Lecture 1:

Course Intro:
Welcome to Computer Graphics!

Computer Graphics
CMU 15-462/662, Spring 2018
Hi!

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What is computer graphics?

**computer graphics** /kəmˈpyʊədər ˈɡrɑːfɪks/ *n.*
The use of computers to synthesize and manipulate visual information.
Why visual information?

About 30% of brain dedicated to visual processing...

...eyes are highest-bandwidth port into the head!

(Allan Ajifo)
Humans are visual creatures!
History of visual depiction

- Humans have always been visual creatures!

Indonesian cave painting (~38,000 BCE)
Visual technology: painting / illustration

- Not purely representational: ideas, feelings, data, ...

![Image of map]

![Image of abstract designs]

![Image of landscape painting]

![Image of abstract art]

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Visual technology: carving / sculpture
Visual technology: photography / imaging

- Processing of visual data no longer happening in the head!

Joseph Niépce, “View from the Window at Le Gras” (1826)
Visual technology: photography / imaging
Visual technology: digital imagery

- Intersection of visual depiction & computation

Ivan Sutherland, “Sketchpad” (1963)
Visual technology: digital imagery
Visual technology: 3D fabrication

- Create physical realization of digital shape

A.J. Herbert / 3M (1979)
Visual technology: 3D fabrication
Technologies for visual depiction

- Drawing/painting/illustration (~40,000 BCE)
- Sculpture (~40,000 BCE)
- Photography (~1826)
- Digital Imagery (~1963)
- 3D Fabrication (~1979)
Definition of Graphics, Revisited

**computer graphics** /kəˈmɪtər ˈɡræfɪks/ *n.*
The use of computers to synthesize and manipulate visual information.

*Why only visual?*
Graphics as Synthesis of Sensory Stimuli

**computer graphics** /kəmˈpyʊdər ˈɡrafiks/ n.
The use of computers to synthesize and manipulate sensory information.

(sound)

(touch)

(...What about taste? Smell?!)
Computer graphics is everywhere!
Entertainment (movies, games)
Entertainment

- Not just cartoons!
Art and design
Industrial design
Computer aided engineering (CAE)
Architecture
Scientific/mathematical visualization
Medical/anatomical visualization
Navigation
Communication
Foundations of computer graphics

- All these applications demand **sophisticated** theory & systems
- **Theory**
  - geometric representations
  - sampling theory
  - integration and optimization
  - radiometry
  - perception and color
- **Systems**
  - parallel, heterogeneous processing
  - graphics-specific programming languages
ACTIVITY: modeling and drawing a cube

■ Goal: generate a realistic drawing of a cube
■ Key questions:
  - Modeling: how do we describe the cube?
  - Rendering: how do we then visualize this model?
ACTIVITY: modeling the cube

- Suppose our cube is...
  - centered at the origin (0,0,0)
  - has dimensions 2x2x2
  - edges are aligned with x/y/z axes

QUESTION: What are the coordinates of the cube vertices?

A: ( 1, 1, 1 )   E: ( 1, 1,−1 )
B: (−1, 1, 1 )   F: (−1, 1,−1 )
C: ( 1,−1, 1 )   G: ( 1,−1,−1 )
D: (−1,−1, 1 )   H: (−1,−1,−1 )

QUESTION: What about the edges?

AB, CD, EF, GH,
AC, BD, EG, FH,
AE, CG, BF, DH
ACTIVITY: drawing the cube

Now have a digital description of the cube:

**VERTICES**
- A: (1, 1, 1)
- B: (-1, 1, 1)
- C: (1, -1, 1)
- D: (-1, -1, 1)
- E: (1, 1, -1)
- F: (-1, 1, -1)
- G: (1, -1, -1)
- H: (-1, -1, -1)

**EDGES**
- AB, CD, EF, GH,
- AC, BD, EG, FH,
- AE, CG, BF, DH

How do we draw this 3D cube as a 2D (flat) image?

