

Ray Tracing from the Ground Up

Errata December 29 2009

Errors

page

xix Erik Rienhard should be Erik Reinhard (Benjamin Hiller). My apologies to Erik.

11 The code statement

```
mattePtr->set_cd(RGBColor(r, g, b));
```

should be

```
matte_ptr->set_cd(RGBColor(r, g, b));
```

The code statement

```
void  
MattePtr::set_cd(const float r, const float g, const float b);
```

should be

```
void  
Matte::set_cd(const float r, const float g, const float b);
```

The code statement

```
mattePtr->set_cd(r, g, b);
```

should be

```
matte_ptr->set_cd(r, g, b);
```

22 The last equation should be $\cos(\theta \pm \pi/2) = \mp \sin\theta$. (Movania Muhammed Mubeen, John Whitlow).

28 The vector operations **ca** and **ac** return a point, not a double. (Christian Henning and Julian Amann).

34 The Section 2.10 heading should be **Solid Angle**.

35 The last two sentences of the first paragraph, and the second paragraph, should be replaced by the following:

The *solid angle* subtended at **p** by the object is 4π times the area a divided by the total surface area of the sphere. Solid angles are measured in steradians and are usually denoted by ω . Like 1D angles, solid angles are dimensionless.

Since the surface area of a sphere with radius r is $4\pi r^2$, the solid angle subtended at **p** is $\omega = 4\pi a / 4\pi r^2 = a / r^2$. When $r = 1$, $\omega = a$ steradians. The maximum value of a solid angle is 4π steradians, which is the solid angle subtended at a point by an object that completely surrounds it. (Lai Steven).

37 In Equation (2.12) the factor of 2π is missing from the expression after the second = sign. (Nelson Max).

53 The assignment operator should be removed from the `ShadeRec` class declaration in Listing 3.3 because the `ShadeRec` class does not have an assignment operator. See the discussion on page 54.

54 In Equation (3.4), the " \bullet " is missing from $(\mathbf{a} - \mathbf{o}) \bullet \mathbf{n}$.

55 The caption for Listing 3.4 should be "Declaration of the `Plane` class". (Kazuhiro Shigekuni).

76 The first paragraph of the **Notes and Discussion** section refers to filtering code in Chapter 4, but there is no filtering code in Chapter 4, or anywhere else in the book.

96 The last sentence in the first paragraph after Listing 5.2 should be: See Figure 5.6 for examples. (Nelson Max).

106 There is a missing "`}`" after the inner for loop in Listing 5.10.

108 In Equation (5.1), the $1/n$ on the RHS should be i/n . (Sylvain Henry).

109 In Listing 5.11, the statement

```
x += f * (double) (!j & 1);
```

should be

```
x += f * (double) (j & 1);
```

(Sylvain Henry).

123 In Listing 6.1 two comments have a line throw where the last part of the comment has been typeset on a new line. These are:

```
// sample point on unit disk
// avoid division by zero at origin
```

Although the code in Listing 6.1 executes correctly on my system, the following changes should be made:

```
Replace  phi = 2 - sp.x / sp.y;    with    phi = 2.0 - sp.x / sp.y;
          phi = 4 - sp.y / sp.x;    with    phi = 4.0 - sp.y / sp.x;
          phi = 6 - sp.x / sp.y;    with    phi = 6.0 - sp.x / sp.y;

and      disk_samples[j].x = r * cos(phi);
          disk_samples[j].y = r * sin(phi);

with     disk_samples.push_back(Point2D(r * cos(phi), r * sin(phi)));
```

127 The second sentence of paragraph 2 should be: From Equation (7.1), $d > 0$ $\forall \theta \in [0, \pi/2)$ and $\forall e \geq 0$.

143 The Listing 8.1 caption should be `World::render_perspective` instead of `World::renderScene`.

145 The images in Figure 8.19 are old versions. The correct versions are in the Chapter 8 and Ray Traced Images downloads. The objects in the new images are the same as those in Figure 8.16.

