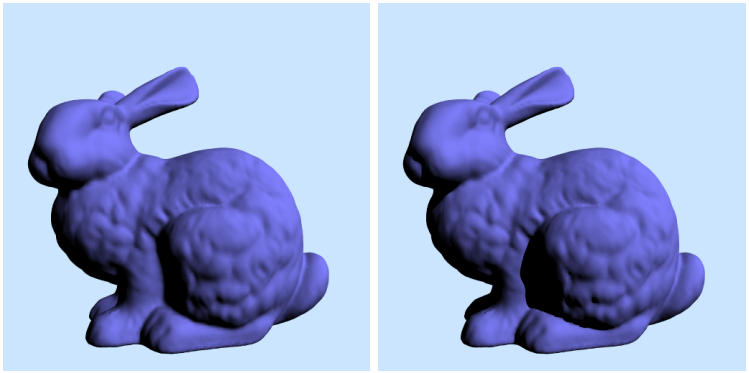
Physically Based Rendering, Reports

Student:
Andrea Distler, 130269

Teacher:
Jeppe Frisvald

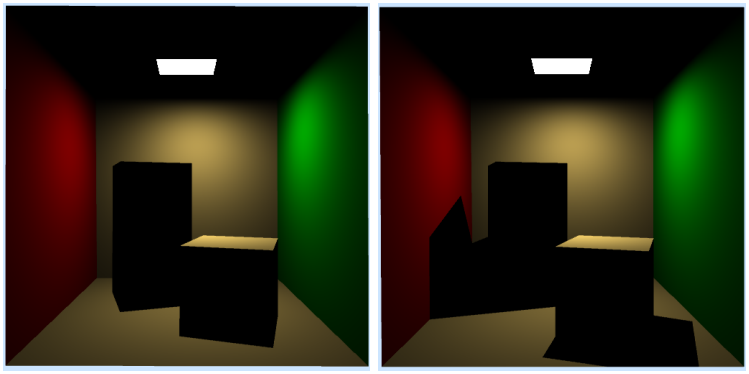
May 3, 2013

Contents



(a) Without shadows: 5s (b) With shadows: 8s

Figure 1: Bunny.obj, Tris: 69451, 36 samples, 1 directional light, Lambertian shader



(a) Without shadows: 0.3s (b) With shadows: 0.5s

Figure 2: Cornellbox.obj and CornellBlocks.obj, Tris: 36, 4 samples, 1 area light, Lambertian shaders

Report Exercise 1

- Implemented a directional light with shadows
- Implemented an area light with shadows

Relevant pictures: figures 1, and 2. Relevant listings: 1, 2, and 3.

Listing 1 : Directional.cpp

```
bool Directional::sample(const Vec3f& pos, Vec3f& dir, Vec3f& L)
    const
{
  dir = -light_dir;
  L = emission;

  // test for shadow
  Ray shadowRay(pos, -light_dir);
  bool inShadow = false;

  if (shadows)
    inShadow = tracer->trace(shadowRay);

  return !inShadow;
}
```

Listing 2 : Lambertian.cpp

```
Vec3f Lambertian::shade(Ray& r, bool emit) const
{
  Vec3f rho_d = get_diffuse(r);
  Vec3f result(0.0f);

  // temp light direction and radiance
  Vec3f lightDirection, radiance;
  for (std::vector<Light*>::const_iterator it = lights.begin(); it
      != lights.end(); it++)
  {
    if ((*it)->sample(r.hit_pos, lightDirection, radiance))
    {
      // output of Lambertian BRDF
      Vec3f f = rho_d * M_1_PIf;

      // directional light radiance
      // f - scattered light radiance, radiance - current light
          radiance, last term: cosine cut off at 0
      result += f * radiance * std::max(dot(r.hit_normal,
          lightDirection), 0.0f);
    }
  }

  return result + Emission::shade(r, emit);
}
```

Listing 3 : AreaLight.cpp

```
bool AreaLight::sample(const Vec3f& pos, Vec3f& dir, Vec3f& L)
    const
{
  // Get geometry info
  const IndexedFaceSet& geometry = mesh->geometry;
  const IndexedFaceSet& normals = mesh->normals;

  // averaged light position
  Vec3f lightPosition = Vec3f(0.0f);
  // averaged normals
  Vec3f lightNormal = Vec3f(0.0f);
  // emission summed up from all faces
  Vec3f emission = Vec3f(0.0f);
```

