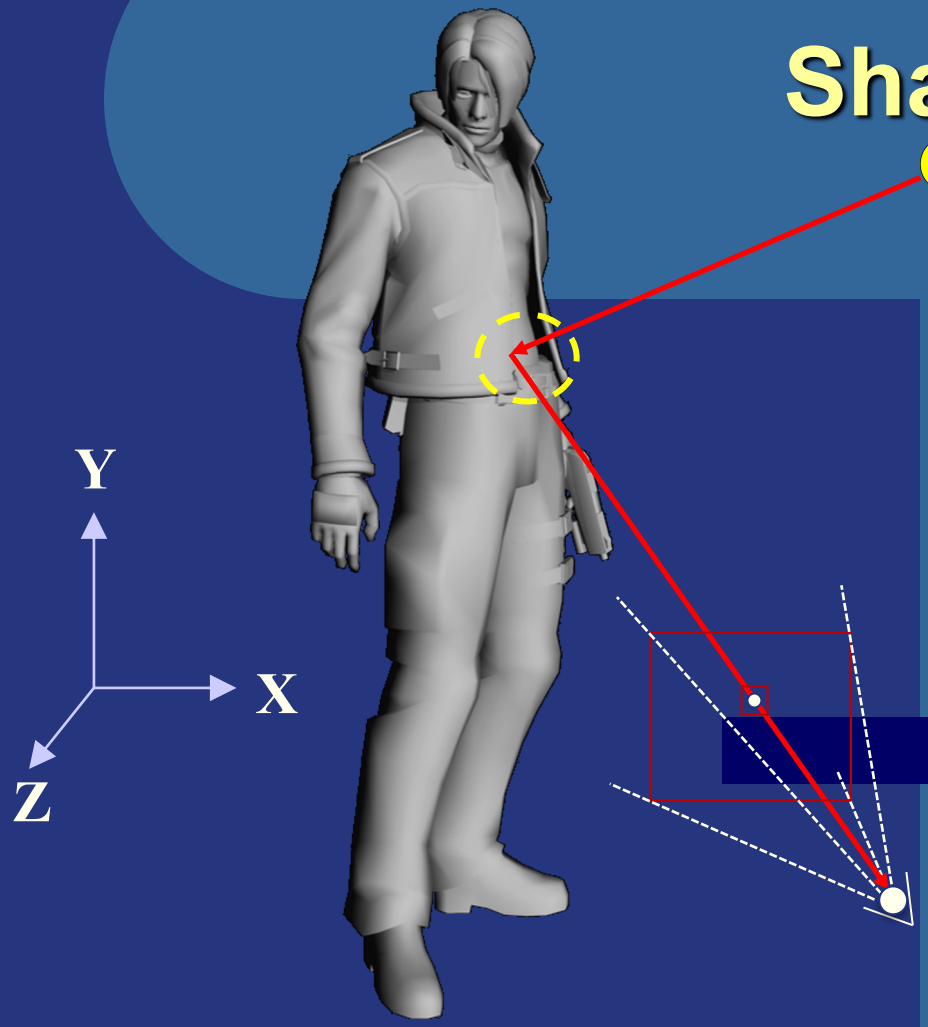
Shading



Slides by Ulf Assarsson and Tomas Akenine-Möller

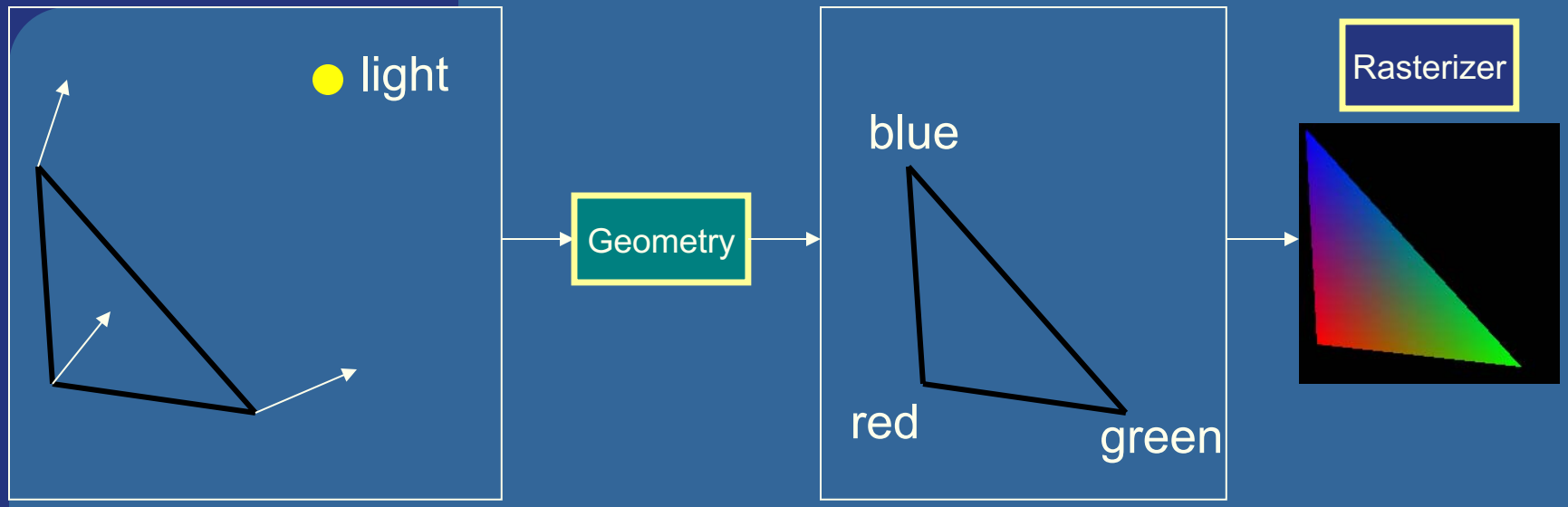
Department of Computer Engineering

Chalmers University of Technology

Overview of today's lecture

- A simple most basic real-time lighting model
  - It is also OpenGL's old fixed pipeline lighting model
- Fog
- Gamma correction
- Transparency and alpha

Compute lighting at vertices, then interpolate over triangle



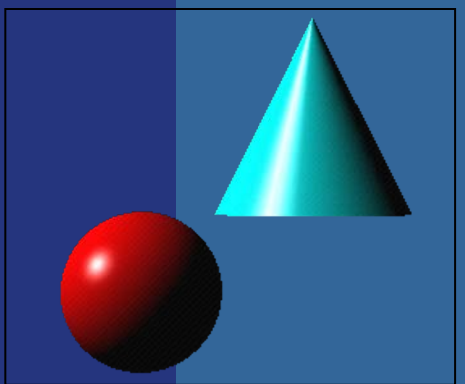
- How compute lighting?
- We could set colors per vertex manually
- For a **little** more realism, compute lighting from
  - Light sources
  - Material properties
  - Geometrical relationships

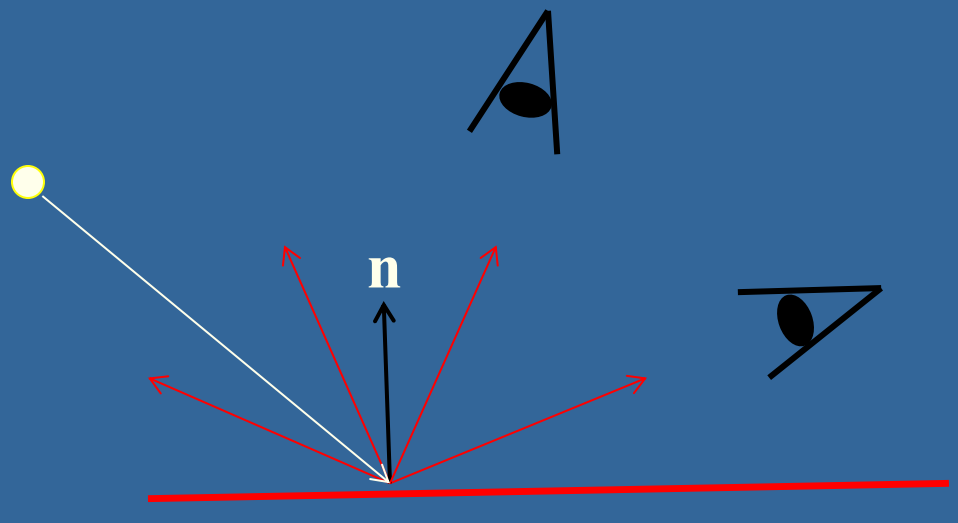
The ambient/diffuse/specular/emission model

- Also the most basic real-time model:
- Light interacts with material and change color at bounces:

$$\mathbf{outColor}_{rgb} \sim \mathbf{material}_{rgb} \otimes \mathbf{lightColor}_{rgb}$$

- Diffuse light: the part that spreads equally in **all** directions (view independent) due to that the surface is very **rough** on microscopic level





