

VGP351 – Week 7

⇒ Agenda:

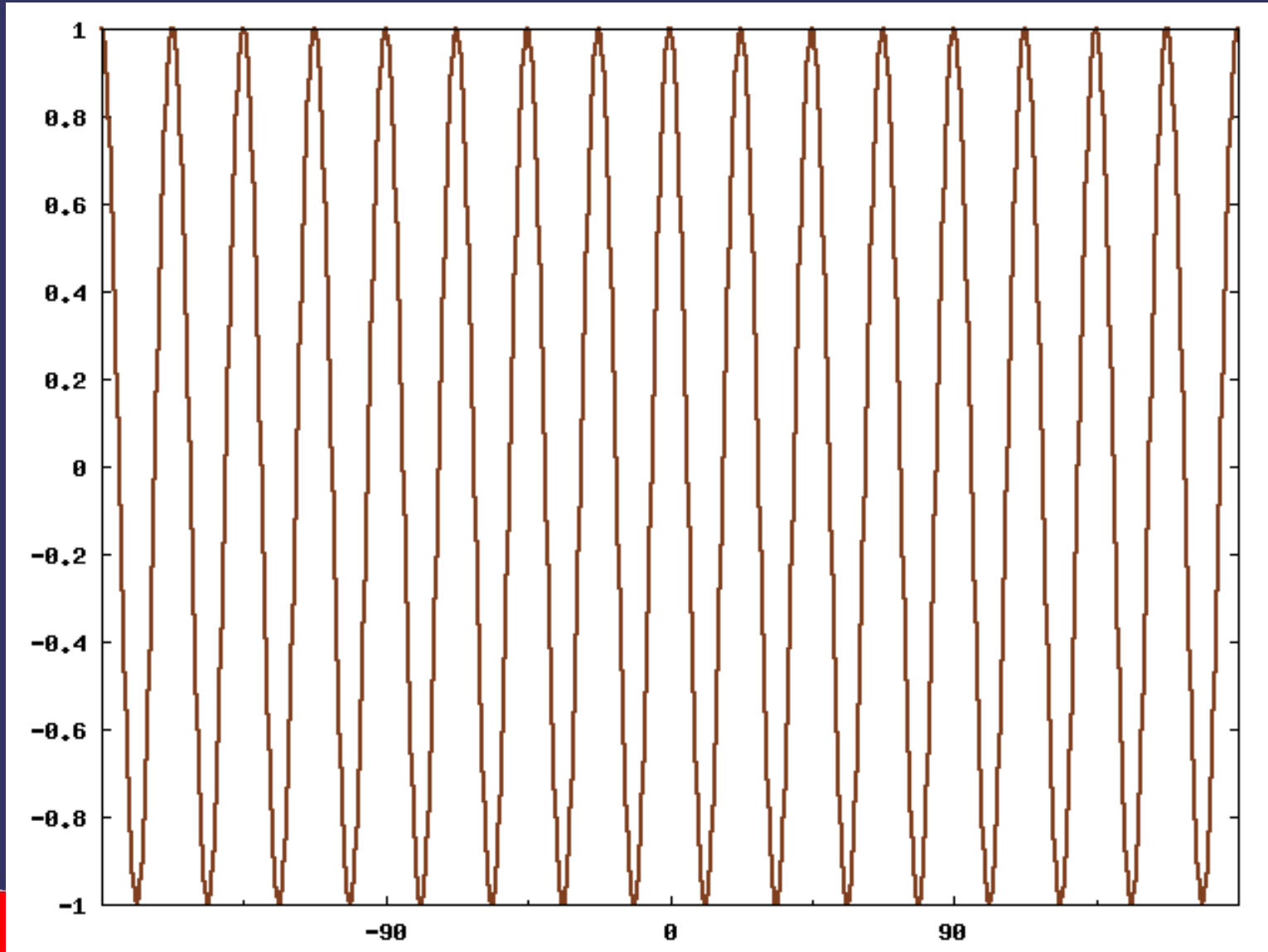
- Quiz #3
- Sampling
 - Theory
 - Application to texture mapping
 - Simple filtering
 - Mipmapping
 - Anisotropic filtering



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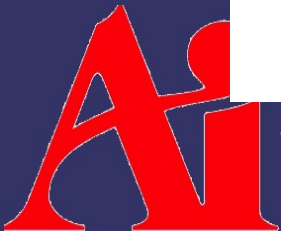
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Sampling

