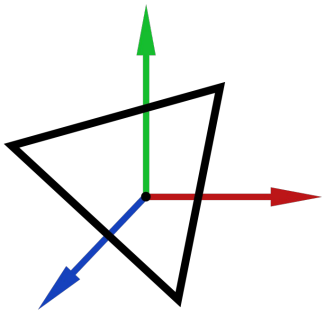
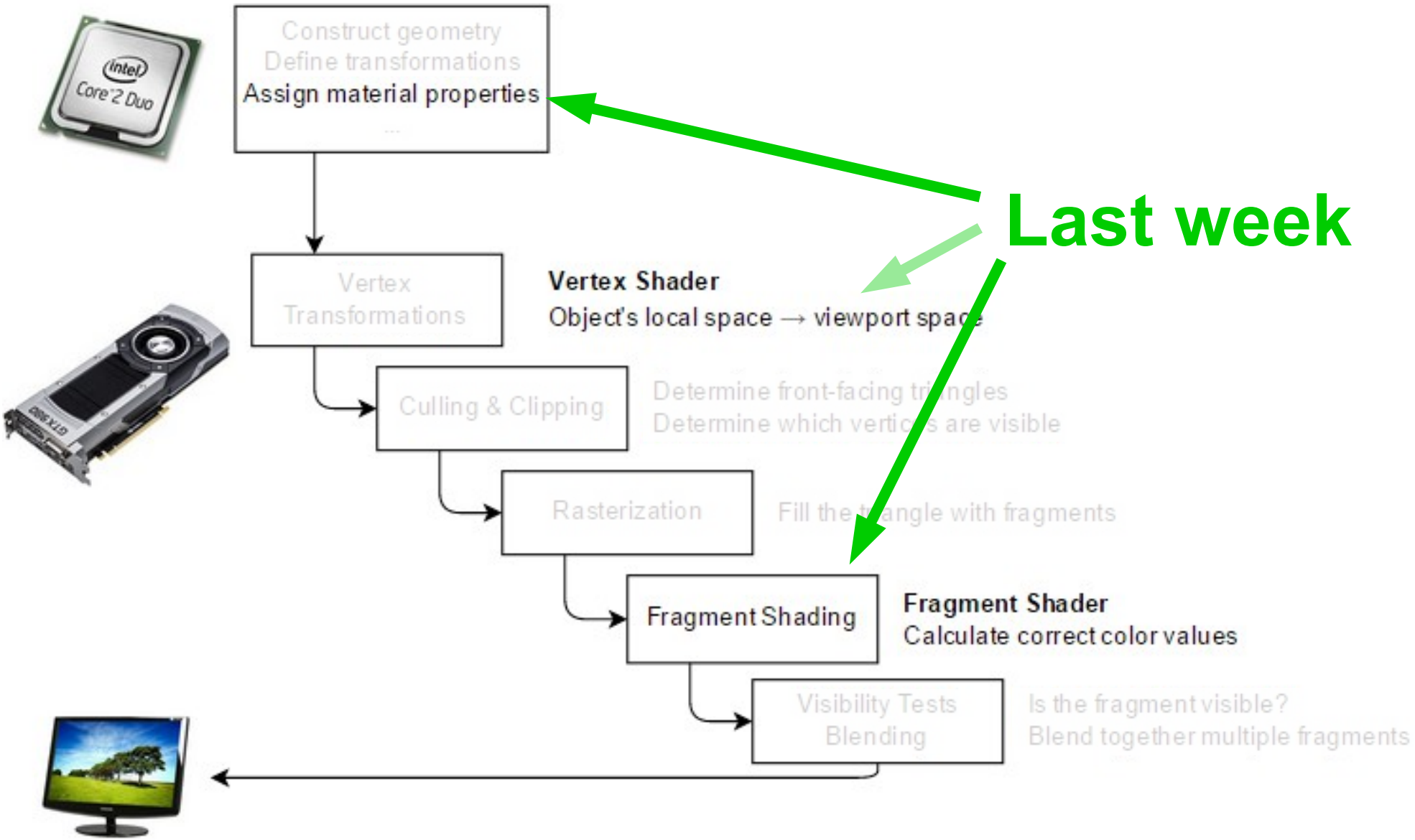


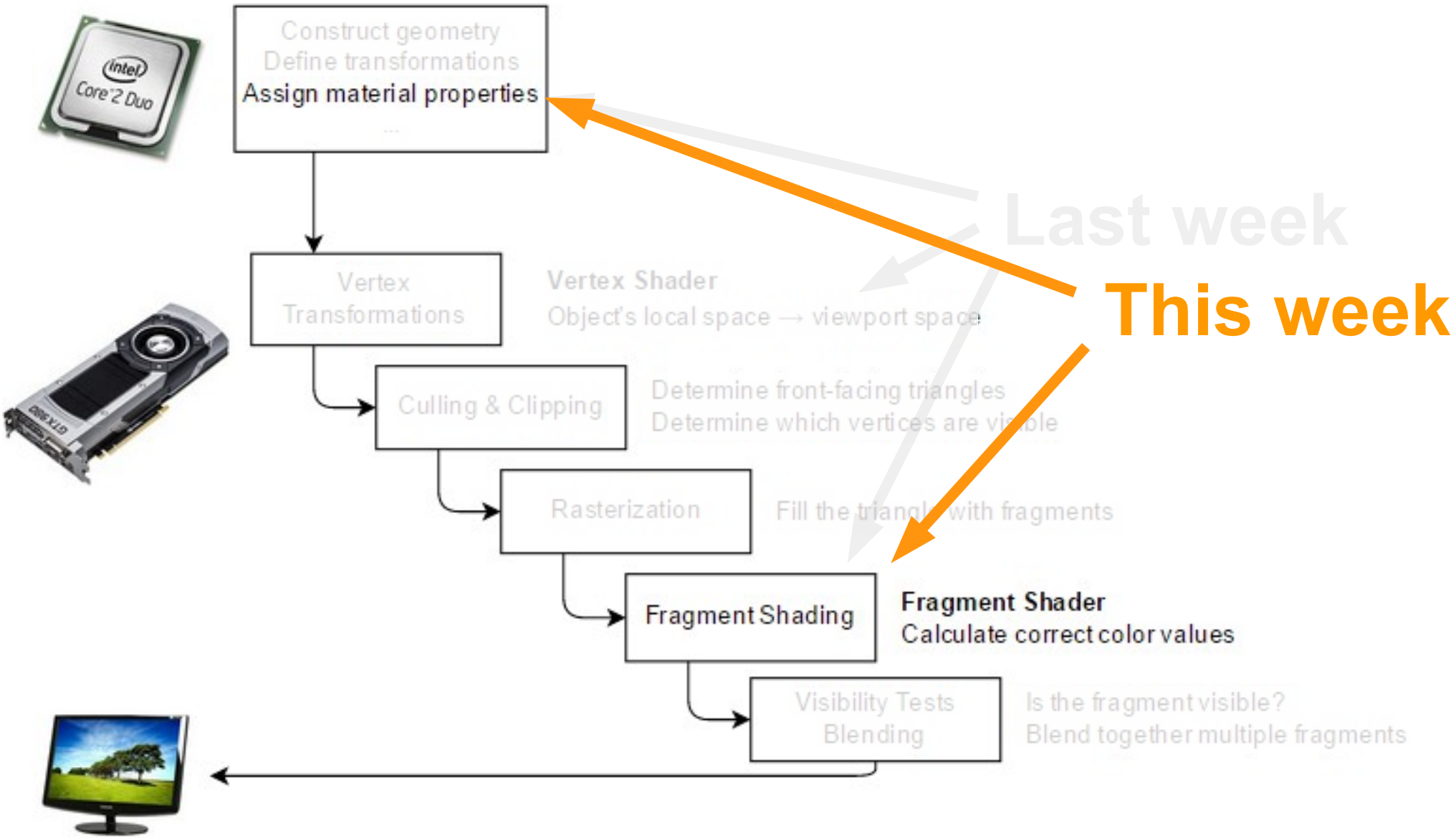
Computer Graphics

MTAT.03.015

Raimond Tunnel

UNIVERSITY OF TARTU
Institute of Computer Science


Construct geometry
Define transformations
Assign material properties
...
Last week
Vertex Transformations
Vertex Shader
Object's local space → viewport space
Culling & Clipping
Determine front-facing triangles
Determine which vertices are visible
Rasterization
Fill the triangle with fragments
Fragment Shading
Fragment Shader
Calculate correct color values
Visibility Tests
Blending
Is the fragment visible?
Blend together multiple fragments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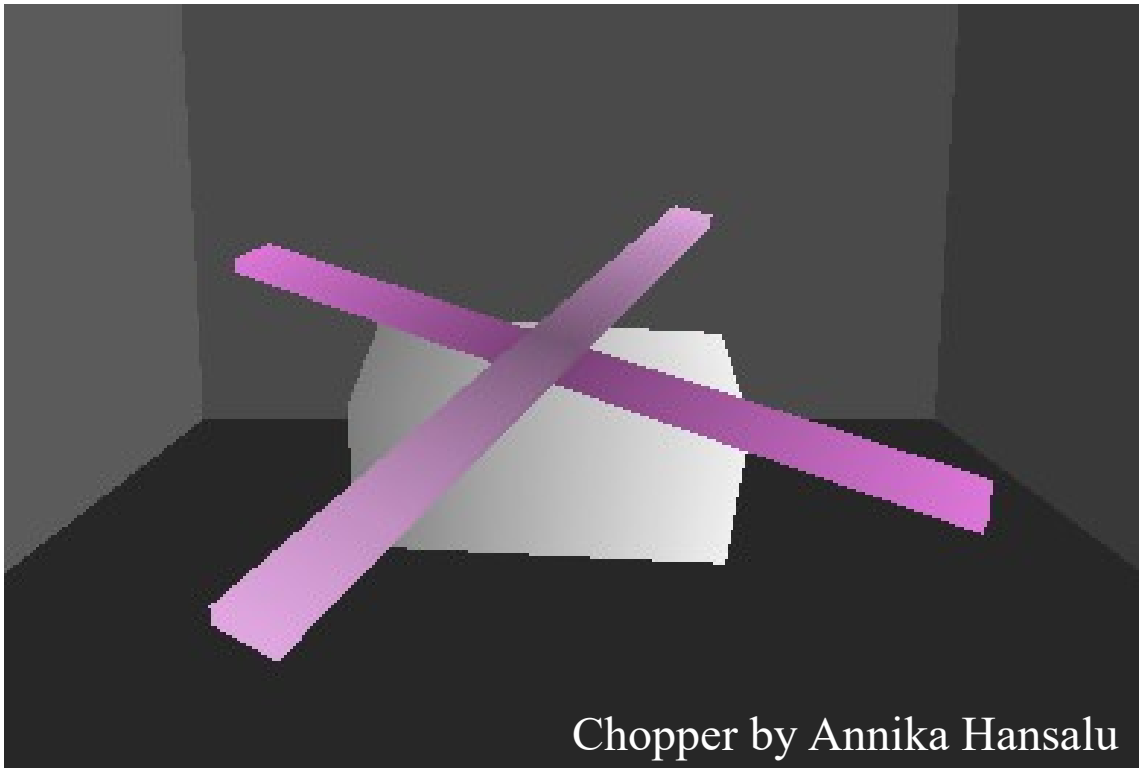
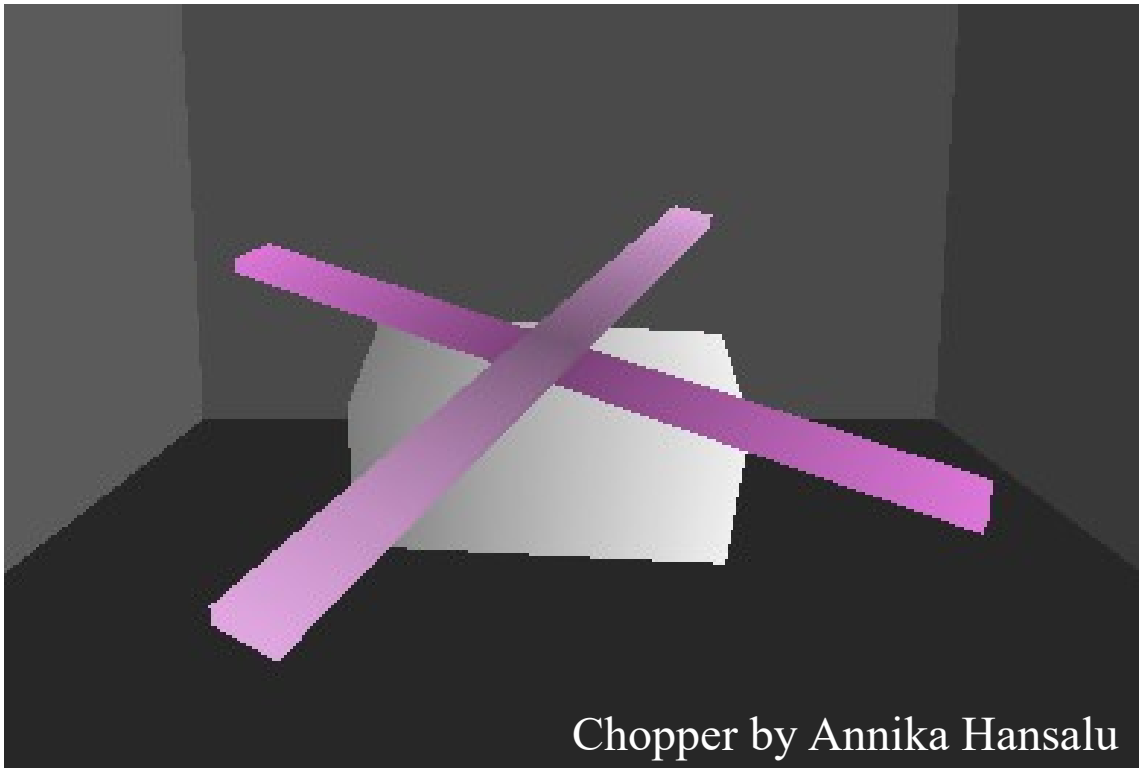
More Granular Surface Color



