Light

Shading

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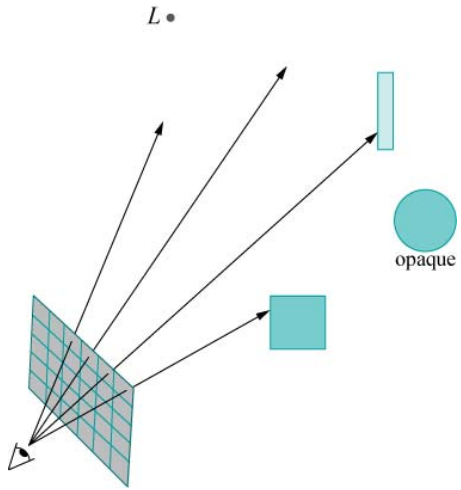

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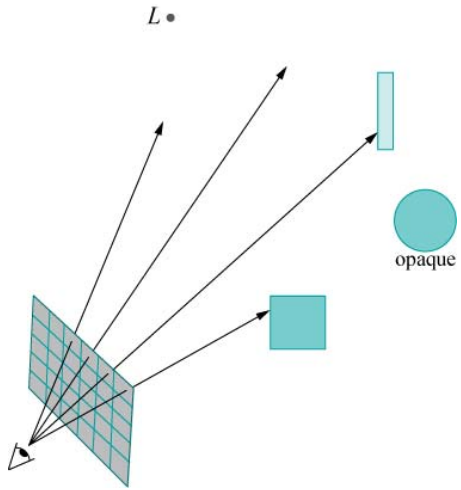

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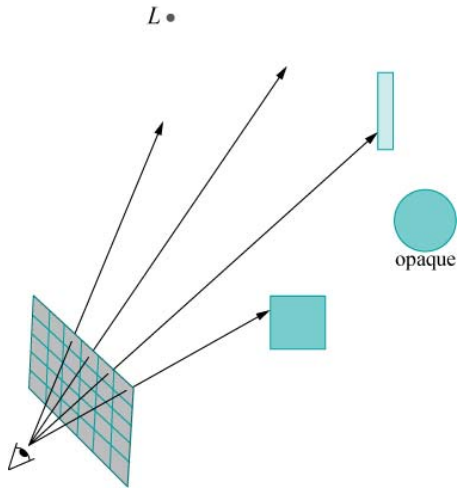

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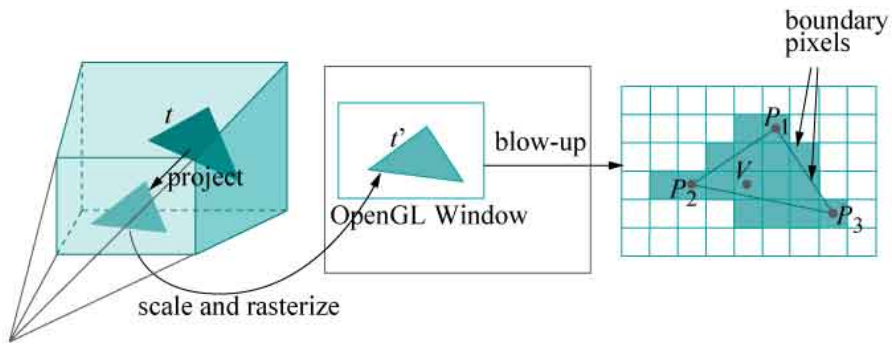
Recall:

- Rendering is triangle-driven (`foreach triangle: render`).
- Triangles are simply (triples of) vertices until rasterization phase, where pixels of the triangle are found from pixels of the vertices.



So the rays relevant for a given triangle are determined in the rasterization phase.

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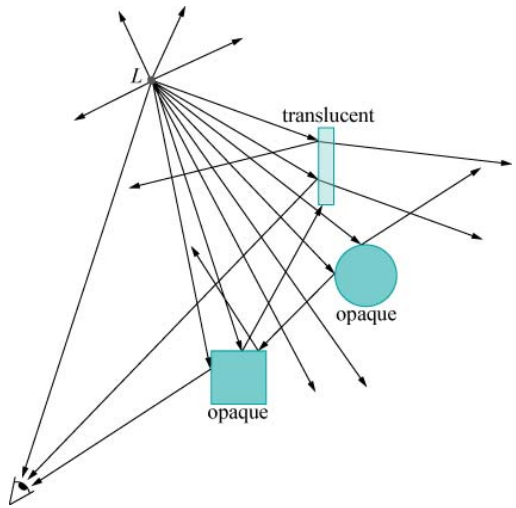
Model physical light (photons)



