Introduction

WELCOME TO CS1950U!

Introduction

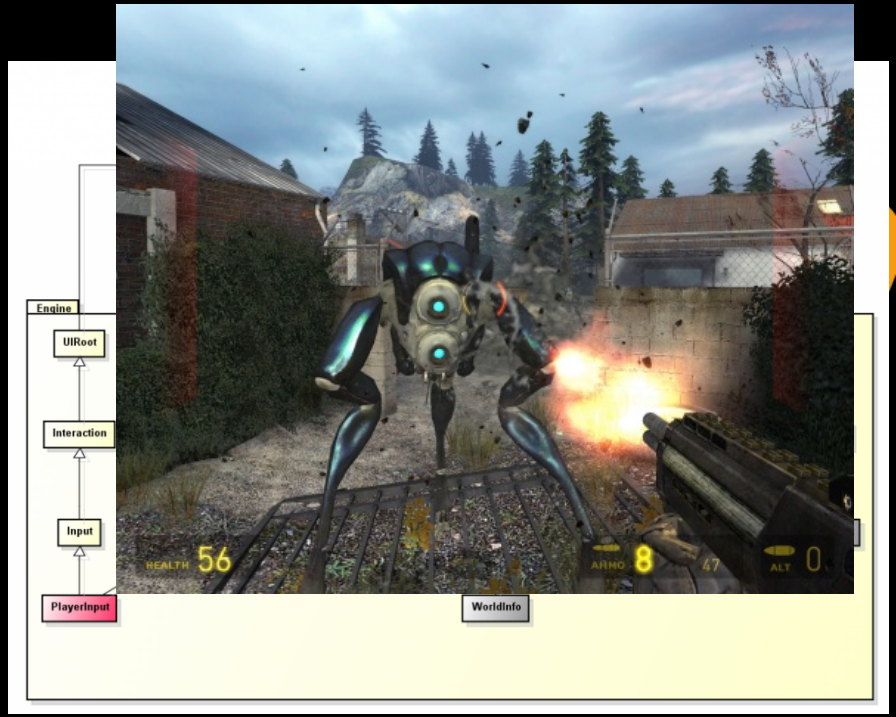
STAFF

Introduction

GOALS

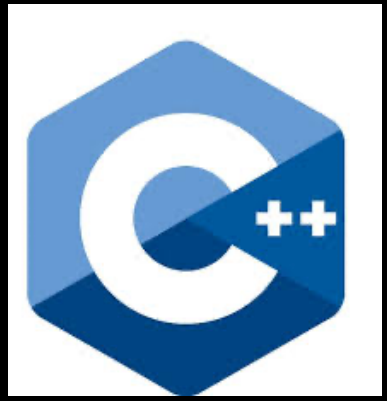
Class Goals

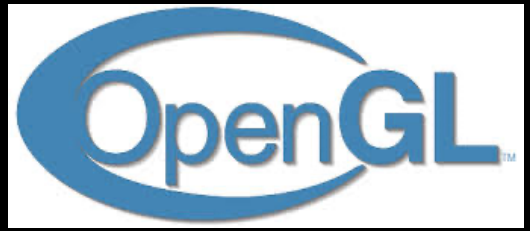
- Build your own 3D game engine, from scratch!
- Build games on top of your game engine!
- Improve your software engineering and design skills!



Useful Skills

- C++
- Graphics/OpenGL
- Basic vector math



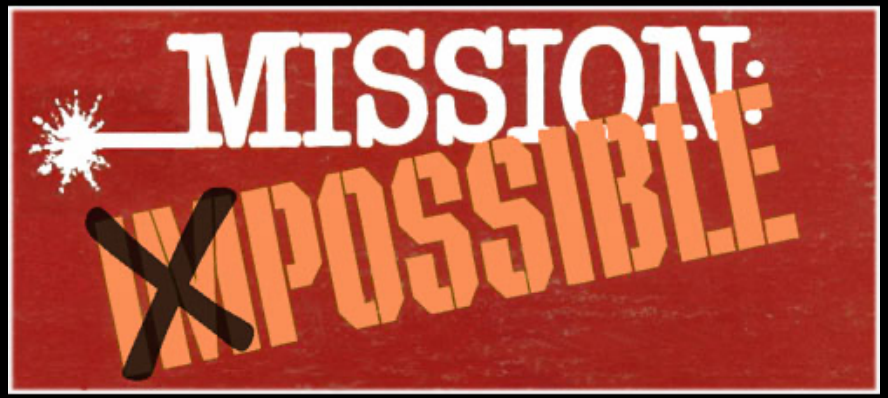


Introduction

ASSIGNMENTS

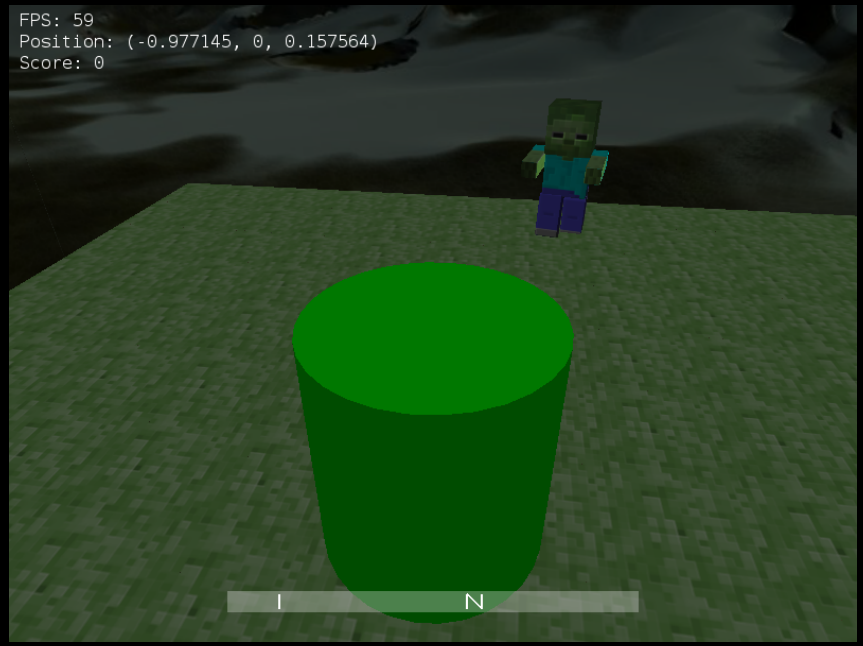
Projects

- Two projects split up into checkpoints
  - Some weeks give you choices!
- One open-ended final project (individual or in groups)