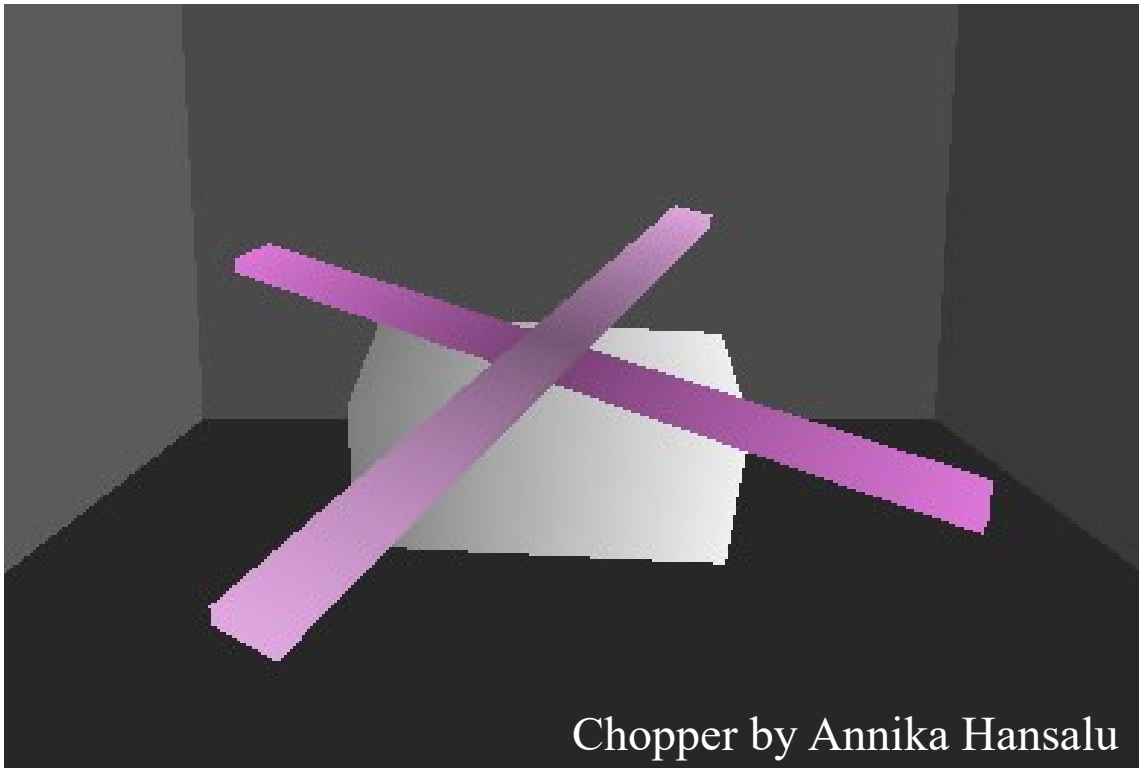
More Granular Surface Color

- Blades – 4 different meshes



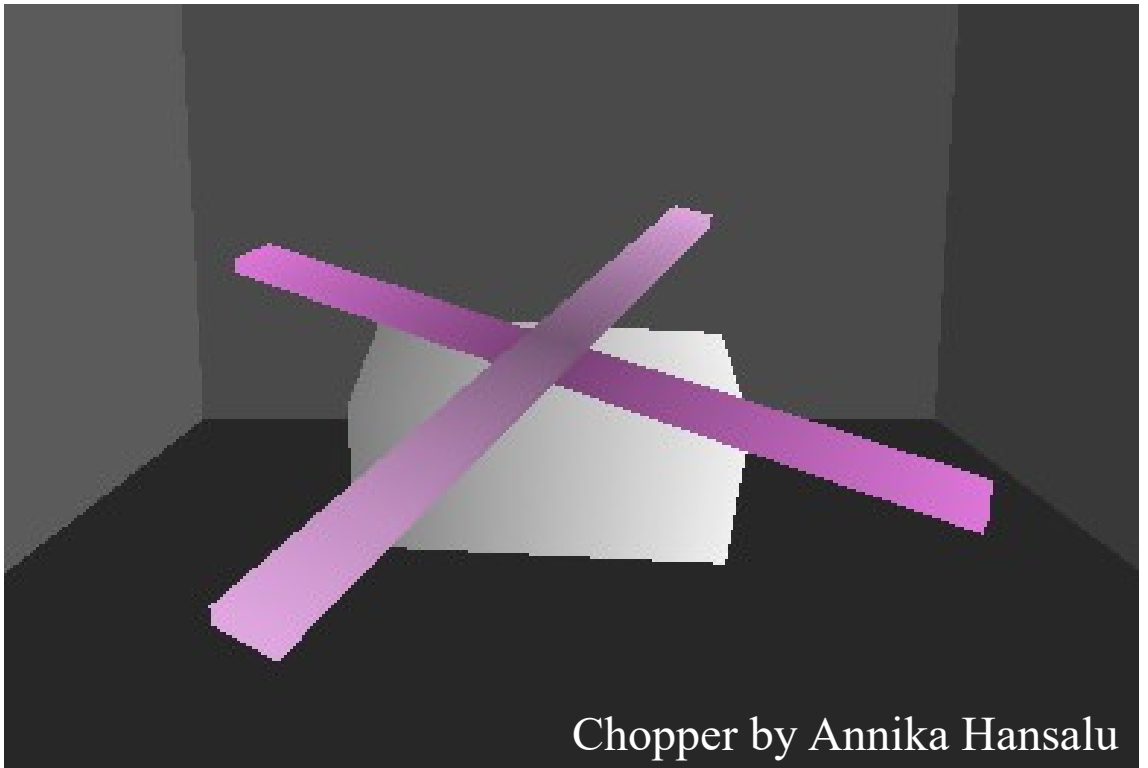
More Granular Surface Color

- Blades – 4 different meshes:
  - 2 blades



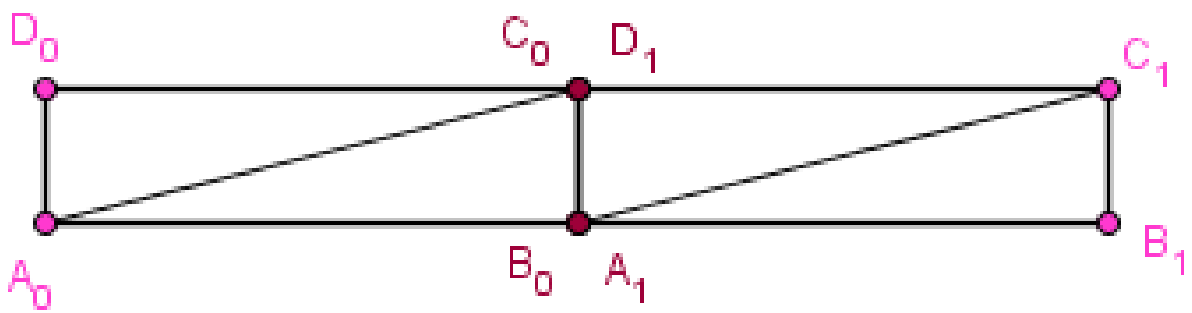
More Granular Surface Color

- Blades – 4 different meshes:
  - 2 blades, each blade consists of 2 parts



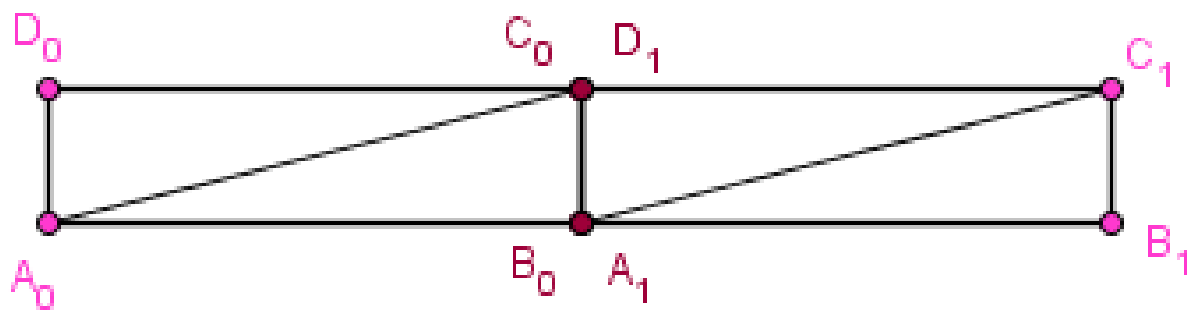
More Granular Surface Color

- Extra vertices and faces that all need parsing

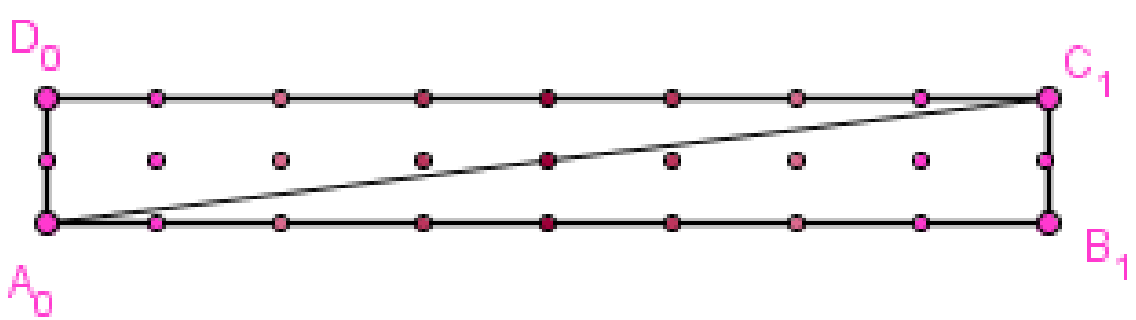


More Granular Surface Color

- Extra vertices and faces that all need parsing



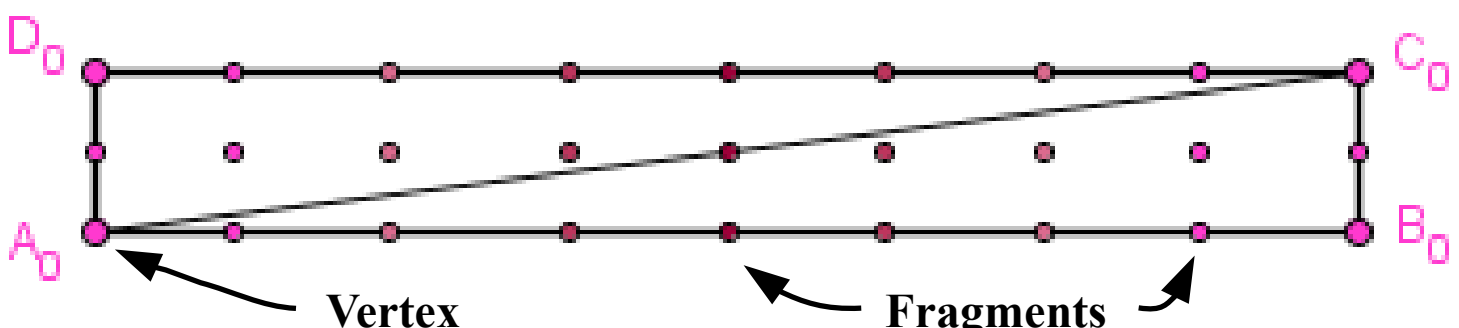
- Could we get the same result with 4 vertices?



More Granular Surface Color

- We need to specify colors per fragment.

Mesh

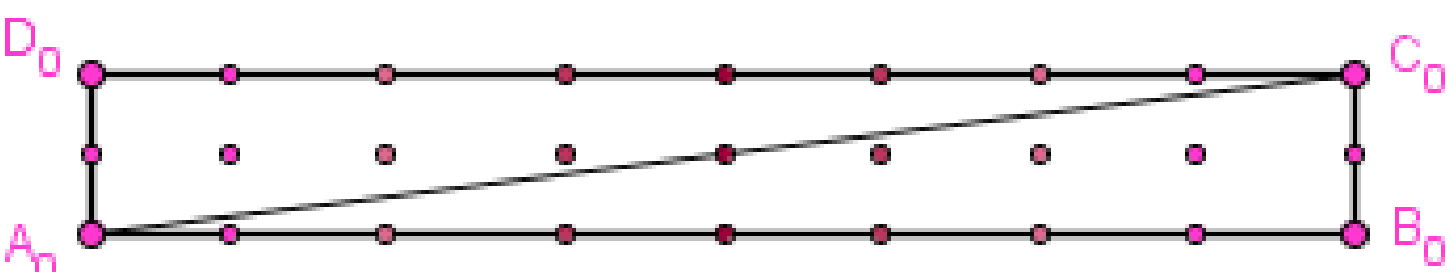


More Granular Surface Color

- We need **an image** to specify colors per fragment.

Texture

Mesh

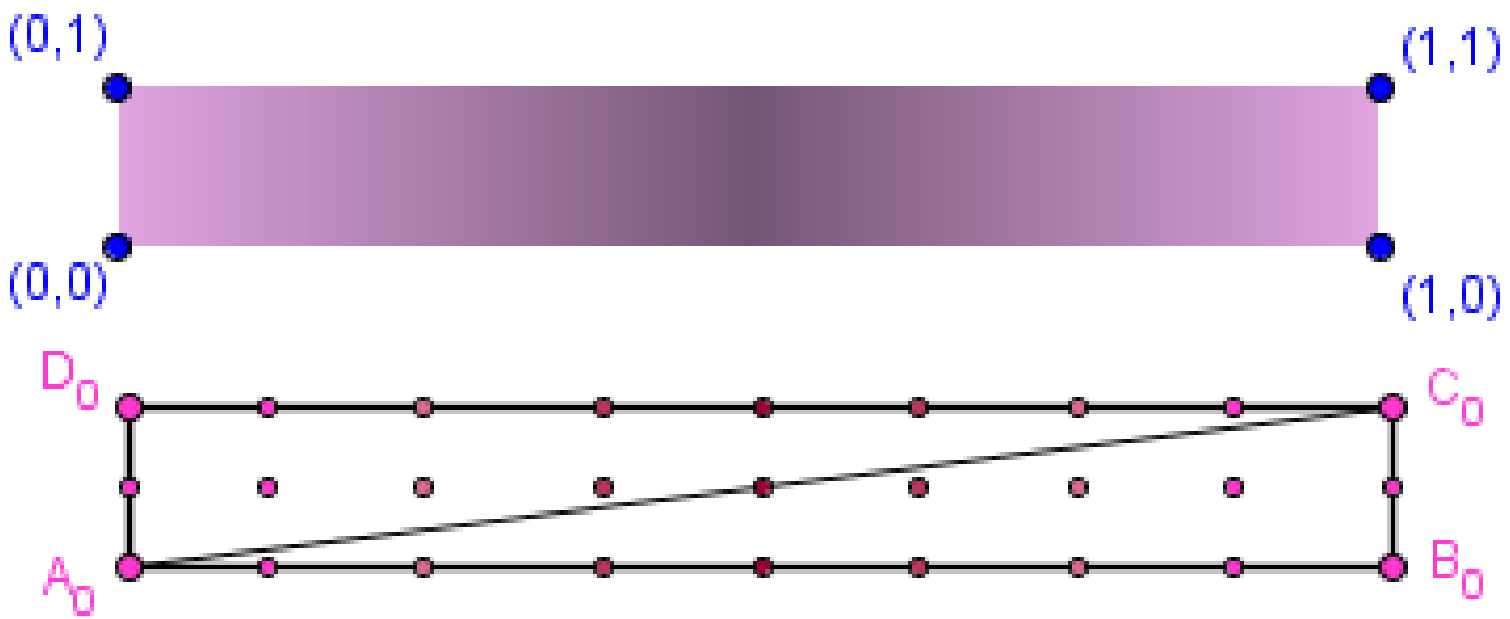


More Granular Surface Color

- We need an image to specify colors per fragment.
- We no longer just interpolate the color, but make and use **a mapping**.

