Advanced Post Processing

Agenda

- Efficient Use of Blur
- Horizon-Based Ambient Occlusion

Efficient Use of Blur

Many Forms of Blur

Bloom

Motion Blur

Depth of Field

God Rays

And more…

Issues of Blur Effect

- Full-screen operation
- Texture intensive
  - Large texture
  - Large filter kernel
- Artifacts caused by undersampling

Increase Effective Samples

- Approach 1: Multiple-pass blurring
- Blurring between two textures iteratively. Each rendering pass uses previous blurring result as input
  - Easily increase the effective samples to 512
- Can be applied to many blur effects:
  - Motion blur
  - Radical blur
  - Light streak
  - Star, cross, glare effects, etc.

Multiple-pass Blurring

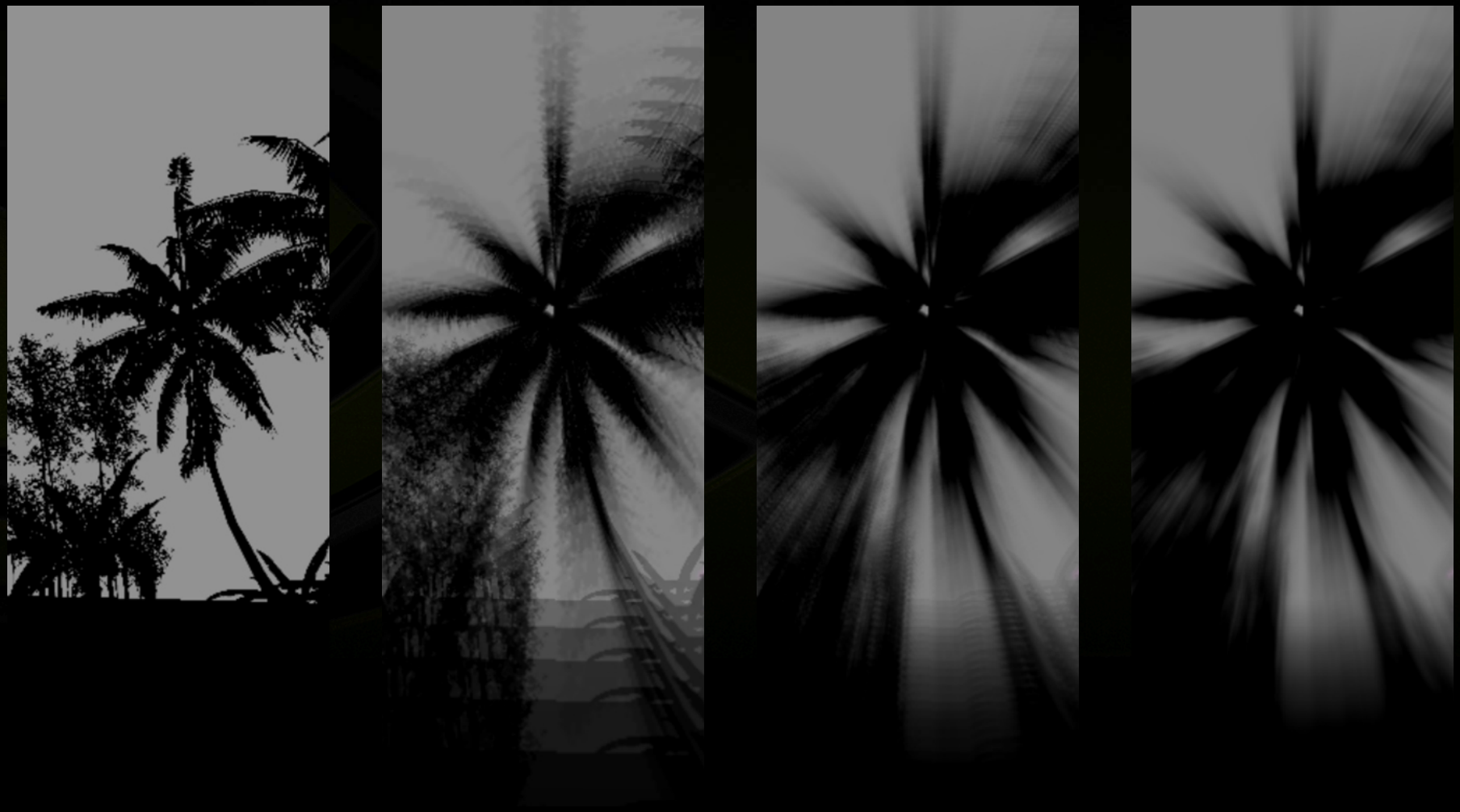


Illustration of god-ray effect in Crysis

Increase Effective Samples

- Approach 2: Utilize hardware linear filtering

- Given two neighbor point samples at location s_0 and s_1, weight w_0, w_1, we can use one linear sample instead:
  - Position: $(s_0 w_1 + s_1 w_0) / (w_0 + w_1)$
  - Weight: $w_0 + w_1$
  - Half samples required

- Bilinear filtering can be used for cubic filtering
  - 2D cubic filtering requires 16 point samples for each pixel. Using 4 bilinear samples instead
  - Check NVSDK sample "Fast Third Order Filtering"
  - When downscaling the frame buffer, e.g. 1600x1200 -> 800x600 -> 400x300…, using cubic filtering can significantly improve image quality.

Utilize hardware linear filtering

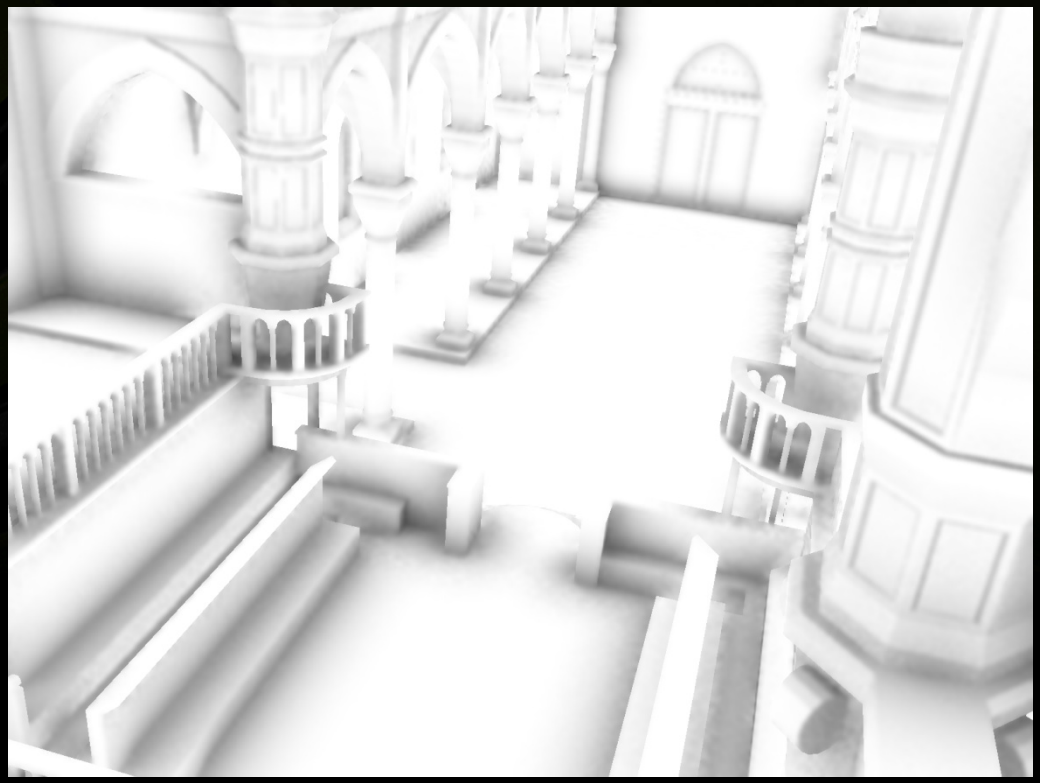
- **Separable kernel is much more effective**

- 31x31 Gaussian filter. 32 actual samples: 16 for horizontal pass and 16 for vertical pass.

Questions?

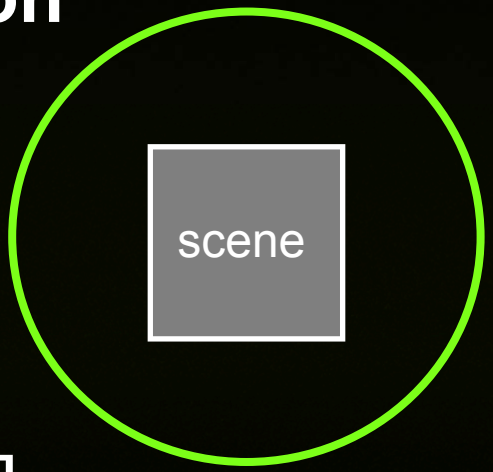
calin@nvidia.com

Horizon-Based Ambient Occlusion



Sky Light

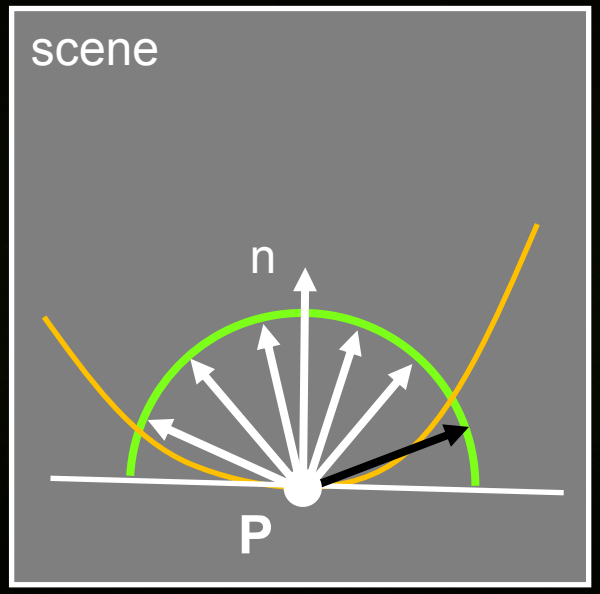
- Simplest form of Ambient Occlusion
- Light source = sky (sphere light)
- Two definitions of AO
  - AO = diffuse illumination from the sky [Landis 02] [Christensen 03]
  - AO = shadow from the sky illumination [Pharr and Green 04] [Hegeman et al. 06]
- Limited to outdoor scenes



sphere light

Ambient Occlusion

- **Light = local hemisphere**
  - **Centered at current surface point**
  - **Radius = user parameter**
- **Can be rendered with ray-tracing**
  - **[Gelato] [Mental Ray]**



local sphere light

Ambient Occlusion

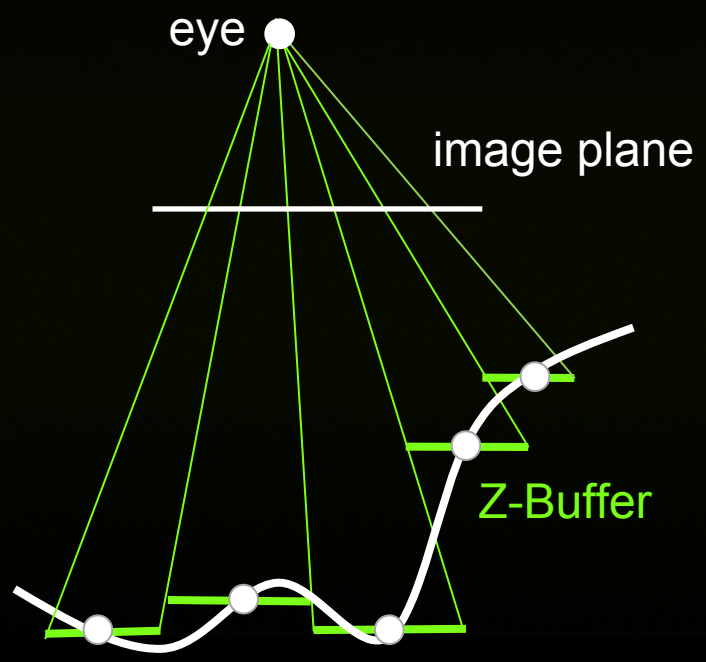
- **Gives perceptual clues of depth, curvature and spatial proximity – “Contact Shadow”**

