

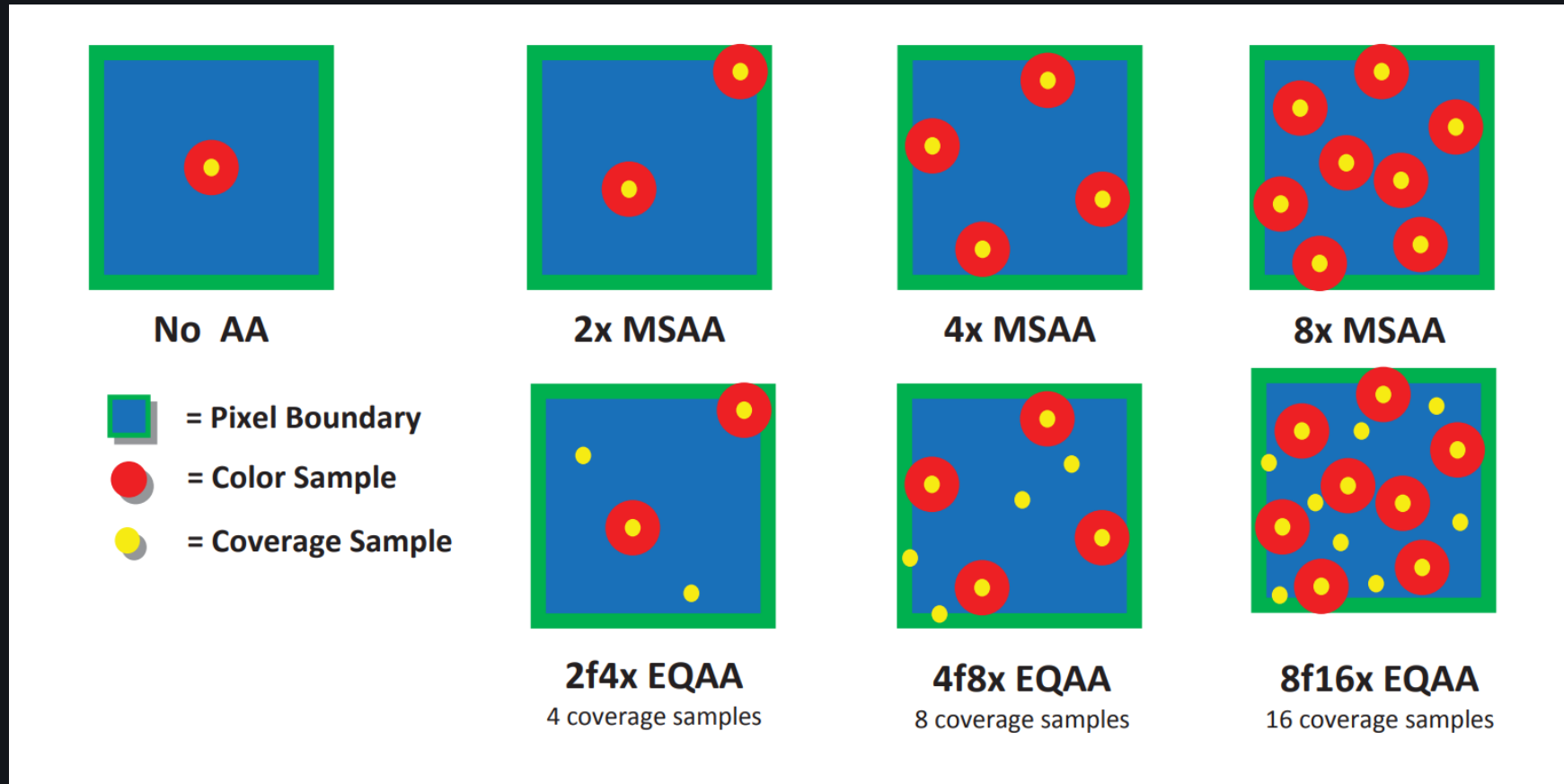
MLAA FROM 2009 TO 2017

Research Impact Retrospective

Alexander Reshetov - Jorge Jimenez

High Performance Graphics 2017

Gold Standards: MSAA – CSAA – EQAA



Edge Detection and Blur

Information from [Leadbetter2009a]

[Sousa2007]

[Shishkovtsov2004]



X360

16.2.2 Edge Smoothing

One big issue when using alpha testing is the hard edges. At the time we developed vegetation main shading, there was no alpha-to-coverage support in any hardware (we do now support it) so we came up with a special solution to smooth out the edges through post-processing.

In CryENGINE 2, we use a deferred rendering approach, by first rendering a z-pass and a floating-point texture.

This technique enables a wide range of effects (Wenzel 2007), which require depth information. Edge smoothing is one such effect; it works by doing edge detection using the depth texture and rotated triangle samples for dependent texture lookups using bilinear filtering. Edge smoothing is only on opaque geometry, however, because nonopaque geometry doesn't write depth information. Figure 16-7 shows how beneficial edge smoothing can be.



Figure 16-7 The Benefits of Edge Smoothing

9.5 Antialiasing

A deferred renderer is just incompatible with current hardware-assisted antialiasing, unfortunately (Hargreaves and Harris 2004). Thus, antialiasing becomes solely the responsibility of the application and the shader; we cannot rely on the GPU alone. Because aliasing itself arises from the mismatched frequencies of the source signal and of the destination discrete representation, a good approximation of an antialiasing filter is just a low-pass filter, which is simple blurring. This is a zero-cost operation in the console world, where any TV display works like a low-pass filter anyway. In the PC world, we need an alternative. Our solution was to trade some signal frequency at the discontinuities for smoothness, and to leave other parts of the image intact. This was performed in a way similar to the edge-detection filters used in nonphotorealistic applications: We detect discontinuities in both depth and normal direction by taking 8-1 samples of depth and finding how depth at the current pixel differs from the ideal line passed through opposite corner points. The normals were used to fix issues such as a wall perpendicular to the floor, where the depth forms a perfect line (or will be similar at all samples) but an aliased edge exists. The normals were processed in a similar cross-filter manner, and the dot product between normals was used to determine the presence of an edge. Listing 9-2 shows the code.

The two detectors were then multiplied to produce a single value indicating how much the current pixel "looks like an edge." This value was used to offset four bilinear texture lookups into the composited [near-final] back buffer. The result was automatic weighting of samples with a very strong edge-detection policy that seamlessly handles edge and alpha-test/texture aliasing without blurring other parts of the image. See Figure 9-7 for a sample result.

