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Unreal Engine 4 Rendering Part 1: Introduction

Introduction

Unreal Engine 4's rendering system is endlessly configurable and supports most of the latest generation rendering techniques across multiple platforms. Writing materials in Unreal is very accessible thanks to the node-based editor but people are often hesitant about diving in deeper than that due to the rendering system's complexity and lack of accessible educational content.

Perspective
Lit
Show
[Pilot Active - CineCameraActor1B]
10
10°
0.25
4
Level: Bust_ScanScene_Outdoors (Persistent)
Epic Game's Photo Realistic Character Example

The information has been broken up into several posts which have been outlined below. They're written building on the information presented in the previous post, but feel free to jump around if desired. Each post contains information that roughly groups together the multiple parts of the render system that make up a particular step in the overall system. There are two tutorial posts at the end of the series which will jump around between the systems we have learned about and shows how to make some specific changes to the areas we've learned about!

When I set out to add a new Shading Model to Unreal, I struggled to understand how the different parts of the rendering system went together. There are a few existing tutorials on how to do this, but without explaining how the systems went together I found it hard to make changes beyond just copying what the tutorial did.

Therefor, the goal of this series is to help outline how the different parts of the render system *are connected together* as opposed to *looking at the technical implementation* of any given part. This series is going to focus on the deferred shading pipeline from the CPU and GPU side but doesn't go too in-depth about the shadowing system, translucent objects or post effects. Because we tend not to look at the specific implementation details our goal is to let you get a feeling for what classes and functions are worth investigating for further self exploration.

Posts in this Series

1. Introduction & Setup - That's this post! This post explains tools and configuration settings that will make our development life easier.

2. Shaders and Vertex Factories - This post will cover the C++ side of how Unreal creates instances of shaders and links them to their corresponding HLSL code, as well as how Unreal gets vertex data onto the GPU.

3. Drawing Policies and Drawing Policy Factories - This post covers how Unreal uses the right shader variations for different techniques and how the engine knows what order to draw different passes in.

4. Shader Architecture - This post covers the deferred shading pipeline on the GPU and follows the order of how a particular pixel takes lighting and shadowing into account.

5. Shader Iteration Tips - Iterating on shaders can be quite time consuming due to permutation compiling so this post will look at ways to spend less time compiling shaders.

6. Tutorial on adding a new Shading Model - This post will cover how to add a toon-like material that respects PBR properties. This is based on an older blog post by Felix Kate.

7. **(Coming Soon)** Modifying the Base Pass via Geometry Shader - This post explains how to modify the deferred base pass to add support for Geometry Shaders and creates a silhouette shader based on these changes.

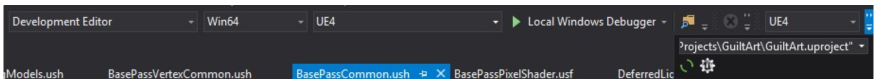
Article Limitations

As much as I would like to cover all aspects of Unreal's rendering capabilities, there's simply too much to cover. Because of this, I've chosen to limit the explanation down to the most common areas. **This series will focus on the deferred shading pipeline** and will ignore Unreal's mobile and clustered forward renderers. Unreal's Mobile and Forward shading pipelines use a different set of classes (both C++ and HLSL) but they should follow relatively similar patterns and they do share some functions/data structures with the main deferred shading pipeline. On the shader side we will ignore translucency and instanced stereo as they're mostly just preprocessor defined variations of the existing code; Per-platform variations will also be ignored for the same reason. On the C++ side we mostly ignore the shadow casting side of things.

Something worth noting is that various code snippets may be abbreviated and simplified. A lot of the apparent complexity of the engine comes from all the various preprocessor defined variations, so we will ignore those for the sake of learning. **This means that this is a series of overview posts, and not a specific tutorial!** That being said, there are two tutorial posts, at the end of this of this series (Post 6 and Post 7) which will give specific examples of modifying the deferred shading pipeline.

Engine Setup

You must be building the engine from GitHub source code. You may be able to get away with modifying existing shaders using the Epic Games Launcher version, but adding new shading models and things like that will require engine source. If you plan to be debugging C++ code often, it's worth building a "**Debug Editor**" profile version of the engine, instead of *Debug Game* or *Development Editor*. Being comfortable with C++, HLSL and templates is a plus, though not required due to the goal being theory more than technical.