Without AO

With our AO

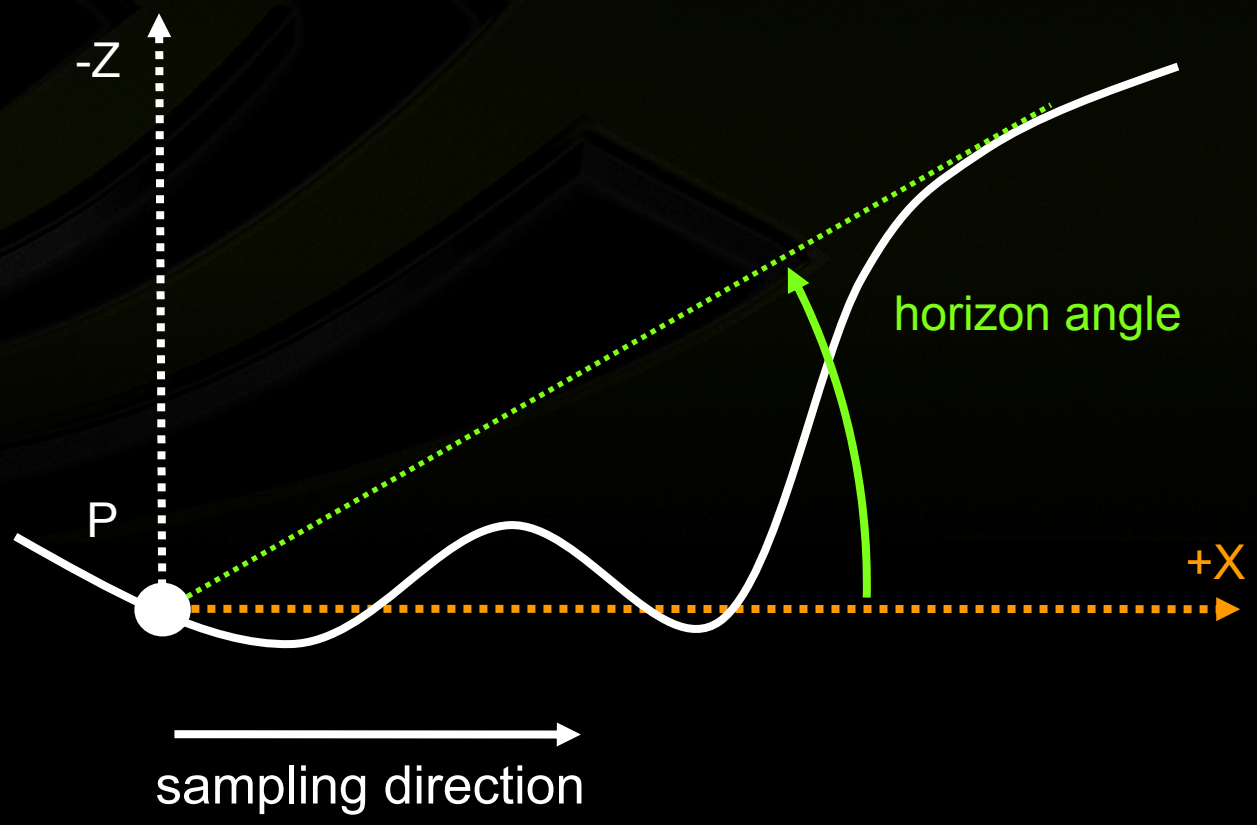
Screen Space Ambient Occlusion

- Approach introduced by
  [Shanmugam and Orikan 07]
  [Mittring 07] [Fox and Compton 08]
- Input = Z-Buffer + normals
  - Render approximate AO for dynamic scenes with no precomputations
- Z-Buffer = Heightfield
  - z = f(x,y)



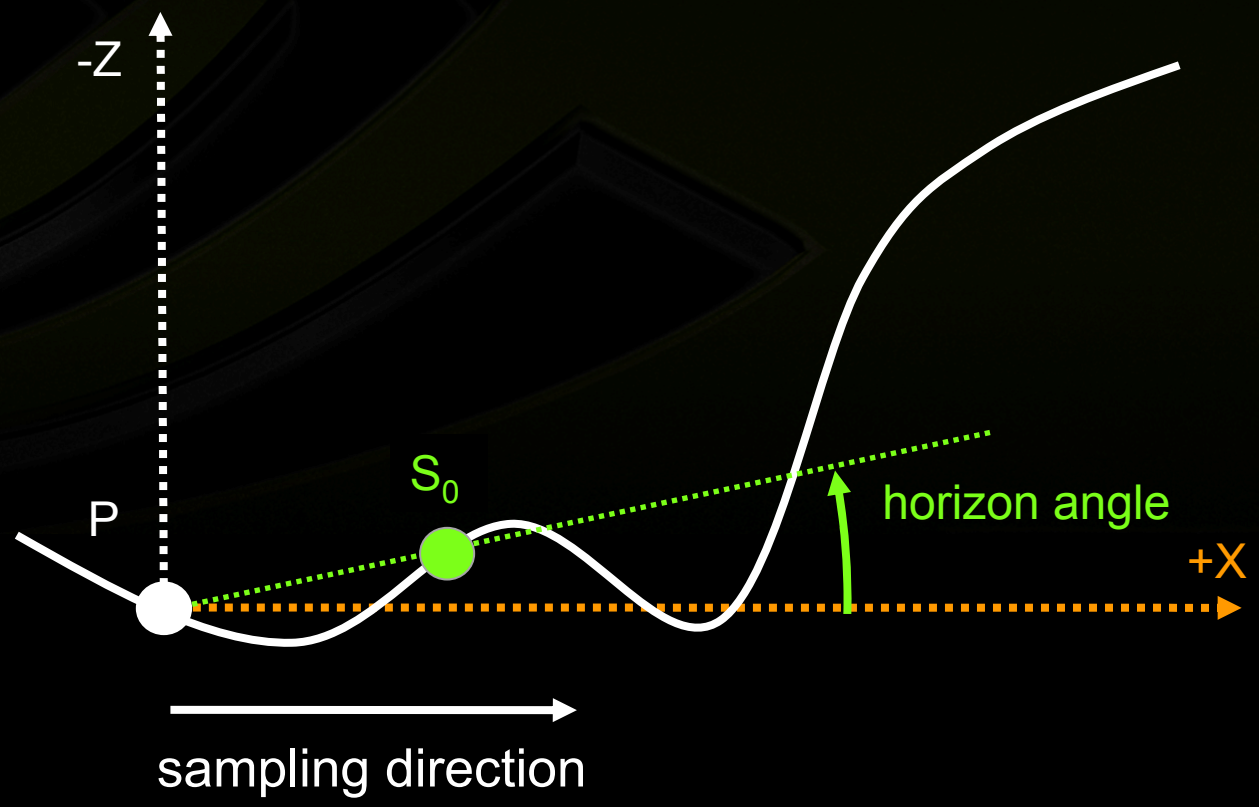
Horizon Mapping [Max 86]

