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, **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
```

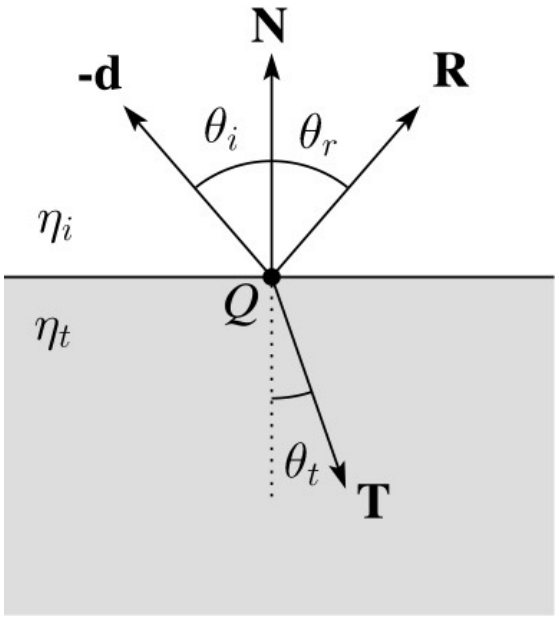
Thinking About Refraction

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")



```
function shade(mtrl, scene, Q, N, d):
    I ← mtrl.k_e + mtrl. k_a * scene->I_a
    for each light source l do:
        atten = l -> distanceAttenuation( Q ) *
        l -> shadowAttenuation( scene, Q  )
        I ← 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

