Frequency Analysis and Filtering for Shadow Reconstruction

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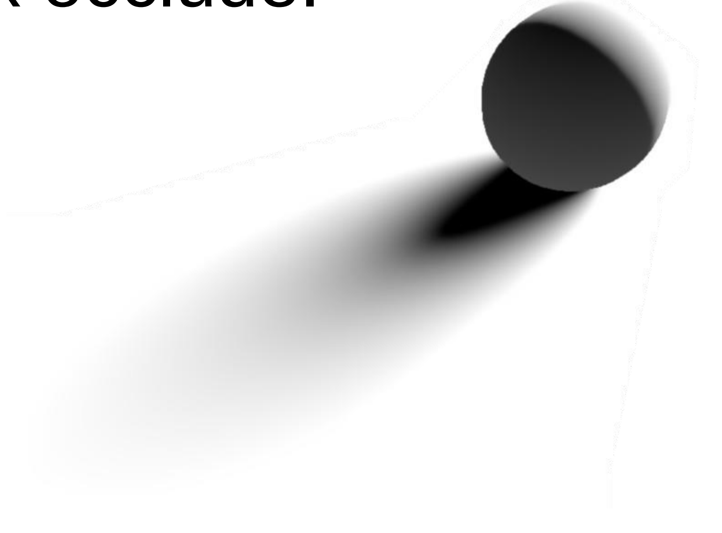
Two Papers

- Frequency Analysis and Sheared Filtering for Shadow Light Field of Complex Occluders
  - Egan, Kevin, et al. SIGGRAPH 2011

- Axis-Aligned Filtering for Interactive Sampled Soft Shadows
  - Mehta, S. U., Wang, B., & Ramamoorthi, R. SIG. Asia 2012

Motivation

- Soft shadows are a key effect in photo realistic rendering.
- However, it requires the use of a prohibitive number of shadow rays with MC method.
- Propose methods for sampling and filtering the light field from a complex occlude.



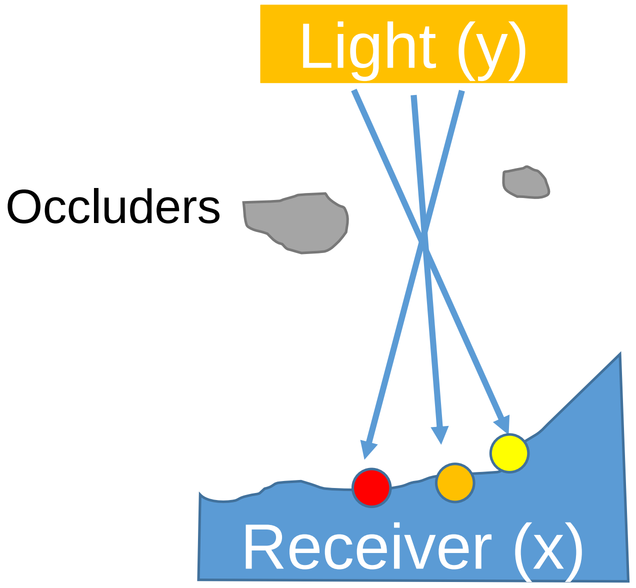
Frequency Analysis and Sheared Filtering for Shadow Light Field of Complex Occluders

