Programmability of Graphics Pipelines

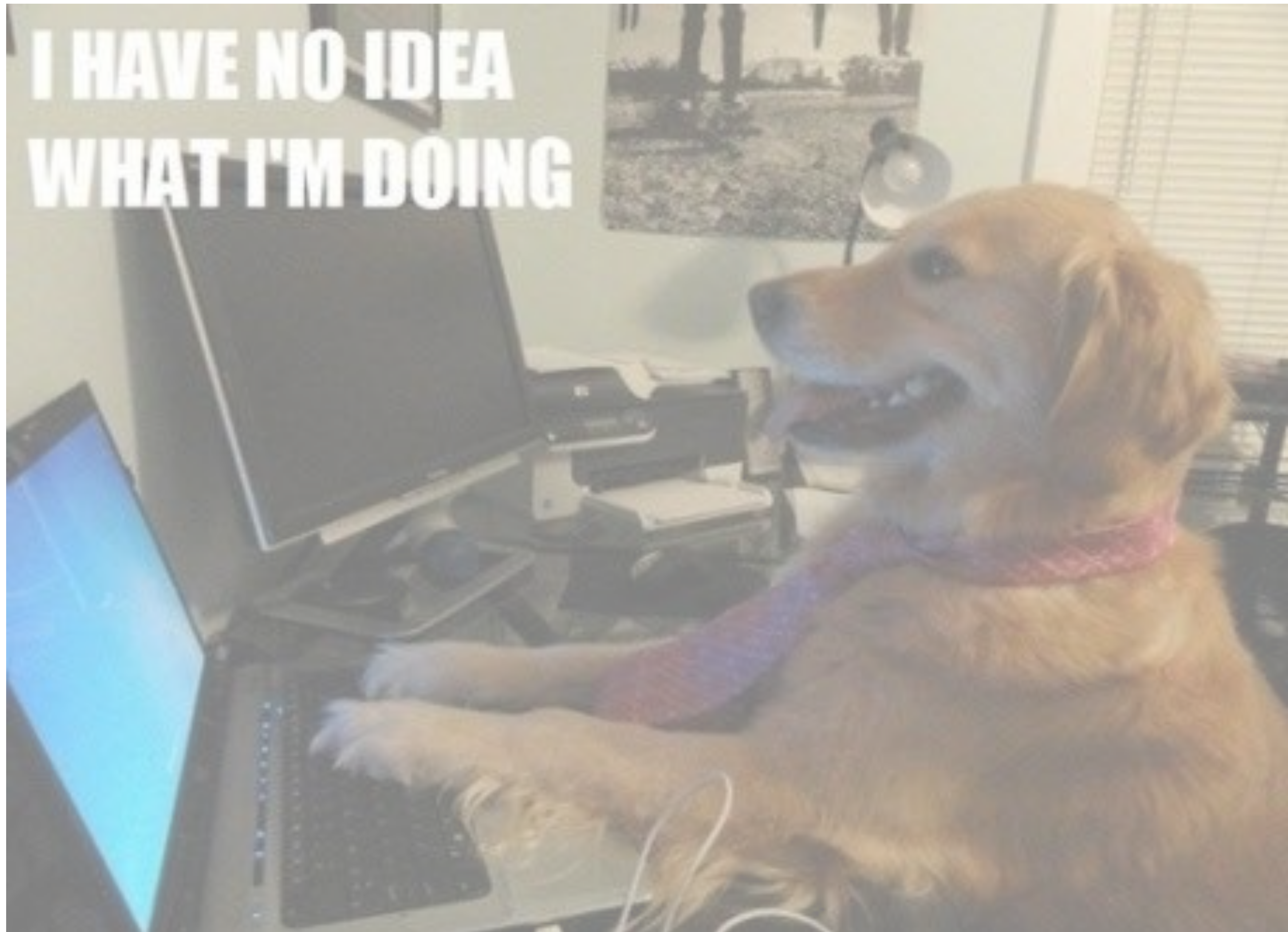
i3D 2018

Generative Art – Made with Unity

unity

Aras Pranckevičius, Unity

- Internal build systems engineer
  - What does that have to do with graphics?
    - Nothing! …however



Aras Pranckevičius, Unity

- Internal build systems engineer
  - What does that have to do with graphics?
    - Nothing! …however

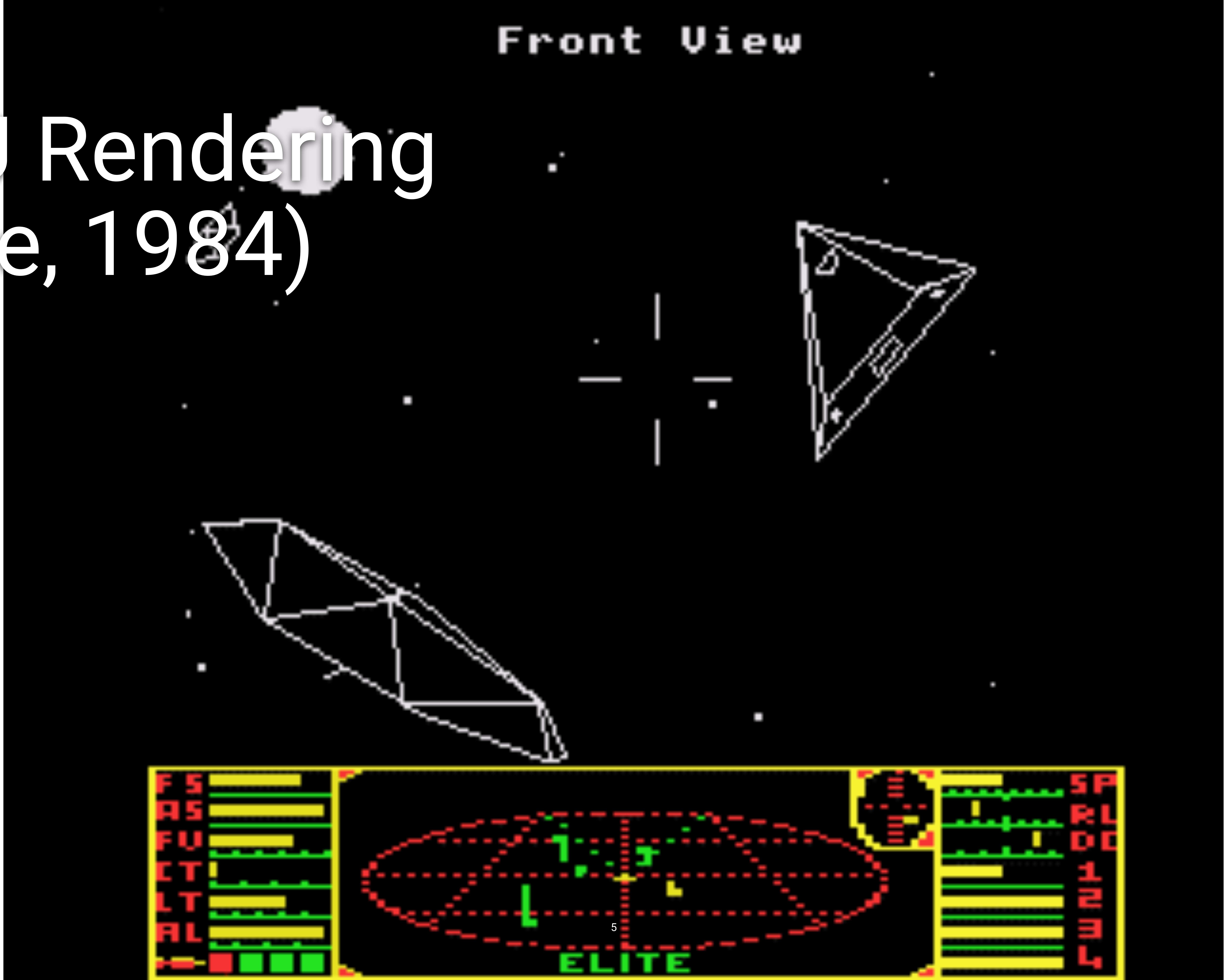
- At Unity since 2006
- Been doing graphics until 2017
- Unity might be the most widely used graphics engine in the world

