05 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
- Going against the stream might pay off in terms of efficiency
  - Engine custom-made for a specific game – e.g. Minecraft

Change

The only constant
in software development

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/OS 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
  - Examples:
    - Playing a sound when you fire a gun
    - Playing an animation for the gun as it fires
    - Updating health of enemy hit by the shot
- 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
- 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

- Game logic
  - Holds the data that describes cars and tracks
    - Car weight distribution, engine performance, tire performance, fuel efficiency, …
    - Track shape, surface properties, physics
  - Input is only regarding what the actual driver does
    - Steering, acceleration, braking
  - Output
    - State changes and events
    - Car and wheel positions and orientations, damage stats, how much ammo is left
    - Events: car collisions, passing checkpoints, …

Racing Game – Human Game View

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

Racing Game – AI Game View

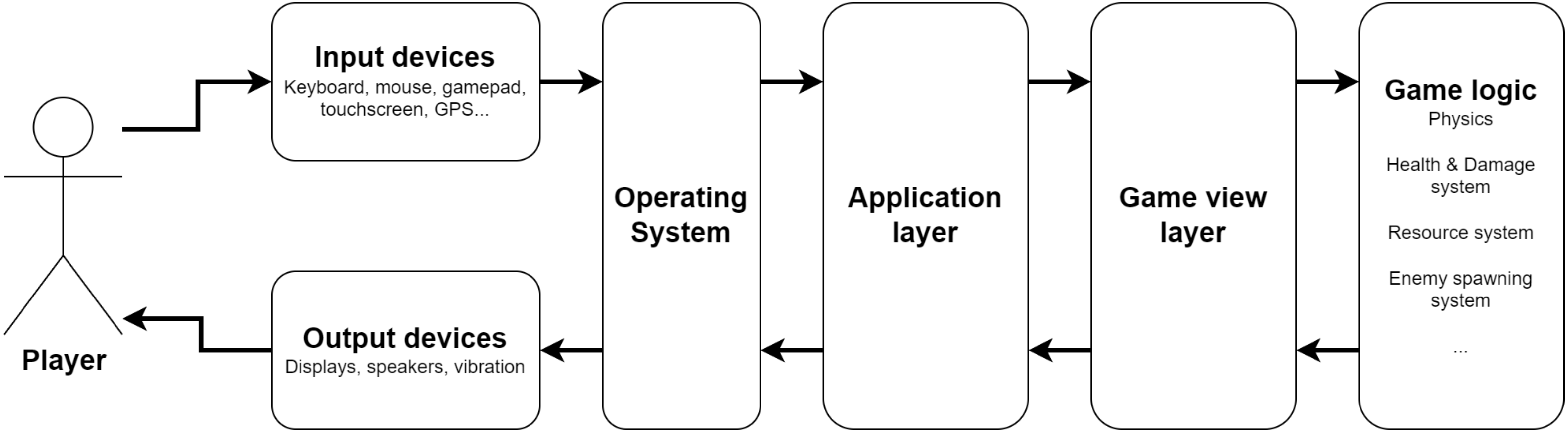
- Receives the same game state and events as the human view
  - Which track, weather, car positions and orientations
- Can react in response to events (such as “Go!”) by sending info to the game logic
  - Set accelerator to 100%
  - Steer left at 50%
- Commands remain the same!

