

Computer Graphics

15-462

Nancy Pollard

T-R: 10:30 am – 11:50 am

SH 125

Introduction

- What is computer graphics?
- Who am I?
- Administrivia.
- Topics

Introduction

- What is computer graphics?
- Who am I?
- Administrivia.
- Topics

Goals of Computer Graphics

- Faking reality – convincingly.
- Creating alternative reality.

Faking Reality



RENDERED USING DALI - HENRIK WANN JENSEN 2000

Faking Reality



Faking Reality



CRAIG DONNER AND HENRIK WANN JENSEN - RENDERED USING DALI - 2005

Alternative reality



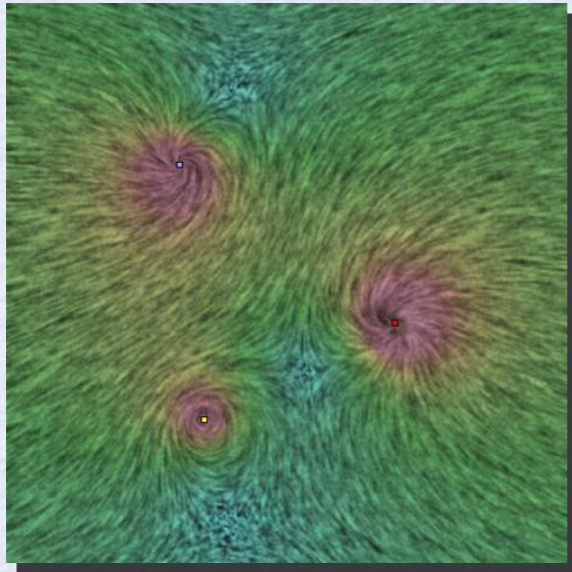
Making of the Gatorade Commercial



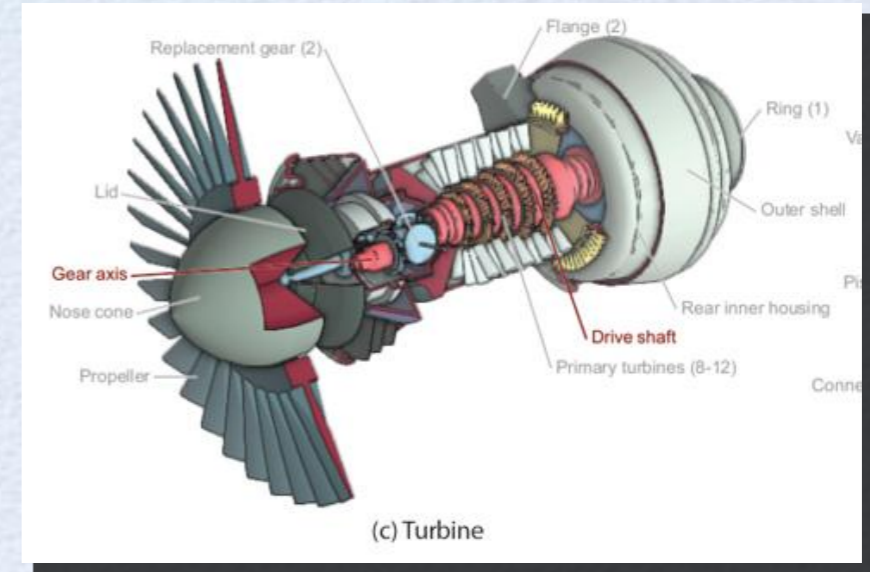
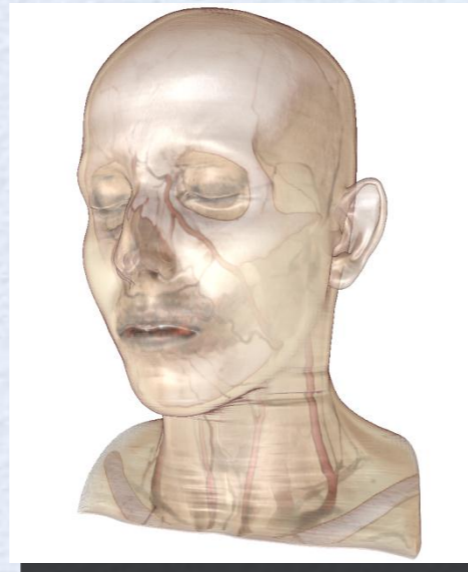
What is Computer Graphics?

- 3D Modeling / Geometry
- Simulation / Animation / Character Animation
- Lighting / Light Transfer
- Textures and Color
- Post-Processing: Image Processing
- Camera tricks / Optics

What Else Is Computer Graphics



Scientific Visualization



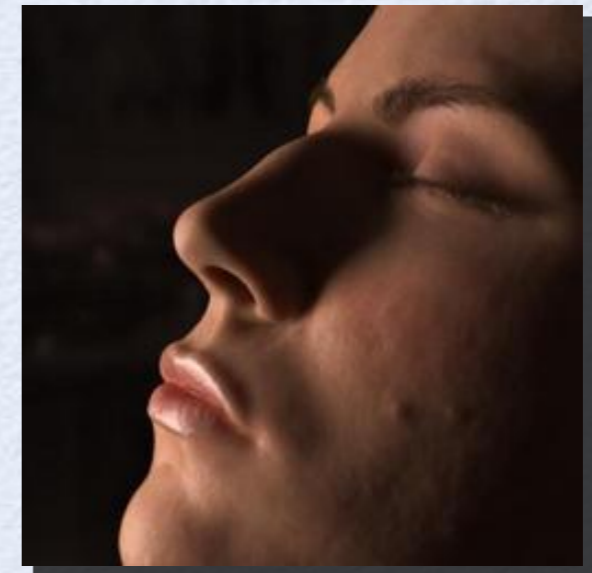
Illustration



NPR / Art



Computational Photography



Virtual Life

and much more....

Introduction

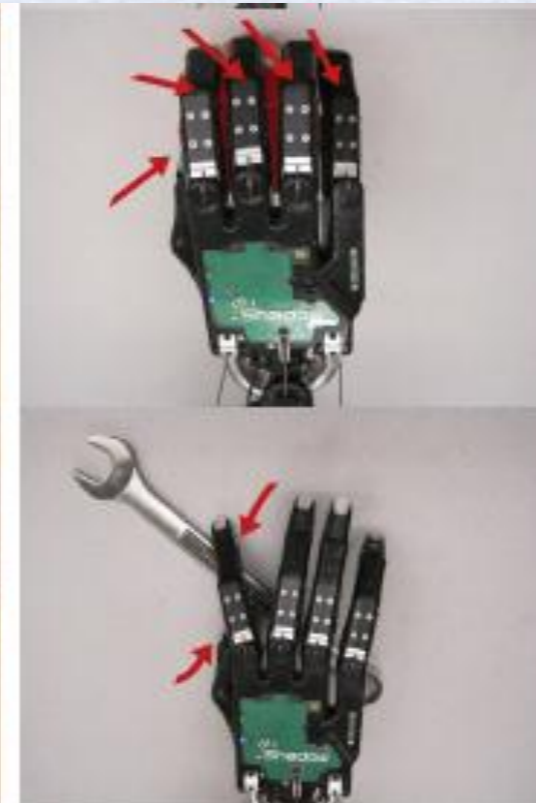
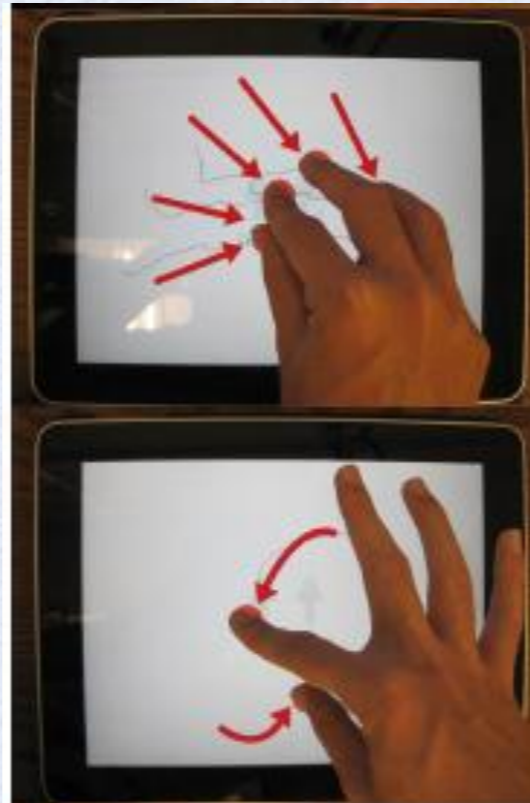
- What is computer graphics?
- **Who am I?**
- Administrivia.
- Topics

Who am I

- I'm a graphics/robotics researcher.
- I've been at SCS (RI and CSD) for 9 yrs.
- Before that, I was at Brown University for 5 yrs.
- PhD 1994 MIT.



What I Do





Dexterity

“Dexterity is the ability to find a motor solution for any external situation, that is, to adequately solve any emerging motor problem

correctly (i.e., adequately and accurately)

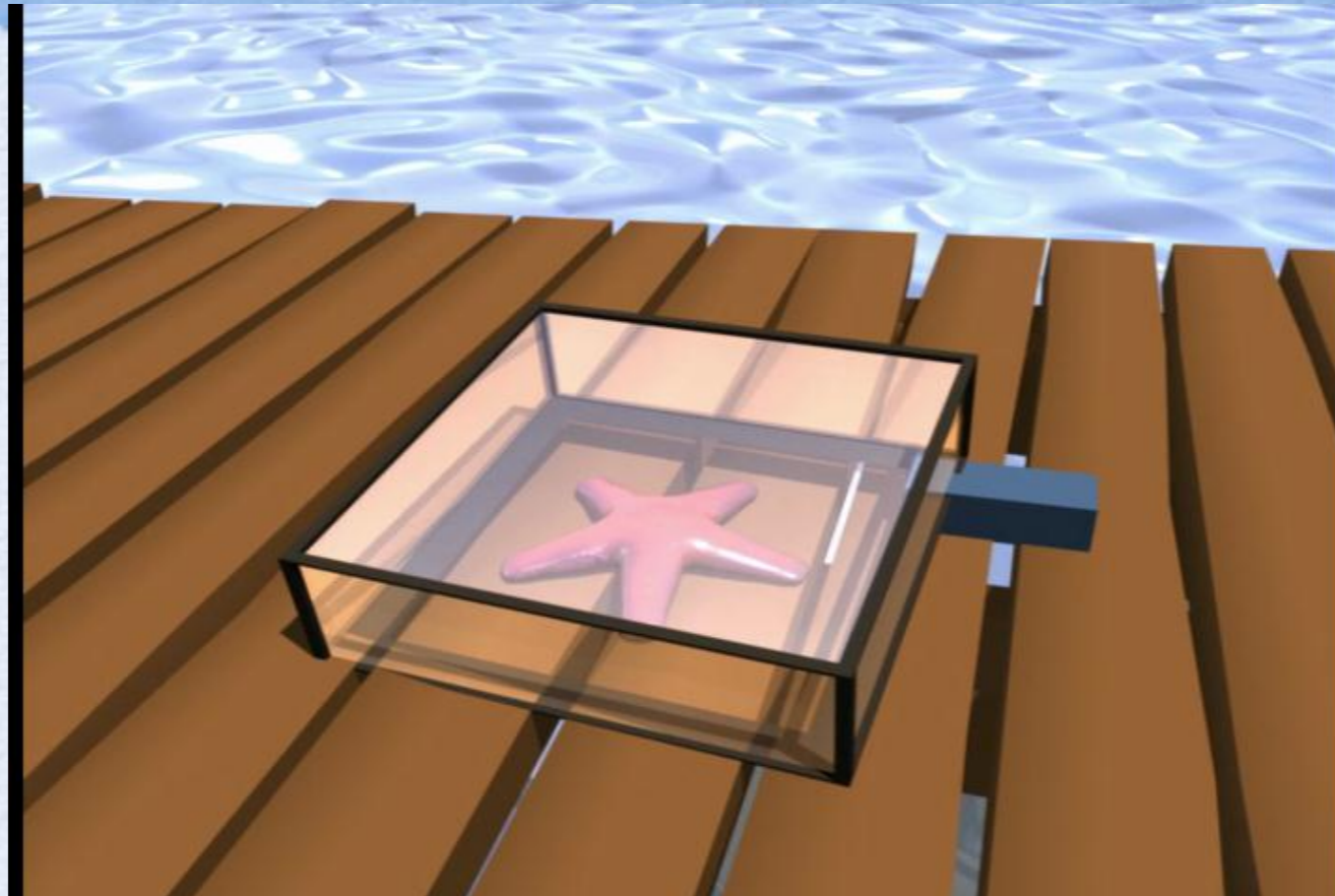
quickly (with respect to both decision making and achieving a correct result)

rationally (i.e., expediently and economically), and

resourcefully (i.e., quick-wittedly and initiatively).

