# *VGP353 – Week 9*

- Agenda:
  - SSAO:
    - Bilateral filtering
    - Horizon-based AO
    - Multi-layer dual-resolution SSAO

# *Bilateral Filtering*

- Special filter that blurs pixels that are near each other

$$A_p = \frac{1}{k(p)} \sum_{p' \in \Omega} g_d(p' - p)\, g_r(A_p - A_{p'})\, A_{p'}$$

  - $g_d$ sets the filter weight based on the image space distance
    - This is the usual Gaussian filter coefficients
  - $g_r$ sets the filter weight based on the distance between the pixel *values*

# Bilateral Filtering

- Special filter that blurs pixels that are near each other

$$A_p = \frac{1}{k(p)} \sum_{p' \in \Omega} g_d(p' - p)\, g_r(A_p - A_{p'})\, A_{p'}$$

  - $k(p)$ is a normalization term:

$$k(p) = \sum_{p' \in \Omega} g_d(p' - p)\, g_r(A_p - A_{p'})$$

# *Bilateral Filtering*

- What does this do?

# *Bilateral Filtering*

- What does this do?
  - Maintains large, high-frequency elements
    - In other words, edges
  - Smooths noise in other areas

# *Bilateral Filtering*

- How is this useful in post-processing 3D images?

# *Bilateral Filtering*

- How is this useful in post-processing 3D images?
  - If we change the definition of $g_r$, we can prevent filtering across geometric edges
  - Have $g_r$ return 0 if the parameter is above some threshold or 1 otherwise

$$A_p = \frac{1}{k(p)} \sum_{p' \in \Omega} g_d(p' - p)\, g_r(Z_p - Z_{p'})\, A_{p'}$$

# Bilateral Filtering

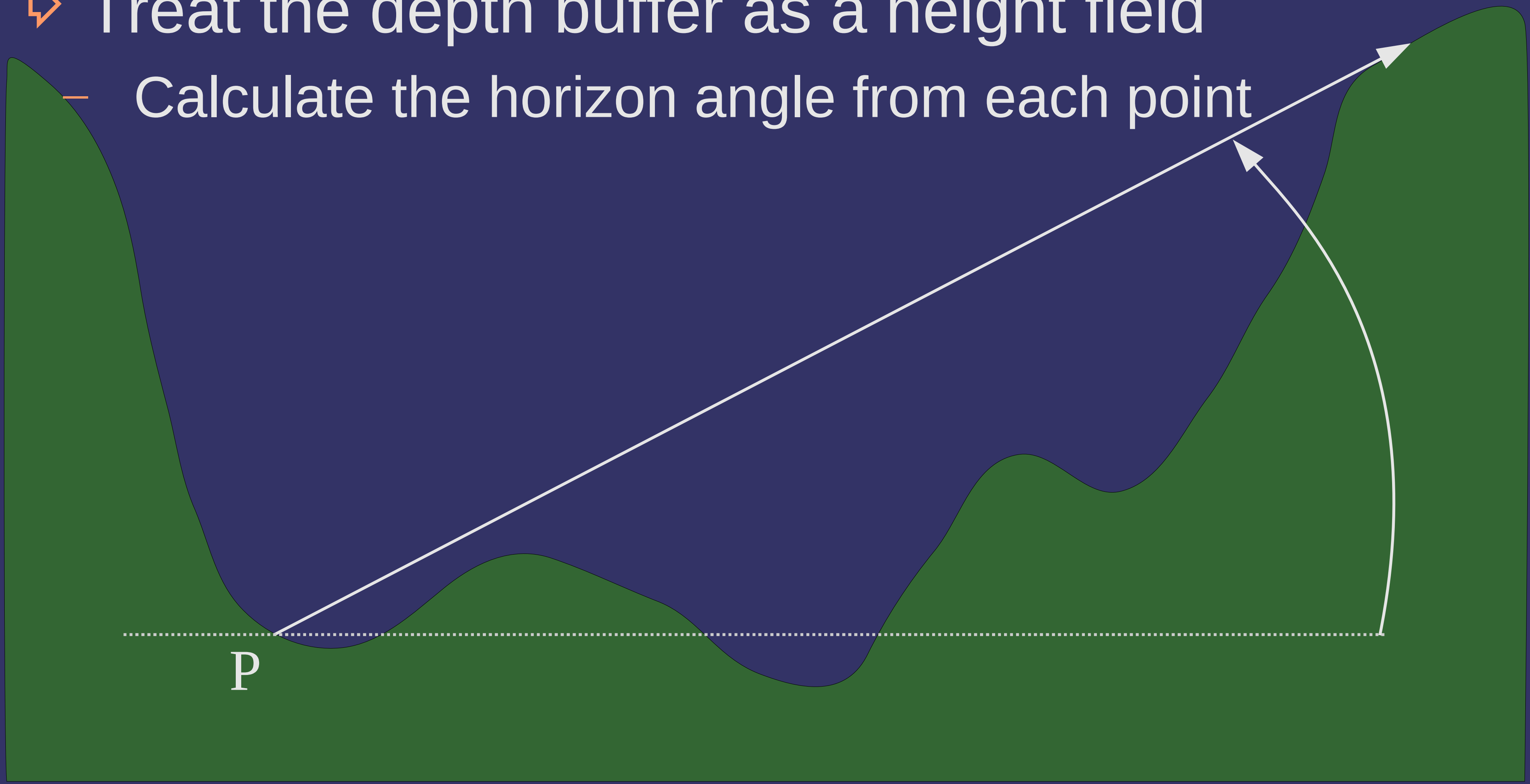
- Is this a separable filter?
  - Technically it isn't due to the $g_r$ term
  - Many uses of bilateral filter can treat it as separable without noticeable side-effects
    - SSAO being one of those uses!