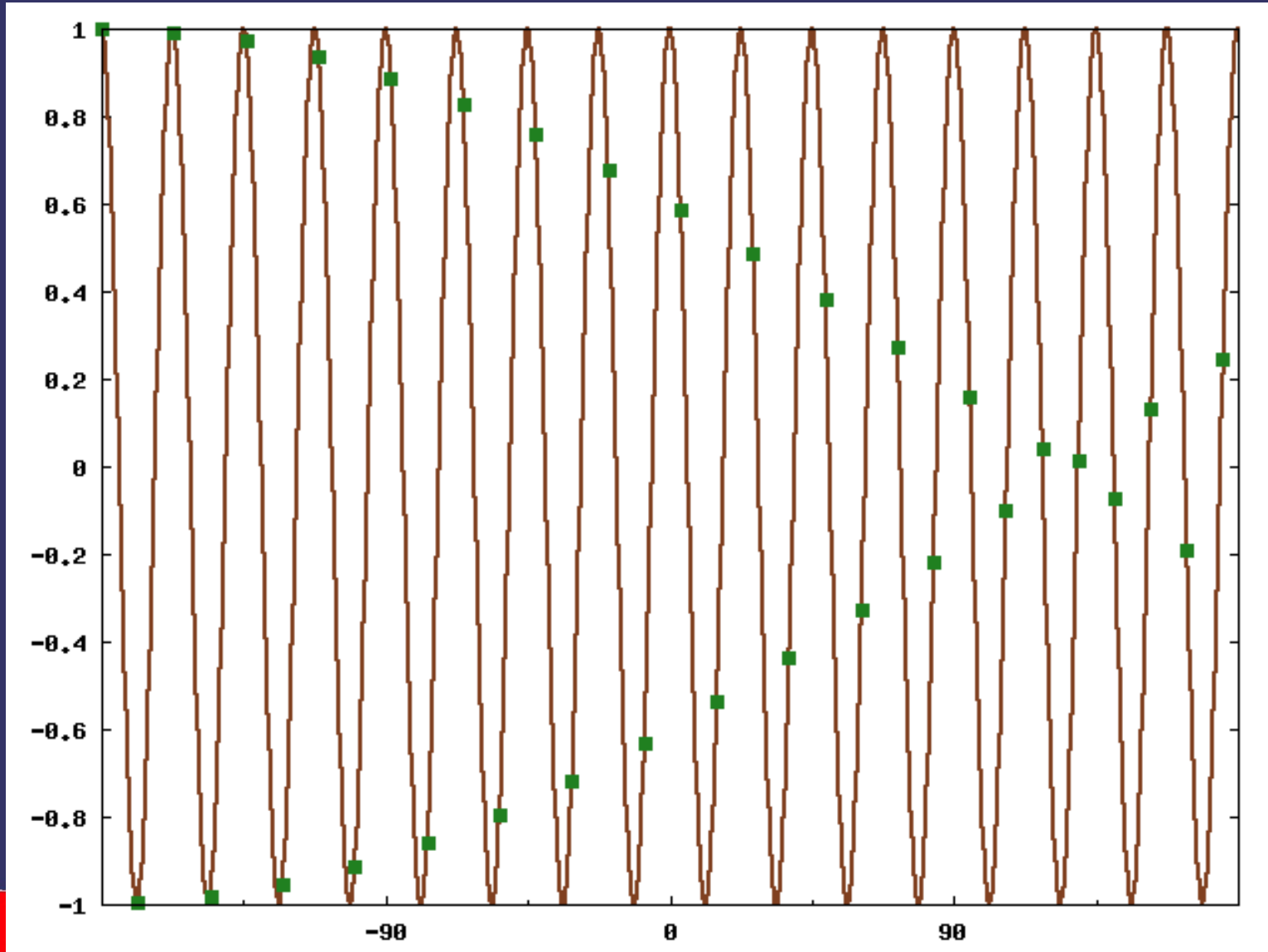


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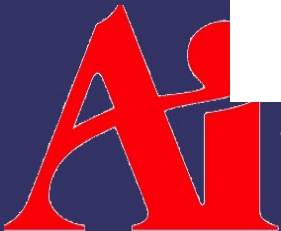


Sampling

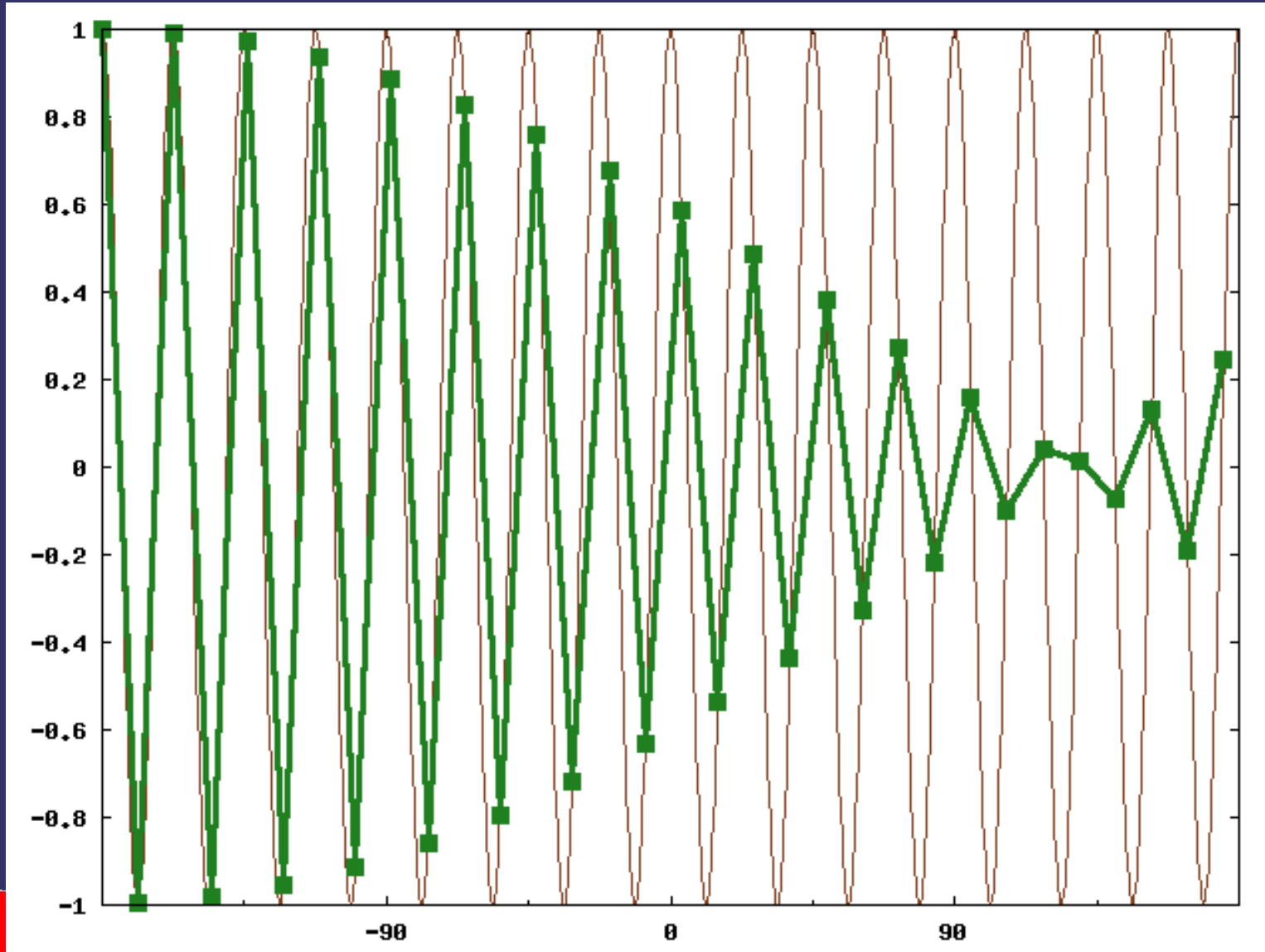


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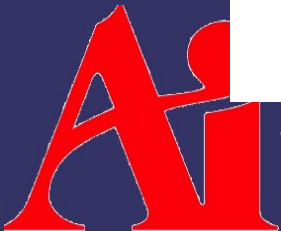