Game views

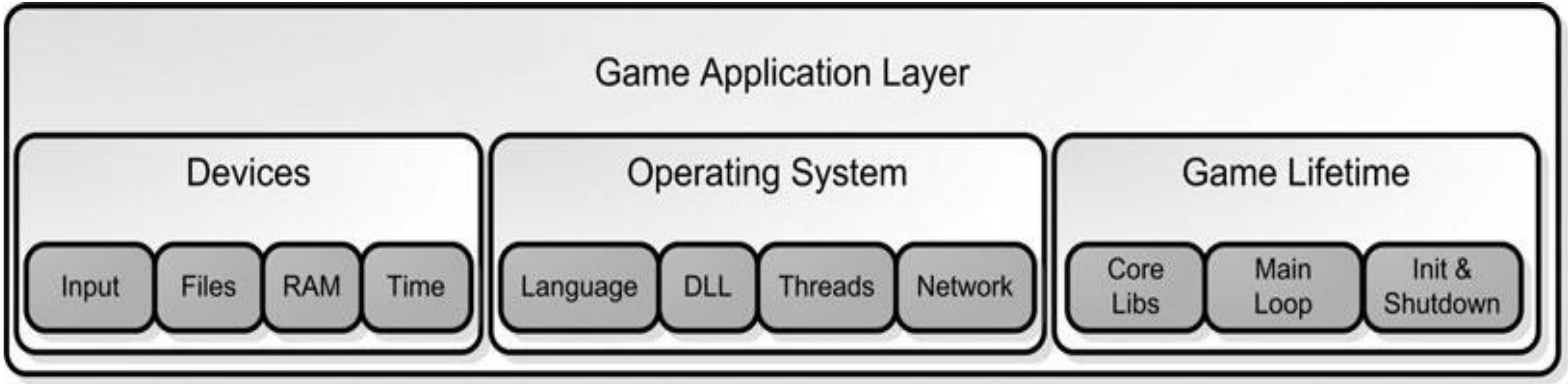
- Very flexible
  - You can have any number of human or AI views
  - Trivial to swap humans with AI and vice versa
- A game view that just records game events into a buffer
  - You might replay them later
  - The game logic is kind of disabled during replay, since a view is sending all the events
  - 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)
- Game views are difficult 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
    - You should know which layers are communicating


Player
Input devices
Keyboard, mouse, gamepad, touchscreen, GPS...
Output devices
Displays, speakers, vibration
Operating System
Application layer
Game view layer
Game logic
Physics
Health & Damage system
Resource system
Enemy spawning system
...

Application layer



Reading input

- Provides 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 direct
  - Input.GetAxis() / Input.GetButton() is indirect and configurable inside the editor or during runtime
  - New Unity Input System is indirect

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
  - Cache misses might occur if it fails to load something in time
  - Solve by loading screens or small lags

