

Lecture slides (CT4201/EC4215 – Computer Graphics)

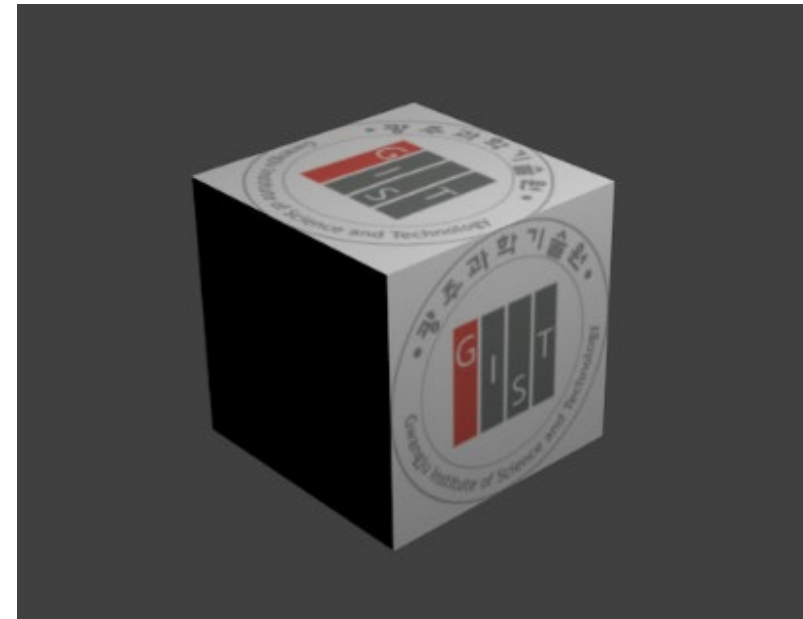
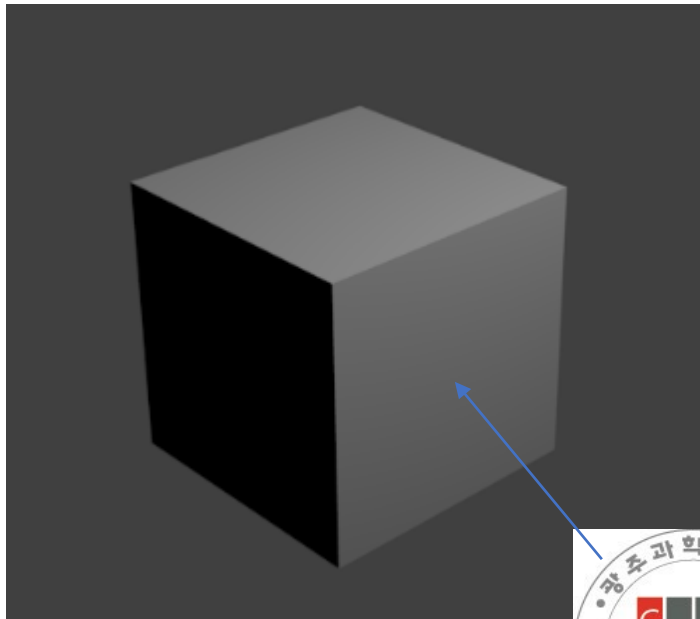
# Texture Mapping

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Lecturer: Bochang Moon

# Texture Mapping

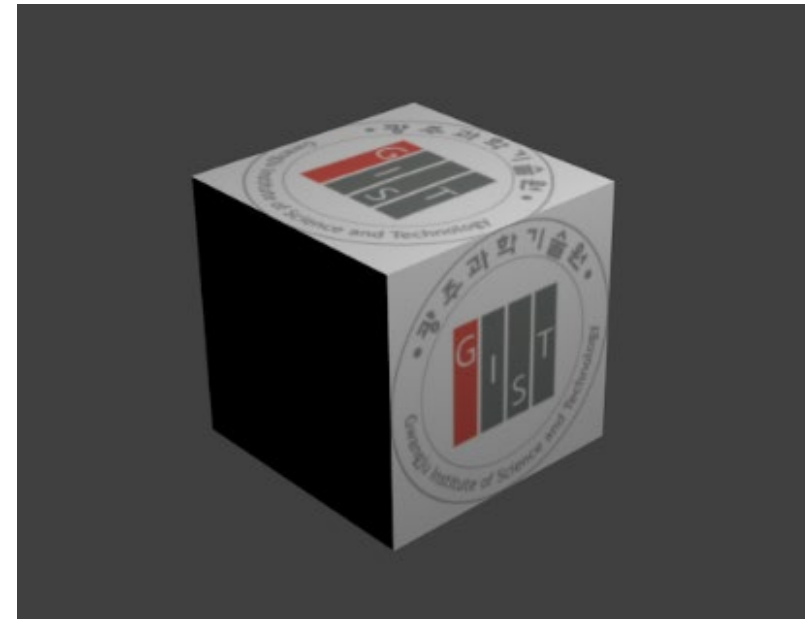
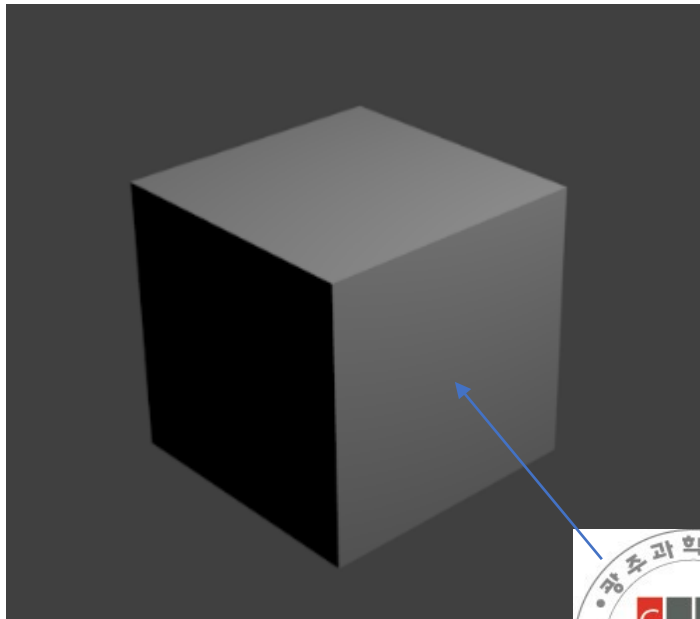
- Simulate spatially varying surface properties
  - Phong illumination model is coupled with a material (e.g., color)
  - Add small polygons with different materials
    - Very expensive



