06 Game and Engine Architecture

Tvorba a dizajn počítačových hier
Návrh a vývoj počítačových hier

Game development is software development

- Use of well-defined design patterns
- Relatively strict structure of a game and game engine
- Not only graphics and physics
- Although lots of concepts are borrowed/required from these fields

Game architecture

- What are all the parts a game consists of?
- How do they fit together?
- Relying on established standards will make your life easier
- You will create maintainable and reusable software pieces
- Instead of doing something that immediately works, you need to think about the one constant in software development
- Going against the stream might pay off in terms of efficiency
- But the results might be harder to comprehend by others

What’s the only constant thing in software development?

Change

Game architecture layers

- Architecture with lots of layers (think TCP/IP)
- Every subsystem can be put into one of these categories:
  - Application layer
    - Deals with the hardware and the operating system
    - This is usually handled by the game engine
  - Game logic layer
    - Manages your game state and how it changes over time
  - Game view layer
    - Presents the game state with graphics and sound
- Similar to the well-known design pattern Model-View-Controller
- Changes in hardware should not affect the game logic or game view layers
  - Just like MVC

Game logic layer

- This is your game – all its mechanics
  - Without input systems, rendering & audio playback…
- Contains subsystems that manage the game world state
- Communicating state changes to other systems
  - Such as playing a sound when you fire a gun
  - Or playing an animation for the gun as it fires
- Also systems that enforce rules of your game world
  - Physics system
  - …

Game view layer

- Presenting the game state to the user
- Translating input into game commands
- As many game view implementations as needed per game
- Not only drawing the game state on the screen
- Other views include:
  - AI agents get a “view” of the game state
  - A remote player gets a view of the game state
  - The state observed from game logic is the same
    - But they do different things

An example – racing game

- How will the game logic and game views look?
- Game logic
  - Holds the data that describes cars and tracks
    - Car weight distribution, engine performance, tire performance, fuel efficiency, …
    - Track shape, surface properties
    - Physics that controls what happens to cars in various states
  - Input is only regarding what the actual driver does
    - Steering, acceleration, braking
    - If we add guns, also some trigger to fire the guns
    - Nothing else is needed to move the cars
  - Output
    - State changes and events
    - Car and wheel positions and orientations, damage stats, how much ammo is left
    - Events could be car collisions, passing checkpoints, …

An example – racing game (2)

- We provide two game views
- Human view
  - A lot of work to do to output video and audio
  - Draw the scene, spawn particles for particle effects, play audio, force feedback
  - Also reads the input devices
    - “Accelerator at 100%”
    - “Steer left”
    - Sends these commands back to the game logic
  - What happens when I press SPACE (emergency brake)
    - The view sends a message to game logic
    - Game logic sets the emergencyBrakeOn to true
    - Game logic notifies the view that state changed (for a racing game, it happens even without input if any of the cars are moving)
    - The view responds by playing a sound and spawning a dust particle effect on tires

An example – racing game (3)

- AI game view
  - Receives the same game state and events as the human view
    - Which track, weather, car positions and orientations
  - Can react in response to events (such as “Go!”) by sending info to the game logic
    - Set accelerator to 100%
    - Steer left at 50%
  - Commands remain the same!