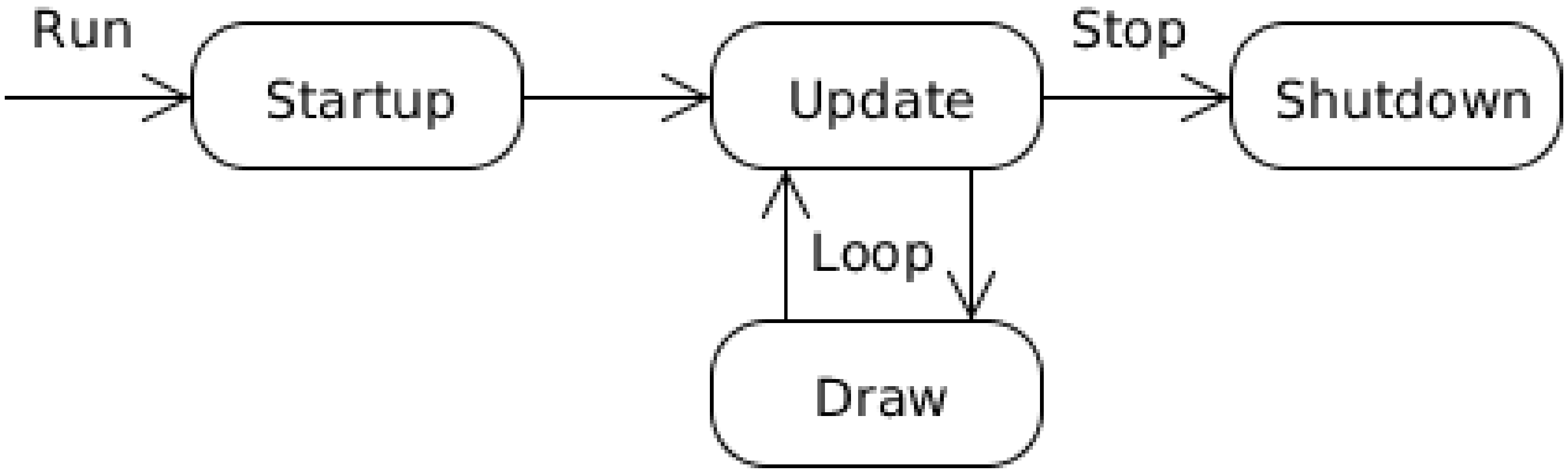
Resource Loading in Unity

- SceneManager.LoadScene()
- SceneManager.LoadSceneAsync()
- Everything that is referenced must be in memory
    - When a scene loads:
        1. Read scene and load all assets that it references – prefabs, textures, models…
        2. For each of those assets, load all assets that they reference (unless already loaded)
- Resources.Load/Addressables allows more fine-grained memory control
    - Can have a “weak reference” and load manually with Addressables
    - Can load by name from a folder with Resources.Load or Addressables

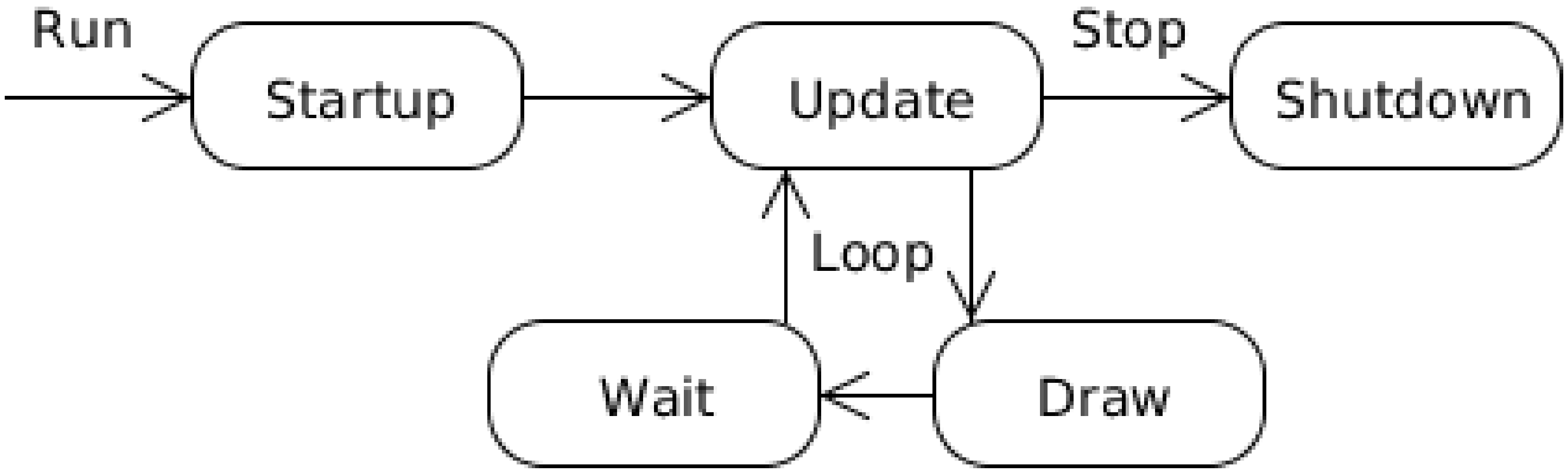
Initialization, Main Loop, and Shutdown

- 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
  1. Grab user input
  2. Update game logic
  3. Present the updated game state through all views
     - Rendering, playing sounds, sending state over the internet

