BATTLEFIELD 3

DirectX 11 Rendering in Battlefield 3

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GDC DICE

Agenda

Overview

Feature:
- Deferred Shading
- Compute Shader Tile-Based Lighting
- Terrain Displacement Mapping
- Direct Stereo 3D rendering

Quality:
- Antialiasing: MSAA
- Antialiasing: FXAA
- Antialiasing: SRAA
- Transparency Supersampling

Performance:
- Instancing
- Parallel dispatch
- Multi-GPU
- Resource Streaming

Conclusions

Q & A

OVERVIEW

Battlefield 3

- FPS
- Fall 2011
- DX11, Xbox 360 and PS3
- Frostbite 2 engine

Frostbite 2

- Developed for Battlefield 3 and future DICE/EA games
- Massive focus on creating simple to use & powerful workflows
- Major pushes in animation, destruction, streaming, rendering, lighting and landscapes

DX11

DX11 API only

- Requires a DX10 or DX11 GPUs
- Requires Vista SP1 or Windows 7
- No Windows XP!

Why?

- CPU performance win
- GPU performance & quality win
- Ease of development - no legacy
- Future proof

BF3 is a *big* title - will drive OS & HW adoption

- Which is good for *your* game as well! ☺

Options for rendering

Switched to Deferred Shading in FB2

- Rich mix of Outdoor + Indoor + Urban environments in BF3
- Wanted *lots* more light sources

Why not Forward Rendering?

- Light culling / shader permutations not efficient for us
- Expensive & more difficult decaling / destruction masking

Why not Light Pre-pass?

- 2x geometry pass too expensive on both CPU & GPU for us
- Was able to generalize our BRDF enough to just a few variations
- Saw major potential in full tile-based deferred shading

See also:

- Nicolas Thibieroz's talk "Deferred Shading Optimizations"

Deferred Shading

Weaknesses with traditional deferred lighting/shading:

- Massive overdraw & ROP cost when having lots of *big* light sources
- Expensive to have multiple per-pixel materials in light shaders
- MSAA lighting can be slow (non-coherent, extra BW)

FEATURES

Tile-based Deferred Shading

1. Divide screen into tiles and determine which lights affects which tiles

2. Only apply the visible light sources on pixels
   - Custom shader with multiple lights
   - Reduced bandwidth & setup cost

How can we do this best in DX11?

Lighting with Compute Shader

Tile-based Deferred Shading using Compute Shaders

Primarily for analytical light sources

- Point lights, cone lights, line lights
- No shadows
- Requires Compute Shader 5.0

Hybrid Graphics/Compute shading pipeline:

- Graphics pipeline rasterizes gbuffers for opaque surfaces
- Compute pipeline uses gbuffers, culls lights, computes lighting & combines with shading
- Graphics pipeline renders transparent surfaces on top

CS requirements & setup

1 thread per pixel, 16x16 thread groups (aka tile)

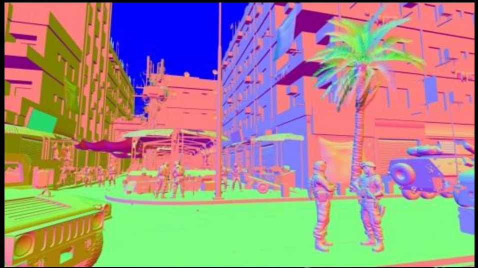
Input: gbuffers, depth buffer & list of lights

Output: fully composited & lit HDR texture

```
Texture2D<float4> gbufferTexture0 : register(t0);
Texture2D<float4> gbufferTexture1 : register(t1);
Texture2D<float4> gbufferTexture2 : register(t2);
Texture2D<float4> depthTexture : register(t3);

RWTexture2D<float4> outputTexture : register(u0);

#define BLOCK_SIZE 16
[numthreads(BLOCK_SIZE,BLOCK_SIZE,1)]
void csMain(
    uint3 groupId : SV_GroupID,
    uint3 groupThreadId : SV_GroupThreadID,
    uint groupIndex: SV_GroupIndex,
    uint3 dispatchThreadId : SV_DispatchThreadID)
{
    ...
}
```


