COMS 30115

Light I

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Last time

- Raycasting
- How to project 3D world to image space
- How to compute ray-"primitive" intersection
- Sometimes called The Visibility Problem

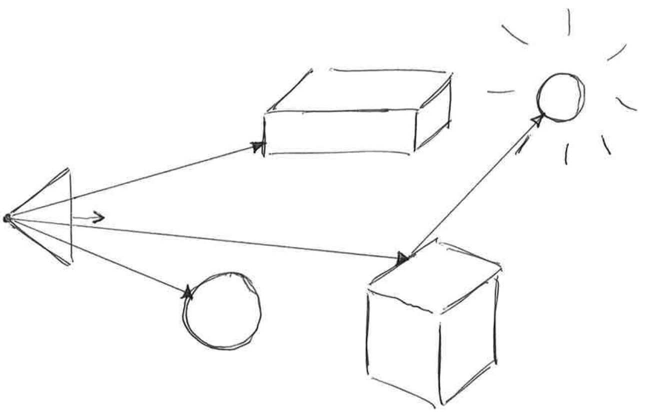
Today

- Lighting
- What happens in the interaction between surface and light
- Parametrise surface
- Often referred to as The Shading Problem
- *Today we are starting to "hack"* so think of the assumptions that we make

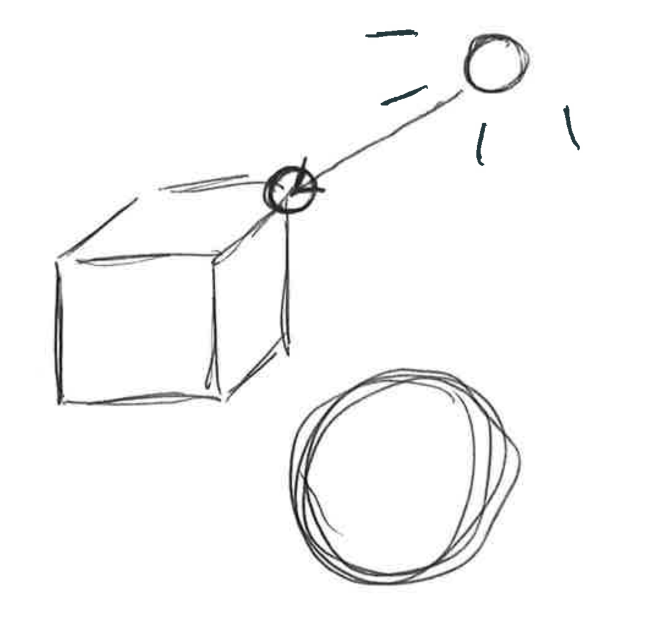
The Book

- Surface properties URL
- Light URL
- Reflection and Refraction URL
- Any old physics book is also a good place to read

Illumination



Illumination



Illumiation

- Local/Global
  - colour of two surfaces *can/cannot* be computed independently
- Depends on
  - material properties
  - surface geometry
  - light properties
- Raytracer - Pixel Shading
- Rasteriser - Vertex Shading
- *we will spend a lot of time in the second part of the unit to try to speed this up*

Surface-Light

Appearance

What does appearance depend on?

- surface properties
    - material
    - geometry
    - orientation
- light properties
- viewing direction

Appearance

What does appearance depend on?

- surface properties
    - material
    - geometry
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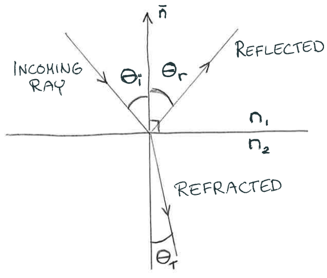
- light properties
- viewing direction
- *To render we need a mathematical model of these things.*

When light meet surface

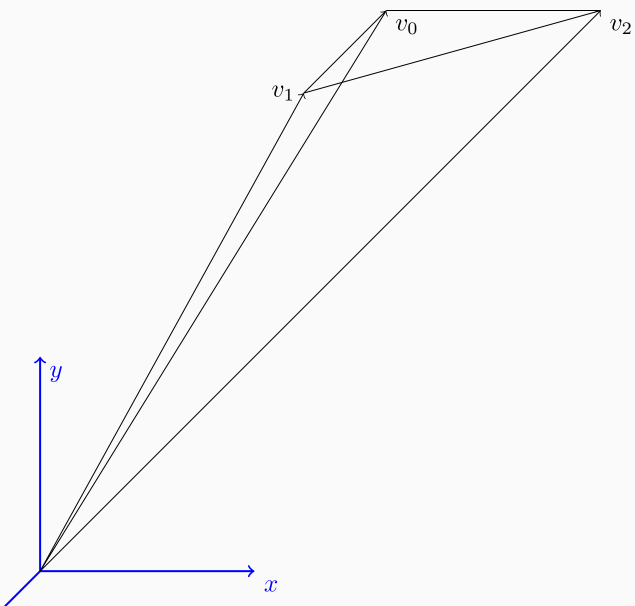
- Reflection & Refraction
  - Angles are based on Fermats principle of "least time"
  - a light ray will take the path of least time
- Snell's Law

