f(x) = x^2$ invertible? Why (not)?

Q14: If x and y are real numbers, what sets are the domain and range of $f(x, y) = x^2 + y^2$? (use $\mathbb{R}$)

Logarithms

Q15: Express $\log(a^b)$ in terms of $\log a$ and b. $\log(a^b) =$

Q16: Express $\log(ab)$ in terms of $\log a$ and $\log b$. $\log(ab) =$

Trigonometry

Q17: Express $\cos(a + b)$ in terms of $\cos a$ and $\cos b$. $\cos(a + b) =$

Q18: Given a triangle with side lengths a, b, c and opposite angles A, B, C, express $\sin A$ in terms of a, b, and $\sin B$.

$\sin A =$

Q19: Given a right triangle with acute angles A and B, express the following in terms of opposite side length a and b:

$\sin A =$ $\cos A =$ $\tan A =$

Quadratic equation

Q20: How many real-value solutions for x are possible to an equation of the form $ax^2 + bx + c = 0$?
A) zero; **B)** one; **C)** two; **D)** three; **E)** zero, one or two; *or* **F)** zero, one, two or three.

Q21: Identify the solution(s), if any, to $x^2 - 4x - 5 = 0$.

Linear interpolation

Q22: What is *the* linear function $f : [0, 1] \to \mathbb{R}$, so that $f(0) = a$ and $f(1) = b$?

Q23: What is *the* linear *vector-valued* function $f : [0, 1] \to \mathbb{R}^3$, so that $f(0) = \mathbf{a}$ and $f(1) = \mathbf{b}$?

Derivatives

Q24: What is the derivative of the function $f(t) = 3t^2$? $\frac{df}{dt} =$

Q25: What is the second derivative of the function $f(t) = 3t^2$? $\frac{d^2f}{dt^2} =$

Q26: What is the partial derivative of the function $f(x, y) = 3x^2 - 3y^2$ with respect to y? $\frac{df}{dy} =$

Q27: Given a function $f : \mathbf{R}^3 \to \mathbf{R}$, how many dimensions does its gradient have?

Q28: Using partial derivative and vector notations express the gradient of a function $f(x, y, z) : \mathbf{R}^3 \to \mathbf{R}$.

$\nabla f =$

C++ Programming

Q29: We want to call `func` on `x`, what should be written in place of the question mark in the following C++ code?
A) `*`; **B)** `&`; *or* **C)** nothing.

```
bool func(double & x);
...
int main()
{
  double * x = new double();
  func( ? x);
}
```

Geometry

Q30: What is the volume of a sphere with radius r?

Lecture Topics

- Introduction: What is Computer Graphics?
- Raster Images (2D image representation, manipulation and compositing) *A1*.
- Ray Casting (camera, visibility, normals, lighting, Phong illumination) *A2.*
- Ray Tracing (shadows, supersampling, global illumination) *A3.*
- Spatial Data Structures (AABB trees, OBB, bounding spheres, octree) *A4.*
- Meshes (connectivity, smooth interpolation, uv-textures, subdivision, Laplacian smoothing) *A5.*
- 2D/3D Transformations (Translate, Rotate, Scale, Affine, Homography, Homogeneous coordinates)
- Viewing and Projection (matrix composition, perspective, Z-buffer)
- Shader Pipeline (Graphics Processing Unit) *A6.*
- Animation (kinematics, keyframing, Catmull-Romm interpolation, physical simulation) *A7.*
- Physical simulation (mass spring systems) *A8.*
- Advanced topics overview

Today

1. Introduction to Computer Graphics.
2. Preview of Assignments.
3. Raster Images.

Introduction to Computer Graphics

What is Computer Graphics?

Computers:

accept, process, transform and present information.

Computer Graphics:

accept, process, transform and present information

in a visual form.

Ok but… what is the course really about?

The science of turning the rules of geometry, motion and physics into (digital) pictures.

What its not about?

Photoshop, AutoCAD, Maya, Blender, Renderman, Graphics APIs.

