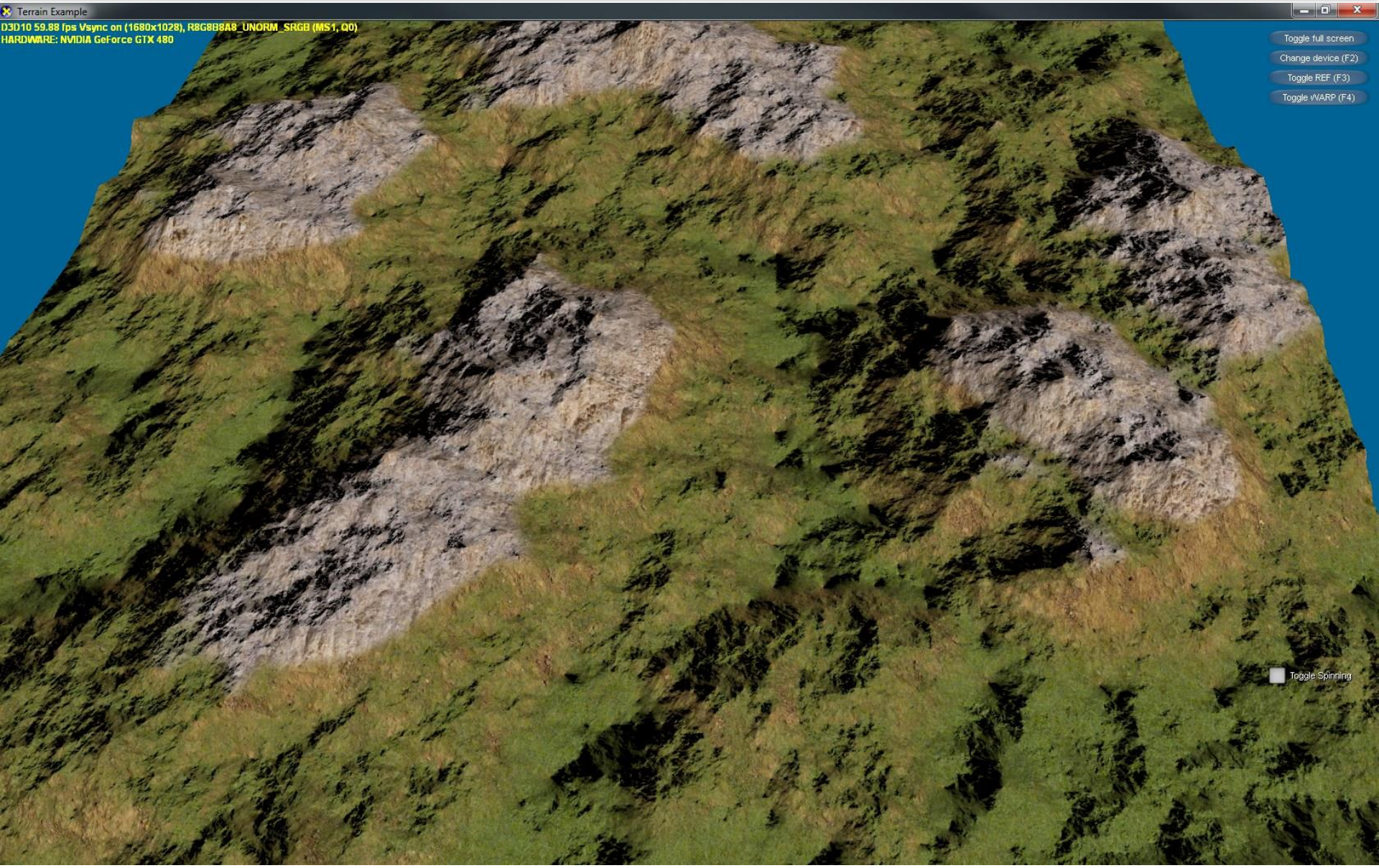
Game Engine Design



tum.3D

computer graphics & visualization

This week: Realtime Rendering



Assignment 4

Goal:

- Render the terrain yourself
  (implement the viewer)
- Input: height map + color texture + normal texture
- Output: realtime rendering of a lit and textured landscape
- Using only the “fixed” function pipeline (no shader programs)

Direct3D Overview

- Direct3D is a graphics API to access the underlying hardware
  - Part of DirectX
  - Provides GPU memory allocation / deallocation („GPU resources“), pipeline configuration, draw calls and much more…

Microsoft® DirectX®

Direct3D Overview

- DirectX API is based on abstract interfaces
  - You never work on real class instances
  - DirectX allocates and deallocates its resources
    - Available through pointers to `IUnknown` (or a descendent of it)
    - Lifecycles management: Internal reference counters via `IUnknown::AddRef()` and `IUnknown::Release()`

Direct3D Overview

- AddRef / Release: Similar to new and delete
  - Each AddRef() requires a Release()
  - DirectX calls AddRef() automatically whenever a pointer to an Interface is created

```
ID3D11Device* device;
...
ID3D11DeviceContext* context;
device->GetImmediateContext(&context);          // Calls AddRef() on the created context
```

Direct3D Overview

- Two main Direct3D interfaces

ID3D11Device

- Access to a Direct3D device (usually a single GPU)
- Used to **create** all resources for a GPU

ID3D11DeviceContext

- Manages the current pipeline state
- Used to **bind** resources to various pipeline stages
- Used for draw calls

- ID3D11DeviceContext: State machine

Resources

- **Resource**: An object allocated in GPU memory
  - Buffers
    - Vertex / Index Buffer: Vertex data and connectivity
    - ConstantBuffer: Variables accessed in GPU shader programs
  - Textures
    - Texture1D, Texture2D, Texture3D
    - Like buffers with additional functionality
      - Multi-dimensional access, hardware interpolation
- All these resources are read-only for the GPU

