

Computer Graphics

15-462

cs.cmu.edu/~15462

Tue, Thur: 1:30 pm - 2:50 pm

HH B131

Introduction

- What is computer graphics?
- Administratrivia.
- Topics

Goals of Computer Graphics

- Faking reality – convincingly.
- Creating alternative reality.



Faking Reality

A serene landscape featuring a calm pond in the foreground, surrounded by lush green trees and reeds. The water reflects the surrounding greenery, and several fallen leaves are scattered on the water's surface. The overall atmosphere is peaceful and natural.

Faking Reality

Faking Reality



fun graphics : infeasible -> feasible =

Making of a soda commercial.



PRESENTS

BEHIND THE SCENES

fun graphics : infeasible -> feasible =

Alternative reality



What is graphics?

- Rendering
- Animation
- Hardware

What is graphics?

- Rendering
- Animation
- Hardware

Rendering

Cornell_box.scene

1. Sphere

```
[pos - (0.1, 0.0, 0.0),  
rad - 0.1)]
```

2. Sphere

```
[pos - (0.3, 0.0, -0.4),  
rad - 0.13)]
```

3. Triangle

```
[pos - [(0.1, 0.4, 0.1),  
        (0.3, 0.14, 2.0),  
        (0.1, 0.5, 0.14)]]
```

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-
-

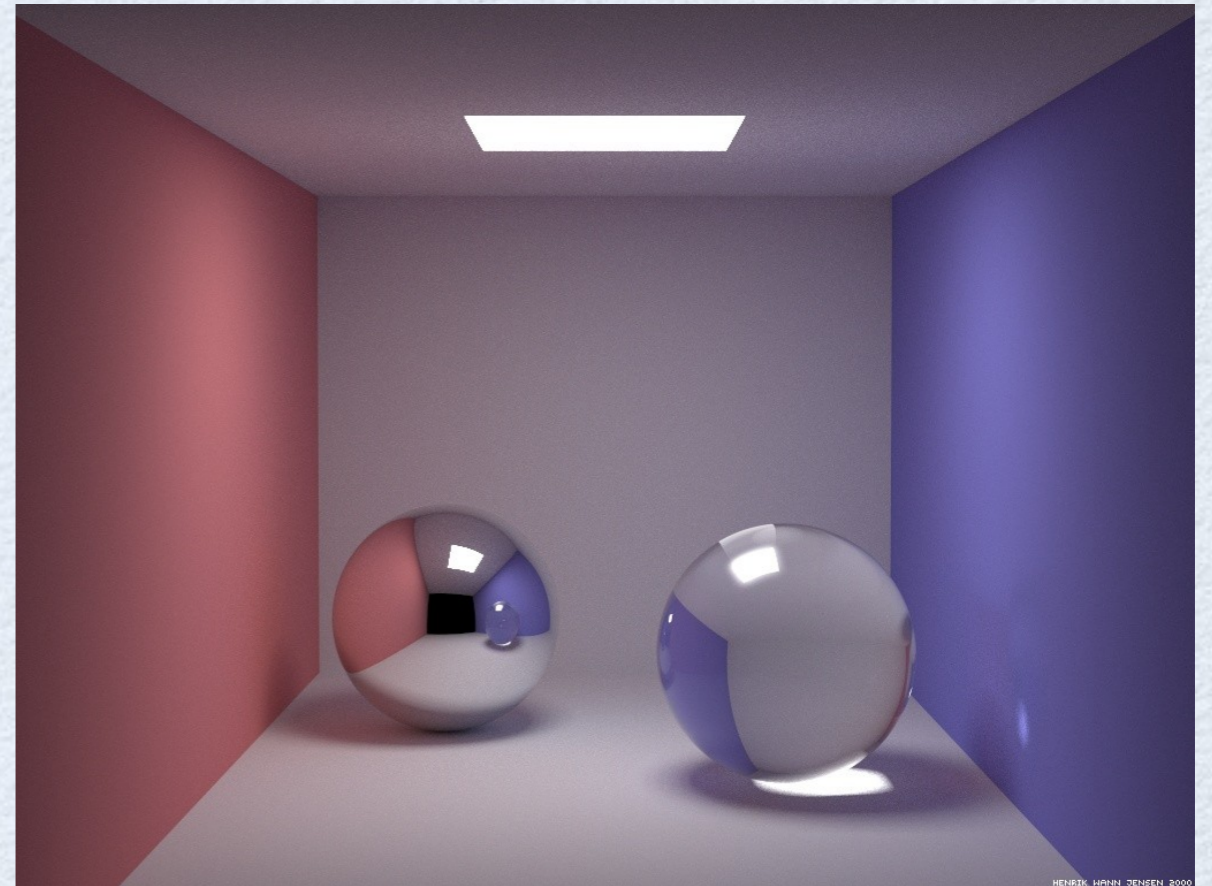


Image credit: Henrik Wann Jensen

'Real time' rendering vs. pre-rendering

1000's of triangles per frame.

~40ms per frame on current consumer desktops.

Billions of triangles per frame.

~10 hours per frame on current consumer desktops.

Brave – video game



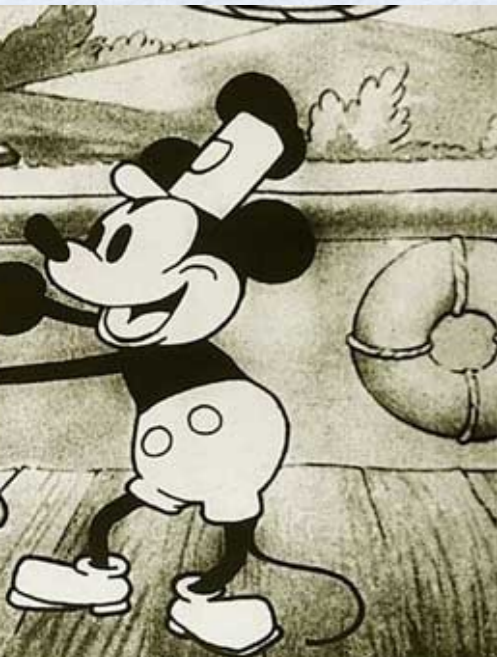
Brave – movie



What is graphics?

- Rendering
- Animation
- Hardware

Animation



Animation

Keyframe ('Traditional' animation)

Motion capture

Hand drawn

Human/Computer hybrid animation

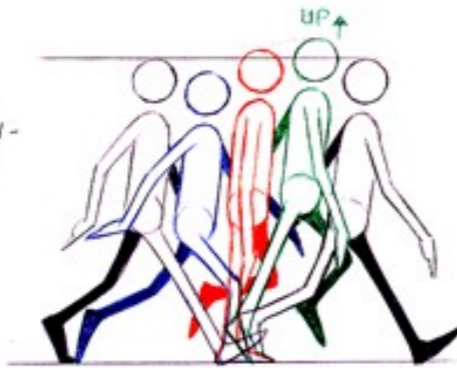
Procedural

Physically based

...

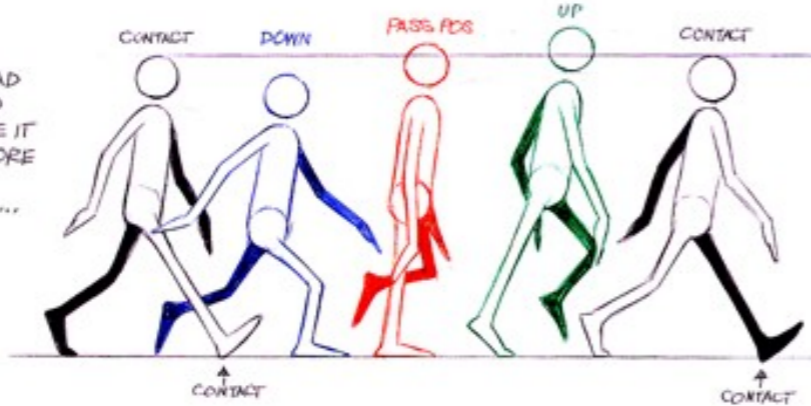
Rule-based

NEXT WE PUT IN THE UP POSITION - THE PUSH-OFF.

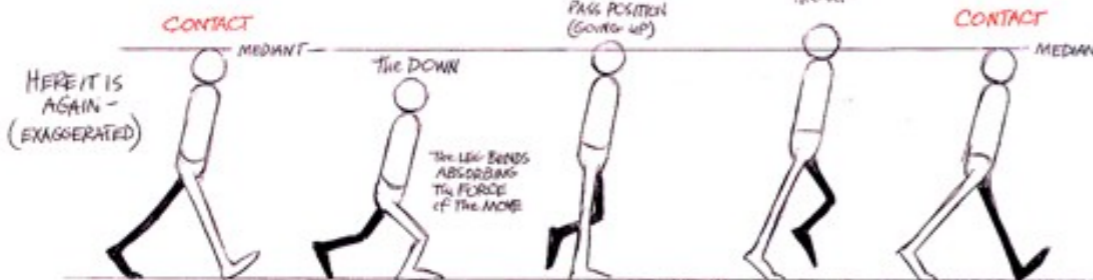


The FOOT PUSHING OFF LIFTS THE PELVIS, BODY and HEAD UP TO ITS HIGHEST POSITION - THEN THE LEG IS THROWN OUT TO CATCH US ON THE CONTACT POSITION - SO WE DON'T FALL ON OUR FACE.

LET'S SPREAD IT OUT AND EXAGGERATE IT A LITTLE MORE SO IT'S CLEARER...

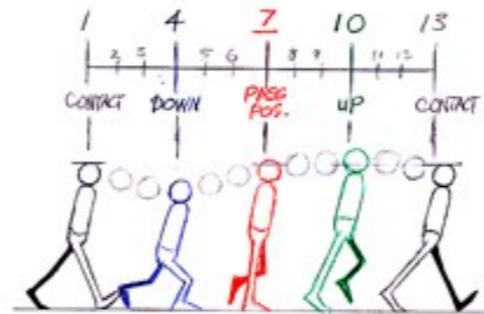


SO, IN A NORMAL 'REALISTIC' WALK THE WEIGHT GOES DOWN JUST AFTER THE STEP - JUST AFTER THE CONTACT. AND THE WEIGHT GOES UP JUST AFTER THE PASSING POSITION.

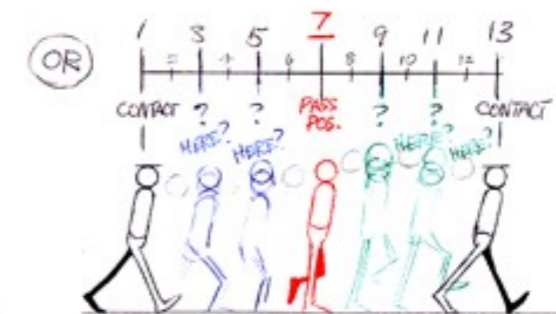


SET THE TEMPO

The FIRST THING TO DO IN A WALK IS SET A BEAT. GENERALLY PEOPLE WALK ON 12'S - MARCH TIME (HALF A SECOND PER STEP - TWO STEPS PER SECOND.) BUT LAZY ANIMATORS DON'T LIKE TO DO IT ON 12'S. IT'S HARD TO DIVIDE UP. YOU HAVE TO USE 'THIRDS' - THINK PARTLY IN THIRDS.

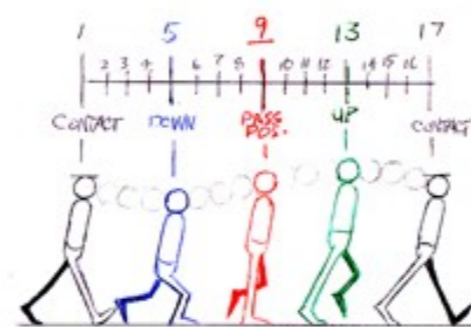


THE IN BETWEENS ARE GOING TO BE ON THIRDS.

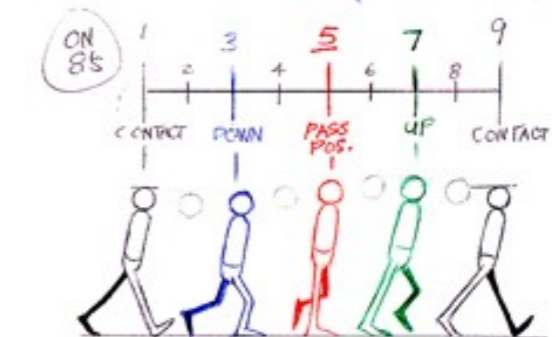


OOPS - NOW WHERE DO WE PUT THE DOWN OR UP? HEY, THIS IS GETTING HARD - ESPECIALLY WHEN WE GET INTO THE ARMS AND HEAD, AND 'ACTING' AND DEADLINEY - MAYBE THERE'S AN EASIER WAY?

THERE IS AN EASIER WAY - HAVE HIM/HER WALK ON 16'S - OR WALK ON 8'S. MUCH EASIER TO WALK ON 16'S - IT'S EASY TO DIVIDE UP - SAME THING ON 8'S. (EACH STEP = 2/3 SEC) (3 STEPS PER SEC.)



