Screen Space Ambient Occlusion (SSAO)

Screen Space Ambient Occlusion

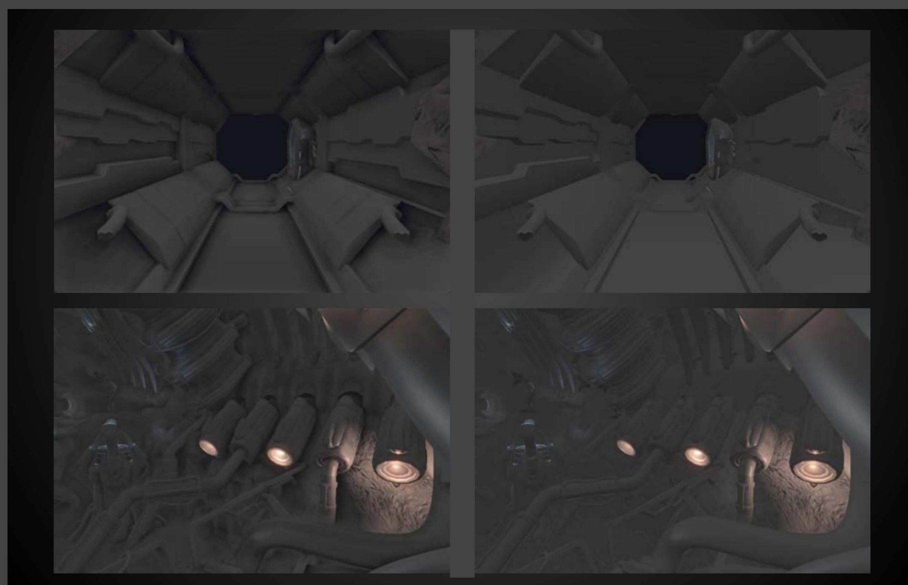
- First introduced by Crytek again

屏幕空间环境光遮蔽.

Screen Space Ambient Occlusion

- Why AO?
  - Cheap to implement
  - But enhances the sense of relative positions

增强了相对位置的感觉 (立体感)



[From CryEngine 2]

Screen Space Ambient Occlusion

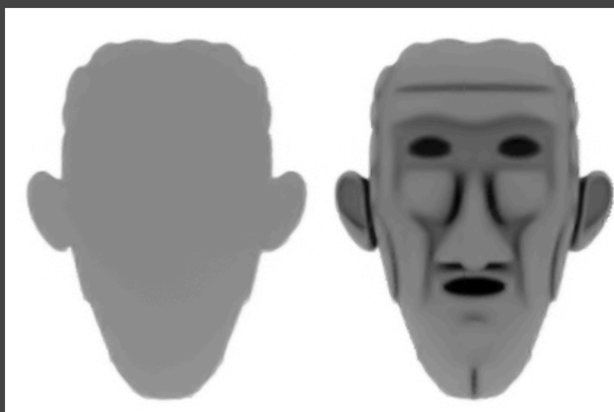
- What is SSAO?
  全局光照的近似
  - An approximation of global illumination
  - In screen space
- Key idea 1
  不知道间接光照事件.
  - We don’t know the incident indirect lighting
  - Let’s assume it is constant 假设它是恒定的.
    (for all shading points, from all directions)
  - Sounds familiar to you?

Screen Space Ambient Occlusion

- Key idea 2 & 3

  考虑不同着色点的不同可见度<朝向所有方向>

  - Considering different visibility (towards all directions) at different shading points (why?)