- Given a 1D heightfield



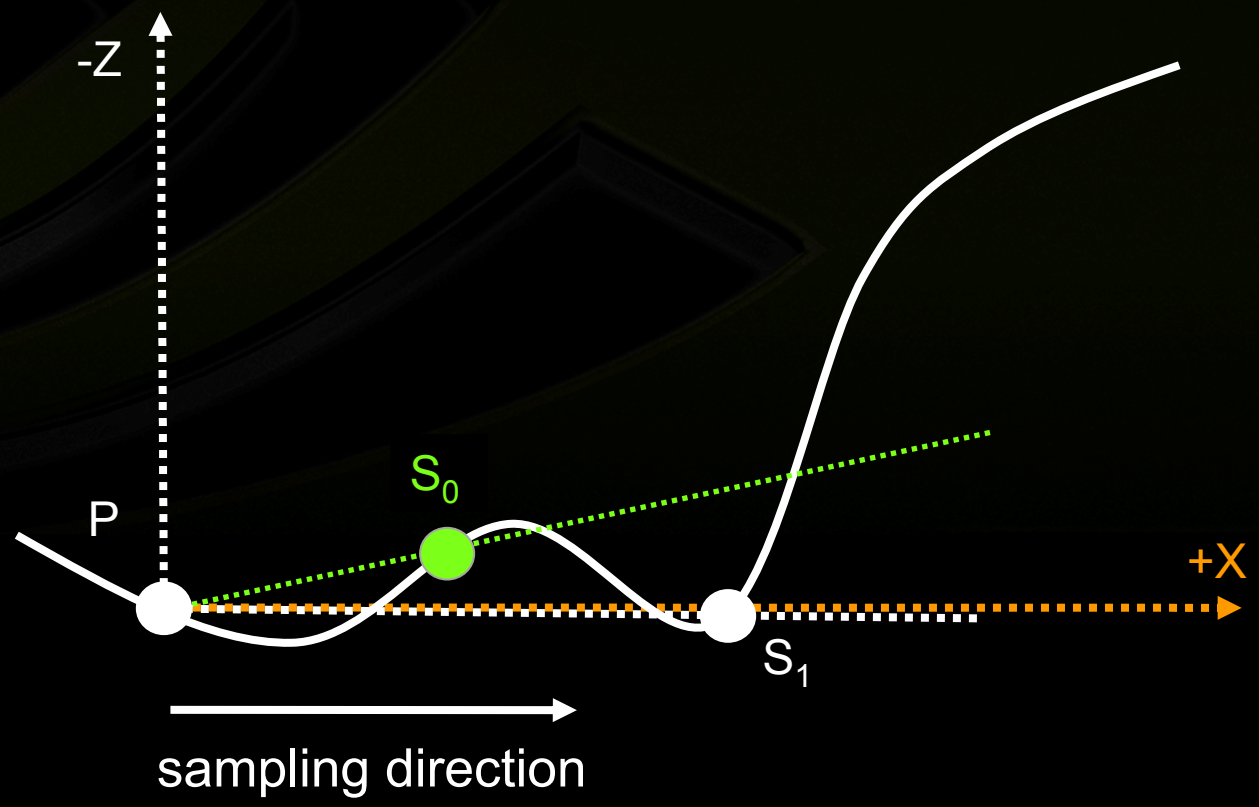
Finding the Horizon

- Marching on the heightfield



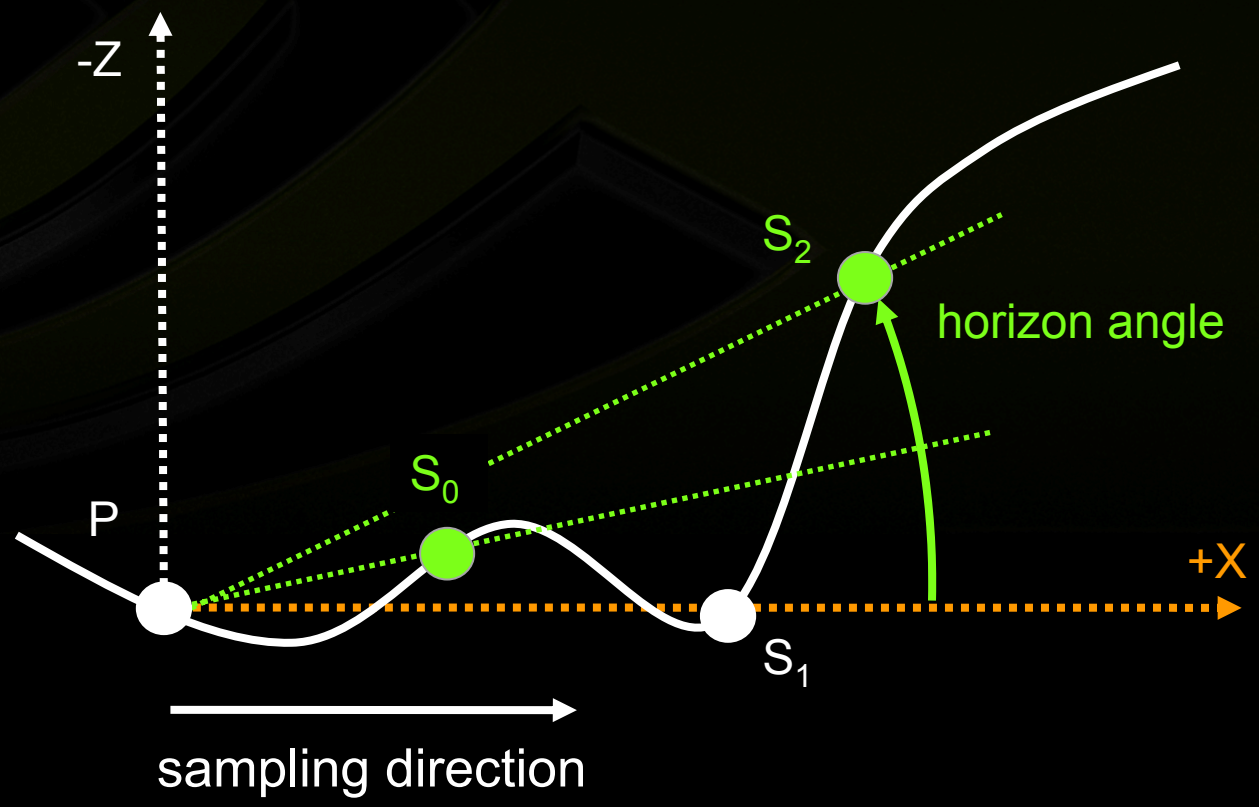
Finding the Horizon

- Marching on the heightfield



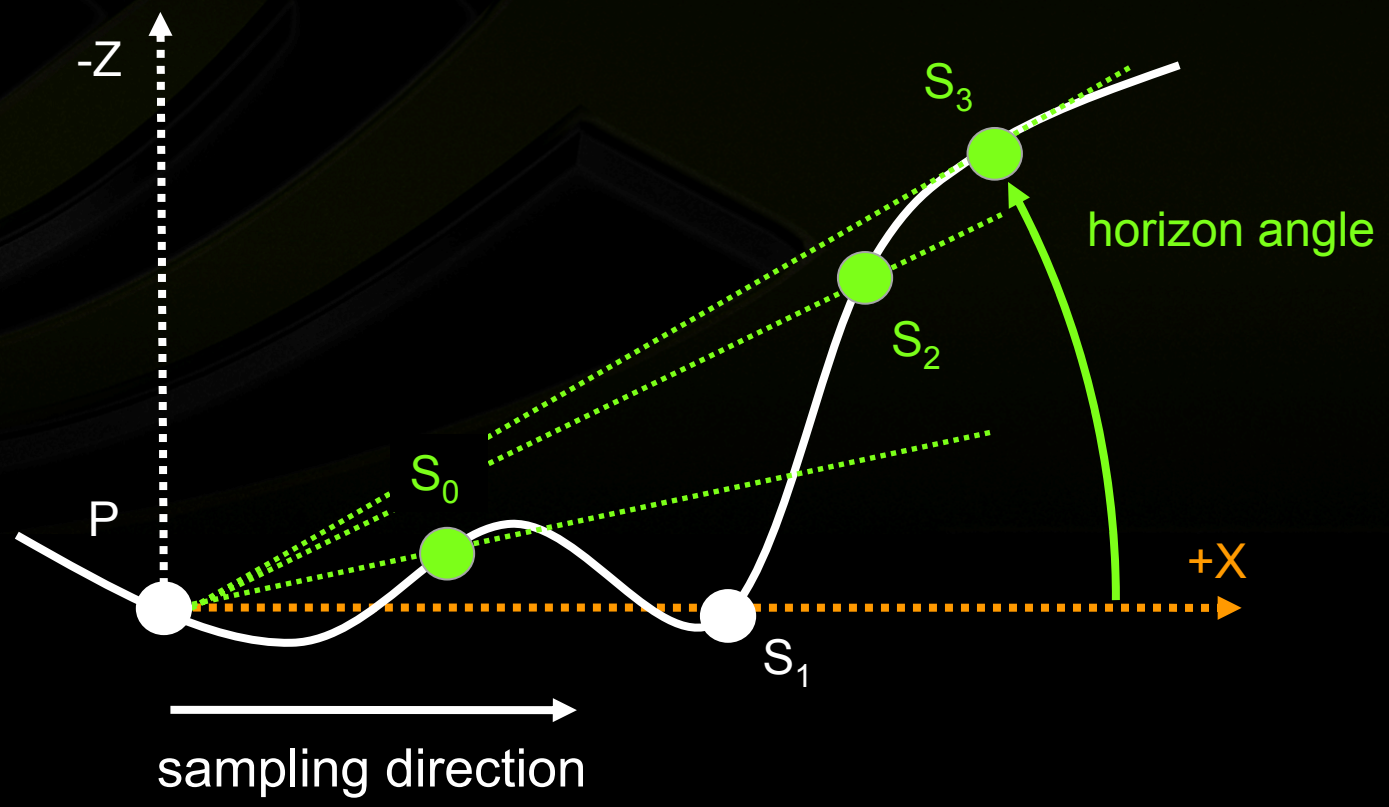
Finding the Horizon

- Marching on the heightfield



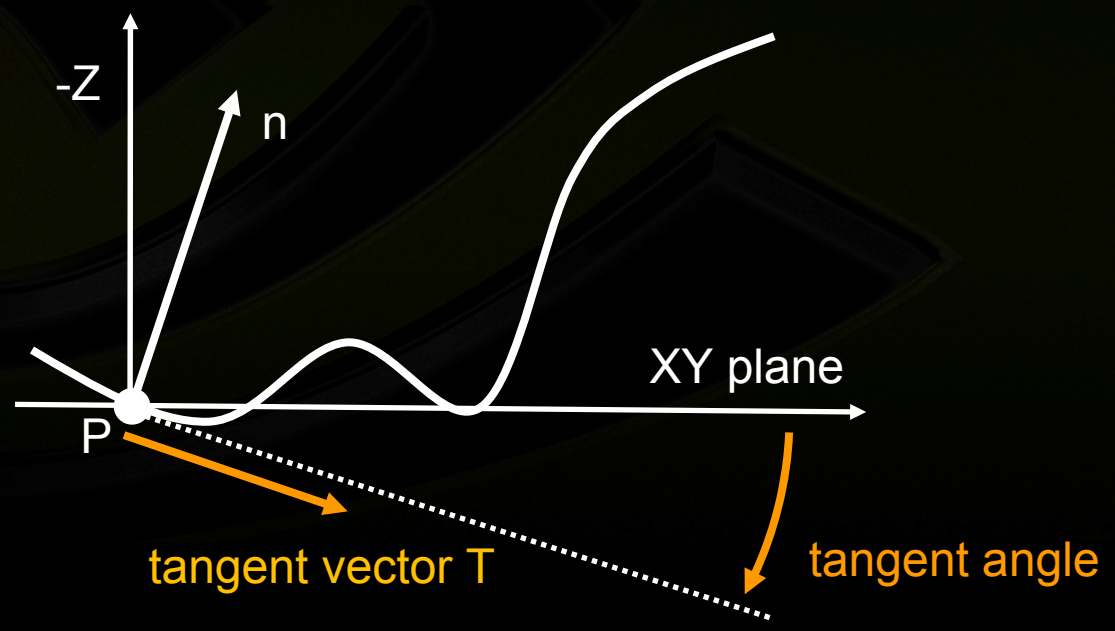
Finding the Horizon

- Marching on the heightfield

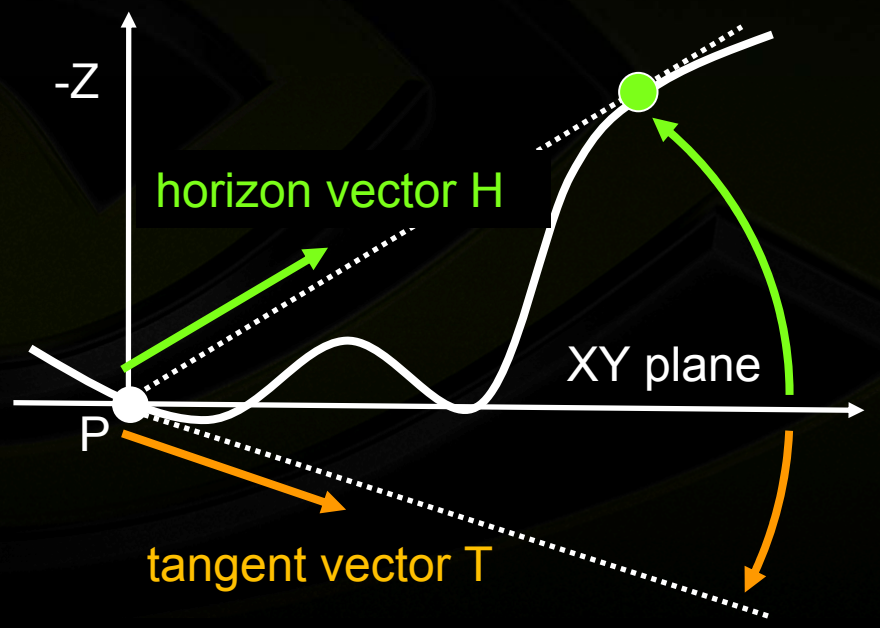


Tangent Plane

- **Given point P and its normal n**



Horizon-Based AO



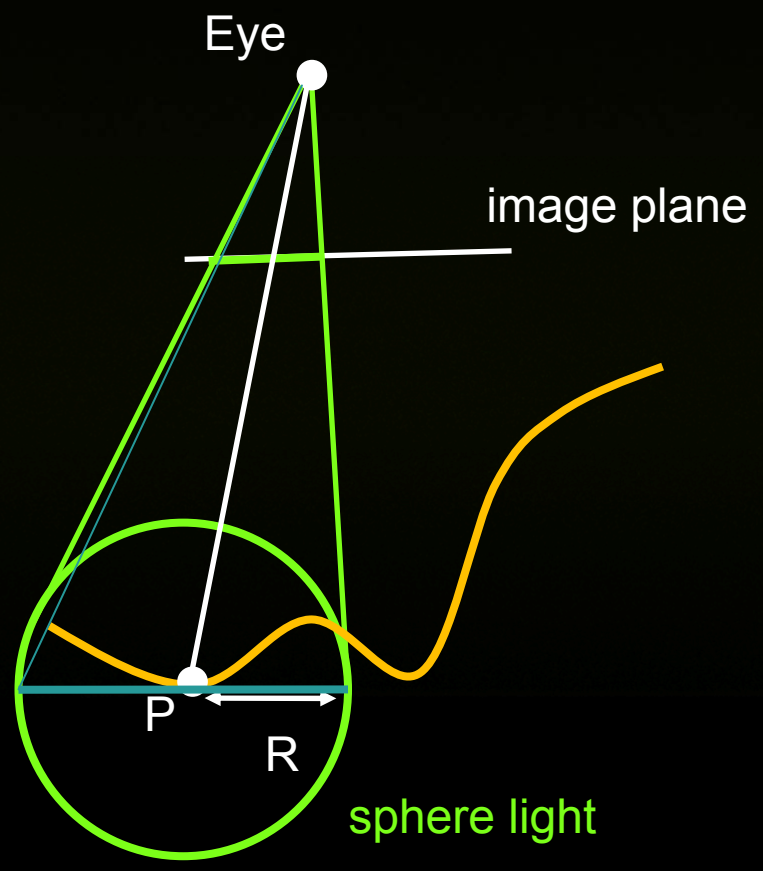
horizon angle in [-π/2, π/2]
h(H) = atan(H.z / ||H.xy||)

tangent angle in [-π/2, π/2]
t(T) = atan(T.z / ||T.xy||)

