# CSC418/2504 Computer Graphics

**Some Slides/Images adapted from Marschner and Shirley**

Some slides courtesy of Karan Singh, Videos courtesy of [AlanBeckerTutorials]

# Announcements

- Assignment 6 due Friday, Assignment 7 due on March 29th
- Office hours will be in BA 5287 until further notice
  - (aka I’ve given up trying to get access to Dave’s office)
- Undergraduate drop date: March 17th
- No lecture next week. We’ll still have tutorial and office hours, and you can ask questions in preparation for Midterm 2.

# Announcements

- A5 marks will be released in a day or so.
- Remark requests:
  - The TAs haven't seen remark requests made after the first round (they don't get MarkUs notifications)
  - A1, A2, A3, A4 remark requests are due by 11:59pm on Wednesday March 13th
  - Remark requests for A5, A6, and A7 will be due **at 11:59pm on the day the remark request office hour takes place.**

Any Questions ?

# Today: Advanced Topics in Rendering

# Lecture 9: Advanced Topics in Rendering

- Advanced ray tracing:
  - Instancing
  - Constructive Solid Geometry
  - Super-sampling/Anti-aliasing
  - Depth of field
  - Glossy reflections
  - Motion blur
- Advanced shading techniques
  - Cel shading/Toon shading

# Lecture 9: Advanced Topics in Rendering

- Advanced ray tracing:
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  - Constructive Solid Geometry
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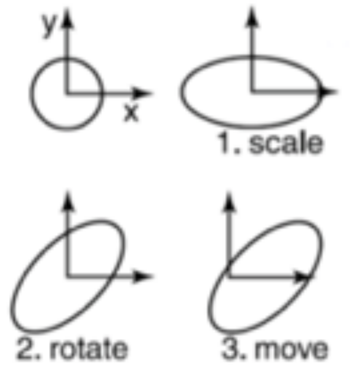
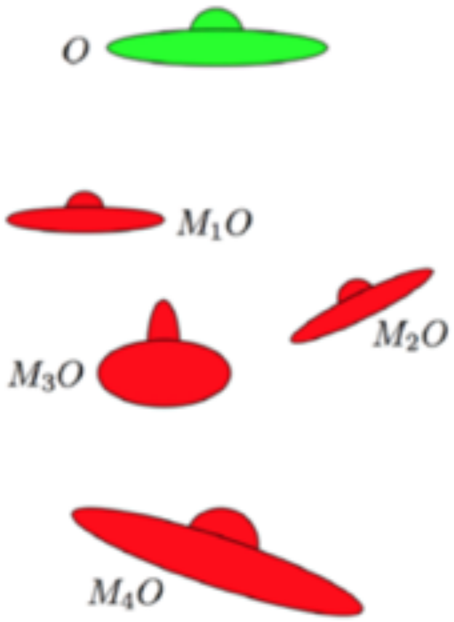
# Copying and transforming objects

Instancing is an elegant technique to place various transformed copies of an object in a scene.

Expl.: circle → elipse

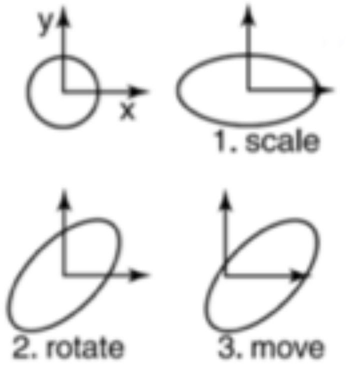


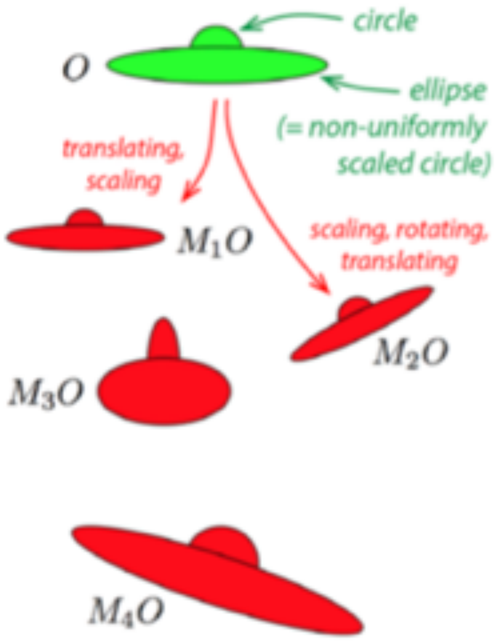



# Copying and transforming objects

Instancing is an elegant technique to place various transformed copies of an object in a scene.

Expl.: circle → elipse



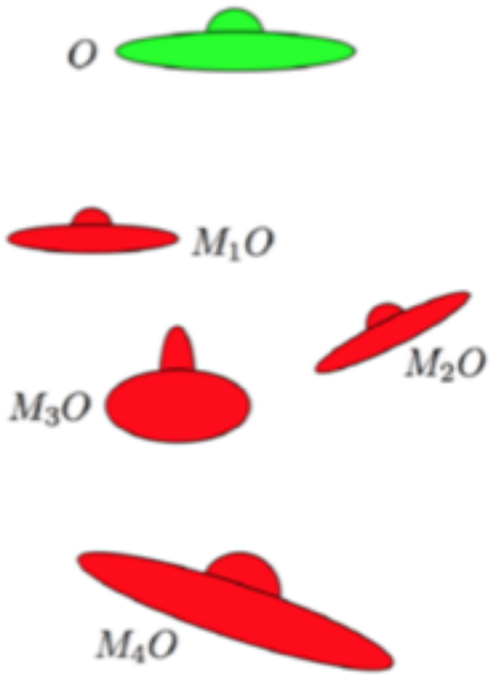



# Copying and transforming objects

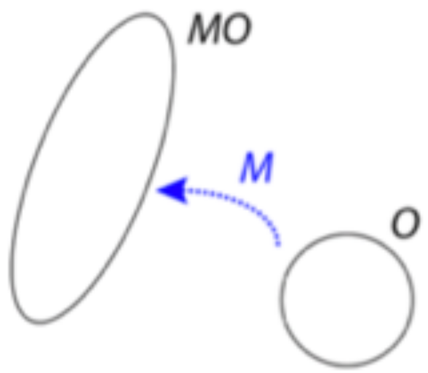
Instead of making actual copies, we simply store a reference to a base object, together with a transformation matrix.

That can save us lots of storage.

Hmm, but how do we compute the intersection of a ray with a randomly rotated elipse?



# Ray-instance intersection

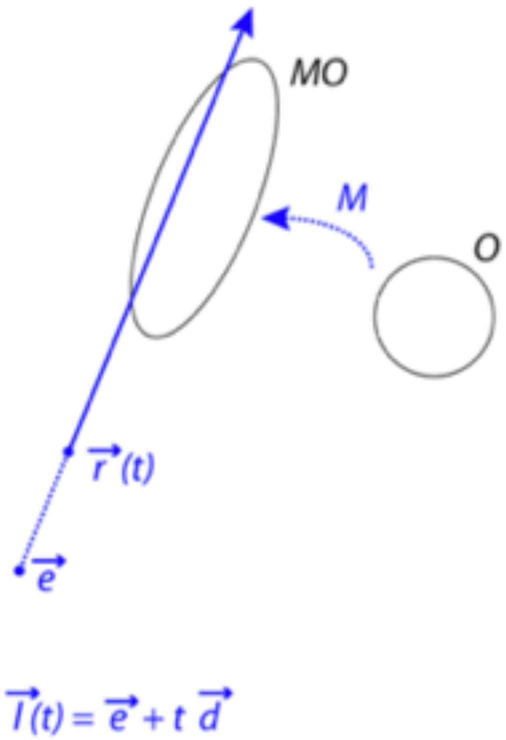



Assume an object $O$ that is used to create an object $MO$ via instancing.

# Ray-instance intersection

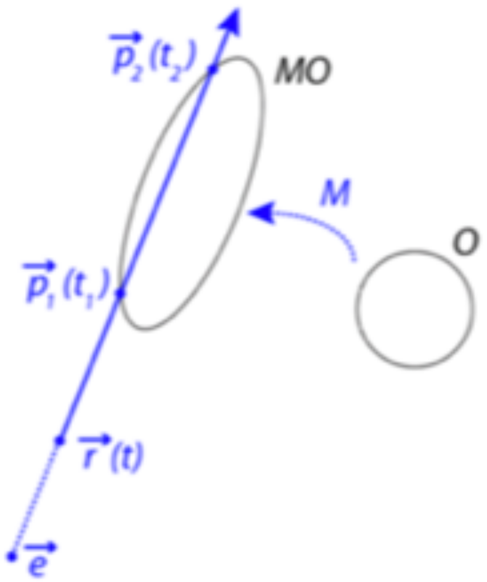
Now, we want to create the intersection of $MO$ with the ray $\vec{r}(t)$, which in turn is defined by the line

$$\vec{l}(t) = \vec{e} + t\vec{d}.$$



# Ray-instance intersection

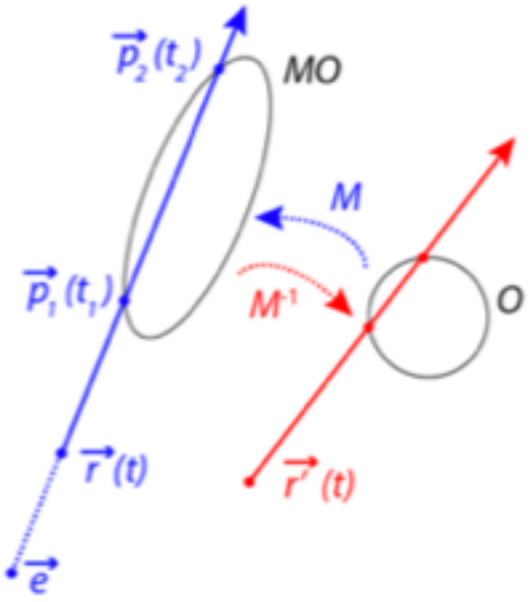
Fortunately, such complicated intersection tests (e.g. ray/ellipsoid) can often be replaced by much simpler tests (e.g. ray/sphere).




$\vec{l}(t) = \vec{e} + t\,\vec{d}$

# Ray-instance intersection

To determine the intersections $\vec{p_i}$ of a ray $\vec{r}$ with the instance $MO$, we first compute the intersections $\vec{p_i'}$ of the inverse transformed ray $M^{-1}\vec{r}$ and the original object $O$.



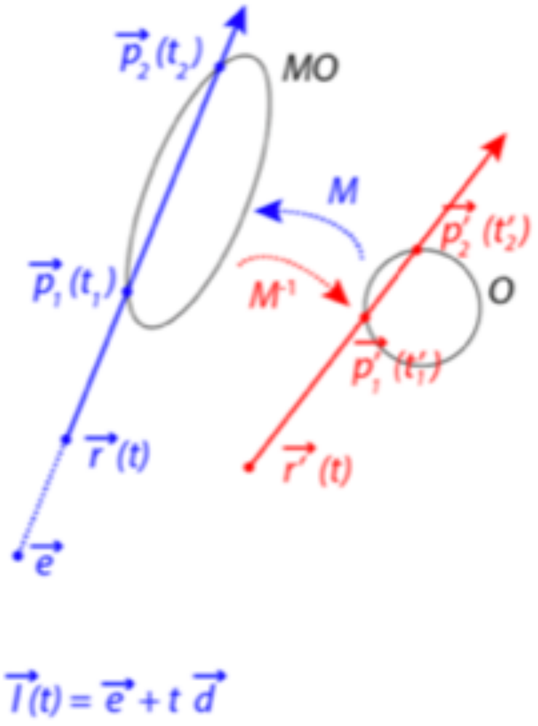

$$\vec{l}(t) = \vec{e} + t\,\vec{d}$$

# Ray-instance intersection

The points $\vec{p_i}$ are then simply

$$M\vec{p_i'} \quad \text{or} \quad \vec{l}(t_i')$$

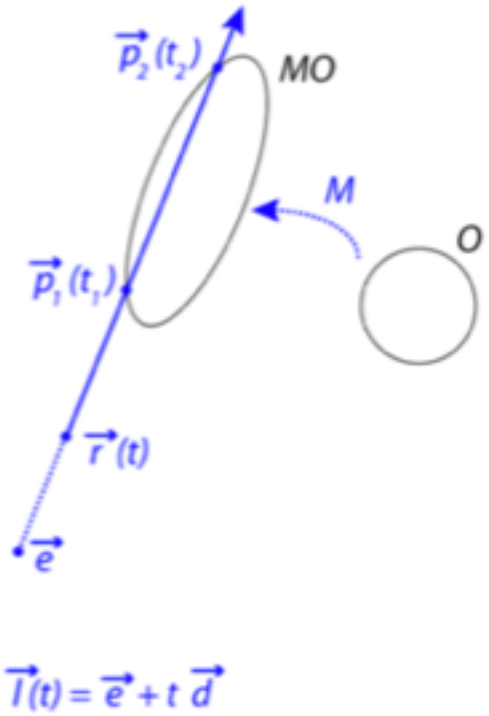
because the linear transformation preserves relative distances along the line.



# Ray-instance intersection

Two pitfalls:

- The direction vector of the ray should *not* be normalized
- Surface normals transform differently!
  $\rightarrow$ use $(M^{-1})^T$ instead of $M$ for normals



# Lecture 9: Advanced Topics in Rendering

- Advanced ray tracing:
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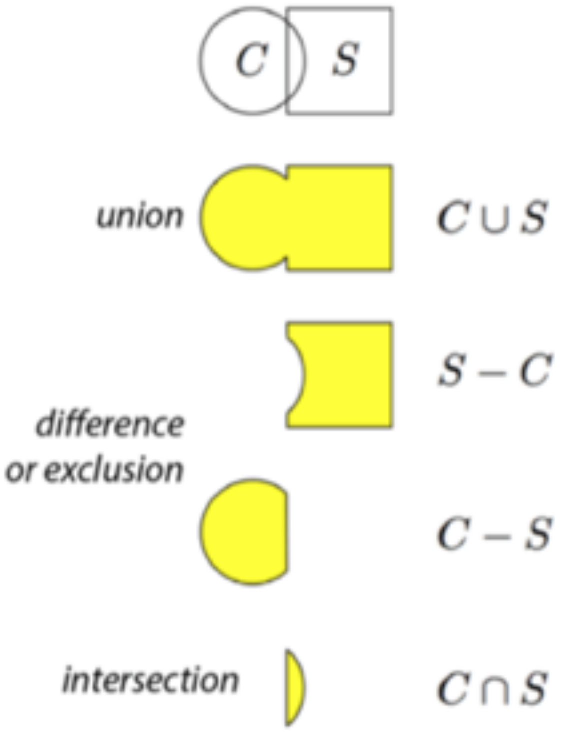
# Constructive solid geometry

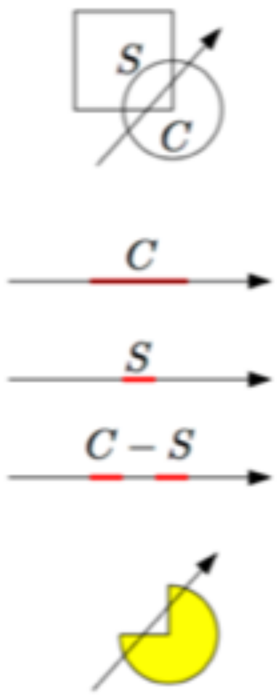
To model our scenes in ray tracing, we can basically use any object that allows us to calculate its intersection with a 3D line.

Using Constructive Solid Geometry (CSG), we can build complex objects from simple ones with set operations.



# Intersection and CSG

Instead of actually constructing the objects, we can calculate ray-object intersections with the original objects and perform set operations on the resulting intervals.