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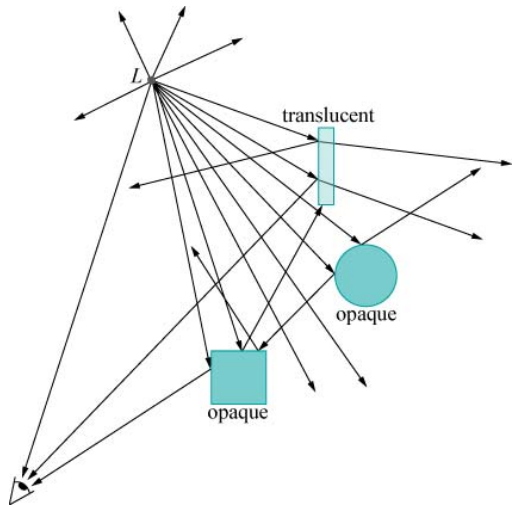

In real life, photons are

- Emitted from ligth sources.
- Reflected, absorbed, re-emitted, transmitted when hitting objects.

Modeling Light

Highly complex physical proces, mainly at surfaces of materials. Zillions of photons involved.

Can only be modeled to a certain degree mathematically (ongoing research expands on the available models).

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(Figure by Jason Jacobs)

Modeling Light

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Framerate ~ 30/sec, screen size $\sim 10^6$ pixels $\Rightarrow$ few GPU cycles available for calculation per ray.

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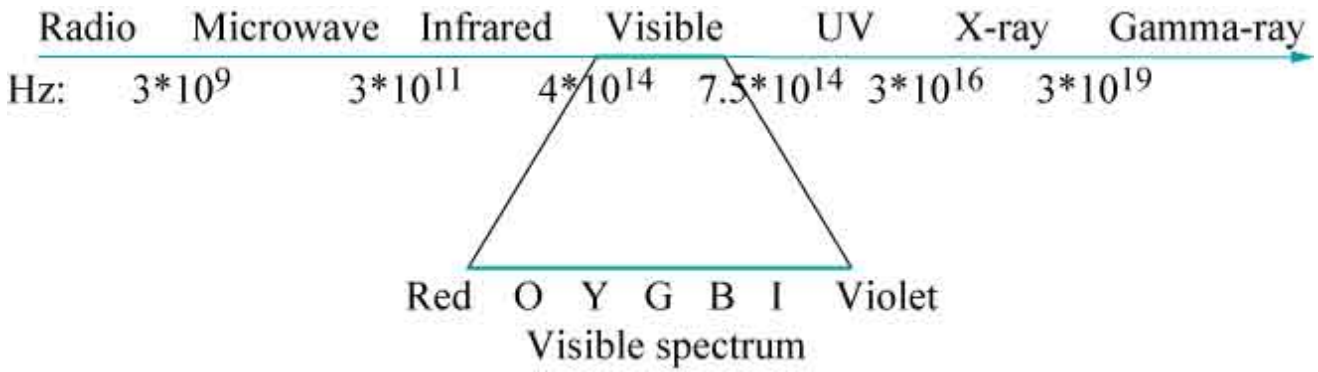
Actually, on modern programmable GPUs, the fixed-functionality pipeline of classic mode OpenGL is just a default shader program. (Used to be hardwired into GPUs).

Color

Photons/light waves have frequencies:



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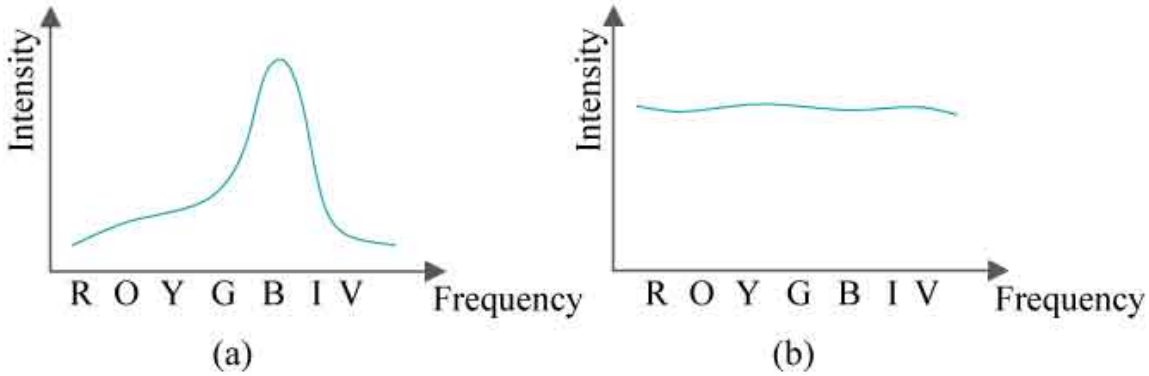
The lights following a ray has in real life a spectrum:



