# Ray Tracing



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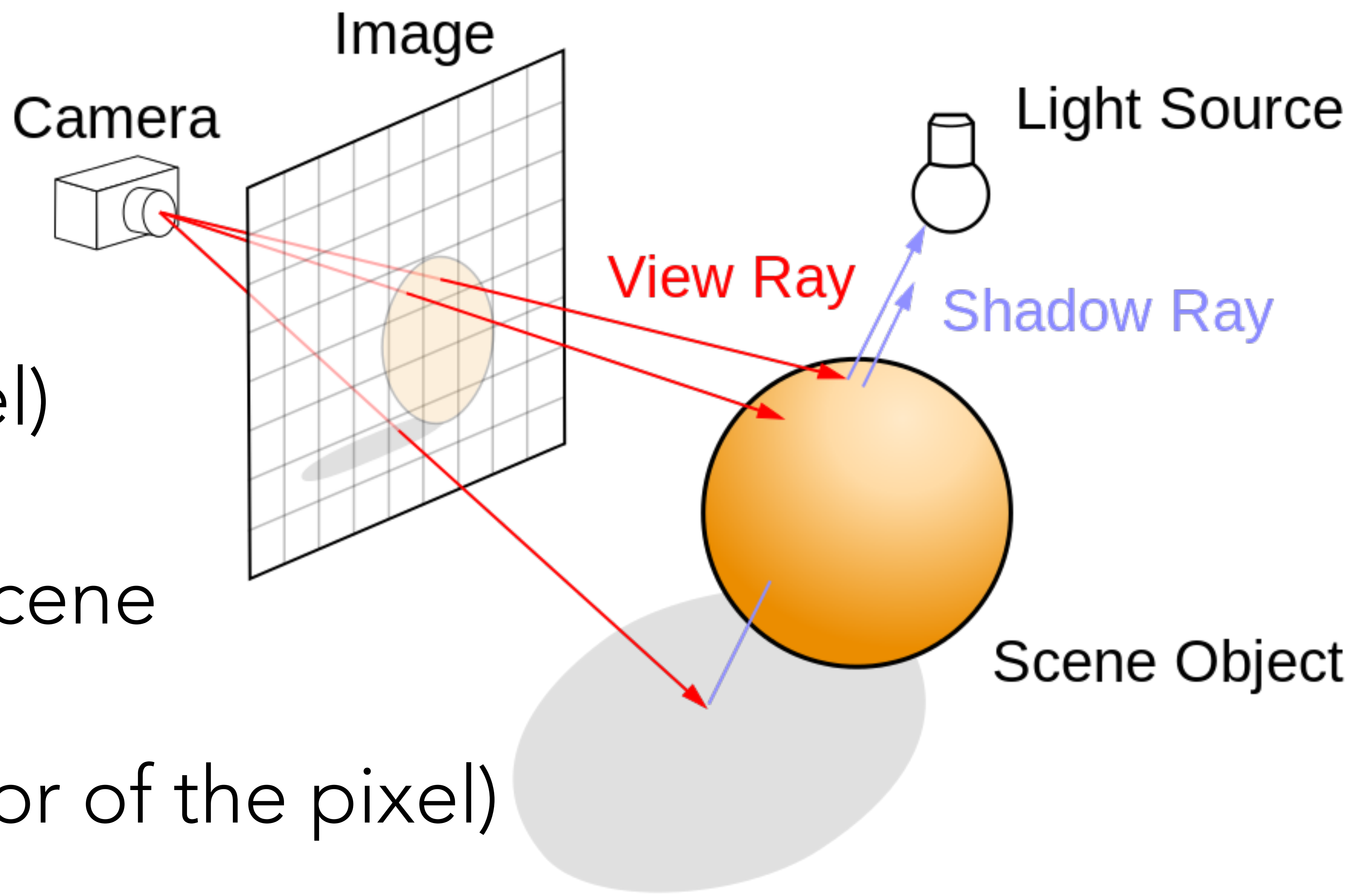
# Basic Raytracing

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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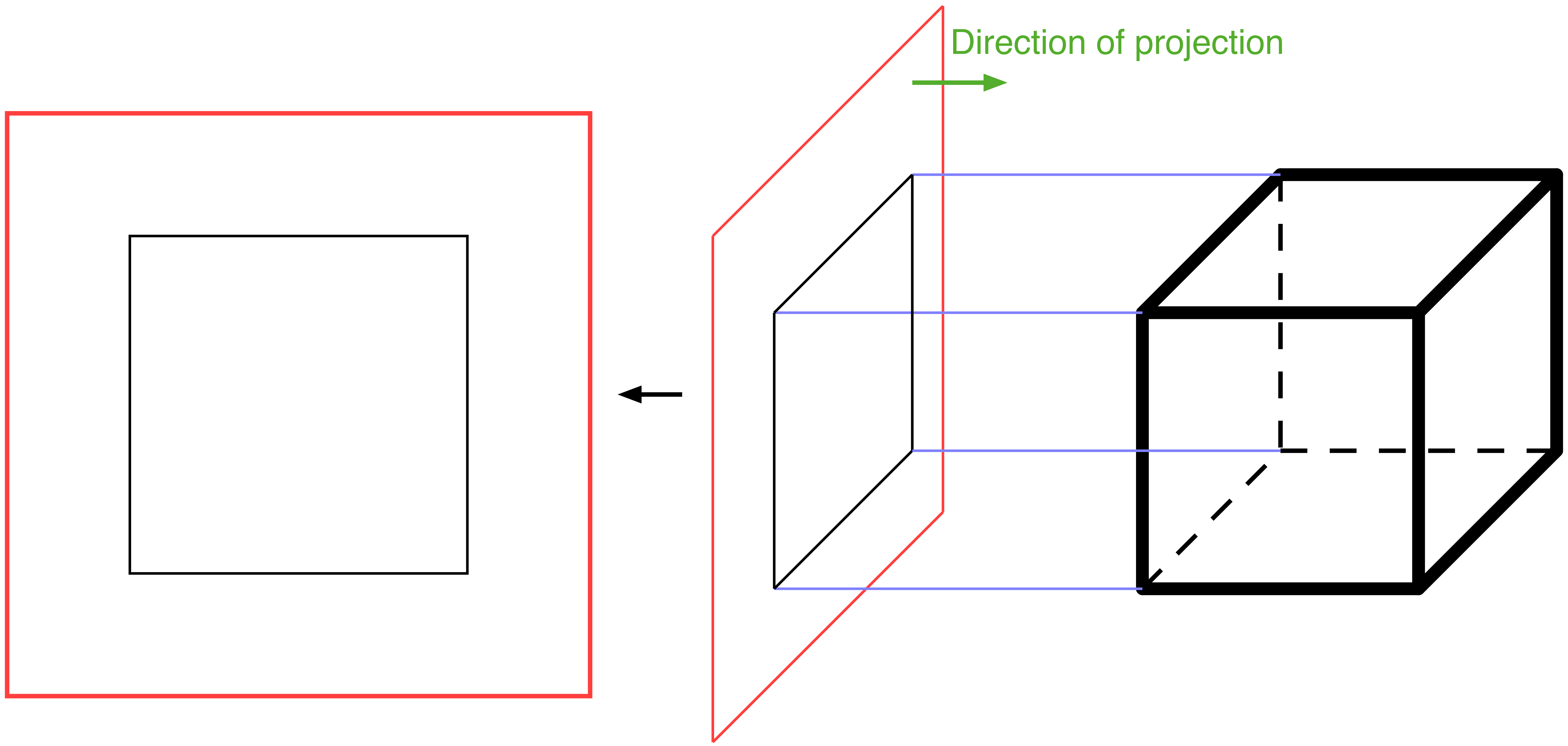
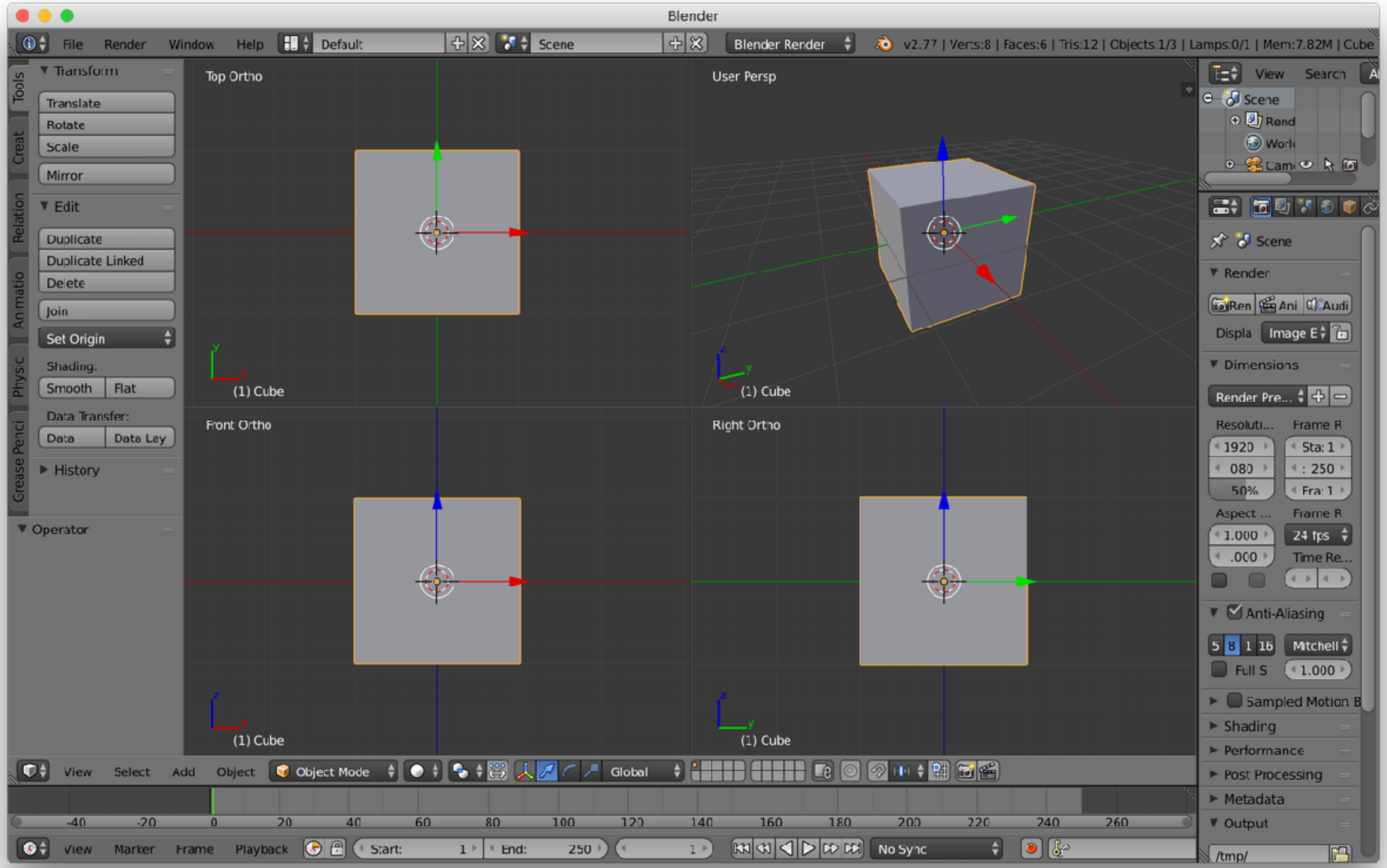
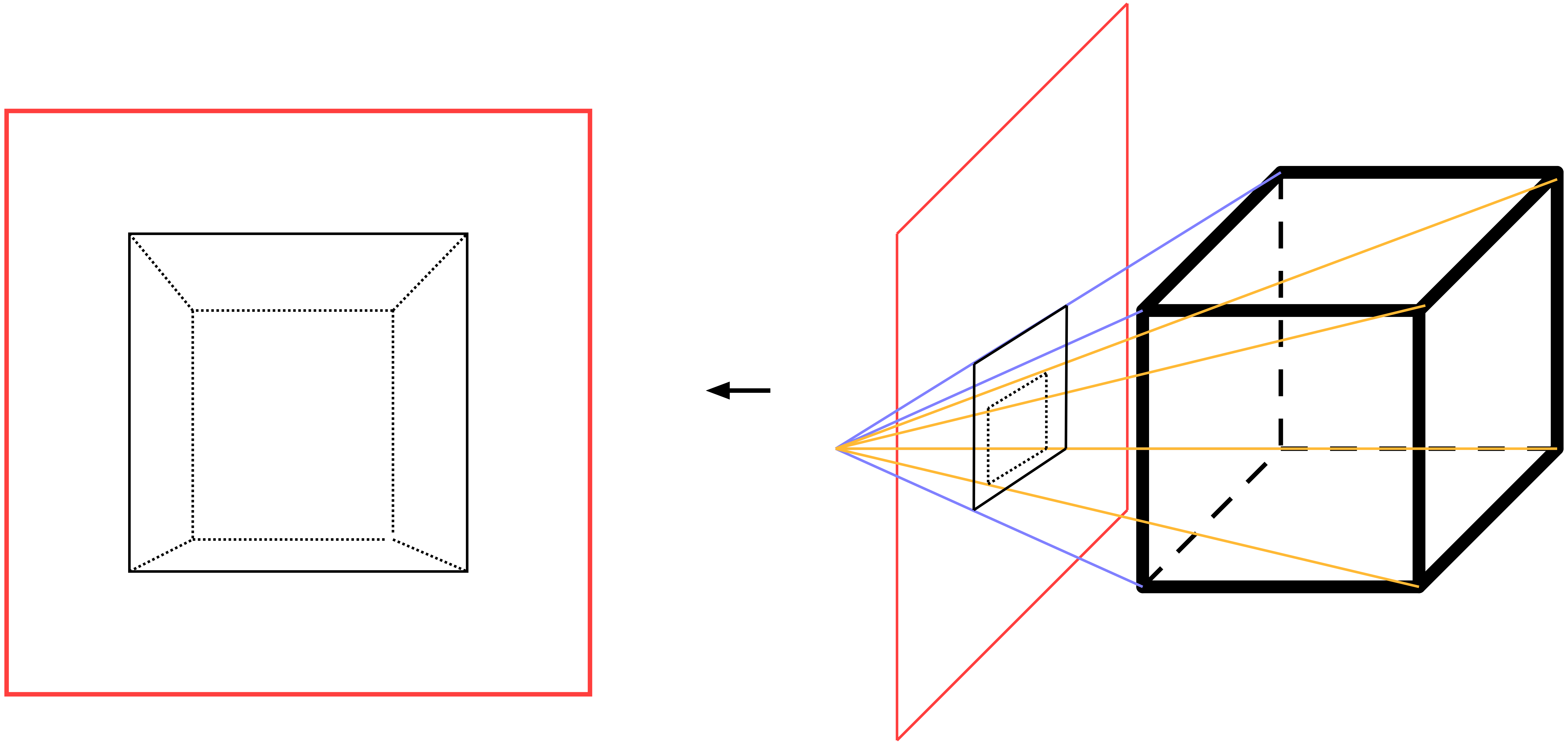
# Projection - Parallel



