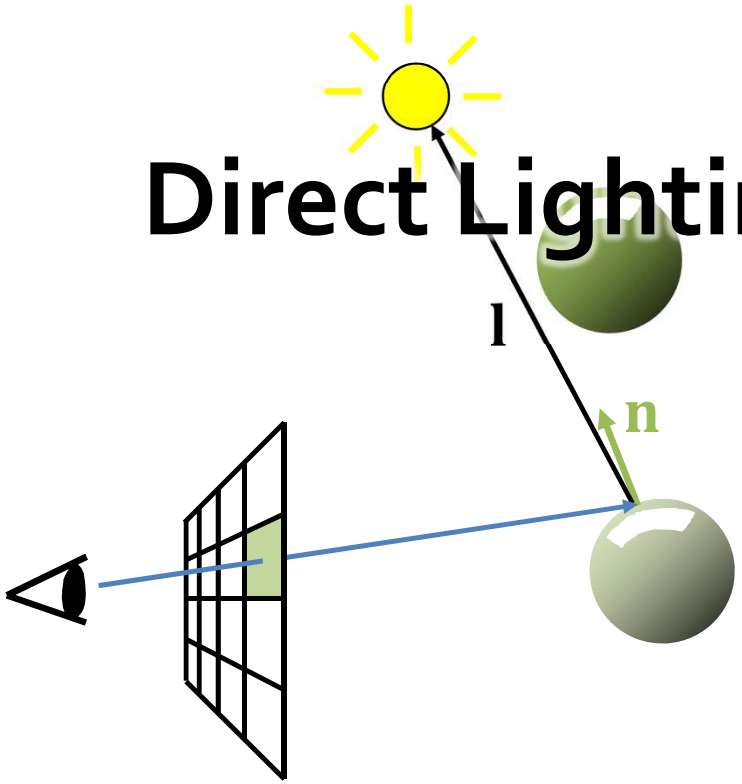
Direct Lighting



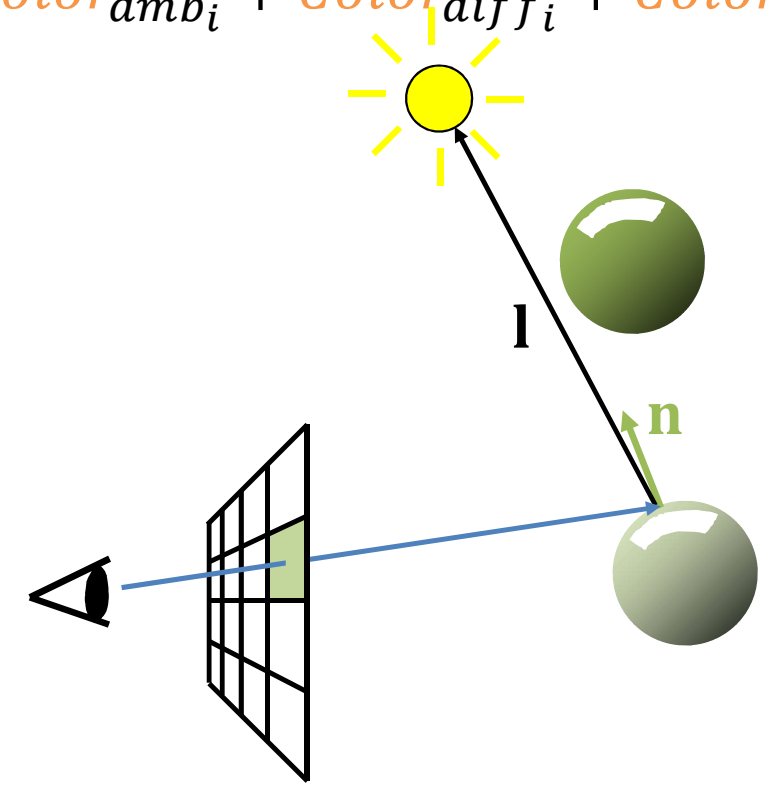
Ray-Tracer Code

```
renderImage() {
  foreach pixel x,y in image {
    ray = createCameraRay(x,y))
    image[x][y] = trace(ray)
}}

color trace(ray) {
  objectHit = findNearestObjectHit(ray)
  if(objectHit == background) return bckGrndColor
  color = directLighting(ray, objectHit)
  color += trace(reflect(ray, objectHit))
  color += trace(refract(ray, objectHit))
  return color
}
```

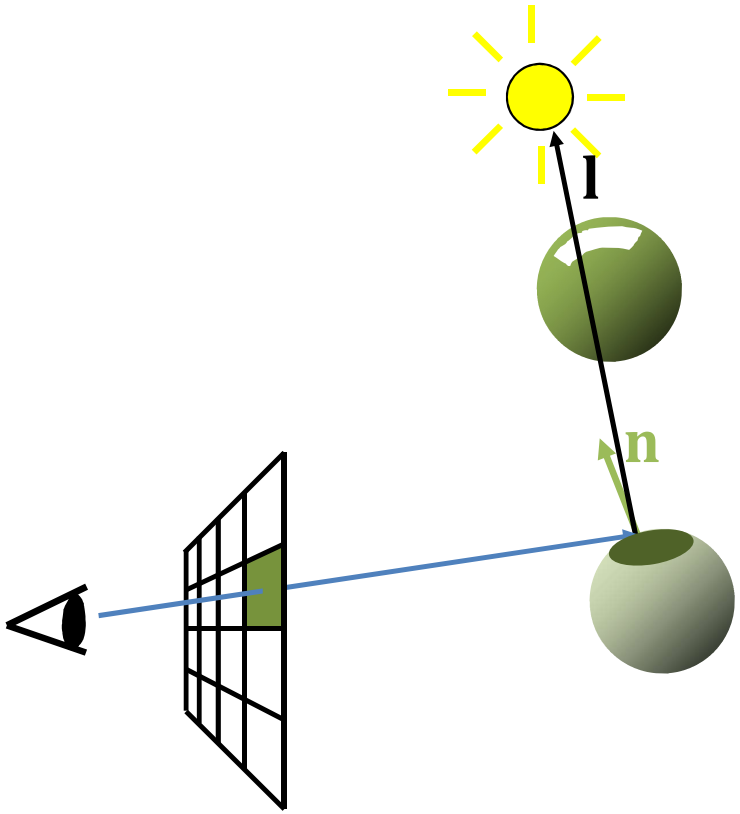
Direct Lighting – Local lighting

- $Color_{direct} = \sum Color_{Light_i}$
- $Color_{Light_i} = Color_{amb_i} + Color_{diff_i} + Color_{spec_i}$