# Texture Mapping

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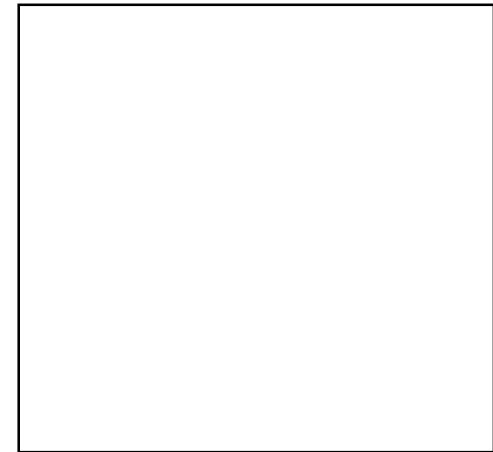
- Simulate spatially varying surface properties
  - Geometry of a surface dose not change, but materials need to be changed
  - Add an image onto the surface
  - Need to define a mapping function from the image to the surface



# Texture Mapping

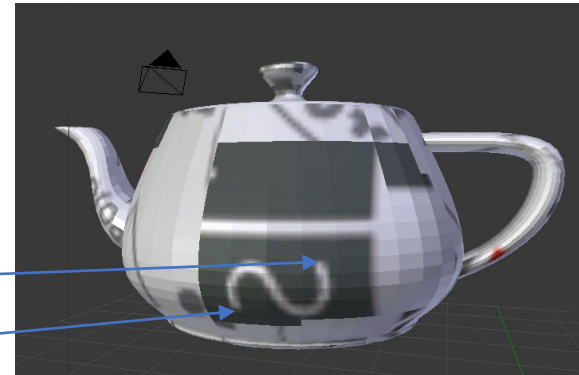
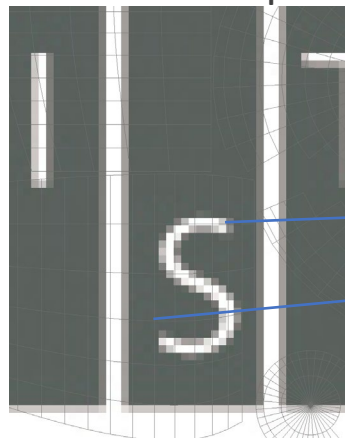
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- Texture lookup
  - Color lookup(Image T, float u, float v) {
    - $(x, y) = \text{map\_function}(u, v)$
    - return T(x,y)}
- Note:
  - Each vertex has a texture coordinate (u, v)
  - A point inside a polygon has an interpolated coordinate



# Texture Mapping

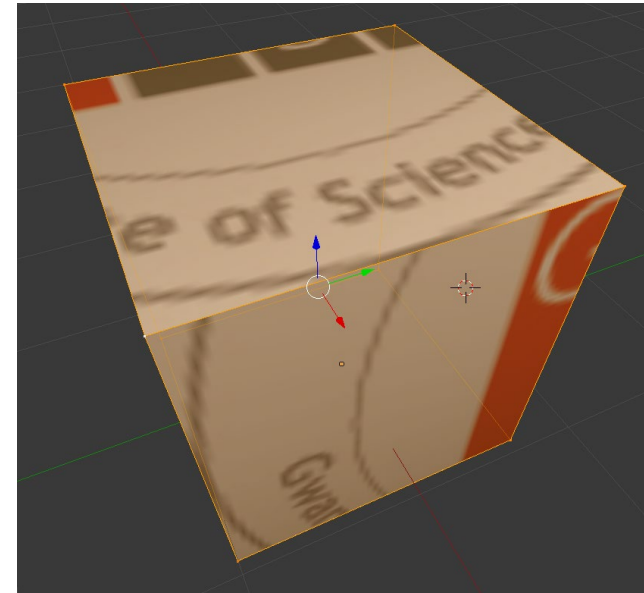
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# Texture Mapping in OpenGL

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- Assign a texture coordinate,  $(u, v)$ , to each vertex



