King Abdullah University of Science and Technology

KAUST

CS 380 - GPU and GPGPU Programming
Lecture 13: GPU Texturing 3

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Reading Assignment #7 (until Mar. 16)

Read (required):

- Interpolation for Polygon Texture Mapping and Shading,
  Paul Heckbert and Henry Moreton

http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.48.7886

- MIP-Map Level Selection for Texture Mapping

http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=765326

Read (optional):

- Frame buffer objects extension specification

http://www.opengl.org/registry/specs/ARB/framebuffer_object.txt

Semester Project (Proposal until March 23!)

- Choosing your own topic encouraged!
  (we can also suggest some topics)
  - Pick something that you think is really cool!
  - Can be completely graphics or completely computation, or both combined
  - Can be built on CS380 frameworks, NVIDIA OpenGL SDK, or CUDA SDK
- Write short (1-2 pages) project proposal until March 23
  - Send email or talk briefly with Peter before (!) you start writing
    to confirm that your plan will be a suitable topic
  - Submit with your programming assignment 3 solution (it‘s the same deadline)
- Submit semester project with report (deadline: May 11)
- Present semester project (final exams week May 17 - 21)

Semester Project Ideas (1)

Some hints for topics

- Procedural shading with noise + marble etc. (GPU Gems 2, chapter 26)
- Procedural shading with noise + bump mapping (GPU Gems 2, chapter 26)
- Subdivision surfaces (GPU Gems 2, chapter 7)
- Ambient occlusion, screen space ambient occlusion
- Shadow mapping, hard shadows, soft shadows
- Deferred shading
- Particle system rendering + CUDA particle sort
- Advanced image filters: fast bilateral filtering, Gaussian kD trees
- PDE solvers (e.g., anisotropic diffusion filtering, 2D level set segmentation, 2D fluid flow)

Semester Project Ideas (2)

Some hints for topics

- Distance field computation (GPU Gems 3, chapter 34)
- Livewire (“intelligent scissors“) in CUDA
- Comparison of parallel sorting algorithms
- Parallel computation of summed area table / multires pyramid, ... use in rendering
- Linear systems solvers, matrix factorization (Cholesky, ...); with/without CUBLAS
- CUDA + matlab
- Fractals (Sierpinski, Koch, ...)
- Image compression

Texture Anti-aliasing

- Basically, everything done in hardware
- `gluBuild2DMipmaps()`generates MIPmaps
- Set parameters in `glTexParameter()`
  - `GL_TEXTURE_MAG_FILTER: GL_NEAREST, GL_LINEAR, …`
  - `GL_TEXTURE_MIN_FILTER: GL_LINEAR_MIPMAP_NEAREST`
- Anisotropic filtering is an extension:
  - `GL_EXT_texture_filter_anisotropic`
  - Number of samples can be varied (4x,8x,16x)
    - Vendor specific support and extensions

Texture Coordinates

- Specified manually (gl*Multi*TexCoord())
- Using classical OpenGL texture coordinate generation
  - Linear: from object or eye space vertex coords
  - Special texturing modes (env-maps)
  - Can be further modified with texture matrix
    - E.g., to add texture animation
  - Can use 3rd or 4th texture coordinate for projective texturing!
- Shader allows complex texture lookups!