Sampling

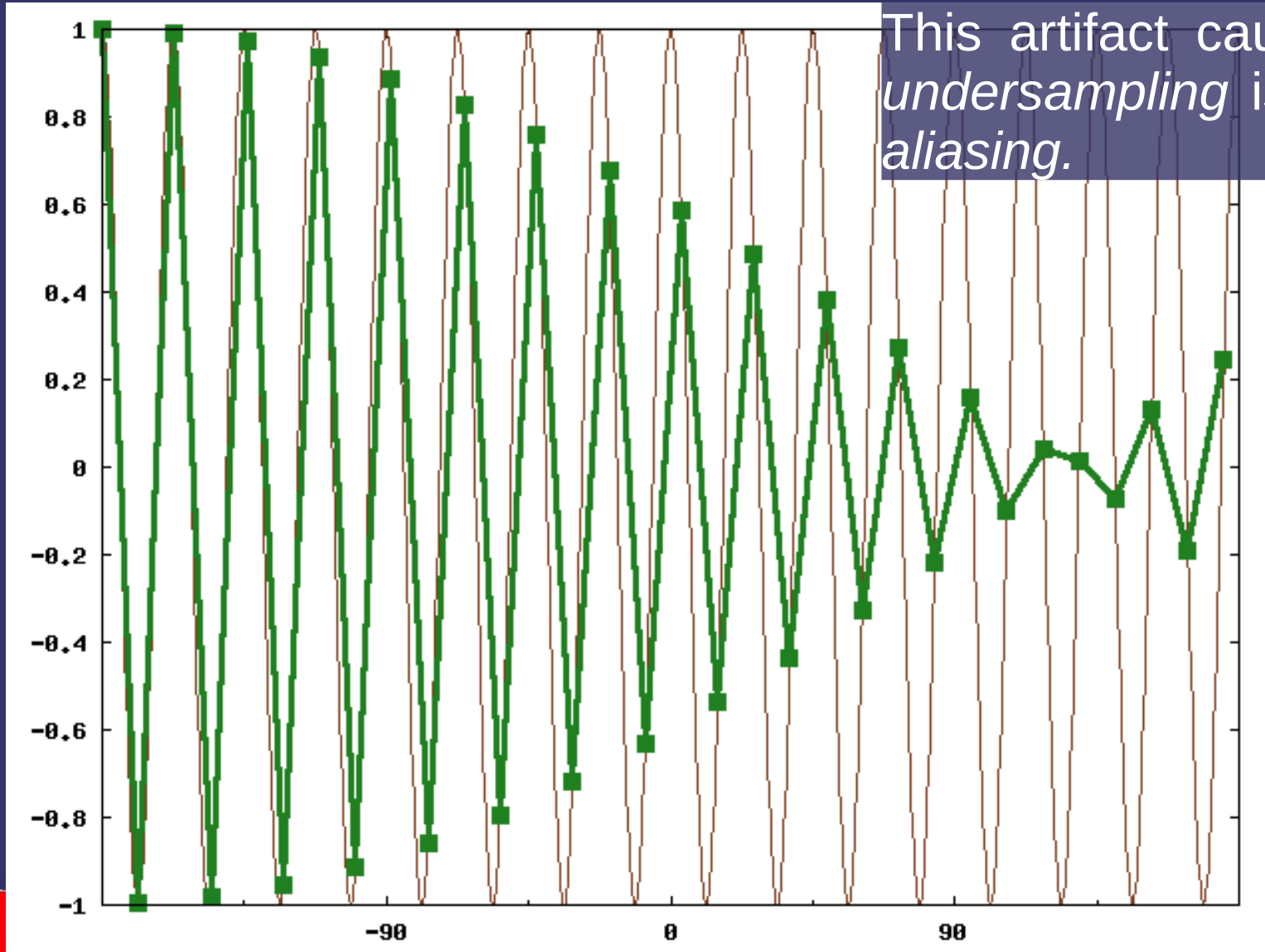


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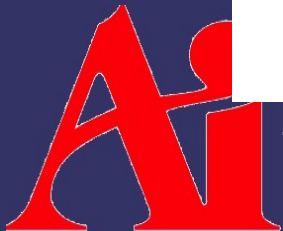
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Sampling