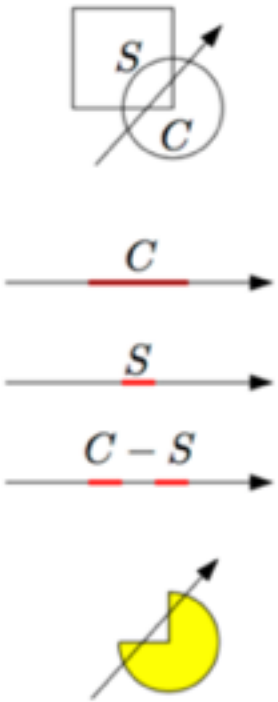


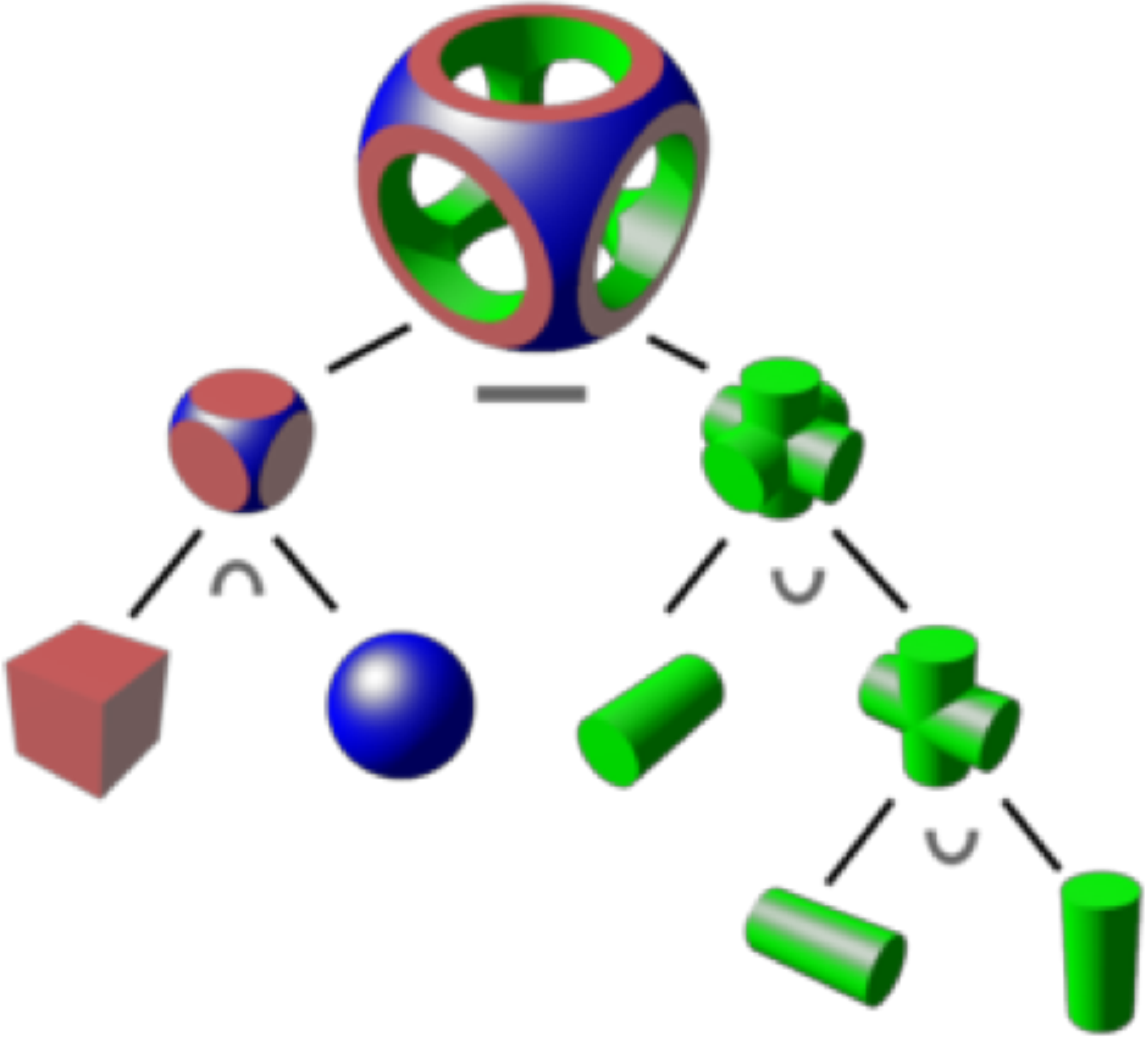
# Intersection and CSG

For every base object, we maintain an interval (or set of intervals) representing the part of the ray inside the object.

The intervals for combined objects are computed with the same set operations that are applied to the base objects.

The borders of the resulting intervals are our intersection points.






wikipedia

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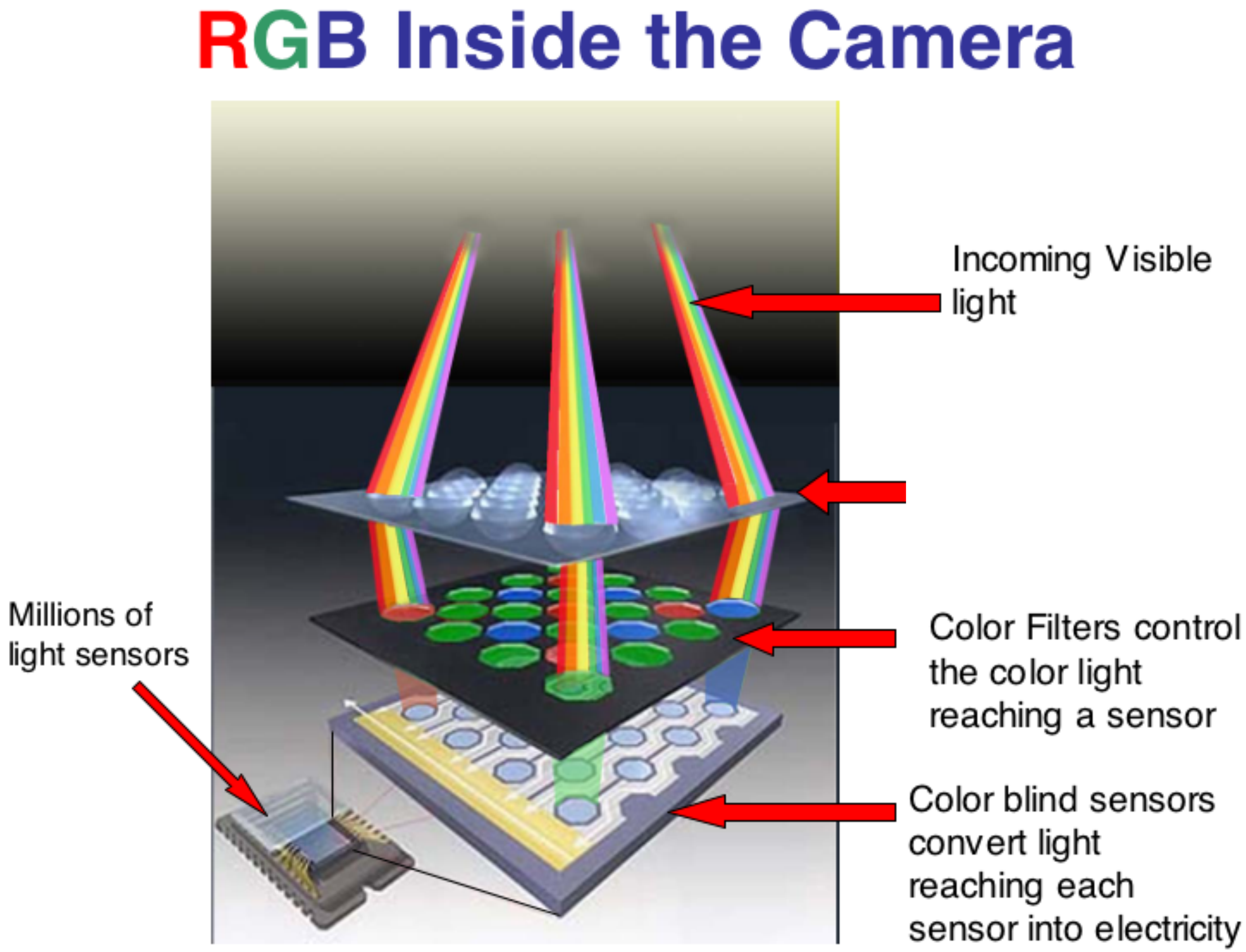
# Distributed Ray Tracing

- Not ray tracing on a distributed system…
- Based on randomly distributed oversampling
- Reduces “aliasing artifacts” in renderings
- What is aliasing?
- Issue of having limited resolution on a screen.

# Distributed Ray Tracing

- Real world has infinite resolution
- Each pixel is a small window through which we can see part of the scene.
- Single ray per pixel is an inaccurate representation

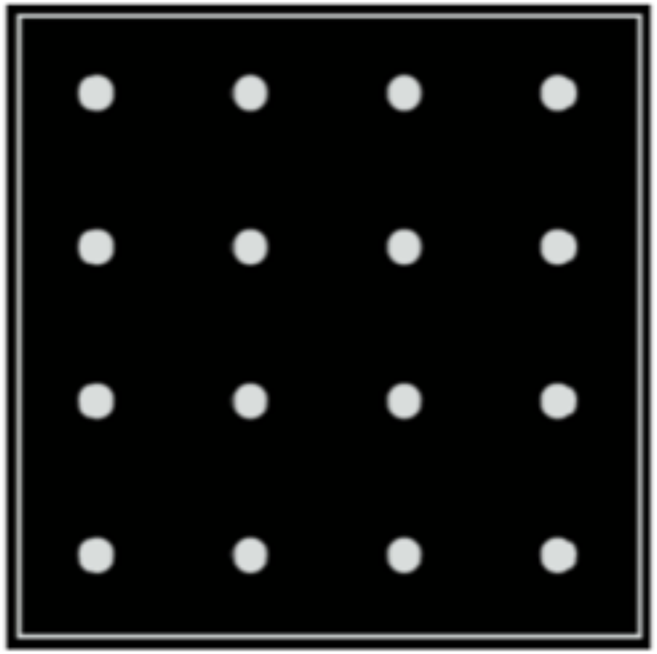
# “Single ray per pixel is inaccurate”



# Solution:

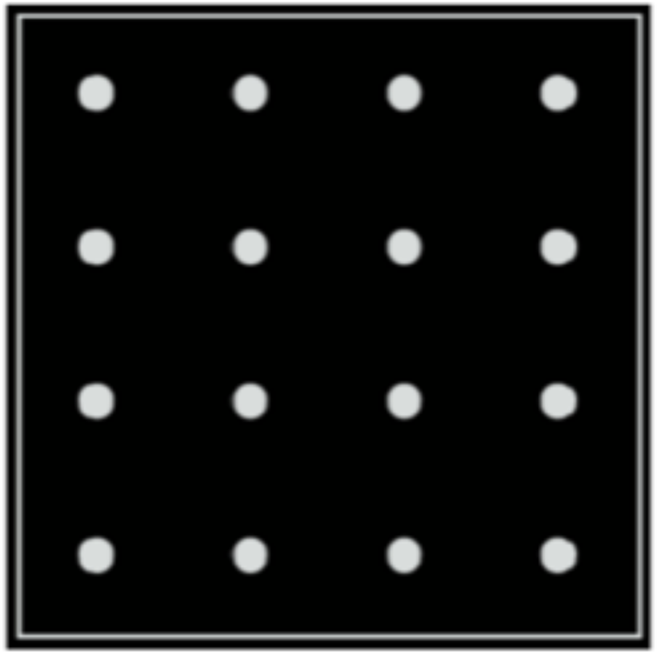
- Send multiple rays through a pixel
- This is called “Super sampling”
- How shall we choose samples (rays) in a given pixel?

# Option 1: Regular sampling



Note, this black square is a **single** pixel

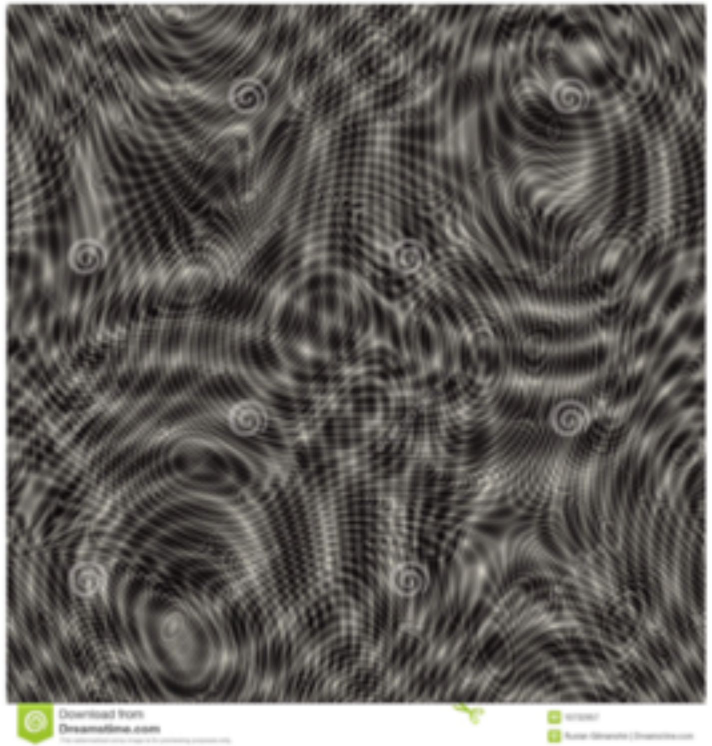
# Option 1: Regular sampling



- Regularities can create moiré pattern (high frequency masquerading for low frequency)

Note, this black square is a **single** pixel

# Aliasing example: Moiré pattern



# Aliasing example: Moiré pattern

**a·li·as·ing**

/ˈālēəsiNG/

*noun*

1. PHYSICS • TELECOMMUNICATIONS
   the misidentification of a signal frequency, introducing distortion or error.
   "high-frequency sounds are prone to aliasing"
2. COMPUTING
   in computer graphics, the jagged, or saw-toothed appearance of curved or diagonal lines on a low-resolution monitor.

# Aliasing example: Moiré pattern

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Signal processing definition

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# Aliasing example: Moiré pattern

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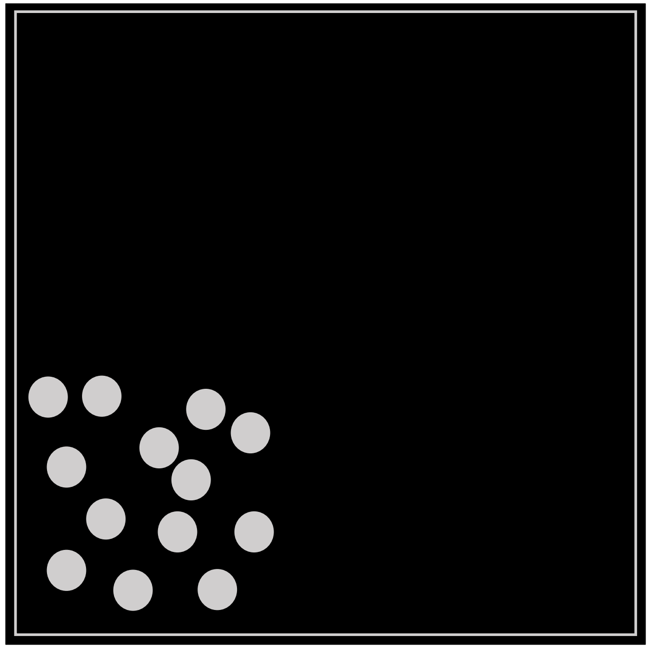
The computer graphics definition. An example of the signal processing def, think of each pixel as being a sample of the image

# Board example

# Option 2: Random sampling



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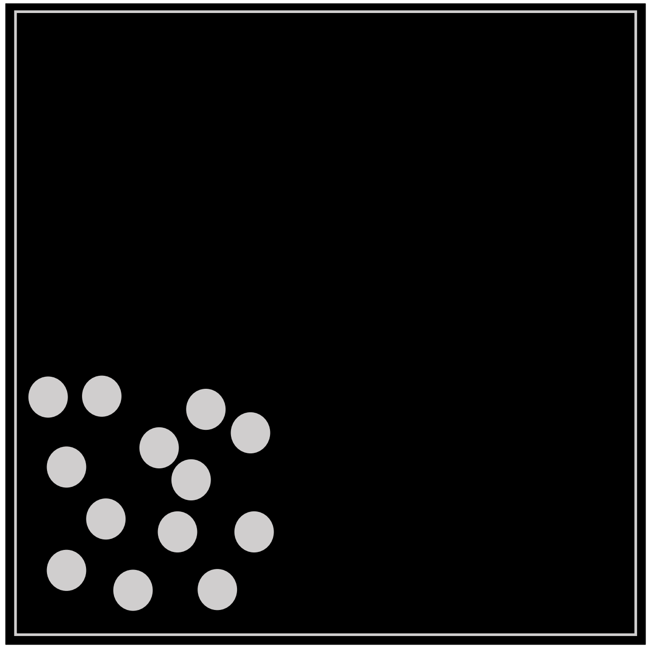
# Option 2: Random sampling

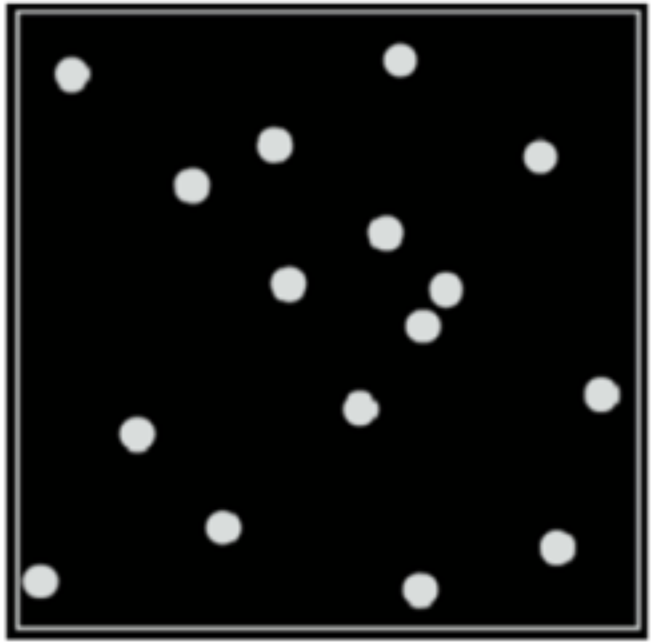


Could lead to a poor distribution (not even over the pixel)