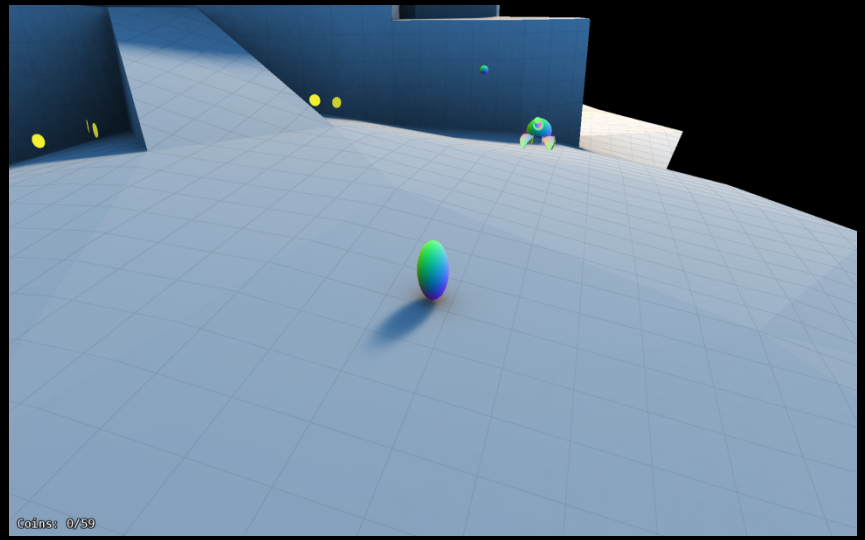
Warmup

- Startup assignment to get familiar with working in 3D space
- 2 week project (2 checkpoints)
- Basic engine architecture, graphics, controls



Platformer

- 4 checkpoints over 6 weeks
- Topics:
  - collisions, rigid body physics
  - spatial acceleration
  - pathfinding, AI
  - UI/HUD
  - animation



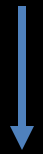
Final

- 4 week project
- Your choice of engine features
- Your choice of game features
- Groups encouraged, but not required
- More details later

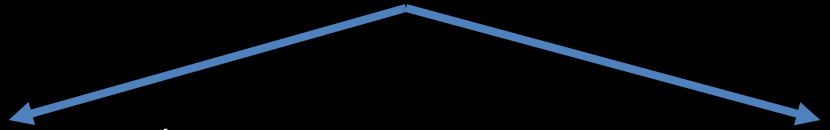
???

Class Roadmap

Week 1 (Basic Engine Architecture)



Week 2 (Gameworld, ECS, Systems)

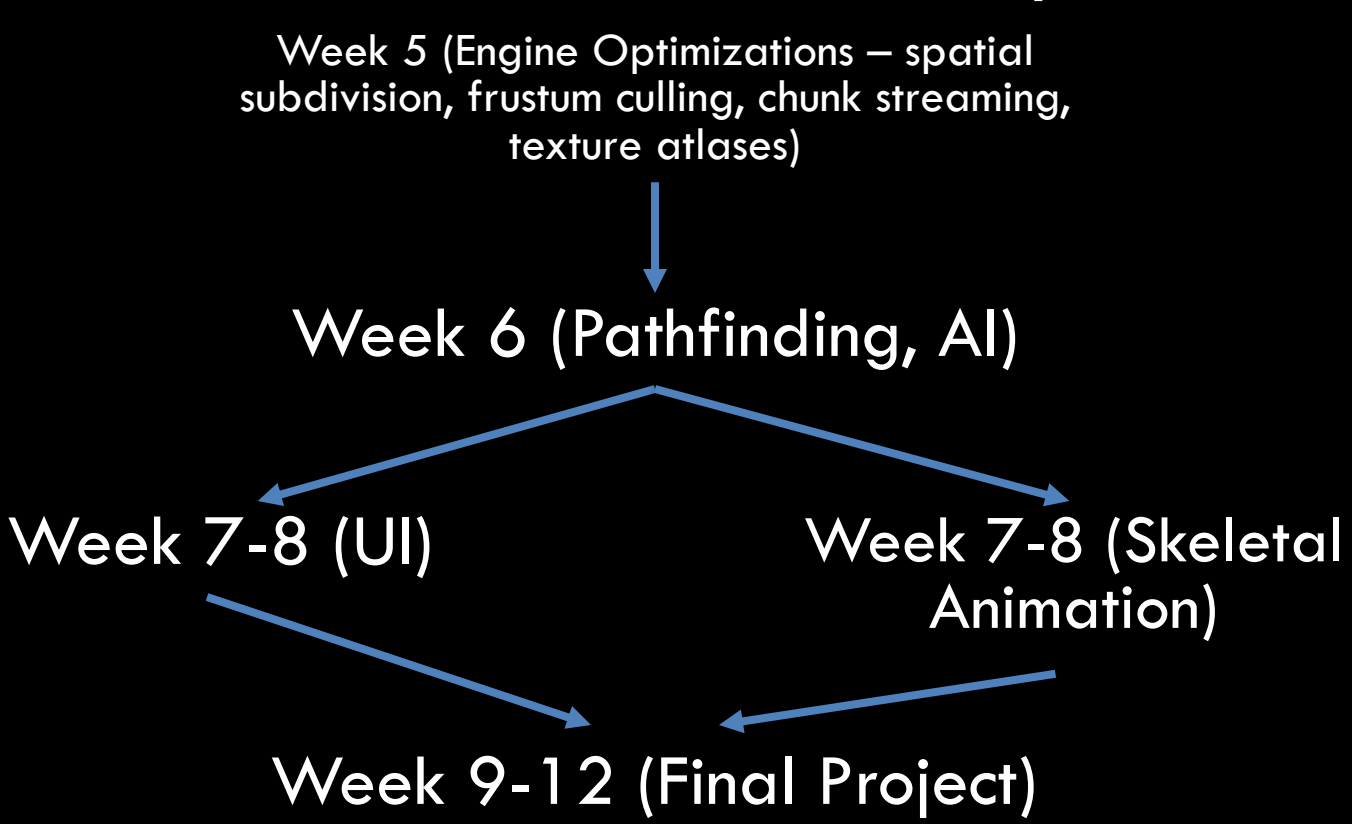


Week 3-4 (Ellipsoid/Triangle, Sphere/Cylinder/AAB Collisions)

