# Computer Graphics



COMP3421/9415



2021 Term 3 Lecture 11

# What did we learn before the break?

**Games and Art**

- Game Design and its relationship with Graphics
- The Art Pipeline
- Details of Modelling and Animation

# What are we starting today?

**Lighting**

- What is light?
- Real World vs Simulation
- Starting on Lighting in Polygon Rendering

# Light

# What is light?

**And why is it important for vision?**

- Physics of real world light
- A particle or a wave (or both)
- A spectrum of electromagnetic radiation
- Travels in (mostly) straight lines
- Is effectively instantaneous
- Reflects off many surfaces in different ways

Image credit: Bungie Studios

# Light and Colour

**Colour is us seeing different wavelengths of light**

- A mix of multiple wavelengths
- Human vision is detecting reflected light
- Different surfaces absorb and reflect different wavelengths
- . . . and in different directions
- Our eyes perceive colour based on which wavelengths reach them



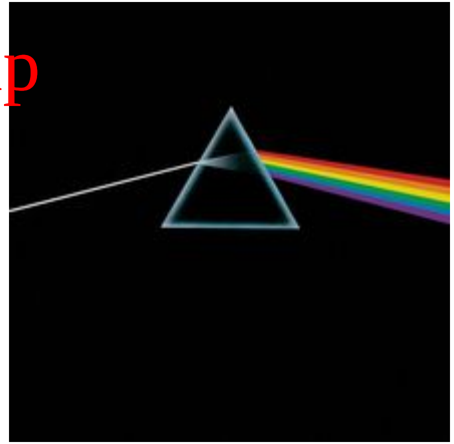


Image credit: Pink Floyd

# Simulate Light

**A physics based model for virtual lighting**



- Send rays of light out from our light sources
  - Could need billions of these to match the number of photons in real light

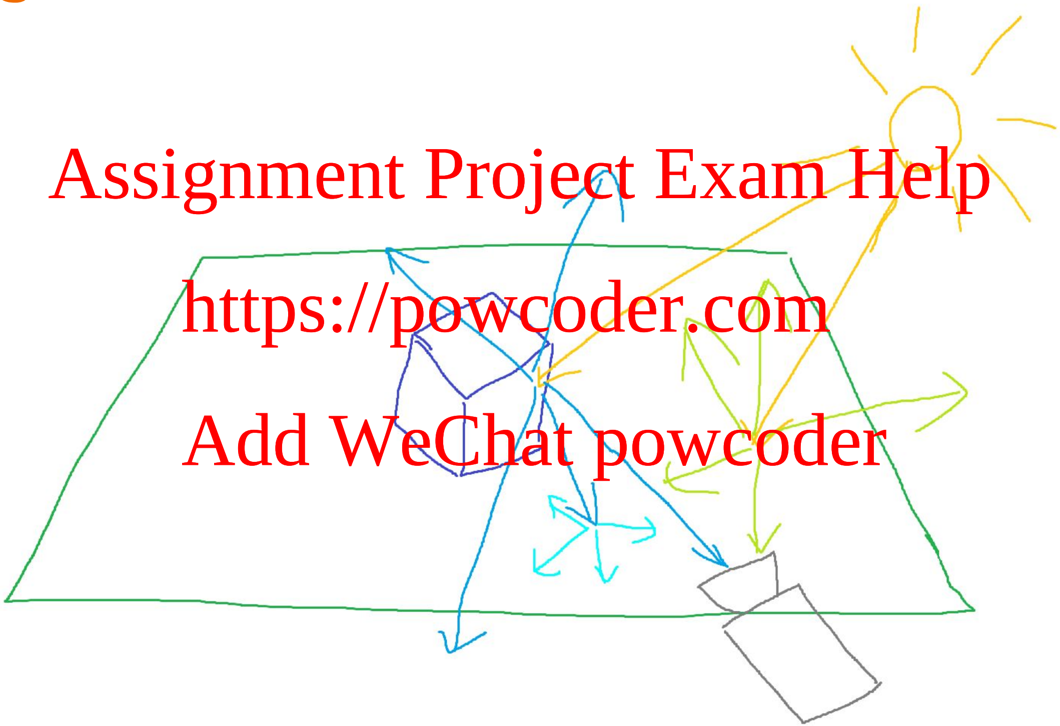


- Bounce them off objects
  - Every bounce reflects the colour of the object



- If a reflected ray passes through the near plane of the frustum
- . . . and hits the camera
- Then colour the pixel with whatever colour the ray was

