Spatiotemporal Blue Noise Masks

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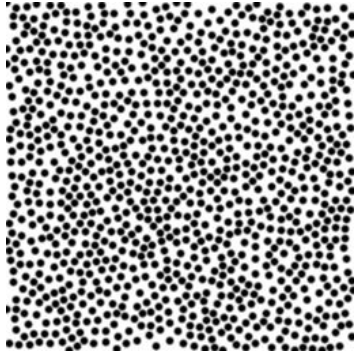
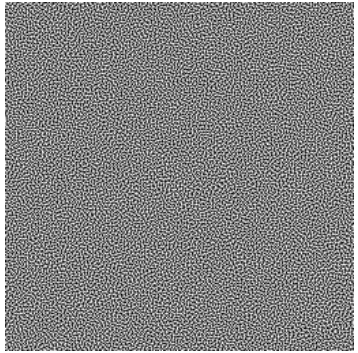
Blue Noise Samples vs. Masks

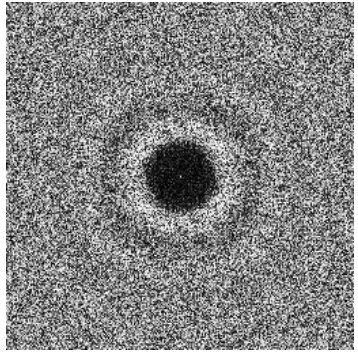
Samples



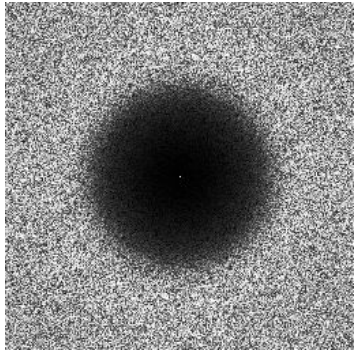
Mask

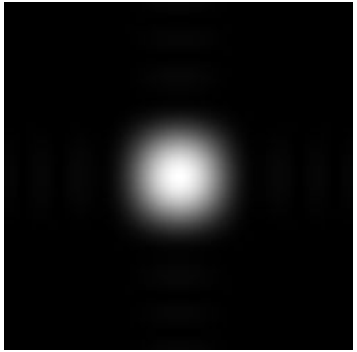


Samples DFT



Mask DFT



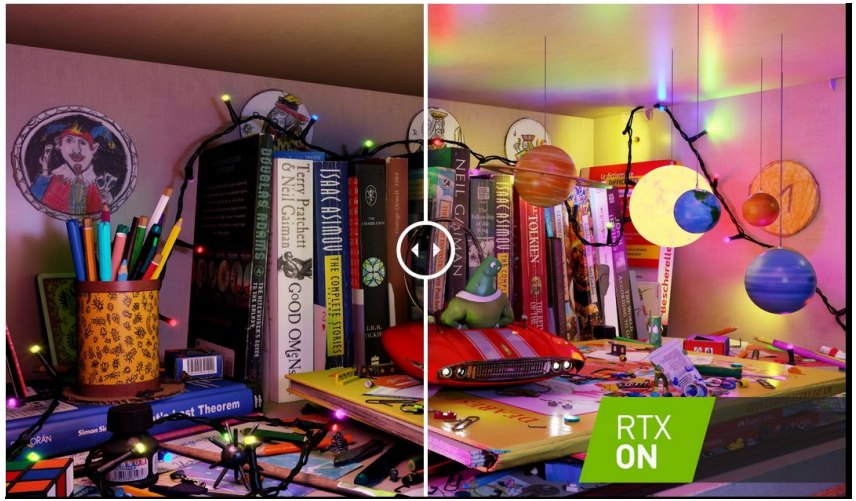


Gaussian Kernel DFT

Real Time: Always Wanting To Do More With Less

Real Time Global Illumination with RTXGI
https://developer.nvidia.com/rtx/ray-tracing/rtxgi

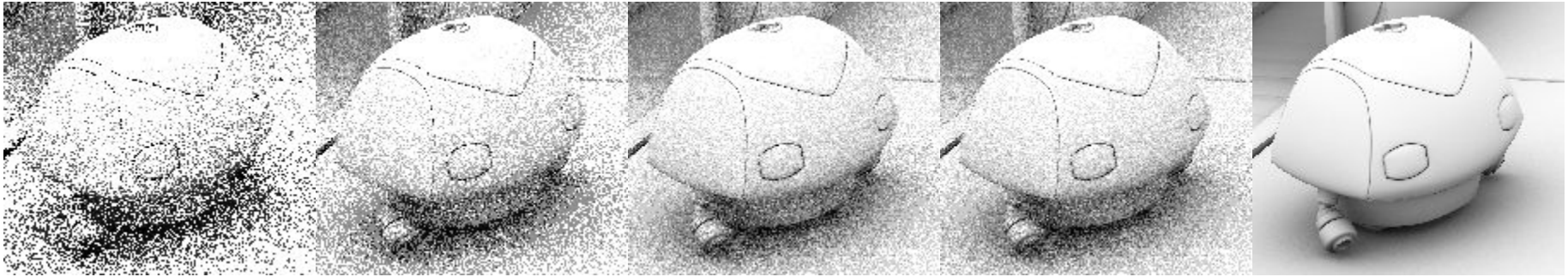
Fast probe grid GI + ray tracing probe updates



Real Time Direct Illumination with RTXDI
https://developer.nvidia.com/rtx/ray-tracing/rtxdi

Solves “many lights” direct illumination by making each pixel learn where to shoot rays for best results.