Normal


Roughness

Diffuse Albedo


Specular Albedo

CS steps 1-2

1. Load gbuffers & depth

2. Calculate min & max z in threadgroup / tile
   - Using `InterlockedMin/Max` on `groupshared` variable
   - Atomics only work on ints ☹
   - Can cast float to int (z is always +)

```
groupshared uint minDepthInt;
groupshared uint maxDepthInt;

// --- globals above, function below -------

float depth =
    depthTexture.Load(uint3(texCoord, 0)).r;
uint depthInt = asuint(depth);

minDepthInt = 0xFFFFFFFF;
maxDepthInt = 0;
GroupMemoryBarrierWithGroupSync();

InterlockedMin(minDepthInt, depthInt);
InterlockedMax(maxDepthInt, depthInt);

GroupMemoryBarrierWithGroupSync();
float minGroupDepth = asfloat(minDepthInt);
float maxGroupDepth = asfloat(maxDepthInt);
```

CS step 3 – Culling

Determine visible light sources for each tile

- Cull all light sources against tile frustum

Input (global):

- Light list, frustum & SW occlusion culled

Output (per tile):

- # of visible light sources
- Index list of visible light sources

	Lights	Indices
Global list	1000+	0 1 2 3 4 5 6 7 8 ..
Tile visible list	~0-40+	0 2 5 6 8 ..

Per-tile visible light count
(black = 0 lights, white = 40)

CS step 3 – Impl

3a. Each thread switches to process lights instead of pixels

- Wow, parallelism switcharoo!
- 256 light sources in parallel
- Multiple iterations for >256 lights

3b. Intersect light and tile

- Multiple variants – accuracy vs perf
- Tile min & max z is used as a ”depth bounds” test

3c. Append visible light indices to list

- Atomic add to threadgroup shared memory
- ”inlined stream compaction”

3d. Switch back to processing pixels

- Synchronize the thread group
- We now know which light sources affect the tile

```
struct Light {
    float3 pos; float sqrRadius;
    float3 color; float invSqrRadius;
};
int lightCount;
StructuredBuffer<Light> lights;

groupshared uint visibleLightCount = 0;
groupshared uint visibleLightIndices[1024];

// --- globals above, cont. function below ---

uint threadCount = BLOCK_SIZE*BLOCK_SIZE;
uint passCount = (lightCount+threadCount-1) / threadCount;

for (uint passIt = 0; passIt < passCount; ++passIt)
{
    uint lightIndex = passIt*threadCount + groupIndex;

    // prevent overrun by clamping to a last ”null” light
    lightIndex = min(lightIndex, lightCount);

    if (intersects(lights[lightIndex], tile))
    {
        uint offset;
        InterlockedAdd(visibleLightCount, 1, offset);
        visibleLightIndices[offset] = lightIndex;
    }
}

GroupMemoryBarrierWithGroupSync();
```

