Diligent Engine: Building a Modern Graphics Abstraction Layer

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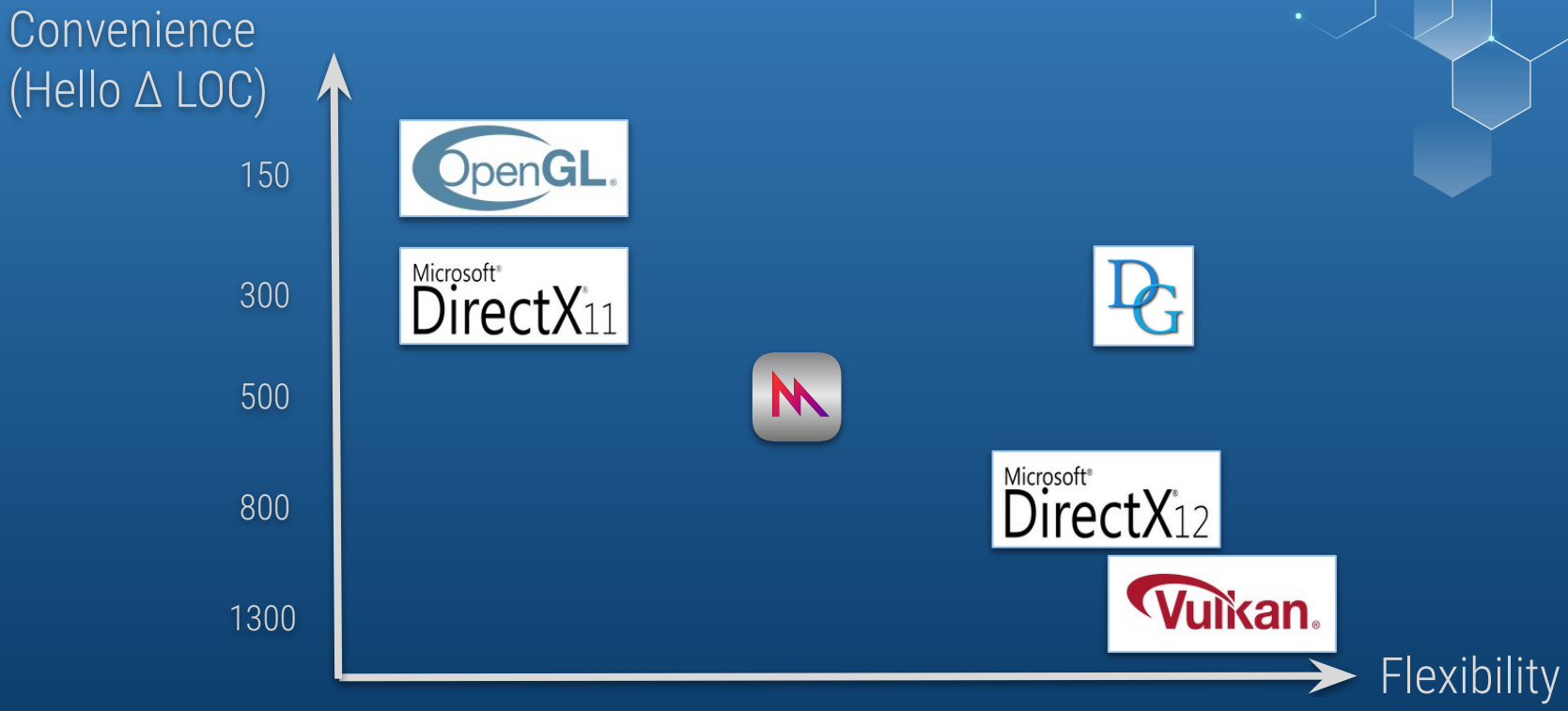
Agenda

- Motivation
- Diligent API Quick Overview
- **Resource Binding System**
- Pipeline State Packaging
- Testing

The Graphics API Diagram



Graphics API vs GPU API

```
layout(set=X, binding=Y) uniform sampler2D Texture;
```

Vulkan:

- Assign non-conflicting X and Y in the shader
- Create a descriptor set layout that uses the exact same binding
- Create pipeline descriptor that uses the set layout
- Create pipeline with the layout
- Create descriptor set from the set layout
- Write descriptor in the set at binding Y
- Bind the set at index X