----- Nicholai Bernstein, “On Dexterity and its Development” 1949/91/96

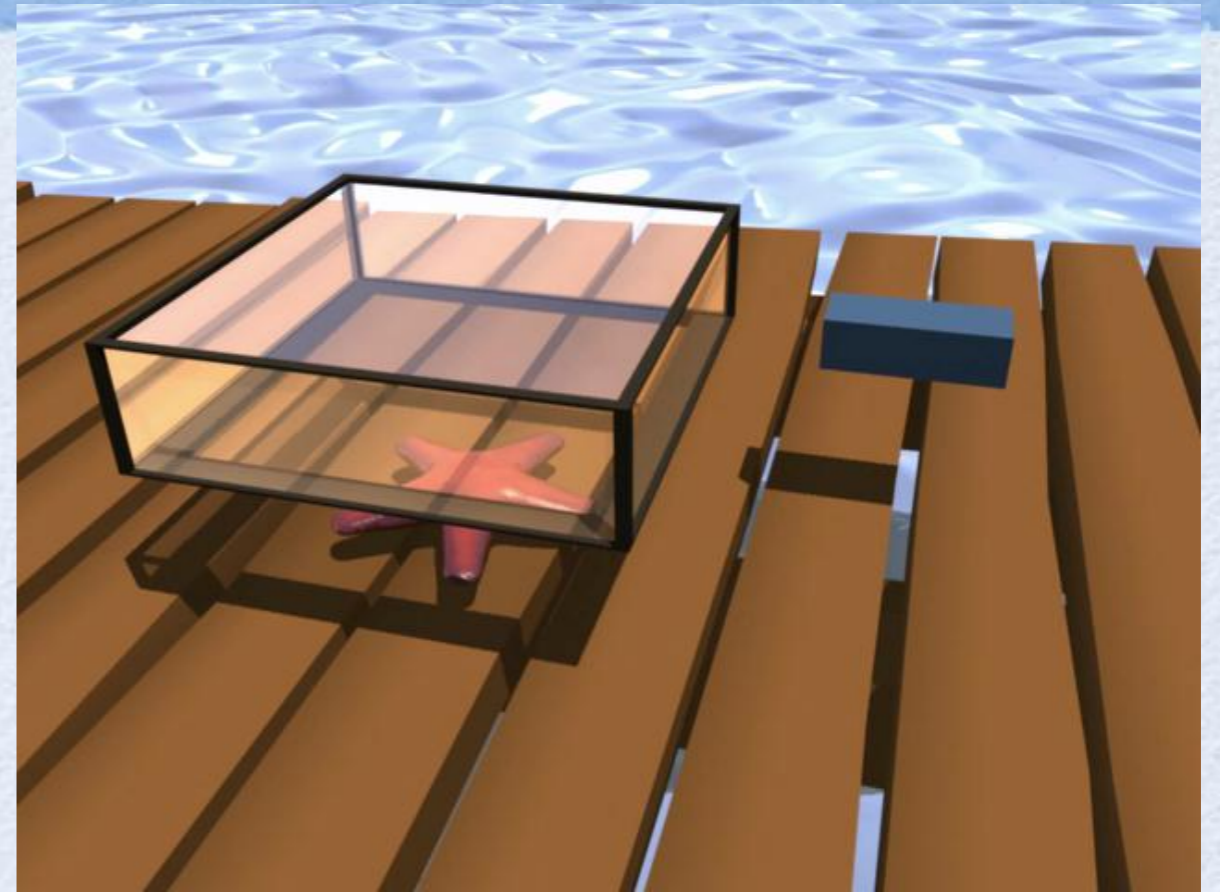
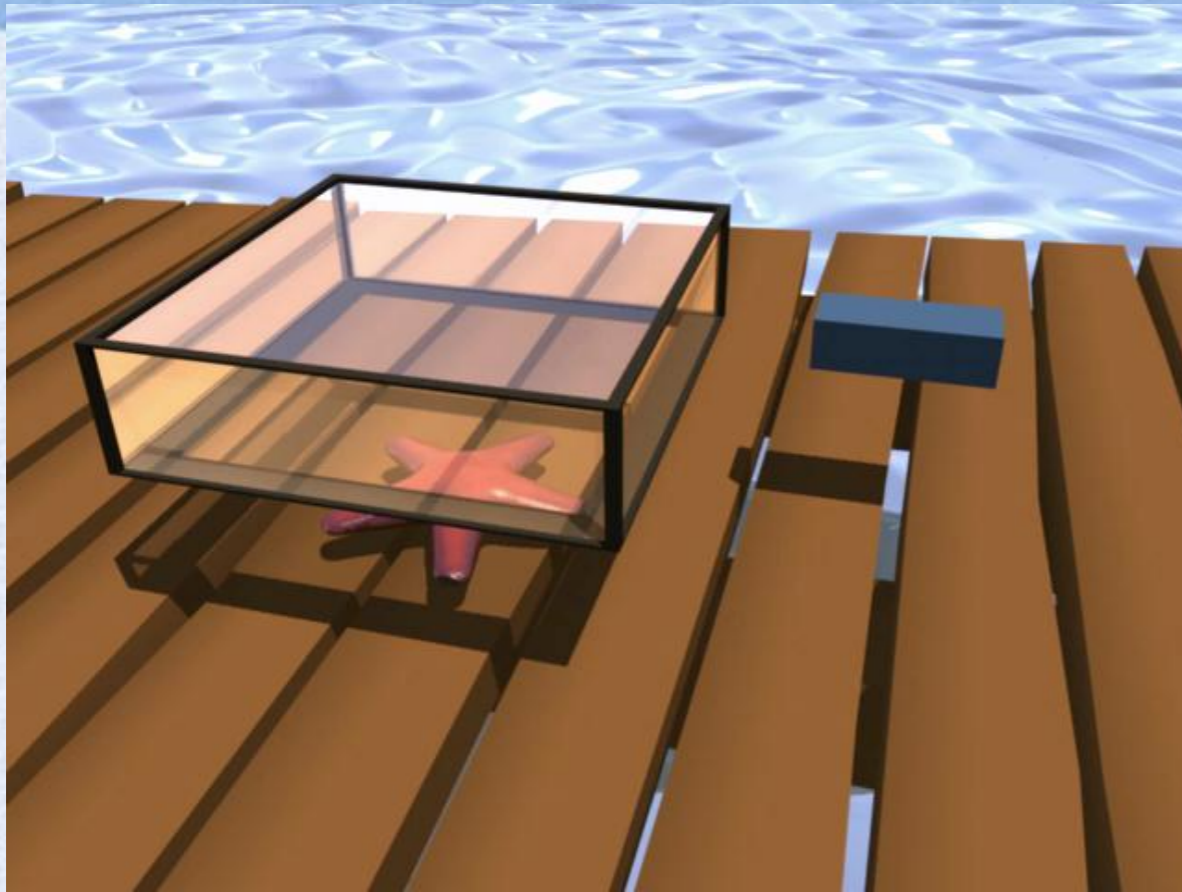
Animating Dexterous Motions



How can we easily animate the starfish's escape?

- Appearance of intelligent motion
- Believable physical interaction with the glass box
 - Dynamic, fun actions
- Animation tools accessible to anyone

Animating Dexterous Motions



Videos created by two novice users using our system.

Demos

**Direct Control of
Simulated Non-human Characters**

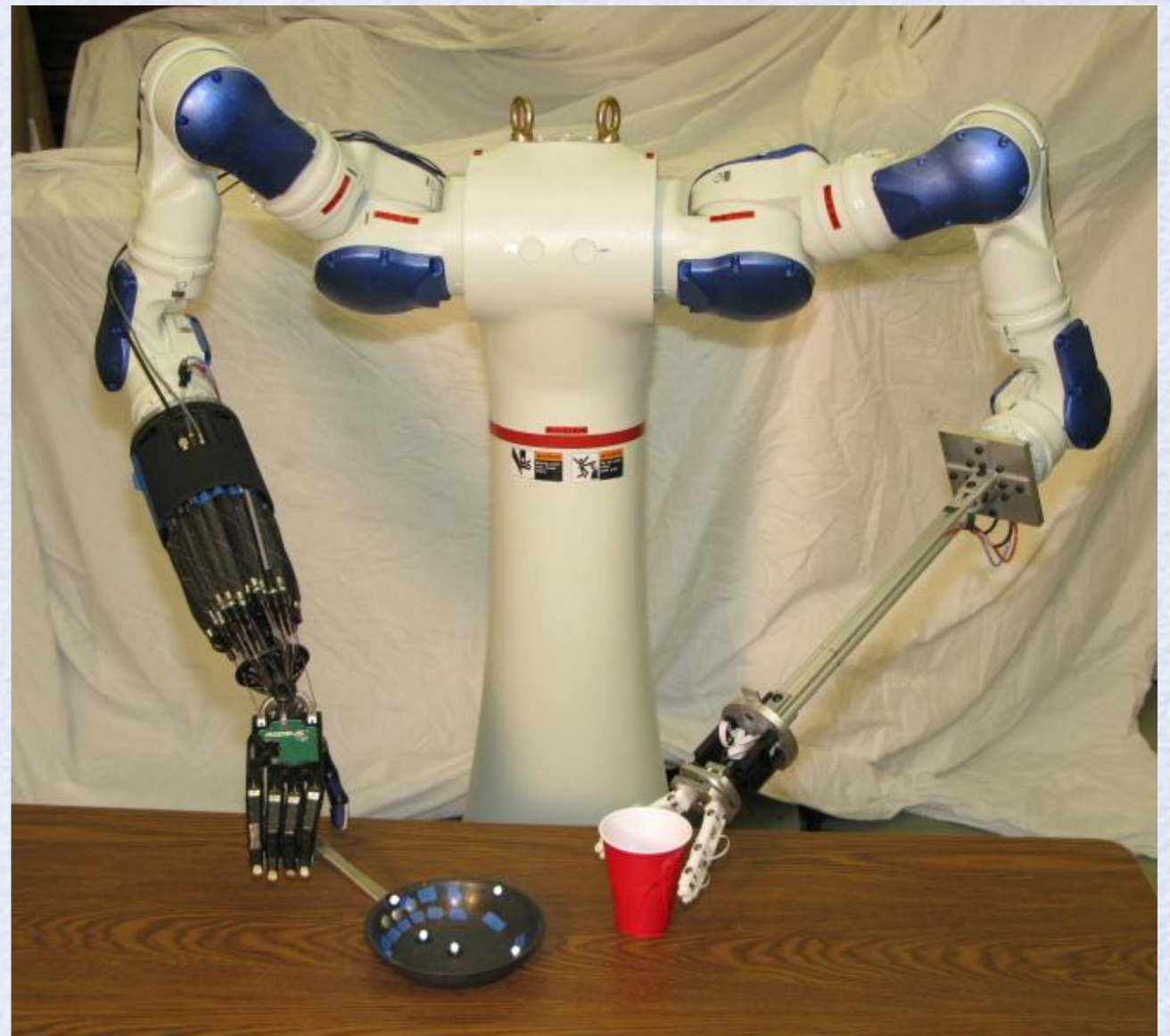
**Results
(animations)**

(No audio)

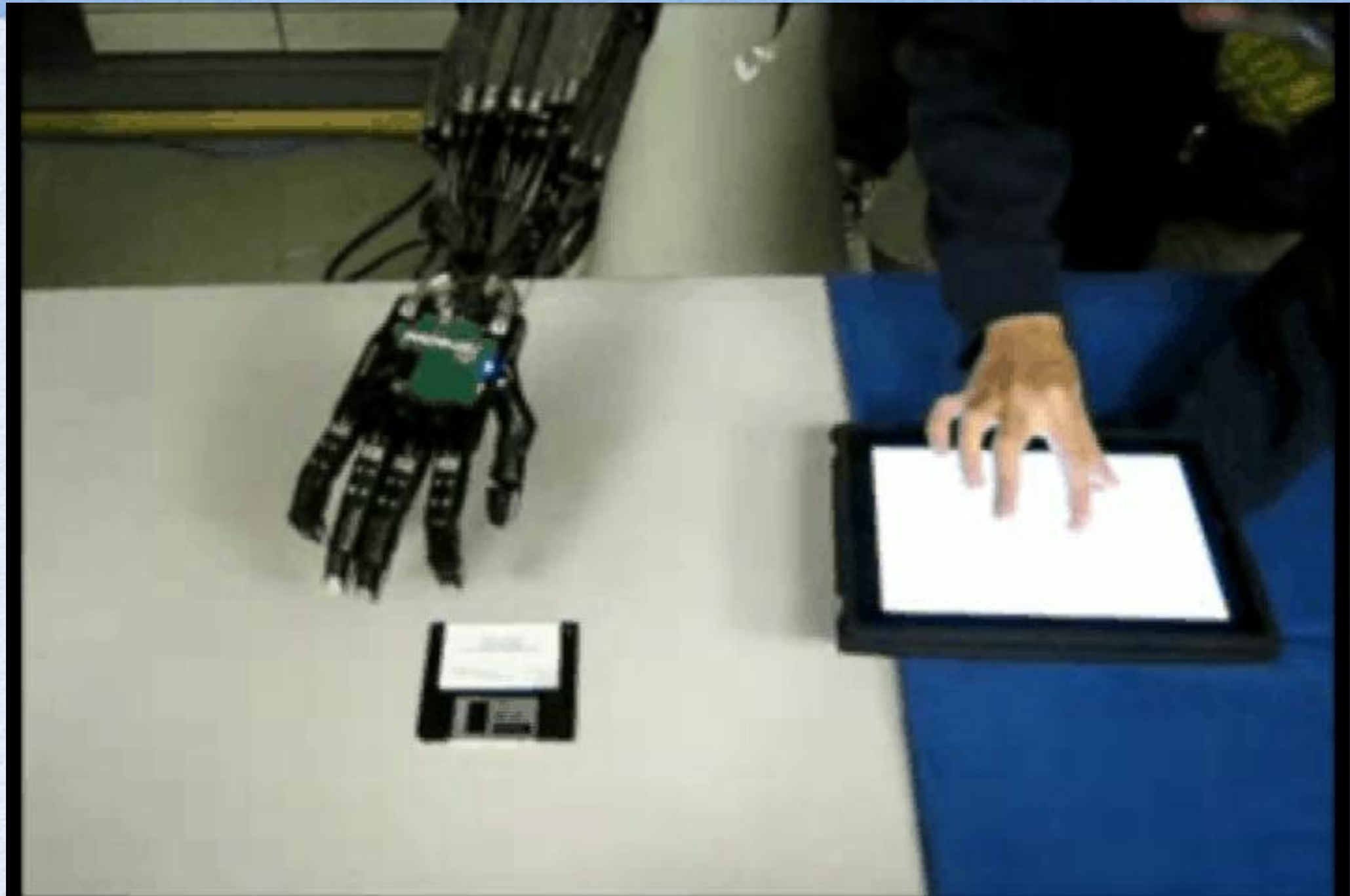
Robotic Telemanipulation

Goal: intuitive interactive control of dexterous manipulation for a robot arm / hand system

- Remote dexterous manipulation
- Scripting new behaviors
- Learning from demonstration



Demo! (3X speed)



When are two motions the same?

