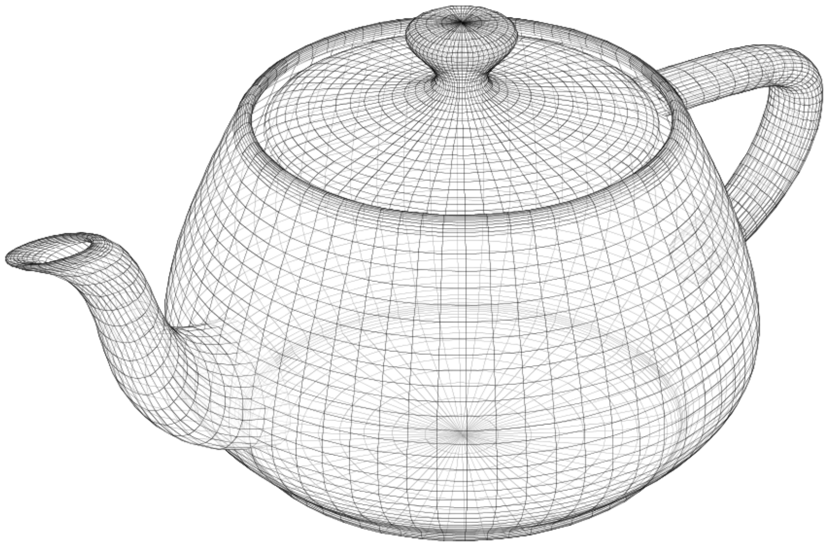
Depth of Field



Production Computer Graphics

Professor Eric Shaffer

ILLINOIS

Depth of Field

Depth of Field is a parameter of the camera

It is the range of distances over which objects appear in focus

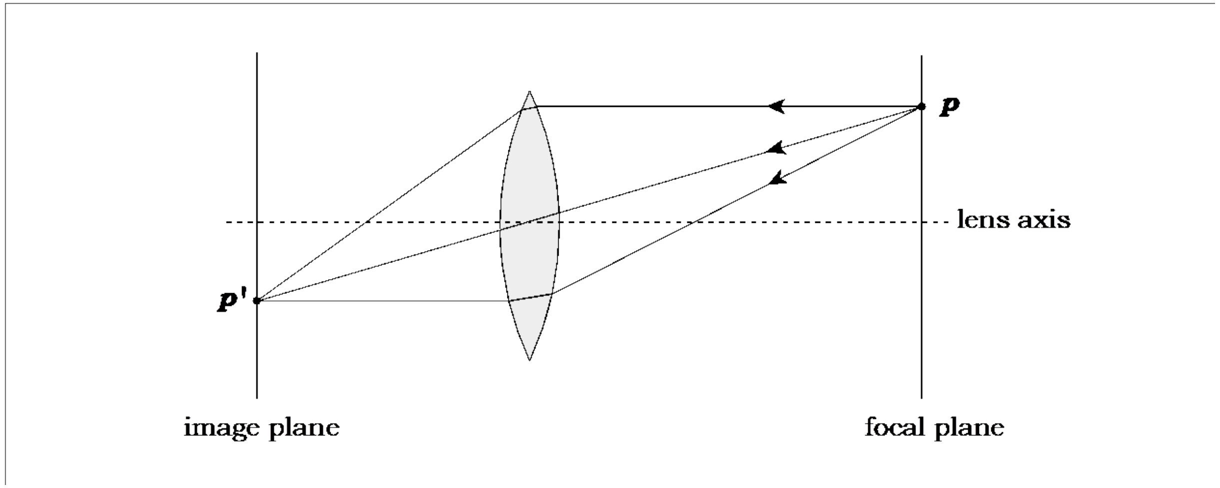
What is the depth of field of our pinhole camera model?

