SCHOOL of ELECTRICAL ENGINEERING & COMPUTING
FACULTY of ENGINEERING & BUILT ENVIRONMENT
The UNIVERSITY of NEWCASTLE

Comp3320/6370 Computer Graphics

Course Coordinator: Associate Professor Stephan Chalup

Semester 2, 2018

LECTURE w05

Lighting, Shading, and Fog

August 27, 2018

OVERVIEW

Note: If not stated otherwise these lecture slides use teaching material/images from ch. 4 of Möller and Haines (1999) and Akenine-Möller and Haines (2002) and ch. 5 of Akenine-Möller et al. (2008) as well as parts of (Akenine-Möller et al., 2018). Recommended reading is also ch. 10 of (Shirley, 2009) and ch. 8 of (Hill and Kelley, 2007).

Visual Appearance

Rendering 3-dimensional objects realistically requires

- Geometrical modelling
- Applying various kinds of light sources
- Associating a material with each surface
- Adding textures
- Using fog, transparency, and others ...

Light Sources

We can see an object because photons are emitted from or bounce off the surface of the object, reach the eye of the viewer, stimulate sensory cells in the eye and then a model of the object is generated (completed) in the viewers brain.

Three types of light sources:

- *Directional lights:* infinitely far away, parallel rays, eg. sun
- *Positional lights:* have a location in space
  - *Point lights:* Point that send rays uniformly in all directions
  - *Spot lights:* Emits light only within the volume of a cone (defined by: cut-off angle, direction), eg. flash light

All these cast shadows with sharp edges.
Real light sources have a volume and therefore cast shadows with soft edges.

Light Source Parameters in OpenGL and DirectX

The following division is not physically accurate but gives the graphics programmer more control over scene appearance. $\mathbf{s}$ is used as short for *source*.

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

Spot light has additional parameters: s_{dir}, $s_{cut} =$ *cut-off angle*, $s_{exp} =$ *spot exponent*.
Positional light sources sometimes allow control of their intensity based on distance. E.g. OpenGL has three parameters s_c, s_l and s_q to control constant, linear and quadratic attenuation, resp., which is proportional to some function of the light source.

Material Parameters

The colour of a surface with material is determined by the lighting model, the parameters of the light sources that illuminate that surface and the following material parameters

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

Lighting and Shading

- *Lighting:* Interaction between material, light sources and geometry of the object to be rendered.

Lighting and Shading

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- *Shading:* Process of performing lighting computations and determining pixels' colors from them.

Lighting and Shading

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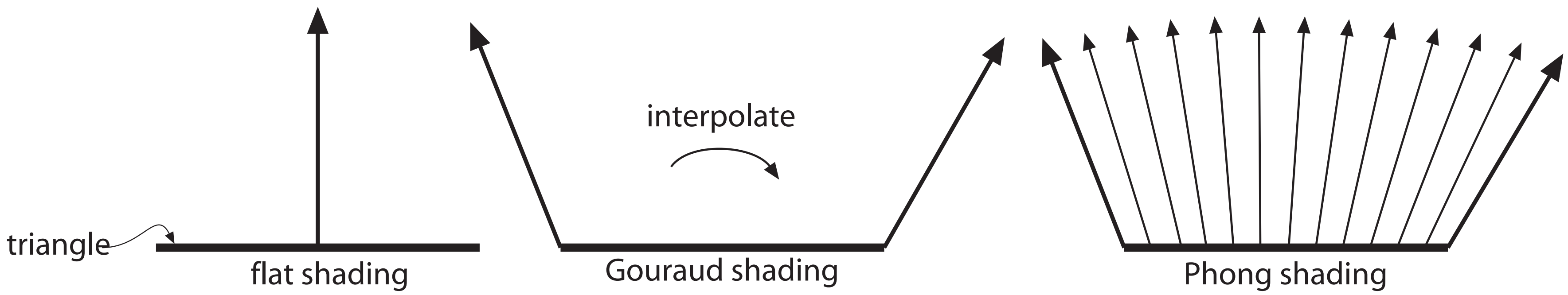
- *Shading:* Process of performing lighting computations and determining pixels' colors from them.

  Three types of shading:

  - Flat: polygon based
  - Gouraud: vertex based
  - Phong: pixel based

Three Types of Shading



Three Types of Shading

- Flat
  - Calculate colour for a triangle and fill triangle with that colour.
  - fast
  - simple to implement
  - Can see underlying facets (can be wanted!)