Graphics API vs GPU API

```
layout(set=X, bi                    sampler2D Texture;
```

Encompasses descriptor sets and other binding details

Diligent:

```
pPSO->CreateShaderResourceBinding(&pSRB);

pSRB->GetVariableByName(SHADER_TYPE_PIXEL, "Texture")->Set(TextureSRV);

pCtx->CommitShaderResources(pSRB, RESOURCE_STATE_TRANSITION_MODE_TRANSITION);
```

Access shader resource by name

Binds all sets and executes barriers if necessary

Diligent API – Key Concepts

- Convenience
  - Resources are accessed by names, no explicit set/bindings
  - Default implementation for common operations
- Modern features
  - Multithreading, bindless, command queues, async compute, ray tracing, mesh shaders, VRS, sparse resources, …
- Flexibility
  - Application can take full control where needed

Diligent API Example – PSO Initialization

```
GraphicsPipelineStateCreateInfo PSOCreateInfo;

auto& PSODesc          = PSOCreateInfo.PSODesc;
auto& GraphicsPipeline = PSOCreateInfo.GraphicsPipeline;

PSODesc.Name         = "My PSO";
PSODesc.PipelineType = PIPELINE_TYPE_GRAPHICS;

GraphicsPipeline.NumRenderTargets              = 1;
GraphicsPipeline.RTVFormats[0]                 = TEX_FORMAT_RGBA8_UNORM_SRGB;
GraphicsPipeline.DSVFormat                     = TEX_FORMAT_D32_FLOAT;
GraphicsPipeline.PrimitiveTopology             = PRIMITIVE_TOPOLOGY_TRIANGLE_LIST;
GraphicsPipeline.RasterizerDesc.CullMode       = CULL_MODE_BACK;
GraphicsPipeline.DepthStencilDesc.DepthEnable = true;
```

Diligent API Example – Creating Shaders

```
ShaderCreateInfo ShaderCI;

ShaderCI.pShaderSourceStreamFactory = pShaderSourceFactory;

ShaderCI.SourceLanguage  = SHADER_SOURCE_LANGUAGE_HLSL;
ShaderCI.Desc.ShaderType = SHADER_TYPE_VERTEX;
ShaderCI.EntryPoint      = "main";
ShaderCI.Desc.Name       = "Cube VS";
ShaderCI.FilePath        = "cube.vsh";
pDevice->CreateShader(ShaderCI, &pVS);

PSOCreateInfo.pVS = pVS;
PSOCreateInfo.pPS = pPS;
```

Abstract shader source code provider

Diligent supports HLSL, GLSL, MSL, DXBC, DXIL, SPIRV, AIR

Diligent API Example – Input Layout

```
LayoutElement LayoutElems[] =
{
    // Attribute 0 - vertex position
    LayoutElement{0, 0, 3, VT_FLOAT32},
    // Attribute 1 - texture coordinates
    LayoutElement{1, 0, 2, VT_FLOAT32}
};

PSOCreateInfo.GraphicsPipeline.InputLayout.LayoutElements = LayoutElems;
PSOCreateInfo.GraphicsPipeline.InputLayout.NumElements    = 2;
```

```
struct VSInput
{
    float3 Pos : ATTRIB0;
    float2 UV  : ATTRIB1;
};
VSOutput main(in VSInput VSIn)
```

Diligent API Example – Resource Layout

```
ShaderResourceVariableDesc Vars[] =
{
    {SHADER_TYPE_PIXEL, "Texture", SHADER_RESOURCE_VARIABLE_TYPE_MUTABLE}
};
PSOCreateInfo.PSODesc.ResourceLayout.Variables    = Vars;
PSOCreateInfo.PSODesc.ResourceLayout.NumVariables = 1;

pDevice->CreateGraphicsPipelineState(PSOCreateInfo, &pPSO);
```

