def ray_trace_good(ray, accum, refatt):
    if (ray_find(ray) != None):
        N = make_unit(ray.best_pt - ray.best_sph.C)
        mat = mats[ray.best_sph.m]
        color = ambi * mat.ka
        toC = -1 * ray.D
        for lt in lghts:
            toL = make_unit(lt.P - ray.best_pt)
            NdotL = np.dot(N, toL)
            if (NdotL > 0.0):
                color += mat.kd * lt.E * NdotL
                spR = make_unit((2 * NdotL * N) - toL)
                CdR = np.dot(toC, spR)
                if (CdR > 0.0):
                    color += (mat.ks * lt.E) * CdR**16
                accum += refatt * color
    return accum
With and Without Test

• 1 Sphere, 1 Light, Specular Only
To-Camera Aligns with Reflection

- Start by thinking about ‘standard’ view

\[ \cos(\Phi) = toC \cdot spR \]

The specular reflection vector and the to-camera vector are becoming near parallel when approaching maximum specular reflection.
But What About This Case?

• Approaching ‘equator’

\[
\cos(\Phi) = toC \cdot spR
\]

The specular reflection vector and the to-camera vector are becoming near anti-parallel when approaching edge of the sphere as seen by the camera.

Once cosine is raised to an even power there will be a ‘highlight’ forming a ring. Fix is to test sign of dot product.
Reflecting on Reflectivity

• Up until now we’ve considered dissipation of energy through multi-bounce reflection.
  – Attention is multiplicative by level
    • \((1.0, 1.0, 1.0)\)
    • \((0.9, 0.9, 0.9) = (1.0, 1.0, 1.0)^* (0.9, 0.9, 0.9)\)
    • \((0.81, 0.81, 0.81) = (0.9, 0.9, 0.9)^* (0.9, 0.9, 0.9)\)
    • ....

• We have not considered weighting between surface illumination and reflected light.
Add ‘reflectivity’

• New material property
• Zero means no reflected light at all
  – No surface ambient, diffuse, specular
• One means only reflected light
• More generally, a weighted average

\[ I = (1 - \rho)I_S + \rho I_R \]

• The parameter rho here is reflectivity
Adding Reflectivity

- Extended the SageMath Example

```python
mats = [Material((0.2, 0.2, 0.2),(1.0, 1.0, 1.0),(0.5, 0.5, 0.5),(1.0, 1.0, 1.0), 0.85),
       Material((0.8, 0.6, 0.2),(0.8, 0.6, 0.2),(0.5, 0.5, 0.5),(1.0, 1.0, 1.0), 0.25),
       Material((0.6, 0.8, 0.2),(0.6, 0.8, 0.2),(0.5, 0.5, 0.5),(1.0, 1.0, 1.0), 0.25),
       Material((0.2, 0.6, 0.8),(0.2, 0.6, 0.8),(0.5, 0.5, 0.5),(1.0, 1.0, 1.0), 0.25),
       Material((0.7, 0.7, 0.2),(0.7, 0.7, 0.2),(0.5, 0.5, 0.5),(1.0, 1.0, 1.0), 0.25)]
```

Five spheres with first material, large sphere, most reflective.
Five Spheres Geometry

• Note relative positions
In Closing: The Darkness of Space

There is one last issue.
What color is emptiness?
The answer here
   – Black
Happy Halloween