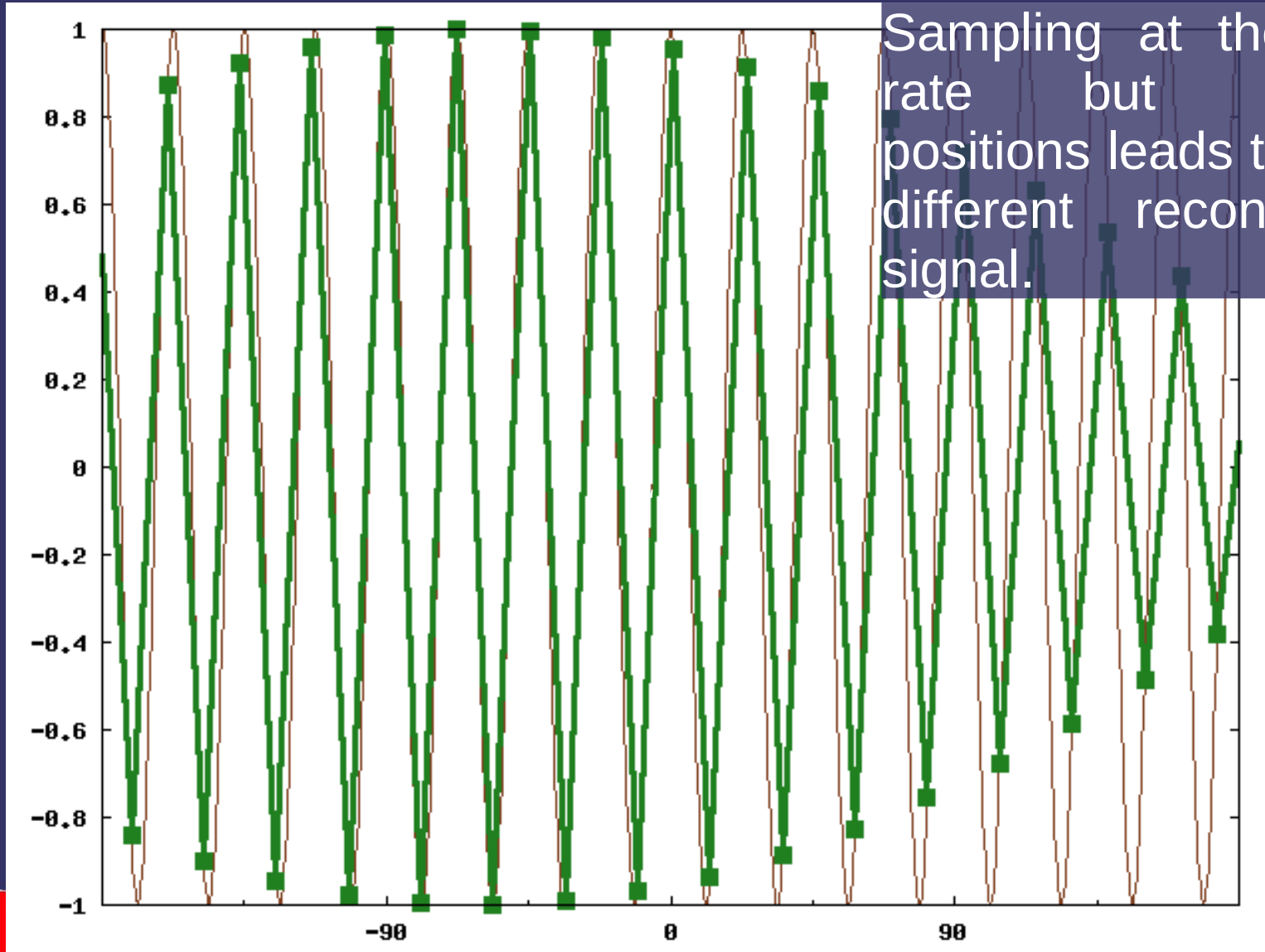
This artifact caused by undersampling is called *aliasing*.



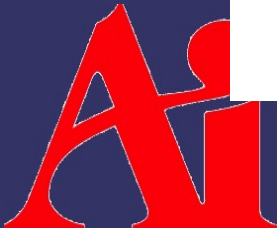
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Sampling



Sampling at the same rate but different positions leads to a very different reconstructed signal.



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Avoiding Aliasing

⇒ How?



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Avoiding Aliasing

⇒ How?

⇒ Sample at a higher rate

- What sample rate is sufficient?
- More samples means more data, and that comes at a cost



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Nyquist-Shannon Sampling Theorem

- If f is the highest frequency element in a signal, the signal must be sampled at a rate of at least $2f$ in order to be accurately reconstructed
