Sampling & Reconstruction

Wolfgang Heidrich

Course News

Assignment 3 (project)

- Out last Friday
- Start thinking about a project soon!

Homework 6

- Texture mapping

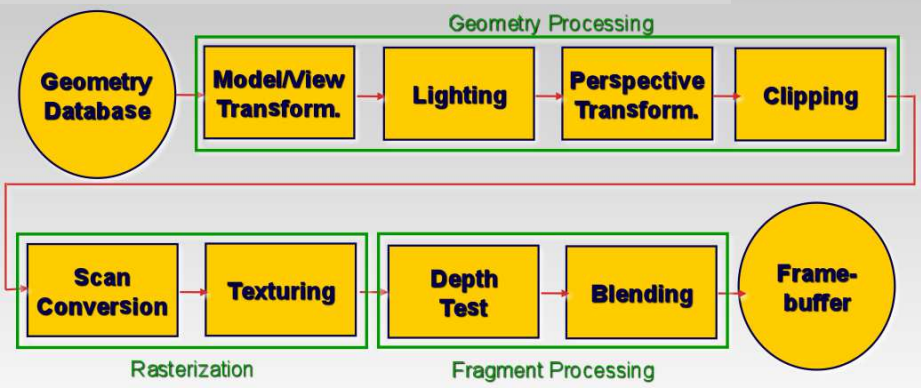
Quiz 2 MOVED!

- Friday, March 13 (instead of Wed, March 11)

Reading

- Chapter 11 (w/o 11.8)

The Rendering Pipeline



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Environment Mapping

Cheap way to achieve reflective effect

- Generate image of surrounding
- Map to object as texture

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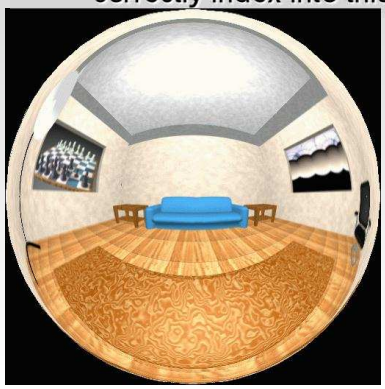
Sphere Mapping

Texture is distorted fish-eye view

- Point camera at mirrored sphere
- Spherical texture mapping creates texture coordinates that correctly index into this texture map



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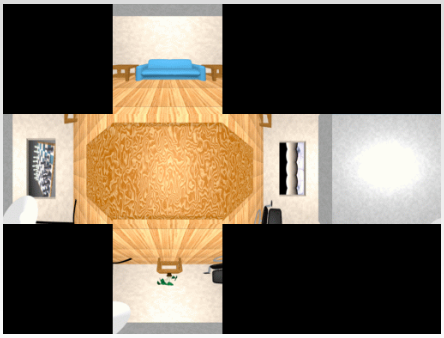
Cube Mapping

6 planar textures, sides of cube

- Point camera in 6 different directions, facing out from origin



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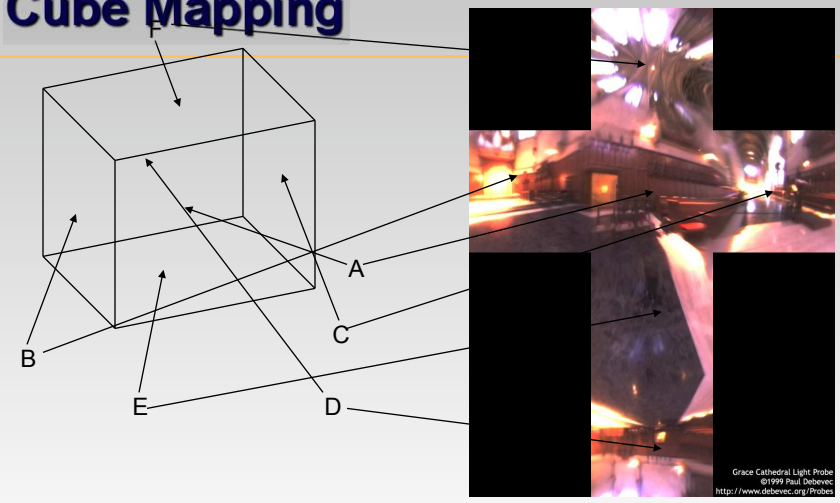
Cube Mapping



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Cube Mapping

Direction of reflection vector r selects the face of the cube to be indexed

- Co-ordinate with largest magnitude
  - *e.g., the vector (-0.2, 0.5, -0.84) selects the –Z face*
- Remaining two coordinates (normalized by the 3rd coordinate) selects the pixel from the face.
  - *E.g., (-0.2, 0.5) gets mapped to (0.38, 0.80).*