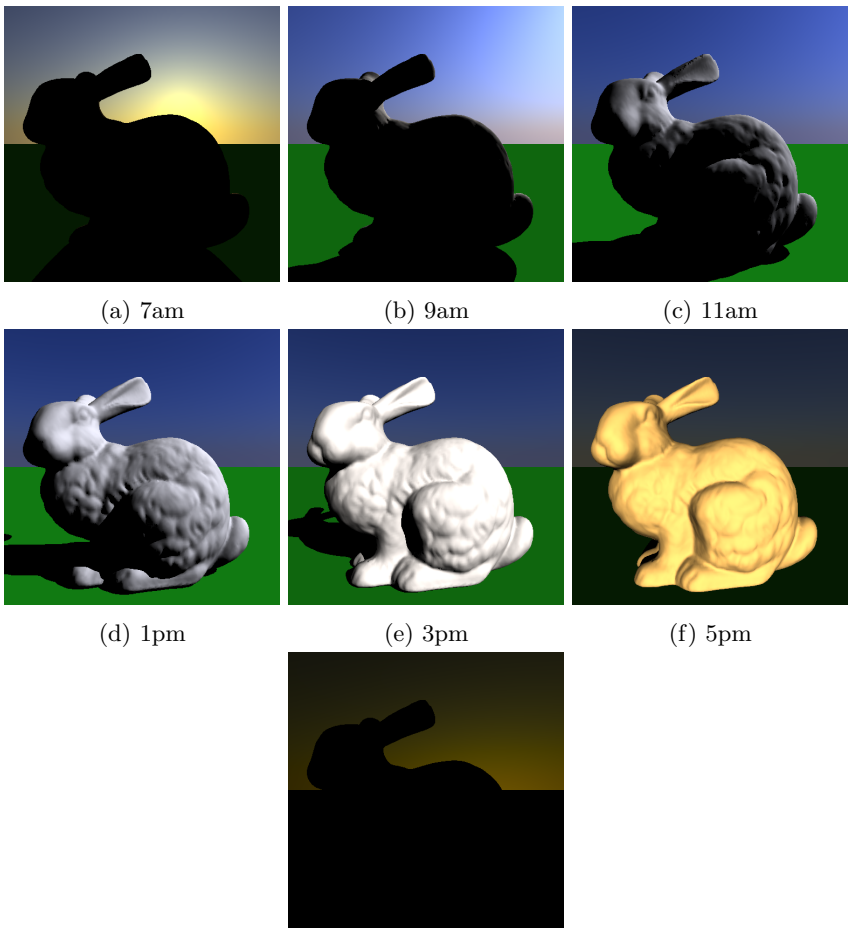
```
14    // iterate over all faces
      for (int i = 0; i < geometry.no_faces(); i++)
16    {
        // get the center of the face
18      Vec3i face = geometry.face(i);
        Vec3f v0 = geometry.vertex(face[0]);
20      Vec3f v1 = geometry.vertex(face[1]);
        Vec3f v2 = geometry.vertex(face[2]);
22      Vec3f faceCenter = v0 + (v1 - v0 + v2 - v0) * 0.5f;

24      // combine light position
        lightPosition += faceCenter;
26
        // average normals
28      lightNormal += (normals.vertex(face[0]) + normals.vertex(face
            [1]) + normals.vertex(face[2])) / 3;

30      // add emission
        emission += mesh->face_areas[i] * get_emission(i);
32    }

34    // average light position
      lightPosition /= geometry.no_faces();
36
      lightNormal.normalize();
38
      // get light direction and distance to light
40    Vec3f lightDirection = lightPosition - pos;
      float lightDistance = length(lightDirection);
42
      // set area light direction, normalize
44    dir = lightDirection / lightDistance;

46    // set radiance
      L = emission * std::max(dot(-dir, lightNormal), 0.0f) / (
          lightDistance * lightDistance);
48
      // trace for shadows
50    bool inShadow = false;
      if (shadows)
52    {
        Ray shadowRay(pos, dir);
54      shadowRay.tmax = lightDistance - 0.1111f;
        inShadow = tracer->trace(shadowRay);
56    }

58    return !inShadow;
  }
```

Report Exercise 2

The input parameters for the sun sky light are theta, and phi, together creating the solar position, and the turbidity (how much light is scattered due to dirt in the atmosphere, using empirical values - Preetham). Using Preetham's paper, theta and phi are calculated from the latitude, declination, julian day of the year and the time of the day, as well as some constants from Preetham's paper. The code for this can be found in listing 4.

