Game Engine Design



tum.3D

computer graphics & visualization

Assignment 11

- This week: Explosions!

Assignment 11

Task overview

1. Extend your sprite renderer to support animated sprites
2. Spawn and update explosions
3. Create an additional particle system

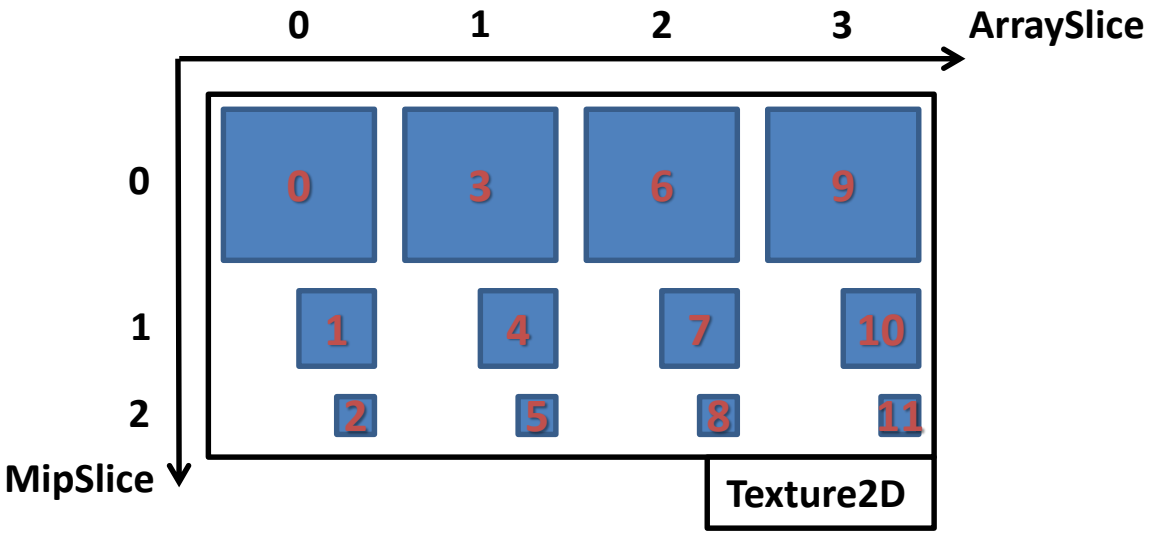
Animated Sprites

- Sequence of keyframes instead of a single, static image

- Internally: 2D texture array instead of 2D texture
  - Texture2DArray != Array of Texture2D
  - Extend sprite vertices by parameters $t, \alpha \in [0;1]$
    - t indicates animation progress of the sprite
    - α is a scalar opacity factor for fading sprites in and out

D3D11 Subresources

- Each texture resource in D3D11 can consist of multiple subresources



  - The subresource index can be calculated with `D3D11CalcSubresource()`
  - Subresources can be initialized individually directly in `ID3D11Device::CreateTexture2D()`

http://msdn.microsoft.com/en-us/library/windows/desktop/ff476901%28v=vs.85%29.aspx

Creating 2D Texture Array

```
HRESULT ID3D11Device::CreateTexture2D(
    const D3D11_TEXTURE2D_DESC *pDesc,          //description of texture
    const D3D11_SUBRESOURCE_DATA *pInitialData, //pointer to an array of subresources
                                  //with pDesc->MipLevels*pDesc->ArraySize elements
    ID3D11Texture2D **ppTexture2D               //output
);
```

- `pDesc->ArraySize`: Size of array

- D3D11_SUBRESOURCE_DATA
  - Basically stores a pointer to subresource bytedata for initialization

```
typedef struct D3D11_SUBRESOURCE_DATA {
    const void *pSysMem;   //pointer to initialization data
    UINT SysMemPitch;      //bytesize of a line in a 2D/3D texture
    UINT SysMemSlicePitch; //bytesize of a xy-slice in a 3D texture
} D3D11_SUBRESOURCE_DATA;
```

