Video Game Design

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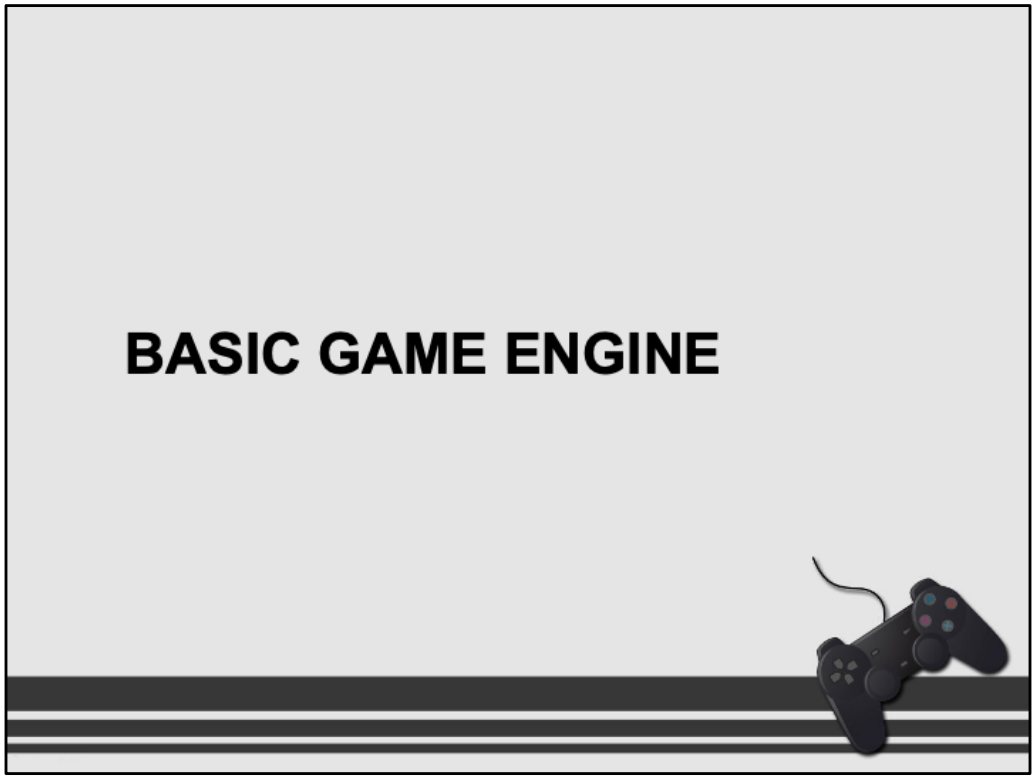
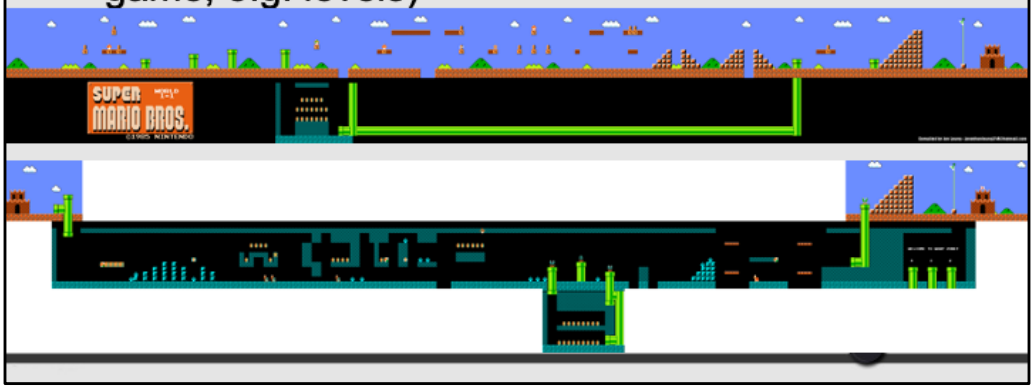
Game Engines

BASIC GAME ENGINE

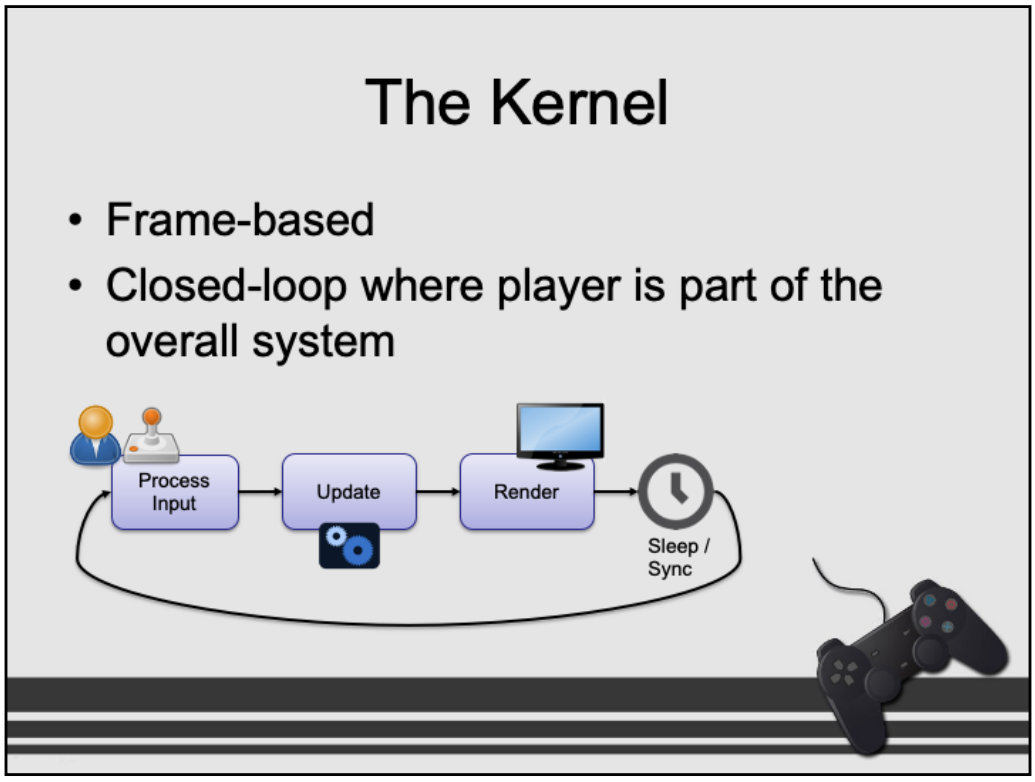


Early Game Engine

- Computational kernel that runs the game
- Operates on internal data models
- Some level of reusability (at least within the game, e.g. levels)

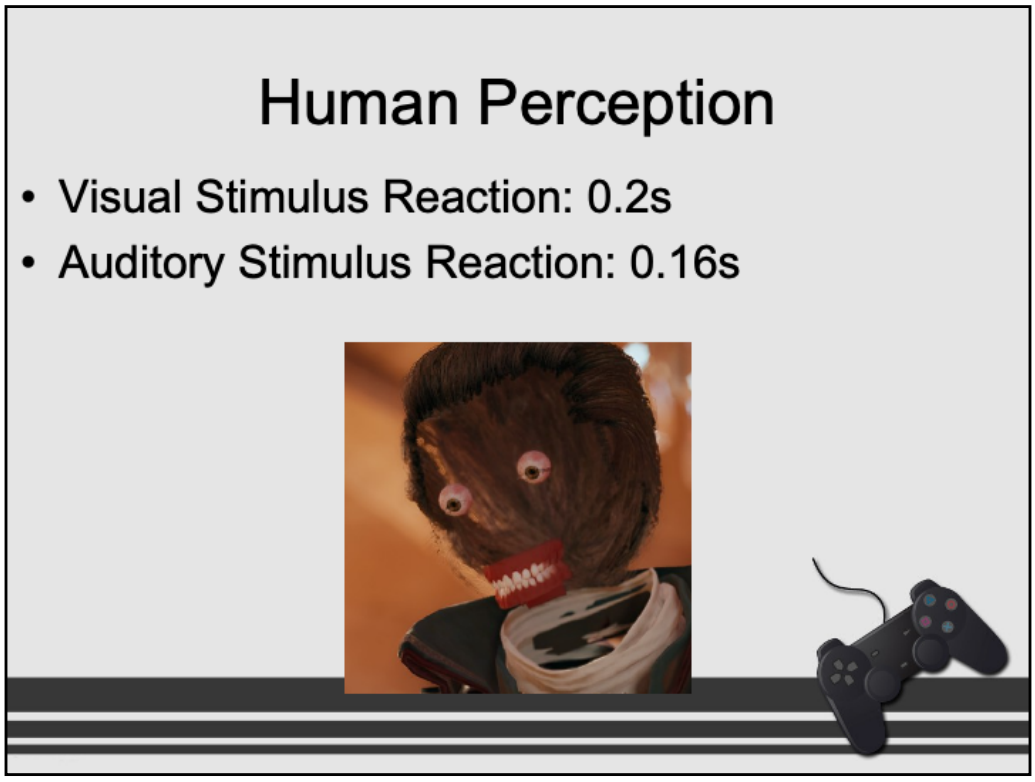


Super Mario Bros. 1st 2 levels tile sets



We make assumption that player is only acting/considering info within the system and isn't influenced by outside information

