COMP130: Game Architecture

4: Game engine architecture

Research journal

Research journal

- Assignment brief is on LearningSpace
- Edit the wiki!
- One wiki for all modules now

What to read?

- **No set reading** this time
- Find and read things relevant to your **team game project** or **other assignments**
- Find and read things in other areas you are interested in
- Look online (Facebook group and elsewhere) for recommendations of "seminal" works in CS
- Share any interesting papers you find on the wiki!

The main loop

Basic game architecture

- CPUs execute **sequences of instructions**
  - At the CPU level, there is no such thing as "when *X* happens, do *Y*"
  - Instead: "keep checking whether *X* has happened; if so, do *Y*"
- Thus games need to have a **main loop**
- The main loop is usually part of the game's **engine**
  - E.g. Unreal implements the main loop for you
  - E.g. PyGame isn't a game engine, so you have to implement your own main loop

The basic main loop

The most basic main game loop does **two** things:

1. **Update** the state of the game
   - Handle player input
   - Update physics, collision detection, AI etc.
   - Do any game-specific updates
2. **Render** the game to the screen
   - Game world
   - User interface

It does these **once per frame** (typically 30 or 60 times per second)

The basic main loop

```
bool running = true;

while (running)
{
    update();
    render();
}
```

Rendering

- This is where you draw the **current state of the game** to the screen
- Also draw any **heads-up display (HUD)** elements, e.g. score, lives, mini-map, etc.
- Most modern game engines **clear the screen and redraw everything** on every frame

Screen refresh rate

- Old CRT monitors worked by scanning an electron beam down the screen
  - `https://www.youtube.com/watch?v=lRidfW_l4vs`
- Hence the term **(vertical) refresh rate**
- Refresh rate is measured in **cycles per second** i.e. **Hz**
- Other monitor technologies work differently, but still refresh the screen at regular intervals

Frame rate

- We generally want to sync it up so that **one display refresh = one main loop iteration**
- If the main loop runs too slowly, we get "lag"
- If the main loop runs too quickly, we waste resources on drawing things faster than the display can show them

Limiting the frame rate

- The game's main loop is generally synchronised to the screen refresh rate
- However, refresh rates can vary
  - Older TVs: $\sim$ 30Hz
  - HDTVs and standard monitors: 60Hz
  - VR headsets: 90Hz
  - High-end gaming monitors: 120Hz or higher

Limiting the update rate

- Having the update frequency depend on the refresh rate would be bad!
  - The game could appear to run in slow or fast motion, completely changing the gameplay
- This was the situation on older consoles: American/Japanese versions of games actually ran a little faster than European versions, due to the NTSC TV standard having a higher refresh rate than PAL!

Variable time step

- Have the update step depend on the **elapsed time since the last update**
- Also known as the **delta time**
- E.g. if the game is running at a steady 60FPS, delta time $= \frac{1}{60}$
- So instead of this:

```
player.positionX += player.velocityX;
```

- do this:

```
player.positionX += player.velocityX * deltaTime;
```

Variable time step

```
bool running = true;
float lastFrameTime = getCurrentTime();

while (running)
{
  float currentFrameTime = getCurrentTime();
  float deltaTime = currentFrameTime - lastFrameTime;

  update(deltaTime);
  render();
  waitForVerticalRefresh();

  lastFrameTime = currentFrameTime;
}
```

Variable time step — the downside

- `deltaTime` will inevitably **fluctuate** slightly
- Recall from COMP110 session 11: floating point numbers are **not perfectly accurate**
  - E.g. `0.1 + 0.2 == 0.30000000000000004`
- This can cause some systems (particularly physics simulations) to become **nondeterministic**
  - I.e. to give different results from the same inputs
  - Very bad for online multiplayer, physics puzzles, replay features, etc.
- If `deltaTime` becomes large (e.g. if the system cannot keep up with the frame rate), physics simulations can be prone to **numerical instability**
  - E.g. `https://www.youtube.com/watch?v=vuTReFhBMPg`