Maybe a problem?

Increasing Fidelity

unity

CPU Rendering (Elite, 1984)



CPU Rendering (Magic Carpet, 1995)

CPU Rendering (Descent, 1995)

WARNING
175
3
LASER
LVL: 1
CONCSN
MISSILE
006
LOCK

GPU DX7 level: T&L (Quake III, 1999)

GPU DX7 level: T&L (Black & White, 2001)

Going To Farm
A:36 L:62% F:58%
Move

GPU DX9 level: Shaders (Far Cry, 2004)

SW
S
W
009
008
1

GPU DX9 level: Shaders (TES IV: Oblivion, 2006)

GPU DX10 level: More Shaders (Mirror's Edge, 2008)

GPU DX10 level: More Shaders (Bioshock Infinite, 2013)

K-putt
GROCERIES & MEATS
DELICATESSEN
HOT DOGS

GPU DX11 level: (Compute) Shaders (Rise of the Tomb Rider, 2016)

GPU DX11 level: (Compute) Shaders (Dreams, 2018)

Problem

Increasing Complexity

2000, Fixed Function: Simple

- Simple model: render states
- States are composable

2002, Shaders

- Lost composability aspect :(
- Uber-shaders, shader variants, preprocessor, branching, …

2009, Compute Shaders

- Now you program 1500-thread machines
- Good luck, have fun!

2014, Low-level APIs (2014: Metal, 2015: D3D12, 2016: Vulkan)

- Now you write half of the driver
- Good night, and good luck

2018, Raytracing (DXR, etc.)

- Maybe this one will actually make things easier
- …eventually

Problem in detail

Composability

“I want fog” in the days of yore

- `glEnable(GL_FOG); // OpenGL 1.x`
- `dev->SetRenderState(D3DRS_FOGENABLE, TRUE); // D3D9 SM2.0`

“I want fog” in shaders

- Have to modify **all shaders**, and add fog code in there
- 2x more variants, with & without fog code?
- A branch inside the shader?
- Specialization constant?

Modify all the shaders

- So we end up building abstractions in our shader code

  ```
  UNITY_APPLY_FOG(i.fogCoord, col);
  ```

  …and the same for a whole bunch of other “states”
- Now our abstractions are project/engine-specific :(
- Shaders are not transferable across different tech stacks :(

Shaders are a big blob

- Large part of lost composability is the fact that a shader has to do “everything”
- All the code effectively inlined
- Previous attempts at fixing this (fragments, interfaces, subroutines) not sucessful
- Maybe with DXR & other raytracing APIs we’ll get “callable shaders”?
  - See also: “Hacking GCN via OpenGL” by Stachowiak https://h3r2tic.github.io/

Problem

Other complexities

Other axes of complexity

- Platforms
- Graphics APIs
- Hardware performance variety
- Hardware featureset variety
- Flexibility

iOS
WebGL
android
ARCore
magic leap
tvOS
PlayStation VR
PS4
Gear VR
NINTENDO 3DS
XBOX ONE
androidtv
ARKit
Microsoft HoloLens
PS VITA
Wii U
Xiaomi
NINTENDO SWITCH
Daydream
intel
Steam VR
Google Cardboard
gameroom
oculus
vuforia

All that stuff is complex!

- Research can ignore some of complexity
- “Production” often can not :(

Goal

Easy innovation in graphics techniques

Sharing of reproducible data

- Ability to validate research findings is critical for adoption
- Please!
  - Share your research code + data
  - We don’t really care if your code is “messy” or “not nice”

Lower amount of unrelated busywork

- Essential vs accidental complexity
- Modern APIs like Vulkan or D3D12 need a lot of plumbing
  - Should not need 10 years of D3D experience to come up with a better BRDF

Suggestion

Game engines & frameworks a good fit!

Unity

- Popular, free version, tools, asset pipeline, platforms
- Fast iteration times
- Allows customizing rendering & shaders quite a lot
  - Even more so with Scriptable Render Pipelines *(see later…)*

NVIDIA Falcor & Slang

- https://github.com/nvidiagameworks/falcor
  - D3D12 (including DXR) & Vulkan
  - Research & prototype oriented
- https://github.com/shader-slang/slang
  - Extended HLSL
  - WIP, might not be production ready at the moment

Microsoft MiniEngine

- https://github.com/Microsoft/DirectX-Graphics-Samples
  - “A DirectX 12 Engine Starter Kit”

bgfx

- https://github.com/bkaradzic/bgfx
  - Rendering library with many API backends/platforms
  - Bindings for many programming languages too!