162 In paragraph 3, line 6, "initiative" should be "intuitive". (Mark Hall).

- 180 Question 10.4 should state that Figure 10.13 was rendered with one regular lens sample per pixel.
- 184 In the footnote, y^0 should be y_n .
- 190 Figure 11.8(c) was rendered with $fov = 200$ degrees, not $fov = 100$ degrees as stated in the caption.
- 219 The units of radiant intensity should be $[W \cdot sr^{-1}]$ instead of $[W \cdot m^{-2} \cdot sr^{-1}]$. (Ugo Erra, Ivan Haralampier).
- 228 In Figure 13.7, `samplerPtr` (near the top) should be `sampler_ptr`.
- The paragraph above Figure 13.7 states that each material will contain at least one BRDF. This is not correct since the `Emissive` material discussed in Section 18.5 does not use any BRDFs.
- 229 In Listing 13.1 the function declarations `BRDF::f` and `BRDF::sample_f` have the last two parameters `wi` and `wo` written in the reverse order to the way the code is written. The code has these in the order `wo, wi`. The code samples later in the book that call these functions have the arguments in the correct order. See for example Listing 14.14.
- 230 Same problem in Listing 13.2 as on page 229.
- 231 Same problem again in Listing 13.3 for the function `Lambertian::f`.
- 239 **Section 13.11.2 Importance Sampling** should be numbered **13.11.3**.
- 258 The following errors are in Listing 14.3:
- The declaration `Vector3D location` should be `Point3D location`. (Brendan Cook).
- In the `PointLight::get_direction` definition, `sr.hitPoint` should be `sr.hit_point`.
- The two `const` declarations in the `PointLight::L` definition should be removed. This function can't be `const` because `AmbientOccluder::L` assigns values to the `AmbientOccluder` class data members `u`, `v`, and `w`. See Listings 17.1 and 17.5. It might be possible for the parameter `sr` to be `const`.
- 261 The `ShadeRec` declaration in Listing 14.6 is missing the ray parameter data member: `double t`. This is assigned in Listing 14.8, but only used to simulate colored transparency in Chapter 24. Listing 14.6 is also missing the destructor declaration: `~ShadeRec(void);`.
- The two `ShadeRec` constructors in Listing 14.7 are missing the `color` data member, which is used in Chapter 3.
- 265 The last paragraph refers to 25 cylinders in Figure 4.15. This should be 4 cylinders.
- 266 The Figure 14.15 caption should state that from left to right: $k_d = 0.1, 0.4, 0.7, 1.0$.
- 273 The first line after Listing 14.15 should state that the light is 1.5 times as bright as in Figure 14.22(a), not twice as bright.
- 277 In the expression for L in Exercise 14.5, " b " should be " l_s ".
- 282 The reference to Equation (15.9) in the bottom line should be to Equation (15.8). (Kent Barber).

- 284 The last paragraph refers to the spheres in Figure 15.7, but it should refer to cylinders. (Mark Hall).
- 285 The reference to Equation (15.9) in the first paragraph should be to Equation (15.8). (Kent Barber).
- 285 The first paragraph refers to the spheres in Figure 15.7, but it should refer to cylinders. (Mark Hall).
- 285 The statement `Vector3D wo = -sr.ray.d;` should be `Vector3D wo = -sr.ray.d;` The "=" is missing. (Ugo Erra and Kent Barber). However, it's more efficient to use `Vector3D wo(-sr.ray.d);`
- 297 The last sentence should be:

Its direction is the light's unit direction vector at \mathbf{p} :

$$\mathbf{l} = (\mathbf{l}_p - \mathbf{p}) / \|\mathbf{l}_p - \mathbf{p}\|.$$

(Ugo Erra).

- 301 The last line before Figure 16.9 states that "Figure 16.9 is the same as ... ". It should be "Figure 16.9(a) is the same as ...".
- 308 Question 16.5 states that there is sample code on the book's website for clip maps. There is currently no code on the site for these.
- 312 The last data member in the `AmbientOccluder` class declaration is `RGBColor min_amount;`, which is incorrect. This needs to be replaced with:

```
float      ls;
RGBColor   color;
float      min_amount;
```

- 319 The images in Figure 17.8 are incorrect. The correct images are in the Chapter 17 and Ray Traced Images downloads.
- 339 In the first sentence, "Figure 18.4(b) and (c) " should be "Figure 18.4(a) and (b)". (Mark Hall).
- 341 The integral in Equation (18.5) should be over $2\pi^+$, not 2π , the π should not be italic, and the domain should be typeset larger.
- 342 The `in_shadow` function in Listing 18.14 should be declared `virtual`.
- 343 In Listing 18.15 the statement

```
v = (0.0034, 1, 0.0071) ^ w;
```

should be

```
v = Vector3D(0.0034, 1, 0.0071) ^ w;
```

(Patrick Bezzima).