The model used for calculating the sun's intensity is calculated as shown in listing 5. The sun covers a solid angle of 2π degrees^2 ($\Rightarrow$ the whole hemisphere).

Relevant figure: 3. Relevant listings: 4, and 5.



(a) 7am (b) 9am (c) 11am

(d) 1pm (e) 3pm (f) 5pm

(g) 9pm

Figure 3: Bunny.obj and plane, Tris: 70.000, 1 sample, 1 skylight, Lambertian shaders $\Rightarrow$ approx. 3s per picture

Listing 4 : RenderEngine::init_tracer()

```
if(use_sun_and_sky)
  {
    // Use the Julian date (day_of_year), the solar time (
        time_of_day), the latitude (latitude),
    // and the angle with South (angle_with_south) to find the
        direction toward the sun (sun_dir).

    // hard coded numbers are from Preetham et al.'s A Practical
        Analytical Model for Daylight, SIGGRAPH 1999
    float declination = 0.4093 * sin(2 * M_PIf * (day_of_year - 81)
         / 368);
    float theta = M_PIf * 0.5f - asin(sin(latitude) * sin(
        declination) -
      cos(latitude) * cos(declination) * cos(M_PIf * time_of_day /
          12));
    float phi = atan(-(cos(declination) * sin(M_PIf * time_of_day /
         12)) /
      (cos(latitude) * sin(declination) - sin(latitude) * cos(
          declination) * cos(M_PIf * time_of_day / 12)));

    sun_sky.setSunTheta(theta);
    sun_sky.setSunPhi(phi);
    sun_sky.setTurbidity(turbidity);
    sun_sky.init();
    tracer.set_background(&sun_sky);
  }
```

Listing 5 : PreethamSunSky::sample(..)

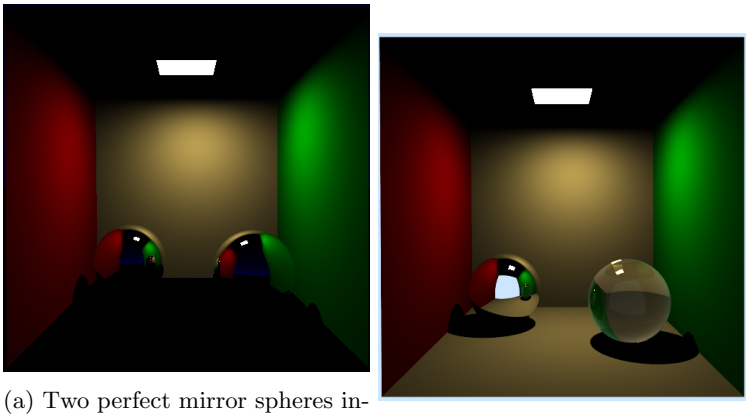
```
bool PreethamSunSky::sample(const Vec3f& pos, Vec3f& dir, Vec3f& L)
    const
{
  dir = const_cast<PreethamSunSky*>(this)->getSunDir();

  float area = 1;
  float solid_angle = 2 * M_PI;
  float cos_theta = dot(Vec3f(0, 1, 0), dir);

  // * 0.00001f to convert to the right unit (cd/m^2)
  L = const_cast<PreethamSunSky*>(this)->sunColor() / (area *
      solid_angle * cos_theta) * 0.00001f;

  // test for shadow
  Ray shadowRay(pos, dir);
  bool inShadow = false;

  if (shadows)
    inShadow = tracer->trace(shadowRay);

  return !inShadow;
}
```

Report Exercise 3

Implemented:

- Transparent shader
- Mirror shader
- Metal shader
- Russian Roulette
- fresnel equations for dielectric materials and conductors

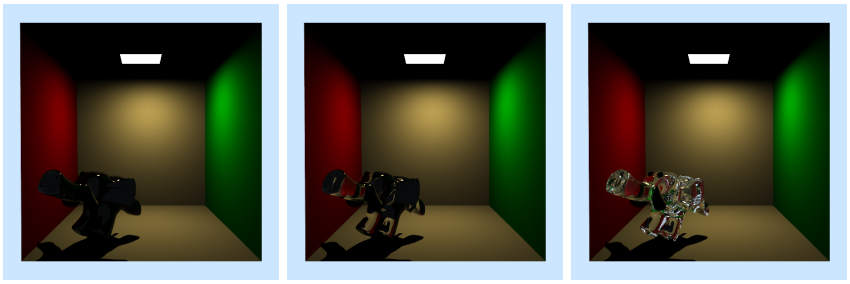
Relevant figures: 4, 5, 6, 7. Relevant listings: 7, and 6.



