CS 380 - GPU and GPGPU Programming
Lecture 14: GPU Texturing, Pt. 1

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Reading Assignment #8 (until Oct 25)

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

- Homogeneous Coordinates

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

Semester Project (proposal until Oct 25!)

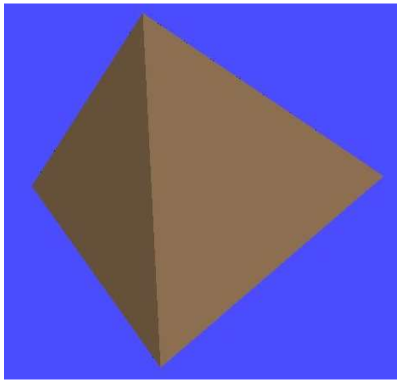
- Choosing your own topic encouraged!
  (we will also suggest some topics)
  - Pick something that you think is really cool!
  - Can be completely graphics or completely computation, or both combined
  - Can be built on CS 380 frameworks, NVIDIA OpenGL SDK, CUDA SDK, ...
- Write short (1-2 pages) project proposal by end of Sep (announced later)
  - Talk to us before you start writing!
    (content and complexity should fit the lecture)
- Submit semester project with report (deadline: Dec 9)
- Present semester project (event in final exams week: Dec 13 (tentative))

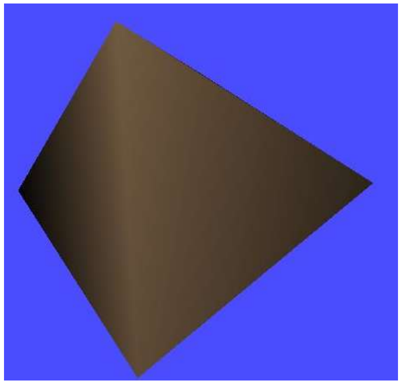
GPU Texturing

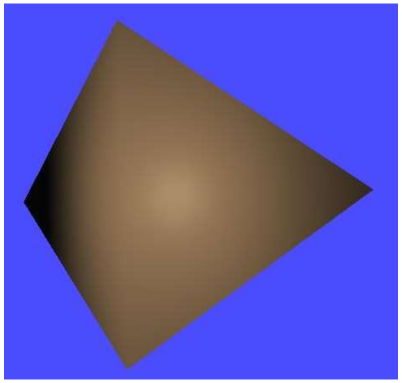
Rage / id Tech 5 (id Software)

Remember: Basic Shading

- Flat shading
  - compute light interaction per polygon
  - the whole polygon has the same color
- Gouraud shading
  - compute light interaction per vertex
  - interpolate the colors
- Phong shading
  - interpolate normals per pixel
- Remember: difference between
  - Phong Lighting Model
  - Phong Shading