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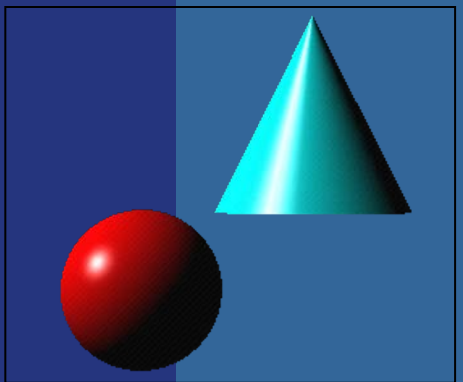
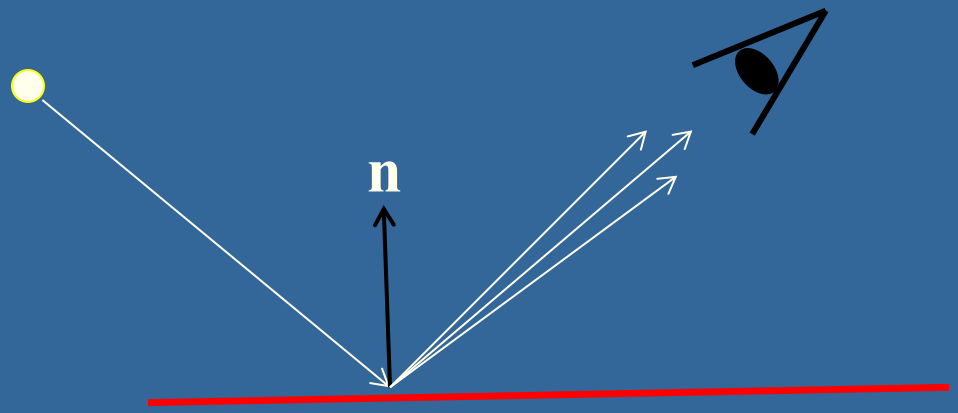
- Specular light: the part that spreads mostly in the reflection direction (often same color as light source)





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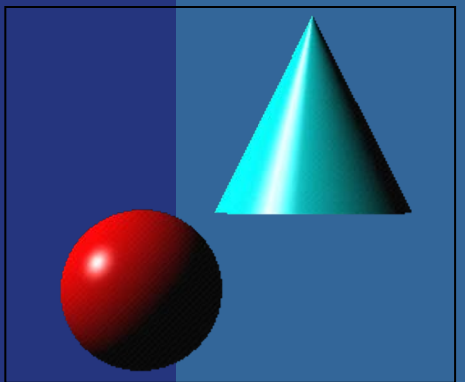
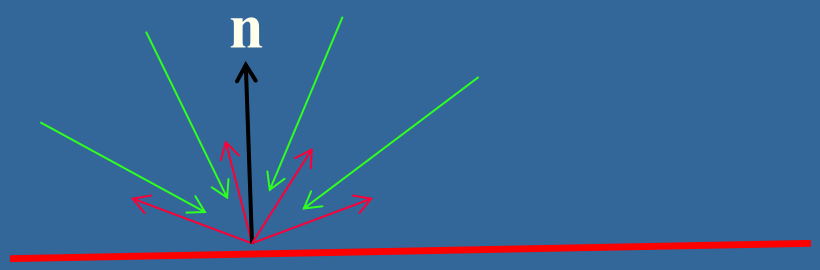
$$\mathbf{outColor}_{rgb} \sim \mathbf{material}_{rgb} \otimes \mathbf{lightColor}_{rgb}$$

- Diffuse light: the part that spreads in all direction (view independent)
- Specular light: the part that spreads mostly in the reflection direction (often same color as light source)
- Ambient light: incoming background light from all directions and spreads in all directions (view-independent and light-position independent color)



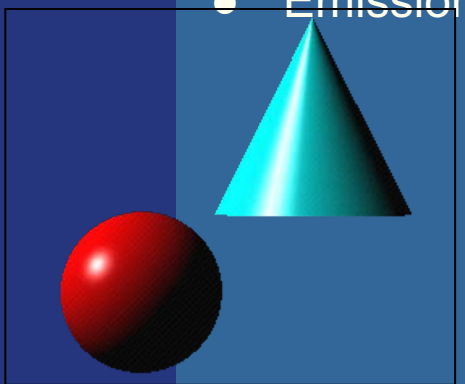


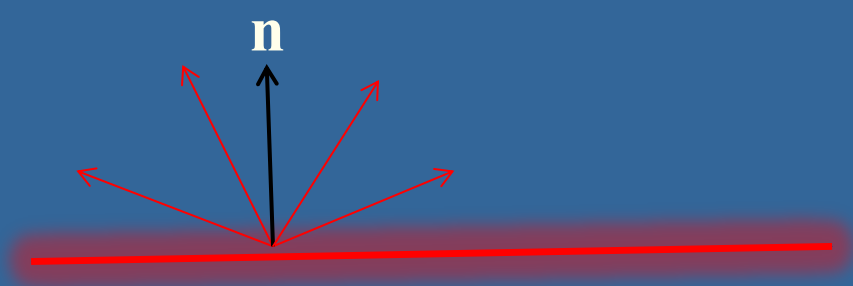
The ambient/diffuse/specular/emission model

- Also the most basic real-time model:
- Light interacts with material and change color at bounces:

$$\mathbf{outColor}_{rgb} \sim \mathbf{material}_{rgb} \otimes \mathbf{lightColor}_{rgb}$$

- Diffuse light: the part that spreads in all direction (view independent)
- Specular light: the part that spreads mostly in the reflection direction (often same color as light source)
- Ambient light: incoming background light from all directions and spreads in all directions (view-independent and light-position independent color)
- Emission: self-glowing surface



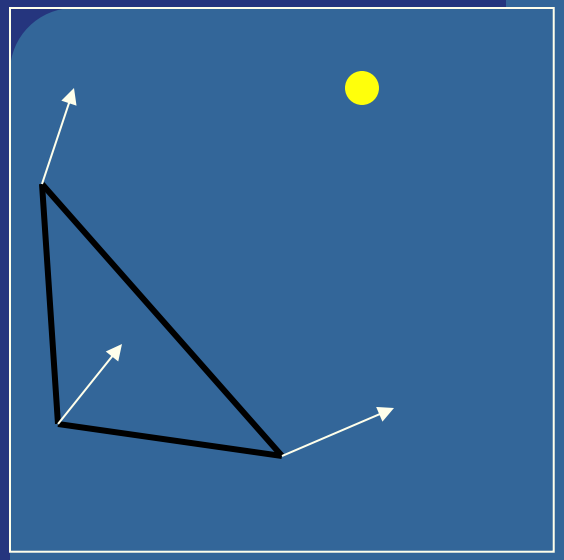


A basic lighting model

Light: (r,g,b)

or even

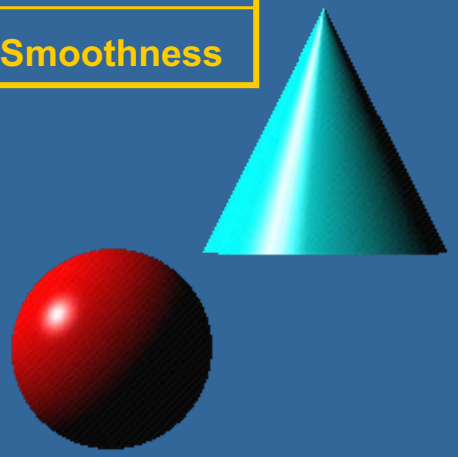
- Ambient (r,g,b,a)
- Diffuse (r,g,b,a)
- Specular (r,g,b,a)



DIFFUSE	Base color
SPECULAR	Highlight Color
AMBIENT	Low-light Color
EMISSION	Glow Color
SHININESS	Surface Smoothness

Material:

- Ambient (r,g,b,a)
- Diffuse (r,g,b,a)
- Specular (r,g,b,a)
- Emission (r,g,b,a) =”självlysande färg”



Ambient component: i_{amb}

- Ad-hoc – tries to account for light coming from other surfaces
- Just add a constant color:

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

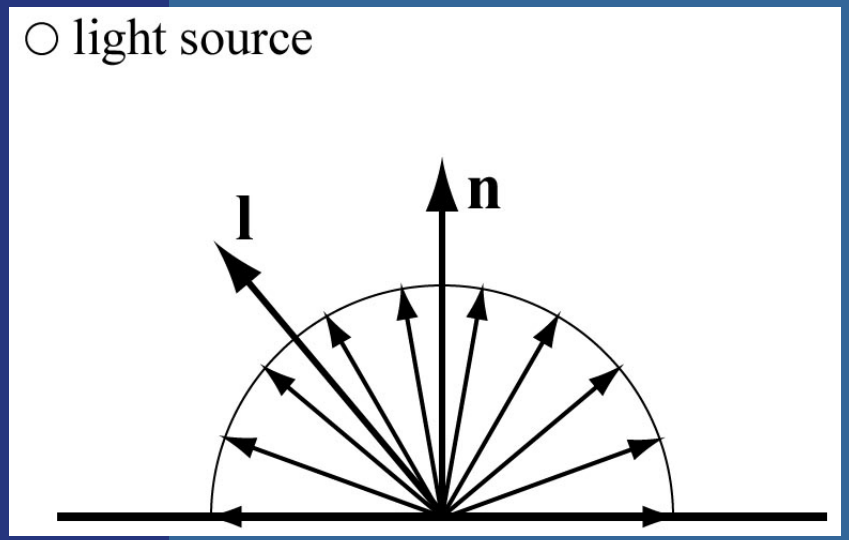
i.e., $(i_r, i_g, i_b, i_a) = (m_r, m_g, m_b, m_a)\ (l_r, l_g, l_b, l_a)$

