Texture Mapping

Wolfgang Heidrich

Course News

Assignment 2

- Due today

Assignment 3 (project)

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

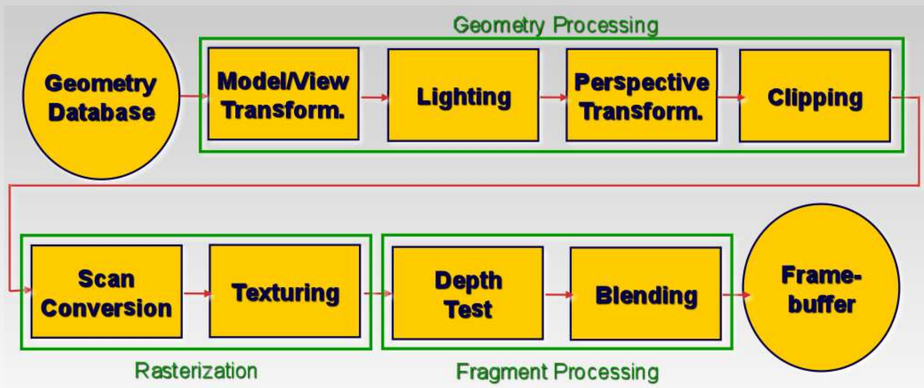
Quiz 2 MOVED!

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

Reading

- Chapter 11 (w/o 11.8)

The Rendering Pipeline



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Texture Mapping

- Real life objects have nonuniform colors, normals
- To generate realistic objects, reproduce coloring & normal variations = **texture**
- Can often replace complex geometric details

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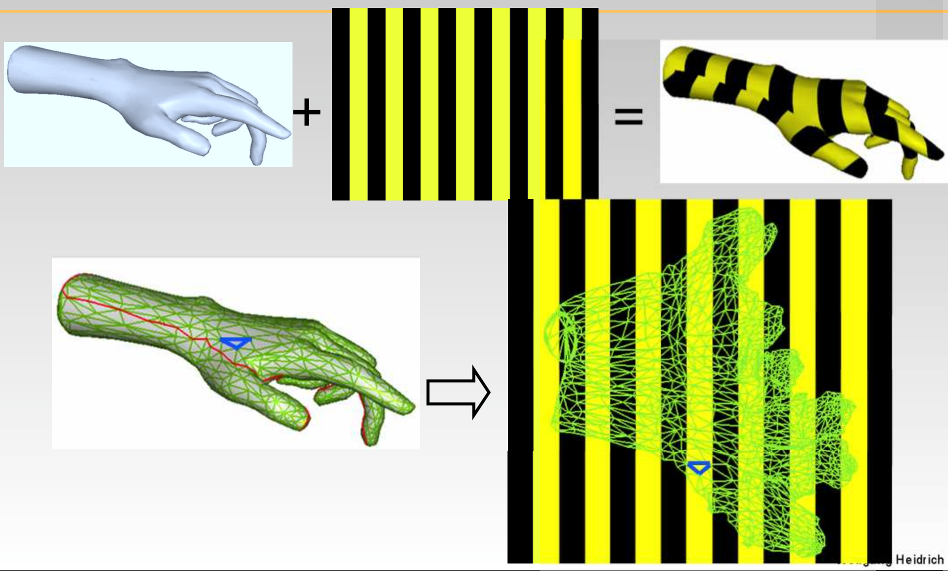
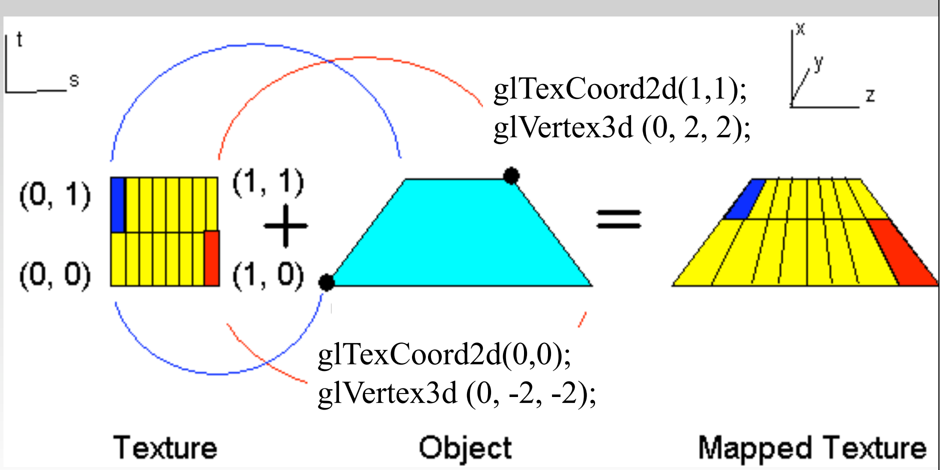
Texture Mapping Example



