King Abdullah University of Science and Technology KAUST

CS 380 - GPU and GPGPU Programming
Lecture 20: GPU Texturing, Pt. 2

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Reading Assignment #11 (until Nov 17)

Read (required):

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

  https://www.ri.cmu.edu/publications/interpolation-for-polygon-texture-mapping-and-shading/

- Homogeneous Coordinates

  https://en.wikipedia.org/wiki/Homogeneous_coordinates

Read (optional; highly recommended!):

- MIP-Map Level Selection for Texture Mapping

  https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=765326

Next Lectures

Lecture 21: Mon, Nov 17 (Quiz #2)

Lecture 22: Tue, Nov 18 (make-up lecture; 14:30 – 16:00, room 3131)

Lecture 23: Thu, Nov 20

Quiz #2: Oct 17

Organization

- First 30 min of lecture
- No material (book, notes, ...) allowed

Content of questions

- Lectures (both actual lectures and slides)
- Reading assignments
- Programming assignments (algorithms, methods)
- Solve short practical examples

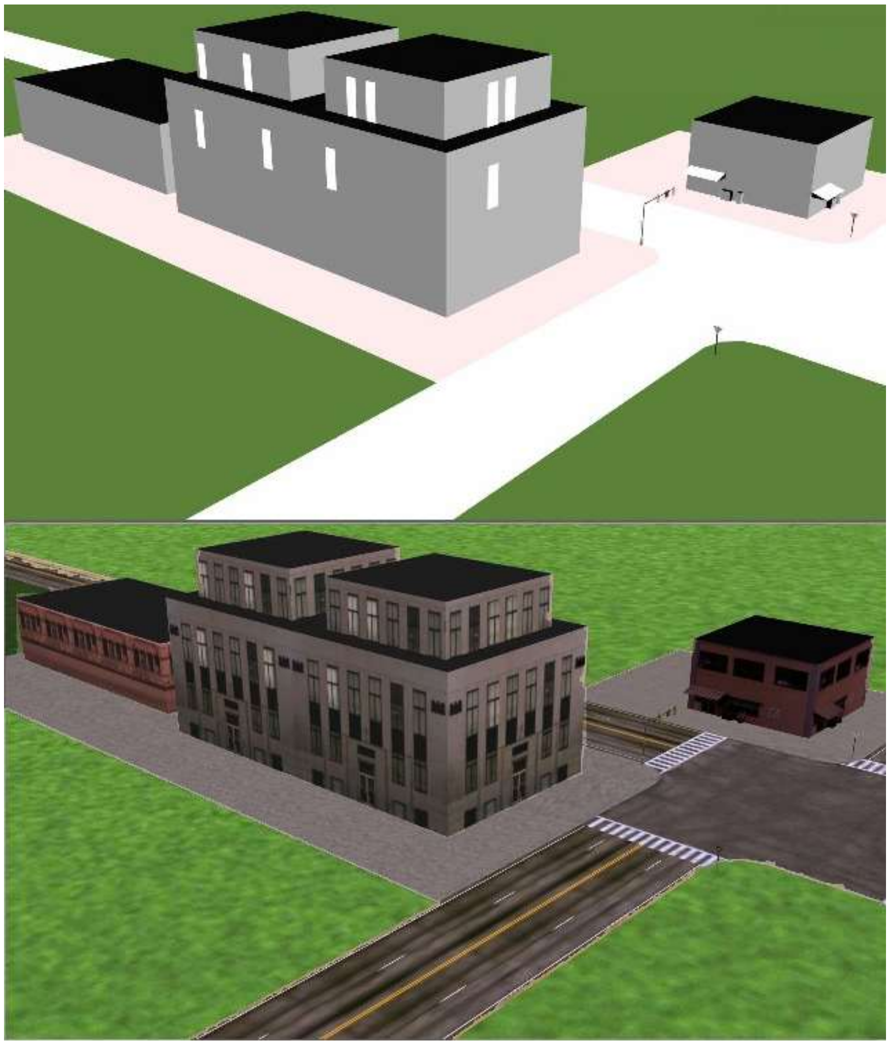
GPU Texturing

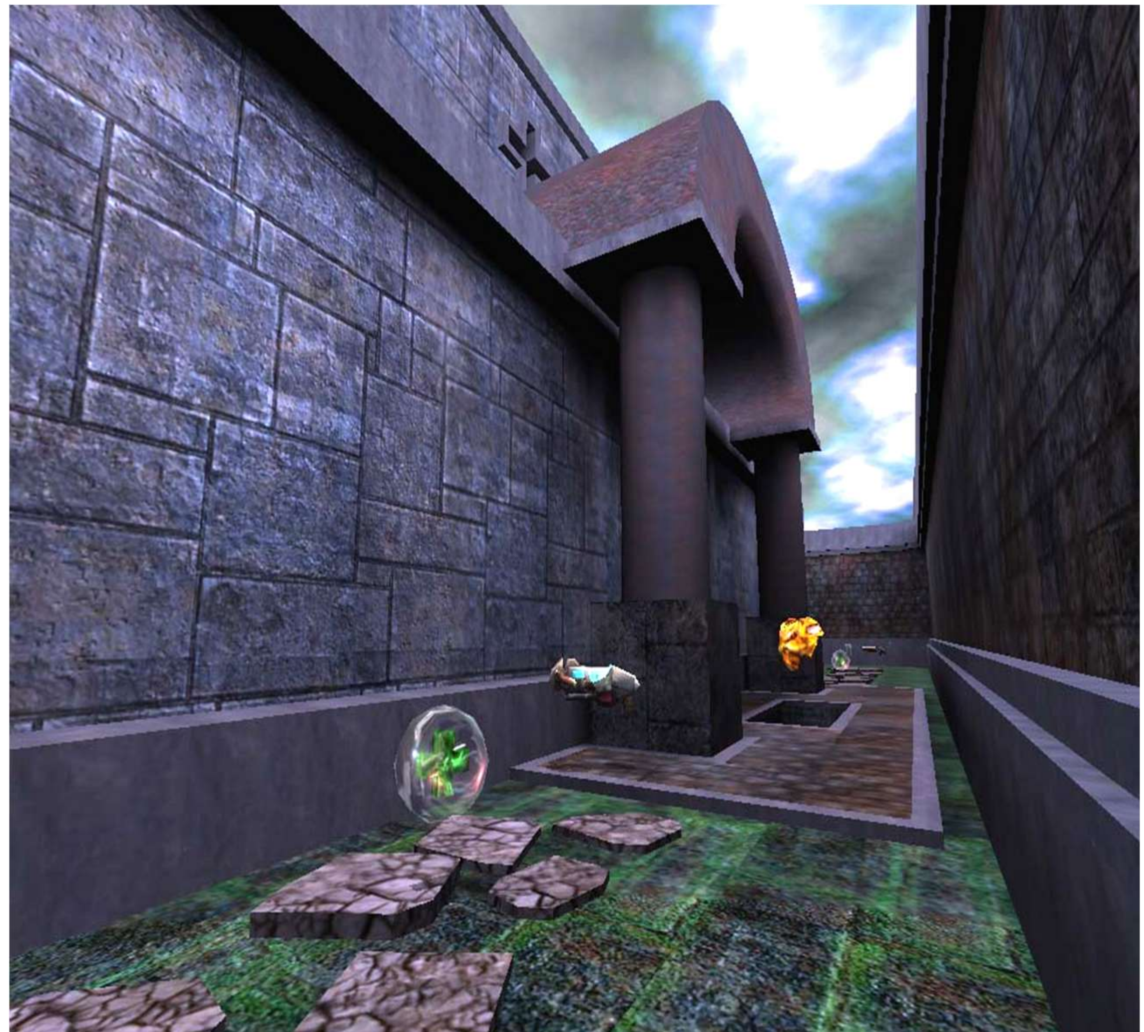
GPU Texturing

Rage / id Tech 5 (id Software)