Stochastic Algorithms Allow Tuning Quality vs Speed

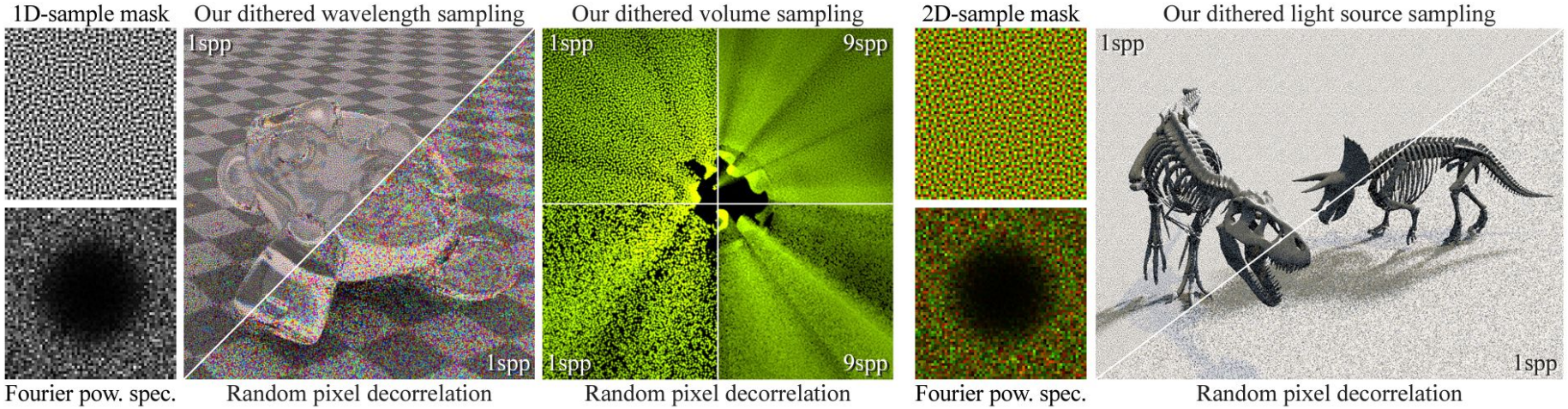


1 sample | 2 | 4 | 8 | 128

More Speed ⇦ ⇨ Higher Quality

Project PICA PICA https://www.ea.com/seed/news/seed-project-picapica

Anti Correlated Blue Noise >> Independent White Noise



“Blue-noise Dithered Sampling”, Georgiev & Fajardo, 2016

Anti Correlated Blue Noise >> Independent White Noise

White Noise Dithered

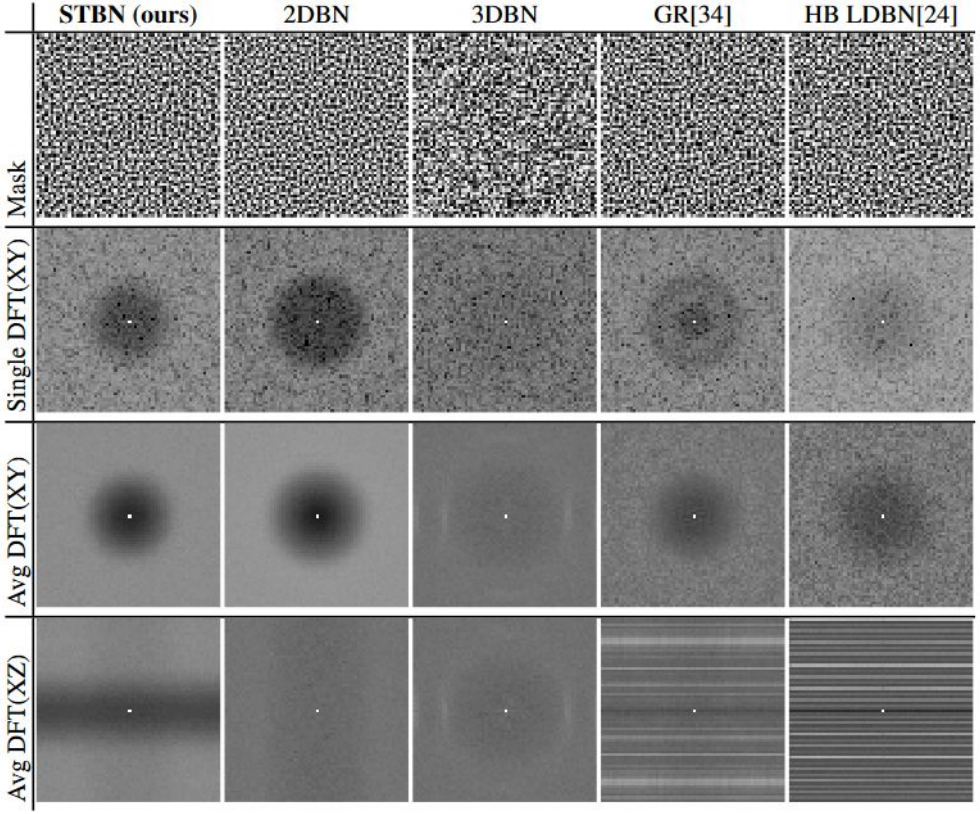
Blue Noise Dithered

1 bit per color channel, Gaussian blurred

Real Time Is Animated & Amortized Over Time

“A Survey of Temporal Antialiasing Techniques” Yang et al, 2020

Animated Blue Noise - Frequencies



Void And Cluster: Scalar Noise Algorithm

Simplified algorithm (see paper for full version):

1. Start with zero energy field
2. Place a point at the lowest energy and update energy field
3. Repeat #2 until all points are filled in
4. Order of point insertion determines pixel value (remap to texture range).

Our modified energy function:

$$E(\mathbf{p},\mathbf{q}) = \begin{cases} \exp\left(-\frac{\|\mathbf{p}-\mathbf{q}\|^2}{2\sigma^2}\right), & \text{if } \mathbf{p}_{xy} = \mathbf{q}_{xy} \text{ or } p_z = q_z \\ 0, & \text{otherwise,} \end{cases}$$

"The Void-and-Cluster Method for Generating Dither Arrays", Ulichney, 1993

Simulated Annealing: Vector Noise Algorithm

1. Initialize texture to uniform white noise vectors (*)
2. Pick 2 pixels at random, swap them if doing so improves overall energy
3. Repeat #2 until overall energy low enough, or enough swaps have occurred.

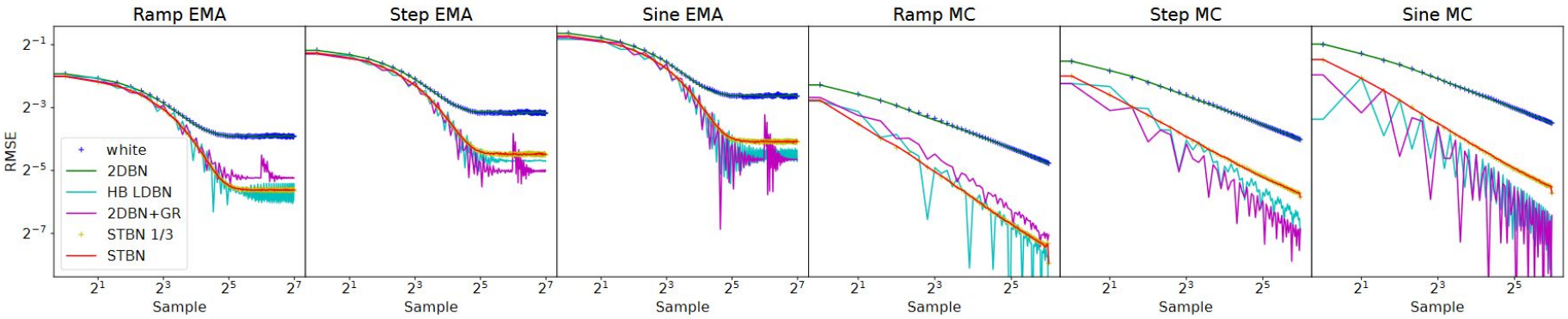
Our modified energy function:

$$E(\mathbf{p},\mathbf{q}) = \begin{cases} \exp\left(-\frac{\|\mathbf{p}-\mathbf{q}\|^2}{\sigma_i^2} - \frac{\|\mathbf{V}_p-\mathbf{V}_q\|^{d/3}}{\sigma_s^2}\right), & \text{if } \mathbf{p}_{xy}=\mathbf{q}_{xy} \text{ or } p_z=q_z \\ 0, & \text{otherwise.} \end{cases}$$

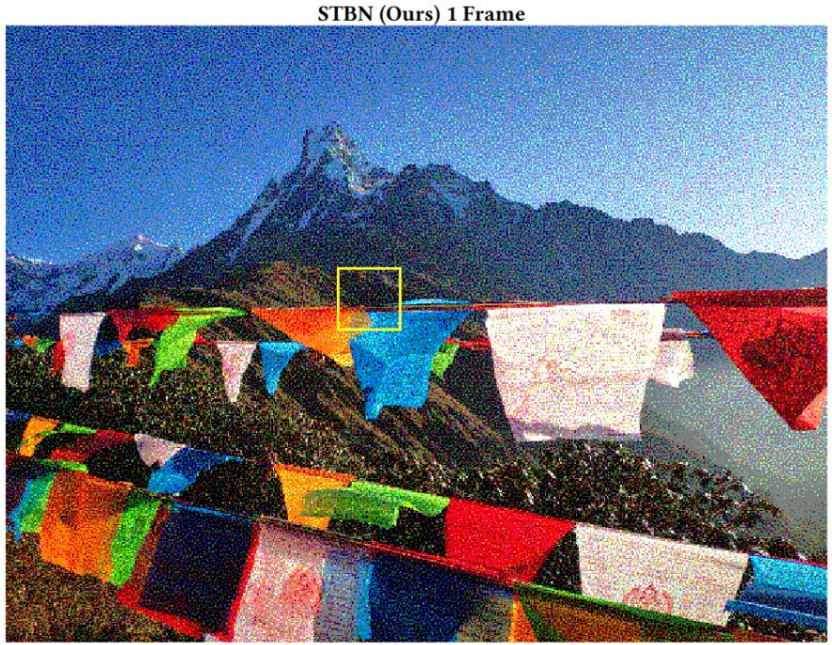
* Can use non uniform noise for importance sampled masks. More on that later!