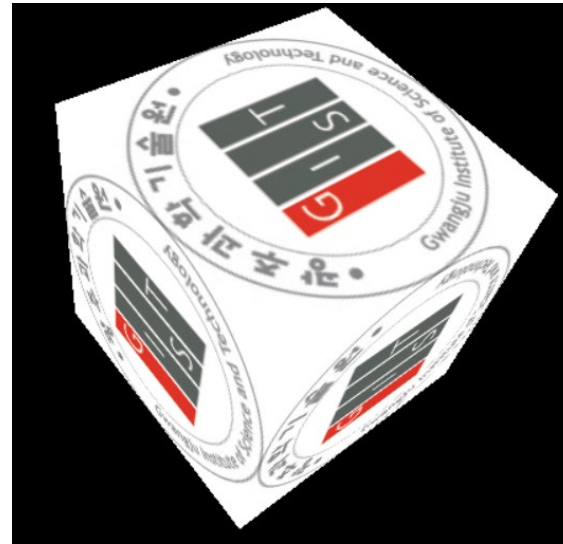
# Texture Mapping in OpenGL

- General procedure for creating a texture map:
  - `texImg = Read an image file (jpg, bmp, png, exr, ...)`
  - `GLuint textureID[1];`
  - `glGenTextures(1, &textureID[0]); // create n texture name(ID) (e.g., n = 1)`
  - `glBindTexture(GL_TEXTURE_2D, textureID[0]); // bind a texture to the target (e.g., GL_TEXTURE_2D)`
  - `glTexImage2D(GL_TEXTURE_2D, 0, 3, width of texImg, height of texImg, 0, GL_RGB, GL_UNSIGNED_BYTE, data of texImg);`
    - // 0: level-of-detail
    - // 3: number of color components



# Texture Mapping in OpenGL

- General procedure of using the generated map:
  - `glBindTexture(GL_TEXTURE_2D, textureID[0]);`
  - `glBegin(GL_QUADS);`
  - `// Front Face`
  - `glTexCoord2f(0.0f, 0.0f); glVertex3f(-1.0f, -1.0f, 1.0f);`
  - `glTexCoord2f(1.0f, 0.0f); glVertex3f( 1.0f, -1.0f, 1.0f);`
  - `glTexCoord2f(1.0f, 1.0f); glVertex3f( 1.0f, 1.0f, 1.0f);`
  - `glTexCoord2f(0.0f, 1.0f); glVertex3f(-1.0f, 1.0f, 1.0f);`
  - ...
  - `glEnd();`



# Texture Mapping

- Assign texture coordinates (normalized coordinates) at each vertex
  - $(u, v)$  in the range  $([0...1], [0...1])$
- Texture pixel (texel) is fetched given a  $(u, v)$  coordinate
  - e.g.,  $(u, v) \rightarrow (u_{tex}, v_{tex})$  in the range  $([0 \dots width_{tex}], [0 \dots height_{tex}])$
  - As a result,  $(x, y) \rightarrow (u, v) \rightarrow (u_{tex}, v_{tex})$

