A *Real* Virtual Pinhole

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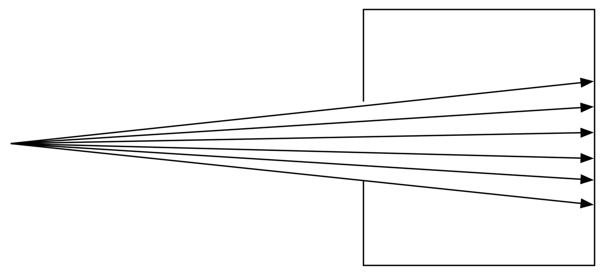
The Ray Tracing Myth

Everything rendered with a pinhole camera is in sharp focus...



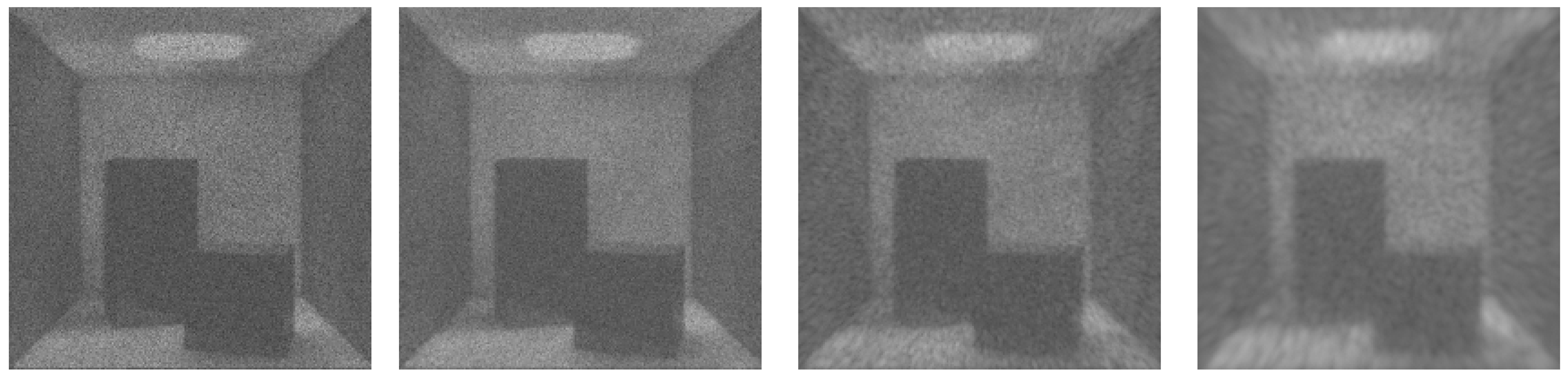
Ray Optics tells us that reducing the pinhole produces a sharper image. An infinitely small hole is perfectly sharp. Practically every rendering text starts with this premiss...

But Ray Optics doesn't work for small apertures - we're using a theory that's totally invalid.

Reducing the aperture will initially improve resolution, but reducing the pinhole size further produces more bluring of the image due to diffraction limiting.

Nothing rendered with a pinhole camera is in sharp focus...

Ray Tracing cannot simulate a pinhole camera.

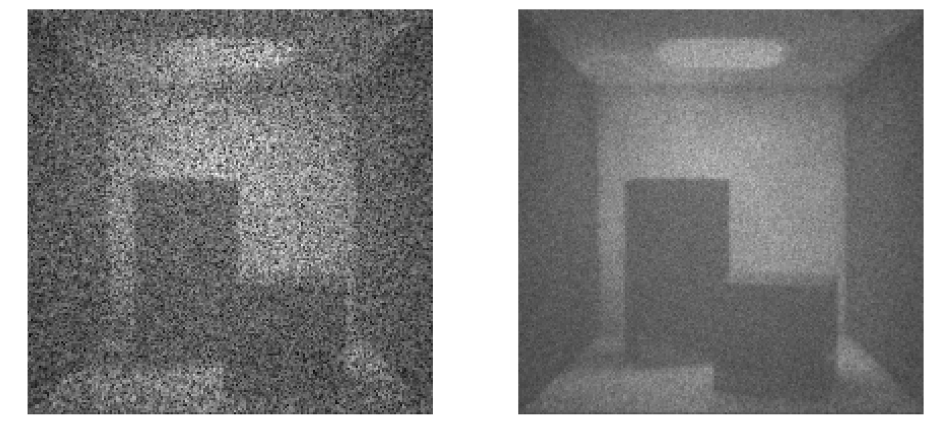


0.2mm Aperture *0.1mm Aperture* *0.04mm Aperture* *0.02mm Aperture*

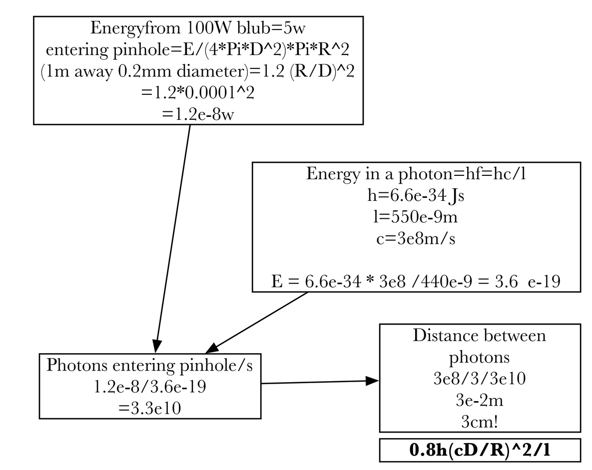
Interference

The samples at all points over the pinhole *in principle* capture the lightfield entering the camera. However when real scenes are used they suffer from interference.