AO = sin h – sin t

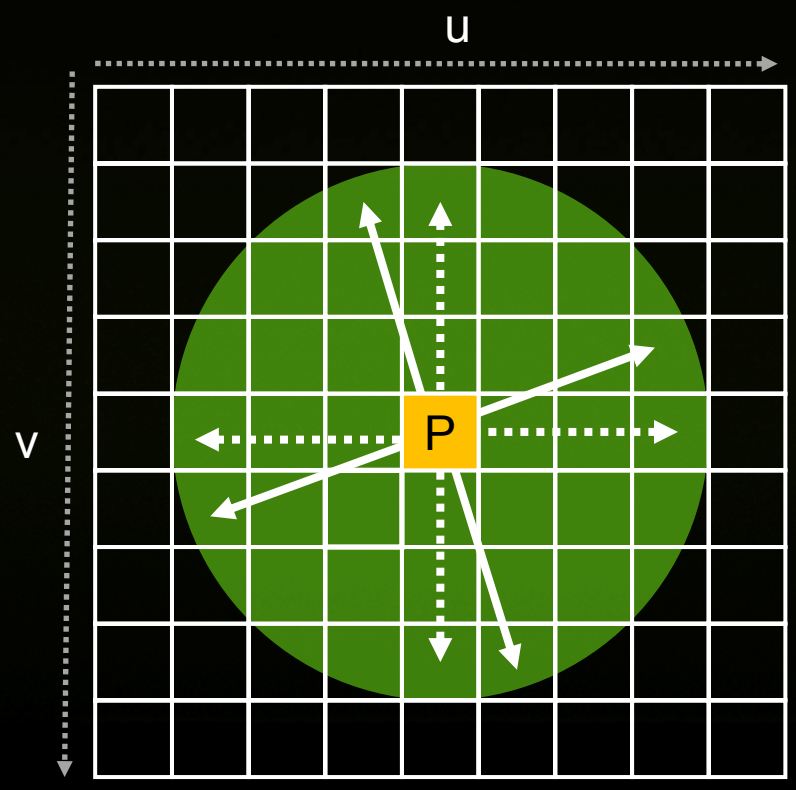
Ambient Occlusion Radius

- Ambient occlusion radius defined in eye space
  - Scene = depth image
- Project light sphere into texture space
  - Approximate projection of the sphere by a disk
  - Project disk onto uv space



Sampling the Depth Image

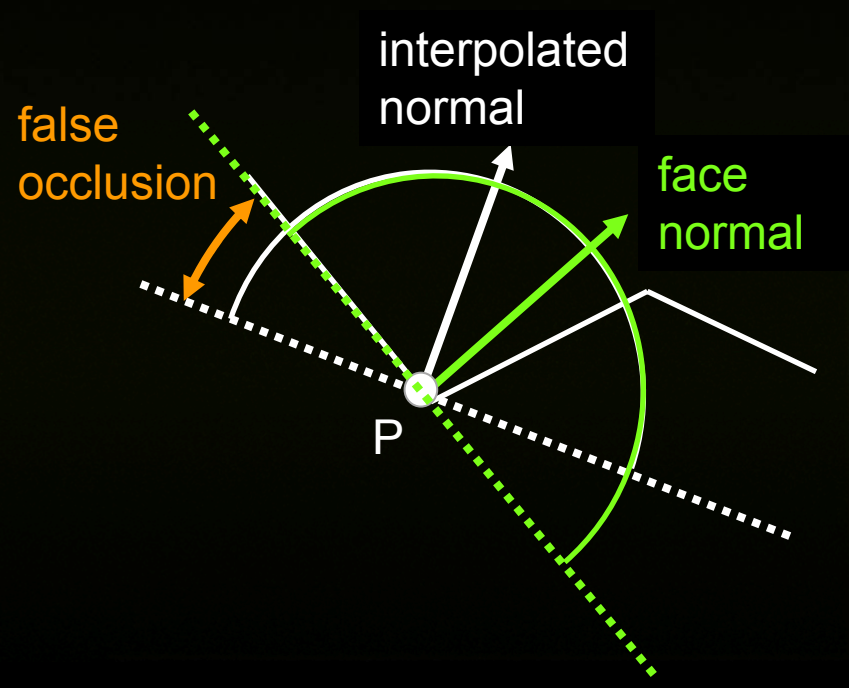
- Use uniform distribution of directions per pixel
  - Fixed num samples / dir
- Per-pixel randomization
  - Rotate directions by random per-pixel angle
  - Jitter samples by a random offset



Example with 4 directions / pixel

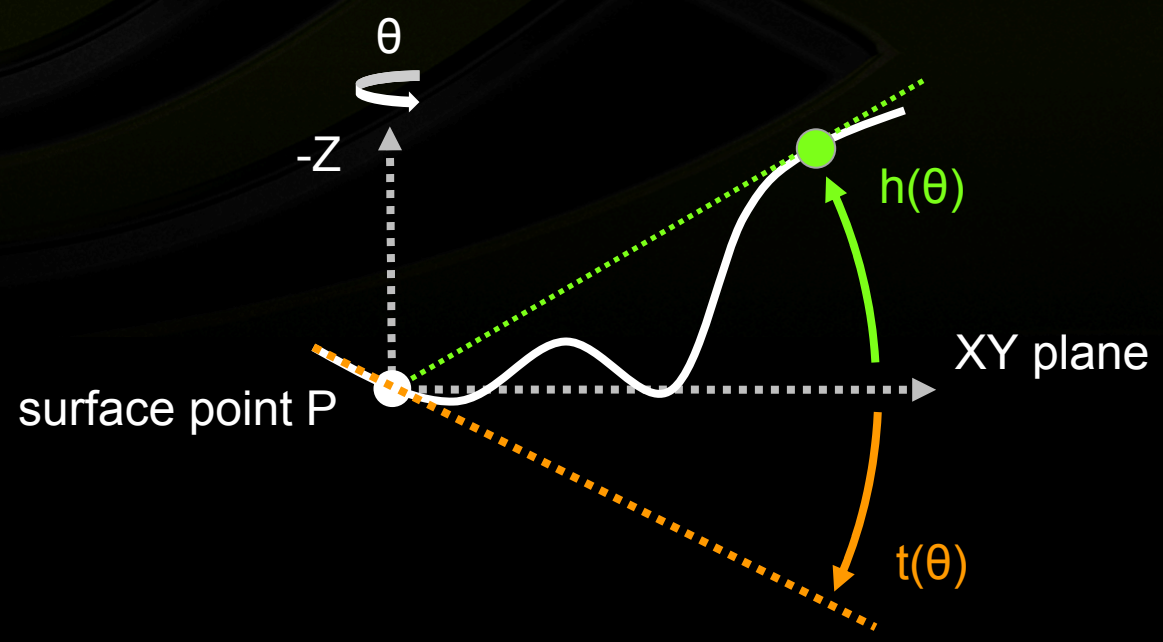
Normals

- We store per-pixel normals
  - Not interpolated normals
    - Would generate false occlusion
  - But face normals
    - Using ddx/ddy instructions on eye-space coordinates in the geometry pass

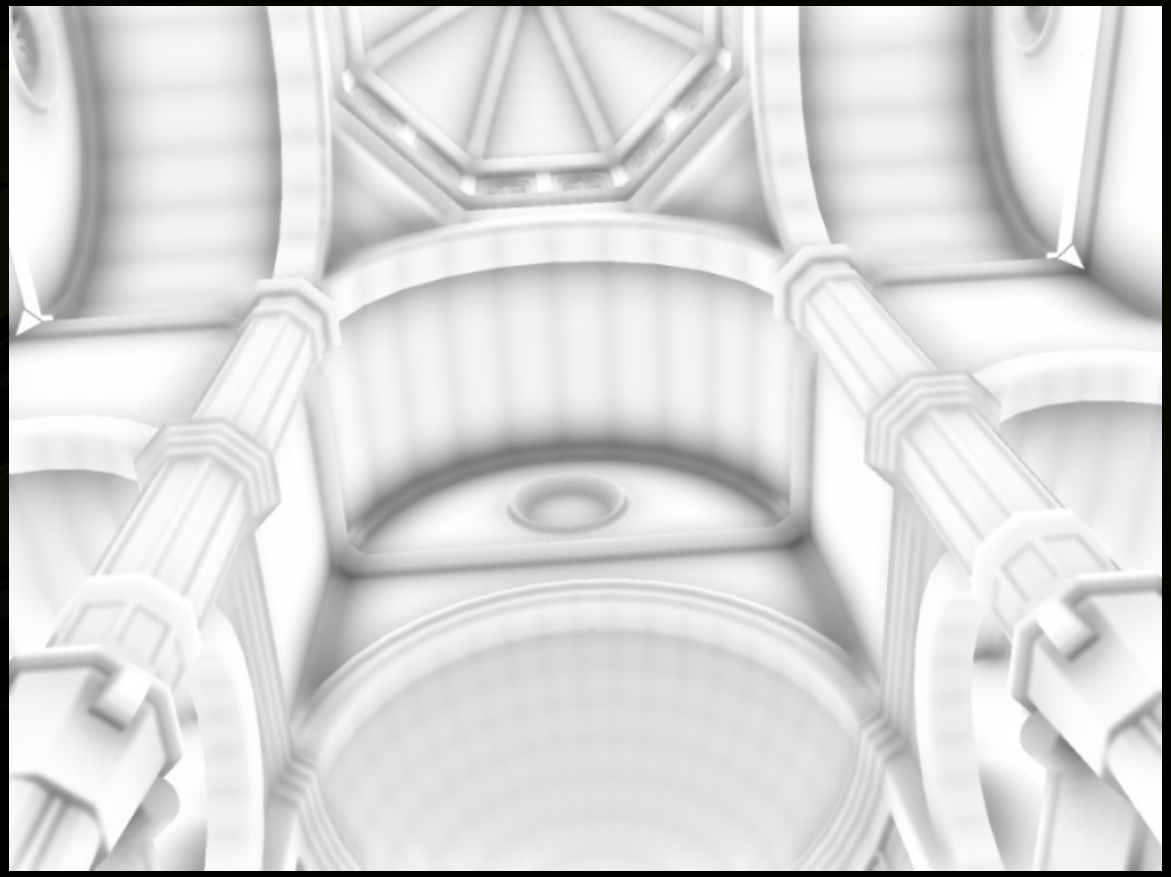


Core Algorithm

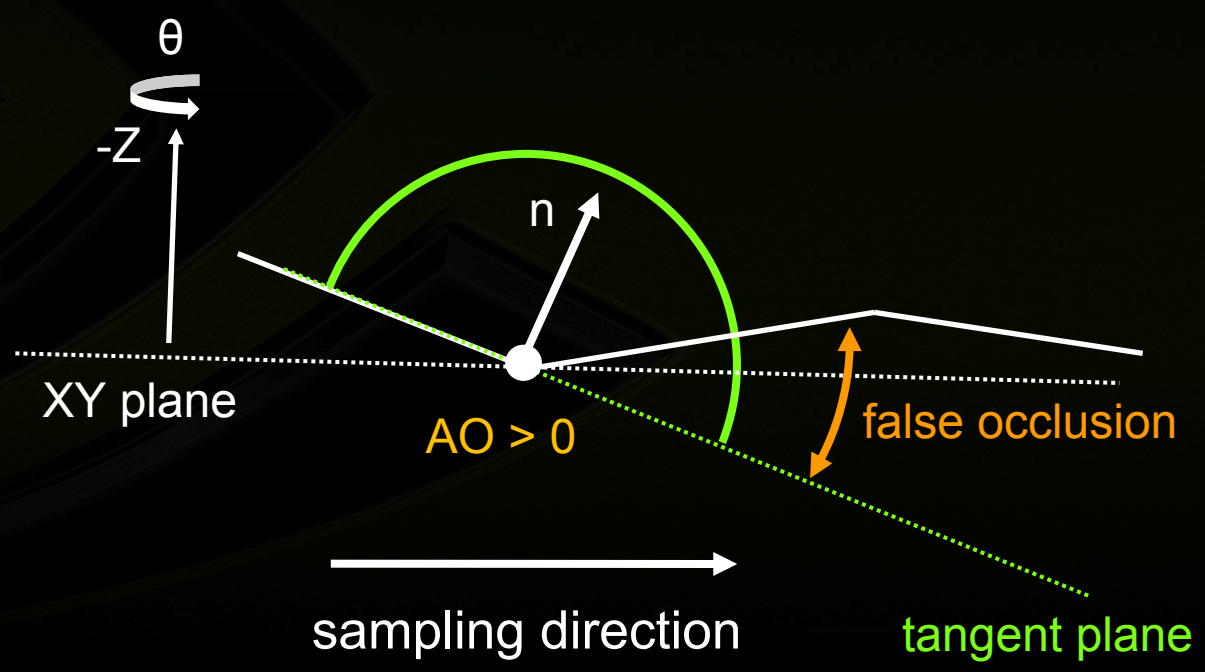
- **Integrate AO in 2D**
  - **Average AO over multiple 2D directions θ**
  - **AO(θ) = sin h(θ) - sin t(θ)**



