Radiance
Tutorial

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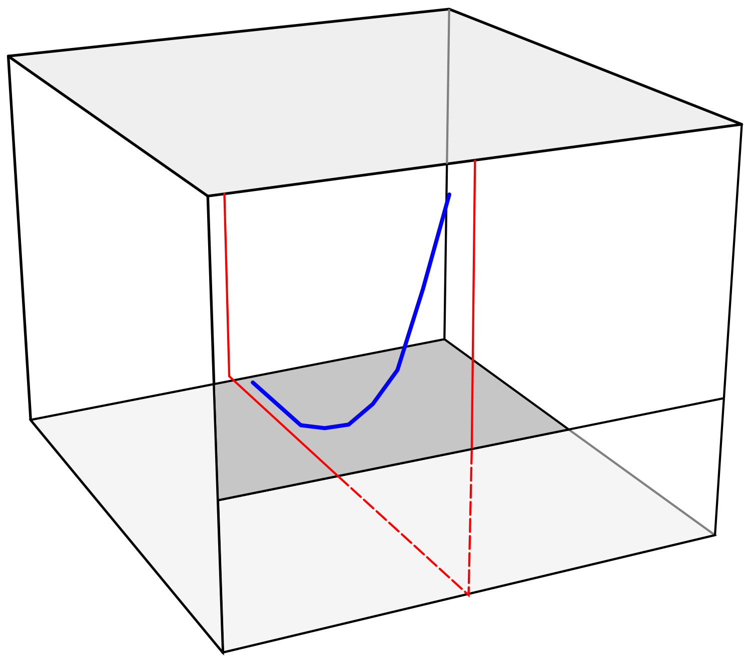

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Revision History

23 Jan 2012

- Fixed minor inconsistencies
- Reflect changes in Radiance 4.1, Dec 2011 (rpict -w) and Radiance HEAD, Jan 2012 (falsecolor)

19 Dec 2010

- Fixed a few inconsistencies

2 Apr 2010

- Moved section 'Secondary Light Sources' to the Cookbook. I haven't found the time to cover it for about five years;
- Derived a simplified formula for the transmissivity in Appendix A.1.1, but put all the explanations in the Cookbook.
- Some tidying up

25 Oct 2008

- Decided to eat my own dog food and be consistend with the recommended file structure and naming conventions as laid out in A.3
- Some tidying-up

26 May 2008

- Added suggested directory structure for projects to the appendix
- Fixed a type with the transmittance formula in the appendid and added a graph
- Moved the Introduction to UNIX to a separate document.
- Change tables to the more formal tabular formatting, newly introduced in LyX 1.5
- Unified the hand-made bibliographies to BibTEX
- Added info on gamma correction to image conversion

26 Dec 2006

- Changed the section dealing with illuminance plots so that the measurement points are read in from a file, and not generated by `cnt`. Many students find the use of `rcalc` too confusing, and it's not necessary here. The old `cnt|rcalc` version is now in the Advanced Tutorial.
- Updated the `falsecolor` pages.
- New section on wild cards
- Added index
- Updated CAD import and primitives sections
- Added margin icons for files in the ZIP archive

10 Nov 2006

- Added nicer front page and page headers

- Put all images into floats and gave them captions
- Added reference to Colour Picker on LUXAL
- Corrected a few typos here and there

6 June 2006

- More explanation on using `rcalc` in 5.2.

18 Feb 2005

- Added 4.2 Ambient Parameters which is essentially copied from *rpict.options*
- Added rule of thumb for setting an appropriate `-av` (based on exposure)
- Increased font size to 11pt for better readability

19 Dec 2004

- Added this revision history
- Added chapter 3: Previews, Visualisation and Image Conversion
- Changed all reference from `rview` to `rvu`
- Included examples for textures and patterns in 2.1 General Information and Syntax
- Updated the listing of the ambient default settings for `rvu` in 4.1 Ambient Calculations to reflect the new settings in Radiance 3.6
- Scrambled author's email addresses on front page to block email harvesters

About the Use of Fonts

Several different fonts are used throughout this document to improve its readability:
`typewriter`: commands, file listings, command lines, console output
italics: paths and file names
sans serif: Radiance primitives, modifiers, identifiers

Suggested Reading

There are number of different Radiance study guides and tutorials available with LEARNIX [3]. Figure 1 illustrates the optimal work flow that will give you the best understanding in the shortest amount of time.

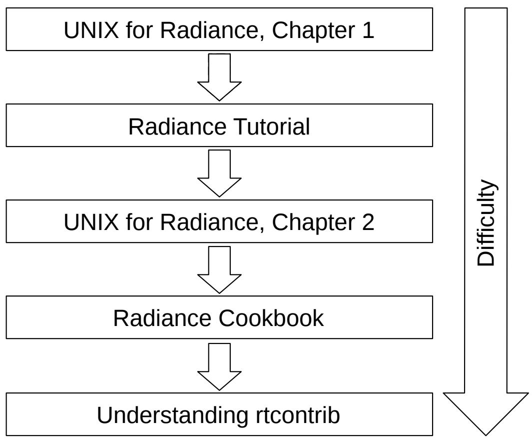


Figure 1: You are strongly encouraged to follow this path while studying the LEARNIX documentation.

You are encouraged to follow this suggestion. If you do feel proficient enough to skip certain sections of a particular document, or even an entire document, you might miss out on some important information that later sections rely upon. Simply skipping over parts that you might find boring or otherwise un-interesting will leave serious gaps in your understanding of Radiance. It is important that you try to understand all exercises, and you absolutely MUST do them yourself. Don't just flick through the pages and look at the pictures.

There are other sources of information, namely:

- The man pages [6],
- The official Radiance web site [7],
- The Radiance mailing list and its archives, available through the Radiance community web site [10],
- The book *Rendering with Radiance* [9].

You may consult them at any time, either while studying with the help of the resources on LEARNIX, or afterwards. Good luck with your efforts.

1 Introduction

1.1 What is Radiance?

Radiance is a sophisticated lighting visualisation system. Originally started off as a research project at the Lawrence Berkeley Laboratories, it has evolved into an extremely powerful package that is capable of producing physically correct results and images that are indistinguishable from real photographs.

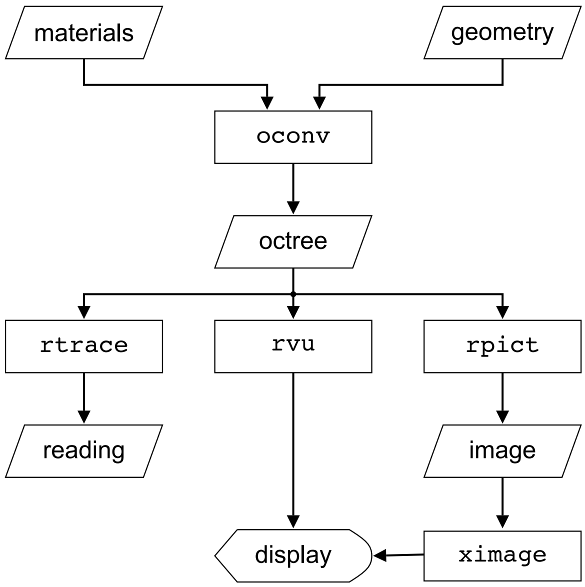


Figure 2: The main components of the Radiance rendering system

Its versatility makes Radiance the ideal choice not only for 'serious' researchers but also for architects, lighting designers and other professionals. Although a challenge to learn, Radiance, especially in a UNIX environment, is capable of producing results that no other visualisation package can achieve.[9]

1.2 Ray-tracing vs. Radiosity

Radiance employs backward ray-tracing algorithms. This means that the light 'rays' are traced back from the point of measurement or view to the light source. There are a number of other ray-tracers on the market because the basic principle is relatively simple to implement on computers. However, where Radiance stands out is its ability to handle diffuse inter-reflections between objects. Very efficient algorithms together with caching are applied for this. Other packages usually try to equate for indirect contributions by defining the 'ambient' light that has no real source and somehow is everywhere. Examples for other ray-tracers include POV or 3DStudio Max.

Because the calculations are started from the view point, an entirely new calculation has to be done for each individual view. Walk-throughs and videos are therefore extremely resource-hungry requiring fast computers and a lot of time.

There is another conceptually different approach to compute light distributions. This method is called radiosity. Radiosity-based algorithms start off with the energy that is radiated from the light source. Assuming diffuse reflectance properties of the objects, the incoming energy is then modified by the material's reflective properties and bounced back into the room. This is done until the contribution of the reflected light towards the average illuminance in the scene becomes insignificant.

The energy distribution of the entire scene is calculated and stored. This means that once all the calculations are done, new view points can be created in no time at all. This makes the radiosity solutions ideal for the creation of virtual worlds such as VRML. Scenes created this way can usually be told because of their lack of reflective and transparent surfaces, although newer software implements get-arounds to these problems. A typical example of a simulation package that uses radiosity is VIZ (ex Lightscape) by AutoDesk.

1.3 Do it the UNIX Way

The Radiance source code is freely available for download from the Internet. Radiance was developed to run on UNIX machines. Part of the reason is that in the early 1990s when Greg Ward started writing Radiance, computers were very slow compared to today's machines. It did not make sense to run processing intensive applications such as ray-tracers on desktop PCs. Most 'serious' workstations, operated under UNIX which provides a multitasking environment.

It is the UNIX philosophy to have very modular software. This is in stark contrast to the concept that MS Windows and the Mac OS follow. They aim to provide GUI-based software packages that do everything the average user could possibly ask for and a lot more. The drawback with this is that the software can only do what its designers had in mind when they programmed it.

Radiance in contrast consists of more than 100 individual programs. This makes it extremely flexible. By defining options and chaining together two or more programs, a maximum flexibility can be achieved. Unfortunately, it also means that a steep learning curve is the price to pay.

Please refer to the separate UNIX for Radiance document for an introduction to UNIX and use of the command line [5]. It is **essential** that you study Chapter 1 of that document before proceeding further! !

2 Describing a Scene in Radiance

2.1 General Information and Syntax

Radiance uses a Cartesian (rectilinear) coordinate system. All information is stored in ASCII text format, so it can be edited with any text editor. Please refer to appendix A.2 for some commonly used file name extensions.

There are 4 basic types of primitives:

Geometry: source, sphere (bubble), polygon, cone (cup), cylinder (tube), ring, mesh, instance

Materials: light, illum, glow, spotlight, mirror, prism1, prism2, mist, plastic, metal, trans, plastic2, metal2, trans2, dielectric, interface, glass, plasfunc, metfunc, transfunc, BRTDfunc, plasdata, metadata, transdata, antimatter

Textures: texfunc, texdata

Patterns: colorfunc, brightfunc, colordata, brightdata, colorpict, colortext, brighttext

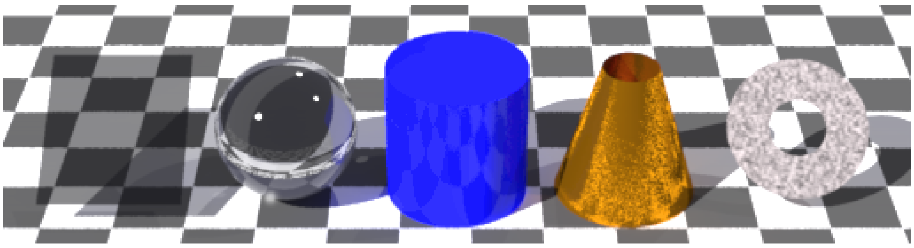


Figure 3: Some of the Radiance primitives (from left to right): a polygon of type glass, a sphere of type dielectric, a cylinder of type plastic, a cone of type metal, a ring of type plastic with a brightfunc texture applied

The syntax for any primitive follows this scheme:

```
modifier type identifier
n S1 S2 ... Sn
0
m R1 R2 ... Rm
```

The type has to be one of the predefined surface, material, pattern or texture types that are known to Radiance. The identifier can be freely chosen but should be unique within your project. Please refer to Appendix A.1 for the most commonly used primitives and their parameters, or to [8] for a full list of primitives and their parameters.