Requires a lot of samples to make it equally distributed

Note, this black square is a **single** pixel

# Option 3: “Jitter” sampling



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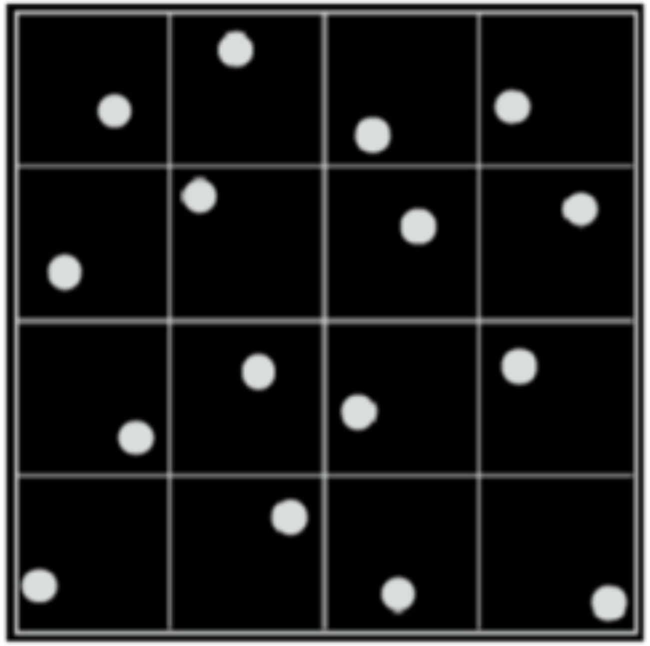
# Option 3: "Jitter" sampling

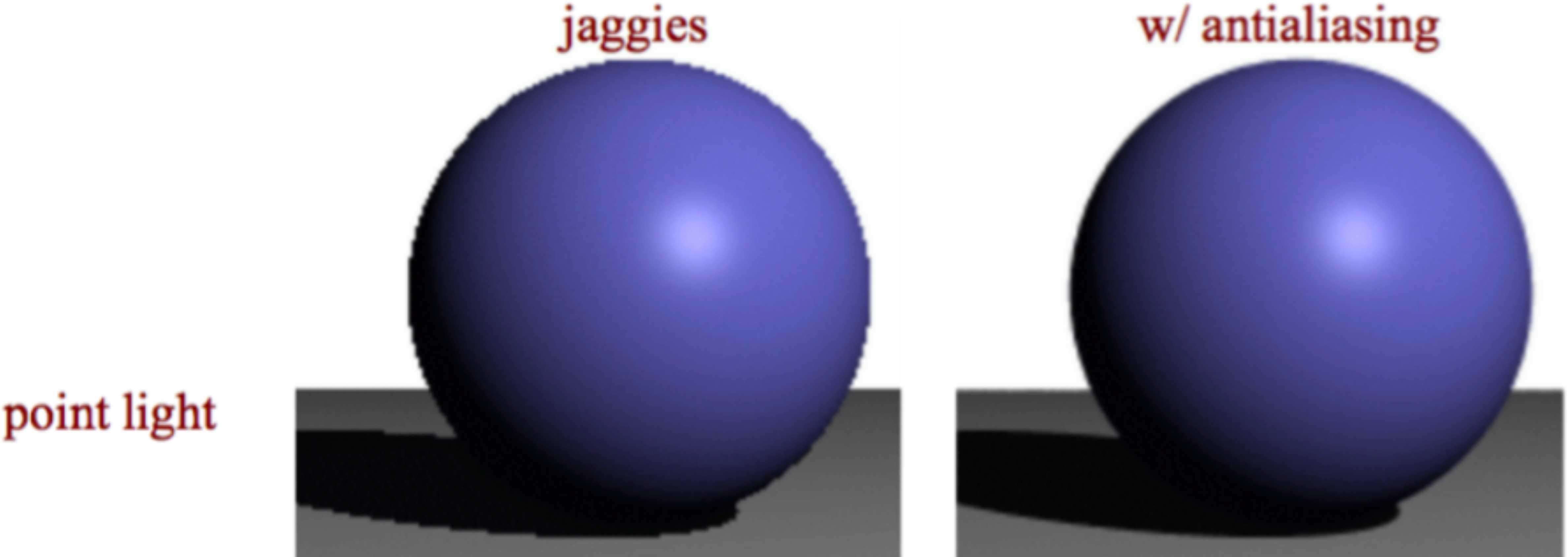


Randomly sample within a regular grid of "sub-pixels"

Ensures randomness as well as being evenly distributed over the pixel

Note, this black square is a **single** pixel

# Antialiasing - Supersampling



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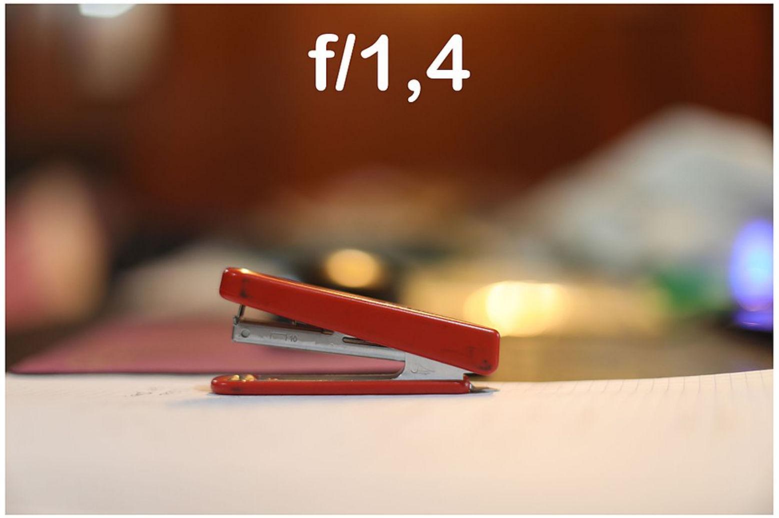
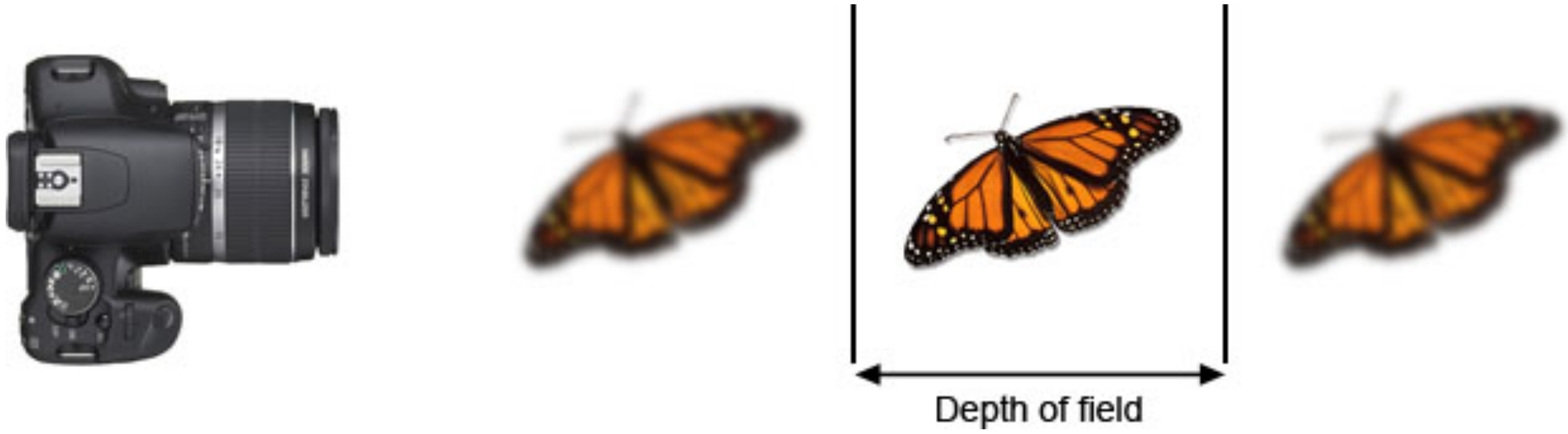
# Depth of field





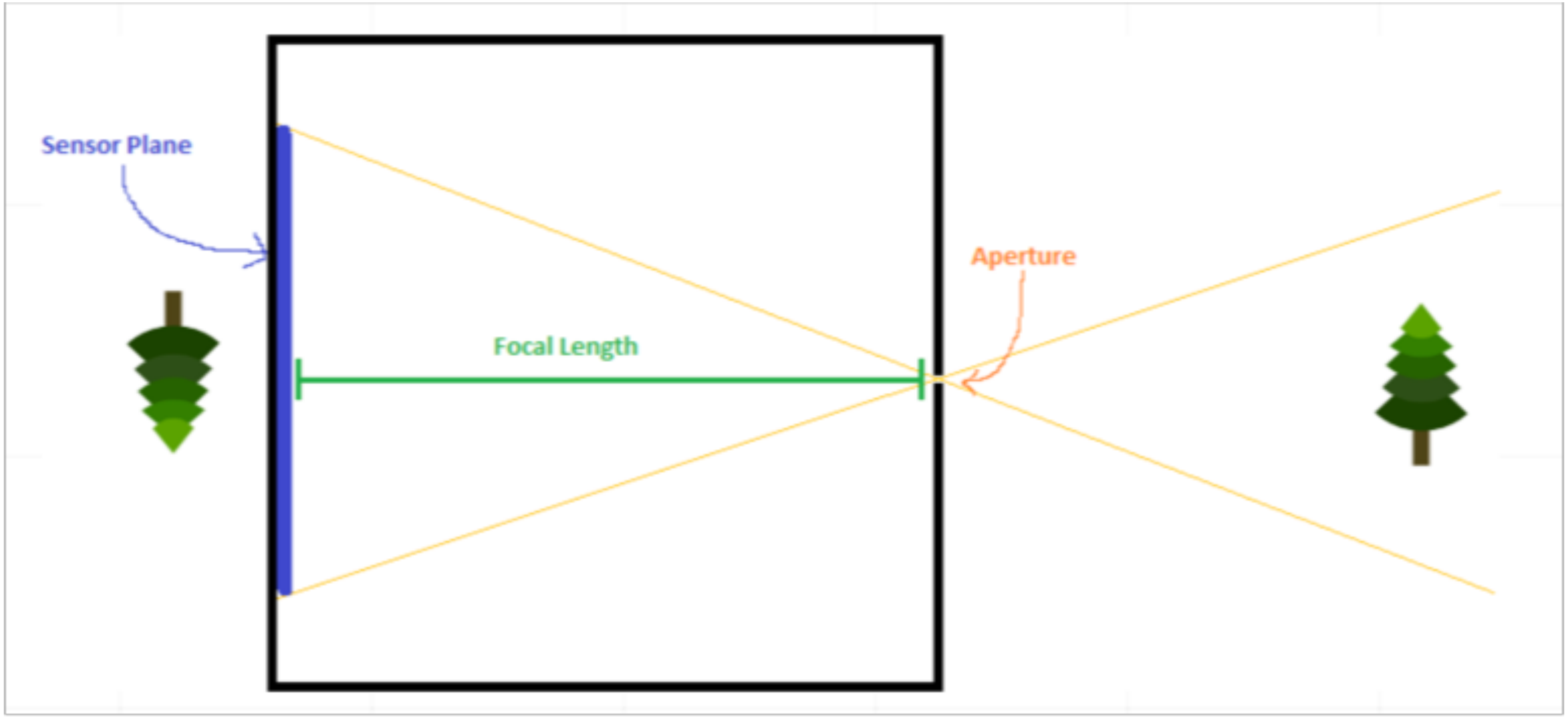
Source: Wikipedia

# Depth of field




Source: [Photography Mad]

# Depth of field




https://blog.demofox.org/2018/07/04/pathtraced-depth-of-field-bokeh/

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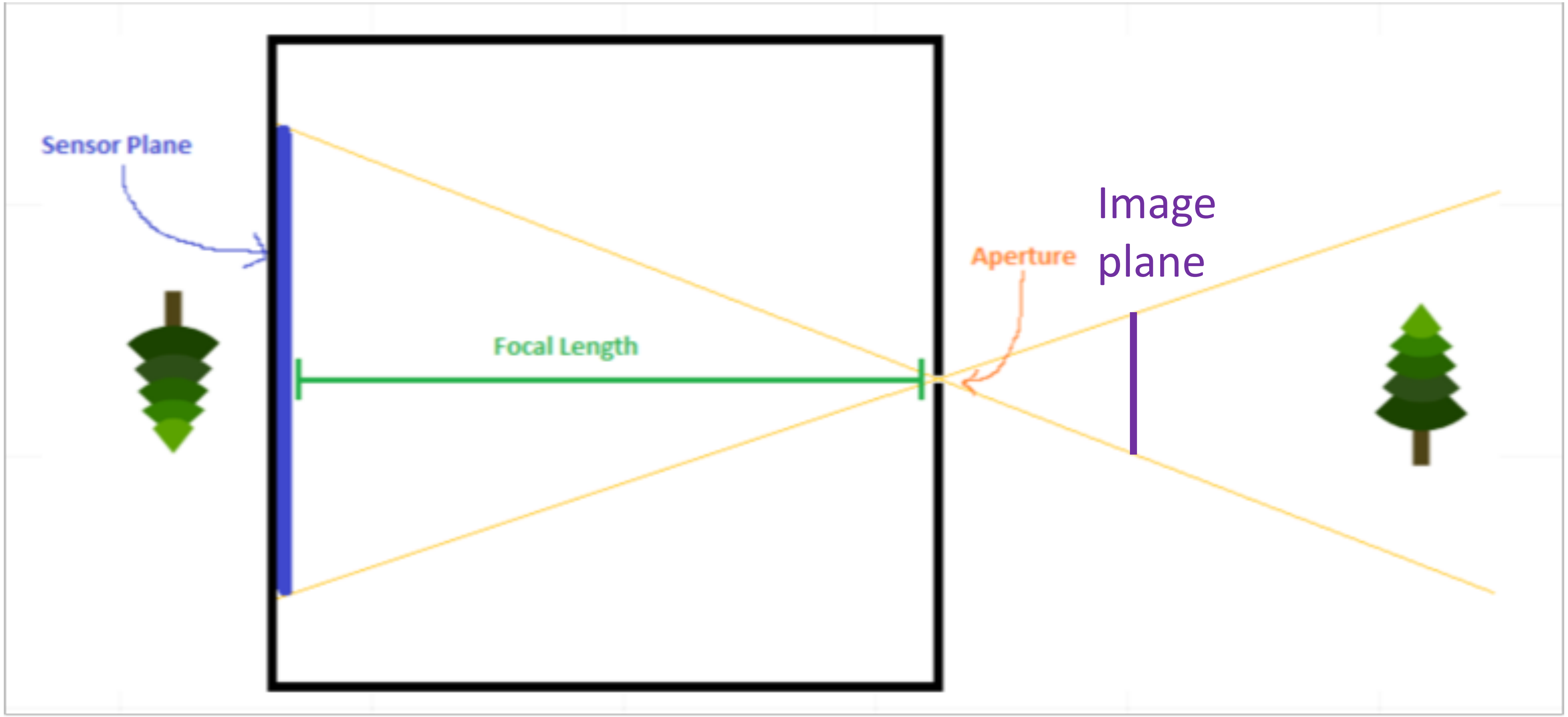