- 344 The third statement in Listing 18.17 should be `emissive_ptr->scale_radiance(1.0);`
- 347 The equation at the bottom should be $\mathbf{n} = \nabla(x, y, z) / \|\nabla(x, y, z)\|$.
- 349 Question 18.3 should be: How do directional and point lights work without modification with the `area_light_shade` functions?

351 Exercise 18.4 should ask you to use the Figures in Section 18.9 to test your implementation, not Section 18.7.

357 The reference to six floats in the second paragraph should be to six doubles.

358 In the last line, (6 floats) should be (6 doubles).

360 The comment at the start of Listing 19.3 states that the first part of the `Box::hit` function is the same as Listing 19.1 down to the statement `float t0, t1`; Other than fact that it should be `double t0, t1`; this comment is not quite correct. The `BBox::hit` function in Listing 19.1 does not have to declare the local variables `x0, x1, y0, y1, z0, z1` because these are data members of the `BBox` class. In contrast, the `Box` class stores the opposite corner coordinates in two vectors `p0` and `p1`. The `Box::hit` function therefore has to include the local variable declarations

```
double x0 = p0.x; double y0 = p0.y; double z0 = p0.z;
double x1 = p1.x; double y1 = p1.y; double z1 = p1.z;
```

(Mark Kim).

367 In Listing 19.6, the statement `double r = r * e * l - h * i`; should be `double r = e * l - h * i`; (Kent Barber).

371 In the second paragraph, the `Rectangle` data member names `a_lenSquared` and `b_lenSquared` should be `a_len_squared` and `b_len_squared` respectively.

382 The `ConvexPartSphere` at the top of Listing 19.10 should be just `PartSphere`. (Tim Biedert).

386 In Listing 19.11 the `Compound::add_object` function should be declared `virtual void` because the class `Compound` inherits this function from the base class `GeometricObject`, and redefines it. See also the errata for page 453.

386 The "const" should be removed from `add_object(const GeometricObject* object_ptr)`. (const pointer arguments generate a compiler warning on my system, but still work).

387 In Listing 19.13, the "const" should be removed from the `Compound::set_material` function.

394 In the code fragment, `OpenCylinder` should be `SolidCylinder`, and the "const" should be removed.

423 The ***n*** on the RHS of Equation (21.13) should not have a prime.

424 There are some primes in the wrong places.

In the first paragraph, the equation $\mathbf{n}' = [n'_x, n'_y, n'_z, 0]$ should be $\mathbf{n} = [n_x, n_y, n_z]$.

The ***n*** on the LHS of Equation (21.14) should have a prime

430 Listing 21.7 is the build function for the ellipsoid in Figure 21.5, not Figure 21.2.

441 In Question 21.12, the statement on line 5 that "there's not a huge choice of numbers to pick from" needs to be qualified. If we allow the angular range of the wedges to be less than one degree, there's actually an infinite number of choices. For example, if each wedge is half a degree wide, there will be 720 of them in a ring. But, if we want the wedges in Figure 21.17 to look attractive, for example, not too narrow, then there is a limited choice of numbers.

