Texture Mapping

Wolfgang Heidrich

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Course News

Assignment 3

- Project
- Handout will be up on Wednesday

Homework 5

- Out later today (this time for real)
- Remember that these are good practice for the exams!

Reading

- Chapter 11 (Texture Mapping)

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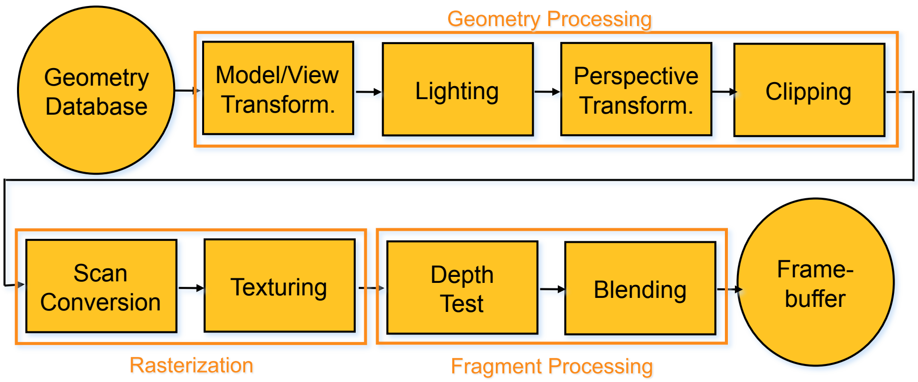
The Rendering Pipeline



Texture Mapping

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

Texture Mapping

Introduced to increase realism

- Lighting/shading models not enough

Hide geometric simplicity

- Images convey illusion of geometry
- Map a brick wall texture on a flat polygon
- Create bumpy effect on surface

Associate 2D information with 3D surface

- Point on surface corresponds to a point in texture
- “Paint” image onto polygon

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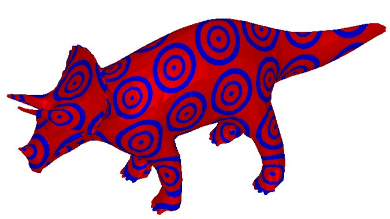
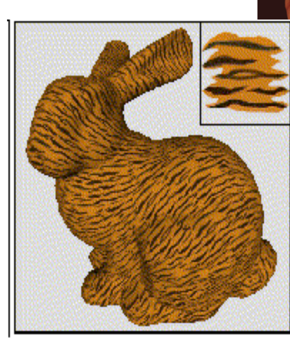
Color Texture Mapping

Define color (RGB) for each point on object surface

Two approaches

- Surface texture map (2D)
- Volumetric texture (3D)





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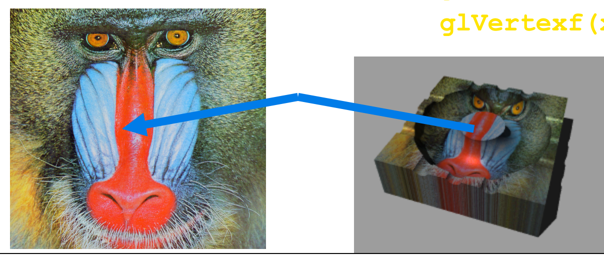
Surface (2D) Textures: Texture Coordinates

Texture map: 2D array of color (texels)

Assigning texture coordinates (s,t) at vertex with object coordinates (x,y,z,w)

- Use interpolated (s,t) for texel lookup at each pixel
- Use value to modify a polygon's color
- Specified by programmer or artist

```
glTexCoord2f(s,t)
glVertexf(x,y,z,w)
```



