Fundamentals of Computer Graphics

Stephen J. Guy

Sep 6, 2017

Today's Objectives

- Understand if you'll enjoy this course
- What is this course about
  - Introduction
  - Topics covered
  - Related courses
- Work load & Course policies

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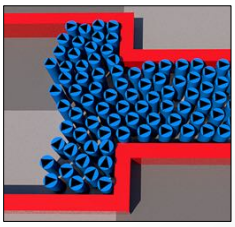
About Me

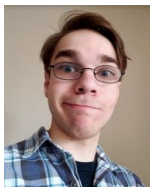
- Joined UMN Faculty in 2012
  - Ph.D. *Comp. Sci.* 2012 UNC
  - B.S. *Comp. Eng.* 2006, UVA
- Applied Motion Lab, Director
  - Intersection of Robotics, AI, & Animation
  - Creating intelligent motion






Teaching Staff

- Instructor: Stephen J. Guy
- Graduate TA:
  - Dalton Hildreth
  - hildr039@umn.edu



  - Researcher in Animation & VR

- Office hours in Keller 2-209
  - Time: Friday, 11:00am - 12:00pm
  - Will host extra this week!
    - 2-3 today and 1-2 tomorrow

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Overview

- Introduction
  - What is Computer Graphics?
  - Where is it used?
  - What kinds of techniques are used?
- Syllabus
  - What will you learn here?
- Course work?
  - How hard will this be?

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What is Computer Graphics?

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What is Computer Graphics?

Computer graphics: The study of creating, manipulating, and using visual images in the computer.

What is Computer Graphics?

- What can you do with graphics
  - Creating images
  - Changing images
  - Blurring, enlarging, shrinking, images
  - Visualizing complex datasets
  - Creating 3D datasets
  - Movies
  - Video games
  - Simulating physical phenomena
  - Simulating plants and animals
  - …

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Though Exercise

- Imagine we want to create a CG video of water being poured in a a glass.
  - What effects do we need to model/simulate?

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Water Pouring:

- Simulate water movement
  - Pour, sloshing, settling, splashing
- Refraction of light through glass (distortion)
- Reflection of light on glass (highlight)
- How filling with water changes refraction
- Texturing on table
- Caustics as water/glass focuses light
- Representing the glass shape/location
- Representing the water!
- Representing materials
- Sound simulation?

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What is Computer Graphics?

- Different aspects of Graphics
  - Imaging
    - Computer representations of 2D images
  - Modeling
    - Computer representations of 3D objects
  - Rendering
    - Creating 2D images from 3D models
  - Animation
    - Simulating changes over time
  - Hardware
    - Architectures which allow efficient handling of the above

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What's cool about graphics!

- Visual
  - Wide appeal
- Interactive
- Interdisciplinary
  - Biology
  - Physiology
  - Psychology
  - Physics
  - Math
  - Art
  - CS

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Graphics in the Economy

- Video Games & Movies are both multi-billion dollar industries
  - Movies: $10.6B (2009)
  - Avatar: $242 Million (opening weekend)
  - Video games: $20.2B (2009)
  - Call of Duty Modern Warfare 2: $310 Million (opening day!)

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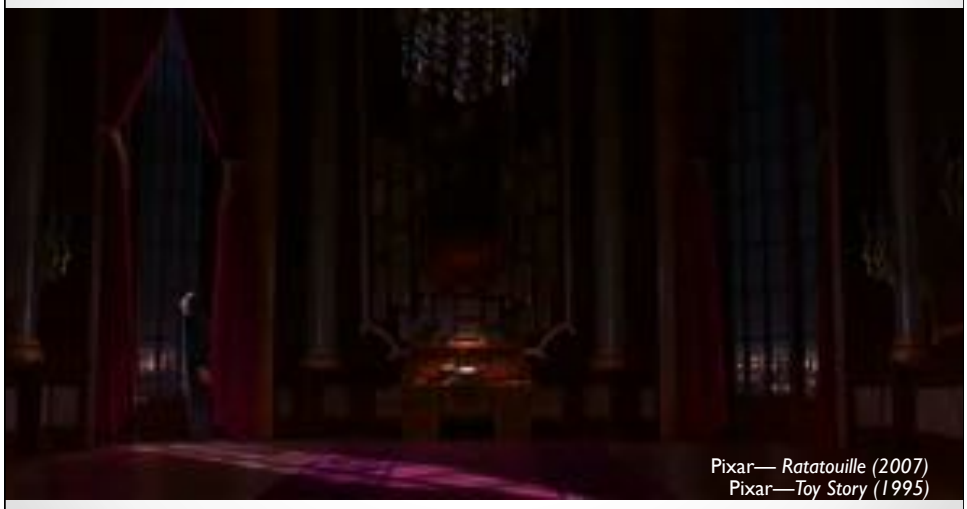
Applications