Example Texture Map



Texture Lookup: Tiling and Clamping

What if s or t is outside the interval [0…1]?

Multiple choices

- Use fractional part of texture coordinates
  - *Cyclic repetition of texture to tile whole surface*
    glTexParameteri(…, GL_TEXTURE_WRAP_S, GL_REPEAT, GL_TEXTURE_WRAP_T, GL_REPEAT, …)

- Clamp every component to range [0…1]
  - *Re-use color values from texture image border*
    glTexParameteri(…, GL_TEXTURE_WRAP_S, GL_CLAMP, GL_TEXTURE_WRAP_T, GL_CLAMP, …)

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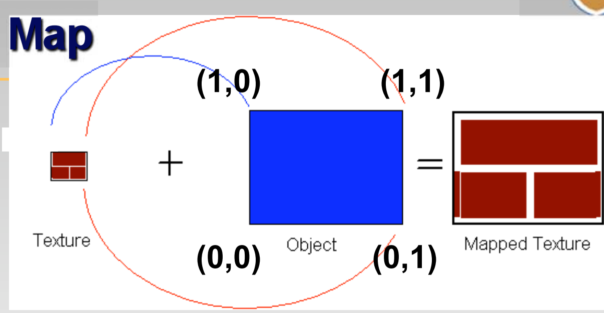
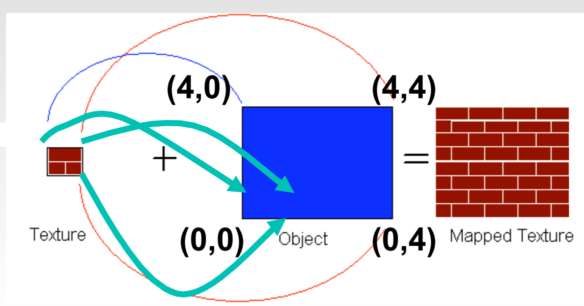
Tiled Texture Map

```
glTexCoord2d(1, 1);
glVertex3d (x, y, z);
```




```
glTexCoord2d(4, 4);
glVertex3d (x, y, z);
```



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Texture Coordinate Transformation

Motivation

- Change scale, orientation of texture on an object

Approach

- *Texture matrix stack*
- Transforms specified (or generated) tex coords

```
glMatrixMode( GL_TEXTURE );
glLoadIdentity();
glRotate();
   ...
```

- More flexible than changing (s,t) coordinates

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Texture Pipeline

(x, y, z)		(s, t)		(s', t')	
Object position	→	Parameter space	→	Transformed parameter space	→
(-2.3, 7.1, 17.7)		(0.32, 0.29)		(0.52, 0.49)	

Texel space		Texel color		Final color
(81, 74)	→	(0.9,0.8,0.7)	→	(0.45,0.4,0.35)
		Object color	↗	
		(0.5,0.5,0.5)		

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Low-Level Details

Large range of functions for controlling layout of texture data

- State how the data in your image is arranged
- e.g.: `glPixelStorei(GL_UNPACK_ALIGNMENT, 1)` tells OpenGL not to skip bytes at the end of a row
- You must state how you want the texture to be put in memory: how many bits per "pixel", which channels,…

Textures must have a size of power of 2

- Common sizes are 32x32, 64x64, 256x256
- But don't need to be square, i.e. 32x64 is fine
- Smaller uses less memory, and there is a finite amount of texture memory on graphics cards