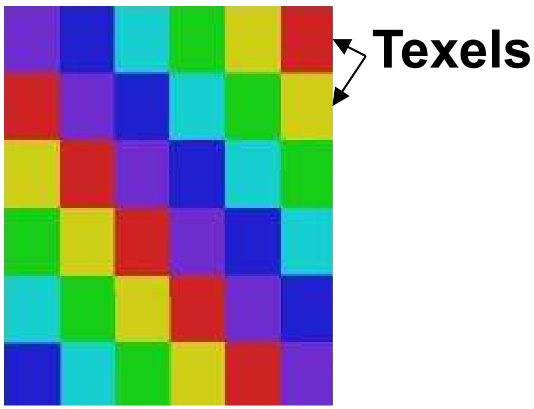
Why Texturing?

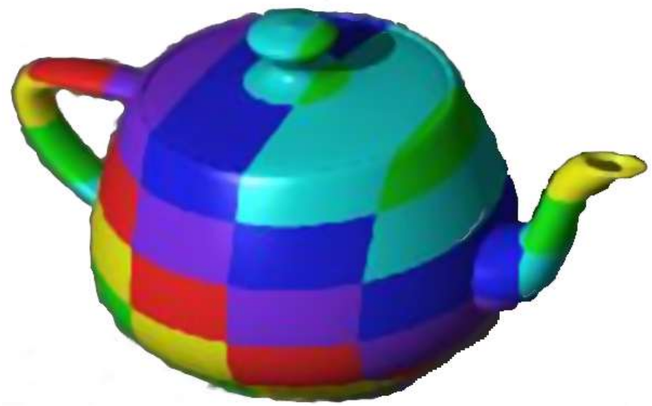
- Idea: enhance visual appearance of surfaces by applying fine / high-resolution details





Texturing: General Approach





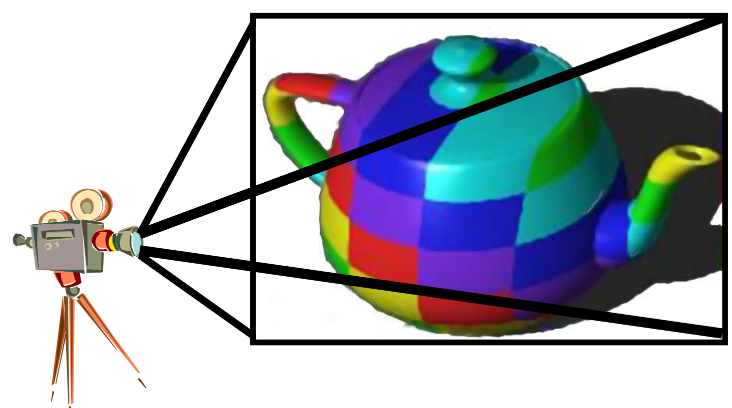
Texture space *(u,v)*

Object space (x_O, y_O, z_O)

Image Space (x_I, y_I)

Parametrization

Rendering (Projection etc.)