Texture Mapping

2D (3D) Texture Space

↓ Texture Transformation

2D Object Parameters

↓ Parameterization

3D Object Space

↓ Model Transformation

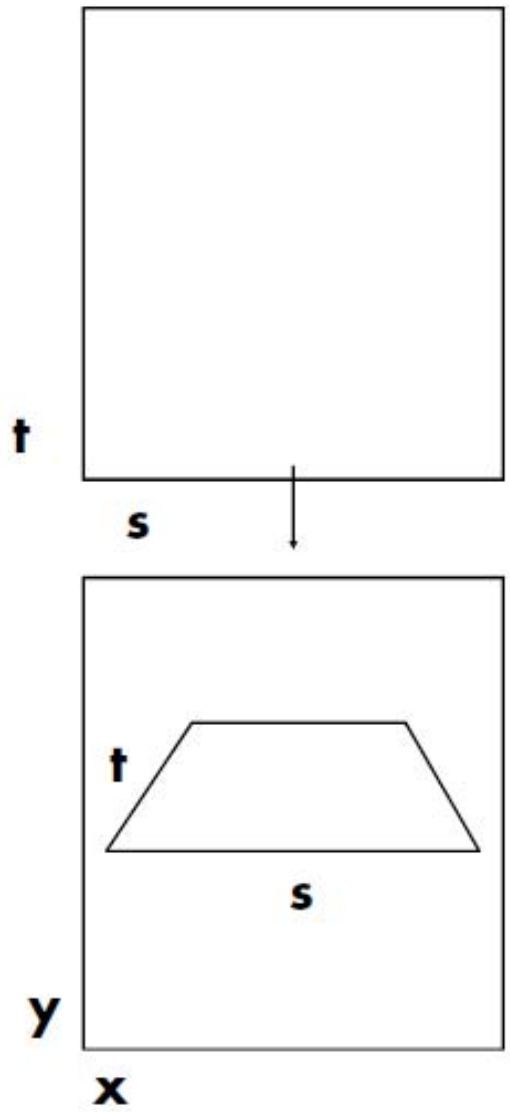
3D World Space

↓ Viewing Transformation

3D Camera Space

↓ Projection

2D Image Space



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Texture Mapping Polygons

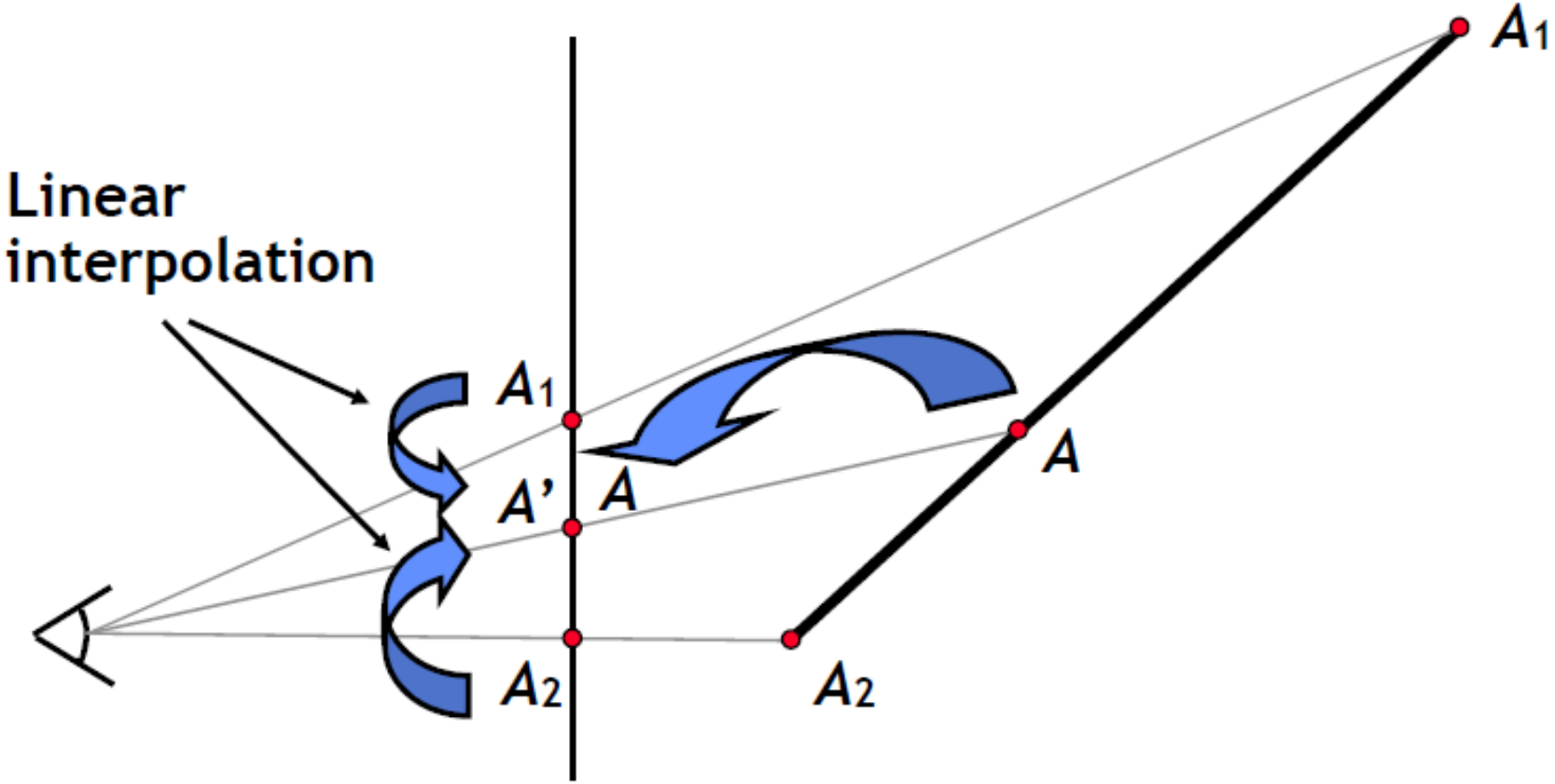
Forward transformation: linear projective map

$$\begin{bmatrix} x \\ y \\ w \end{bmatrix} = \begin{bmatrix} a & b & c \\ d & e & f \\ g & h & i \end{bmatrix} \begin{bmatrix} s \\ t \\ r \end{bmatrix}$$