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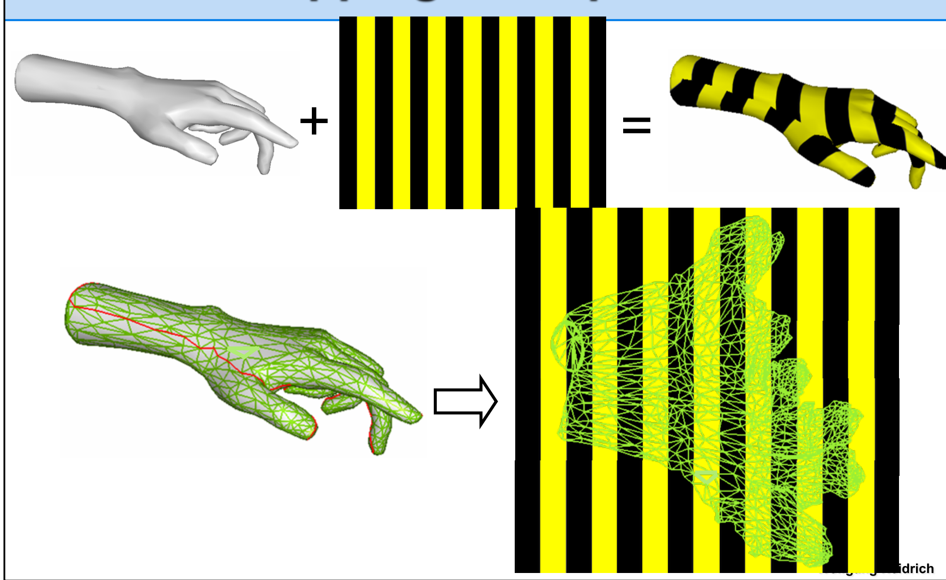
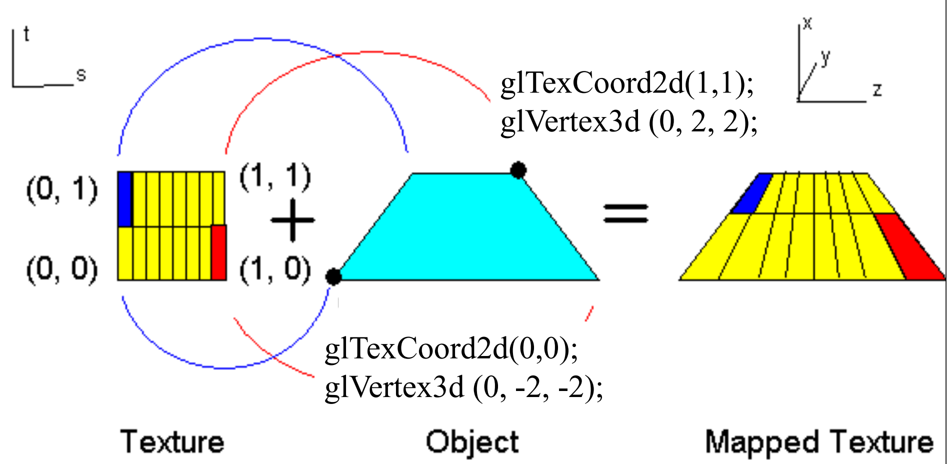
Texture Mapping Example



Example Texture Map



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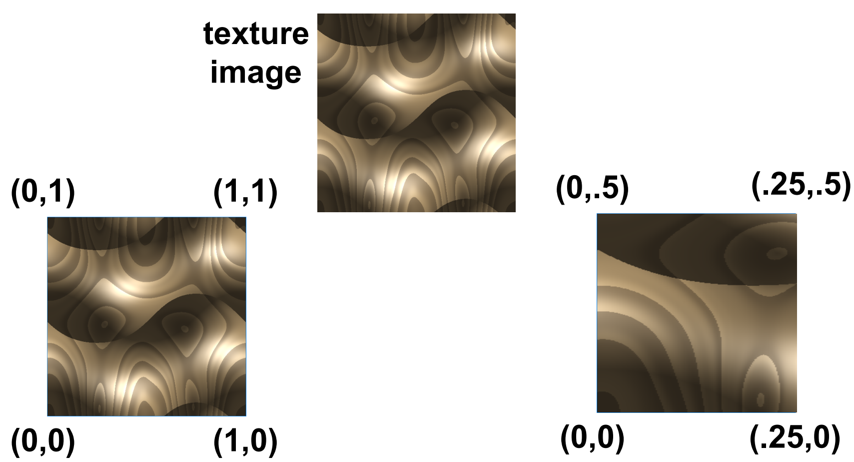
Fractional Texture Coordinates