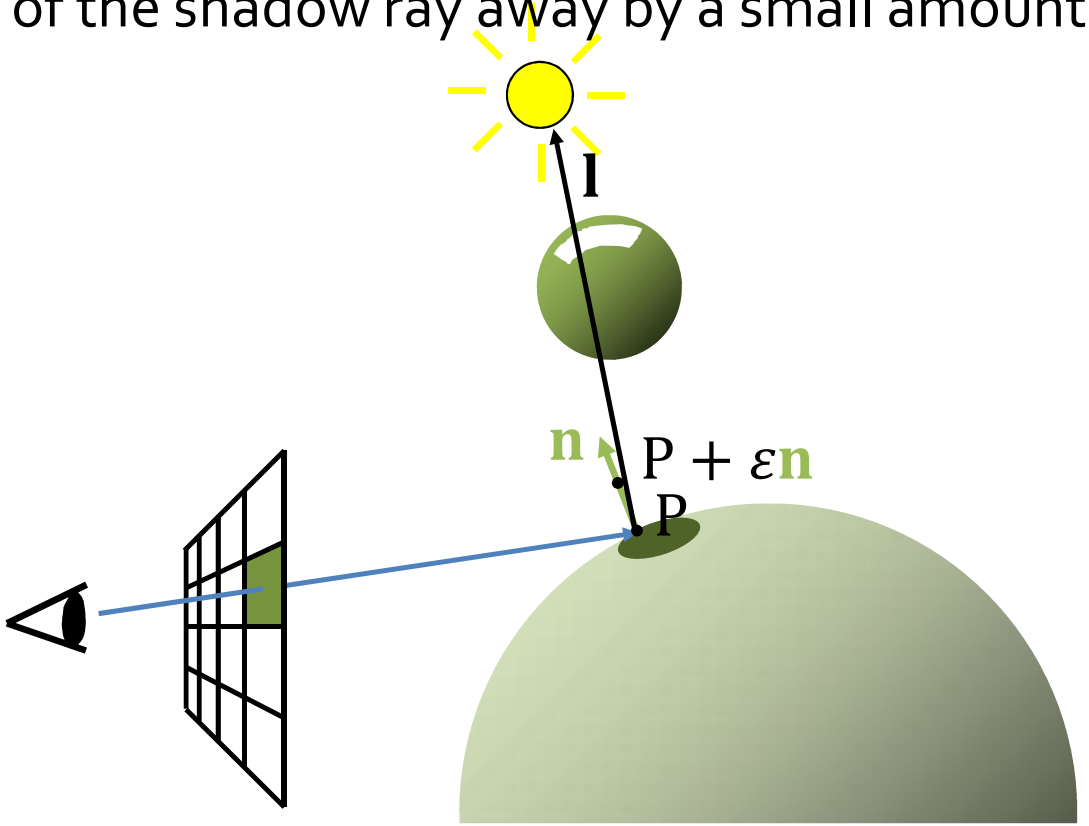
Direct Lighting – Adding Shadows

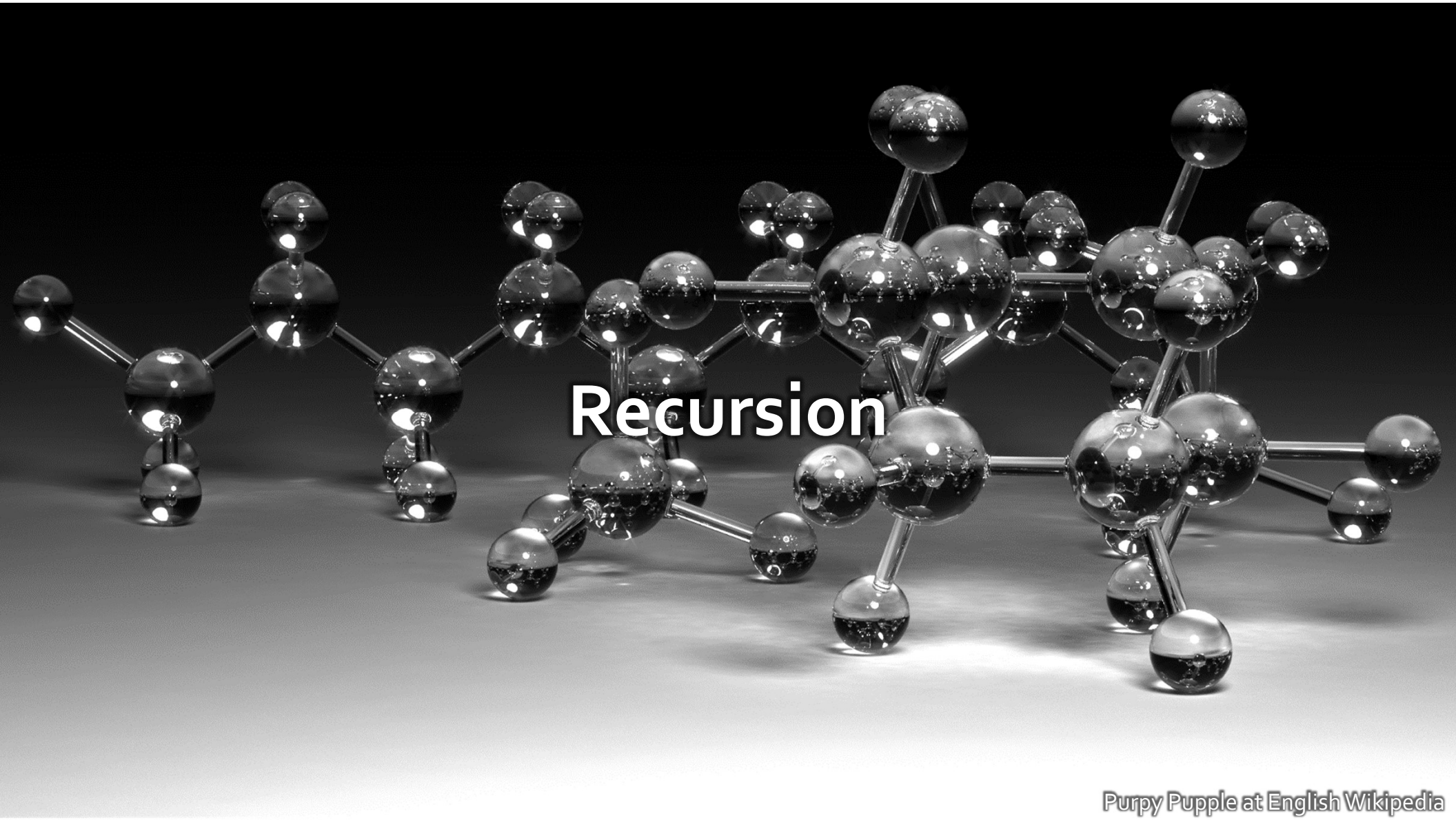
- Add local lighting from a light source only if point is seen by this light



Direct Lighting – "Self-Shadowing"

- Intersection of shadow ray with object itself
- Move start point of the shadow ray away by a small amount




