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# Computer Graphics

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2021 Term 3 Lecture 4

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# What did we cover last lecture?

## Starting to look at 2D Rendering

- The OpenGL Pipeline
- How pixels are coloured in a polygon
- Textures

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# What are we covering today

## Making games in 2D (not quite, but close!)

- Textures and some subtleties
- Transformation Matrices
- A breakdown of a Sprite based game

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# Textures

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# Textures Recap

## What we've seen about Textures

- Use of image files in polygon rendering
- Using Vertex attributes to "map" vertices to coordinates in the image
- Using Fragment shaders to pick up colours from the image
  - and interpolate them across the shape



Images credit: id Software

# Why are Textures useful?

## Textures vs Coloured Vertices

- If we colour vertices . . .
  - We'd need a lot of verts to do detailed colour patterns
  - Simple, flat surfaces like walls, carpets etc would need a LOT of verts to represent things like weave patterns or wallpaper
  - All these extra verts will take a lot of time for our GPU to process and a lot more memory to store
- If we use a texture . . .
  - We can use simple geometry and allow the texture to carry the details
  - Minimal amount of verts
  - Minimal amount of extra work in the vert and frag shaders

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# Simple Geometry, Complex Colours



Image credit: Gearbox Software

# Texturing in the OpenGL Pipeline

## We're starting with using 2D Textures

- We load our image into OpenGL (code details in your tutorials)
- We sample from textures using a coordinate system from 0 to 1 (floats)
- We can add texture coordinates to our verts
- This allows the fragment shader to sample from the colours in the texture

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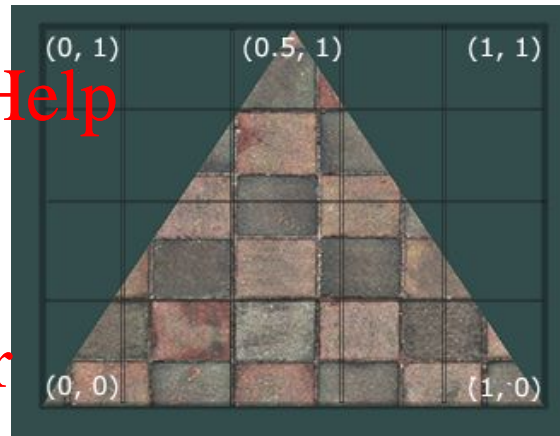


Image credit: learnopengl.com



# Texture Wrapping

## How do textures deal with sampling outside 0-1

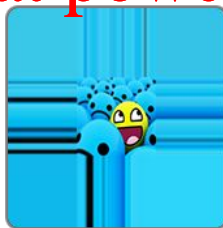
- We can sample past 0 and 1 if we want
- Sampling behaviour changes depending on how we want to deal with this
- Default just repeats the texture again
- But other options have their uses . . .



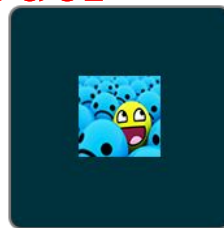
GL\_REPEAT



GL\_MIRRORED\_REPEAT



GL\_CLAMP\_TO\_EDGE



GL\_CLAMP\_TO\_BORDER

Image credit: learnopengl.com

# Texture Wrapping Options

Why might we go outside the 0-1 range for texture sampling?

- Repeat: Wallpaper, wire mesh or other constructed surface
- Mirrored Repeat: Grass, dirt or other natural surface (google seamless grass texture)
- Clamp to Edge: hmm . . . you are only going outside a little and don't want things to reappear?
- Clamp to Border: Posters, stickers, decals? Treat the texture as a one off that never repeats

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# Texture Filtering

## It's not a one to one match between fragments and Texture Pixels

- We call the Texture Pixels Texels (they're definitely not pixels!!!)
- When a fragment samples, it's not guaranteed to land in the middle of a texel
- OpenGL has different options for this:
  - GL Nearest - take the texel that you're the closest to the centre of
  - GL Linear - Take a linear interpolation of the colours in all the texels you're near



GL\_NEAREST



GL\_LINEAR

Image credit: learnopengl.com

# Mipmaps

Do both of those filtering options look bad?