Week 3-4 (GJK, EPA Collisions)

+ Rigid Body Physics (if you want)

Class Roadmap



Introduction

GRADING

Grading

- Only projects
- Grades and feedback will be given on Canvas
- Handins due on Monday at 11:59 PM, except for final, which is due on Sunday 4/18 at 11:59 PM
- Checkpoints are worth 3 points (except for collisions checkpoint which is worth 6 points), final is worth 9 points

Grading

- For each checkpoint, you have…
- Engine requirements
- Game Requirements
- You can get extra credit by implementing extra features

Final Grades

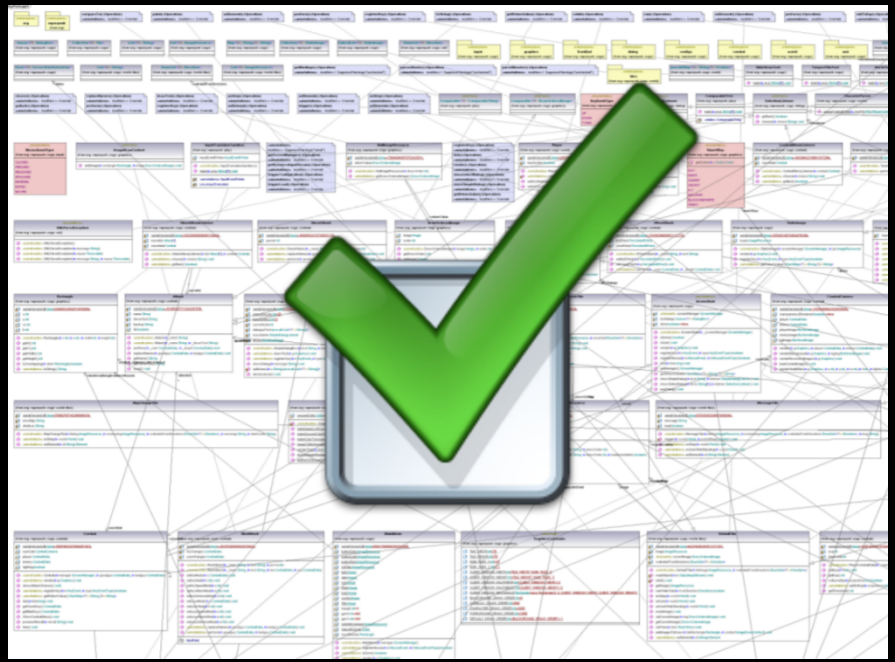
- No curve!
  - Do the work, get an A
- 30 points possible across all projects, not counting extra credit
- Need to complete all primary engine requirements and a final project

Grading

Points	Missing	Grade
27+	0-3	A
24-26	4-6	B
23-	7+	C

Design Checks

- High-level conceptual questions
- Gives one standard retry, which bring us to …



Incomplete Handins

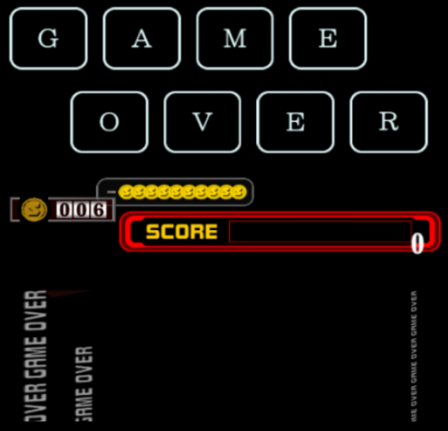
- Standard Retry
  - As long as you complete a design check, you are allowed to re-hand in a checkpoint
- Extra retries
  - You have two for the whole class
  - Can use to retry a checkpoint that you already retried
- You have a week to use each retry (from when you get your grade back)

Incomplete Handins

- Minimum requirements *cannot* be retried
- Extra credit *can* be retried
- No extra credit until all requirements are met
- Only your best handin will count (retries never hurt your grade)

Out of Retries

- Used the standard retry, out of extra retries, now what?
- You can still do well in the class
  - Don't have to get credit for all requirements
- You can still pass the class
  - Hand in working version of all engine requirements by the end of the semester



Introduction

QUESTIONS?

Introduction

CLASS TIMES

Class Times

- Class: Tuesday 9am-10:20pm (Zoom)
- Design Checks and Hours: Thursday 9am – 10:20pm (Zoom)
  - Optional
  - Signmeup for design checks and hours
  - more hours TBA
- Website: http://cs.brown.edu/courses/cs195u/

Introduction

OTHER COURSE POLICIES

Collaboration Policy

- Full version is on our website
- Short version:
  - Can discuss lectures and assignments
  - Can play each other's games
  - Cannot look at or give any code
  - Can cooperate with other students during TA hours (at TA discretion)

CS1950U as a Capstone

- Requirements
  - More final project engine features
    - Students taking the capstone should get their project proposals approved before March 22 so that they can start early
    - See the final project handout for details
  - Capstone form filled out, signed by Daniel Ritchie
  - That's it!