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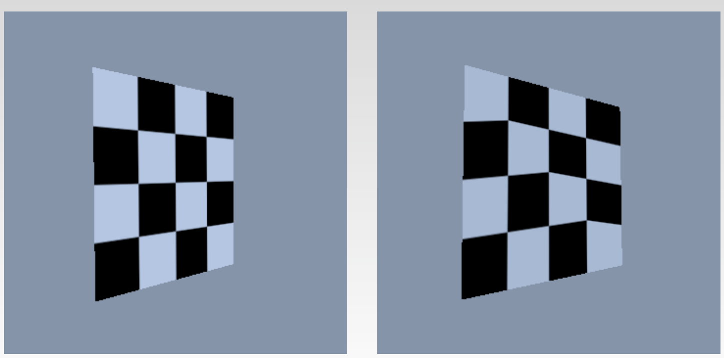
Texture Mapping

Texture coordinate interpolation

- Perspective foreshortening problem



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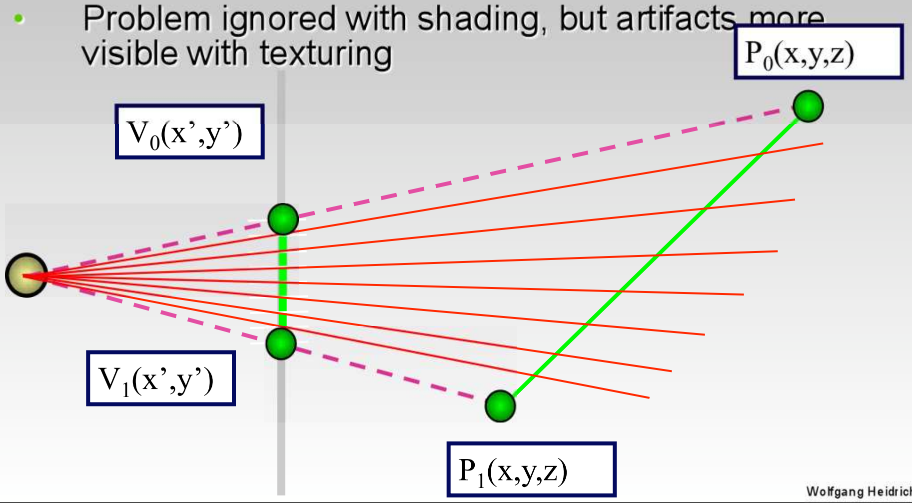
Interpolation: Screen vs. World Space

Screen space interpolation incorrect

- Problem ignored with shading, but artifacts more visible with texturing



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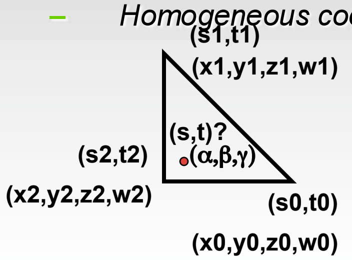
Texture Coordinate Interpolation

Perspective correct interpolation

- α, β, γ :
  - *Barycentric coordinates of a point **P** in a triangle*
- *s0, s1, s2 :*
  - *Texture coordinates of vertices*
- *w0, w1,w2 :*
  - *Homogeneous coordinates of vertices*



$$s = \frac{\alpha \cdot s_0 / w_0 + \beta \cdot s_1 / w_1 + \gamma \cdot s_2 / w_2}{\alpha / w_0 + \beta / w_1 + \gamma / w_2}$$

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Texture Parameters

In addition to color can control other material/object properties

- Surface normal (bump mapping)
- Reflected color (environment mapping)

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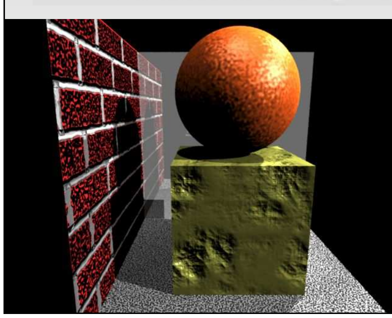
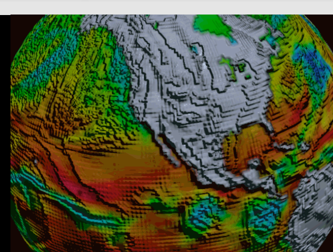
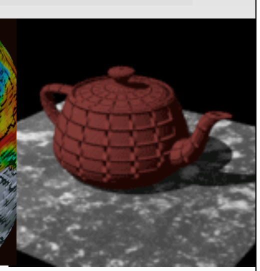
Bump Mapping: Normals As Texture