HUMAN PERCEPTION

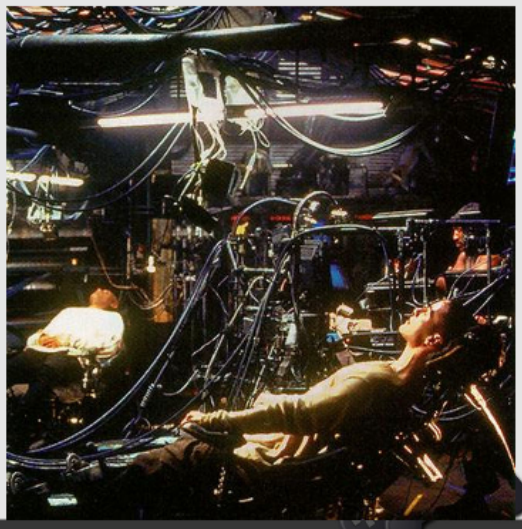


Similar for self-stimulus (e.g. move physically and expect world view to change in 0.2s)

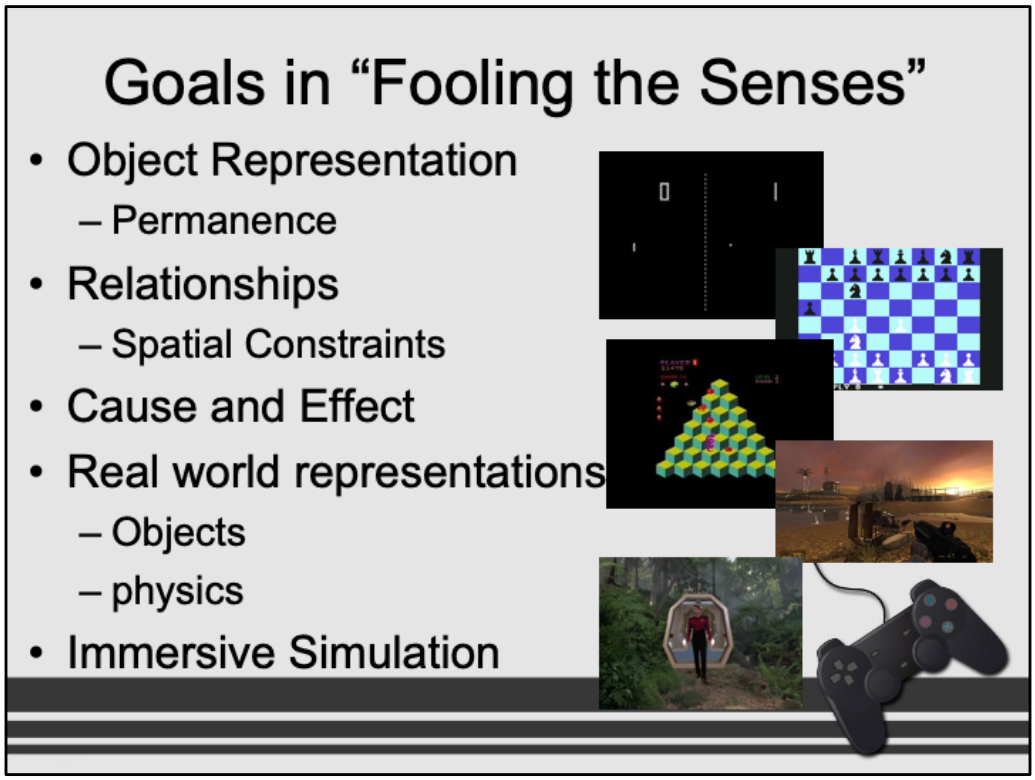
Render bug from one of the Assassins Creed games

Fool the Senses

- Sensory Illusions
- Vision
- Hearing
- Other senses?



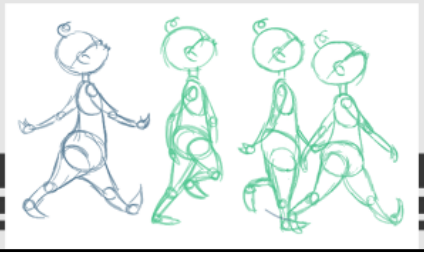
The Matrix



Pong, Sargon II, Qbert, Half Life 2, Holodeck

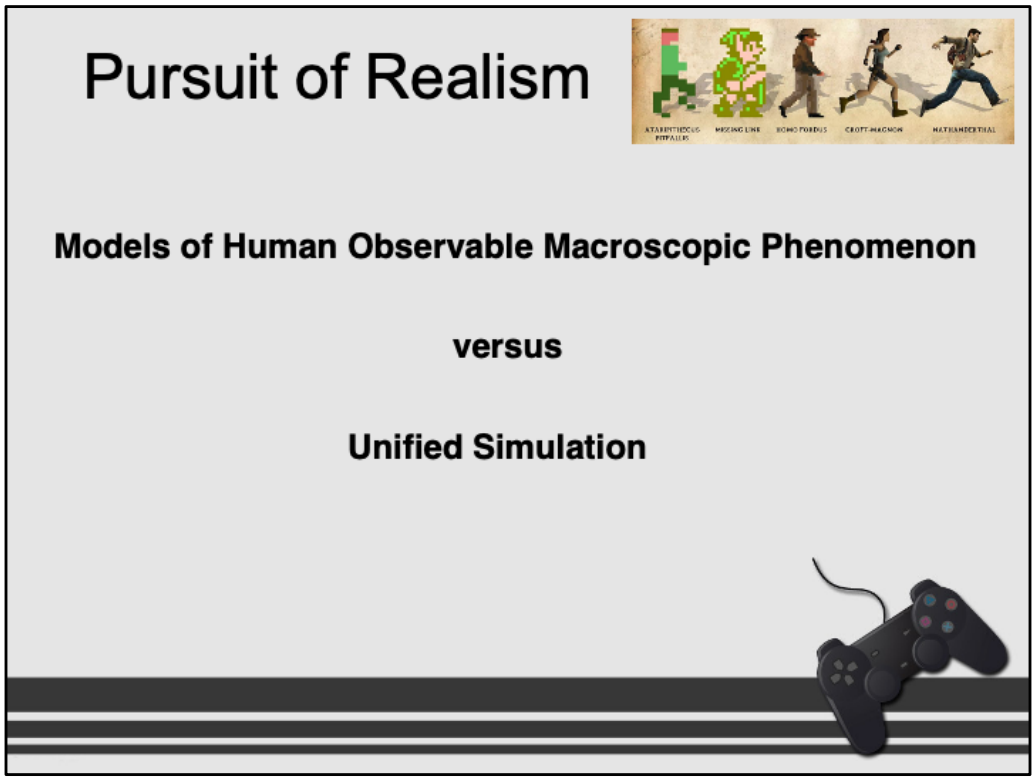
Animation

- **Consecutive similar images appear to be persistent shapes that move/change if image change rate is "fast enough"**
- 10 FPS enough for sense of spatial presence, Movies (from camera) 24 FPS, Games aim for >=30 FPS



Flicker fusion threshold > 50 Hz (consider florescent lighting)

SIMULATION CONCEPTS



What is more realistic: Minecraft or GTA5?

Models of Human Observable Macroscopic Phenomenon

- Often disparate models that must be synchronized
  - (e.g. surface rendering + digital audio + Newtonian physics + animation system)
- Limited interaction of elements within the simulation
- Illusions
- Computation dedicated to only the observable phenomenon

Storytellers have more direct control of consequences

Unified Simulation

Emergent observable phenomenon

High computational costs

There is no Theory of Everything (yet)

Would be difficult for a storyteller to control or constrain

A Matter of Minutes episode from the New Twilight Zone:
https://en.wikipedia.org/wiki/A_Matter_of_Minutes

https://www.youtube.com/watch?v=TKbylBQ0igk

Simulation Concepts?

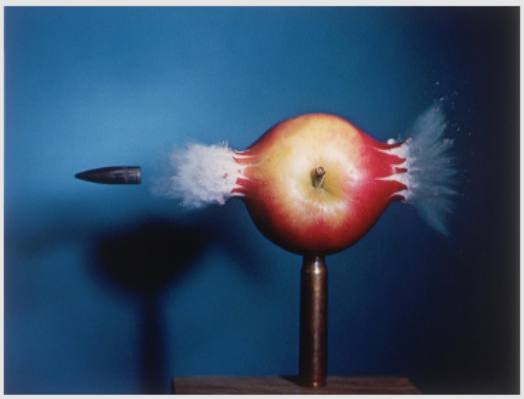
- What are some of the things that the Twilight Zone got right?

Simulation Concepts?

- What are some of the things that the Twilight Zone got right?
- Simulation of time slices
- Rebuild for every time slice
- Only build what you need
- Glitch out of game world
- Objects disappearing or pop-in/pop-up