Ambient term from Phong　　Ambient Occlusion

环境光遮挡

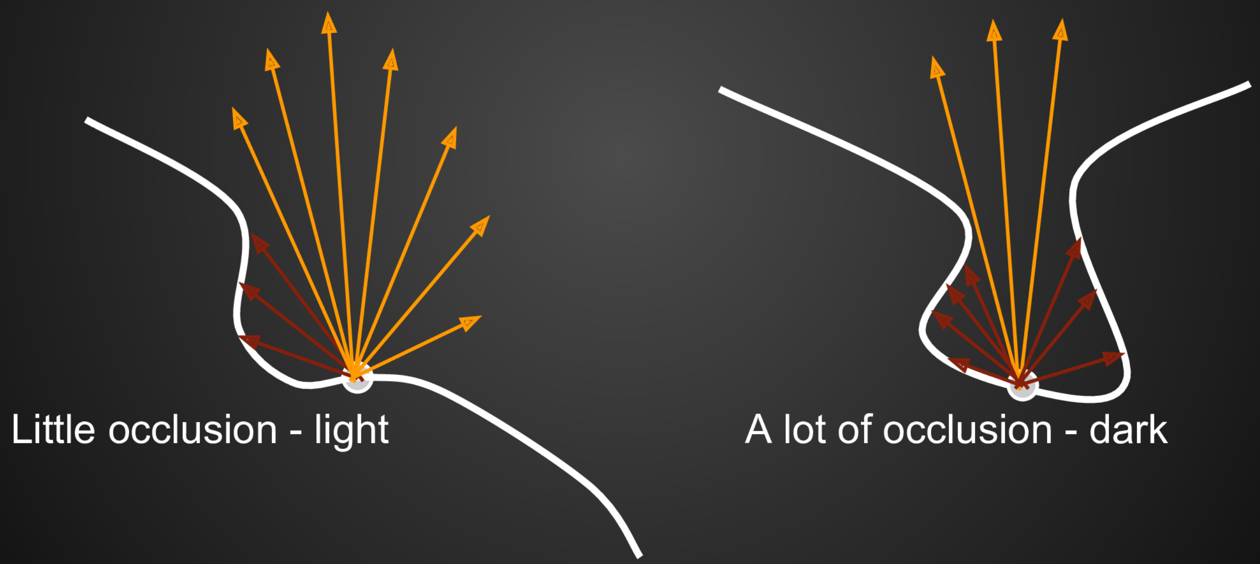
[Autodesk 3ds Max]

Ambient Occlusion

  - Also, assuming diffuse materials

  假设漫反射材质.

Ambient occlusion



Screen Space Ambient Occlusion

- Theory
  - Still, everything starts from the rendering equation

$$L_o(\mathrm{p},\omega_o) = \int_{\Omega^+} \boxed{L_i(\mathrm{p},\omega_i)}\,\boxed{f_r(\mathrm{p},\omega_i,\omega_o)}\,\boxed{V(\mathrm{p},\omega_i)}\cos\theta_i\,\mathrm{d}\omega_i$$

  - And again, from "the RTR approximation / equation"!

$$\int_{\Omega} f(x)g(x)\,\mathrm{d}x \approx \frac{\int_{\Omega_G} f(x)\,\mathrm{d}x}{\int_{\Omega_G}\,\mathrm{d}x} \cdot \int_{\Omega} g(x)\,\mathrm{d}x$$

Screen Space Ambient Occlusion

- Separating the visibility term

$$L_o^{\text{indir}}(\mathrm{p},\omega_o) \approx \boxed{\frac{\int_{\Omega^+} V(\mathrm{p},\omega_i)\cos\theta_i\,\mathrm{d}\omega_i}{\int_{\Omega^+}\cos\theta_i\,\mathrm{d}\omega_i}} \cdot \boxed{\int_{\Omega^+} \underbrace{L_i^{\text{indir}}(\mathrm{p},\omega_i)}_{\text{常量}}\, \underbrace{f_r(\mathrm{p},\omega_i,\omega_o)}_{\text{diffuse 常量.}} \cos\theta_i\,\mathrm{d}\omega_i}$$

$$\square \triangleq k_A = \frac{\int_{\Omega^+} V(\mathrm{p},\omega_i)\cos\theta_i\,\mathrm{d}\omega_i}{\pi}$$

(the weight-averaged visibility $\overline{V}$ from all directions)

来自各个方向的加权平均可见度 $\overline{V}$

$$\square = L_i^{\text{indir}}(p)\cdot\frac{\rho}{\pi}\cdot\pi = L_i^{\text{indir}}(p)\cdot\rho$$

(constant for AO)

对于AO是常量.

Screen Space Ambient Occlusion

- A deeper understanding 1

$$\int_{\Omega} f(x) g(x)\,\mathrm{d}x \approx \underbrace{\frac{\int_{\Omega_G} f(x)\,\mathrm{d}x}{\int_{\Omega_G} \mathrm{d}x}} \cdot \int_{\Omega} g(x)\,\mathrm{d}x$$

$$= \underbrace{\overline{f(x)}} \cdot \int_{\Omega} g(x)\,\mathrm{d}x$$

(the average f(x) in the support of G)

在G的覆盖范围上 f(x)的平均值.

- Also, in AO, the approximation is accurate (const $G = L \cdot f_r$) →

g(x) 常数

Screen Space Ambient Occlusion

- A deeper understanding 2 $\int_{\Omega} f(x)g(x)\,\mathrm{d}x \approx \frac{\int_{\Omega_G} f(x)\,\mathrm{d}x}{\int_{\Omega_G}\,\mathrm{d}x} \cdot \int_{\Omega} g(x)\,\mathrm{d}x$
  - Why can we take the cosine term with $d\omega_i$?