Texture

Mesh



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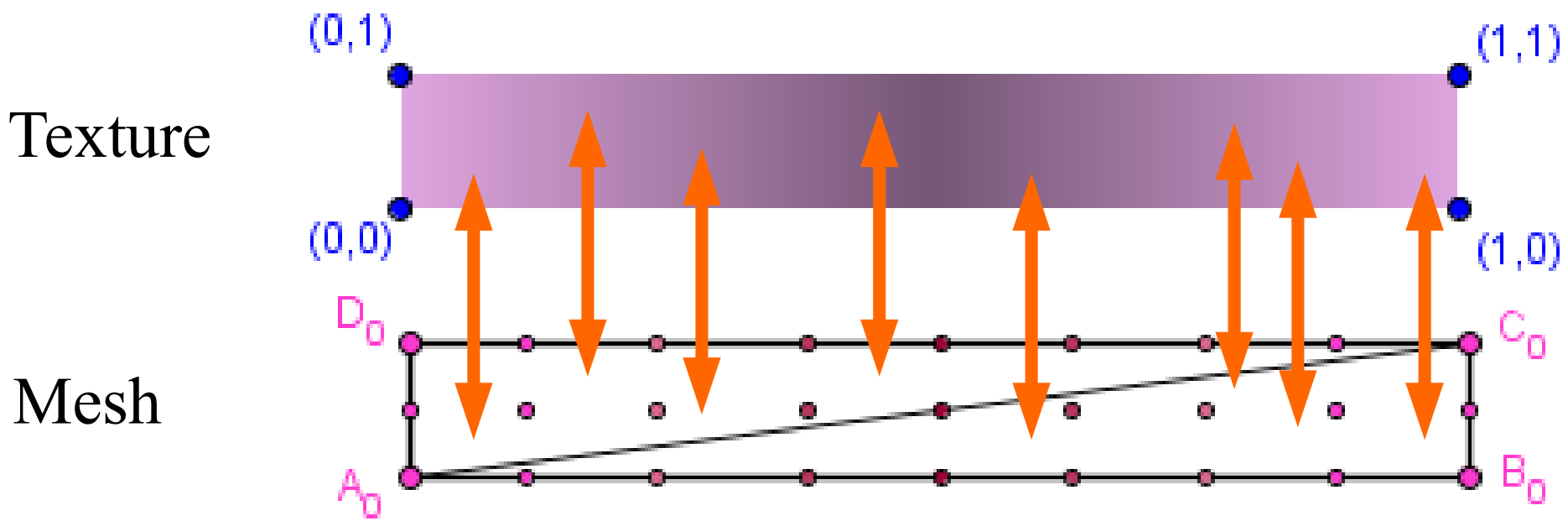
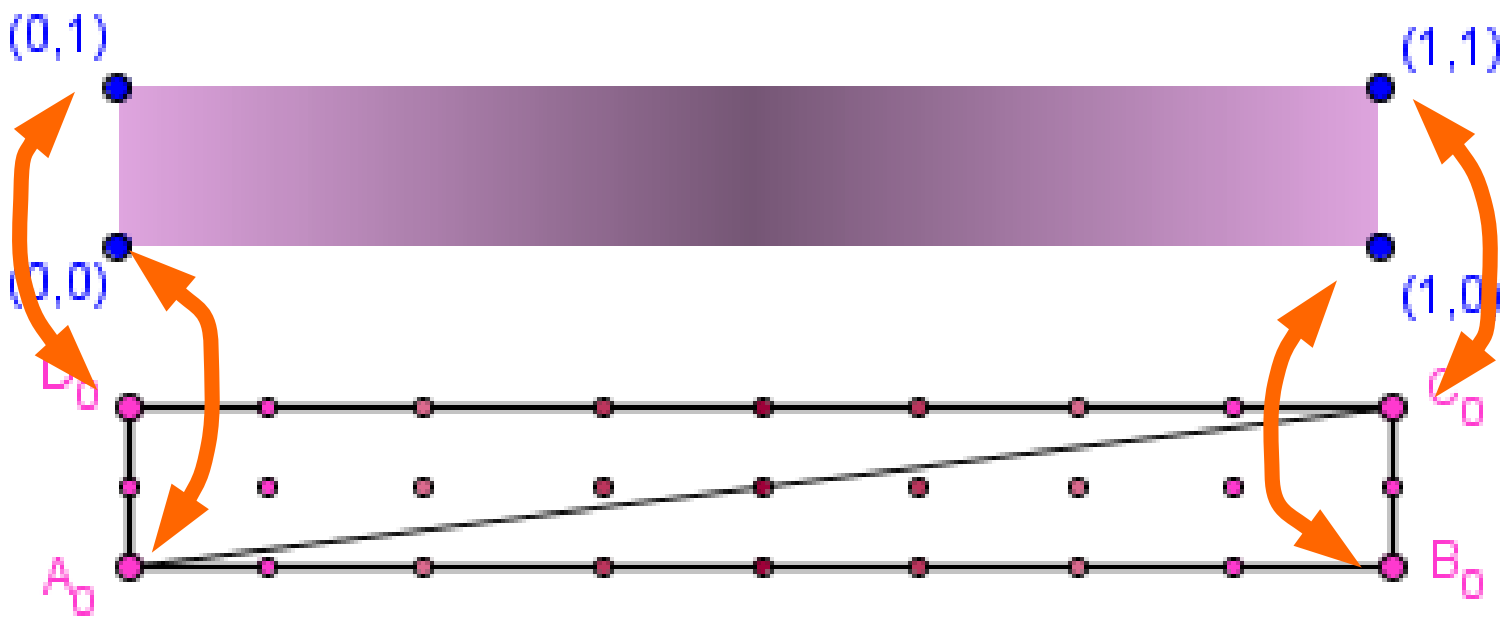


More Granular Surface Color

- We need an image to specify colors per fragment.
- We no longer just interpolate the color, but make and use **a UV mapping**.

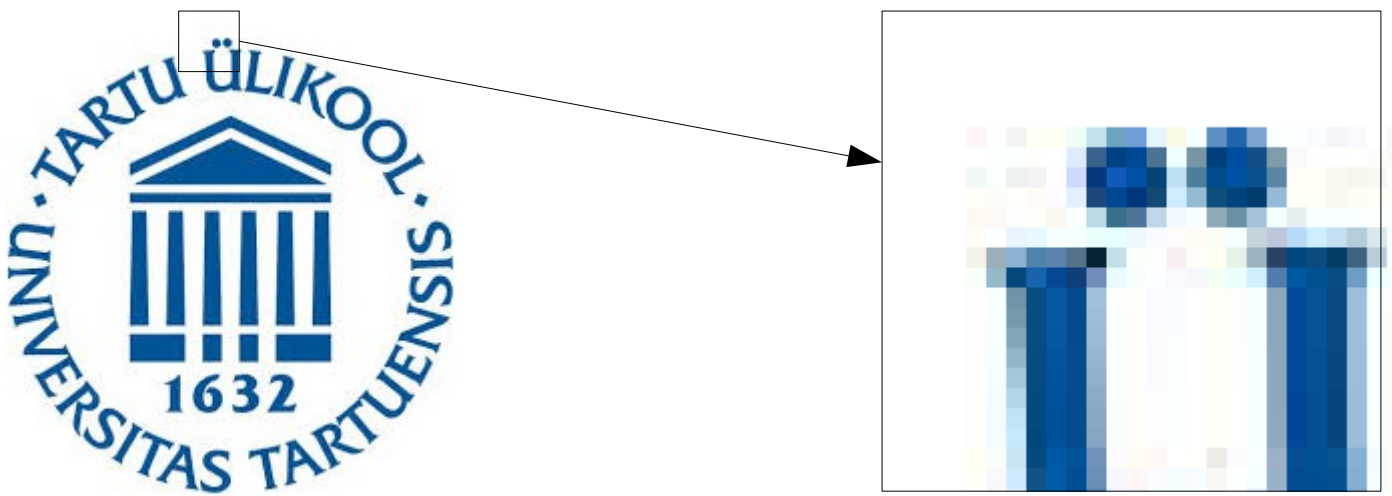
Texture

Mesh



(Raster) Image

- Image is a matrix (2D array) of point values.



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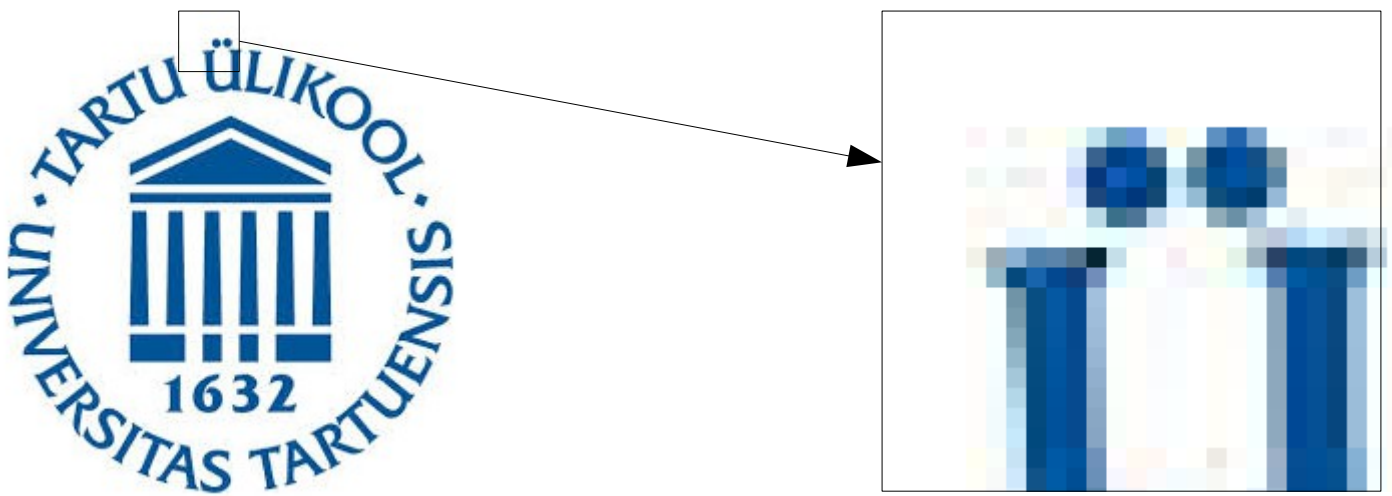

- Our 3D surface is **continuous**, we may rasterize a **varying amount** of points for a face.

Upscale

- Sometimes we want to see the surface in **more detail** than there are point values in the image.

Upscale

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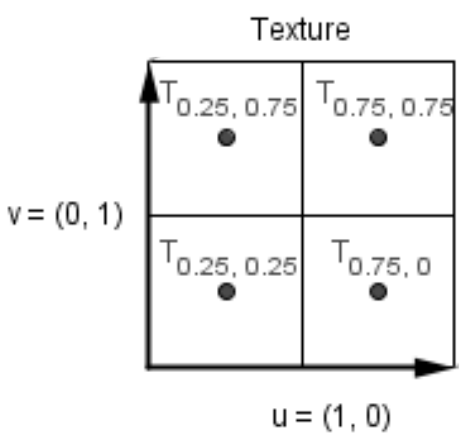

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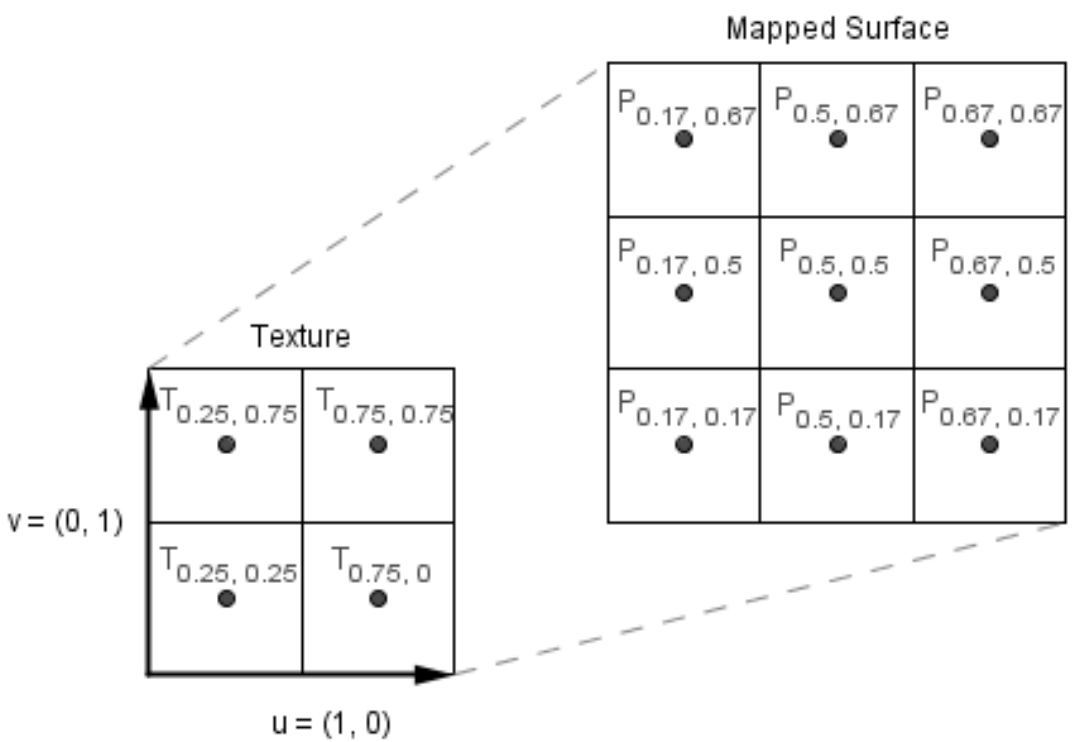