2D Texture Array

- Description for shader resource view needs to be set manually

  – ID3D11Device::CreateShaderResourceView(…, const D3D11_SHADER_RESOURCE_VIEW_DESC *pDesc, …)

```C++
typedef struct D3D11_SHADER_RESOURCE_VIEW_DESC {
  DXGI_FORMAT          Format;
  D3D11_SRV_DIMENSION ViewDimension;
  union {
    D3D11_BUFFER_SRV        Buffer;
    D3D11_TEX1D_SRV         Texture1D;
    D3D11_TEX1D_ARRAY_SRV   Texture1DArray;
    D3D11_TEX2D_SRV         Texture2D;
    D3D11_TEX2D_ARRAY_SRV   Texture2DArray;
    D3D11_TEX2DMS_SRV       Texture2DMS;
    D3D11_TEX2DMS_ARRAY_SRV Texture2DMSArray;
    D3D11_TEX3D_SRV         Texture3D;
    D3D11_TEXCUBE_SRV       TextureCube;
    D3D11_TEXCUBE_ARRAY_SRV TextureCubeArray;
    D3D11_BUFFEREX_SRV      BufferEx;
  };
} D3D11_SHADER_RESOURCE_VIEW_DESC;
```

2D Texture Array

- Format = „texture format“ (DXGI_FORMAT_*, from texture description)
- ViewDimension = D3D11_SRV_DIMENSION_TEXTURE2DARRAY
- Texture2DArray:
  - ArraySize = „size of array“ (from texture description)
  - MipLevels = „number of miplevels“ (from texture description)
  - FirstArraySlice = MostDetailedMip = 0

```C++
typedef struct D3D11_SHADER_RESOURCE_VIEW_DESC {
  DXGI_FORMAT          Format;
  D3D11_SRV_DIMENSION ViewDimension;
  union {
    D3D11_BUFFER_SRV        Buffer;
    D3D11_TEX1D_SRV         Texture1D;
    D3D11_TEX1D_ARRAY_SRV   Texture1DArray;
    D3D11_TEX2D_SRV         Texture2D;
    D3D11_TEX2D_ARRAY_SRV   Texture2DArray;
    D3D11_TEX2DMS_SRV       Texture2DMS;
    D3D11_TEX2DMS_ARRAY_SRV Texture2DMSArray;
    D3D11_TEX3D_SRV         Texture3D;
    D3D11_TEXCUBE_SRV       TextureCube;
    D3D11_TEXCUBE_ARRAY_SRV TextureCubeArray;
    D3D11_BUFFEREX_SRV      BufferEx;
  };
} D3D11_SHADER_RESOURCE_VIEW_DESC;
```

2D Texture Array

- CreateDDSTextureFromFile() takes care of all this!
  - Loads texture arrays from single DDS
  - Creates resource and resource views

- `DirectXTex: texAssemble` command line tool
  - Generates 2D Arrays / Cubemaps from multiple images
  - Outputs a single DDS

  - Add the texAssemble project to your solution…
  - … and call it in your ResourceGenerator

TexAssemble

- TexAssemble requires explicit specification of all images
  - We‘ll provide you a batch file to convert complete folders
  - See assignment

- TexAssemble does not provide MipMap-Generation and compression
  - Call texconv on the resulting DDS!

Texture2DArray in HLSL

- Texture object declaration

```hlsl
Texture2DArray g_SpriteTex;
```

- Binding shader resource variable (as usual)

```cpp
m_pEffect->GetVariableByName("g_SpriteTex")->AsShaderResource()
         ->SetResource(...);
```

- Sampling the array

```hlsl
//position.xy: texture coordinates
//position.z : array index
float3 position;
g_SpriteTex.Sample(samAnisotropic, position);
```

  - Array index position.z: rounded to next integer (array index)
  - Use GetDimensions() to get the texture size in the shader

```hlsl
float3 dims; //(x-width, y-height, arraysize)
g_SpriteTex.GetDimensions(dims.x, dims.y, dims.z); //dims is written here!
```

Texture2DArray in HLSL

- How to handle multiple sprite texture indices?
  - Only a single draw call for all particles (sorting!)
  - Use an array with a reasonable upper bound

```
Texture2DArray g_SpriteTex[5];
```

  - Binding resources, two alternatives:

```
m_pEffect->GetVariableByName("g_SpriteTex")->AsShaderResource()
         ->SetResourceArray(...);
```

```
m_pEffect->GetVariableByName("g_SpriteTex")->GetElement(index)
         ->AsShaderResource()->SetResource (...);
```

  - HLSL does not support texture fetches with dynamic indices
    - `switch()` with all possible indices does the job…
    - Won‘t win a price for the most beautiful code, though

Explosions

- Same procedure as for your projectiles
- Add each explosion to a global list
  - Store texture index, position and current animation state `t`
  - Each frame, advance the animation state of all explosions
  - Use `fElapsedTime` and the total duration
  - Don‘t forget to delete explosions!