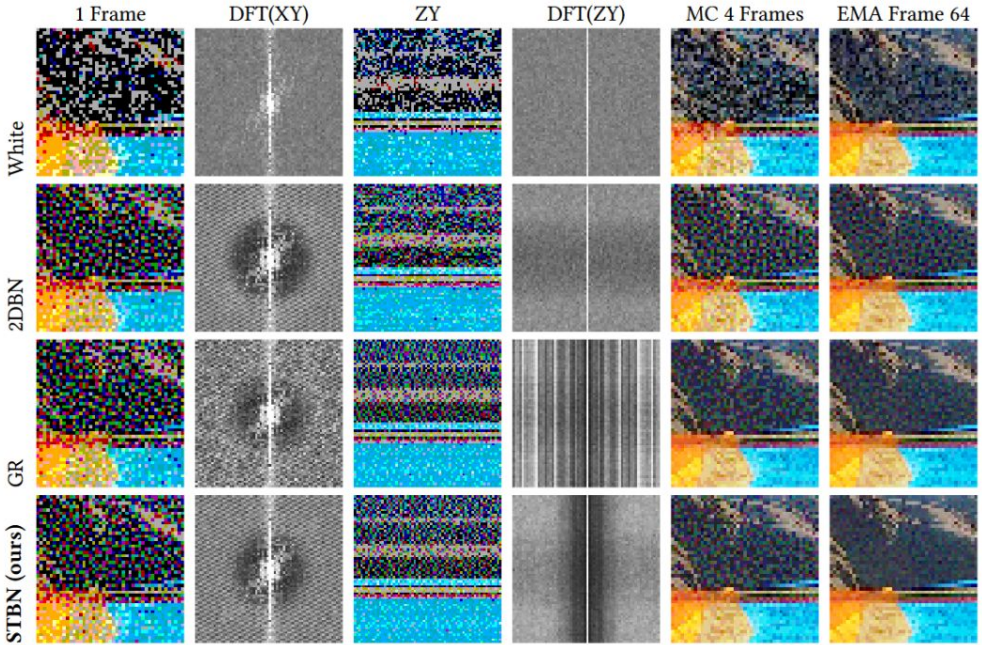
“Blue-noise Dithered Sampling”, Georgiev & Fajardo, 2016

