King Abdullah University of Science and Technology KAUST

CS 380 - GPU and GPGPU Programming
Lecture 18: GPU Texturing, Pt. 4

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Reading Assignment #10 (until Nov 6)

Read (required):

- MIP-Map Level Selection for Texture Mapping

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

Read (optional):

- Vulkan Tutorial

  `https://vulkan-tutorial.com`

Quiz #2: Nov 9

Organization

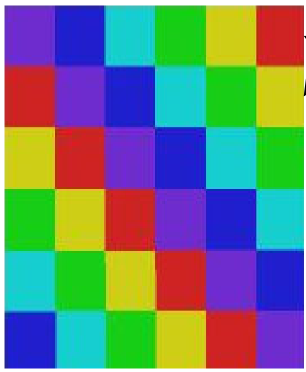
- First 30 min of lecture
- No material (book, notes, ...) allowed

Content of questions

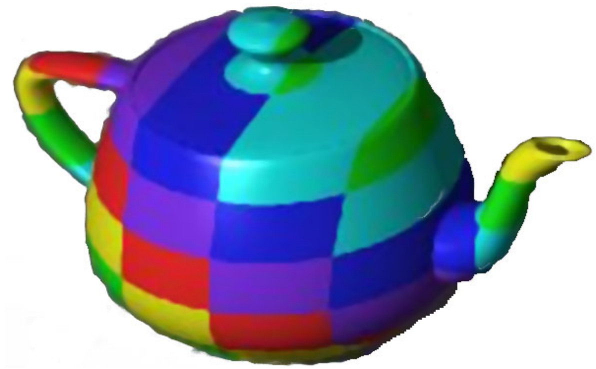
- Lectures (both actual lectures and slides)
- Reading assignments
- Programming assignments (algorithms, methods)
- Solve short practical examples

GPU Texturing

Texturing: General Approach

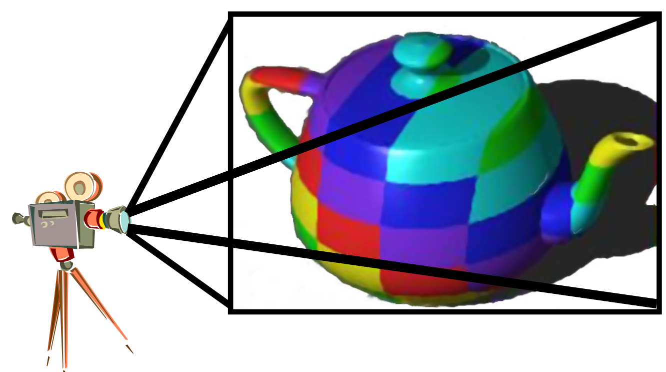


Texels



Texture space *(u,v)* **Object space** (x_O,y_O,z_O) **Image Space** (x_I,y_I)

Parametrization → **Rendering (Projection etc.)** →



Interpolation Type + Purpose #1:

Interpolation of Texture Coordinates

(Linear / Rational-Linear Interpolation)

Interpolation Type + Purpose #2:

Interpolation of Samples in Texture Space

(Multi-Linear Interpolation)

Magnification (Bi-linear Filtering Example)

Original image

Nearest neighbor

Bi-linear filtering

Bi-Linear Interpolation

Weights in 2x2 format:

$$\begin{bmatrix} \alpha_2 \\ (1-\alpha_2) \end{bmatrix} \begin{bmatrix} (1-\alpha_1) & \alpha_1 \end{bmatrix} = \begin{bmatrix} (1-\alpha_1)\alpha_2 & \alpha_1\alpha_2 \\ (1-\alpha_1)(1-\alpha_2) & \alpha_1(1-\alpha_2) \end{bmatrix}$$

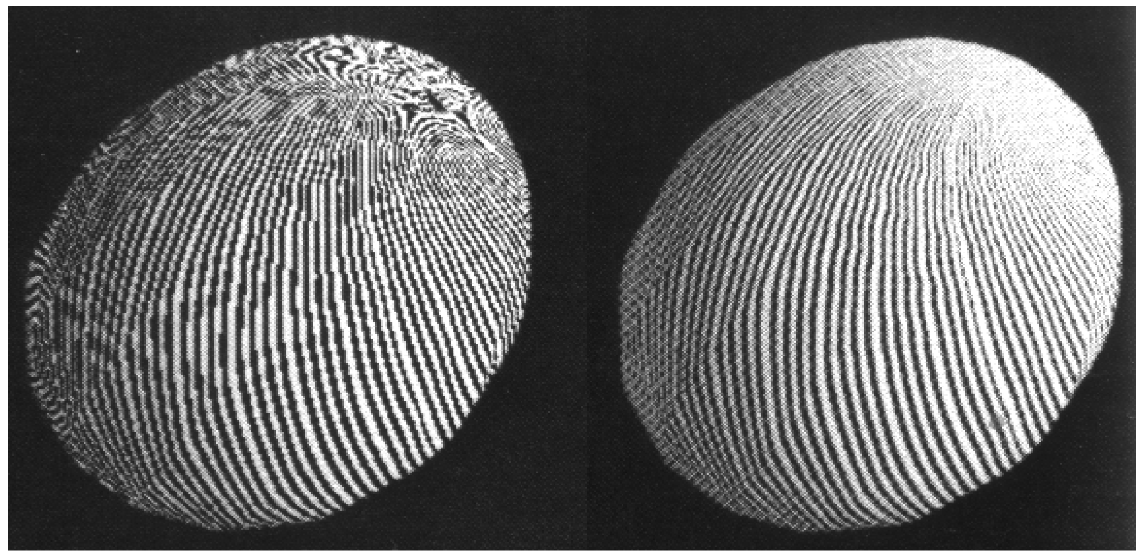
Interpolate function at (fractional) position (α_1, α_2) :