CS deferred shading final steps

4. For each pixel, accumulate lighting from visible lights

- Read from tile visible light index list in groupshared memory

5. Combine lighting & shading albedos

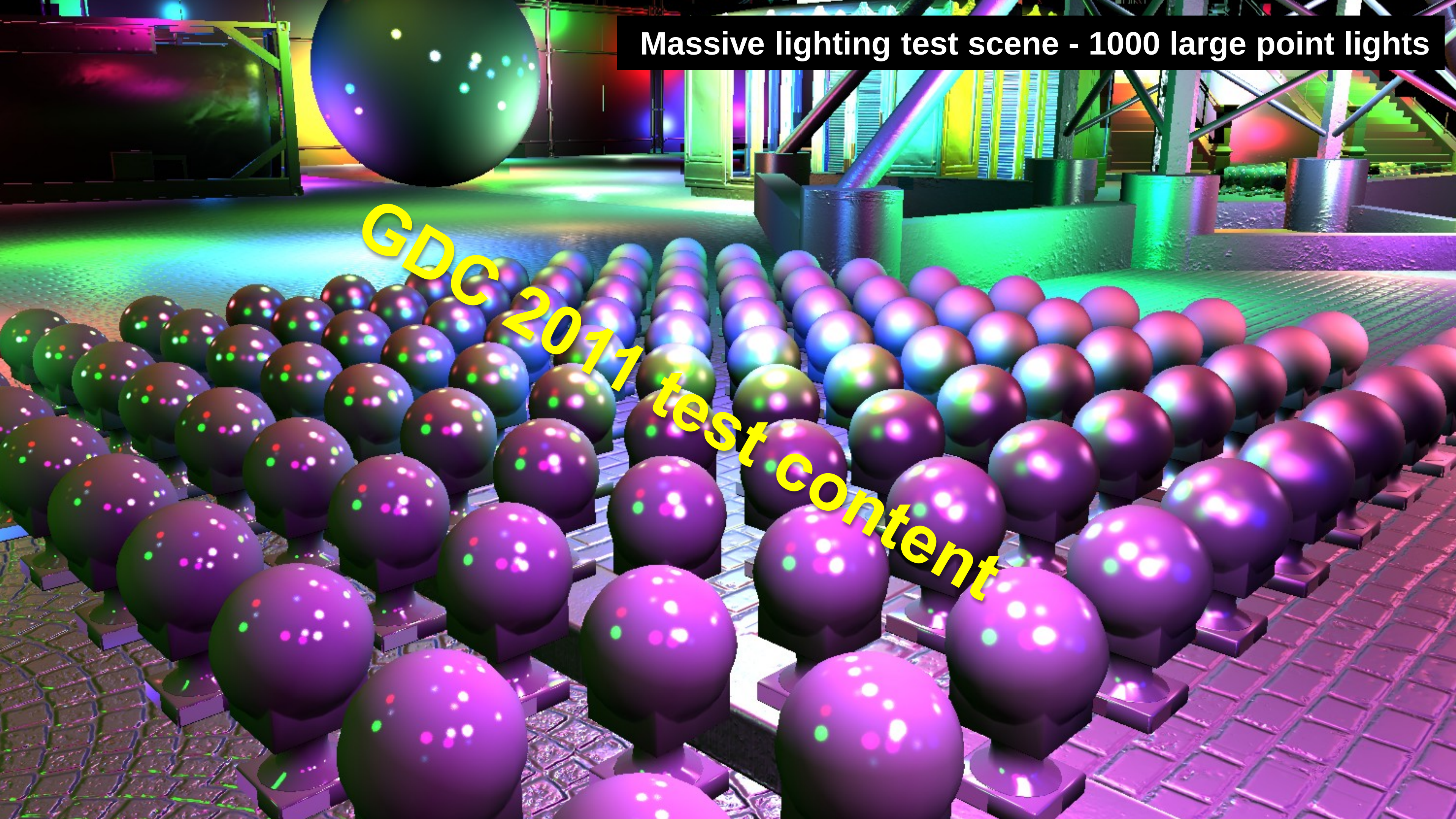
- Output is non-MSAA HDR texture
- Render transparent surfaces on top

Computed lighting

```
float3 color = 0;

for (uint lightIt = 0; lightIt < visibleLightCount; ++lightIt)
{
    uint lightIndex = visibleLightIndices[lightIt];
    Light light = lights[lightIndex];

    color += diffuseAlbedo * evaluateLightDiffuse(light, gbuffer);
    color += specularAlbedo * evaluateLightSpecular(light, gbuffer);
}
```


Massive lighting test scene - 1000 large point lights
GDC 2011 test content

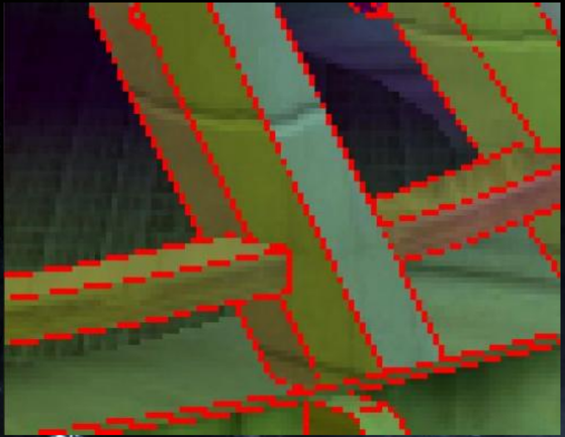
MSAA Compute Shader Lighting

Only edge pixels need full per-sample lighting

- But edges have bad screen-space coherency! Inefficient

Compute Shader can build efficient coherent pixel list

- Evaluate lighting for each pixel (sample 0)
- Determine if pixel requires per-sample lighting
- If so, add to atomic list in shared memory
- When all pixels are done, synchronize
- Go through and light sample 1-3 for pixels in list



Major performance improvement!