# Commonly used in modeling tools

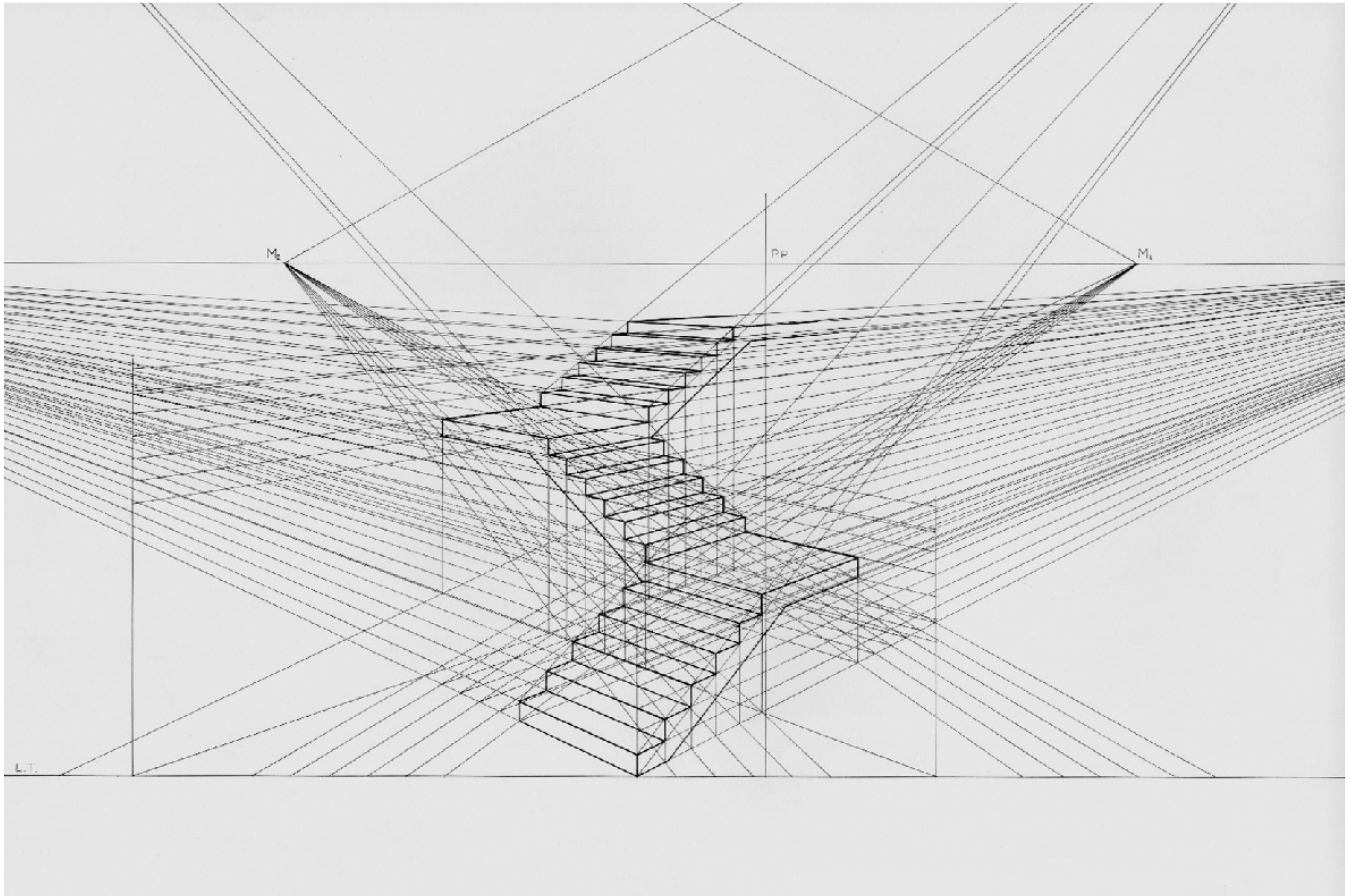


# Perspective Projection



Each ray has a different direction!