Real cameras have a finite-aperture lens

Focus perfectly at a single distance called the *focal distance*

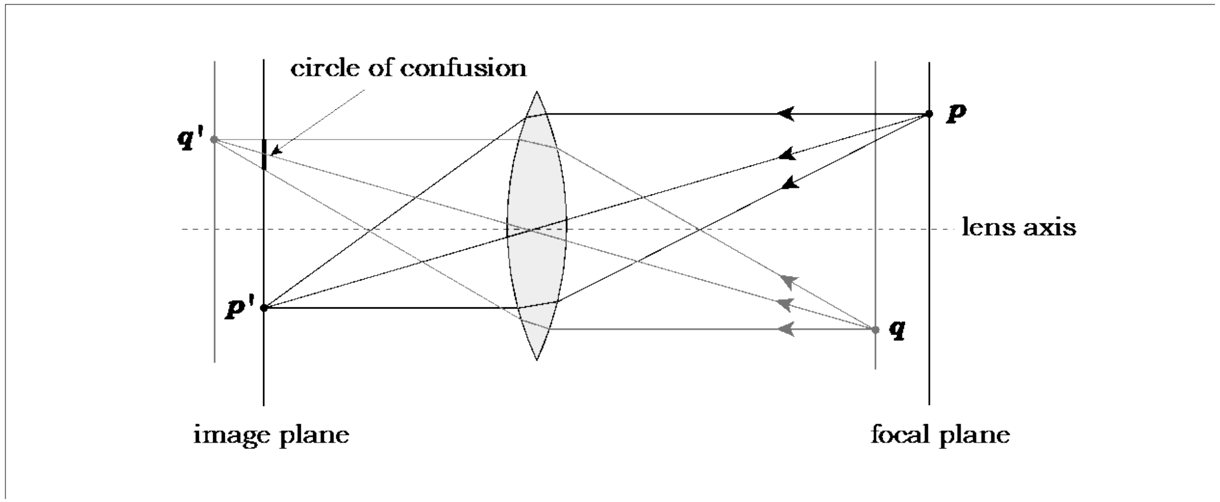
Thin Lens Theory

- Thin lens: when the thickness of the lens is negligible compared to the radius
- Focal planes and image planes exist in matched pairs



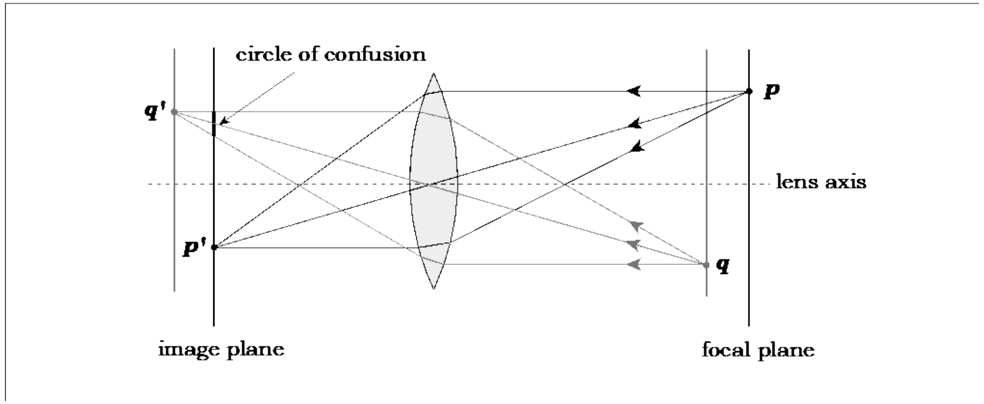
Thin Lens Theory

- Points off the focal plane generate a *circle of confusion* on the image plane
- The further point q gets from the focal plane, the more out of focus it gets (larger circle)