- Described in detail in [Lauritzen10]

Terrain rendering

Terrain rendering

Battlefield 3 terrains

- Huge area & massive view distances
- Dynamic destructible heightfields
- Procedural virtual texturing
- Streamed heightfields, colormaps, masks
- Full details at at a later conference

We stream in source heightfield data at close to pixel ratio

- Derive high-quality per-pixel normals in shader

How can we increase detail even further on DX11?

- Create better silhouettes and improved depth
- Keep small-scale detail (dynamic craters & slopes)


GDC 2011 pre-alpha


Normal mapped terrain
GDC 2011 pre-alpha


Displacement mapped terrain
GDC 2011 pre-alpha

Terrain Displacement Mapping

Straight high-res heightfields, no procedural detail

- *Lots* of data in the heightfields
- Pragmatic & simple choice
- No changes in physics/collisions
- No content changes, artists see the true detail they created

Uses DX11 fixed edge tessellation factors

- Stable, no swimming vertices
- Though can be wasteful
- Height morphing for streaming by fetching 2 heightfields in domain shader & blend based on patch CLOD factor

More work left to figure optimal tessellation scheme for our use case

Stereo 3D rendering in DX11

Nvidia's 3D Vision drivers is a good and *almost* automatic stereo 3D rendering method

- But only for forward rendering, doesn't work with deferred shading
- Or on AMD or Intel GPUs
- Transparent surfaces do not get proper 3D depth

We instead use *explicit* 3D stereo rendering

- Render unique frame for each eye
- Works with deferred shading & includes all surfaces
- Higher performance requirements, 2x draw calls

Works with *Nvidia's 3D Vision* and *AMD's HD3D*

- Similar to OpenGL quad buffer support
- Ask your friendly IHV contact how

PERFORMANCE

Instancing

Draw calls can still be major performance bottleneck

- Lots of materials / lots of variation
- Complex shadowmaps
- High detail / long view distances
- Full 3D stereo rendering

Battlefield have lots of use cases for heavy instancing

- Props, foliage, debris, destruction, mesh particles

Batching submissions is still important, just as before!

Richard Huddy:
"Batch batch batch!"

Instancing in DirectX

DX9-style stream instancing is good, but restrictive

- Extra vertex attributes, GPU overhead
- Can't be (efficiently) combined with skinning
- Used primarily for tiny meshes (particles, foliage)

DX10/DX11 brings support for shader *Buffer* objects

- Vertex shaders have access to *SV_InstanceID*
- Can do completely arbitrary loads, not limited to fixed elements
- Can support per-instance arrays and other data structures!

Let's rethink how instancing can be implemented..