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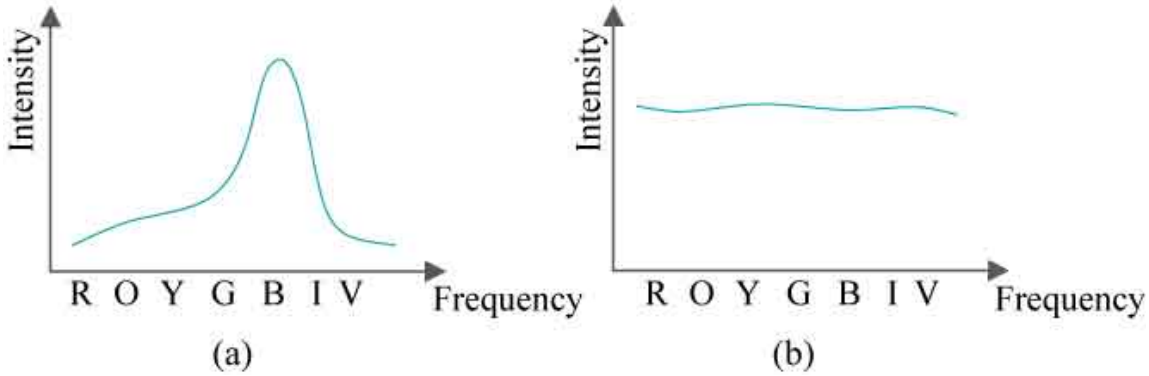

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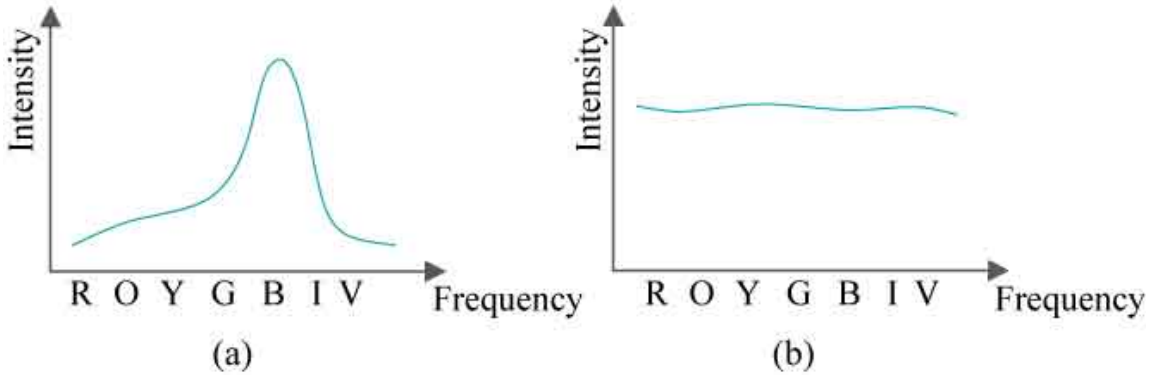

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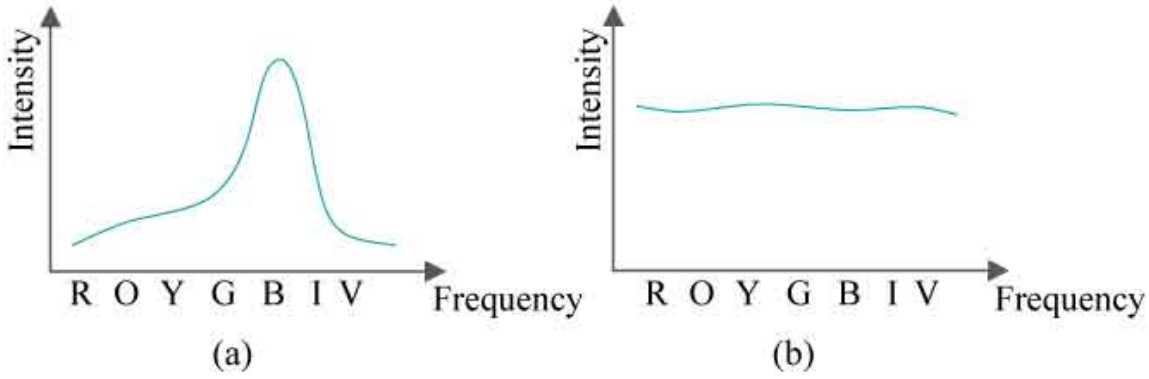

