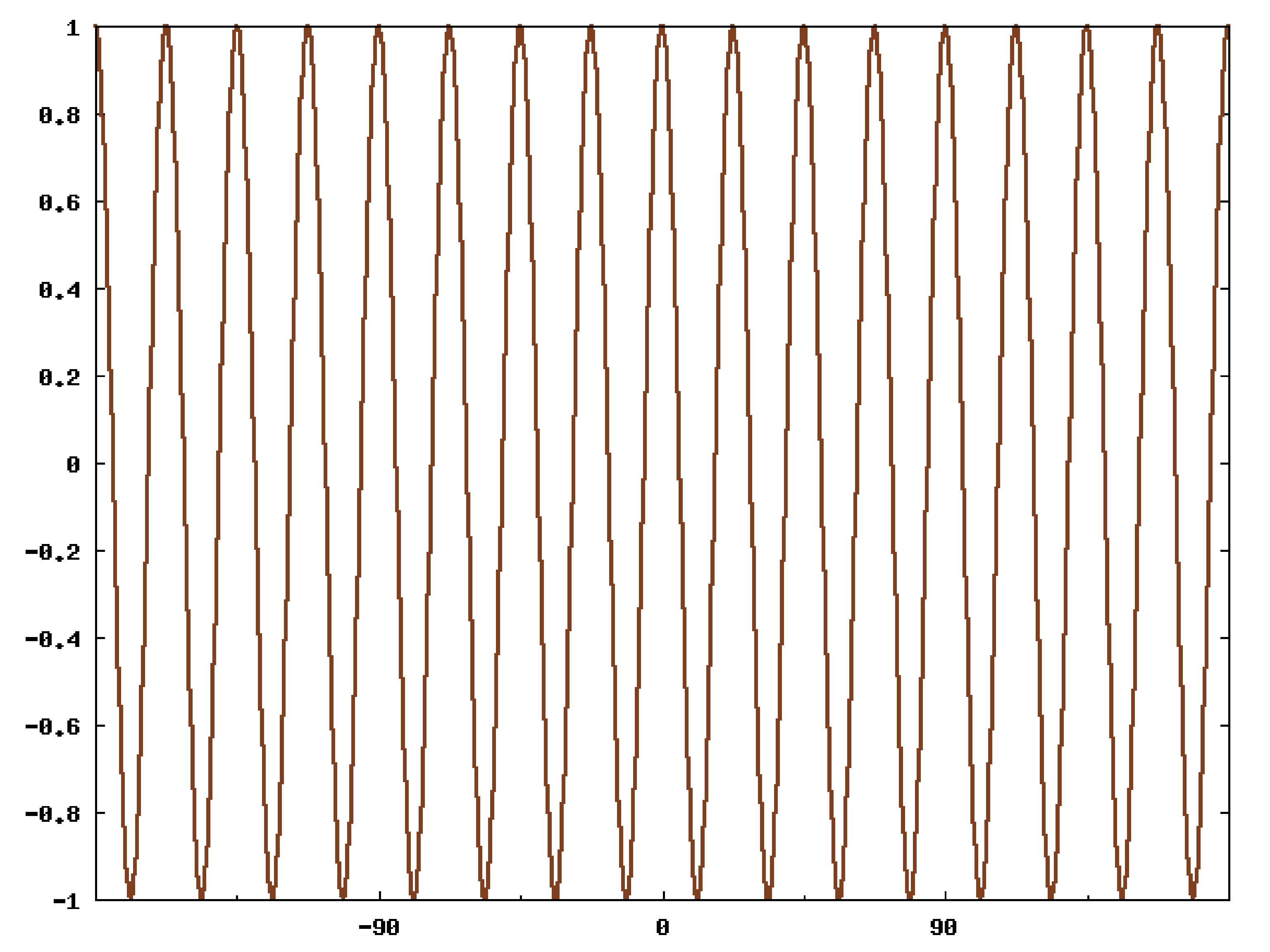
VGP351 – Week 8.1

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

Sampling



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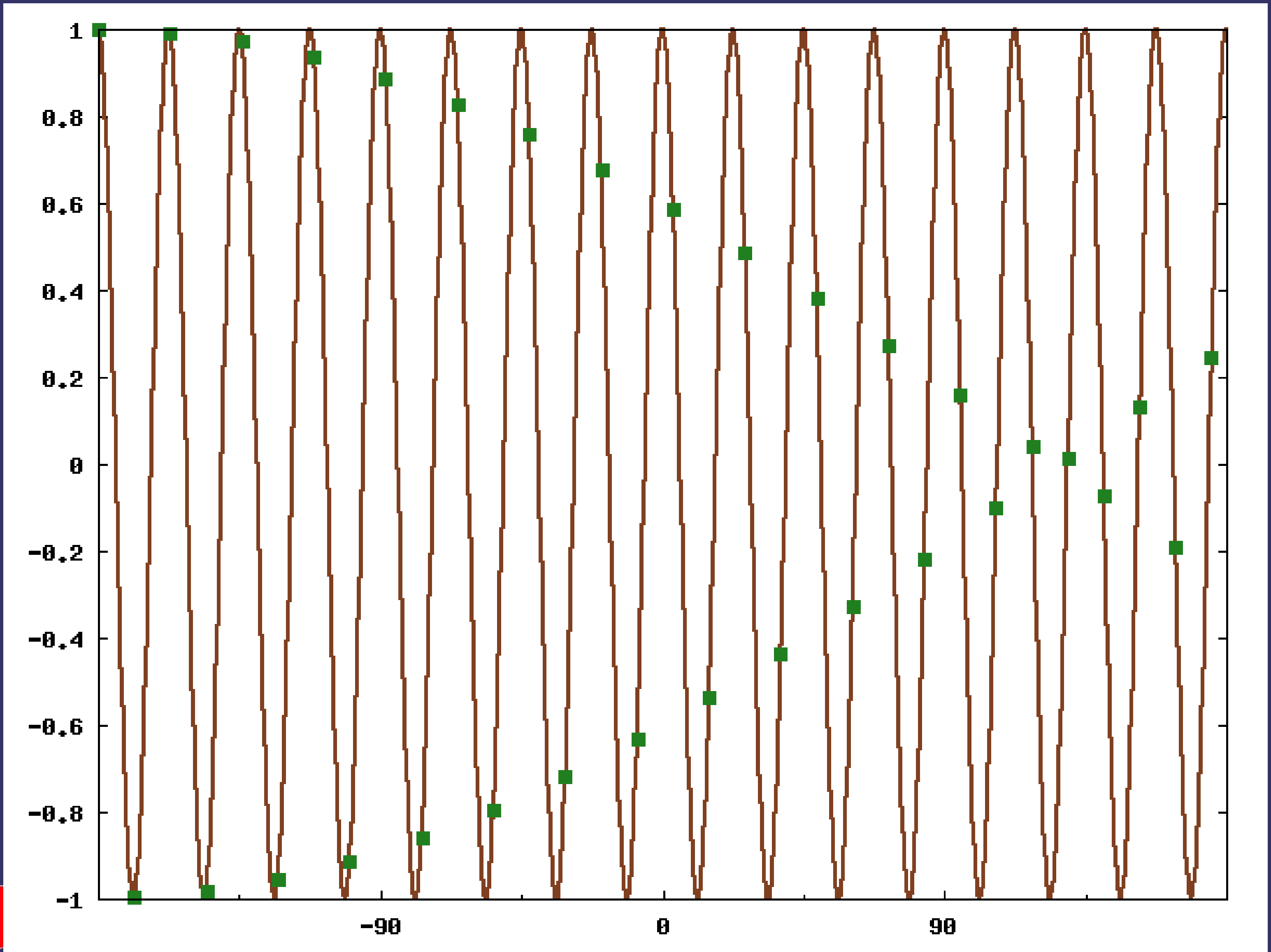
Sampling