$$n_1 \sin(\theta_1) = n_2 \sin(\theta_2)$$

- Varies with wavelength
- Isotropic (pure) media



Normals



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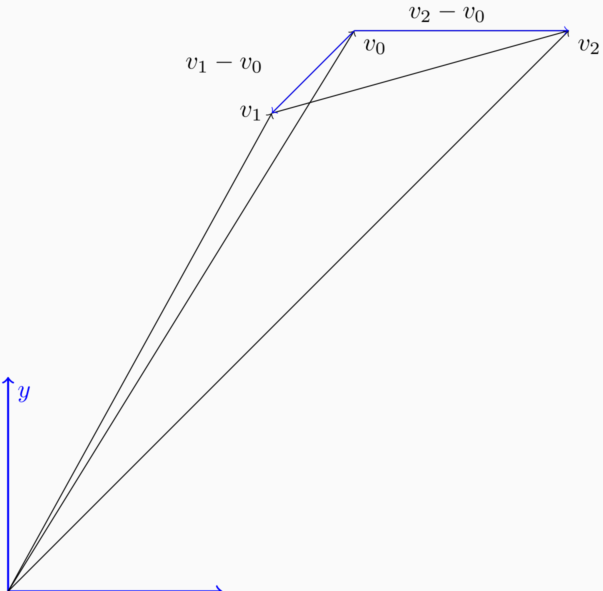

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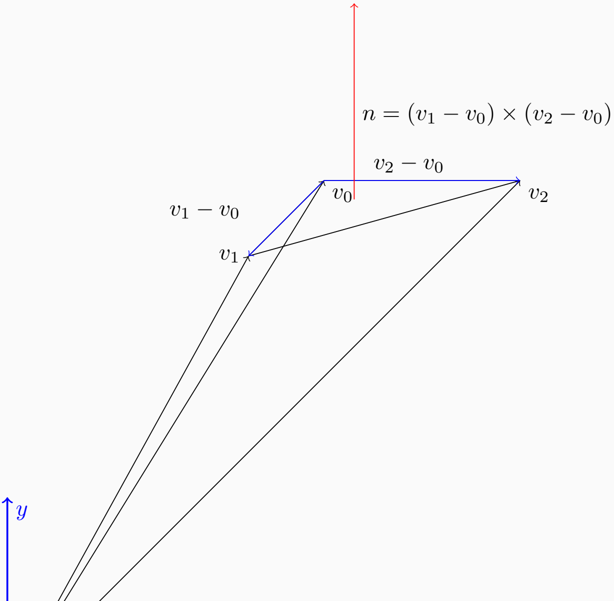