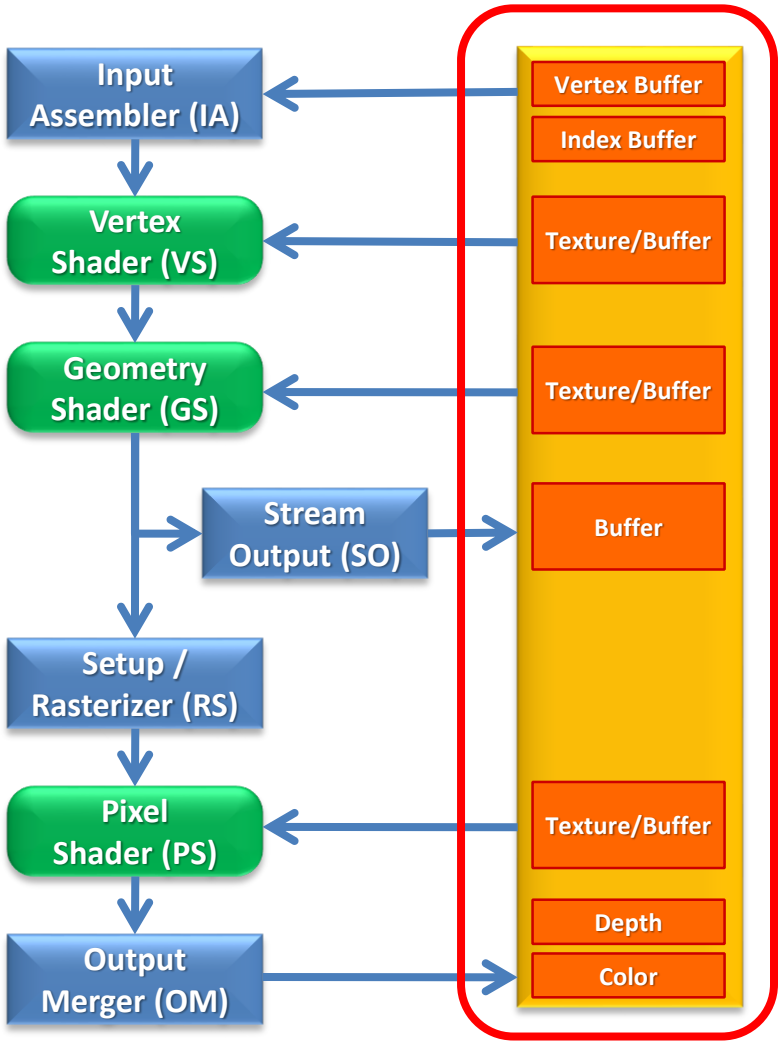
Resources

- All resources descend from `ID3D11Resource`
  - `ID3D11Buffer`
  - `ID3D11Texture2D`

- Creation:
  - `ID3D11Device::CreateBuffer()`
  - `ID3D11Device::CreateTexture2D()`
  - …

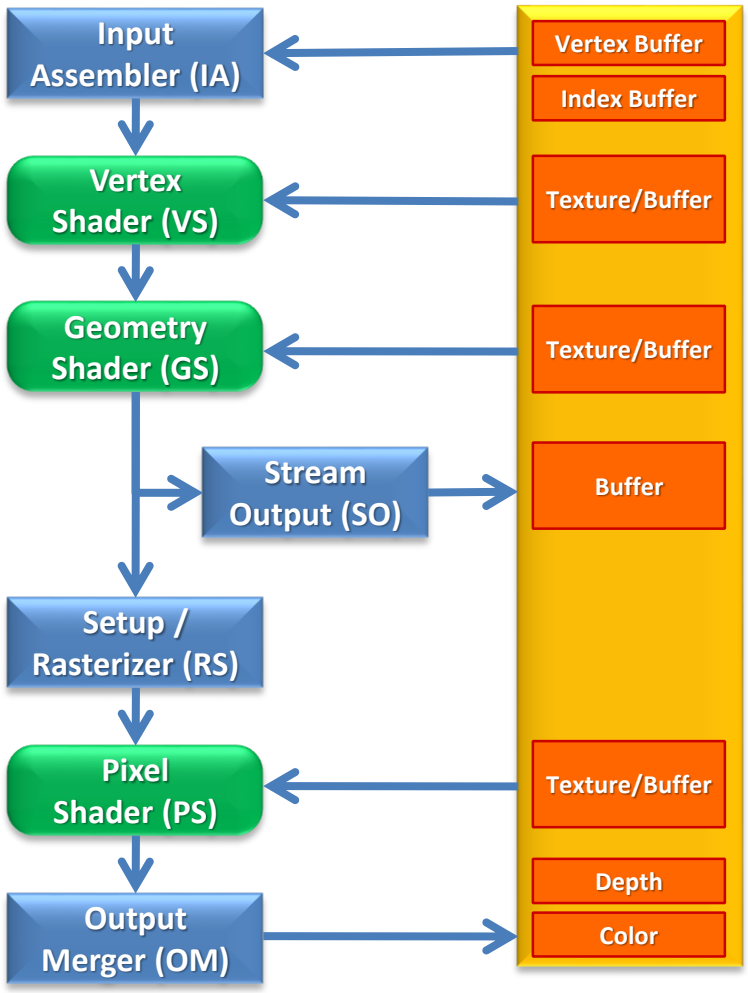
Graphics Pipeline

- Resources are **bound** to the graphics pipeline
  - Draw call: Process a fixed number of vertices
  - Resources cannot change during a draw call
  - Different stages may have access to different resources
  - Pipeline state: `ID3D11DeviceContext`



Input Assembler

- Purpose:
  - Generate vertex data from input
- Input:
  - Vertex Buffers + Index Buffer
- Output:
  - Vertices with attributes
- Controllable through:
  - `IASetVertexBuffers` / `IASetIndexBuffer`
  - `IASetInputLayout`
  - `IASetPrimitiveTopology`



Input Assembler (IA)

The *Input Assembler* stage supplies geometry data (e.g. Lines or Triangles) for the rest of the pipeline

- It reads user defined data blocks and
  - Uses an *Input Layout* to interpret the data
  - Generates a set of geometric primitives controlled by `D3D11_PRIMITIVE_TOPOLOGY`
    - `D3D11_PRIMITIVE_TOPOLOGY_TRIANGLELIST`
  - Supplies the assembled primitives to the rest of the pipeline
- The elemental unit thereby is the edge point (vertex), which can carry arbitrary user defined attributes (e.g. position, normal, color, …)