(a) Two perfect mirror spheres inside of the Cornell Box (using the sunsky lighting).

(b) A mirror and a glass sphere (using default lighting).

Figure 4: Two spheres with different shaders.

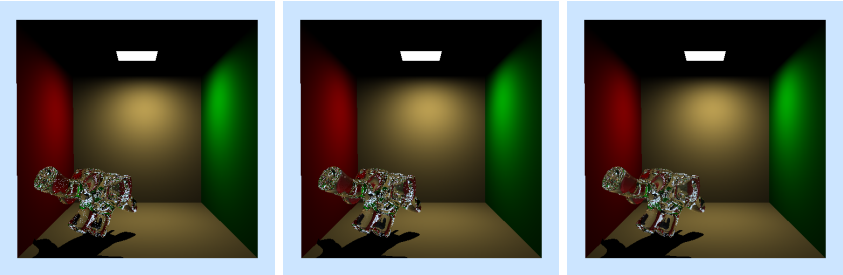


(a) Transparent elephant with cutoff of 1.

(b) Transparent elephant with cutoff of 2.

(c) Transparent elephant with cutoff of 10.

Figure 5: Transparent elephant with different cutoff depths. All pictures used 9 rays per pixel.



(a) Transparent elephant with cutoff of 1, russian roulette.

(b) Transparent elephant with cutoff of 2, russian roulette.

(c) Transparent elephant with cutoff of 10, russian roulette.

Figure 6: Transparent elephant with different cutoff dephts, using russian roulette. 9 rays per pixel

Listing 6 : Transparent::shade

```
Vec3f Transparent::shade(Ray& r, bool emit) const
{
  Vec3f radiance = Vec3f(0.0f);

  if (r.trace_depth < splits)
  {
    radiance = split_shade(r, emit);
  }
  else if (r.trace_depth < max_depth)
  {
    // refraction
    Ray refracted;
    double fresnelR;
    tracer->trace_refracted(r, refracted, fresnelR); // fresnelR =>
        use as step probability

    // russian roulette for reflections
    float rand = randomizer.mt_random();

    // 1st cond. -> russian roulette with fresnelR => pdf, 2nd cond
        . -> eliminating rays following surface
    if (rand <= fresnelR && fresnelR > 0.001)
    {
      // reflect
      Ray reflected;
      tracer->trace_reflected(r, reflected);
      radiance = shade_new_ray(reflected); // * fresnelR / fresnelR
          ; // divide by fresnelR, since fresnelR is used as the
          step probability
    }
    // if not reflecting, take refraction
    else if (1 - fresnelR > 0.001)
    {
      radiance = shade_new_ray(refracted); // * (1 - fresnelR) / (1
          - fresnelR);
    }
  }

  return radiance;
}
```

Listing 7 : Transparent::split_shade

```
Vec3f Transparent::split_shade(Ray& r, bool emit) const
{
  Vec3f radiance(0.0f);

  if (r.trace_depth < splits)
  {
    Ray refracted;
    double fresnelR;
    tracer->trace_refracted(r, refracted, fresnelR);

    if (1 - fresnelR > 0.001)
      radiance += shade_new_ray(refracted) * (1.0f - fresnelR);

    // eliminate rays following the surface
    if (fresnelR > 0.001)
    {
      Ray reflected;
      tracer->trace_reflected(r, reflected);
      radiance += shade_new_ray(reflected) * fresnelR;
    }
  }

  return radiance;
}
```