$$L_o^{\text{indir}}(\mathrm{p}, \omega_o) \approx \frac{\int_{\Omega^+} V(\mathrm{p}, \omega_i) \cos\theta_i \,\mathrm{d}\omega_i}{\int_{\Omega^+} \cos\theta_i \,\mathrm{d}\omega_i} \cdot \int_{\Omega^+} L_i^{\text{indir}}(\mathrm{p}, \omega_i) f_r(\mathrm{p}, \omega_i, \omega_o) \cos\theta_i \,\mathrm{d}\omega_i$$

Screen Space Ambient Occlusion

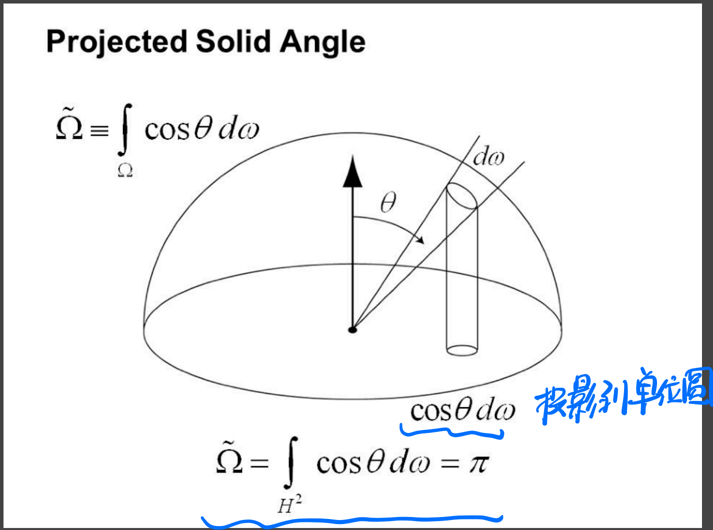
- Why can we take the cosine term with $d\omega_i$?

投影立体角

- Projected solid angle $dx_\perp = \cos\theta_i \, \mathrm{d}\omega_i$
  - Unit hemisphere -> unit disk

    投影立体角积分
  - Integration of projected solid angle == the area of the unit disk == π

    单位圆面积



Screen Space Ambient Occlusion

- Actually, a much simpler understanding
  - Uniform incident lighting — L_i is constant
  - Diffuse BSDF — $f_r = \dfrac{\rho}{\pi}$ is also constant
  - Therefore, taking both out of the integral:

$$L_o(\mathrm{p}, \omega_o) = \int_{\Omega^+} L_i(\mathrm{p}, \omega_i) f_r(\mathrm{p}, \omega_i, \omega_o)\, V(\mathrm{p}, \omega_i) \cos\theta_i \,\mathrm{d}\omega_i$$

$$= \frac{\rho}{\pi} \cdot L_i(p) \cdot \int_{\Omega^+} V(\mathrm{p}, \omega_i) \cos\theta_i \,\mathrm{d}\omega_i$$

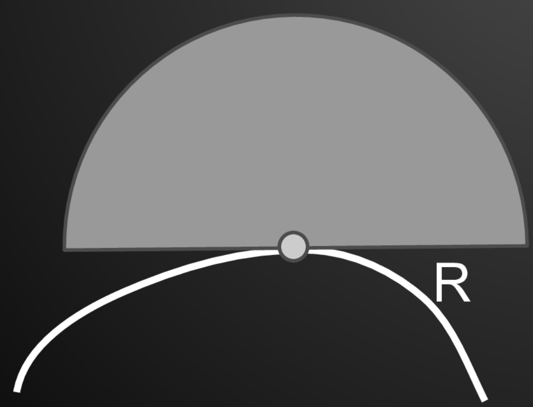
How to compute the occlusion values $k_A(p)$ in real time

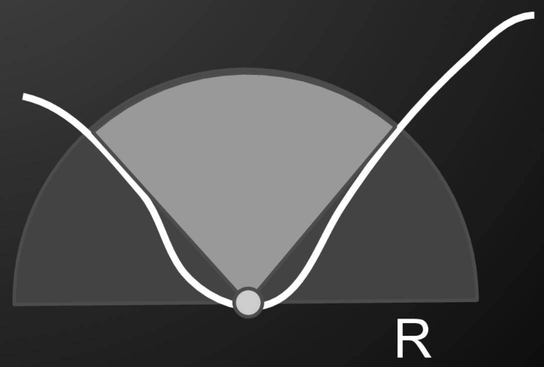
- In object space
  - Raycasting against geometry
  - Slow, requires simplifications and/or spatial data structures
  - Depends of scene complexity
- In screen space
  - Done in a post-rendering pass
  - No pre-processing required
  - Doesn't depend on scene complexity
  - **Simple**
  - Not physically accurate

Ambient occlusion approximation: limited radius

Limit to local occlusion in a hemisphere of radius R.

More efficient and works better in enclosed areas such as indoors, that would be fully occluded otherwise.