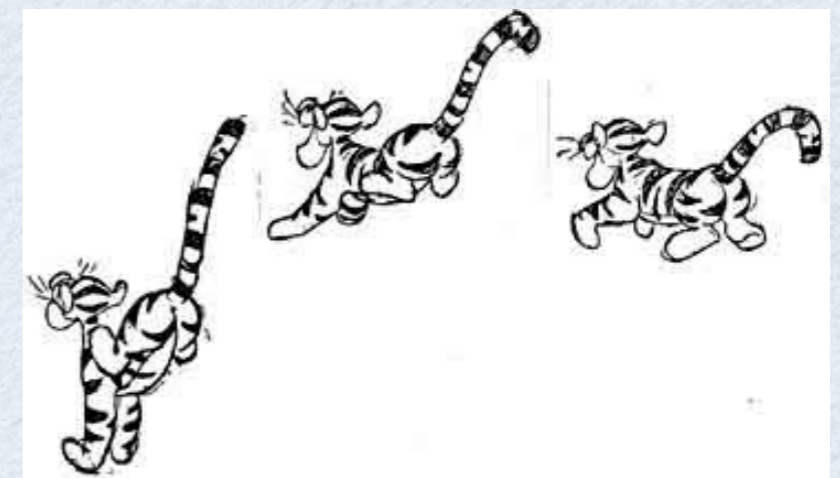
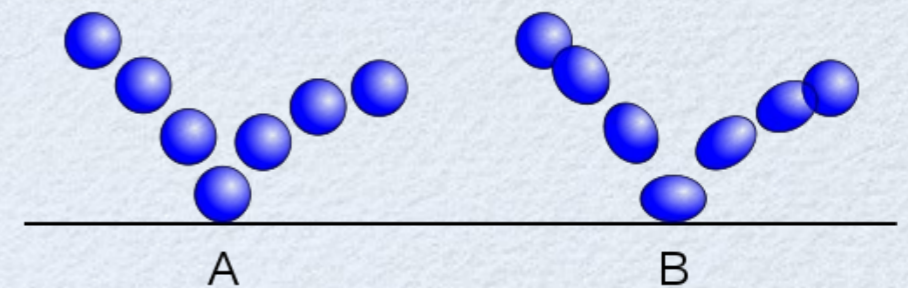
WHEW, THAT MAKES LIFE EASIER. NICE EVEN DIVISIONS NOW -



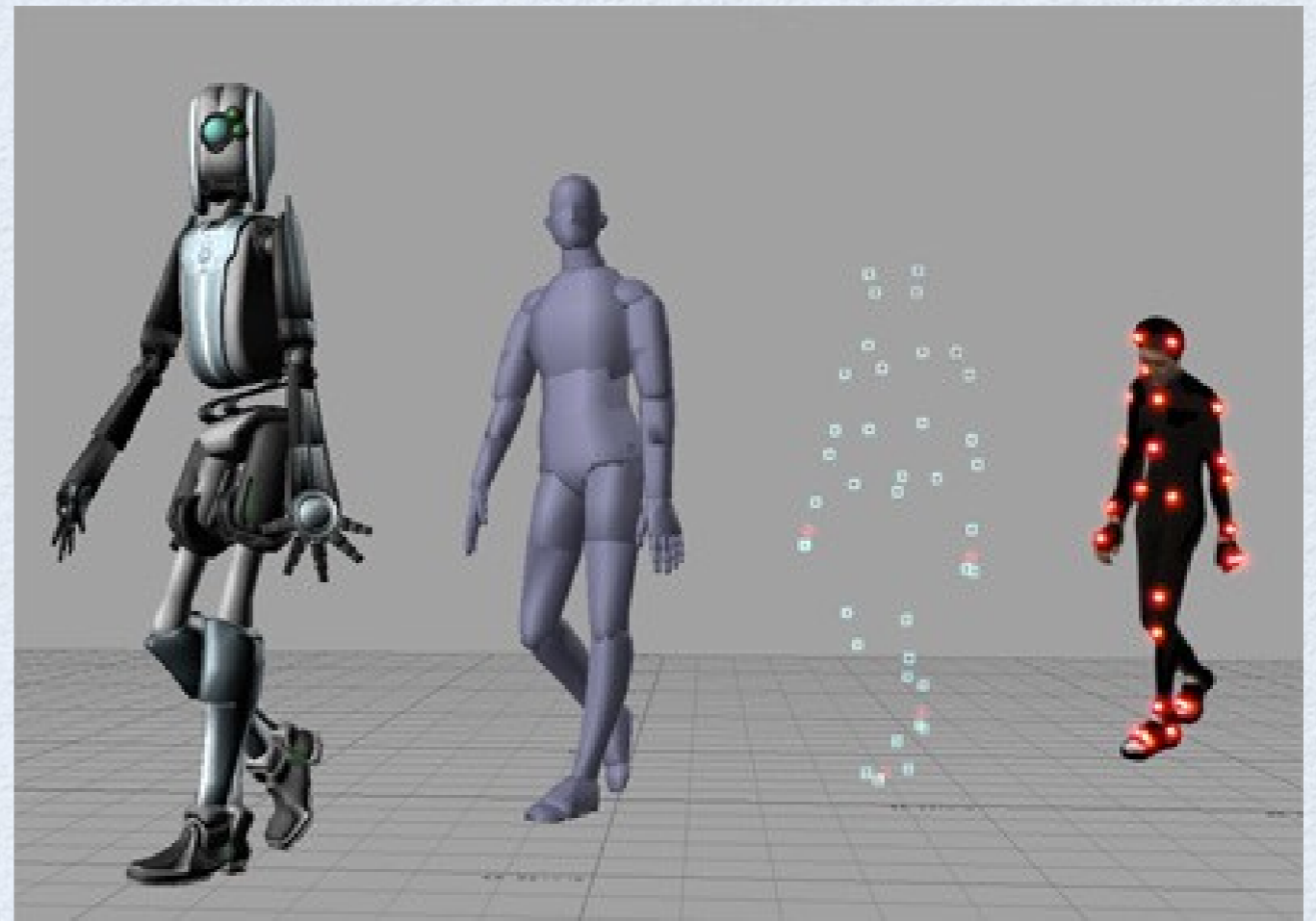
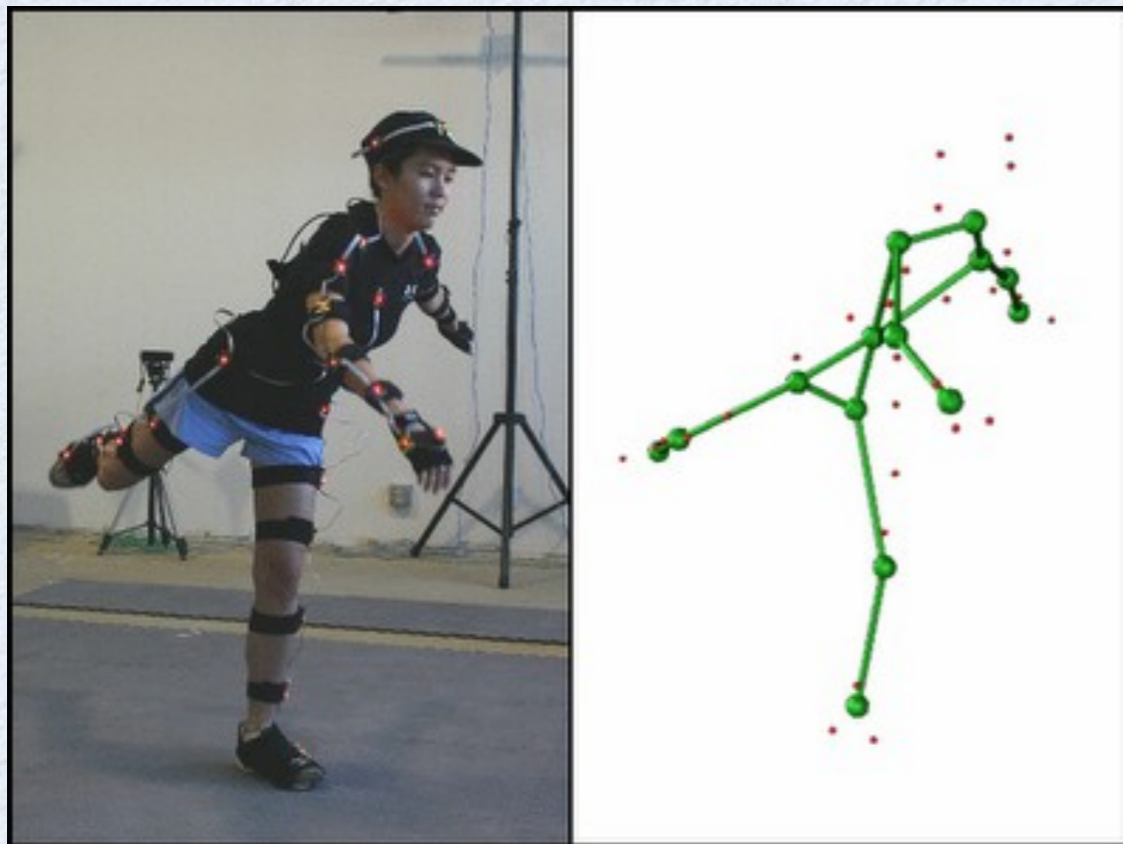
(REDUCED UP AND DOWN ACTION - SINCE IT'S TAKING PLACE IN A SHORTER TIME) THIS IS WHY CARTOON WALKS ARE OFTEN ON 8'S. BUMP, BUMP, BUMP, 3 STEPS A SECOND.

Principles of Traditional Animation - Lasseter

- 1) Squash and Stretch - defining the rigidity and mass of an object by distorting its shape during an action
- 2) Timing and Motion - spacing actions to define the weight and size of objects and the personality of characters
- 3) Anticipation - the preparation for an action
- 4) Staging - presenting an idea so that it is unmistakably clear
- 5) Follow Through and Overlapping Action - the termination of an action and establishing its relationship to the next action
- 6) Straight Ahead Action and Pose-to-Pose Action - The two contrasting approaches to the creation of movement
- 7) Slow In and Out - the spacing of the in-between frames to achieve subtlety of timing and movement
- 8) Arcs - the visual path of action for natural movement
- 9) Exaggeration - Accentuating the essence of an idea via the design and the action
- 10) . Secondary Action - the action of an object resulting from another action
- 11) . Appeal - creating a design or an action that the audience enjoys watching



Data driven animation - motion capture



Data driven mocap



State of the art physically-based animation

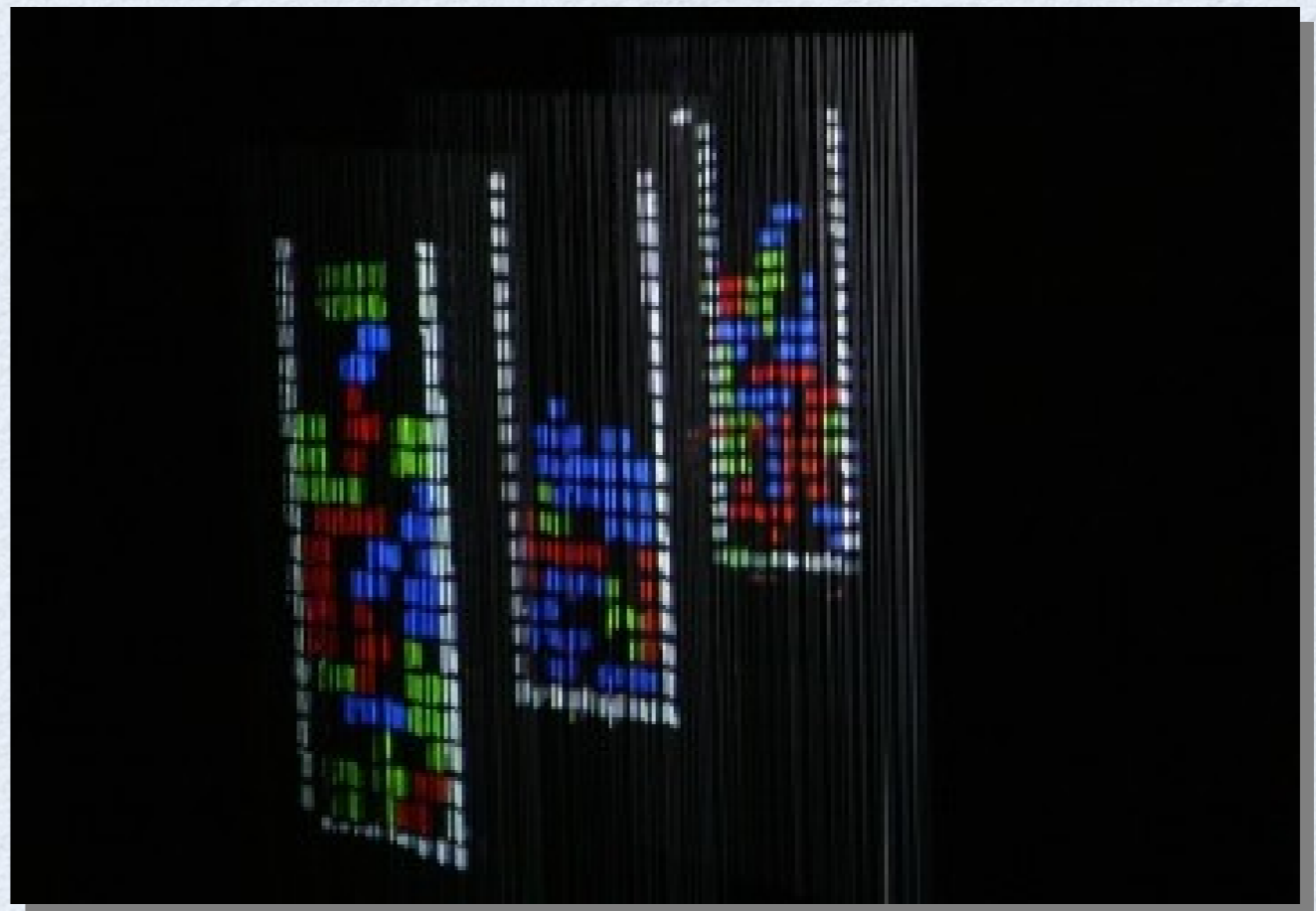
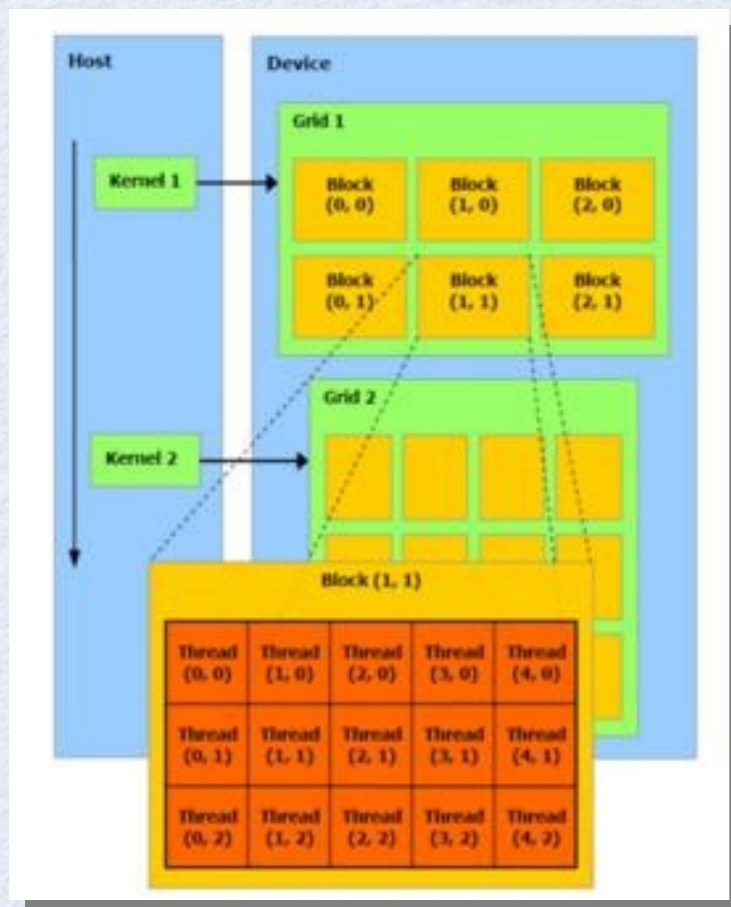
<http://www.cs.cornell.edu/projects/YarnCloth/>

What is graphics?

