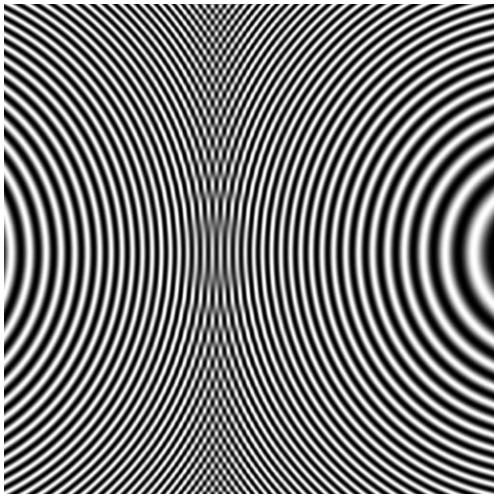
CS148: Introduction to Computer Graphics and Imaging

Sampling and Aliasing



Key Concepts

Sampling

Aliasing

Nyquist frequency

Filters and convolution

Antialiasing

Sampling

Image Generation = Sampling

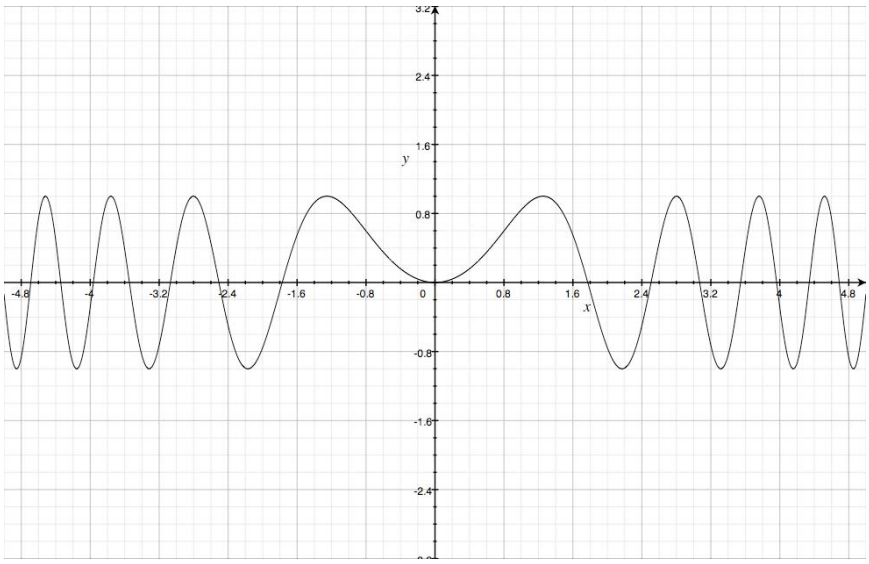
Rasterization is performed by testing whether a point is inside a triangle

More generally, evaluate a function at a point

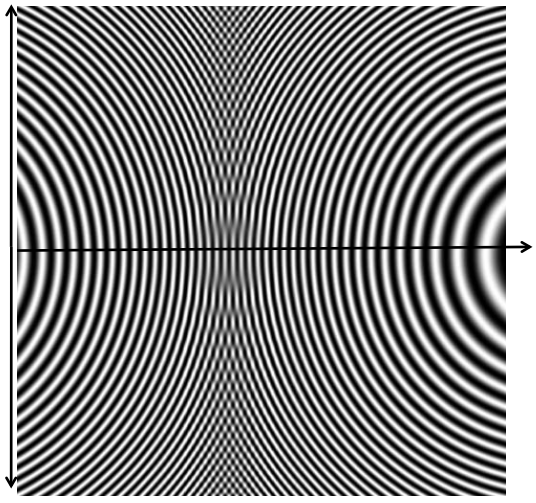
```
for( int x = 0; x < xmax; x++ )
  for( int y = 0; y < ymax; y++ )
      I[x][y] = f( float(x), float(y));
```

Take a continuous function f and convert to set of samples I, a discrete representation of the func.