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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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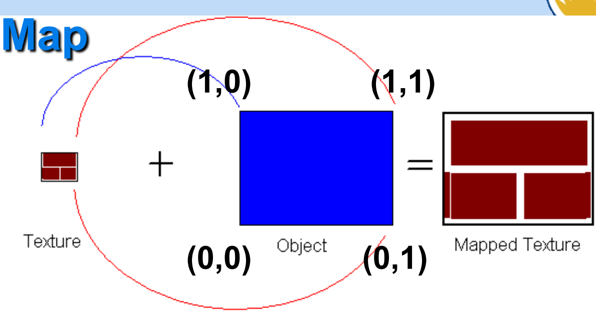
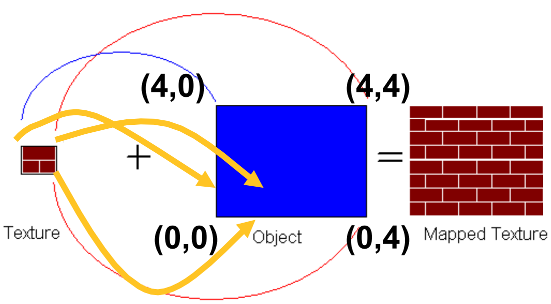
Tiled Texture Map

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 Functions

Given value from the texture map, we can:

- Directly use as surface color: GL_REPLACE
  - *Throw away old color, lose lighting effects*
- Modulate surface color: GL_MODULATE
  - *Multiply old color by new value, keep lighting info*
  - *Texturing happens after lighting, not relit*
- Use as surface color, modulate alpha: GL_DECAL
  - *Like replace, but supports texture transparency*
- Blend surface color with another: GL_BLEND
  - *New value controls which of 2 colors to use*

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Texture Pipeline

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

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

Object color (0.5,0.5,0.5) → Final color

Texture Objects and Binding

Texture object

- An OpenGL data type that keeps textures resident in memory and provides identifiers to easily access them
- Provides efficiency gains over having to repeatedly load and reload a texture
- You can prioritize textures to keep in memory
- OpenGL uses least recently used (LRU) if no priority is assigned

Texture binding

- Which texture to use right now
- Switch between preloaded textures

Basic OpenGL Texturing

Create a texture object and fill w/ data:

- glGenTextures(num, &indices) to get identifiers for the objects
- glBindTexture(GL_TEXTURE_2D, identifier) to bind
  - *Following texture commands refer to the bound texture*
- glTexParameteri(GL_TEXTURE_2D, …, …) to specify parameters for use when applying the texture
- glTexImage2D(GL_TEXTURE_2D, ….) to specify the texture data (the image itself)

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Basic OpenGLTexturing (cont.)

Enable texturing:

- glEnable(GL_TEXTURE_2D)

State how the texture will be used:

- glTexEnvf(…)

Specify texture coordinates for the polygon:

- Use glTexCoord2f(s,t) before each vertex:
  - *glTexCoord2f(0,0); glVertex3f(x,y,z);*

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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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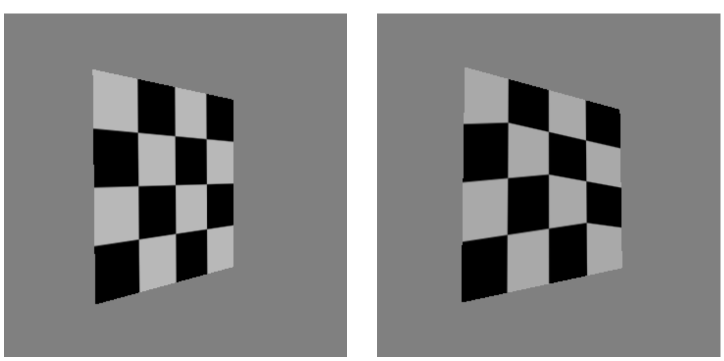
Texture Mapping

Texture coordinate interpolation

- Perspective foreshortening problem



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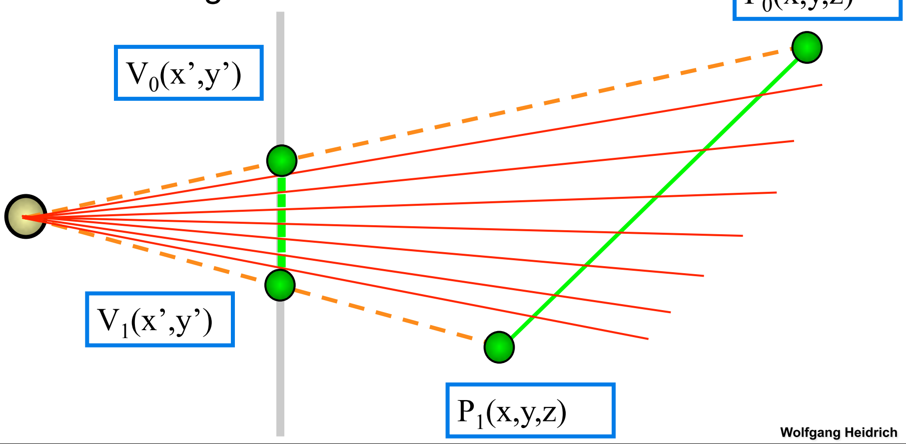
Interpolation: Screen vs. World Space