Vertices

- Vertices contain arbitrary user defined attributes
- Most common:
  - Position(s)
  - Normal(s)
  - Color(s)
  - Texture coordinate(s)
  - Material parameter(s)

Vertex Data

- C++ side: vertices are stored in linear arrays

```
float triangle[] = {
    // Vertex 0
       0.0f,    0.0f,    0.0f,  1.0f, // Position
       0.0f,    1.0f,    0.0f,  0.0f, // Normal
       0.0f,    0.0f,                 // Texcoords

    // Vertex 1
       1.0f,     0.0f,    0.0f, 1.0f, // Position
       0.0f,     1.0f,    0.0f, 0.0f, // Normal
       0.0f,     1.0f,                // Texcoords

    // Vertex 2
       0.0f,    0.0f,    1.0f,  1.0f, // Position
       0.0f,    1.0f,    0.0f,  0.0f, // Normal
       1.0f,    0.0f,                 // Texcoords
};
```

- Usually represented by a `struct` for cleaner code:
  -
```
struct SimpleVertex
{
    DirectX::XMFLOAT4 Pos;          // Position
    DirectX::XMFLOAT4 Normal;       // Normal
    DirectX::XMFLOAT2 UV;           // Texture coordinates
};
```

Input Layout

- The GPU gets the raw data in one (or several) buffer(s)
- Additionally it needs an ***Input-Layout*** to interpret the data
- A `D3D11_INPUT_ELEMENT_DESC` thereby describes each vertex attribute
- Must be consistent with the vertex on C++ (struct) and HLSL (GPU vertex shader input) sides!
- Is already defined in our template!

Input Layout

- Example:

```
// Define the input layout
const D3D11_INPUT_ELEMENT_DESC layout[] = // http://msdn.microsoft.com/en-us/library/bb205117%28v=vs.85%29.aspx
{
       { "SV_POSITION",    0, DXGI_FORMAT_R32G32B32A32_FLOAT, 0, 0, D3D11_INPUT_PER_VERTEX_DATA, 0 },
       { "NORMAL",         0, DXGI_FORMAT_R32G32B32A32_FLOAT, 0, 16, D3D11_INPUT_PER_VERTEX_DATA, 0 },
       { "TEXCOORD",       0, DXGI_FORMAT_R32G32_FLOAT,       0, 32, D3D11_INPUT_PER_VERTEX_DATA, 0 },
};
UINT numElements = sizeof( layout ) / sizeof( layout[0] );

// Create the input layout
D3DX11_PASS_DESC pd;
V_RETURN(g_gameEffect.pass0->GetDesc(&pd));
V_RETURN( pd3dDevice->CreateInputLayout( layout, numElements, pd.pIAInputSignature,
        pd.IAInputSignatureSize, &g_terrainVertexLayout ) );
```

- To create the InputLayout, the *input signature* of the vertex shader is required (here: signature of a *pass*)
- The input layout is bound to the pipeline via:

```
// Set input layout
pd3dImmediateContext->IASetInputLayout( g_terrainVertexLayout );
```

Vertex Buffer

- Now the GPU knows how to interpret the data, but it still needs the data itself.
- Therefore we create a ***Vertex Buffer*** on the GPU and fill it with our data.
- Creation requires two additional structures:
  - `D3D11_BUFFER_DESC` describes the buffer
  - `D3D11_SUBRESOURCE_DATA` to deliver the data

Vertex Buffer

- Vertex buffer creation:

```
// Create and fill description
D3D11_SUBRESOURCE_DATA id;
id.pSysMem = &triangle[0];
id.SysMemPitch = 10 * sizeof(float); // Stride
id.SysMemSlicePitch = 0;

// Define initial data
D3D11_BUFFER_DESC bd;
bd.BindFlags = D3D11_BIND_VERTEX_BUFFER;
bd.ByteWidth = triangle.size() * sizeof(float);
bd.CPUAccessFlags = 0;
bd.MiscFlags = 0;
bd.Usage = D3D11_USAGE_DEFAULT;

// Create buffer
V(device->CreateBuffer(&bd, &id, &vertexBuffer));
```

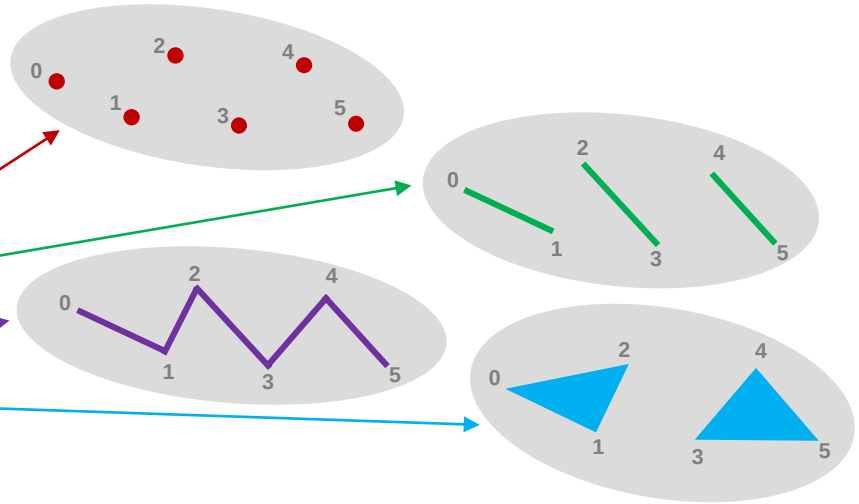
- Vertex buffer binding:

```
context->IASetVertexBuffers(0, 1, vbs, strides, offsets);
```

  - Stride: size of one element
  - Offset: offset of the first element in the buffer

Primitive Topology

- Now the GPU has the vertex data and knows how to interpret it
- Now we tell it the kind of geometric primitive we want to describe
- Examples:
  - D3D11_PRIMITIVE_TOPOLOGY_POINTLIST
  - D3D11_PRIMITIVE_TOPOLOGY_LINELIST
  - D3D11_PRIMITIVE_TOPOLOGY_LINESTRIP
  - D3D11_PRIMITIVE_TOPOLOGY_TRIANGLELIST