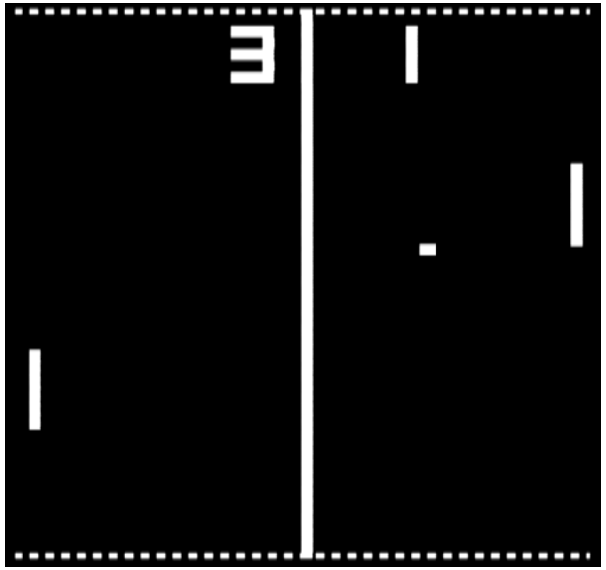
Movies

- Drive new directions in CG
- Set quality standards for CG

Games

Drive interactivity and AI in CG

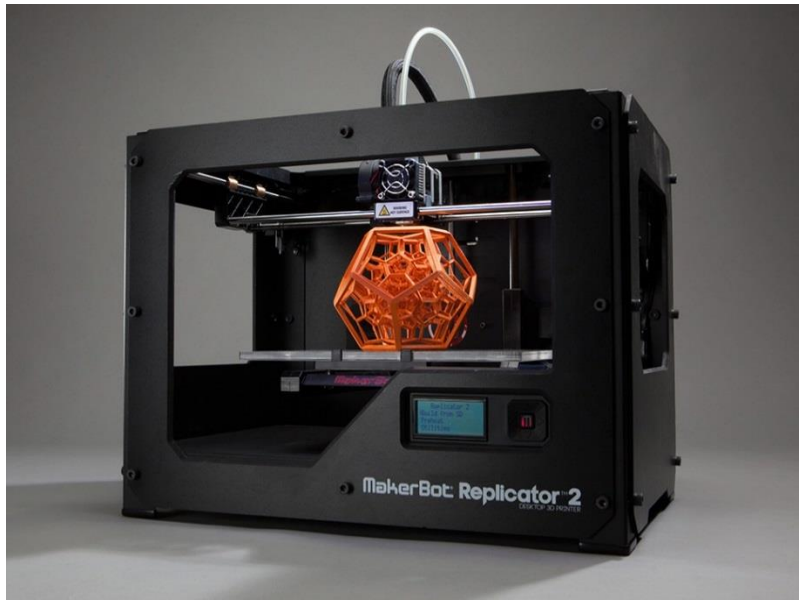
Push CG hardware to its limits

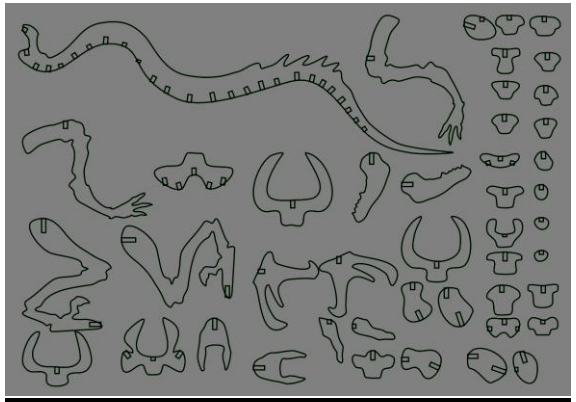


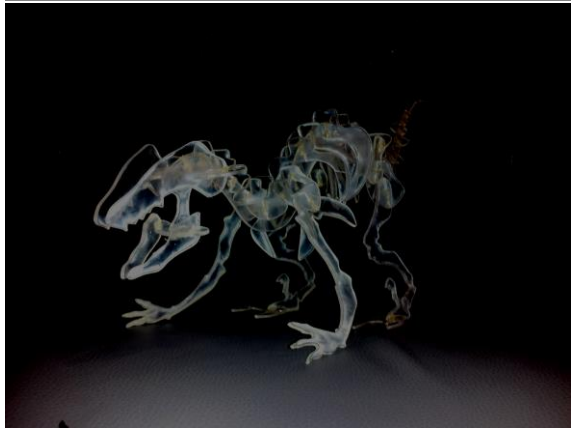
Design

CG for prototyping and fabrication

Drives precision modeling and engineering visualization





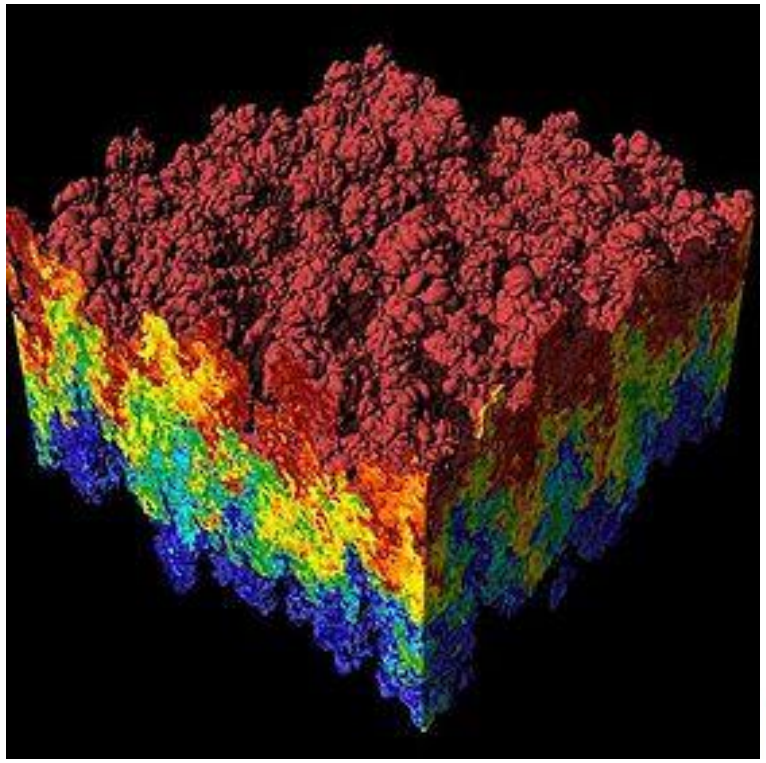


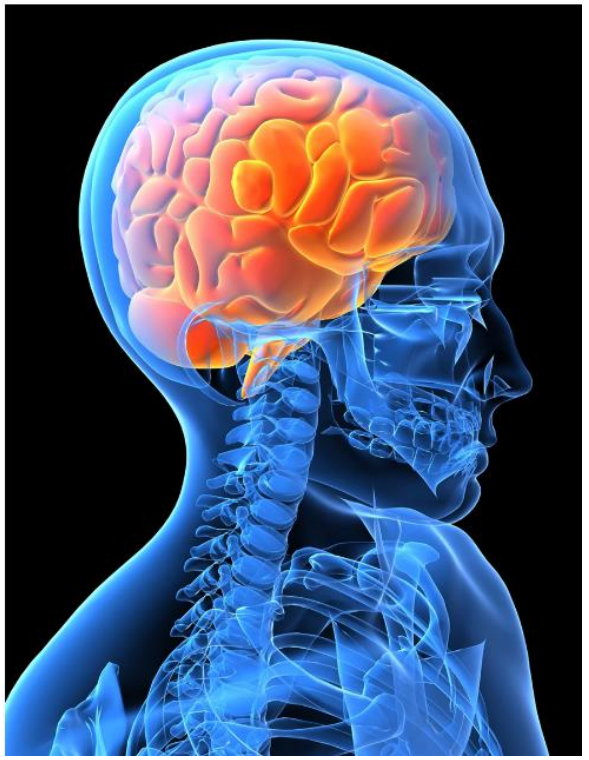
Scientific and Medical Visualization, Operation

