Raytracing: Quality

COSC 4328/5327
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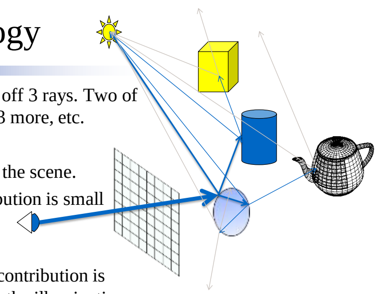
Ray Genealogy



- Primary rays spawn off 3 rays. Two of those can spawn of 3 more, etc.
- When do you stop?
  - When ray leaves the scene.
  - When the contribution is small enough.

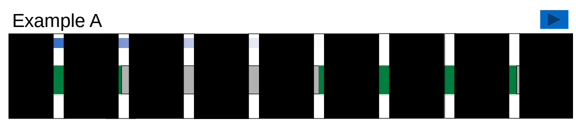
After each bounce the contribution is attenuated by the k's in the illumination model. Check this value and set a maximum recursion level.

Ray Genealogy

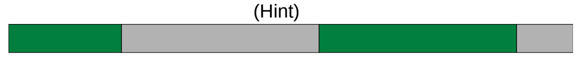
- 1 Ray/pixel at 1k × 1k image = 1M rays.
- Say on avg. 6 secondary rays = 7M rays
- 100k objects with 10 ops for intersection = 7, 000, 000M ops
- 4GHz processor 5 cycles per op = 800MFLOPS
- How long to render? 70000/8 = 8750s ~ 146m ~ 2.5hr
- Will this image look really good for our 2.5hr?

Describe what you see!

Example A



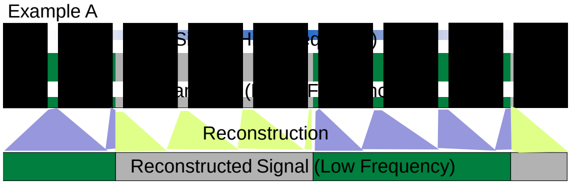
(Hint)



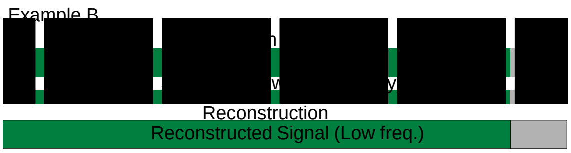
Example B

Describe what you see!

Example A

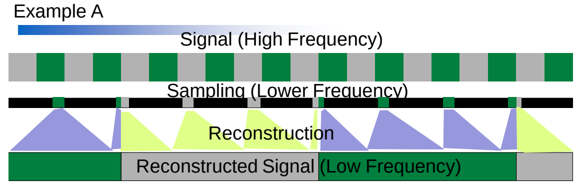


Example B



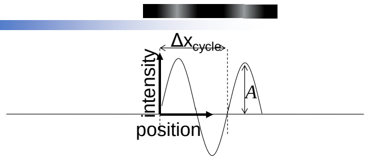
Describe what you see!

Example A



Aliasing = a high frequency signal masquarading as a low frequency signal due to a poor sampling frequency.

Recall: frequency, cycle/wavelength



$$y = A\sin\left(x\left(2\pi / \Delta x_{cycle}\right)\right)$$

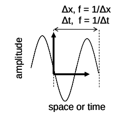
A is amplitude

Δx_{cycle} is wavelength

(ignoring y-offset and phase shift)

$f = 1/\Delta x_{cycle}$ frequency

What is a "poor sampling frequency"?



Nyquist Sampling Frequency:

$f_s = 2 f_{max}$

$\Delta x_s = \Delta x_{cycle} / 2$

f_s : Nyquist Sampling Frequency

f_{max} : maximum frequency component in signal

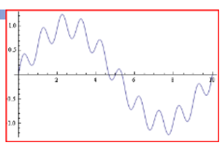
Δx_s : Nyquist Sampling Interval

Δx_{cycle} : Cycle interval

"To avoid losing information we need to set sampling frequency to at least twice the highest frequency component of signal."

Example of highest frequency component

- What is highest frequency component of this signal, S(x)?



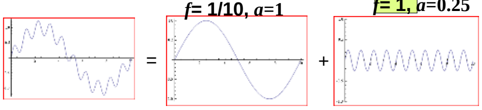
- What if I tell you the equation is:

TADA!

highest freq. comp. of S(x)

Sin[x (2 Pi /10)] + Sin[x (2 Pi / 1)]*0.25

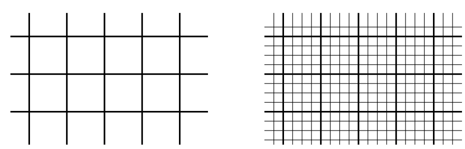
f= 1/10, a=1 **f= 1, a=0.25**



Sin[x (2 Pi /10)] **Sin[x (2 Pi / 1)]*0.25**

Super-Sampling

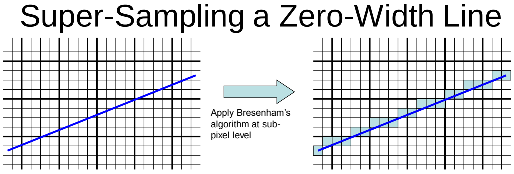
- Split single pixel into sub-pixels.
- Pixel's final color is a mixture of sub-pixels' colors. Simple method: Sample at the middle of each sub-pixel. Then, pixel's color is the average of the sub-pixels' color.