- We set the topology like this:

```
context->IASetPrimitiveTopology(D3D11_PRIMITIVE_TOPOLOGY_LINESTRIP);
```

Execute the Rendering (Draw)

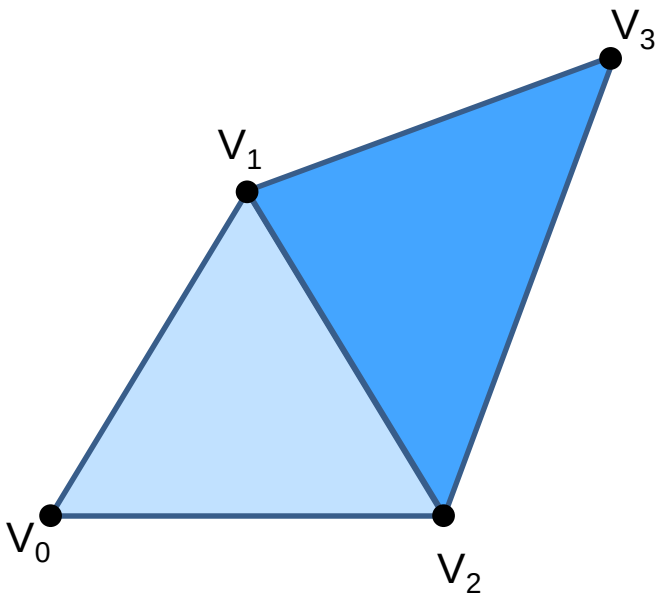
- When the pipeline state is completely set, we „draw“ our data using a certain *pass* of an effect *technique*:

```
// Render
D3D11_TECHNIQUE_DESC techDesc;
g_pTechnique->GetDesc( &techDesc );
for( UINT p = 0; p < techDesc.Passes; ++p ) {
    // A technique may require multiple rendering passes
    g_pTechnique->GetPassByIndex( p )->Apply(0, context);
    context->Draw( 3, 0 );
}
```

Number of vertices to draw

Index of the first vertex within the buffer to daw

Draw() vs. DrawIndexed()



- Draw
  - VB[]={V_0,V_1,V_2,V_2,V_1,V_3};
  - Implicit topology
  - **Redundant data, e.g.**
    - **Position, Normal, UV …**
- DrawIndexed
  - VB[]={V_0,V_1,V_2,V_3};
  - IB[] ={0,1,2, 2,1,3};
  - Explicit topology

Index Buffer

- Creation similar to Vertex Buffer:

```
// Create and fill description
ZeroMemory(&bd, sizeof(bd));
bd.Usage = D3D11_USAGE_DEFAULT;
bd.ByteWidth = sizeof(unsigned int) * indices.size();
bd.BindFlags = D3D11_BIND_INDEX_BUFFER;
bd.CPUAccessFlags = 0;
bd.MiscFlags = 0;

// Define initial data
ZeroMemory(&id, sizeof(id));
id.pSysMem = &indices[0];

// Create Buffer
V(device->CreateBuffer( &bd, &id, &indexBuffer ));
```

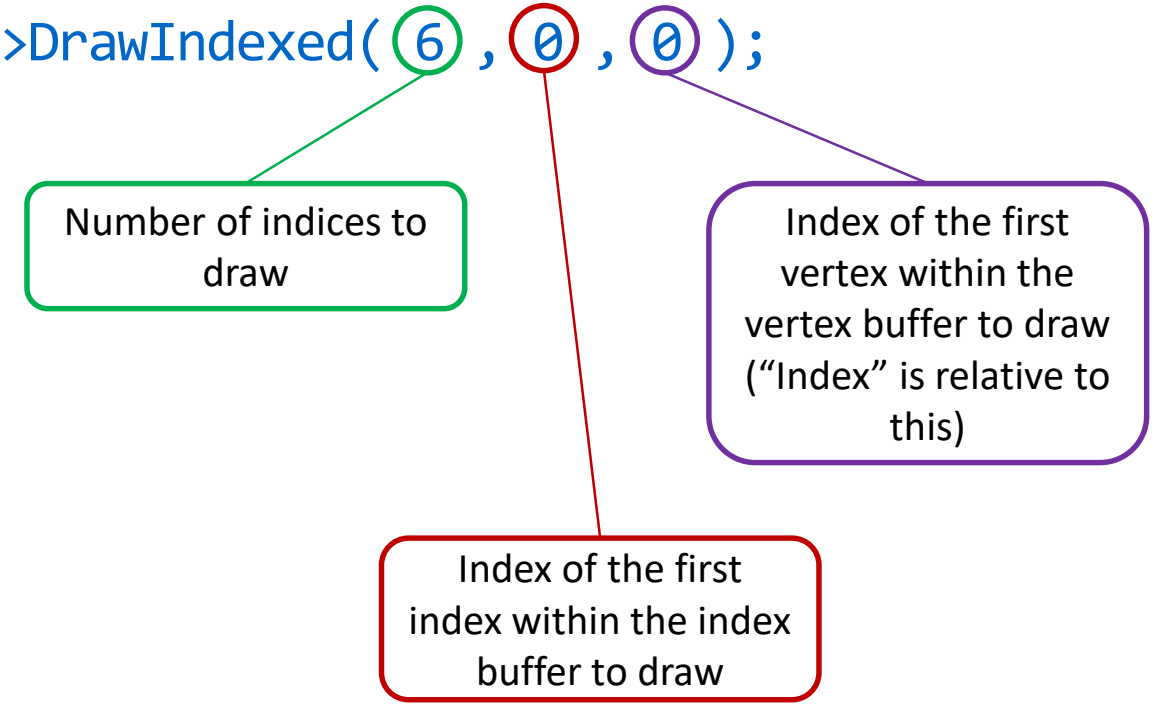
- Binding:

```
context->IASetIndexBuffer(indexBuffer, DXGI_FORMAT_R32_UINT, 0);
```

DrawIndexed

- Slightly different draw command:

```
…
context->DrawIndexed( 6 , 0 , 0 );
…
```



Resource Views

- Shader programs do not access resources directly

- Instead: **ResourceViews** are bound to the pipeline
  - `ID3D11ShaderResourceView`
  - `ID3D11Device::CreateShaderResourceView()`
  - Each resource needs at least one ResourceView when it is accessed by a shader

- ResourceViews offer more flexible control
  - E.g. only bind a specific mip-map of a texture

Resource Views

```
HRESULT CreateShaderResourceView(
        [in]   ID3D11Resource *pResource,
        [in]   const D3D11_SHADER_RESOURCE_VIEW_DESC *pDesc,
        [out]  ID3D11ShaderResourceView **ppSRView
);
```

- `D3D11_SHADER_RESOURCE_VIEW_DESC` describes the resource view to be created (width, height, etc)

- Common usecase: Textures
  - You can pass `nullptr` for pDesc!

