COMP220: Graphics & Simulation

# 6: Materials and Lighting

# Learning outcomes

- **Explain** the Blinn-Phong illumination model
- **Implement** Blinn-Phong illumination in your own programs
- **Describe** how effects such as normal mapping can be used to render realistic materials

# Vector products

# Dot and cross product

$$a \cdot b = |a||b| \cos\theta$$

where $\theta$ is the **angle** between $a$ and $b$

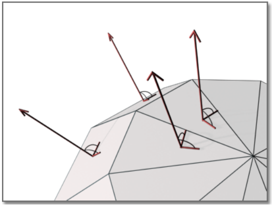
$$a \times b = (|a||b| \sin\theta)n$$

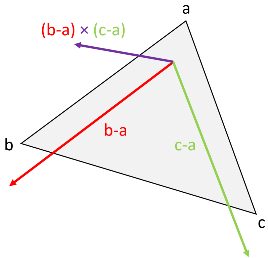
where $n$ is a unit vector **perpendicular** to both $a$ and $b$ with direction given by the **right-hand rule**

# Uses

- Both dot and cross product are **quick to calculate**
- Dot product can be used to find the **angle** between vectors
  - Actually the **cosine** of the angle
  - If $a \cdot b = 0$ (and $a, b$ are non-zero) then $\cos\theta = 0$, i.e. $\theta = 90^\circ$ — $a$ and $b$ are **perpendicular**
  - If $a \cdot b = 1$ and $a, b$ are unit vectors then $\cos\theta = 1$, i.e. $\theta = 0^\circ$ — $a$ and $b$ are **parallel**
- Cross product can be used to find a vector **perpendicular** to two others
- vector $\cdot$ vector $=$ number; vector $\times$ vector $=$ vector

# Surface normals






- The **normal** to a surface is a **unit vector** that is **perpendicular** to the surface
- If we have two non-parallel vectors that are **tangent** to the surface, we can use the **cross product** to find the normal
- For a triangle with vertices $a$, $b$, $c$, two such vectors are $b - a$ and $c - a$
- So the normal is

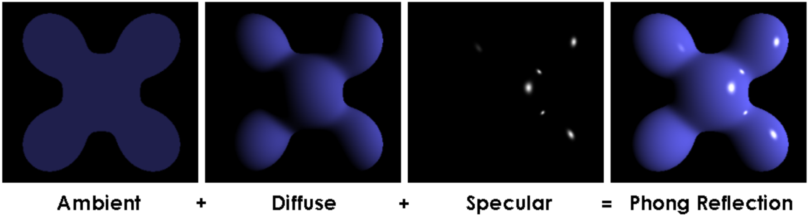
$$\frac{n}{|n|} \quad \text{where} \quad n = (b - a) \times (c - a)$$

# The Blinn-Phong illumination model

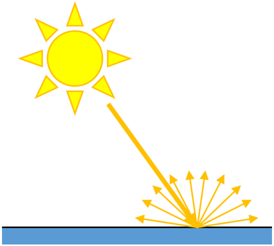
# The Blinn-Phong illumination model

Jim Blinn, "Models of light reflection for computer synthesized pictures". *ACM SIGGRAPH Computer Graphics*, 11(2):192–198, 1977.

The Blinn-Phong model builds on the Phong shading model It breaks lighting down into three parts: **ambient**, **diffuse**, and **specular**.

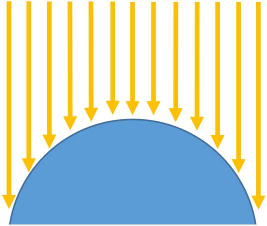


# Diffuse lighting

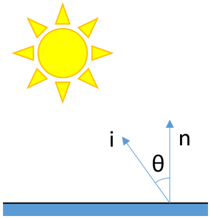


When light hits a “”rough surface, it is **scattered equally in all directions**

The amount of light hitting the surface depends on the **angle** between the surface and the light source



# Diffuse lighting formula

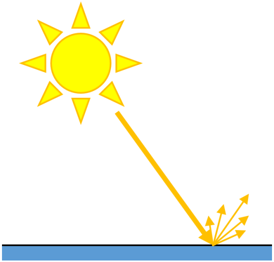



- Light intensity is proportional to the **cosine** of the angle between the **light direction** and the **surface normal**
- Let *n* be the normal, and *i* be a unit vector pointing towards the light source
- Light intensity is proportional to $\cos\theta = n \cdot i$
- If the surface is **pointing away** from the light source, we get $\theta > \frac{\pi}{2}$ so $\cos\theta < 0$ — in this case we **clamp** the answer to 0

# Light direction and intensity

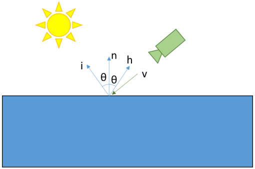
- For a **distant** light source (e.g. the sun), direction and intensity are **constant**
- For a **point** light source (e.g. a lightbulb):
  - Direction is calculated by subtracting the light position from the fragment position
  - Intensity obeys an **inverse square law**: if the distance between the fragment and the light source is $d$, then the light intensity is $\frac{1}{d^2}$

# Specular lighting



When light hits a "smooth" surface, it is **reflected** across a narrow range of angles

# Specular lighting formula




- Let $h$ be the halfway vector, calculated by $i + v$
- $h$ can be thought of as the surface normal which leads to the maximum reflection in $v$
- Specular light intensity is proportional to

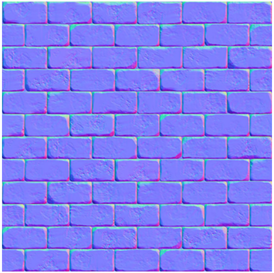
$$\mathsf{clamp}(n \cdot h)^s$$

  where $s$ is a "shininess" parameter, and $\mathsf{clamp}(x)$ clamps its argument between 0 and 1

# Ambient lighting

- Currently, surfaces pointing away from the light are completely **black** (light intensity = 0)
- In the real world, light scattered from one surface illuminates others
- In the Phong model, we cheat and add a little **ambient** intensity to the lighting
- Another option would be to add more light sources...

# Normal mapping



- A **normal map** is a texture which is used to slightly alter the normal across a surface
  - Each pixel in the normal map represents a 3D vector, with *xyz* mapped to RGB
- Can be used to add detail to flat, low-poly surfaces
- Can use textures to change other lighting parameters across a surface, e.g. **specular mapping**