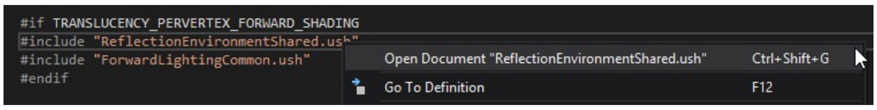


UnrealVS is a great addition to Visual Studio for working with UE4 engine builds too!

Below is a list of recommended setup changes and explanations as to what they do and why you might want them.

HLSL Tools for Visual Studio

This can be found at this URL, as a free extension for Visual Studio. This enables basic HLSL syntax highlighting and Go to Definition for Unreal's .usf/.ush files. To make it work with .usf/.ush files you will need to follow the instruction in one of the author's tweets to add them via the `Tools > Text Editor > File Extensions` section of the editor.

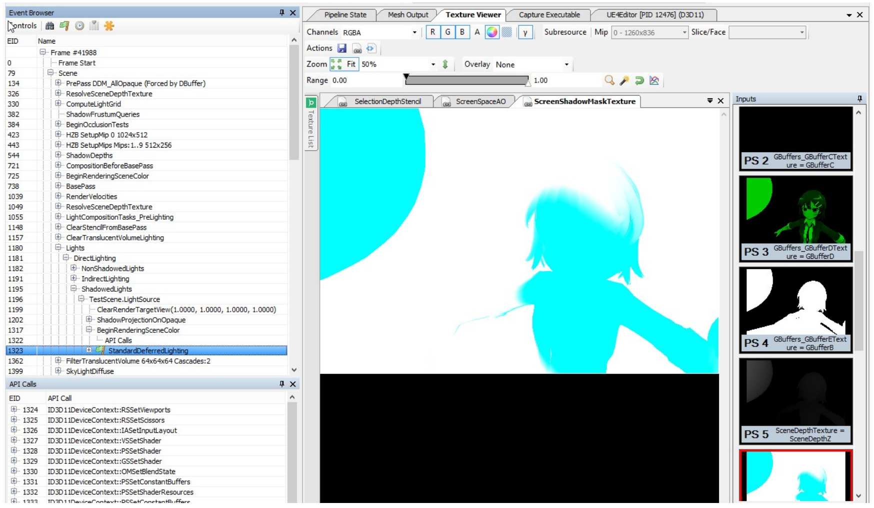


```
#if TRANSLUCENCY_PERVERTEX_FORWARD_SHADING
#include "ReflectionEnvironmentShared.ush"
#include "ForwardLightingCommon.ush"
#endif
```

Open Document "ReflectionEnvironmentShared.ush"   Ctrl+Shift+G
Go To Definition   F12

RenderDoc

RenderDoc is an amazing tool for inspecting what's going on in the GPU. RenderDoc will let you see draw calls, inspect the data as it passes through each stage on the GPU and (combined with some flags below) show you the source code that Unreal is producing and running . Once downloaded and installed there's a RenderDoc plugin pre-installed in Unreal that you can enable which adds a capture button to the main viewport.



Event Browser

EID	Name
	Frame #41988
0	Frame Start
79	Scene
134	PrePass DDM_AllOpaque (Forced by DBuffer)
326	ResolveSceneDepthTexture
330	ComputeLightGrid
382	ShadowFrustumQueries
384	BeginOcclusionTests
423	HZB SetupMip 0 1024x512
443	HZB SetupMips Mips:1..9 512x256
544	ShadowDepths
721	CompositionBeforeBasePass
725	BeginRenderingSceneColor
738	BasePass
1039	RenderVelocities
1049	ResolveSceneDepthTexture
1055	LightCompositionTasks_PreLighting
1148	ClearStencilFromBasePass
1157	ClearTranslucentVolumeLighting
1180	Lights
1181	DirectLighting
1182	NonShadowedLights
1191	IndirectLighting
1195	ShadowedLights
1196	TestScene.LightSource
1199	ClearRenderTargetView(1.0000, 1.0000, 1.0000, 1.0000)
1202	ShadowProjectionOnOpaque
1317	BeginRenderingSceneColor
1322	API Calls
1323	StandardDeferredLighting
1362	FilterTranslucentVolume 64x64x64 Cascades:2
1399	SkyLightDiffuse

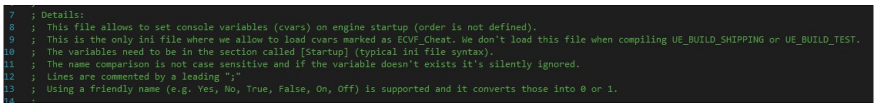
API Calls

EID	API Call
1324	ID3D11DeviceContext::RSSetViewports
1325	ID3D11DeviceContext::RSSetScissors
1326	ID3D11DeviceContext::IASetInputLayout
1327	ID3D11DeviceContext::VSSetShader
1328	ID3D11DeviceContext::PSSetShader
1329	ID3D11DeviceContext::GSSetShader
1330	ID3D11DeviceContext::OMSetBlendState
1331	ID3D11DeviceContext::PSSetConstantBuffers
1332	ID3D11DeviceContext::PSSetShaderResources

RenderDoc lets you break down a frame draw call by draw call and inspect GPU data!