# Reference

Petschnigg, G., Szeliski, R., Agrawala, M., Cohen, M., Hoppe, H., and Toyama, K. 2004. Digital photography with flash and no-flash image pairs. ACM Trans. Graph. 23, 3 (Aug. 2004), 664-672. http://research.microsoft.com/en-us/um/people/hoppe/flash.pdf

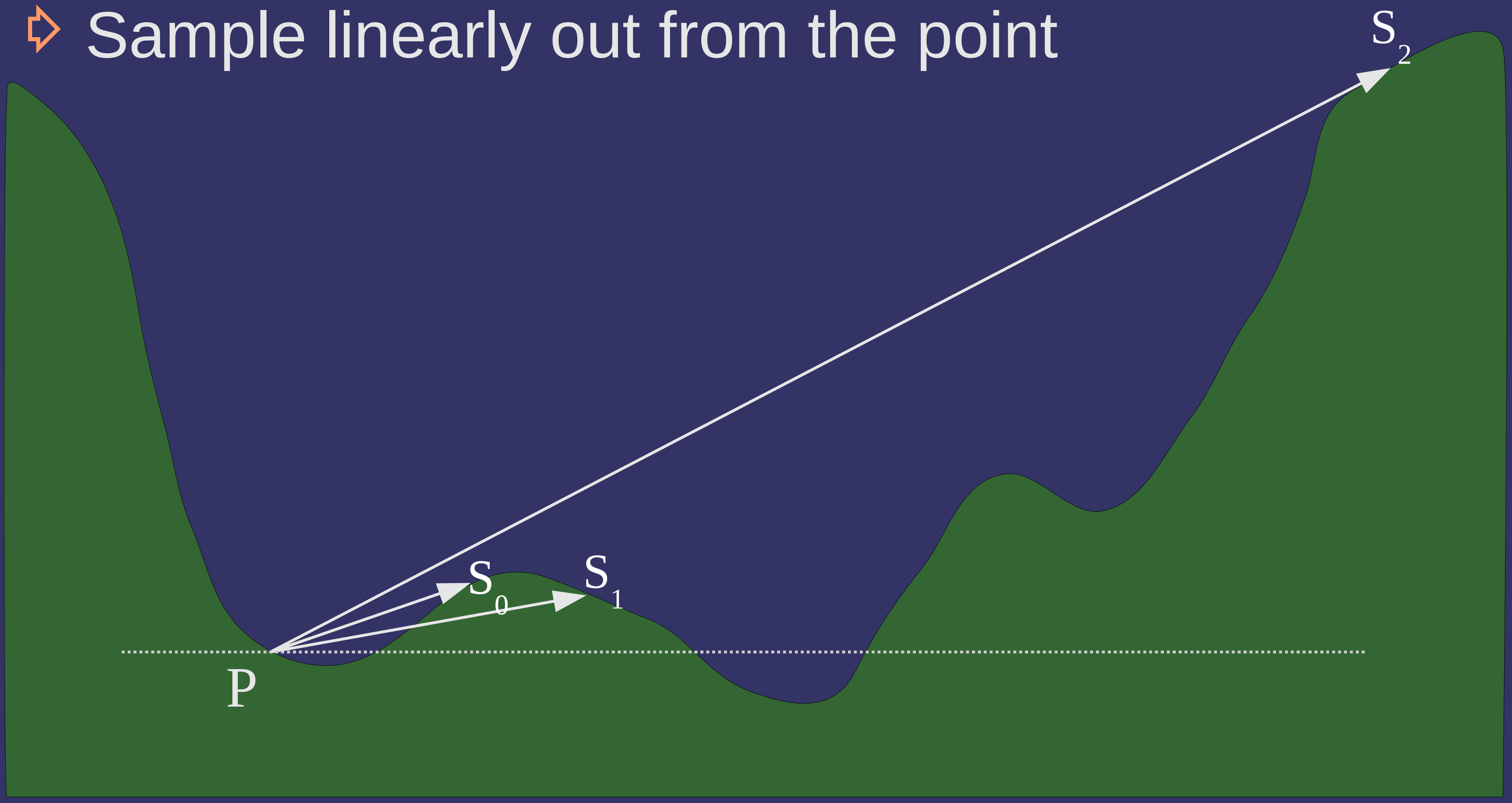
# Horizon-Based AO

- Treat the depth buffer as a height field
  - Calculate the horizon angle from each point