- 446 In Listing 22.1 the ray parameters in the `Grid::hit` and `Grid::shadow_hit` function headers should be declared as `const Ray& ray`. The `ShadeRec` parameter in `Grid::hit` should be called `sr` for consistency. (Kent Barber).
- 452 The statement `cells.reserve(num_objects);` should be `cells.reserve(num_cells);`. (Kent Barber).
- 450 The third paragraph has the following sentence: I use (22.2) because it has a small footprint and runs fastest on my computer. This idea comes from Shirley (2000), and although it's not an errata, I should have referred readers to the Further Reading section of Chapter 22, where this is discussed.
- 453 In Listing 22.4, the statement `cells[index]->add_object(objects[j]);` will not compile unless `add_object` is a member function of the class `GeometricObject`. (`cells[index]` is a `GeometricObject` pointer). The original skeleton programs' code did not include this function in the `GeometricObject` class. This created problems when people added the `Grid` class to the skeleton programs and tried to compile it. The current versions of the skeleton programs now include it, and it's also included in the code download on the website. See also the errata for page 386. (Paul Heraty).
- The end parenthesis ")" is missing from the statement `for (int iz = izmin; iz <= izmax; iz++)`. (Kent Barber).
- The code `"index = 1"` at the end of the first `counts[index] += 1;` statement should be the comment `// counts[index] = 1;`. The comment `// index = 2` further down should be `// counts[index] = 2;`.
- 462 In Listing 22.8, the three calls to `randf` in the statement `matte_ptr->set_cd(randf(), randf(), randf());` should be calls to `rand_float`.
- 466 In Listing 22.9, `shadow_hitt` should be `shadow_hit`. To be consistent with other class declarations, this should also be declared after the `hit` function declaration.
- 472 The same image has been used for all parts of Figure 22.18. The correct images are in the `RayTracedImages.zip` download, and the `Chapter22.zip` download.
- 478 In Figure 23.5, the function `interpolate_normals` should be `interpolate_normal`.
- 479 In Listing 23.3, the boolean expression `(beta < 0.0 || beta > 1.0)` should just be `(beta < 0.0)`, and `(gamma < 0.0 || gamma > 1.0)` should just be `(gamma < 0.0)`.
- 494 L_i should be L_o in Equation (24.1) and the first line after this equation.
- 511 The caption for Figure 24.20(a) states that there are four reflective spheres with a Phong material. The reference to the Phong material should be removed as the material `Reflective` inherits from `Phong`.
- 518 The (3K) Stanford bunny should be the (4K) Stanford bunny.
- 527 Exercise 24.19 states that a paraboloid class is on the book's website. Currently, this is not on the website.
- 533 The reference to Figure 24.5(a) in the second paragraph should be to Figure 25.5.
- In the footnote, θ_1 should be θ_o .
- 541 The reference to uniform sampling in Question 25.2 should be to regular sampling.

- 554 In the bottom paragraph the code fragment `material_ptr-global_shade` should be `material_ptr->global_shade`.
- 556 In Listing 26.7 the code `return_le`, should be removed from the third line from the bottom.
- 571 In the line above Equation (27.10), the reference to Equation (27.8) should be to (27.9).
- 578 All three images in Figure 27.13 are the same. The correct images are in the ray traced images download and the Chapter 22 download.
- 588 The references to the z -axis in Question 27.13 should be to the y -axis.
- 589 The references to the z -axis in Question 27.13 should be to the y -axis.
- 599 In the first paragraph of Section 28.3 there are two BRDFs that should be BTDFs. In the first sentence: "a BTDF to handle the transmission", and in last sentence: "the BTDF will also need ..."
- 605 Figure 28.6(c) is labelled Figure 28.6(b).
- 630 The equation

$$x_c = [(r_0 - r_m)^2 - (h + r_m)^2]^2$$

should be

$$x_c = [(r_0 - r_m)^2 - (h + r_m)^2]^{1/2}.$$

- 635 In the first sentence of Question 28.13 the word "too" should be removed.
- In the second paragraph of Question 28.13, the two references to Figure 28.45 should be to Figure 28.46.
- 636 The third line of Question 28.16 states that the top halves of the spheres are yellow. They are actually orange.
- 647 The statement that the spatially varying versions of the functions `rho`, `f`, and `sample_f` have a `ShadeRec` reference as an addition parameter, is incorrect. Because all versions of these functions must have the same public interface, the `ShadeRec` parameter has always been present. See Listing 13.1. Non spatially varying BRDFs such as `PerfectSpecular` and `GlossySpecular` also use this parameter.
- 648 The last sentence states that the only difference between the functions `Matte::shade` in Listing 14.14 and `SV_Matte::shade` in Listing 29.5 is that `SV_Matte::shade` calls the spatially varying versions of `rho` and `f`. This part of the code is actually same because both versions of `rho` and `f` have the same interface. See Listings 13.3, 13.4, and 29.3. However, `SV_Matte::shade` contains code for shadows, which `Matte::shade` in Listing 14.1 does not. Also, `compute_direction` should be `get_direction`, and on page 649, `light->G(sr)` should be removed. The corrected version of Listing 29.5 is in the Chapter 29 download.
- 659 In Listing 29.8, `get_pixel_coordinates` should be `get_texel_coordinates`.
- 669 The images in Figure 29.27 are incorrect. This is discussed in the document **NotesOnTexuring.pdf** in the Chapter 29 download. The corrected images are in this document, and the Chapter 29 and Ray Traced Images downloads.