Pixels

Sub-divide into sub-pixels

Super-Sampling a Zero-Width Line



Sub-divide each pixel into sub-pixels, for example 4x4 sub-pixels

Each pixel can have a maximum of 4 colored sub-pixels

0	0	0	4
2	4	4	0
2	0	0	0

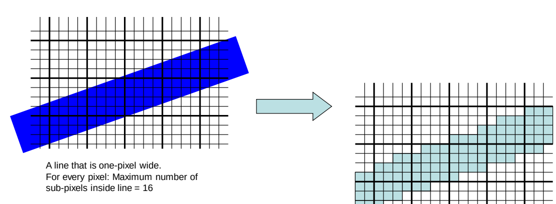
How many sub-pixels are colored?

Assign color

0.0	0.0	0.0	1.0
0.5	1.0	1.0	0.0
0.5	0.0	0.0	0.0

Fraction of pixel's color to be line's color

Super-Sampling a Line with Non-Zero Width



A line that is one-pixel wide.
For every pixel: Maximum number of sub-pixels inside line = 16

A sub-pixel is considered in if its lower-left corner is inside the line

0	0	5/16	9/16
10/16	15/16	13/16	7/16
8/16	2/16	0	0

Fraction of sub-pixels are in = fraction of color of the pixel should be line color

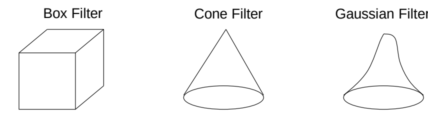
Sub-pixel Weighting Masks

- Instead of considering each sub-pixel to be of equal importance, assign a weight to each sub-pixel.
- Usually consider the center sub-pixel to be most important

1	2	2	1
2	3	3	2
2	3	3	2
1	2	2	1

Example weight for each sub-pixel
Total weight = 32
Final color of pixel = Sum of each (sub-pixel colors x sub-pixel weight) / total weight

Common Filter Functions



Box Filter

1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1
1	1	1	1	1

Cone Filter

1	2	3	2	1
2	4	5	4	2
3	5	6	5	3
2	4	5	4	2
1	2	3	2	1

Gaussian Filter

1	2	3	2	1
2	5	6	5	2
3	6	8	6	3
2	5	6	5	2
1	2	3	2	1

Gaussian function = $\frac{1}{\sigma\sqrt{2\pi}} \exp\left(-\frac{(x-\mu)^2}{2\sigma^2}\right)$

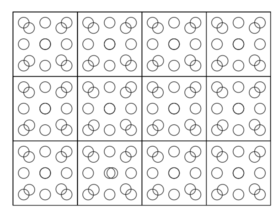
where σ is the standard deviation and μ is the mean

Super-Sampling

- A simple method is to shoot more than one ray per pixel and average the values.

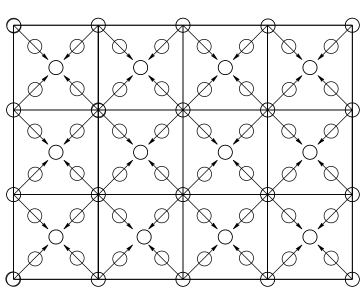
Super-Sampling

- If we shoot one ray/pixel we get one sample/pixel
- What if we shoot more rays/pixel?
- How many rays to double the resolution?
- How about triple the resolution?
- How many rays/pixel to remove aliasing?

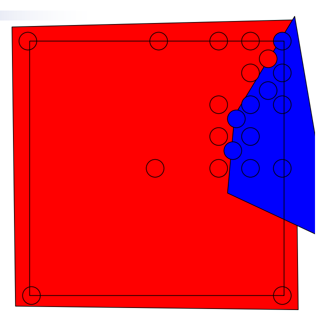


Super-Sampling

- How many total rays for an NxN image?

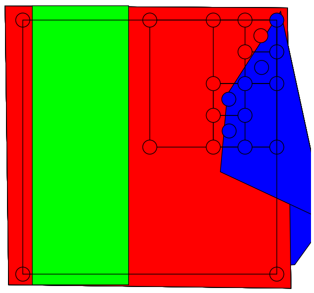


Adaptive Supersampling



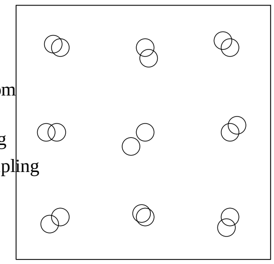
Adaptive Supersampling

- Tries to only fire rays that are needed
- Is the assumption that if the rays are the same color, that color is the right pixel color valid?
  - Small objects cause problems
  - Slender objects cause problems
  - If moving very noticeable artifacts



Distriuted/Stochastic Raytracing

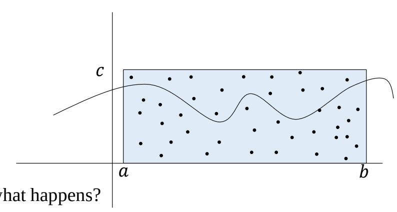
- We can't remove all aliasing.
- What can we do to lessen how noticeable the artifacts are?
- How does the news stop you from recognizing a person?
- Change the aliasing into blurring
- Do that by randomizing the sampling frequency.