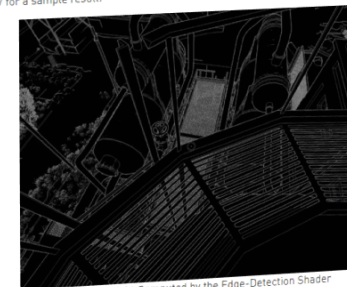
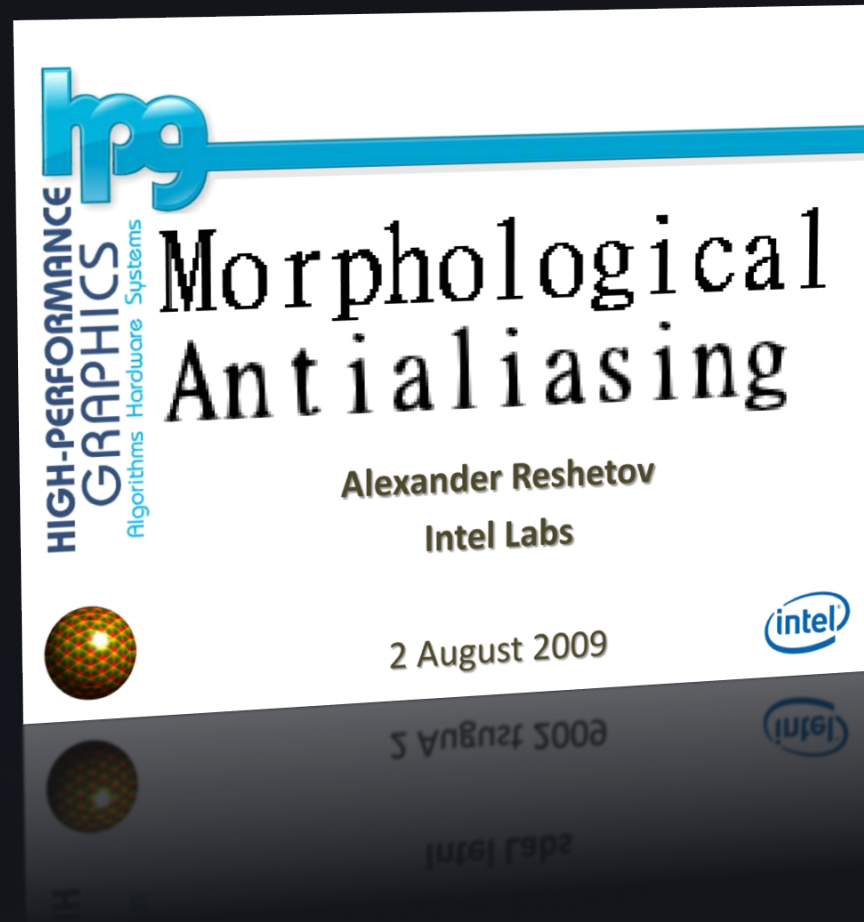


Figure 9-7 Weight Computed by the Edge-Detection Shader

Morphological Antialiasing (2009)



[Reshetov2009]

Explosion of Post-AA Techniques

[Jimenez2011a]

ACM SIGGRAPH 2011 Course


Filtering Approaches for Real-Time Anti-Aliasing

Jorge Jimenez¹ Diego Gutierrez¹ Jason Yang² Alexander Reshetov³ Pete Demoreuille⁴
jorge@iryoku.com diegog@unizar.es jasonc.yang@amd.com alexander.reshetov@intel.com pbd@pod6.org

Tobias Berghoff⁵ Cedric Perthuis⁶ Henry Yu⁷ Morgan McGuire^{8,9} Timothy Lottes⁸
berghoff.tobias@gmail.com cedric.perthuis@gmail.com henry@kalloc.com morgan@cs.williams.edu tlottes@nvidia.com

Hugh Malan¹⁰ Emil Persson¹¹ Dmitry Andreev¹² Tiago Sousa¹³
hughmalan@gmail.com humus@comhem.se andcoder@gmail.com tiago@crytek.de

¹ Universidad de Zaragoza ² AMD ³ Intel Labs ⁴ Double Fine
⁵ Sony Computer Entertainment WWS ATG ⁶ Sony Computer Entertainment WWS Santa Monica
⁷ Kalloc Studios ⁸ NVIDIA ⁹ Williams College ¹⁰ CCP ¹¹ Avalanche Studios ¹² Lucas Arts ¹³ Crytek



NEWS ABSTRACT TALKS & COURSE NOTES BIBTEX LINKS

Morphological versus Edge Detect and Blur

- Morphological
 - Edge detect + **Search** + Blur
 - Non local information available (patterns)
- Edge Detect and Blur
 - Edge detect + Blur
 - Only local information available (neighborhood)

Saboteur (2009)



Information from [Leadbetter2009b]

Sony's Edge MLAA (2009)

[Perthuis2011]

Relative Thresholding



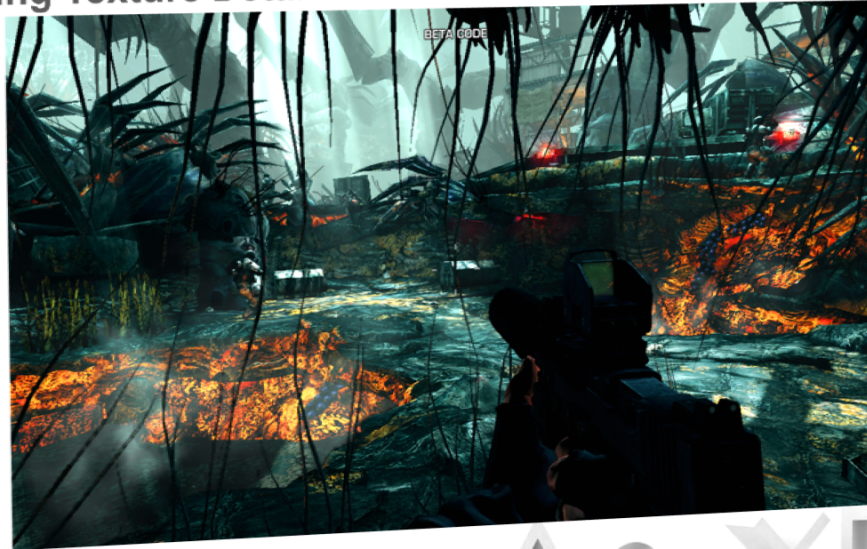
Advanced Technology Group SCE WWS

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Sony's Edge MLAA (2009)

[Perthuis2011]

Preserving Texture Detail



Advanced Technology Group SCE WWS

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Double Fine's Costume Quest (2010)

SIGGRAPH2011
VANCOUVER

Example Results



[Demoreuille2011]



Double Fine's Costume Quest (2010)



Hybrid MLAA: Overview

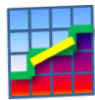


[Demoreuille2011]