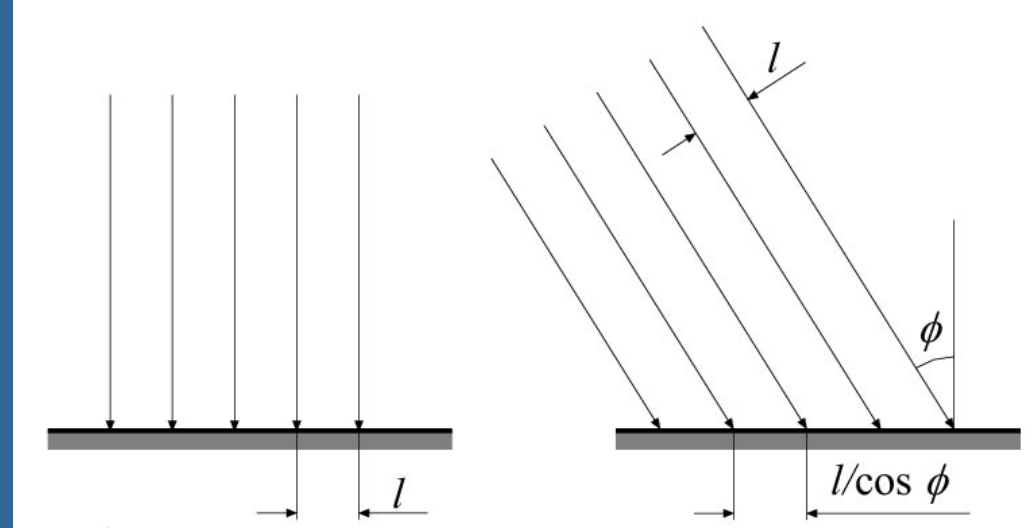
Diffuse component : i_{diff}

- $i = i_{amb} + i_{diff} + i_{spec}$
- Diffuse (Lambert's law): $i_{diff} = \mathbf{n} \cdot \mathbf{l} = \cos\phi$
- Photons are scattered equally in all directions

$$\mathbf{i}_{diff} = (\mathbf{n} \cdot \mathbf{l})\mathbf{m}_{diff} \otimes \mathbf{s}_{diff}$$

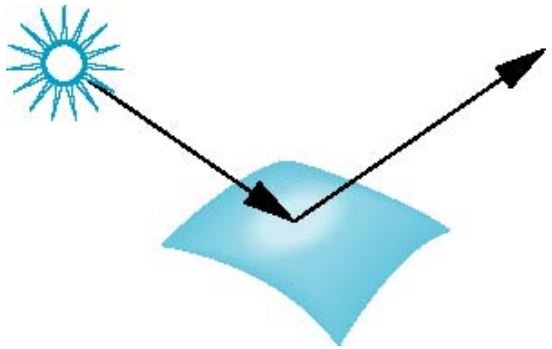
n and **l** are assumed being unit vectors



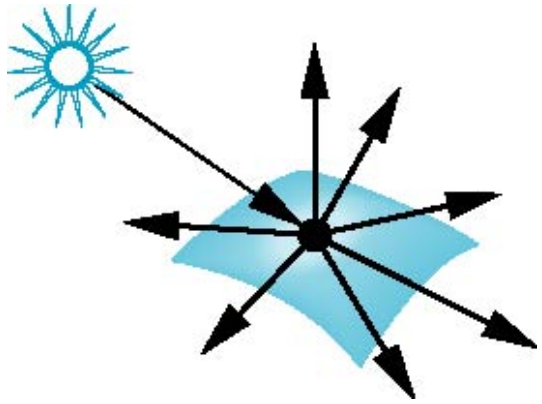


Lambertian Surfaces

- Perfectly diffuse reflector
- Light scattered equally in all directions

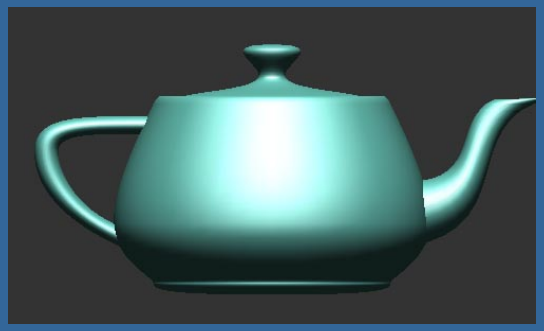


Highly reflective surface (specular)

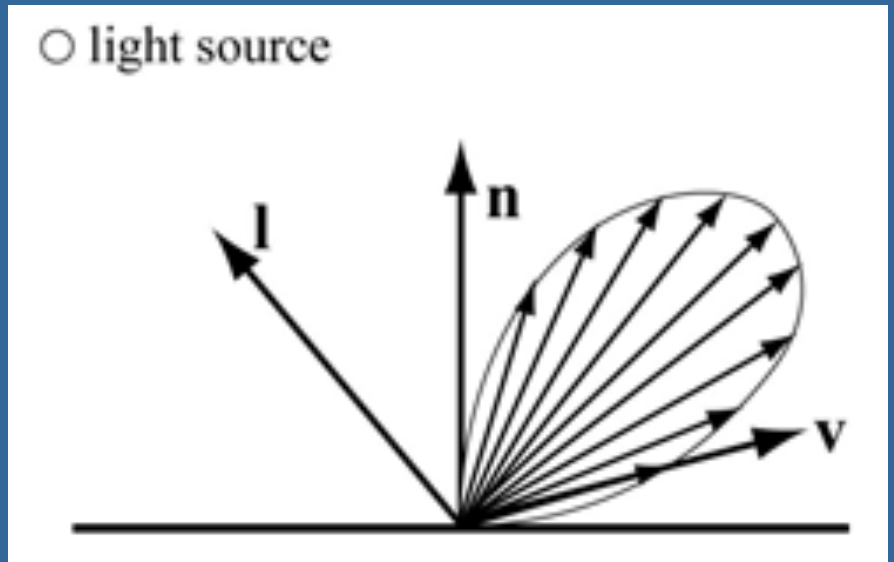


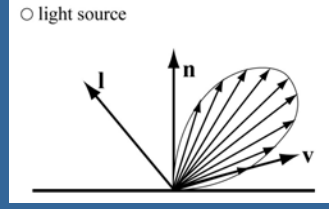
Fully diffuse surface (Lambertian)

Lighting
Specular component : i_{spec}



- Diffuse is dull (left)
- Specular: simulates a highlight



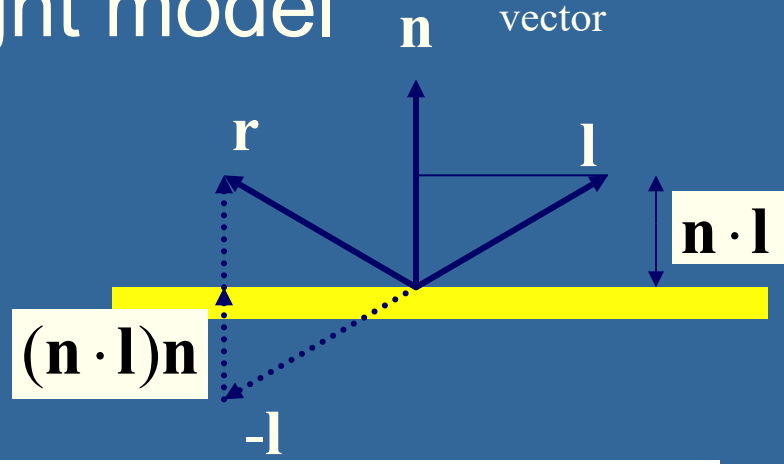


Specular component: Phong

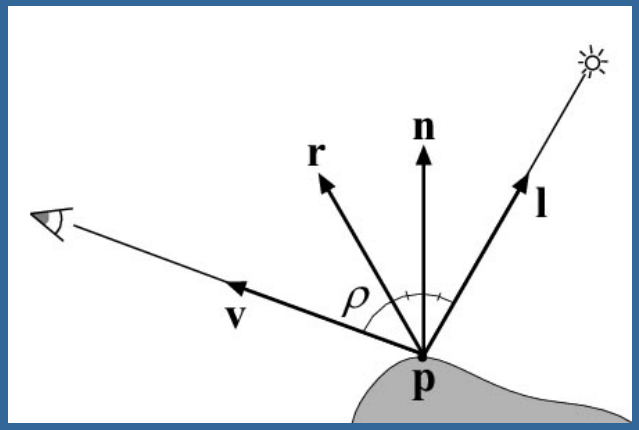
- Phong specular highlight model
- Reflect **l** around **n**:

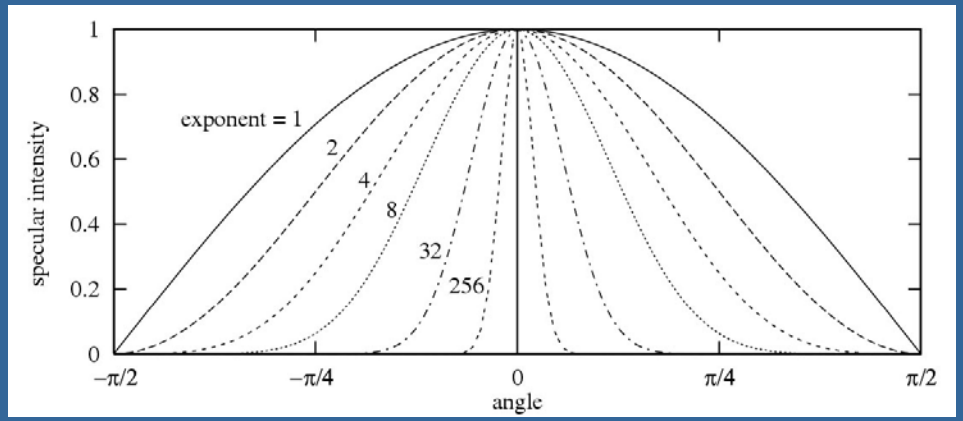
$$\mathbf{r} = -\mathbf{l} + 2(\mathbf{n} \cdot \mathbf{l})\mathbf{n}$$

n must be unit vector



$$i_{spec} = (\mathbf{r} \cdot \mathbf{v})^{m_{shi}} = (\cos\rho)^{m_{shi}}$$





$$\mathbf{i}_{spec} = ((\mathbf{n} \cdot \mathbf{l}) < 0) \ ? \ 0 \ : \ \max(0, (\mathbf{r} \cdot \mathbf{v}))^{m_{shi}} \mathbf{m}_{spec} \otimes \mathbf{s}_{spec}$$