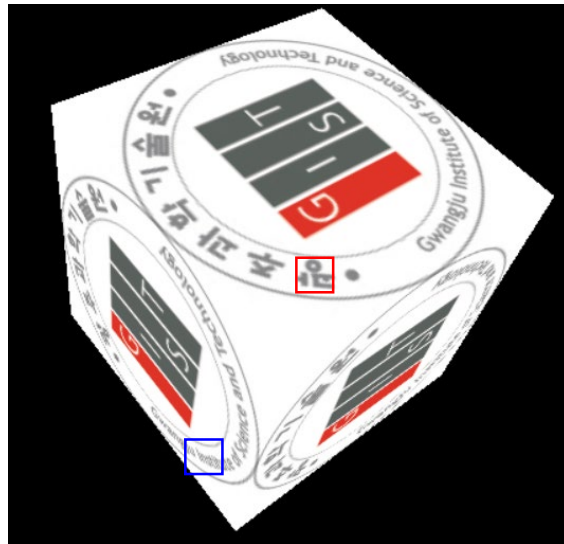


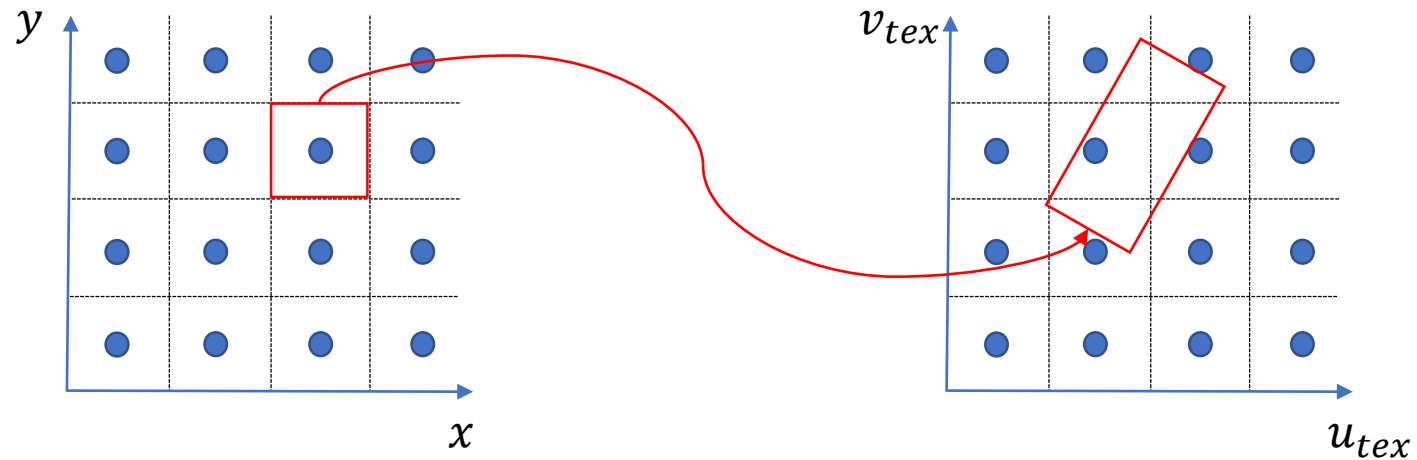
Image space



Texture space

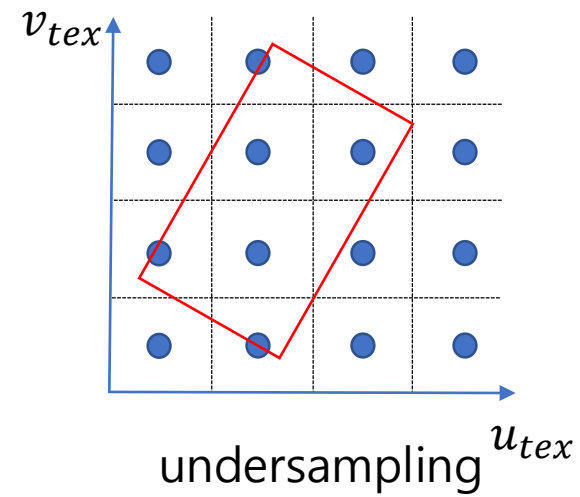
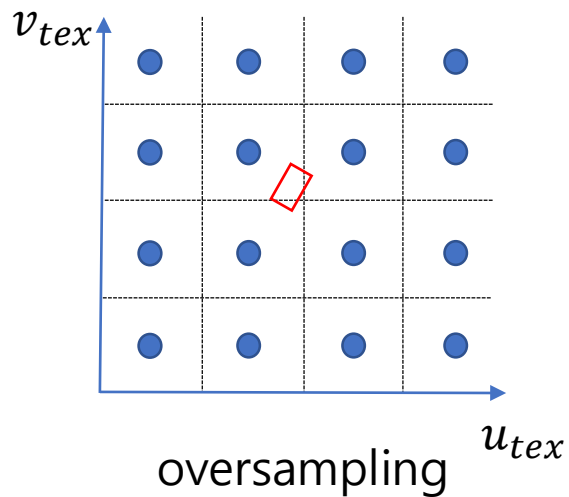
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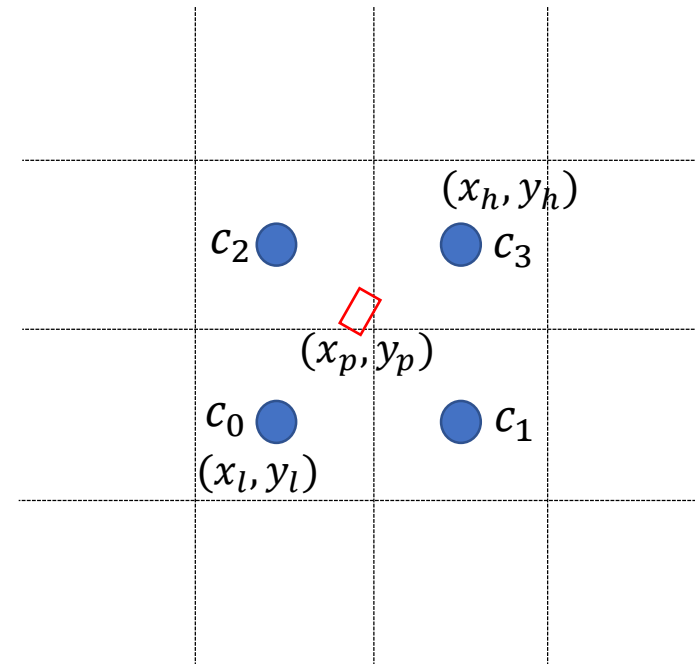
# Issues of Texture Mapping

- Oversampling (magnification): one pixel is corresponding to less than a texel
- Undersampling (minification): one pixel is corresponding to more than a texel



