CMSC 435
Introductory Computer Graphics

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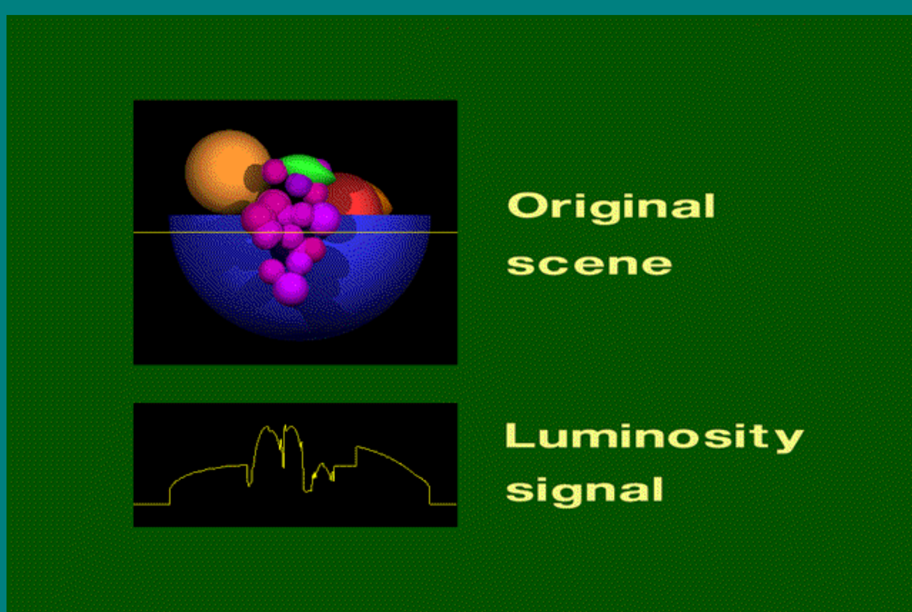
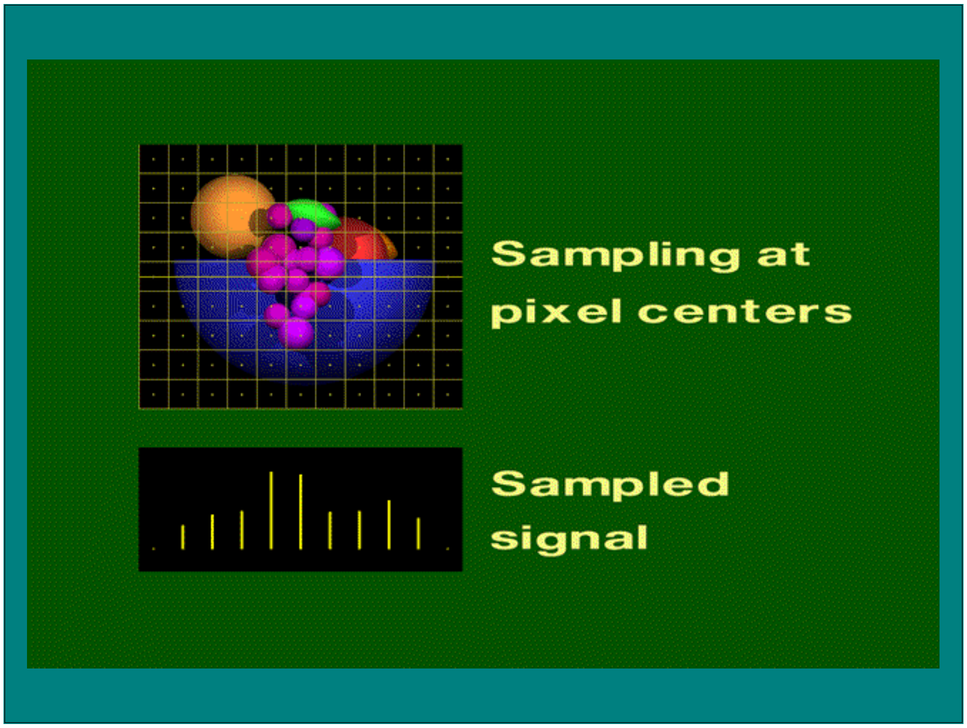
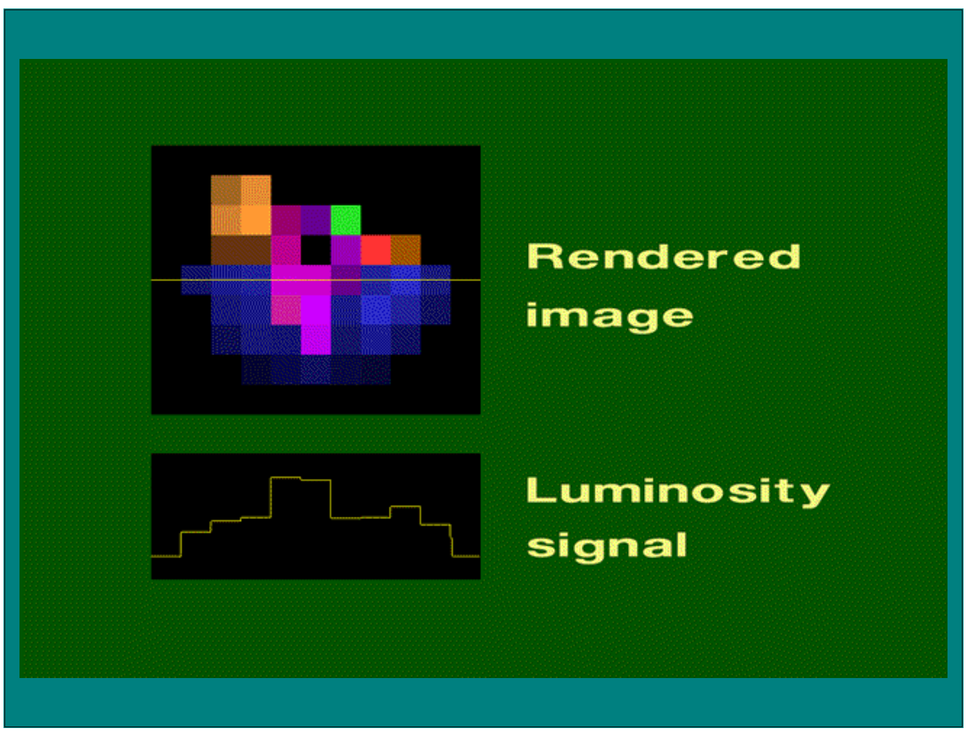
Announcements

Rendering Process

- Two basic stages
  - sampling
  - Reconstruction
- Sampling in rasterization
  - Ray locations in ray tracing
  - Evaluation points in barycentric formulation
  - Implicit evaluation locations in scanline rasterization
- Assuming discrete sampling