Motivation for Evolutionary Biology:

- Trace evolution of locomotor movements through the tree of life, using comparative methods
 - Clarify relationships between species
- Deduce likely movement patterns of common ancestors
 - Answer questions such as “How did T-Rex run?”

Are these motions the same?

Pinocchio

Automatic Rigging and Animation of 3D Characters

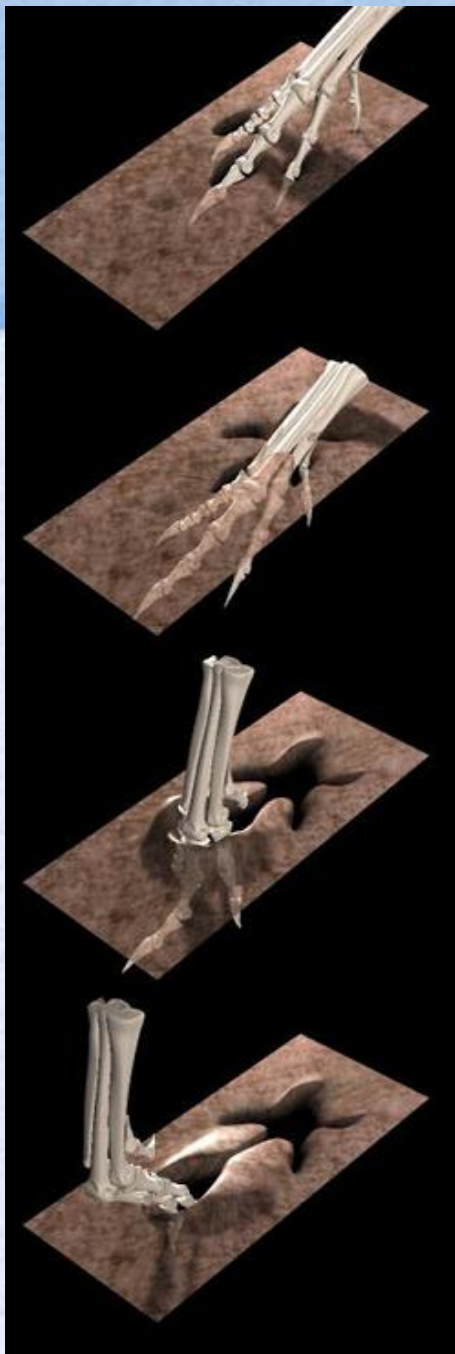
Ilya Baran and Jovan Popović

SIGGRAPH 2007

papers_0030

Baran and Popovic

Reference



Steve Gatesy
Dept. of Evolutionary
Biology, Brown Univ.

Stephen M. Gatesy and Nancy S. Pollard, "Apples, oranges, and angles: Comparative kinematic analysis of disparate limbs," Journal of Theoretical Biology 2011

Gradient Paint



Introduction

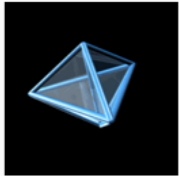
- What is computer graphics?
- Who am I?
- **Administrivia.**
- Topics

Administrivia

- Web Page
 - <http://www.cs.cmu.edu/~15462/>
 - linked from my web page

Computer Graphics

Number:	CSD 15-462
Instructor:	Adrien Treuille
Teaching Assistants:	Eric Butler Linus Li Frank Palermo Kristin Siu
Office Hours:	TBA
Time:	TR 10:30AM - 11:50AM
Location:	WEH 7500



Summary

This course provides a comprehensive introduction to computer graphics modeling, animation, and rendering. Topics covered include basic image processing, geometric transformations, geometric modeling of curves and surfaces, animation, 3-D viewing, visibility algorithms, shading, and ray tracing.

Overview

Prerequisites

The programming assignments in this course will be written in C++ and require knowledge of mathematics involving matrices, vectors, etc. Therefore successful completion of the following courses is required:

15-213/18-243 Introduction to Computer Systems
and either
18-202 Mathematical Foundations of Electrical Engineering
or both
21-241 Matrix Algebra, and
21-259 Calculus in Three Dimensions

Once you've completed 15-462, you may be interested in other [courses](#) offered by the Carnegie Mellon Graphics Lab.

Textbook

There is no required textbook for 15-462 this semester.

Assignments & Grading

This semester's offering of 15-462 will include four programming assignments. For detailed information, please visit the [projects](#) page.

[Under Construction]

Syllabus

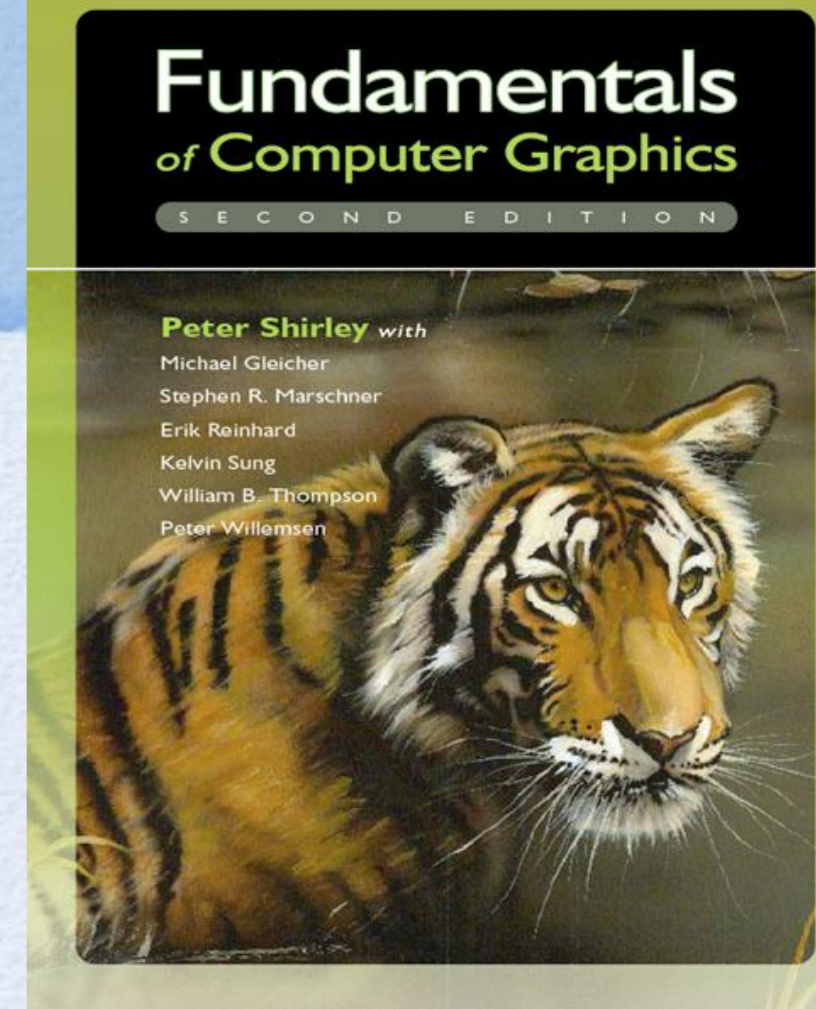
Note: This syllabus may change during the course. Keep checking back.

Name:	TBA
Date:	Tues 01/13

TA Office Hours

- TAs:
 - Derek Basehore (dbasehor@andrew.cmu.edu)
 - At least one other TA expected
- No office hours this week.

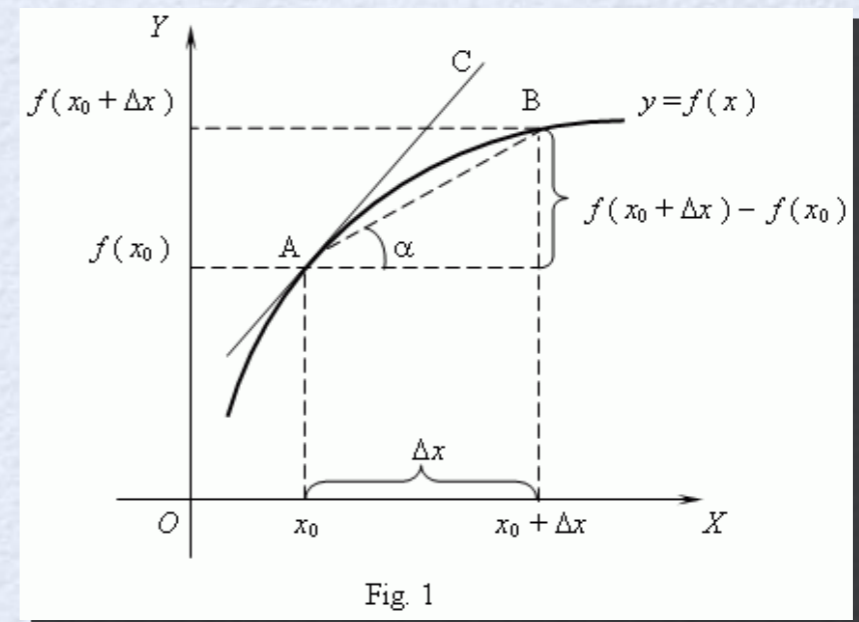
Textbook



- Shirley, **2nd Edition**
- OpenGL Red Book
 - <http://www.glprogramming.com/red/>
- **For Thursday:**
 - Red Book Chapters 1 and 2

Pre-requisites

- Talk to us if you're missing these!
 - 15-213: Introduction to Computer Systems
 - 21-241: Matrix Algebra (matrix & vector algebra)
 - 21-259: Calculus in Three Dimensions (i.e. planes, quadratic surfaces,
- Basic 3-D geometry/C++



Grading

- Project 1 (10%)
- Project 2 (10%)
- Project 3 (10%)
- Project 4 (15%)
- Project 5 (10%)
- Homework 1 (10%)
- Homework 2 (10%)

- Midterm (10%)
- Final Exam (15%)



Late Policy

- 3 late days for projects.
- No further extensions without explicit permission 2 days before deadline.



Cheating – Zero Tolerance

- Please don't cheat! Using code from the web is ok as long as it is a **SMALL** percentage of the code for written the assignment.
- Do projects and homeworks individually.



Introduction

- What is computer graphics?
- Who am I?
- Administrivia.
- **Topics**

Syllabus and Schedule

Intro	<ul style="list-style-type: none">• 01 Tues 01/17 - Introduction• 02 Thurs 01/19 - OpenGL [PROJ 1 ASSIGNED]	Ray Tracing	<ul style="list-style-type: none">• 18 Tues 03/20 – Ray Tracing [PROJ 3 DUE, PROJ 4 ASSIGNED]• 19 Thurs 03/22 – Spatial Data Structures
Geometry	<ul style="list-style-type: none">• 03 Tues 01/24 - Math for Computer Graphics• 04 Thurs 01/26 - Transformations• 05 Tues 01/31 –Viewing/Camera• 07 Thurs 02/02 - Curves and Splines [PROJ 1 DUE]• 08 Tues 02/07 - Meshes and Surfaces [PROJ 2 ASSIGNED]	Indirect Lighting	<ul style="list-style-type: none">• 20 Tues 03/27 – Radiosity• 21 Thurs 03/29 - Photon Mapping• 22 Tues 04/03 - Direct-Indirect Separation
Light	<ul style="list-style-type: none">• 09 Thurs 02/09 – Shading/Light• 10 Tues 02/14 – Materials• 11 Thurs 02/16 – Texture mapping + GLSL	Animation	<ul style="list-style-type: none">• 23 Thurs 04/05 – Animation and Mocap• 24 Tues 04/10 - Differential Eqn & Particle Systems [PROJ 4 DUE, PROJ 5 ASSIGNED]• 25 Thurs 04/12 – Fluids
NPR	<ul style="list-style-type: none">• 12 Tues 02/21 – Non-photorealistic rendering [PROJ 2 DUE, PROJ 3 ASSIGNED]• 13 Thurs 02/23 – Illusions	Images	<ul style="list-style-type: none">• 26 Tues 04/17 – Image Processing• 27 Thurs 04/19 – NO CLASS – CARNIVAL• 29 Tues 04/24 – High Dynamic Range Imaging + Tone Mapping [HOMEWORK2 DUE]• 28 Thurs 04/26 – Photo and Webcam Clipart [PROJ 5 DUE]
Color	<ul style="list-style-type: none">• 14 Tues 02/28 – Color [HOMEWORK1 DUE]• 15 Thurs 03/01 – Light• 16 Tues 03/06 – Midterm review• 17 Thurs 03/08 - [MIDTERM EXAM]• [SPRING BREAK]	Final	<ul style="list-style-type: none">• 30 Tues 05/01 – Final Review• 31 Thurs 05/03 – Project Showcase• 32 TBD – [FINAL EXAM]

Syllabus and Schedule

Intro

- 01 Tues 01/17 - Introduction
- 02 Thurs 01/19 - OpenGL
[PROJ 1 ASSIGNED]

Geometry

- 03 Tues 01/24 - Math for
- 04 Thurs 01/26 - Transfor
- 05 Tues 01/31 - Viewing/
- 07 Thurs 02/02 - Curves a
[PROJ 2 ASSIGNED]
- 08 Tues 02/07 - Meshes a
[PROJ 3 ASSIGNED]

Light

- 09 Thurs 02/09 - Shading
- 10 Tues 02/14 - Materials
- 11 Thurs 02/16 - Texture