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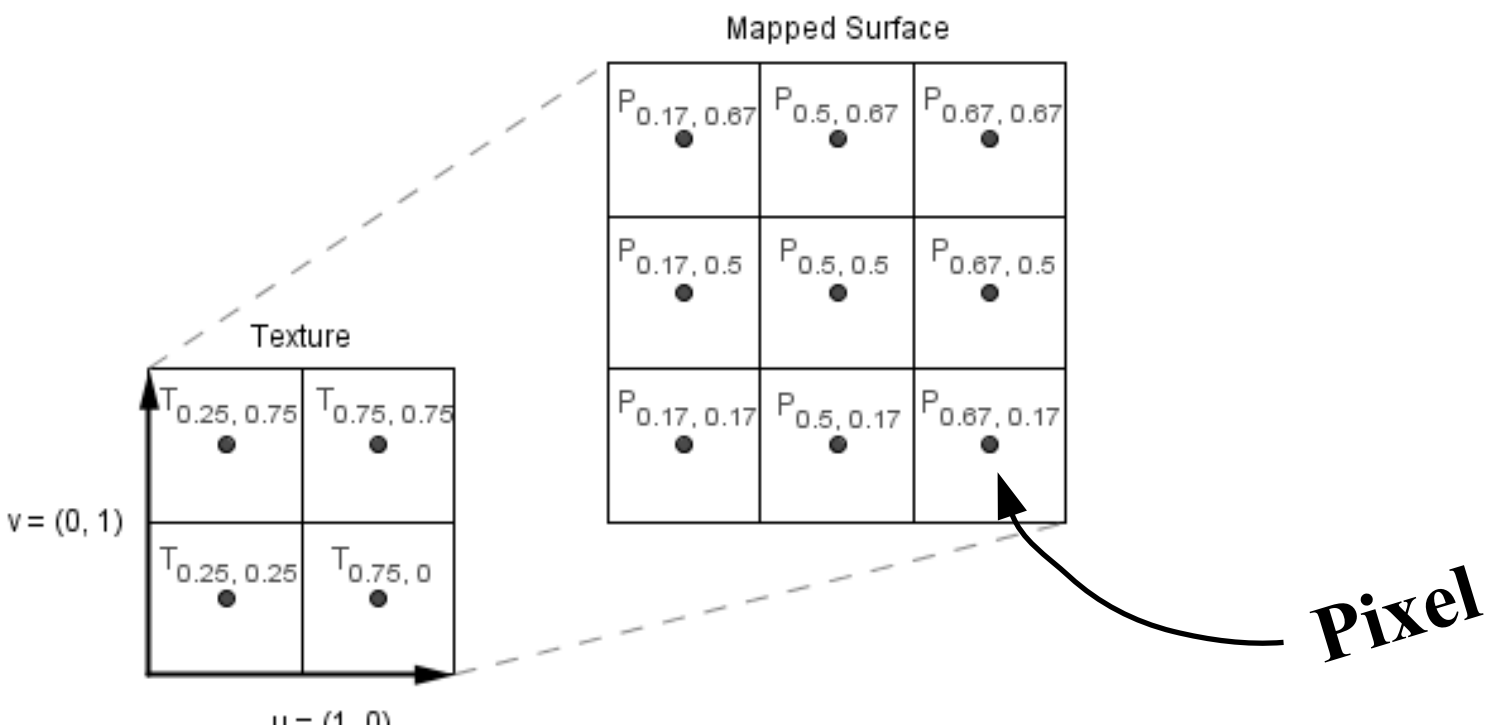

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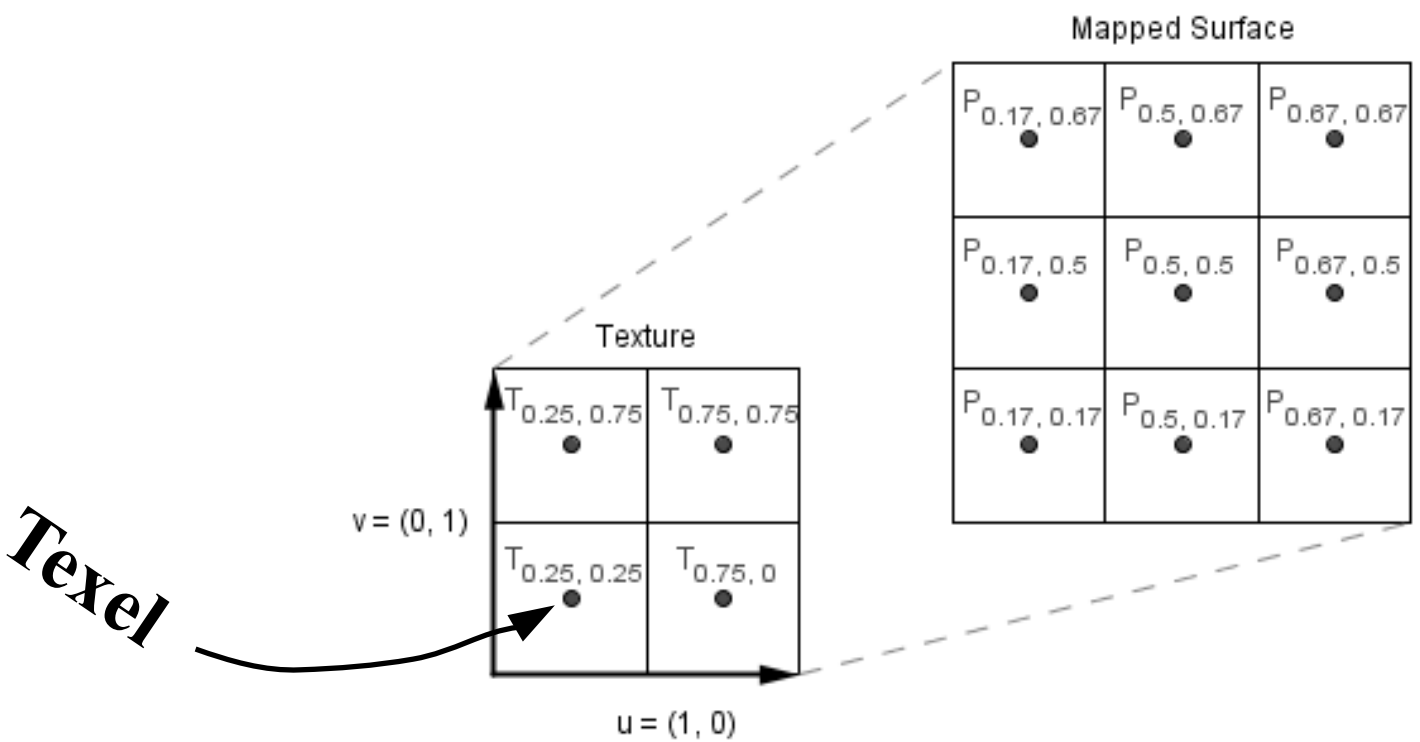
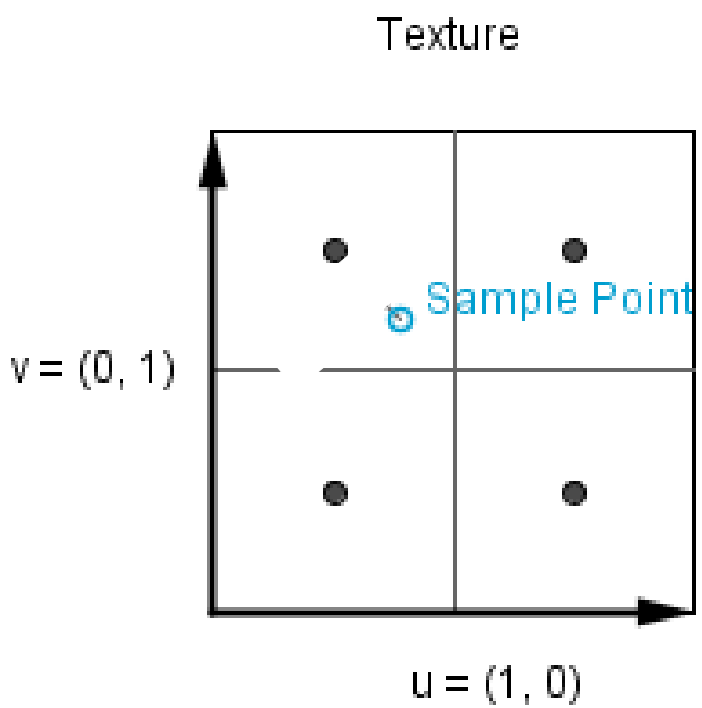


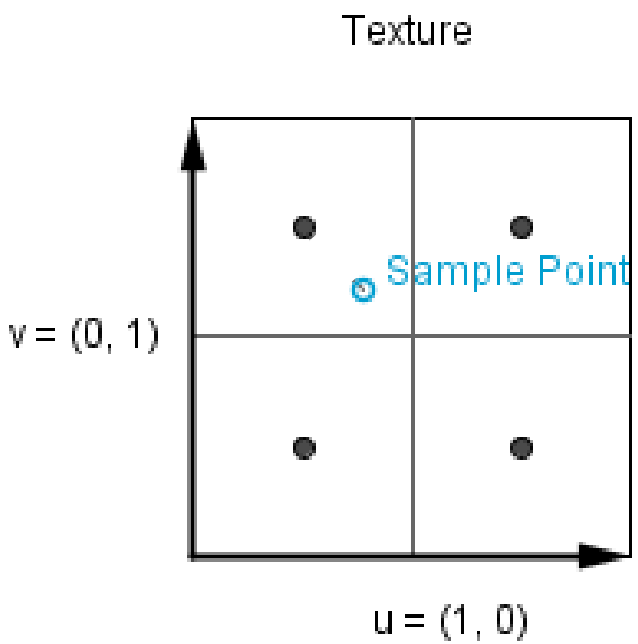
Upscale

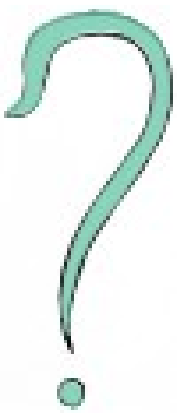
- For a single point in the larger surface, we usually have **4 neighbours in the texture**.



Upscale

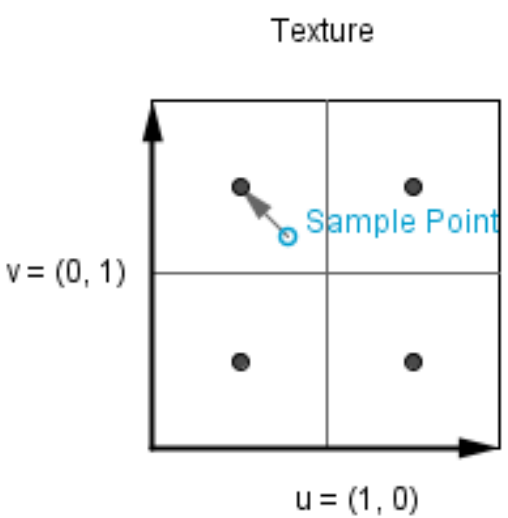
- For a single point in the larger surface, we usually have **4 neighbours in the texture**.
- What are the exceptions?

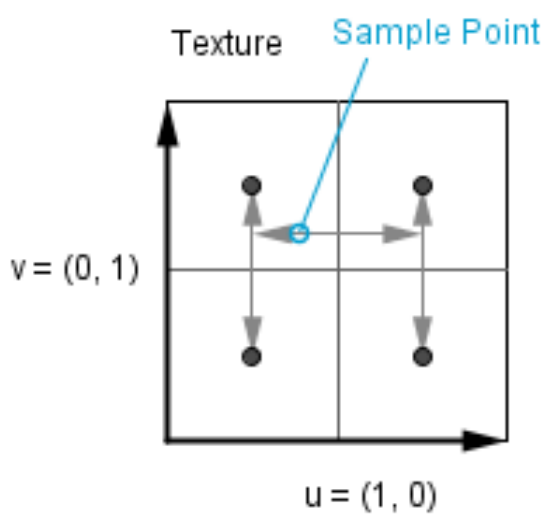




Upscale

- For a single point in the larger surface, we usually have 4 neighbours in the texture.
- What are the exceptions?
- How could we find the sample value?





Upscale

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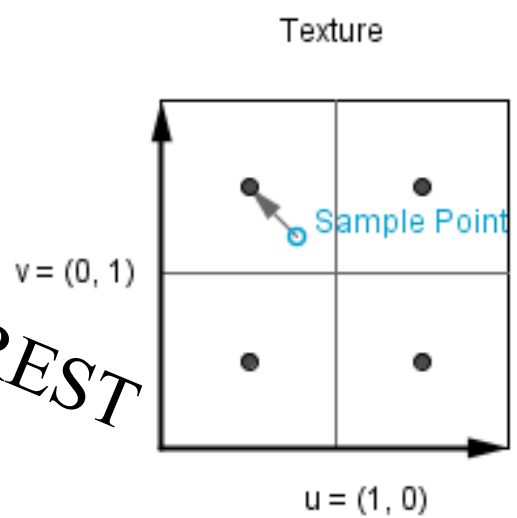
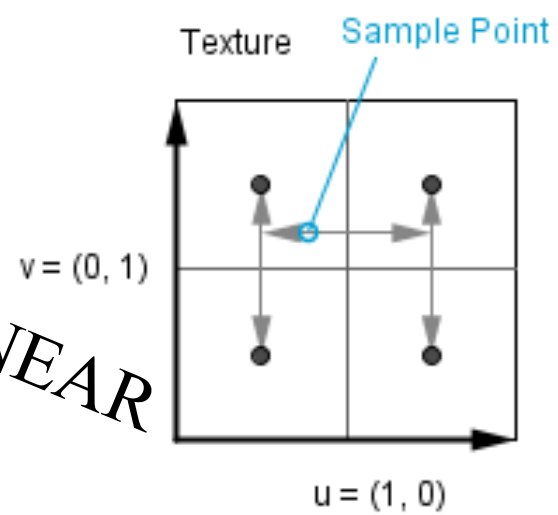
GL_NEAREST

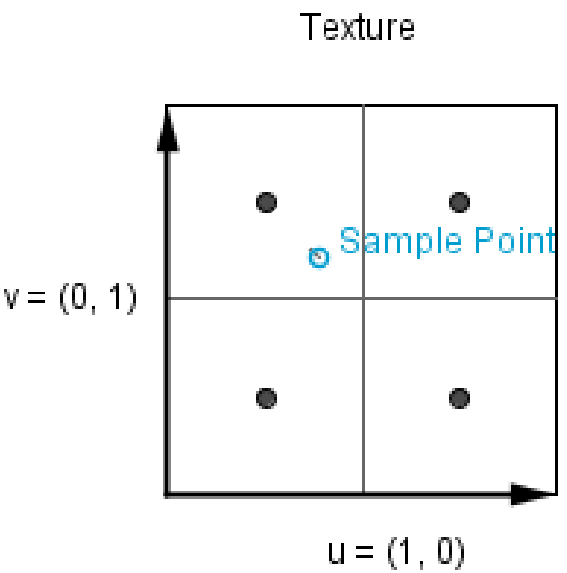


GL_LINEAR



What do these do?