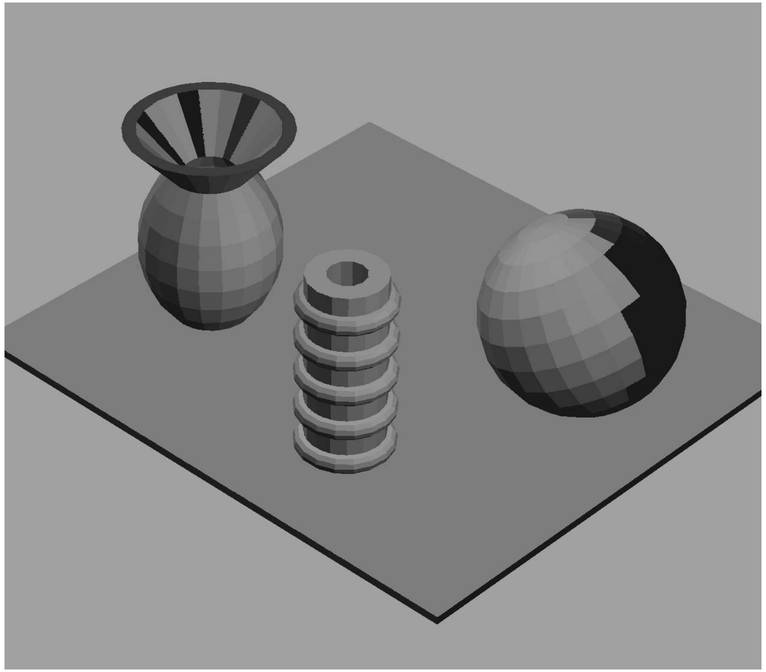
Three Types of Shading

- Flat
- Gouraud
  - Calculate lighting at each vertex and interpolate over the triangle's surface.
  - Smoother and still fast
  - Dependent on the level of detail of the object
  - Problems: Missing highlights, failure to capture spotlight effects. (Textures can help)
  - If triangles smaller than pixels, then Gouraud is as good as Phong (cf. RenderMan).

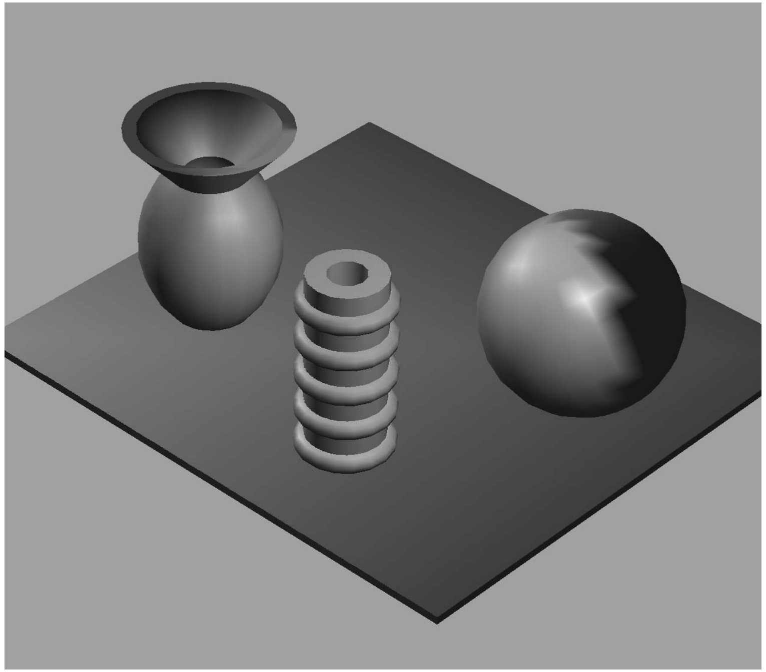
Three Types of Shading

- Flat
- Gouraud
- Phong
  - Use shading normals stored at the vertices to interpolate the shading normal at each pixel. Use this normal to calculate the colour for that pixel.
  - Costly.

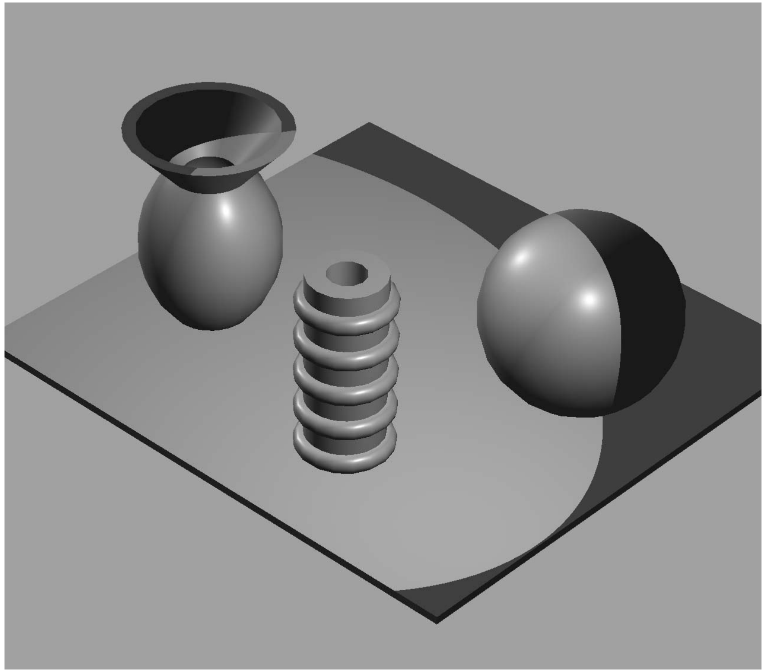
Flat Shading



Gouraud Shading



Phong Shading



Three Types of Shading

©Akenine-Möller et al. (2008)

The Lighting Model

The illumination at vertices or pixels (Phong) is calculated using a lighting model. It usually has three components:

- diffuse: catch behaviour of matte surfaces
- specular: make a surface look shiny by creating highlights
- ambient: light bouncing off walls etc.

These can be combined into a lighting equation for computer graphics, not physics ! Many graphics accelerators and API's use this sort of model.

