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Game Developers Conference®
March 23-27, 2009 | Moscone Center, San Francisco

High Quality Direct3D 10.0 & 10.1 Accelerated Techniques

Jon Story, AMD
Holger Gruen, AMD

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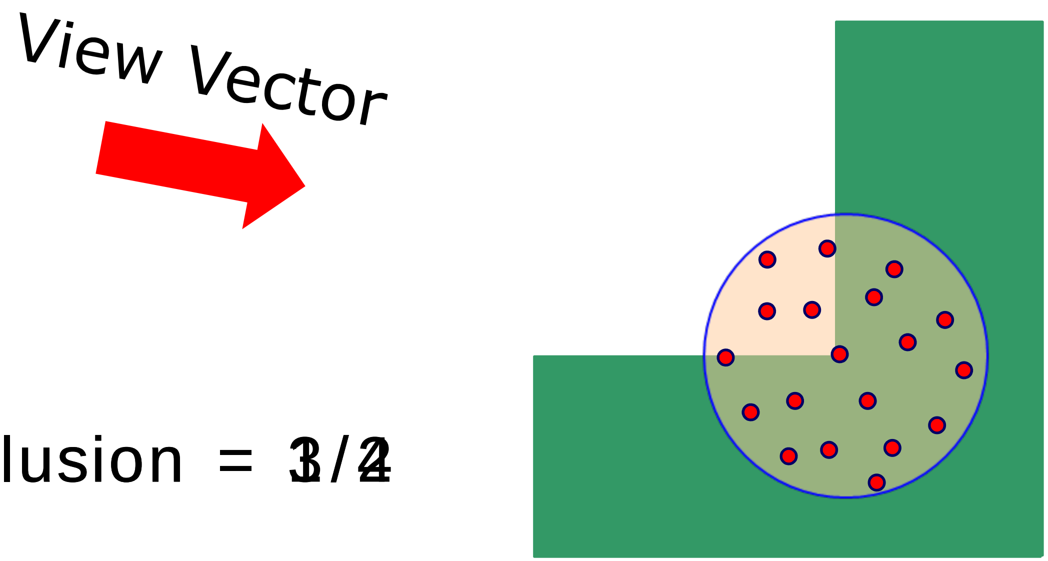
Agenda

- High Definition Ambient Occlusion
- High Quality Shadow Filtering

High Definition Ambient Occlusion (HDAO)

Conventional AO : 1

- » [illegible]
- » Occlusion Factor ~= Failure Rate



Occlusion = 3/4

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Conventional AO : 2

- Usually requires many depth samples to achieve acceptable results
- Maths overhead per sample is high
  - Transform to post-perspective space
  - Depth testing
  - Result attenuation
- Filtering pass almost essential to smooth out dithering and banding artifacts

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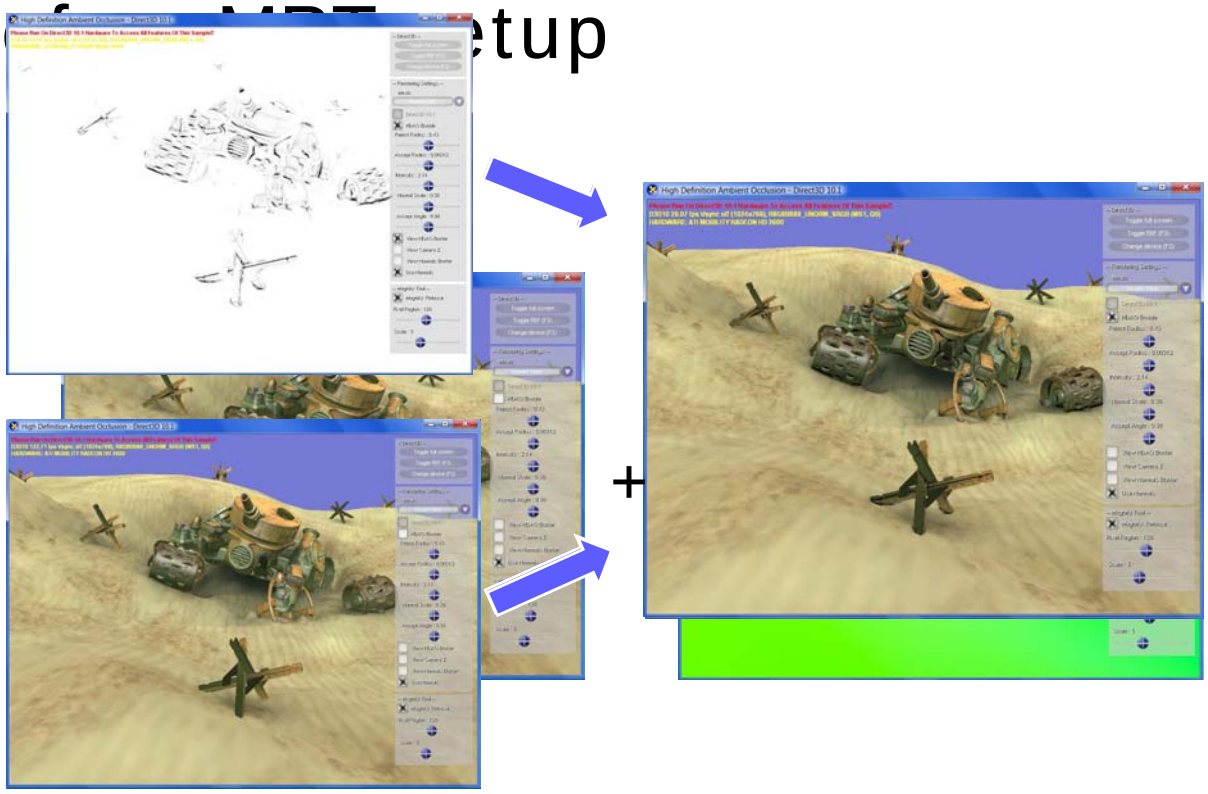
The Aim of HDAO

- Deliver a believable AO look
- Achieve affordable performance on today‘s HW
- Avoid need for filtering pass(es)
  - Keep performance higher
  - No additional render targets required
- Easy to incorporate
  - No normals required
  - Account for normals with ease if available

How does HDAO Fit into the Rendering Pipeline?

- Render scene (and normals)
- Optionally render normals as part of MRT setup

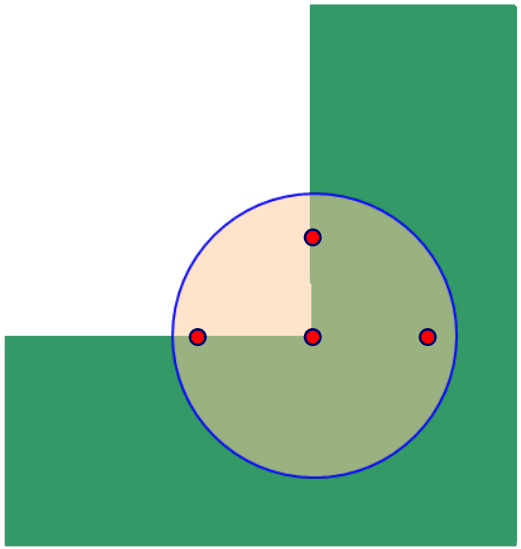


How does HDAO Work?