Slack

- We are using Slack instead of Piazza this semester
- Email course staff if you have not been invited to the Slack workspace
- There is a public “help” channel
- You can DM me for private questions
  - I’ll paste questions and answers into the help channel if I think they would be helpful to others (question asker will remain anonymous)

Style Guide

- We expect you to have a reasonable style, but don't require any specific style guide
- If you're unsure of what counts as reasonable style, pick your favorite style guide from a course you've taken and follow it

Test Your Code

- Your code needs to **compile** and **run** on department machines
  - Let me know if there is a problem with FastX
- We can't grade it if we can't run it
- Should run at 20+ FPS

Introduction

ABOUT REGISTRATION

Registering for CS1950U

- If you can't register for CS1950U because you don't meet the prerequisites
  - Don't panic
  - Request an override in Courses@Brown

Registering for CS1950U

- If you can't register for CS1950U because you're a RISD student
  - Don't panic
  - Email our professor (Daniel Ritchie)

Introduction

QUESTIONS?

Introductions!

- Please share
  - Your name
  - Your pronouns
  - A video game you enjoy!

Basic Engine Architecture

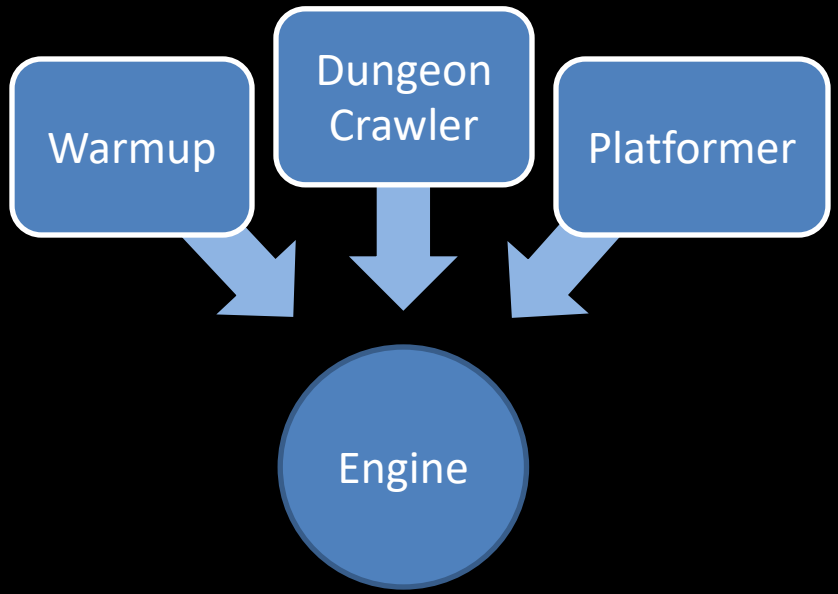
WHAT IS A GAME ENGINE?

What is a game engine?

- The things that games are built on
- Games tend to have a ton of functionality in common
- Create engines that abstract out common functionality

What is a game engine?

- Usable by many games
  - It should be able to easily create a game without modifying engine code
- Should be general
  - No game-specific logic!



What does this look like?

- Sample hierarchy
  - src/
    - engine/
      - Screen.cpp
      - Screen.h
    - warmup/
      - WarmupScreen.cpp
      - WarmupScreen.h

What does this look like?

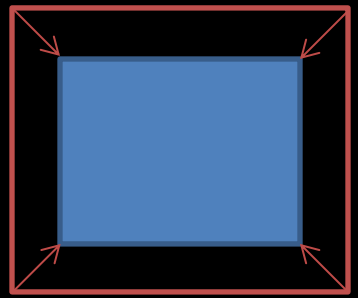
- **Engine code should never #include game files**

Basic Engine Architecture

AN ESSENTIAL INTERFACE

A game generally needs…

- Timed updates (ticks)
- To render to the screen (draws)
- Input events
- Resize events



Ticks

- General contract:
  - `void tick(float seconds)`
- Tells the game that a given amount of time has elapsed since the previous tick
  - Nearly all logic takes place during ticks
  - No drawing should take place during ticks

Draws

- General contract:
  - `void draw(Graphics *g);`
  - `void draw();`
- Tells the game to draw itself
  - Convert game state into viewable form
  - No side effects from draw calls
- More information coming up in Graphics section

Input Events

- Most APIs provide input events rather than making you manually poll mouse and keyboard
- Exact contract differs depending on type, but usually of the form:
  - `void onDDDEEE(QDDDEvent *event);`
  - DDD = device type (e.g. mouse, key)
  - EEE = event type (e.g. moved, pressed)
- Tells the game that an event has occurred
  - Event object contains information about the event
    - e.g. how far the mouse moved; what key was pressed…

Putting it Together

- The `Application` class

```
class Application {
public:
        void tick(float seconds);
        void draw(Graphics *g);
        void onKeyPressed(QKeyEvent *event);
        // more device and event types here...
        void onMouseDragged(QKeyEvent *event);
}
```

Putting it Together

- Application represents an instance of a game
- You will implement an `Application` class in Warmup1

The Most Basic Interface

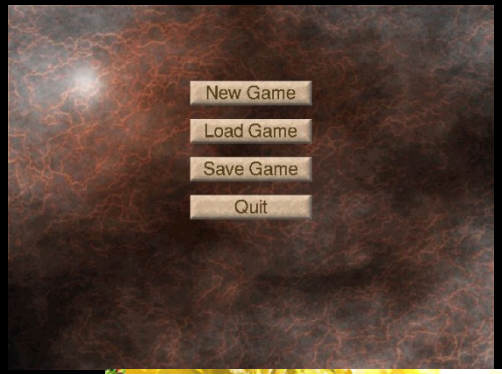
QUESTIONS?