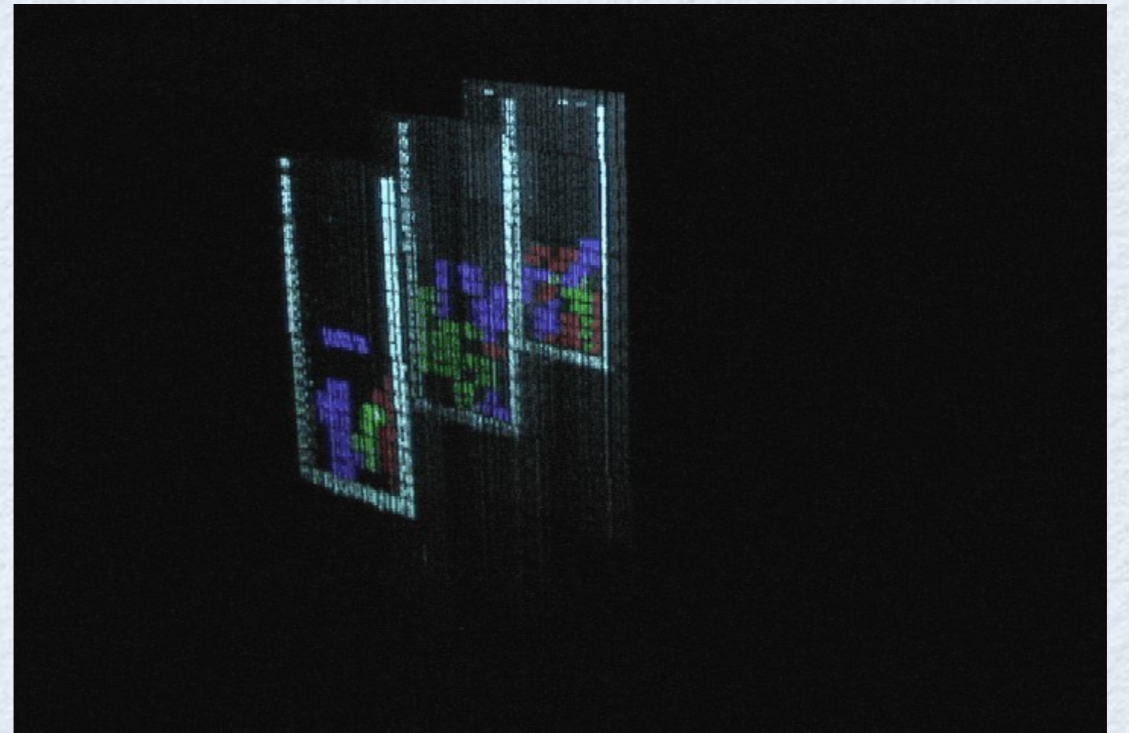
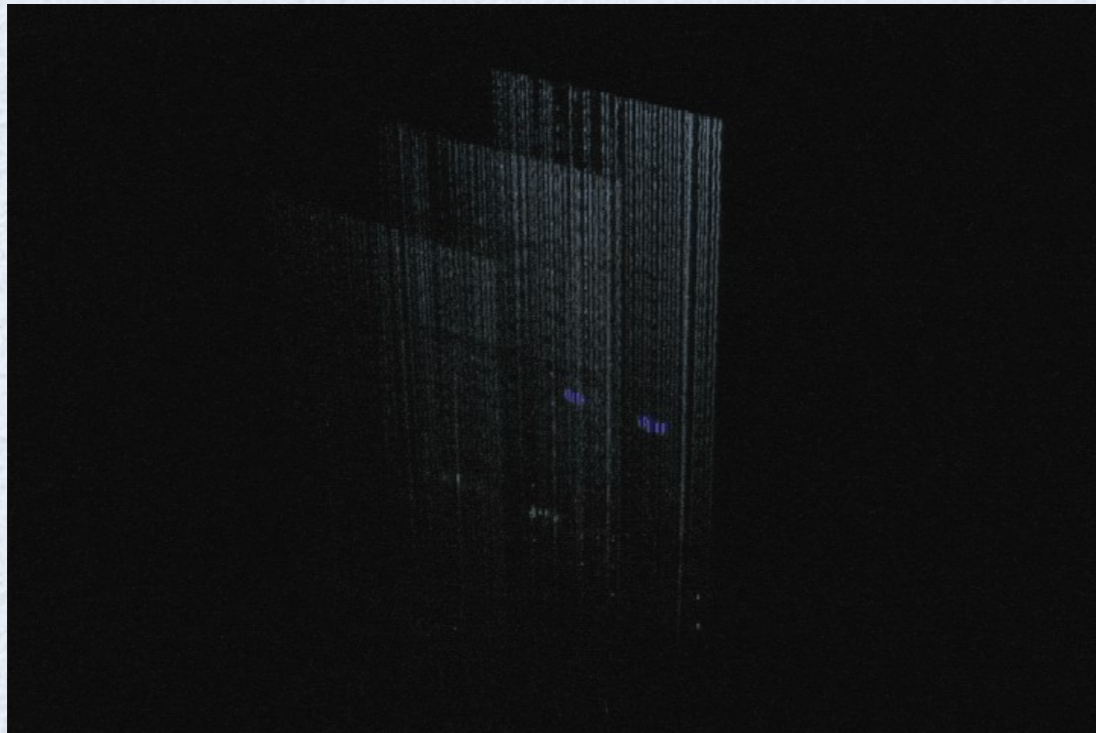
- Rendering
- Animation
- Hardware