Sokol

- https://github.com/floooh/sokol
  - Minimalistic C *(not C++!)* graphics API / app model wrapper
  - D3D11, Metal, GLES3, GLES2
  - http://floooh.github.io/2017/07/29/sokol-gfx-tour.html

G3D Innovation Engine

- https://casual-effects.com/g3d
  - Research oriented 3D engine

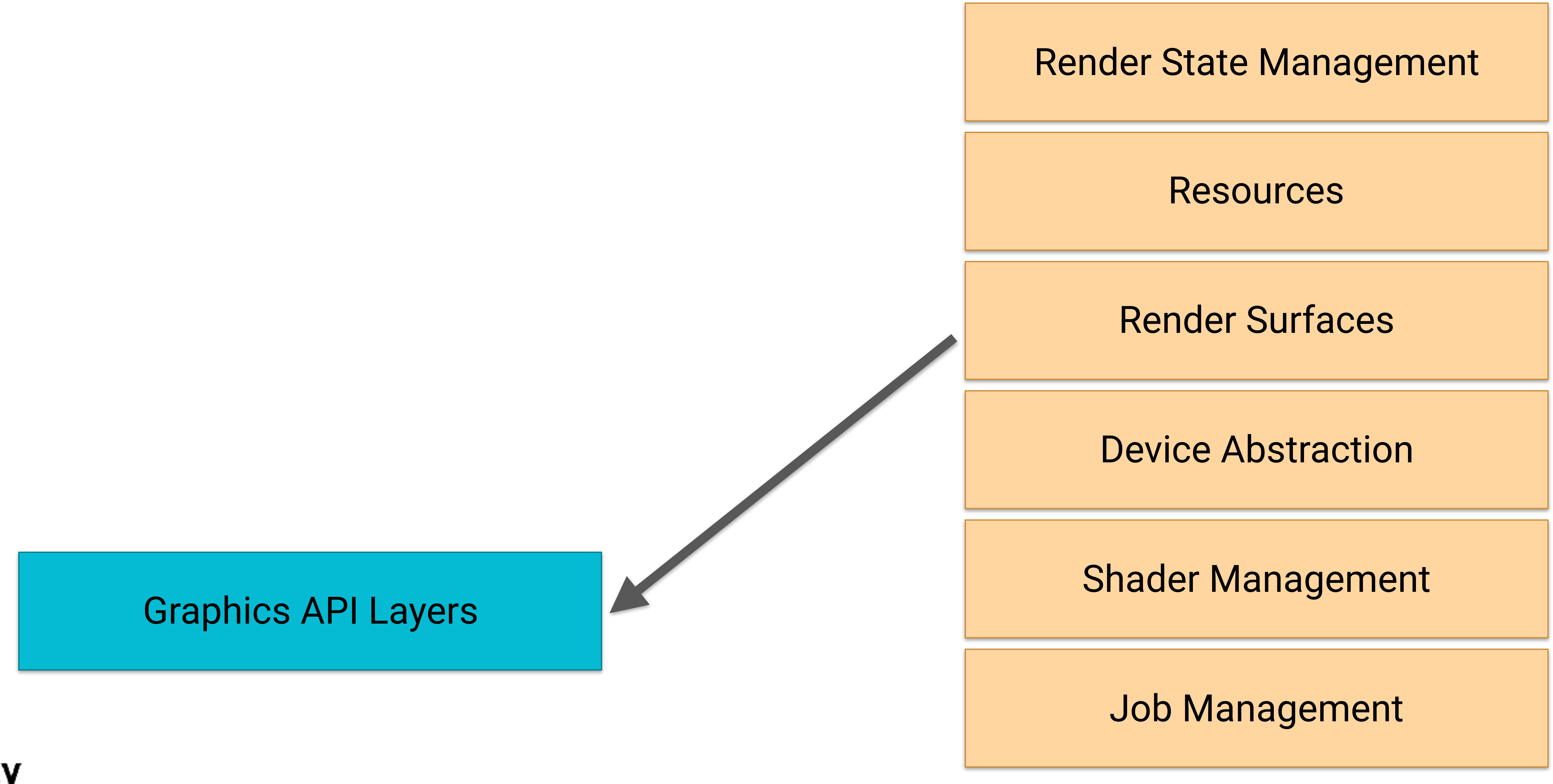
Shadertoy

- https://www.shadertoy.com/
  - In-browser, shareable experiments
  - If your problem can be expressed in one/several shaders with WebGL limitations

In Detail

Unity & Scriptable Render Pipeline (SRP)