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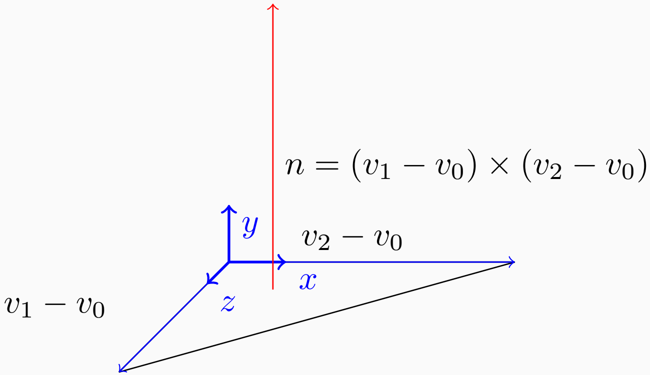
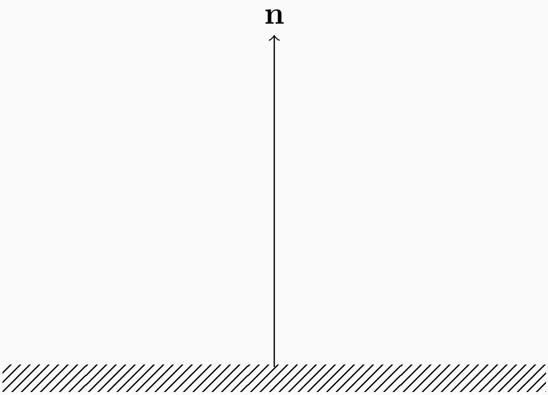
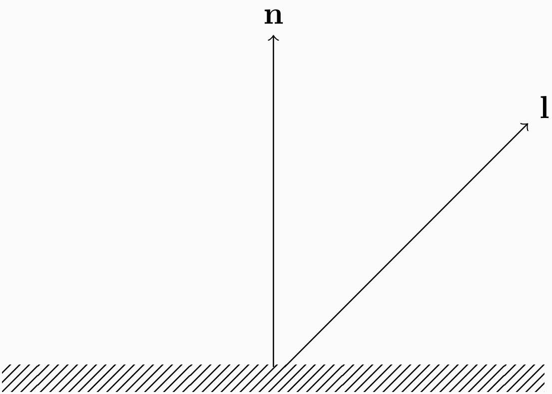


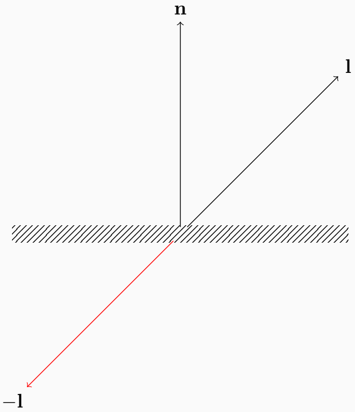
Reflection



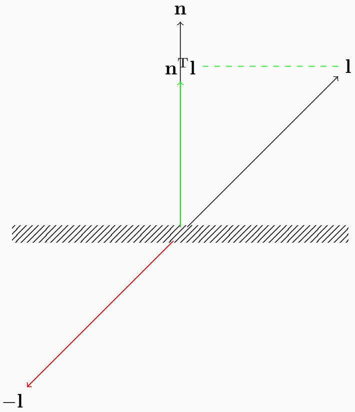
Reflection



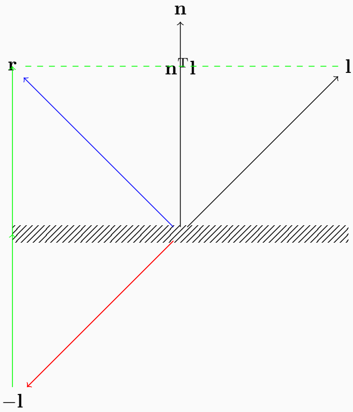
Reflection



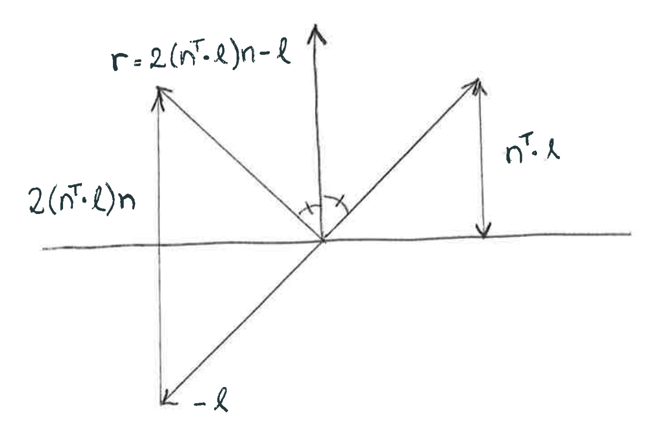
Reflection



Reflection



Reflection



$$\mathbf{r} = 2\left(\mathbf{n}^{\mathrm{T}}\mathbf{l}\right)\mathbf{n} - \mathbf{l}$$