# Two and Three Point Perspectives



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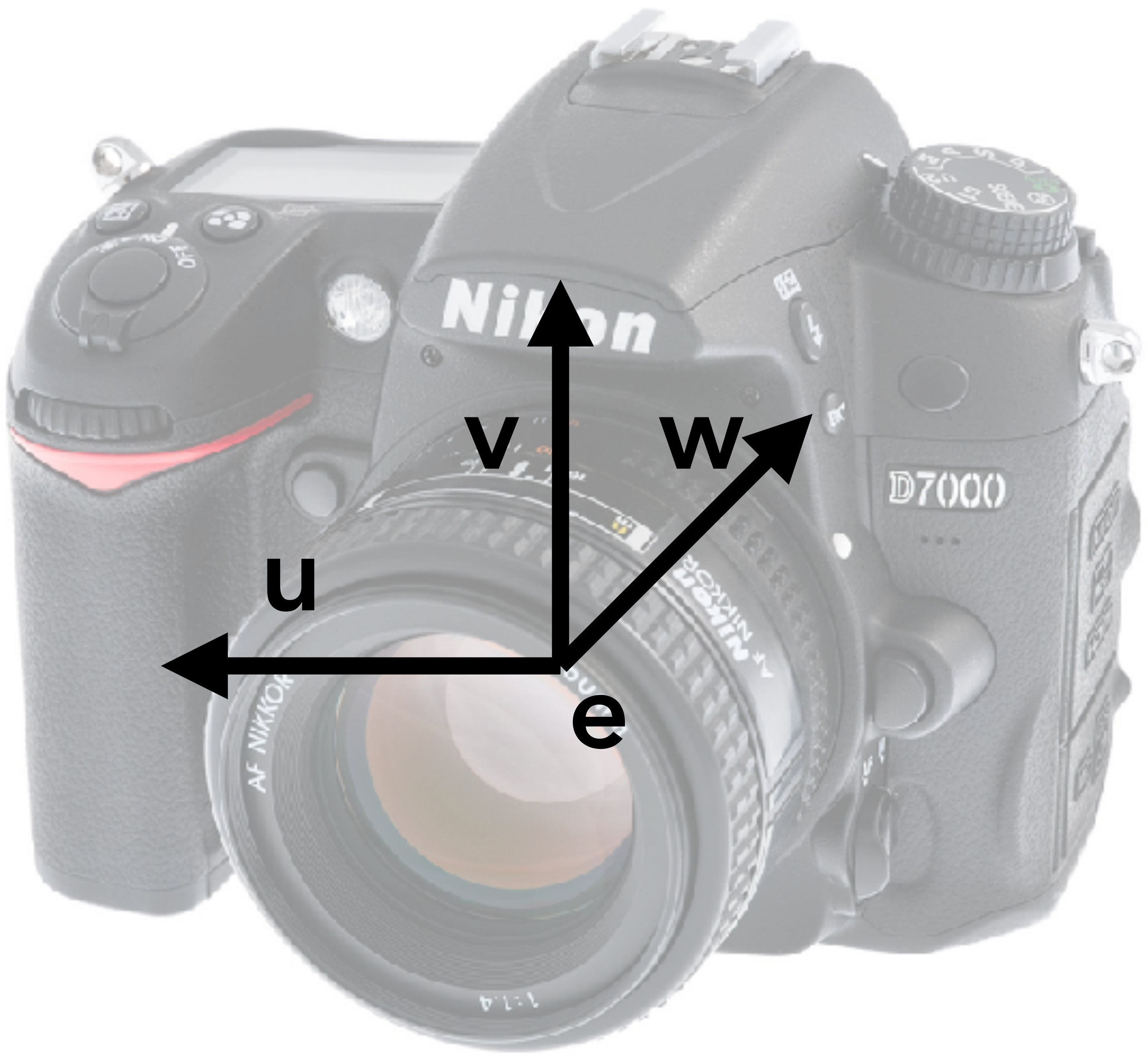
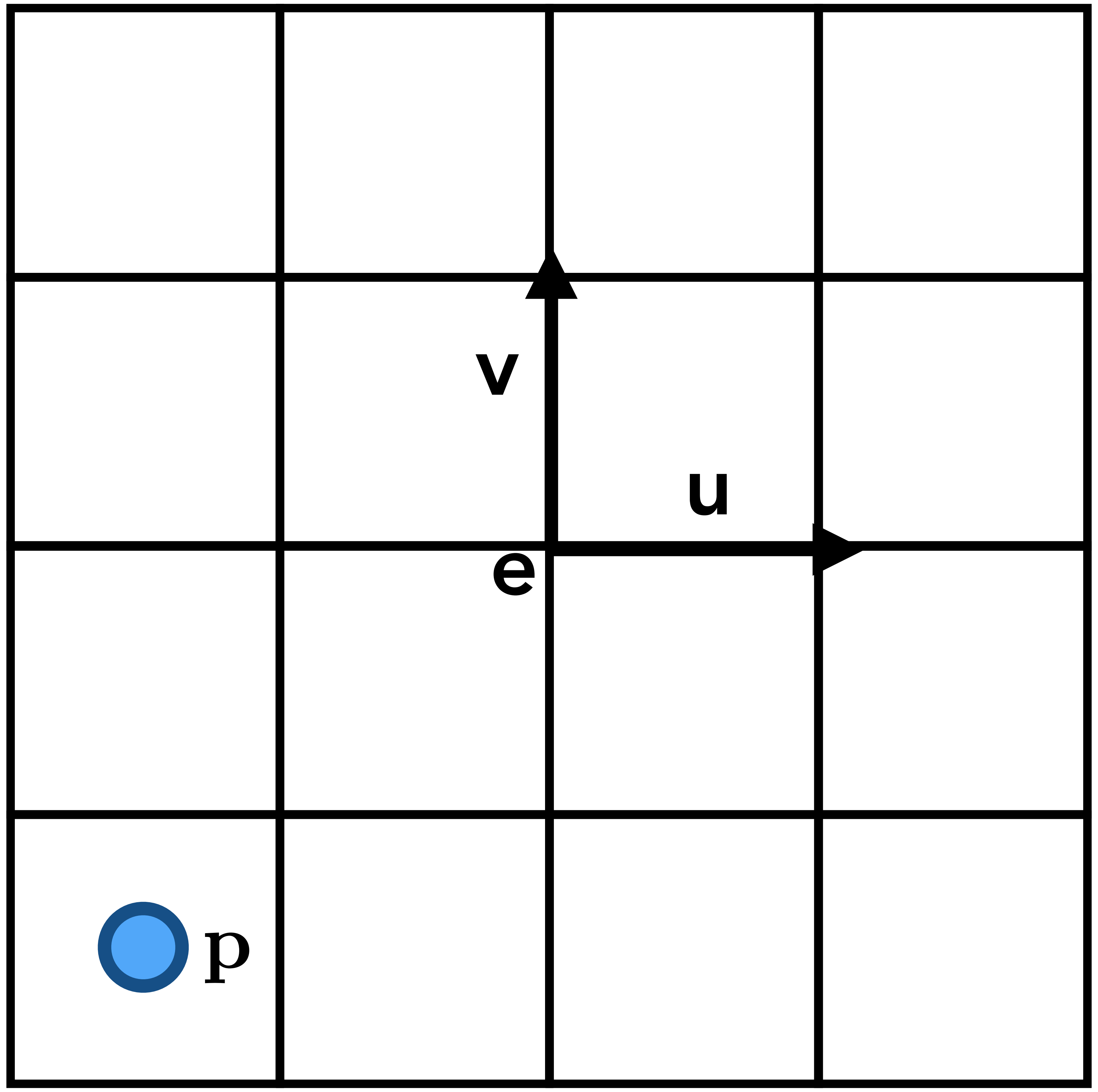
# 1. Compute Rays