Animated Blue Noise - Simple Function Convergence

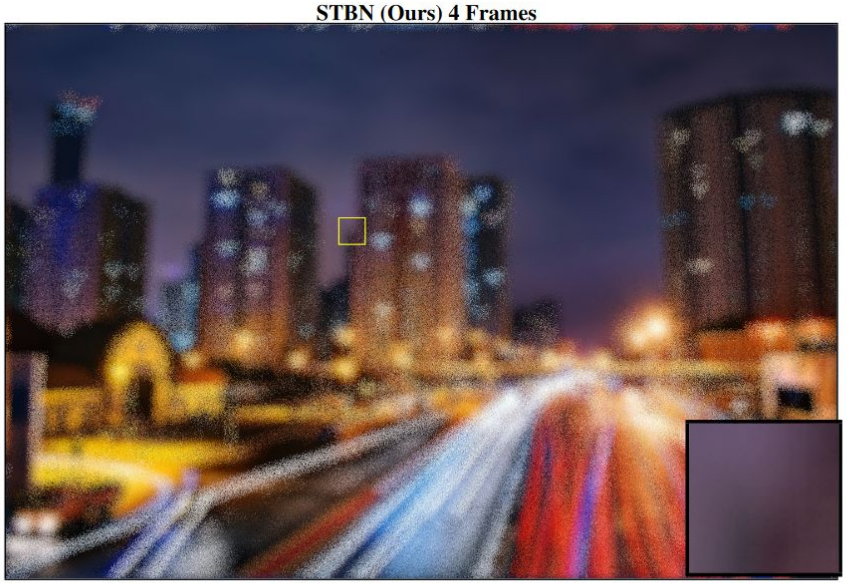


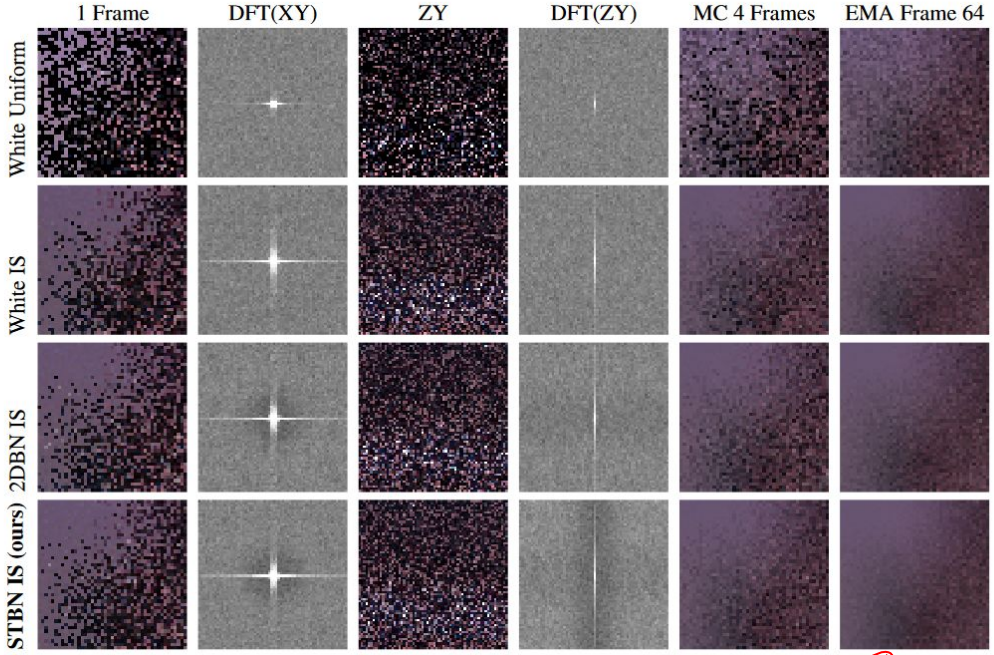
Rendered Results - Dithering



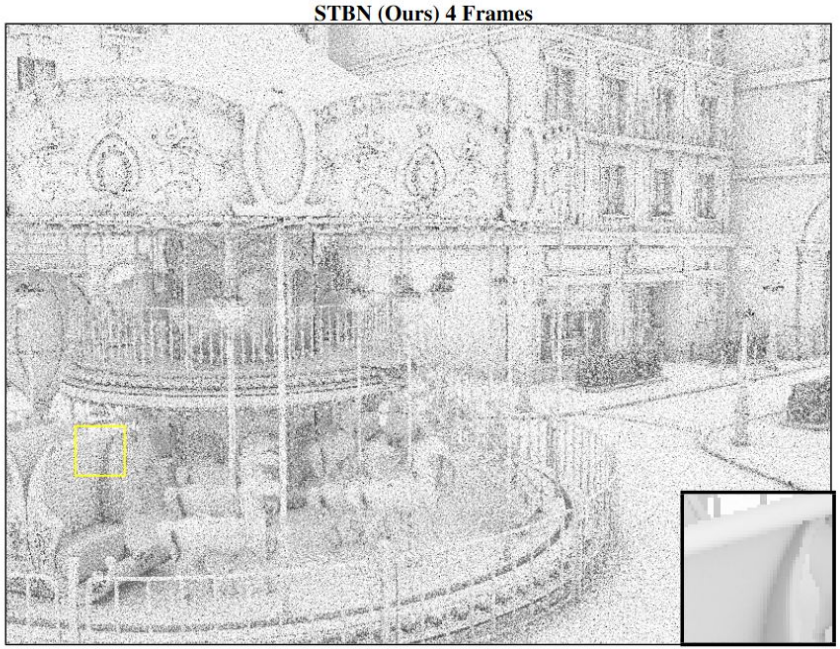


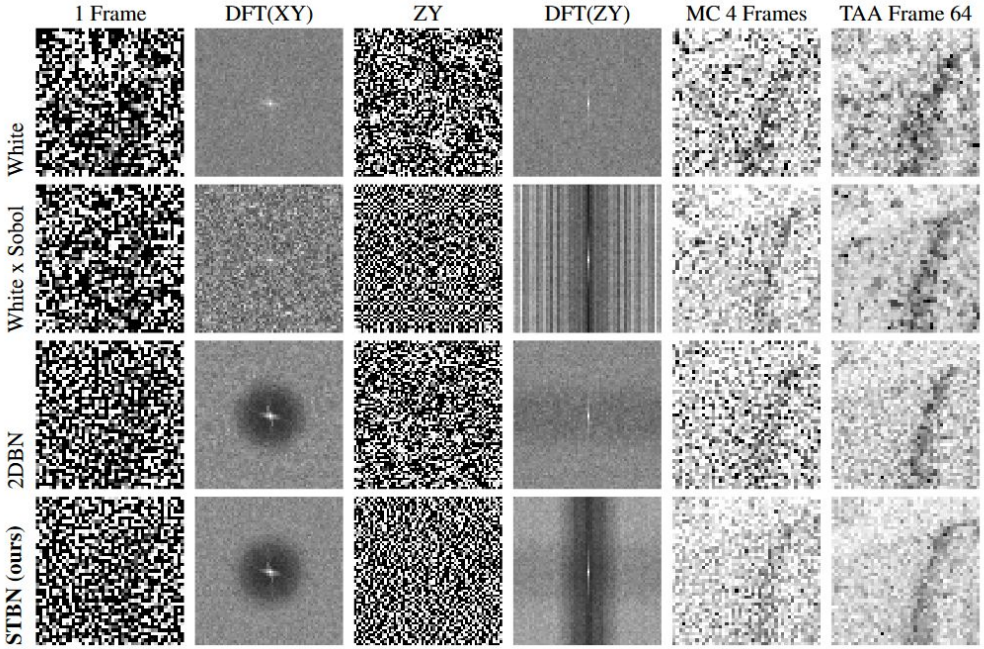
Rendered Results - Stochastic Convolution