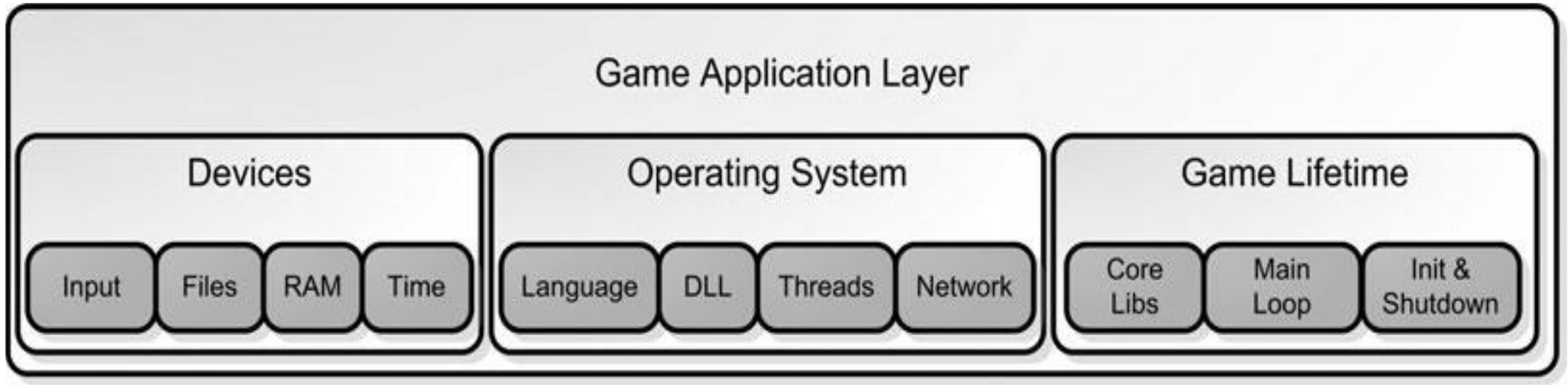
Game views

- Very flexible
  - You can have any number of human or AI views
  - Trivial to swap humans with AI and vice versa
- You could create a game view that just records game events into a buffer
  - You might replay them later
  - The game logic is kind of disabled during replay, since a view is sending all the events
  - With a little extra work, you can get a rewind feature working
    - Need to handle undoing events (continuous Memento pattern?)
- Or a special game view that forwards game status to a remote player
  - Handle network logic with regard to game events
  - Pack and send
  - Receive input, unpack, create events

Game views (2)

- Views can give advantages or disadvantages
  - 4:3 aspect ratio might give smaller field of view than 16:9 aspect ratio
  - AI might know more about game state than the player (see through walls)
- A little hard to get used to
- Unity does not offer a strict separation of views from logic implicitly
- Using it explicitly will make more maintainable code
- Even if you do not strictly separate, it’s good practice to know which layers are communicating

Application layer



Reading input

- Need to provide a layer between the OS and the rest of the game application layer
- The state is translated into game commands
- Should be configurable
- Game state should never change directly from reading user input
  - Not flexible
  - Lots of changes when controls change
- Unity offers both ways
  - Input.GetKey() is the direct way
  - Input.GetAxis() / Input.GetButton() is indirect and configurable inside the editor or during runtime

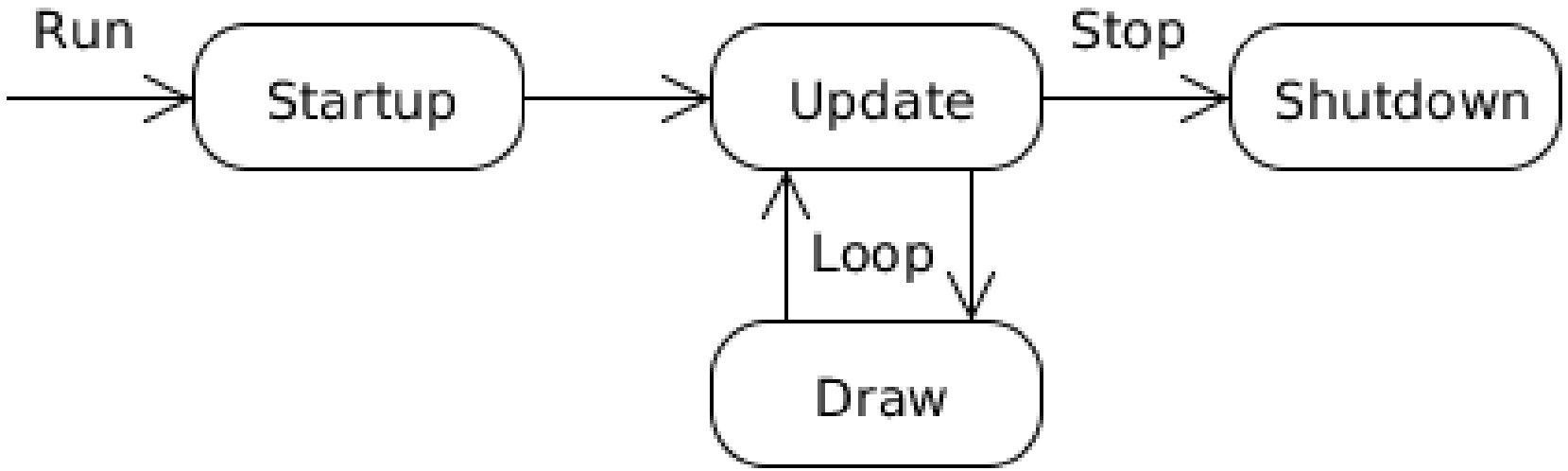
File System and Resource Caching

- Reading and writing from disk and other storage media
- Managing resource files can be complicated
- One of the hidden systems is the resource cache
  - Commonly used assets are always in memory
  - Rarely used assets are in memory only when needed (end-game video)
  - The resource cache tries to “fool” the game into thinking that all the assets are available in memory
  - If all goes well, the cache can load files **before** they are needed
    - SceneManager.LoadSceneAsync()
  - Cache misses might occur if it fails to load something in time
  - Solve by loading screens or small lags