- **Entertainment**
  - **Movies**
  - **Games**
- GUIs
- Science & Engineering
- Training & Simulation
- Graphic Arts
- Fine Arts

Entertainment (movies)

Pixar—*Toy Story (1995)*

Entertainment (movies)



Pixar— *Ratatouille (2007)*
Pixar—*Toy Story (1995)*

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Entertainment (movies)

King Kong (Universal Pictures, 2005)—visual effects: WETA Digital

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Applications

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  - **Games**
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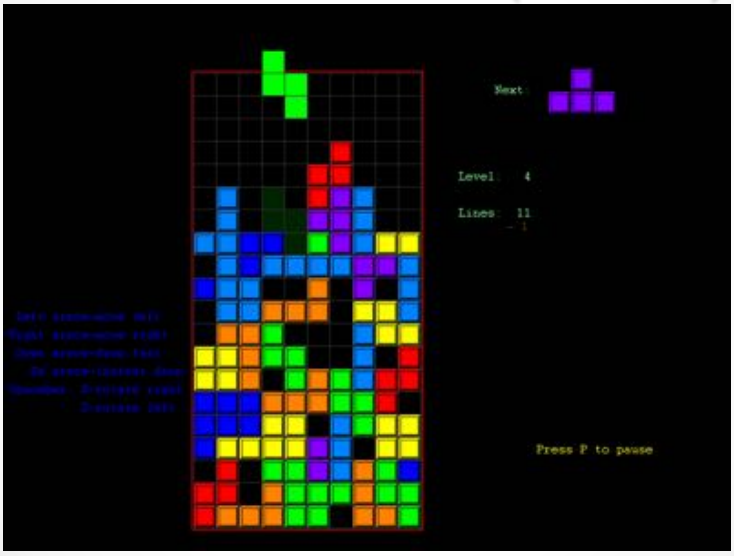
- Fine Arts

Entertainment (active)



Entertainment (active)

id Software—*Quake 4* (screenshot: Planet Quake)

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Entertainment (active)

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NBA 2K18

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Reality

Entertainment (active)

Crytek GmBH—*advertisement for CryEngine 2 game engine*


CRYTEK


2016 FEATURES
UNREAL ENGINE 4

Applications

- Entertainment
  - Movies
  - Games
- **GUIs**
- Science & Engineering
- Training & Simulation
- Graphic Arts
- Fine Arts

Graphical User Interfaces

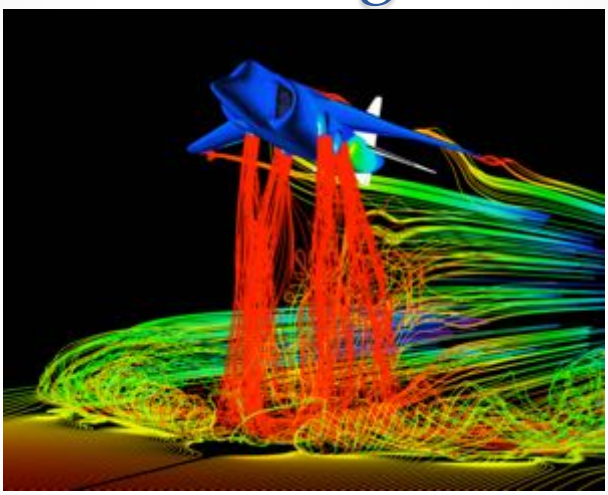
Graphical User Interface

Window system and large-screen inter

Applications

- Entertainment
  - Movies
  - Games
- GUIs
- **Science & Engineering**
- Training & Simulation
- Graphic Arts
- Fine Arts

Science & Engineering



- Airflow on a Harrier Jet (NASA Ames)