Backward transformation: linear projective map

$$\begin{bmatrix} s \\ t \\ r \end{bmatrix} = \begin{bmatrix} a & b & c \\ d & e & f \\ g & h & i \end{bmatrix}^{-1} \begin{bmatrix} x \\ y \\ w \end{bmatrix}$$

Incorrect attribute interpolation



$A' \neq A$!

Kurt Akeley, Pat Hanrahan

Linear interpolation

Compute intermediate attribute value

- Along a line: $A = aA_1 + bA_2$, $a+b=1$
- On a plane: $A = aA_1 + bA_2 + cA_3$, $a+b+c=1$

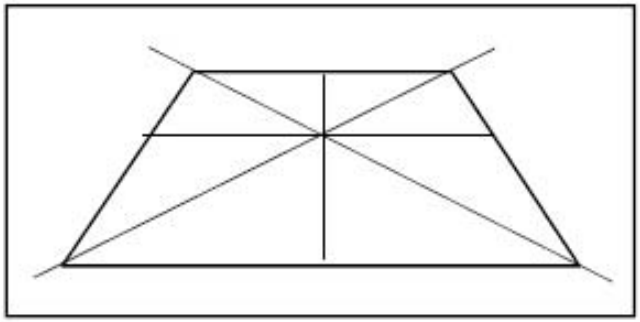
Only projected values interpolate linearly in screen space (straight lines project to straight lines)

- x and y are projected (divided by w)
- Attribute values are not naturally projected

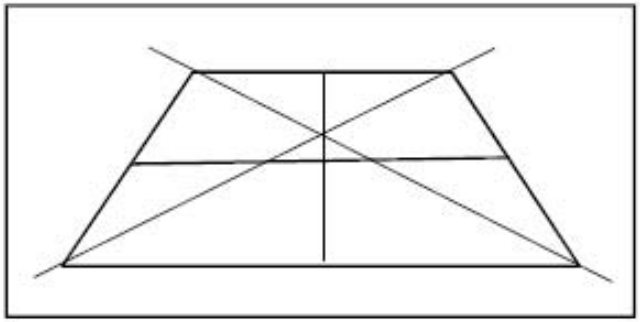
Choice for attribute interpolation in screen space

- Interpolate unprojected values
  - Cheap and easy to do, but gives wrong values
  - Sometimes OK for color, but
  - Never acceptable for texture coordinates
- Do it right

