

Ray Tracing

Acknowledgements: Daniele Panozzo

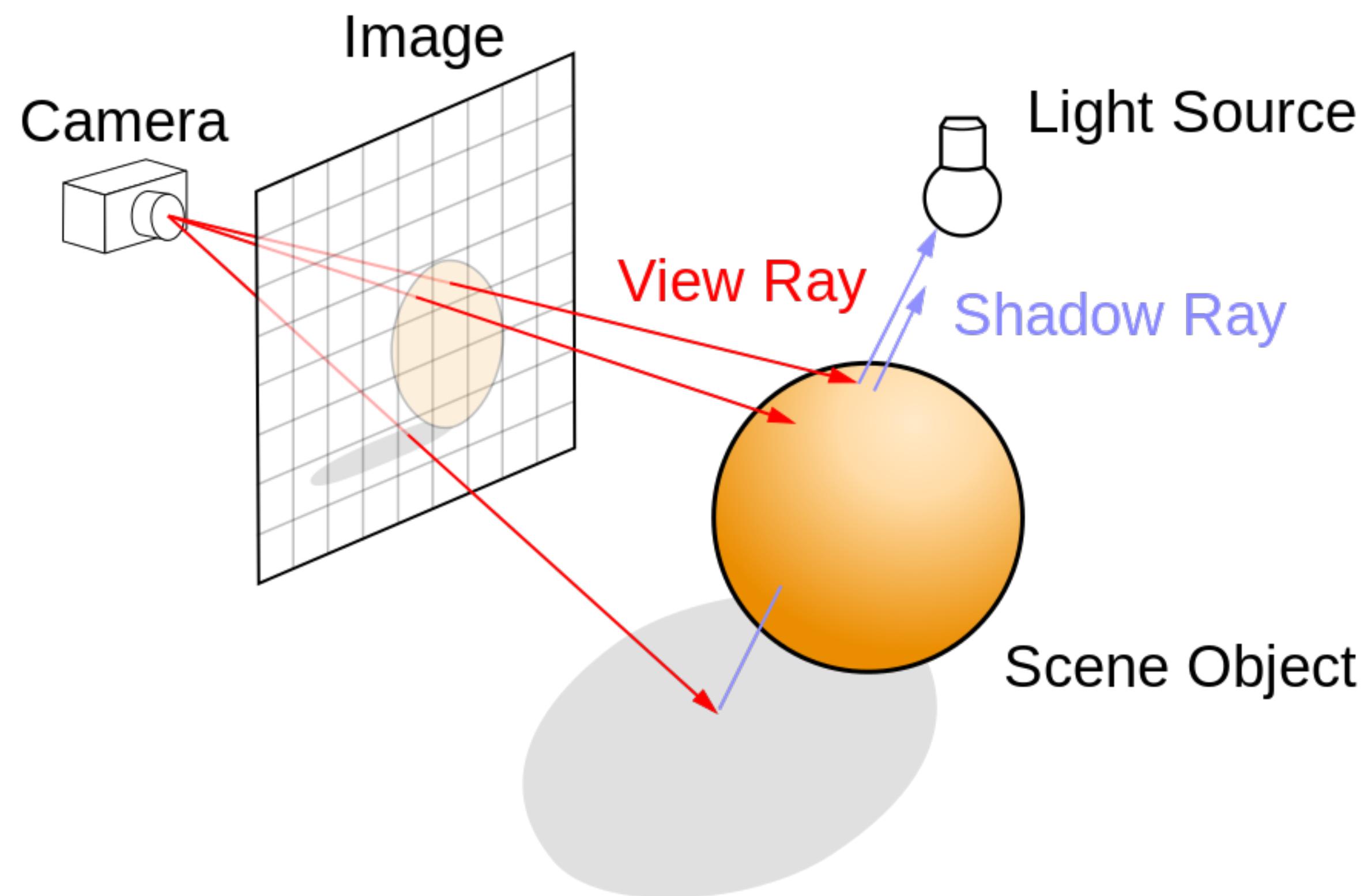
CAP 5726 - Computer Graphics - Fall 18 – Xifeng Gao



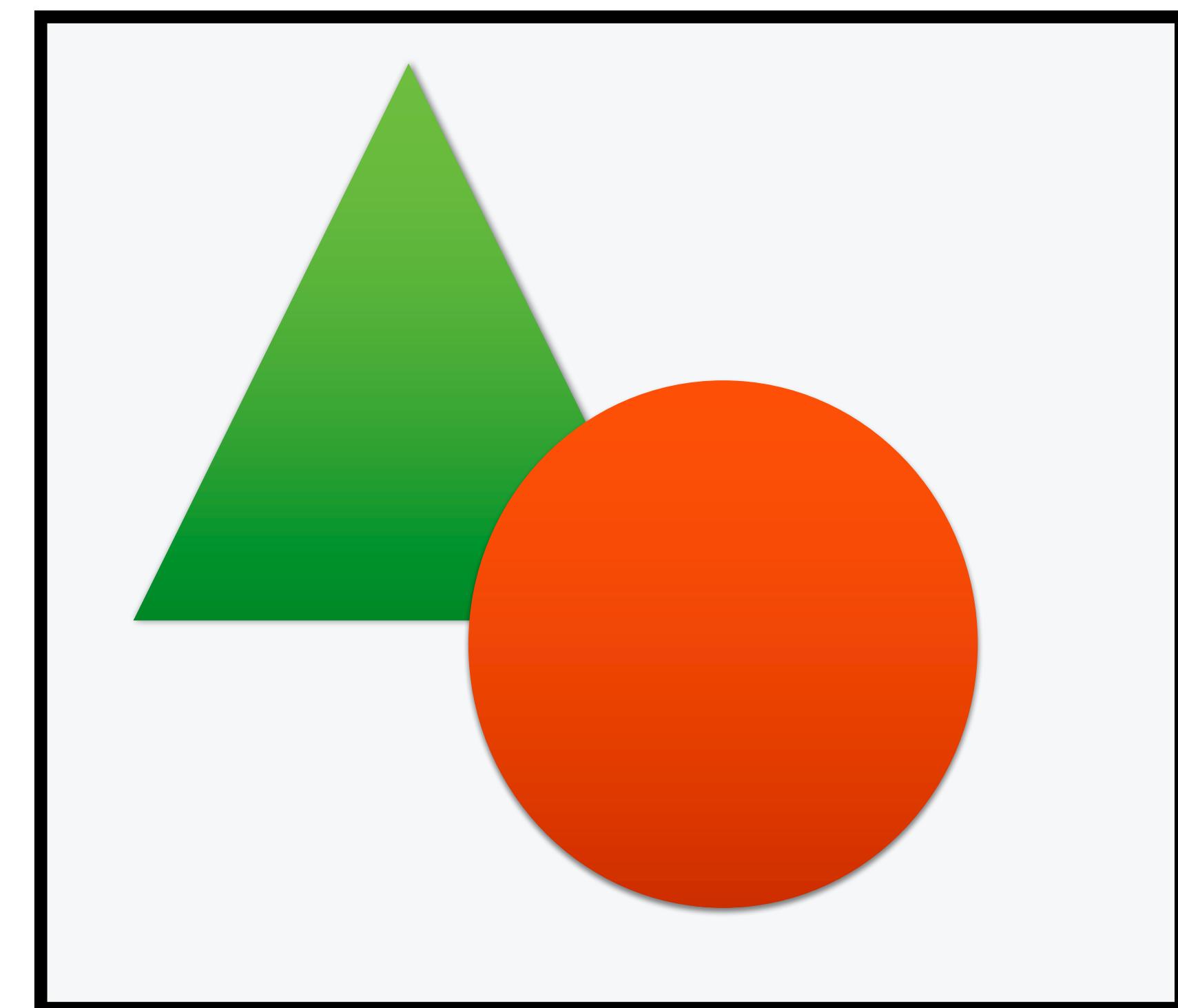
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Two major approaches

Per-pixel - “Raytracing”

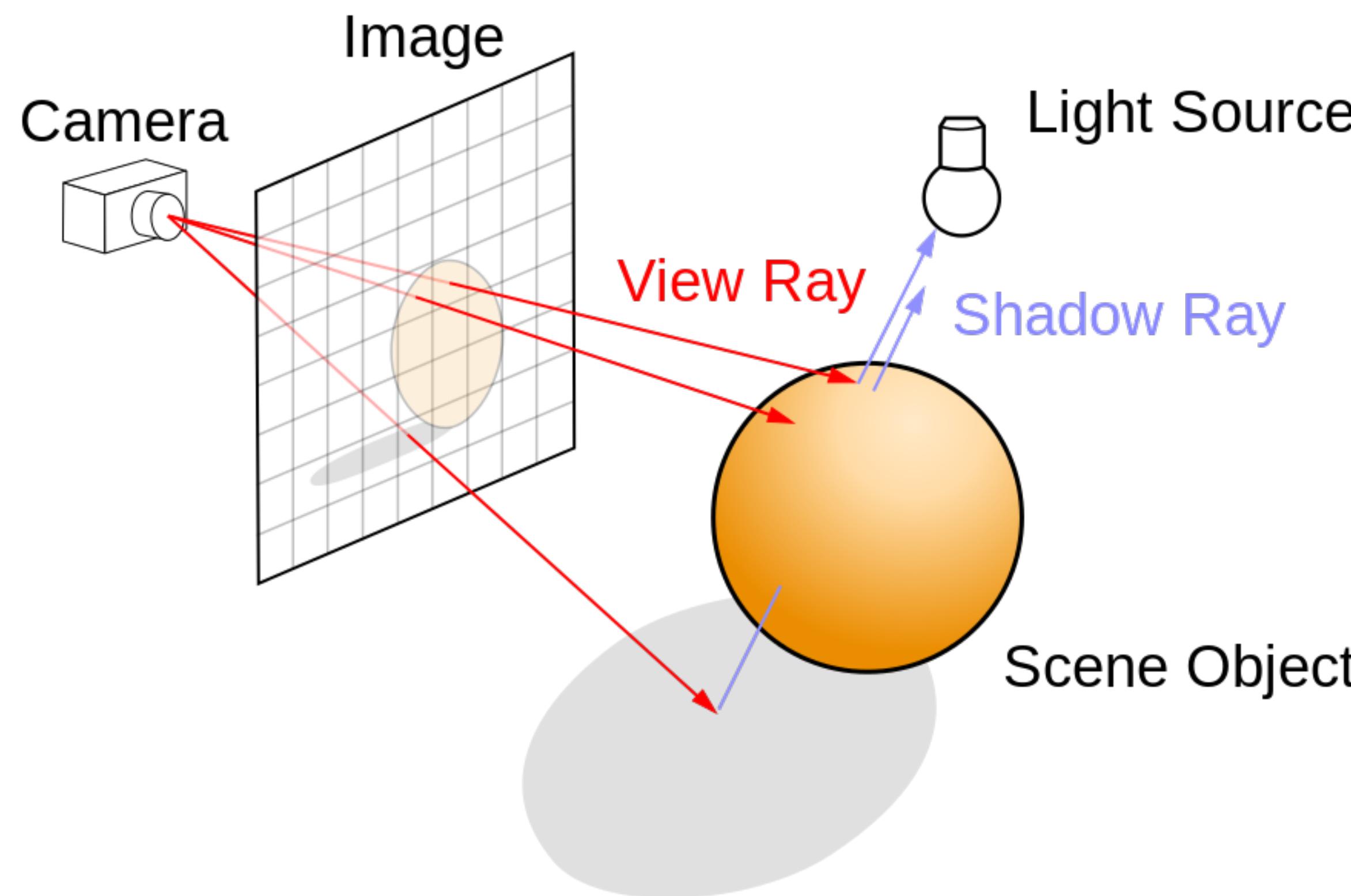


Per-object - “Rasterization”



By Henrik - Own work, GFDL, <https://commons.wikimedia.org/w/index.php?curid=3869326>

Per-pixel



- Easy to parallelize but hard to map to hardware
- Expensive!
- It can be extended to model many physical phenomena such as internal scattering, diffraction, reflections, etc.
- Used to obtain high quality images