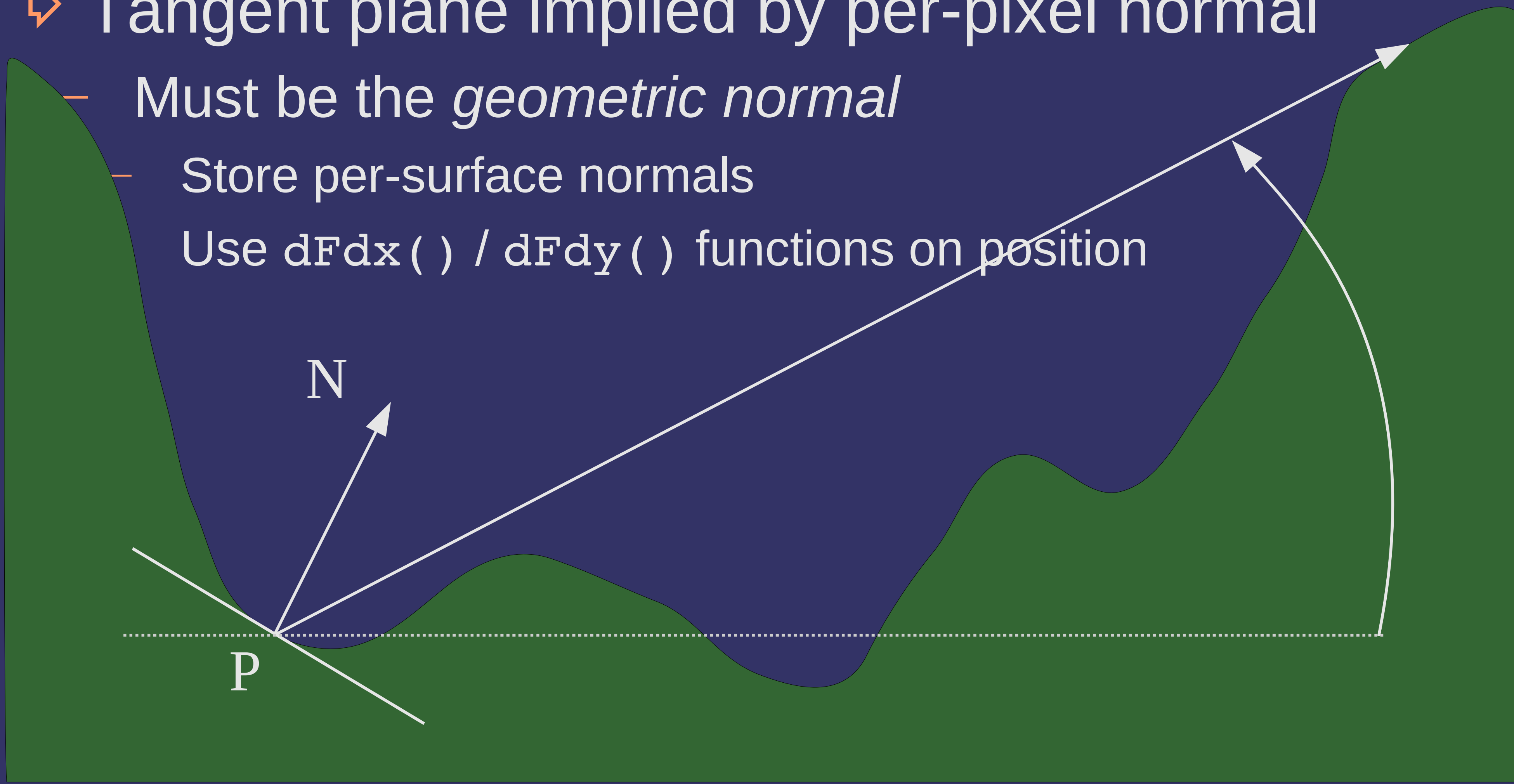
# Horizon-Based AO

- Sample linearly out from the point



# *Horizon-Based AO*

- Tangent plane implied by per-pixel normal
  - Must be the *geometric normal*
    - Store per-surface normals
    - Use `dFdx()` / `dFdy()` functions on position