- Next: Blinns highlight formula: $(\mathbf{n} \cdot \mathbf{h})^{m}$

Halfway Vector

Blinn proposed replacing **v**·**r** by **n**·**h** where

h = (**l**+**v**)/|**l** + **v**|

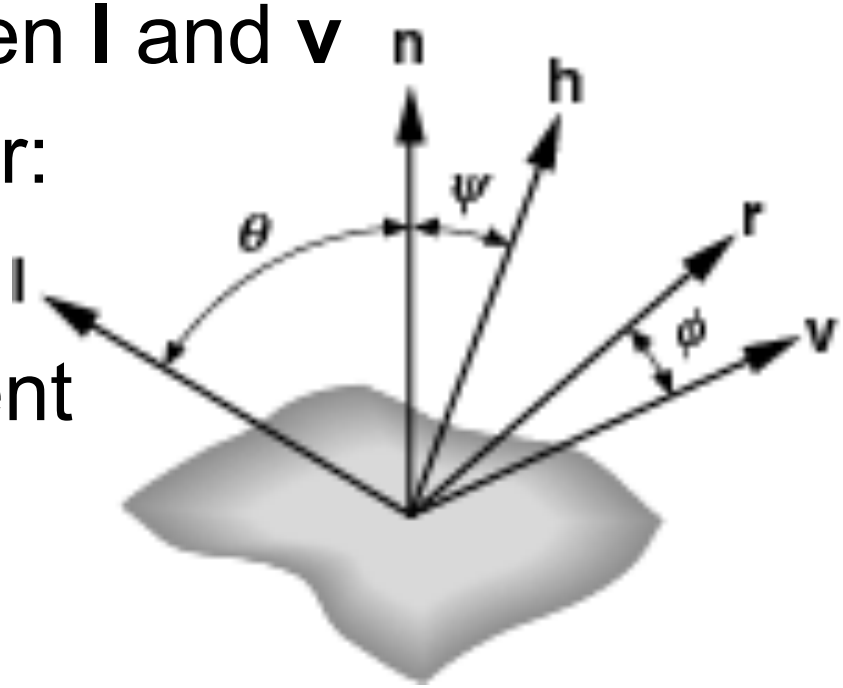
(**l**+**v**)/2 is halfway between **l** and **v**

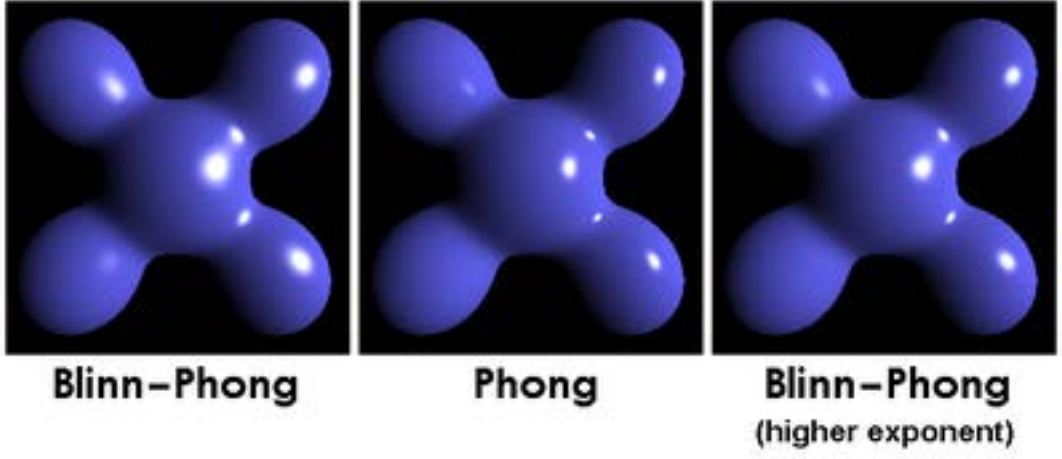
If **n**, **l**, and **v** are coplanar:

$$\psi = \phi/2$$

Must then adjust exponent so that $(\mathbf{n}\cdot\mathbf{h})^{e'} \approx (\mathbf{r}\cdot\mathbf{v})^{e}$

$$(e' \approx 4e)$$





Efficiency

The Blinn rendering model is less efficient than pure Phong shading in most cases, since it contains a square root calculation. While the original Phong model only needs a simple vector reflection, this modified form takes more into consideration. However, as many CPUs and GPUs contain single and double precision square root functions (as standard features) and other instructions that can be used to speed up rendering -- the time penalty for this kind of shader will not be noticed in most implementations.

However, Blinn-Phong will be faster in the case where the viewer and light are treated to be at infinity. This is the case for directional lights. In this case, the half-angle vector is independent of position and surface curvature. It can be computed once for each light and then used for the entire frame, or indeed while light and viewpoint remain in the same relative position. The same is not true with Phong's original reflected light vector which depends on the surface curvature and must be recalculated for each pixel of the image (or for each vertex of the model in the case of vertex lighting).

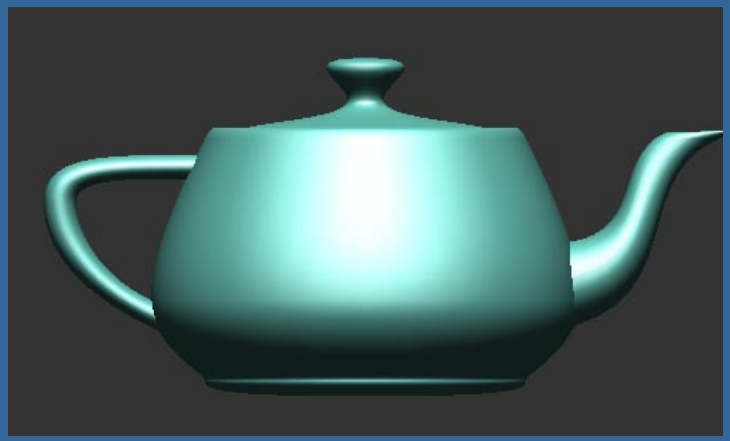
In most cases where lights are not treated to be at infinity, for instance when using point lights, the original Phong model will be faster.

Lighting

$i = i_{amb} + i_{diff} + i_{spec}$


+

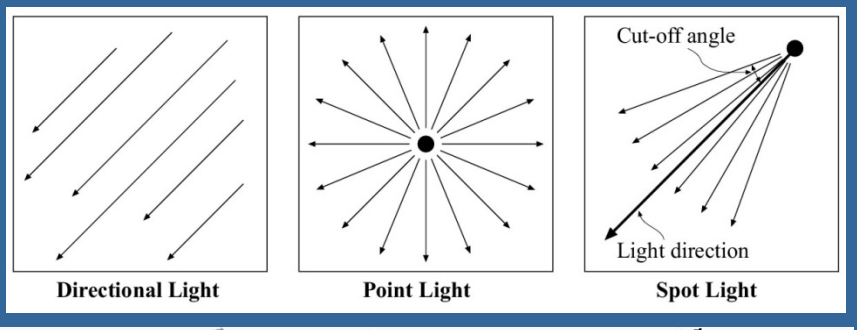
+

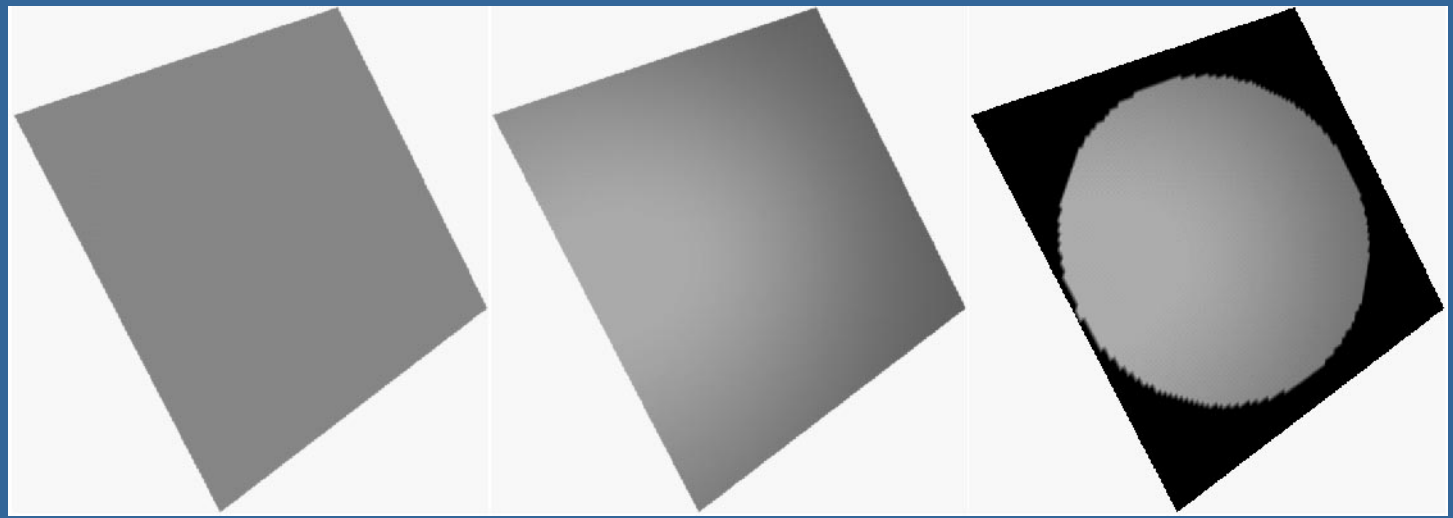
=


- This is just a hack!
- Has little to do with how reality works!