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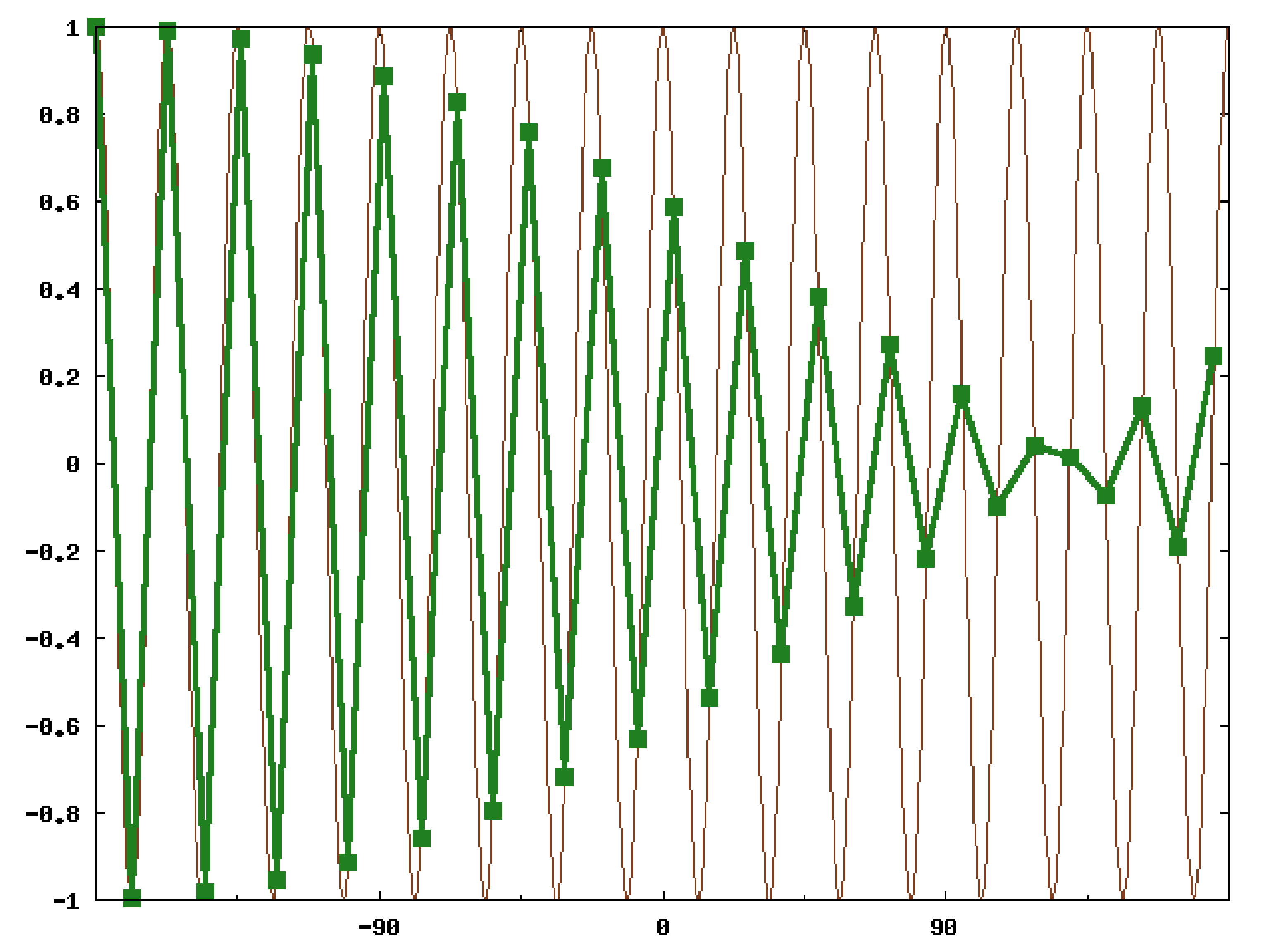
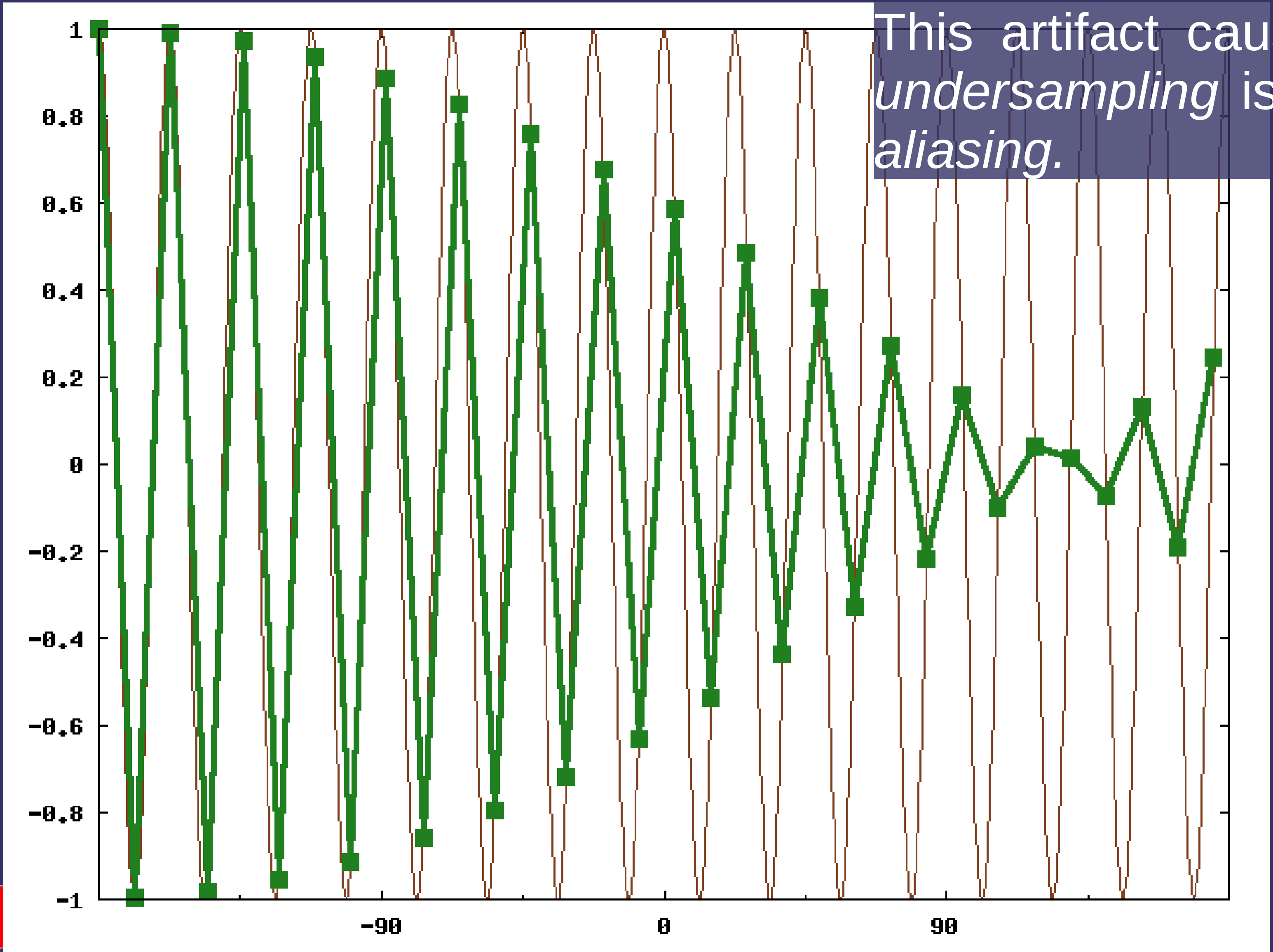
Sampling