When light meet surface

- Reflection & Refraction
  - Angles are based on Fermats principle of "least time"
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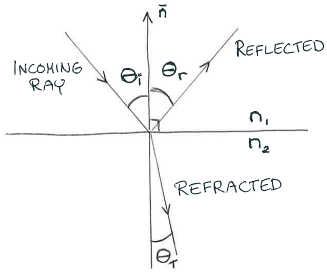
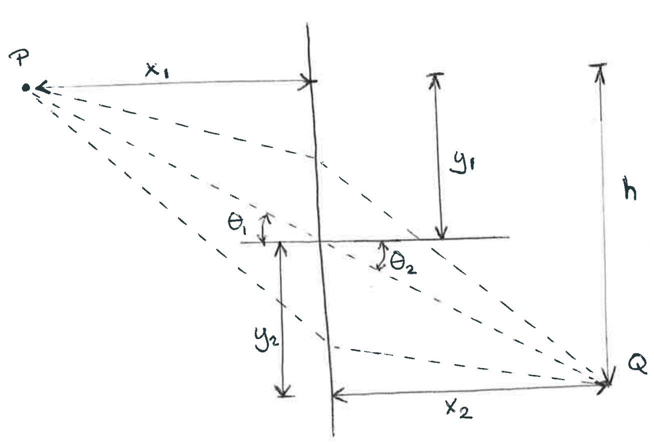


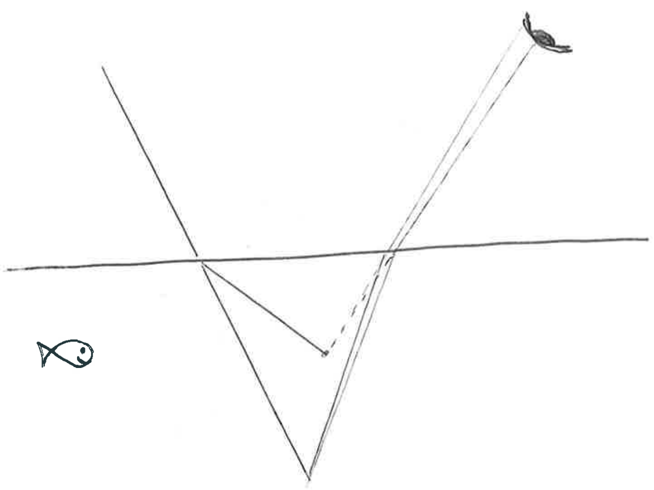
Snell's Law



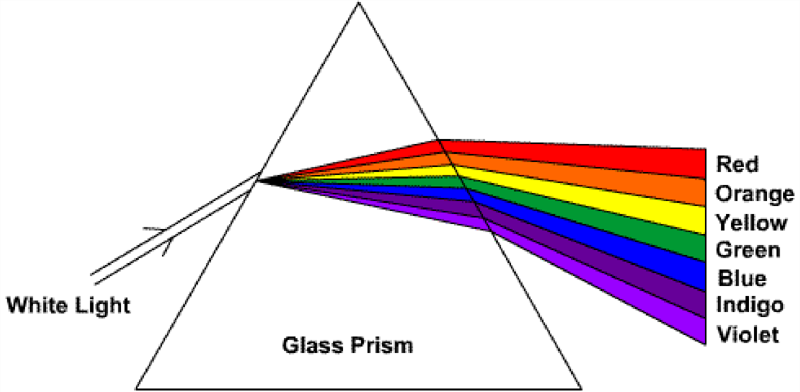
Snell's Law

$$
\begin{aligned}
t &= \frac{(x_1^2 + y_1^2)^{\frac{1}{2}}}{v_1} + \frac{(x_2^2 + y_2^2)^{\frac{1}{2}}}{v_2} \\
y_2 &= h - y_1 \\
\frac{\delta t}{\delta y_1} &= \frac{1}{v_1} \frac{y_1}{(x_1^2 + y_1^2)^{\frac{1}{2}}} + \frac{1}{v_2} \frac{-(h - y_1)}{(x_2^2 + (h - y_1)^2)^{\frac{1}{2}}} \\
\frac{\delta t}{\delta y_1} &= \frac{\sin\theta_1}{v_1} - \frac{\sin\theta_2}{v_2} = 0 \\
n_1 &= \frac{c}{v_1} \\
\frac{n_1 \sin\theta_1}{c} &= \frac{n_2 \sin\theta_2}{c} \\
n_1 \sin\theta_1 &= n_2 \sin\theta_2
\end{aligned}
$$