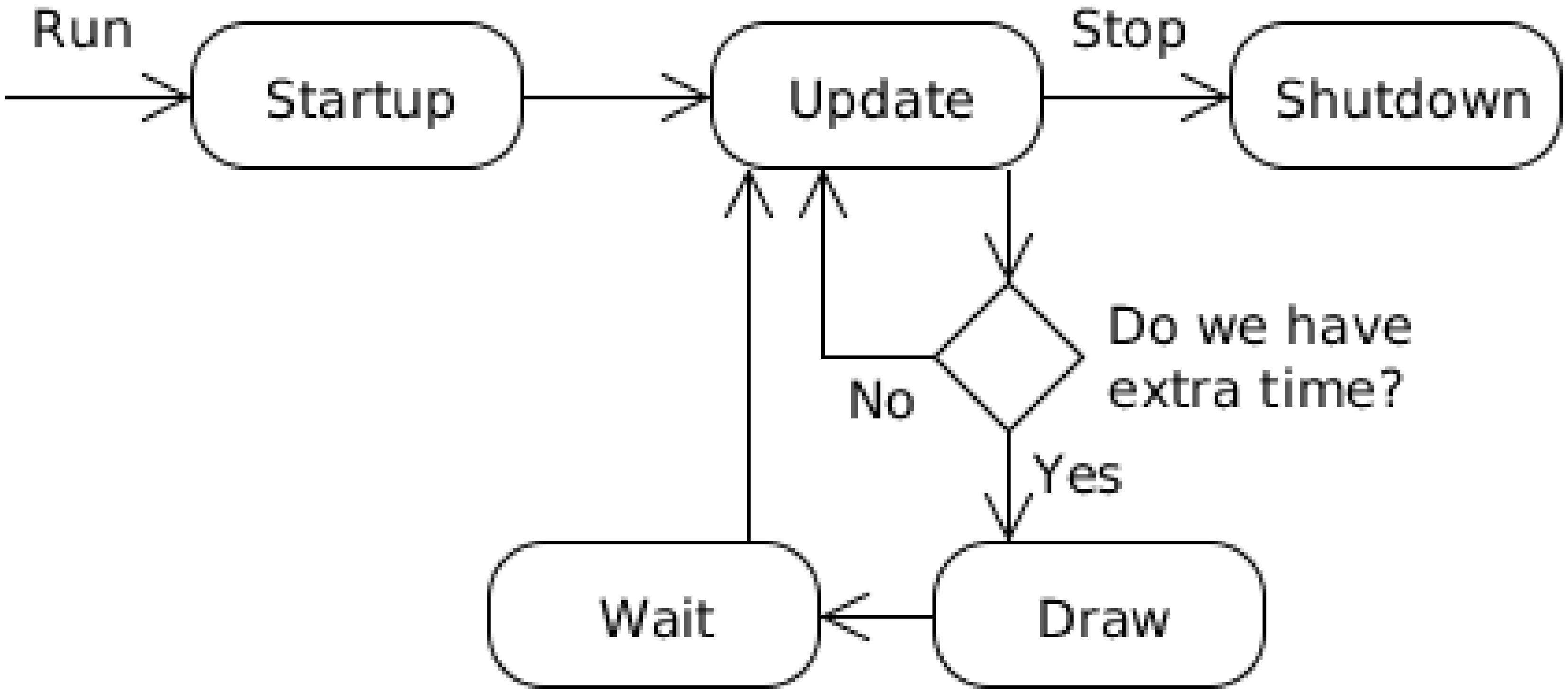
Simple game loop



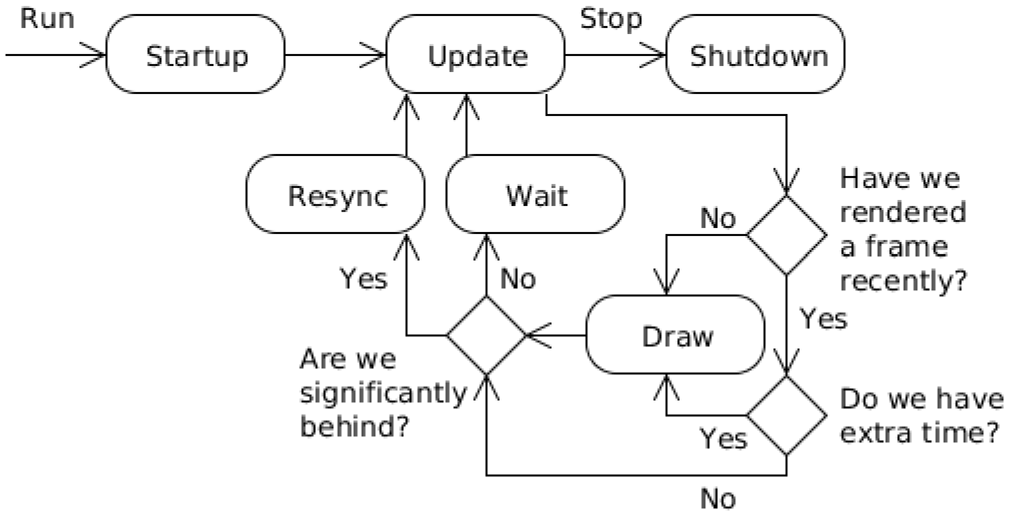
FPS limited game loop



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 (lower FPS => less updates)
  - `FixedUpdate()`
    - Updates in fixed intervals (by default every 20ms => 50 FixedUpdates per second)