Sampling



This artifact caused by *undersampling* is called *aliasing.*

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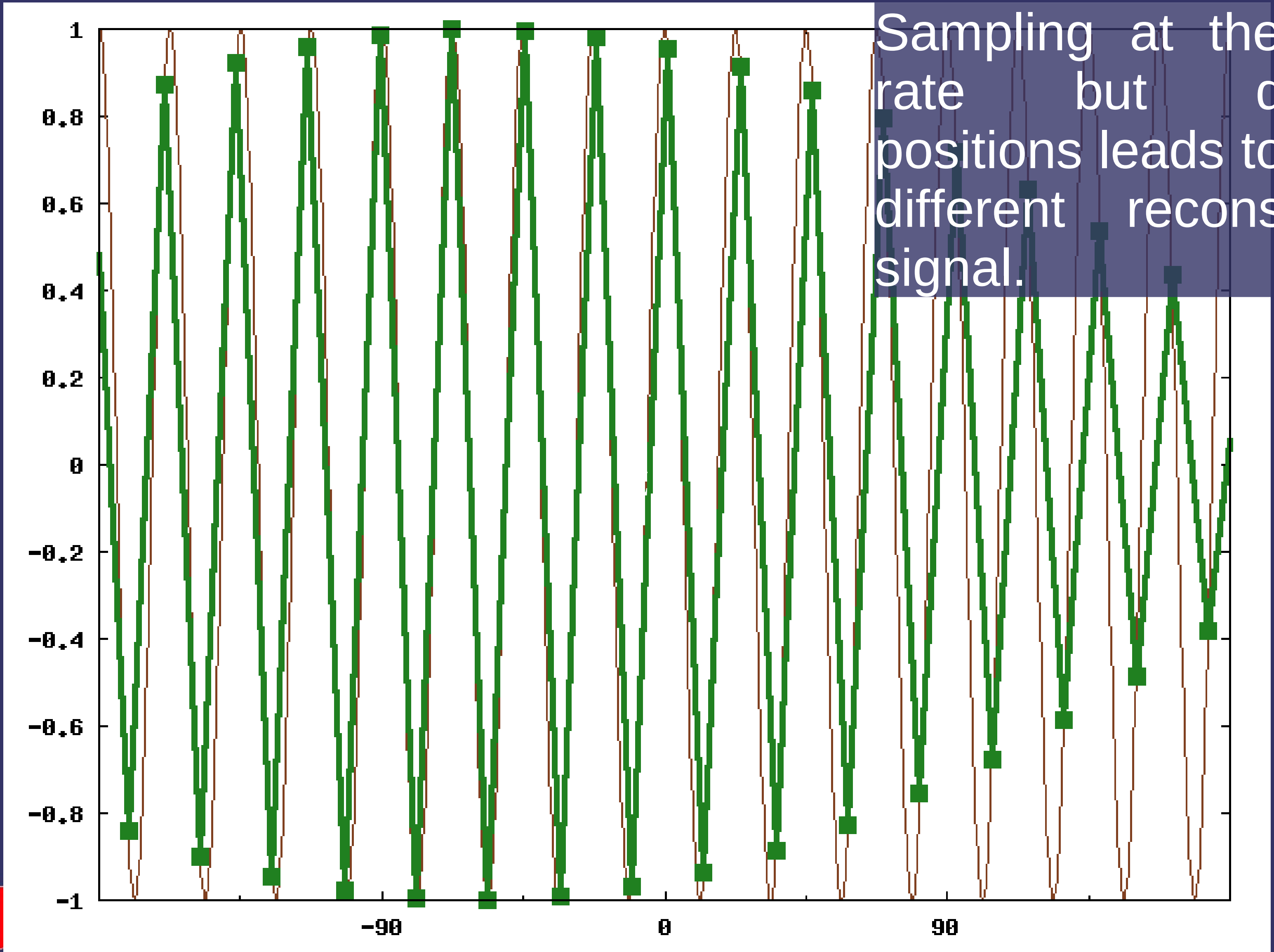
Sampling