# Texture Filtering for Oversampling

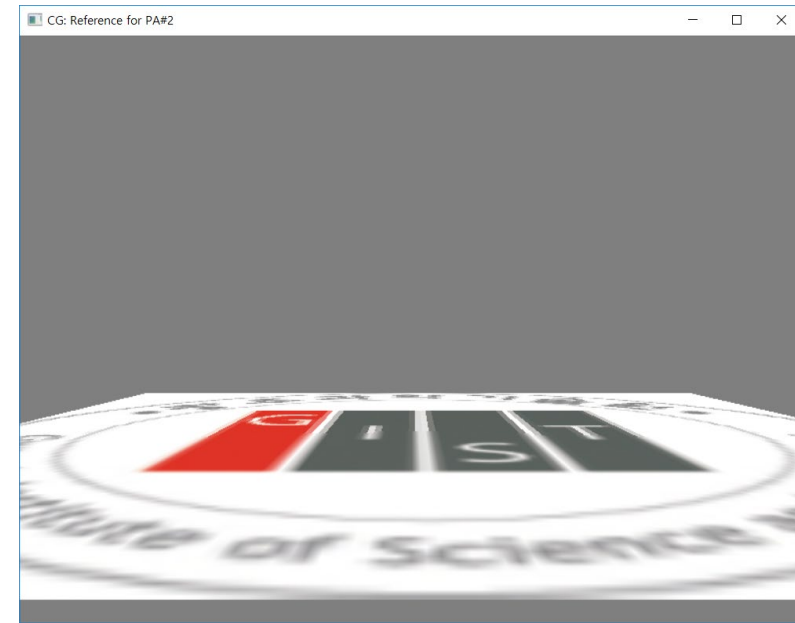
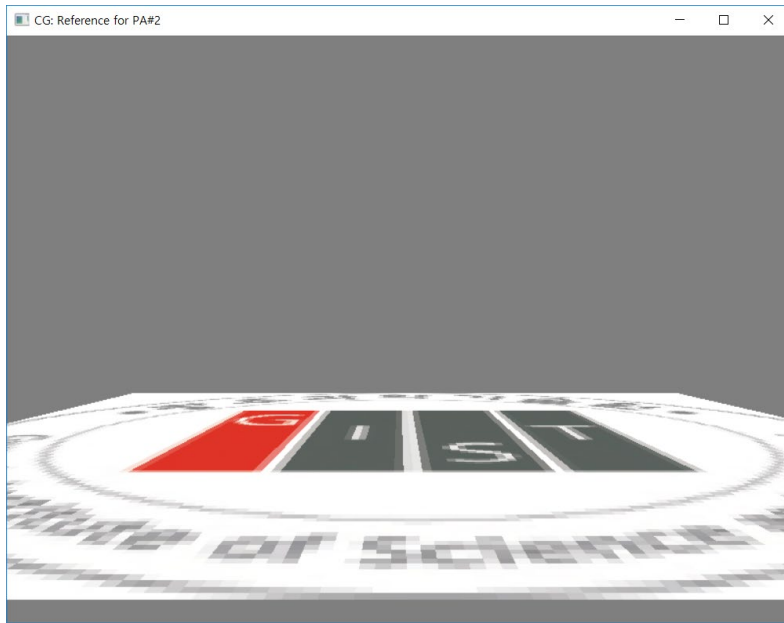
- Filtering methods
  - Nearest neighbor: take the color of the closest texel
  - Bilinear interpolation:
    - $\alpha = \frac{x_p - x_l}{x_h - x_l}$
    - $\beta = \frac{y_p - y_l}{y_h - y_l}$
    - $c_p = (1 - \beta)((1 - \alpha)c_0 + \alpha c_1) + \beta((1 - \alpha)c_2 + \alpha c_3)$



# Texture Filtering for Oversampling

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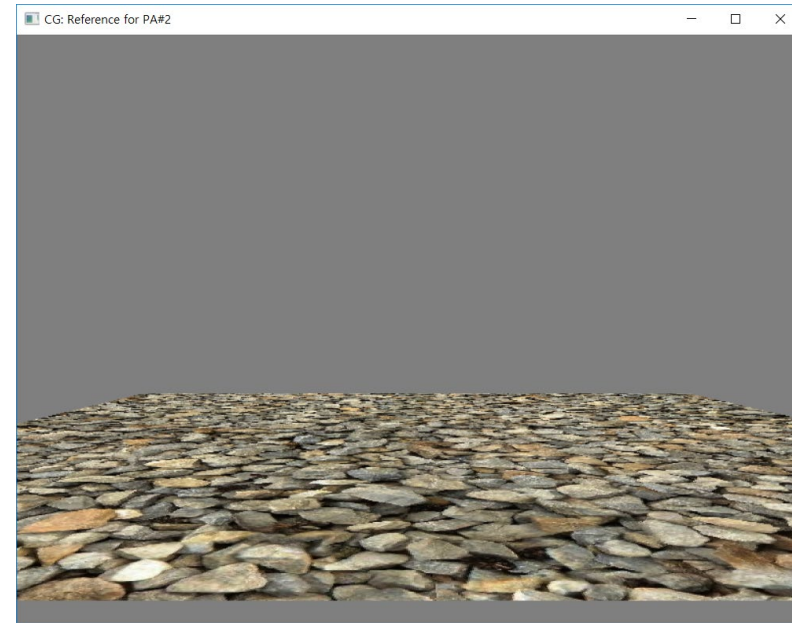
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# Texture Filtering for Undersampling

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- High-frequency details in a small region introduce an image artifact (e.g., aliasing)
  - Should integrate multiple texels on the fly
    - Requires multiple read operations (expensive)



# Texture Filtering for Undersampling

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  - MIP Mapping: Prepare multiple-resolution (pre-filtered) images in preprocessing and select a texel from a MIP level