Snell's Law

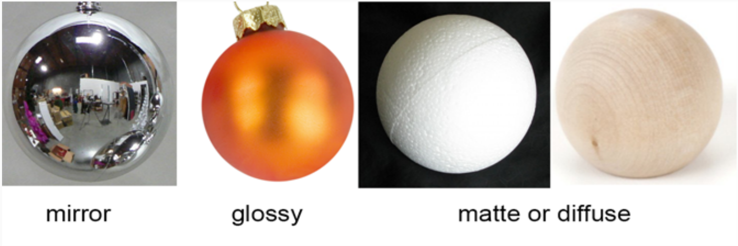


Snell's Law



$$\eta_1(\lambda)\sin(\theta_1) = \eta_2(\lambda)\sin(\theta_2))$$

Surfaces



- Surfaces are usually cathegorised on a continum
- Mirror $\Rightarrow$ Glossy $\Rightarrow$ Diffuse

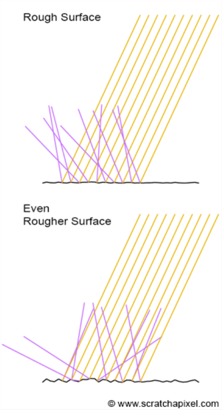
Mirrors [1]

- We only see one ray from each point
- Perfect reflection

[1] Cloud Gate Chicago ("The Egg") Image URL

Glossy Surfaces

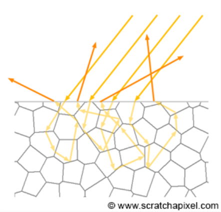
- Surfaces look glossy because of imperfections
- Random surface pertubations



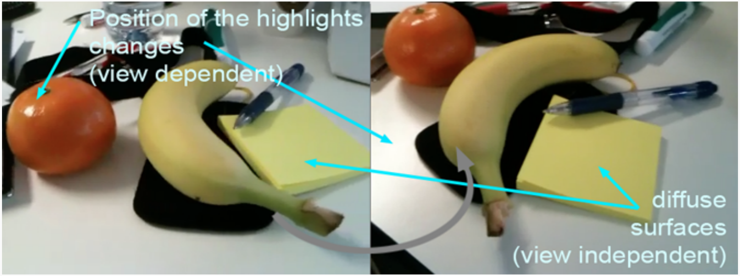
Glossy Surfaces

Diffuse Surfaces

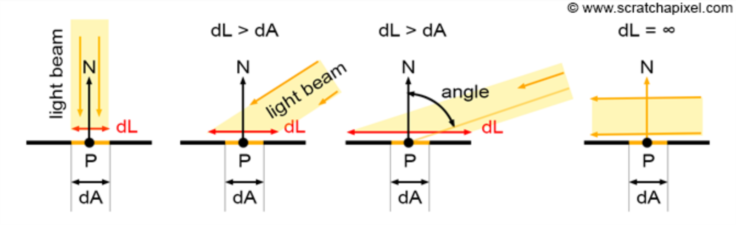
- Often due to internal structures inside object
- Light exits object at angles independent from input angle
- Sometimes we have structured internals such that they are not independent
    - sub-surface scattering (skin)



Diffuse Surfaces



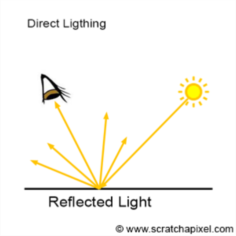
Diffuse Surfaces (foreshortening term)



- the surface would get more light once the light is angled
- to avoid this effect, keep the surface const.

$$\mathrm{d}A = \cos(n, l)\mathrm{d}L = n^{\mathrm{T}} l \mathrm{d}L$$

Lights


Direct Ligthing
Reflected Light
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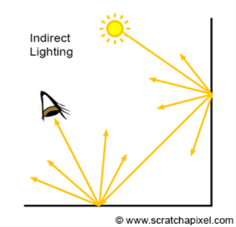
Indirect
Lighting
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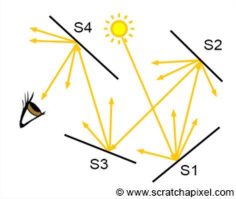
S4
S2
S3
S1
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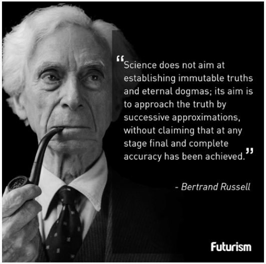
Approximations