Object surface often not smooth – to recreate correctly need complex geometry model

Can control shape "effect" by locally perturbing surface normal

- Random perturbation
- Directional change over region

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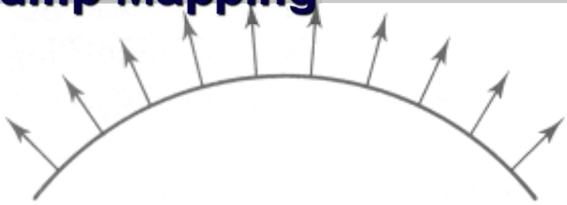
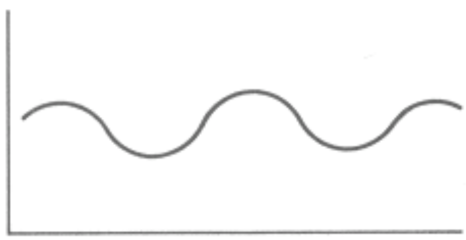
Bump Mapping



$O(u)$

Original surface



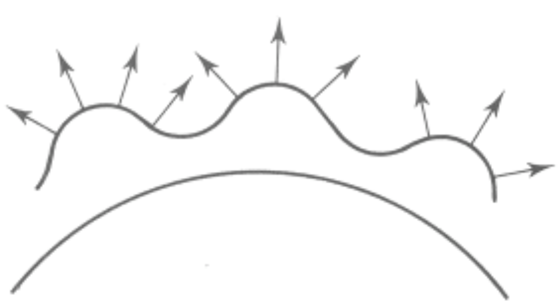
$B(u)$

A bump map

Bump Mapping

$O'(u)$

Lengthening or shortening $O(u)$ using $B(u)$



$N'(u)$

The vectors to the 'new' surface

Displacement Mapping

Bump mapping gets silhouettes wrong

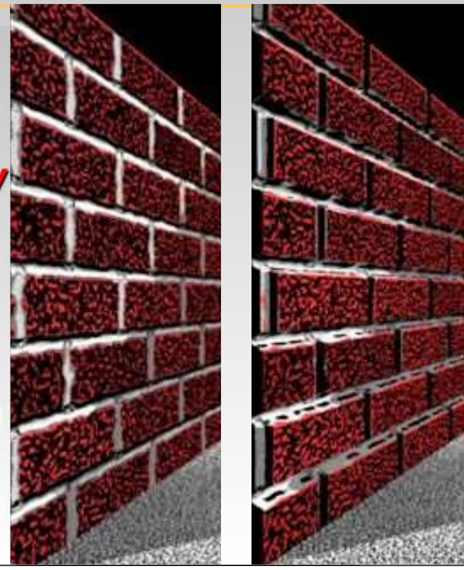
- Shadows wrong too

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



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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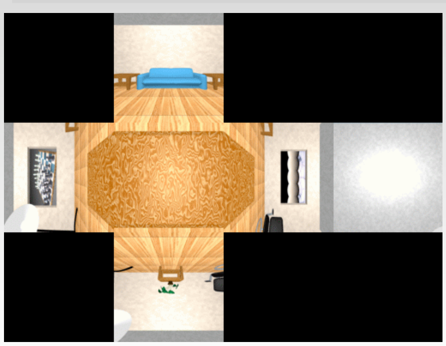
Cube Mapping