Zone Plate $\sin x^2$

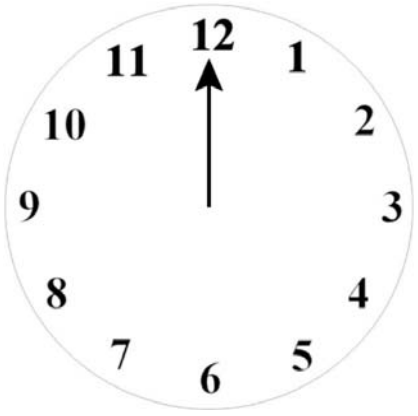


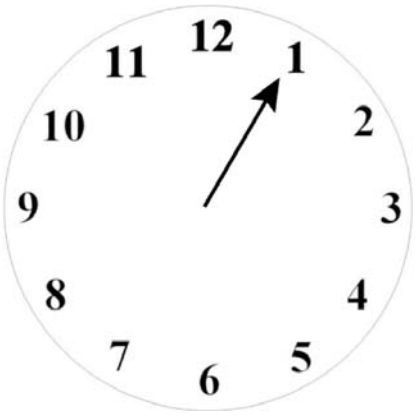
Zone Plate



$$\sin(x^2 + y^2)$$

Aliasing

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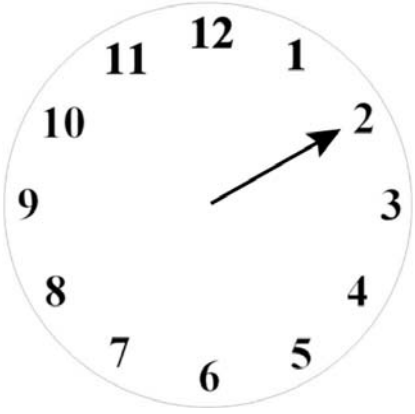
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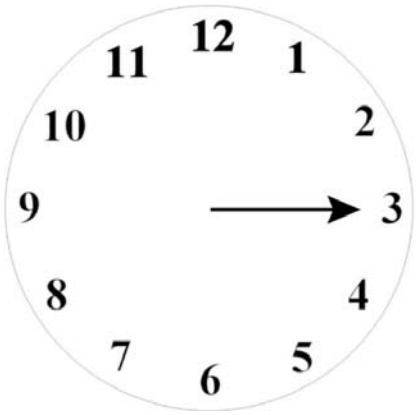