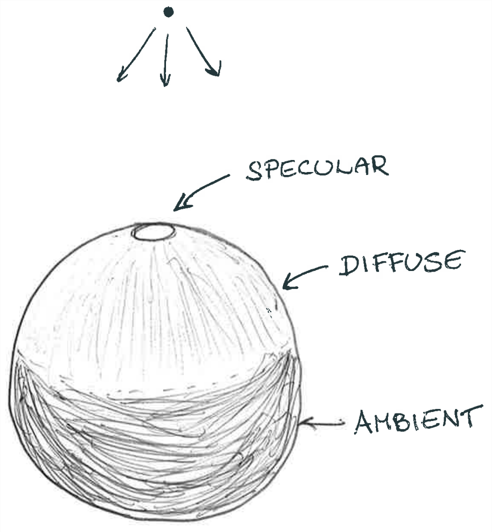
- Lights interaction with a surface is simple in *forward* tracing
- Rather complicated *backward* tracing
- Approximate all lights as different types of direct light



#Science #Truth

Lights

Lights Ball

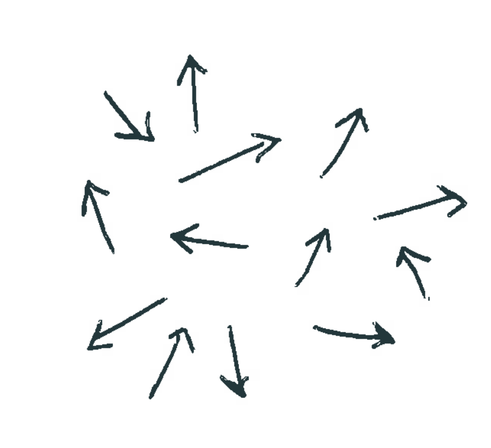


Light Factorisation

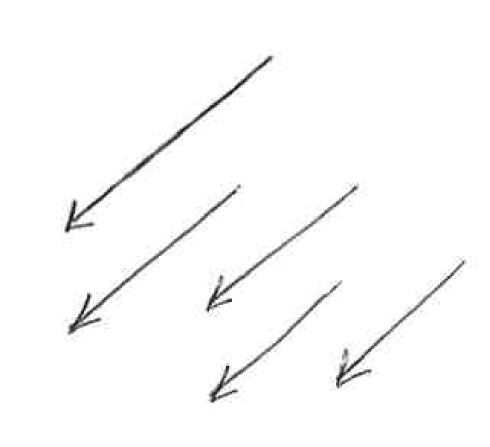
$$\mathbf{i}_{tot} = f(\mathbf{i}_{amb}, \mathbf{i}_{diff}, \mathbf{i}_{spec})$$

- There is only one type of light
- Approximation: Factorise into Ambient, Diffuse and Specular

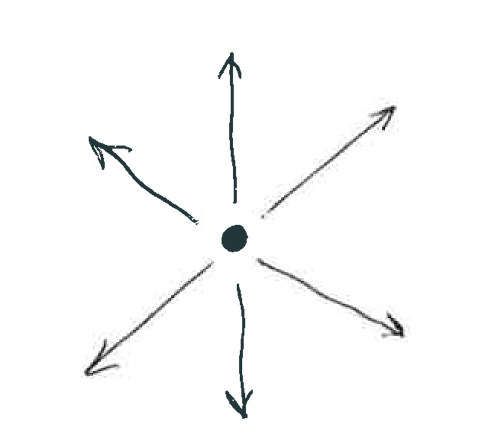
Light Factorisation (Ambient)



Light Factorisation (Diffuse)



Light Factorisation (Point)



Approximations

Hadamard Product [2]

$$\mathbf{a} = \mathbf{b} \circ \mathbf{c}$$
$$(\mathbf{a})_i = (\mathbf{b})_i \cdot (\mathbf{c})_i$$

[2] Wikipedia URL

Colour

$$\mathbf{i} = \mathbf{m} \circ \mathbf{s}$$

- **s** light intensity
- **m** material properties
- **i** colour of reflected light

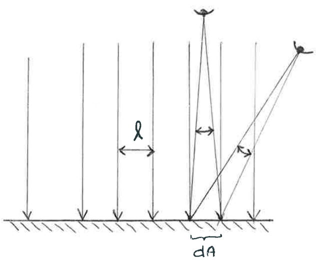
Parametrisation

Material and Light

Notation	Description
$\mathbf{s}_{amb}$	Ambient intensity
$\mathbf{s}_{diff}$	Diffuse intensity
$\mathbf{s}_{spec}$	Specular intensity
$\mathbf{s}_{pos}$	Light source position

Notation	Description
$\mathbf{m}_{amb}$	Ambient material
$\mathbf{m}_{diff}$	Diffuse material
$\mathbf{m}_{spec}$	Specular material
m_{shi}	"Shininess"
$\mathbf{m}_{emi}$	Emitting