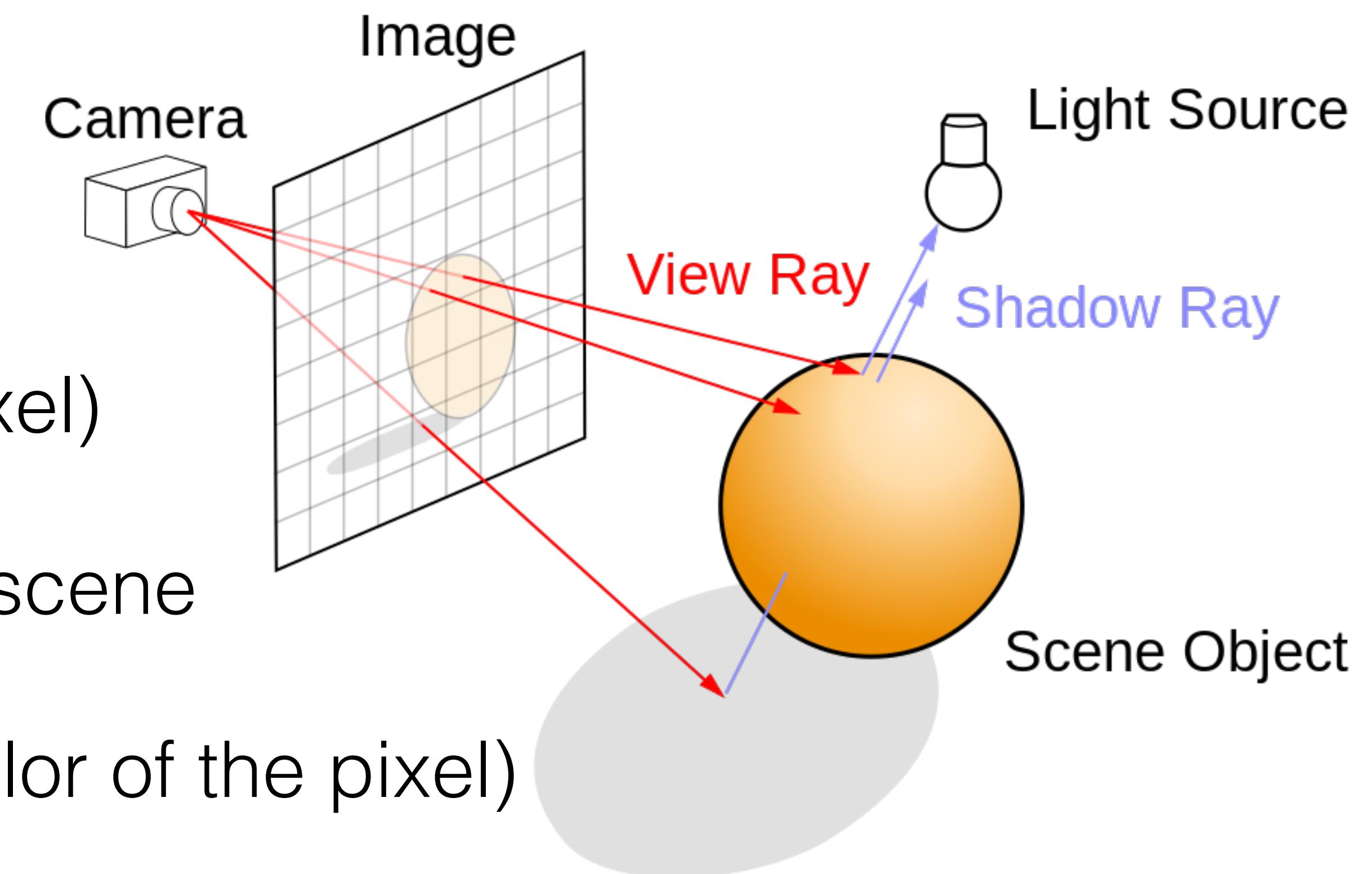
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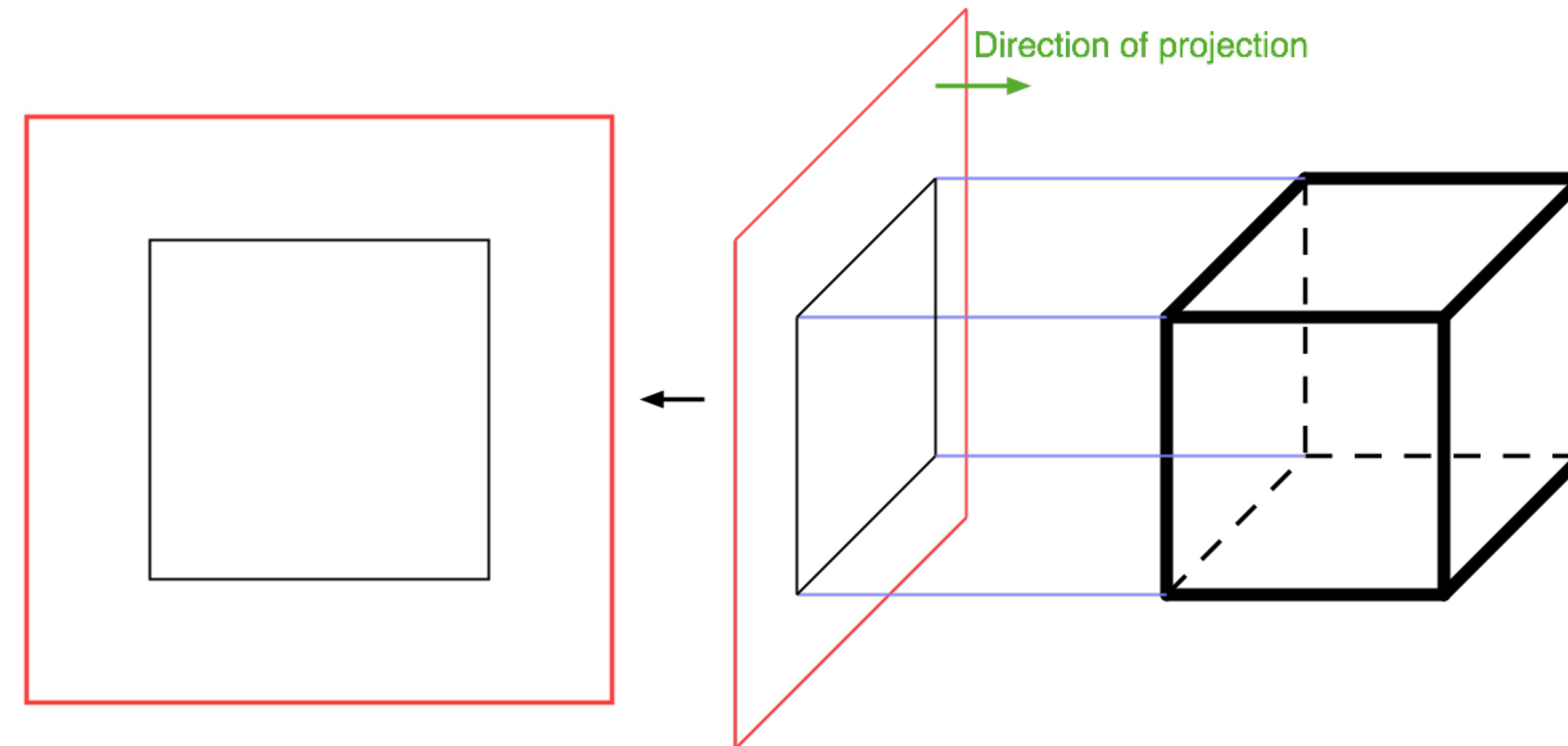
Basic Raytracing

1. Generation of Rays (one per pixel)
2. Intersection with objects in the scene
3. Shading (computation of the color of the pixel)