Basic strategy:
1. map 3D vertices to 2D points in the image
2. connect 2D points with straight lines

...Ok, but how?
Perspective projection

- Objects look smaller as they get further away ("perspective")
- Why does this happen?
- Consider simple ("pinhole") model of a camera:
Perspective projection: side view

- Where exactly does a point \( p = (x, y, z) \) end up on the image?
- Let’s call the image point \( q = (u, v) \)
Perspective projection: side view

- Where exactly does a point $p = (x,y,z)$ end up on the image?
- Let’s call the image point $q = (u,v)$
- Notice two similar triangles:

Assume camera has unit size, origin is at pinhole $c$

Then $v/1 = y/z$, i.e., vertical coordinate is just the slope $y/z$

Likewise, horizontal coordinate is $u = x/z$
**ACTIVITY:** now draw it!

- Need 12 volunteers
  - each person will draw one cube edge
  - assume camera is at $c=(2,3,5)$
  - convert $(X,Y,Z)$ of both endpoints to $(u,v)$:
    1. subtract camera $c$ from vertex $(X,Y,Z)$ to get $(x,y,z)$
    2. divide $(x,y)$ by $z$ to get $(u,v)$—write as a fraction
  - draw line between $(u_1,v_1)$ and $(u_2,v_2)$

<table>
<thead>
<tr>
<th>VERTICES</th>
<th>EDGES</th>
</tr>
</thead>
<tbody>
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<td>A: (1, 1, 1)</td>
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EDGES: AB, CD, EF, GH, AC, BD, EG, FH, AE, CG, BF, DH
ACTIVITY: output on graph paper

Graph paper with axes labeled: x-axis from 0 to 1, y-axis from 0 to 12.
Number labels on the x-axis: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12.
Number labels on the y-axis: 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12.
ACTIVITY: How did we do?

2D coordinates:

A: 1/4, 1/2
B: 3/4, 1/2
C: 1/4, 1
D: 3/4, 1
E: 1/6, 1/3
F: 1/2, 1/3
G: 1/6, 2/3
H: 1/2, 2/3
ACTIVITY: Previous year’s result
But wait…
How do we draw lines on a computer?
Close up photo of pixels on a modern display
Output for a raster display

- Common abstraction of a raster display:
  - Image represented as a 2D grid of “pixels” (picture elements) **
  - Each pixel can take on a unique color value

** We will strongly challenge this notion of a pixel “as a little square” soon enough.
But let’s go with it for now. ;-)

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What pixels should we color in to depict a line?

“Rasterization”: process of converting a continuous object to a discrete representation on a raster grid (pixel grid)
What pixels should we color in to depict a line?

Light up all pixels intersected by the line?
What pixels should we color in to depict a line?

Diamond rule (used by modern GPUs):
light up pixel if line passes through associated diamond
What pixels should we color in to depict a line?

Is there a right answer?
(consider a drawing a “line” with thickness)
How do we find the pixels satisfying a chosen rasterization rule?

- Could check every single pixel in the image to see if it meets the condition...
  - $O(n^2)$ pixels in image vs. at most $O(n)$ “lit up” pixels
  - must be able to do better! (e.g., work proportional to number of pixels in the drawing of the line)
Incremental line rasterization

- Let’s say a line is represented with integer endpoints: \((u_1,v_1), (u_2,v_2)\)
- Slope of line: \(s = (v_2-v_1) / (u_2-u_1)\)
- Consider a very easy special case:
  - \(u_1 < u_2, v_1 < v_2\) (line points toward upper-right)
  - \(0 < s < 1\) (more change in \(x\) than \(y\))

\[
v = v_1;
\text{for( } u=u_1; u<=u_2; u++ \text{ ) }
\{
    v += s;
    \text{draw( } u, \text{ round}(v) \text{ )}
\}
\]

Common optimization: rewrite algorithm to use only integer arithmetic (Bresenham algorithm)
Our line drawing!