Additions to the lighting equation

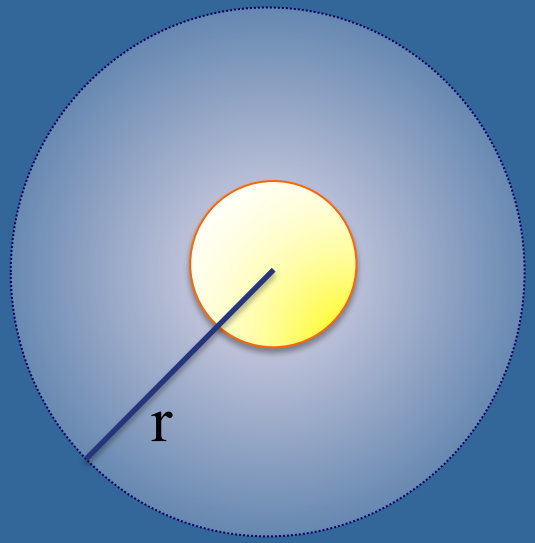
- Accounting for distance: $1/(a+bt+ct^2)$
- Several lights: just sum their respective contributions
- Different light types:





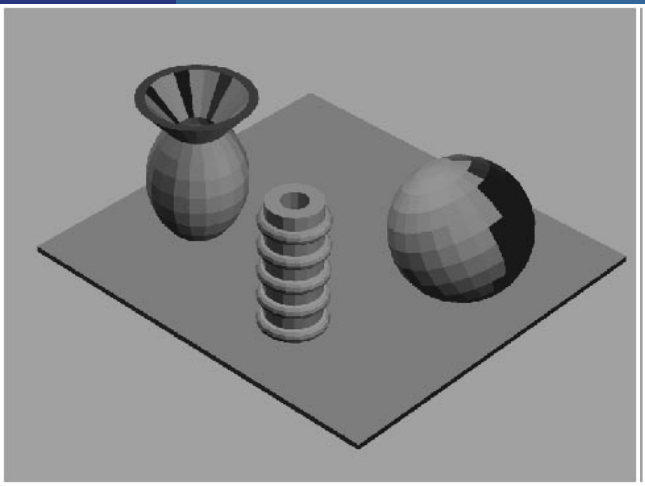
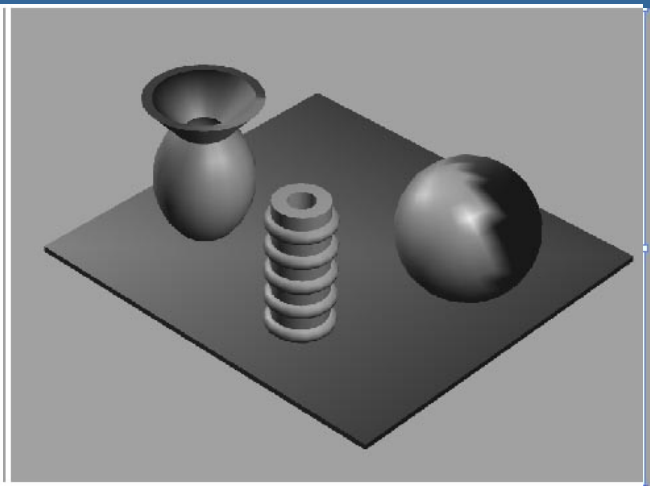
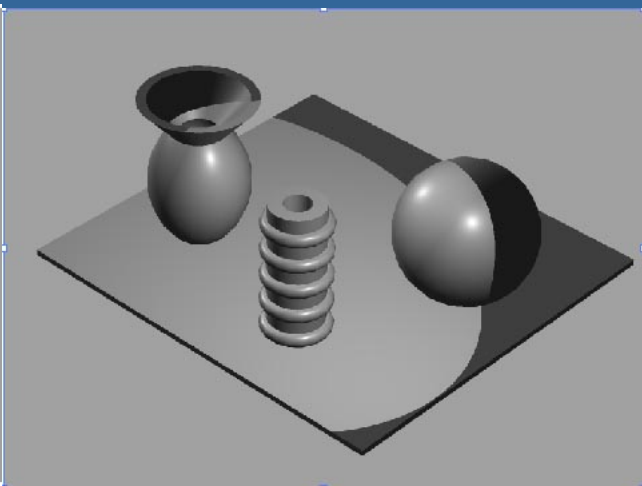
Clarifications

- Energy is emitted at equal proportions in all directions from a spherical radiator. Due to energy conservation, the intensity is proportional to the spherical area at distance r from the light center.
- $A = 4\pi r^2$
- Thus, the intensity scales $\sim 1/r^2$



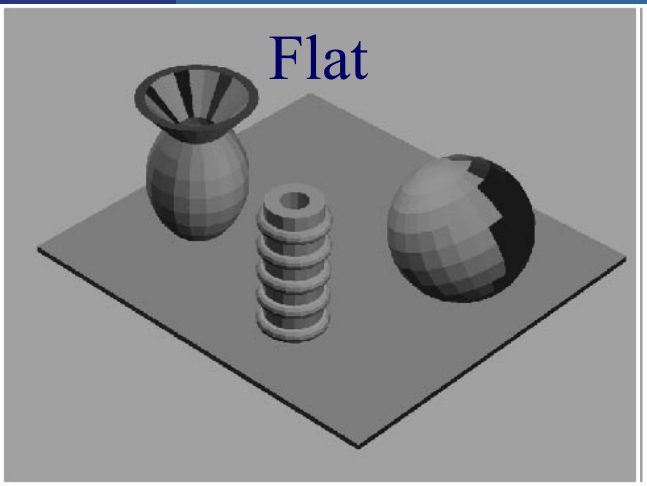
Shading

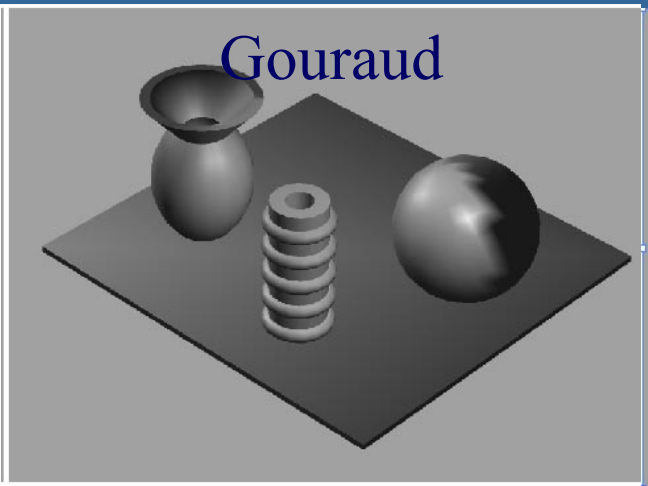
- Shading: do lighting (at e.g. vertices) and determine pixel's colors from these
- Three common types of shading:
  - Flat, Goraud, and Phong

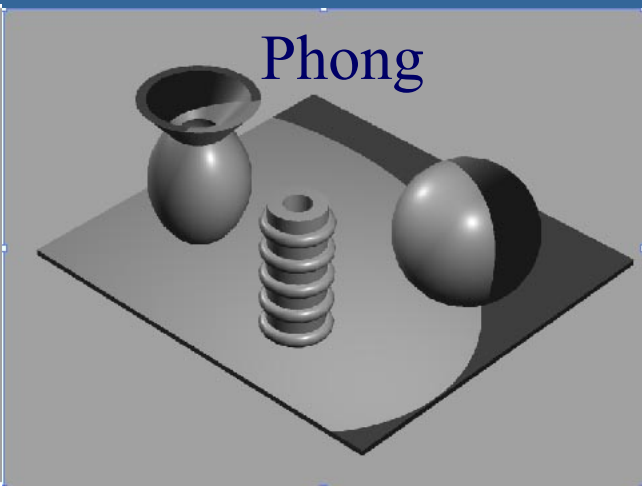




Shading

- Three common types of shading:
  - Flat, Goraud, and Phong
- In standard Gouraud shading the lighting is computed per triangle vertex and for each pixel, the **color is interpolated** from the colors at the vertices.
- In Phong Shading the lighting is **not** computed per vertex. Instead the **normal is interpolated** per pixel from the normals defined at the vertices and full lighting is computed per pixel using this normal. This is of course more expensive but looks better.







