CS 380 - GPU and GPGPU Programming
Lecture 21: GPU Texturing, Pt. 3

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Reading Assignment #12 (until Nov 24)

Read (required):

- Look at Vulkan *sparse resources*, especially *sparse partially-resident images*
  - https://docs.vulkan.org/spec/latest/chapters/sparsemem.html
- Read about shadow mapping
  - https://en.wikipedia.org/wiki/Shadow_mapping
- Look at Unreal Engine 5 virtual texturing
  - https://dev.epicgames.com/documentation/en-us/unreal-engine/virtual-texturing-in-unreal-engine/
- Look at Unreal Engine 5 MegaLights
  - https://dev.epicgames.com/documentation/en-us/unreal-engine/megalights-in-unreal-engine/

Read (optional):

- CUDA Warp-Level Primitives
  - https://developer.nvidia.com/blog/using-cuda-warp-level-primitives/
- Warp-aggregated atomics
  - https://developer.nvidia.com/blog/cuda-pro-tip-optimized-filtering-warp-aggregated-atomics/

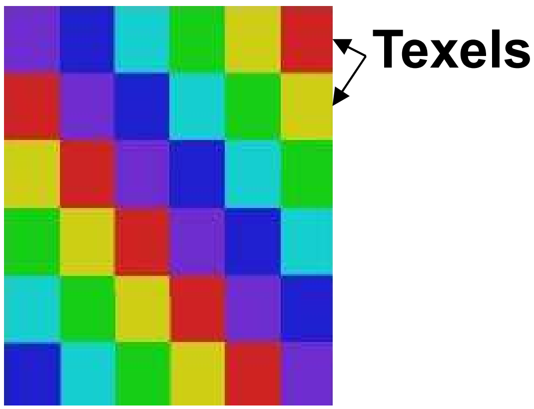
Next Lectures

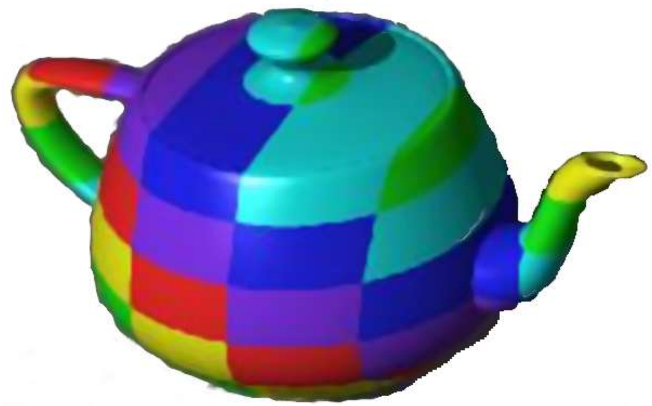
Lecture 22: Tue, Nov 18 (make-up lecture; 14:30 – 16:00, room 3131)