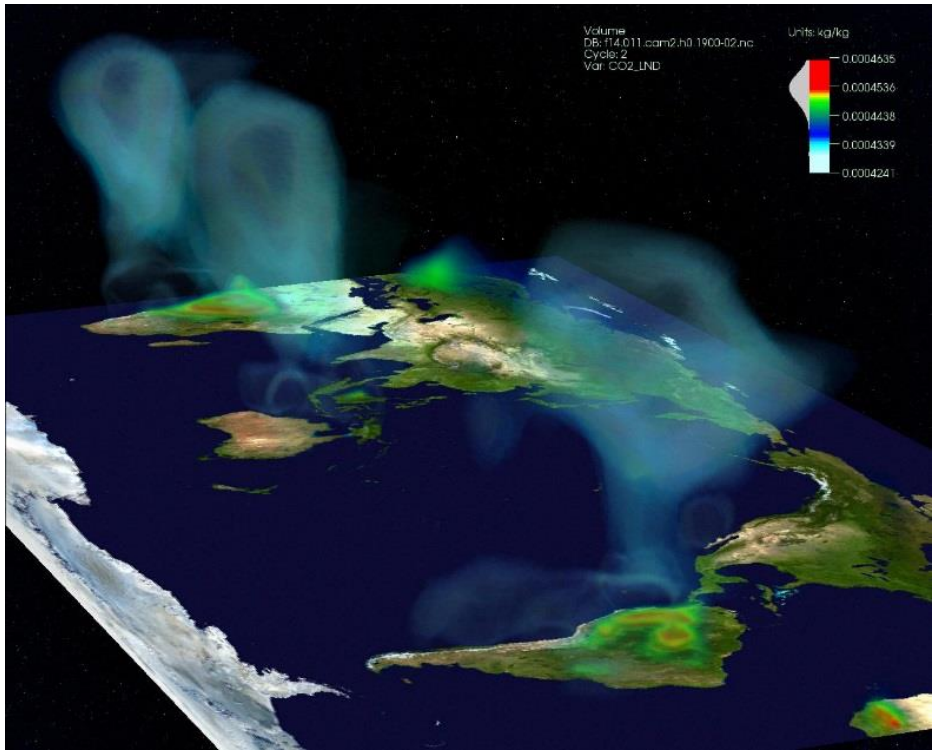
Drives the rendering of large datasets

May need device integration

Real-time and interactive



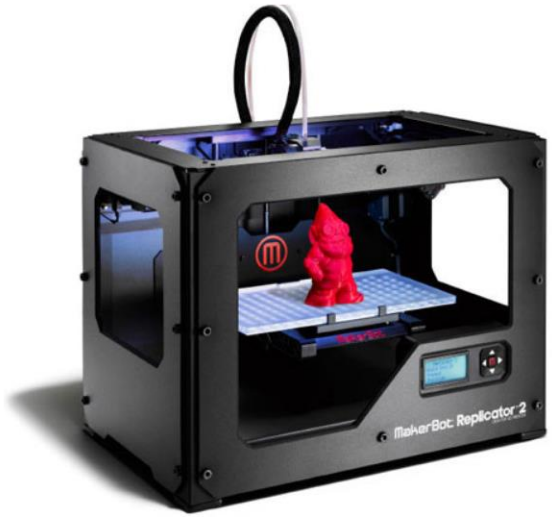




GUIs, AR/VR, scanners, Computational Photography…

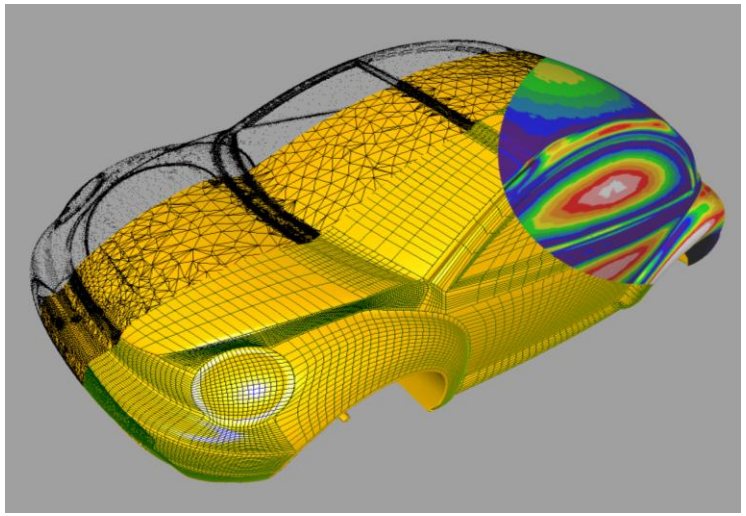
I/O of 3D data in CG

Drives interaction and usability



“Core” Areas of Computer Graphics

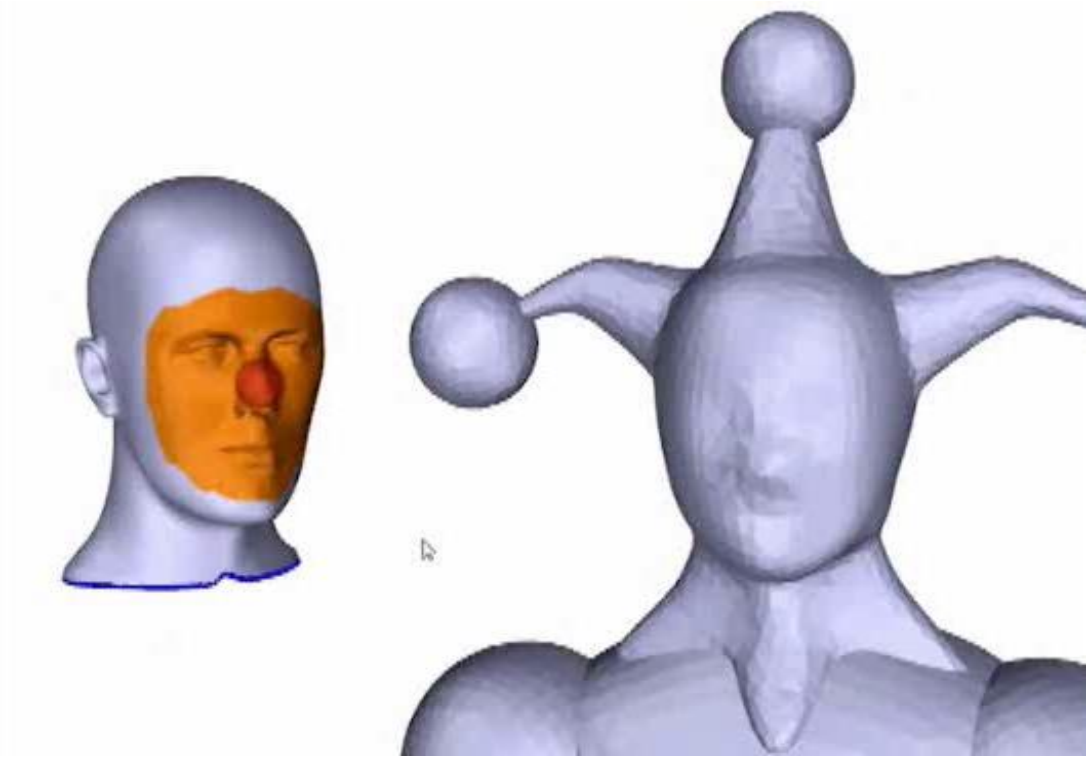
- Form (modeling)
  - How do we represent (2D or 3D) objects & scenes?
  - How do we build these representations?



- Function, Behavior (animation)
  - How do we represent the way objects move?
  - How do we define & control their motion?

- Appearance (rendering)
  - How do we represent the appearance of objects?
  - How do we simulate the image-forming process?