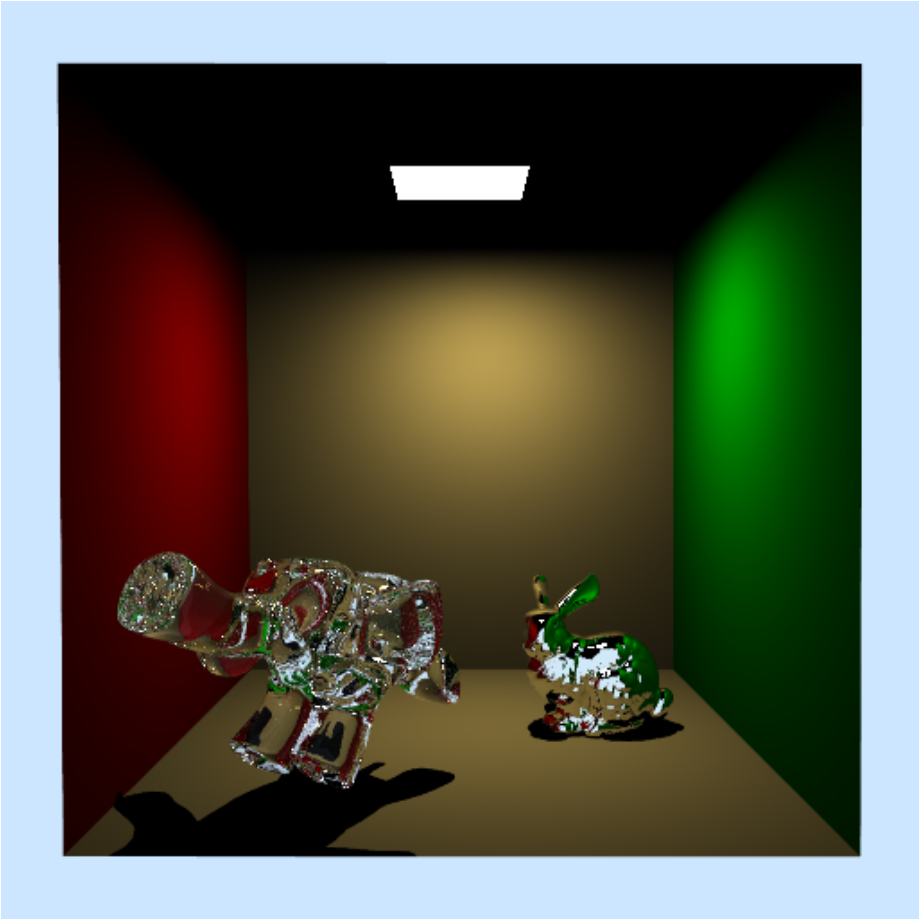


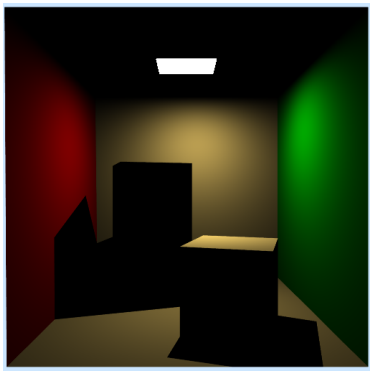
Figure 7: A silver bunny and a transparent elephant, using russian roulette, 9 rays per pixel.

Report Exercise 4

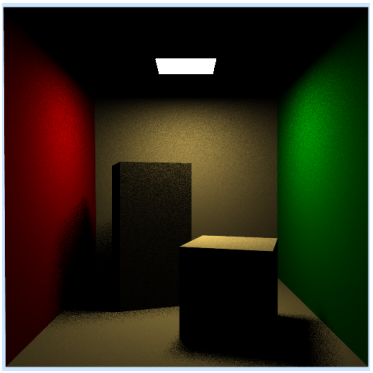
Implemented

- an area light using Monte Carlo integration
- ambient occlusion using cosine weighted sampling

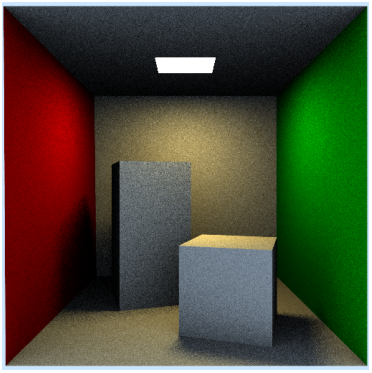
Relevant figures: 8, 9, 11, 10, and 12. Relevant listings: 8, 9, and 10.



(a) Hard shadows, 9 rays per pixel, 5 seconds



(b) Area light with Monte Carlo integration, 9rpp, 5s



(c) Area light with Monte Carlo integration and ambient light, 9rpp, 20s, 5 samples

Figure 8: The Cornellbox with its blocks, comparing hard shadows, soft shadows, and ambient light.