Ambient Occlusion in Creases

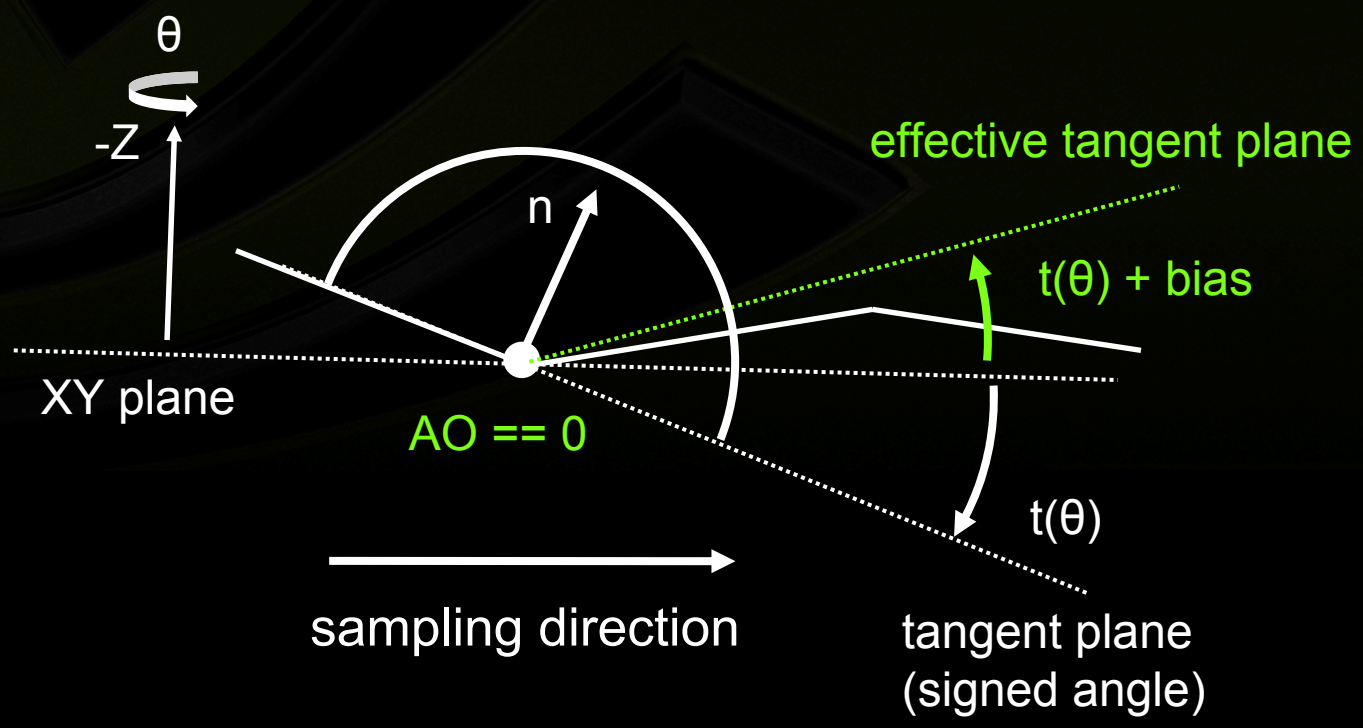


Low-Tessellation Problem

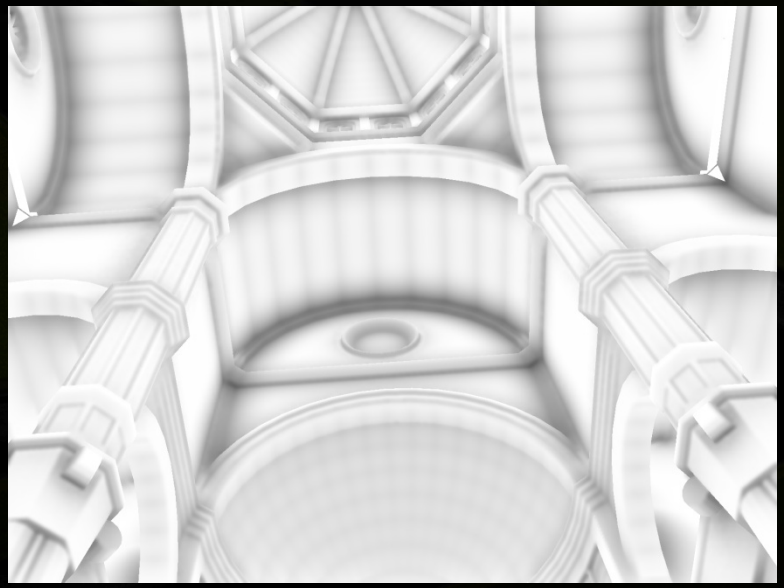


Solution: Angle Bias

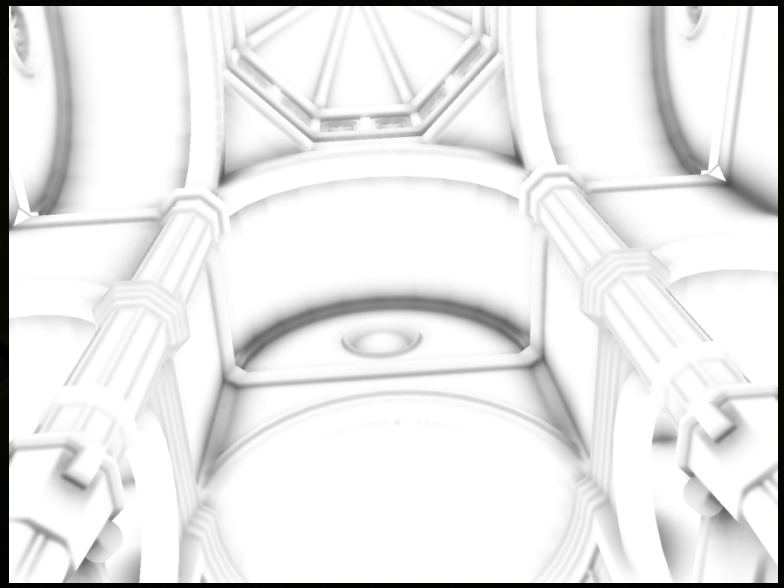
- **Similar to "spread" parameter in [Mental Ray]**
- **Ignore occlusion near the tangent plane**



The Angle Bias in Action



Without angle bias



With angle bias = 30 deg

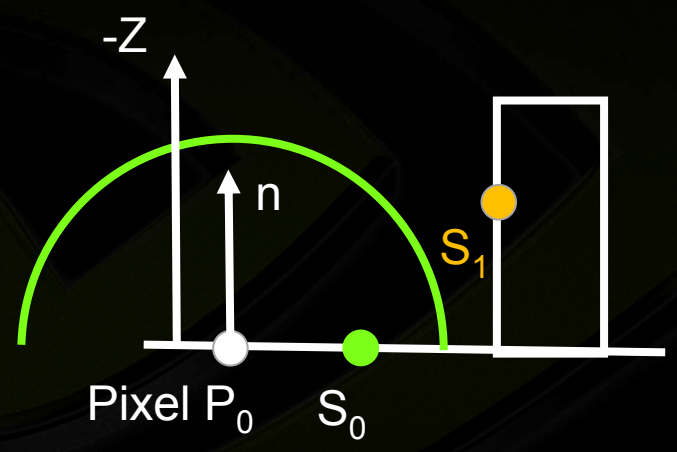
Sampling Outside the Screen

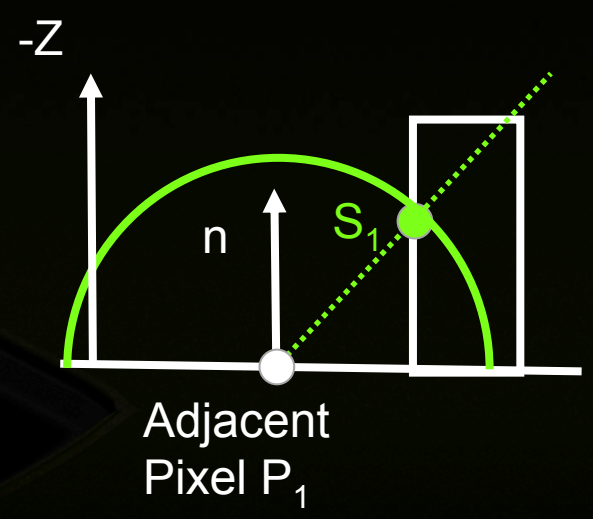
- No scene information outside view frustum
  - We remove false occlusion by using clamping to edge and an angle bias

angle bias = 0

angle bias = 30 deg

Discontinuity Problem





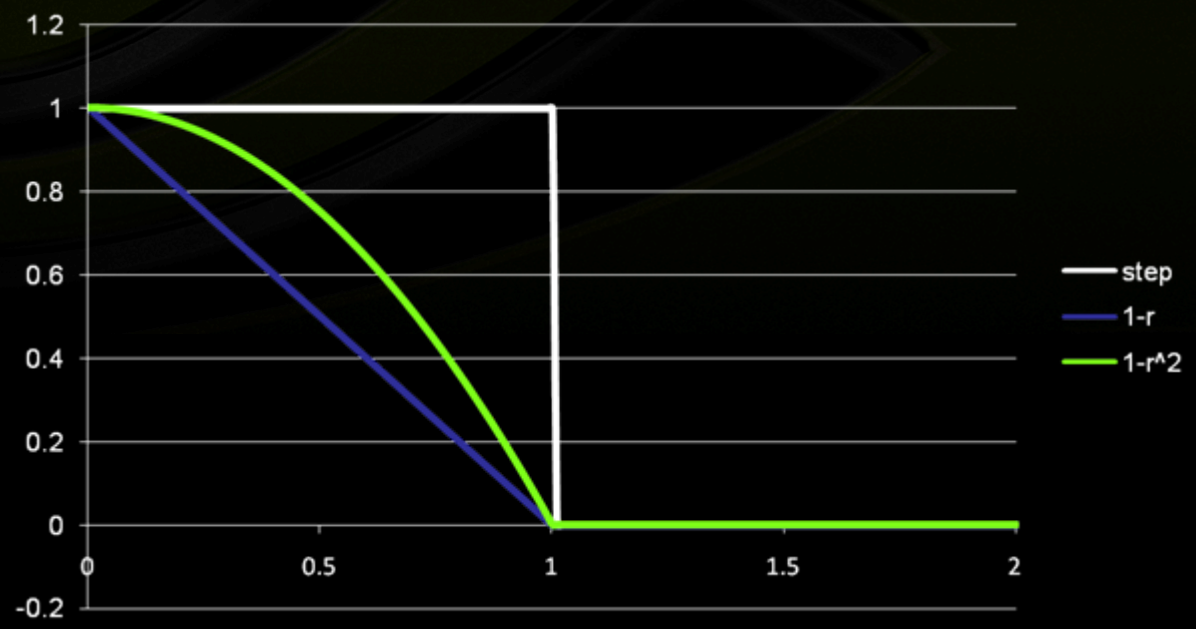
$AO(P_0) = \sin h - \sin t$
$= \sin 0 - \sin 0 = 0$