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

Avoiding Aliasing

- How?

Avoiding Aliasing

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

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

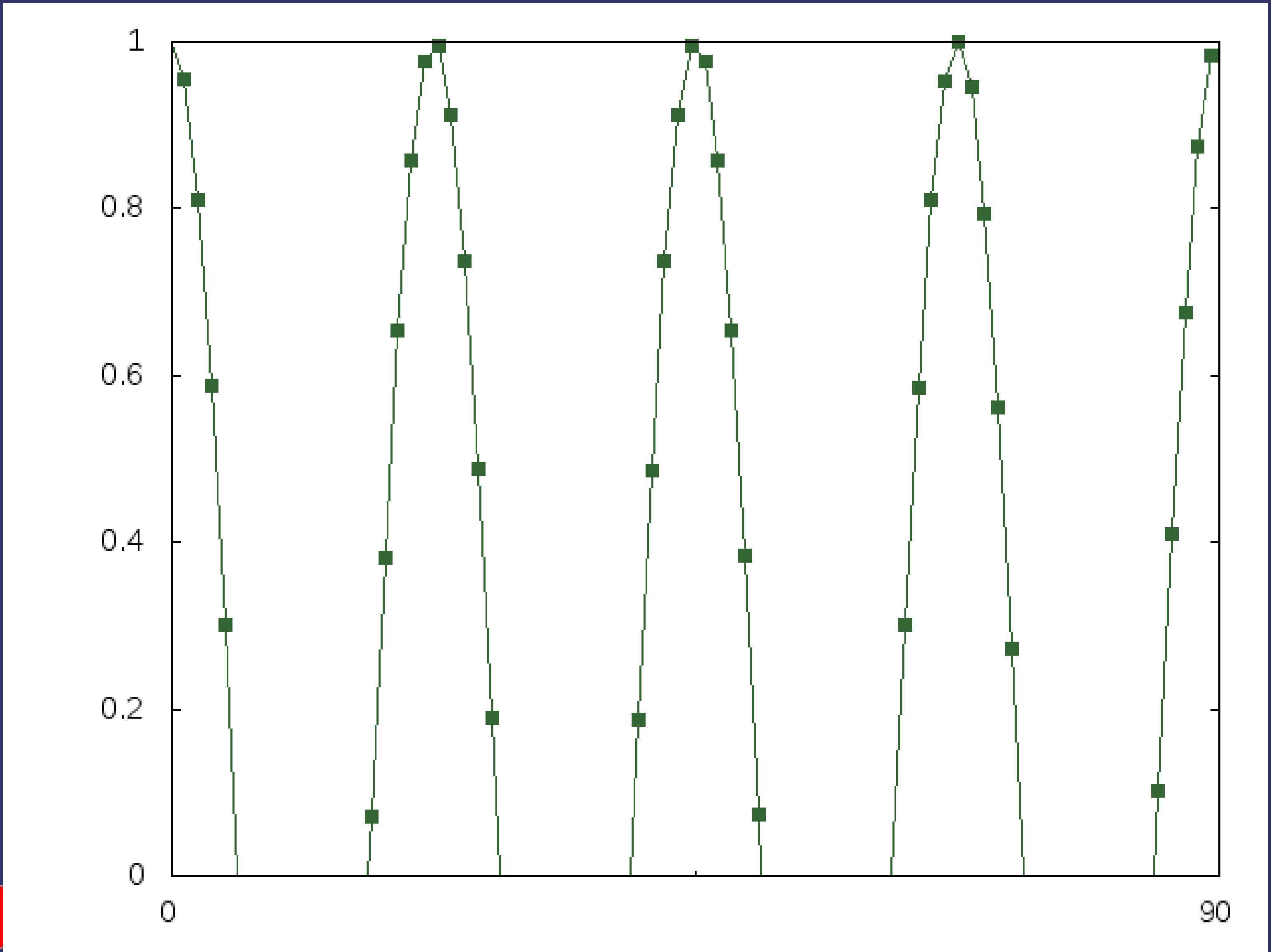
Avoiding Aliasing