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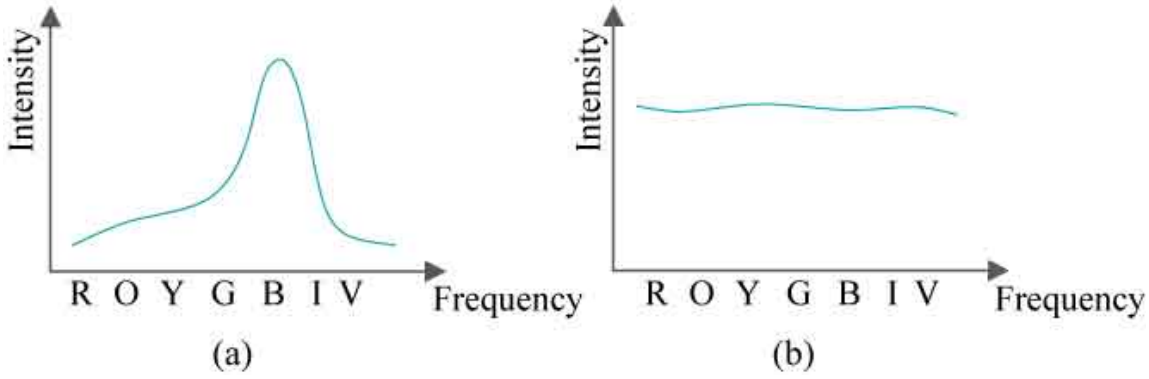

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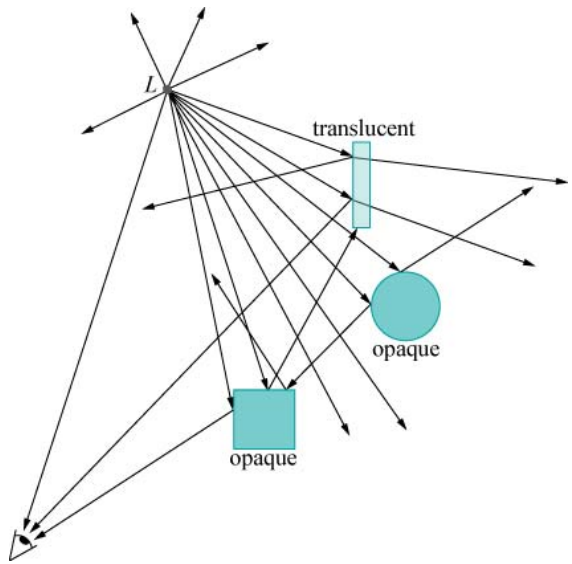
Hence, displays (and hence OpenGL) work with (R,G,B)-tuples as color values. [Or four-tuples, if alpha/transparency information is included.]

Lightning Models

- Define virtual lights.
- Define light/surface interactions.



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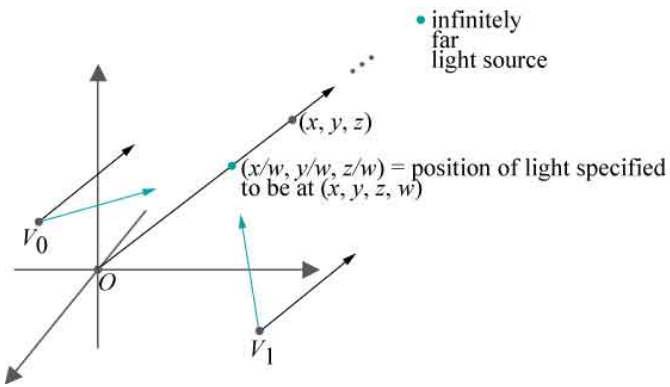

