Raytracing Pseudocode

function *traceImage* (scene):

    for each pixel (i,j) in image

        S = PointInPixel

        P = CameraOrigin

        $\mathbf{d} = (S - P)/\| S - P\|$

        I(i,j) = *traceRay*(scene, P, $\mathbf{d}$)

    end for

end function

```
function traceRay(scene, P, d):
    (t, N, mtrl)  ← scene.intersect (P, d)
    Q ←    ray (P, d) evaluated at t
    I = shade(mtrl, scene, Q, N, d)
    R = reflectDirection(N, -d)
    I ← I + mtrl.k_r * traceRay(scene, Q, R)
    if ray is entering object then
      n_i = index_of_air
      n_t = mtrl.index
    else
      n_i = mtrl.index
       n_t = index_of_air
    if (mtrl.k_t > 0 and notTIR (n_i, n_t, N, -d)) then
      T = refractDirection (n_i, n_t, N, -d)
      I ← I + mtrl.k_t * traceRay(scene, Q, T)
    end if
    return I
end function
```

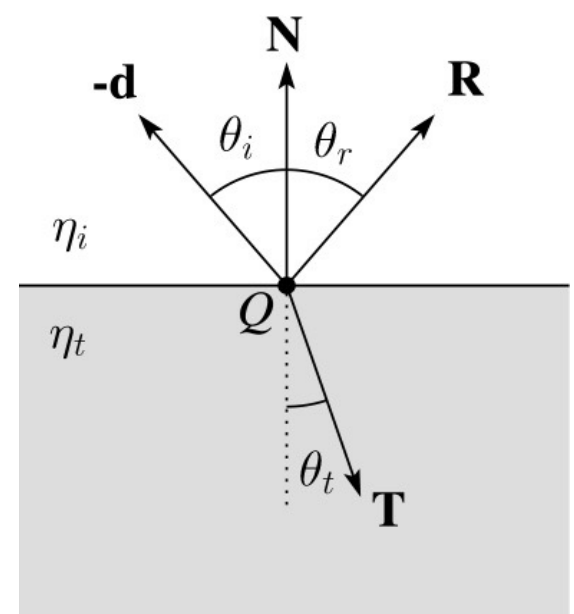
Thinking About Refraction

Remember Snell's law?

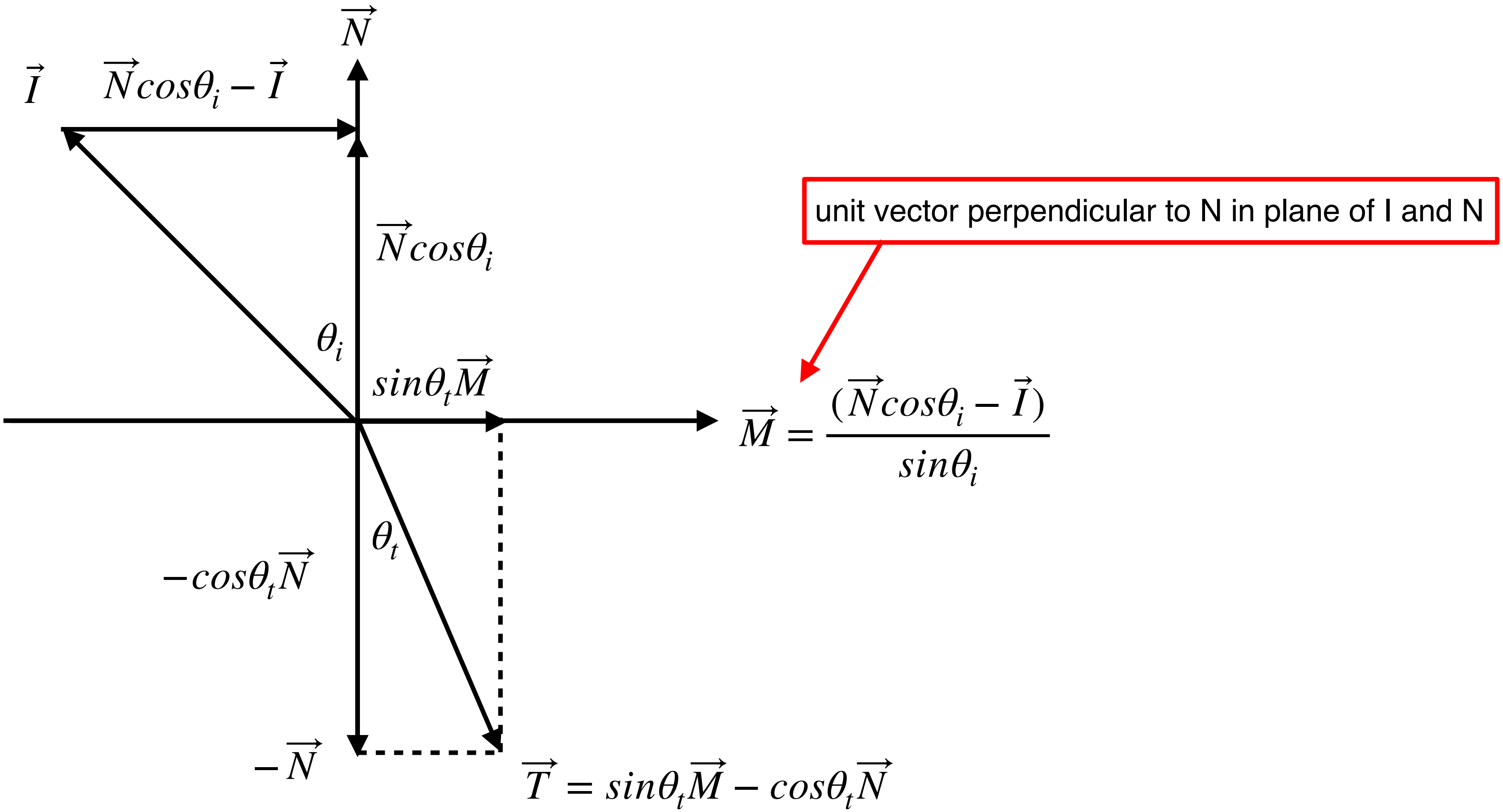
- $\eta_i \sin\theta_i = \eta_t \sin\theta_t$