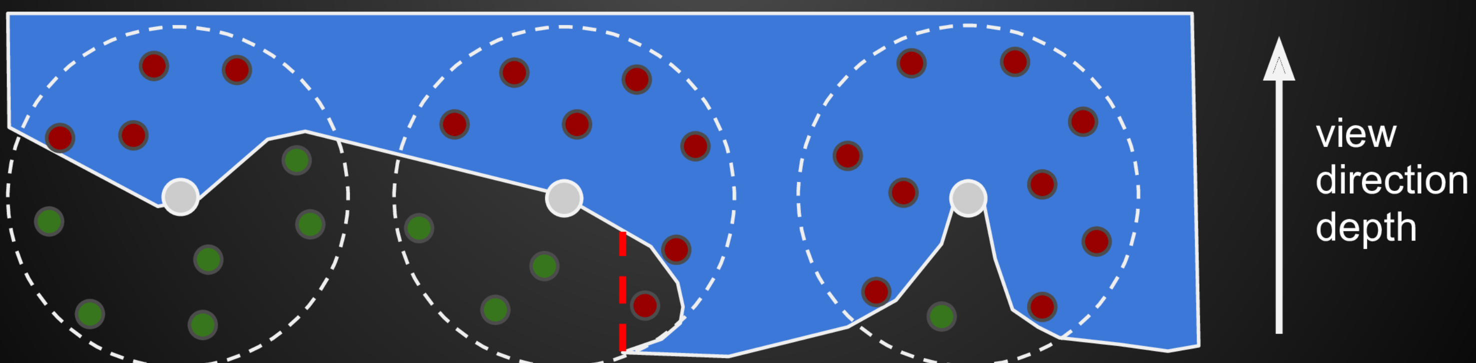




SSAO:
Ambient occlusion using the z-buffer

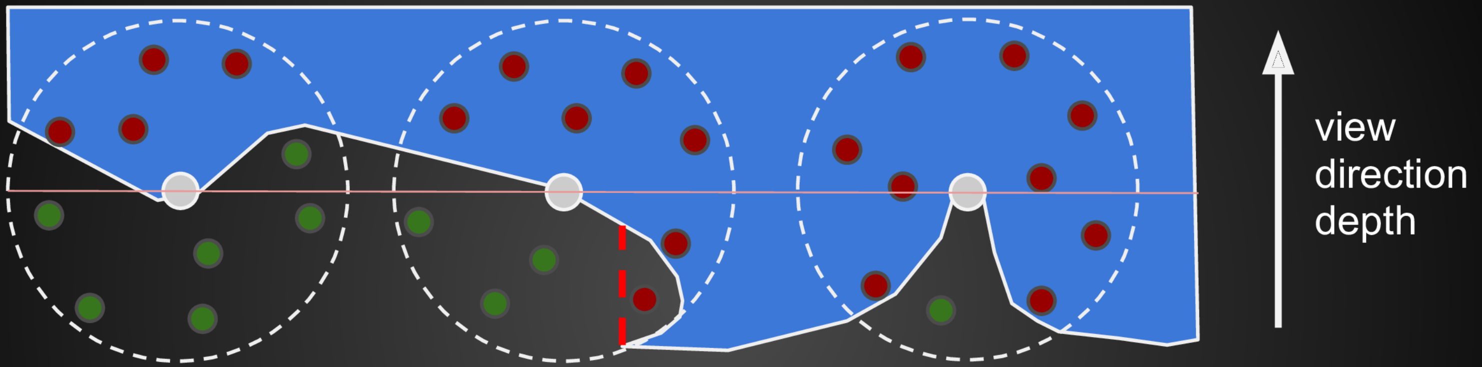
Use the readily available depth buffer as an approximation of the scene geometry.

Take samples in a sphere around each pixel and test against buffer.