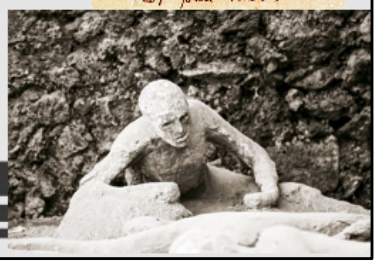
A Frame is Frozen in Time

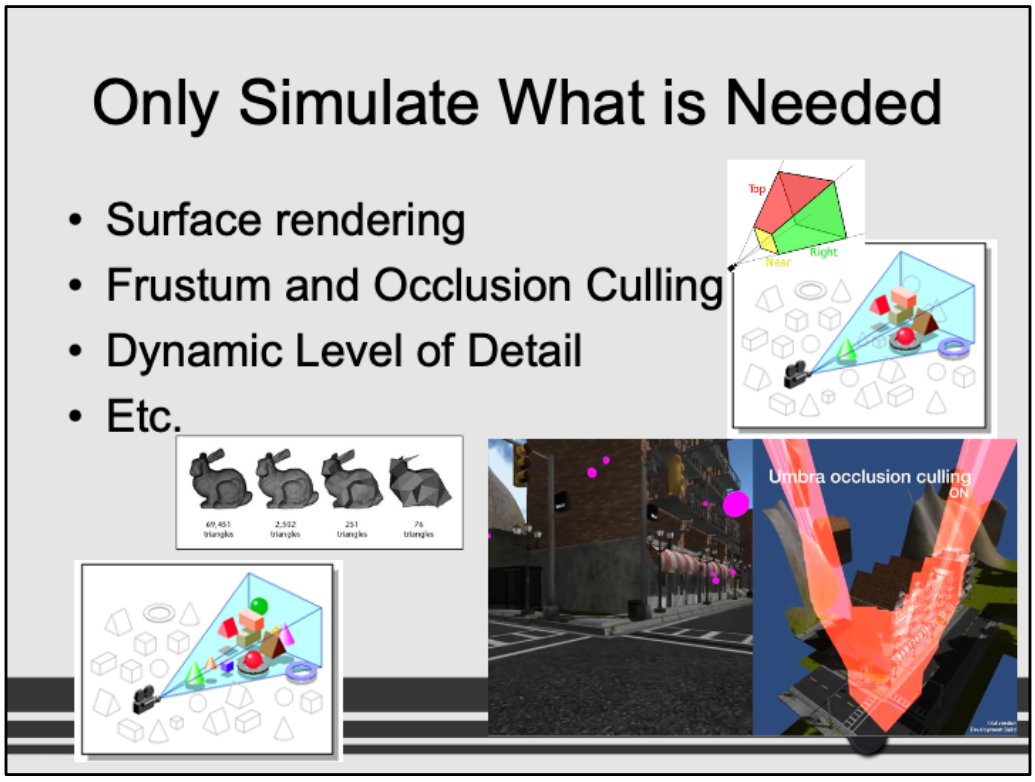
- Almost everything in a frame update shares a common reference time (from the start of frame processing)
- Visuals rebuilt from scratch
- Only simulate what is needed to create the illusion



Why is frame time fixed/frozen?

- Consistent output (especially visual) as all game objects animate by the same amount of time
- Potentially avoid race conditions in logic that dictates object interactions





Umbra's culling demo. Used in Unity

Note that Frustum Culling isn't only for reducing render complexity. In fact it is primarily for avoiding rendering anomalies during projection

A game tends to only simulated what can be seen in the given moment. But this can create problems and be at odds with things like object permanence, etc.

Zelda: Breath of the Wild

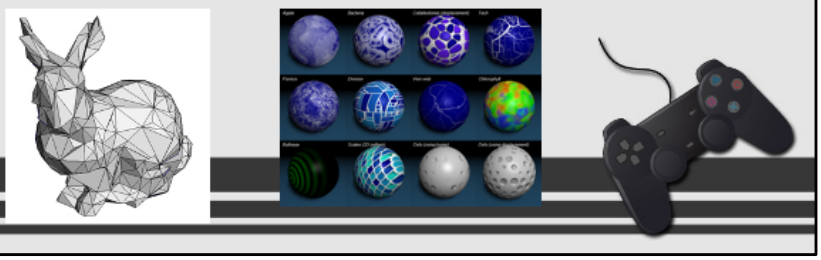
Side Effects of Detail Management

- Pop-in/Pop-up of objects and characters
- Un-activated characters
- Characters teleport when you aren't looking/out of range
- Glitch out of levels
- Disappearing objects
- See inside solids

Zelda: OoT

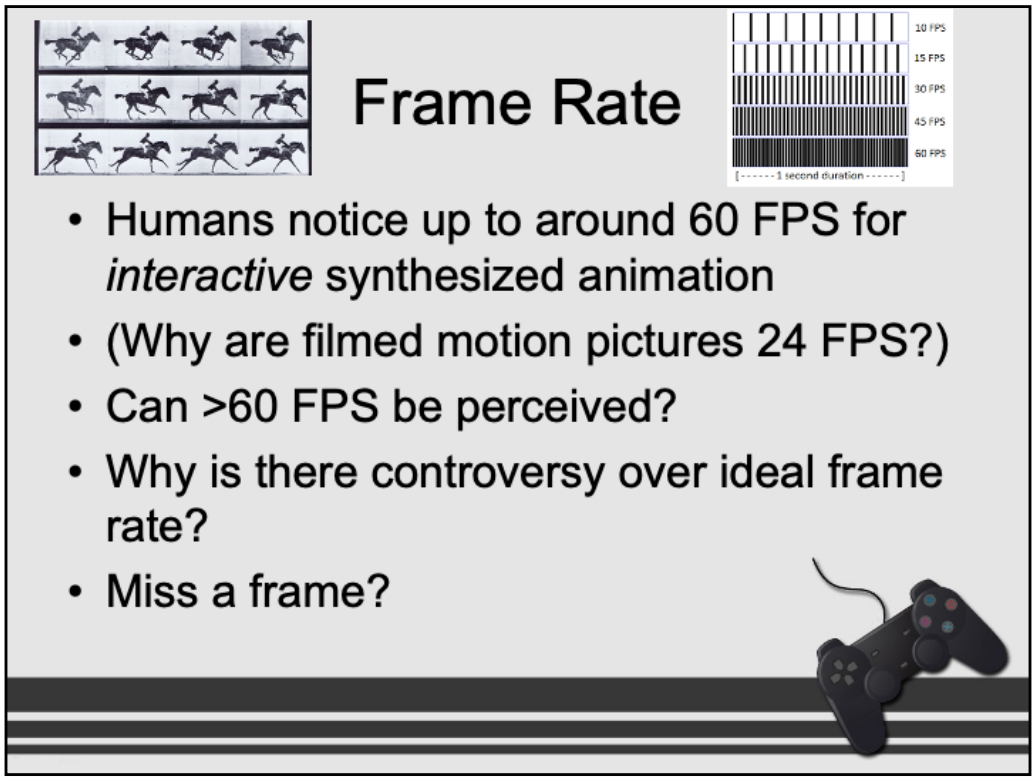
Game Simulation: Focus on Rendering Surfaces

- Only model what is seen
- Model surfaces and surface material light interactions
- What's inside? Nothing!
- Limited or incomplete modeling of matter
- Susceptible to rendering artifacts



Examples beyond just looking at surface: Subsurface scattering, volumetric rendering

Artifacts come from inconsistent physics modeling related to camera position (and clipping planes) and object positions



It may be possible to devise experiments where higher framerates can be noticed by game player, perhaps indirectly by looking for motion blur, display flicker, aggregate assessment of game play performance (confounded by input sampling, LCD refresh/ghosting, vsync misses, interaction of pipeline and/or cache induced latency with target rate, etc.)

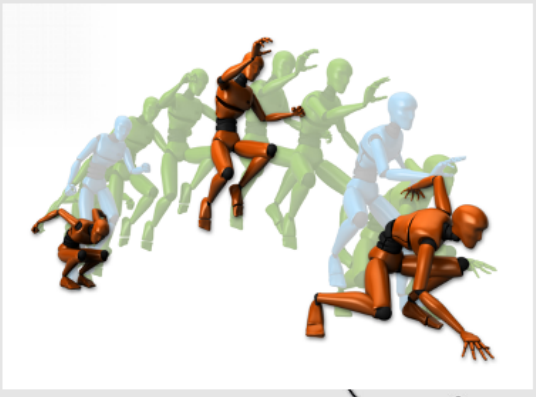
Some interesting comments from John Carmack @ Oculus http://oculusrift-blog.com/john-carmacks-message-of-latency/682/

Demo App

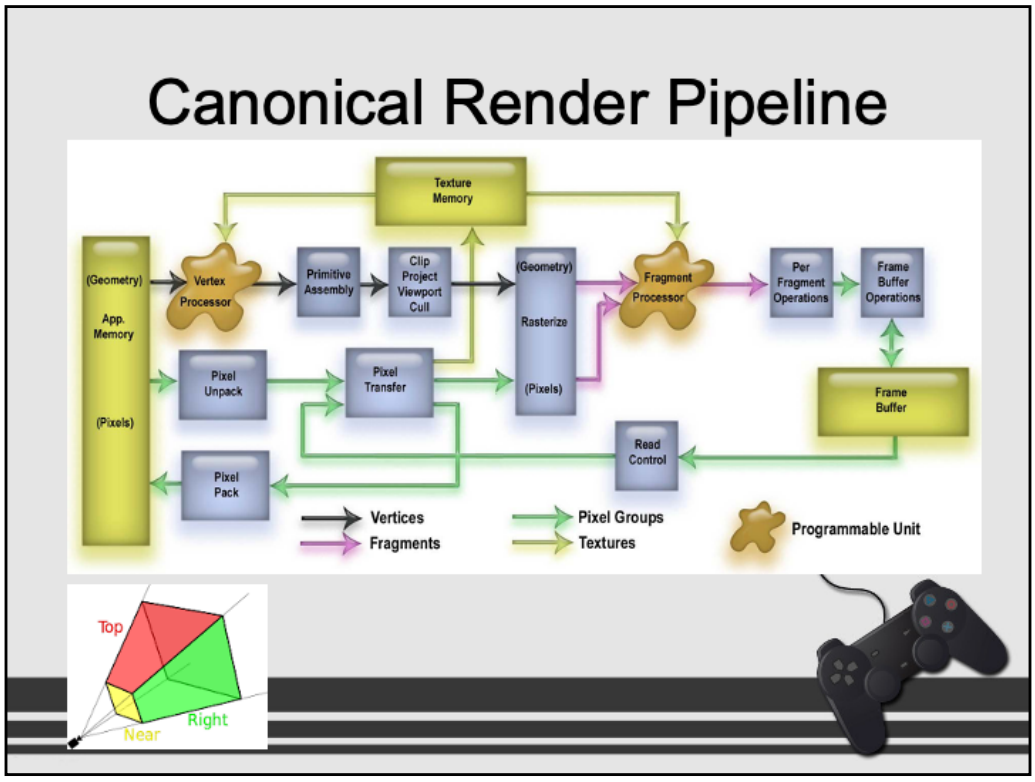
https://frames-per-second.appspot.com

Why Frames?