Diligent API Example – Shader Resource Binding

Static resources are set in the PSO

```
pPSO->GetStaticVariableByName(SHADER_TYPE_VERTEX, "Constants")->Set(pVSConstants);

pPSO->CreateShaderResourceBinding(&pSRB, true);


TextureLoadInfo loadInfo;
loadInfo.IsSRGB = true;
RefCntAutoPtr<ITexture> pTex;
CreateTextureFromFile("Texture.png", loadInfo, m_pDevice, &pTex);
auto* pTextureSRV = pTex->GetDefaultView(TEXTURE_VIEW_SHADER_RESOURCE);

pSRB->GetVariableByName(SHADER_TYPE_PIXEL, "Texture")->Set(pTextureSRV);
```

Shader Resource Binding object is created from the Pipeline

Mutable and dynamic resources are set in the SRB

Diligent API Example – Rendering

```
auto* pRTV = pSwapChain->GetCurrentBackBufferRTV();
auto* pDSV = pSwapChain->GetDepthBufferDSV();
pCtx->SetRenderTargets(1, &pRTV, pDSV, RESOURCE_STATE_TRANSITION_MODE_TRANSITION);

const float ClearColor[] = {0.35f, 0.35f, 0.35f, 1.0f};
pCtx->ClearRenderTarget(pRTV, ClearColor, RESOURCE_STATE_TRANSITION_MODE_TRANSITION);

pCtx->ClearDepthStencil(pDSV, CLEAR_DEPTH_FLAG, 1.f, 0,
RESOURCE_STATE_TRANSITION_MODE_TRANSITION);
```

Tells the engine how to handle resource state transitions

Possible options are:
- None
- Transition
- Verify

Diligent API Example – Rendering

```
const Uint64 offset   = 0;
IBuffer*       pBuffs[] = {pVertexBuffer};
pCtx->SetVertexBuffers(0, 1, pBuffs, &offset, RESOURCE_STATE_TRANSITION_MODE_TRANSITION);
pCtx->SetIndexBuffer(pIndexBuffer, 0, RESOURCE_STATE_TRANSITION_MODE_TRANSITION);

pCtx->SetPipelineState(pPSO);
pCtx->CommitShaderResources(pSRB, RESOURCE_STATE_TRANSITION_MODE_TRANSITION);

DrawIndexedAttribs DrawAttrs;
DrawAttrs.IndexType    = VT_UINT32;
DrawAttrs.NumIndices = 36;
pCtx->DrawIndexed(DrawAttrs);
```

Binds descriptor sets

Shader Resource Binding Model 1.0

- Use reflection to get the list of resources
- Each resource is classified by the app as
  - Static - can only be set once in the PSO
  - Mutable - can only be set once in each SRB instance
  - Dynamic - can be set multiple times in each SRB instance
- Programmatically assign descriptor sets and bindings
- Patch SPIRV to make it consistent with bindings

Shader Resource Binding Model 1.0

- Two descriptor sets (if necessary)
  - Static/Mutable resources
  - Dynamic resources
- Within each set, 3 groups (total 6 groups)
  - Dynamic-offset uniform buffers
  - Dynamic-offset storage buffers
  - All other resources

Shader Resource Binding Model 1.0

Descriptor Set/Binding Allocation Algorithm

```
ShaderResourceVariableDesc Vars[] =
{
    {SHADER_TYPE_PIXEL, "Texture",
     SHADER_RESOURCE_VARIABLE_TYPE_MUTABLE}
};
```

```
for (const auto& ResDesc : PipelineResources)
{
    const auto SetId          = VarTypeToDescriptorSetId(ResDesc.VarType); // 0 - Static/Mutable, 1 - Dynamic
    const auto DescrType      = GetDescriptorType(ResDesc);
    const auto CacheGroup = GetResourceCacheGroup(ResDesc); // [Static/Mutable, Dynamic] x [Dyn UB, Dyn SB, Other]

    AddDescriptor(Binding[CacheGroup],
                  ResDesc.ArraySize,
                  DescrType,
                  SetId,
                  CacheOffsets[CacheGroup]);

    Binding        [CacheGroup] += 1;
    CacheOffsets[CacheGroup] += ResDesc.ArraySize;
}
```

Initial values are computed by counting the number of resources in each group

Shader Resource Binding Model 1.0

Example

```
uniform GlobalAttribsUB        {}; // Static, no dyn offsets
uniform FrameTransformsUB {}; // Mutable, no dyn offsets
uniform MeshTransformsUB  {}; // Mutable, dyn offsets
uniform SpecialAttribsUB       {}; // Dynamic, dyn offsets

buffer LightsSB {}; // Static, dyn offsets

uniform sampler2D ShadowMap;      // Static
uniform sampler2D BaseColor[8];   // Mutable
uniform sampler2D Normals[8];     // Mutable
uniform sampler2D ColorCorection; // Dynamic
```