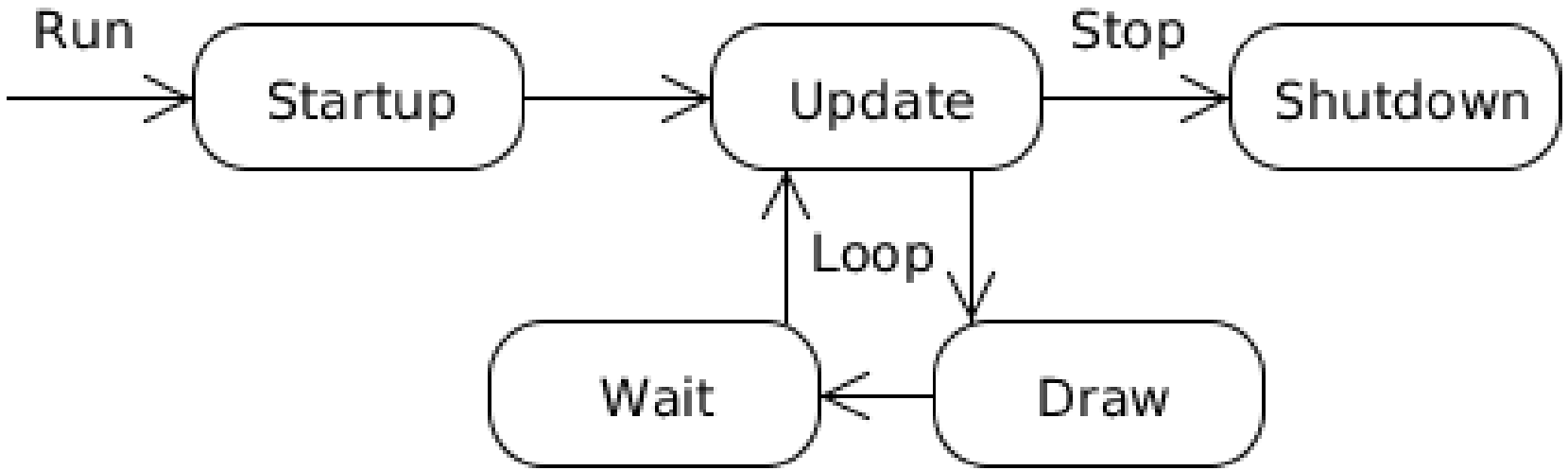
Initialization, Main Loop, and Shutdown

- Most software waits for user interaction, doing almost nothing
  - Can have lots of these running with minimal overhead
- Games are simulations that have a life of their own
  - Player input is not required for the game to continue simulation
- The system controlling the game simulation is the **main loop** or **game loop**
- Usually has three stages
  - Grabbing user input
  - Updating game logic
  - Presenting the state through all views
    - Rendering, playing sounds, sending state over the internet