 - If the sample rate is f_s then we call $f_s/2$ the *critical frequency* or the *Nyquist frequency*
 - Any elements in the signal with frequency higher than the critical frequency will alias



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Avoiding Aliasing

- If having frequencies above the critical frequency causes aliasing, how can we eliminate the aliasing?



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Avoiding Aliasing

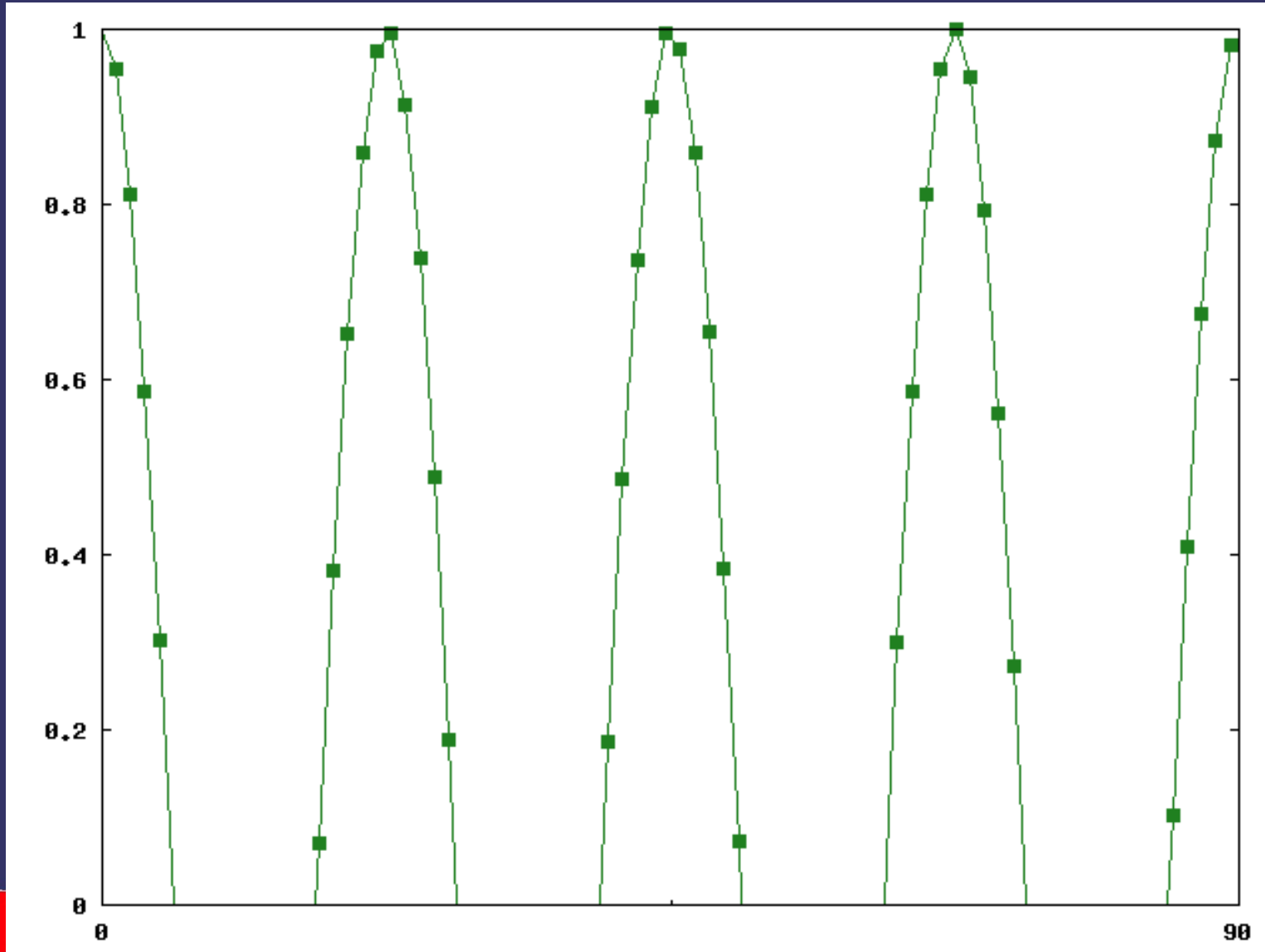
- If having frequencies above the critical frequency causes aliasing, how can we eliminate the aliasing?
 - Remove elements above the critical frequency!
 - This is done using a low-pass filter