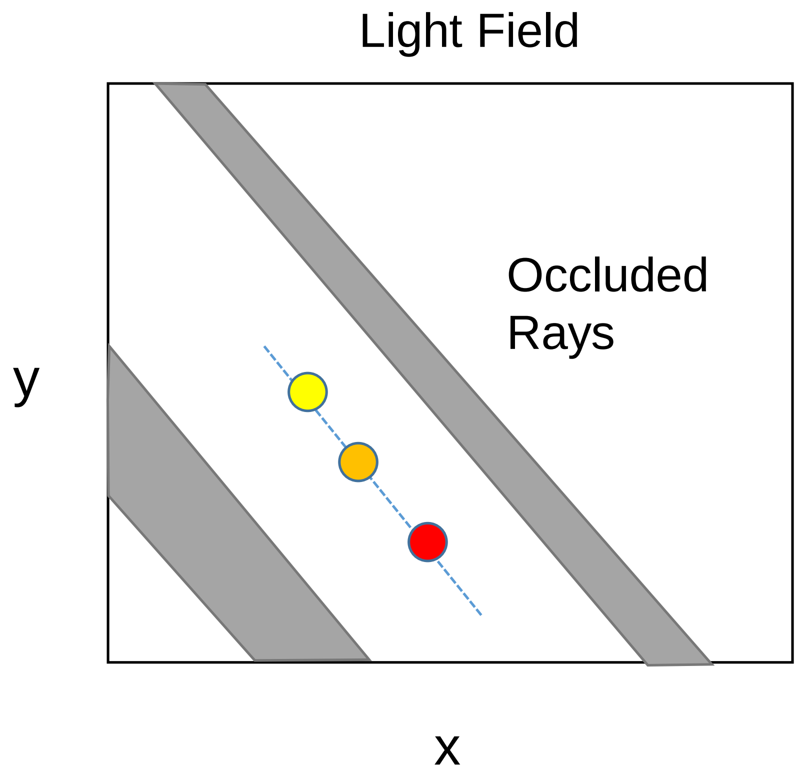
Egan, Kevin, et al. SIGGRAPH 2011

Overview

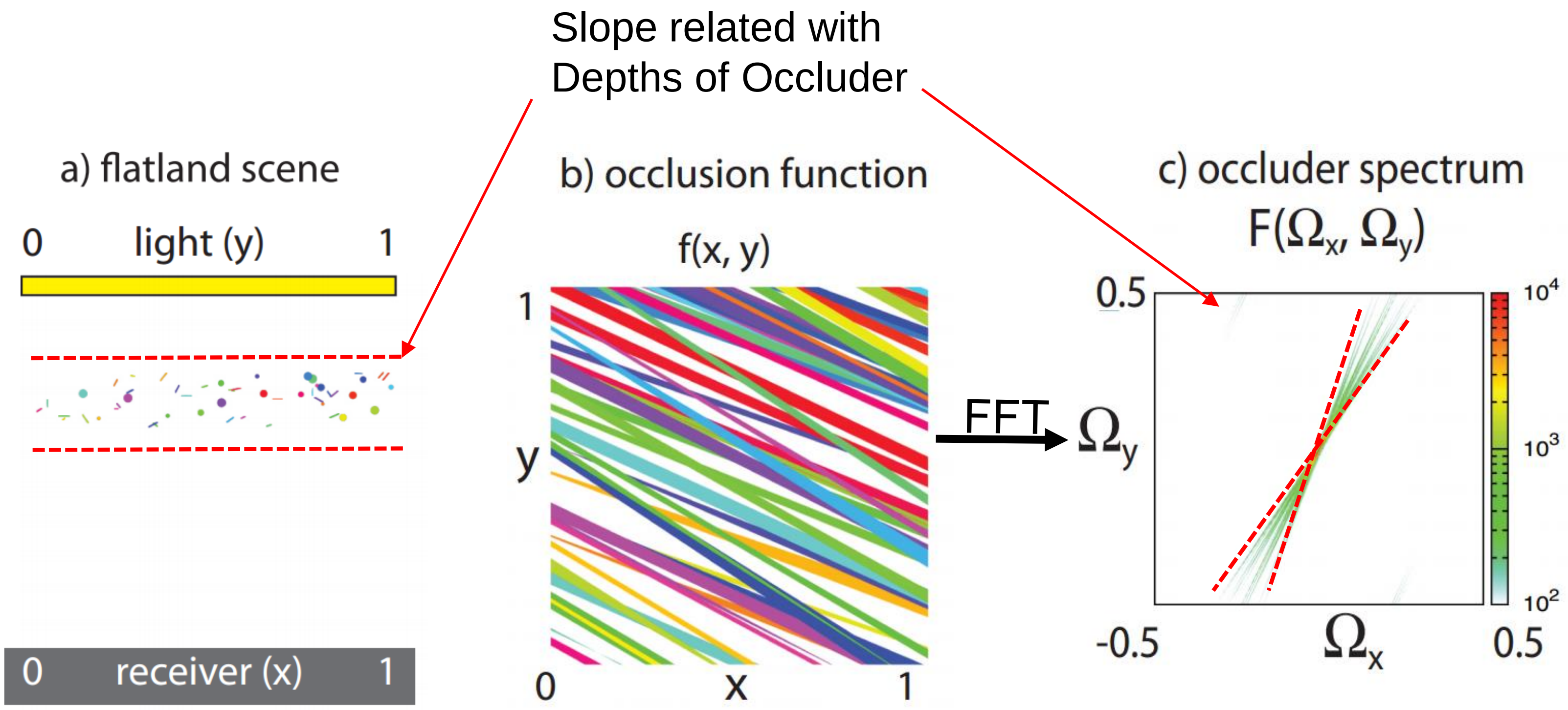
- Frequency Analysis
  - Find relation with light and occlude and an idea for sheared filter design.
- Sheared Filter
  - Share data between neighboring pixels and reduce sample count.
- System Overview

Frequency Analysis





Frequency Analysis



Frequency Analysis

- Shadow Equation

$$h(x) = r(x) \int f(x,y) l(y) dy$$

  - r(x) = BRDF(independent of shadows)
  - f(x,y) = visibility function(occlusion)
  - l(y) = the intensity of light source

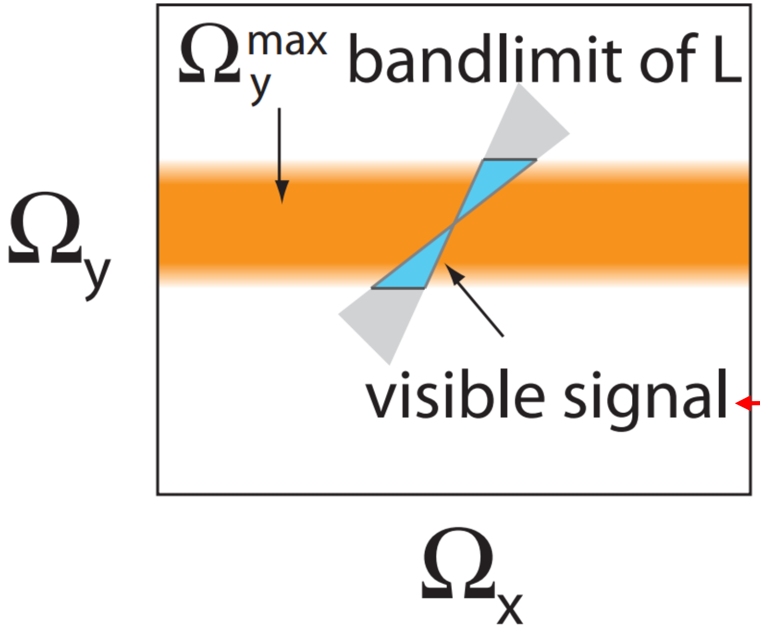
  - With some derivation from [Soler and Sillion 1998]

$$H(\Omega_x) = \left(\frac{d_1}{d_2}\right) G\left(\frac{d_1}{d_2}\Omega_x\right) L\left(\left[1 - \frac{d_1}{d_2}\right]\Omega_x\right)$$