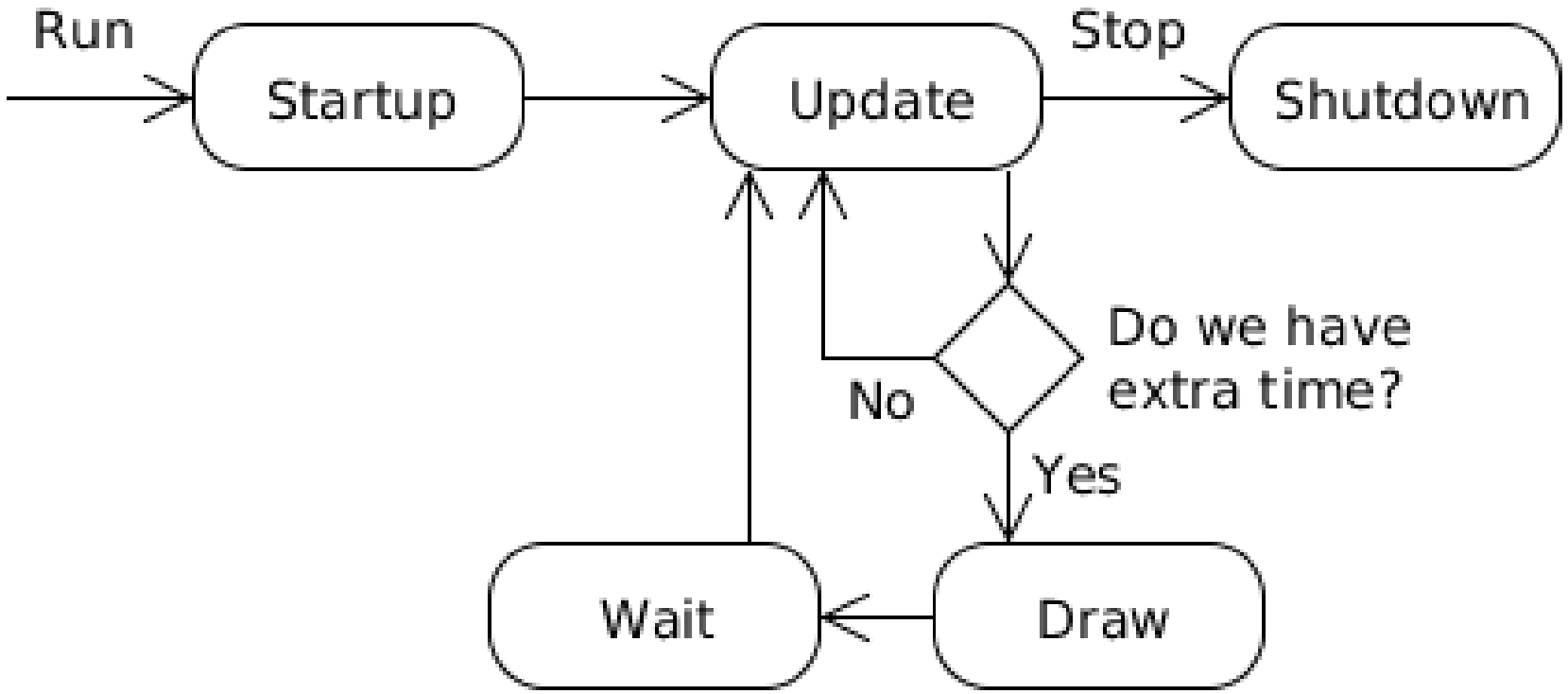
Simple game loop



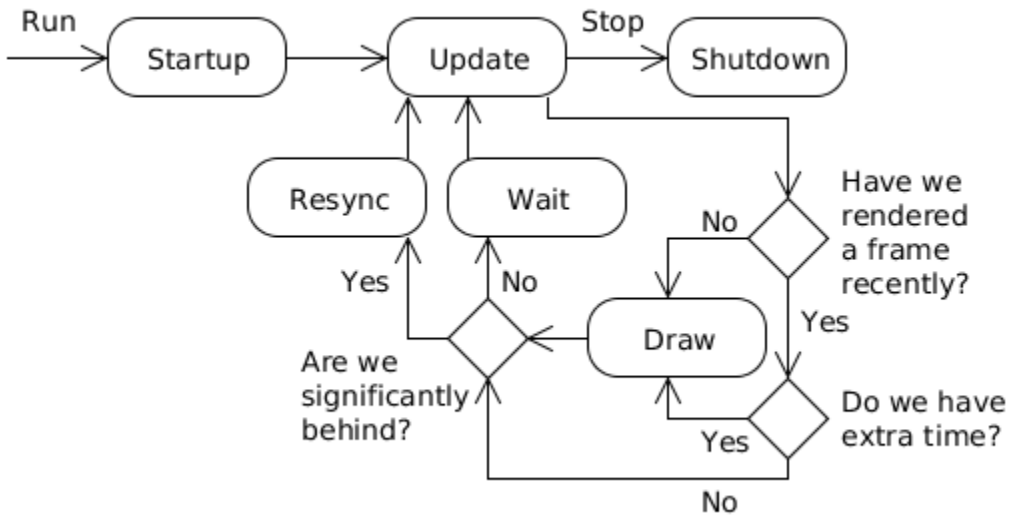
FPS limited game loop



Advanced game loop



Very advanced game loop



Game loop in Unity

- Game loop handled implicitly
- Querying user input is handled by the engine
- Game programmers are given two main callbacks
  - `Update()`
    - Updates as often as possible
    - Called once for each frame rendered
  - `FixedUpdate()`
    - Updates in fixed intervals
    - Called once for each physics engine step
- Rendering is done by the engine as well!
  - We only set what will be rendered
  - The actual rendering is executed somewhere inside Unity
  - Exception: Using low-level rendering access with the `GL` or `Graphics` class