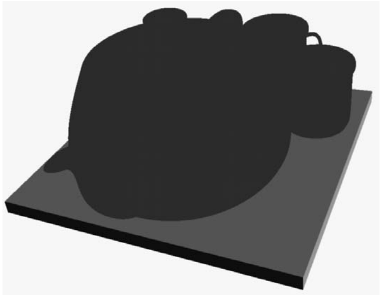
Alternatives

- Global models:
  - Radiosity
  - Ray tracing
- Non-photorealistic rendering

The Total Lighting Equation

$$\mathbf{i}_{tot} = \mathbf{i}_{amb} + \mathbf{i}_{diff} + \mathbf{i}_{spec}$$

$$\mathbf{i}_{amb} + \mathbf{i}_{diff} + \mathbf{i}_{spec} = \mathbf{i}_{tot}$$



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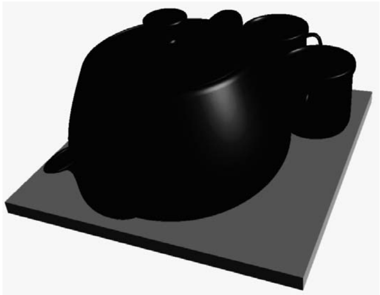

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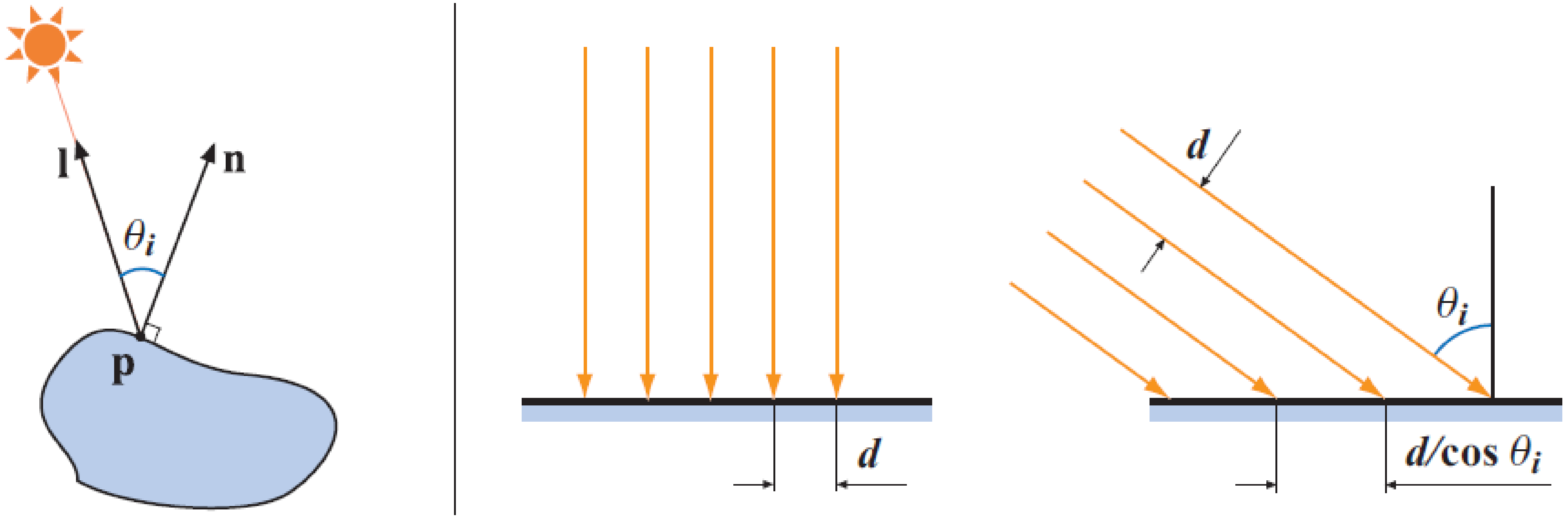
Diffuse Component

- *Lambert's law:* For ideally diffuse (totally matte, without shininess) surfaces, the reflected light is determined by the cosine between the surface normal $\mathbf{n}$ and the light vector $\mathbf{l}$. (The light vector goes from the surface point $\mathbf{p}$ to the light source.)
- view independent
- A surface can only reflect photons of the same colour as the surface. The other photons are absorbed by the surface.

According to Lambert's law we have $\mathbf{n} \cdot \mathbf{l} = \cos\theta$. I.e. the intensity of the reflected light increases for $\theta \longrightarrow 0$.



©Akenine-Möller et al. (2008)

Diffuse Component

$$\mathbf{i}_{diff} = (\mathbf{n} \cdot \mathbf{l}) = \cos\theta$$

Intensity is inversely proportional to the distance between the light rays.

Diffuse Component

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

Make use of the diffuse colour of the light source $\mathbf{s}_{diff}$ and the diffuse colour of the material $\mathbf{m}_{diff}$ (where $\otimes$ is componentwise multiplication).

RGB example: Blue light source $\mathbf{s}_{diff} = (0,0,1)$ and red material $\mathbf{m}_{diff} = (1,0,0)$ $\rightsquigarrow \mathbf{m}_{diff} \otimes \mathbf{s}_{diff} = (0,0,0)$, i. e. no reflection.