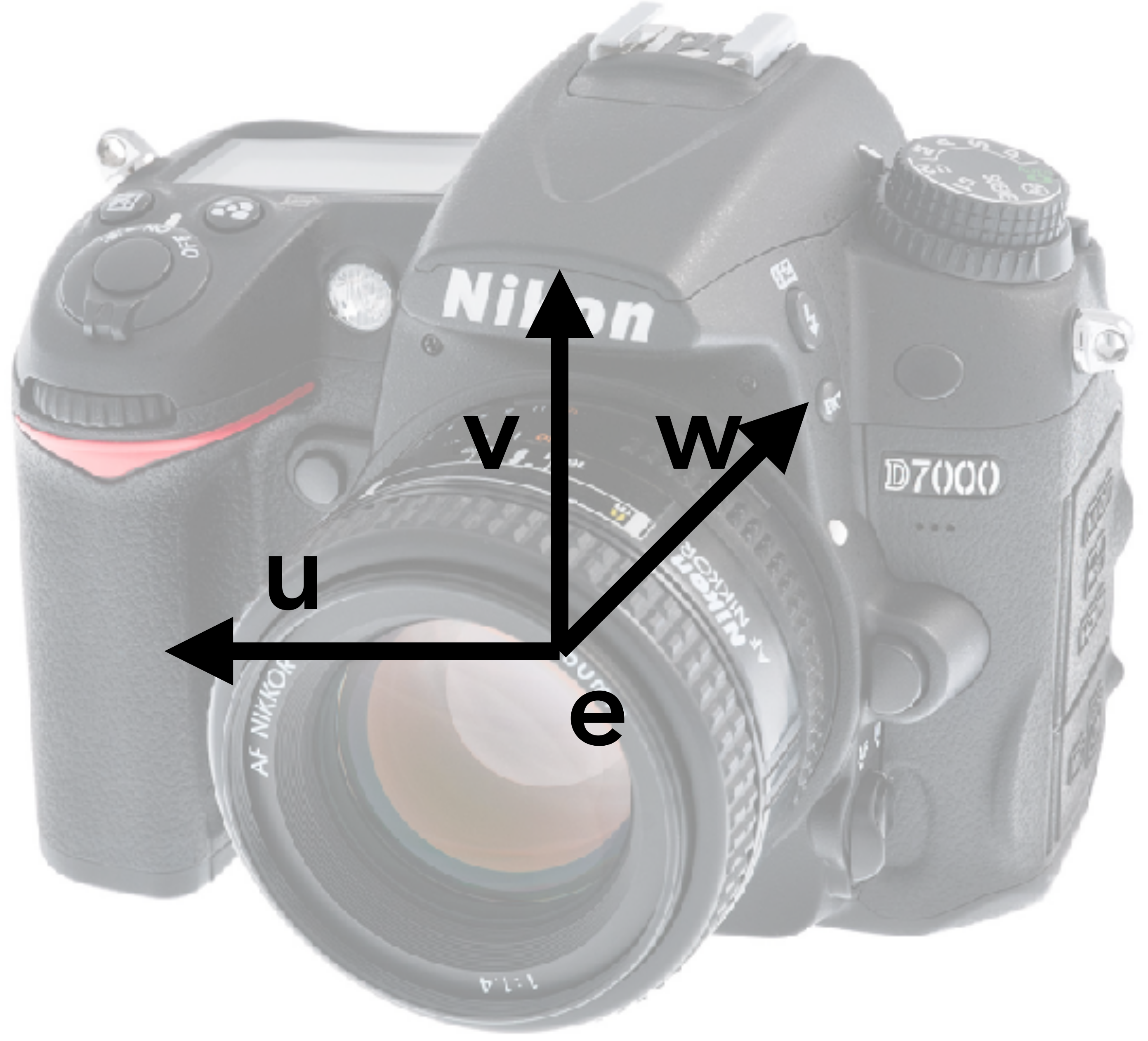



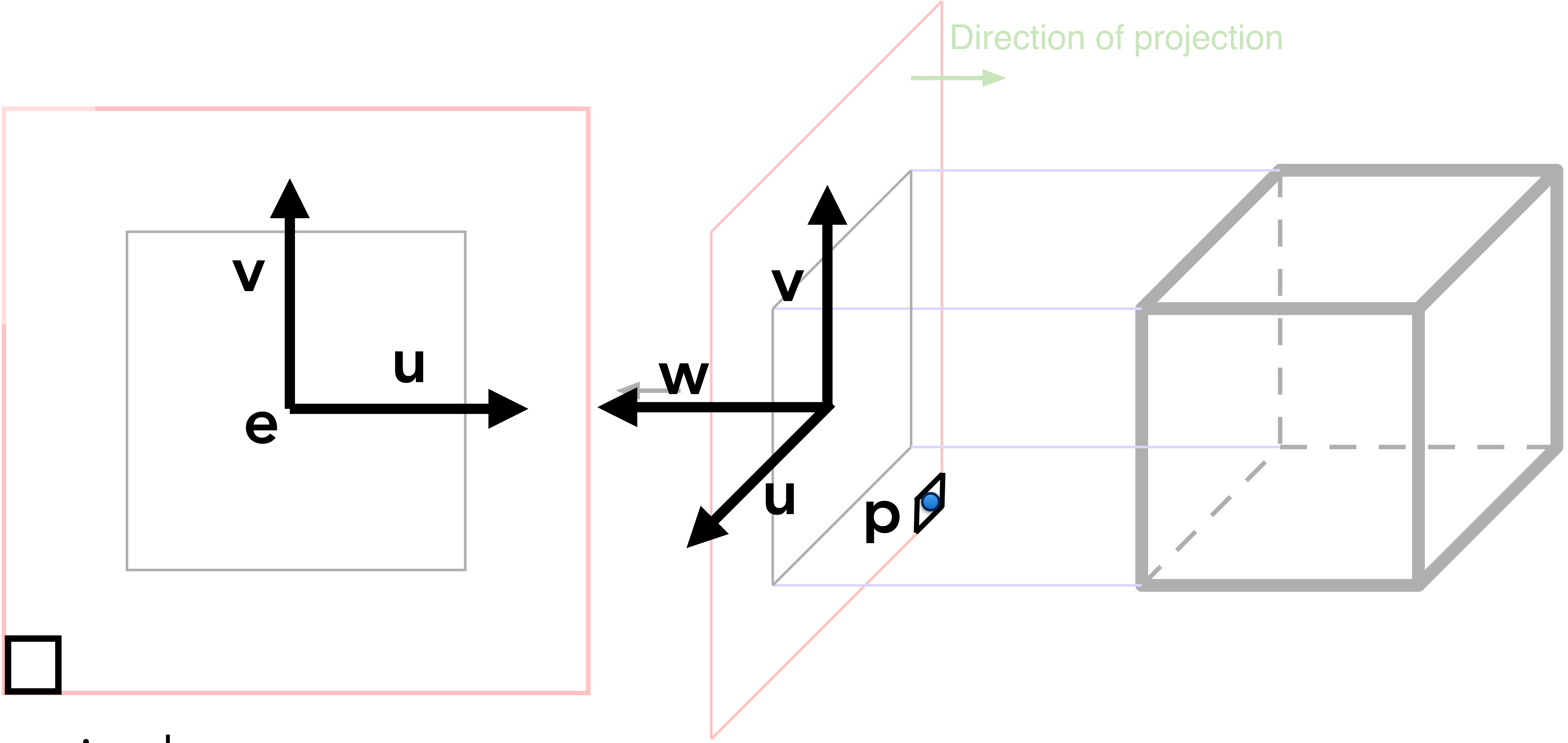

$$\mathbf{p} = \mathbf{e} + u\mathbf{u} + v\mathbf{v} + w\mathbf{w}$$

**e** is the origin of the reference system

**p** is the center of the pixel

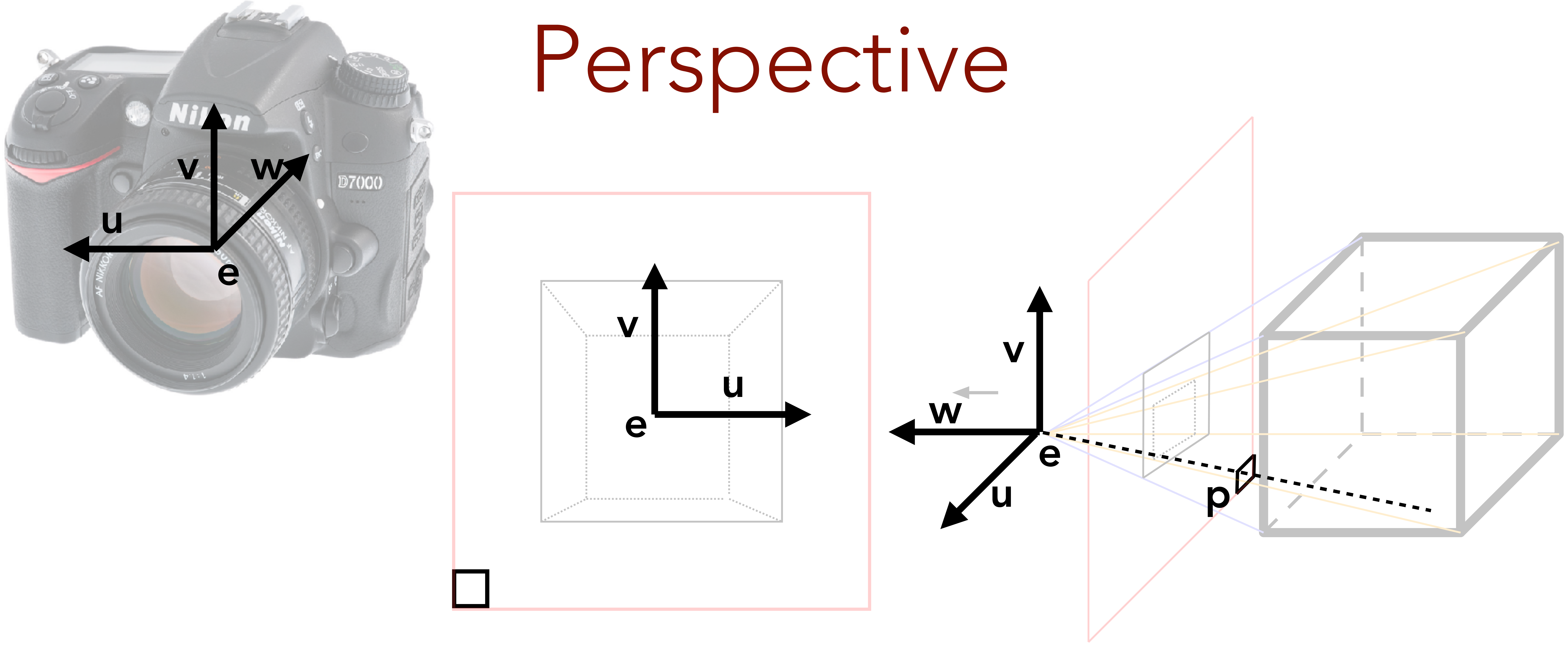
# Orthographic




- For the ray assigned to pixel **p**:
  - Origin: **p**
  - Direction: -**w**

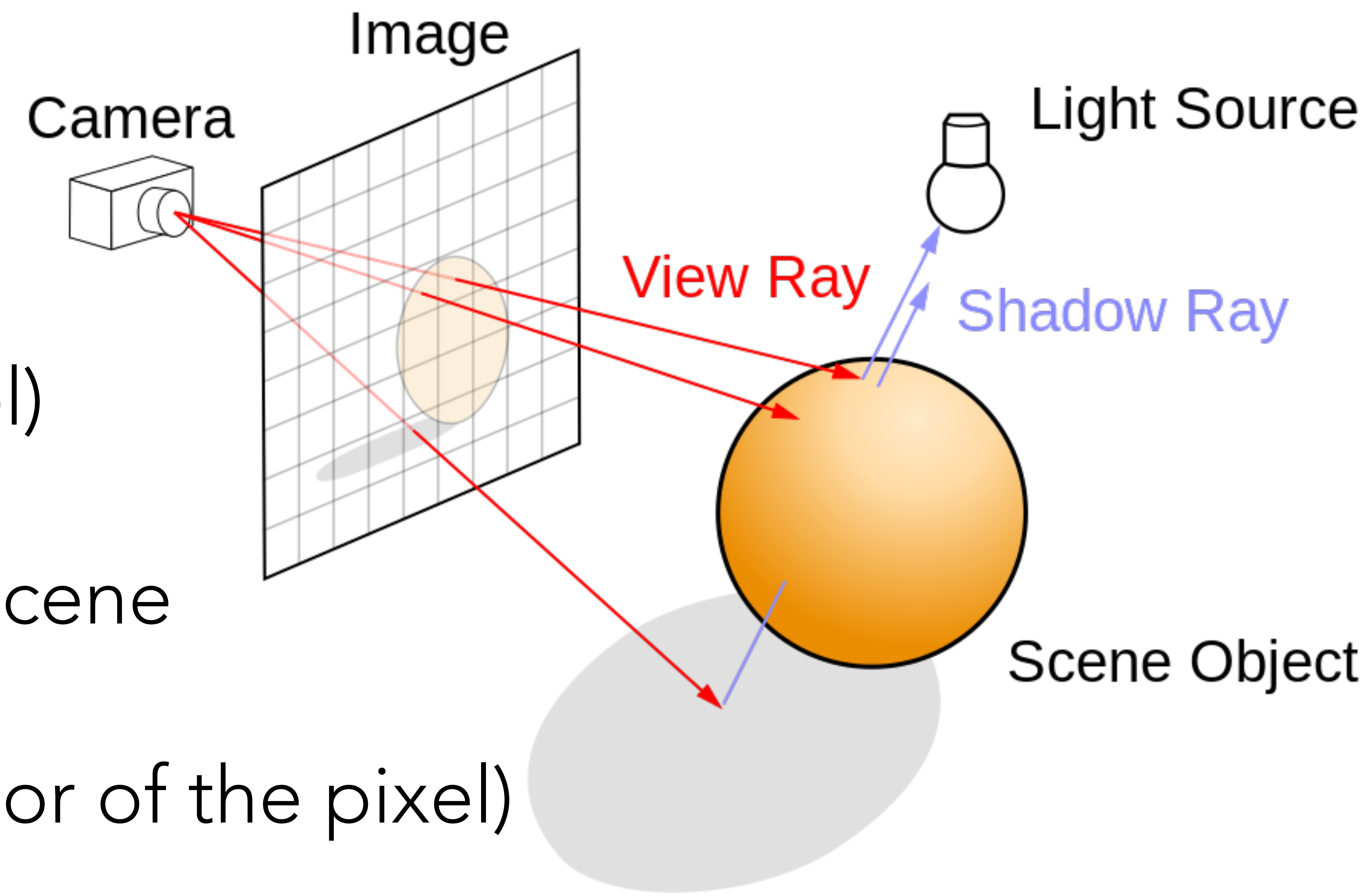
# Perspective




- For the ray assigned to pixel **p**:
  - Origin: **e**
  - Direction: **p - e**

# 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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# 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)