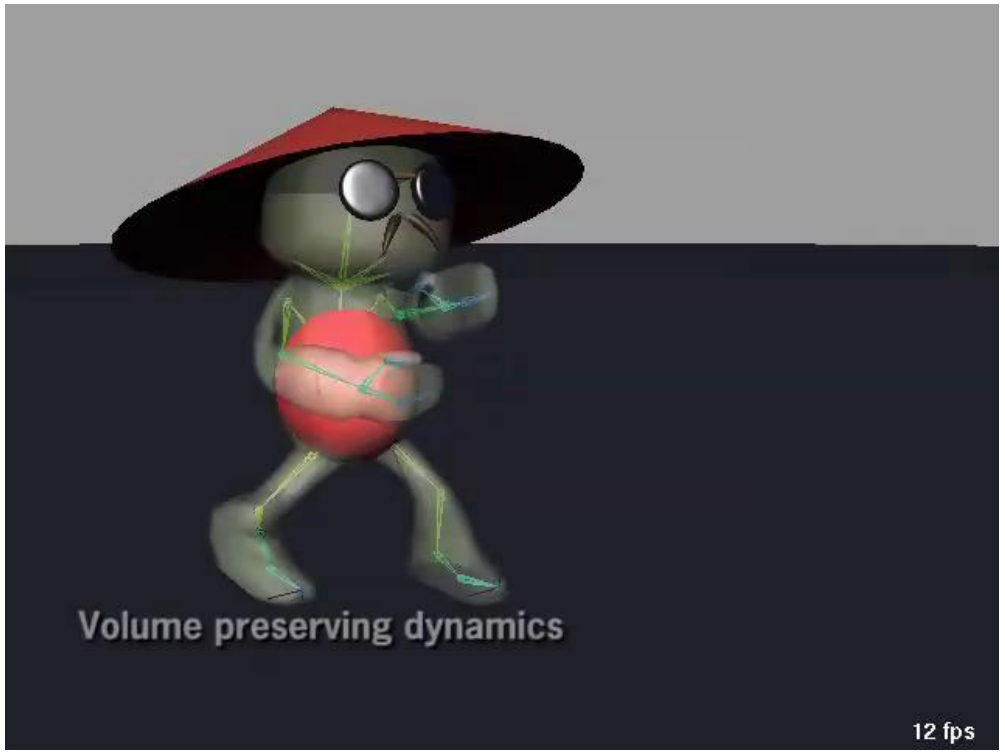
Modeling



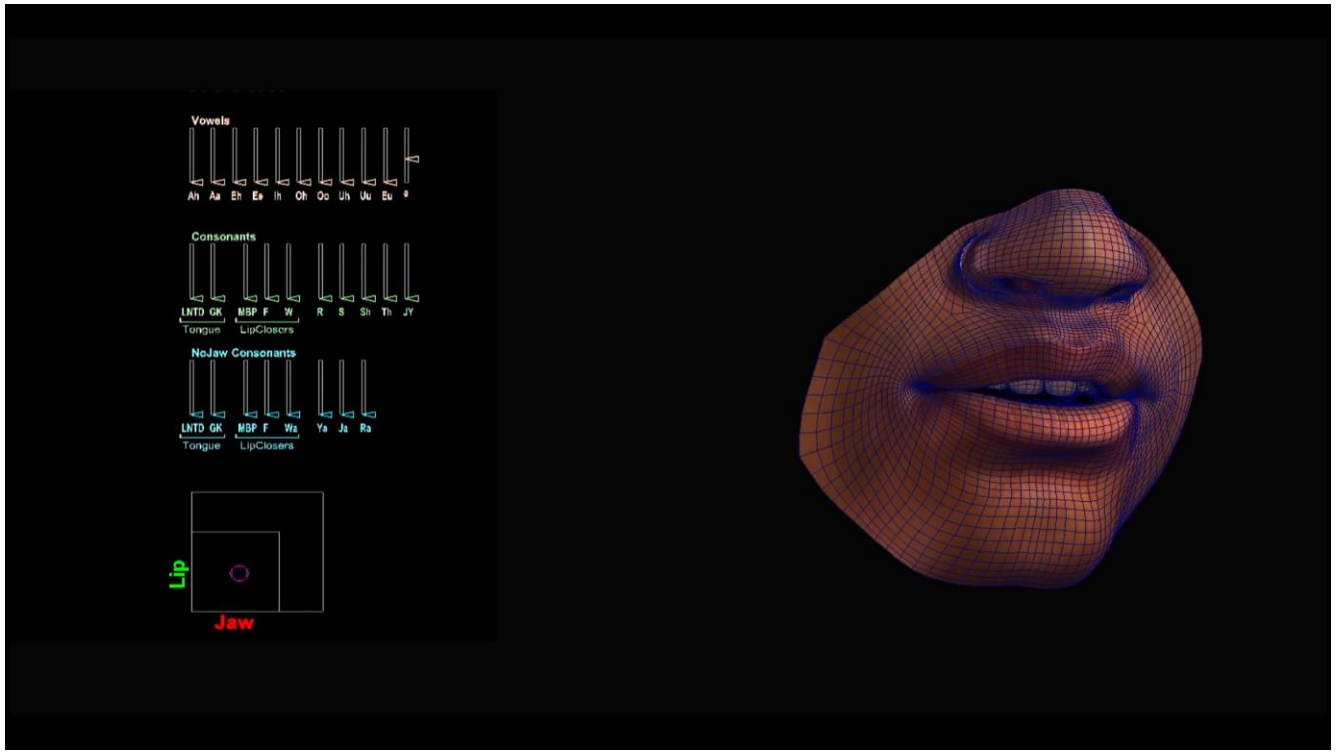
[MeshMixer. Schmidt, Singh, *SIGGRAPH 2010*]
www.meshmixer.com (acquired by Autodesk Inc.)

[Face-Extrusion Quadmeshes. Pandey, Baerentzen ,Singh, *SIGGRAPH 2022*]

Animation

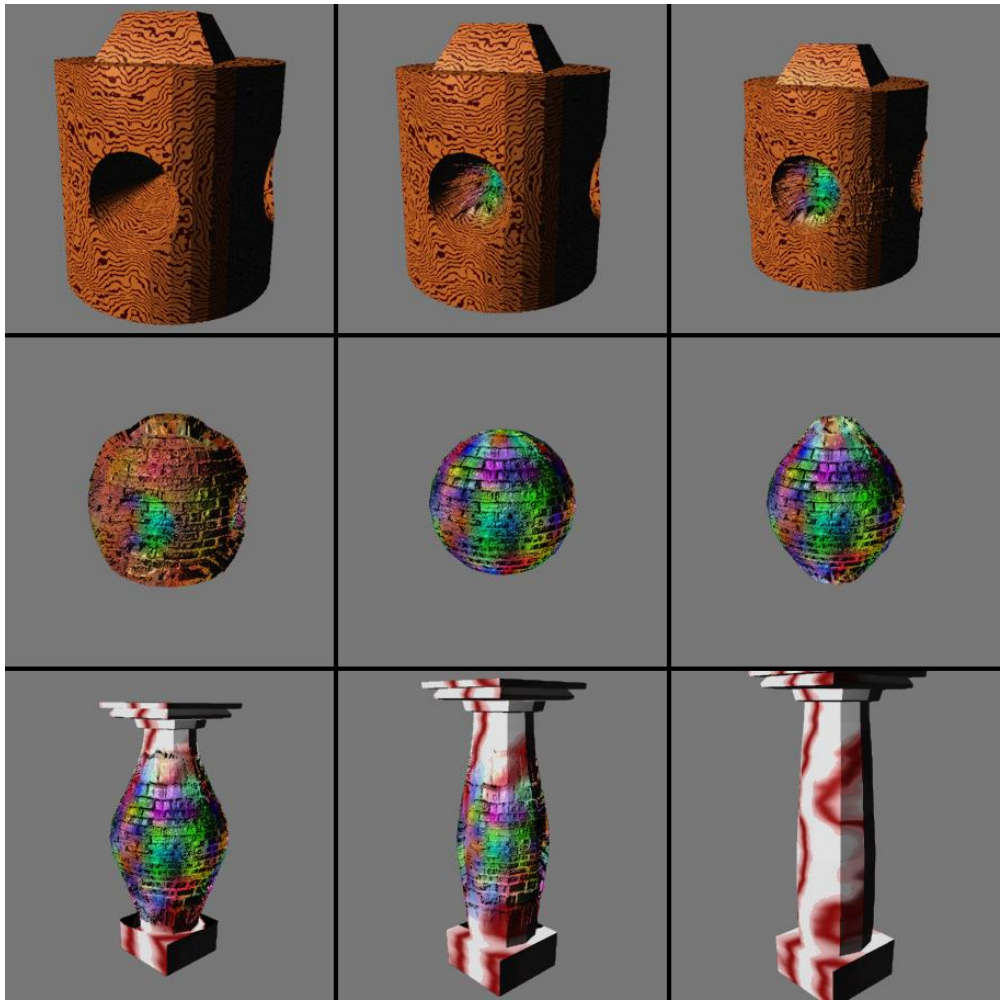


[Kinodynamic skinning using volume-preserving deformations, Angelidis, Singh, *ACM SCA 2007*]



[Visemenet: Zhou et al. *SIGGRAPH 2018*]