Listing 8 : AreaLight::sample

```
bool AreaLight::sample(const Vec3f& pos, Vec3f& dir, Vec3f& L)
    const
{
  // this method uses monte carlo integration to create soft
      shadows

  // Get geometry info
  const IndexedFaceSet& geometry = mesh->geometry;
  const IndexedFaceSet& normals = mesh->normals;

  // get random triangle
  int triangleIndex = randomizer.mt_random_int32() % geometry.
      no_faces();

  // get index for vertices of triangle
  Vec3i vertexIndex = geometry.face(triangleIndex);
  // get index for normals of triangle
  Vec3i normalIndex = normals.face(triangleIndex);

```

```
    // get random position on triangle
    // ref: http://mathworld.wolfram.com/TrianglePointPicking.html
    float sqrt_e1 = sqrt(randomizer.mt_random());
    float e2 = randomizer.mt_random();

    // sample barycentric coordinates
    float u = 1 - sqrt_e1;
    float v = (1 - e2) * sqrt_e1;
    float w = e2 * sqrt_e1;

    // linear interpolation of vertices and normals, to get a point
        on the triangle and the according normal
    Vec3f lightPosition = Vec3f(0.0f);
    Vec3f lightNormal = Vec3f(0.0f);

    Vec3f uvw = Vec3f(u, v, w);
    for (int i=0; i<3; i++)
    {
      lightPosition += geometry.vertex(vertexIndex[i]) * uvw[i];
      lightNormal += normals.vertex(normalIndex[i]) * uvw[i];
    }
    lightNormal.normalize();

    // get light direction and distance to light
    Vec3f lightDirection = lightPosition - pos;
    float lightDistance = length(lightDirection);

    // set area light direction, normalize
    dir = lightDirection / lightDistance;

    // emission is scaled by geometry.no_faces() bec only 1/n are
        sampled
    Vec3f emission = mesh->face_areas[triangleIndex] * get_emission(
        triangleIndex) * geometry.no_faces();
    // set radiance
    L = emission * max(dot(lightNormal, -dir), 0.0f) / (lightDistance
         * lightDistance);

    // trace for shadows
    bool inShadow = false;
    if (shadows)
    {
      Ray shadowRay(pos, dir);
      shadowRay.tmax = lightDistance - 0.1111f;
      inShadow = tracer->trace(shadowRay);
    }

    return !inShadow;
}
```

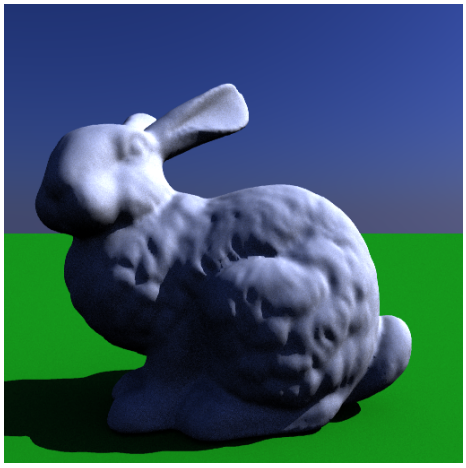
Listing 9 : Ambient::shade

```
Vec3f Ambient::shade(Ray& r, bool emit) const
{
  Vec3f rho_d = get_diffuse(r);
  Vec3f radiance(0.0f);

  for (int sample = 0; sample < samples; sample++)
  {
    Ray ray;

    bool inShadow = tracer->trace_cosine_weighted(r, ray);

    if (!inShadow)
    {
      Vec3f sampleRadiance = tracer->get_background(ray.direction);
      radiance += sampleRadiance * dot(r.hit_normal, ray.direction)
          ;
    }
  }
  radiance *= rho_d / samples;

  radiance += Lambertian::shade(r, emit);

  return radiance;
}
```

Listing 10 : sampler.h sample_cosine_weighted

```
inline CGLA::Vec3f sample_cosine_weighted(const CGLA::Vec3f&
    normal)
{
  // ref: http://www.rorydriscoll.com/2009/01/07/better-sampling/
  // ref: http://pathtracing.wordpress.com/2011/03/03/cosine-
      weighted-hemisphere/
  // Get random numbers
  const float r1 = randomizer.mt_random();
  const float r2 = randomizer.mt_random();

  const float theta = acos(sqrt(1.0f - r1));
  const float phi = 2.0f * M_PI * r2;

  // Calculate new direction as if the z-axis were the normal
  CGLA::Vec3f _normal(sin(theta) * cos(phi), sin(theta) * sin(phi),
      cos(theta));

  // Rotate from z-axis to actual normal and return
  rotate_to_normal(normal, _normal);
  return _normal;
}
```

(a) The bunny with sunsky lighting model, 4rpp, 15s



(b) The bunny with sunsky lighting model at 12am, with ambient light. 9rpp, 83s

Figure 9: The bunny in different light conditions. Ambient light adds much to the realism of the picture.

