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Shader Model 5.0 and Compute Shader

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DX11 Basics

- New API from Microsoft
- Will be released alongside Windows 7
  - Runs on Vista as well
- Supports downlevel hardware
  - DX9, DX10, DX11-class HW supported
  - Exposed features depend on GPU
- Allows the use of the same API for multiple generations of GPUs
  - However Vista/Windows7 required
- Lots of new features...

Shader Model 5.0

SM5.0 Basics

- All shader types support Shader Model 5.0
  - Vertex Shader
  - Hull Shader
  - Domain Shader
  - Geometry Shader
  - Pixel Shader
- Some instructions/declarations/system values are shader-specific
- Pull Model
- Shader subroutines

Uniform Indexing

- Can now index resource inputs
  - Buffer and Texture resources
  - Constant buffers
  - Texture samplers
- Indexing occurs on the *slot number*
  - E.g. Indexing of multiple texture arrays
  - E.g. indexing *across* constant buffer slots
- Index must be a constant expression

```
Texture2D txDiffuse[2] : register(t0);
Texture2D txDiffuse1   : register(t1);
static uint Indices[4] = { 4, 3, 2, 1  };
float4 PS(PS_INPUT i) : SV_Target
{
  float4 color=txDiffuse[Indices[3]].Sample(sam, i.Tex);
  // float4 color=txDiffuse1.Sample(sam, i.Tex);
}
```

SV_Coverage

- System value available to PS stage only
- Bit field indicating the samples covered by the current primitive
  - E.g. a value of 0x09 (1001b) indicates that sample 0 and 3 are covered by the primitive
- Easy way to detect MSAA edges for per-pixel/per-sample processing optimizations
  - E.g. for MSAA 4x:
  - **`bIsEdge=(uCovMask!=0x0F && uCovMask!=0);`**

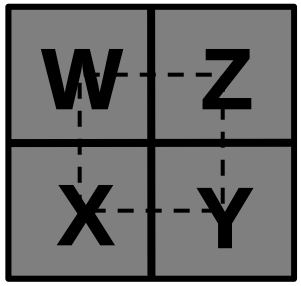
Double Precision

- Double precision optionally supported
  - IEEE 754 format with full precision (0.5 ULP)
  - Mostly used for applications requiring a high amount of precision
  - Denormalized values support
- Slower performance than single precision!
- Check for support:

```
D3D11_FEATURE_DATA_DOUBLES fdDoubleSupport;
pDev->CheckFeatureSupport( D3D11_FEATURE_DOUBLES,
                           &fdDoubleSupport,
                           sizeof(fdDoubleSupport) );
if (fdDoubleSupport.DoublePrecisionFloatShaderOps)
{
   // Double precision floating-point supported!
}
```

Gather()

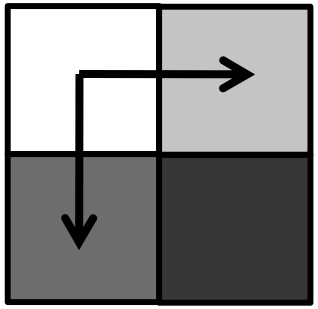
- Fetches 4 point-sampled values in a single texture instruction
- Allows reduction of texture processing
  - Better/faster shadow kernels
  - Optimized SSAO implementations
- SM 5.0 Gather() more flexible
  - Channel selection now supported
  - Offset support (-32..31 range) for Texture2D
  - Depth compare version e.g. for shadow mapping




```
Gather[Cmp]Red()
Gather[Cmp]Green()
Gather[Cmp]Blue()
Gather[Cmp]Alpha()
```

Coarse Partial Derivatives

- **`ddx()/ddy()`** supplemented by coarse version
  - **`ddx_coarse()`**
  - **`ddy_coarse()`**
- Return *same* derivatives for whole 2x2 quad
  - Actual derivatives used are IHV-specific
- Faster than “fine” version
  - Trading quality for performance