- Intuitive
- Built on what we know (geometric methods)
- Entrenchment (classic celluloid animation, algorithms, application of sampling theory, raster display, etc.)
- Compatible with human perception
- Audio frames?



Digital audio is continuous and is instead implemented as a circular buffer fed incrementally from the main loop. Audio can only be updated at the frame rate though and incurs a latency related to the size of the circular buffer



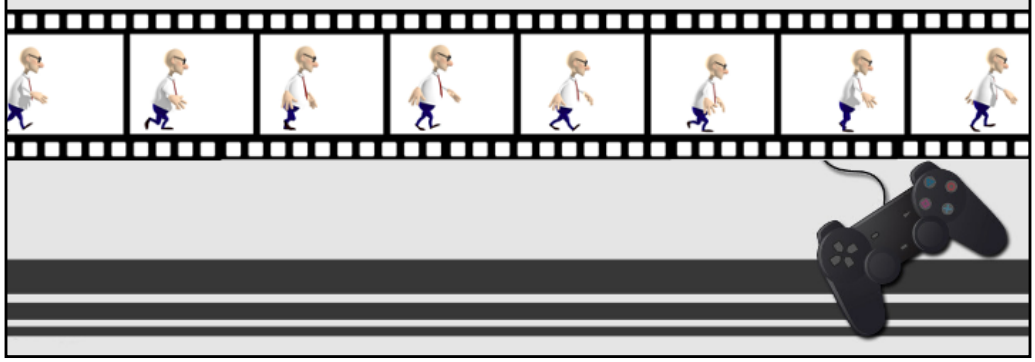
Geometric raster based rendering

Massive parallelization

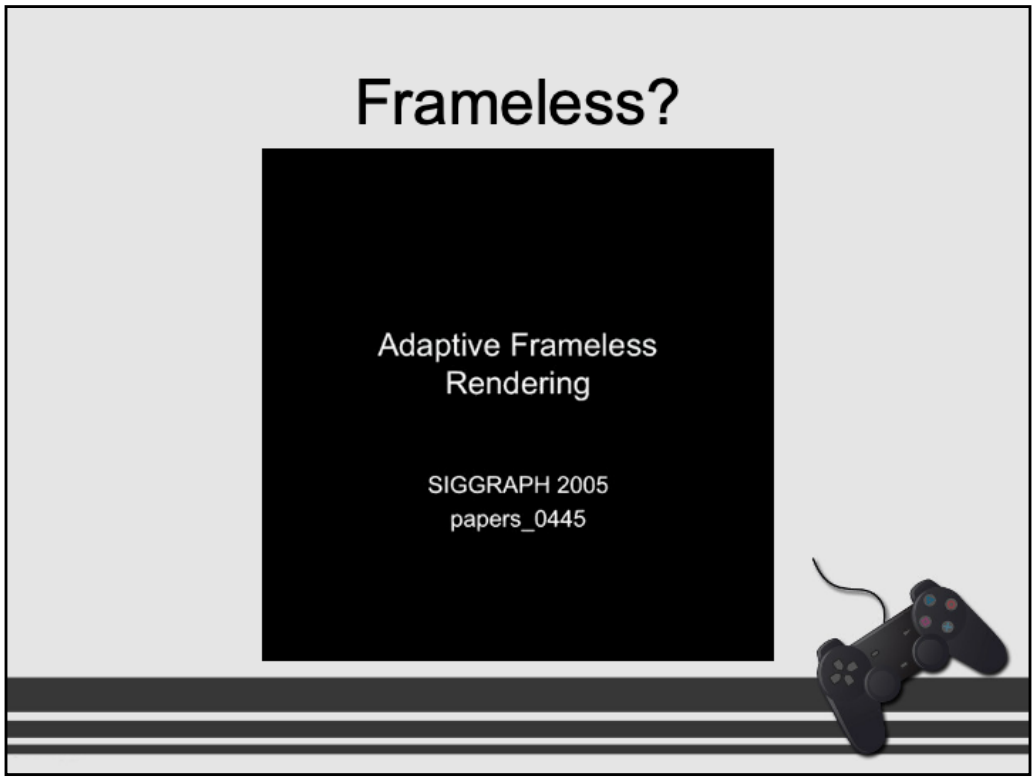
SIDE QUESTS: BREAKING WITH TRADITION

Side Quest: Can We Simulate Without Frames?

- How?
- Pros?
- Cons?



Continuous Rendering?



Note the high frequency artifacts. A side effect of raytracing over time

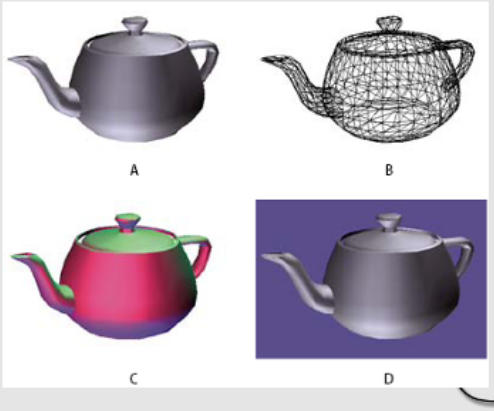
One could rasterize conventionally but frustum clipping is prohibitive

https://www.youtube.com/watch?v=JNeYl_3WlMs

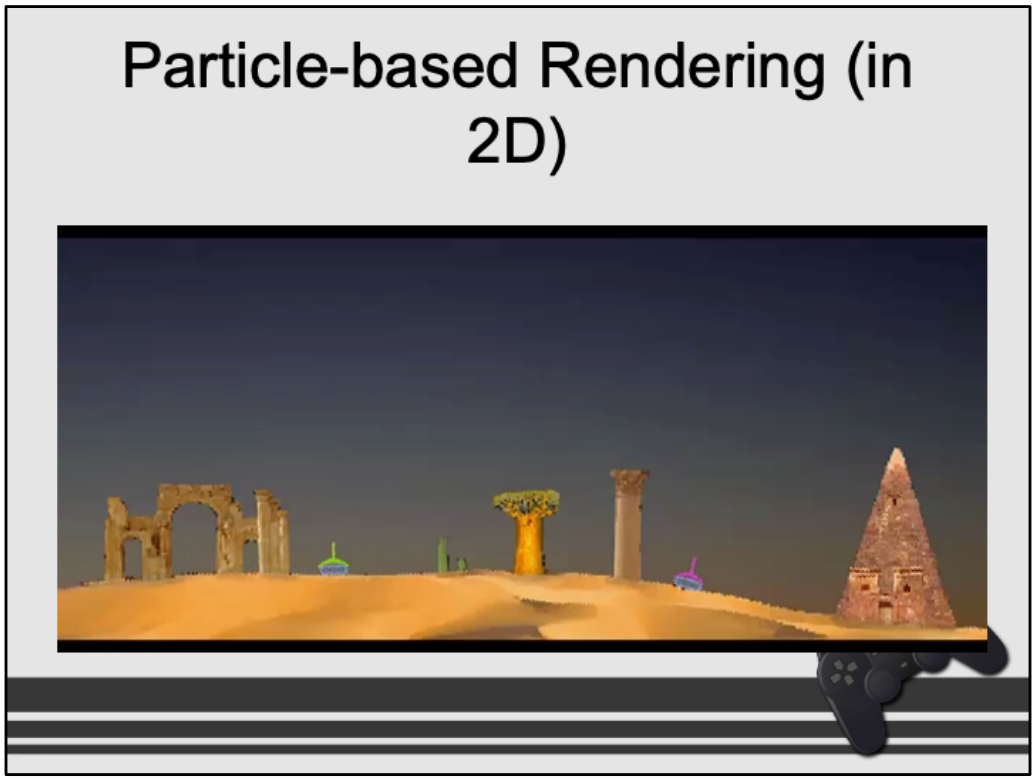
Note that the corresponding paper wasn't actually accepted at SIGGRAPH, even though it's in the video title

Side Quest: Move away from surface rendering?

- How?
- Pros?
- Cons?



Particle-based Rendering (in 2D)



Jelly in the Sky – everything is a particle

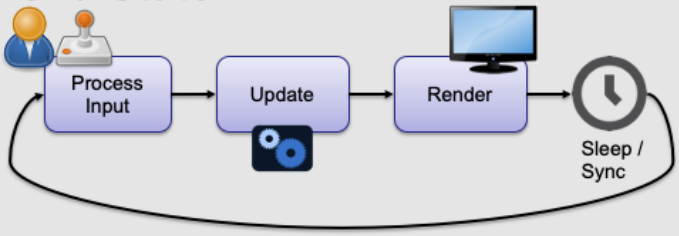
One might also consider voxels, though most voxel techniques rely on mapping the voxels to surfaces of some sort