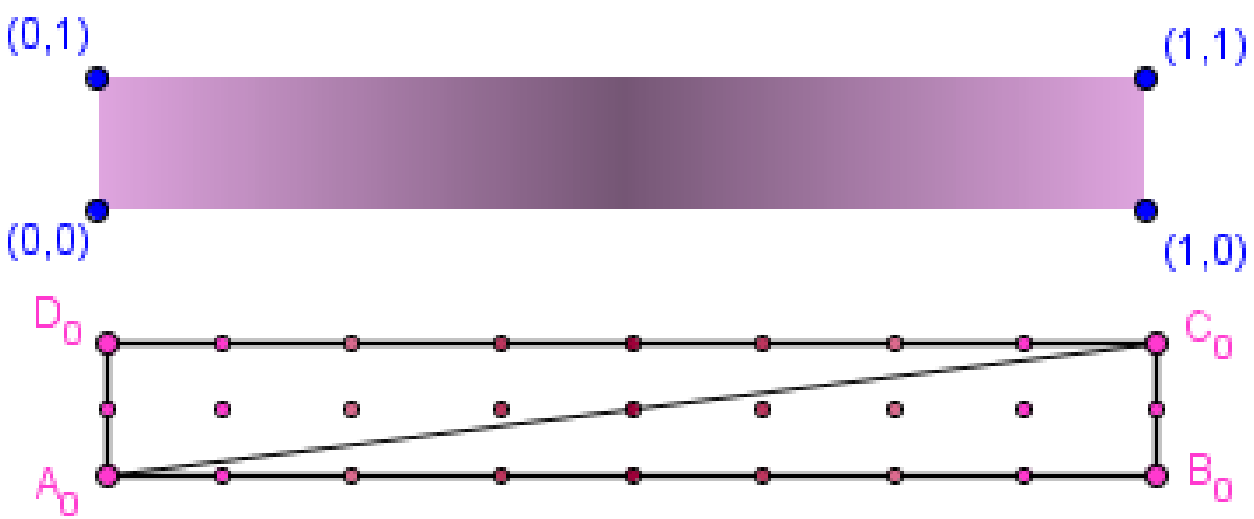
- GL_CLAMP_TO_EDGE
- GL_CLAMP_TO_BORDER
- GL_MIRRORED_REPEAT
- GL_REPEAT



https://www.khronos.org/registry/OpenGL-Refpages/gl4/html/glTexParameter.xhtml

Upscale

- With that in mind, what would be the smallest texture we need for the chopper blade here?

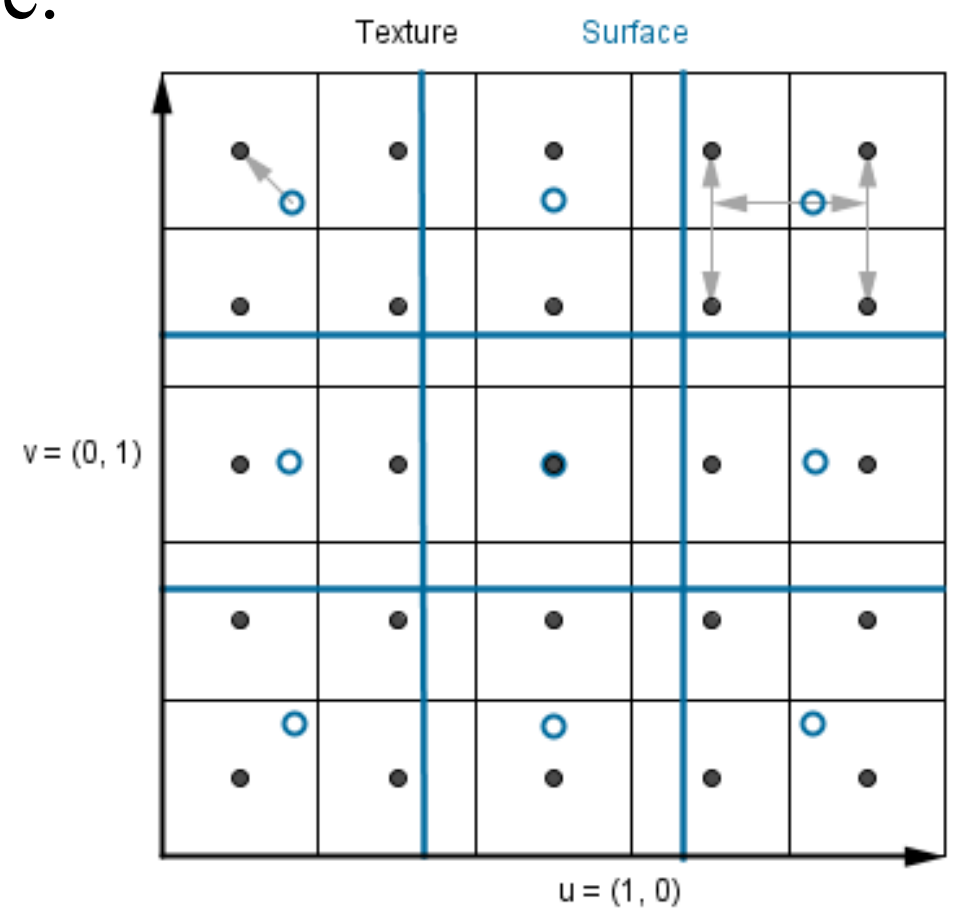


Upscale

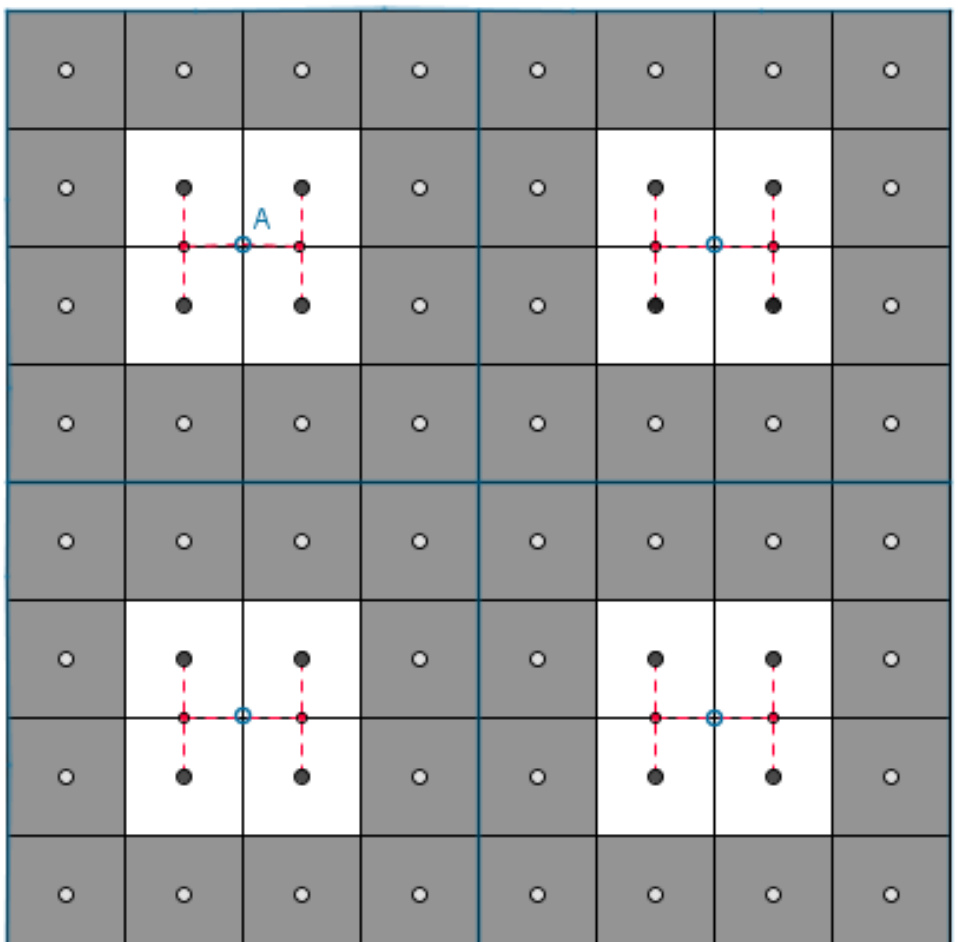
- Given a texture with some *width*×*height*, how to find the nearest texels for a sample with UV coordinates?

Downscale

- We can try to do the same interpolation for the downscale.

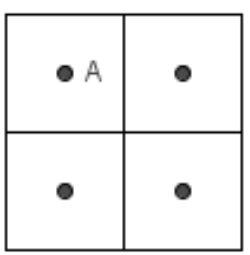


Downscale



Texture

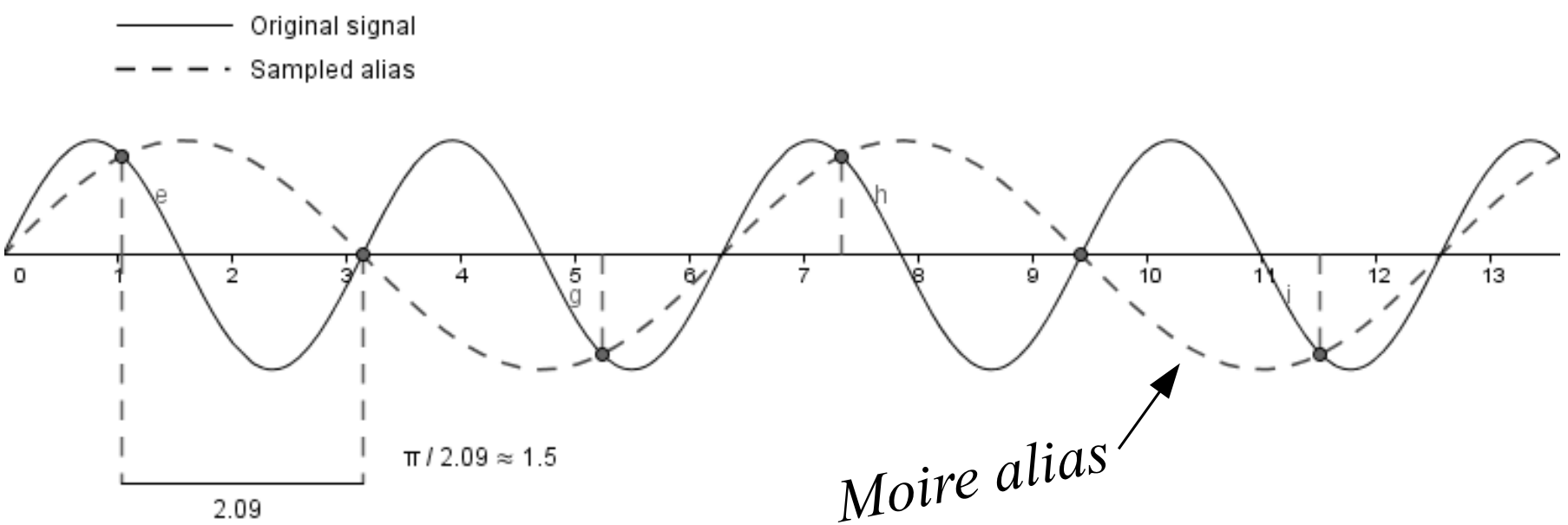
- What can go wrong?



Downscaled

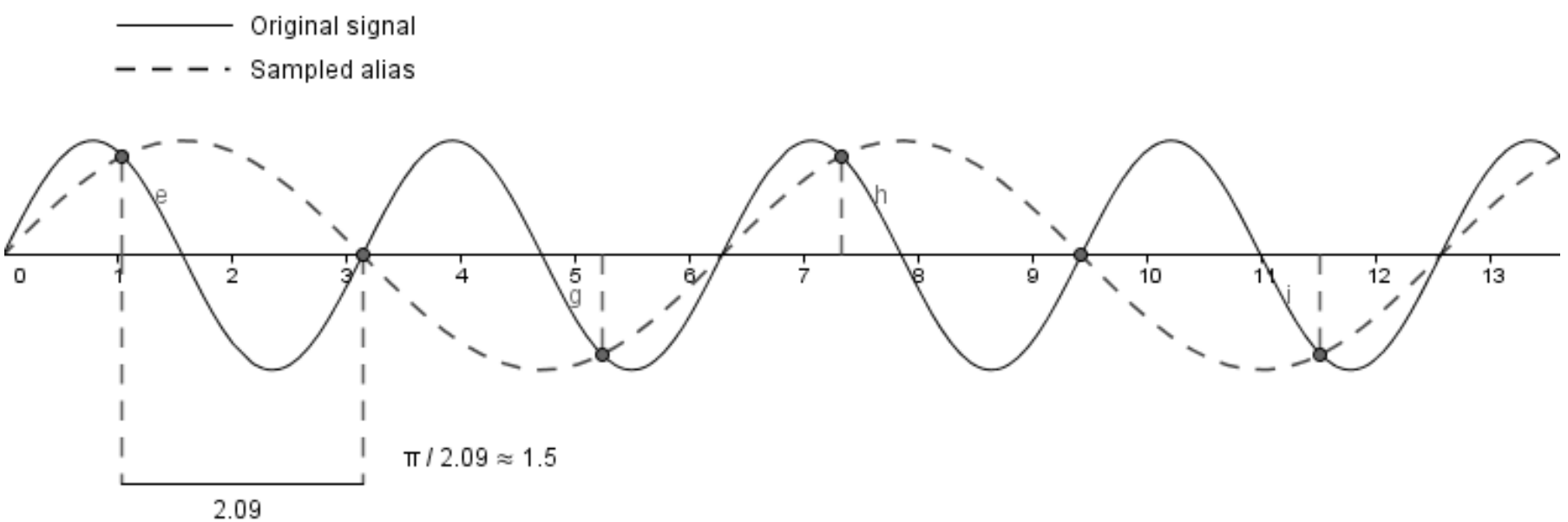
Nyquist–Shannon Sampling Theorem

- *In order to reconstruct a band-limited signal, one has to sample with sampling rate more than twice the highest frequency.*



Nyquist–Shannon Sampling Theorem

- *In order to reconstruct a band-limited signal, one has to* ***sample*** *with sampling rate* ***more than twice*** *the* ***highest frequency****.*



This means more than 2 samples per period, every period.

Nyquist–Shannon Sampling Theorem

- Band-limited signal – there **is** a fixed highest frequency in the signal.