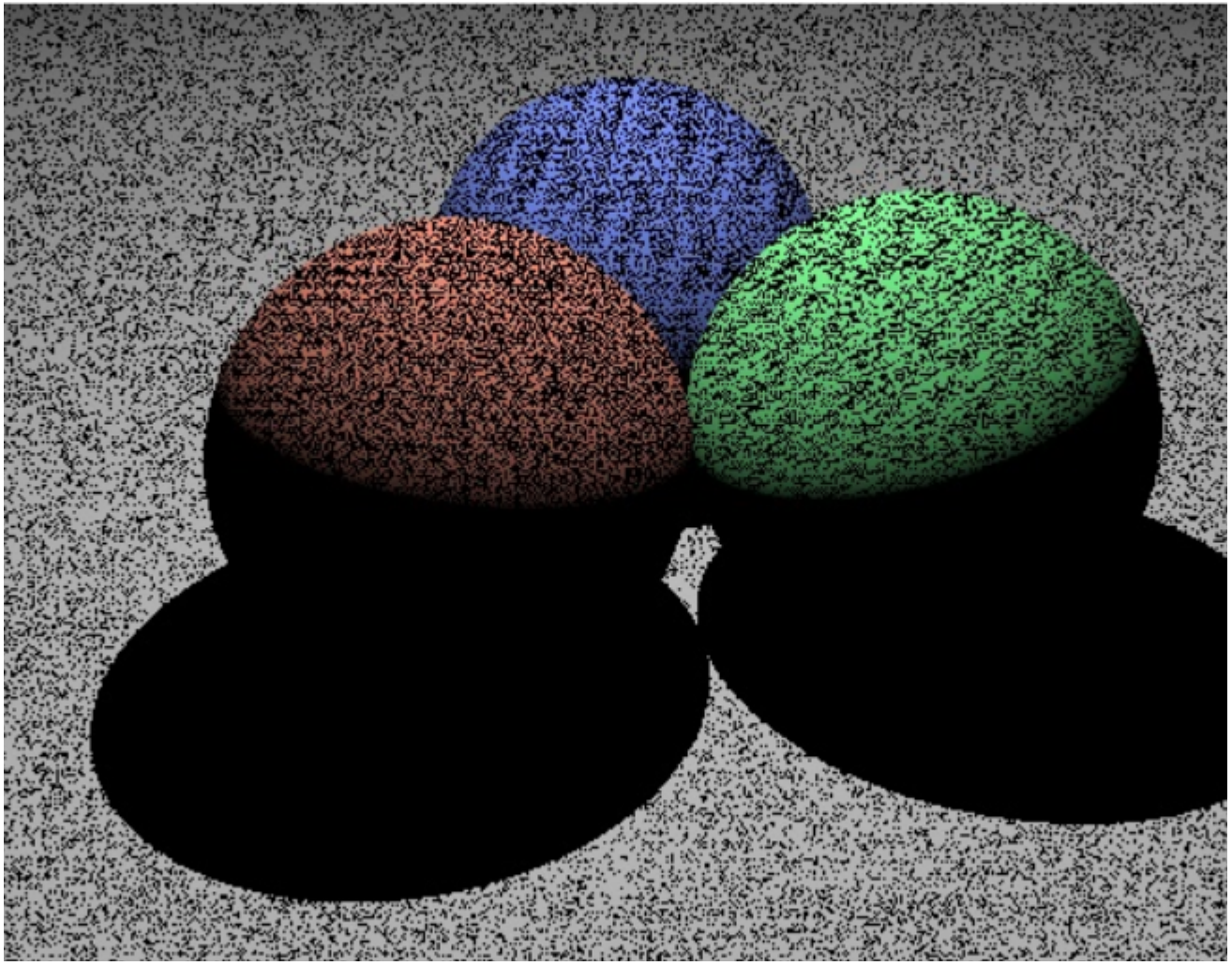
tmax and tmin

Parametric values that define the bounding box around the scene

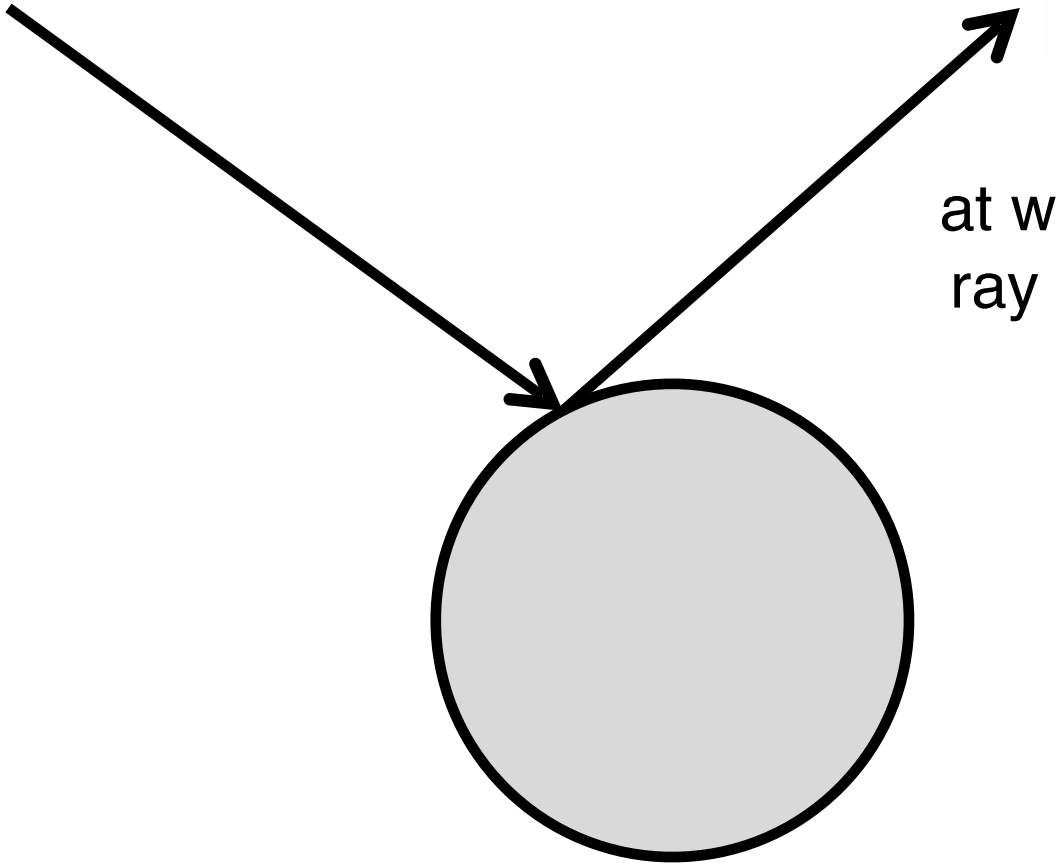
- Returned t values are within this range

Scene can be further subdivided for additional intersect optimizations!