$AO(P_1) = \sin h - \sin t =$
$= \sin(45deg) - \sin 0 = 0.7$

➔ Large AO discontinuity between P_0 and P_1

Attenuation Function

- **Weight AO by a radial function W(r)**
  - **Similar to obscurances [Zhukov et al. 98]**
  - **"Falloff" in [Gelato] and [Mental Ray]**

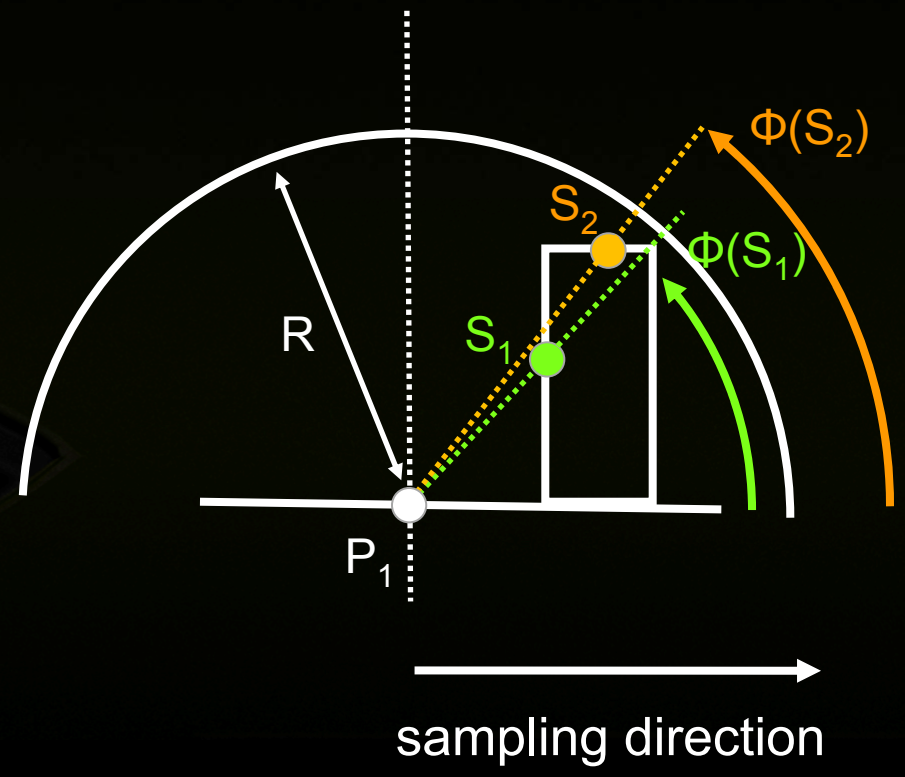


Normalized distance
$r = ||S – P|| / R$

We use the attenuation
$W(r) = 1 - r^2$

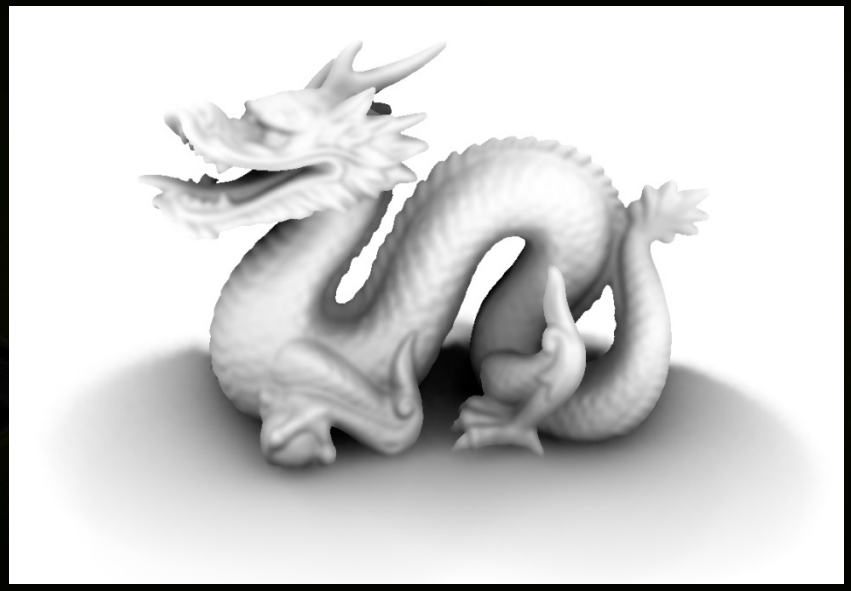
Per-Sample Attenuation

- Initialize WAO = 0
- After sample S_1
  - $AO(S_1) = \sin \Phi(S_1) - \sin t$
  - $WAO \mathrel{+}= W(S_1)\, AO(S_1)$
- After sample S_2
  - If $\Phi(S_2) > \Phi(S_1)$
    - $AO(S_2) = \sin \Phi(S_2) - \sin t$
    - $WAO \mathrel{+}= W(S_2)\, (AO(S_2) - AO(S_1))$



With and Without Attenuation

With Attenuation
$W(r) = 1 - r^2$



Without Attenuation
$W(r) = 1$

Noise

- **Per-pixel randomization generates noise**

AO with 6 directions x 6 steps/dir

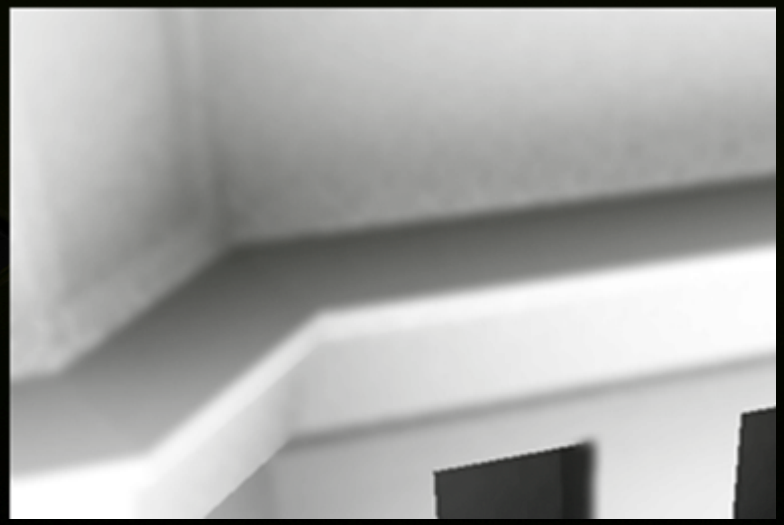
Cross Bilateral Filter

- We blur the ambient occlusion
- Depth-dependent Gaussian blur
  - [Petschnigg et al. 04]
  - [Eisemann and Durand 04]
  - Reduces blurring across edges
- Although it is a non-separable filter, we apply it separately in the X and Y directions