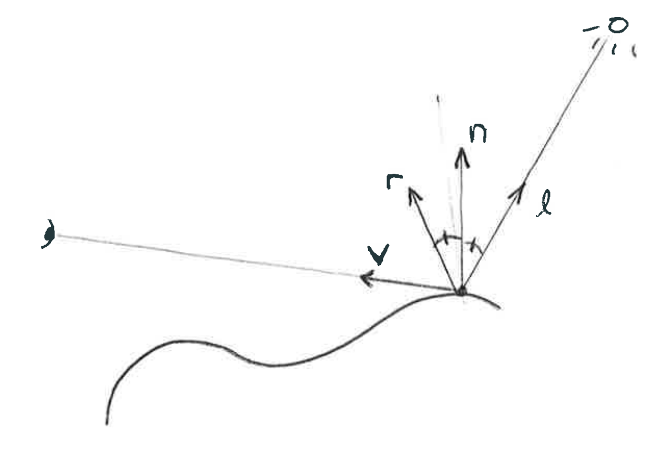
Diffuse/Lambertian



- View independent
- Lambertian Surface (Looks the same from all directions)

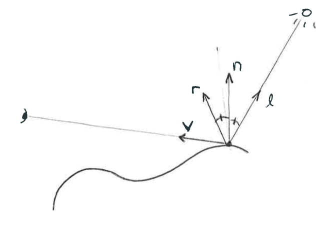
$$i_{diff} = \mathbf{n}^{\mathrm{T}}\mathbf{l} = \cos\theta$$
$$\mathbf{i}_{diff} = \max\left((0, \mathbf{n}^{\mathrm{T}}\mathbf{l})\right) \mathbf{m}_{diff} \circ \mathbf{s}_{diff}$$

Specular



Specular

- View dependent
- Non-linear "highlights"
  $\mathbf{r} = 2(\mathbf{n}^{\mathrm{T}}\mathbf{l})\mathbf{n} - \mathbf{l}$

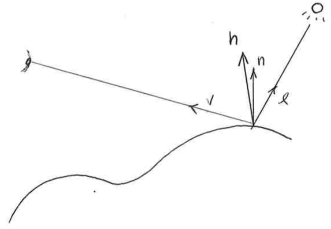


Phong $i_{spec} = (\mathbf{r}^{\mathrm{T}}\mathbf{v})^{m_{shi}}$

Blinn

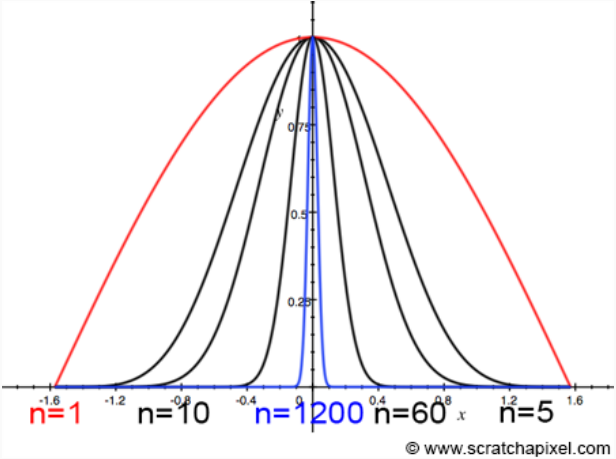
$$i_{spec} = (\mathbf{n}^{\mathrm{T}}\mathbf{h})^{m_{shi}}$$

$$\mathbf{h} = \frac{\mathbf{l} + \mathbf{v}}{((\mathbf{l} + \mathbf{v})^{\mathrm{T}}(\mathbf{l} + \mathbf{v}))^{\frac{1}{2}}}$$



- Specular colour $\mathbf{i}_{spec} = \max((0, i_{spec}))\,\mathbf{m}_{spec} \circ \mathbf{s}_{spec}$