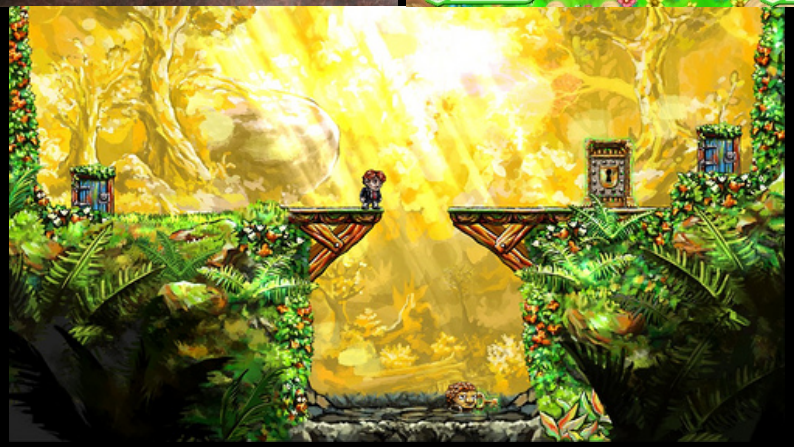
Basic Engine Architecture

SCREEN MANAGEMENT

We have an Application

- But how do we build a game around that?
- Drawing/ticking/event handling is very different depending on what's going on!
  - Menu system
  - The actual game
  - Minigames within game



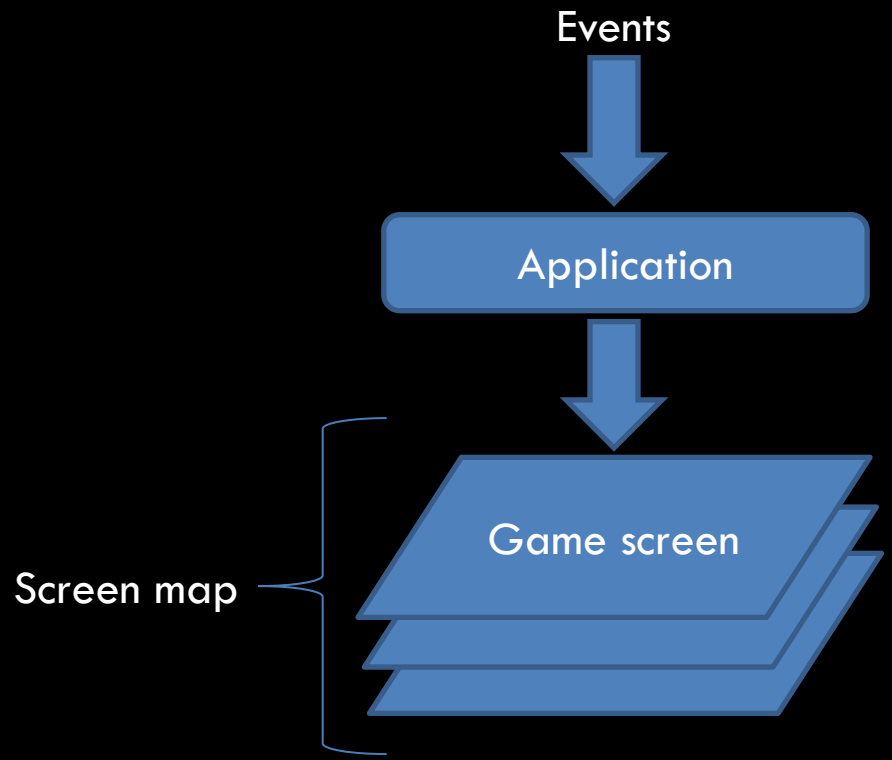


`Screen`s within `Application`

- Rather than keeping track of “modes”, separate each “mode” into a dedicated `Screen` subclass
  - MenuScreen, GameScreen, etc.
- A `Screen` has similar methods to the `Application`
  - tick
  - draw
  - input event methods

Keeping track of Screens

- Simplest way:
  - Single Screen in Application at a time
  - Application forwards all events to this screen
- Alternatively:
  - Map of Screens maintained by the Application
  - Screens can consume events or pass them to a different screen



What are `Screen`s good for?

- For Warmup1, `Screen`s may
  - Draw the entire game
  - Handle all of the game logic
- In general, `Screen`s shouldn't do this
  - Results in serious spaghetti code
- Solution: `GameWorld`
  - Covered next week…

Application Management

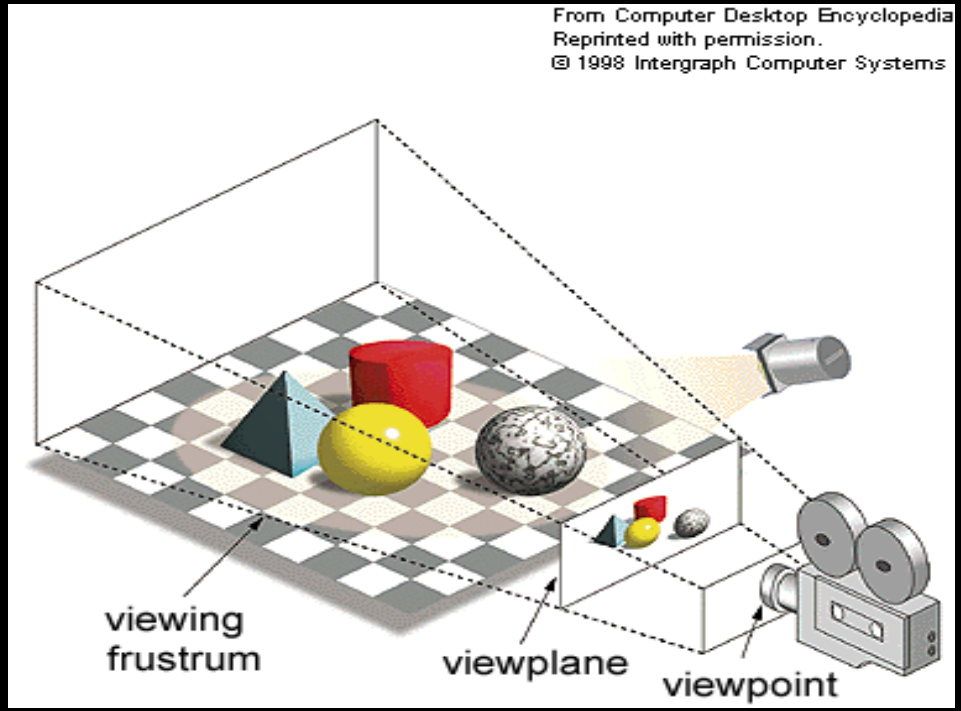
QUESTIONS?