Instancing data

Multiple object types

- Rigid / skinned / composite meshes

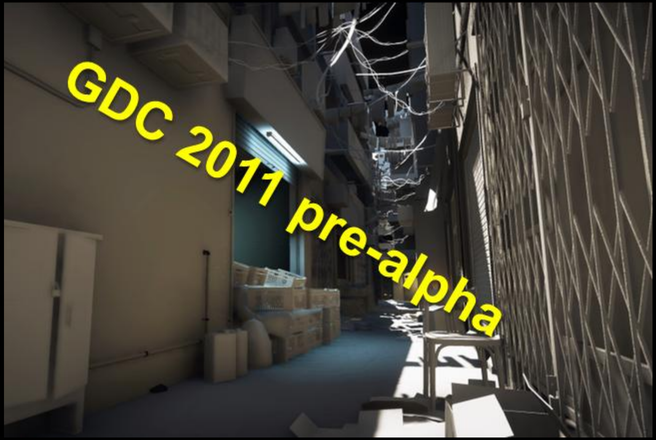
Multiple object lighting types

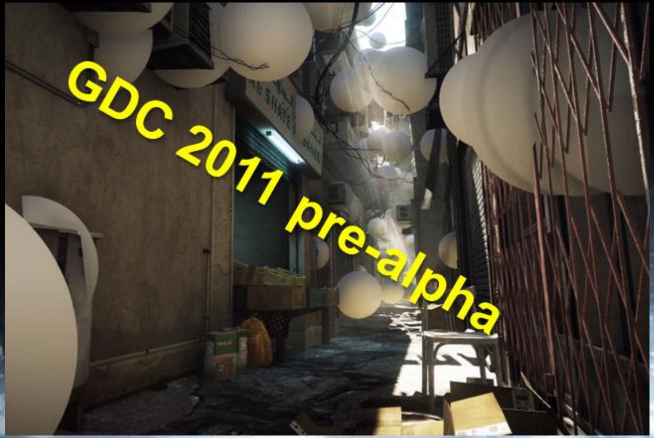
- Small/dynamic: light probes
- Large/static: light maps

Different types of instancing data we have

Transform	`float4x3`
Skinning transforms	`float4x3 array`
SH light probe	`float4 x 4`
Lightmap UV scale/offset	`float4`

Let's pack all instancing data into single big buffer!





Instancing example: transform + SH

```
Buffer<float4> instanceVectorBuffer : register(t0);

cbuffer a
{
    float g_startVector;
    float g_vectorsPerInstance;
}

VsOutput main(
    // ....
    uint instanceId : SV_InstanceId)
{
    uint worldMatrixVectorOffset = g_startVector + input.instanceId * g_vectorsPerInstance + 0;
    uint probeVectorOffset       = g_startVector + input.instanceId * g_vectorsPerInstance + 3;

    float4 r0 = instanceVectorBuffer.Load(worldMatrixVectorOffset + 0);
    float4 r1 = instanceVectorBuffer.Load(worldMatrixVectorOffset + 1);
    float4 r2 = instanceVectorBuffer.Load(worldMatrixVectorOffset + 2);

    float4 lightProbeShR = instanceVectorBuffer.Load(probeVectorOffset + 0);
    float4 lightProbeShG = instanceVectorBuffer.Load(probeVectorOffset + 1);
    float4 lightProbeShB = instanceVectorBuffer.Load(probeVectorOffset + 2);
    float4 lightProbeShO = instanceVectorBuffer.Load(probeVectorOffset + 3);

    // ....
}
```

Instancing example: skinning

```
half4 weights = input.boneWeights;
int4 indices = (int4)input.boneIndices;
```

```
float4 skinnedPos =  mul(float4(pos,1), getSkinningMatrix(indices[0])).xyz * weights[0];
       skinnedPos += mul(float4(pos,1), getSkinningMatrix(indices[1])).xyz * weights[1];
       skinnedPos += mul(float4(pos,1), getSkinningMatrix(indices[2])).xyz * weights[2];
       skinnedPos += mul(float4(pos,1), getSkinningMatrix(indices[3])).xyz * weights[3];
```

```
// ...
```

```
float4x3 getSkinningMatrix(uint boneIndex)
{
    uint vectorOffset = g_startVector + instanceId * g_vectorsPerInstance;
    vectorOffset += boneIndex*3;
    float4 r0 = instanceVectorBuffer.Load(vectorOffset + 0);
    float4 r1 = instanceVectorBuffer.Load(vectorOffset + 1);
    float4 r2 = instanceVectorBuffer.Load(vectorOffset + 2);
    return createMat4x3(r0, r1, r2);
}
```

Instancing benefits

Single draw call per object *type* instead of per *instance*

- Minor GPU hit for big CPU gain

Instancing does not break when skinning parts

- More deterministic & better overall performance

End result is typically 1500-2000 draw calls

- Regardless of how many object *instances* the artists place!
- Instead of 3000-7000 draw calls in some heavy cases

Parallel Dispatch in Theory

Great key DX11 feature!

- Improve performance by scaling dispatching to D3D to more cores
- Reduce frame latency

How we use it:

- DX11 deferred context per HW thread
- Renderer builds list of all draw calls we want to do for each rendering ”layer” of the frame
- Split draw calls for each layer into chunks of ~256
- Dispatch chunks in parallel to the deferred contexts to generate command lists
- Render to immediate context & execute command lists
- Profit! *

* but theory != practice

Parallel Dispatch in Practice

Still no performant drivers available for our use case ☹

- Have waited for 2 years and still are
- Big driver codebases takes time to refactor
- IHVs vs Microsoft quagmire
- Heavy driver threads collide with game threads

quagmire [ˈkwæɡˌmaɪə ˈkwɒɡ-]*n*
1. (Earth Sciences / Physical Geography) a soft wet area of land that gives way under the feet; bog
2. an awkward, complex, or embarrassing situation

How it should work (an utopia?)