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Applic

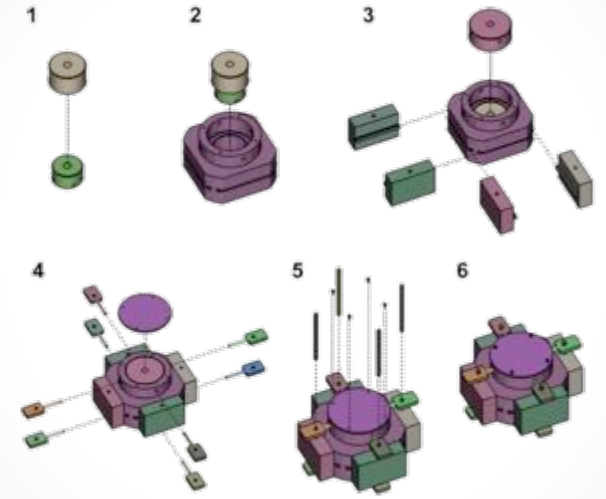
- Entertainment
  - Movies
  - Games
- GUIs
- Science & Engineering
- **Training & Simulation**
- Graphic Arts
- Fine Arts

NASA/Ames—ACFS

Army Research Lab—IES

Course Overview

Training & Education

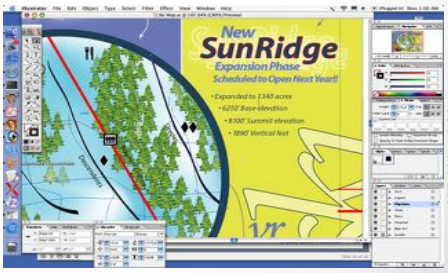


- Designing Effective Step-By-Step Assembly Instructions *(Maneesh Agrawala et. al)*

Applications

- Entertainment
  - Movies
  - Games
- GUIs
- Science & Engineering
- Training & Simulation
- **Graphic Arts**
- Fine Arts

Adobe Photoshop [Photo: P. Greenspun]



Adobe Illustrator

Applications

- Entertainment
  - Movies
  - Games
- GUIs
- Science & Engineer
- Training & Simulatio
- Graphic Arts
- **Fine Arts**

Computer aided sculptures
Ergun Akleman

Arts

- Blair Arch (Marissa Range, Princeton University)

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Overview

- Introduction
  - What is Computer Graphics?
  - Where is it used?
  - **What kinds of techniques are used?**
- Syllabus
  - What will you learn here?
- Course work?
  - How hard will this be?

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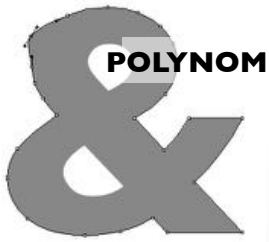
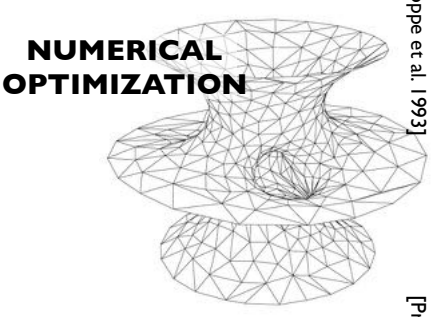
Tools in Graphics – 2D

- 2D imaging
  - compositing and layering
  - digital filtering
  - color transformations
- 2D drawing
  - illustration, draftin
  - text, GUIs

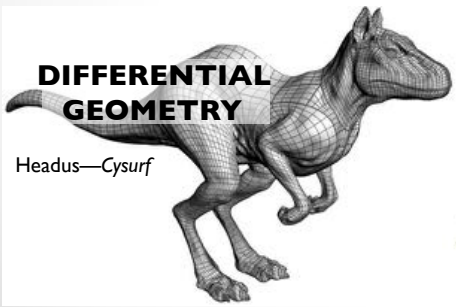


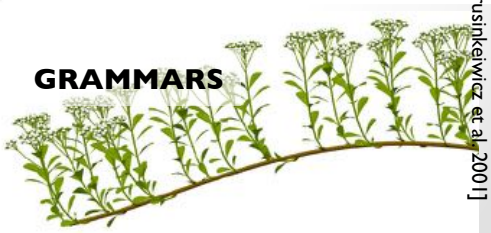
Tools in Graphics – Modeling

- 3D modeling
  - representing 3D shapes
  - polygons, curved surfaces, …
  - procedural modeling



[Hoppe et al. 1993]