Before a surface primitive can be used, a material primitive must exists whose identifier is the same as the modifier of the surface primitive. By chaining several material and texture/pattern descriptions together, very detailed and realistic materials can be defined. This chain is shown in Fig 4. While material and geometry primitives are always required, textures and patterns are optional.

The first primitive in this chain has no modifier, so void is used. The identifier of the first primitive becomes the modifier of the second one. We need at least one material primitive and one geometry primitive:

```
void plastic chairmat
                chairmat cylinder leg1
```

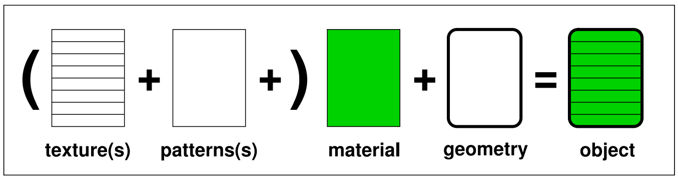


Figure 4: Describing an object

It is possible, however, to have more than one material applied to an object. In this case, the primitives are hooked up like a chain, connected by identifier-modifier pairs:

```
void brightfunc dusty
           dusty texfunc woody
                     woody plastic chairmat
                               chairmat cylinder leg1
```

Patterns modify the reflectance of a material, textures are perturbations of a surfaces normal. Below is one example of each, described by a mathematical model. The material descriptions are listed in Appendix A.5.

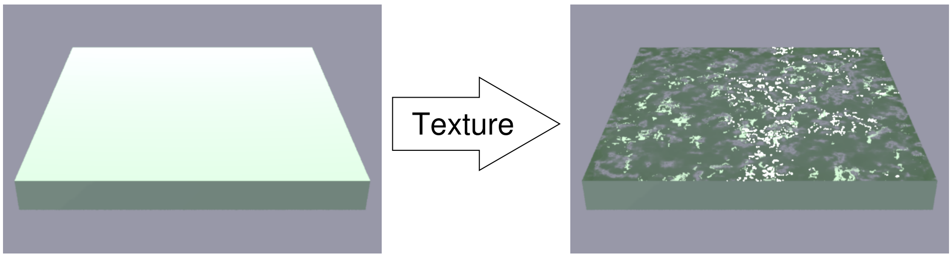


Figure 5: Example of a Radiance texture: Water

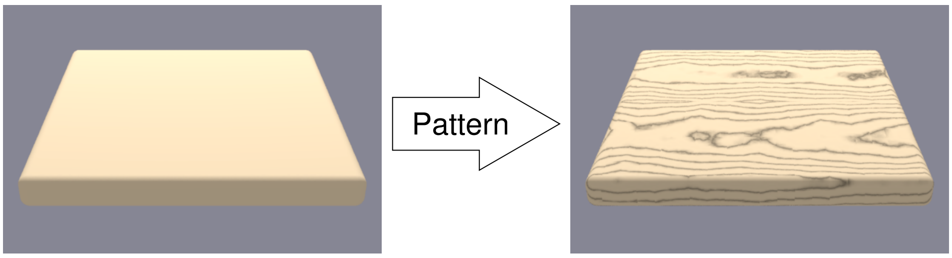


Figure 6: Example of a Radiance pattern: Wood

The second line in every primitive contains all string arguments that are needed to describe the primitive. The very first character ('n') is an indicator for the number of string arguments to follow.

The third line must always read 0. It was intended to be used for integer arguments when new primitives are introduced into Radiance but until now no primitive uses integer arguments.

The last line holds real arguments or floating point numbers. Again, the integer in front ('m') indicates the total number of arguments to follow.

Comments are preceded by a hash sign ('#') and proceed to the end of the line. If the first character in a line is an exclamation mark ('!'), then this is taken as a shell command. The line is executed and the result of this command returned.

2.2 Describing the Geometry

2.2.1 Approaches to Modelling

All Radiance scene files are stored as plain text. This allows us to edit them with any text editor. It is thus possible to build up a model by simply deciding which geometry primitives to use, and supplying the required coordinates, dimensions etc.

To aid in the creation of such hand-build models, Radiance comes with a number of helper programs that are commonly referred to as generators. You can get a list of available generators by running the following command in your terminal:

```
$ ls /usr/bin/gen*
genblinds
genbox
genclock
genprism
genrev
gensky
gensurf
genworm
```

In this tutorial, we will be using the `genbox` command to create a simple rectangular room, as well as `gensky` which defines the distribution of certain CIE-defined standard skies.

The complexity of hand-generated models is limited. You will find that generating the scene geometry with a CAD or 3D modelling package is more convenient and faster. Converters are available that allow us to export from a limited number of commonly used 3D file formats to Radiance. Such converters might be plug-ins to the relevant software package as is the case with the `su2rad` plug-in for Sketchup [12]. Others are command-line applications. Examples include converters for the 3DS, OBJ and DXF formats

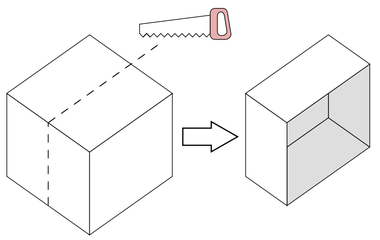
If you decide to use a CAD package for doing the modelling, you should be aware that objects can be modelled in different ways. A box, for instance, may be modelled as:

1. The six surfaces if the box. This is a surface model.

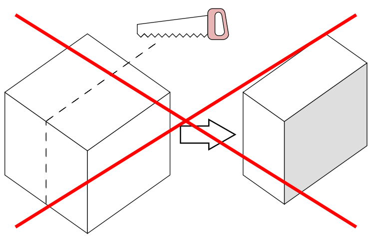
2. The volume contained by the box. A solid model.

Only surface models are suited for use in Radiance. See Fig 7. A well-written translator might be able to convert volume models into surface models, because all the necessary information is contained within the model. When in doubt consult the documentation of your CAD software.

Most CAD modellers will only export objects of type `polygon`. This is fine. Polygons are by far the most frequently used type of geometry. Just be aware that once a polygon is defined, you can't later cut a hole in it, e.g. to put in a window. If this is what you need to do, there are several options to your disposal. Some obvious and useful ones



(a) Surface model



(b) Solid model

Figure 7: Only surface models can be imported into Radiance.

are depicted in Fig 8. It's usually best to split up the larger polygon into smaller ones, leaving the opening free.

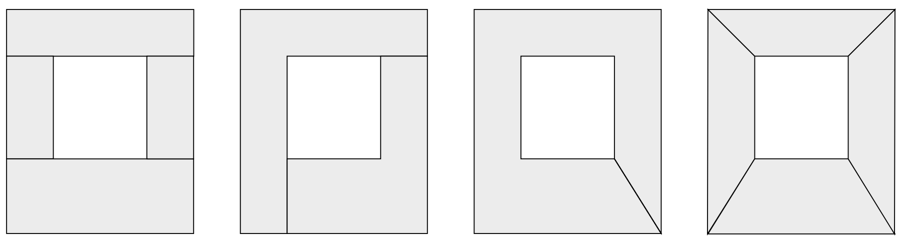


Figure 8: Cutting a hole into a polygon

2.2.2 Modelling Geometry

A Radiance scene should always be aligned so that the x-axis points East, the y-axis points North, and the z-axis points upwards to the zenith, as shown in Fig 9. This is in contrast to some 3D modelling packages which use x and y for the horizontal and vertical dimensions and describe the depth. i.e. the distance behind or in front of the computer screen with the z coordinate.

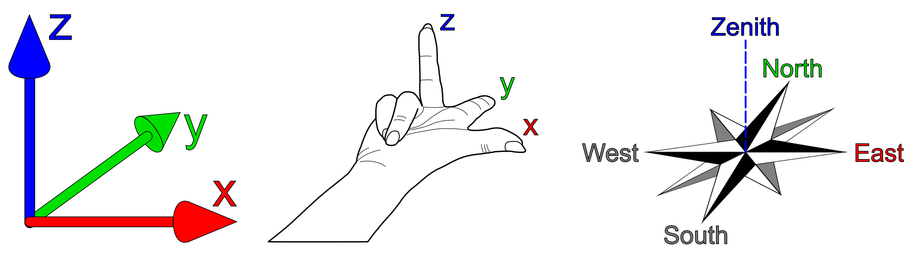


Figure 9: The Radiance convention on alignment of the coordiante system follows the right-hand rule

Sizes and distances can be given in any unit of length, as long as they are used consistently throughout the entire project.

When flicking through the Radiance User Manual [8], you will find that many surface primitives come in two flavors. An example is `sphere` and `bubble`. Both describe a ball-shaped object. The difference between the two is that a `sphere` has a surface normal that point outwards, whereas the normal of a bubble points inwards. As long as the -bv+ switch to rpict is set to turn on back-face visibility, this doesn't really matter for most materials. It does matter, however, for light sources and mirror. The different surface orientations also need to be remembered when using the genbox command and other generators. It creates outward pointing surfaces normals by default. To swap this, use the -i switch with genbox.

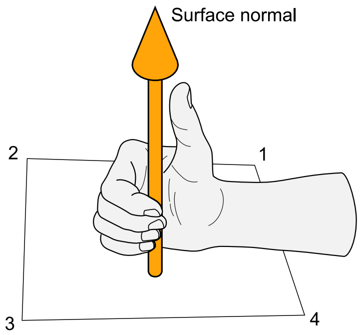


Figure 10: Direction of the surface normal

The surface normal follows the right-hand rule. Form a loose fist with your right hand but have your thumb stick up. Hold your hand in such a way that the axis defined by your thumb is perpendicular to the plane of the polygon. Now turn your hand around the thumb-axis following the direction given by the other four fingers. If the indices follow the same direction, the surface normal of the polygon is pointing into the direction of your thumb. Otherwise, it's the opposite. Please see Fig 10.

To get a rough idea about the dimensions and position of an object, use the getbbox command. It returns the minimum and maximum of an enclosing box along the x, y and z axis.

```
$ getbbox chair.rad
      xmin      xmax      ymin      ymax      zmin      zmax
         0       0.5         0       0.5         0         1
```

Use your favorite text editor to create the description of a sphere in a new file named *objects/things.rad*. The general syntax is:

```
modifier sphere identifier
0
0
4  xcent ycent zcent radius
```

Look at your first Radiance object with the objline command. It creates what is known as a meta file which can not be viewed directly. To display it on the screen, simply pipe it into x11meta.

```
$ objline objects/things.rad | x11meta
```

Click anywhere on the picture to quit. Also, see what getbbox returns when called with *objects/things.rad* now.

Next, use the genbox command to create a box. Append it to *objects/things.rad*. The general syntax for genbox is:

```
genbox material name xsize ysize zsize
```

Additional options are available, such as rounded or chamfered edges. Please refer to the `genbox` man page for details. Open *objects/things.rad* in a text editor and remove two or three adjacent faces. Look at the result with `objline`.

Create another box of different dimensions. This time, don't call it from the command line. Instead, put an extra line in *objects/things.rad* that calls the generator. Remember to begin the line with '!'.

We have just explored two different ways of calling generators:

- The first one creates quite large and cumbersome files but allows us to make modifications to individual parts of the object. Unfortunately, this is what most converters from CAD packages will produce. A perfect cylinder, for instance, which is very simple to model using a native Radiance primitive, will be split up into a number of polygons. The result will not look not very nice, unless a very large number of polygons is created. However, this will result in large file sizes.
- The second way is nice because it is only one line of text that we can easily understand. To change the size of the box only requires the alteration of one argument, compared to twelve coordinates done the other way. The drawback of this method is that only the whole object can be modified, not just parts of it.

For what we've done so far, no material definitions were required. This is going to change.