6 planar textures, sides of cube

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



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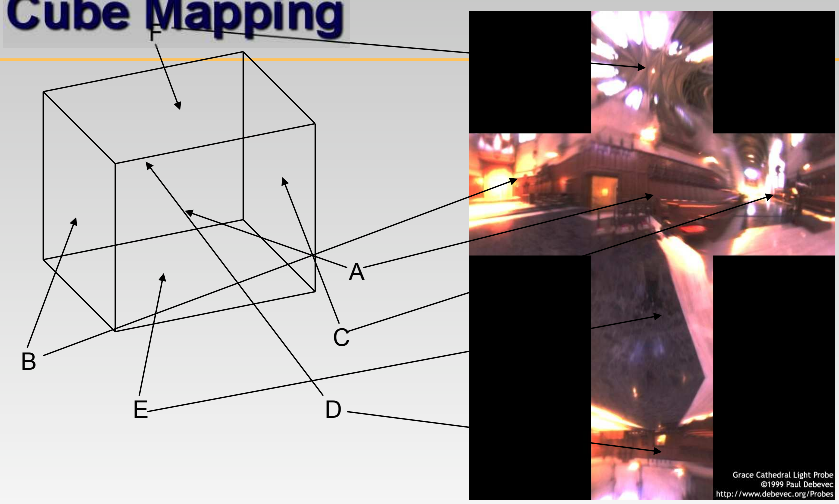
Cube Mapping



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).*

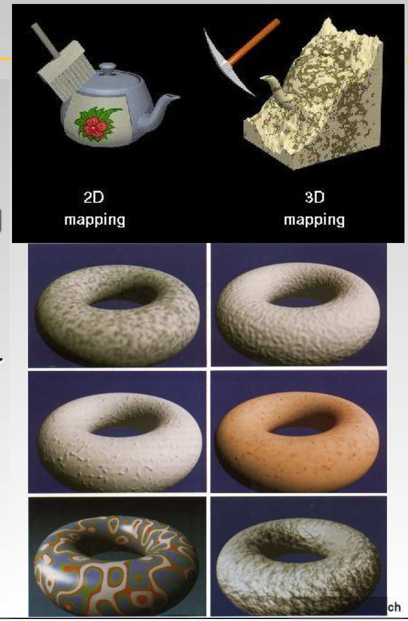
Difficulty in interpolating across faces

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…)



Procedural Textures

Generate "image" on the fly, instead of loading from disk

- Also called **shader**
- Often saves space
- Allows arbitrary level of detail
  - *"magnification" not an issue*
  - *"minification" less so than for sampled representation*
- But can be quite slow for complicated shaders

Volumetric Bump Mapping

Marble

Bump

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Volumetric Texture Mapping

In Hardware:

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

- Procedural textures supported with modern GPUs
  - *More in upcoming lectures*

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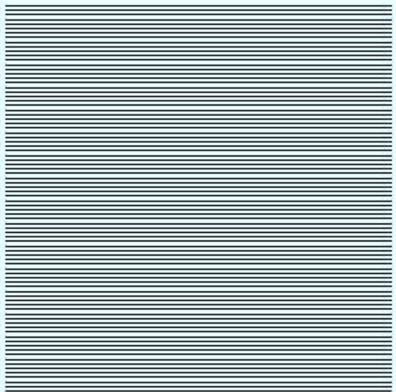
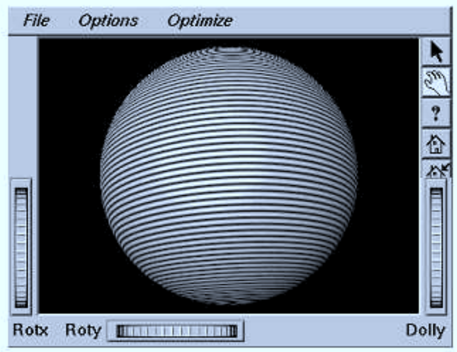
Texture Lookup – Sampling & Reconstruction





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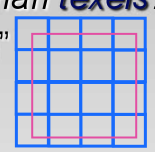
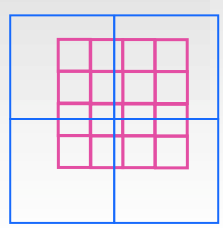
Texture Lookup – Sampling & Reconstruction