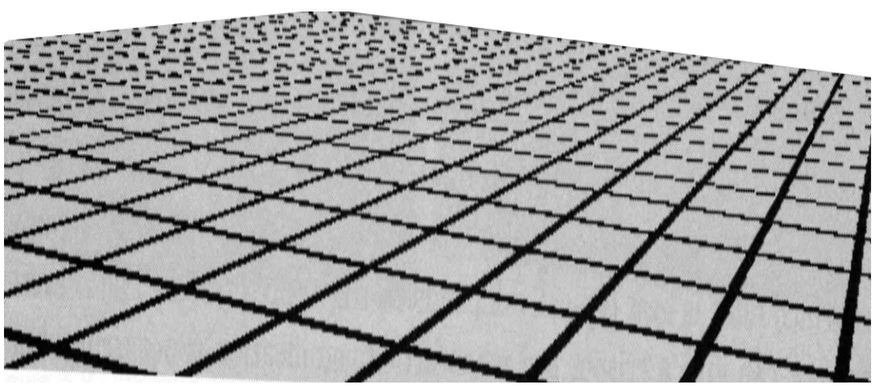
$$f(\alpha_1, \alpha_2) = \begin{bmatrix} \alpha_2 & (1-\alpha_2) \end{bmatrix} \begin{bmatrix} v_{01} & v_{11} \\ v_{00} & v_{10} \end{bmatrix} \begin{bmatrix} (1-\alpha_1) \\ \alpha_1 \end{bmatrix}$$