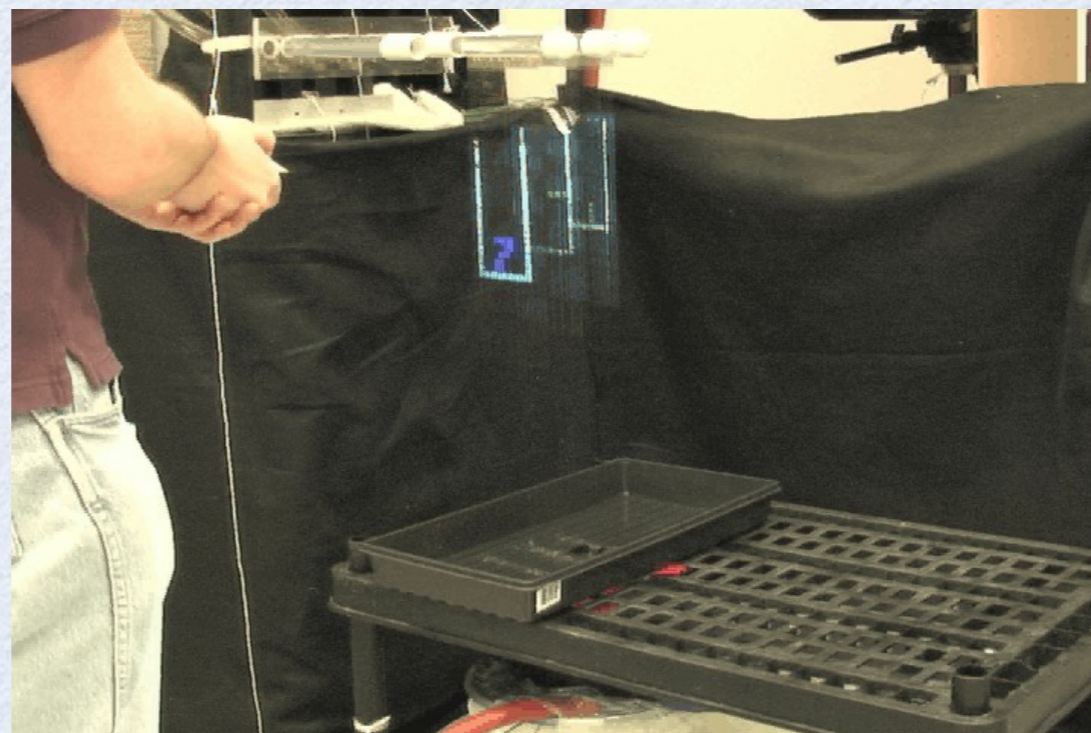
Hardware



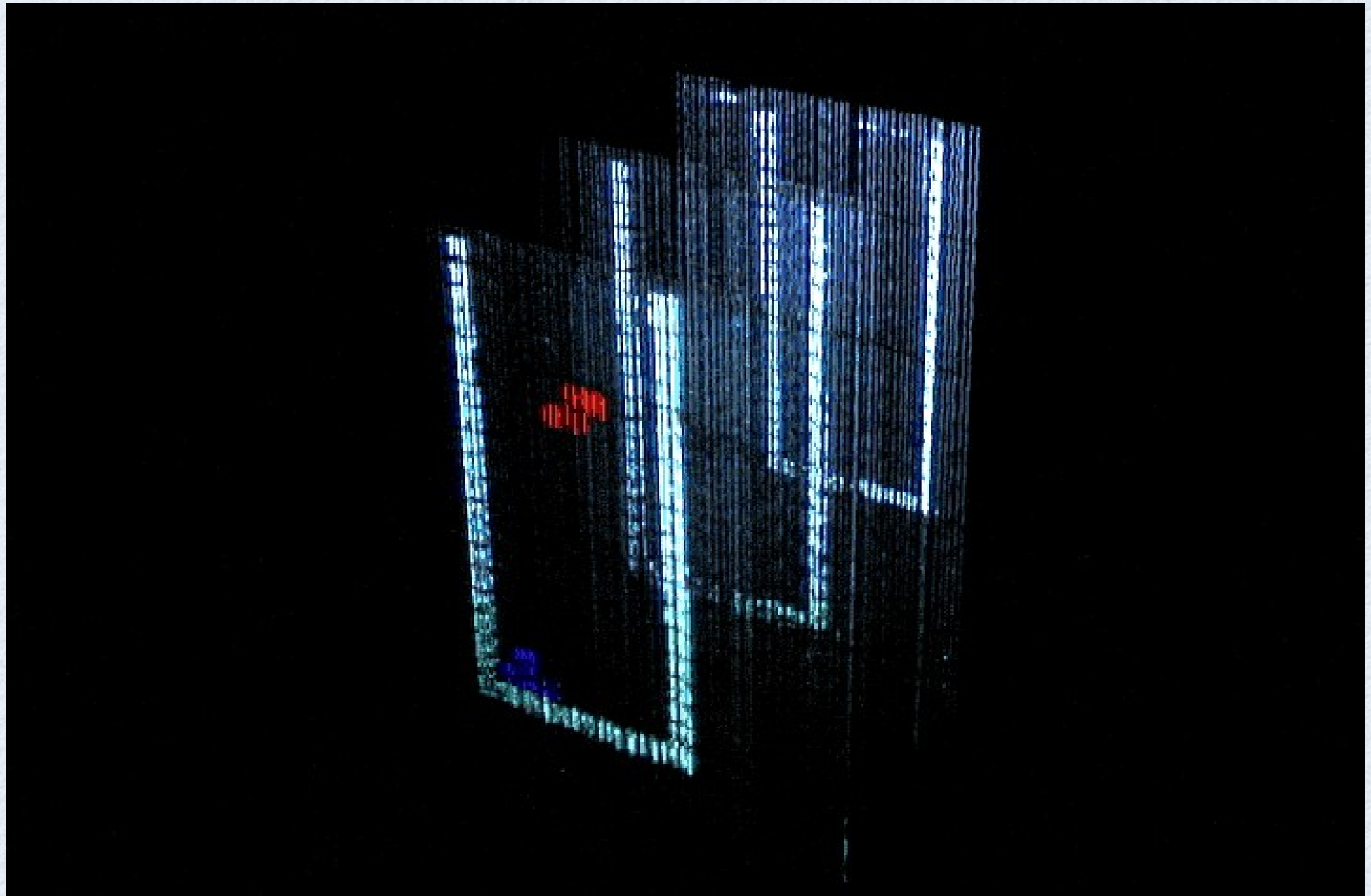
Multi-layered Water Display



“Honey! Look! The TV ran out of water again!!” – Youtube



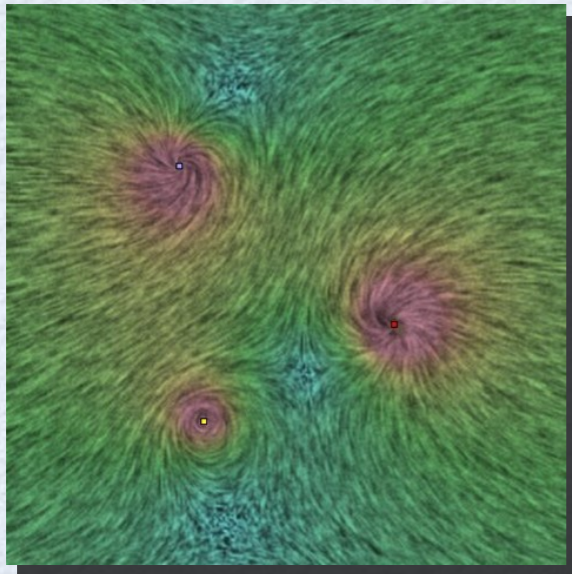
Three level TETRIS



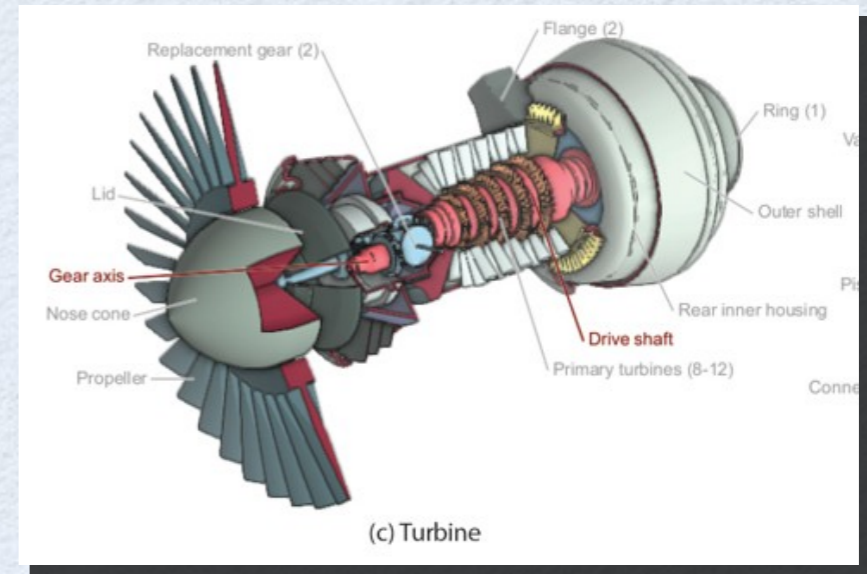
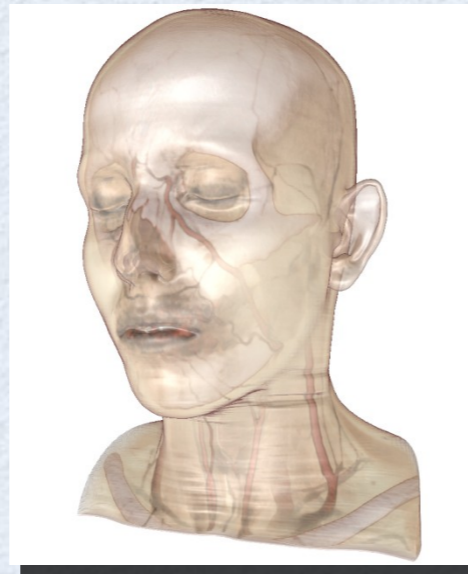
Real world example



What Else Is Computer Graphics



Scientific Visualization



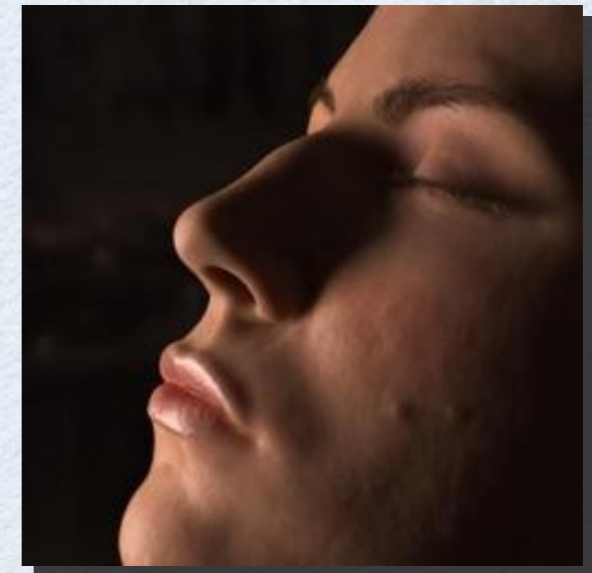
Illustration



NPR / Art



Computational Photography



Virtual Life

and much more....

Current Research

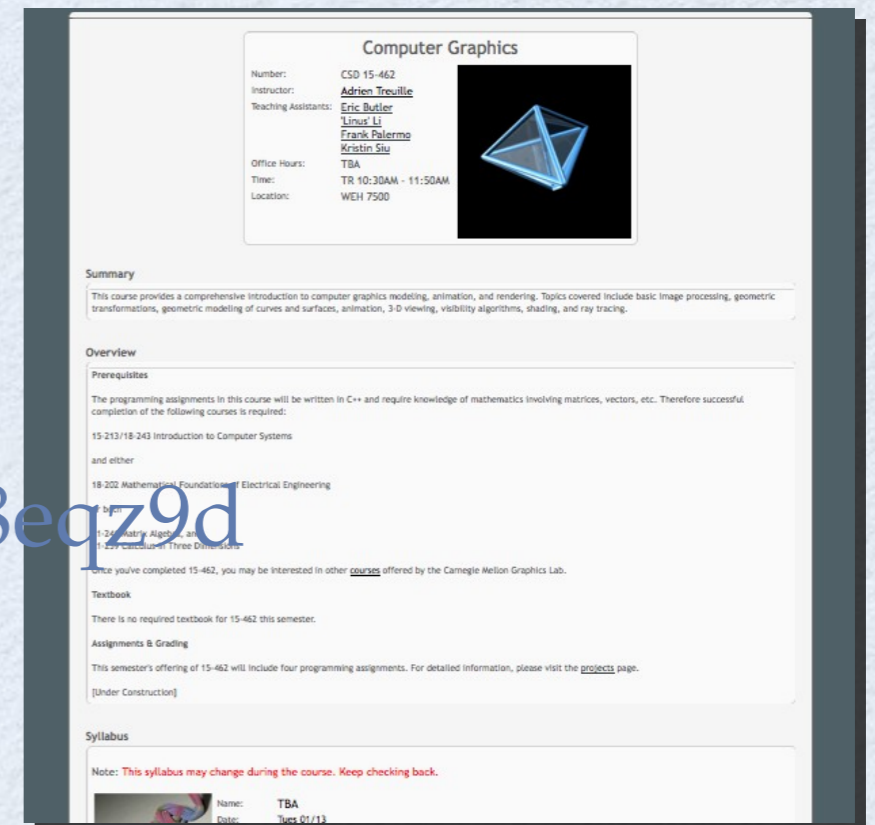
<http://s2013.siggraph.org/attendees/technical-papers-video-preview>

Introduction

- What is computer graphics?
- **Administrivia**
- Topics

Administrivia

- Web Page
 - <http://www.cs.cmu.edu/~15462/>
 - linked from my web page
- Piazza
 - <https://piazza.com/class/hiz3n3n8eqz9d>
 - linked from webpage.
 - Enroll on Piazza. We use this for most questions/discussion.



The screenshot shows the course page for "Computer Graphics" (CSD 15-462) on the Carnegie Mellon University website. The page includes the following information:

- 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

There is a small image of a blue wireframe cube on a black background to the right of the course details.

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
1-2-3 Matrix Algebra
1-2-3 Calculus of 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]

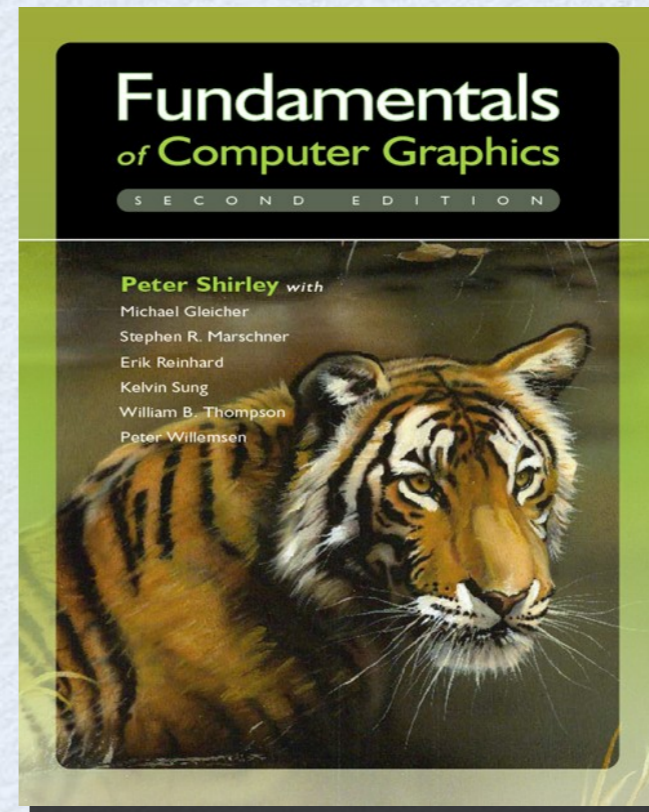
Syllabus
Note: This syllabus may change during the course. Keep checking back.

Name: TBA
Date: Tues 01/13

TA Office Hours

- TAs:
 - Prasanth Somasundar (psomasu1@andrew.cmu.edu) **Tue 20:00 – 22:00**
 - Luo Yi Tan (luoyit@andrew.cmu.edu) **Wed 20:00 – 22:00**
 - Harry Gifford (hgifford@cmu.edu) **Thur 20:00 - 22:00**
- **No office hours this week.**

Textbook



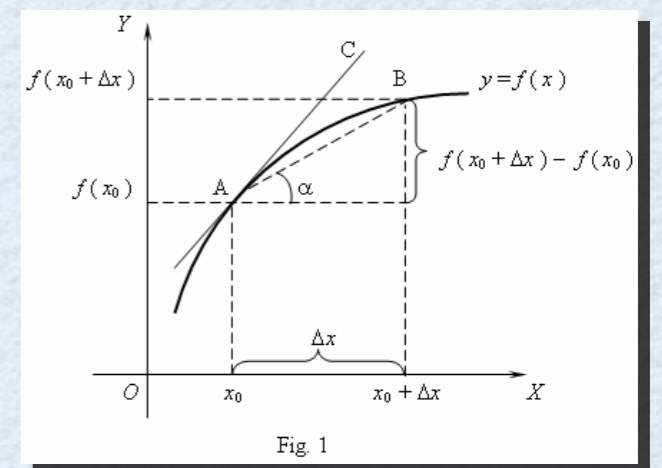
- Shirley, 2nd or 3rd Edition

- OpenGL Red Book

–<http://www.glprogramming.com/red/>

Pre-requisites

- Talk to us if you're missing any of these!
 - 15/18-213/513/243: Introduction to Computer Systems
 - 21-241: Matrix Algebra (matrix & vector algebra)
 - 21-259: Calculus in Three Dimensions (i.e. planes, quadratic surfaces etc.)
- Basic 3-D geometry/C++ (C is fine)



Grading

- Project 1 (10%)
- Project 2 (10%)
- Project 3 (15%)
- Project 4 (10%)
- Project 5 (15%)
- Homework 1 (7.5%)
- Homework 2 (7.5%)
- 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. Please cite any code you use.
- Do projects and homeworks individually.



Introduction

- Administratrivia.
- What is computer graphics?
- **Topics**

Syllabus and Schedule

See website for *accurate* schedule.

Intro

- 01 Tues 08/28 - Introduction
- 02 Thur 09/30 - OpenGL
[PROJ 1 ASSIGNED]

Geometry

- 03 Tues 09/04 - Math for Computer Graphics
- 04 Thur 09/06 - Transformations
- 05 Tues 09/11 – Viewing/Camera
- 07 Thur 09/13 - Curves and Splines
[PROJ 1 DUE, HW1 ASSIGNED]
- 08 Tues 09/18 - Meshes and Surfaces
[PROJ 2 ASSIGNED]

Light

- 09 Thur 09/20 – Shading/Light
- 10 Tues 09/25 – Materials
- 11 Thur 09/27 – Texture mapping + GLSL
[HW1 DUE]

NPR

- 12 Tues 10/02 – Non-photorealistic rendering
[PROJ 2 DUE, PROJ 3 ASSIGNED]
- 13 Thur 10/04 – Illusions

Ray Tracing

- 14 Tues 10/09 – Raycasting/Raytracing
- 15 Thur 10/11 – Spatial Data Structures **[P3 Check Point]**
- 16 Tues 10/16 – Midterm review
- 17 Thur 10/18 - **[MIDTERM EXAM]**

Indirect Lighting

- 18 Tues 10/23 – Radiosity
[PROJ 3 DUE, PROJ 4 ASSIGNED]

Animation

- 19 Thur 10/25 - Photon Mapping
- 20 Tues 10/30 – Direct-Indirect Separation
- 21 Thur 11/01 - Animation and Motion-capture
- 22 Tues 11/06 - Differential Eqn & Particle Systems
- 23 Thur 11/08 – Fluids
[HW2 ASSIGNED]

Images

- 24 Tues 11/13 - Image Processing
[PROJ 4 DUE, PROJ 5 ASSIGNED]
- 25 Thur 11/15 – High Dynamic Range Imaging & Tone Mapping

Advanced

- 26 Tues 11/20 – Photo and Webcam Clipart
- 27 Thur 11/22 – THANKSGIVING
- 29 Tues 11/27 – Displays
[PROJ 5 DUE]
- 28 Thur 11/29 – Cool new research in Graphics
[HW 2 DUE]

Final

- 30 Tues 12/04 – Final Review and Project Showcase
- 31 Thur 12/06 – **[FINAL EXAM]**