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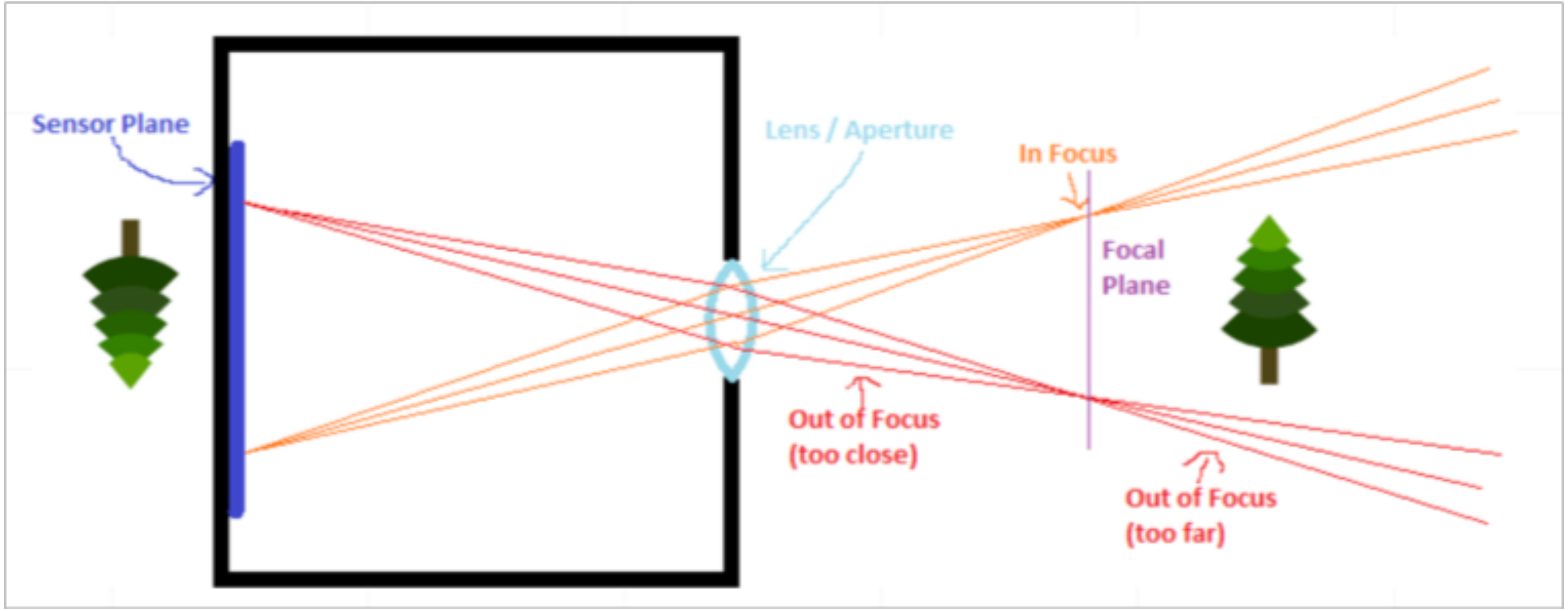
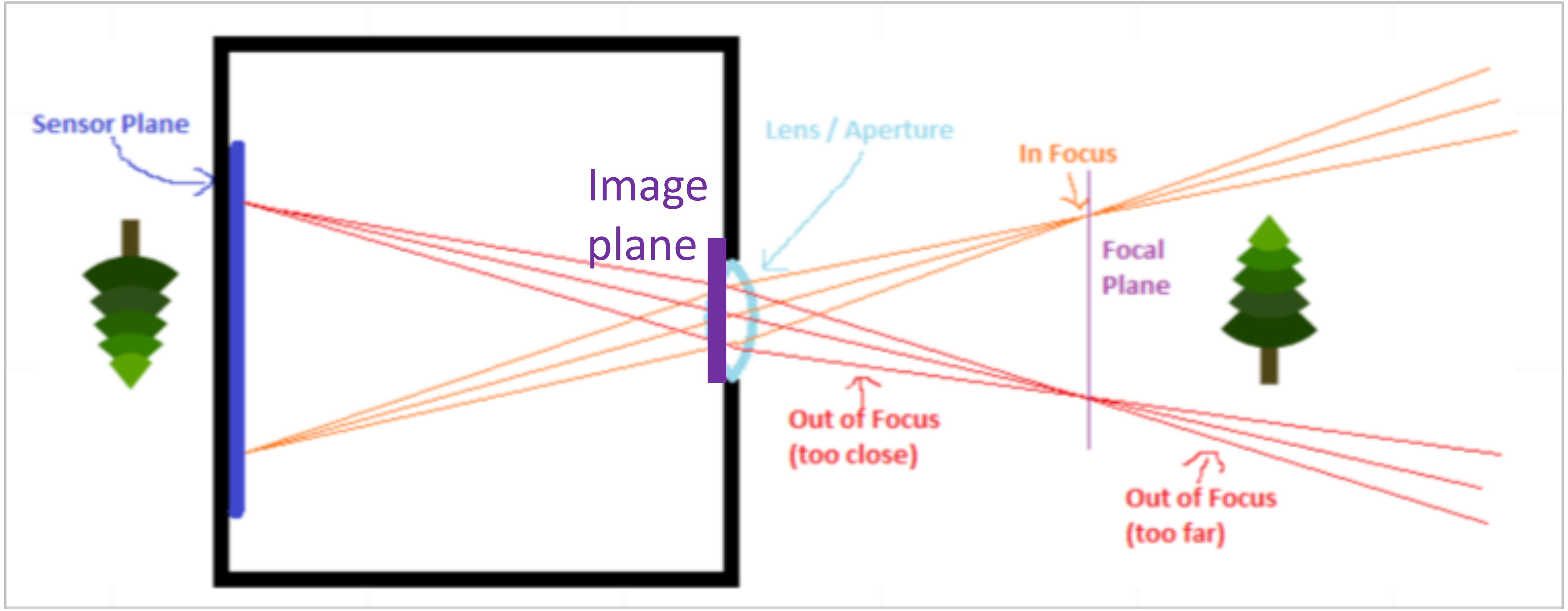



https://blog.demofox.org/2018/07/04/pathtraced-depth-of-field-bokeh/

# Depth of field

- Remember, our image plane was in front of the pinhole, let’s put it on the lens

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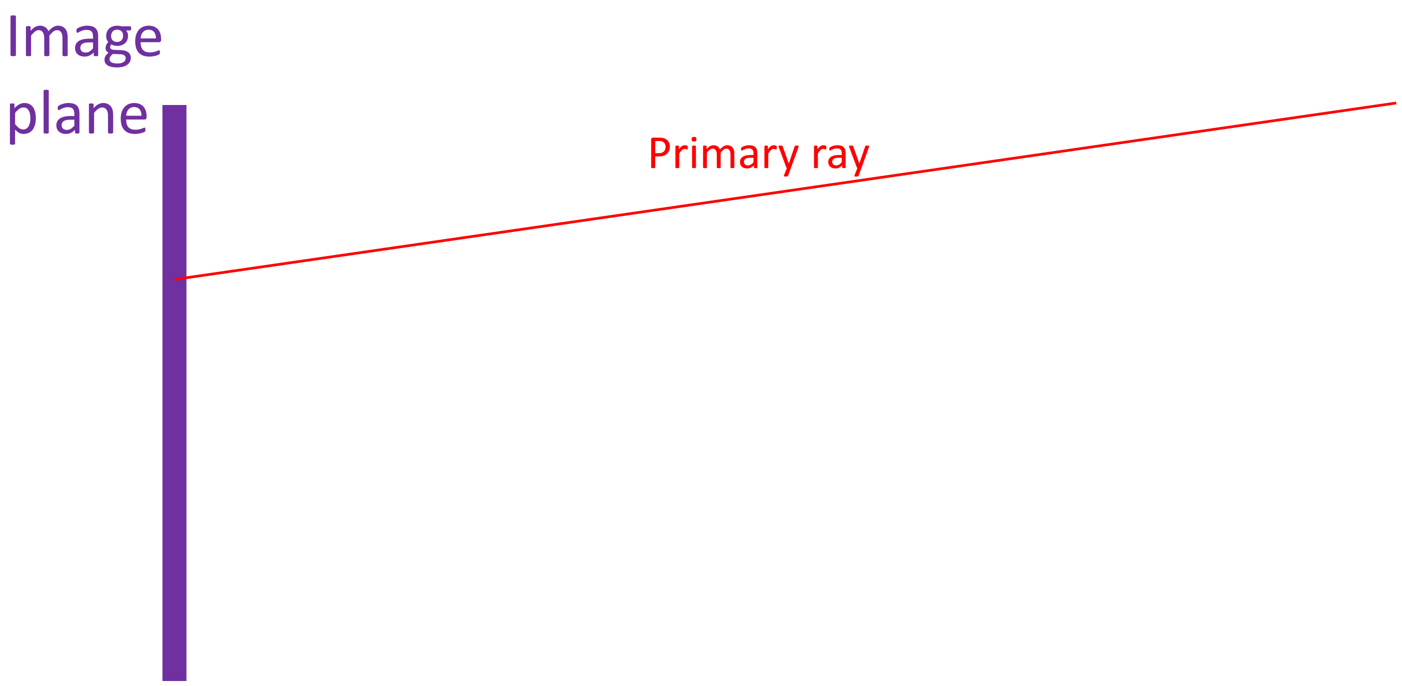
# Simulating a lens

- The color for a **single pixel** is an average from a bunch of rays, all from a different origin



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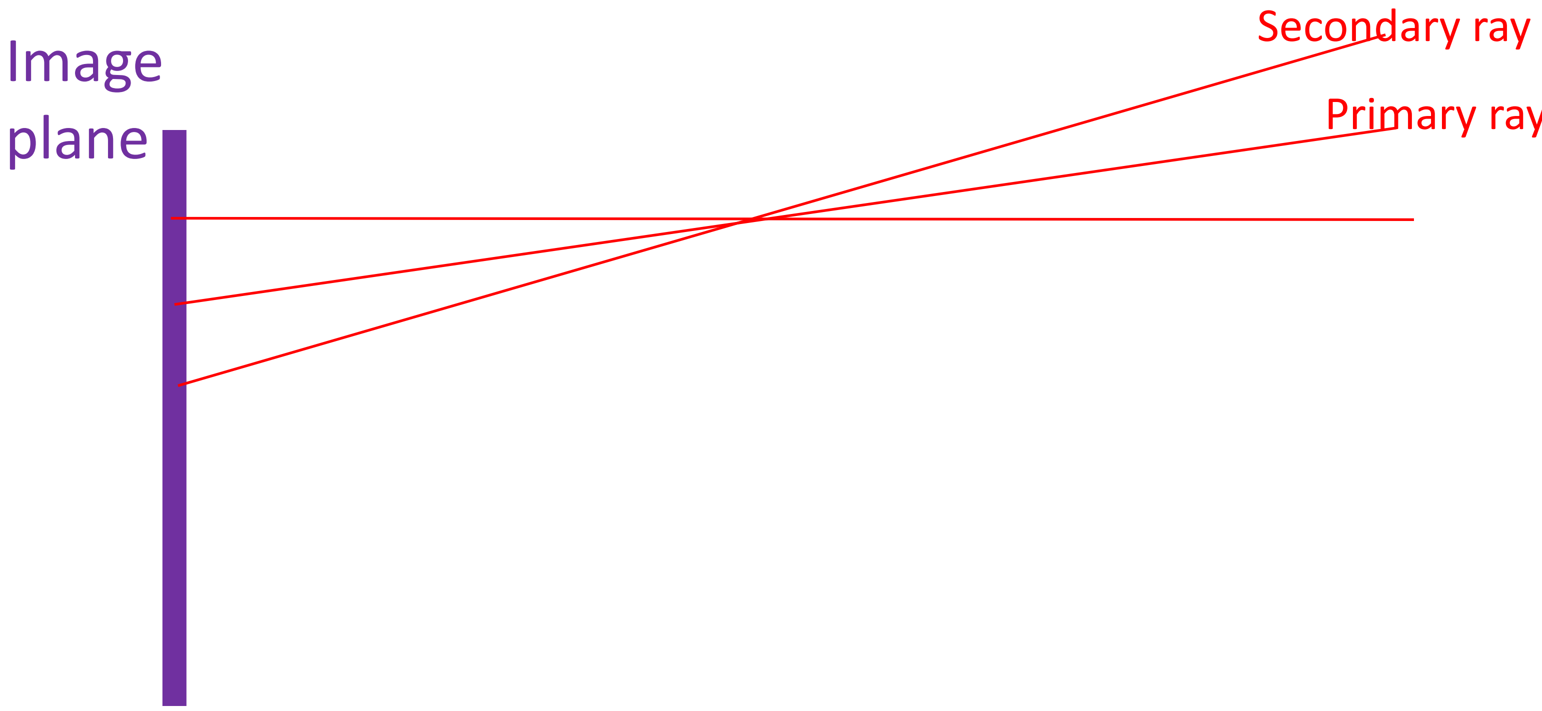
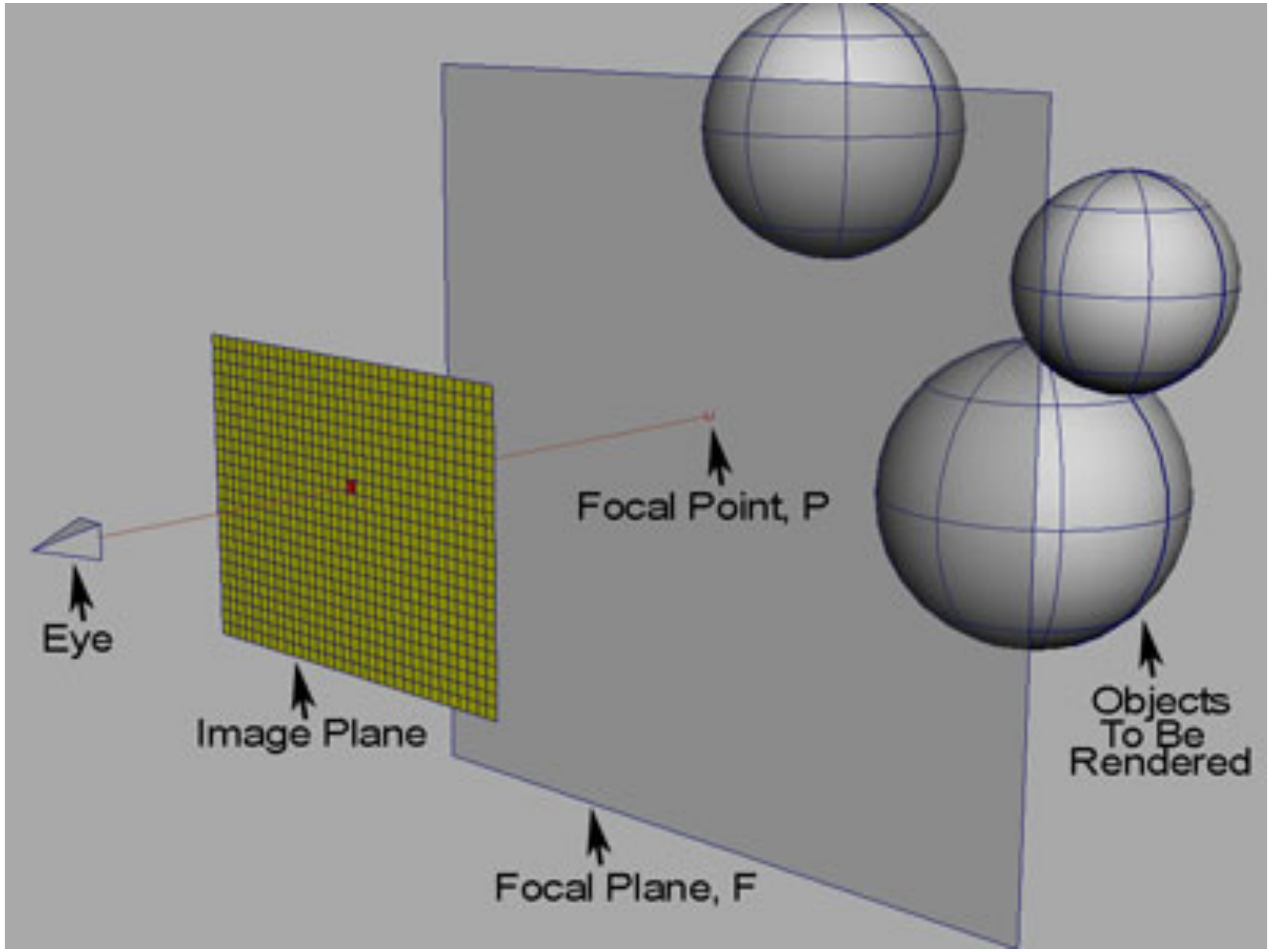



Note that although these other rays have origins at a different part of the image plane, they all color the same pixel

# Depth of field

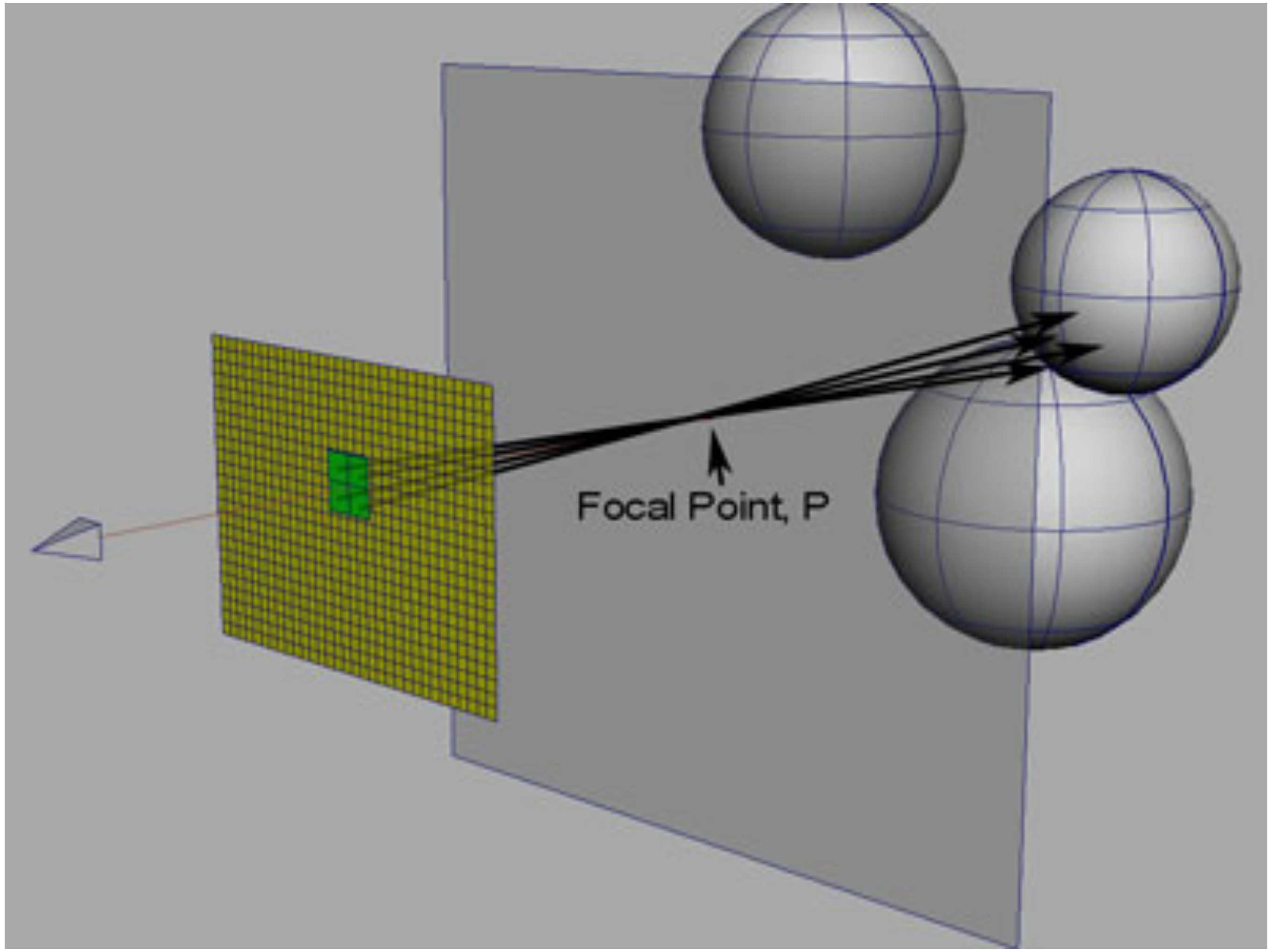
- For a single pixel:
- First, pick the focal distance from the image plane, and cast the primary ray that distance.
- This gives the focal point P of the primary ray