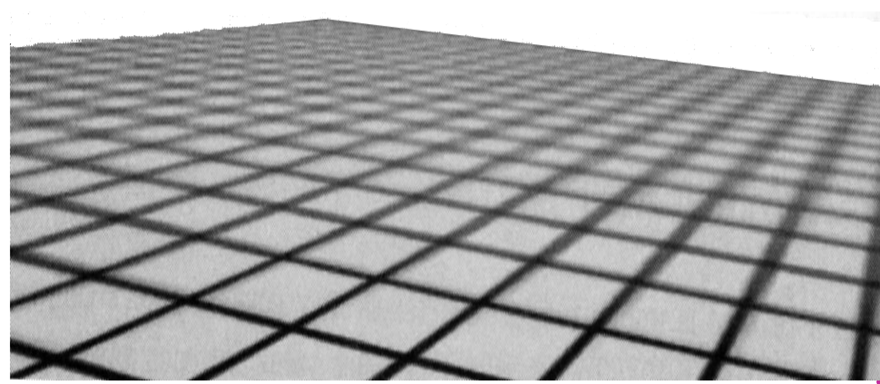
Texture Minification

Texture Aliasing: Minification

- Problem: One pixel in image space covers many texels

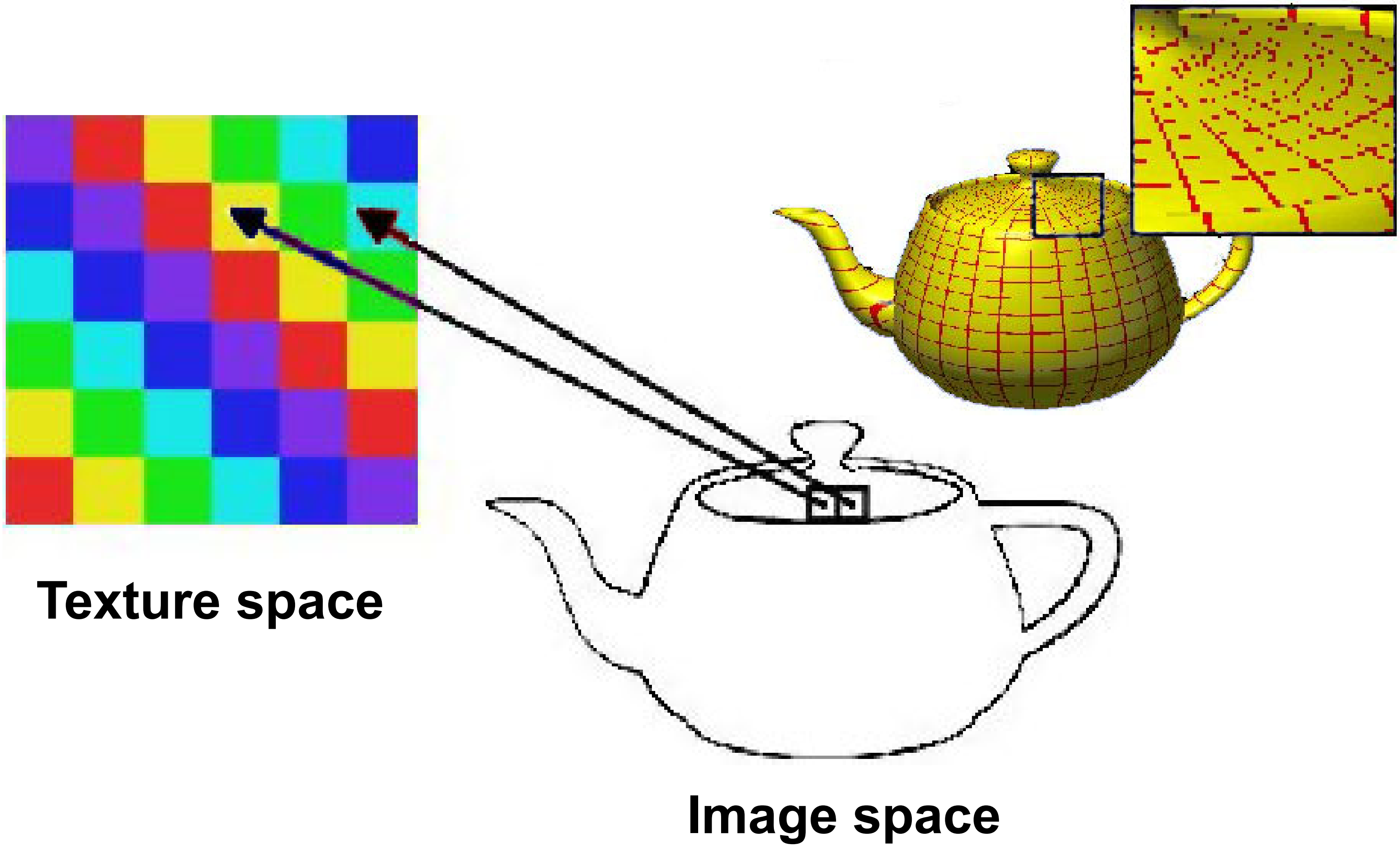






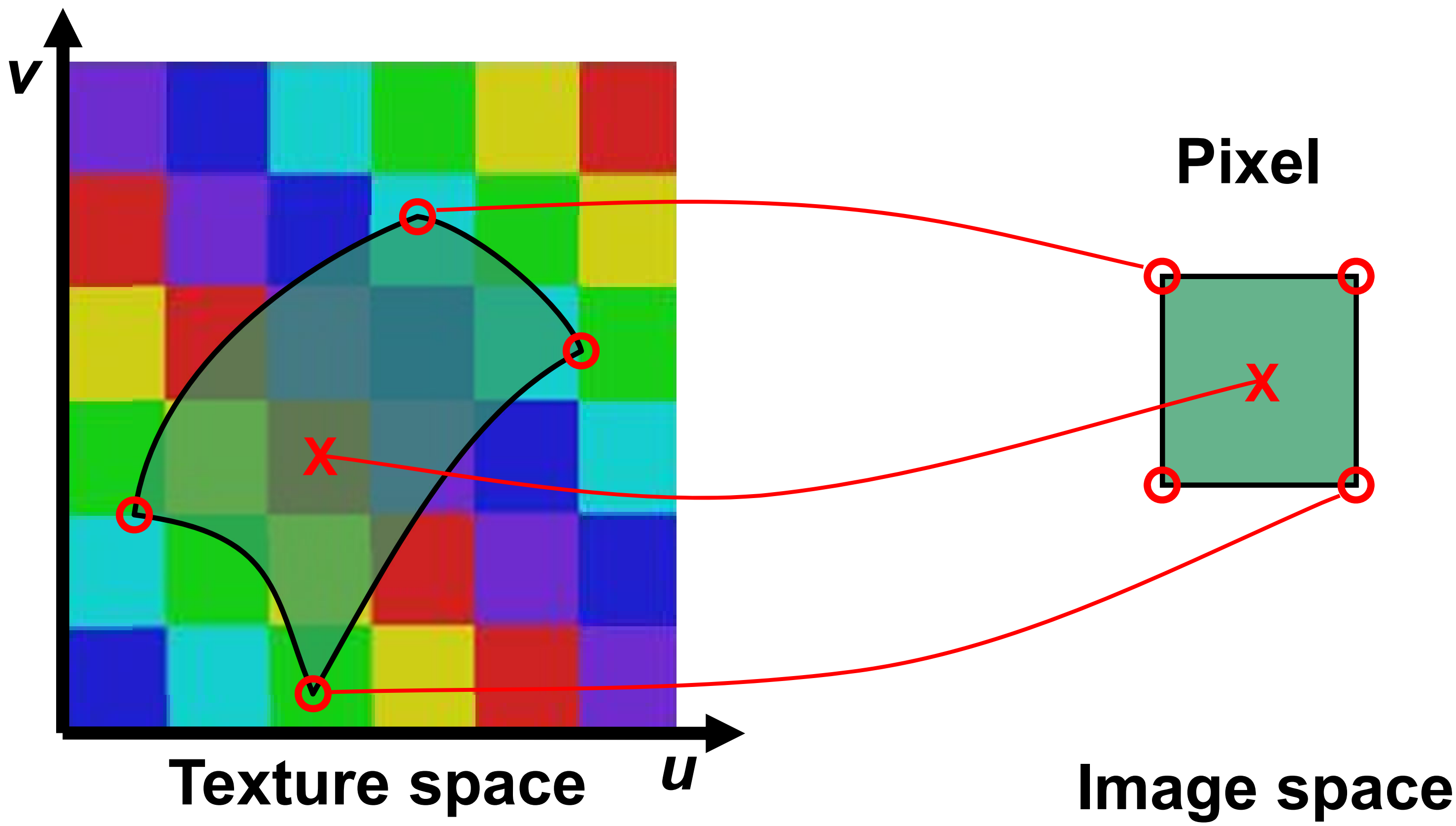
Texture Aliasing: Minification

- Caused by *undersampling*: texture information is lost



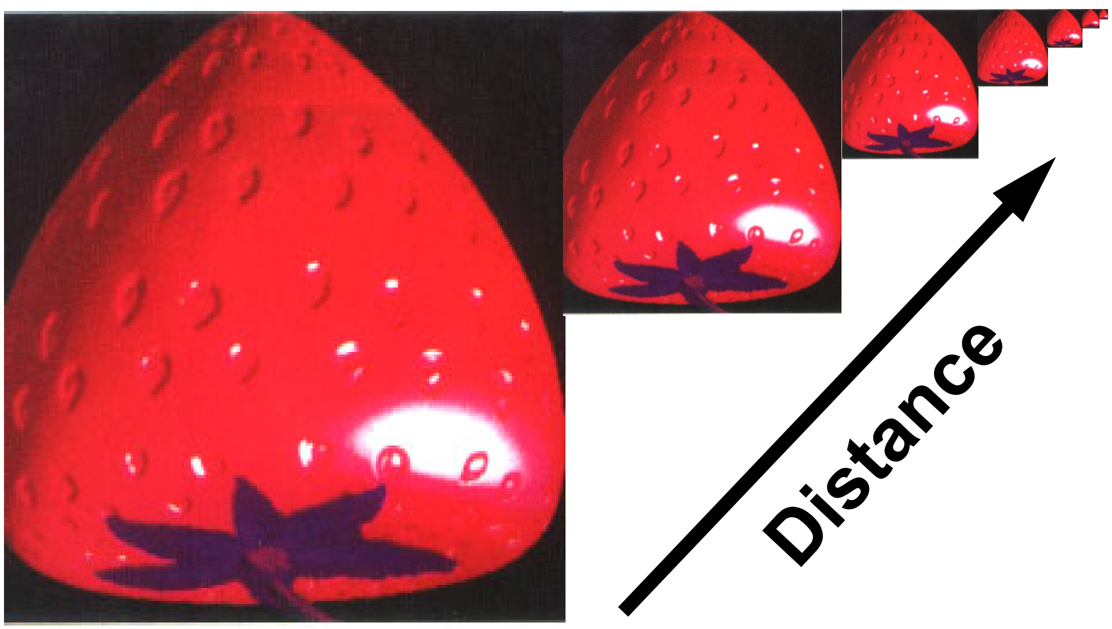
Texture Anti-Aliasing: Minification

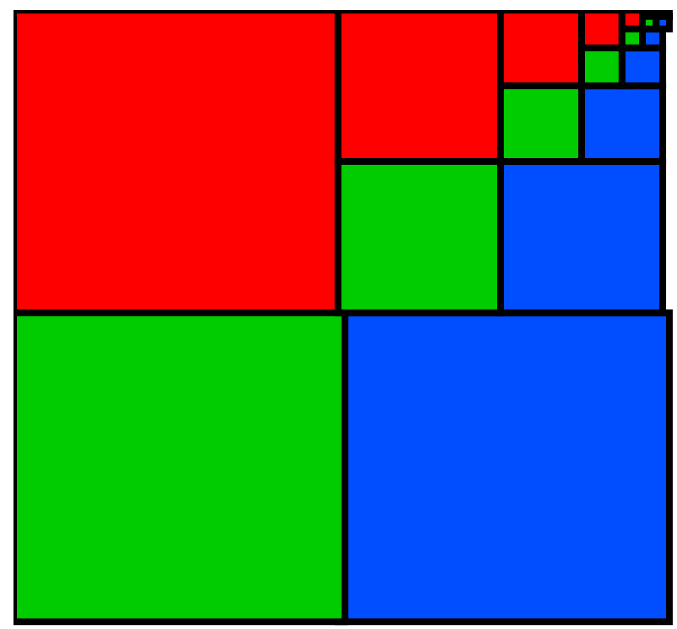
- A good pixel value is the weighted mean of the pixel area projected into texture space