Rendering

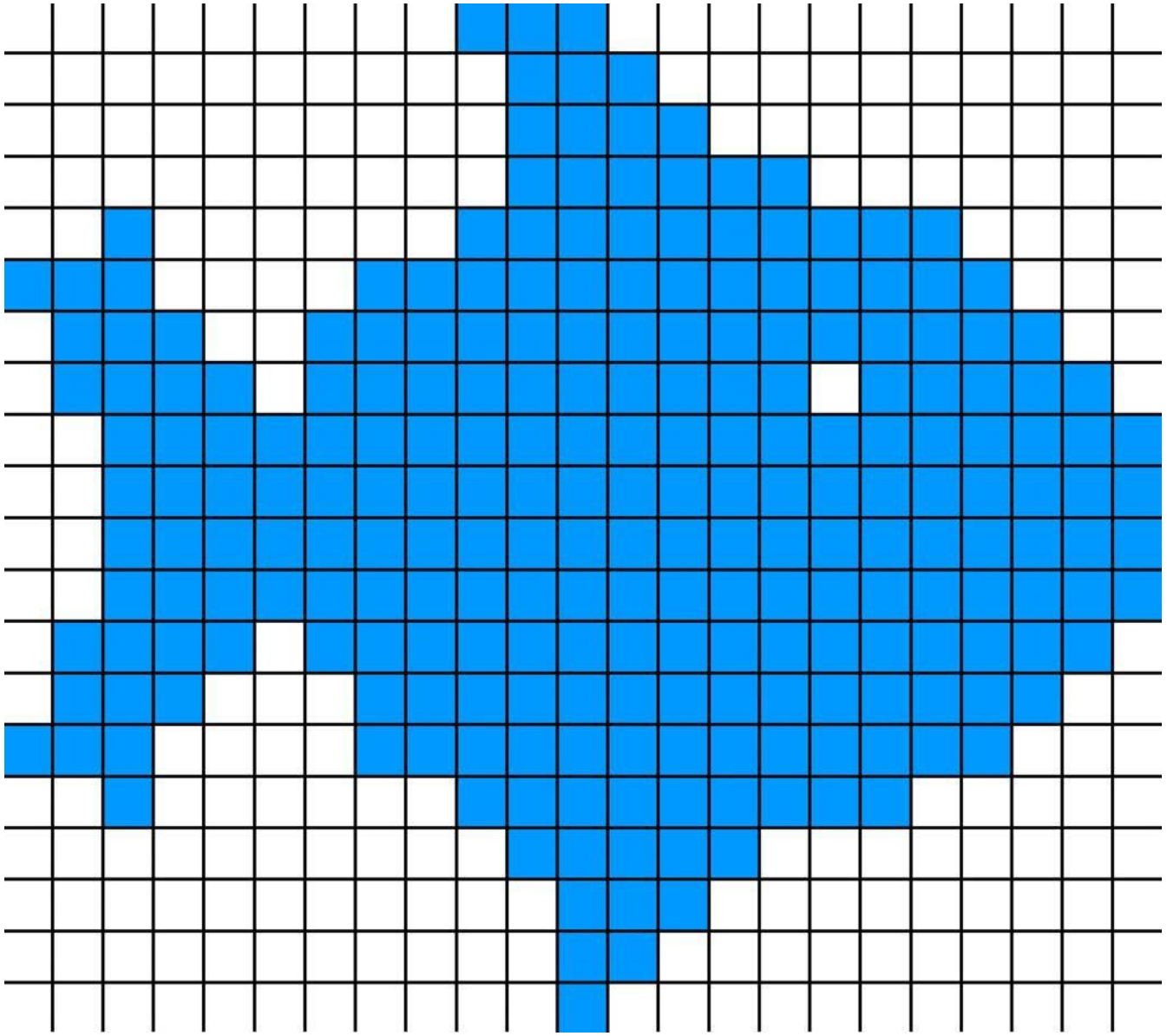


Assignment Previews

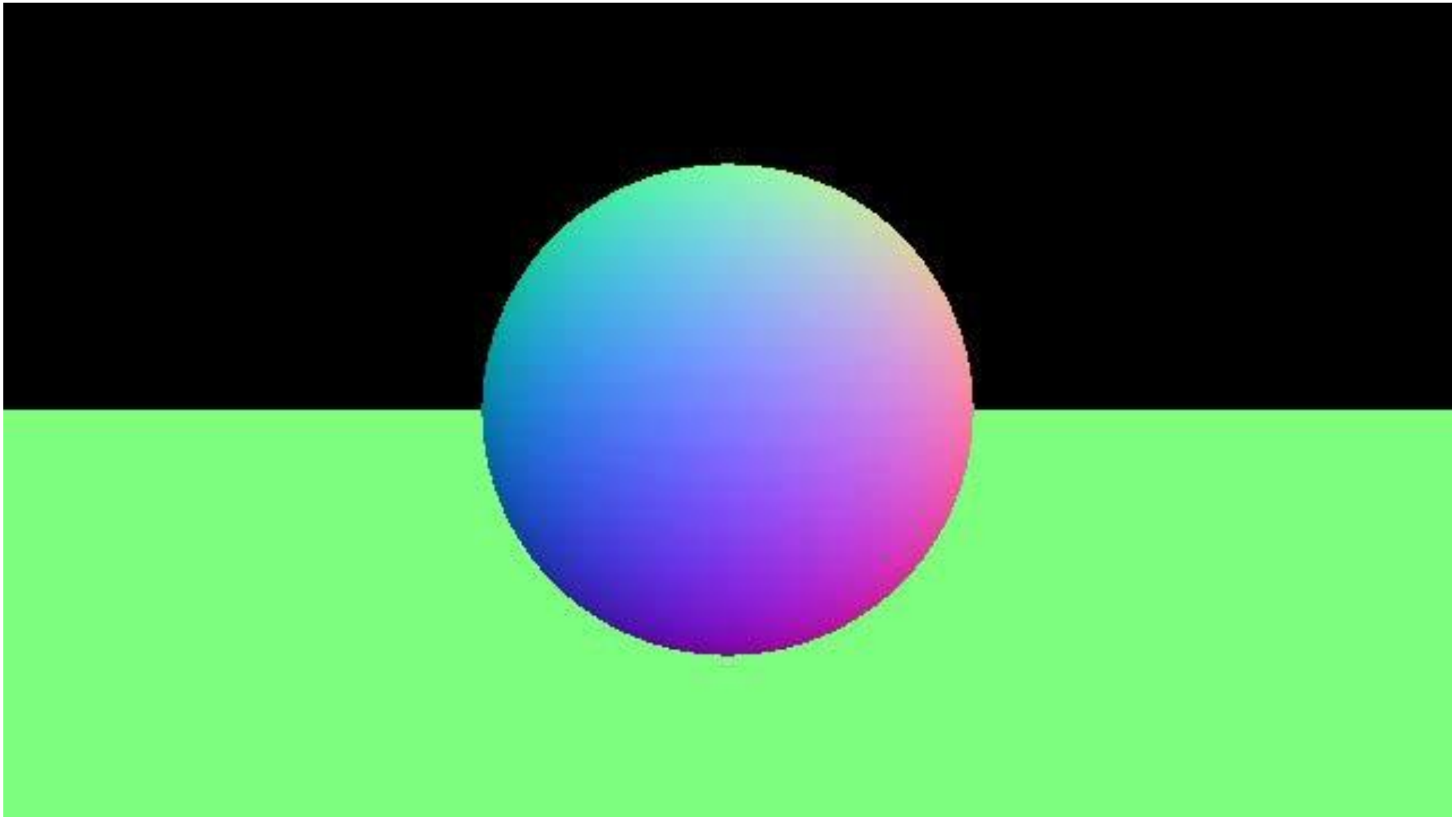
1. Raster Images
2. Ray Casting
3. Ray Tracing
4. Boundary Volume Hierarchies
5. Meshes
6. Shaders
7. Kinematics
8. Mass-Springs

Project Showcase: (extra credit 5%)