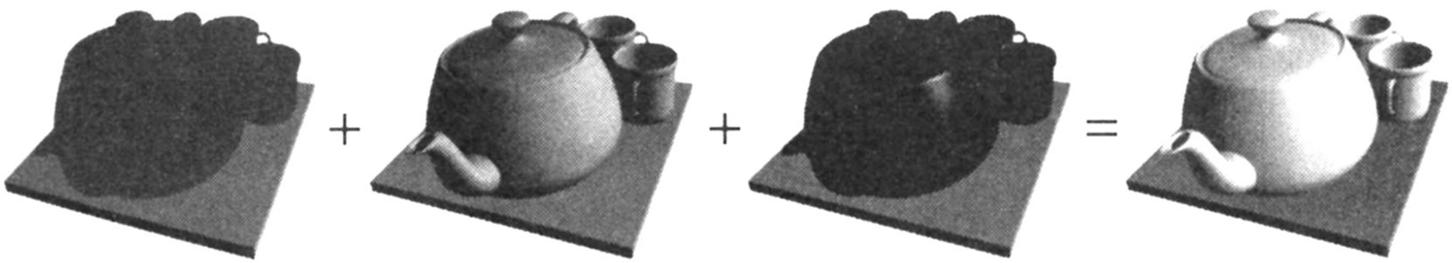






Traditional OpenGL Lighting

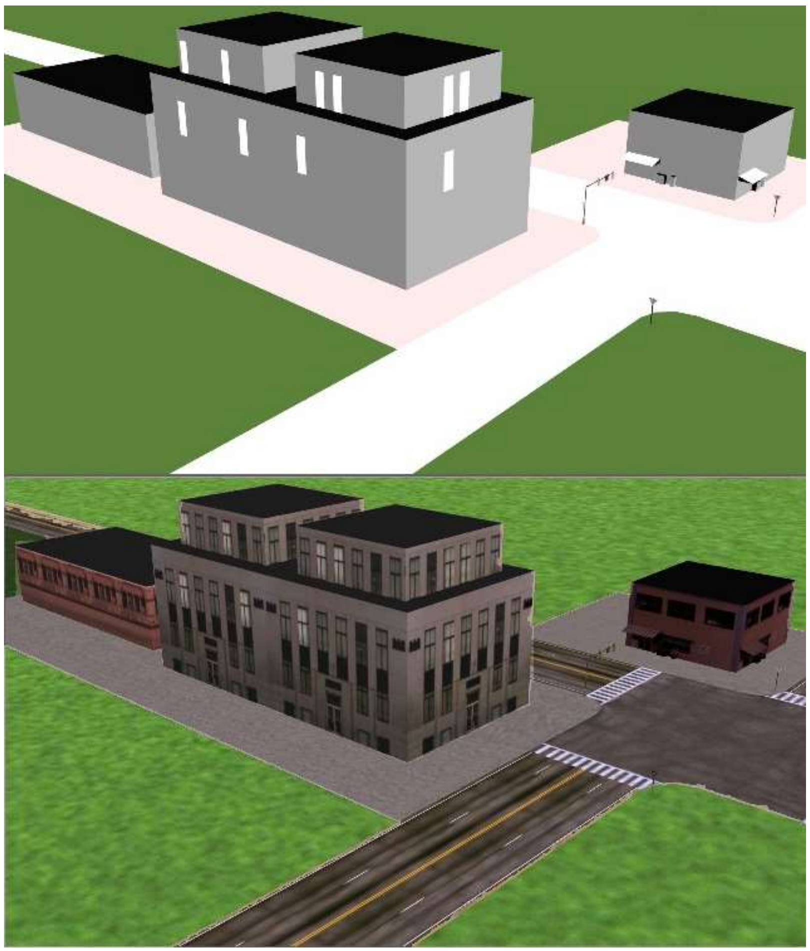
- Phong lighting model at each vertex (glLight, …)
- Local model only (no shadows, radiosity, …)
- ambient + diffuse + specular (glMaterial!)

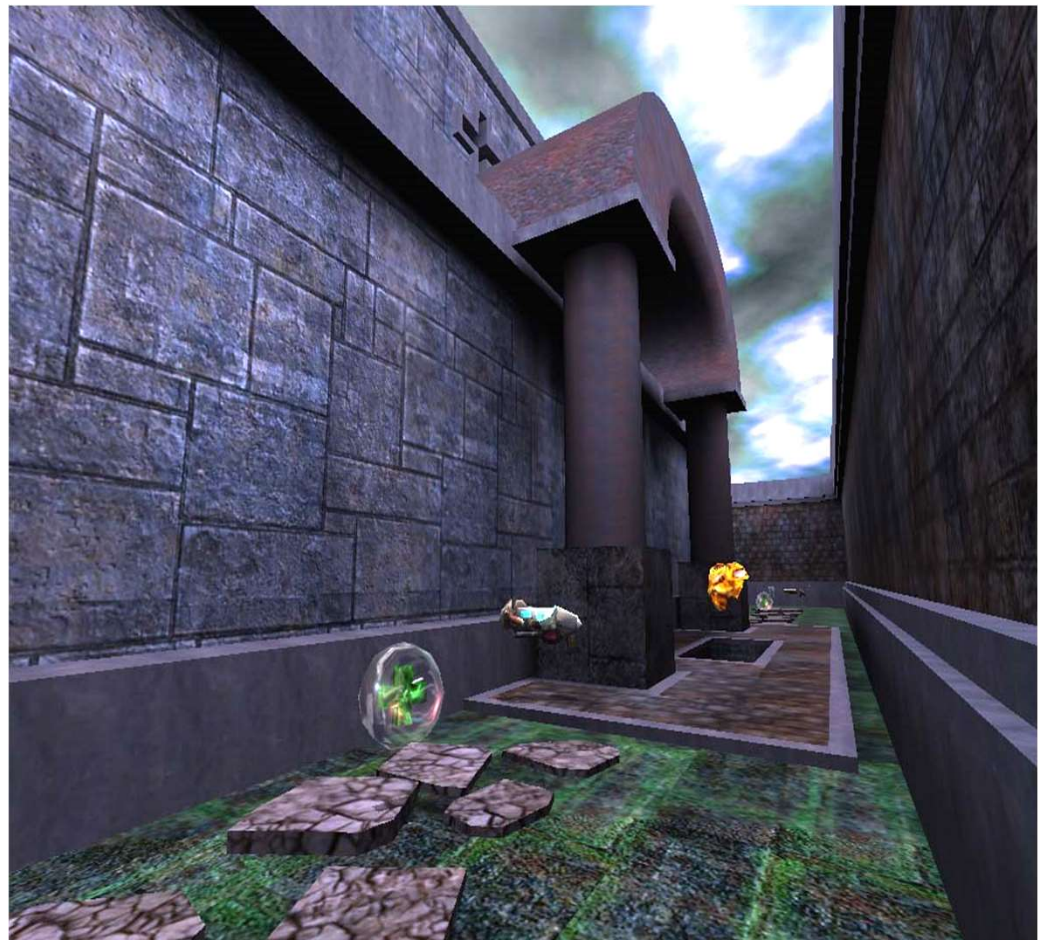


- Fixed function: Gouraud shading
  - Note: need to interpolate specular separately!
- Phong shading: evaluate Phong lighting model in fragment shader (per-fragment evaluation!)