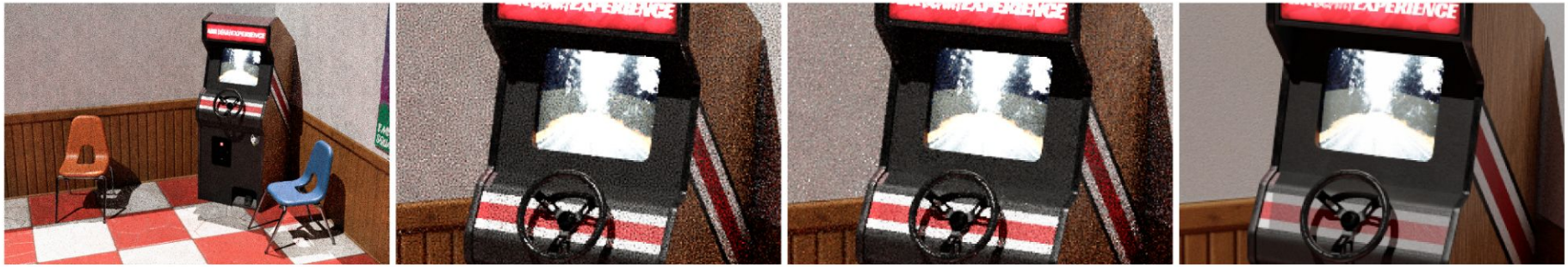


Rendered Results - Ray Traced Ambient Occlusion





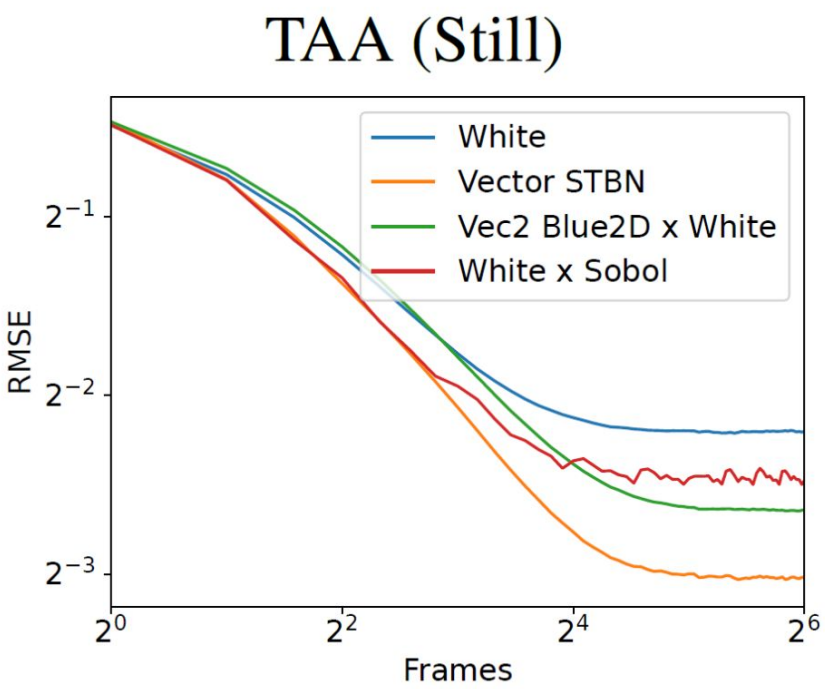
Rendered Results - Heitz and Belcour

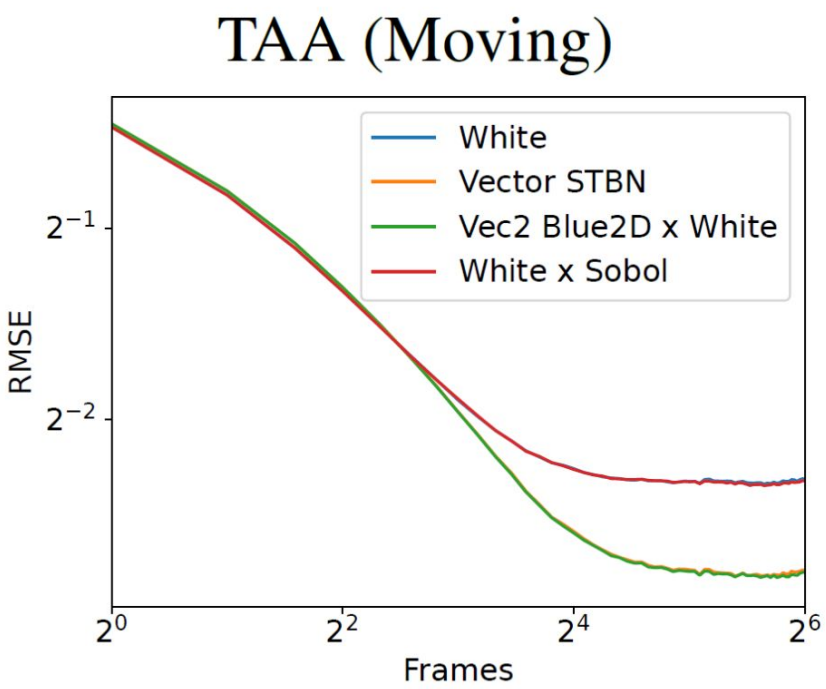


(a) Heitz and Belcour w/ STBN (b) 2D BN (c) STBN (Ours) (d) Ground Truth

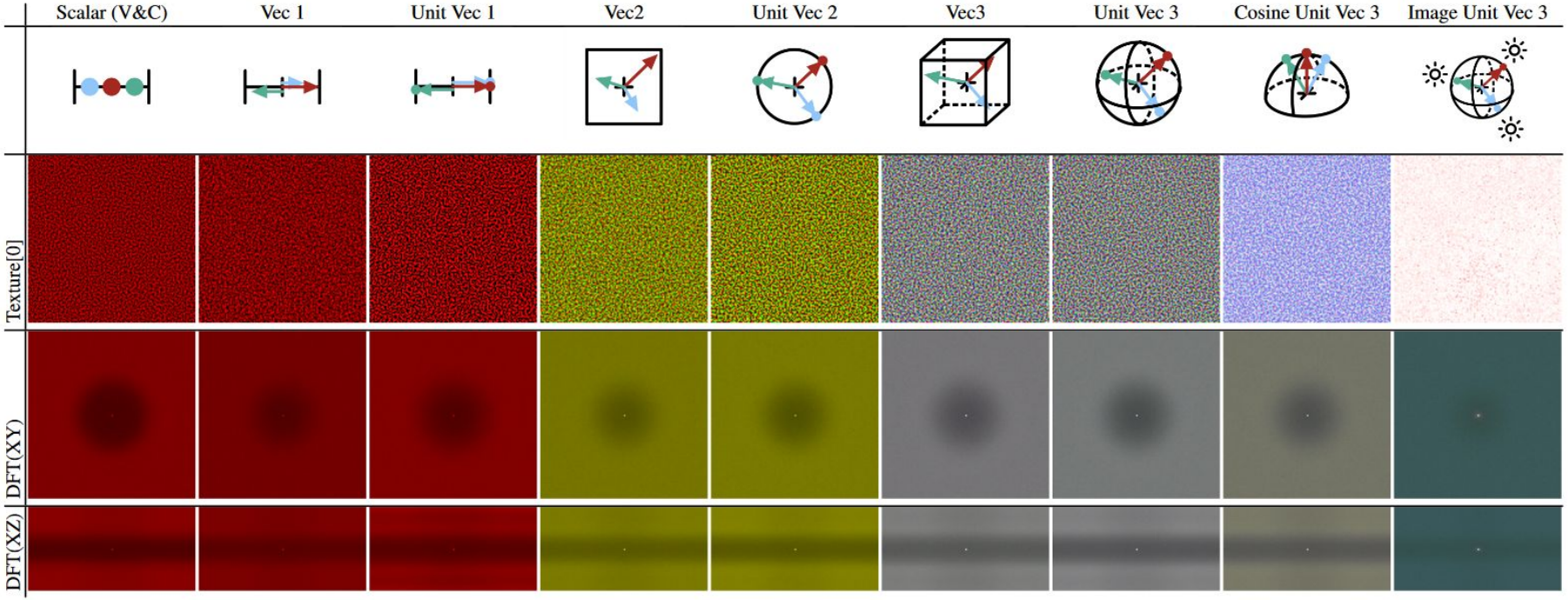
"Distributing Monte Carlo Errors as a Blue Noise in Screen Space by Permuting Pixel Seeds Between Frames"
Heitz and Belcour, 2019