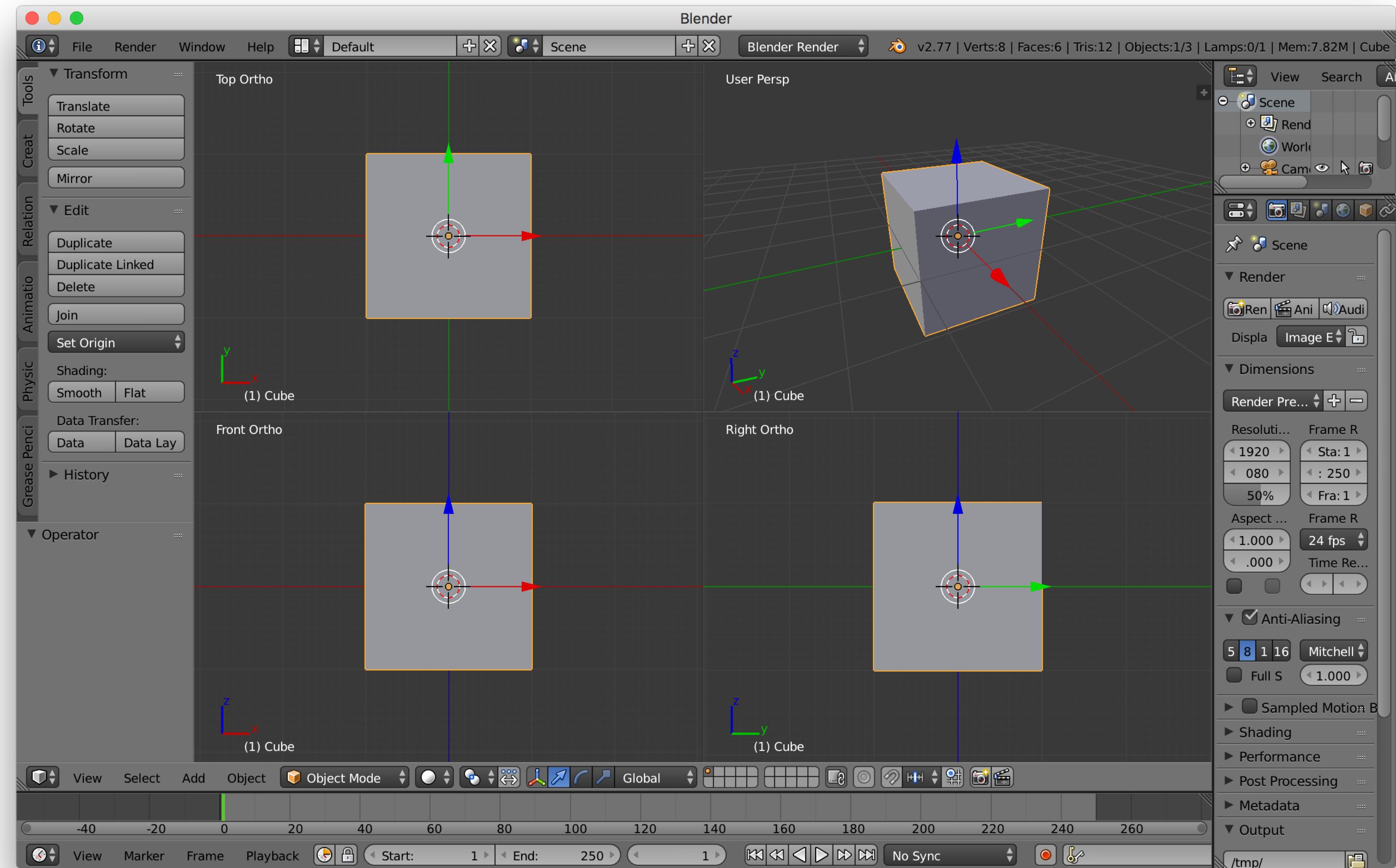


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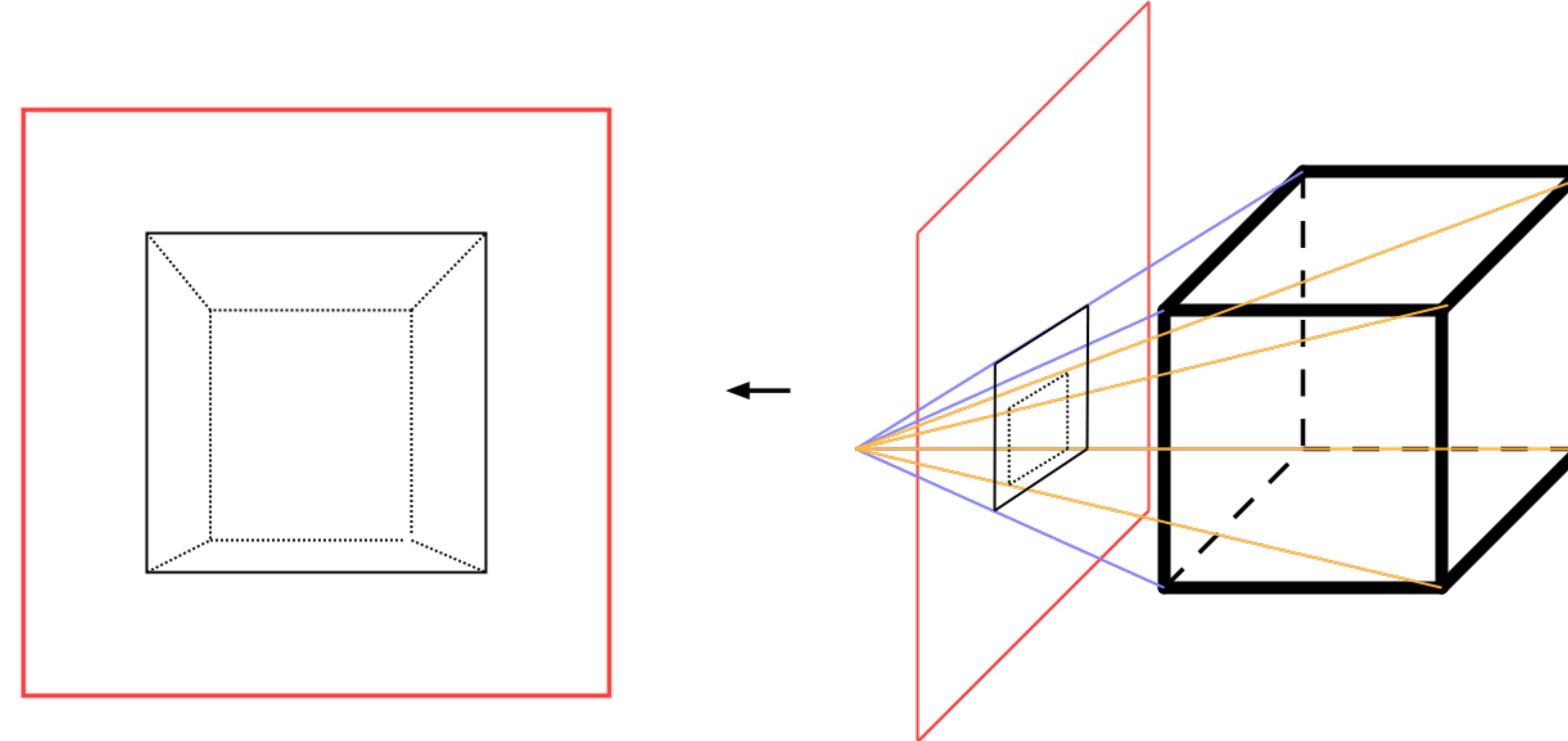
Parallel Projection



Commonly used in modeling tools



Perspective Projection

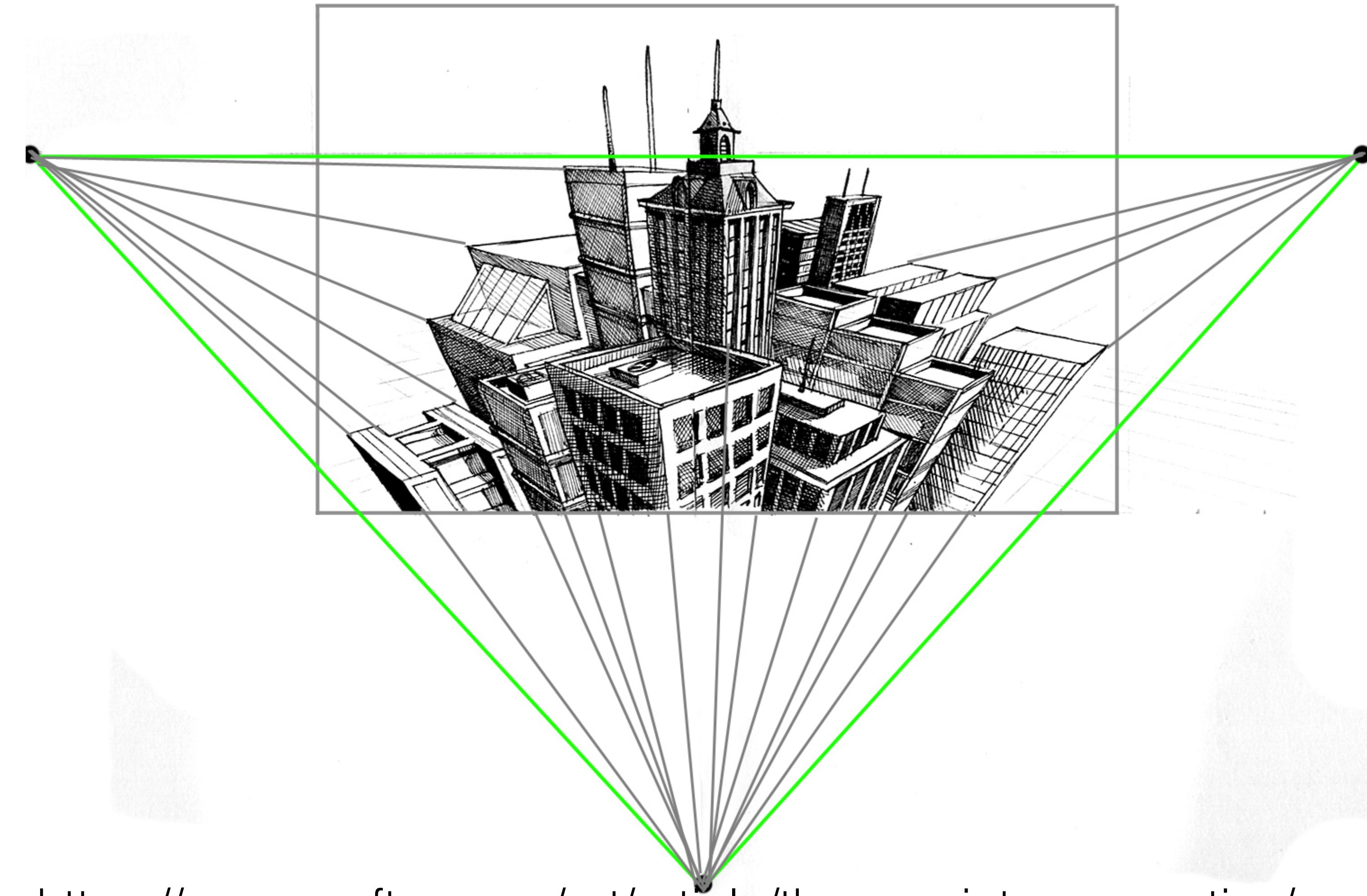


Each ray has a different direction!



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Three Point Perspective

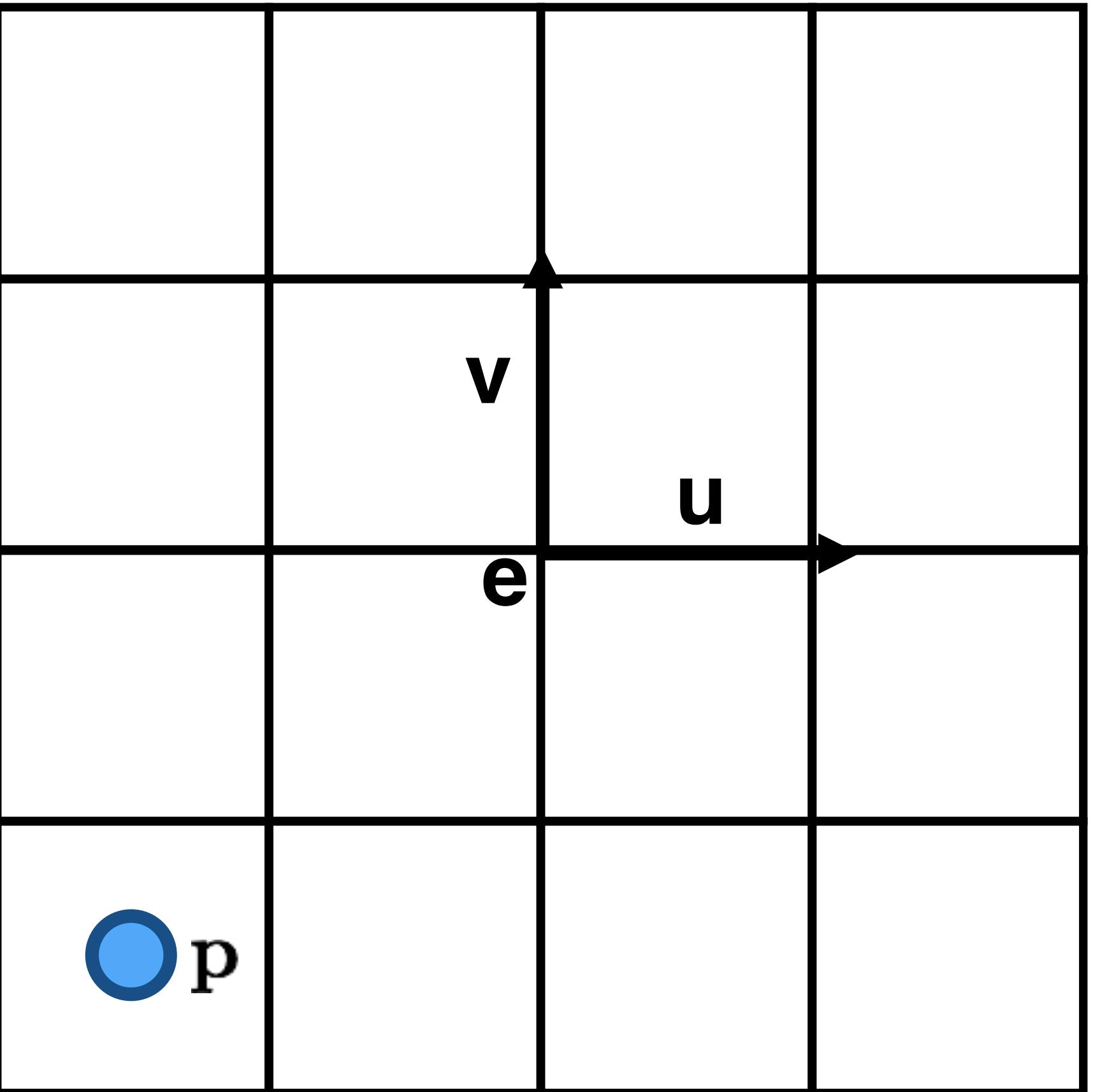
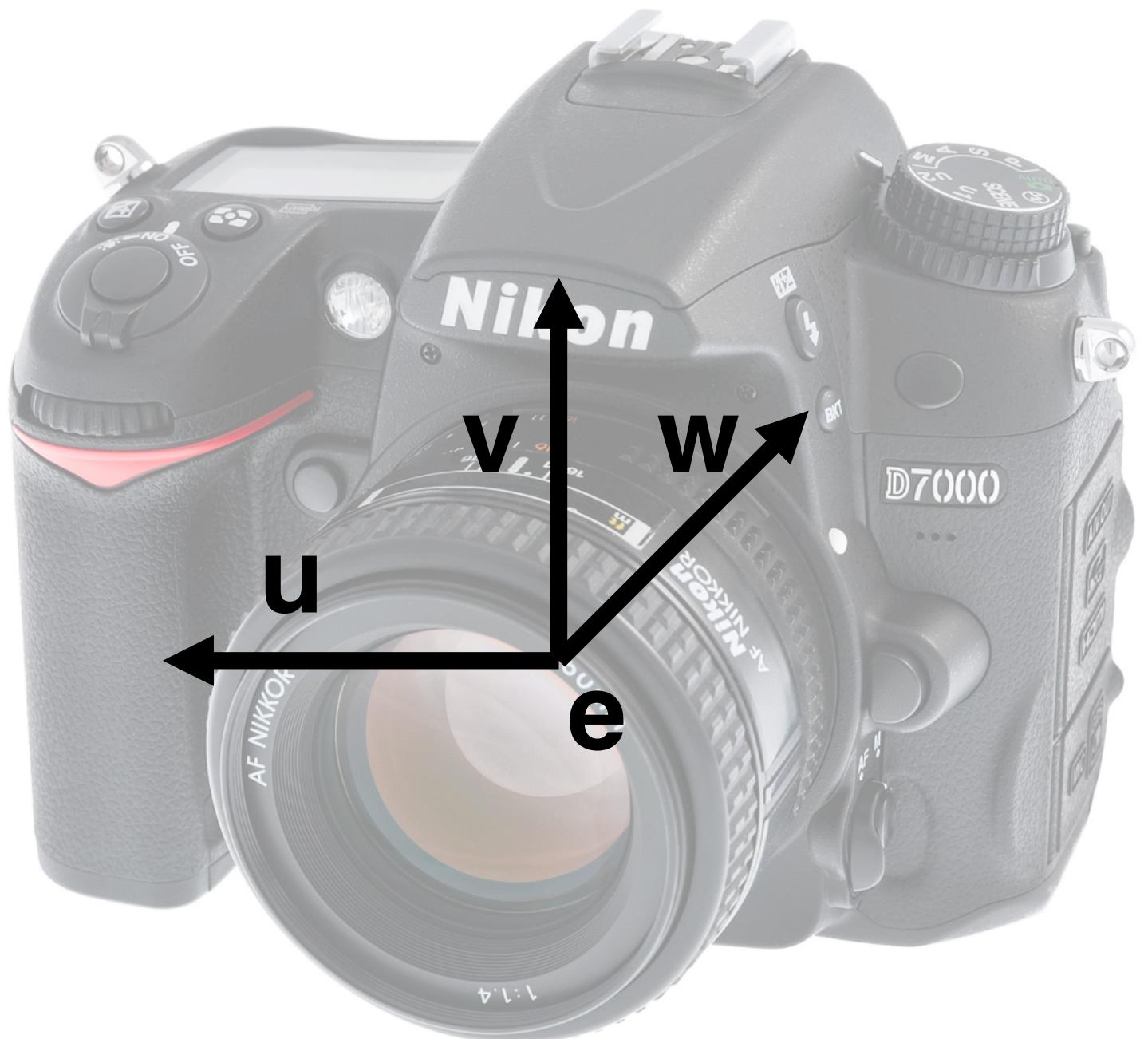