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

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

Resampling



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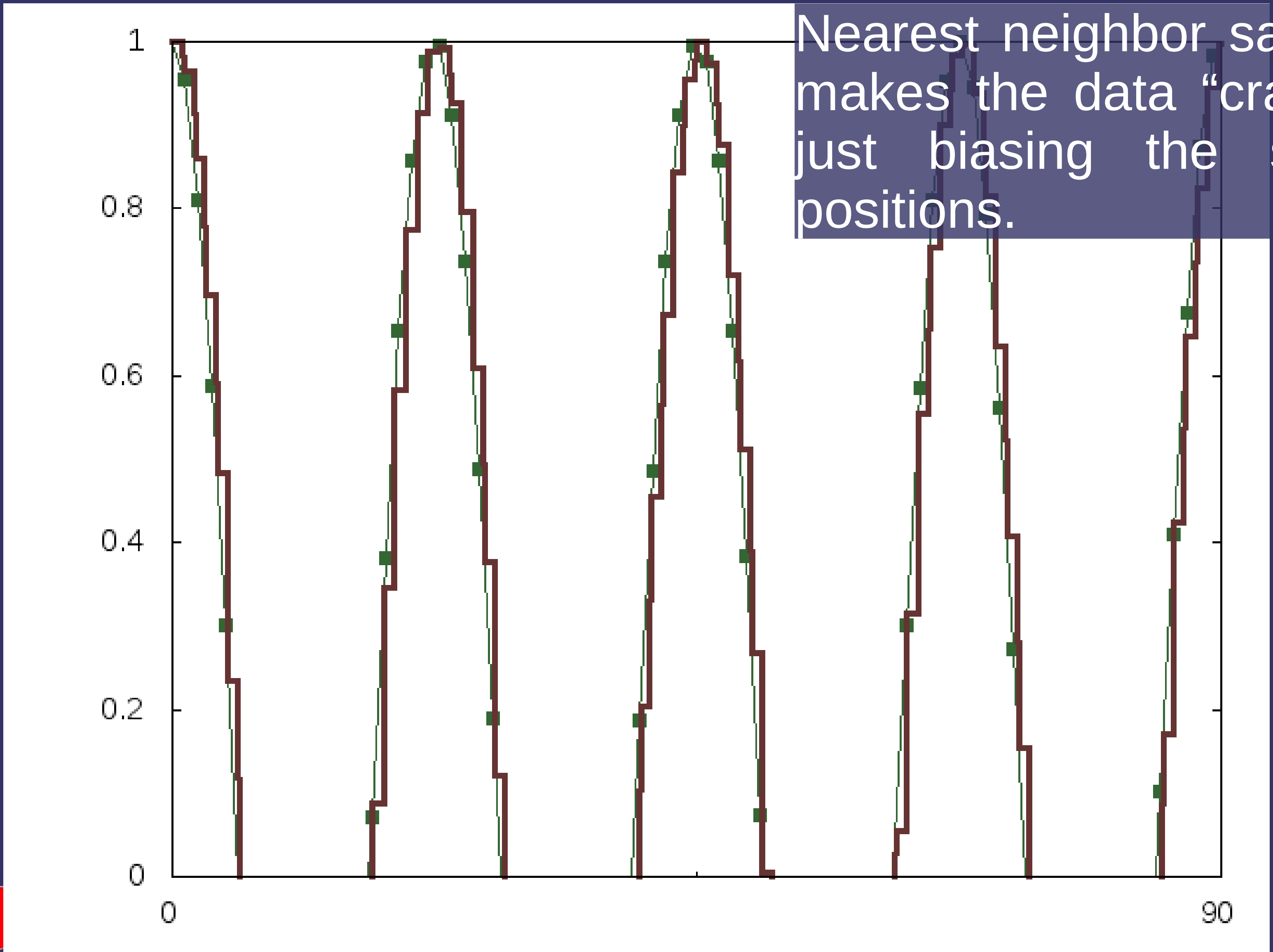
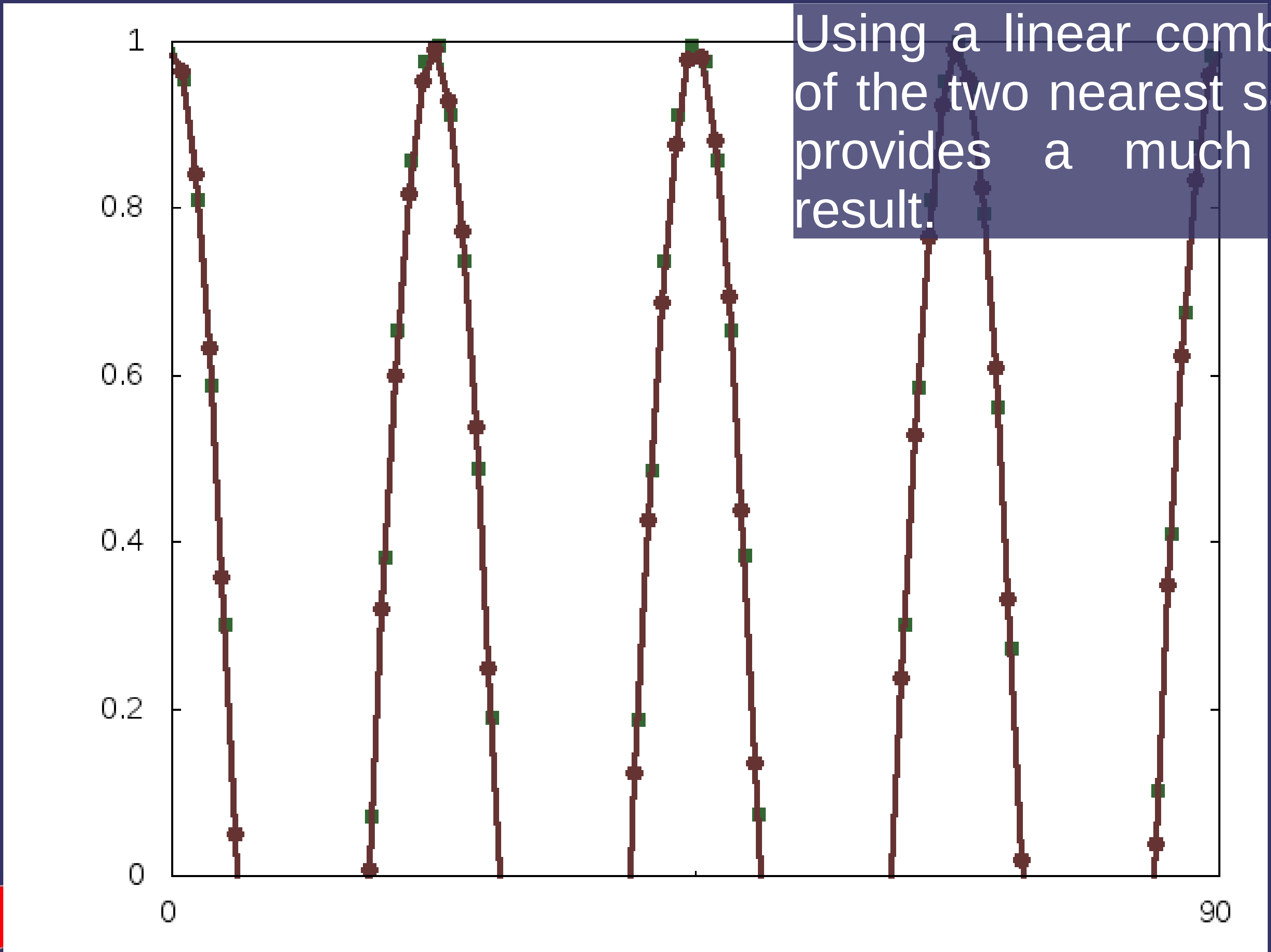
Resampling