Simple multiplication in the frequency domain
(= a convolution of occludes by light in the spatial domain)

Frequency Analysis

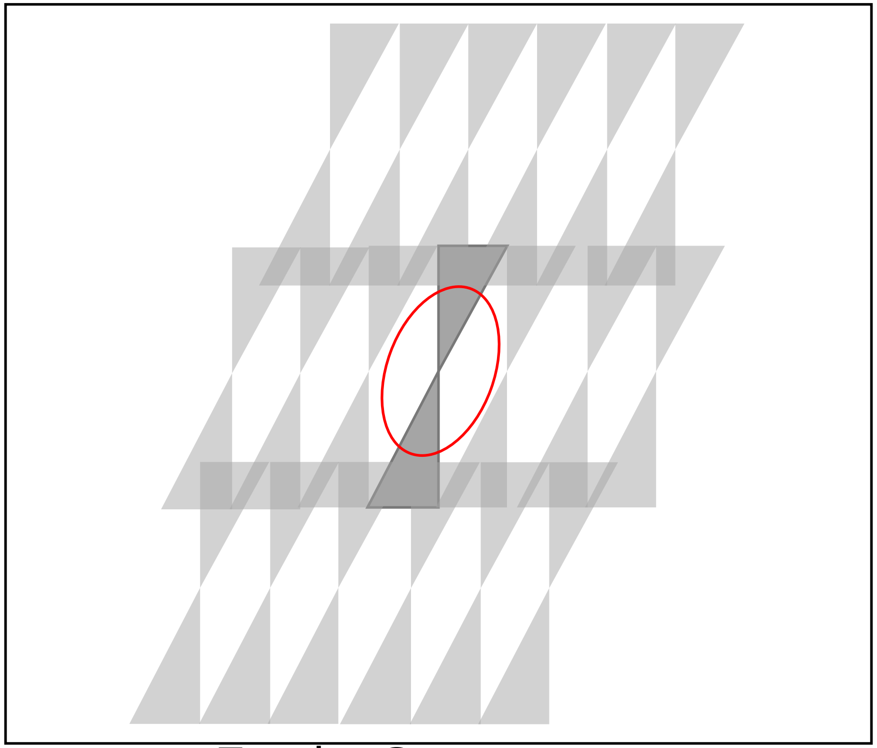
- Convolution
  - Multiplication in frequency domain



Should be considered in sheared filter

Sheared Filter

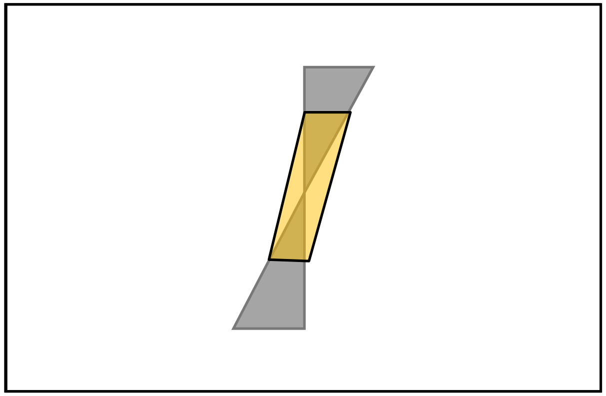
- Filtering Issue
  - Sparse sampling makes aliasing.
  - Filtering for useful frequency



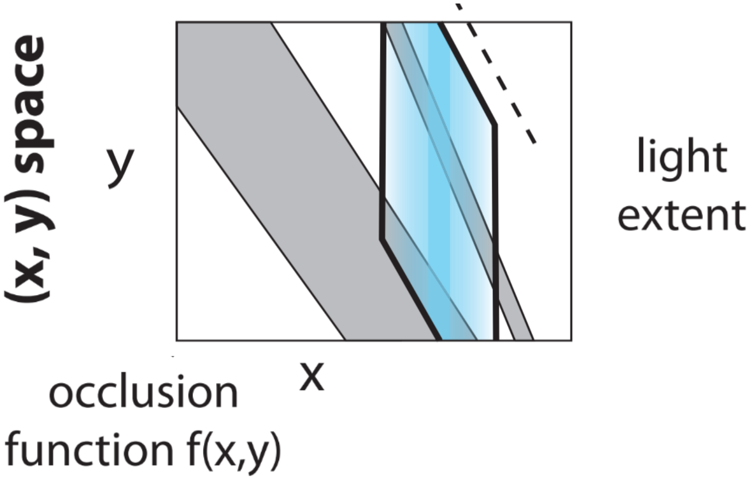
Fourier Spectrum

Sheared Filter

- Design sheared filter to be as compact as possible
  - Tight packing of replicas in the Fourier domain
  - Sparse sampling in the spatial domain

