

**IG3D**  
**Travaux sur Machine Encadrés**

**Compte Rendu**

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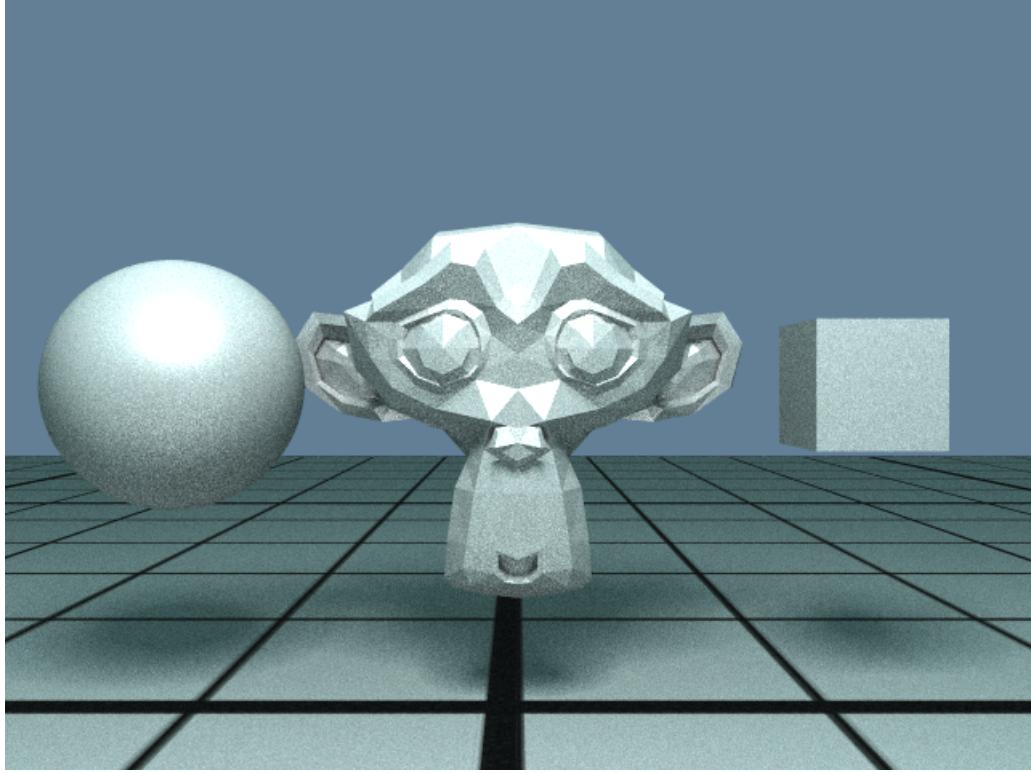


FIGURE 1 – An example of objects rendered with pathtracing.

## 0.1 Path Tracing

This project was focused on developing a path tracer. This technique can render photorealistic images by approximating the bidirectional reflectance distribution function or BRDF. This function is defined recursively so it is natural to implement it as a recursive function as long as recursion depth is not excessive.

$$L(p, \omega_{out}) = L_e(p, \omega_{out}) \int_{\omega_{in} \in H(p, n)} L(p, \omega_{in}) * brdf(p, \omega_{in}, \omega_{out})(n \cdot \omega_{in}) d\omega_{in}$$

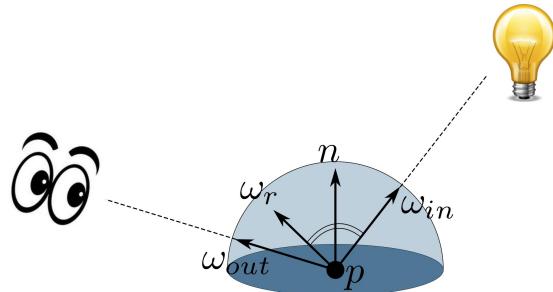


FIGURE 2 – a schematic representation of BRDF in a point  $p$ , there are several BRDFs depending on the material.