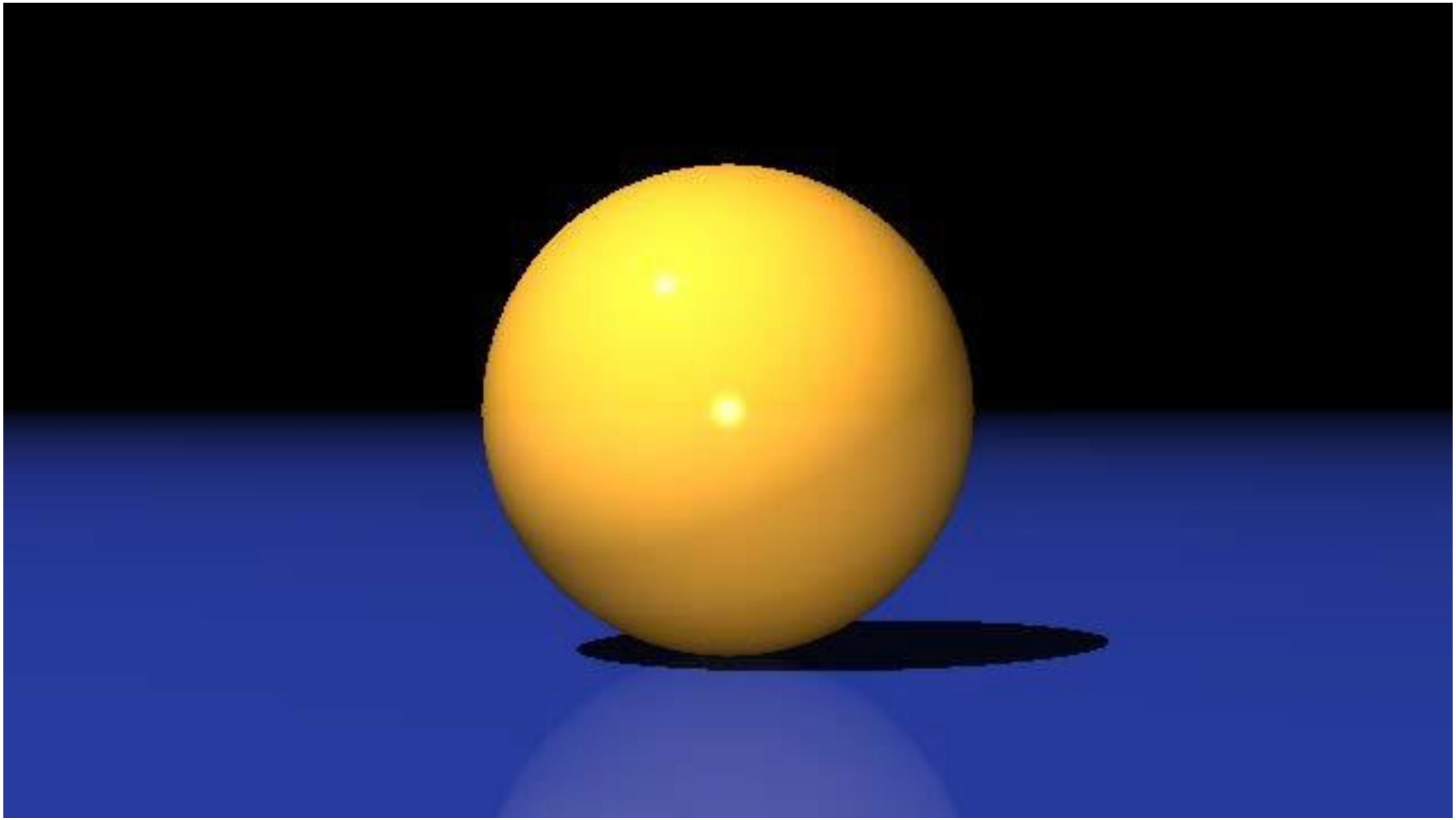
Raster Images



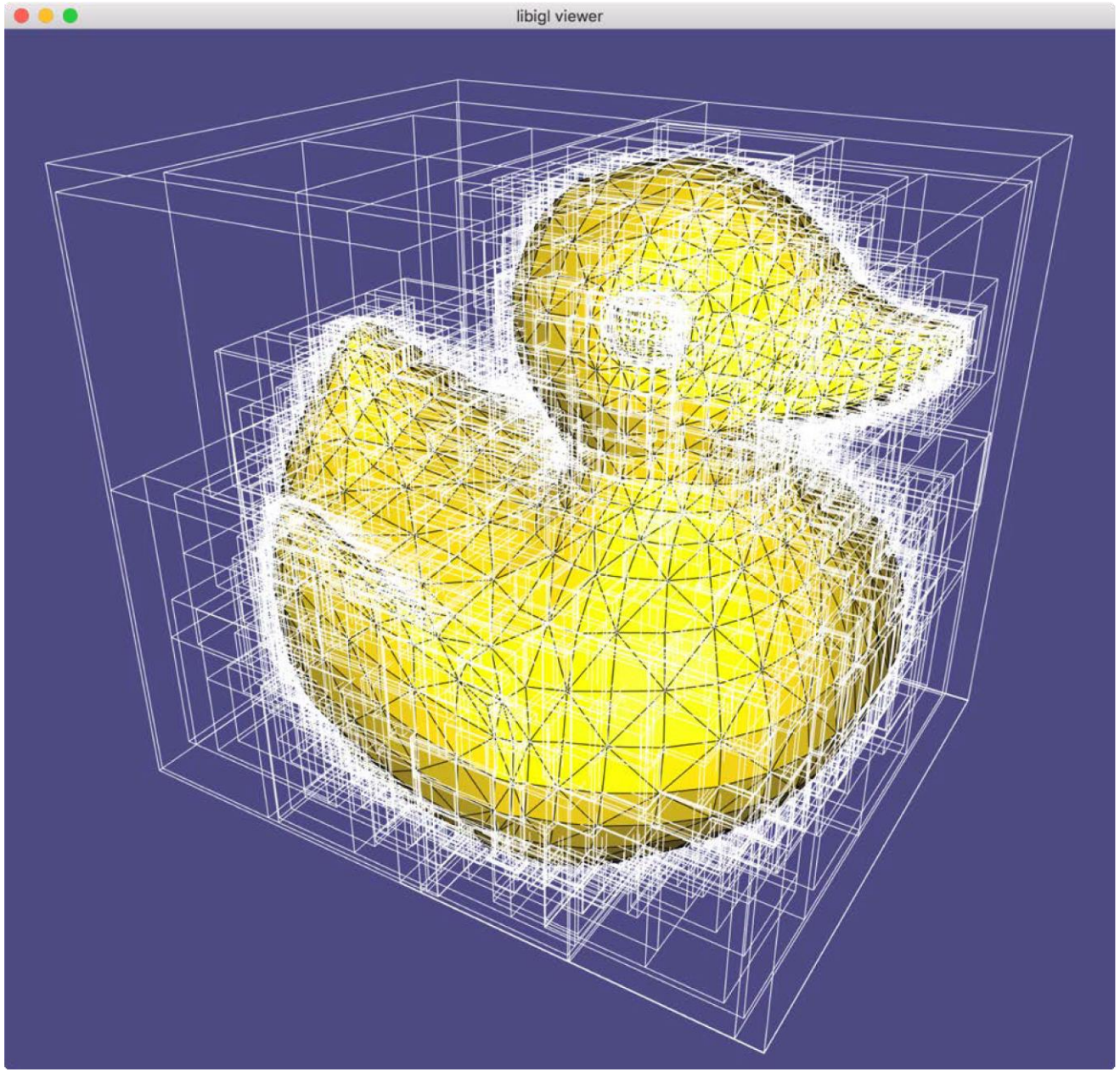
Ray Casting



Ray Tracing

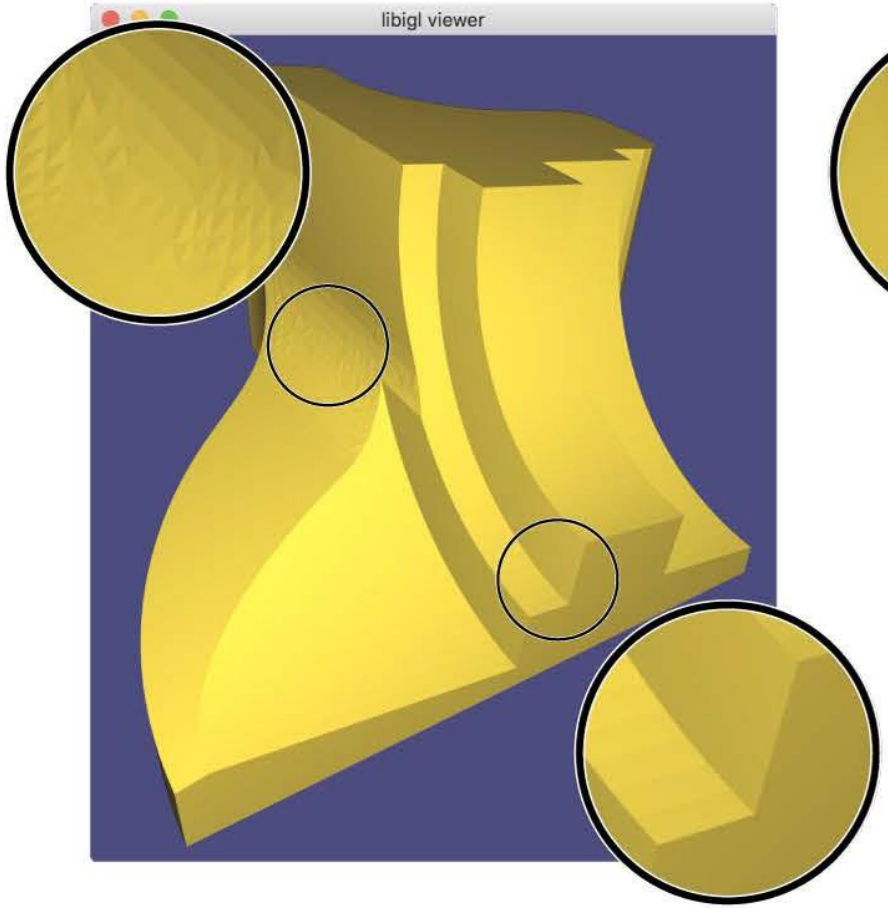