Texture Mapping

2D (3D) Texture Space

Texture Transformation

2D Object Parameters

Parameterization

3D Object Space

Model Transformation

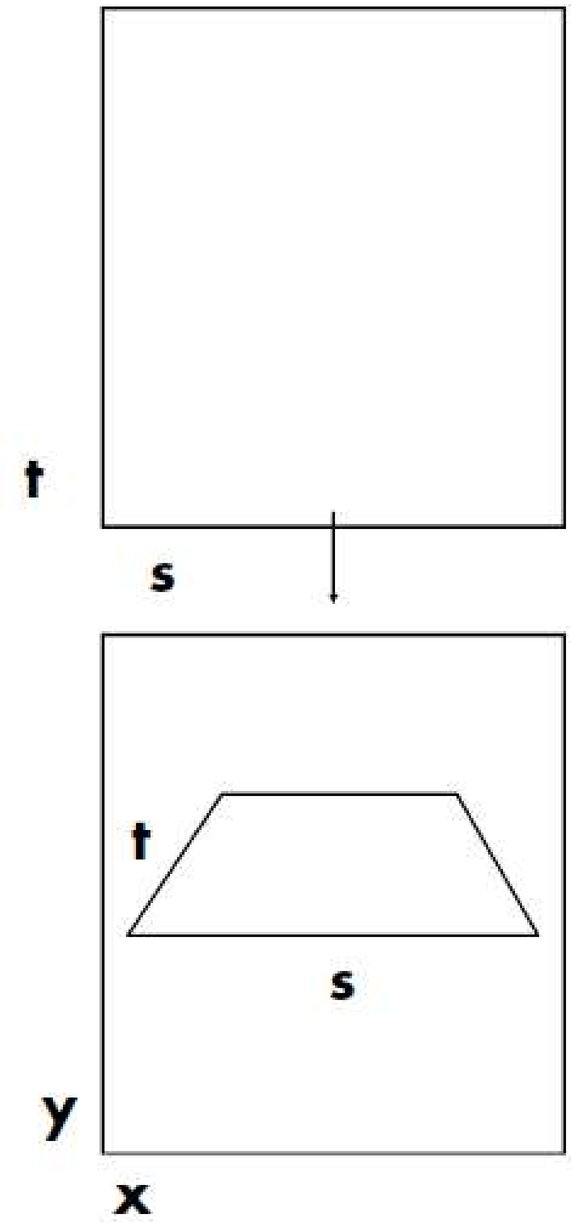
3D World Space

Viewing Transformation

3D Camera Space

Projection

2D Image Space



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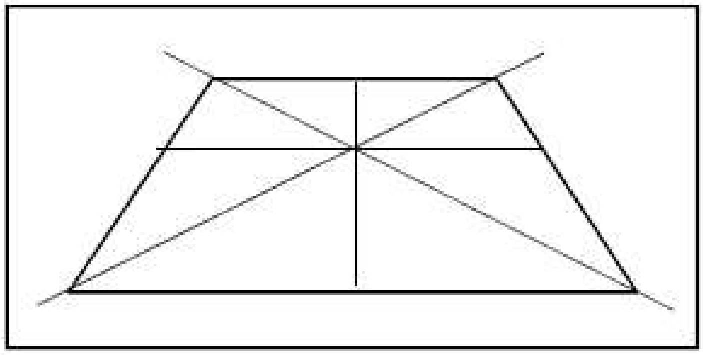
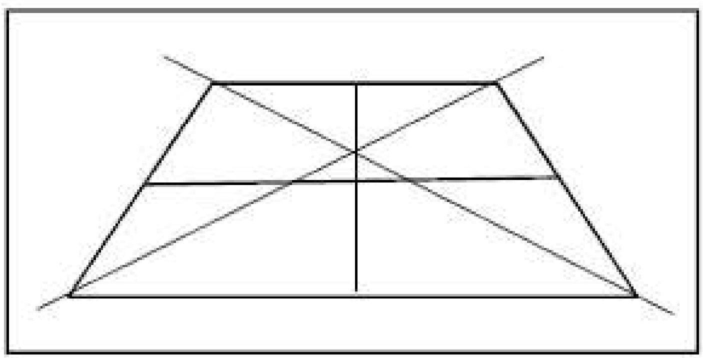
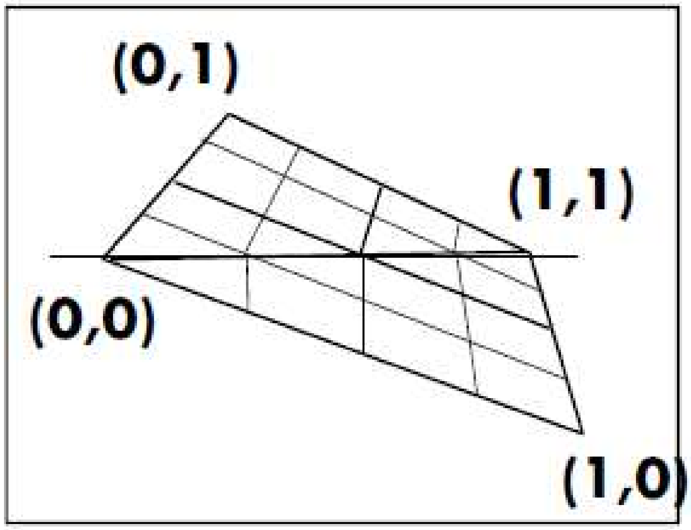
Linear Perspective