How Unity game loop looks (probably)

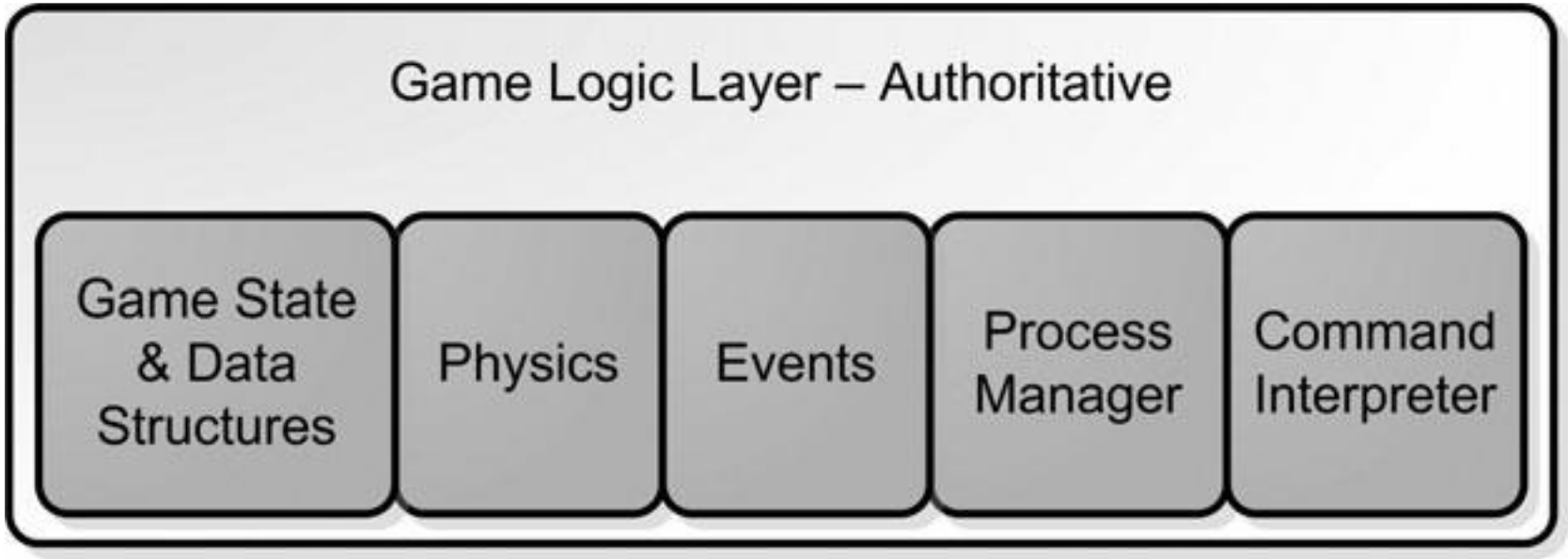
```
float timer = 0;
while (true)
{
    while (timer > fixedTimeStep)
    {
        FixedUpdate();
        timer -= fixedTimeStep;
    }
    Update();
    LateUpdate();
    Render();
    timer += deltaTime;
}
```

http://docs.unity3d.com/Manual/ExecutionOrder.html

Other Application Layer Code

- System clock
- String handling
- DLLs
- Threads and thread synchronization
- Network communication
- Initialization
- Shutdown
- (Scripting language)

Game logic


Game Logic Layer – Authoritative
Game State & Data Structures
Physics
Events
Process Manager
Command Interpreter

Game logic

- Defines the game universe
- What things (entities) are there
- How they interact
- Defines how game state can be changed by external stimulus

Game state and data structures

- A game needs to store its game objects in a container
  - Must be able to traverse quickly to change game state
  - Should be flexible as to what data it will hold
  - Special game data (hitpoints, inventory, …) are stored in some custom data structure
- In Unity:
  - Upgraded scene graph hierarchy
  - Retrieve objects either by pointing directly to them, or special functions
  - Static function part of GameObject:
    - `GameObject.Find()`
    - `GameObject.FindWithTag()`
    - `GameObject.FindObjectsWithTag()`
  - Implicitly traverses a tree or a hash table to efficiently find the objects
  - Special game data stored as public variables of script components