<https://www.craftsy.com/art/article/three-point-perspective/>



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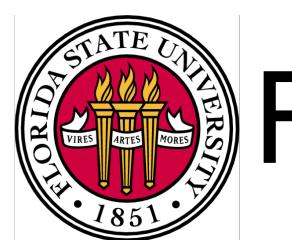
1. Compute Rays



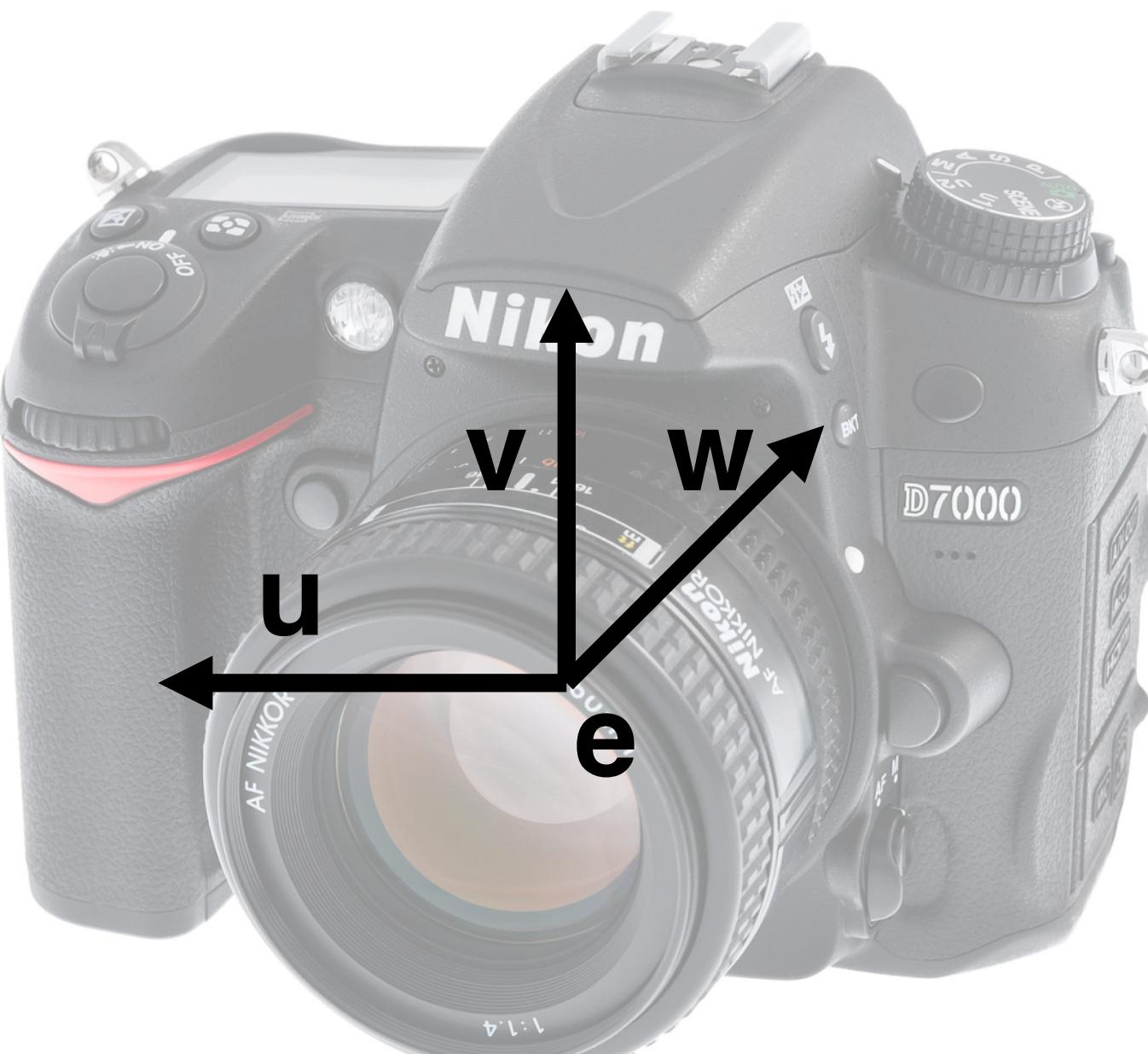
e is the origin of the reference system

p is the center of the pixel

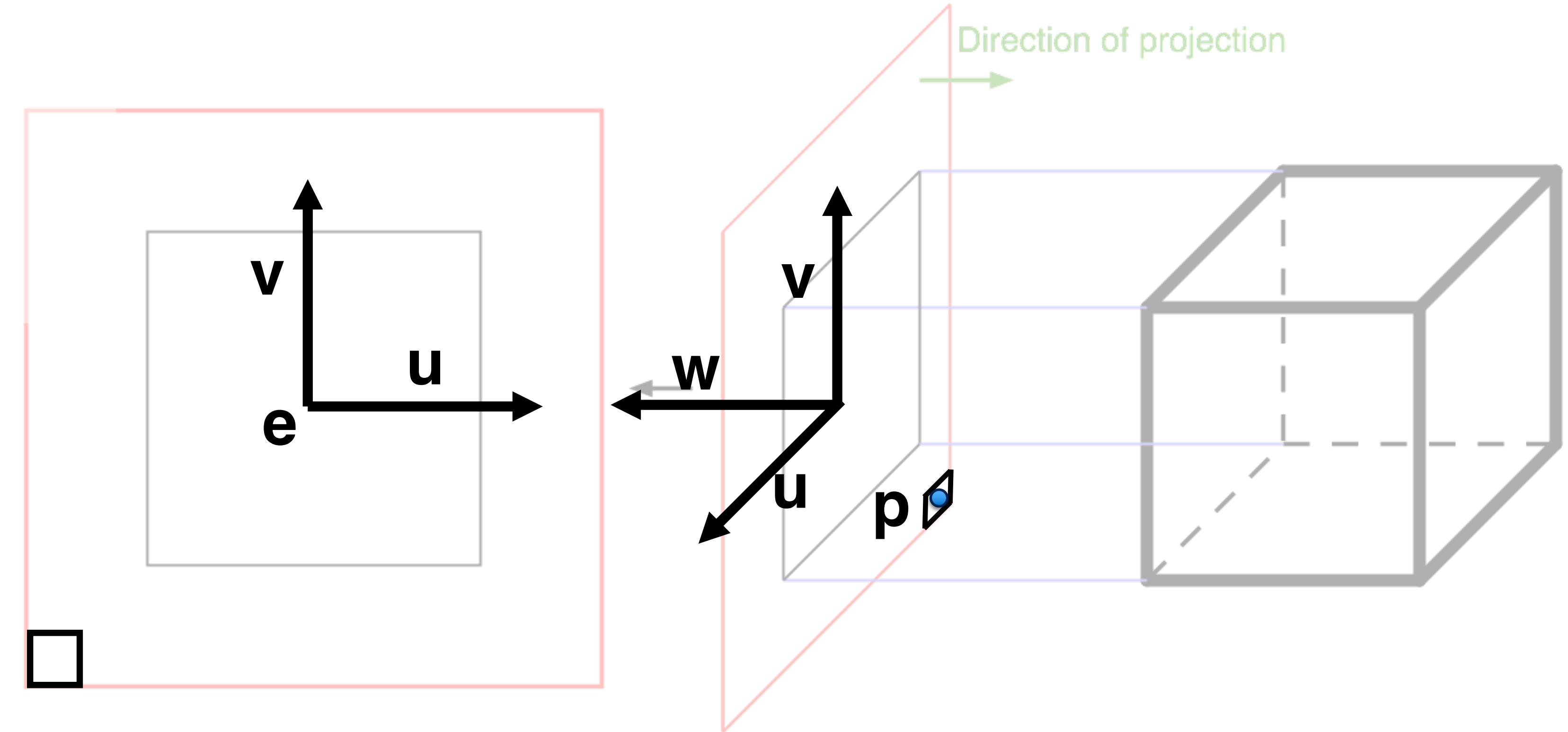
$$\mathbf{p} = \mathbf{e} + u\mathbf{u} + v\mathbf{v} + w\mathbf{w}$$