Boundary Volume Hierarchies

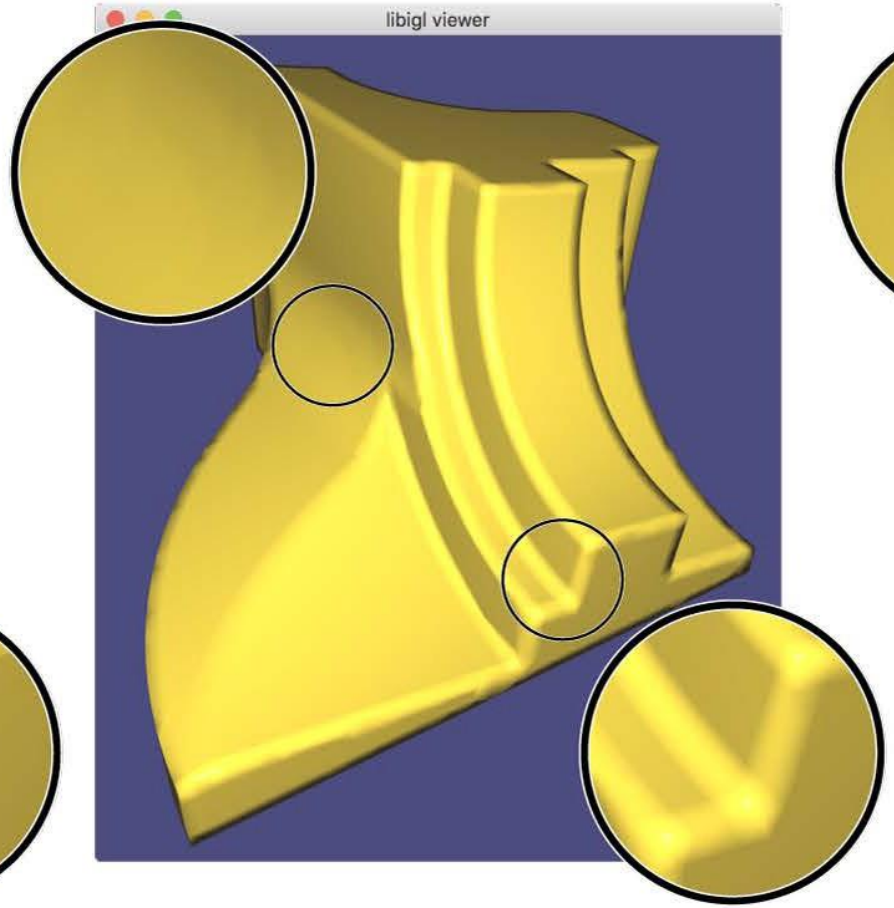


Meshes

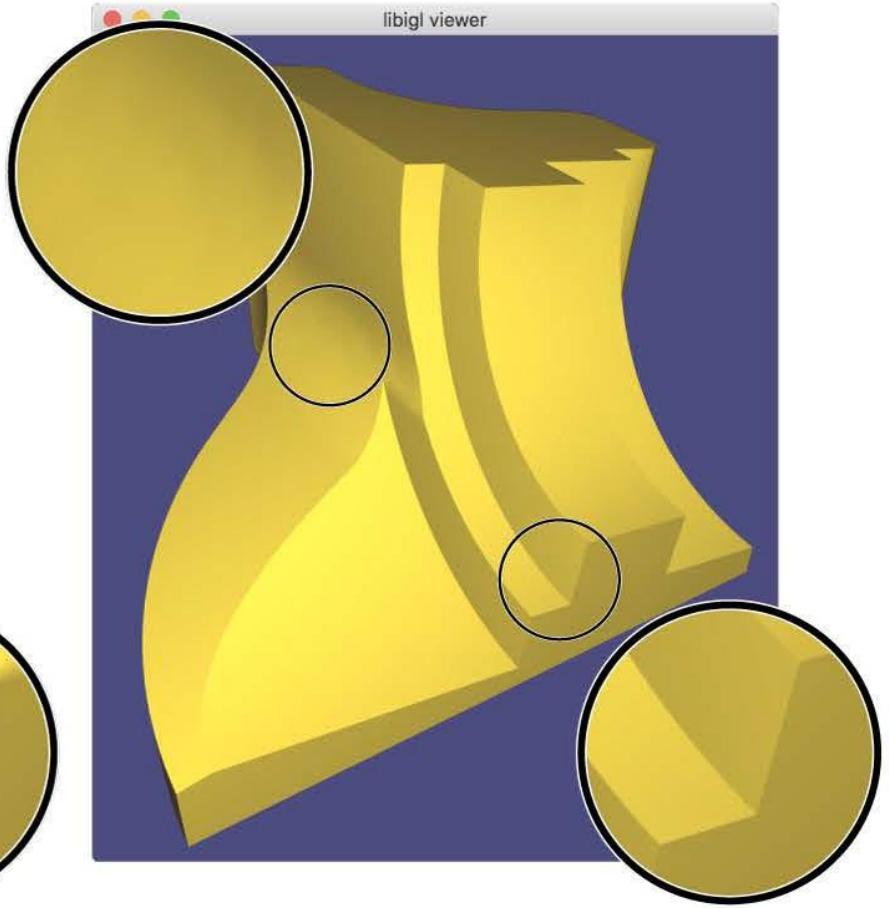
Per-face normals



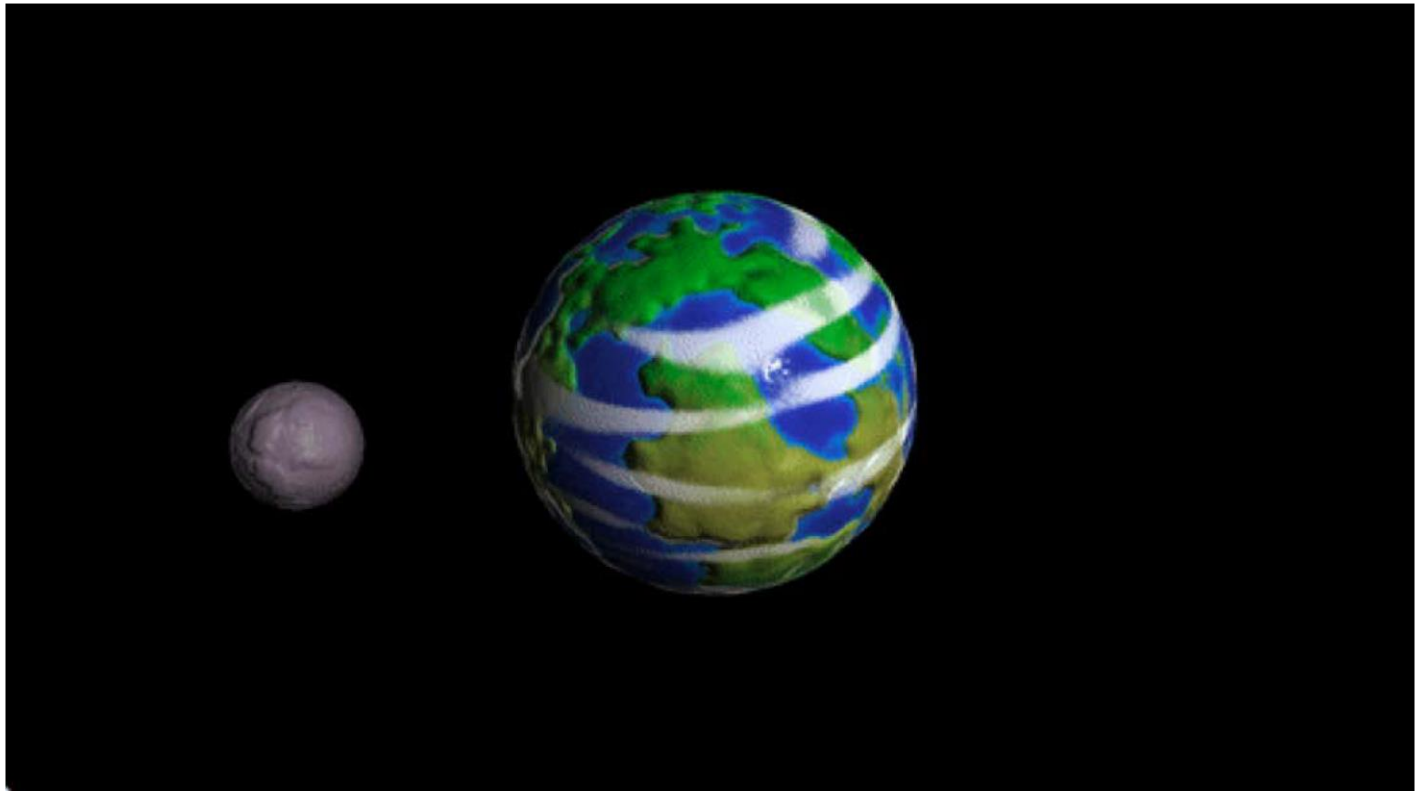