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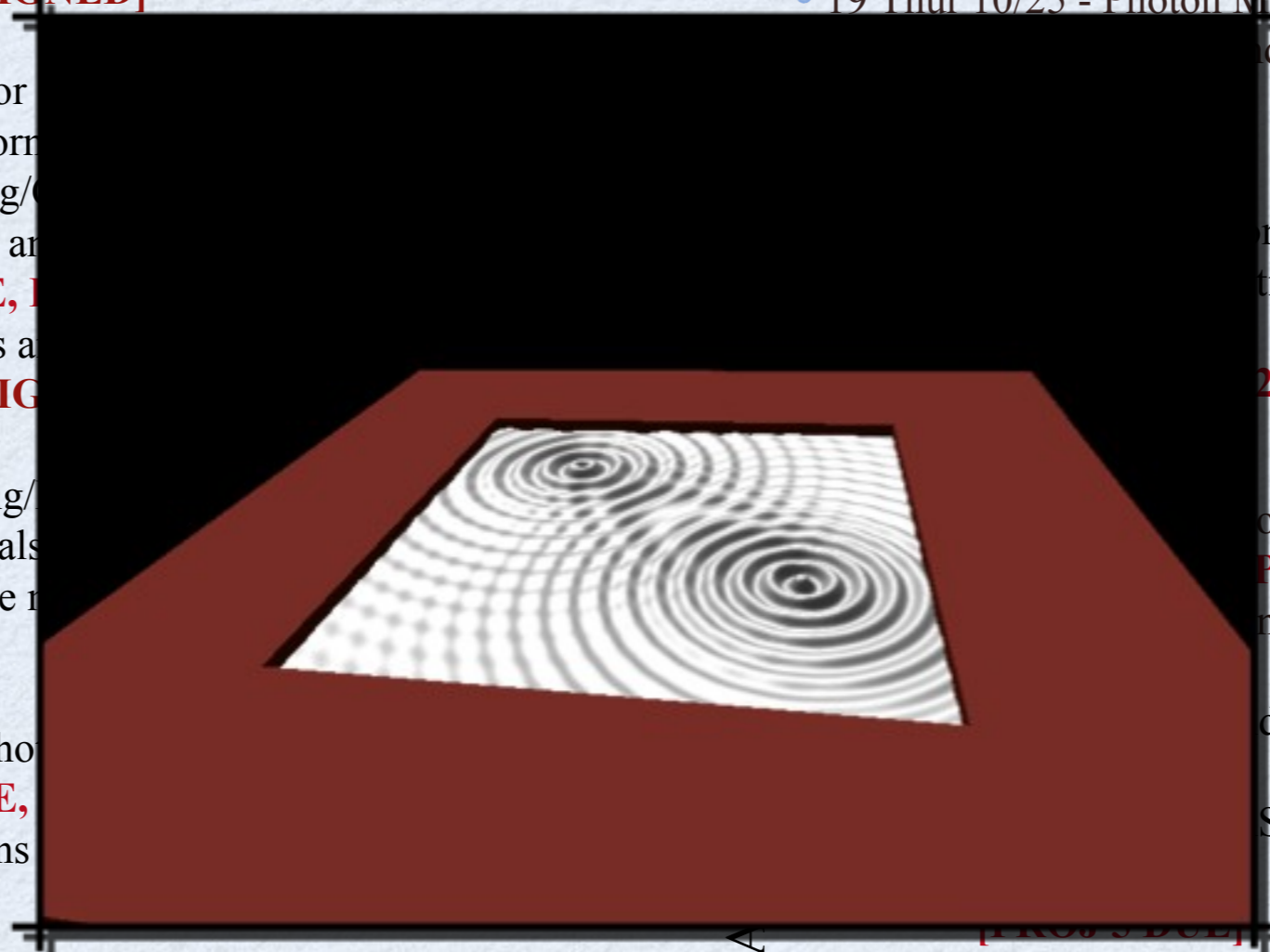
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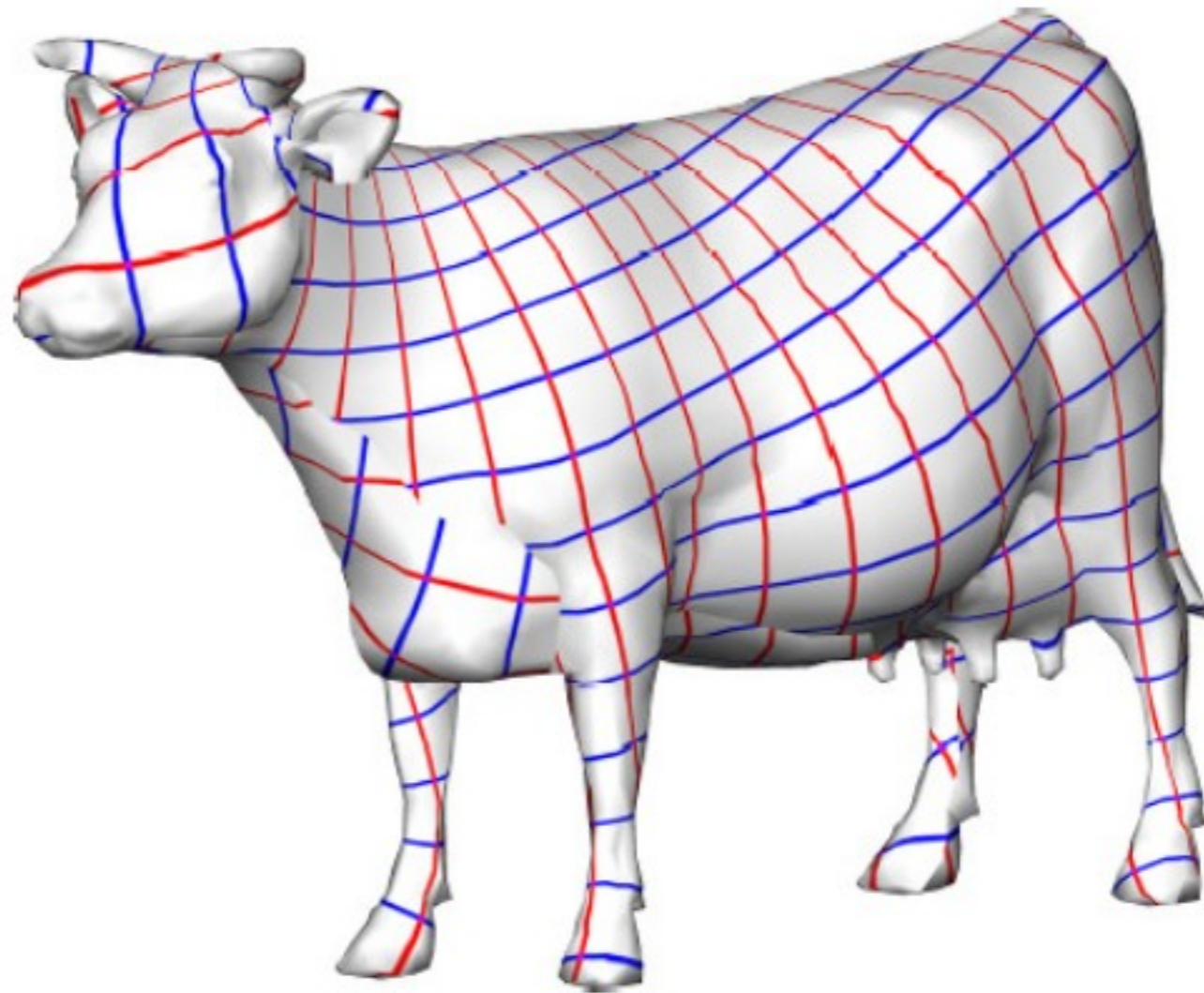
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[PROJ 3 DUE, PROJ 4



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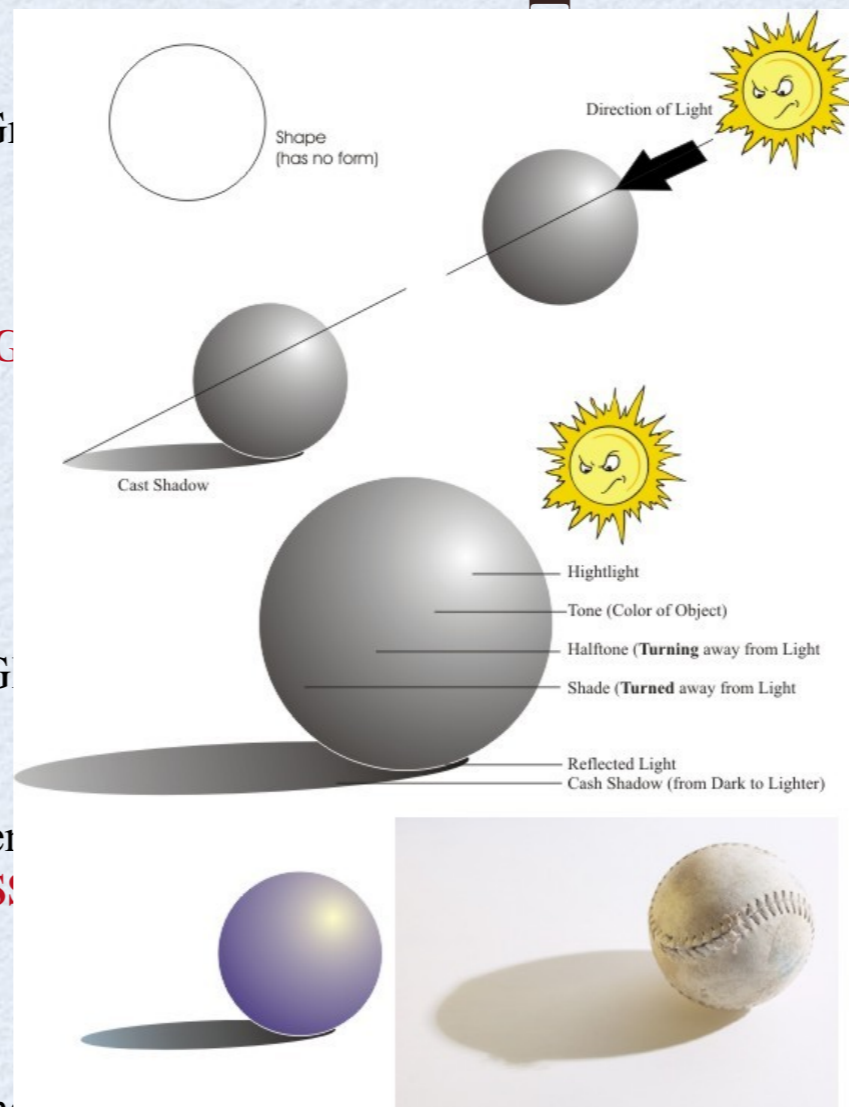
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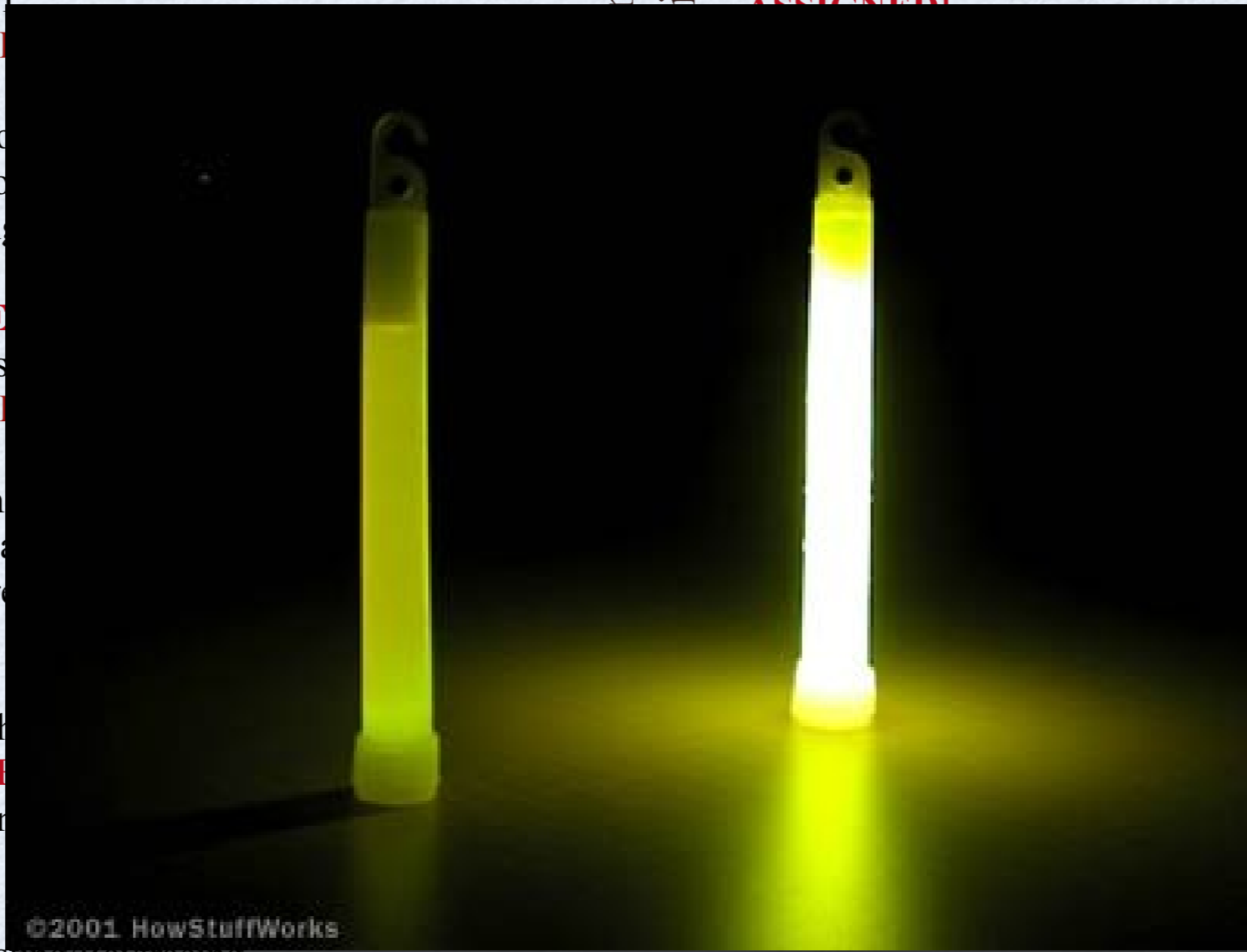
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[PROJ 3 DUE, PROJ 4 ASSIGNED]



Separation

Motion-capture
& Particle Systems

[ASSIGNED]

[ASSIGNED]
Range Imaging & Tone

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[HW 2 DUE]

