CSE167: Introduction to Computer Graphics

Lecture #10

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Fall 2009
Announcements

• Until this Thursday accepting late submissions of project 3 during lab hours
• Reduced lab hours this Wednesday: 2-4pm
• Reduced lab hours this Friday, Oct 30: 2:30-3:30pm:
  Jason introducing homework project #4
• Tuesday, Nov 3rd:
  Guest lecture on CUDA by Raj Singh from the National Center for Microscopy and Imaging Research (NCMIR)
Midterm Exam

- Midterm exam Thursday Oct 29 during lecture slot, 2-3:20pm
- Use previous exams on course web site to study
- TAs will answer questions about midterm during all lab hours this week
- Exam will be closed book, no calculators. Permitted is one single sided, hand-written index card (3x5 inch). You will need to bring a pen/pencil and a ruler, as well as a few blank sheets of paper.
- More information about midterm on course web site under Grading and Exams.
Today

Texturing

- Antialiasing
- Advanced Texture Mapping
What is going on here?
Aliasing

Sufficiently sampled, no aliasing

Insufficiently sampled, aliasing

High frequencies in the input appear as low frequencies in the sampled signal
Antialiasing: intuition

- Pixel may cover large area on triangle in camera space
Antialiasing: intuition

- Pixel may cover large area on triangle in camera space
- Corresponds to many texels in texture space
- Need to compute average

Image plane  Camera space  Texture space

Pixel area

Texels
Antialiasing: The Math

• Pixels are samples, not little squares
  http://www.alvyray.com/memos/6_pixel.pdf

• Use frequency analysis to explain sampling artifacts
  - Fourier transforms

• Antialiasing is achieved through low-pass filtering

• For more information:
  - Glassner: Principles of digital image synthesis
Antialiasing using mipmaps

- Averaging over texels is expensive
  - Many texels as objects get smaller
  - Large memory access and computation cost
- Precompute filtered (averaged) textures
  - Mipmaps
- Practical solution to aliasing problem
  - Fast and simple
  - Available in OpenGL, implemented in GPUs
  - Reasonable quality
**Mipmaps**

- MIP stands for *multum in parvo* = “much in little” (Williams 1983)

**Before rendering**

- Pre-compute and store down scaled versions of textures
  - Reduce resolution by factors of two successively
  - Use high quality filtering (averaging) scheme
- Increases memory cost by 1/3
  - \(1/3 = \frac{1}{4} + 1/16 + 1/64 + \ldots\)
- Width and height of texture need to be powers of two
Mipmaps

- Example: resolutions 512x512, 256x256, 128x128, 64x64, 32x32 pixels

“multum in parvo”
Mipmaps

- 1 texel in level 4 is an average of $4^4=256$ texels in level 0

“multum in parvo”
Mipmaps

Level 0

Level 1

Level 2

Level 3

Level 4
Rendering with mipmaps

- “Mipmapping”
- Interpolate texture coordinates of each pixel as without mipmapping
- Compute approximate size of pixel in texture space
- Look up color in nearest mipmap
  - E.g., if pixel corresponds to 10x10 texels use mipmap level 3
  - Use nearest neighbor or bilinear interpolation as before
Mipmapping

- Image plane
- Camera space
- Texture space

- Texels

- Mip-map level 0
- Mip-map level 1
- Mip-map level 2
- Mip-map level 3
Nearest mipmap, nearest neighbor

- Visible transition between mipmap levels
Nearest mipmap, bilinear

- Visible transition between mipmap levels
Trilinear Mipmapping

- Use two nearest mipmap levels
  - E.g., if pixel corresponds to 10x10 texels, use mipmap levels 3 (8x8) and 4 (16x16)
- Perform bilinear interpolation in both mipmap maps
- Linearly interpolate between the results
- Requires access to 8 texels for each pixel
- Standard method, supported by hardware with no performance penalty
Nearest mipmap, bilinear

- Visible transition between mipmap levels
Trilinear mipmaping

• Smooth transition between mipmap levels
Note on OpenGL

- Distinguishes between minification and magnification
  - Minification: a texel is smaller than a pixel
  - Magnification: a texel is larger than a pixel
  - Minification, magnification may vary across pixels of individual triangles

- OpenGL allows you to specify different interpolation techniques separately:
  - `glTexParameterf(GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER, GL_LINEAR_MIPMAP_NEAREST)`
  - `glTexParameterf(GL_TEXTURE_2D, GL_TEXTURE_MAG_FILTER, GL_LINEAR)`
Are we satisfied?

Trilinear mipmapmapping
Mipmapping Limitations

- Mipmap texels always represent square areas
- Pixel area is not always square in texture space
- Mipmapping tries to balance between aliasing effects and a fuzzy image

A circular area in the image plane can be generated by an ellipse in object space
Anisotropic Texture Filtering

- Average texture over elliptical area
  - Higher quality than trilinear mip-mapping
  - More expensive

- Anisotropic filtering in hardware
  - Take several bilinear probes approximating the ellipse
  - Reduces rendering performance on current GPUs
Example #1

Source:
http://www.garry.tv/img/css/source/texture-filtering.jpg
Example #1

Source: http://www.tomshardware.com/reviews/ati,819-5.html
Today

Texturing

- Antialiasing

- Advanced Texture Mapping
Advanced Texture Mapping

• Textures are most commonly used to modulate ambient and diffuse reflection
  - OpenGL `glTexEnvf(..., GL_MODULATE)`

• Other applications:
  - Bump mapping
  - Displacement mapping
Bump mapping

- Uses the color (usually grayscale) values from a texture map to perturb surface normals to create variations in the shading of the surface
- No modification of geometry: shows in silhouette
- Render using per-pixel shading with fragment shader
Displacement mapping

- Texture map contains local height field
- Modifies geometry: correct silhouettes, shadows
- Requires sophisticated fragment shader
Other effects

Multi-texturing

• Several layers of textures for different effects
  - Scratches, dents, rust, ...
  - Illumination textures

Animated textures

• Raindrops

• A TV screen, projector in a 3D scene
Next Lecture

- Tuesday, Nov 3\textsuperscript{rd}:
  Guest lecture on CUDA by Raj Singh from the National Center for Microscopy and Imaging Research (NCMIR)