2.2.3 More Complex Scenes

The next exercise will produce something a bit more useful. We are going to build a simple room with a window opening. The room will then be used for our daylighting excercises.

1. Create a room that is 4.0 m wide (x-dimension), 5.0 m deep and 3.0 m high. Give it the material wall_mat. Call the `genbox` generator from the command line and direct the output of the command into a file *objects/room.rad*:

   ```
   $ genbox wall_mat room 4 5 3 > objects/room.rad
   ```

2. Change the material of the polygons that form the floor and the ceiling to floor_mat and ceiling_mat respectively. The materials wall_mat, floor_mat, and ceiling_mat are already defined in *materials/course.mat*. You'll find the listings of most files used in our exercises in Appendix A.6 of this document.

3. Lower the south wall to create an opening, setting the height of the wall to 1.0 m. See Fig 11 for help.

4. Create a pane of glass that fits into the new opening. Make sure there are no gaps and that the entire room remains airtight. Assign glazing_mat as a modifier.

5. Create a file called *furniture.rad*[1] from which you call `xform` to place a table in the scene and a couple of chairs around it. You'll find them in *objects/table.rad*

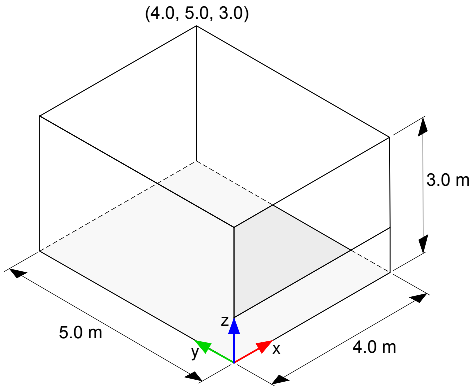
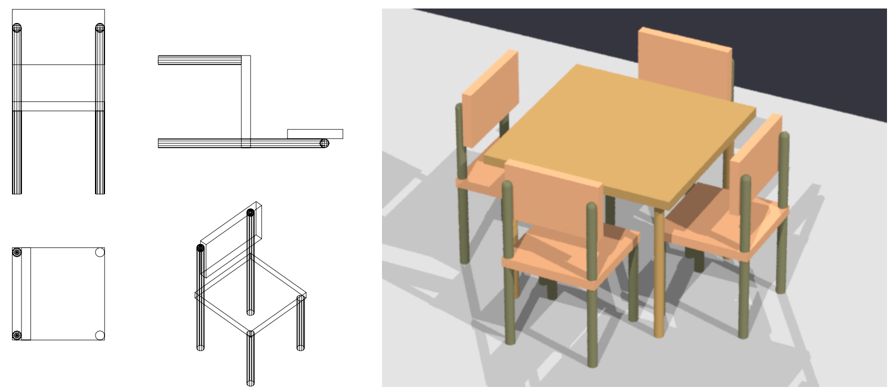


Figure 11: A simple room with an opening

and *objects/chair.rad*, respectively. Use `getbbox` and `objline` to see whether you get the desired result.



(a) A chair viewed with `objline` (b) Four chairs around the table

Figure 12: Arranging the furniture.

`objline` is somewhat unusual in the sense that is produces X11 meta files. This is a special vector format that looks like garbage when output to the terminal. To render the image, we need to pipe it into `x11meta` like so:

```
$ objline objects/chair.rad | x11meta
```

We will later on meet another program that works in tandem with `x11meta`: `bgraph`.

6. Create a file *objects/bulb.rad*[2] which describes the geometry and the material for

[1]You would be right in saying that *furniture.rad* should sit in the *objects/* subdirectory. Unfortunately, objline and objview don't parse nested in-line calls to xform the same way, and it is safer if *furniture.rad* remains in the root of our project directory.

[2]You shouldn't really call this thing a 'bulb'. In the vocabulary of a lighting engineer, a bulb is something you plant in your garden. A 'lamp' is the thing inside a 'luminaire' that generates the light which the luminaire shapes and models. An example for a 'lamp' would be a tungsten halogen reflector lamp, an example for a luminaire could be that thing on your desk that looks very stylish, throws really bad light, and has a lamp inside.

the light bulb. Place the sphere at the origin of the coordinate system and give it a radius of 3.0 cm. For now, we assume a white light source. Use the material `light` and give it equal values for the red, green, and blue radiance. Please refer to section 2.3.3 for more information on coloured lamps.

7. In a file called *lights.rad*, us `xform` commands to place two of your bulbs at a height between 2.5 and 3.0 m.

Before we catch a first glimpse of the image, the scene needs to be compiled into an octree. The purpose of an octree is to speed up the calculation by only considering the objects that lay within the path of a ray. The command to use is `oconv`. It takes as arguments all material and scene files that we want to include. `oconv` will not compile a scene file unless all materials that are used are defined. To make things easier, the file *materials/course.mat* contains everything that is needed in this exercise. The materials have to be given first, or `oconv` will drop out with an error. The octree is produced at `STDOUT`, so you will need to redirect it into a file.

```
$ oconv materials/course.mat objects/room.rad \
objects/furniture.rad objects/lights.rad > scene.oct
```

There are three commands that accept an octree as an input and trace rays within the scene. They all start with 'r':

`rvu` for in interactive preview[3],

`rpict` for producing an image, and

`rtrace` to trace a single ray.

Use `rvu` for an interactive view of the scene using the view parameters stored in the file *views/nice.vf*.

```
$ rvu -vf views/nice.vf scene.oct
```

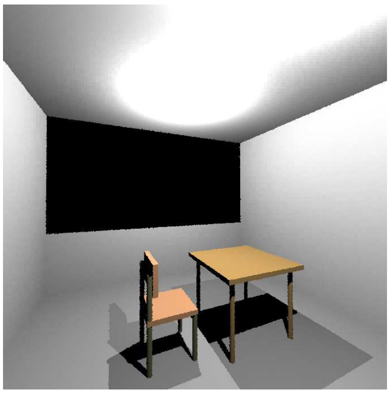


Figure 13: Our first interactive view

Once the `rvu` window is up, there are a number of interactive commands to adjust parameters and views. You will probably have to adjust the exposure of the image before you can see all the details correctly. The most commonly used commands are listed below. They may be typed in full, or called by the first letter, e.g `e` for `exposure`.

[3] prior to Radiance version 3.6, `rvu` used to be called `rview`.

Command	Explanation
`aim`	Zoom
`exposure`	Set the exposure
`frame`	Set frame for refinement
`last`	Restore the previous view
`new`	Redraw display
`pivot`	Pivot view about selected point
`quit`	Quit
`rotate`	Rotate the camera
`set`	Change program variable
`trace`	Trace a ray
`view`	Change view parameters
`write`	Write picture file

Please look up the exact syntax and more detailed explanation in the `rvu` man page.

Another very hand little program is `objview`. It calls `rvu` for an interactive preview of one or more objects. The difference between the two is that `rvu` will only work on octrees, i.e. compiled scenes, whereas `objview` takes material (*.mat*) and geometry files (*.rad*) as inputs, so the compilation is unnecessary. Additionally, `objview` will put light sources into the scene, so objects can be looked at without putting a sky or luminaires into the scene.

```
$ objview materials/course.mat objects/chair.rad
```

2.3 Describing the Materials

2.3.1 Standard Materials

A total of 25 different materials are available to describe the characteristics of the surfaces. They range from the simple to use plastic or metal to the more complex ones like dielectric and BRTDfunc which allow for the most accurate (and difficult) use, but has settings for all directional aspects of reflectance and transmittance. Please refer to [8] for a complete list, as well as detailed descriptions. Some further details can also be found in Appendix A.1.1 of this document.

The material used for the majority of cases is plastic which defines a surface that does not alter the colour of the highlights, i.e. highlights appear in the colour of the light source rather than the colour of the material. This is true for most materials around us, be it wood, paper, concrete, plastic or fabric.

Those are the arguments that the plastic primitive expects:

```
modifier plastic identifier
0
0
5 redrefl greenrefl bluerefl spec rough
```

All values must be within the range of [0...1]. Most materials in reality have a roughness below 0.2 and a specularity below 0.1. The contribution of the individual RGB components towards the average reflectance is weighted and equates to:

$$\rho = 0.265R + 0.670G + 0.065B \tag{1}$$

for metal and to

$$\rho = (0.265R + 0.670G + 0.065B) \times (1 - S) + S \tag{2}$$

for plastic, with S being the specularity of the material. Don't get confused when reading through old documentation. You might find differing multipliers there. As of version 2.5, Radiance uses the multipliers found in Eqn 1. The reason for this has to do with cones in the retina of our eyes, which are more responsive to green light than they are for red and blue.

Use your favorite image manipulation package such the `The GIMP` to pick a nice colour and apply it to the seat and back of our office chair. The range of colours in most graphics packages is between 0 and 255. So you'll need to scale this down to a range between 0 and 1. What is the reflectance of the fabric?

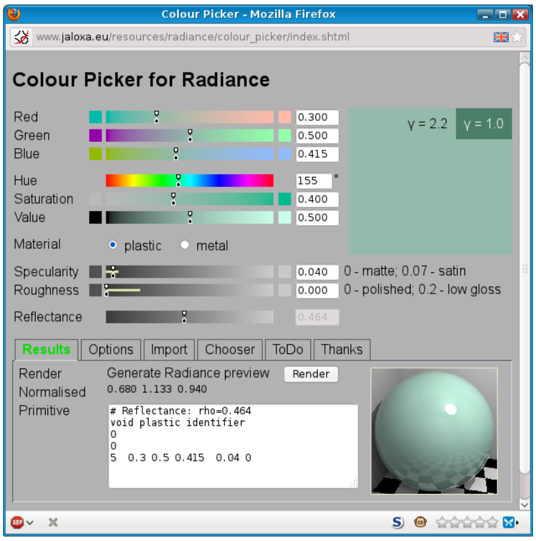


Figure 14: The JALOXA colour picker is a handy tool for specifying materials

There is quite a useful colour picker for Radiance on the JALOXA web site. You may use it for picking a plastic or metal material by moving the interactive sliders across [4]. With its help it's much easier to choose materials, as it will also compute the reflectance and normalised colour (important for sky and ground) for you. You can just copy-and-past the results into your **.mat* file.

2.3.2 Materials Modified by Patterns and Textures

While defining the materials for plain colours is a straight-forward process, the scene will look more interesting and real when we apply patterns and textures to the object.

Patterns describe changes in colour, while textures refer to perturbations of the surface normal. A picture mapped onto a frame hanging on the wall is an example for a pattern. Ripples on a body of water, on the other hand, can be created through textures.

We can string as many patterns and textures together as we like, the sky is the limit. How about a dusty wooden table with stains and a chess board laid in and some scribble on it? A combination of brightfunc, colorpic and texfunc will do the trick.

materials/course.mat has two brightfunc and one colorfunc primitives defined for you. Create a nice blue stripe across the walls by applying blue_band to wall_mat. Additionally, use floorpat to put some random tiles on the floor and make them look dirty with dirt. Try to understand what each function does.

2.3.3 Light Sources

The available materials for light sources in Radiance are: light, illum, glow and spotlight.

light is the basic material for self-luminous surfaces. It is used for most light emitting objects. It's used to model the sun in a clear sky.

illum is used for secondary light sources with broad distribution, i.e. windows. illum sources are treated like ordinary light sources except when looked at directly. They then act as if they were made of a different material. See section **??** for details.

glow is for self-luminous surfaces that have a limited effect. For daylighting, it is used for the sky hemisphere, as well as for the ground.

spotlight is used for light sources with a directional output. It has little relevance, since it gives rather unrealistic results. For 'real' spot lights, it's much preferrable to use the light material in combination with a data file describing the luminance distribution of the fitting.