Set 0 - Static / Mutable		
Name	Binding	Offset
MeshTransformsUB	0	0
LightsSB	1	1
GlobalAttribsUB	2	2
FrameTransformsUB	3	3
ShadowMap	4	4
BaseColor	5	5
Normals	6	13

Set 1 - Dynamic		
Name	Binding	Offset
SpecialAttribsUB	0	0
ColorCorection	1	1

Shader Resource Binding Model 1.0

SPIRV Patching

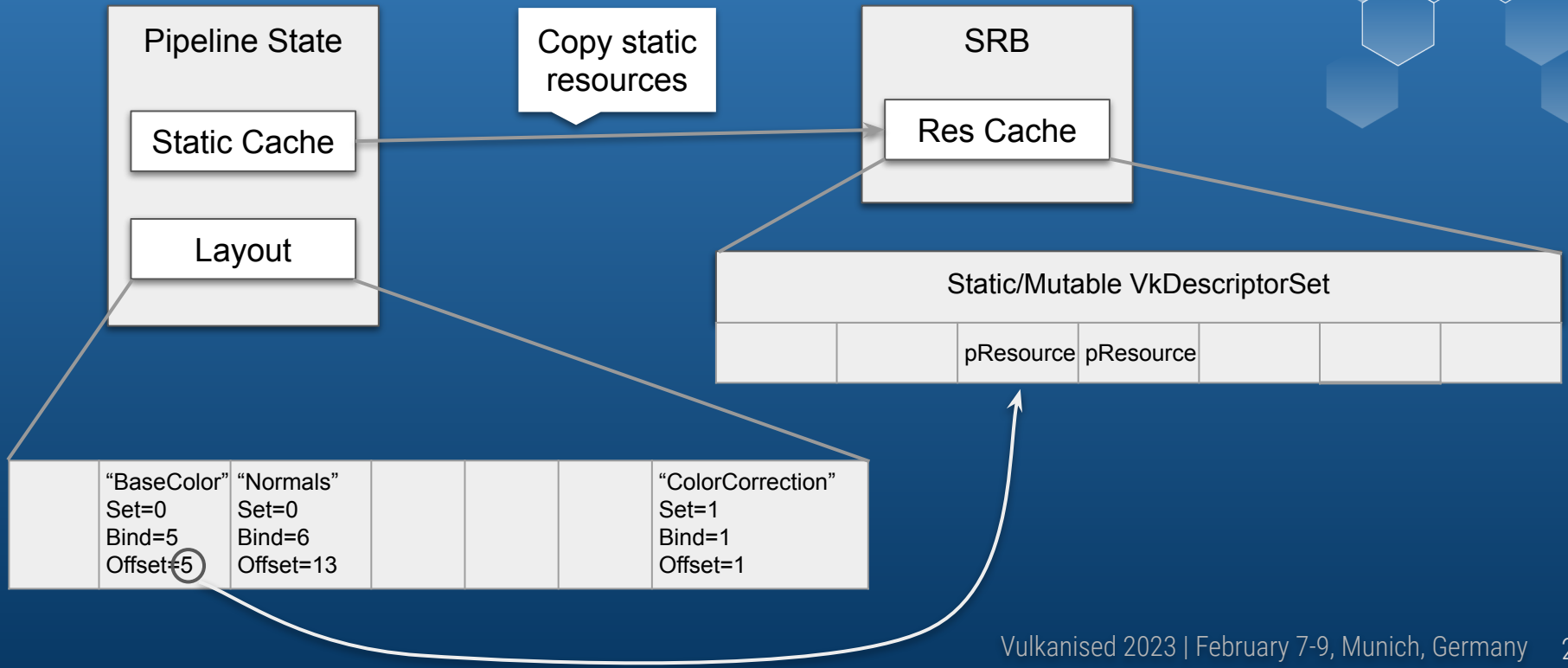
```
// Load SPIRV resources
spirv_cross::Parser parser{move(spirv_binary)};
parser.parse();

const auto ParsedIRSource = parser.get_parsed_ir().source;
spirv_cross::Compiler Compiler{std::move(parser.get_parsed_ir())};

spirv_cross::ShaderResources resources = Compiler.get_shader_resources();
for (const auto& UB : resources.uniform_buffers)
{
    Compiler.get_binary_offset_for_decoration(UB.id, spv::Decoration::DecorationBinding,          &BindingDecorationOffset);
    Compiler.get_binary_offset_for_decoration(UB.id, spv::Decoration::DecorationDescriptorSet, &DescrSetDecorationOffset);
    // Save decorations
}

for (const auto& SB : resources.storage_buffers)
// Process other resource types
```