## 0.2 Materials

### 0.2.1 Diffuse Material

The diffuse contribution is calculated as  $(n \cdot \omega_{in})$  which models shading. This material approximates an ambient contribution of the BRDF by using Monte Carlo sampling. A refinement to this effect is to use the solid

angle  $\Omega$  as a coefficient to simulate color dimming or solarization with distance from the light source. When the light source is spherical, it's easy to calculate the solid angle on an hemisphere.  $r$  being the ray of the light source,  $D$  the distance from  $p$  to the light source.

$$\Omega = 4\pi \left(\frac{r}{D}\right)^2$$

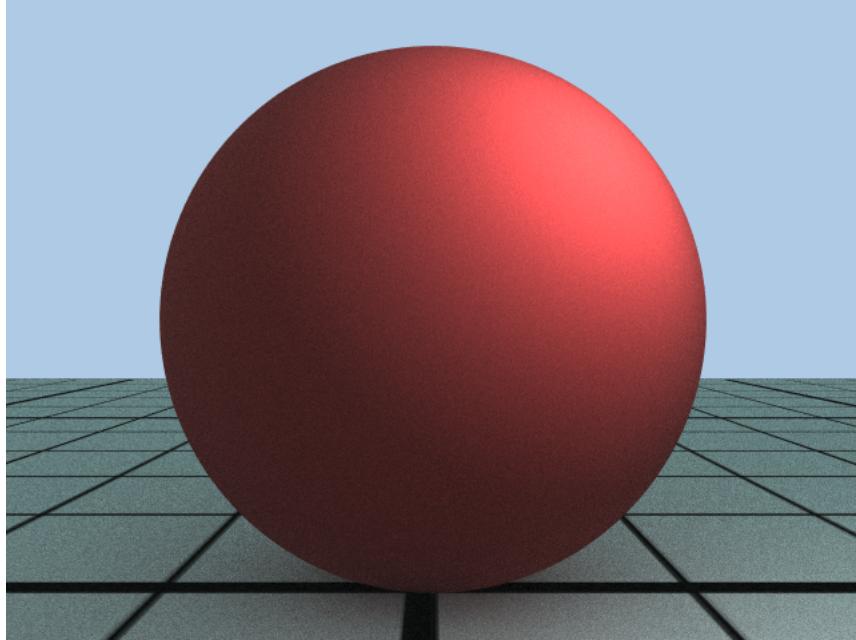


FIGURE 3 – Sphere with diffuse material.

### 0.2.2 Diffuse Specular Material

This method adds a specular term to the BRDF diffuse. By making use of  $(\omega_{out} \cdot \omega_{in})$  it models the effect of reflected light towards the viewer. This effect can result in polarization of the material in certain points of the surface.

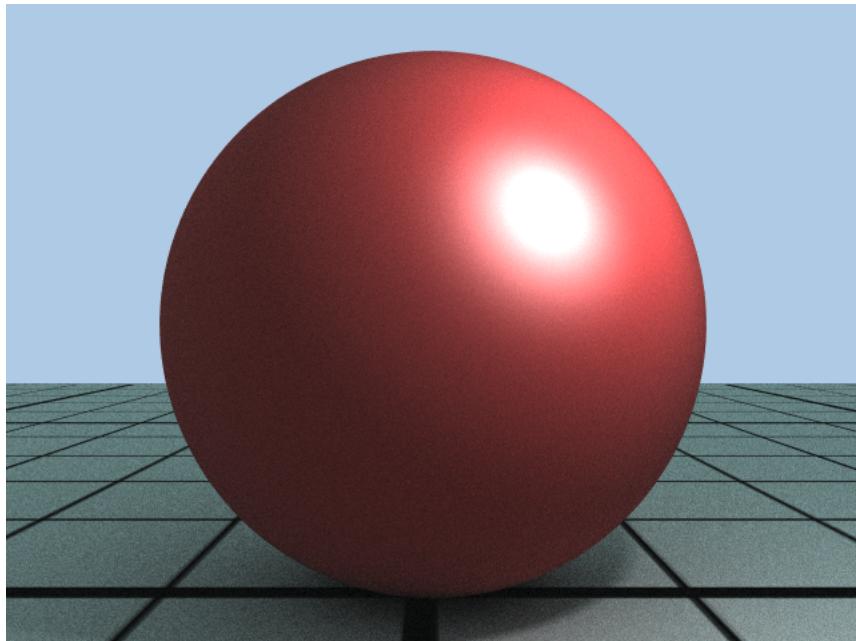


FIGURE 4 – Sphere with specular material.