Why Texturing?

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





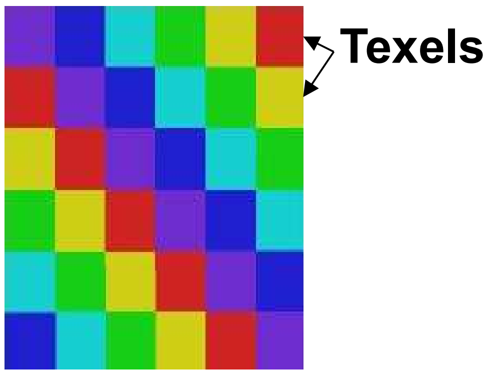
OpenGL Texture Mapping

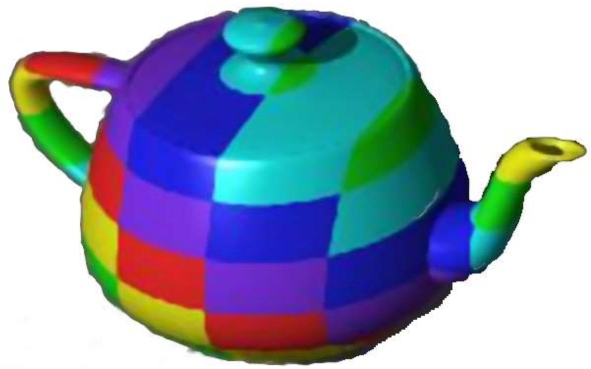
- Basis for most real-time rendering effects
- Look and feel of a surface
- Definition:
  - A *regularly sampled function* that is mapped onto every *fragment* of a surface
  - Traditionally an image, but…
- Can hold arbitrary information
  - Textures become general data structures
  - Sampled and interpreted by fragment programs
  - Can render into textures → important!

Types of Textures

- Spatial layout
  - Cartesian grids: 1D, 2D, 3D, 2D_ARRAY, …
  - Cube maps, …
- Formats (too many), e.g. OpenGL
  - GL_LUMINANCE16_ALPHA16
  - GL_RGB8, GL_RGBA8, …: integer texture formats
  - GL_RGB16F, GL_RGBA32F, …: float texture formats
  - compressed formats, high dynamic range formats, …
- External (CPU) format vs. internal (GPU) format
  - OpenGL driver converts from external to internal