Shader Resource Binding Model 1.0

SPIRV Patching

```
// Patch SPIRV using the assigned sets and bindings
for (size_t s = 0; s < ShaderStages.size(); ++s) // There may be multiple shaders in the stage in case of ray tracing
{
    const auto& Shaders = ShaderStages[s].Shaders;
    auto&       SPIRVs  = ShaderStages[s].SPIRVs;
    for (size_t i = 0; i < Shaders.size(); ++i)
    {
        auto* pShader = Shaders[i];
        auto& SPIRV   = SPIRVs[i];
        for (const auto& Res : pShader->GetShaderResources())
        {
            const auto& ResAttribs = Layout.GetResourceAttribs(Res.Name);
            SPIRV[Res.BindingDecorationOffset]         = ResAttribs.Binding;
            SPIRV[Res.DescriptorSetDecorationOffset] = ResAttribs.DescriptorSet;
        }
    }
}
```

Shader Resource Binding Model 1.0



Shader Resource Binding Model 1.0

Committing Resources

- Set Static/Mutable descriptor set from the SRB (if any)
- Allocate dynamic descriptor set (if any)
  - Copy all dynamic descriptors from the SRB
- Write dynamic offsets and commit descriptor sets

Shader Resource Binding Model 2.0

Limitations of version 1.0:

- Shader resource binding objects of different pipelines are incompatible
  - SRB of pipeline 1 can only be used with pipeline 2 when they use the exact same resources
- All pipeline resources are consolidated
  - Can’t split resources based on the frequency of change (e.g. frame / pass / object)

Shader Resource Binding Model 2.0

Pipeline Resource Signature

- Defines resource layout independently of any pipeline state
- Each pipeline state may use up to 8 signatures
  - Descriptor sets of each signature stack on top of previous sets
- SRBs can be reused between pipelines
- Pipeline states take bindings from the resource signatures

Shader Resource Binding Model 2.0

Pipeline Resource Signature

```
PipelineResourceSignatureDesc PRSDesc;
PRSDesc.Name = "Ray tracing scene resources";

const PipelineResourceDesc Resources[] =
{
    {SHADER_TYPE_COMPUTE, "g_TLAS",         1,  ACCEL_STRUCT,      VARIABLE_TYPE_STATIC},
    {SHADER_TYPE_COMPUTE, "g_Constants",    1,  CONSTANT_BUFFER,   VARIABLE_TYPE_MUTABLE},
    {SHADER_TYPE_COMPUTE, "g_VertexBuffer", 1,  BUFFER_SRV,        VARIABLE_TYPE_DYNAMIC},
    {SHADER_TYPE_COMPUTE, "g_IndexBuffer",  1,  BUFFER_SRV,        VARIABLE_TYPE_DYNAMIC},
    {SHADER_TYPE_COMPUTE, "g_Textures",     8,  TEXTURE_SRV,       VARIABLE_TYPE_MUTABLE},
    {SHADER_TYPE_COMPUTE, "g_Samplers",     2,  SAMPLER,           VARIABLE_TYPE_STATIC}
};
PRSDesc.BindingIndex    = 0;
PRSDesc.Resources       = Resources;
PRSDesc.NumResources = 6;

pDevice->CreatePipelineResourceSignature(PRSDesc, &pRayTracingSign);
```