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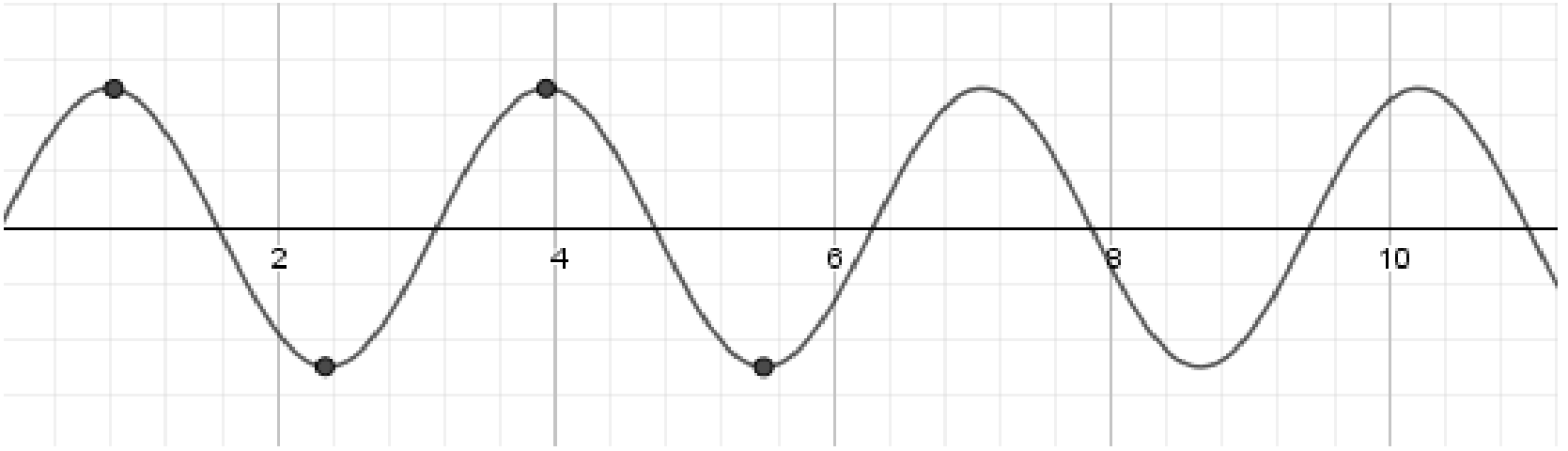

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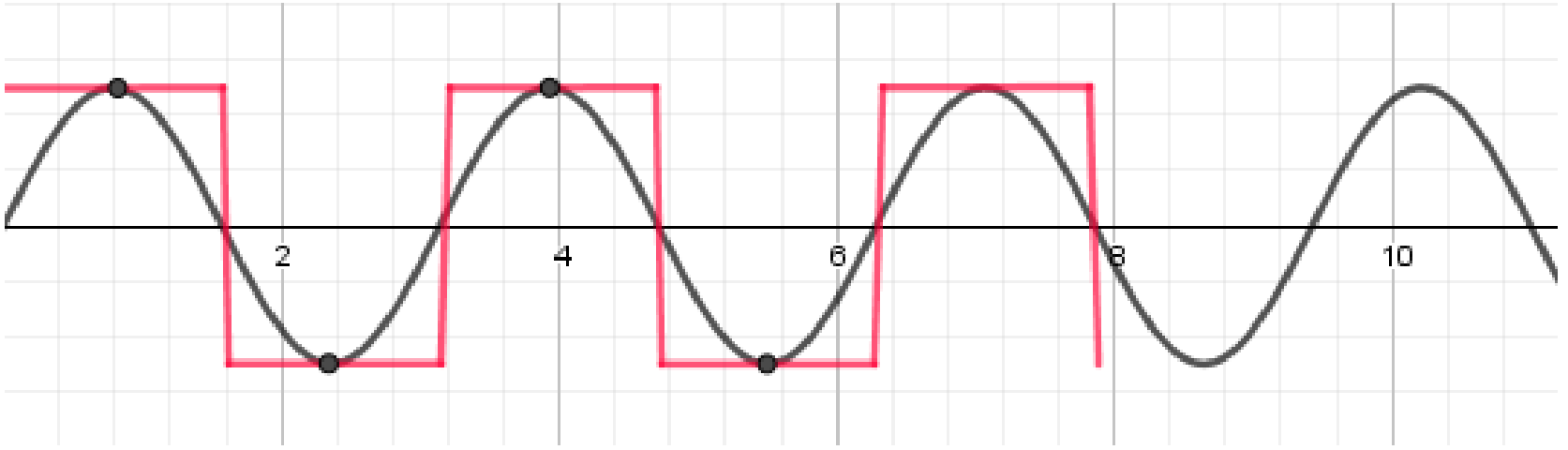

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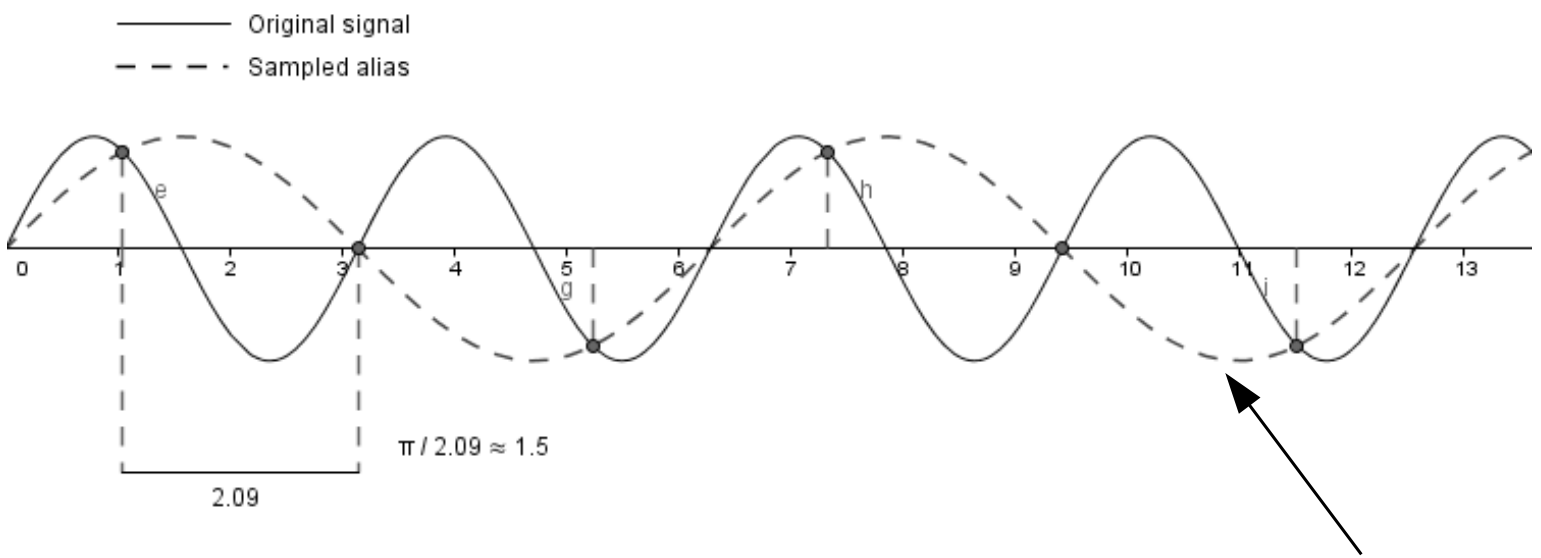
- Sampling less frequently, we produce **an alias**.

Nyquist–Shannon Sampling Theorem



- Sampling less frequently, we produce **an alias**.

Alias – Something unwanted, emerging because of our algorithm, a signal non-existent in the original data, masquerading as the original signal.

Nyquist–Shannon Sampling Theorem

- Band-limited signal – there **is** a fixed highest frequency in the signal.
- The signals in real life are not band-limited.
- Reconstruction is possible only when we know the **shape** of the signal.
- Sampling less frequently, we produce **an alias**.
- Usually assumes samples are taken over time.

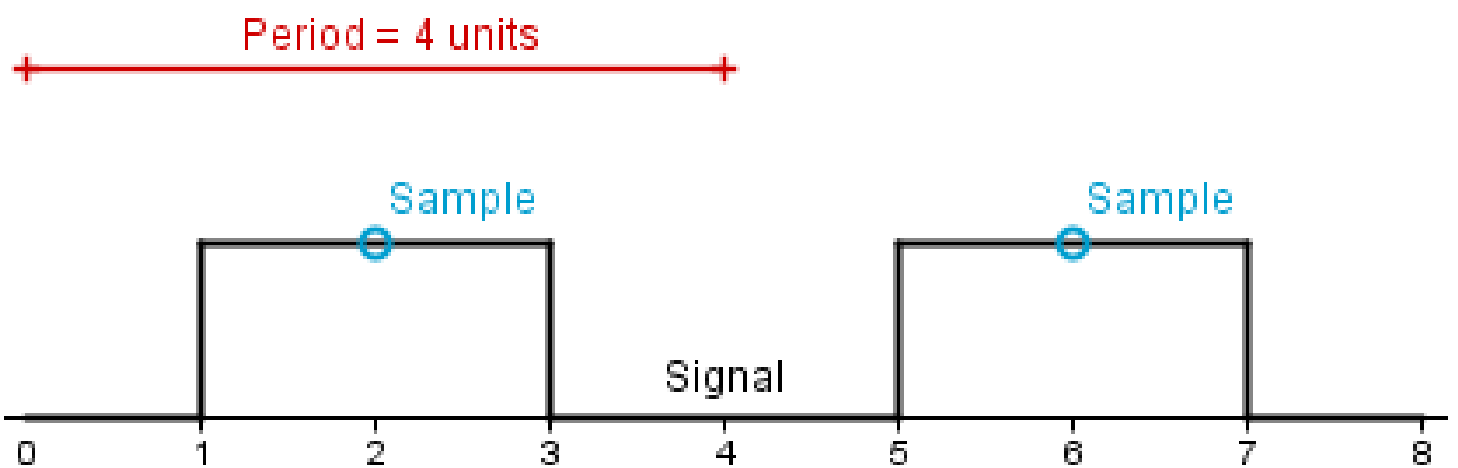
This is how radio works...

Nyquist–Shannon Sampling Theorem

- Band-limited signal – there **is** a fixed highest frequency in the signal.
- The signals in real life are not band-limited.
- Reconstruction is possible only when we know the **shape** of the signal.
- Sampling less frequently, we produce **an alias**.
- Usually assumes samples are taken over time.
- More info:
  - http://www.skillbank.co.uk/SignalConversion/rate.htm
  - http://www.shawnhargreaves.com/blog/texture-aliasing.html

Downscale

- So, what is happening in our example?



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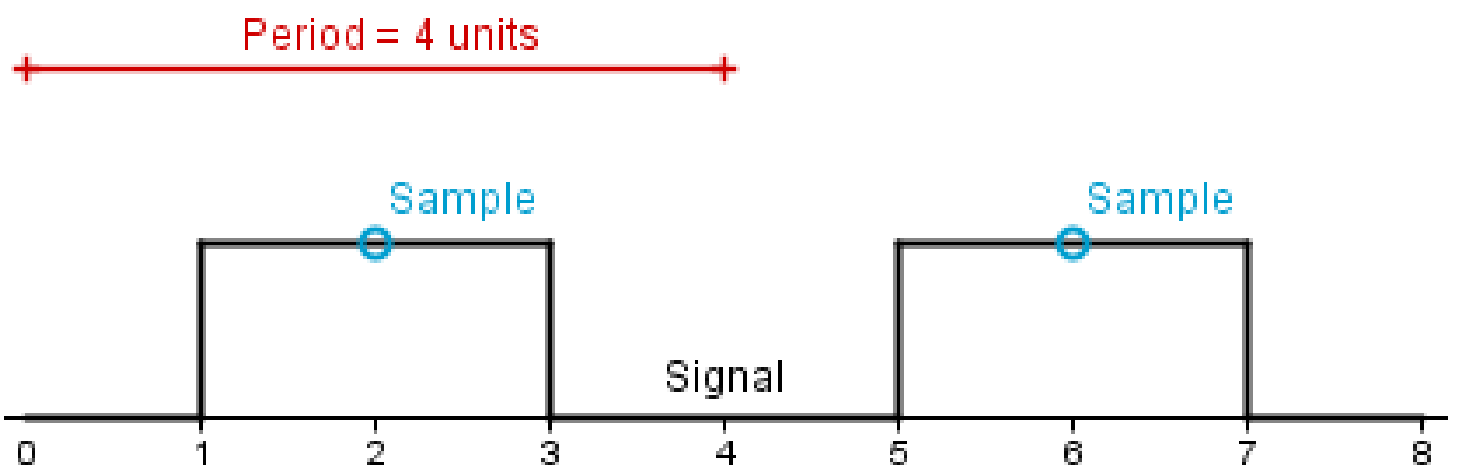
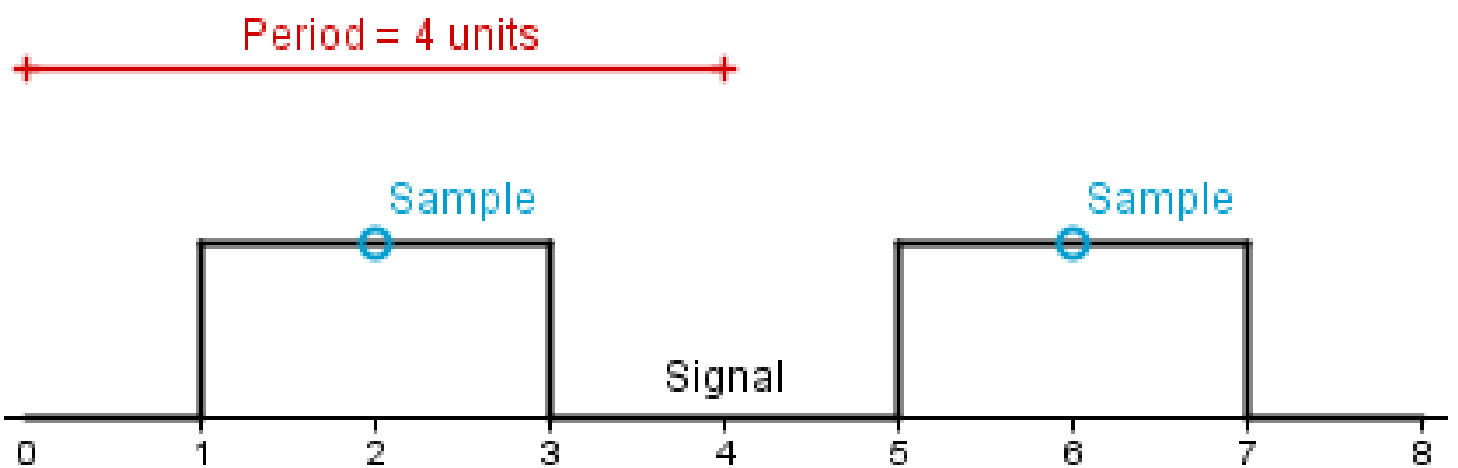


$$period = 4 \Rightarrow frequency = \frac{1}{4}$$

Downscale

- So, what is happening in our example?



