Tutorial 7

CS3241 Computer Graphics (AY22/23)

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Recap of Texture Mapping

Texture Mapping

- One of the most foreign parts of graphics programming
- Many parameters and states for **fragment processing**
  - Texture magnification
  - Mipmapping (texture minification)
  - Framebuffer data
  - Texture environments

Local parameters (Bound texture)

```
void init( void ) {
  ...
  glPixelStorei(GL_UNPACK_ALIGNMENT, 1);

  glGenTextures(1, &texObj);

  glBindTexture(GL_TEXTURE_2D, texObj);
                                                  Local to the currently bound texture.
  glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_S, GL_REPEAT);
  glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_WRAP_T, GL_REPEAT);
  glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MAG_FILTER, GL_LINEAR);
  glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER, GL_LINEAR);

  glTexImage2D(GL_TEXTURE_2D, 0, GL_RGBA, imageWidth, imageHeight,
               0, GL_RGBA, GL_UNSIGNED_BYTE, texImage);
  ...
}
```

Global state (Texture Environment)

```
void display( void )  {
  ...
  glEnable(GL_TEXTURE_2D);    Global state (which env and env mode)

  glTexEnvf(GL_TEXTURE_ENV, GL_TEXTURE_ENV_MODE, GL_DECAL);

  glBindTexture(GL_TEXTURE_2D, texObj);

  glBegin(GL_QUADS);
    glTexCoord2f(0.0, 0.0); glVertex3f(-2.0, -1.0, 0.0);
    glTexCoord2f(0.0, 1.0); glVertex3f(-2.0, 1.0, 0.0);
    glTexCoord2f(1.0, 1.0); glVertex3f(0.0, 1.0, 0.0);
    glTexCoord2f(1.0, 0.0); glVertex3f(0.0, -1.0, 0.0);
    glTexCoord2f(0.0, 0.0); glVertex3f(1.0, -1.0, 0.0);
    glTexCoord2f(0.0, 1.0); glVertex3f(1.0, 1.0, 0.0);
    glTexCoord2f(1.0, 1.0); glVertex3f(2.4, 1.0, -1.4);
    glTexCoord2f(1.0, 0.0); glVertex3f(2.4, -1.0, -1.4);
  glEnd();
  ...
}
```

Texture Environments

Texture Functions / Environments

- Texture function can be set using

```
glTexEnvf(GL_TEXTURE_ENV, GL_TEXTURE_ENV_MODE, f );
```

  where `f` is `GL_DECAL`, `GL_REPLACE`, `GL_MODULATE`, `GL_BLEND`, `GL_ADD`, or `GL_COMBINE`

- Defines how the texture color is combined with the underlying primary color of the fragment

Color

Alpha

Texture Base Internal Format	Texture source color C_s	A_s
ALPHA	$(0, 0, 0)$	A_t
LUMINANCE	(L_t, L_t, L_t)	1
LUMINANCE_ALPHA	(L_t, L_t, L_t)	A_t
INTENSITY	(I_t, I_t, I_t)	I_t
RGB	(R_t, G_t, B_t)	1
RGBA	(R_t, G_t, B_t)	A_t

Texture function

A **texture function** acts on the fragment to be textured using the texture image value that applies to the fragment and produces an RGBA color for that fragment.

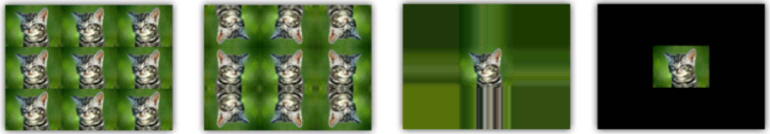
- C = color (RGB) $\in [0, 1]$
- A = alpha (A) $\in [0, 1]$
- $_p$ = color from previous texture stage/incoming fragment
- $_s$ = texture source color
- $_c$ = texture environment color
- $_v$ = final value produced

Common texture functions

Texture Base Internal Format	Value	GL_REPLACE Function	GL_MODULATE Function
GL_ALPHA	$C_v =$	C_p	C_p
	$A_v =$	A_s	$A_p A_s$
GL_LUMINANCE	$C_v =$	C_s	$C_p C_s$
(or 1)	$A_v =$	A_p	A_p
GL_LUMINANCE_ALPHA	$C_v =$	C_s	$C_p C_s$
(or 2)	$A_v =$	A_s	$A_p A_s$
GL_RGB	$C_v =$	C_s	$C_p C_s$
(or 3)	$A_v =$	A_p	A_p
GL_RGBA	$C_v =$	C_s	$C_p C_s$
(or 4)	$A_v =$	A_s	$A_p A_s$