知道法线信息（只关心半球即可）
不知 〃 （关心整个球）

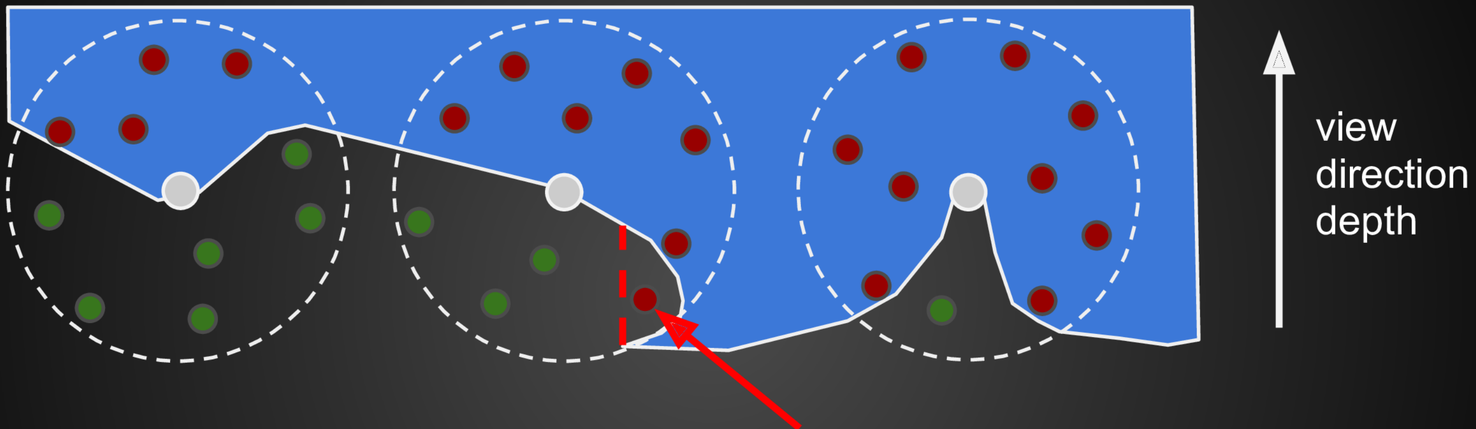
SSAO:
Ambient occlusion using the z-buffer



If more than half of the samples are inside, AO is applied, amount depending on ratio of samples that pass and fail depth test.

Uses sphere instead of hemisphere, since normal information isn't available.

SSAO:
Ambient occlusion using the z-buffer



Approximation of the scene geometry, some fails are incorrect. The one behind the red line for example. False occlusions.

Samples are not weighted by cos(theta), so not physically accurate, but looks convincing.