Camera and Graphics

CAMERA

Cameras

- Physical camera will render a “film” – a 2D representation of the 3D space
- For virtual cameras, goal is similar
  - Render by squashing view volume (or frustum) onto 2D plane

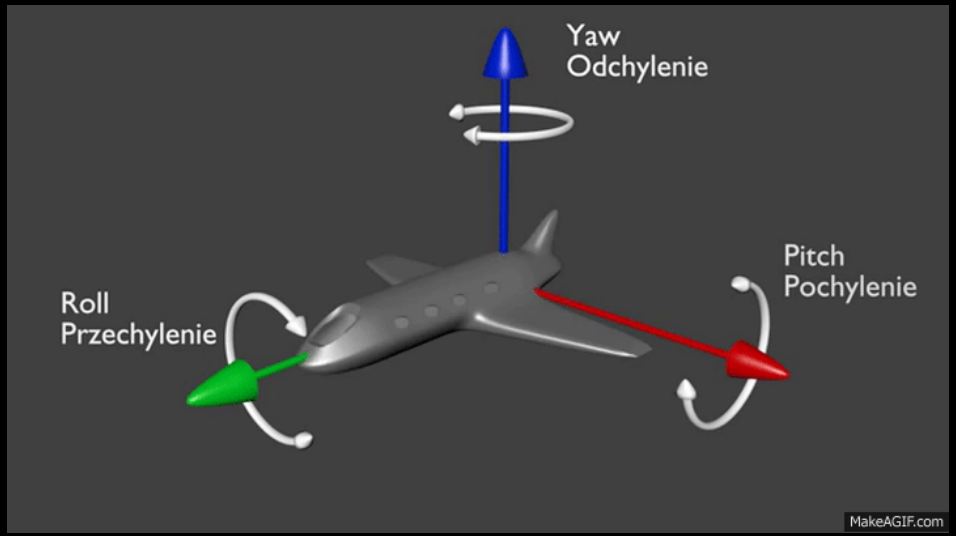


Cameras in 3D Space

- Camera is not very useful unless we know
  - Where it is (position)
  - What its orientation is (pitch, roll, yaw)

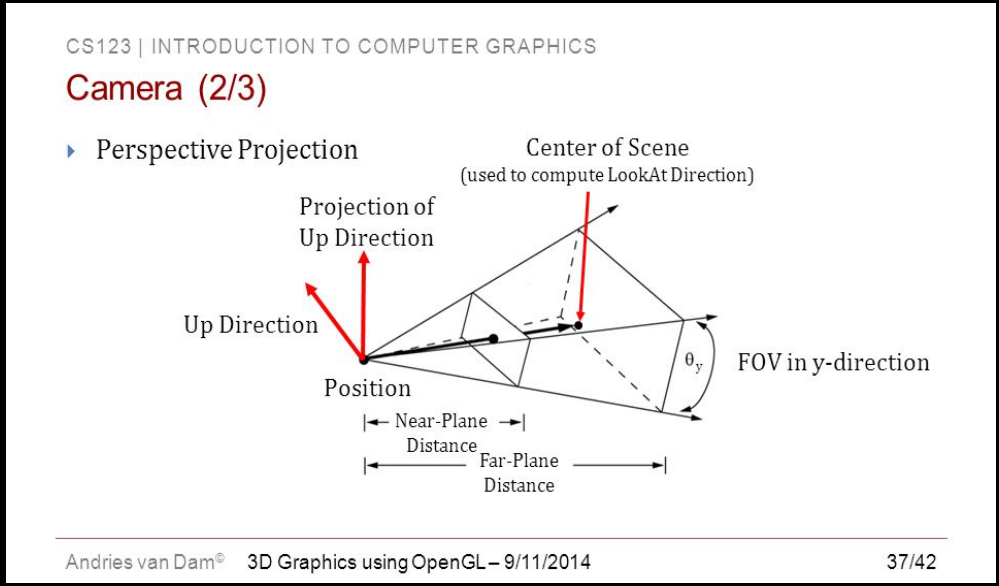
Camera Orientation

- Yaw
  - Stick a pin in the top of the camera and rotate it around it by this angle
- Pitch
  - The camera looking up and looking down by this angle
- Roll
  - Only really used in flight simulators



Camera Orientation

- Alternatively…
- Specify direction the camera is facing as a vector
  - Called the “look vector”

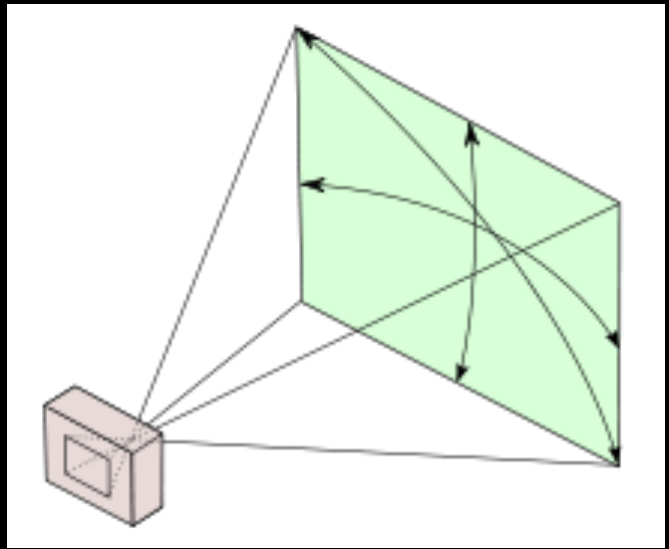


Camera position

- Position of camera in the world
- For Warmup 1, in order to achieve first person…
  - Make camera position same as player position
  - Update camera position to make the same as player position

Other Camera Parameters

- Field of view angle
  - How wide is the view volume?
- Aspect ratio
  - Ratio of the width of screen to the height of the screen



Our Camera Class

- Default Camera class provided
  - src/engine/graphics/Camera.h(cpp)
- Allows you to specify all of the above attributes
  - Most likely will only modify position, pitch, yaw

First Person Camera

QUESTIONS?