For physically correct results, it is important to determine the correct radiance values for the red, green, and blue channel. The `lampcolor` program does this for us. We use the type WHITE here. Use this whenever you are rendering a scene that is only lit by one type of light source, irrespective of what this may be. A mechanism called 'colour adaptiation' causes our brains to automatically adjust to the colour temperature of the predominant light source in a scene. This is similar to the auto-whitebalance function that is built into digital cameras. Choosing a none-white lamp type is only recommended if there are different types of lamps in a scene, e.g. metal halides and tungsten. If you assign a WHITE (i.e. non-coloured) lamp type to all your light sources, you can colour-balance the white point of the final rendering with the `pfilt` command at a later stage. A list of available lamp types can be found in *lamp.tab*. On our LEARNIX system, this file resides under */usr/share/radiance*[4]. A normal tungsten lamp has a luminous efficacy of around 15 lm/W. We assume a 100 W lamp.

```
$ lampcolor
Program to compute lamp radiance. Enter '?' for help.
Enter lamp type [WHITE]: incandescent
Enter length unit [meter]: meter
Enter lamp geometry [polygon]: sphere
Sphere radius [1]: .03
```

[4]If you have compiled Radiance yourself, it will be in */usr/local/lib/ray*

```
Enter total lamp lumens [0]: 1500
Lamp color (RGB) = 235.85 235.85 235.85
^C
```

These values need to be given as real arguments to the material primitive defining the material of the bulb. Use the material light.

2.3.4 Daylight

Descriptions of daylight are generated with the gensky command. It defines the distribution of sky and ground radiance. It is left to the user to define two hemispheres of type source—one for the sky, the other for the ground. source objects are infinitely far away from any observer and defined by their direction and an angle, rather than their absolute x, y, z coordinates, as all other Radiance geometry primitives are. It is also left to he user to take care of the colours of sky and ground.

To start with, let's create a sunny sky for London at today's date. You should redirect the output to a file called *skies/sky.mat*.

```
$ gensky 12 09 14:00 -a 51 -o 0 -m 0
# gensky 12 09 14:00 -a 51 -o 0 -m 0
# Local solar time: 14.14
# Solar altitude and azimuth: 11.0 29.9
# Ground ambient level: 8.7

void light solar
0
0
3 2.72e+06 2.72e+06 2.72e+06

solar source sun
0
0
4 -0.489041 -0.851114 0.190903 0.5

void brightfunc skyfunc
2 skybr skybright.cal
0
7 1 3.76e+00 3.72e+00 2.98e-01 -0.489041 -0.851114 0.190903
```

gensky will only create the distribution of sky and ground as well as the material definition and the actual object for the sun. Materials for sky and ground and the two hemispheres are left to the user to define.

	Sun	Sky
Distribution	-	gensky > *skies/sky.mat*
Material	gensky > *skies/sky.mat*	user > *skies/sky.rad*
Geometry	gensky > *skies/sky.mat*	user > *skies/sky.rad*

You might notice that the table above is not consistent with our naming conventions to always keep the materials in a *.mat* file and the geometry in a *.rad* file. This is because `gensky` produces materials (sky distribution and sun material), as well as the sun geometry.

When defining the material properties, care must be taken to use skyfunc as modifier to the material for both, the sky and the ground. This is already done in the file *skies/sky.rad*. The photometric average of the radiances according to Eqn 3 must be equal to 1.0, otherwise the light levels will not be correct.

$$1.0 = 0.265R + 0.670G + 0.065B \tag{3}$$

Now bring up the result in `rvu`. Set up a nice fisheye view of the sky hemisphere and save the parameters into *views/fish.vf*.

```
$ oconv skies/sky_overcast.mat skies/sky.rad > sky.oct
$ rvu sky.oct
```

When run with the `-c` option, the `gensky` command produces a CIE overcast sky whose absolute brightness and hence the horizontal illuminance that it produces is a function of the solar altitude. The actual sun is, of course, not generated.

When daylight factors rather than illuminance readings are required, it is convenient to work with a 10,000 lx sky. This way, we can simply divide the illuminance by 100 to get the daylight factor. To create a sky that produces a certain horizontal illuminance, we run `gensky` with the `-B` option. The `-a`, `-o` and `-m` options are not necessary for this. `-B` requires the horizontal diffuse irradiance, R_{horiz}, so we need to divide the illuminance, E_{horiz}, by Radiance's luminous efficacy:

$$R_{horiz} = \frac{E_{horiz}}{179 \mathrm{lm}/\mathrm{W}} \tag{4}$$

```
$ gensky 12 4 +12:00 -c -B 55.866 > skies/sky_10klx.mat
```

Re-create the octree again and look at it interactively using the view file from the last exercise.

Now look in the file *skies/sky_10klx.mat*. Find the ground ambient level, multiply it by π (illuminance from a hemispherical source) and multiply again by 179 (luminous efficacy). This should result in the diffuse horizontal illuminance, which we set to 10,000 lx.

The sky and ground must both be made of the material glow. However, glow, in contrast to light, spotlight and illum, does not get sampled during the direct calculation. It will only make indirect contributions. See section 4.1 for more details.

3 Previews, Visualisation and Image Conversion

Radiance objects and scenes can be visualised with a number of different programs. Except for `objline`, they are all based on either `rvu` or `rpict`, and add functionality or convenience through scripts. The diagram in Fig 15 attempts to give an overview of the viewers in Radiance and when they can be used. The programs on the right-hand side are sorted in increasing complexity and image quality from top to bottom.

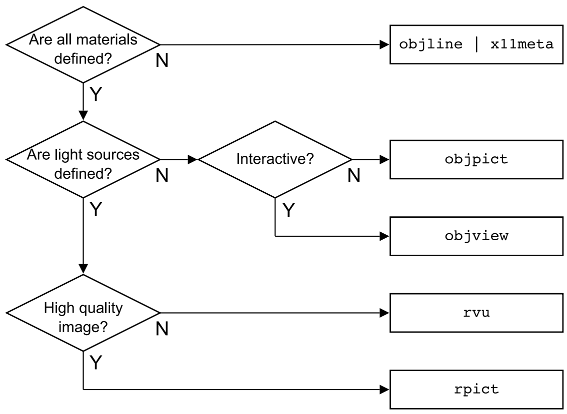


Figure 15: Different commands are available to view your scene

3.1 Quick Preview of Objects

3.1.1 objline

Whilst modelling the geometry of an object or scene, it is often useful to get a quick overview of the size and position of objects. The `objline` program is useful for quickly visualising the geometry without having to worry about correct material definitions. The software produces the result in meta format which is vector rather than pixel-based. To display it on the screen, please pipe it through `x11meta`.

```
$ objline objects/chair.rad | x11meta
```

Alternatively, an Encapsulated PostScript output can be produced which can then be imported into other documents. The `evince` document viewer that is available on LEARNIX can display the EPS format.

```
$ objline objects/chair.rad | psmeta > images/chair.eps
```

Don't forget that there is also the `getbbox` command which will tell you how big the object is and where it is located.

3.1.2 objpict

If all materials, as well as the geometry of the objects, are defined except for the light sources, the `objpict` program can generate a four-view image of the objects by taking care of placing some light sources in the scene to make sure the objects are actually visible. The output is a Radiance image, so don't forget to redirect the output into a **.hdr* file or pipe it into `ximage`:

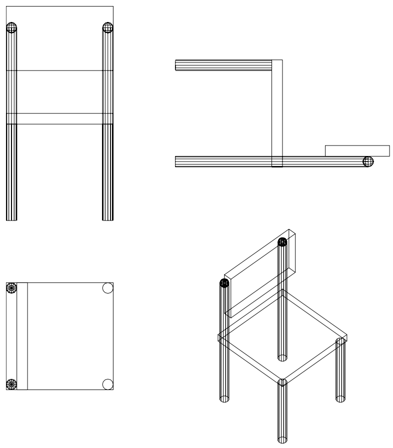


Figure 16: The chair again...

```
$ objpict objects/chair.rad | ximage
```

or

```
$ objpict objects/chair.rad > images/chair.hdr
$ ximage images/chair.hdr
```

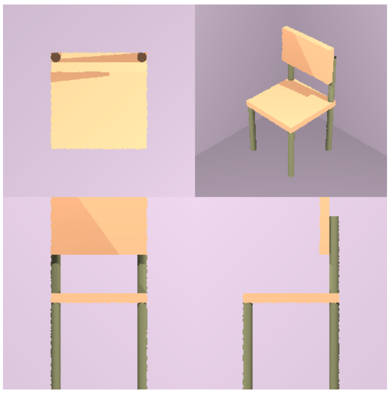


Figure 17: Previewing the chair with `objpict`

3.2 Visualisation

3.2.1 Interactive Visualisation

If an interactive visualisation with `rvu` is required but light sources have not been defined yet, `objview` will take a list of material and geometry files, compile an octree and call `rvu`.

```
$ objview objects/chair.rad
```

After setting up the model including materials, objects and light sources, the last step before running a proper simulation with `rpict` is oftentimes to define a nice view. This is rather difficult to achieve on the command line, but very easily done interactively within `rvu`.

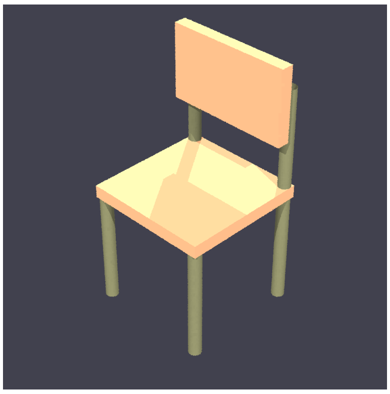


Figure 18: The chair in `rvu`

```
$ oconv skies/skyovercast.mat skies/sky.rad \
objects/chair.rad > chair.oct
$ rvu -vp 10 10 10 -vd -1 -1 -.98 -vh 5 -vv 5 -ab 1 chair.oct
```

On the `rvu` command line, adjust the exposure and save the image. For a list of commands that are available in the `rvu` shell, please refer to the table in section 2.2.3.

```
done: e
Pick point for exposure
w chair_rvu.hdr
writing chair_rvu.hdr...
v views/chair.vf
done:
```

Once you have a good view, save the view parameters into a file. Make sure it has a **.vf* extension. This is not necessary for Radiance to pick it up, but makes it a lot easier on you to remember what all those files in your directory are. That is also the reason why you are encouraged to store all of your view files in the *views/* directory.

3.2.2 Non-interactive Visualisation

After all these preparations, it's finally time to hit the BIG button (not that this exists on the command line...). Most commands in the next section assume that the image has been given a good exposure that makes most of the objects visible within the dynamic range of the display device (monitor or printer). This is done with the `pfilt` command.

```
$ rpict -vp 10 10 10 -vd -1 -1 -.98 -vh 5 -vv 5 -e .1 -ab 1 \
chair.oct > images/chair_rpict.hdr
$ pfilt -e .5 images/chair_rpict.hdr \
> images/chair_rpict_pfilt.hdr
$ ximage images/chair_rpict_pfilt.hdr &
```

3.3 Image Conversion

Radiance comes with tools for converting images from the special Radiance RGBE format other formats. All such converters start with `ra_*` in their name, for example `ra_tiff` will convert the Radiance RGBE format to a TIFF. The TIFF format is understood by virtually all image processing software, but results in rather large file sizes. It might therefore be a good idea to convert from TIFF to a file format which results in smaller files. The PNG (pronounce “ping”) format is ideally suited for this.