Difficulty in interpolating across faces

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Displacement Mapping

Bump mapping gets silhouettes wrong

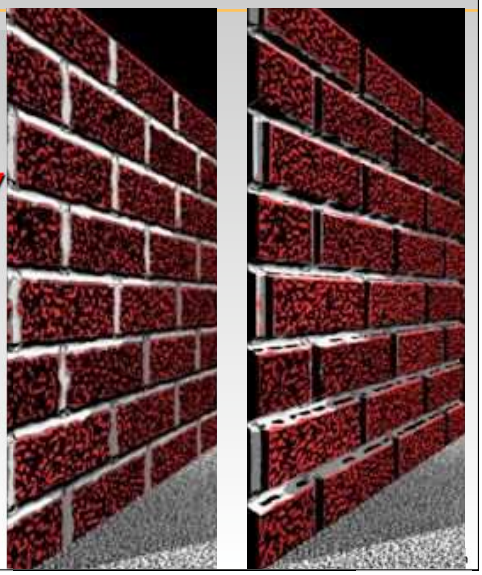
- Shadows wrong too

Change surface geometry instead

- Need to subdivide surface

GPU support

- Bump and displacement mapping not directly supported: require per-pixel lighting
- However: modern GPUs allow for programming both yourself

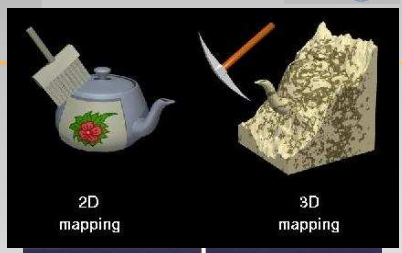


Volumetric (3D) Texture

Define texture pattern over 3D domain - 3D space containing the object

- Texture function can be sampled
  - *3D table of texels*
- Or procedural
  - *A function describes the color at each point*
  - *Implemented in special shading language*

Common for natural material/ irregular textures (stone, wood,etc…)



Volumetric Bump Mapping

Marble

Bump

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Volumetric Texture Mapping

In OpenGL:

- Sampled 3D textures supported very much analogously to 2D textures:
  - *glTexCoord3f, glTexImage3f…*

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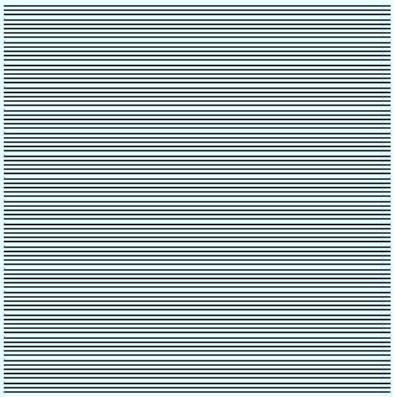
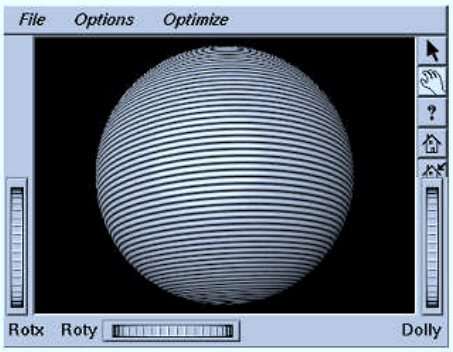
Texture Lookup – Sampling & Reconstruction





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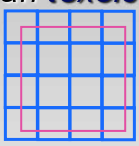
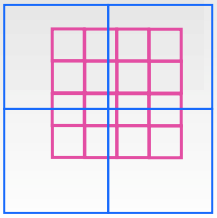
Texture Lookup – Sampling & Reconstruction

- How to deal with:
  - *Pixels that are much larger than texels?*
    - Apply filtering, "averaging"
    - "Minification"



  - *Pixels that are much smaller than texels ?*
    - Interpolate
    - "Magnification"



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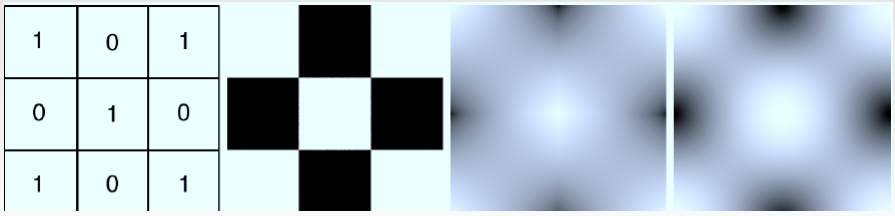
Magnification: Interpolating Textures

- Nearest neighbor
- Bilinear
- Hermite (cubic)