`ddx_coarse(□) ==`
`ddx_coarse(□) ==`
`ddx_coarse(□) ==`
`ddx_coarse(□)`

Same principle applies to **`ddy_coarse()`**

Other Instructions

- FP32 to/from FP16 conversion
  - **`uint  f32tof16(float value);`**
  - **`float f16tof32(uint value);`**
  - fp16 stored in low 16 bits of uint
- Bit manipulation
  - Returns the first occurrence of a set bit
    - **`int firstbithigh(int value);`**
    - **`int firstbitlow(int value);`**
  - Reverse bit ordering
    - **`uint reversebits(uint value);`**
  - Useful for packing/compression code
  - And more…

Unordered Access Views

- New view available in Shader Model 5.0
- UAVs allow binding of resources for arbitrary (unordered) read or write operations
  - Supported in PS 5.0 and CS 5.0
- Applications
  - Scatter operations
  - Order-Independent Transparency
  - Data binning operations
- Pixel Shader limited to 8 RTVs+UAVs *total*
  - **OMSetRenderTargetsAndUnorderedAccessViews()**
- Compute Shader limited to 8 UAVs
  - **CSSetUnorderedAccessViews()**

Raw Buffer Views

- New Buffer and View creation flag in SM 5.0
  - Allows a buffer to be viewed as array of typeless 32-bit aligned values
    - Exception: Structured Buffers
  - Buffer must be created with flag D3D11_RESOURCE_MISC_BUFFER_ALLOW_RAW_VIEWS
  - Can be bound as SRV or UAV
    - SRV: need D3D11_BUFFEREX_SRV_FLAG_RAW flag
    - UAV: need D3D11_BUFFER_UAV_FLAG_RAW flag

```
ByteAddressBuffer   MyInputRawBuffer;    // SRV
RWByteAddressBuffer MyOutputRawBuffer;   // UAV

float4 MyPS(PSINPUT input) : COLOR
{
  uint u32BitData;
  u32BitData = MyInputRawBuffer.Load(input.index);// Read from SRV
  MyOutputRawBuffer.Store(input.index, u32BitData);// Write to UAV
  // Rest of code ...
}
```

Structured Buffers

- New Buffer creation flag in SM 5.0
  - Ability to read or write a data structure at a specified index in a Buffer
  - Resource must be created with flag D3D11_RESOURCE_MISC_BUFFER_STRUCTURED
  - Can be bound as SRV or UAV

```
struct MyStruct
{
    float4 vValue1;
    uint   uBitField;
};
StructuredBuffer<MyStruct>   MyInputBuffer;    // SRV
RWStructuredBuffer<MyStruct> MyOutputBuffer;   // UAV

float4 MyPS(PSINPUT input) : COLOR
{
  MyStruct StructElement;
  StructElement = MyInputBuffer[input.index];  // Read from SRV
  MyOutputBuffer[input.index] = StructElement; // Write to UAV
  // Rest of code ...
}
```

Buffer Append/Consume

- Append Buffer enables *global* write counter
  - Can be used to append() new data at the end of the buffer – useful for building lists
- Declaration

```
Append[ByteAddress/Structured]Buffer MyAppendBuf;
```

- Access to write counter

```
uint uWriteCounter = MyAppendBuf.IncrementCounter();
```

- Append data to buffer using counter

```
MyAppendBuf.Store(uWriteCounter, value);
```

- Same rules for Consume with read counter

```
Consume[ByteAddress/Structured]Buffer MyConsumeBuf;
uint uReadCounter = MyConsumeBuf.DecrementCounter();
value = MyConsumeBuf.Load(uReadCounter);
```

Atomic Operations

- CS supports atomic operations
  - Can be used when multiple threads try to modify the same data location (UAV or TLS)
  - Avoid contention

  `InterlockedAdd`

  `InterlockedAnd/InterlockedOr/InterlockedXor`

  `InterlockedCompareExchange`

  `InterlockedCompareStore`

  `InterlockedExchange`

  `InterlockedMax/InterlockedMin`
- Can optionally return original value
- Potential cost in performance
  - Especially if original value is required
  - More latency hiding required

Compute Shader

Compute Shader Intro

- A new programmable shader stage in DX11
  - Independent of the graphic pipeline
- New industry standard for GPGPU applications
- CS enables general processing operations
  - Post-processing
  - Video filtering
  - Sorting/Binning
  - Setting up resources for rendering
  - Etc.
- Not limited to graphic applications
  - E.g. AI, pathfinding, physics, compression…

