Persistence of Vision™

Ray-Tracer

(POV-Ray™)

User's Documentation 3.0.10

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Introduction

Note that this document is still in work and there may (and will) be some larger changes. Do not waste your time, money and paper to print this document! You should also note that we will release a nicely formatted Postscript version of the docs in the near future.

This document details the use of the Persistence of Vision™ Ray Tracer (POV-Ray™). It is broken down into four parts: the installation guide, the tutorial guide, the reference guide and the appendix. The first part (see chapter 2 on page 5 chapter and 3 on page 21) tells you where to get and how to install POV-Ray. It also gives a short introduction to ray-tracing. The tutorial explains step by step how to use the different features of POV-Ray (see chapter 4 on page 33). The reference gives a complete description of all features available in POV-Ray by explaining all command line options (INI file keywords) and the scene description language (see chapter 5 on page 145, chapter 6 on page 147 and chapter 7 on page 183). The appendix includes some tips and hints, suggested reading, contact addresses and legal information.

POV-Ray™ is based on DKBTrace 2.12 by David K. Buck and Aaron A. Collins.

1.1 Notation

Throughout this document the following notation is used to mark keywords of the scene description language, command line options, INI file keywords and file names.

`name`	scene description keyword
name	command line option
name	INI file keyword
NAME	file name
name	Internet address, Usenet group

Part I

Installation Guide

Chapter 2

Program Description

The Persistence of Vision™ Ray-Tracer creates three-dimensional, photo-realistic images using a rendering technique called ray-tracing. It reads in a text file containing information describing the objects and lighting in a scene and generates an image of that scene from the view point of a camera also described in the text file. Ray-tracing is not a fast process by any means, but it produces very high quality images with realistic reflections, shading, perspective and other effects.

2.1 What is Ray-Tracing?

Ray-tracing is a rendering technique that calculates an image of a scene by shooting rays into the scene. The scene is build from shapes, light sources, a camera, materials, special features, etc.

For every pixel in the final image a viewing ray is shot into the scene and tested for intersection with any of the objects in the scene. Viewing rays originate from the viewer, represented by the camera, and pass through the viewing window (representing the final image).

Every time an object is hit, the color of the surface at that point is calculated. For this purpose the amount of light coming from any light source in the scene is determined to tell wether the surface point lies in shadow or not. If the surface is reflective or translucent new rays are set up and traced in order to determine the contribution of the reflected and refracted light to the final surface color.

Special features like interdiffuse reflection (radiosity), atmospheric effects and area lights make it necessary to shoot a lot of additional rays into the scene for every pixel.

2.2 What is POV-Ray?

The Persistence of Vision™ Ray-Tracer was developed from DKBTrace 2.12 (written by David K. Buck and Aaron A. Collins) by a bunch of people, called the POV-Team™, in their spare time. The headquarters of the POV-Team is in the GRAPHDEV forum on CompuServe (see 2.4.1 on page 17 for more details).

The POV-Ray™ package includes detailed instructions on using the ray-tracer and creating scenes. Many stunning scenes are included with POV-Ray so you can start creating images immediately when you get the package. These scenes can be modified so you don't have to start from scratch.

In addition to the pre-defined scenes is a large library of predefined shapes and materials that you can use in your own scenes by just including the appropriate files and typing the name of the shape or material.

Here are some highlights of POV-Ray's features:

- Easy to use scene description language.
- Large library of stunning example scene files.
- Standard include files that pre-define many shapes, colors and textures.
- Very high quality output image files (up to 48-bit color).
- 15 and 24 bit color display on IBM-PC's using appropriate hardware.
- Create landscapes using smoothed height fields.
- Spotlights, cylindrical lights and area lights for sophisticated lighting.
- Phong and specular highlighting for more realistic-looking surfaces.
- Interdiffuse reflection (radiosity) for more realistic lighting.
- Atmospheric effects like atmosphere, fog and rainbow.
- Halos to model effects like clouds, dust, fire and steam.
- Several image file output formats including Targa, PNG and PPM.
- Basic shape primitives such as ... spheres, boxes, quadrics, cylinders, cones, triangles and planes.
- Advanced shape primitives such as ... torii (donuts), hyperboloids, paraboloids, bezier patches, height fields (mountains), blobs, quartics, smooth triangles, text, fractals, superquadrics, surfaces of revolution, prisms, polygons, lathes and fractals.
- Shapes can easily be combined to create new complex shapes using Constructive Solid Geometry (CSG). POV-Ray supports unions, merges, intersections and differences.
- Objects are assigned materials called textures (a texture describes the coloring and surface properties of a shape).
- Built-in color and normal patterns: Agate, Bozo, Bumps, Checker, Crackle, Dents, Granite, Gradient, Hexagon, Leopard, Mandel, Marble, Onion, Quilted, Ripples, Spotted, Sprial, Radial, Waves, Wood, Wrinkles and image file mapping.
- Users can create their own textures or use pre-defined textures such as ... Brass, Chrome, Copper, Gold, Silver, Stone, Wood.

- Combine textures using layering of semi-transparent textures or tiles of textures or material map files.
- Display preview of image while computing (not available on all platforms).
- Halt rendering when part way through.
- Continue rendering a halted partial scene later.

2.3 Which Version of POV-Ray should you use?

POV-Ray can be used under MS-Dos, Windows 3.x, 95 and NT; Apple Macintosh 68k and Power PC; Commodore Amiga; Linux, UNIX and other platforms.

The latest versions of the necessary files are available over CompuServe, Internet, America Online and several BBS's. See section 2.4 on page 16 for more info.

2.3.1 IBM-PC and Compatibles

Currently there are three different versions for the IBM-PC running under different operating systems (MS-Dos, Windows, Linux) as described below.

2.3.1.1 MS-Dos

The MS-Dos version runs under Ms-Dos or as a dos application under Windows'95, Windows NT, Windows 3.1 or 3.11. It also runs under OS/2 and Warp.

Required hardware and software:

- A 386 or better CPU and at least 4 meg of RAM.
- About 6 meg disk space to install and 2-10 meg or more beyond that for working space.
- A text editor capable of editing plain ASCII text files. The `EDIT` program that comes with MS-Dos will work for moderate size files.
- Graphic file viewer capable of viewing GIF and perhaps TGA and PNG formats.

Required POV-Ray files:

- `POVMSDOS.EXE` — a self-extracting archive containing the program, sample scenes, standard include files and documentation in a hypertext help format with help viewer. This file may be split into smaller files for easier downloading. Check the directory of your download or ftp site to see if other files are needed.

Recommended:

- Pentium or 486dx or math co-processor for 386 or 486sx.
- 8 meg or more RAM.
- SVGA display preferably with VESA interface and high color or true color ability.

Optional: The source code is not needed to use POV-Ray. It is provided for the curious and adventurous.

- POVMSD_S.ZIP —- The C source code for POV-Ray for MS-Dos Contains generic parts and MS-Dos specific parts. It does not include sample scenes, standard include files and documentation so you should also get the executable archive as well
- A C compiler that can create 32-bit protected mode applications. We support Watcom 10.5a, Borland 4.52 with Dos Power Pack and DGJPP 2.0 (GNU GCC) compilers.

2.3.1.2 Windows

The Windows version runs under Windows'95, Windows NT and under Windows 3.1 or 3.11 if Win32s extensions are added. Also runs under OS/2 Warp.

Required hardware and software:

- A 386 or better CPU and at least 8 meg of RAM.
- About 12 meg disk space to install and 2-10 meg or more beyond that for working space.

Required POV-Ray files:

- User archive POVWIN3.EXE — a self-extracting archive containing the program, sample scenes, standard include files and documentation. This file may be split into smaller files for easier downloading. Check the directory of your download or ftp site to see if other files are needed.

Recommended:

- Pentium or 486dx or math co-processor for 386 or 486sx.
- 16 meg or more RAM.
- SVGA display preferably with high color or true color ability and drivers installed.

Optional: The source code is not needed to use POV-Ray. It is provided for the curious and adventurous.

- POVWIN_S.ZIP — The C source code for POV-Ray for Windows. Contains generic parts and Windows specific parts. It does not include sample scenes, standard include files and documentation so you should also get the executable archive as well.
- POV-Ray can only be compiled using C compilers that create 32-bit Windows applications. We support Watcom 10.5a, Borland 4.52/5.0 compilers. The source code is not needed to use POV-Ray. It is provided for the curious and adventurous.

2.3.1.3 Linux

Required hardware and software:

- A 386 or better CPU and at least 4 meg of RAM.
- About 6 meg disk space to install and 2-10 meg or more beyond that for working space.
- A text editor capable of editing plain ASCII text files.
- Any recent (1994 onwards) Linux kernel and support for ELF format binaries. POV-Ray for Linux is not in a.out-format.
- ELF libraries libc.so.5, libm.so.5 and one or both of libX11.so.6 or libvga.so.1.

Required POV-Ray files:

- POVLINUX.TGZ or POVLINUX.TAR.GZ — archive containing an official binary for each SVGALib and X-Windows modes. Also contains sample scenes, standard include files and documentation.

Recommended:

- Pentium or 486dx or math co-processor for 386 or 486sx.
- 8 meg or more RAM.
- SVGA display preferably high color or true color ability.
- If you want display, you'll need either SVGALib or X-Windows.
- Graphic file viewer capable of viewing PPM, TGA or PNG formats.

Optional: The source code is not needed to use POV-Ray. It is provided for the curious and adventurous.

- POVUNI_S.TAR.GZ or POVUNI_S.TGZ — The C source code for POV-Ray for Linux. Contains generic parts and Linux specific parts. It does not include sample scenes, standard include files and documentation so you should also get the executable archive as well.
- The GNU C compiler and (optionally) the X include files and libraries and **knowledge of how to use it**. Although we provide source code for generic Unix systems, we do not provide technical support on how to compile the program.

2.3.2 Apple Macintosh

The Macintosh versions run under Apple's MacOS operating system version 7.0 or better, on any 68020/030/040-based Macintosh (with or without a floating point coprocessor) or any of the Power Macintosh computers.

Required hardware and software:

- A 68020 or better CPU without a floating point unit (LC or Performa or Centris series) and at least 8 meg RAM or
- A 68020 or better CPU *with* a floating point unit (Mac II or Quadra series) and at least 8 meg RAM or
- Any Power Macintosh computer and at least 8 meg RAM.
- System 7 or newer and color QuickDraw (System 6 is no longer supported).
- About 6 meg free disk space to install and an additional 2-10 meg free space for working space.
- Graphic file viewer utility capable of viewing Mac PICT, GIF, and perhaps TGA and PNG formats (the shareware GIFConverter or GraphicConverter applications are good.)

Required POV-Ray files:

- POVMACNF.SIT or POVMACNF.SIT.HQX — a Stuffit archive containing the non-FPU 68K Macintosh application, sample scenes, standard include files and documentation (slower version for Macs without an FPU) or
- POVMAC68.SIT or POVMAC68.SIT.HQX — a Stuffit archive containing the FPU 68K Macintosh application, sample scenes, standard include files and documentation (faster version for Macs WITH an FPU) or
- POVPMAC.SIT or POVPMAC.SIT.HQX — a Stuffit archive containing the native Power Macintosh application, sample scenes, standard include files and documentation.

Recommended:

- 68030/33 or faster with FPU, or any Power Macintosh
- 8 meg or more RAM for 68K Macintosh; 16 meg or more for Power Macintosh systems.
- Color monitor preferred, 256 colors OK, but thousands or millions of colors is even better.

Optional: The source code is not needed to use POV-Ray. It is provided for the curious and adventurous. POV-Ray can be compiled using Apple's MPW 3.3, Metrowerks CodeWarrior 8 or Symantec 8.

- POVMACS.SIT or POVMACS.SIT.HQX — The full C source code for POV-Ray for Macintosh. Contains generic parts and Macintosh specific parts. It does not include sample scenes, standard include files and documentation so you should also get the executable archive as well.

2.3.3 Commodore Amiga

The Amiga version comes in several flavors: 68000/68020 without FPU (not recommended, very slow), 68020/68881(68882), 68030/68882 and 68040. There are also two sub-versions, one with a CLI-only interface, and one with a GUI (requires MUI 3.1). All versions run under OS2.1 and up. Support exists for pensharing and window display under OS3.x with 256 color palettes and CybeGFX display library support.

Required:

- at least 4 meg of RAM.
- at least 2 meg of hard disk space for the necessities, 5-20 more recommended for workspace.
- an ASCII text editor, GUI configurable to launch the editor of your choice.
- Graphic file viewer - POV-Ray outputs to PNG, Targa (TGA) and PPM formats, converters from the PPMBIN distribution are included to convert these to IFF ILBM files.

Required POV-Ray files:

- POVAMI.LHA – a LHA archive containing executible, sample scenes, standard include files and documentation.

Recommended:

- 8 meg or more of RAM.
- 68030 and 68882 or higher processor.
- 24bit display card (CyberGFX library supported)

As soon as a stable compiler is released for Amiga PowerPC systems, plans are to add this to the flavor list.

Optional: The source code is not needed to use POV-Ray. It is provided for the curious and adventurous.

- POVLHA_S.ZIP — The C source code for POV-Ray for Amiga. Contains generic parts and Amiga specific parts, includes sample scenes, standard include files and documentation. It does not include sample scenes, standard include files and documentation so you should also get the executable archive as well.

2.3.4 SunOS

Required hardware and software:

- A Sun SPARC processor and at least 4 meg of RAM.
- About 6 meg disk space to install and 2-10 meg or more beyond that for working space.
- A text editor capable of editing plain ASCII text files.
- SunOS 4.1.3 or other operating system capable of running such a binary (Solaris or possibly Linux for Sparc).

Required POV-Ray files:

- POVSUNOS.TGZ or POVSUNOS.TAR.GZ — archive containing an official binary for each text-only and X-Windows modes. Also contains sample scenes, standard include files and documentation.

Recommended:

- 8 meg or more RAM.
- If you want display, you'll need X-Windows or an X-Term.
- preferably 24-bit TrueColor display ability, although the X display code is known to work with ANY combination of visual and color depth.
- Graphic file viewer capable of viewing PPM, TGA or PNG formats.

Optional: The source code is not needed to use POV-Ray. It is provided for the curious and adventurous.

- POVUNI_S.TGZ or POVUNI_S.TAR.GZ — The C source code for POV-Ray for UNIX. Contains generic UNIX parts and Linux specific parts. It does not include sample scenes, standard include files and documentation so you should also get the executable archive as well.
- A C compiler and (optionally) the X include files and libraries and **knowledge of how to use it**.

Although we provide source code for generic Unix systems, we do not provide technical support on how to compile the program.

2.3.5 Generic Unix

Required:

- POVUNI_S.TGZ or POVUNI_S.TAR.GZ — The C source code for POV-Ray for Unix. Either archive contains full generic source, Unix and X-Windows specific source.

- POVUNI_D.TGZ or POVUNI_D.TAR.GZ or any archive containing the sample scenes, standard include files and documentation. This could be the Linux or SunOS executable archives described above.
- A C compiler for your computer and **knowledge of how to use it**. Although we provide source code for generic Unix systems, we do not provide technical support on how to compile the program.
- A text editor capable of editing plain ASCII text files.

Recommended:

- Math co-processor.
- 8 meg or more RAM.
- Graphic file viewer capable of viewing PPM, TGA or PNG formats.

Optional:

- X Windows if you want to be able to display as you render.
- You will need the X-Windows include files as well. If you're not familiar with compiling programs for X-Windows you may need some help from someone who is knowledgeable at your installation because the X include files and libraries are not always in a standard place.

2.3.6 All Versions

Each executable archive includes full documentation for POV-Ray itself as well as specific instructions for using POV-Ray with your type of platform.

All versions of the program share the same ray-tracing features like shapes, lighting and textures. In other words, an IBM-PC can create the same pictures as a Cray supercomputer as long as it has enough memory.

The user will want to get the executable that best matches their computer hardware. See the section 2.4 on page 16 for where to find these files. You can contact those sources to find out what the best version is for you and your computer.

2.3.7 Compiling POV-Ray

The following sections will help you to compile the portable C source code into a working executable version of POV-Ray. They are only for those people who want to compile a custom version of POV-Ray or to port it to an unsupported platform or compiler.

The first question you should ask yourself before proceeding is *Do I really need to compile POV-Ray at all?* Official POV-Ray Team executable versions are available for MS-Dos, Windows 3.1x/95/NT, Mac 68k, Mac Power PC, Amiga, Linux for Intel x86, and SunOS. Other unofficial compiles may soon be available for other platforms. If you do not intend to add any custom or experimental features to the program and if an executable already exists for your platform then you need not compile this program yourself.

If you do want to proceed you should be aware that you are very nearly on your own. The following sections and other related compiling documentation assume you know what you are doing. It assumes you have an adequate C compiler installed and working. It assumes you know how to compile and link large, multi-part programs using a MAKE utility or an IDE project file if your compiler supports them. Because makefiles and project files often specify drive, directory or path information, we cannot promise our makefiles or projects will work on your system. We assume you know how to make changes to makefiles and projects to specify where your system libraries and other necessary files are located.

In general you should not expect any technical support from the POV-Ray Team on how to compile the program. Everything is provided here as is. All we can say with any certainty is that we were able to compile it on our systems. If it doesn't work for you we probably cannot tell you why.

There is no technical documentation for the source code itself except for the comments in the source files. We try our best to write clear, well- commented code but some sections are barely commented at all and some comments may be out dated. We do not provide any technical support to help you to add features. We do not explain how a particular feature works. In some instances, the person who wrote a part of the program is no longer active in the Team and we don't know exactly how it works.

When making any custom version of POV-Ray or any unofficial compile, please make sure you read and follow all provisions of our license in A on page 371. In general you can modify and use POV-Ray on your own however you want but if you distribute your unofficial version you must follow our rules. You may not under any circumstances use portions of POV-Ray source code in other programs.

2.3.7.1 Directroy Structure

POV-Ray source code is distributed in archives with files arranged in a particular hierarchy of directories or folders. When extracting the archives you should do so in a way that keeps the directory structure intact. In general we suggest you create a directory called POVRAY3 and extract the files from there. The extraction will create a directory called SOURCE with many files and sub-directories.

In general, there are separate archives for each hardware platform and operating system but each of these archives may support more than one compiler. For example here is the directory structure for the MS-Dos archive.

```
SOURCE
SOURCE\LIBPNG
```

SOURCE\ZLIB
SOURCE\MSDOS
SOURCE\MSDOS\PMODE
SOURCE\MSDOS\BORLAND
SOURCE\MSDOS\DJGPP
SOURCE\MSDOS\WATCOM

The SOURCE directory contains source files for the generic parts of POV-Ray that are the same on all platforms. The SOURCE\LIBPNG contains files for compiling a library of routines used in reading and writing PNG (Portable Network Graphics) image files. The SOURCE\ZLIB contains files for compiling a library of routines used by LIBPNG to compress and uncompress data streams. All of these files are used by all platforms and compilers. They are in every version of the source archives.

The SOURCE\MSDOS directory contains all source files for the MS-Dos version common to all supported MS-Dos compilers. The PMODE sub-directory contains source files for PMODE.LIB which is required by all MS-Dos versions. The BORLAND, DJGPP, and WATCOM sub-directories contain source, makefiles and project files for C compilers by Borland, DJGPP and Watcom.

The SOURCE\MSDOS directory is only in the MS-Dos archive. Similarly the Windows archive contains a SOURCE\WINDOWS directory. The Unix archive contains SOURCE/UNIX etc.

The SOURCE\MSDOS directory contains a file CMPL_MSD.DOC which contains compiling information specific to the MS-Dos version. Other platform specific directories contain similar CMPL_XXX.DOC files and the compiler specific sub-directories also contain compiler specific CMPL_XXX.DOC files. Be sure to read all pertinent CMPL_XXX.DOC files for your platform and compiler.

2.3.7.2 Configuring POV-Ray Source

Every platform has a header file CONFIG.H that is generally in the platform specific directory but may be in the compiler specific directory. Some platforms have multiple versions of this file and you may need to copy or rename it as CONFIG.H. This file is included in every module of POV-Ray. It contains any prototypes, macros or other definitions that may be needed in the generic parts of POV-Ray but must be customized for a particular platform or compiler.

For example different operating systems use different characters as a separator between directories and file names. MS-Dos uses back slash, Unix a front slash or Mac a colon. The CONFIG.H file for MS-Dos and Windows contains the following:

```
#define FILENAME_SEPARATOR '\\'
```

which tells the generic part of POV-Ray to use a back slash.

Every customization that the generic part of the code needs has a default setting in the file SOURCE\FRAME.H which is also included in every module after CONFIG.H. The FRAME.H header contains many groups of defines such as this:

```
#ifndef FILENAME_SEPARATOR
#define FILENAME_SEPARATOR '/'
#endif
```

which basically says *if we didn't define this previously in* CONFIG.H *then here's a default value*. See FRAME.H to see what other values you might wish to configure.

If any definitions are used to specify platform specific functions you should also include a prototype for that function. The file SOURCE\MSDOS\CONFIG.H, for example, not only contains the macro:

```
#define POV_DISPLAY_INIT(w,h) MSDOS_Display_Init ((w), (h));
```

to define the name of the graphics display initialization function, it contains the prototype:

```
void MSDOS_Display_Init (int w, int h);
```

If you plan to port POV-Ray to an unsupported platform you should probably start with the simplest, non-display generic Unix version. Then add new custom pieces via the CONFIG.H file.

2.3.7.3 Conclusion

We understand that the above sections are only the most trivial first steps but half the fun of working on POV-Ray source is digging in and figuring it out on your own. That's how the POV-Ray Team members got started. We've tried to make the code as clear as we can.

Be sure to read the CMPL_XXX.DOC files in your platform specific and compiler specific directories for some more minor help if you are working on a supported platform or compiler.

Good luck!

2.4 Where to Find POV-Ray Files

The latest versions of the POV-Ray software are available from the following sources.

2.4.1 Graphics Developer Forum on CompuServe

POV-Ray's headquarters are on CompuServe, GRAPHDEV forum, ray-tracing sections. We meet there to share info and graphics and discuss ray tracing, fractals and other kinds of computer art. Everyone is welcome to join in on the action on CIS GRAPHDEV. Hope to see you there! You can get information on joining CompuServe by calling (800)848-8990 or visit the CompuServe home page `http://www.compuserve.com`. Direct CompuServe access is also available in Japan, Europe and many other countries.

2.4.2 Internet

The internet home of POV-Ray is reachable on the World Wide Web via the address `http://www.povray.org` and via ftp as `ftp.povray.org`. Please stop by often for the latest files, utilities, news and images from the official POV-Ray internet site.

The `comp.graphics.rendering.raytracing` newsgroup has many competent POV-Ray users that are very willing to share their knowledge. They generally ask that you first browse a few files to see if someone has already answered the same question, and of course, that you follow proper "netiquette". If you have any doubts about the qualifications of the folks that frequent the group, a few minutes spend at the Ray Tracing Competition pages at `www.povray.org` will quickly convince you!

2.4.3 PC Graphics Area on America On-Line

There's an area now on America On-Line dedicated to POV-Ray support and information. You can find it in the PC Graphics section of AOL. Jump keyword POV (the keyword PCGRAPHICS brings you to the top of the graphics related section). This area includes the Apple Macintosh executables also. It is best if messages are left in the *Company Support* section. Currently, Bill Pulver (BPulver) is our representative there.

2.4.4 The Graphics Alternative BBS in El Cerrito, CA

For those on the West coast, you may want to find the POV-Ray files on *The Graphics Alternative BBS*. It's a great graphics BBS run by Adam Shiffman. TGA is high quality, active and progressive BBS system which offers both quality messaging and files to its 1300+ users.

510-524-2780	(PM14400FXSA v.32bis 14.4k, Public)
510-524-2165	(USR DS v.32bis/HST 14.4k, Subscribers)

USA and Canada			
411-Exchange	Alpharetta	GA	404-345-0008
Autodesk Global Village	San Rafael	CA	415-507-5921
CAD/Engineering Services	Hendersonville	TN	615-822-2539
Canis Major	Nashville	TN	615-385-4268
CEAO BBS	Columbus	OH	614-481-3194
CHAOS BBS	Columbia	MO	314-874-2930
Joes CODE BBS	West Bloomfield	MI	810-855-0894
John's Graphics	Brooklyn Park	MN	612-425-4436
PC-AUG	Phoenix	AZ	602-952-0638
SAUG BBS	Bellevue	WA	206-644-7115
Space Command BBS	Kennewick	WA	509-735-4894
The CAD/fx BBS	Mesa	AZ	602-835-0274
The Drawing Board BBS	Anchorage	AK	907-349-5412
The Graphics Alternative	El Cerrito	CA	510-524-2780
The Happy Canyon	Denver	CO	303-759-3598
The New Graphics BBS	Piscataway	NJ	908-271-8878
The University	Shrewsbury Twp	NJ	908-544-8193
The Virtual Dimension	Oceanside	CA	619-722-0746
Time-Out BBS	Sadsburyville	PA	610-857-2648

Table 2.1: Graphic-orientated BBSs in North America.

2.4.5 PCGNet

The Professional CAD and Graphics Network (PCGnet) serves both the CAD and Graphics communities by making information useful to them widely available.

Formerly known as ADEnet, PCGnet is a new network created from the ground up, incorporating new nodes and focusing evenly on both CAD and graphics related topics, including, but not limited to the following topics: design, drafting, engineering, 2d and 3d modeling, multimedia, systems, raster imaging, raytracing, 3d rendering and animation.

PCGnet is designed to serve the needs of all callers by stimulating interest and generating support forums for active users who have an interest in the CAD and graphics related topics previously mentioned; interest and support is generated through PCGnet's message conferences, file sharing across the network, and industry news and press releases. PCGnet's message conference are moderated forums designed to accommodate friendly, yet professional and informative discussion of CAD and graphics related subjects.

TGA BBS serves as the central hub for a large network of graphics-oriented BBS systems around the world. In table 2.1, table 2.2 on the next page and table 2.3 on the facing page you wil find a concise listing of active PCGNet nodes at the time of this writing. The POV-Team can not vouch for the currency of this information, nor verify that any of these boards may carry POV-Ray.

Austria		
AutoCAD User Group	Graz	43-316-574-426
Belgium		
Lucas Visions BBS	Boom	32-3-8447-229
Denmark		
Horreby SuperBBS	Nykoebing Falster	45-53-84-7074
Finland		
DH-Online	Jari Hiltunen	358-0-40562248
Triplex BBS	Helsinki	358-0-5062277
France		
CAD Connection	Montesson	33-1-39529854
Zyllius BBS!	Saint Paul	33-93320505
Germany		
Ray BBS Munich	Munich	49-89-984723
Tower of Magic	Gelsenkirchen	49-209-780670
Netherlands		
BBS Bennekom: Fractal Board	Bennekom	31-318-415331
CAD-BBS	Nieuwegein	31-30-6090287
		31-30-6056353
Foundation One	Baarn	31-35-5422143
Slovenia		
MicroArt	Koper	386-66-34986
Sweden		
Autodesk On-line	Gothenburg	46-31-401718
United Kingdom		
CADenza BBS	Leicester, UK	44-116-259-6725
Raytech BBS	Tain, Scotland	44-1862-83-2020
The Missing Link	Surrey, England	44-181-641-8593

Table 2.2: Graphic-orientated BBSs in Europe.

Australia		
MULTI-CAD Magazine BBS	Toowong QLD	61-7-878-2940
My Computer Company	Erskineville NSW	61-2-557-1489
Sydney PCUG Compaq BBS	Caringbah NSW	61-2-540-1842
The Baud Room	Melbourne VIC	61-3-481-8720
New Zealand		
The Graphics Connection	Wellington	64-4-566-8450
The Graphics Connection II	New Plymouth	64-6-757-8092
The Graphics Connection III	Auckland	64-9-309-2237

Table 2.3: Graphic-orientated BBSs in the rest of the world.

Country or long distance dial numbers may require additional numbers to be used. Consult your local phone company.

2.4.6 POV-Ray Related Books and CD-ROMs

The following items were produced by POV-Team members. Although they are only current to POV-Ray 2.2 they will still be helpful. Steps are being taken to update the POV-Ray CDROM to version 3.0, with a new version expected around October 1996.

The books listed below have been recently listed as out-of-print but may still be found in some bookstores or libraries (Visit http://www.dnai.com:80/waite/ for more details).

Ray Tracing Creations, 2d Ed.
Chris Young and Drew Wells
ISBN 1-878739-69-7
Waite Group Press 1994
700 pages with color insert and POV-Ray 2.2 on 3.5" MS-Dos disk.

Ray Tracing Worlds with POV-Ray
Alexander Enzmann, Lutz Kretzschmar, Chris Young
ISBN 1-878739-64-6
Waite Group Press 1994
Includes Moray 1.5x modeler and POV-Ray 2.2 on 3.5" MS-Dos disks.

Ray Tracing for the Macintosh CD
Eduard Schwan
ISBN 1-878739-72-7
Waite Group Press, 1994
Comes with a CD-ROM full of scenes, images, and QuickTime movies, and an interactive keyword reference. Also a floppy with POV-Ray for those who don't have a CD ROM drive.

The Official POV-Ray CDROM: The Official POV-Ray CDROM is a compilation of images, scene source, program source, utilities and tips on POV-Ray and 3D graphics from the Internet and Compuserve. This CD is aimed not only at those who want to create their own images or do general 3D programming work, but also at those who want simply to experience some high-quality renderings done by some of the best POV-Ray artists, and to learn from their source code. The CDROM contains over 500 ray-traced images.

It's a good resource for those learning POV-Ray as well as those who are already proficient, and contains a Microsoft Windows-based interactive tutorial. The disk comes with a fold-out poster and reference sheet. The CD is compatible with DOS/Windows and Macintosh formats.

The CDROM is available for free retrieval and browsing on the World Wide Web at `http://www.povray.org/pov-cdrom`. For more details you may also visit `http://www.povray.org/povcd`.

Chapter 3

Quick Start

The next section describes how to quickly install POV-Ray and render sample scenes on your computer. It is assumed that you are using an IBM-PC compatible computer with MS-Dos. For other platforms you must refer to the specific documentation included in POV-Ray's archive.

3.1 Installing POV-Ray

[*** STILL BEING WRITTEN ***]

Specific installation instructions are included with the executable program for your computer. In general, there are two ways to install POV-Ray.

[Note that the generic word ”directory” is used throughout. Your operating system may use another word (subdirectory, folder, etc.)]

1) The messy way: Create a directory called POVRAY and copy all POV-Ray files into it. Edit and run all files and programs from this directory. This method works, but is not recommended.

Or the preferred way:

2) Create a directory called POVRAY and several subdirectories called INCLUDE, DEMO, SCENES, UTIL. The self-extracting archives used in some versions of the program will create subdirectories for you. If you create your own, the file tree for this should look something like this:

Copy the executable file and docs into the directory POVRAY. Copy the standard include files into the subdirectory INCLUDE. Copy the sample scene files into the subdirectory SCENES. And copy any POV-Ray related utility programs and their related files into the subdirectory UTIL. Your own scene files will go into the SCENES subdirectory. Also, you'll need to add the directories \POVRAY and \POVRAY\UTIL to your ”search path” so the executable programs can be run from any directory.

Note that some operating systems don't have an equivalent to the multi-path search command.

The second method is a bit more difficult to set-up, but is preferred. There are many files associated with POV-Ray and they are far easier to deal with when separated into several directories.

3.2 Basic Usage

Notice: If you did not install the program using the INSTALL.EXE system, the examples and instructions given here may not work! The installation process configures POVRAY.INI and several important batch files. Without these files configured, the examples herein may not work.

POV-Ray's basic purpose is to read a scene description written in the POV language and to write an image file. The scene files are plain ASCII text files that you create using a text editor. Dozens of sample files are included with this package to illustrate the various features.

You invoke POV-Ray by typing a command at the MS-Dos prompt. The command is POVRAY and it must be followed by one or more command line switches. Each switch begins with a plus or minus sign. Blanks separate the switches. The switches may be upper or lower case.

Note: The examples in this documentation assume you installed POV-Ray in the C:\POVRAY3 directory. The installer will let you install POV-Ray anywhere and will properly configure it for the drive and directory you specified. You just substitute that drive and directory anywhere we tell you to use C:\POVRAY3. Change to that directory now. Then type the following command line and press [ENTER]

```
POVRAY +ISHAPES +D1
```

The **+I** command (for *input*) tells the program what file to read as input. If you don't give an extension on the file name, .POV is assumed. Thus **+I**SHAPES tells it to read in SHAPES.POV to be rendered.

The **+D** switch (for *display*) tells the program to turn the graphic preview display on. A **–D** would turn it off. The number "1" tells it what type of display to use. Type "1" is the old fashioned standard generic VGA at 320 by 200 resolution and just 256 colors. This is pretty much guaranteed to work on any VGA video system.

There are other options in effect besides those you typed on the command line. They are stored in a file called POVRAY.INI which was created by the install system. POV-Ray automatically looks for this file in the same directory where POVRAY.EXE resides. See 3.2.2 on page 25 and 6.1.2 on page 148 for more information on POVRAY.INI and other INI files.

When you enter the command shown above, you will see brightly colored geometric shapes begin to appear as POV-Ray calculates the color of each pixel row by row. You will probably be disappointed with the graphic display results. That is because this is only a preview display. The actual image is in full 24-bit color but we cannot display that high quality using simple VGA with a fixed set of 256 colors. If your hardware supports the VESA interface standard or you have a VESA TSR driver loaded, try running with **+DG** rather than **+D1**. This will give you access to all of the various modes your video hardware can use. If you have 15-bit or 16- bit high color capability try **+DGH** or if you have 24-bit true color capability try **+DGT** to see the image in all its glory. See section 3.2.5 on page 27 below for more information on graphics preview.

When the program finishes, you will hear beeps. After admiring the image, press [ENTER]. You will see a text screen of statistics. If the text is too much to fit on the screen you may press [CURSOR UP] or [CURSOR DOWN] keys to read more text. Notice that there are tabs at the bottom of the screen. Press [CURSOR LEFT] or [CURSOR RIGHT] keys to view other interesting text information. Press [ENTER] again to exit POV-Ray.

If you do not have high color or true color ability you will have to view the image file to see the real colors. The image file SHAPES.TGA is written to your current directory. By default POV-Ray creates files in TGA format. This is a standard format for storing 24-bit true-color images. You will need an image viewing program to view the file. Such programs are usually available from the same place where you obtained POV-Ray but a viewer is not included in this package.

If you cannot view TGA files you may add the switch **+FN** and POV-Ray will output PNG (Portable Network Graphic) format. If PNG format viewer is not available then type the following

```
T2G SHAPES
```

and press [ENTER]. This will run a batch file that invokes the TGA2GIF program. The program will read your SHAPES.TGA file, create an optimal 256 color palette and write a GIF format file SHAPES.GIF. Most image viewing programs support GIF.

3.2.1 Running Files in Other Directories

Normally POV-Ray only looks in the current directory for the files it needs. It does not search your MS-Dos path for data files; it only searches for programs. In the sample scene you just ran, file SHAPES.POV was in the current directory so this was no problem. That scene also needed other files but your POVRAY.INI file tells POV-Ray other places to search for necessary files.

If you allowed the install system to update your AUTOEXEC.BAT file, then you can change to any drive or directory and can run POV-Ray from that directory. You will also be able to use the batch files and utilities that came with this package in any directory. For future reference let's call the "use-C:\POVRAY3-in-your-path-plan" as *plan one*.

There are some circumstances where you may not want to put C:\POVRAY3 in your path. There is a limit of 128 characters in your path statement and you may not have room for it. Try rendering the SHAPES example from a different directory. If it doesn't work, then you forgot to re-boot your system so the new path takes effect. If after re-booting it still doesn't work, it probably means your path is too full. You will have to adopt a different plan.

Chances are, you already have several directories in your path. Most systems have C:\DOS, C:\WINDOWS or some directory such as C:\UTILITY already in the path. We have provided several small batch files that you can copy to that directory. For future reference we'll call the "put-batch-files-in-a-directory-already-on-the-path-plan" as *plan two*.

At any dos prompt, type the word *path* and press [ENTER]. It will show you what directories are already on your path. Then copy the following files from your C:\POVRAY3 directory to any of the directories already on your path. The files are:

RUNPOV.BAT RERUNPOV.BAT RUNPHELP.BAT T2G.BAT

Once you have copied these files, try the following example. In this case, do not invoke the program with the command POVRAY. Instead use RUNPOV as follows:

cd \POVRAY3\POV3DEMO\SHOWOFF
RUNPOV **+I**SUNSET3 **+D1**

This changes to the \POVRAY3\POV3DEMO\SHOWOFF directory where the file SUNSET3.POV is found. It runs the file RUNPOV.BAT. That batch file is set up to run POV-Ray even if it is not on the dos path. It also passes the switches along to POV-Ray. These batch files have other uses, even if you are using *plan one* as described above or *plan three* as described below. For more on these batch files, see 3.2.4 on page 26.

All of the early examples in this document assumed you were running POV-Ray from the directory where it was installed such as C:\POVRAY3. This approach of always using the installation directory is in fact *plan three*. If you are using this method, you need to tell POV-Ray where else to look for files. In the case of SUNSET3.POV you could do this:

POVRAY **+I**C:\POVRAY3\POV3DEMO\SHOWOFF\SUNSET3 **+D1**

However some scenes need more than one file. For example the directory DRUMS2 that can be found under \POVRAY3\POVSCN\LEVEL3 contains three files: DRUMS.POV, DRUMS.INC and REDNEWT.GIF all of which are required for that one scene. In this case you should use the **+L** switch (for *library*) to add new library paths to those that POV-Ray will search. You would render the scene with this command.

POVRAY **+L**\POVRAY3\POVSCN\LEVEL3\DRUMS2 **+I**DRUMS **+D1**

3.2.2 INI Files

There were more options used in these renderings than just the switches **+I**, **+D**, and **+L** that you specify. When you run the program, POV- Ray automatically looks for the file POVRAY.INI in whatever directory that POVRAY.EXE is in. The POVRAY.INI file contains many options that control how POV-Ray works. We have set this file up so that it is especially easy to run your first scene with minimal problems. The file should be placed in the same directory as POVRAY.EXE and it will automatically read when POV-Ray is run. If you ever move POVRAY.EXE to a different directory, be sure to move POVRAY.INI too.

Complete details on all of the available switches and options that can be given on the command line or in POVRAY.INI are given in 6 on page 147.

You may also create INI files of your own with switches or options similar to POVRAY.INI. If you put a file name on the command line without a plus or minus sign before it, POV-Ray reads it as an INI file. Try this . . .

```
POVRAY RES120 +ISHAPES +D1
```

This causes POV-Ray to look for a file called RES120.INI which we have provided. It sets your resolution to 120 by 90 pixels for a quick preview. The following INI files have been provided for you.

RES120.INI	Sets resolution to 120 by 90.
RES320.INI	Sets resolution to 320 by 200.
RES640.INI	Sets resolution to 640 by 480.
RES800.INI	Sets resolution to 800 by 600.
RES1K.INI	Sets resolution to 1024 by 768.
LOW.INI	Sets low quality at 120 by 90.
SLOW.INI	Turns on radiosity and anti-aliasing; slow but beautiful.
TGAFLI.INI	Create an FLI animation from TGA images.
PNGFLI.INI	Create an FLI animation from DTA images.
ZIPFLI.INI	Create an FLI animation from zipped images.
TGAFLC.INI	Create an FLC animation from TGA images.
PNGFLC.INI	Create an FLC animation from DTA images.
ZIPFLC.INI	Create an FLC animation from zipped images.

You can create your own custom INI's which can contain any command in the reference guide.

3.2.3 Alternatives to POVRAY.INI

The POVRAY.INI file is supposed to hold your favorite global default options that you want to use all the time. You should feel free to edit it with new options that suit your needs. However it must be located in the same directory as POVRAY.EXE or it won't be found. The dos path isn't searched nor will **+L** commands help because POVRAY.INI is processed before any command line switches.

If your POVRAY.EXE resides on a CD-ROM then you can't edit the POVRAY.INI on the CD. There is an alternative. You may use an environment variable to specify an alternative global default.

In your AUTOEXEC.BAT file add a line similar to this:

```
set POVINI=D:\DIRECT\FILE.INI
```

which sets the POVINI environment variable to whatever drive, directory and INI file you choose. If you specify any POVINI environment variable then POVRAY.INI is **not read**. This is true even if the file you named doesn't exist. Note that you are specifying an entire path and file name. This is not a pointer to a directory containing POVRAY.INI. It is a pointer to the actual file itself.

Note that the POVRAYOPT environment variable in previous versions of POV-Ray is no longer supported.

3.2.4 Batch Files

We've already described how the file RUNPOV.BAT can be used as an alternative to running POV-Ray directly. RUNPOV.BAT also has one other use. It uses the **+GI** switch to create a file called RERUN.INI. This makes it very easy to run the same file over again with the same parameters. When creating your own scene files you will probably make dozens of test renders. This is a very valuable feature. Here is how it works ... Suppose you render a scene as follows:

```
RUNPOV +IMYSCENE +D1 RES120
```

This renders MYSCENE.POV at 120 by 90 resolution. Note there is no such scene. This is hypothetical. After viewing it, you noticed a mistake which you fixed with your text editor. To rerun the scene type:

```
RERUNPOV
```

and that's all. It will rerun the same scene you just ran. Suppose you want more detail on the next run. You can add more switches or INI files. For example:

```
RERUNPOV RES320
```

will rerun at higher resolution. Subsequent uses of RERUNPOV will be at 320 by 200 until you tell it differently. As another example, the **+A** switch turns on anti-aliasing. Typing "RERUNPOV **+A**" reruns with anti- aliasing on. All subsequent reruns will have it on until you do a "RERUNPOV **–A**" to turn it off. Note if you do another RUNPOV it starts over from your POVRAY.INI defaults and it overwrites the old RERUN.INI.

Two other batch files are included. RUNPHELP.BAT is only used as an alternative way to run POVHELP from another directory. If you used installation *plan two* then use RUNPHELP.BAT rather than POVHELP.EXE. This batch file serves no other purpose.

Finally T2G.BAT invokes the TGA2GIF.EXE program for converting TGA files to GIF files. You could run TGA2GIF directly but its default parameters do not generally produce the best results. If you use T2G instead, it adds some command line switches which work better. For a full list of switches available for TGA2GIF, type TGA2GIF with no parameters and it will display the available switches and options.

3.2.5 Display Types

You have already seen how to turn on graphics preview using **+D1**. Here are details on other variations of the **+D** switch. Use **–D** to turn the display off. If you use **–D** then you will probably want to add the **+V** switch to turn on verbose status messages so you can monitor the progress of the rendering while in progress.

The number "1" after the **+D** tells it what kind of video hardware to use. If you use **+D** alone or **+D0** then POV-Ray will attempt to auto detect your hardware type. Use **+D?** to see a message about what type of hardware POV-Ray found.

You may also explicitly tell POV-Ray what hardware to use. The following chart lists all of the supported types.

+D0	Auto detect (S)VGA type (Default)
+D1	Standard VGA 320×200
+D2	Standard VGA 360×480
+D3	Tseng Labs 3000 SVGA 640×480
+D4	Tseng Labs 4000 SVGA
+D5	AT&T VDC600 SVGA 640×400
+D6	Oak Technologies SVGA 640×480
+D7	Video 7 SVGA 640×480
+D8	Video 7 Vega (Cirrus) VGA 360×480
+D9	Paradise SVGA 640×480
+DA	Ahead Systems Ver. A SVGA 640×480
+DB	Ahead Systems Ver. B SVGA 640×480
+DC	Chips & Technologies SVGA 640×480
+DD	ATI SGVA 640×480
+DE	Everex SVGA 640×480
+DF	Trident SVGA 640×480
+DG	VESA Standard SVGA Adapter

+DH ATI XL display card
+DI Diamond Computer Systems SpeedSTAR 24X

The most common type is a VESA standard card which uses **+DG**. VESA is a standard software interface that works on a wide variety of cards. Those cards which do not have VESA support directly built-in, generally have a video driver that you can load to provide VESA support. The program UNIVBE is a high quality universal VESA driver that may work for you. It can be found at `http://www.povray.org` or possibly other POV-Ray sites.

The options listed above had been tested worked under earlier versions of POV-Ray but there have been many changes in the program and we cannot guarantee these all still work. If you can use VESA then do so. It has been well tested and will give you the most flexibility.

After the **+D** and the type, you may specify a 3rd character that specifies the palette type.

+D?3 Use 332 palette with dithering (default and best for VGA systems). This is a fixed palette of 256 colors with each color consisting 3-bits of red data, 3-bits green and 2-bits blue.
+D?0 Use HSV palette option for VGA display. This is a fixed palette of 256 colors where colors are matched according to hue, saturation and intensity rather than the amount of red, green and blue.
+D?G Use fixed gray scale palette option for VGA display.
+D?H Use HiColor option. Displays more than 32000 colors with dithering. Supported on VESA, SpeedSTAR 24X, ATI XL HiColor and Tseng 4000 based cards with high color 15 or 16 bit options.
+D?T For Truecolor 24 bit cards. Use 24 bit color. Supported on the Diamond SpeedSTAR 24X and cards with 24bit VESA support only.

Here are some examples:

+D0H Auto detect the VGA display type and display the image to the screen as it's being worked on. Use the 15-bit HiColor chip and dithering to display more than 32,000 colors on screen.
+D4 Display to a TSENG 4000 chipset VGA using the 332 palette option.
+D4H Display to a TSENG 4000 chipset VGA using the HiColor option.
+DG0 Display to a VESA VGA adapter and use the HSV palette option.
+DG3 Display to a VESA VGA adapter and use the 332 palette option.
+DGH Display to a VESA VGA adapter and use the HiColor option for over 32,000 colors.
+DGT Display to a VESA VGA adapter and use the TrueColor option for over 16 million colors.

Note that your VESA BIOS must support these options in order for you to use them. Some cards may support HiColor and/or TrueColor at the hardware level but not through their VESA BIOS.

Part II

Tutorial Guide

Chapter 4

Beginning Tutorial

The beginning tutorial explains step by step how to use POV-Ray's scene description language to create your own scenes. The use of almost every feature of POV-Ray's language is explained in detail. You will learn basic things like placing cameras and light sources. You will also learn how to create a large variety of objects and how to assign different textures to them. The more sophisticated features like radiosity, halos, and atmospheric effects will also be explaind in detail.

The following sections explain the features in roughly the same order as they are described in the reference chapter.

4.1 Your First Image

Let's create the scene file for a simple picture. Since ray-tracers thrive on spheres, that's what we'll render first.

4.1.1 Understanding POV-Ray's Coordinate System

First, we have to tell POV-Ray where our camera is and where it's looking. To do this, we use 3D coordinates. The usual coordinate system for POV-Ray has the positive Y axis pointing up, the positive X axis pointing to the right, and the positive Z axis pointing into the screen as shown in figure 4.1 on the following page.

This kind of coordinate system is called a left-handed coordinate system. If you use your left hand's fingers you can easily see why it is called left-handed. Just point your thumb in the direction of the positive x-axis, your index finger in the direction of the positive y-axis and your middle finger in the positive z-axis direction. You can only do this with your left hand. If you had used your right hand you would not have been able to point the middle finger in the correct direction.

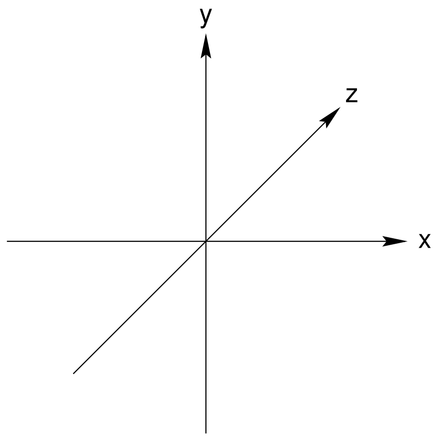


Figure 4.1: The left-handed coordinate system (the z-axis is pointing away from the viewer).

The left hand can also be used to determine rotation directions. To do this you must perform the famous *Computer Graphics Aerobics* exercise. Hold up your left hand. Point your thumb in the positive direction of the axis of rotation. Your fingers will curl in the positive direction of rotation. Similarly if you point your thumb in the negative direction of the axis your fingers will curl in the negative direction of rotation.

If you want to use a right-handed system, as some CAD systems such as AutoCAD do, the `right` vector in the camera specification needs to be changed. See the detailed description in 7.4.4.5.2 on page 226. In a right-handed system you use your right hand for the *Aerobics*.

Note that there is some controversy over whether POV-Ray's method of doing a right-handed system is really proper. If you want to avoid problems we suggest you stick with the left-handed system which is not in dispute.

4.1.2 Adding Standard Include Files

Using your personal favorite text editor, create a file called `demo.pov`. Now type in the following (the input is case sensitive, so be sure to get capital and lowercase letters correct).

```
#include "colors.inc"    // The include files contain
#include "shapes.inc"    // pre-defined scene elements
#include "finish.inc"
#include "glass.inc"
#include "metals.inc"
#include "stones.inc"
#include "woods.inc"
```

The first include statement reads in definitions for various useful colors. The second include statement reads in some useful shapes. The next read pre-defined finishes, glass, metal, stone, and wood textures. When you get a chance, have a look through them to see but a few of the many possible shapes and textures available.

You should only include files you really need in your scene. Some of the include files coming with POV-Ray are quite large and you should better save the parsing time (and memory) if you don't need them. In the following examples we will only use the `colors.inc`, `finish.inc` and `stones.inc` include files so you'll better remove the appropriate lines from your scene file.

You may have as many include files as needed in a scene file. Include files may themselves contain include files, but you are limited to declaring includes nested only ten levels "deep".

Filenames specified in the include statements will be searched for in the current directory first and, if not found, will then be searched for in directories specified by any **+L** or Library_Path options active. This would facilitate keeping all your "include" (.INC) files such as SHAPES.INC, COLORS.INC, and TEXTURES.INC in an "include" subdirectory, and giving an **+L** option on the command line to where your library of include files are.

4.1.3 Adding a Camera

The camera declaration describes where and how the camera sees the scene. It gives x, y, z coordinates to indicate the position of the camera and what part of the scene it is pointing at. You describe x, y, z coordinates using a three-part *vector*. A vector is specified by putting three numeric values between a pair of angle brackets and separating the values with commas.

Add the following camera statement to the scene.

```
camera {
  location <0, 2, -3>
  look_at  <0, 1,  2>
}
```

Briefly, `location` $\langle 0,2,-3\rangle$ places the camera up two units and back three units from the center of the ray-tracing universe which is at $\langle 0,0,0\rangle$. Remember that by default $+z$ is into the screen and $-z$ is back out of the screen.

Also `look_at` $\langle 0,1,2\rangle$ rotates the camera to point at x, y, z coordinates $\langle 0,1,2\rangle$. A point 5 units in front of and 1 unit lower than the camera. The look_at point should be the center of attention of your image.

4.1.4 Describing an Object

Now that the camera is set up to record the scene, let's place a yellow sphere into the scene. Add the following to your scene file:

```
sphere {
  <0, 1, 2>, 2
  texture {
    pigment { color Yellow }
  }
}
```

The first vector specifies the center of the sphere. In this example the x coordinate is zero so it is centered left and right. It is also at $y = 1$ or 1 unit up from the origin. The z coordinate is 2 which is 5 units in front of the camera, which is at $z = -3$. After the center vector is a comma followed by the radius which in this case is 2 units. Since the radius is half the width of a sphere, the sphere is 4 units wide.

4.1.5 Adding Texture to an Object

After we have defined the location and size of the sphere, we need to describe the appearance of the surface. The `texture { ... }` block specifies these parameters. Texture blocks describe the color, bumpiness and finish properties of an object. In this example we will specify the color only. This is the minimum we must do. All other texture options except color will use default values.

The color you define is the way you want it to look if fully illuminated. If you were painting a picture of a sphere you would use dark shades of a color to indicate the shadowed side and bright shades on the illuminated side. However ray-tracing takes care of that for you. You pick the basic color inherent in the object and POV-Ray brightens or darkens it depending on the lighting in the scene. Because we are defining the basic color the object actually **has** rather than how it **looks** the parameter is called *pigment*.

Many types of color patterns are available for use in a `pigment { ... }` statement. The keyword `color` specifies that the whole object is to be one solid color rather than some pattern of colors. You can use one of the color identifiers previously defined in the standard include file `colors.inc`.

If no standard color is available for your needs, you may define your own color by using the color keyword followed by `red`, `green` and `blue` keywords specifying the amount of red, green and blue to be mixed. For example a nice shade of pink can be specified by:

```
color red 1.0 green 0.8 blue 0.8
```

The values after each keyword should be in the range 0.0 to 1.0. Any of the three components not specified will default to 0. A shortcut notation may also be used. The following produces the same shade of pink:

```
color rgb <1.0, 0.8, 0.8>
```

Colors are explained in more detail in section 7.1.5 on page 192.

4.1.6 Defining a Light Source

One more detail is needed for our scene. We need a light source. Until you create one, there is no light in this virtual world. Thus add the line

```
light_source { <2, 4, -3> color White}
```

to your scene file to get your first complete POV-Ray scene file as shown below.

```
#include "colors.inc"

background { color Cyan }

camera {
  location <0, 2, -3>
  look_at  <0, 1,  2>
}

sphere {
  <0, 1, 2>, 2
  texture {
    pigment { color Yellow }
  }
}

light_source { <2, 4, -3> color White}
```

The vector in the `light_source` statement specifies the location of the light as 2 units to our right, 4 units above the origin and 3 units back from the origin. The light source is invisible, it only casts light, so no texture is needed.

That's it! Close the file and render a small picture of it using the command

POVRAY **+W**160 **+H**120 **+P +X +D0 –V -I**DEMO.POV

If your computer does not use the command line, see your platform specific docs for the correct command to render a scene.

You may also set any other command line options you like. The scene is written to the image file `demo.tga` (or some suffix other than .TGA if your computer uses a different default file format).

The scene you just traced isn't quite state of the art but we'll have to start with the basics before we soon get to much more fascinating features and scenes.

4.2 Using the Camera

[*** STILL BEING WRITTEN ***]

4.2.1 Camera Types

[*** STILL BEING WRITTEN ***]

4.2.2 Using Focal Blur

[*** STILL BEING WRITTEN ***]

4.2.3 Using Camera Ray Perturbation

[*** STILL BEING WRITTEN ***]

4.3 Simple Shapes

So far we've just used the sphere shape. There are many other types of shapes that can be rendered by POV-Ray. The following sections will describe how to use some of the more simple objects as a replacement for the sphere used above.

4.3.1 Box Object

The box is one of the most common objects used. Try this example in place of the sphere:

```
box {
  <-1, 0,   -1>,  // Near lower left corner
  < 1, 0.5,  3>   // Far upper right corner

  texture {
    T_Stone25     // Pre-defined from stones.inc
    scale 4       // Scale by the same amount in all
                  // directions
  }

  rotate y*20     // Equivalent to "rotate <0,20,0>"
}
```

In this example you can see that a box is defined by specifying the 3D coordinates of its opposite corners. The first vector must be the minimum x, y, z coordinates and the 2nd vector must be the maximum x, y, z values. Box objects can only be defined parallel to the axes of the world coordinate system. You can later rotate them to any angle. Note that you can perform simple math on values and vectors. In the rotate parameter we multiplied the vector identifier `y` by 20. This is the same as $\langle 0,1,0\rangle \times 20$ or $\langle 0,20,0\rangle$.

4.3.2 Cone Object

Here's another example showing how to use a cone:

```
cone {
  <0, 1, 0>, 0.3    // Center and radius of one end
  <1, 2, 3>, 1.0    // Center and radius of other end

  texture { T_Stone25 scale 4 }
}
```

The cone shape is defined by the center and radius of each end. In this example one end is at location $\langle 0,1,0\rangle$ and has radius of 0.3 while the other end is centered at $\langle 1,2,3\rangle$ with $radius = 1$. If you want the cone to come to a sharp point then use $radius = 0$. The solid end caps are parallel to each other and perpendicular to the cone axis. If you want an open cone with no end caps then add the keyword `open` after the 2nd radius like this:

```
cone {
  <0, 1, 0>, 0.3    // Center and radius of one end
  <1, 2, 3>, 1.0    // Center and radius of other end
  open              // Removes end caps

  texture { T_Stone25 scale 4 }
}
```

4.3.3 Cylinder Object

You may also define a cylinder like this:

```
cylinder {
  <0, 1, 0>,     // Center of one end
  <1, 2, 3>,     // Center of other end
  0.5            // Radius
  open           // Remove end caps

  texture { T_Stone25 scale 4 }
}
```

4.3.4 Plane Object

Let's try out a computer graphics standard — *The Checkered Floor*. Add the following object to the first version of the DEMO.POV file, the one including the sphere.

```
plane { <0, 1, 0>, -1
  pigment {
    checker color Red, color Blue
  }
}
```

The object defined here is an infinite plane. The vector $\langle 0,1,0 \rangle$ is the surface normal of the plane (i.e. if you were standing on the surface, the normal points straight up). The number afterward is the distance that the plane is displaced along the normal from the origin — in this case, the floor is placed at $y = -1$ so that the sphere at $y = 1$, $radius = 2$, is resting on it.

Notice that there is no `texture { ... }` statement. There really is an implied texture there. You might find that continually typing statements that are nested like `texture {pigment { ... }}` can get to be a tiresome so POV-Ray lets you leave out the `texture { ... }` under many circumstances. In general you only need the texture block surrounding a texture identifier (like the *T_Stone25* example above), or when creating layered textures (which are covered later).

This pigment uses the checker color pattern and specifies that the two colors red and blue should be used.

Because the vectors $\langle 1,0,0 \rangle$, $\langle 0,1,0 \rangle$ and $\langle 0,0,1 \rangle$ are used frequently, POV-Ray has three built-in vector identifiers `x`, `y`, and `z` respectively that can be used as a shorthand. Thus the plane could be defined as:

```
plane { y, -1
  pigment { ... }
}
```

Note that you do not use angle brackets around vector identifiers.

Looking at the floor, you'll notice that the ball casts a shadow on the floor. Shadows are calculated very accurately by the ray-tracer, which creates precise, sharp shadows. In the real world, penumbral or "soft" shadows are often seen. Later you'll learn how to use extended light sources to soften the shadows.

4.3.5 Standard Include Objects

The standard include file SHAPES.INC contains some pre-defined shapes that are about the size of a sphere with a radius of one unit. You can invoke them like this:

```
#include "shapes.inc"

object {
  UnitBox
  texture { T_Stone25 scale 4 }
  scale 0.75
  rotate <-20,25,0>
  translate y
}
```

4.4 Advanced Shapes

After you have gained some experience with the simpler shapes available in POV-Ray it is time to go on to the more advanced, thrilling shapes.

You should be aware that the shapes described below are not trivial to understand. Don't worry if you do not know how to use them or how they work. Just try the examples and play with the features described in the reference chapter. There is nothing better than learning by doing.

4.4.1 Bicubic Patch Object

Bicubic or Bezier patches are useful surface representations because they allow an easy definition of surfaces using only a few control points. For ray tracing (or rendering) the patches are approximated using triangles. The control points serve to determine the shape of the patch. Instead of defining the vertices of triangles, you simply give the coordinates of the control points. A single patch has 16 control points, four at each corner, and the rest positioned to divide the patch into smaller sections. Bezier patches are almost always created using a third party modeler so for this tutorial, we will use MORAY (any other modeler that supports Bezier patches and POV can also be used). We will use MORAY only to create the patch itself, not the other elements of the scene.

Bezier patches are actually very useful and, with a little practice, some pretty amazing things can be created with them. For our first tutorial, let's make a sort of a teepee/tent shape using a single sheet patch.

First, start MORAY and, from the main edit screen, click on "CREATE". Name your object *Teepee*. The "CREATE BEZIER PATCH" dialogue box will appear. Make sure that "SHEET" is depressed. Click on "OK, CREATE". At the bottom of the main edit screen, click on "EXTENDED EDIT".

Hold the cursor over the "TOP" view and right click to make the pop-up menu appear. Click on "MAXIMIZE". [ALT]-drag to zoom in a little. Click on "MARK ALL", and under the transformation mode box, "UFRM SCL". Drag the mouse to scale the patch until it is approximately four units wide. Click on ”TRANSLATE”, and move the patch so that its center is over the origin. Right click — ”MINIMIZE”, ”UNMARK ALL”.

[SHIFT]-drag a box around the lower right control point to mark it. [ALT]-zoom into the ”FRONT” view so that you can see the patch better. In the ”FRONT” view, ”TRANSLATE” that point 10 units along the negative z-axis (note that in MORAY z is up). ”UNMARK ALL”. Repeat this procedure for each of the other three corner points. Make sure you remember to ”UNMARK ALL” once each point has been translated. You should have a shape that looks as though it is standing on four pointed legs. ”UNMARK ALL”.

Working once again in the ”TOP” view, [SHIFT]-drag a box around the four center control points to mark them. Right-click over the ”TOP” view, ”MAXIMIZE”. Click on ”UFRM SCL” and drag the mouse to scale the four points close together. [ALT]-drag to zoom closer and get them as close together as you can. [ALT]-drag to zoom out, right click, ”MINIMIZE”.

In the ”FRONT” view, ”TRANSLATE” the marked points 10 units along the positive z-axis. ”UNMARK ALL”. The resulting shape is quite interesting, was simple to model, and could not be produced using CSG primitives. Now let’s use it in a scene.

Click on ”DONE” to return to the main edit screen. Notice that U_STEPS and V_STEPS are both set to 3 and flatness is set to 0.01. Leave them alone for now. Click on ”FILES”, and then ”SAVE SEL” (save selection). Name your new file TEEPEE1.MDL. Press [F3] and open TEEPEE1.MDL. There is no need to save the original file. When TEEPEE1 is open, create a quick ”dummy” texture (MORAY will not allow you to export data without a texture), say, white with default finish, name it *TeePeeTex*, and apply it to the object. Save the file and press [CTRL-F9]. MORAY will create two files: TEEPEE1.INC and TEEPEE1.POV.

Exit MORAY and copy TEEPEE1.INC and TEEPEE1.POV into your working directory where you are doing these tutorials. Create a new file called BEZDEMO.POV and edit it as follows:

```
#include "colors.inc"

camera {
  location <0, .1, -60>
  look_at 0
  angle 36
}

background { color Gray25 }

light_source { <300, 300, -700> White }

plane { y, -12
  texture {
    pigment {
```

```
        checker
        color Green
        color Yellow
      }
    }
  }
```

Using a text editor, create and declare a simple texture for your teepee object:

```
#declare TeePeeTex = texture {
  pigment {
    color rgb <1, 1, 1,>
  }
  finish {
    ambient .2
    diffuse .6
  }
}
```

Now, paste in the bezier patch data from TEEPEE1.POV (the additional object keywords added by MORAY were removed):

```
bicubic_patch {
  type 1 flatness 0.0100 u_steps 3 v_steps 3,
  <-5.174134, 5.528420, -13.211995>,
  <-1.769023, 5.528420, 0.000000>,
  <1.636088, 5.528420, 0.000000>,
  <5.041199, 5.528420, -13.003932>,
  <-5.174134, 1.862827, 0.000000>,
  <0.038471, 0.031270, 18.101474>,
  <0.036657, 0.031270, 18.101474>,
  <5.041199, 1.862827, 0.000000>,
  <-5.174134, -1.802766, 0.000000>,
  <0.038471, 0.028792, 18.101474>,
  <0.036657, 0.028792, 18.101474>,
  <5.041199, -1.802766, 0.000000>,
  <-5.174134, -5.468359, -13.070366>,
  <-1.769023, -5.468359, 0.000000>,
  <1.636088, -5.468359, 0.000000>,
  <4.974128, -5.468359, -12.801446>
  texture {
    TeePeeTex
  }
  rotate -90*x  // to orient the object to LHC
  rotate 25*y   // to see the four "legs" better
}
```

Add the above rotations so that the patch is oriented to POV's left-handed coordinate system (remember the patch was made in MORAY in a right handed coordinate system) and so we can see all four legs. Rendering this at 200x150 -a we see pretty much what we expect, a white *teepee* over a green and yellow checkered plane. Let's take a little closer look. Render it again, this time at 320x200.

Now we see that something is amiss. There appears to be sharp angling, almost like faceting, especially near the top. This is indeed a kind of faceting and is due to the U_STEPS and V_STEPS parameters. Let's change these from 3 to 4 and see what happens.

That's much better, but it took a little longer to render. This is an unavoidable tradeoff. If you want even finer detail, use a U_STEPS and V_STEPS value of 5 and set flatness to 0. But expect to use lots of memory and an even longer tracing time.

Well, we can't just leave this scene without adding a few items just for interest. Declare the patch object and scatter a few of them around the scene:

```
#declare TeePee = bicubic_patch {
  type 1 flatness 0.0100 u_steps 3 v_steps 3,
  <-5.174134, 5.528420, -13.211995>,
  <-1.769023, 5.528420, 0.000000>,
  <1.636088, 5.528420, 0.000000>,
  <5.041199, 5.528420, -13.003932>,
  <-5.174134, 1.862827, 0.000000>,
  <0.038471, 0.031270, 18.101474>,
  <0.036657, 0.031270, 18.101474>,
  <5.041199, 1.862827, 0.000000>,
  <-5.174134, -1.802766, 0.000000>,
  <0.038471, 0.028792, 18.101474>,
  <0.036657, 0.028792, 18.101474>,
  <5.041199, -1.802766, 0.000000>,
  <-5.174134, -5.468359, -13.070366>,
  <-1.769023, -5.468359, 0.000000>,
  <1.636088, -5.468359, 0.000000>,
  <4.974128, -5.468359, -12.801446>
  texture {
    TeePeeTex
   }
   rotate -90*x // to orient the object to LHC
   rotate 25*y  // to see the four "legs" better
}

object { TeePee }
object { TeePee translate <8, 0, 8> }
object { TeePee translate <-9, 0, 9> }
object { TeePee translate <18, 0, 24> }
object { TeePee translate <-18, 0, 24> }
```

That looks good. Let's do something about that boring gray background. Delete the background declaration and replace it with:

```
plane { y, 500
  texture {
    pigment { SkyBlue }
    finish { ambient 1 diffuse 0}
   }
   texture {
     pigment {
       bozo
       turbulence .5
       color_map {
         [0 White]
         [1 White filter 1]
       }
     }
     finish { ambient 1 diffuse 0 }
     scale <1000, 250, 250>
     rotate <5, 45, 0>
  }
}
```

This adds a pleasing cirrus-cloud filled sky. Now, let's change the checkered plane to rippled sand dunes:

```
plane {y,-12
  texture {
    pigment {
      color <.85, .5, .15>
    }
    finish {
      ambient .25
      diffuse .6
      crand .5
    }
    normal {
      ripples .35
      turbulence .25
      frequency 5
    }
    scale 10
    translate 50*x
  }
}
```

Render this at 320x240 -a. Not bad! Let's just add one more element. Let's place a golden egg under each of the teepees. And since this is a bezier patch tutorial, let's make the eggs out of bezier patches.

Return to MORAY and create another bezier patch. Name it *Egg1* and select "CYLINDRICAL 2 - PATCH" from the "CREATE BEZIER PATCH" dialogue box. Click on

”EXTENDED EDIT”. ”MARK ALL”, and rotate the patch so that the cylinder lays on its side. ”UNMARK ALL”. In the ”FRONT” view, [SHIFT]-drag a box around the four points on the right end to mark them. In the ”SIDE” view, right click, ”MAXIMIZE”. [ALT]-drag to zoom in a little closer. ”UFRM SCL” the points together as close as possible. Zoom in closer to get them nice and tight. Zoom out, right click, ”MINIMIZE”.

Click on ”TRANSLATE” and drag the points to the left so that they are aligned on the z-axis with the next group of four points. This should create a blunt end to the patch. Repeat this procedure for the other end. ”UNMARK ALL”.

In the ”FRONT” view, the control grid should be a rectangle now and the patch should be an ellipsoid. [SHIFT]-drag a box around the upper right corner of the control grid to mark those points. Then [SHIFT]-drag a box around the lower right corner to mark those points as well. In the ”SIDE” view, ”UFRM SCL” the points apart a little to make that end of the egg a little wider than the other. ”UNMARK ALL”.

The egg may need a little proportional adjustment. You should be able to ”MARK ALL” and ”LOCAL SCL” in the three views until you get it to look like an egg. When you are satisfied that it does, ”UNMARK ALL” and click on done. Learning from our teepee object, we now go ahead and change U_STEPS and V_STEPS to 4.

Create a dummy texture, white with default finish, name it *EggTex*, and apply it to the egg. From the FILES menu, ”SAVE SEL” to filename EGG1.MDL. Load this file and export ([CTRL F9]). Exit MORAY and copy the files EGG1.INC and EGG1.POV into your working directory.

Back in BEZDEMO.POV, create a nice, shiny gold texture:

```
#declare EggTex = texture {
  pigment { BrightGold }
  finish {
    ambient .1
    diffuse .4
    specular 1
    roughness 0.001
    reflection .5
    metallic
  }
}
```

And while we’re at it, let’s dandy up our *TeePeeTex*:

```
#declare TeePeeTex = texture {
  pigment { Silver }
  finish {
    ambient .1
    diffuse .4
    specular 1
```

```
    roughness 0.001
    reflection .5
    metallic
  }
}
```

Now paste in your egg patch data and declare your egg:

```
#declare Egg = union { // Egg1
  bicubic_patch {
    type 1 flatness 0.0100 u_steps 4 v_steps 4,
    <2.023314, 0.000000, 4.355987>,
    <2.023314, -0.000726, 4.355987>,
    <2.023312, -0.000726, 4.356867>,
    <2.023312, 0.000000, 4.356867>,
    <2.032037, 0.000000, 2.734598>,
    <2.032037, -1.758562, 2.734598>,
    <2.027431, -1.758562, 6.141971>,
    <2.027431, 0.000000, 6.141971>,
    <-1.045672, 0.000000, 3.281572>,
    <-1.045672, -1.758562, 3.281572>,
    <-1.050279, -1.758562, 5.414183>,
    <-1.050279, 0.000000, 5.414183>,
    <-1.044333, 0.000000, 4.341816>,
    <-1.044333, -0.002947, 4.341816>,
    <-1.044341, -0.002947, 4.345389>,
    <-1.044341, 0.000000, 4.345389>
  }
  bicubic_patch {
    type 1 flatness 0.0100 u_steps 4 v_steps 4,
    <2.023312, 0.000000, 4.356867>,
    <2.023312, 0.000726, 4.356867>,
    <2.023314, 0.000726, 4.355987>,
    <2.023314, 0.000000, 4.355987>,
    <2.027431, 0.000000, 6.141971>,
    <2.027431, 1.758562, 6.141971>,
    <2.032037, 1.758562, 2.734598>,
    <2.032037, 0.000000, 2.734598>,
    <-1.050279, 0.000000, 5.414183>,
    <-1.050279, 1.758562, 5.414183>,
    <-1.045672, 1.758562, 3.281572>,
    <-1.045672, 0.000000, 3.281572>,
    <-1.044341, 0.000000, 4.345389>,
    <-1.044341, 0.002947, 4.345389>,
    <-1.044333, 0.002947, 4.341816>,
    <-1.044333, 0.000000, 4.341816>
  }
  texture { EggTex }
  translate <0.5, 0, -5>  // center egg around origin
```

```
  translate -9.8*y        // place egg on the ground
}
```

Now place a copy of the egg under each teepee. This should require only the x and z coordinates of each teepee:

```
object { Egg }
object { Egg translate <8, 0, 8> }
object { Egg translate <-9, 0, 9> }
object { Egg translate <18, 0, 24> }
object { Egg translate <-18, 0, 24> }
```

Render this at 320x240 **–A**. Everything looks good so run it again at 640x480 **+A**. Now we see that there is still some faceting near the top of the teepees and on the eggs as well. The only solution is to raise U_STEPS and V_STEPS from 4 to 5 and set flatness to 0 for all our bezier objects. Make the changes and render it again at 640x480 **+A**.