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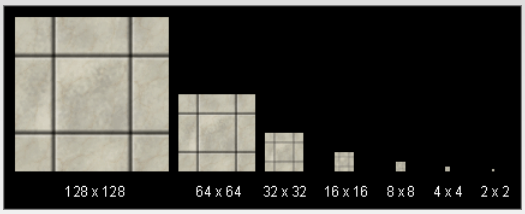
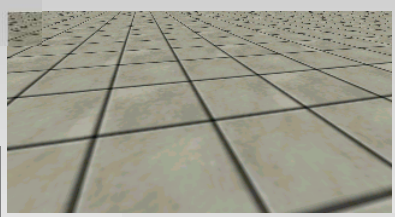
Minification: MIPmapping

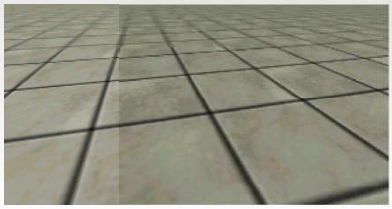
use “image pyramid” to precompute averaged versions of the texture



store whole pyramid in single block of memory



Without MIP-mapping



With MIP-mapping

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MIPmaps

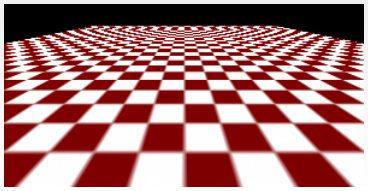
Multum in parvo -- ***many things in a small place***

- Prespecify a series of prefiltered texture maps of decreasing resolutions
- Requires more texture storage
- Avoid shimmering and flashing as objects move

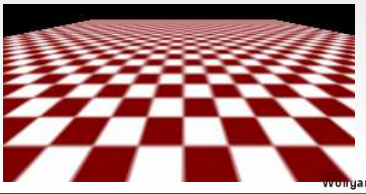
gluBuild2DMipmaps

- Automatically constructs a family of textures from original texture size down to 1x1

without



with



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MIPmap storage

only 1/3 more space required

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Sampling & Reconstruction

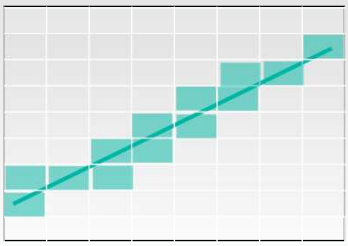
CPSC 314

Samples

- Most things in the real world are continuous
- Everything in a computer is discrete
- The process of mapping a continuous function to a discrete one is called sampling
- The process of mapping a discrete function to a continuous one is called reconstruction
- The process of mapping a continuous variable to a discrete one is called quantization
- Rendering an image requires sampling and quantization
- Displaying an image involves reconstruction

Line Segments

- We tried to sample a line segment so it would map to a 2D raster display
- We quantized the pixel values to 0 or 1
- We saw stair steps, or jaggies



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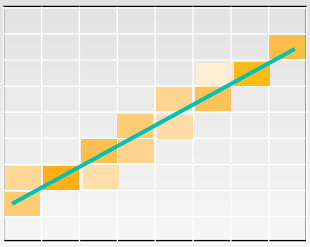
Line Segments

- Instead, quantize to many shades
- But what sampling algorithm is used?



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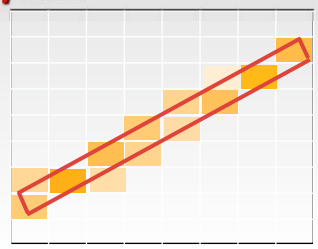
Unweighted Area Sampling

Shade pixels wrt area covered by thickened line

Equal areas cause equal intensity, regardless of distance from pixel center to area

- Rough approximation formulated by dividing each pixel into a finer grid of pixels

Primitive cannot affect intensity of pixel if it does not intersect the pixel



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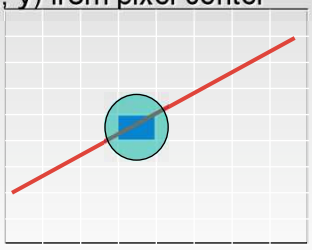
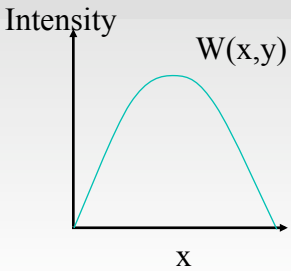
Weighted Area Sampling

Intuitively, pixel cut through the center should be more heavily weighted than one cut along corner

Weighting function, W(x,y)

- Specifies the contribution of primitive passing through the point (x, y) from pixel center





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Images

An image is a 2D function I(x, y)

- Specifies intensity for each point (x, y)
- (we consider each color channel independently)