Photons from different parts of the scene interfere with each other to add noise to the scene. Averaging mulitple simulations reduces this problem. Increasing the samples in one simulation is ineffective.

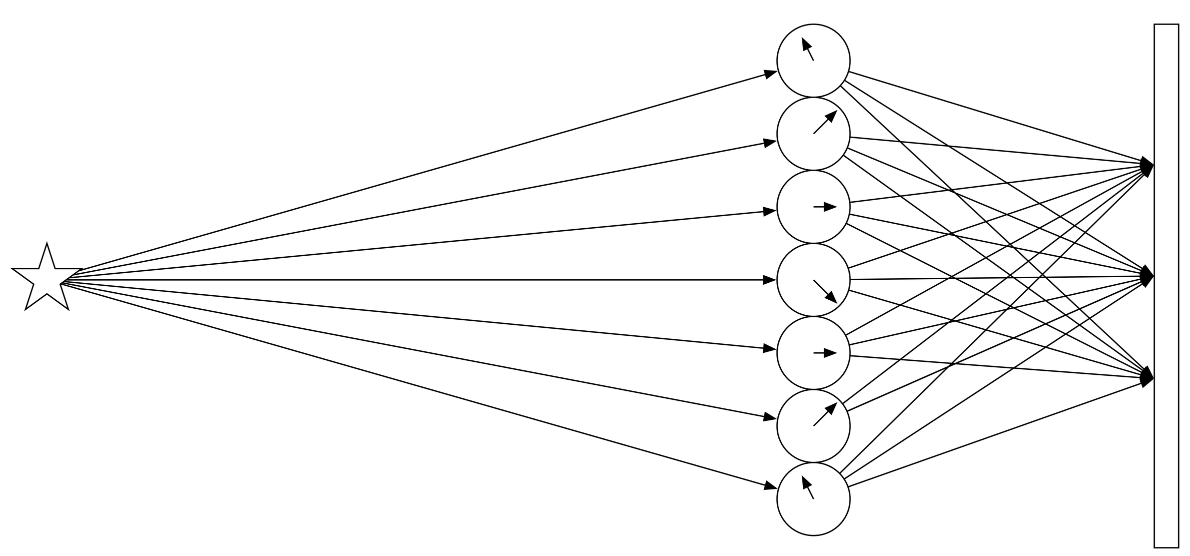


In "real life" photon's pass through the pinhole one at a time, rather than all at once. Therefore they don't signifigantly interfere with each other.



Simulating Waves

To simulate diffraction we need to model waves, using Huygens' Contruction



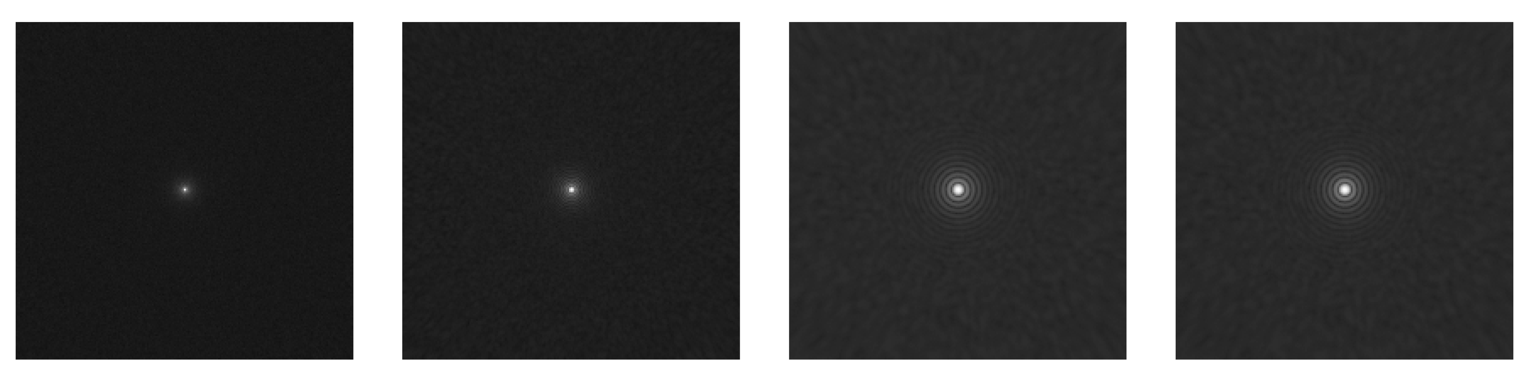
The incoming light is summed at every point across the pinhole, taking into account is amplitude and phase. This is simplified by considering a single wavelength of 550nm.

These pinhole points become emitters of light which are summed at every point in the film plane.

Diffraction Limiting

We need to sample the wavefront at intervals of $\lambda/2$ - that is every 275nm - a *lot* of samples. This rapidly becomes inpractical for complex optical systems. Fortunately pinholes are small.

The diffraction patterns produced behave like real pinhole images.



0.1mm Aperture *0.04mm Aperture* *0.02mm Aperture* *0.01mm Aperture*

Large pinholes have as ray optics predict, and reducing the pinhole reduces the point size, but for very small pinholes diffraction effects dominate, and the point image increases in size.

Nyquist and Camera Resolution

If we sample at $\lambda/2$ then we have $2d/\lambda$ samples across the pinhole. We cannot have more information than this in the final image. This provides an upper bound on the resolution of our image *and the image produced by a real camera!*

A pinhole is too small to squeeze the information through...

A pinhole of diameter d cannot produce an image smaller than itself, so we have a second resolution limit of d/D.

When these limits are equal: $D/d = 2d/\lambda$. Sampling theory predicts an optimal pinhole size of $d = \sqrt{(D\lambda/2)}$.

This matches traditional models of diffraction, and real world behaviour.