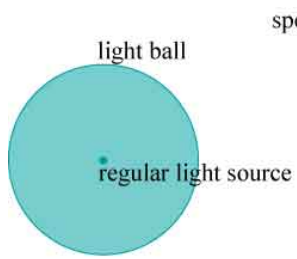

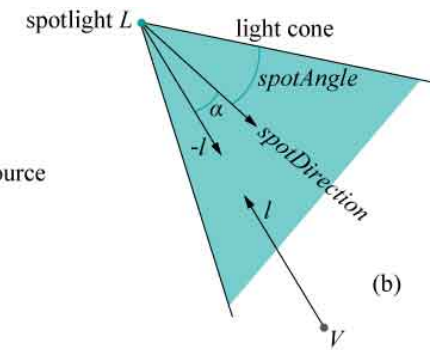

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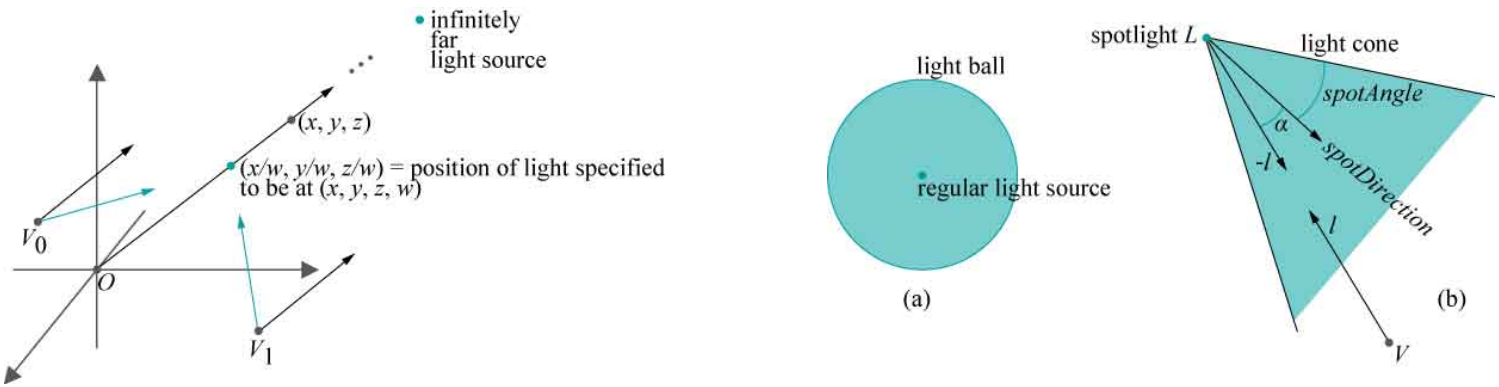
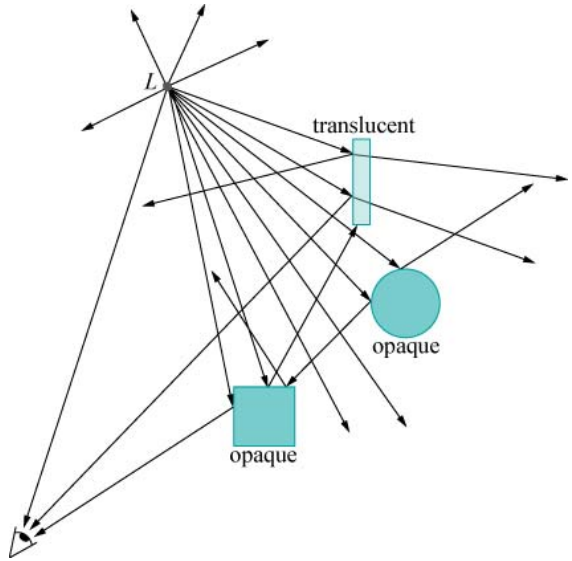


Attenuation factor for positional/spot lights (d = distance from surface point to light position):

$$\frac{1}{a + b \cdot d + c \cdot d^2}$$

Phongs Lightning Model



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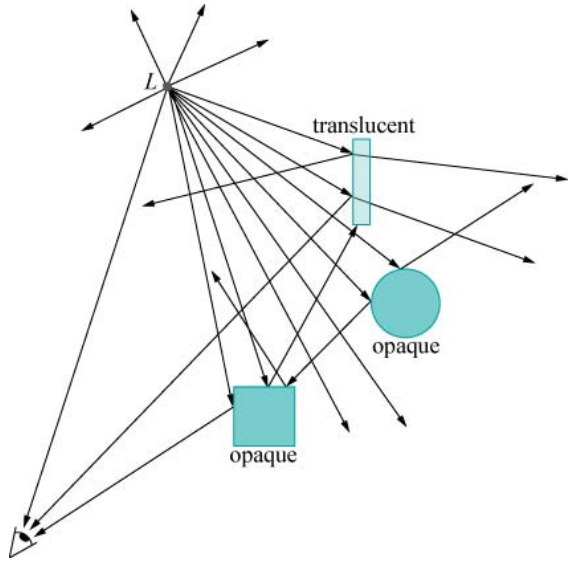

- Models only opaque objects.
- Models generally only *one* level of light/surface interactions (except ambient term, see below).
- Light/surface interaction is modeled by two simple submodels, diffuse and specular term.
- Models indirect light effects *very* crudely (ambient term).
- Light actually generated at surface can be added (emissive term).
- Occlusion is not modeled (all objects see all lights).