CS 5.0 Features

- Supports Shader Model 5.0 instructions
- Texture sampling and filtering instructions
  - Explicit derivatives required
- Execution not limited to fixed input/output
- Thread model execution
  - Full control on the number of times the CS runs
- Read/write access to “on-cache” memory
  - Thread Local Storage (TLS)
  - Shared between threads
  - Synchronization support
- Random access writes
  - At last! ☺ Enables new possibilities (scattering)

CS Threads

- A thread is the basic CS processing element
- CS declares the number of threads to operate on (the “thread group”)
  - `[numthreads(X, Y, Z)]`
    `void MyCS(…)`

CS 5.0

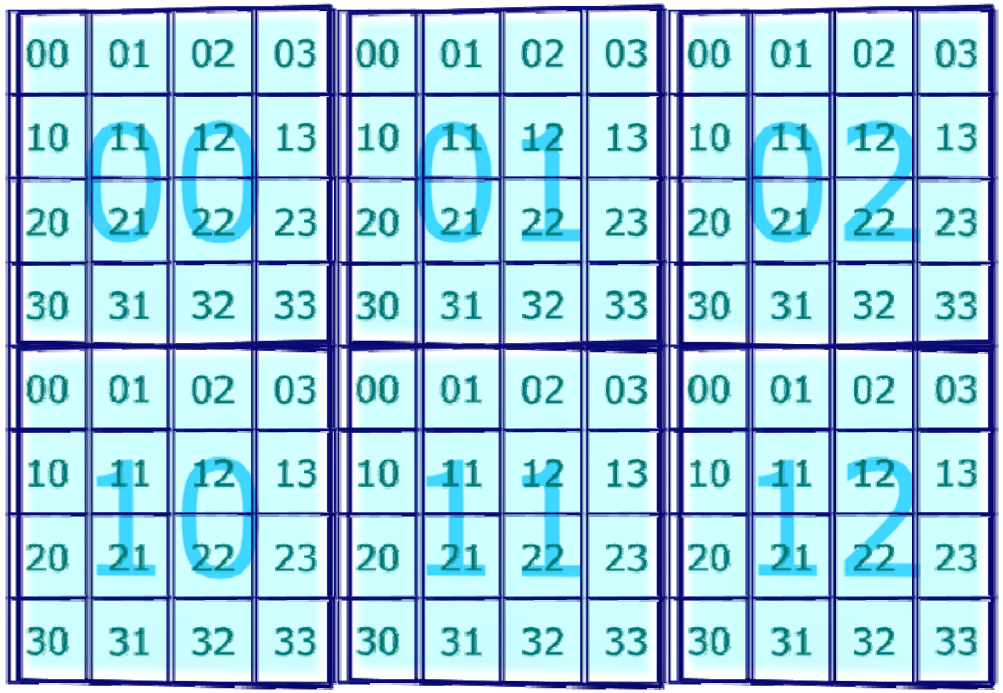
X*Y*Z<=1024

Z<=64

- To kick off CS execution:
  - `pDev11->Dispatch( nX, nY, nZ );`
  - **nX, nY, nZ**: number of thread *groups* to execute
- Number of thread groups can be written out to a Buffer as pre-pass
  - `pDev11->DispatchIndirect(LPRESOURCE *hBGroupDimensions, DWORD dwOffsetBytes);`
  - Useful for conditional execution

CS Threads & Groups

- `pDev11->Dispatch(3, 2, 1);`
- `[numthreads(4, 4, 1)]`
  `void MyCS(…)`
- Total threads = 3*2*4*4 = 96



CS Parameter Inputs

- `pDev11->Dispatch(nX, nY, nZ);`
-
```
[numthreads(X, Y, Z)]
void MyCS(
    uint3 groupID:          SV_GroupID,
    uint3 groupThreadID:    SV_GroupThreadID,
    uint3 dispatchThreadID: SV_DispatchThreadID,
    uint  groupIndex:       SV_GroupIndex);
```
- **groupID.xyz**: *group* offsets from Dispatch()
  - `groupID.xyz ∈ (0..nX-1, 0..nY-1, 0..nZ-1);`
  - *Constant within a CS thread group invocation*
- **groupThreadID.xyz**: thread ID in group
  - `groupThreadID.xyz ∈ (0..X-1, 0..Y-1, 0..Z-1);`
  - *Independent of Dispatch() parameters*
- **dispatchThreadID.xyz**: global thread offset
  - `= groupID.xyz*(X,Y,Z) + groupThreadID.xyz`
- **groupIndex**: flattened version of groupThreadID