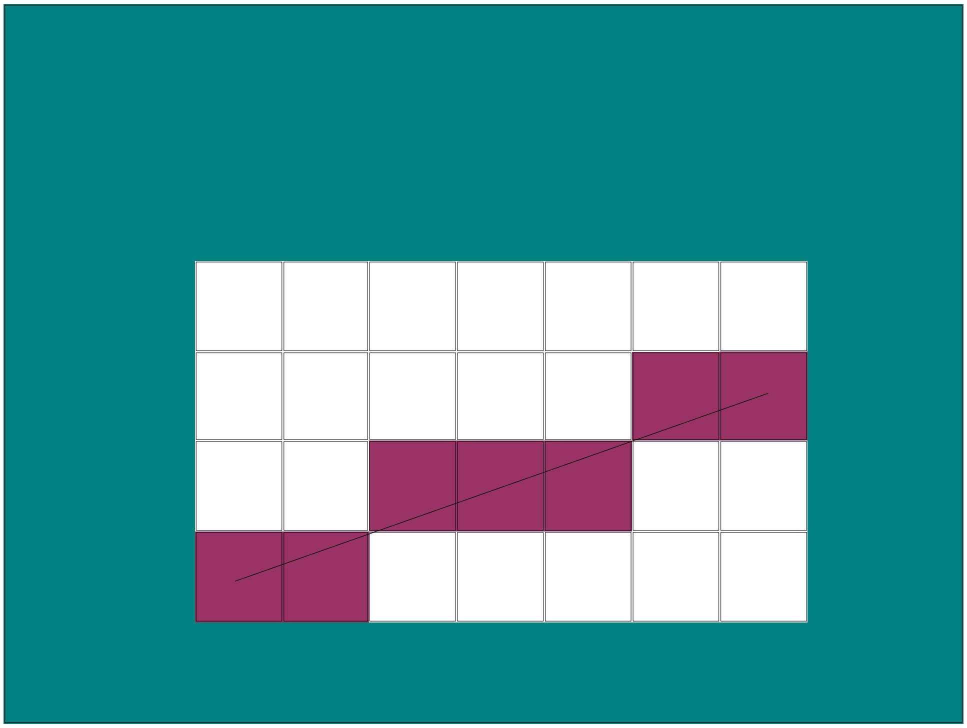

Sampling at
pixel centers
Sampled
signal

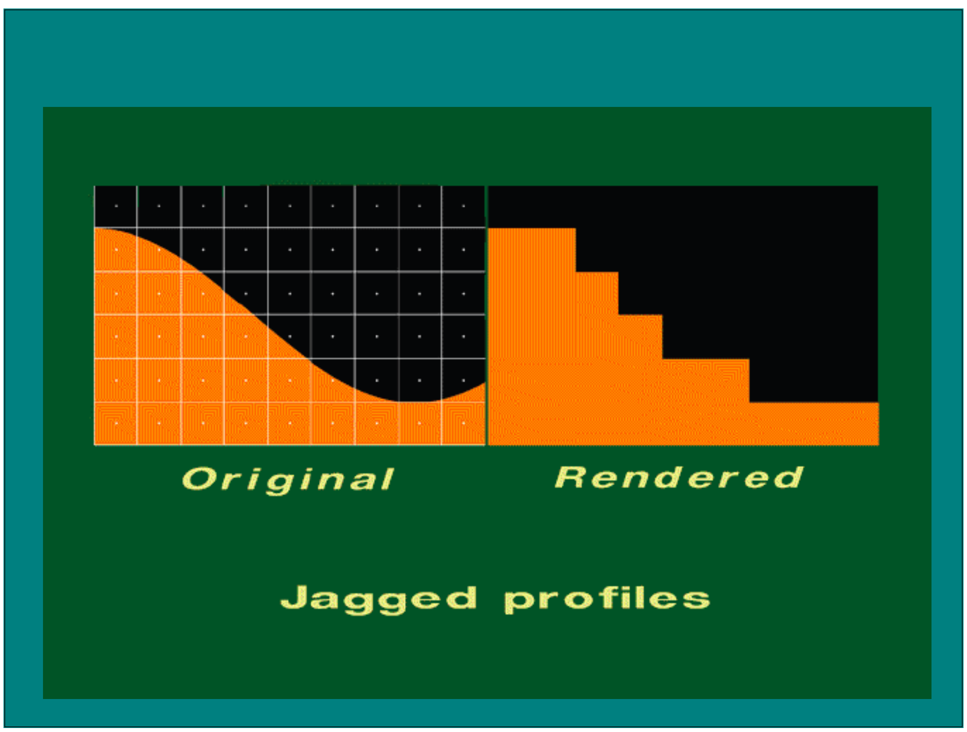

Rendered
image
Luminosity
signal

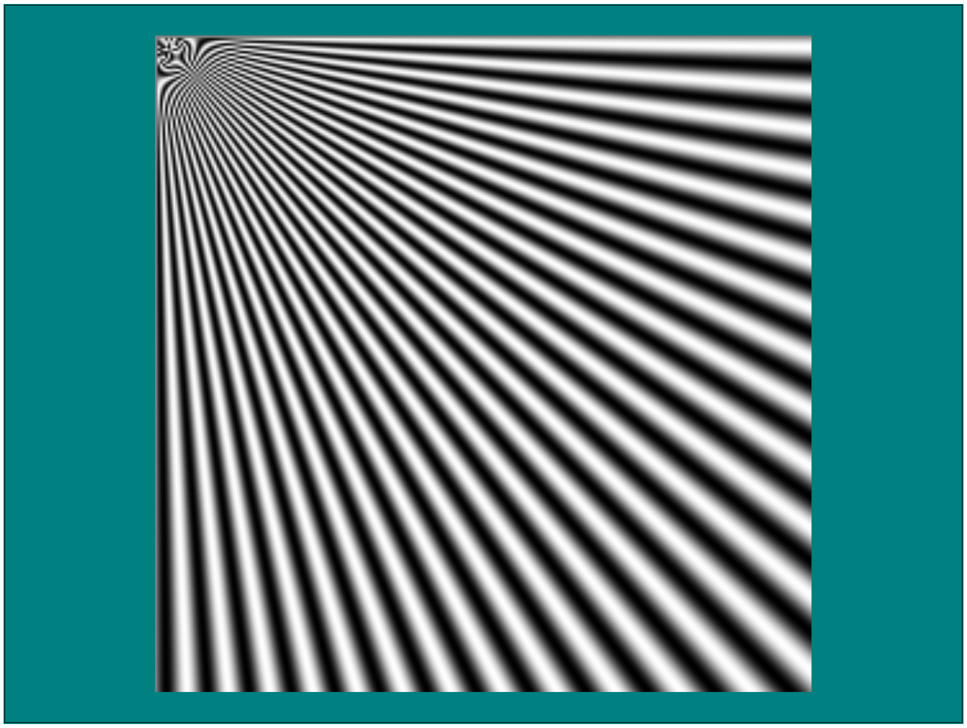
What went wrong?