# 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 **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

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

# 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.:

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

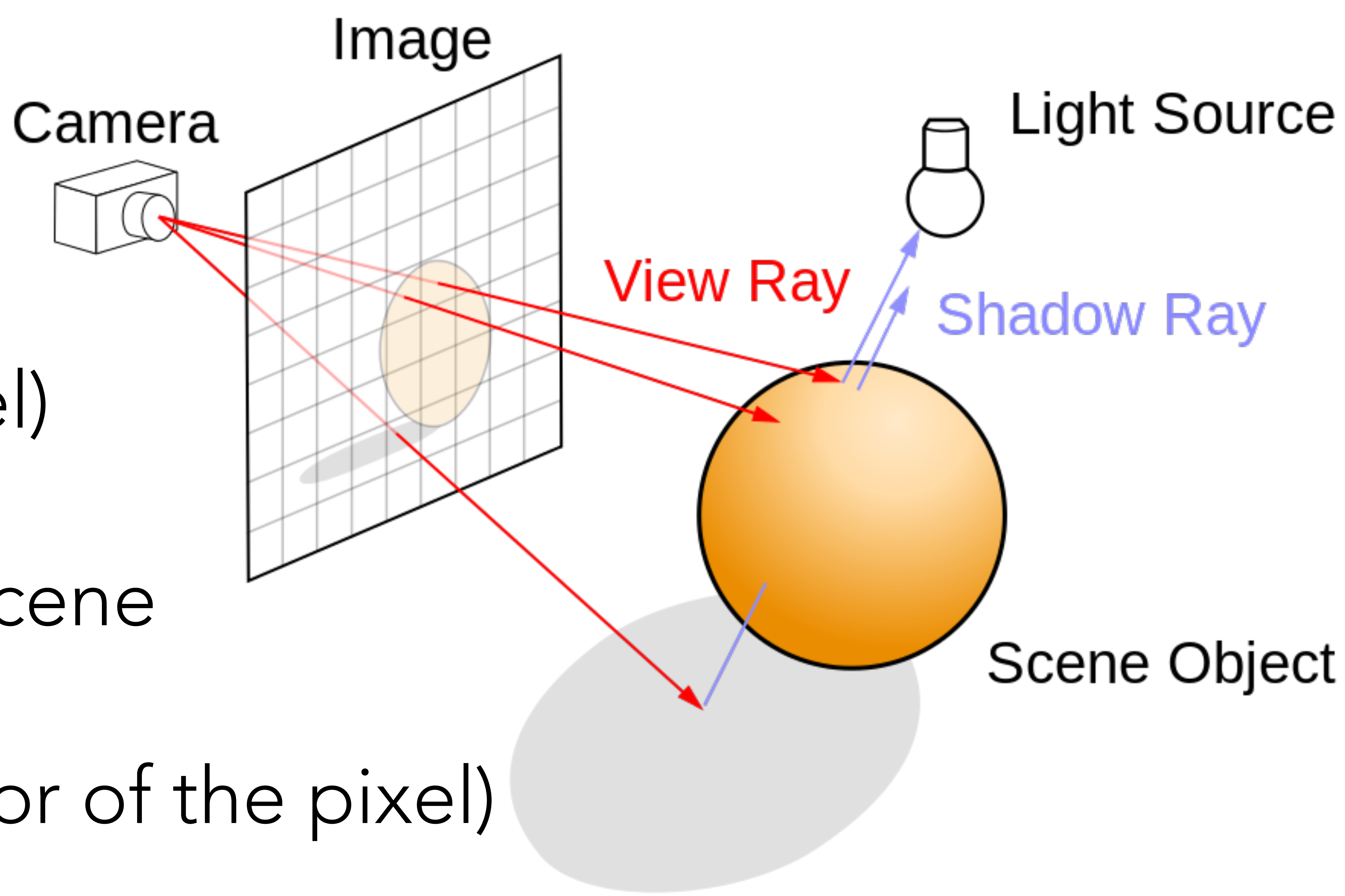
$$t > 0 \qquad 0 \leq u, v \qquad u + v \leq 1$$

# 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

# Basic Raytracing




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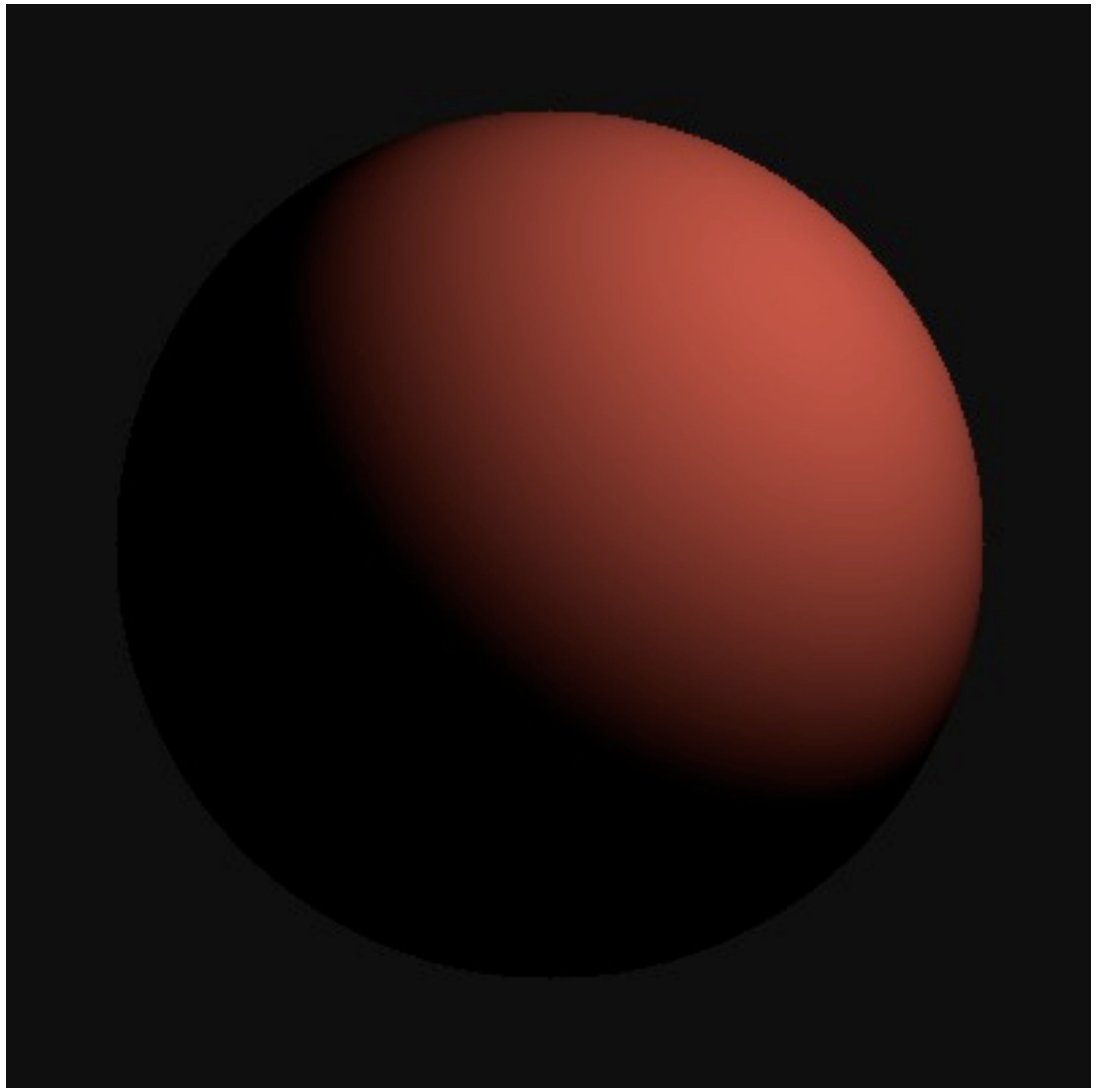
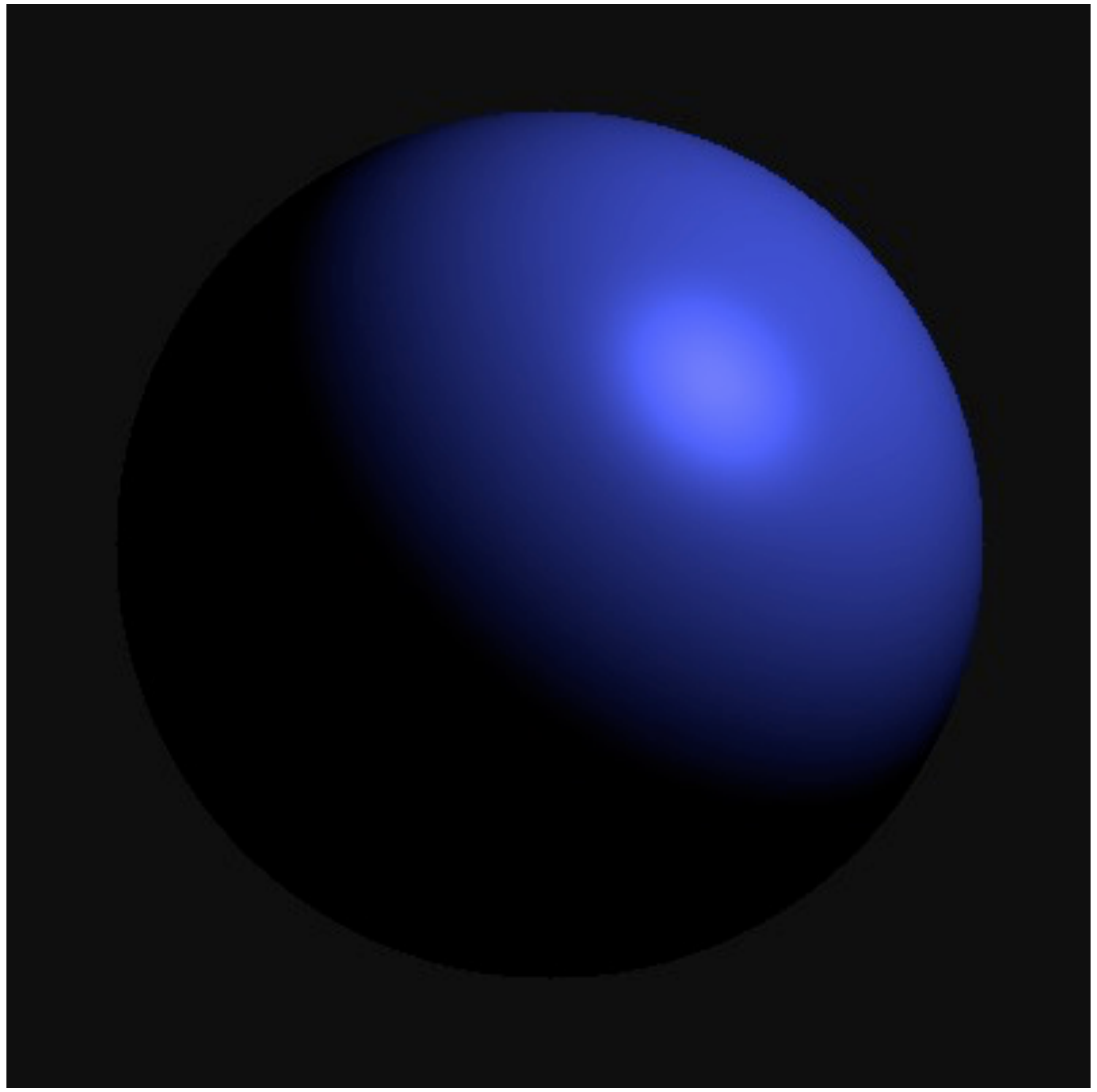
# Shading

- 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 (Blinnn-Phong) Shading
  - Ambient Shading
- The three terms will be summed together to obtain the final color