Gouraud Shading Code

For one light source

```
// Vertex Shader
#version 130

in  vec3 vertex;
in vec3 normal;
uniform  vec4 mtrlAmb, mtrlDiffuse, mtrlSpec, mtrlEmission;
uniform  vec4 lightAmb, lightDiffuse, lightSpec;
uniform float shininess;
uniform mat4 modelViewProjectionMatrix, normalMatrix, modelViewMatrix;
uniform vec4 lightPos; // in view space
out vec3 outColor;

void main()
{
      gl_Position = modelViewProjectionMatrix*vec4(vertex,1);
      // ambient
      outColor = lightAmb * mtrlAmb;

      // diffuse
      vertex = vec3(modelViewMatrix * vec4(vertex,1)); // vertex in view space
      normal = normalize(normalMatrix * normal);          // normal in view space
      vec3 lightDirection = normalize(lightPos – vertex.xyz);
      float intensity=max(0, dot(normal, lightDirection)    // “n dot l”
      outColor += lightDiffuse*mtrlDiffuse*intensity;       // l_rgba dot mtrl_rgba

      // specular
      vec3 viewVec = normalize(-vertex.xyz); // because we are in view space
      vec3 reflVec = -lightDirection + normal*(2*dot(normal, lightDirection));
      intensity=pow(max(0,(dot(reflVec, viewVec)), shininess));
      outColor += lightSpec * mtrlSpec * intensity;
}
```

```
// Fragment Shader:
#version 130
in  vec3 outColor;
out vec4 fragColor;

void main()
{
      fragColor =
      vec4(outColor,1);
}
```

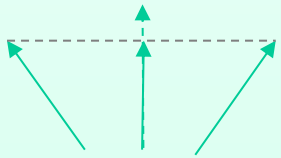
$$\mathbf{r} = -\mathbf{l} + 2(\mathbf{n}\cdot\mathbf{l})\mathbf{n}$$

$$\mathbf{i}_{spec} = ((\mathbf{n}\cdot\mathbf{l}) < 0) \ ? \ 0 \ : \ \max(0,(\mathbf{r}\cdot\mathbf{v}))^{m_{shi}}\,\mathbf{m}_{spec} \otimes \mathbf{s}_{spec}$$

Phong Shading Code **For one light source**

```
// Vertex Shader
#version 130

in  vec3 vertex;
in vec3 normal;
uniform  vec3 mtrlAmb;
uniform  vec3 lightAmb;
uniform vec4 lightPos;
uniform mat4 modelViewProjectionMatrix;
uniform mat4 normalMatrix;
uniform mat4 modelViewMatrix;
out vec3 outColor;
out vec3 N;
out vec3 viewVec;
out vec3 lightDirection;

void main()
{
      gl_Position = modelViewProjectionMatrix*
                  vec4(vertex,1);

      // ambient
      outColor = lightAmb * mtrlAmb;

      N= normalize(normalMatrix * normal);
      lightDirection = normalize(lightPos – vertex.xyz);
      viewVec=-vec3(modelViewMatrix*vec4(vertex,1));
}
```

```
// Fragment Shader:
#version 130
in  vec3 outColor, lightDirection, N, pos;
in vec3 viewVec;
uniform  vec3 mtrlDiffuse, mtrlSpec, mtrlEmission;
uniform  vec3 lightDiffuse, lightSpec;
uniform float shininess;
out vec4 fragColor;


void main()
{
   N = normalize(N); // renormalize due to the interpolation
   lightDirection = normalize(lightDirection);
   // diffuse lighting contribution:
   float intensity=max(0, dot(N, lightDirection)
   outColor += lightDiffuse*mtrlDiffuse*intensity;

   // specular
   vec3 reflVec = -lightDirection + N*(2*dot(N,lightDirection));
   intensity=pow(max(0,(dot(reflVec, viewVec)), shininess));
   outColor += lightSpec * mtrlSpec * intensity;
   fragColor = vec4(outColor,1);
}
```



Transparency and alpha

- Transparency
  - Very simple in real-time contexts
- The tool: alpha blending (mix two colors)
- Alpha (α) is the forth color component (r,g,b,α)
  - e.g., of the material for a triangle
  - Represents the opacity
  - 1.0 is totally opaque
  - 0.0 is totally transparent
- The over operator:

$$\mathbf{c}_o = \alpha \mathbf{c}_s + (1-\alpha)\mathbf{c}_d$$

Rendered object

Transparency

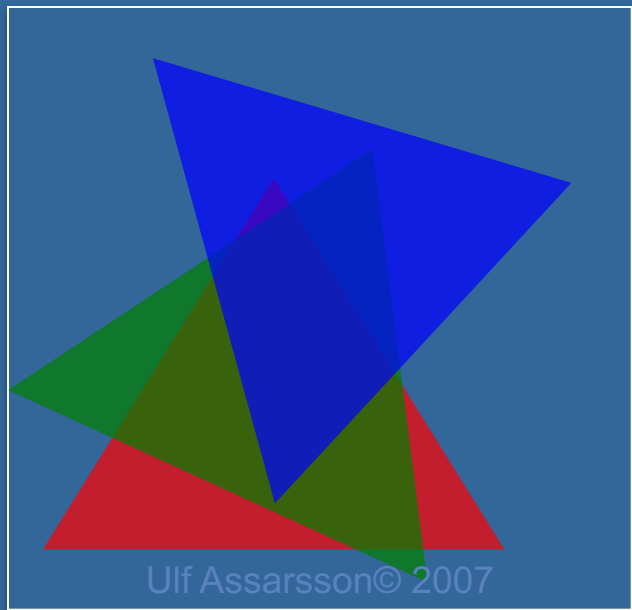
$$\mathbf{c}_o = \alpha \mathbf{c}_s + (1-\alpha)\mathbf{c}_d$$

Rendered fragment

Background

- Need to sort the transparent objects
  - Render back to front (blending is order dep.)
    - See next slide…
- Lots of different other blending modes
- Can store RGBα in textures as well

So the texels with α=0.0 do not not hide the objects behind



Transparency

- Need to sort the transparent objects
  - **First, render all non-transparent triangles as usual.**
  - **Then, sort all transparent triangles and render them back-to-front with blending enabled.**
    - **The reason for sorting is that the blending operation (i.e., over operator) is order dependent.**

If we have high frame-to-frame coherency regarding the objects to be sorted per frame, then Bubble-sort (or Insertion sort) are really good! (superior to Quicksort).
Because, they have expected runtime of resorting already almost sorted input in O(n) instead of O(n log n), where n is number of elements.

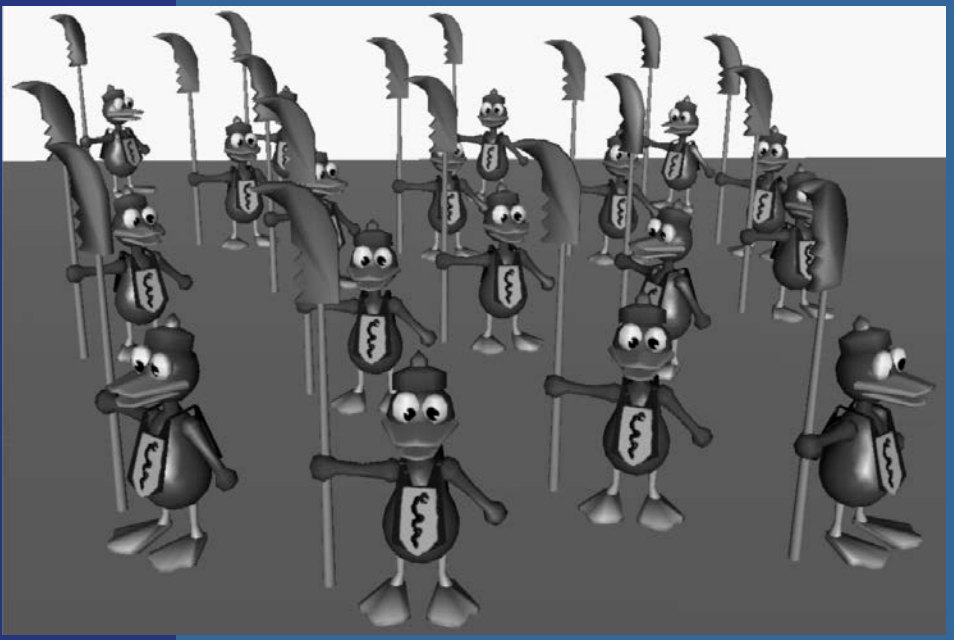
Blending

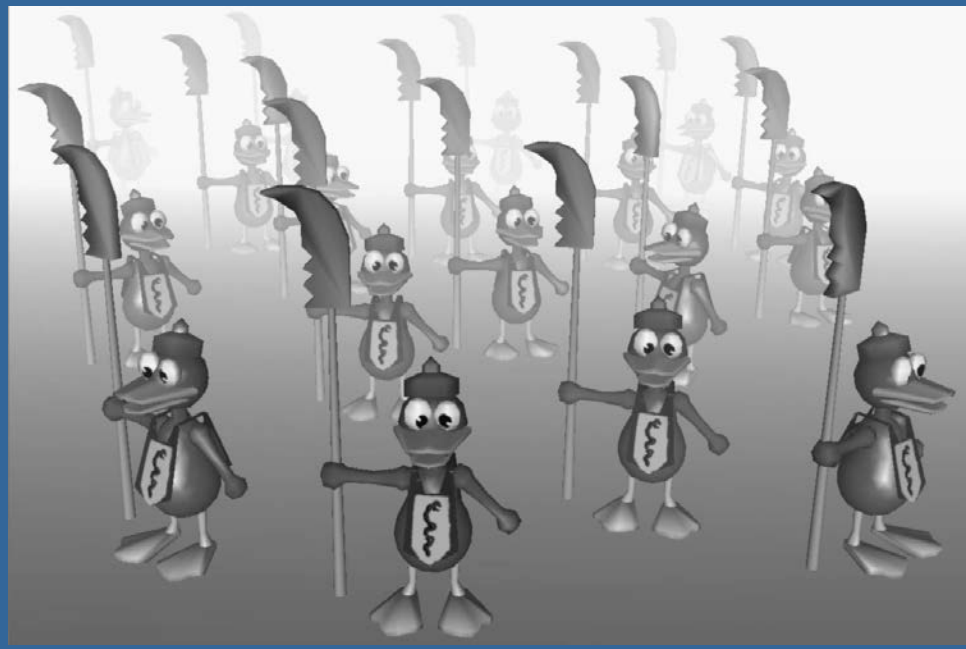
- Used for
  - Transparency
    - **glBlendFunc(GL_SRC_ALPHA, GL_ONE_MINUS_SRC_ALPHA)**
  - Effects (shadows, reflections)
  - (Complex materials)
    - Quake3 used up to 10 rendering passes, blending toghether contributions such as:
      - Diffuse lighting (for hard shadows)
      - Bump maps
      - Base texture
      - Specular and emissive lighting
      - Volumetric/atmospheric effects
  - Enable with **glEnable(GL_BLEND)**