When does light bend?

- Must account for entering **and** leaving!
- How do we know if we're entering or leaving? (hint: all geometry has a "front face" and a "back face")



Calculating Refraction



Adapted from *Computer Graphics* (James Foley)

Calculating Refraction

$$\vec{T} = \frac{sin\theta_t}{sin\theta_i}(\vec{N}cos\theta_i - \vec{I}) - cos\theta_t\vec{N}$$

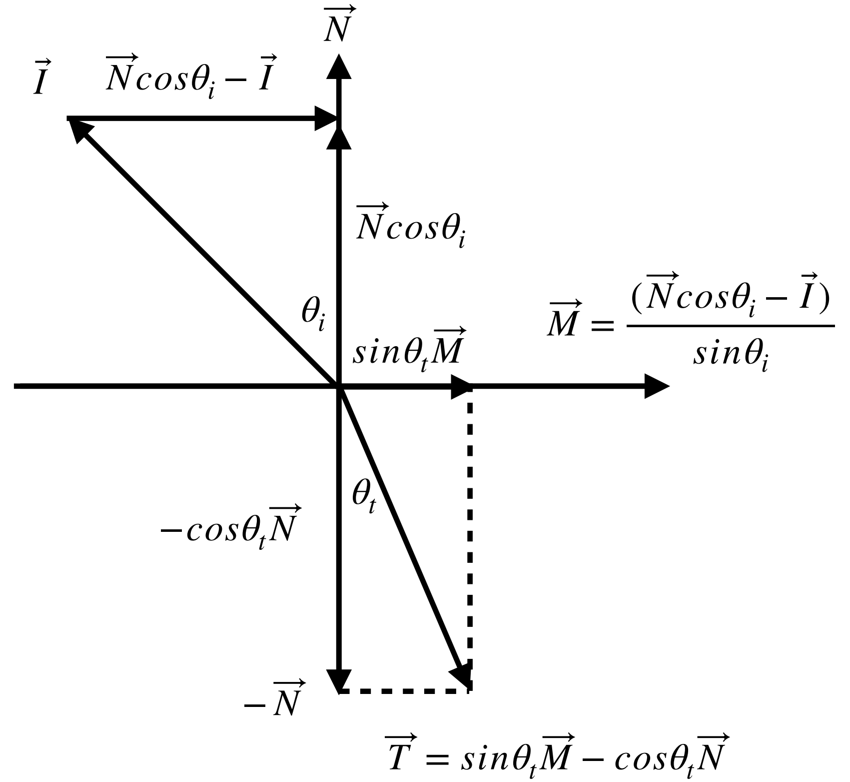
Let $\eta_r = \frac{\eta_i}{\eta_t} = \frac{sin\theta_t}{sin\theta_i}$ (Snell's Law)