Source: http://cg.skeelogy.com/depth-of-field-using-raytracing/

# Depth of field

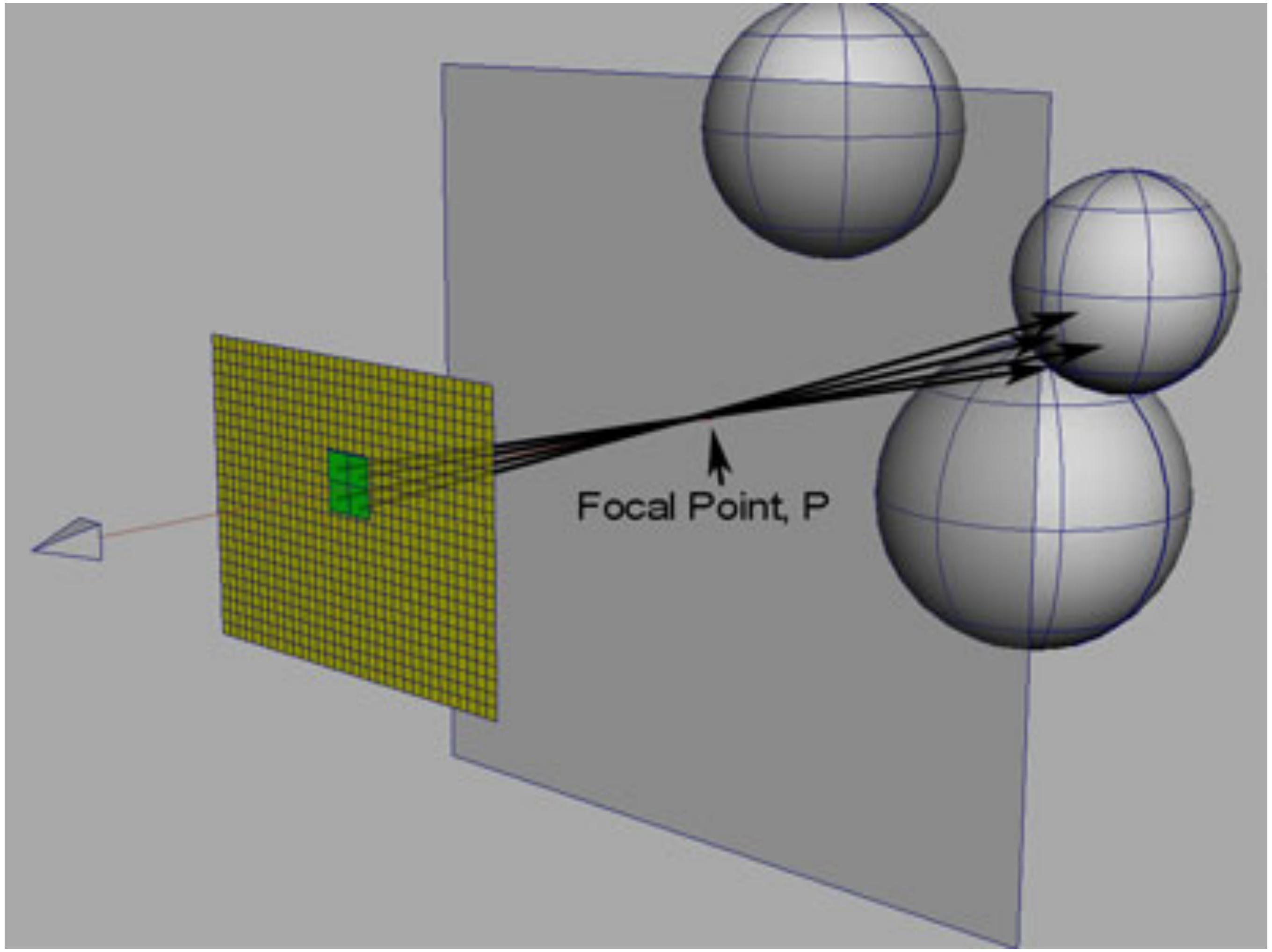
- For a single pixel:
- Next, to cast a secondary ray, change the origin to a nearby point, and change the direction so the secondary ray points to P
- (change the origin from O to O', and the new direction is P-O')




Source: http://cg.skeelogy.com/depth-of-field-using-raytracing/

# Depth of field

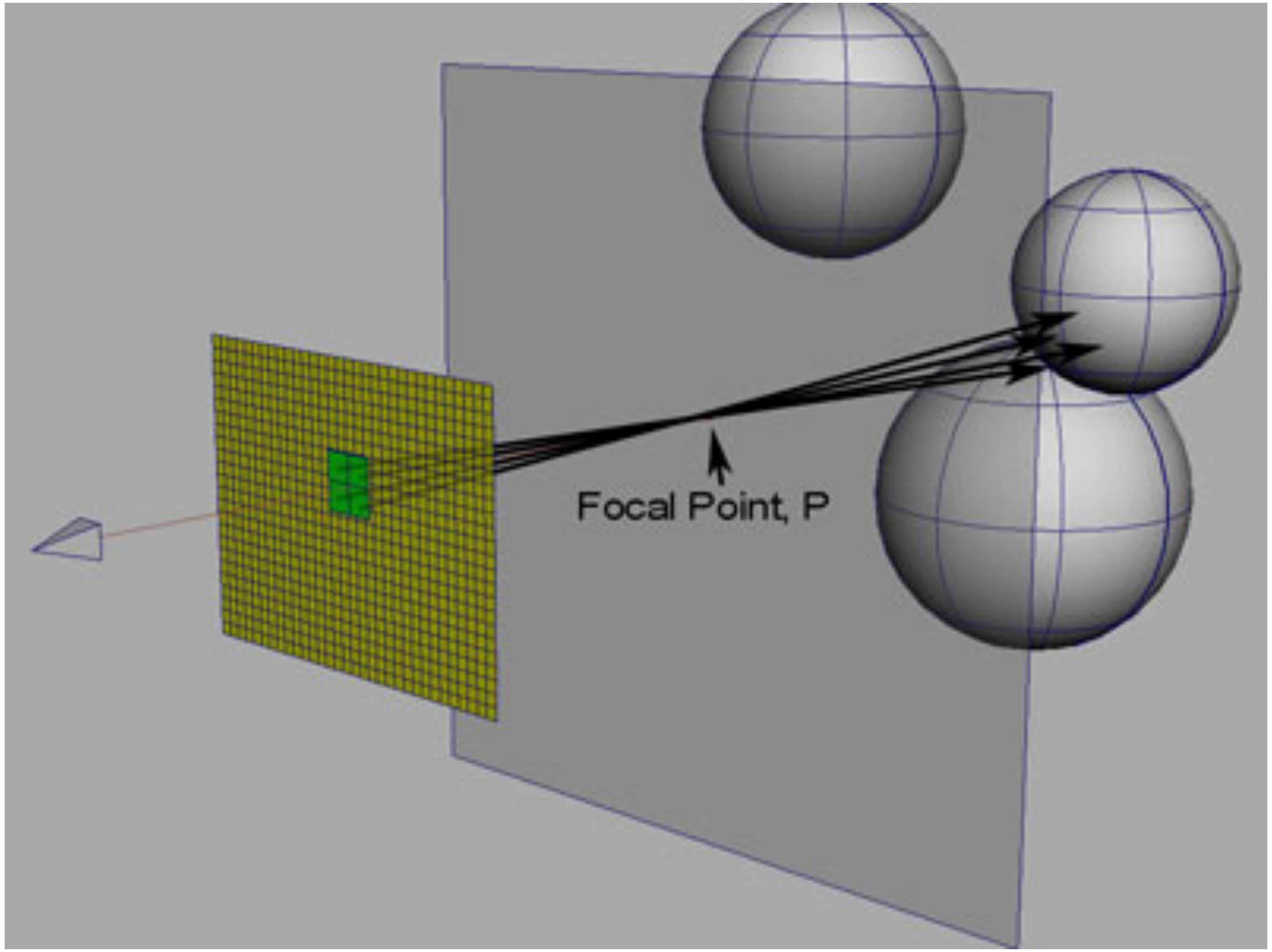
- For a single pixel:
- Do this a lot of times per pixel, averaging the color from casting each secondary ray
- (Note you'll still need to do anti-aliasing, or there will be jaggies for objects that are in-focus)




Source: http://cg.skeelogy.com/depth-of-field-using-raytracing/

# Depth of field – Aperture shape

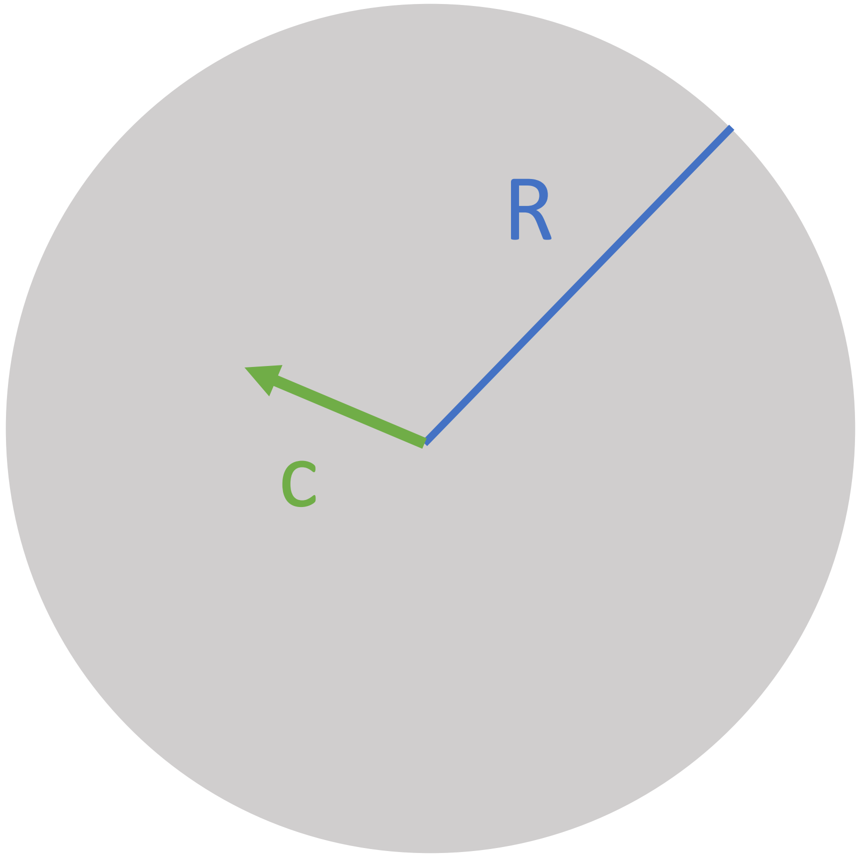
- Picking an aperture shape:
  - In this picture, the origin is changed to be somewhere in this green square
  - Personally I prefer to change it by a vector on a disk




Source: http://cg.skeelogy.com/depth-of-field-using-raytracing/

# Depth of field – Aperture shape

- O’ = O + c
- Where c is a random vector on the 2D disk of radius R centered at the origin
- The larger R is, the larger the aperture, the narrower the depth of field.
- (Look up how to randomly sample a disk uniformly)