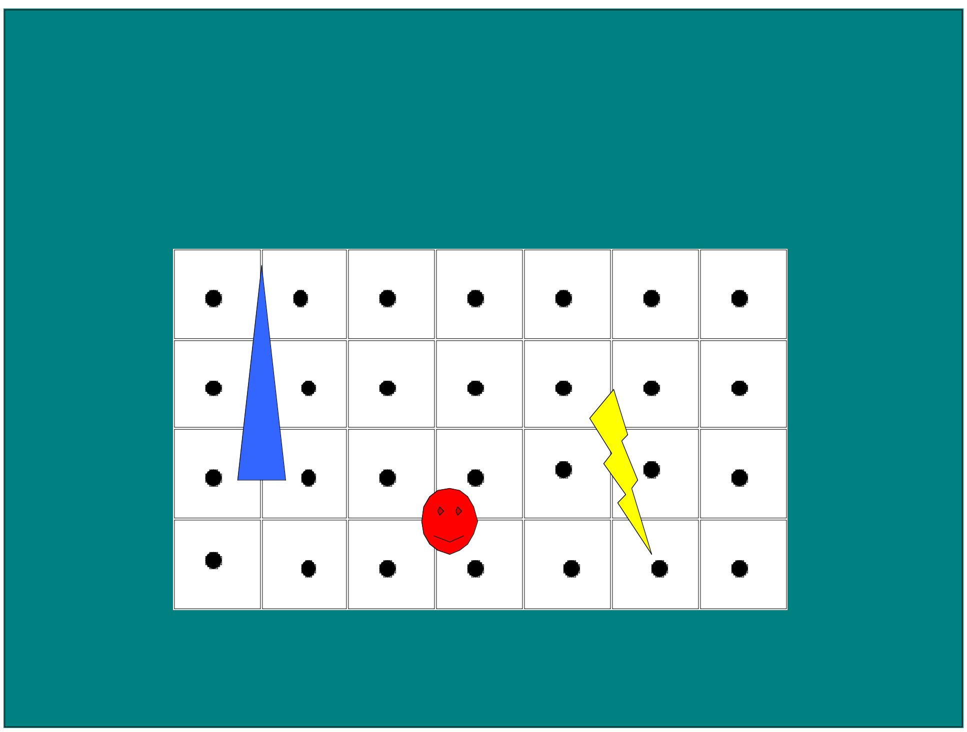
Aliasing

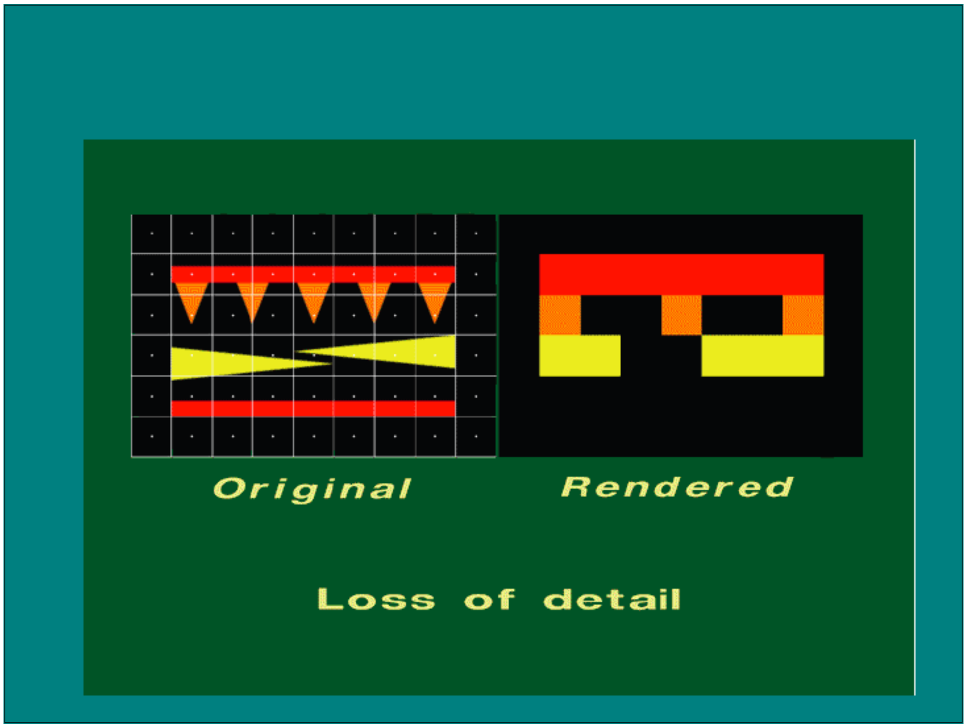
- Visual artifacts
  - jagged lines and edges
  - high frequencies appearing as low
  - small objects missed
  - texture distortions
  - strobing and popping
  - backward movement