4.4.2 Blob Object

[*** STILL BEING WRITTEN *** Dieter Bayer]

4.4.3 Height Field Object

A height field is an object that has a surface that is determined by the color value or palette index number of an image designed for that purpose. With height fields, realistic mountains and other types of terrain can easily be made. First, you need an image from which to create the height field. It just so happens that POV-Ray is ideal for creating such an image.

Make a new file called IMAGE.POV and edit it to contain the following:

```
#include "colors.inc"

global_settings {
  assumed_gamma 2.2
  hf_gray_16
}
```

The `hf_gray_16` keyword causes the output to be in a special 16 bit grayscale that is perfect for generating height fields. The normal 8 bit output will lead to less smooth surfaces.

Now create a camera positioned so that it points directly down the z-axis at the origin.

```
camera {
  location <0, 0, -10>
  look_at 0
}
```

Then create a plane positioned like a wall at $z = 0$. This plane will completely fill the screen. It will be colored with white and gray wrinkles.

```
plane { z, 10
  pigment {
    wrinkles
    color_map {
     [0 0.3*White]
     [1 White]
    }
  }
}
```

Finally, create a light source.

```
light_source { <0, 20, -100> color White }
```

Render this scene at 640x480 **+A0.1 +FT**. You will get an image that will produce an excellent height_field.

Now we will use this image to create a height field. Create a new file called HFDEMO.POV and edit it as follows:

```
#include "colors.inc"
```

Add a camera that is two units above the origin and ten units back ...

```
camera{
  location <0, 2, -10>
  look_at 0
  angle 15
}
```

... and a light source.

```
light_source{ <1000,1000,-1000> White }
```

Now add the height field. In the following syntax, a Targa image file is specified, the height field is *smoothed*, it is given a simple white pigment, it is translated to center it around the origin, and it is scaled so that it resembles mountains and fills the screen.

```
height_field {
  tga "image.tga"
  smooth
  pigment { White }
  translate <-.5, -.5, -.5>
  scale <17, 1.75, 17>
}
```

Save the file and render it at 320x240 **−A**. Later, when you are satisfied that the height field is the way you want it render it at a higher resolution with antialiasing.

Wow! The Himalayas have come to your computer screen!

4.4.4 Julia Fractal Object

[*** STILL BEING WRITTEN ***]

4.4.5 Lathe Object

[*** STILL BEING WRITTEN *** Dieter Bayer]

4.4.6 Mesh Object

Mesh objects are very useful because they allow you to create objects containing hundreds or thousands of triangles. Compared to a simple union of triangles the mesh object stores the triangles more efficiently. Copies of mesh objects need only a little additional memory because the triangles are stored only once.

Almost every object can be approximated using triangles but you may need a lot of triangles to create more complex shapes. Thus we will only create a very simple mesh example. This example will show a very useful feature of the triangles meshs though: a different texture can be assigned to each triangle in the mesh.

Now let us start. We'll create a simple box with differently colored sides. Create an empty file called MESHDEMO.POV and add the following lines.

```
camera {
  location <20, 20, -50>
  look_at <0, 5, 0>
}
```

```
light_source { <50, 50, -50> color rgb<1, 1, 1> }

#declare Red = texture {
  pigment { color rgb<0.8, 0.2, 0.2> }
  finish { ambient 0.2 diffuse 0.5 }
}

#declare Green = texture {
  pigment { color rgb<0.2, 0.8, 0.2> }
  finish { ambient 0.2 diffuse 0.5 }
}

#declare Blue = texture {
  pigment { color rgb<0.2, 0.2, 0.8> }
  finish { ambient 0.2 diffuse 0.5 }
}
```

We must declare all textures we want to use inside the mesh before the mesh is created. Textures cannot be specified inside the mesh due to the worser memory performance that would result.

Now add the mesh object. Three sides of the box will use individual textures while the other will use the ”global” mesh texture.

```
mesh {
  /* top side */
  triangle { <-10,10,-10>,<10,10,-10>,<10,10,10>
    texture { Red }
  }
  triangle { <-10,10,-10>,<-10,10,10>,<10,10,10>
    texture { Red }
  }
  /* bottom side */
  triangle { <-10,-10,-10>,<10,-10,-10>,<10,-10,10> }
  triangle { <-10,-10,-10>,<-10,-10,10>,<10,-10,10> }
  /* left side */
  triangle { <-10,-10,-10>,<-10,-10,10>,<-10,10,10> }
  triangle { <-10,-10,-10>,<-10,10,-10>,<-10,10,10> }
  /* right side */
  triangle { <10,-10,-10>,<10,-10,10>,<10,10,10>
    texture { Green }
  }
  triangle { <10,-10,-10>,<10,10,-10>,<10,10,10>
    texture { Green }
  }
  /* front side */
  triangle { <-10,-10,-10>,<10,-10,-10>,<-10,10,-10>
    texture { Blue }
```

```
  }
  triangle { <-10,10,-10>,<10,10,-10>,<10,-10,-10>
    texture { Blue }
  }
  /* back side */
  triangle { <-10,-10,10>,<10,-10,10>,<-10,10,10> }
  triangle { <-10,10,10>,<10,10,10>,<10,-10,10> }
  texture {
    pigment { color rgb<0.9, 0.9, 0.9> }
    finish { ambient 0.2 diffuse 0.7 }
  }
}
```

Trace the scene at 320x240. You'll see that the top, right, and front side of the box have different textures. Thought this is not a very impressive example it shows what you can do with mesh objects. More complex examples, also using smooth triangles, can be found under the scene directory as CHESMSH.POV and ROBOTMSH.POV.

4.4.7 Polygon Object

The polygon object can be used to create any planar, n-sided shapes like squares, rectangles, pentagons, hexagons, octagons, etc.

A polygon is defined by a number of points that describe its shape. Since polygons have to be closed the first point has to be repeated at the end of the point sequence.

In the following example we will create the word *POV* using just one polygon statement.

We start with thinking about the points we need to describe the desired shape. We want the letters to lie in the x-y-plane with the letter *O* being at the center. The letters extend from $y = 0$ to $y = 1$. Thus we get the following points for each letter (the z coordinate is automatically set to zero).

```
Letter P (outer polygon):
    <-0.8, 0.0>, <-0.8, 1.0>,
    <-0.3, 1.0>, <-0.3, 0.5>,
    <-0.7, 0.5>, <-0.7, 0.0>

Letter P (inner polygon):
    <-0.7, 0.6>, <-0.7, 0.9>,
    <-0.4, 0.9>, <-0.4, 0.6>

Letter O (outer polygon):
    <-0.25, 0.0>, <-0.25, 1.0>,
    < 0.25, 1.0>, < 0.25, 0.0>
```

```
Letter O (inner polygon):
    <-0.15, 0.1>, <-0.15, 0.9>,
    < 0.15, 0.9>, < 0.15, 0.1>

Letter V:
    <0.45, 0.0>, <0.30, 1.0>,
    <0.40, 1.0>, <0.55, 0.1>,
    <0.70, 1.0>, <0.80, 1.0>,
    <0.65, 0.0>
```

Both letters *P* and *O* have a hole while the letter *V* consists of only one polygon. We'll start with the letter *V* because it is easier to define than the other two letters.

Create a new file called POLYGDEM.POV and add the following text.

```
camera {
  orthographic
  location <0, 0, -10>
  right 1.3 * 4/3 * x
  up 1.3 * y
  look_at <0, 0.5, 0>
}

light_source { <25, 25, -100> color rgb 1 }

polygon {
  8,

  <0.45, 0.0>, <0.30, 1.0>, // Letter "V"
  <0.40, 1.0>, <0.55, 0.1>,
  <0.70, 1.0>, <0.80, 1.0>,
  <0.65, 0.0>,
  <0.45, 0.0>

  pigment { color rgb <1, 0, 0> }
}
```

As noted above the polygon has to be closed by appending the first point to the point sequence. A closed polygon is always defined by a sequence of points that ends when a point is the same as the first point.

After we have created the letter *V* we'll continue with the letter *P*. Since it has a hole we have to find a way of cutting this hole into the basic shape. This is quite easy. We just define the outer shape of the letter *P*, which is a closed polygon, and add the sequence of points that describes the hole, which is also a closed polygon. That's all we have to do. There'll be a hole where both polygons overlap.

In general you'll get holes whenever an even number of sub-polygons inside a single polygon statement overlap. A sub-polygon is defined by a closed sequence of points.

The letter *P* consists of two sub-polyons, one for the outer shape and one for the hole. Since the hole polygon overlaps the outer shape polygon we'll get a hole.

After you've understood how multiple sub-polygons in a single polygon statement work, it's quite easy to add the missing *O* letter.

Finally, we get the complete word *POV*.

```
polygon {
  30,

  <-0.8, 0.0>, <-0.8, 1.0>,    // Letter "P"
  <-0.3, 1.0>, <-0.3, 0.5>,    // outer shape
  <-0.7, 0.5>, <-0.7, 0.0>,
  <-0.8, 0.0>,

  <-0.7, 0.6>, <-0.7, 0.9>,    // whole
  <-0.4, 0.9>, <-0.4, 0.6>,
  <-0.7, 0.6>

  <-0.25, 0.0>, <-0.25, 1.0>,  // Letter "O"
  < 0.25, 1.0>, < 0.25, 0.0>,  // outer shape
  <-0.25, 0.0>,

  <-0.15, 0.1>, <-0.15, 0.9>,  // whole
  < 0.15, 0.9>, < 0.15, 0.1>,
  <-0.15, 0.1>,

  <0.45, 0.0>, <0.30, 1.0>,    // Letter "V"
  <0.40, 1.0>, <0.55, 0.1>,
  <0.70, 1.0>, <0.80, 1.0>,
  <0.65, 0.0>,
  <0.45, 0.0>

  pigment { color rgb <1, 0, 0> }
}
```

4.4.8 Prism Object

[*** STILL BEING WRITTEN *** Dieter Bayer]

4.4.9 Superquadric Ellipsoid Object

Sometimes we want to make an object that does not have perfectly sharp edges like a box does. Then, the super quadric ellipsoid is a useful object. It is described by the simple syntax:

```
superellipsoid { <r, n> }
```

Where r and n are float values greater than zero and less than or equal to one. Let's make a superellipsoid and experiement with the values of r and n to see what kind of shapes we can make.

Create a file called SUPELLPS.POV and edit it as follows:

```
#include "colors.inc"

camera {
  location <10, 5, -20>
  look_at 0
  angle 15
}

background { color rgb <.5, .5, .5> }

light_source { <10, 50, -100> White }
```

The addition of a gray background makes it a little easier to see our object. Now type:

```
superellipsoid { <.25, .25>
  pigment { Red }
}
```

Save the file and trace it at 200x150 **–A** to see the shape. It will look like a box, but the edges will be rounded off. Now let's experiment with different values of r and n. For the next trace, try $\langle 1, 0.2\rangle$. The shape now looks like a cylinder, but the top edges are rounded. Now try $\langle 0.1, 1\rangle$. This shape is an odd one! We don't know exactly what to call it, but it is interesting. Finally, lets try $\langle 1, 1\rangle$. Well, this is more familiar ... a sphere!

There are a couple of facts about superellipsoids you should know. First, you should not use a value of 0 for either r nor n. This will cause POV-Ray to incorrectly make a black box instead of your desired shape. Second, very small values of r and n may yield strange results so they should be avoided. Finally, the Sturmian root solver will not work with superellipsoids.

Superellipsoids are finite objects so they respond to auto-bounding and can be used in CSG.

Now let's use the superellipsoid to make something that would be useful in a scene. We will make a tiled floor and place a couple of superellipsoid objects hovering over it. We can start with the file we have already made.

Rename it TILES.POV. Edit it so that it reads as follows:

```
#include "colors.inc"
#include "textures.inc"
```

```
camera {
  location <10, 5, -20>
  look_at 0
  angle 15
}
background { color rgb <.5, .5, .5> }

light_source{ <10, 50, -100> White }
```

Note that we have added `#include "textures.inc"` so we can use pre-defined textures. Now we want to define the superellipsoid which will be our tile.

```
#declare Tile = superellipsoid { <0.5, 0.1>
  scale <1, .05, 1>
}
```

Superellipsoids are roughly $2 \times 2 \times 2$ units unless you scale them otherwise. If we wish to lay a bunch of our tiles side by side, they will have to be offset from each other so they don't overlap. We should select an offset value that is slightly more than 2 so that we have some space between the tiles to fill with grout. So now add this:

```
#declare Offset = 2.1
```

We now want to lay down a row of tiles. Each tile will be offset from the original by an ever-increasing amount in both the $+z$ and $-z$ directions. We refer to our offset and multiply by the tile's rank to determine the position of each tile in the row. We also union these tiles into a single object called *Row* like this:

```
#declare Row = union {
  object { Tile }
  object { Tile translate z*Offset }
  object { Tile translate z*Offset*2 }
  object { Tile translate z*Offset*3 }
  object { Tile translate z*Offset*4 }
  object { Tile translate z*Offset*5 }
  object { Tile translate z*Offset*6 }
  object { Tile translate z*Offset*7 }
  object { Tile translate z*Offset*8 }
  object { Tile translate z*Offset*9 }
  object { Tile translate z*Offset*10 }
  object { Tile translate -z*Offset }
  object { Tile translate -z*Offset*2 }
  object { Tile translate -z*Offset*3 }
  object { Tile translate -z*Offset*4 }
  object { Tile translate -z*Offset*5 }
```

```
  object { Tile translate -z*Offset*6 }
}
```

This gives us a single row of 17 tiles, more than enough to fill the screen. Now we must make copies of the *Row* and translate them, again by the offset value, in both the $+x$ and $-x$ directions in ever increasing amounts in the same manner.

```
object { Row }
object { Row translate x*Offset }
object { Row translate x*Offset*2 }
object { Row translate x*Offset*3 }
object { Row translate x*Offset*4 }
object { Row translate x*Offset*5 }
object { Row translate x*Offset*6 }
object { Row translate x*Offset*7 }
object { Row translate -x*Offset }
object { Row translate -x*Offset*2 }
object { Row translate -x*Offset*3 }
object { Row translate -x*Offset*4 }
object { Row translate -x*Offset*5 }
object { Row translate -x*Offset*6 }
object { Row translate -x*Offset*7 }
```

Finally, our tiles are complete. But we need a texture for them. To do this we union all of the *Rows* together and apply a *White Marble* pigment and a somewhat shiny refelctive surface to it:

```
union{
  object { Row }
  object { Row translate x*Offset }
  object { Row translate x*Offset*2 }
  object { Row translate x*Offset*3 }
  object { Row translate x*Offset*4 }
  object { Row translate x*Offset*5 }
  object { Row translate x*Offset*6 }
  object { Row translate x*Offset*7 }
  object { Row translate -x*Offset }
  object { Row translate -x*Offset*2 }
  object { Row translate -x*Offset*3 }
  object { Row translate -x*Offset*4 }
  object { Row translate -x*Offset*5 }
  object { Row translate -x*Offset*6 }
  object { Row translate -x*Offset*7 }
  pigment { White_Marble }
  finish { phong 1 phong_size 50 reflection .35 }
}
```

We now need to add the *grout*. This can simply be a white plane. We have stepped up the ambient here a little so it looks whiter.

```
plane { y, 0  //this is the grout
  pigment { color White }
  finish { ambient .4 diffuse .7 }
}
```

To complete our scene, let's add five different superellipsoids, each a different color, so that they hover over our tiles and are reflected in them.

```
superellipsoid {
  <0.1, 1>
  pigment { Red }
  translate <5, 3, 0>
  scale .45
}

superellipsoid {
  <1, 0.25>
  pigment { Blue }
  translate <-5, 3, 0>
  scale .45
}

superellipsoid {
  <0.2, 0.6>
  pigment { Green }
  translate <0, 3, 5>
  scale .45
}

superellipsoid {
  <0.25, 0.25>
  pigment { Yellow }
  translate <0, 3, -5>
  scale .45
}

superellipsoid {
  <1, 1>
  pigment { Pink }
  translate y*3
  scale .45
}
```

Trace the scene at 320x200 **–A** to see the result. If you are happy with that, do a final trace at 640x480 **+A0.2**.

4.4.10 Surface of Revolution Object

Bottles, vases, and glasses make nice objects in ray-traced scenes. We want to create a golden, cup using the surface of revolution object (SOR object).

We first start by thinking about the shape of the final object. It is quite difficult to come up with a set of points that describe a given curve without the help of a modelling program supporting POV's surface of revolution object. If such a program is available you should take advantage of it.

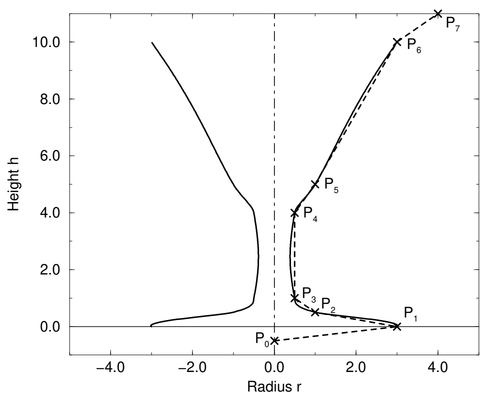


Figure 4.2: The point configuration of our cup object.

We will use the point configuration shown in figure 4.2. There are eight points describing the curve that will be rotated about the y-axis to get our cup. The curve was calculated using the method described in the reference section (see 7.5.2.11 on page 247).

Now it is time to come up with a scene that uses the above SOR object. Edit a file called **sordemo.pov** and enter the following text.

```
#include "colors.inc"
#include "golds.inc"

global_settings { assumed_gamma 2.2 }

camera {
  location <10, 15, -20>
  look_at <0, 5, 0>
  angle 45
}

background { color rgb<0.2, 0.4, 0.8>  }
```

```
light_source { <100, 100, -100> color rgb 1 }

plane { y, 0
  pigment { checker color Red, color Green scale 10 }
}

sor {
  8,
  <0.0,  -0.5>,
  <3.0,   0.0>,
  <1.0,   0.2>,
  <0.5,   0.4>,
  <0.5,   4.0>,
  <1.0,   5.0>,
  <3.0,  10.0>,
  <4.0,  11.0>
  texture { T_Gold_1B }
}
```

The scene contains our cup object resting on a checkered plane. Trace the scene at 320x240 to see the resulting image.

The surface of revolution is described by starting with the number of points followed by the points with ascending heights. Each point determines the radius the curve for a given height. E. g. the first point tells POV-Ray that at height -0.5 the radius is 0. You should take care that each point has a larger height than its predecessor. If this is not the case the program will abort with an error message.

4.4.11 Text Object

Creating text objects using POV-Ray always used to mean that the letters had to be built either from CSG, a painstaking process, or by using a black and white image of the letters as a height field, a method that was only somewhat satisfactory. Now, for POV-Ray 3.0, a new primitive has been introduced that can use any TrueType font to create text objects. These objects can be used in CSG, transformed, and textured just like any other POV primitive.

For this tutorial, we will make two uses of the text object. First, let's just make some block letters sitting on a checkered plane. Any TTF font should do, but for this tutorial, we will use the ones bundled with POV-Ray 3.0.

Create a file called `TEXTDEMO.POV` and edit it as follows:

```
#include "colors.inc"

camera {
  location <0, 1, -10>
```

```
  look_at 0
  angle 36
}

light_source { <500,500,-1000> White }

plane { y,0
  pigment { checker Green White }
}
```

Now let's add the text object. We will use the font TIMROM.TTF and we will create the string *POV-RAY 3.0*. For now, we will just make the letters red. The syntax is very simple. The first string in quotes is the font name, the second one is the string to be rendered. The two floats are the thickness and offset values. The thickness float determines how thick the block letters will be. Values of .5 to 2 are usually best for this. The offset value will add to the kerning distance of the letters. We will leave this a 0 for now.

```
text { ttf "timrom.ttf" "POV-RAY 3.0" 1, 0
  pigment { Red }
}
```

Rendering this at 200x150 **–A**, we notice that the letters are off to the right of the screen. This is because they are placed so that the lower left front corner of the first letter is at the origin. To center the string we need to translate it $-x$ some distance. But how far? In the docs we see that the letters are all 0.5 to 0.75 units high. If we assume that each one takes about 0.5 units of space on the x-axis, this means that the string is about 6 units long (12 characters and spaces). Let's translate the string 3 units along the negative x-axis.

```
text { ttf "timrom.ttf" "POV-RAY 3.0" 1, 0
  pigment { Red }
  translate -3*x
}
```

That's better. Now let's play around with some of the parameters of the text object. First, let's raise the thickness float to something outlandish ... say 25!

```
text { ttf "timrom.ttf" "POV-RAY 3.0" 25, 0
  pigment { Red }
  translate -2.25*x
}
```

Actually, that's kind of cool. Now let's return the thickness value to 1 and try a different offset value. Change the offset float from 0 to 0.1 and render it again.

Wait a minute?! The letters go wandering off up at an angle! That is not what the docs describe! It almost looks as if the offset value applies in both the x- and y-axis instead of just the *x* axis like we intended. Could it be that a vector is called for here instead of a float? Let's try it. Replace `0.1` with `0.1*x` and render it again.

That works! The letters are still in a straight line along the *x* axis, just a little further apart. Let's verify this and try to offset just in the *y* axis. Replace `0.1*x` with `0.1*y`. Again, this works as expected with the letters going up to the right at an angle with no additional distance added along the x axis. Now let's try the *z* axis. Replace `0.1*y` with `0.1*z`. Rendering this yields a disappointment. No offset occurs! The offset value can only be applied in the *x* and *y* directions.

Let's finish our scene by giving a fancier texture to the block letters, using that cool large thickness value, and adding a slight y offset. For fun, we will throw in a sky sphere, dandy up our plane a bit, and use a little more interesting camera viewpoint (render the following scene at 640x480 **+A0.2**):

```
#include "colors.inc"

camera {
  location <-5,.15,-2>
  look_at <.3,.2,1>
  angle 36
}

light_source { <500,500,-1000> White }

plane { y,0
  texture {
    pigment { SeaGreen }
    finish { reflection .35 specular 1 }
    normal { ripples .35 turbulence .5 scale .25 }
  }
}

text { ttf "timrom.ttf" "POV-RAY 3.0" 25, 0.1*y
  pigment { BrightGold }
  finish { reflection .25 specular 1 }
  translate -3*x
}

#include "skies.inc"

sky_sphere { S_Cloud5 }
```

Now. let's try using text in a CSG object. We will attempt to create an inlay in a stone block using a text object. Create a new file called `TEXTCSG.POV` and edit it as follows:

```
#include "colors.inc"
#include "stones.inc"
```

```
background { color rgb 1 }

camera {
  location <-3, 5, -15>
  look_at 0
  angle 25
}

light_source { <500,500,-1000> White }
```

Now let's create the block. We want it to be about eight units across because our text string (*POV-RAY 3.0*) is about six units long. We also want it about four units high and about one unit deep. But we need to avoid a potential coincident surface with the text object so we will make the first z coordinate 0.1 instead of 0. Finally, we will give this block a nice stone texture.

```
box { <-3.5, -1, 0.1>, <3.5, 1, 1>
  texture { T_Stone10 }
}
```

Next, we want to make the text object. We can use the same object we used in the first turorial except we will use slightly different thickness and offset values.

```
text { ttf "timrom.ttf" "POV-RAY 3.0" 0.15, 0
  pigment { BrightGold }
  finish { reflection .25 specular 1 }
  translate -3*x
}
```

Remember that the text object is placed by default so that its front surface lies directly on the x-y-plane. If the front of the box begins at $z = 0.1$ and thickness is set at 0.15, the depth of the "inlay" will be 0.05 units. Go ahead and place a difference block around the two objects.

```
difference {
  box { <-3.5, -1, 0.1>, <3.5, 1, 1>
    texture { T_Stone10 }
  }
  text { ttf "timrom.ttf" "POV-RAY 3.0" 0.15, 0
    pigment { BrightGold }
    finish { reflection .25 specular 1 }
    translate -3*x
  }
}
```

Render this at 200x150 **–A**. We can see the inlay clearly and that it is indeed a bright gold color. Render this at 640x480 **+A0.2** to see the results more clearly, but be forewarned ... this trace will take a little time.

4.4.12 Torus Object

A torus can be thought of as a donut or an innertube. It is a shape that is vastly useful in many kinds of CSG so POV-Ray has adopted this 4th order quartic polynomial as a primitive shape. The syntax for a torus is so simple that it makes it a very easy shape to work with once you learn what the two float values mean. Instead of a lecture on the subject, let's create one and do some experiments with it.

Create a file called TORDEMO.POV. Edit it as follows:

```
#include "colors.inc"

camera {
  location <0, .1, -25>
  look_at 0
  angle 36
}

background { color Gray50 }

light_source{ <300, 300, -1000> White }

torus { 4, 1         // major and minor radius
  rotate -90*x       // so we can see it from the top
  pigment { Green }
}
```

Go ahead and trace this. Well, it's a donut allright. Let's try changing the major and minor radius values and see what happens. Change them as follows:

```
torus { 5, .25       // major and minor radius
```

That looks more like a hula-hoop! Let's try this:

```
torus { 3.5, 2.5     // major and minor radius
```

Whoa! A donut with a serious weight problem!

With such a simple syntax, there isn't much else you can do to a torus besides change its texture ... or is there? Let's see ...

Torus' are very useful objects in CSG. Let's try a little experiment. Make a difference of a torus and a box:

```
difference {
  torus { 4, 1
    rotate x*-90  // so we can see it from the top
  }
  box { <-5, -5, -1>, <5, 0, 1> }
  pigment { Green }
}
```

Interesting … a half-torus. So? So, now add another one flipped the other way. Only, let's declare the original half-torus and the necessary transformations so we can use them again:

```
#declare Half_Torus = difference {
  torus { 4, 1
    rotate -90*x  // so we can see it from the top
  }
  box { <-5, -5, -1>, <5, 0, 1> }
  pigment { Green }
}

#declare Flip_It_Over = 180*x

#declare Torus_Translate = 8  // 2 * major radius
```

Now create a union of two *Half_Torus* objects:

```
union {
  object { Half_Torus }
  object { Half_Torus
    rotate Flip_It_Over
    translate Torus_Translate*x
  }
}
```

This makes an *S*-shaped object, but we can't see the whole thing from our present camera. Let's add a few more links, three in each direction, move the object along the +z direction and rotate it about the +y axis so we can see more of it. We also notice that there appears to be a small gap where the *Half_Torus'* meet. This is due to the fact that we are viewing this scene from directly on the *x-z* plane. We will change the camera *y* coordinate from 0 to 0.1 to eliminate this.

```
union {
  object { Half_Torus }
  object { Half_Torus
    rotate Flip_It_Over
    translate x*Torus_Translate
  }
```

```
  object { Half_Torus
    translate x*Torus_Translate*2
  }
  object { Half_Torus
    rotate Flip_It_Over
    translate x*Torus_Translate*3
  }
  object { Half_Torus
    rotate Flip_It_Over
    translate -x*Torus_Translate
  }
  object { Half_Torus
    translate -x*Torus_Translate*2
  }
  object { Half_Torus
    rotate Flip_It_Over
    translate -x*Torus_Translate*3
  }
  object { Half_Torus
    translate -x*Torus_Translate*4
  }
  rotate y*45
  translate z*20
}
```

Rendering this we see a cool, undulating, snake-like something-or-other. Neato. But we want to model something useful, something that we might see in real life. How about a chain?

Thinking about it for a moment, we realize that a single link of a chain can be easily modeled using two half toruses and two cylinders. Go ahead and create a new file. You can use the same camera, background, light source, and declared objects and transformations as you used in TORDEMO.POV:

```
#include "colors.inc"

camera {
  location <0, .1, -25>
  look_at 0
  angle 36
}

background { color Gray50 }

light_source{ <300, 300, -1000> White }

#declare Half_Torus = difference {
  torus { 4,1
    sturm
```

```
    rotate x*-90  // so we can see it from the top
  }
  box { <-5, -5, -1>, <5, 0, 1> }
  pigment { Green }
}

#declare Flip_It_Over = x*180

#declare Torus_Translate = 8
```

Now, make a complete torus of two half toruses:

```
union {
  object { Half_Torus }
  object { Half_Torus rotate Flip_It_Over }
}
```

This may seem like a wasteful way to make a complete torus, but we are really going to move each half apart to make room for the cylinders. First, add the declared cylinder before the union:

```
#declare Chain_Segment =
  cylinder { <0, 4, 0>, <0, -4, 0>, 1
  pigment { Green }
}
```

Then add two *Chain_Segments* to the union and translate them so that they line up with the minor radius of the torus on each side:

```
union {
  object { Half_Torus }
  object { Half_Torus rotate Flip_It_Over }
  object { Chain_Segment
    translate  x*Torus_Translate/2
  }
  object { Chain_Segment
    translate -x*Torus_Translate/2
  }
}
```

Now translate the two half toruses $+y$ and $-y$ so that the clipped ends meet the ends of the cylinders. This distance is equal to half of the previously declared *Torus_Translate*:

```
union {
  object { Half_Torus
```

```
    translate y*Torus_Translate/2
  }
  object { Half_Torus
    rotate Flip_It_Over
    translate -y*Torus_Translate/2
  }
  object { Chain_Segment
    translate x*Torus_Translate/2
  }
  object { Chain_Segment
    translate -x*Torus_Translate/2
  }
}
```

Render this and voila! A single link of a chain. But we aren't done yet! Whoever heard of a green chain? We would rather use a nice metallic color instead. First, remove any pigment blocks in the declared toruses and cylinders. Then add the following before the union:

```
#declare Chain_Gold = texture {
  pigment { BrightGold }
  finish {
    ambient .1
    diffuse .4
    reflection .25
    specular 1
    metallic
  }
}
```

Then add the texture to the union and declare the union as a single link:

```
#declare Link = union {
  object { Half_Torus
    translate y*Torus_Translate/2
  }
  object { Half_Torus
    rotate Flip_It_Over
    translate -y*Torus_Translate/2
  }
  object { Chain_Segment
    translate x*Torus_Translate/2
  }
  object { Chain_Segment
    translate -x*Torus_Translate/2
  }
  texture { Chain_Gold }
}
```

Now make a union of two links. The second one will have to be translated $+y$ so that its inner wall just meets the inner wall of the other link, just like the links of a chain. This distance turns out to be double the previously declared *Torus_Translate* minus 2 (twice the minor radius). This can be described by the expression:

```
Torus_Translate*2-2*y
```

Declare this expression as follows:

```
#declare Link_Translate = Torus_Translate*2-2*y
```

In the object block, we will use this declared value so that we can multiply it to create other links. Now, rotate the second link `90*y` so that it is perpendicular to the first, just like links of a chain. Finally, scale the union by 1/4 so that we can see the whole thing:

```
union {
  object { Link }
  object { Link translate y*Link_Translate rotate y*90 }
  scale .25
}
```

Render this and you will see a very realistic pair of links. If we want to make an entire chain, we must declare the above union and then create another union of this declared object. Be sure to remove the scaling from the declared object:

```
#declare Link_Pair =
union {
  object { Link }
  object { Link translate y*Link_Translate rotate y*90 }
}
```

Now declare your chain:

```
#declare Chain = union {
  object { Link_Pair}
  object { Link_Pair translate  y*Link_Translate*2 }
  object { Link_Pair translate  y*Link_Translate*4 }
  object { Link_Pair translate  y*Link_Translate*6 }
  object { Link_Pair translate -y*Link_Translate*2 }
  object { Link_Pair translate -y*Link_Translate*4 }
  object { Link_Pair translate -y*Link_Translate*6 }
}
```

And, finally create your chain with a couple of transformations to make it easier to see. These include scaling it down by a factor of 1/10, and rotating it so that you can clearly see each link:

```
object { Chain scale .1 rotate <0, 45, -45> }
```

Render this and you should see a very realistic gold chain stretched diagonally across the screen.

4.5 CSG Objects

Constructive solid geomerty, CSG, is a powerful tool to combine primitve objects to create more complex objects as shown in the following sections.

4.5.1 What is CSG?

CSG stands for *Constructive Solid Geometry*. POV-Ray allows you to construct complex solids by combining primitive shapes in four different ways. These are union, where two or more shapes are added together, intersection where two or more shapes are combined to make a new shape that consists of the area common to both shapes, difference where subsequent shapes are subtracted from the first shape, and merge which is like a union where the surfaces inside the union are removed (useful in transparent CSG objects). We will deal with each of these in detail in the next few sections.

CSG objects can be extremely complex. They can be deeply nested. In other words there can be unions of differences or intersections of merges or differences of intersections or even unions of intersections of differences of merges … ad infinitum. CSG objects are (almost always) finite objects and so respond to auto-bounding and can be transformed like any other POV primitive shape.

4.5.2 CSG Union

Let's try making a simple union. Create a file called CSGDEMO.POV and edit it as follows:

```
#include "colors.inc"

camera {
  location <0, 1, -10>
  look_at 0
  angle 36
}
```

```
light_source { <500, 500, -1000> White }

plane { y, -1.5
  pigment { checker Green White }
}
```

Now let's add two spheres each translated 0.5 units along the *x*-axis in each direction. Color one blue and the other red.

```
sphere { <0, 0, 0>, 1
  pigment { Blue }
  translate -0.5*x
}
sphere { <0, 0, 0>, 1
  pigment { Red }
  translate 0.5*x
}
```

Try tracing this file now at 200x150 **–A**. Now place a union block around the two spheres. This will create a single CSG union out of the two objects.

```
union{
  sphere { <0, 0, 0>, 1
    pigment { Blue }
    translate -0.5*x
  }
  sphere { <0, 0, 0>, 1
    pigment { Red }
    translate 0.5*x
  }
}
```

Trace the file again. The union will appear no different from what each sphere looked like on its own, but now we can give the entire union a single texture and transform it as a whole. Let's do that now.

```
union{
  sphere { <0, 0, 0>, 1
    translate -0.5*x*
  }
  sphere { <0, 0, 0>, 1
    translate 0.5*x
  }
  pigment { Red }
  scale <1, .25, 1>
  rotate <30, 0, 45>
}
```

Trace the file again. As you can see, the object has changed dramatically. Experiment with different values of scale and rotate and try some different textures.

There are some advantages of assigning only one texture to a CSG object instead of assigning the texture to each individual component. First, it is much easier to use one texture if your CSG object has a lot of components because changing the objects appereance involves changing only one single texture. Second, the file parses faster because the texture has to be parsed only once. This may be a great factor when doing large scenes or animatons. Third, using only one texture saves memory because the texture is only stored once and referenced by all components of the CSG object. Assigning the texture to all n components means that it is stored n times.

4.5.3 CSG Intersection

Now let's use these same spheres to illustrate the next kind of CSG object, the *intersection*. Change the word `union` to `intersection` and delete the `scale` and `rotate` statements:

```
intersection {
  sphere { <0, 0, 0>, 1
    translate -0.5*x
  }
  sphere { <0, 0, 0>, 1
    translate 0.5*x
  }
  pigment { Red }
}
```

Trace the file and you will see a lens-shaped object instead of the two spheres. This is because an intersection consists of the area shared by both shapes, in this case the lens-shaped area where the two spheres overlap. We like this lens-shaped object so we will use it to demostrate differences.

4.5.4 CSG Difference

Rotate the lens-shaped intersection about the *y*-axis so that the broad side is facing the camera.

```
intersection{
  sphere { <0, 0, 0>, 1
    translate -0.5*x
  }
  sphere { <0, 0, 0>, 1
    translate 0.5*x
```

```
  }
  pigment { Red }
  rotate 90*y
}
```

Now let's create a cylinder and stick it right in the middle of the lens.

```
cylinder { <0, 0, -1> <0, 0, 1>, .35
  pigment { Blue }
}
```

Render the scene now to see the position of the cylinder. We will place a difference block around both the lens-shaped intersection and the cylinder like this:

```
difference {
  intersection {
    sphere { <0, 0, 0>, 1
      translate -0.5*x
    }
    sphere { <0, 0, 0>, 1
      translate 0.5*x
    }
    pigment { Red }
    rotate 90*y
  }
  cylinder { <0, 0, -1> <0, 0, 1>, .35
    pigment { Blue }
  }
}
```

Now render the file. You should see the lens-shaped intersection with a neat hole in the middle of it where the cylinder was. The cylinder has been *subtracted* from the intersection. Note that the pigment of the cylinder causes the surface of the hole to be colored blue. If you eliminate this pigment the surface of the hole will be red.

OK, let's get a little wilder now. Let's declare our perforated lens object to give it a name. Let's also eliminate all textures in the declared object because we will want them to be in the final union instead.

```
#declare Lens_With_Hole = difference {
  intersection {
    sphere { <0, 0, 0>, 1
      translate -0.5*x
    }
    sphere { <0, 0, 0>, 1
      translate 0.5*x
```

```
      }
      rotate 90*y
    }
    cylinder { <0, 0, -1> <0, 0, 1>, .35 }
  }
```

Now, let's use union to build a complex shape composed of copies of this object.

```
  union {
    object { Lens_With_Hole translate <-.65, .65, 0> }
    object { Lens_With_Hole translate <.65, .65, 0> }
    object { Lens_With_Hole translate <-.65, -.65, 0> }
    object { Lens_With_Hole translate <.65, -.65, 0> }
    pigment { Red }
  }
```

Render it. An interesting object to be sure. But let's try something more. Let's make it a partially-transparent object by adding some filter to the pigment block.

```
  union {
    object { Lens_With_Hole translate <-.65, .65, 0> }
    object { Lens_With_Hole translate <.65, .65, 0> }
    object { Lens_With_Hole translate <-.65, -.65, 0> }
    object { Lens_With_Hole translate <.65, -.65, 0> }
    pigment { Red filter .5 }
  }
```

Now render the file again. This looks pretty good ... only ... you can see parts of each of the lens objects inside the union! This is no good.

4.5.5 CSG Merge

This brings us to the fourth kind of CSG object, the *merge*. Merges are the same as unions, but the geometry of the objects in the CSG that is inside the merge is not traced. This should eliminate the problem with our object. Let's try it.

```
  merge {
    object { Lens_With_Hole translate <-.65, .65, 0> }
    object { Lens_With_Hole translate <.65, .65, 0> }
    object { Lens_With_Hole translate <-.65, -.65, 0> }
    object { Lens_With_Hole translate <.65, -.65, 0> }
    pigment { Red filter .5 }
  }
```

Sure enough, it does!

4.5.6 CSG Pitfalls

There is a severe pitfall in the POV-Ray's CSG code that you have to be aware of.

4.5.6.1 Coincidence Surfaces

POV-Ray uses inside/outside tests to determine the points at which a ray intersects a CSG object. A problem arises when the surfaces of two different shapes coincide because there is no way (due to numerical problems) to tell wether a point on the coincident surface belongs to one shape or the other.

Look at the following example where a cylinder is used to cut a hole in a larger box.

```
difference {
  box { -1, 1 pigment { Red } }
  cylinder { -z, z, 0.5 pigment { Green } }
}
```

If you trace this object you'll see red speckles where the hole is supposed to be. This is caused by the coincident surfaces of the cylinder and the box. One time the cylinder's surface is hit first by a viewing ray, resulting in the correct rendering of the hole, and another time the box is hit first, leading to a wrong result where the hole vanishes and red speckles appear.

This problem can be avoided by increasing the size of the cylinder to get rid of the coincidence surface. This is done by:

```
difference {
  box { -1, 1 pigment { Red } }
  cylinder { -1.001*z, 1.001*z, 0.5 pigment { Green } }
}
```

In general you have to make the subtracted object a little bit larger in a CSG difference. Just look for coincident surfaces and increase the subtracted object appropreatly to get rid of those surfaces.

The same problem occurs in CSG intersections and is also avoided by scaling some of the involved objects.

4.6 The Light Source

In any ray-traced scene, the light needed to illuminate your objects and their surfaces must come from a light source. There are many kinds of light sources available in POV-Ray and careful use of the correct kind can yield very impressive results. Let's take a moment to explore some of the different kinds of light sources and their various parameters.

4.6.1 The Ambient Light Source

The ambient light source is used to simulate the effect of interdiffuse reflection. If there wasn't interdiffuse reflection all areas not directly lit by a light source would be completely dark. POV-Ray uses the `ambient` keyword to determine how much light coming from the ambient light source is reflected by a surface.

By default the ambient light source, which emits its light everywhere and in all directions, is pure white (rgb$< 1,1,1 >$). Changing its color can be used to create interesting effects. First of all the overall light level of the scene can be adjusted easily. Instead of changing all `ambient` values only the ambient light source is modified. By assigning different colors you can create nice effects like a moody reddish ambient lighting. For more details about the ambient light source see 7.8.2 on page 356.

Below is an example of a red ambient light source.

```
global_settings { ambient_light rgb<1, 0, 0> }
```

4.6.2 The Point Light Source

Pointlights are exactly what the name indicates. A pointlight has no size, is invisible, and illuminates everything in the scene equally no matter how far away from the light source it may be. This is the simplest and most basic light source. There are only two important parameters, location and color. Let's design a simple scene and place a pointlight source in it.

Create a new file and name it LITEDEMO.POV. Edit it as follows:

```
#include "colors.inc"
#include "textures.inc"

camera {
  location  <-4, 3, -9>
  look_at   <0, 0, 0>
  angle 48
}
```

Add the following simple objects:

```
plane { y, -1
  texture {
    pigment {
      checker
      color rgb<0.5, 0, 0>
      color rgb<0, 0.5, 0.5>
    }
    finish {
```

```
        diffuse 0.4
        ambient 0.2
        phong 1
        phong_size 100
        reflection 0.25
      }
    }
  }

  torus { 1.5, 0.5
    texture { Brown_Agate }
    rotate <90, 160, 0>
    translate  <-1, 1, 3>
  }

  box { <-1, -1, -1>, <1, 1, 1>
    texture { DMFLightOak }
    translate  <2, 0, 2.3>
  }

  cone { <0,1,0>, 0, <0,0,0>, 1
    texture { PinkAlabaster }
    scale <1, 3, 1>
    translate  <-2, -1, -1>
  }

  sphere { <0,0,0>,1
    texture { Sapphire_Agate }
    translate  <1.5, 0, -2>
  }
```

Now add a pointlight:

```
  light_source {
    <2, 10, -3>
    color White
  }
```

Render this at 200x150 **-A**. You will see that the objects are clearly visible with sharp shadows. The sides of curved objects nearest the light source are brightest in color with the areas that are facing away from the light source darkest. Note also that the checkered plane is illuminated evenly all the way to the horizon. This allows us to see the plane, but it is not very realistic.

4.6.3 The Spotlight Source

Spotlights are a very useful type of light source. They can be used to add highlights and illuminate features much as a photographer uses spots to do the same thing. There are a few more parameters with spotlights than with pointlights. These are `radius`, `falloff`, `tightness`, and `point_at`. The `radius` parameter is the angle of the fully illuminated cone. The `falloff` parameter is the angle of the *umbra* cone where the light falls off to darkness. The `tightness` is a parameter that determines the rate of the light falloff. `point_at` is just what it says, where the spotlight is pointing to. Let's change the light in our scene as follows:

```
light_source {
  <0, 10, -3>
  color White
  spotlight
  radius 15
  falloff 20
  tightness 10
  point_at <0, 0, 0>
}
```

Render this at 200x150 **–A** and you will see that only the objects are illuminated. The rest of the plane and the outer portions of the objects are now unlit. There is a broad falloff area, but the shadows are still razor sharp. Let's try fiddling with some of these parameters to see what they do. Try changing the `falloff` value to 16 (it must always be larger than `radius`) and render again. Now the falloff is very narrow, and the objects are either brightly lit, or in total darkness. Now, change `falloff` back to 20 and change the `tightness` value to 100 (higher is tighter) and render again. The spotlight appears to have gotten much smaller, but what has really happened is that the falloff has become so steep that the radius actually appears smaller.

We decide that a `tightness` value of 10 (the default) and a `falloff` value of 18 are best for this spotlight and we now want to put a few spots around the scene for effect. Lets place a slightly narrower blue and a red one in addition to the white one we already have:

```
light_source {
  <10, 10, -1>
  color Red
  spotlight
  radius 12
  falloff 14
  tightness 10
  point_at <2, 0, 0>
}

light_source {
  <-12, 10, -1>
  color Blue
  spotlight
  radius 12
```

```
    falloff 14
    tightness 10
    point_at <-2, 0, 0>
  }
```

Rendering this we see that the scene now has a wonderfully mysterious air to it. The three spotlights all converge on the objects making them blue on one side and red on the other with enough white in the middle to provide a balance.

4.6.4 The Cylindrical Light Source

Spotlights are cone shaped, meaning that their effect will change with distance. The farther away from the spotlight an object is, the larger the apparant radius will be. But we may want the radius and falloff to be a particular size no matter how far away the spotlight is. For this reason, cylindrical light sources are needed. A cylindrical light source is just like a spotlight, except that the radius and falloff regions are the same no matter how far from the light source your object is. The shape is therefore a cylinder rather than a cone. You can specify a cylindrical lightsource by replacing the `spotlight` keyword with `cylinder`. Try this now with our scene. Replace all three spotlights with cylinder lights and render again. We see that the scene is much dimmer. This is because the cylindrical constraints do not let the light spread out like in a spotlight. Larger `radius` and `falloff` values are needed to do the job. Try a `radius` of 20 and a `falloff` of 30 for all three lights. That's the ticket!

4.6.5 The Area Light Source

So far all of our light sources have one thing in common. They produce sharp shadows. This is because the actual light source is a point that is infinitely small. Objects are either in direct sight of the light, in which case they are fully illuminated, or they are not, in which case they are fully shaded. In real life, this kind of stark light and shadow situation exists only in outer space where the direct light of the sun pierces the total blackness of space. But here on Earth, light bends around objects, bounces off objects, and usually the source has some dimension, meaning that it can be partially hidden from sight (shadows are not sharp anymore). They have what is known as an umbra, or an area of fuzziness where there is neither total light or shade. In order to simulate these *soft* shadows, a ray-tracer must give its light sources dimension. POV-Ray accomplishes this with a feature known as an area light.

Area lights have dimension in two axis'. These are specified by the first two vectors in the area light syntax. You must also specify how many lights are to be in the array. More will give you cleaner soft shadows but will take longer to render. Usually a 3×3 or a 5×5 array will suffice. You also have the option of specifying an `adaptive` value. The `adaptive` command tells the ray-tracer that it can adapt to the situation and send only the needed rays to determine the value of the pixel. If `adaptive` is not used, a separate ray will be sent for every light in the area light. This can really slow things down. The higher the `adaptive` value the cleaner the umbra will be but the longer the trace will take. Usually an adaptive value of 1 is sufficient. Finally, you probably should use the `jitter` command. This tells the raytracer to slightly move the position of each light in the area light so that the shadows appear truely soft instead of giving you an umbra consisting of closely banded shadows.

OK, let's try one. Comment out the cylinder lights and add the following:

```
light_source {
  <2, 10, -3>
  color White
  area_light <5, 0, 0>, <0, 0, 5>, 5, 5
  adaptive 1
  jitter
}
```

This is a white area light centered at $\langle 2, 10, -3\rangle$. It is 5 units (along the x-axis) by 5 units (along the z-axis) in size, and has 25 (5×5) lights in it. We have specified adaptive 1 and jitter. Render this at 200x150 **–A**.

Right away we notice two things. The trace takes quite a bit longer than it did with a point or a spotlight, and the shadows are no longer sharp! They all have nice soft umbras around them. Wait, it gets better.

Spotlights and cylinder lights can be area lights too! Remember those sharp shadows from the spotlights in our scene? It would not make much sense to use a 5×5 array for a spotlight, but a smaller array might do a good job of giving us just the right amount of umbra for a spotlight. Let's try it. Comment out the area light and change the cylinder lights so that they read as follows:

```
light_source {
  <2, 10, -3>
  color White
  spotlight
  radius 15
  falloff 18
  tightness 10
  area_light <1, 0, 0>, <0, 0, 1>, 2, 2
  adaptive 1
  jitter
  point_at <0, 0, 0>
}

light_source {
  <10, 10, -1>
  color Red
  spotlight
  radius 12
```

```
    falloff 14
    tightness 10
    area_light <1, 0, 0>, <0, 0, 1>, 2, 2
    adaptive 1
    jitter
    point_at <2, 0, 0>
  }

  light_source {
    <-12, 10, -1>
    color Blue
    spotlight
    radius 12
    falloff 14
    tightness 10
    area_light <1, 0, 0>, <0, 0, 1>, 2, 2
    adaptive 1
    jitter
    point_at <-2, 0, 0>
  }
```

You now have three area-spotlights, one unit square consisting of an array of four (2×2) lights, three different colors, all shining on your scene. Render this at 200x150 **–A**. This appears to work perfectly. All our shadows have small, tight umbras, just the sort you would expect to find on an object under a real spotlight.

4.6.6 Assigning an Object to a Light Source

Light sources are invisible. They are just a location where the light appears to be coming from. They have no true size or shape. If you want your light source to be a visible shape, you can use the `looks_like` keyword. You can specify that your light source can look like any object you choose. When you use `looks_like`, `no_shadow` is applied to the object automatically. This is done so that the object will not block any illumination from the light source. If you want some blocking to occur (as in a lampshade), it is better to simply use a union to do the same thing. Let's add such an object to our scene. Here is a light bulb I have made just for this purpose:

```
  #declare Lightbulb = union {
    merge {
      sphere { <0,0,0>,1 }
      cylinder { <0,0,1>, <0,0,0>, 1
        scale <0.35, 0.35, 1.0>
        translate  0.5*z
      }
      texture {
        pigment {color rgb <1, 1, 1>}
```

```
        finish {ambient .8 diffuse .6}
      }
    }
    cylinder { <0,0,1>, <0,0,0>, 1
      scale <0.4, 0.4, 0.5>
      texture { Brass_Texture }
      translate  1.5*z
    }
    rotate -90*x
    scale .5
  }
```

Now add the light source:

```
  light_source {
    <0, 2, 0>
    color White
    looks_like { Lightbulb }
  }
```

Rendering this we see that a fairly believable light bulb now illuminates the scene. However, if we do not specify a high ambient value, the light bulb is not lit by the light source. On the plus side, all of the shadows fall away from the light bulb, just as they would in a real situation. The shadows are sharp, so let's make our bulb an area light:

```
  light_source {
    <0, 2, 0>
    color White
    area_light <1, 0, 0>, <0, 1, 0>, 2, 2
    adaptive 1
    jitter
    looks_like { Lightbulb }
  }
```

Note that we have placed this area light in the *x*-*y*-plane instead of the *x*-*z*-plane. Note also that the actual appearance of the light bulb is not affected in any way by the light source. The bulb must be illuminated by some other light source or by, as in this case, a high ambient value. More interesting results might therefore be obtained in this case by using halos (see section 4.8.5 on page 104).

4.6.7 Light Source Specials

4.6.7.1 Using Shadowless Lights

Light sources can be assigned the `shadowless` keyword and no shadows will be cast due to its presence in a scene. What good is that you may ask. Sometimes, scenes are difficult to illuminate properly using the lights you have chosen to illuminate your objects. It is impractical and unrealisitic to apply a higher ambient value to the texture of every object in the scene. So instead, you would place a couple of *fill* lights around the scene. Fill lights are simply dimmer lights with the `shadowless` keyword that act to boost the illumination of other areas of the scene that may not be lit well. Let's try using one in our scene.

Remember the three colored area spotlights? Go back now and uncomment them and comment out any other lights you have made. Now add the following:

```
light_source {
  <0, 20, 0>
  color Gray75
  shadowless
}
```

This is a fairly dim (*Gray75*) light 20 units over the center of the scene. It will give a dim illumination to all objects including the plane in the background. Render it and see.

4.6.7.2 Using Light Fading

If it is realism we want, it is not realistic for the plane to be evenly illuminated off into the distance. In real life, light gets scattered as it travels so it diminishes its ability to illuminate objects the farther it gets from its source. To simulate this, POV-Ray allows you to use two keywords: `fade_distance`, which specifies the distance at which full illumination is achieved; and `fade_power`, an exponential value which determines the actual rate of attenuation. Let's apply these keywords to our fill light.

First, make the fill light a little brighter by changing *Gray75* to *Gray50*. Now change that fill light as follows:

```
light_source {
  <0, 20, 0>
  color Gray50
  fade_distance 5
  fade_power 1
  shadowless
}
```

This means that the full value of the fill light will be achieved at a distance of 5 units away from the light source. The `fade_power` of 1 means that the falloff will be linear (the light falls of at a constant rate). Render this to see the result.

That definitely worked! Now let's try a `fade_power` of 2 and a `fade_distance` of 10. Again, this works well. The falloff is much sharper with a `fade_power` of 2 so we had ot raise the `fade_distance` to 10.

4.6.7.3 Light Sources and Atmosphere

By definition more than default, light sources are affected by atmosphere, i.e. their light is scattered by the atmosphere. This can be turned off by adding `atmosphere off` to the light source block. The light emitted by a light source can also be attenuated by the atmosphere (and also fog), that is it will be diminished as it travells through it, by adding `atmospheric_attenuation on`. The falloff is exponential and dependes on the `distance` parameter of the atmosphere (or fog). You should note that this featuer only affects light coming directly from the light source. Reflected and refracted light is ignored.

Let's experiment with these keywords. First we must add an atmosphere to our scene:

```
#include "atmos.inc"

atmosphere { Atmosphere2 }
```

Then, so the trace will not take as long and the effect will be easier to see, comment out the three lines that turn each of the three spotlights into area lights:

```
//area_light <1, 0, 0>, <0, 0, 1>, 2, 2
//adaptive 1
//jitter
```

Tracing the scene at 200x150 **-A** we see that indeed the spotlights are visible. We can see where the blue and red spots cross each other and where the white overhead light shines down through the center of the scene. We also notice that the spotlights appear to diminish in their intensity as the light descends from the light source to the objects. The red light is all but gone in the lower left part of the scene and the blue light all but gone in the lower right. This is due to the atmospheric attenuation and lends a further realism to the scene. The atmosphere-lightsource interaction gives our scene a smoky, mysterious appearance, but the trace took a long time. Make those spotlights area lights and it will take even longer. This is an inevitable trade-off — tracing speed for image quality.

4.7 Simple Texture Options

The pictures rendered so far where somewhat boring regarding the appearance of the objects. Let's add some fancy features to the texture.

4.7.1 Surface Finishes

One of the main features of a ray-tracer is its ability to do interesting things with surface finishes such as highlights and reflection. Let's add a nice little phong highlight (shiny spot) to the sphere. To do this you need a `finish` parameter. Change the definition of the sphere to this:

```
sphere { <0, 1, 2>, 2
  texture {
    pigment { color Yellow } // pre-defined in COLORS.INC
    finish { phong 1 }
  }
}
```

Now render this the same way you did before. The `phong` keyword adds a highlight the same color of the light shining on the object. It adds a lot of credibility to the picture and makes the object look smooth and shiny. Lower values of `phong` will make the highlight less bright (values should be between 0 and 1).

4.7.2 Adding Bumpiness

The highlight you've added illustrates how much of our perception depends on the reflective properties of an object. Ray-tracing can exploit this by playing tricks on our perception to make us see complex details that aren't really there.

Suppose you wanted a very bumpy surface on the object. It would be very difficult to mathematically model lots of bumps. We can however simulate the way bumps look by altering the way light reflects off of the surface. Reflection calculations depend on a vector called a *surface normal* vector. This is a vector which points away from the surface and is perpendicular to it. By artificially modifying (or perturbing) this normal vector you can simulate bumps. Change the scene to read as follows and render it:

```
sphere { <0, 1, 2>, 2
  texture {
    pigment { color Yellow }
    normal { bumps 0.4 scale 0.2 }
    finish { phong 1 }
  }
}
```

This tells POV-Ray to use a `bump` pattern to modify the surface normal. The value 0.4 controls the apparent depth of the bumps. Usually the bumps are about 1 unit wide which doesn't work very well with a sphere of radius 2. The scale makes the bumps 1/5th as wide but does not affect their depth.

4.7.3 Creating Color Patterns

You can do more than assign a solid color to an object. You can create complex patterns in the pigment block. Consider this example:

```
sphere { <0, 1, 2>, 2
  texture {
    pigment {
      wood
      color_map {
        [0.0 color DarkTan]
        [0.9 color DarkBrown]
        [1.0 color VeryDarkBrown]
      }
      turbulence 0.05
      scale <0.2, 0.3, 1>
    }
    finish { phong 1 }
  }
}
```

The keyword `wood` specifies a pigment pattern of concentric rings like rings in wood. The `color_map` specifies that the color of the wood should blend from *DarkTan* to *DarkBrown* over the first 90% of the vein and from *DarkBrown* to *VeryDarkBrown* over the remaining 10%. The `turbulence` slightly stirs up the pattern so the veins aren't perfect circles and the `scale` factor adjusts the size of the pattern.

Most patterns are set up by default to give you one *feature* across a sphere of radius 1.0. A *feature* is very roughly defined as a color transition. For example, a `wood` texture would have one band on a sphere of radius 1.0. In this example we scale the pattern using the `scale` keyword followed by a vector. In this case we scaled 0.2 in the *x* direction, 0.3 in the *y* direction and the *z* direction is scaled by 1, which leaves it unchanged. Scale values larger than one will stretch an element. Scale values smaller than one will squish an element. And a scale value of one will leave an element unchanged.

4.7.4 Pre-defined Textures

POV-Ray has some very sophisticated textures pre-defined in the standard include files GLASS.INC, METALS.INC, STONES.INC and WOODS.INC. Some are entire textures with `pigment`, `normal` and/or `finish` parameters already defined. Some are just pigments or just finishes. Change the definition of our sphere to the following and then re-render it:

```
sphere { <0, 1, 2>, 2
  texture {
    pigment {
      DMFWood4        // pre-defined in textures.inc
      scale 4         // Scale by the same amount in all
                      // directions
```

```
    }
    finish { Shiny } // pre-defined in finish.inc
  }
}
```

The pigment identifier *DMFWood4* has already been scaled down quite small when it was defined. For this example we want to scale the pattern larger. Because we want to scale it uniformly we can put a single value after the scale keyword rather than a vector of *x*, *y*, *z* scale factors.

Look through the file TEXTURES.INC to see what pigments and finishes are defined and try them out. Just insert the name of the new pigment where *DMFWood4* is now or try a different finish in place of *Shiny* and re-render your file.

Here is an example of using a complete texture identifier rather than just the pieces.

```
sphere { <0, 1, 2>, 2
  texture { PinkAlabaster }
}
```

4.8 Advanced Texture Options

The extremely powerful texturing ability is one thing that really sets POV-Ray apart from other raytracers. So far we have not really tried anything too complex but by now you should be comfortable enough with the program's syntax to try some of the more advanced texture options.

Obviously, we cannot try them all. It would take a tutorial a lot more pages to use every texturing option available in POV-Ray. For this limited tutorial, we will content ourselves to just trying a few of them to give you an idea of how textures are created. With a little practice, you will soon be creating beautiful textures of your own.

4.8.1 Pigment and Normal Patterns

Previous versions of POV-Ray made a distinction between pigment and normal patterns, i. e. patterns that could be used inside a `normal { ... }` or `pigment { ... }` statement. With POV-Ray 3.0 this restriction was removed so that all patterns listed in section 7.6.7 on page 318 can be used as a pigment or normal pattern.

4.8.2 Pigments

Every surface must have a color. In POV-Ray, this color is called a *pigment*. It does not have to be a single color. It can be a color pattern, a color list, or even an image map.

Pigments can also be layered one on top of the next so long as the uppermost layers are at least partially transparent so the ones beneath can show through. Let's play around with some of these kinds of pigments.

Create a file called TEXDEMO.POV and edit it as follows:

```
#include "colors.inc"

camera {
  location <1, 1, -7>
  look_at 0
  angle 36
}

light_source { <1000, 1000, -1000> White }

plane { y, -1.5
  pigment { checker Green, White }
}

sphere { <0,0,0>, 1
  pigment { Red }
}
```

Giving this file a quick test render at 200x150 **-A** we see that it is a simple red sphere against a green and white checkered plane. We will be using the sphere for our textures.

4.8.2.1 Using Color List Pigments

Before we begin you should note that we have already made one kind of pigment, the color list pigment. In the previous example we have used a checkered pattern on our plane. There are two other kinds of color list pigments, `brick` and `hexagon`. Let's quickly try each of these. First, change the plane's pigment as follows:

```
pigment { hexagon Green, White, Yellow }
```

Rendering this we see a three-color hexagonal pattern. Note that this pattern requires three colors. Now change the pigment to$ldots

```
pigment { brick Gray75, Red rotate -90*x scale .25 }
```

Looking at the resulting image see that the plane now has a brick pattern. Note that we had to rotate the pattern to make it appear correctly on the flat plane. This pattern normally is meant to be used on vertical surfaces. We also had to scale the pattern down a bit so we could see it more easily. Feel free to play around with these color list pigments, change the colors, etc. until you get a *floor* that you like.

4.8.2.2 Using Pigment and Patterns

Let's begin texturing our sphere by using a pattern and a color map consisting of three colors. Replace the pigment block with the following.

```
pigment {
  gradient x
  color_map {
    [0.00 color Red]
    [0.33 color Blue]
    [0.66 color Yellow]
    [1.00 color Red]
  }
}
```

Rendering this we see that it gives us an interesting pattern of vertical stripes. Try changing the gradient direction to *y*. The stripes are horizontal now. Try changing the gradient direction to *z*. The stripes are now more like concentric rings. This is because the gradient direction is directly away from the camera. Change the direction back to *x* and add the following change to the pigment block.

```
pigment {
  gradient x
  color_map {
    [0.00 color Red]
    [0.33 color Blue]
    [0.66 color Yellow]
    [1.00 color Red]
  }
  rotate -45*z          // <- add this line
}
```

The vertical bars are now slanted at a 45 degree angle. All patterns can be rotated, scaled, and translated in this manner. Let's now try some different types of patterns. One at a time, substitute the following keywords for `gradient x` and render to see the result: `bozo`, `marble`, `agate`, `granite`, `leopard`, `spotted`, and `wood` (if you like you can test all patterns listed in section 7.6.7 on page 318).

Rendering these we see that each results in a slightly different pattern. But to get really good results each type of pattern requires the use of some pattern modifiers.

4.8.2.3 Using Pattern Modifiers

Let's take a look at some pattern modifiers. First, change the pattern type to bozo. Then add the following change.

```
pigment {
  bozo
  frequency 3            // <- add this line
  color_map {
    [0.00 color Red]
    [0.33 color Blue]
    [0.66 color Yellow]
    [1.00 color Red]
  }
  rotate -45*z
}
```

The `frequency` modifier determines the number of times the color map repeats itself per unit of size. This change makes the `bozo` pattern we saw earlier have many more bands in it. Now change the pattern type to `marble`. When we rendered this earlier, we saw a banded pattern similar to `gradient y` that really did not look much like marble at all. This is because marble really is a kind of gradient and it needs another pattern modifier to look like marble. This modifier is called `turbulence`. Change the line `frequency 3` to `turbulence 1` and render again. That's better! Now let's put `frequency 3` back in right after the turbulence and take another look. Even more interesting!

But wait, it gets better! Turbulence itself has some modifiers of its own. You can adjust the turbulence several ways. First, the float that follows the `turbulence` keyword can be any value with higher values giving you more turbulence. Second, you can use the keywords `omega`, `lambda`, and `octaves` to change the turbulence parameters. Let's try this now:

```
pigment {
  marble
  turbulence 0.5
  lambda 1.5
  omega 0.8
  octaves 5
  frequency 3
  color_map {
    [0.00 color Red]
    [0.33 color Blue]
    [0.66 color Yellow]
    [1.00 color Red]
  }
  rotate 45*z
}
```

Rendering this we see that the turbulence has changed and the pattern looks different. Go ahead and play around with the numerical values of `turbulence`, `lambda`, `omega`, and `octaves` to see what they do.

4.8.2.4 Using Transparent Pigments and Layered Textures

Pigments are described by numerical values that give the rgb value of the color to be used (like `color rgb`$\langle 1,0,0\rangle$ giving you a red color). But this syntax will give you more than just the rgb values. You can specify filtering transparency by changing it as follows: `color rgbf`$\langle 1,0,0,1\rangle$. The *f* stands for `filter`, POV-Ray's word for filtered transparency. A value of one means that the color is completely transparent, but still filters the light according to what the pigment is. In this case, the color will be a transparent red, like red cellophane.

There is another kind of transparency in POV-Ray. It is called *transmittance* or non-filtering transparency (the keyword is `transmit`). It is different from `filter` in that it does not filter the light according to the pigment color. It instead allows all the light to pass through unchanged. It can be specified like this: `rgbt`$\langle 1,0,0,1\rangle$.

Let's use some transparent pigments to create another kind of texture, the layered texture. Returning to our previous example, declare the following texture.

```
#declare LandArea = texture {
    pigment {
      agate
      turbulence 1
      lambda 1.5
      omega .8
      octaves 8
      color_map {
        [0.00 color rgb <.5, .25, .15>]
        [0.33 color rgb <.1, .5, .4>]
        [0.86 color rgb <.6, .3, .1>]
        [1.00 color rgb <.5, .25, .15>]
      }
    }
  }
}
```

This texture will be the *land* area. Now let's make the oceans by declaring the following.

```
#declare OceanArea = texture {
  pigment {
    bozo
      turbulence .5
      lambda 2
      color_map {
        [0.00, 0.33 color rgb <0, 0, 1>
                    color rgb <0, 0, 1>]
        [0.33, 0.66 color rgbf <1, 1, 1, 1>
                    color rgbf <1, 1, 1, 1>]
```

```
          [0.66, 1.00 color rgb <0, 0, 1>
                      color rgb <0, 0, 1>]
        }
      }
    }
  }
```

Note how the *ocean* is the opaque blue area, and the *land* is the clear area which will allow the underlying texture to show through.

Now, let's declare one more texture to simulate an atmosphere with swirling clouds.

```
#declare CloudArea = texture {
  pigment {
    agate
    turbulence 1
    lambda 2
    frequency 2
    color_map {
      [0.0 color rgbf <1, 1, 1, 1>]
      [0.5 color rgbf <1, 1, 1, .35>]
      [1.0 color rgbf <1, 1, 1, 1>]
    }
  }
}
```

Now apply all of these to our sphere.

```
sphere { <0,0,0>, 1
  texture { LandArea }
  texture { OceanArea }
  texture { CloudArea }
}
```

Render this and you'll have a pretty good rendition of a little planetoid. But it could be better. We don't particularly like the appearance of the clouds. There is a way they could be done that would be much more realistic.

4.8.2.5 Using Pigment Maps

Pigments may be blended together in the same way as the colors in a `color_map` using the same pattern keywords that you can use for pigments. Rather than trying to impress you with the possible implications of this powerful feature, let's just give it a try.

Add the following declarations, making sure they appear before the other declarations in the file.

```
#declare Clouds1 = pigment {
    bozo
    turbulence 1
    color_map {
      [0.0 color White filter 1]
      [0.5 color White]
      [1.0 color White filter 1]
    }
  }
#declare Clouds2 = pigment {
  agate
  turbulence 1
  color_map {
    [0.0 color White filter 1]
    [0.5 color White]
    [1.0 color White filter 1]
    }
  }
#declare Clouds3 = pigment {
  marble
  turbulence 1
  color_map {
    [0.0 color White filter 1]
    [0.5 color White]
    [1.0 color White filter 1]
  }
}
#declare Clouds4 = pigment {
  granite
  turbulence 1
  color_map {
    [0.0 color White filter 1]
    [0.5 color White]
    [1.0 color White filter 1]
  }
}
```

Now use these declared pigments in our cloud layer on our planetoid. Replace the declared cloud layer with.

```
#declare CloudArea = texture {
  pigment {
    gradient y
    pigment_map {
      [0.00 Clouds1]
      [0.25 Clouds2]
      [0.50 Clouds3]
      [0.75 Clouds4]
```

```
          [1.00 Clouds1]
        }
      }
    }
```

Render this and you'll see a remarkable pattern that looks very much like weather patterns on the planet earth. They are separated into bands, simulating the different weather types found at different latitudes.

4.8.3 Normals

Objects in POV-Ray have very smooth surfaces. This is not very realistic so there are several ways to disturb the smoothness of an object by perturbing the surface normal. The surface normal is the vector that is perpendicular to the angle of the surface. By changing this normal the surface can be made to appear bumpy, wrinkled, or any of the many patterns available. Let's try a couple of them.

4.8.3.1 Using Basic Normal Modifiers

Comment out the planetoid sphere for now and, at the bottom of the file, create a new sphere with a simple, single color texture.

```
sphere { <0,0,0>, 1
  pigment { Gray75 }
  normal { bumps 1 scale .2 }
}
```

Here we have added a `normal` block in addition to the `pigment` block (note that these do not have to be included in a `texture` block unless they need to be transformed together or need to be part of a layered texture). Render this to see what it looks like. Now, one at a time, substitute for the keyword `bumps` the following keyowrds: `dents`, `wrinkles`, `ripples`, and `waves` (you can also use any of the patterns listed in 7.6.7 on page 318). Render each to see what they look like. Play around with the float value that follows the keyword. Try experimenting with the scale value too.

For added interest, change the plane texture to a single color with a normal as follows.

```
plane { y, -1.5
  pigment { color rgb <.65, .45, .35> }
  normal { dents .75 scale .25 }
}
```

4.8.3.2 Blending Normals

Normals can be layered similar to pigments but the results can be unexpected. Let's try that now by editing the sphere as follows.

```
sphere { <0,0,0>, 1
  pigment { Gray75 }
    normal { radial frequency 10 }
    normal { gradient y scale .2 }
}
```

As you can see, the resulting pattern is neither a radial nor a gradient. It is instead the result of first calculating a radial pattern and then calculating a gradient pattern. The results are simply additive. This can be difficult to control so POV-Ray gives the user other ways to blend normals.