Modifying ConsoleVariables.ini

This file is located in the `\Engine\Config\` directory and lets you specify values for variables to be set before the engine is started up. Most of these variables are already in there and explained.



```
; Details:
;  This file allows to set console variables (cvars) on engine startup (order is not defined).
;  This is the only ini file where we allow to load cvars marked as ECVF_Cheat. We don't load this file when compiling UE_BUILD_SHIPPING or UE_BUILD_TEST.
;  The variables need to be in the section called [Startup] (typical ini file syntax).
;  The name comparison is not case sensitive and if the variable doesn't exists it's silently ignored.
;  Lines are commented by a leading ";"
;  Using a friendly name (e.g. Yes, No, True, False, On, Off) is supported and it converts those into 0 or 1.
```

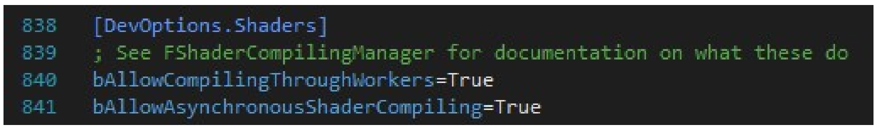
Setting **r.ShaderDevelopmentMode=1** will make Unreal prompt you for a shader recompile when the default material fails to compile. Under normal conditions Unreal will crash if it cannot compile the default material (for use as a fallback) so this makes Unreal prompt us and allows us to fix the compile error and retry without having to restart the editor. **Note:** If you have the debugger attached Unreal will still hit an assert even if this is enabled. This behavior can be disabled by commenting out an if statement in *ShaderCompiler.cpp* near the middle of `FShaderCompilingManager::HandlePotentialRetryOnError` just search for `FPlatformMisc::DebugBreak()`.

Setting **r.Shaders.Optimize=0** and **r.Shaders.KeepDebugInfo=1** makes Unreal instruct the shader compile to use lower levels of optimizations and to leave debug info. Lower levels of optimization should cut down on compile times and leaving the debug info in the shader will allow better debugging through RenderDoc.

Setting **r.DumpShaderDebugInfo=1** and **r.DumpShaderDebugShortNames=1** can be useful in certain situations. This writes generated HLSL to disk (which is about 2gb worth of data on an empty project), but I've found using RenderDoc to be a more effective debug tool. The second one just shortens the names of various things to help it fit under OS maximum path lengths.

Modifying BaseEngine.ini

If you scroll down to the **[DevOptions.Shaders]** section you will find **bAllowCompilingThroughWorker=True**, and **bAllowAsynchronousShaderCompiling=True**. These two flags combined will allow Unreal to do multi-threaded compiling of all the required shader maps. It can be useful to turn these off if you are trying to debug a section of the C++ shader pipeline (so that it only works on one shader at a time) but it will make shader compiles take a really long time!



```
[DevOptions.Shaders]
; See FShaderCompilingManager for documentation on what these do
bAllowCompilingThroughWorkers=True
bAllowAsynchronousShaderCompiling=True
```

Start an Empty Project

If it’s at all possible to start a new project to develop your shaders in then do it. **Every time you modify a shader file, Unreal recompiles all permutations that use that file.** This means that if you’re poking around in some of the base shaders (like we will be!) that you have to compile the ~125 shaders built into the engine which generate ~10,000 permutations on their own, yikes! Having an empty project will keep this number from getting any bigger, as it can take around 10 minutes on an i7–4770k.

Unreal has the ability to hot-reload some of the files in the shader pipeline on a per-material basis. This allows you to make a change in the shader code, modify the in-engine material and hit apply and have it reload the shader code. **Shader source hot reloading does not work with all files you can modify** as far as I can tell. One of the later blog posts will have a section on speeding up iteration for testing shader changes that goes into this in more detail.

Helpful Links

Below are some links to other existing documentation that may prove helpful in your understanding or provide alternative explanations to concepts that may make more sense to you. The articles here are linked in no particular order.