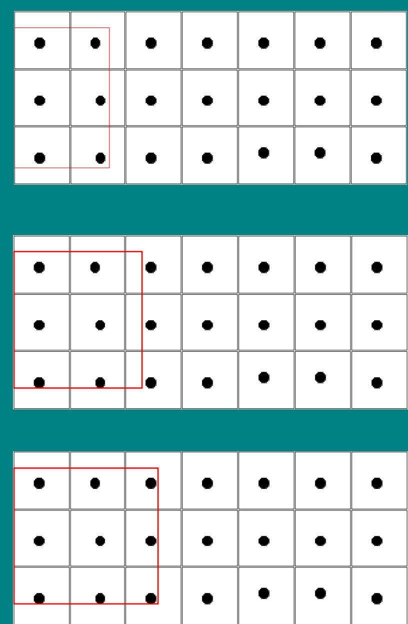

Original
Rendered
Jagged profiles



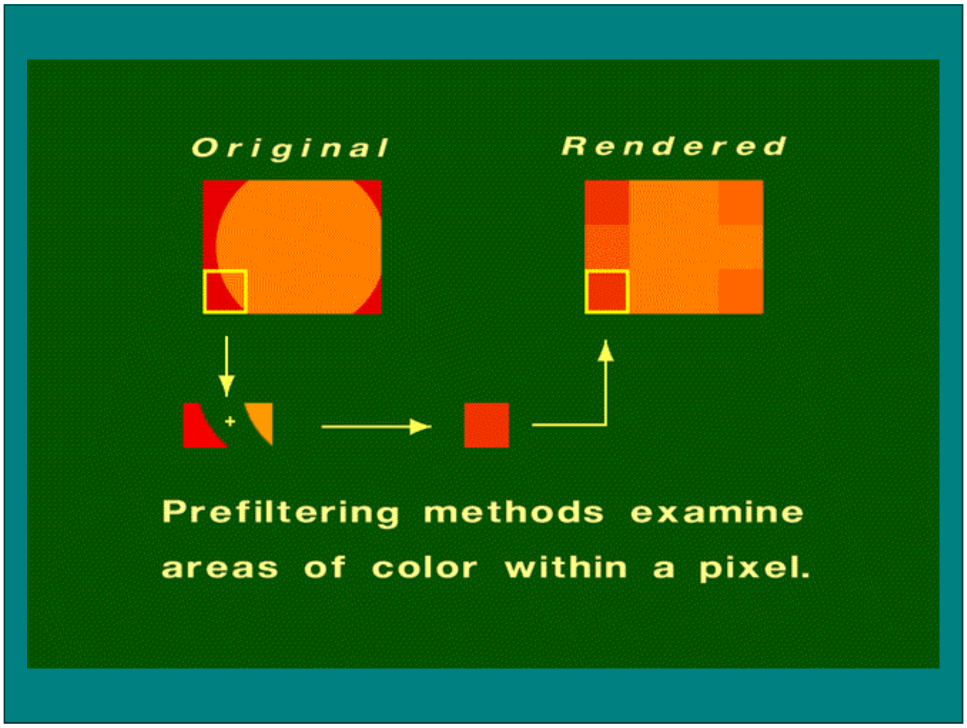



Original
Rendered
Loss of detail


No antialiasing

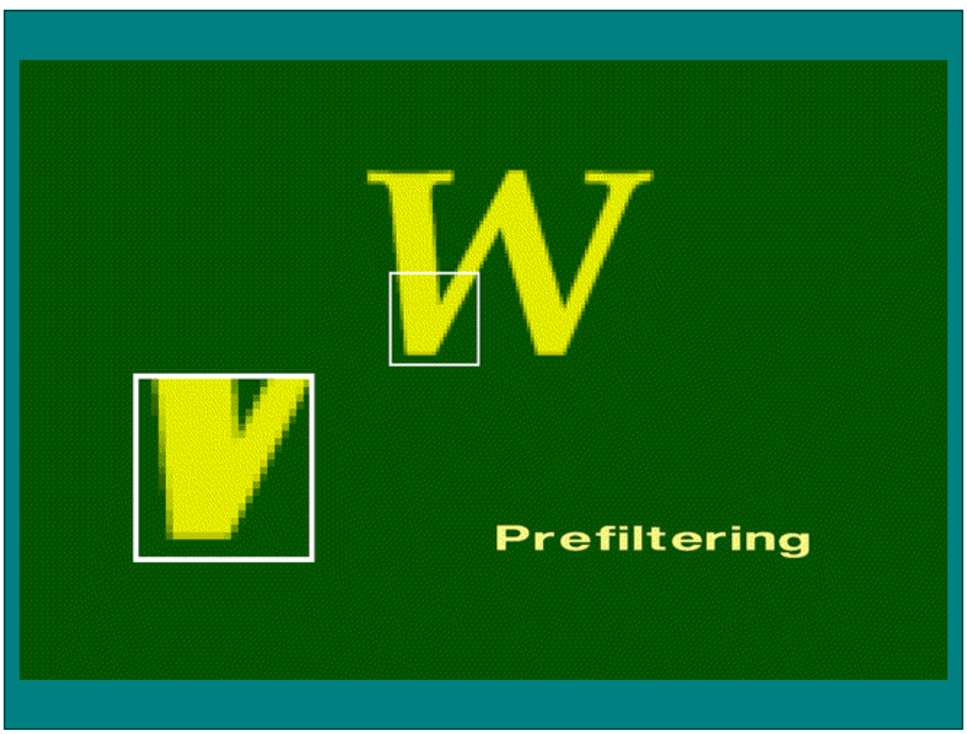


How might you fix aliasing?


Original
Rendered
Prefiltering methods examine areas of color within a pixel.


Hello World
Hello World
A demonstration

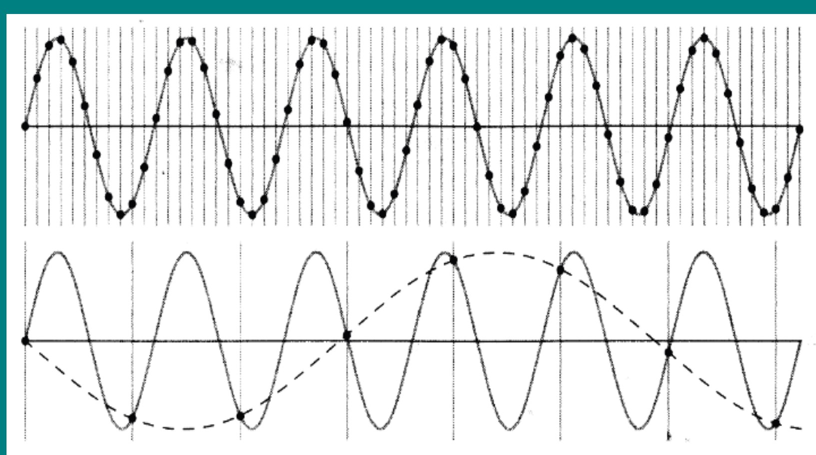

W
No antialiasing


W
Prefiltering

Sampling Theory

- Shannon's sampling theory (1D):
  - A band limited signal f(t) with cut off frequency w_F may be perfectly reconstructed from its samples $f(nT_0)$ if $2\pi/T_0 >= 2w_F$
  - w_F == Nyquist limit
- Alternatively:
  - a signal can be reconstructed exactly from samples only if the highest frequency is less than half the sampling rate

Sampling a Sine Wave



Convolution

- Operation on two functions that produces another function as the result
- Indicated by *
- Example: Moving average

$$h(x) = \frac{1}{2r}\int_{x-r}^{x+r} g(t)dt$$

$$c[i] = \frac{1}{2r+1}\sum_{j=i-r}^{i+r} b[j]$$

Discrete Convolution

$$(a*b)[i] = \sum_{j} a[j][b[i-j]$$

- Finite support: some r such that a[j]=0 whenever |j| >= r
- Alternatively, convolution as sum of shifted filters
  - Filter gives weights

Example: Moving average as convolution with box

$$b[i] = \begin{cases} 1 : i \geq 0 \\ 0 : i < 0 \end{cases}$$

$$a[j] = \begin{cases} 1 : -2 \leq j \leq 2 \\ 0 : otherwise \end{cases}$$

Convolution with continuous filters

$$(f * g)(x) = \int_{-\infty}^{+\infty} f(t)g(x-t)dt$$

- Area under curve of product after shifting

Example: convolution of 2 boxes

$$f(x) = \{ \begin{matrix} 1: -1/2 \le x \le 1/2 \\ 0: otherwise \end{matrix}$$

Fourier Transforms

- Basis Functions
  - orthogonal: projection of any onto another is 0
  - complex exponentials as foundations for Fourier Series
- Concepts
  - image space
  - frequency space

Fourier Transforms (cont.)

- Fourier Transform

$$X(\omega) = \frac{1}{\sqrt{2\pi}} \int x(t) e^{-j\omega t} dt$$

- Inverse Fourier Transform

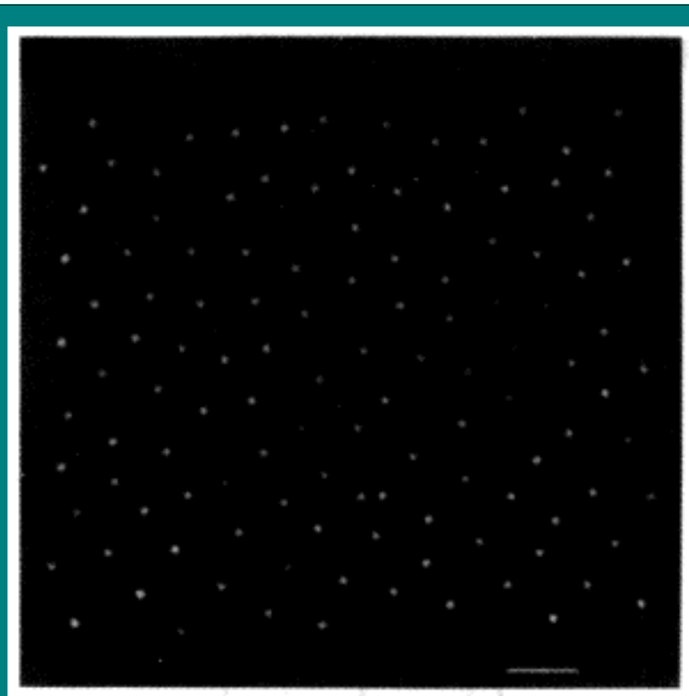
$$x(t) = \frac{1}{\sqrt{2\pi}} \int X(\omega) e^{j\omega t} d\omega$$

Properties of Filters

- Interpolating vs approximating
  - Through sample points vs near
- Degree of continuity
  - Degree of differentiability
- Separable
  - Different dimensions do not interact

Sampling Schemes

- Regular supersampling
- Jittered supersampling
- Adaptive supersampling
- Stochastic sampling



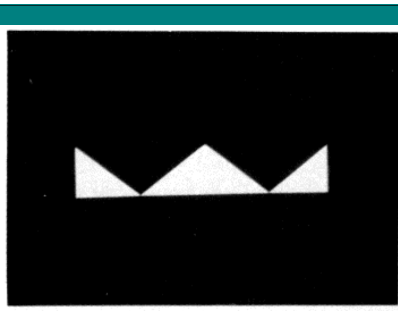


Fig. 12c. Comb rendered with a regular grid, one sample per pixel.