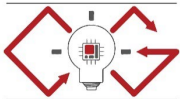
$$\frac{\text{width}}{2} \times \frac{\text{height}}{2}$$



$$\frac{\text{width}}{8} \times \frac{\text{height}}{8}$$



$$\frac{\text{width}}{4} \times \frac{\text{height}}{4}$$

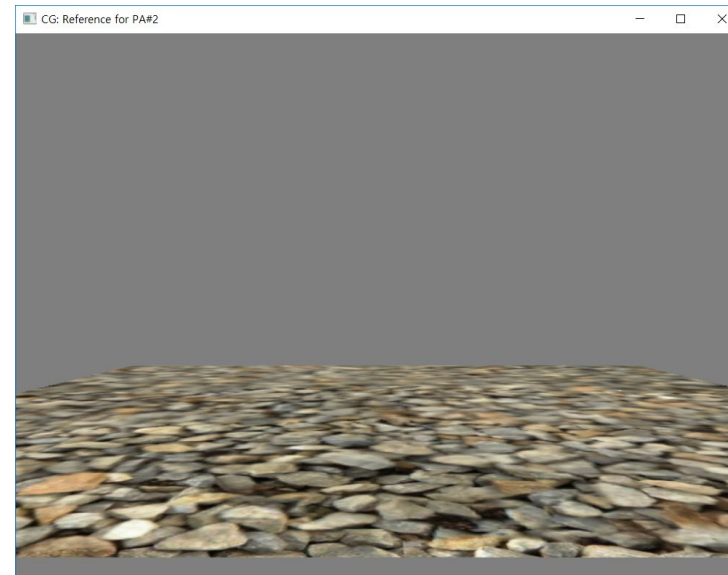


*width* × *height*  
Computer Graphics  
Laboratory

# Texture Filtering for Undersampling

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- High-frequency details in a small region introduce an image artifact (e.g., aliasing)
  - Should integrate multiple texels on the fly
    - Requires multiple read operations (expensive)
  - MIP Mapping: Prepare multiple-resolution (pre-filtered) images in preprocessing and select a texel from a MIP level
    - Two adjacent MIP levels can be interpolated



# Texture Filtering in OpenGL

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- MIP map generation
  - `gluBuild2DMipmaps(GL_TEXTURE_2D, 3, width, height, GL_RGB, GL_UNSIGNED_BYTE, image data);`
- Filtering methods
  - `glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MAG_FILTER, filter);`
  - `glTexParameteri(GL_TEXTURE_2D, GL_TEXTURE_MIN_FILTER, filter);`
- Filters for magnification
  - `GL_NEAREST, GL_LINEAR`
- Filters for minification
  - `GL_NEAREST, GL_LINEAR, GL_NEAREST_MIPMAP_NEAREST, GL_LINEAR_MIPMAP_NEAREST, GL_NEAREST_MIPMAP_LINEAR, GL_LINEAR_MIPMAP_LINEAR`
  - Note: `GL_XX_MIPMAP_LINEAR` // choose the two MIP maps that closely match the size of pixels for an interpolation
  - Note: `GL_LINEAR_MIPMAP_NEAREST` // use the `GL_LINEAR` interpolation within a MIP level

# Applications: Material Parameters

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- Phong illuming model

- $I = \sum_{i=1}^{\# \text{ of lights}} L_a^i k_a + L_d^i k_d \max(0, \mathbf{n} \cdot \mathbf{l}^i) + L_s^i k_s \max(0, \mathbf{r}^i \cdot \mathbf{v})^s$

- Q. Which parameters can be changed from the texture mapping?

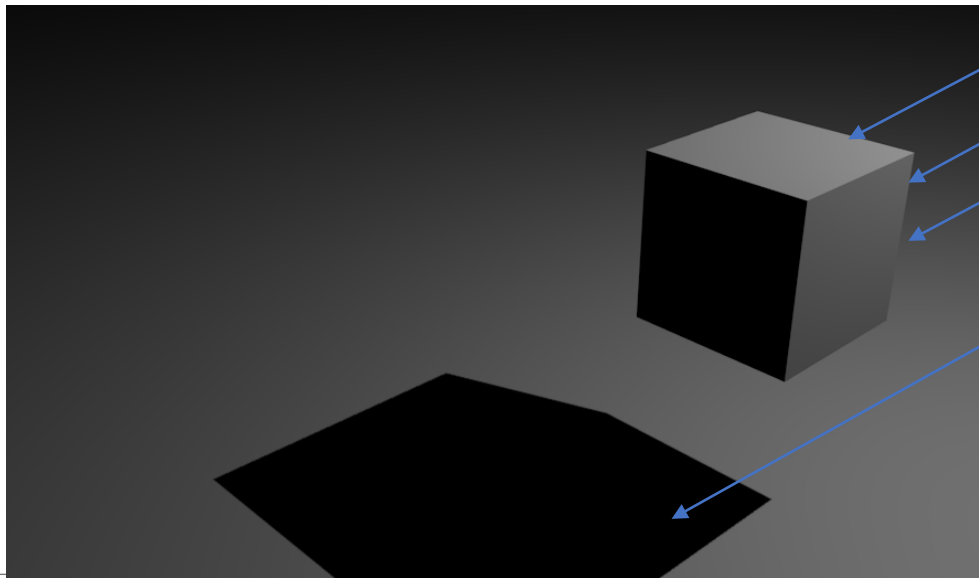
- $k_a, k_d, k_s$

- Lights can be textured as well

- e.g., TV screen or your monitor (area lights)