Texturing: General Approach





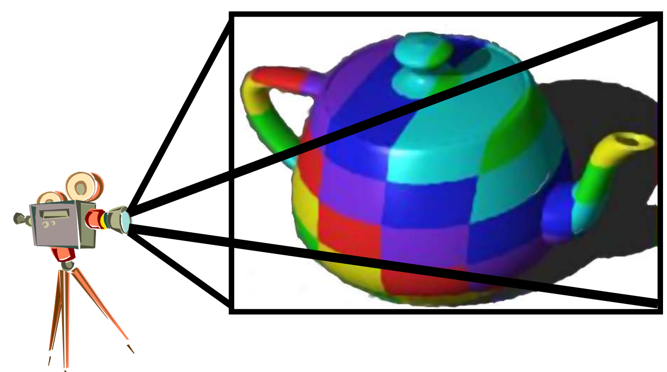
Texture space *(u,v)*

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

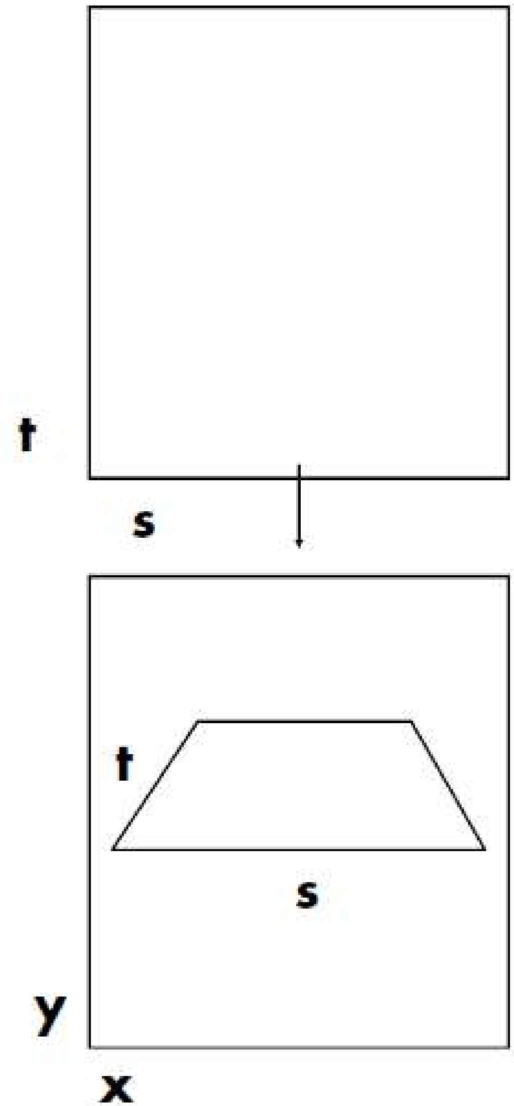
3D World Space

↓ Viewing Transformation

3D Camera Space

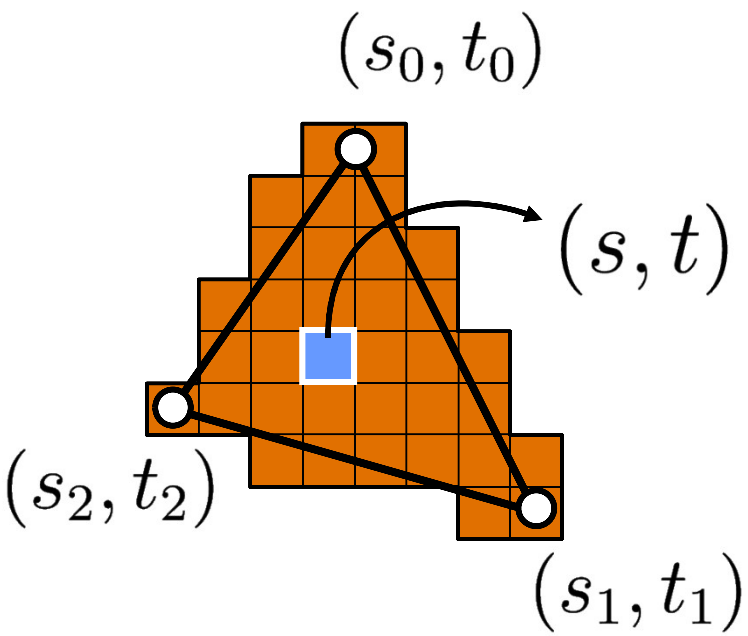
↓ Projection

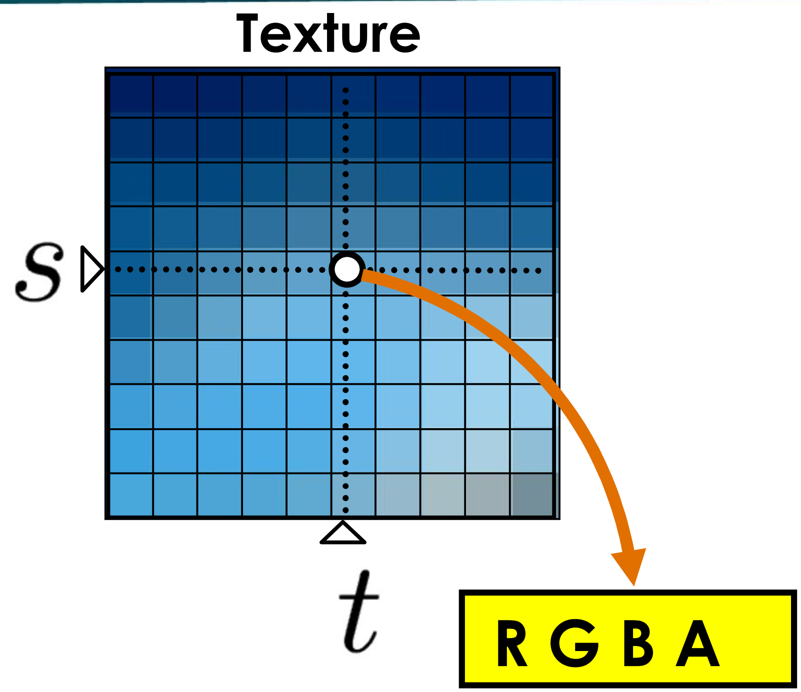
2D Image Space



Kurt Akeley, Pat Hanrahan