Lecture 23: Thu, Nov 20

GPU Texturing

Texturing: General Approach





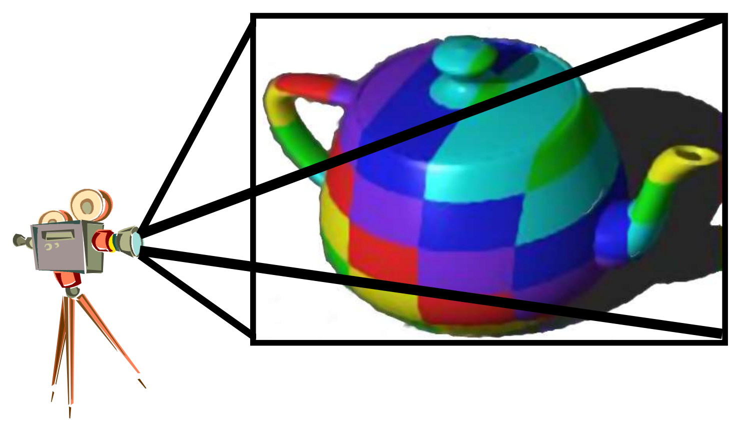
Texture space *(u,v)*

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

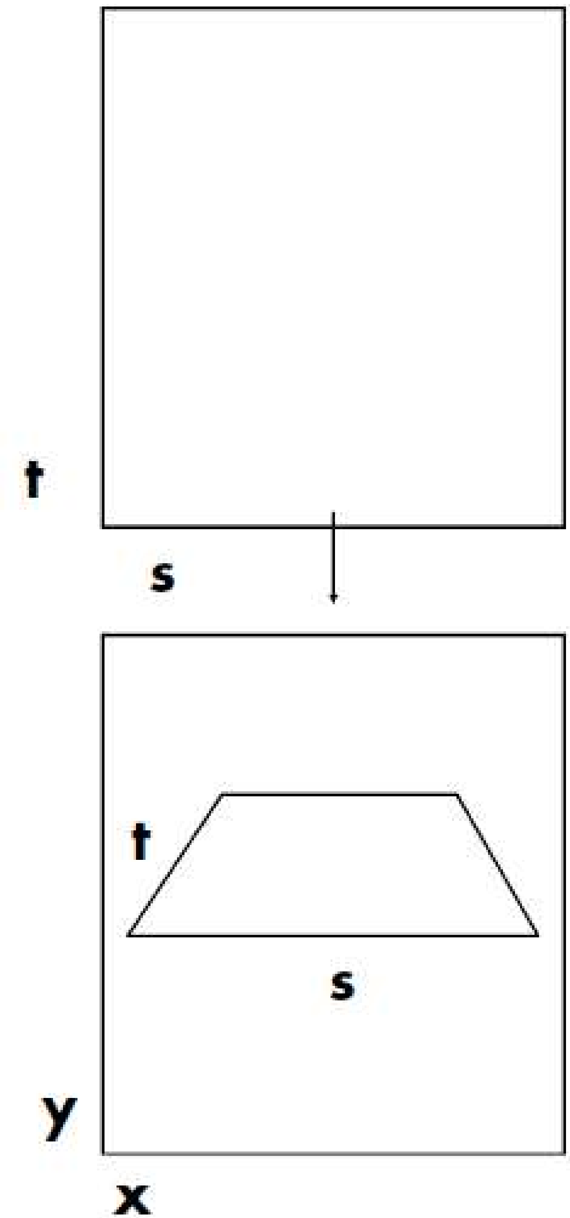
3D World Space

↓ Viewing Transformation

3D Camera Space

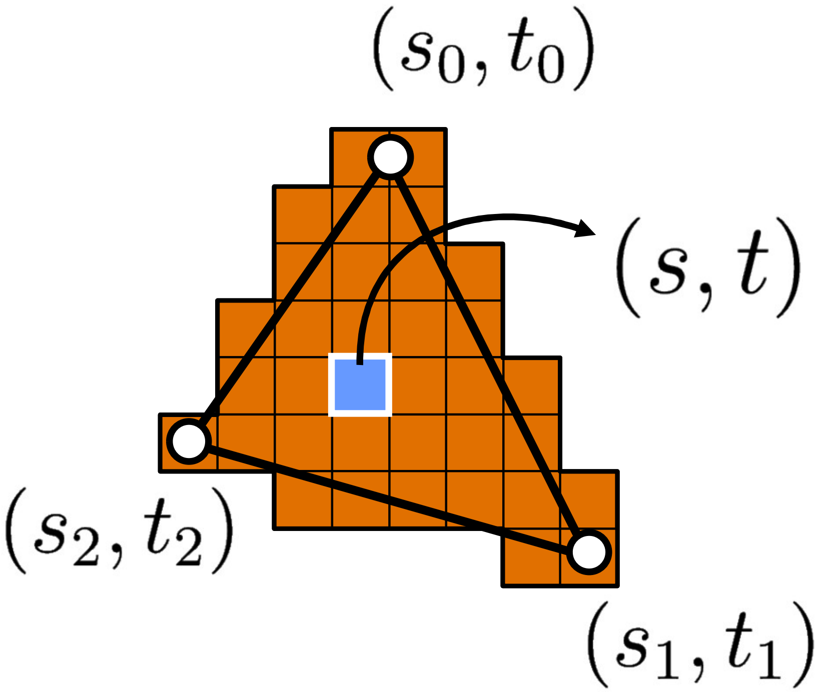