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(Note: actually one light intensity triple (for lights) and one material attenuation factor (for vertices) for each of the terms ambient, diffuse, and specular (see later). But this flexibility often not used/needed.)

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- Light influx per area on surface depends on angle θ between *light vector* (light direction) and *surface normal* at point. Dependency/attenuation is factor of $\cos\theta$.
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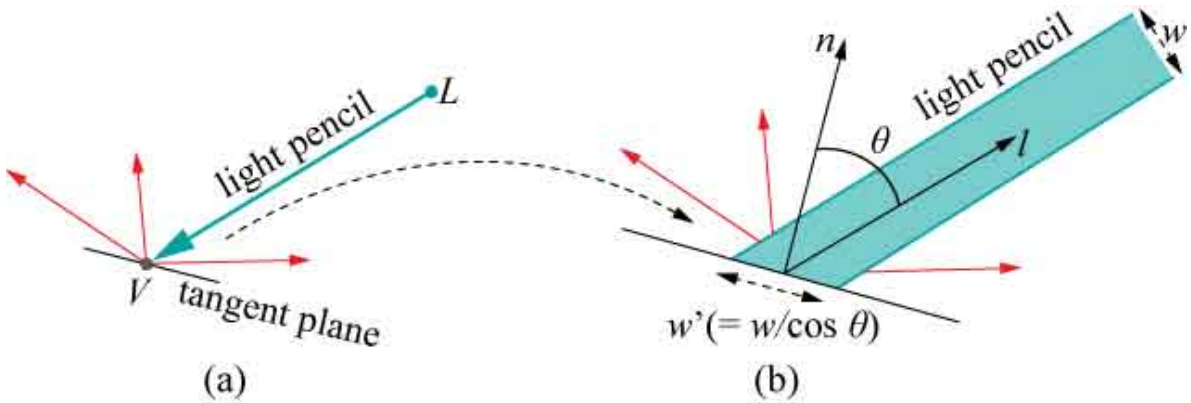

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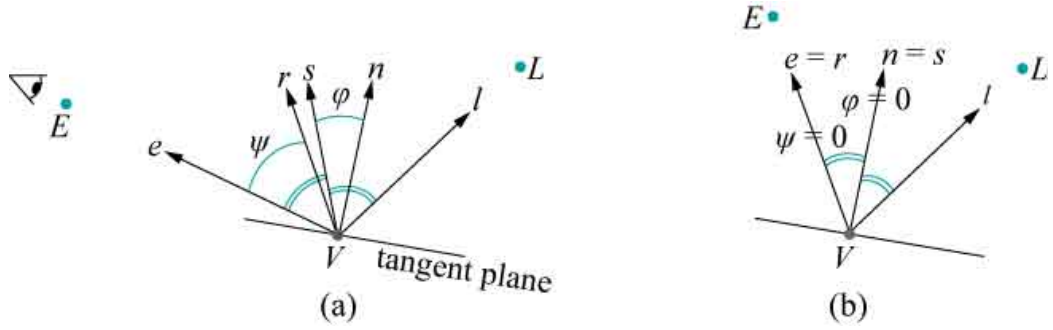

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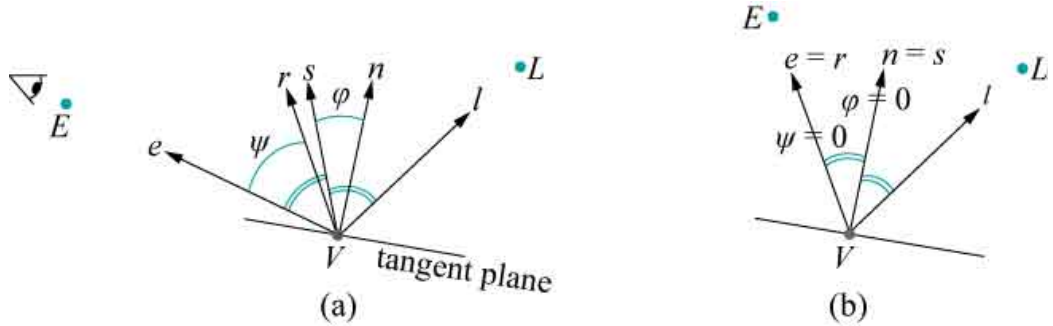