Screen space interpolation incorrect

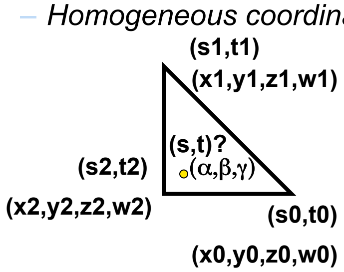
- Problem ignored with shading, but artifacts more visible with texturing



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*

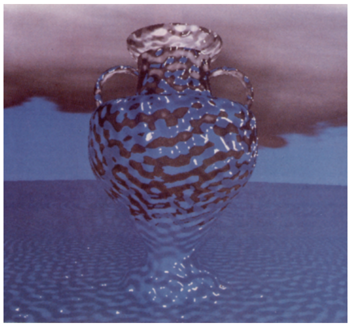


$$s = \frac{\alpha \cdot s_0 / w_0 + \beta \cdot s_1 / w_1 + \gamma \cdot s_2 / w_2}{\alpha / w_0 + \beta / w_1 + \gamma / w_2}$$

Texture Parameters

In addition to color can control other material/object properties

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



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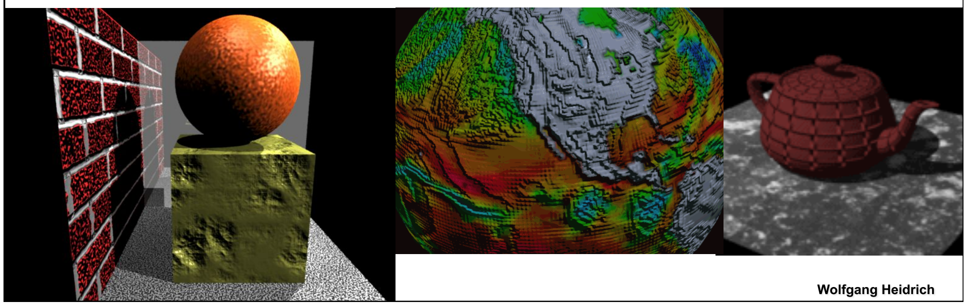
Bump Mapping: Normals As Texture

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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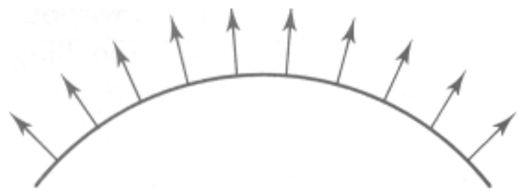
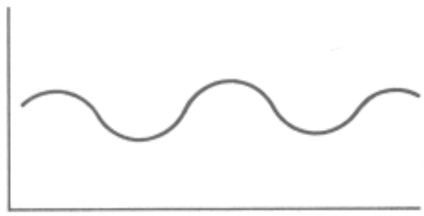
Bump Mapping





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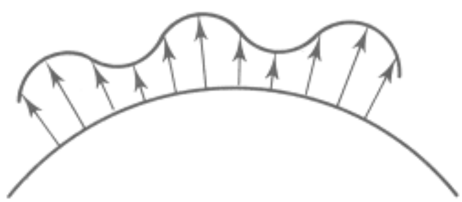
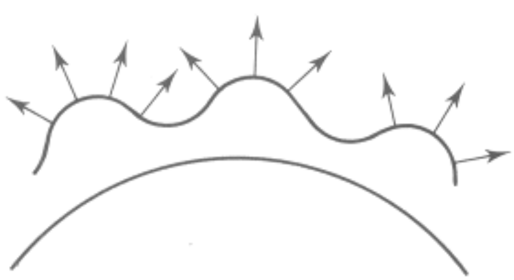
Bump Mapping





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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