Diffuse Component

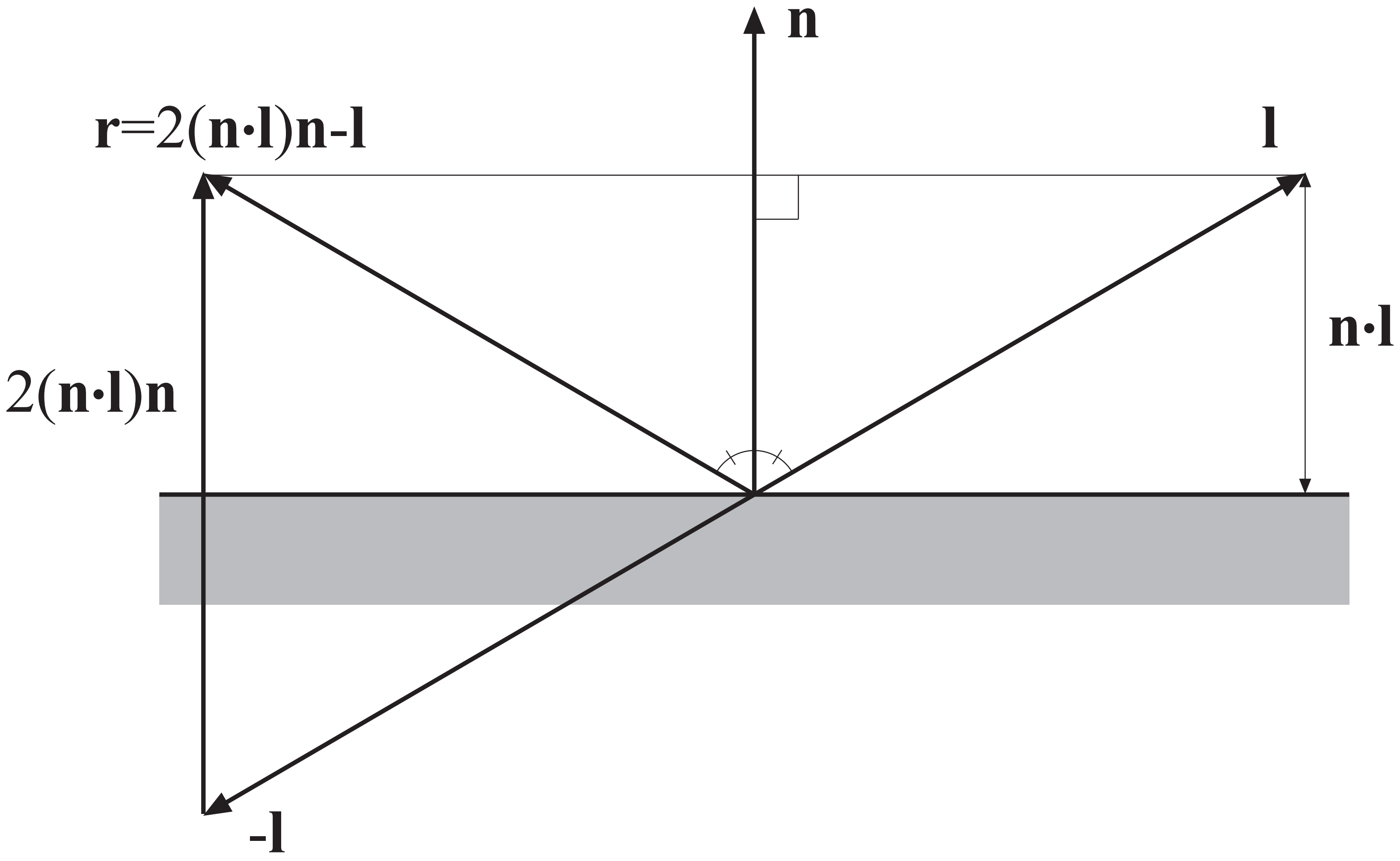
$$\mathbf{i}_{diff} = \max((\mathbf{n} \cdot \mathbf{l}), 0)\mathbf{m}_{diff} \otimes \mathbf{s}_{diff}$$

Diffuse lighting is zero if the angle between normal vector $\mathbf{n}$ and light vector $\mathbf{l}$ is greater than 90^o. Due to $\max$ it does not become negative.

Specular Component

- Make a surface look shiny by making highlights appear.
- view dependent
- $\mathbf{v}$ = view vector = vector from the point to be shaded to the viewer
- $\mathbf{r}$ = reflection of light vector
- *Phong lighting equation:* The specular contribution gets stronger the more closely aligned the reflection vector $\mathbf{r}$ is with the view vector $\mathbf{v}$.