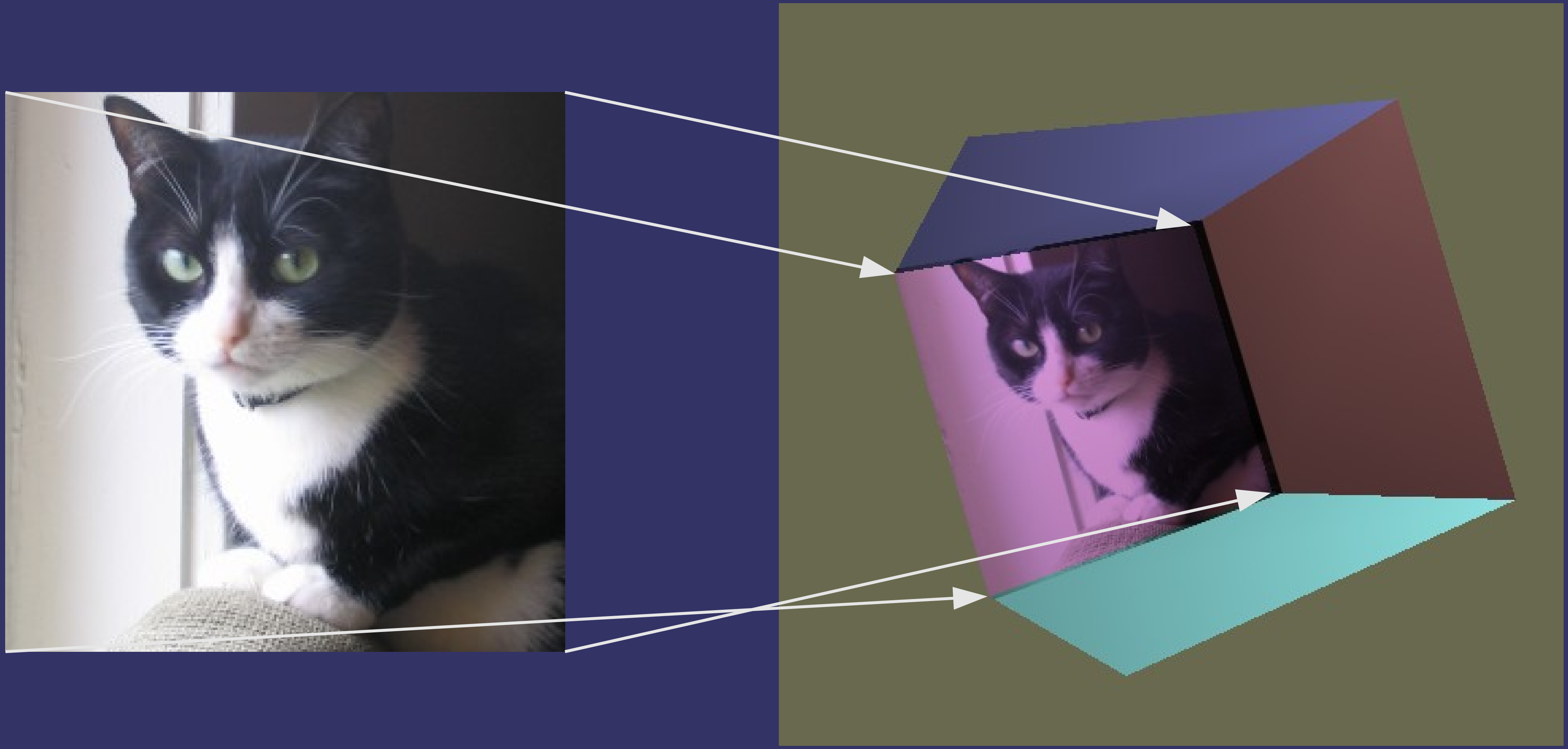
Nearest neighbor sampling makes the data “crawl” by just biasing the sample positions.

Resampling



Using a linear combination of the two nearest samples provides a much better result.

Texture Mapping



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?

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!