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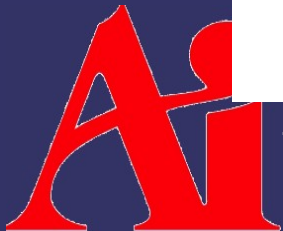
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Resampling

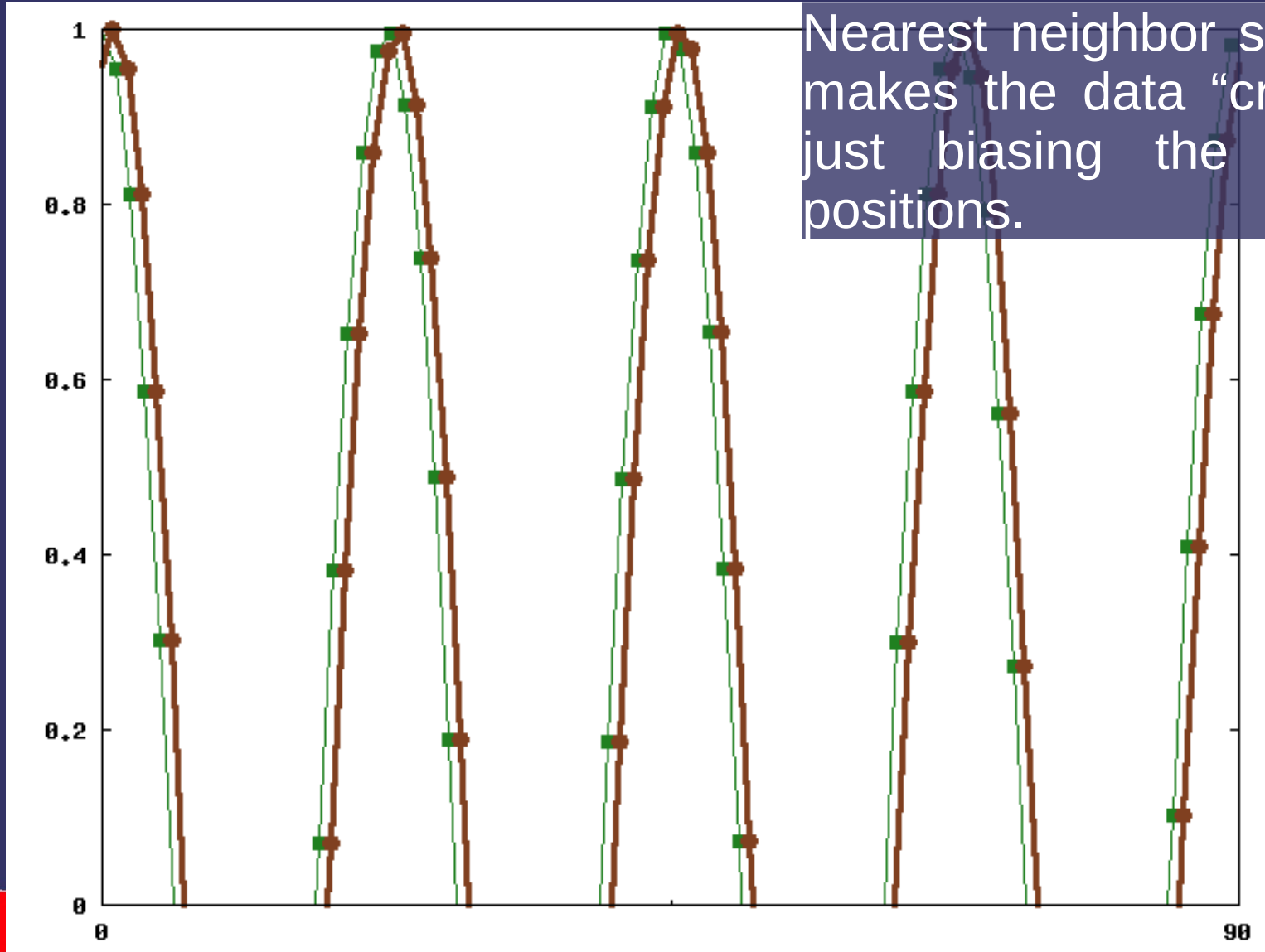


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Resampling



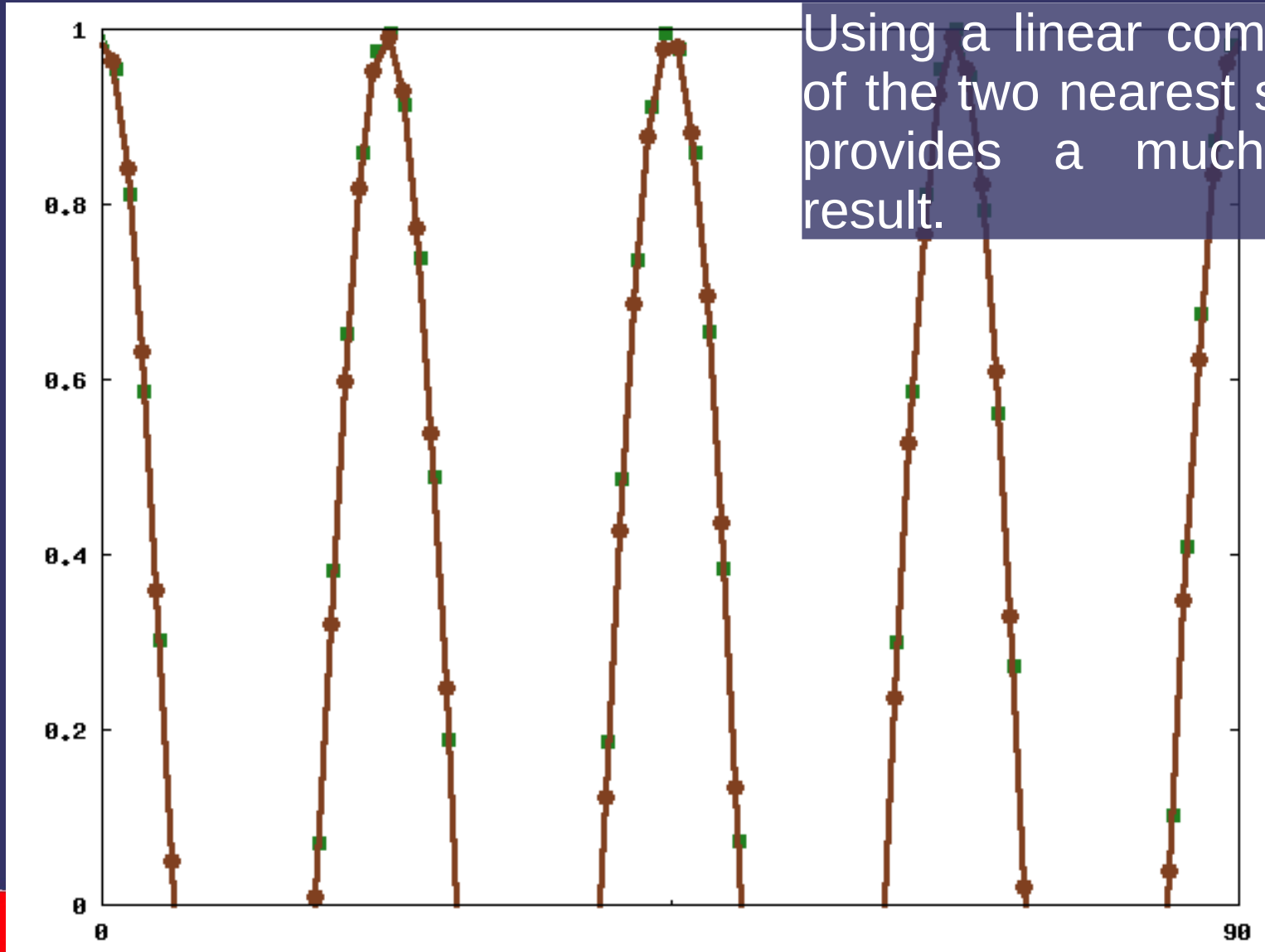
Nearest neighbor sampling makes the data "crawl" by just biasing the sample positions.



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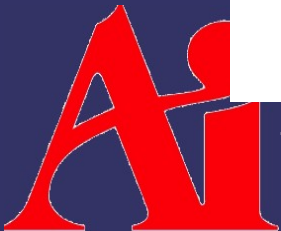
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Resampling