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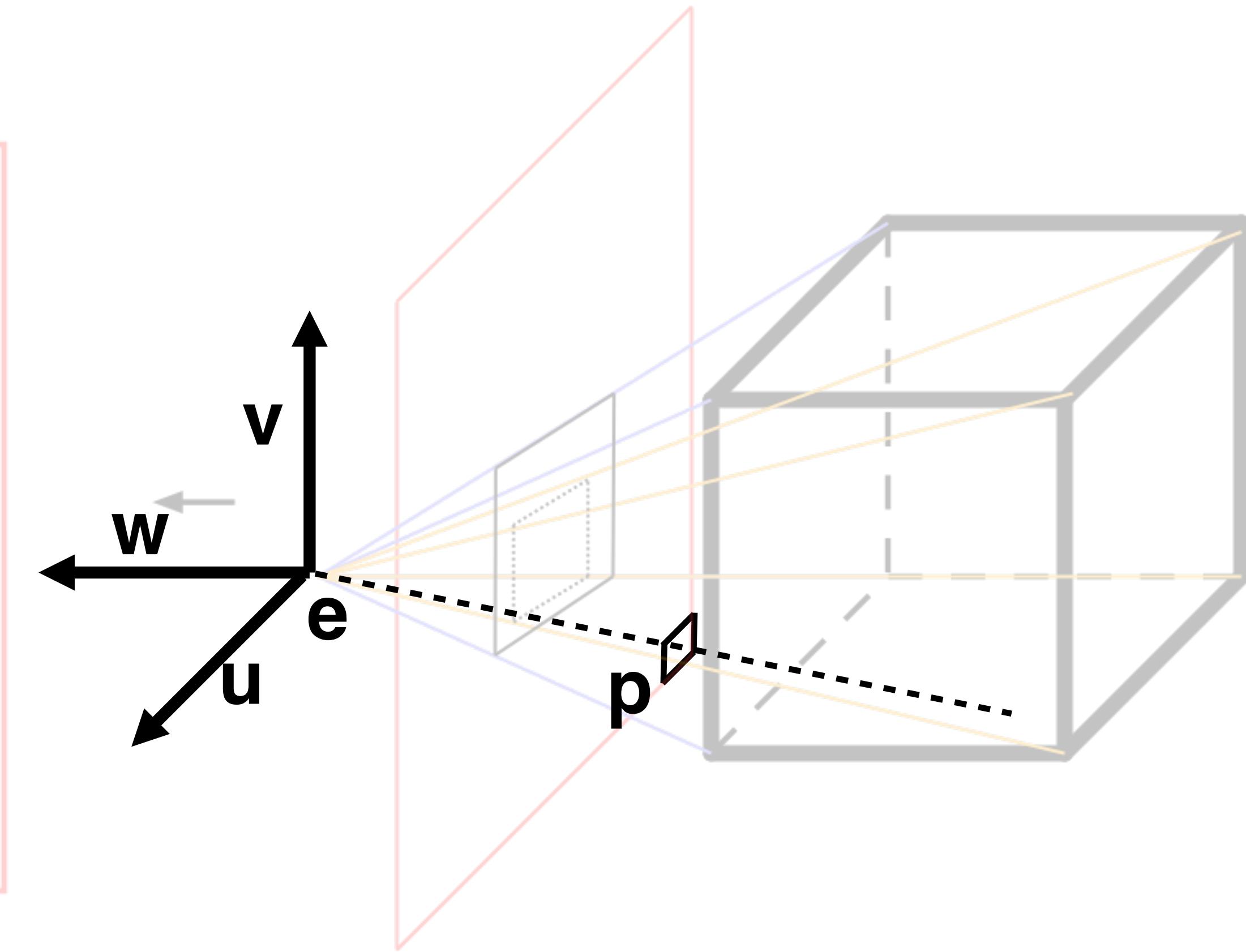
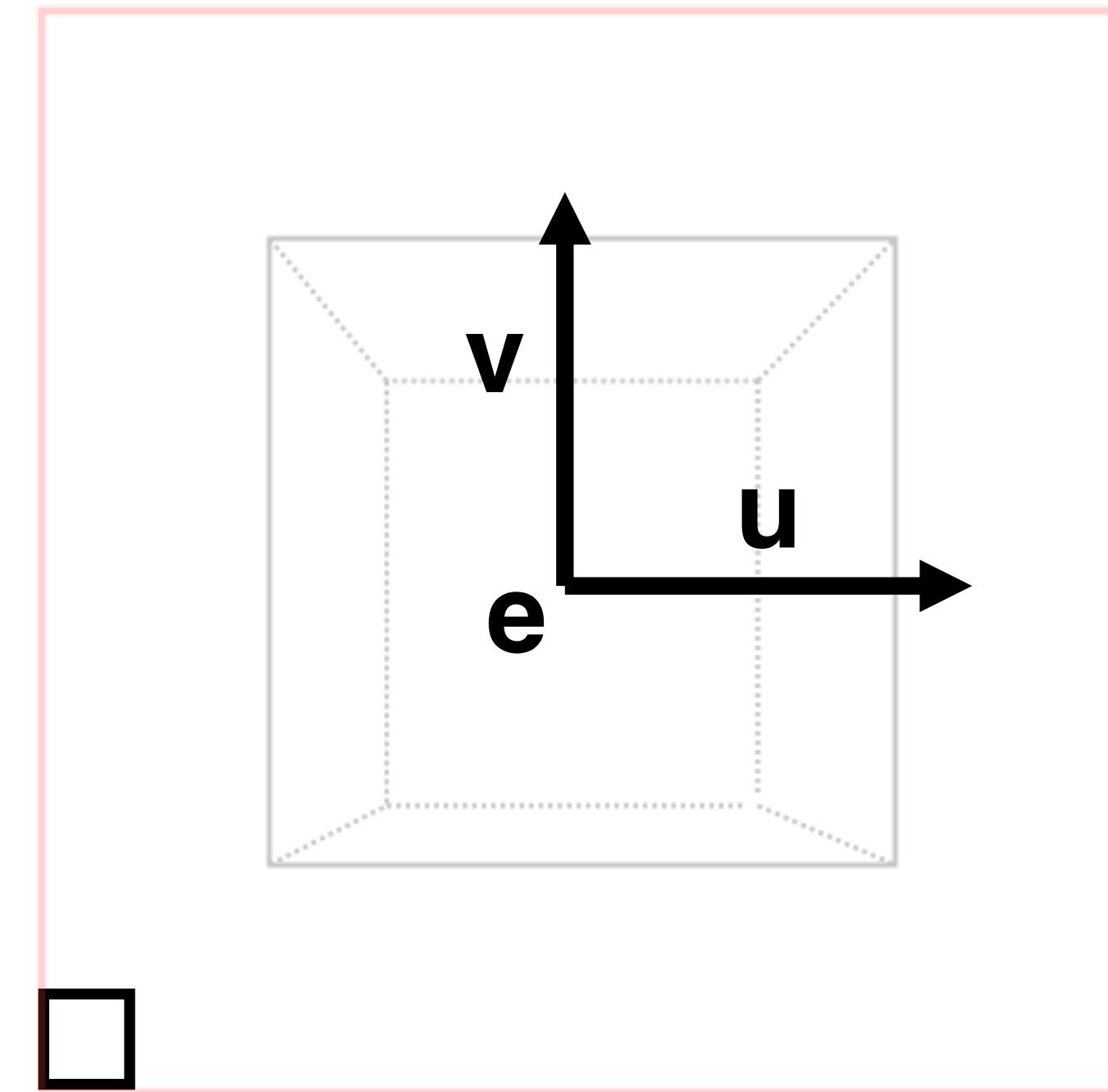
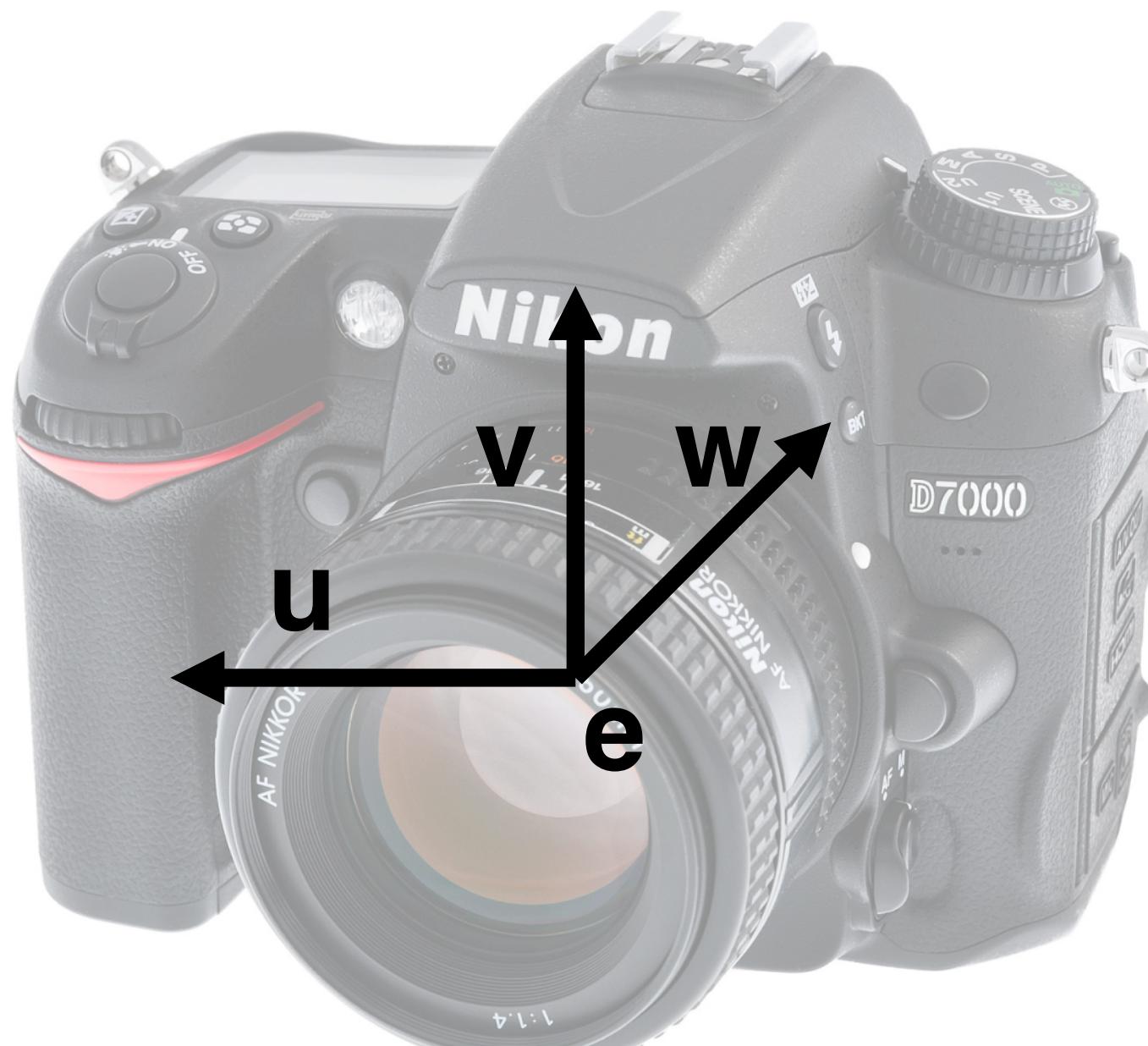


Orthographic



- For the ray assigned to pixel \mathbf{p} :
 - Origin: \mathbf{p}
 - Direction: $-\mathbf{w}$

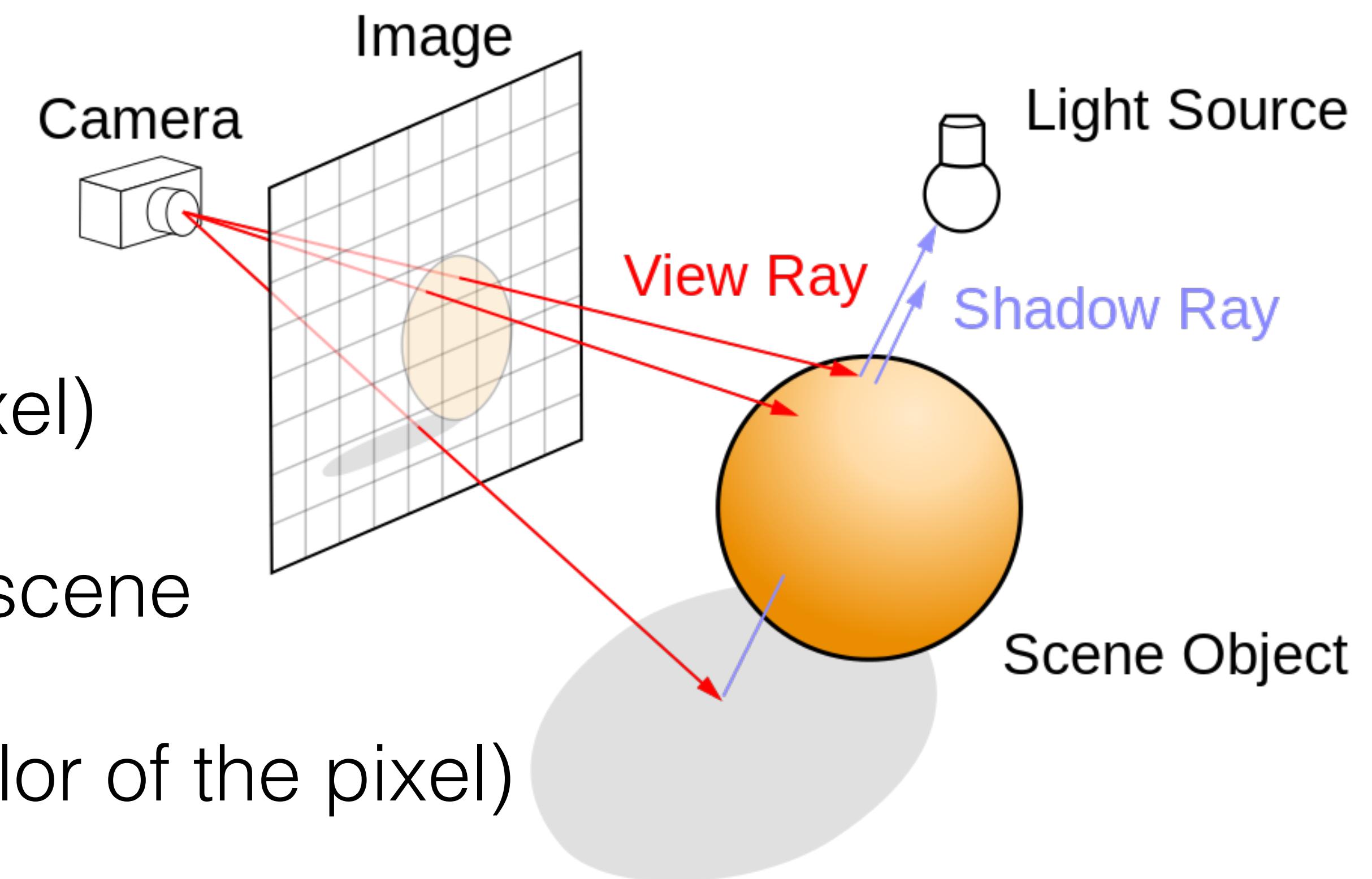
Perspective



- For the ray assigned to pixel \mathbf{p} :
 - Origin: \mathbf{e}
 - Direction: $\mathbf{p} - \mathbf{e}$

Basic Raytracing

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Intersections

- This is an expensive operation
- There is a large literature, a good overview is here:
<http://www.realtimerendering.com/intersections.html>
- We will study two very useful cases:
 - Spheres
 - Triangles (by combining many triangles you can approximate complex surfaces)



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Ray-Sphere Intersection

- We have a ray in explicit form:

$$\mathbf{p}(t) = \mathbf{e} + t\mathbf{d}$$

- and a sphere of radius r and center \mathbf{c} in implicit form

$$f(\mathbf{p}) = (\mathbf{p} - \mathbf{c}) \cdot (\mathbf{p} - \mathbf{c}) - R^2 = 0$$