- Detects valleys in camera Z space
- Not _only_ creases ☺

View Vector

Valley = false



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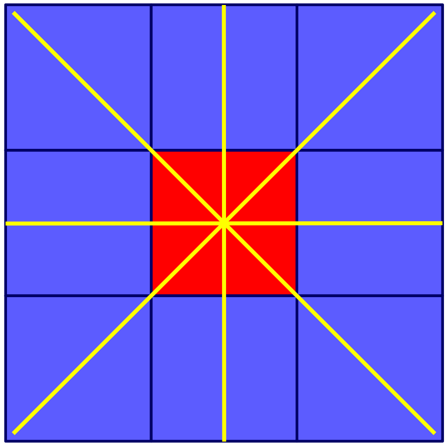
Valley Detection

- Start by sampling the central depth (raw Z) converted to camera Z
- The simplest implementation would be a 3x3 sample pattern
- Perform valley detection for each twin point (pixel pair) comparison
- Valley test produces binary result



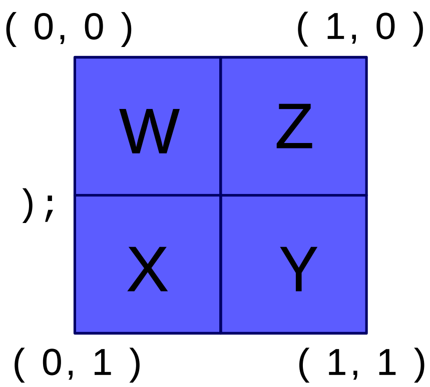
Credit to Holger Gruen for this idea

Occlusion Factor = Valley Test

How does Gather Work?

- Gather fetches 4 point sampled texels in a single instruction
- Similar to Fetch4 exposed on DX9 ATI GPUs
- Available in Direct3D 10.1 & 11 hardware
- There are known issues in previous versions of the HLSL compiler
- Used on single channel formats (restriction gone for DX11)
  - depth buffer
  - Shadow maps
- Must use March 2009 SDK or later

```
f4Depth = DepthTex.Gather( SamPoint, f2Coord );
```



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Direct3D 10.0 Version of Gather

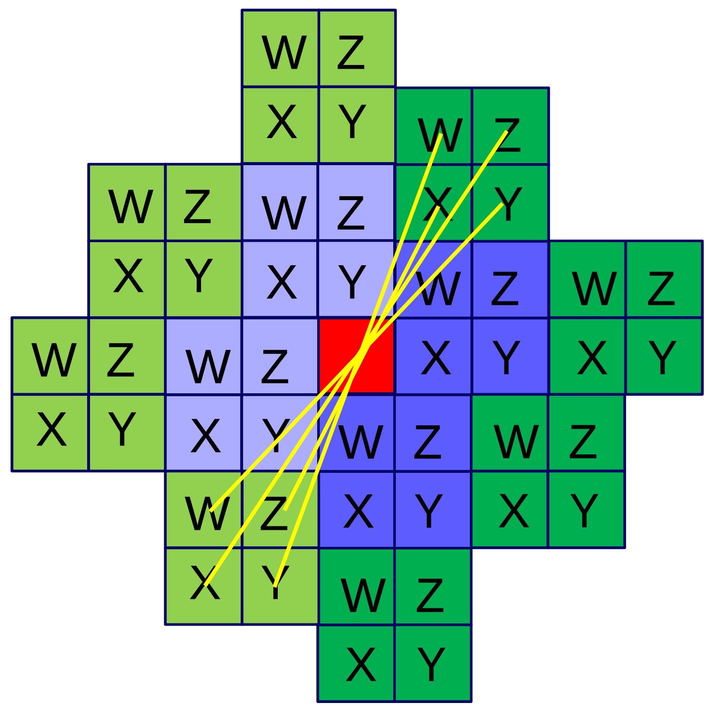
- Be sure to get the integer offsets correct for the 4 samples

```
// Direct3D 10.1
f4Ret = Tex.Gather( g_SamplePoint, f2TexCoord );

// Direct3D 10.0
f4Ret.x = Tex.SampleLevel( g_SamplePoint, f2TexCoord, 0, int2( 0, 1 ) ).x;
f4Ret.y = Tex.SampleLevel( g_SamplePoint, f2TexCoord, 0, int2( 1, 1 ) ).x;
f4Ret.z = Tex.SampleLevel( g_SamplePoint, f2TexCoord, 0, int2( 1, 0 ) ).x;
f4Ret.w = Tex.SampleLevel( g_SamplePoint, f2TexCoord, 0, int2( 0, 0 ) ).x;
```

Gather Pattern

- [illegible] only [illegible] depth sampling using Gather [illegible] swizzle xyzw with zwxy



Natural Vectorization

```
for( iGather=0; iGather<NUM_GATHERS; iGather++ )
{
    // Gather mirrored tw
    f4SampledZ[0] = Depth
    f4SampledZ[0] = -g_f
    f4SampledZ[1] = Depth
    f4SampledZ[1] = -g_fQ

    // Detect valleys
    // First twin
    f4Diff = fCenterZ.xxx
    f4Compare[0] = ( f4Di
    f4Compare[0] *= ( f4Di
    // Mirrored twin
    f4Diff = fCenterZ.xxxx - f4Sample
    f4Compare[1] = ( f4Diff < g_fHDA      dius.xxxx ) ? ( 1.0f ) : ( 0.0f );
    f4Compare[1] *= ( f4Diff > g_fHD      ceptRadius.xxxx ) ? ( 1.0f ) : ( 0.0f );
    // Accumulate occlusion factor
    f4Occlusion.xyzw += ( g_f4RingWeight[iGather].xyzw * f4Compare[0].xyzw *
    f4Compare[1].zwxy );
}
```

We perform the valley detection logic on 4 valleys at once

Finally we weight and store the occlusion factor of 4 valleys at a time

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HDAO Buffer (depth only)