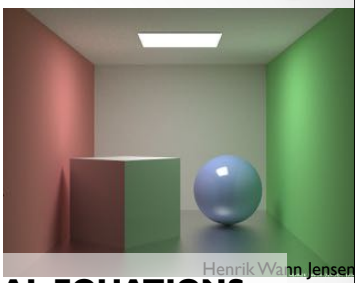




[Prusinkeiwicz et al. 2001]

Graphics Topics: Rendering

- 3D rendering
  - 2D views of 3D geometry
  - projection and perspective
  - removing hidden surfaces
  - lighting simulation



INTEGRAL EQUATIONS

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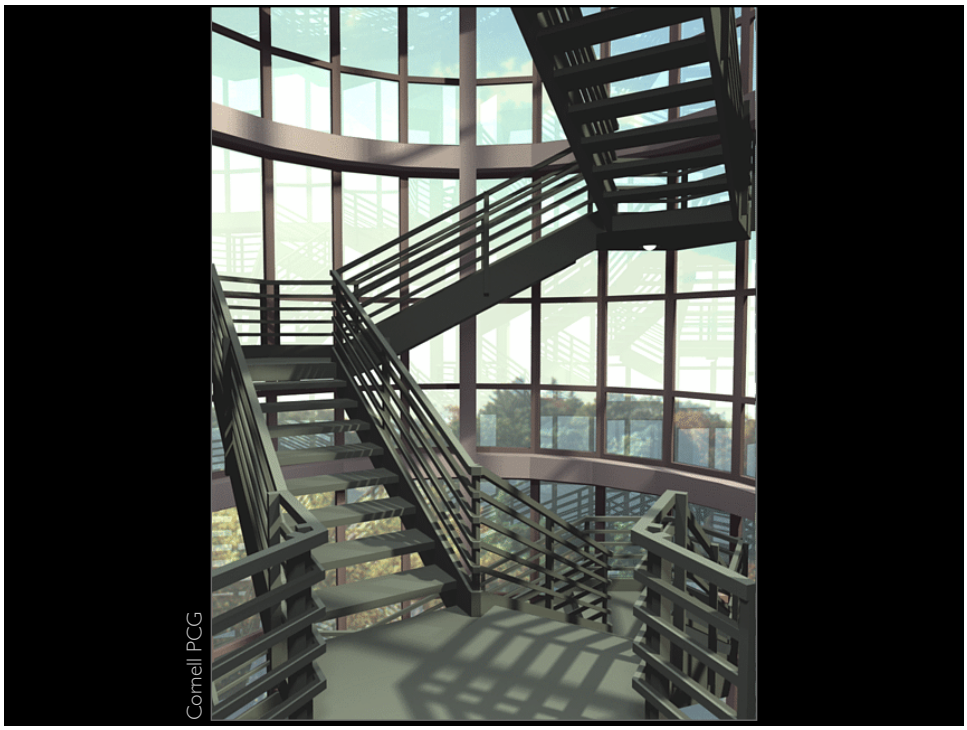
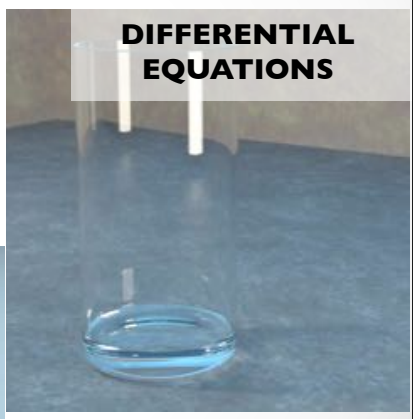


Graphics Topics: Animation

- Animation
  - keyframe animation
  - physical simulation



INTERPOLATION

NUMERICAL OPTIMIZATION

DIFFERENTIAL EQUATIONS

Computer graphics:
Mathematics made visible.

DIFFERENTIAL GEOMETRY

SIGNAL PROCESSING

GRAMMARS

POLYNOMIALS

INTERPOLATION

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Overview

- Introduction
  - What is Computer Graphics?
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  - What kinds of techniques are used?
- **Syllabus**
  - **What will you learn here?**
- Course work?
  - How hard will this be?