Cross Bilateral Filter

- **Depth-dependent Blur**

Without Blur

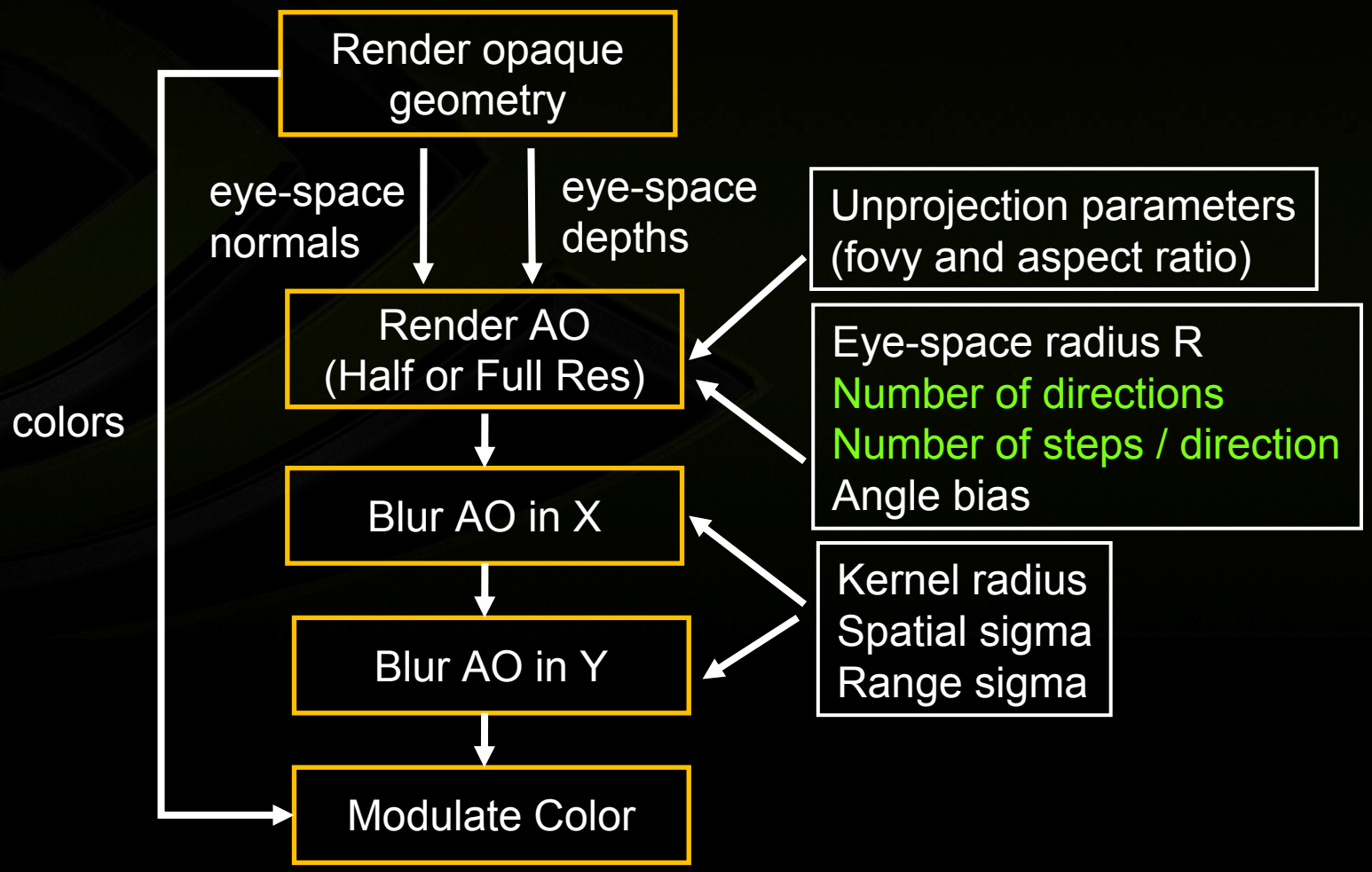


With 15x15 Blur

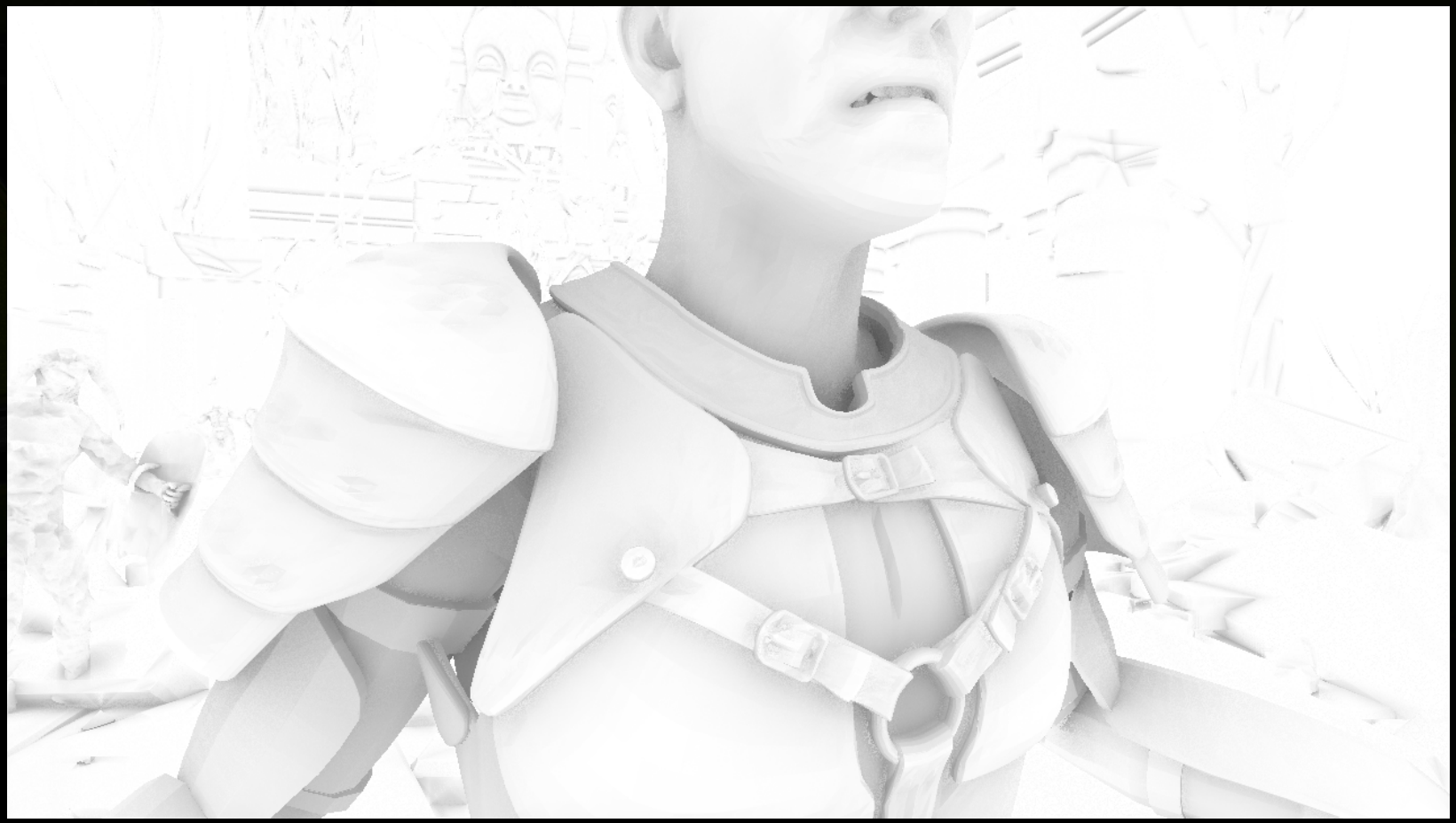
Half-Resolution AO

- AO is mostly low frequency
  - Can render the AO in half resolution
    - Source half-resolution depth image
- Still do the blur passes in full resolution
  - To avoid bleeding across edges
  - Source full resolution eye-space depths
    - [Kopf et al. 07]

Rendering Pipeline



Demo



Performance

- Depends on
  - Screen Resolution
  - Ambient Occlusion Resolution
  - Number of samples (directions * steps)
  - Blur Size

Half-Resolution AO

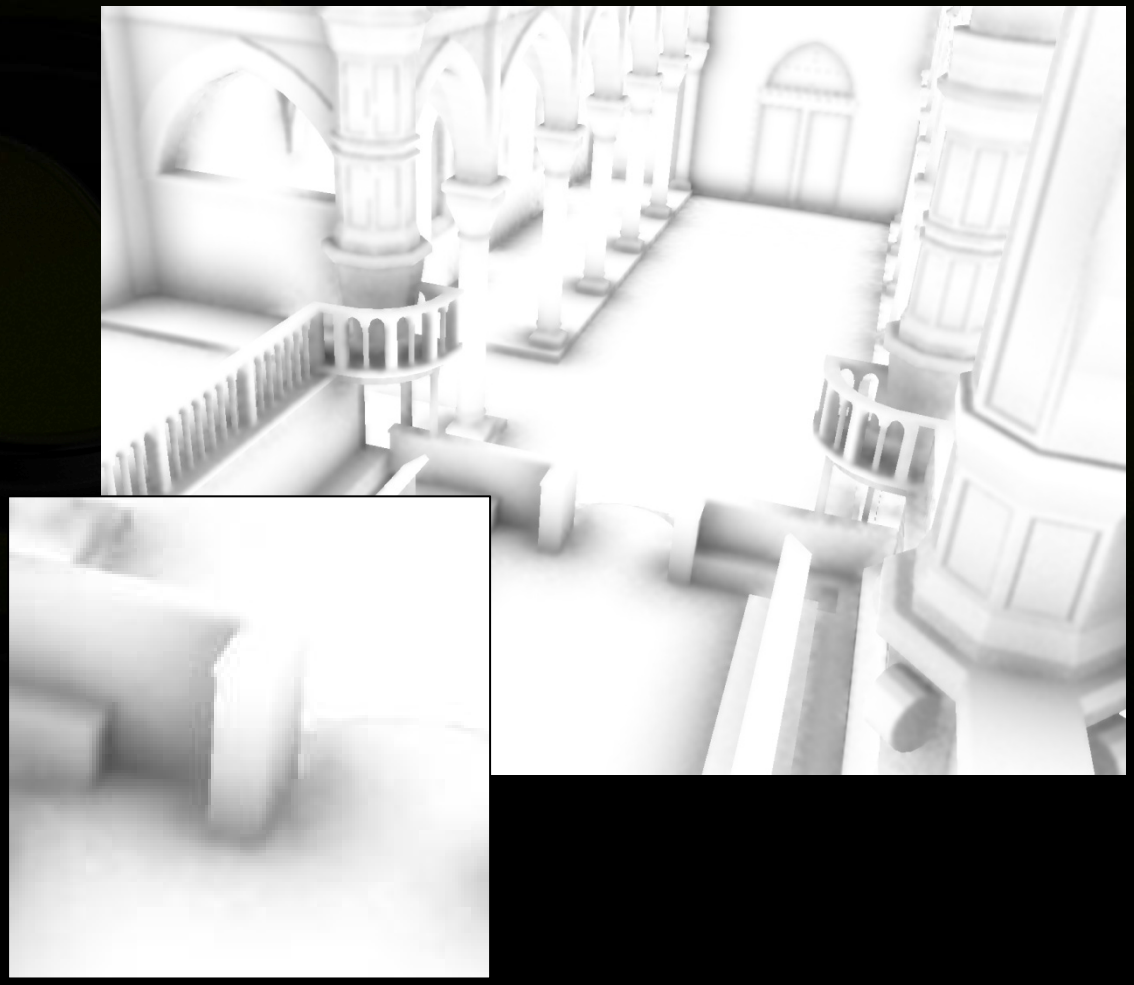


Image Size	1600x1200
AO Resolution	800x600
Blur Resolution	1600x1200

Half-Res AO	GeForce GTX 280
Geometry	1.0 ms
AO	3.5 ms
Blur	2.5 ms
Total	7.0 ms 143 fps