- 40 **Gathers**
- No filtering needed

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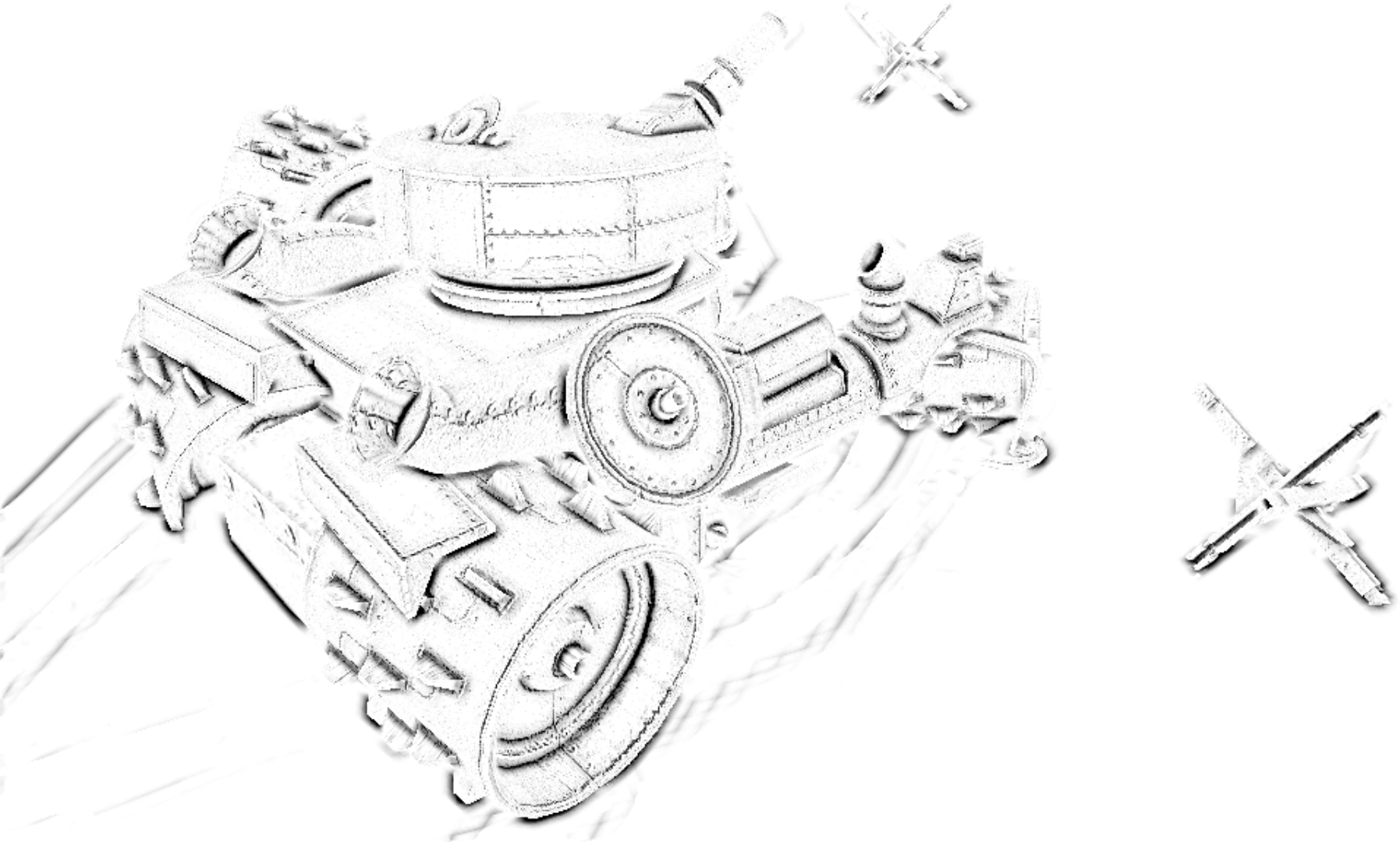
Bringing in Camera Space Normals

- HDAO easily accounts for normals
- Scale Z component of camera space normal by desired amount
- Add scaled normal to camera Z value
- Run valley detection code as before

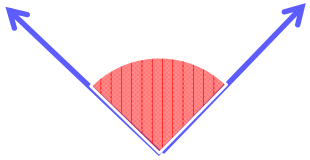
```
// Offset by scaled normal
f4CameraZ += ( f4NormalZ * g_fNormalScale );
```

HDAO - Buffer (depth & normals)
- 80 **Gathers** (could use alot less)
- No filtering needed

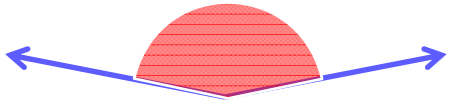


Early Rejection Test

- For mostly convex meshes, can produce good results
- Or compute direction vectors from full camera space positions
- Reject if too shallow



Pass



Fail

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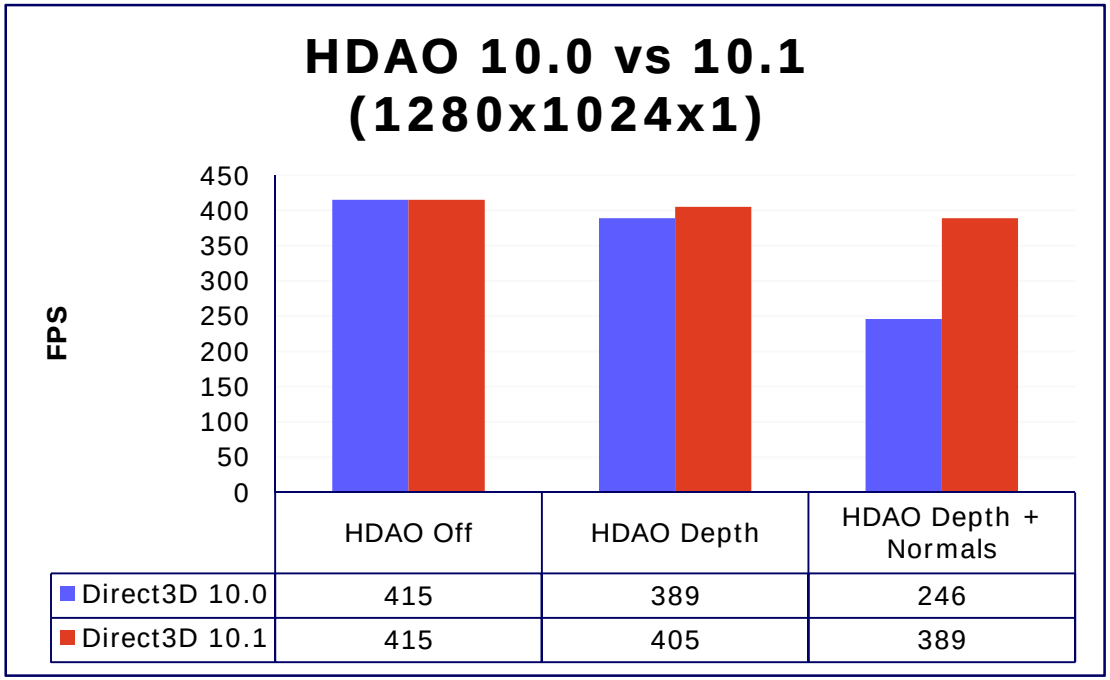
Performance

- HDAO (depth and normals):
  - Direct3D 10.0: 0.65 MS
  - Direct3D 10.1: 0.59 MS



Phenom 2.3GHz, HD4870X2, 2 GB RAM, Windows Vista 32 (SP1)

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Tom Clancy‘s HAWX
Publisher: Ubisoft
Developer: Ubisoft Romania

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Stormrise
Publisher: SEGA
Developer: The Creative Assembly Australia

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BattleForge
Publisher: EA
Developer: EA Phenomic

Future Work

- Looking into a compute shader accelerated version
  - Solid sampling pattern lends itself well to Thread Local Storage
- Account for strong light sources
  - AO for many scenes is not low frequency
- Real valley tracing...