NPR

- 12 Tues 02/21 - Non-pho
[PROJ 4 ASSIGNED]
- 13 Thurs 02/23 - Illusions

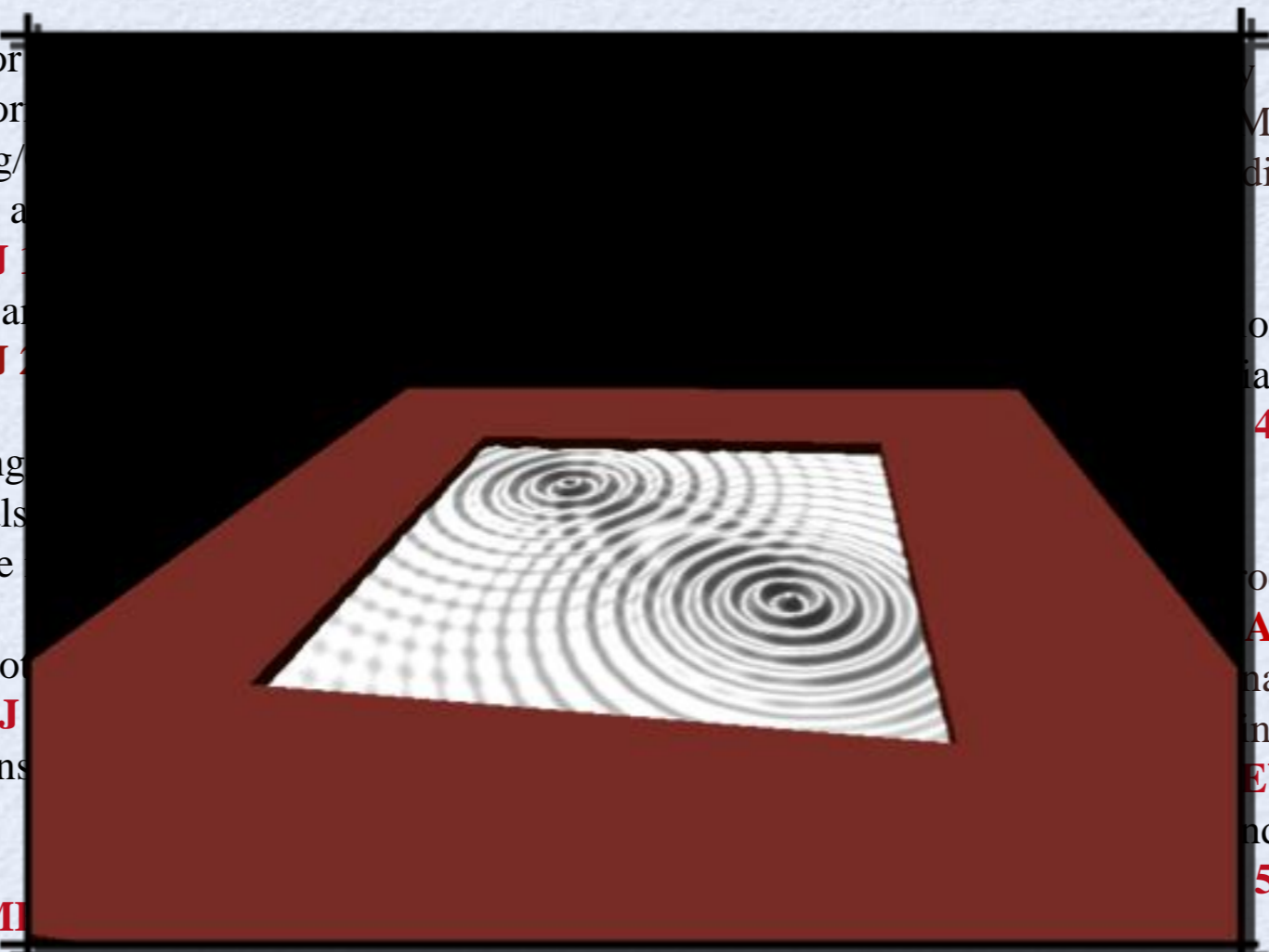
Color

- 14 Tues 02/28 - Color
[HOMEWORK1 DUE]
- 15 Thurs 03/01 - Light
- 16 Tues 03/06 - Midterm review
- 17 Thurs 03/08 - [MIDTERM EXAM]

• [SPRING BREAK]

Ray Tracing

- 18 Tues 03/20 - Ray Tracing
[PROJ 3 DUE, PROJ 4 ASSIGNED]
- 19 Thurs 03/22 - Spatial Data Structures



Final

- 30 Tues 05/01 - Final Review
- 31 Thurs 05/03 - Project Showcase
- 32 TBD - [FINAL EXAM]

Mapping
direct Separation

on and Mocap
ial Eqn & Particle Systems
4 DUE, PROJ 5 ASSIGNED]

rocessing
ASS - CARNIVAL
namic Range Imaging + Tone
ng
[HOMEWORK2 DUE]
nd Webcam Clipart
5 DUE]

Syllabus and Schedule

Intro

- 01 Tues 01/17 - Introduction
- 02 Thurs 01/19 - OpenGL

[PROJ 1 ASSIGNED]

Geometry

- 03 Tues 01/24 - Math for
- 04 Thurs 01/26 - Transfor
- 05 Tues 01/31 - Viewing
- 07 Thurs 02/02 - Curves &

[PROJ 2 ASSIGNED]

- 08 Tues 02/07 - Meshes &

[PROJ 3 ASSIGNED]

Light

- 09 Thurs 02/09 - Shading
- 10 Tues 02/14 - Material
- 11 Thurs 02/16 - Texture

NPR

- 12 Tues 02/21 - Non-pho
- 13 Thurs 02/23 - Illusion

[PROJ 4 ASSIGNED]

Color

- 14 Tues 02/28 - Color
- 15 Thurs 03/01 - Light

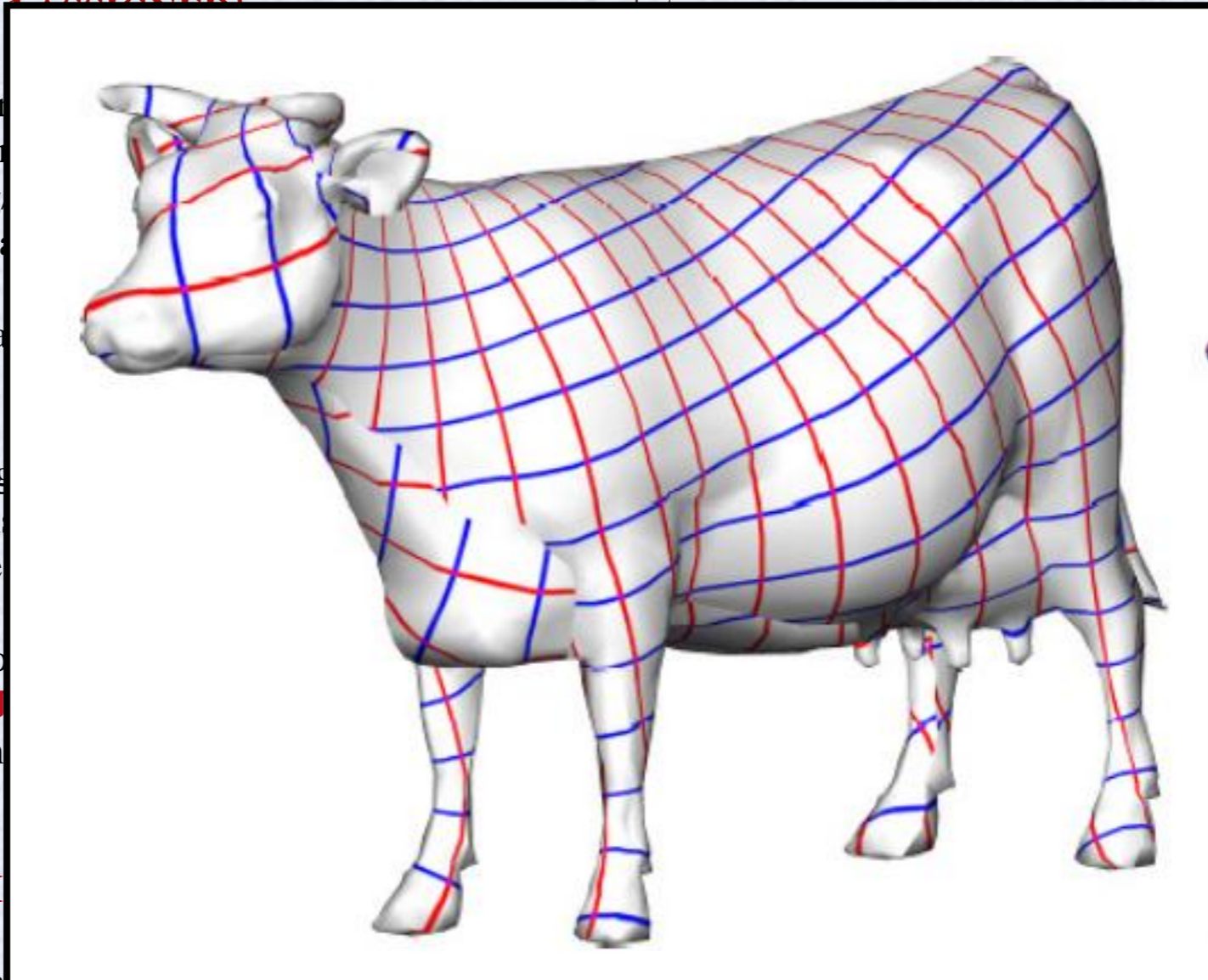
[HOMEWORK]

- 16 Tues 03/06 - Midterm Review
- 17 Thurs 03/08 - [MIDTERM EXAM]

[SPRING BREAK]

Ray Tracing

- 18 Tues 03/20 - Ray Tracing
- [PROJ 3 DUE, PROJ 4 ASSIGNED]
- 19 Thurs 03/22 - Spatial Data Structures



ng
Separation

d Mocap
n & Particle Systems
E, PROJ 5 ASSIGNED]

ng
- CARNIVAL
Range Imaging + Tone

[RK2 DUE]
bcam Clipart
E]

Fin

- 31 Thurs 05/05 - Project Showcase
- 32 TBD - [FINAL EXAM]

Syllabus and Schedule

Intro

- 01 Tues 01/17 - Introduction
- 02 Thurs 01/19 - OpenGL
[PROJ 1 ASSIGNED]

Geometry

- 03 Tues 01/24 - Math for Computer C
- 04 Thurs 01/26 - Transformations
- 05 Tues 01/31 - Viewing/Camera
- 07 Thurs 02/02 - Curves and Splines
[PROJ 1 DUE]
- 08 Tues 02/07 - Meshes and Surfaces
[PROJ 2 ASSIGNED]

Light

- 09 Thurs 02/09 - Shading/Light
- 10 Tues 02/14 - Materials
- 11 Thurs 02/16 - Texture mapping + C

NPR

- 12 Tues 02/21 - Non-photorealistic re
[PROJ 2 DUE, PR
- 13 Thurs 02/23 - Illusions

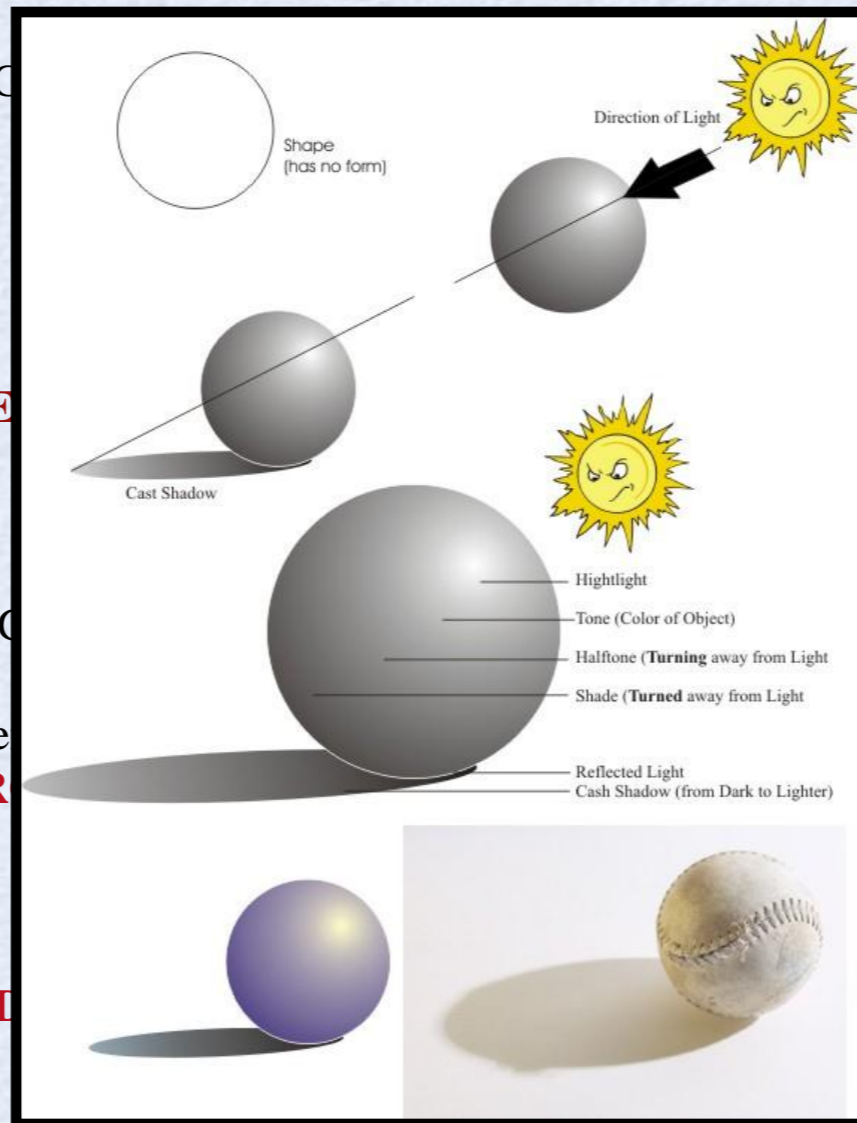
Color

- 14 Tues 02/28 - Color
[HOMEWORK1 D
- 15 Thurs 03/01 - Light
- 16 Tues 03/06 - Midterm review
- 17 Thurs 03/08 - [MIDTERM EXAM]