Minification

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

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

Minification

- Nearest neighbor sampling
  - Most likely to have aliasing

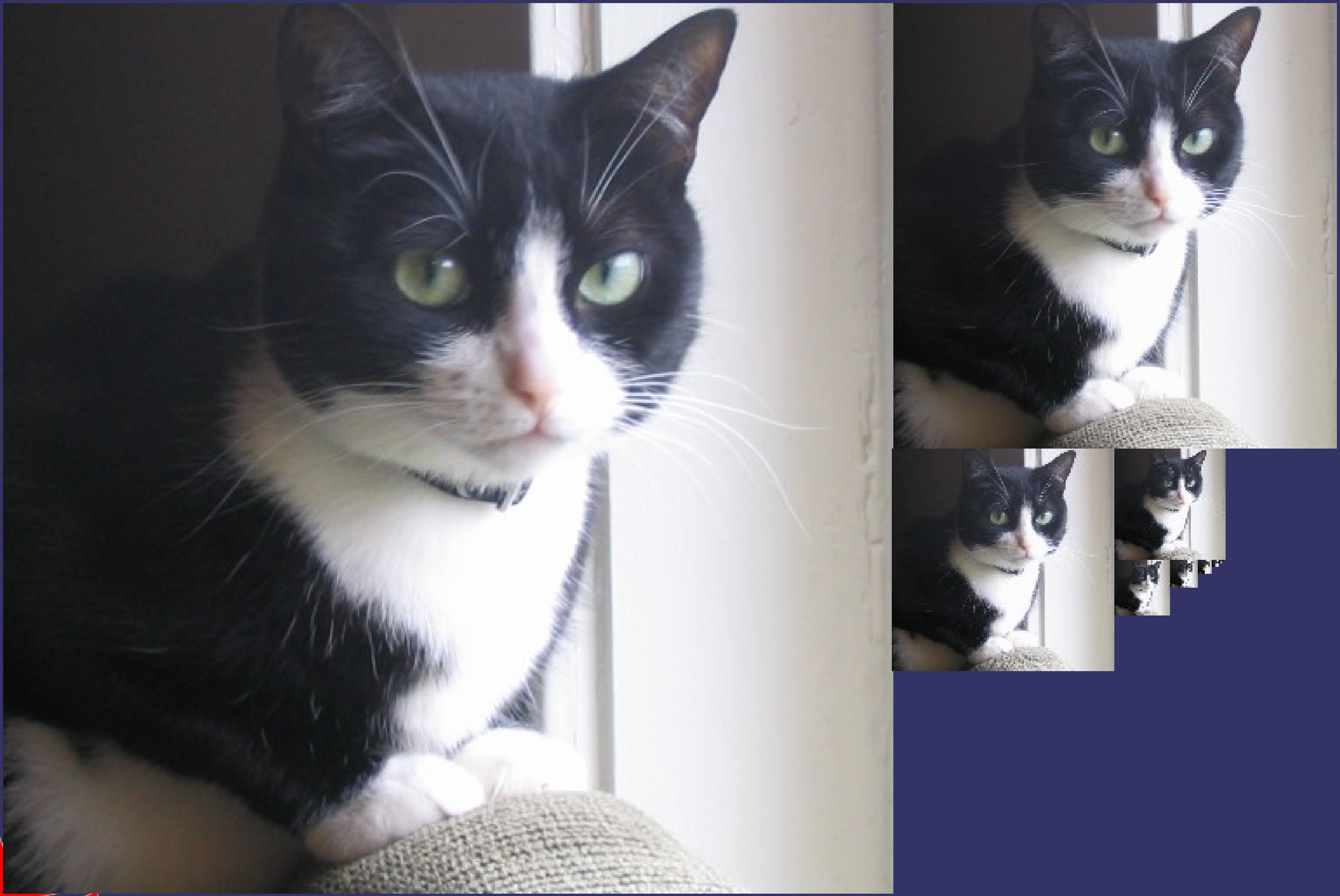
Minification

- 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

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

Example Mipmap Stack



Mipmapping

- What's the trade-off?

Mipmapping

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  - What is the increase in size for a 2D texture?

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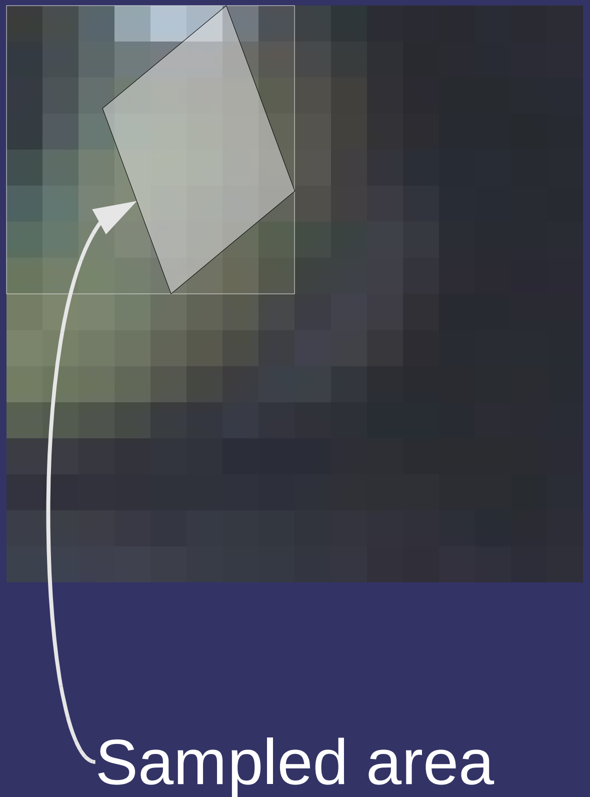
  - Memory *size* versus memory *bandwidth*
  - What is the increase in size for a 2D texture?

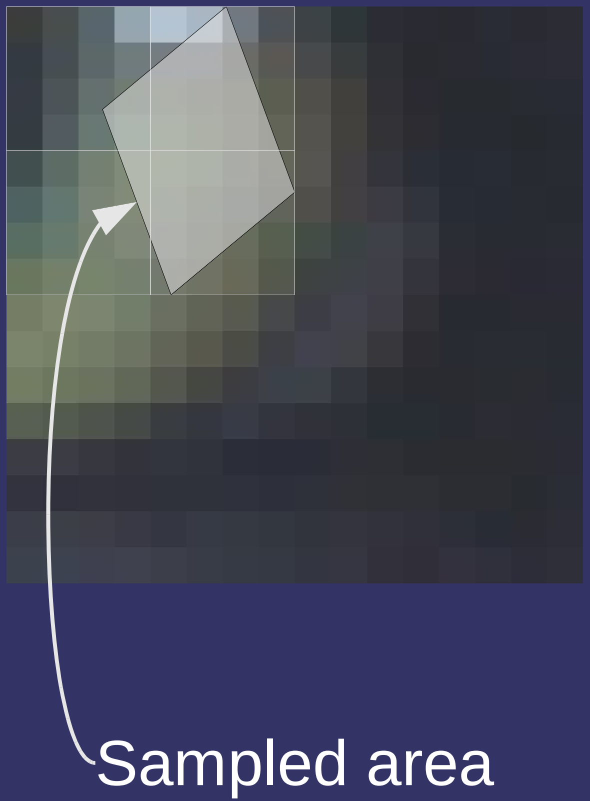
$$\frac{1}{2^2}+\frac{1}{4^2}+\frac{1}{8^2}+\ldots+\frac{1}{2^{2n}}\approx\frac{1}{3}$$