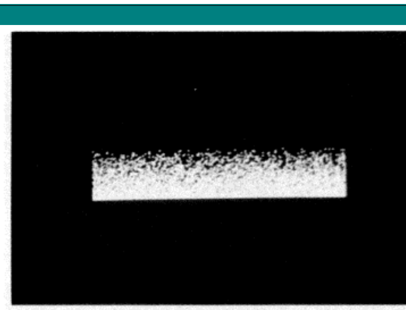
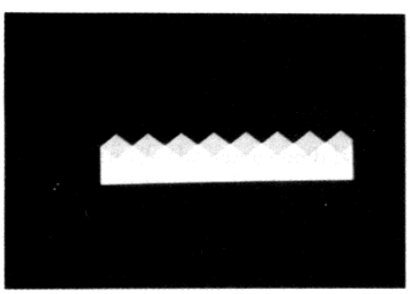
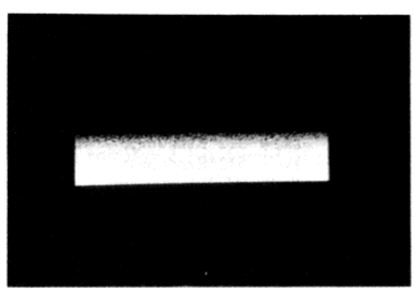
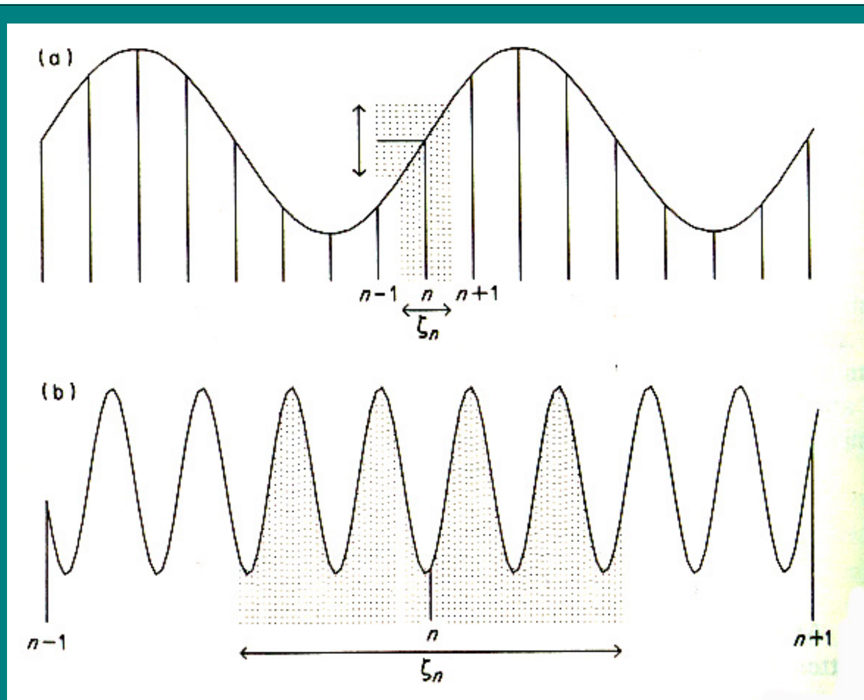


Fig. 12d. Comb rendered with a jittered grid, one sample per pixel.



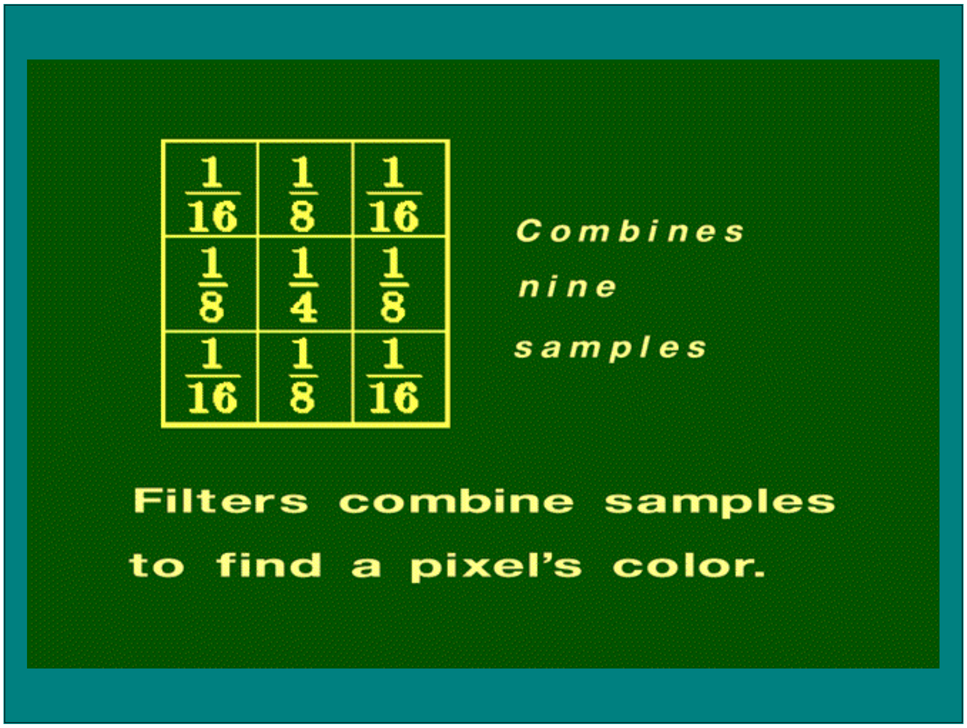


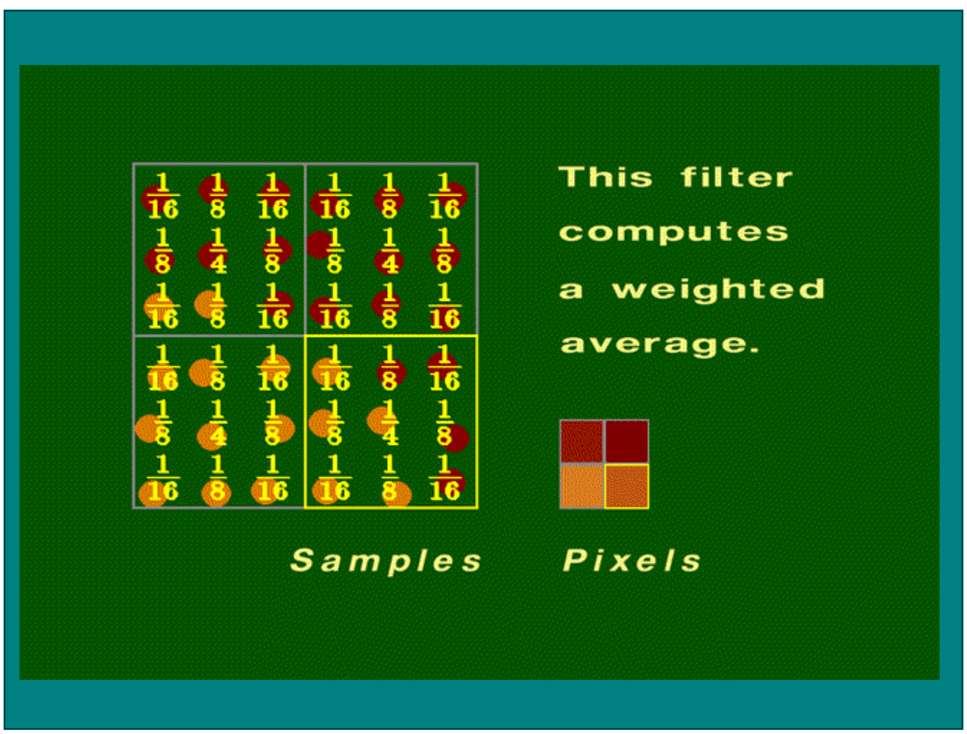


Reconstruction

- Two basic stages
  - Sampling : continuous to discrete
  - Reconstruction : discrete to continuous
- Tasks of reconstruction filter
  - remove extraneous replicas of signal spectrum
  - pass the original signal base unchanged
- 2D version