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High Quality Shadow Filtering

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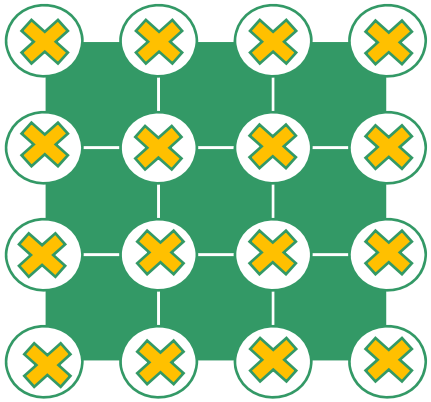
How Direct3D 10.1 helps filtering

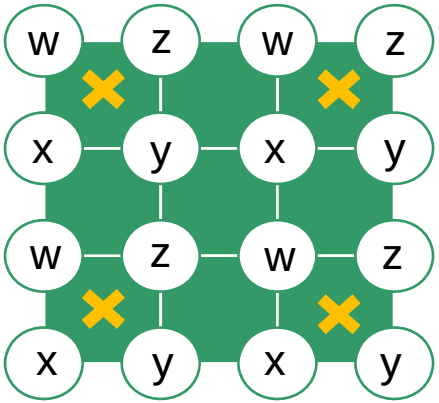
for single channel textures

Direct3D 10.0



NxN point samples if you need all data points – e.g. 4x4 = 16

Direct3D 10.1



(N/2)x(N/2) Gather operations get all data - e.g. 2x2 = 4

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Why revisit conventional shadow filtering? - 1

- There are advanced techniques for smooth shadows
  - The most prominent are
    - VSMs, layered VSMs, CSMs, ESMs, ACDF SMs
  - Can be combined with SATs for arbitary smoothness
- But these methods bring other problems
  - The renderer gets more complex
  - May need to work around specific artifacts
  - Use only if neccessary

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Why revisit conventional shadow filtering? - 2

- Advanced methods come at a cost
  - More RTs at a high memory cost
  - Costly postprocessing operations
  - Non optimal RT formats
- Is an advanced techique needed?
  - Depth buffer based deferred shadowing does not depend on depth complexity
  - Big conventional shadow filters not that expensive

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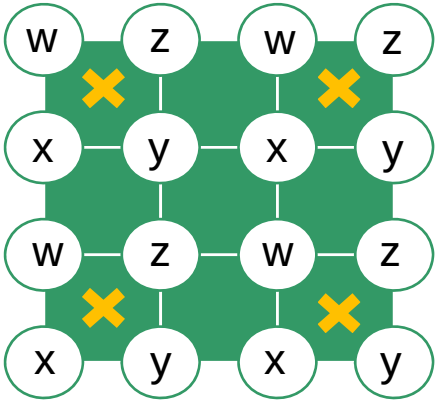
Surprising insights about uniform shadow filtering 1

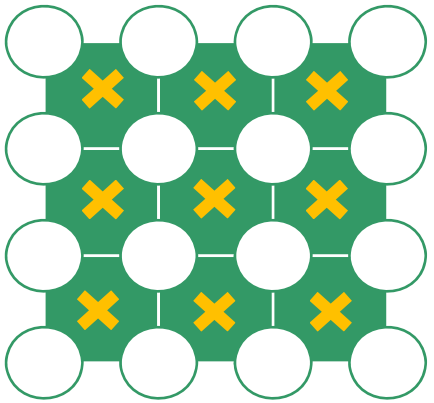
Let’s filter a 4x4 visibility sample block

Direct3D 10.1



4 Gather operations plus some ALU – (N/2)x(N/2) Gather ops for NxN

Direct3D 10.0



9 PCF samples plus some ALU right ?

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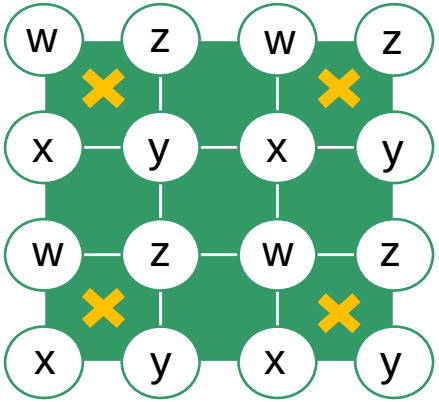

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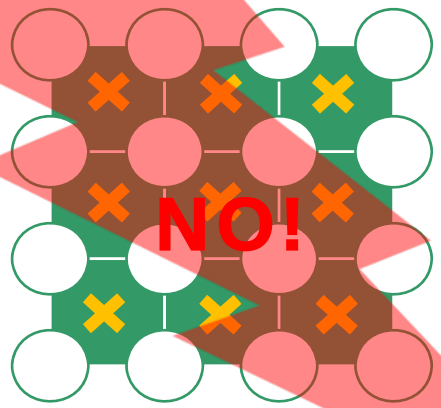

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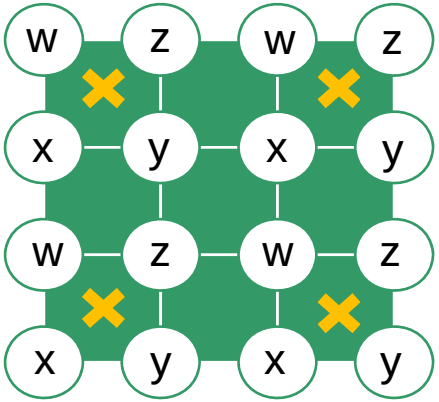
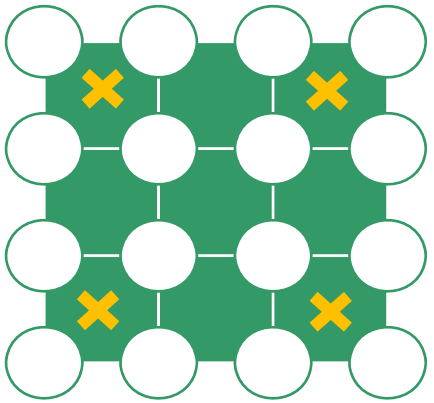