- Graphics Programming Overview Official Unreal documentation on the high-level overview of the rendering system, includes the parallels between the game thread and the render thread.
- Threaded Rendering covers inter-thread communication between Game and Rendering, and limitations and potential race conditions.
- Shader Development covers a high-level look at vertex factories, material shaders and global shaders.
- Coordinate Space Teminology covers what values various spaces are in, and—more importantly—what they’re relative to!

- How Unreal Renders a Frame covers the GPU side of a rendered frame, showing what order passes come in and examples of what a lot of the GPU data looks like.

Terminology

Below are some of the terms that will come up fairly often in this series so I felt it worth calling them out so that we're all on the same page here.

RHI

Render Hardware Interface which is a layer that abstracts the different graphics APIs for different platforms. All rendering commands are passed through the RHI layer to be translated to the applicable renderer.

Deferred Rendering

The default renderer in Unreal Engine 4. This document is mostly limited to this renderer. Gets its name from the fact it defers lighting/shading calculations to a full-screen pass instead of when each mesh is drawn. A full explanation of deferred rendering is beyond the scope of this document, so a passing familiarity is encouraged before diving into Unreal's rendering codebase. More information about deferred rendering can be found via the Wikipedia article, a nice compare/contrast of Forward vs Deferred, and an Intel Developer Zone example on Forward Clustered.

(Clustered) Forward Rendering

Unreal's desktop forward rendering implementation. This topic is not covered by this tutorial but you will come across many preprocessor defines related to it. This is different from the mobile renderer as well, which uses a more traditional tiled deferred renderer.

View

A single "window" into a `FScene` . Can have multiple views for a given `FScene` (ie: local split screen) but can also have multiple `FScene` 's in the Editor. Shaders have a similar usage as they call `ResolveView()` before rendering which can be either the Player's view, or the specific eye being rendered in VR.

Drawing Policy / Drawing Policy Factory

Unreal coins the term “Drawing Policy” to refer to a class that contains the logic to render specific meshes with specific shaders. For example, the Depth Only drawing policy finds the correct depth-only shader variant for a given material so that objects drawn using this policy use the optimized depth-only shaders. Drawing Policies do not tend to know specifics about the shaders or meshes they’re rendering. A Drawing Policy Factory is more type specific and handles creating a Drawing Policy for each object that should be rendered and adding them to different lists for later.

Vertex Factory

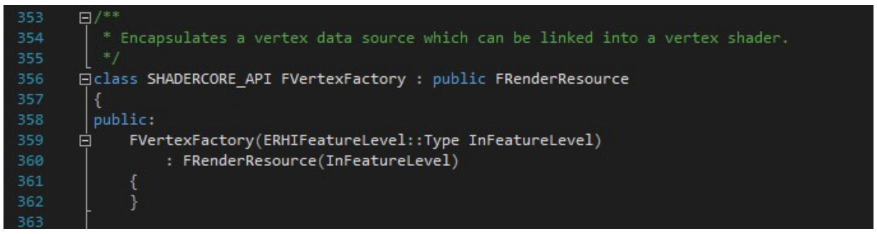
A Vertex Factory is a class that encapsulates a vertex data source and is linked to the input on a vertex shader. Static Meshes, Skeletal Meshes, and Procedural Mesh Components all use different Vertex Factories.

Shader

In Unreal a shader is a combination of HLSL code (in the form of .ush/.usf files) and the contents of a material graph. When creating a material in Unreal it compiles several shader permutations based on settings (like shading mode) and usages.

Next Post

In our next post we will be covering Shaders and Vertex Factories in more detail. We will talk about how the C++ code is bound to the HLSL code, how the C++ code modifies variables in the HLSL code, and how you can customize the data going into the vertex shader! That post is available here!



```
/**
 * Encapsulates a vertex data source which can be linked into a vertex shader.
 */
class SHADERCORE_API FVertexFactory : public FRenderResource
{
public:
    FVertexFactory(ERHIFeatureLevel::Type InFeatureLevel)
        : FRenderResource(InFeatureLevel)
    {
    }

```

Credits

Mostly written by Matt Hoffman @lordned, and peer reviewed by the following people: Sai Narayan @nightmask3, Jeremy Abel @jabelsjabels, Stephen Whittle @mov_eax_rgb, Joe Radak @Fr0z3nR,

Steve Biegun, Steve Davey @llnesisll, and Javad Kouchakzadeh @stoopdapoop. Thanks for sifting through 40+ pages of technical writing!