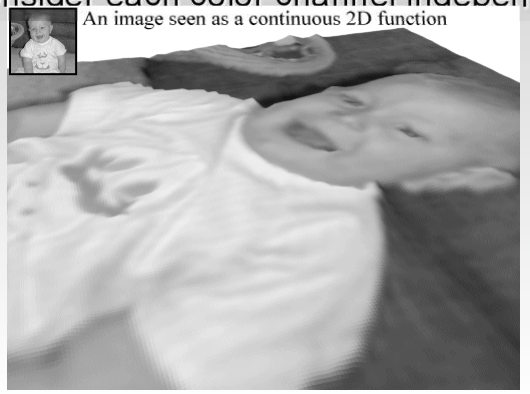

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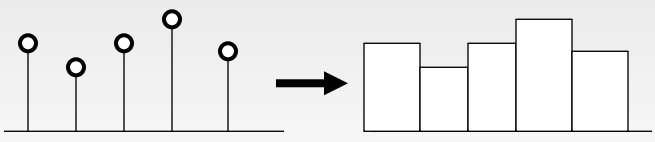
Image Sampling and Reconstruction

- Convert continuous image to discrete set of samples
- Display hardware reconstructs samples into continuous image
  - *Finite sized source of light for each pixel*



discrete input values

continuous light output

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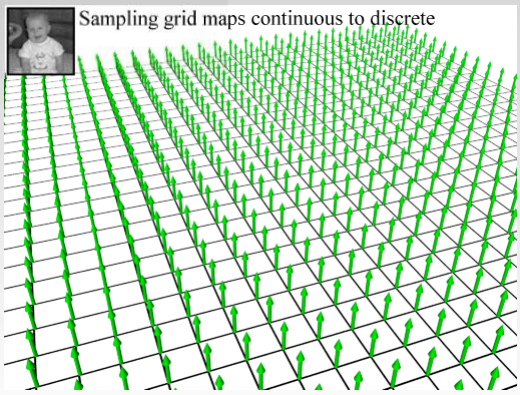
Point Sampling an Image

- Simplest sampling is on a grid
- Sample depends solely on value at grid points



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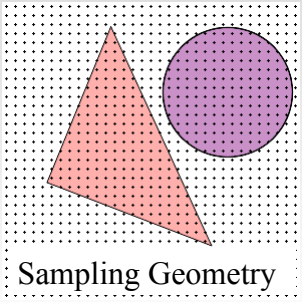
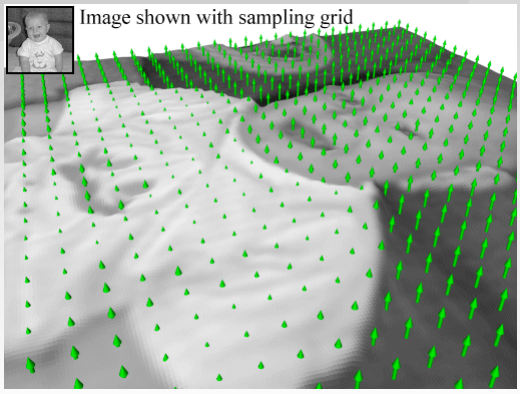
Point Sampling

Multiply sample grid by image intensity to obtain a discrete set of points, or samples.





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Sampling Errors

Some objects missed entirely, others poorly sampled

- Could try unweighted or weighted area sampling
- But how can we be sure we show everything?

Need to think about entire class of solutions!

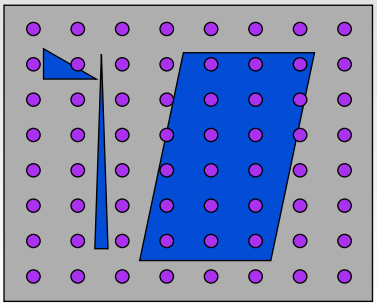

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Image As Signal

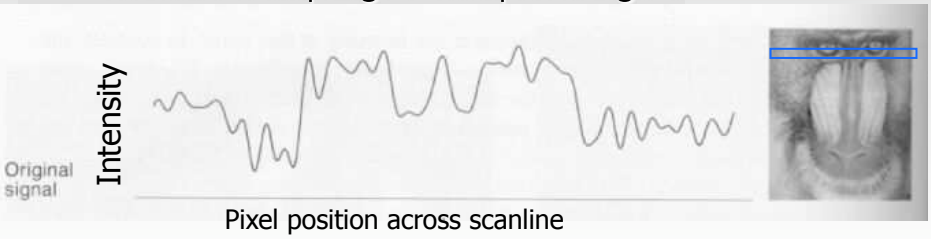
Image as spatial signal

2D raster image

- Discrete sampling of 2D spatial signal

1D slice of raster image

- Discrete sampling of 1D spatial signal



Examples from Foley, van Dam, Feiner, and Hughes

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Sampling Theory

How would we generate a signal like this out of simple building blocks?