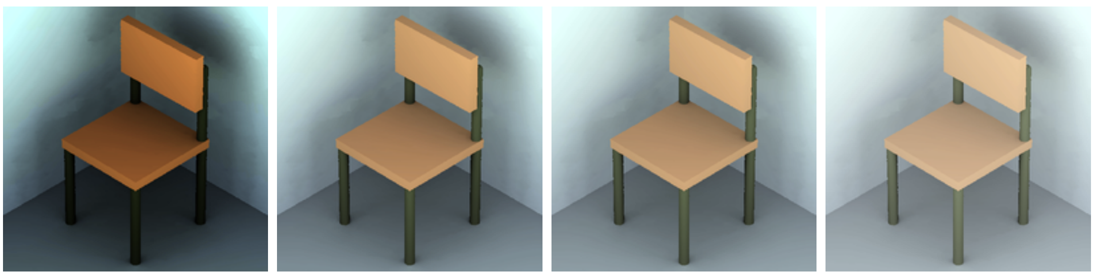
Although ImageMagick is not part of the Radiance distribution, it is installed on many UNIX and LINUX systems and also on LEARNIX. ImageMagick [1] provides a number of programs for displaying and manipulating image files. The `convert` command uses the file extension to decide what format to export to.

```
$ cd images
$ pfilt -e 1 chair_rpict.hdr > chair_rpict_pfilt.hdr
$ ra_tiff chair_rpict_pfilt.hdr chair_rpict_pfilt.tif
$ convert chair_rpict_pfilt.tif chair_rpict_pfilt.png
$ rm chair_rpict_pfilt.tif
$ cd ..
```

All of the above assumes that the Radiance image file has a proper exposure set using the `pfilt` command. Run it without any options to automatically set a good exposure without having to worry about the correct exposure multiplier. If the dynamic range of the image is too high, the bright regions in the image will become washed out, while subtle shades of dark grey turn into black.

It is possible to take the unfiltered image and compress the dynamic range so that both dark and bright regions are visible. Radiance supplies the `normtiff` program for this, which may also be used to mimic certain characteristics of the human visial system.

```
$ normtiff images/chair_rpict.hdr \
images/chair_rpict_normtiff.tif
$ convert images/chair_rpict_normtiff.tif \
images/chair_rpict_normtiff.png
```



(a) 1.0: Default of ImageMagick’s `convert` (b) 1.8: Used in printing (c) 2.2: Default for Radiance’s `normtiff` and `ra_tiff`. Used for CRT monitors (d) 3.0: For comparison

Figure 19: The same image with different gamma values applied. The image was prepared with `normtiff` rather than `pfilt` and `ra_tiff`. This ensures that there is pure black and pure white in the image. The gamma value affects mostly the mid-tones.

It is very important to be aware that Radiance’s `normtiff` and `ra_tiff` default to a gamma correction of 2.2, while ImageMagick’s `convert` has a default of 1.0. 19 shows the same image with different gamma values applied.

ImageMagick is one of the few packages that can read the Radiance image format directly [5]. To convert a Radiance image file to PNG format, type

```
$ convert -gamma 2.2 images/chair_rpict_pfilt.hdr \
images/chair_rpict_pfilt.png
```

The PNG image format utilses a loss-less file compression which is perfect for reports and similar documents where the overall document size is not important.

If you want to publish the images on the Internet, you want to make sure the file size is as small as possible, in which case it is advisable to use the JPEG format instead. JPEG images use a lossy compression which creates potentially much smaller files, but might suffer from artifacts when high compression factors are used. Compression factors below 50 will almost certainly exhibit such artifacts. A compression factor of 100, which is the maximum, will minimise such problems, but results in larger file sizes.

```
$ convert -gamma 2.2 -quality 80 \
images/chair_rpict_pfilt.hdr images/chair_rpict_pfilt.jpg
```

It is also possible to create GIF images, however, this format can only display a maximum of 255 colours. The PNG format does not have those disadvantages.

The `mogrify` program of ImageMagick allows for the quick conversion of multiple images to a different format. Combined with a little shell magic, it is possible to convert a large number of files in one go:

```
$ cd images
$ for file in *.hdr ; do normtiff $file \
$(basename $file hdr)tif ; done
$ mogrify -gamma 2.2 -format jpg *.tif
$ cd ..
```

to convert to TIFF using Radiance's `normtiff` command and then to JPEG, or

```
$ mogrify -gamma 2.2 -format png images/*.hdr
```

to convert to PNG with ImageMagick's `mogrify`.

[5] `convert` actually relies on the Radiance `ra_ppm` to do the work

4 How Radiance Works

4.1 Ambient Calculations

Compile a new octree and include the following files: *materials/course.mat, skies/sky.mat, skies/sky.rad* and *objects/room.rad*. Give it the name *scene.oct*. Make sure there is no furniture in the room and that you have an overcast sky in *sky.mat*.

We now view the octree s*cene.oct* with `rvu`:

```
$ oconv materials/course.mat skies/sky.mat skies/sky.rad \
objects/room.rad > scene.oct
$ rvu -vf views/nice.vf scene.oct
rvu: warning - no light sources found
```

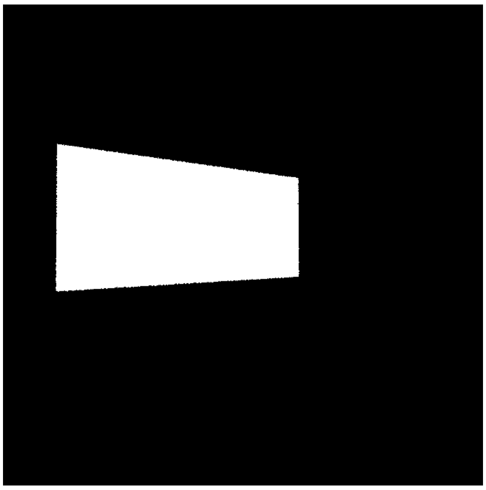


Figure 20: A black room

You will notice that everything inside the room appears black. Using the `trace` command from within `rvu`, check whether this is just a question of poor exposure or if the room really is black.

Check the default settings for `-ab` and `-av` for `rvu`.

```
$ rvu -defaults |grep ^-a
-av 0.000000 0.000000 0.000000  # ambient value
-aw 0                           # ambient value weight
-ab 0                           # ambient bounces
-aa 0.300000                    # ambient accuracy
-ar 32                          # ambient resolution
-ad 256                         # ambient divisions
-as 64                          # ambient super-samples
```

Both parameters have 0 as default. A value of zero for the number of ambient bounces turns the ambient calculation off. So only light sources of type light, spotlight or illum will be sampled. Since the sky is made of glow, it does not take part in the direct calculations, resulting in the black interior.

To view the scene, it is sufficient to set an ambient value that is greater than zero. In Radiance ambient light is light that is not emitted from a source but instead is assumed to be constant over the whole scene. Remember that in reality, the intensity of the illuminance decreases with the squared distance from the light source.

To determine the value of the ambient irradiance the following formula can be applied. The `-av` option enables us to supply different values for the red, green, and blue channel, however, the three of them will usually be the same.

$$R_{amb} = \frac{E_{amb}}{179\pi} \tag{5}$$

For outdoor simulations, set `-av` to the *Ground ambient level*[6] as generated by `gensky`. For indoor scenes, the following approximation may be used[7]:

1. Start with an `-av` setting that could be about right;
2. Run `rvu` and interactively set the exposure of the image (don't forget to set `-ab`). Typing 'e =' at the `rvu` prompt will return the current exposure.
3. Re-run `rvu` with an `-av` of 0.5/exposure.
4. Repeat 2. and 3. a few times until the values no longer change dramatically.

Set `-av` to a value that is equivalent to 500 lx and call `rvu` again.

```
$ rvu -vf views/nice.vf -w -av .89 .89 .89 scene.oct
```

Different faces of the room can now be distinguished, but the image looks very artificial because all objects are uniformly lit without any shadows.

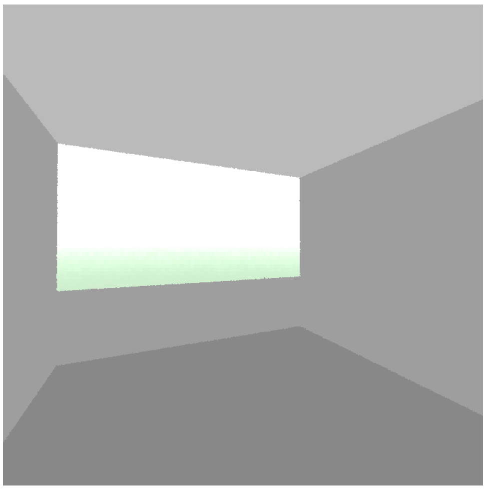


Figure 21: Our room lit only by ambient light. This is almost certainly not what you want.

This approach does have advantages, though. For every pixel in the image, only one ray needs to be traced making this a 'quick and dirty' solution.

[6] This value is in units of W/m^2.

[7] Radiance Digest V3n2

Before you quit `rvu`, create a plan view of the entire floor and save it as *views/floor.vf*. The appropriate view type is '`l`' for a parallel view.

In order to find out how the indirect calculation affects the quality of the rendering, set `-av` back to zero and run `rvu` with one ambient bounce. Additionally, set the number of ambient divisions to one with the `-ad 1` option.

```
$ rvu -vf views/floor.vf -av 0 0 0 -ab 1 -ad 1 scene.oct
```

This is now quite a strange looking result (Fig 22)[8]. The majority of the floor is still black, but there are a number of circular splotches that have a bright centre and fade towards their periphery.

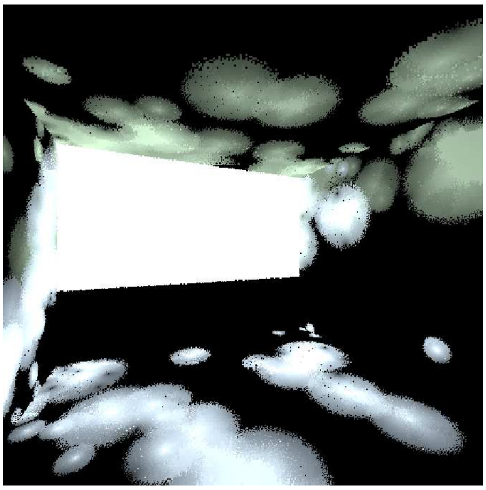


Figure 22: Ugly splotches

The `-ab 1` option that we used here turns the ambient calculations on. However, only one ambient sample ray is sent off for each position where ambient sampling occurs (`-ad 1` option). So the chances of this ray eventually going through the window and hitting the sky are rather small and decrease even more with the distance from the window.

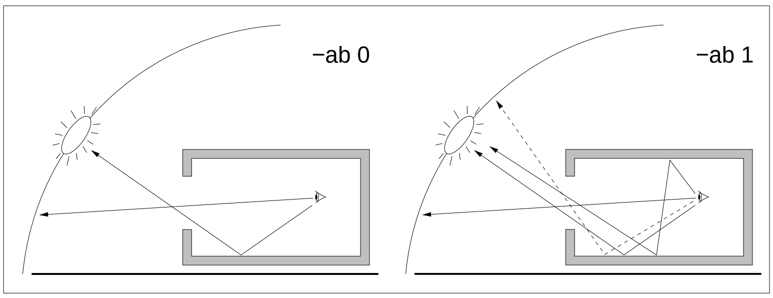


Figure 23: Light from the sky needs one more bounce than sun light

But we also see a cheat that Radiance does. In order to reduce its workload, ambient sample rays are not sent out for every pixel. It is assumed that the ambient light does

[8]Update Nov. 2006: Creating this particular result is no longer possible under Radiance version 3.7 or higher. The minimum number of ambient division (-ad) is now set to 27, or 3 if -ab is set to zero. I left this image here, because it shows rather well what happens during the ambient calculation.

not change a lot throughout the scene, which is usually correct. Every point for which the ambient light did get sampled carries a 'sphere of influence'. As long as a new pixel lies within a radius R of this sphere, a new ambient sampling is not carried out. Instead, the values of adjacent sampling points are interpolated. The radius of the 'sphere of influence' is:

$$R_{min} = \frac{maxSize \times aa}{ar} \tag{6}$$

MaxSize is the maximum scene dimension as returned by `getbbox`, aa and ar refer the settings for `-aa` and `-ar` which control the ambient accuracy and the ambient resolution, resp.

Increase the ambient divisions to 64 and see what this results in. Does it look like Fig 24?