- The ideal is 1 fragment samples 1 texel
- Textures need to be sized based on the object?
- This is awkward if we can move around and objects change size based on our distance to them!
- Mipmaps are sets of textures that all represent the same texture at different sizes

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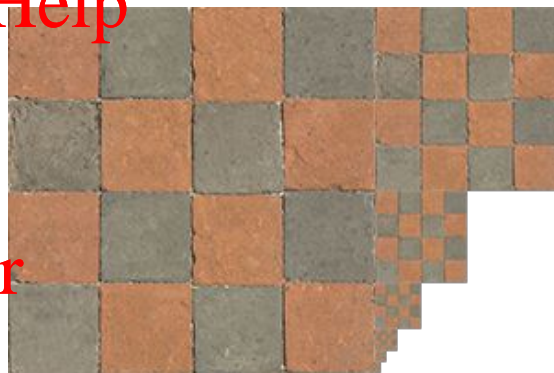
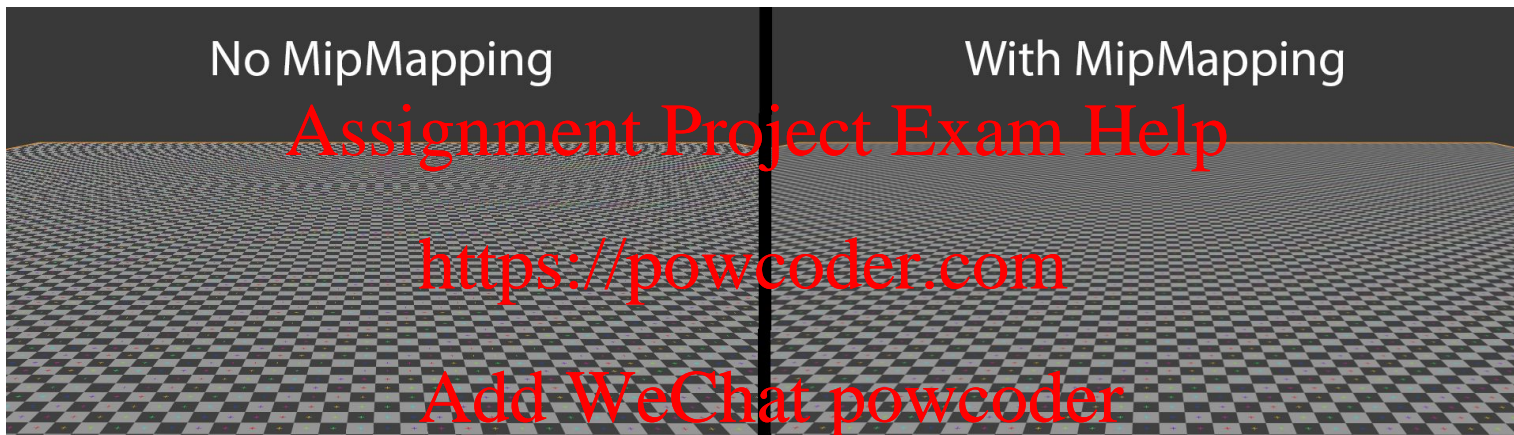


Image credit: learnopengl.com

# Mipmaps



- Sampling without mipmapping can lead to some strange patterns
- Mipmapping allows textures to degrade gracefully into the distance

# Matrix Transforms

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# Transforming Objects

Our vertices have been set in stone up to this point

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- Wouldn't it be interesting if they were more than meets the eye?
- We should roll out a new technique to change the position of vertices
- Option 1: We do this manually
  - Write new vertex positions and rebuild the VBO 60 times a second
  - While technically possible, this is very cumbersome
- Option 2: We use the Matrix of leadership
  - Linear Algebra gives us some easy tools for transforming vectors
  - 2D or 3D vertices happen to be very similar to maths vectors



Image credit: Hasbro

# Vectors and Matrices

How well do you remember your Linear Algebra?

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- We're not going to go over it in lectures
- But you might need to refresh:
  - Vector arithmetic, especially dot product, cross product and normalisation
  - Matrix arithmetic, especially multiplying matrices and multiplying matrices and vectors
- Vectors are directions, measured by coordinates
- Vertices can be thought of as vectors starting at  $(0,0)$  and ending where the vert is

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# Vector Math in a visual sense

If we're going to use vectors in a visual system . . .