    - Called once before 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 (simplified)

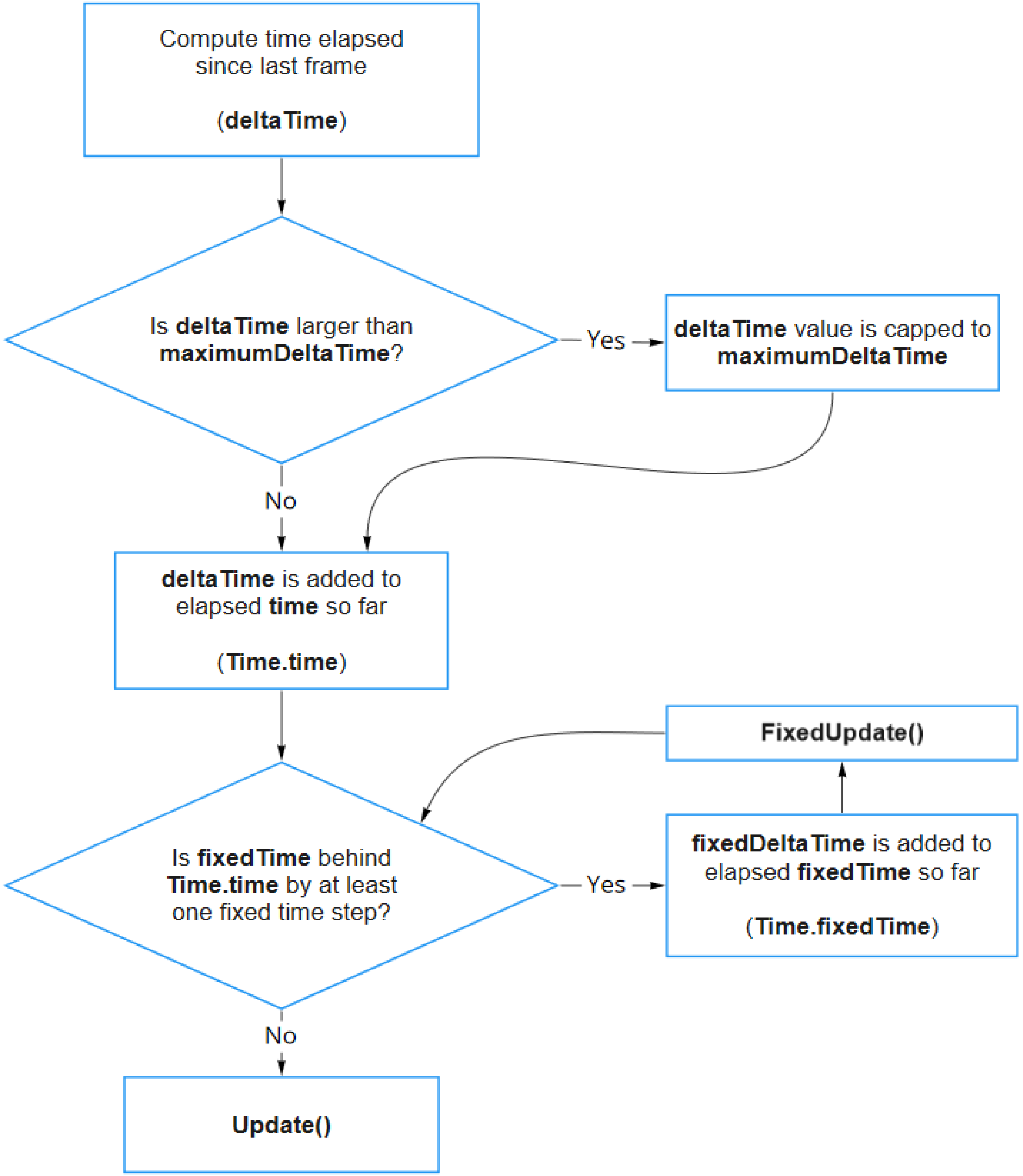
```
float timer = 0;
while (true)
{
    while (timer > fixedTimeStep)
    {
        FixedUpdate();
        PhysicsUpdate();
        timer -= fixedTimeStep;
    }
    Update();
    LateUpdate();
    Render();
    timer += deltaTime;
}
```