Texture Anti-Aliasing: MIP Mapping

- MIP Mapping ("Multum In Parvo")
  - Texture size is reduced by factors of 2 (*downsampling* = "many things in a small place")
  - Simple (4 pixel average) and memory efficient
  - Last image is only ONE texel





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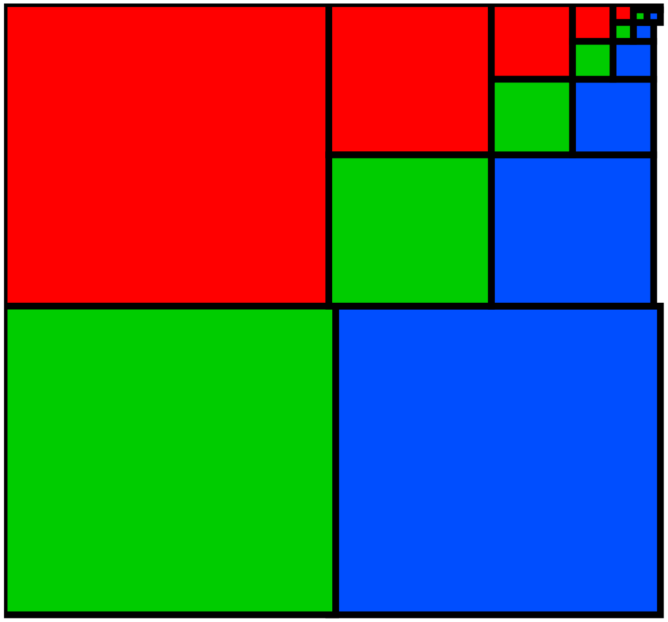
geometric series:

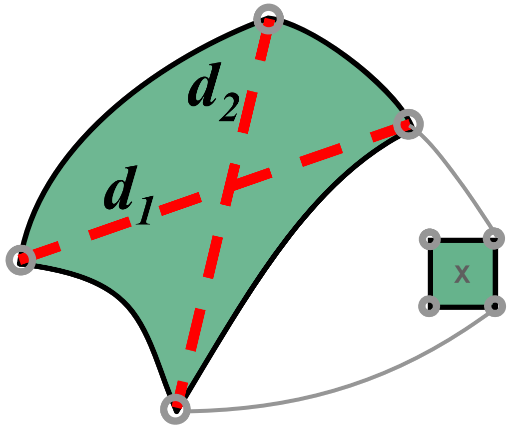
$$a + ar + ar^2 + ar^3 + \cdots + ar^{n-1} =$$

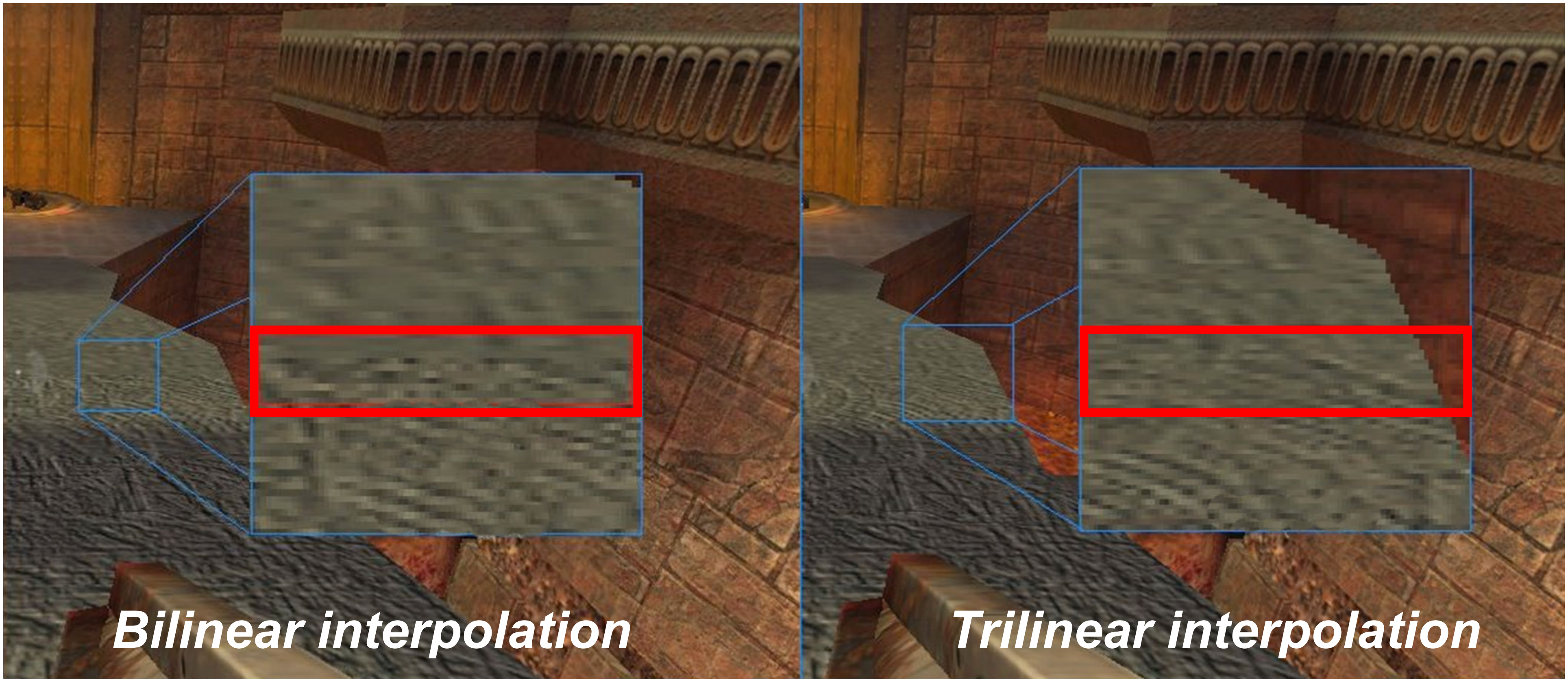
$$= \sum_{k=0}^{n-1} ar^k = a\left(\frac{1-r^n}{1-r}\right)$$