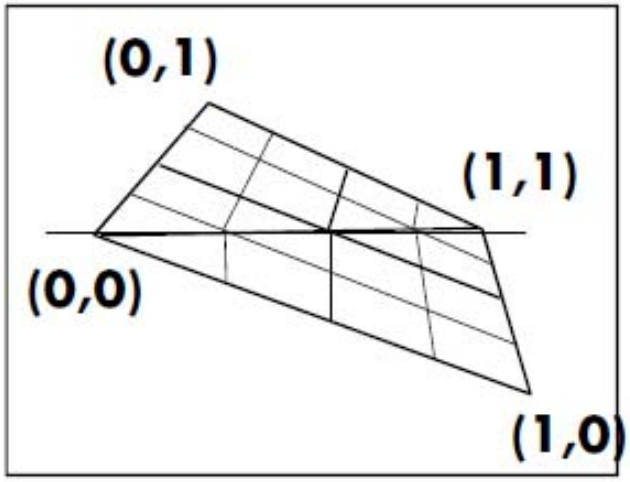
Linear Perspective



Correct Linear Perspective



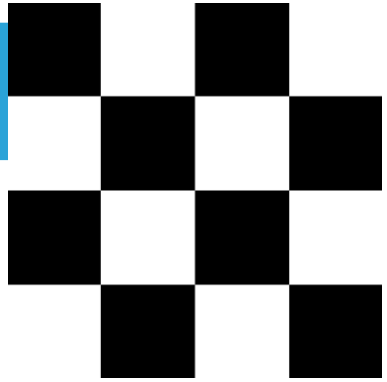
Incorrect Perspective



Linear Interpolation, *Bad*

Perspective Interpolation, *Good*

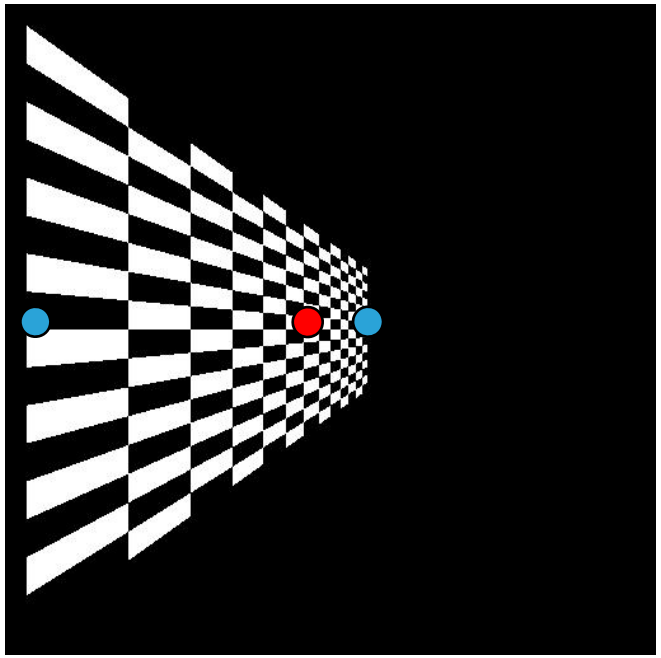
Perspective Texture Mapping

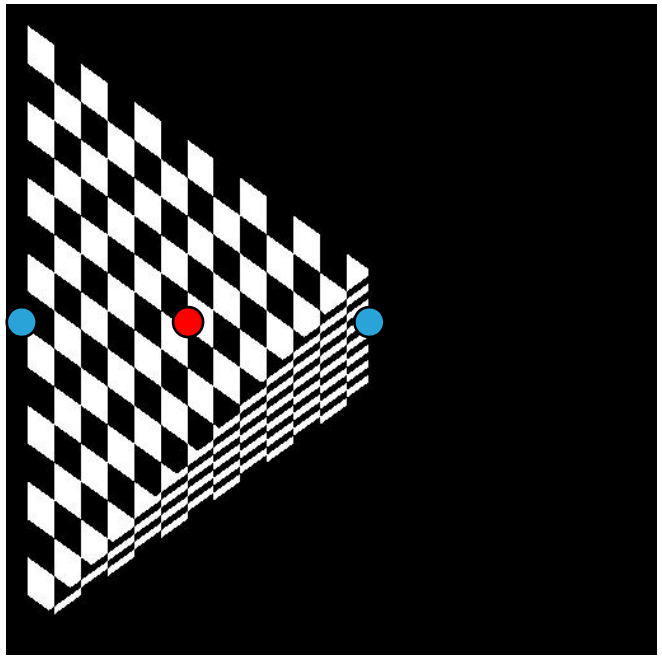


linear interpolation in object space

$$\frac{ax_1 + bx_2}{aw_1 + bw_2} \neq a\frac{x_1}{w_1} + b\frac{x_2}{w_2}$$

linear interpolation in screen space





$$a = b = 0.5$$

Early Perspective Texture Mapping in Games

DOOM (id Software, 1993)

Early Perspective Texture Mapping in Games

Quake (id Software, 1996)