$$(a * b)[i,j] = \sum_{i'} \sum_{j'} a[i',j']b[i-i',j-j']$$


1/16 1/8 1/16
1/8 1/4 1/8
1/16 1/8 1/16
Combines
nine
samples
Filters combine samples
to find a pixel's color.

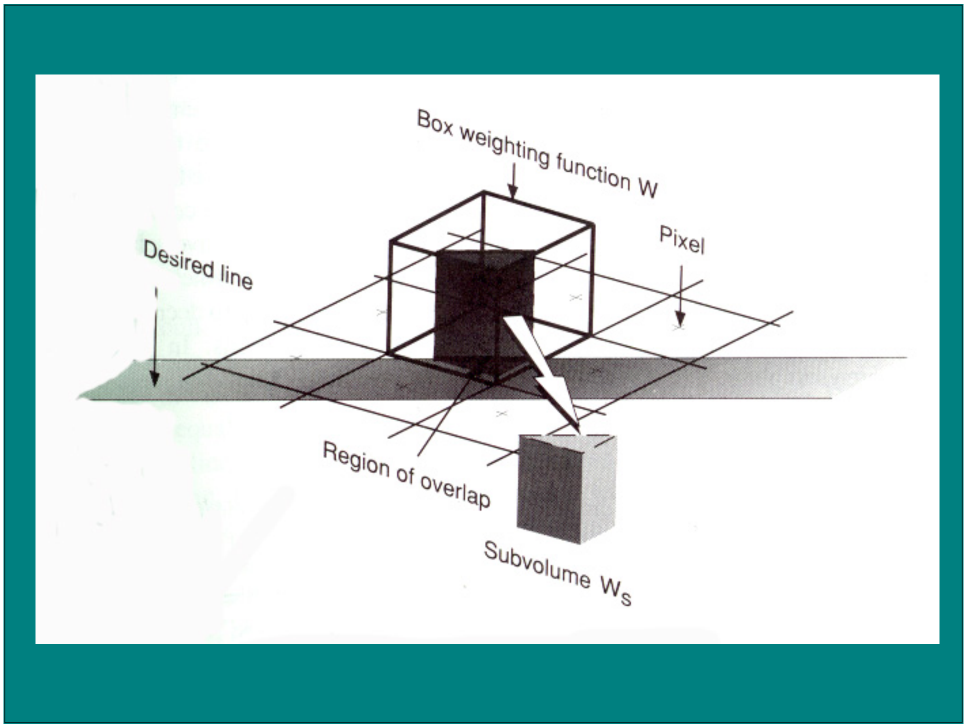

This filter
computes
a weighted
average.
Samples
Pixels

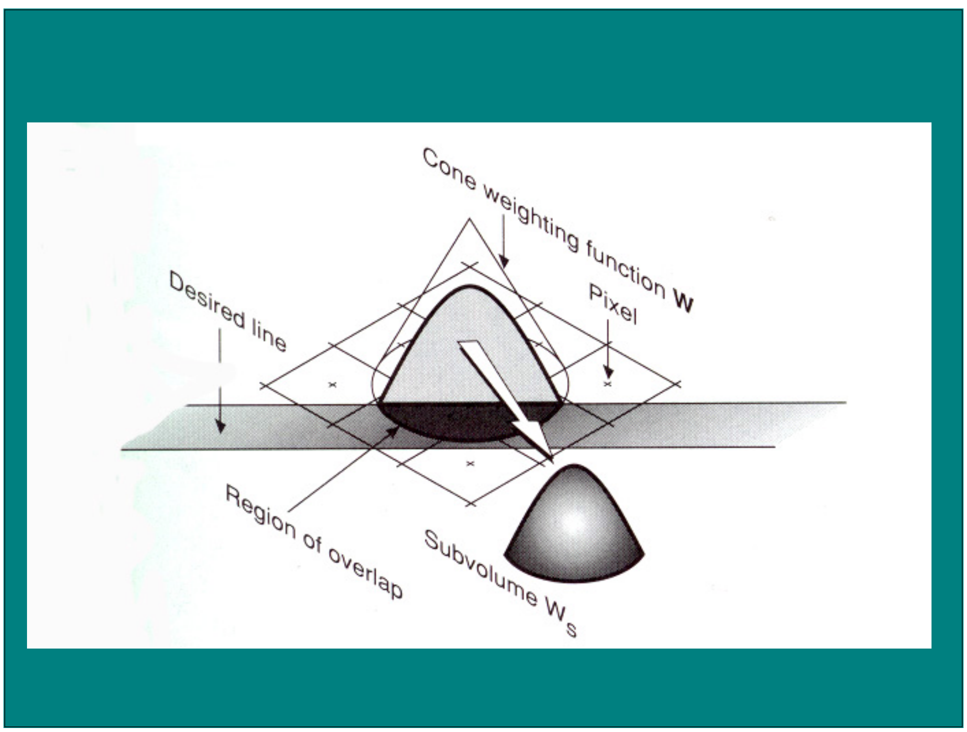

No antialiasing


3x3 supersampling
3x3 unweighted filter

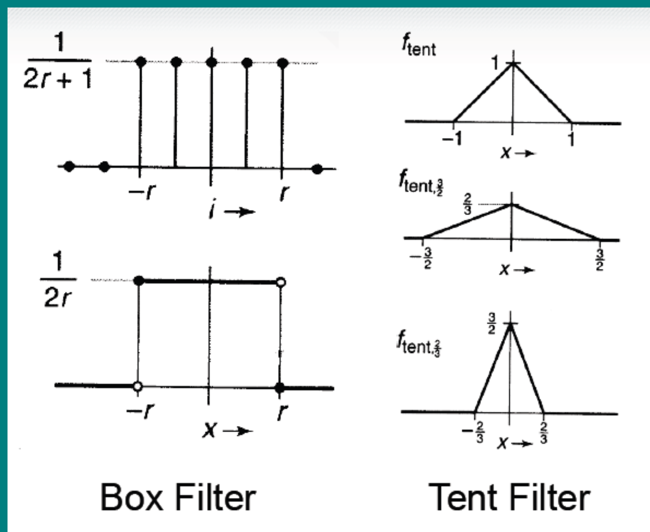

3x3 supersampling
5x5 weighted filter


3x3 jittered supersampling
5x5 weighted filter

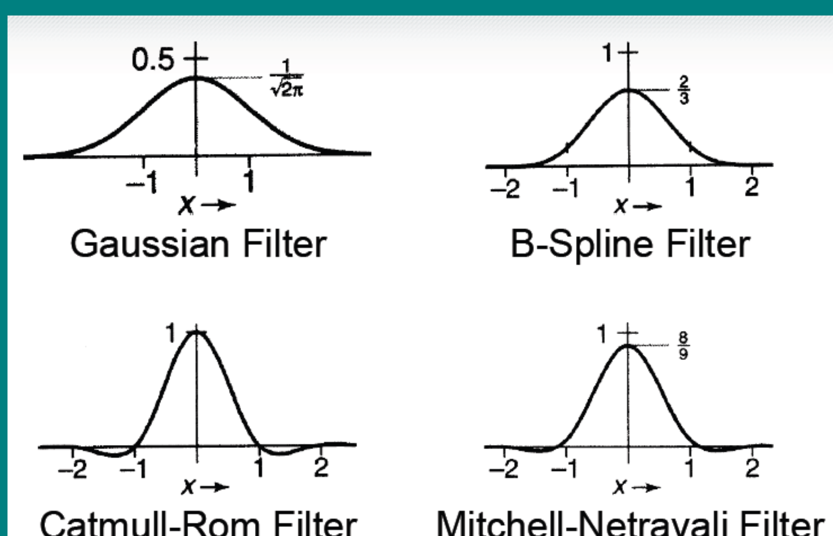

Box weighting function W
Pixel
Desired line
Region of overlap
Subvolume W_S


Cone weighting function **W**
Pixel
Desired line
Region of overlap
Subvolume W_S

Convolution Filters



Convolution Filters



Reconstruction Artifacts

- Aliasing
  - prealiasing: from undersampling
  - postaliasing: from poor reconstruction
- Blurring
- Ringing
- Sample-frequency ripple
- Anisotropic effects