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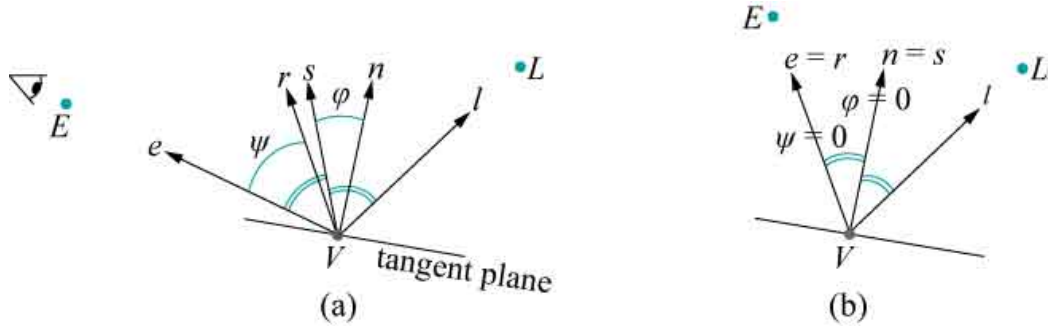

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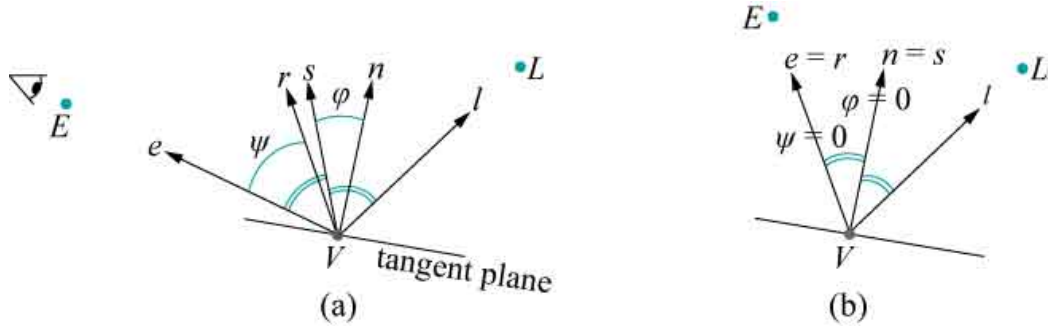

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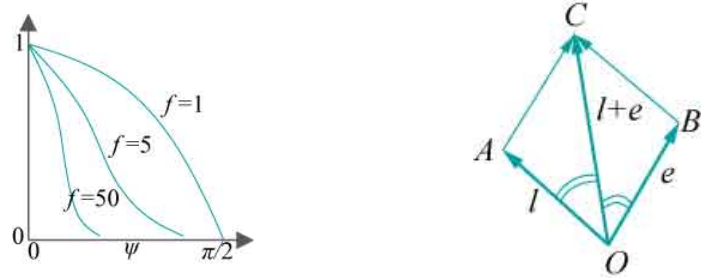

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More precisely: there is one global ambient term, plus one ambient term for each light. The latter allows for individually colored light, and distance and spot attenuation. Besides distance and spot attenuation, the calculation is just the basic multiplication of material and light.

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Thus, having a bulb both visible and giving light in a scene will involve:

- Creating polygons for the bulb and setting their emissive properties to non-zero (probably close to (1,1,1)).
- Creating a virtual light at the center of the bulb.

Lighting Equation

Add basic interactions between material and light as follows:

- One term for object light emission (usually zero).
- One term for global ambient light.
- For each light defined: add terms for per-light ambient term, diffuse term, and specular term (with distance and spot attenuation where appropriate).

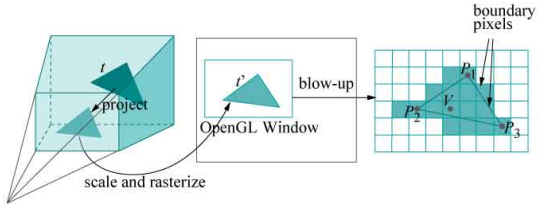
This is done once for each RGB-channel. A resulting value above 1.0 is just truncated to 1.0.

Lighting Equation in Math

$$
\begin{aligned}
\text{channel value} \quad = \quad & \text{emissive\_term} \\
+ \quad & \text{amb\_material} \times \text{amb\_global} \\
+ \quad & \sum_{\text{all lights}} \text{dist\_attenuation} \times \text{spot\_attenuation} \times \\
& (\text{amb\_material} \times \text{amb\_light} + \\
& \max\{\vec{l} \cdot \vec{n}, 0\} \times \text{diff\_material} \times \text{diff\_light} + \\
& (\max\{\vec{s} \cdot \vec{n}, 0\})^f \times \text{spec\_material} \times \text{spec\_light})
\end{aligned}
$$

Shading models

So we now have information in each vertex. How spread color calculation over entire triangle pixels?