Perspective-correct linear interpolation

Only projected values interpolate correctly, so project A

- Linearly interpolate A_1/w_1 and A_2/w_2

Also interpolate $1/w_1$ and $1/w_2$

- These also interpolate linearly in screen space

Divide interpolants at each sample point to recover A

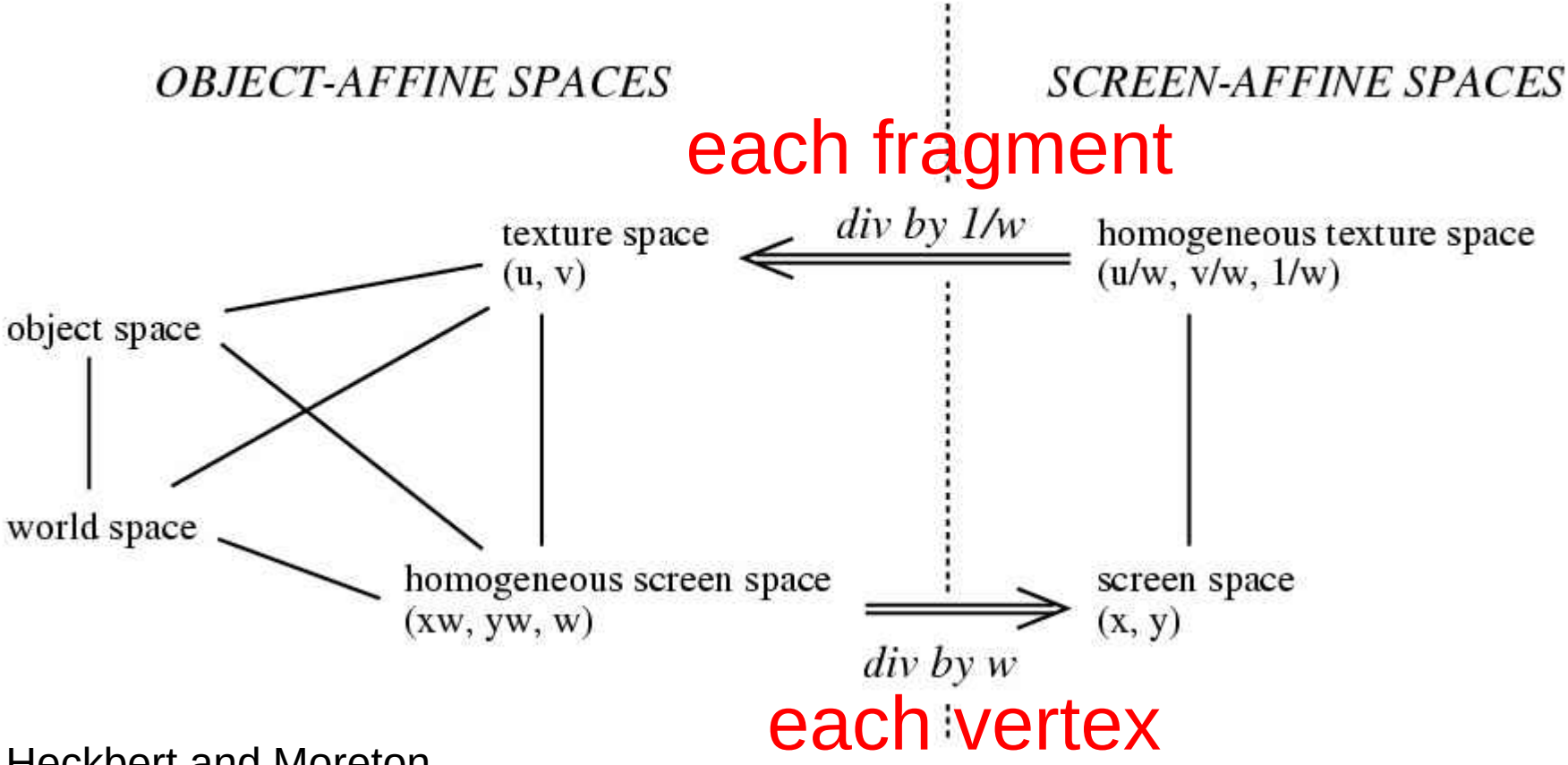
- $(A/w) \,/\, (1/w) = A$
- Division is expensive (more than add or multiply), so
  - Recover w for the sample point (reciprocate), and
  - Multiply each projected attribute by w

Barycentric triangle parameterization:

$$A = \frac{aA_1/w_1 + bA_2/w_2 + cA_3/w_3}{a/w_1 + b/w_2 + c/w_3} \qquad a + b + c = 1$$

Perspective Texture Mapping

- Solution: interpolate (s/w, t/w, 1/w)
- (s/w) / (1/w) = s etc. at every fragment



Heckbert and Moreton

Perspective-Correct Interpolation Recipe

$$r_i(x,y) = \frac{r_i(x,y)/w(x,y)}{1/w(x,y)}$$

(1) Associate a record containing the n parameters of interest $(r_1, r_2, \cdots, r_n)$ with each vertex of the polygon.

(2) For each vertex, transform object space coordinates to homogeneous screen space using 4×4 object to screen matrix, yielding the values (xw, yw, zw, w).

(3) Clip the polygon against plane equations for each of the six sides of the viewing frustum, linearly interpolating all the parameters when new vertices are created.

(4) At each vertex, divide the homogeneous screen coordinates, the parameters r_i, and the number 1 by w to construct the variable list $(x, y, z, s_1, s_2, \cdots, s_{n+1})$, where $s_i = r_i/w$ for $i \leq n$, $s_{n+1} = 1/w$.

(5) Scan convert in screen space by linear interpolation of all parameters, at each pixel computing $r_i = s_i/s_{n+1}$ for each of the n parameters; use these values for shading.

Heckbert and Moreton

Thank you.