Figure 24: The room with one ambient bounce

In order to make the scene look less patchy, two approaches can be taken:

- Greatly increase the setting for `-ad`
- Get Radiance to sample our window as if it was a 'real' light source. This is done with the `mkillum` command and is explained in the Radiance Cookbook [2].

Raphael Compagnon's Radiance Course Notes [11] feature a table showing the minimum number of sample rays needed to certainly hit a glow source that sustains a certain solid angle. Here are examples taken from there:

Angular Resolution (°)	Required `-ad`	Required `-ds`
1	33863247	0.02
5	54446	0.09
10	3455	0.17
20	230	0.35
30	50	0.54

It is clear that as the light source gets smaller, the number of ambient sample rays required to hit the `glow` source explodes. For very small sources, this stochastic sampling becomes too unreliable and computing intensive.

4.2 Ambient Parameters

The following tables are copied from the file *rpict.options* which is distrisbuted with Radiance. Only ambient parameters are listed. Please refer to the original file for a complete listing. The column labelled 'Very Accur' is not from the original table but was added because it gives you a better idea about appropriate options for accurate daylighting simulations.

4.2.1 Useful Ranges

Parameter	Description	Min	Fast	Accur	Very Accur	Max
`-ab`	ambient bounces	0	0	2	5	8
`-aa`	ambient accuracy	0.5	0.2	0.15	0.08	0
`-ar`	ambient resolution	8	32	128	512	0
`-ad`	ambient divisions	0	32	512	2048	4096
`-as`	ambient super-samples	0	32	256	512	1024

min for fastest, crudest rendering. It is not necessarily the smallest value numerically.
fast for reasonably fast rendering.
accur for reasonably accurate rendering (artificial lighting)
very accur for accurate rendering or complicated scenes (daylighting)
max for the ultimate in accuracy.

Avoid using the "max" setting for `-aa` and `-ar`. This disables optimisation and can be very expensive in terms of rendering time.

4.2.2 Artifacts Associated with Options

Parameter	Artifact	Solution
`-ab`	lighting in shadows too flat	increment value
`-av`	overall light level seems too high/low	decrease/increase value
`-aa`	uneven shading boundaries in shadows	decrease value by 25%
`-ar`	shading wrong in some areas	double or quadruple value
`-ad`	"splotches" of light	double value
`-as`	"splotches" of light	increase to half of `-ad` setting

4.2.3 Timings Associated with Options

Parameter	Effect on Execution Time
`-ab`	doubling this value can double rendering time
`-aa`	doubling this value approximately quadruples rendering time
`-ar`	effect depends on scene, can quadruple time for double value
`-ad`	doubling value may double rendering time
`-as`	effectively adds to `-ad` parameter and its cost

5 Analysing Scenes

5.1 Analysing Radiance pictures

5.1.1 Creating False Colour Images

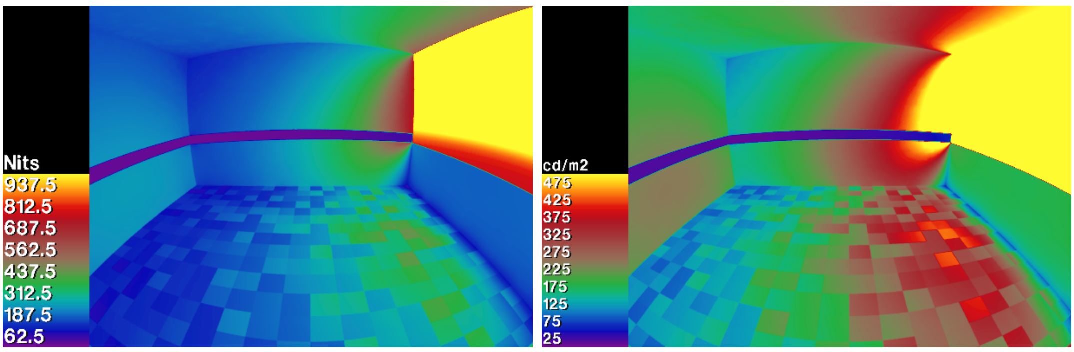
The `falsecolor` command allows us to create looking false colour images which map the luminance or illuminance values in the image to colours. This makes the interpretation easier for us humans, since we are more adept to distinguish colours than shades of grey. The following command line will do just this:

```
$ falsecolor -ip imagegs/scene.hdr > images/fc_defaults.hdr
```

`falsecolor` creates a legend[9] with the mapping of colours to photometric values. The default label is cd/m^2. To make the displayed values a bit rounder, set the number of divisions to ten, and pick a round number for the maximum scale value (the default here is 'auto'):

```
$ falsecolor -ip images/scene.hdr -s 500 -n 10 \
> images/fc_better.hdr
```

Fig 25 shows the results of these operations: The image on the left was created with the default options, the one on the right has some adjustments made to it.



(a) Default options (b) Better scale and nicer legend

Figure 25: `falsecolor` called with the default options usually isn't what you want

It is possible to use values from one image, let's say an illuminance picture, and overlay them onto another one, such as the corresponding luminance picture. This only makes sense when using contour lines rather a full false colour image. The following command creates false colour contour lines of the luminance which are overlayed onto a background image, as shown in Fig 26 on the left:

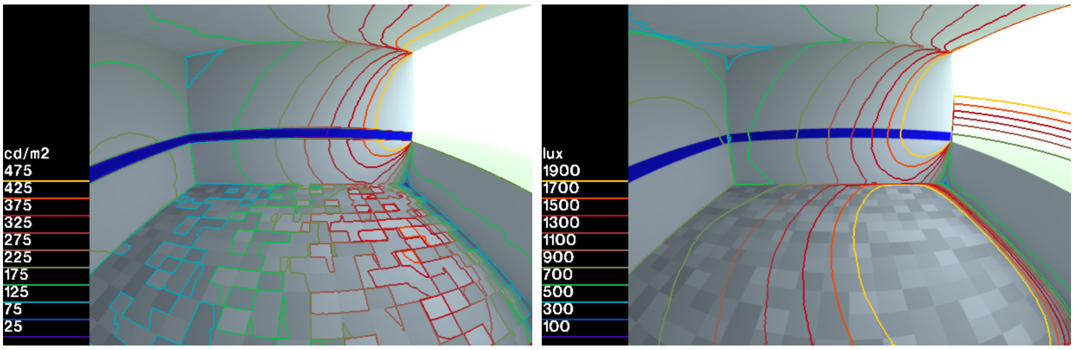
```
$ falsecolor -ip images/scene.hdr -cl -s 500 -n 10 \
> images/fc_overlay.hdr
```

To have contour lines of the illuminance instead, use:

[9]The default palette has changed in version 3.8 of Radiance. The new palette has more colours in it, which makes it easier to interpret.

```
$ falsecolor -i images/scene_i.hdr -p images/scene.hdr -cl \
-n 10 -s 2000 -l lux > images/false.hdr
```

The `-l` option sets the label of the legend[10]. The result is shown in Fig 26 on the right.



(a) Luminance (b) Illuminance

Figure 26: Producing false colour contour lines

If you're still not entirely happy with the way that pixel values are represented by `falsecolor`, please feel free to try out alternative colour palettes (`-pal` option). An HDR image of the available palettes can be generated with the `-palettes` switch[11]. Don't forget to pipe this to `ximage`, or to save it to a file. You may also want to experiment with the `-cb` or `-cp` options that create contour bands or a posterisation effect, resp.

Understanding the difference between the illuminance and luminance, you will appreciate why the contour lines follow the carpet pattern in the false colour luminance picture, but not in the illuminance one.

When using `falsecolor` with overlaid contour lines, you might have to adjust the exposure of the background image. Do this before running `pfilt`. The image from which the values are extracted never needs to have its exposure adjusted. Figs 27 and 28 summarise the use of the `falsecolor` command for luminance and illuminance scales.

5.1.2 Analysis With `ximage`

If only a handful of values are required from an image or if other values such as pixel position or the ray direction are of interest, the `ximage` command can be of help. The L key will display the luminance/illuminance value at that point on the screen. If `ximage` was started from a command line, typing the T key or pressing the middle mouse button will print out one or more of the following: Ray origin, ray direction, radiance value, luminance value or pixel position. This output can be controlled with the `-o` option when calling `ximage`. It can then be processed in a spread sheet or dealt with directly, for instance with the `rcalc` command.

[10] Until version 4.1 of Radiance (Dec 2011), this had a default of 'nits', which is the same as 'cd/m2'. It now defaults to 'cd/m2'.

[11] This and the `-cp` option have been available in Radiance HEAD since Jan 2012, and will be released in Radiance proper with version 4.2

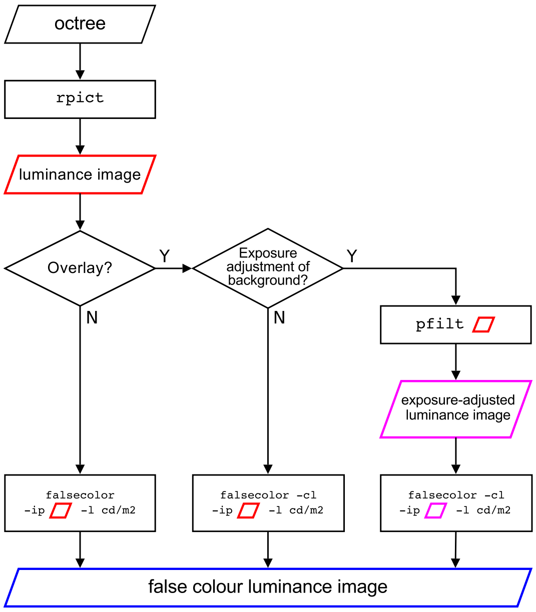


Figure 27: Flowchart for creating false colour images of the pixel luminance

5.2 Analysing Models with `rtrace`

`rtrace` traces rays given to it on `STDIN` and produces the result on `STDOUT`. Like the two other `r*`-commands (`rvu` and `rpict`), it operates on an octree.

The rays need to be specified in the following format:

```
xorg yorig zorig xdir ydir zdir
```

Technically, it is possible to create entire images with `rtrace`. Because it is usually only used for individual rays, the rendering parameters default to more accurate settings. Check `rtrace -defaults` to find out more.

5.2.1 Getting an Illuminance Reading

In a first step, we will use `rtrace` to find out the horizontal illuminance that is created by our overcast sky. Since we're only passing the one ray, we do this from the command line rather than through a file. The UNIX `echo` command will do the job–it sends its arguments to `STDOUT`. Make sure the file *sky.oct* only contains the description and the material of a 10,000 lx overcast sky.

```
$ echo '0 0 0  0 0 1' | rtrace -I -ab 1 sky.oct
#?Radiance
oconv skies/sky_10klx.mat skies/sky.rad
rtrace -I -ab 1
SOFTWARE= Radiance 3.8
lastmod Sun Nov 11 17:10:54 GMT 2007 by root on birdie
CAPDATE= 2007:12:15 08:52:17
FORMAT=ascii
5.594485e+01    5.594485e+01    5.594485e+01
```

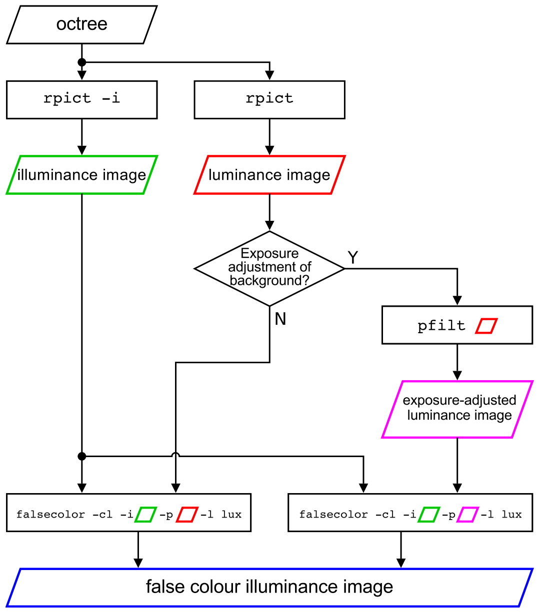


Figure 28: Flowchart for creating false colour images of the pixel illuminance

The first eight lines of the output are the header which can be disabled with the `-h` option to `rvu`[12]:

```
$ echo '0 0 0  0 0 1' | rtrace -I -h -ab 1 sky.oct
5.591661e+01 5.591661e+01 5.591661e+01
```

Since *sky.oct* contains the description of a non-coloured grey sky, all three colour channels have the same value of `5.587436e+01`, or 55.87 W/m^2. This is an irradiance reading. If the sky was non-grey, we'd have to compute the average, weighted irradiance.