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	Light	<ul style="list-style-type: none"> • 09 Thur 09/20 – Shading • 10 Tues 09/25 – Material • 11 Thur 09/27 – Texture [HW1 DUE] 		<ul style="list-style-type: none"> • 29 Tues 11/24 – Ray Tracing • 30 Thur 11/26 – Ray Tracing
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	Filtering	<ul style="list-style-type: none"> • 14 Tues 10/09 – Raycasting • 15 Thur 10/11 – Spatial Indexing • 16 Tues 10/16 – Midterm • 17 Thur 10/18 - [MIDTERM EXAM] 		<ul style="list-style-type: none"> • 27 Tues 11/10 – Ray Tracing • 28 Tues 11/17 – Ray Tracing • 29 Tues 11/24 – Ray Tracing • 30 Thur 11/26 – Ray Tracing
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[DUE, PROJ 4]

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- 08 Tues 09/

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Light

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- 11 Thur 09/

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[SIGNED]
e Imaging & Tone

NPR

- 12 Tues 10/
- 13 Thur 10/

Clipart

Ray Tracing

- 14 Tues 10/
- 15 Thur 10/
- 16 Tues 10/16 – Midterm review
- 17 Thur 10/18 - **[MIDTERM EXAM]**

n Graphics

Final

- 30 Tues 12/04 – Final Review and Project Showcase
- 31 Thur 12/06 – **[FINAL EXAM]**

HENRIK WANN JENSEN 1995

Syllabus and Schedule

Intro

- 01 Tues 08/28 -
- 02 Thur 09/30 -

[PROJ

Geometry

- 03 Tues 09/04 -
- 04 Thur 09/06 -
- 05 Tues 09/11 -
- 07 Thur 09/13 -

[PROJ

- 08 Tues 09/18 -

[PROJ

Light

- 09 Thur 09/20 -
- 10 Tues 09/25 -
- 11 Thur 09/27 -

[HW1

NPR

- 12 Tues 10/02 -
- 13 Thur 10/04 -

[PROJ

Ray Tracing

- 14 Tues 10/09 -
- 15 Thur 10/11 -
- 16 Tues 10/16 -
- 17 Thur 10/18 -

Midterm Review

[MIDTERM EXAM]

Scene



Direct



Global

Final

- 30 Tues 12/04 – Final Review and Project Showcase
- 31 Thur 12/06 – [FINAL EXAM]

E, PROJ 4

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cle Systems

[FINED]
aging & Tone

art

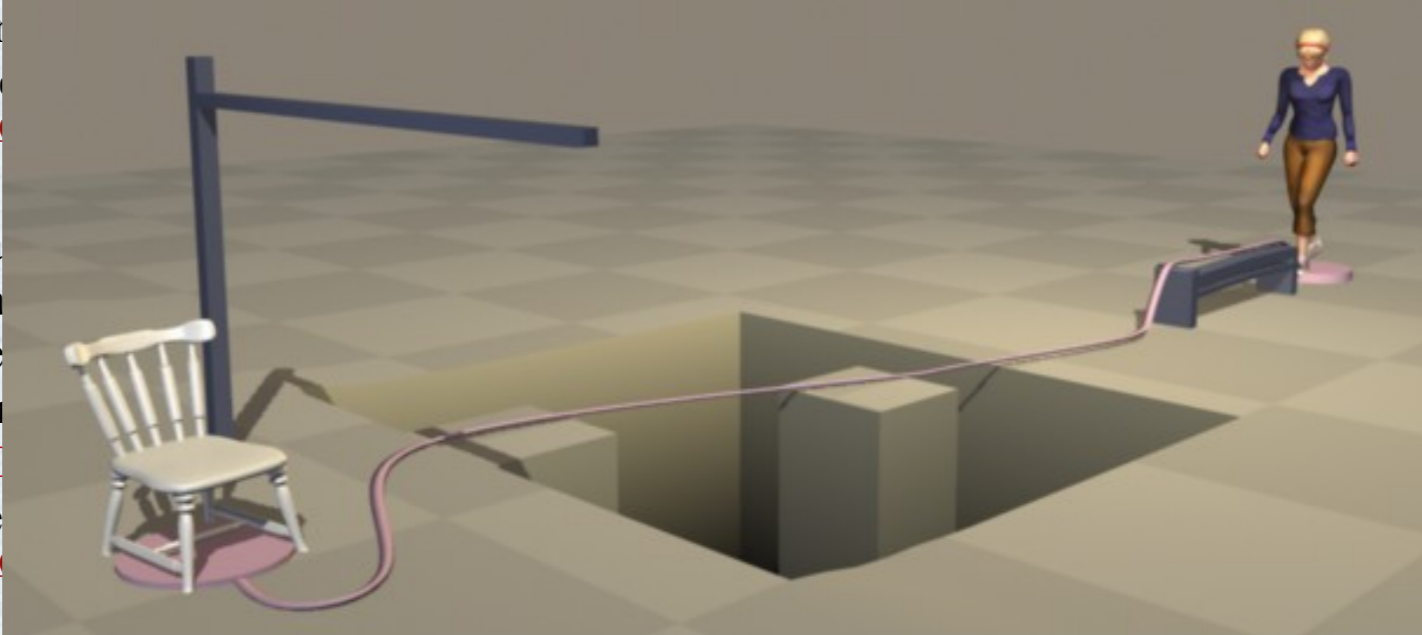
raphics

Syllabus and Schedule

Intro	• 01 Tues 08/28 - Introduction • 02 Thur 09/30 - [PROJ 3 DUE, PROJ 4	Direct Lighting	• 18 Tues 10/23 – Radiosity
Geometry	• 03 Tues 09/04 - • 04 Thur 09/06 - • 05 Tues 09/11 - • 07 Thur 09/13 - [PROJ • 08 Tues 09/18 - [PROJ	Preparation Motion-capture & Particle Systems	
Light	• 09 Thur 09/20 - • 10 Tues 09/25 - • 11 Thur 09/27 - [HW1	[ASSIGNED] Image Imaging & Tone	
NPR	• 12 Tues 10/02 - [PROJ • 13 Thur 10/04 -	Image Clipart G	
Ray Tracing	• 14 Tues 10/09 - • 15 Thur 10/11 – Spatial Data Structures [P3 Check Point] • 16 Tues 10/16 – Midterm review • 17 Thur 10/18 - [MIDTERM EXAM]	Techniques in Graphics	Final
			• 30 Tues 12/04 – Final Review and Project Showcase • 31 Thur 12/06 – [FINAL EXAM]



Syllabus and Schedule

Ray Tracing	Intro	<ul style="list-style-type: none"> • 01 Tues 08/28 - Intro • 02 Thur 09/30 - Op [PROJ 1 A 		<ul style="list-style-type: none"> • 18 Tues 10/23 – Radiosity 	<ul style="list-style-type: none"> • [PROJ 3 DUE, PROJ 4
	Geometry	<ul style="list-style-type: none"> • 03 Tues 09/04 - Ma • 04 Thur 09/06 - Tra • 05 Tues 09/11 – Vie • 07 Thur 09/13 - Cur [PROJ 1 D • 08 Tues 09/18 - Me [PROJ 2 A 		<ul style="list-style-type: none"> • Mapping • Indirect Separation 	
	Light	<ul style="list-style-type: none"> • 09 Thur 09/20 – Sha • 10 Tues 09/25 – Ma • 11 Thur 09/27 – Te [HW1 DU 		<ul style="list-style-type: none"> • on and Motion-capture • tial Eqn & Particle Systems 	
	NPR	<ul style="list-style-type: none"> • 12 Tues 10/02 – No [PROJ 2] • 13 Thur 10/04 – Illu 		<ul style="list-style-type: none"> • [2 ASSIGNED] 	
	Tracing	<ul style="list-style-type: none"> • 14 Tues 10/09 – Ra • 15 Thur 10/11 – Spa • 16 Tues 10/16 – Midterm review • 17 Thur 10/18 - [MIDTERM EXAM] 		<ul style="list-style-type: none"> • Processing • [PROJ 5 ASSIGNED] • Dynamic Range Imaging & Tone 	
	Fin	<ul style="list-style-type: none"> • 30 Tues 12/04 – Final Review and Project Showcase • 31 Thur 12/06 – [FINAL EXAM] 		<ul style="list-style-type: none"> • and Webcam Clipart • SGIVING • w research in Graphics • [2 DUE] 	

Syllabus and Schedule

Intro

- 01 Tues 08/28 - Introduction
- 02 Thur 09/30 - OpenGL
[PROJ 1 ASSIGN]

PROJ 3 DUE, PROJ 4

Geometry

- 03 Tues 09/04 - Math for Co
- 04 Thur 09/06 - Transformat
- 05 Tues 09/11 - Viewing/Ca
- 07 Thur 09/13 - Curves and
[PROJ 1 DUE, HW
- 08 Tues 09/18 - Meshes and
[PROJ 2 ASSIGN]

g
Separation

Motion-capture
& Particle Systems

[IGNED]

Light

- 09 Thur 09/20 - Shading/Lig
- 10 Tues 09/25 - Materials
- 11 Thur 09/27 - Texture ma
[HW1 DUE]

lig
[5 ASSIGNED]
Range Imaging & Tone

NPR

- 12 Tues 10/02 - Non-photor
[PROJ 2 DUE, PH
- 13 Thur 10/04 - Illusions

cam Clipart

NG

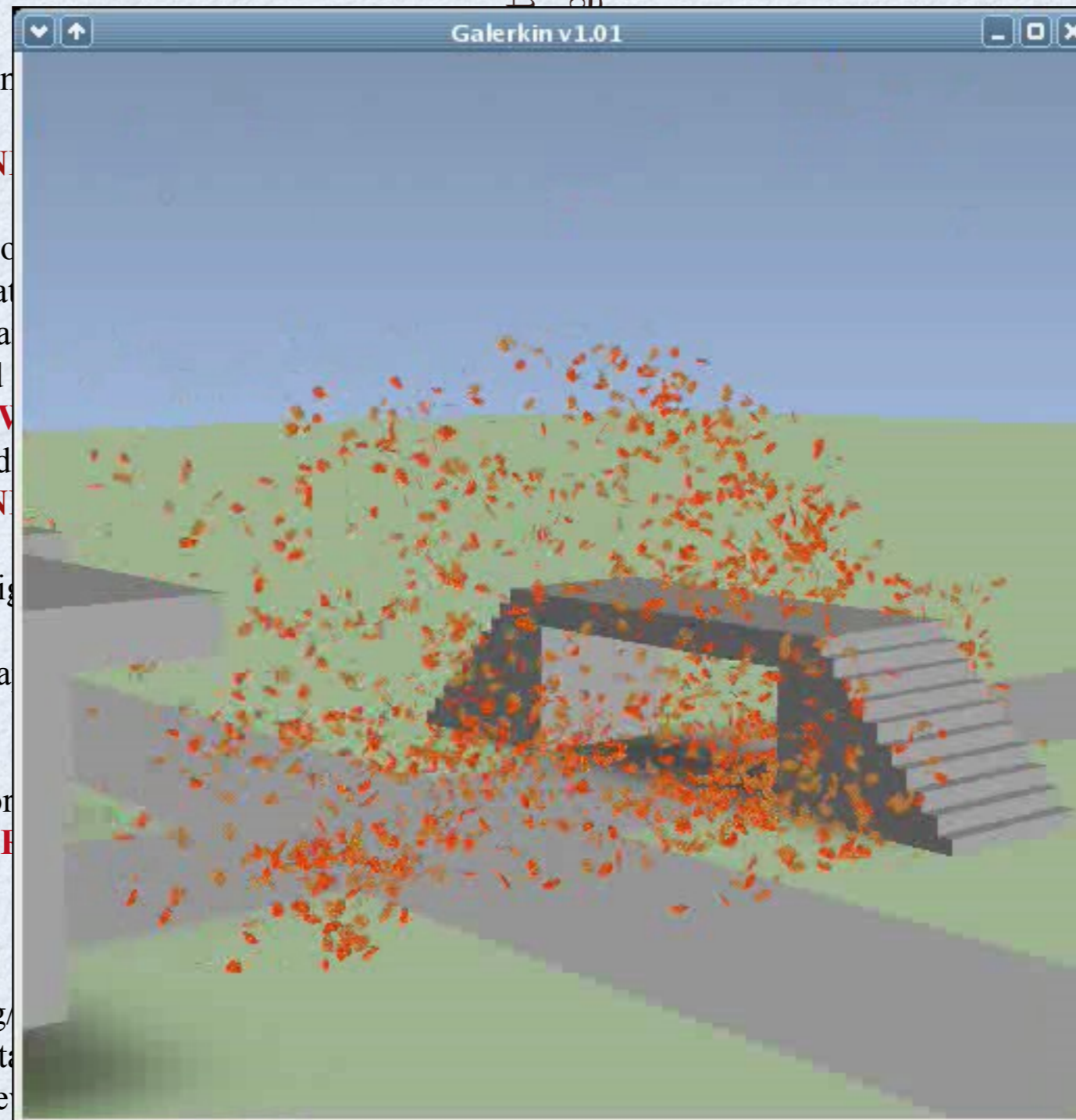
Ray Tracing

- 14 Tues 10/09 - Raycasting/
- 15 Thur 10/11 - Spatial Data
- 16 Tues 10/16 - Midterm re
- 17 Thur 10/18 - [MIDTERM EXAM]

arch in Graphics

]

- 30 Tues 12/04 - Final Review and Project Showcase
- 31 Thur 12/06 - [FINAL EXAM]



Syllabus and Schedule

Intro

- 01 Tues 08/28 - Introduction
- 02 Thur 09/30 - OpenGL

[PROJ 1 ASSIGNED]

Geometry

- 03 Tues 09/04 -
- 04 Thur 09/06 -
- 05 Tues 09/11 -
- 07 Thur 09/13 -

[PROJ 2 ASSIGNED]

- 08 Tues 09/18 -

[PROJ 3 ASSIGNED]

Light

- 09 Thur 09/20 -
- 10 Tues 09/25 -
- 11 Thur 09/27 -

[HW1 DUE]

NPR

- 12 Tues 10/02 -

[PROJ 4 ASSIGNED]

- 13 Thur 10/04 -

Ray Tracing

- 14 Tues 10/09 - Ray Casting Ray Tracing
- 15 Thur 10/11 - Spatial Data Structures [P3 Check Point]
- 16 Tues 10/16 - Midterm review
- 17 Thur 10/18 - [MIDTERM EXAM]

Indirect Lighting

- 18 Tues 10/23 - Radiosity

[ASSIGNED]