# Simulate Light



# Pros and Cons

**This technique seems to make sense**

- Accurate simulation of real light
- Nothing looks too complicated mathematically
- Realistic shadows and reflections



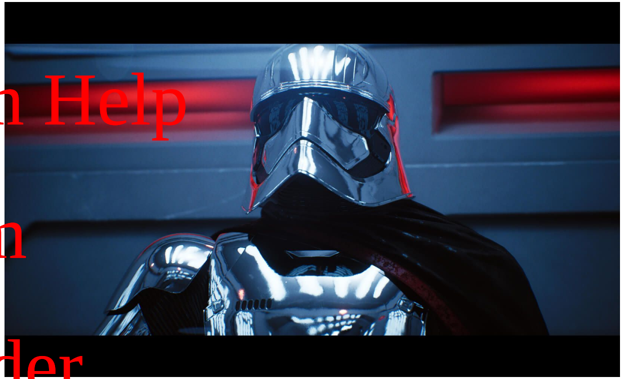
**Wait, did you say Billions?**

- Computationally very expensive
- Collision Detection is very expensive
- Most calculation is wasted

# Ray Tracing

**This technique has a name!**

- A very big buzz word in present day Graphics
- Commercially available from 2018
- Before that, thought infeasible for realtime (still incredibly resource hungry)
- Used in film from the late 1990s



Real Time Ray Tracing
Image credit: Unreal Engine

# Phong Lighting

# Polygon Rendering and Light

**We don't have a physics model**



- We can't trace rays of light easily
- What are our tools?
- Vertices, and Triangles, Coordinates, Camera
- Vector and Matrix math
- Can we build an approximate lighting model?
- That computes a lot faster?

# Phong Lighting

**A Simple Idea for Polygon Rendering Lighting**

- Compute Lighting per fragment
- Simplify the idea of bouncing light
- Three main parts:
- Ambient Light
- Diffuse Light
- Specular Light

# Ambient Light

**Indirect Light**

- Even outside of direct light, there's some light
- Reflections off other surfaces
- Correct calculation takes a lot of light bounces
- . . . and doesn't usually have much effect!



**In Phong Lighting**

- Ambient light is constant throughout the scene

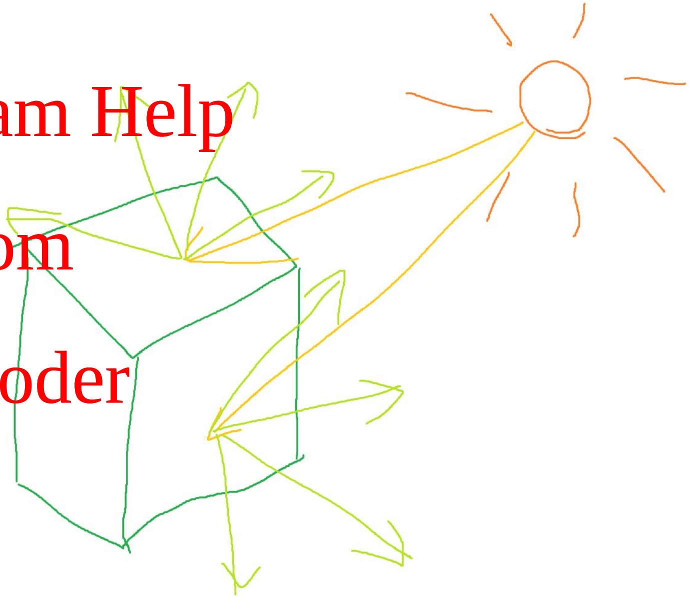
# Diffuse Light

**Directional Light on non-shiny surfaces**

- Light directly from a source
- Hits a surface and scatters
- Matte or rough surface objects