4 Gather operations plus some ALU => (N/2)x(N/2) Gather() samples for NxN

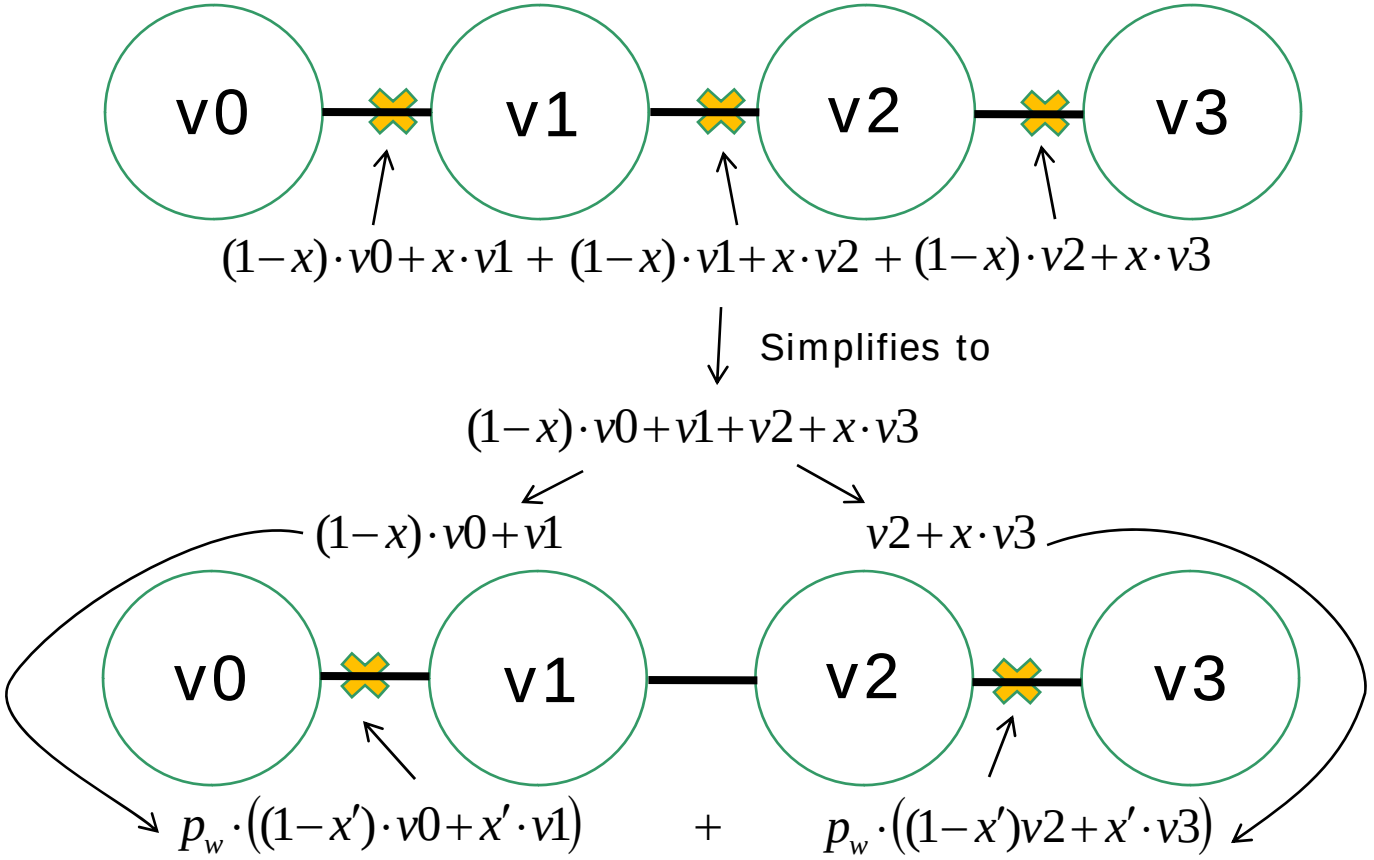
Direct3D 10.0



4 shifted PCF samples plus a post weight factor is enough => (N/2)x(N/2) PCF samples for NxN

Surprising insights about uniform shadow filtering 2

Let's look at only 1 row of 4 visibility samples



Credit for this idea goes to: Sergey Nenakhov at Funcom

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Surprising insights about uniform shadow filtering 3

- Only (N/2)x(N/2) PCF samples necessary instead for a uniform filter
- Cheaper than commonly assumed
  - 8x8 with only 16 PCF samples
  - Not only for shadow filtering
- Same texture op count as Direct3D 10.1
- Why bother with Direct3D 10.1?


From DICE's Frostbite Engine:
Uniform shadow filtering


From DICE's Frostbite Engine:
Gaussian shadow filtering

Disadvantages of uniform shadow filtering

Uniform filtering blurs away too many details

Gaussian filtering preserves more details

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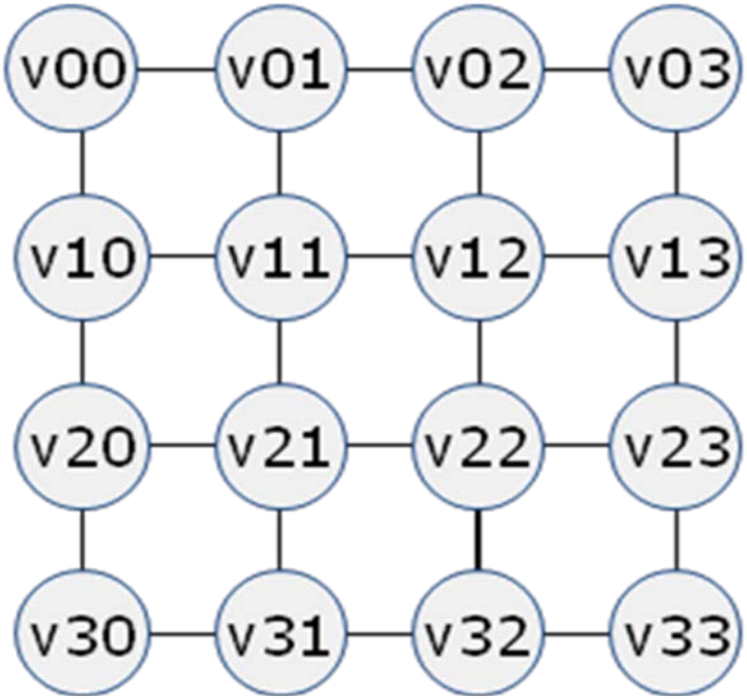
Advanced Direct3D 10.1 shadow filtering 1

Use a unique weight per PCF sample



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Advanced Direct3D 10.1 shadow filtering 1

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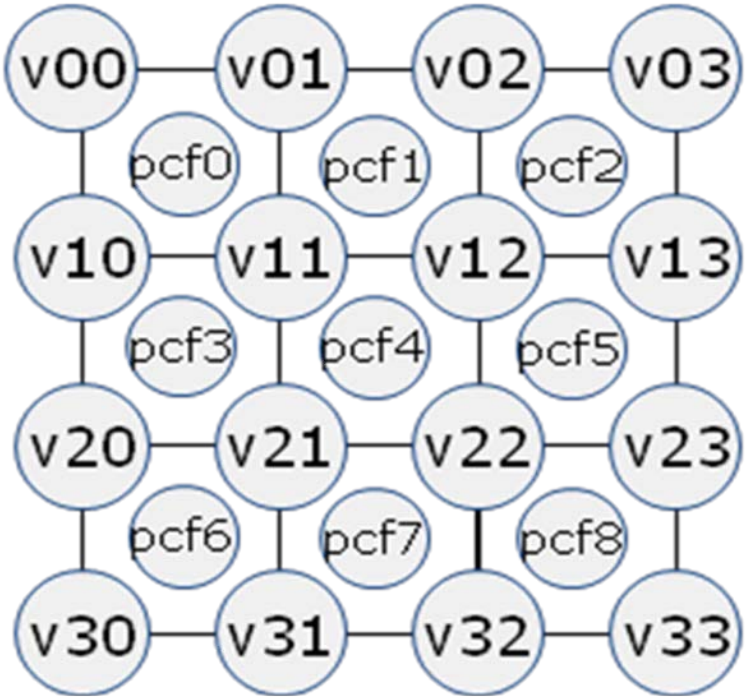