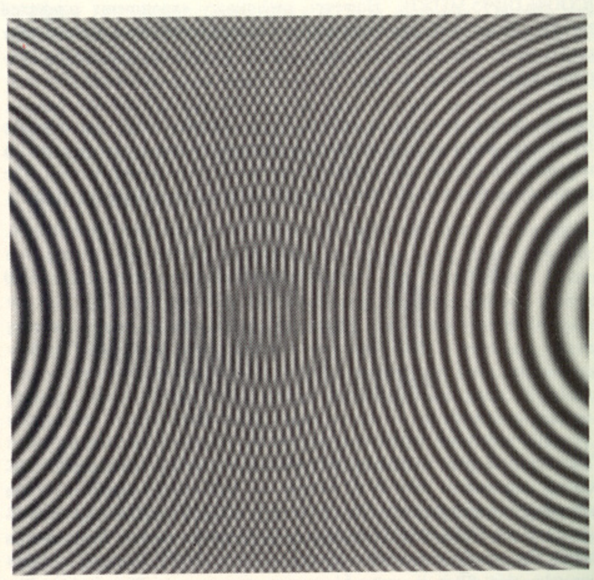


Figure 4. Prealiasing and Postaliasing Example

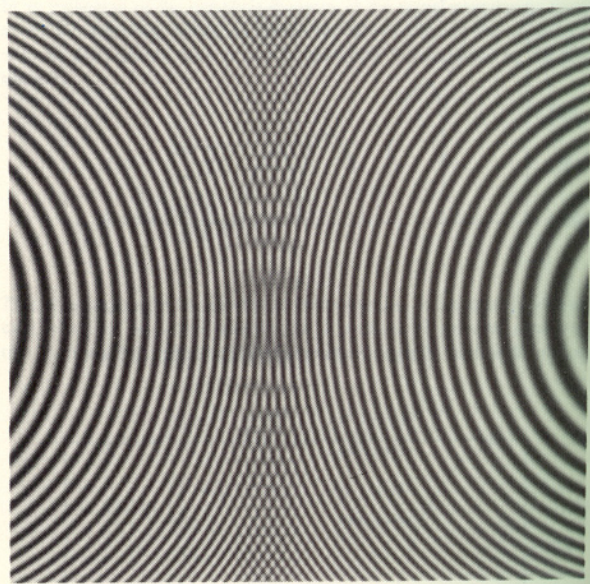


Figure 5. Nearly Ideal Postfiltering

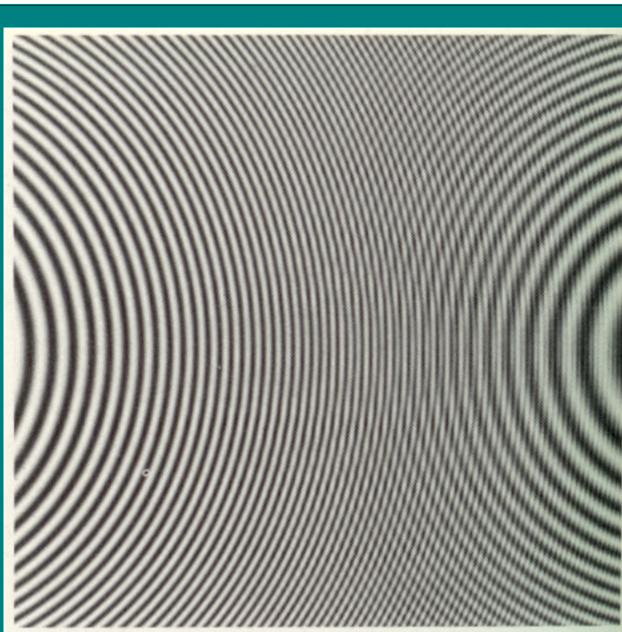


Figure 15. Using Derivative Reconstruction

Figure 11. Excessive Blurring

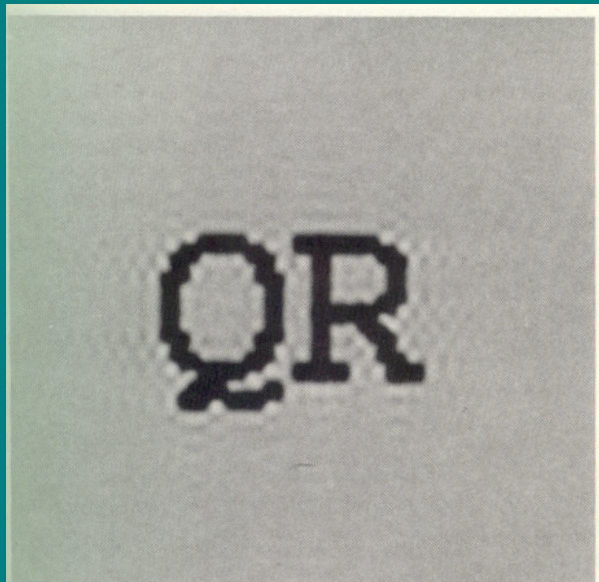


Figure 6. Ringing Caused By Sinc Postfilter

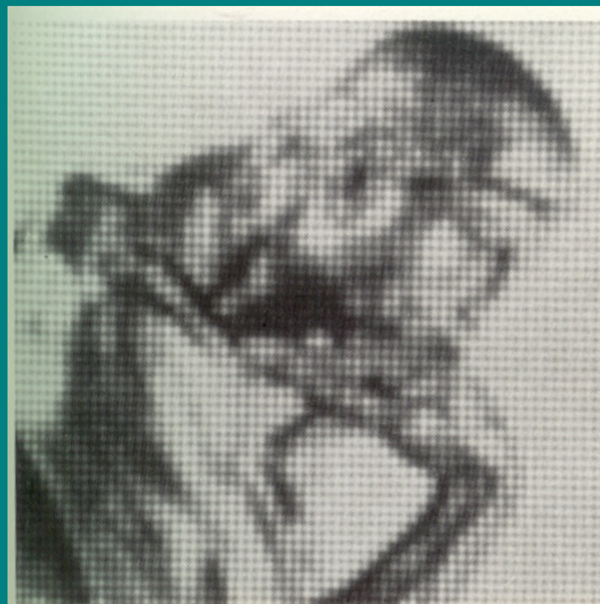


Figure 8. Sample-Frequency Ripple

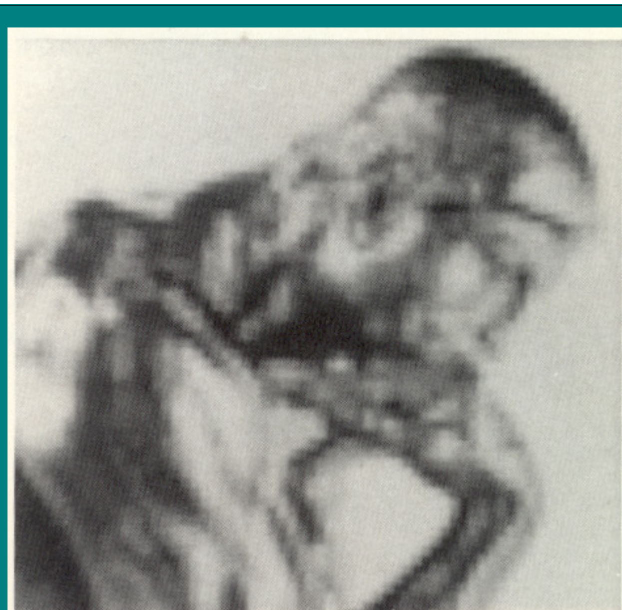


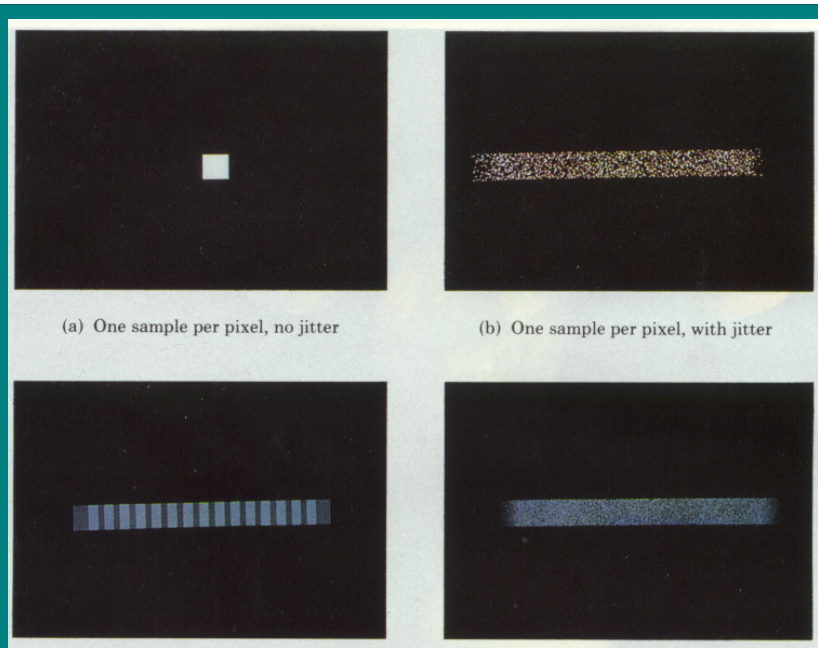