Game state and data structures

- Easy to confuse game logic representation with the visual representation of objects
  - Amount of damage a weapon deals is stored in game logic
  - The weapon’s model, textures, icons are only relevant to the game view
- Another example:
  - Skeletal mesh object that is used for skinning the character when rendering
  - It seems that it has something to do with the character’s weight
  - Skeletal mesh – view, weight – logic (probably for physics calculations)

Entity-Component-System (ECS)

- Design pattern used to store and manipulate game state
- Favor composition over inheritance
- Entities consist of Components
- Each component has a single responsibility
- Systems run in background and handle component changes
- One system serves only one purpose
  - Physics System, Player Damage System
- Components register in one or more systems
- Entities are affected indirectly (through their components)

ECS in Unity

- Entity = GameObject
- Component = Component
- System
  - Configurable but not directly visible
  - Can create own systems
  - Individual components register with their respective systems
  - **Split across multiple components**
- Examples
  - Collider and Rigidbody register with the Physics System
  - MeshRenderer, Camera, Light register with the Rendering System
  - Scripts register with the Scripting System and Event System
  - You create other systems through scripts – Player Damage System, Items & Inventory…

New ECS in Unity

- Entity = just an ID (64-bit int)
- Component = component of an entity, holds only data
  - **Does not hold functionality**
- System = Programmable
  - **Has all the functionality**
  - Iterates over all components that it works with
- Hybrid => Each game object is also an entity
- Pure => Screw game objects, just use entities
- MVC again?
  - Entity+Components = Model
  - Visual/Audio Components + Rendering System = View
  - System = Controller
- This is all in alpha preview – DO NOT USE YET!

Physics and Collision

- Rules of your game universe
- No need for over-complicated physics to make a game fun
- If our game is completely abstract, unrealistic physics will not be disturbing the player that much
- If, however, we simulate the real world, small errors might cause players to be very disturbed by those errors
- Usually rigid body dynamics with dynamic objects being mostly convex
- Few exceptions:
  - Ragdoll physics
  - Fluid simulation
  - …

Game Events

- When the game state changes, a lot of other systems need to react accordingly
- Game logic is responsible for generating these events and passing them further
- Subsystems register with the Event Manager to listen to events that they react to
- Clean and efficient separation of unrelated code with a simple abstraction and the use of a unified event interface
- The Observer pattern

Process Manager

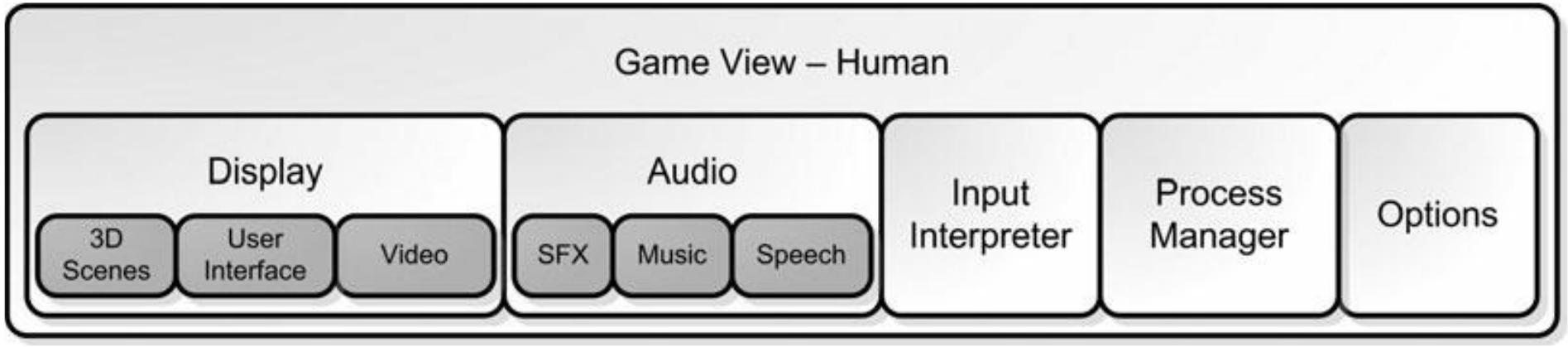
- The game logic is composed of small parts of code that need to be executed periodically for the game to work correctly
- Multiple processes that are completely independent (but we might provide dependencies)
- Mostly script executions
  - If we have a scripting language
  - Otherwise, it’s just one class per operation to keep things simple
- Chaining processes together (throwing a grenade, explode on collision)
- Unity handles this by calling the Update() (or other event) functions on all script components attached to currently enabled game objects in the scene
  - You may sometimes come up with code that needs a certain order of execution, **AVOID IT as much as you can**