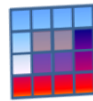
GPU edge detection

Variety of color/depth/id data used



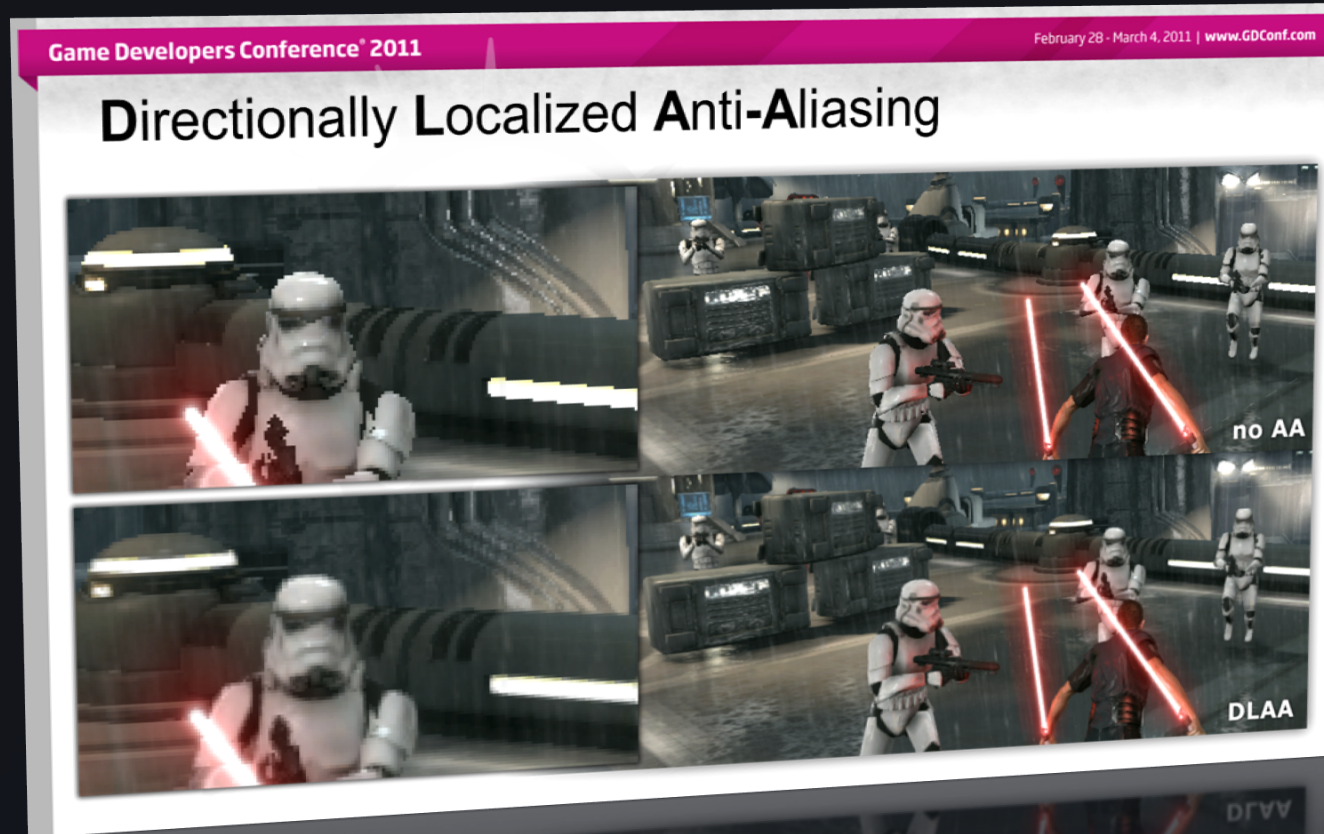
CPU blend weight computation

Fast transpose using tiling and VMX 128



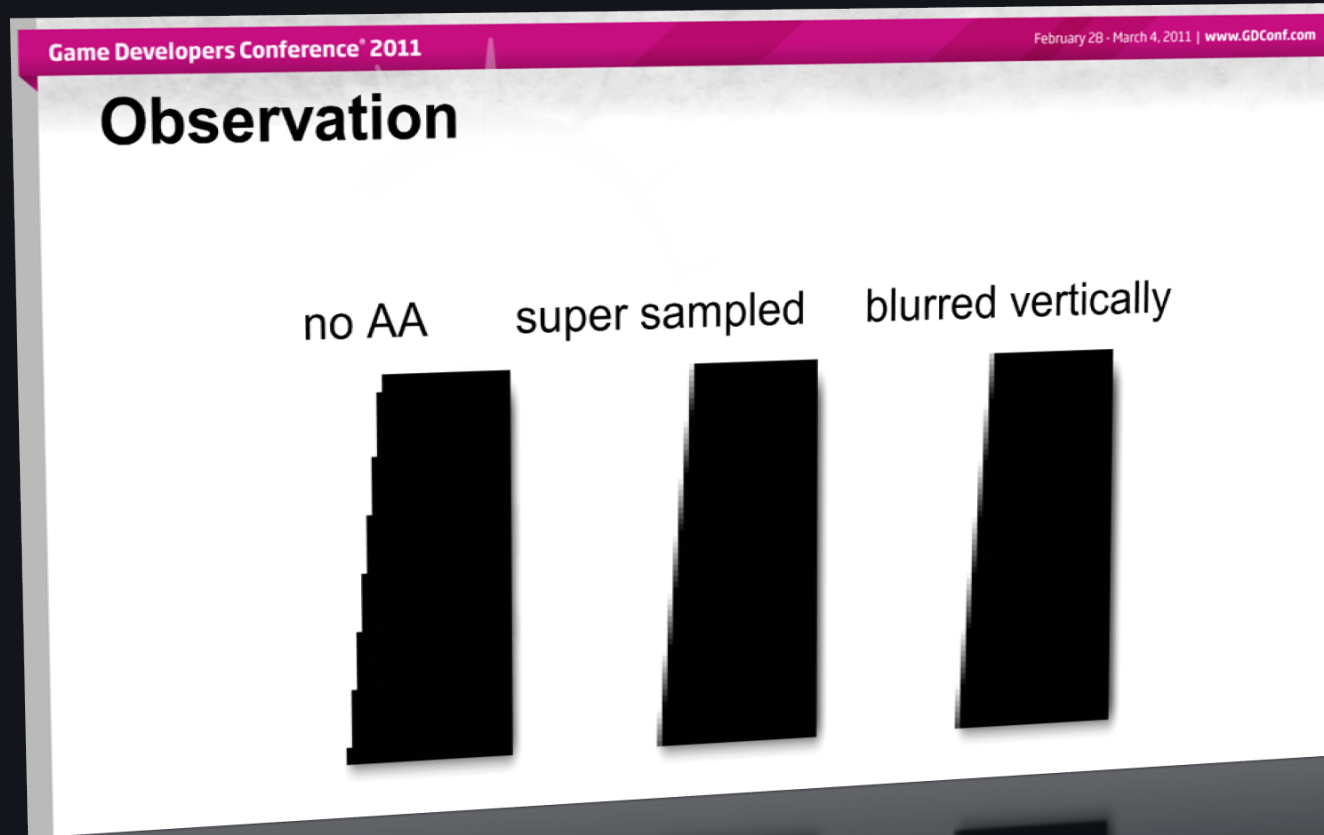
GPU blending

Star Wars: The Force Unleashed II - DLAA (2010)



[Andreev2011]

Star Wars: The Force Unleashed II - DLAA (2010)



[Andreev2011]

FXAA Console (2010)

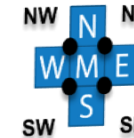


FXAA 3.11 Console Taps

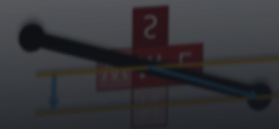


[Lottes2011]