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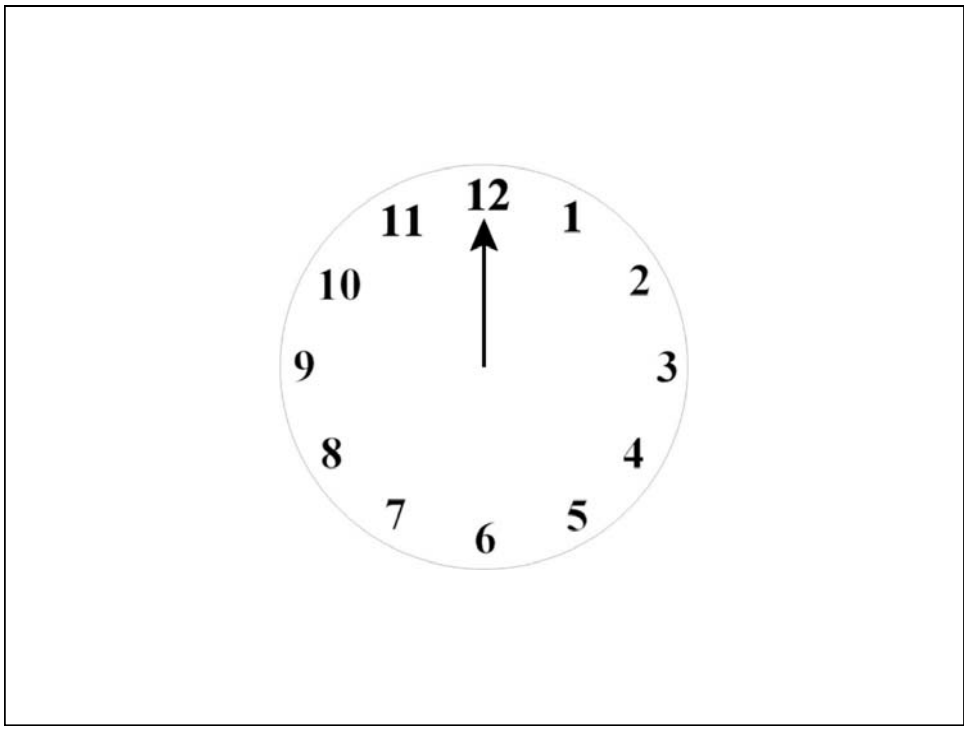
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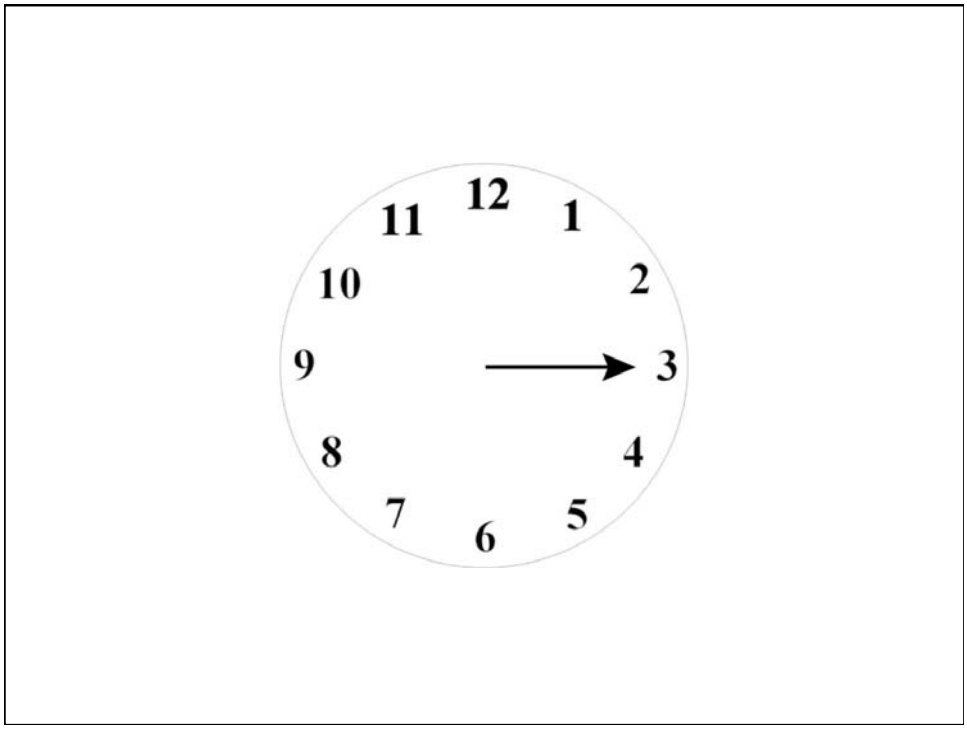
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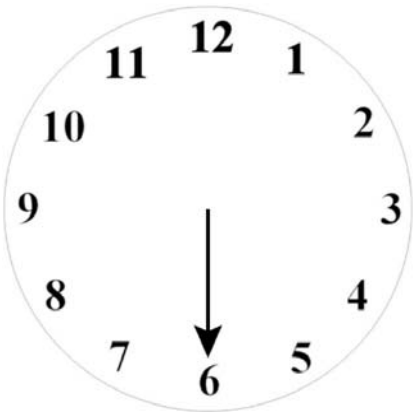
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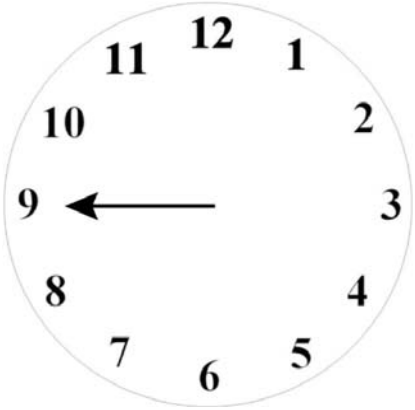