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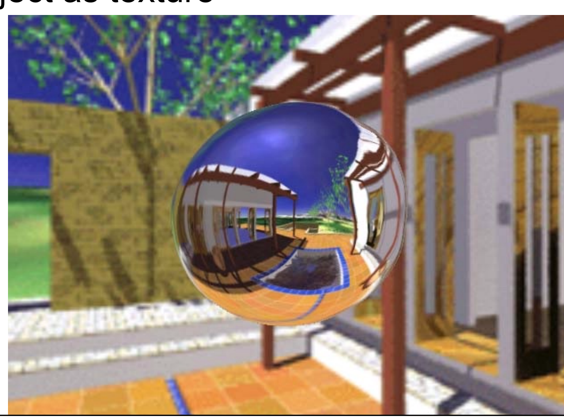
Environment Mapping

Cheap way to achieve reflective effect

- Generate image of surrounding
- Map to object as texture



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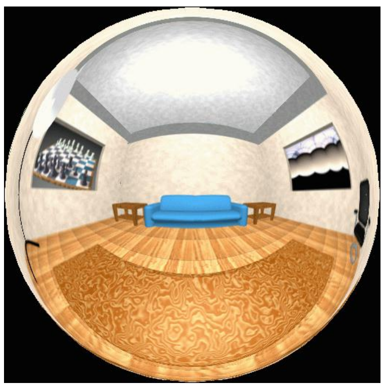
Sphere Mapping

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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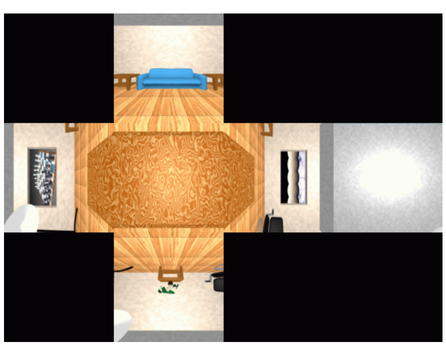
Cube Mapping

6 planar textures, sides of cube

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



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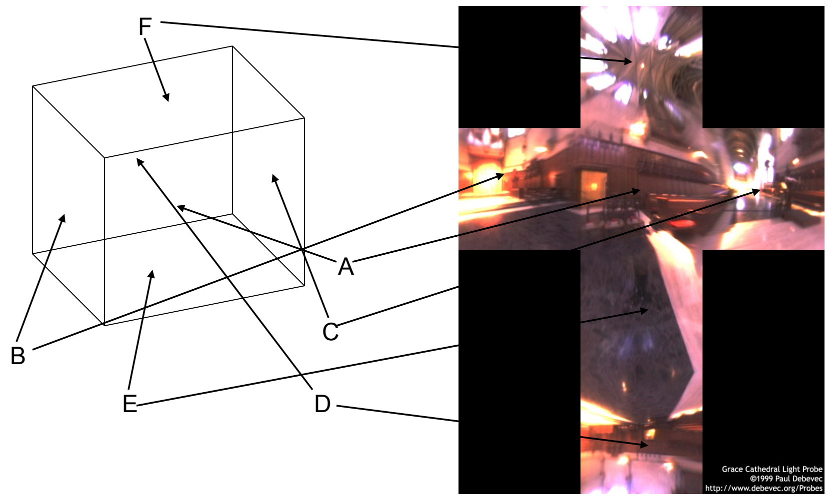
Cube Mapping



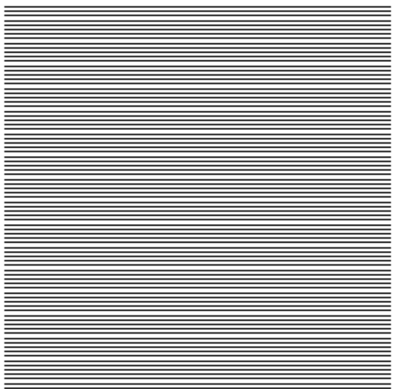
Cube Mapping

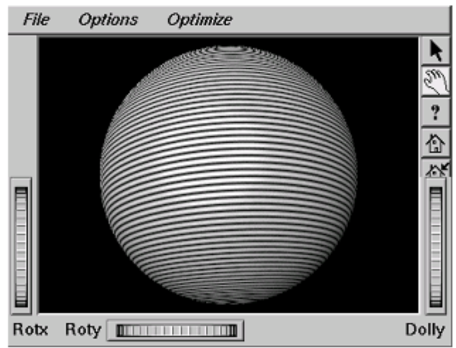
Direction of reflection vector r selects the face of the cube to be indexed

- 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)*
    - Why?