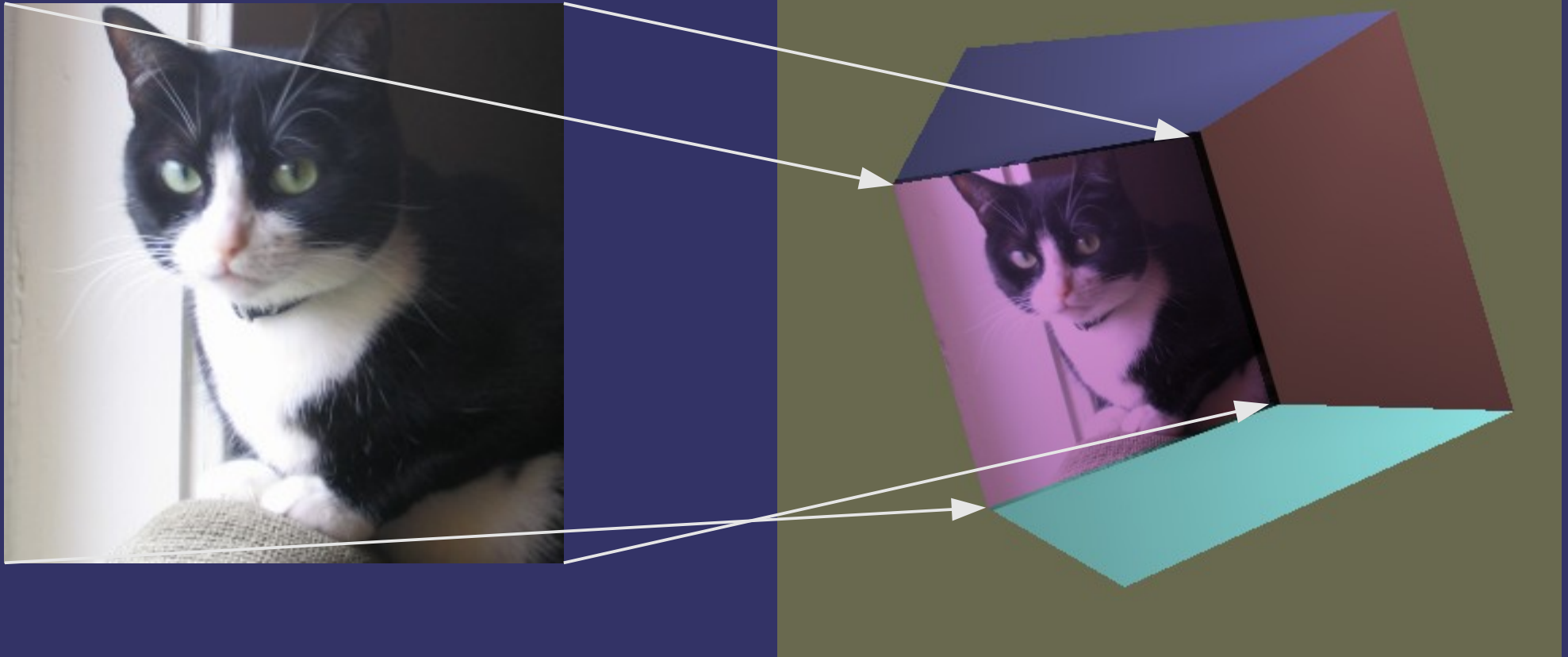


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Texture Mapping



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Magnification

- When a single texel is mapped to multiple fragments, the texture is magnified
- What happens when the location sampled from the texture lies between texels?



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Magnification

- When a single texel is mapped to multiple fragments, the texture is magnified
- What happens when the location sampled from the texture lies between texels?
 - Nearest neighbor sample
 - Linear sample
 - Cubic convolution
 - Rarely implemented in hardware, but you could write a shader to do it!



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Minification

- ⇒ When a single fragment covers multiple texels, the texture is minimized
 - This is where texture aliasing can occur
- ⇒ What to do?



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Minification

- When a single fragment covers multiple texels, the texture is minimized
 - This is where texture aliasing can occur
- What to do?
 - In a perfect world, sample and filter all of the covered texels
 - Since an entire 1024×1024 texture could be minimized to a single fragment, this is impractical



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Minification

- ⇒ Nearest neighbor sampling
 - Most likely to have aliasing



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Minification

- Linear filtering of nearest neighbors
 - In 2D this is called *bilinear filtering*
 - Better results because we're effectively doubling our sample rate
 - We also increase the memory bandwidth requirements by 2^n
 - At some point the texture will be minimized enough that the sample rate will still be too low to prevent aliasing



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Mipmapping

- Create multiple pre-filtered, down-sampled versions of the “base” texture
 - Down-sampled textures are called *mipmaps*
 - The collection of mipmaps for a particular base texture is called its *mipmap stack*
 - From Latin “multum in pavro” for “many things in one place”
- As the texel area covered by a fragment increases, use a smaller mipmap
 - In smaller mipmaps, each texel represents more samples from the base texture



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Example Mipmap Stack



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Mipmapping

⇒ What's the trade-off?



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Mipmapping

- ⇒ What's the trade-off?
 - Memory *size* versus memory *bandwidth*
 - What is the increase in size for a 2D texture?



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Mipmapping

⇒ What's the trade-off?

- Memory *size* versus memory *bandwidth*
- What is the increase in size for a 2D texture?

$$\frac{1}{2^0} + \frac{1}{2^1} + \frac{1}{2^2} + \dots + \frac{1}{2^n} \approx \frac{1}{2}$$



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Mipmapping



Sampled area

- LOD will be used where the outlined area is a single texel
 - No aliasing, but lots of unneeded data is filtered in
 - Results in images that are too blurry or over-filtered



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Mipmapping



Sampled area

- Can *partially* fix the oversampling by taking multiple samples from the next higher LOD
 - This is a bi-linear filter of the mipmap
 - Can extend further by filtering between LODs

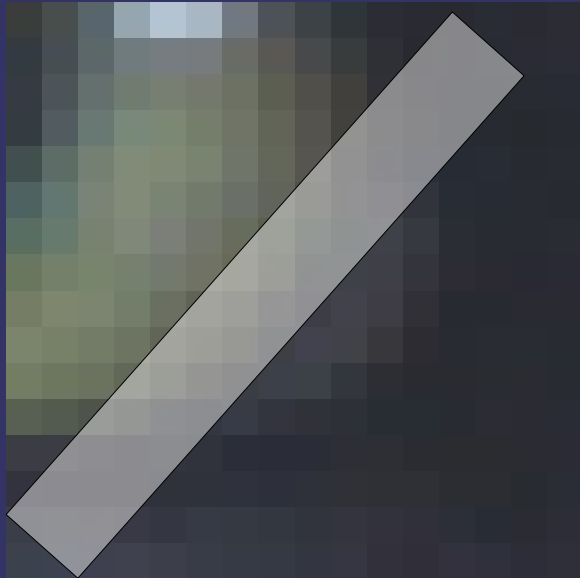


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Mipmapping

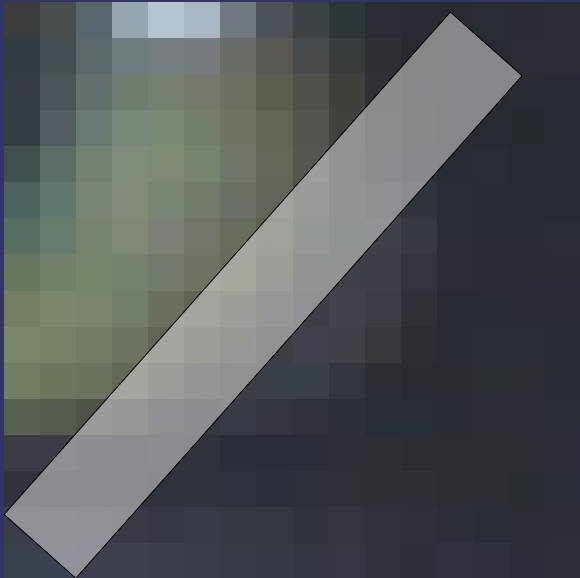
- For this case, mipmapping filtering will either oversample or undersample