Texture wrapping modes

GL_REPEAT GL_MIRRORED_REPEAT GL_CLAMP_TO_EDGE GL_CLAMP_TO_BORDER

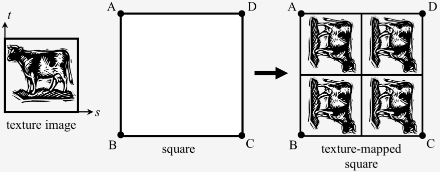


GL_REPEAT GL_MIRRORED_REPEAT GL_CLAMP_TO_EDGE GL_CLAMP_TO_BORDER

Questions

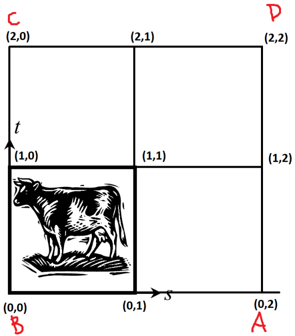
Question 1

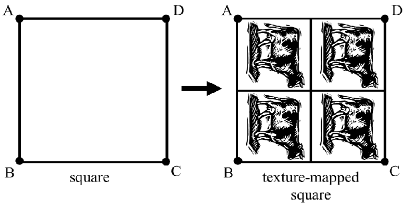
Suppose the texture coordinate wrapping mode has been set to `GL_REPEAT` for both the *s* and *t* texture coordinates.



Given a texture image and a square as shown in the following diagram, what are the 2D texture coordinates assigned to vertices A, B, C and D so that texture-mapped square appears as shown below?

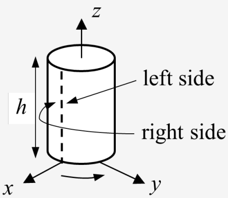
Question 1


C
D
(2,0)
(2,1)
(2,2)
t
(1,0)
(1,1)
(1,2)
s
(0,0)
(0,1)
(0,2)
B
A


A
D
B
C
square
A
D
B
C
texture-mapped square

Question 2

We would like to wrap an entire texture map around the side of the cylinder shown in the diagram.



The center of the base of the cylinder is located at (0, 0, 0). Given any point (p_x, p_y, p_z) on the side of the cylinder, write the two expressions to compute the s and t texture coordinates at the point.

Question 2

Demo!

Question 2

$$s = \text{arc length between vector } (1,0) \text{ and } (p_x, p_y)$$
$$t = p_z$$

$$s \in [0,1] \mapsto [0, 2\pi]$$
$$t \in [0,1] \mapsto [0, h]$$

Question 3a

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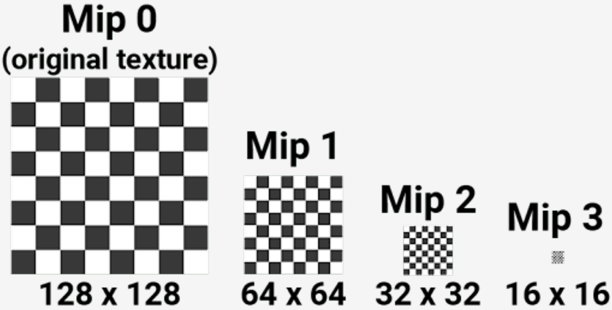
Given a 512×512 texture image, we want to create a mipmap from it and use the appropriate mipmap level during rendering.

How many levels are in the mipmap? (including the original texture level)

Question 3a



Mipmap level 0 is original texture. Additionally can halve it's length and width $\log(n)$ times (given $n = \min(h, w)$).

$$\log(512) + 1 = 10$$

Question 3b

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The mipmap is used to texture-map a 3D square that appears in a 100 $\times$ 100 region on the screen. What is the best integer mipmap level to use to texture-map the square? Assume that we *prefer a more blurred rendered image* if the exact level is not an integer.

The highest-resolution texture image is level 0, the next is level 1, and so on.