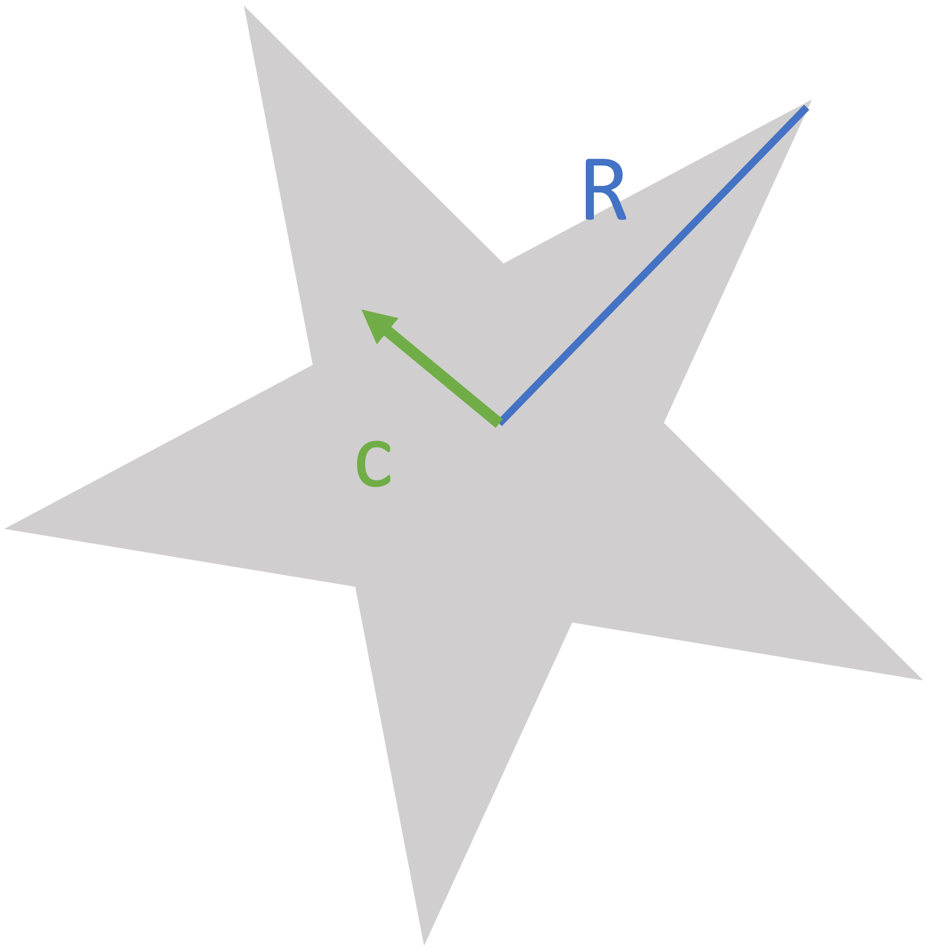


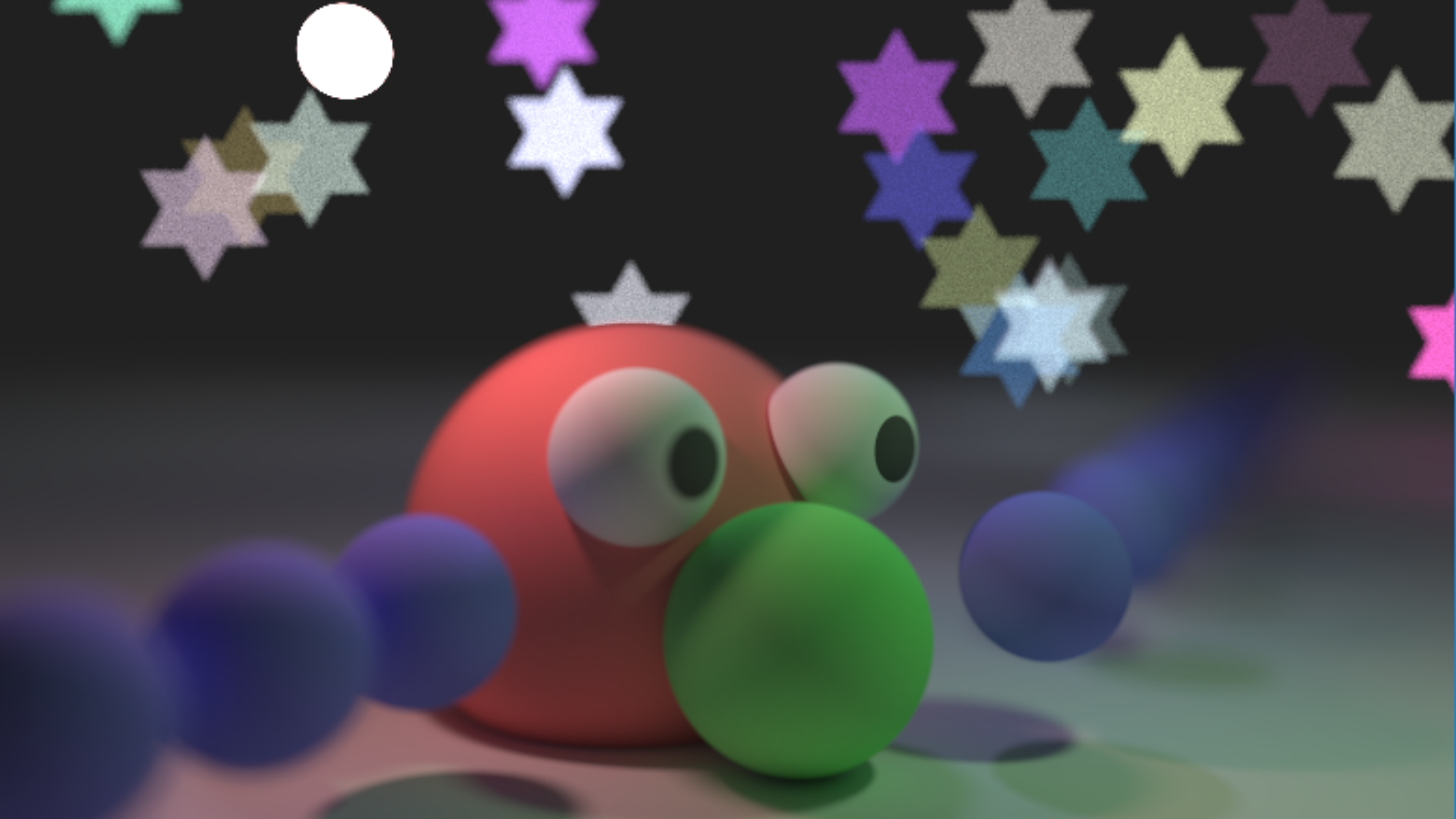
# Bokeh

# Aperture shape impacts the Bokeh


https://www.diyphotography.net/diy_create_your_own_bokeh/

# Depth of field – Aperture shape





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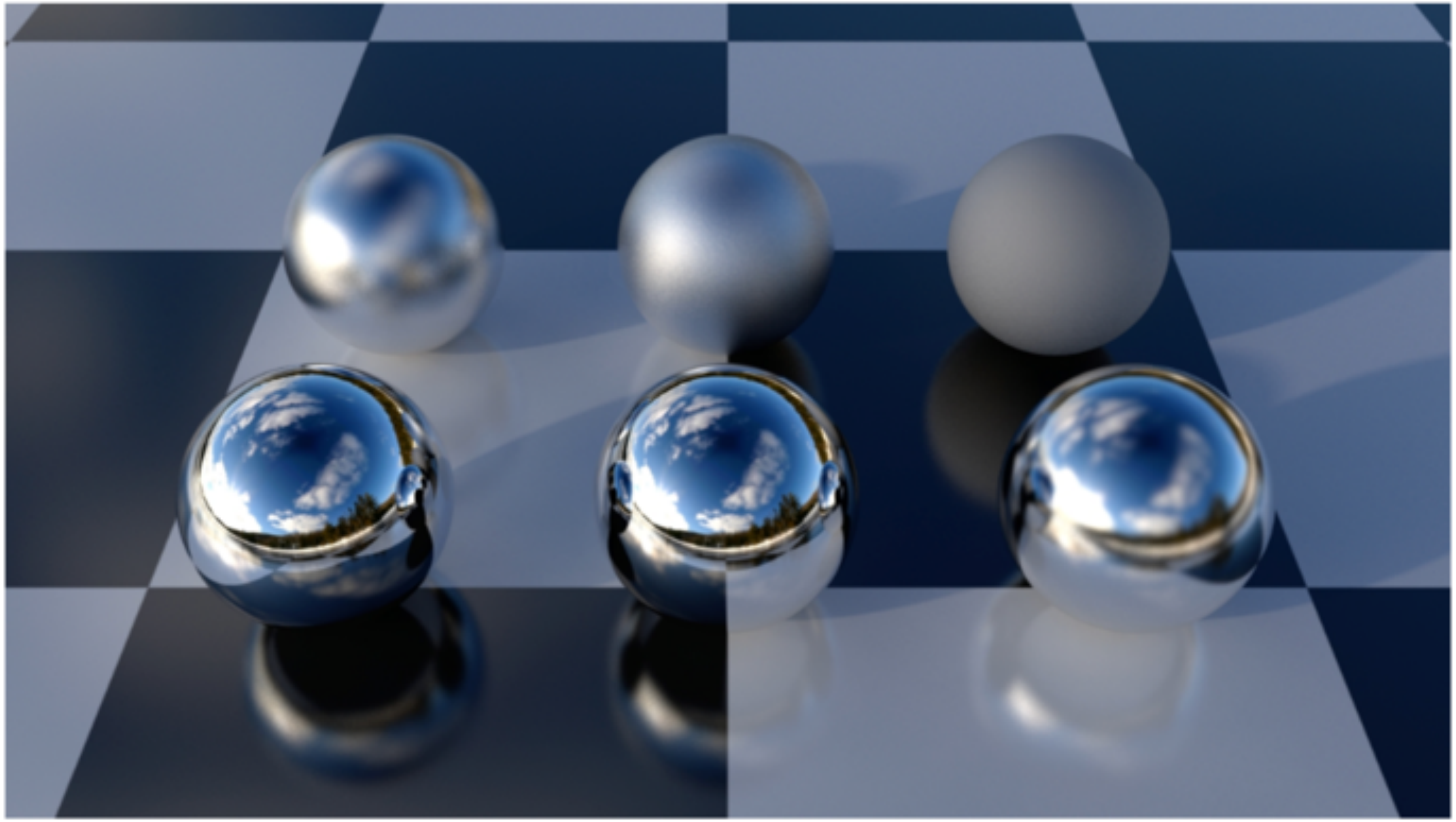
# Glossy Reflections



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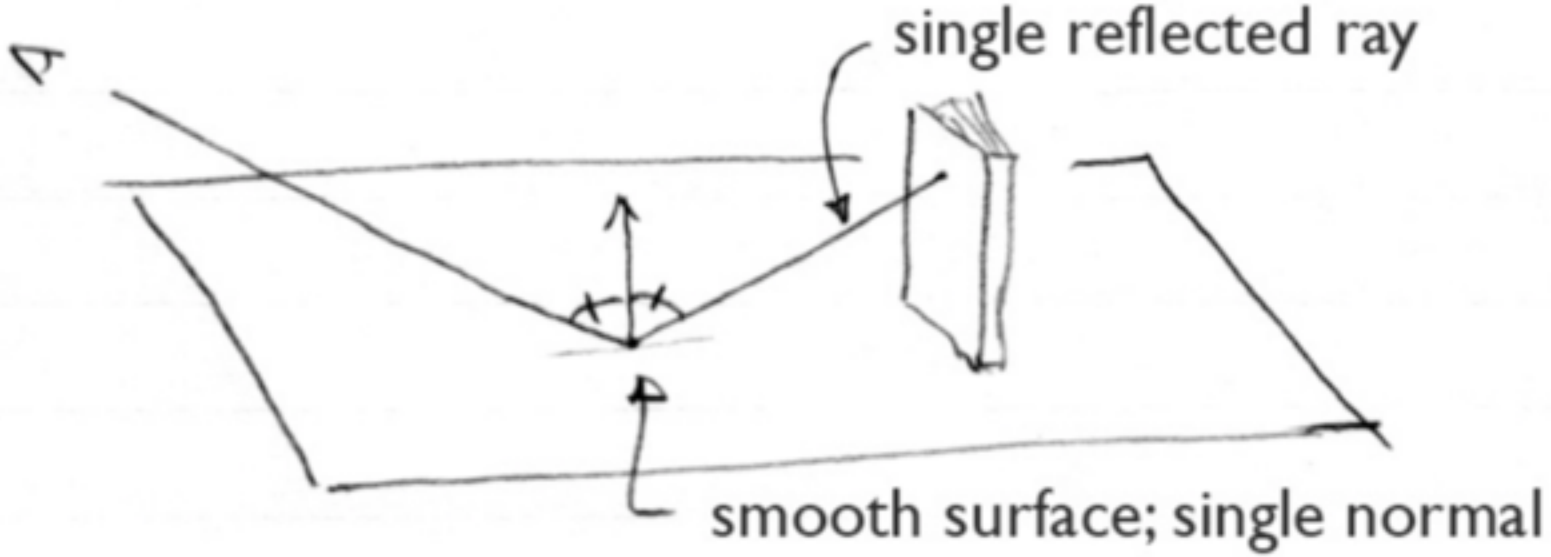
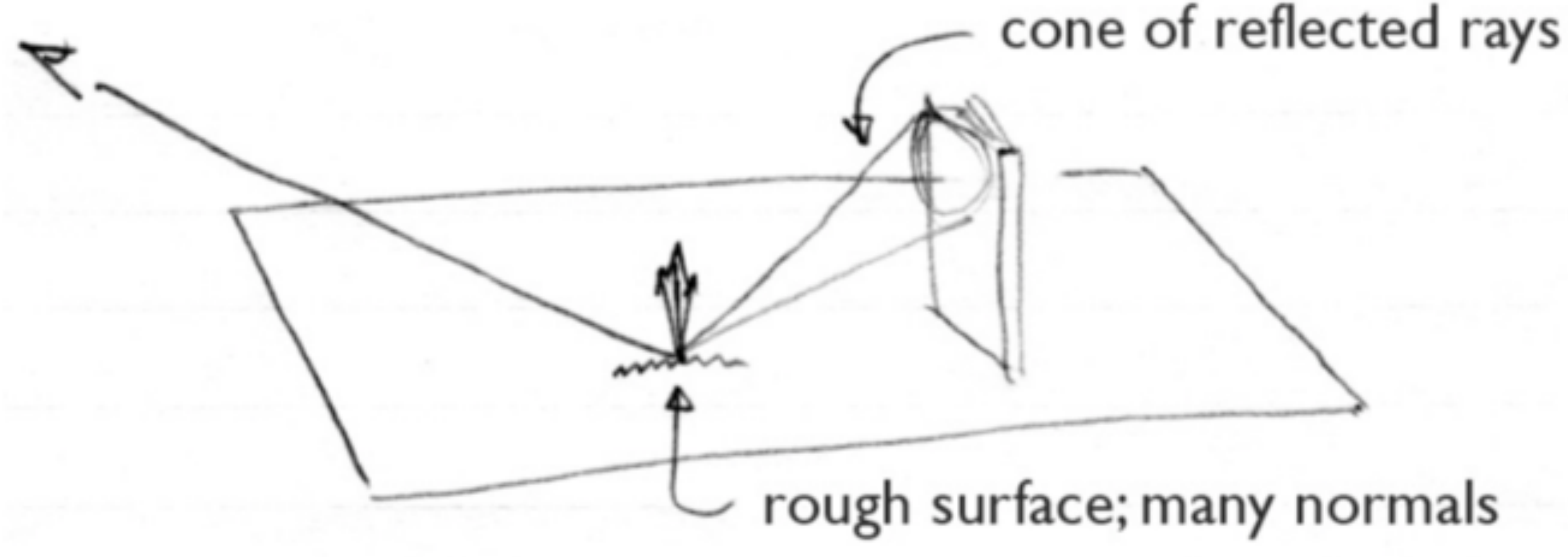
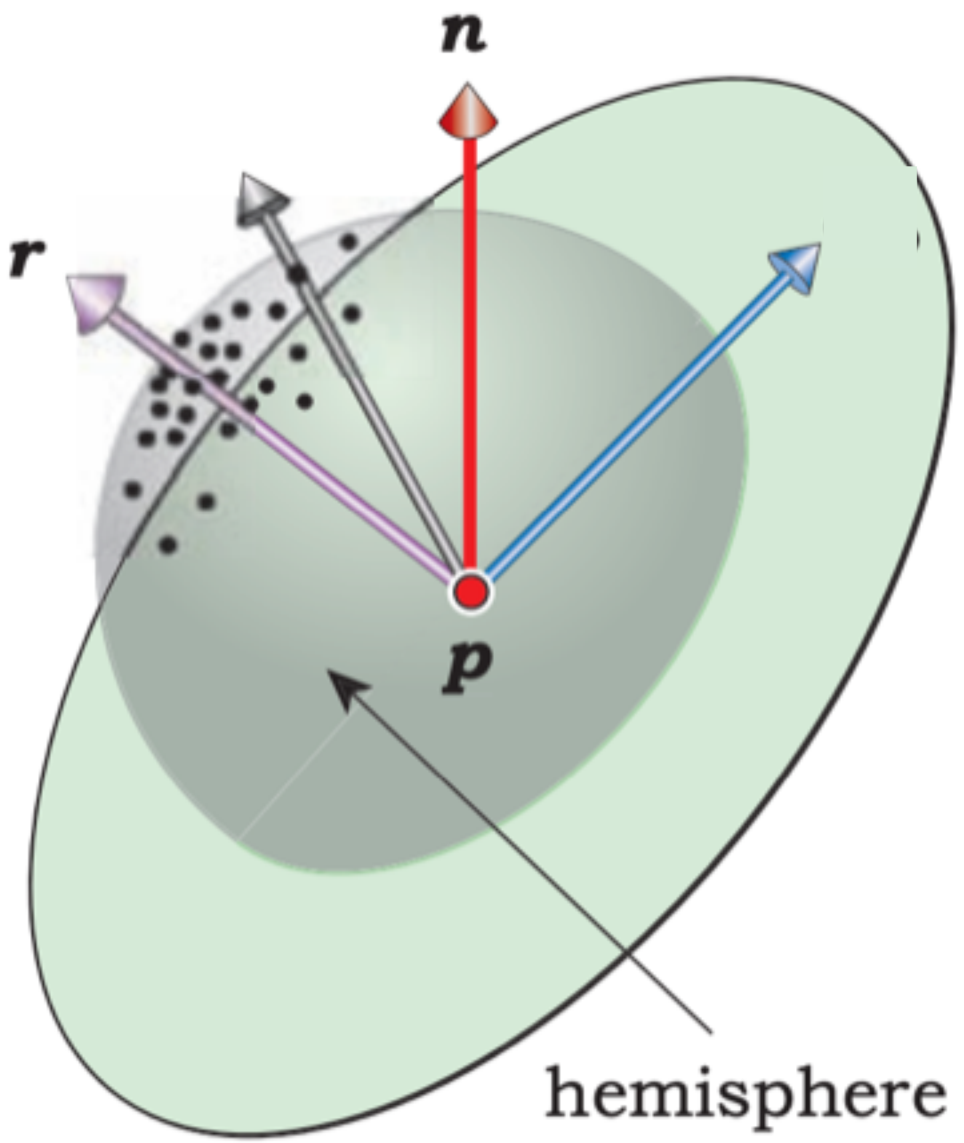


# Glossy Reflections



# Glossy Reflection

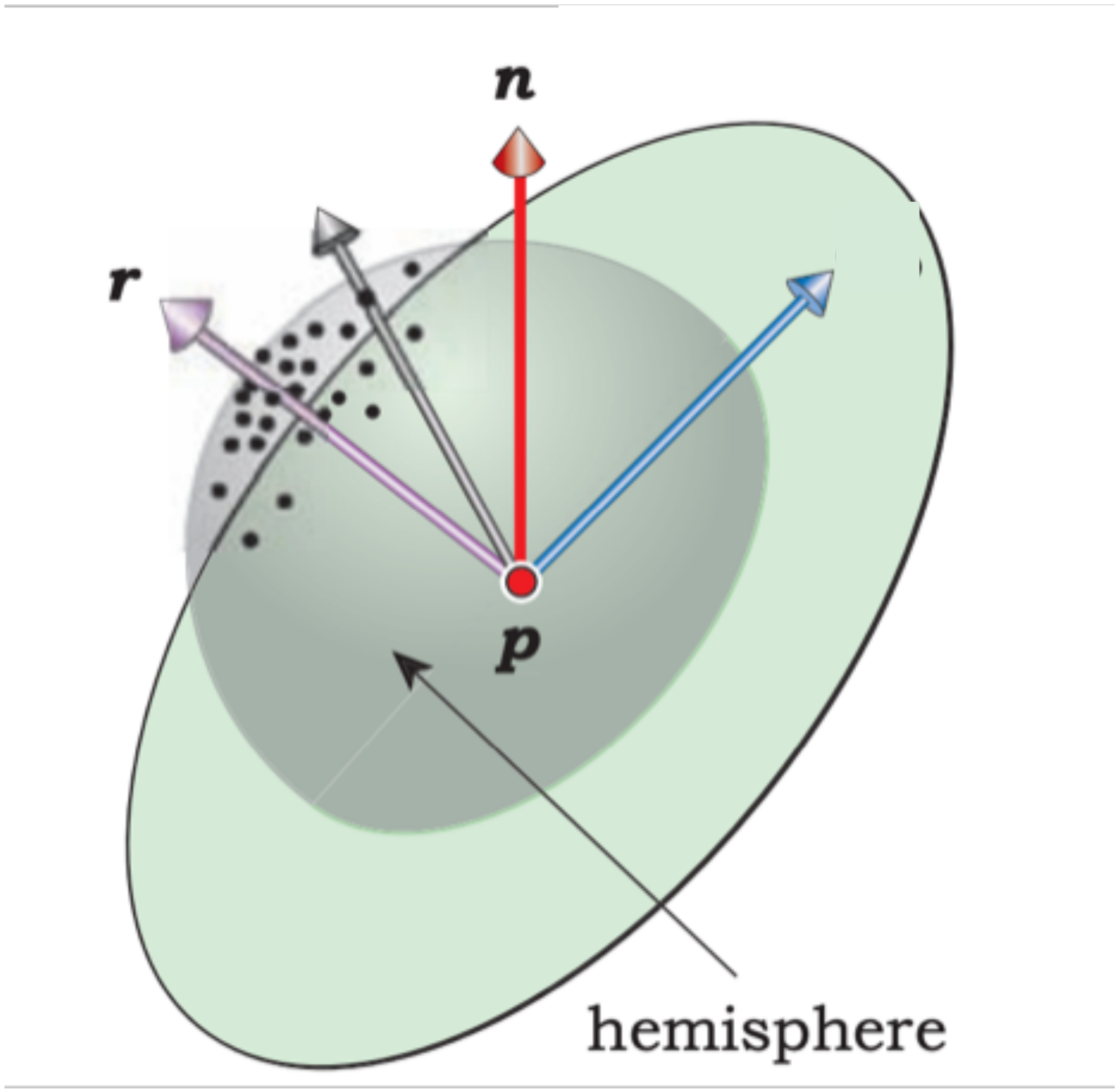
- We want to sample rays that are randomly clustered near the reflected ray