CS Bandwidth Advantage

- Memory bandwidth often still a bottleneck
  - Post-processing, compression, etc.
- Fullscreen filters often require input pixels to be fetched multiple times!
  - Depth of Field, SSAO, Blur, etc.
  - BW usage depends on TEX cache and kernel size
- TLS allows reduction in BW requirements
- Typical usage model
  - Each thread reads data from input resource
  - ...and write it into TLS group data
  - Synchronize threads
  - Read back and process TLS group data

Thread Local Storage

- Shared between threads
- Read/write access at any location
- Declared in the shader
  - groupshared float4 vCacheMemory[1024];
- Limited to 32 KB
- Need synchronization before reading back data written by other threads
  - To ensure all threads have finished writing
  - **`GroupMemoryBarrier();`**
  - **`GroupMemoryBarrierWithGroupSync();`**

CS 4.X

- Compute Shader supported on DX10(.1) HW
  - CS 4.0 on DX10 HW, CS 4.1 on DX10.1 HW
- Useful for prototyping CS on HW device before DX11 GPUs become available
- Drivers available from ATI and NVIDIA
- Major differences compared to CS5.0
  - Max number of threads is 768 total
  - Dispatch Zn==1 & no DispatchIndirect() support
  - TLS size is 16 KB
  - Thread can only write to its own offset in TLS
  - Atomic operations *not* supported
  - Only one UAV can be bound
  - Only writable resource is Buffer type

PS 5.0 vs CS 5.0 Example: Gaussian Blur

- Comparison between a PS 5.0 and CS5.0 implementation of Gaussian Blur
- Two-pass Gaussian Blur
  - High cost in texture instructions and bandwidth
- Can the compute shader perform better?

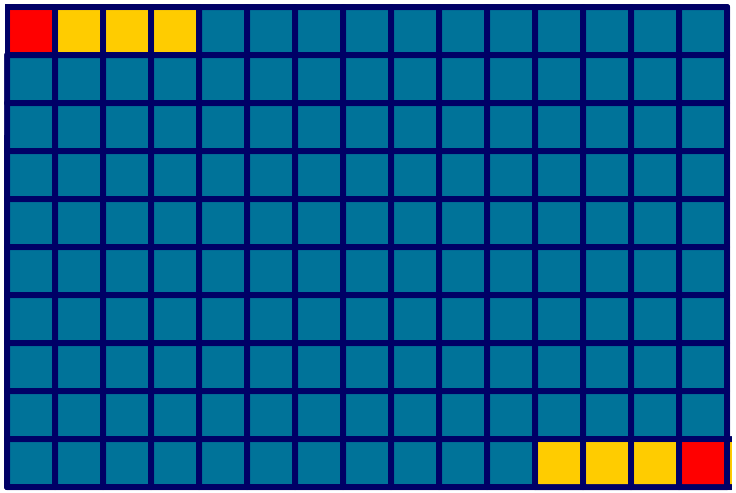
Gaussian Blur PS

- Separable filter Horizontal/Vertical pass
  - Using kernel size of x*y
- For each pixel of each line:
  - Fetch x texels in a horizontal segment
  - Write H-blurred output pixel in RT: $B_H = \sum_{i=1}^{x} G_i P_i$
- For each pixel of each column:
  - Fetch y texels in a vertical segment from RT
  - Write fully blurred output pixel: $B = \sum_{i=1}^{y} G_i P_i$
- Problems:
  - Texels of source texture are read multiple times
  - This will lead to cache trashing if kernel is large
  - Also leads to many texture instructions used!