Resource Views

```
DirectX::CreateDDSTextureFromFile(device, L"resources\\debug_green.dds", nullptr, &debugSRV)
```

- DDSTextureLoader.h: Simple DDS loading
  - Creates a resource and a resource view
  - Can also be `nullptr` if you do not need both
  - Top example: Resource is also created, of course!
    - Released upon release of the resource view (by reference counting)
    - You'll need to release the resource view (debugSRV) yourself

The Template Project

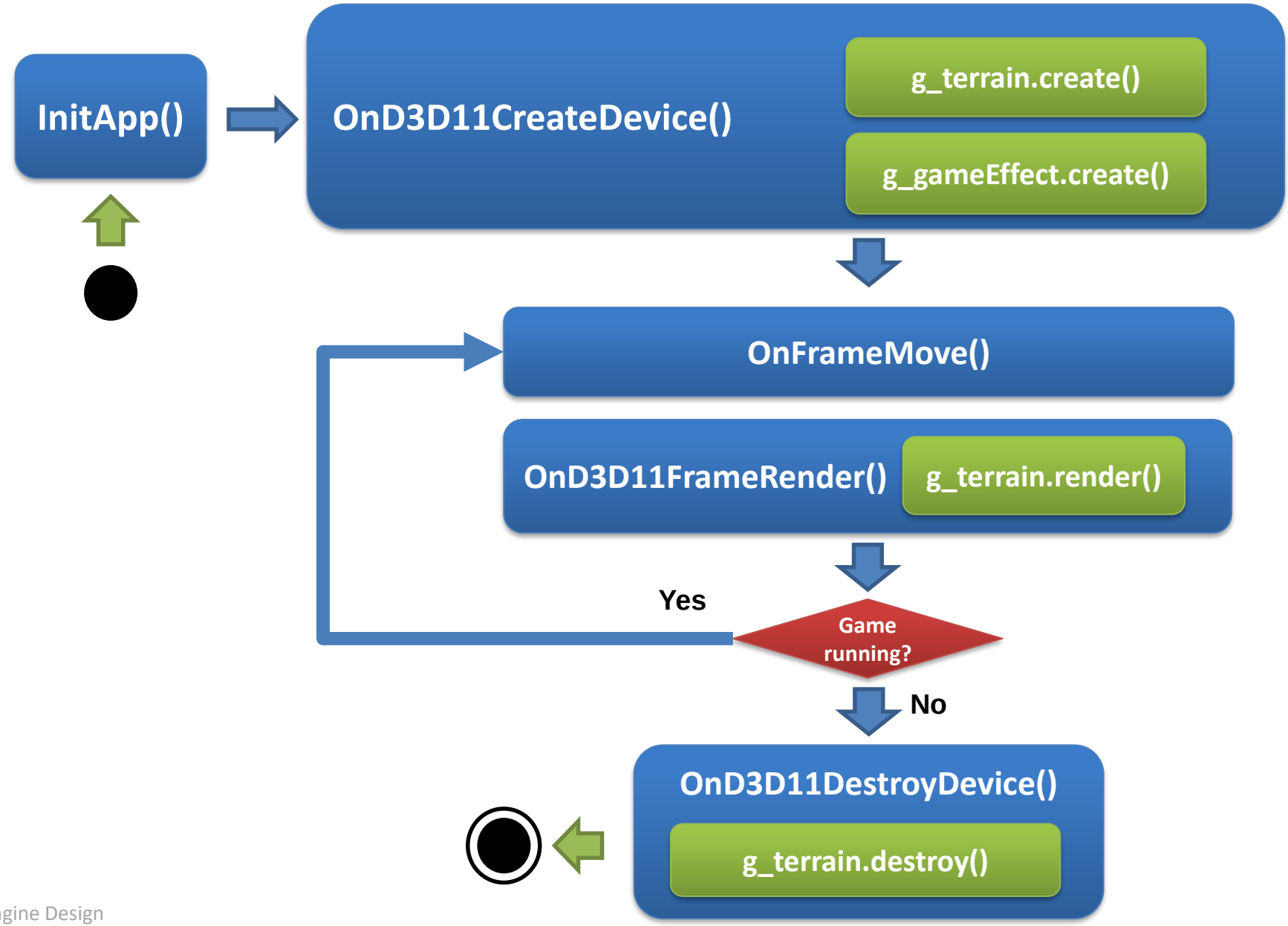
- A sample project to get started fast
  - Initializes Direct3D
  - Manages the Window
  - Manages all Graphics Resources
  - Implements the Rendering Loop
  - Handles Mouse/Keyboard Inputs
  - Draws the User Interface
  - and much more
  - Looks complicated first, but you'll get used to it

- Alternative: Starting from scratch
  - Next three weeks would be Direct3D initialization…

The Template Project

- Important files
  - game.cpp
    - (De-)Initialization
    - Main rendering loop, calls all neccessary functions
    - Keyboard / mouse callbacks
  - Terrain.h / Terrain.cpp
    - Terrain loading, (GPU) creation and rendering
  - game.fx
    - GPU shader code for terrain rendering
    - Not relevant for the current assignment!
  - GameEffect.h
    - The „CPU part“ of our shader (game.fx)
    - Access to „GPU variables“

Program Flow (Simplified)



GameEffect

- g_gameEffect is globally accessable
  - As long as you include „GameEffect.h“
  - In GameEffect.h:

```
extern GameEffect g_gameEffect;
```

    - Tells the Linker: „g_gameEffect is instantiated in some other .obj file“
    - Exactly one .cpp file must contain an instantiation of g_gameEffect
    - See game.cpp:

```
GameEffect g_gameEffect;
```

The template project: DXUT

- The template project makes heavy use of DXUT
  - The DirectX Utility Library (DXUT) simplifies the usage of the WINDOWS and D3D APIs
- DXUT was developed for the DXSDK samples
  - Keeps sample code clean and easy to understand
- DXUT helps with:
  - Window / device creation, window events (e.g. user input)
  - Simple user interfaces
  - ...