Debugging Visually: What Happened?

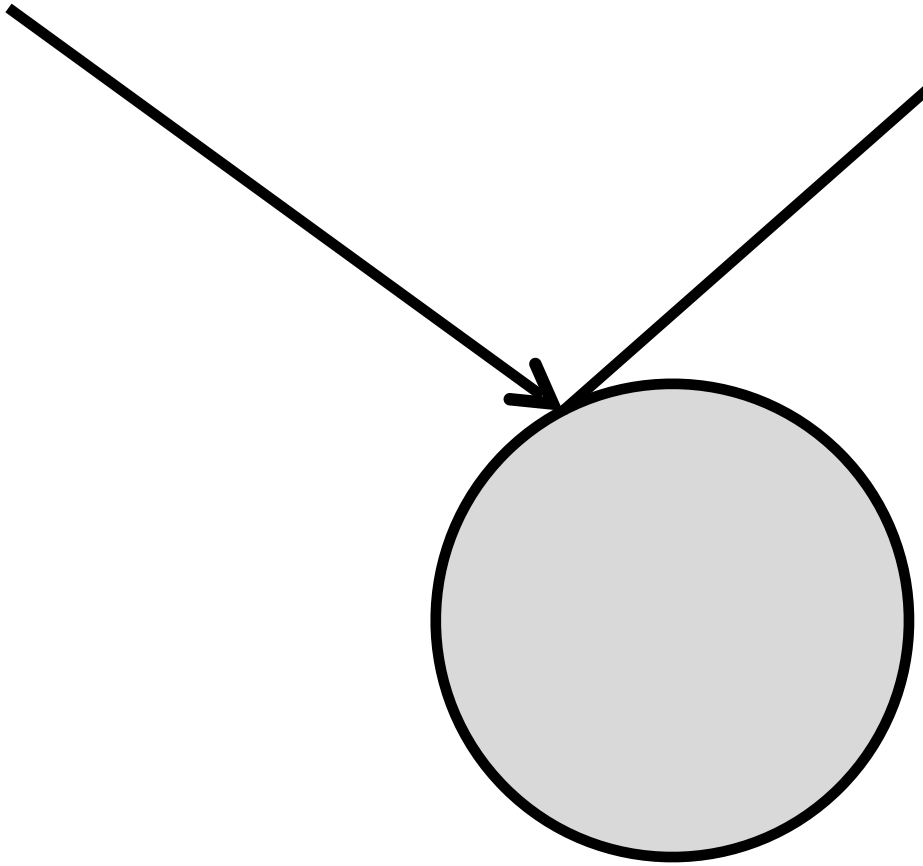


Casting Shadow Rays



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

Casting Shadow Rays

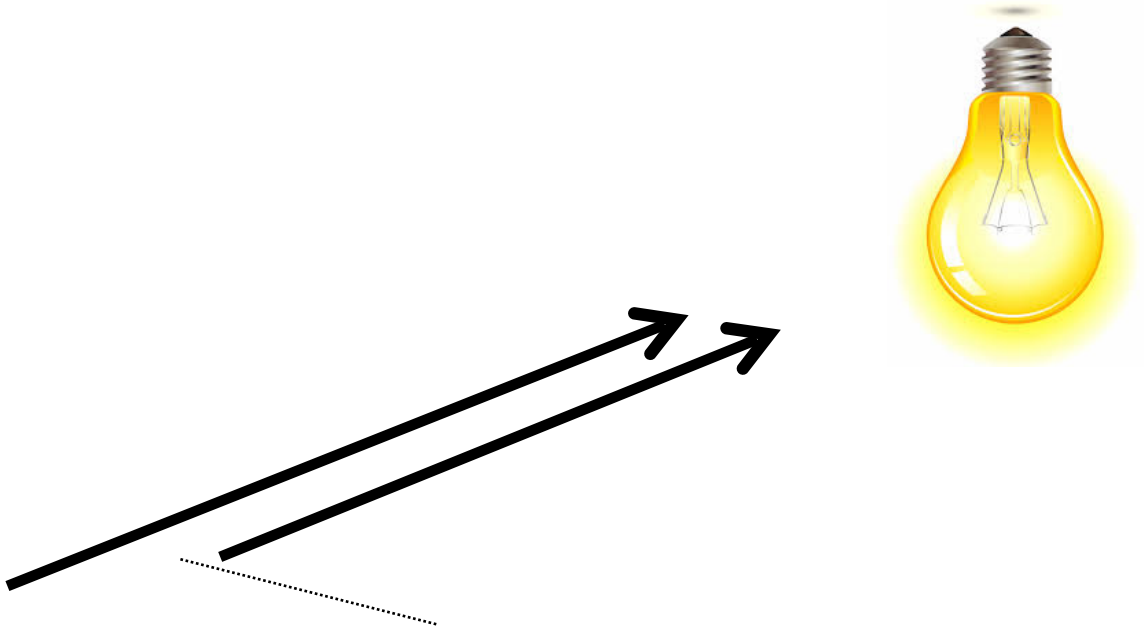


at what **t** does the ray hit an object?