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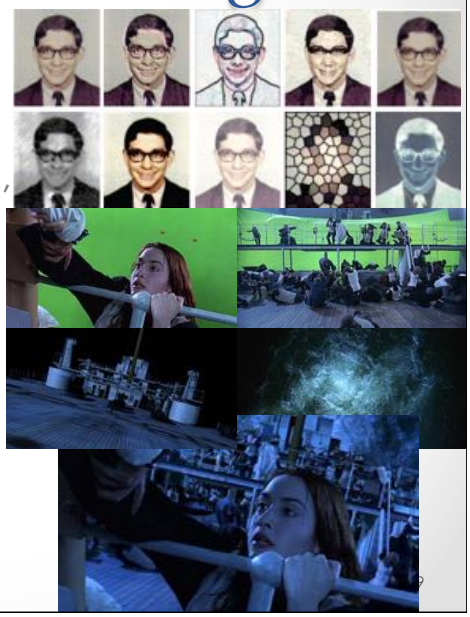
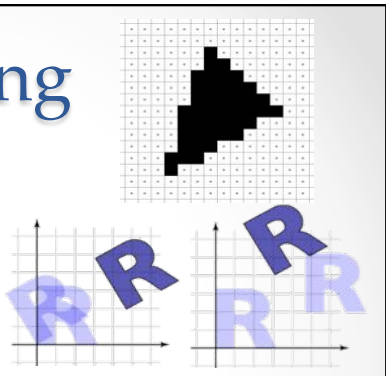
Image Processing

- Image Representation
  - Sampling
  - Reconstruction
  - Aliasing, Quantization,
- Image Processing
  - Filters
  - Warping & Morphing
  - Compositing
- Display Technologies
  - Color Models
  - Devices



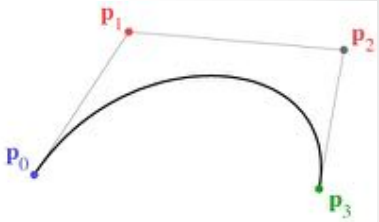
Rendering

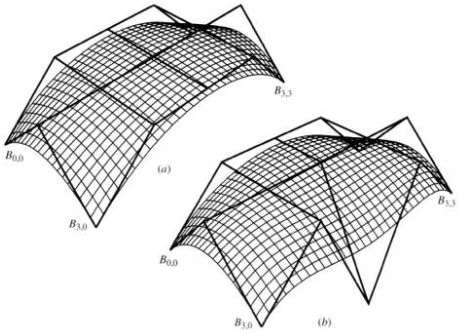
- 3D Rendering Pipeline
  - Scan conversion
  - Model Transformations
  - Hidden surface removal
  - Clipping
  - OpenGL
- Global Illumination
  - Ray tracing
  - Radiosity
  - Monte Carlo Techniques

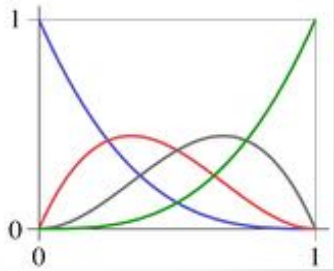


Modeling

- Representing Geometry
  - Curves: Splines
  - Surfaces: Splines, Meshes
  - Solids: Voxels, CSG







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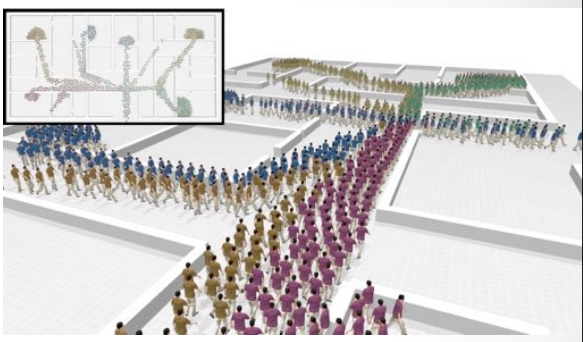
Animation

- Keyframing
  - Kinematics
  - Interpolation
- Motion capture
  - Capture
  - Warping
- Dynamics
  - Physically-based animation
- Behaviors
  - AI, learning
  - Planning



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Are You in the Right Course?

- This course focuses on the theory of graphics
  - Although:
    - We will discuss practical issues
    - You will be expected to make stuff work
- We will not:
  - Learn existing tools (e.g., Photoshop, Unity, Maya)
  - Teach programming practices

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The Right Course? (cont.)