**In Phong Lighting**

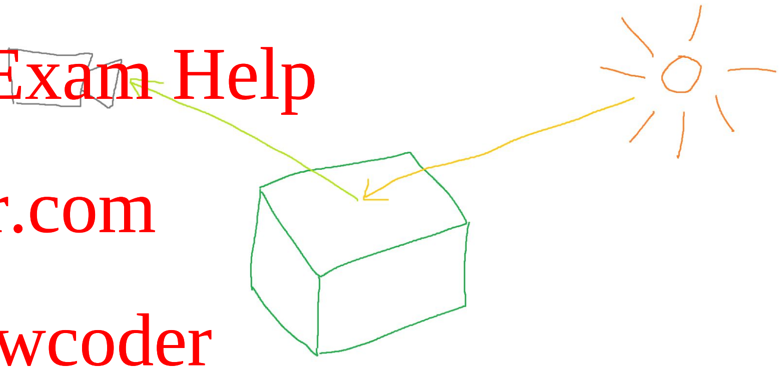
- Calculated based on light source
- and angle to surface



# Specular Light

**Direct Reflections from shiny surfaces**

- Light from a source
- Hits a surface and bounces directly
- Shiny or reflective objects





**In Phong Lighting**

- Calculated based on direction to camera as well as direction to light source

# Light Calculation per Fragment

$$I_{\text{p}} = k_{\text{a}} i_{\text{a}} + \sum_{m \in \text{lights}} \left( k_{\text{d}} (\hat{L}_m \cdot \hat{N}) i_{m,\text{d}} + k_{\text{s}} (\hat{R}_m \cdot \hat{V})^{\alpha} i_{m,\text{s}} \right).$$

Image credit: Wikipedia



**Equation for the colour of a fragment**





- Ambient: ambient light colour * surface colour
- +
- Diffuse: light colour * angle of light to surface * surface colour
- +
- Specular: light colour * angle of reflected light compared to viewing angle * surface colour
- =
- Total colour in the fragment

# Break Time

**Cutting Corners**



- Graphics is a field full of dirty hacks for optimisation
- We know that Ray Tracing is accurate but expensive
- So we invent tricks like Phong Lighting
- Polygon Rendering is itself a trick to reduce computation



**Graphics is all a compromise between visual quality and speed**

# Lights and Materials

# Where does light come from?

**In the real world**

- The Sun
- Lamps and light bulbs

**In our virtual scenes**

- Directional Lights (simulates the sun)
- Point Lights (have a position in the scene)
- And others . . .

# Representation of Light sources

**Directional Light**



- Represented by a vector (a direction!)
- Considered to be so far away that its direction is the same everywhere in the scene



**Point Light(s)**



- Represented by a point (a position in the scene!)
- Direction to fragments will need to be calculated

# Materials

**We've been calling these textures**



- But there's so much more!
- Materials are surface information

- Colour is one part of the surface information
- But there are other things:

    - How shiny is it?
    - Does it have ripples or bumps in it?
- An object can have multiple materials!

# Ambient Lighting

# Ambient Lighting Equation

**Calculated per scene per fragment**

- $I_a = i_a * k_a$
- $I_a$ Final intensity of ambient light
- $i_a$ Intensity of ambient light in the scene
- $k_a$ Ambient reflectivity of fragment



Eg: Ambient Light is a bit reddish (0.1, 0.05, 0.05), the object's material reflects bluish in ambient light (0.2, 0.9. 0.2)

Final ambient Light: (0.1, 0.05, 0.05) * (0.2, 0.9. 0.2) = (0.02, 0.045, 0.01)