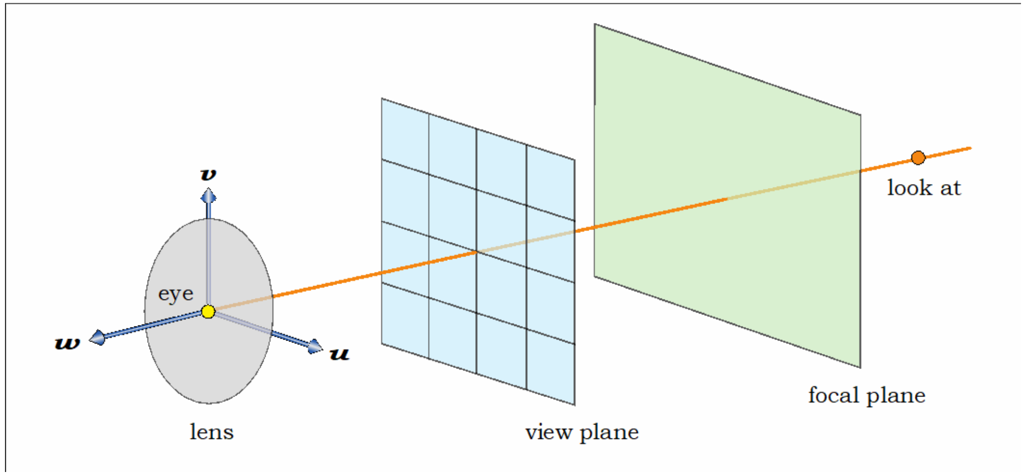
Thin Lens Theory

- This idealized camera has 0 depth of field
- Traditional film has finite grain sizes which allow a range of distances to be in focus
- Digital cameras will be in focus when the circle of confusion is smaller than a pixel



Simulating a Thin Lens

- We’ll do the traditional CG thing and approximate and hack
- We’ll use a disc centered on the eye point, parallel to the view plane
  - it has 0 thickness
- We won’t calculate exactly how the light is refracted ….



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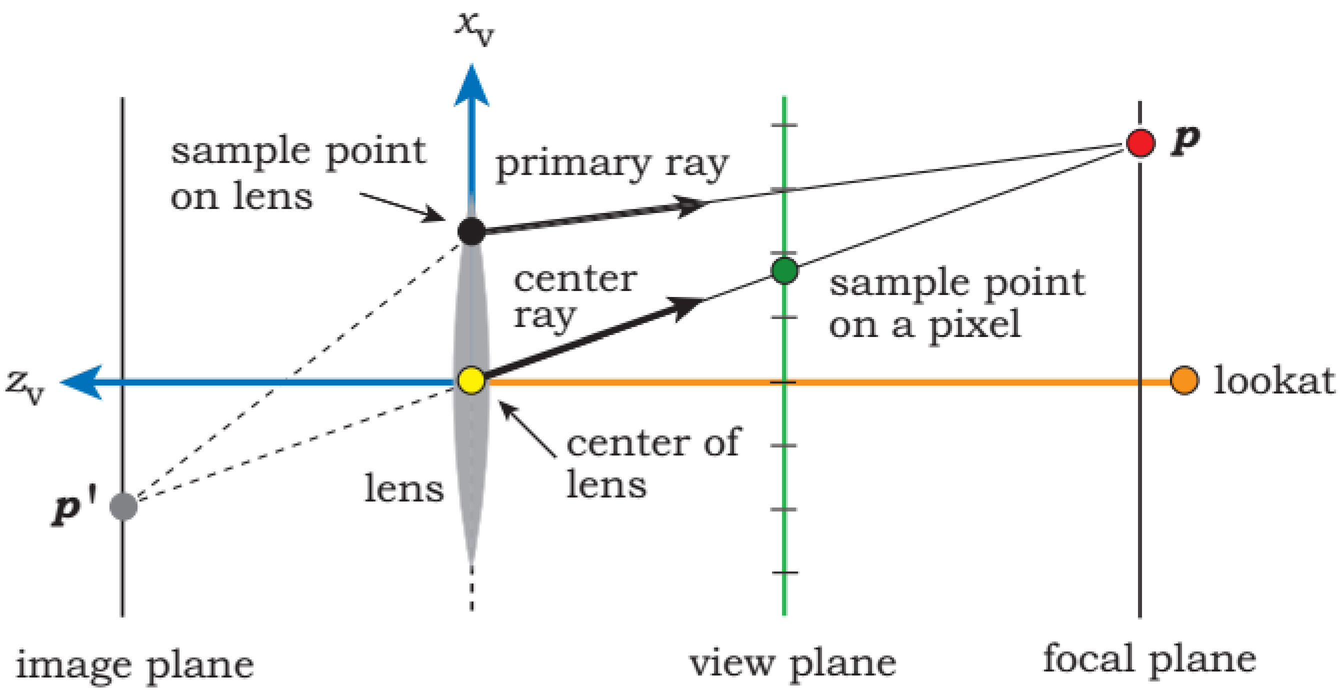
Multiple rays are shot per-pixel