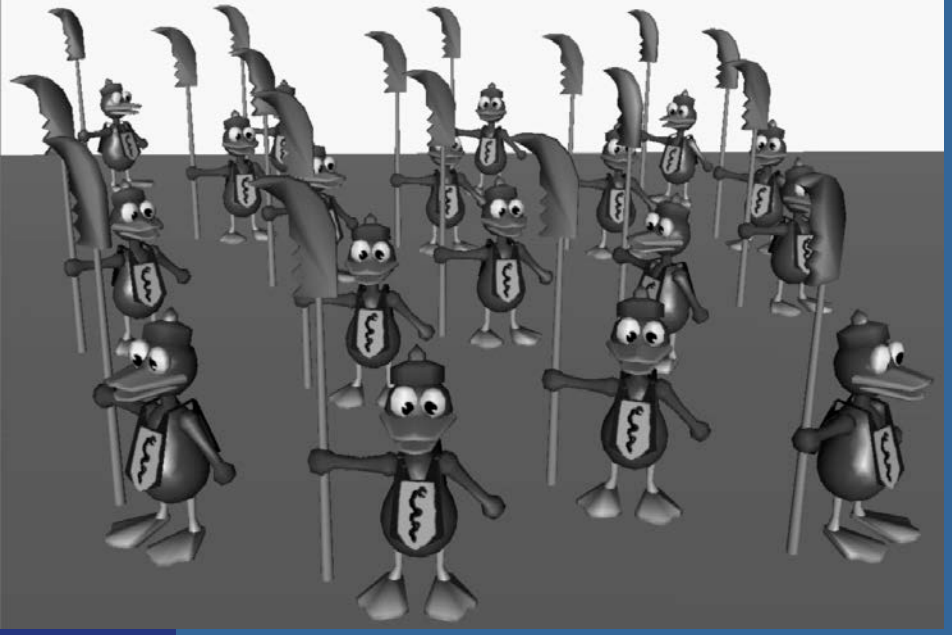
$$\mathbf{c}_o = \alpha \mathbf{c}_s + (1-\alpha)\mathbf{c}_d$$

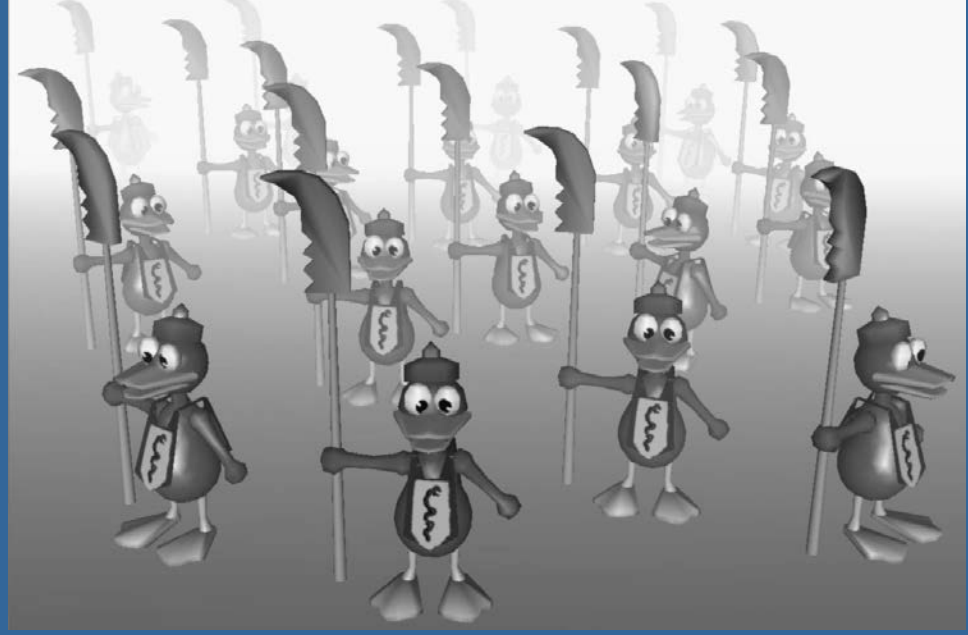
Fog

- Simple atmospheric effect
  - A little better realism
  - Help in determining distances









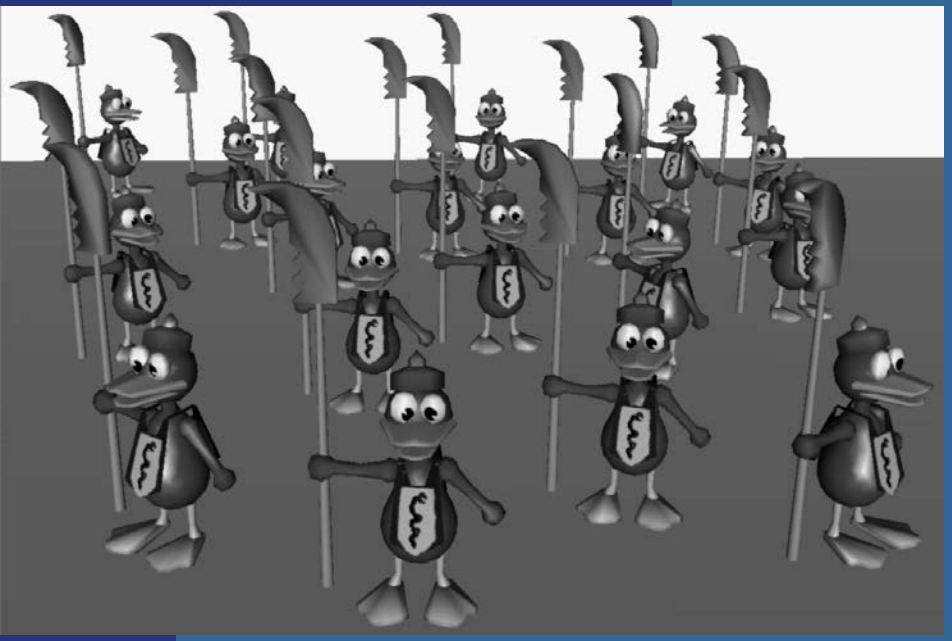
- Color of fog: $\mathbf{c}_f$ color of surface: $\mathbf{c}_s$

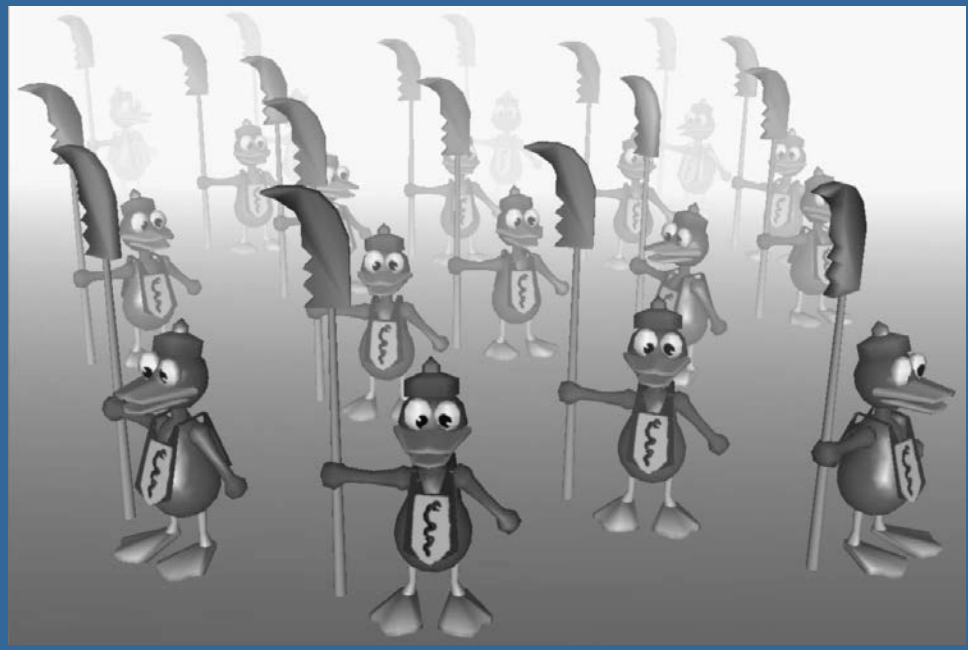
$$\mathbf{c}_p = f\mathbf{c}_s + (1-f)\mathbf{c}_f \qquad f \in [0,1]$$