- Driver <u>**does not**</u> create any processing threads of its own
- Game submits workload in parallel to multiple deferred contexts
- Driver make sure almost all processing required happens on the draw call on the deferred context
- Game dispatches command list on immediate context, driver does absolute minimal work with it

Still good to design engine for + instancing is great!

Resource streaming

Even with modern GPUs with lots of memory, resource streaming is often required

- Can't require 1+ GB graphics cards
- BF3 levels have much more than 1 GB of textures & meshes
- Reduced load times

But creating & destroying DX resources in-frame has never been a good thing

- Can cause non-deterministic & large driver / OS stalls ☹
- Has been a problem for a very long time in DX
- About time to fix it

DX11 Resource Streaming

Have worked with Microsoft, Nvidia & AMD to make sure we can do stall free async resource streaming of GPU resources in DX11

- Want neither CPU nor GPU perf hit
- Key foundation: DX11 concurrent creates

```
D3D11_FEATURE_DATA_THREADING threadingCaps;

FB_SAFE_DX(m_device->CheckFeatureSupport(
    D3D11_FEATURE_THREADING,
    &threadingCaps, sizeof(threadingCaps)));

if (threadingCaps.DriverConcurrentCreates)
```

Resource creation flow:

- Streaming system determines resources to load (texture mipmaps or mesh LODs)
- Add up DX resource creation on to queue on our own separate low-priority thread
- Thread creates resources using initial data, signals streaming system
- Resource created, game starts using it

Enables async stall-free DMA in drivers!

Resource destruction flow:

- Streaming system deletes D3D resource
- Driver keeps it internally alive until GPU frames using it are done. NO STALL!

Multi-GPU

Efficiently supporting Crossfire and SLI is important for us

- High-end consumers expect it
- IHVs expect it (and can help!)
- Allows targeting higher-end HW then currently available during dev

AFR is easy: Do not reuse GPU resources from previous frame!

- UpdateSubResource is easy & robust to use for dynamic resources, but not ideal

All of our playtests run with exe named AFR-FriendlyD3D.exe

- Disables all driver AFR synchronization workarounds
- Rather find corruption during dev then have bad perf
- ForceSingleGPU.exe is also useful to track down issues

QUALITY

Antialiasing

Reducing aliasing is one of our key visual priorities

- Creates a more smooth gameplay experience
- Extra challenging goal due to deferred shading

We use multiple methods:

- MSAA –Multisample Antialiasing
- FXAA – Fast Approximate Antialiasing
- SRAA – Sub-pixel Reconstruction Antialiasing
- TSAA – Transparency Supersampling Antialiasing

Aliasing ☹

MSAA

Our solution:

- Deferred geometry pass renders with MSAA (2x, 4x or 8x)
- Light shaders evaluate per-sample (when needed), averages the samples and writes out per-pixel
- Transparent surfaces rendered on top without MSAA

1080p gbuffer+z with 4x MSAA is 158 MB

- Lots of memory and lots of bandwidth ☹
- Could be tiled to reduce memory usage
- Very nice quality though ☺

Our (overall) highest quality option

- But not fast enough for more GPUs
- Need additional solution(s)..

FXAA

"Fast Approximate Antialiasing"

- GPU-based MLAA implementation by Timothy Lottes (Nvidia)
- Multiple quality options
- ~1.3 ms/f for 1080p on Geforce 580

Pros & cons:

- Superb antialiased long edges! ☺
- Smooth overall picture ☺
- Reasonably fast ☺
- Moving pictures do not benefit as much ☹
- "Blurry aliasing" ☹

Will be released here at GDC'11

- Part of Nvidia's example SDK

SRAA

"Sub-pixel Reconstruction Antialiasing"

- Presented at I3D'11 2 weeks ago [Chajdas11]
- Use 4x MSAA buffers to improve reconstruction

Multiple variants:

- MSAA depth buffer
- MSAA depth buffer + normal buffer
- MSAA Primitive ID / spatial hashing buffer