Select ***focus distance:*** distance from eye to focal plane

For each pixel:

Center ray finds p

Primary rays
- Origin random on lens
- Go through P

Average samples to get final color for pixel

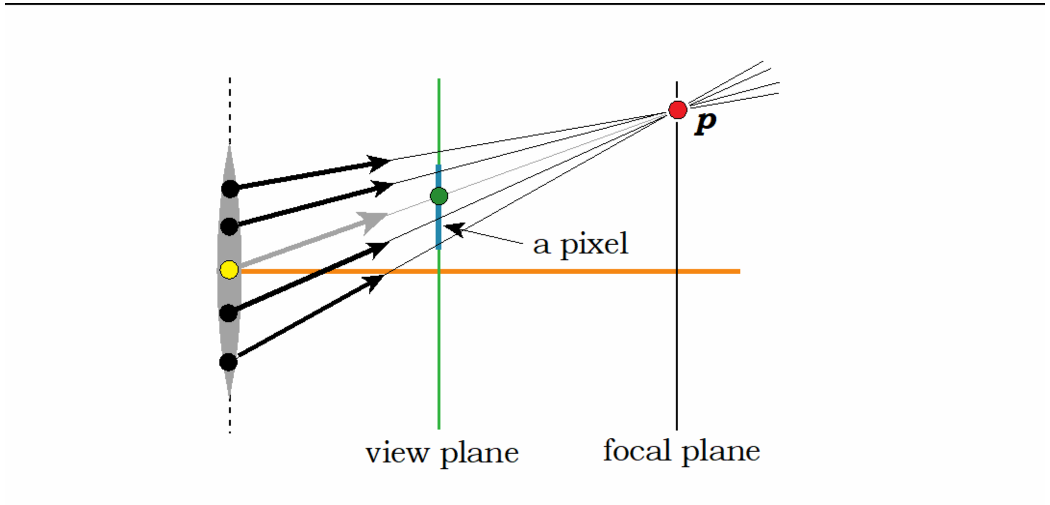
Some questions

- How do we generate the samples on the lens?

```
vec3 random_in_unit_disk() {
    while (true) {
        auto p = vec3(random_double(-1,1), random_double(-1,1), 0);
        if (p.length_squared() >= 1) continue;
        return p;
    }
}
```

- What happens as we make the lens radius bigger?

We can add anti-aliasing

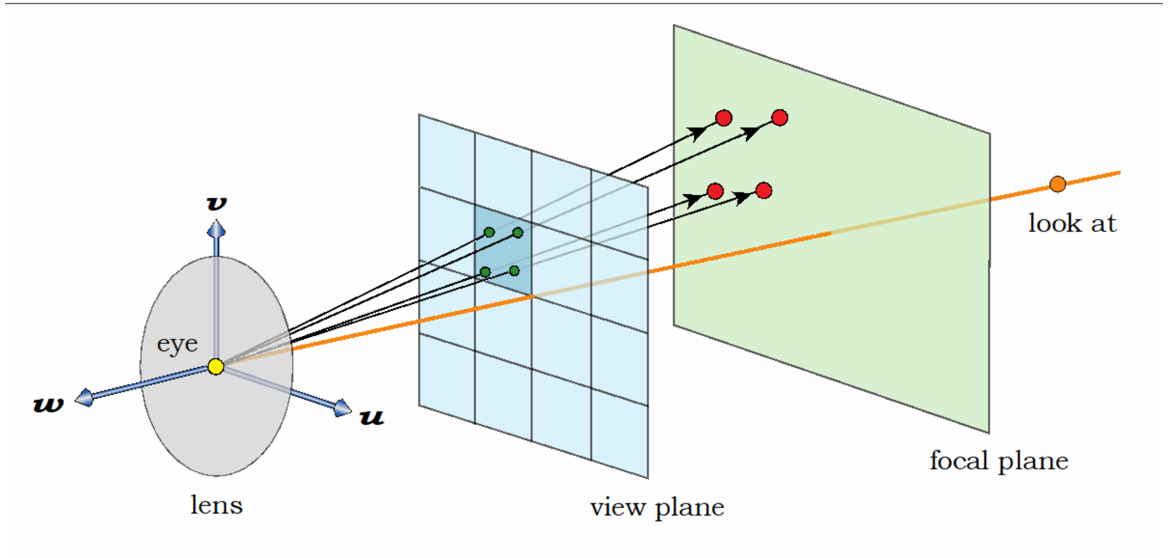


Since all primary rays for a pixel go though p,
we aren’t really anti-aliasing

For hit points away from the focal plane,
the blur from depth of field obliterates aliasing