Recursion
Purpy Pupple at English Wikipedia

Ray-Tracer Code

```
renderImage() {
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  color += trace(reflect(ray, objectHit))
  color += trace(refract(ray, objectHit))
  return color
}
```
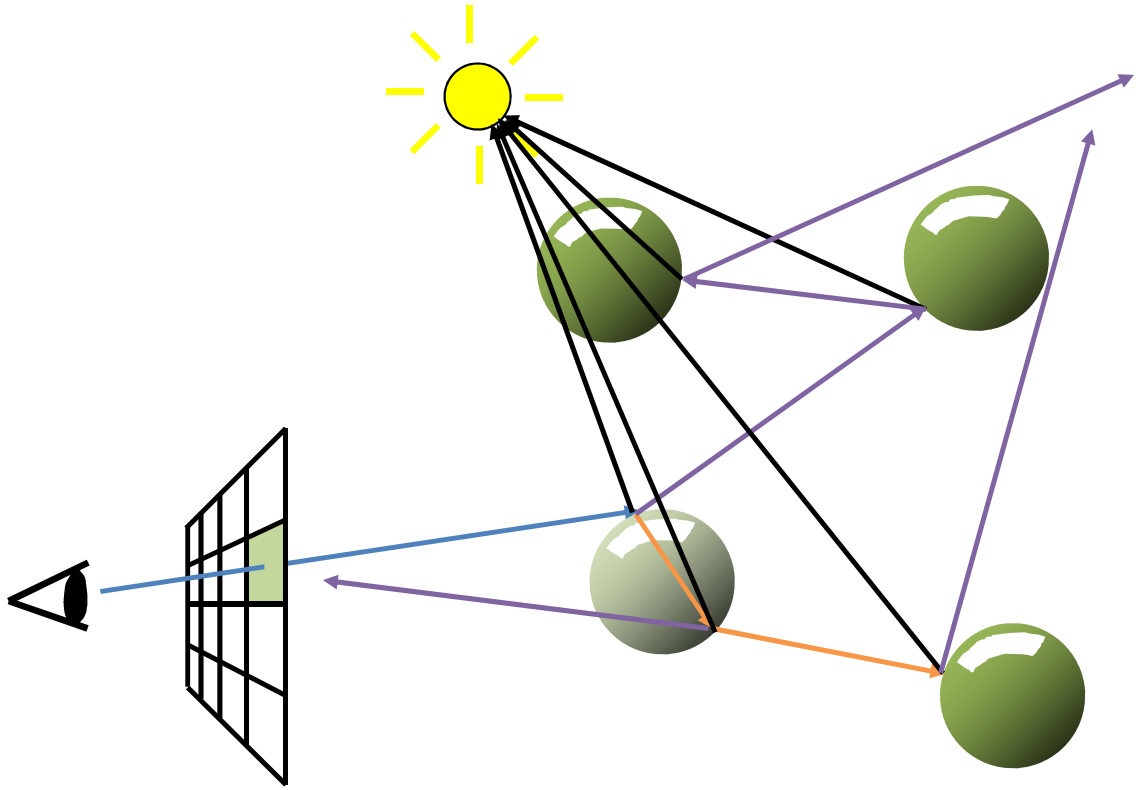
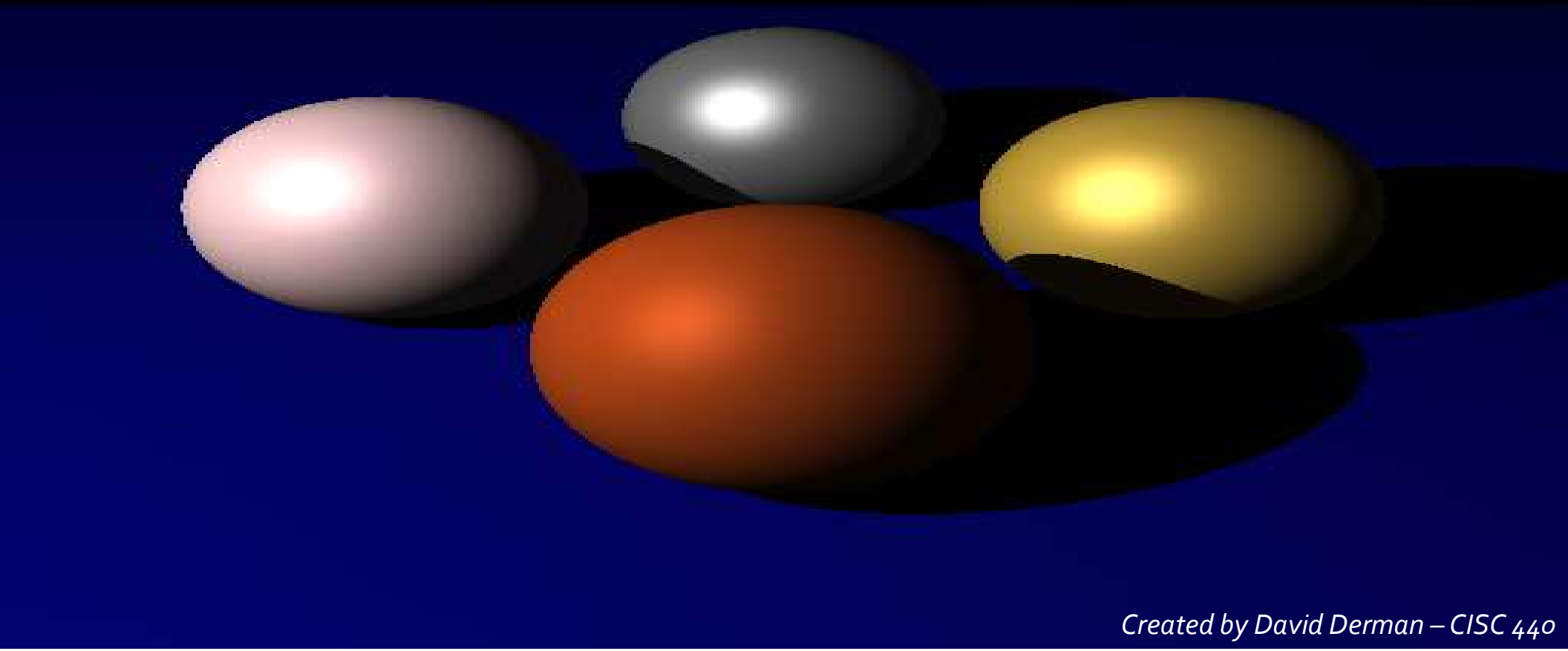