• [SPRING BREAK]

Ray Tracing

- 18 Tues 03/20 - Ray Tracing
[PROJ 3 DUE, PROJ 4 ASSIGNED]
- 19 Thurs 03/22 - Spatial Data Structures



Final

- 31 Thurs 03/03 - Project Showcase
- 32 TBD - [FINAL EXAM]

- 27 - Radiosity
- 29 - Photon Mapping
- 30 - Direct-Indirect Separation
- 31 - Animation and Mocap
- 32 - Differential Eqn & Particle Systems
[PROJ 4 DUE, PROJ 5 ASSIGNED]
- 33 - Fluids
- 34 - Image Processing
- 35 - NO CLASS - CARNIVAL
- 36 - High Dynamic Range Imaging + Tone Mapping
[HOMEWORK2 DUE]
- 37 - Photo and Webcam Clipart
[PROJ 5 DUE]
- 38 - Final Review
- 39 - Project Showcase
- 40 - [FINAL EXAM]

Syllabus and Schedule

Intro

- 01 Tues 01/17 - Introduction
- 02 Thurs 01/19 - OpenGL
[PROJ 1 ASSIGNED]

Geometry

- 03 Tues 01/24 - Math f
- 04 Thurs 01/26 - Transf
- 05 Tues 01/31 - Viewin
- 07 Thurs 02/02 - Curves
[PROJ 2 ASSIGNED]
- 08 Tues 02/07 - Meshes
[PROJ 3 ASSIGNED]

Light

- 09 Thurs 02/09 - Shadi
- 10 Tues 02/14 - Materia
- 11 Thurs 02/16 - Textur

NPR

- 12 Tues 02/21 - Non-ph
[PROJ 4 ASSIGNED]
- 13 Thurs 02/23 - Illusio

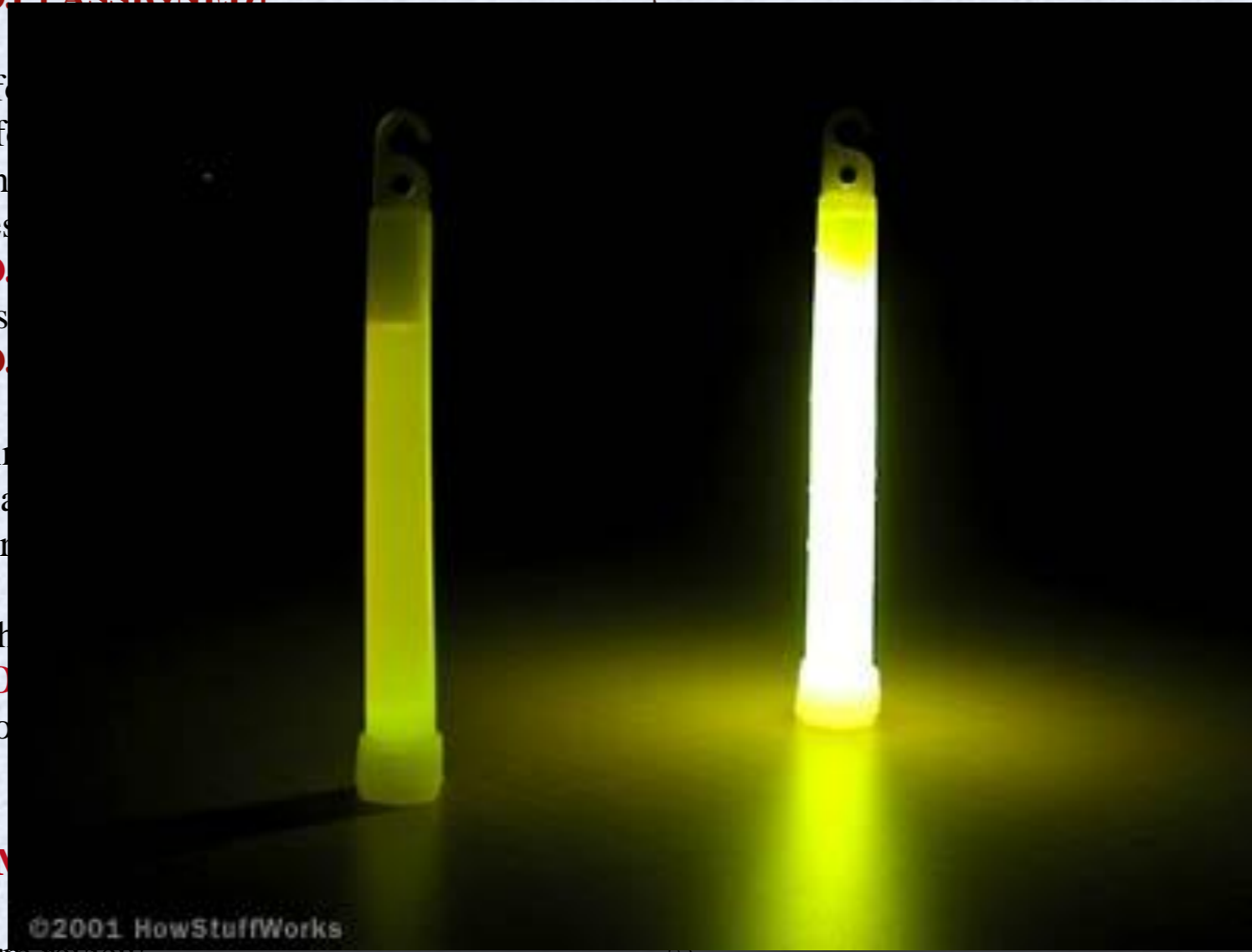
Color

- 14 Tues 02/28 - Color
[HONORARY]
- 15 Thurs 03/01 - Light
- 16 Tues 03/06 - Midterm review
- 17 Thurs 03/08 - [MIDTERM EXAM]

• [SPRING BREAK]

Ray Tracing

- 18 Tues 03/20 - Ray Tracing
[PROJ 3 DUE, PROJ 4 ASSIGNED]
- 19 Thurs 03/22 - Spatial Data Structures



Final

- 31 Thurs 05/03 - Project Showcase
- 32 TBD - [FINAL EXAM]

eparation
Mocap
& Particle Systems
[PROJ 5 ASSIGNED]
g
CARNIVAL
ange Imaging + Tone
[K2 DUE]
cam Clipart

Syllabus and Schedule

Intro

- 01 Tues 01/17 - Introduction
- 02 Thurs 01/19 - OpenGLES

Geometry

- 03 Tues 01/24 - Math for
- 04 Thurs 01/26 - Transfo
- 05 Tues 01/31 - Viewing
- 07 Thurs 02/02 - Curves
- 08 Tues 02/07 - Meshes

Light

- 09 Thurs 02/09 - Shadin
- 10 Tues 02/14 - Material
- 11 Thurs 02/16 - Texture

NPR

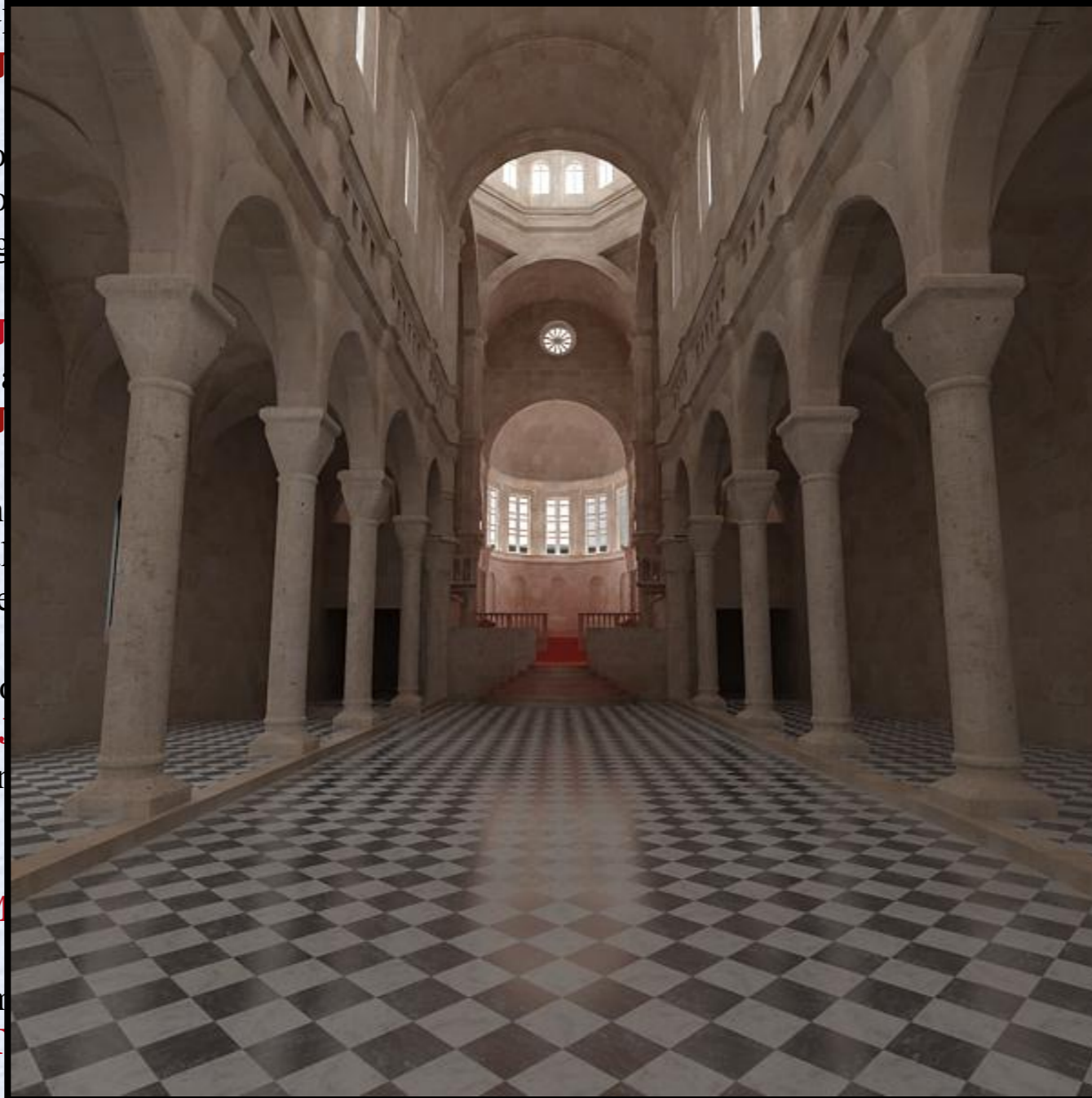
- 12 Tues 02/21 - Non-ph
- 13 Thurs 02/23 - Illusion

Color

- 14 Tues 02/28 - Color
- 15 Thurs 03/01 - Light
- 16 Tues 03/06 - Midterm
- 17 Thurs 03/08 - [MIDT

Ray Tracing

- 18 Tues 03/20 - Ray Tracing



[PROJ 3 DUE, PROJ 4 ASSIGNED]

Data Structures

Clipping
Direct Separation

on and Mocap
al Eqn & Particle Systems
4 DUE, PROJ 5 ASSIGNED]

rocessing
ASS - CARNIVAL
amic Range Imaging + Tone

g
[WORK2 DUE]
d Webcam Clipart
5 DUE]

iew
howcase

[FINAL EXAM]

• [SPRING BREAK]

Syllabus and Schedule

		• 18 Tues 03/20 – Ray Tracing	
Intro	• 01 Tues 01/17 – Introduction • 02 Thurs 01/19 – Ray Tracing		[HOJ 4 ASSIGNED] res
Geometry	• 03 Tues 01/24 – Ray Tracing • 04 Thurs 01/26 – Ray Tracing • 05 Tues 01/31 – Ray Tracing • 07 Thurs 02/02 – Ray Tracing • 08 Tues 02/07 – Ray Tracing		ation ap rticle Systems [HOJ 5 ASSIGNED]
Light	• 09 Thurs 02/16 – Ray Tracing • 10 Tues 02/21 – Ray Tracing • 11 Thurs 02/23 – Ray Tracing		
NPR	• 12 Tues 02/28 – Ray Tracing • 13 Thurs 03/01 – Ray Tracing		[FINAL] e Imaging + Tone
Color	• 14 Tues 03/06 – Ray Tracing • 15 Thurs 03/08 – Ray Tracing • 16 Tues 03/13 – Ray Tracing • 17 Thurs 03/15 – Ray Tracing		[DUE] Clipart
		• 32 TBD	– [FINAL EXAM]
	• [SPRING BREAK]		



HENRIK WANN JENSEN 1995

Syllabus and Schedule

Intro

- 01 Tues 01/17 -
- 02 Thurs 01/19 -

Geometry

- 03 Tues 01/24 -
- 04 Thurs 01/26 -
- 05 Tues 01/31 -
- 07 Thurs 02/02 -
- 08 Tues 02/07 -