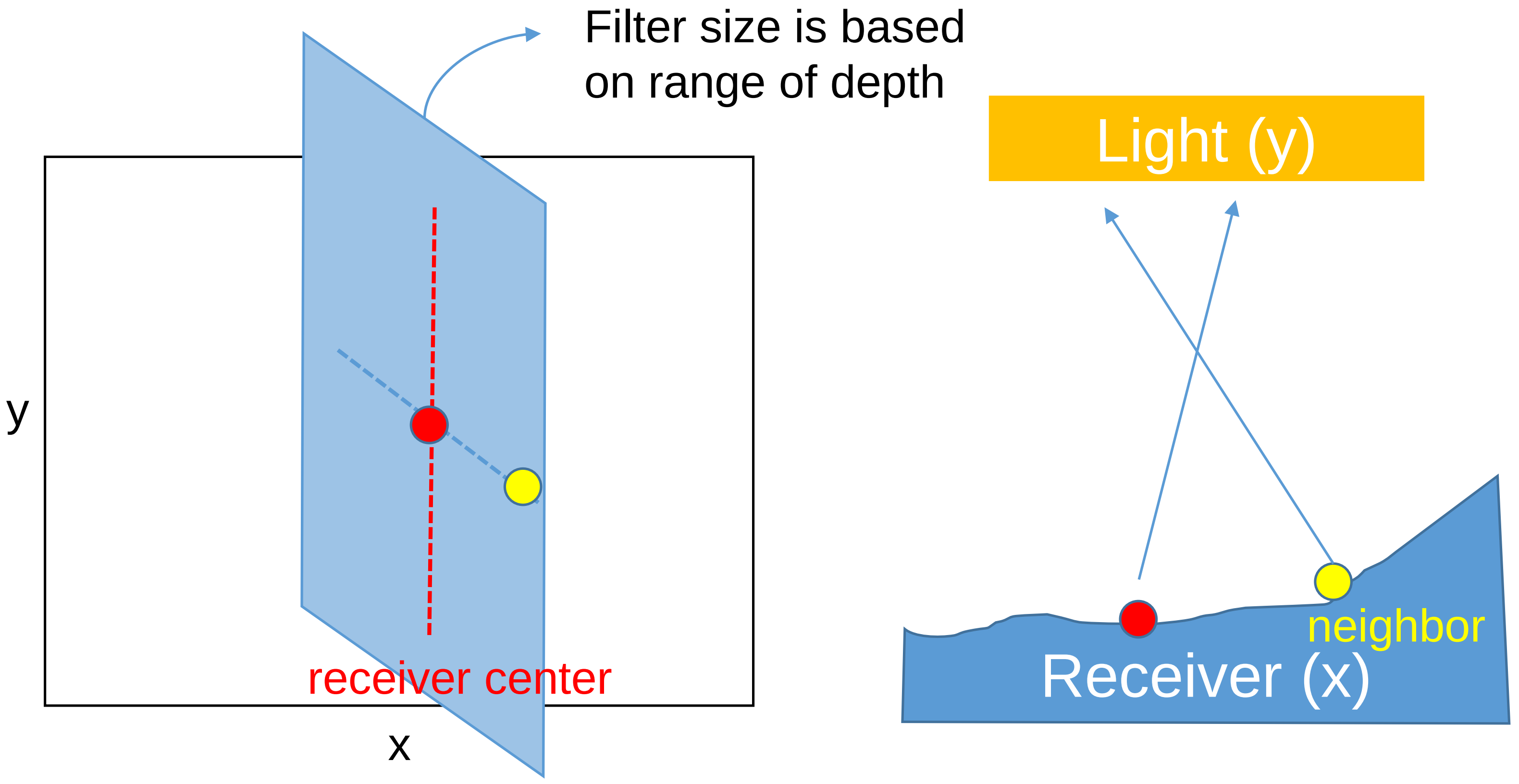


Sheared filter in Fourier spectrum



Sheared Filter

- Share data between neighboring pixels

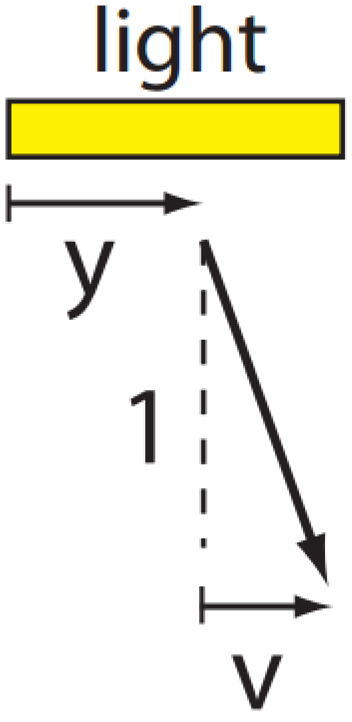


System Overview

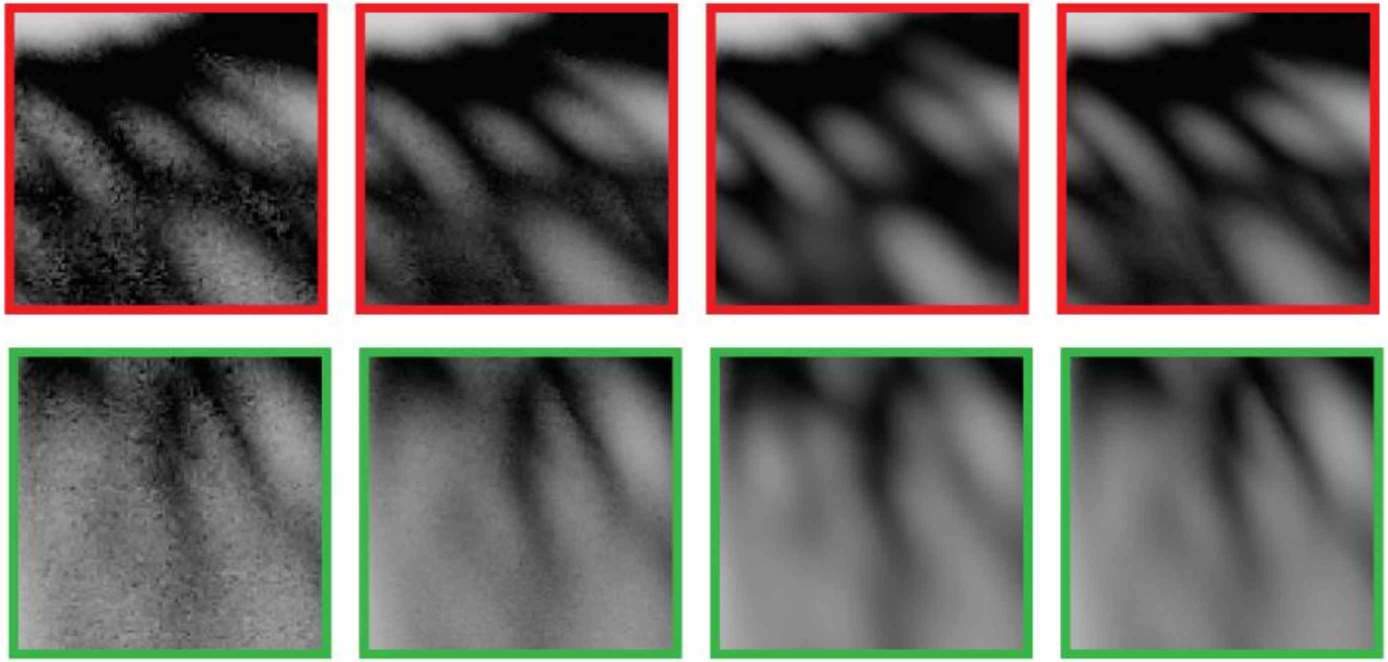
- Sparsely sample the light field using shadow rays
  - Often 1 ray per pixel
- Store all ray samples in a ray database
- Calculate the best filter shape for the each receiver with frequency analysis

*Parameterization

- To share rays across many receiver, store ray samples in a receiver-independent (v, y)