- 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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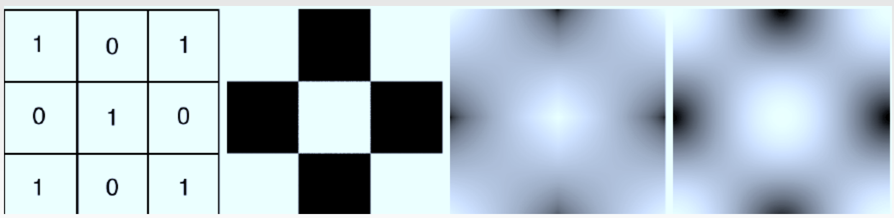
Magnification: Interpolating Textures

- Nearest neighbor
- Bilinear
- Hermite (cubic)



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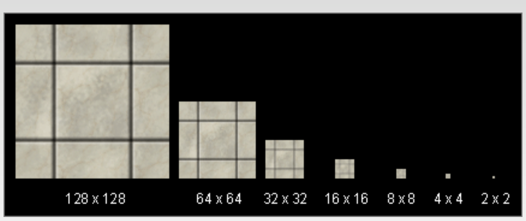
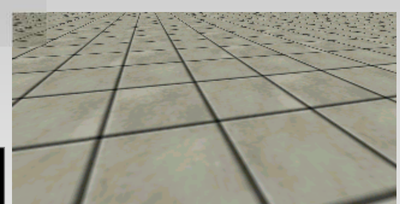
Minification: MIPmapping

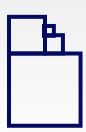
use “image pyramid” to precompute averaged versions of the texture

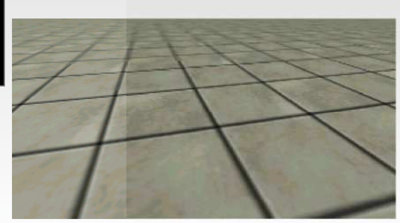




Without MIP-mapping

store whole pyramid in single block of memory





With MIP-mapping

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MIPmaps

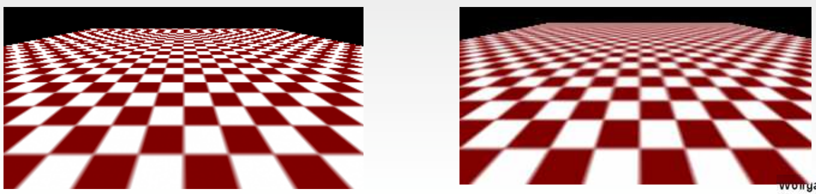
Multum in parvo -- ***many things in a small place***

- 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

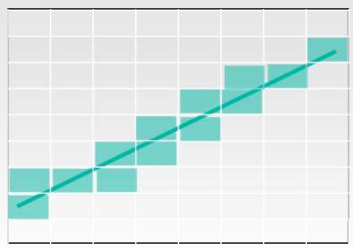
CPSC 314

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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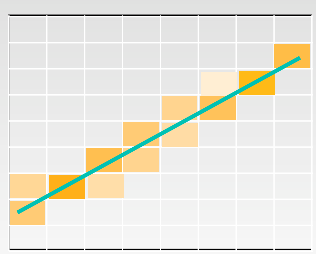
Line Segments

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



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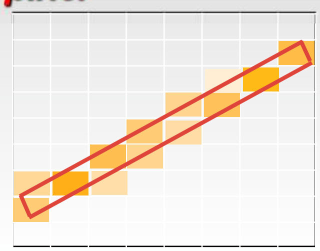
Unweighted Area Sampling

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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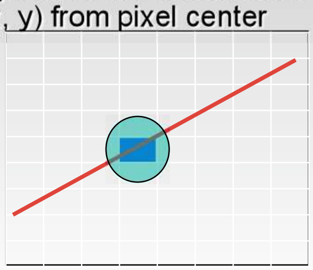
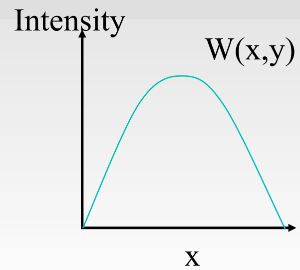
Weighted Area Sampling

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)