Ray-Tracer Recursion

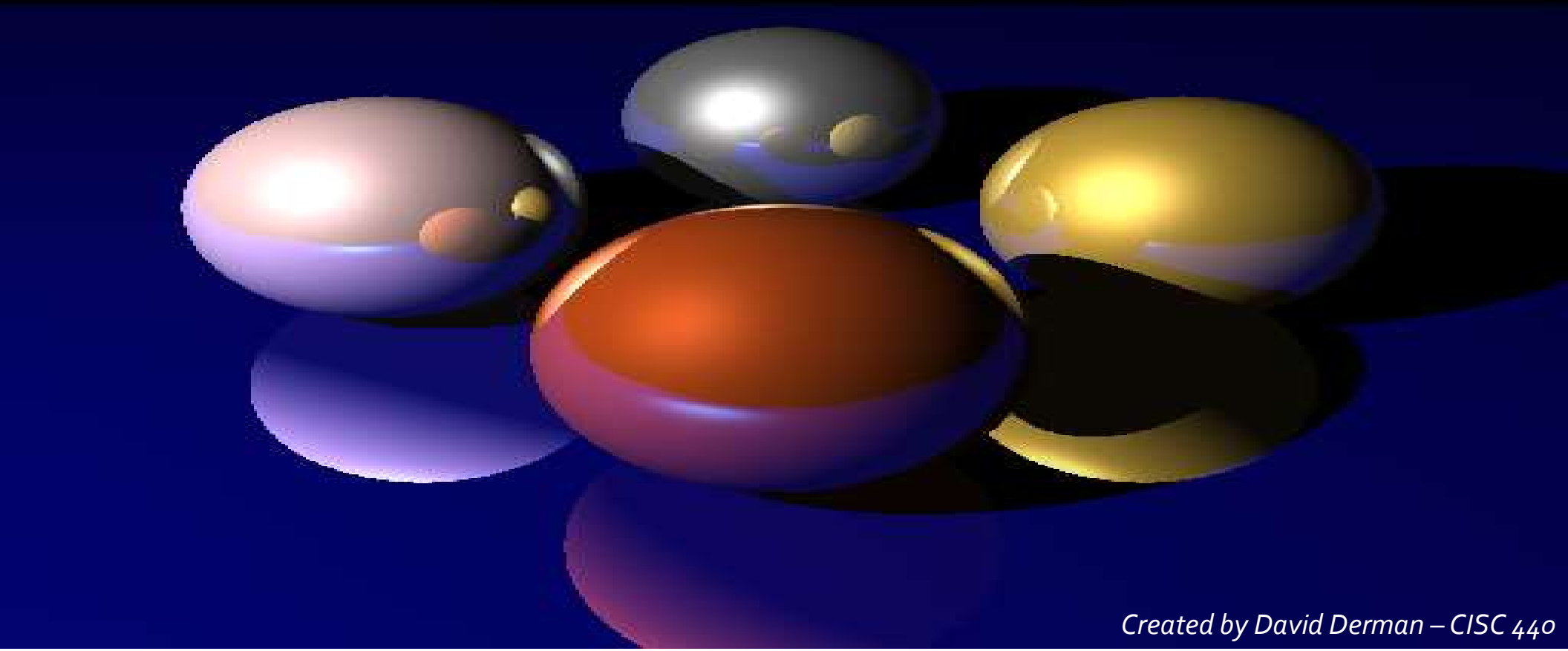
- Primary rays
- Shadow rays
- Reflected rays
- Refracted rays



No Reflection



Reflection (1)



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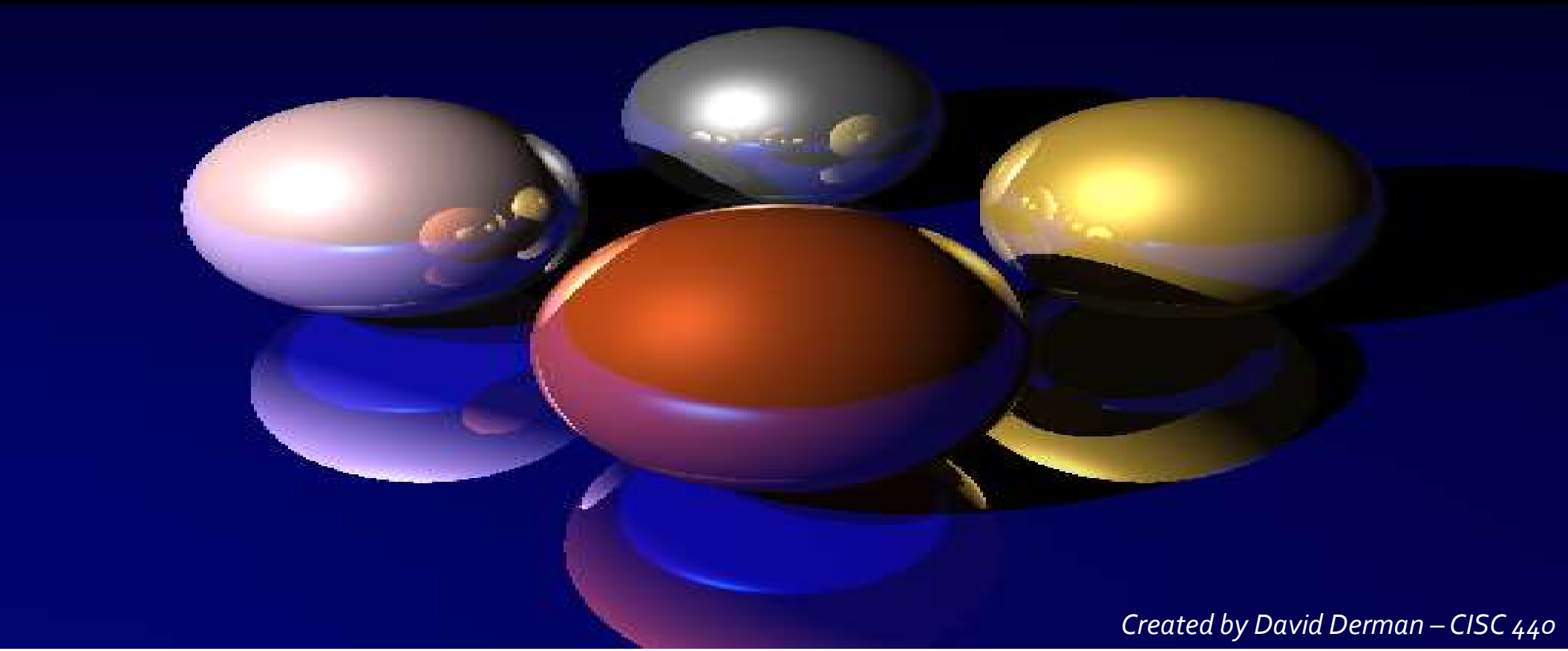
Reflection (2)



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Reflection (3)