# Applications: Shadow Maps

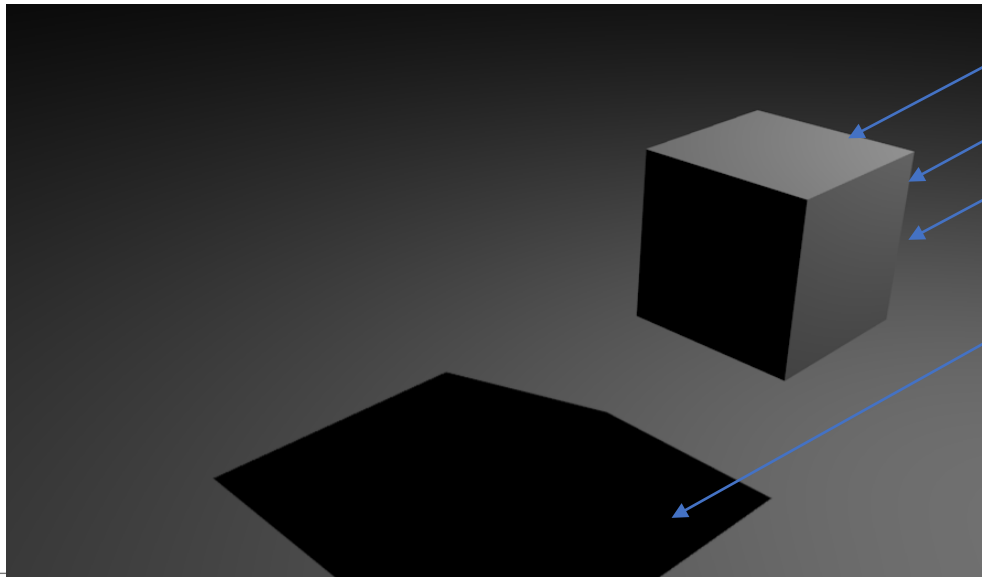
- Shadow mapping
  - 1. Pre-render a scene from a light source and store depths in a shadow map
  - 2. Render a scene from a view point while performing an extra test
    - If (distance between the point (i.e., fragment) and a light  $>$  the stored depth)
    - This point is in shadow.



# Applications: Shadow Maps

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- Issues with shadow mapping
  - Area lights
  - Multiple lights
  - ...



# Applications: Environment Maps

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- Environment mapping (reflection mapping) is an image-based lighting that approximates reflections (e.g., indirect illumination) on surfaces, by using pre-computed textures
  - Simple geometries (e.g., sphere, cube) are usually used to approximate the environment
    - The geometries are intermediate objects for texture mapping