The URL in the Figure 29.27 caption should be <http://www.lfggrafix.com>. The link on the website's Links page is correct.

706 In the third paragraph Peachy (1998) should be Peachy (2003).

711 In Equation (31.5), $(1/2)^{n-1}$ should be $(1/2)^n$. This occurs twice. The code in the Chapter 31 download is correct. Because fractal sum noise is a subset of fBM noise, there is no specific fractal sum code. See also the errata for page 715.

715 In Equation (31.8) $gain^{n-1}$ should be $gain^n$. This occurs twice. The code in the Chapter 31 download is correct. The relevant function is `LatticeNoise::compute_fbm_bounds`.

The consequences of the errors on pages 711 and 715 are discussed in the document **ReadMe31.pdf** in the Chapter 31 download. Most of the ray traced images in Chapter 31 have been re-rendered, and are now correct.

726 In the Figure 31.34(d) caption, the scaling factors should be (2.0, 0.2, 2.0).

729 The last sentence in Exercise 31.6 should be "...using two and three colors".

Ambient occlusion problem

Chapter 17 Images

The ambient occlusion ray traced images in Chapter 17 are incorrect because I used a cosine ($p = 1.0$) distribution in the polar angle for the shadow rays instead of a constant ($p = 0.0$) distribution. Any non-uniform sample distribution requires the Monte Carlo estimator (13.40) to be used with a matching pdf. As I wanted to keep this chapter as simple as possible, I used the Monte Carlo estimator (13.31) for a uniform sample distribution. This is, of course inconsistent with using a cosine distribution. As a result, the images that are too dark in the occluded regions because not enough rays are cast there.

The problem is simple to correct. In Listing 17.2 on page 313 just replace "1" with "0.0" in the statement `sampler_ptr->map_samples_to_hemisphere(1);`. You don't have to change any build functions.

Parts of the text in this chapter should also be changed accordingly.

Corrected images for Figures 17.3(b), 17.4, 17.6, 17.7, and 17.8 are in the Chapter 17 and Ray Traced Images downloads. The other ray traced images in this chapter also need to be re-rendered.

Chapter 18 Images

In Chapter 18, the following figures use ambient occlusion: the page 1 figure, and Figures 18.7(a), 18.7(c), 18.8, 18.9, 18.10, and 18.11. Figures 18.7(a), 18.7(c), 18.8, and 18.9 are in the Chapter 18 and Ray Traced Images downloads.

Chapter 29 Images

Figure 29.27 uses ambient occlusion. The corrected images are in the Chapter 29 and Ray Traced Images downloads. See also the errata for page 669.

Doubles and floats

The ray tracer uses doubles for intersection calculations and floats for shading, but a number of code examples use floats where they should use doubles. These are mainly the "t" or "tmin" parameters of `hit` and `shadow_hit` functions, local variables in these functions, and physical parameters of geometric objects. All code currently available on the website, or to be placed on the website, is written consistently.

The following is a list of affected code examples where floats should be replaced by doubles.