Figure 9. Anisotropic Artifacts

Preventing Aliasing

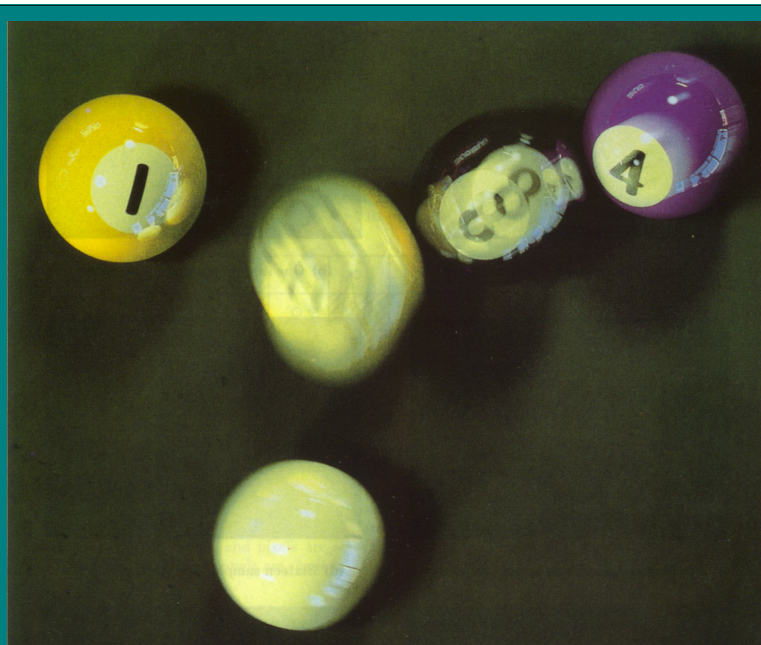
- Sufficient sampling rate/scheme
  - Determined by Nyquist limit
  - Non-regular sampling as substitute
- Appropriate reconstruction filter
  - Good lowpass filter
  - Reduce leakage of high frequencies

Other Stochastic Effects

- Motion blurring
- Depth of Field
- Gloss



- Cook '86



- Cook '86

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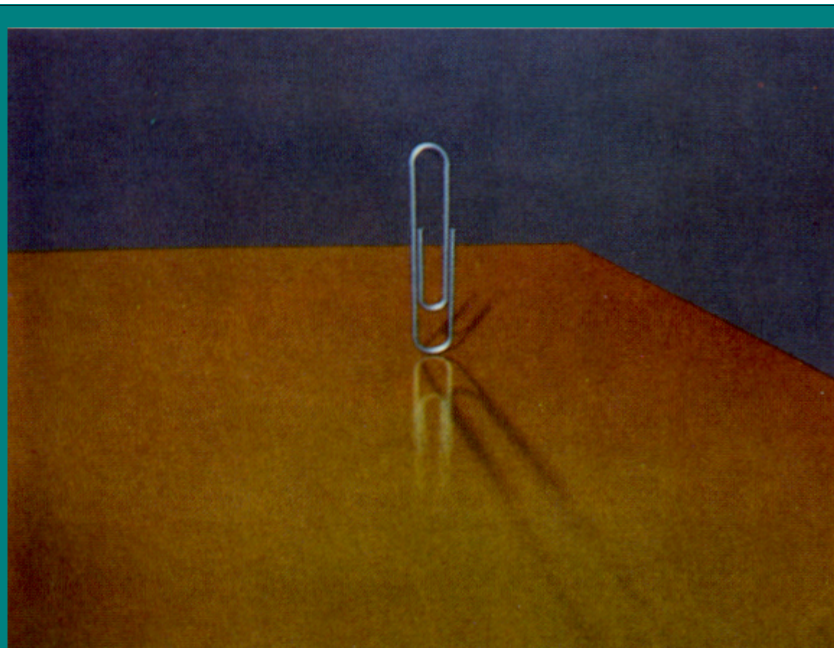
- Cook '86

- Cook '86



- Cook '86