↓ Projection

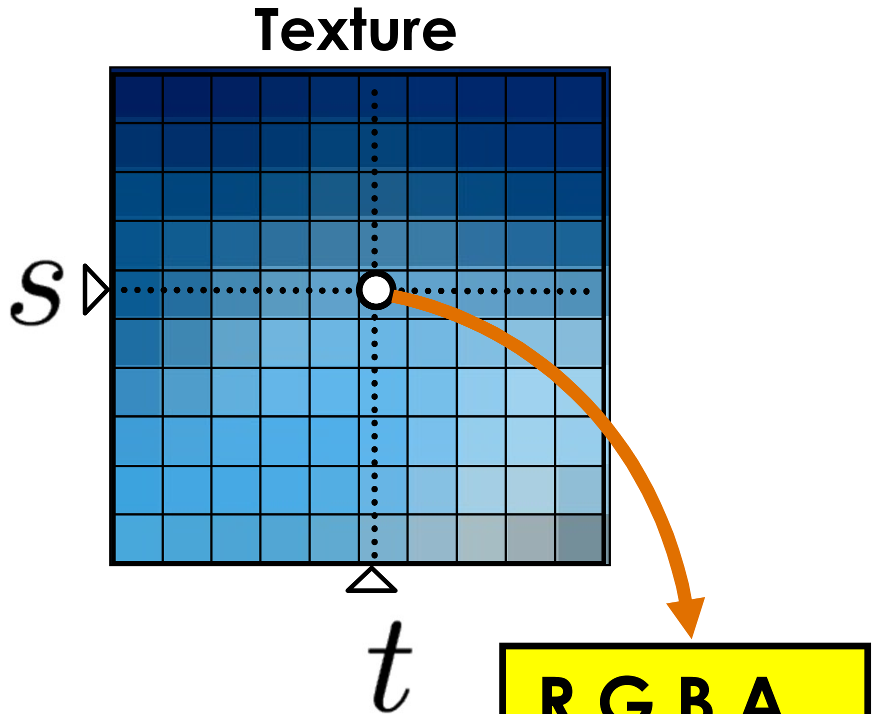
2D Image Space



Kurt Akeley, Pat Hanrahan

2D Texture Mapping

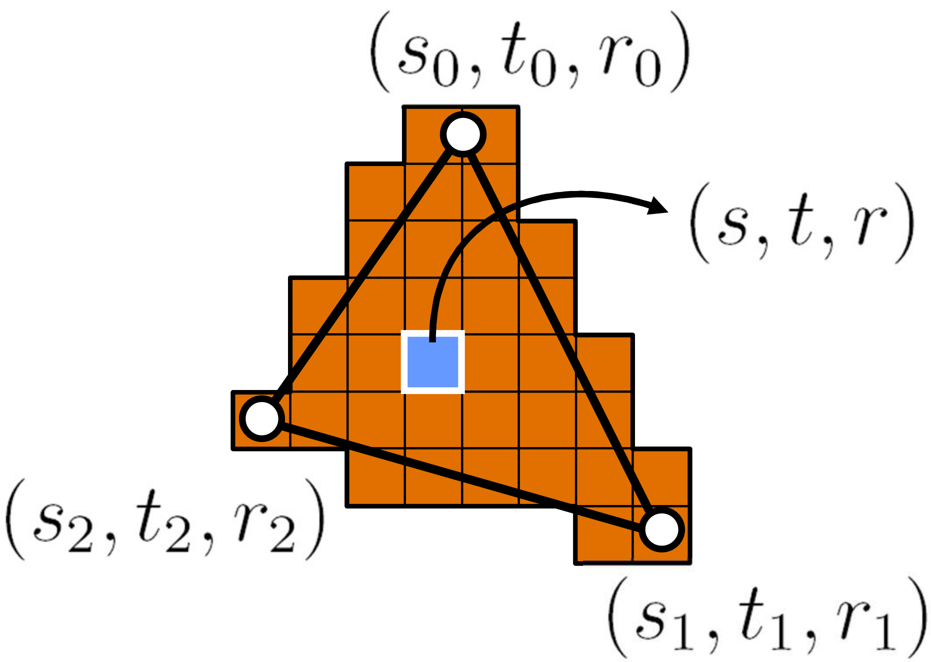




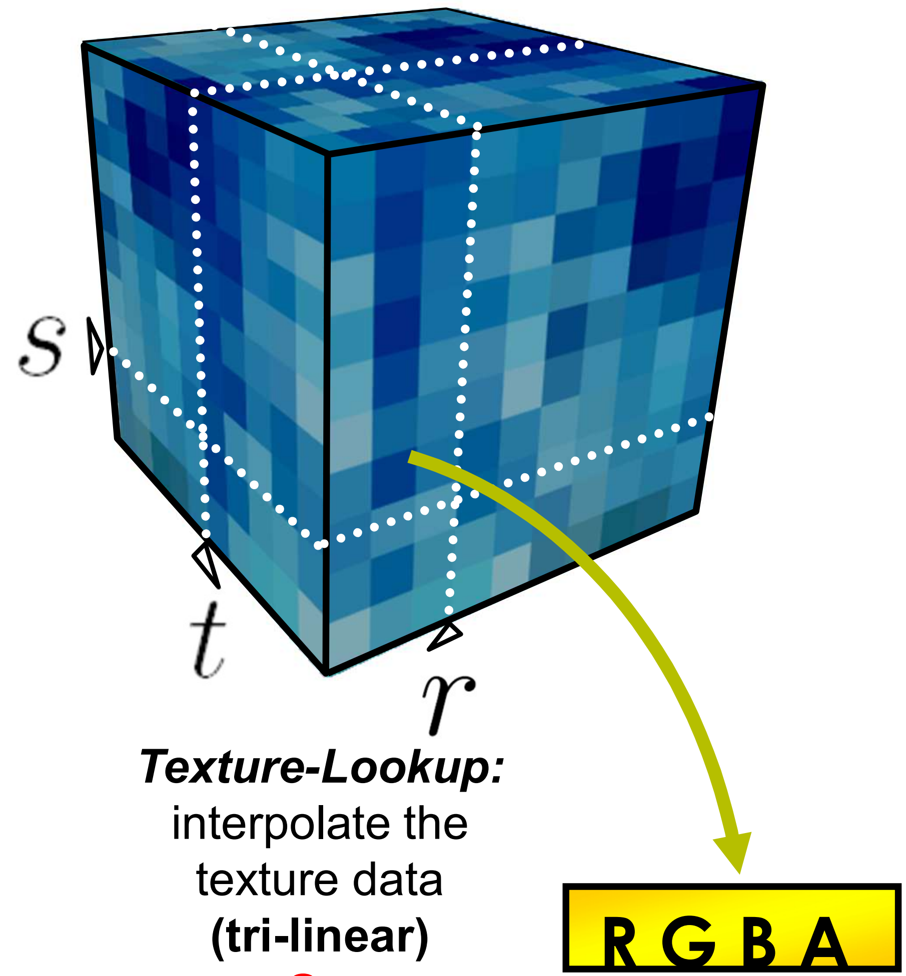
For each fragment:
interpolate the
texture coordinates
(barycentric)
Or:
Use arbitrary, computed coordinates

Texture-Lookup:
interpolate the
texture data
(bi-linear)
Or:
Nearest-neighbor for "array lookup"

3D Texture Mapping



For each fragment:
interpolate the
texture coordinates
(barycentric)
Or:
Use arbitrary, computed coordinates



Texture-Lookup:
interpolate the
texture data
(tri-linear)
Or:
Nearest-neighbor for “array lookup”