### 0.2.3 Reflective Material

This material simulate a perfect mirror, only perfect reflection are calculated. In addition a tint can be used to simulate mirrors of various colors.

The reflected ray is calculated as a mirrored image of  $\omega_{out}$  with respect to the normal  $n$ .

$$\omega_{refl} = \omega_{out} - 2n(\omega_{out}n)$$



FIGURE 5 – Sphere with perfect mirror material, to enhance the effect it reflects a background image wrapped around a scenario sphere and depth of field.

### 0.2.4 Transpaernt Material

The BRDF of this material is completely different from the previous. To render different thickness of the transparent object we calculate the refracted ray by means of the *Snell-Descartes* law.

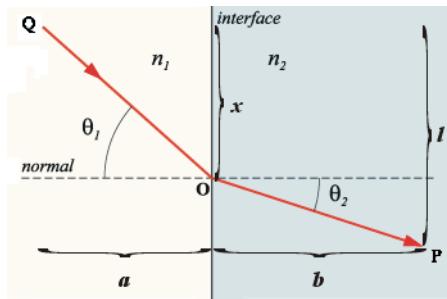


FIGURE 6 – Diagram representing refraction of a ray passing from a medium to another by *Snell-Descartes* law.

The index of refraction or *IOR* express this difference as  $IOR = \frac{\sin\theta_1}{\sin\theta_2}$  with  $\theta_1$  being the incident angle of the light source and the normal to the surface and  $\theta_2$  the resulting angle of refraction, *IOR* is usually denoted as  $\eta_1$  and  $\eta_2$  respectively. In optics, the refractive index or index of refraction  $n$  of a material is a dimensionless number that describes how light propagates through that medium. A transparent objects emits 2 component, a refracted and a reflected ray originating from the same point. The resulting BRDF is than :

$$BRDF_{refl}(\omega_{out}) = \alpha BRDF(\omega_{refr}(ior)) + (1 - \alpha)BRDF(\omega_{refr})$$

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1.  $\alpha$  is usually calculated by applying Fersnell equation or Schlick's approximation (not implemented).

The refracted ray is computed geometrically as follows :

$$\omega_{refr} = \frac{\eta_1}{\eta_2} * (-\omega_{out}) + (\frac{\eta_1}{\eta_2} \cos\theta_1 - \sqrt{1 - \sin\theta_1})n$$

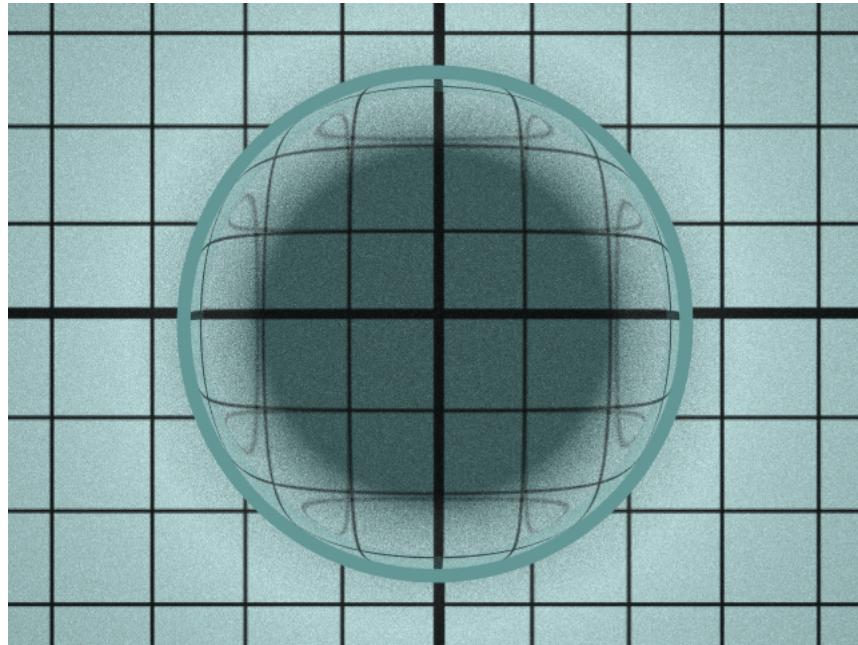


FIGURE 7 – IOR bigger than 1. Ring caused by total internal refraction.