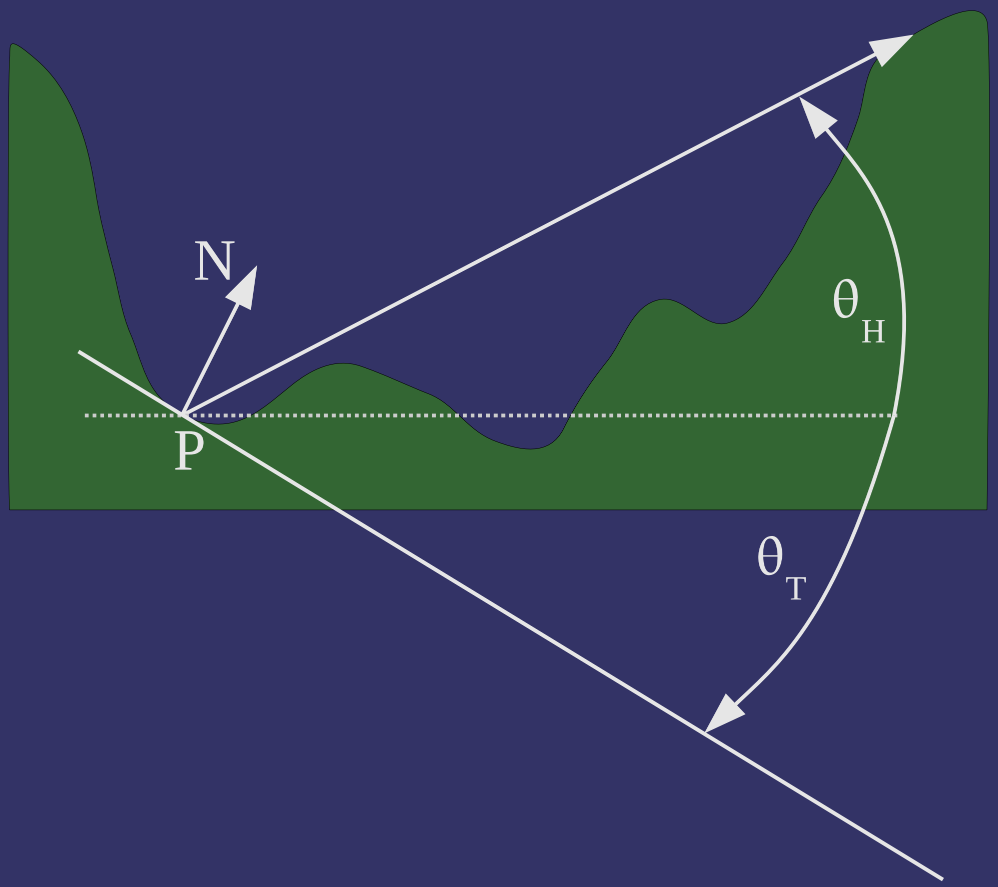
# Horizon-Based AO

- Calculate two angles:
  - Horizon angle:

$$\theta_H = atan\left(\frac{H_z}