Fixed time step

- Perform the update at a **fixed rate**, e.g. 50 times per second
- If refresh rate $<$ 50Hz, update several times per frame
- If refresh rate $>$ 50Hz, update once every few frames

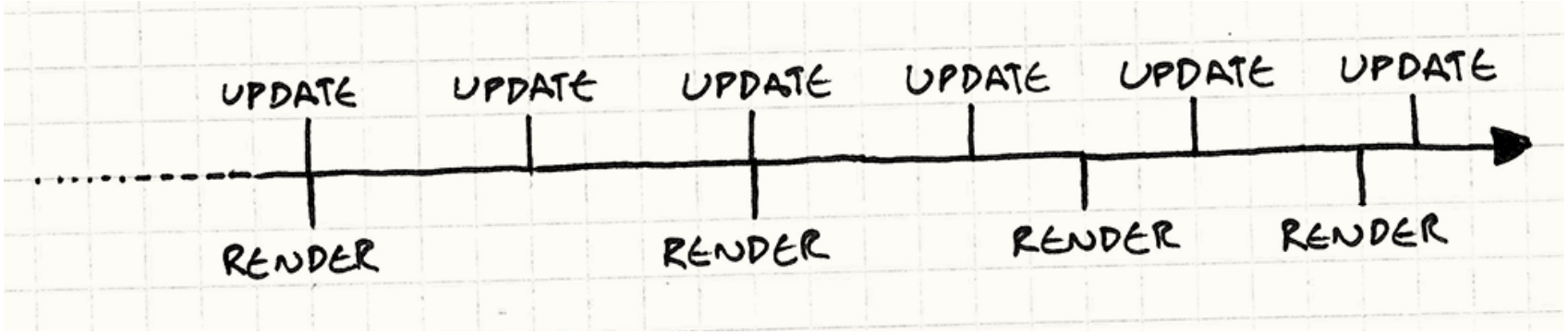
Fixed time step

```
bool running = true;
float lastUpdateTime = getCurrentTime();
float timePerUpdate = 1.0f / 50.0f;

while (running)
{
  float currentFrameTime = getCurrentTime();

  while (currentFrameTime - lastUpdateTime >=
      timePerUpdate)
  {
    update();
    lastUpdateTime += timePerUpdate;
  }

  render();
  waitForVerticalRefresh();
}
```

Stalling

- What if `update` takes longer than `timePerUpdate` to execute?
- The **`while`** loop will perform more and more iterations in an effort to catch up, eventually grinding the game to a halt
- **Solution:** **`break`** out of the loop after a maximum number of iterations (e.g. 10)

Interpolation



- Rendering at "irregular" intervals (with respect to update) can result in jerky movement
- Solution: **interpolate** between the two previous updates
  - E.g. if the render falls exactly halfway between two updates, render each object exactly halfway between its positions **before** and **after** the most recent update

Further information on fixed time steps

- `http://gafferongames.com/game-physics/fix-your-timestep/`
- `http://gameprogrammingpatterns.com/game-loop.html`

Substepping

- Aims to be a "best of both worlds" between fixed and variable time steps
- Use fixed time step at low frame rates, variable at high frame rates
- E.g. again with a target update rate of 50Hz
- If refresh rate $<$ 50Hz, update several times per frame, with a `deltaTime` of $\frac{1}{50}$
- If refresh rate $>$ 50Hz, update once every frame, with `deltaTime` measured as for variable time step

Substepping

```
bool running = true;
float lastFrameTime = getCurrentTime();
float timePerUpdate = 1.0f / 50.0f;

while (running)
{
  float currentFrameTime = getCurrentTime();
  float deltaTime = currentFrameTime - lastFrameTime;

  if (deltaTime <= timePerUpdate)
  { // Variable time step
    update(deltaTime);
  }
  else
  { // Fixed time step
    while (deltaTime > 0)
    {
      update(timePerUpdate);
      deltaTime -= timePerUpdate;
    }
  }

  render();
  waitForVerticalRefresh();
  lastFrameTime = currentFrameTime;
}
```