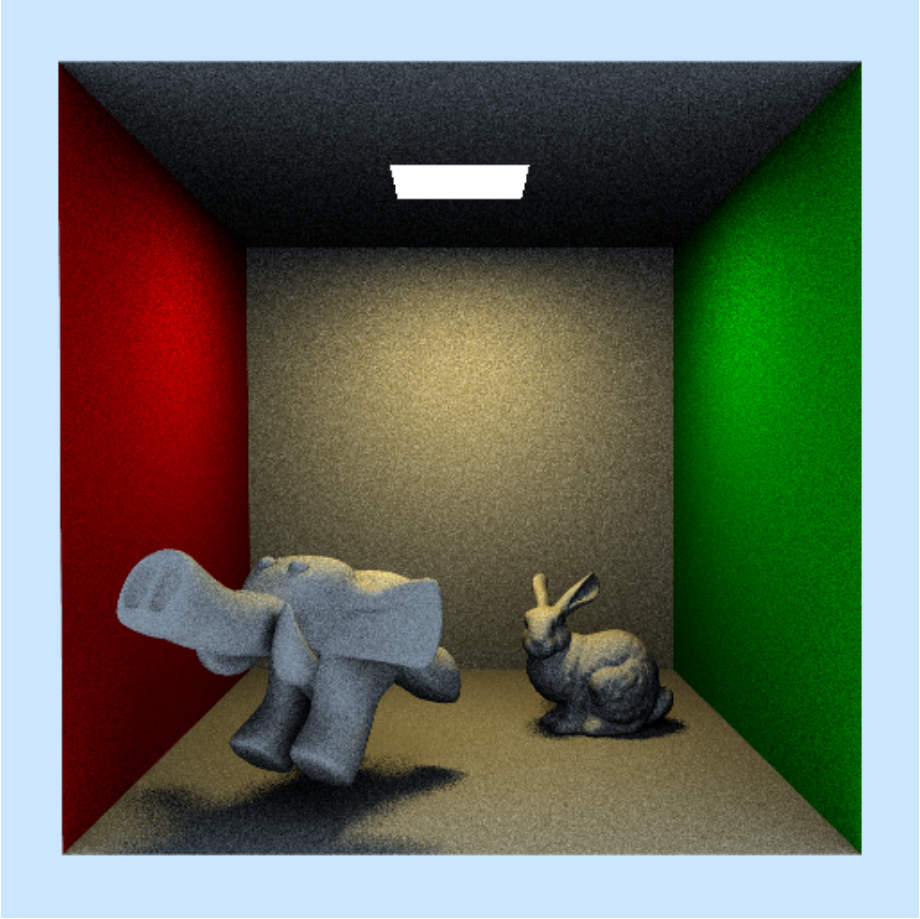
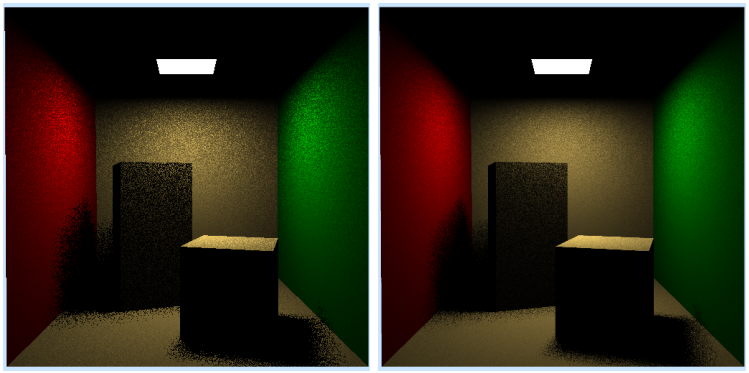
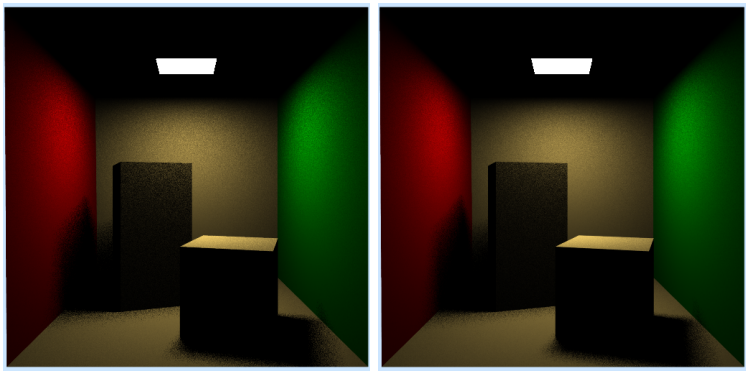