# Ambient Lighting Result

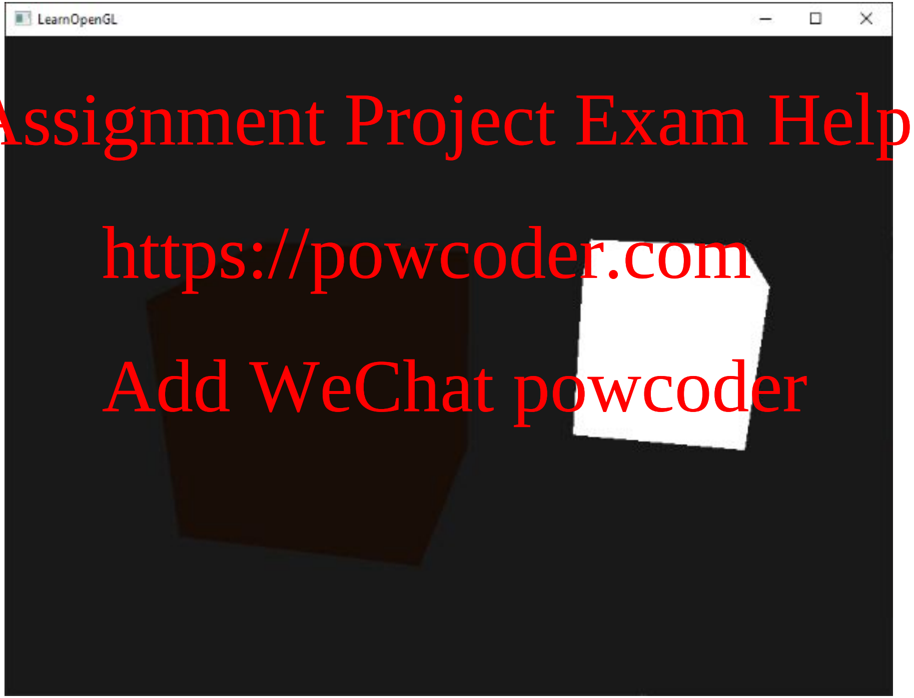





Image credit: learnopengl.com

# Normals

# Normals - Directions of surfaces

**Diffuse Lighting needs to know where a surface is facing**



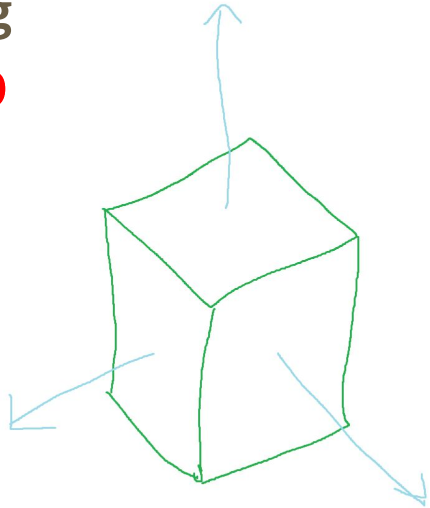
- Normal: a vector perpendicular to the surface
- Shows the "facing" direction



**Attaching Normals to polygons**



- Where can we store information in a polygon?
- Triangles have no data storage!
- It has to be in the vertices!



# Normals attached to Vertices

**Normals, Vertices and Triangles**



- Normal data in vertices makes sense
- Frag shaders can already use vertex data



- Normals can be generated using triangle data
- Specific normals can be stored in the vertex attributes

# Making Normals

### Generating Normals from Triangles



- Cross Product of triangle edges
- Triangle winding order is now important!
- If we create vectors between vertices
- 1->3 x 1->2 is different from 1->2 x 1->3
- Counter-clockwise is the convention for the "front" of a polygon

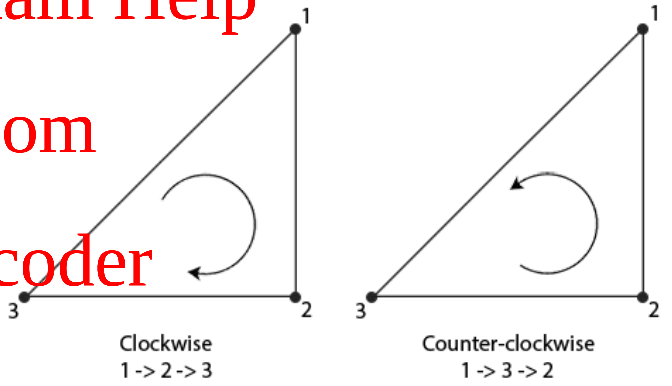



Image credit: learnopengl.com

# Normalise Normals

**Directions shouldn't have magnitude**



- Vectors can have a direction and magnitude
- If we're using them purely as a direction . . .
- They should be length 1
- Lighting calculations will rely on all directions being length 1 vectors
- When in doubt, normalise!