Per-vertex normals



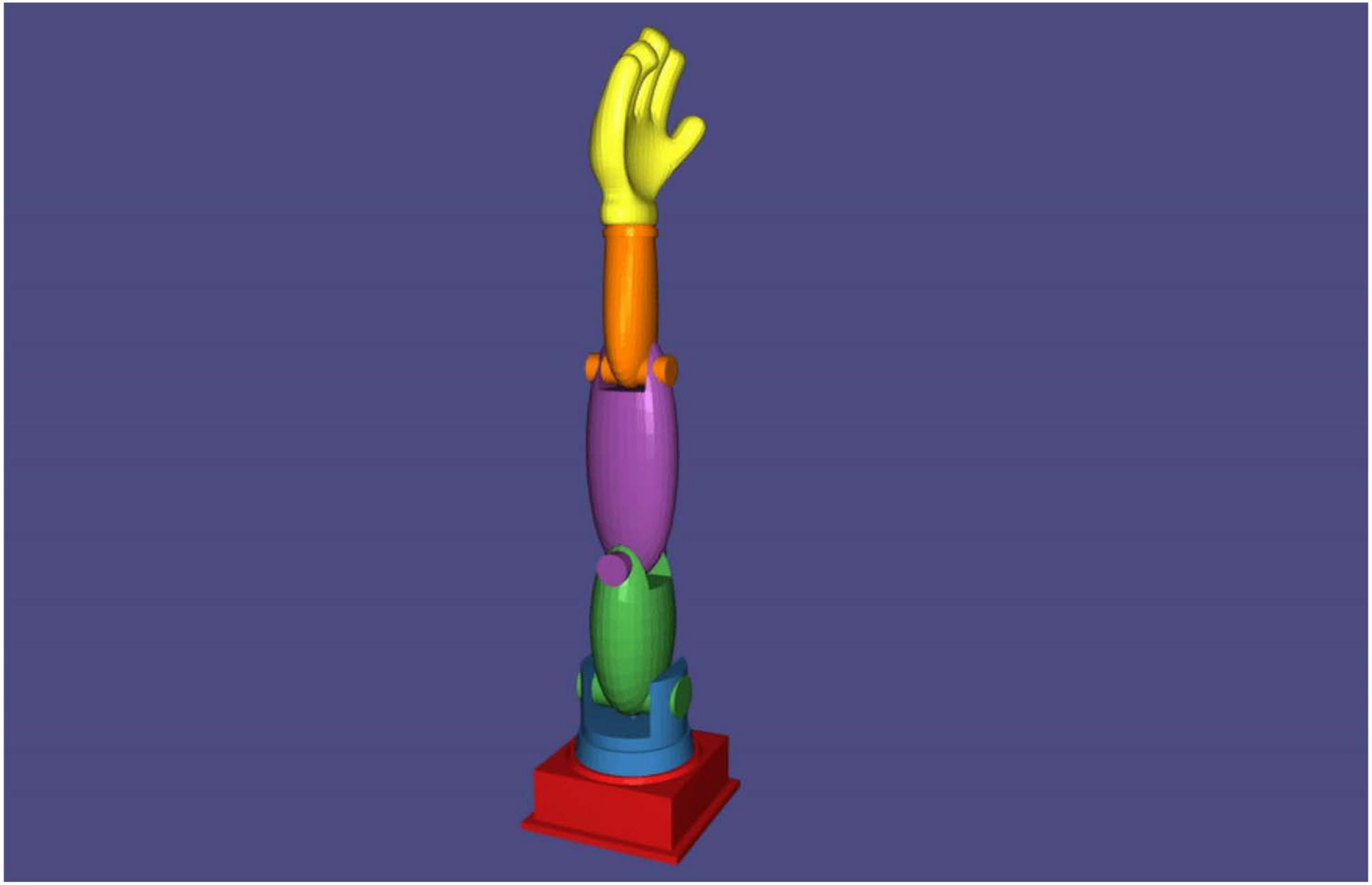
Per-corner normals



Shaders



Kinematics



Mass-Springs

Next lecture >
Raster Images