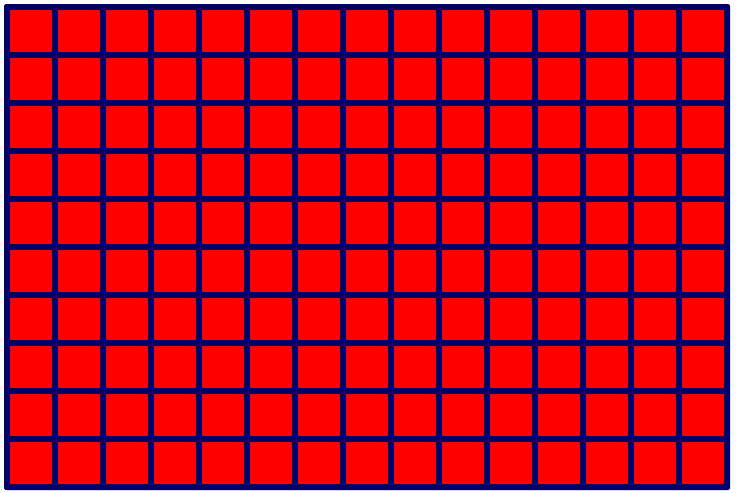
Gaussian Blur PS

Horizontal Pass

Source texture



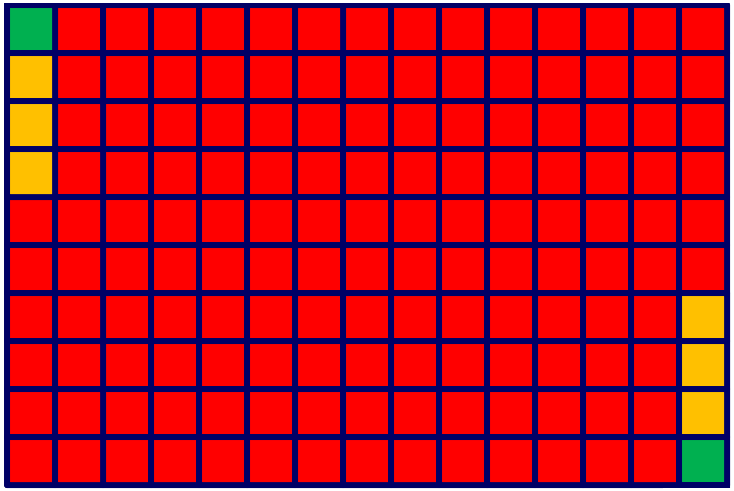
Temp RT



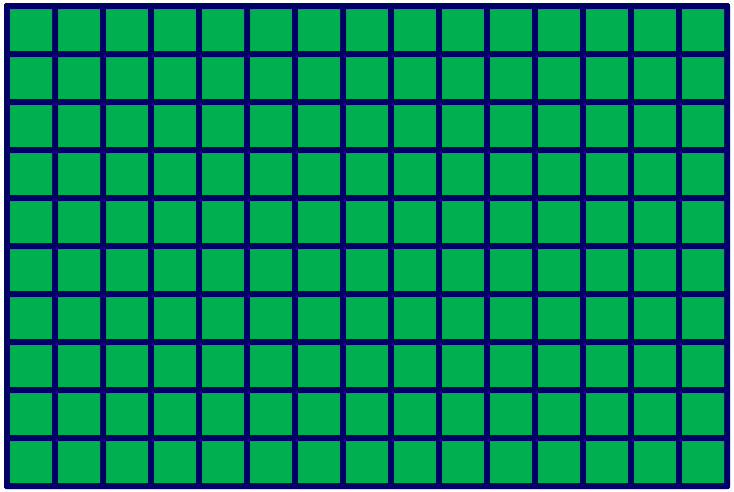
Gaussian Blur PS

Vertical Pass

Source texture (temp RT)