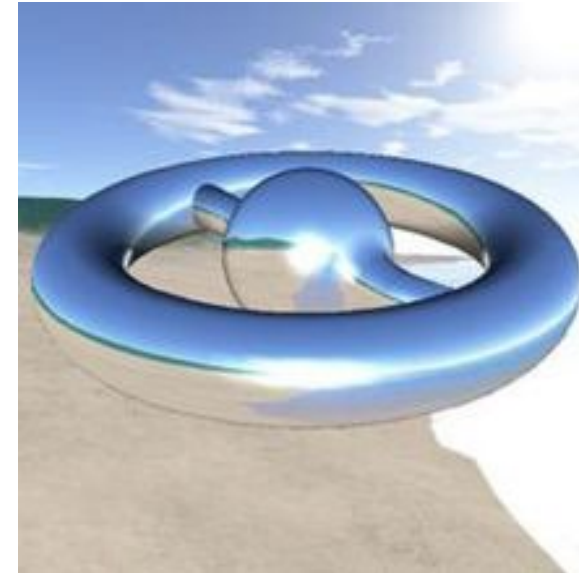
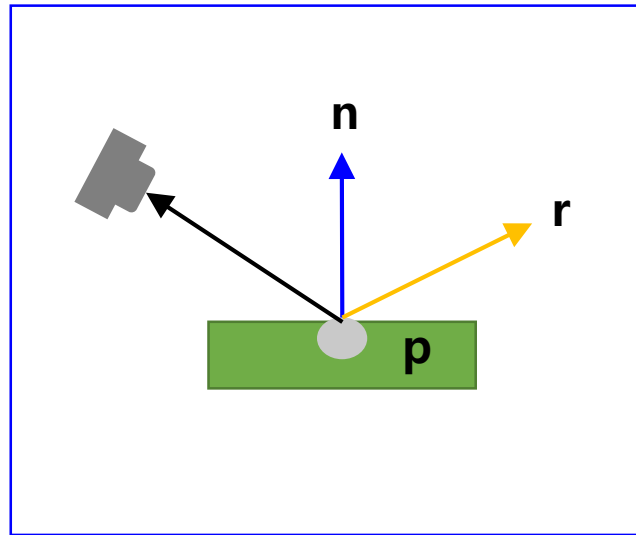
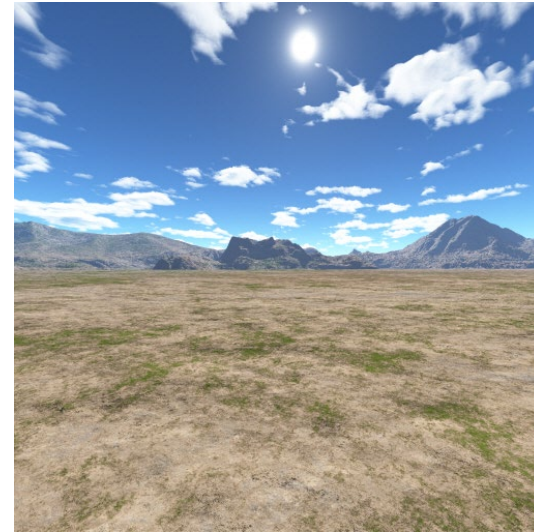
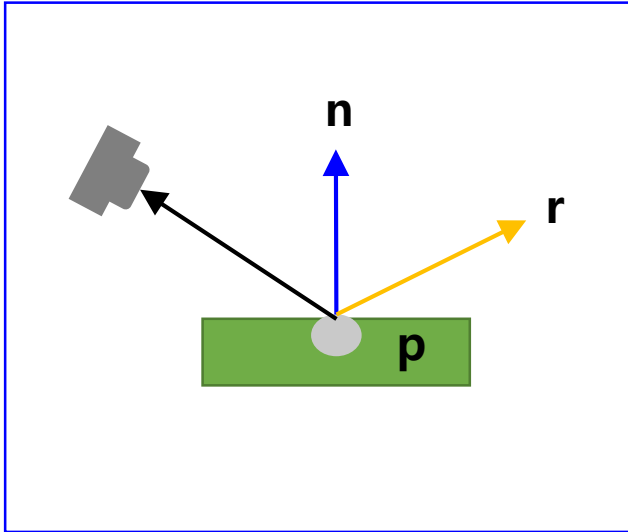
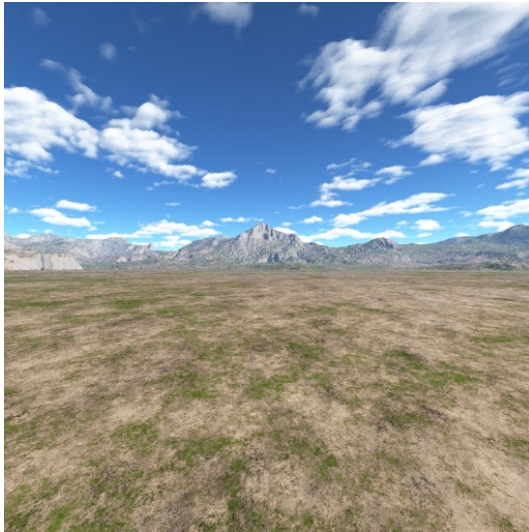


Image from en.wikipedia

# Applications: Environment Maps

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  - Simple geometries (e.g., sphere, cube) are usually used to approximate the environment
    - The geometries are intermediate objects for texture mapping



# Applications: Bump Maps

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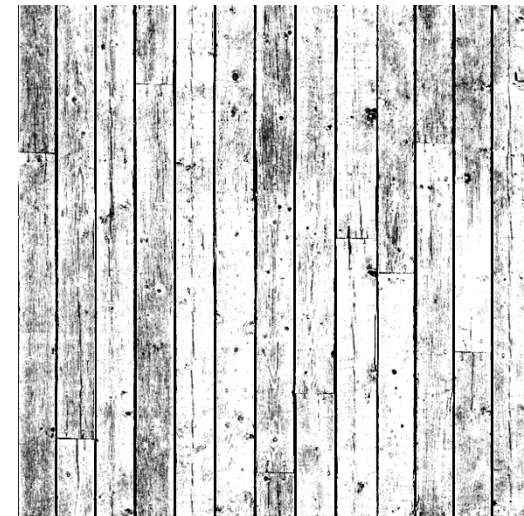
- Approaches to model rough (bumpy) surfaces
  - Add complex geometries
  - Perturb surface normal based on a texture image



Rendering result



Diffuse texture  
map

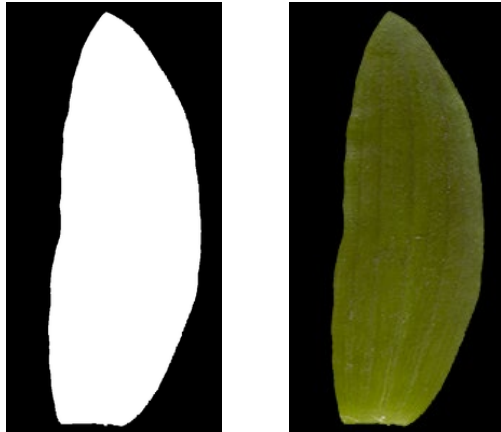


Bump map

# Applications: Other Maps

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- Normal mapping
  - Replace the normal at a point with a pre-computed normal  $(r, g, b)$  at texel
- Opacity maps
  - Use black and white (or alpha channels) to make some areas of a surface transparent



# Further Readings

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- Chapter 11