Theorem

- Any signal can be represented as an (infinite) sum of sine waves at different frequencies

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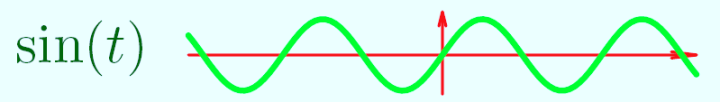
Sampling Theory in a Nutshell

Terminology

- Wavelength – length of repeated sequence on infinite signal
- Frequency – 1/wavelength (number of repeated sequences in unit length)

Example – sine wave

- Wavelength = 2π
- Frequency = $1/2\pi$



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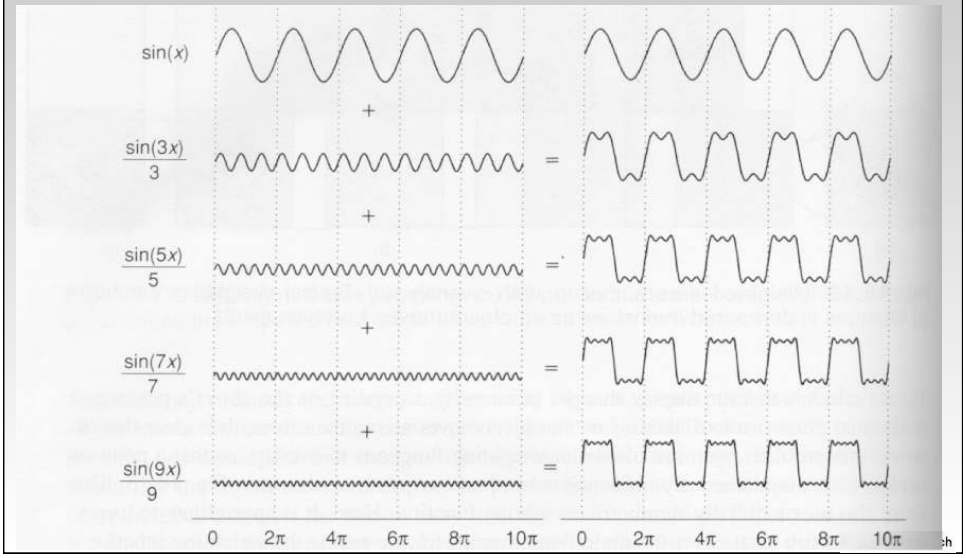
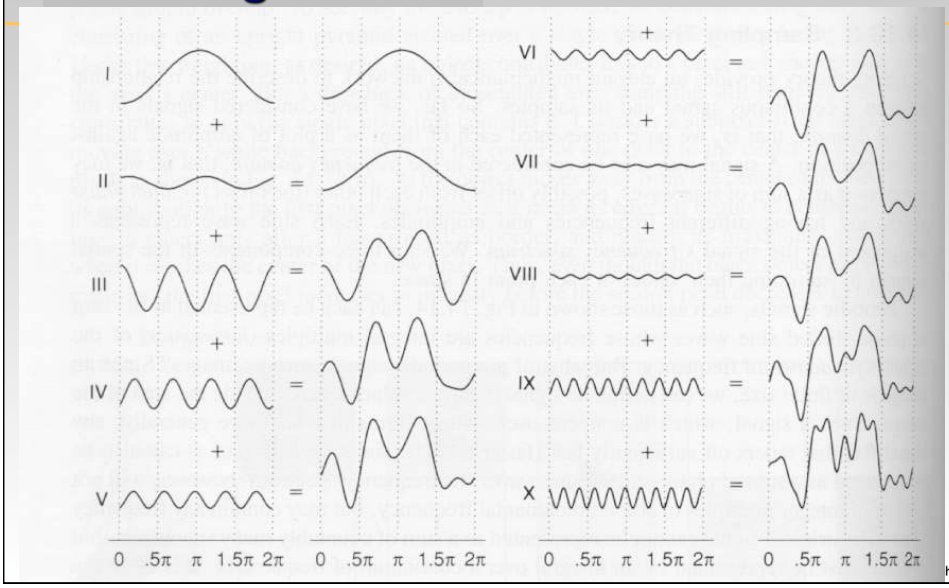
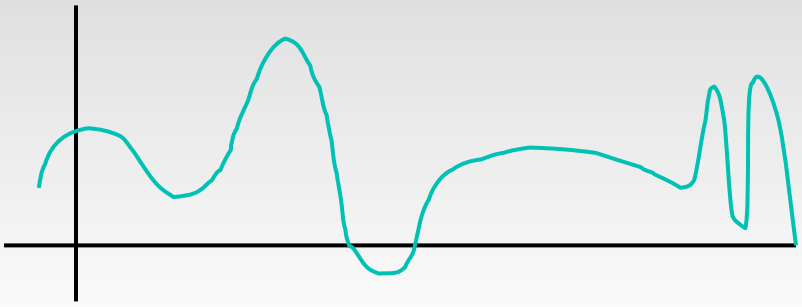
Summing Waves I