Pros:

- Better at capturing small scale detail ☺
- Less "pixel snapping" than MLAA variants ☺

Cons:

- Extra MSAA z/normal/id pass can be prohibitive ☹
- Integration not as easy due to extra pass ☹


GDC 2011 pre-alpha


No antialiasing


4x MSAA


4x SRAA, depth-only


4x SRAA, depth+normal


FXAA


No antialiasing

MSAA Sample Coverage

None of the AA solutions can solve all aliasing
- Foliage & other alpha-tested surfaces are extra difficult cases
- Undersampled geometry, requires sub-samples

DX 10.1 added **SV_COVERAGE** as a pixel shader *output*
DX 11 added **SV_COVERAGE** as a pixel shader *input*

What does this mean?
- We get full programmable control over the coverage mask
- No need to waste the alpha channel output (great for deferred)
- We can do partial supersampling on alpha-tested surfaces!

Transparency Supersampling

Shade per-pixel but evaluate alpha test per-sample

- Write out coverage bitmask
- MSAA offsets are defined in DX 10.1
- Requires shader permutation for each MSAA level

Gradients still quite limited

- But much better than standard MSAA! ☺
- Can combine with screen-space dither

See also:

- DirectX SDK 'TransparencyAA10.1
- GDC'09 STALKER talk [Lobanchikov09]

```
static const float2 msaaOffsets[4] =
{
    float2(-0.125, -0.375),    float2(0.375, -0.125),
    float2(-0.375,  0.125),    float2(0.125,  0.375)
};

void psMain(
    out float4 color : SV_Target,
    out uint coverage : SV_Coverage)
{
    float2 texCoord_ddx = ddx(texCoord);
    float2 texCoord_ddy = ddy(texCoord);

    coverage = 0;

    [unroll]
    for (int i = 0; i < 4; ++i)
    {
        float2 texelOffset = msaaOffsets[i].x * texCoord_ddx;
        texelOffset +=       msaaOffsets[i].y * texCoord_ddy;

        float4 temp = tex.SampleLevel(sampler, texCoord + texelOffset);

        if (temp.a >= 0.5)
            coverage |= 1<<i;
    }
}
```


GDC 2011 test content
Alpha testing
4x MSAA + Transparency Supersampling

Conclusions

DX11 is here – in force

- 2011 is a great year to focus on DX11
- 2012 will be a great year for more to drop DX9

We've found lots & lots of quality & performance enhancing features using DX11

- And so will *you* for your game!
- Still have only started, lots of potential

Take advantage of the PC strengths, don't hold it back

- Big end-user value
- Good preparation for Gen4

Thanks

- Christina Coffin (@ChristinaCoffin)
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- Matthäus G. Chajdas (@NIV_Anteru)
- Miguel Sainz
- Nicolas Thibieroz

- Battlefield team
- Frostbite team

- Microsoft
- Nvidia
- AMD
- Intel

Questions?

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Twitter: @repi

Battlefield 3 & Frostbite 2 talks at GDC'11:

Mon 1:45	*DX11 Rendering in Battlefield 3*	Johan Andersson
Wed 10:30	*SPU-based Deferred Shading in Battlefield 3 for PlayStation 3*	Christina Coffin
Wed 3:00	*Culling the Battlefield: Data Oriented Design in Practice*	Daniel Collin
Thu 1:30	*Lighting You Up in Battlefield 3*	Kenny Magnusson
Fri 4:05	*Approximating Translucency for a Fast, Cheap & Convincing Subsurface Scattering Look*	Colin Barré-Brisebois

For more DICE talks: http://publications.dice.se

References

- [Lobanchikov09] Igor A. Lobanchikov, ”GSC Game World’s STALKER: Clear Sky – a showcase for Direct3D 10.0/1” GDC’09. http://developer.amd.com/gpu_assets/01gdc09ad3ddstalkerclearsky210309.ppt
- [Lauritzen10] Andrew Lauritzen, ”Deferred Rendering for Current and Future Rendering Pipelines” SIGGRAPH’10 http://bps10.idav.ucdavis.edu/
- [Chajdas11] Matthäus G. Chajdas et al ”Subpixel Reconstruction Antialiasing for Deferred Shading.”. I3D’11