- To find the intersection we need to find the solutions of

$$f(\mathbf{p}(t)) = 0$$



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2. Ray-Triangle Intersection

- Explicit parametrization of a triangle with vertices **a,b,c**:

$$\mathbf{f}(u, v) = \mathbf{a} + u(\mathbf{b} - \mathbf{a}) + v(\mathbf{c} - \mathbf{a})$$

- Explicit ray:

$$\mathbf{p}(t) = \mathbf{e} + t\mathbf{d}$$

- The ray intersects the triangle if a t, u, v exist s.t.:

$$\mathbf{f}(u, v) = \mathbf{p}(t)$$

$$t > 0 \quad 0 \leq u, v \quad u + v \leq 1$$



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Multiple Objects

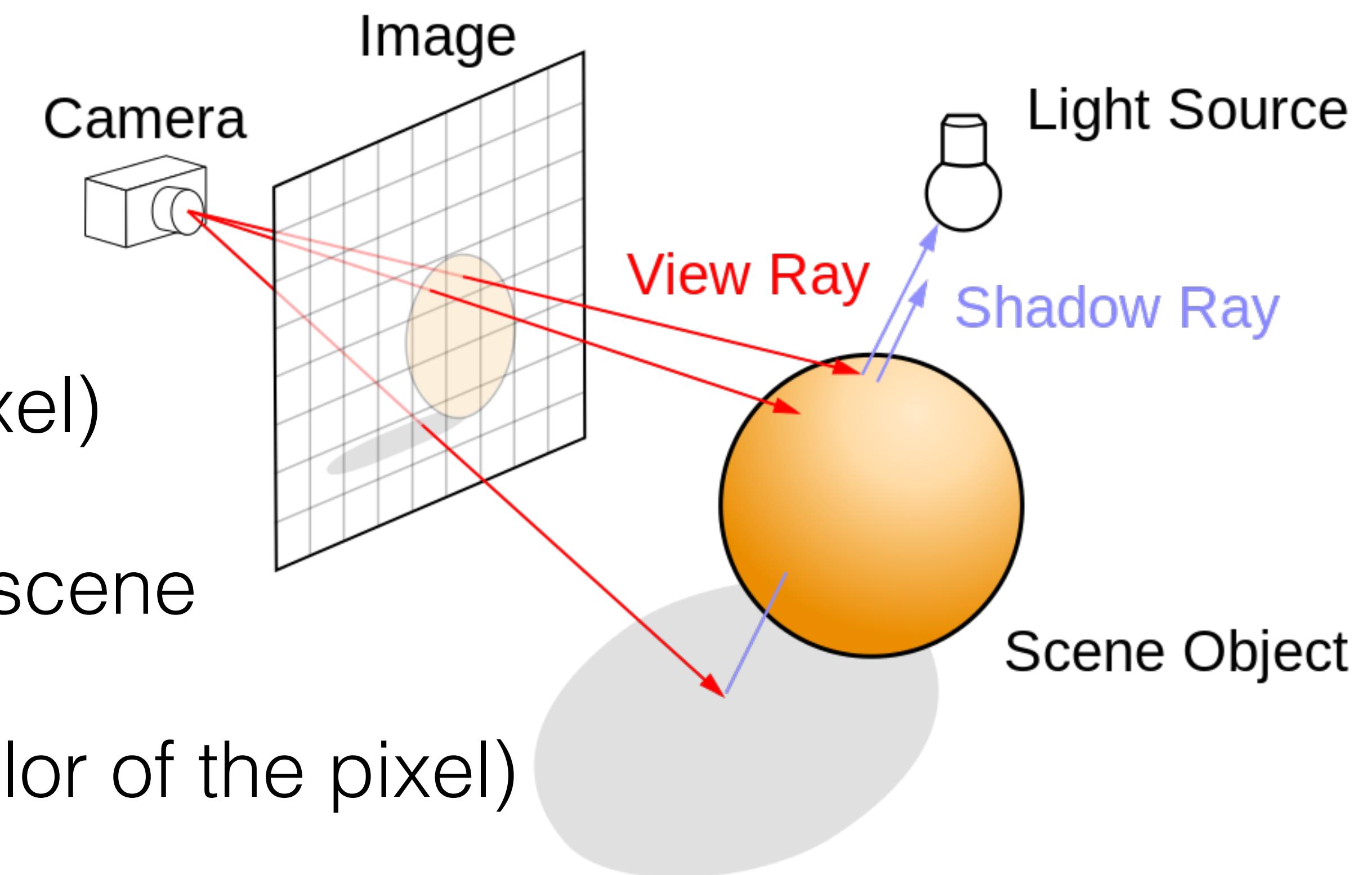
- It is simple, intersect it with all of them and only keep the closest intersection
- To speed up computation, you can use a spatial data structure to prune the number of collisions that you need to check



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Basic Raytracing

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Shading

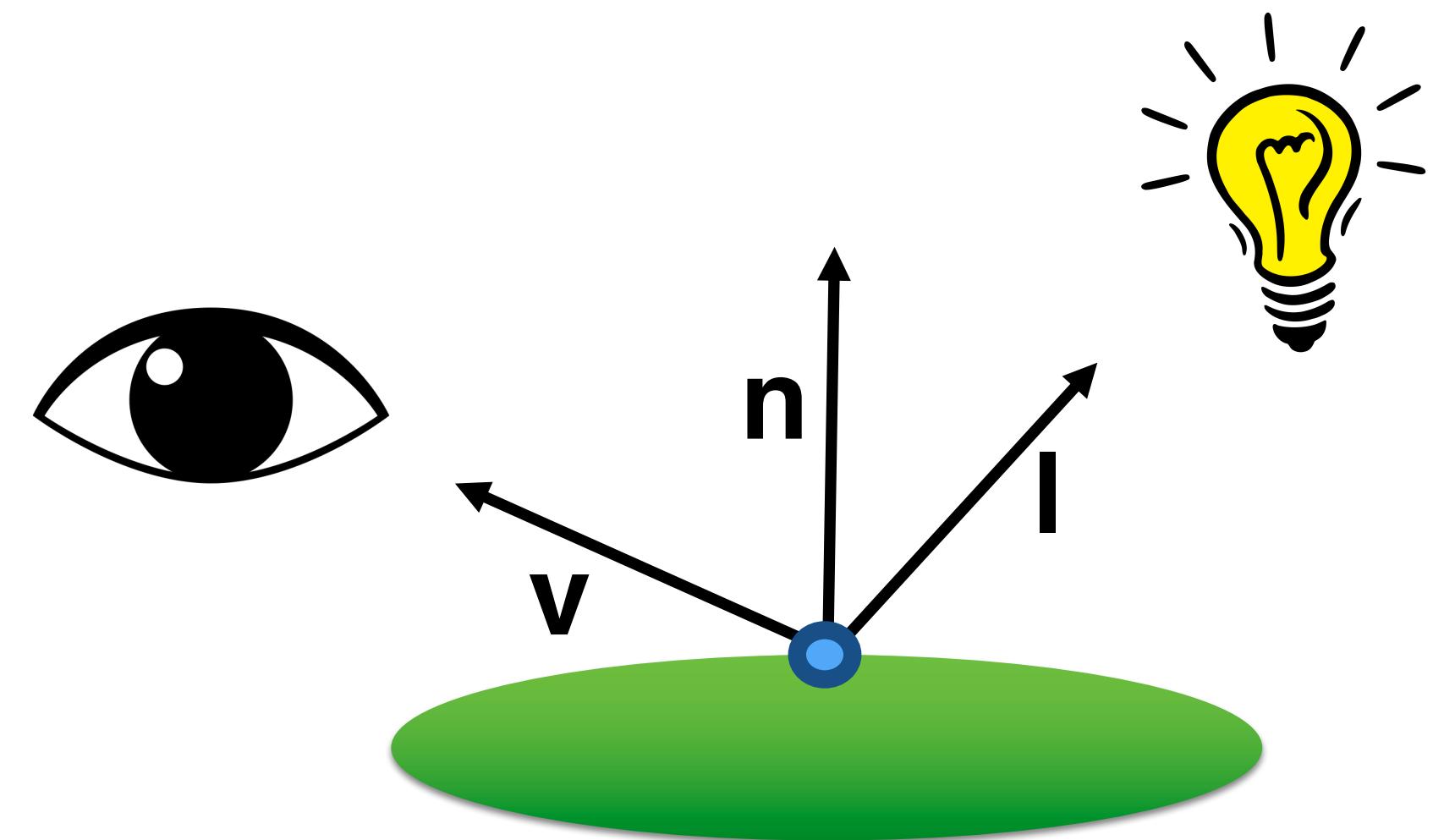
- Modeling accurately the behavior of light is difficult and computationally expensive
- We will use an approximation that is simple and efficient. It is divided in 3 parts:
 - Diffuse (Lambertian) Shading
 - Specular (Blinn-Phong) Shading
 - Ambient Shading
- The three terms will be summed together to obtain the final color



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Shading Variables

- The shading depends on the entire scene, the light can bounce, reflect and be absorbed by anything that it encounters
- We will simplify it so that it depends only on:
 - The light direction \mathbf{l} (a *unit* vector pointing to the light source)
 - The view direction \mathbf{v} (a *unit* vector pointing toward the camera)
 - The surface normal \mathbf{n} (a vector perpendicular to the surface at the point of intersection)

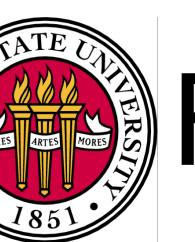
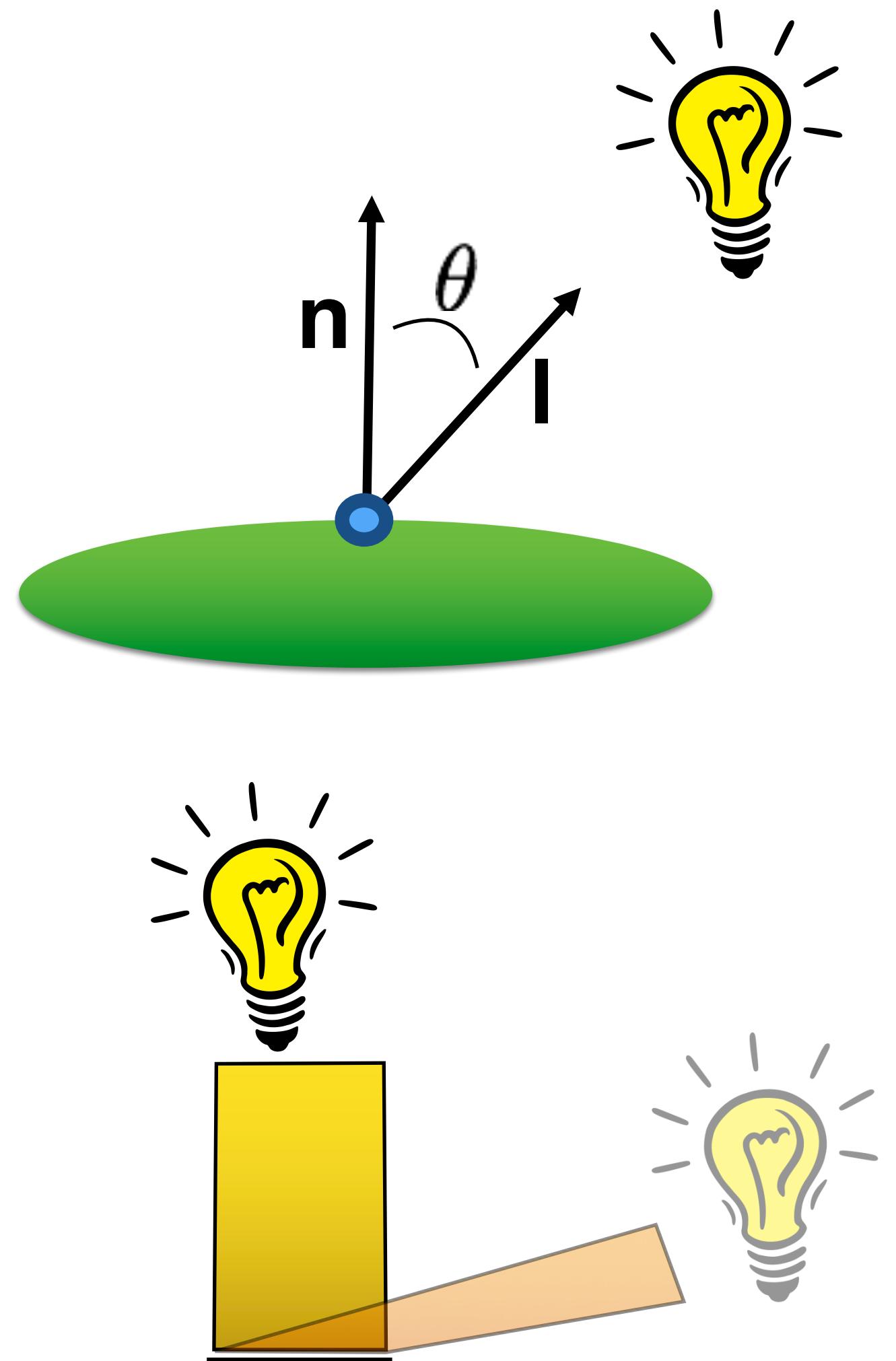