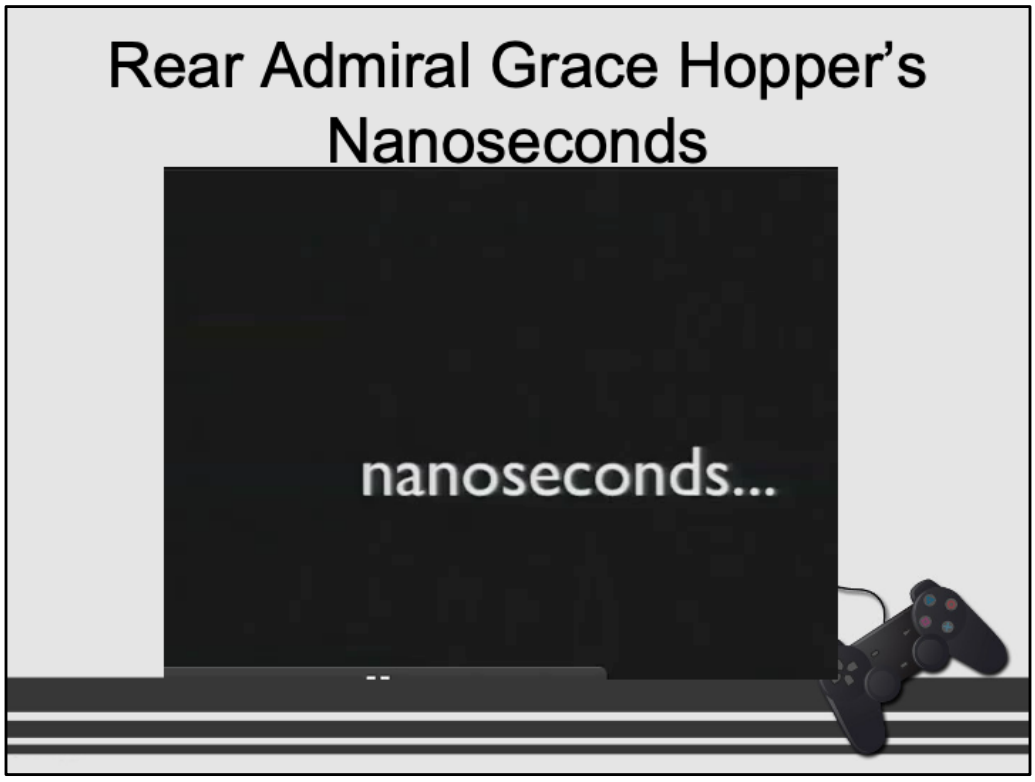
https://www.youtube.com/watch?v=SyCSEAfGGwU

SYNCHRONIZING REAL TIME WITH SIMULATION

The Main Loop

- Input
- Update World State
- Render
- Repeat
- Time….





https://www.youtube.com/watch?v=JEpsKnWZrJ8

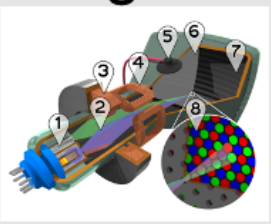
Time to Work

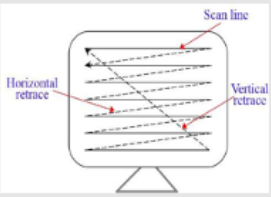
- 60 Hz (frames per second)
- 0.01667 seconds per frame
- 16.67 milliseconds per frame
- 16666.67 microseconds per frame
- Can you get everything done before the next frame?
- You usually want to get done before the next frame and sleep. Why?

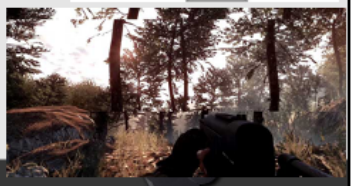
One of the Lemmings games

Display's Impact on Timing Schedule

- Legacy of Cathode Ray Tube fixed update rate
- Screen Tearing – Updates of game loop and display not aligned
- Stuttering – Game loop is (v)synced with display but misses a frame boundary occasionally
- Adaptive VSync? - Nvidia







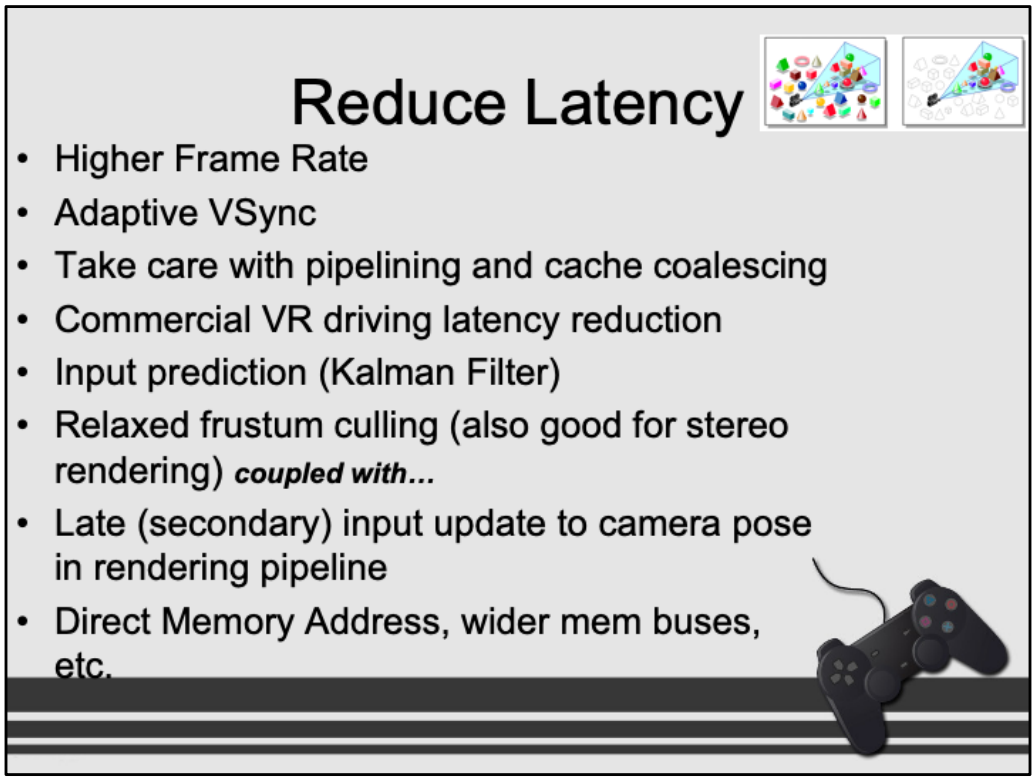
Yesterday's News Today!

- Holy Grail < 20 ms latency (we aren't there)
- Frame-based nature introduces latency
- Rendering based on old data
- User input -> painfully long time -> Draw screen
- Pipelining good for throughput, bad for latency
- Caching good for throughput and smoothing jitter, but bad for latency
- Can we reduce latency?

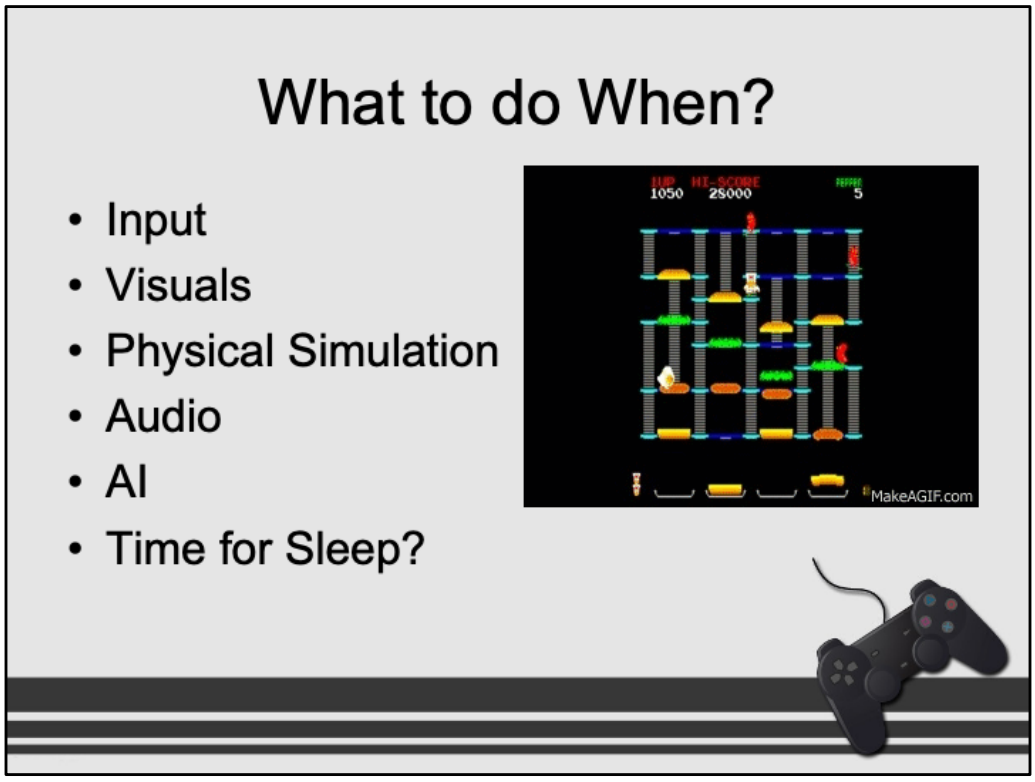
Paperboy!

Latency Really A Concern?