[PROJ 3 DUE, PROJ 4 ASSIGNED]



[HW 2 DUE]

Final

- 30 Tues 12/04 - Final Review and Project Showcase
- 31 Thur 12/06 - [FINAL EXAM]

Comparison

motion-capture
& Particle Systems

[ASSIGNED]

[ASSIGNED]
Image Imaging & Tone

in Clipart

h in Graphics

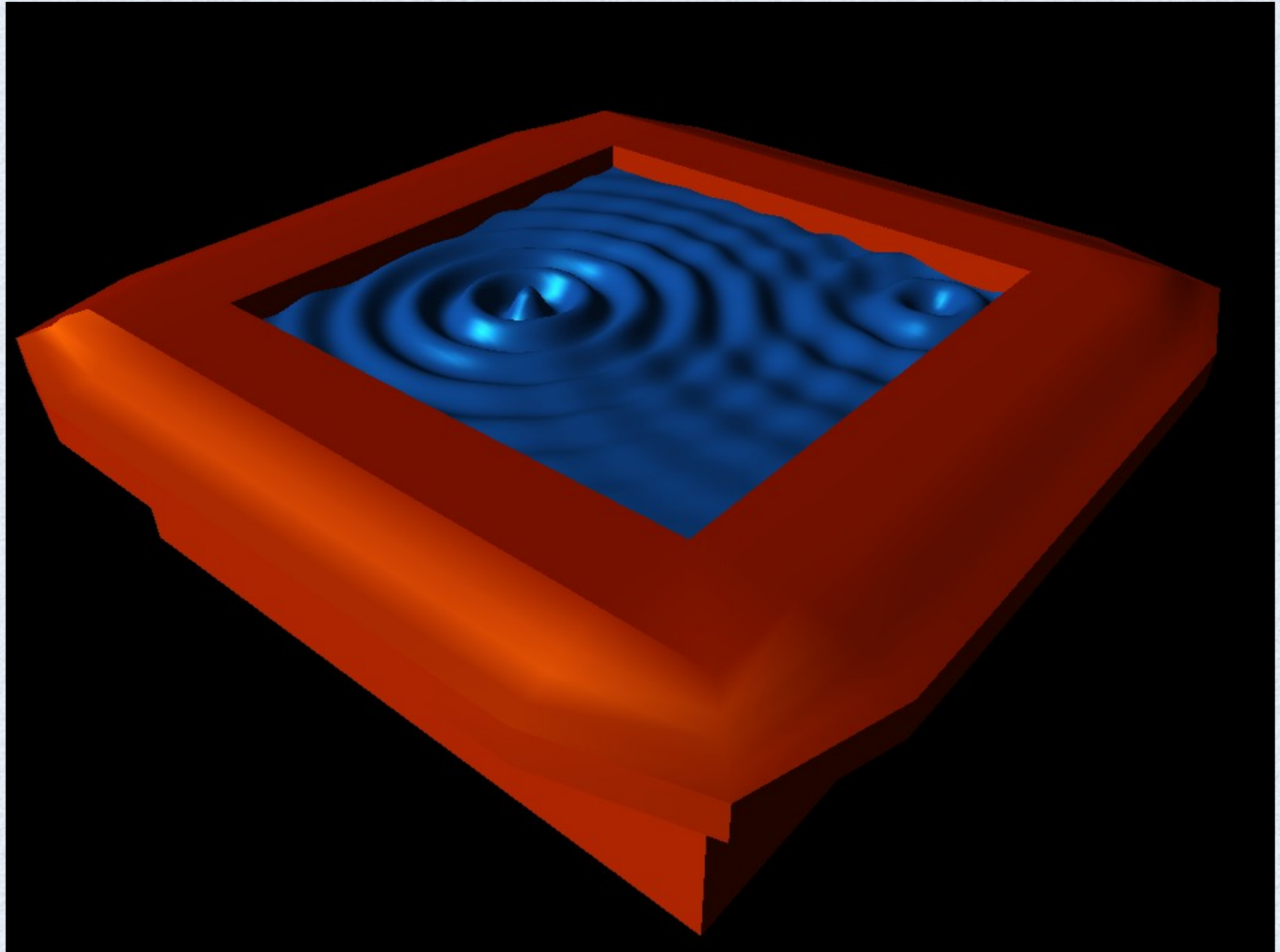
Syllabus and Schedule

Ray Tracing		<ul style="list-style-type: none"> • 14 Tues 10/09 – Raycasting/Ray • 15 Thur 10/11 – Spatial Data Structures [P3 Check Point] • 16 Tues 10/16 – Midterm review • 17 Thur 10/18 - [MIDTERM EXAM] 		<ul style="list-style-type: none"> • Cool new research in Graphics [HW 2 DUE]
	NPR	<ul style="list-style-type: none"> • 12 Tues 10/02 – Non-photorealistic rendering [PROJ 2 DUE, PROJ 3 DUE] • 13 Thur 10/04 – Illusions 		<ul style="list-style-type: none"> • Thanksgiving • Displays [5 DUE]
Light		<ul style="list-style-type: none"> • 09 Thur 09/20 – Shading/Lighting • 10 Tues 09/25 – Materials • 11 Thur 09/27 – Texture mapping [HW1 DUE] 	<ul style="list-style-type: none"> • Image Processing [4 DUE, PROJ 5 ASSIGNED] • High Dynamic Range Imaging & Tone Mapping 	
Geometry		<ul style="list-style-type: none"> • 03 Tues 09/04 - Math for Computer Graphics • 04 Thur 09/06 - Transformations • 05 Tues 09/11 – Viewing/Camera • 07 Thur 09/13 - Curves and Splines [PROJ 1 DUE, HW1 ASSIGNED] • 08 Tues 09/18 - Meshes and Surfaces [PROJ 2 ASSIGNED] 	<ul style="list-style-type: none"> • Animation and Motion-capture • Differential Eqn & Particle Systems • Fluids [HW2 ASSIGNED] 	
Intro		<ul style="list-style-type: none"> • 01 Tues 08/28 - Introduction • 02 Thur 09/30 - OpenGL [PROJ 1 ASSIGNED] 	<ul style="list-style-type: none"> • Photon Mapping • Direct-Indirect Separation 	
Final		<ul style="list-style-type: none"> • 30 Tues 12/04 – Final Review and Project Showcase • 31 Thur 12/06 – [FINAL EXAM] 	Project	• 18 Tues 10/23 – Radiosity [PROJ 3 DUE, PROJ 4 DUE]

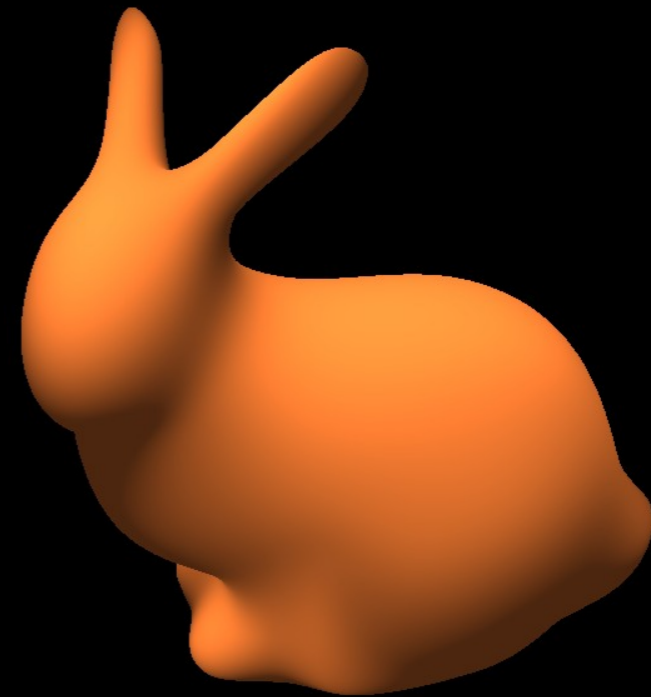
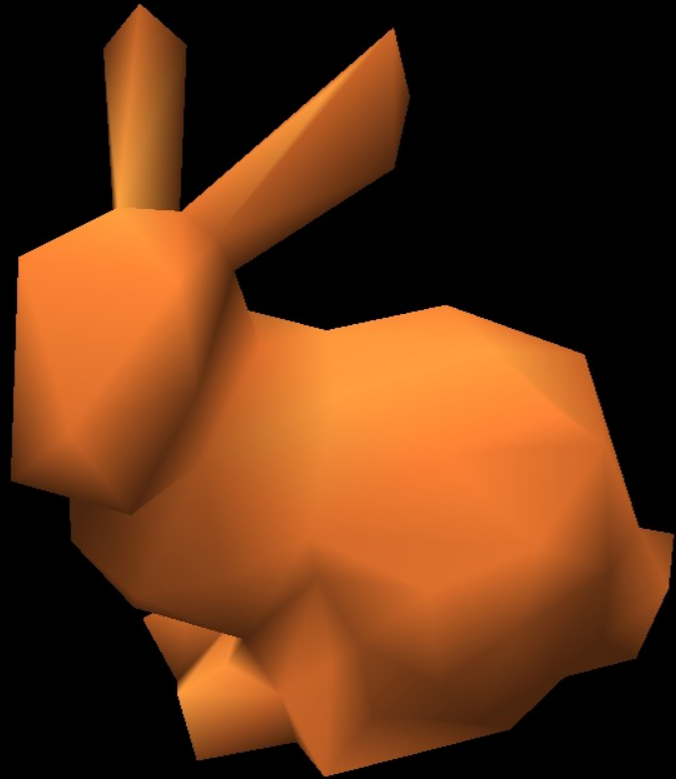
Projects

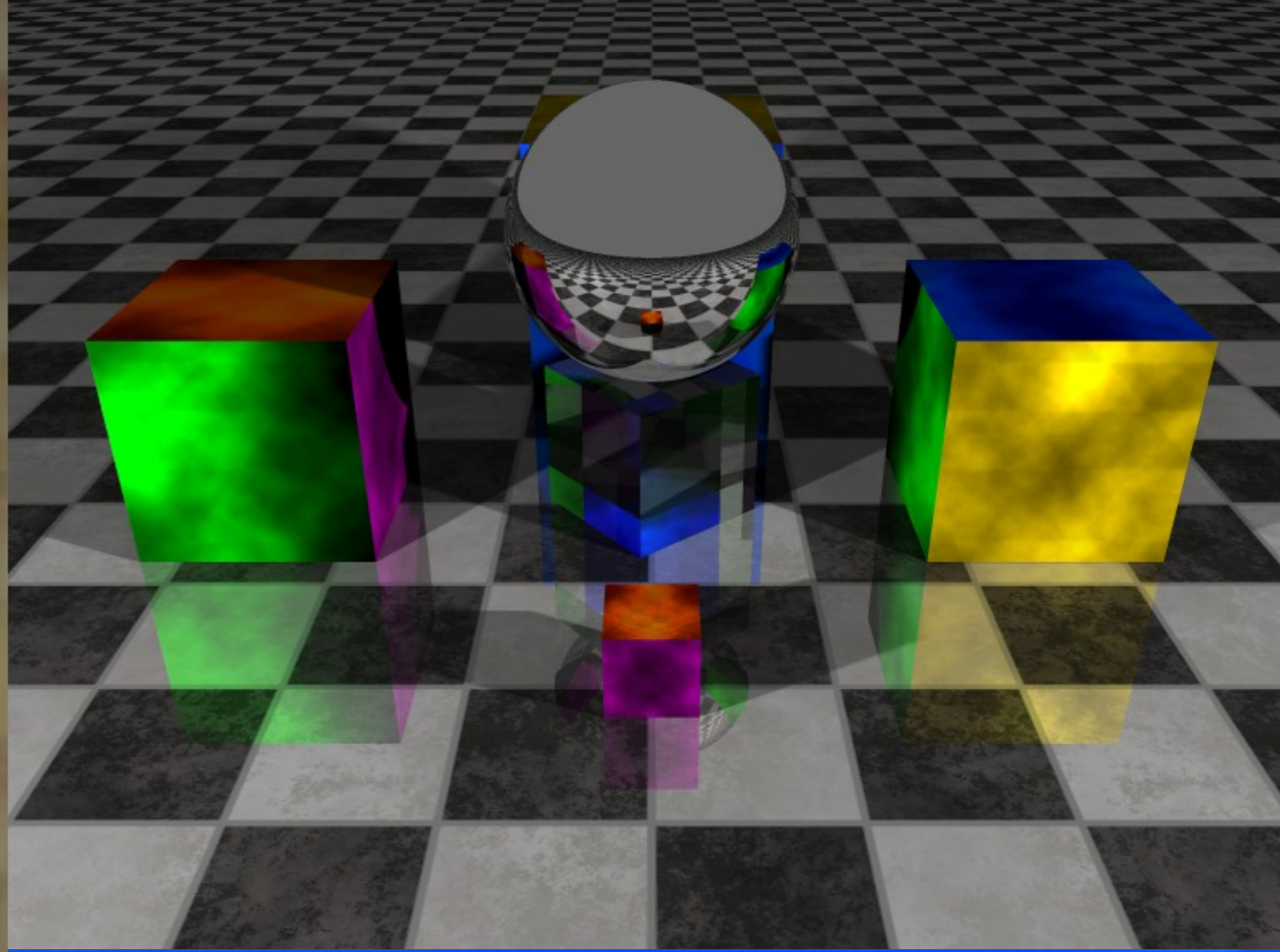
- Five Projects:
 - Starter project - OpenGL
 - Geometry and Meshes
 - Ray Tracing
 - Global Illumination
 - Animation and Physical Simulation