Array Size

Resource type

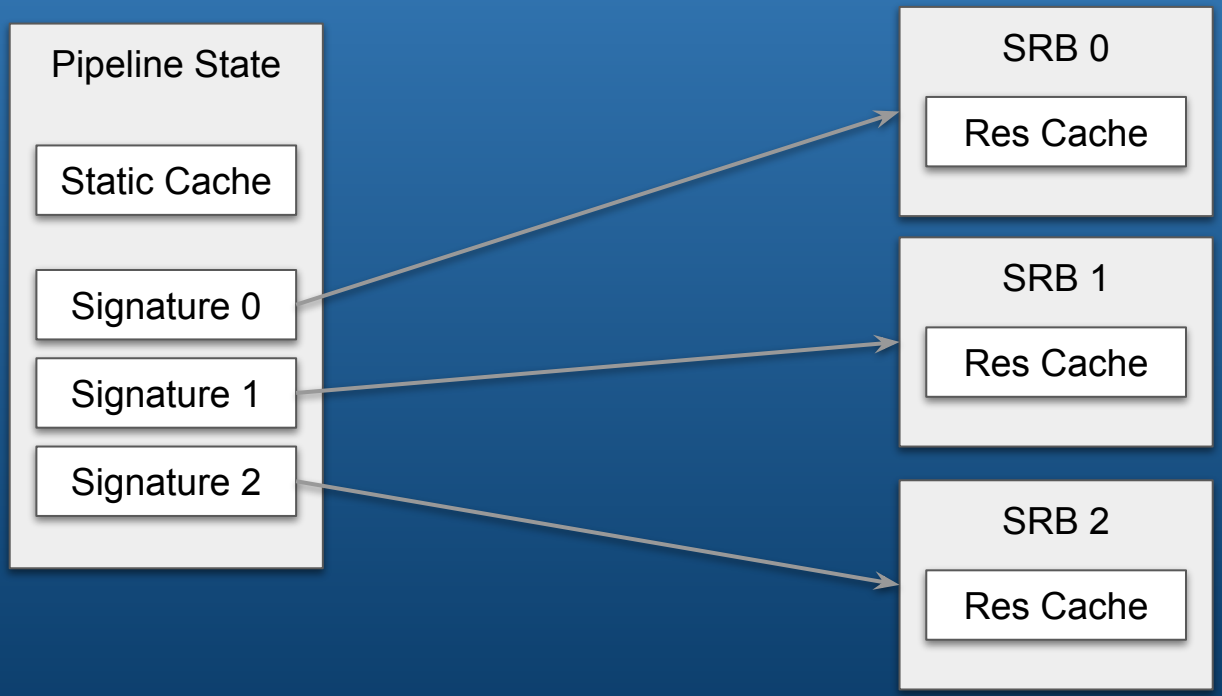
Variable type

Shader Resource Binding Model 2.0

Pipeline Resource Signature

```
IPipelineResourceSignature* ppSignatures[] =
{
    pRayTracingSign,
    pScreenResourcesSign
};
PSOCreateInfo.ppResourceSignatures      = ppSignatures;
PSOCreateInfo.ResourceSignaturesCount = 2;

pDevice->CreateComputePipelineState(PSOCreateInfo, &pRayTracingPSO);
```

Shader Resource Binding Model 2.0



Shader Resource Binding Model 2.0

Example

```
// Signature 0 - Frame Constants
uniform                FrameConstantsUB{}; // Static
uniform sampler2D SunShadowMap;        // Static

// Signature 1 - Render Pass Constants
uniform                CameraTransformUB{}; // Mutable
uniform sampler2D AmbientOcclusion;        // Mutable

// Signature 2 - Object constants
uniform ObjectTransformUB  {}; // Mutable
buffer    LightsSB {};                 // Dynamic

uniform sampler2D ObjectShadowMap; // Mutable
uniform sampler2D BaseColor;              // Mutable
uniform sampler2D Normals;                // Mutable
```

Signature 0 - Set 0 (0)
FrameConstantsUB
SunShadowMap

Signature 1 - Set 0 (1)
CameraTransformUB
AmbientOcclusion

Signature 2 - Set 0 (2)
ObjectTransformUB
ObjectShadowMap
BaseColor
Normals

Signature 2 - Set 1 (3)
LightsSB

Shader Resource Binding Model 2.0

Example

```
pFrameSign->CreateShaderResourceBinding(&pFrameSRB, true);
pCtx->CommitShaderResources(pFrameSRB);

for (size_t pass = 0; pass < PassCount; ++pass)
{
    pCtx->CommitShaderResources(pPassSRB);
    for (size_t obj = 0; obj < NumObjects; ++obj)
    {
        pCtx->SetPipelineState(pObjectPSO);
        pCtx->CommitShaderResources(pObjectSRB);
        pCtx->DrawIndexed();
    }
}
```