The template project: Main

```
int WINAPI wWinMain(...) {

    DXUTSetCallbackMsgProc( MsgProc );
    DXUTSetCallbackKeyboard( OnKeyboard );
    DXUTSetCallbackFrameMove( OnFrameMove );
    DXUTSetCallbackDeviceChanging( ModifyDeviceSettings );
    DXUTSetCallbackD3D11DeviceAcceptable( IsD3D11DeviceAcceptable );
    DXUTSetCallbackD3D11DeviceCreated( OnD3D11CreateDevice );
    DXUTSetCallbackD3D11SwapChainResized( OnD3D11ResizedSwapChain );
    DXUTSetCallbackD3D11SwapChainReleasing( OnD3D11ReleasingSwapChain );
    DXUTSetCallbackD3D11DeviceDestroyed( OnD3D11DestroyDevice );
    DXUTSetCallbackD3D11FrameRender( OnD3D11FrameRender );

    InitApp();

    DXUTInit( true, true, NULL );

    DXUTSetCursorSettings( true, true );

    DXUTCreateWindow( L“My Game" );

    DXUTCreateDevice( D3D_FEATURE_LEVEL_10_0, true, 1280, 720 );

    DXUTMainLoop();

    return DXUTGetExitCode();
}
```

The template project: DXUT

- Interaction with DirectX and Windows is controlled via callback functions:
  - `DXUTSetCallbackD3D11DeviceCreated`:

    Create (device->CreateX) and initialize everything which does **not** depend on the window size.
  - `DXUTSetCallbackD3D11SwapChainResized`:

    Create and initialize everything which depends on the window size.
  - `DXUTSetCallbackD3D11SwapChainReleasing`:

    Release everything which was *Created* in SwapChainResized.
  - `DXUTSetCallbackD3D11DeviceDestroyed`:

    Release everything which was *Created* in DeviceCreated.

The template project: DXUT

- Callback-functions continued:
  - `DXUTSetCallbackD3D11FrameRender`:

    Render your scene (context->DrawX). Unless you control all device states yourself, also place all your context->SetX calls here.

  - `DXUTSetCallbackFrameMove`:

    Called **before** the rendering. Place your sound, physics, game-logic, etc. here.

  - `DXUTSetCallbackMsgProc`:

    Handle window messages (e.g. mouse/UI events).

  - `DXUTSetCallbackKeyboard`:

    Handle keyboard events

The template project: DXUT

- Additional features:
  - Camera-Classes
    - `CFirstPersonCamera` („First Person“)
    - `CModelViewerCamera` („Third Person“)
  - Graphical User Interface
  - Text rendering

Terrain-Viewer Implementation

- Load the config file
  - Parser provided (by you :P)
- Load the terrain files
  - Everything provided
- Convert the terrain heightfield into a vertex buffer
- Triangulate the terrain using an index buffer
- Create the terrain color texture
  - File format loader provided
- Draw the terrain
  - Complete the provided renderer
  - Some small modifications necessary

- Everything else:
  - Provided

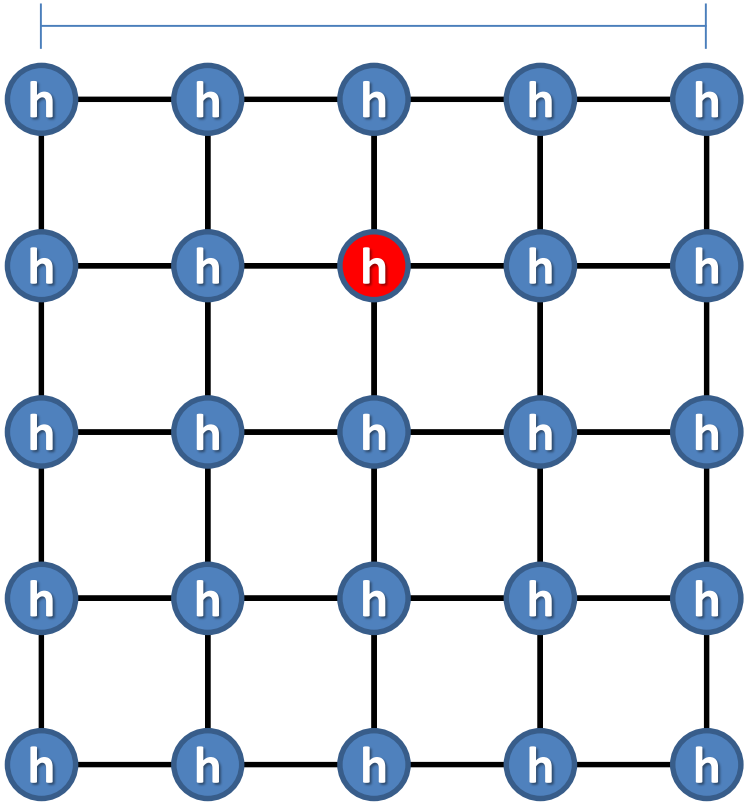
Height Field to Vertex Buffer

- Heightfield:
  - Entry count
    - N = Res * Res
  - Entry
    - Height: h

Vertex position:	**p.x = [-width / 2,**	**width / 2]**
	p.y = [0,	**height]**
	p.x = [-depth / 2,	**depth / 2]**
Texture:	**t.u, t.v = [0.0,**	**1.0]**
Heightfield:	**i.x, i.y = [0,**	**Res-1]**