Command Interpreter

- Provides a good separation of the game view and game logic
- Need to interpret commands sent by AI or human players
- Unified interface, no mixing of unrelated code
- Provides more efficient debugging
  - You can send separate commands while debugging
  - This is usually what consoles are for
  - Not the hardware, the Counter-Strike console
  - The Elder Scrolls also had a console
  - As well as many others

Game view - Human

- Views are a collection of systems that communicate with game logic to present the game to an observer
- Observers can be human, AI,…
- The view responds to game events as well as controller input
- Works as a translator component that outputs game commands on one side and the presentation of the game on the other side



Graphics Display

- Renders the objects in the scene
- Renders the user interface (HUD)
- Must draw the scene as fast as possible
- Lots of problems
  - Which objects to draw
  - How to handle complex transforms
  - How to handle complex visual effects
  - Handles animation interpolation
  - Lighting conditions
  - Post-processing
  - Level-of-detail
  - …

Graphics Display (2)

- For very complex 3D scenes, need a lot of pre-computation
  - Light maps
  - Potentially visible sets (PVS)
  - Light Probes
- The artist must be aware of the game engine capabilities
- Lots of constraints
- Unity tries to handle all of this
- You might reduce performance of the game without even knowing it

Audio

- Playing sounds
- Three main areas
  - Sound effects
    - Pretty simple, when an event occurs, play some audio
  - Music
    - A little harder when done right
    - Tone of music adjusting according to game situation (Elder Scrolls, Halo, …)
  - Speech
    - Very tricky
    - Lip-sync and storage of lots of sounds are the main problems
- Take into account 3D audio
  - 3D positions of listener and sources

User Interface Presentation

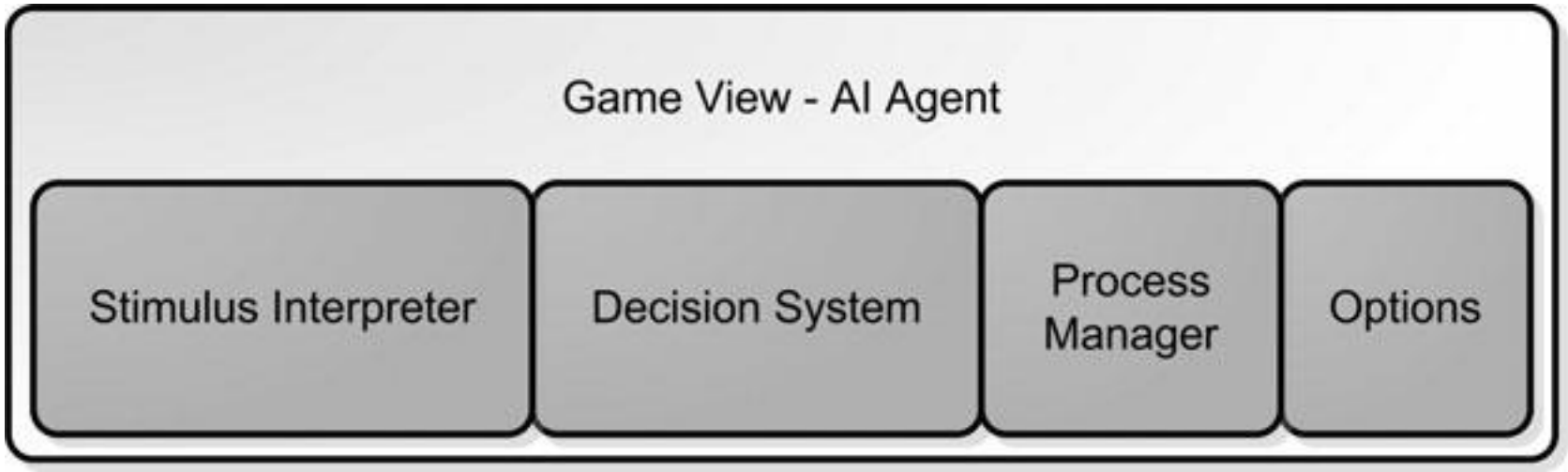
- Every UI must be very specific and adjusted to the game
- Re-using components is possible, but only to a certain extent
- Sometimes you need a completely new GUI component to fit the game
  - A compass, special inventory, …
- Unity offers simple GUI components – Unity UI
  - Separate layer of rendering
  - You still position UI elements, but must choose which camera will be showing them