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Improved Filtering



- All of these filter modes assume that the sample region is *isotropic*
 - Isotropy is the property of being uniform in all directions
 - We clearly can have ideal sample regions that are *anisotropic*

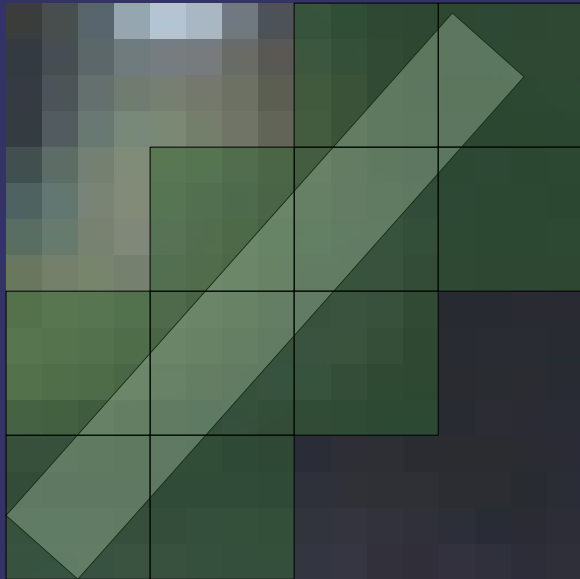


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Improved Filtering

- An anisotropic filter might sample these 10 positions in the appropriate mipmap



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Improved Filtering

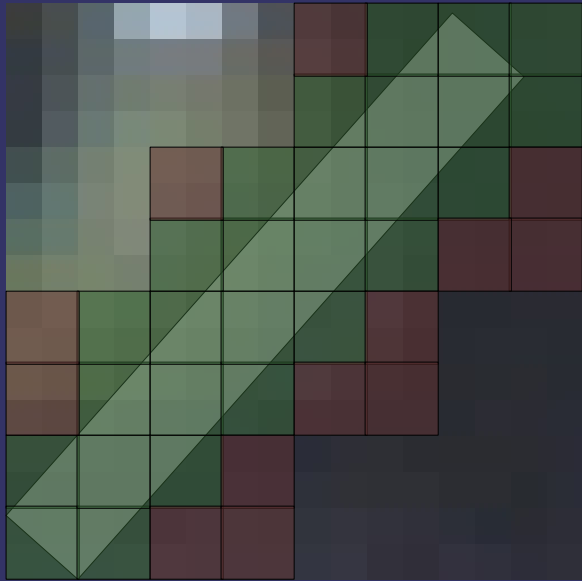
- An anisotropic filter might sample these 27 positions in the appropriate mipmap



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Improved Filtering



- An anisotropic filter might sample these 27 positions in the appropriate mipmap
 - The red boxes show the regions where over-filtering would occur with only 10 samples



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Setting Filter Modes

- OpenGL has a name for each each of these filter modes:
 - `GL_NEAREST` – Point sampling
 - `GL_LINEAR` – Bi-linear in 2D
 - `GL_NEAREST_MIPMAP_NEAREST` – Point-sampling from mipmap
 - `GL_LINEAR_MIPMAP_NEAREST` – Linear sampling from one mipmap
 - `GL_NEAREST_MIPMAP_LINEAR` – Linear blend of two point-sampled mipmaps
 - `GL_LINEAR_MIPMAP_LINEAR` – Linear blend of two bi-linear sampled mipmaps. Also known as *tri-linear filtering* in 2D



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Setting Filter Modes

⇒ Set texture filter modes with:

```
void glTexParameteri(GLenum target,  
                     GLenum pname, GLint param);
```

- `pname` is either `GL_TEXTURE_MAG_FILTER` or `GL_TEXTURE_MIN_FILTER`
- `param` is one of the modes from the previous page



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Setting Filter Modes

- Texture filter anisotropy is controlled by setting `GL_TEXTURE_MAX_ANISOTROPY_EXT`
 - Maximum amount of anisotropy is queried by `GL_MAX_TEXTURE_MAX_ANISOTROPY_EXT` to `glGetIntegerv`
 - Requires that the extension `GL_EXT_texture_filter_anisotropic` be available



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Setting Mipmaps

- Mipmap is selected with the level parameter to the `glTexImage` functions:

```
void glTexImage1D(GLenum target, GLint level,  
                 GLint internalFormat, GLsizei width,  
                 GLint border, GLenum format, GLenum type,  
                 const GLvoid *pixels);
```

- Zero is the “base” level, 1 is $\frac{1}{2}$ size, 2 is $\frac{1}{4}$ size, etc.
- Textures that use mipmap filtering must be *mipmap complete*
 - All mipmaps down to 1×1 that might be used must be specified



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Mipmap Generation

- ⇒ OpenGL can automatically generate the full set of mipmaps each time the base level is modified
 - Set `GL_GENERATE_MIPMAP` to `GL_TRUE`
 - This causes the mipmap stack to be regenerated if even one texel is modified in the base level!



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Mipmap Generation

➤ Later versions of GL add a different mechanism

```
void GenerateMipmapEXT(GLenum target);
```

- Generates mipmaps from base level to max level
- Function only available if `GL_EXT_framebuffer_object` is supported
 - Drop “EXT” from the name if OpenGL 3.0 or `GL_ARB_framebuffer_object` is supported



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LoD Clamping

- Used mipmaps can be restricted to a subset of the possible range
 - `GL_TEXTURE_BASE_LEVEL` specifies the base level. The default is zero.
 - `GL_TEXTURE_MAX_LEVEL` specifies the highest level (smallest mipmap / lowest LoD) that will be used.
 - These settings also affect automatic mipmap generation



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Next week...

- ⇒ Texture mapping part 3
 - Environment mapping
 - Projective texturing
 - Texture atlases
 - Texture compression



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