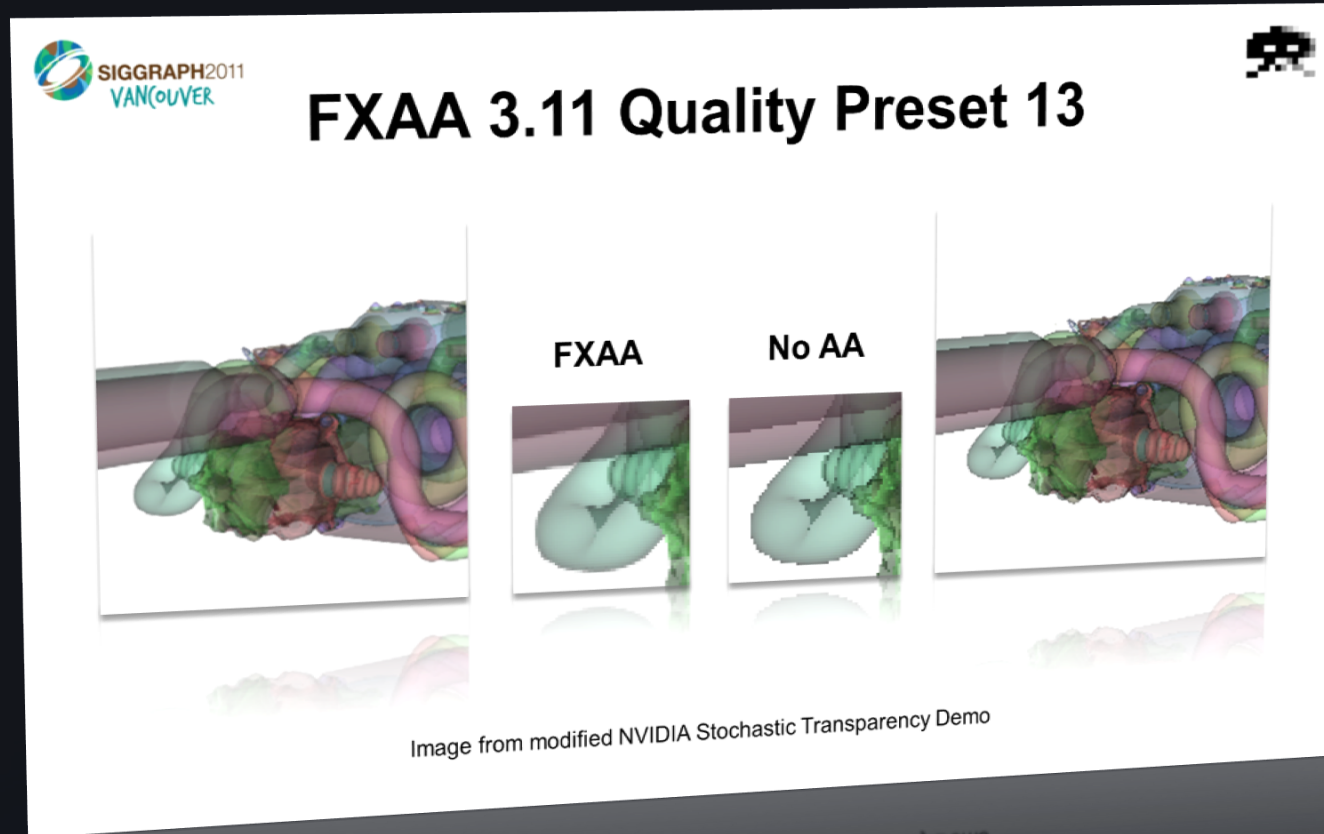
- All pixels which do not exit get this 2 tap filter
 - Direction perpendicular to local luma gradient



- Use the four 2x2 box filtered luma values
 - $dir.x = -((NW+NE)-(SW+SE))$
 - $dir.y = ((NW+SW)-(NE+SE))$
 - $dir.xy = normalize(dir.xy) * scale$
- Optional extra 2 taps
 - Scale $dir.xy$ by $1/minDir$
 - $minDir = \min(|dir.x|, |dir.y|) * sharpness$
 - Then limit filter width to 8 pixels

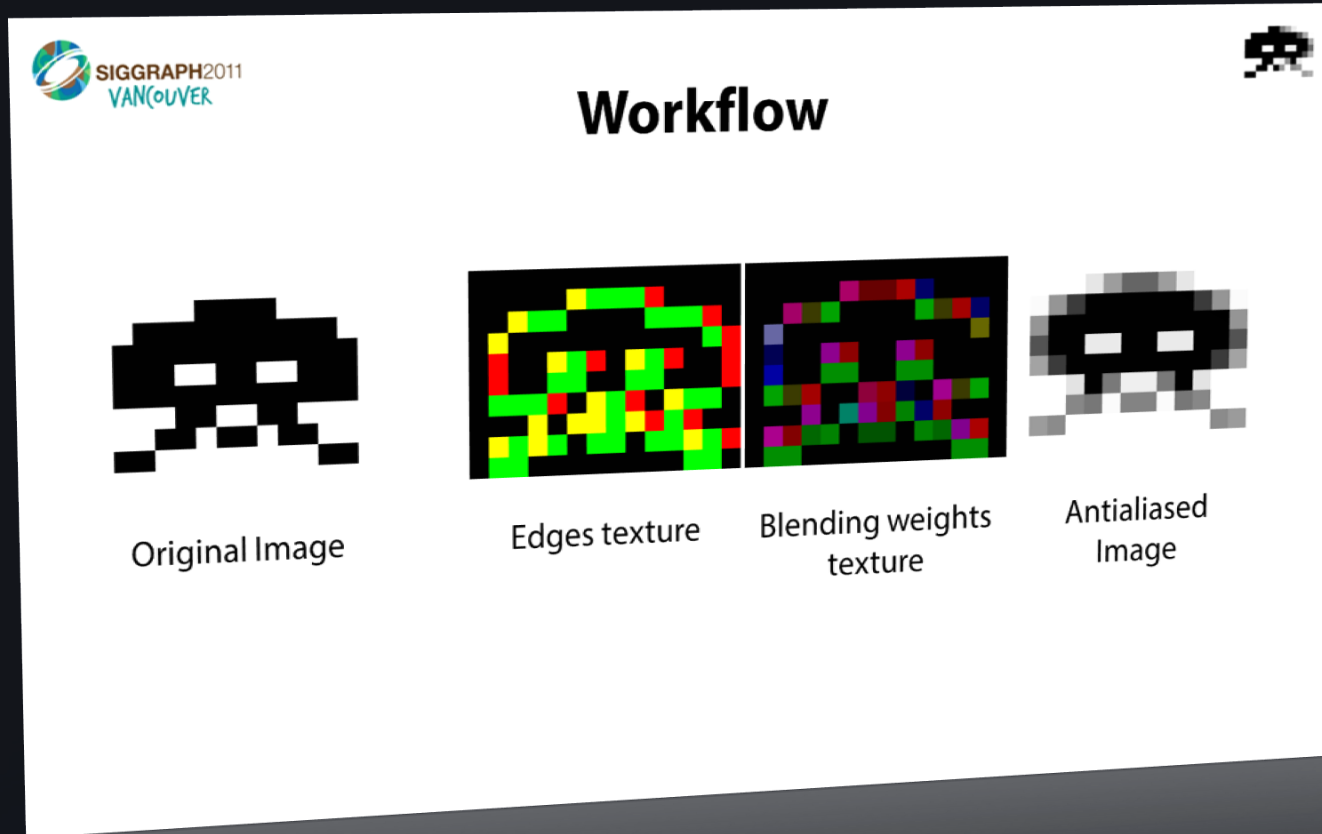


FXAA Quality (2010)



[Lottes2011]

Jimenez's MLAA (2010)



[Jimenez2011b]

Jimenez's MLAA (2010)



Key Features

- **High Quality**
 - ★ 16× gradients (or more!)
 - ★ Noise proof → **Temporally Stable**
 - ★ Sharpness preservation
- **Fast**
 - ★ 0.28ms@720p (GeForce GTX 470)
 - ★ Beats MSAA by about a 1180% (GeForce 9800 GTX+)
- **Low Memory Footprint**
 - ★ 2× the backbuffer size
- **Portable**
- **Customizable Edge Detection**



Practical Morphological Anti-Aliasing
In GPU Pro 2: Advanced Rendering Techniques

[Jimenez2011b]

SMAA (2011)



SMAA:

Subpixel Morphological Antialiasing



[Jimenez2011b]



Temporal AA
Great
subpixel
features!