Interpolation #1

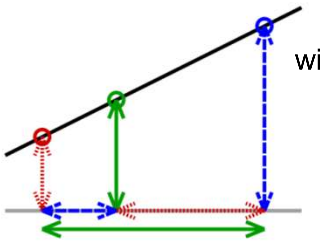
Interpolation Type + Purpose #1:

Interpolation of Texture Coordinates

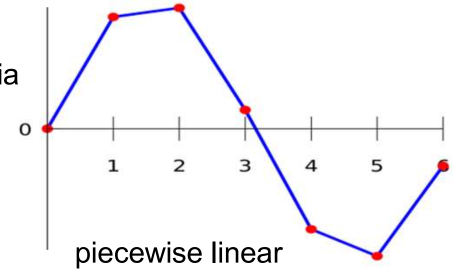
(Linear / Rational-Linear Interpolation)

Linear Interpolation / Convex Combinations

Linear interpolation in 1D:



wikipedia



piecewise linear

$$f(\alpha) = (1-\alpha)v_1 + \alpha v_2$$

Line embedded in 2D (linear interpolation of vertex coordinates/attributes):

$$f(\alpha_1, \alpha_2) = \alpha_1 v_1 + \alpha_2 v_2 \qquad f(\alpha) = v_1 + \alpha(v_2 - v_1)$$

$$\alpha_1 + \alpha_2 = 1 \qquad \alpha = \alpha_2$$

Line segment: $\alpha_1, \alpha_2 \geq 0$ (→ convex combination)

Compare to line parameterization with parameter t: $v(t) = v_1 + t(v_2 - v_1)$

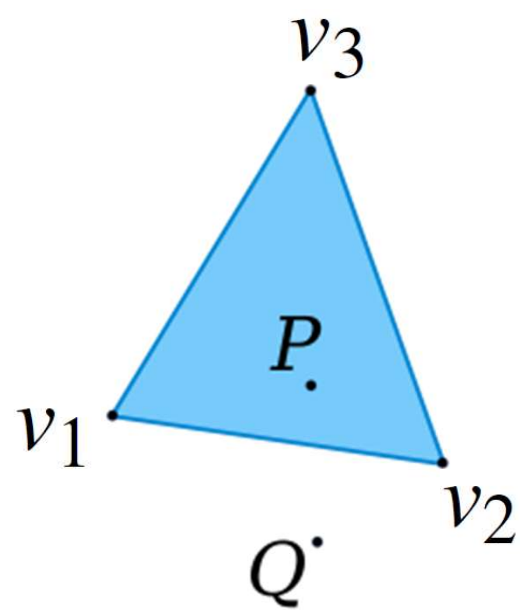
Linear Interpolation / Convex Combinations

Linear combination (n-dim. space):

$$\alpha_1 v_1 + \alpha_2 v_2 + \ldots + \alpha_n v_n = \sum_{i=1}^{n} \alpha_i v_i$$

Affine combination: Restrict to $(n-1)$-dim. subspace:

$$\alpha_1 + \alpha_2 + \ldots + \alpha_n = \sum_{i=1}^{n} \alpha_i = 1$$



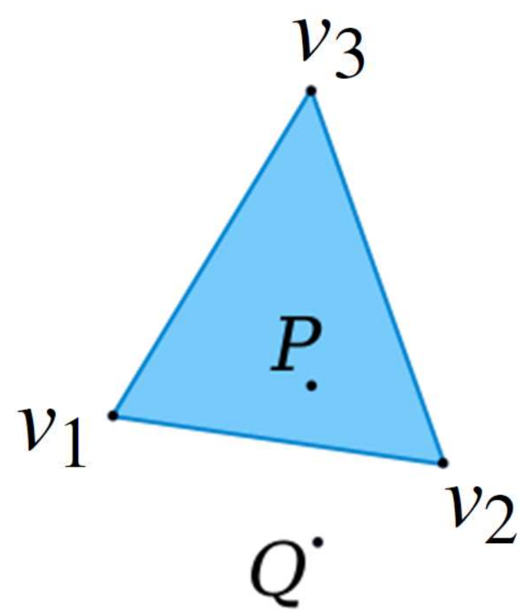
Convex combination: $\alpha_i \geq 0$

(restrict to simplex in subspace)