Diffuse Shading

- Lambert (18th century) observed that the amount of energy from a light source that falls on an area of surface depends on the angle of the surface to the light
- To model it, we make the amount of light proportional to the angle θ between the \mathbf{n} and \mathbf{l} diffuse coefficient

$$L = k_d I \max(0, \mathbf{n} \cdot \mathbf{l})$$

intensity of the light



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Specular Shading

$p = 100 \rightarrow$ Shiny
 $p = 1000 \rightarrow$ Glossy
 $p > 10,000 \rightarrow$ Mirror

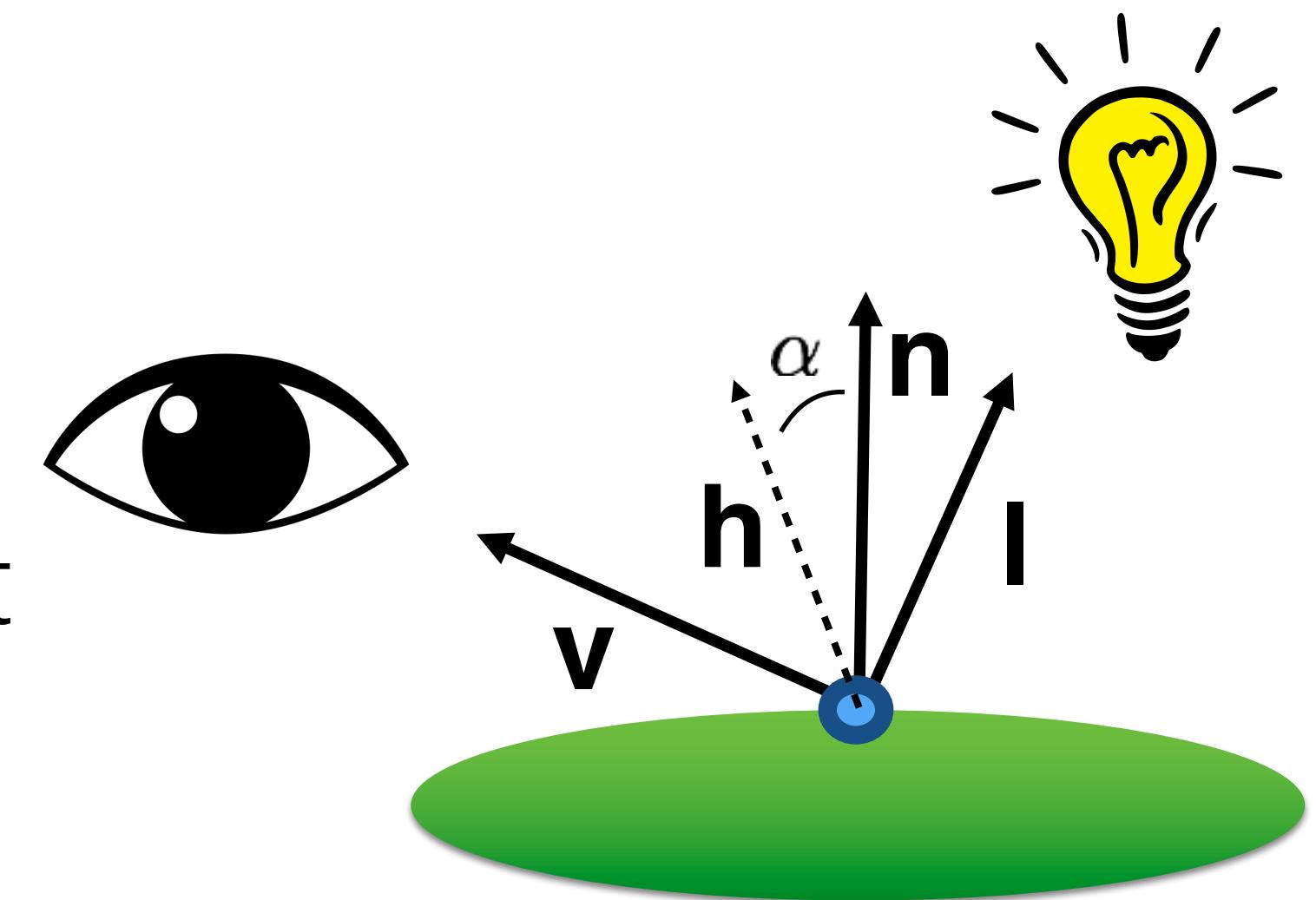
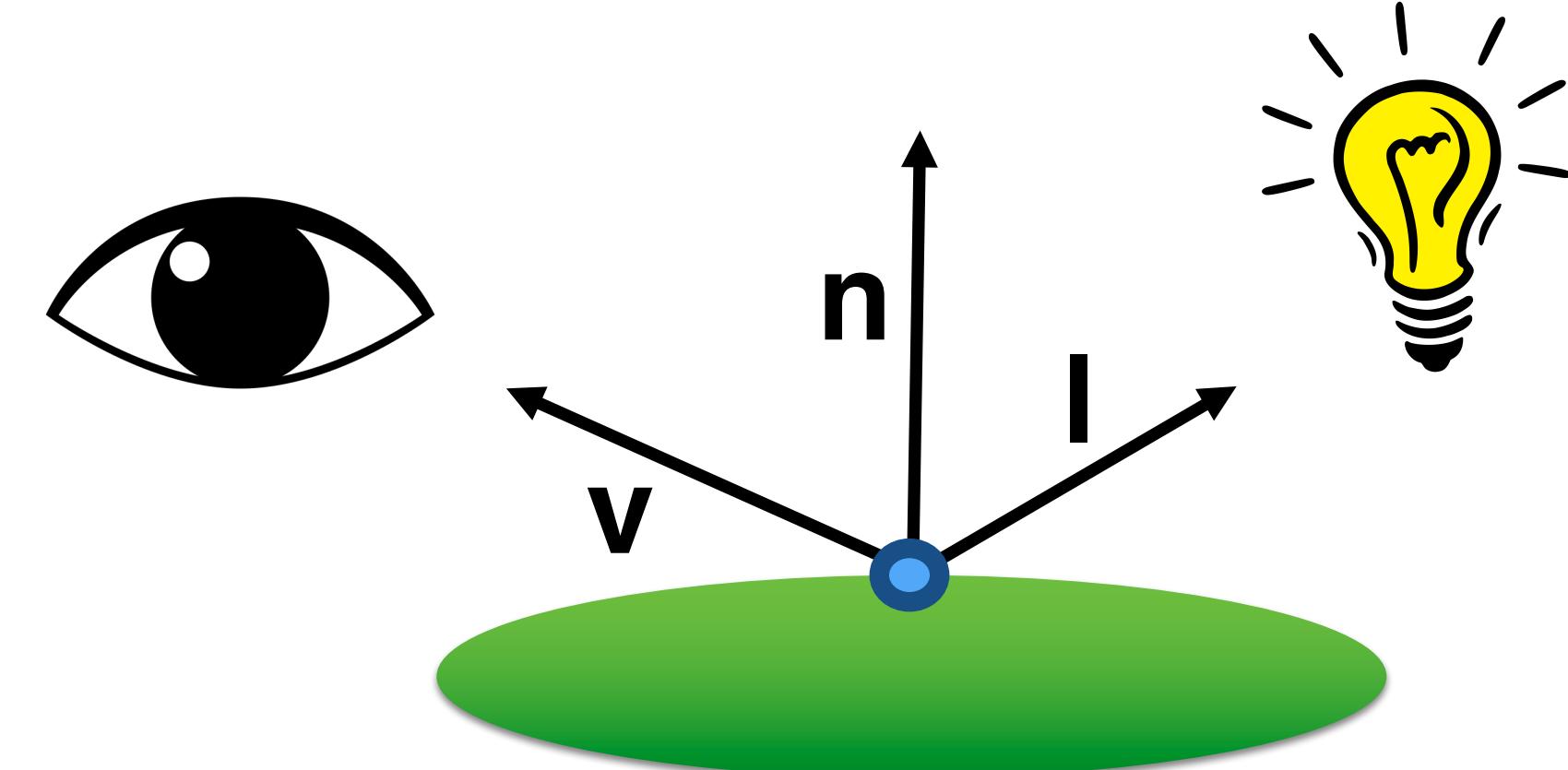
- Specular highlights depend on the position of the viewer
- A simple and effective model to model them has been proposed by Phong (1975) and refined by Blinn (1976)
- The idea is to produce a reflection that is bright if \mathbf{v} and \mathbf{l} are symmetric wrt \mathbf{n}
- To measure the asymmetry we measure the angle between \mathbf{h} (the bisector of \mathbf{v} and \mathbf{l}) and \mathbf{n}