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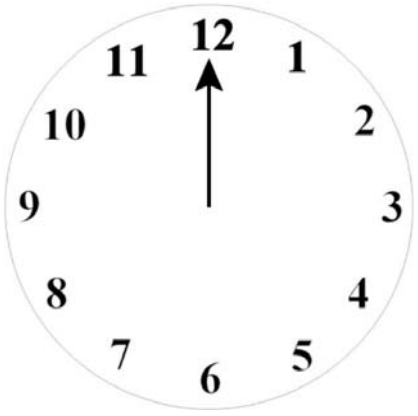
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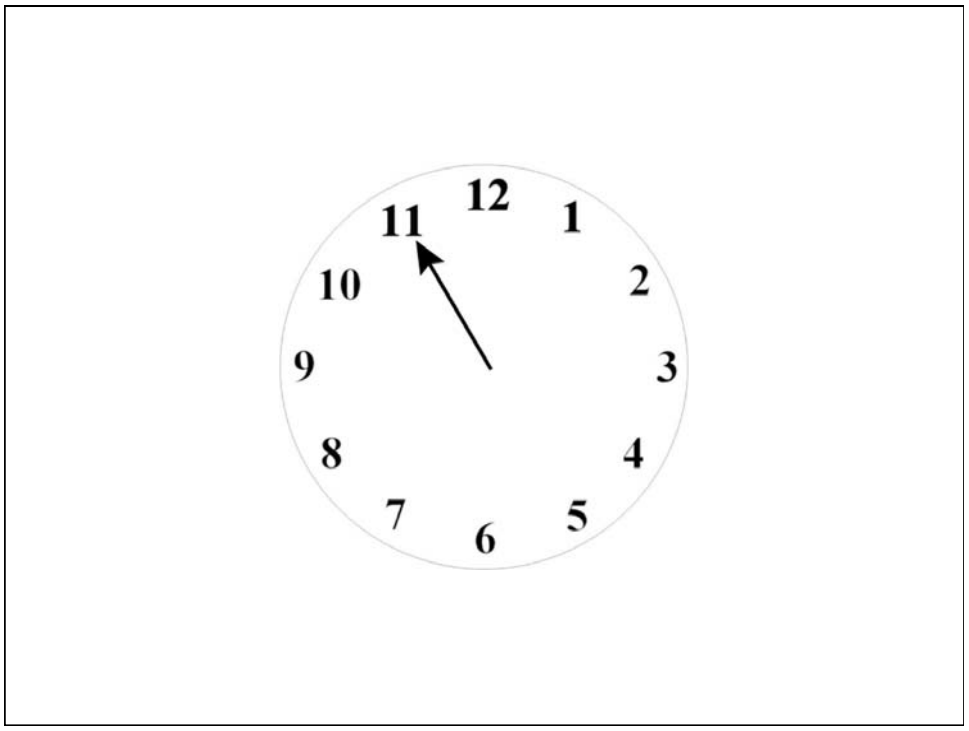
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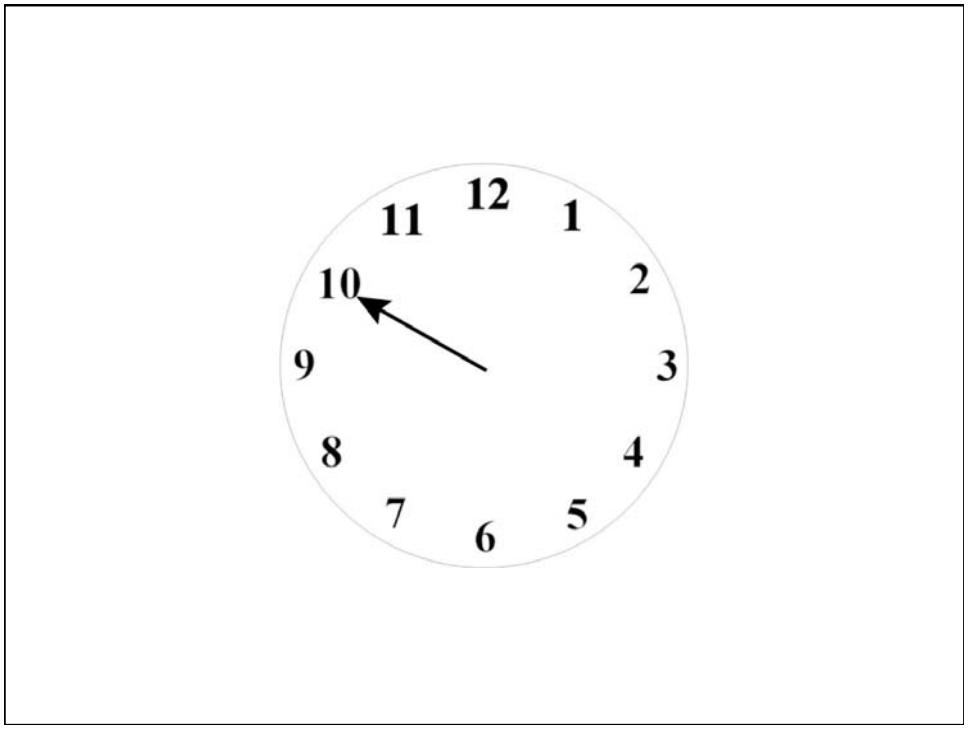
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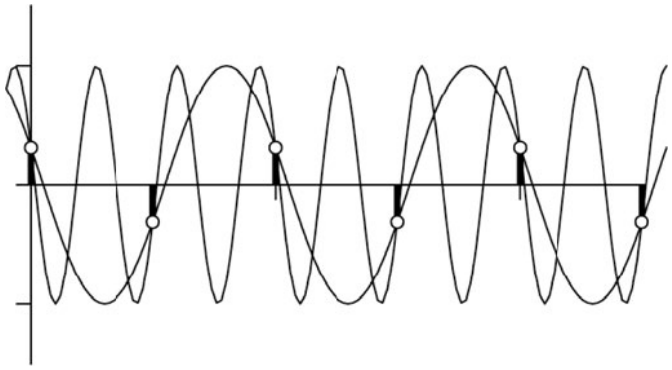
Wagon Wheel Effect