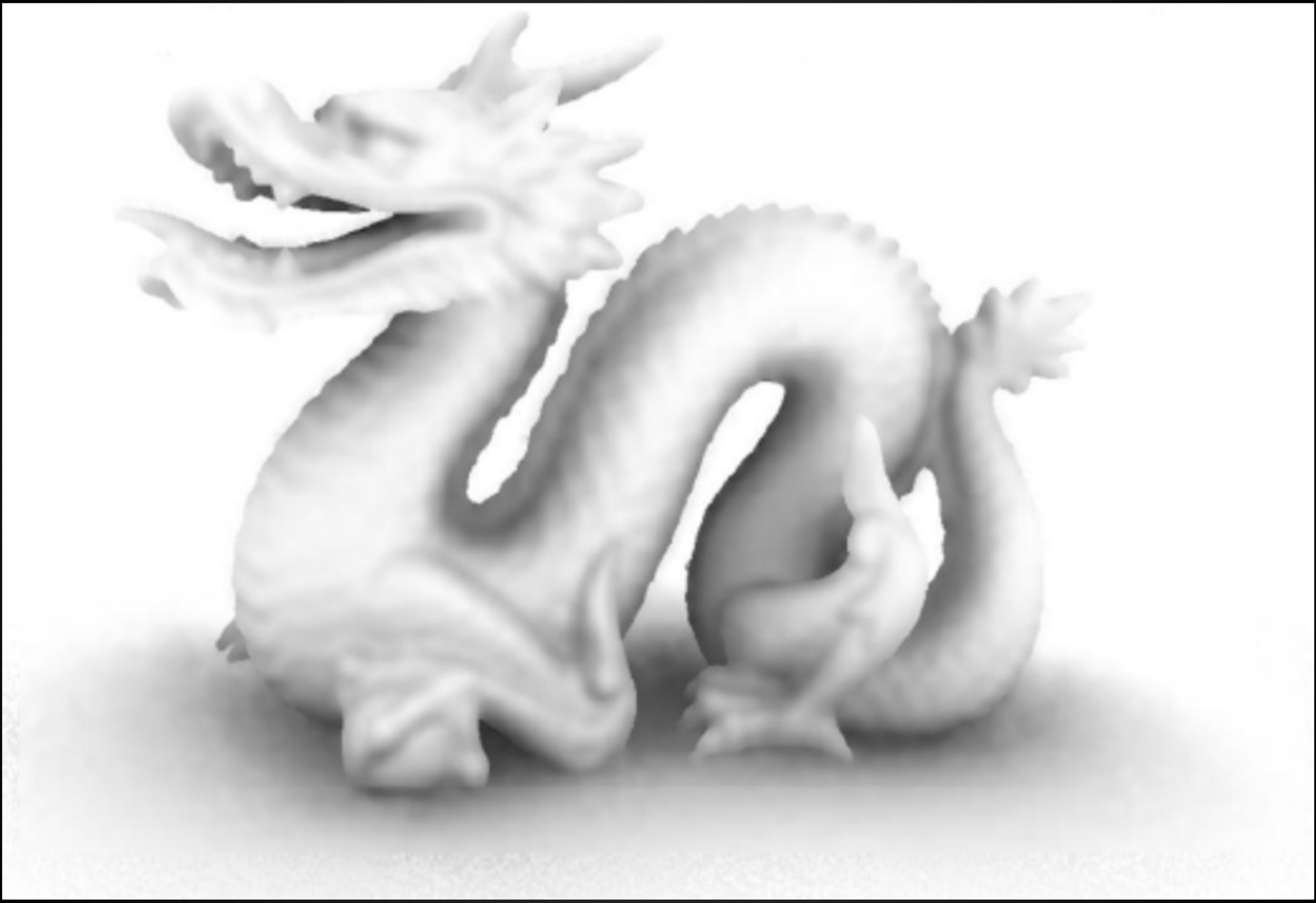
SSAO: False occlusions, halos

No SSAO

SSAO

Choosing samples

- More samples -> greater accuracy
- Many samples are needed for a good result, but for performance only about 16 samples are used.
- Positions from randomized texture to avoid banding.
- Noisy result, blurred with edge preserving blur.

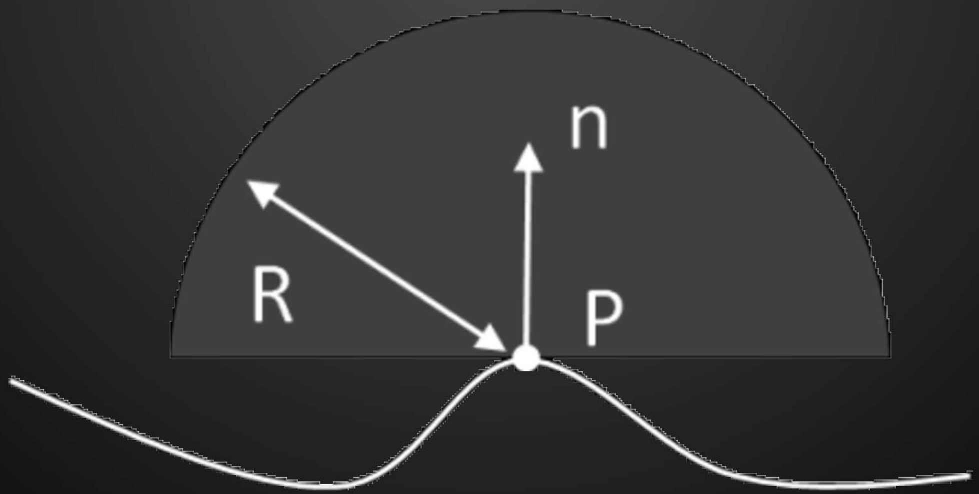


Horizon based ambient occlusion: HBAO

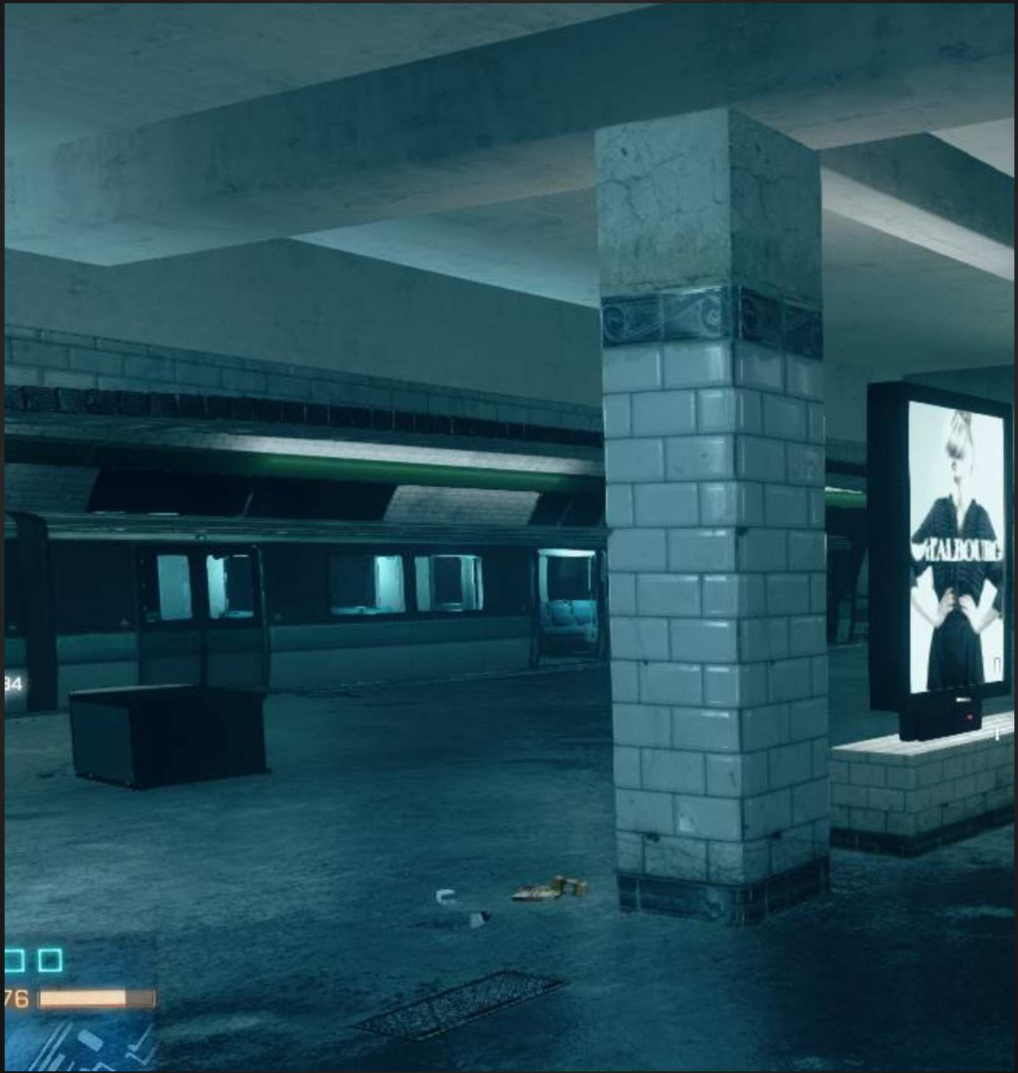
Also done in screen space.