Light

- 09 Thurs 02/09 -
- 10 Tues 02/14 -
- 11 Thurs 02/16 -

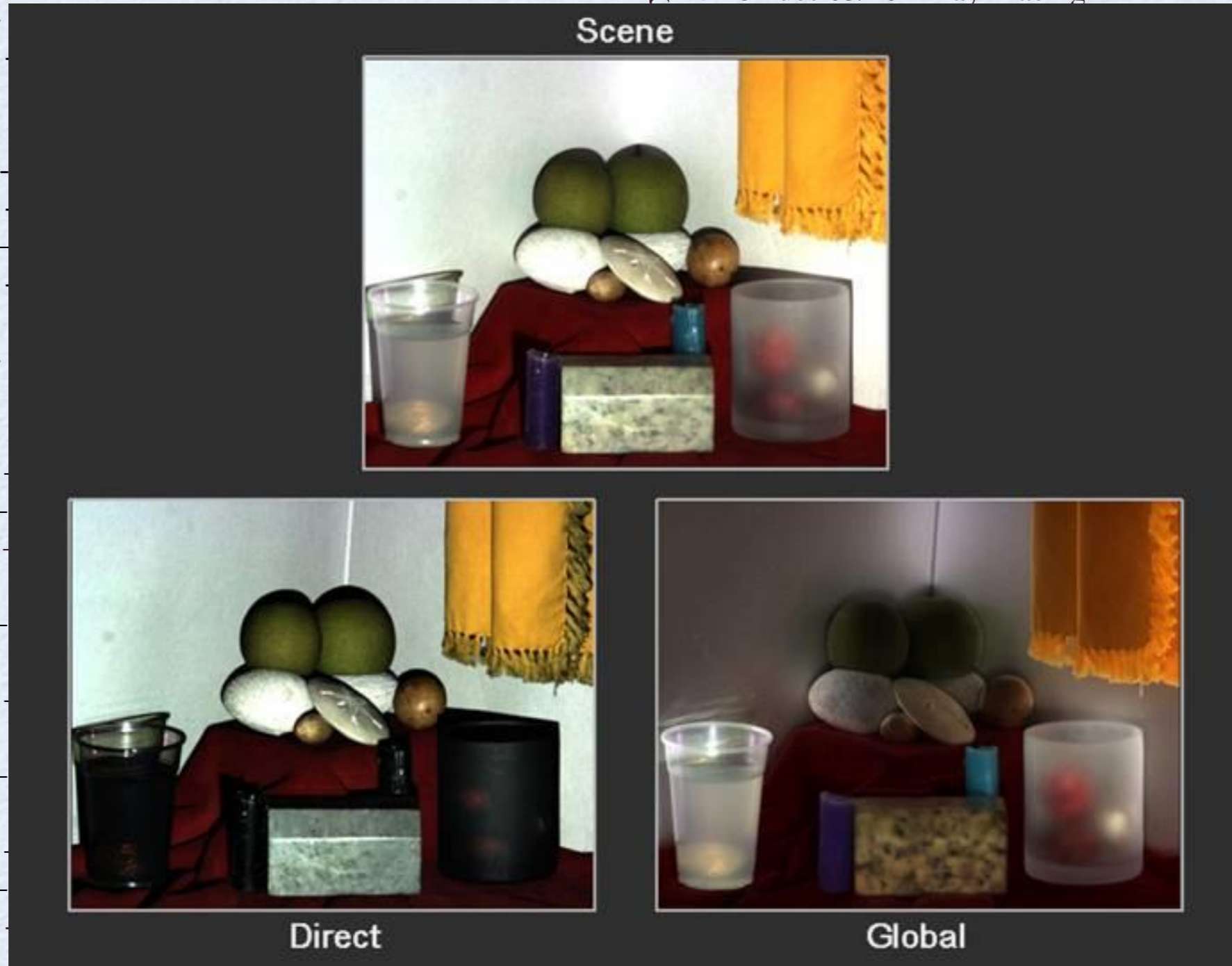
NPR

- 12 Tues 02/21 -
- 13 Thurs 02/23 -

Color

- 14 Tues 02/28 -
- 15 Thurs 03/01 -
- 16 Tues 03/06 -
- 17 Thurs 03/08 -

• 18 Tues 03/20 – Ray Tracing



4 ASSIGNED]

le Systems
5 ASSIGNED]

VAL
aging + Tone

E]
part

• **[SPRING BREAK]**

• 32 TBD – **[FINAL EXAM]**

Syllabus and Schedule

Intro

- 01 Tues 01/17 - Introduction
- 02 Thurs 01/19 - OpenGL

Geometry

- 03 Tues 01/24 -
- 04 Thurs 01/26 -
- 05 Tues 01/31 -
- 07 Thurs 02/02 -
- 08 Tues 02/07 -

Light

- 09 Thurs 02/09 -
- 10 Tues 02/14 -
- 11 Thurs 02/16 -

NPR

- 12 Tues 02/21 -
- 13 Thurs 02/23 -

Color

- 14 Tues 02/28 -
- 15 Thurs 03/01 -
- 16 Tues 03/06 -

• 17 Thurs 03/08 - **[MIDTERM EXAM]**

• **[SPRING BREAK]**

Ray
Tracing

- 18 Tues 03/20 - Ray Tracing

[PROJ 3 DUE, PROJ 4 ASSIGNED]

- 19 Thurs 03/22 - General Data Structures

Comparison

Mocap

& Particle Systems

[PROJ 5 ASSIGNED]

CARNIVAL

Image Imaging + Tone

[PROJ 2 DUE]

Game Clipart

Fi

- 32 TBD

- **[FINAL EXAM]**



Syllabus and Schedule

Intro

- 01 Tues 01/17 - Introduction
- 02 Thurs 01/19 - Op [P

Geometry

- 03 Tues 01/24 - Ma
- 04 Thurs 01/26 - Tr
- 05 Tues 01/31 - Vie
- 07 Thurs 02/02 - Cu [P
- 08 Tues 02/07 - Me [P

Light

- 09 Thurs 02/09 - Sh
- 10 Tues 02/14 - Ma
- 11 Thurs 02/16 - Te

NPR

- 12 Tues 02/21 - No [I
- 13 Thurs 02/23 - Ill

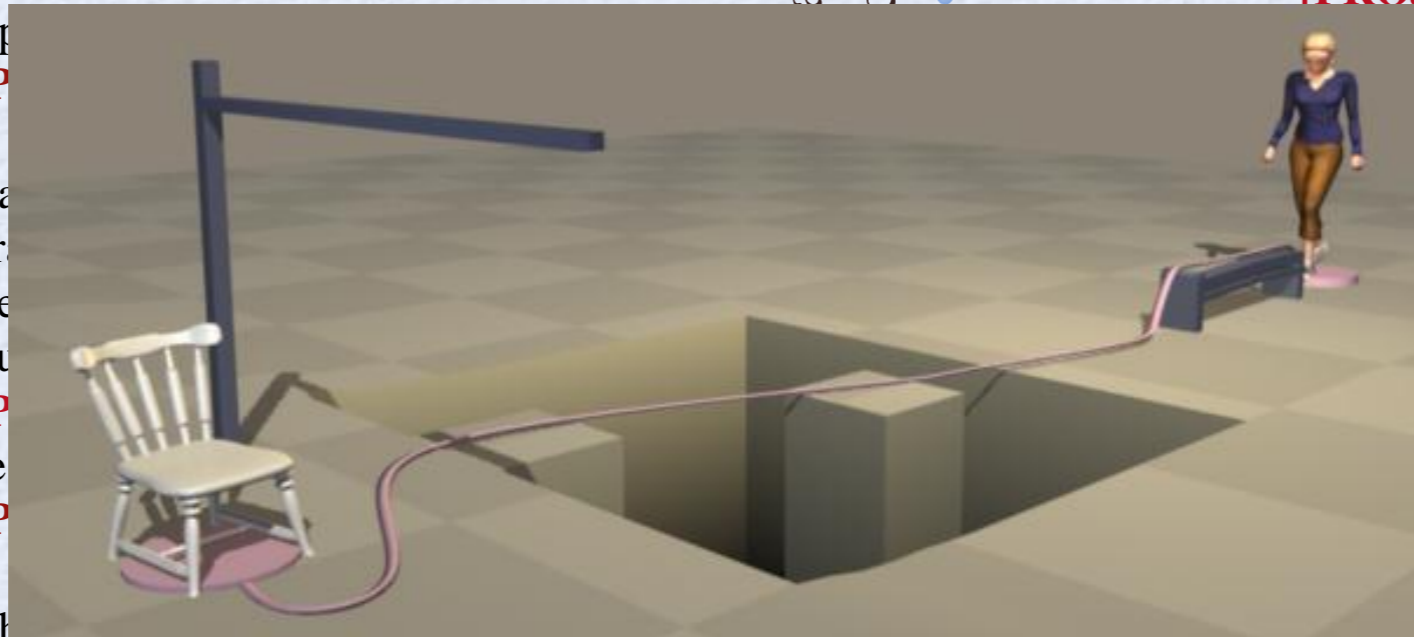
Color

- 14 Tues 02/28 - Co [I
- 15 Thurs 03/01 - Li
- 16 Tues 03/06 - Mi
- 17 Thurs 03/08 - [M

Ray Tracing

- 18 Tues 03/20 - Ray Tracing

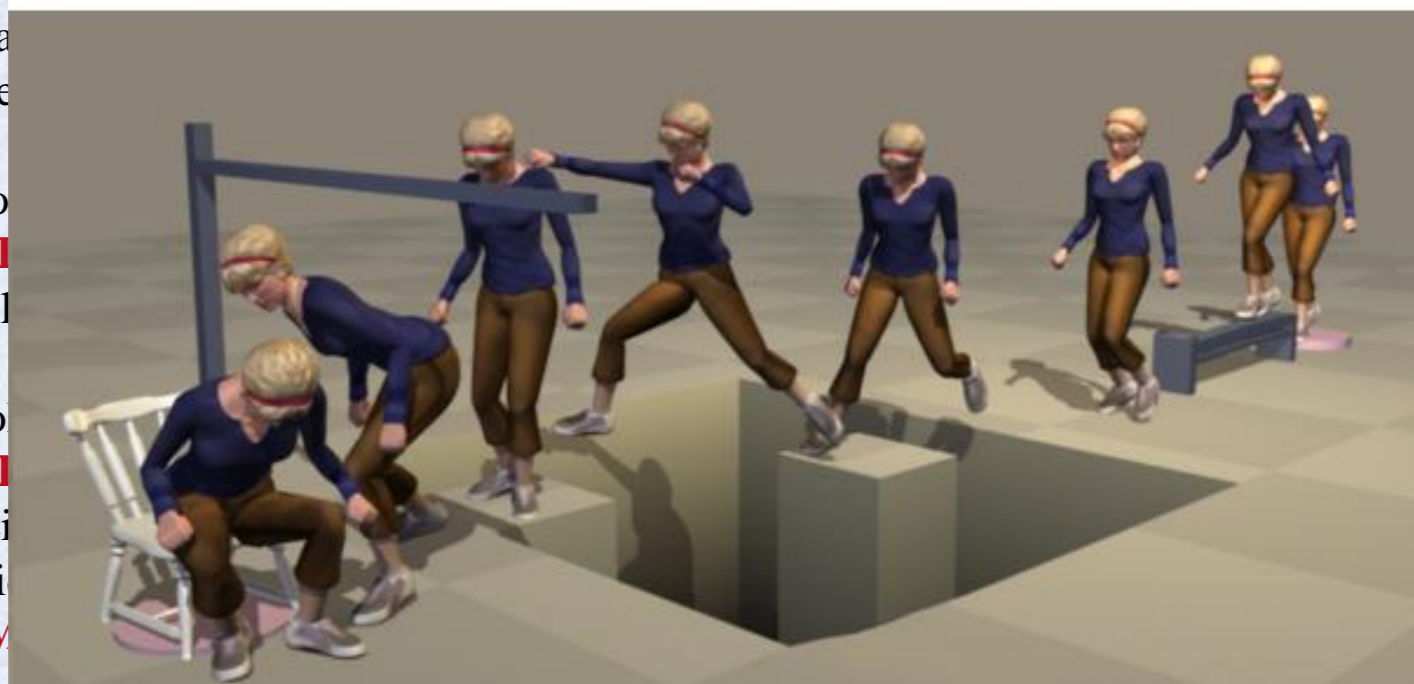
[PROJ 3 DUE, PROJ 4 ASSIGNED]



Data Structures

Mapping
direct Separation

on and Mocap
ial Eqn & Particle Systems
4 DUE, PROJ 5 ASSIGNED]



rocessing
ASS - CARNIVAL
namic Range Imaging + Tone
ing
WORK2 DUE]
nd Webcam Clipart
5 DUE]

view
Showcase

• [SPRING BREAK]

• 32 TBD - [FINAL EXAM]

Syllabus and Schedule

Intro

- 01 Tues 01/17 - Introduction
- 02 Thurs 01/19 - OpenGL

[PROJ 1 A]

Geometry

- 03 Tues 01/24 - Math for Co
- 04 Thurs 01/26 - Transforma
- 05 Tues 01/31 - Viewing/Ca
- 07 Thurs 02/02 - Curves and

[PROJ 1 I]

- 08 Tues 02/07 - Meshes and

[PROJ 2 A]

Light

- 09 Thurs 02/09 - Shading/L
- 10 Tues 02/14 - Materials
- 11 Thurs 02/16 - Texture ma

NPR

- 12 Tues 02/21 - Non-photor
- 13 Thurs 02/23 - Illusions

[PROJ 2 I]