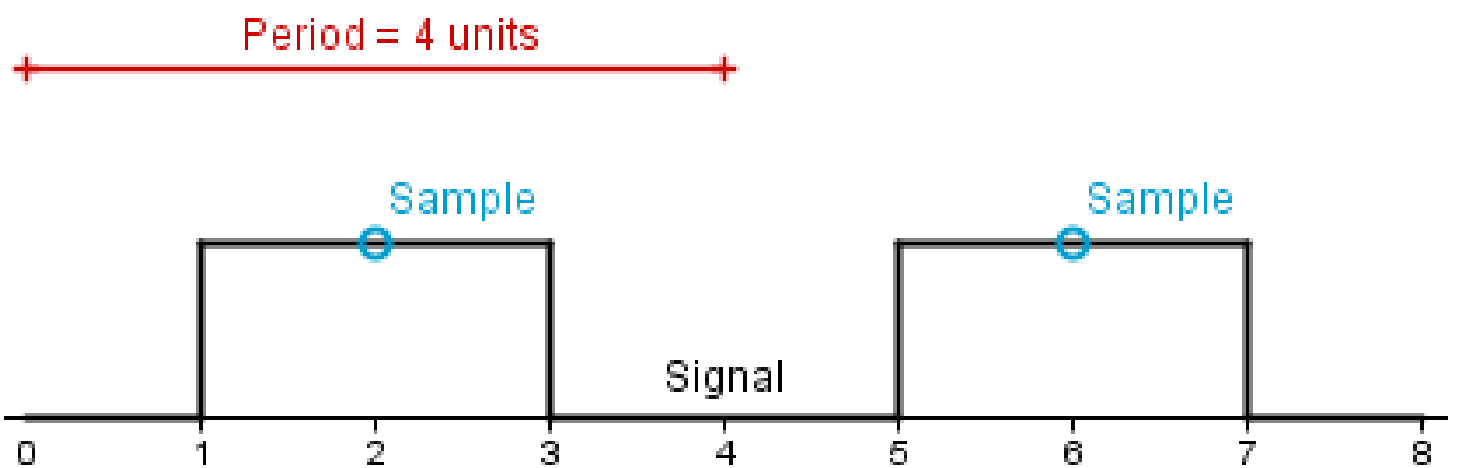
$$period = 4 \Rightarrow frequency = \frac{1}{4}$$

$$frequency_{Nyquist} = \frac{2}{4} = \frac{1}{2}$$

We need more than 1 sample for every 2 units!

Downscale

- So, what is happening in our example?



$$period = 4 \Rightarrow frequency = \frac{1}{4}$$

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Downscale

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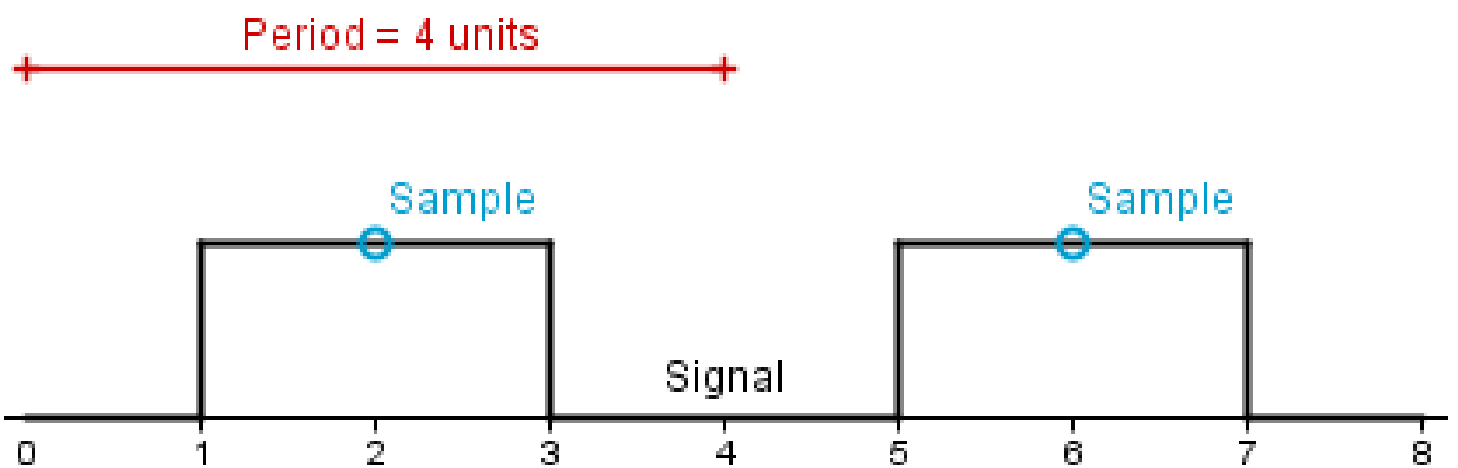


$$period = 4 \Rightarrow frequency = \frac{1}{4}$$

Aliasing

$$frequency_{Nyquist} = \frac{2}{4} = \frac{1}{2}$$

$$\boxed{frequency_{Us} = \frac{1}{4} < \frac{1}{2}}$$

Downscale

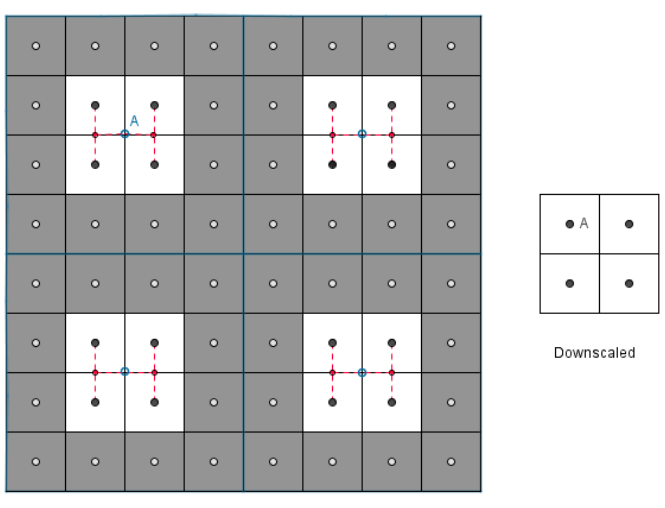
- We need more than 1 sample per 2 units.

Downscale

- We need more than 1 sample per 2 units.
- Is this even possible, if we want to downscale our pattern from 8×8 to 2×2?

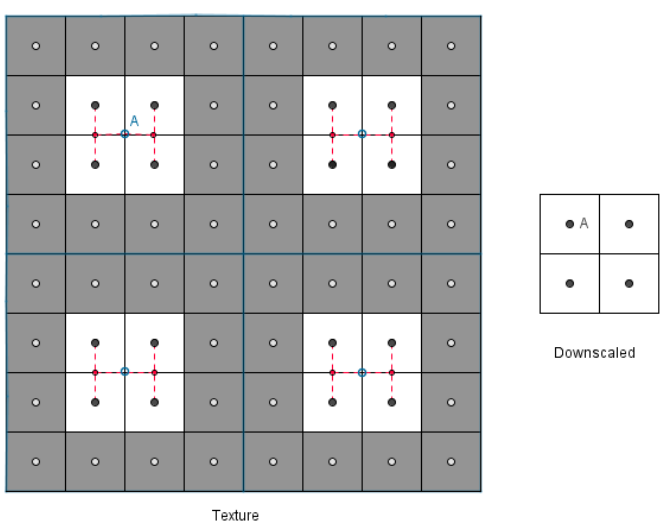
Downscale

- We do not want to create *Moire aliasing*.



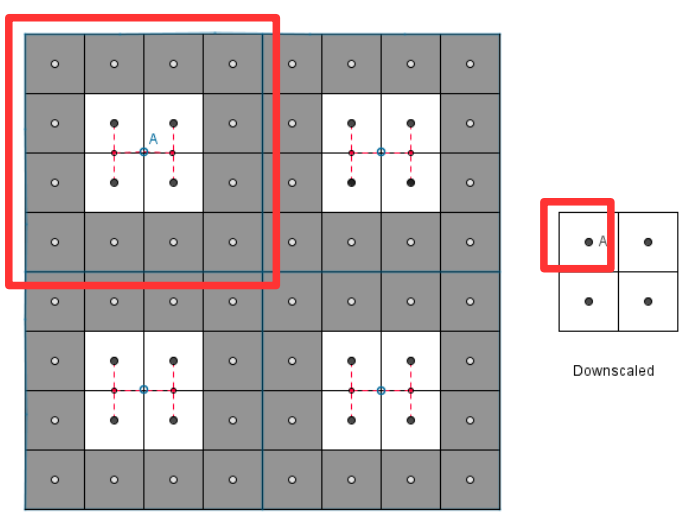
Downscale

- We do not want to create *Moire aliasing*.
- The 2×2 downscale should not be white!



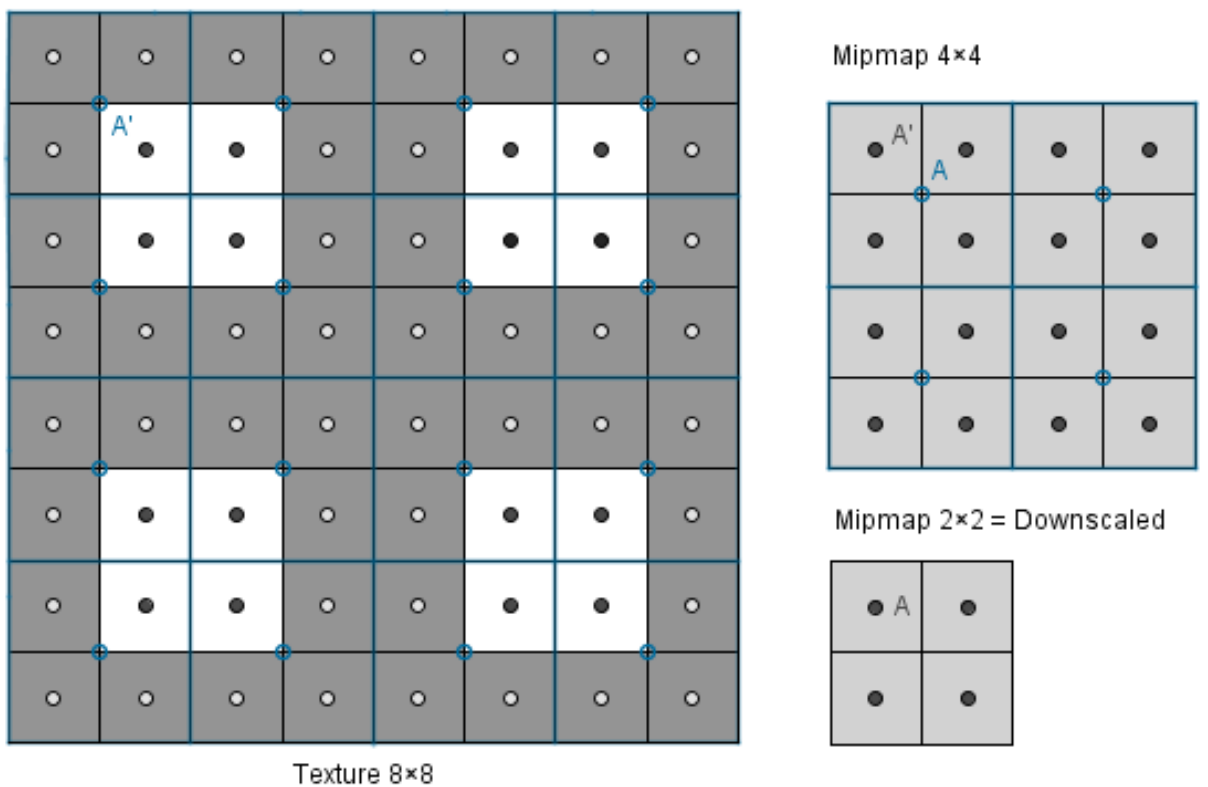
Downscale

- We do not want to create *Moire aliasing*.
- The 2×2 downscale should not be white!
- One unit in the result covers 16 units in the texture. How to represent all those 16 values?



Mipmapping

- In order not to take that many samples each time for downscaling, we take them beforehand.



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- **How not to have that problem?**