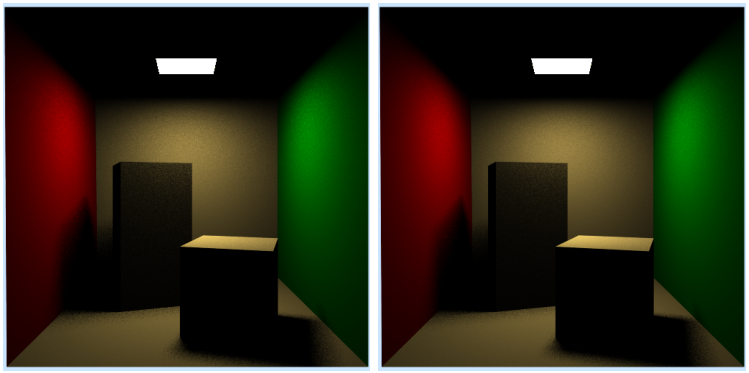
Figure 10: Bunny and elephant inside the cornellbox, ambient and area light. 9rpp, 36s, 5 samples



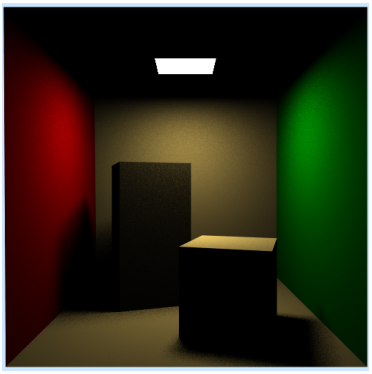
(a) 1rpp, 1s (b) 4rpp, 2s



(c) 9rpp, 5s (d) 16rpp, 10s

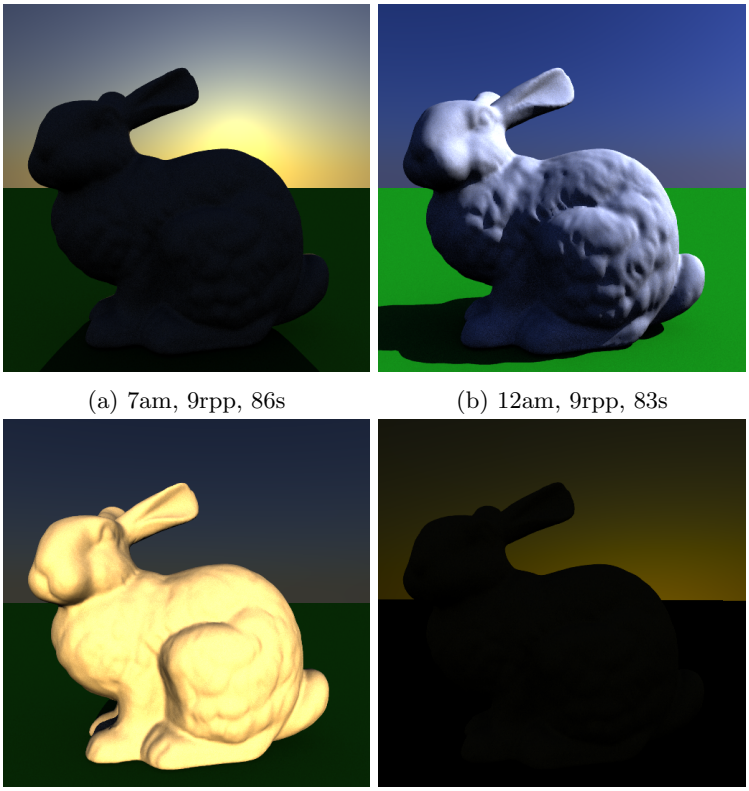


(e) 25rpp, 17s (f) 36rpp, 22s



(g) 49rpp, 34s

Figure 11: Different ray densities, between 1 to 49 rays per pixel.



(a) 7am, 9rpp, 86s (b) 12am, 9rpp, 83s

(c) 7pm, 9rpp, 84s (d) 7pm, 9rpp, 245s

Figure 12: The bunny at different times of the day. Lightmodel: sunsky, using ambient lighting