2D Texture Mapping

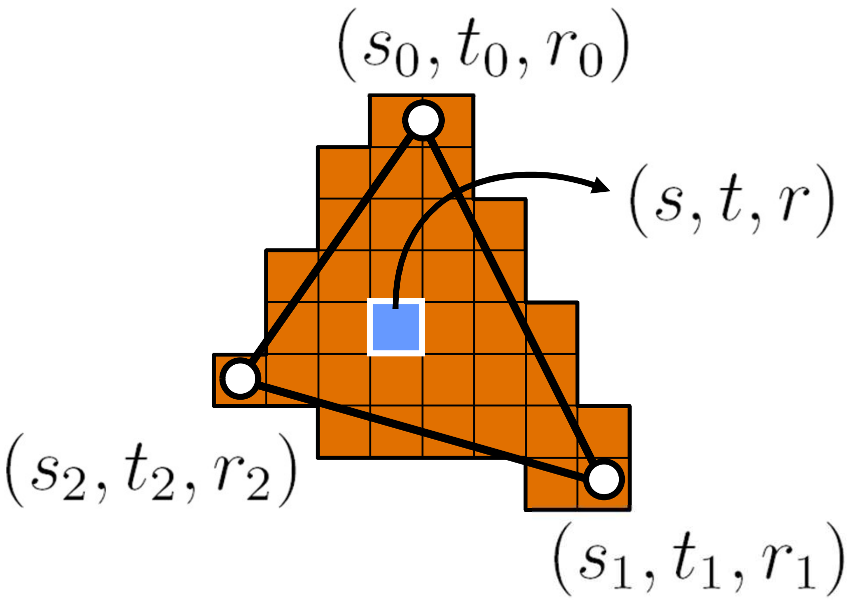


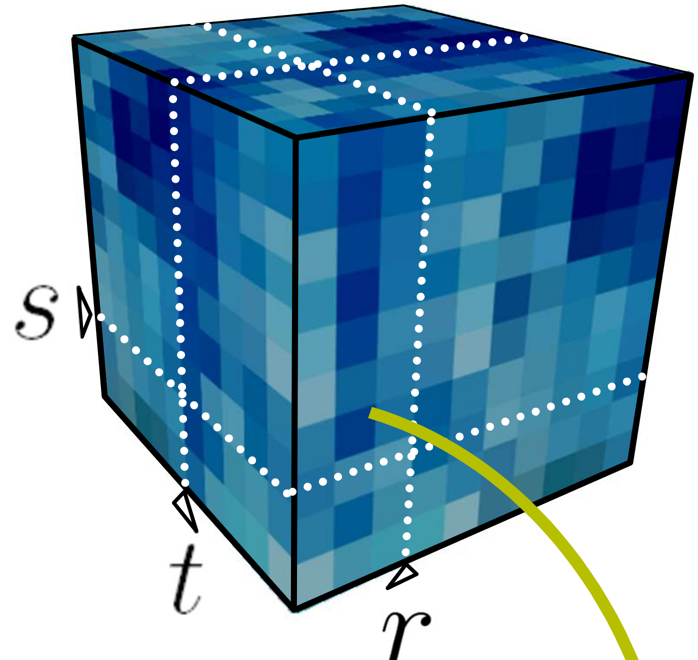


For each fragment:
interpolate the
texture coordinates
(barycentric)
Or:
Use arbitrary, computed coordinates

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

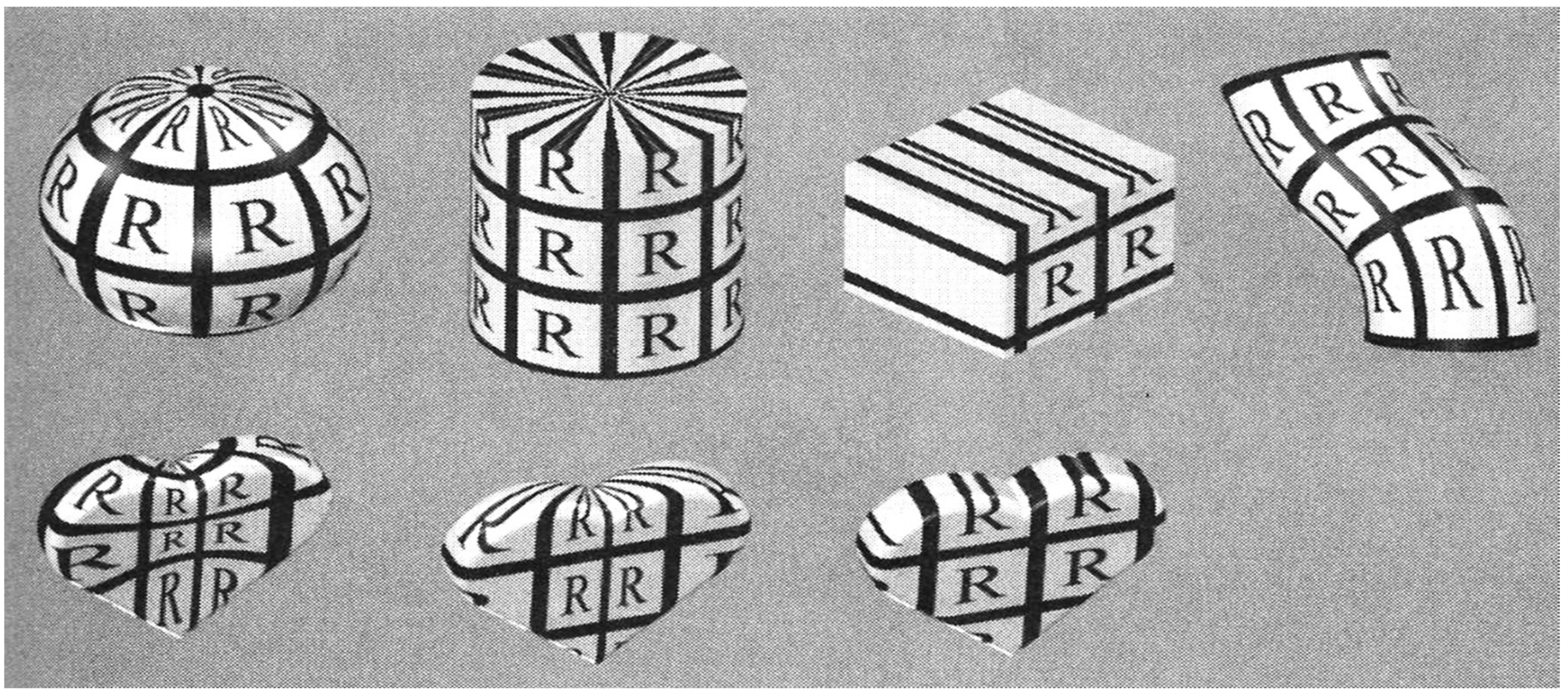
Texture-Lookup:
interpolate the
texture data
(tri-linear)
Or:
Nearest-neighbor for "array lookup"