Source: “Ray Tracing from the ground up” By Kevin Suffern

# Glossy Reflection

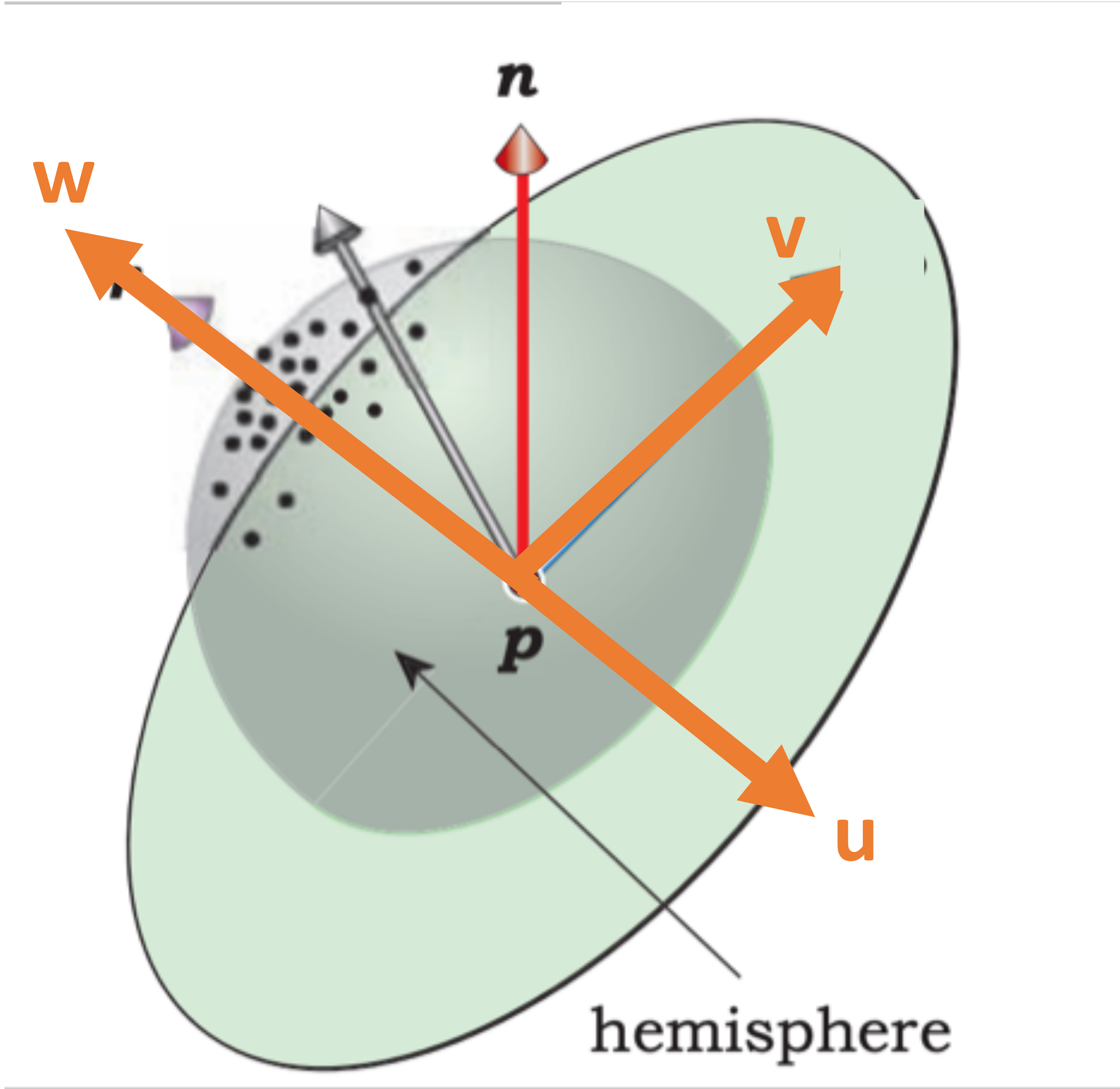
- This green plane is perpendicular to the reflected ray **r**




Source: "Ray Tracing from the ground up" By Kevin Suffern

# Glossy Reflection

- This green plane is perpendicular to the reflected ray **r**
- Make an orthonormal frame of reference (u,v,w) where w = r
  - Similar to making the camera basis, use **n** as the "up" vector

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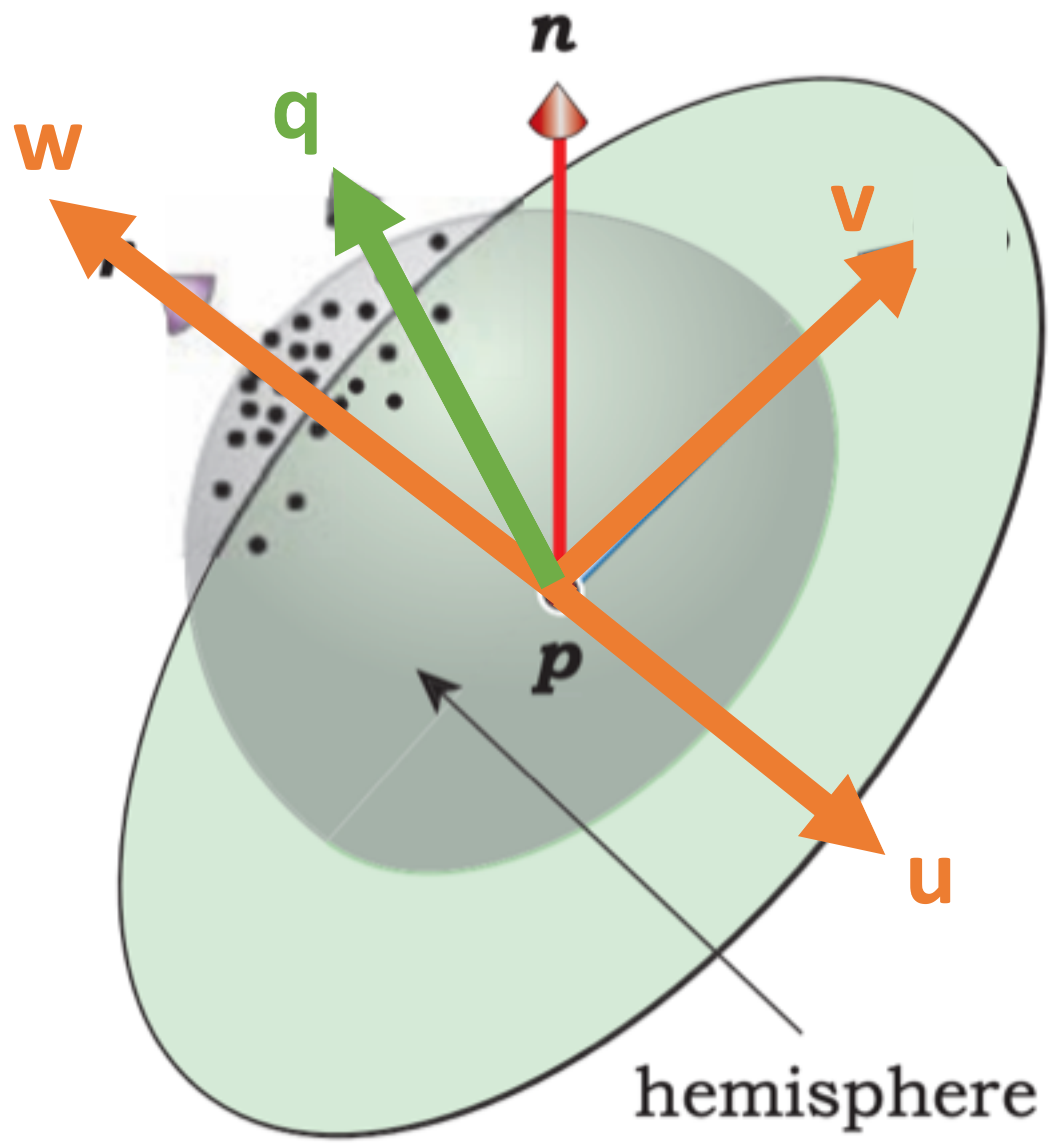
# Glossy Reflection

- In (u,v,w) space it's easy to pick a vector near w. This will be our new ray to cast. Call it q

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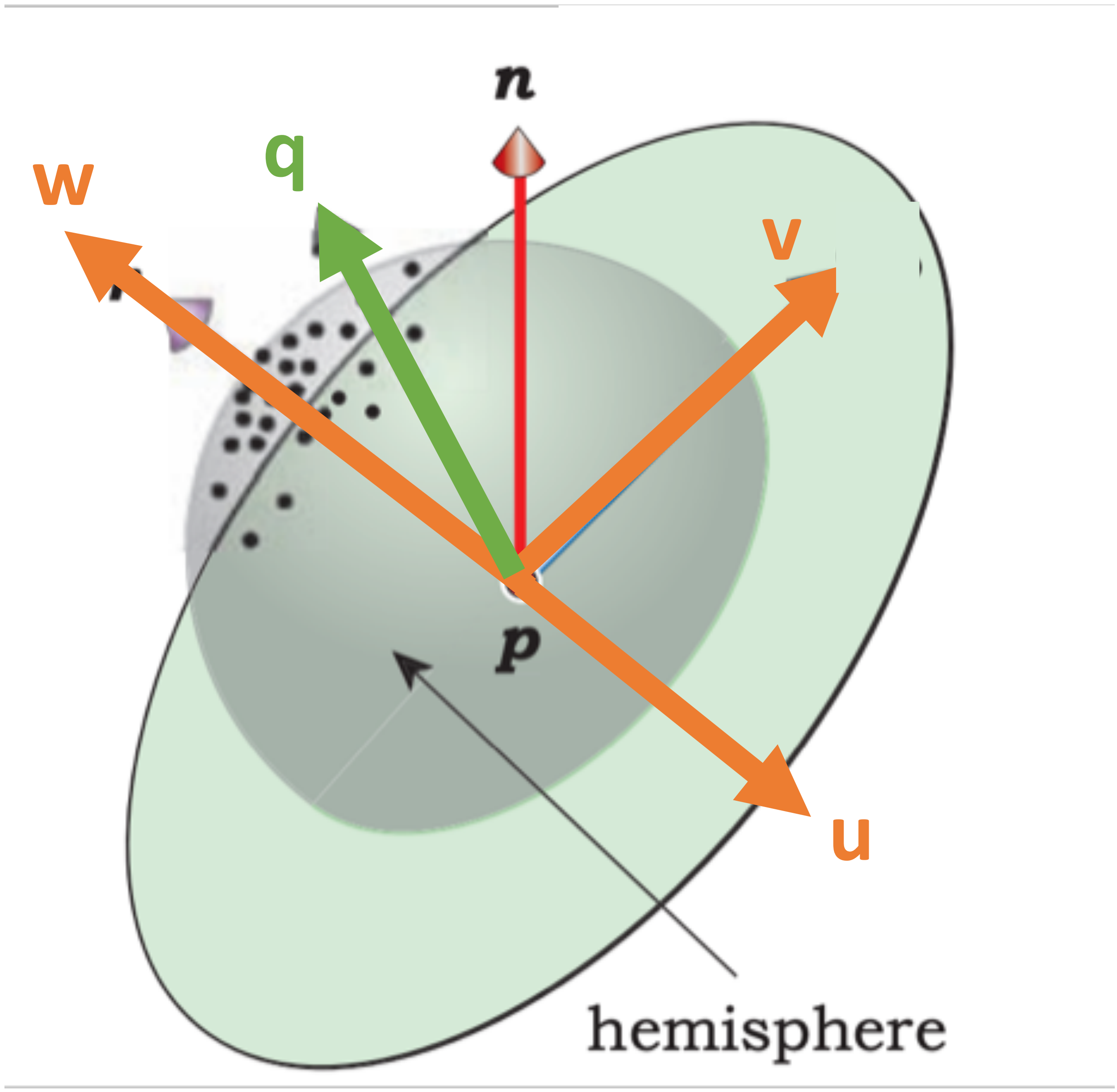
# Glossy Reflection

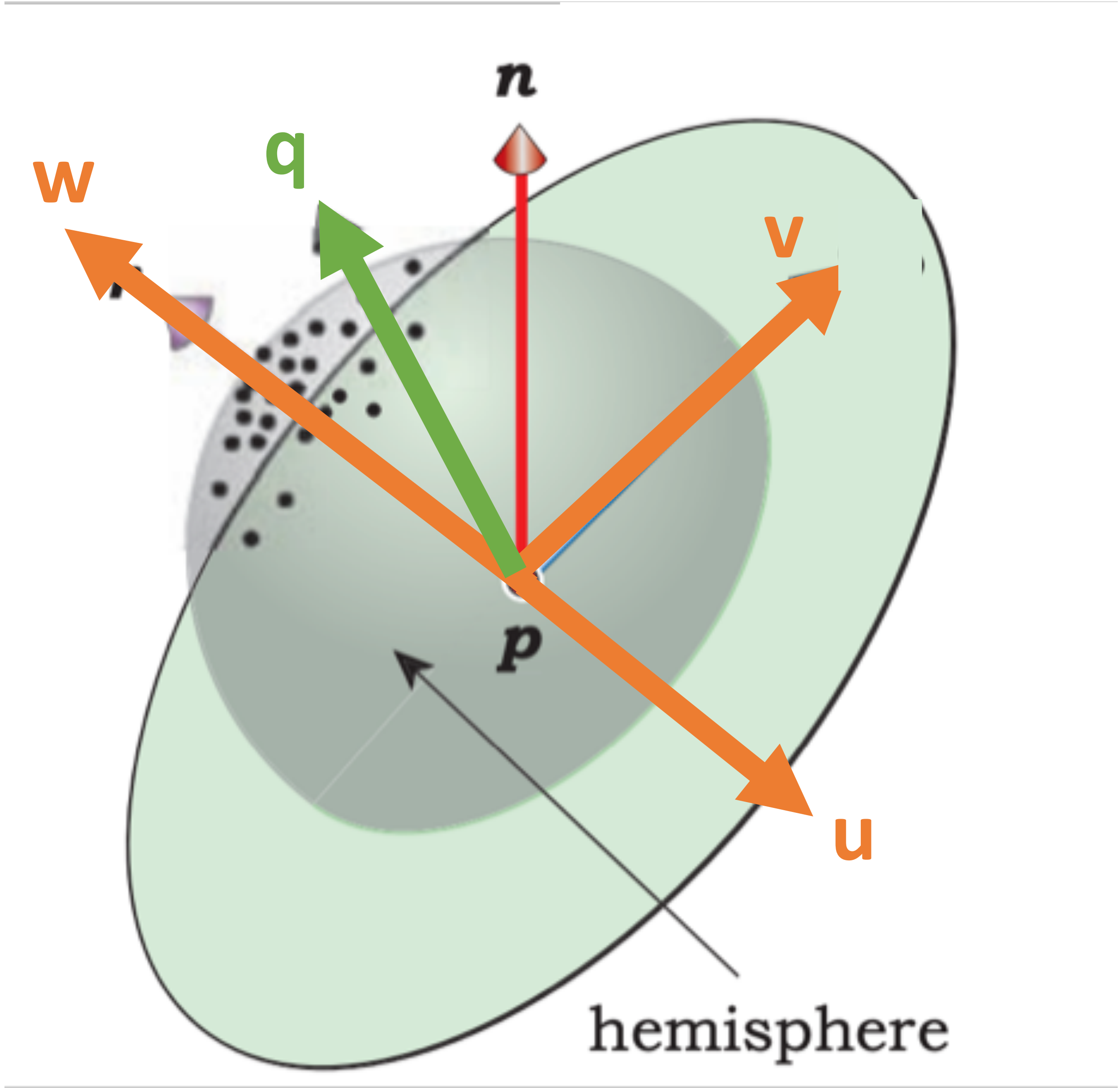
- In (u,v,w) space it's easy to pick a vector near w. This will be our new ray to cast. Call it q
- Use trigonometry and random distributions to pick q near w.