One way is to use normal maps. A normal map works the same way as the pigment map we used earlier. Let's change our sphere texture as follows.

```
sphere { <0,0,0>, 1
  pigment { Gray75 }
  normal {
    gradient y
    frequency 3
    turbulence .5
    normal_map {
      [0.00 granite]
      [0.25 spotted turbulence .35]
      [0.50 marble turbulence .5]
      [0.75 bozo turbulence .25]
      [1.00 granite]
    }
  }
}
```

Rendering this we see that the sphere now has a very irregular bumpy surface. The gradient pattern type separates the normals into bands but they are turbulated, giving the surface a chaotic appearance. But this give us an idea.

Suppose we use the same pattern for a normal map that we used to create the oceans on our planetoid and applied it to the land areas. Does it follow that if we use the same pattern and modifiers on a sphere the same size that the shape of the pattern would be the same? Wouldn't that make the land areas bumpy while leaving the oceans smooth? Let's try it. First, let's render the two spheres side-by-side so we can see if the pattern is indeed the same. Un-comment the planetoid sphere and make the following changes.

```
sphere { <0,0,0>, 1
  texture { LandArea }
  texture { OceanArea }
  //texture { CloudArea }  // <-comment this out
  translate -x             // <- add this transformation
}
```

Now change the gray sphere as follows.

```
sphere { <0,0,0>, 1
  pigment { Gray75 }
  normal {
    bozo
    turbulence .5
    lambda 2
    normal_map {
      [0.4 dents .15 scale .01]
      [0.6 agate turbulence 1]
      [1.0 dents .15 scale .01]
    }
  }
  translate x // <- add this transformation
}
```

Now render this to see if the pattern is the same. We see that indeed it is. So let's comment out the gray sphere and add the `normal` block it contains to the land area texture of our planetoid. Remove the transformations so that the planetoid is centered in the scene again.

```
#declare LandArea = texture {
  pigment {
    agate
    turbulence 1
    lambda 1.5
    omega .8
    octaves 8
    color_map {
      [0.00 color rgb <.5, .25, .15>]
      [0.33 color rgb <.1, .5, .4>]
      [0.86 color rgb <.6, .3, .1>]
      [1.00 color rgb <.5, .25, .15>]
    }
  }
  normal {
    bozo
    turbulence .5
    lambda 2
```

```
      normal_map {
        [0.4 dents .15 scale .01]
        [0.6 agate turbulence 1]
        [1.0 dents .15 scale .01]
      }
    }
  }
```

Looking at the resulting image we see that indeed our idea works! The land areas are bumpy while the oceans are smooth. Add the cloud layer back in and our planetoid is complete.

There is much more that we did not cover here due to space constraints. On your own, you should take the time to explore `slope_map`, `average`, and `bump_map`.

4.8.4 Finishes

The final part of a POV-Ray texture is the *finish*. It controls the properties of the surface of an object. It can make it shiny and reflective, or dull and flat. It can also specify what happens to light that passes through transparent pigments, what happens to light that is scattered by less-than-perfectly-smooth surfaces, and what happens to light that is reflected by surfaces with thin-film interference properties. There are twelve different properties available in POV-Ray to specify the `finish` of a given object. These are `ambient`, `diffuse`, `brilliance`, `phong`, `specular`, `metallic`, `reflection`, `refraction`, `caustics`, `attenuation`, `crand`, and `iridescence`. Let's design a couple of textures that make use of these parameters.

4.8.4.1 Using Ambient

Since objects in POV-Ray are illuminated by light sources, the portions of those objects that are in shadow would be completely black were it not for the first two finish properties, `ambient` and `diffuse`. Ambient is used to simulate the light that is scattered around the scene that does not come directly from a light source. Diffuse determines how much of the light that is seen comes directly from a light source. These two keywords work together to control the simulation of ambient light. Let's use our gray sphere to demonstrate this. Let's also change our plane back to its original green and white checkered pattern.

```
plane {y,-1.5
  pigment {checker Green, White}
}

sphere { <0,0,0>, 1
  pigment {Gray75}
  finish {
```

```
    ambient .2
    diffuse .6
}
```

In the above example, the default values for ambient and diffuse are used. Render this to see what the effect is and then make the following change to the finish.

```
ambient 0
diffuse 0
```

The sphere is black because we have specified that none of the light coming from any light source will be reflected by the sphere. Let's change `diffuse` back to the default of 0.6.

Now we see the gray surface color where the light from the light source falls directly on the sphere but the shaded side is still absolutely black. Now let's change `diffuse` to 0.3 and `ambient` to 0.3.

The sphere now looks almost flat. This is because we have specified a fairly high degree of ambient light and only a low amount of the light coming from the light source is diffusely reflected towards the camera. The default values of `ambient` and `diffuse` are pretty good averages and a good starting point. In most cases, an ambient value of 0.1...0.2 is sufficient and a diffuse value of 0.5...0.7 will usually do the job. There are a couple of exceptions. If you have a completely transparent surface with high refractive and/or reflective values, low values of both ambient and diffuse may be best. Here is an example.

```
sphere { <0,0,0>, 1
   pigment { White filter 1 }
     finish {
       ambient 0
       diffuse 0
       reflection .25
       refraction 1
       ior 1.33
       specular 1
       roughness .001
     }
   }
}
```

This is glass, obviously. Glass is a material that takes nearly all of its appearance from its surroundings. Very little of the surface is seen because it transmits or reflects practically all of the light that shines on it. See GLASS.INC for some other examples.

If you ever need an object to be completely illuminated independently of the lighting situation in a given scene, you can do this artificially by specifying an `ambient` value of 1 and a `diffuse` value of 0. This will eliminate all shading and simply give the object its fullest and brightest color value at all points. This is good for simulating objects that emit light like lightbulbs, and for skies in scenes where the sky may not be adequately lit by any other means.

Let's try this with our sphere now.

```
sphere { <0,0,0>, 1
  pigment { White }
    finish {
      ambient 1
      diffuse 0
    }
  }
}
```

Rendering this we get a blinding white sphere with no visible highlights or shaded parts. It would make a pretty good streetlight.

4.8.4.2 Using Surface Highlights

In the glass example above, we noticed that there were bright little *hotspots* on the surface. This gave the sphere a hard, shiny appearance. POV-Ray gives you two ways to specify surface specular highlights. The first is called *Phong highlighting*. Usually, Phong highlights are described using two keywords: `phong` and `phong_size`. The float that follows `phong` determines the brightness of the highlight while the float following `phong_size` determines its size. Let's try this.

```
sphere { <0,0,0>, 1
  pigment { Gray50 }
  finish {
    ambient .2
    diffuse .6
    phong .75
    phong_size 25
  }
}
```

Rendering this we see a fairly broad, soft highlight that gives the sphere a kind of plastic appearance. Now let's change `phong_size` to 150. This makes a much smaller highlight which gives the sphere the appearance of being much harder and shinier.

There is another kind of highlight that is calculated by a different means called *specular highlighting*. It is specified using the keyword `specular` and operates in conjunction with another keyword called `roughness`. These two keywords work together in much the same way as `phong` and `phong_size` to create highlights that alter the apparent shininess of the surface. Let's try using specular in our sphere.

```
sphere { <0,0,0>, 1
  pigment { Gray50 }
    finish {
      ambient .2
      diffuse .6
      specular .75
      roughness .1
    }
  }
}
```

Looking at th result we see a broad, soft highlight similar to what we had when we used phong_size of 25. Change roughness to .001 and render again. Now we see a small, tight highlight similar to what we had when we used phong_size of 150. Generally speaking, specular is slightly more accurate and therefore slightly more realistic than phong but you should try both methods when designing a texture. There are even times when both phong and specular may be used on a finish.

4.8.4.3 Using Reflection and Metallic

There is another surface parameter that goes hand in hand with highlights, *reflection*. Surfaces that are very shiny usually have a degree of reflection to them. Let's take a look at an example.

```
sphere { <0,0,0>, 1
  pigment { Gray50 }
    finish {
      ambient .2
      diffuse .6
      specular .75
      roughness .001
      reflection .5
    }
  }
}
```

We see that our sphere now reflects the green and white checkered plane and the black background but the gray color of the sphere seems out of place. This is another time when a lower diffuse value is needed. Generally, the higher reflection is the lower diffuse should be. Try lowering the diffuse value to 0.3 and the ambient value to 0.1 and render again. That is much better. Let's make our sphere as shiny as a polished gold ball bearing.

```
sphere { <0,0,0>, 1
  pigment { BrightGold }
```

```
    finish {
      ambient .1
      diffuse .1
      specular 1
      roughness .001
      reflection .75
    }
  }
}
```

That is very close but there is something wrong with the highlight. To make the surface appear more like metal the keyword `metallic` is used. Add it now to see the difference.

```
sphere { <0,0,0>, 1
  pigment { BrightGold }
    finish {
      ambient .1
      diffuse .1
      specular 1
      roughness .001
      reflection .75
      metallic
    }
  }
}
```

We see that the highlight has taken on the color of the surface rather than the light source. This gives the surface a more metallic appearance.

4.8.4.4 Using Refraction

Objects that are transparent allow light to pass through them. With some substances, the light is bent as it traves from one substance into the other because of the differing optical densities of the objects. This is called *refraction*. Water and glass both bend light in this manner so to create water or glass, POV-Ray gives you a way to specify refraction. This is done with the keywords `refraction` and `ior`. The amount of light that passes through an object is determined by the value of the filtering and/or transmittance channel in the pigment. You should use the refraction value only to switch refraction on or off using vaules of 1 or 0 respectively (or the boolean values `on` and `off`). See section 7.6.3.5 on page 299 for a detailed explanation of the reasons.

The degree of refraction, i. e. the amount of bending that occurs, is given by the keyword `ior`, short for *index of refraction*. If you know the index of refraction of the substance you are trying to create, you may just use that. For instance, water is 1.33, glass is around 1.45 and diamond is 1.75. Let's return to the example of a glass sphere we used earlier.

```
sphere { <0,0,0>, 1
  pigment { White filter 1 }
    finish {
      ambient 0
      diffuse 0
      reflection .25
      refraction 1
      ior 1.45
      specular 1
      roughness .001
    }
  }
}
```

Render this again and notice how the plane that is visible through the sphere is distorted and turned upside-down. This is because the light passing through the sphere is being bent or refracted to the degree specified. Try reducing `ior` to 1.25. Try increasing it to 1.75. Notice how the distortion changes.

4.8.4.5 Light Attenuation and Caustics

Transparent objects can be made to cause the intensity of light passing through them to be reduced. In reality, this is due to impurities in scattering the light. Two float values determine the effect: `fade_distance` is the distance the light has to travel to reach one-half its original intensity and `fade_power` is the degree of falloff. Let's try an example of this.

```
sphere { <0,0,0>, 1
  pigment { White filter 1 }
    finish {
      ambient .1
      diffuse .1
      reflection .15
      refraction 1
      ior 1.45
      specular 1
      roughness .001
      fade_distance 5
      fade_power 1
  }
}
```

This gives the sphere a slightly clouded look as if not all of the light was able to pass through it. For interesting variations of this texture, try lowering `ior` to 1.15 and raising `reflection` to 0.5.

One thing we do notice is that the shadow of the sphere is still the same old flat gray shadow we have had all along. If there is all this light refraction going on shouldn't there be something going on with the shadow as well? That something would be due to an effect known as *caustics*. POV-Ray cannot do caustics but it can fake them to some degree. This is an easy one. Simply add `caustics 1` to the `finish` block and re-render to see the effect. What we see is a highlight in the shadow that simulates the effect of light passing through the sphere and being focused because of the curved surface. Remember that this is not real caustics, so changing other finish parameters like `ior` will not affect the caustic highlight. The faked caustic is limited to the area shadowed by the corresponding object.

4.8.4.6 Using Iridescence

Iridescence is what you see on the surface of an oil slick when the sun shines on it. The rainbow effect is created by something called *thin-film interference* (read section 7.6.3.6 on page 301 for details). For now let's just try using it. Iridescence is specified by the `irid` keyword and three values: `amount`, `thickness` and `turbulence`. The amount is the contribution to the overall surface color. Usually 0.1 to 0.5 is sufficient here. The thickness affects the *busyness* of the effect. Keep this between 0.25 and 1 for best results. The turbulence is a little different from pigment or normal turbulence. You cannot set `octaves`, `lambda` or `omega` but you can specify an amount which will affect the thickness in a slightly different way from the thickness value. Values between 0.25 and 1 work best here too. Finally, iridescence will respond to the surface normal since it depends on the angle of incidence of the light rays striking the surface. With all of this in mind, let's add some iridescence our glass sphere.

```
sphere { <0,0,0>, 1
  pigment { White filter 1 }
    finish {
      ambient .1
      diffuse .1
      reflection .2
      refraction 1
      ior 1.5
      specular 1
      roughness .001
      fade_distance 5
      fade_power 1
      caustics 1
      irid {
        0.35
        thickness .5
        turbulence .5
      }
    }
}
```

Try varying the values for `amount`, `thickness` and `turbulence` to see what changes they make. Try adding a `normal` block to see what happens.

4.8.5 Halos

Halos are a powerful feature that can be used to create a lot of different effects like clouds, fogs, fire, lasers, etc. The name actually comes from the ability to render halos with it, like the ones seen around the moon or the sun.

Due to the complexity of the halo feature and the large amount of parameters provided it is very difficult to get satisfying results. The following sections will help you to create a halo step by step, starting with the basic things and going to the more subtle stuff.

It is also helpful to read the halo reference sections to get a better understanding of the halo feature. You should especially read the sections 7.5.1 on page 229 and 7.6.4.1 on page 303 because they are essential for understanding halos.

4.8.5.1 What are Halos?

Halos are a texture feature allowing you to fill the interior of an object with particles. The distribution of these particles can be modified using several density mappings and density functions. The particles can emit light to give fire- or laser-like effects or they can absorb light to create clouds or fog.

A halo is attached to an object, the so called container object, just like a pigment, normal or finish. This object is completely filled by the halo but you won't see anything if you do not make sure that the object is hollow and the surface is translucent. How this is accomplished will be shown in the next section.

When working with halos you always have to keep in mind that the container object has to be hollow and translucent.

4.8.5.2 The Emitting Halo

We start with one of the simpler types, the emitting halo. It uses particles that only emit light. There are no particles that absorb the light coming from other particles.

4.8.5.2.1 Starting with a Basic Halo

A clever approach in designing a nice halo effect is to start with a simple, unit-sized shape that sits on the coordinate system's origin.

In the first example (HALO01.POV) we try to create a fiery explosion, which the sphere is best suited for. We start with a simple scene consisting of a camera, a light source (we don't care about shadows so we add the shadowless keyword), a checkered plane and a unit-sized sphere containing the halo.

```
camera {
  location <0, 0, -2.5>
  look_at <0, 0, 0>
}

light_source { <10, 10, -10> color rgb 1 shadowless }

plane { z, 2
  pigment { checker color rgb 0, color rgb 1 }
  finish { ambient 1 diffuse 0 }
  scale 0.5
  hollow
}

sphere { 0, 1
  pigment { color rgbt <1, 1, 1, 1> }
  halo {
    emitting
    spherical_mapping
    linear
    color_map {
      [ 0 color rgbt <1, 0, 0, 1> ]
      [ 1 color rgbt <1, 1, 0, 0> ]
    }
    samples 10
  }
  hollow
}
```

You'll note that the sphere is set to be hollow and has a translucent surface (the transmittance channel in the pigment color is 1), just like it is required for halos. You'll also note that the plane has a `hollow` keyword even though it has no halo. Why is this necessary?

The reason is quite simple. As described in section 7.5.1 on page 229 there can be no halo inside any other non-hollow object. Since the camera is *inside* the plane object, i.e. it is one the side of the plane that is considered be inside, the halo will never be visible unless the plane is made hollow (or the `negative` keyword is added to bring the camera on the *outside* side of the plane).

What do all those halo keywords and values mean? At the beginning of the halo the `emitting` keyword is used to specify what type of halo we want to use. The emitting halo emits light. That's what's best suited for our fiery explosion.

The `spherical_mapping` and `linear` keyword need a more detailed explanation of how a halo work (this is also done in chapter 7.6.4 on page 302 in more detail).

As noted above the halo is made up of lots of small particles. The distribution of these particles is described by a density function. In general, a density function tells us how much particles we'll find at a given location.

Instead of using an explicitly, mathematical density function, halos rely on a given set of density mappings and density functions to model a variety of particle distributions.

The first step in this model is the density mapping function that is used to map three-dimensional points onto a one-dimensional range of values. In our example we use a spherical mapping, i.e. we take the distance of a point from the center of the coordinate system. This is the reason why it is clever to start with a container object sitting on the coordinate system's center. Since all density mappings are made relative to this center you won't see anything if you start with an object sitting somewhere else. Moving the **whole** object (including textures and halos) to another location is the correct way of placing a container object.

Now we have a single value in the range from 0 to 1. This value will be transformed using a density function to get density values instead of distance values. Just using this single value won't work because we want to have particle distributions were the density decreases as we move from the *middle* the container object to the outside.

This is done by the density function. There are several alternatives available as described in the halo reference (see section 7.6.4.5 on page 308). We use the simple linear function that just maps values between 0 and 1 onto a 1 to 0 range. Thus we get a density value of 1 at the center of our sphere and a value of 0 at its surface.

Now that we have a density function what do we do to see something? This is where the `colour_map` keyword comes into play. It is used to describe a color map that actually tells the program what colors have to be used for what density. The relation is quite simple: colors at the beginning of the color map (with small values) will be used for low density values and colors at the end of the map (high values) will be used for high densities. In our example the halo will be yellow at the center of the sphere where the density is greatest and it will blend to red at the surface of the sphere where the density approaches zero.

The transmittance channel of the colors in the color map is used to model the translucency of the density field. A value of 0 represents no translucency, i. e. that areas with the corresponding density will be (almost) opaque, while a value of 1 means (almost) total translucency.

In our example we use

```
color_map {
  [ 0 color rgbt <1, 0, 0, 1> ]
  [ 1 color rgbt <1, 1, 0, 0> ]
}
```

which results in a halo with a very translucent, reddish outer area and a nearly opaque, yellowish inner areas as you can see after tracing the example image.

There is one parameter that still needs to be explained: the `samples` keyword. This keyword tells POV-Ray how many samples along any ray travelling through the halo have to be taken to calculate the halo. Using a low value will result in a high tracing speed while a high value will lead to a low speed. The sample value has to be increased if the halo looks somewhat *strange*, i. e. if some artifacts of the low sampling rate appear. For more details see section 7.6.4.7 on page 310.

A good starting value for the number of samples is 10.

4.8.5.2.2 Increasing the Brightness

The colors of the halo in the above image are somewhat dim. There is too much of the background visible through the halo. That does not look much like fire, does it? An easy way to fix this is to decrease the transparency of the particles in the areas of high density. Just use the following color map instead of the old one (the negative transmittance is correct).

```
color_map {
  [ 0 color rgbt <1, 0, 0,  1> ]
  [ 1 color rgbt <1, 1, 0, -1> ]
}
```

Looking at the result of HALO02.POV we will see that the halo is indeed much brighter.

4.8.5.2.3 Adding Some Turbulence

What we now have does not look like a fiery explosion. It's more a glowing ball than anything else. Somehow we have to make it look more *chaotic*, we have to add some turbulence to it.

This is done by using the `turbulence` keyword together with the amount of turbulence we want to add. Just like in the following example.

```
sphere { 0, 1
  pigment { color rgbt <1, 1, 1, 1> }
  halo {
    emitting
    spherical_mapping
    linear
    turbulence 1.5
    color_map {
      [ 0 color rgbt <1, 0, 0,  1> ]
      [ 1 color rgbt <1, 1, 0, -1> ]
    }
    samples 10
  }
  hollow
}
```

Adding turbulence to the halo moves all points inside the halo container in a pseudo-random manner. This results in a particle distribution that looks like there was some kind of *flow* in the halo (depending on the amount of turbulence you'll get a laminar or turbulent flow). The hight turbulence value is used because an explosion is highly turbulent.

Looking at the example image (HALO03.POV) you'll see that this looks more like a fiery explosion than the glowing ball we got until now.

You'll notice that the time it took to render the image increased after we added the turbulence. This is due to the fact that for every sample taken from the halo the slow turbulence function has to be evaluated.

4.8.5.2.4 Resizing the Halo

There is one strange thing about our fiery explosion though. It still looks like a sphere. Why does this happen and what can we do to avoid it?

As noted above adding turbulence moves the particles inside the halo container around. The problem is that some of the particles are actually moved out of the container object. This leads to high densities at the surface of the container object revealing the shape of the object (all particles outside the container are lost and will not visible resulting in a large, highly visible density change at the surface).

An easy way of avoiding this is to make sure that the particles stay inside the container object even if we add some turbulence. This is done by scaling the halo to reduce its size. We do **not** scale the container object, just the halo.

This is done by adding the `scale` keyword inside the halo statement.

```
sphere { 0, 1
  pigment { color rgbt <1, 1, 1, 1> }
  halo {
    emitting
    spherical_mapping
    linear
    turbulence 1.5
    color_map {
      [ 0 color rgbt <1, 0, 0,  1> ]
      [ 1 color rgbt <1, 1, 0, -1> ]
    }
    samples 10
    scale 0.5
  }
  hollow
  scale 1.5
}
```

The `scale 0.5` command tells POV-Ray to scale all points inside the halo by this amount. This effectively scales the radius we get after the density mapping to a range of 0 to 0.5 instead of 0 to 1 (without turbulence). If we now add the turbulence the points are allowed to move half a unit in every direction without leaving the container object. That is excactly what we want.

To compensate for the smaller halo we would get we scale the sphere (and the halo inside) by 1.5.

Looking at the new example image (HALO04.POV) you will no longer see any signs of the container sphere. We finally have a nice fiery explosion.

The amount by which to scale the halo depends on the amount of turbulence you use. The higher the turbulence value the smaller the halo has to be scaled. That is something to experiment with.

Another way to avoid that points move out of the sphere is to use a larger sphere, i. e. a sphere with a radius larger than one. It is important to resize the sphere before the halo is added because otherwise the halo will also be scaled.

You should note that this only works for spherical and box mapping (and a non-constant density function). All other mapping types are (partially) infinite, i.e. the resulting particle distribution covers an infinite space (see also 7.6.4.1 on page 303).

4.8.5.2.5 Using Frequency to Improve Realism

Another very good way of improving the realism of our explosion is to use a frequency value other than one. The way frequency works is explained in section 7.6.4.8.5 on page 312 in the reference part.

The rather mathematical explanation used there doesn't help much in understanding how this feature is used. It is quite simple though. The frequency value just tells the program how many times the color map will be repeated in the density range from 0 to 1. If a frequency of one (the default) is specified the color map will be visible once in the density field, e. g. the color at 0 will be used for density 0, color at 0.5 will be used for density 0.5 and the color at 1 will be used for density 1. Simple, isn't it?

If you choose a frequency of two, the color at 0 will be used for density 0, the color at 0.5 will be used for density 0.25 and the color at 1 will be used for density 0.5. What about the densities above 0.5? Since there are no entries in the color map for values above 1 we just start at 0 again. Thus the color at 0.1 will be used for density 0.55 ($(2 \times 0.55) \bmod 1 = 1.1 \bmod 1 = 0.1$), the color at 0.5 will be used for density 0.75 and the color at 1 will be used for density 1.

If you are good at mathematics you'll note that the above example is not quite right because $(1 * 2) \bmod 1 = 0$ and not 1. Just think that we used a value slightly smaller than one and everything will be fine.

You may have noticed that in order to avoid sudden changes in the halo color for frequencies larger than one you'll have to used a periodic color map, i.e. a color map whose entries at 0 and 1 are the same.

We'll change our example by using a periodic color map and changing the frequency value to two.

```
sphere { 0, 1
  pigment { color rgbt <1, 1, 1, 1> }
  halo {
    emitting
    spherical_mapping
    linear
    turbulence 1.5
    color_map {
      [ 0.0 color rgbt <1, 0, 0,  1> ]
      [ 0.5 color rgbt <1, 1, 0, -1> ]
      [ 1.0 color rgbt <1, 0, 0,  1> ]
    }
    frequency 2
    samples 20
    scale 0.5
  }
  hollow
  scale 1.5
}
```

Looking at the result of (HALO05.POV) we can be quite satisfied with the explosion we just have created, can't we?

There's one thing left you should be aware of when increasing the frequency value. It is often necessary to increase the sample rate in (nearly) the same way as you change the frequency. If you don't do this you'll probably get some severe aliasing artefacts (like color jumps or strange bands of colors). If this happens just change the samples value according to the frequency value (twice sampling rate for a doubled frequency).

4.8.5.2.6 Changing the Halo Color

We have a nice fiery explosion but we want to try to add some *science fiction* touch to it by using different colors. How about a nice green, less turbulent explosion that gets red at its borders?

Nothing easier than that!

```
sphere { 0, 1.5
  pigment { color rgbt <1, 1, 1, 1> }
  halo {
```

```
      emitting
      spherical_mapping
      linear
      turbulence 0.5
      color_map {
        [ 0 color rgbt <0, 1, 0,  1> ]
        [ 1 color rgbt <1, 0, 0, -1> ]
      }
      samples 10
      scale 0.75
    }
    hollow
    scale 1.5
  }
```

This should do the trick. Looking at the result of HALO06.POV you may be disappointed. Where is the red center of the explosion? The borders are green as expected but there is a lot of yellow in the center and only a little bit red. What is happening?

We use an emitting halo in our example. According to the corresponding section in the halo reference chapter (see 7.6.4.3.3 on page 306) this type of halo uses very small particles that do not attenuate light passing through the halo. Especially particles near the viewer do not attenuate the light coming from particles far away from the viewer.

During the calculation of the halo's color near the center of the container sphere, the ray steps through nearly all possible densities of the particle distribution. Thus we get red and green colors as we march on, depending on the current position in the halo. The sum of these colors is used which will gives as a yellow color (the sum of red and green is yellow). This is what is happening here.

How can we still get what we want? The answer is to use a glowing halo instead of the emitting halo. The glowing halo is very similar to the emitting one except that it attenuates the light passing through. Thus the light of particles lying behind other particles will be attenuated by the particles in front.

For the results of the glowing halo see 4.8.5.3.

4.8.5.3 The Glowing Halo

We have mentioned the glowing halo in the section about the emitting halo as one way to avoid the color mixing that is happening with emitting halos.

The gowing halo is very similar to the emitting halo except that it also absorbs light. You can view it as a combination of the emitting and the attenuating halo described in section 4.8.5.4 on the following page.

By just replacing the `emitting` keyword in the example in section 4.8.5.2.6 on the preceding page with the `glowing` keyword we get the desired effect as shown in the example image (HALO11.POV).

Even though the red color of the high density areas is not very visible because the green colored, lower density areas lying in front absorb most of the red light, you don't get yellow color where you would have expected a red one.

Due to its similarity with the emitting halo we leave it up to you to make some experiments with this halo type. You just have to keep all those things you learned in the previous sections in mind to get some satisfying results.

4.8.5.4 The Attenuating Halo

Another simple halo type is the attenuating halo that only absorbs light. It doesn't radiate on its own.

A great difference between the attenuating halo and the other halo types is that the color of the attenuating halo is calculated from the halo's color map using the total particle density along a given ray. The other types calculated a (weighted) average of the colors calculated from the density at each sample.

4.8.5.4.1 Making a Cloud

Attenuating halos are ideal to create clouds and smoke. In the following examples we will try to make a neat little cloud. We start again by using a unit-sized sphere that is filled with a basic attenuating halo (HALO21.POV).

```
camera {
  location <0, 0, -2.5>
  look_at <0, 0, 0>
}

light_source { <10, 10, -10> color rgb 1 shadowless }

plane { z, 2
  pigment { checker color rgb 0, color rgb 1 }
  finish { ambient 1 diffuse 0 }
  scale 0.5
  hollow
}

sphere { 0, 1
  pigment { color rgbt <1, 1, 1, 1> }
  halo {
    attenuating
    spherical_mapping
    linear
    color_map {
      [ 0 color rgbt <1, 0, 0, 1> ]
```

```
        [ 1 color rgbt <1, 0, 0, 0> ]
      }
      samples 10
    }
    hollow
  }
```

Even though clouds normally are not red but white or gray, we use the red color to make it more visible against the black/white checkerboard background.

The color of an attenuating halo is calculated from the total accumulated density after a ray has marched through the complete particle field. This has to be kept in mind when creating the color map. We want the areas of the cloud with a low density to have a high translucency so we use a color of rgbt$\langle 1,0,0,1\rangle$ and we want the high density areas to be opaque so we choose a color of rgbt$\langle 1,0,0,0\rangle$.

4.8.5.4.2 Scaling the Halo Container

The cloud we have created so far doesn't look very realistic. It's just a red, partially translucent ball. In order to get a better result we use some of the methods we have already learned in the sections about emitting halos above. We add some turbulence to get a more realistic shape, we scale the halo to avoid the container object's surface to become visible and we decrease the translucency of the areas with a high particle density.

Another idea is to scale the container object to get an ellipsoid shape that can be used to model a cloud pretty good. This is done by the `scale` $\langle 1.5, 0.75, 1\rangle$ command at the end of the sphere. It scales both, the sphere and the halo inside.

```
sphere { 0, 1
  pigment { color rgbt <1, 1, 1, 1> }
  halo {
    attenuating
    spherical_mapping
    linear
    turbulence 1
    color_map {
      [ 0 color rgbt <1, 0, 0,  1> ]
      [ 1 color rgbt <1, 0, 0, -1> ]
    }
    samples 10
    scale 0.75
  }
  hollow
  scale <1.5, 0.75, 1>
}
```

Looking at the results of HALO22.POV you'll see that this looks more like a real cloud (besides the color).

4.8.5.4.3 Adding Additional Halos

Another trick to get some more realism is to use multiple halos. If you look at cumulus clouds e. g. you'll notice that they often extend at the top while they are quite flat at the bottom.

We want to model this appearance by adding two additional halos to our current container object (see section 7.6.4.2 on page 304 for more details). This is done in the following way:

```
sphere { 0, 1.5
  pigment { color rgbt <1, 1, 1, 1> }
  halo {
    attenuating
    spherical_mapping
    linear
    turbulence 1
    color_map {
      [ 0 color rgbt <1, 0, 0,  1> ]
      [ 1 color rgbt <1, 0, 0, -1> ]
    }
    samples 10
    scale <0.75, 0.5, 1>
    translate <-0.4, 0, 0>
  }
  halo {
    attenuating
    spherical_mapping
    linear
    turbulence 1
    color_map {
      [ 0 color rgbt <1, 0, 0,  1> ]
      [ 1 color rgbt <1, 0, 0, -1> ]
    }
    samples 10
    scale <0.75, 0.5, 1>
    translate <0.4, 0, 0>
  }
  halo {
    attenuating
    spherical_mapping
    linear
    turbulence 1
    color_map {
      [ 0 color rgbt <1, 0, 0,  1> ]
```

```
      [ 1 color rgbt <1, 0, 0, -1> ]
    }
    samples 10
    scale 0.5
    translate <0, 0.2, 0>
  }
  hollow
}
```

The three halos used differ only in their location, i. e. in the translation vector we have used. The first two halos are used to form the base of the cloud while the last sits on top of the others. The sphere has a different radius than the previous ones because more space is needed for all three halos.

The result of HALO23.POV somehwat looks like a cloud, even though it may need some work.

4.8.5.5 The Dust Halo

The dust halo is a very complex halo type. It allows you to see the interaction of light coming from light sources with the particles in the halo. Those particles do absorb light like the attenuating halo. In addition they scatter light coming from light sources passing through them. This makes beams of light and shadows cast by objects onto the halo become visible.

4.8.5.5.1 Starting With an Object Lit by a Spotlight

We start with a box shaped object that is lit by a spotlight. We don't use any halo at this moment because we want to see if the object is completely lit by the light source (HALO31.POV).

```
camera {
  location <0, 0, -2.5>
  look_at <0, 0, 0>
}

background { color rgb <0.2, 0.4, 0.8> }

light_source {
  <2.5, 2.5, -2.5>
  colour rgb <1, 1, 1>
  spotlight
  point_at <0, 0, 0>
  radius 12
  falloff 15
  tightness 1
```

```
}

difference {
  box { -1, 1 }
  box { <-1.1, -0.8, -0.8>, <1.1, 0.8, 0.8> }
  box { <-0.8, -1.1, -0.8>, <0.8, 1.1, 0.8> }
  box { <-0.8, -0.8, -1.1>, <0.8, 0.8, 1.1> }
  pigment { color rgb <1, 0.2, 0.2> }
  scale 0.5
  rotate 45*y
  rotate 45*x
}
```

As you see the whole object is lit by the light source. Now we can start to add some dust.

4.8.5.5.2 Adding Some Dust

We use a box to contain the dust halo. Since we use a constant density function it doesn't matter what kind of density mapping is used. The density has the value specified by the `max_value` keyword everywhere inside the halo (the default value is one). The isotropic scattering is selected with `dust_type` .

```
box { -1, 1
  pigment { colour rgbt <1, 1, 1, 1> }
  halo {
    dust
    dust_type 1
    box_mapping
    constant
    colour_map {
      [ 0 color rgbt <1, 1, 1, 1> ]
      [ 1 color rgbt <1, 1, 1, 0> ]
    }
    samples 10
  }
  hollow
  scale 5
}
```

The result of HALO32.POV is too bright. The dust is too thick and we can only see some parts of the object and no background.

4.8.5.5.3 Decreasing the Dust Density

The density inside the halo has the constant value one. This means that only the color map entry at position one is used to determine the density and color of the dust.

We use a transmittance value of 0.7 to get a much thinner dust.

```
box { -1, 1
  pigment { colour rgbt <1, 1, 1, 1> }
  halo {
    dust
    dust_type 1
    box_mapping
    constant
    colour_map {
      [ 0 color rgbt <1, 1, 1, 1.0> ]
      [ 1 color rgbt <1, 1, 1, 0.7> ]
    }
    samples 10
  }
  hollow
  scale 5
}
```

Beside the ugly aliasing artefacts the image looks much better. We can see the whole object and even the background is slightly visible (HALO33.POV).

4.8.5.5.4 Making the Shadows Look Good

In order to reduce the aliasing artefacts we use three different techniques: jittering, super-sampling and an increased overall sampling rate.

The jittering is used to add some randomness to the sampling points making the image look more noisy. This helps because the regular aliasing artefacts are more annoying than noise. A low `jitter` value is a good choice.

The super-sampling tries to detect fine features by taking additional samples in areas of high intensity changes. The threshold at which super-sampling is used and the maximum recursion level can be specified using the `aa_threshold` and `aa_level` keywords.

The approach that always works is to increase the overall sampling rate. Since this is also the slowest method you should always try to use the other methods first. If they don't suffice you'll have to increase the sampling rate.

We use the following halo to reduce the aliasing artefacts (HALO34.POV).

```
box { -1, 1
  pigment { colour rgbt <1, 1, 1, 1> }
  halo {
    dust
    dust_type 1
```

```
      box_mapping
      constant
      colour_map {
        [ 0 color rgbt <1, 1, 1, 1.0> ]
        [ 1 color rgbt <1, 1, 1, 0.7> ]
      }
      samples 50
      aa_level 3
      aa_threshold 0.2
      jitter 0.1
    }
    hollow
    scale 5
  }
```

The image looks much better now. There are hardly any aliasing artefacts left.

The same parameters we have used are discussed in the section about the atmosphere feature (see 4.9.4 on page 131 for further explanations).

4.8.5.5.5 Adding Turbulence

The major difference between the halo's dust and the atmosphere described in 4.9.4 on page 131 is the ability to choose a non-uniform particle distribution for the dust. This includes the fact that the halo is limited to a container object as well as the different density mappings and functions.

Another interesting way of getting an irregular disribution is to add some turbulence to the dust. This is done with the `turbulence` keyword followed by the amount of turbulence to use, like the following example shows (HALO35.POV).

```
  box { -1, 1
    pigment { colour rgbt <1, 1, 1, 1> }
    halo {
      dust
      dust_type 1
      box_mapping
      linear
      turbulence 1
      colour_map {
        [ 0 color rgbt <1, 1, 1, 1.0> ]
        [ 1 color rgbt <1, 1, 1, 0.5> ]
      }
      samples 50
      aa_level 3
      aa_threshold 0.2
      jitter 0.1
    }
```

```
    hollow
    scale 5
  }
```

The image we now get looks much more interesting due to the shifts in the particle density.

You should note that we use a linear density function instead of the previous constant one. This is necessary because with a constant density function the density has the same value everywhere. Adding turbulence would have no effect because wherever the points are moved the density will have this same value. Only a non-constant density distribution makes sense when turbulence is added.

The fact that the turbulence value is actually a vector can be used to create effects like waterfalls by using a large turbulence value in on direction only (e.g. `turbulence` $\langle 0.2, 1, 0.2\rangle$).

4.8.5.5.6 Using a Coloured Dust

If you want to create a colored dust you can easily do this by using a non-white color in the halo's color map. In this case you'll also have to set the filter channels in the color map to non-zero values to specify the amount of light that will be filtered by the dust's color.

Use the following color map to get a partially filtering, red dust for example:

```
colour_map {
  [ 0 color rgbft <1, 0, 0, 0.5, 1.0> ]
  [ 1 color rgbft <1, 0, 0, 0.5, 0.7> ]
}
```

4.8.5.6 Halo Pitfalls

Due to the complexity of the halo feature and the few experiences people have made so far there are a lot of things still to discover.

Some of the most common problems and pitfalls are described below in order to help you to avoid the most common problems.

4.8.5.6.1 Where Halos are Allowed

As mentioned above a halo completly fills the interior of an object. Keeping this in mind it is reasonable that the following example does not make sense.

```
sphere { 0, 1
  pigment {
    checker
    texture {
      pigment { color Clear }
      halo { ... }
    }
    texture {
      pigment { color Red }
    }
  }
  hollow
}
```

What's wrong with this example? It's simply that a halo is used to describe the **interior** of an object and that you cannot describe this interior by describing how the surface of the object looks like. But that's what was done in the example above. Can you imagine what the interior of the sphere will look like? Will it be filled completey with the halo? Will there be areas filled by the halo and some filled by air? How will those areas look like?

You won't be able to tell the interior's properties from looking at the surface. It's just not possible. This should always be kept in mind.

If the above example was meant to create a sphere filled with a halo and covered with a checker board pattern that partially hid the halo you would have used the following syntax:

```
sphere { 0, 1
  pigment {
    checker
    texture {
      pigment { color Clear }
    }
    texture {
      pigment { color Red }
    }
  }
  halo { ... }
  hollow
}
```

A halo is always applied to an object in the following way:

```
OBJECT {
  texture {
```

```
    pigment { ... }
    normal { ... }
    finish { ... }
    halo { ... }
  }
  hollow
}
```

There's no halo allowed inside any pigment statement, color map, pigment map, texture map, material map, or whatever. You are not hindered to do this but you will not get what you want.

You can use a halo with a layered textures as long as you make sure that the halos are only attached to the lowest layer (this layer has to be partially transparent to see the halo of course).

4.8.5.6.2 Overlapping Container Objects

POV-Ray is not able to handle overlapping container objects correctly. If you create two overlapping spheres that contain a halo you won't get correct results where the spheres overlap. The halo effect is calculated independently for each sphere and the results are added.

If you want to add different halos you have to put all halos inside a single container object to make sure the halo is calculated correctly (see also 7.6.4.2 on page 304).

You should also note non-overlapping, stacked halo containers are handled correctly. If you put a container object in front of another container object the halos are rendered correctly.

4.8.5.6.3 Multiple Attenuating Halos

It is currently not possible to use mutliple attenuating halos with different color maps. The color map of the last halo will be used for all halos in the container object.

4.8.5.6.4 Halos and Hollow Objects

In order to correctly render halo effects you have to make sure that all objects the camera is inside are hollow. This is done by adding the `hollow` keyword.

For a detailed explanation see 7.5.1 on page 229.

4.8.5.6.5 Scaling a Halo Container

If you scale a halo container object you should keep in mind that it makes a great difference where you place the scale keyword.

Scaling the object before the halo statement will only scale the container object not the halo. This is useful if you want to avoid that the surface of the container object becomes visible due to the use of turbulence. As you've learned in the sections above particles may move out of the container object — where they are invisible — if turbulence is added. This only works for spherical and box mapping because the density fields described by the other mapping types don't have finite dimensions.

If the scale keyword is used after the halo statement both, the halo and the container object, are scaled. This is useful to scale the halo to your needs.

The halo keeps its appearance regardless of the transformations applied to the container object (after the halo), i.e. the halo's translucency, color and turbulence characteristics will not change.

4.8.5.6.6 Choosing a Sampling Rate

Normally you'll start with a low sampling rate and you'll only increase it if any aliasing artefacts turn up (and don't vanish by using super-sampling and jittering).

The halo's appearance is independent from the sampling rate as long as there are enough samples to get a good estimate of what the halo really looks like. This means that one or two samples are hardly ever enough to determine the halo's appearance. As you increase the number of samples the halo will quickly approach its real appearance.

To put it in a nutshell, the halo will not change its appearance with the sample rate as long as you have a sufficient number of samples and no aliasing artefacts occur.

4.8.5.6.7 Using Turbulence

As noted in one of the above sections turbulence will have no effect if the constant density function is used (keyword `constant).` It doesn't matter how much or where you move a point if the density is constant and thus does not depend on the points location. You'll get the same density value for all location.

Whenever you add turbulence to a halo do not use the constant density function.

4.9 Using Atmospheric Effects

POV-Ray offers a variety of atmospheric effects, i. e. features that affect the background of the scene or the air by which everything is surrounded.

It is easy to assign a simple color or a complex color pattern to a virtual sky sphere. You can create anything from a cloud free, blue summer sky to a stormy, heavy clouded sky. Even starfields can easily be created.

You can use different kinds of fog to create foggy scenes. Multiple fog layers of different colors can add an eerie touch to your scene.

A much more realistic effect can be created by using an atmosphere, a constant fog that interacts with the light coming from light sources. Beams of light become visible and objects will cast shadows into the fog.

Last but not least you can add a rainbow to your scene.

4.9.1 The Background

The background feature is used to assign a color to all rays that don't hit any object. This is done in the following way.

```
camera {
  location <0, 0, -10>
  look_at <0, 0, 0>
}

background { color rgb <0.2, 0.2, 0.3> }

sphere { 0, 1
  pigment { color rgb <0.8, 0.5, 0.2> }
}
```

The background color will be visible if a sky sphere is used and if some translucency remains after all sky sphere pigment layers are processed.

4.9.2 The Sky Sphere

The sky sphere can be used to easily create a cloud covered sky, a nightly star sky or whatever sky you have in mind.

In the following examples we'll start with a very simple sky sphere that will get more and more complex as we add new features to it.

4.9.2.1 Creating a Sky with a Color Gradient

Beside the single color sky sphere that is covered with the background feature the simplest sky sphere is a color gradient.

You may have noticed that the color of the sky varies with the angle to the earth's surface normal. If you look straight up the sky normally has a much deeper blue than it has at the horizon.

We want to model this effect using the sky sphere as shown in the scene below (SKYSPH1.POV).

```
#include "colors.inc"

camera {
  location <0, 1, -4>
  look_at <0, 2, 0>
  angle 82
}

light_source { <10, 10, -10> White }

sphere { 2*y, 1
  pigment { color rgb <1, 1, 1> }
  finish { ambient 0.2 diffuse 0 reflection 0.6 }
}

sky_sphere {
  pigment {
    gradient y
    color_map {
      [0 color Red]
      [1 color Blue]
    }
    scale 2
    translate -1
  }
}
```

The interesting part is the sky sphere statement. It contains a pigment that describe the look of the sky sphere. We want to create a color gradient along the viewing angle measured against the earth's surface normal. Since the ray direction vector is used to calculate the pigment colors we have to use the *y*-gradient.

The scale and translate transformation are used to map the points derived from the direction vector to the right range. Without those transformations the pattern would be repeated twice on the sky sphere. The `scale` statement is used to avoid the repetition and the `translate -1` statement moves the color at index zero to the bottom of the sky sphere (that's the point of the sky sphere you'll see if you look straight down).

After this transformation the color entry at position 0 will be at the bottom of the sky sphere, i. e. below us, and the color at position 1 will be at the top, i. e. above us.

The colors for all other positions are interpolated between those two colors as you can see in the resulting image.

If you want to start one of the colors at a specific angle you'll first have to convert the angle to a color map index. This is done by using the formula

$$color\_map\_index = \frac{1 - \cos(angle)}{2} \tag{4.1}$$

where the angle is measured against the negated earth's surface normal. This is the surface normal pointing towards the center of the earth. An angle of 0 degrees describes the point below us while an angle of 180 degrees represents the zenith.

In POV-Ray you first have to convert the degree value to radian values as it is shown in the following example.

```
sky_sphere {
  pigment {
    gradient y
    color_map {
      [(1-cos(radians( 30)))/2 color Red]
      [(1-cos(radians(120)))/2 color Blue]
    }
    scale 2
    translate -1
  }
}
```

This scene uses a color gradient that starts with a red color at 30 degrees and blends into the blue color at 120 degrees. Below 30 degrees everything is red while above 120 degrees all is blue.

4.9.2.2 Adding the Sun

In the following example we will create a sky with a red sun surrounded by a red color halo that blends into the dark blue night sky. We'll do this using only the sky sphere feature.

The sky sphere we use is shown below. A ground plane is also added for greater realism (SKYSPH2.POV).

```
sky_sphere {
  pigment {
    gradient y
    color_map {
      [0.000 0.002 color rgb <1.0, 0.2, 0.0>
                   color rgb <1.0, 0.2, 0.0>]
      [0.002 0.200 color rgb <0.8, 0.1, 0.0>
                   color rgb <0.2, 0.2, 0.3>]
    }
    scale 2
    translate -1
  }
  rotate -135*x
}
```

```
plane { y, 0
  pigment { color Green }
  finish { ambient .3 diffuse .7 }
}
```

The gradient pattern and the transformation inside the pigment are the same as in the example in the previous section.

The color map consists of three colors. A bright, slightly yellowish red that is used for the sun, a darker red for the halo and a dark blue for the night sky. The sun's color covers only a very small portion of the sky sphere because we don't want the sun to become too big. The color is used at the color map values 0.000 and 0.002 to get a sharp contrast at value 0.002 (we don't want the sun to blend into the sky). The darker red color used for the halo blends into the dark blue sky color from value 0.002 to 0.200. All values above 0.200 will reveal the dark blue sky.

The `rotate -135*x` statement is used to rotate the sun and the complete sky sphere to its final position. Without this rotation the sun would be at 0 degrees, i.e. right below us.

Looking at the resulting image you'll see what impressive effects you can achieve with the sky sphere.

4.9.2.3 Adding Some Clouds

To further improve our image we want to add some clouds by adding a second pigment. This new pigment uses the bozo pattern to create some nice clouds. Since it lays on top of the other pigment it needs some translucent colors in the color map (look at entries 0.5 to 1.0).

```
sky_sphere {
  pigment {
    gradient y
    color_map {
      [0.000 0.002 color rgb <1.0, 0.2, 0.0>
                   color rgb <1.0, 0.2, 0.0>]
      [0.002 0.200 color rgb <0.8, 0.1, 0.0>
                   color rgb <0.2, 0.2, 0.3>]
    }
    scale 2
    translate -1
  }
  pigment {
    bozo
    turbulence 0.65
    octaves 6
```

```
      omega 0.7
      lambda 2
      color_map {
          [0.0 0.1 color rgb <0.85, 0.85, 0.85>
                   color rgb <0.75, 0.75, 0.75>]
          [0.1 0.5 color rgb <0.75, 0.75, 0.75>
                   color rgbt <1, 1, 1, 1>]
          [0.5 1.0 color rgbt <1, 1, 1, 1>
                   color rgbt <1, 1, 1, 1>]
      }
      scale <0.2, 0.5, 0.2>
    }
    rotate -135*x
  }
```

The sky sphere has one drawback as you might notice when looking at the final image (SKYSPH3.POV). The sun doesn't emit any light and the clouds will not cast any shadows. If you want to have clouds that cast shadows you'll have to use a real, large sphere with an appropriate texture and a light source somewhere outside the sphere.

4.9.3 The Fog

You can use the fog feature to add fog of two different types to your scene: constant fog and ground fog. The constant fog has a constant density everywhere while the ground fog's density decreases as you move upwards.

The usage of both fog types will be described in the next sections in detail.

4.9.3.1 A Constant Fog

The simplest fog type is the constant fog that has a constant density in all locations. It is specified by a `distance` keyword which actually describes the fog's density and a fog `color`.

The distance value determines the distance at which 36.8% of the background are still visible (for a more detailed explanation of how the fog is calculated read the reference section 7.7.3 on page 351).

The fog color can be used to create anything from a pure white to a red, bloodish fog. You can also use a black fog to simulate the effect of a limited range of vision.

The following example will show you how to add fog to a simple scene (FOG1.POV).

```
#include "colors.inc"

camera {
```

```
  location  <0, 20, -100>
}

background { colour SkyBlue }

plane { y, -10
  pigment {
    checker colour Yellow colour Green
    scale 20
  }
}

sphere { <0, 25, 0>, 40
  pigment { Red }
  finish { phong 1.0 phong_size 20 }
}

sphere { <-100, 150, 200>,  20
  pigment { Green }
  finish { phong 1.0 phong_size 20 }
}

sphere { <100, 25, 100>, 30
  pigment { Blue }
  finish { phong 1.0 phong_size 20 }
}

light_source { <100, 120, 40> colour White}

fog {
  distance 150
  colour rgb<0.3, 0.5, 0.2>
}
```

According to their distance the spheres in this scene more or less vanish in the greenish fog we used, as does the checkerboard plane.

4.9.3.2 Setting a Minimum Translucency

If you want to make sure that the background does not completely vanish in the fog you can set the transmittance channel of the fog's color to the amount of background you always want to be visible.

Using as transmittance value of 0.2 as in

```
fog {
  distance 150
  colour rgbt<0.3, 0.5, 0.2, 0.2>
```

```
}
```

the fog's translucency never drops below 20% as you can see in the resulting image (FOG2.POV).

4.9.3.3 Creating a Filtering Fog

The greenish fog we have used so far doesn't filter the light passing through it. All it does is to diminish the light's intensity. We can change this by using a non-zero filter channel in the fog's color (FOG3.POV).

```
fog {
  distance 150
  colour rgbf<0.3, 0.5, 0.2, 1.0>
}
```

The filter value determines the amount of light that is filtered by the fog. In our example 100% of the light passing through the fog will be filtered by the fog. If we had used a value of 0.7 only 70% of the light would have been filtered. The remaining 30% would have passed unfiltered.

You'll notice that the intensity of the objects in the fog is not only diminished due to the fog's color but that the colors are actually influenced by the fog. The red and especially the blue sphere got a green hue.

4.9.3.4 Adding Some Turbulence to the Fog

In order to make our somewhat boring fog a little bit more interesting we can add some turbulence, making it look like it had a non-constant density (FOG4.POV).

```
fog {
  distance 150
  colour rgbf<0.3, 0.5, 0.2, 1.0>
  turbulence 0.2
  turb_depth 0.3
}
```

The `tubulence` keyword is used to specify the amount of turbulence used while the `turb_depth` value is used to move the point at which the turbulence value is calculated along the viewing ray. Values near zero move the point to the viewer while values near one move it to the intersection point (the default value is 0.5). This parameter can be used to avoid noise that may appear in the fog due to the turbulence (this normally happens at very far away intersecion points, especially if no intersection occurs, i. e.

the background is hit). If this happens just lower the turb_depth value until the noise vanishes.

You should keep in mind that the actual density of the fog does not change. Only the distance-based attenuation value of the fog is modified by the turbulence value at a point along the viewing ray.

4.9.3.5 Using Ground Fog

The much more interesting and flexible fog type is the ground fog, which is selected with the fog_type statement. It's appearance is described with the fog_offset and fog_alt keywords. The fog_offset specifies the height, i. e. y value, below which the fog has a constant density of one. The fog_alt keyword determines how fast the density of the fog will approach zero as one moves along the y axis. At a height of $fog\_offset + fog\_alt$ the fog will have a density of 25%.

The following example (FOG5.POV) uses a ground fog which has a constant density below $y = 25$ (the center of the red sphere) and quickly falls off for increasing altitudes.

```
fog {
  distance 150
  colour rgbf<0.3, 0.5, 0.2, 1.0>
  fog_type 2
  fog_offset 25
  fog_alt 1
}
```

4.9.3.6 Using Multiple Layers of Fog

It is possible to use several layers of fog by using more than one fog statement in your scene file. This is quite useful if you want to get nice effects using turbulent ground fogs. You could add up several, differently colored fogs to create an eerie scene for example.

Just try the following example (FOG6.POV).

```
fog {
  distance 150
  colour rgb<0.3, 0.5, 0.2>
  fog_type 2
  fog_offset 25
  fog_alt 1
  turbulence 0.1
  turb_depth 0.2
}
```

```
fog {
  distance 150
  colour rgb<0.5, 0.1, 0.1>
  fog_type 2
  fog_offset 15
  fog_alt 4
  turbulence 0.2
  turb_depth 0.2
}

fog {
  distance 150
  colour rgb<0.1, 0.1, 0.6>
  fog_type 2
  fog_offset 10
  fog_alt 2
}
```

You can combinate constant density fogs, ground fogs, filtering fogs, non-filtering fogs, fogs with a translucency threshold, etc.

4.9.3.7 Fog and Hollow Objects

Whenever you use the fog feature and the camera is inside a non-hollow object you won't get any fog effects. For a detailed explanation why this happens see 7.5.1 on page 229.

In order to avoid this problem you have to make all those objects hollow by either making sure the camera is outside these objects (using the `inverse` keyword) or by adding the `hollow` to them (which is much easier).

4.9.4 The Atmosphere

The atmosphere feature can be used to model the interaction of light with particles in the air. Beams of light will become visible and objects will cast shadows *into* the fog or dust that's filling the air.

The atmosphere model used in POV-Ray assumes a constant particle density everywhere except solid objects. If you want to create cloud like fogs or smoke you'll have to use the halo texturing feature described in section 4.8.5 on page 104.

4.9.4.1 Starting With an Empty Room

We want to create a simple scene to explain how the atmosphere feature works and how you'll get good results.

Imagine a simple room with a window. Light falls through the window and is scattered by the dust particles in the air. You'll see beams of light coming from the window and shining on the floor.

We want to model this scene step by step. The following examples start with the room, the window and a spotlight somewhere outside the room. Currently there's no atmosphere to be able to verify if the lighting is correct (ATMOS1.POV).

```
camera {
  location <-10, 8, -19>
  look_at <0, 5, 0>
  angle 82
}

background { color rgb <0.2, 0.4, 0.8> }

light_source { <0, 19, 0> color rgb 0.5 atmosphere off }

light_source {
  <40, 25, 0> color rgb <1, 1, 1>
  spotlight
  point_at <0, 5, 0>
  radius 20
  falloff 20
  atmospheric_attenuation on
}

union {
  difference {
    box { <-21, -1, -21>, <21, 21, 21> }
    box { <-20, 0, -20>, <20, 20, 20> }
    box { <19.9, 5, -3>, <21.1, 15, 3> }
  }
  box { <20, 5, -0.25>, <21, 15, 0.25> }
  box { <20, 9.775, -3>, <21, 10.25, 3> }
  pigment { color red 1 green 1 blue 1 }
  finish { ambient 0.2 diffuse 0.5 }
}
```

The point light source is used to illuminate the room from inside without any interaction with the atmosphere. This is done by adding `atmosphere off` . We don't have to care about this light when we add the atmosphere later.

The spotlight is used with the `atmospheric_attenuation` keyword. This means that light coming from the spotlight will be diminished by the atmosphere.

The union object is used to model the room and the window. Since we use the difference between two boxes to model the room (the first two boxes in the difference statement) there is no need for setting the union hollow. If we are inside this room we actually will be outside the object (see also 4.9.4.5.5 on page 137).

4.9.4.2 Adding Dust to the Room

The next step is to add an atmosphere to the room. This is done by the following few lines (ATMOS2.POV).

```
atmosphere {
  type 1
  samples 10
  distance 40
  scattering 0.2
}
```

The `type` keyword selects the type of atmospheric scattering we want to use. In this case we use the isotropic scattering that equally scatters light in all directions (see 7.7.1 on page 347 for more details about the different scattering types).

The `samples` keyword determines the number of samples used in accumulating the atmospheric effect. For every ray samples are taken along the ray to determine wether a sample is lit by a light source or not. If the sample is lit the amount of light scattered into the direction of the viewer is determined and added to the total intensity.

You can always start with an arbitrary number of samples. If the results do not fit your ideas you can increase the sampling rate to get better results. The problem of choosing a good sampling rate is the trade-off between a satisfying image and a fast rendering. A high sampling rate will almost always work but the rendering will also take a very long time. That's something to experiment with.

The `distance` keyword specifies the density of the atmosphere. It works in the same way as the distance parameter of the fog feature.

Last but not least will the `scattering` value determine the amount of light that is scattered by the particles (the remaining light is absorbed). As you'll later see this parameter is very useful in adjusting the overall brightness of the atmosphere.

Looking at the image created from the above scene you'll notice some very ugly anti-aliasing artefacts known as mach-bands. They are the result of a low sampling rate.

How this effect can be avoid is described in the following section.

4.9.4.3 Choosing a Good Sampling Rate

As you've seen a too low sampling rate can cause some ugly results. There are some ways of reducing or even avoiding those problems.

The brute force approach is to increase the sampling rate until the artefacts vanish and you get a satisfying image. Though this will always work it is a bad idea because it is very time consuming. A better approach is to use jittering and anti-aliasing first. If both features don't help you'll have to increase the sampling rate.

Jittering moves each sample point by a small, random amount along the sampling direction. This helps to reduce regular features resulting from aliasing. There is (hardly) nothing more annyoing to the human visual system than the regular features resulting from a low sampling rate. It's much better to add some extra noise to the image by jittering the sample positions. The human eye is much more forgiving to that.

Use the `jitter` keyword followed by the amount of jittering you want to use. Good jittering values are up to 0.5, higher values result in too much noise.

You should be aware that jittering can not fix the artefacts introduced by a too low sampling rate. It can only make them less visible.

An additional and better way of reducing aliasing artefacts is to use (adaptive) supersampling. This method casts additional samples where it is likely that they are needed. If the intensity between two adjactent samples differs too much additional samples are taken inbetween. This step is done recursively until a specified recursion level is reached or the sample get close to each other.

The `aa_level` and `aa_threshold` keywords are used to control the supersampling. The `aa_level` keyword determines the maximum recursion level while the `aa_threshold` keyword specifies the maximum allowed difference between two sample before the super-sampling is done.

After all this theory we get back to our sample scene and add the appropriate keywords to use both jittering and supersamling (ATMOS3.POV).

```
  atmosphere {
    type 1
    samples 50
    distance 40
    scattering 0.2
    aa_level 4
    aa_threshold 0.1
    jitter 0.2
}
```

A very low threshold value was choosen to super-sample even between adjactent points with a very similar intensity. The maximum recursion level of 4 will lead to a maximum of fifteen super-samples.

If you are looking at the results that you get after adding jittering and super-sampling you won't be satisfied. The only way of reducing the still visible artefacts is to increase the sampling rate by choosing a higher number of samples.

Doing this you'll get a good result showing (almost) no artefacts. Btw. the amount of dust floating around in this room may be a little bit exaggerated but it's just an example. And examples tend to be exaggerated.

4.9.4.4 Using a Coloured Atmosphere

You can assign a color to the atmosphere that gives you more control over the atmosphere's appearance. First of all the color is used to filter all light passing through it, wether it comes from light sources, relfected and refracted rays, or the background. The amount by which the passing light is filtered by the atmosphere's color is determined by the color's filter value. A value of 0 means that the light is not influenced by the atmosphere's color while a value of 1 means that all light will be filtered by the color.

If you want to create a reddish atmosphere for example, you can add the following line to the atmosphere statement used in the above example.

```
color rgbf <1, 0, 0, 0.25>
```

Just using `rgb` $\langle 1,0,0\rangle$ does not work because the color's filter value will be zero and thus no light will be filtered by the color, i. e. no light will be multiplied with the color's RGB components.

The filter value of 0.25 means that 25% of the light passing through the atmosphere will be filtered by the red color and 75% will pass unfiltered.

The transmittance channel of the atmosphere's color is used to specify a minimum translucency. By default the transmittance channel is zero and thus there is no such minimum translucency. Using a positive value lets you determine the amount of background light that will always pass through the atmosphere, regardless of its thickness set by the `distance` keyword.

If you use e.g. a color of `rgbt` $\langle 0,0,0,0.3\rangle$ with our room example you can make the blue background become visible. Until now it was hidden by the atmosphere.

4.9.4.5 Atmosphere Tips

It is very difficult to get satisfying results when using the atmosphere feature. Some of the more common problems will be discussed in the next sections to help you to solve them (see also the FAQ section about the atmosphere in G.3 on page 396).

4.9.4.5.1 Choosing the Distance and Scattering Parameters

The first difficult step is to choose a good distance and scattering value. You need to be able to control the visibility of the objects in the scene and the atmospheric effects.

The best approach is to choose the distance value first. This value determines the visibility of the objects in the scene regardless of atmospheric light scattering. It works in the same way as the distance value of the fog feature.

Since fog is very similar to the unlit atmosphere you can use a fog instead of an atmosphere to quickly choose a working distance value. If you do this with room scene we used earlier you would use the following fog statement instead of the atmosphere (ATMOS4.POV).

```
fog {
  distance 40
  color rgb <0, 0, 0>
}
```

The black color is used to simulate the attenuation you'll get in those parts of the atmosphere scene lying in shadow.

If you want to use a colored atmosphere you'll have to use the same color for the fog as you want to use for the atmosphere, including the filter and transmittance channel values (see 4.9.4.4 on the page before and 7.7.1 on page 347 for an explanation of the atmosphere's color).

If you (roughly) want to simulate the appearance of those parts lit by a light source you can use the color of the atmosphere inside the fog statement instead.

After you are satisfied with the distance value you'll have to choose a scattering value. This value lets you fit the atmosphere's intensity to your needs. Starting with a value of one you have to increase the value if the atmosphere effects are hardly visible. If you don't see anything in the lit parts of the atmosphere you'll have to decrease the value.

You should be aware that you may have to use very small or very large values to get the desired results.

4.9.4.5.2 Atmosphere and Light Sources

The best results are generated with spotlights and cylindrical light sources. They create nice beams of light and are fast to render because the atmospheric sampling takes only place inside the light cone of the spotlight or light cylinder of the cylindrical light.

If you want to add a light source that does not interact with the atmosphere you can use the `atmosphere` keyword inside the light source statement (see 7.5.6.8 on page 272). Just add `atmosphere off`.

By default the light coming from any light source will not be diminished by the atmosphere. Thus the highlights in your scene will normally be too bright. This can be changed with `atmospheric_attenuation on`.

4.9.4.5.3 Atmosphere Scattering Types

The different scattering types listed in 7.7.1 on page 347 can be used to model different types of particles. This is something for you to experiment with.

The Rayleigh scattering is used for small particles like dust and smoke while the Mie scattering is used for fog.

If you ever saw the lighthouse scene in the movie *Casper* you'll know what effect the scattering type has. In this scene the beam of light coming from the lighthouse becomes visible while it points nearly towards the viewer. As it starts to point away from the viewer it vanishes. This behaviour is typical for miniscule water droplets as modeled by the Mie scattering.

4.9.4.5.4 Increasing the Image Resolution

You have to be aware that you may have to increase the atmosphere sampling rate if you increase the resolution of the image. Otherwise some aliasing artefacts that were no visible at the lower resolution may become visible.

4.9.4.5.5 Using Hollow Objects and Atmosphere

Whenever you use the atmosphere feature you have to make sure that all objects that ought to be filled with atmosphere are set to hollow using the `hollow` keyword.

Even though this is not obvious this holds for infinite and patch objects like quadrics, quartics, triangles, polygons, etc. Whenever you add one of those objects you should add the hollow keyword as long as you are not absolutely sure you don't need it. You also have to make sure that all objects the camera is inside are set to be hollow.

Whenever you get unexpected results you should check for solid objects and set them to be hollow.

4.9.5 The Rainbow

The rainbow feature can be used to create rainbows and maybe other more strange effects. The rainbow is a fog like effect that is restricted to a cone-like volume.

4.9.5.1 Starting With a Simple Rainbow

The rainbow is specified with a lot of parameters: the angle under which it is visible, the width of the color band, the direction of the incoming light, the fog-like distance based particle density and last not least the color map to be used.

The size and shape of the rainbow are determined by the `angle` and `width` keywords. The `direction` keyword is used to set the direction of the incoming light, thus setting the rainbow's position. The rainbow is visible when the angle between the direction vector and the incident light direction is larger than $angle - width/2$ and smaller than $angle + width/2$.

The incoming light is the virtual light source that is responsible for the rainbow. There needn't be a real light source to create the rainbow effect.

The rainbow is a fog-like effect, i.e. the rainbow's color is mixed with the background color based on the distance to the intersection point. If you choose small distance values the rainbow will be visible on objects, not just in the background. You can avoid this by using a very large distance value.

The color map is the crucial part of the rainbow since it contains all the colors that normally can be seen in a rainbow. The color of the innermost color band is taken from the color map entry 0 while the outermost band is take from entry 1. You should note that due to the limited color range any monitor can display it is impossible to create a real rainbow. There are just some colors that you cannot display.

The filter channel of the rainbow's color map is used in the same way as with fogs. It determines how much of the light passing through the rainbow is filtered by the color.

The following example shows a simple scene with a ground plane, three spheres and a somewhat exaggerated rainbow (RAINBOW1.POV).

```
#include "colors.inc"

camera {
  location <0, 20, -100>
  look_at <0, 25, 0>
  angle 82
}

background { color SkyBlue }

plane { y, -10 pigment { colour Green } }

light_source {<100, 120, 40> colour White}

// declare rainbow's colours

#declare r_violet1 = colour rgbf<1.0, 0.5, 1.0, 1.0>
#declare r_violet2 = colour rgbf<1.0, 0.5, 1.0, 0.8>
#declare r_indigo  = colour rgbf<0.5, 0.5, 1.0, 0.8>
#declare r_blue    = colour rgbf<0.2, 0.2, 1.0, 0.8>
#declare r_cyan    = colour rgbf<0.2, 1.0, 1.0, 0.8>
#declare r_green   = colour rgbf<0.2, 1.0, 0.2, 0.8>
#declare r_yellow  = colour rgbf<1.0, 1.0, 0.2, 0.8>
#declare r_orange  = colour rgbf<1.0, 0.5, 0.2, 0.8>
#declare r_red1    = colour rgbf<1.0, 0.2, 0.2, 0.8>
#declare r_red2    = colour rgbf<1.0, 0.2, 0.2, 1.0>

// create the rainbow

rainbow {
```

```
  angle 42.5
  width 5
  distance 1.0e7
  direction <-0.2, -0.2, 1>
  jitter 0.01
  colour_map {
    [0.000  colour r_violet1]
    [0.100  colour r_violet2]
    [0.214  colour r_indigo]
    [0.328  colour r_blue]
    [0.442  colour r_cyan]
    [0.556  colour r_green]
    [0.670  colour r_yellow]
    [0.784  colour r_orange]
    [0.900  colour r_red1]
  }
}
```

Some irregularity is added to the color bands using the `jitter` keyword.

The rainbow in our sample is much too bright. You'll never see a rainbow like this in reality. You can decrease the rainbow's colors by decreasing the RGB values in the color map.

4.9.5.2 Increasing the Rainbow's Translucency

The result we have so far looks much too bright. Just reducing the rainbow's color helps but it's much better to increase the translucency of the rainbow because it is more realistic if the background is visible through the rainbow.

We can use the transmittance channel of the colors in the color map to specify a minimum translucency, just like we did with the fog. To get realistic results we have to use very large transmittance values as you can see in the following example (RAINBOW2.POV).

```
rainbow {
  angle 42.5
  width 5
  distance 1.0e7
  direction <-0.2, -0.2, 1>
  jitter 0.01
  colour_map {
    [0.000  colour r_violet1 transmit 0.98]
    [0.100  colour r_violet2 transmit 0.96]
    [0.214  colour r_indigo  transmit 0.94]
    [0.328  colour r_blue    transmit 0.92]
    [0.442  colour r_cyan    transmit 0.90]
```

```
      [0.556  colour r_green   transmit 0.92]
      [0.670  colour r_yellow  transmit 0.94]
      [0.784  colour r_orange  transmit 0.96]
      [0.900  colour r_red1    transmit 0.98]
    }
  }
```

The transmittance values increase at the outer bands of the rainbow to make it softly blend into the background.

The resulting image looks much more realistic than our first rainbow.

4.9.5.3 Using a Rainbow Arc

Currently our rainbow has a circular shape, even though most of it is hidden below the ground plane. You can easily create a rainbow arc by using the `arc_angle` keyword with an angle below 360 degrees.

If you use `arc_angle 120` for example you'll get a rainbow arc that abruptly vanishes at the arc's ends. This does not look good. To avoid this the `falloff_angle` keyword can be used to specify a region where the arc smoothly blends into the background.

As explained in the rainbow's reference section (see 7.7.5 on page 353) the arc extends from $-arc\_angle/2$ to $arc\_angle/2$ while the blending takes place from $-arc\_angle/2$ to $-falloff\_angle/2$ and $falloff\_angle/2$ to $arc\_angle/2$. This is the reason why the `falloff_angle` has to be smaller or equal to the `arc_angle`.

In the following examples we use an 120 degrees arc with a 45 degree falloff region on both sides of the arc (RAINBOW3.POV).

```
  rainbow {
    angle 42.5
    width 5
    arc_angle 120
    falloff_angle 30
    distance 1.0e7
    direction <-0.2, -0.2, 1>
    jitter 0.01
    colour_map {
      [0.000  colour r_violet1 transmit 0.98]
      [0.100  colour r_violet2 transmit 0.96]
      [0.214  colour r_indigo  transmit 0.94]
      [0.328  colour r_blue    transmit 0.92]
      [0.442  colour r_cyan    transmit 0.90]
      [0.556  colour r_green   transmit 0.92]
      [0.670  colour r_yellow  transmit 0.94]
      [0.784  colour r_orange  transmit 0.96]
```

```
      [0.900  colour r_red1    transmit 0.98]
    }
  }
```

The arc angles are measured against the rainbows up direction which can be specified using the `up` keyword. By default the up direction is the *y*-axis.

We finally have a realistic looking rainbow arc.

Part III

Reference Guide

Chapter 5

POV-Ray Reference

The reference section describes all command line options and INI file switches, the scene description language and all other features that are part of POV-Ray. It is supposed to be used as a reference for looking up things. It does not contain detailed explanations on how scenes are written or how POV-Ray is used. It just explains all features, their syntax, applications, limits, drawbacks, etc.

Chapter 6

POV-Ray Options

POV-Ray was originally created as a command-line program for operating systems without graphical interfaces, dialog boxes and pull-down menus. Most versions of POV-Ray still use command-line switches to tell it what to do. This documentation assumes you are using the command-line version. If you are using Macintosh, MS-Windows or other GUI versions, there will be dialog boxes or menus which do the same thing. There is system-specific documentation for each system describing the specific commands.