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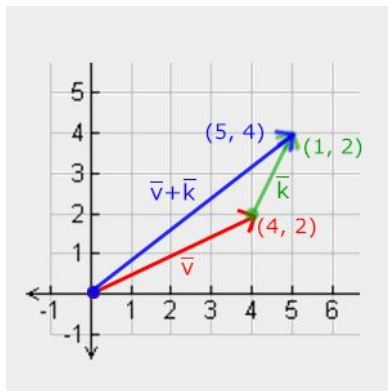
- Adding vectors is like following them on a journey, each vector one after another
- Subtracting vectors tells you how far apart they are
- Dot product gives us an idea of whether two vectors are aiming in similar directions (great for lighting and reflections)
- Cross product takes two vectors and gives us another that's perpendicular (90 degrees) to the other two (great for building up coordinate axes)

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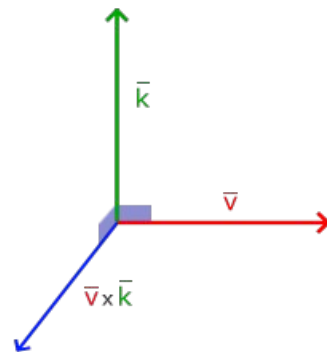
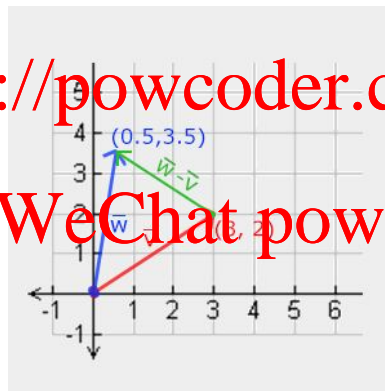
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# Visual Vector Arithmetic

Adding **Assignment Project Exam Help** Subtracting Cross Product



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Images credit: learnopengl.com

# Applying Matrices to Vertices (by multiplying)

**We can multiply a vector by a matrix**

- Which means we can apply a matrix to a vertex
- The output of multiplying a matrix with a vector is a vector
- So what it will do is possibly change the values in the vertex, which changes its position
- Even more interesting is applying the same matrix to all the verts in a shape or object
- We have some pre-made transform matrices that we'll use a LOT in graphics . . .

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# Vectors in OpenGL

**x,y,z,w**

- There's always one more coordinate than the number of dimensions
- We call this 'w'
- For the moment it's just going to be 1
- It won't make a difference now, but definitely will in the future
- So a 2D vector (or a vertex being transformed) is: {x,y,w}
- and 3D is: {x,y,z,w}

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# Scale

## Changing the size of an object

- This matrix can change how far vertices are from the origin by a multiplicative amount
- If applied to multiple verts in an object, they will change the size of the object

Scale x	0	0
0	Scale y	0
0	0	1

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# Translate

## Moving an object

- This matrix can move points by a fixed amount
- Applying this to all the vertices in an object will move the object to a new location without changing the object

1	0	$T_x$
0	1	$T_y$
0	0	1

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# Rotate

## Spinning an object

- This matrix will rotate a vertex around (0,0)
- If applied to the verts in an object, it will rotate the entire object around (0,0) without changing the object

$\cos\theta$	$-\sin\theta$	0
$\sin\theta$	$\cos\theta$	0
0	0	1

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# Combining Transforms

Matrices can be multiplied with each other

- This combines the effects of the two transforms
- Remember that this is NOT commutative
- $A.B \neq B.A$
- The order you use transforms is important!
- There is no limit to the number of transforms that can be combined into a single matrix

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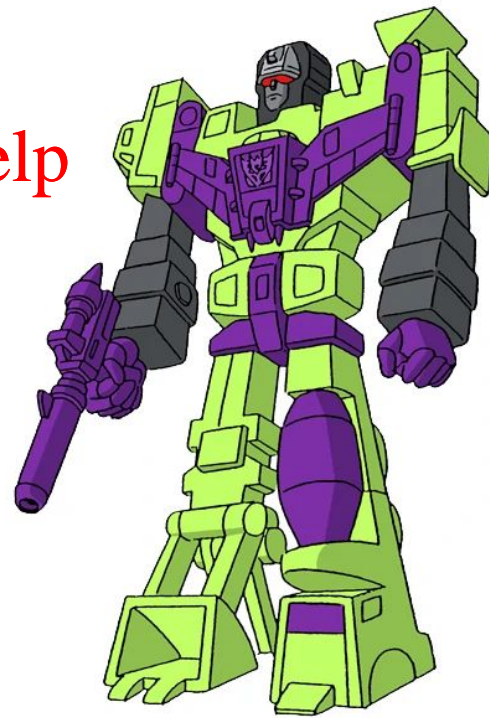


