Multi-Resolution Screen-Space Ambient Occlusion

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Ambient Occlusion (AO)
\[ AO(p) = \frac{1}{\pi} \int_{\Omega} \rho(p, d_i) \cos \theta_i \, dw_i \]

\[ d_i \geq d_{max} : \rho = 0 \]
\[ d_i = 0 : \rho = 1 \]
Screen-Space AO (SSAO)

Volumetric AO [SKUT10]
SSAO

(Dis)Advantages

- Inaccurate
  - Local AO
  - Over/underestimated AO
- Low quality
  - Noise
  - Blur

- Simple
- Fast
- General
- Easy to integrate
Multi-Resolution AO (MSSAO) Intuition

\[ AO_{\text{final}} = \max(AO_i) \]
Multi-Resolution AO (MSSAO) Intuition

\[
AO_{final} = f(\max(AO_i), \text{average}(AO_i))
\]

\[
AO_{final} \geq \max(AO_i)
\]

\[
AO_{final} \propto \text{average}(AO_i)
\]
MSSAO Overview

Geometry → g-buffer (1024x1024) → Downsampling

→ AO buffer (256x256) → Compute AO (256x256)
→ Blur & Upsample

→ AO buffer (512x512) → Compute AO (512x512)
→ Blur & Upsample

→ AO buffer (1024x1024) → Compute AO (1024x1024)
→ g-buffer (1024x1024)
MSSAO
AO from Multiple Resolutions
MSSAO
Overview
MSSAO

Downsampling

\[ p_1^z \leq p_2^z \leq p_3^z \leq p_4^z \]

if \( p_4^z - p_1^z \leq d_{\text{threshold}} \)

\[ p \leftarrow (p_2 + p_3)/2 \]
\[ n \leftarrow (n_2 + n_3)/2 \]
else

\[ p \leftarrow p_2 \]
\[ n \leftarrow n_2 \]
MSSAO Overview

Geometry → g-buffer (1024x1024) → Downsampling → Compute AO (256x256) → AO buffer (256x256) → Blur & Upsample → AO buffer (512x512) → Compute AO (512x512) → AO buffer (512x512) → Blur & Upsample → AO buffer (1024x1024) → Compute AO (1024x1024) → AO buffer (1024x1024) → g-buffer (1024x1024)
MSSAO

Neighborhood Sampling

• Project the AO radius of influence to screen space at each pixel \( p \) at resolution \( Res_i \) to get \( r_i(p) \) (in terms of pixels)
• Cap \( r_i(p) \) to some value \( r_{max} \) (typical value is 5)

Works well with a 3x3 Gaussian filter
MSSAO
Computing AO

\[ AO(\mathbf{p}) = \frac{1}{N} \sum_{i=1}^{N} \rho(\mathbf{p}, d_i) \frac{(\mathbf{n} \cdot \mathbf{q}_i - \mathbf{p})}{\rho(\mathbf{p}, d_i)} \]

model after the Monte-Carlo approximation of

\[ AO(\mathbf{p}) = \frac{1}{\pi} \int_{\Omega} \rho(\mathbf{p}, d_i) \cos \theta_i \, d\omega_i \]
MSSAO Overview

Geometry → g-buffer (1024x1024) → Downsampling

AO buffer (256x256) → Compute AO (256x256) → g-buffer (256x256)

Blur & Upsample

AO buffer (512x512) → Compute AO (512x512) → g-buffer (512x512)

Blur & Upsample

AO buffer (1024x1024) → Compute AO (1024x1024) → g-buffer (1024x1024)
MSSAO

Bilateral Upsampling

- Bilinear weights $w_b$
- Depth weights

\[ w_z(p_i) = \left( \frac{1}{1 + |z_i - z|} \right)^{t_z} \]

- Normal weights

\[ w_n(p_i) = \left( \frac{n \cdot n_i + 1}{2} \right)^{t_n} \]

\[ AO(p) = \sum_{i=1}^{4} w_b(p_i)w_z(p_i)w_n(p_i)AO(p_i) \]
MSSAO
Combining AO Values

\[ AO_{final} = 1 - \left(1 - \max(AO_i)\right)\left(1 - \text{avg}(AO_i)\right) \]

- \( \max(AO_i) \) and \( \text{avg}(AO_i) \) are computed by “propagating” appropriate values across resolutions

- Avoid underestimating AO by ensuring \( AO_{final} \geq \max(AO_i) \)

- And a plausible heuristic \( AO_{final} \propto \text{avg}(AO_i) \)
MSSAO
Temporal Filtering

\[ AO_{\text{curr}} = k \ AO_{\text{prev}} + (1 - k) \ AO_{\text{final}} \]
Results
Quality

Blizzard [FM08]  MSSAO
Results
Quality

HBAO [BSD08]  MSSAO
Results
Quality

VAO [SKUT10]  MSSAO
Results

Ground-truth Comparison

Blender

MSSAO
Results
Noise/Blur

Blizzard [FM08]  HBAO [BSD08]  MSSAO
Results
Multiple AO Scales

Small AO radius
Large AO radius
MSSAO
Results
Performance

- Scenes rendered at 1024x1024 on GeForce GTX 460M
- Exclusive of geometry pass
- The same parameters used to produce the shown images

<table>
<thead>
<tr>
<th>Scene</th>
<th>MSSAO</th>
<th>VAO</th>
<th>Blizzard</th>
<th>HBAO</th>
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</thead>
<tbody>
<tr>
<td>Sibenik Cathedral</td>
<td>21.9  ms</td>
<td>22.9</td>
<td>25.7</td>
<td>50.1</td>
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<td>Conference Room</td>
<td>24.0  ms</td>
<td>24.8</td>
<td>24.9</td>
<td>49.5</td>
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<td>Sponza Atrium</td>
<td>22.2  ms</td>
<td>24.0</td>
<td>28.9</td>
<td>54.3</td>
</tr>
</tbody>
</table>
MSSAO
Conclusions

- Inaccurate
  - Local AO
  - Over/underestimated AO
- Low quality
  - Noise
  - Blur
- Use more memory
- Poor temporal coherence on very thin geometry
  - Not too noticeable
- Errors due to the use of coarse resolutions
  - Not too noticeable unless compared with ground-truths

- Simple
- Fast
- General
- Easy to integrate
- Capture multiple shadow frequencies
Results
Additional Results
Results
Additional Results
Results

Additional Results
Results
Additional Results
Thank You