Time steps in Unreal

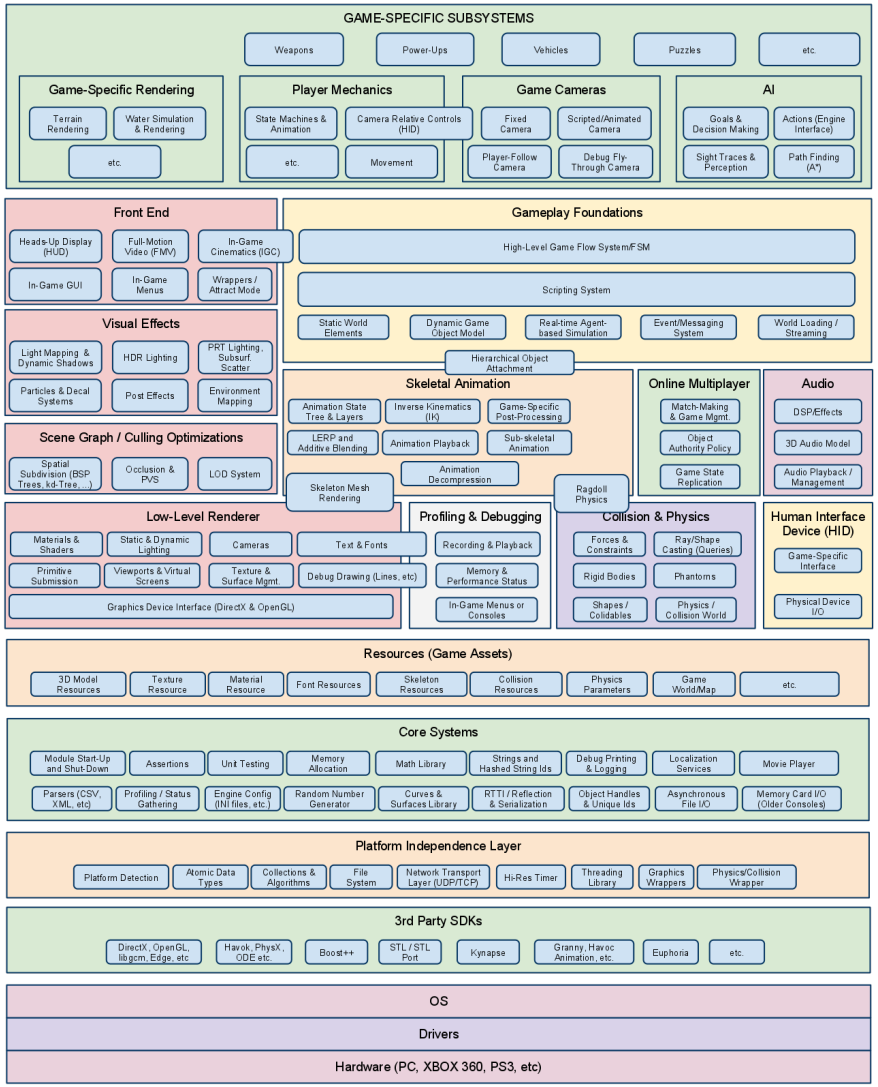
- Unreal uses **variable time step** by default
- Can be switched to use **substepping**
- `Tick` function on C++ classes is called once per frame
- `FCalculateCustomPhysics` delegate can be used to do something once per substep
- Blueprints are updated once per frame; substep updates require C++
- More info: `http://www.aclockworkberry.com/unreal-engine-substepping/`

Time steps in Unity

- Unity uses both **fixed** and **variable time step**
- `Update` function on `MonoBehaviour`s is tied to frame rate
- `FixedUpdate` function is tied to fixed physics updates

Game engine components

Common engine components



Jason Gregory, Game Engine Architecture. CRC Press, 2009.