6.1 Setting POV-Ray Options

There are two distinct ways of setting POV-Ray options: command line switches and INI file keywords. Both are explained in detail in the following sections.

6.1.1 Command Line Switches

Command line switches consist of a **+** (plus) or **–** (minus) sign, followed by one or more alphabetic characters and possibly a numeric value. Here is a typical command line with switches.

```
POVRAY +ISIMPLE.POV +V +W80 +H60
```

POVRAY is the name of the program and it is followed by several switches. Each switch begins with a plus or minus sign. The **+I** switch with the filename tells POV-Ray what scene file it should use as input and **+V** tells the program to output its status to the text screen as it's working. The **+W** and **+H** switches set the width and height of the image in pixels. This image will be 80 pixels wide by 60 pixels high.

In switches which toggle a feature, the plus turns it on and minus turns it off. For example **+P** turns on the *pause for keypress when finished* option while **–P** turns it off. Other switches are used to specify values and do not toggle a feature. Either plus or minus may be used in that instance. For example **+W**320 sets the width to 320 pixels. You could also use **–W**320 and get the same results.

Switches may be specified in upper or lower case. They are read left to right but in general may be specified in any order. If you specify a switch more than once, the previous value is generally overwritten with the last specification. The only exception is the **+L** switch for setting library paths. Up to ten unique paths may be specified.

Almost all **+/–** switches have an equivalent option which can be used in an INI file which is described in the next section. A detailed description of each switch is given in the option reference section.

6.1.2 Using INI Files

Because it is difficult to set more than a few options on a command line, you have the ability to put multiple options in one or more text files. These *initialization files* or *INI files* have .INI as their default extension. Previous versions of POV-Ray called them *default files* or *DEF files*. You may still use existing DEF files with this version of POV-Ray.

The majority of options you use will be stored in INI files. The command line switches are recommended for options which you will turn off or on frequently as you perform test renderings of a scene you are developing. The file POVRAY.INI is automatically read if present. You may specify additional INI files on the command-line by simply typing the file name on the command line. For example:

```
POVRAY MYOPTS.INI
```

If no extension is given, then .INI is assumed. POV-Ray knows this is not a switch because it is not preceded by a plus or minus. In fact a common error among new users is that they forget to put the **+I** switch before the input file name. Without the switch, POV-Ray thinks that the scene file SIMPLE.POV is an INI file. Don't forget! If no plus or minus precedes a command line switch, it is assumed to be an INI file name.

You may have multiple INI files on the command line along with switches. For example:

```
POVRAY MYOPTS +V OTHER
```

This reads options from MYOPTS.INI, then sets the **+V** switch, then reads options from OTHER.INI.

An INI file is a plain ASCII text file with options of the form ...

```
Option_Keyword=VALUE ; Text after semicolon is a comment
```

For example the INI equivalent of the switch **+I**SIMPLE.POV is ...

```
Input_File_Name=simple.pov
```

Options are read top to bottom in the file but in general may be specified in any order. If you specify an option more than once, the previous values are generally overwritten with the last specification. The only exception is the Library_Path=PATH options. Up to ten unique paths may be specified.

Almost all INI-style options have equivalent **+/–** switches. The option reference section gives a detailed description of all POV-Ray options. It includes both the INI-style settings and the **+/–** switches.

The INI keywords are not case sensitive. Only one INI option is permitted per line of text. You may also include switches in your INI file if they are easier for you. You may have multiple switches per line but you should not mix switches and INI options on the same line. You may nest INI files by simply putting the file name on a line by itself with no equals sign after it. Nesting may occur up to ten levels deep.

For example:

```
; This is a sample INI file. This entire line is a comment.
; Blank lines are permitted.

Input_File_Name=simple.pov ; This sets the input file name

+W80 +H60 ; Traditional +/- switches are permitted too

MOREOPT   ; Read MOREOPT.INI and continue with next line

+V        ; Another switch

; That's all folks!
```

INI files may have labeled sections so that more than one set of options may be stored in a single file. Each section begins with a label in [] brackets. For example:

```
; RES.INI
; This sample INI file is used to set resolution.

+W120 +H100  ; This section has no label.
             ; Select it with "RES"

[Low]
```

```
+W80 +H60     ; This section has a label.
              ; Select it with "RES[Low]"

[Med]
+W320 +H200   ; This section has a label.
              ; Select it with "RES[Med]"

[High]
+W640 +H480   ; Labels are not case sensitive.
              ; "RES[high]" works

[Really High]
+W800 +H600   ; Labels may contain blanks
```

When you specify the INI file you should follow it with the section label in brackets. For example ...

POVRAY RES[Med] **+I**MYFILE.POV

POV-Ray reads RES.INI and skips all options until it finds the label *Med*. It processes options after that label until it finds another label and then it skips. If no label is specified on the command line then only the unlabeled area at the top of the file is read. If a label is specified, the unlabeled area is ignored.

6.1.3 Using the POVINI Environment Variable

The environment variable POVINI is used to specify the location and name of a default INI file that is read every time POV-Ray is executed. If POVINI is not specified a default INI file may be read depending on the platform used. If the specified file does not exist a warning message is printed.

To set the environment variable under MS-Dos you might put the following line in your AUTOEXEC.BAT file ...

set POVINI=C:\POVRAY3\DEFAULT.INI

On most operating systems the sequence of reading options is as follows:

1. Read options from default INI file specified by the POVINI environment variable or platform specific INI file.
2. Read switches from command line (this includes reading any specified INI/DEF files).

The POVRAYOPT environment variable supported by previous POV-Ray versions is no longer available.

6.2 Options Reference

As explained in the previous section, options may be specified by switches or INI-style options. Almost all INI-style options have equivalent **+/–** switches and most switches have equivalent INI-style option. The following sections give a detailed description of each POV-Ray option. It includes both the INI-style settings and the **+/–** switches.

The notation and terminology used is described in the tables below.

Keyword=bool	turn Keyword on if *bool* equals *true*, *yes*, *on* or *1* and turn it off if it is any other value.
Keyword=true	do this option if *true*, *yes*, *on* or *1* is specified.
Keyword=false	do this option if *false*, *no*, *off* or *0* is specified.
Keyword=file	any valid file name. Note: some options prohibit the use of any of the above *true* or *false* values as a file name. They are noted in later sections.

n	any integer such as in +W320
n.n	any float such as in Clock=3.45
0.n	any float < 1.0 even if it has no leading 0
s	any string of text
x or y	any single character
path	any directory name, drive optional, no final path separator ("\" or "/", depending on the operating system)

Unless otherwise specifically noted, you may assume that either a plus or minus sign before a switch will produce the same results.

6.2.1 Animation Options

POV-Ray 3.0 greatly improved its animation capability with the addition of an internal animation loop, automatic output file name numbering and the ability to shell out to the operating system to external utilities which can assemble individual frames into an animation. The internal animation loop is simple yet flexible. You may still use external programs or batch files to create animations without the internal loop as you may have done in POV-Ray 2.

6.2.1.1 External Animation Loop

Clock=n.n	Sets *clock* float identifier to n.n
+Kn.n	Same as Clock=n.n

The Clock=n.n option or the **+K**n.n switch may be used to pass a single float value to the program for basic animation. The value is stored in the float identifier *clock*. If an object had a rotate $\langle 0, clock, 0 \rangle$ attached then you could rotate the object by different amounts over different frames by setting **+K**10.0, **+K**20.0 ... etc. on successive renderings. It is up to the user to repeatedly invoke POV-Ray with a different Clock value and a different Output_File_Name for each frame.

6.2.1.2 Internal Animation Loop

Initial_Frame=n	Sets initial frame number to n
Final_Frame=n	Sets final frame number
Initial_Clock=n.n	Sets initial clock value
Final_Clock=n.n	Sets final clock value
+KFIn	Same as Initial_Frame=n
+KFFn	Same as Final_Frame=n
+KIn.n	Same as Initial_Clock=n.n
+KFn.n	Same as Final_Clock=n.n

The internal animation loop new to POV-Ray 3.0 relieves the user of the task of generating complicated sets of batch files to invoke POV-Ray multiple times with different settings. While the multitude of options may look intimidating, the clever set of default values means that you will probably only need to specify the Final_Frame=n or the **+KFF**n option to specify the number of frames. All other values may remain at their defaults.

Any Final_Frame setting other than -1 will trigger POV-Ray's internal animation loop. For example Final_Frame=10 or **+KFF**10 causes POV-Ray to render your scene 10 times. If you specified Output_File_Name=FILE.TGA then each frame would be output as FILE01.TGA, FILE02.TGA, FILE03.TGA etc. The number of zero-padded digits in the file name depends upon the final frame number. For example **+KFF**100 would generate FILE001.TGA through FILE100.TGA. The frame number may encroach upon the file name. On MS-Dos with an eight character limit, MYSCENE.POV would render to MYSCE001.TGA through MYSCE100.TGA.

The default Initial_Frame=1 will probably never have to be changed. You would only change it if you were assembling a long animation sequence in pieces. One scene might run from frame 1 to 50 and the next from 51 to 100. The Initial_Frame=n or **+KFI**n option is for this purpose.

Note that if you wish to render a subset of frames such as 30 through 40 out of a 1 to 100 animation, you should not change Frame_Initial or Frame_Final. Instead you should use the subset commands described in section 6.2.1.3 on the facing page.

Unlike some animation packages, the action in POV-Ray animated scenes does not depend upon the integer frame numbers. Rather you should design your scenes based upon the float identifier `clock`. By default, the clock value is 0.0 for the initial frame and 1.0 for the final frame. All other frames are interpolated between these values. For example if your object is supposed to rotate one full turn over the course of the animation, you could specify `rotate 360*clock*y`. Then as clock runs from 0.0 to 1.0, the object rotates about the *y*-axis from 0 to 360 degrees.

The major advantage of this system is that you can render a 10 frame animation or a 100 frame or 500 frame or 329 frame animation yet you still get one full 360 degree rotation. Test renders of a few frames work exactly like final renders of many frames.

In effect you define the motion over a continuous float valued parameter (the clock) and you take discrete samples at some fixed intervals (the frames). If you take a movie or video tape of a real scene it works the same way. An object's actual motion depends only on time. It does not depend on the frame rate of your camera.

Many users have already created scenes for POV-Ray 2 that expect clock values over a range other than the default 0.0 to 1.0. For this reason we provide the Initial_Clock=n.n or **+KI**n.n and Final_Clock=n.n or **+KF**n.n options. For example to run the clock from 25.0 to 75.0 you would specify Initial_Clock=25.0 and Final_Clock=75.0. Then the clock would be set to 25.0 for the initial frame and 75.0 for the final frame. Inbetween frames would have clock values interpolated from 25.0 through 75.0 proportionally.

Users who are accustomed to using frame numbers rather than clock values could specify Initial_Clock=1.0 and Final_Clock=10.0 and Frame_Final=10 for a 10 frame animation.

For new scenes, we recommend you do not change the Initial_Clock or Final_Clock from their default 0.0 to 1.0 values. If you want the clock to vary over a different range than the default 0.0 to 1.0, we recommend you handle this inside your scene file as follows ...

```
#declare Start    = 25.0
#declare End      = 75.0
#declare My_Clock = Start+(End-Start)*clock
```

Then use My_Clock in the scene description. This keeps the critical values 25.0 and 75.0 in your `.POV` file.

Note that more details concerning the inner workings of the animation loop are in the section on shell-out operating system commands in section 6.2.4 on page 168.

6.2.1.3 Subsets of Animation Frames

Subset_Start_Frame=n	Set subset starting frame to n
Subset_Start_Frame=0.n	Set subset starting frame to n percent
Subset_End_Frame=n	Set subset ending frame to n
Subset_End_Frame=0.n	Set subset ending frame to n percent
+SFn or **+SF**0.n	Same as Subset_Start_Frame
+EFn or **+EF**0.n	Same as Subset_End_Frame

When creating a long animation, it may be handy to render only a portion of the animation to see what it looks like. Suppose you have 100 frames but only want to render frames 30 through 40. If you set Initial_Frame=30 and Final_Frame=40 then the clock would vary from 0.0 to 1.0 from frames 30 through 40 rather than 0.30 through 0.40 as it should. Therefore you should leave Initial_Frame=1 and Final_Frame=100 and use Subset_Start_Frame=30 and Subset_End_Frame=40 to selectively render part of the scene. POV-Ray will then properly compute the clock values.

Usually you will specify the subset using the actual integer frame numbers however an alternate form of the subset commands takes a float value in the range $0.0 \leq n.nnn \leq 1.0$ which is interpreted as a fraction of the whole animation. For example, Subset_Start_Frame=0.333 and Subset_End_Frame=0.667 would render the middle 1/3rd of a sequence regardless of the number of frames.

6.2.1.4 Cyclic Animation

Cyclic_Animation=bool	Turn cyclic animation on/off
+KC	Turn cyclic animation on
–KC	Turn cyclic animation off

Many computer animation sequences are designed to be run in a continuous loop. Suppose you have an object that rotates exactly 360 degrees over the course of your animation and you did `rotate 360*clock*y` to do so. Both the first and last frames would be identical. Upon playback there would be a brief one frame jerkiness. To eliminate this problem you need to adjust the clock so that the last frame does not match the first. For example a ten frame cyclic animation should not use clock 0.0 to 1.0. It should run from 0.0 to 0.9 in 0.1 increments. However if you change to 20 frames it should run from 0.0 to 0.95 in 0.05 increments. This complicates things because you would have to change the final clock value every time you changed Final_Frame. Setting Cyclic_Animation=on or using **+KC** will cause POV-Ray to automatically adjust the final clock value for cyclic animation regardless of how many total frames. The default value for this setting is off.

6.2.1.5 Field Rendering

Field_Render=bool	Turn field rendering on/off
Odd_Field=bool	Set odd field flag
+UF	Turn field rendering on
–UF	Turn field rendering off
+UO	Set odd field flag on
–UO	Set odd field flag off

Field rendering is sometimes used for animations when the animation is being output for television. TVs only display alternate scan lines on each vertical refresh. When each frame is being displayed the fields are interlaced to give the impression of a higher resolution image. The even scan lines make up the even field, and are drawn first (i. e. scan lines 0, 2, 4, etc.), followed by the odd field, made up of the odd numbered scan lines are drawn afterwards. If objects in an animation are moving quickly, their position can change noticably from one field to the next. As a result, it may be desirable in these cases to have POV-Ray render alternate fields at the actual field rate (which is twice the frame rate), rather than rendering full frames at the normal frame rate. This would save a great deal of time compared to rendering the entire animation at twice the frame rate, and then only using half of each frame.

By default, field rendering is not used. Setting Field_Render=on or using **+UF** will cause alternate frames in an animation to be only the even or odd fields of an animation. By default, the first frame is the even field, followed by the odd field. You can have POV-Ray render the odd field first by specifying Odd_Field=on, or by using the **+UO** switch.

6.2.2 Output Options

6.2.2.1 General Output Options

6.2.2.1.1 Height and Width of Output

Height=n	Set screen height to n
Width=n	Sets screen width to n pixels
+Hn	Same as Height=n (when n $>$ 8)
+Wn	Same as Width=n

These switches set the height and width of the image in pixels. This specifies the image size for file output. The preview display, if on, will generally attempt to pick a video mode to accommodate this size but the display settings do not in any way affect the resulting file output.

6.2.2.1.2 Partial Output Options

Start_Column=n	Set first column to n
Start_Column=0.n	Set first column to n percent of width
+SCn or **+SC**0.n	Same as Start_Column
Start_Row=n	Set first row to n pixels
Start_Row=0.n	Set first row to n percent of height
+SRn or **+S**n	Same as Start_Row=n
+SR0.n or **+S**0.n	Same as Start_Row=0.n

End_Column=n	Set last column to n pixels
End_Column=0.n	Set last column to n percent of width
+ECn or **+EC**0.n	Same as End_Column
End_Row=n	Set last row to n pixels
End_Row=0.n	Set last row to n percent of height
+ERn or **+E**n	Same as End_Row=n
+ER0.n or **+E**0.n	Same as End_Row=0.n

When doing test rendering it is often convenient to define a small, rectangular subsection of the whole screen so you can quickly check out one area of the image. The Start_Row, End_Row, Start_Column and End_Column options allow you to define the subset area to be rendered. The default values are the full size of the image from (1,1) which is the upper left to (w,h) on the lower right where w and h are the Width=n and Height=n values you have set.

Note if the number specified is greater than 1 then it is interpreted as an absolute row or column number in pixels. If it is a decimal value between 0.0 and 1.0 then it is interpreted as a percent of the total width or height of the image. For example: Start_Row=0.75 and Start_Column=0.75 starts on a row 75% down from the top at a column 75% from the left. Thus it renders only the lower-right 25% of the image regardless of the specified width and height.

The **+SR**, **+ER**, **+SC** and **+EC** switches work in the same way as the corresponding INI-style settings for both absolute settings or percentages. Early versions of POV-Ray allowed only start and end rows to be specified with **+S**n and **+E**n so they are still supported in addition to **+SR** and **+ER**.

6.2.2.1.3 Interrupting Options

Test_Abort=bool	Turn test for user abort on/off
+X	Turn test abort on
–X	Turn test abort off
Test_Abort_Count=n	Set to test for abort every n pixels
+Xn	Set to test for abort every n pixels on
–Xn	Set to test for abort off (in future test every n pixels)

On some operating systems once you start a rendering you must let it finish. The Test_Abort=on option or **+X** switch causes POV-Ray to test the keyboard for keypress. If you have pressed a key, it will generate a controlled user abort. Files will be flushed and closed but only data through the last full row of pixels is saved. POV-Ray exits with an error code 2 (normally POV-Ray returns 0 for a successful run or 1 for a fatal error).

When this option is on, the keyboard is polled on every line while parsing the scene file and on every pixel while rendering. Because polling the keyboard can slow down a rendering, the Test_Abort_Count=n option or **+X**n switch causes the test to be performed only every n pixels rendered or scene lines parsed.

6.2.2.1.4 Resuming Options

Continue_Trace=bool	Sets continued trace on/off
+C	Sets continued trace on
–C	Sets continued trace off
Create_Ini=FILE	Generate an INI file named FILE
Create_Ini=true	Generate FILE.INI where file is the scene name.
Create_Ini=false	Turn off generation of previously set FILE.INI
+GIFILE	Same as Create_Ini=FILE

If you abort a render while it's in progress or if you used the End_Row option to end the render prematurely, you can use Continue_Trace=on or **+C** option to continue the render later at the point where you left off. This option reads in the previously generated output file, displays the partial image rendered so far, then proceeds with the raytracing. This option cannot be used if file output is disabled with Output_to_file=off or **–F**.

The Continue_Trace option may not work if the Start_Row option has been set to anything but the top of the file, depending on the output format being used.

POV-Ray tries to figure out where to resume an interrupted trace by reading any previously generated data in the specified output file. All file formats contain the image size, so this will override any image size settings specified. Some file formats (namely TGA and PNG) also store information about where the file started (i. e. **+SC**n and **+SR**n options), alpha output **+UA**, and bit-depth **+FN**n, which will override these settings. It is up to the user to make sure that all other options are set the same as the original render.

The Create_Ini option or **+GI** switch provides an easy way to create an INI file with all of the rendering options, so you can re-run files with the same options, or ensure you have all the same options when resuming. This option creates an INI file with every option set at the value used for that rendering. This includes default values which you have not specified. For example if you run POV-Ray with ...

```
POVRAY +ISIMPLE.POV MYOPTS +GIRERUN.INI MOREOPTS
```

POV-Ray will create a file called RERUN.INI with all of the options used to generate this scene. The file is not written until all options have been processed. This means that in the above example, the file will include options from both MYOPTS.INI and MOREOPTS.INI despite the fact that the **+GI** switch is specified between them. You may now re-run the scene with ...

```
POVRAY RERUN
```

or resume an interrupted trace with

```
POVRAY RERUN +C
```

If you add other switches with the RERUN.INI reference, they will be included in future re-runs because the file is re-written every time you use it.

The Create_Ini option is also useful for documenting how a scene was rendered. If you render WAYCOOL.POV with Create_Ini=on then it will create a file WAYCOOL.INI that you could distribute along with your scene file so other users can exactly re-create your image.

6.2.2.2 Display Output Options

6.2.2.2.1 Display Hardware Settings

Display=bool	Turns graphic display on/off
+D	Turns graphic display on
–D	Turns graphic display off
Video_Mode=x	Set video mode to *x*; does not affect on/off
+Dx	Set display on; Set mode to *x*
–Dx	Set display off; but for future use mode *x*
Palette=y	Set display palette to *y*; d oes not affect on/off
+Dxy	Set display on; Set mode *x*; Set palette *y*
–Dxy	Set display off; use mode *x*, palette *y* in future
Display_Gamma=n.n	Sets the display gamma to n.n

The Display=on or **+D** switch will turn on the graphics display of the image while it is being rendered. Even on some non-graphics systems, POV-Ray may display an 80 by 24 character *ASCII-Art* version of your image. Where available, the display may be full, 24-bit true color. Setting Display=off or using the **–D** switch will turn off the graphics display which is the default.

The Video_Mode=x option sets the display mode or hardware type chosen where *x* is a single digit or letter that is machine dependent (see section 3.2.5 on page 27 for a description of the modes supported by the MS-Dos version). Generally Video_Mode=0 means the default or an auto-detected setting should be used. When using switches, this character immediately follows the switch. For example the +D0 switch will turn on the graphics display in the default mode.

The Palette=y option selects the palette to be used. Typically the single character parameter *y* is a digit which selects one of several fixed palettes or a letter such *G* for gray scale, *H* for 15-bit or 16-bit high color or *T* for 24-bit true color. When using switches, this character is the 2nd character after the switch. For example the **+D0T** switch will turn on the graphics display in the default mode with a true color palette.

The Display_Gamma=n.n setting is new with POV-Ray 3.0, and is not available as a command-line switch. The Display_Gamma setting overcomes the problem of images (whether ray-traced or not) having different brightness when being displayed on different monitors, different video cards, and under different operating systems. Note that the Display_Gamma is a setting based on your computer's display hardware, and should be set correctly once and not changed. The Display_Gamma INI setting works in conjunction with the new `assumed_gamma` global setting to ensure that POV scenes and the images they create look the same on all systems. See section 7.8.3 on page 357 which describes the `assumed_gamma` global setting and describes gamma more thoroughly.

While the Display_Gamma can be different for each system, there are a few general rules that can be used for setting Display_Gamma if you don't know it exactly. If the Display_Gamma keyword does not appear in the INI file, POV-Ray assumes that the display gamma is 2.2. This is because most PC monitors have a gamma value in the range 1.6 to 2.6 (newer models seem to have a lower gamma value). MacOS has the ability to do gamma correction inside the system software (based on a user setting in the gamma control panel). If the gamma control panel is turned off, or is not available, the default Macintosh system gamma is 1.8. Some high-end PC graphics cards can do hardware gamma correction and should use the current Display_Gamma setting, usually 1.0. A gamma test image is also available to help users to set their Display_Gamma accurately.

For scene files that do not have an `assumed_gamma` global setting the Display_Gamma will not have any affect on the preview output of POV-Ray or for most output file formats. However, the Display_Gamma value is used when creating PNG format output files, and also when rendering the POV-Ray example files (because they have an `assumed_gamma`), so it should still be correctly set for your system to ensure proper results.

6.2.2.2.2 Display Related Settings

Pause_When_Done=bool	Sets pause when done on/off
+P	Sets pause when done on
–P	Sets pause when done off
Verbose=bool	Set verbose messages on/off
+V	Set verbose messages on
–V	Set verbose messages off

Draw_Vistas=bool	Turn draw vistas on/off
+UD	Turn draw vistas on
–UD	Turn draw vistas off

On some systems, when the image is complete, the graphics display is cleared and POV-Ray switches back into text mode to print the final statistics and to exit. Normally when the graphics display is on, you want to look at the image awhile before continuing. Using Pause_When_Done=on or **+P** causes POV-Ray to pause in graphics mode until you to press a key to continue. The default is not to pause (**–P**).

When the graphics display is not used, it is often desirable to monitor progress of the rendering. Using Verbose=on or **+V** turns on verbose reporting of your rendering progress. This reports the number of the line currently being rendered, the elapsed time for the current frame and other information. On some systems, this textual information can conflict with the graphics display. You may need to turn this off when the display is on. The default setting is off (**–V**).

The option Draw_Vistas=on or **+UD** was originally a debugging help for POV-Ray's vista buffer feature but it was such fun we decided to keep it. Vista buffering is a spatial sub-division method that projects the 2-D extents of bounding boxes onto the viewing window. POV-Ray tests the 2-D x, y pixel location against these rectangular areas to determine quickly which objects, if any, the viewing ray will hit. This option shows you the 2-D rectangles used. The default setting is off (**–UD**) because the drawing of the rectangles can take considerable time on complex scenes and it serves no critical purpose. See section 6.2.6.3 on page 177 for more details.

6.2.2.2.3 Mosaic Preview

Preview_Start_Size=n	Set mosaic preview start size to n
+SPn	Same as Preview_Start_Size=n
Preview_End_Size=n	Set mosaic preview end size to n
+EPn	Same as Preview_End_Size=n

Typically, while you are developing a scene, you will do many low resolution test renders to see if objects are placed properly. Often this low resolution version doesn't give you sufficient detail and you have to render the scene again at a higher resolution. A feature called *mosaic preview* solves this problem by automatically rendering your image in several passes.

The early passes paint a rough overview of the entire image using large blocks of pixels that look like mosaic tiles. The image is then refined using higher resolutions on subsequent passes. This display method very quickly displays the entire image at a low resolution, letting you look for any major problems with the scene. As it refines the image, you can concentrate on more details, like shadows and textures. You don't have to wait for a full resolution render to find problems, since you can interrupt the rendering early and fix the scene, or if things look good, you can let it continue and render the scene at high quality and resolution.

To use this feature you should first select a *width* and *height* value that is the highest resolution you will need. Mosaic preview is enabled by specifying how big the mosaic blocks will be on the first pass using Preview_Start_Size=n or **+SP**n. The value n should be a number greater than zero that is a power of two (1, 2, 4, 8, 16, 32, etc.) If it is not a power of two, the nearest power of two less than n is substituted. This sets the size of the squares, measured in pixels. A value of 16 will draw every 16th pixel as a 16×16 pixel square on the first pass. Subsequent passes will use half the previous value (such as 8×8, 4×4 and so on.)

The process continues until it reaches 1×1 pixels or until it reaches the size you set with Preview_End_Size=n or **+EP**n. Again the value n should be a number greater than zero that is a power of two and less than or equal to Preview_Start_Size. If it is not a power of two, the nearest power of two less than n is substituted. The default ending value is 1. If you set Preview_End_Size to a value greater than 1 the mosaic passes will end before reaching 1×1, but POV-Ray will always finish with a 1×1. For example, if you want a single 8×8 mosaic pass before rendering the final image, set Preview_Start_Size=8 and Preview_End_Size=8.

No file output is performed until the final 1×1 pass is reached. Although the preliminary passes render only as many pixels as needed, the 1×1 pass re-renders every pixel so that anti-aliasing and file output streams work properly. This makes the scene take up to 25% longer than the regular 1×1 pass to render, so it is suggested that mosaic preview not be used for final rendering. Also, the lack of file output until the final pass means that renderings which are interrupted before the 1×1 pass can not be resumed without starting over from the beginning.

Future versions of POV-Ray will include some system of temporary files or buffers which will eliminate these inefficiencies and limitations. Mosaic preview is still a very useful feature for test renderings.

6.2.2.3 File Output Options

Output_to_File=bool	Sets file output on/off
+F	Sets file output on (use default type)
–F	Sets file output off

By default, POV-Ray writes an image file to disk. When you are developing a scene and doing test renders, the graphic preview may be sufficient. To save time and disk activity you may turn file output off with Output_to_File=off or **–F**.

6.2.2.3.1 Output File Type

Output_File_Type=x	Sets file output format to *x*

+Fxn	Sets file output on; sets format *x*, depth *n*
–Fxn	Sets file output off; but in future use format *x*, depth *n*
Output_Alpha=bool	Sets alpha output on/off
+UA	Sets alpha output on
–UA	Sets alpha output off
Bits_Per_Color=n	Sets file output bits/color to *n*

The default type of image file depends on which platform you are using. MS-Dos and most others default to 24-bit uncompressed Targa. See your platform-specific documentation to see what your default file type is. You may select one of several different file types using Output_File_Type=x or **+F**x where x is one of the following ...

+FC	Compressed Targa-24 format (RLE, run length encoded)
+FN	New PNG (portable network graphics) format
+FP	Unix PPM format
+FS	System-specific such as Mac Pict or Windows BMP
+FT	Uncompressed Targa-24 format

Note that the obsolete **+FD** dump format and **+FR** raw format have been dropped from POV-Ray 3.0 because they were rarely used and no longer necessary. PPM, PNG, and system specific formats have been added. PPM format images are uncompressed, and have a simple text header, which makes it a widely portable image format. PNG is a new image format designed not only to replace GIF, but to improve on its shortcomings. PNG offers the highest compression available without loss for high quality applications, such as ray-tracing. The system specific format depends on the platform used and is covered in the appropriate system specififc documentation.

Most of these formats output 24 bits per pixel with 8 bits for each of red, green and blue data. PNG allows you to optionally specify the output bit depth from 5 to 16 bits for each of the red, green, and blue colors, giving from 15 to 48 bits of color information per pixel. The default output depth for all formats is 8 bits/color (16 million possible colors), but this may be changed for PNG format files by setting Bits_Per_Color=n or by specifying **+FN**n, where n is the desired bit depth.

Specifying a smaller color depth like 5 bits/color (32768 colors) may be enough for people with 8- or 16-bit (256 or 65536 color) displays, and will improve compression of the PNG file. Higher bit depths like 10 or 12 may be useful for video or publishing applications, and 16 bits/color is good for grayscale height field output (See section 7.5.2.5 on page 236 for details on height fields).

Targa format also allows 8 bits of alpha transparency data to be output, while PNG format allows 5 to 16 bits of alpha transparency data, depending on the color bit depth as specified above. You may turn this option on with Output_Alpha=on or **+UA**. The default is off or **–UA**. See section 7.6.1.5.4 on page 285 for further details on transparency.

In addition to support for variable bit-depths, alpha channel, and grayscale formats, PNG files also store the Display_Gamma value so the image displays properly on all systems (see section 6.2.2.2.1 on page 158). The `hf_gray_16` global setting, as described in section 7.8.4 on page 359 will also affect the type of data written to the output file.

6.2.2.3.2 Output File Name

Output_File_Name=FILE	Sets output file to file
+OFILE	Same as Output_File_Name=FILE

The default output filename is created from the scene name and need not be specified. The scene name is the input name with all drive, path, and extension information stripped. For example if the input file name is C:\POVRAY3\MYSTUFF\MYFILE.POV the scene name is MYFILE. The proper extension is appended to the scene name based on the file type. For example MYFILE.TGA or MYFILE.PNG might be used.

You may override the default output name using Output_File_Name=FILE or **+O**FILE. For example:

```
Input_File_Name=MYINPUT.POV
Output_File_Name=MYOUTPUT.TGA
```

If an output file name of "–" is specified (a single minus sign), then the image will be written to standard output, usually the screen. The output can then be piped into another program or to a GUI if desired.

6.2.2.3.3 Output File Buffer

Buffer_Output=bool	Turn output buffering on/off
+B	Turn output buffering on
–B	Turn output buffering off
Buffer_Size=n	Set output buffer size to *n* kilobytes. If *n* is zero, no buffering occurs. If *n* is smaller than the default, the system default is used.
+Bn	Turn buffer on, set size *n*
–Bn	Turn buffer off, but for future set size *n*

The Buffer_Output and Buffer_Size options and the **+B** switch allows you to assign large buffers to the output file. This reduces the amount of time spent writing to the disk. If this parameter is not specified, then as each row of pixels is finished, the line is written to the file and the file is flushed. On most systems, this operation ensures that the file is written to the disk so that in the event of a system crash or other catastrophic event, at least a part of the picture has been stored properly and retrievable on disk. The default is not to use any buffer.

6.2.2.4 CPU Utilization Histogram

The CPU utilization histogram is a way of finding out where POV-Ray is spending its rendering time, as well as an interesting way of generating heightfields. The histogram splits up the screen into a rectangular grid of blocks. As POV-Ray renders the image, it calculates the amount of time it spends rendering each pixel and then adds this time to the total rendering time for each grid block. When the rendering is complete, the histogram is a file which represents how much time was spent computing the pixels in each grid block.

Not all versions of POV-Ray allow the creation of histograms. The histogram output is dependent on the file type and the system that POV-Ray is being run on.

6.2.2.4.1 File Type

Histogram_Type=x	Set histogram type to *x* (turn off if type is *X*)
+HTx	Same as Histogram_Type=x

The histogram output file type is nearly the same as that used for the image output file types in 6.2.2.3.1 on page 161. The available histogram file types are as follows.

+HTC	Comma separated values (CSV) often used in spreadsheets
+HTN	New PNG (portable network graphics) format grayscale
+HTP	Unix PPM format
+HTS	System-specific such as Mac Pict or Windows BMP
+HTT	Uncompressed Targa-24 format (TGA)
+HTX	No histogram file output is generated

Note that **+HTC** does not generate a compressed Targa-24 format output file but rather a text file with a comma-separated list of the time spent in each grid block, in left-to-right and top-to bottom order. The units of time output to the CSV file are system dependent. See the system specific documentation for further details on the time units in CSV files.

The Targa and PPM format files are in the POV heightfield format (see 7.5.2.5 on page 236), so the histogram information is stored in both the red and green parts of the image, which makes it unsuitable for viewing. When used as a height field, lower values indicate less time spent calculating the pixels in that block, while higher indicate more time spent in that block.

PNG format images are stored as grayscale images and are useful for both viewing the histogram data as well as for use as a heightfield. In PNG files, the darker (lower) areas indicate less time spent in that grid block, while the brighter (higher) areas indicate more time spent in that grid block.

6.2.2.4.2 File Name

Histogram_Name=FILE	Set histogram name to FILE
+HNFILE	Same as Histogram_Name=FILE

The histogram file name is the name of the file in which to write the histogram data. If the file name is not specified it will default to HISTGRAM.EXT, where ext is based on the file type specified previously. Note that if the histogram name is specified the file name extension should match the file type.

6.2.2.4.3 Grid Size

Histogram_Grid_Size=x.y	Set histogram grid to *x* by *y*
+HSx.y	Same as Histogram_Grid_Size=x.y

The histogram grid size gives the number of times the image is split up in both the horizontal and vertical directions. For example

```
POVRAY +ISAMPLE +W640 +H480
    +HTN +HS160.120 +HNHISTOGRM.PNG
```

will split the image into 160×120 grid blocks, each of size 4×4 pixels, and output a PNG file, suitable for viewing or for use as a heightfield. Smaller numbers for the grid size mean more pixels are put into the same grid block. With CSV output, the number of values output is the same as the number of grid blocks specified. For the other formats the image size is identical to the rendered image rather than the specified grid size, to allow easy comparison between the histogram and the rendered image. If the histogram grid size is not specified, it will default to the same size as the image, so there will be one grid block per pixel.

Note that on systems that do task-switching or multi-tasking the histogram may not exactly represent the amount of time POV-Ray spent in a given grid block since the histogram is based on real time rather than CPU time. As a result, time may be spent for operating system overhead or on other tasks running at the same time. This will cause the histogram to have speckling, noise or large spikes. This can be reduced by decreasing the grid size so that more pixels are averaged into a given grid block.

6.2.3 Scene Parsing Options

POV-Ray reads in your scene file and processes it to create an internal model of your scene. The process is called *parsing*. As your file is parsed other files may be read along the way. This section covers options concerning what to parse, where to find it and what version specific assumptions it should make while parsing it.

6.2.3.1 Input File Name

Input_File_Name=FILE	Sets input file name to FILE
+IFILE	Same as Input_File_Name=FILE

You will probably always set this option but if you do not the default input filename is OBJECT.POV. If you do not have an extension then .POV is assumed. On case-sensitive operating systems both .POV and .POV are tried. A full path specification may be used (on MS-Dos systems +IC:\POVRAY3\MYSTUFF\MYFILE.POV is allowed for example). In addition to specifying the input file name this also establishes the *scene name*.

The scene name is the input name with drive, path and extension stripped. In the above example the scene name is MYFILE. This name is used to create a default output file name and it is referenced other places.

If you use "–" as the input file name the input will be read from standard input. Thus you can pipe a scene created by a program to POV-Ray and render it without having a scene file.

Under MS-Dos you can try this feature by typing.

type ANYSCENE.POV — POVRAY **+I–**

6.2.3.2 Library Paths

Library_Path=PATH	Add path to list of library paths
+LPATH	Same as Library_Path=PATH

POV-Ray looks for files in the current directory. If it does not find a file it needs it looks in various other library directories which you specify. POV-Ray does not search your operating system path. It only searches the current directory and directories which you specify with this option. For example the standard include files are usually kept in one special directory. You tell POV-Ray to look there with . . .

```
Library_Path=c:\povray3\include
```

You must not specify any final path seperators ("\" or "/") at the end.

Multiple uses of this option switch do not override previous settings. Up to ten unique paths may be specified. If you specify the exact same path twice it is only counts once. The current directory will be searched first followed by the indicated library directories in the order in which you specified them.

6.2.3.3 Language Version

Version=n.n	Set initial language compatibility to version *n.n*
+MVn.n	Same as Version=n.n

While many language changes have been made for POV-Ray 3.0, all of version 2.0 syntax and most of version 1.0 syntax still works. Whenever possible we try to maintain backwards compatibility. One feature introduced in 2.0 that was incompatible with any 1.0 scene files is the parsing of float expressions. Setting Version=1.0 or using **+MV**1.0 turns off expression parsing as well as many warning messages so that nearly all 1.0 files will still work. The changes between 2.0 and 3.0 are not as extensive. Setting Version=2.0 is only necessary to eliminate some warning messages. Naturally the default setting for this option is Version=3.0.

The `#version` language directive can also be used to change modes several times within scene files. The above options affect only the initial setting. See 7.2.4 on page 208 for more details about the language version directive.

6.2.3.4 Removing User Bounding

Remove_Bounds=bool	Turn unnecessary bounds removal on/off
+UR	Turn unnecessary bounds removal on
–UR	Turn unnecessary bounds removal off
Split_Unions=bool	Turn split bounded unions on/off
+SU	Turn split bounded unions on
–SU	Turn split bounded unions off

Early versions of POV-Ray had no system of automatic bounding or spatial subdivision to speed up ray-object intersection tests. Users had to manually create bounding boxes to speed up the rendering. POV-Ray 3.0 has more sophisticated automatic bounding than any previous version. In many cases the manual bounding on older scenes is slower than the new automatic systems. Therefore POV-Ray removes manual bounding when it knows it will help. In rare instances you may want to keep manual bounding. Some older scenes incorrectly used bounding when they should have used clipping. If POV-Ray removes the bounds in these scenes the image will not look right. To turn off the automatic removal of manual bounds you should specify Remove_Bounds=off or use **–UR**. The default is Remove_Bounds=on.

One area where the jury is still out is the splitting of manually bounded unions. Unbounded unions are always split into their component parts so that automatic bounding works better. Most users do not bound unions because they know that doing so is usually slower. If you do manually bound a union we presume you really want it bound. For safety sake we do not presume to remove such bounds. If you want to remove manual bounds from unions you should specify Split_Unions=on or use **+SU**. The default is Split_Unions=off.

6.2.4 Shell-out to Operating System

Pre_Scene_Command=s	Set command before entire scene
Pre_Frame_Command=s	Set command before each frame
Post_Scene_Command=s	Set command after entire scene
Post_Frame_Command=s	Set command after each frame
User_Abort_Command=s	Set command when user aborts POV-Ray
Fatal_Error_Command=s	Set command when POV-Ray has fatal error

Note that no **+/–** switches are available for these options. They cannot be used from the command line. They may only be used from INI files.

POV-Ray offers you the opportunity to shell-out to the operating system at several key points to execute another program or batch file. Usually this is used to manage files created by the internal animation loop however the shell commands are available for any scene. The CMD is a single line of text which is passed to the operating system to execute a program. For example

```
Post_Scene_Command=tga2gif -d -m myfile
```

would use the utility TGA2GIF with the **–d** and **–m** parameters to convert MYFILE.TGA to MYFILE.GIF after the scene had finished rendering.

6.2.4.1 String Substitution in Shell Commands

It could get cumbersome to change the Post_Scene_Command every time you changed scene names. POV-Ray can substitute various values into a CMD string for you. For example:

```
Post_Scene_Command=tga2gif -d -m %s
```

POV-Ray will substitute the *%s* with the scene name in the command. The *scene name* is the Input_File_Name or **+I** setting with any drive, directory or extension removed. For example:

```
Input_File_Name=c:\povray3\scenes\waycool.pov
```

is stripped down to the scene name WAYCOOL which results in ...

```
Post_Scene_Command=tga2gif -d -m waycool
```

In an animation it may be necessary to have the exact output file name with the frame number included. The string *%o* will substitute the output file name. Suppose you want to save your output files in a zip archive using PKZIP. You could do ...

```
Post_Frame_Command=pkzip -m %s %o
```

After rendering frame 12 of MYSCENE.POV POV-Ray would shell to the operating system with "PKZIP –m MYSCENE MYSCE012.TGA". The **–m** switch in PKZIP moves MYSCE012.TGA to MYSCENE.ZIP and removes it from the directory. Note that *%o* includes frame numbers only when in an animation loop. During the Pre_Scene_Command and Post_Scene_Command there is no frame number so the original, unnumbered Output_File_Name is used. Any User_Abort_Command or Fatal_Error_Command not inside the loop will similarly give an unnumbered *%o* substitution.

Here is the complete list of substitutions available for a common string.

%o	Output file name with extension and embedded frame number if any.
%s	Scene name derived by stripping path and ext from input name.
%n	Frame number of this frame.
%k	Clock value of this frame.
%h	Height of image in pixels.
%w	Width of image in pixels.
%%	A single % sign.

6.2.4.2 Shell Command Sequencing

Here is the sequence of events in an animation loop. Non-animated scenes work the exact same way except there is no loop.

1. Process all INI file keywords and command line switches just once.
2. Open any text output streams and do Create_INI if any.
3. Execute Pre_Scene_Command if any.
4. Loop through frames (or just do once on non-animation).
   (a) Execute Pre_Frame_Command if any.
   (b) Parse entire scene file, open output file and read settings, turn on display, render the frame, destroy all objects, textures etc., close output file, close display.
   (c) Execute Post_Frame_Command if any.
   (d) Go back to 4 until all frames done.
5. Execute Post_Scene_Command if any.
6. Exit POV-Ray.

If the user interrupts processing the User_Abort_Command, if any, is executed. User aborts can only occur during the parsing and rendering parts of step 4a above.

If a fatal error occurs that POV-Ray notices the Fatal_Error_Command, if any, is executed. Sometimes an unforeseen bug or memory error could cause a total crash of the program in which case there is no chance to shell out. Fatal errors can occur just about anywhere including during the processing of switches or INI files. If a fatal error occurs before POV-Ray has read the Fatal_Error_Command string then obviously no shell can occur.

Note that the entire scene is re-parsed for every frame. Future versions of POV-Ray may allow you to hold over parts of a scene from one frame to the next but for now it starts from scratch every time. Note also that the Pre_Frame_Command occurs before the scene is parsed. You might use this to call some custom scene generation utility before each frame. This utility could rewrite your .POV or .INC files if needed. Perhaps you will want to generate new .GIF or .TGA files for image maps or height fields on each frame.

6.2.4.3 Shell Command Return Actions

Pre_Scene_Return=s	Set pre scene return actions
Pre_Frame_Return=s	Set pre frame return actions
Post_Scene_Return=s	Set post scene return actions
Post_Frame_Return=s	Set post frame return actions
User_Abort_Return=s	Set user abort return actions
Fatal_Error_Return=s	Set fatal return actions

Note that no +/– switches are available for these options. They cannot be used from the command line. They may only be used from INI files.

Most operating systems allow application programs to return an error code if something goes wrong. When POV-Ray executes a shell command it can make use of this error code returned from the shell process and take some appropriate action if the code is zero or non-zero. POV-Ray itself returns such codes. It returns 0 for success, 1 for fatal error and 2 for user abort.

The actions are designated by a single letter in the different ... _Return=s options. The possible actions are:

I	ignore the code
S	skip one step
A	all steps skipped
Q	quit POV-Ray immediately
U	generate a user abort in POV-Ray
F	generate a fatal error in POV-Ray

For example if your Pre_Frame_Command calls a program which generates your height field data and that utility fails then it will return a non-zero code. We would probably want POV-Ray to abort as well. The option Pre_Frame_Return=F will cause POV-Ray to do a fatal abort if the Pre_Frame_Command returns a non-zero code.

Sometimes a non-zero code from the external process is a good thing. Suppose you want to test if a frame has already been rendered. You could use the *S* action to skip this frame if the file is already rendered. Most utilities report an error if the file is not found. For example the command PKZIP –v MYSCENE MYSCE012.TGA tells pkzip you want to view the catalog of MYSCENE.ZIP for the file MYSCE012.TGA. If the file isn't in the archive PKZIP returns a non-zero code.

However we want to skip if the file is found. Therefore we need to reverse the action so it skips on zero and doesn't skip on non-zero. To reverse the zero vs. non-zero triggering of an action precede it with a "-" sign (note a "!" will also work since it is used in many programming languages as a negate operator).

Pre_Frame_Return=S will skip if the code shows error (non-zero) and will proceed normally on no error (zero). Pre_Frame_Return=–S will skip if there is no error (zero) and will proceed normally if there is an error (non-zero).

The default for all shells is *I* which means that the return action is ignored no matter what. POV-Ray simply proceeds with whatever it was doing before the shell command. The other actions depend upon the context. You may want to refer back to the animation loop sequence chart in the previous section. The action for each shell is as follows.

On return from any User_Abort_Command if there is an action triggered and you have specified ...

F	then turn this user abort into a fatal error. Do the Fatal_Error_Command if any. Exit POV-Ray with error code 1.
S, A, Q, or U	then proceed with the user abort. Exit POV-Ray with error code 2.

On return from any Fatal_Error_Command proceed with the fatal error no matter what. Exit POV-Ray with error code 1. On return from any Pre_Scene_Command, Pre_Frame_Command, Post_Frame_Command or Post_Scene_Commands if there is an action triggered and you have specified ...

F	then generate a fatal error. Do the Fatal_Error_Command if any. Exit POV-Ray with an error code 1.
U	then generate a user abort. Do the User_Abort_Command if any. Exit POV-Ray with an error code 2.
Q	then quit POV-Ray immediately. Acts as though POV-Ray never really ran. Do no further shells (not even Post_Scene_Command and exit POV-Ray with an error code 0.

On return from a Pre_Scene_Command if there is an action triggered and you have specified ...

S then skip rendering all frames. Acts as though the scene completed all frames normally. Do not do any Pre_Frame_Command or Post_Frame_Commands. Do the Post_Scene_Command if any. Exit POV-Ray with error code 0. On the earlier chart this means skip step 4 on page 169.

A then skip all scene activity. Works exactly like *Q quit*. On the earlier chart this means skip to step 6 on page 169.

On return from a Pre_Frame_Command if there is an action triggered and you have specified ...

S then skip only this frame. Acts as though this frame never existed. Do not do the Post_Frame_Command. Proceed with the next frame. On the earlier chart this means skip steps 4b on page 169 and 4c on page 169 but loop back as needed in 4d on page 169.

A then skip rendering this frame and all remaining frames. Acts as though the scene completed all frames normally. Do not do any further Post_Frame_Command. Do the Post_Scene_Command if any. Exit POV-Ray with error code 0. On the earlier chart this means skip the rest of step 4 on page 169 and proceed at step 5 on page 169.

On return from a Post_Frame_Command if there is an action triggered and you have specified ...

S then skip rendering all remaining frames. Acts as though the scene completed all frames normally. Do the Post_Scene_Command if any. Exit POV-Ray with error code 0. On the earlier chart this means skip the rest of step 4 on page 169 and proceed at step 5 on page 169.

A same as *S* for this shell command.

On return from any Post_Scene_Command if there is an action triggered and you have specified ...

S or A same as *I* for this shell command.

6.2.5 Text Output

Text output is an important way that POV-Ray keeps you informed about what it is going to do, what it is doing and what it did. New to POV-Ray 3.0, the program splits its text messages into 7 separate streams. Some versions of POV-Ray color codes the various types of text. Some versions allow you to scroll back several pages of messages. All versions allow you to turn some of these text streams off/on or to direct a copy of the text output to one or several files. This section details the options which give you control over text output.

6.2.5.1 Text Streams

There are seven distinct text streams that POV-Ray uses for output. On some versions each stream is designated by a particular color. Text from these streams are displayed whenever it is appropriate so there is often an intermixing of the text. The distinction is only important if you choose to turn some of the streams off or to direct some of the streams to text files. On some systems you may be able to review the streams separately in their own scroll-back buffer.

Here is a description of each stream.

BANNER: This stream displays the program's sign-on banner, copyright, contributor's list, and some help screens. It cannot be turned off or directed to a file because most of this text is displayed before any options or switches are read. Therefore you cannot use an option or switch to control it. There are switches which display the help screens. They are covered in section 6.2.5.4 on page 176.

DEBUG: This stream displays debugging messages. It was primarily designed for developers but this and other streams may also be used by the user to display messages from within their scene files. See 7.2.6.1 on page 212 for details on this feature. This stream may be turned off and/or directed to a text file.

FATAL: This stream displays fatal error messages. After displaying this text, POV-Ray will terminate. When the error is a scene parsing error, you may be shown several lines of scene text that leads up to the error. This stream may be turned off and/or directed to a text file.

RENDER: This stream displays information about what options you have specified to render the scene. It includes feedback on all of the major options such as scene name, resolution, animation settings, anti-aliasing and others. This stream may be turned off and/or directed to a text file.

STATISTICS: This stream displays statistics after a frame is rendered. It includes information about the number of rays traced, the length of time of the processing and other information. This stream may be turned off and/or directed to a text file.

STATUS: This stream displays one-line status messages that explain what POV-Ray is doing at the moment. On some systems this stream is displayed on a status line at the bottom of the screen. This stream cannot be directed to a file because there is generally no need to. The text displayed by the `Verbose` option or `+V` switch is output to this stream so that part of the status stream may be turned off.

WARNING: This stream displays warning messages during the parsing of scene files and other warnings. Despite the warning, POV-Ray can continue to render the scene. You will be informed if POV-Ray has made any assumptions about your scene so that it can proceed. In general any time you see a warning, you should also assume that this means that future versions of POV-Ray will not allow the warned action. Therefore you should attempt to eliminate warning messages so your scene will be able to run in future versions of POV-Ray. This stream may be turned off and/or directed to a text file.

6.2.5.2 Console Text Output

Debug_Console=bool	Turn console display of debug info text on/off
+GD	Same as Debug_Console=on
–GD	Same as Debug_Console=off
Fatal_Console=bool	Turn console display of fatal error text on/off
+GF	Same as Fatal_Console=on
–GF	Same as Fatal_Console=off
Render_Console=boo	Turn console display of render info text on/off
+GR	Same as Render_Console=on
–GR	Same as Render_Console=off
Statistic_Console=bool	Turn console display of statistic text on/off
+GS	Same as Statistic_Console=on
–GS	Same as Statistic_Console=off
Warning_Console=bool	Turn console display of warning text on/off
+GW	Same as Warning_Console=on
–GW	Same as Warning_Console=off
All_Console=bool	Turn on/off all debug, fatal, render, statistic and warning text to console.
+GA	Same as All_Console=on
–GA	Same as All_Console=off

You may suppress the output to the console of the *Debug*, *Fatal*, *Render*, *Statistic* or *Warning* text streams. For example the Statistic_Console=off option or the **–GS** switch can turn off the *Statistic* stream. Using *on* or **+GS** you may turn it on again. You may also turn all five of these streams on or off at once using the All_Console option or **+GA** switch.

Note that these options take effect immediately when specified. Obviously any *Error* or *Warning* messages that might occur before the option is read are not be affected.

6.2.5.3 Directing Text Streams to Files

Debug_File=true	Echo debug info text to DEBUG.OUT
Debug_File=false	Turn off file output of debug info
Debug_File=FILE	Echo debug info text to FILE
+GDFILE	Both Debug_Console=on, Debug_File=FILE
–GDFILE	Both Debug_Console=off, Debug_File=FILE
Fatal_FILE=true	Echo fatal text to FATAL.OUT

Fatal_File=false	Turn off file output of fatal
Fatal_File=FILE	Echo fatal info text to FILE
+GFFILE	Both Fatal_Console=on, Fatal_File=FILE
–GFFILE	Both Fatal_Console=off, Fatal_File=FILE
Render_File=true	Echo render info text to RENDER.OUT
Render_File=false	Turn off file output of render info
Render_File=FILE	Echo render info text to FILE
+GRFILE	Both Render_Console=on, Render_File=FILE
–GRFILE	Both Render_Console=off, Render_File=FILE
Statistic_File=true	Echo statistic text to STATS.OUT
Statistic_File=false	Turn off file output of statistics
Statistic_File=FILE	Echo statistic text to FILE
+GSFILE	Both Statistic_Console=on, Statistic_File=FILE
–GS File	Both Statistic_Console=off, Statistic_File=FILE
Warning_File=true	Echo warning info text to WARNING.OUT
Warning_File=false	Turn off file output of warning info
Warning_File=FILE	Echo warning info text to FILE
+GWFILE	Both Warning_Console=on, Warning_File=FILE
–GWFILE	Both Warning_Console=off, Warning_File=FILE
All_File=true	Echo all debug, fatal, render, statistic and and warning text to ALLTEXT.OUT
All_File=false	Turn off file output of all debug, fatal, render, statistic and warning text
All_File=FILE	Echo all debug, fatal, render, statistic and warning text to file
+GAFILE	Both All_Console=on, All_File=FILE
–GAFILE	Both All_Console=off, All_File=FILE

You may direct a copy of the text streams to a text file for the *Debug*, *Fatal*, *Render*, *Statistic* or *Warning* text streams. For example the Statistic_File=s option or the **+GS**s switch. If the string *s* is *true* or any of the other valid *true* strings then that stream is redirected to a file with a default name. Valid *true* values are *true*, *yes*, *on* or *1*. If the value is *false* the direction to a text file is turned off. Valid *false* values are *false*, *no*, *off* or *0*. Any other string specified turns on file output and the string is interpreted as the output file name.

Similarly you may specify such a true, false or file name string after a switch such as +GSfile. You may also direct all five streams to the same file using the All_File option or **+GA** switch. You may not specify the same file for two or more streams because POV-Ray will fail when it tries to open or close the same file twice.

Note that these options take effect immediately when specified. Obviously any *Error* or *Warning* messages that might occur before the option is read will not be affected.

6.2.5.4 Help Screen Switches

+H or **+?**	Show help screen 0 if this is the only switch
+H0 to **+H**8	Show help screen 0 to 8 if this is the only switch
+?0 to **+?**8	Same as **+H**0 to **+H**8

Note that there are no INI style equivalents to these options.

Graphical interface versions of POV-Ray such as Mac or Windows have extensive on-line help. Other versions of POV-Ray have only a few quick-reference help screens. The **+?** switch, optionally followed by a single digit from 0 to 8, will display these help screens to the *Banner* text stream. After displaying the help screens, POV-Ray terminates. Because some operating systems do not permit a question mark as a command line switch you may also use the **+H** switch. Note however that this switch is also used to specify the height of the image in pixels. Therefore the **+H** switch is only interpreted as a help switch if it is the only switch on the command line and if the value after the switch is less than or equal to 8.

6.2.6 Tracing Options

There is more than one way to trace a ray. Sometimes there is a trade-off between quality and speed. Sometimes options designed to make tracing faster can slow things down. This section covers options that tell POV-Ray how to trace rays with the appropriate speed and quality settings.

6.2.6.1 Quality Settings

Quality=n	Set quality value to $n = 0 \ldots 9$
+Qn	Same as Quality=n

The Quality=n option or +Qn switch allows you to specify the image rendering quality. You may choose to lower the quality for test rendering and raise it for final renders. The quality adjustments are made by eliminating some of the calculations that are normally performed. For example settings below 4 do not render shadows. Settings below 8 do not use reflection or refraction. The values correspond to the following quality levels:

0, 1	Use ambient lighting and quick colors only. Quick colors are used only at 5 or below.
2, 3	Show specified diffuse and ambient lighting.
4	Render shadows but no extended lights.
5	Render shadows including extended lights.
6, 7	Compute texture patterns.
8	Compute reflected, refracted and transmitted rays.
9	Compute halos.

The default is 9 if not specified.

6.2.6.2 Radiosity Setting

Radiosity=bool	Turns radiosity on/off
+QR	Turns radiosity on
–QR	Turns radiosity on

Radiosity is an additional calculation which computes diffuse inter-reflection. It is an extremely slow calculation that is somewhat experimental. The parameters which control how radiosity calculations are performed are specified in the `global_settings { radiosity { ... } }` statement. See 7.8.9 on page 362 for further details.

6.2.6.3 Automatic Bounding Control

Bounding=bool	Turn bounding on/off
+MB	Turn bounding on; threshold 25 or previous amount
–MB	Turn bounding off
Bounding_Threshold=n	Set bound threshold to n
+MBn	Turn bounding on; set future threshold to n
–MBn	Turn bounding off; set future threshold to n
Light_Buffer=bool	Turn light buffer on/off
+UL	Turn light buffer on
–UL	Turn light buffer off
Vista_Buffer=bool	Turn vista buffer on/off
+UV	Turn vista buffer on
–UV	Turn vista buffer off

POV-Ray uses a variety of spatial sub-division systems to speed up ray-object intersection tests. The primary system uses a hierarchy of nested bounding boxes. This system compartmentalizes all finite objects in a scene into invisible rectangular boxes that are arranged in a tree-like hierarchy. Before testing the objects within the bounding boxes the tree is descended and only those objects are tested whose bounds are hit by a ray. This can greatly improve rendering speed. However for scenes with only a few objects the overhead of using a bounding system is not worth the effort. The Bounding=off option or **–MB** switch allows you to force bounding off. The default value is on.

The Bounding_Threshold=n or **+MB**n switch allows you to set the minimum number of objects necessary before bounding is used. The default is **+MB**25 which means that if your scene has fewer than 25 objects POV-Ray will automatically turn bounding off because the overhead isn't worth it. Generally it's a good idea to use a much lower threshold like **+MB**5.

Additionally POV-Ray uses systems known as *vista buffers* and *light buffers* to further speed things up. These systems only work when bounding is on and when there are a sufficient number of objects to meet the bounding threshold. The vista buffer is created by projecting the bounding box hierarchy onto the screen and determining the rectangular areas that are covered by each of the elements in the hierarchy. Only those objects whose rectangles enclose a given pixel are tested by the primary viewing ray. The vista buffer can only be used with perspective and orthographic cameras because they rely on a fixed viewpoint and a *reasonable* projection (i. e. straight lines have to stay straight lines after the projection).

The light buffer is created by enclosing each light source in an imaginary box and projecting the bounding box hierarchy onto each of its six sides. Since this relies on a fixed light source, light buffers will not be used for area lights.

Reflected and transmitted rays do not take advantage of the light and vista buffer.

The default settings are Vista_Buffer=on or **+UV** and Light_Buffer=on or **+UL**. The option to turn these features off is available to demonstrate their usefulness and as protection against unforeseen bugs which might exist in any of these bounding systems.

In general, any finite object and many types of CSG of finite objects will properly respond to this bounding system. In addition blobs and meshes use an additional internal bounding system. These systems are not affected by the above switch. They can be switched off using the appropriate syntax in the scene file (see 7.5.2.1 on page 231 and 7.5.3.3 on page 254 for details). Text objects are split into individual letters that are bounded using the bounding box hierarchy. Some CSG combinations of finite and infinite objects are also automatically bound. The end result is that you will rarely need to add manual bounding objects as was necessary in earlier versions of POV-Ray unless you use many infinite objects.

6.2.6.4 Anti-Aliasing Options

Antialias=bool	Turns anti-aliasing on/off
+A	Turns anti-aliasing on with threshold 0.3 or previous amount
–A	Turns anti-aliasing off
Sampling_Method=n	Sets anti-aliasing sampling method (1 or 2)
+AMn	Same as Sampling_Method=n
Antialias_Threshold=n.n	Sets anti-aliasing threshold
+An.n	Sets anti-aliasing on with threshold at *n.n*
–An.n	Sets anti-aliasing off (threshold *n.n* in future)
Jitter=bool	Sets jitter on/off
+J	Sets jitter on with 1.0 or previous amount
–J	Sets jitter off

Jitter_Amount=n.n	Sets jitter amount to *n.n*. If $n.n \leq 0$ jitter is set off
+Jn.n	Sets jitter on; jitter amount to *n.n*. If $n.n \leq 0$ jitter is set off
–Jn.n	Sets jitter off (jitter amount *n.n* in future)
Antialias_Depth=n	Sets anti-aliasing depth ($n = 1\ldots9$)
+Rn	Same as Antialias_Depth=n

The ray-tracing process is in effect a discrete, digital sampling of the image with typically one sample per pixel. Such sampling can introduce a variety of errors. This includes a jagged, stair-step appearance in sloping or curved lines, a broken look for thin lines, moire patterns of interference and lost detail or missing objects, which are so small they reside between adjacent pixels. The effect that is responsible for those errors is called *aliasing*.

Anti-aliasing is any technique used to help eliminate such errors or to reduce the negative impact they have on the image. In general, anti-aliasing makes the ray-traced image look *smoother*. The Antialias=on option or **+A** switch turns on POV-Ray's anti-aliasing system.

When anti-aliasing is turned on, POV-Ray attempts to reduce the errors by shooting more than one viewing ray into each pixel and averaging the results to determine the pixel's apparent color. This technique is called super-sampling and can improve the appearance of the final image but it drastically increases the time required to render a scene since many more calculations have to be done.

POV-Ray gives you the option to use one of two alternate super-sampling methods. The Sampling_Method=n option or **+AM**n switch selects non-adaptive super-sampling (method 1) or adaptive super-sampling (method 2). Selecting one of those methods does not turn anti-aliasing on. This has to be done by using the **+A** command line switch or Antialias=on option.

In the default, non-adaptive method (**+AM**1), POV-Ray initially traces one ray per pixel. If the color of a pixel differs from its neighbors (to the left or above) by more than a threshold value then the pixel is super-sampled by shooting a given, fixed number of additional rays. The default threshold is 0.3 but it may be changed using the Antialias_Threshold=n.n option. When the switches are used, the threshold may optionally follow the **+A**. For example **+A**0.1 turns anti-aliasing on and sets the threshold to 0.1.

The threshold comparison is computed as follows. If r_1, g_1, b_1 and r_2, g_2, b_2 are the rgb components of two pixels then the difference between pixels is computed by

$$diff = |r_2 - r_1| + |g_2 - g_1| + |b_2 - b_1|. \tag{6.1}$$

If this difference is greater than the threshold both pixels are super-sampled. The rgb values are in the range from 0.0 to 1.0 thus the most two pixels can differ is 3.0. If the anti-aliasing threshold is 0.0 then every pixel is super-sampled. If the threshold is 3.0 then no anti-aliasing is done. Lower threshold means more anti-aliasing and less speed. Use anti-aliasing for your final version of a picture, not the rough draft. The lower the contrast, the lower the threshold should be. Higher contrast pictures can get away with higher tolerance values. Good values seem to be around 0.2 to 0.4.

When using the non-adaptive method, the default number of super-samples is nine per pixel, located on a 3×3 grid. The Antialias_Depth=n option or **+R**n switch controls the number of rows and columns of samples taken for a super-sampled pixel. For example **+R**4 would give $4 \times 4 = 16$ samples per pixel.

The second, adaptive super-sampling method starts by tracing four rays at the corners of each pixel. If the resulting colors differ more than the threshold amount additional samples will be taken. This is done recursively, i. e. the pixel is divided into four sub-pixels that are separately traced and tested for further subdivision. The advantage of this method is the reduced number of rays that have to be traced. Samples that are common among adjacent pixels and sub-pixels are stored and reused to avoid re-tracing of rays. The recursive character of this method makes it adaptive, i. e. the super-sampling concentrates on those parts of the pixel that are more likely to need super-sampling (see figure 6.1).

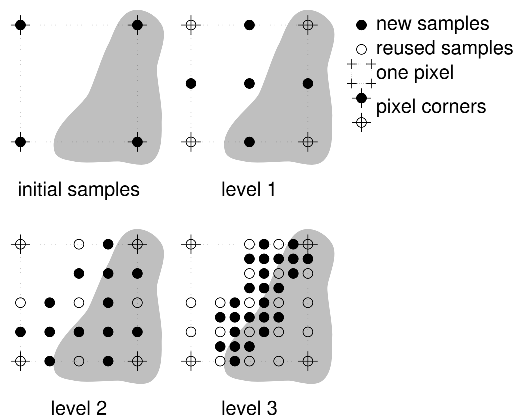


Figure 6.1: Example of how the adpative super-sampling works.

The maximum number of subdivisions is specified by the Antialias_Depth=n option or **+R**n switch. This is different from the non-adaptive method were the total number of super-samples is specified. A maximum number of n subdivisions results in a maximum number of samples per pixel that is given by table 6.1 on the facing page.

You should note that the maximum number of samples in the adaptive case is hardly ever reached for a given pixel. If the adaptive method is used with no anti-aliasing each pixel will be the average of the rays traced at its corners. In most cases a recursion level of three is sufficient.

+Rn	non-adaptive method	the adaptive method
1	1	9
2	4	25
3	9	81
4	16	289
5	25	1089
6	36	4225
7	49	16641
8	64	66049
9	81	263169

Table 6.1: Number of samples for the non-adaptive and adaptive super-sampling methods.

Another way to reduce aliasing artifacts is to introduce noise into the sampling process. This is called *jittering* and works because the human visual system is much more forgiving to noise than it is to regular patterns. The location of the super-samples is jittered or wiggled a tiny amount when anti-aliasing is used. Jittering is used by default but it may be turned off with the Jitter=off option or **–J** switch. The amount of jittering can be set with the Jitter_Amount=n.n option. When using switches the jitter scale may be specified after the **+J** switch. For example **+J**0.5 uses half the normal jitter. The default amount of 1.0 is the maximum jitter which will insure that all super-samples remain inside the original pixel. Note that the jittering *noise* is random and non-repeatable so you should avoid using jitter in animation sequences as the anti-aliased pixels will vary and flicker annoyingly from frame to frame.

If anti-aliasing is not used one sample per pixel is taken regardless of the super-sampling method specified.

Chapter 7

Scene Description Language

The Scene Description Language allows you to describe the world in a readable and convenient way. Files are created in plain ASCII text using an editor of your choice. The input file name is specified using the Input_File_Name=FILE option or **+I**FILE switch. By default the files have the extension **.pov**. POV-Ray reads the file, processes it by creating an internal model of the scene and then renders the scene.

The overall syntax of a scene is a file that contains any number of the following items in any order.

```
LANGUAGE_DIRECTIVES
camera{ CAMERA_ITEMS }
OBJECT_STATEMENTS
ATMOSPHERE_STATEMENTS
global_settings { GLOBAL_ITEMS }
```

See 7.2 on page 204, 7.5 on page 228, 7.4 on page 219, 7.7 on page 347 and 7.8 on page 355 for details.

7.1 Language Basics

The POV-Ray language consists of identifiers, reserved keywords, floating point expressions, strings, special symbols and comments. The text of a POV-Ray scene file is free format. You may put statements on separate lines or on the same line as you desire. You may add blank lines, spaces or indentations as long as you do not split any keywords or identifiers.

7.1.1 Identifiers and Keywords

POV-Ray allows you to define identifiers for later use in the scene file. An identifier may be 1 to 40 characters long. It may consist of upper or lower case letters, the digits

0 through 9 or an underscore character ("_"). The first character must be an alphabetic character. The declaration of identifiers is covered later.

POV-Ray has a number of reserved keywords which are listed below.

aa_level	fog_offset	reciprocal
aa_threshold	fog_type	recursion_limit
abs	frequency	red
acos	gif	reflection
acosh	global_settings	refraction
adaptive	glowing	render
adc_bailout	gradient	repeat
agate	granite	rgb
agate_turb	gray_threshold	rgbf
all	green	rgbft
alpha	halo	rgbt
ambient	height_field	right
ambient_light	hexagon	ripples
angle	hf_gray_16	rotate
aperture	hierarchy	roughness
arc_angle	hollow	samples
area_light	hypercomplex	scale
asc	if	scallop_wave
asin	ifdef	scattering
asinh	iff	seed
assumed_gamma	image_map	shadowless
atan	incidence	sin
atan2	include	sine_wave
atanh	int	sinh
atmosphere	interpolate	sky
atmospheric_attenuation	intersection	sky_sphere
attenuating	inverse	slice
average	ior	slope_map
background	irid	smooth
bicubic_patch	irid_wavelength	smooth_triangle
black_hole	jitter	sor
blob	julia_fractal	specular
blue	lambda	sphere
blur_samples	lathe	spherical_mapping
bounded_by	leopard	spiral
box	light_source	spiral1
box_mapping	linear	spiral2
bozo	linear_spline	spotlight
break	linear_sweep	spotted
brick	location	sqr
brick_size	log	sqrt
brightness	looks_like	statistics
brilliance	look_at	str
bumps	low_error_factor	strcmp
bumpy1	mandel	strength

bumpy2
bumpy3
bump_map
bump_size
camera
case
caustics
ceil
checker
chr
clipped_by
clock
color
color_map
colour
colour_map
component
composite
concat
cone
confidence
conic_sweep
constant
control0
control1
cos
cosh
count
crackle
crand
cube
cubic
cubic_spline
cylinder
cylindrical_mapping
debug
declare
default
degrees
dents
difference
diffuse
direction
disc
distance
distance_maximum
div
dust
dust_type
eccentricity
map_type
marble
material_map
matrix
max
max_intersections
max_iteration
max_trace_level
max_value
merge
mesh
metallic
min
minimum_reuse
mod
mortar
nearest_count
no
normal
normal_map
no_shadow
number_of_waves
object
octaves
off
offset
omega
omnimax
on
once
onion
open
orthographic
panoramic
pattern1
pattern2
pattern3
perspective
pgm
phase
phong
phong_size
pi
pigment
pigment_map
planar_mapping
plane
png
point_at
poly
strlen
strlwr
strupr
sturm
substr
superellipsoid
switch
sys
t
tan
tanh
test_camera_1
test_camera_2
test_camera_3
test_camera_4
text
texture
texture_map
tga
thickness
threshold
tightness
tile2
tiles
torus
track
transform
translate
transmit
triangle
triangle_wave
true
ttf
turbulence
turb_depth
type
u
ultra_wide_angle
union
up
use_color
use_colour
use_index
u_steps
v
val
variance
vaxis_rotate
vcross
vdot

```
else            polygon          version
emitting        pot              vlength
end             pow              vnormalize
error           ppm              volume_object
error_bound     precision        volume_rendered
exp             prism            vol_with_light
exponent        pwr              vrotate
fade_distance   quadratic_spline v_steps
fade_power      quadric          warning
falloff         quartic          warp
falloff_angle   quaternion       water_level
false           quick_color      waves
file_exists     quick_colour     while
filter          quilted          width
finish          radial           wood
fisheye         radians          wrinkles
flatness        radiosity        x
flip            radius           y
floor           rainbow          yes
focal_point     ramp_wave        z
fog             rand
fog_alt         range
```

All reserved words are fully lower case. Therefore it is recommended that your identifiers contain at least one upper case character so it is sure to avoid conflict with reserved words.