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


n
r=2(n·l)n-l
l
n·l
2(n·l)n
-l

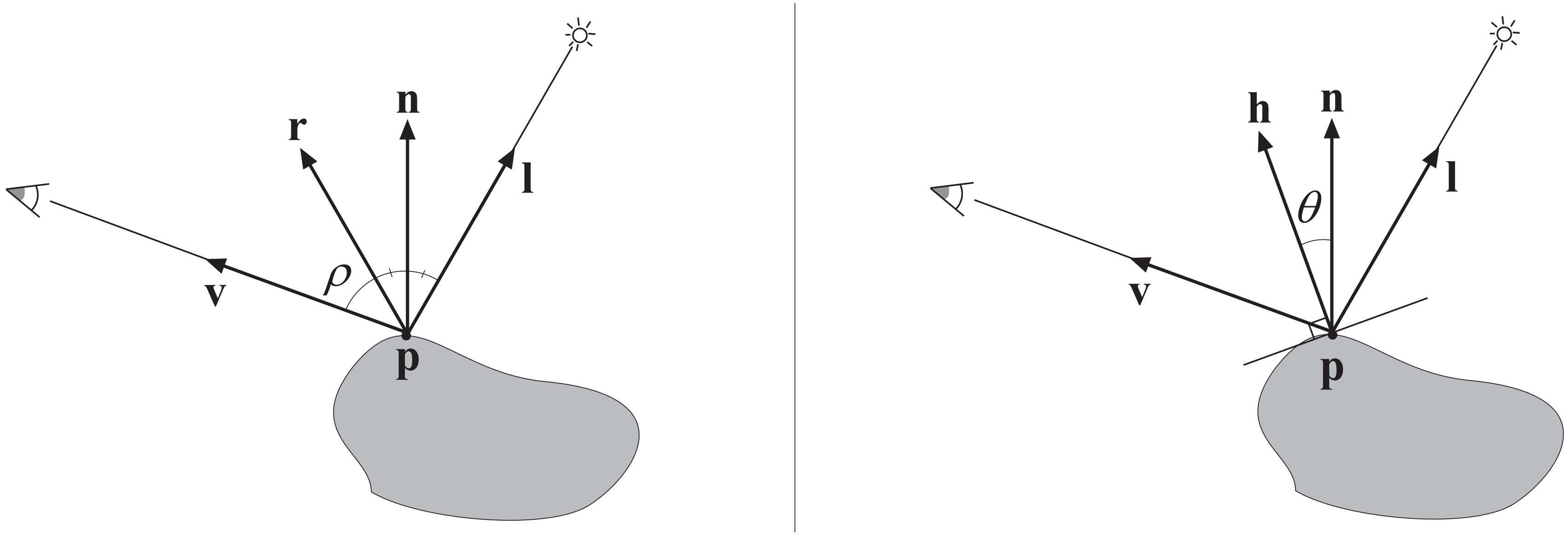
Specular Component

- Faster to calculate than Phong lighting is Blinn lighting.
- *Blinn lighting equation:* Let $\mathbf{h}$ be the normalised half vector between $\mathbf{l}$ and $\mathbf{v}$, i.e. $\mathbf{h} = \frac{\mathbf{l}+\mathbf{v}}{||\mathbf{l}+\mathbf{v}||}$. Then

$$\mathbf{i}_{spec} = (\mathbf{n} \cdot \mathbf{h})^{m_{shi}} = (\cos\theta)^{m_{shi}}$$

- I.e. $\mathbf{h}$ is normal to the plane through the point $\mathbf{p}$ that reflects the light from the light source perfectly into the eye of the viewer.

Phong Lighting and Blinn Lighting



ⒸAkenine-Möller and Haines (2002)

Specular Component

Let's use Blinn lighting, then the specular component looks like

$$\mathbf{i}_{spec} = \max((\mathbf{n} \cdot \mathbf{h}), 0)^{m_{shi}} \mathbf{m}_{spec} \otimes \mathbf{s}_{spec}$$

It is zero if the angle between the two normalised vectors is greater than 90^o.

Ambient Component

- Light that bounces off walls and then reaches the object.
- Radiosity is a sophisticated technique that takes this into account.
- We attempt to simulate indirect lighting by adding a simple term to the lighting model:

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

- OpenGL supports ambient values per light.

Ambient Component

- Using only ambient light for the backsides lets the 3D effect be poor.
- Solutions:
  - Strategically placing additional lights in the scene.
  - Headlights

Controlling Attenuation by Distance

$$d = \frac{1}{s_c + s_l||\mathbf{s}_{pos} - \mathbf{p}|| + s_q||\mathbf{s}_{pos} - \mathbf{p}||^2}$$

$||\mathbf{s}_{pos} - \mathbf{p}||$ is the distance from the light source $\mathbf{s}_{pos}$.

Spotlight Control

$$c_{spot} = \max(-\mathbf{l} \cdot \mathbf{s}_{dir}, 0)^{s_{exp}}$$

where $\mathbf{l}$ is the light vector
$\mathbf{s}_{dir}$ is the direction of the spotlight
s_{exp} is used to control the fall-off from the center of the spotlight

The Lighting Equation

$$\mathbf{i}_{tot} = \mathbf{i}_{amb} + \mathbf{i}_{diff} + \mathbf{i}_{spec}$$

The Lighting Equation

$$\mathbf{i}_{tot} = \mathbf{i}_{amb} + d(\mathbf{i}_{diff} + \mathbf{i}_{spec})$$

The Lighting Equation

$$\mathbf{i}_{tot} = c_{spot}[\mathbf{i}_{amb} + d(\mathbf{i}_{diff} + \mathbf{i}_{spec})]$$

The Lighting Equation

$$\mathbf{i}_{tot} = \mathbf{a}_{glob} \otimes \mathbf{m}_{amb} + \mathbf{m}_{emi} + c_{spot}[\mathbf{i}_{amb} + d(\mathbf{i}_{diff} + \mathbf{i}_{spec})]$$

The Lighting Equation for Multiple Light Sources

$$\mathbf{i}_{tot} = \mathbf{a}_{glob} \otimes \mathbf{m}_{amb} + \mathbf{m}_{emi} + \sum_{k=1}^{n} c_{spot}^{k}[\mathbf{i}_{amb}^{k} + d^{k}(\mathbf{i}_{diff}^{k} + \mathbf{i}_{spec}^{k})]$$

The Lighting Equation for Multiple Light Sources

$$\begin{aligned}\mathbf{i}_{tot} &= \mathbf{a}_{glob} \otimes \mathbf{m}_{amb} + \mathbf{m}_{emi} \\ &\quad + \sum_{k=1}^{n} c^k_{spot}[\mathbf{i}^k_{amb} + d^k(\mathbf{i}^k_{diff} + \mathbf{i}^k_{spec})]\end{aligned}$$