2D coordinates:
A: $1/4, 1/2$
B: $3/4, 1/2$
C: $1/4, 1$
D: $3/4, 1$
E: $1/6, 1/3$
F: $1/2, 1/3$
G: $1/6, 2/3$
H: $1/2, 2/3$
We just rendered a simple line drawing of a cube.

But to render more realistic pictures (or animations) we need a much richer model of the world.

- surfaces
- motion
- materials
- lights
- cameras
2D shapes
Complex 3D surfaces

(Stanislav Orekhov)

[Kaldor 2008]
Modeling material properties

[Wann Jensen 2001]

[Zhao 2013]

[Jakob 2014]
Realistic lighting environments

Up, (Pixar 2009)
Realistic lighting environments

Toy Story 3 (Pixar 2010)
Realistic lighting environments

Big Hero 6 (Disney 2014)
This image is rendered in real-time on a modern GPU

Unreal Engine Kite Demo (Epic Games 2015)
So is this.
Animation: modeling motion

https://www.youtube.com/watch?v=wYfYtV_2ezs

Luxo Jr. (Pixar 1986)
Physically-based simulation of motion

https://www.youtube.com/watch?v=tT81VPk_ukU

[James 2004]
Course Logistics
About this course

- A broad overview of major topics and techniques in computer graphics: geometry, rendering, animation, imaging

- Outline:
  - Focus on fundamental data structures and algorithms that are reused across all areas of graphics
  - Assignments on:
    - Rasterization
    - Geometric Modeling
    - Photorealistic Rendering
    - Animation
  - In-class midterm/final
Assignment 0: Math (P)Review
Assignment 1: Rasterization
Assignment 2: Geometric Modeling
Assignment 3: Photorealistic Rendering
Assignment 4: Animation

(cribbed from Alec Jacobson)
Midterm / Final

- Both cover cumulative material seen so far
- In-class, proctored exam
- Can bring one sticky note (both sides) w/ any information on it
Getting started

- Create an account on the course web site:
  - http://15462.courses.cs.cmu.edu/spring2018/home

- Sign up for the course on Piazza
  - https://piazza.com/class/jcgp5uqmriq8b

- There is no textbook for this course, but please see the course website for references (there are some excellent graphics textbooks)
Assignments / Grading

- **(10%)** Warm-up Math (P)Review
  - Written exercises on basic linear algebra and vector calc. (individually)

- **(60%)** Four programming assignments
  - Four programming assignments
  - Each worth 15% of overall course grade

- **(25%)** Midterm / final
  - Both cover cumulative material seen so far

- **(5%)** Class participation
  - In-class/website comments, other contributions to class
Late hand-in policy

- Programming assignments
  - Five late day points for the semester
  - First four programming assignments only
  - No more late points? 10% penalty per day
  - No assignments will be accepted more than 3 days past the deadline
Cheating Policy

Let’s keep it simple: if you are caught cheating, you will get a zero for the entire course (not just the assignment).
The course web site

We have no textbook for this class — the lecture slides and instructor/TA/student discussions on the web are the primary course reference.

Perspective projection

- Objects look smaller as they get further away (“perspective”)
- Why does this happen?
- Consider simple (“pinhole”) model of a camera:

Slide comments and discussion

“Add private note” button: You can add notes to yourself about this slide here.

Slide comments and discussion

Question: During class Keenan asked a question about why do objects look smaller when they are viewed at a distance. I liked one of the arguments made because it appealed to the angle subtended by an object. Could someone elaborate on that here?
Our philosophy

- We want a very active class: come to class, participate in the class, contribute to the web site
- Challenging assignments (with tons of “going further” opportunities: see what you can do!)
- Challenging exams (see what you can do!)
- Very reasonable grading (at least the instructors think so)
See you next time!

- Next time, we’ll do a math review & preview
  - Linear algebra, vector calculus
  - Help make the rest of the course easier!