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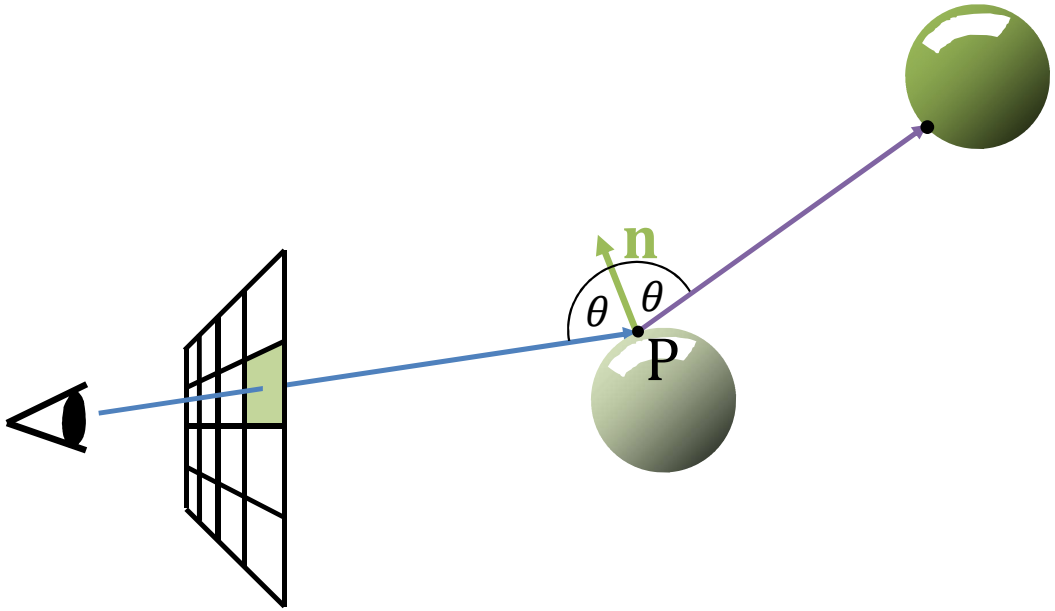
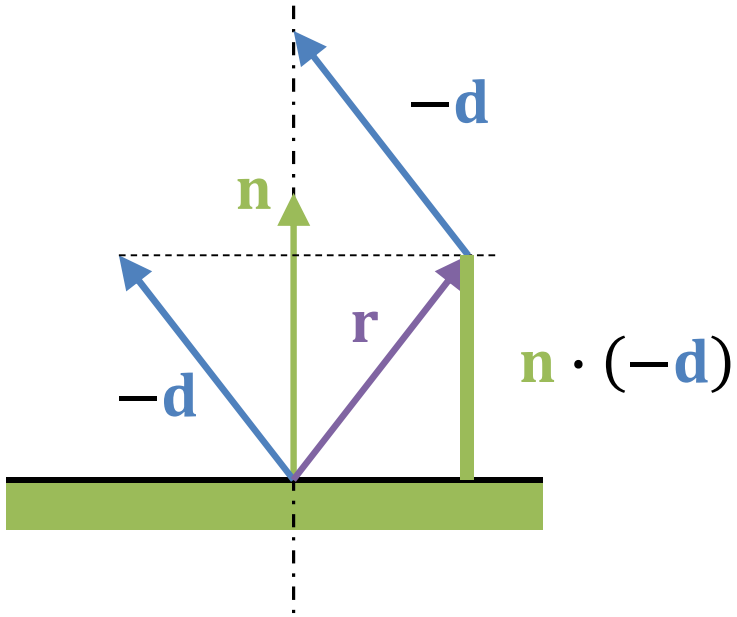
Reflection

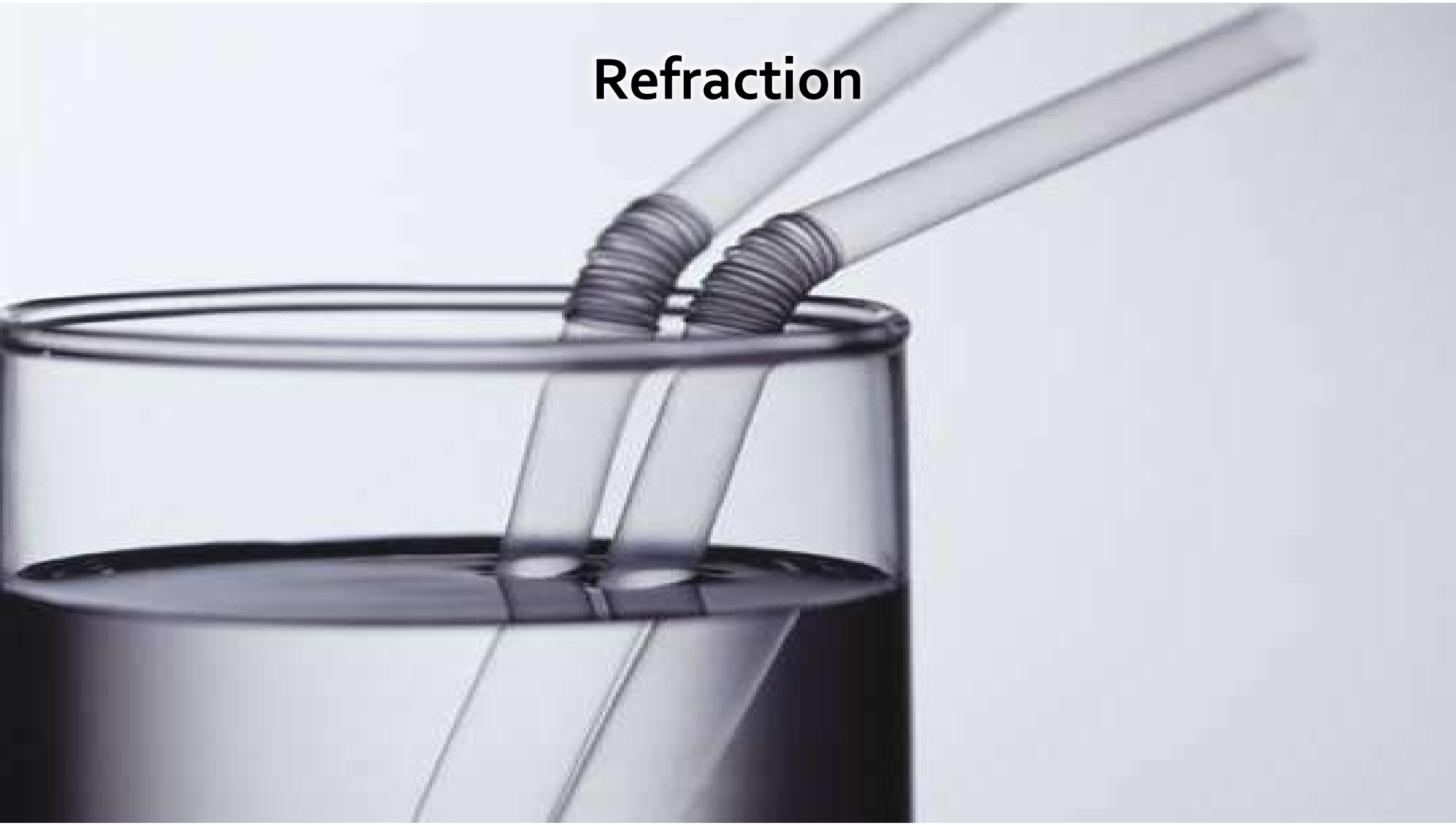
- Incoming $ray(\mathrm{O}, \mathbf{d})$
- Outgoing $ray\big(\mathrm{P} + \varepsilon\mathbf{n}\,, \mathrm{reflect}(\mathbf{d}, \mathbf{n})\big)$
- $\mathrm{reflect}(\mathbf{d}, \mathbf{n}) = \mathbf{d} - 2(\mathbf{n} \cdot \mathbf{d})\mathbf{n}$