http://www.michaelbach.de/ot/mot_wagonWheel/

"Aliases"



Two frequencies are indistinguishable

Nyquist Frequency

Definition: The Nyquist frequency is ½ the sampling frequency = 1/(2 Ts)

A periodic signal above the Nyquist frequency cannot be distinguished from a periodic signal below the Nyquist frequency

Indistinguishable frequencies look alike

Hence, they are called aliases

Sampling in Computer Graphics

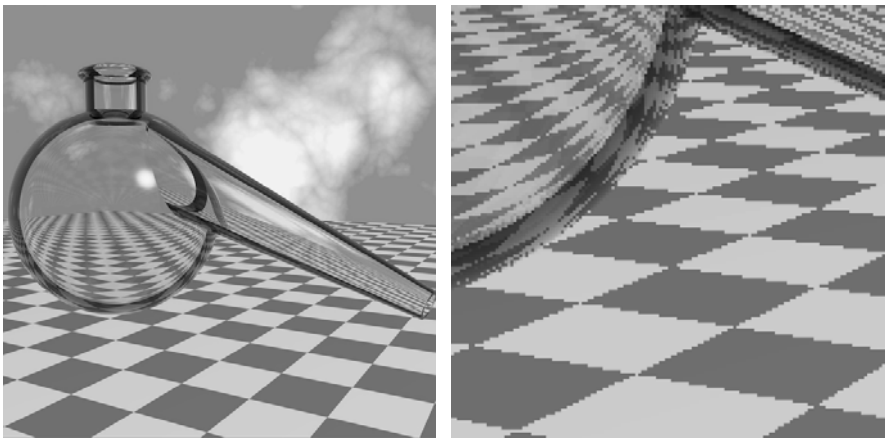
Artifacts due to sampling - Aliasing

- **Jaggies**
- **Moire**
- **Flickering small objects**
- **Sparkling highlights**
- **Temporal strobing**

Preventing these artifacts - Antialiasing

Jaggies

Retort sequence by Don Mitchell



Staircase pattern or jaggies

Antialiasing

Antialiasing

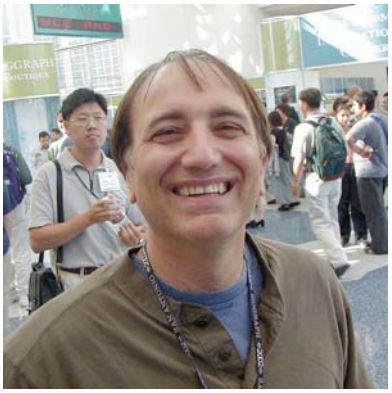
Simple idea:

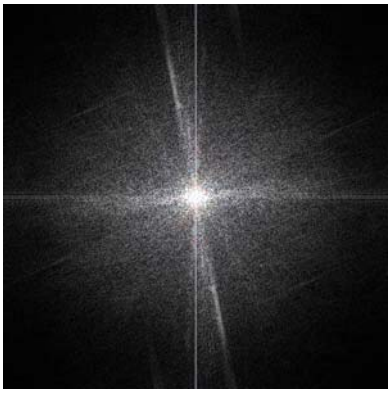
Remove frequencies above the Nyquist frequency before sampling

How? Filtering

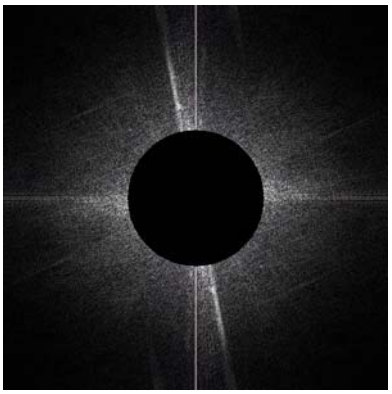
Filters

My Frequencies



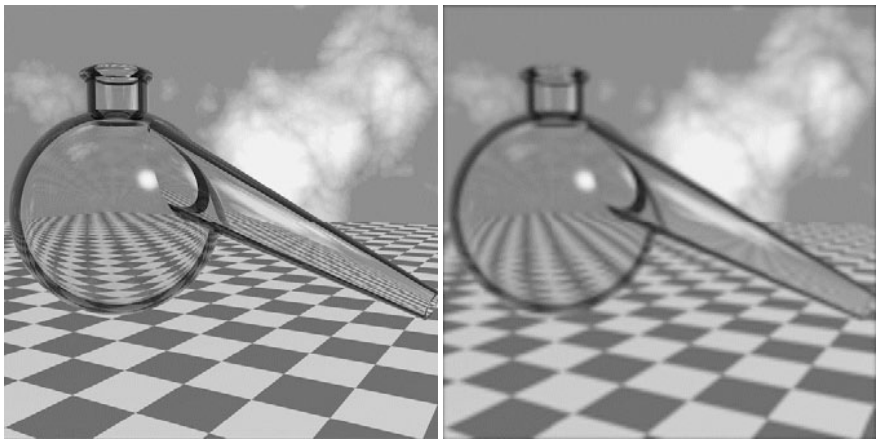


High-Pass Filtering Me



Box Filter = Low-Pass Filter

Low-Pass means low frequencies are "passed"
High frequencies are removed by the filter