Difficulty in interpolating across faces

Texture Lookup – Sampling & Reconstruction





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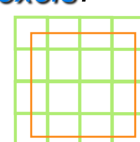
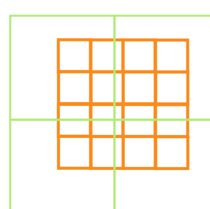
Texture Lookup – Sampling & Reconstruction

- 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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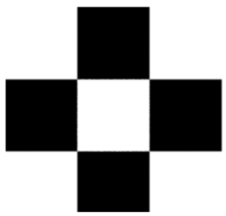
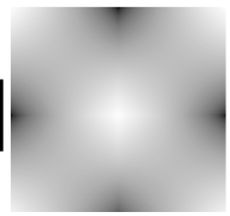
Magnification: Interpolating Textures

- Nearest neighbor
- Bilinear
- Hermite (cubic)

1	0	1
0	1	0
1	0	1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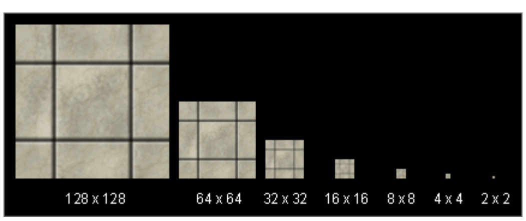
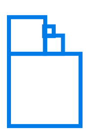
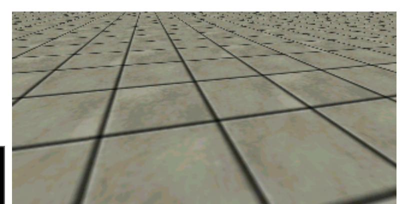
Minification: MIPmapping

use "image pyramid" to precompute averaged versions of the texture

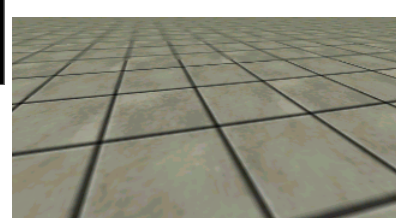


store whole pyramid in single block of memory





Without MIP-mapping



With MIP-mapping

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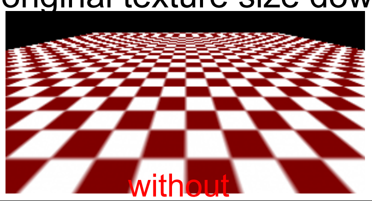
MIPmaps

Multum in parvo

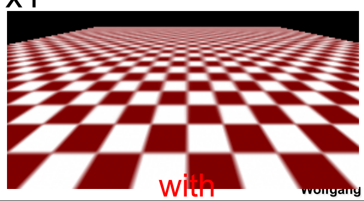
- "many things in a small place"
- Series of prefiltered texture maps of decreasing resolutions
- Avoid shimmering and flashing as objects move

gluBuild2DMipmaps

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



without



with

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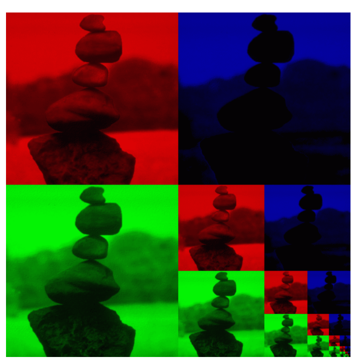
MIPmap storage

Only 1/3 more space required



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Sampling & Reconstruction

CPSC 314

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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 both sampling and quantization
- Displaying an image involves reconstruction

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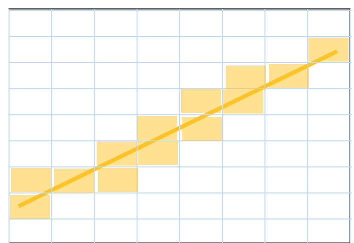
Line Segments

- 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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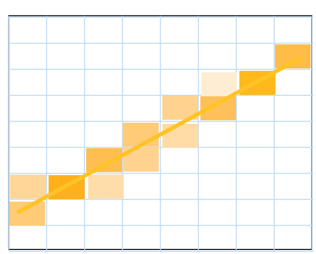
Line Segments

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



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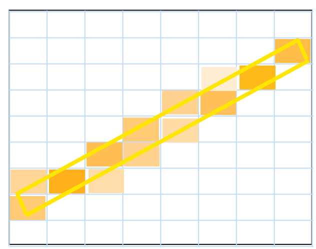
Unweighted Area Sampling