Listing 14.4	The <code>tmin</code> parameter in the <code>World::hit_objects</code> function declaration.
Listing 14.8	The local variables <code>t</code> and <code>tmin</code> in the <code>World::hit_objects</code> function.
Listing 14.9	The <code>tmin</code> parameter in the <code>Tracer::trace_ray</code> function declaration.
Listing 16.2	The local variables <code>t</code> and <code>d</code> in the <code>PointLight::in_shadow</code> function
Listing 16.3	The <code>tmin</code> parameter and the local variable <code>t</code> in the <code>Plane::shadow_hit</code> function.
Listing 19.7	The local variable <code>t</code> in the <code>Disk::hit</code> function.
Listing 19.8	Three local variables in the <code>Rectangle::hit</code> function.
Listing 19.12	The local variable <code>t</code> in the <code>Compound::hit</code> function.
Listing 19.14	All six floats.
Listing 21.4	The local variable <code>t</code> in the <code>Plane::hit</code> function.
Listing 21.6	The parameter in the <code>Instance::hit</code> function.
Listing 21.9	All four parameters of the <code>BeveledCylinder</code> constructor.
Listing 22.1	The <code>tmin</code> parameter in the <code>Grid::hit</code> and <code>Grid::shadow_hit</code> function declarations.
Listing 22.3	All three parameters of the function <code>clamp</code> .
Listing 22.4	The local variables <code>wx</code> , <code>wy</code> , <code>wz</code> , <code>multiplier</code> , and <code>s</code> in the <code>Grid::setup_cells</code> function.
Listing 22.6	All four floats.
Listing 22.8	The local variables <code>volume</code> and <code>radius</code> in the <code>World::build</code> function. Also, 3.14159 should be π , and there should be more decimal points in 0.333333. None of these changes will affect the computations because the radius will be cast to a double when it's stored in the sphere.
Listing 22.9	All five floats.
Listing 22.10	All three parameters of the <code>Instance::translate</code> function.
Listing 23.3	The <code>tmin</code> parameter of the <code>FlatMeshTriangle::hit</code> function.
Listing 28.3	The local variable <code>t</code> in the <code>Dielectric::shade</code> function.
Listing 28.4	The <code>tmin</code> parameter of the <code>Whitted::trace_ray</code> function.
Listing 29.12	The <code>tmin</code> parameter of the <code>SmoothMeshTriangle::hit</code> function.

Typographic matters

page

- xvi In paragraph 3, line 2 in the **Pathways through This Book** section, "Although" should be removed.
- 37 In Equation (2.12) the upper limit of the integral sign (the digit 1) is not centered properly; the right bracket is not printed correctly.
- 74 In Listing 3.15, blank lines should be removed from the function declarations `World::build` and `World::render_scene`.
- 97 In the Listing 5.5 caption, `setSamples` should be `set_samples`.
- 153 The thin vertical line on the right of Figure 9.3 should not be there.
- 224 The "+" superscript after the π in the last line is too small.
- 241 In Equation 13.40 the italic x in the numerator and denominator should be bold italic **\mathbf{x}** .

- 271 In Listing 14.14 `numLights` should be `num_lights` (twice). This is just for naming consistency.
- 273 Listing 14.15, `light_ptr2` should be just `light_ptr` (four times).
- 277 In Question 14.3, `World::hit_objects` should be in a larger font size.
- 311 In the first line, k_a and k_d should be k_a and k_d respectively.
- 333 In line 5 of the second last paragraph, there should be a "the" before the first "area".
- 342 The three π 's in the first equation should not be italic.
- 365 The variables in Equation (19.10) are typeset in bold italic. They should just be italic. The matrix brackets are also in typeset in bold, and should not be.
- 384 The right border is missing from Figure 19.21(b).
- 435 The last sentence in the second paragraph: "The beveled wedge class is on the book's website." should be removed because this statement is repeated at the top of page 436.
- 450 In the second Equation in (22.4) the expression between `[]` should not be bold.
- 494 The domain of the integral in Equation (24.1) should be typeset larger, and the π should not be italic.
- 570 The two η 's in Figure 27.8 are "too italic".
- 597 The equation $\sigma = (\sigma_r, \sigma_g, \sigma_b)$ in the paragraph before Equation (28.10) should be $\sigma = (\sigma_r, \sigma_g, \sigma_b)$.
- 648 The word constructors is misspelt in Listing 29.4.
- 660 In Listing 29.10, the three statements that set `ka`, `kd`, and `cd` for the `sv_matte_ptr` material have a space before the "->". These spaces should be removed. There are a number of other extra spaces in this listing.
- 663 In Figure 29.20, `compute_normal` should have (...) after it.
- 668 In Exercise 29.1 `JPG` should be `JPEG`.
- 669 In Exercise 29.7 `JPG` should be `JPEG`.
- 726 In the Figure 31.34(b) caption "scaling" should be "scaled".