# Diffuse and Specular





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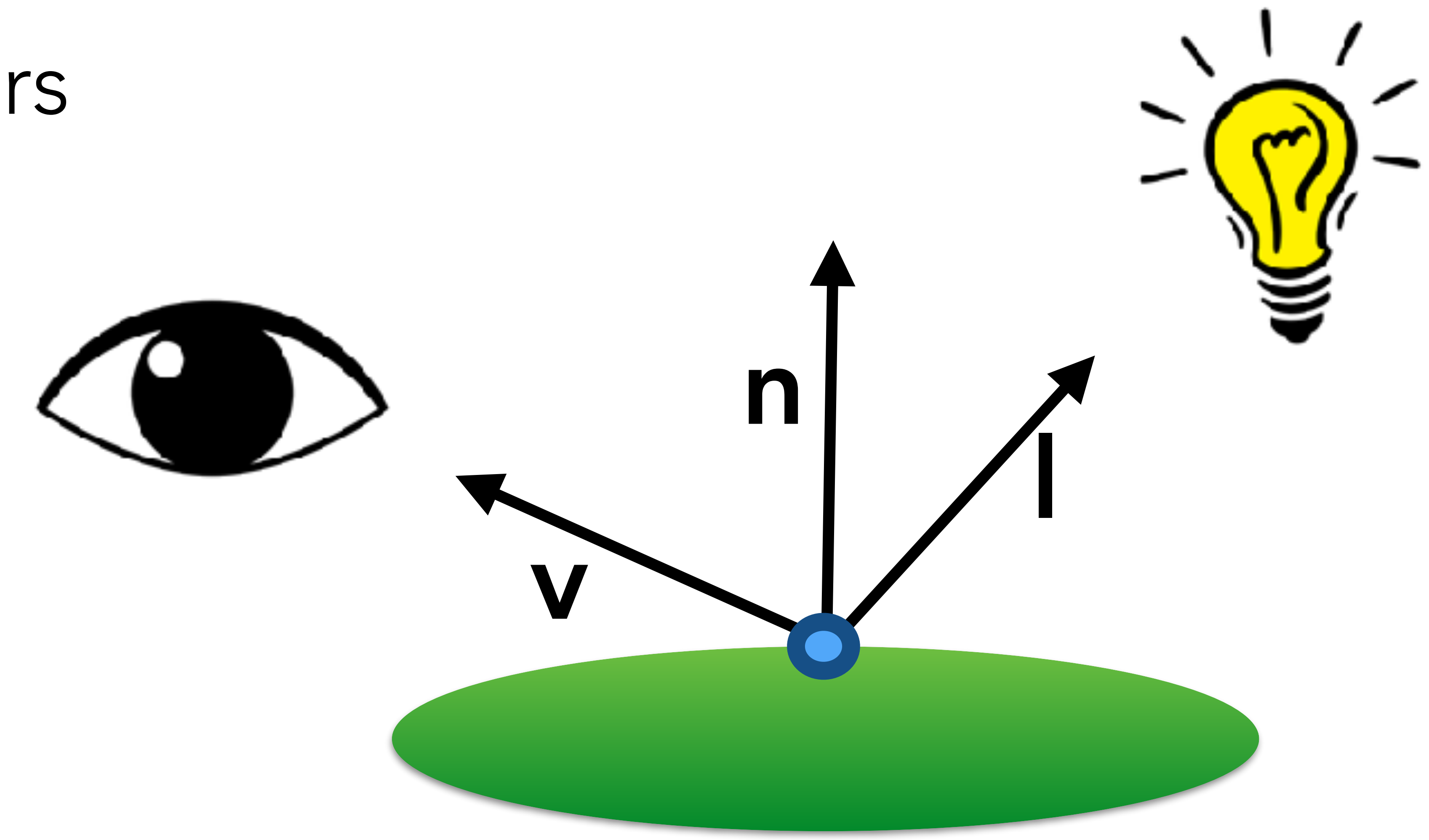
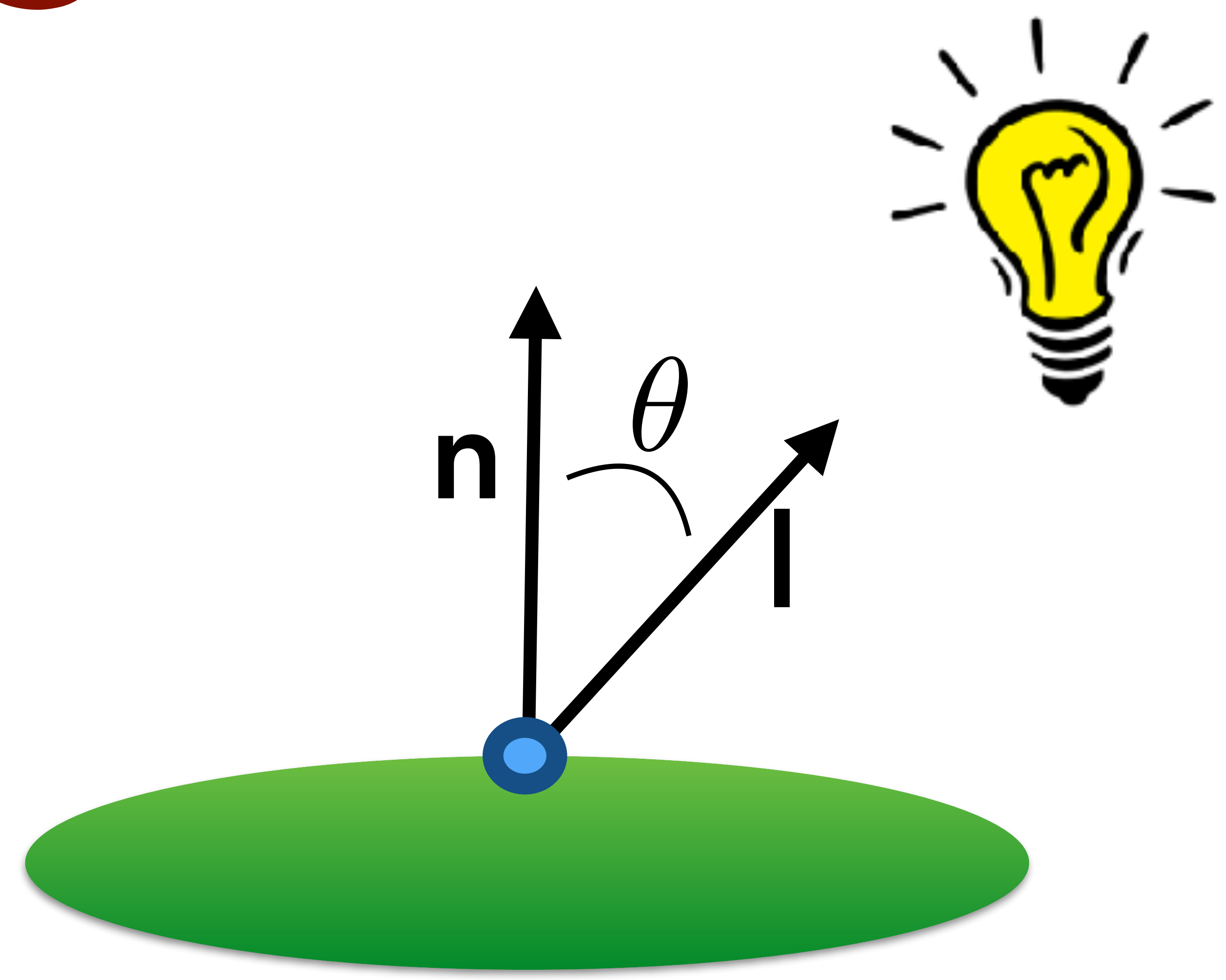
# Shading Variables

- 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 **l** (a *unit* vector pointing to the light source)
  - The view direction **v** (a *unit* vector pointing toward the camera)
  - The surface normal **n** (a vector perpendicular to the surface at the point of intersection)



# Diffuse Shading

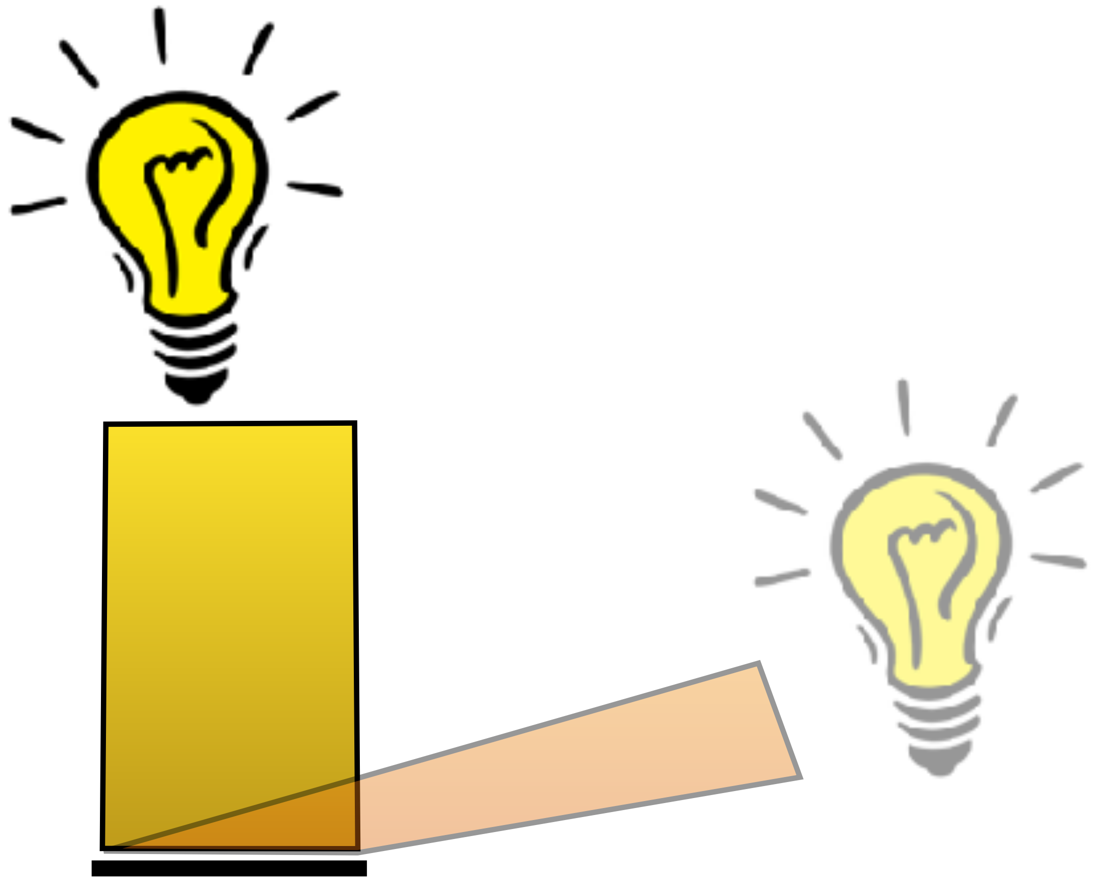
- Lambert (18th century) observed that the amount of energy from a light source that falls on an area of surface depends on the angle of the surface to the light
- To model it, we make the amount of light proportional to the angle $\theta$ between the **n** and **l**