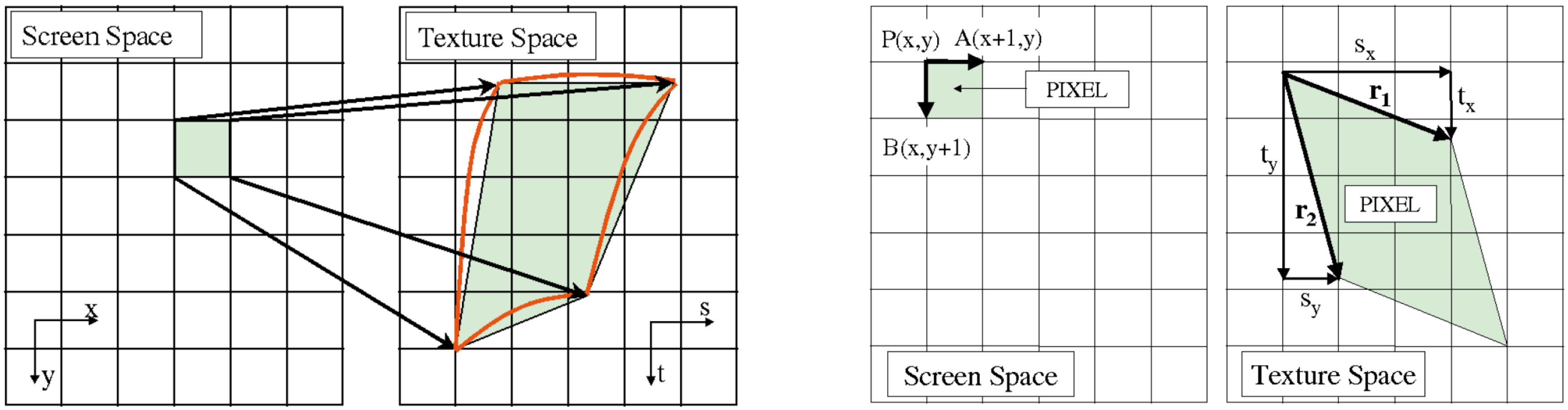
Texture Anti-Aliasing: MIP Mapping

- MIP Mapping Algorithm
- $D := ld(max(d_1,d_2))$ "Mip Map level"
- T_0 := value from texture $D_0 = trunc\ (D)$
  - Use *bilinear interpolation*





MIP-Map Level Computation



- Use the partial derivatives of texture coordinates with respect to screen space coordinates
- This is the Jacobian matrix

$$\begin{pmatrix} \partial u/\partial x & \partial u/\partial y \\ \partial v/\partial x & \partial v/\partial y \end{pmatrix} = \begin{pmatrix} s_x & s_y \\ t_x & t_y \end{pmatrix}$$

- Area of parallelogram is the absolute value of the Jacobian determinant (the *Jacobian*)

MIP-Map Level Computation (OpenGL)

- OpenGL 4.6 core specification, pp. 251-264

(3D tex coords!)

$$\lambda_{base}(x, y) = \log_2[\rho(x, y)]$$

$$\rho = \max\left\{\sqrt{\left(\frac{\partial u}{\partial x}\right)^2 + \left(\frac{\partial v}{\partial x}\right)^2 + \left(\frac{\partial w}{\partial x}\right)^2}, \sqrt{\left(\frac{\partial u}{\partial y}\right)^2 + \left(\frac{\partial v}{\partial y}\right)^2 + \left(\frac{\partial w}{\partial y}\right)^2}\right\}$$

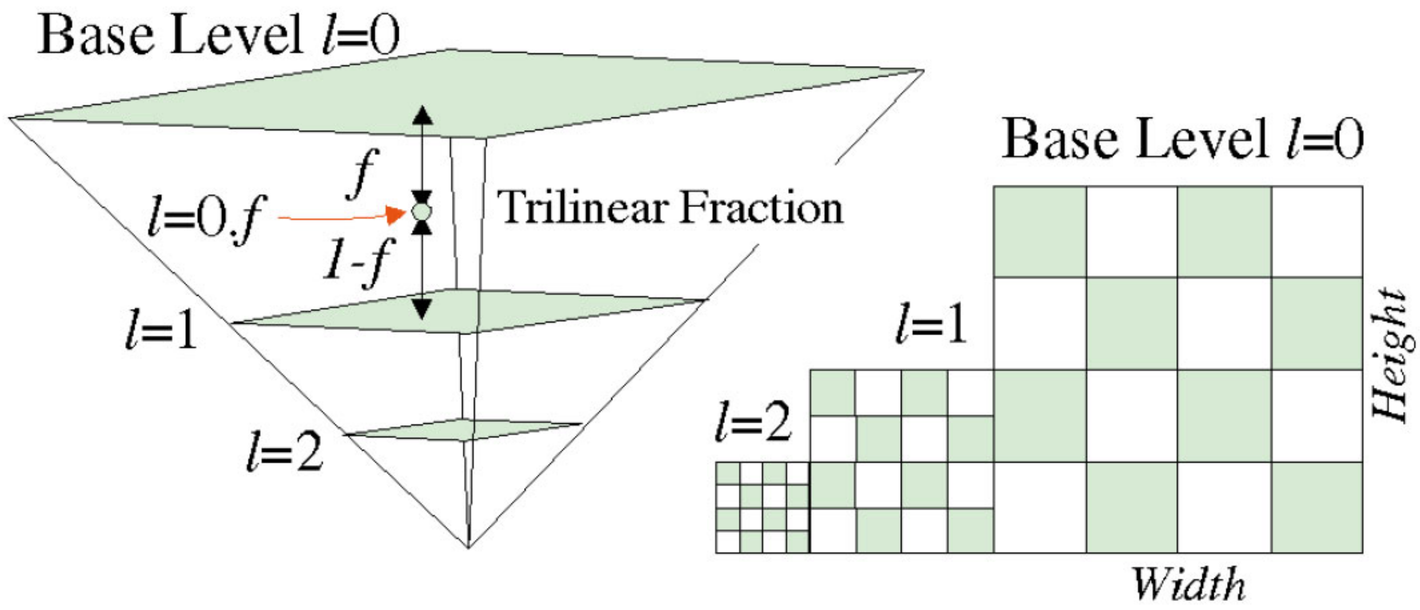
Does not use area of parallelogram but greater hypotenuse [Heckbert, 1983]