Summing Waves II



1D Sampling and Reconstruction



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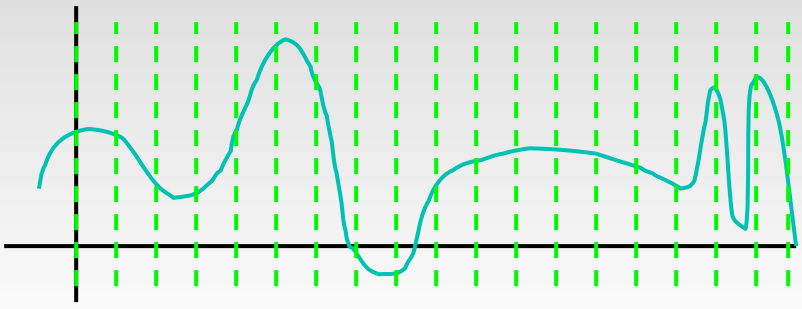
1D Sampling and Reconstruction



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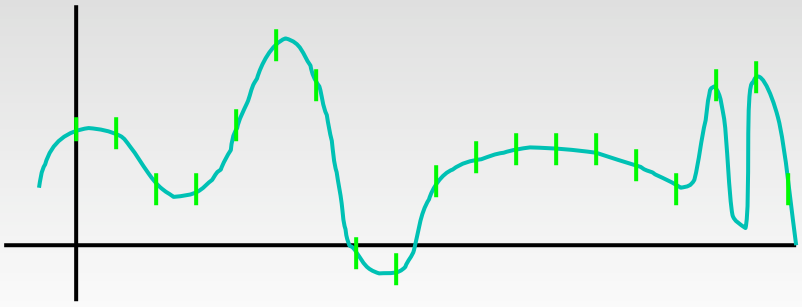
1D Sampling and Reconstruction



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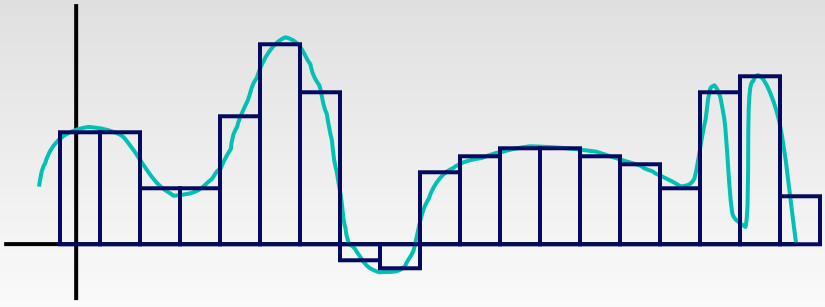
1D Sampling and Reconstruction



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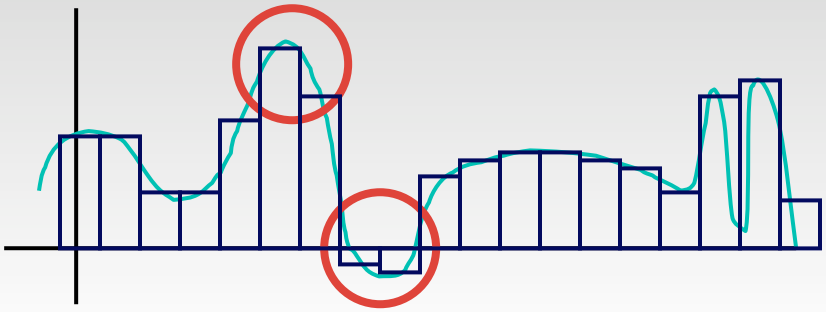
1D Sampling and Reconstruction

Problems

- Jaggies – abrupt changes



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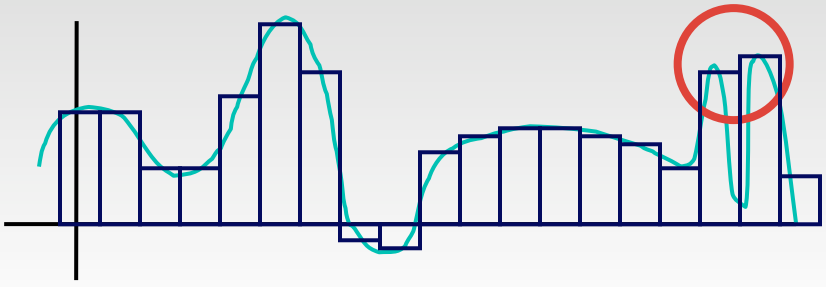
1D Sampling and Reconstruction