Approximates ray-tracing the depth buffer.

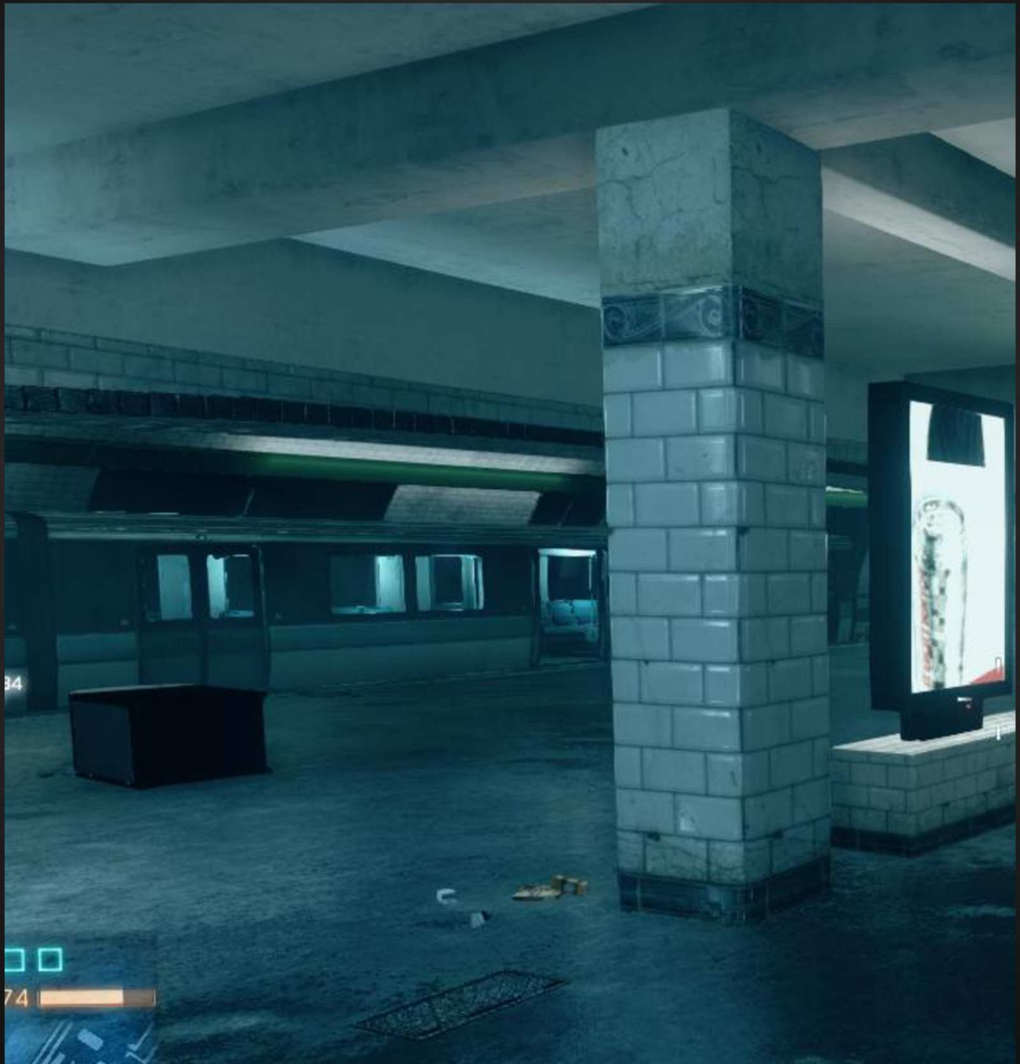
Requires that the normal is known, and only samples in a hemisphere.