Monte Carlo Integration

- Let rectangle g enclose a function f.
- Choose set of random points within g.
- How does the # of points within g, n_g, compare with the # of points within f, n_f?
- That is, what is

$$\frac{n_f}{n_g}(b-a)c$$

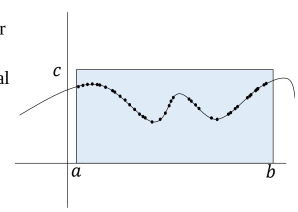


- As n_g increases what happens?

Monte Carlo Integration

- Let's use random numbers more efficiently.
- Instead of picking (x, y) pairs, just pick random x values and plug them into the function.
- How do we use the y values for integration?
- The average y times the interval gives an estimate of area.

$$\int_a^b f(x)\,dx \approx \frac{b-a}{n}\sum_{i=1}^{n} f(x_i)$$



Monte Carlo Integration

- In general

$$I \approx \frac{V}{n}\sum_{i=1}^{n} f(x_i)$$

Where V is the measure of the set to integrate over. So if we had

$\int_{a_1}^{b_1}\int_{a_2}^{b_2}\cdots\int_{a_d}^{b_d} f(x_1, x_2, \cdots, x_3)\,dx_1\,dx_2\cdots dx_d$

then

$$V = \prod_{i=1}^{d}(b_i - a_i)$$

For example:

$\int_1^3\int_0^5\int_0^1\int_0^2 f(x,y,z,t)\,dxdydzdy \approx \frac{24}{n}\sum_{i=1}^{n} f(x,y,z,t)$

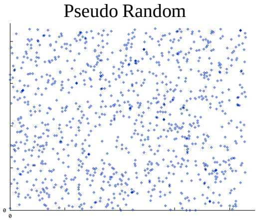
Random Numbers

- What makes a sequence random?
- A sequence is **uniformly distributed** if all subsets contain a random sequence. For example, say we have random points in a plane. The number of points that fall in a rectangle with area k should only depend on k and not the location of the rectangle.
- In a computer, random numbers are generated *deterministically* and are not truly random. They are often called *psuedorandom*.
- Not all random number generators are equal. And if fact most are down right bad (at least those that come with compilers.)

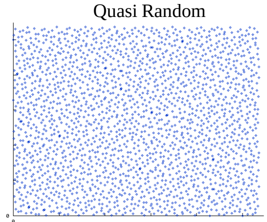
Pseudo vs. Quasi

- Pseudo a bit too random for Monte Carlo, use Quasi instead
  - For super-sampling, generate evenly spaced samples then jitter within sub-pixel.

Pseudo Random



Quasi Random



Motion Blur

Cook, Porter, Carpetner 1984

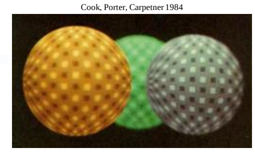
- Sample the image temporally; temporal anti-aliasing.
- Can perform with other rendering techniques.
- Modeling the shutter of a camera.
- In ray tracing, can combine with spatial anti-aliasing by giving each ray a jittered time.

Motion Blur

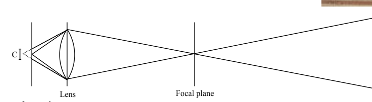
Source: wikipedia

Depth of Field

Cook, Porter, Carpetner 1984

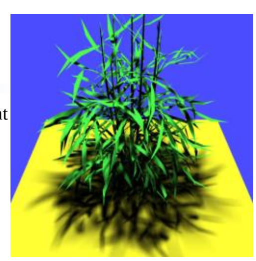


- Model the lens of a camera.
- All points in the scene project as a circle on the image plane, called the *circle of confusion*.
  - Objects at the focal distance are sharp, others are blurred.
- Not only jitter the ray direction, jitter where on the lens it hits

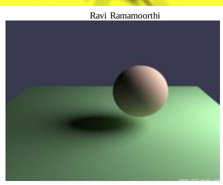


Soft Shadows

- Hard shadows result from using point light sources.
- Instead, model a light source with some geometry.
- If only part of the light is visible, determine that amount and decrease light accordingly.
- Stochastic shadow rays work well.



Ravi Ramamoorthi



Links

- http:://www.povray.org (POV)
- http:://www.irtc.org (IRTC)
- http://radsite.lbl.gov/radiance/HOME.html (radiance)
- http://www-graphics.stanford.edu/~cek/rayshade/rayshade.html (rayshade)
- http://www.acm.org/tog/resources/RTNews/html/ (ray tracing news)
- http://www.cs.cmu.edu/~efros/java/tracer/tracer.html