- This is a broad course intended to be of general interest.
  - It may be the only graphics course you take!
  - You will leave with lots of pretty images, cool demos, and broad understanding of a new field.
- If you find yourself excited about graphics, the U has many good courses to follow up with…

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Graphics@UMN

- **CSCI 5607** [This course!]
  - Foundations of Computer Graphics
  - Basics of rendering, modeling & animation
  - Broad *theoretical* overview of the field
- **CSCI 4611** – Interactive Graphics & Games
  - Focused on practical experience
  - Undergrads only
- **CSCI 5608** – Computer Graphics 2
  - Advanced Rendering & the cutting edge of graphics
  - Focus varies by professor

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Graphics@UMN

- **CSCI 5619** – Virtual Reality & 3D Interaction
  - Bringing people physically into computer graphics
  - [T/Th 11:15 with Victoria Interrante]
- **CSCI 5611** – Animation & Planning in Games
  - Making dynamic, interactive worlds
  - [Likely taught by me next semester]
- **CSCI 5609** – Visualization
  - Turning data into compelling images
  - [Likely taught by Dan Keefe next year]
- **CSCI 5980** – New seminar(s) in Spring/Fall

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Overview

- Introduction
  - What is Computer Graphics?
  - Where is it used?
  - What kinds of techniques are used?
- Syllabus
  - What will you learn here?
- **Course work?**
  - **How hard will this be?**

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Theory of the Course

- My goals for you:
  - Broad exposure to graphics topics
  - Experience writing (C++) graphics applications
  - Experience with graphics APIs (OpenGL)
  - Familiarity with mathematical concepts that drive graphics (linear algebra, trig, etc.)
- Why:
  - Will prepare you for self exploration
  - Will prepare you for jobs in the field

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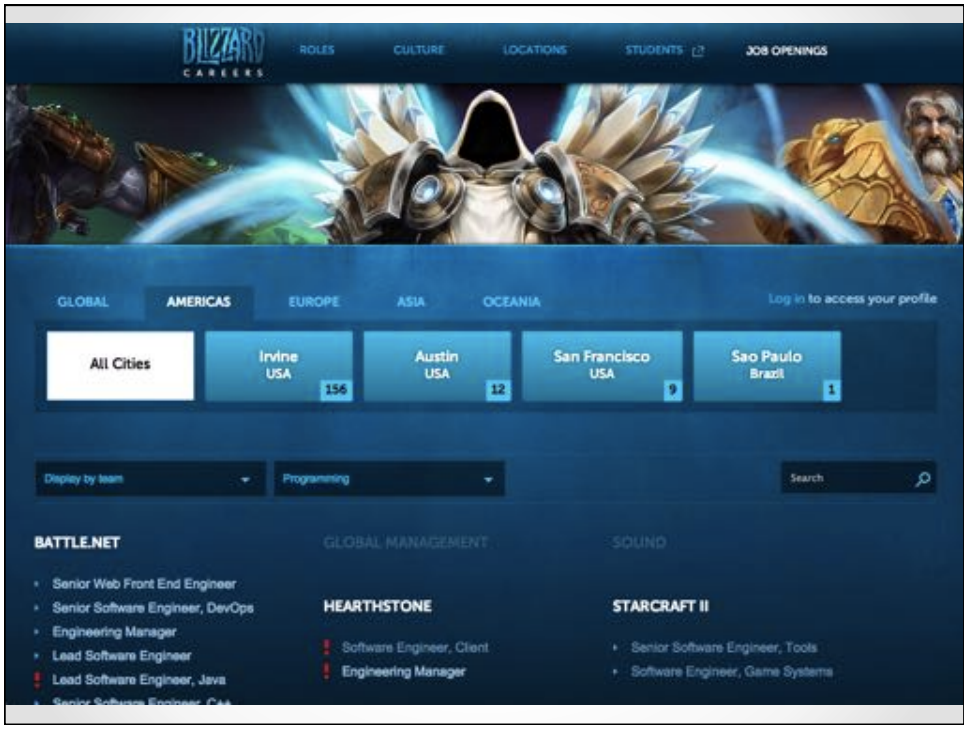