{|H_{xy}|}\right)$$

  - Tangent angle:

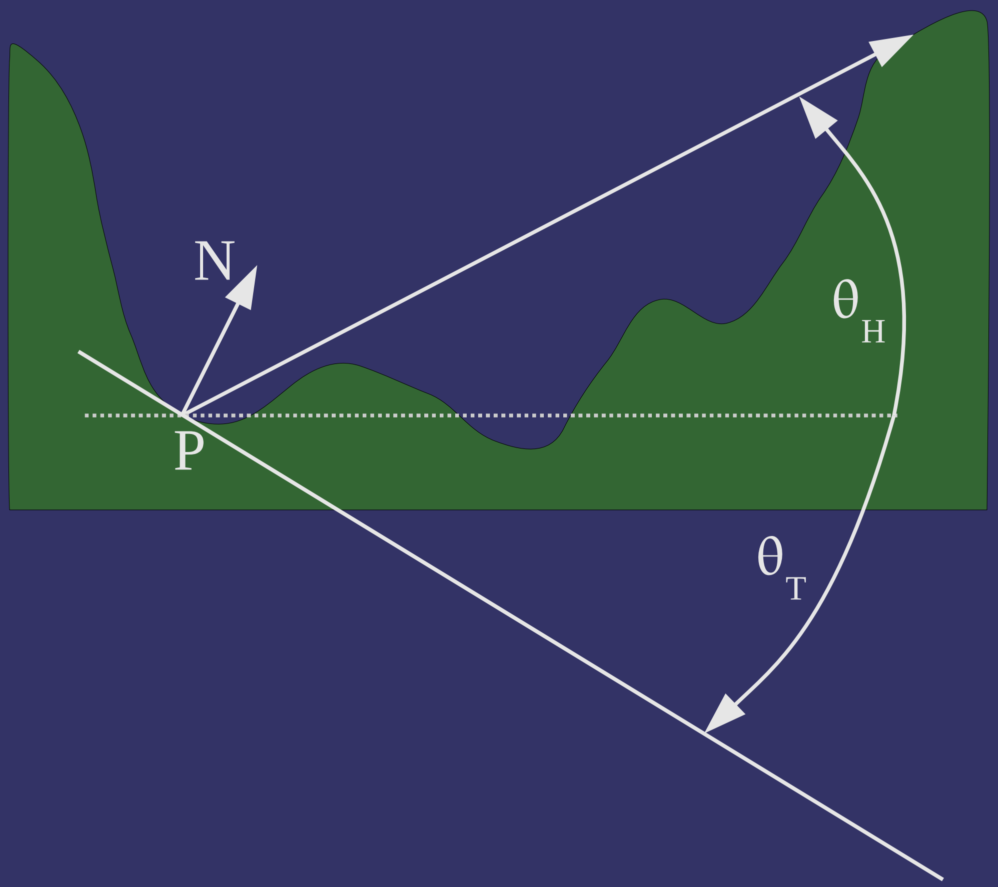
$$\theta_T = atan\left(\frac{T_z}{|T_{xy}|}\right)$$