For a scene near the focal plane,
we need anti-aliasing

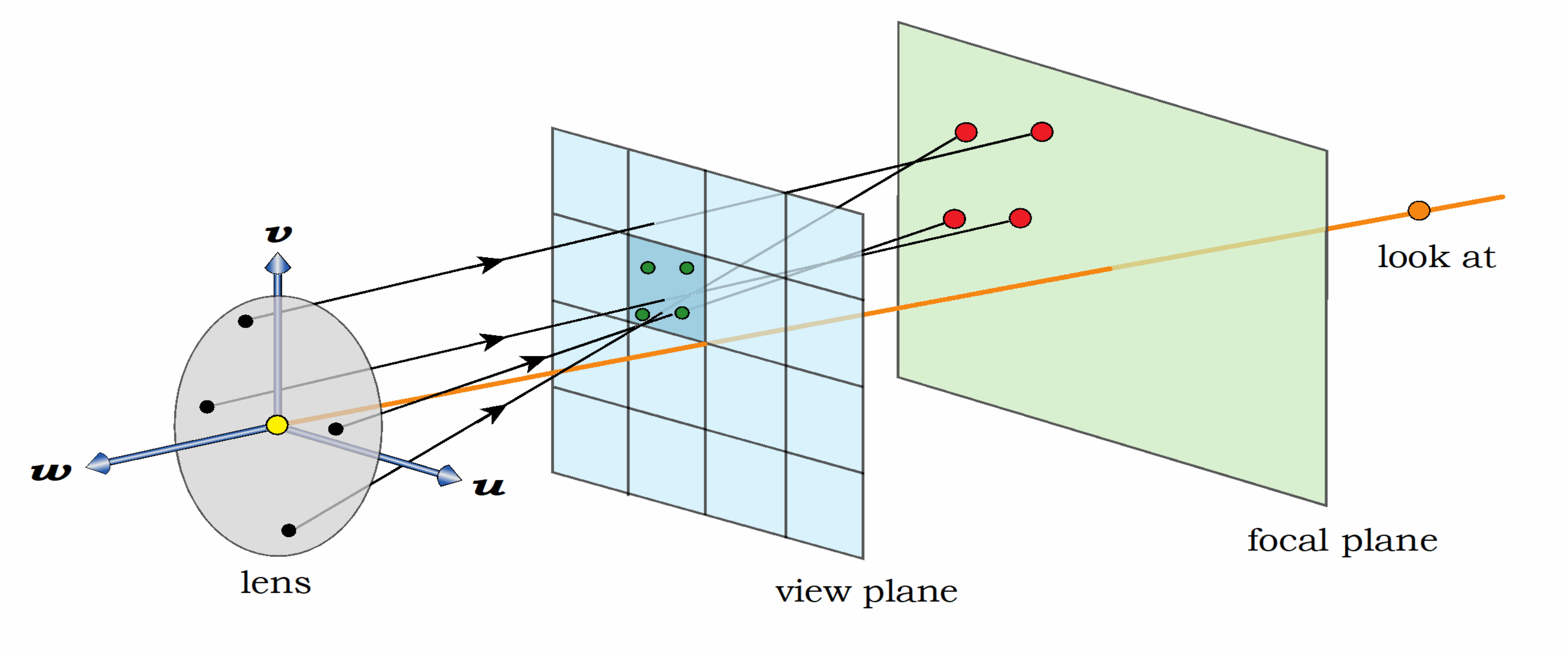
Depth of Field and Anti-aliasing



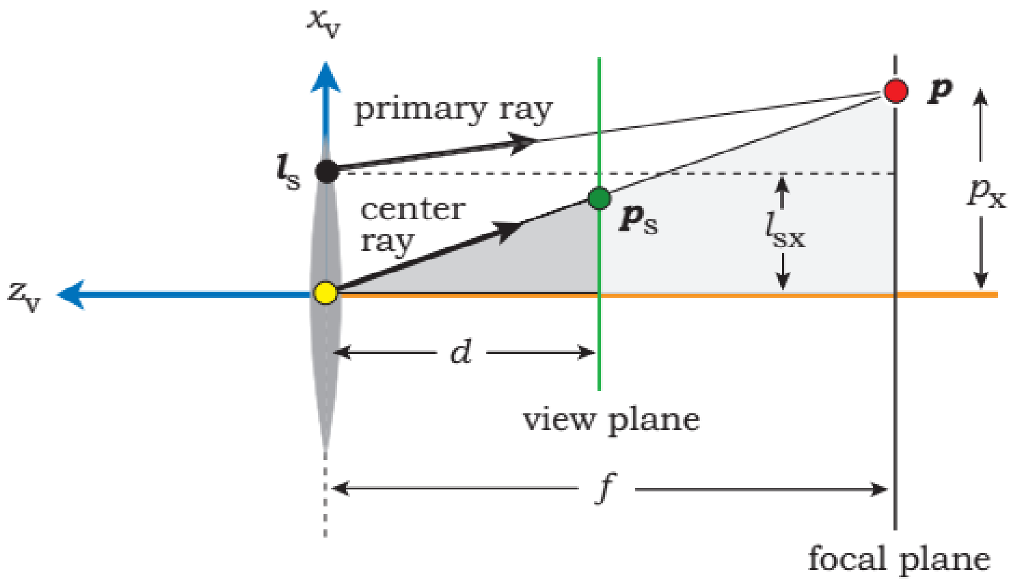
Use a different center ray for each primary…use jittering or multi-jittering

The focal plane intersections will be at slightly different locations

Anti-aliasing and Depth of Field



Fast Intersection of Center Rays



Can use similar triangles to find p

f is the focal length

d is the view plane distance

Note:

We need to convert from viewing coordinates to world