The following keywords are in the above list of reserved keywords but are not currently used by POV-Ray however they remain reserved.

```
bumpy1    test_camera_1
bumpy2    test_camera_2
bumpy3    test_camera_3
incidence test_camera_4
pattern1  track
pattern2  volume_object
pattern3  volume_rendered
spiral    vol_with_light
```

7.1.2 Comments

Comments are text in the scene file included to make the scene file easier to read or understand. They are ignored by the ray-tracer and are there for your information. There are two types of comments in POV-Ray.

Two slashes are used for single line comments. Anything on a line after a double slash (//) is ignored by the ray-tracer. For example:

```
// This line is ignored
```

You can have scene file information on the line in front of the comment as in:

```
object { FooBar }  // this is an object
```

The other type of comment is used for multiple lines. It starts with "`/*`" and ends with "`*/`". Everything in-between is ignored. For example:

```
/* These lines
   are ignored
   by the
   ray-tracer */
```

This can be useful if you want to temporarily remove elements from a scene file. `/* ... */` comments can *comment out* lines containing other `//` comments and thus can be used to temporarily or permanently comment out parts of a scene. `/* ... */` comments can be nested, the following is legal:

```
/* This is a comment
// This too
/* This also */
*/
```

Use comments liberally and generously. Well used, they really improve the readability of scene files.

7.1.3 Float Expressions

Many parts of the POV-Ray language require you to specify one or more floating point numbers. A floating point number is a number with a decimal point. Floats may be specified using literals, identifiers or functions which return float values. You may also create very complex float expressions from combinations of any of these using various familiar operators.

Where POV-Ray needs an integer value it allows you to specify a float value and it truncates it to an integer. When POV-Ray needs a logical or boolean value it interprets any non-zero float as true and zero as false. Because float comparisons are subject to rounding errors POV-Ray accepts values extremely close to zero as being false when doing boolean functions. Typically values whose absolute values are less than a preset value *epsilon* are considered false for logical expressions. The value of *epsilon* is system dependent but is generally about $1.0e-10$. Two floats a and b are considered to be euqal if $|a-b| < epsilon$.

7.1.3.1 Float Literals

Float literals are represented by an optional sign ("+" or "–") digits, an optional decimal point and more digits. If the number is an integer you may omit the decimal point and trailing zero. If it is all fractional you may omit the leading zero. POV-Ray supports scientific notation for very large or very small numbers. The following are all valid float literals:

```
-2.0    -4    34    3.4e6    2e-5    .3    0.6
```

7.1.3.2 Float Identifiers

Float identifiers may be declared to make scene files more readable and to parameterize scenes so that changing a single declaration changes many values. An identifier is declared as follows.

```
#declare IDENTIFIER = EXPRESSION
```

Where `IDENTIFIER` is the name of the identifier up to 40 characters long and `EXPRESSION` is any valid expression which evaluates to a float value. Here are some examples.

```
#declare Count = 0
#declare Rows = 5.3
#declare Cols = 6.15
#declare Number = Rows*Cols
#declare Count = Count+1
```

As the last example shows, you can re-declare a float identifier and may use previously declared values in that re-declaration. There are several built-in identifiers which POV-Ray declares for you. See 7.1.7 on page 197 for details.

7.1.3.3 Float Operators

Arithmetic float expressions can be created from float literals, identifiers or functions using the following operators in this order of precedence ...

`()`	expressions in parentheses first
`+A`	unary plus
`-A`	unary minus
`!A`	logical *not*
`A*B`	multiplication

`A/B`	division
`A+B`	addition
`A-B`	subtraction

Relational, logical and conditional expressions may also be created. However there is a restriction that these types of expressions must be enclosed in parentheses first. This restriction, which is not imposed by most computer languages, is necessary because POV-Ray allows mixing of float and vector expressions. Without the parentheses there is an ambiguity problem. Parentheses are not required for the unary logical not operator "!" as shown above. The operators and their precedence are shown here.

Relational expressions: The operands are arithmetic expressions and the result is always boolean with 1 for true and 0 for false. All relational operators have the same precedence.

`(A < B)`	A is less than B
`(A <= B)`	A is less than or equal to B
`(A = B)`	A is equal to B (actually $\|A-B\| < epsilon$)
`(A != B)`	A is not equal to B (actually $\|A-B\| \geq epsilon$)
`(A >= B)`	A is greater than or equal to B
`(A > B)`	A is greater than B

Logical expressions: The operands are converted to boolean values of 0 for false and 1 for true. The result is always boolean. All logical operators have the same precedence. Note that these are not bitwise operations, they are logical.

`(A & B)`	true only if both A and B are true, false otherwise
`(A | B)`	true if either A or B or both are true

Conditional expressions: The operand C is boolean while operands A and B are any expressions. The result is of the same type as A and B.

`(C ? A : B)`	if C then A else B

Assuming the various identifiers have been declared, the following are examples of valid expressions ...

```
1+2+3        2*5          1/3          Row*3        Col*5

(Offset-5)/2              This/That+Other*Thing

((This<That) & (Other>=Thing)?Foo:Bar)
```

Expressions are evaluated left to right with innermost parentheses evaluated first, then unary $+$, $-$ or !, then multiply or divide, then add or subtract, then relational, then logical, then conditional.

7.1.4 Vector Expressions

POV-Ray often requires you to specify a *vector*. A vector is a set of related float values. Vectors may be specified using literals, identifiers or functions which return vector values. You may also create very complex vector expressions from combinations of any of these using various familiar operators.

POV-Ray vectors may have from two to five components but the vast majority of vectors have three components. Unless specified otherwise, you should assume that the word *vector* means a three component vector. POV-Ray operates in a 3D x, y, z coordinate system and you will use three component vectors to specify x, y and z values. In some places POV-Ray needs only two coordinates. These are often specified by a 2D vector called an *UV vector*. Fractal objects use 4D vectors. Color expressions use 5D vectors but allow you to specify 3, 4 or 5 components and use default values for the unspecified components. Unless otherwise noted, all 2, 4 or 5 component vectors work just like 3D vectors but they have a different number of components.

7.1.4.1 Vector Literals

Vectors consist of two to five float expressions that are bracketed by angle brackets $\langle$ and $\rangle$. The terms are separated by commas. For example here is a typical three component vector:

```
< 1.0, 3.2, -5.4578 >
```

The commas between components are necessary to keep the program from thinking that the 2nd term is the single float expression $3.2-5.4578$ and that there is no 3rd term. If you see an error message such as *Float expected but '$\rangle$' found instead* you probably have missed a comma.

Sometimes POV-Ray requires you to specify floats and vectors side-by-side. The rules for vector expressions allow for mixing of vectors with vectors or vectors with floats so commas are required separators whenever an ambiguity might arise. For example $\langle 1,2,3\rangle - 4$ evaluates as a mixed float and vector expression where 4 is subtracted from each component resulting in $\langle -3,-2,-1\rangle$. However the comma in $\langle 1,2,3\rangle, -4$ means this is a vector followed by a float.

Each component may be a full float expression. For example $\langle This+3, That/3, 5*Other\_Thing\rangle$ is a valid vector.

7.1.4.2 Vector Identifiers

Vector identifiers may be declared to make scene files more readable and to parameterize scenes so that changing a single declaration changes many values. An identifier is declared as follows ...

```
#declare IDENTIFIER = EXPRESSION
```

Where IDENTIFIER is the name of the identifier up to 40 characters long and EXPRESSION is any valid expression which evaluates to a vector value. Here are some examples ...

```
#declare Here = <1,2,3>
#declare There = <3,4,5>
#declare Jump = <Foo*2,Bar-1,Bob/3>
#declare Route = There-Here
#declare Jump = Jump+<1,2,3>
```

Note that you invoke a vector identifier by using its name without any angle brackets. As the last example shows, you can re-declare a vector identifier and may use previously declared values in that re-declaration. There are several built-in identifiers which POV-Ray declares for you. See 7.1.7 on page 197 for details.

7.1.4.3 Vector Operators

Vector literals, identifiers and functions may also be combined in expressions the same as float values. Operations are performed on a component-by-component basis. For example $\langle 1,2,3\rangle + \langle 4,5,6\rangle$ evaluates the same as $\langle 1+4,2+5,3+6\rangle$ or $\langle 5,7,9\rangle$. Other operations are done on a similar component-by-component basis. For example $(\langle 1,2,3\rangle = \langle 3,2,1\rangle)$ evaluates to $\langle 0,1,0\rangle$ because the middle components are equal but the others are not. Admittedly this isn't very useful but its consistent with other vector operations.

Conditional expressions such as `(C ? A : B)` require that C is a float expression but A and B may be vector expressions. The result is that the entire conditional evaluates as a valid vector. For example if `Foo` and `Bar` are floats then

```
Foo < Bar ? <1,2,3> : <5,6,7>
```

evaluates as the vector $\langle 1,2,3\rangle$ if `Foo` is less than `Bar` and evaluates as $\langle 5,6,7\rangle$ otherwise.

You may use the dot operator to extract a single component from a vector. Suppose the identifier `Spot` was previously defined as a vector. Then `Spot.x` is a float value that is the first component of this x, y, z vector. Similarly `Spot.y` and `Spot.z` reference the 2nd and 3rd components. If `Spot` was a two component UV vector you could use `Spot.u` and `Spot.v` to extract the first and second component. For a 4D vector use `.x`, `.y`, `.z` and `.t` to extract each float component. The dot operator is also used in color expressions which are covered later.

7.1.4.4 Operator Promotion

You may use a lone float expression to define a vector whose components are all the same. POV-Ray knows when it needs a vector of a particular type and will promote a float into a vector if need be. For example the POV-Ray `scale` statement requires a three component vector. If you specify scale 5 then POV-Ray interprets this as scale $\langle 5,5,5\rangle$ which means you want to scale by 5 in every direction.

Versions of POV-Ray prior to 3.0 only allowed such use of a float as a vector in various limited places such as `scale` and `turbulence.` However you may now use this trick anywhere. For example ...

```
box { 0, 1 }    // This is the same as box { <0,0,0>, <1,1,1> }
sphere { 0, 1 } // This is the same as sphere { <0,0,0>, 1 }
```

When promoting a float into a vector of 2, 3, 4 or 5 components, all components are set to the float value, however when promoting a vector of a lower number of components into a higher order vector, all remaining components are set to zero. For example if POV-Ray expects a 4D vector and you specify 9 the result is $\langle 9,9,9,9\rangle$ but if you specify $\langle 7,6\rangle$ the result is $\langle 7,6,0,0\rangle$.

7.1.5 Specifying Colors

POV-Ray often requires you to specify a color. Colors consist of five values or color components. The first three are called `red`, `green` and `blue.` They specify the intensity of the primary colors red, green and blue using an additive color system like the one used by the red, green and blue color phosphors on a color monitor.

The 4th component, called `filter`, specifies the amount of filtered transparency of a substance. Some real-world examples of filtered transparency are stained glass windows or tinted cellophane. The light passing through such objects is tinted by the appropriate color as the material selectively absorbs some frequencies of light while allowing others to pass through. The color of the object is subtracted from the light passing through so this is called subtractive transparency.

The 5th component, called `transmit`, specifies the amount of non-filtered light that is transmitted through a surface. Some real-world examples of non-filtered transparency are thin see-through cloth, fine mesh netting and dust on a surface. In these examples, all frequencies of light are allowed to pass through tiny holes in the surface. Although the amount of light passing through is diminished, the color of the light passing through is unchanged. The color of the object is added to the light passing through so this is called additive transparency.

Note that early versions of POV-Ray used the keyword `alpha` to specify filtered transparency. However that word is often used to describe non-filtered transparency. For this reason `alpha` is no longer used.

Each of the five components of a color are float values which are normally in the range between 0.0 and 1.0. However any values, even negatives may be used.

Colors may be specified using vectors, keywords with floats or identifiers. You may also create very complex color expressions from combinations of any of these using various familiar operators. The syntax for specifying a color has evolved since POV-Ray was first released. We have maintained the original keyword-based syntax and added a short-cut vector notation. Either the old or new syntax is acceptable however the vector syntax is easier to use when creating color expressions.

7.1.5.1 Color Vectors

The syntax for a color vector is any of the following ...

```
color rgb VECTOR3
color rgbf VECTOR4
color rgbt VECTOR4
color rgbft VECTOR5
```

where `VECTOR3`, `VECTOR4` or `VECTOR5` are any valid vector expressions of 3, 4 or 5 components. For example

```
color rgb <1.0, 0.5, 0.2>
```

This specifies a color whose red component is 1.0 or 100% of full intensity. The green component is 0.5 or 50% of full intensity and the blue component is 0.2 or 20% of full intensity. Although the filter and transmit components are not explicitly specified, they exist and are set to their default values of 0 or no transparency.

The `rgbf` keyword requires a four component vector. The 4th component is the filter component and the transmit component defaults to zero. Similarly the `rgbt` keyword requires four components where the 4th value is moved to the 5th component which is transmit and then the filter component is set to zero.

The `rgbft` keyword allows you to specify all five components. Internally in expressions all five are always used.

Under most circumstances the keyword `color` is optional and may be omitted. We also support the British or Canadian spelling `colour`. Under some circumstances, if the vector expression is a 5 component expression or there is a color identifier in the expression then the `rgbtf` keyword is optional.

7.1.5.2 Color Keywords

The older keyword method of specifying a color is still useful and many users prefer it. Like a color vector, you begin with the optional keyword `color`. This is followed by any of five additional keywords `red`, `green`, `blue`, `filter` or `transmit`. Each of these component keywords is followed by a float expression. For example

```
color red 1.0 green 0.5
```

This specifies a color whose red component is 1.0 or 100% of full intensity and the green component is 0.5 or 50% of full intensity. Although the blue, filter and transmit components are not explicitly specified, they exist and are set to their default values of 0. The component keywords may be given in any order and if any component is unspecified its value defaults to zero.

7.1.5.3 Color Identifiers

Color identifiers may be declared to make scene files more readable and to parameterize scenes so that changing a single declaration changes many values. A color identifier is declared as either of the following ...

```
#declare IDENTIFIER = COLOR_VECTOR
#declare IDENTIFIER = COLOR_KEYWORDS...
```

Where `IDENTIFIER` is the name of the identifier up to 40 characters long and `COLOR_VECTOR` or `COLOR_KEYWORDS` are any valid color specifications as described in the two previous sections of this document. Here are some examples ...

```
#declare White = rgb <1,1,1>
#declare Cyan = color blue 1.0  green 1.0
#declare Weird = rgb <Foo*2,Bar-1,Bob/3>
#declare LightGray = White*0.8
#declare LightCyan = Cyan red 0.6
```

As the `LightGray` example shows you do not need any color keywords when creating color expressions based on previously declared colors. The last example shows you may use a color identifier with the keyword style syntax. Make sure that the identifier comes first before any other component keywords.

Like floats and vectors, you may re-define colors throughout a scene but the need to do so is rare.

7.1.5.4 Color Operators

Color vectors may be combined in expressions the same as float or vector values. Operations are performed on a component-by-component basis. For example `rgb` $\langle 1.0, 0.50.2\rangle$ `* 0.9` evaluates the same as `rgb` $\langle 1.0, 0.50.2\rangle$ `*` $\langle 0.9, 0.9, 0.9\rangle$ or `rgb` $\langle 0.9, 0.45, 0.18\rangle$. Other operations are done on a similar component-by-component basis.

You may use the dot operator to extract a single component from a color. Suppose the identifier `Shade` was previously defined as a color. Then `Shade.red` is the float value of the red component of `Shade`. Similarly `Shade.green`, `Shade.blue`, `Shade.filter` and `Shade.transmit` extract the float value of the other color components.

7.1.5.5 Common Color Pitfalls

The variety and complexity of color specification methods can lead to some common mistakes. Here are some things to consider when specifying a color.

When using filter transparency, the colors which come through are multiplied by the primary color components. For example if grey light such as `rgb` $\langle 0.9, 0.9, 0.9\rangle$ passes through a filter such as `rgbf` $\langle 1.0, 0.5, 0.0, 1.0\rangle$ the result is `rgb` $\langle 0.9, 0.45, 0.0\rangle$ with the red let through 100%, the green cut in half from 0.9 to 0.45 and the blue totally blocked. Often users mistakenly specify a clear object by

```
color filter 1.0
```

but this has implied red, green and blue values of zero. You've just specified a totally black filter so no light passes through. The correct way is either

```
color red 1.0   green 1.0   blue 1.0   filter 1.0
```

or

```
color transmit 1.0
```

In the 2nd example it doesn't matter what the rgb values are. All of the light passes through untouched.

Another pitfall is the use of color identifiers and expressions with color keywords. For example ...

```
color My_Color red 0.5
```

this substitutes whatever was the red component of `My_Color` with a red component of 0.5 however ...

```
color My_Color + red 0.5
```

adds 0.5 to the red component of My_Color and even less obvious ...

```
color My_Color * red 0.5
```

that cuts the red component in half as you would expect but it also multiplies the green, blue, filter and transmit components by zero! The part of the expression after the multiply operator evaluates to `rgbft` $\langle 0.5, 0, 0, 0, 0\rangle$ as a full 5 component color.

The following example results in no change to `My_Color`.

```
color red 0.5 My_Color
```

This is because the identifier fully overwrites the previous value. When using identifiers with color keywords, the identifier should be first.

One final issue, some POV-Ray syntax allows full color specifications but only uses the rgb part. In these cases it is legal to use a float where a color is needed. For example:

```
finish { ambient 1 }
```

The ambient keyword expects a color so the value 1 is promoted to $\langle 1, 1, 1, 1, 1\rangle$ which is no problem. However

```
pigment { color 0.4 }
```

is legal but it may or may not be what you intended. The 0.4 is promoted to $\langle 0.4, 0.4, 0.4, 0.4, 0.\rangle$ with the filter and transmit set to 0.4 as well. It is more likely you wanted ...

```
pigment { color rgb 0.4 }
```

in which case a 3 component vector is expected. Therefore the 0.4 is promoted to $\langle 0.4, 0.4, 0.4, 0.0, 0.0\rangle$ with default zero for filter and transmit.

7.1.6 Strings

The POV-Ray language requires you to specify a string of characters to be used as a file name, text for messages or text for a text object. Strings may be specified using literals, identifiers or functions which return string values. Although you cannot build string expressions from symbolic operators such as are used with floats, vectors or colors, you may perform various string operations using string functions. Some applications of strings in POV-Ray allow for non-printing formatting characters such as newline or form-feed.

7.1.6.1 String Literals

String literals begin with a double quote mark ”” which is followed by up to 256 printable ASCII characters and are terminated by another double quote mark. The following are all valid string literals:

```
"Here"   "There"    "myfile.gif"    "textures.inc"
```

7.1.6.2 String Identifiers

String identifiers may be declared to make scene files more readable and to parameterize scenes so that changing a single declaration changes many values. An identifier is declared as follows ...

```
#declare IDENTIFIER = STRING
```

Where `IDENTIFIER` is the name of the identifier up to 40 characters long and `STRING` is a string literal, string identifier or function which returns a string value. Here are some examples ...

```
#declare Font_Name = "ariel.ttf"
#declare Inc_File = "myfile.inc"
#declare Name = "John"
#declare Name = concat(Name," Doe")
```

As the last example shows, you can re-declare a string identifier and may use previously declared values in that re-declaration.

7.1.7 Built-in Identifiers

There are several built-in float and vector identifiers. You can use them to specify values or to create expressions but you cannot re-declare them to change their values.

7.1.7.1 Constant Built-in Identifiers

Most built-in identifiers never change value. They are defined as though the following lines were at the start of every scene.

```
#declare pi = 3.1415926535897932384626
#declare true = 1
#declare yes = 1
#declare on = 1
#declare false = 0
#declare no = 0
#declare off = 0
#declare u = <1,0>
#declare v = <0,1>
#declare x = <1,0,0>
#declare y = <0,1,0>
#declare z = <0,0,1>
#declare t = <0,0,0,1>
```

The built-in float identifier `pi` is obviously useful in math expressions involving circles.

The built-in float identifiers `on`,`off`, `yes`, `no`, `true` and `false` are designed for use as boolean constants.

The built-in vector identifiers `x`, `y` and `z` provide much greater readability for your scene files when used in vector expressions. For example ....

```
plane { y, 1}         // The normal vector is obviously "y".
plane { <0,1,0>, 1}   // This is harder to read.

translate 5*x         // Move 5 units in the "x" direction.
translate <5,0,0>     // This is less obvious.
```

An expression like `5*x` evaluates to $5\langle 1,0,0\rangle$ or $\langle 5,0,0\rangle$.

Similarly `u` and `v` may be used in 2D vectors. When using 4D vectors you should use `x`, `y`, `z`, and `t` and POV-Ray will promote `x`, `y` and `z` to 4D when used where 4D is required.

7.1.7.2 Built-in Identifier `clock`

The built-in float identifier `clock` is used to control animations in POV-Ray. Unlike some animation packages, the action in POV-Ray animated scenes does not depend upon the integer frame numbers. Rather you should design your scenes based upon the float identifier `clock`. For non-animated scenes its default value is 0 but you can set it to any float value using the INI file option Clock=n.n or the command-line switch **+Kn.n** to pass a single float value your scene file.

Other INI options and switches may be used to animate scenes by automatically looping through the rendering of frames using various values for `clock`. By default, the clock value is 0 for the initial frame and 1 for the final frame. All other frames are interpolated between these values. For example if your object is supposed to rotate one full turn over the course of the animation you could specify `rotate 360*clock*y`. Then as clock runs from 0 to 1, the object rotates about the *y*-axis from 0 to 360 degrees.

Although the value of `clock` will change from frame-to-frame, it will never change throughout the parsing of a scene.

See 6.2.1 on page 151 for more details.

7.1.7.3 Built-in Identifier `version`

The built-in float identifier `version` contains the current setting of the version compatibility option. Although this value defaults to 3 which is the current POV-Ray version number, the initial value of `version` may be set by the INI file option Version=n.n or by the **+MVn.n** command-line switch. This tells POV-Ray to parse the scene file using syntax from an earlier version of POV-Ray.

The INI option or switch only affects the initial setting. Unlike other built-in identifiers, you may change the value of `version` throughout a scene file. You do not use `#declare` to change it though. The `#version` language directive is used to change modes. Such changes may occur several times within scene files.

Together with the built-in `version` identifier the `#version` directive allows you to save and restore the previous values of this compatibility setting. For example suppose MYSTUFF.INC is in version 1 format. At the top of the file you could put:

```
#declare Temp_Vers = version     // Save previous value
#version 1.0                     // Change to 1.0 mode

... // Version 1.0 stuff goes here...

#version Temp_Vers               // Restore previous version
```

7.1.8 Functions

POV-Ray defines a variety of built-in functions for manipulating floats, vectors and strings. The functions are listed grouped according to their usage and not by the type of value they return. For example `vdot` computes the dot product of two vectors and is listed as a vector function even though it returns a single float value.

Function calls consist of a keyword which specifies the name of the function followed by a parameter list enclosed in parentheses. Parameters are separated by commas. For example:

```
keyword(param1,param2)
```

Functions evaluate to values that are floats, vectors or strings and may be used in expressions or statements anywhere that literals or identifiers of that type may be used.

7.1.8.1 Float Functions

The following are the functions which take one or more float parameters and return float values. Assume that `A` and `B` are any valid expression that evaluates to a float. See 7.1.8.2 on page 201 and 7.1.8.3 on page 202 for other functions which return float values but whose primary purpose is more closely related to vectors and strings.

`abs(A)`: Absolute value of `A`. If `A` is negative, returns `--A` otherwise returns `A`.

`acos(A)`: Arc-cosine of `A`. Returns the angle, measured in radians, whose cosine is `A`.

`asin(A)`: Arc-sine of `A`. Returns the angle, measured in radians, whose sine is `A`.

`atan2(A,B)`: Arc-tangent of `(A/B)`. Returns the angle, measured in radians, whose tangent is `(A/B)`. Returns appropriate value even if `B` is zero. Use `atan2(A,1)` to compute usual `atan(A)` function.

`ceil(A)`: Ceiling of `A`. Returns the smallest integer greater than `A`. Rounds up to the next higher integer.

`cos(A)`: Cosine of `A`. Returns the cosine of the angle `A`, where `A` is measured in radians.

`degrees(A)`: Convert radians to degrees. Returns the angle measured in degrees whose value in radians is `A`. The formula is

$$A_{degrees} = \frac{180}{\pi} A_{radians}. \tag{7.1}$$

`div(A,B)`: Integer division. The integer part of `(A/B)`.

`exp(A)`: Exponential of `A`. Returns the value of `e` raised to the `A` power where `e` is the non-repeating value approximately equal to 2.71828182846 the base of natural logarithms.

`floor(A)`: Floor of `A`. Returns the largest integer less than `A`. Rounds down to the next lower integer.

`int(A)`: Integer part of `A`. Returns the truncated integer part of `A`. Rounds towards zero.

`log(A)`: Natural logarithm of `A`. Returns the natural logarithm base `e` of the value `A` where `e` is the non-repeating value approximately equal to 2.71828182846.

`max(A,B)`: Maximum of `A` and `B`. Returns `A` if `A` larger than `B`. Otherwise returns `B`.

`min(A,B)`: Minimum of `A` and `B`. Returns `A` if `A` smaller than `B`. Otherwise returns `B`.

`mod(A,B)`: Value of `A` modulo `A`. Returns the remainder after the integer division of `A/B`. The Formula is[1]

$$\mathrm{mod}(A,B) = \left(\frac{A}{B} - \left\lfloor \frac{A}{B} \right\rfloor\right) B. \tag{7.2}$$

`pow(A,B)`: Exponentiation. Returns the value of `A` raised to the power `B`.

`radians(A)`: Convert degrees to radians. Returns the angle measured in radians whose value in degrees is `A`. The formula is

$$A_{radians} = \frac{\pi}{180} A_{degree}. \tag{7.3}$$

[1] $\lfloor x \rfloor$ is the smallest integer number larger than x.

rand(A): Returns the next pseudo-random number from the stream specified by the positive integer A. You must call seed() to initialize a random stream before calling rand(). The numbers are uniformly distributed, and have values between 0.0 and 1.0, inclusively. The numbers generated by separate streams are independent random variables.

seed(A): Initializes a new pseudo-random stream with the initial seed value A. The number corresponding to this random stream is returned. Any number of pseudo-random streams may be used as shown in the example below:

```
#declare R1 = seed(0)
#declare R2 = seed(12345)

#sphere {
  <rand(R1), rand(R1), rand(R1)>,
  rand(R2)
}
```

Multiple random generators are very useful in situations where you use rand() to place a group of objects, and then decide to use rand() in another location earlier in the file to set some colors or place another group of objects. Without separate rand() streams, all of your objects would move when you added more calls to rand(). This is very annoying.

sin(A): Sine of `A`. Returns the sine of the angle `A`, where `A` is measured in radians.

sqrt(A): Square root of `A`. Returns the value whose square is `A`.

tan(A): Tangent of `A`. Returns the tangent of the angle `A`, where `A` is measured in radians.

7.1.8.2 Vector Functions

The following are the functions which take one or more vector and float parameters and return vector or float values. All of these functions support only three component vectors. Assume that `A` and `B` are any valid expression that evaluates to a three component vector and that `F` is any valid expression that evaluates to a float.

vaxis_rotate(A,B,F): Rotate `A` about `B` by `A`. Given the x, y, z coordinates of a point in space designated by the vector `A`, rotate that point about an arbitrary axis defined by the vector `B`. Rotate it through an angle specified in degrees by the float value `F`. The result is a vector containing the new x, y, z coordinates of the point.

vcross(A,B): Cross product of `A` and `B`. Returns a vector that is the vector cross product of the two vectors. The resulting vector is perpendicular to the two original vectors and its length is proportional to the angle between them. See the animated demo scene VECT2.POV for an illustration.

vdot(A,B): Dot product of `A` and `B`. Returns a float value that is the dot product (sometimes called scaler product of `A` with `B`). The formula is

$$vdot = A_x B_x + A_y B_y + A_z B_z. \tag{7.4}$$

See the animated demo scene `VECT2.POV` for an illustration.

vlength(A): Length of `A`. Returns a float value that is the length of vector `A`. Can be used to compute the distance between two points. The formula is

$$vlength = \sqrt{\text{vdot}(A,A)}. \tag{7.5}$$

vnormalize(A): Normalize vector `A`. Returns a unit length vector that is the same direction as `A`. The formula is $vnormalize = A/vlength(A)$.

vrotate(A,B): Rotate `A` about origin by `B`. Given the x, y, z coordinates of a point in space designated by the vector `A`, rotate that point about the origin by an amount specified by the vector `B`. Rotate it about the x-axis by an angle specified in degrees by the float value `B.x`. Similarly `B.y` and `B.z` specify the amount to rotate in degrees about the y-axis and z-axis. The result is a vector containing the new x,y,z coordinates of the point.

7.1.8.3 String Functions

The following are the functions which take one or more string and float parameters and return string or float values. Assume that `S1` and `S2` are any valid strings and that `A`, `L` and `P` are any valid expressions that evaluate to floats.

asc(S1): ASCII value of `S1`. Returns an integer value in the range 0 to 255 that is the ASCII value of the first character of `S1`. For example `asc("ABC")` is 65 because that is the value of the character "A".

chr(A): Character whose ASCII value is `A`. Returns a single character string. The ASCII value of the character is specified by an integer `A` which must be in the range 0 to 255. For example `chr(70)` is the string "F". If you use chr() when rendering text objects you should be aware that the characters rendered for values of A > 127 are dependent on the (TTF) font being used. Many (TTF) fonts use the Latin-1 (ISO 8859-1) character set, but not all do.

concat(S1,S2,[S3 ...]): Concatenate strings `S1` and `S2`. Returns a string that is the concatenation of all parameter strings. Must have at least 2 parameters but may have more. For example:

```
concat("Value is ", str(A,3,1), " inches")
```

If the float value A was 12.34 the result is ”Value is 12.3 inches”, which is a string.

file_exists(S1): Search for file specified by S1. Attempts to open the file whose name is specified the string S1. The current directory and all directories specified in any Library_Path INI options or **+L** command line switches are searched. File is immediately closed. Returns a boolean value 1 on success and 0 on failure.

str(A,L,P): Convert float A to formatted string. Returns a formatted string representation of float value A. The float parameter L specifies the minimum length of the string and the type of left padding used if the string's representation is shorter than the minimum. If L is positive then the padding is with blanks. If L is negative then the padding is with zeros. The overall minimum length of the formatted string is abs(L). If the string needs to be longer, it will be made as long as necessary to represent the value.

The float parameter P specifies the number of digits after the decimal point. If P is negative then a compiler-specific default precision is use. Here are some examples:

```
str(123.456,0,3)    "123.456"
str(123.456,4,3)    "123.456"
str(123.456,9,3)    "  123.456"
str(123.456,-9,3)   "00123.456"
str(123.456,0,2)    "123.46"
str(123.456,0,0)    "123"
str(123.456,5,0)    "  123"
str(123.000,7,2)    " 123.00"
str(123.456,0,-1)   "123.456000" (platform specific)
```

strcmp(S1,S2): Compare string S1 to S2. Returns a float value zero if the strings are equal, a positive number if S1 comes after S2 in the ASCII collating sequence, else a negative number.

strlen(S1): Length of S1. Returns an integer value that is the number of characters in the string S1.

strlwr(S1): Lower case of S1. Returns a new string in which all upper case letters in the string S1 are converted to lower case. The original string is not affected. For example strlwr("Hello There!") results in ”hello there!”.

substr(S1,P,L): Sub-string from S1. Returns a string that is a subset of the characters in parameter S1 starting at the position specified by the integer value P for a length specified by the integer value L. For example substr("ABCDEFGHI",4,2) evaluates to the string ”‘EF”. If $\mathrm{P}+\mathrm{L} > \mathrm{strlen}(S1)$ an error occurs.

strupr(S1): Upper case of `S1`. Returns a new string in which all lower case letters in the string `S1` are converted to upper case. The original string is not affected. For example `strupr("Hello There!")` results in "HELLO THERE!".

val(S1): Convert string `S1` to float. Returns a float value that is represented by the text in `S1`. For example `val("123.45")` is 123.45 as a float.

7.2 Language Directives

The POV Scene Language contains several statements called *language directives* which tell the file parser how to do its job. These directives can appear in almost any place in the scene file — even in the middle of some other statements. They are used to include other text files in the stream of commands, to declare identifiers, to define conditional or looped parsing and to control other important aspects of scene file processing.

Each directive begins with the hash character `#` (often called a number sign or pound sign). It is followed by a keyword and optionally other parameters.

In versions of POV-Ray prior to 3.0, the use of this # character was optional. Language directives could only be used between objects, camera or light_source statements and could not appear within those statements. The exception was the `#include` which could appear anywhere. Now that all language directives can be used almost anywhere, the # character is mandatory.

The following keywords introduce language directives.

#break	#default	#statistics
#case	#else	#switch
#debug	#end	#version
#declare	#render	#warning

Earlier versions of POV-Ray considered `#max_intersections` and `#max_trace_level` to be language directives but they have been moved to the `global_settings` statement. Their use as a directive still works but it generates a warning and may be discontinued in the future.

7.2.1 Include Files

The language allows include files to be specified by placing the line

```
#include "filename.inc"
```

at any point in the input file. The filename may be specified by any valid string expression but it usually is a literal string enclosed in double quotes. It may be up to 40 characters long (or your computer's limit), including the two double-quote characters.

The include file is read in as if it were inserted at that point in the file. Using include is the same as actually cutting and pasting the entire contents of this file into your scene.

Include files may be nested. You may have at most 10 nested include files. There is no limit on un-nested include files.

Generally, include files have data for scenes but are not scenes in themselves. By convention scene files end in .POV and include files end with .INC.

It is legal to specify drive and directory information in the file specification however it is discouraged because it makes scene files less portable between various platforms.

It is typical to put standard include files in a special sub-directory. POV-Ray can only read files in the current directory or one referenced by the Library_Path option (See section 6.2.3.2 on page 166).

7.2.2 Declare

Identifiers may be declared and later referenced to make scene files more readable and to parametrize scenes so that changing a single declaration changes many values. There are several built-in identifiers which POV-Ray declares for you. See 7.1.7 on page 197 for details.

7.2.2.1 Declaring identifiers

An identifier is declared as follows.

```
#declare IDENTIFIER = ITEM
```

Where `IDENTIFIER` is the name of the identifier up to 40 characters long and `ITEM` is any of the following

float, vector, color or string expressions
objects (all kinds)
texture, pigment, normal, finish or halo
color_map, pigment_map, slope_map, normal_map
camera, light_source
atmosphere
fog
rainbow
sky_sphere
transform

Here are some examples.

```
#declare Rows = 5
#declare Count = Count+1
#declare Here = <1,2,3>
#declare White = rgb <1,1,1>
#declare Cyan = color blue 1.0  green 1.0
#declare Font_Name = "ariel.ttf"
#declare Ring = torus {5,1}
#declare Checks = pigment{ checker White, Cyan }

object{ Rod scale y*5 }          // not "cylinder { Rod } "
object {
  Ring
  pigment { Checks scale 0.5 }
  transform Skew
}
```

Declarations, like most language directives, can appear anywhere in the file — even within other statements. For example:

```
#declare Here=<1,2,3>
#declare Count=0                    // initialize Count

union {
  object { Rod translate Here*Count }
  #declare Count=Count+1           // re-declare inside union
  object { Rod translate Here*Count }
  #declare Count=Count+1           // re-declare inside union
  object { Rod translate Here*Count }
}
```

As this example shows, you can re-declare an identifier and may use previously declared values in that re-declaration. However if you attempt to re-declare an identifier as anything other than its original type, it will generate a warning message.

Declarations may be nested inside each other within limits. In the example in the previous section you could declare the entire union as a object. However for technical reasons you may not use any language directive inside the declaration of floats, vectors or color expressions.

7.2.3 Default Directive

POV-Ray creates a default texture when it begins processing. You may change those defaults as described below. Every time you specify a `texture { ... }` statement, POV-Ray creates a copy of the default texture. Anything you put in the texture statement overrides the default settings. If you attach a `pigment`, `normal` or `finish` to an object without any texture statement then POV-Ray checks to see if a texture has already been attached. If it has a texture then the pigment, normal or finish will modify the existing texture. If no texture has yet been attached to the object then the default texture is copied and the pigment, normal or finish will modify that texture.

You may change the default texture, pigment, normal or finish using the language directive `#default { ... }` as follows:

```
#default {
  texture {
    pigment {...}
    normal  {...}
    finish  {...}
  }
}
```

Or you may change just part of it like this:

```
#default {
  pigment {...}
}
```

This still changes the pigment of the default texture. At any time there is only one default texture made from the default pigment, normal and finish. The example above does not make a separate default for pigments alone. Note that the special textures `tiles` and `material_map` or a texture with a `texture_map` may not be used as defaults.

You may change the defaults several times throughout a scene as you wish. Subsequent `#default` statements begin with the defaults that were in effect at the time. If you wish to reset to the original POV-Ray defaults then you should first save them as follows:

```
//At top of file
#declare Original_Default = texture {}
```

later after changing defaults you may restore it with ...

```
#default {texture {Original_Default}}
```

If you do not specify a texture for an object then the default texture is attached when the object appears in the scene. It is not attached when an object is declared. For example:

```
#declare My_Object=
  sphere{ <0,0,0>, 1 }  // Default texture not applied
object { My_Object }    // Default texture added here
```

You may force a default texture to be added by using an empty texture statement as follows:

```
#declare My_Thing =
  sphere { <0,0,0>, 1 texture {} }  // Default texture applied
```

The original POV-Ray defaults for all items are given throughout the documentation under each appropriate section.

7.2.4 Version Directive

While many language changes have been made for POV-Ray 3.0, all of version 2.0 syntax and most of version 1.0 syntax still works. Whenever possible we try to maintain backwards compatibility. One feature introduced in 2.0 that was incompatible with any 1.0 scene files is the parsing of float expressions. Setting **+MV**1.0 command line switch or the Version=1.0 INI option turns off expression parsing as well as many warning messages so that nearly all 1.0 files will still work. The changes between 2.0 and 3.0 are not as extensive. Setting Version=2.0 is only necessary to eliminate some warning messages. Naturally the default setting for this option is Version=3.0.

The `#version` language directive is used to change modes within scene files. This switch or INI options only affects the initial setting.

Together with the built-in `version` identifier the `#version` directive allows you to save and restore the previous values of this compatibility setting. For example suppose MYSTUFF.INC is in version 1.0 format. At the top of the file you could put:

```
#declare Temp_Vers = version // Save previous value
#version 1.0                 // Change to 1.0 mode

... // Version 1.0 stuff goes here ...

#version Temp_Vers           // Restore previous version
```

Previous versions of POV-Ray would not allow you to change versions inside an object or declaration but that restriction has been lifted for POV-Ray 3.0.

Future versions of POV-Ray may not continue to maintain full backward compatibility even with the `#version` directive. We strongly encourage you to phase in 3.0 syntax as much as possible.

7.2.5 Conditional Directives

POV-Ray 3.0 allows a variety of new language directives to implement conditional parsing of various sections of your scene file. This is especially useful in describing the motion for animations but it has other uses as well. Also available is a `#while` loop directive. You may nest conditional directives 200 levels deep.

7.2.5.1 IF ELSE Directives

The simplest conditional directive is a traditional `#if` directive. It is of the form ...

```
#if (COND)
  // This section is
  //  parsed if COND is true
#else
  // This section is
  // parsed if COND is false
#end // End of conditional part
```

where `(COND)` is a float expression that evaluates to a boolean value. A value of 0.0 is false and any non-zero value is true. Note that extremely small values of about $1e-10$ are considered zero in case of round off errors. The parentheses around the condition are required. The `#else` directive is optional. The `#end` directive is required.

7.2.5.2 IFDEF Directives

The `#ifdef` directive is similar to the `#if` directive however it is used to determine if an identifier has been previously declared. After the `#ifdef` directive instead of a boolean expression you put a lone identifier enclosed in parentheses. For example:

```
#ifdef (User_Thing)
  // This section is parsed if the
  // identifier "User_Thing" was
  // previously declared
  object{User_Thing} // invoke identifier
#else
  // This section is parsed if the
  // identifier "User_Thing" was not
  // previously declared
  box{<0,0,0>,<1,1,1>} // use a default
#end
  // End of conditional part
```

The `#else` directive is optional. The `#end` directive is required.

7.2.5.3 IFNDEF Directives

The `#ifndef` directive is similar to the `#ifdef` directive however it is used to determine if the given identifier isn't declared yet. For example:

```
#ifndef (User_Thing)
  // This section is parsed if the
  // identifier "User_Thing" was not
  // previously declared
  box{<0,0,0>,<1,1,1>} // use a default
#else
  // This section is parsed if the
  // identifier "User_Thing" was
  // previously declared
  object{User_Thing} // invoke identifier
#end
  // End of conditional part
```

The `#else` directive is optional. The `#end` directive is required.

7.2.5.4 SWITCH CASE and RANGE Directives

A more powerful conditional is the `#switch` directive. The syntax is as follows ...

```
#switch (VALUE)
  #case (TEST_1)
    // This section is parsed if VALUE=TEST_1
  #break  //First case ends

  #case (TEST_2)
    // This section is parsed if VALUE=TEST_2
  #break  //Second case ends

  #range (LOW_1,HIGH_1)
    // This section is parsed if
    // (VALUE >= LOW_1) and (VALUE <= HIGH_1)
  #break  //Third case ends

  #range (LOW_2,HIGH_2)
    // This section is parsed if
    // (VALUE >= LOW_2) and (VALUE <= HIGH_2)
  #break  //Fourth case ends

  #else
    // This section is parsed if no other case or
    // range is true.
#end // End of conditional part
```

The float expression VALUE following the #switch directive is evaluated and compared to the values in the #case or #range directives. When using #case, it is followed by a float expression TEST_1 in parentheses. It is compared to the VALUE. As usual in POV-Ray, float comparisons are considered equal if their difference is under $1e-10$. If the values are equal, parsing continues normally until a #break, #else or #end directive is reached. If the comparison fails POV-Ray skips until another #case or #range is found.

If you use the #range directive it is followed by two float expressions LOW_1 and HIGH_1 which are enclosed in parentheses and separated by a comma. If the switch VALUE is in the range specified then parsing continues normally until a #break, #else or #end directive is reached. If the VALUE is outside the range the comparison fails and POV-Ray skips until another #case or #range is found.

If no #case or #range succeeds the #else section is parsed. The #else directive is optional. If no #else is specified and no match succeeds then parsing resumes after the #end directive.

There may be any number of #case or #range directives in any order you want. If a segment evaluates true but no #break is specified, the parsing will fall through to the next #case or #range and will continue until a #break, #else or #end. Hitting a #break while parsing a successful section causes an immediate jump to the #end without processing subsequent sections, even if a subsequent condition would also have been satisfied.

7.2.5.5 WHILE Directive

The #while directive is a looping feature that makes it easy to place multiple objects in a pattern or other uses. The #while directive is followed by a float expression that evaluates to a boolean value. A value of 0.0 is false and any non-zero value is true. Note that extremely small values of about $1e-10$ are considered zero in case of round off errors. The parentheses around the expression are required. If the condition is true parsing continues normally until an #end directive is reached. At the end, POV-Ray loops back to the #while directive and the condition is re-evaluated. Looping continues until the condition fails. When it fails, parsing continues after the #end directive. For example:

```
#declare Count=0
#while (Count < 5)
  object{MyObject translate x*3*Count}
  #declare Count=Count+1
#end
```

This example places five copies of MyObject in a row spaced three units apart in the *x*-direction.

7.2.6 User Message Directives

With the addition of conditional and loop directives, the POV-Ray language has the potential to be more like an actual programming language. This means that it will be necessary to have some way to see what is going on when trying to debug loops and conditionals. To fulfill this need we have added the ability to print text messages to the screen. You have a choice of five different text streams to use including the ability to generate a fatal error if you find it necessary. Limited formatting is available for strings output by this method.

7.2.6.1 Text Message Streams

The syntax for a text message is any of the following:

```
#debug      STRING
#error      STRING
#error      STRING
#render     STRING
#statistics STRING
#warning    STRING
```

Where `STRING` is any valid string of text including string identifiers or functions which return strings. For example:

```
#switch (clock*360)
  #range (0,180)
    #render "Clock in 0 to 180 range\n"
  #break

  #range (180,360)
    #render "Clock in 180 to 360 range\n"
  #break

  #else
    #warning "Clock outside expected range\n"
    #warning concat("Value is:",str(clock*360,5,0),"\n")
#end
```

There are seven distinct text streams that POV-Ray uses for output. You may output only to five of them. On some versions of POV-Ray, each stream is designated by a particular color. Text from these streams are displayed whenever it is appropriate so there is often an intermixing of the text. The distinction is only important if you choose to turn some of the streams off or to direct some of the streams to text files. On some systems you may be able to review the streams separately in their own scroll-back buffer. See 6.2.5.2 on page 174 for details on re-directing the streams to a text file.

Here is a description of how POV-Ray uses each stream. You may use them for whatever purpose you want except note that use of the `#error` stream causes a fatal error after the text is displayed.

DEBUG: This stream displays debugging messages. It was primarily designed for developers but this and other streams may also be used by the user to display messages from within their scene files.

FATAL: This stream displays fatal error messages. After displaying this text, POV-Ray will terminate. When the error is a scene parsing error, you may be shown several lines of scene text that leads up to the error.

RENDER: This stream displays information about what options you have specified to render the scene. It includes feedback on all of the major options such as scene name, resolution, animation settings, antialiasing and others.

STATISTICS: This stream displays statistics after a frame is rendered. It includes information about the number of rays traced, the length of time of the processing and other information.

WARNING: This stream displays warning messages during the parsing of scene files and other warnings. Despite the warning, POV-Ray can continue to render the scene.

The *BANNER* and *STATUS* streams can not be accessed by the user.

7.2.6.2 Text Formatting

Some escape sequences are available to include non-printing control characters in your text. These sequences are similar to those used in string literals in the C programming language. Note that these control characters only apply in text message directives. They are not implemented for other string usage in POV-Ray such as text objects or file names. Depending on what platform you are using, they may not be fully supported for console output. However they will appear in any text file if you re-direct a stream to a file. The sequences are:

”\a”	Bell or alarm, 0x07
”\b”	Backspace, 0x08
”\f”	Form feed, 0x0C
”\n”	New line (line feed) 0x0A
”\r”	Carriage return 0x0D
”\t”	Horizontal tab 0x09
”\v”	Vertical tab 0x0B
”\0”	Null 0x00
”\\”	Backslash 0x5C
”\’”	Single quote 0x27

"\"" Double quote 0x22

For example:

```
#debug "This is one line.\nBut this is another"
```

7.3 POV-Ray Coordinate System

Objects, lights and the camera are positioned using a typical 3D coordinate system. The usual coordinate system for POV-Ray has the positive y-axis pointing up, the positive x-axis pointing to the right and the positive z-axis pointing into the screen. The negative values of the axes point the other direction as shown in the images in section 4.1.1 on page 33.

Locations within that coordinate system are usually specified by a three component vector. The three values correspond to the x, y and z directions respectively. For example, the vector $\langle 1,2,3\rangle$ means the point that's one unit to the right, two units up and three units in front of the center of the *universe* at $\langle 0,0,0\rangle$.

Vectors are not always points though. They can also refer to an amount to size, move or rotate a scene element or to modify the texture pattern applied to an object.

The supported transformations are `rotate`, `scale` and `translate`. They are used to turn, size and translate an object or texture. A transformation matrix may also be used to specify complex transformations directly.

7.3.1 Transformations

The supported transformations are rotate, scale and translate. They are used to turn, size and translate an object or texture.

```
rotate <VECTOR>
scale <VECTOR>
translate <VECTOR>
```

7.3.1.1 Translate

An object or texture pattern may be moved by adding a *translate* parameter. It consists of the keyword `translate` followed by a vector expression. The terms of the vector specify the number of units to move in each of the x, y and z directions. Translate moves the element relative to it's current position. For example

```
sphere { <10, 10, 10>, 1
  pigment { Green }
  translate <-5, 2, 1>
}
```

will move the sphere from $\langle 10,10,10\rangle$ to $\langle 5,12,11\rangle$. It does not move it to the absolute location $\langle -5,2,1\rangle$. Translating by zero will leave the element unchanged on that axis. For example:

```
sphere { <10, 10, 10>, 1
  pigment { Green }
  translate 3*x // evaluates to <3,0,0> so move 3 units
                // in the x direction and none along y or z
}
```

7.3.1.2 Scale

You may change the size of an object or texture pattern by adding a *scale* parameter. It consists of the keyword `scale` followed by a vector expression. The 3 terms of the vector specify the amount of scaling in each of the x, y and z directions.

Scale is used to *stretch* or *squish* an element. Values larger than one stretch the element on that axis while values smaller than one are used to squish it. Scale is relative to the current element size. If the element has been previously re-sized using scale then scale will size relative to the new size. Multiple scale values may used.

For example

```
sphere { <0,0,0>, 1
  scale <2,1,0.5>
}
```

will stretch and smash the sphere into an ellipsoid shape that is twice the original size along the x-direction, remains the same size in the y-direction and is half the original size in the z-direction.

If a lone float expression is specified it is promoted to a three component vector whose terms are all the same. Thus the item is uniformly scaled by the same amount in all directions. For example:

```
object {
  MyObject
  scale 5 // Evaluates as <5,5,5> so uniformly scale
          // by 5 in every direction.
}
```

7.3.1.3 Rotate

You may change the orientation of an object or texture pattern by adding a *rotate* parameter. It consists of the keyword `rotate` followed by a vector expression. The three terms of the vector specify the number of degrees to rotate about each of the x-, y- and z-axes.

Note that the order of the rotations does matter. Rotations occur about the x-axis first, then the y-axis, then the z-axis. If you are not sure if this is what you want then you should only rotate on one axis at a time using multiple rotation statements to get a correct rotation. As in

```
rotate <0, 30, 0>  // 30 degrees around Y axis then,
rotate <-20, 0, 0> // -20 degrees around X axis then,
rotate <0, 0, 10>  // 10 degrees around Z axis.
```

Rotation is always performed relative to the axis. Thus if an object is some distance from the axis of rotation it will not only rotate but it will *orbit* about the axis as though it was swinging around on an invisible string.

To work out the rotation directions you must perform the famous *Computer Graphics Aerobics* exercise as explained in the section 4.1.1 on page 33.

7.3.1.4 Matrix Keyword

The `matrix` keyword can be used to explicitly specify the transformation matrix to be used for objects or textures. Its syntax is:

```
matrix < m00, m01, m02,
         m10, m11, m12,
         m20, m21, m22,
         m30, m31, m32 >
```

Where `m00` through `m32` are float expressions that specify the elements of a 4×4 matrix with the fourth column implicitly set to $\langle 0, 0, 0, 1 \rangle$. A point P, $P = \langle p_x, p_y, p_z \rangle$, is transformed into Q, $Q = \langle q_x, q_y, q_z \rangle$, by

$$\begin{aligned} q_x &= m_{0,0} p_x + m_{1,0} p_y + m_{2,0} p_z + m_{3,0} \\ q_y &= m_{0,1} p_x + m_{1,1} p_y + m_{2,1} p_z + m_{3,1} \\ q_z &= m_{0,2} p_x + m_{1,2} p_y + m_{2,2} p_z + m_{3,2} \end{aligned} \tag{7.6}$$

Normally you won't use the matrix keyword because it's less descriptive than the transformation commands and harder to visualize. There is an intersecting aspect of the matrix command though. It allows more general transformation like shearing. The following matrix causes an object to be sheared along the y-axis.

```
object {
  MyObject
  matrix < 1, 1, 0,
           0, 1, 0,
           0, 0, 1,
           0, 0, 0 >
}
```

7.3.2 Transformation Order

Because rotations are always relative to the axis and scaling is relative to the origin, you will generally want to create an object at the origin and scale and rotate it first. Then you may translate it into its proper position. It is a common mistake to carefully position an object and then to decide to rotate it because a rotation of an object causes it to orbit about the axis, the position of the object may change so much that it orbits out of the field of view of the camera!

Similarly scaling after translation also moves an object unexpectedly. If you scale after you translate the scale will multiply the translate amount. For example

```
translate <5, 6, 7>
scale 4
```

will translate to $\langle 20, 24, 28\rangle$ instead of $\langle 5, 6, 7\rangle$. Be careful when transforming to get the order correct for your purposes.

7.3.3 Transform Identifiers

At times it is useful to combine together several transformations and apply them in multiple places. A `transform` identifier may be used for this purpose. Transform identifiers are declared as follows:

```
#declare IDENT = transform { TRANSFORMATION... }
```

Where `IDENT` is the identifier to be declared and `TRANSFORMATION` is one or more `translate`, `rotate`, `scale` or `matrix` specifications or a previously declared transform identifier. A transform identifier is invoked by the `transform` keyword without any brackets as shown here:

```
object {
  MyObject           // Get a copy of MyObject
  transform MyTrans  // Apply the transformation
```

```
  translate -x*5     // Then move it 5 units left
}
object {
  MyObject           // Get another copy of MyObject
  transform MyTrans  // Apply the same transformation
  translate -x*5     // Then move this one 5 units right
}
```

On extremely complex CSG objects with lots of components it may speed up parsing if you apply a declared transformation rather than the individual `translate`, `rotate`, `scale` or `matrix` specifications. The `transform` is attached just once to each component. Applying each individual `translate`, `rotate`, `scale` or `matrix` specifications takes long. This only affects parsing — rendering works the same either way.

7.3.4 Transforming Textures and Objects

When an object is transformed all textures attached to the object **at that time** are transformed as well. This means that if you have a `translate`, `rotate`, `scale` or `matrix` in an object **before** a texture the texture will not be transformed. If the transformation is **after** the texture then the texture will be transformed with the object. If the transformation is **inside** the `texture { ... }` statement then **only the texture** is affected. The shape remains the same. For example:

```
sphere { 0, 1
  texture { Jade }  // texture identifier from TEXTURES.INC
  scale 3           // this scale affects both the
                    // shape and texture
}

sphere { 0, 1
  scale 3           // this scale affects the shape only
  texture { Jade }
}

sphere { 0, 1
  texture {
    Jade
    scale 3         // this scale affects the texture only
  }
}
```

Transformations may also be independently applied to pigment patterns and surface normal patterns. Note that scaling a normal pattern affects only the width and spacing. It does not affect the apparent height or depth of the bumps. For example:

```
box { <0, 0, 0>, <1, 1, 1>
  texture {
    pigment {
      checker Red, White
      scale 0.25 // This affects only the color pattern
    }
    normal {
      bumps 0.3  // This specifies apparent height of bumps
      scale 0.2  // Scales diameter and space between bumps
                 // but not the height. Has no effect on
                 // color pattern.
    }
    rotate y*45  // This affects the entire texture but
  }              // not the object.
}
```

7.4 Camera

The camera definition describes the position, projection type and properties of the camera viewing the scene. Its syntax is:

```
camera {
  [ perspective | orthographic | fisheye |
    ultra_wide_angle | omnimax | panoramic |
    cylinder FLOAT ]
  location <VECTOR>
  look_at <VECTOR>
  right <VECTOR>
  up <VECTOR>
  direction <VECTOR>
  sky <VECTOR>
  right <VECTOR>
  angle FLOAT
  blur_samples FLOAT
  aperture FLOAT
  focal_point <VECTOR>
  normal { NORMAL }
}
```

Depending on the projection type some of the parameters are required, some are optional and some aren't used. If no projection type is given the perspective camera will be used (pinhole camera). If no camera is specified a default camera is used.

Regardless of the projection type all cameras use the `location`, `look_at`, `right`, `up`, `direction` and `sky` keywords to determine the location and orientation of the camera. Their meaning differs with the projection type used. A more detailed explanation of the camera placement follows later.

7.4.1 Type of Projection

The following list explains the different projection types that can be used with the camera. The most common types are the perspective and orthographic projections.

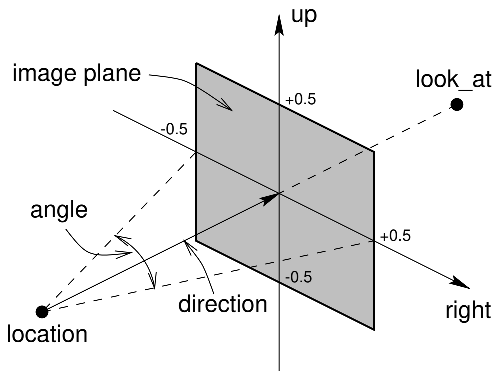


Figure 7.1: The perspective camera.

Perspective projection: This projection represents the classic pinhole camera. The (horizontal) viewing angle is either determined by the ratio between the length of the direction vector and the length of the right vector or by the optional keyword `angle`, which is the preferred way. The viewing angle has to be larger than 0 degrees and smaller than 180 degrees. See figure 7.1 for an overview of the perspective camera's geometry.

Orthographic projection: This projection uses parallel camera rays to create an image of the scene. The size of the image is determined by the lengths of the right and up vectors.
If you add the orthographic keyword after all other parameters of a perspective camera you'll get an orthographic view with the same image area, i. e. the size of the image is the same. In this case you needn't specify the lengths of the right and up vector because they'll be calculated automatically. You should be aware though that the visible parts of the scene change when switching from perspective to orthographic view. As long as all objects of interest are near the look_at location they'll be still visible if the orthographic camera is used. Objects farer away may get out of view while nearer objects will stay in view.

Fisheye projection: This is a spherical projection. The viewing angle is specified by the `angle` keyword. An angle of 180 degrees creates the *standard fisheye* while an angle of 360 degrees creates a *super-fisheye* (*I-see-everything-view*). If you use this projection you should get a circular image. If this isn't the case, i. e. you get an elliptical image, you should read 7.4.4.5.1 on page 225.

Ultra wide angle projection: This projection is somewhat similar to the fisheye but it projects the image onto a rectangle instead of a circle. The viewing angle can be specified using the `angle` keyword.

Omnimax projection: The omnimax projection is a 180 degrees fisheye that has a reduced viewing angle in the vertical direction. In reality this projection is used to make movies that can be viewed in the dome-like Omnimax theaters. The image will look somewhat elliptical. The `angle` keyword isn't used with this projection.

Panoramic projection: This projection is called *cylindrical equirectangular projection*. It overcomes the degeneration problem of the perspective projection if the viewing angle approaches 180 degrees. It uses a type of cylindrical projection to be able to use viewing angles larger than 180 degrees with a tolerable lateral-stretching distortion. The `angle` keyword is used to determine the viewing angle.

Cylindrical projection: Using this projection the scene is projected onto a cylinder. There are four different types of cylindrical projections depending on the orientation of the cylinder and the position of the viewpoint. The viewing angle and the length of the up or right vector determine the dimensions of the camera and the visible image. The camera to use is specified by a number. The types are:

1	vertical cylinder, fixed viewpoint
2	horizontal cylinder, fixed viewpoint
3	vertical cylinder, viewpoint moves along the cylinder's axis
4	horizontal cylinder, viewpoint moves along the cylinder's axis

If the perspective camera is used the `angle` keyword overrides the viewing angle specified by the `direction` keyword and vice versa. Each time `angle` is used the length of the direction vector is adjusted to fit the new viewing angle.

There is no limitation to the viewing angle except for the perspective projection. If you choose viewing angles larger than 360 degrees you'll see repeated images of the scene (the way the repetition takes place depends on the camera). This might be useful for special effects.

You should note that the vista buffer can only be used with the perspective and orthographic camera.

7.4.2 Focal Blur

Simulates focal depth-of-field by shooting a number of sample rays from jittered points within each pixel and averaging the results.

The aperture setting determines the depth of the sharpness zone. Large apertures give a lot of blurring, while narrow apertures will give a wide zone of sharpness. Note that, while this behaves as a real camera does, the values for aperture are purely arbitrary and are not related to f-stops.

The center of the *zone of sharpness* is the `focal_point` vector (the default `focal_point` is $\langle 0,0,0\rangle$).

The *blur_samples* value controls the maximum number of rays to use for each pixel. More rays give a smoother appearance but is slower, although this is controlled somewhat by an adaptive mechanism that stops shooting rays when a certain degree of confidence has been reached that shooting more rays would not result in a significant change.

The `confidence` and `variance` keywords control the adaptive function. The confidence value is used to determine when the samples seem to be *close enough* to the correct color. The variance value specifies an acceptable tolerance on the variance of the samples taken so far. In other words, the process of shooting sample rays is terminated when the estimated color value is very likely (as controlled by the confidence probability) near the real color value.

Since the confidence is a probability its values can range from 0 to 1 (the default is 0.9, i. e. 90%). The value for the variance should be in the range of the smallest displayable color difference (the default is 1/128).

Larger confidence values will lead to more samples, slower traces and better images. The same holds for smaller variance thresholds.

By default no focal blur is used, i. e. the default aperture is 0 and the default number of samples is 0.

7.4.3 Camera Ray Perturbation

The optional keyword `normal` may be used to assign a normal pattern to the camera. All camera rays will be perturbed using this pattern. This lets you create special effects. See the animated scene CAMERA2.POV for an example.

7.4.4 Placing the Camera

In the following sections the placing of the camera will be further explained.

7.4.4.1 Location and Look_At

Under many circumstances just two vectors in the camera statement are all you need to position the camera: `location` and `look_at`. For example:

```
camera {
  location <3,5,-10>
  look_at  <0,2,1>
}
```

The location is simply the x, y, z coordinates of the camera. The camera can be located anywhere in the ray-tracing universe. The default location is $\langle 0,0,0 \rangle$. The `look_at` vector tells POV-Ray to pan and tilt the camera until it is looking at the specified x, y, z coordinates. By default the camera looks at a point one unit in the z-direction from the location.

The `look_at` specification should almost always be the last item in the camera statement. If other camera items are placed after the `look_at` vector then the camera may not continue to look at the specified point.

7.4.4.2 The Sky Vector

Normally POV-Ray pans left or right by rotating about the y-axis until it lines up with the `look_at` point and then tilts straight up or down until the point is met exactly. However you may want to slant the camera sideways like an airplane making a banked turn. You may change the tilt of the camera using the `sky` vector. For example:

```
camera {
  location <3,5,-10>
  sky      <1,1,0>
  look_at  <0,2,1>
}
```

This tells POV-Ray to roll the camera until the top of the camera is in line with the sky vector. Imagine that the sky vector is an antenna pointing out of the top of the camera. Then it uses the `sky` vector as the axis of rotation left or right and then to tilt up or down in line with the `sky` vector. In effect you're telling POV-Ray to assume that the sky isn't straight up. Note that the sky vector must appear before the `look_at` vector.

The `sky` vector does nothing on its own. It only modifies the way the `look_at` vector turns the camera. The default value for sky is $\langle 0,1,0 \rangle$.

7.4.4.3 The Direction Vector

The `direction` vector tells POV-Ray the initial direction to point the camera before moving it with `look_at` or `rotate` vectors (the default is `direction` $\langle 0,0,1 \rangle$). It may also be used to control the (horizontal) field of view with some types of projection. This should be done using the easier to use `angle` keyword though.

If you are using the ultra wide angle, panoramic or cylindrical projection you should use a unit length direction vector to avoid strange results.

The length of the direction vector doesn't matter if one of the following projection types is used: orthographic, fisheye or omnimax.

7.4.4.4 Angle

The `angle` keyword specifies the (horizontal) viewing angle in degress of the camera used. Even though it is possible to use the direction vector to determine the viewing angle for the perspective camera it is much easier to use the angle keyword.

The necessary calculations to convert from one method to the other are described below. These calculations are used to determine the length of the direction vector whenever the `angle` keyword is encountered.

The viewing angle is converted to a direction vector length and vice versa using the formula The viewing angle α is given by the formula

$$\alpha = 2\tan^{-1}\frac{l_r}{2l_d} \tag{7.7}$$

where l_r and l_d are the lengths of the right and direction vector respectively.

From this the length of the direction vector can be calculated for a given viewing angle and right vector. From this the length of the direction l_d vector can be calculated for a given viewing angle $\angle$ and right vector.

$$l_d = \frac{l_r}{2\tan\left(\frac{\alpha}{2}\right)}. \tag{7.8}$$

7.4.4.5 Up and Right Vectors

The direction of the `up` and `right` vectors (together with the direction vector) determine the orientation of the camera in the scene. They are set implicitly by their default values of

```
right 4/3*x
up y
```

or the `look_at` parameter (in combination with `location)`. The directions of an explicitly specified right and up vector will be overridden by any following `look_at` parameter.

While some camera types ignore the length of these vectors others use it to extract valuable information about the camera settings. The following list will explain the meaning of the right and up vector for each camera type. Since the direction the vectors is always used to describe the orientation of the camera it will not be explained again.

Perspective projection: The lengths of the up and right vectors are used to set the size of the viewing window and the aspect ratio as described in detail in section 7.4.4.5.1. Since the field of view depends on the length of the direction vector (implicitly set by the `angle` keyword or explicitly set by the `direction` keyword) and the lengths of the right and up vectors you should carefully choose them in order to get the desired results.

Orthographic projection: The lengths of the right and up vector set the size of the viewing window regardless of the direction vector length, which is not used by the orthographic camera. Again the relation of the lengths is used to set the aspect ratio.

Fisheye projection: The right and up vectors are used to set the aspect ratio.

Ultra wide angle projection: The up and right vectors work in a similar way as for the perspective camera.

Omnimax projection: The Omnimax projection is quite similar to the fish-eye and thus the right and up vectors are also used to determine the aspect ratio of the resulting image.

Panoramic projection: The up and right vectors work in a similar way as for the perspective camera.

Cylindrical projection: In cylinder type one and three the axis of the cylinder lies along the `up` vector and the width is determined by the length of `right` vector or it may be overridden with the `angle` vector. In type three the `up` vector determines how many units high the image is. For example if you have `up 4*y` on a camera at the origin only points from $y = -2$ to $y = 2$ are visible. All viewing rays are perpendicular to the y-axis. For type two and four, the cylinder lies along the `right` vector. Viewing rays for type four are perpendicular to the `right` vector.

Note that the up, right and direction vectors should always remain perpendicular to each other or the image will be distorted. If this is not the case a warning message will be printed. The vista buffer will not work for non-perpendicular camera vectors.

7.4.4.5.1 Aspect Ratio

Together the right and up vectors define the *aspect ratio* (height to width ratio) of the resulting image. The default values `up` $\langle 0,1,0 rangle$ and `right` $\langle 1.33,0,0\rangle$ result in an aspect ratio of 4 to 3. This is the aspect ratio of a typical computer monitor. If you wanted a tall skinny image or a short wide panoramic image or a perfectly square image you should adjust the up and right vectors to the appropriate proportions.

Most computer video modes and graphics printers use perfectly square pixels. For example Macintosh displays and IBM S-VGA modes 640x480, 800x600 and 1024x768 all use square pixels. When your intended viewing method uses square pixels then the width and height you set with the **+W** and **+H** switches should also have the same ratio as the right and up vectors. Note that 640/480 = 4/3 so the ratio is proper for this square pixel mode.

Not all display modes use square pixels however. For example IBM VGA mode 320x200 and Amiga 320x400 modes do not use square pixels. These two modes still produce a 4/3 aspect ratio image. Therefore images intended to be viewed on such hardware should still use 4/3 ratio on their up and right vectors but the **+W** and **+H** settings will not be 4/3.

For example:

```
camera {
  location <3,5,-10>
  up       <0,1,0>
  right    <1,0,0>
  look_at  <0,2,1>
}
```

This specifies a perfectly square image. On a square pixel display like SVGA you would use **+W** and **+H** settings such as **+W**480 **+H**480 or **+W**600 **+H**600. However on the non-square pixel Amiga 320x400 mode you would want to use values of **+W**240 **+H**400 to render a square image.

7.4.4.5.2 Handedness

The `right` vector also describes the direction to the right of the camera. It tells POV-Ray where the right side of your screen is. The sign of the right vector can be used to determine the handedness of the coordinate system in use. The default right statement is:

```
right <1.33, 0, 0>
```

This means that the $+x$-direction is to the right. It is called a *left-handed* system because you can use your left hand to keep track of the axes. Hold out your left hand with your palm facing to your right. Stick your thumb up. Point straight ahead with your index finger. Point your other fingers to the right. Your bent fingers are pointing to the $+x$-direction. Your thumb now points into $+y$-direction. Your index finger points into the $+z$-direction.

To use a right-handed coordinate system, as is popular in some CAD programs and other ray-tracers, make the same shape using your right hand. Your thumb still points up in the $+y$-direction and your index finger still points forward in the $+z$-direction but your other fingers now say the $+x$-direction is to the left. That means that the `right` side of your screen is now in the $-x$-direction. To tell POV-Ray to act like this this you can use a negative x value in the `right` vector like this:

```
right <-1.33, 0, 0>
```

Since x increasing to the left doesn't make much sense on a 2D screen you now rotate the whole thing 180 degrees around by using a positive z value in your camera's location. You end up with something like this.

```
camera {
  location <0,0,10>
  up       <0,1,0>
  right    <-1.33,0,0>
  look_at  <0,0,0>
}
```

Now when you do your ray-tracer's aerobics, as explained in the section 4.1.1 on page 33, you use your right hand to determine the direction of rotations.

In a two dimensional grid, x is always to the right and y is up. The two versions of handedness arise from the question of whether z points into the screen or out of it and which axis in your computer model relates to up in the real world.

Architectural CAD systems, like AutoCAD, tend to use the *God's Eye* orientation that the z-axis is the elevation and is the model's up direction. This approach makes sense if you're an architect looking at a building blueprint on a computer screen. z means up, and it increases towards you, with x and y still across and up the screen. This is the basic right handed system.

Stand alone rendering systems, like POV-Ray, tend to consider you as a participant. You're looking at the screen as if you were a photographer standing in the scene. Up in the model is now y, the same as up in the real world and x is still to the right, so z must be depth, which increases away from you into the screen. This is the basic left handed system.

7.4.4.6 Transforming the Camera

The `translate` and `rotate` commands can re-position the camera once you've defined it. For example:

```
camera {
  location  < 0,  0,  0>
  direction < 0,  0,  1>
  up        < 0,  1,  0>
  right     < 1,  0,  0>
  rotate    <30, 60, 30>
  translate < 5,  3,  4>
}
```

In this example, the camera is created, then rotated by 30 degrees about the x-axis, 60 degrees about the y-axis and 30 degrees about the z-axis, then translated to another point in space.