A Challenge With Moving Pixels & 1 SPP

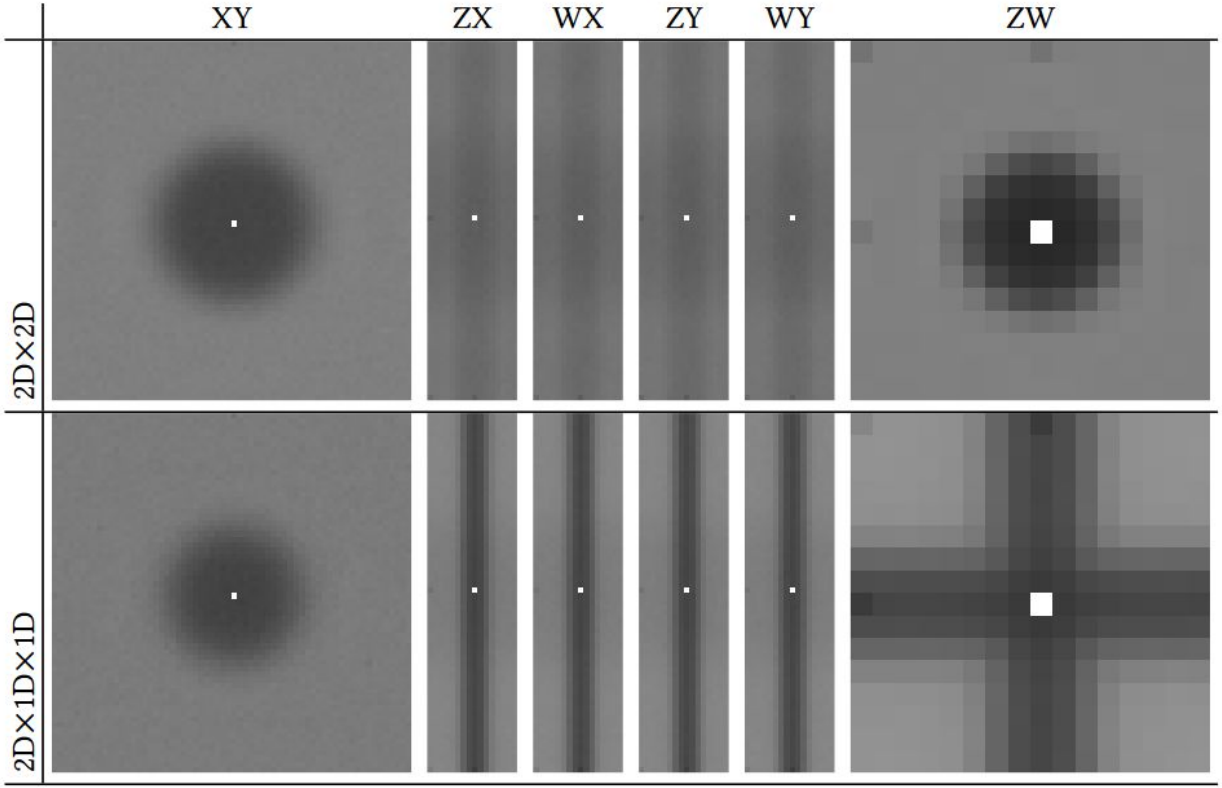




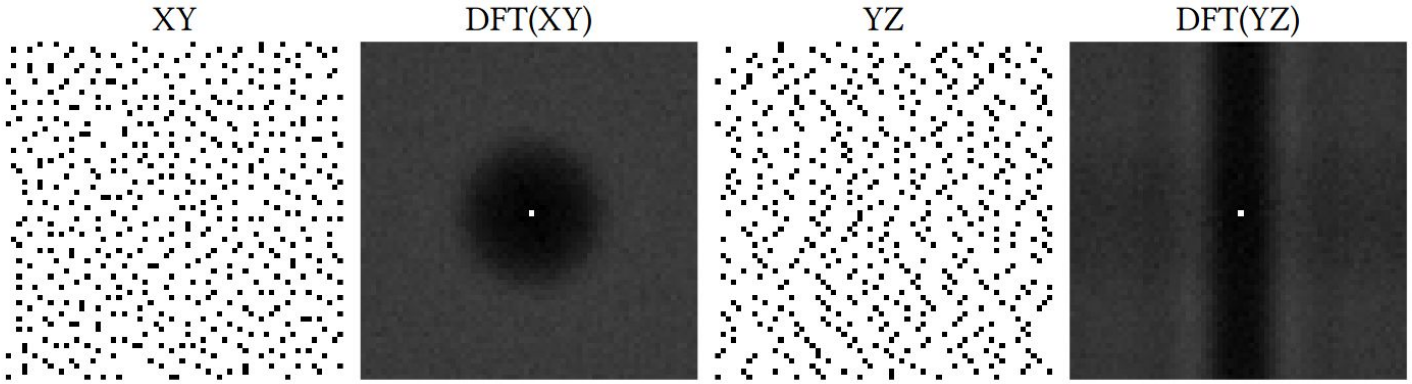
Other Results: Scalars, Vectors and Importance Sampling

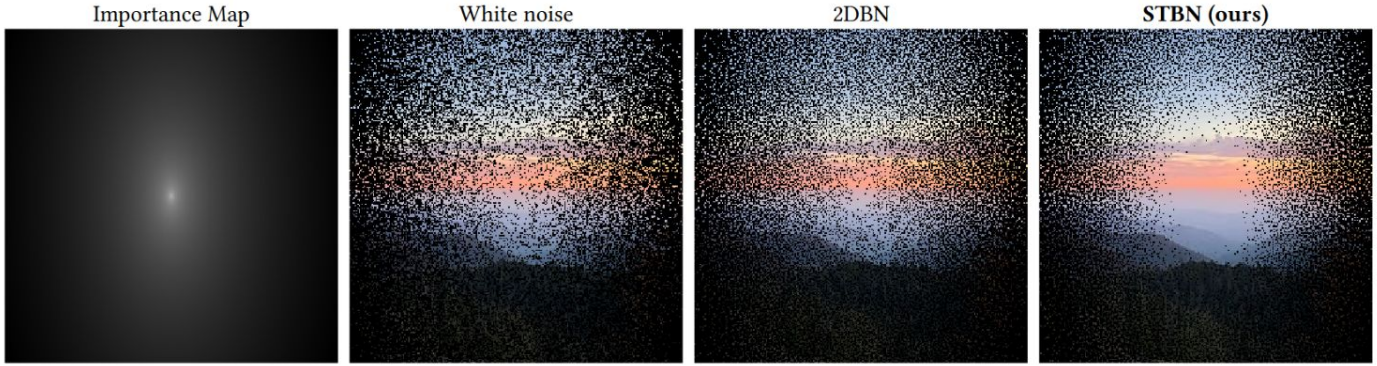


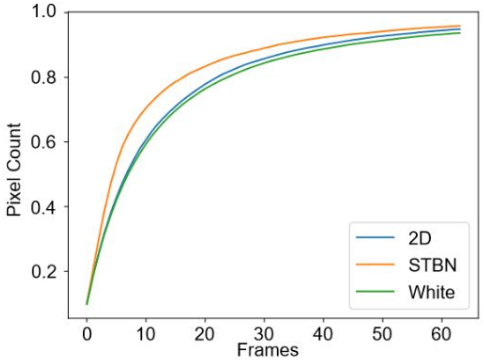
Other Results: Higher dimensionality



Other Results: Thresholded Spatiotemporal Point Sets







Summary

- STBN is a drop-in replacement for traditional Blue Noise Masks
- Optimized temporally to be “better than white noise”
- Can be scalar or vector, uniform or importance sampled