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



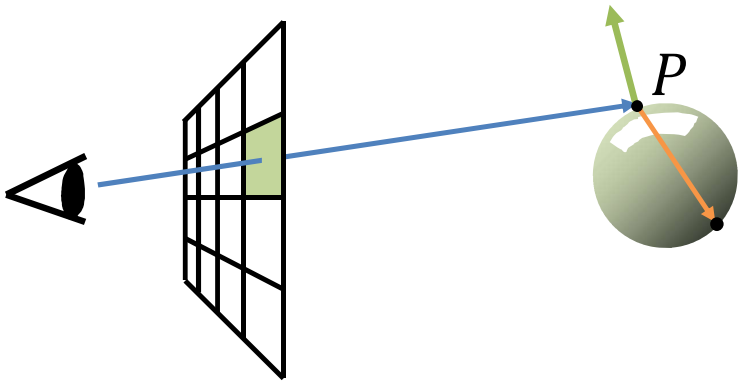


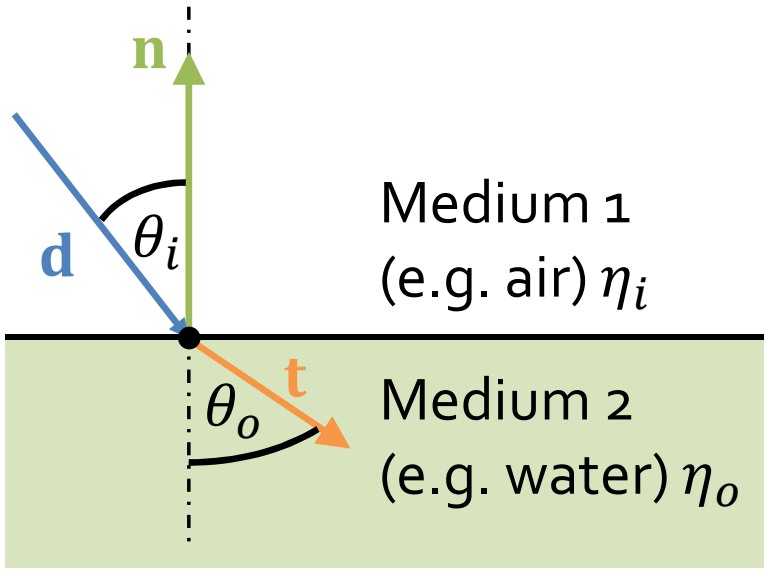
Refraction



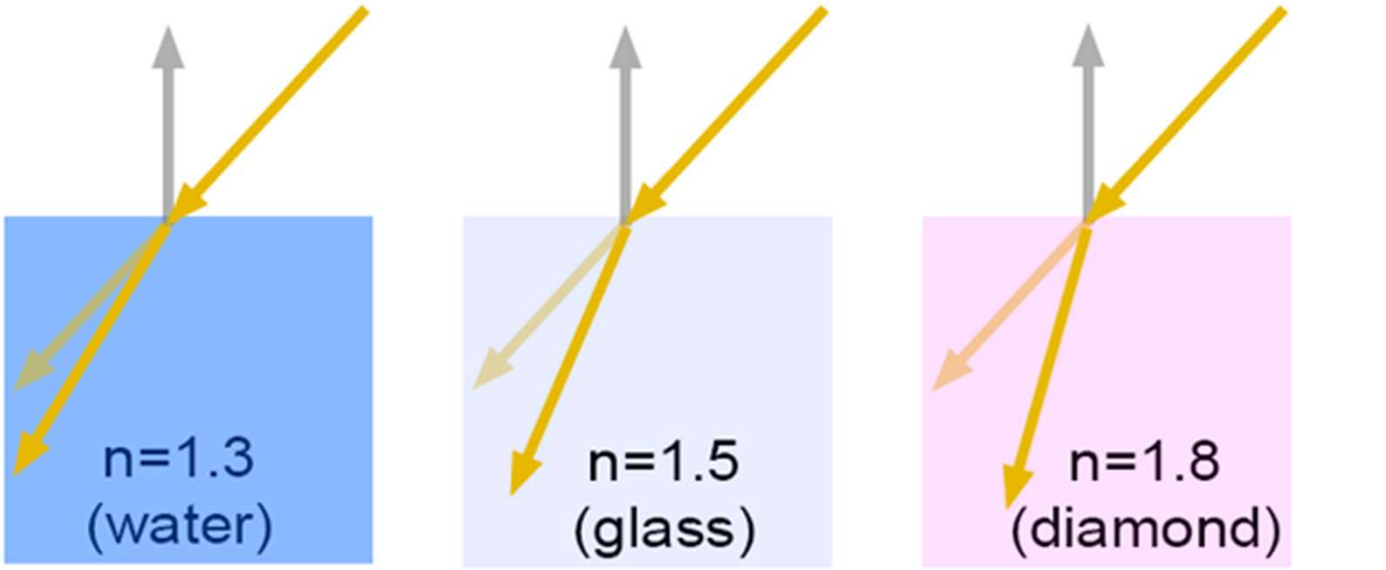
Refraction

- Need *index of refraction* η of medium (air, glass, …)
- Snell's Law $\frac{\sin\theta_o}{\sin\theta_i} = \frac{\eta_i}{\eta_o}$
- Outgoing $ray\left(\mathrm{P} - \varepsilon\mathbf{n}\,, \mathrm{refract}\left(\mathbf{d}, \mathbf{n}, \frac{\eta_i}{\eta_o}\right)\right)$
- $\mathrm{refract}\left(\mathbf{d}, \mathbf{n}, \frac{\eta_i}{\eta_o}\right)$ is lengthy to calculate





Refraction – Common Media



Total Internal Reflection

- $\theta_i >$ critical angel
- Refraction turns into reflection
  - Usually $0 = \text{refract}(\mathbf{d}, \mathbf{n})$
- Light ray from medium to another medium with a lower index of refraction
  - E.x.: water-air, diamond-water or glass-water