7.4.5 Camera Identifiers

You may declare several camera identifiers if you wish. This makes it easy to quickly change cameras. For example:

```
#declare Long_Lens =
  camera {
    location -z*100
    angle 3
  }

#declare Short_Lens =
  camera {
    location -z*50
    angle 15
  }

camera {
  Long_Lens    // edit this line to change lenses
  look_at Here
}
```

7.5 Objects

Objects are the building blocks of your scene. There are a lot of different types of objects supported by POV-Ray: finite solid primitives, finite patch primitives, infinite solid polynomial primitives and light sources. Constructive Solid Geometry (CSG) is also supported.

The basic syntax of an object is a keyword describing its type, some floats, vectors or other parameters which further define its location and/or shape and some optional object modifiers such as texture, pigment, normal, finish, bounding, clipping or transformations.

The texture describes what the object looks like, i. e. its material. Textures are combinations of pigments, normals, finishes and halos. Pigment is the color or pattern of colors inherent in the material. Normal is a method of simulating various patterns of bumps, dents, ripples or waves by modifying the surface normal vector. Finish describes the reflective and refractive properties of a material. The halo is used to describe the interior of the object.

Bounding shapes are finite, invisible shapes which wrap around complex, slow rendering shapes in order to speed up rendering time. Clipping shapes are used to cut away parts of shapes to expose a hollow interior. Transformations tell the ray-tracer how to move, size or rotate the shape and/or the texture in the scene.

7.5.1 Empty and Solid Objects

It is very important that you know the basic concept behind empty and solid objects in POV-Ray to fully understand how features like halos and translucency are used.

Objects in POV-Ray can either be solid, empty or filled with (small) particles.

A solid object is made from the material specified by its pigment and finish statements (and to some degree its normal statement). By default all objects are assumed to be solid. If you assign a stone texture to a sphere you'll get a ball made completely of stone. It's like you had cut this ball from a block of stone. A glass ball is a massive sphere made of glass.

You should be aware that solid objects are conceptual things. If you e. g. clip away parts of the sphere you'll see that the sphere is empty, i. e. you'll clearly see that the interior is empty and it just has a very thin surface.

This is not contrary to the concept of a solid object used in POV-Ray. It is assumed that all space inside the sphere is covered by the sphere's material. Thus there is no room for any other particles like those used by fog or halos.

Empty objects are created by adding the `hollow` keyword (see 7.5.7.3 on page 276) to the object statement. An empty (or hollow) object is assumed to be made of a very thin surface which is of the material specified by the pigment, finish and normal statements. The object's interior is empty, i. e. it normally contains air molecules.

An empty object can be filled with particles by adding fog or atmosphere to the scene or by adding a halo to the object. It is very important to understand that in order to fill an object with any kind of particles it first has to be made hollow.

7.5.1.1 Halo Pitfall

There is a piftall in the current empty/solid object implementation that you have to be aware of.

In order to be able to put solid objects inside a halo (this also holds for fog and atmosphere) a test has to be made for every ray that passes through the halo. If this ray travels through a solid object the halo will not be calculated. This is what anyone will expect.

The problem arises when the camera ray is inside any non-hollow object. In this case the ray is already travelling through a solid object and even if the halo's container object is hit and it is hollow, the halo will not be calculated. There is no way of telling between these two cases.

POV-Ray has to determine wether the camera is inside any object prior to tracing a camera ray in order to be able to correctly render halos when the camera is inside the container object. There's no way around doing this.

The solution to this problem (that will often happen with infinite objects like planes) is to make those objects hollow too. Thus the ray will travel through a hollow object, will hit the container object and the halo will be calculated.

Note that the above is also true for atmosphere and fog.

7.5.1.2 Refraction Pitfall

There is a pitfall in the way refractive (and non-refractive translucent) objects are handled.

Imagine you want to create an object that's partially made of glass and stone. You'd use something like the following merge because you don't want to see any inside surfaces.

```
merge {
  sphere { <-1,0,0>, 2 texture { Stone } }
  sphere { <+1,0,0>, 2 texture { Glass } }
}
```

What's wrong with this, you may ask? The problem is that there is no way of telling what the interior of the actual object will look like. This is not a problem of POV-Ray, it's a general problem. You can't define the interior of any object in a surface based model. You would have to create some (complex) rules to decide what the interior will look like. Is it made of stone? Is it made of glass? Is it made of some bizarre mixture between glass and stone? Is it half stone and half glass? Where is the boundary between the two materials and what does it look like?

You will not be able to answer any of the above questions by just looking at the above object. You need more informations.

If you wanted to create an object made half of stone and half of glass you would have used the following statements.

```
union {
  intersection {
    sphere { <-1,0,0>, 2 }
    plane { x, 0 }
    texture { Stone }
  }
  intersection {
    sphere { <+1,0,0>, 2 }
    plane { x, 0 inverse }
    texture { Glass }
  }
}
```

This example is correct because there is one object made only of stone and one made only of glass.

You should never use objects whose interior is not well defined, i. e. there must not be different textures for the object having different refractive (and translucent) properties. You should be aware that this holds only for the lowest layer if you use layered textures.

See also 7.5.1.1 on page 229 for a similar problem with halos.

7.5.2 Finite Solid Primitives

There are twelve different solid finite primitive shapes: blob, box, cone, cylinder, fractal, height field, lathe, sphere, superellipsoid, surface of revolution, text object and torus. These have a well-defined *inside* and can be used in CSG (see section 7.5.5 on page 261). They are finite and respond to automatic bounding. As with all shapes they can be translated, rotated and scaled.

7.5.2.1 Blob

Blobs are an interesting and flexible object type. Mathematically they are iso-surfaces of scalar fields, i. e. their surface is defined by the strength of the field in each point. If this strength is equal to a threshold value you're on the surface otherwise you're not.

Picture each blob component as an object floating in space. This object is *filled* with a field that has its maximum at the center of the object and drops off to zero at the object's surface. The field strength of all those components are added together to form the field of the blob. Now POV-Ray looks for points where this field has a given value, the *threshold* value. All these points form the surface of the blob object. Points with a greater field value than the threshold value are considered to be inside while points with a smaller field value are outside.

There's another, simpler way of looking at blobs. They can be seen as a union of *flexible* components that attract or repel each other to form a *blobby* organic looking shape. The components' surfaces actually stretch out smoothly and connect as if they were made of honey or something like that.

A blob is made up of spherical and cylindrical components and is defined as follows:

```
blob {
  threshold THRESHOLD_VALUE
  cylinder { <END1>, <END2>, RADIUS, [ strength ] STRENGTH }
  sphere { <CENTER>, RADIUS, [ strength ] STRENGTH }
  [ component STRENGTH, RADIUS, <CENTER> ]
  [ hierarchy FLAG ]
  [ sturm ]
}
```

The `threshold` keyword determines the total field strength value that POV-Ray is looking for. By following the ray out into space and looking at how each blob component affects the ray, POV-Ray will find the points in space where the field strength is equal to the threshold value. The following list shows some things you should know about the threshold value.

1. The threshold value must be positive.
2. A component disappears if the threshold value is greater than its strength.
3. As the threshold value gets larger the surface you see gets closer to the centers of the components.
4. As the threshold value gets smaller the surface you see gets closer to the surface of the components.

Cylindrical components are specified by the keyword `cylinder` giving a cylinder formed by the base $\langle END1\rangle$, the apex $\langle END2\rangle$ and the *radius*. The cylinder has hemispherical caps at the base and apex. Spherical components are specified by the keyword `sphere` forming a sphere at $\langle CENTER\rangle$ with the given radius. Each component can be individually translated, rotated, scaled and textured. The complete syntax for the cylindrical and spherical components is:

```
sphere { <CENTER>, RADIUS, [strength] STRENGTH
  [ translate <VECTOR> ]
  [ rotate <VECTOR> ]
  [ scale <VECTOR> ]
  TEXTURE_MODIFIERS
}

cylinder { <END1>, <END2>, RADIUS, [strength] STRENGTH
  [ translate <VECTOR> ]
  [ rotate <VECTOR> ]
  [ scale <VECTOR> ]
  TEXTURE_MODIFIERS
}
```

By unevenly scaling a spherical component you can create ellipsoidal components. The `component` keyword gives a spherical component and is only used for compatibility with earlier POV-Ray versions.

The `strength` parameter is a float value specifying the field strength at the center of the object. The strength may be positive or negative. A positive value will make that component attract other components while a negative value will make it repel other components. Components in different, separate blob shapes do not affect each other.

You should keep the following things in mind.

1. The strength value may be positive or negative. Zero is a bad value, as the net result is that no field was added — you might just as well have not used this component.
2. If strength is positive POV-Ray will add the component's field to the space around the center of the component. If this adds enough field strength to be greater than the `threshold` value you will see a surface.
3. If the strength value is negative POV-Ray will subtract the component's field from the space around the center of the component. This will only do something if there happen to be positive components nearby. What happens is that the surface around any nearby positive components will be dented away from the center of the negative component.

The components of each blob object are internally bounded by a spherical bounding hierarchy to speed up blob intersection tests and other operations. By using the optional keyword `hierarchy` you can switch this hierarchy off.

An example of a three component blob is:

```
blob {
  threshold 0.6
  sphere { <.75, 0, 0>, 1, 1 }
  sphere { <-.375, .64952, 0>, 1, 1 }
  sphere { <-.375, -.64952, 0>, 1, 1 }
  scale 2
}
```

If you have a single blob component then the surface you see will just look like the object used, i. e. a sphere or a cylinder, with the surface being somewhere inside the surface specified for the component. The exact surface location can be determined from the blob equation listed below (you will probably never need to know this, blobs are more for visual appeal than for exact modeling).

For the more mathematically minded, here's the formula used internally by POV-Ray to create blobs. You don't need to understand this to use blobs. The formula used for a single blob component is:

$$density = strength\left(1 - radius^2\right)^2 \tag{7.9}$$

This formula has the nice property that it is exactly equal to the *strength* parameter at the center of the component and drops off to exactly 0 at a distance from the center of the component that is equal to the *radius* value. The density formula for more than one blob component is just the sum of the individual component densities:

$$density = \sum_i density_i. \tag{7.10}$$

The calculations for blobs must be very accurate. If this shape renders improperly you may add the keyword `sturm` after the last component to use POV-Ray's slower-yet-more-accurate Sturmian root solver.

7.5.2.2 Box

A simple box can be defined by listing two corners of the box like this:

```
box { <CORNER1>, <CORNER2> }
```

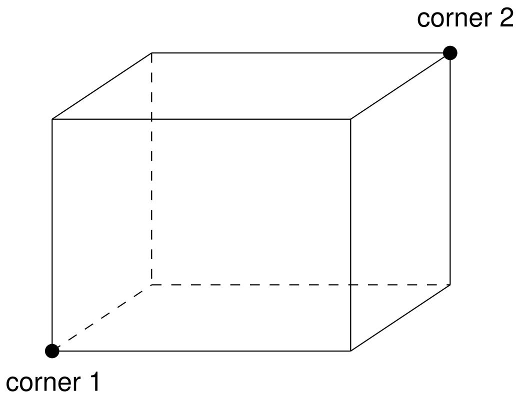


Figure 7.2: The geometry of a box.

Where $\langle CORNER1\rangle$ and $\langle CORNER2\rangle$ are vectors defining the x, y, z coordinates of the opposite corners of the box. See figure 7.2 for details about the box geometry.

Note that all boxes are defined with their faces parallel to the coordinate axes. They may later be rotated to any orientation using the `rotate` keyword.

Each element of $\langle CORNER1 \rangle$ should always be less than the corresponding element in $\langle CORNER2 \rangle$. If any elements of $\langle CORNER1 \rangle$ are larger than $\langle CORNER2 \rangle$ the box will not appear in the scene.

Boxes are calculated efficiently and make good bounding shapes (if manually bounding seems to be necessary).

7.5.2.3 Cone

A finite length cone or a *frustum* (a cone with the point cut off) may be defined by.

```
cone {
  <BASE_POINT>, BASE_RADIUS, <CAP_POINT>, CAP_RADIUS
  [ open ]
}
```

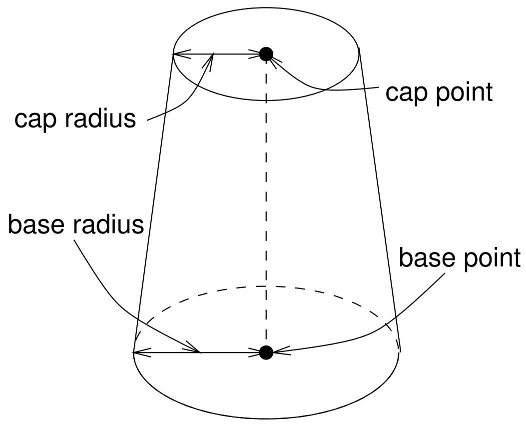


Figure 7.3: The geometry of a cone.

Where $\langle BASE\_POINT \rangle$ and $\langle CAP\_POINT \rangle$ are vectors defining the x, y, z coordinates of the center of the cone's base and cap and BASE_RADIUS and CAP_RADIUS are float values for the corresponding radii. See figure 7.3 for details about the cone geometry.

Normally the ends of a cone are closed by flat planes which are parallel to each other and perpendicular to the length of the cone. Adding the optional keyword `open` after CAP_RADIUS will remove the end caps and results in a tapered hollow tube like a megaphone or funnel.

7.5.2.4 Cylinder

A finite length cylinder with parallel end caps may be defined by.

```
cylinder {
  <BASE_POINT>, <CAP_POINT>, RADIUS
  [ open ]
}
```

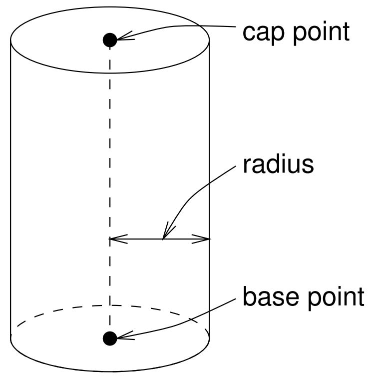


Figure 7.4: The geometry of a cylinder.

Where ⟨*BASE_POINT*⟩ and ⟨*CAP_POINT*⟩ are vectors defining the *x*, *y*, *z* coordinates of the cylinder's base and cap and RADIUS is a float value for the radius. See figure 7.4 for details about the cylinder geometry.

Normally the ends of a cylinder are closed by flat planes which are parallel to each other and perpendicular to the length of the cylinder. Adding the optional keyword `open` after the radius will remove the end caps and results in a hollow tube.

7.5.2.5 Height Field

Height fields are fast, efficient objects that are generally used to create mountains or other raised surfaces out of hundreds of triangles in a mesh. The height field syntax is:

```
height_field {
  FILE_TYPE "FILENAME"
  [ hierarchy BOOL ]
  [ smooth BOOL ]
  [ water_level FLOAT ]
}
```

A height field is essentially a one unit wide by one unit long square with a mountainous surface on top. The height of the mountain at each point is taken from the color number or palette index of the pixels in a graphic image file. The maximum height is one, which corresponds to the maximum possible color or palette index value in the image file. See figure 7.5 for details about the height field geometry.

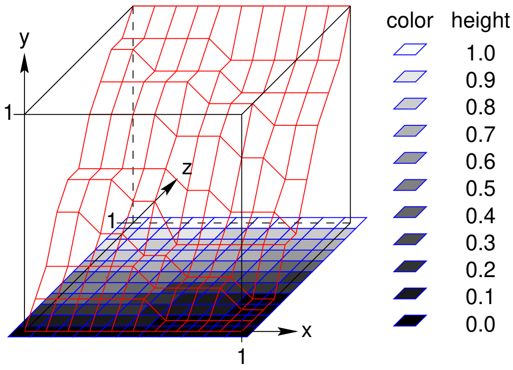


Figure 7.5: The size and orientation of an un-scaled height field.

The mesh of triangles corresponds directly to the pixels in the image file. Each square formed by four neighboring pixels is divided into two triangles. An image with a resolution of $N \times M$ pixels has $(N-1) \times (M-1)$ squares that are divided into $2 \times (N-1) \times (M-1)$ triangles.

The resolution of the height field is influenced by two factors: the resolution of the image and the resolution of the color/index values. The size of the image determines the resolution in the x- and z-direction. A larger image uses more triangles and looks smoother. The resolution of the color/index value determines the resolution along the y-axis. A height field made from an 8 bit image can have 256 different height levels while one made from a 16 bit image can have up to 65536 different height levels. Thus the second height field will look much smoother in the y-direction if the height field is created appropriately.

The size/resolution of the image does not affect the size of the height field. The un-scaled height field size will always be 1×1. Higher resolution image files will create smaller triangles, not larger height fields.

There are six or possibly seven types of files which can define a heightfield, as follows:

```
height_field { gif "filename.gif" }
height_field { pgm "filename.pgm" }
height_field { png "filename.png" }
height_field { pot "filename.pot" }
height_field { ppm "filename.ppm" }
height_field { sys "filename.???" }
height_field { tga "filename.tga" }
```

The image file used to create a height field can be a GIF, TGA, POT, PNG, PGM, PPM and possibly a system specific (e. g. Windows BMP or Macintosh Pict) format file. The GIF, PNG, PGM and possibly system format files are the only ones that can be created using a standard paint program. Though there are paint programs for creating TGA image files they won't be of much use for creating the special 16 bit TGA files used by POV-Ray (see below and 7.8.4 on page 359 for more details).

In an image file like GIF that uses a color palette the color number is the palette index at a given pixel. Use a paint program to look at the palette of a GIF image. The first color is palette index zero, the second is index one, the third is index two and so on. The last palette entry is index 255. Portions of the image that use low palette entries will result in lower parts of the height field. Portions of the image that use higher palette entries will result in higher parts of the height field.

Height fields created from GIF files can only have 256 different height levels because the maximum number of colors in a GIF file is 256.

The color of the palette entry does not affect the height of the pixel. Color entry 0 could be red, blue, black or orange but the height of any pixel that uses color entry 0 will always be 0. Color entry 255 could be indigo, hot pink, white or sky blue but the height of any pixel that uses color entry 255 will always be 1.

You can create height field GIF images with a paint program or a fractal program like FRACTINT. You can usually get FRACTINT from most of the same sources as POV-Ray.

A POT file is essentially a GIF file with a 16 bit palette. The maximum number of colors in a POT file is 65536. This means a POT height field can have up to 65536 possible height values. This makes it possible to have much smoother height fields. Note that the maximum height of the field is still 1 even though more intermediate values are possible.

At the time of this writing the only program that created POT files was a freeware IBM-PC program called FRACTINT. POT files generated with this fractal program create fantastic landscapes.

The TGA and PPM file formats may be used as a storage device for 16 bit numbers rather than an image file. These formats use the red and green bytes of each pixel to store the high and low bytes of a height value. These files are as smooth as POT files but they must be generated with special custom-made programs. Several programs can create TGA heightfields in the format POV uses, such as GFORGE and *Terrain Maker*.

PNG format heightfields are usually stored in the form of a grayscale image with black corresponding to lower and white to higher parts of the height field. Because PNG files can store up to 16 bits in grayscale images they will be as smooth as TGA and PPM images. Since they are grayscale images you will be able to view them with a regular image viewer. GFORGE can create 16-bit heightfields in PNG format. Color PNG images will be used in the same way as TGA and PPM images.

SYS format is a platform specific file format. See your platform specific documentation for details.

An optional water_level parameter may be added after the file name. It consists of the keyword water_level followed by a float value telling the program to ignore parts of the height field below that value. The default value is zero and legal values are between zero and one. For example water_level .5 tells POV-Ray to only render the top half of the height field. The other half is *below the water* and couldn't be seen anyway. This term comes from the popular use of height fields to render landscapes. A height field would be used to create islands and another shape would be used to simulate water around the islands. A large portion of the height field would be obscured by the *water* so the water_level parameter was introduced to allow the ray-tracer to ignore the unseen parts of the height field. water_level is also used to cut away unwanted lower values in a height field. For example if you have an image of a fractal on a solid colored background, where the background color is palette entry 0, you can remove the background in the height field by specifying, water_level .001.

Normally height fields have a rough, jagged look because they are made of lots of flat triangles. Adding the keyword smooth causes POV-Ray to modify the surface normal vectors of the triangles in such a way that the lighting and shading of the triangles will give a smooth look. This may allow you to use a lower resolution file for your height field than would otherwise be needed. However, smooth triangles will take longer to render.

In order to speed up the intersection tests an one-level bounding hierarchy is available. By default it is always used but it can be switched off to eventually improve the rendering speed for small height fields (i. e. low resolution images).

7.5.2.6 Julia Fractal

A julia fractal object is a 3-D slice of a 4-D object created by generalizing the process used to create the classic Julia sets. You can make a wide variety of strange objects using julia_fractal, including some that look like bizarre blobs of twisted taffy.

The julia_fractal syntax (with default values listed in comments) is:

```
julia_fractal {
  4DJULIA_PARAMETER                  // default is <1,0,0,0>
  [ quaternion | hypercomplex ]      // default is quaternion
  [ sqr | cube | exp |
    reciprocal | sin | asin |
    sinh | asinh | cos | acos |
    cosh | acosh | tan | atan |
    tanh | atanh | log | pwr(X,Y) ] // default is sqr
  [ max_iteration MAX_ITERATION ]    // default value 20
  [ precision PRECISION ]            // default value 20
  [ slice 4DNORMAL, DISTANCE ]       // default <0,0,0,1>,0
}
```

The 4-D vector *4DJULIA_PARAMETER* is the classic Julia parameter p in the iterated formula $f(h)+p$.

The julia fractal object is calculated by using an algorithm that determines whether an arbitrary point $h(0)$ in 4-D space is inside or outside the object. The algorithm requires generating the sequence of vectors $h(0)$, $h(1)$, ... by iterating the formula

$$h(n+1) = f(h(n)) + p, \quad n = 0,1,\ldots,max\_iteration - 1, \tag{7.11}$$

where p is the fixed 4-D vector parameter of the julia fractal and $f()$ is one of the functions sqr, cube, ... specified by the presence of the corresponding keyword. The point $h(0)$ that begins the sequence is considered inside the julia fractal object if none of the vectors in the sequence escapes a hypersphere of radius 4 about the origin before the iteration number reaches the *max_iteration* value. As you increase *max_iteration*, some points escape that did not previously escape, forming the julia fractal. Depending on the *JULIA_PARAMETER*, the julia fractal object is not necessarily connected; it may be scattered fractal *dust*. Using a low *max_iteration* can fuse together the dust to make a solid object. A high *max_iteration* is more accurate but slows rendering. Even though it is not accurate, the solid shapes you get with a *low_maximum* iteration value can be quite interesting.

Since the mathematical object described by this algorithm is four-dimensional and POV-Ray renders three dimensional objects, there must be a way to reduce the number of dimensions of the object from four dimensions to three. This is accomplished by intersecting the 4-D fractal with a 3-D *plane* defined by the `slice` field and then projecting the intersection to 3-D space. The slice plane is the 3-D space that is perpendicular to *NORMAL4D* and is *DISTANCE* units from the origin. Zero length *NORMAL4D* vectors or a *NORMAL4D* vector with a zero fourth component are illegal.

You can get a good feel for the four dimensional nature of a julia fractal by using POV-Ray's animation feature to vary a slice's *DISTANCE* parameter. You can make the julia fractal appear from nothing, grow, then shrink to nothing as *DISTANCE* changes, much as the cross section of a 3-D object changes as it passes through a plane.

The `precision` parameter is a tolerance used in the determination of whether points are inside or outside the fractal object. Larger values give more accurate results but slower rendering. Use as low a value as you can without visibly degrading the fractal object's appearance.

The presence of the keywords `quaternion` or `hypercomplex` determine which 4-D algebra is used to calculate the fractal. Both are 4-D generalizations of the complex numbers but neither satisfies all the field properties (all the properties of real and complex numbers that many of us slept through in high school). Quaternions have non-commutative multiplication and hypercomplex numbers can fail to have a multiplicative inverse for some non-zero elements (it has been proved that you cannot successfully generalize complex numbers to four dimensions with all the field properties intact, so something has to break). Both of these algebras were discovered in the 19th century. Of the two, the quaternions are much better known, but one can argue that hypercomplex numbers are more useful for our purposes, since complex valued functions such as sin, cos, etc. can be generalized to work for hypercomplex numbers in a uniform way.

For the mathematically curious, the algebraic properties of these two algebras can be derived from the multiplication properties of the unit basis vectors $1 = \langle 1,0,0,0\rangle$, $i = \langle 0,1,0,0\rangle$, $j = \langle 0,0,1,0\rangle$ and $k = \langle 0,0,0,1\rangle$. In both algebras $1x = x1 = x$ for any x (1 is the multiplicative identity). The basis vectors 1 and i behave exactly like the familiar complex numbers 1 and i in both algebras.

Quaternion basis vector multiplication rules:

$$\begin{aligned} &ij = k && jk = i && ki = j && (7.12)\\ &ji = -k && kj = -i && ik = -j && (7.13)\\ &ii = jj = kk = -1 && ijk = -1 && && (7.14)\end{aligned}$$

Hypercomplex basis vector multiplication rules:

$$\begin{aligned} &ij = k && jk = -i && ki = -j && (7.15)\\ &ji = k && kj = -i && ik = -j && (7.16)\\ &ii = jj = kk = -1 && ijk = 1 && && (7.17)\end{aligned}$$

A distance estimation calculation is used with the quaternion calculations to speed them up. The proof that this distance estimation formula works does not generalize from two to four dimensions but the formula seems to work well anyway, the absence of proof notwithstanding!

The presence of one of the function keywords `sqr`, `cube`, etc. determines which function is used for $f(h)$ in the iteration formula $h(n+1) = f(h(n)) + p$. Most of the function keywords work only if the hypercomplex keyword is present. Only sqr and cube work with quaternions. The functions are all familiar complex functions generalized to four dimensions. See table 7.1 on the following page for a list of the available functions.

A simple example of a julia fractal object is:

```
julia_fractal {
  <-0.083,0.0,-0.83,-0.025>
  quaternion
  sqr
  max_iteration 8
  precision 15
}
```

The first renderings of julia fractals using quaternions were done by Alan Norton and later by John Hart in the '80's. This new POV-Ray implementation follows FRACTINT in pushing beyond what is known in the literature by using hypercomplex numbers

Function Keyword	Maps 4-D value h to
`sqr`	h^2
`cube`	h^3
`exp`	e raised to the power h
`reciprocal`	$1/h$
`sin`	sine of h
`asin`	arcsine of h
`sinh`	hyperbolic sine of h
`asinh`	inverse hyperbolic sine of h
`cos`	cosine of h
`acos`	arccosine of h
`cosh`	hyperbolic cos of h
`acosh`	inverse hyperbolic cosine of h
`tan`	tangent of h
`atan`	arctangent of h
`tanh`	hyperbolic tangent of h
`atanh`	inverse hyperbolic tangent of h
`log`	natural logarithm of h
`pwr(x,y)`	h raised to the complex power $x + \imath y$

Table 7.1: All available julia fractal functions.

and by generalizing the iterating formula to use a variety of transcendental functions instead of just the classic Mandelbrot $z^2 + c$ formula. With an extra two dimensions and eighteen functions to work with, intrepid explorers should be able to locate some new fractal beasties in hyperspace, so have at it!

7.5.2.7 Lathe

The lathe is an object generated from rotating a two-dimensional curve about an axis. This curve is defined by a set of points which are connected by linear, quadratic or cubic spline curves. The syntax is:

```
lathe {
  [ linear_spline | quadratic_spline | cubic_spline ]
  NUMBER_OF_POINTS,
  <POINT_1>, <POINT_2>, ..., <POINT_n>
  [ sturm ]
}
```

The parameter *NUMBER_OF_POINTS* determines how many two-dimensional points are forming the curve. These points are connected by linear, quadratic or cubic splines as specified by an optional keyword (the default is `linear_spline`). Since the curve is not automatically closed, i. e. the first and last points are not automatically connected, you'll have to do this by your own if you want a closed curve. The curve thus defined is rotated about the y-axis to form the lathe object which is centered at the origin.

The following examples creates a simple lathe object that looks like a *thick* cylinder, i. e. a cylinder with a thick wall:

```
lathe {
  linear_spline
  5,
  <2, 0>, <3, 0>, <3, 5>, <2, 5>, <2, 0>
  pigment {Red}
}
```

The cylinder has an inner radius of 2 and an outer radius of 3, giving a wall width of 1. It's height is 5 and it's located at the origin pointing up, i. e. the rotation axis is the y-axis. Note that the first and last point are equal to get a closed curve.

The splines that are used by the lathe and prism objects are a little bit difficult to understand. The basic concept of splines is to draw a curve through a given set of points in a determined way. The linear spline is the simplest spline because it's nothing more than connecting consecutive points with a line. This means that the curve that is drawn between two points only depends on those two points. No additional information is taken into account. Quadratic and cubic splines are different in that they do not only take other points into account when connecting two points but they also look smoother and — in the case of the cubic spline — produce smoother transitions at each point.

Quadratic splines are made of quadratic curves. Each of them connects two consecutive points. Since those two points (call them second and third point) aren't enough to describe a quadratic curve the predecessor of the third point is taken into account when the curve is drawn. Mathematically the relationship (their location on the 2-D plane) between the third and fourth point determines the slope of the curve at the third point. The slope of the curve at the second point is out of control. Thus quadratic splines look much *smoother* than linear splines but the transitions at each point are generally not smooth because the slopes on *both sides* of the point are different.

Cubic splines overcome the transition problem of quadratic splines because they also take the first point into account when drawing the curve between the second and third point. The slope at the second point is under control now and allows a smooth transition at each point. Thus cubic splines produce the most flexible and smooth curves.

You should note that the number of spline segments, i. e. curves between two points, depends on the spline type used. For linear splines you get $n-1$ segments connecting the points P_i, $i = 1, \ldots, n$. A quadratic spline gives you $n-2$ segments because the last point is only used for determining the slope as explained above (thus you'll need at least three points to define a quadratic spline). The same holds for cubic splines where you get $n-3$ segments with the first and last point used only for slope calculations (thus needing at least four points).

If you want to get a closed quadratic and cubic spline with smooth transitions at the end points you have to make sure that in the cubic case $P_{n-1} = P_2$ (to get a closed curve), $P_n = P_3$ and $P_{n-2} = P_1$ (to smooth the transition). In the quadratic case $P_{n-1} = P_1$ (to close the curve) and $P_n = P_2$ (for a smooth transition).

The slower but more accurate Sturmian root solver may be used with the quadratic spline lathe if the shape does not render properly. Since a quadratic polynomal has to be solved for the linear spline lathe the Sturmian root solver is not needed. In case of cubic splines the Sturmian root solver is always used because a 6th order polynomal has to be solved.

7.5.2.8 Prism

The prism is an object generated from sweeping one or more two-dimensional, closed curves along an axis. These curves are defined by a set of points which are connected by linear, quadratic or cubic splines.

The syntax for the prism is:

```
prism {
  [ linear_sweep | conic_sweep ]
  [ linear_spline | quadratic_spline | cubic_spline ]
  HEIGHT1,
  HEIGHT2,
  TOTAL_NUMBER_OF_POINTS,
  <POINT_1>, <POINT_2>, ..., <POINT_n>
  [ open ]
  [ sturm ]
}
```

The prism object allows you to use any number of sub-prisms inside one prism statement (they are of the same spline and sweep type). Wherever an even number of sub-prisms overlaps a whole appears.

The syntax of the prism object depends on the type of spline curve used. Below the syntax of the linear spline prism is given.

```
prism {
  linear_spline
  HEIGHT1,
  HEIGHT2,
  TOTAL_NUMBER_OF_POINTS,
  <A_1>, <A_2>, ..., <A_na>, <A_1>,
  <B_1>, <B_2>, ..., <B_nb>, <B_1>,
  <C_1>, <C_2>, ..., <C_nc>, <C_1>,
  ...
}
```

Each of the sub-prisms has to be closed by repeating the first point of a sub-prism at the end of the sub-prism's point sequence. If this is not the case a warning is issued and the prism is ignored (with linear splines automatic closing is used). This implies that all points of a prism are different (except the first and last of course). This applies to all spline types though the control points of the quadratic and cubic splines can be arbitrarily chosen.

The last sub-prism of a linear spline prism is automatically closed — just like the last sub-polygon in the polygon statement — if the first and last point of the sub-polygon's point sequence are not the same. This make it very easy to convert between polygons and prisms. Quadratic and cubic splines are never automatically closed.

The syntax for quadratic spline prisms is:

```
prism {
  quadratic_spline
  HEIGHT1,
  HEIGHT2,
  TOTAL_NUMBER_OF_POINTS,
  <CL_A>, <A_1>, <A_2>, ..., <A_na>, <A_1>,
  <CL_B>, <B_1>, <B_2>, ..., <B_nb>, <B_1>,
  <CL_C>, <C_1>, <C_2>, ..., <C_nc>, <C_1>,
  ...
}
```

Quadratic spline sub-prisms need an additional control point at the beginning of each sub-prisms' point sequence to determine the slope at the start of the curve.

Last but not least the syntax for the cubic spline prism.

```
prism {
  cubic_spline
  HEIGHT1,
  HEIGHT2,
  TOTAL_NUMBER_OF_POINTS,
  <CL_A1>, <A_1>, <A_2>, ..., <A_na>, <A_1>, <CL_A2>,
  <CL_B1>, <B_1>, <B_2>, ..., <B_nb>, <B_1>, <CL_B2>,
  <CL_C1>, <C_1>, <C_2>, ..., <C_nc>, <C_1>, <CL_C2>,
  ...
}
```

In addition to the closed point sequence each cubic spline sub-prism needs two control points to determine the slopes at the start and end of the curve.

The parameter TOTAL_NUMBER_OF_POINTS determines how many two-dimensional points (lying in the x-z-plane) form the curves (this includes all control points needed for quadratic and cubic splines). The curves are swept along the y-axis from HEIGHT1 to HEIGHT2 to form the prism object. By default linear sweeping is used to create the prism, i. e. the prism's walls are perpendicular to the *x*-*z*-plane (the size of the curve does not change during the sweep). You can also use conic sweeping /`conic_sweep` that leads to a prism with *cone-like* walls by scaling the curve down during the sweep.

Like cylinders the prism is normally closed. You can remove the caps on the prism by using the `open` keyword. If you do so you shouldn't use it with CSG because the results may get wrong.

The following example creates a simple prism object that looks like a piece of cake:

```
prism {
  linear_sweep
  linear_spline
  0, 1,
  4,
  <-1, 0>, <1, 0>, <0, 5>, <-1, 0>
  pigment {Red}
}
```

For an explanation of the spline concept read the description of the lathe object.

The slower but more accurate Sturmian root solver may be used with the cubic spline prisms if the shape does not render properly. The linear and quadratic spline prisms do not need the Sturmian root solver.

7.5.2.9 Sphere

The syntax of the sphere object is:

```
sphere {
  <CENTER>, RADIUS
}
```

Where $\langle CENTER \rangle$ is a vector specifying the x, y, z coordinates of the center of the sphere and RADIUS is a float value specifying the radius. Spheres may be scaled unevenly giving an ellipsoid shape. See figure 7.6 on the next page for details about the sphere geometry.

Because spheres are highly optimized they make good bounding shapes (if manal bounding seems to be necessary).

7.5.2.10 Superquadric Ellipsoid

The superquadric ellipsoid is an extension of the quadric ellipsoid. It can be used to create boxes and cylinders with round edges and other interesting shapes. Mathemati-

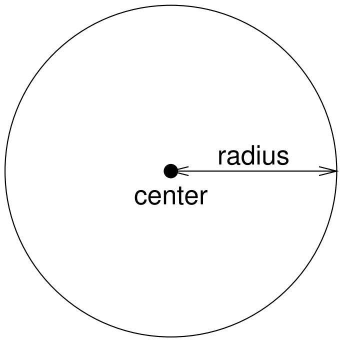


Figure 7.6: The geometry of a sphere.

cally it is given by the equation:

$$f(x,y,z) = \left(|x|^{2/e} + |y|^{2/e}\right)^{e/n} + |z|^{2/n} - 1 = 0 \tag{7.18}$$

The values of e and n, called the *east-west* and *north-south* exponent, determine the shape of the superquadric ellipsoid. Both have to be greater than zero. The sphere is e. g. given by $e = 1$ and $n = 1$.

The syntax of the superquadric ellipsoid, which is located at the origin, is:

```
superellipsoid { <e, n> }
```

Two useful objects are the rounded box and the rounded cylinder. These are declared in the following way.

```
#declare Rounded_Box = superellipsoid { <r, r> }
#declare Rounded_Cylinder = superellipsoid { <1, r> }
```

The roundedness r determines the roundedness of the edges and has to be greater than zero and smaller than one. The smaller you choose the values of r the smaller and sharper the edges will get.

Very small values of e and n might cause problems with the root solver (the Sturmian root solver cannot be used).

7.5.2.11 Surface of Revolution

The surface of revolution (SOR) object is generated by rotating the graph of a function about an axis. This function describes the dependence of the radius from the position on the rotation axis. The syntax of the SOR object is:

```
sor {
  NUMBER_OF_POINTS,
  <POINT0>, <POINT1>, ..., <POINTn-1>
  [ open ]
  [ sturm ]
}
```

The points $\langle POINT0\rangle$ through $\langle POINT\,n-1\rangle$ are two-dimensional vectors consisting of the radius and the corresponding height, i. e. the position on the rotation axis. These points are smoothly connected (the curve is passing through the specified points) and rotated about the y-axis to form the SOR object. The first and last points are only used to determine the slopes of the function at the start and end point. The function used for the SOR object is similar to the splines used for the lathe object. The difference is that the SOR object is less flexible because it underlies the restrictions of any mathematical function, i. e. to any given point y on the rotation axis belongs at most one function value, i. e. one radius value. You can't rotate closed curves with the SOR object.

The optional keyword `open` allows you to remove the caps on the SOR object. If you do this you shouldn't use it with CSG anymore because the results may be wrong.

The SOR object is useful for creating bottles, vases, and things like that. A simple vase could look like this:

```
#declare Vase = sor {
  7,
  <0.000000, 0.000000>
  <0.118143, 0.000000>
  <0.620253, 0.540084>
  <0.210970, 0.827004>
  <0.194093, 0.962025>
  <0.286920, 1.000000>
  <0.468354, 1.033755>
  open
}
```

One might ask why there is any need for a SOR object if there is already a lathe object which is much more flexible. The reason is quite simple. The intersection test with a SOR object involves solving a cubic polynomial while the test with a lathe object requires to solve of a 6th order polynomial (you need a cubic spline for the same *smoothness*). Since most SOR and lathe objects will have several segments this will make a great difference in speed. The roots of the 3rd order polynomial will also be more accurate and easier to find.

The slower but more accurate Sturmian root solver may be used with the surface of revolution object if the shape does not render properly.

The following explanations are for the mathematically interested reader who wants to know how the surface of revolution is calculated. Though it is not necessary to read on it might help in understanding the SOR object.

The function that is rotated about the y-axis to get the final SOR object is given by

$$r^2 = f(h) = Ah^3 + Bh^2 + Ch + D \tag{7.19}$$

with radius r and height h. Since this is a cubic function in h it has enough flexibility to allow smooth curves.

The curve itself is defined by a set of n points P_i, $i = 0 \dots n-1$, which are interpolated using one function for every segment of the curve. A segment j, $j = 1 \dots n-3$, goes from point P_j to point P_{j+1} and uses points P_{j-1} and P_{j+2} to determine the slopes at the endpoints. If there are n points we will have $n-3$ segments. This means that we need at least four points to get a proper curve.

The coefficients A_j, B_j, C_j and D_j are calculated for every segment using the equation

$$b = \mathbf{M}\, x \tag{7.20}$$

that is

$$\begin{pmatrix} r_j^2 \\ r_{j+1}^2 \\ 2r_j \dfrac{r_{j+1} - r_{j-1}}{h_{j+1} - h_{j-1}} \\ 2r_{j+1} \dfrac{r_{j+2} - r_j}{h_{j+2} - h_j} \end{pmatrix} = \begin{pmatrix} h_j^3 & h_j^2 & h_j & 1 \\ h_{j+1}^3 & h_{j+1}^2 & h_{j+1} & 1 \\ 3h_j^2 & 2h_j & 1 & 0 \\ 3h_{j+1}^2 & 2h_{j+1} & 1 & 0 \end{pmatrix} \begin{pmatrix} A_j \\ B_j \\ C_j \\ D_j \end{pmatrix} \tag{7.21}$$

where r_j is the radius and h_j is the height of point P_j.

Figure 7.7 on the following page shows the configuration of the points P_i, the location of segment j and the curve that is defined by this segment.

7.5.2.12 Text

A text object creates 3-D text as an extruded block letter. Currently only TrueType fonts are supported but the syntax allows for other font types to be added in the future. The syntax is:

```
text {
  ttf "FONTNAME.TTF",
  "STRING_OF_TEXT",
  THICKNESS_FLOAT, OFFSET_VECTOR
}
```

Where `FONTNAME.TTF` is the name of the TrueType font file. It is a quoted string literal or string expression. The string expression which follows is the actual text of the string object. It too may be a quoted string literal or string expression. See 7.1.6 on page 196 for more on string expressions.

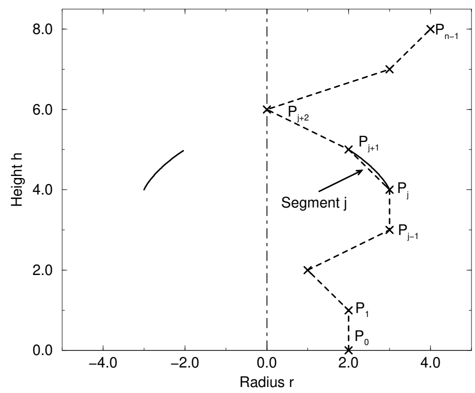


Figure 7.7: Segment j of $n-3$ segments in a point configuration of n points. The points describe the curve of a surface of revolution

.

The text will start with the origin at the lower left, front of the first character and will extend in the $+x$-direction. The baseline of the text follows the x-axis and decenders drop into the $-y$-direction. The front of the character sits in the x-y-plane and the text is extruded in the $+z$-direction. The front-to-back thickness is specified by the required value THICKNESS_FLOAT.

Characters are generally sized so that 1 unit of vertical spacing is correct. The characters are about 0.5 to 0.75 units tall.

The horizontal spacing is handled by POV-Ray internally including any kerning information stored in the font. The required vector OFFSET_VECTOR defines any extra translation between each character. Normally you should specify a zero for this value. Specifing `0.1*x` would put additional 0.1 units of space between each character.

Only printable characters are allowed in text objects. Characters such as return, line feed, tabs, backspace etc. are not supported.

7.5.2.13 Torus

A torus is a 4th order quartic polynomial shape that looks like a donut or inner tube. Because this shape is so useful and quartics are difficult to define, POV-Ray lets you take a short-cut and define a torus by:

```
torus {
  MAJOR, MINOR
  [ sturm ]
}
```

where MAJOR is a float value giving the major radius and MINOR is a float specifying the minor radius. The major radius extends from the center of the hole to the mid-line of the rim while the minor radius is the radius of the cross-section of the rim. The torus is centered at the origin and lies in the *x*-*z*-plane with the *y*-axis sticking through the hole. See fihure 7.8 for details about the torus geometry.

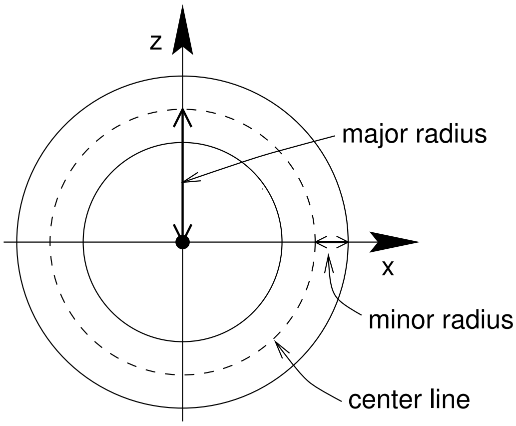


Figure 7.8: Major and minor radius of a torus.

The torus is internally bounded by two cylinders and two rings forming a *thick* cylinder. With this bounding cylinder the performance of the torus intersection test is vastly increased. The test for a valid torus intersection, i. e. solving a 4th order polynomial, is only performed if the bounding cylinder is hit. Thus a lot of slow root solving calculations are avoided.

Calculations for all higher order polynomials must be very accurate. If the torus renders improperly you may add the keyword `sturm` after the MINOR value to use POV-Ray's slower-yet-more-accurate Sturmian root solver.

7.5.3 Finite Patch Primitives

There are six totally thin, finite objects which have no well-defined inside. They are bicubic patch, disc, smooth triangle, triangle, polygon and mesh. They may be combined in CSG union but cannot be use in other types of CSG (or inside a `clipped_by` statement). Because these types are finite POV-Ray can use automatic bounding on them to speed up rendering time. As with all shapes they can be translated, rotated and scaled.

7.5.3.1 Bicubic Patch

A bicubic patch is a 3D curved surface created from a mesh of triangles. POV-Ray supports a type of bicubic patch called a Bezier patch. A bicubic patch is defined as follows:

```
bicubic_patch {
  type PATCH_TYPE
  flatness FLATNESS_VALUE
  u_steps NUM_U_STEPS
  v_steps NUM_V_STEPS
  <CP1>,  <CP2>,   <CP3>,   <CP4>,
  <CP5>,  <CP6>,   <CP7>,   <CP8>,
  <CP9>,  <CP10>,  <CP11>,  <CP12>,
  <CP13>, <CP14>,  <CP15>,  <CP16>
}
```

The keyword `type` is followed by a float PATCH_TYPE which currently must be either 0 or 1. For type 0 only the control points are retained within POV-Ray. This means that a minimal amount of memory is needed but POV-Ray will need to perform many extra calculations when trying to render the patch. Type 1 preprocesses the patch into many subpatches. This results in a significant speedup in rendering at the cost of memory.

The four parameters `type`, `flatness`, `u_steps` and `v_steps` may appear in any order. They are followed by 16 vectors that define the x, y, z coordinates of the 16 control points which define the patch. The patch touches the four corner points $\langle CP1\rangle$, $\langle CP4\rangle$, $\langle CP13\rangle$ and $\langle CP16\rangle$ while the other 12 points pull and stretch the patch into shape. The Bezier surface is enclosed by the convex hull formed by the 16 control points, this is known as the *convex hull property*.

The keywords `u_steps` and `v_steps` are each followed by float values which tell how many rows and columns of triangles are the minimum to use to create the surface. The maximum number of individual pieces of the patch that are tested by POV-Ray can be calculated from the following:

$$pieces = 2^{u\_steps}\, 2^{v\_steps} \tag{7.22}$$

This means that you really should keep `u_steps` and `v_steps` under 4. Most patches look just fine with `u_steps 3` and `v_steps 3`, which translates to 64 subpatches (128 smooth triangles).

As POV-Ray processes the Bezier patch it makes a test of the current piece of the patch to see if it is flat enough to just pretend it is a rectangle. The statement that controls this test is `flatness`. Typical flatness values range from 0 to 1 (the lower the slower).

If the value for flatness is 0 POV-Ray will always subdivide the patch to the extend specified by `u_steps` and `v_steps`. If flatness is greater than 0 then every time the patch is split, POV-Ray will check to see if there is any need to split further.

There are both advantages and disadvantages to using a non-zero flatness. The advantages include:

- If the patch isn't very curved, then this will be detected and POV-Ray won't waste a lot of time looking at the wrong pieces.
- If the patch is only highly curved in a couple of places, POV-Ray will keep subdividing there and concentrate it's efforts on the hard part.

The biggest disadvantage is that if POV-Ray stops subdividing at a particular level on one part of the patch and at a different level on an adjacent part of the patch there is the potential for *cracking*. This is typically visible as spots within the patch where you can see through. How bad this appears depends very highly on the angle at which you are viewing the patch.

Like triangles, the bicubic patch is not meant to be generated by hand. These shapes should be created by a special utility. You may be able to acquire utilities to generate these shapes from the same source from which you obtained POV-Ray.

```
bicubic_patch {
  type 1
  flatness 0.01
  u_steps 4
  v_steps 4
  <0, 0, 2>, <1, 0, 0>, <2, 0, 0>, <3, 0,-2>,
  <0, 1  0>, <1, 1, 0>, <2, 1, 0>, <3, 1, 0>,
  <0, 2, 0>, <1, 2, 0>, <2, 2, 0>, <3, 2, 0>,
  <0, 3, 2>, <1, 3, 0>, <2, 3, 0>, <3, 3, -2>
}
```

The triangles in a POV-Ray `bicubic_patch` are automatically smoothed using normal interpolation but it is up to the user (or the user's utility program) to create control points which smoothly stitch together groups of patches.

7.5.3.2 Disc

One other flat, finite object available with POV-Ray is the disc. The disc is infinitely thin, it has no thickness. If you want a disc with true thickness you should use a very short cylinder. A disc shape may be defined by:

```
disc {
  <CENTER>, <NORMAL>, RADIUS [, HOLE_RADIUS ]
}
```

The vector $\langle CENTER \rangle$ defines the x, y, z coordinates of the center of the disc. The $\langle NORMAL \rangle$ vector describes its orientation by describing its surface normal vector. This is followed by a float specifying the RADIUS. This may be optionally followed by another float specifying the radius of a hole to be cut from the center of the disc.

7.5.3.3 Mesh

The mesh object can be used to efficiently store large numbers of triangles. Its syntax is:

```
mesh {
  triangle {
    <CORNER1>, <CORNER2>, <CORNER3>
    [ texture { STRING } ]
  }
  smooth_triangle {
    <CORNER1>, <NORMAL1>,
    <CORNER2>, <NORMAL2>,
    <CORNER3>, <NORMAL3>
    [ texture { STRING } ]
  }
  [ hierarchy FLAG ]
}
```

Any number of triangles and/or smooth triangles can be used and each of those triangles can be individually textured by assigning a texture name to it. The texture has to be declared before the mesh is parsed. It is not possible to use texture definitions inside the triangle or smooth triangle statements. This is a restriction that is necessary for an efficient storage of the assigned textures.

The mesh's components are internally bounded by a bounding box hierarchy to speed up intersection testing. The bounding hierarchy can be turned off with the `hierarchy` keyword. This should only be done if memory is short or the mesh consists of only a few triangles.

Copies of a mesh object refer to the same triangle data and thus consume very little memory. You can easily trace hundred copies of an 10000 triangle mesh without running out of memory (assuming the first mesh fits into memory).

The mesh object has two advantages over a union of triangles: it needs less memory and it is transformed faster. The memory requierements are reduced by efficiently storing the triangles vertices and normals. The parsing time for transformed meshes is reduced because only the mesh object has to be transformed and not every single triangle as it is necessary for unions.

The mesh object can currently only include triangle and smooth triangle components. That restriction is liable to change, allowing polygonal components, at some point in the future.

7.5.3.4 Polygon

Polygons are useful for creating rectangles, squares and other planar shapes with more than three edges. Their syntax is:

```
polygon {
  TOTAL_NUMBER_OF_POINTS,
  <A_1>, <A_2>, ..., <A_na>, <A_1>,
  <B_1>, <B_2>, ..., <B_nb>, <B_1>,
  <C_1>, <C_2>, ..., <C_nc>, <C_1>,
  ...
}
```

The points $\langle A\_1 \rangle$ through $\langle A\_na \rangle$ describe the first sub-polygon, the points $\langle B\_1 \rangle$ through $\langle B\_nb \rangle$ describe the second sub-polygon, and so on. A polygon can contain any number of sub-polygons, either overlapping or not. In places where an even number of polygons overlaps a whole appears. You only have to be sure that each of these polygons is closed. This is insured by repeating the first point of a sub-polygon at the end of the sub-polygon's point sequence. This implies that all points of a sub-polygon are different.

If the (last) sub-polygon is not closed a warning is issued and the program automatically closes the polygon. This is useful because polygons imported from other programs may not be closed, i. e. their first and last point are not the same.

All points of a polygon are three-dimensional vectors that have to lay on one plane. If this is not the case an error occurs. You can also use two-dimensional vectors to describe the polygon. POV-Ray assumes that the z value is zero in this case.

A square polygon that matches the default planar imagemap is simply:

```
polygon {
  4,
  <0, 0>, <0, 1>, <1, 1>, <1, 0>
  texture {
    finish { ambient 1 diffuse 0 }
    pigment { image_map { gif "test.gif"  } }
  }
  //scale and rotate as needed here
}
```

The sub-polygon feature can be used to generate complex shapes like the letter "P", where a whole is cut into another polygon:

```
#declare P = polygon {
  12,
  <0, 0>, <0, 6>, <4, 6>, <4, 3>, <1, 3>, <1, 0>, <0, 0>,
  <1, 4>, <1, 5>, <3, 5>, <3, 4>, <1, 4>
}
```

The first sub-polygon (on the first line) describes the outer shape of the letter "P". The second sub-polygon (on the second line) describes the rectangular hole that is cut in the top of the letter "P". Both rectangles are closed, i. e. their first and last points are the same.

The feature of cutting holes into a polygon is based on the polygon inside/outside test used. A point is considerd to be inside a polygon if a straight line drawn from this point in an arbitrary direction crosses an odd number of edges (this is known as *Jordan's curve theorem*).

Another very complex example showing one large triangle with three small holes and three seperate, small triangles is given below:

```
polygon {
  28,
  <0,0> <1,0> <0,1> <0,0>         // large outer tri.
  <.3,.7> <.4,.7> <.3,.8> <.3,.7> // small outer tri. #1
  <.5,.5> <.6,.5> <.5,.6> <.5,.5> // small outer tri. #2
  <.7,.3> <.8,.3> <.7,.4> <.7,.3> // small outer tri. #3
  <.5,.2> <.6,.2> <.5,.3> <.5,.2> // inner tri. #1
  <.2,.5> <.3,.5> <.2,.6> <.2,.5> // inner tri. #2
  <.1,.1> <.2,.1> <.1,.2> <.1,.1> // inner tri. #3
}
```

7.5.3.5 Triangle and Smooth Triangle

The triangle primitive is available in order to make more complex objects than the built-in shapes will permit. Triangles are usually not created by hand but are converted from other files or generated by utilities. A triangle is defined by

```
triangle {
  <CORNER1>, <CORNER2>, <CORNER3>
}
```

where $\langle CORNERn \rangle$ is a vector defining the x, y, z coordinates of each corner of the triangle.

Because triangles are perfectly flat surfaces it would require extremely large numbers of very small triangles to approximate a smooth, curved surface. However much of our perception of smooth surfaces is dependent upon the way light and shading is done. By artificially modifying the surface normals we can simulate as smooth surface and hide the sharp-edged seams between individual triangles.

The smooth triangle primitive is used for just such purposes. The smooth triangles use a formula called Phong normal interpolation to calculate the surface normal for any point on the triangle based on normal vectors which you define for the three corners. This makes the triangle appear to be a smooth curved surface. A smooth triangle is defined by

```
smooth_triangle {
  <CORNER1>, <NORMAL1>,
  <CORNER2>, <NORMAL2>,
  <CORNER3>, <NORMAL3>
}
```

where the corners are defined as in regular triangles and ⟨*NORMALn*⟩ is a vector describing the direction of the surface normal at each corner.

These normal vectors are prohibitively difficult to compute by hand. Therefore smooth triangles are almost always generated by utility programs. To achieve smooth results, any triangles which share a common vertex should have the same normal vector at that vertex. Generally the smoothed normal should be the average of all the actual normals of the triangles which share that point.

7.5.4 Infinite Solid Primitives

There are five polynomial primitive shapes that are possibly infinite and do not respond to automatic bounding. They are plane, cubic, poly, quadric and quartic. They do have a well defined inside and may be used in CSG and inside a `clipped_by` statement. As with all shapes they can be translated, rotated and scaled..

7.5.4.1 Plane

The plane primitive is a simple way to define an infinite flat surface. The plane is specified as follows:

```
plane { <NORMAL>, DISTANCE }
```

The ⟨*NORMAL*⟩ vector defines the surface normal of the plane. A surface normal is a vector which points up from the surface at a 90 degree angle. This is followed by a float value that gives the distance along the normal that the plane is from the origin (that is only true if the normal vector has unit length; see below). For example:

```
plane { <0, 1, 0>, 4 }
```

This is a plane where *straight up* is defined in the positive *y*-direction. The plane is 4 units in that direction away from the origin. Because most planes are defined with surface normals in the direction of an axis you will often see planes defined using the `x`, `y` or `z` built-in vector identifiers. The example above could be specified as:

```
plane { y, 4 }
```

The plane extends infinitely in the x- and z-directions. It effectively divides the world into two pieces. By definition the normal vector points to the outside of the plane while any points away from the vector are defined as inside. This inside/outside distinction is only important when using planes in CSG and `clipped_by`.

A plane is called a *polynomial* shape because it is defined by a first order polynomial equation. Given a plane:

```
plane { <A, B, C>, D }
```

it can be represented by the equation

$$Ax + By + Cz - D\sqrt{A^2 + B^2 + C^2} = 0. \tag{7.23}$$

Therefore our example `plane { y,4 }` is actually the polynomial equation $y = 4$. You can think of this as a set of all x, y, z points where all have y values equal to 4, regardless of the x or z values.

This equation is a *first order* polynomial because each term contains only single powers of x, y or z. A second order equation has terms like x^2, y^2, z^2, xy, xz and yz. Another name for a 2nd order equation is a quadric equation. Third order polys are called cubics. A 4th order equation is a quartic. Such shapes are described in the sections below.

7.5.4.2 Poly, Cubic and Quartic

Higher order polynomial surfaces may be defined by the use of a poly shape. The syntax is

```
poly { ORDER, <T1, T2, T3, .... Tm> }
```

where ORDER is a whole number from 2 to 7 inclusively that specifies the order of the equation. $T1$, $T2$, ... Tm are float values for the coefficients of the equation. There are m such terms where

$$m = \frac{((ORDER+1)(ORDER+2)(ORDER+3))}{6}. \tag{7.24}$$

An alternate way to specify 3rd order polys is:

```
cubic { <T1, T2,... T20> }
```

Also 4th order equations may be specified with:

```
quartic { <T1, T2,... T35> }
```

Here's a more mathematical description of quartics for those who are interested. Quartic surfaces are 4th order surfaces and can be used to describe a large class of shapes including the torus, the lemniscate, etc. The general equation for a quartic equation in three variables is (hold onto your hat):

$$\begin{aligned}
a_{00}x^4 + a_{01}x^3y + a_{02}x^3z + a_{03}x^3 + a_{04}x^2y^2 +& \\
a_{05}x^2yz + a_{06}x^2y + a_{07}x^2z^2 + a_{08}x^2z + a_{09}x^2 +& \\
a_{10}xy^3 + a_{11}xy^2z + a_{12}xy^2 + a_{13}xyz^2 + a_{14}xyz +& \\
a_{15}xy + a_{16}xz^3 + a_{17}xz^2 + a_{18}xz + a_{19}x +& \\
a_{20}y^4 + a_{21}y^3z + a_{22}y^3 + a_{23}y^2z^2 + a_{24}y^2z +& \\
a_{25}y^2 + a_{26}yz^3 + a_{27}yz^2 + a_{28}yz + a_{29}y +& \\
a_{30}z^4 + a_{31}z^3 + a_{32}z^2 + a_{33}z + a_{34} = 0& \quad (7.25)
\end{aligned}$$

To declare a quartic surface requires that each of the coefficients $a_{00} \ldots a_{34}$ be placed in order into a single long vector of 35 terms.

As an example let's define a torus the hard way. A Torus can be represented by the equation:

$$\begin{aligned}
x^4 + y^4 + z^4 + 2x^2y^2 + 2x^2z^2 + 2y^2z^2 -& \\
2(r_0^2 + r_1^2)x^2 + 2(r_0^2 - r_1^2)y^2 - 2(r_0^2 + r_1^2)z^2 + (r_0^2 - r_1^2)^2 = 0& \quad (7.26)
\end{aligned}$$

Where r_0 is the *major* radius of the torus, the distance from the hole of the donut to the middle of the ring of the donut, and r_1 is the *minor* radius of the torus, the distance from the middle of the ring of the donut to the outer surface. The following object declaration is for a torus having major radius 6.3 minor radius 3.5 (Making the maximum width just under 20).

```
// Torus having major radius sqrt(40), minor radius sqrt(12)

quartic {
  < 1,    0,    0,    0,    2,    0,    0,    2,    0,
 -104,    0,    0,    0,    0,    0,    0,    0,    0,
    0,    0,    1,    0,    0,    2,    0,   56,    0,
    0,    0,    0,    1,    0, -104,    0,  784 >
  sturm
  bounded_by { // bounded_by speeds up the render,
               // see bounded_by
               // explanation later
               // in docs for more info.
   sphere { <0, 0, 0>, 10 }
  }
}
```

Poly, cubic and quartics are just like quadrics in that you don't have to understand what one is to use one. The file SHAPESQ.INC has plenty of pre-defined quartics for you to play with. The syntax for using a pre-defined quartic is:

```
object { Quartic_Name }
```

Polys use highly complex computations and will not always render perfectly. If the surface is not smooth, has dropouts, or extra random pixels, try using the optional keyword `sturm` in the definition. This will cause a slower but more accurate calculation method to be used. Usually, but not always, this will solve the problem. If sturm doesn't work, try rotating or translating the shape by some small amount. See the sub-directory MATH in the scene files directory for examples of polys in scenes.

There are really so many different quartic shapes, we can't even begin to list or describe them all. If you are interested and mathematically inclined, an excellent reference book for curves and surfaces where you'll find more quartic shape formulas is:

The CRC Handbook of Mathematical Curves and Surfaces
David von Seggern
CRC Press, 1990

7.5.4.3 Quadric

Quadric surfaces can produce shapes like ellipsoids, spheres, cones, cylinders, paraboloids (dish shapes) and hyperboloids (saddle or hourglass shapes). Note that you do not confuse *quaDRic* with *quaRTic*. A quadric is a 2nd order polynomial while a quartic is 4th order. Quadrics render much faster and are less error-prone.

A quadric is defined in POV-Ray by

```
quadric { <A,B,C>, <D,E,F>, <G,H,I>, J }
```

where A through J are float expressions that define a surface of x, y, z points which satisfy the equation

$$Ax^2 + By^2 + Cz^2 + Dxy + Exz + Fyz + Gx + Hy + Iz + J = 0 \quad (7.27)$$

Different values of A, B, C, ... J will give different shapes. If you take any three dimensional point and use its x, y and z coordinates in the above equation the answer will be 0 if the point is on the surface of the object. The answer will be negative if the point is inside the object and positive if the point is outside the object. Here are some examples:

$$X^2+Y^2+Z^2-1=0 \quad \text{Sphere} \quad (7.28)$$

$$X^2+Y^2-1=0 \quad \text{Infinite cylinder along the z-axis} \quad (7.29)$$

$$X^2+Y^2-Z^2=0 \quad \text{Infinite cone along the z-axis} \quad (7.30)$$

The easiest way to use these shapes is to include the standard file SHAPES.INC into your program. It contains several pre-defined quadrics and you can transform these pre-defined shapes (using translate, rotate and scale) into the ones you want. You can invoke them by using the syntax:

```
object { Quadric_Name }
```

The pre-defined quadrics are centered about the origin $\langle 0,0,0\rangle$ and have a radius of 1. Don't confuse radius with width. The radius is half the diameter or width making the standard quadrics 2 units wide.

Some of the pre-defined quadrics are,

```
Ellipsoid
Cylinder_X, Cylinder_Y, Cylinder_Z
QCone_X, QCone_Y, QCone_Z
Paraboloid_X, Paraboloid_Y, Paraboloid_Z
```

For a complete list, see the file SHAPES.INC.

7.5.5 Constructive Solid Geometry

POV-Ray supports *Constructive Solid Geometry* (CSG) with five different operations: difference, intersection, merge, union and negation (inversion). While the first four operations represent binary operators, i. e. they need two arguments, the negation is a unary operator, it takes only one argument.

7.5.5.1 About CSG

Constructive Solid Geometry is a technique for combining two or more objects to create a new object using the three boolean set operators `union`, `intersection`, and `negation`. It only works with solid objects, i. e. objects that have a well-defined interior. This is the case for all objects described in the sections 7.5.2 on page 231 and 7.5.4 on page 257.

CSG shapes may be used anywhere a standard shape can be used, even inside other CSG shapes. They can be translated, rotated or scaled in the same way as any other shape. The shapes making up the CSG shape may be individually translated, rotated and scaled as well.

7.5.5.2 Inside and Outside

Most shape primitives, like spheres, boxes and blobs divide the world into two regions. One region is inside the object and one is outside.

Given any point in space you can say it's either inside or outside any particular primitive object. Well, it could be exactly on the surface but this case is rather hard to determine due to numerical problems.

Even planes have an inside and an outside. By definition, the surface normal of the plane points towards the outside of the plane. You should note that triangles and triangle-based shapes cannot be used as solid objects in CSG since they have no well defined inside and outside.

CSG uses the concepts of inside and outside to combine shapes together as explained in the following sections.

Imagine you have to objects that partially overlap like shown in figure 7.9. Four different areas of points can be distinguished: points that are neither in object A nor in object B, points that are in object A but not in object B, points that are not in object A but in object B and last not least points that are in object A and object B.

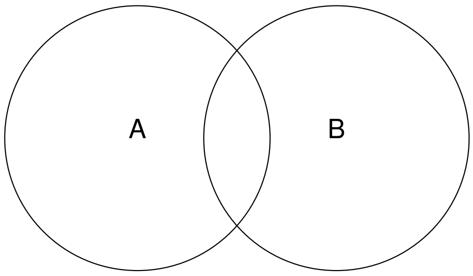


Figure 7.9: Two overlapping objects.

Keeping this in mind it will be quite easy to understand how the CSG operations work.

7.5.5.3 Inverse

When using CSG it is often useful to invert an object so that it'll be inside-out. The appearance of the object is not changed, just the way that POV-Ray perceives it. When the `inverse` keyword is used the *inside* of the shape is flipped to become the *outside* and vice versa.

Note that the difference operation is performed by intersecting the first object with the negation of the second object.

7.5.5.4 Union

Unions are simply *glue* used to bind two or more shapes into a single entity that can be manipulated as a single object. Figure 7.10 on the facing page shows the union of

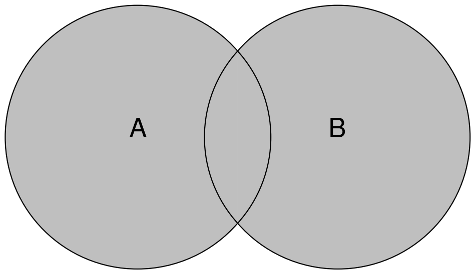


Figure 7.10: The union of two objects.

A and B. The new object created by the union operation can be scaled, translated and rotated as a single shape. The entire union can share a single texture but each object contained in the union may also have its own texture, which will override any matching texture statements in the parent object.

You should be aware that the surfaces inside the union will not be removed. As you can see from the figure this may be a problem for transparent unions. If you want those surfaces to be removed you'll have to use the merge operations explained in a later section.

The following union will contain a box and a sphere.

```
union {
  box { <-1.5, -1, -1>, <0.5, 1, 1> }
  cylinder { <0.5, 0, -1>, <0.5, 0, 1>, 1 }
}
```

Earlier versions of POV-Ray placed restrictions on unions so you often had to combine objects with `composite` statements. Those earlier restrictions have been lifted so composite is no longer needed. Composite is still supported for backwards compatibility but it is recommended that union is now used in it's place since future support for the composite keyword is not guaranteed.

7.5.5.5 Intersection

A point is inside an intersection if it is inside both objects, A and B, as show in figure 7.11 on the next page.

For example:

```
intersection {
```

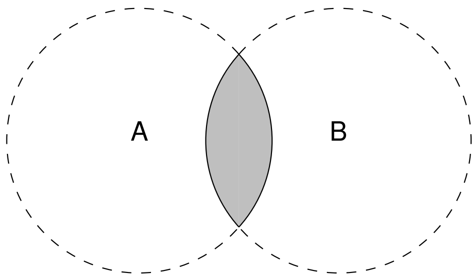


Figure 7.11: The intersection between two objects.

```
  box { <-1.5, -1, -1>, <0.5, 1, 1> }
  cylinder { <0.5, 0, -1>, <0.5, 0, 1>, 1 }
}
```

7.5.5.6 Difference

The CSG difference operation takes the intersection between the first object and the negation of the second object. Thus only points inside object A and outside object B belong to the difference of both objects.

The results is a *subtraction* of the 2nd shape from the first shape as shown in figure 7.12.

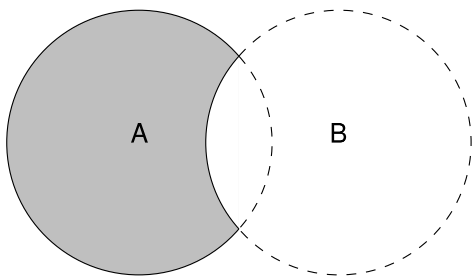


Figure 7.12: The difference between two objects.

For example:

```
difference {
  box { <-1.5, -1, -1>, <0.5, 1, 1> }
```

```
  cylinder { <0.5, 0, -1>, <0.5, 0, 1>, 1 }
}
```

7.5.5.7 Merge

The union operation just glues objects together, it does not remove the objects' surfaces inside the union. If a transparent union is used those surface will get visible.

The merge operations can be used to avoid this problem. It works just like union but it eliminates the inner surfaces like shown in figure 7.13.

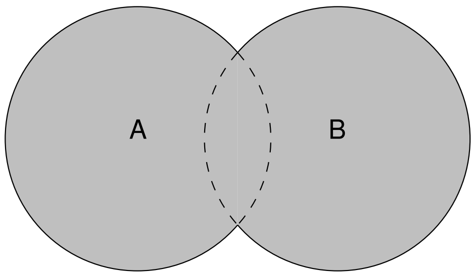


Figure 7.13: Merge removes inner surfaces.

7.5.6 Light Sources

The last object covered is the light source. Light sources have no visible shape of their own. They are just points or areas which emit light. Their full syntax is:

```
light_source {
  <LOCATION>
  color <COLOUR>
  [ spotlight ]
  [ point_at <POINT_AT> ]
  [ radius RADIUS ]
  [ falloff FALLOFF ]
  [ tightness TIGHTNESS ]
  [ area_light <AXIS1>, <AXIS2>, SIZE1, SIZE2 ]
  [ adaptive ADAPTIVE ]
  [ jitter JITTER ]
  [ looks_like { OBJECT } ]
  [ fade_distance FADE_DISTANCE ]
  [ fade_power FADE_POWER ]
  [ atmospheric_attenuation BOOL ]
}
```

The different types of light sources and the optional modifiers are described in the following sections.