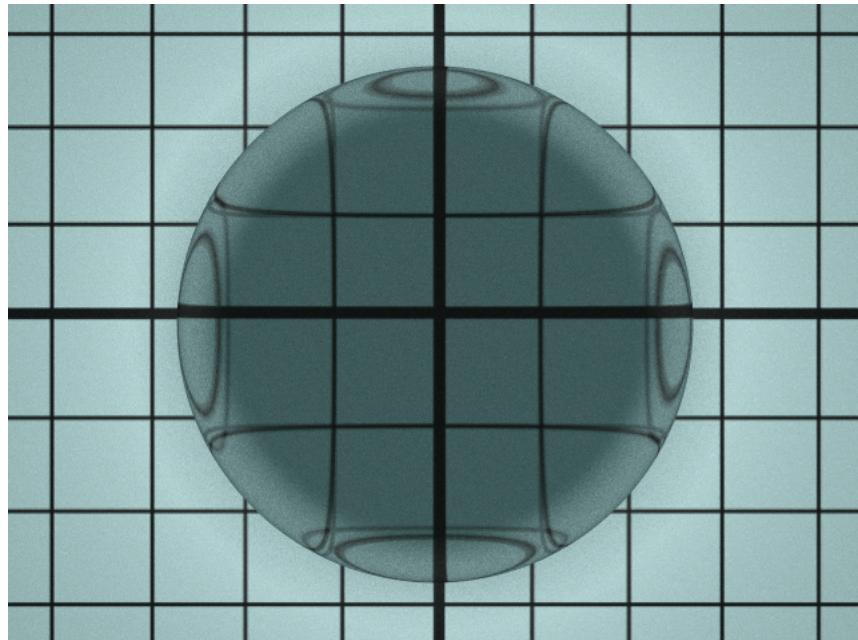


FIGURE 8 – IOR smaller than 1.

### 0.2.5 Ambient Occlusion

Ambient occlusion effect comes as a side effect of the path tracing implementation, even if no light is present in the scene objects close together shade each other, the montecarlo sampling gives this effect of smooth ambiental light.

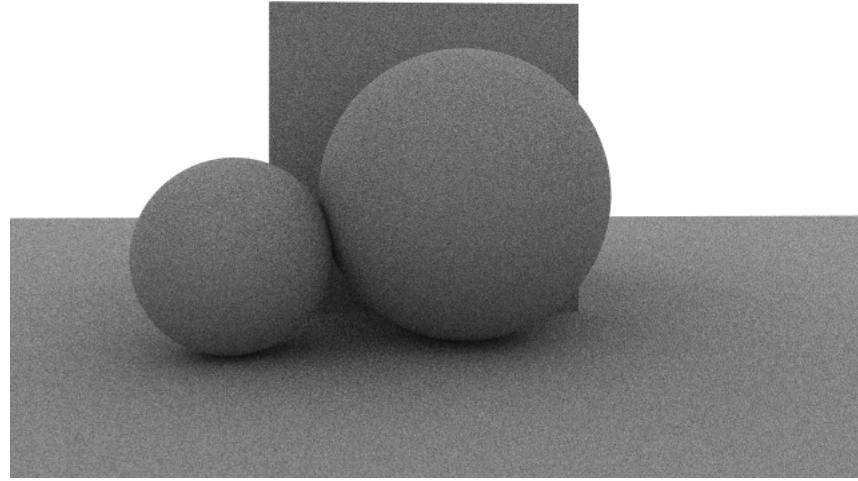


FIGURE 9 – Objects shading each other.

## 0.3 Effects

### 0.3.1 Texture Projection

Dependinf on the geometry it's possible to project a rectangular image on a manifold surface.

To be projected onto a smooth surface an image has to be sampled : however, mapping from  $\mathbb{F} \times \mathbb{F} \times \mathbb{F} \rightarrow \mathbb{N} \times \mathbb{N}$  may lead to aliasing. To avoid or limit aliasing Antialiasing filters or *AA* techniques are applied, like bilinear filtering (Fig 12).

### 0.3.2 Anti Aliasing

Montecarlo sampling introduces noise due to the randomess of the method, a way around this is to sample multiple times the same pixel wich will randomly calculate portions of the *BRDF*. A positive side effect to sampling with an high number of sample per pixel or *SPP* is indirect coloring or color bleeding (Fig 13) (Fig 14) .