Correct Linear Perspective



Incorrect Perspective



Linear Interpolation, *Bad*

Perspective Interpolation, *Good*

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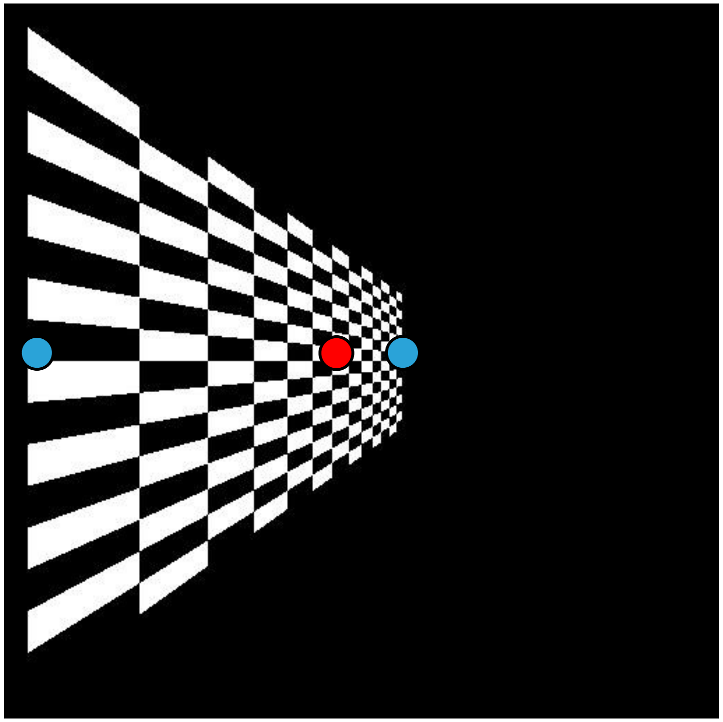
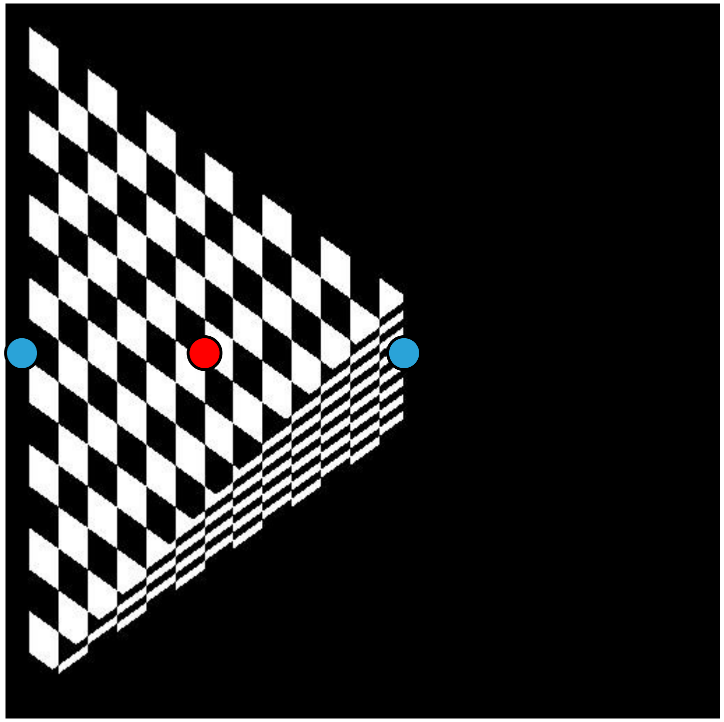
Perspective Texture Mapping

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

Ultima Underworld (Looking Glass, 1992)

Early Perspective Texture Mapping in Games

DOOM (id Software, 1993)

Early Perspective Texture Mapping in Games

Quake (id Software, 1996)