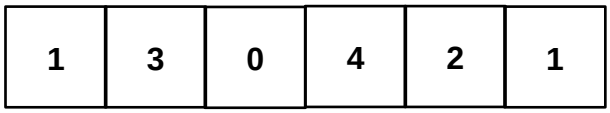


Original **Box-Filter**

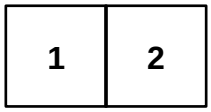
Filters = Convolution

Convolution

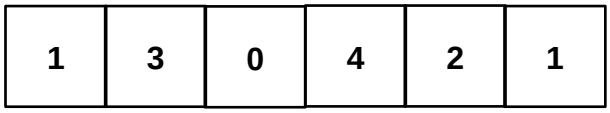
Signal / Image

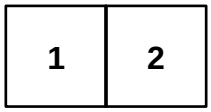


Filter

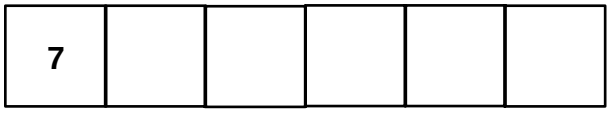


Convolution

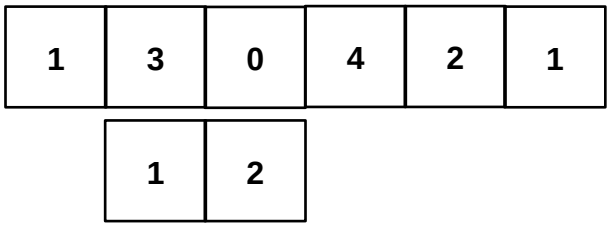




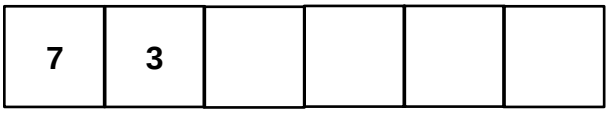
1 * 1 + 3 * 2 = 7



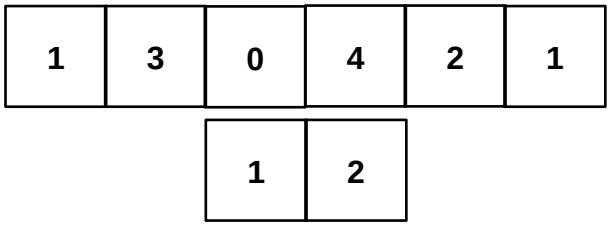
Convolution



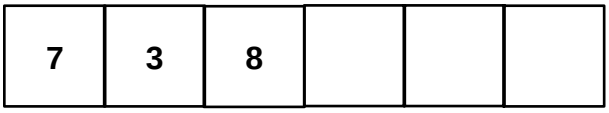
3 * 1 + 0 * 2 = 3



Convolution



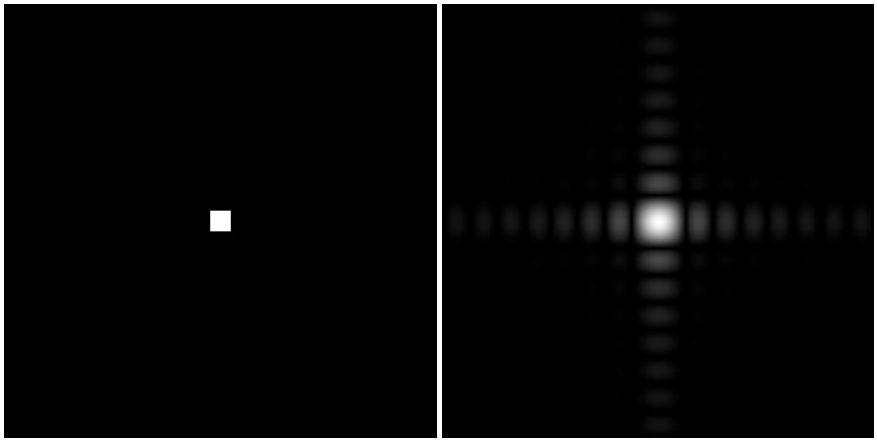
0 * 1 +4 * 2 = 8



Box Filter

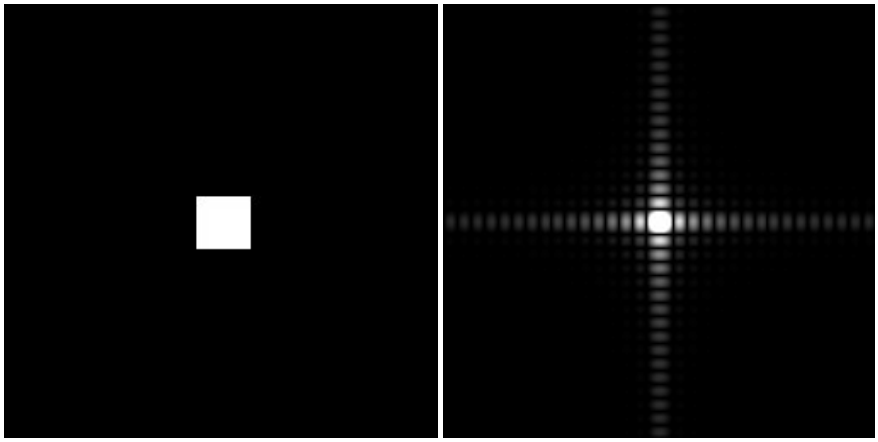
1	1
1	1

Box Filter = Low-Pass Filter



Spatial Domain Frequency Domain

Wider Filters, Lower Frequencies



Spatial Domain

Frequency Domain

Antialiasing

Antialiasing

Simple idea:

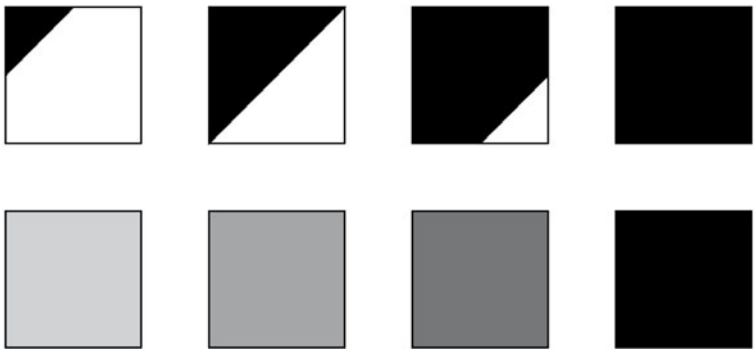
Remove frequencies above the Nyquist frequency before sampling