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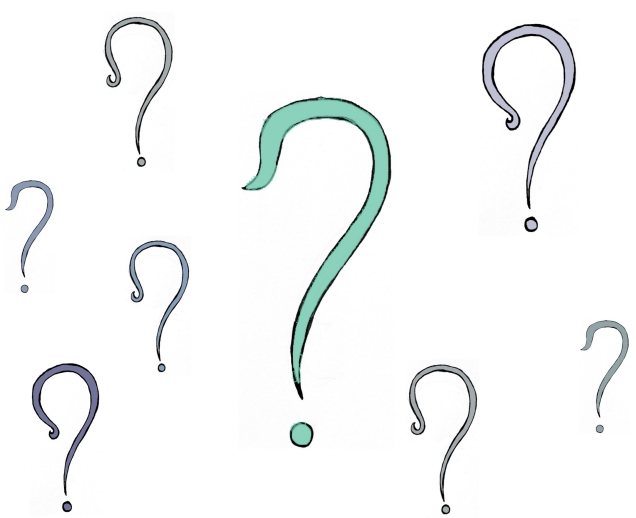
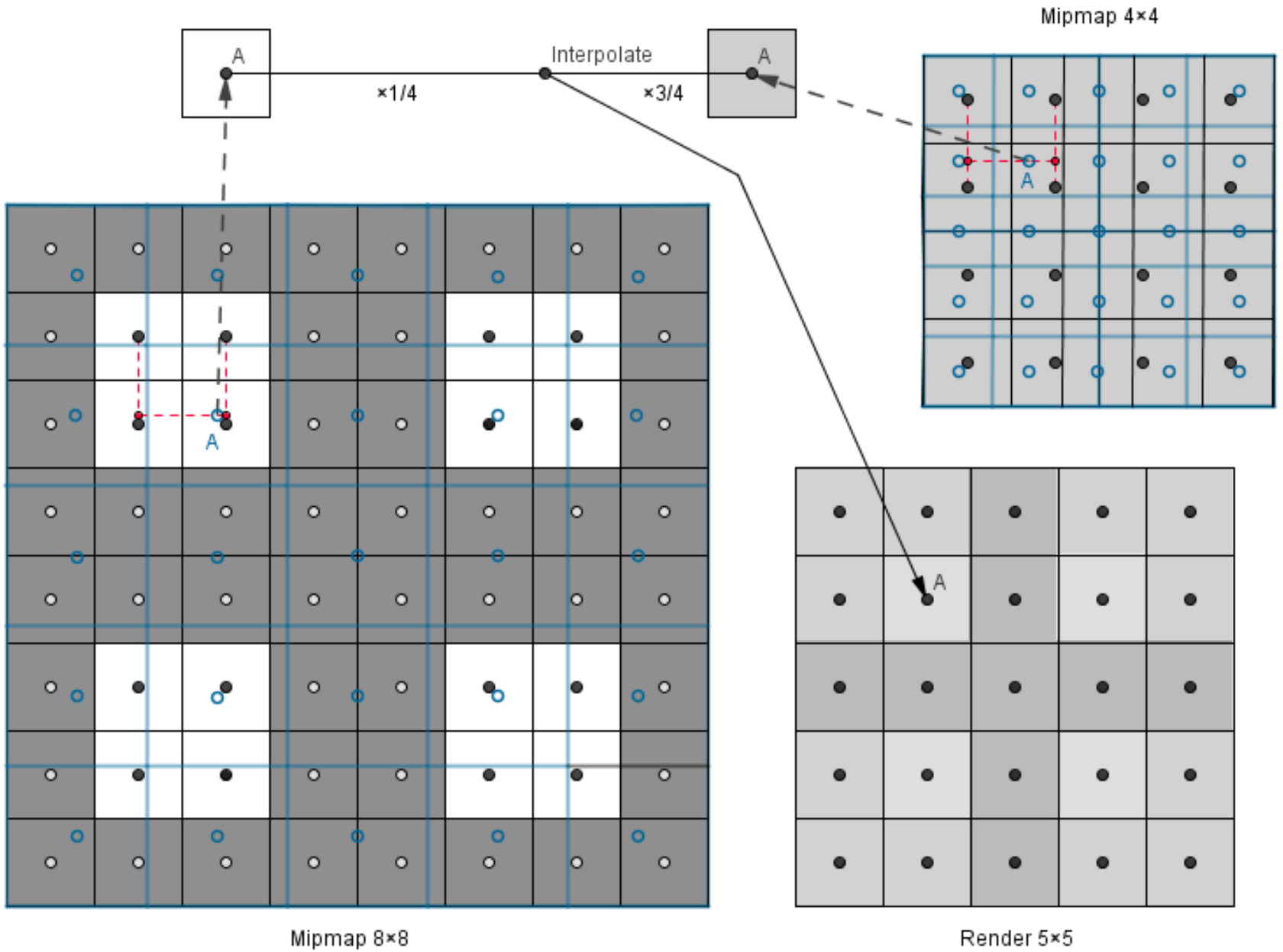
- **Which mipmap should we sample?**




Mipmap 4×4
A
Interpolate
A
×1/4
×3/4
A
A
A
Mipmap 8×8
Render 5×5

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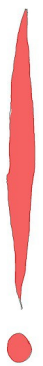
- Downscale (minification filtering)



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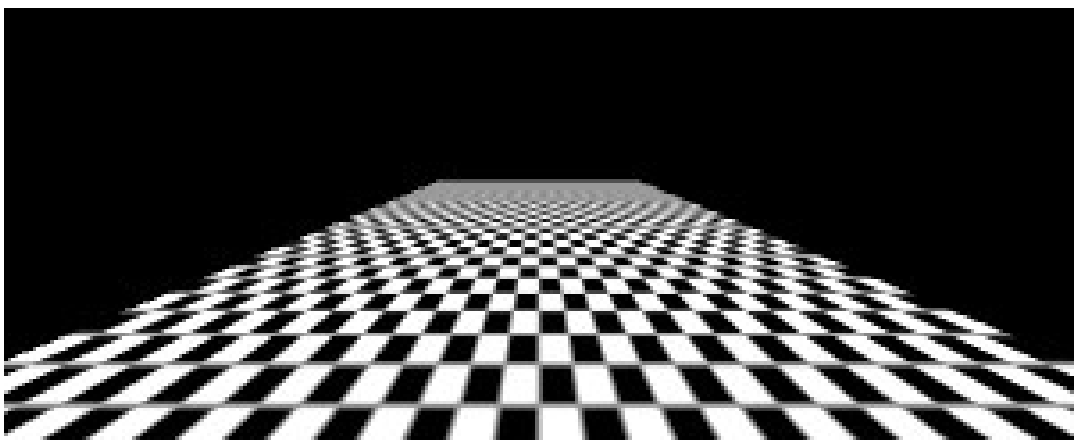
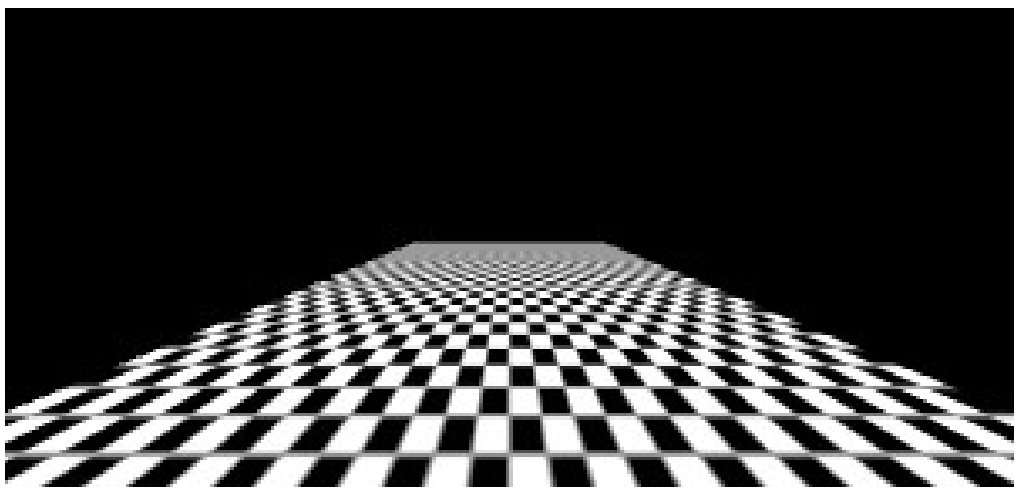
- We assumed that the result we are showing our texture on is shown as a square. This is usually not the case.
- If we rotate our quad around the x-axis for example, then we might get that the texture needs to be shown on a 10×5 area instead of 10×10.



Anisotropic Filtering

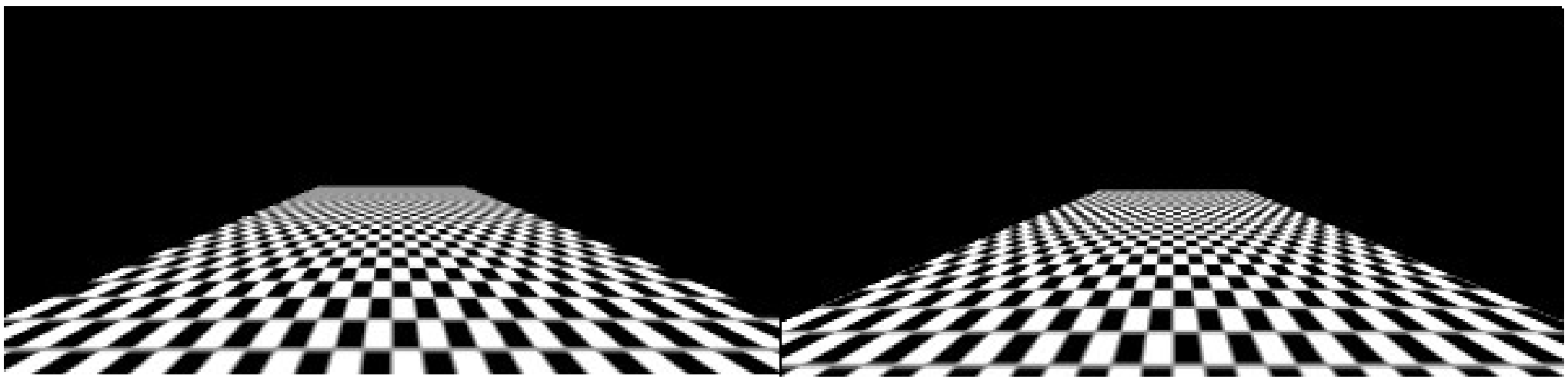
- We have more resolution in width then in height. It is unfair to average both dimensions equally.



No anisotropic filtering

Anisotropic Filtering

- We have more resolution in width then in height. It is unfair to average both dimensions equally.
- Anisotropic filtering will use the higher mipmap and take more samples along the denser direction.

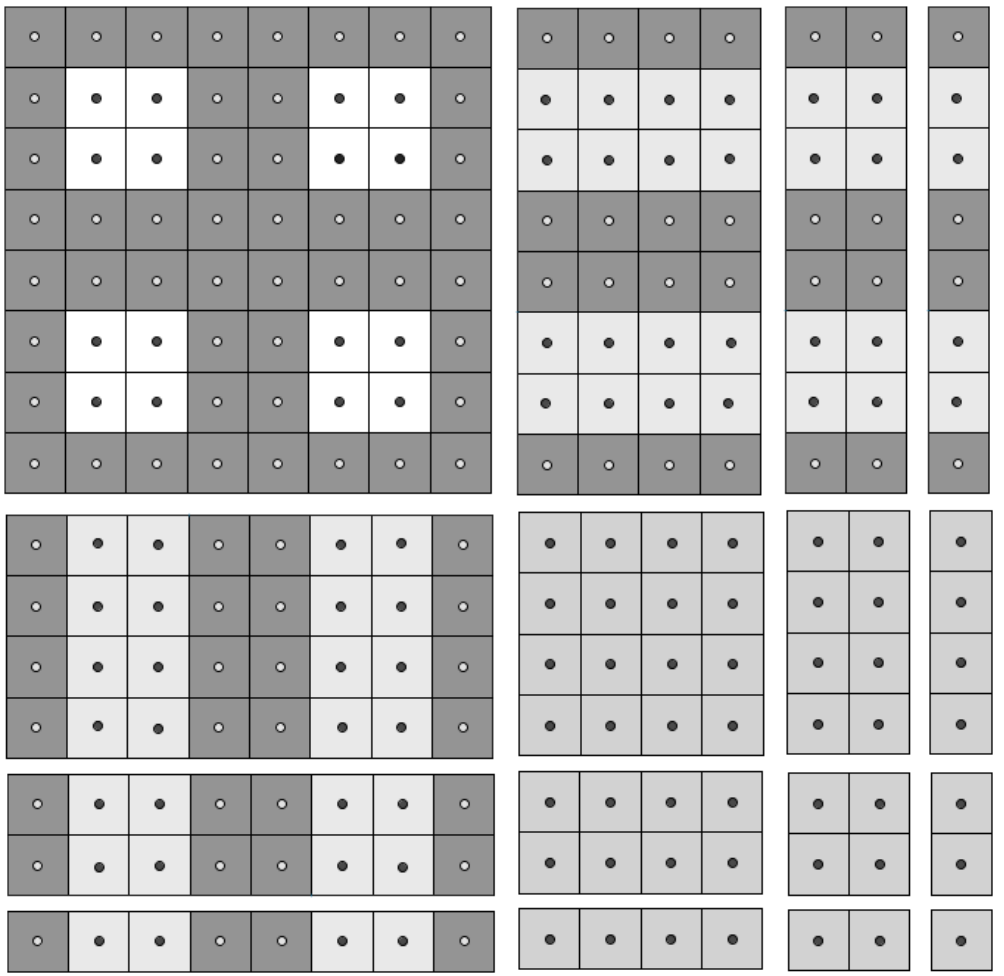


No anisotropic filtering

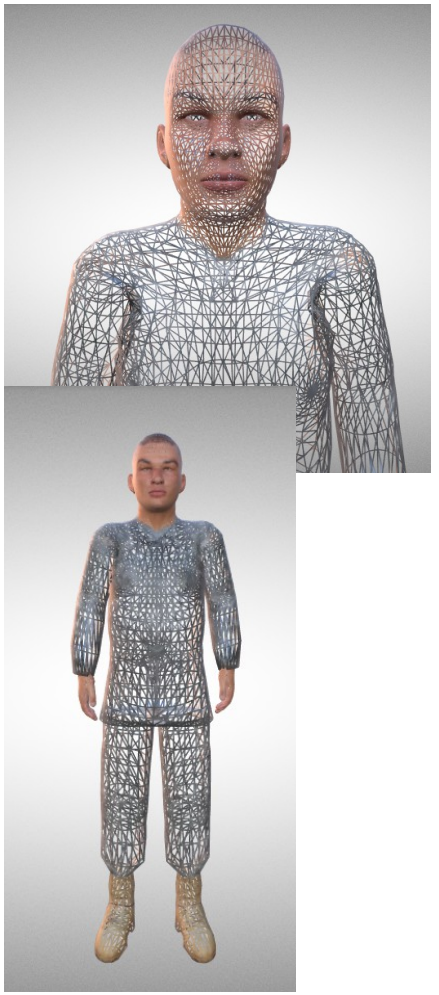
16x anisotropic filtering

Anisotropic Filtering

- Actual implementations are vendor dependant.
- One way would be to just create anisotropic mipmaps.



Textures



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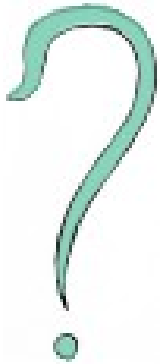

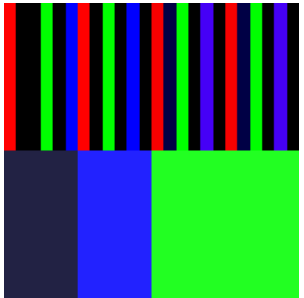

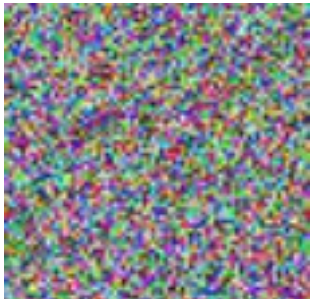

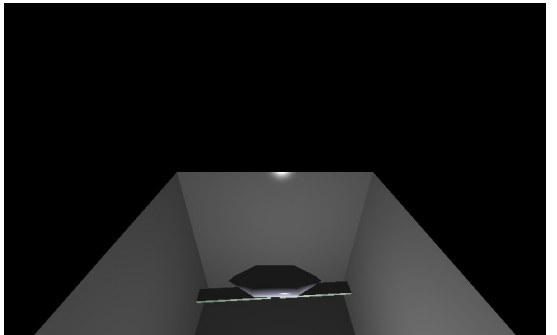

What seemed useful today?

What more would you like to know?

Next time
Blending – *Jaanus Jaggo*