Graphics Engine Pipeline



Render State Management

Resources

Render Surfaces

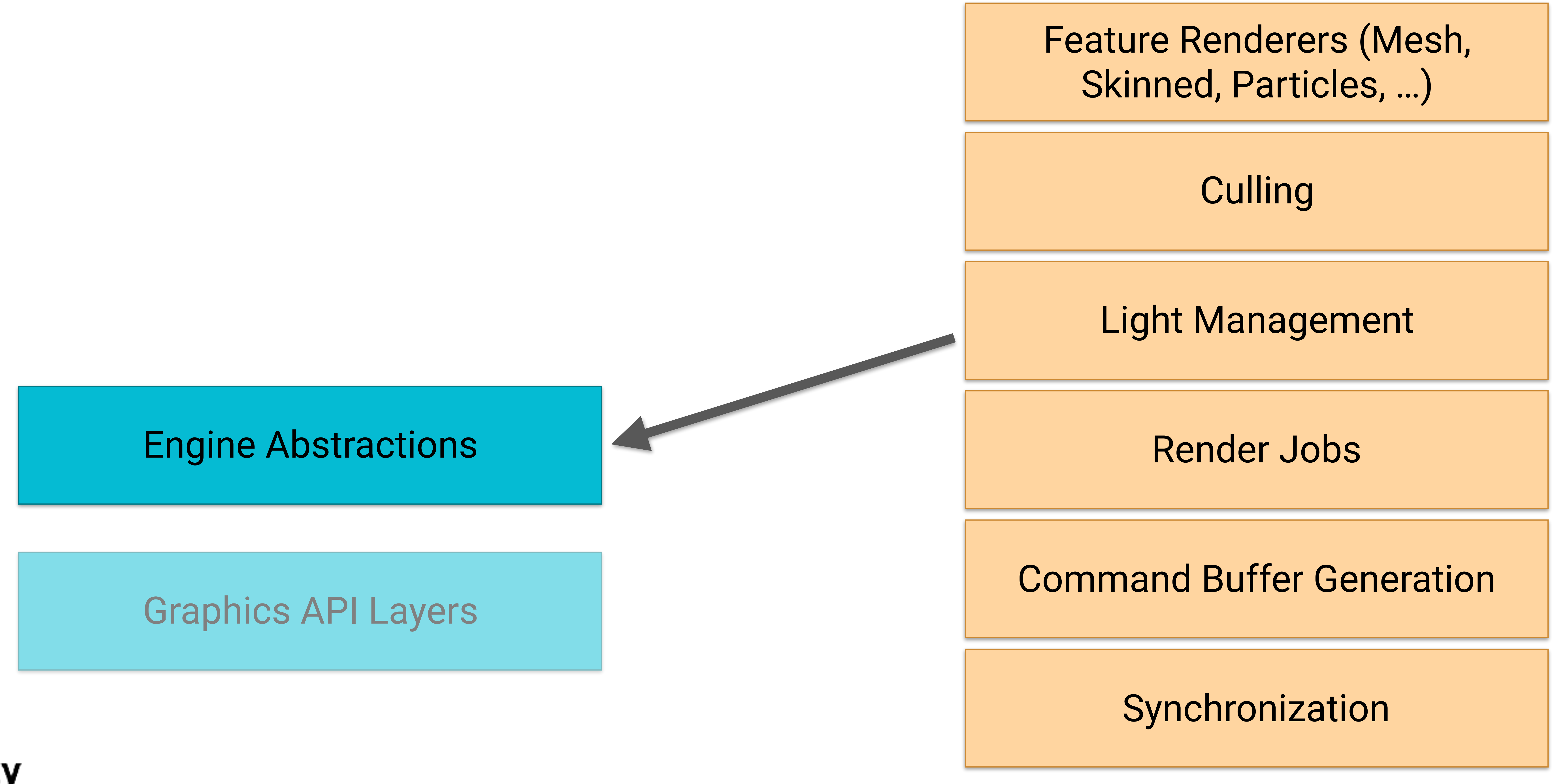
Device Abstraction

Shader Management

Job Management

Graphics API Layers

Graphics Engine Pipeline



Feature Renderers (Mesh, Skinned, Particles, …)