- Convert sheared filter into (v, y) space
- Analysis in flatland is easy to extend to 3D with 4 dimensions (v_1, v_2, y_1, y_2)



Result



MC
64 rpp

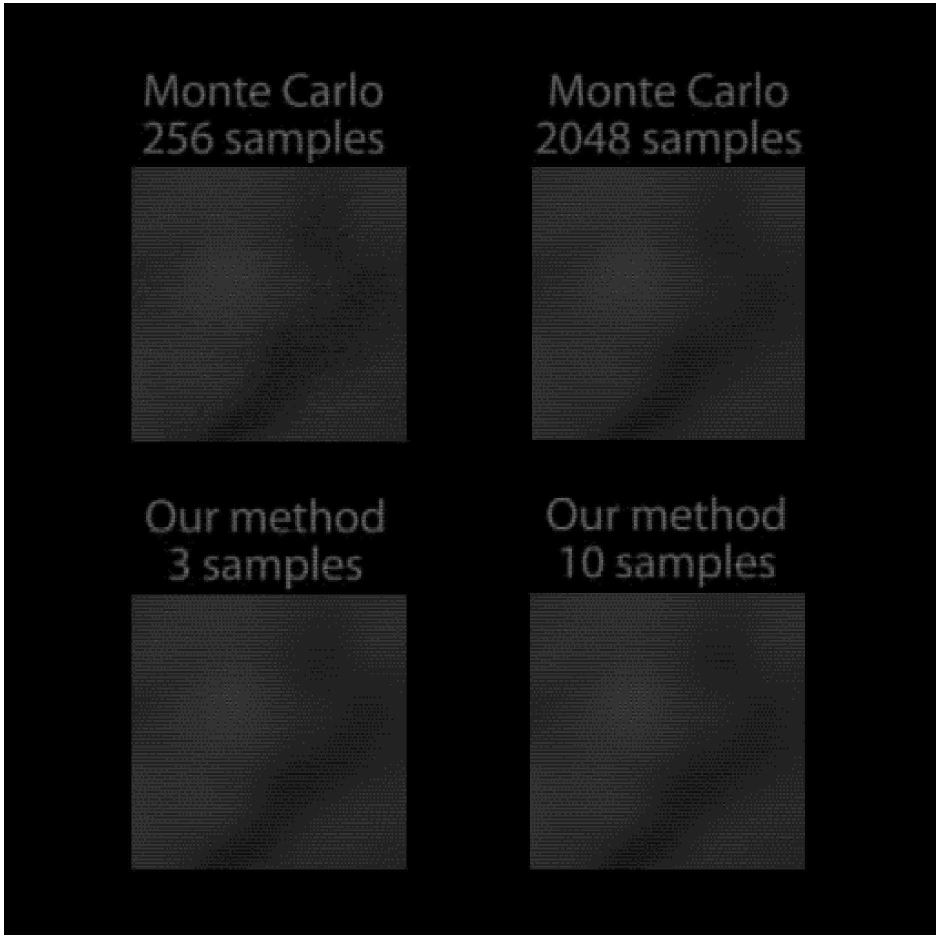
MC
320 rpp

Paper
1.0 rpp

MC
2048 rpp

Rays per pixl (rpp)

Result


Monte Carlo
256 samples
Monte Carlo
2048 samples
Our method
3 samples
Our method
10 samples

Conclusion

- Frequency analysis of complex occluders
- Sheared filter for sharing data between neighbors over 4D light field
- 100x reduction of ray casts
- 10x speedup