Camera and Graphics

BASIC GRAPHICS

Motivation

- Certain graphics calls are common to many games
  - Setting up a camera
  - Drawing shapes
  - Setting material properties for shapes
  - Drawing text
- We can store all of our shapes, materials, fonts, etc. in one centralized object
  - Helps us not load them into memory more than once
  - Helps us keep track of them and delete them
- Encapsulated in a “Graphics” object

Graphics Object

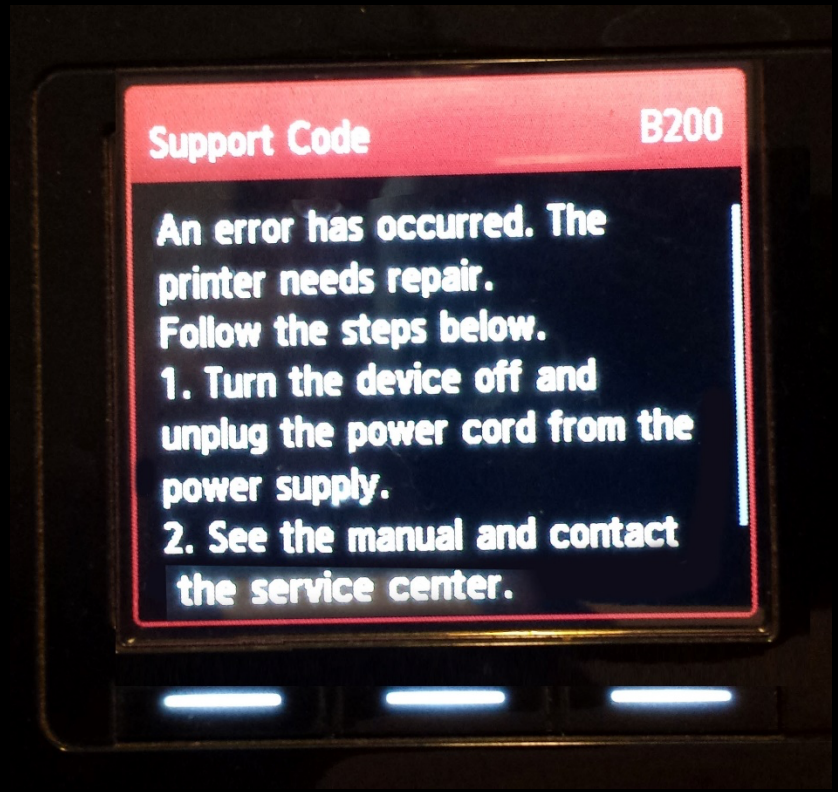
- Default Graphics object provided
  - src/engine/graphics/Graphics.h(cpp)
- Methods for …
  - Setting the active camera
    - This camera will be used for rendering
  - Drawing shapes
    - Rectangles (quads), cylinders, and spheres for now
  - Setting materials
    - Change color, texture, lighting of shapes
  - More!

Other Classes

- src/graphics/Shape.h(cpp)
  - Describes the geometry of a shape
- src/graphics/Material.h(cpp)
  - Describes material properties of a shape
- More!

Doing it Yourself

- Feel free to modify graphics support code!
- Feel free to write your own graphics code!



Basic Graphics

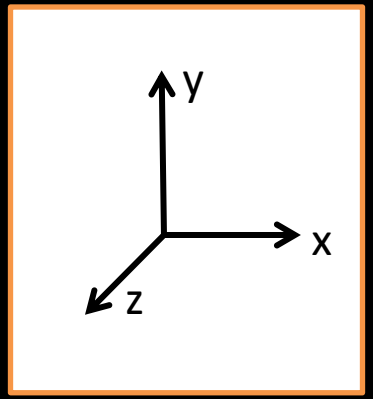
QUESTIONS?

Controls

PLAYER MOVEMENT

Coordinate systems

- Different game engines define 3D coordinate systems differently
- Most commonly:
- “Horizontal plane”
  - Plane parallel to the ground (the xz-plane)
- “Up-axis”
  - Axis perpendicular to horizontal plane (the y-axis)



Horizontal Movement

- Keep track of your player position
- Forward movement:
  - Use the horizontal component of the look vector
  - *forward_speed = some positive constant*
  - *dir = normalize(look.x, 0, look.y)*
  - *pos = pos + forward_speed * dir*
- Strafing
  - Use the perpendicular of the horizontal direction
  - *sideways_speed = some positive constant*
  - *perp = normalize(dir.z, 0, -dir.x)*
  - *pos = pos + sideways_speed * perp*

Vertical Movement

- Keep track of the player's vertical position and velocity
- Jump
  - Assign some positive velocity when the player jumps
  - Make sure the player is on the ground (*pos.y == 0*) before jumping
- Apply gravitational acceleration each tick
  - *dt = time since last tick*
  - *g = some negative constant*
  - *velocity = velocity + g * dt*
  - *pos.y = pos.y + velocity*
- Collision with ground
  - After moving the player, set *pos.y = max(pos.y, 0)*

CS195U SUPPORT CODE

Support Code Overview

- Qt Framework
  - main.cpp – starts up program, toggles fullscreen
  - mainwindow.h/.ui/.cpp – sets up window
  - view.h/.cpp – basic even framework, where your Application class should reside
- Vector math – glm (important!)
  - 2,3,4 dimensional vectors and matrices
  - Tons of math – see online documentation
- QRC files
  - Allows for easy access of external resources
  - Can use to load your own resources

```
12  public:
13      View(QWidget *parent);
14      ~View();
15
16  private:
17      QTime time;
18      QTimer timer;
19
20      void initializeGL();
21      void paintGL();
22      void resizeGL(int w, int h);
23
24      void mousePressEvent(QMouseEvent *event);
25      void mouseMoveEvent(QMouseEvent *event);
26      void mouseReleaseEvent(QMouseEvent *event);
27
28      void keyPressEvent(QKeyEvent *event);
29      void keyReleaseEvent(QKeyEvent *event);
30
31  private slots:
32      void tick();
```