$$\vec{T} = (\eta_r cos\theta_i - cos\theta t)\vec{N} - \eta_r\vec{I}$$

$$cos\theta_i = \vec{N} \cdot \vec{I}$$

$$cos\theta_t = \sqrt{1 - sin^2\theta_t} = \sqrt{1 - \eta_r^2 sin^2\theta_i}$$

$$cos\theta_t = \sqrt{1 - \eta_r^2(1 - (\vec{N} \cdot \vec{I})^2)}$$



$$\boxed{\vec{T} = \left(\eta_r(\vec{N} \cdot \vec{I}) - \sqrt{1 - \eta_r^2(1 - (\vec{N} \cdot \vec{I})^2)}\right)\vec{N} - \eta_r\vec{I}}$$

Determining TIR

$$\vec{T} = \left(\eta_r(\vec{N} \cdot \vec{I}) - \sqrt{1 - \eta_r^2(1 - (\vec{N} \cdot \vec{I})^2)}\right)\vec{N} - \eta_r\vec{I}$$

- TIR occurs when index of refraction of current medium (η_i) > index of refraction of other medium (η_t)
  - going from more dense to less dense medium
- Critical angle is value of $\sin\Theta_i$ when $\sin\Theta_t$ is 1
- Critical angle $\Theta_c = \sin^{-1}(\eta_t/\eta_i)$
- TIR occurs when square root of expanded $\cos\Theta_t$ is imaginary

function *shade*(mtrl, scene, *Q*, **N**, **d**):

  I $\leftarrow$ mtrl.k_e + mtrl. k_a * scene->I_a

  for each light source l **do**:

    atten = l -> *distanceAttenuation*(Q) *

    l -> *shadowAttenuation*(scene, Q)

    I $\leftarrow$ I + atten*(diffuse term + spec term)

  end for

  return I

end function

```
function PointLight::shadowAttenuation(scene, P)
   d = (l.position  - P).normalize()
   (t, N, mtrl) ← scene.intersect(P, d)
   Q ← ray(t)
   if Q is before the light source then:
     atten = 0
   else
     atten = 1
   end if
   return atten
end function
```

Some Additional Notes

The raytracer skeleton code is extensive but largely undocumented

- Taking time to look through the code to understand what it does is **essential**

- Mathematical elegance doesn't mean there's a simple codebase

Passing by Reference

Many important values are **passed by reference**!

- Look carefully to determine where/how values are being updated
- Very common in C and C++ codebases