- Approximation without square-roots

$$m_u = \max\left\{\left|\frac{\partial u}{\partial x}\right|, \left|\frac{\partial u}{\partial y}\right|\right\} \quad m_v = \max\left\{\left|\frac{\partial v}{\partial x}\right|, \left|\frac{\partial v}{\partial y}\right|\right\} \quad m_w = \max\left\{\left|\frac{\partial w}{\partial x}\right|, \left|\frac{\partial w}{\partial y}\right|\right\}$$

$$\max\{m_u, m_v, m_w\} \leq f(x, y) \leq m_u + m_v + m_w$$

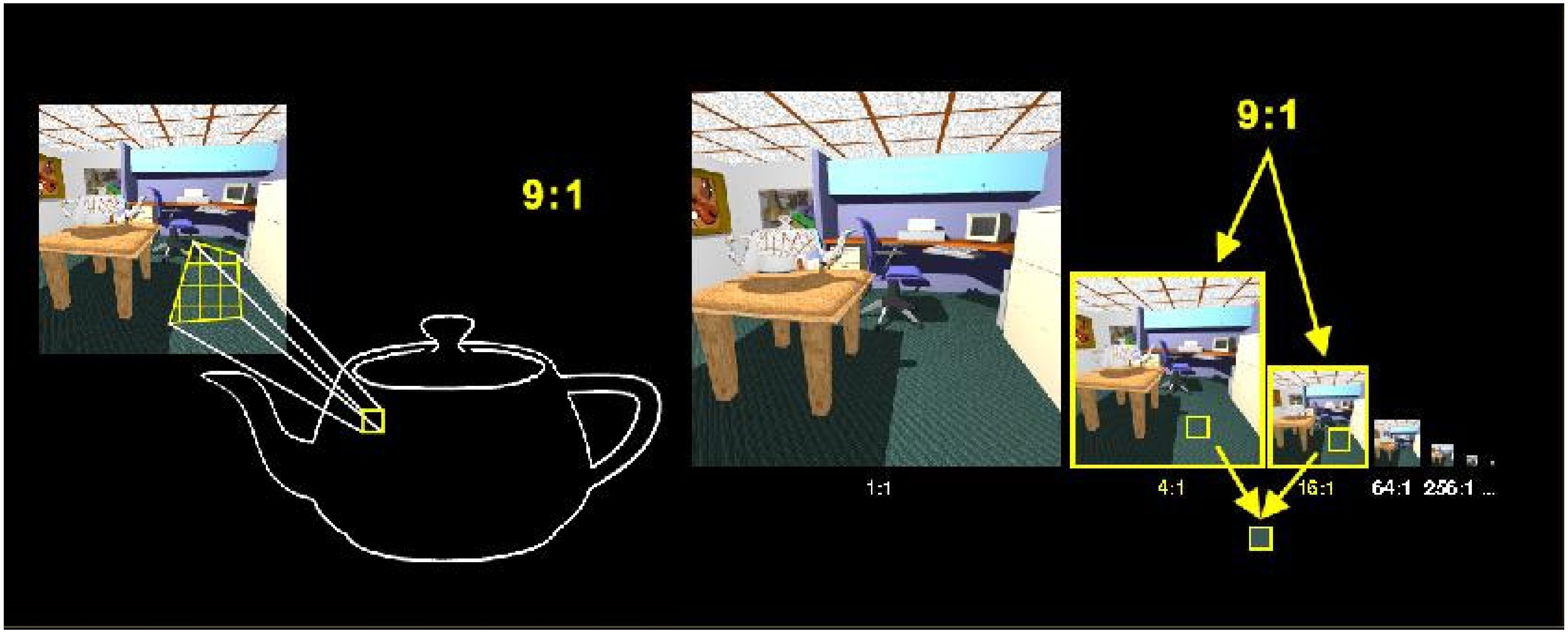
MIP-Map Level Interpolation



- Level of detail value is fractional!
- Use fractional part to blend (lin.) between two adjacent mipmap levels