MLAA
Great
gradients!



MSAA
Great
subpixel
features!

SMAA (2011)



SMAA:

Subpixel Morphological Antialiasing

- Improves pattern handling

★ Diagonals



MLAA



SMAA S2x



SSAA 16x



[Jimenez2011b]

FXAA / SMAA Features

FXAA Console

- Focus on ultimate performance
- Very easy to integrate
- Blurrier texture details
- Decreased temporal stability
- Worse subpixel features

FXAA Quality

- Target medium quality/performance tradeoff
- Better gradients than MSAA
- Very easy to integrate
- Blurrier texture details
- Decreased temporal stability
- Worse subpixel features

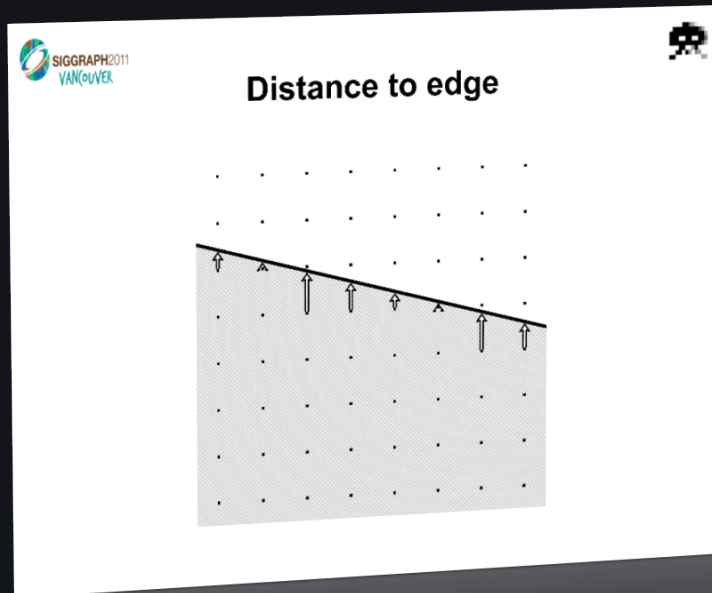
SMAA T2x

- Focus on ultimate quality
 - Sharpness
 - Extended pattern recognition
 - Optional TAA/MSAA combos for subpixel features
- Better gradients than MSAA
- More complex integration

For Both FXAA/SMAA

- Not dealing with MSAA
- Compatible with deferred

DEAA & GBAA (2011)



[Malan2011]

GBAA

- Geometry shader passes down geometry info
 - Stores distance to edge in the major direction
 - Use interpolator instead of line equation math
 - Using noperspective keyword
- Pixel shader selects closest edge

$$d_{dir} = d / (|n.x| > |n.y| ? n.x : n.y)$$

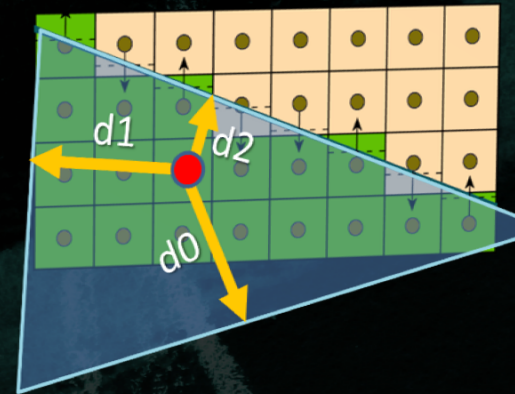
[Persson2011]

Low Level Optimizations for GCN [Drobot2014]

PS LDS access : Distance to Edge

[Drobot2014a]

- Example : Distance To Edge AA
 - Output distance to closest edge
 - Directly from PS bypassing GS
 - Used in multiple analytical AA methods
 - GBAA
 - DEAA



Killzone AA Transition

[Valient2007]

MSAA Lighting Details

- ▶ Run light shader at pixel resolution
 - ▶ Read G-Buffer for both pixel samples
 - ▶ Compute lighting for both samples
 - ▶ Average results and add to frame buffer
- ▶ Optimization in shadow map filtering
 - ▶ Max 12 shadow taps per pixel
 - ▶ Alternate taps between both samples
 - ▶ Half quality on edges, full quality elsewhere
 - ▶ Performance equal to non-MSAA case



GUERRILLA | DEVELOP CONFERENCE | JULY '07 | BRIGHTON

KILLZONE™



GUERRILLA | DEVELOP CONFERENCE | JULY '07 | BRIGHTON

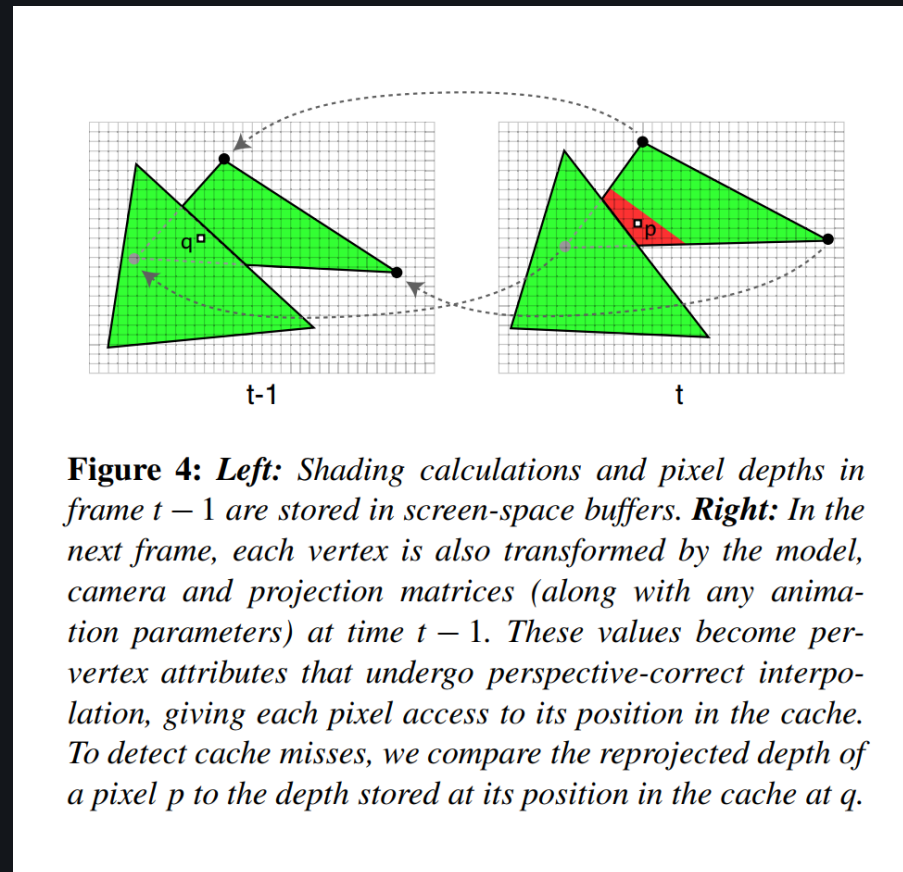
KILLZONE™

Uncharted 4 (2016)



Temporal AA

Accelerating Real-Time Shading with Reverse Reprojection Caching [Nehab2007]



[Nehab2007]

Gran Turismo PSP (2009)

Information from [Greer2009]



Slow Motion



Full Speed, as observed on a PSP

Halo Reach (2010)

Information from [Leadbetter2010]



Crysis 2 [2011]



[Sousa2011]

SMAA (2011)

[Jimenez2012]

SMAA: Enhanced Subpixel Morphological Antialiasing

Jorge Jimenez¹ Jose I. Echevarria¹ Tiago Sousa² Diego Gutierrez¹

¹Universidad de Zaragoza, Spain

²Crytek GmbH, Germany



Figure 1: Example of SMAA 4x integrated in the Crysis 2 game. The insets show the differences between MLAA [JME^{*}11], our novel SMAA T2x and 4x algorithms and MSAA 8x as reference. For 1080p frames, the average cost of SMAA T2x is 1.3 ms and 2.6 ms for SMAA 4x, measured on a NVIDIA GeForce GTX 470.