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

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

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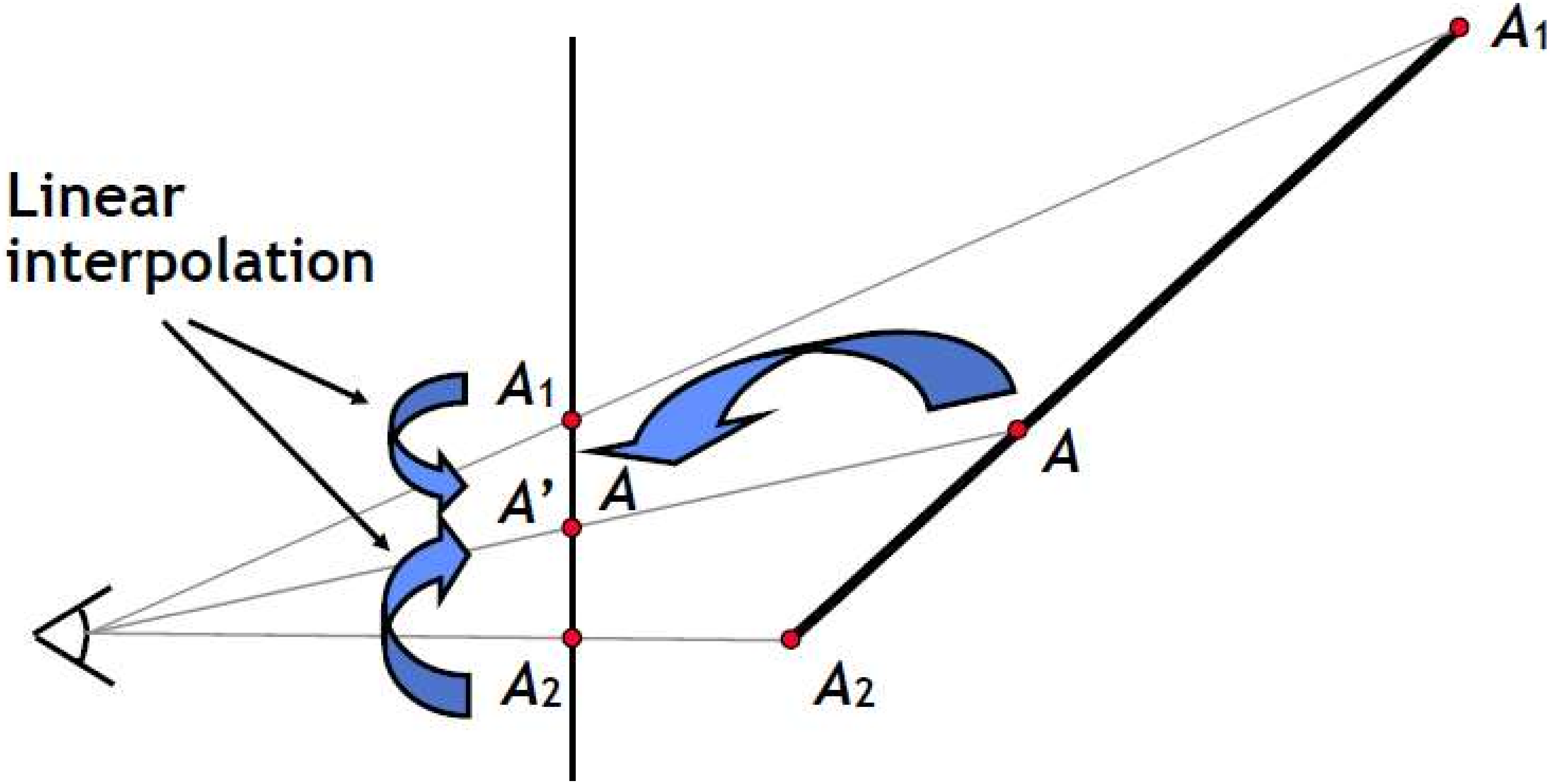
Incorrect attribute interpolation



$\boxed{A' \neq A\,!}$

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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

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:

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

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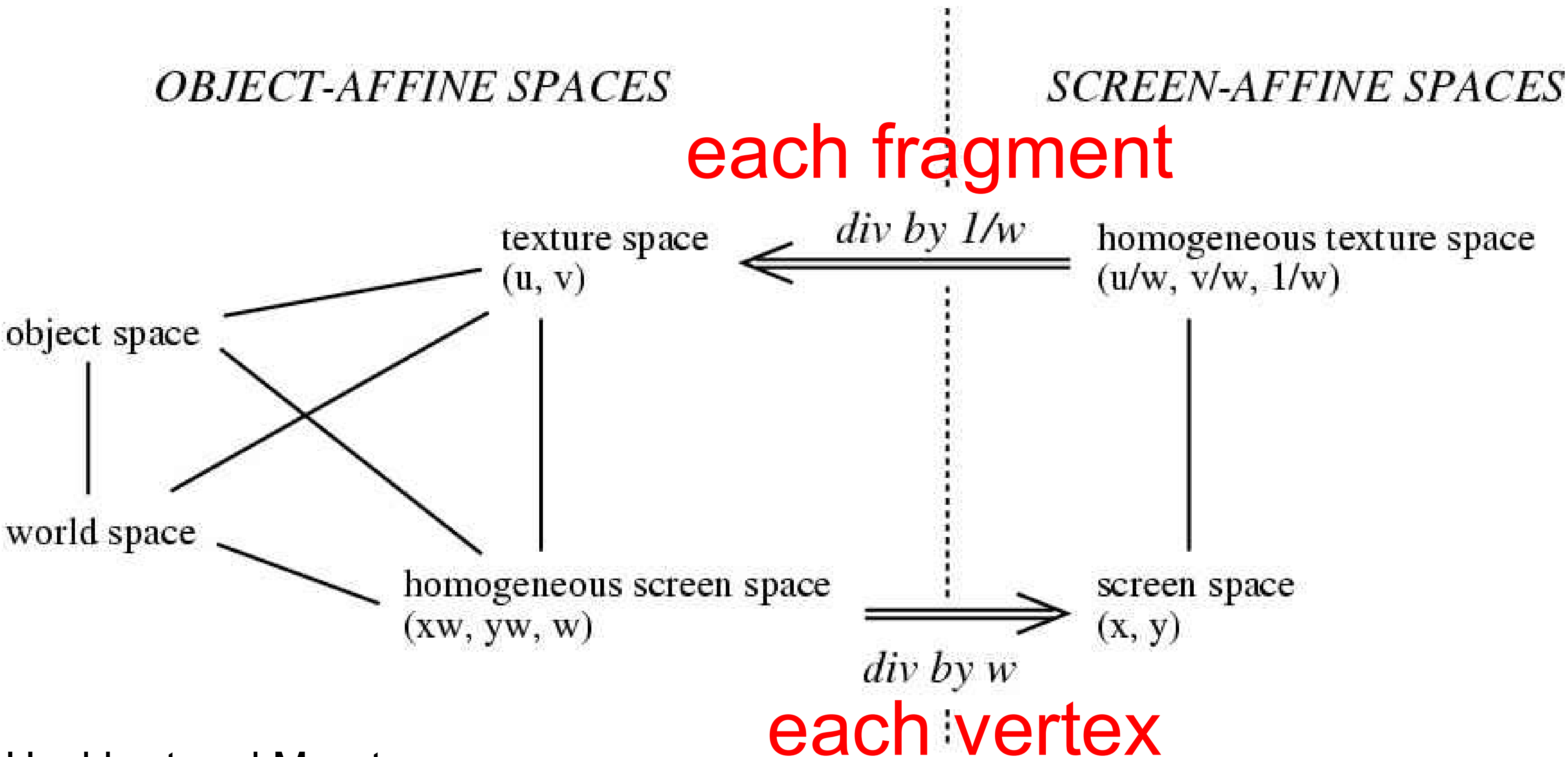
Perspective Texture Mapping

- 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 $i \le n$, $s_{n+1} = 1/w$.

(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.