Unity Execution Order

- You need to know what happens and in which order!

- **This is the most important graph for understanding Unity**

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

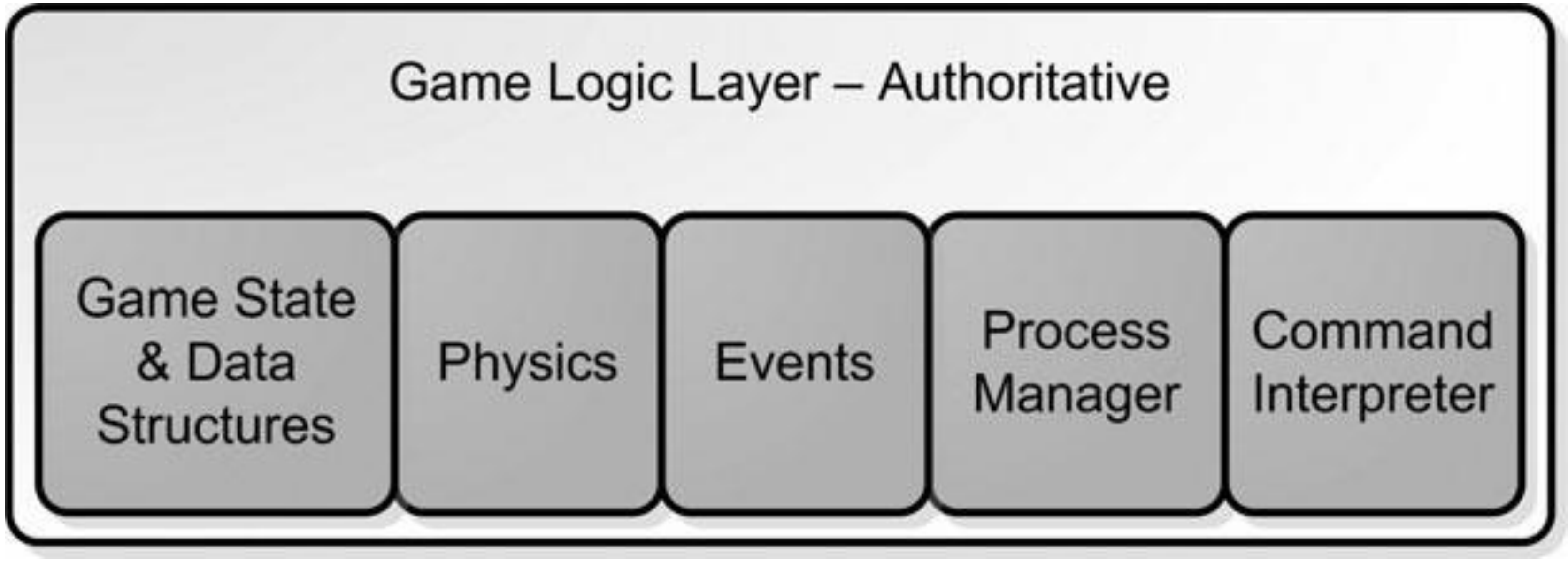


- From https://docs.unity3d.com/Manual/TimeFrameManagement.html

Other Application Layer Code

- System clock
- String handling
- System libraries
- 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 functions 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 serialized 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
- Favors 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 current Unity