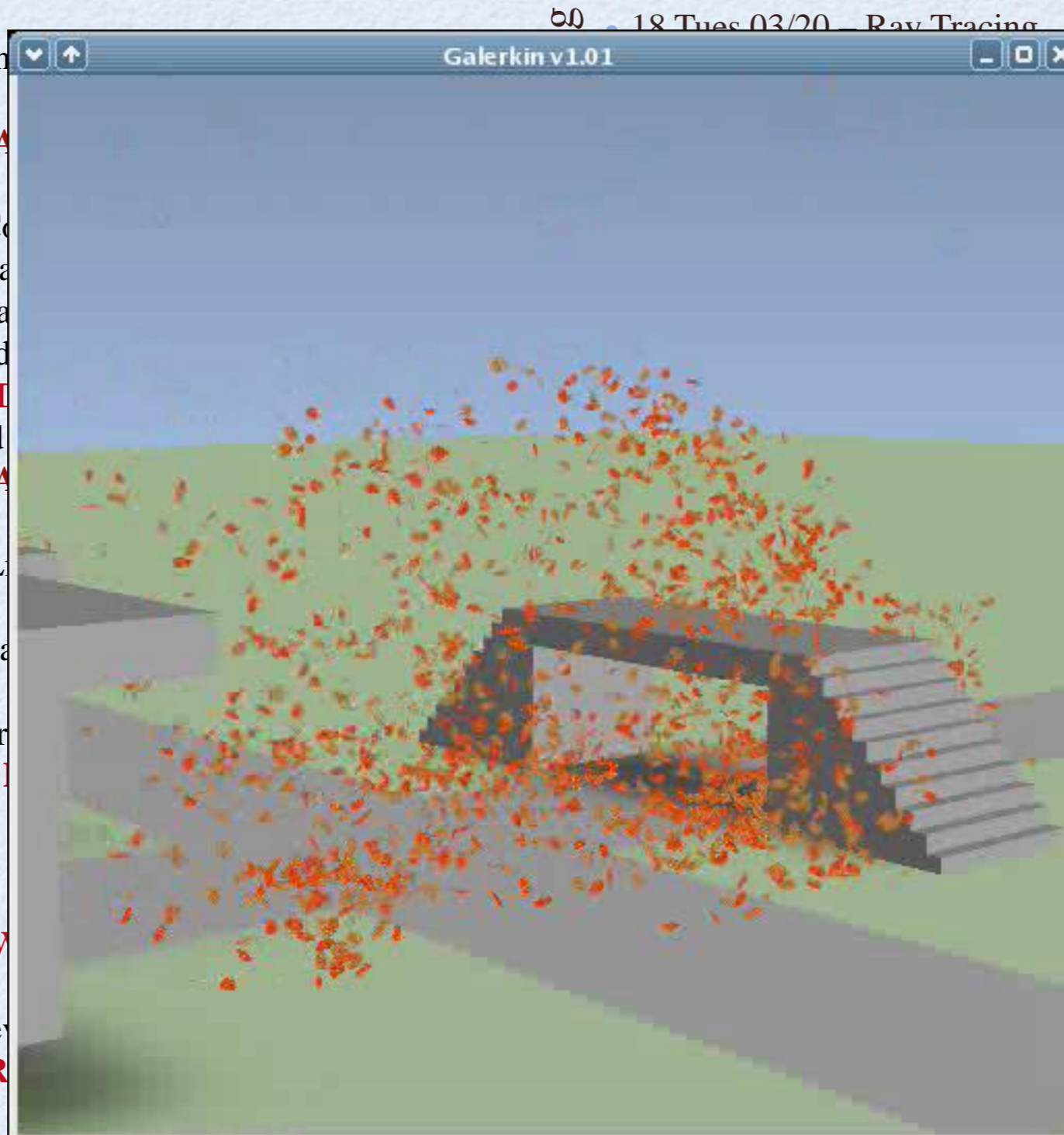
Color

- 14 Tues 02/28 - Color
- [HOMEV]
- 15 Thurs 03/01 - Light
- 16 Tues 03/06 - Midterm rev
- 17 Thurs 03/08 - [MIDTER

[HOMEV]

[MIDTER]

• [SPRING BREAK]



[E, PROJ 4 ASSIGNED]

tructures

ig
Separation

l Mocap
& Particle Systems
[E, PROJ 5 ASSIGNED]

ng
CARNIVAL
Range Imaging + Tone

[RK2 DUE]
ocam Clipart
[E]

ase

[M]

Syllabus and Schedule

Intro

- 01 Tues 01/17 - Introduction
- 02 Thurs 01/19 - OpenGL
[PROJ 1 ASSIGNED]

Geometry

- 03 Tues 01/24
- 04 Thurs 01/26
- 05 Tues 01/31
- 07 Thurs 02/02
- 08 Tues 02/07 -

Light

- 09 Thurs 02/09
- 10 Tues 02/14 -
- 11 Thurs 02/16

NPR

- 12 Tues 02/21 -
- 13 Thurs 02/23

Color

- 14 Tues 02/28 -
- 15 Thurs 03/01
- 16 Tues 03/06 -

- 17 Thurs 03/08 - [MIDTERM EXAM]

• [SPRING BREAK]

Ray Tracing

- 18 Tues 03/20 – Ray Tracing
[PROJ 3 DUE, PROJ 4 ASSIGNED]
- 19 Thurs 03/22 – Spatial Data Structures



Fin

- 31 Thurs 05/05 – Project Showcase

- 32 TBD – [FINAL EXAM]

paration

ocap
Particle Systems
[PROJ 5 ASSIGNED]

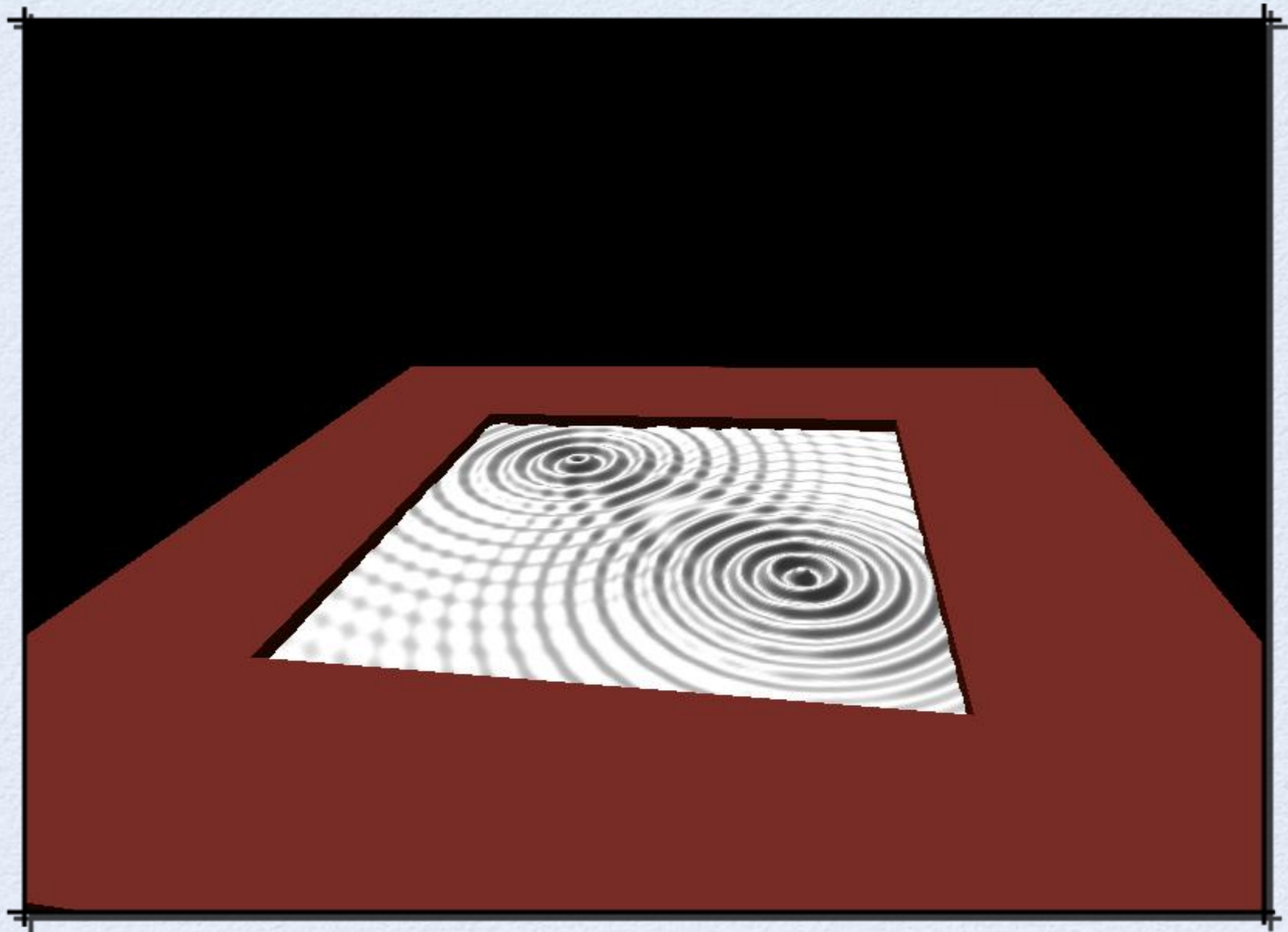
[CARNIVAL]
Image Imaging + Tone

[PROJ 2 DUE]
Image Clipart

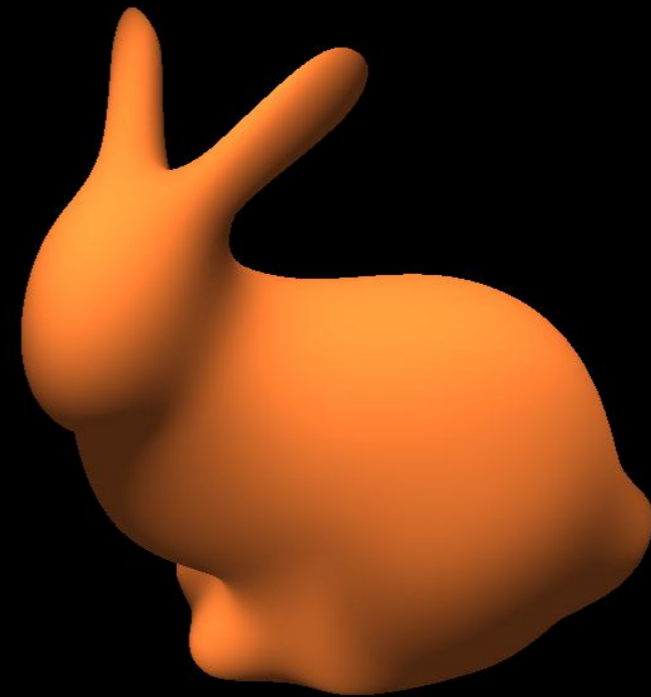
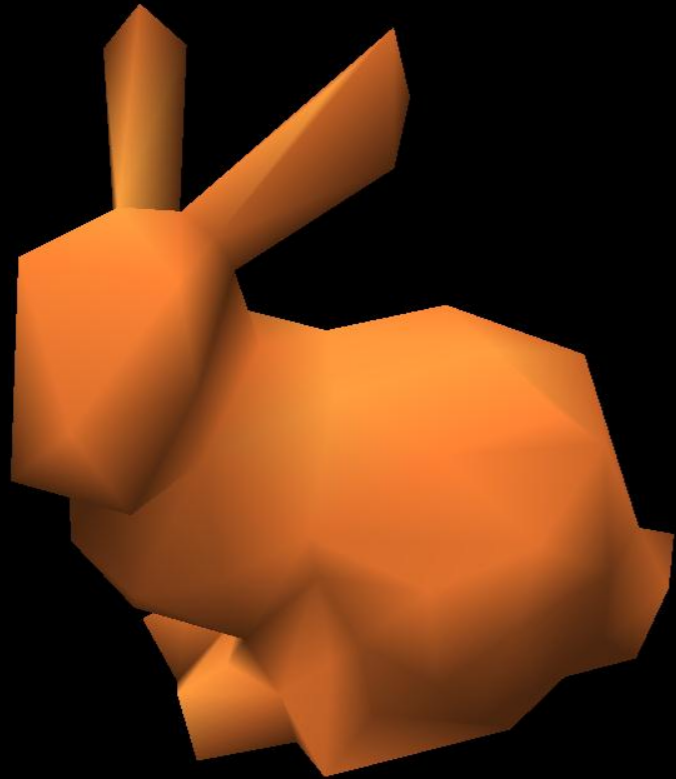
Projects

- We will have full class votes and prizes too!
- Five Projects:
 - Starter project - OpenGL
 - Geometry and Meshes
 - GLSL Shader Language – Special effects
 - Ray Tracing
 - Animation and Flocking