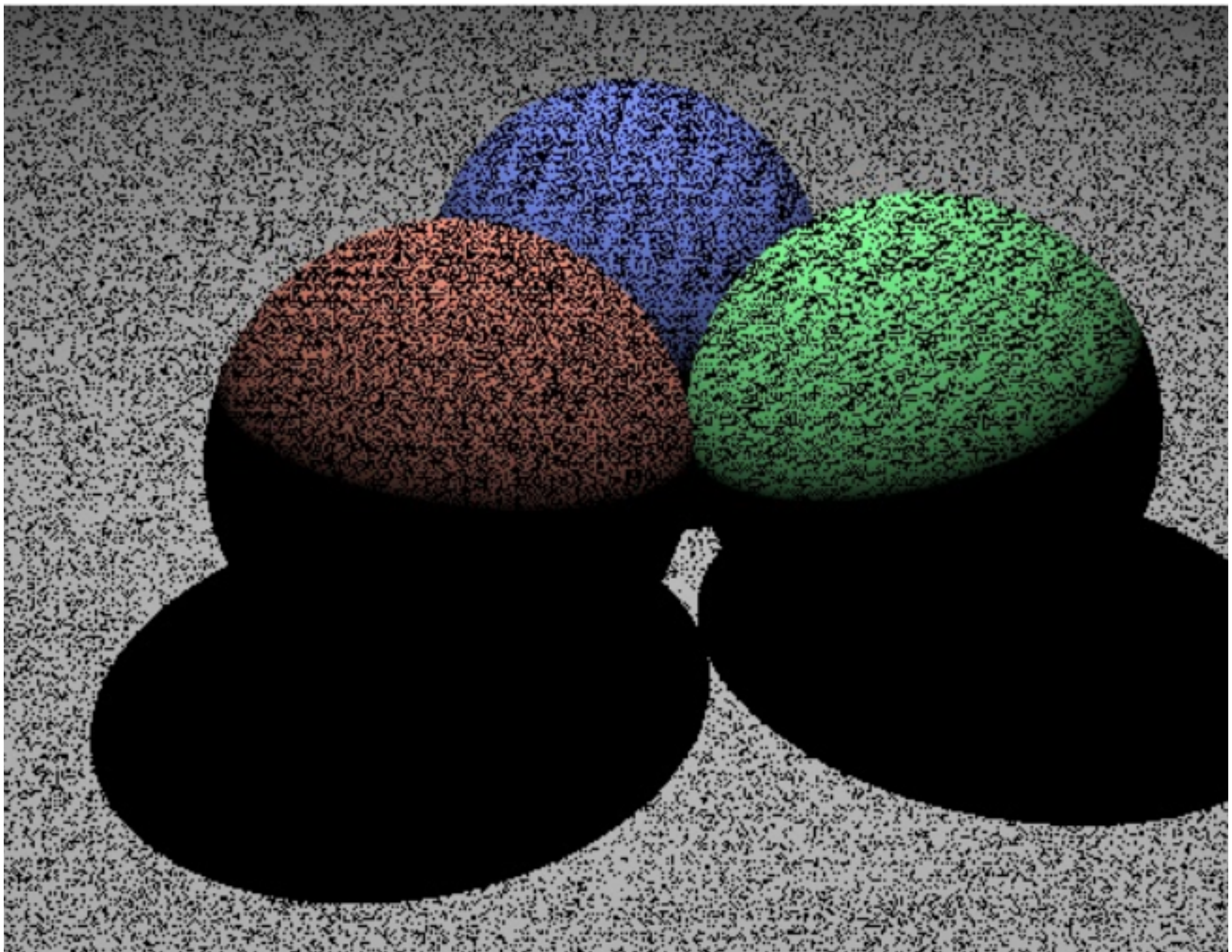
tmax and tmin

Parametric values that define the bounding box