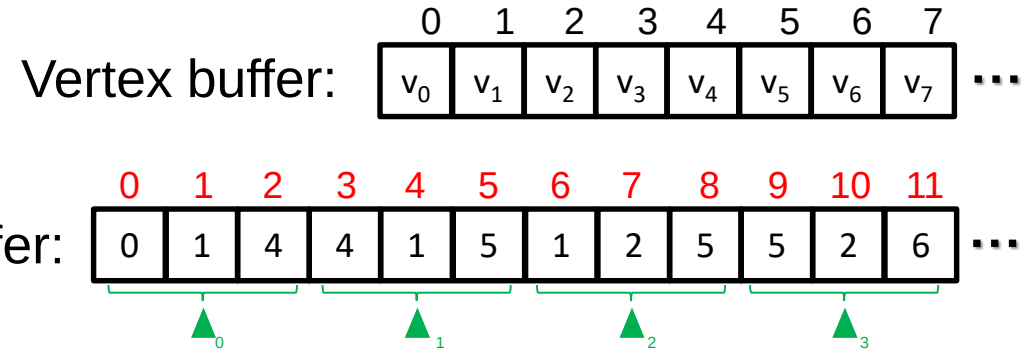
- Vertex buffer:
  - Entry count
    - N = Res * Res
  - Entry
    - Position: p = (p.x, p.y, p.z, 1)
    - Normal: n = (n.x, n.y, n.z, 0)
    - Tex Coord: t = (t.u, t.v)

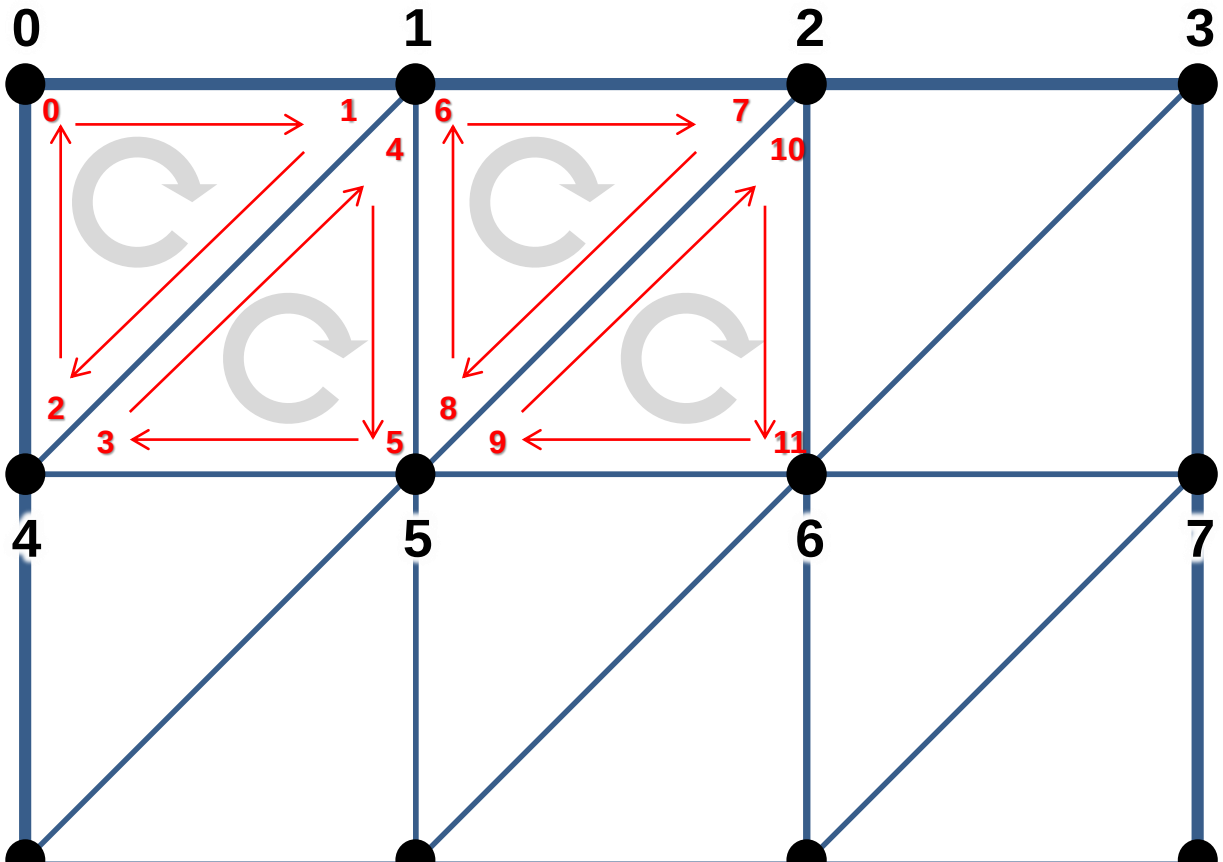
For now, just recalculate this – the normalmap will be used next assignment!



- Conversion necessary
  - Vertex buffer: „height“ is stored in y!
  - h = hf[IDX(i.x, i.y, Res)]
  - t.u = i.x / (Res - 1)
  - p.x = (i.x / Res - 0.5) * width
  - p.y = h * height

Index Buffer Content





- Index buffer
  - List of triangles
  - Triangle:
    - 3 vertex indices

Height Field Normals

- The Normal-Map isn‘t used at this point
  - For now, recalculate the normals from the heightfield

- The normals need to be scaled depending on your terrain configuration
  - Calculate them as if depth == width == height
  - Rescale the normals before storage in the vertex buffer

Height Field Normals

- Normal transformation: DirectXMath
  http://msdn.microsoft.com/en-us/library/windows/desktop/ee415574(v=vs.85).aspx
  - #include <DirectXMath.h>
  - Contains Matrix / Vector operations in the DirectX namespace (DirectX::XM…)
  - Less typing effort: `using namespace DirectX;`
    - Only do this in .cpp files, not in header files!