- Entity = GameObject – name, tag, active/inactive, layer…
- Component = Component (MonoBehaviour)
- System
  - Configurable but not directly visible
  - Can create own systems
  - Individual components register with their respective systems
  - **Split across multiple components**

Example of systems

- 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 MonoBehaviours – Damage System, Items & Inventory…
  - Health, Weapon and Explosive are all part of the damage system

DOTS packages

As we're rebuilding the core of Unity with DOTS, we're continuously adding new features. Here's an overview of the essential DOTS packages we're working on at the moment.

- Entities (preview)
- C# Job System
- Burst Compiler
- Unity Physics (preview)
- Unity NetCode (preview)
- DSPGraph (experimental)
- Unity Animation (experimental)
- DOTS Runtime (preview)

Physics and Collision

- Rules of your physical 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

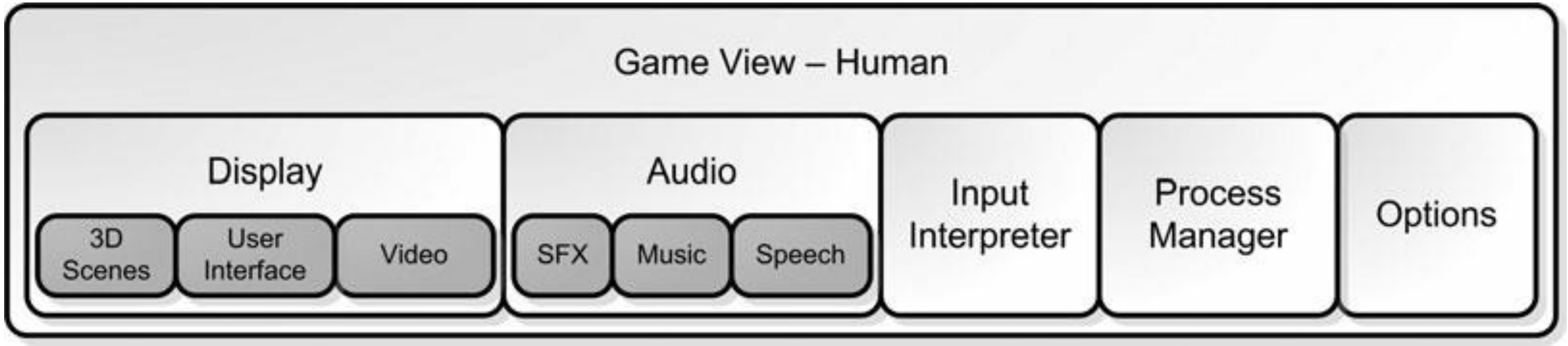
- The game logic is composed of small parts of code that need to be executed periodically for the game to work correctly
- Multiple processes that are completely independent (but we might provide dependencies)
- Mostly script executions
  - If we have a scripting language
  - Otherwise, it’s just one 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 – 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

Audio in Unity

- AudioSource and AudioListener components
- AudioMixer, groups, filters, effects
- Can use other audio engine – FMOD, Wwise…

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 UI

- Uses separate rendering from 2D and 3D
  - All components rendered on a Canvas
  - Objects use 2D sprites for rendering
- Has numerous tools for anchoring, scaling for different resolutions, events…
- Can do screen-space, camera-space and world-space UI
  - Can mix UI rendering and standard rendering

- Alternative: UI Toolkit
  - https://docs.unity3d.com/Manual/UI-system-compare.html

Options

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

References

- McShaffry, M. & Graham, D. (2013). *Game Coding Complete*. Boston, Mass: Course Technology PTR. 4th ed.
  - Chapter 2 – What's in a game?
- http://gameprogrammingpatterns.com/
- http://entropyinteractive.com/2011/02/game-engine-design-the-game-loop/