7.5.6.1 Point Lights

A point light source sends light of the specified color uniformly in all directions. Its location is described by the `location` keyword and its color is given by the `color` keyword. The complete syntax is:

```
light_source {
  <LOCATION>
  color <COLOUR>
  [ looks_like { OBJECT } ]
  [ fade_distance FADE_DISTANCE ]
  [ fade_power FADE_POWER ]
  [ atmospheric_attenuation BOOL ]
}
```

The other keywords will be explained later.

7.5.6.2 Spotlights

A spotlight is a point light source where the rays of light are constrained by a cone. The light is bright in the center of this cone and falls off or darkens at the edges of the cone. The syntax is:

```
light_source {
  <LOCATION>
  color <COLOUR>
  spotlight
  point_at <POINT_AT>
  radius RADIUS
  falloff FALLOFF
  tightness TIGHTNESS
  [ looks_like { OBJECT } ]
  [ fade_distance FADE_DISTANCE ]
  [ fade_power FADE_POWER ]
  [ atmospheric_attenuation BOOL ]
}
```

The spotlight is identified by the `spotlight` keyword. It is located at LOCATION and points at POINT_AT.

The spotlight's other parameters are `radius`, `falloff` and `tightness`.

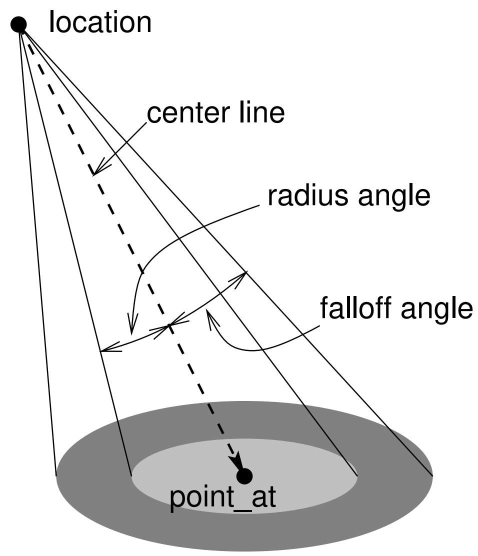


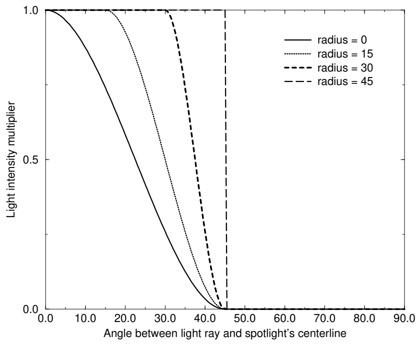
Figure 7.14: The geometry of a spotlight.

Think of a spotlight as two nested cones as shown in the figure. The inner cone is specified by the radius parameter and is fully lit. The outer cone is the falloff cone beyond which there is no light. The values for these two parameters are half the opening angles of the corresponding cones, both angles have to be smaller than 90 degrees. The light smoothly falls off between the radius and the falloff angle like shown in the figures in 7.15 on the following page (as long as the radius angle is not negative).

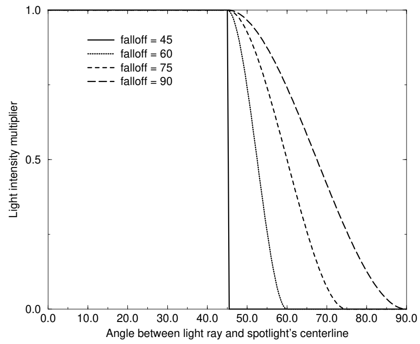
The tightness value specifies how quickly the light dims, or falls off, from the spotlight's center line to the the falloff cone (full darkness outside). The default value for tightness is 10. Lower tightness values will make the spotlight brighter, making the spot *wider* and the edges sharper. Higher values will dim the spotlight, making the spot *tighter* and the edges softer. Values from 1 to 100 are acceptable.

You should note from the figures that the radius and falloff angles interact with the tightness parameter. Only negative radius angles will give the tightness value full control over the spotlight's appearance as you can see from the figure in 7.15 on the next page. In that case the falloff angle has no effect and the lit area is only determined by the tightness parameter.

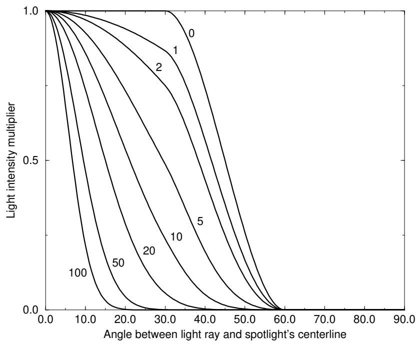
Spotlights may be used anyplace that a normal light source is used. Like any light sources, they are invisible. They are treated as shapes and may be included in CSG shapes. They may also be used in conjunction with area lights.



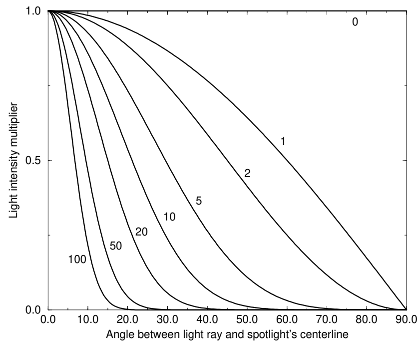
(a)



(b)



(c)



(d)

Figure 7.15: Different light intensity multiplier curves: (a) fixed falloff angle of 45 degrees; (b) fixed radius angle of 45 degrees; (c) fixed angle and falloff angles of 30 and 60 degrees respectively and different tightness values; (d) negative radius angle and different tightness values

.

7.5.6.3 Cylindrical Lights

Cylindrical light sources work pretty much like spotlights except that the light rays are constraint by a cylinder and not a cone. The syntax is:

```
light_source {
  <LOCATION>
  color <COLOUR>
  cylinder
  point_at <POINT_AT>
  radius RADIUS
  falloff FALLOFF
  tightness TIGHTNESS
  [ looks_like { OBJECT } ]
```

```
    [ fade_distance FADE_DISTANCE ]
    [ fade_power FADE_POWER ]
    [ atmospheric_attenuation BOOL ]
  }
```

The `radius`, `falloff` and `tightness` keywords control the same features as with the spotlight.

You should keep in mind that the cylindrical light source is still a point light source. The rays are emitted from one point and are only constraint by a cylinder. The light rays are not parallel.

7.5.6.4 Area Lights

Area light sources occupy a finite, one- or two-dimensional area of space. They can cast soft shadows because they can partially block light.

The area lights used in POV-Ray are rectangular in shape, sort of like a flat panel light. Rather than performing the complex calculations that would be required to model a true area light, it is approximated as an array of point light sources spread out over the area occupied by the light. The intensity of each individual point light in the array is dimmed so that the total amount of light emitted by the light is equal to the light color specified in the declaration. The syntax is:

```
light_source {
  <LOCATION>
  color <COLOUR>
  area_light <AXIS1>, <AXIS2>, SIZE1, SIZE2
  adaptive ADAPTIVE
  jitter JITTER
  [ spotlight ]
  [ point_at <POINT_AT> ]
  [ radius RADIUS ]
  [ falloff FALLOFF ]
  [ tightness TIGHTNESS ]
  [ looks_like { OBJECT } ]
  [ fade_distance FADE_DISTANCE ]
  [ fade_power FADE_POWER ]
  [ atmosphere BOOL ]
  [ atmospheric_attenuation BOOL ]
}
```

The light's location and color are specified in the same way as a for a regular light source.

The `area_light` command defines the size and orientation of the area light as well as the number of lights in the light source array. The vectors AXIS1 and AXIS2 specify the lengths and directions of the edges of the light. Since the area lights are rectangular in shape these vectors should be perpendicular to each other. The larger the size of the light the thicker the soft part of shadows will be. The numbers SIZE1 and SIZE2 specify the dimensions of the array of point lights. The more lights you use the smoother your shadows will be but the longer they will take to render.

The `jitter` command is optional. When used it causes the positions of the point lights in the array to be randomly jittered to eliminate any shadow banding that may occur. The jittering is completely random from render to render and should not be used when generating animations.

Note that it is possible to specify spotlight parameters along with the area light parameters to create *area spotlights*. Using area spotlights is a good way to speed up scenes that use area lights since you can confine the lengthy soft shadow calculations to only the parts of your scene that need them.

An interesting effect can be created using a linear light source. Rather than having a rectangular shape, a linear light stretches along a line sort of like a thin fluorescent tube. To create a linear light just create an area light with one of the array dimensions set to 1.

The `adaptive` command is used to enable adaptive sampling of the light source. By default POV-Ray calculates the amount of light that reaches a surface from an area light by shooting a test ray at every point light within the array. As you can imagine this is very slow. Adaptive sampling on the other hand attempts to approximate the same calculation by using a minimum number of test rays. The number specified after the keyword controls how much adaptive sampling is used. The higher the number the more accurate your shadows will be but the longer they will take to render. If you're not sure what value to use a good starting point is `adaptive 1`. The `adaptive` keyword only accepts integer values and cannot be set lower than 0.

When performing adaptive sampling POV-Ray starts by shooting a test ray at each of the four corners of the area light. If the amount of light received from all four corners is approximately the same then the area light is assumed to be either fully in view or fully blocked. The light intensity is then calculated as the average intensity of the light received from the four corners. However, if the light intensity from the four corners differs significantly then the area light is partially blocked. The area light is split into four quarters and each section is sampled as described above. This allows POV-Ray to rapidly approximate how much of the area light is in view without having to shoot a test ray at every light in the array. Visually the sampling goes like shown in 7.16 on the facing page.

While the adaptive sampling method is fast (relatively speaking) it can sometimes produces inaccurate shadows. The solution is to reduce the amount of adaptive sampling without completely turning it off. The number after the adaptive keyword adjusts the number of times that the area light will be split before the adaptive phase begins. For example if you use `adaptive 0` a minimum of 4 rays will be shot at the light. If you use `adaptive 1` a minimum of 9 rays will be shot (`adaptive 2` gives 25 rays, `adaptive 3` gives 81 rays, etc). Obviously the more shadow rays you shoot the

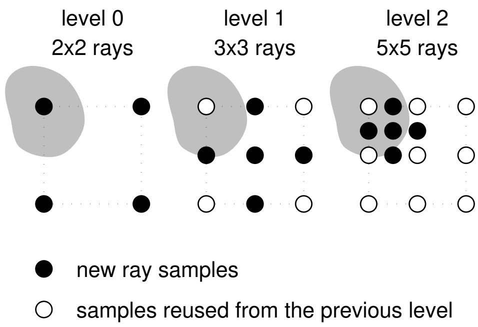


Figure 7.16: Area light adaptive sampling.

slower the rendering will be so you should use the lowest value that gives acceptable results.

The number of rays never exceeds the values you specify for rows and columns of points. For example `area_light x,y,4,4` specifies a 4 by 4 array of lights. If you specify `adaptive 3` it would mean that you should start with a 9 by 9 array. In this case no adaptive sampling is done. The 4 by 4 array is used.

7.5.6.5 Shadowless Lights

Using the `shadowless` keyword you can stop a light source from casting shadows.

7.5.6.6 Looks_like

Normally the light source itself has no visible shape. The light simply radiates from an invisible point or area. You may give a light source any shape by adding a `looks_like { OBJECT }` statement.

There is an implied `no_shadow` attached to the `looks_like` object so that light is not blocked by the object. Without the automatic `no_shadow` the light inside the object would not escape. The object would, in effect, cast a shadow over everything.

If you want the attached object to block light then you should attach it with a union and not a `looks_like` as follows:

```
union {
  light_source { <100, 200, -300> color White }
  object { My_Lamp_Shape }
}
```

Presumably parts of the lamp shade are translucent to let some light out.

7.5.6.7 Light Fading

By default POV-Ray does not diminish light from any light source as it travels through space. In order to get a more realistic effect `fade_distance` and `fade_power` can be used to model the distance based falloff in light intensity.

The `fade_distance` keyword is used to specify the distance at which the full light intensity arrives, i. e. the intensity which was given by the `color` keyword. The actual attenuation is described by the `fade_power` keyword, which determines the falloff rate. E. g. linear or quadratic falloff can be used by setting FADE_POWER to 1 or 2 respectively. The complete formula to calculate the factor by which the light is attenuated is

$$attenuation = \frac{2}{1+\left(\frac{d}{FADE\_DISTANCE}\right)^{FADE\_POWER}} \tag{7.31}$$

with d being the distance the light has traveled.

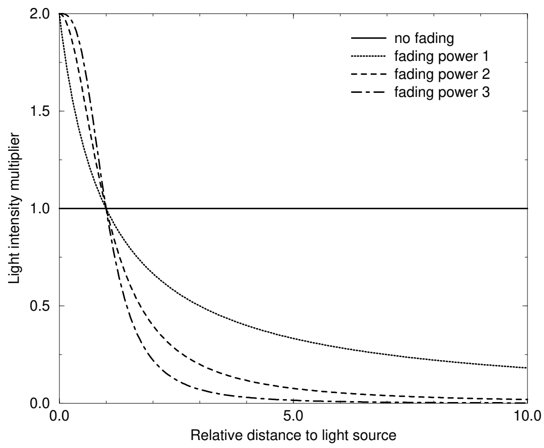


Figure 7.17: Light fading functions for different fading powers.

You should note two important facts: First, for FADE_DISTANCEs larger than one the light intensity at distances smaller than FADE_DISTANCE actually increases. This is necessary to get the light source color if the distance traveled equals the FADE_DISTANCE. Second, only light coming directly from light sources is attenuated. Reflected or refracted light is not attenuated by distance.

7.5.6.8 Atmosphere Interaction

By default light sources will interact with an atmosphere added to the scene. This behaviour can be switched off by using the `atmosphere` keyword inside the light source statement.

```
light_source {
  ...
  atmosphere off
}
```

7.5.6.9 Atmospheric Attenuation

Normally light coming from light sources is not influenced by fog or atmosphere. This can be changed by turning the atmospheric attenuation for a given light source on. All light coming from this light source will now be diminished as it travels through the fog or atmosphere. This results in an distance-based, exponential intensity falloff ruled by the used fog or atmosphere. If there is no fog or atmosphere no change will be seen.

7.5.7 Object Modifiers

A variety of modifiers may be attached to objects. Transformations such as translate, rotate and scale have already been discussed. Textures are in a section of their own below. Here are three other important modifiers: `clipped_by`, `bounded_by` and `no_shadow`. Although the examples below use object statements and object identifiers, these modifiers may be used on any type of object such as sphere, box etc.

7.5.7.1 Clipped_By

The `clipped_by` statement is technically an object modifier but it provides a type of CSG similar to CSG intersection. You attach a clipping object like this:

```
object {
  My_Thing
  clipped_by{plane{y,0}}
}
```

Every part of the object *My_Thing* that is inside the plane is retained while the remaining part is clipped off and discarded. In an intersection object the hole is closed off. With `clipped_by` it leaves an opening. For example the figure in 7.18 on the next page shows object A being clipped by object B.

`clipped_by` may be used to slice off portions of any shape. In many cases it will also result in faster rendering times than other methods of altering a shape.

Often you will want to use the `clipped_by` and `bounded_by` options with the same object. The following shortcut saves typing and uses less memory.

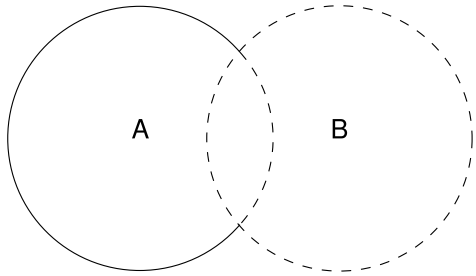


Figure 7.18: An object clipped by another object.

```
object {
  My_Thing
  bounded_by { box { <0,0,0>, <1,1,1> } }
  clipped_by { bounded_by }
}
```

This tells POV-Ray to use the same box as a clip that was used as a bounds.

7.5.7.2 Bounded_By

The calculations necessary to test if a ray hits an object can be quite time consuming. Each ray has to be tested against every object in the scene. POV-Ray attempts so speed up the process by building a set of invisible boxes, called bounding boxes, which cluster the objects together. This way a ray that travels in one part of the scene doesn't have to be tested against objects in another, far away part of the scene. When large a number of objects are present the boxes are nested inside each other. POV-Ray can use bounding boxes on any finite object and even some clipped or bounded quadrics. However infinite objects (such as a planes, quartic, cubic and poly) cannot be automatically bound. CSG objects are automatically bound if they contain finite (and in some cases even infinite) objects. This works by applying the CSG set operations to the bounding boxes of all objects used inside the CSG object. For difference and intersection operations this will hardly ever lead to an optimal bounding box. It's sometimes better (depending on the complexity of the CSG object) to use a `bounded_by` statement with such shapes.

Normally bounding shapes are not necessary but there are cases where they can be used to speed up the rendering of complex objects. Bounding shapes tell the ray-tracer that the object is totally enclosed by a simple shape. When tracing rays, the ray is first tested against the simple bounding shape. If it strikes the bounding shape the ray is further tested against the more complicated object inside. Otherwise the entire complex shape is skipped, which greatly speeds rendering.

To use bounding shapes, simply include the following lines in the declaration of your object:

```
bounded_by {
  object { ... }
}
```

An example of a bounding shape:

```
intersection {
  sphere { <0,0,0>, 2 }
  plane  { <0,1,0>, 0 }
  plane  { <1,0,0>, 0 }
  bounded_by {sphere { <0,0,0>, 2 } }
}
```

The best bounding shape is a sphere or a box since these shapes are highly optimized, although, any shape may be used. If the bounding shape is itself a finite shape which responds to bounding slabs then the object which it encloses will also be used in the slab system.

CSG shapes can benefit from bounding slabs without a `bounded_by` statement however they may do so inefficiently in intersection, difference and merge. In these three CSG types the automatic bound used covers all of the component objects in their entirety. However the result of these intersections may result in a smaller object. Compare the sizes of the illustrations for union and intersection in the CSG section above. It is possible to draw a much smaller box around the intersection of A and B than the union of A and B yet the automatic bounds are the size of the union of A and B regardless of the kind of CSG specified.

While it is almost always a good idea to manually add a `bounded_by` to intersection, difference and merge, it is often best to **not** bound a union. If a union has no `bounded_by` and no `clipped_by` POV-Ray can internally split apart the components of a union and apply automatic bounding slabs to any of its finite parts. Note that some utilities such as RAW2POV may be able to generate bounds more efficiently than POV-Ray's current system. However most unions you create yourself can be easily bounded by the automatic system. For technical reasons POV-Ray cannot split a merge object. It is probably best to hand bound a merge, especially if it is very complex.

Note that if bounding shape is too small or positioned incorrectly it may clip the object in undefined ways or the object may not appear at all. To do true clipping, use `clipped_by` as explained above. Often you will want to use the `clipped_by` and `bounded_by` options with the same object. The following shortcut saves typing and uses less memory.

```
object {
```

```
  My_Thing
  clipped_by{ box { <0,0,0>,<1,1,1 > }}
  bounded_by{ clipped_by }
}
```

This tells POV-Ray to use the same box as a bounds that was used as a clip.

7.5.7.3 Hollow

POV-Ray by default assumes that objects are made of a solid material that completely fills the interior of an object. By adding the `hollow` keyword to the object you can make it hollow. That is very useful if you want atmospheric effects to exist inside an object. It is even required for objects containing a halo (see 7.6.4 on page 302 for details).

In order to get a hollow CSG object you just have to make the top level object hollow. All children will assume the same *hollow* state except their state is explicitly set. The following example will set both spheres inside the union hollow

```
union {
  sphere { -0.5*x, 1 }
  sphere {  0.5*x, 1 }
  hollow
}
```

while the next example will only set the second sphere hollow because the first sphere was explicitly set to be not hollow.

```
union {
  sphere { -0.5*x, 1 hollow off }
  sphere {  0.5*x, 1 }
  hollow
}
```

7.5.7.4 No_Shadow

You may specify the `no_shadow` keyword in an object to make that object cast no shadow. This is useful for special effects and for creating the illusion that a light source actually is visible. This keyword was necessary in earlier versions of POV-Ray which did not have the `looks_like` statement. Now it is useful for creating things like laser beams or other unreal effects.

Simply attach the keyword as follows:

```
object {
  My_Thing
  no_shadow
}
```

7.5.7.5 Sturm

Some of POV-Ray's objects allow you to choose between a fast but sometimes inaccurate root solver and a slower but more accurate one. This is the case for all objects that involve the solution of a cubic or quartic polynomial. There are analytic mathematical solutions for those polynomals that can be used.

Lower order polynomals are trivial to solve while higher order polynomials require iterative algorithms to solve them. One of those algorithms is the Sturmian root solver.

The following list shows all objects for which the Sturmian root solver can be used.

```
blob
cubic
lathe    (only with quadratic splines)
poly
prism    (only with cubic splines)
quartic
sor
```

7.6 Textures

The texture describes what the object looks like, i. e. its material. Textures are combinations of pigments, normals, finishes and halos. Pigment is the color or pattern of colors inherent in the material. Normal is a method of simulating various patterns of bumps, dents, ripples or waves by modifying the surface normal vector. Finish describes the reflective and refractive properties of a material. Halo simulates effects like clouds, fog, fire etc. by using a density field defined inside the object.

A *plain texture* consists of a single pigment, an optional normal, a single finish and optionally one or more halos. A *special texture* combines two or more textures using a pattern or blending function. Special textures may be made quite complex by nesting patterns within patterns. At the innermost levels however, they are made up from plain textures. Note that allthough we call a plain texture *plain* it may be a very complex texture. The term *plain* only means that it has a single pigment, normal, finish and halo.

The most complete form for defining a plain texture is as follows:

```
texture {
  TEXTURE_IDENTIFIER
  pigment {..}.
  normal {..}.
  finish {..}.
  halo {..}.
  TRANSFORMATIONS
}
```

Each of the items in a texture are optional but if they are present the identifier must be first and the transformations must be last. The pigment, normal and finish parameters modify any pigment, normal and finish already specified in the TEXTURE_IDENTIFIER. Any halos are added to the already existing halos. If no texture identifier is specified the pigment, normal and finish statements modify the current default values and any halo is added to the default halo, if any. TRANSFORMATIONs are translate, rotate, scale and matrix statements. They should be specified last.

The sections below describe all of the options available in pigments, normals, finishes and halos. Special textures are covered later.

7.6.1 Pigment

The color or pattern of colors for an object is defined by a `pigment` statement. All plain textures must have a pigment. If you do not specify one the default pigment is used. A pigment statement is part of a texture specification. However it can be tedious to type `texture { pigment { ... } }` just to add a color to an object. Therefore you may attach a pigment directly to an object without explicitly specifying that it as part of a texture. For example:

```
//this...                 //can be shortened to this...

object {                  object {
  My_Object                 My_Object
  texture {                 pigment {color Red}
    pigment {color Red}   }
  }
}
```

The color you define is the way you want the object to look if fully illuminated. You pick the basic color inherent in the object and POV-Ray brightens or darkens it depending on the lighting in the scene. The parameter is called *pigment* because we are defining the basic color the object actually is rather than how it looks.

The most complete form for defining a pigment is as follows:

```
pigment {
  PIGMENT_IDENTIFIER
  PATTERN_TYPE
  PIGMENT_MODIFIERS...
}
```

Each of the items in a pigment are optional but if they are present, they should be in the order shown above to insure that the results are as expected. Any items after the PIGMENT_IDENTIFIER modify or override settings given in the identifier. If no identifier is specified then the items modify the pigment values in the current default texture. Valid PIGMENT_MODIFIERS are `color_map`, `pigment_map`, `image_map` and `quick_color` statements as well as any of the generic PATTERN_MODIFIERS such as `translate`, `rotate`, `scale`, `turbulence`, wave shape and warp statements. Such modifiers apply only to the pigment and not to other parts of the texture. Modifiers should be specified last.

The various pattern types fall into roughly four categories. Each category is discussed below. They are solid color, color list patterns, color mapped patterns and image maps.

7.6.1.1 Solid Color Pigments

The simplest type of pigment is a solid color. To specify a solid color you simply put a color specification inside a pigment. For example:

```
pigment {color Orange}
```

A color specification consists of the option keyword `color` followed by a color identifier or by a specification of the amount of red, green, blue, filtered and unfiltered transparency in the surface. See section 7.1.5 on page 192 for more details about colors. Any pattern modifiers used with a solid color are ignored because there is no pattern to modify.

7.6.1.2 Color List Pigments

There are three color list patterns: `checker`, `hexagon` and `brick`. The result is a pattern of solid colors with distinct edges rather than a blending of colors as with color mapped patterns. Each of these patterns is covered in more detail in a later section. The syntax for each is:

```
pigment { brick COLOR1, COLOR2 MODIFIERS ... }
pigment { checker COLOR1, COLOR2 MODIFIERS ... }
pigment { hexagon COLOR1, COLOR2, COLOR3 MODIFIERS ... }
```

Each COLORn is any valid color specification. There should be a comma between each color or the `color` keyword should be used as a separator so that POV-Ray can determine where each color specification starts and ends.

7.6.1.3 Color Maps

Most of the color patterns do not use abrupt color changes of just two or three colors like those in the brick, checker or hexagon patterns. They instead use smooth transitions of many colors that gradually change from one point to the next. The colors are defined in a pigment modifier called a *color map* that describes how the pattern blends from one color to the next.

Each of the various pattern types available is in fact a mathematical function that takes any x, y, z location and turns it into a number between 0.0 and 1.0 inclusive. That number is used to specify what mix of colors to use from the color map.

A color map is specified by ...

```
pigment{
  PATTERN_TYPE
  color_map {
    [ NUM_1 COLOR_1]
    [ NUM_2 COLOR_2]
    [ NUM_3 COLOR_3]
     ...
  }
  PIGMENT_MODIFIERS...
}
```

Where NUM_1, NUM_2, ... are float values between 0.0 and 1.0 inclusive. COLOR_1, COLOR_2, ... are color specifications. Note that the `[]` brackets are part of the actual statement. They are not notational symbols denoting optional parts. The brackets surround each entry in the color map. There may be from 2 to 256 entries in the map. The alternate spelling `colour_map` may be used.

For example

```
sphere {
  <0,1,2>, 2
  pigment {
    gradient x       //this is the PATTERN_TYPE
    color_map {
      [0.1  color Red]
      [0.3  color Yellow]
      [0.6  color Blue]
      [0.6  color Green]
      [0.8  color Cyan]
    }
  }
}
```

The pattern function is evaluated and the result is a value from 0.0 to 1.0. If the value is less than the first entry (in this case 0.1) then the first color (red) is used. Values from

0.1 to 0.3 use a blend of red and yellow using linear interpolation of the two colors. Similarly values from 0.3 to 0.6 blend from yellow to blue. Note that the 3rd and 4th entries both have values of 0.6. This causes an immediate abrupt shift of color from blue to green. Specifically a value that is less than 0.6 will be blue but exactly equal to 0.6 will be green. Moving along, values from 0.6 to 0.8 will be a blend of green and cyan. Finally any value greater than or equal to 0.8 will be cyan.

If you want areas of unchanging color you simply specify the same color for two adjacent entries. For example:

```
color_map {
  [0.1  color Red]
  [0.3  color Yellow]
  [0.6  color Yellow]
  [0.8  color Green]
}
```

In this case any value from 0.3 to 0.6 will be pure yellow.

The `color_map` keyword may be used with any pattern except `brick`, `checker`, `hexagon` and `image_map`. You may declare and use `color_map` identifiers. For example:

```
#declare Rainbow_Colors=
  color_map {
    [0.0   color Magenta]
    [0.33  color Yellow]
    [0.67  color Cyan]
    [1.0   color Magenta]
  }

object{My_Object
  pigment{
    gradient x
    color_map{Rainbow_Colors}
  }
}
```

7.6.1.4 Pigment Maps

In addition to specifying blended colors with a color map you may create a blend of pigments using a *pigment map*. The syntax for a pigment map is identical to a color map except you specify a pigment in each map entry (and not a color).

A pigment map is specified by ...

```
pigment{
  PATTERN_TYPE
  pigment_map {
    [ NUM_1 PIGMENT_BODY_1]
    [ NUM_2 PIGMENT_BODY_2]
    [ NUM_3 PIGMENT_BODY_3]
     ...
  }
  PIGMENT_MODIFIERS...
}
```

Where NUM_1, NUM_2, ... are float values between 0.0 and 1.0 inclusive. A PIGMENT_BODY is anything that would normally appear inside a `pigment { ... }` statement but the `pigment` keyword and {} braces are not needed. Note that the `[]` brackets are part of the actual statement. They are not notational symbols denoting optional parts. The brackets surround each entry in the map. There may be from 2 to 256 entries in the map.

For example

```
sphere {
  <0,1,2>, 2
  pigment {
    gradient x       //this is the PATTERN_TYPE
    pigment_map {
      [0.3 wood scale 0.2]
      [0.3 Jade]    //this is a pigment identifier
      [0.6 Jade]
      [0.9 marble turbulence 1]
    }
  }
}
```

When the `gradient x` function returns values from 0.0 to 0.3 the scaled wood pigment is used. From 0.3 to 0.6 the pigment identifier Jade is used. From 0.6 up to 0.9 a blend of Jade and a turbulent marble is used. From 0.9 on up only the turbulent marble is used.

Pigment maps may be nested to any level of complexity you desire. The pigments in a map may have color maps or pigment maps or any type of pigment you want. Any entry of a pigment map may be a solid color however if all entries are solid colors you should use a color map which will render slightly faster.

Entire pigments may also be used with the block patterns such as checker, hexagon and brick. For example ...

```
pigment {
```

```
    checker
    pigment { Jade scale .8 }
    pigment { White_Marble scale .5 }
  }
```

Note that in the case of block patterns the `pigment { ... }` wrapping is required around the pigment information.

A pigment map is also used with the `average` pigment type. See 7.6.7.2 on page 319 for details.

You may not use `pigment_map` or individual pigments with an `image_map`. See 7.6.5.1 on page 313 for an alternative way to do this.

7.6.1.5 Image Maps

When all else fails and none of the above pigment pattern types meets your needs you can use an image map to wrap a 2-D bit-mapped image around your 3-D objects.

7.6.1.5.1 Specifying an Image Map

The syntax for an *image map* is ...

```
  pigment {
    image_map {
      FILE_TYPE "filename"
      MODIFIERS...
    }
  }
```

Where FILE_TYPE is one of the following keywords `gif`, `tga`, `iff`, `ppm`, `pgm`, `png` or `sys`. This is followed by the name of the file in quotes. Several optional modifiers may follow the file specification. The modifiers are described below. Note that earlier versions of POV-Ray allowed some modifiers before the FILE_TYPE but that syntax is being phased out in favor of the syntax described here.

Filenames specified in the `image_map` statements will be searched for in the home (current) directory first and, if not found, will then be searched for in directories specified by any **–L** (library path) options active. This would facilitate keeping all your image maps files in a separate subdirectory and giving an **–L** option on the command line to where your library of image maps are.

By default, the image is mapped onto the *x*-*y*-plane. The image is *projected* onto the object as though there were a slide projector somewhere in the $-z$-direction. The image exactly fills the square area from (x,y) coordinates (0,0) to (1,1) regardless of the image's original size in pixels. If you would like to change this default you may translate, rotate or scale the pigment or texture to map it onto the object's surface as desired.

In section 7.6.7.6 on page 322 the checker pigment pattern is explained. The checks are described as solid cubes of colored clay from which objects are carved. With image maps you should imagine that each pixel is a long, thin, square, colored rod that extends parallel to the *z*-axis. The image is made from rows and columns of these rods bundled together and the object is then carved from the bundle.

If you would like to change this default orientation you may translate, rotate or scale the pigment or texture to map it onto the object's surface as desired.

7.6.1.5.2 The map_type Option

The default projection of the image onto the *x*-*y*-plane is called a *planar map type*. This option may be changed by adding the `map_type` keyword followed by a number specifying the way to wrap the image around the object.

A `map_type 0` gives the default planar mapping already described.

A `map_type 1` gives a spherical mapping. It assumes that the object is a sphere of any size sitting at the origin. The *y*-axis is the north/south pole of the spherical mapping. The top and bottom edges of the image just touch the pole regardless of any scaling. The left edge of the image begins at the positive *x*-axis and wraps the image around the sphere from *west* to *east* in a $-y$-rotation. The image covers the sphere exactly once. The `once` keyword has no meaning for this mapping type.

With `map_type 2` you get a cylindrical mapping. It assumes that a cylinder of any diameter lies along the *y*-axis. The image wraps around the cylinder just like the spherical map but the image remains one unit tall from $y = 0$ to $y = 1$. This band of color is repeated at all heights unless the `once` keyword is applied.

Finally `map_type 5` is a torus or donut shaped mapping. It assumes that a torus of major radius one sits at the origin in the *x*-*z*-plane. The image is wrapped around similar to spherical or cylindrical maps. However the top and bottom edges of the map wrap over and under the torus where they meet each other on the inner rim.

Types 3 and 4 are still under development.

Note that the `map_type` option may also be applied to `bump_map` and `material_map` statements.

7.6.1.5.3 The Filter and Transmit Bitmap Modifiers

To make all or part of an image map transparent you can specify filter and/or transmit values for the color palette/registers of PNG, GIF or IFF pictures (at least for the modes that use palettes). You can do this by adding the keyword `filter` or `transmit` following the filename. The keyword is followed by two numbers. The first number is the palette number value and the second is the amount of transparency. The values should be separated by a comma. For example:

```
image_map {
  gif "mypic.gif"
  filter   0, 0.5 // color 0  50% filtered transp.
  filter   5, 1.0 // color 5 100% filtered transp.
  transmit 8, 0.3 // color 8  30% non-filtered transp.
}
```

You can give the entire image a `filter` or `transmit` value using `filter all VALUE` or `transmit all VALUE`. For example:

```
image_map {
  gif "stnglass.gif"
  filter all 0.9
}
```

Note that early versions of POV-Ray used the keyword `alpha` to specify filtered transparency however that word is often used to describe non-filtered transparency. For this reason `alpha` is no longer used.

See 7.1.5 on page 192 and 7.1.5 on page 192 for details on the differences between filtered and non-filtered transparency.

7.6.1.5.4 Using the Alpha Channel

Another way to specify non-filtered transmit transparency in an image map is by using the *alpha channel*.

PNG allows you to store a different transparency for each color index in the PNG file, if desired. If your paint programs support this feature of PNG you can do the transparency editing within your paint program rather than specifying transmit values for each color in the POV file. Since PNG and TGA image formats can also store full alpha channel (transparency) information you can generate image maps that have transparency which isn't dependent on the color of a pixel but rather its location in the image.

Although POV uses transmit 0.0 to specify no transparency and 1.0 to specify full transparency, the alpha data ranges from 0 to 255 in the opposite direction. Alpha data 0 means the same as transmit 1.0 and alpha data 255 produces transmit 0.0.

7.6.1.6 Quick Color

When developing POV-Ray scenes its often useful to do low quality test runs that render faster. The **+Q** command line switch can be used to turn off some time consuming color pattern and lighting calculations to speed things up. However all settings of **+Q5** or lower turns off pigment calculations and creates gray objects.

By adding a `quick_color` to a pigment you tell POV-Ray what solid color to use for quick renders instead of a patterned pigment. For example:

```
pigment {
  gradient x
  color_map{
    [0.0 color Yellow]
    [0.3 color Cyan]
    [0.6 color Magenta]
    [1.0 color Cyan]
  }
  turbulence 0.5
  lambda 1.5
  omega 0.75
  octaves 8
  quick_color Neon_Pink
}
```

This tells POV-Ray to use solid *Neon_Pink* for test runs at quality **+Q**5 or lower but to use the turbulent gradient pattern for rendering at **+Q**6 and higher.

Note that solid color pigments such as

```
pigment {color Magenta}
```

automatically set the `quick_color` to that value. You may override this if you want. Suppose you have 10 spheres on the screen and all are yellow. If you want to identify them individually you could give each a different `quick_color` like this:

```
sphere {
  <1,2,3>, 4
  pigment { color Yellow  quick_color Red }
}

sphere {
  <-1,-2,-3>, 4
  pigment { color Yellow  quick_color Blue }
}
```

and so on. At **+Q**6 or higher they will all be yellow but at **+Q**5 or lower each would be different colors so you could identify them.

7.6.2 Normal

Ray-tracing is known for the dramatic way it depicts reflection, refraction and lighting effects. Much of our perception depends on the reflective properties of an object. Ray tracing can exploit this by playing tricks on our perception to make us see complex details that aren't really there.

Suppose you wanted a very bumpy surface on the object. It would be very difficult to mathematically model lots of bumps. We can however simulate the way bumps look by altering the way light reflects off of the surface. Reflection calculations depend on a vector called a *surface normal* vector. This is a vector which points away from the surface and is perpendicular to it. By artificially modifying (or perturbing) this normal vector you can simulate bumps.

The `normal { ... }` statement is the part of a texture which defines the pattern of normal perturbations to be applied to an object. Like the pigment statement, you can omit the surrounding texture block to save typing. Do not forget however that there is a texture implied. For example ...

```
// this...                     // can be shortened to this...

object {                      object {
  My_Object                     My_Object
  texture {                     pigment { color Purple }
    pigment { color Purple }    normal { bumps 0.3 }
    normal { bumps 0.3 }      }
  }
}
```

Note that attaching a normal pattern does not really modify the surface. It only affects the way light reflects or refracts at the surface so that it looks bumpy.

The most complete form for defining a normal is as follows:

```
normal {
  NORMAL_IDENTIFIER
  PATTERN_TYPE FloatValue
  NORMAL_MODIFIERS
  TRANSFORMATIONS...
}
```

Each of the items in a normal are optional but if they are present they should be in the order shown above to insure that the results are as expected. Any items after the NORMAL_IDENTIFIER modify or override settings given in the identifier. If no identifier is specified then the items modify the normal values in the current default texture. The PATTERN_TYPE may optionally be followed by a float value that controls the apparent depth of the bumps. Typical values range from 0.0 to 1.0 but any value may be used. Negative values invert the pattern. The default value if none is specified is 0.5.

Valid NORMAL_MODIFIERS are `slope_map`, `normal_map`, `bump_map` and `bump_size` statements as well as any of the generic PATTERN_MODIFIERS such as translate, rotate, scale, turbulence, wave shape and warp statements. Such modifiers apply only to the normal and not to other parts of the texture. Modifiers should be specified last.

There are three basic types of NORMAL_PATTERN_TYPEs. They are pattern normals, specialized normals and bump maps. They differ in the types of modifiers you may use with them. Originally POV-Ray had some patterns which were exclusively used for pigments while others were exclusively used for normals. Since POV-Ray 3.0 you can use any pattern for either pigments or normals. For example it is now valid to use `ripples` as a pigment or `wood` as a normal type. The patterns `bumps`, `dents`, `ripples`, `waves`, `wrinkles` and `bump_map` were once exclusively normal patterns which could not be used as pigments. Because these six types use specialized normal modification calculations they cannot have `slope_map`, `normal_map` or wave shape modifiers. All other normal pattern types may use them.

7.6.2.1 Slope Maps

A *slope map* is a normal pattern modifier which gives the user a great deal of control over the exact shape of the bumpy features. It is best illustrated with a gradient normal pattern. Suppose you have ...

```
plane{ z, 0
  pigment{ White }
  normal { gradient x }
}
```

This gives a ramp wave pattern that looks like small linear ramps that climb from the points at $x = 0$ to $x = 1$ and then abruptly drops to 0 again to repeat the ramp from $x = 1$ to $x = 2$. A slope map turns this simple linear ramp into almost any wave shape you want. The syntax is as follows ...

```
normal{
  PATTERN_TYPE Value
  slope_map {
    [ NUM_1 POINT_SLOPE_1]
    [ NUM_2 POINT_SLOPE_2]
    [ NUM_3 POINT_SLOPE_3]
     ...
  }
  NORMAL_MODIFIERS...
}
```

Note that the `[]` brackets are part of the actual statement. They are not notational symbols denoting optional parts. The brackets surround each entry in the slope map. There may be from 2 to 256 entries in the map.

The NUM_1, NUM_2, ... are float values between 0.0 and 1.0 inclusive. POINT_SLOPE_1, POINT_SLOPE_2, ... are 2 component vectors such as $\langle 0,1\rangle$ where the first value represents the apparent height of the wave and the second value represents the slope of the wave at that point. The height should range between 0.0 and 1.0 but any value could be used.

The slope value is the change in height per unit of distance. For example a slope of zero means flat, a slope of 1.0 means slope upwards at a 45 degree angle and a slope of -1 means slope down at 45 degrees. Theoretically a slope straight up would have infinite slope. In practice, slope values should be kept in the range -3.0 to +3.0. Keep in mind that this is only the visually apparent slope. A normal does not actually change the surface.

For example here is how to make the ramp slope up for the first half and back down on the second half creating a triangle wave with a sharp peak in the center.

```
normal {
  gradient x       // this is the PATTERN_TYPE
  slope_map {
    [0   <0, 1>]   // start at bottom and slope up
    [0.5 <1, 1>]   // halfway through reach top still climbing
    [0.5 <1,-1>]   // abruptly slope down
    [1   <0,-1>]   // finish on down slope at bottom
  }
}
```

The pattern function is evaluated and the result is a value from 0.0 to 1.0. The first entry says that at $x = 0$ the apparent height is 0 and the slope is 1. At $x = 0.5$ we are at height 1 and slope is still up at 1. The third entry also specifies that at $x = 0.5$ (actually at some tiny fraction above 0.5) we have height 1 but slope -1 which is downwards. Finally at $x = 1$ we are at height 0 again and still sloping down with slope -1.

Although this example connects the points using straight lines the shape is actually a cubic spline. This example creates a smooth sine wave.

```
normal {
  gradient x          // this is the PATTERN_TYPE
  slope_map {
    [0    <0.5, 1>]   // start in middle and slope up
    [0.25 <1.0, 0>]   // flat slope at top of wave
    [0.5  <0.5,-1>]   // slope down at mid point
    [0.75 <0.0, 0>]   // flat slope at bottom
    [1    <0.5, 1>]   // finish in middle and slope up
  }
}
```

This example starts at height 0.5 sloping up at slope 1. At a fourth of the way through we are at the top of the curve at height 1 with slope 0 which is flat. The space between these two is a gentle curve because the start and end slopes are different. At half way we are at half height sloping down to bottom out at 3/4ths. By the end we are climbing at slope 1 again to complete the cycle. There are more examples in SLOPEMAP.POV in the sample scenes.

A `slope_map` may be used with any pattern except `brick`, `checker`, `hexagon`, `bumps`, `dents`, `ripples`, `waves`, `wrinkles` and `bump_map`.

You may declare and use slope map identifiers. For example:

```
#declare Fancy_Wave =
  slope_map {       // Now let's get fancy
    [0.0  <0, 1>]   // Do tiny triangle here
    [0.2  <1, 1>]   //  down
    [0.2  <1,-1>]   //     to
    [0.4  <0,-1>]   //       here.
    [0.4  <0, 0>]   // Flat area
    [0.5  <0, 0>]   //   through here.
    [0.5  <1, 0>]   // Square wave leading edge
    [0.6  <1, 0>]   //   trailing edge
    [0.6  <0, 0>]   // Flat again
    [0.7  <0, 0>]   //   through here.
    [0.7  <0, 3>]   // Start scallop
    [0.8  <1, 0>]   //   flat on top
    [0.9  <0,-3>]   //     finish here.
    [0.9  <0, 0>]   // Flat remaining through 1.0
  }

object{ My_Object
  pigment { White }
  normal {
    wood
    slope_map { Fancy_Wave }
  }
}
```

7.6.2.2 Normal Maps

Most of the time you will apply single normal pattern to an entire surface but you may also create a pattern or blend of normals using a *normal map*. The syntax for a normal map is identical to a pigment map except you specify a normal in each map entry.

A normal map is specified by ...

```
normal{
  PATTERN_TYPE
  normal_map {
    [ NUM_1 NORMAL_BODY_1]
    [ NUM_2 NORMAL_BODY_2]
    [ NUM_3 NORMAL_BODY_3]
```

```
      ...
    }
    NORMAL_MODIFIERS...
  }
```

Where NUM_1, NUM_2, ... are float values between 0.0 and 1.0 inclusive. A NORMAL_BODY is anything that would normally appear inside a `normal { ... }` statement but the normal keyword and {} braces are not needed. Note that the `[]` brackets are part of the actual statement. They are not notational symbols denoting optional parts. The brackets surround each entry in the map. There may be from 2 to 256 entries in the map.

For example

```
normal {
  gradient x       //this is the PATTERN_TYPE
  normal_map {
    [0.3  bumps scale 2]
    [0.3  dents]
    [0.6  dents]
    [0.9  marble turbulence 1]
  }
}
```

When the `gradient x` function returns values from 0.0 to 0.3 then the scaled bumps normal is used. From 0.3 to 0.6 dents are From 0.6 up to 0.9 a blend of dents and a turbulent marble is used. From 0.9 on up only the turbulent marble is used.

Normal maps may be nested to any level of complexity you desire. The normals in a map may have slope maps or normal maps or any type of normal you want.

A normal map is also used with the `average` normal type. See 7.6.7.2 on page 319 for details.

Entire normals may also be used with the block patterns such as checker, hexagon and brick. For example ...

```
normal {
  checker
    normal { gradient x scale .2 }
    normal { gradient y scale .2 }
  }
}
```

Note that in the case of block patterns the `normal { ... }` wrapping is required around the normal information.

You may not use `normal_map` or individual normals with a `bump_map`. See 7.6.5.1 on page 313 for an alternative way to do this.

7.6.2.3 Bump Maps

When all else fails and none of the above normal pattern types meets your needs you can use a bump map to wrap a 2-D bit-mapped bump pattern around your 3-D objects.

Instead of placing the color of the image on the shape like an image map a *bump map* perturbs the surface normal based on the color of the image at that point. The result looks like the image has been embossed into the surface. By default, a bump map uses the brightness of the actual color of the pixel. Colors are converted to gray scale internally before calculating height. Black is a low spot, white is a high spot. The image's index values may be used instead (see section 7.6.2.3.3 on the next page below).

7.6.2.3.1 Specifying a Bump Map

The syntax for bump_map is ...

```
normal {
  bump_map {
    FILE_TYPE "filename"
    BITMAP_MODIFIERS...
  }
  NORMAL_MODIFIERS...
}
```

Where FILE_TYPE is one of the following keywords `gif`, `tga`, `iff`, `ppm`, `pgm`, `png` or `sys`. This is followed by the name of the file using any valid string expression. Several optional modifiers may follow the file specification. The modifiers are described below. Note that earlier versions of POV-Ray allowed some modifiers before the FILE_TYPE but that syntax is being phased out in favor of the syntax described here.

Filenames specified in the `bump_map` statement will be searched for in the home (current) directory first and, if not found, will then be searched for in directories specified by any **+L** switches or Library_Path options. This would facilitate keeping all your bump maps files in a separate subdirectory, and specifying a library path to them. Note that any operating system default paths are not searched unless you also specify them as a Library_Path.

By default, the bump pattern is mapped onto the *x*-*y*-plane. The bumps are *projected* onto the object as though there were a slide projector somewhere in the $-z$-direction. The bump pattern exactly fills the square area from (x,y) coordinates (0,0) to (1,1) regardless of the bitmaps's original size in pixels. If you would like to change this default, you may translate, rotate or scale the normal or texture to map it onto the object's surface as desired.

The file name is optionally followed by one or more BITMAP_MODIFIERS. The bump_size, use_color and use_index modifiers are specific to bump maps and are discussed in the following sections. See 7.6.8.9 on page 345 for other general bitmap modifiers.

After a bump_map statement but still inside the normal statement you may apply any legal normal modifiers except slope_map and pattern wave forms.

7.6.2.3.2 Bump_Size

The relative bump size can be scaled using the bump_size modifier. The bump size number can be any number other than 0 but typical values are from about 0.1 to as high as 4.0 or 5.0.

```
normal {
  bump_map {
    gif "stuff.gif"
    bump_size 5.0
  }
}
```

Originally bump_size could only be used inside a bump map but it can now be used with any normal. Typically it is used to override a previously defined size. For example:

```
normal {
  My_Normal   //this is a previously defined normal identifier
  bump_size 2.0
}
```

7.6.2.3.3 Use_Index and Use_Color

Usually the bump map converts the color of the pixel in the map to a gray scale intensity value in the range 0.0 to 1.0 and calculates the bumps based on that value. If you specify use_index, the bump map uses the color's palette number to compute as the height of the bump at that point. So, color number 0 would be low and color number 255 would be high (if the image has 256 palette entries). The actual color of the pixels doesn't matter when using the index. This option is only available on palette based formats. The use_color keyword may be specified to explicitly note that the color methods should be used instead. The alternate spelling use_colour is also valid. These modifiers may only be used inside the bump_map statement.

7.6.3 Finish

The finish properties of a surface can greatly affect its appearance. How does light reflect? What happens when light passes through? What kind of highlights are visible. To answer these questions you need a finish statement.

The `finish { ... }` statement is the part of a texture which defines the various finish properties to be applied to an object. Like the pigment or normal statement you can omit the surrounding texture block to save typing. Do not forget however that there is a texture implied. For example ...

```
// this...                      // can be shortened to this...

object {                        object {
  My_Object                       My_Object
  texture {                       pigment { color Purple }
    pigment { color Purple }      finish { phong 0.3 }
    finish { phong 0.3 }        }
  }
}
```

The most complete form for defining a finish is as follows:

```
finish {
  FINISH_IDENTIFIER
  [ ambient COLOR ]
  [ diffuse FLOAT ]
  [ brilliance FLOAT ]
  [ phong FLOAT ]
  [ phong_size FLOAT ]
  [ specular FLOAT ]
  [ roughness FLOAT ]
  [ metallic [ FLOAT ] ]
  [ reflection COLOR ]
  [ refraction FLOAT ]
  [ ior FLOAT ]
  [ caustics FLOAT ]
  [ fade_distance FLOAT ]
  [ fade_power FLOAT ]
  [ irid { thickness FLOAT turbulence VECTOR } ]
  [ crand FLOAT ]
}
```

The FINISH_IDENTIFIER is optional but should proceed all other items. Any items after the FINISH_IDENTIFIER modify or override settings given in the IDENTIFIER. If no identifier is specified then the items modify the finish values in the current default texture. Note that transformations are not allowed inside a finish because finish items cover the entire surface uniformly.

7.6.3.1 Ambient

The light you see in dark shadowed areas comes from diffuse reflection off of other objects. This light cannot be directly modeled using ray-tracing. However we can use a trick called *ambient lighting* to simulate the light inside a shadowed area.

Ambient light is light that is scattered everywhere in the room. It bounces all over the place and manages to light objects up a bit even where no light is directly shining. Computing real ambient light would take far too much time, so we simulate ambient light by adding a small amount of white light to each texture whether or not a light is actually shining on that texture.

This means that the portions of a shape that are completely in shadow will still have a little bit of their surface color. It's almost as if the texture glows, though the ambient light in a texture only affects the shape it is used on.

Usually a single float value is specified even though the syntax calls for a color. For example a float value of 0.3 gets promoted to the full color vector $\langle 0.3, 0.3, 0.3, 0.3, 0.3\rangle$ which is acceptible because only the red, green and blue parts are used.

The default value is very little ambient light (0.1). The value can range from 0.0 to 1.0. Ambient light affects both shadowed and non-shadowed areas so if you turn up the ambient value you may want to turn down the diffuse value.

Note that this method doesn't account for the color of surrounding objects. If you walk into a room that has red walls, floor and ceiling then your white clothing will look pink from the reflected light. POV-Ray's ambient shortcut doesn't account for this. There is also no way to model specular reflected indirect illumination such as the flashlight shining in a mirror.

You may color the ambient light using one of two methods. You may specify a color rather than a float after the ambient keyword in each finish statement. For example

```
finish { ambient rgb <0.3,0.1,0.1> } //a pink ambient
```

You may also specify the overall ambient light source used when calculating the ambient lighting of an object using the global `ambient_light` setting. The formula is given by

$$ambient = ambient_{finish}\ ambient_{light\_source} \tag{7.32}$$

See section 7.8.2 on page 356 for details.

7.6.3.2 Diffuse Reflection Items

When light reflects off of a surface the laws of physics say that it should leave the surface at the exact same angle it came in. This is similar to the way a billiard ball bounces off a bumper of a pool table. This perfect reflection is called *specular* reflection. However only very smooth polished surfaces reflect light in this way. Most of the time, light reflects and is scattered in all directions by the *roughness* of the surface. This scattering is called *diffuse reflection* because the light diffuses or spreads in a variety of directions. It accounts for the majority of the reflected light we see.

POV-Ray and most other ray-tracers can only simulate directly one of these three types of illumination. That is the light which comes directly from actual light sources. Light coming from other objects such as mirrors via specular reflection (shine a flashlight onto a mirror for example). And last not least light coming from other objects via diffuse reflections (look at some dark area under a desk or in a corner: even though a lamp may not directly illuminate that spot you can still see a little bit because light comes from diffuse reflection off of nearby objects).

7.6.3.2.1 Diffuse

The keyword `diffuse` is used in a `finish` statement to control how much of the light coming directly from any light sources is reflected via diffuse reflection. For example

```
finish {diffuse 0.7}
```

means that 70% of the light seen comes from direct illumination from light sources. The default value is diffuse 0.6.

7.6.3.2.2 Brilliance

The amount of direct light that diffuses from an object depends upon the angle at which it hits the surface. When light hits at a shallow angle it illuminates less. When it is directly above a surface it illuminates more. The `brilliance` keyword can be used in a `finish` statement to vary the way light falls off depending upon the angle of incidence. This controls the tightness of the basic diffuse illumination on objects and slightly adjusts the appearance of surface shininess. Objects may appear more metallic by increasing their brilliance. The default value is 1.0. Higher values from to about 10.0 cause the light to fall off less at medium to low angles. There are no limits to the brilliance value. Experiment to see what works best for a particular situation. This is best used in concert with highlighting.

7.6.3.2.3 Crand Graininess

Very rough surfaces, such as concrete or sand, exhibit a dark graininess in their apparent color. This is caused by the shadows of the pits or holes in the surface. The `crand` keyword can be added to cause a minor random darkening in the diffuse reflection of direct illumination. Typical values range from `crand 0.01` to `crand 0.5` or higher. The default value is 0. For example:

```
finish { crand 0.05 }
```

The grain or noise introduced by this feature is applied on a pixel-by-pixel basis. This means that it will look the same on far away objects as on close objects. The effect also looks different depending upon the resolution you are using for the rendering. For these reasons it is not a very accurate way to model the rough surface effect but some objects still look better with a little crand thrown in.

Note that this should not be used when rendering animations. This is the one of a few truly random features in POV-Ray and will produce an annoying flicker of flying pixels on any textures animated with a `crand` value.

7.6.3.3 Highlights

Highlights are the bright spots that appear when a light source reflects off of a smooth object. They are a blend of specular reflection and diffuse reflection. They are specular-like because they depend upon viewing angle and illumination angle. However they are diffuse-like because some scattering occurs. In order to exactly model a highlight you would have to calculate specular reflection off of thousands of microscopic bumps called micro facets. The more that micro facets are facing the viewer the shinier the object appears and the tighter the highlights become. POV-Ray uses two different models to simulate highlights without calculating micro facets. They are the *specular* and *Phong* models.

Note that specular and Phong highlights are **not** mutually exclusive. It is possible to specify both and they will both take effect. Normally, however, you will only specify one or the other.

7.6.3.3.1 Phong Highlights

The `phong` keyword controls the amount of Phong highlighting on the object. It causes bright shiny spots on the object that are the color of the light source being reflected.

The Phong method measures the average of the facets facing in the mirror direction from the light sources to the viewer.

Phong's value is typically from 0.0 to 1.0, where 1.0 causes complete saturation to the light source's color at the brightest area (center) of the highlight. The default phong 0.0 gives no highlight.

The size of the highlight spot is defined by the `phong_size` value. The larger the phong size the tighter, or smaller, the highlight and the shinier the appearance. The smaller the phong size the looser, or larger, the highlight and the less glossy the appearance.

Typical values range from 1.0 (very dull) to 250 (highly polished) though any values may be used. Default phong size is 40 (plastic) if `phong_size` is not specified. For example:

```
finish { phong 0.9 phong_size 60 }
```

If `phong` is not specified `phong_size` has no effect.

7.6.3.3.2 Specular Highlight

A specular highlight is very similar to Phong highlighting but it uses slightly different model. The specular model more closely resembles real specular reflection and provides a more credible spreading of the highlights occuring near the object horizons.

The specular value is typically from 0.0 to 1.0, where 1.0 causes complete saturation to the light source's color at the brightest area (center) of the highlight. The default specular 0.0 gives no highlight.

The size of the spot is defined by the value given for `roughness`. Typical values range from 1.0 (very rough — large highlight) to 0.0005 (very smooth — small highlight). The default value, if roughness is not specified, is 0.05 (plastic).

It is possible to specify wrong values for roughness that will generate an error when you try to render the file. Don't use 0 and if you get errors check to see if you are using a very, very small roughness value that may be causing the error. For example:

```
finish { specular 0.9 roughness 0.02 }
```

If `specular` is not specified `roughness` has no effect.

7.6.3.3.3 Metallic Highlight Modifier

The keyword `metallic` may be used with Phong or specular highlights. This keyword indicates that the color of the highlights will be calculated by an empirical function that models the reflectivity of metallic surfaces.

White light relfected specularly from a metallic surface takes the color of the surface, except then the incidence angle approaches 90 degrees, where it becomes white again.

The `metallic` keyword may be follow by a numeric value to specify the influence the above effect has (the default value is one). For example:

```
finish {
  phong 0.9
  phong_size 60
  metallic
}
```

If phong or specular is not specified metallic has no effect.

7.6.3.4 Specular Reflection

When light does not diffuse and it **does** reflect at the same angle as it hits an object, it is called *specular reflection.* Such mirror-like reflection is controlled by the reflection keyword in a finish statement. For example:

```
finish { reflection 1.0 ambient 0 diffuse 0 }
```

This gives the object a mirrored finish. It will reflect all other elements in the scene. Usually a single float value is specified after the keyword even though the syntax calls for a color. For example a float value of 0.3 gets promoted to the full color vector $\langle 0.3, 0.3, 0.3, 0.3, 0.3\rangle$ which is acceptible because only the red, green and blue parts are used.

The value can range from 0.0 to 1.0. By default there is no reflection.

Adding reflection to a texture makes it take longer to render because an additional ray must be traced. The reflected light may be tinted by specifying a color rather than a float. For example

```
finish { reflection rgb <1,0,0> }
```

gives a *real* red mirror that only reflects red light.

Note that although such reflection is called *specular* it is not controlled by the specular keyword. That keyword controls a *specular highlight*.

7.6.3.5 Refraction

When light passes through a surface either into or out of a dense medium the path of the ray of light is bent. Such bending is called *refraction.* Normally transparent or semi-transparent surfaces in POV-Ray do not refract light. Adding refraction 1.0 to the finish statement turns on refraction.

Note that it is recommended that you only use refraction 0 or refraction 1 (or even better refraction off and refraction on). Values in between will darken the refracted light in ways that do not correspond to any physical property. Many POV-Ray scenes were created with intermediate refraction values before this *bug* was discovered so the *feature* has been maintained. A more appropriate way to reduce the brightness of refracted light is to change the `filter` or `transmit` value in the colors specified in the pigment statement. Note also that refraction does not cause the object to be transparent. Transparency only occurs if there is a non-zero filter or transmit value in the color.

The amount of bending or refracting of light depends upon the density of the material. Air, water, crystal and diamonds all have different densities and thus refract differently. The *index of refraction* or *ior* value is used by scientists to describe the relative density of substances. The `ior` keyword is used in POV-Ray to specify the value. For example:

```
texture {
  pigment { White filter 0.9 }
  finish {
    refraction 1
    ior 1.5
  }
}
```

The default ior value of 1.0 will give no refraction. The index of refraction for air is 1.0, water is 1.33, glass is 1.5 and diamond is 2.4. The file CONSTS.INC pre-defines several useful values for ior.

Note that if a texture has a filter component and no value for refraction and ior are supplied the renderer will simply transmit the ray through the surface with no bending. In layered textures, the refraction and ior keywords **must** be in the last texture, otherwise they will not take effect.

7.6.3.5.1 Light Attenuation

Light attenuation is used to model the decrease in light intensity as the light travels through a translucent object. Its syntax is:

```
finish {
  fade_distance FADE_DISTANCE
  fade_power FADE_POWER
}
```

The `fade_distance` keyword determines the distance the light has to travel to reach half intensity while the `fade_power` keyword describes how fast the light will fall off. For realistic effects a fade power of 1 to 2 should be used.

The attenuation is calculated by a formula similar to that used for light source attenuation.

$$attenuation = \frac{1}{1 + \left(\frac{d}{FADE\_DISTANCE} \right)^{FADE\_POWER}} \tag{7.33}$$

7.6.3.5.2 Faked Caustics

The syntax is:

```
finish {
  caustics POWER
}
```

STILL BEING WRITTEN

7.6.3.6 Iridescence

Iridescence, or Newton's thin film interference, simulates the effect of light on surfaces with a microscopic transparent film overlay. The effect is like an oil slick on a puddle of water or the rainbow hues of a soap bubble (see also 7.8.5 on page 360).

The syntax is:

```
finish {
  irid {
    AMOUNT
    thickness FLOAT
    turbulence VECTOR
  }
}
```

This finish modifies the surface color as a function of the angle between the light source and the surface. Since the effect works in conjunction with the position and angle of the light sources to the surface it does not behave in the same ways as a procedural pigment pattern.

The AMOUNT parameter is the contribution of the iridescence effect to the overall surface color. As a rule of thumb keep to around 0.25 (25% contribution) or less, but experiment. If the surface is coming out too *white*, try lowering the diffuse and possibly the ambient values of the surface.

The `thickness` keyword represents the film's thickness. This is an awkward parameter to set, since the thickness value has no relationship to the object's scale. Changing it affects the scale or *busy-ness* of the effect. A very thin film will have a high frequency of color changes while a thick film will have large areas of color.

The thickness of the film can be varied with the `turbulence` keyword. You can only specify the amount of turbulence with iridescence. The octaves, lambda, and omega values are internally set and are not adjustable by the user at this time.

In addition, perturbing the object's surface normal through the use of bump patterns will affect iridescence.

For the curious, thin film interference occurs because, when the ray hits the surface of the film, part of the light is reflected from that surface, while a portion is transmitted into the film. This *subsurface* ray travels through the film and eventually reflects off the opaque substrate. The light emerges from the film slightly out of phase with the ray that was reflected from the surface.

This phase shift creates interference, which varies with the wavelength of the component colors, resulting in some wavelengths being reinforced, while others are cancelled out. When these components are recombined, the result is iridescence.

The concept used for this feature came from the book *Fundamentals of Three-Dimensional Computer Graphics* by Alan Watt (Addison-Wesley).

7.6.4 Halo

A halo is used to simulate some of the atmospheric effects that occur when small particles interact with light or radiate on their own. Those effects include clouds, fogs, fire, etc.

Halos are attached to an object, the so called *container object*, which they completely fill. If the object is partially or completely translucent and the object is specified to be hollow (see section 7.5.7.3 on page 276 for more details) the halo will be visible. Thus the halo effects are limited to the space that the object covers. This should always be kept in mind.

What the halo actually will look like depends on a lot of parameters. First of all you have to specify which kind of effect you want to simulate. After this you need to define the distribution of the particles. This is basically done in two steps: a mapping function is selected and a density function is chosen. The first function maps world coordinates onto a one-dimensional interval while the later describes how this linear interval is mapped onto the final density values.

The properties of the particles, such as their color and their translucency, are given by a color map. The density values calculated by the mapping processes are used to determine the appropriate color using this color map.

A ray marching process is used to volume sample the halo and to accumulate the intensities and opacity of each interval.

The following sections will describe all of the halo parameters in more detail. The complete halo syntax is given by:

```
halo {
  attenuating | emitting | glowing | dust
  [ constant | linear | cubic | poly ]
  [ planar_mapping | spherical_mapping |
    cylindrical_mapping | box_mapping ]
  [ dust_type DUST_TYPE ]
  [ eccentricity ECCENTRICITY ]
  [ max_value MAX_VALUE ]
  [ exponent EXPONENT ]
  [ samples SAMPLES ]
  [ aa_level AA_LEVEL ]
  [ aa_threshold AA_THRESHOLD ]
  [ jitter JITTER ]
  [ turbulence <TURBULENCE> ]
  [ octaves OCTAVES ]
  [ omega OMEGA ]
  [ lambda LAMBDA ]
  [ colour_map COLOUR_MAP ]
  [ frequency FREQUENCY ]
  [ phase PHASE ]
  [ scale <VECTOR> ]
  [ rotate <VECTOR> ]
  [ translate <VECTOR> ]
}
```

7.6.4.1 Halo Mapping

As described above the actual particle distribution and halo appearance is influenced by a lot of parameters. The steps that are performed during the halo calculation will be explained below. It will also be noted where the different halo keywords will have an effect on the calculations.

1. Depending on the current sampling position along the ray, point P (coordinates x, y, z) inside the halo container object is calculated. The actual location is influenced by the `jitter` keyword, the number of `samples` and the use of anti-aliasing (`aa_level` and `aa_threshold`).
2. Point P is transformed into point Q using the (current) halo's transformation. Here all local halo transformations come into play, i. e. all transformations specified inside the (current) halo statement.
3. Turbulence is added to point Q. The amount of turbulence is given by the `turbulence` keyword. The turbulence calculation is influenced by the `octaves`, `omega` and `lambda` keywords.
4. Radius r is calculated depending on the specified density mapping (`planar_mapping`, `spherical_mapping`, `cylindrical_mapping` or `box_mapping`). The radius is clipped to the range from 0 to 1, i. e. $0 \leq r \leq 1$.

5. The density d is calculated from the radius r using the specified density function (constant, linear, cubic or poly) and the maximum value given by max_value. The density will be in the range from 0 to max_value.
6. The density d is first multiplied by the frequency value, added to the phase value and clipped to the range from 0 to 1 before it is used to get the color from the color_map. If an attenuating halo is used the color will be determined by the total density along the ray and not by the sum of the colors for each sample.

All steps are repeated for each sample point along the ray that is inside the halo container object. Steps 2 through 6 are repeated for all halos attached to the halo container object.

It should be noted that in order to get a finite particle distribution, i. e. a particle distribution that vanishes outside a finite area, a finite density mapping and a finite density function has to be used.

A finite density mapping gives the constant value one for all points outside a finite area. The box and spherical mappings are the only finite mapping types.

A finite density function vanishes for all parameter values above one (there are no negative parameter values). The only infinte density function is the constant function.

Finite particle distributions are especially useful because they can always be transformed to stay inside the halo container object. If particles leave the container object they become invisible and the surface of the container will be visible due to the density discontiniuty at the surface.

7.6.4.2 Multiple Halos

It is possible to put more than one halo inside a container object. This is simply done by putting more than one halo statement inside the container object statement like:

```
sphere { 0, 1
  pigment { Clear }
  halo { here comes halo nr. 1 }
  halo { here comes halo nr. 2 }
  halo { here comes halo nr. 3 }
  ...
}
```

The effects of the different halos are added. This is in fact similar to the CSG union operation.

You should note that currently multiple attenuating halos will use the color map of the last halo only. It is not possible to use different color maps for multiple attenuating halos.

7.6.4.3 Halo Type

The type of the halo is defined by one of the following mutually exclusive keywords (if more than one is specified the last will be used). The default is `attenuating`.

```
halo {
  attenuating | emitting | glowing | dust
}
```

The halo type determines how the light will interact with the particles inside the container object. There are two basic categories of light interaction: self-illuminated and illuminated. The first type includes the *attenuating*, *emitting* and *glowing* effects while the *dust* effect is of the second type.

The four types will be covered in detail in the next sections.

7.6.4.3.1 Attenuating

The attenuating halo that only absorbs light passing through it is rendered by accumulating the particle density along a ray. The total halo color is determined from the total, accumulated density and the specified color map (see section 7.6.4.6 on page 310 for details about the color map). The background light, i. e. the light passing through the halo, is attenuated by the total density and added to the total halo color to get the final color of the halo.

This model is suited to render particle distributions with a high *albedo* because the final color does not depend on the transparency of single volume elements but only on the total transparency along the ray. The albedo of a particle is given by the amount of light scattered by this particle in all directions in relation to the amount of incoming light. If the particle doesn't absorb any light the albedo is one.

Clouds and steams are two of the effects that can be rendered quite realistic by adding enough turbulence.

7.6.4.3.2 Dust

The dust halo consists of particles that do not emit any light. They only reflect and absorb incoming light. Its syntax is:

```
halo {
  dust
  [ dust_type DUST_TYPE ]
  [ eccentricity ECCENTRICITY ]
}
```

As the ray marches through the dust all light coming from any light sources is accumulated and scattered according to the dust type and the current dust density. Since this light accumulation includes a test for occlusion, other objects may cast shadows *into* the dust.

The same scattering types that are used with the atmosphere in section 7.7.1 on page 347 can be used with the dust (the default type is isotropic scattering). They are:

```
#declare ISOTROPIC_SCATTERING         = 1
#declare MIE_HAZY_SCATTERING          = 2
#declare MIE_MURKY_SCATTERING         = 3
#declare RAYLEIGH_SCATTERING          = 4
#declare HENYEY_GREENSTEIN_SCATTERING = 5
```

The Henyey-Greenstein function needs the additional parameter `eccentricity` that is described in the section about atmosphere. This keyword only applies to dust type 5, the Henyey-Greenstein scattering.

7.6.4.3.3 Emitting

Emitting halos only emit light. Every particle is a small light source that emits some light. This light is not attenuated by the other particles because they are assumed to be very small.

As the ray travels through the density field of an emitting halo the color of the particles in each volume element and their differential transparency is determined from the color map. These intensities are accumulated to get the total color of the density field. This total intensity is added to the light passing through the halo. The background light is attenuated by the total density of the halo.

Since the emitted light is not attenuated it can be used to model effects like fire, explosions, light beams, etc. By choosing a well suited color map those effects can be rendered with a high degree of realism.

Fire is best modeled using planar mapping. Spherical mapping and high turbulence values can be used to create explosions (it's best to use a periodic color map and frequencies larger than one).

Emitting halos do not cast any light on other objects like light sources do, even though they are made up of small, light-emitting particles. In order to make them actually emit light hundreds or thousands of small light sources would have to be used. This would slow down tracing by a degree that would make it useless.

7.6.4.3.4 Glowing

The glowing halo is similar to the emitting halo. The difference is that the light emitted by the particles is attenuated by the other particles. This can be seen as a combination of the attenuating and the emitting model.

7.6.4.4 Density Mapping

The density mapping is used to map points in space onto a linear, one-dimensional interval between 0.0 and 1.0, thus describing the appearance of the three-dimensional particle distribution. The different mapping types are specified by:

```
halo {
  planar_mapping | spherical_mapping |
  cylindrical_mapping | box_mapping
}
```

The default mapping type is planar mapping.

Since the mapping takes place in relation to the origin of the world coordinate system the following rule must always be kept in mind: *Halo container objects ought to be unit sized objects centered at the origin.* They can be transformed later to suit the individuals needs.