if lucky: {-1.2, 0.0}

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

Shadow Rounding Error

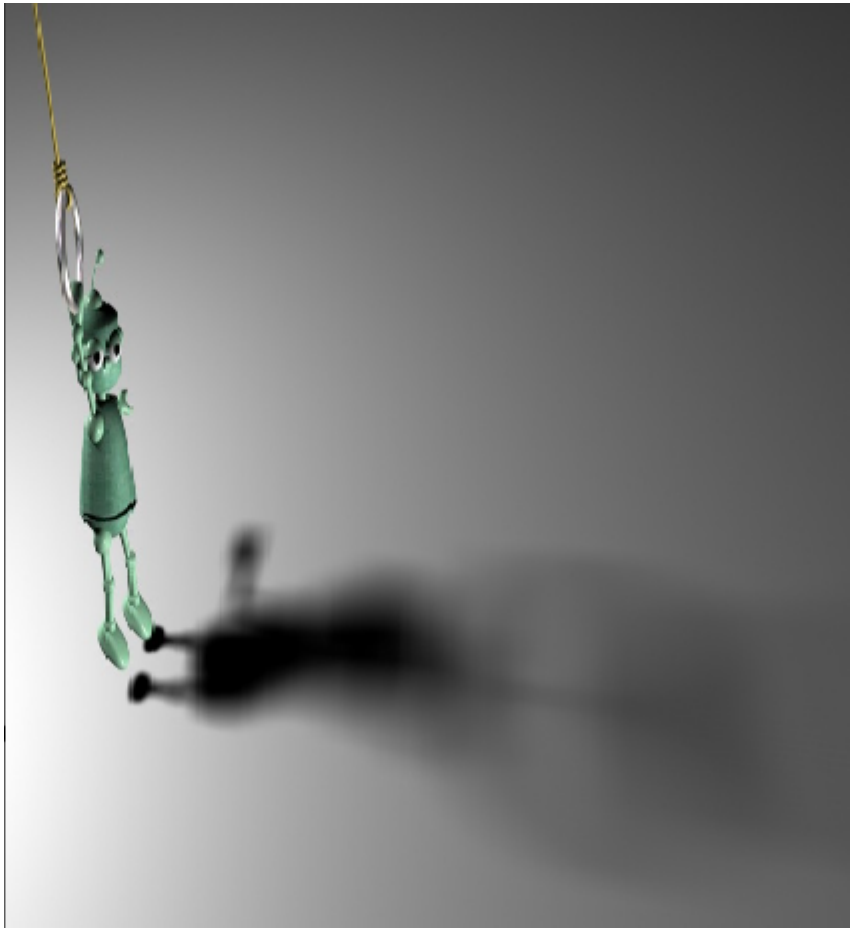


Classic fix: move slightly in normal direction before shooting shadow ray

- 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!)