How? Filtering

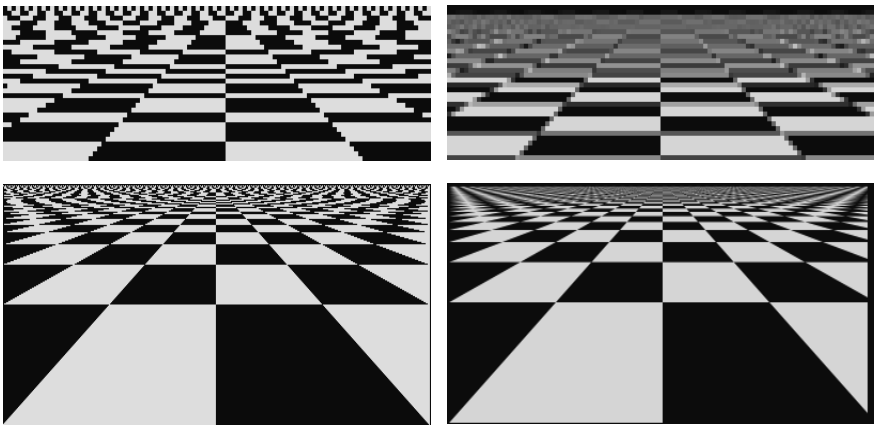
Filter during rasterization

Prefiltering by Computing Coverage

Pixel Area = Box Filter



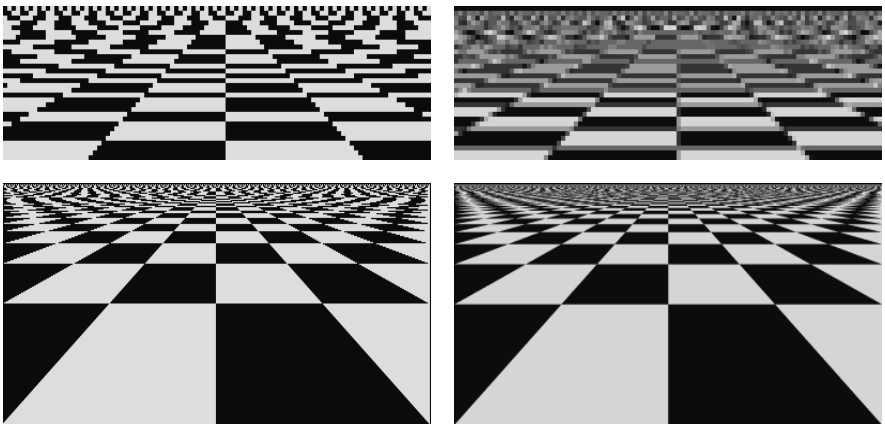
Point- vs. Area-Sampled



Point Area

Checkerboard sequence by Tom Duff

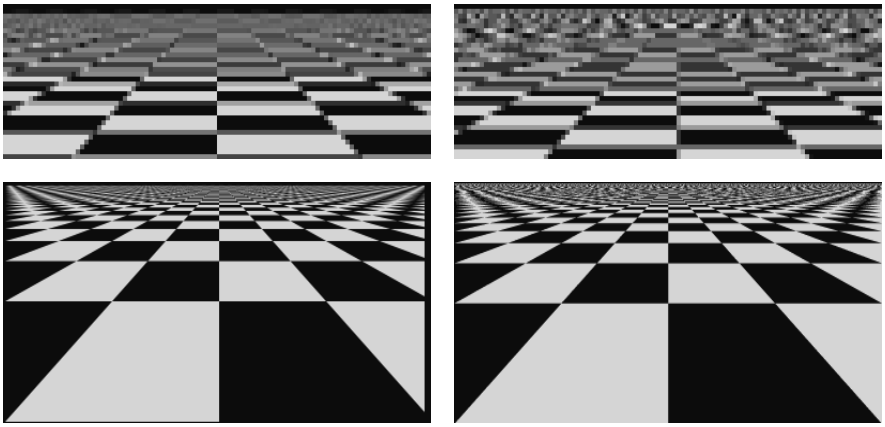
Point-sampling vs. Super-sampling



Point 4x4 Super-sampled

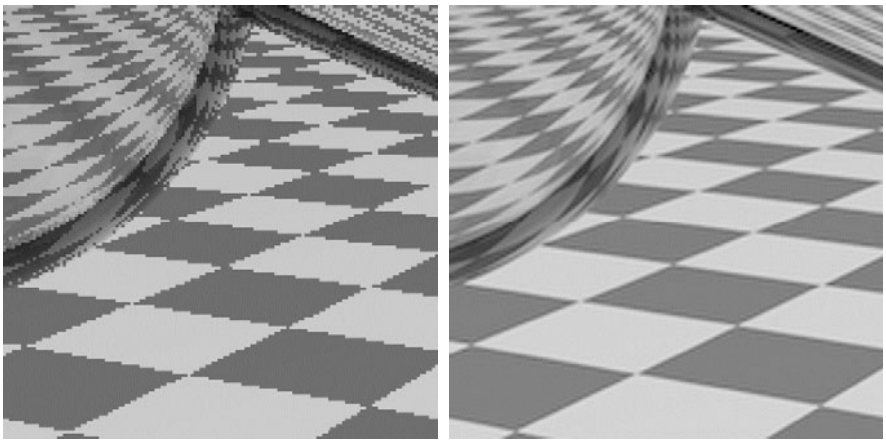
Checkerboard sequence by Tom Duff

Area-Sampling vs. Super-sampling



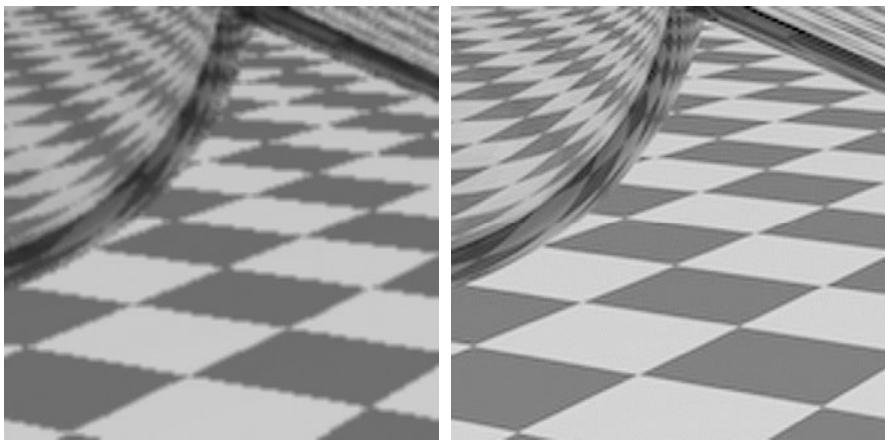
Exact Area **4x4 Super-sampled**

Antialiasing



Jaggies **Prefilter**

Antialiasing vs. Blurred Aliases



Blurred Jaggies **Prefilter**

Things to Remember

Sampling converts continuous to discrete

Image generation involves sampling

- **May also sample geometry, motion, …**

Nyquist frequency is ½ the sampling rate

Frequencies above the Nyquist frequency can aliases

- **That is, appear as other frequencies**

Antialiasing – Filter before sampling

Output is coverage; removes jaggies