# Horizon-Based AO

- Calculate AO from those angles:

$$AO = \sin\theta_H - \sin\theta_T$$



# Horizon-Based AO

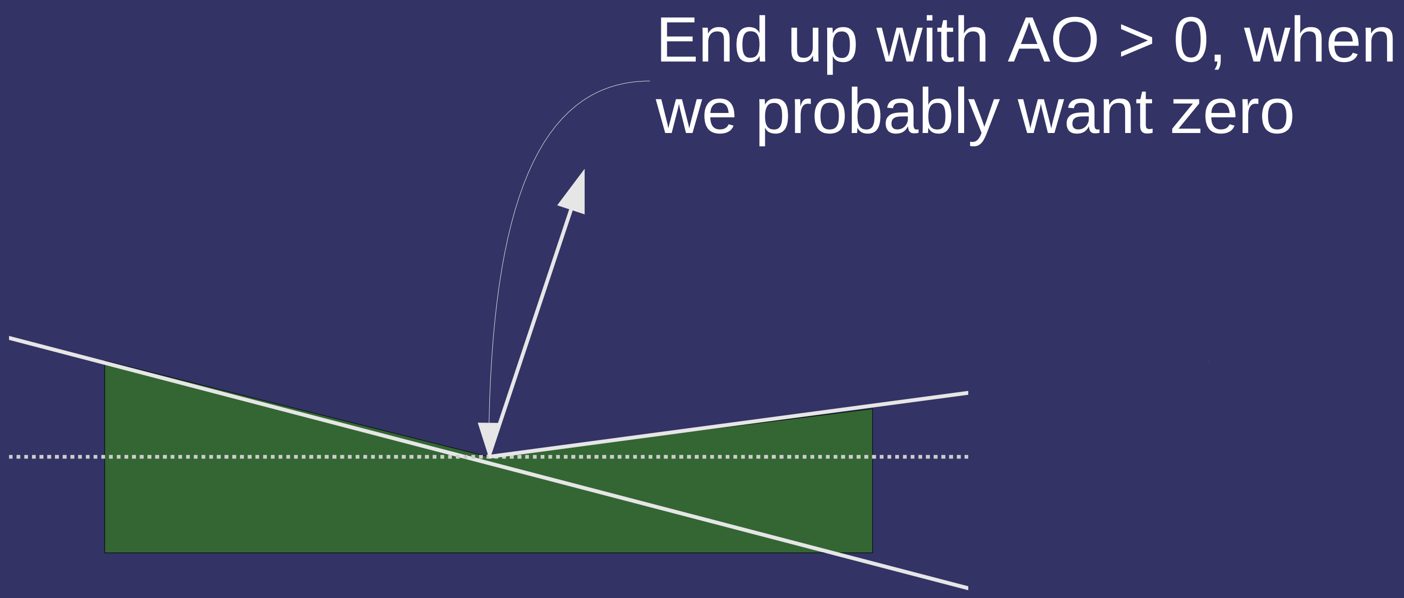
- Sampling is in screen space, but ray tracing is typically done in object space
  - Calculate a sphere in eye space
  - Project that sphere into screen space
  - Use this to set the filter radius

# *Horizon-Based AO*

- Sample from the point in a few uniformly spaced directions
  - Four directions of the compass work well
  - As usual, randomize sampling per-pixel
    - Rotate sampling directions
    - Jitter samples off the true sample direction