- How to compute f?
- 3 ways: linear, exponential, exponential-squared
- Linear:

$$f = \frac{z_{end} - z_p}{z_{end} - z_{start}}$$

Fog example

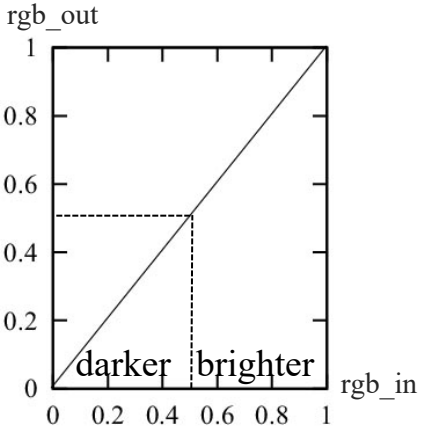




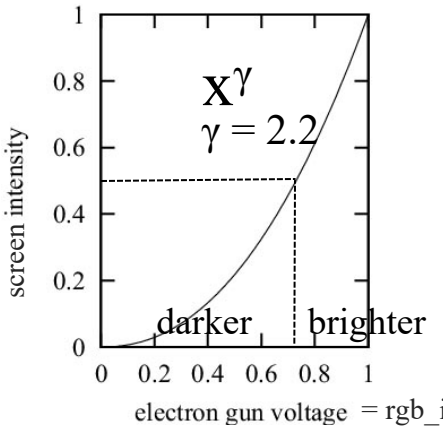
- Often just a matter of
  - Choosing fog color
  - Choosing fog model
  - Old OpenGL – just turn it on. New OpenGL – program it yourself in the fragment shader

Fog in up-direction

Gamma correction



Lighting computes rgb color intensities in linear space from [0,1]



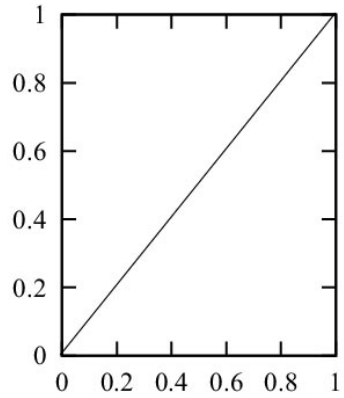
However, CRT-monitor output is exponential. Has more precision for darker regions. Very Good! But we need to adapt the input to utilize this. Else, our images will be too dark.

Expon. distribution better for humans. Our eyes have non-linear sensitivity and monitors have limited brightness

Intensities: x^γ vs linear

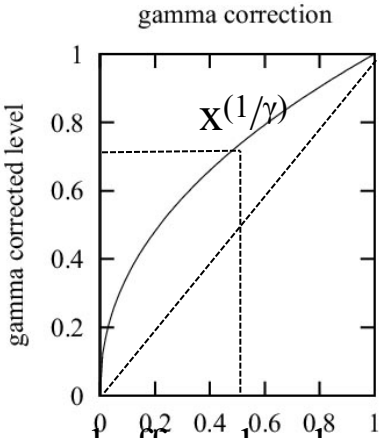
Textures: store in gamma space for better ditributed precision.

So, store color intensities with more precision for darker colors: i.e., convert color to $x^{(1/\gamma)}$ before storing in 8- bits in the frame buffer. Conversion to $x^{(1/\gamma)}$ is called gamma correction.

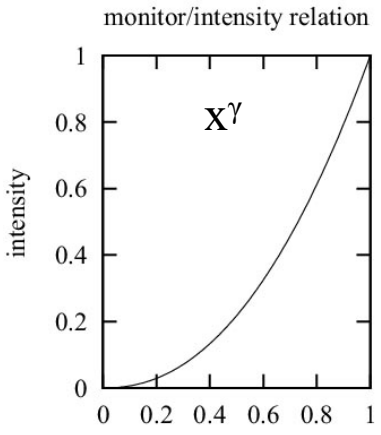


Shader rgb colors

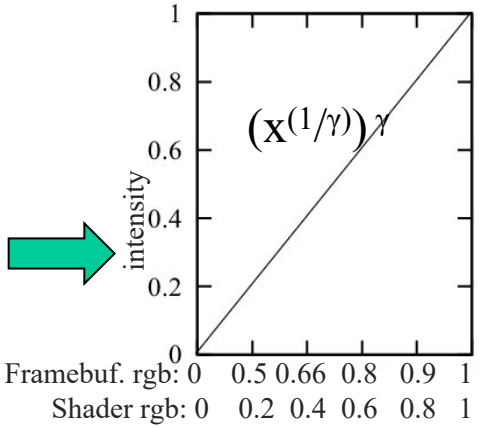
$x^{(1/\gamma)}$



Frame buffer rgb colors.
"Dark pixels are made brighter"

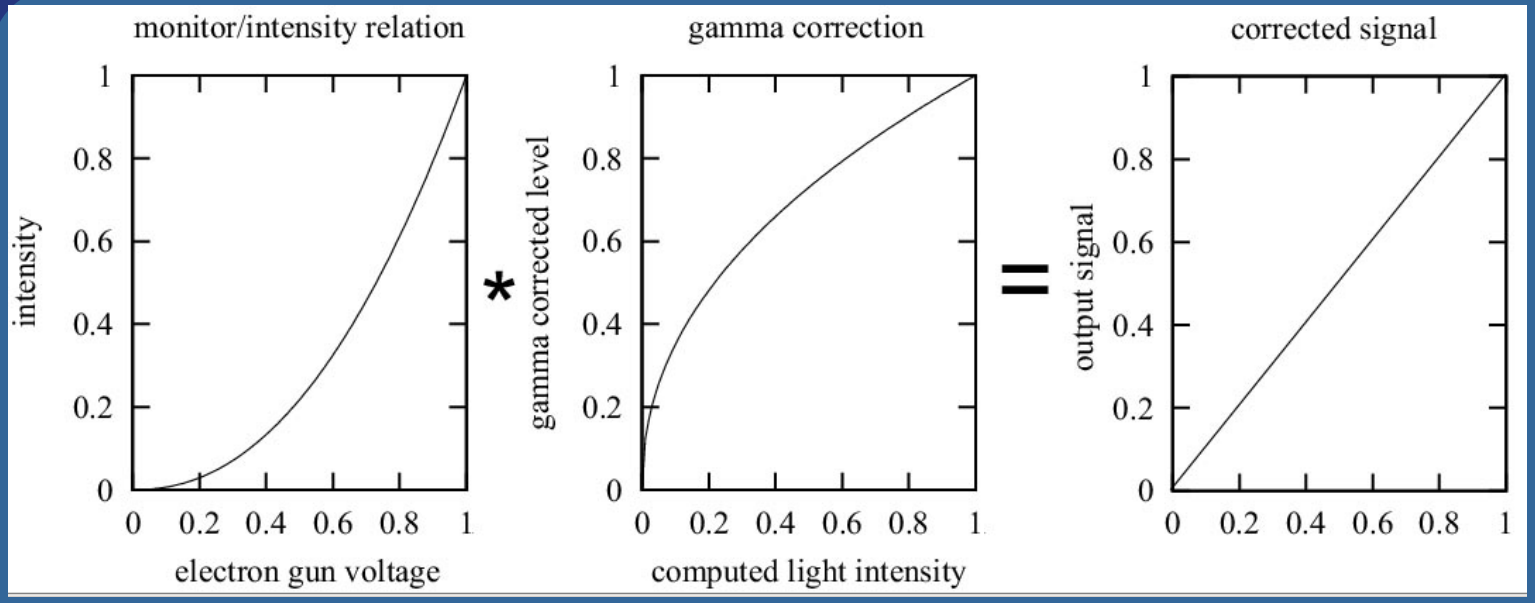


Displayed by CRT



Linear output again, but redistributed precision.

Gamma correction



- If input to gun is 0.5, then you don't get 0.5 as output in intensity
- Instead, gamma correct that signal: gives linear relationship

Gamma correction

$$I = a(V + \varepsilon)^{\gamma}$$

- *I*=intensity on screen
- *V*=input voltage (electron gun)
- *a*, ε, *and* γ *are* constants for each system
- Common gamma values: 2.2-2.6
- Assuming ε=0, gamma correction is:

$$c = c_i^{(1/\gamma)}$$

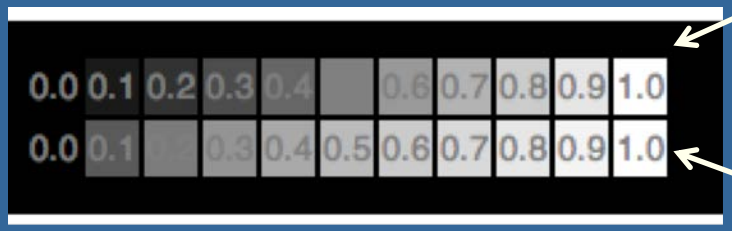
Why is it important to care about gamma correction?

- Portability across platforms
- Image quality
  - Texturing
  - Anti-aliasing
- One solution is to put gamma correction in hardware…
- sRGB asumes gamma=2.2
- Can use EXT_framebuffer_sRGB to render with gamma correction directly to frame buffer

Gamma correction today

- Reasons for wanting gamma correction (standard is 2.2):

1. Screen has non-linear color intensity
   - We often really want linear output (e.g. for correct antialiasing)
   - (But, today, screens can be made with linear output, so non-linearity is more for backwards compatibility reasons.)
2. Also happens to give more efficient color space (when compressing intensity from 32-bit floats to 8-bits). Thus, often desired when storing textures.



Gamma of 2.2. Better distribution for humans. Perceived as linear.

Truly linear intensity increase.

A linear intensity output (bottom) has a large jump in perceived brightness between the intensity values 0.0 and 0.1, while the steps at the higher end of the scale are hardly perceptible.
A nonlinearly-increasing intensity (upper), will show much more even steps in perceived brightness.

What is important

- Amb-, diff-, spec-, emission model + formulas
- Phong's + Blinn's highlight model
- Flat-, Gouraud- and Phong shading
- Transparency
- Fog
- Two reasons for wanting gamma correction

THE END