diffuse coefficient

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

intensity of the light

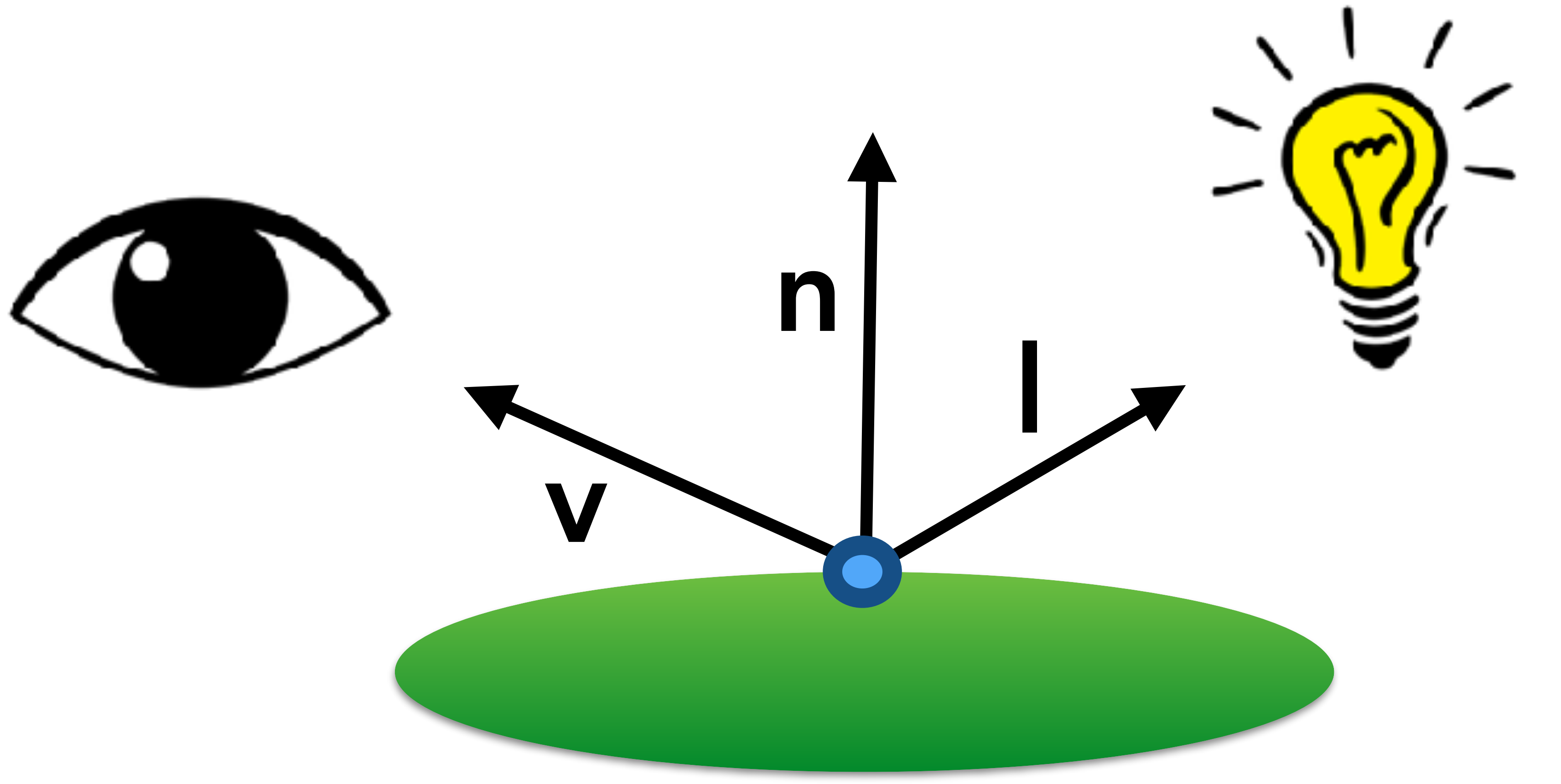


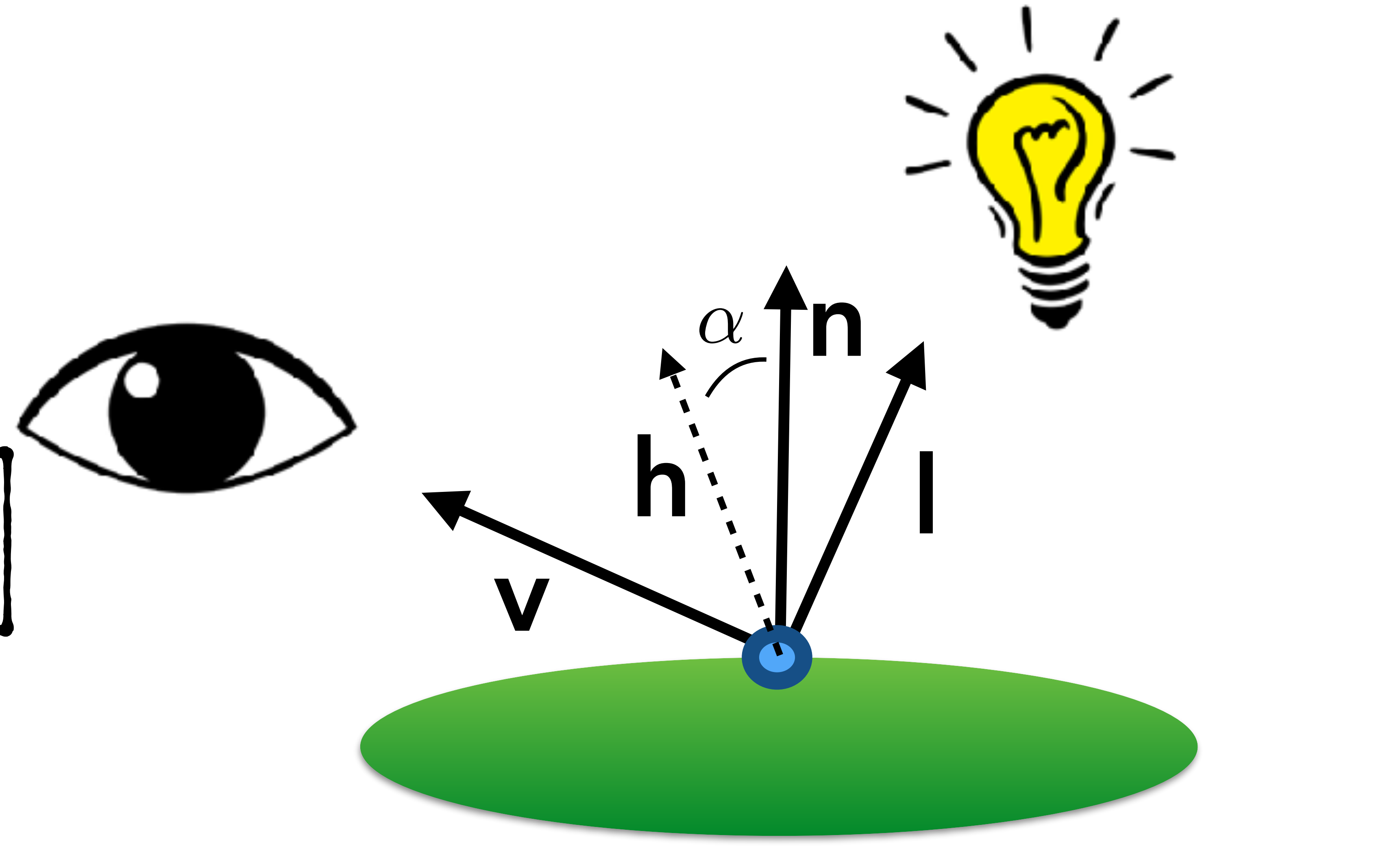
The position of the camera is not used!

# Specular Shading

p = 100 -> Shiny
p = 1000 -> Glossy
p > 10,000 -> 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 **v** and **l** are symmetric wrt **n**
- To measure the asymmetry we measure the angle between **h** (the bisector of **v** and **l**) and **n**