Question 3b

Manually halving the dimension: $512 \longrightarrow 256 \longrightarrow 128 \longrightarrow 64 < 100$

$$\lceil \log(512/100) \rceil = \lceil \log(5.12) \rceil = 3$$

Question 3c

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Some rendering systems can actually take non-integer mipmap level and compute the result by interpolating between two mipmap levels. (aka ***Trilinear interpolation***)

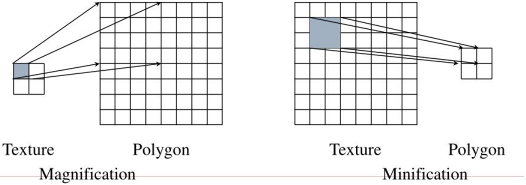
In the case of Part (b), what is the exact mipmap level to use to texture-map the square? Round your answer to 2 decimal places. You can use the formula $\log_2(x) = \log_{10}(x)/\log_{10}(2)$.

Magnification and Minification

Magnification and Minification

More than one texel can cover a pixel (*minification*) or more than one pixel can cover a texel (*magnification*)

Can use point sampling (nearest texel) or linear filtering (2 x 2 filter) to obtain texture values



Question 4

Given a gray-scale image $I[1 \ldots W, 1 \ldots H]$, we can compute a special table $S[1 \ldots W, 1 \ldots H]$ such that $S[m,n] = \sum_{i=1}^{m} \sum_{j=1}^{n} I[i \ldots j]$. Then using S, the sum of pixel values within any rectangular region of the range $I[x_i \ldots x_2, y_1 \ldots y_2]$ can be computed in constant time:

$$S[x_2, y_2] - S[x_1 - 1, y_2] - S[x_2, y_1 - 1] + S[x_1 - 1, y_1 - 1]$$

Summed Area Table

Summed Area Table

Regular image

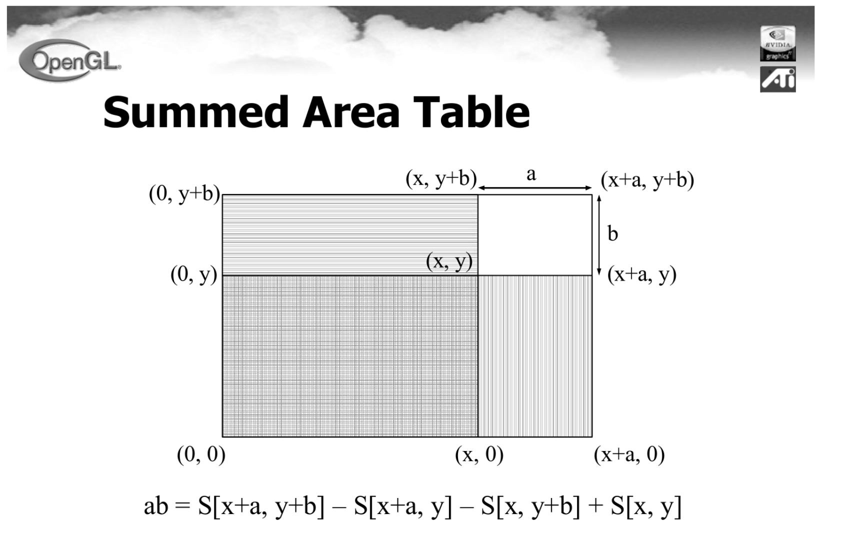
1	1	1	1
1	1	1	1
1	1	1	1
1	1	1	1

$\longrightarrow$

Summed area table

4	8	12	16
3	6	9	12
2	4	6	8
1	2	3	4

Summed Area Table



Question 4a

What could be the use of the special table S for overcoming a particular problem in texture mapping? Explain why it is suitable.

Solves **anti-aliasing**!

We can approximate the pre-image of a fragment as a rectangle, and use the special table S to quickly find the average of the texel values within the rectangular region.

- efficient area sampling within **any rectangular region**
- S can be precomputed before real-time rendering

Question 4b

Compare the quality of the rendered image produced by the technique you have learned in class, with that using the special table S? What attributes to the difference?

> What do we compare Summed Area Table to?

Quality comparison

Ans: Mipmapping

The rendered image will look better and sharper This is because it can have a **more accurate approximation** of the pre-image region of the fragment (**arbitrary region in constant time**).

Question 5a

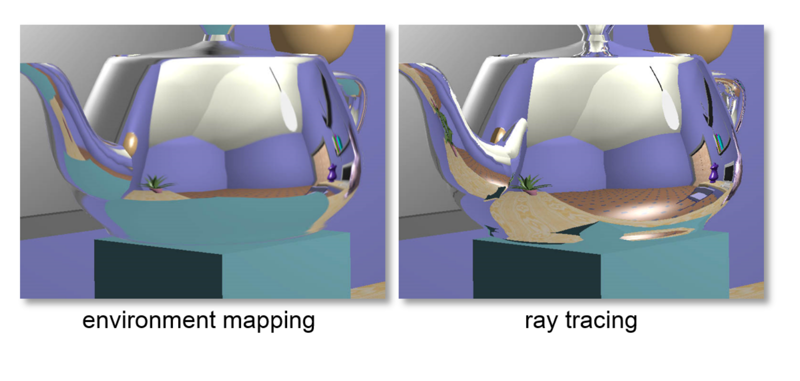
A reflective object can be rendered using reflection mapping or ray tracing. List two situations where there will be obvious differences between the images produced by the two methods.