- On render, add all your explosions to the list of `SpriteVertex`
  - Sort and render along with your projectiles

Particles

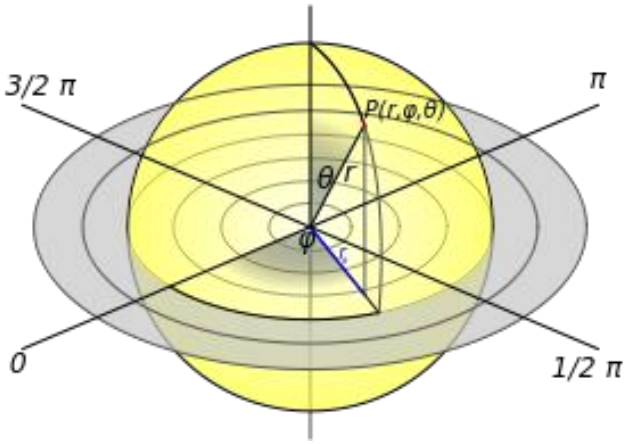
- Adding some fancyness: additional particles

Particles

- Create a number of „explosion particles“ at the center
  - Again, like your projectiles!
  - Update (speed, position, animation?, alpha?), render
- Storage
  - Either use a new global container for this
  - … or unify all properties (explosion, particles, projectiles)
  - Using seperate containers might be better for experimenting though
- Initialization
  - Random direction
  - Random speed, size & position?

- Some hints for random directions
  - See the slides for Assignment 2 for random number generators and distributions!
  - Randomizing x, y, z in [-1, 1] will result in a bad distribution
  - Alternative 1: **Rejection sampling**, discard if length((x, y, z)) > 1
  - Alternative 2: **Spherical coordinates**, two random angles θ in [0°; 180°] and φ in [0°; 360°]:

$$\begin{pmatrix} x \\ y \\ z \end{pmatrix} = \begin{pmatrix} \sin(\theta) \cdot \cos(\varphi) \\ \sin(\theta) \cdot \sin(\varphi) \\ \cos(\theta) \end{pmatrix}$$



Questions?

(we're not done, don't run away yet!)

Appendix: Performance Hints

Maybe it‘s time to address your particle system performance.

At least a tiny bit.

Study at home!

CPU Performance Hints

- Keep an eye on your function calls
  - Function calls aren‘t for free
  - Calling overriden functions is more expensive!
  - Worst case scenario:

```
class IParticle {
        virtual void Update(float fElapsedTime) = 0;
}

class Particle: public IParticle { … }


for (int i = 0; i < particleCount; ++i)
{
        g_particles[i].Update(fElapsedTime);
}
```

CPU Performance Hints

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for (int i = 0; i < m_particleCount; ++i)
{
    m_particles[i].Update(fElapsedTime);
}
```

CPU Performance Hints

- Keep an eye on your function calls
  - Instead:

```
struct Particle {
        XMFLOAT3 m_position
        // Speed, etc
}

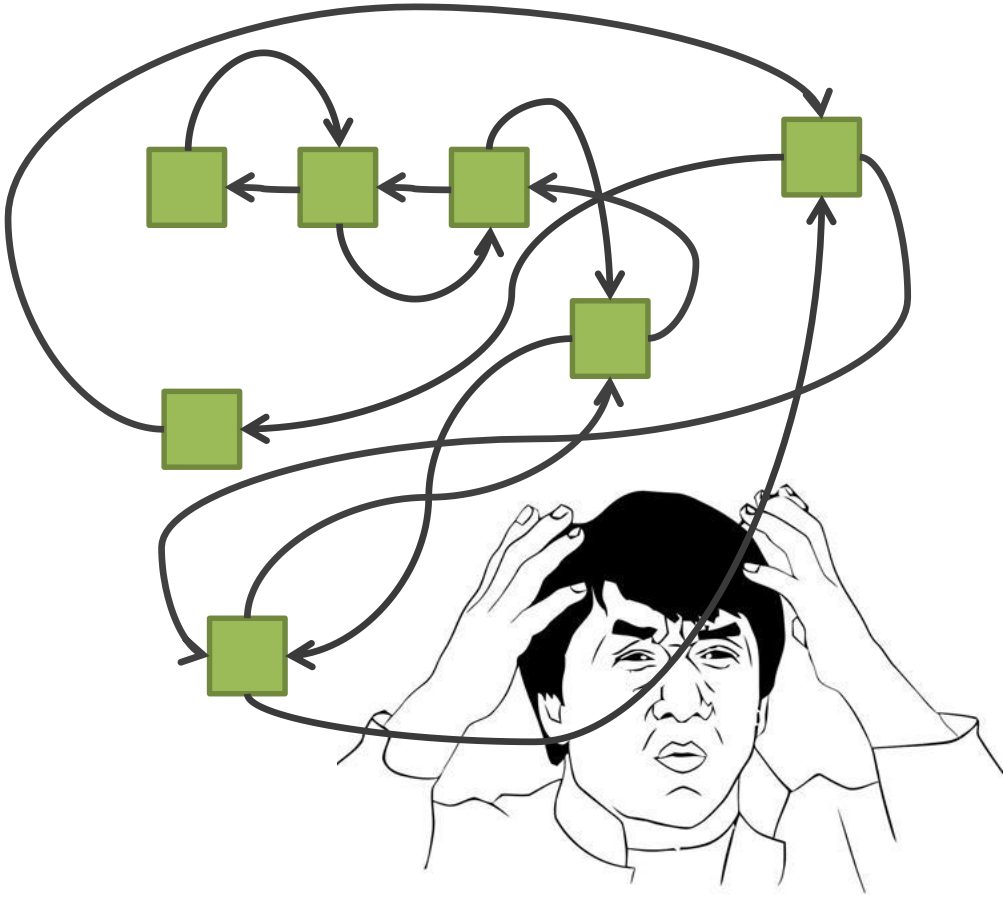
for (int i = 0; i < particleCount; ++i)
{
        g_particles[i].m_position = …;
}
```

CPU Performance Hints

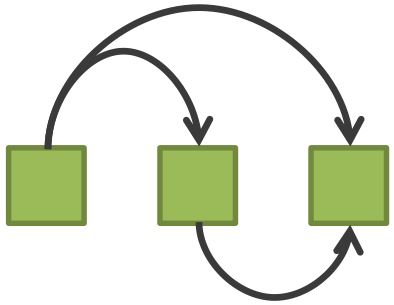
`std::vector` **VS** `std::list`

- Array of elements
- Consecutively stored in memory
- Single pointer to first element

- Each elements points to next & prev
- Can be anywhere in memory



CPU Performance Hints



- `std::list`
  - Removal at a random position is fast
  - Iteration over all elements is „okay-ish“
  - No random access – always iterate over all elements
  - Adding elements at random positions is okay, but memory allocations / deallocations can kill you

CPU Performance Hints

- `std::vector`
  - Iteration over all elements is fast
  - Random access is fast
  - Appending elements is fast - most of the time!
    - All elements are copied when no more space is available
    - Amount of reserved memory is doubled -> minimizes reallocation operations
  - Removal of the last element is fast
  - Removal of intermediate elements (`erase()`) is deadly…

CPU Performance Hints

- `std::vector`
  - Iteration over all elements is fast
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  - Appending elements is fast - most of the time!
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  - Removal of intermediate elements (`erase()`) is deadly…

CPU Performance Hints

- Avoid removal of intermediate elements in `std::vector`
  - For „bulk removal“: instead of removing an element, „cut and paste“ the last one

```
int count = vec.size();
for (int i = 0; i < count; ++i) {

    bool remove = ...;
    if (remove) {
        --count;
        vec[i] = vec[count];
        --i;       // Check the same index again
    }