The Lighting Equation for Multiple Light Sources

$$\begin{aligned}
\mathbf{i}_{tot} &= \mathbf{a}_{glob} \otimes \mathbf{m}_{amb} + \mathbf{m}_{emi} \\
&+ \sum_{k=1}^{n} c_{spot}^{k}[\mathbf{i}_{amb}^{k} \\
&+ d^{k}(\mathbf{i}_{diff}^{k} + \mathbf{i}_{spec}^{k})]
\end{aligned}$$

The Lighting Equation for Multiple Light Sources

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\begin{aligned}
\mathbf{i}_{tot} = \ & \mathbf{a}_{glob} \otimes \mathbf{m}_{amb} + \mathbf{m}_{emi} \\
& + \sum_{k=1}^{n} \max(-\mathbf{l}^k \cdot \mathbf{s}^k_{dir}, 0)^{s^k_{exp}} [\mathbf{i}^k_{amb} \\
& + d^k (\mathbf{i}^k_{diff} + \mathbf{i}^k_{spec})]
\end{aligned}
$$

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& + \sum_{k=1}^{n} \max(-\mathbf{l}^k \cdot \mathbf{s}^k_{dir}, 0)^{s^k_{exp}} \Big[\mathbf{m}_{amb} \otimes \mathbf{s}^k_{amb} \\
& + {\color{red} d}^k (\mathbf{i}^k_{diff} + \mathbf{i}^k_{spec}) \Big]
\end{aligned}
$$

The Lighting Equation for Multiple Light Sources

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\mathbf{i}_{tot} = {} & \mathbf{a}_{glob} \otimes \mathbf{m}_{amb} + \mathbf{m}_{emi} \\
& + \sum_{k=1}^{n} \max(-\mathbf{l}^k \cdot \mathbf{s}^k_{dir}, 0)^{s^k_{exp}} \Bigg[\mathbf{m}_{amb} \otimes \mathbf{s}^k_{amb} \\
& + \frac{(\mathbf{i}^k_{diff} + \mathbf{i}^k_{spec})}{s^k_c + s^k_l ||\mathbf{s}^k_{pos} - \mathbf{p}|| + s^k_q ||\mathbf{s}^k_{pos} - \mathbf{p}||^2} \Bigg]
\end{aligned}
$$

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& + \frac{\color{red}{\mathbf{i}^k_{diff}} + \mathbf{i}^k_{spec}}{s^k_c + s^k_l ||\mathbf{s}^k_{pos} - \mathbf{p}|| + s^k_q ||\mathbf{s}^k_{pos} - \mathbf{p}||^2} \Big]
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& + \frac{\max((\mathbf{n} \cdot \mathbf{l}^k), 0)\mathbf{m}_{diff} \otimes \mathbf{s}^k_{diff} + \mathbf{i}^k_{spec}}{s^k_c + s^k_l ||\mathbf{s}^k_{pos} - \mathbf{p}|| + s^k_q ||\mathbf{s}^k_{pos} - \mathbf{p}||^2} \Big]
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\mathbf{i}_{tot} &= \mathbf{a}_{glob} \otimes \mathbf{m}_{amb} + \mathbf{m}_{emi} \\
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&+ \frac{\max((\mathbf{n} \cdot \mathbf{l}^k), 0)\mathbf{m}_{diff} \otimes \mathbf{s}^k_{diff} + \mathbf{i}^k_{spec}}{s^k_c + s^k_l ||\mathbf{s}^k_{pos} - \mathbf{p}|| + s^k_q ||\mathbf{s}^k_{pos} - \mathbf{p}||^2}\Big]
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& + \frac{\max((\mathbf{n} \cdot \mathbf{l}^k), 0)\mathbf{m}_{diff} \otimes \mathbf{s}^k_{diff} + \mathbf{i}^k_{spec}}{s^k_c + s^k_l ||\mathbf{s}^k_{pos} - \mathbf{p}|| + s^k_q ||\mathbf{s}^k_{pos} - \mathbf{p}||^2} \Bigg]
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& + \frac{\max((\mathbf{n} \cdot \mathbf{l}^k), 0)\mathbf{m}_{diff} \otimes \mathbf{s}^k_{diff} + \max((\mathbf{n} \cdot \mathbf{h}^k), 0)^{m_{shi}} \mathbf{m}_{spec} \otimes \mathbf{s}^k_{spec}}{s^k_c + s^k_l ||\mathbf{s}^k_{pos} - \mathbf{p}|| + s^k_q ||\mathbf{s}^k_{pos} - \mathbf{p}||^2} \Big]
\end{aligned}$$

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\end{aligned}
$$

Fog

Fog is a simple effect that can be used for several purposes:

- Increases the level of realism.
- Depth effect (fog increases with distance).
- Smoother culling of objects by the far plane.
- Often implemented in hardware.

Fog Factor

Let $f \in [0, 1]$ be a number, called the *fog factor*, which decreases with the distance from the viewer.

- Colour of the fog: $\mathbf{c}_f$.
- Let $\mathbf{c}_s$ be the colour of a shaded surface.
- Then the colour, $\mathbf{c}_p$, of the pixel is determined by

$$\mathbf{c}_p = f\mathbf{c}_s + (1 - f)\mathbf{c}_f \tag{1}$$

(equation used by OpenGL and Direct3D).