To get the illuminance, we simply multiply with the luminous efficacy of 179 lm/W:

```
$ echo '0 0 0  0 0 1' | rtrace -I -ab 1 -h sky.oct \
| rcalc -e '$1=179*(.265*$1+.670*$2+.065*$3)'
10006.6961
```

The result is 10,000 lx. This is no surprise to us, because the sky was created with the `-b` option to produce a horizontal illuminance of 10,000 lx.

5.2.2 Plotting Illuminance Values

This exercise is based on the previous one and uses the `bgraph` command to plot a graph of lux levels at working plane height against the distance from the window. The height of the working plane is usually taken to be 0.85 m. Fig 29 illustrates the task at hand.

The readings are spaced 0.5 m, with the first and last reading being no closer to the walls than 0.5 m. Since the room is 5.0 m deep, that's nine points in total. The direction is up, or +z, to get the horizontal illuminance. A file called *data/line.pts* has

[12]Before Radiance version 4.1 (Dec 2011), `rtrace` and `rpict` would issue a warning if the sky was without sun and if the number of ambient bounces `-ab` was set to zero. Such warnings can be disabled with the `-w` switch. This should no longer be necessary if you know what you're doing.

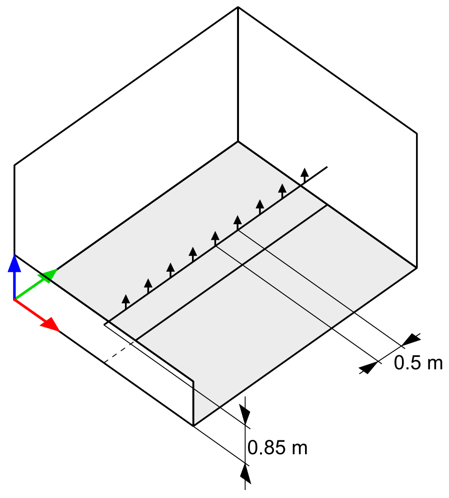


Figure 29: Taking illuminance readings

already been prepared for you. It lists the points of the measurement and the direction vectors as (x,y,z) triplets:

```
$ cat data/line.pts
2.0 0.5 0.85  0 0 1
2.0 1.0 0.85  0 0 1
2.0 1.5 0.85  0 0 1
2.0 2.0 0.85  0 0 1
2.0 2.5 0.85  0 0 1
2.0 3.0 0.85  0 0 1
2.0 3.5 0.85  0 0 1
2.0 4.0 0.85  0 0 1
2.0 4.5 0.85  0 0 1
```

You can easily see that only the y-coordinate differs between the points. If you are interested in how such a grid file can be created with Radiance's `rcalc` command, please refer to the chapter titled 'Dynamic grids with `cnt`' in the Radiance CookbookAxel Jacobs [2].

The points are now fed into `rtrace`:

```
$ cat data/line.pts | rtrace -I -ab 3 -h scene.oct
#?Radiance
oconv materials/course.mat skies/sky.mat \
skies/sky.rad objects/room.rad
rtrace
SOFTWARE= Radiance 3.7
lastmod Sat Nov 18 23:28:38 WET 2006 by ...
FORMAT=ascii

6.0374e+00   7.3870e+00   8.5235e+00
3.8192e+00   4.6729e+00   5.3918e+00
1.3492e+00   1.6508e+00   1.9047e+00
```

```
...
```

rtrace will normally only output the value which is in our case the irradiance for the Red, Green, and Blue channel. If run without the -I switch, this would be the radiance instead. This is fine, except that plotting is easier if the position of the sensor is printed as well the reading. This is done with the -o option: The default is -ov which prints the values. Over-writing this with -oov will output the position, too. While we are fiddling with the command-line options, we also need to get rid of the header (-h).

```
$ cat data/line.pts | rtrace -I -ab 3 -h -oov scene.oct
2.00e+00    5.0e-01    1.85e+00    6.037e+00    7.387e+00    8.524e+00
2.00e+00    1.0e+00    1.85e+00    3.819e+00    4.673e+00    5.392e+00
2.00e+00    1.5e+00    1.85e+00    1.349e+00    1.651e+00    1.905e+00
...
```

To get the reading in lux rather than red, green, and blue irradiance values, Eqn (3) has to help us out once more.

```
$ cat data/line.pts | rtrace -I -ab 3 -h -oov scene.oct \
| rcalc -e '$1=$2;$2=179*(.265*$4+.670*$5+.065*$6)' \
> results/lux.csv
$ cat results/lux.csv
0.5       1271.4789
1         804.313407
1.5       284.135595
2         477.732247
2.5       463.546922
3         405.675942
3.5       387.179138
4         431.251321
4.5       158.74665
```

Prepared for you is a file named *lux.plt* which gives some instructions to the bgraph command. Modify it as you like. To output to the screen and to a PostScript file, resp, use the following two command lines:

```
$ bgraph lux.plt | x11meta
$ bgraph lux.plt | psmeta > results/graph.eps
```

The plot in Fig 30 shows the results for 2, 4, 6, and 8 ambient bounces. You will see that the graph changes dramatically for small numbers of -ab, but then approaches a final (correct!) value.

Such and similar plots are a good approach to fine-tune the parameters for rpict in order to get convincing images and, more importantly, realistic readings. In computing terms, such an excercise is called a 'sensitivity study'. It is part of any building simulation done properly, since it is the only way of determining reliable and accurate settings for the calculation engine.

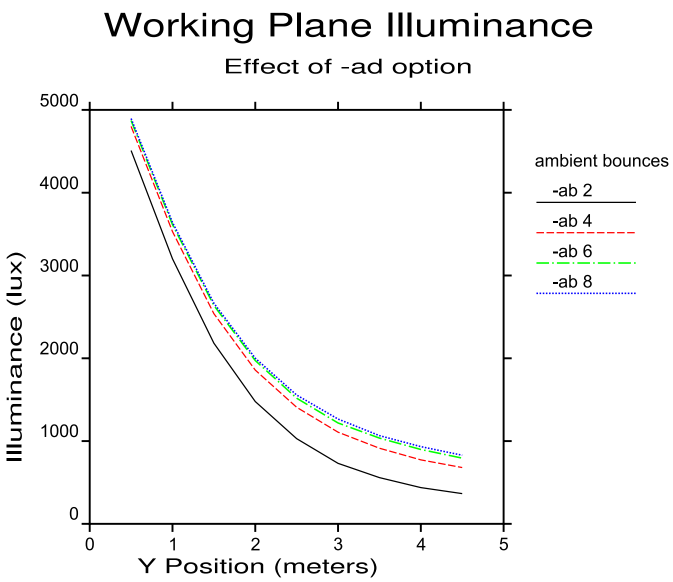


Figure 30: An illuminance graph with low accuracy settings

6 The Joy of Rendering

6.1 Too Much to Remember

`rpict -defaults` displays more than 40 options that allow complete control over all aspects of the rendering process. While this allows experienced Radiance users to fine-tune the results, even they sometimes wish they could just hit a button and get some result quickly without having to fiddle all those options. This is certainly even more true for the beginner. We already found out that sticking to the defaults hardly ever produces the desired result.

6.2 The `rad` command

But don't despair, help is there! It comes in form of the `rad` command. Once the control file is set up, which doesn't take more than a couple of minutes, a short command will either bring up an interactive view of the model with `rvu` or create a high quality image calling `rpict`. But it does even more than that: By setting only three variables for the overall quality, the importance of indirect calculations and the level of detail in the scene, `rad` automatically takes care of most of the `rpict` options that are vital for getting a good quality image. The file *room.rif* is set up for the simple test room we have been working with:

```
$ cat room.rif
# Rad Input File
DETAIL= Low
INDIRECT= 1
OCTREE= room.oct
PICTURE= images/room
QUALITY= Medium
RESOLUTION= 800
VARIABILITY= Low
ZONE= Interior 0 4 0 5 0 3
materials= materials/course.mat
materials= skies/sky_overcast.mat
scene= objects/room.rad skies/sky.rad
view= nice -vf views/nice.vf
```

Options in `UPPERCASE` can only appear once within the RIF file, those in `lowercase` may be repeated. This is the case for the `materials=` option in `room.rif`.

To call it with `rvu`, you need to give it an output device. Type `rvu -devices` to get a list. Use `x11` for now.

```
$ rad -o x11 -v nice room.rif
rvu -vu 0 0 1 -vf views/nice.vf -ps 6 -pt .08 -dp 512 -ar 20
-ms 0.1 -ds .3 -dt .1 -dc .5 -dr 1 -sj .7 -st .1 -ab 1
-aa .25 -ad 196 -as 0 -av 0.01 0.01 0.01 -lr 6 -lw .002
-R nice.rif -o x11 nice.oct
```

To run `rpict`, simply drop the `-o x11` option. If you also drop `-v`, one image for each view will be rendered. Using the example RIF file above, the image would be named *images/room_nice.hdr*.

The table below lists the available variables, and how they affect rendering times and quality. They are listed in order of most to least important to rendering time. For instance, increasing QUALITY from 'low' to 'high' will increase the rendering time by a factor of 25, while doing the same for DETAIL will only result in the simulation taking 10 times as long. The multipliers are relative to the 'low' setting within the same row. Please compare to table 12.1 in [9].

	affected parameters	low	medium	high
QUAL	most -a*	-ab 0; -as 0; -ar x1; -aa x1	-ab INDIRECT; -ar x2; -aa x0.8	-ab INDIRECT+1; -ar x4; -aa x0.6
VAR	-ad; -aa	-ad x1; -aa x1	-ad x2; -aa x0.7	-aa x0.3; -ad x2
DET	-ar	-ar x1	-ar x2	-ar x4

6.3 Being Lazy

As if all this wasn't enough, there is even a graphical user interface (GUI) with Radiance. It is called `trad`. `trad` is a front-end for the `rad` command. It doesn't need any explanation. Just try it out. It comes with a help system that will happily answer all your questions.

```
$ trad &
```

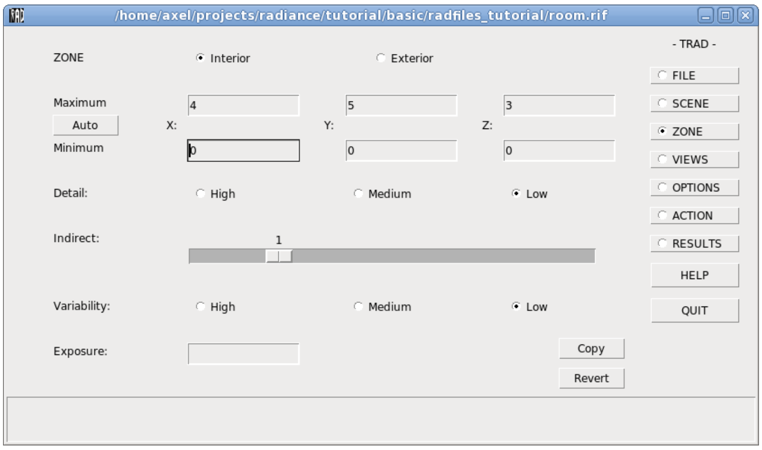


Figure 31: `trad` is a graphical interface to the Radiance `rad` command

References

[1] ImageMagick. URL http://www.imagemagick.org.