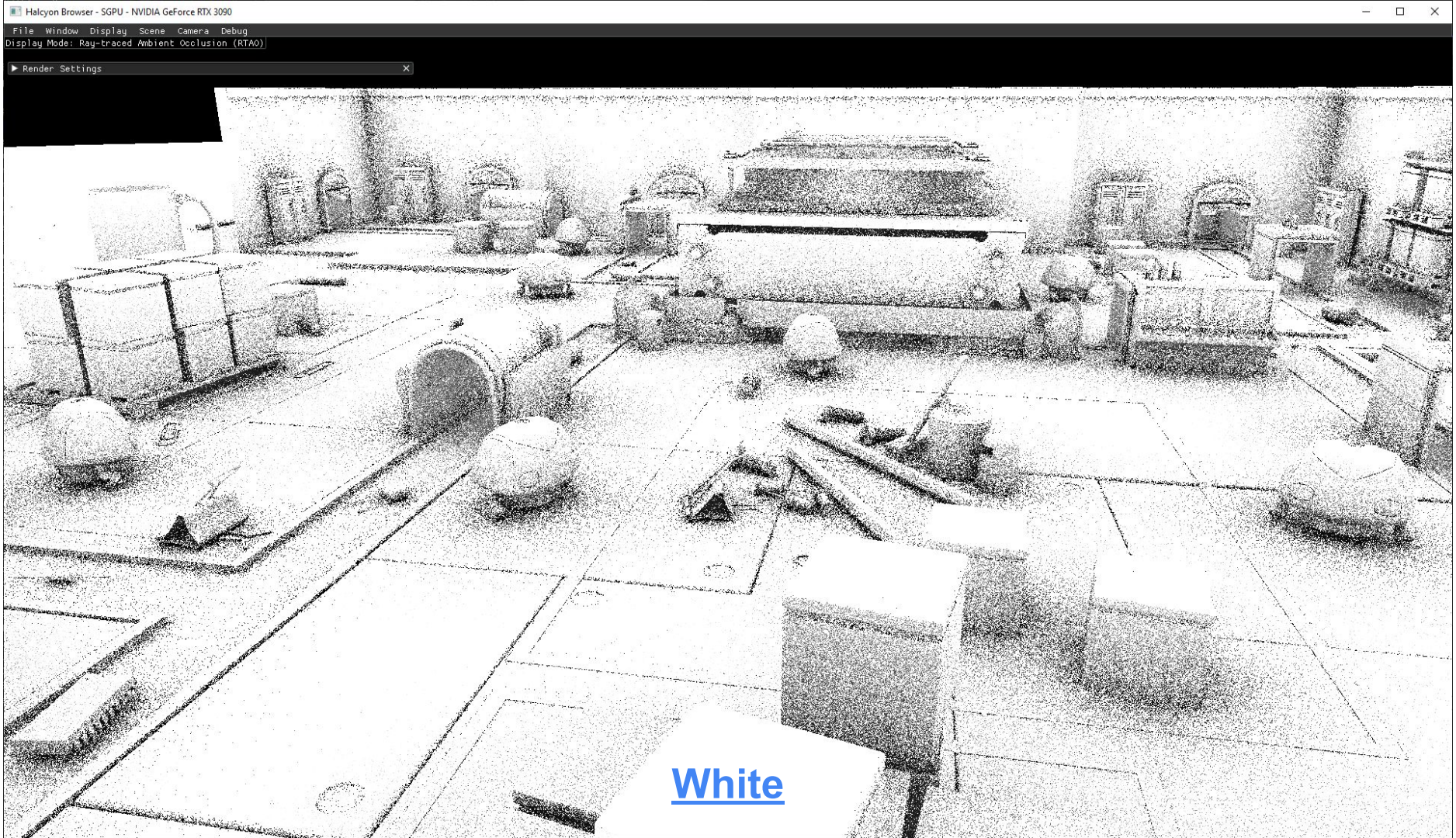
Future Work

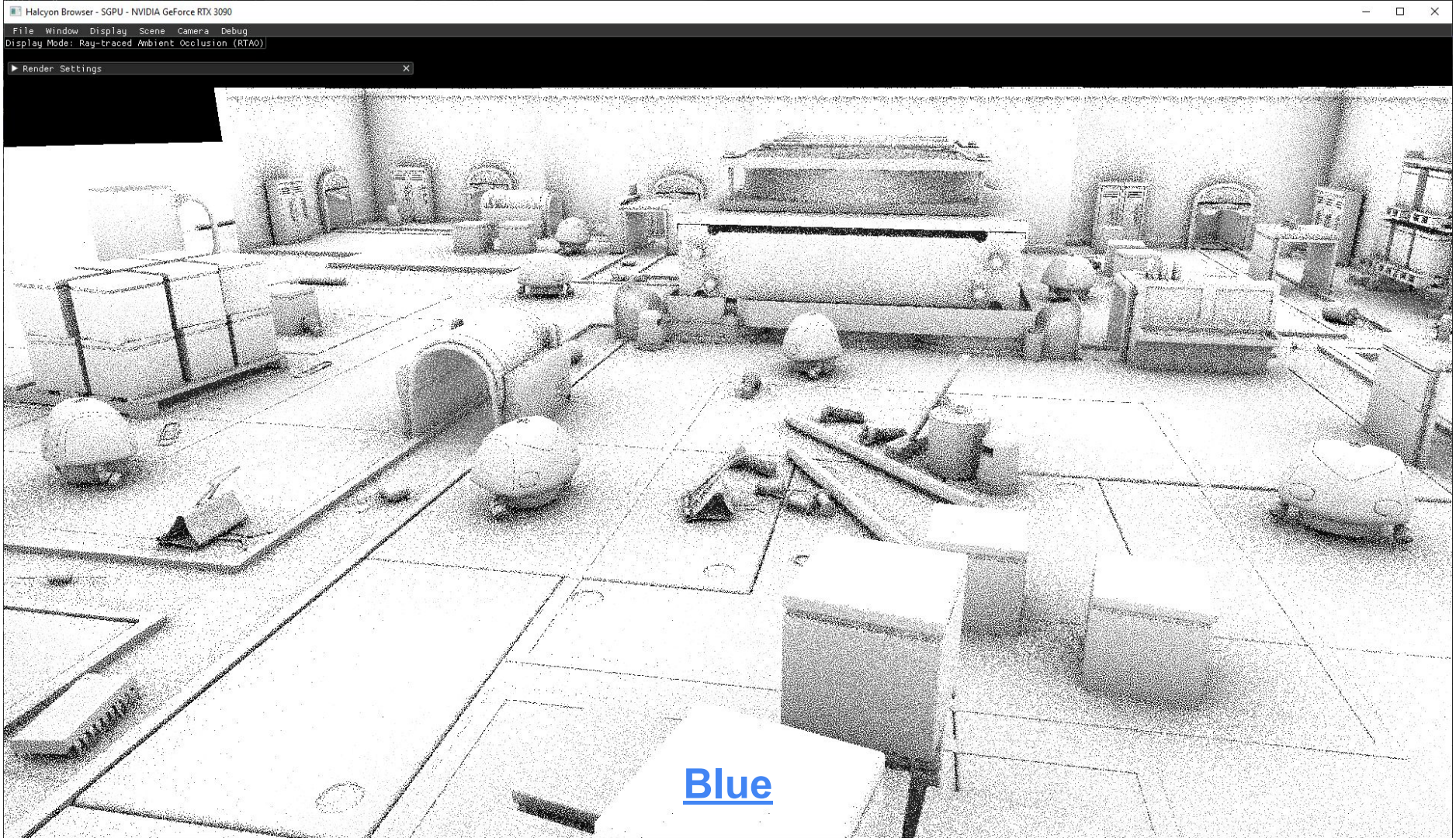
- Optimize for other filters (box blur? Unsharp mask?), rendering techniques, content
- Temporal optimization targeting TAA / EMA or others better
- Address convergence of moving pixels

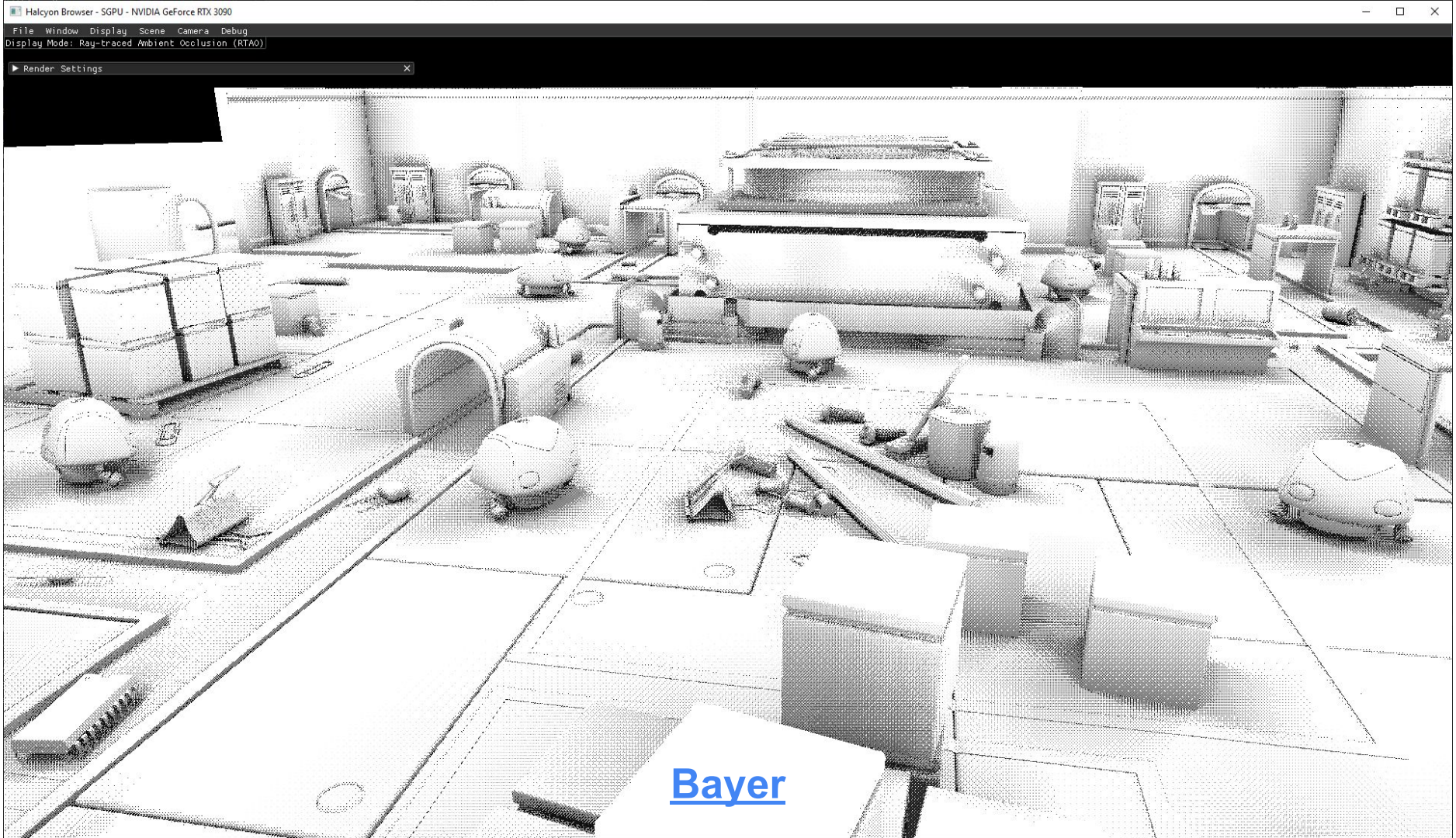
How/Why Do Blue Noise Masks (Textures) Work?