# Horizon-Based AO

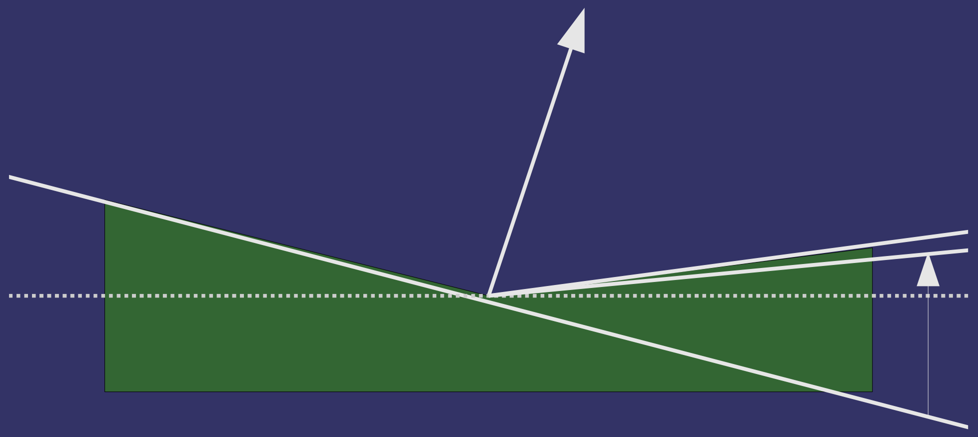
- Can get over-shadowing in curved areas due to too little tessellation



# Horizon-Based AO

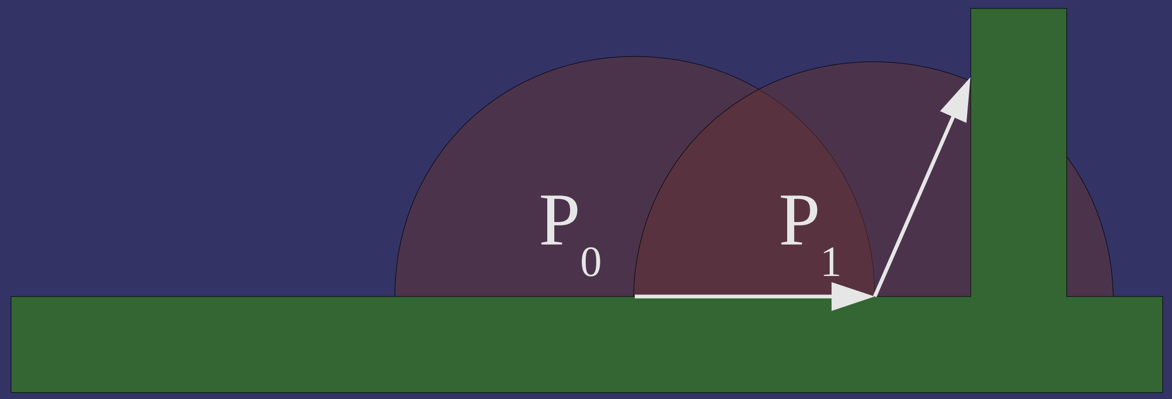
- Can get over-shadowing in curved areas due to too little tessellation
  - Fix this by setting an angle bias on $\theta_T$

$$AO = \sin\theta_H - \sin\left(\theta_T + \theta_{bias}\right)$$



# Horizon-Based AO

- Discontinuities between neighboring pixels
  - Consider $P_0$ and $P_1$:
    - $P_0$ has 0 occlusion
    - $P_1$ has a very high occlusion



# Horizon-Based AO

- Use a per-sample attenuation factor:

$$r = \frac{|S - P|}{R}$$

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

  - $P$ is the position of the point being calculated
  - $S$ is the position of the sample
  - $R$ is the sampling radius

# Horizon-Based AO

- Modify update algorithm using per-sample attenuation factor:

```
WAO = 0;    // Weighted ambient occlusion
AO_prev = 0;
horizon_prev = 0;

For all samples:
    If (horizon > horizon_prev)
        AO = sin(horizon) – sin(tangent);
        WAO += W(S)(AO – AO_prev);
        horizon_prev = horizon;
        AO_prev = AO;
```