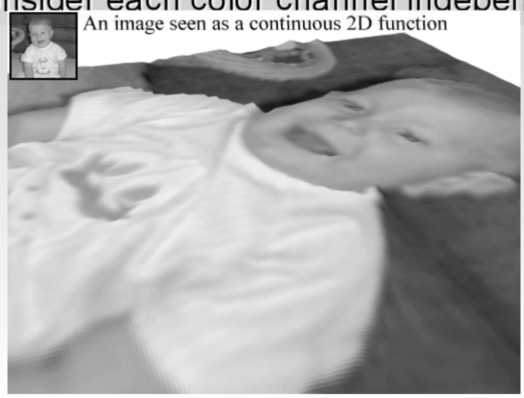
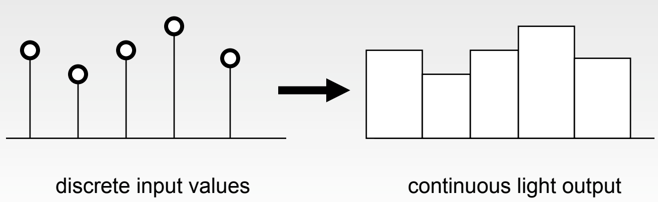


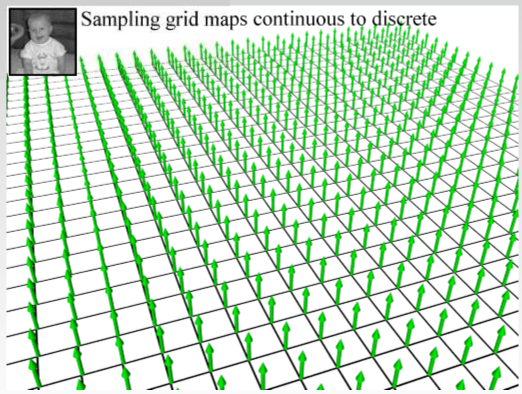
Image Sampling and Reconstruction

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



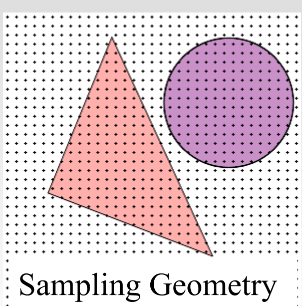
Point Sampling an Image

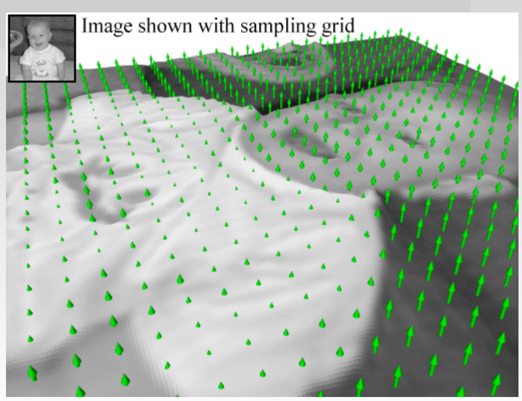
- Simplest sampling is on a grid
- Sample depends solely on value at grid points



Point Sampling

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





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!

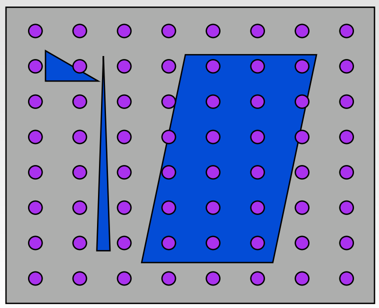


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Image As Signal

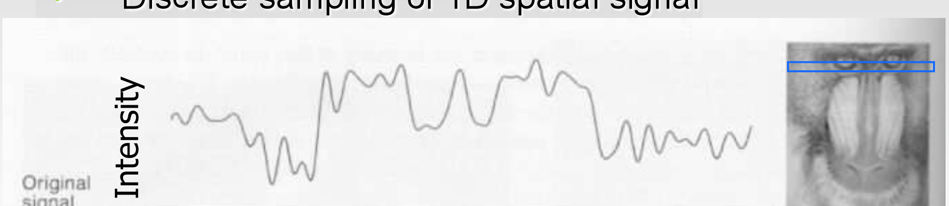
Image as spatial signal

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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Coming Up:

Wednesday / Friday

- More sampling & reconstruction

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