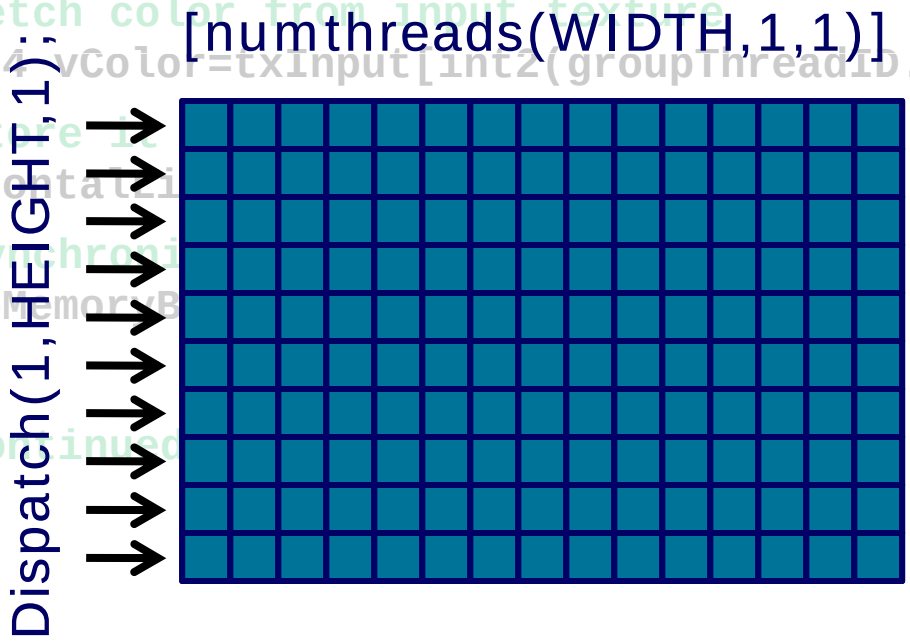
Destination RT



Gaussian Blur CS – HP(1)

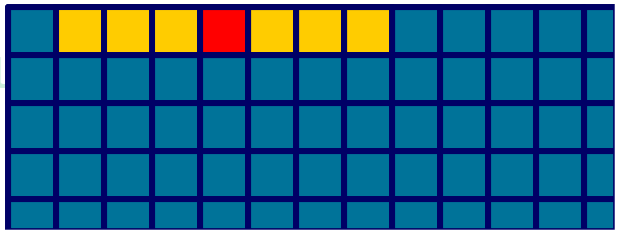
```
groupshared float4 HorizontalLine[WIDTH];    // TLS
Texture2D txInput;     // Input texture to read from
RWTexture2D<float4> OutputTexture;    // Tmp output
[numthreads(WIDTH,1,1)]
void
                                                    eadID)
{
    // Fetch color from input texture
    float4 vColor=txInput[int2(groupThreadID.x,groupID.y)];
    // Store in
    HorizontalLi
    // Synchroni
    GroupMemoryB

    // Continue
```

```
pDevContext->Dispatch(1,HEIGHT,1);
```



Gaussian Blur CS – HP(2)

```
    // Compute horizontal Gaussian blur for each pixel
    vColor = float4(0,0,0,0);

    [unroll]for (int i=-GS2; i<=GS2; i++)
    {
      // Determine offset of pixel
      int nOffset = groupThreadID.

      // Clamp offset
      nOffset = clamp(nOffset, 0,

      // Add color for pixels within horizontal filter
      vColor += G[GS2+i] * HorizontalLine[nOffset];
    }


    // Store result
    OutputTexture[int2(groupThreadID.x,groupID.y)]=vColor;

}
```



Gaussian Blur BW:PS vs CS

- Pixel Shader
  - # of reads per source pixel: 7 (H) + 7 (V) = 14
  - # of writes per source pixel: 1 (H) + 1 (V) = 2
  - Total number of memory operations per pixel: 16
  - For a 1024x1024 RGBA8 source texture this is **64** MBytes worth of data transfer
    - Texture cache will reduce this number
    - But become less effective as the kernel gets larger
- Compute Shader
  - # of reads per source pixel: 1 (H) + 1 (V) = 2
  - # of writes per source pixel: 1 (H) + 1 (V) = 2
  - Total number of memory operations per pixel: 4
  - For a 1024x1024 RGBA8 source texture this is **16** MBytes worth of data transfer

Conclusion

- New Shader Model 5.0 feature set extensively powerful
  - New instructions
  - Double precision support
  - Scattering support through UAVs
- Compute Shader
  - No longer limited to graphic applications
  - TLS memory allows considerable performance savings
- DX11 SDK available for prototyping
  - Ask your IHV for a CS4.X-enabled driver
  - REF driver for full SM 5.0 support

Questions?

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