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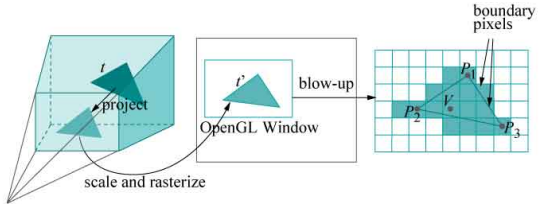

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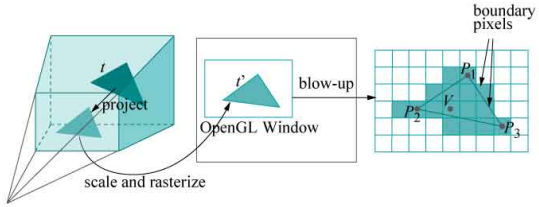

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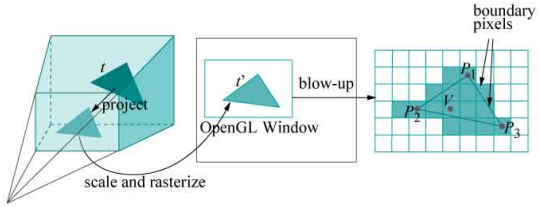

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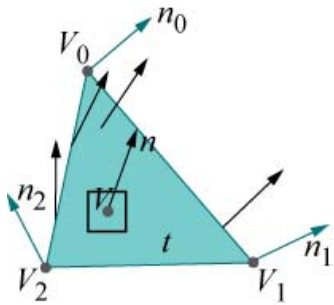
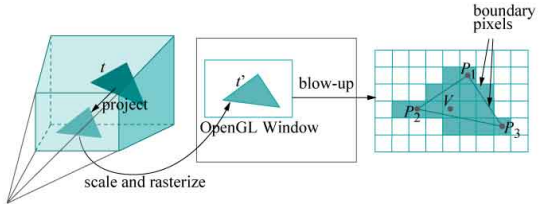
- Smooth shading (aka. Gouraud shading): Colors calculated for three vertices are interpolated across the entire triangle (individually for each RGB-channel).

- Phong shading: Color calculation done for all points of pixels.



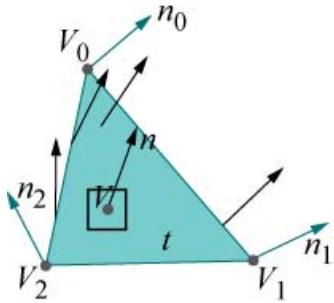
Shading models

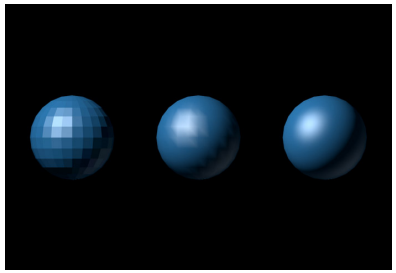
So we now have information in each vertex. How spread color calculation over entire triangle pixels?



- Flat shading: Color calculated for one point is used for entire triangle.
- Smooth shading (aka. Gouraud shading): Colors calculated for three vertices are interpolated across the entire triangle (individually for each RGB-channel).

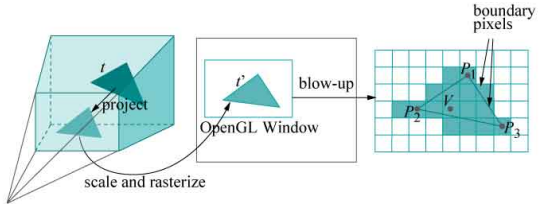
- Phong shading: Color calculation done for all points of pixels.





Shading models

So we now have information in each vertex. How spread color calculation over entire triangle pixels?



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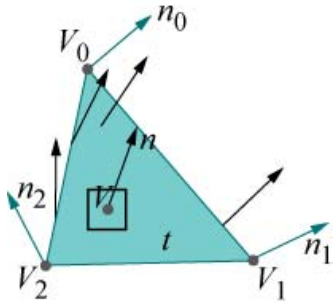

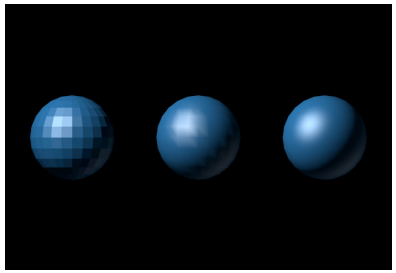

Calculation time increases down the list. Phong shading needs programmable shaders (not part of OpenGL fixed-functionality pipeline).