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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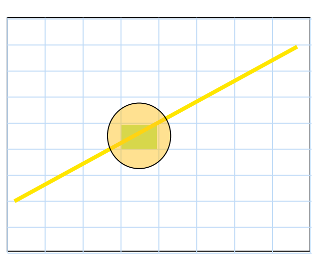
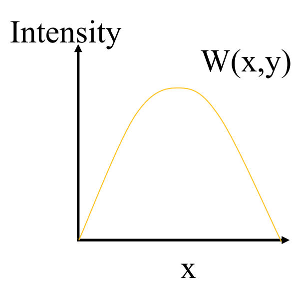
Weighted Area Sampling

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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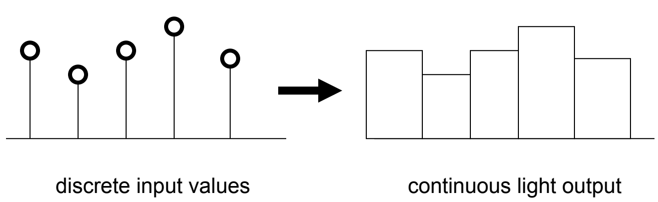
Image Sampling and Reconstruction

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



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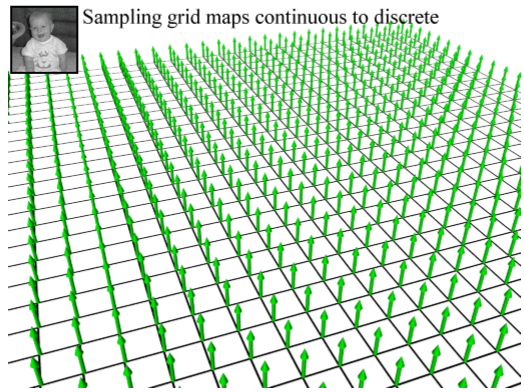
Point Sampling an Image

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



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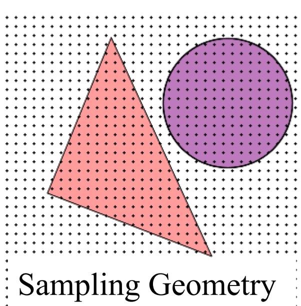
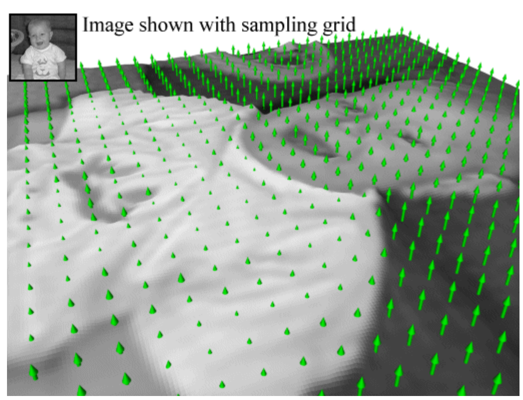
Point Sampling

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!

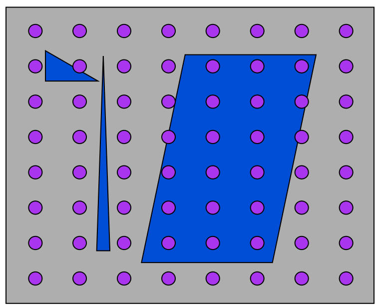

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Image As Signal

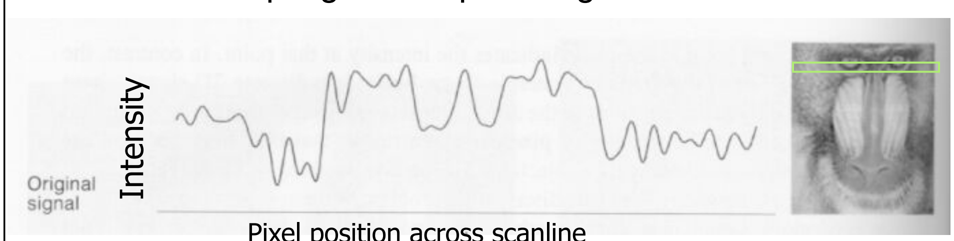
Image as spatial signal

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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Coming Up:

Friday

- Sampling & reconstruction

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