Advanced Direct3D 10.1 shadow filtering 1

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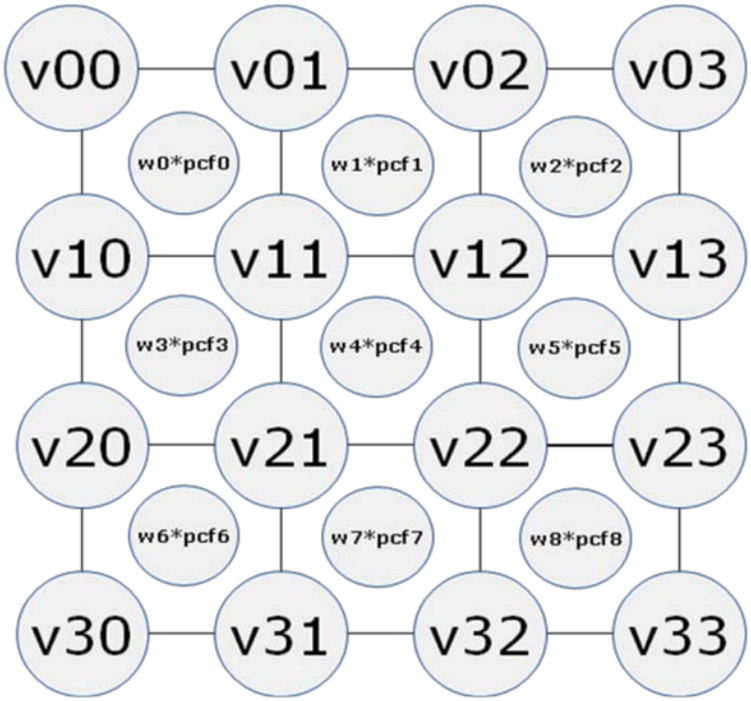

$$\frac{\sum_{k=0}^{(N-1)\cdot(N-1)} w_k \cdot pcf_k}{\sum_{k=0}^{(N-1)\cdot(N-1)} w_k}$$

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Advanced Direct3D 10.1 shadow filtering 2

- Direct3D 10.1 needs (N/2)x(N/2) Gather() samples
- A (N/2)x(N/2) PCF samples solution is no longer possible for unique weights
  - Filter weights are not symmetric
    - Equation system not solvable
  - It is possible to get below NxN PCF ops for Direct3D 10.0 though

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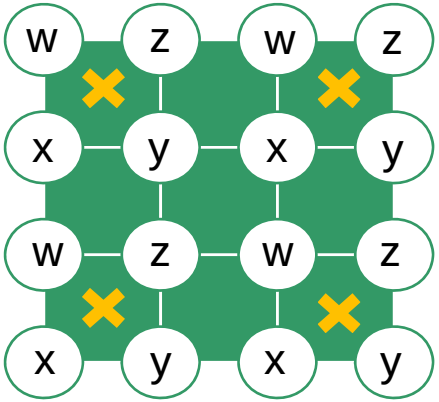
Advanced Direct3D 10.1 shadow filtering 3

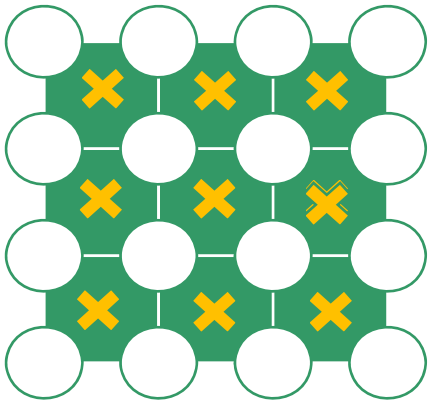
Let’s filter a 4x4 visibility sample block using unique weights

Direct3D 10.1



4 Gather() operations plus some ALU => (N/2)x(N/2) Gather samples for NxN

Direct3D 10.0



9 PCF samples plus some ALU right ?

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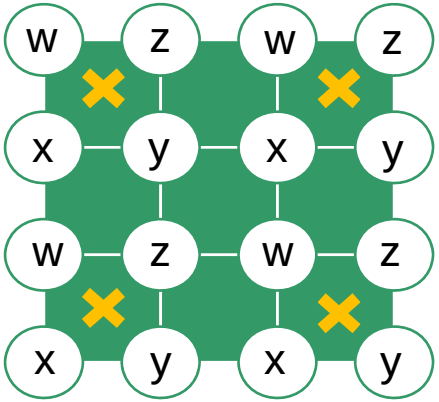

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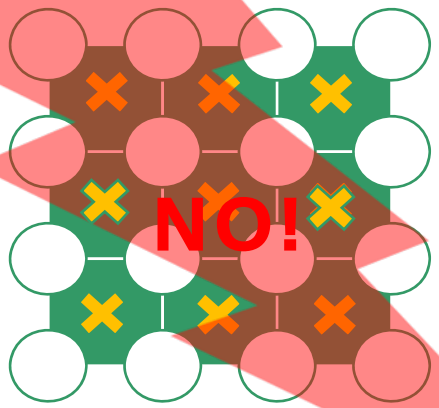

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Advanced Direct3D 10.1 shadow filtering 3

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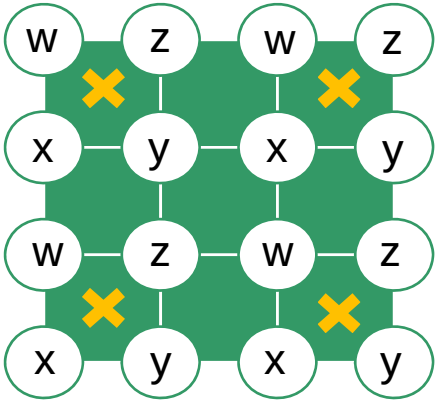
Direct3D 10.1



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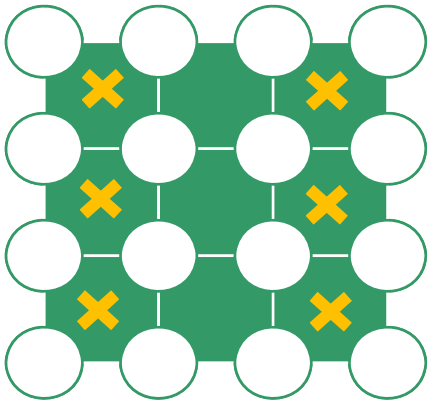
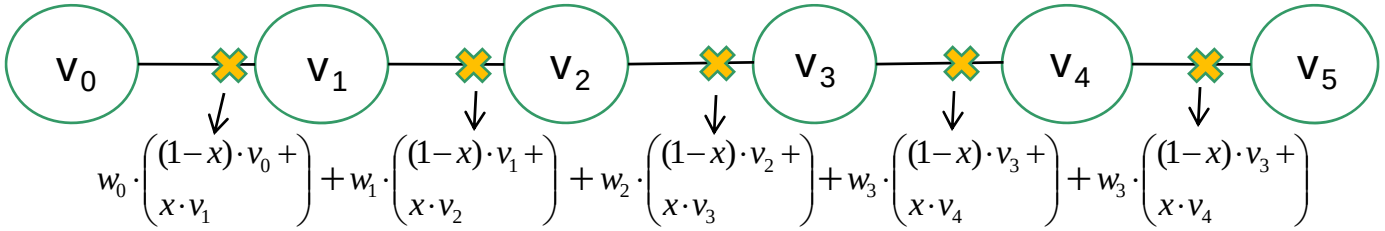
Direct3D 10.0