- Depends on type of game
- **Latency can be recognized if response takes longer than visual stimulus reaction! (0.2s)**
- VR <– very big deal
- FPS
- Game Feel style of game
- Indirect Control (real time strategy)
- Turn based <- much less important



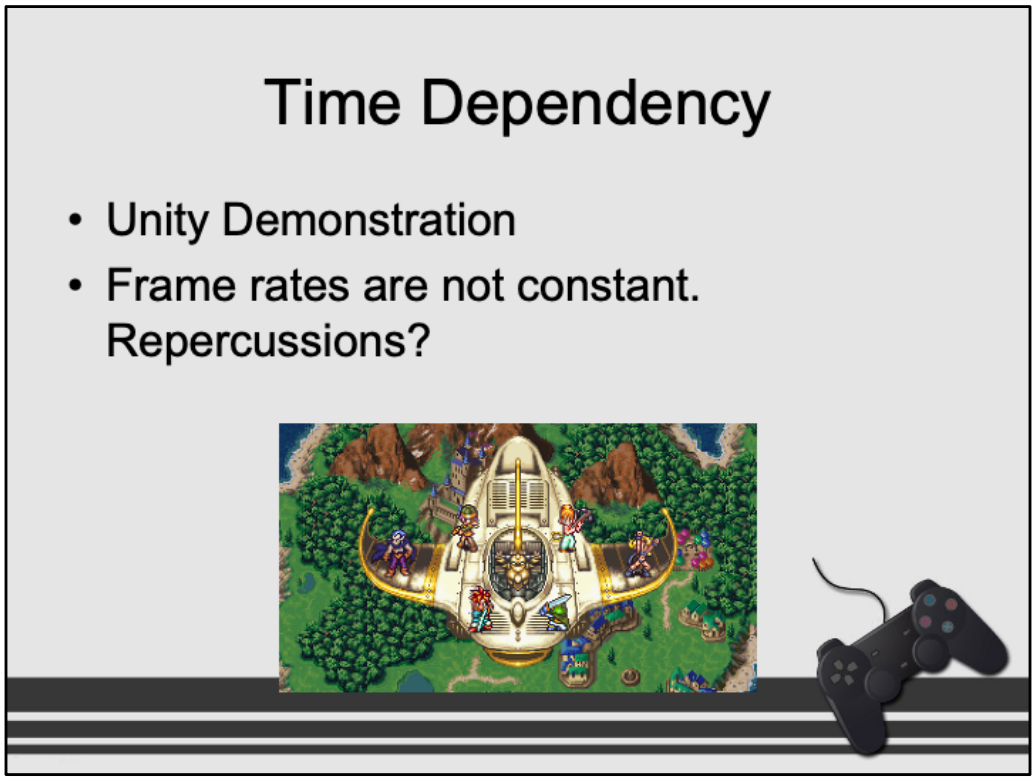
Of course input devices must be able to provide measurements as often as the framerate and can have their on pipeline latency



Physical simulation requires more frequent updates typically

Audio is essentially doing it's own thing in effectively a separate precisely-timed process. Not too big a deal for one shot sounds (so long as latency is not too bad). However, dynamic sounds can be a problem.

Burgertime



Once upon a time, frame rate didn't matter so much. MSDOS was effectively a real-time system (no multi-tasking). Also, games were often sprite based, with a fixed amount of graphical objects onscreen (so processing load was effectively constant). Games could simplify calculations for animations by just counting frames. Provided that everyone had the same clock speeds on their CPU, this approach worked fine for 2D sprite-based games, which have pretty constant processing demands.

A side effect of this, is that newer computers ran the games too fast. Utilities such as "Mo'Slo" allowed a partial fix

Chrono Trigger

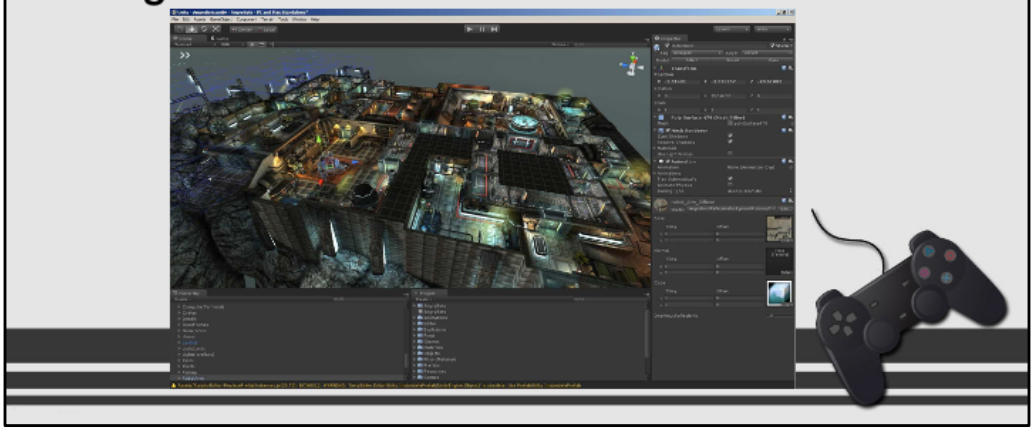
What in a game has time dependency?

- Pretty much everything!
- Game object movement including velocity and acceleration
- Animation Systems
- Physics simulation
- AI decision making
- Probabilistic behavior
- Etc.

THE MODERN GAME ENGINE

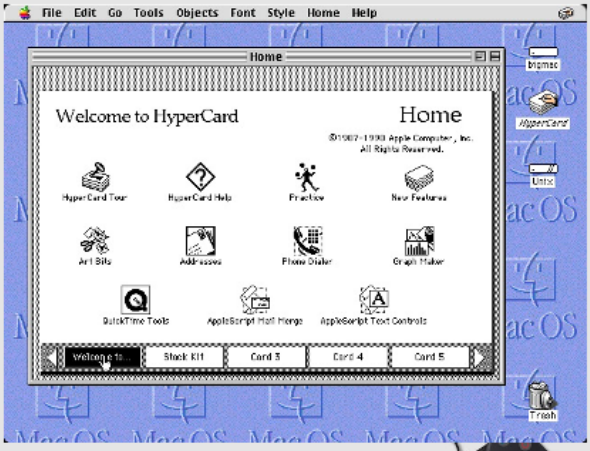
Modern Game Engine

- Software framework supporting the creation, development, and deployment of a game.



Influences on GEs

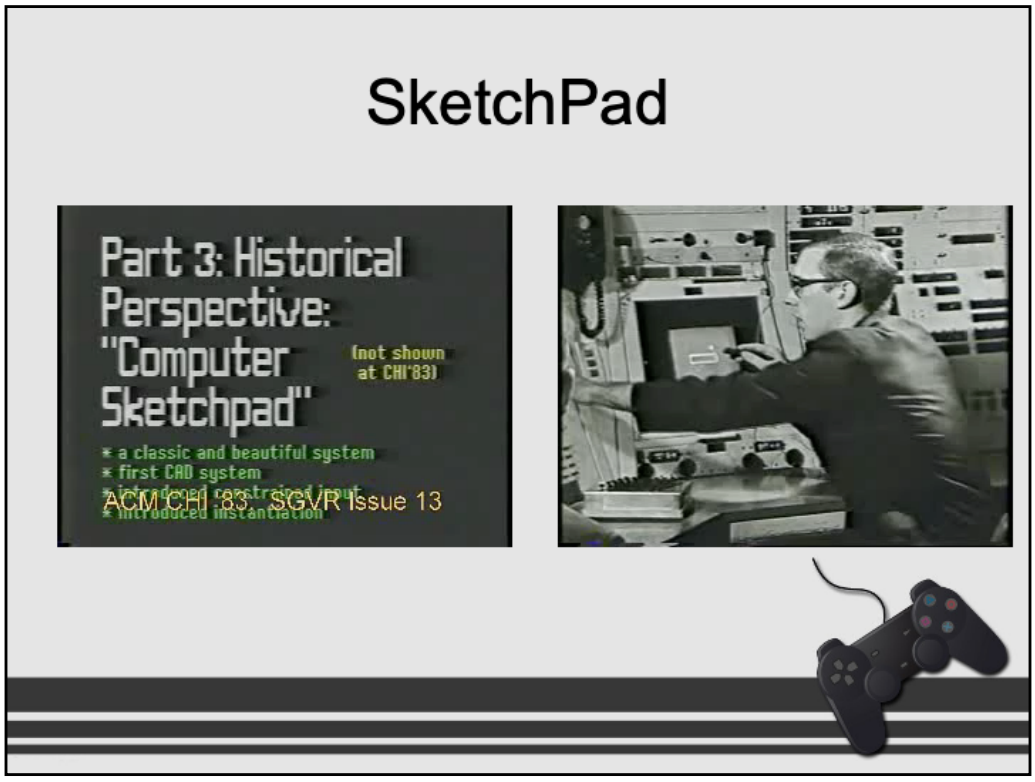
- Ivan Sutherland's SketchPad
- HyperCard



SketchPad late 1950's/early 1960's

HyperCard 1987

Vannevar Bush's Memex from "As We May Think"



Ivan Sutherland's SketchPad

Early CAD like software. Defining constraints (e.g. declarative)

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

Part 2

https://www.youtube.com/watch?v=BKM3CmRqK2o

Geometric Manipulations
Referential objects (like prefabs)

Declaratively define graphical data objects via constraints

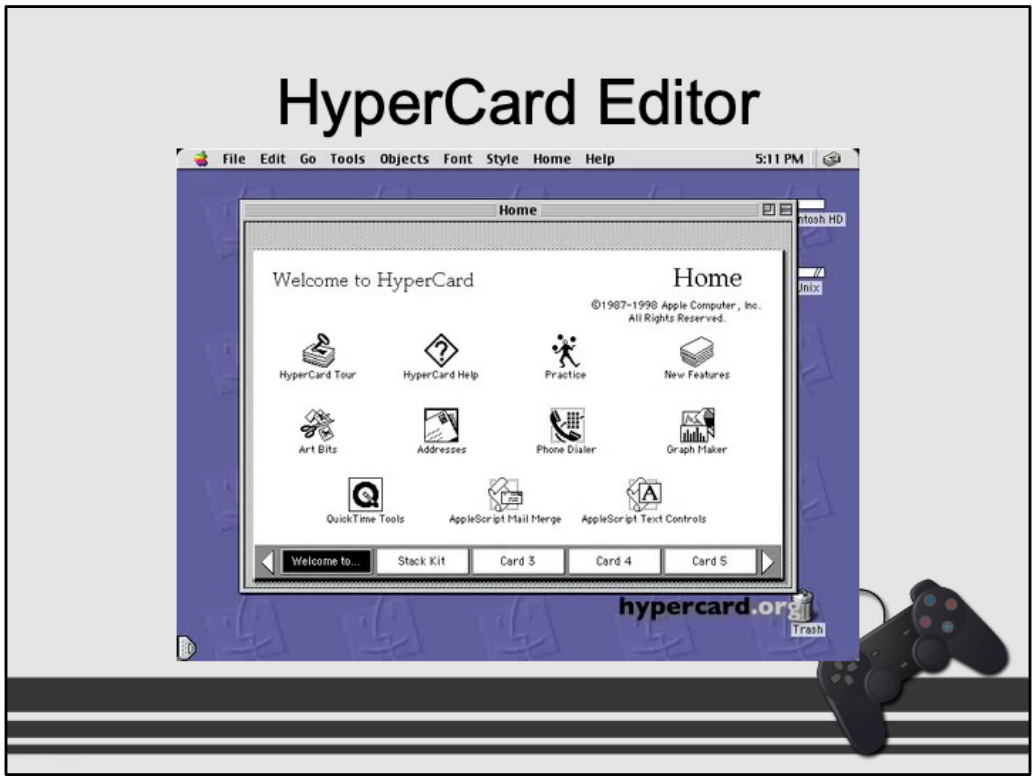
Interface metaphors

-Paper (but 2 miles wide! And multiple workspaces)