Direction will need to be normalized

$$\boldsymbol{p} = (p_x, p_y, -f),$$
$$\boldsymbol{p}_s = (p_{sx}, p_{sy}, -d),$$
$$\boldsymbol{l}_s = (l_{sx}, l_{sy}, 0),$$

$$\boxed{\begin{aligned} p_x &= p_{sx}\,(f/d) \\ p_y &= p_{sy}(f/d). \end{aligned}}$$

$$\begin{aligned} \boldsymbol{d}_r &= \boldsymbol{p} - \boldsymbol{l}_s \\ &= (p_x - l_{sx})\boldsymbol{u} + (p_y - l_{sy})\boldsymbol{v} - f\boldsymbol{w}. \end{aligned}$$

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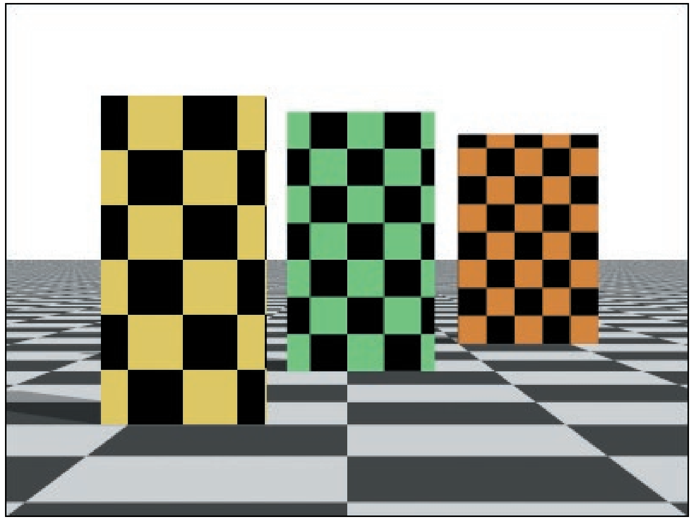
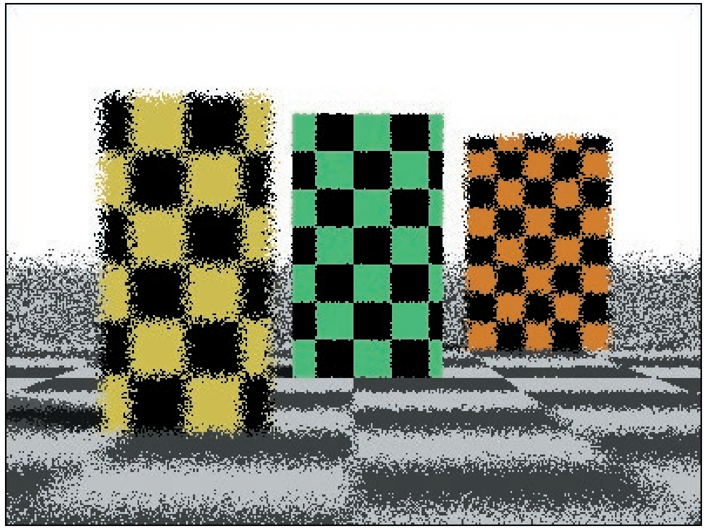
Results