Uses pFrameSign, pPassSign, pObjectSign

Diligent Render State Notation

- JSON-based state description language
  - Shaders
  - Resource signatures
  - Pipeline states
- Can be parsed at run-time or off-line
- Off-line archiver tool processes all states and packages them into archive
  - Compiles shaders, defines layouts, patches byte code
  - Run-time loading is very fast

Diligent Render State Notation

```
"PSODesc": {
    "Name": "G-Buffer PSO",
    "ResourceLayout": {
        "Variables": [
            {
                "Name": "cbConstants",
                "ShaderStages": "PIXEL",
                "Type": "STATIC"
            }
        ]
    }
},
"GraphicsPipeline": {
    "PrimitiveTopology": "TRIANGLE_LIST",
    "RasterizerDesc": {
        "CullMode": "NONE"
    },
    "DepthStencilDesc": {
        "DepthEnable": false
    }
},
```

```
"pVS": {
    "Desc": {
        "Name": "Screen Triangle VS"
    },
    "FilePath": "screen_tri.vsh",
    "EntryPoint": "main"
},
"pPS": {
    "Desc": {
        "Name": "G-Buffer PS"
    },
    "FilePath": "g_buffer.psh",
    "EntryPoint": "main"
}
```

Testing

- Render reference image using native API, compare with what Diligent renders
  - Robust to driver updates, API differences, different GPUs
- Intercept errors, fail tests if any detected
  - Run special tests to simulate error situations
- Run tests on each commit
  - Linux -> Vulkan/OpenGL
  - Windows -> Direct3D11/Direct3D12
- Run golden image tests for Tutorial and Sample applications

Links

- GitHub: https://github.com/DiligentGraphics/DiligentEngine
- Vulkan Backend
  - https://github.com/DiligentGraphics/DiligentCore/tree/master/Graphics/GraphicsEngineVulkan
- Resource Binding:
  - PipelineResourceSignatureVkImpl.cpp
  - PipelineStateVkImpl.cpp
  - ShaderResourceBindingVkImpl.cpp
  - SPIRVShaderResources.cpp

Thank you!

Backup

Shader Resource Binding

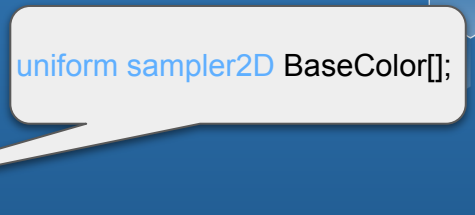
Immutable Samplers

- Backed into the pipeline state
- Don’t require sampler at run time
- More efficient

```
ImmutableSamplerDesc ImtblSamplers[] =
{
    {SHADER_TYPE_PIXEL, "Texture", LinearClamp}
};
ResourceLayout.ImmutableSamplers        = ImtblSamplers;
ResourceLayout.NumImmutableSamplers = 1;
```

Shader Resource Binding

Other features



- Run-time resource arrays
  - PIPELINE_RESOURCE_FLAG_RUNTIME_ARRAY
- Disallow dynamic offsets
  - PIPELINE_RESOURCE_FLAG_NO_DYNAMIC_BUFFERS
- Update mutable variables
  - SET_SHADER_RESOURCE_FLAG_ALLOW_OVERWRITE

Multithreaded Command Recording

- Create one deferred context per thread
- Record commands in each thread using the RESOURCE_STATE_TRANSITION_MODE_NONE to disable automatic state handling
  - Manually issue synchronization commands
- Get command lists from each deferred context and execute them in immediate context

Multiple Command Queues

- Immediate context = command queue + command list + state (e.g., dynamic memory)
- Multiple command queues = multiple immediate contexts
- An application may run commands directly in each immediate context or record them through deferred contexts and execute
- Manual synchronization between contexts is done through fences