Ray-Tracer Code

```
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}}

color trace(ray) {
  objectHit = findNearestObjectHit(ray)
  if(objectHit == background) return bckGrndColor
  color = directLighting(ray, objectHit)
  color += trace(reflect(ray, objectHit))
  color += trace(refract(ray, objectHit))
  return color
}
```
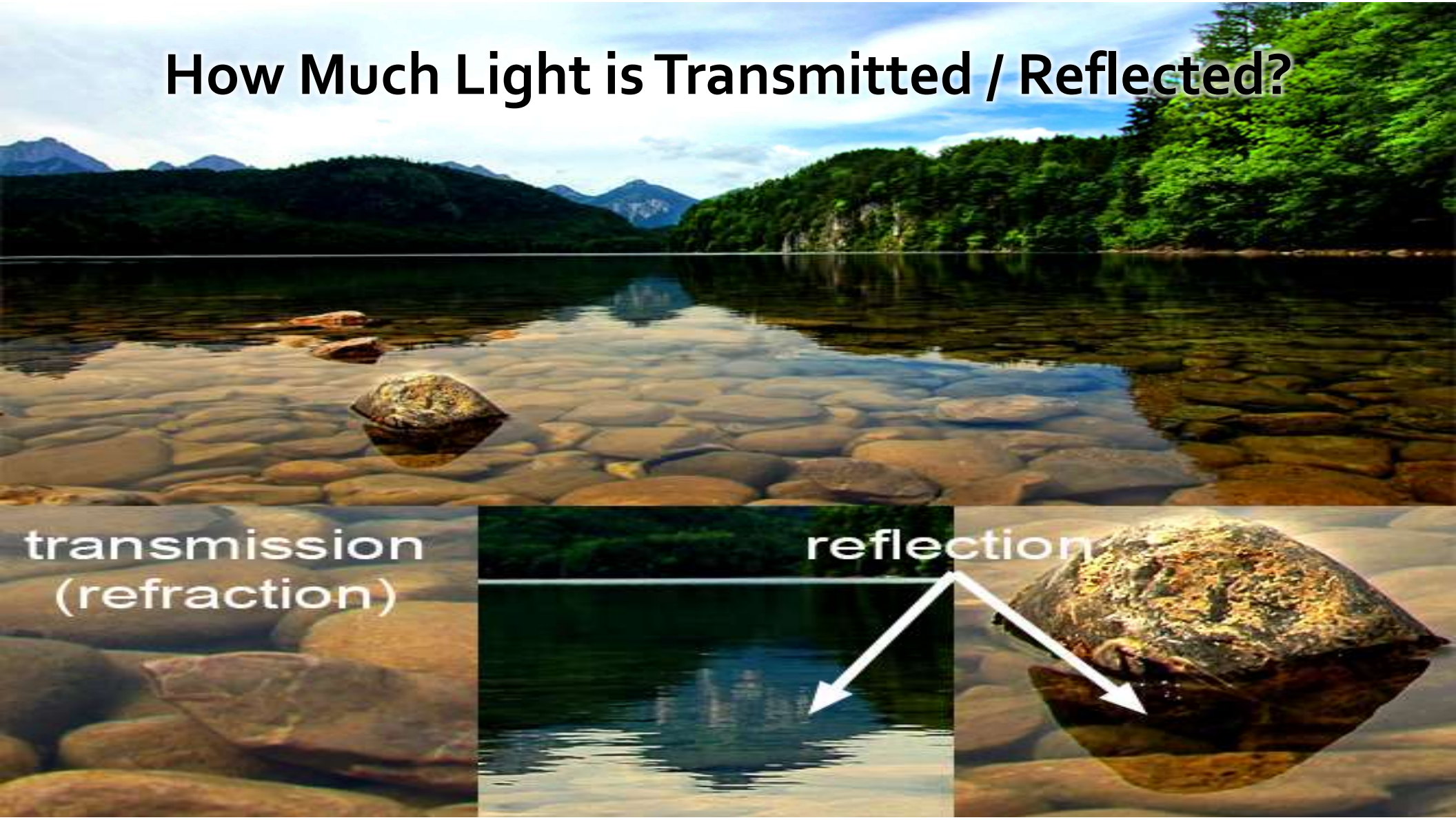
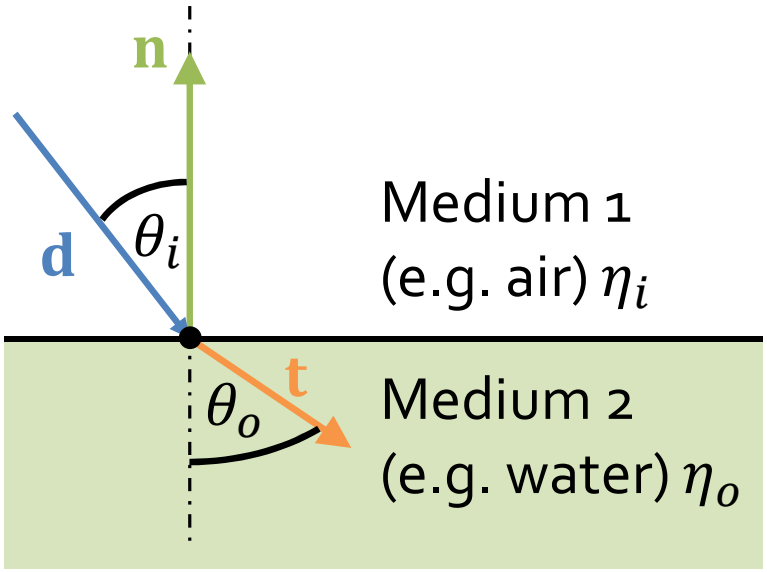

How Much Light is Transmitted / Reflected?



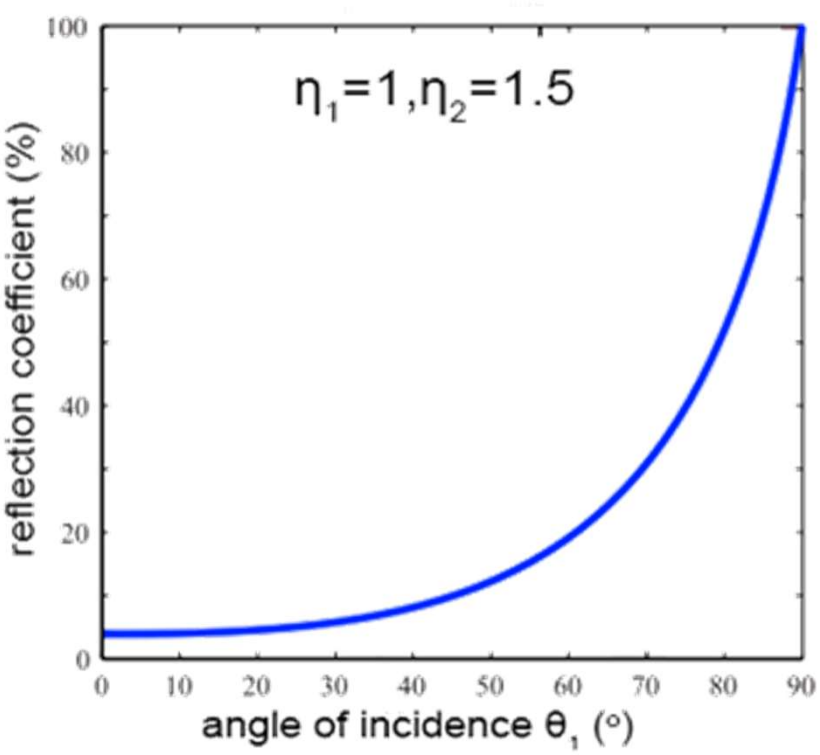
How Much Light is Transmitted / Reflected?