Height Field Normals

`DirectX::XMVECTOR`: 4-component 32bit float vector

`DirectX::XMMATRIX`: 4x4 32bit float matrix

- Optimized for speed
  - You can not access member of those classes directly

```
XMMATRIX matTest = XMMatrixIdentity();
XMVECTOR vTest = XMVectorSet(x, y, z, 1);

XMFLOAT4 vectorDest;
XMStoreFloat4(&vectorDest, vTest);

XMFLOAT4X4 matrixDest;
XMStoreFloat4x4(&matrixDest, matTest);
```

Height Field Normals

- Important: Normals need to be scaled using the inverted, transposed matrices!

```
XMMATRIX matNormalScaling = XMMatrixScaling(x, y, z);
matNormalScaling = XMMatrixTranspose(XMMatrixInverse(nullptr, matNormalScaling));
```

- Transform each normal vector

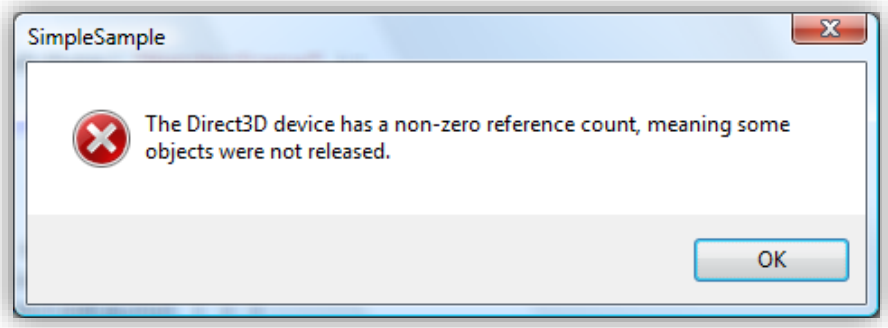
```
vNormal = XMVector4Transform(vNormal, matNormalScaling);
```

- Don‘t forget to normalize afterwards

```
vNormal = XMVector3Normalize(vNormal);
```

GPU memory management (DXUT)

- All allocated GPU memory must also be freed.
- DXUT convenience macro: `SAFE_RELEASE (Pointer)`
- In debug builds the following message is displayed if resources are not yet released when the program is closed:



- We NEVER want to see this message
  - Whenever your write device->CreateX you should immediately also write SAFE_RELEASE(x)

Direct3D Debugging Tipps

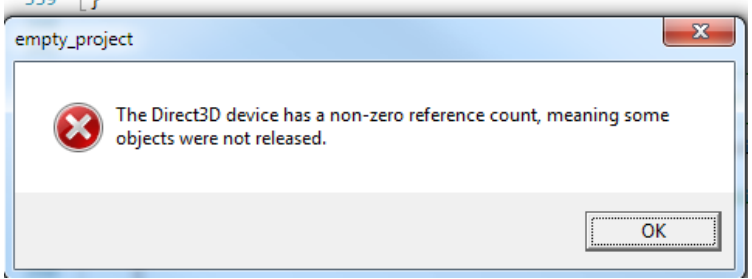
- At Runtime (in debug builds):
  - Direct3D emits warnings and error messages
    - When you see them popping up every frame, your code is almost certainly doing something wrong

```
398     pd3dDevice->IASetIndexBuffer(0, DXGI_FORMAT_R8_UINT, 0);
399     pd3dDevice->DrawIndexed(3, 0, 0);
```

```
Output
Show output from: Debug
D3D10: ERROR: ID3D10Device::IASetIndexBuffer: The Format (0x3e, R8_UINT) is not valid for usage as an IAIndexBuffer f
D3D10: ERROR: ID3D10Device::IASetIndexBuffer: The Format (0x3e, R8_UINT) is not valid for usage as an IAIndexBuffer f
D3D10: WARNING: ID3D10Device::DrawIndexed: An Index Buffer is expected, but none is bound. This is OK, as reading fro
Output | Find Results 1 | Find Symbol Results
```

  - DXUT reports GPU memory leaks when the process terminates

```
330 void CALLBACK OnD3D10DestroyDevice( void* pUserContext )
331 {
332     g_DialogResourceManager.OnD3D10DestroyDevice();
333     g_SettingsDlg.OnD3D10DestroyDevice();
334     SAFE_RELEASE( g_Font10 );
335     //SAFE_RELEASE( g_Effect10 );
336     SAFE_RELEASE( g_VertexLayout );
337     SAFE_RELEASE( g_Sprite10 );
338     SAFE_DELETE( g_TxtHelper );
339 }
```



Tip for finding CPU memory leaks

- At Runtime (in debug builds):
  - Memory leak detection when the process terminates can be enabled (already in the template project):

```
81  int WINAPI wWinMain( HINSTANCE hInstance, HINSTANCE hPrevInstance, LPWSTR lpCmdLine, int nCmdShow )
82  {
83      // Enable run-time memory check for debug builds.
84  #if defined(DEBUG) | defined(_DEBUG)
85      _CrtSetDbgFlag( _CRTDBG_ALLOC_MEM_DF | _CRTDBG_LEAK_CHECK_DF );
86  #endif
```

  - By including “debug.h” as last include in all .cpp files, memory leaks can be found with one click

```
225     char* foo = new char[20];
226     return;
227 }
```

```
Output
Show output from: Debug
The thread 'Win32 Thread' (0x13a0) has exited with code 0 (0x0).
'empty_project.exe': Unloaded 'C:\Windows\SysWOW64\nvwgf2um.dll'
The thread 'Win32 Thread' (0x1e64) has exited with code 0 (0x0).
Detected memory leaks!
Dumping objects ->
d:\development\pra1112\external\empty_project\empty_project.cpp(225) : {777} normal block at 0x003F70A8, 20 bytes lon
 Data: <                > CD CD CD CD CD CD CD CD CD CD CD CD CD CD CD CD
Object dump complete.
The program '[4288] empty_project.exe: Native' has exited with code 0 (0x0).
Output  Find Results 1  Find Symbol Results
```

References

- Direct3D Reference and programming guide:
  http://msdn.microsoft.com/en-us/library/windows/desktop/hh309466%28v=vs.85%29.aspx

- DXUT samples and documentation:
  http://dxut.codeplex.com/documentation

- DirectXMath:
  http://msdn.microsoft.com/en-us/library/windows/desktop/ee415574(v=vs.85).aspx

Questions?