6 shifted PCF samples plus post weight factors is enough => (N/2)x(N-1) PCF samples for NxN

Advanced Direct3D 10.1 shadow filtering 4

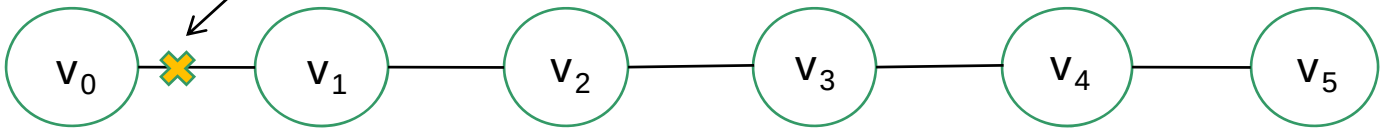


$$w_0 \cdot \begin{pmatrix} (1-x)\cdot v_0 + \\ x \cdot v_1 \end{pmatrix} + w_1 \cdot \begin{pmatrix} (1-x)\cdot v_1 + \\ x \cdot v_2 \end{pmatrix} + w_2 \cdot \begin{pmatrix} (1-x)\cdot v_2 + \\ x \cdot v_3 \end{pmatrix} + w_3 \cdot \begin{pmatrix} (1-x)\cdot v_3 + \\ x \cdot v_4 \end{pmatrix} + w_3 \cdot \begin{pmatrix} (1-x)\cdot v_3 + \\ x \cdot v_4 \end{pmatrix}$$

$$(1 - x) \cdot v_0 \cdot w_0 + \left(\sum_{k=1}^{N-2} v_k \cdot \left((w_{k-1} - w_k) \cdot x + w_k \right) \right) + x \cdot v_{N-1} \cdot w_{N-2}$$

left

$$\begin{pmatrix} (1-x)\cdot v_0 \cdot w_0 + \\ v1 \cdot (w1 + x \cdot (w_0 - w_1)) \end{pmatrix}$$



$$(1 - x') \cdot wp \cdot v_0 = (1-x) \cdot w_0 \cdot v_0$$

$$x' \cdot wp \cdot v_1 = v_1 \cdot (x \cdot (w_0 - w_1) + w_1)$$

$$\longrightarrow$$

$$x' = \frac{(w_1 - w_0) \cdot x - w_1}{w_1 \cdot x - w_1 - w_0}$$

$$wp = -w_1 \cdot x + w_1 + w_0$$

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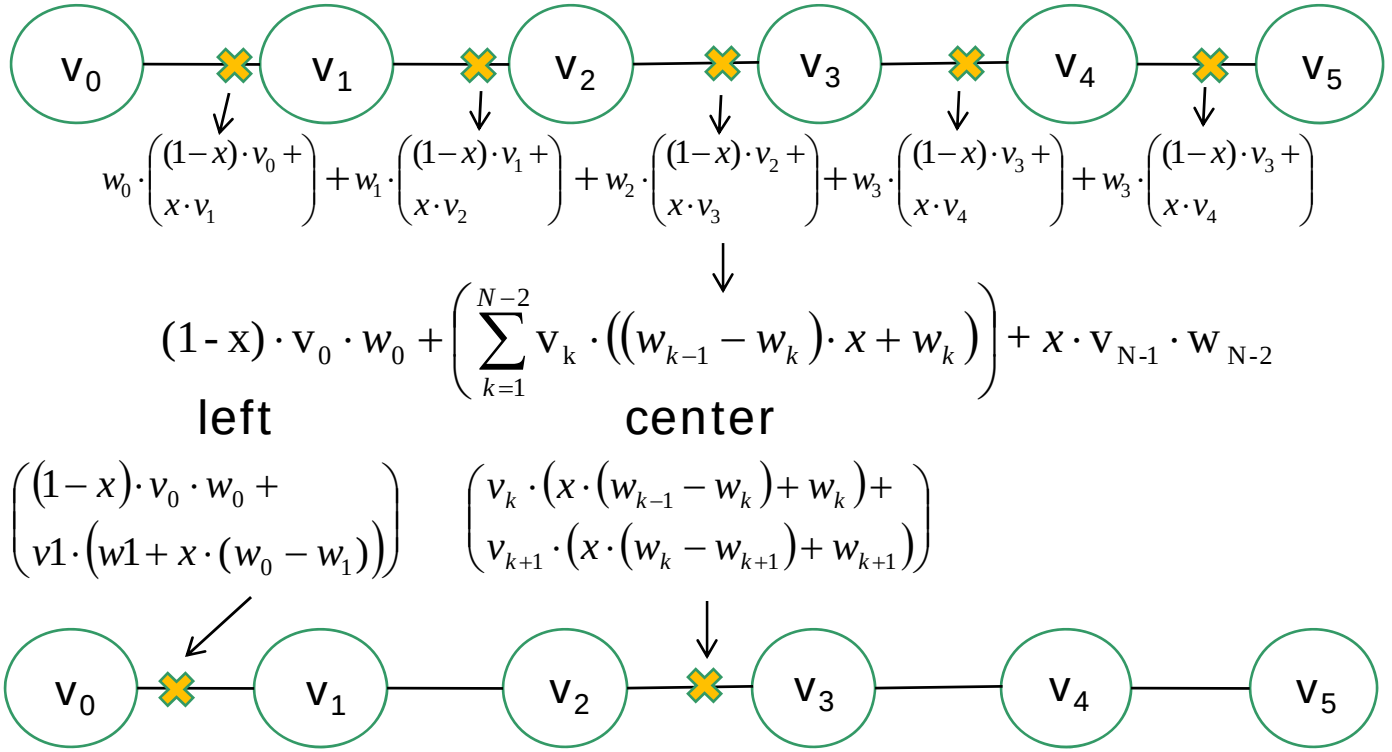
Advanced Direct3D 10.1 shadow filtering 4



$$w_0 \cdot \begin{pmatrix} (1-x)\cdot v_0 + \\ x \cdot v_1 \end{pmatrix} + w_1 \cdot \begin{pmatrix} (1-x)\cdot v_1 + \\ x \cdot v_2 \end{pmatrix} + w_2 \cdot \begin{pmatrix} (1-x)\cdot v_2 + \\ x \cdot v_3 \end{pmatrix} + w_3 \cdot \begin{pmatrix} (1-x)\cdot v_3 + \\ x \cdot v_4 \end{pmatrix} + w_3 \cdot \begin{pmatrix} (1-x)\cdot v_3 + \\ x \cdot v_4 \end{pmatrix}$$

$$(1 - x) \cdot v_0 \cdot w_0 + \left(\sum_{k=1}^{N-2} v_k \cdot \left((w_{k-1} - w_k) \cdot x + w_k \right) \right) + x \cdot v_{N-1} \cdot w_{N-2}$$