Crysis 3 - SMAA (2013)



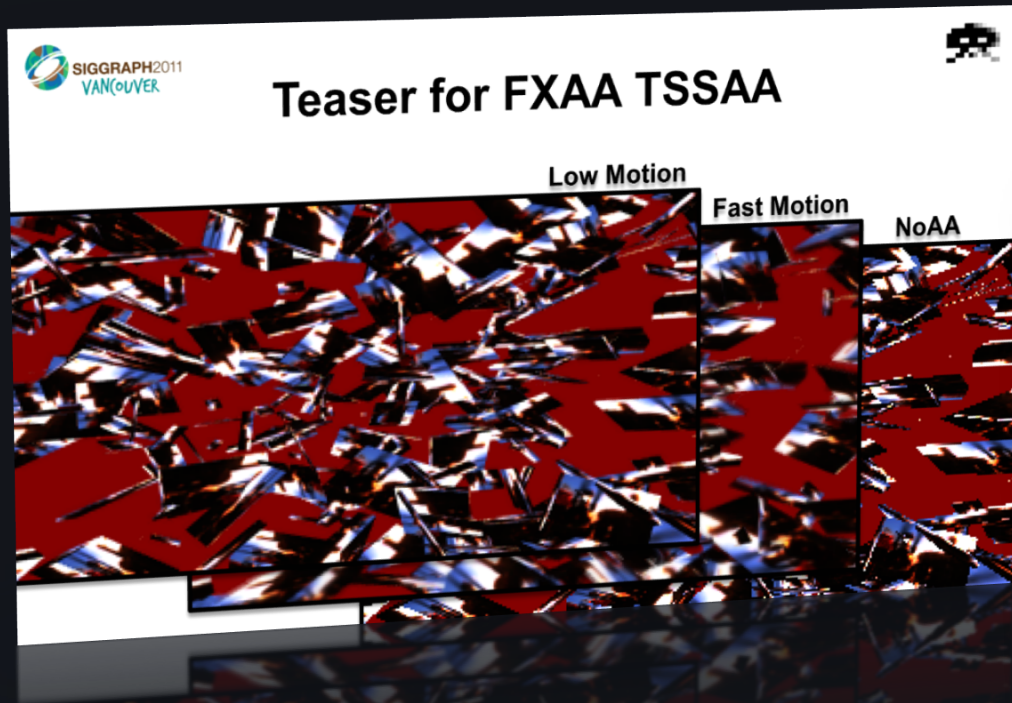
Assassins Creed 4 and Ryse - SMAA (2013)



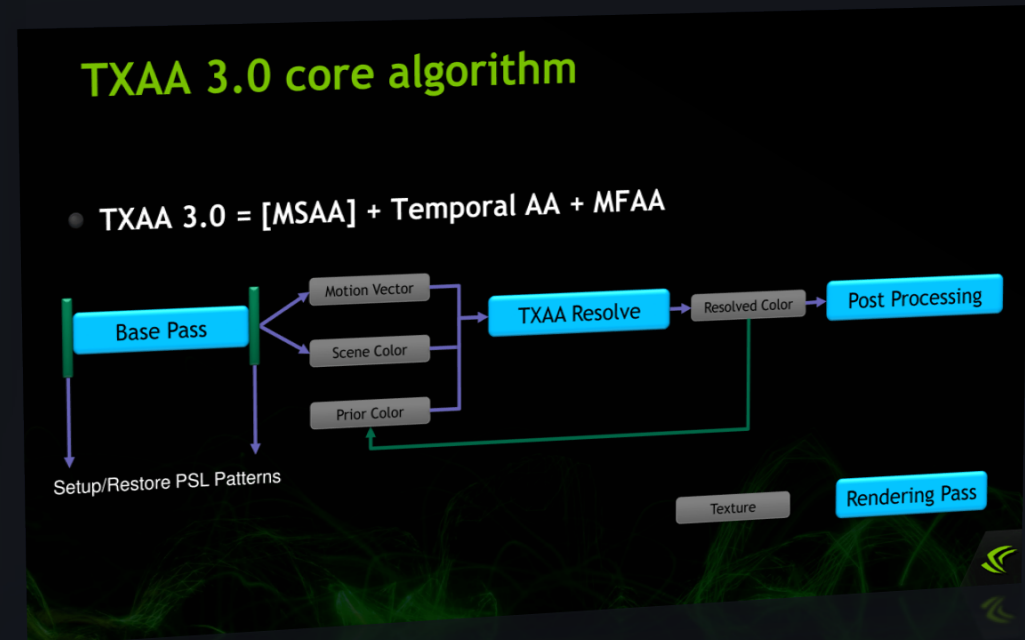
The Last Guardian (2016)



Lottes' TSSAA & TXAA (2011)



[Lottes2011]



[Cao2016]

Evolution

[Sousa2013]

SMAA ITX: A MORE ROBUST TEMPORAL AA

Concept: Only track signal changes, don't rely on geometry information

- For higher temporal stability, accumulate multiple frames in an accumulation buffer, alike TAA (Lettes2)
- Re-project accumulation buffer
- Weighting: Map acc. buffer colors into the range of curr. frame neighborhood color extents (Malan2012); different weight for hi/low frequency regions (for sharpness preservation).

Current Frame (M) Accumulation Buffer (M)

Advances in Real-Time Rendering course, Siggraph 2013

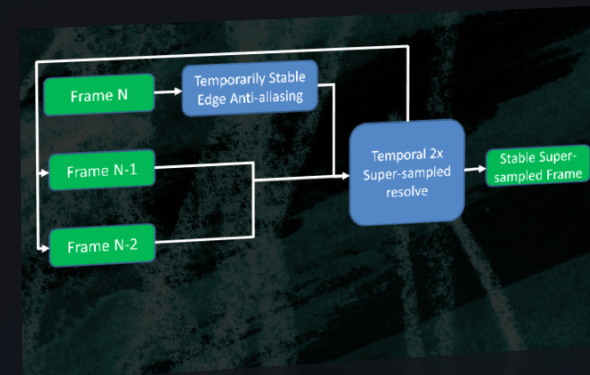
[Karis2014]

High Quality Temporal Supersampling

Brian Karis (@BrianKaris)

SIGGRAPH 2014 EPIC

[Drobot2014b]



[Salvi2016]

Variance clipping

- Compute 1st and 2nd color moments
- AABB from mean μ and variance σ^2
- $\mu \pm \gamma\sigma$

```

    for all local samples..
    #1 += color[i];
    #2 += color[i] * color[i];
  
```

```

    mu = #1 / N;
    sigma = sqrt(#2 / N - mu * mu);
    minC = mu - gamma * sigma;
    maxC = mu + gamma * sigma;
  