around the scene

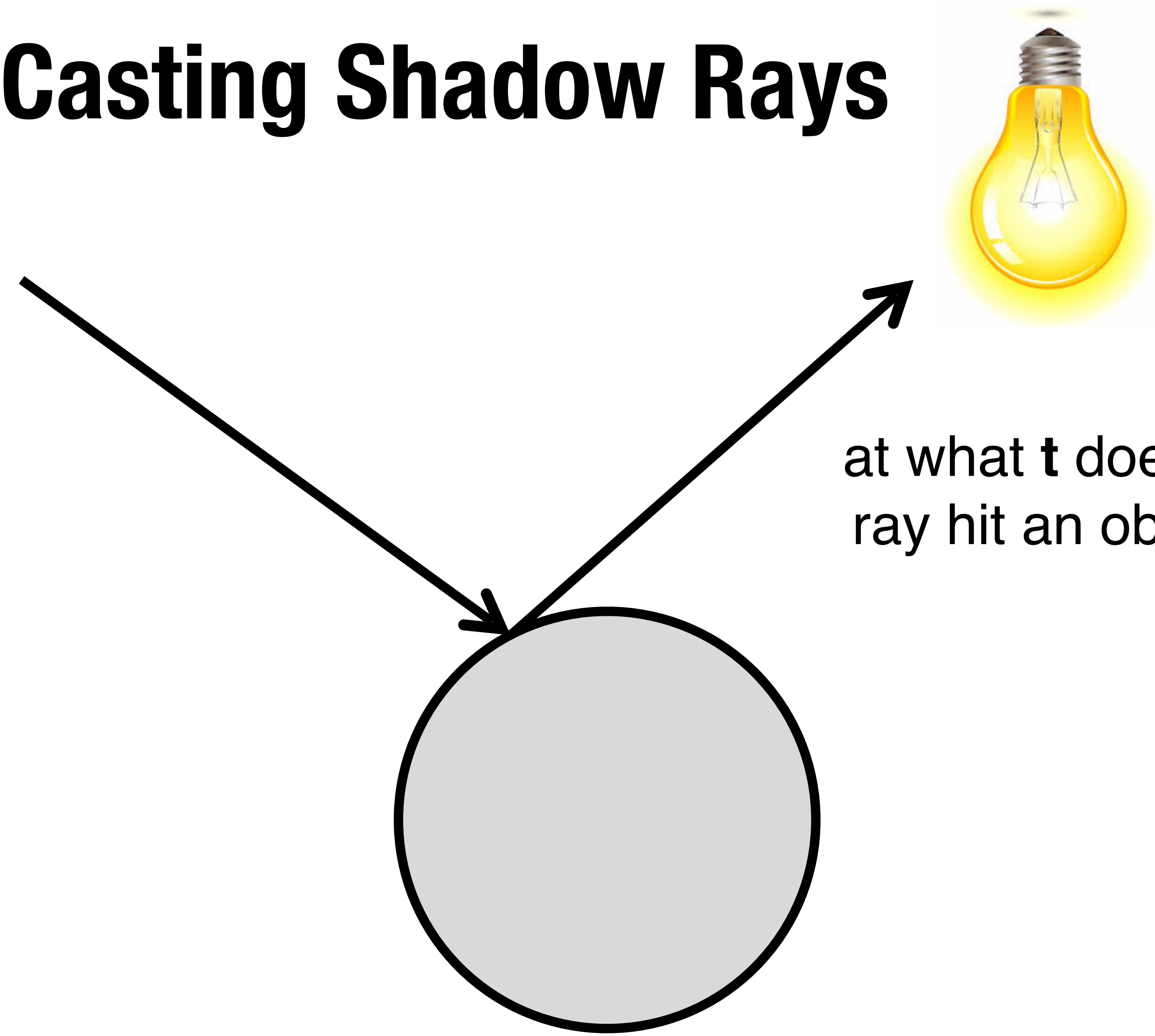
- Returned t values are within this range