Source: "Ray Tracing from the ground up" By Kevin Suffern

# Glossy Reflection

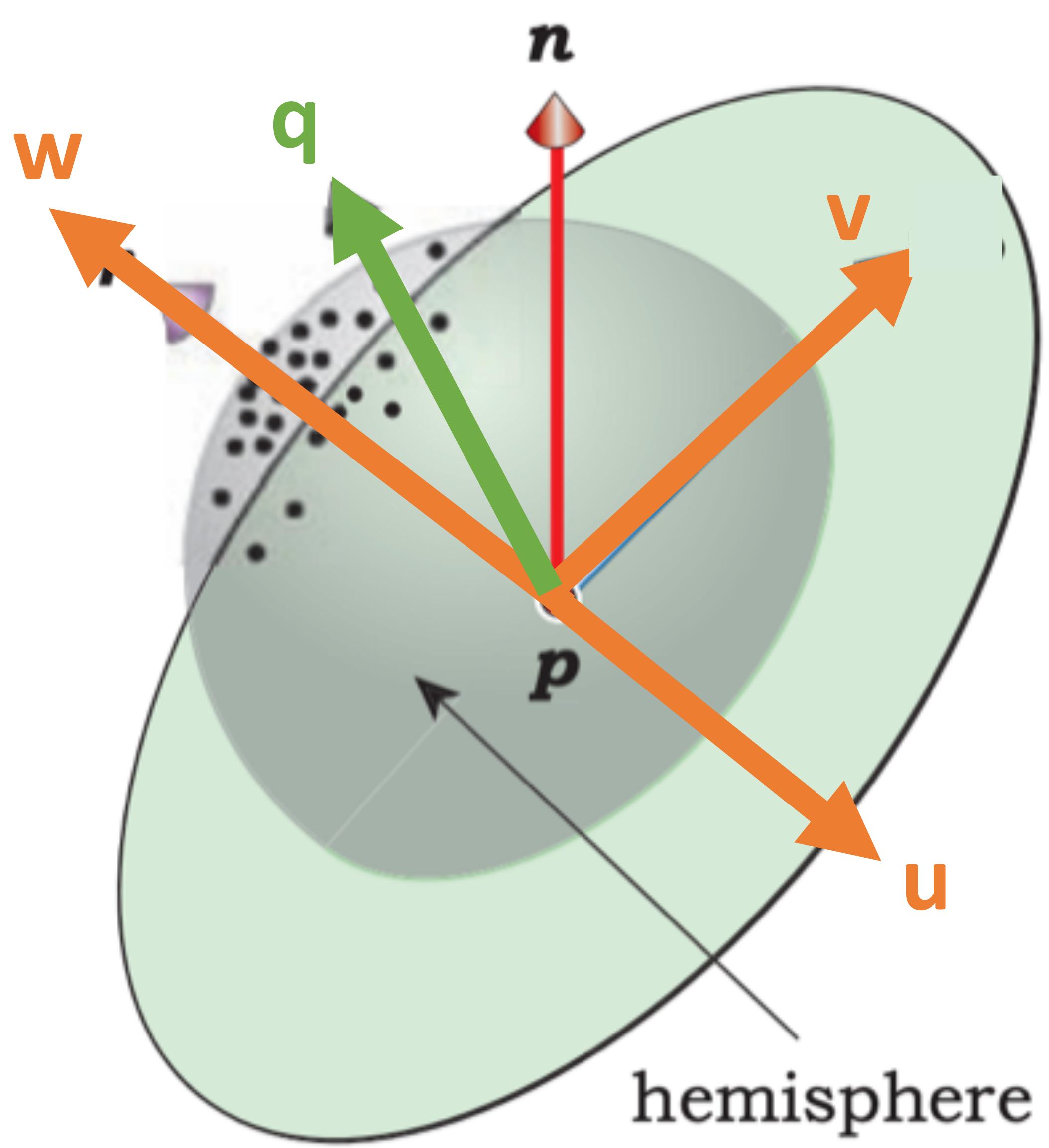
- In (u,v,w) space it's easy to pick a vector near w. This will be our new ray to cast. Call it q
- Use trigonometry and random distributions to pick q near w.
- The larger the variance in the distribution, the more rough the surface




Source: "Ray Tracing from the ground up" By Kevin Suffern

# Glossy Reflection

- Transform q out of (u,v,w) space to cast the new ray




Source: “Ray Tracing from the ground up” By Kevin Suffern

# Lecture 9: Advanced Topics in Rendering

- Advanced ray tracing:
  - Instancing
  - Constructive Solid Geometry
  - Super-sampling/Anti-aliasing
  - Depth of field
  - Glossy reflections
  - Motion blur
- Advanced shading techniques
  - Cel shading/Toon shading

# Motion Blur

- Scene is still and sampled over time (temporal sampling)
- When image is taken and shutter is open for fixed amount of time, the final image is an average of the light rays over time period.
- When objects are in motion, they will appear blurred
- Introduce time variable throughout the system.
    - i.e. objects are hit by rays given their position at a particular time
- Generate rays over shutter interval $T = T_0 + \xi(T_1 - T_0)$

# Motion blur

- Parameterize each object's motion by time, p(t)
- Each ray, when cast, gets a time $t_0$ in a range (ie, [0,1])
- The time $t_0$ each ray has, determines the scene the ray "sees"
  - Ie, the positions of the objects the ray might hit are $p(t_0)$

# Motion Blur

# Lecture 9: Advanced Topics in Rendering

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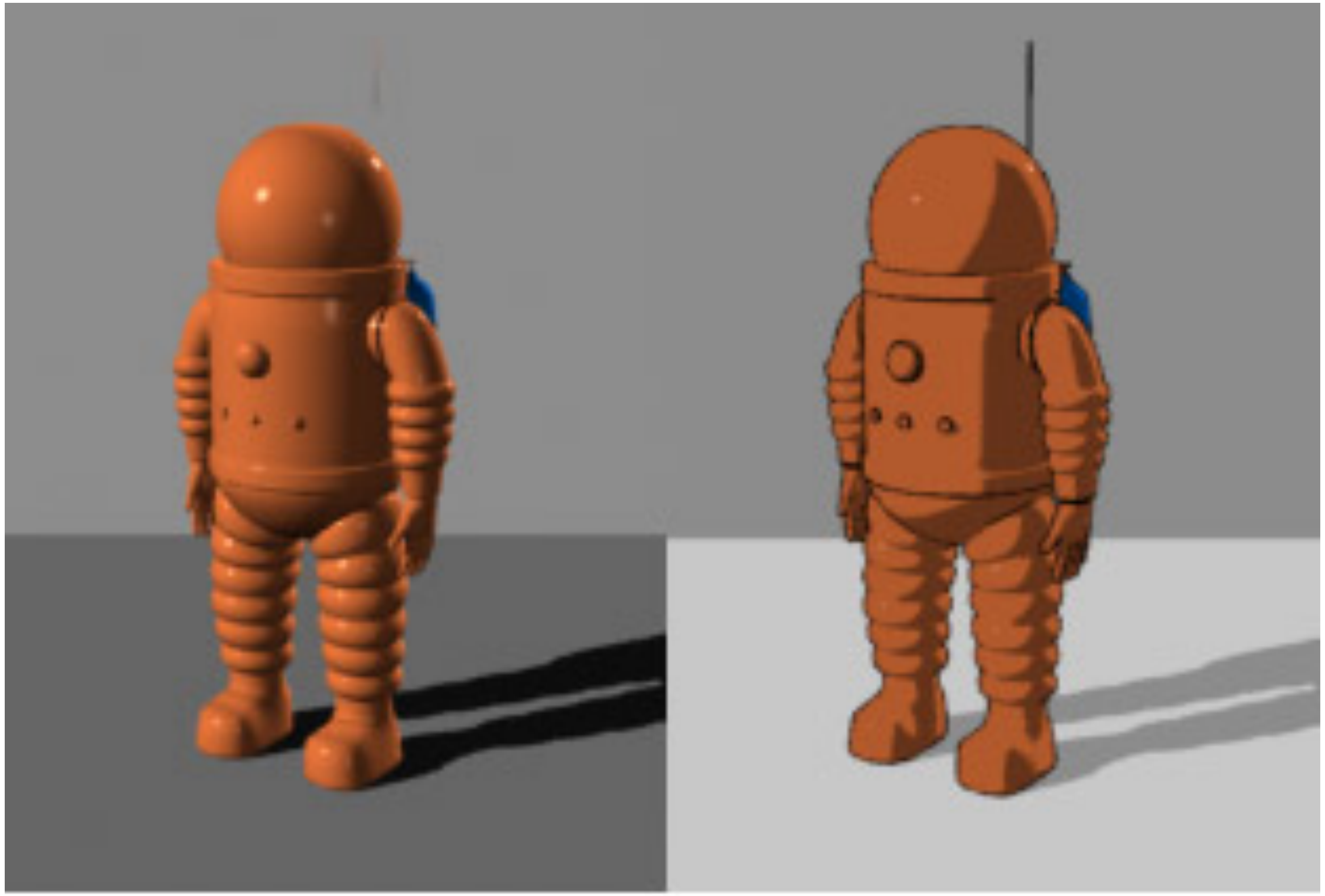
  - Cel shading/Toon shading

# Cel Shading

- Cel shading, or toon shading is an artistic rendering style meant to mimic a cartoon



plastic shader toon shader

wikipedia

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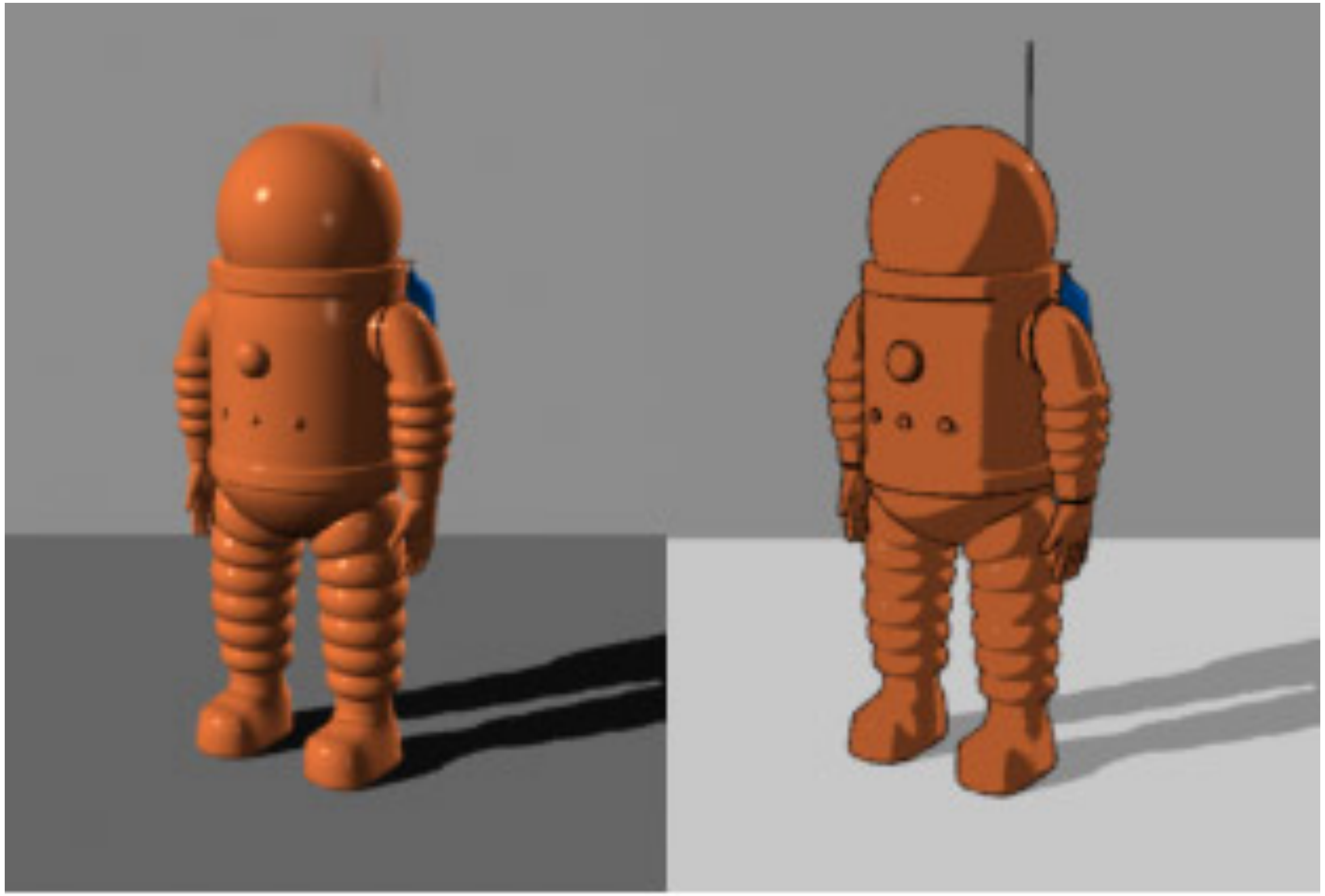

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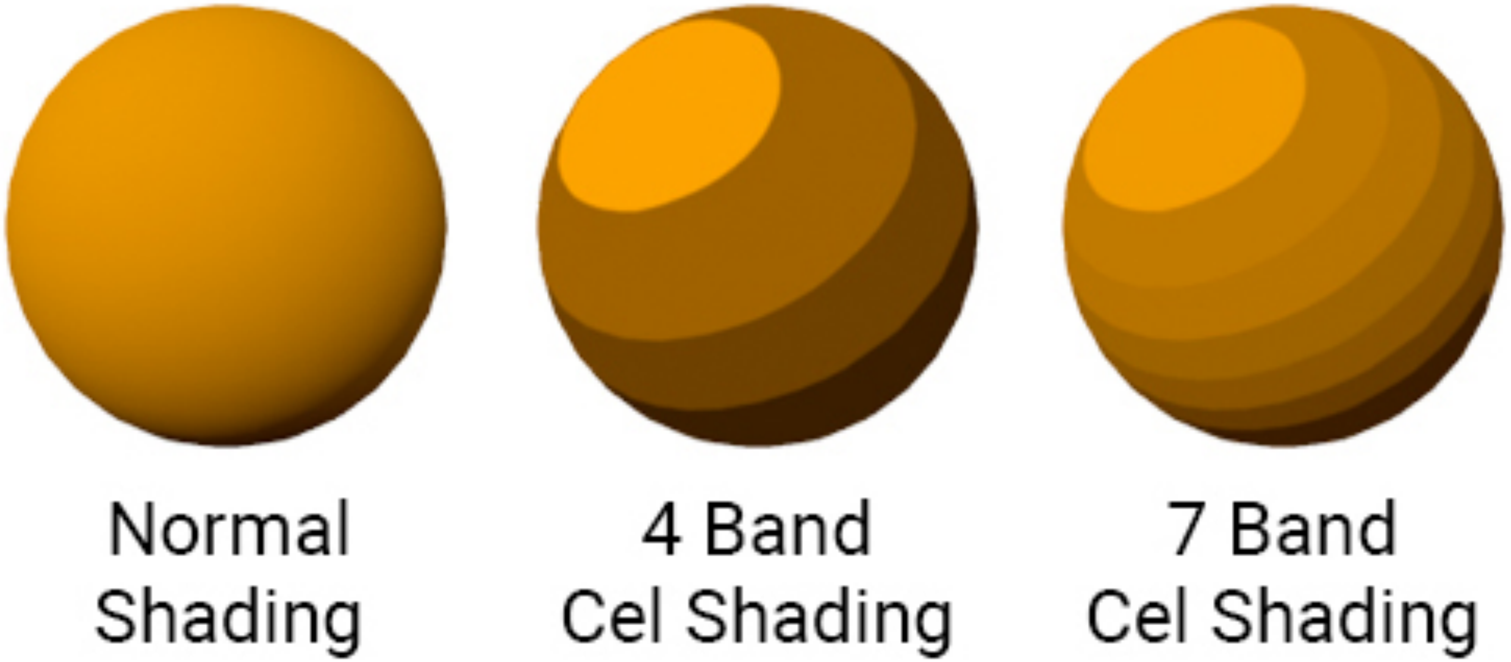
wikipedia

# Cel Shading

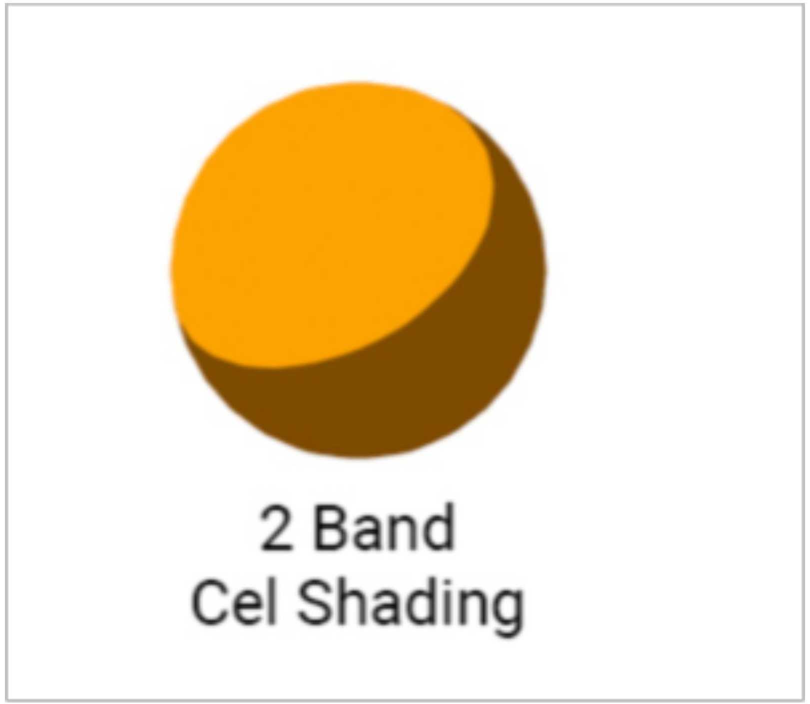
- Render using multiple bands of color, rather than a continuous gradient




https://www.raywenderlich.com/146-unreal-engine-4-cel-shading-tutorial

# Cel Shading

- Key idea: threshold the dot products in the Blinn-Phong model. Use multiple thresholds for multiple bands

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