# Diffuse Lighting

# Diffuse Lighting Equation

**Calculated per light per fragment**

- $I_d = k_d * (L.N) * i_d$
- $I_d$ Final intensity of diffuse light
- $k_d$ Diffuse reflectivity of fragment
- $L$ Direction to light from fragment
- $N$ Surface Normal
- $i_d$ Diffuse intensity of light source

# Breaking down the Diffuse Equation

**What's the L.N bit?**



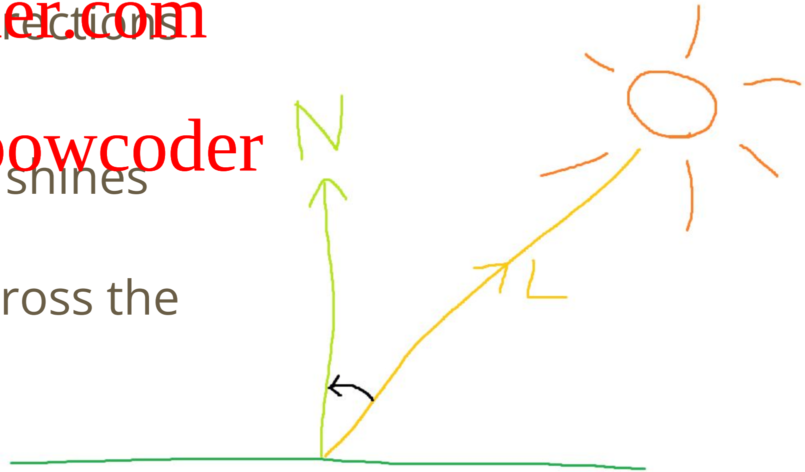
- A dot product of two direction vectors
- dot product results in a single number



- Scale of the difference in the vectors' directions
  - 90°, dot product = 0
  - 0°, dot product = 1



- The light is the brightest when the light shines directly at the surface
- There is no light if the light is shining across the surface



# Diffuse Lighting

**The Equation Explained**



- Take the intensity of the light
- and the diffuse reflectivity of the surface (surface colour)
- Multiply them (just like ambient lighting)
- Then multiply that colour by 0.0-1.0
- This number is a representation of how directly the surface normal is aiming at the light source
- We find that out by using dot product of the two normalised vectors

# Diffuse Lighting Result

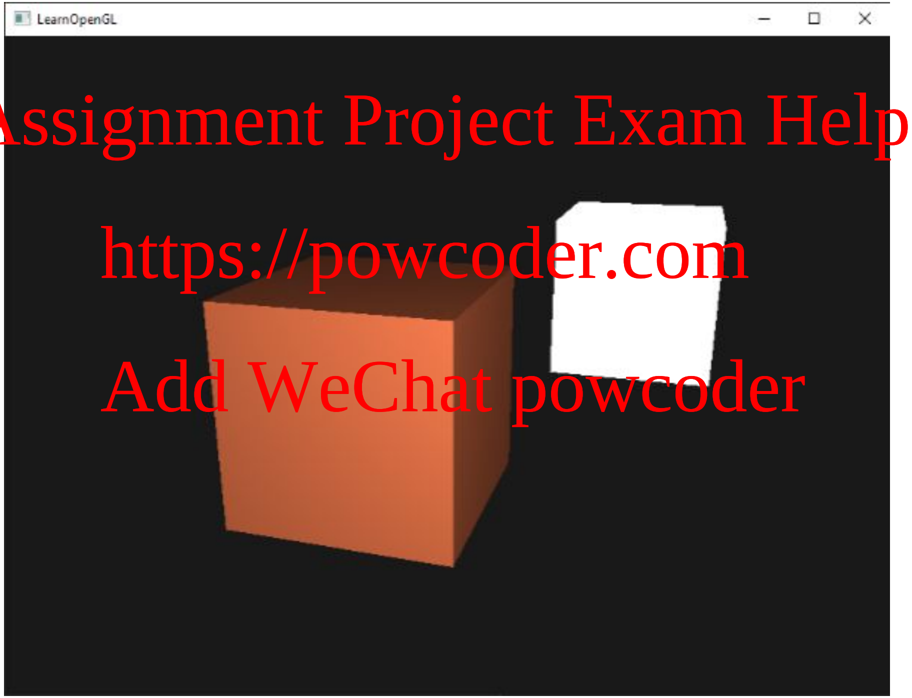





Image credit: learnopengl.com

# What did we learn today?

**Lighting**



- The difference between real and virtual
- Possibilities for simulation of light



- Phong Lighting, an approximation of light
- Beginning to look in detail at the lighting algorithm