- Depends on incident angle
- Amount of reflected light F_R given by Fresnel equations
- $F_R = \frac{1}{2}\left(F_{R\parallel} + F_{R\perp}\right)$
- $F_{R\parallel} = \left(\frac{\eta_o \cos\theta_i - \eta_i \cos\theta_o}{\eta_o \cos\theta_i + \eta_i \cos\theta_o}\right)^2$
- $F_{R\perp} = \left(\frac{\eta_i \cos\theta_o - \eta_o \cos\theta_i}{\eta_i \cos\theta_o + \eta_o \cos\theta_i}\right)^2$
- Amount of transmitted light $F_T = 1 - F_R$

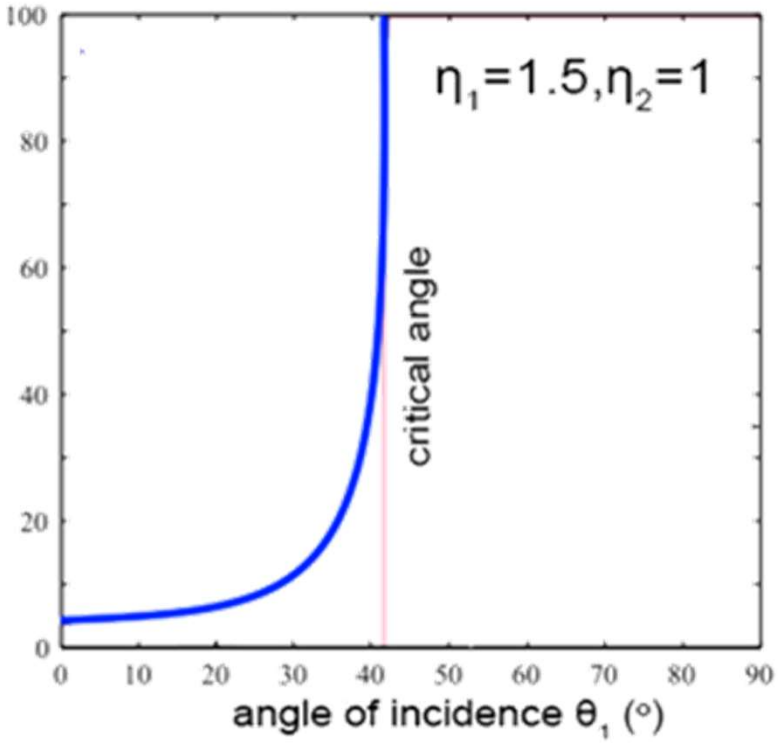


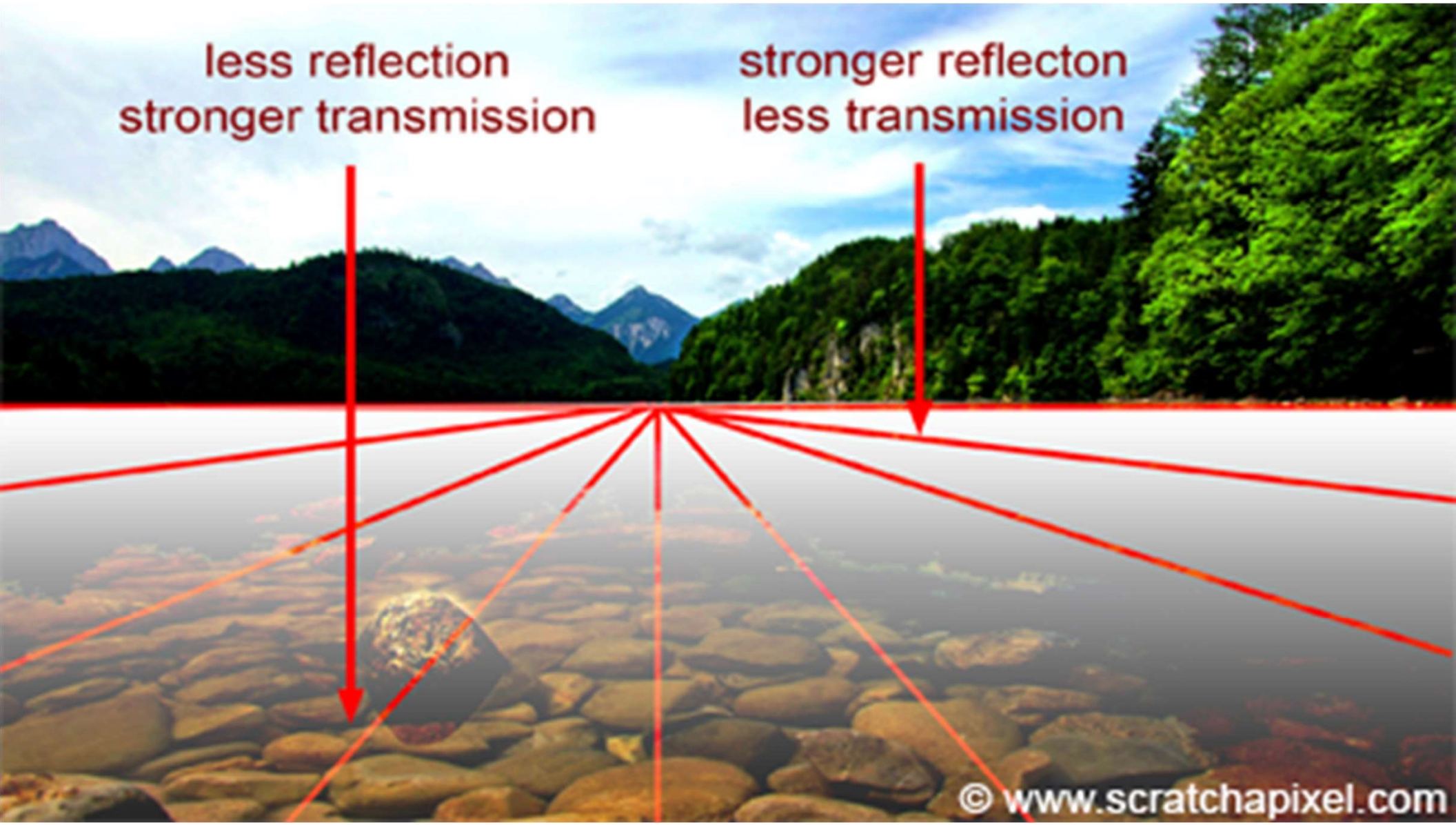
Fresnel

Air-glass transition



Glass-air transition (total reflection)




less reflection
stronger transmission
stronger reflecton
less transmission
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More Reflective for Grazing Angle