Culling

Light Management

Render Jobs

Command Buffer Generation

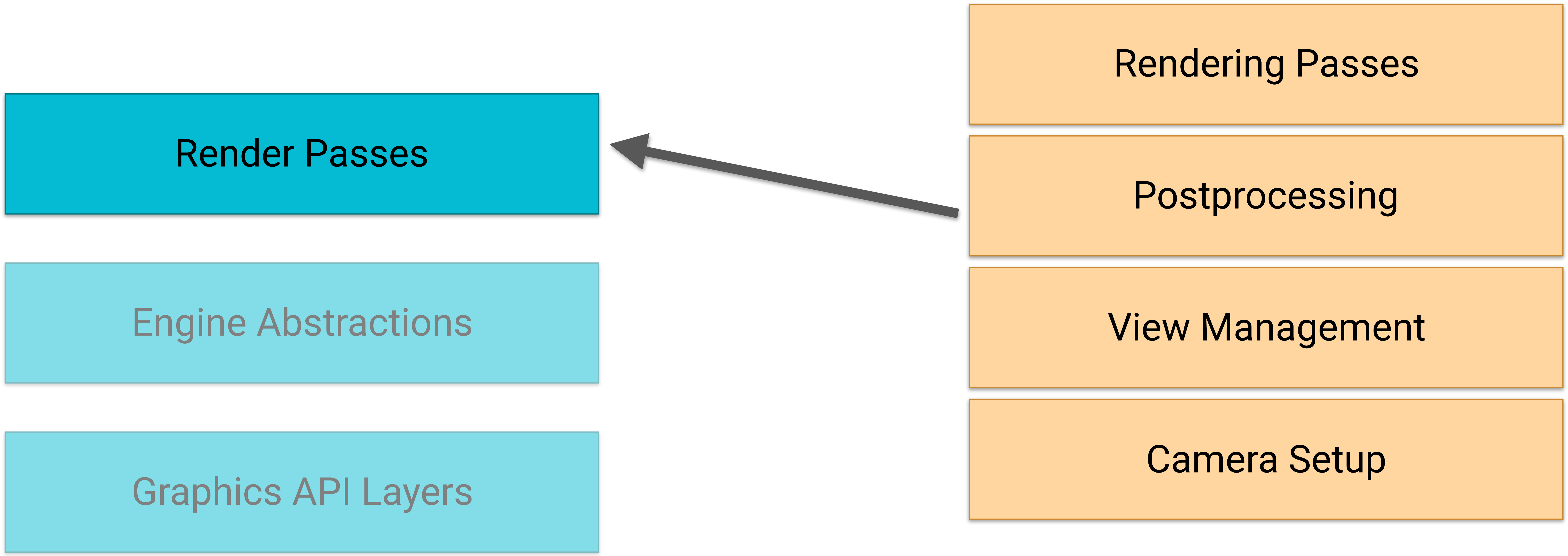
Synchronization

Engine Abstractions

Graphics API Layers

unity

Graphics Engine Pipeline



Render Passes

Engine Abstractions

Graphics API Layers

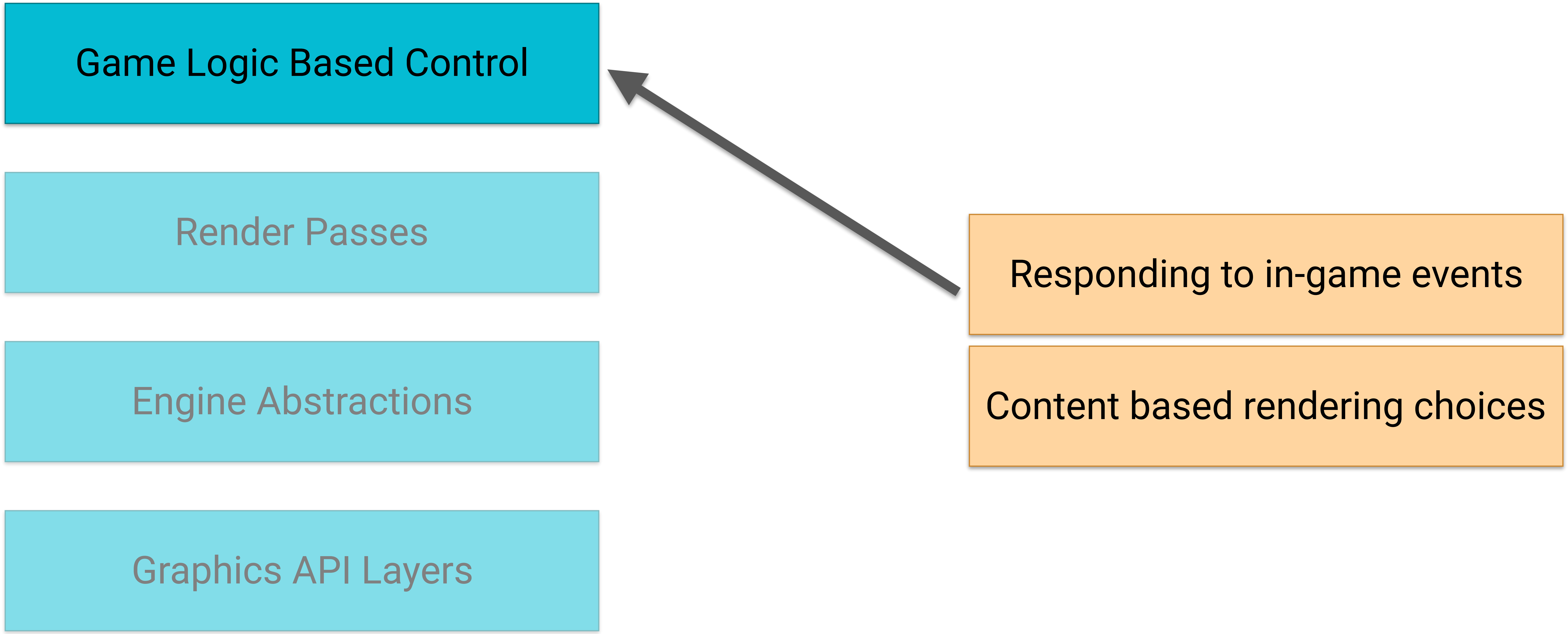
Rendering Passes

Postprocessing

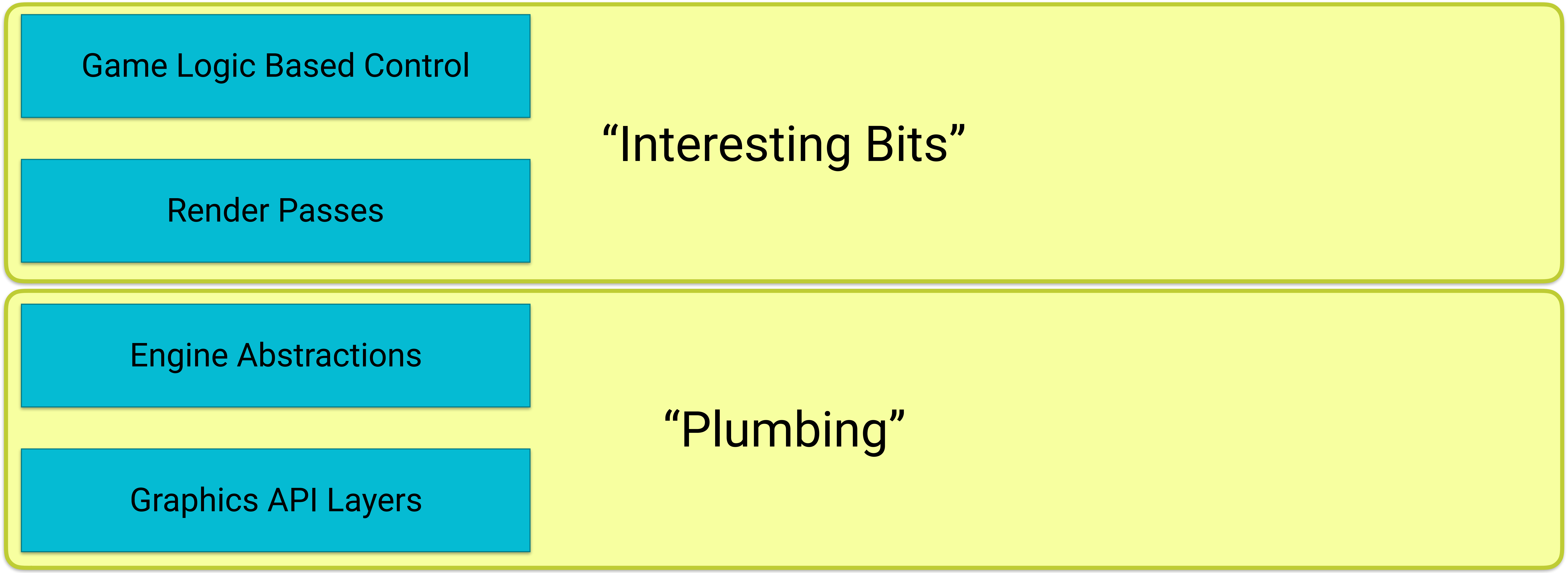
View Management

Camera Setup

Graphics Engine Pipeline



Graphics Engine Pipeline



Game Logic Based Control

Render Passes

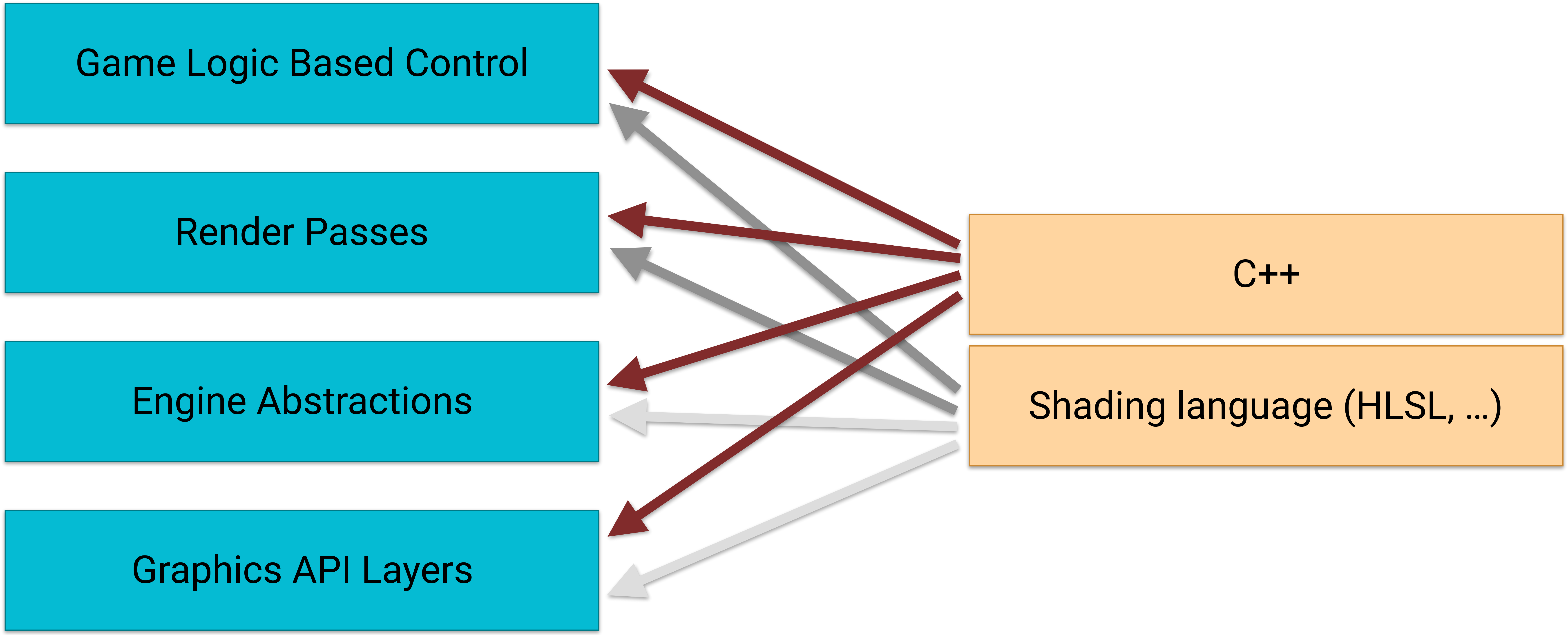
"Interesting Bits"

Engine Abstractions

Graphics API Layers

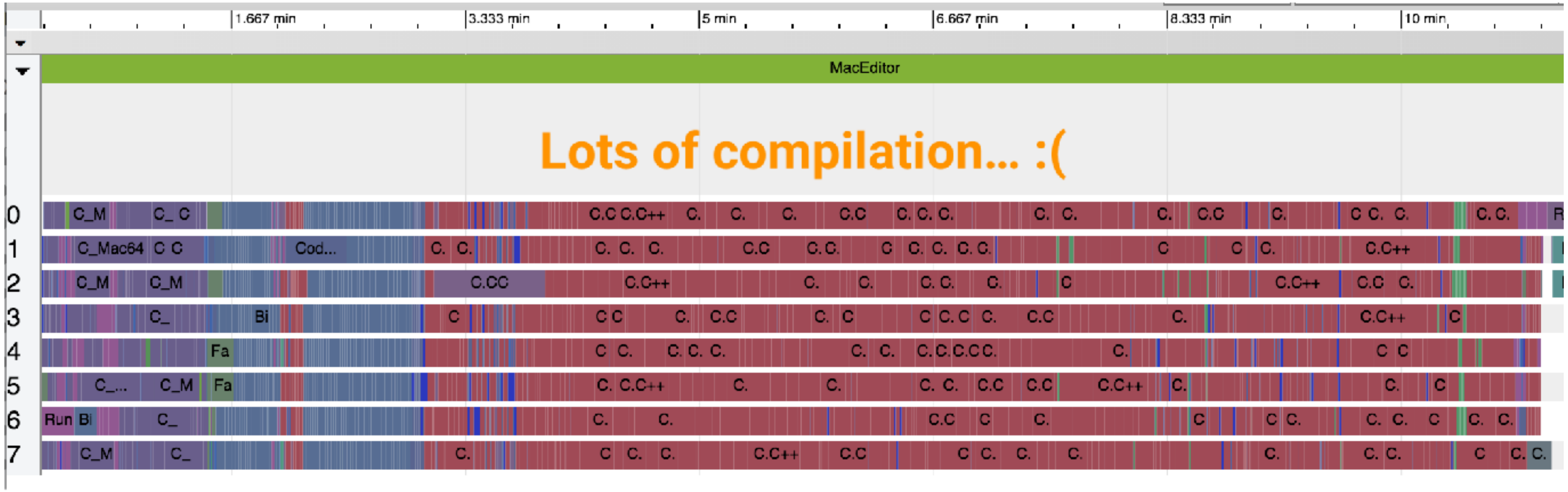
"Plumbing"

Traditional development



Traditional development

- Slow iteration



Lots of compilation... :(

- *(Unity specific)* rift between “engine dev” (C++) and “users” (C#)

unity

High/Low level split from research community

- Python for high level, NumPy/TensorFlow/CUDA for low level
- R, MATLAB, Octave, Mathematica

High/Low split in graphics

- ATI demo engine Sushi (2003)
- Bitsquid/Stingray data driven renderer (2011)
- Destiny’s rendering architecture (2015)
- Frostbite Framegraph (2017)

Styles of games made with Unity

ANTIGRAVIATOR
COMBO
×8

Styles of games made with Unity

WARDEN OBJECTIVE
Woods
ZONE

Styles of games made with Unity

Cindy
Cindy—Cid's grease-monkey granddaughter.