$$\mathbf{h} = \frac{\mathbf{v} + \mathbf{l}}{\|\mathbf{v} + \mathbf{l}\|}$$

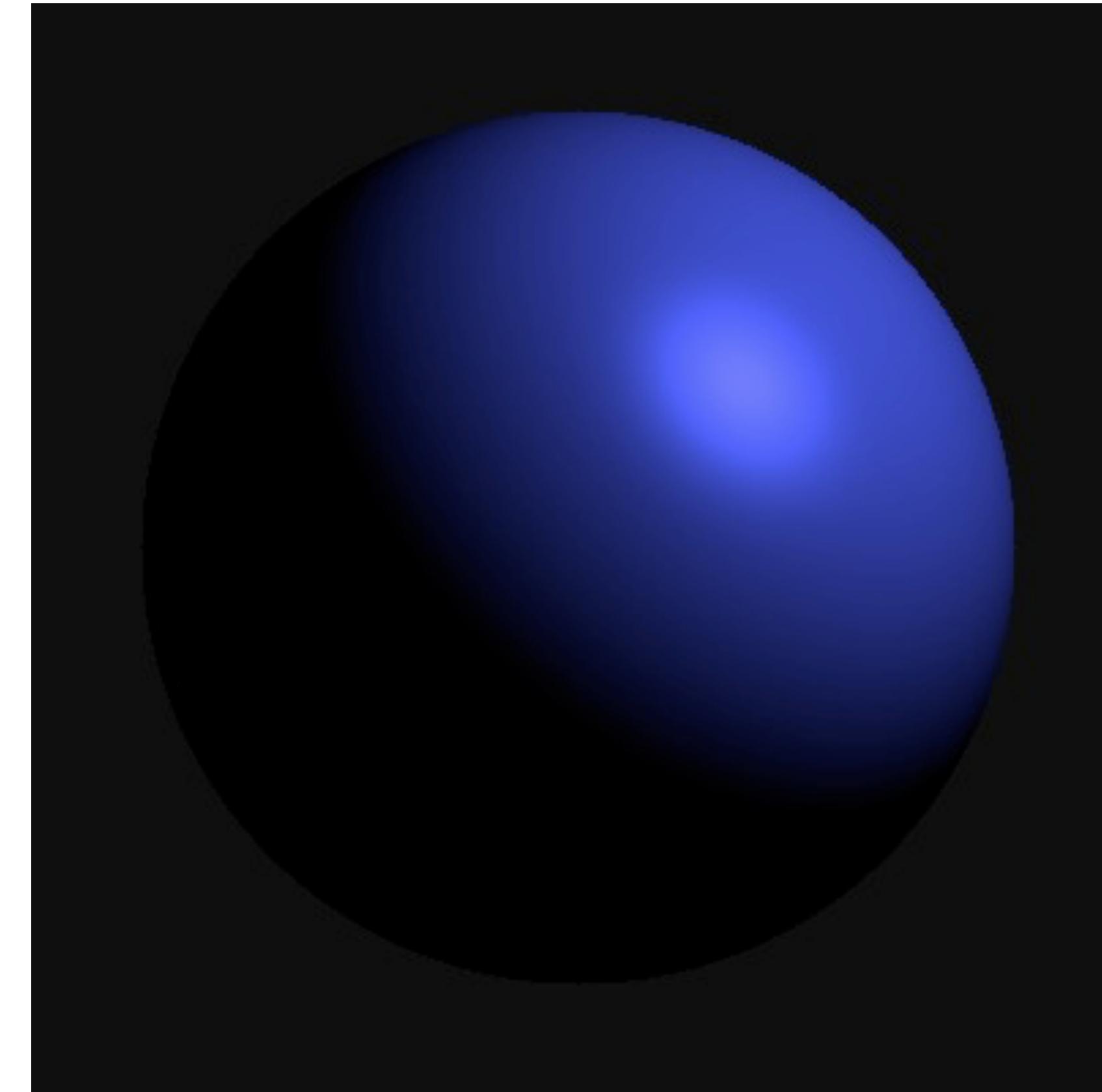
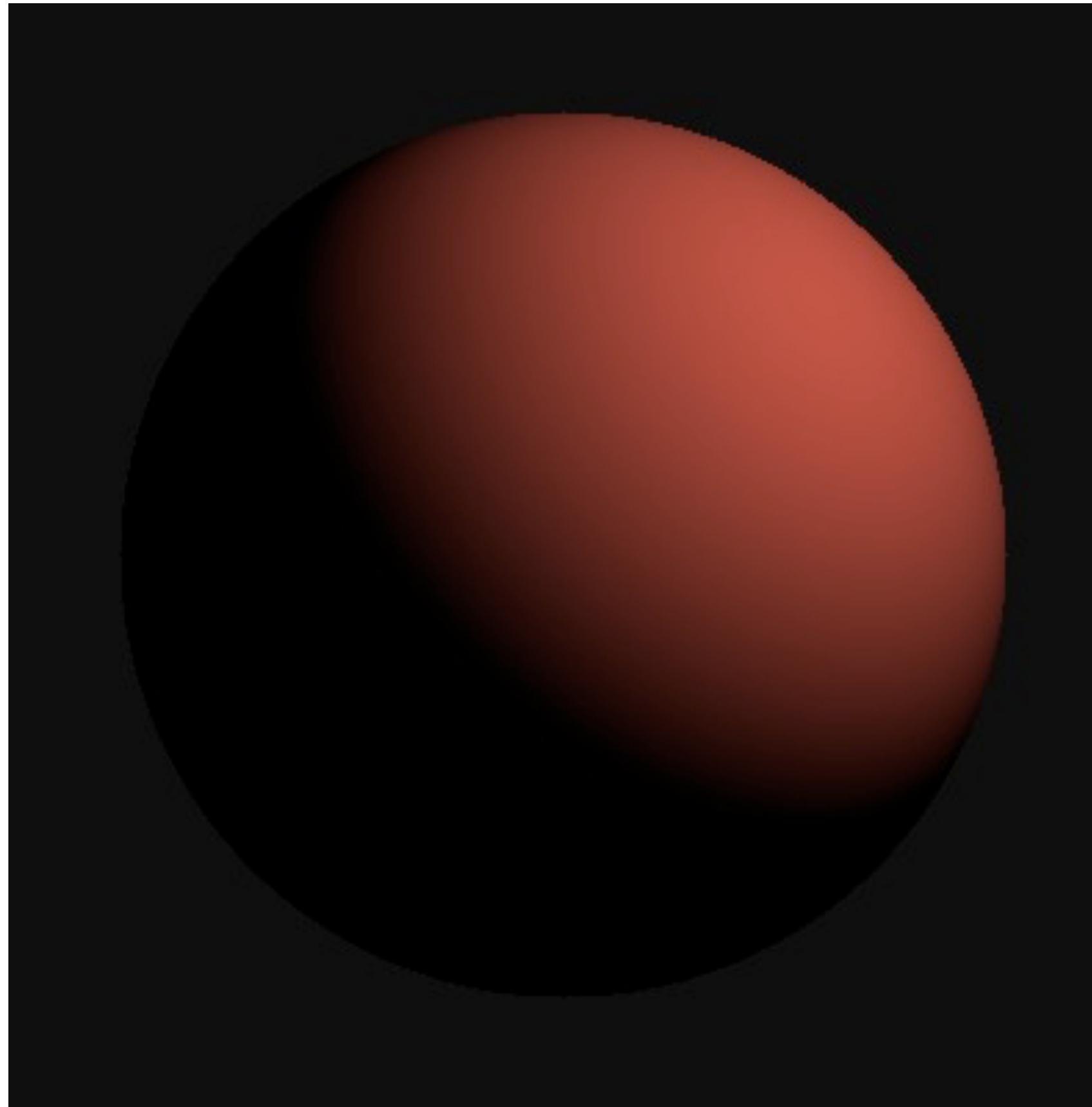
$$L = k_d I \max(0, \mathbf{n} \cdot \mathbf{l}) + k_s I \max(0, \mathbf{n} \cdot \mathbf{h})^p$$

specular coefficient

Phong exponent



Diffuse and Specular



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Final Shading Equation

$$L = k_a I_a + k_d I \max(0, \mathbf{n} \cdot \mathbf{l}) + k_s I \max(0, \mathbf{n} \cdot \mathbf{h})^p$$



Ambient



Diffuse



Specular

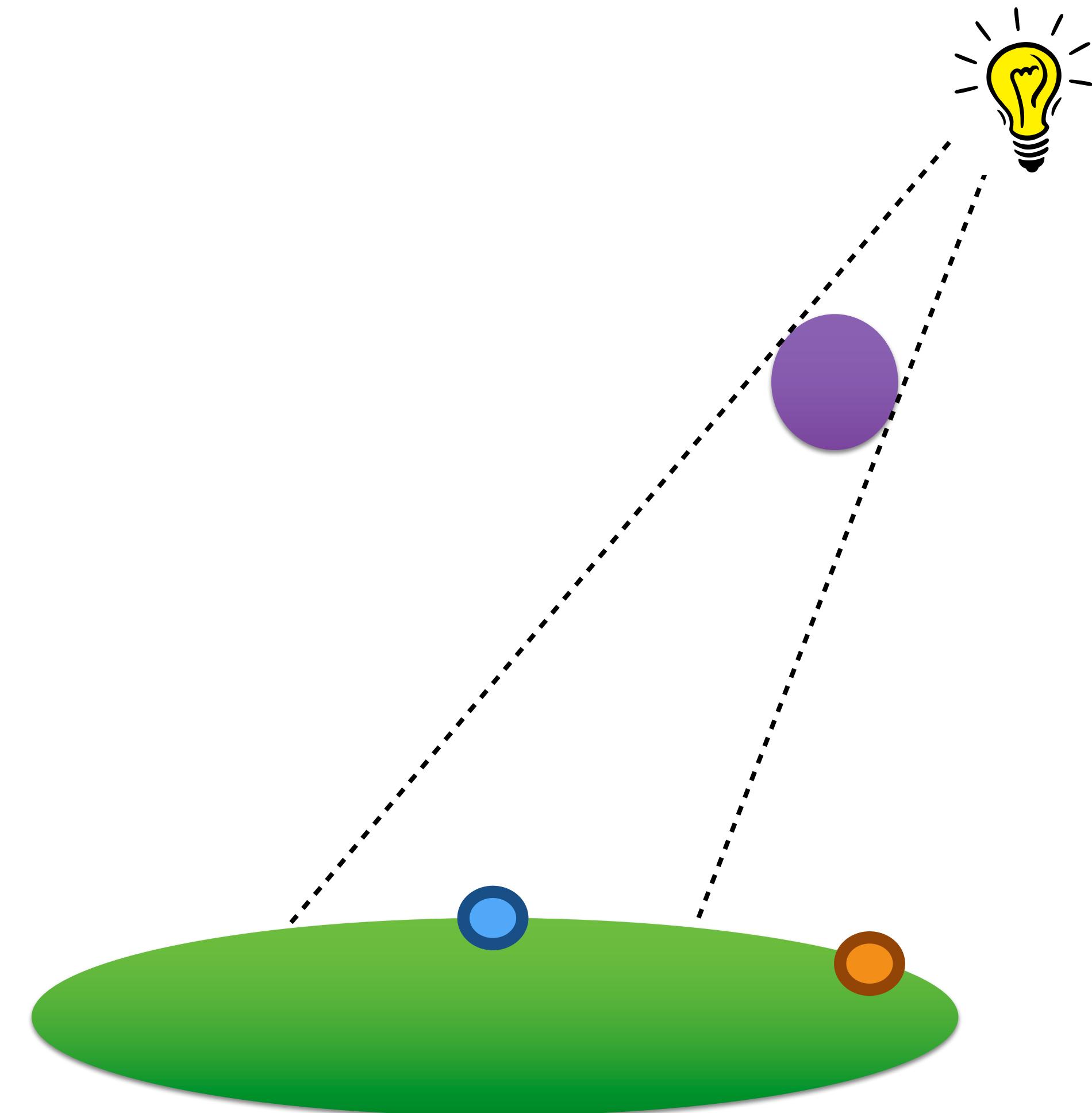
If you have multiple lights, simply sum them up all together.
Note that the ambience light should be considered only once.



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Shadows

- The blue point does not receive light, while the orange one does
- To check it, cast a ray from each point to the light — if you intersect something (before reaching the light) then it is in a shadow area, and the light should not contribute to its color
- These rays are usually called **shadow rays**



The shadow rays should be casted an epsilon away from the source



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Ideal Reflections

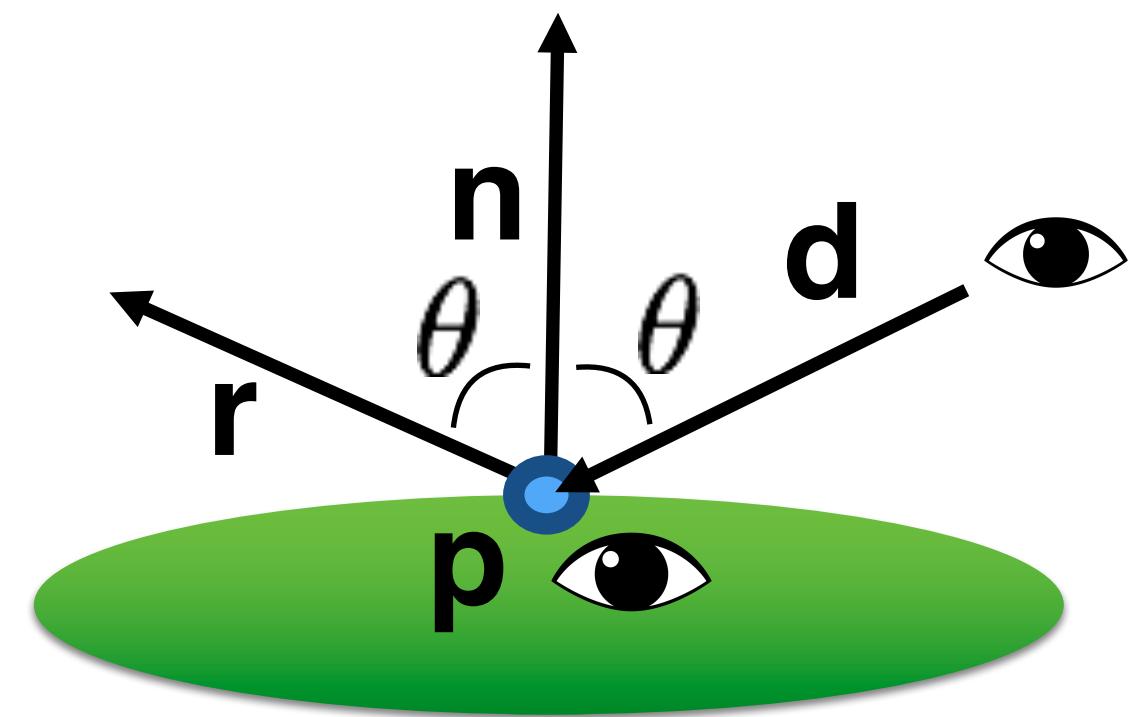
Limit the recursion depth!

- It is easy to add ideal reflections (also called mirror reflections) to your ray tracing program

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

$$\text{color } c = c + k_m \text{raycolor}(\mathbf{p} + s\mathbf{r}), \epsilon, \infty)$$

↑
specular color



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A simple ray-tracing program

- The source code of Assignment 1 is a simple ray tracer
- We will take a look at it after the C++ overview



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Conclusions

- Ray tracing is an effective way to render images
 - Specular reflection and Shadows are straightforward to implement
 - It is ubiquitously used even in rasterization pipelines to “pick” objects



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References

Fundamentals of Computer Graphics, Fourth Edition
4th Edition by [Steve Marschner, Peter Shirley](#)

Chapters 4, 10, 13