left

center

$$\begin{pmatrix} (1-x)\cdot v_0 \cdot w_0 + \\ v1 \cdot (w1 + x \cdot (w_0 - w_1)) \end{pmatrix} \qquad \begin{pmatrix} v_k \cdot (x \cdot (w_{k-1} - w_k) + w_k) + \\ v_{k+1} \cdot (x \cdot (w_k - w_{k+1}) + w_{k+1}) \end{pmatrix}$$

$$(1 - x') \cdot wp \cdot v_k = v_k \cdot (x \cdot (w_{k-1} - w_k) + w_k)$$
$$x' \cdot wp \cdot v_{k+1} = v_{k+1} \cdot (x \cdot (w_k - w_{k+1}) + w_{k+1})$$

$$\longrightarrow \quad x' = \frac{(w_{k+1} - w_k) \cdot x - w_{k+1}}{(w_{k+1} - w_{k-1}) \cdot x - w_{k+1} - w_k}$$

$$wp = (w_{k-1} - w_{k+1}) \cdot x + w_{k+1} + w_k$$

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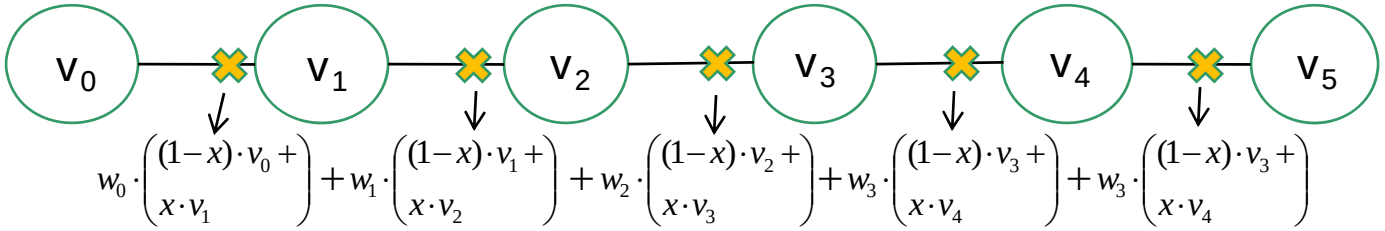
Advanced Direct3D 10.1 shadow filtering 4

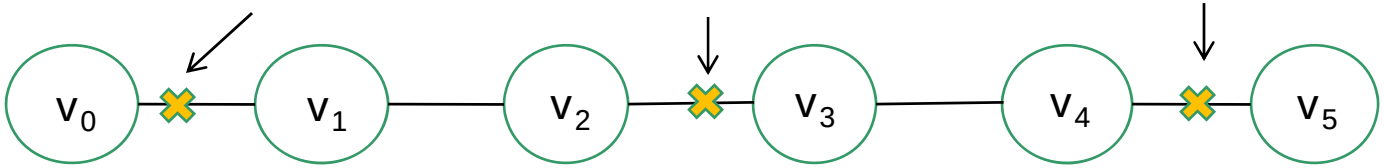


$$w_0 \cdot \begin{pmatrix} (1-x)\cdot v_0 + \\ x \cdot v_1 \end{pmatrix} + w_1 \cdot \begin{pmatrix} (1-x)\cdot v_1 + \\ x \cdot v_2 \end{pmatrix} + w_2 \cdot \begin{pmatrix} (1-x)\cdot v_2 + \\ x \cdot v_3 \end{pmatrix} + w_3 \cdot \begin{pmatrix} (1-x)\cdot v_3 + \\ x \cdot v_4 \end{pmatrix} + w_3 \cdot \begin{pmatrix} (1-x)\cdot v_3 + \\ x \cdot v_4 \end{pmatrix}$$

$$(1 - x) \cdot v_0 \cdot w_0 + \left(\sum_{k=1}^{N-2} v_k \cdot \left((w_{k-1} - w_k) \cdot x + w_k \right) \right) + x \cdot v_{N-1} \cdot w_{N-2}$$

left center right

$$\begin{pmatrix} (1-x)\cdot v_0 \cdot w_0 + \\ v1 \cdot (w1 + x \cdot (w_0 - w_1)) \end{pmatrix} \quad \begin{pmatrix} v_k \cdot (x \cdot (w_{k-1} - w_k) + w_k) + \\ v_{k+1} \cdot (x \cdot (w_k - w_{k+1}) + w_{k+1}) \end{pmatrix} \quad \begin{pmatrix} v_{N-2} \cdot (x \cdot (w_{N-2} - w_{N-1}) + w_{N-1}) + \\ x \cdot w_{N-1} v_{N-1} \end{pmatrix}$$



$$(1 - x') \cdot wp \cdot v_{N-2} = v_{N-2} \cdot (x \cdot (w_{N-2} - w_{N-1}) + w_{N-1})$$

$$x' \cdot wp \cdot v_{N-1} = x \cdot w_{N-1} \cdot v_{N-1}$$

$$x' = \frac{w_{N-1} \cdot x}{w_{N-2} \cdot x + w_{N-1}}$$

$$wp = w_{N-2} \cdot x + w_{N-1}$$

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Advanced Direct3D 10.1 shadow filtering 5

- Direct3D 10.0
  - needs (N/2)x(N-1) PCF samples for Gaussian shadows – not (N-1)x(N-1)!
  - can do one row with (N/2) samples with shifted x texture coords
  - y texture coord stays untouched
- Stats of an optimized shader for 8x8
  - Direct3D 10.1 shader roughly twice as fast as the Direct3D10.0 version
  - Direct3D 10.1 shader as fast as the optimized uniform (N/2)x(N/2) filter under Direct3D10.0


From DICE’s Frostbite Engine:
Standard 2x2 shadow filtering


From DICE’s Frostbite Engine:
5x5 Gaussian filtering

Tom Clancy‘s HAWX
Publisher: Ubisoft
Developer: Ubisoft Romania
Normal Quality – Blurred VSM


Tom Clancy‘s HAWX
Publisher: Ubisoft
Developer: Ubisoft Romania
Gaussian Shadows
ATK 1 2 DEF
Reach downtown
1196 KMH
ALT 1444
Rio
100%
35929m
JStrike 240
100

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Stormrise, Publisher: SEGA
Developer: The Creative Assembly Australia
Normal Shadow Quality

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Stormrise, Publisher: SEGA
Developer: The Creative Assembly Australia
Gaussian Shadows

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Summary: 1

- HDAO adds enourmous depth to the scene, at an affordable cost
- Using Direct3D 10.1 `gather4` instruction greatly accelerates performance
- Growing number of game developers using the effect
- Mail jon.story@amd.com if you would like to know more...

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Summary: 2

- Conventional high quality shadow filtering is suprisingly fast
  - Even under Direct3D 10.0/9
- Direct3D 10.1 delivers the best performance
  - No reason not to use gaussian shadows!
  - Direct3D 11 supports Gather()!
- Mail holger.gruen@amd.com if you want the shaders or the derivations for (N/2)x(N/2) PCF sample shadows

Questions?

Please fill in the feedback forms...