Mipmapping



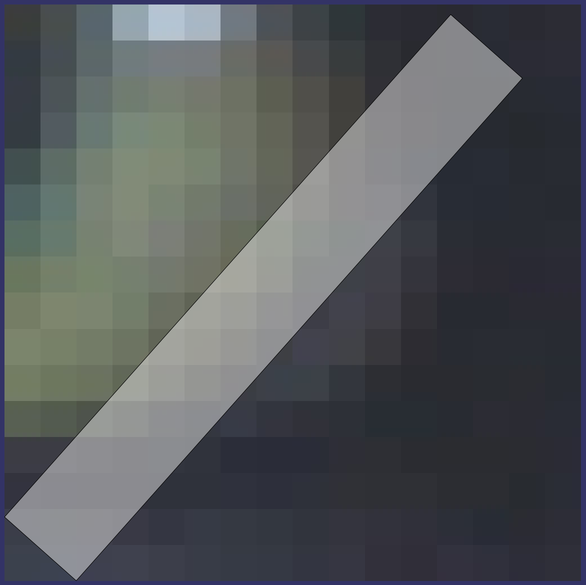
- LOD will be used where the outlined area is a single texel
  - No aliasing, but lots of unneeded data is filtered in
  - Results in images that are too blurry or over-filtered

Mipmapping



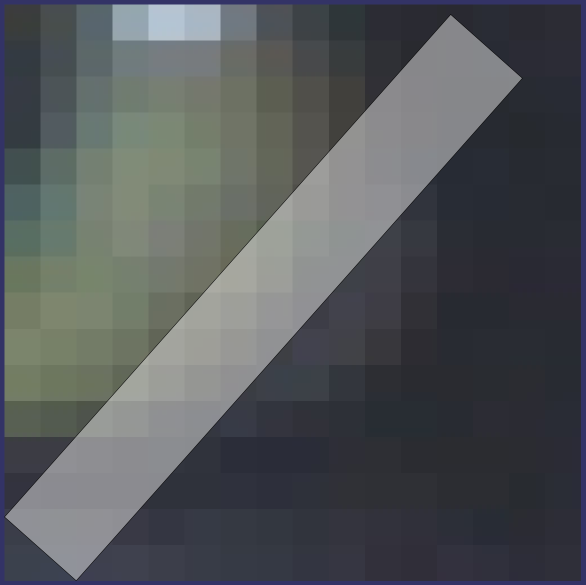
- Can *partially* fix the oversampling by taking multiple samples from the next higher LOD
  - This is a bi-linear filter of the mipmap
  - Can extend further by filtering between LODs

Mipmapping



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

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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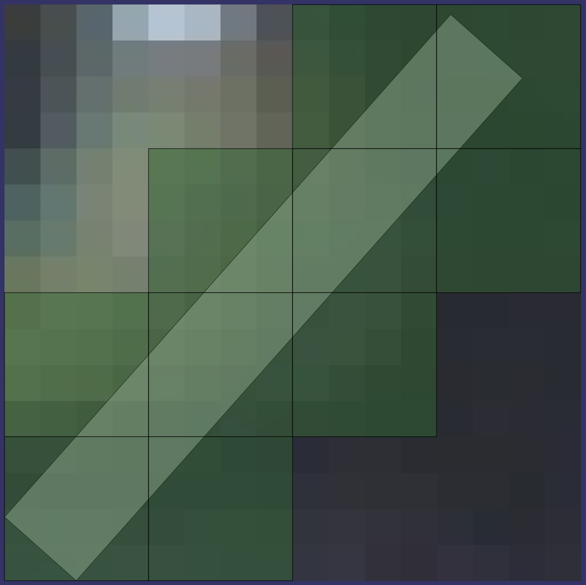
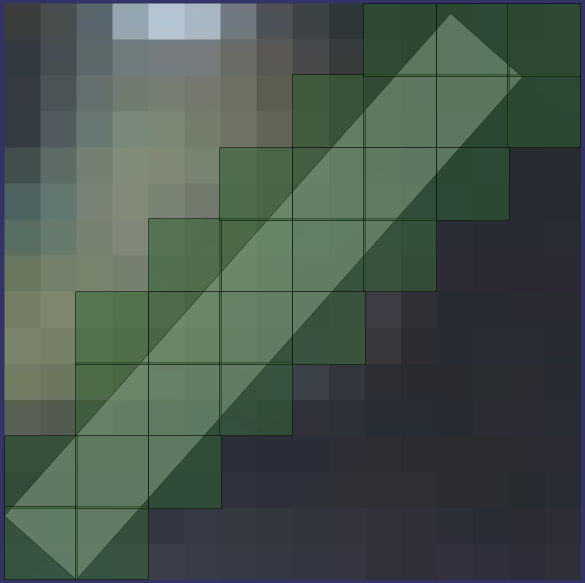
Improved Filtering



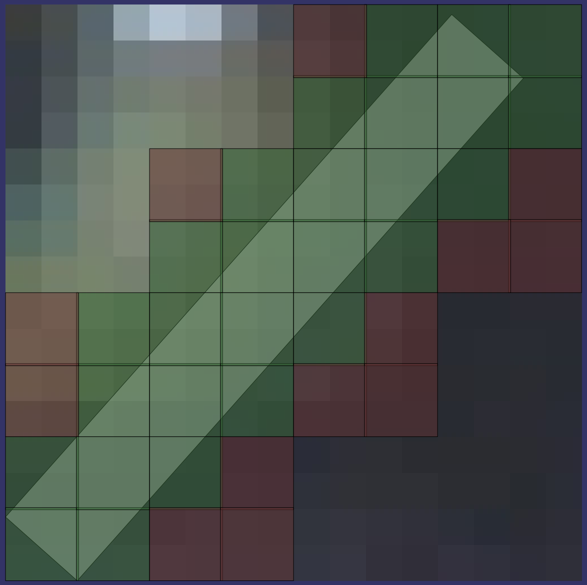
- An anisotropic filter might sample these 10 positions in the appropriate mipmap

Improved Filtering



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

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

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

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

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

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 ½ size, 2 is ¼ size, etc.
  - Textures that use mipmap filtering must be *mipmap complete*
    - All mipmaps down to 1×1 that might be used must be specified

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!

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

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

Next week...

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

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