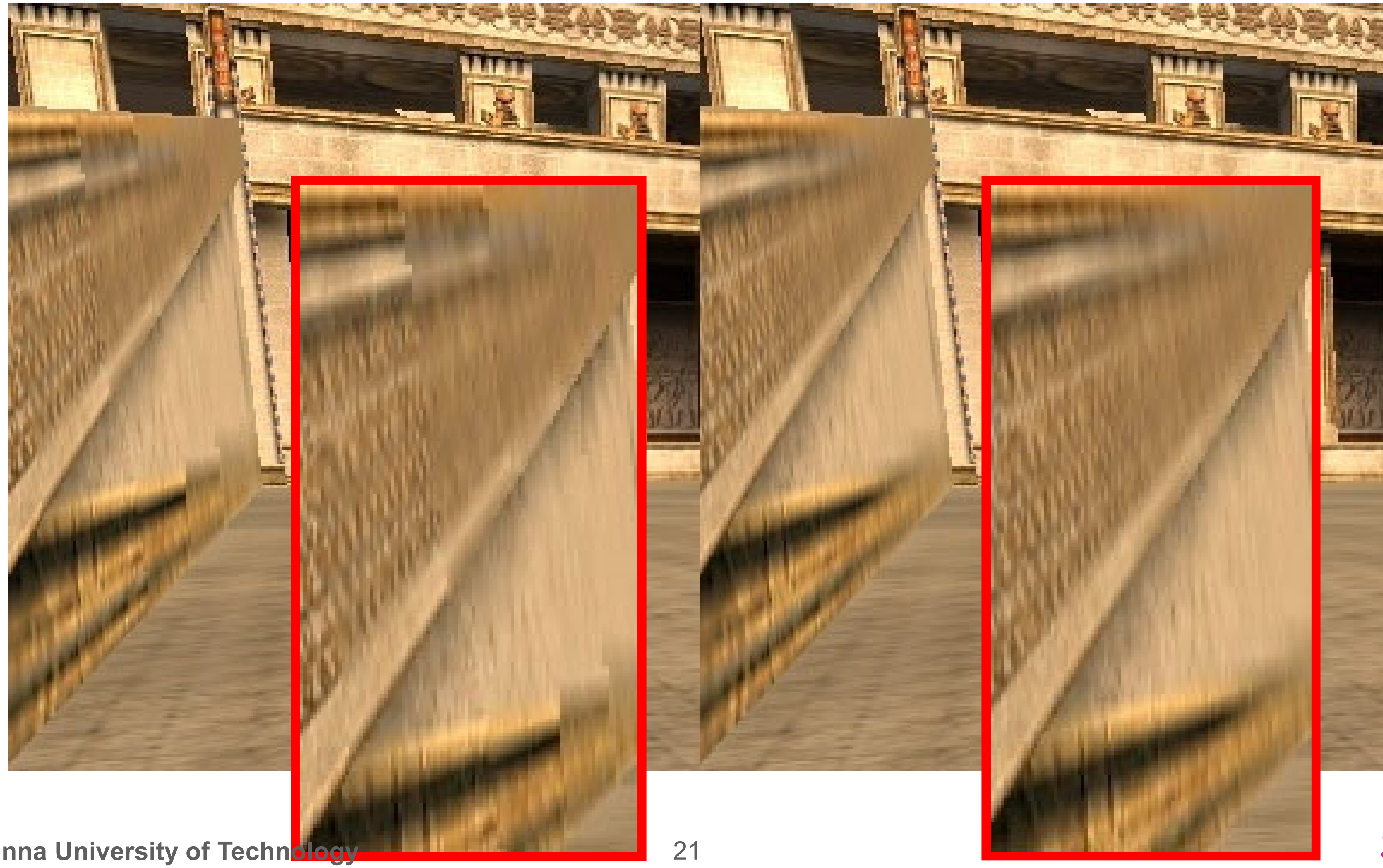
Texture Anti-Aliasing: MIP Mapping

- Trilinear interpolation:
  - T_1 := value from texture $D_1 = D_0+1$ (bilin.interpolation)
  - Pixel value := $(D_1–D)\cdot T_0 + (D–D_0)\cdot T_1$
    - Linear interpolation between successive MIP Maps
  - Avoids "Mip banding" (but doubles texture lookups)



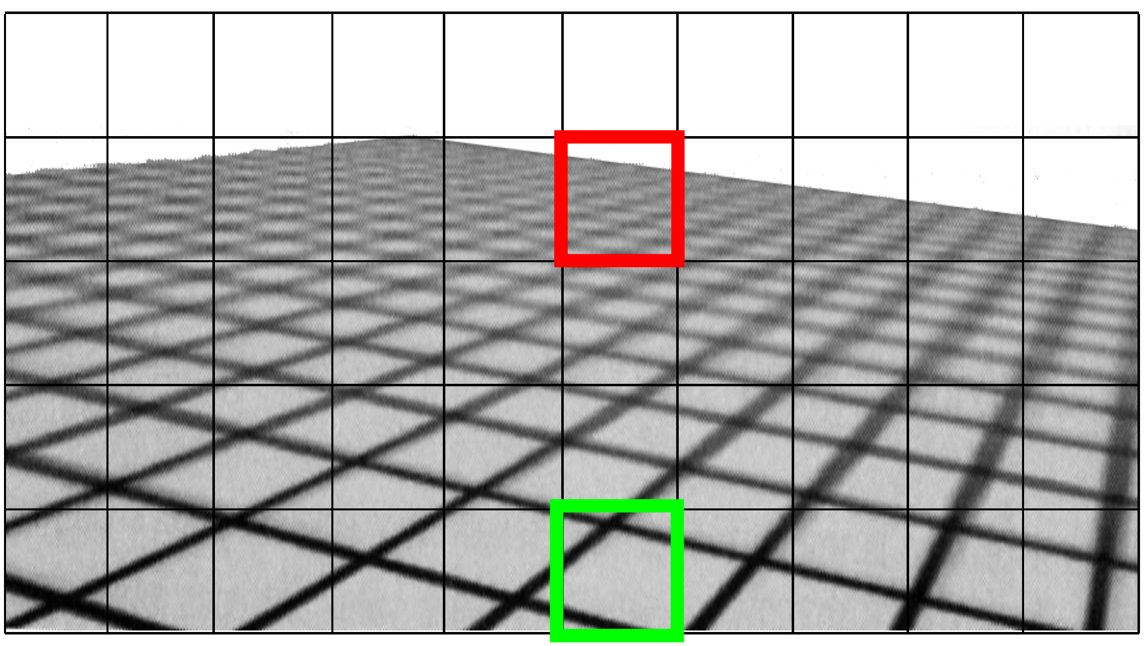
Texture Anti-Aliasing: MIP Mapping

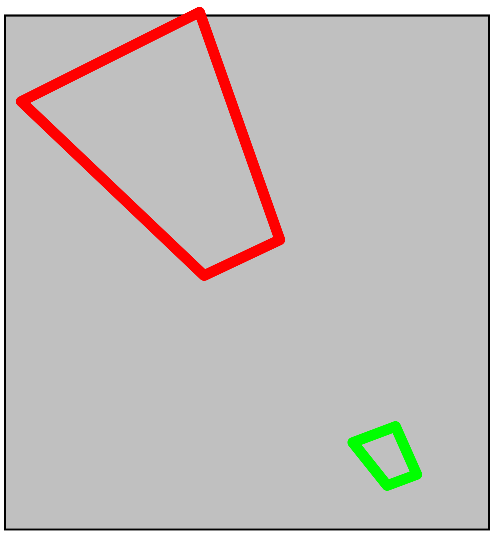
- Other example for bilinear vs. trilinear filtering