# References

Bavoil, L., Sainz, M., and Dimitrov, R. 2008. Image-space horizon-based ambient occlusion. In *ACM SIGGRAPH 2008 Talks* (Los Angeles, California, August 11 - 15, 2008). SIGGRAPH '08. ACM, New York, NY, 1-1. http://developer.nvidia.com/object/siggraph-2008-HBAO.html

Note: There is a pending patent application for this technique. http://www.faqs.org/patents/app/20090153557

# SSAO Problems

- Several problems with SSAO:
  - Lots of pixels to process and filter – slow
  - Missing depth information – over or underocclusion
    - This occurs because we only know the nearest depth value at each X/Y location
  - Missing information at borders – underocclusion at edges

# *Multi-Layer*

- Render enlarged, depth-peeled layers
  - Clamp filter kernel size with a parameter $B$
  - Render layers of $W \times H$ as $(W+B) \times (H+B)$
  - Enlarge the view frustum to cover this new area

# *Multi-Layer*

- Calculate maximum AO from multiple layers
  - At each sample location determine which layer gives the maximal AO, use just that layer
- How many layers?
  - [Bavoil & Sainz 2009] suggest that 3 is *usually* good enough
  - They note that surfaces at grazing angles to the view rays (e.g., ground planes) can cause problems

# SSAO Problems

- Several problems with SSAO:
  - Lots of pixels to process and filter – slow
  - ~~Missing depth information – over or underocclusion~~
    - This occurs because we only know the nearest depth value at each X/Y location
  - ~~Missing information at borders – underocclusion at edges~~

# *Dual Resolution*

- Most AO effects are low frequency
  - Render depth and normals to half resolution buffers
  - Use bilateral filter to upscale
  - Example:
    - For a 1600×1200 display, calculate AO in a (800+B)×(600+B) buffer
    - Upscale AO buffer to 1600x1200, then apply

# *Dual Resolution*

- In some cases, AO effects aren't low frequency
  - What happens with geometry that's less than 2×2?
    - We get both temporal and spatial aliasing effects. Yuck!
- Determine which areas need more resolution
  - Compute AO variance
  - If variance is above a certain threshold, compute at full resolution

# Dual Resolution

- Variance computation is fairly expensive
  - Use (max(AO) – min(AO)) as a rough approximation
  - Compute over small kernel in half-resolution buffer
    - 3×3 or 5×5 is probably sufficient
    - If you actually calculate the minimum and maximum (instead of the difference), this is a separable filter

# *Dual Resolution*

- Based on variance, use half-resolution value or recalculate full-resolution value
  - Setting the threshold to 0 causes all values to be recalculated
  - Setting the threshold to 1 uses all half-resolution values
  - [Bavoil & Sainz 2009] suggest using 0.1

# References

Bavoil, L. and Sainz, M. 2009. Multi-Layer Dual-Resolution Screen-Space Ambient Occlusion. In *ACM SIGGRAPH 2009 Talks* (New Orleans, Louisiana, August 3 - 7, 2009). SIGGRAPH '09. ACM, New York, NY, 1-1. http://www.sci.utah.edu/~bavoil/

# Next week...

- Quiz #4
- Various algorithms:
  - “Mesh colors”
  - Improving the performance of depth peeling

Yuksel, Cem and Keyser, John and House, Donald H., "Mesh colors." ACM Transactions on Graphics, vol. 29, pages 15:1–15:11. ACM, 2010. http://www.cemyuksel.com/research/meshcolors/

Liu, Fang and Huang, Meng-Cheng and Liu, Xue-Hui and Wu, En-Hua, "Efficient depth peeling via bucket sort." In *Proceedings of the Conference on High Performance Graphics 2009*, pages 51–57. ACM, 2009. http://umir.umac.mo/jspui/handle/123456789/15580

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