Another positive side effect is that the projection of a smooth curve on a grid results in a stepwise function, by using more samples per pixel, the curve will result smoother thanks to the montecarlo approximation of the integral of the curve (and therefore object color).

The downside of this method is that computational time scales linearly with the number of *SPP*.

### 0.3.3 Depth of Field

Depth of field can be achieved by simulating a thin lens camera model.

With this effect it's possible to render in focus out ouf focus object depending on the distance to the focal plane. A fixed focal plane can have different dof depending on the *aperture* values measured in  $f/$  (Fig 15), known as the focal ratio between the f or focal lenght and the *aperture* diameter.

A smaller  $f/$  will introduce stronger blur when objects are not aligned with the focal plane (Fig 17) while a smaller aperture and an higher  $f/$  will have less blurring effect (Fig 16).

In real settings depth of field is allways present when taking photos, whilst it takes extra effort to be modeled in rendering.



FIGURE 10 – Original Texture.

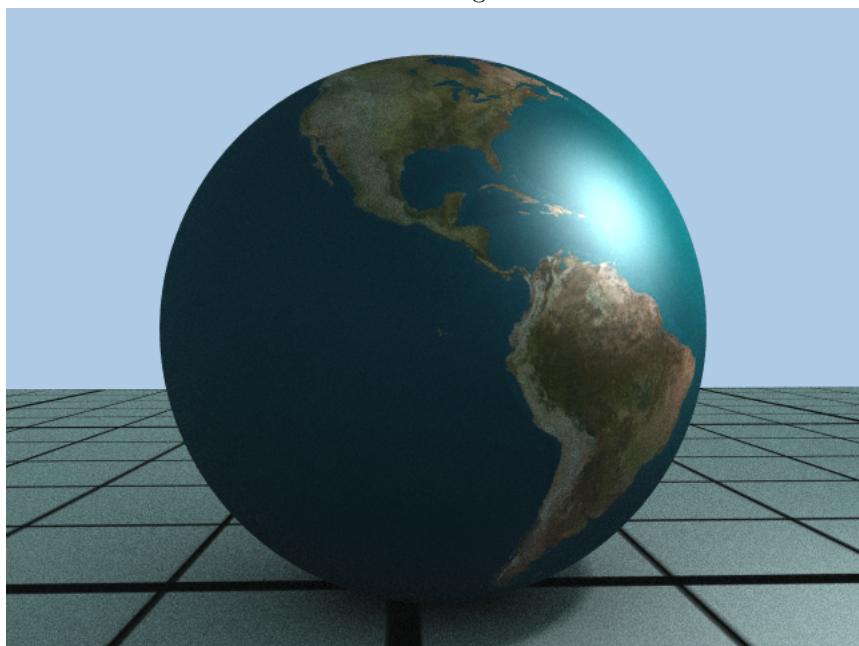


FIGURE 11 – Projection on a sphere of the original Texture.