}

vec.resize(count);
```

CPU Performance Hints

- `std::map` and `std::unordered_map`
  - Use those if you need a „dictionary“ style container
  - `std::map`
    - (Binary) tree
    - Elements have an order
    - Access time: O(log n)
  - `std::unordered_map`
    - Hash map
    - Elements have no order
    - Access time: „Usually“ constant, O(1)

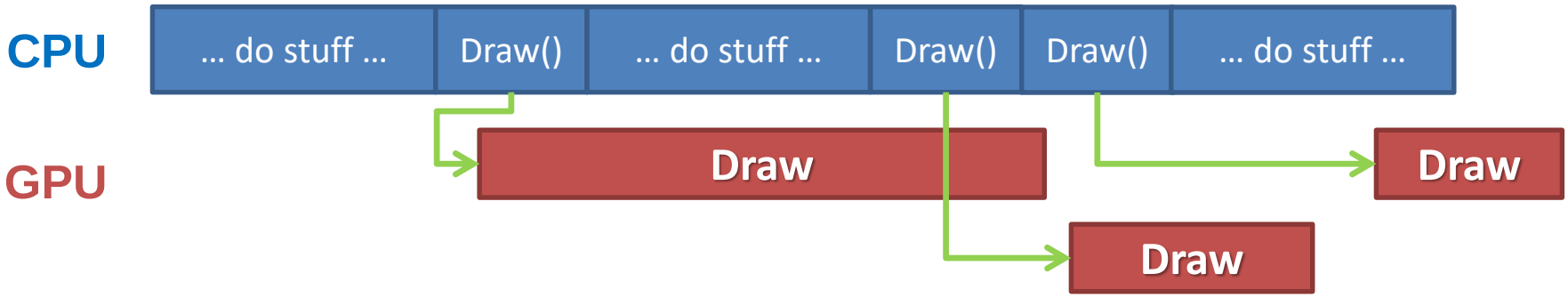
CPU Performance Hints

- `std::vector` is the best choice most of the time
  - Keep in mind how the data is organized
  - Avoid `erase()`
  - Reserved memory isn‘t released if you resize a vector
    - So appending elements is basically free at some point
    - Only if your vector isn‘t a local variable!

- Always iterate „front to back“ over your data
  - Access the data in the order it‘s stored in memory
  - Keyword „caching“: The next values might already be stored in the fast CPU caches

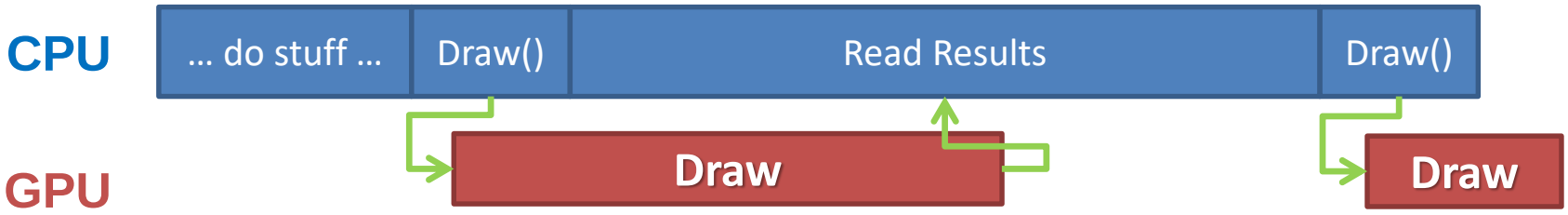
GPU Performance Hints

- Keep in mind that data is processed in **parallel** and **asynchronously** on the GPU
  - Parallelism: enough data must be available to process
  - Asynchronism: synchronization must be minimized



GPU Performance Hints

- Keep the GPU busy!
  - Reduce the number of draw calls
    - In fact: Increase the data per draw call to avoid GPU idle time
  - Avoid synchronization points
    - GPU output is CPU input
      - Could you use the data from the previous frame?
      - Could you draw something else during the idle-time?
    - Sidenote: Of course this cannot be completely avoided…



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    - In fact: Increase the data per draw call to avoid GPU idle time
  - Avoid synchronization points
    - GPU output is CPU input 
      - Could you use the data from the previous frame?
      - Could you draw something else during the idle-time?
    - Sidenote: Of course this cannot be completely avoided…
  - Avoid overdraw
    - Many large, transparent particles are expensive

GPU Performance Hints

- Avoid unneccessary calculations in the shader: Precalculate on the CPU
  - Combine transformation matrices

```
T3dVertexPSIn MeshVS(T3dVertexVSIn Input)
{
	T3dVertexPSIn Output = (T3dVertexPSIn) 0;
	Output.Pos = mul(float4(Input.Pos, 1.f), g_matObject);
	Output.Pos = mul(Output.Pos, g_matAnim);
	Output.Pos = mul(Output.Pos, g_matWorld);
	Output.Pos = mul(Output.Pos, g_matView);
	Output.Pos = mul(Output.Pos, g_matProjection);

	return Output;
}
```

```
T3dVertexPSIn MeshVS(T3dVertexVSIn Input)
{
	T3dVertexPSIn Output = (T3dVertexPSIn) 0;
	Output.Pos = mul(float4(Input.Pos, 1.f), g_WorldViewProjection);
	return Output;
}
```

  - Precalculate per-frame constant factors in complex formulas

GPU Performance Hints

- Shaders are executed on SIMD Units
  - Single instruction, multiple data
  - Consequence: „Multiple data“ must be available to run the same instruction on…

➢ **Coherence** is important: Works best if all data is processed the same way

➢ Each group is as slow as its slowest member…

  - Avoid divergent branches
  - Avoid pixel shaders with highly varying local complexity

Performance Hints

Always check your performance without a debugger!

- Build in Release configuration
- Start with **Ctrl + F5**
- `std` containers are quite slow in Debug build

Questions?