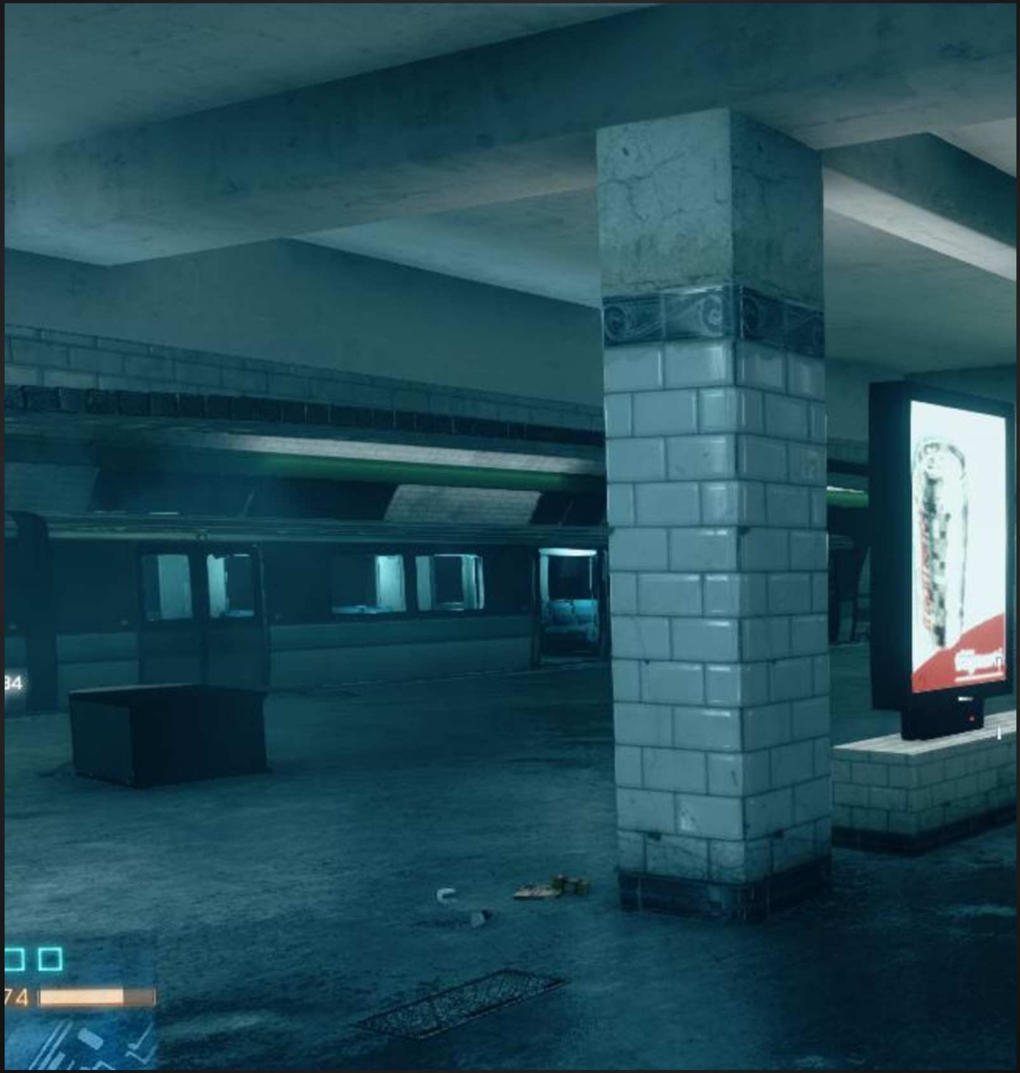
Battlefield 3 - No SSAO



Battlefield 3 - SSAO



Battlefield 3 - HBAO



Battlefield 3 - SSAO

Battlefield 3 - HBAO

Questions?

Next Lecture

- Real-time global illumination cont.
  - Screen Space Reflection (SSR)

[Onmyoji by NetEase]

Thank you!

(Many SSAO slides courtesy of the
Chalmers University of Technology)