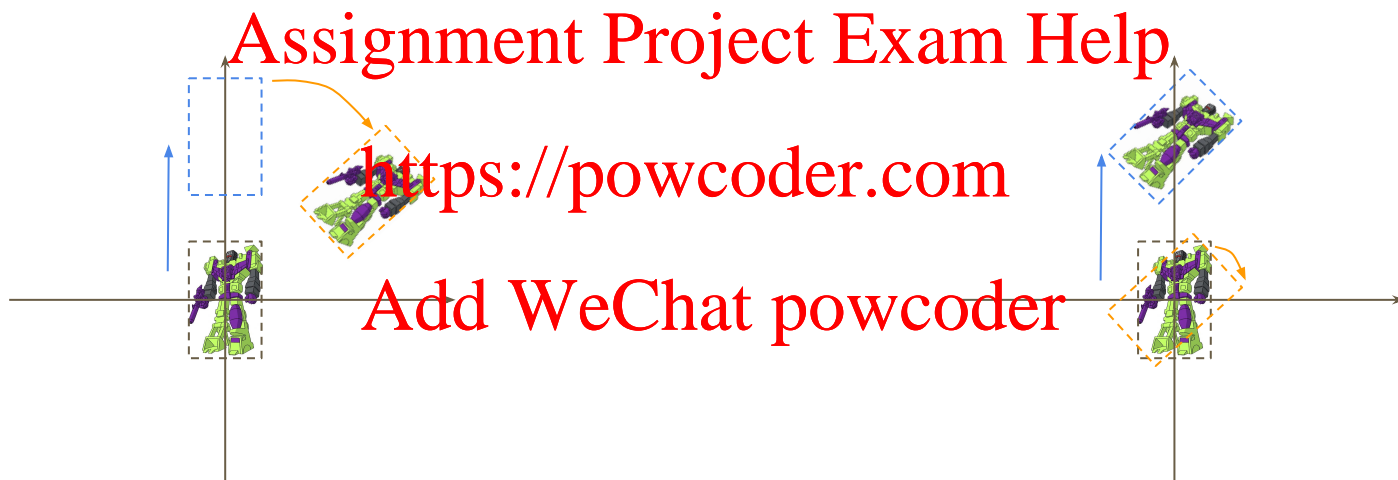
Image credit: Hasbro



# Two different orders

Translate then Rotate

Rotate then Translate



# Transforms in OpenGL

Now that we've reviewed all that maths

- We're now going to delegate the work to a library
- GLM applies the matrices for us
- We only rarely will have to manually enter values into a matrix or memorise Scale/Rotate/Translate

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# A small Case Study

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# With Textures and Transforms ...

Is it possible to replicate Mario?



Image credit: Nintendo (but totally an artwork by Marc Chee)

# Sprites (Textures)

We could use this image as a texture for Mario

- Change texture coordinates based on what actions we take
- Or what state Mario is in (mushroom or flower)
- This means Mario is just a rectangle with some code handling texture coords

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Sprites of Mario  
Image credit: Nintendo

# Transforms for Mario

## How do controls affect the character?

- Directional input:
  - Translate the character somewhere
  - Change the sprite to a running sequence
  - Jumps might need special code
  - Wait, do we translate Mario or do we translate the whole world?
- Change of state:
  - Picking up a mushroom makes us scale Mario vertically to match the larger sprite
  - Do we scale the verts before or after we translate to the current position?

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# Environment

## Sprites/Textures for the Environment

- Repeated textures for the ground
  - What kind of texture coordinates might we use for the ground under Mario?
  - What wrapping system would we use?
- How are we building the background?
  - Flat colour per level?
  - Individual objects with things like clouds or mountain textures on them?
  - Or one big sliding texture on a big rectangle?

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# What did we learn today?

## Textures and Transforms

- Details on Texturing
- Using Linear Algebra to transform vertices
- A quick look at making 2D games

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