Texture Projectors

Where do texture coordinates come from?

- Online: texture matrix/texcoord generation
- Offline: manually (or by modeling program)

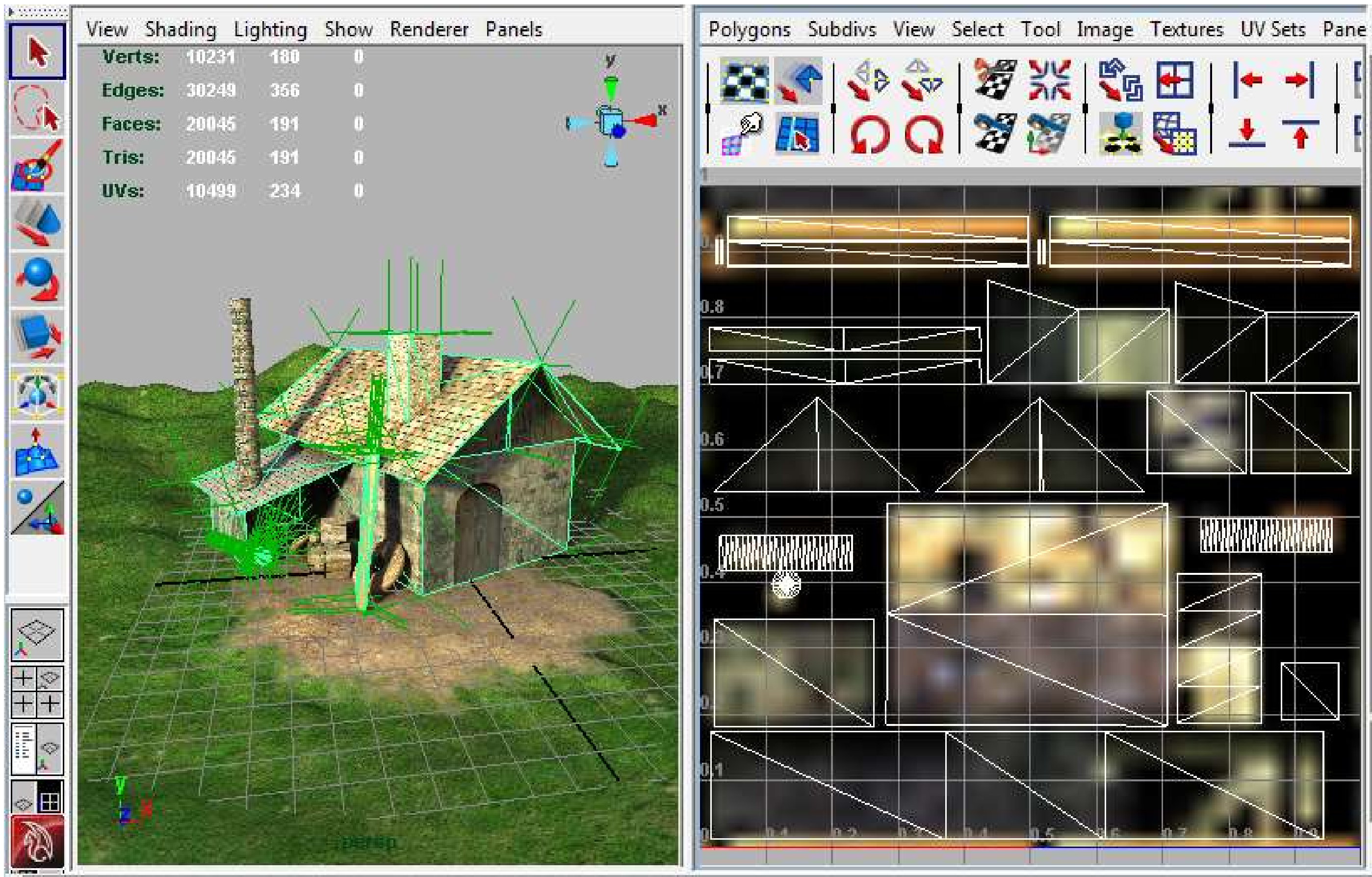
spherical *cylindrical* *planar* *natural*



Texture Projectors

Where do texture coordinates come from?