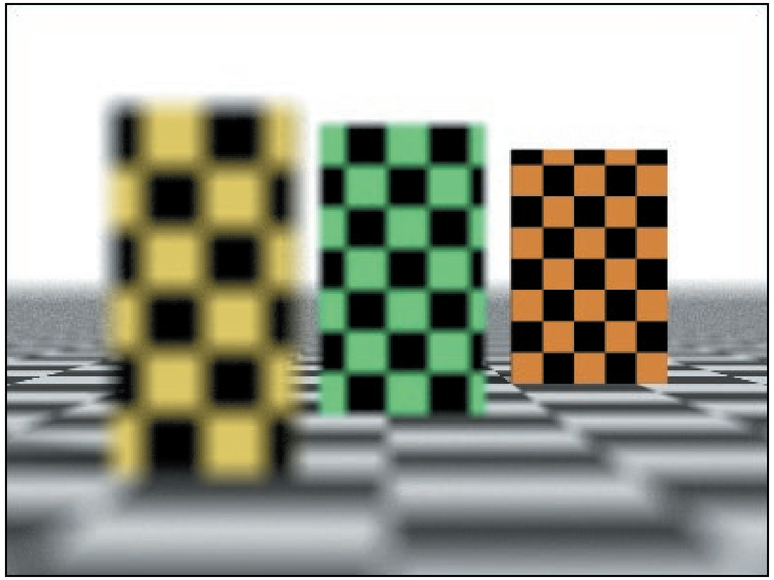


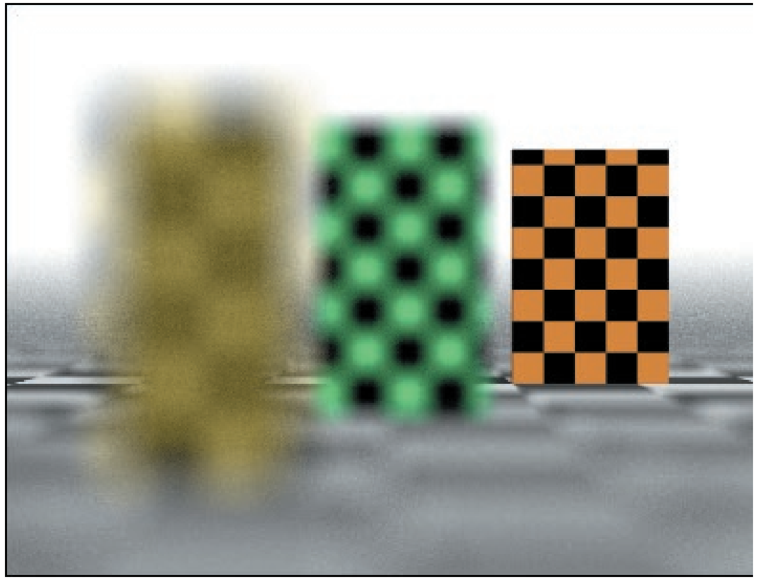
zero radius lens



lens radius 1
1 sample per pixel

Results





Increasing lens radius requires more samples per pixel for quality image