Problems

- Jaggies – abrupt changes
- Lose data



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Sampling Theorem

- Continuous signal can be completely recovered from its samples

Iff

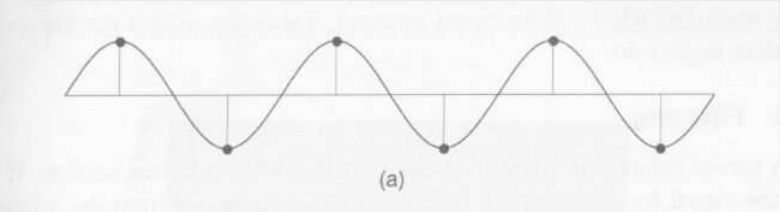
- Sampling rate greater than twice highest frequency present in signal

- Claude Shannon

Nyquist Rate

Lower bound on sampling rate

- Twice the highest frequency component in the image's spectrum



Falling Below Nyquist Rate

When sampling below Nyquist Rate, resulting signal looks like a lower-frequency one

- This is aliasing!

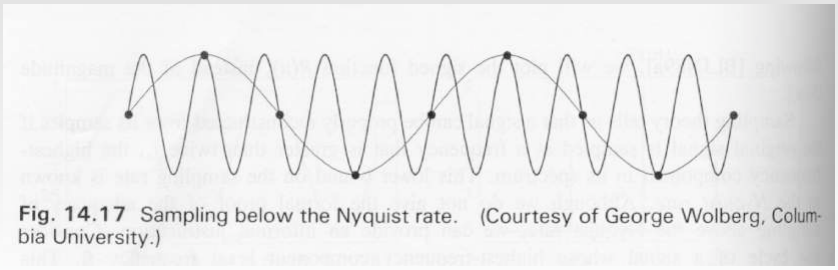


Fig. 14.17 Sampling below the Nyquist rate. (Courtesy of George Wolberg, Columbia University.)

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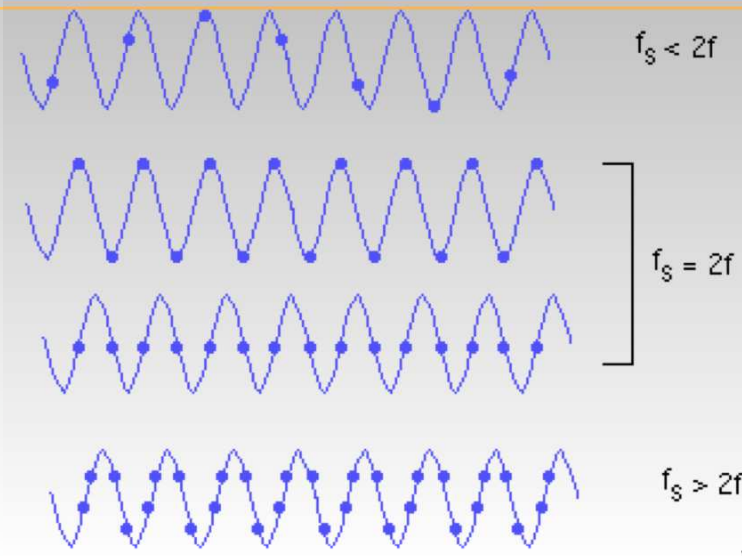
Nyquist Rate



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Aliasing

Incorrect appearance of high frequencies as low frequencies

To avoid: anti-aliasing

- Supersample
  - *Sample at higher frequency*
- Low pass filtering
  - *Remove high frequency function parts*
  - *Aka prefiltering, band-limiting*

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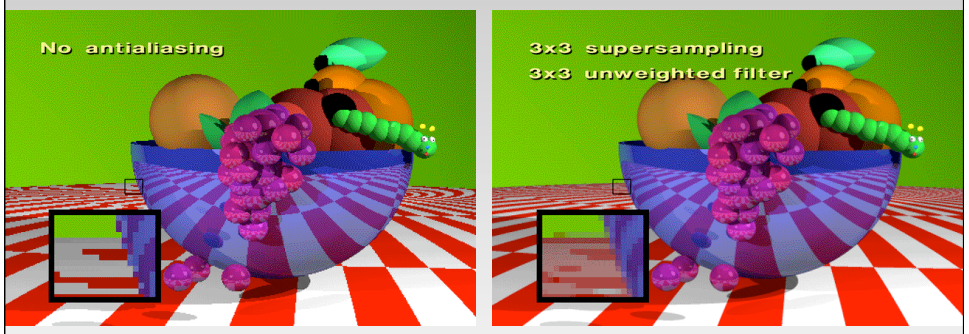
Supersampling