6 directions per pixel
6 steps per direction
15x15 Blur Size

Full-Resolution AO

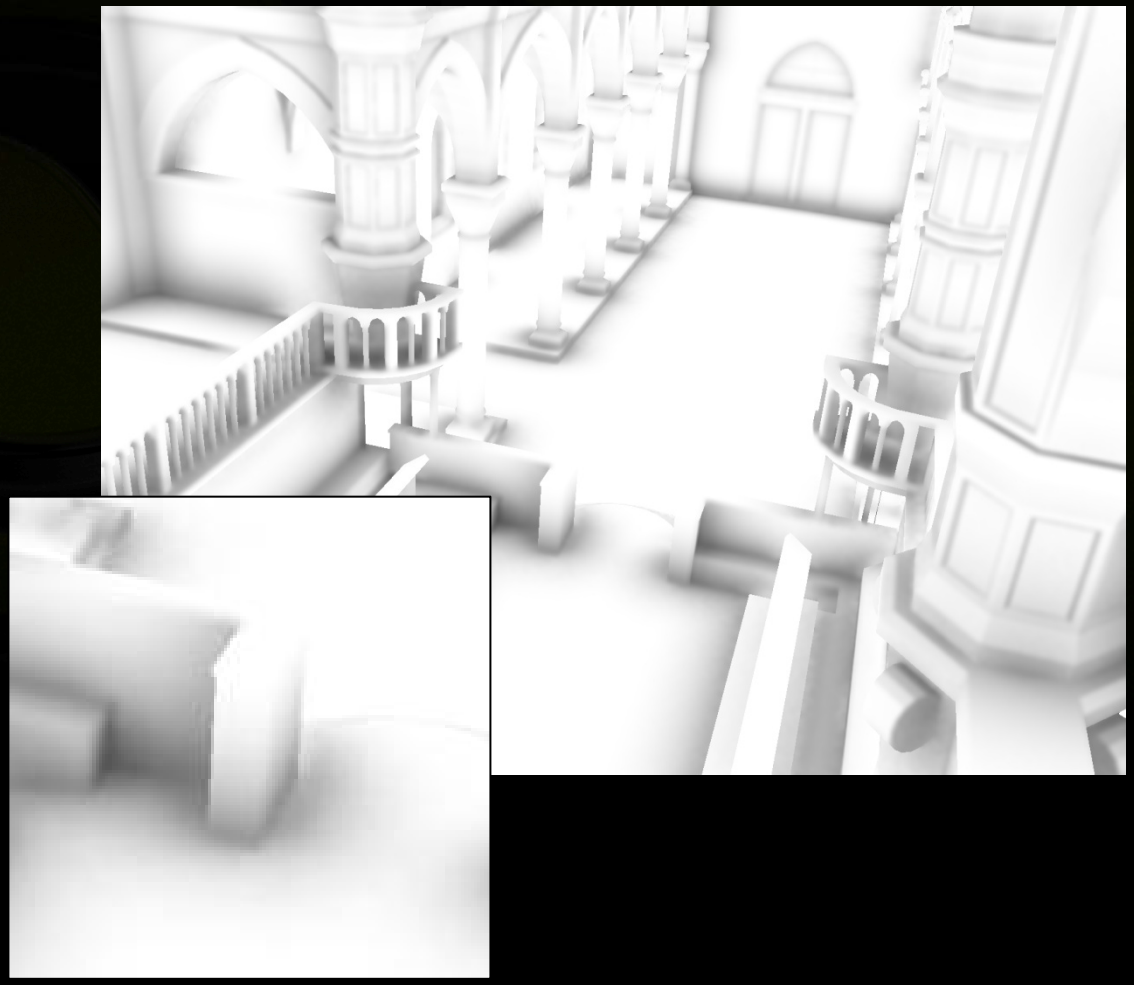


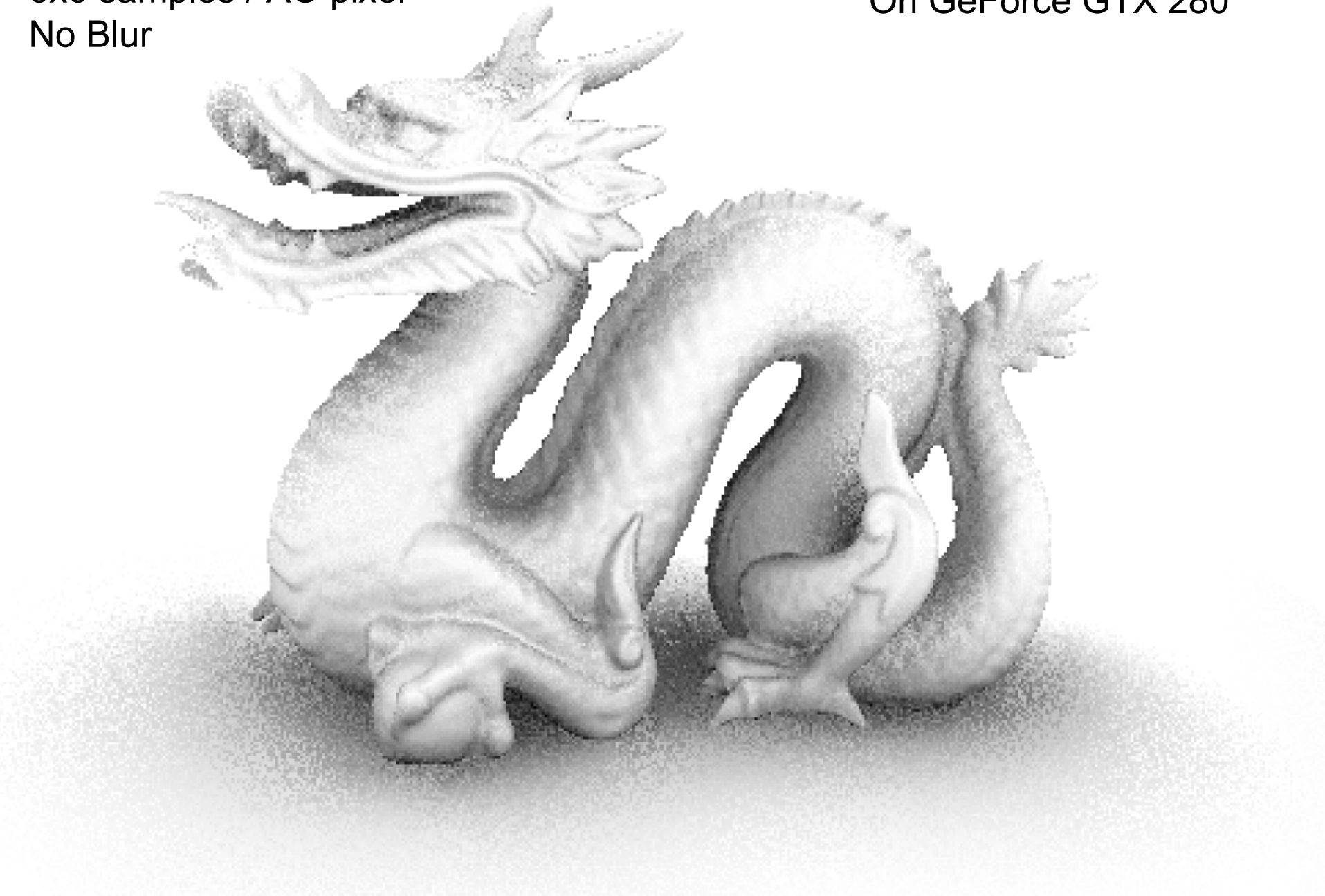
Image Size	1600x1200
AO Resolution	1600x1200
Blur Resolution	1600x1200

Full-Res AO	GeForce GTX 280
Geometry	1.0 ms
AO	30.0 ms
Blur	2.5 ms
Total	33.5 ms 30 fps

6 directions per pixel
6 steps per direction
15x15 Blur Size

Half-Resolution AO
6x6 samples / AO pixel
No Blur

AO = 3.5 ms @ 800x600
On GeForce GTX 280

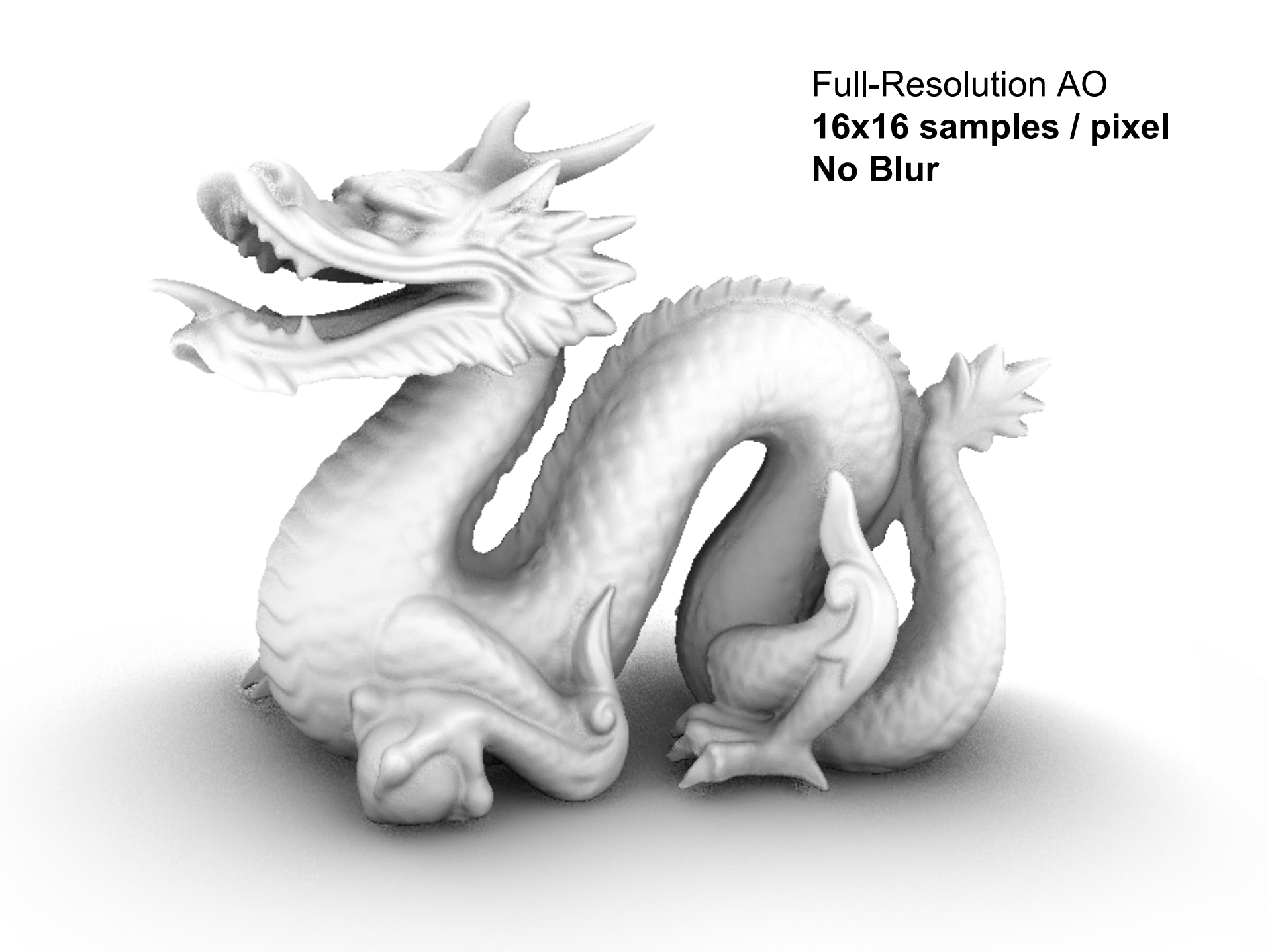


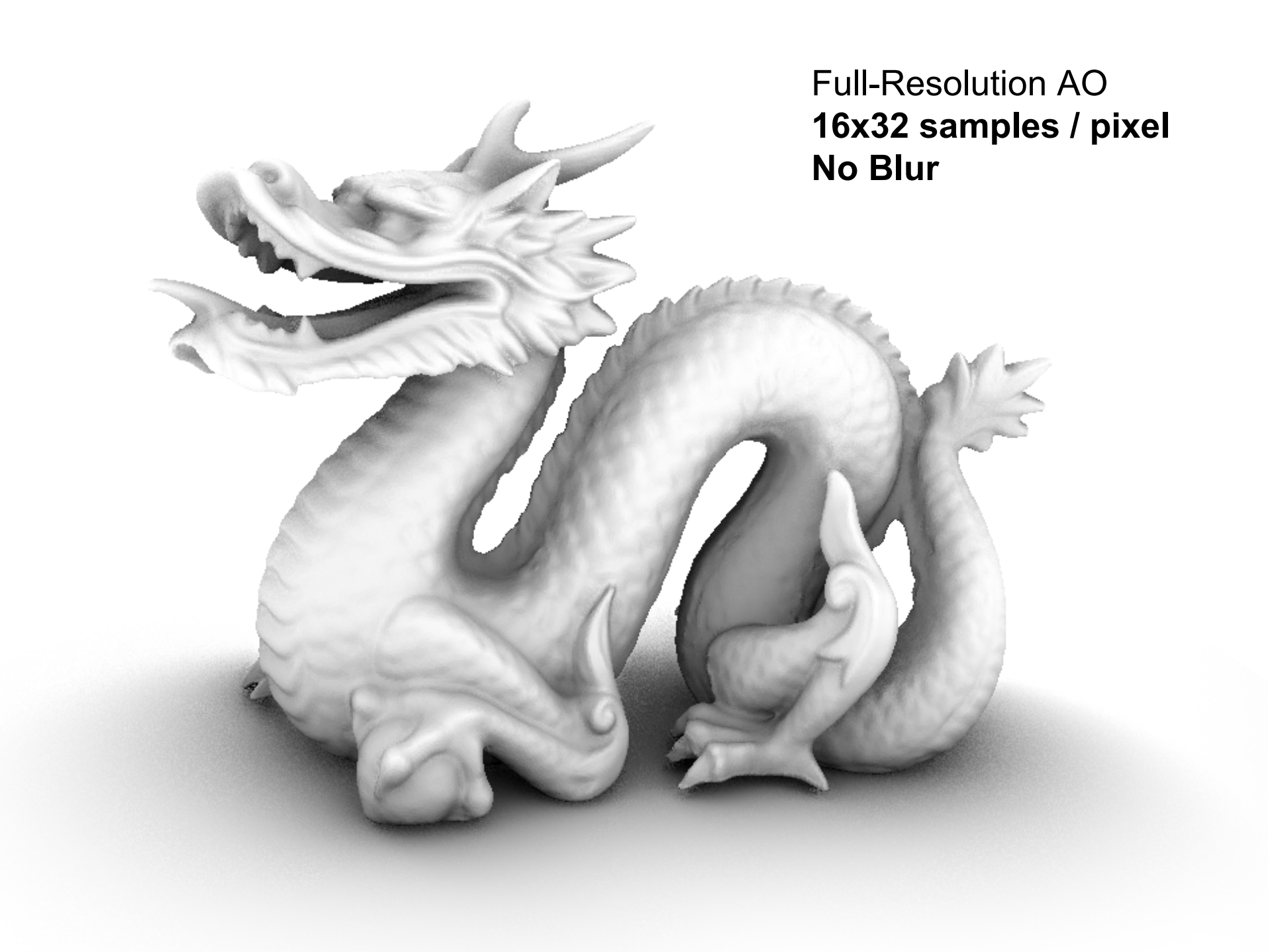
Half-Resolution AO
6x6 samples / AO pixel
15x15 Blur

AO = 3.5 ms @ 800x600
Blur = 2.5 ms @ 1600x1200
On GeForce GTX 280

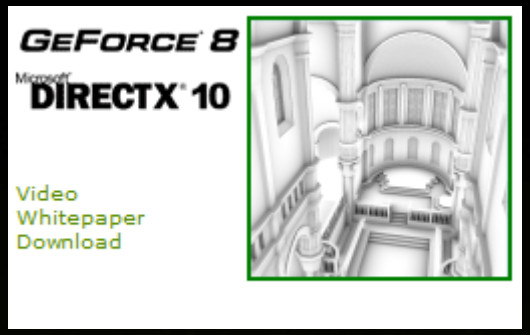
Full-Resolution AO
6x6 samples / AO pixel
15x15 Blur

AO = 30 ms @ 800x600
Blur = 2.5 ms @ 1600x1200
On GeForce GTX 280


Full-Resolution AO
16x16 samples / pixel
No Blur


Full-Resolution AO
16x32 samples / pixel
No Blur

Conclusion



- DirectX10 SDK sample
  - Now available on developer.nvidia.com
  - Including video and brief whitepaper
- Easy to integrate into a game engine
  - Input Data = eye-space depths and normals
  - Rendered in a post-processing pass
- More details in ShaderX^7 (to appear)

Acknowledgments

- NVIDIA
  - Rouslan Dimitrov, Samuel Gateau, Michael Thompson, Ignacio Castano, the demo team
- Models
  - Dragon - Stanford 3D Scanning Repository
  - Sibenik Cathedral - Marko Dabrovic

Questions?

calin@nvidia.com

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