Options

- Configuring the view
- Resolution, aspect ratio
- Controls
- Sound effects
- Graphics quality and performance

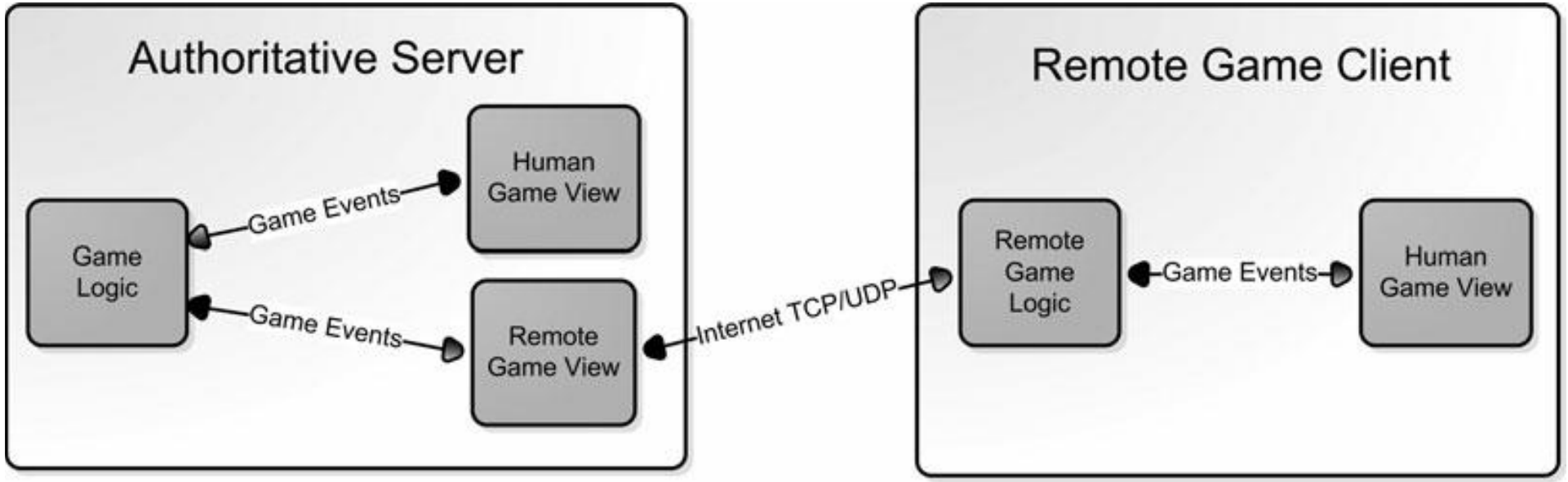
Game view - AI

- Stimulus interpreter receives all game events
- Up to the AI programmer to choose which events will be ignored, which it should react to etc.
- A blind AI ignores that the enemy is in front of him
  - Even though it will receive the event
- The decision system uses advanced AI techniques to determine what the AI will do next (might be a finite state machine)



Upgrading to a networked game

- We implement two additional classes to enable networking
  - Remote game view
  - Remote game logic
  - Proxy design pattern



Remote Game View

- On the server, a remote player is just like an AI agent
- What happens inside the game view is totally different
- Game events are packed up and sent via TCP or UDP to a client
  - Need to compress data, select only important game events
  - No need to send “object moved” if several such events occurred since the last packet was sent, we send only the most recent
- Receives game commands from the client
  - Should not trust these entirely
  - Need sanity checks to prevent hacking
  - After filtering impossible commands, they are passed on to the game logic

Remote Game Logic

- The game logic is an authoritative server, it represents the real game state
- Clients need a copy of the game state to be able to present the player the game correctly
  - The job of Remote Game Logic
- They also need to account for network delays and network errors
- It is similar to the server game logic
- There is a need to simulate the game without receiving events from the server
  - Reduce bandwidth
- Allow for “against the rules” corrections when the server sends the correct data

References

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