Axis-Aligned Filtering for Interactive Sampled Soft Shadows

Mehta, S. U., Wang, B., & Ramamoorthi, R.
SIGGRAPH Asia 2012

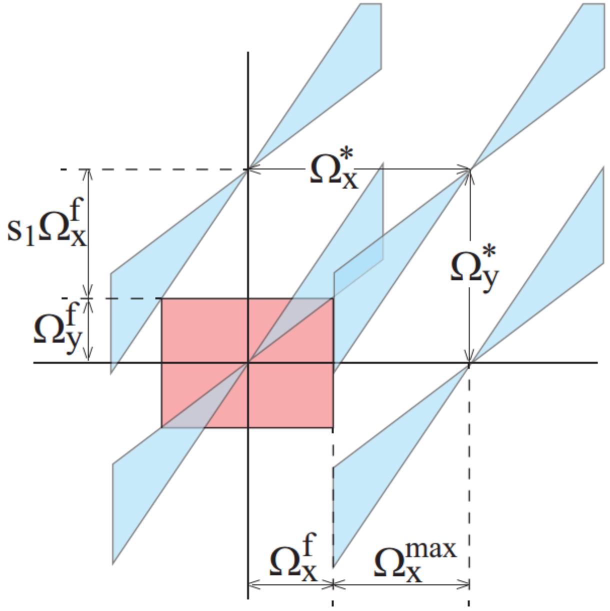
Overview

- Sheared filter method is slow(offline rendering)
- Propose method using simpler axis-aligned filter for real-time rendering.

- Adaptive Sampling
- Axis-aligned Filtering(Adaptive Filtering)

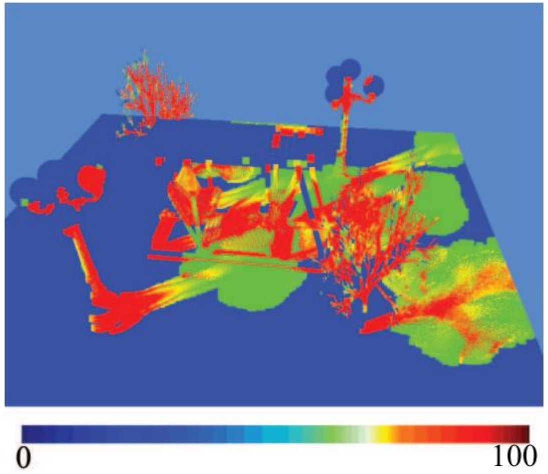
Adaptive Sampling

- Produce anti-aliasing results.
- Pack the spectra such that adjacent copies do not overlap the axis-aligned filter.



Using denser packing not makes overlap in red box

Adaptive Sampling



(b) *'Bench', spp n*

- Per-pixel Sampling Rate

$$n_{\text{axis}} = 4\left(1 + \frac{s_1}{s_2}\right)^2 \left(\Omega_{\text{x}}^f \cdot d + \alpha(1 + s_2)^{-1}\right)^2$$

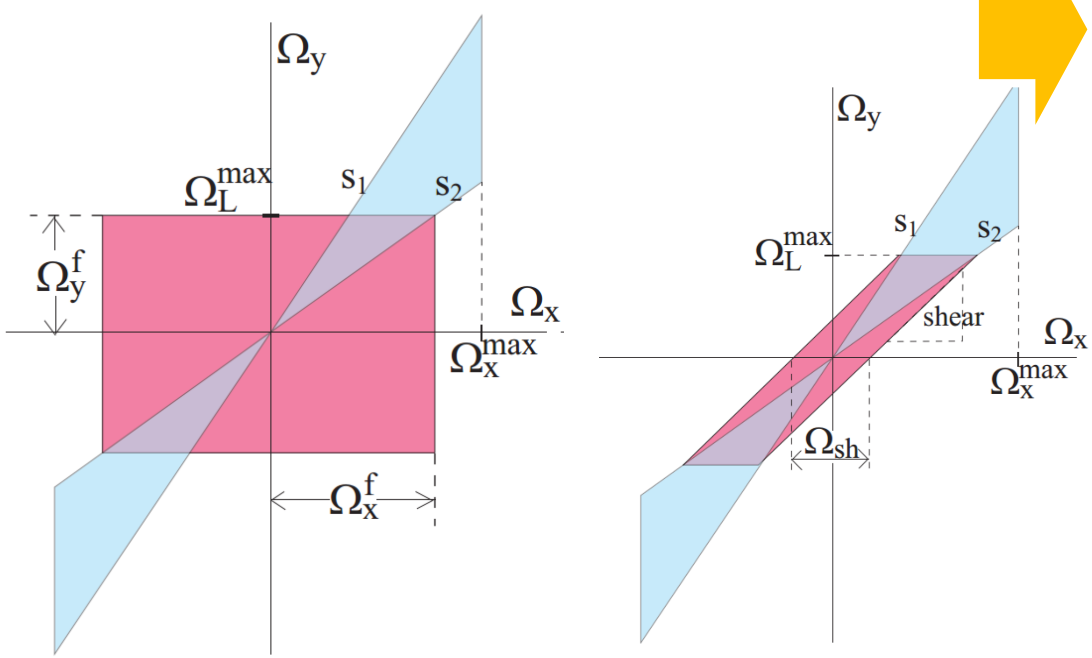
  - $n_{axis} > n_{shear}$

★ However, the reduction in Monte Carlo samples is more efficient than implementing the sheared filter with smaller samples

Axis-Aligned Filtering

- Define the axis-aligned filter in the frequency domain with bandlimits

$$\Omega_{\mathrm{x}}^{f} = \min\left[\frac{\Omega_{\mathrm{L}}^{\max}}{s_2}, \Omega_{x}^{\max}\right] \qquad \Omega_{\mathrm{y}}^{f} = \Omega_{\mathrm{L}}^{\max}$$