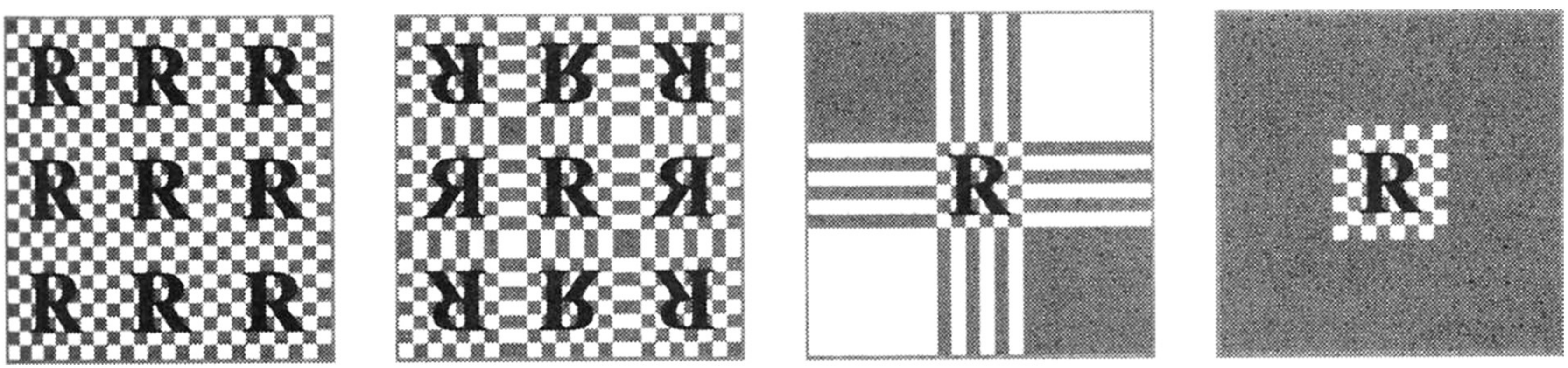
- Offline: manual UV coordinates by DCC program
- Note: a modeling problem!



Texture Wrap Mode

- How to extend texture beyond the border?
- Border and repeat/clamp modes
- Arbitrary (s,t,…) → [0,1] x [0,1] → [0,255] x [0,255]

repeat mirror/repeat clamp border



Interpolation Type + Purpose #1:

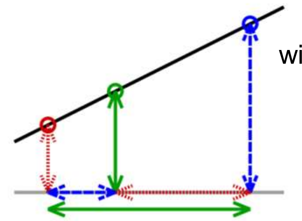
Interpolation of Texture Coordinates

(Linear / Rational-Linear Interpolation)

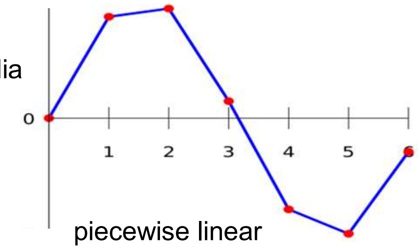
Linear Interpolation / Convex Combinations

Linear interpolation in 1D:

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



wikipedia



piecewise linear

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

$$f(\alpha_1, \alpha_2) = \alpha_1 v_1 + \alpha_2 v_2$$
$$\alpha_1 + \alpha_2 = 1$$

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

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

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

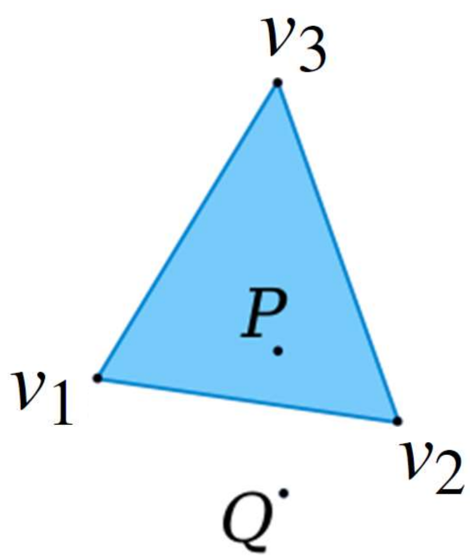
Linear Interpolation / Convex Combinations

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:

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



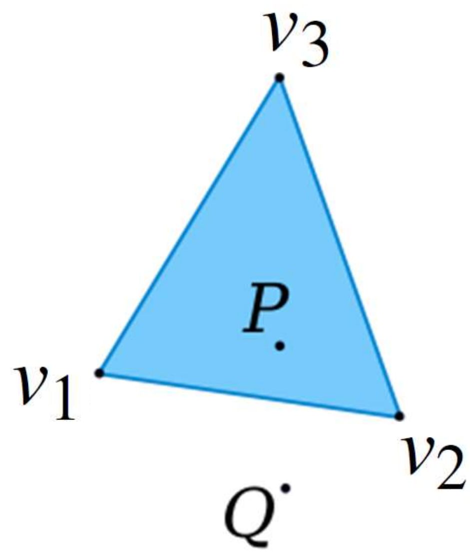
Convex combination: $\alpha_i \geq 0$

(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

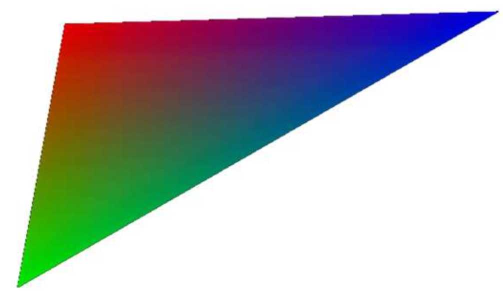
→ linear attribute interpolation in simplex

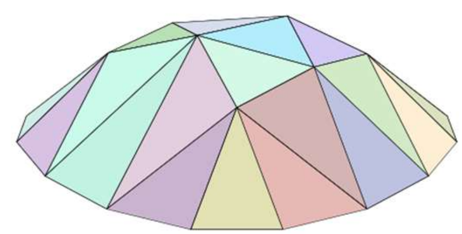
$$\alpha_1 v_1 + \alpha_2 v_2 + \ldots + \alpha_n v_n = \sum_{i=1}^{n} \alpha_i v_i$$

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

$$\alpha_i \geq 0$$

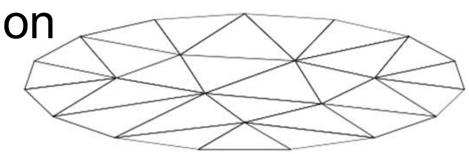
attribute interpolation





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

  (λx, λy, λ) 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"

  (λx, λy, 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

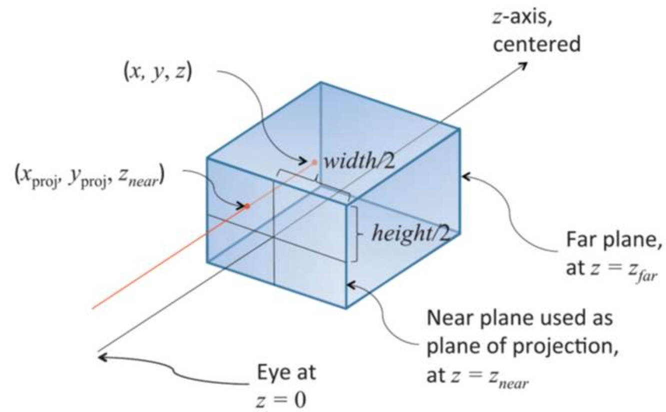
Homogeneous Coordinates (3)

Examples of usage

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

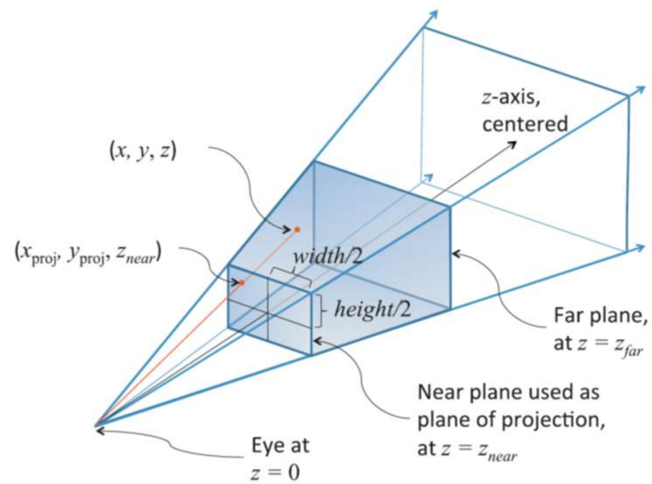
$$\begin{bmatrix} \frac{2}{\text{right}-\text{left}} & 0 & 0 & -\frac{\text{right}+\text{left}}{\text{right}-\text{left}} \\ 0 & \frac{2}{\text{top}-\text{bottom}} & 0 & -\frac{\text{top}+\text{bottom}}{\text{top}-\text{bottom}} \\ 0 & 0 & \frac{-2}{\text{far}-\text{near}} & -\frac{\text{far}+\text{near}}{\text{far}-\text{near}}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

orthographic



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

perspective



Thank you.