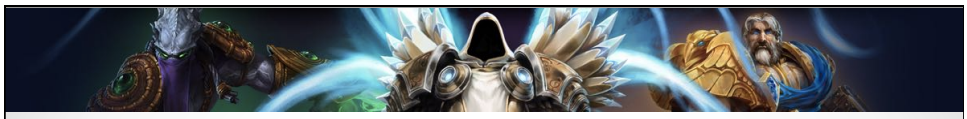

- *Software Engineer, Graphics/Engine*–Secret Game
  - Strong C++ skills
  - Strong passion for graphics programming and algorithms / mathematics (linear algebra, trig.)
  - Familiar with rendering techniques, shader development and graphics hardware and API's
- *Software Engineer, Tools* (Starcraft II)
  - Advanced understanding of C++
  - Understanding of game content pipeline
- *Software Engineer, Game System* (Starcraft II)
  - C / C++ programming skills
  - Mathematics skills, including proficiency with trigonometry and linear algebra

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Others…

- *Telltale Games*, Core Technology
  - C++/STL experience is required
  - Solid foundation in 3D math, algorithms, and modern computing fundamentals
- *Pixar*, Software Engineer
  - Experience in C++
  - Experience and/or knowledge of 3D graphics and interaction techniques
- *Insomniac Games*, Core Programming
  - Advanced C, C++, and assembly
  - Strong grasp of mathematical concepts, graphics, and collision detection

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Language

- Official Course Language: **C++**
  - Widely used in the industry
  - Fast
  - Lots of graphics resources
- You can turn projects in in **Java**, but there won't be able help from the course staff if things don't work!
  - If you intend to use some other language come talk to me
  - Python (or similar languages) not allowed
  - Graphics engines (e.g., Unity) not allowed

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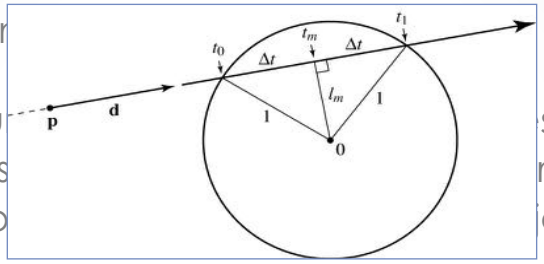
Perquisites

- Programm
  - ability
    mediu
  - unders
  - comfo



s)
res
ects

- Mathematics
  - vector geometry (dot/cross products, etc.)
  - linear algebra (just basic matrices in 2-4D)
  - basic calculus (simple derivatives)
  - graphics is a good place to pick up some, but not all, of this

Arc of the Course

- Beginning:
  - Mathematical background
  - External libraries
  - Compiler errors
- Middle:
  - Graphics & Rendering Theory
  - Midterm
- End:
  - Applications
  - Recent developments

Course Load

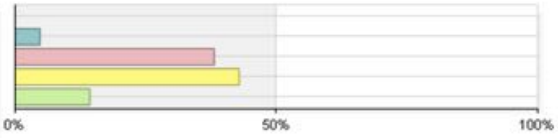
- 4-5 Major Programming assignments
  - Every couple weeks
  - First one is due in already posted!
- Midterm
- In-class activities (bring a pencil & paper)
- Final project (can be in small teams)

- Take away:
  - New skill set
  - Comfort with 3D graphics
  - Portfolio of exciting projects
  - Cool demos to show friends & family!

Student Evaluations

Approximately how many hours per week do you spend working on homework, reading, and projects for this course?

0-2 hours per week	0	0.00%
3-5 hours per week	1	4.76%
6-9 hours per week	8	38.10%
10-14 hours per week	9	42.86%
15 hours per week or more	3	14.29%
Total	21	

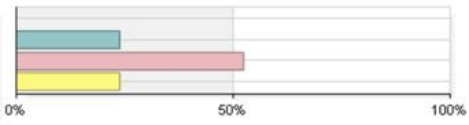


Compared to other courses at this level, the difficulty of this course is:

Less	1	4.76%
About the same	6	28.57%
More	9	42.86%
I have not taken other courses at this level	5	23.81%
Total	21	

Compared to other courses at this level, the amount I have learned in this course is:

Less	0	0.00%
About the same	5	23.81%
More	11	52.38%
I have not taken other courses at this level	5	23.81%
Total	21	



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Class Resources

- Webpage:
  - https://ay17.moodle.umn.edu/course/view.php?id=6060
- Online Forum
  - Don't post code!
- Office Hours
  - Will be posted on Moodle soon
  - No office hours from me this week, extended ones from Dalton
- Unite
  - Videos of lecture available after 10 days