Advantage: Decoupling of filtering over the spatial x and light y dimensions

Axis-Aligned Filtering

- Shadow Equation

x and y dimension are treated separately.

$$h(x) = r(x) \int f(x, y) l(y) dy$$

  - Approximation with Gaussian

$$\bar{h}(x') = \int \bar{f}(x', y) l(y) dy$$

Pre-integeration

$$h(x) = \int \bar{h}(x') w(x - x'; \beta(x)) dx'$$

Spatially varying
(Adaptive filtering)

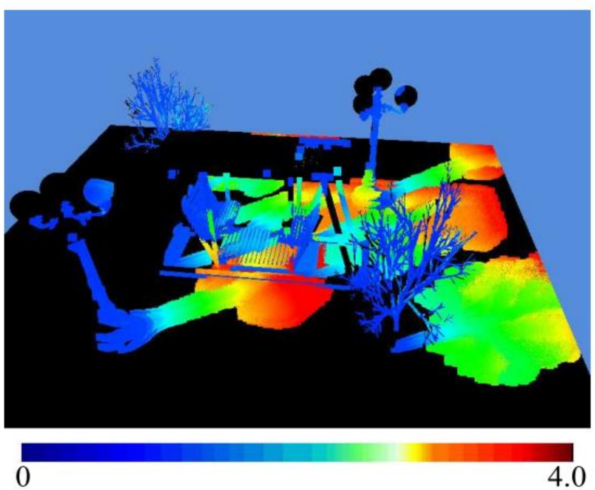
    - $\bar{h}$(x) : standard noisy visibility
      w() : the spatial domain Gaussian filters
      β(x) : standard deviation in pixel domain

Axis-Aligned Filtering

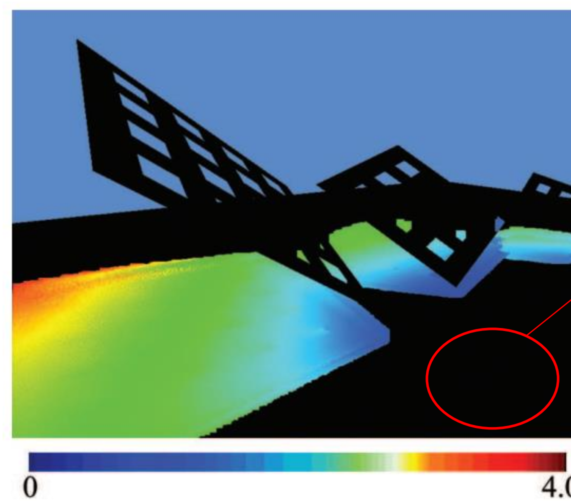
- Shadow Equation

$$h(x) = \int \bar{h}(x')w(x - x'; \beta(x))dx'$$

Spatially varying
(Adaptive filtering)