Support Code Overview

- Utility
  - src/engine/util/CommonIncludes.h
    - Includes glm, iostream
    - Include this anywhere you need glm
- Graphics
  - src/engine/graphics/*
  - Described in previous section

```
1  #ifndef COMMONINCLUDES_H
2  #define COMMONINCLUDES_H
3
4  /*A file for any includes or structs
5
6  #include "GL/glew.h"
7  #include <iostream>
8
9  #define GLM_FORCE_RADIANS
10 #include <glm/glm.hpp>
11 #include <glm/gtx/string_cast.hpp>
12 #include <glm/gtx/transform.hpp>
13 #include <glm/gtc/type_ptr.hpp>
14 #include <glm/gtc/constants.hpp>
15
16 #endif // COMMONINCLUDES_H
17
```

Support Code Overview

- Methods in view.h/.cpp
  - DDDEEEEvent(QEEEvent *event) – call app.DDDEEE(event)
  - tick(float seconds) – call app.tick(seconds)
  - paintGL() – call app.draw(graphics) or app.draw()
  - resizeGL(int x, int y) – call app.resize(dimensions)
- Make Application a separate class from View!
  - Put instance of Application class in View, so that you can pass events on to Application

Setup Guide

- If you have time, go through the CS1950U setup guide! (highly recommended)
  - On the Docs page of the website
- It covers …
  - How to set up a camera
  - How to draw something using the graphics object
  - How to add basic player controls

On Your Own

- Play around with graphics object calls
- Specifically try to move, resize and rotate shapes
- 3D graphics can be tricky, especially if you haven't done it before
  - Feel free to email us or come to hours if there's something you don't understand

Qt vs. STDLib

- QString – substrings, splitting, hashcodes
- QList – type-generic dynamic array
- QHash – type-generic hashtable
- QSet – type-generic set
- QTimer – sets up the game loop
- QThread – easy-to-use threading API
- QPair – great for vector hashcodes

http://qt-project.org/doc/qt-4.8/qtcore.html

Qt vs. C++ STDLib

- QString – std::string
- QList – std::vector
- QHash – std::unordered_map
- QSet – std::unordered_set
- QPair – std::pair

http://qt-project.org/doc/qt-4.8/qtcore.html

C++ Tip of the Week

SMART POINTERS

Raw pointers

- Problems:
  - Declaration doesn't indicate who owns the object (i.e. who destroys it)
  - Must destroy exactly once
  - Memory leaks

Smart Pointers

- The solution to all of the problems (and more)
  - Most importantly, delete / free object they refer to automatically if pointer goes out of scope
- 3 types in modern C++
  - `std::unique_ptr`
  - `std::shared_ptr`
  - `std::weak_ptr`

Shared Pointers

- In general the one to use
- Same size as raw pointers and perform the exact same instructions

Creating a Shared Pointer

- Use “`std::make_shared<T>(args);`”
- More verbose than creating a normal pointer, but worth it

Creating a Shared Pointer

- With shared pointers

```
#include <memory> // Include header file
…
…

std::shared_ptr<Camera> cam =
        std::make_shared<Camera>();
…
…
```

- Without shared pointers

```
…
…
…

Camera *cam = new Camera();
…
…
delete cam;
```

Copying a Shared Pointer

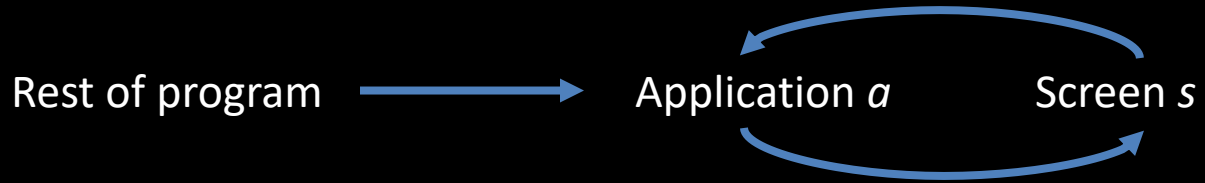
- Can make as many copies of a shared pointer as you want
  - `std::make_shared<T> s1 = …;`
  - `std::make_shared<T> s2 = s1;`
  - `std::make_shared<T> s3 = s2;`
  - `…`
  - Each refer to the same object
- Object managed by all shared pointers only deleted when all shared pointers go out of scope

Avoid Shared Pointer Cycles

- A shared pointer counts how many other objects reference it (i.e. how many copies of the shared pointer exist)
  - When this counter reaches 0, the shared pointer's destructor is called
- Do not create "cycles" of shared pointers!
  - If a shared pointer *s1* owns a shared pointer *s2* and *s2* also owns a shared pointer of *s1*, you will get a memory leak!

Avoid Shared Pointer Cycles

- Consider an Application *a* that owns a std::shared_ptr<Screen> *s*. If *s* owns a std::shared_ptr<Application> to *a*, then *a* cannot be destroyed without manually destroying *s*
  - Why? Consider the diagram below. Application *a* is referenced **twice** (by the rest of the program and by *s*)
  - When we destroy the rest of the program, Application *a* is not destroyed because its reference counter decreases from 2 to 1 (so the counter does not reach 0)



Avoid Shared Pointer Cycles

- It is very common for a Screen to want to reference the Application that owns it
  - We can have this behavior and avoid memory leaks by having the screen own a ***raw*** pointer to the application
  - This is safe to do because the Application owns the Screen, but the Screen does not own the application (shared pointers shown ownership)
- This pattern will be useful when we talk about about GameWorlds, GameObjects and Components as well!

In Summary…

- Unique/shared pointers make memory management easier
- Please don’t have memory leaks in your handin code

Warmup 1 is released! Good luck!