```

- Scale down σ for reduced ghosting
- $\gamma = 1$ works well
- Can clip new AABB against old AABB

GDC NVIDIA

[Jimenez2016]

Filmic SMAA

Sharp Morphological and Temporal Antialiasing

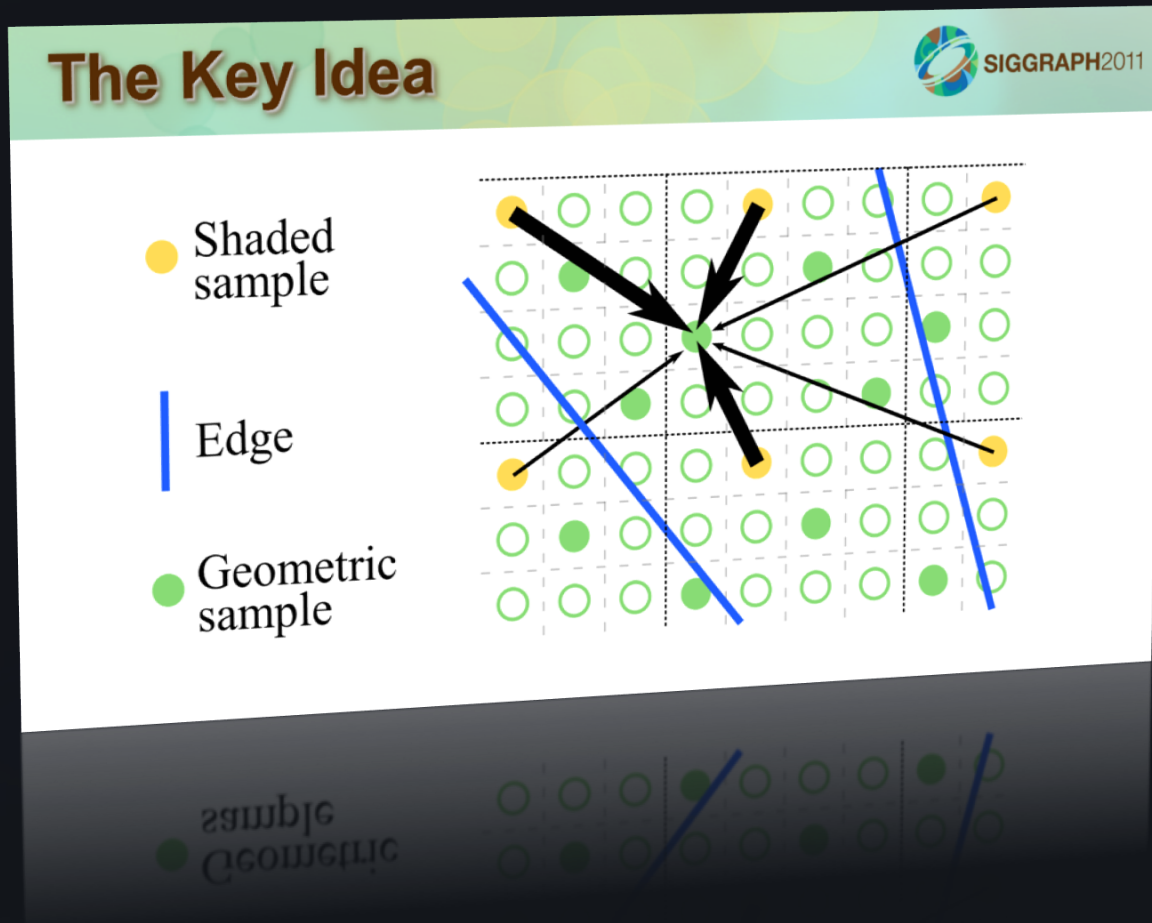
Jorge Jimenez - Graphics R&D Technical Director (Activision Blizzard)

Advances in Real-Time Rendering course

SIGGRAPH 2016 ACTIVISION BLIZZARD

Temporal Upsampling and 4k Reconstruction

SRAA (2011)

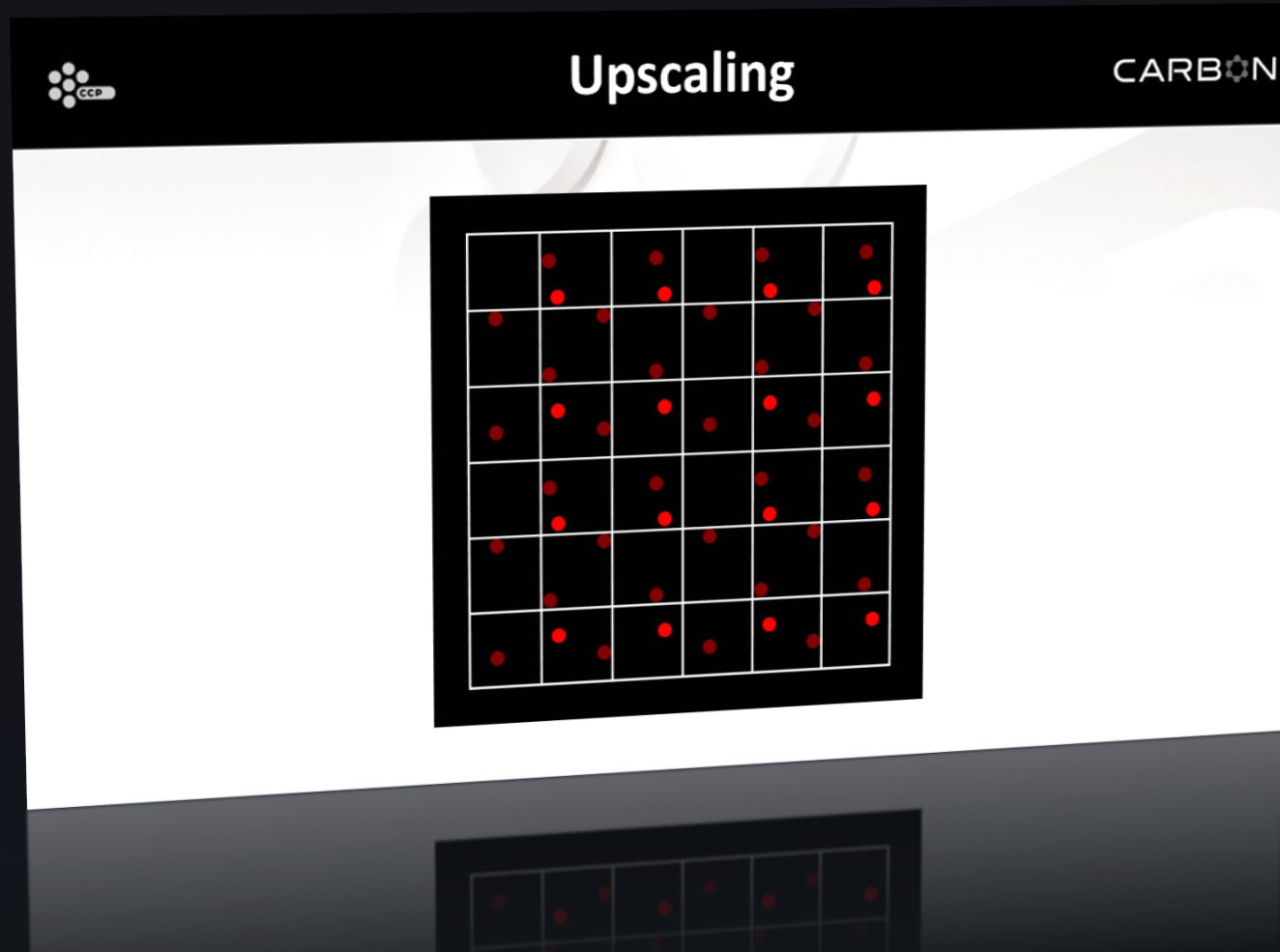


[McGuire2011]