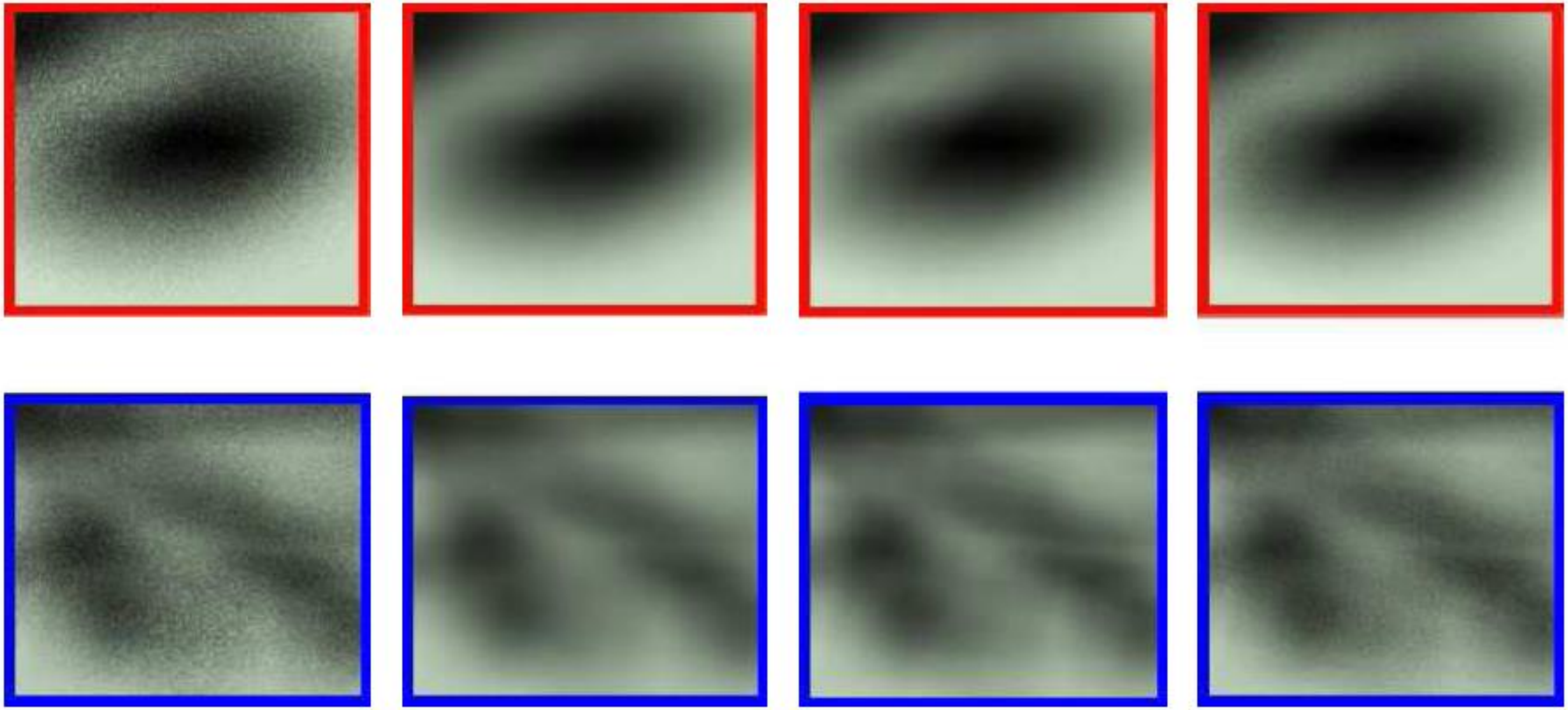
(a) *'Bench', scale β*



(c) *'Grids', scale β*

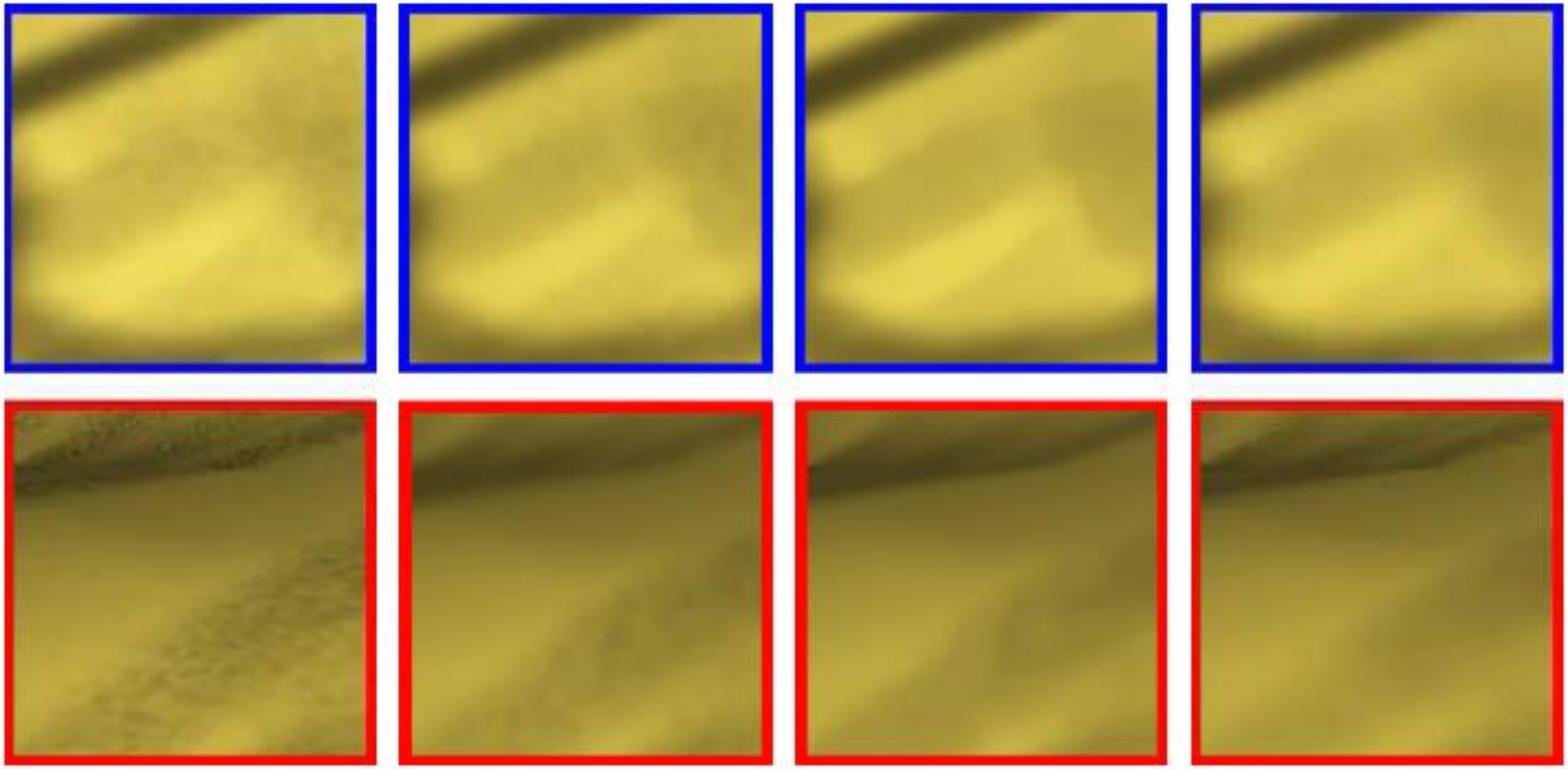
Do not consider

Result



(b) *equal time, unfiltered, 37 spp* **(c)** *our method, 37 spp* **(d)** *ground truth 4000 spp* **(e)** *equal error, unfiltered, 153 spp*

Result



(a) *fixed blur, 0.003 sec* **(b)** *bilateral filter, 200 sec* **(c)** *bm3d, 8 sec* **(d)** *our method, 0.005 sec*

Conclusion

- Adaptive sampling and adaptive filtering
- Adjust filter size for the sampling rate
- Real-time method

Thank you☺