[2] Axel Jacobs. *Radiance Cookbook*, 2012. URL http://www.jaloxa.eu/resources/radiance/documentation/index.shtml.

[3] Axel Jacobs. LEARNIX. Web site, Nov 2012. URL http://www.jaloxa.eu/mirrors/learnix/index.shtml.

[4] Axel Jacobs. Radiance resources on www.jaloxa.eu. URL http://www.jaloxa.eu/resources/radiance.

[5] Axel Jacobs. *UNIX for Radiance*, 2012. URL http://www.jaloxa.eu/resources/radiance/documentation/index.shtml.

[6] Greg Ward. *Radiance man Pages*, 2008. URL http://radsite.lbl.gov/radiance/whatis.html.

[7] Greg Ward. Official Radiance web site, 2012. URL http://radsite.lbl.gov/radiance.

[8] Greg Ward. *Radiance 4.1 Reference Manual*, 2011. URL http://radsite.lbl.gov/radiance/refer/refman.pdf.

[9] Greg Ward Larson and Rob Shakespeare. *Rendering with Radiance: The Art and Science of Lighting Visualisation*. Morgan Kaufmann Publishers, San Francisco, 1997.

[10] Radiance Community. Radiance-Online. Web site, Nov 2009. URL http://www.radiance-online.org.

[11] Raphael Compagnon. *Radiance Course on Daylighting*, 1997. URL http://radsite.lbl.gov/radiance/refer/rc97tut.pdf.

[12] Thomas Bleicher. su2rad - Radiance Exporter for Google Sketchup, 2008. URL http://code.google.com/p/su2rad/.

A Appendices

A.1 The Main Primitives and Their Parameters

A.1.1 Materials

```
modifier light identifier
0
0
3  red green blue
```

The RGB triplet for the light primitive is given as radiance values [W/m^2/sr].

```
modifier plastic identifier
0
0
5  red green blue  specularity roughness
```

plastic is a material with uncoloured highlights. All values are in the range between 0 and 1. Specularity values above 0.1 and roughness of more than 0.2 are uncommon and look unrealistic.

The material metal is similar to plastic, except that it produces highlights which are modified by the surface colour. For metal, the specularity is usually above 0.9.

```
modifier glass identifier
0
0
3  rtn gtn btn
```

glass is similar to dielectric, but it is optimized for thin glass surfaces (n = 1.52). One transmitted ray and one reflected ray are produced. The glass primitive requires us to specify the red, green and blue transmissivity, t_n, as arguments. This is a somewhat inconvenient since manufacturers' specifications, as well as measurements are done for the transmittance, T_n. To convert from transmittance to transmissivity, use the simple formula

$$t_n = 1.09 \times T_n$$

The transmissivity is always higher than the transmittance. For instance, standard 88% transmittance glass has a transmissivity of 0.96. Note that this formula looks different to the one in the Radiance Reference Manual [8]. It is much simpler but produces the same results. You can find a discussion of the 'full' vs this simplified formula in the Radiance Cookbook [2].

A.1.2 Surfaces

```
modifier sphere identifier
0
0
4  xcent ycent zcent  radius
```

```
modifier polygon identifier
0
0
3n  x1 y1 z1
    x2 y2 z2
    ...
    xn yn zn

modifier cylinder identifier
0
0
7  x0 y0 z0
   x1 y1 z1
   radius

modifier cone identifier
0
0
7  x0 y0 z0
   x1 y1 z1
   radius0 radius1

modifier ring identifier
0
0
8  x y z
   dx dy dz
   inner_radius outer_radius
```

A.2 Suggested File Name Extensions

Under UNIX, it is not necessary to stick to certain file extensions. However, it is highly recommended to always use the same extensions. This will help you stay organised even in directories that contain a large number of files.

File Type	Extension
scene description	*.rad*
material definition	*.mat*
octree	*.oct*
view file	*.vf*
project file	*.rif*
image file	*.hdr*[13]
rcalc file	*.cal*
ambient file	*.amb*
data table	*.dat*
plot file	*.plt*
points file	*.pts*
BASH shell script	*.bash*

A.3 Suggested Project Directory Structure

When working on larger projects with many differenct input files and results, you will very likely notice that keeping an overview of all the different files and versions quickly turns into a challenge. While this is not so important for the exercises during the Radiance course or for your assessment, you might want to adapt a structured file hierarchy for your projects. Here is my personal recommendation:

ambient Ambient files (*.amb). Such files can grow rather large and should therefore be deleted once a project is finished.

model if the geometry was modelled in a CAD package, keep the files here;

data files that define grid points (**.pts*) and any other data files that are not directly part of the scene.

docs any correspondence relating to the project, as well as standards, downloaded web pages etc.

images HDR images (**.hdr*). I always keep the Radiance images, and additionally create PNGs or JPEGs.

materials Radiance material files (**.mat*)

objects Radiance geometry files (**.rad*)

results Numerial results, usually illuminance or daylight factor calculations with `rtrace`, as well as any graphs created from them

skies Radiance sky definitions, both, geometry and materials

tmp any temporary files apart from ambient files (**.amb*). All files in here may be deleted before a projects gets archived.

views any view file (**.vf*)

octrees Compiled Radiance octrees (**.oct*)

I tend to only keep RIF files (**.rif*) in the top-level directory of a project. Everything else gets tucked away in some sub-directory. It is also a good idea to make generous use of `README.txt` files. In those, you should write notes to yourself (and anybody who might potentially be confronted with making sense of all the files), explaining what the files are, who created them and for what purpose, how to use scripts you might have written etc.

A.4 Files Used in the Course

File Name	**Use**
objects/chair.rad	simple chair (incl. materials)
objects/table.rad	simple table (incl. materials)
objects/arrows.rad	arrows indicating the coordinate system
materials/course.mat	material definitions
skies/sky.rad	definition of sky and ground
skies/sky_overcast.mat	material for an overcast sky
views/nice.vf	example view file
room.rif	Radiance control file
data/line.pts	points for illuminance measurements
lux.plt	plotfile for `bgraph`

A.5 Material files for the pattern and texture example

The board and the basin are both 1 by 1 unit in dimensions.

A.5.1 *wood.mat*

```
void brightfunc zwoodgrain
4 zgrain wood_pat.cal -s .005
0
1 1
zwoodgrain plastic board_mat
0
0
5  .67 .54 .37  0 0
```

A.5.2 *wood_pat.cal*

```
{
 Wood grain pattern:
 A1 - magnitude (0 to 1)
}
xgrain = woodgrain(Ring(Py,Pz)); { along x axis }
ygrain = woodgrain(Ring(Px,Pz)); { along y axis }
zgrain = woodgrain(Ring(Px,Py)); { along z axis }

woodgrain(r) = hermite(.95-A1/20,.95+A1/20,3,.3,1*tri(r,1));
```

```
Ring(a,b) = sqrt( 25 + sq(mod(a,50)-25) + sq(mod(b,50)-25)) \
           + 3 * fnoise3(Px/40,Py/40,Pz/100);
```

A.5.3 *water.mat*

```
void texfunc wavy
6 xwrink ywrink zwrink wrinkle.cal -s .25
0
3  .2 .1 .1

wavy dielectric wavy_water
0
0
5  .9 .9 .91  1.33 0

void plastic basin_mat
0
0
5  .5 .7 .5  0 0
```

A.5.4 *wrinkle.cal*

```
{
 A texture function for wrinkled materials.
 11/23/93 Greg Ward
 A1 - average rise of wrinkles
 A2 - average run of wrinkles
 A3 - average spacing of wrinkles
}
diri = noise3(Px/A2/3,Py/A2/3,Pz/A2/3);

mx = Sqrt(-diri);
my = Sqrt(1-abs(diri));
mz = Sqrt(diri);

xwrink = Rdot*A1/A3*mx*fnoise3(Px/A3,Py/A2,Pz/A2);
ywrink = Rdot*A1/A3*my*fnoise3(Px/A2,Py/A3,Pz/A2);
zwrink = Rdot*A1/A3*mz*fnoise3(Py/A2,Py/A2,Pz/A3);
```

A.6 File Listings

A.6.1 *objects/chair.rad*

```
# This is a very simple chair.
# Dimensions are in metres.
# It is 0.5 m high (back 1.0 m) and 0.4 by 0.4 m wide.
# The centre is at (0,0).

void plastic chairmat
0
0
5  .2 .2 .1  0 0

void plastic fabric
0
0
5  .8 .4 .2  0 0

!genbox fabric seat .5 .5 .05 | xform -t -.25 -.25 .45
!genbox fabric back .05 .5 .3 | xform -t -.2 -.25 .7
chairmat cylinder leg1
0
0
7  -.225 -.225 0  -.225 -.225 .9  .025

chairmat sphere knob1
0
0
4  -.225 -.025 .9  .025

chairmat cylinder leg2
0
0
7  .225 -.225 0  .225 -.225 .45  .025

chairmat cylinder leg3
0
0
7  -.225 .225 0  -.225 .225 .9  .025

chairmat sphere knob3
0
0
4  -.225 .225 .9  .025

chairmat cylinder leg4
0
0
```

```
7  .225 .225 0  .225 .225 .45  .025
```

A.6.2 *objects/table.rad*

```
# This is a very simple table.
# Dimensions are in metres.
# It is 0.85 m high and 1 by 1 m wide.
# The centre is at (0,0).

void plastic tablemat
0
0
5  .5 .3 .1  0 0

!genbox tablemat tabletop 1 1 .05 | xform -t -.5 -.5 .8

tablemat cylinder leg1
0
0
7  -.4 -.4 0  -.4 -.4 .8  .025

tablemat cylinder leg2
0
0
7  .4 -.4 0  .4 -.4 .8  .025

tablemat cylinder leg3
0
0
7  -.4 .4 0  -.4 .4 .8  .025

tablemat cylinder leg4
0
0
7  .4 .4 0  .4 .4 .8  .025
```

A.6.3 *materials/course.mat*

```
void brightfunc dusty
4 dirt dirt.cal -s .1
0
1 .4

void brightfunc floorpat
2 .4*rand(floor(Px/.25)-.25* floor(Py/.25)-.25)+.6 .
0
0

void colorfunc blue_band
4 if(Pz-1.2,1,if(Pz-1,0,1)) if(Pz-1.2,1,if(Pz-1,0,1)) 1 .
0
```

```
0

void plastic wall_mat
0
0
5  .7 .7 .7  0 0

void plastic ceiling_mat
0
0
5  .9 .9 .9  0 0

void plastic floor_mat
0
0
5  .5 .5 .5  0 0

# Total, dirt-corrected glazing transm. after CIBSE LG10:1999
# JALOXA LG10 Glazing Calculator for Radiance
# http://www.jaloxa.eu/resources/radiance/lg10_glazing.shtml
# Glazing transmittance (A1.5) => 0.69
# - Double glazing clear float + low E glass
# Loss of daylight compared with clean glazing (A1.5) => 10%
# - Urban
# - Commercial, educational - rooms used by groups of people
# Multiplier for calculating maintenance factor (A1.10) => x 1
# - Normal vertical glazing
# Exposure multiplier for calculating MF (A1.11) => x 1
# - Vertical glazing
# - Normal exposure for location
# Maintenance factor  ==> 90%
# Total transmittance ==> 0.62
void glass glazing_mat
0
0
3  0.68 0.68 0.68
```

A.6.4 *skies/sky.rad*

```
skyfunc glow skyglow
0
0
4  .85 1.04 1.2  0

skyglow source sky
0
0
4  0 0 1  180

skyfunc glow groundglow
0
0
4  .8 1.1 .8  0
```

```
groundglow source ground
0
0
4  0 0 -1  180
```

A.6.5 *lux.plt*

```
include=line.plt
title="Working Plane Illuminance"
xlabel="Y Position [meters]"
ylabel="Illuminance [lux]"
Adata=results/lux.csv
Acolor="2"
```

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