Linear Interpolation / Convex Combinations

$$\alpha_1 v_1 + \alpha_2 v_2 + \ldots + \alpha_n v_n = \sum_{i=1}^{n} \alpha_i v_i$$

$$\alpha_1 + \alpha_2 + \ldots + \alpha_n = \sum_{i=1}^{n} \alpha_i = 1$$



Re-parameterize to get affine coordinates:

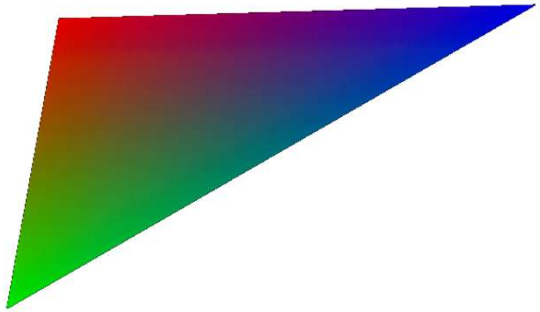
$$\alpha_1 v_1 + \alpha_2 v_2 + \alpha_3 v_3 =$$
$$\tilde{\alpha}_1 (v_2 - v_1) + \tilde{\alpha}_2 (v_3 - v_1) + v_1$$
$$\tilde{\alpha}_1 = \alpha_2$$
$$\tilde{\alpha}_2 = \alpha_3$$

Linear Interpolation / Convex Combinations

The weights α_i are the (normalized) barycentric coordinates

→ linear attribute interpolation in simplex

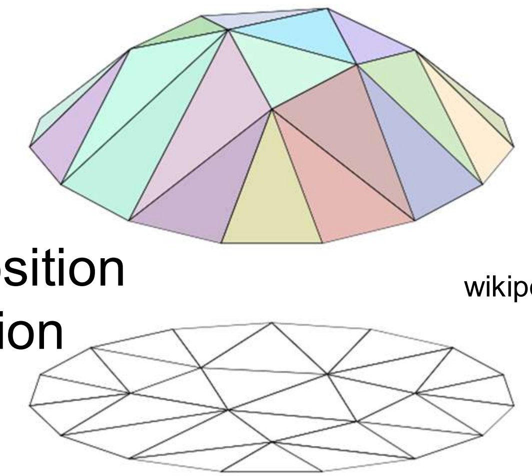
attribute interpolation



$$\alpha_1 v_1 + \alpha_2 v_2 + \ldots + \alpha_n v_n = \sum_{i=1}^{n} \alpha_i v_i$$

$$\alpha_1 + \alpha_2 + \ldots + \alpha_n = \sum_{i=1}^{n} \alpha_i = 1$$

$$\alpha_i \geq 0$$



spatial position interpolation

wikipedia

Homogeneous Coordinates (1)

Projective geometry

- (Real) projective spaces RP^n:

  Real projective line RP^1, real projective plane RP^2, ...
- A point in RP^n is a line through the origin (i.e., all the scalar multiples of the same vector) in an (n+1)-dimensional (real) vector space

Homogeneous coordinates of 2D projective point in RP^2

- Coordinates differing only by a non-zero factor λ map to the same point

  $(\lambda x, \lambda y, \lambda)$ dividing out the λ gives $(x, y, 1)$, corresponding to (x,y) in R^2
- Coordinates with last component = 0 map to "points at infinity"

  $(\lambda x, \lambda y, 0)$ division by last component not allowed; but again this is the same point if it only differs by a scalar factor, e.g., this is the same point as $(x, y, 0)$

Homogeneous Coordinates (2)

Examples of usage

- Translation (with translation vector $\vec{b}$)
- Affine transformations (linear transformation + translation)

$$\vec{y} = A\vec{x} + \vec{b}.$$

- With homogeneous coordinates:

$$\begin{bmatrix} \vec{y} \\ 1 \end{bmatrix} = \left[\begin{array}{ccc|c} & A & & \vec{b} \\ 0 & \dots & 0 & 1 \end{array} \right] \begin{bmatrix} \vec{x} \\ 1 \end{bmatrix}$$