Scene can be further subdivided for additional intersect optimizations!

Debugging Visually: What Happened?

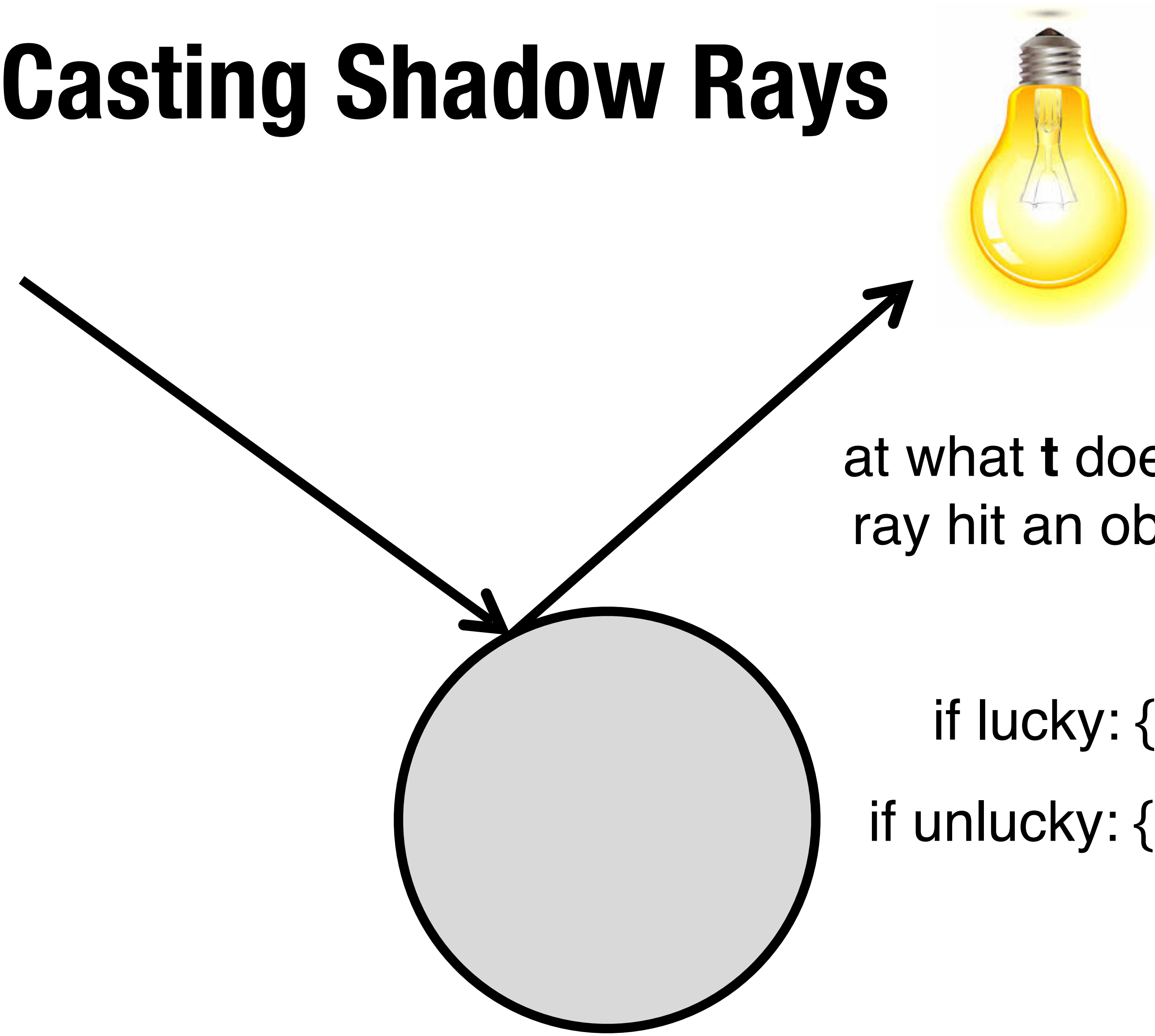


Casting Shadow Rays



at what **t** does the ray hit an object?

Casting Shadow Rays

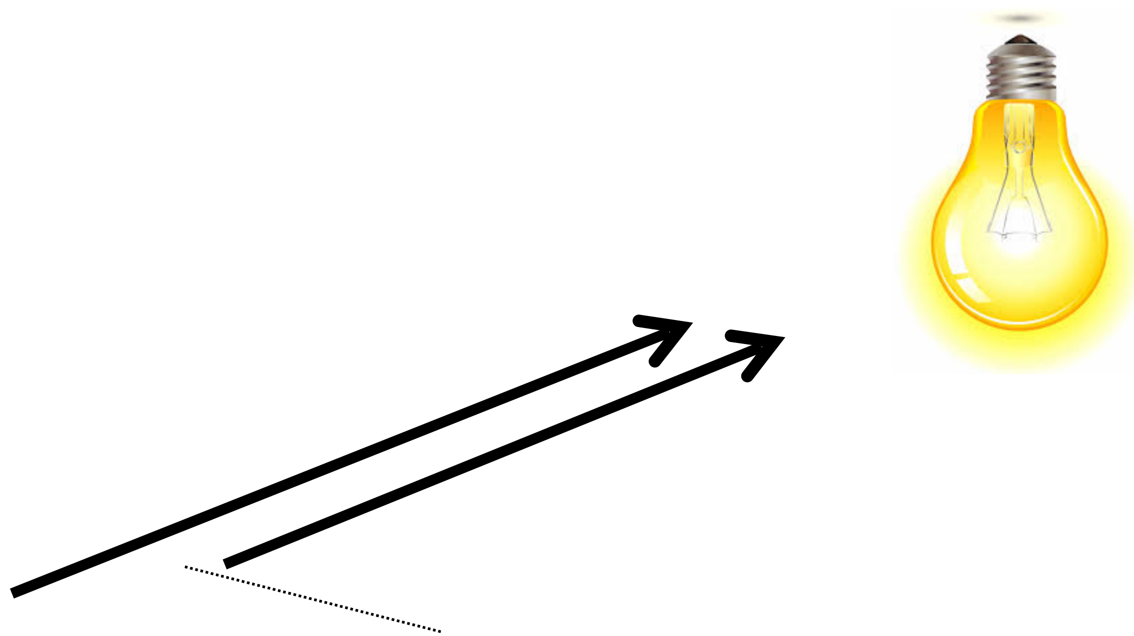


at what **t** does the ray hit an object?

if lucky: {-1.2, 0.0}

if unlucky: {-1.2, 1e-12}

Shadow Rounding Error



Classic fix: move slightly in normal direction before shooting shadow ray

- RAY_EPSILON provided for this

But Shadows Don't Look Like This!

Hard vs Soft Shadows

Calculate Penumbra

Use full lighting equation or calculate geometrically (not required for A1!)