Anti-Aliasing: Anisotropic Filtering

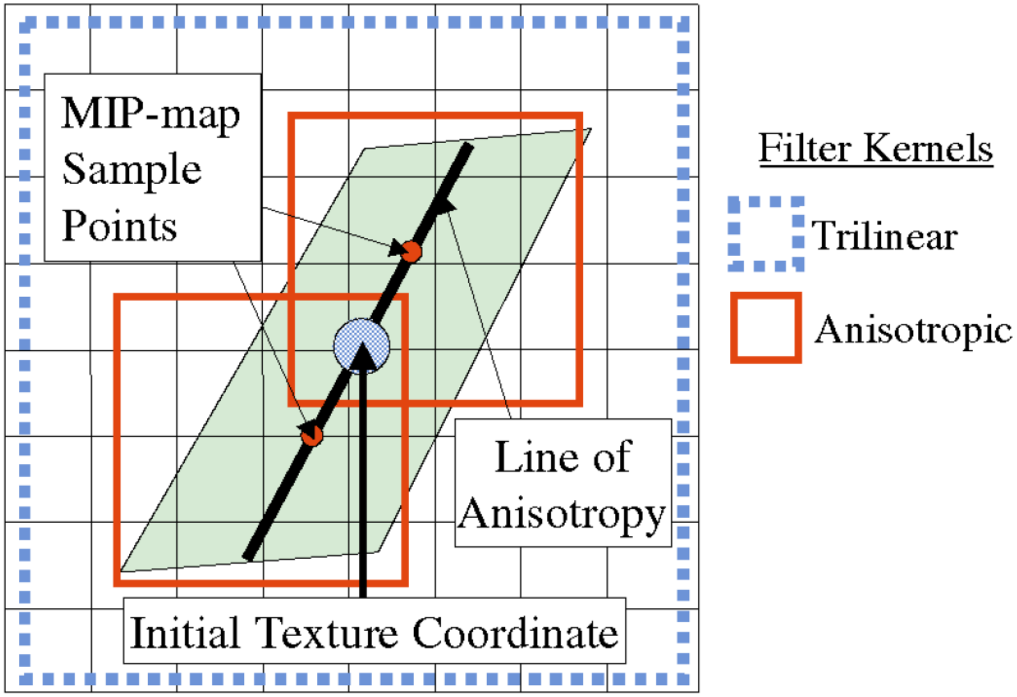
- Anisotropic filtering
  - View-dependent filter kernel
  - Implementation: *summed area table*, "*RIP Mapping*", *footprint assembly*, *elliptical weighted average* (EWA)





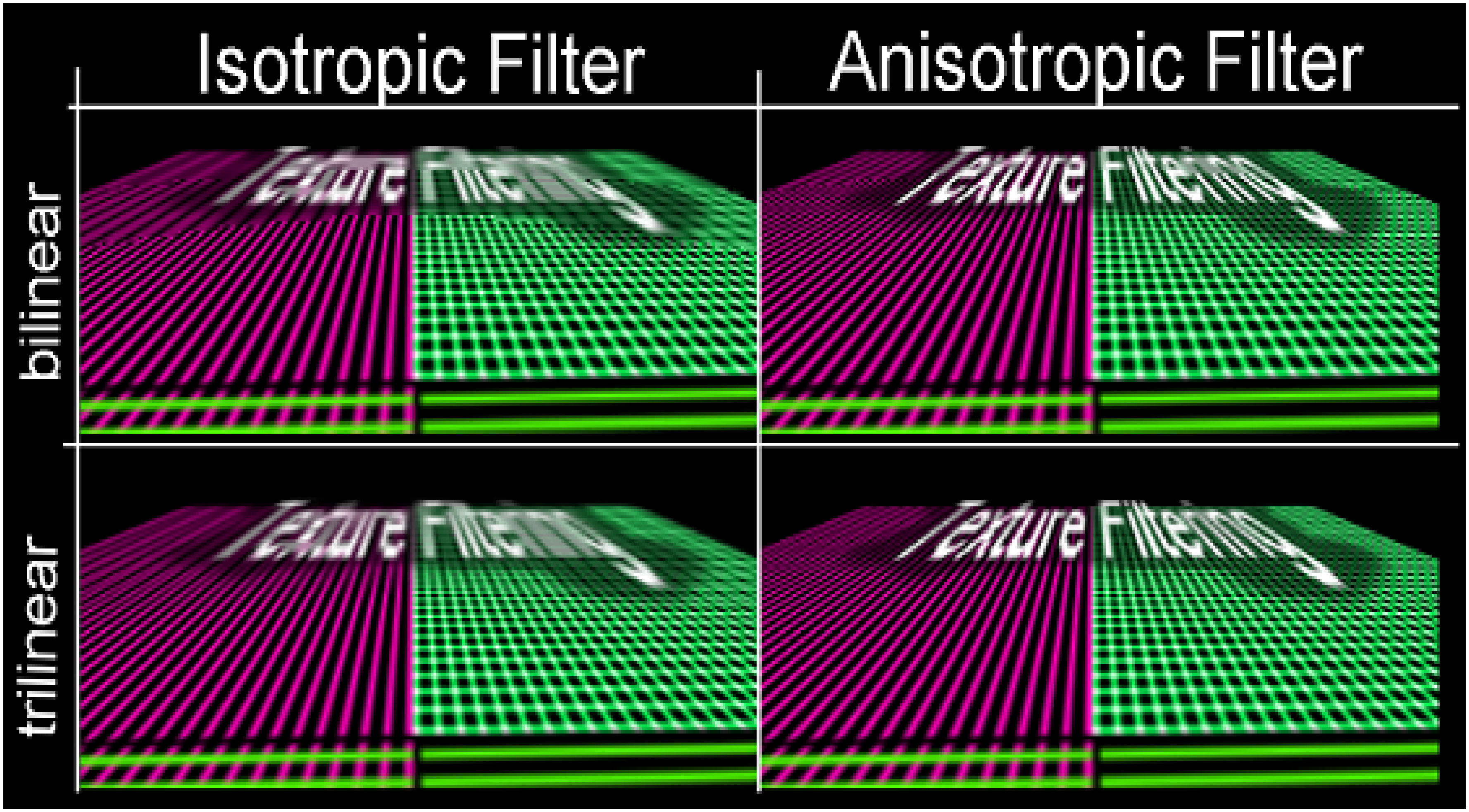
Texture space

Anisotropic Filtering: Footprint Assembly



Anti-Aliasing: Anisotropic Filtering

- Example



Texture Anti-aliasing

- Basically, everything done in hardware
- `gluBuild2DMipmaps()` generates MIPmaps
- Set parameters in `glTexParameter()`
  - `GL_TEXTURE_MAG_FILTER: GL_NEAREST, GL_LINEAR, …`
  - `GL_TEXTURE_MIN_FILTER: GL_LINEAR_MIPMAP_NEAREST`
- Anisotropic filtering is an extension:
  - `GL_EXT_texture_filter_anisotropic`
  - Number of samples can be varied (4x,8x,16x)
    - Vendor specific support and extensions

Thank you.