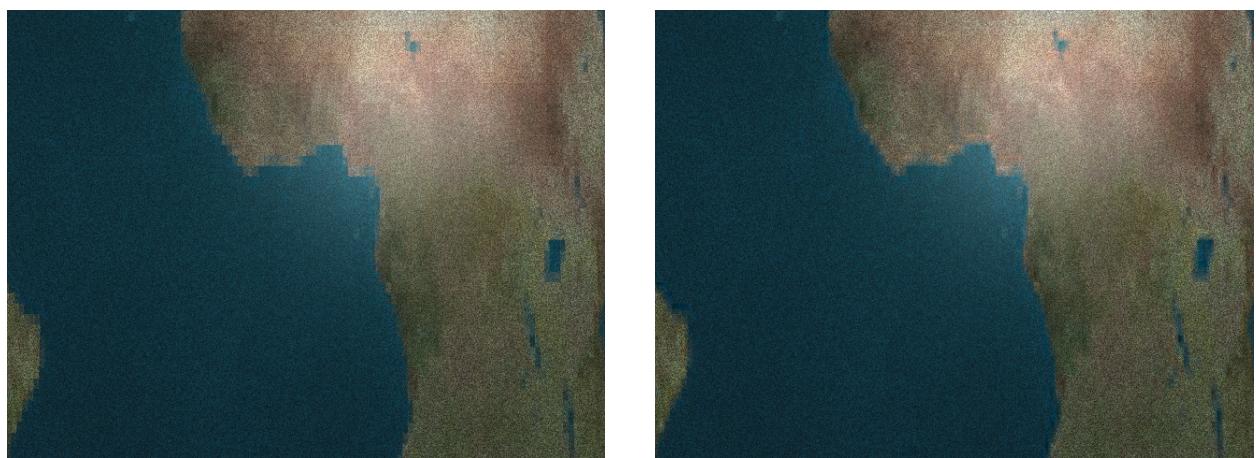


FIGURE 12 – Difference between  $AA$  bilinear filter off and on.

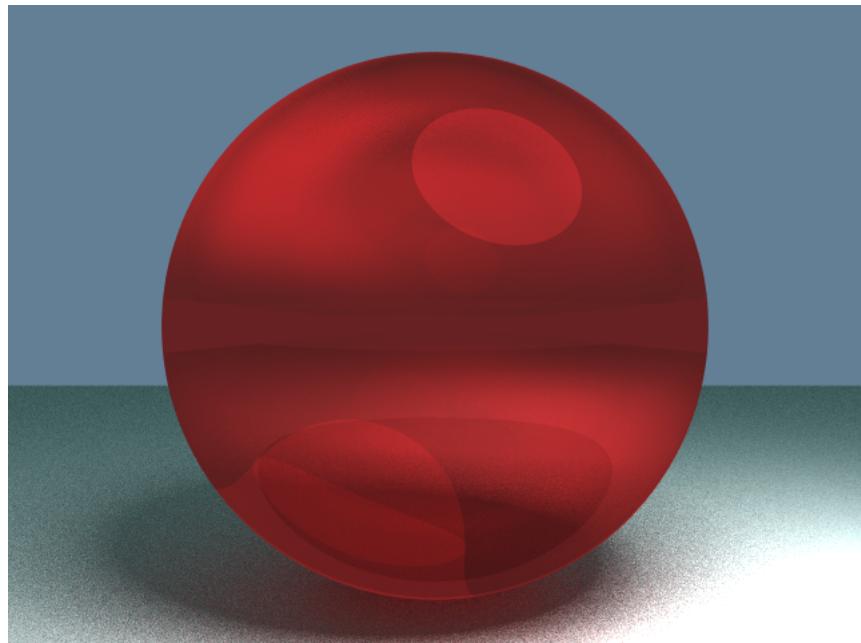


FIGURE 13 – 64 *SPP*.

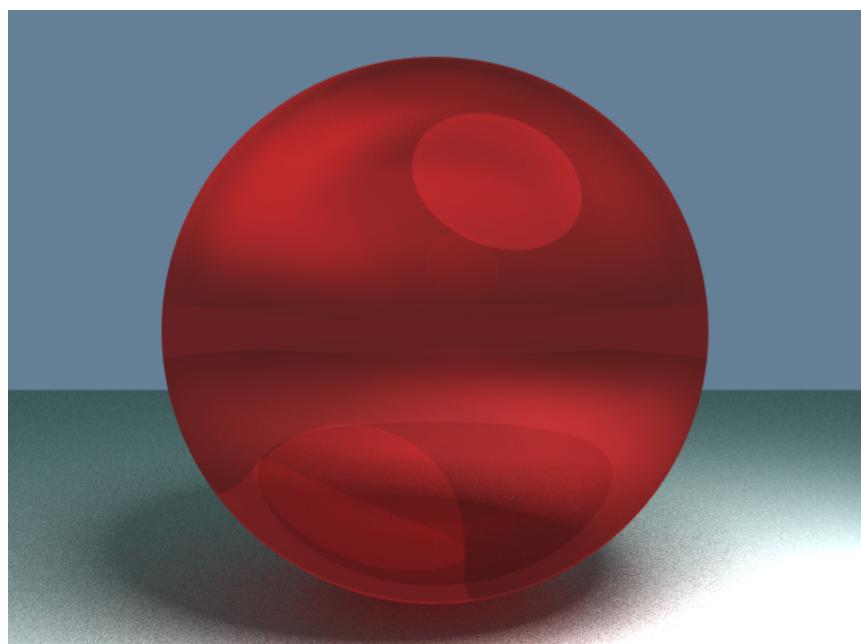


FIGURE 14 – 128 *SPP*.