Infamous Second Son (2014, patched for 4k)



Dust Experimental Temporal Upsampling (2012)



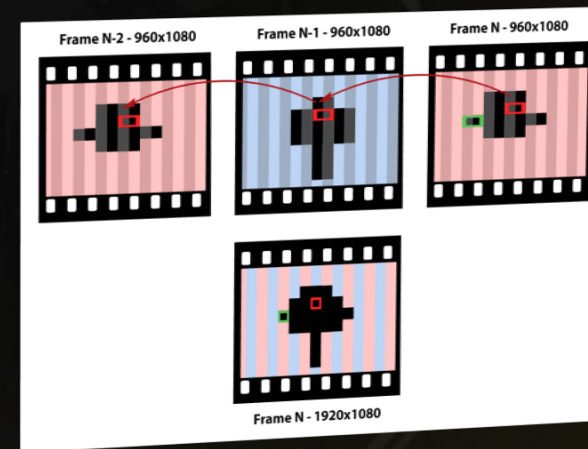
[Malan2012]

Killzone Shadow Fall (2014)

[Valient2014]

TEMPORAL 1080P

- › Keep two previous half-frames
 - › Use double reprojection
- › Check similarity of N and N-2
 - › Color neighborhood similarity
 - › Motion continuity
- › Accept pixel N-1 for similar frames
 - › Otherwise just interpolate from N



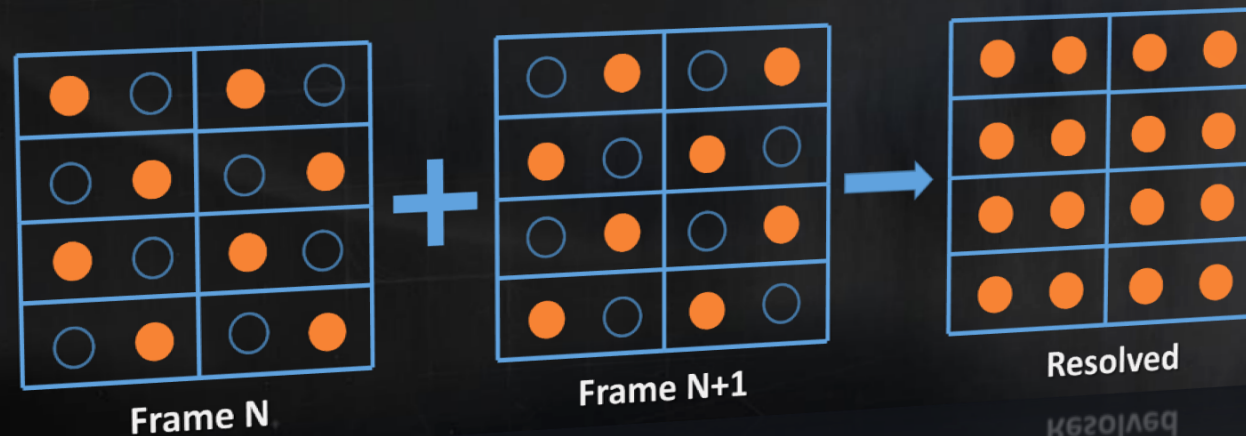
Killzone Shadow Fall / GDC 2014

Battlefield 1 (2016) and Mass Effect Andromeda (2017)

[Wihlidal2016]

Exploration

- ▶ Settled on “packed checkerboard” technique
 - ▶ Started with PS4™Pro reference implementation
 - ▶ Customized + optimized further, and incorporated our own TAA



Dynamic Antialiasing

- [Jimenez2017] Dynamic Antialiasing in Call of Duty: Infinite Warfare
 - Combines dynamic resolution with temporal upsampling
 - Always outputs 1080p frames, with varying degrees of AA depending on load
- Advances in Real-Time Rendering in Games: Part I
 - Monday 11:40 am

Summary

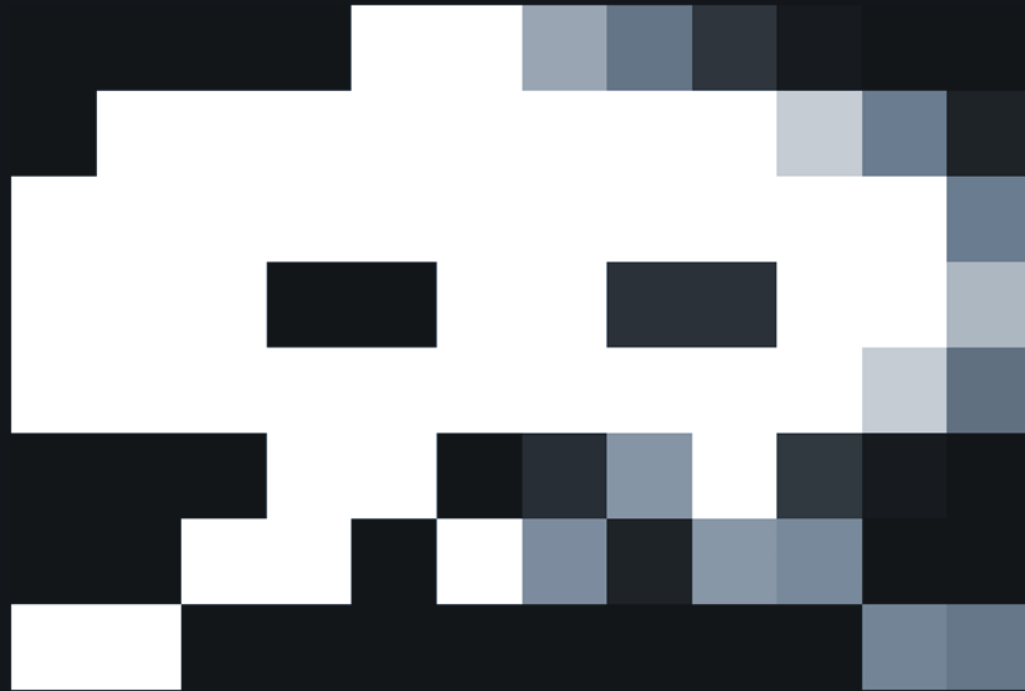
- MLAA questioned the status quo.
- MLAA went against the trend.
- MLAA possibly slowed down MSAA and hardware antialiasing advances.
- Unreal Engine added support for MSAA.
- Interesting tradeoffs to be found on hybrid solutions.

Summary

- MLAA questioned the status quo.
- MLAA went against the trend.
- MLAA possibly slowed down MSAA and hardware antialiasing advances.
- Unreal Engine added support for MSAA.
- Interesting tradeoffs to be found on hybrid solutions.

Q&A - Acknowledgements

Special thanks to **Peter-Pike Sloan**



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- [\[Valient2007\]](#) Deferred Rendering in Killzone 2
- [\[Valient2014\]](#) Real-Time Global Illumination and Reflections in Dust 514
- [\[Wihlidal2016\]](#) 4k Checkerboard in Battlefield 1 and Mass Effect Andromeda