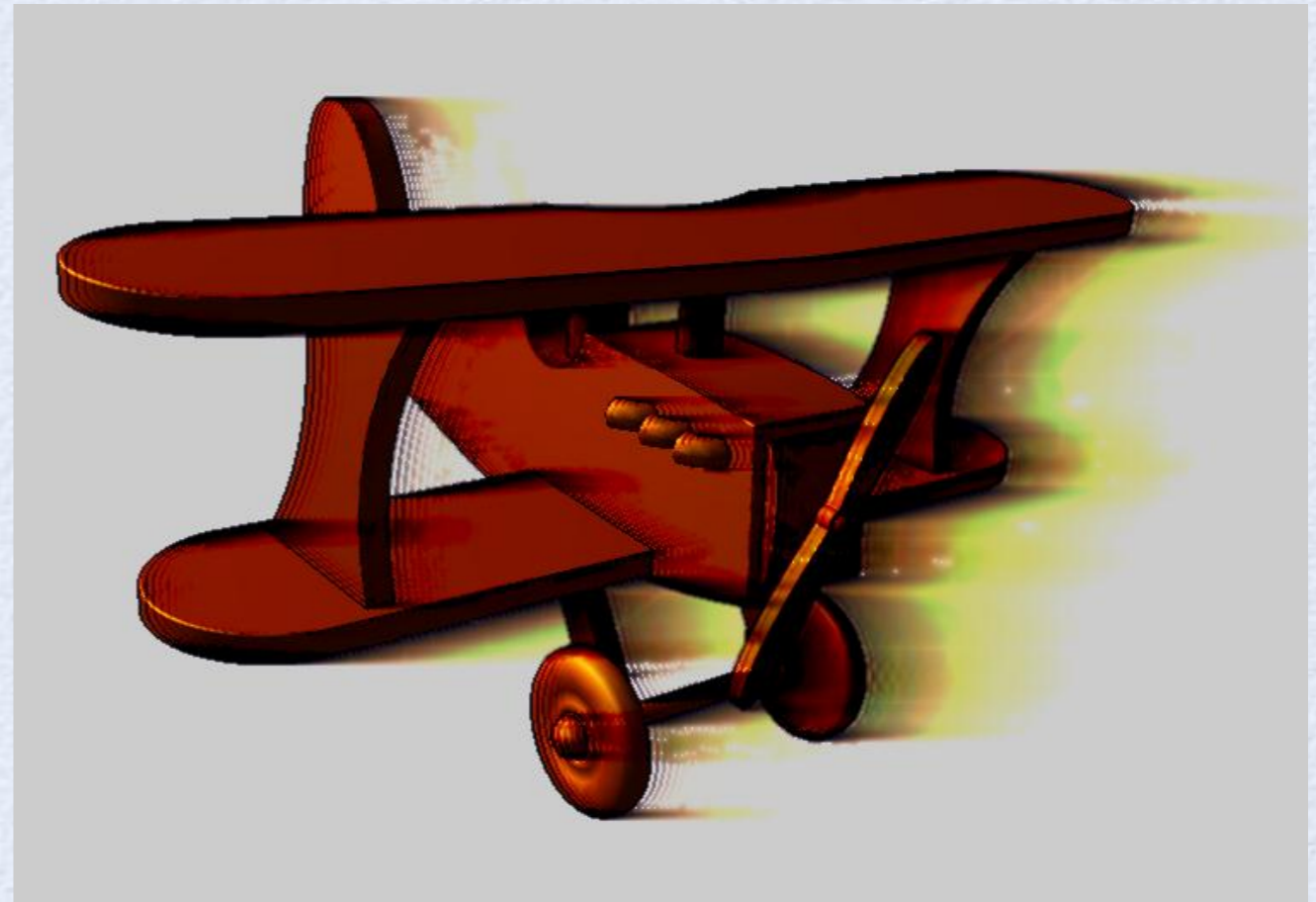
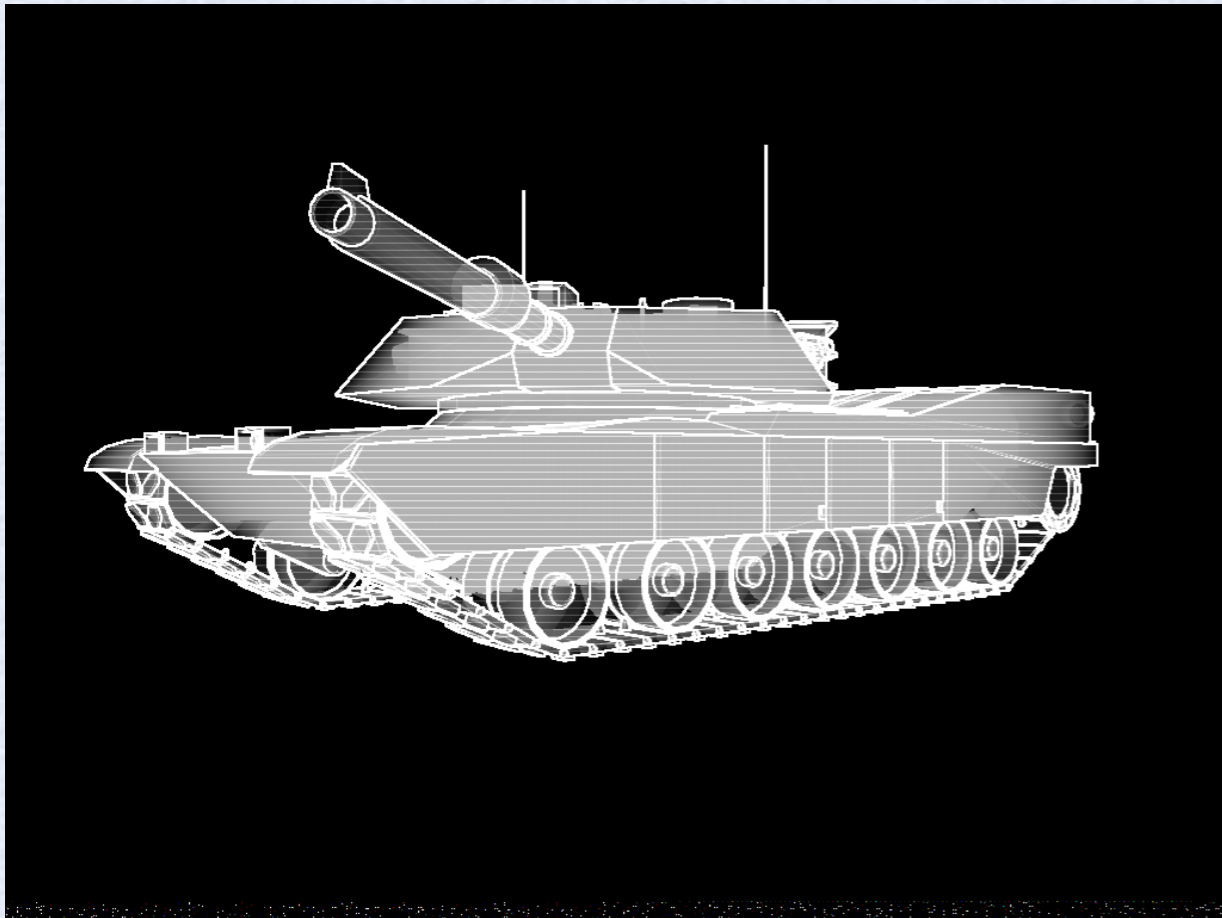
Project 1: Basics of OpenGL



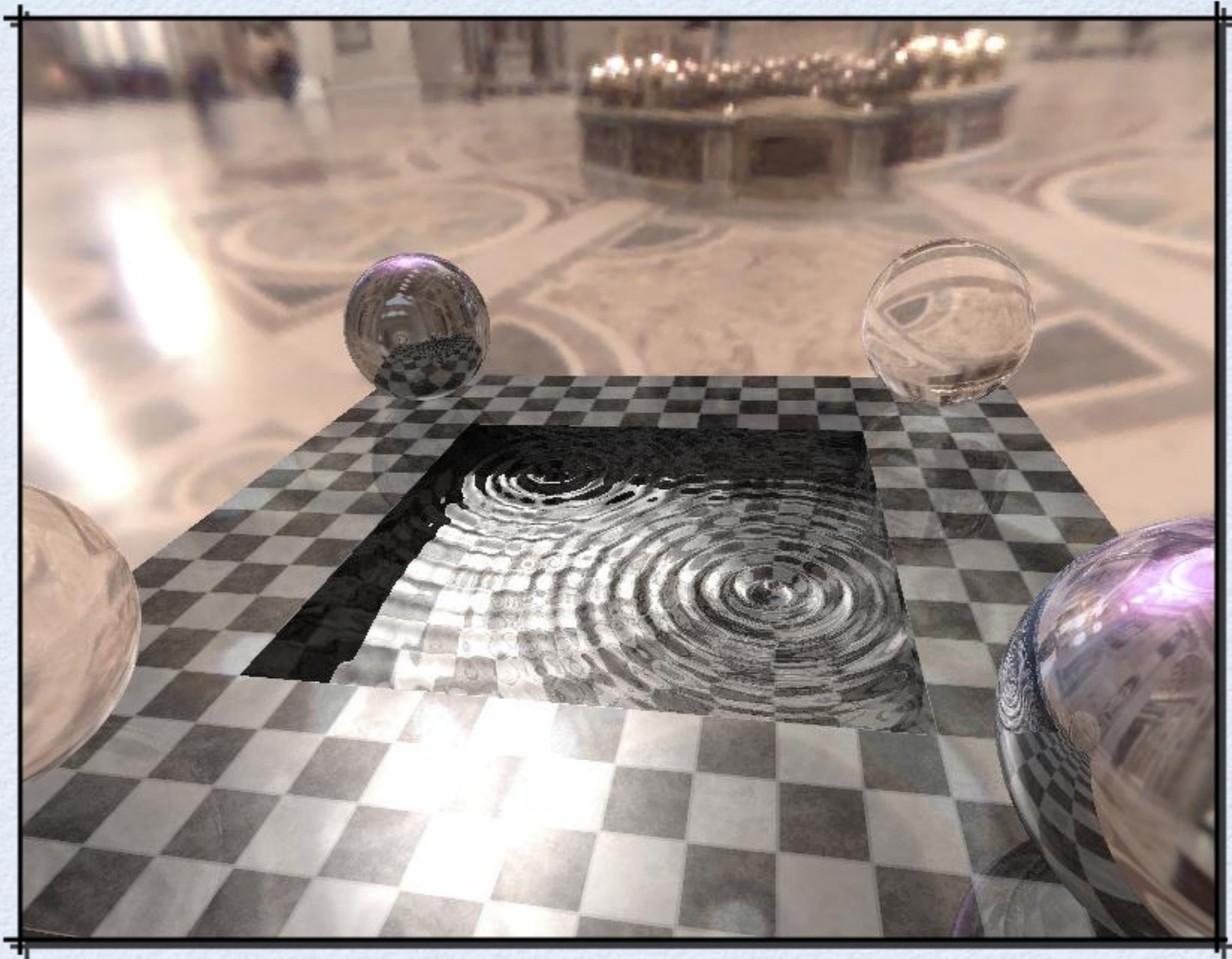
Project 2: Geometry and Meshes



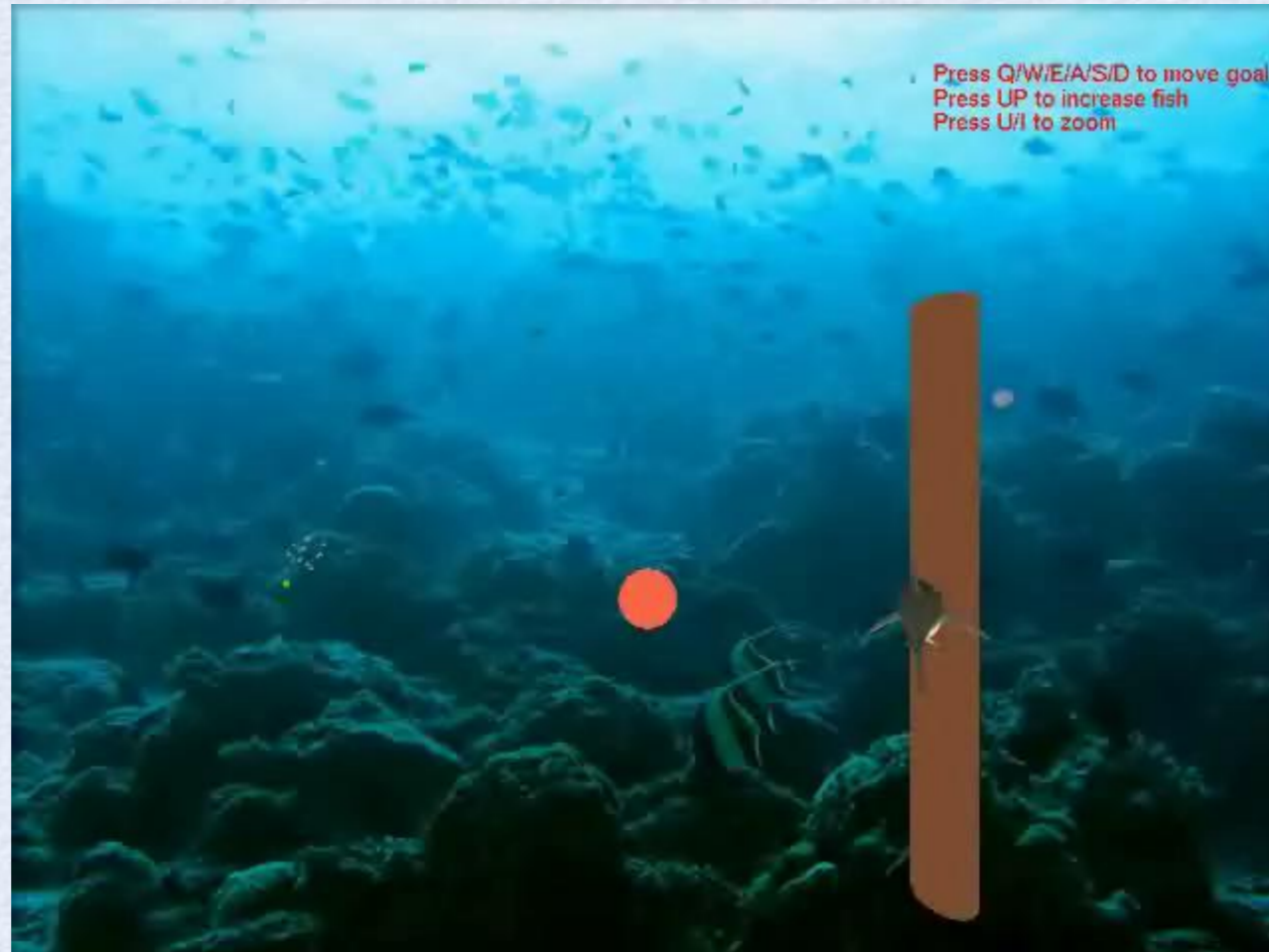
Project 3: OpenGL Shaders



Project 4: Ray Tracing



Project 5: Animation and Flocking



Next Lecture

- Basics of OpenGL
- How to access CMU machines and start programming
- Project 1 assigned