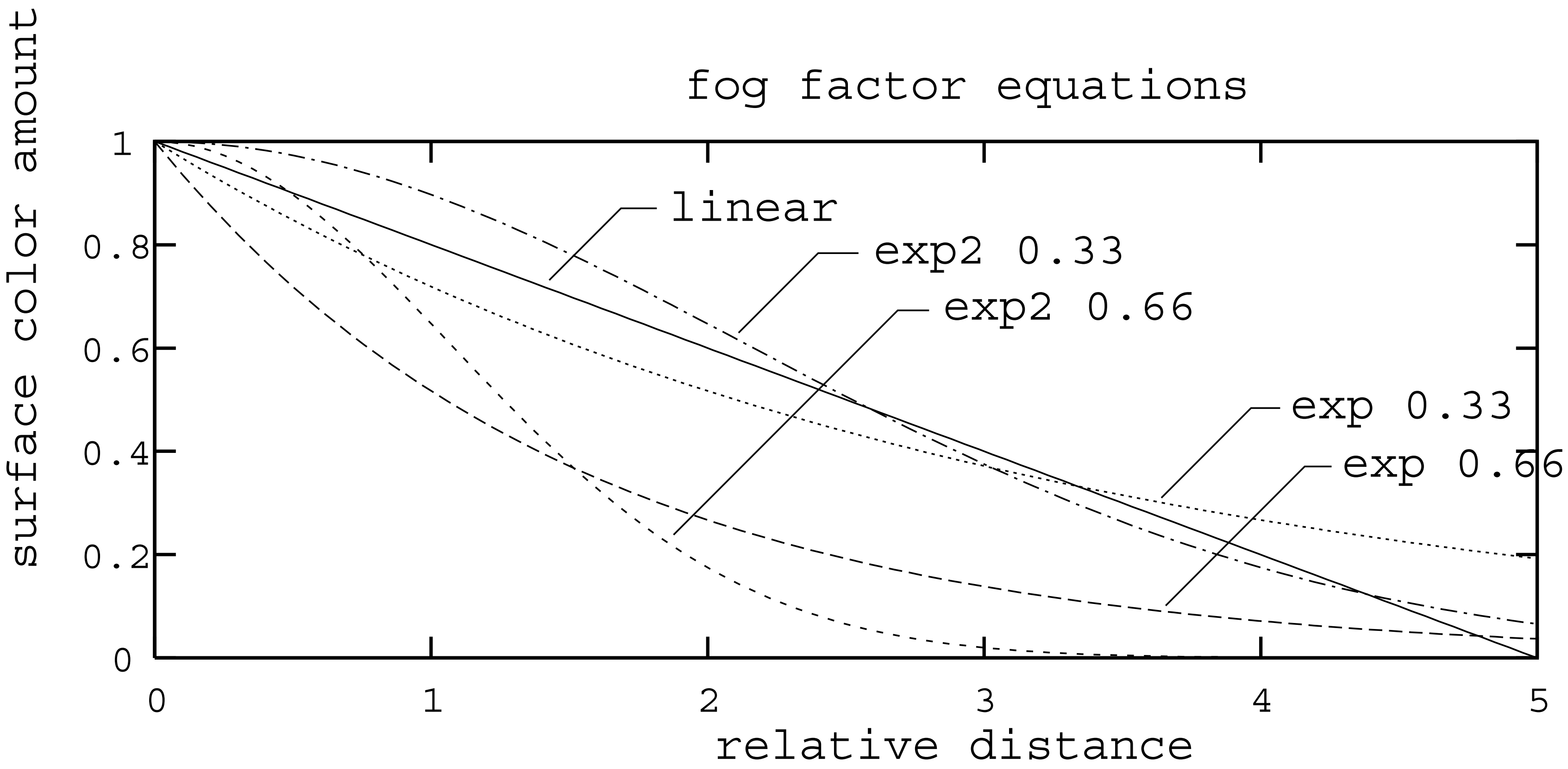
Fog Equations

Let $f \in [0, 1]$ be called the *fog factor*, which decreases with the distance from the viewer.

- Linear fog:
$$f = \frac{z_{end} - z_p}{z_{end} - z_{start}} \tag{2}$$
where z_p is the z-value of the pixel where fog is to be computed.
- Exponential fog:
$$f = \exp^{-d_f z_p} \tag{3}$$
where $\mathbf{d}_f$ is a factor controlling the density of the fog.
- Squared exponential fog:
$$f = \exp^{-(d_f z_p)^2} \tag{4}$$

Usually first the fog actor f is computed and then the fog equation is applied to calculate the final value of the pixel.