- Setting the last coordinate = 1 and the last row of the matrix to [0, ..., 0, 1] results in translation of the point $\vec{x}$ (via addition of translation vector $\vec{b}$)
- The matrix above is a linear map, but because it is one dimension higher, it does not have to move the origin in the (n+1)-dimensional space for translation

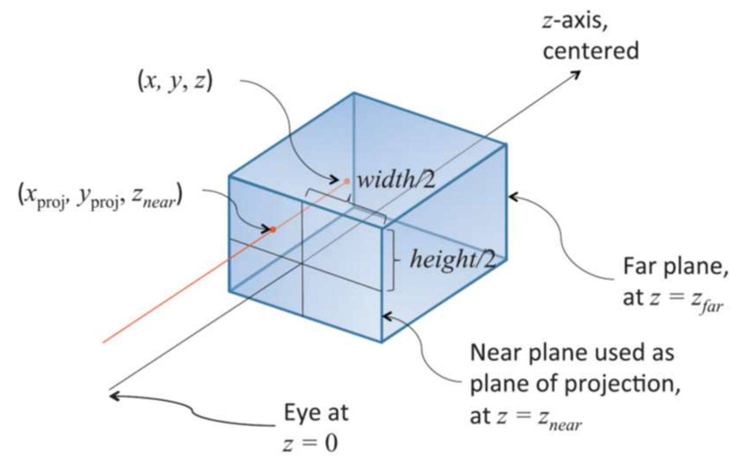
Homogeneous Coordinates (3)

Examples of usage

- Projection (e.g., OpenGL projection matrices)

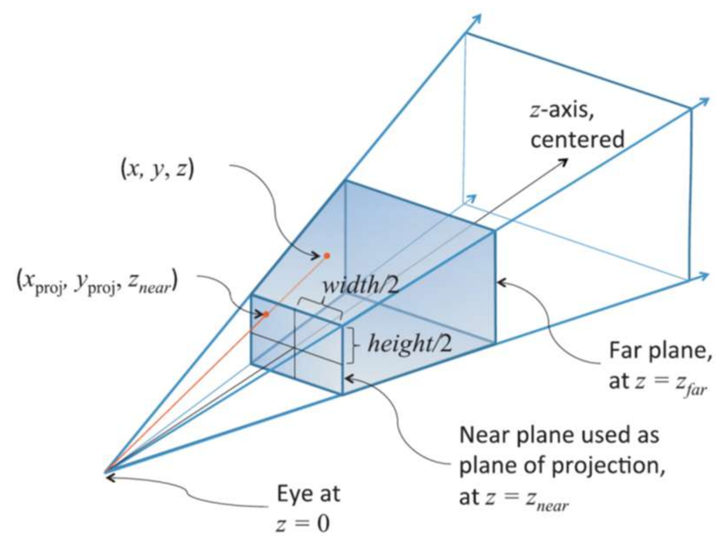
$$\begin{bmatrix} \frac{2}{\text{right}-\text{left}} & 0 & 0 & -\frac{\text{right}+\text{left}}{\text{right}-\text{left}} \\ 0 & \frac{2}{\text{top}-\text{bottom}} & 0 & -\frac{\text{top}+\text{bottom}}{\text{top}-\text{bottom}} \\ 0 & 0 & \frac{-2}{\text{far}-\text{near}} & -\frac{\text{far}+\text{near}}{\text{far}-\text{near}} \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

orthographic



$$\begin{bmatrix} \frac{z_{near}}{width/2} & 0.0 & \frac{left+right}{width/2} & 0.0 \\ 0.0 & \frac{z_{near}}{height/2} & \frac{top+bottom}{height/2} & 0.0 \\ 0.0 & 0.0 & -\frac{z_{far}+z_{near}}{z_{far}-z_{near}} & \frac{2z_{far}z_{near}}{z_{far}-z_{near}} \\ 0.0 & 0.0 & -1.0 & 0.0 \end{bmatrix}$$

perspective



Thank you.