-Pen

-Mechanical Drafting Plan View (top, sides, perspective, all synchronized in real-time)

State machine visual programming



https://www.youtube.com/watch?v=AmeUt3_yQ8c

Similar to modern web development

Event-based programming

WYSIWYG – What You See Is What You Get Editor

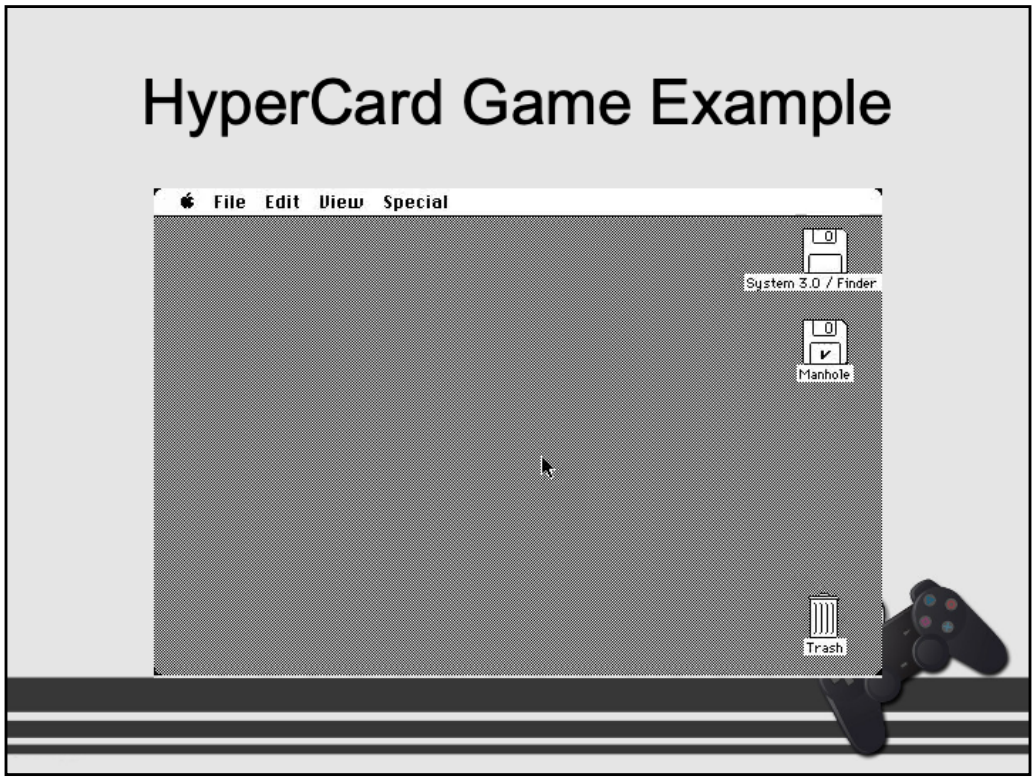
Integrated Development Environment – Interface Designer coupled with code writing (HyperTalk)

Foreground/background (shared background)

Some primitive animation (e.g. Juggler)

Save state between cards

HyperCard Game Example



The Manhole - https://en.wikipedia.org/wiki/The_Manhole

https://www.youtube.com/watch?v=YyOTq1EpV5o

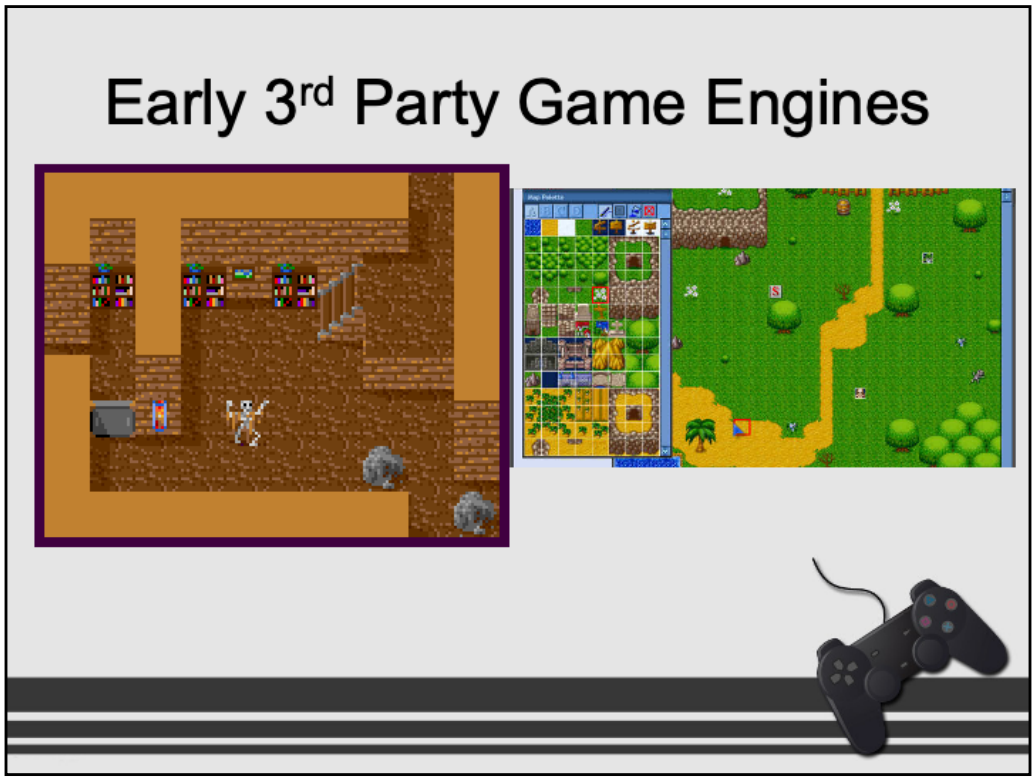
Early Internal Game Engines

- Z-machine by Infocom
- SCUMM

Ease of authoring and Cross-platform big motivating factors

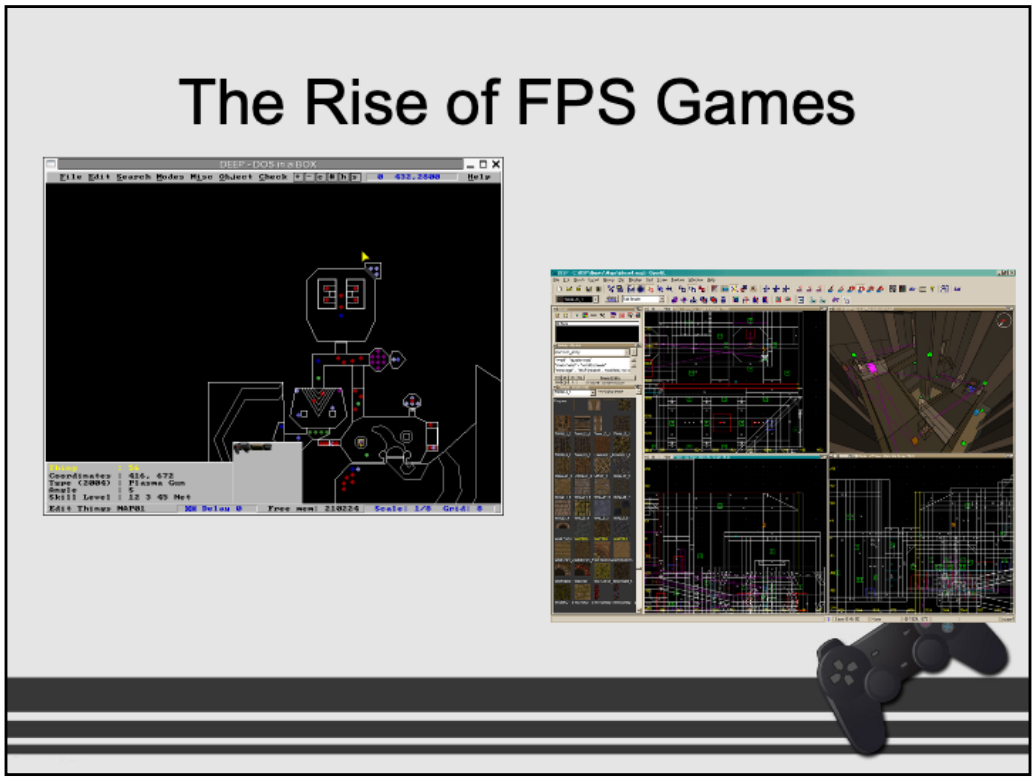
Clear emphasis on non-expert constraint authoring