Styles of games made with Unity

Morty
UAL
ALITY
CAUTION
SUBNAUTICA
EARLY ACCESS

Problem

Hard to serve all of them with one render pipeline

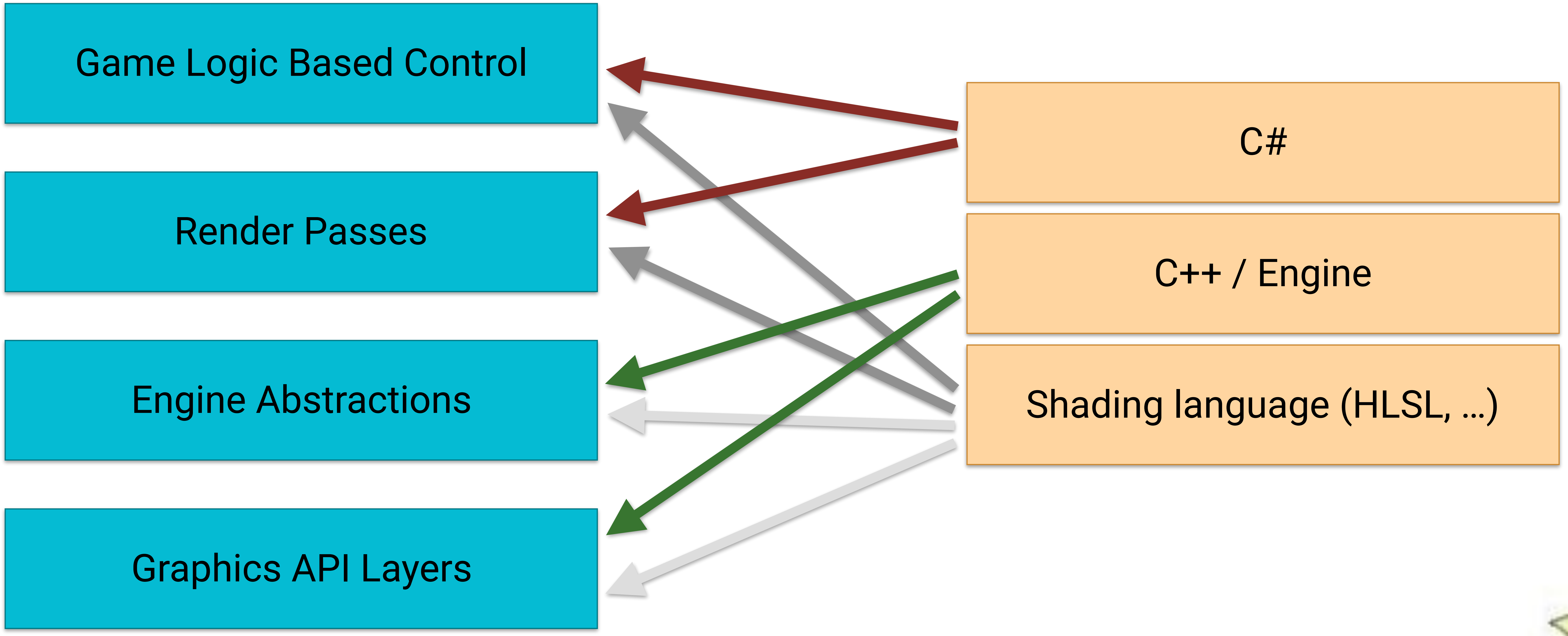
Traditional render pipeline in Unity

- Forward or Deferred
- A whole bunch of options & knobs
- Shaders mostly customizable
- Render pipeline itself less so
- Black box, complex, fragile
- Still enables all these different games, so that’s good :)

Our wishes

- Lean
- User centric
- Optimal
- Explicit

Scriptable Render Pipelines! (SRP)



Game Logic Based Control

Render Passes

Engine Abstractions

Graphics API Layers

C#

C++ / Engine

Shading language (HLSL, …)

SRP Concept

- What to render: culling/filtering. World -> sets of objects
- Render: draw sets of objects with some flags/params
- Setup render passes around all that
- Setup per-frame/renderpass data

https://blogs.unity3d.com/2018/01/31/srp-overview/

SRP High/Low Level Split

- Perf-critical things (culling, drawing sets of objects, …): C++
  - Might move to C#/Burst* at some point
- Control/logic, render pass setup: C#
- GPU code (shaders, compute): HLSL
  - Maybe subset of C# at some point?

* Unity Burst Compiler: LLVM-based compiler for a high performance subset of C#
https://unity3d.com/unity/features/job-system-ECS

SRP Advantages

- Quick iteration of new algorithms
- All benefits of Unity engine/tooling
- Focus on algorithm, not busywork/plumbing
- Hot reload of C#/shader code

SRP, iterating on the render pipeline

Assets GameObject Component RenderPipeline Tests HDRenderPipeline Demo Photogrammetry Lighting Tools Window Help
Center Local
Account Layers Layout
Scale 1x
Maximize On Play Mute Audio Stats Gizmos
File Edit View Navigate Code Refactor Build Run Tools VCS Window Help
Demo_beta2017-07-28 Assets ScriptableRenderPipeline HDRenderPipeline HDRenderPipeline.cs
Debug | Any CPU
Attach to Unity Editor
StopAfterTimeline.cs HDRenderPipeline.cs Bloom.cs PostProcessLayer.cs TilePass.cs

```
        if (camera.cameraType == CameraType.Reflection)
        {
            using (new Utilities.ProfilingSample("Blit to final RT", cmd))
            {
                // Simple blit
                cmd.Blit(m_CameraColorBufferRT, BuiltinRenderTextureType.CameraTarget);
            }
        }
        else
        {
            RenderVelocity(m_CullResults, hdCamera, renderContext, cmd); // Note we may have to render

            // TODO: Check with VFX team.
            // Rendering distortion here have off course lot of artifact.
            // But resolving at each objects that write in distortion is not possible (need to sort tra
            // Instead we chose to apply distortion at the end after we cumulate distortion vector and
            RenderDistortion(m_CullResults, camera, renderContext, cmd);

            // Final frame blit
            cmd.Blit(m_CameraColorBufferRT, BuiltinRenderTextureType.CameraTarget);
        }
    }

    RenderDebug(hdCamera, cmd);

    // bind depth surface for editor grid/gizmo/selection rendering
    if (camera.cameraType == CameraType.SceneView)
    {
        cmd.SetRenderTarget(BuiltinRenderTextureType.CameraTarget, m_CameraDepthStencilBufferRT);
    }

    renderContext.ExecuteCommandBuffer(cmd);
    CommandBufferPool.Release(cmd);
    renderContext.Submit();
}

void RenderOpaqueRenderList(CullResults cull, Camera camera, ScriptableRenderContext renderContext, Com
{
    if (!m_DebugDisplaySettings.renderingDebugSettings.displayOpaqueObjects)
        return;

    // This is done here because DrawRenderers API lives outside command buffers so we need to make cal
    renderContext.ExecuteCommandBuffer(cmd);
    cmd.Clear();

    var settings = new DrawRendererSettings(cull, camera, new ShaderPassName(passName))
    {
        rendererConfiguration = rendererConfiguration,
        sorting = { flags = SortFlags.CommonOpaque }
```