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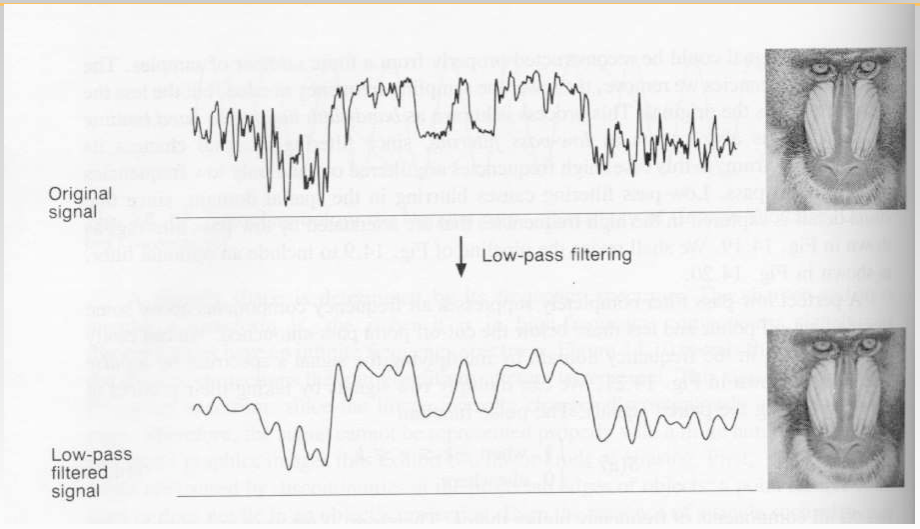
Low-Pass Filtering



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Low-Pass Filtering

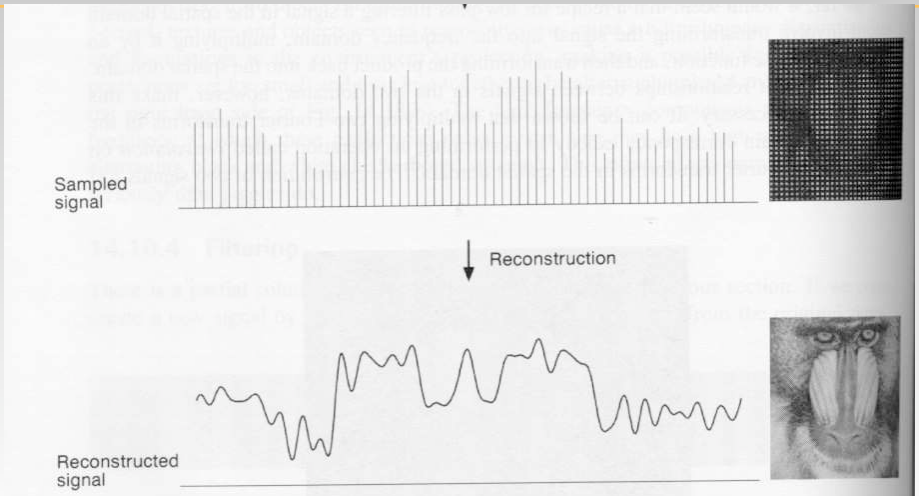
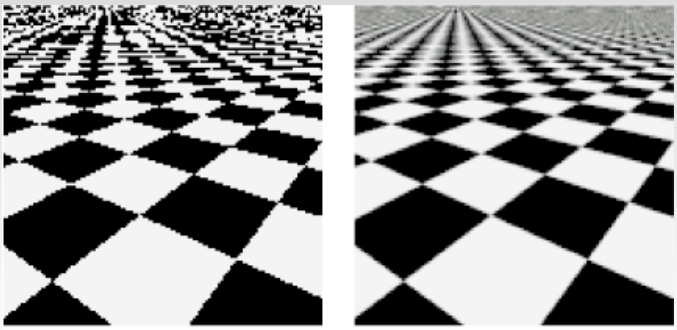


Fig. 14.20 The sampling pipeline with filtering. (Courtesy of George Wolberg, Columbia University.)

Previous Antialiasing Example

Texture mipmapping: low pass filter



(a) (b)

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Discussion

Sampling & Reconstruction

- Fundamental issue in graphics, vision, and many other areas of computer science
  - *Whenever continuous signals need to be represented in a computer*
- Aliasing refers to the problem of reconstruction errors due to frequencies above the Nyquist limit
  - *These frequencies show up as erroneous low frequency content*

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Discussion

Anti-Aliasing Approaches

- Low-pass filtering (**before** sampling!)
  - *Avoids aliasing*
  - *May not be practical in all settings*
  - *For images: artifacts around edges?!*
- Supersampling
  - *General algorithmic approach*
  - *Hoever: even the higher resolution image has a Nyquist limit!*
  - *Slow*

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Coming Up:

Friday

- More sampling & reconstruction

Monday

- Programmable GPU architectures (Gordon Wetzstein)

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