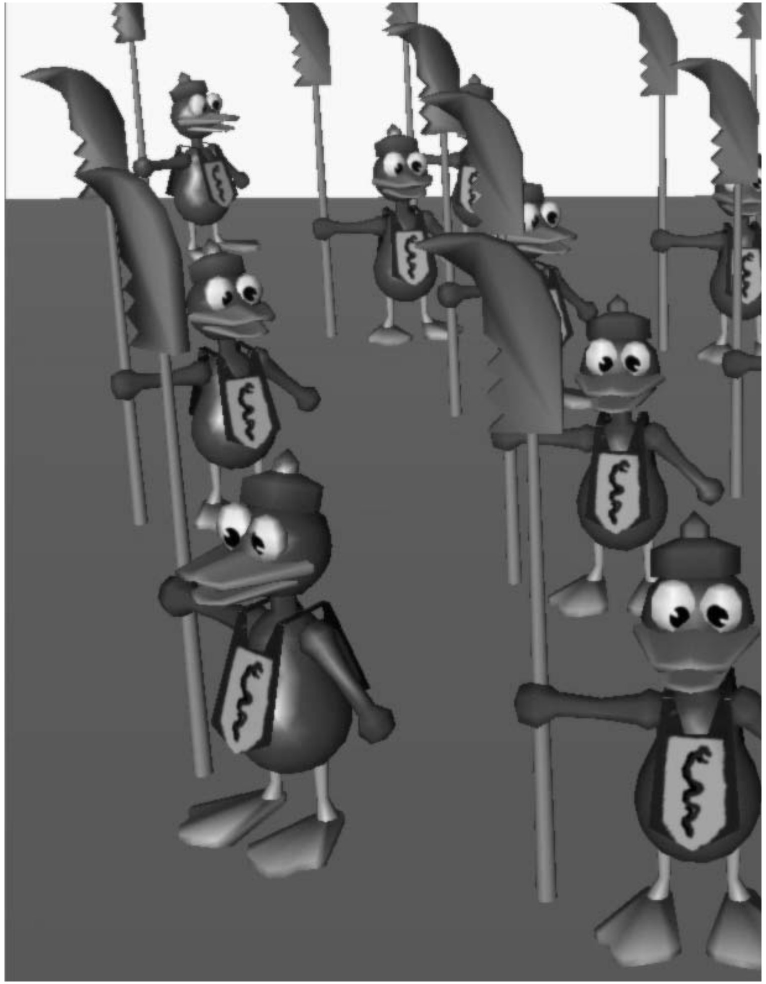
Fog curves


fog factor equations
surface color amount
relative distance
linear
exp2 0.33
exp2 0.66
exp 0.33
exp 0.66
1
0.8
0.6
0.4
0.2
0
0
1
2
3
4
5

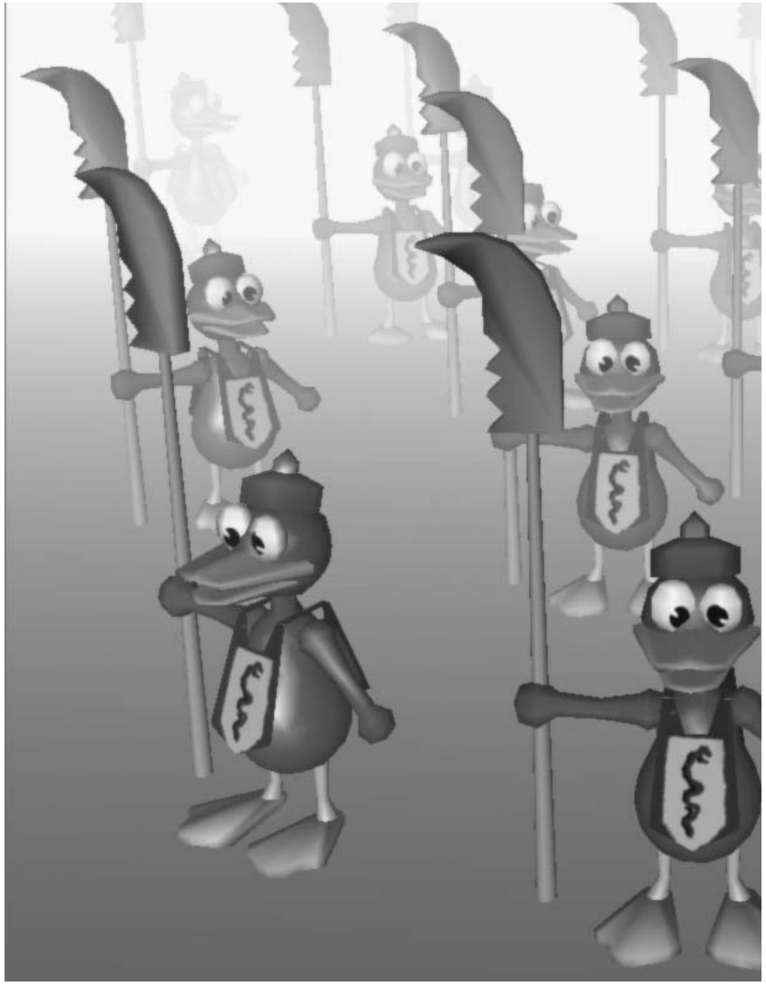
Remarks on Fog

- Tables can be used in implementing the fog factors in hardware. For several depths a fog factor is computed and stored in advance. For the depth in between these values the fog factor is interpolated.
- Fog can be applied on vertex level: I.e. fog is calculated as part of the illumination equation and interpolated across the polygon using Gouraud shading.
- Fog can be applied on pixel level: It is computed using the depth stored at each pixel. This usually gives the better result.
- Highest-quality fog is obtained using pixel-level radial fog.

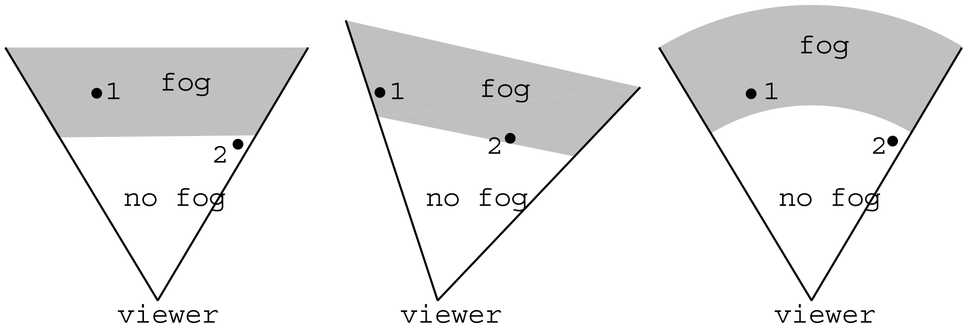
No Fog



Fog



z-depth versus radial fog



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