SRP Disadvantages *(today)*

- If something needs native code tweaks/additions, it needs a new Unity release
- Not all the latest graphics features are exposed by Unity yet
  - Raytracing, conservative raster, bindless, …
  - We’re trying to catch up though
- SRP with C#/HLSL code not easily transferable to other engines

Built-in SRP: Lightweight

- Simpler
- Runs on all platforms*
- Optimized for mobile / VR
- Single pass forward renderer

* At the very moment does not work on WebGL yet due to lack of threads/jobs

Built-in SRP: High-Definition

- More features!
  - Materials: SSS, Anisotropic, Clearcoat, Iridescent, Rough Refraction, Layered
  - Lighting: Area lights, better probes, better shadows, volumetrics, …
  - Lots of debug views
- Requires compute (DX11 HW)
- Tile/Clustered Forward/Deferred

Built-in SRPs

- Full live source code of both LWRP & HDRP
  - https://github.com/Unity-Technologies/ScriptableRenderPipeline
- Look at how things are done!
- Extend them!
- Build new research on top!

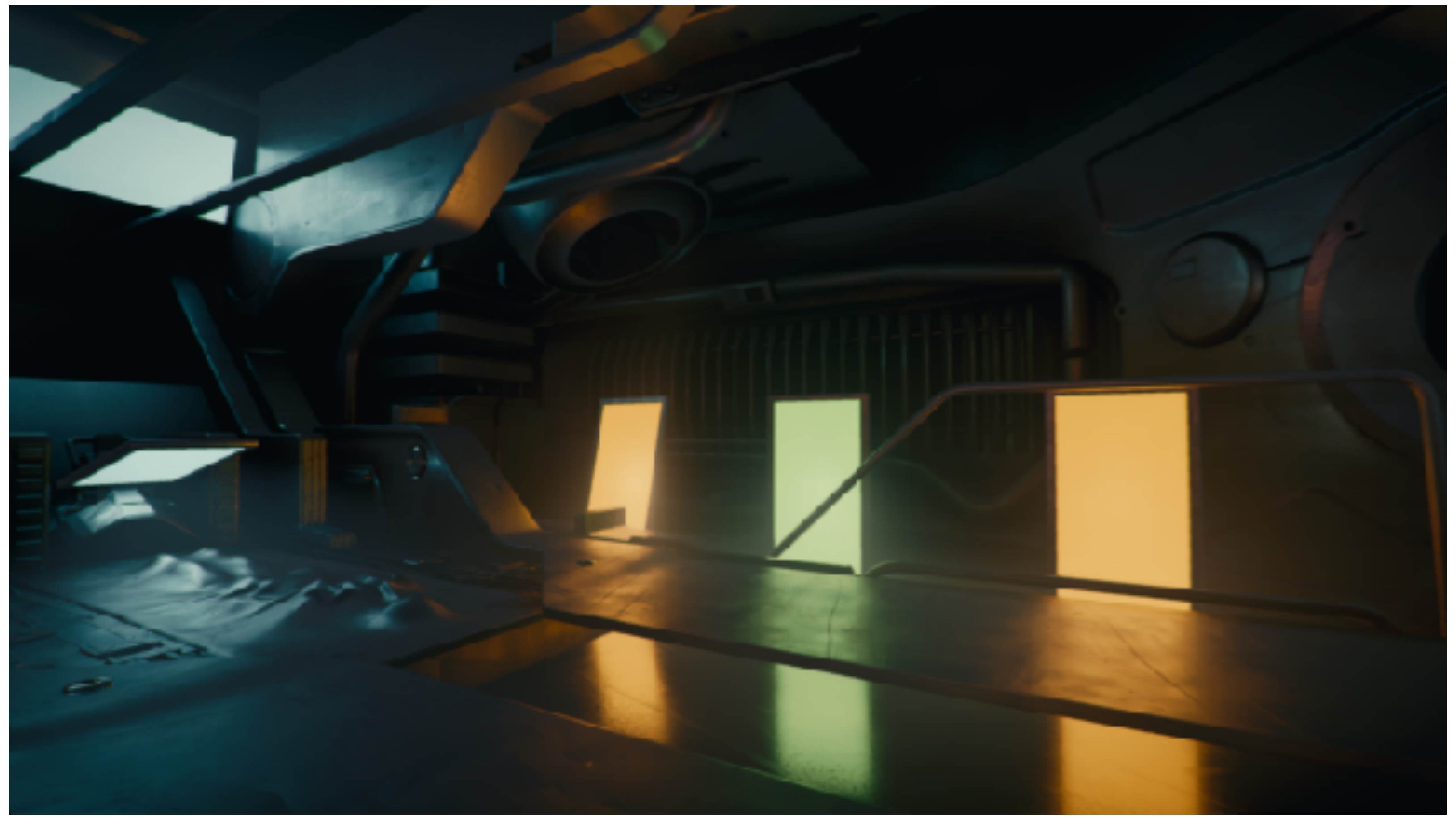
SRP in Research

- Real-Time Polygonal-Light Shading with Linearly Transformed Cosines

  Heitz, Dupuy, Hill, Neubelt; SIGGRAPH 2016
- A Practical Extension to Microfacet Theory for the Modeling of Varying Iridescence

  Belcour, Barla; SIGGRAPH 2017
- Efficient Rendering of Layered Materials using an Atomic Decomposition with Statistical Operators

  Belcour; SIGGRAPH 2018
- Next up: you!



SRP as Education Tool

- Simple API makes graphics pipeline more accessible
- Unity’s built-in LWRP/HDRP reference implementations
- Quick iteration & hot-reload

That’s it! Questions?

Book of the Dead by Unity’s Demo Team — Made with Unity