Situation 1: Self-intersection

The object itself is not part of the environment!

Situation 2: Relatively large object

When the reflective object is quite large compared to the size of its surrounding.



Question 5b

Describe a way you can use to detect that the features on an object are actually bump-mapped instead of real geometry.

Question 5c

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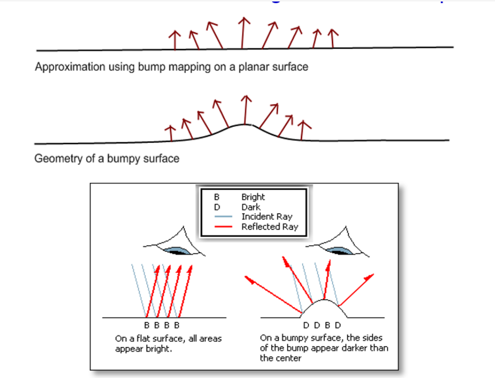
Suppose you can extend the functionalities in any stage of the raster graphics pipeline. We want to render polygons with bump-mapping.

1. Should the lighting computation be performed per fragment, per vertex, or per polygon?
2. At which pipeline stage should the lighting computation be performed?

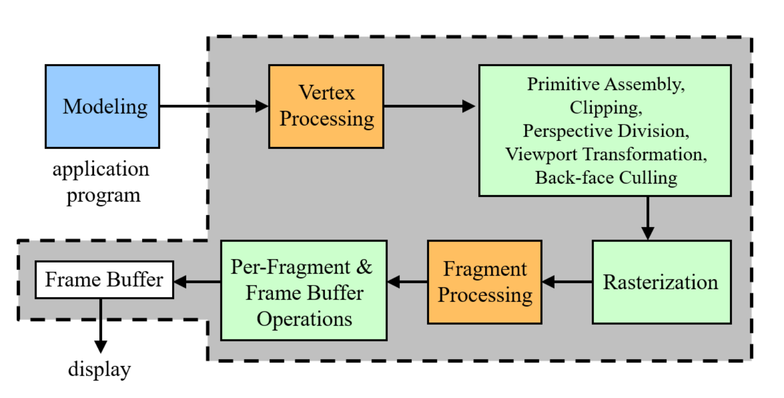
Bump mapping



Normals provided by the bump map **per fragment** to do lighting computation with (e.g. Phong Illumination Equation).

Lighting computation

Probably in the fragment processing stage



Question 5d

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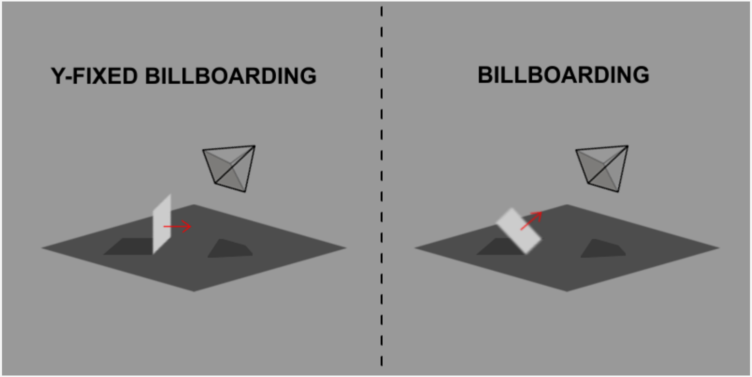
In a virtual outdoor scene, each tree is rendered using a vertical rectangular billboard. The vertical axis of the world is the z-axis. The viewpoint is at (v_x, v_y, v_z). For a billboard whose center is at (b_x, b_y, b_z), what should be the normal vector of the billboard rectangle? You need not normalize the vector.

Question 5d



- z-axis is fixed: $(v_x - b_x, v_y - b_y, 0)$
- completely billboarded: $(v_x - b_x, v_y - b_y, v_z - b_z)$

Attendance taking

Thanks! Get the slides here after the tutorial.

https://trxe.github.io/cs3241-notes