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

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

Phong exponent

specular coefficient



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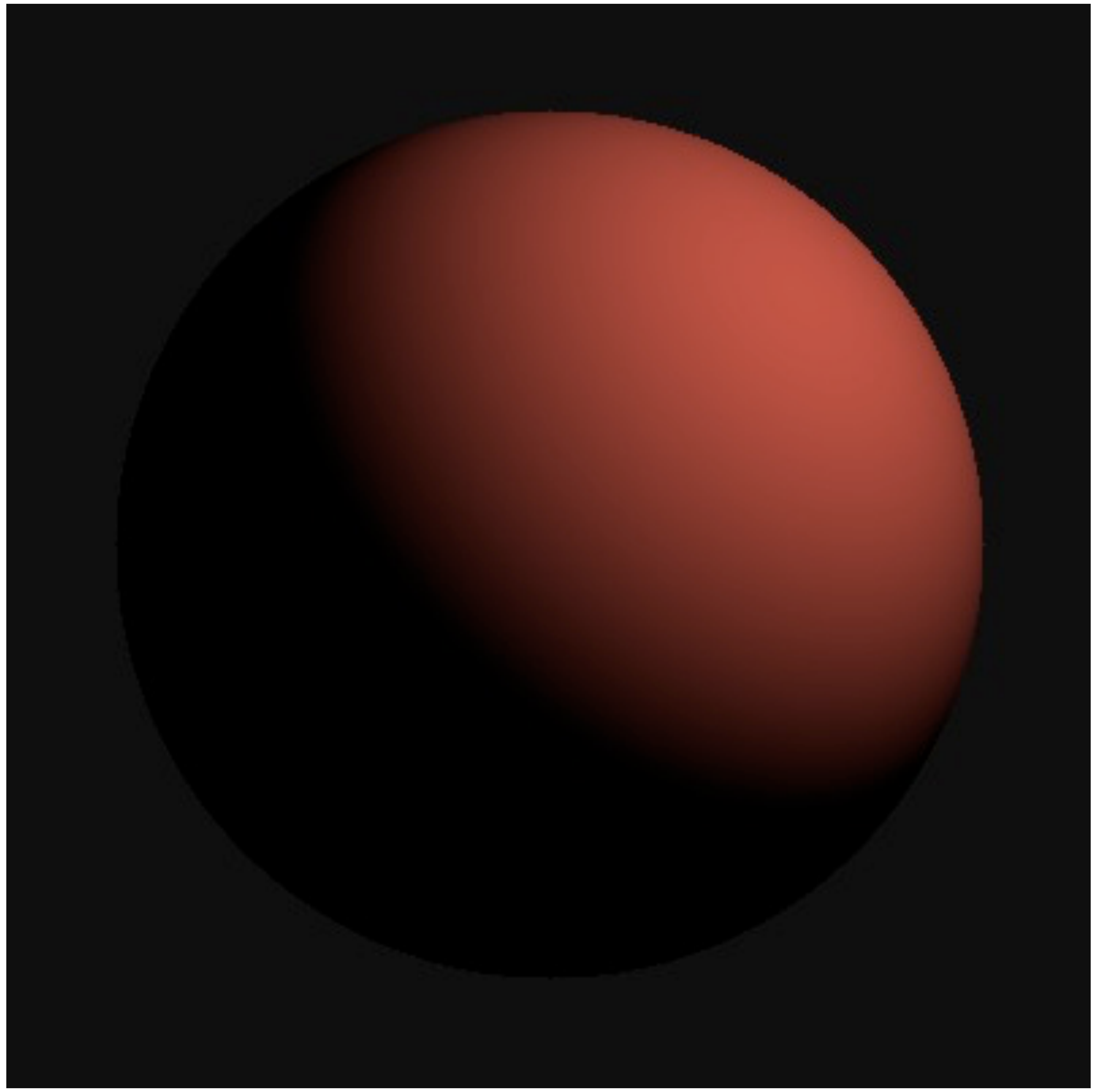
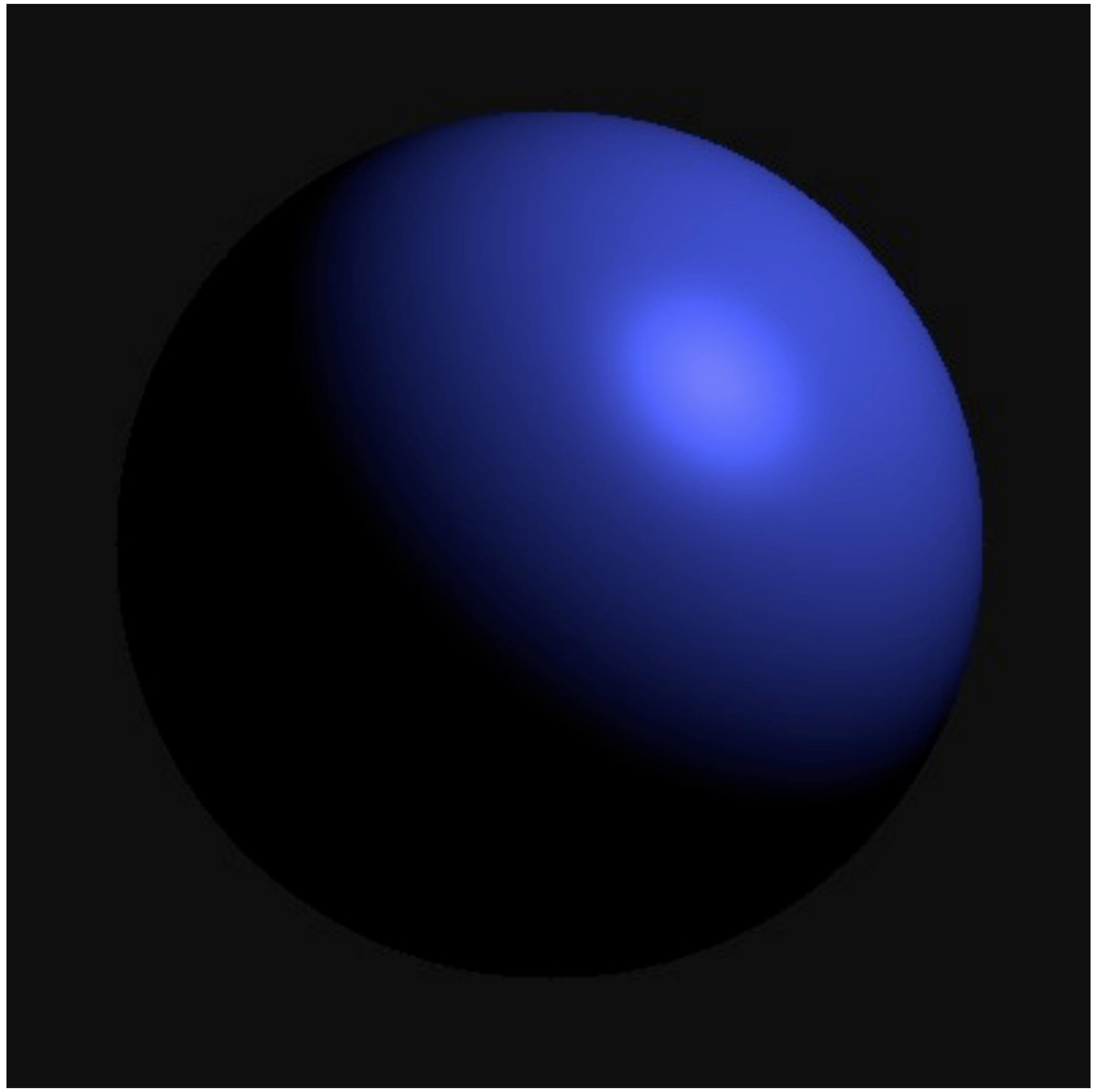
# Diffuse and Specular





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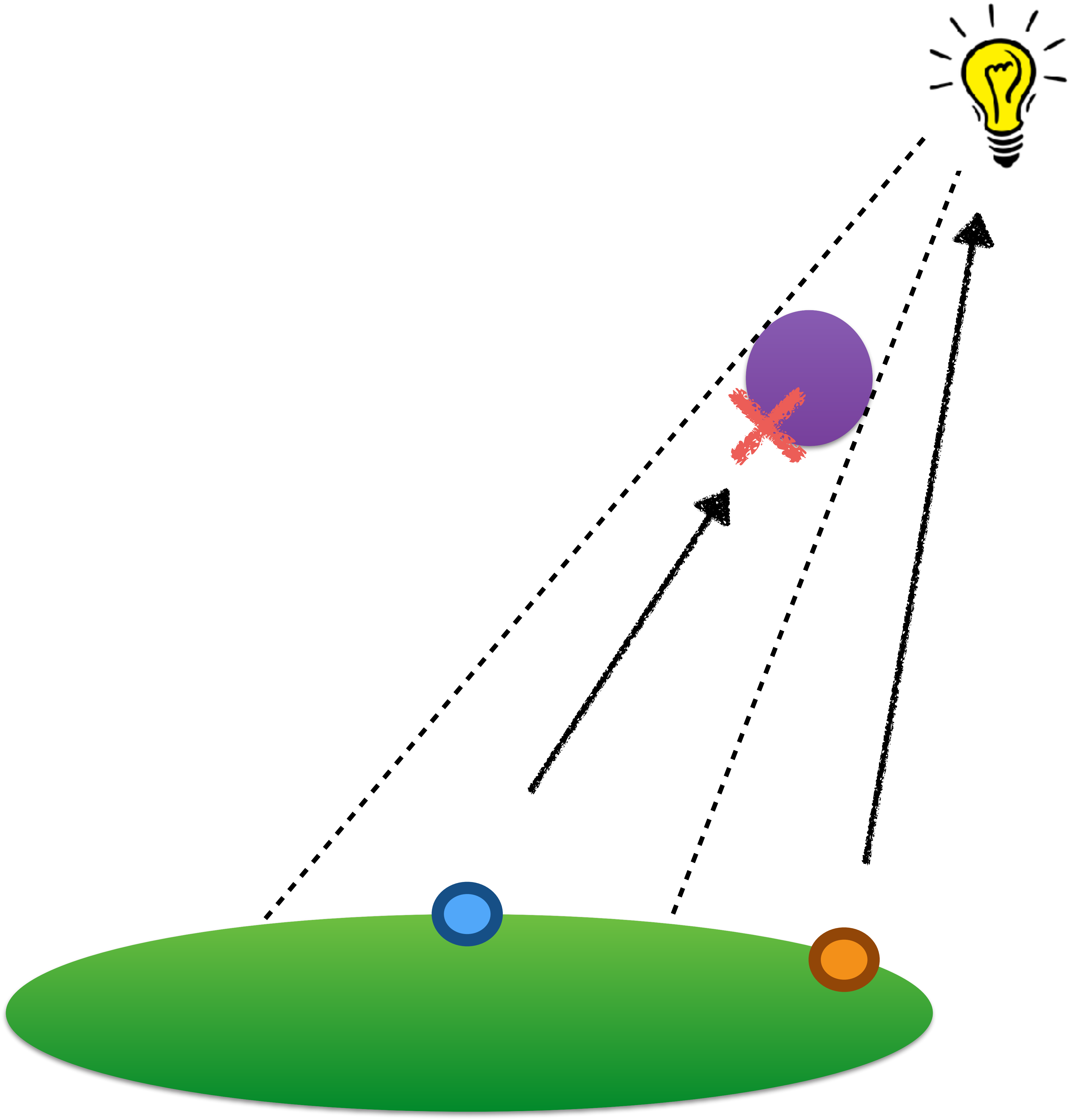
# Final Shading Equation

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

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

# 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**

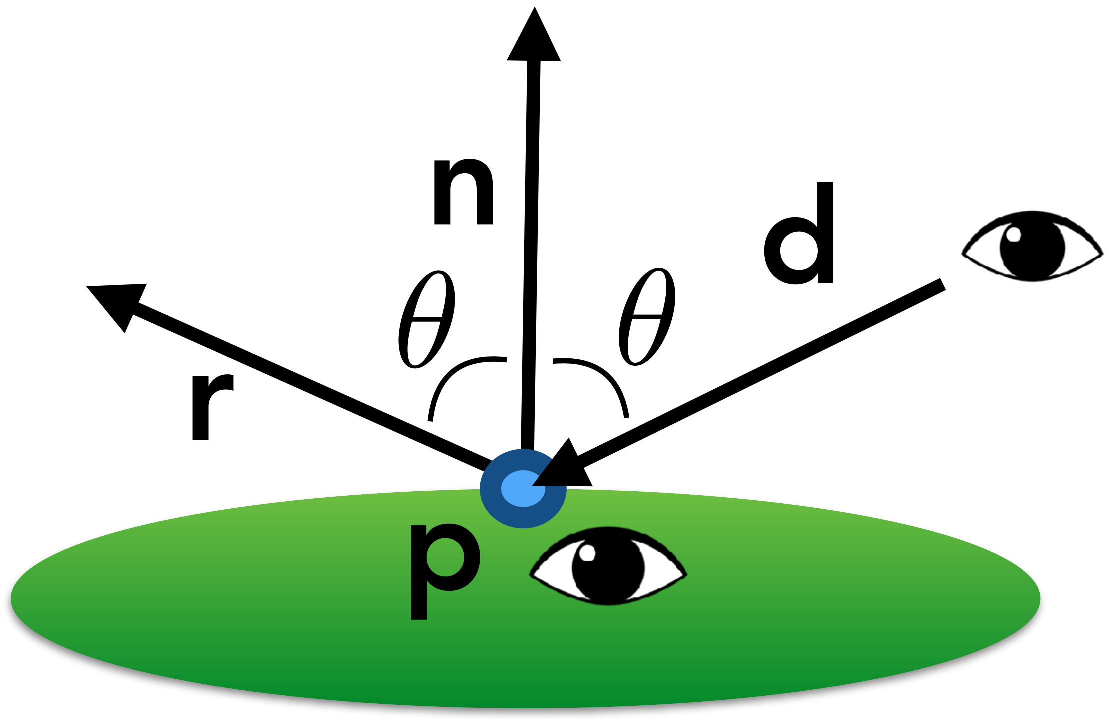


The shadow rays should be casted an epsilon away from the source

# Ideal Reflections

Limit the recursion depth!

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




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

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

Reflection color

# A simple ray-tracing program

- The source code of Assignment 2 is a simple ray tracer

# 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

# References

**Fundamentals of Computer Graphics, Fourth Edition**
4th Edition **by Steve Marschner, Peter Shirley**

Chapters 4, 10, 13