Specular



y
0.75
0.5
0.25
-1.6
-1.2
-0.8
-0.4
0
0.4
0.8
1.2
1.6
x
n=1
n=10
n=1200
n=60
n=5
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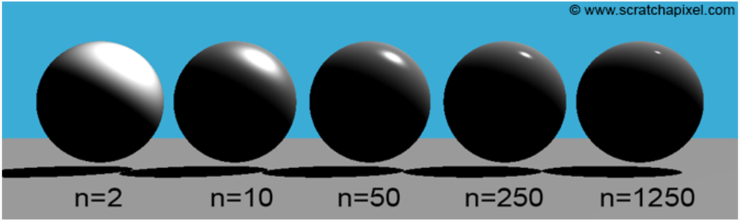
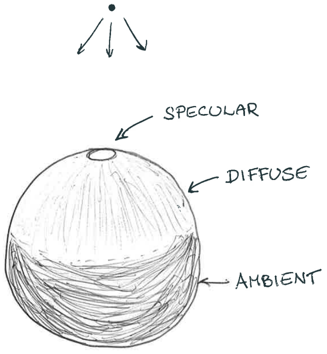
Specular



Ambient



- Accounts for indirect light
- Not particularly realistic

$$\mathbf{i}_{amb} = \mathbf{m}_{amb} \circ \mathbf{s}_{amb}$$

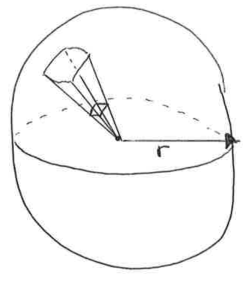
Distance Attenuation

$$\mathbf{i}_{tot} = f(\mathbf{i}_{amb}, \mathbf{i}_{diff}, \mathbf{i}_{spec})$$

- Law of conservation of matter: $A = 4\pi r^2$
- Distance attenuation

$$d = \left(s_c + s_l \cdot r + s_q \cdot r^2\right)^{-1}$$
$$r = \left((\mathbf{s}_{pos} - \mathbf{p})^{\mathrm{T}}(\mathbf{s}_{pos} - \mathbf{p})\right)^{\frac{1}{2}}$$

Distance Attenuation



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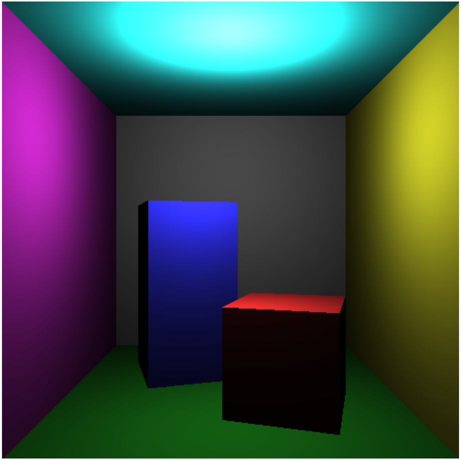
$$r = \left((\mathbf{s}_{pos} - \mathbf{p})^{\mathrm{T}}(\mathbf{s}_{pos} - \mathbf{p})\right)^{\frac{1}{2}}$$

All Together

$$
\begin{aligned}
\mathbf{i}_{tot} &= f(\mathbf{i}_{amb}, \mathbf{i}_{diff}, \mathbf{i}_{spec}) \\
&= \mathbf{m}_{emi} + \sum_{i=0}^{N-1} \Big(\mathbf{m}_{amb} \circ \mathbf{s}^i_{amb} \\
&+ \frac{\max((\mathbf{n}^{\mathrm{T}}\mathbf{l}^i), 0)\mathbf{m}_{diff} \circ \mathbf{s}^i_{diff} + \max((\mathbf{n}^{\mathrm{T}}\mathbf{h}^i), 0)^{m_{shi}}\mathbf{m}_{spec} \circ \mathbf{s}^i_{spec}}{s^i_c + s^i_l\left((\mathbf{s}_{pos} - \mathbf{p})^{\mathrm{T}}(\mathbf{s}_{pos} - \mathbf{p})\right)^{\frac{1}{2}} + s^i_q\left((\mathbf{s}^i_{pos} - \mathbf{p})^{\mathrm{T}}(\mathbf{s}^i_{pos} - \mathbf{p})\right)^{\frac{1}{2}}}\Bigg)
\end{aligned}
$$

Lab



Summary

Summary

- Light is really simple but unrealistic to render correctly
- Approximations
  - Factorise light
  - Add control parameters

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- *Graphics is physics but we are not making simulators, if it looks good its correct*

Summary

- Light is really simple but unrealistic to render correctly
- Approximations
  - Factorise light
  - Add control parameters
- *"Cheating is art"* - Azure/Artwork
- *Graphics is physics but we are not making simulators, if it looks good its correct*
- Play, be innovative, there is no right or wrong

Next Time

Lecture Monday 5th of February

- Illumination: Light II
- BRDFs
- Shadows
- Mappings

Lab Continue with Lab 1

END

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