Project 1: Basics of OpenGL

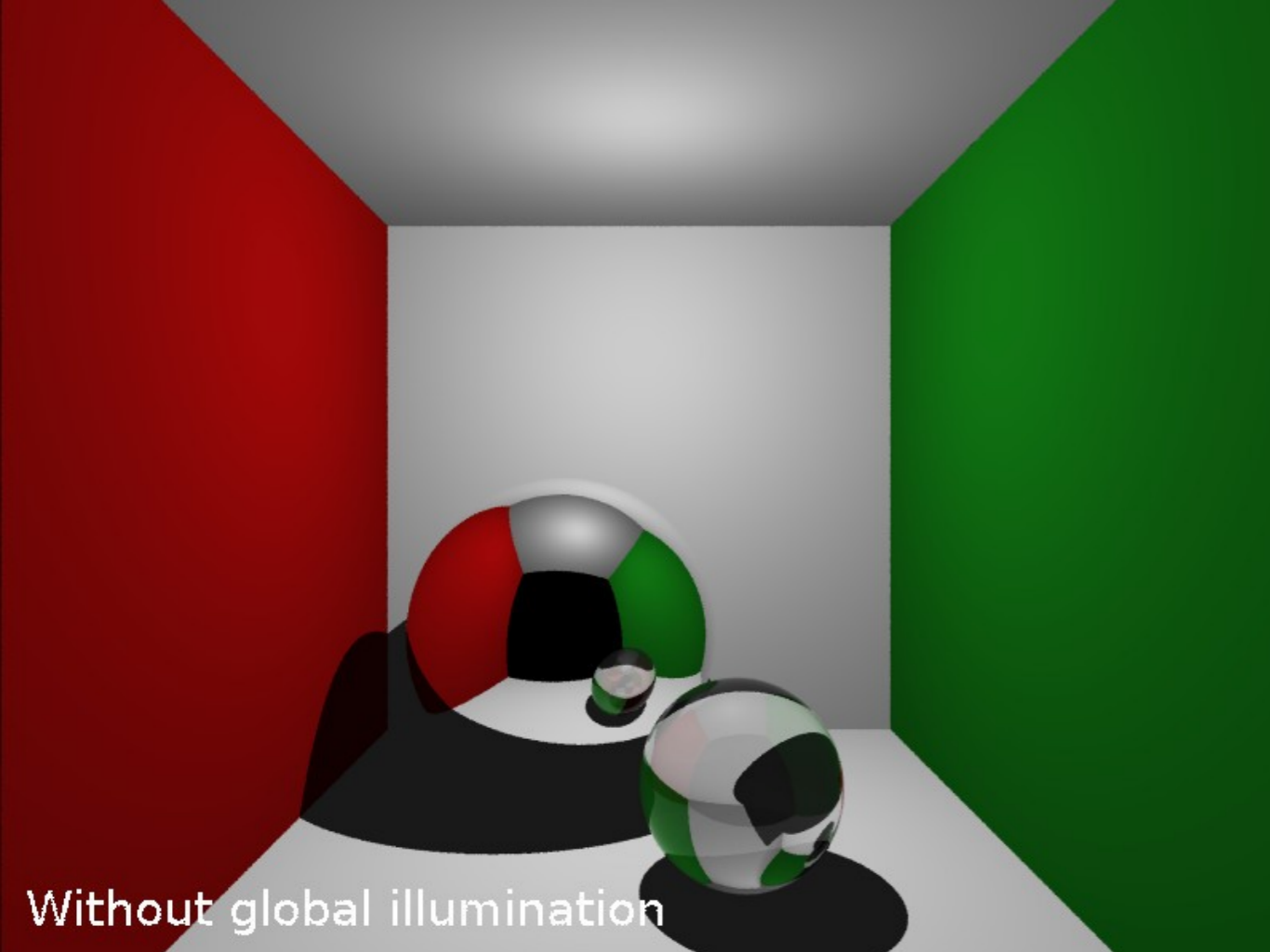


Project 2: Geometry and Meshes

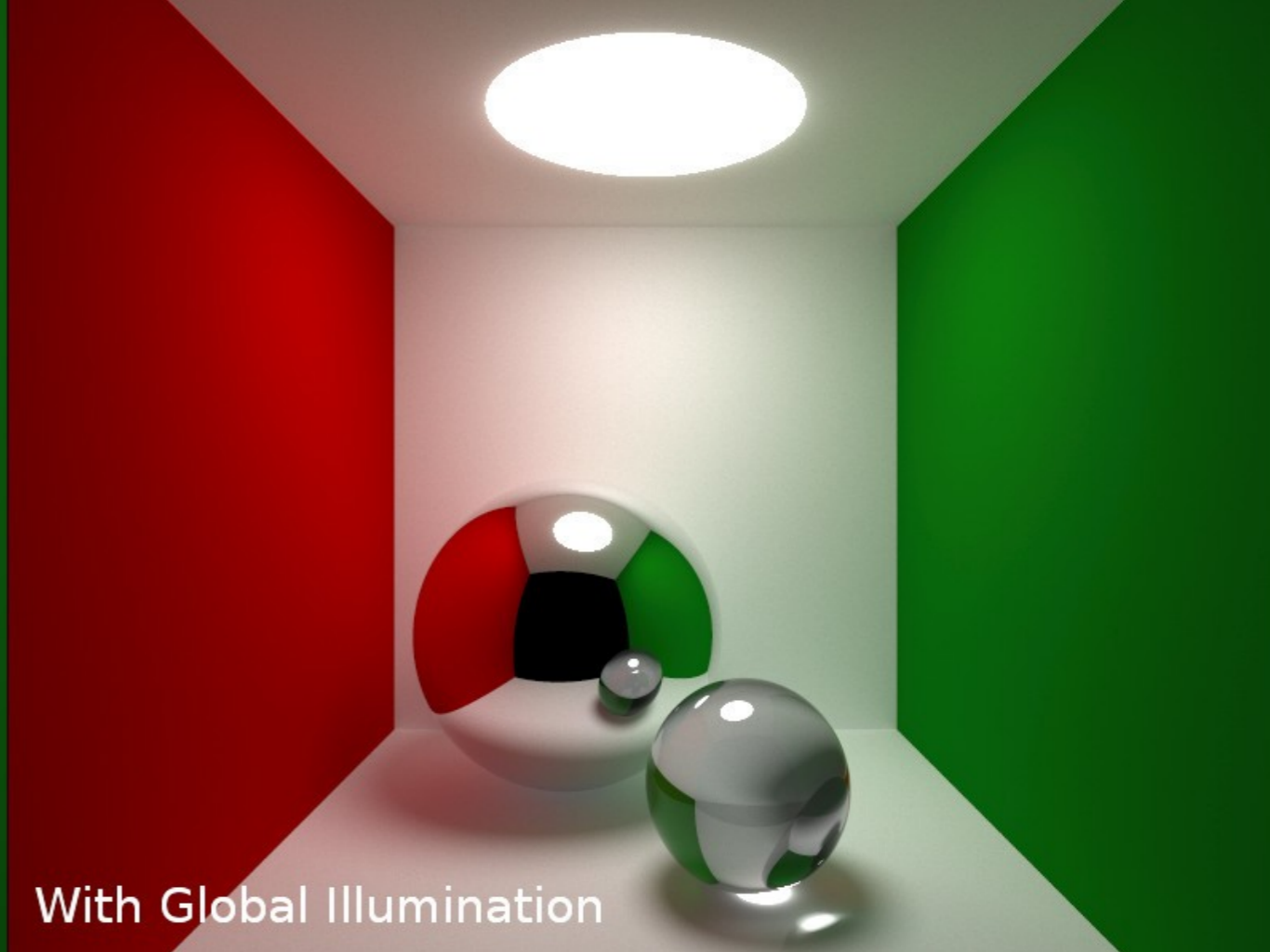




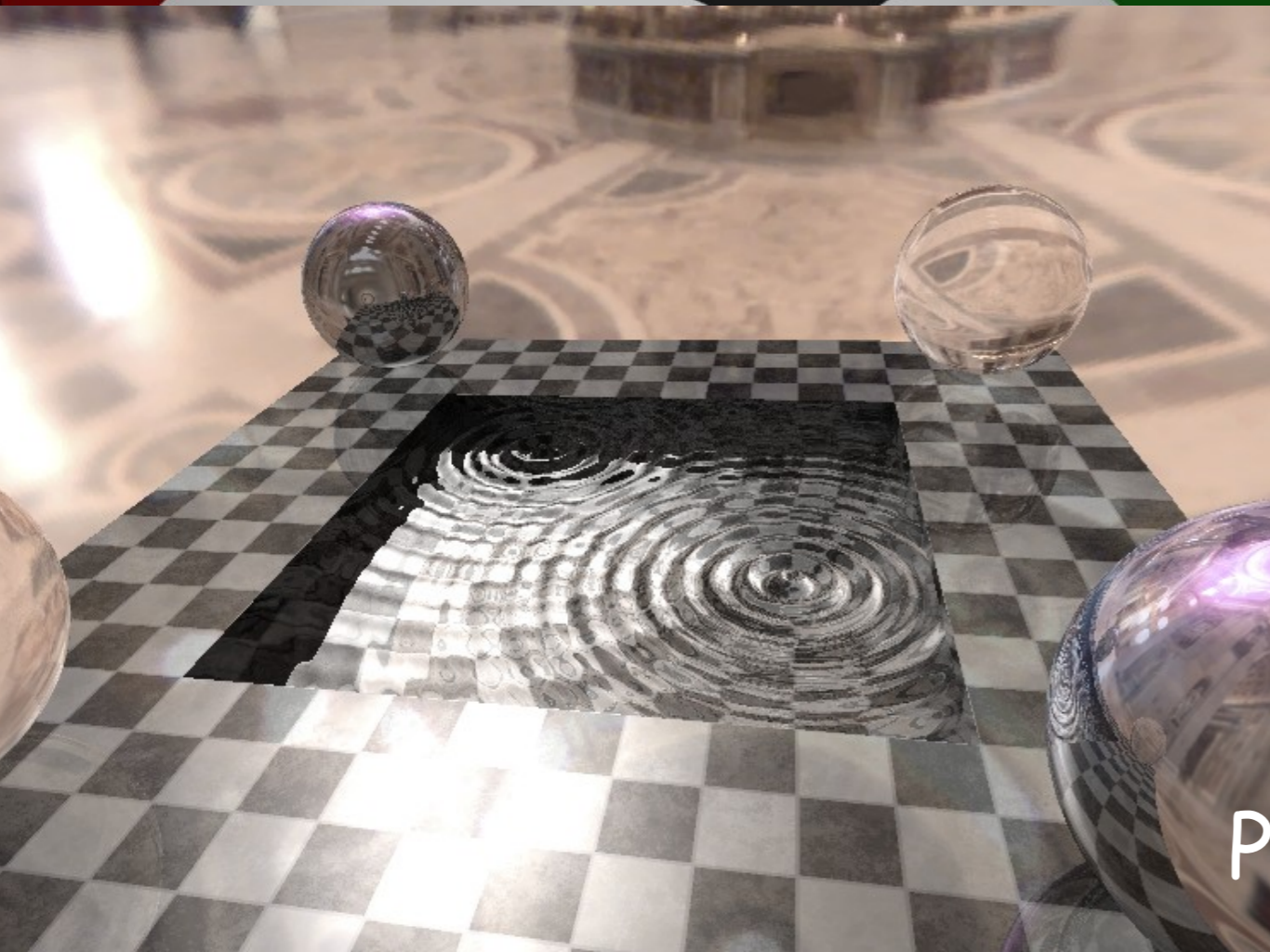
Project 3: Monte Carlo Ray Tracing



Without global illumination

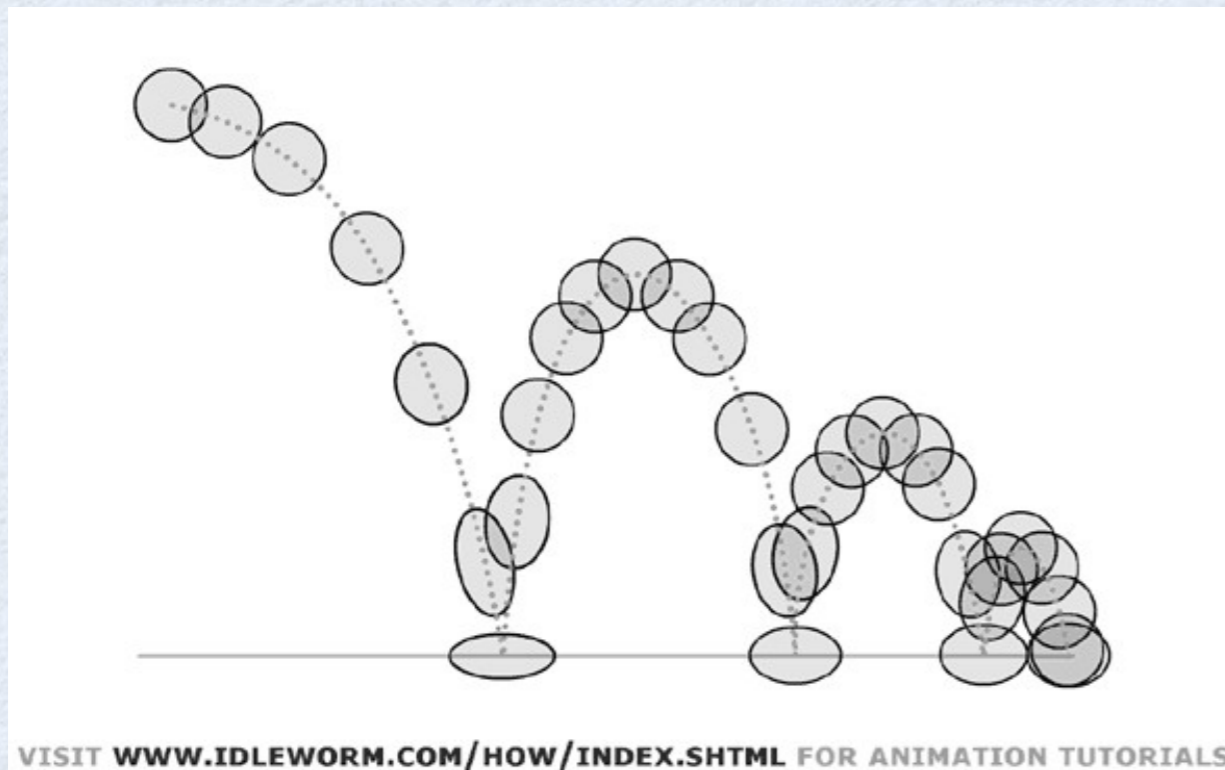


With Global Illumination



Project 4: Photon Mapping

Project 5: Physical Simulation



Thank you

Project 1 will be assigned
Thursday. Start early!