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Grading Breakdown

- Final Grade:
  - 50% - Projects(~5 total)
  - 25% - Midterms & Quizzes
  - 25% - Final Project
  - Missing more than 2 in class activities will bring down your grade
- Percentages may shuffle a small amount

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Programming Assignments

- Individual task
  - Assignments are due the day of class, before class starts!
  - If you are in class, you have an extension until11:59pm
- Late assignments:
  - Up to 5 "grace days" may be used on programming assignments (24 extension)
  - Intended for (unforeseen) emergencies

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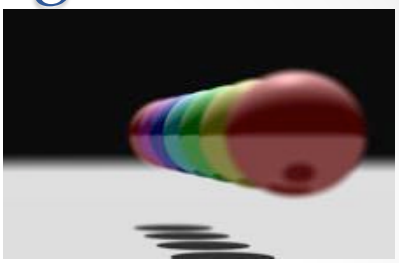
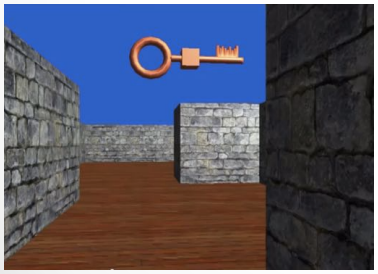
Likely Assignments

Image Manipulation



Ray Tracing



Realtime Rendering & Game Programming

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Final Project

Collaboration Policy

- You must write your own code!
- You must reference when you use an outside source

- OK:
  - Talking to other students about ideas, approaches, etc
  - Get ideas from books, websites, etc
  - Reference any code that is not yours!
- Not OK:
  - Sharing code with someone else
  - Not crediting ideas
  - Directly fixing someone else code

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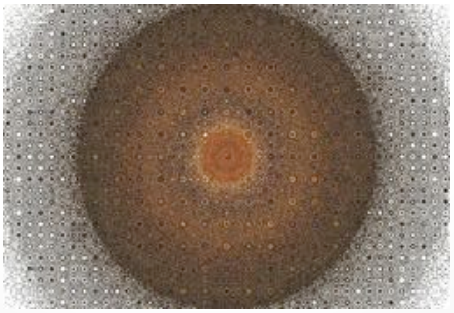
Art Contest

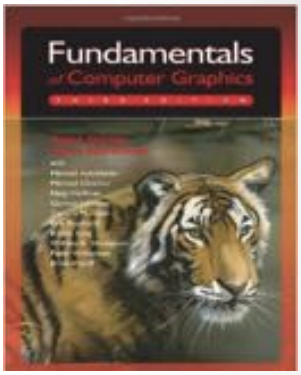
- Awards (points) for pretty pictures
- Everybody should submit
  - 5 points for honorable mention (several)
  - 15 points for the winning entry
- Save "Accidental Art"!



Michael Cistera

Course Text Book

- Fundamentals of Computer Graphics, 4th Edition
  - Official course book
  - Readings will complement lectures



- Computer Graphics: Principles and Practice, 3rd Edition
  - "The Bible" of graphics
  - You should own this if you continue in the field

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Classroom Policy

- No Laptops!
  - Very distracting to those behind you
  - Tablets okay
- Feel free to ask questions or correct mistakes
  - Please raise your hand though, it's a fairly large class…

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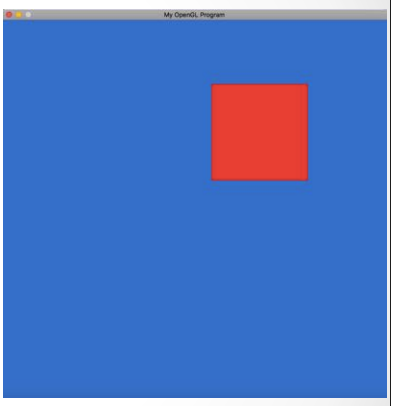
HW 0

- Get OpenGL running
- Get SDL installed
- Practice thinking about the connection between math and graphics
- Goal:
  - Allow a user to drag, scale, and rotate a square using their mouse
- Starter code is posted online



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HW 0 (cont.)

- Due in ~2 weeks
- Very easy*
  - Get started now before classes ramp up!
- Extra help
  - Dalton is holding extra office hours this week to help people get the sample code running

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Summary

- Computer Graphics is visual math
- The first assignment will be out soon
- Extended TA office hours this week
- Use Moodle – Don't post Code
- Get started on HW 0

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