Note that these are highly genre specific

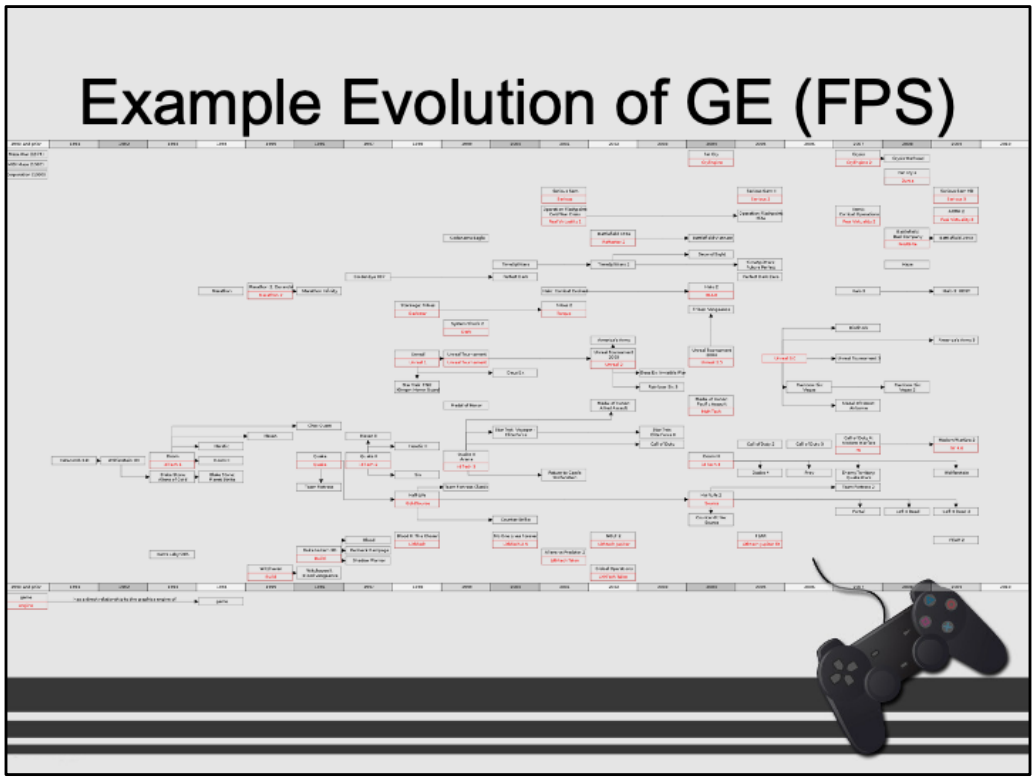


Adventure Game Maker and RPG Maker 95

Appeal to kids that want to make games



Doom Editor and a Quake Editor



From wikipedia

Game Engine Features

- Creation is often declarative
- Some procedural extension of tools and underlying computational kernel
- Platform Abstraction
- Integrated Development Environment (IDE)
- WYSIWYG (e.g. live editing)
- Asset Mgt/Content Pipeline/Workflow Support
- Often Standalone
- Genre flexibility

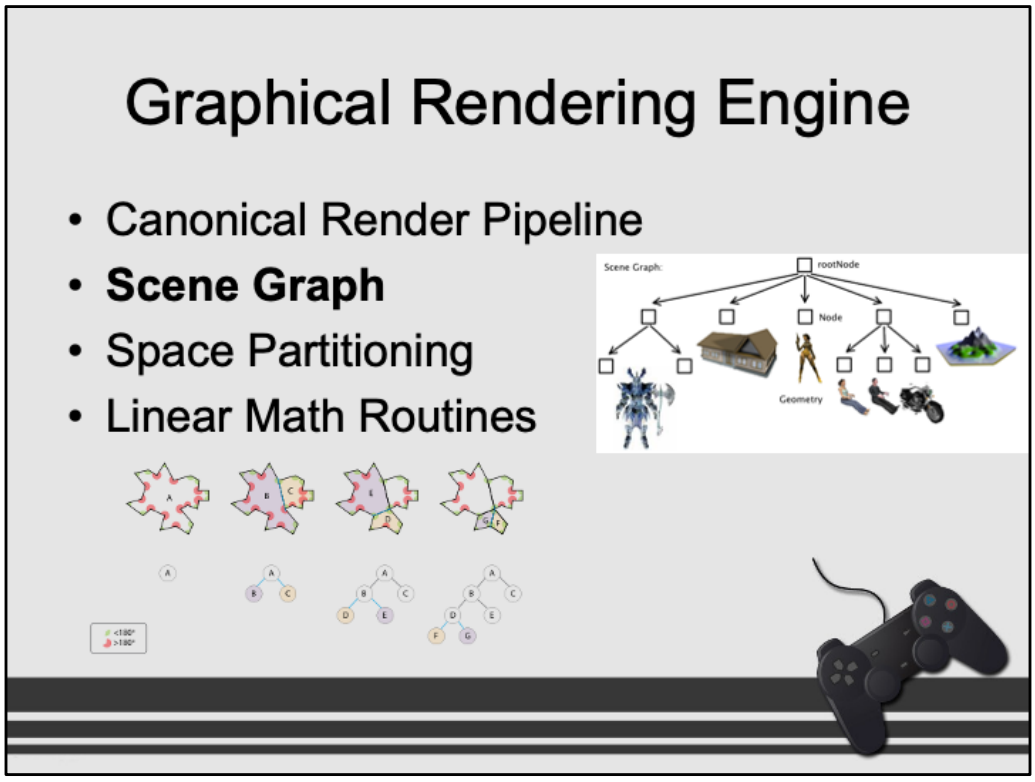
Zelda Spirit Tracks

GE Components

- Computational Kernel (Main Loop)
- Input Management
- Rendering Engine
- Physics Engine
- Audio Engine
- Networking Module
- Scheduling Updates…

Input Management

- Low Latency Desired
- Abstraction/Mapping of common input controls across variety of hardware

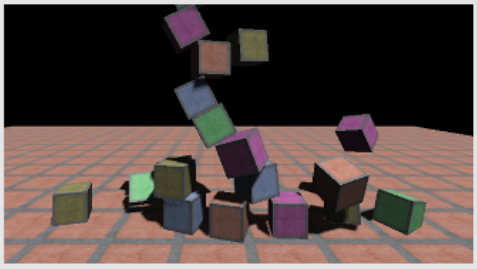


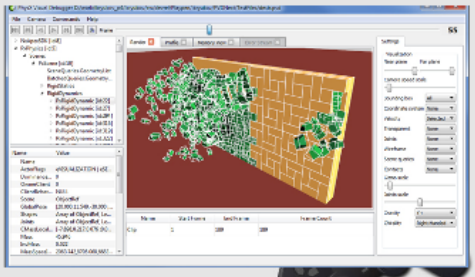
2D Binary Space Partitioning (BSP) figure shown

Also, Scene Graph example

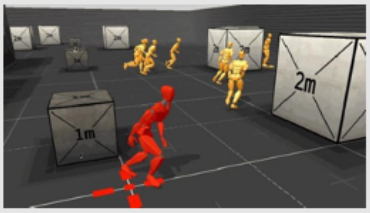
Physics Engine

- Constraint Solver
- Simultaneous “world” synchronized with graphical and audio representations

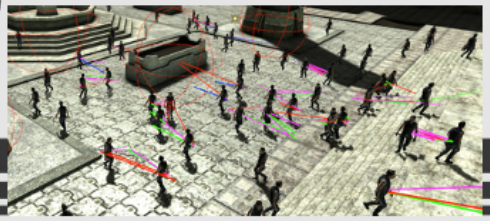




Artificial Intelligence Module



- Path Planning
- Behavior Implementation
- Behavior Planning
- Time is on a different scale
- But still time dependencies!!! (e.g. account for FPS)

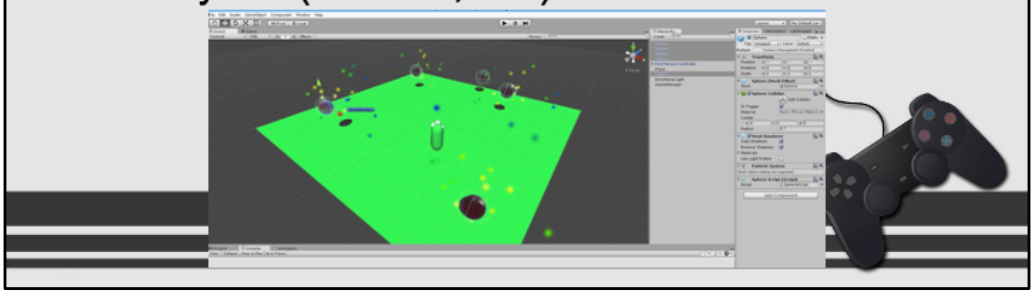


Networking Module

- Platform Abstraction (big- little endian, etc.)
- Event Synchronization (input and/or game object state)
- Priority Management of synchronization
- Prediction

Event Based Architecture

- Message-driven (queues)
- User input
- Constraint Solver Triggers
  - Time based
  - Physics (collision, etc.)



Event Based Architecture

- Supports Modularity/Loose Coupling
- Emitters don't need to know anything about consumers
- Event streams can be readily dispatched via network
- Downside: Can be difficult to read existing event-based code without executing and following events in debugger

What is a Game Engine? (Revisited)

- A closed-loop sensory simulation meant to convince a game player that a virtual world exists and can be interacted with, often in real time
- A simulation based on a rapid sequence of frames (like frozen slices of time)
- A constraint solver declaratively defined by the game designer and further extendable via event-based callbacks/handlers (events generated by the constraint solver, user input, or connected system)
- A set of interactive tools supporting creation, development, and deployment of a game