1. If x is a pixel's random seed and f(x) is the shaded output of the pixel…
2. The assumption is that if x correlated with x', then f(x) will also be correlated with f(x').
3. Blue noise mask values are anti correlated among neighbors, so the rendering results have that property too.

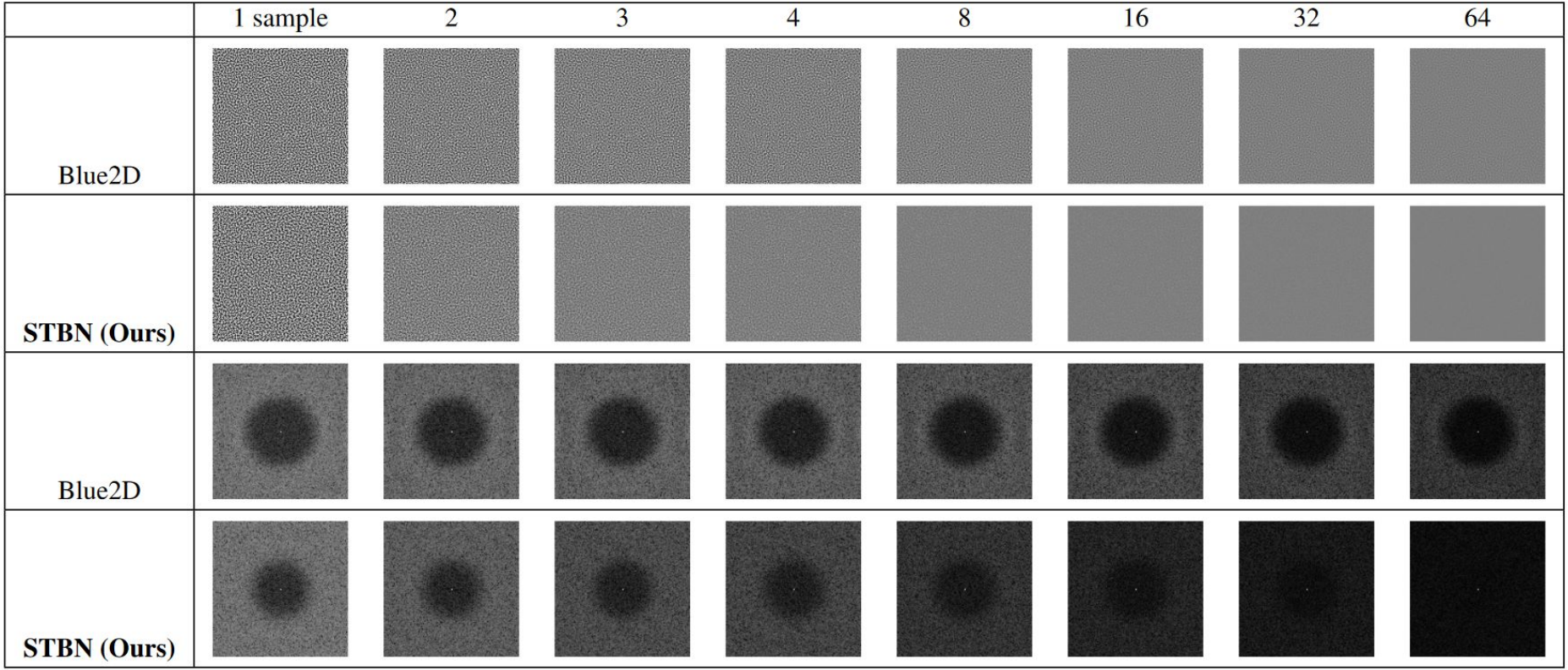
See next images…


Halcyon Browser - SGPU - NVIDIA GeForce RTX 3090
File Window Display Scene Camera Debug
Display Mode: Ray-traced Ambient Occlusion (RTAO)
Render Settings
White

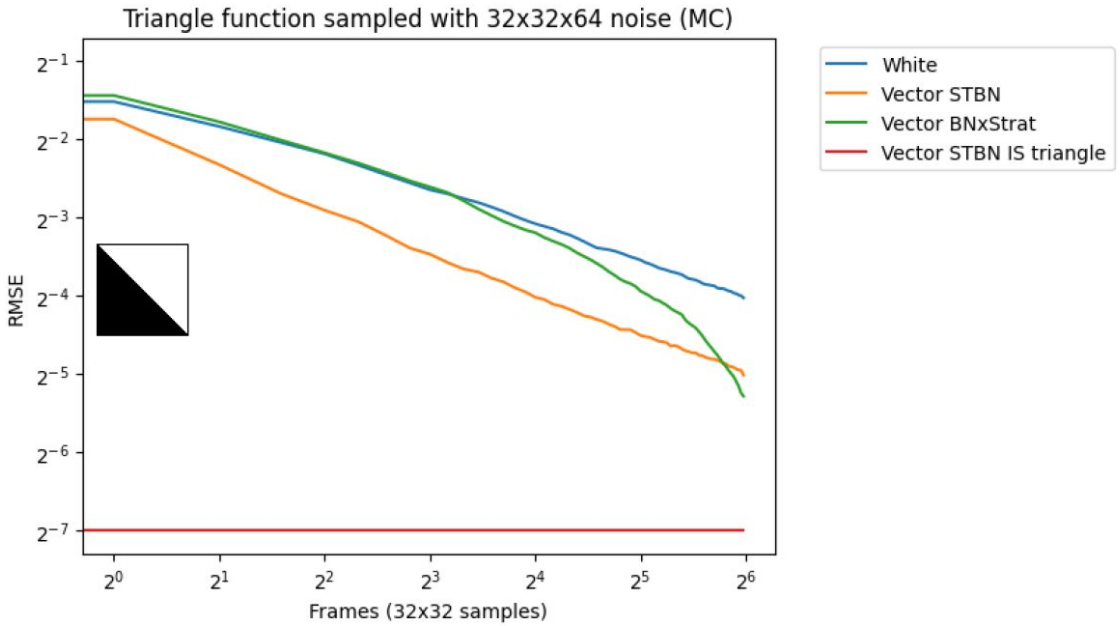

Halcyon Browser - SGPU - NVIDIA GeForce RTX 3090
File Window Display Scene Camera Debug
Display Mode: Ray-traced Ambient Occlusion (RTAO)
Render Settings
Blue


Halcyon Browser - SGPU - NVIDIA GeForce RTX 3090
File Window Display Scene Camera Debug
Display Mode: Ray-traced Ambient Occlusion (RTAO)
Render Settings
Bayer

Does STBN Stay Blue As It Converges?



Blue Over Space, Stratified Over Time



Vector Blue Noise Through Curve Inversion