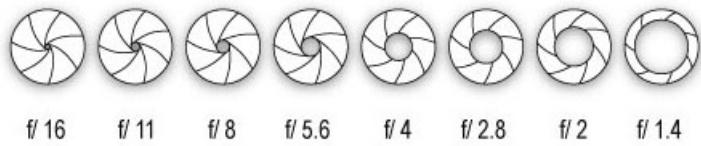


FIGURE 15 – aperture scale representation.

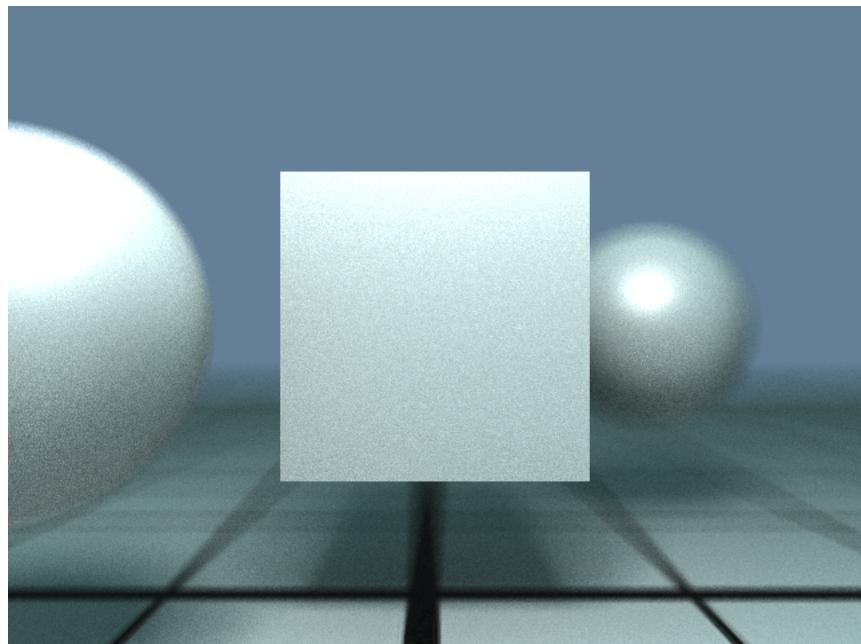


FIGURE 16 – a high  $f/$  or stop.

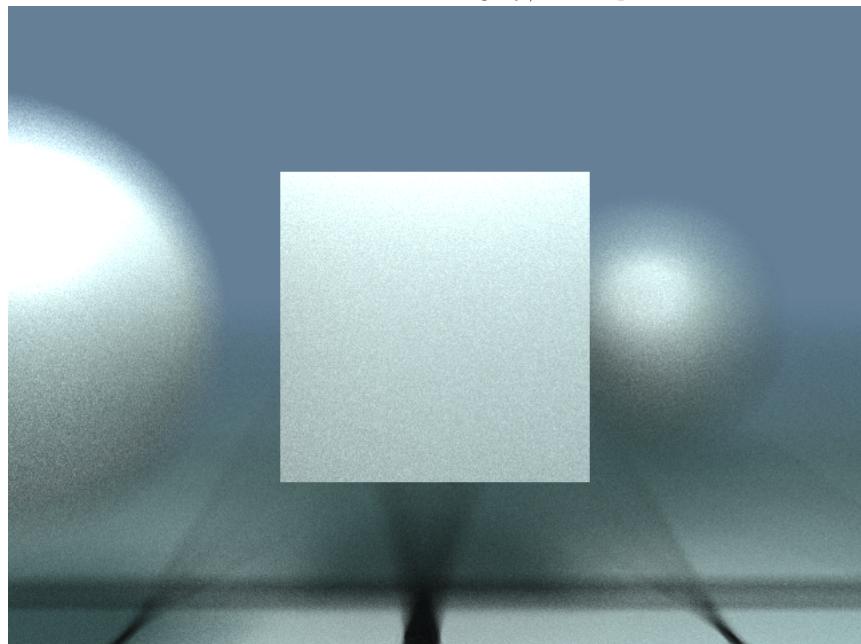


FIGURE 17 – a low  $f/$  or stop.