The different mapping types are explained in more detail in the following sections.

7.6.4.4.1 Box Mapping

The box mapping can be used to create a box-shaped particle distribution. The mapping is calculated by getting the maximum of the absolute values of each coordinate as given by the formula:

$$f(x,y,z) = \max\left(|x|, |y|, |z|\right) \tag{7.34}$$

Values larger than one are clipped to one.

7.6.4.4.2 Cylindrical Mapping

The distance $r(x,y,z)$ from the y-axis given by

$$r(x,y,z) = \sqrt{x^2+z^2} \tag{7.35}$$

is used to get the interval values. Values larger than one are clipped to one.

7.6.4.4.3 Planar Mapping

The distance $r(x,y,z)$ from the x-z-plane given by

$$r(x,y,z) = |y| \tag{7.36}$$

is used to get the interval values. Values larger than one are clipped to one.

7.6.4.4.4 Spherical Mapping

The distance $r(x,y,z)$ from the origin given by

$$r(x,y,z) = \sqrt{x^2+y^2+z^2} \tag{7.37}$$

is used to get the interval values. Values larger than one are clipped to one.

7.6.4.5 Density Function

The density function determines how the actual density values are calculated from the linear, one-dimensional interval that resulted from the density mapping.

The density function is specified by the following keywords:

```
halo {
  [ constant | linear | cubic | poly ]
  [ max_value MAX_VALUE ]
  [ exponent EXPONENT ]
}
```

The `exponent` keyword is only used together with the `poly` density function.

The individual functions $f(r)$ are described in the following sections. They all map the value $r(x,y,z)$ calculated by the density mapping onto a suitable density range between 0 and MAX_VALUE (specified with the keyword `max_value`).

7.6.4.5.1 Constant

The constant function gives the constant value MAX_VALUE regardless of the interval value and the type of density mapping. It is calculated by the trivial formula

$$f(r) = MAX\_VALUE. \tag{7.38}$$

The constant density function can be used to create a constant particle distribution that is only constrained by the container object. See figure 7.19 on the facing pagea for a plot of the function.

7.6.4.5.2 Linear

A linear falloff from MAX_VALUE at $r = 0$ to zero at $r = 1$ is created with the linear density function. It is given by:

$$f(r) = MAX\_VALUE\,(1-r) \tag{7.39}$$

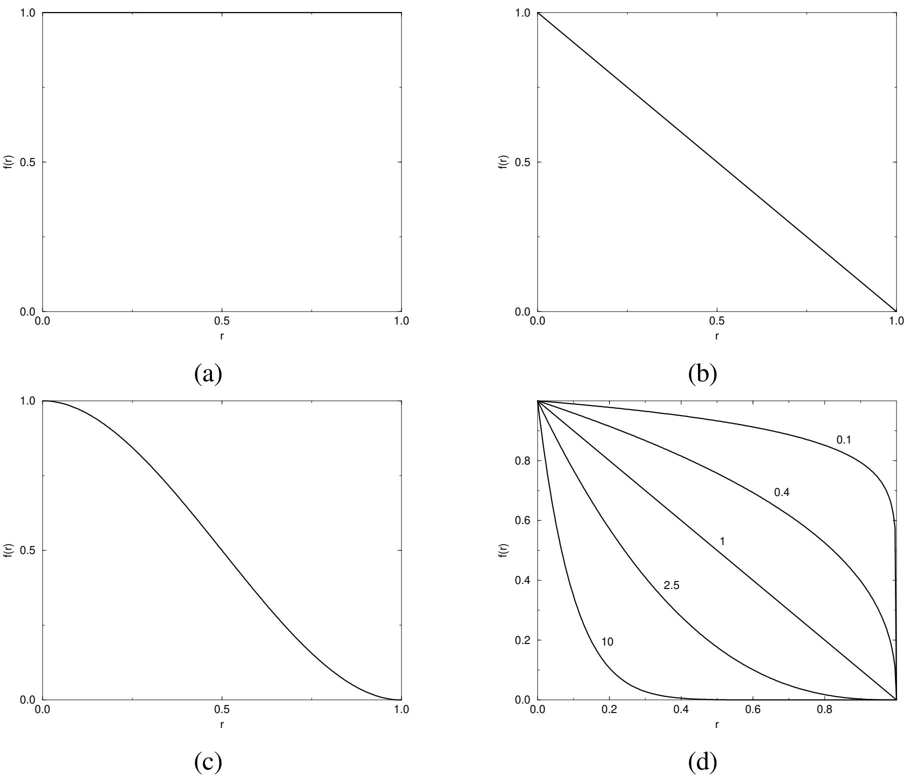


Figure 7.19: The different halo density functions: (a) constant, (b) linear, (c) cubic, and (d) polynomial

.

See figure 7.19b for a plot of the function.

7.6.4.5.3 Cubic

The cubic function gives a smooth blend between the maximum value MAX_VALUE at $r = 0$ and 0 at $r = 1$. It is given by:

$$f(r) = MAX\_VALUE \; (2r^3 - 3r^2 + 1) \qquad (7.40)$$

This is actually a cubic spline. See figure 7.19a for a plot of the function.

7.6.4.5.4 Poly

A polynomial function can be used to get a large variety of density functions. All have the maximum value MAX_VALUE at $r = 0$ and the minimum value 0 at $r = 1$. It is given by:

$$f(r) = MAX\_VALUE\ (1-r)^{EXPONENT} \tag{7.41}$$

The exponent is given by the `exponent` keyword. In case of $EXPONENT = 0$ you'll get a linear falloff. See figure 7.19 on the page beforea for a plot of the function.

7.6.4.6 Halo Color Map

The density $f(r)$, which ranges from 0 to MAX_VALUE, is mapped onto the color map to get the color and differential translucency for each volume element as the ray marches through the density field (the final color of attenuating halos is calculated from the total density; see section 7.6.4.1 on page 303 and section 7.6.4.3.1 on page 305). The differential translucency determines for each value of $f(r)$ how much the total opacity has to be increased (or decreased).

The color map is specified by:

```
halo {
  [ colour_map COLOUR_MAP ]
}
```

The differential translucency is stored in the transmittance channel of the map's color entries. A simple example is given by

```
colour_map {
  [0 rgbt<1, 1, 1, 1>]
  [1 rgbt<1, 1, 1, 0>]
}
```

In this example areas with a low density (small $f(r)$) will be translucent (large differential translucency of $1 = 100\%$) and areas with a high density (large $f(r)$) will be opaque (small differential translucency of $0 = 0\%$). You should note that negative transmittance values can be used to create very dense fields.

In the case of the dust halo the filter channels of the colors in the color map are used to specify the amount of light that will be filtered by the corresponding color map entry. For all other halo types the filter value is ignored.

There is no default color map.

7.6.4.7 Halo Sampling

The halo effects are calculated by marching through the density field along a ray. At discrete steps samples are taken from the density field and evaluated according to the color map and all other parameters. The effects of all volume elements are accumulated to get the total effect.

The following parameters are used to tune the sampling process:

```
halo {
  [ samples SAMPLES ]
  [ aa_level AA_LEVEL ]
  [ aa_threshold AA_THRESHOLD ]
  [ jitter JITTER ]
}
```

The individual sampling parameters are described in the sections below.

7.6.4.7.1 Number of Samples

The number of samples that are taken along the ray inside the halo container object is specified by the `samples` keyword. The greater the number of samples the more denser the density field is sampled and the more accurate but slower the result will be.

The default number of samples is 10. This is sufficient for simple density fields that don't use turbulence.

High turbulence values and dust halos normally need a large number of samples to avoid aliasing artifacts.

7.6.4.7.2 Super-Sampling

The sampling is prone to alias (like the atmosphere sampling in section 7.7.1 on page 347). One way to reduce possible aliasing artifacts is to use super-sampling. If two neighboring samples differ too much an additional sampling is taken in-between. This process recurses until the values of the samples are close too each other or the maximum recursion level given by `AA_LEVEL` is reached. The threshold to kick super-sampling in is given by `AA_THRESHOLD`.

By default super-sampling is not used. The default values for `AA_THRESHOLD` and `AA_LEVEL` are 0.3 and 3 respectively.

7.6.4.7.3 Jitter

Jitter can be used to introduce some noise to the sampling locations. This may help to reduce aliasing artifacts at the cost of an increased noise level in the image. Since the human visual system is much more forgiving to noise than it is to regular patterns this is not much of a problem.

By default jittering is not used. The values should be smaller than 1.0.

Note that jittering is used even if super-sampling is not used.

7.6.4.8 Halo Modifiers

This section covers all general halo modifiers. They are:

```
halo {
  [ turbulence <TURBULENCE> ]
  [ octaves OCTAVES ]
  [ omega OMEGA ]
  [ lambda LAMBDA ]
  [ frequency FREQUENCY ]
  [ phase PHASE ]
  [ scale <VECTOR> ]
  [ rotate <VECTOR> ]
  [ translate <VECTOR> ]
}
```

STILL BEING WRITTEN [DB]

7.6.4.8.1 Turbulence Modifier

STILL BEING WRITTEN [DB]

7.6.4.8.2 Octaves Modifier

STILL BEING WRITTEN [DB]

7.6.4.8.3 Omega Modifier

STILL BEING WRITTEN [DB]

7.6.4.8.4 Lambda Modifier

STILL BEING WRITTEN [DB]

7.6.4.8.5 Frequency Modifier

The `frequency` parameter adjusts the number of times the density interval is mapped onto itself, i. e. the range from 0.0 to 1.0, before it is mapped onto the color map. The formula doing this is:

$$\hat{f}(r) = (frequency\ f(r) + phase) \mod 1. \tag{7.42}$$

Thus the halo color map will be repeated by the specified frequency.

7.6.4.8.6 Phase Modifier

The phase parameter determines the offset at which the mapping of the density field onto itself starts. See equation 7.42 on the preceding page for how the phase is used.

Thus the color entry for density $f(r) = 0$ can be moved to *phase* mod 1.

7.6.4.8.7 Transformation Modifiers

Halos can be transformed using the rotate, scale and translate keywords. You have to be careful that you don't move the density field out of the container object though.

7.6.5 Special Textures

Special textures are complex textures made up of multiple textures. The component textures may be plain textures or may be made up of special textures. A plain texture has just one pigment, normal and finish statement (and maby some halo statements). Even a pigment with a pigment map is still one pigment and thus considered a plain texture as are normals with normal map statements.

Special textures use either a `texture_map` keyword to specify a blend or pattern of textures or they use a bitmap similar to an image map called a *material map* (specified with the `material_map` keyword).

There are restrictions on using special textures. A special texture may not be used as a default texture (see section 7.2.3 on page 206). A special texture cannot be used as a layer in a layered texture however you may use layered textures as any of the textures contained within a special texture.

7.6.5.1 Texture Maps

In addition to specifying blended color with a color map or a pigment map you may create a blend of textures using `texture_map`. The syntax for a texture map is identical to the pigment map except you specify a texture in each map entry.

A texture map is specified by ...

```
texture{
  PATTERN_TYPE
  texture_map {
    [ NUM_1 TEXTURE_BODY_1]
    [ NUM_2 TEXTURE_BODY_2]
    [ NUM_3 TEXTURE_BODY_3]
```

```
      ...
    }
    TEXTURE_MODIFIERS...
  }
```

Where NUM_1, NUM_2, ... are float values between 0.0 and 1.0 inclusive. A TEXTURE_BODY is anything that would normally appear inside a `texture { ... }` statement but the texture keyword and {} braces are not needed. Note that the `[]` brackets are part of the actual statement. They are not notational symbols denoting optional parts. The brackets surround each entry in the map. There may be from 2 to 256 entries in the map.

For example:

```
texture {
  gradient x       //this is the PATTERN_TYPE
  texture_map {
    [0.3  pigment{Red} finish{phong 1}]
    [0.3  T_Wood11]    //this is a texture identifier
    [0.6  T_Wood11]
    [0.9  pigment{DMFWood4} finish{Shiny}]
  }
}
```

When the `gradient x` function returns values from 0.0 to 0.3 the red highlighted texture is used. From 0.3 to 0.6 the texture identifier *T_Wood11* is used. From 0.6 up to 0.9 a blend of *T_Wood11* and a shiny *DMFWood4* is used. From 0.9 on up only the shiny wood is used.

Texture maps may be nested to any level of complexity you desire. The textures in a map may have color maps or texture maps or any type of texture you want.

The blended area of a texture map works by fully calculating both contributing textures in their entirety and then linearly interpolating the apparent colors. This means that reflection, refraction and lighting calculations are done twice for every point. This is in contrast to using a pigment map and a normal map in a plain texture, where the pigment is computed, then the normal, then reflection, refraction and lighting are calculated once for that point.

Entire textures may also be used with the block patterns such as checker, hexagon and brick. For example ...

```
texture {
  checker
    texture { T_Wood12 scale .8 }
    texture { pigment { White_Marble } finish { Shiny } scale .5 }
  }
}
```

Note that in the case of block patterns the `texture { ... }` wrapping is required around the texture information. Also note that this syntax prohibits the use of a layered texture however you can work around this by declaring a texture identifier for the layered texture and referencing the identifier.

A texture map is also used with the `average` pattern type. See 7.6.7.2 on page 319 for details.

7.6.5.2 Tiles

Earlier versions of POV-Ray had a special texture called *tiles texture* that created a checkered pattern of textures. Although it is still supported for backwards computability you should use a checker block texture pattern described in section 7.6.5.1 on page 313 rather than tiles textures.

7.6.5.3 Material Maps

The *material map* special texture extends the concept of image maps to apply to entire textures rather than solid colors. A material map allows you to wrap a 2-D bit-mapped texture pattern around your 3-D objects.

Instead of placing a solid color of the image on the shape like an image map, an entire texture is specified based on the index or color of the image at that point. You must specify a list of textures to be used like a *texture palette* rather than the usual color palette.

When used with mapped file types such as GIF, and some PNG and TGA images, the index of the pixel is used as an index into the list of textures you supply. For unmapped file types such as some PNG and TGA images the 8 bit value of the red component in the range 0-255 is used as an index.

If the index of a pixel is greater than the number of textures in your list then the index is taken modulo *N* where *N* is the length of your list of textures.

7.6.5.3.1 Specifying a Material Map

The syntax of a material map is ...

```
texture {
  material_map {
    FILE_TYPE "filename"
    BITMAP_MODIFIERS...
    texture {..}. // First used for index 0
    texture {..}. // Second texture used for index 1
    texture {..}. // Third texture used for index 2
```

```
      texture {..}. // Fourth texture used for index 3
                    // and so on for however many used.
    }
    TRANSFORMATION...
  }
```

Where FILE_TYPE is one of the following keywords gif, tga, iff, ppm, pgm, png or sys. This is followed by the name of the file using any valid string expression. Several optional modifiers may follow the file specification. The modifiers are described below. Note that earlier versions of POV-Ray allowed some modifiers before the FILE_TYPE but that syntax is being phased out in favor of the syntax described here.

Filenames specified in the material_map statements will be searched for in the home (current) directory first and, if not found, will then be searched for in directories specified by any **+L** switches or Library_Path options. This would facilitate keeping all your material map files in a separate subdirectory and specifying a library path to them. Note that any operating system default paths are not searched unless you also specify them as a Library_Path.

By default, the material is mapped onto the x-y-plane. The material is *projected* onto the object as though there were a slide projector somewhere in the $-z$-direction. The material exactly fills the square area from (x, y) coordinates (0,0) to (1,1) regardless of the bitmap's original size in pixels. If you would like to change this default you may translate, rotate or scale the texture to map it onto the object's surface as desired.

The file name is optionally followed by one or more BITMAP_MODIFIERS. See 7.6.8.9 on page 345 for other details.

After a material_map statement but still inside the texture statement you may apply any legal texture modifiers. Note that no other pigment, normal, finish or halo statements may be added to the texture outside the material map. The following is illegal:

```
  texture {
    material_map {
      gif "matmap.gif"
      texture {T1}
      texture {T2}
      texture {T3}
    }
    finish {phong 1.0}
  }
```

The finish must be individually added to each texture.

Note that earlier versions of POV-Ray allowed such specifications but they were ignored. The above restrictions on syntax were necessary for various bug fixes. This means some POV-Ray 1.0 scenes using material maps many need minor modifications that cannot be done automatically with the version compatibility mode.

If particular index values are not used in an image then it may be necessary to supply dummy textures. It may be necessary to use a paint program or other utility to examine the map file's palette to determine how to arrange the texture list.

The textures within a material map texture may be layered but material map textures do not work as part of a layered texture. To use a layered texture inside a material map you must declare it as a texture identifier and invoke it in the texture list.

7.6.6 Layered Textures

It is possible to create a variety of special effects using layered textures. A layered texture consists of several textures that are partially transparent and are laid one on top of the other to create a more complex texture. The different texture layers show through the transparent portions to create the appearance of one texture that is a combination of several textures.

You create layered textures by listing two or more textures one right after the other. The last texture listed will be the top layer, the first one listed will be the bottom layer. All textures in a layered texture other than the bottom layer should have some transparency. For example:

```
object {
  My_Object
  texture {T1}  // the bottom layer
  texture {T2}  // a semi-transparent layer
  texture {T3}  // the top semi-transparent layer
}
```

In this example T2 shows only where T3 is transparent and T1 shows only where T2 and T3 are transparent.

The color of underlying layers is filtered by upper layers but the results do not look exactly like a series of transparent surfaces. If you had a stack of surfaces with the textures applied to each, the light would be filtered twice: once on the way in as the lower layers are illuminated by filtered light and once on the way out. Layered textures do not filter the illumination on the way in. Other parts of the lighting calculations work differently as well. The results look great and allow for fantastic looking textures but they are simply different from multiple surfaces. See STONES.INC in the standard include files directory for some magnificent layered textures.

Note layered textures must use the `texture { ... }` wrapped around any pigment, normal or finish statements. Do not use multiple pigment, normal or finish statements without putting them inside the texture statement.

Layered textures may be declared. For example

```
#declare Layered_Examp =
  texture {T1}
  texture {T2}
  texture {T3}
```

may be invoked as follows:

```
object {
  My_Object
  texture {
    Layer_Examp
    // Any pigment, normal or finish here
    // modifies the bottom layer only.
  }
}
```

If you wish to use a layered texture in a block pattern, such as checker, hexagon, or brick, or in a material map, you must declare it first and then reference it inside a single texture statement. A special texture cannot be used as a layer in a layered texture however you may use layered textures as any of the textures contained within a special texture.

7.6.7 Patterns

POV-Ray uses a method called *three-dimensional solid texturing* to define the color, bumpiness and other properties of a surface. You specify the way that the texture varies over a surface by specifying a *pattern*. Patterns are used in pigments, normals and texture maps.

All patterns in POV-Ray are three dimensional. For every point in space, each pattern has a unique value. Patterns do not wrap around a surface like putting wallpaper on an object. The patterns exist in 3d and the objects are carved from them like carving an object from a solid block of wood or stone.

Consider a block of wood. It contains light and dark bands that are concentric cylinders being the growth rings of the wood. On the end of the block you see these concentric circles. Along its length you see lines that are the veins. However the pattern exists throughout the entire block. If you cut or carve the wood it reveals the pattern inside. Similarly an onion consists of concentric spheres that are visible only when you slice it. Marble stone consists of wavy layers of colored sediments that harden into rock.

These solid patterns can be simulated using mathematical functions. Other random patterns such as granite or bumps and dents can be generated using a random number system and a noise function.

In each case, the x, y, z coordinate of a point on a surface is used to compute some mathematical function that returns a float value. When used with color maps or pigment maps, that value looks up the color of the pigment to be used. In normal statements the pattern function result modifies or perturbs the surface normal vector to give a bumpy appearance. Used with a texture map, the function result determines which combinations of entire textures to be used.

The following sections describe each pattern. See the sections 7.6.1 on page 278 and 7.6.2 on page 286 for more details on how to use patterns.

7.6.7.1 Agate

The `agate` pattern is a banded pattern similar to marble but it uses a specialized built-in turbulence function that is different from the traditional turbulence. The traditional turbulence can be used as well but it is generally not necessary because agate is already very turbulent. You may control the amount of the built-in turbulence by adding the `agate_turb` keyword followed by a float value. For example:

```
pigment {
  agate
  agate_turb 0.5
  color_map {
    ...
  }
}
```

The agate pattern uses the `ramp_wave` wave type by default but may use any wave type. The pattern may be used with `color_map`, `pigment_map`, `normal_map`, `slope_map` and `texture_map`.

7.6.7.2 Average

Technically `average` is not a pattern type but it is listed here because the syntax is similar to other patterns. Typically a pattern type specifies how colors or normals are chosen from a pigment map or normal map, however `average` tells POV-Ray to average together all of the patterns you specify. Average was originally designed to be used in a normal statement with a normal map as a method of specifying more than one normal pattern on the same surface. However average may be used in a pigment statement with a pigment map or in a texture statement with a texture map to average colors too.

When used with pigments, the syntax is:

```
pigment {
  average
  pigment_map
```

```
    {
      [WEIGHT_1 PIGMENT_BODY_1]
      [WEIGHT_2 PIGMENT_BODY_2]
      ...
      [WEIGHT_n PIGMENT_BODY_n]
    }
    PIGMENT_MODIFIER
  }
```

Similarly you may use a texture map in a texture statement. All textures are fully computed. The resulting colors are then weighted and averaged.

When used with a normal map in a normal statement, multiple copies of the original surface normal are created and are perturbed by each pattern. The perturbed normals are then weighted, added and normalized.

See the sections 7.6.1.4 on page 281, 7.6.2.2 on page 290 and 7.6.5.1 on page 313 for more information.

7.6.7.3 Bozo

The `bozo` pattern is a very smooth, random noise function that is traditionally used with some turbulence to create clouds. The spotted pattern is identical to bozo but in early versions of POV-Ray spotted did not allow turbulence to be added. Turbulence can now be added to any pattern so these are redundant but both are retained for backwards compatibility. The bumps pattern is also identical to bozo when used anywhere except in a normal statement. When used as a normal, bumps uses a slightly different method to perturb the normal with a similar noise function.

The bozo noise function has the following properties:

1. It's defined over 3D space, i. e. it takes the x, y and z coordinates and returns the noise value there.
2. If two points are far apart the noise values at those points are relatively random.
3. If two points are close together the noise values at those points are close to each other.

You can visualize this as having a large room and a thermometer that ranges from 0.0 to 1.0. Each point in the room has a temperature. Points that are far apart have relatively random temperatures. Points that are close together have close temperatures. The temperature changes smoothly but randomly as we move through the room.

Now let's place an object into this room along with an artist. The artist measures the temperature at each point on the object and paints that point a different color depending on the temperature. What do we get? A POV-Ray bozo texture!

The `bozo` pattern uses the `ramp_wave` wave type by default but may use any wave type. The pattern may be used with `color_map`, `pigment_map`, `normal_map`, `slope_map` and `texture_map`.

7.6.7.4 Brick

The `brick` pattern generates a pattern of bricks. The bricks are offset by half a brick length on every other row in the x- and z-directions. A layer of mortar surrounds each brick. The syntax is given by

```
pigment {
  brick COLOR_1, COLOR_2
  brick_size VECTOR
  mortar FLOAT
}
```

where COLOR_1 is the color of the mortar and COLOR_2 is the color of the brick itself. If no colors are specified a default deep red and dark gray are used. The default size of the brick and mortar together is $\langle 8, 3, 4.5 \rangle$ units. The default thickness of the mortar is 0.5 units. These values may be changed using the optional `brick_size` and `mortar` pattern modifiers. You may also use pigment statements in place of the colors. For example:

```
pigment {
  brick pigment{Jade}, pigment{Black_Marble}
}
```

When used with normals, the syntax is

```
normal {
  brick BUMP_FLOAT
}
```

Where BUMP_FLOAT is an optional bump size float value. You may also use full normal statements. For example:

```
normal {
  brick normal { bumps 0.2 }, normal { granite 0.3 }
}
```

When used with textures, the syntax is

```
texture {
  brick texture { T_Gold_1A }, texture { Stone12 }
}
```

This is a block pattern which cannot use wave types, color map, or slope map modifiers.

7.6.7.5 Bumps

The bumps pattern was originally designed only to be used as a normal pattern. It uses a very smooth, random noise function that creates the look of rolling hills when scaled large or a bumpy orange peal when scaled small. Usually the bumps are about 1 unit apart.

When used as a normal, bumps uses a specialized normal perturbation function. This means that the bumps pattern cannot be used with normal map, slope map or wave type modifiers in a normal statement.

When used as a pigment pattern or texture pattern, the bumps pattern is identical to bozo or spotted and is similar to normal bumps but is not identical as are most normals when compared to pigments. When used as pigment or texture statements the bumps pattern uses the ramp_wave wave type by default but may use any wave type. The pattern may be used with color_map, pigment_map, and texture_map.

7.6.7.6 Checker

The checker pattern produces a checkered pattern consisting of alternating squares of COLOR_1 and COLOR_2. If no colors are specified then default blue and green colors are used.

```
pigment { checker COLOR_1, COLOR_2 }
```

The checker pattern is actually a series of cubes that are one unit in size. Imagine a bunch of 1 inch cubes made from two different colors of modeling clay. Now imagine arranging the cubes in an alternating check pattern and stacking them in layer after layer so that the colors still alternate in every direction. Eventually you would have a larger cube. The pattern of checks on each side is what the POV-Ray checker pattern produces when applied to a box object. Finally imagine cutting away at the cube until it is carved into a smooth sphere or any other shape. This is what the checker pattern would look like on an object of any kind.

You may also use pigment statements in place of the colors. For example:

```
pigment { checker pigment { Jade }, pigment { Black_Marble } }
```

When used with normals, the syntax is

```
normal { checker BUMP_FLOAT }
```

Where BUMP_FLOAT is an optional bump size float value. You may also use full normal statements. For example:

```
normal {
  checker normal { gradient x scale .2 }, normal { gradient y scale .2 }
}
```

When used with textures, the syntax is ...

```
texture { checker texture { T_Wood_3A }, texture { Stone12 } }
```

This use of checker as a texture pattern replaces the special tiles texture in previous versions of POV-Ray. You may still use `tiles` but it may be phased out in future versions so checker textures are best.

This is a block pattern which cannot use wave types, color map, or slope map modifiers.

7.6.7.7 Crackle

The `crackle` pattern is a set of random tiled polygons. With a large scale and no turbulence it makes a pretty good stone wall or floor. With a small scale and no turbulence it makes a pretty good crackle ceramic glaze. Using high turbulence it makes a good marble that avoids the problem of apparent parallel layers in traditional marble.

Mathematically, the set $crackle(p) = 0$ is a 3D Voronoi diagram of a field of semi random points and $crackle(p) < 0$ is the distance from the set along the shortest path (a Voronoi diagram is the locus of points equidistant from their two nearest neighbors from a set of disjoint points, like the membranes in suds are to the centers of the bubbles).

The `crackle` pattern uses the `ramp_wave` wave type by default but may use any wave type. The pattern may be used with `color_map`, `pigment_map`, `normal_map`, `slope_map` and `texture_map`.

7.6.7.8 Dents

The `dents` pattern was originally designed only to be used as a normal pattern. It is especially interesting when used with metallic textures. It gives impressions into the metal surface that look like dents have been beaten into the surface with a hammer. Usually the dents are about 1 unit apart.

When used as a normal pattern, dents uses a specialized normal perturbation function. This means that the dents pattern cannot be used with normal map, slope map or wave type modifiers in a normal statement.

When used as a pigment pattern or texture pattern, the `dents` pattern is similar to normal dents but is not identical as are most normals when compared to pigments. When used in pigment or texture statements the `dents` pattern uses the `ramp_wave` wave type by default but may use any wave type. The pattern may be used with `color_map`, `pigment_map` and `texture_map`.

7.6.7.9 Gradient

ne of the simplest patterns is the `gradient` pattern. It is specified as

```
pigment {gradient VECTOR}
```

where VECTOR is a vector pointing in the direction that the colors blend. For example

```
    pigment { gradient x } // bands of color vary as you move
                           // along the "x" direction.
LATEX-ONLY
\begin{QUOTE}
\begin{CF}
```

produces a series of smooth bands of color that look like layers of colors next to each other. Points at $x = 0$ are the first color in the color map. As the x location increases it smoothly turns to the last color at $x = 1$. Then it starts over with the first again and gradually turns into the last color at $x = 2$. The pattern reverses for negative values of x. Using `gradient y` or `gradient z` makes the colors blend along the y- or z-axis. Any vector may be used but x, y and z are most common.

As a normal pattern, gradient generates a saw-tooth or ramped wave appearance. The syntax is

```
normal { gradient VECTOR, BUMP_FLOAT}
```

where the VECTOR giving the orientation is a required parameter but the BUMP_FLOAT bump size which follows is optional.

The pattern uses the `ramp_wave` wave type by default but may use any wave type. The pattern may be used with `color_map`, `pigment_map`, `normal_map`, `slope_map` and `texture_map`.

7.6.7.10 Granite

This pattern uses a simple $1/f$ fractal noise function to give a good granite pattern. This pattern is used with creative color maps in STONES.INC to create some gorgeous layered stone textures.

As a normal pattern it creates an extremely bumpy surface that looks like a gravel driveway or rough stone.

The pattern uses the `ramp_wave` wave type by default but may use any wave type. The pattern may be used with `color_map`, `pigment_map`, `normal_map`, `slope_map` and `texture_map`.

7.6.7.11 Hexagon

The `hexagon` pattern is a block pattern that generates a repeating pattern of hexagons in the *x*-*y*−-plane. In this instance imagine tall rods that are hexagonal in shape and are parallel to the *y*-axis and grouped in bundles like shown in figure 7.20. Three separate colors should be specified as follows:

```
pigment { hexagon COLOR_1, COLOR_2, COLOR_3 }
```

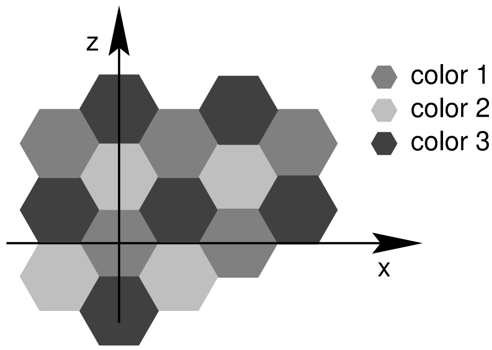


Figure 7.20: The hexagon pattern.

The three colors will repeat the hexagonal pattern with hexagon COLOR_1 centered at the origin, COLOR_2 in the $+z$-direction and COLOR_3 to either side. Each side of the hexagon is one unit long. The hexagonal *rods* of color extend infinitely in the $+y$- and $-y$-directions. If no colors are specified then default blue, green and red colors are used.

You may also use pigment statements in place of the colors. For example:

```
pigment {
  hexagon pigment { Jade },
          pigment { White_Marble },
          pigment { Black_Marble }
}
```

When used with normals, the syntax is

```
normal { hexagon BUMP_FLOAT }
```

Where BUMP_FLOAT is an optional bump size float value. You may also use full normal statements. For example:

```
normal {
  hexagon
    normal { gradient x scale .2 },
    normal { gradient y scale .2 },
    normal { bumps scale .2 }
}
```

When used with textures, the syntax is ...

```
texture {
  hexagon
    texture { T_Gold_3A },
    texture { T_Wood_3A },
    texture { Stone12 }
}
```

This is a block pattern which cannot use wave types, color map, or slope map modifiers.

7.6.7.12 Leopard

Leopard creates regular geometric pattern of circular spots.

The pattern uses the `ramp_wave` wave type by default but may use any wave type. The pattern may be used with `color_map`, `pigment_map`, `normal_map`, `slope_map` and `texture_map`.

7.6.7.13 Mandel

The `mandel` pattern computes the standard Mandelbrot fractal pattern and projects it onto the *x*-*y*-plane. It uses the *x* and *y* coordinates to compute the Mandelbrot set. The pattern is specified with the keyword `mandel` followed by an integer number. This number is the maximum number of iterations to be used to compute the set. Typical values range from 10 up to 256 but any positive integer may be used. For example:

```
pigment {
  mandel 25
  color_map {
    [0.0  color Cyan]
    [0.3  color Yellow]
    [0.6  color Magenta]
    [1.0  color Cyan]
  }
  scale .5
}
```

The value passed to the color map is computed by the formula:

$$value = \frac{number\_of\_iterations}{max\_iterations} \tag{7.43}$$

When used as a normal pattern, the syntax is ...

```
normal {
  mandel ITER, BUMP_AMOUNT
}
```

where the required integer ITER value is optionally followed by a float bump size.

The pattern extends infinitely in the z-direction similar to a planar image map. The pattern uses the `ramp_wave` wave type by default but may use any wave type. The pattern may be used with `color_map`, `pigment_map`, `normal_map`, `slope_map` and `texture_map`.

7.6.7.14 Marble

The `marble` pattern is very similar to the `gradient x` pattern. The gradient pattern uses a default `ramp_wave` wave type which means it uses colors from the color map from 0.0 up to 1.0 at location $x = 1$ but then jumps back to the first color for $x > 1$ and repeats the pattern again and again. However the `marble` pattern uses the `triangle_wave` wave type in which it uses the color map from 0 to 1 but then it reverses the map and blends from 1 back to zero. For example:

```
pigment {
  gradient x
  color_map {
    [0.0  color Yellow]
    [1.0  color Cyan]
  }
}
```

This blends from yellow to cyan and then it abruptly changes back to yellow and repeats. However replacing `gradient x` with `marble` smoothly blends from yellow to cyan as the x coordinate goes from 0.0 to 0.5 and then smoothly blends back from cyan to yellow by $x = 1.0$.

Earlier versions of POV-Ray did not allow you to change wave types. Now that wave types can be changed for most any pattern, the distinction between `marble` and `gradient x` is only a matter of default wave types.

When used with turbulence and an appropriate color map, this pattern looks like veins of color of real marble, jade or other types of stone. By default, marble has no turbulence.

The pattern may be used with `color_map`, `pigment_map`, `normal_map`, `slope_map` and `texture_map`.

7.6.7.15 Onion

Onion is a pattern of concentric spheres like the layers of an onion. Each layer is one unit thick.

The pattern uses the `ramp_wave` wave type by default but may use any wave type. The pattern may be used with `color_map`, `pigment_map`, `normal_map`, `slope_map` and `texture_map`.

7.6.7.16 Quilted

The `quilted` pattern was originally designed only to be used as a normal pattern. The quilted pattern is so named because it can create a pattern somewhat like a quilt or a tiled surface. The squares are actually 3-D cubes that are 1 unit in size.

When used as a normal pattern it uses a specialized normal perturbation function. This means that the quilted pattern cannot be used with normal map, slope map or wave type modifiers in a normal statement.

When used as a pigment pattern or texture pattern, the quilted pattern is similar to normal quilted but is not identical as are most normals when compared to pigments. When used in pigment or texture statements the quilted pattern uses the `ramp_wave` wave type by default but may use any wave type. The pattern may be used with `color_map`, `pigment_map` and `texture_map`.

The two parameters `control0` and `control1` are used to adjust the curvature of the *seam* or *gouge* area between the *quilts*. The syntax is:

```
normal {
  quilted AMOUNT
  control0 C0
  control1 C1
}
```

The values should generally be kept to around the 0.0 to 1.0 range. The default value is 1.0 if none is specified. Think of this *gouge* between the tiles in cross-section as a sloped line.

This straight slope can be made to curve by adjusting the two control values. The control values adjust the slope at the top and bottom of the curve. A control values of 0 at both ends will give a linear slope, as shown in figure 7.21 on the facing page, yielding a hard edge. A control value of 1 at both ends will give an ”s” shaped curve, resulting in a softer, more rounded edge.

7.6.7.17 Radial

The `radial` pattern is a radial blend that wraps around the $+y$-axis. The color for value 0.0 starts at the $+x$-direction and wraps the color map around from east to west

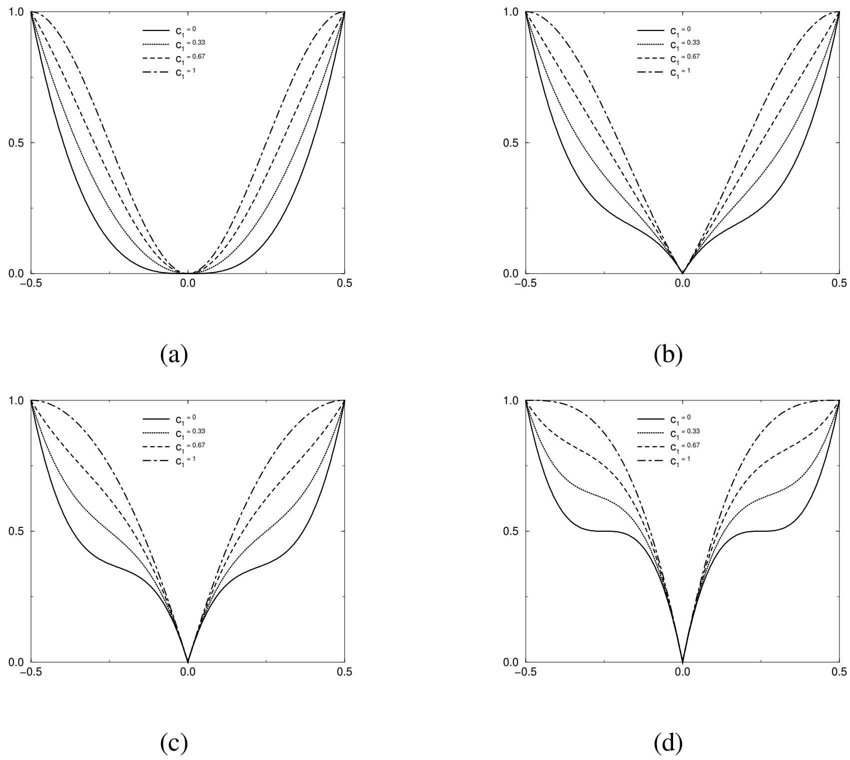


Figure 7.21: Quilted pattern function for different values of c_0 and c_1: (a) $c_0 = 0$, (b) $c_0 = 0.33$, (c) $c_0 = 0.67$, and (d) $c_0 = 1$
.

with 0.25 in the $-z$-direction, 0.5 in $-x$, 0.75 at $+z$ and back to 1.0 at $+x$. Typically the pattern is used with a `frequency` modifier to create multiple bands that radiate from the y-axis.

The pattern uses the `ramp_wave` wave type by default but may use any wave type. The pattern may be used with `color_map`, `pigment_map`, `normal_map`, `slope_map` and `texture_map`.

7.6.7.18 Ripples

The `ripples` pattern was originally designed only to be used as a normal pattern. It makes the surface look like ripples of water. The ripples radiate from 10 random locations inside the unit cube area $\langle 0,0,0\rangle$ to $\langle 1,1,1\rangle$. Scale the pattern to make the centers closer or farther apart.

Usually the ripples from any given center are about 1 unit apart. The `frequency` keyword changes the spacing between ripples. The `phase` keyword can be used to move the ripples outwards for realistic animation.

The number of ripple centers can be changed with the global parameter `global_settings { number_of_waves FLOAT }` somewhere in the scene. This affects the entire scene. You cannot change the number of wave centers on individual patterns. See 7.8.8 on page 362 for details.

When used as a normal pattern, ripples uses a specialized normal perturbation function. This means that the ripples pattern cannot be used with normal map, slope map or wave type modifiers in a normal statement.

When used in pigment or texture statements the `ripples` pattern uses the `ramp_wave` wave type by default but may use any wave type. The pattern may be used with `color_map`, `pigment_map` and `texture_map`.

7.6.7.19 Spiral1

The `spiral1` pattern creates a spiral that winds around the *y*-axis similar to a screw. Its syntax is:

```
pigment {
  spiral1 NUMBER_OF_ARMS
}
```

The NUMBER_OF_ARMS value determins how may *arms* are winding around the *y*-axis.

The pattern uses the `triangle_wave` wave type by default but may use any wave type. The pattern may be used with `color_map`, `pigment_map`, `normal_map`, `slope_map` and `texture_map`.

7.6.7.20 Spiral2

The `spiral2` pattern is a modification of the `spiral1` pattern with an extraordinary look.

The pattern uses the `triangle_wave` wave type by default but may use any wave type. The pattern may be used with `color_map`, `pigment_map`, `normal_map`, `slope_map` and `texture_map`.

7.6.7.21 Spotted

The `spotted` pattern is identical to the `bozo` pattern. Early versions of POV-Ray did not allow turbulence to be used with spotted. Now that any pattern can use turbulence there is no difference between bozo and spotted. See 7.6.7.3 on page 320 for details.

7.6.7.22 Waves

The waves pattern was originally designed only to be used as a normal pattern. The waves pattern looks similar to the ripples pattern except the features are rounder and broader. The effect is to make waves that look more like deep ocean waves. The waves radiate from ten random locations inside the unit cube area $\langle 0,0,0 \rangle$ to $\langle 1,1,1 \rangle$. Scale the pattern to make the centers closer or farther apart.

Usually the waves from any given center are about 1 unit apart. The frequency keyword changes the spacing between waves. The phase keyword can be used to move the waves outwards for realistic animation.

The number of ripple centers can be changed with the global parameter global_settings { number_of_waves FLOAT } somewhere in the scene. This affects the entire scene. You cannot change the number of wave centers on individual patterns. See 7.8.8 on page 362 for details.

When used as a normal pattern, waves uses a specialized normal perturbation function. This means that the waves pattern cannot be used with normal map, slope map or wave type modifiers in a normal statement.

When used in pigment or texture statements the waves pattern uses the ramp_wave wave type by default but may use any wave type. The pattern may be used with color_map, pigment_map and texture_map.

7.6.7.23 Wood

The wood pattern consists of concentric cylinders centered on the z-axis. When appropriately colored, the bands look like the growth rings and veins in real wood. Small amounts of turbulence should be added to make it look more realistic. By default, wood has no turbulence.

Unlike most patterns, the wood pattern uses the triangle_wave wave type by default. This means that like marble, wood uses color map values 0.0 to 1.0 then repeats the colors in reverse order from 1.0 to 0.0. However you may use any wave type. The pattern may be used with color_map, pigment_map, normal_map, slope_map and texture_map.

7.6.7.24 Wrinkles

The wrinkles pattern was originally designed only to be used as a normal pattern. It uses a $1/f$ noise pattern similar to granite but the features in wrinkles are sharper. The pattern can be used to simulate wrinkled cellophane or foil. It also makes an excellent stucco texture.

When used as a normal pattern it uses a specialized normal perturbation function. This means that the wrinkles pattern cannot be used with normal map, slope map or wave type modifiers in a normal statement.

When used as a pigment pattern or texture pattern, the `wrinkles` pattern is similar to normal wrinkles but is not identical as are most normals when compared to pigments. When used in pigment or texture statements the `wrinkles` pattern uses the `ramp_wave` wave type by default but may use any wave type. The pattern may be used with `color_map`, `pigment_map` and `texture_map`.

7.6.8 Pattern Modifiers

Pattern modifiers are statements or parameters which modify how a pattern is evaluated or tells what to do with the pattern. The modifiers `color_map` and `pigment_map` apply only to pigments. See section 7.6.1 on page 278. The modifiers `bump_size`, `slope_map` and `normal_map` apply only to normals. See section 7.6.2 on page 286. The `texture_map` modifier can only be used with textures. See section 7.6.5.1 on page 313.

The pattern modifiers in the following section can be used with pigment, normal or texture patterns.

7.6.8.1 Transforming Patterns

The most common pattern modifiers are the transformation modifiers `translate`, `rotate`, `scale` and `matrix`. For details on these commands see 7.3.1 on page 214.

These modifiers may be placed inside pigment, normal and texture statements to change the position, size and orientation of the patterns.

In general the order of transformations relative to other pattern modifiers such as `turbulence`, `color_map` and other maps is not important. For example scaling before or after turbulence makes no difference. The turbulence is done first, then the scaling regardless of which is specified first. However the order in which transformations are performed relative to `warp` statements is important. See 7.6.8.8 on page 336 for details.

7.6.8.2 Frequency and Phase

The `frequency` and `phase` modifiers act as a type of scale and translate modifiers for `color_map`, `pigment_map`, `normal_map`, `slope_map` and `texture_map`. This discussion uses a color map as an example but the same principles apply to pigment maps, normal maps, slope maps and texture maps.

The `frequency` keyword adjusts the number of times that a color map repeats over one cycle of a pattern. For example `gradient` covers color map values 0 to 1 over the range from $x = 0$ to $x = 1$. By adding `frequency 2.0` the color map repeats twice over that same range. The same effect can be achieved using `scale 0.5*x` so the frequency keyword isn't that useful for patterns like gradient.

However the radial pattern wraps the color map around the $+y$-axis once. If you wanted two copies of the map (or 3 or 10 or 100) you'd have to build a bigger map. Adding `frequency 2.0` causes the color map to be used twice per revolution. Try this:

```
pigment {
  radial
  color_map{[0.5 color Red][0.5 color White]}
  frequency 6
}
```

The result is six sets of red and white radial stripes evenly spaced around the object.

The float after `frequency` can be any value. Values greater than 1.0 causes more than one copy of the map to be used. Values from 0.0 to 1.0 cause a fraction of the map to be used. Negative values reverses the map.

The `phase` value causes the map entries to be shifted so that the map starts and ends at a different place. In the example above if you render successive frames at phase 0 then phase 0.1, phase 0.2 etc you could create an animation that rotates the stripes. The same effect can be easily achieved by rotating the radial pigment using `rotate y*Angle` but there are other uses where phase can be handy.

Sometimes you create a great looking gradient or wood color map but you want the grain slightly adjusted in or out. You could re-order the color map entries but that's a pain. A phase adjustment will shift everything but keep the same scale. Try animating a mandel pigment for a color palette rotation effect.

Frequency and phase have no effect on block patterns checker, brick and hexagon nor do they effect image maps, bump maps or material maps. They also have no effect in normal statements when used with bumps, dents, quilted or wrinkles because these normal patterns cannot use `normal_map` or `slope_map`.

They can be used with normal patterns ripples and waves even though these two patterns cannot use `normal_map` or `slope_map` either. When used with ripples or waves, frequency adjusts the space between features and phase can be adjusted from 0.0 to 1.0 to cause the ripple or waves to move relative to their center for animating the features.

These values work by applying the following formula

$$new\_value = (old\_value * frequency + phase) \mod 1.0. \tag{7.44}$$

7.6.8.3 Waveform

Most patterns that take `color_map`, `pigment_map`, `slope_map`, `normal_map` or `texture_map` use the entries in the map in order from 0.0 to 1.0. The wood and marble patterns use the map from 0.0 to 1.0 and then reverses it and runs it from 1.0 to

0.0. The difference can easily be seen when these patterns are used as normal patterns with no maps.

Patterns such as gradient or onion generate a grove or slot that looks like a ramp that drops off sharply. This is called a `ramp_wave` wave type. However wood and marble slope upwards to a peak, then slope down again in a `triangle_wave`. In previous versions of POV-Ray there was no way to change the wave types. You could simulate a triangle wave on a ramp wave pattern by duplicating the map entries in reverse, however there was no way to use a ramp wave on wood or marble.

Now any pattern that takes a map can have the default wave type overridden. For example:

```
pigment { wood color_map { MyMap } ramp_wave }
```

Also available are `sine_wave` and `scallop_wave` types. These types are of most use in normal patterns as a type of built-in slope map. The `sine_wave` takes the zig-zag of a ramp wave and turns it into a gentle rolling wave with smooth transitions. The `scallop_wave` uses the absolute value of the sine wave which looks like corduroy when scaled small or like a stack of cylinders when scaled larger.

Although any of these wave types can be used for pigments, normals or textures, the `sine_wave` and `scallop_wave` types are not as noticeable on pigments or textures as they are for normals.

Wave types have no effect on block patterns checker, brick and hexagon nor do they effect image maps, bump maps or material maps. They also have no effect in normal statements when used with bumps, dents, quilted or wrinkles because these normal patterns cannot use `normal_map` or `slope_map`.

7.6.8.4 Turbulence

he keyword `turbulence` followed by a float or vector may be used to stir up any pigment, normal, texture, irid or halo. A number of optional parameters may be used with turbulence to control how it is computed. For example:

```
pigment  {
  wood color_map { MyMap }
  turbulence TURB_VECTOR
  octaves FLOAT
  omega FLOAT
  lambda FLOAT
}
```

Typical turbulence values range from the default 0.0, which is no turbulence, to 1.0 or more, which is very turbulent. If a vector is specified different amounts of turbulence are applied in the *x*-, *y*- and *z*-direction. For example

```
turbulence <1.0, 0.6, 0.1>
```

has much turbulence in the x-direction, a moderate amount in the y-direction and a small amount in the z-direction.

Turbulence uses a random noise function called *DNoise*. This is similar to the noise used in the bozo pattern except that instead of giving a single value it gives a direction. You can think of it as the direction that the wind is blowing at that spot. Points close together generate almost the same value but points far apart are randomly different.

In general the order of turbulence parameters relative to other pattern modifiers such as transformations, color maps and other maps is not important. For example scaling before or after turbulence makes no difference. The turbulence is done first, then the scaling regardless of which is specified first. See 7.6.8.8 on the next page for a way to work around this behavior.

Turbulence uses DNoise to push a point around in several steps called `octaves`. We locate the point we want to evaluate, then push it around a bit using turbulence to get to a different point then look up the color or pattern of the new point.

It says in effect *Don't give me the color at this spot ... take a few random steps in different directions and give me that color*. Each step is typically half as long as the one before.

The magnitude of these steps is controlled by the turbulence value. There are three additional parameters which control how turbulence is computed. They are `octaves`, `lambda` and `omega`. Each is optional. Each is followed by a single float value. Each has no effect when there is no turbulence.

7.6.8.5 Octaves

he `octaves` value controls the number of steps of turbulence that are computed. Legal values range from 1 to 10. The default value of 6 is a fairly high value; you won't see much change by setting it to a higher value because the extra steps are too small. Float values are truncated to integer. Smaller numbers of octaves give a gentler, wavy turbulence and computes faster. Higher octaves create more jagged or fuzzy turbulence and takes longer to compute.

7.6.8.6 Lambda

he `lambda` parameter controls how statistically different the random move of an octave is compared to its previous octave. The default value is 2.0 which is quite random. Values close to lambda 1.0 will straighten out the randomness of the path in the diagram above. The zig-zag steps in the calculation are in nearly the same direction. Higher values can look more *swirly* under some circumstances.

7.6.8.7 Omega

he omega value controls how large each successive octave step is compared to the previous value. Each successive octave of turbulence is multiplied by the omega value. The default omega 0.5 means that each octave is $1/2$ the size of the previous one. Higher omega values mean that 2nd, 3rd, 4th and up octaves contribute more turbulence giving a sharper, *crinkly* look while smaller omegas give a fuzzy kind of turbulence that gets blurry in places.

7.6.8.8 Warps

The warp statement is a pattern modifier that is similar to turbulence. Turbulence works by taking the pattern evaluation point and pushing it about in a series of random steps. However warps push the point in very well-defined, non-random, geometric ways. The warp statement also overcomes some limitations of traditional turbulence and transformations by giving the user more control over the order in which turbulence, transformation and warp modifiers are applied to the pattern.

Currently there are three types of warps but the syntax was designed to allow future expansion. The first two, the repeat warp and the black_hole warp are new features for POV-Ray that modify the pattern in geometric ways. The other warp provides an alternative way to specify turbulence.

The syntax for using a warp statement in a pigment is

```
pigment {
  PATTERN_TYPE
  PIGMENT_MODIFIERS...
  warp { WARP_ITEMS..}.
  OTHER_PIGMENT_MODIFIERS...
}
```

Similarly warps may be used in normals and textures. You may have as many separate warp statements as you like in each pattern. The placement of warp statements relative to other modifiers such as color_map or turbulence is not important. However placement of warp statements relative to each other and to transformations is significant. Multiple warps and transformations are evaluated in the order in which you specify them. For example if you translate, then warp or warp, then translate, the results can be different.

7.6.8.8.1 Black Hole Warp

A black hole is so named because of its similarity to real black holes. Just like the real thing, you cannot actually see a black hole. The only way to detect its presence is by the effect it has on things that surround it. Unlike the real thing, however, it won't swallow you up and compress your entire body to a volume of, say, 2.010 – 10 microns in diameter if you get too close (We're working on that part).

Take, for example, a woodgrain. Using POV-Ray's normal turbulence and other texture modifier functions, you can get a nice, random appearance to the grain. But in its randomness it is regular — it is regularly random! Adding a black hole allows you to create a localised disturbance in a woodgrain in either one or multiple locations. The black hole can have the effect of either *sucking* the surrounding texture into itself (like the real thing) or *pushing* it away. In the latter case, applied to a woodgrain, it would look to the viewer as if there were a knothole in the wood. In this text we use a woodgrain regularly as an example, because it is ideally suitable to explaining black holes. However, black holes may in fact be used with any texture.

The effect that the black hole has on the texture can be specified. By default, it *sucks* with the strength calculated expotentially (inverse-square). You can change this if you like.

Black holes may be used anywhere a Warp is permitted. The syntax is:

```
warp
{
  black_hole <CENTER>, RADIUS
  [falloff VALUE]
  [strength VALUE]
  [repeat <VECTOR>]
  [turbulence <VECTOR>]
  [inverse]
}
```

Some examples are given by

```
warp
{
  black_hole <0, 0, 0>, 0.5
}

warp
{
  black_hole <0.15, 0.125, 0>, 0.5
  falloff 7
  strength 1.0
  repeat <1.25, 1.25, 0>
  turbulence <0.25, 0.25, 0>
  inverse
}

warp
{
```

```
    black_hole <0, 0, 0>, 1.0
    falloff 2
    strength 2
    inverse
  }
```

In order to fully understand how a black hole works, it is important to know the theory behind it. A black hole (or any warp) works by taking a point and *perturbing* it to another location. The amount of perturbation depends on the strength of the black hole at the original point passed in to it. The amount of perturbation directly relates to the amount of visual movement that you can see occur in a texture. The stronger the black hole at the input co-ordinate the more that original co-ordinate is moved to another location (either closer to or further away from the center of the black hole.)

Movement always occurs on the vector that exists between the input point and the center of the black hole.

Black holes are considered to be spheres. For a point to be affected by a black hole, it must be within the sphere's volume.

Suppose you have a black hole at $\langle 1,1,1\rangle$ and a point at $\langle 1,2,1\rangle$. If this point is perturbed by a total amount of $+1$ units its new location is $\langle 1,3,1\rangle$, which is on a direct line extrapolated from the vector between $\langle 1,1,1\rangle$ and $\langle 1,2,1\rangle$. In this case the point is *pushed* away from the black hole, which is not *normal* behaviour but is good for demonstration purposes.

The internal properties of a black hole are as follows.

Center	The center of the black hole.
Radius	Its radius.
Falloff	The power by which the effect falls off (default 2).
Strength	The magnitude of the transformation effect (see below).
Inverted	If set *push* points away instead of *pulling* them in.
Repeat	If set we have many black holes instead of one.
Turbulence	If set each new repeated black hole's position is uncertain.
Repeat_Vector	The $\langle x,y,z\rangle$ factor to repeat by.
Turbulence_Vector	The maximum $\langle x,y,z\rangle$ factor for turbulence randomness.

Each of these are discussed below.

Center: A vector defining the center of the sphere that represents the black hole. If the black hole has *Repeat* set it is the offset within each block.

Radius: A number giving the length, in units, of the radius of the sphere that represents the black hole.

If a point is not within radius units of $\langle center \rangle$ it cannot be affected by the black hole and will not be perturbed.

Falloff: The power by which the effect of the black hole falls off. The default is two. The force of the black hole at any given point, before applying the *Strength* modifier, is as follows.

First, convert the distance from the point to the center to a proportion (0 to 1) that the point is from the edge of the black hole. A point on the perimeter of the black hole will be 0.0; a point at the centre will be 1.0; a point exactly halfway will be 0.5, and so forth.

Mentally you can consider this to be a *closeness* factor. A closeness of 1.0 is as close as you can get to the center (i. e. *at* the center), a closeness of 0.0 is as far away as you can get from the center and still be inside the black hole and a closeness of 0.5 means the point is exactly halfway between the two.

Call this value c. Raise c to the power specified in *Falloff*. By default Falloff is 2, so this is c^2 or c squared. The resulting value is the force of the black hole at that exact location and is used, after applying the *Strength* scaling factor as described below, to determine how much the point is perturbed in space.

For example, if c is 0.5 the force is 0.5^2 or 0.25. If c is 0.25 the force is 0.125. But if c is exactly 1.0 the force is 1.0.

Recall that as c gets smaller the point is farther from the center of the black hole. Using the default power of 2, you can see that as c reduces, the force reduces expotentially in an inverse-square relationship. Put in plain english, it means that the force is much stronger (by a power of two) towards the center than it is at the outside.

By increasing *Falloff*, you can increase the magnitude of the falloff. A large value will mean points towards the perimeter will hardly be affected at all and points towards the center will be affected strongly.

A value of 1.0 for *Falloff* will mean that the effect is linear. A point that is exactly halfway to the center of the black hole will be affected by a force of exactly 0.5.

A value of *Falloff* of less than one but greater than zero means that as you get closer to the outside, the force increases rather than decreases. This can have some uses but there is a side effect. Recall that the effect of a black hole ceases outside its perimiter. This means that points just within the permiter will be affected strongly and those just outside not at all. This would lead to a visible border, shaped as a sphere.

A value for *Falloff* of 0 would mean that the force would be 1.0 for all points within the black hole, since any number larger 0 raised to the power of 0 is 1.0.

The magnitude of the movement of the point is determined basically by the value of force after scaling. We'll consider scaling later. Lets take an example.

Suppose we have a black hole of radius 2.0 and a point that is exactly 1.0 units from the center. That means it is exactly half-way to the center and that c would be 0.5. If we use the default falloff of 2 the force at that point is 0.5^2 or 0.25. What this means is that we must move the point by 0.25 of its distance from the center. In this case it is 1.0 units from the center, so we move it by $1.0 * 0.25$ or 0.25 units. This gives a final distance of $1.0 - (1.0 * 0.25)$ or 0.75 units from the center, on a direct line in 3D space between the original position and the center.

If the point were part of, say, a wood grain, the wood grain would appear to bend towards the (invisible) center of the black hole. If the *Inverse* flag were set, however, it would be *pushed* away, meaning its final position would be $1.0 + (1.0 * 0.25)$ or 1.25 units from the center.

Strength: The *Strength* gives you a bit more control over how much a point is perturbed by the black hole. Basically, the force of the black hole (as determined above) is multipled by the value of *Strength*, which defaults to 1.0. If you set Strength to 0.5, for example, all points within the black hole will be moved by only half as much as they would have been. If you set it to 2.0 they will be moved twice as much.

There is a rider to the latter example, though — the movement is clipped to a maximum of the original distance from the center. That is to say, a point that is 0.75 units from the center may only be moved by a maximum of 0.75 units either towards the center or away from it, regardless of the value of *Strength*. The result of this clipping is that you will have an *exclusion* area near the centre of the black hole where all points whose final force value exceeded or equalled 1.0 were moved by a fixed amount.

Inverted: If *Inverted* is set points are *pushed* away from the center instead of being pulled in.

Repeat: *Repeat* allows you to simulate the effect of many black holes without having to explicitly declare them. Repeat is a vector that tells POV-Ray to use this black hole at multiple locations.

If you're not interested in the theory behind all this, just skip the following text and use the values given in the summary below.

Using *Repeat* logically divides your scene up into cubes, the first being located at $\langle 0,0,0\rangle$ and going to $\langle repeat\rangle$. Suppose your repeat vector was $\langle 1,5,2\rangle$. The first cube would be from $\langle 0,0,0\rangle$ to $\langle 1,5,2\rangle$. This cube repeats, so there would be one at $\langle -1,-5,-2\rangle$, $\langle 1,5,2\rangle$, $\langle 2,10,4\rangle$ and so forth in all directions, ad infinitum.

When you use *Repeat*, the center of the black hole does not specify an absolute location in your scene but an offset into each block. It is only possible to use positive offsets. Negative values will produce undefined results.

Suppose your center was $\langle 0.5,1,0.25\rangle$ and the repeat vector is $\langle 2,2,2\rangle$. This gives us a block at $\langle 0,0,0\rangle$ and $\langle 2,2,2\rangle$, etc. The centers of the black hole's for these blocks would be $\langle 0,0,0\rangle + \langle 0.5,1.0,0.25\rangle$, i. e. $\langle 0.5,1.0,0.25\rangle$, and $\langle 2,2,2\rangle + \langle 0.5,1.0,0.25\rangle$, i. e. $\langle 2,5,3.0,2.25\rangle$.

Due to the way repeats are calculated internally, there is a restriction on the values you specify for the repeat vector. Basically, each black hole must be totally enclosed within each block (or cube), with no part crossing into a neighbouring one. This means that, for each of the *x*, *y* and *z* dimensions, the offset of the center may not be less than the radius, and the repeat value for that dimension must be $\geq$ the center plus the radius since any other values would allow the black hole to cross a boundary. Put another way, for each of x, y and z

$$\text{radius} \leq \text{offset or center} <= \text{repeat} - \text{radius}. \tag{7.45}$$

If the repeat vector in any dimension is too small to fit this criteria, it will be increased and a warning message issued. If the center is less than the radius it will also be moved but no message will be issued.

Note that none of the above should be read to mean that you can't overlap black holes. You most certainly can and in fact this can produce some most useful effects. The restriction only applies to elements of the **same** black hole which is repeating. You can declare a second black hole that also repeats and its elements can quite happily overlap the first and causing the appropriate interactions.

It is legal for the repeat value for any dimension to be 0, meaning that POV-Ray will not repeat the black hole in that direction.

Turbulence: *Turbulence* can only be used with *Repeat*. It allows an element of randomness to be inserted into the way the black holes repeat, to cause a more *natural* look. A good example would be an array of knotholes in wood — it would look rather artificial if each knothole were an exact distance from the previous.

The *turbulence vector* is a measurement that is added to each individual back hole in an array, after each axis of the vector is multipled by a different random amount ranging from 0 to 1.

For example, suppose you have a repeating element of a black hole that is supposed to be at $\langle 2,2,2\rangle$. You have specified a turbulence vector of $\langle 4,5,3\rangle$, meaning you want the position to be able to vary by no more than 1.0 units in the X direction, 3.0 units in the Y direction and 2.0 in Z. This means that the valid ranges of the new position are as follows

x can be from 2 to 6.
y can be from 2 to 7.
z can be from 2 to 5.

The resulting actual position of the black hole's center for that particular repeat element is random (but consistent, so renders will be repeatable) and somewhere within the above co-ordinates.

There is a rider on the use of turbulence, which basically is the same as that of the repeat vector. Yyou can't specify a value which would cause a black hole to potentially cross outside of its particular block.

Since POV-Ray doesn't know in advance how much a position will be changed due to the random nature of the changes, it enforces a rule that is similar to the one for

Repeat, except it adds the maximum possible variation for each axis to the center. For example, suppose you had a black hole with a center of $\langle 1.0, 1.0, 1.0\rangle$, radius of 0.5 and a turbulence of $\langle 0.5, 0.25, 0\rangle$ — normally, the mimimum repeat would be $\langle 1.5, 1.5, 1.5\rangle$. However, now we take into account the turbulence, meaning the minimum repeat vector is actually $\langle 2.0, 1.75, 1.5\rangle$.

Repeat summarized: For each of x, y and z the offset of the center must be $\geq$ radius and the value of the repeat must be $\geq$ center + radius + turbulence. The exception being that repeat may be 0 for any dimension, which means do not repeat in that direction.

7.6.8.8.2 Repeat Warp

The `repeat` warp causes a section of the pattern to be repeated over and over. It takes a slice out of the pattern and makes multiple copies of it side-by-side. The warp has many uses but was originally designed to make it easy to model wood veneer textures. Veneer is made by taking very thin slices from a log and placing them side-by-side on some other backing material. You see side-by-side nearly identical ring patterns but each will be a slice perhaps $1/32th$ of an inch deeper.

The syntax for a repeat warp is

```
warp { repeat VECTOR  offset VECTOR  flip VECTOR }
```

The repeat vector specifies the direction in which the pattern repeats and the width of the repeated area. This vector must lie entirely along an axis. In other words, two of its three components must be 0. For example

```
pigment {
  wood
  warp { repeat 2*x }
}
```

which means that from $x = 0$ to $x = 2$ you get whatever the pattern usually is. But from $x = 2$ to $x = 4$ you get the same thing exactly shifted two units over in the x-direction. To evaluate it you simply take the x-coordinate modulo 2. Unfortunately you get exact duplicates which isn't very realistic. The optional `offset` vector tells how much to translate the pattern each time it repeats. For example

```
pigment {
  wood
  warp { repeat 2*x  offset 0.05*z }
}
```

means that we slice the first copy from $x = 0$ to $x = 2$ at $z = 0$ but at $x = 2$ to $x = 4$ we offset to $z = 0.05$. In the 4 to 6 interval we slice at $z = 0.10$. At the n-th copy we slice at $0.05nz$. Thus each copy is slightly different. There are no restrictions on the offset vector.

Finally the `flip` vector causes the pattern to be flipped or mirrored every other copy of the pattern. The first copy of the pattern in the positive direction from the axis is not flipped. The next farther is, the next is not, etc. The flip vector is a three component x, y, z vector but each component is treated as a boolean value that tells if you should or should not flip along a given axis. For example

```
pigment {
  wood
  warp { repeat 2*x flip <1,1,0> }
}
```

means that every other copy of the pattern will be mirrored about the x- and y- axis but not the z-axis. A non-zero value means flip and zero means do not flip about that axis. The magnitude of the values in the flip vector doesn't matter.

7.6.8.8.3 Turbulence Warp

The POV-Ray language contains an ambiguity and limitation on the way you specify turbulence and transformations such as translate, rotate, scale and matrix transforms. Usually the turbulence is done first. Then all translate, rotate, scale and matrix operations are always done after turbulence regardless of the order in which you specify them. For example this

```
pigment {
  wood
  scale .5
  turbulence .2
}
```

works exactly the same as

```
pigment {
  wood
  turbulence .2
  scale .5
}
```

The turbulence is always first. A better example of this limitation is with uneven turbulence and rotations.

```
pigment {
  wood
  turbulence 0.5*y
  rotate z*60
}

// as compared to

pigment {
 wood
 rotate z*60
 turbulence 0.5*y
}
```

The results will be the same either way even though you'd think it should look different.

We cannot change this basic behavior in POV-Ray now because lots of scenes would potentially render differently if suddenly the order transformation vs turbulence suddenly mattered when in the past, it didn't.

However, by specifying our turbulence inside warp statement you tell POV-Ray that the order in which turbulence, transformations and other warps are applied is significant. Here's an example of a turbulence warp.

```
warp { turbulence <0,1,1> octaves 3 lambda 1.5 omega 0.3 }
```

The significance is that this

```
pigment {
  wood
  translate <1,2,3> rotate x*45 scale 2
  warp { turbulence <0,1,1> octaves 3 lambda 1.5 omega 0.3 }
}
```

produces **different results** than this . . .

```
pigment {
  wood
  warp { turbulence <0,1,1> octaves 3 lambda 1.5 omega 0.3 }
  translate <1,2,3> rotate x*45 scale 2
}
```

You may specify turbulence without using a warp statement. However you cannot control the order in which they are evaluated unless you put them in a warp.

The evaluation rules are as follows:

- First any turbulence not inside a warp statement is applied regardless of the order in which it appears relative to warps or transformations.
- Next each warp statement, translate, rotate, scale or matrix one-by-one, is applied in the order the user specifies. If you want turbulence done in a specific order, you simply specify it inside a warp in the proper place.

7.6.8.9 Bitmap Modifiers

A bitmap modifier is a modifier used inside an 7.6.1.5 on page 283, 7.6.2.3 on page 292 or 7.6.5.3 on page 315 to specify how the 2-D bitmap is to be applied to the 3-D surface. Several bitmap modifiers apply to specific kinds of maps and they are covered in the appropriate sections. The bitmap modifiers discussed in the following sections are applicable to all three types of bitmaps.

7.6.8.9.1 The once Option

Normally there are an infinite number of repeating image maps, bump maps or material maps created over every unit square of the *x*-*y*-plane like tiles. By adding the `once` keyword after a file name you can eliminate all other copies of the map except the one at $(0,0)$ to $(1,1)$. In image maps, areas outside this unit square are treated as fully transparent. In bump maps, areas outside this unit square are left flat with no normal modification. In material maps, areas outside this unit square are textured with the first texture of the texture list.

For example:

```
image_map {
  gif "mypic.gif"
  once
}
```

7.6.8.9.2 The "map_type" Option

The default projection of the bump onto the *x*-*y*-plane is called a *planar map type*. This option may be changed by adding the `map_type` keyword followed by a number specifying the way to wrap the bump around the object.

A `map_type 0` gives the default planar mapping already described.

A `map_type 1` gives a spherical mapping. It assumes that the object is a sphere of any size sitting at the origin. The *y*-axis is the north/south pole of the spherical mapping. The top and bottom edges of the bitmap just touch the pole regardless of any scaling. The left edge of the bitmap begins at the positive *x*-axis and wraps the pattern around the sphere from *west* to *east* in a $-y$-rotation. The pattern covers the sphere exactly once. The `once` keyword has no meaning for this type.

With `map_type 2` you get a cylindrical mapping. It assumes that a cylinder of any diameter lies along the y-axis. The bump pattern wraps around the cylinder just like the spherical map but remains one unit tall from $y = 0$ to $y = 1$. This band of the pattern is repeated at all heights unless the `once` keyword is applied.

Finally `map_type 5` is a torus or donut shaped mapping. It assumes that a torus of major radius 1 sits at the origin in the x-z-plane. The pattern is wrapped around similar to spherical or cylindrical maps. However the top and bottom edges of the map wrap over and under the torus where they meet each other on the inner rim.

Types 3 and 4 are still under development.

For example:

```
sphere{<0,0,0>,1
  pigment{
    image_map {
      gif "world.gif"
      map_type 1
    }
  }
}
```

7.6.8.9.3 The interpolate Option

Adding the `interpolate` keyword can smooth the jagged look of a bitmap. When POV-Ray asks an image map color or a bump amount for a bump map, it often asks for a point that is not directly on top of one pixel but sort of between several differently colored pixels. Interpolations returns an *in-between* value so that the steps between the pixels in the map will look smoother.

Although `interpolate` is legal in material maps the color index is interpolated before the texture is chosen. It does not interpolate the final color as you might hope it would. In general, interpolation of material maps serves no useful purpose but this may be fixed in future versions.

There are currently two types of interpolation:

Bilinear	— `interpolate 2`
Normalized Distance	— `interpolate 4`

For example:

```
image_map {
  gif "mypic.gif"
  interpolate 2
}
```

Default is no interpolation. Normalized distance is the slightly faster of the two, bilinear does a better job of picking the between color. Normally bilinear is used.

If your map looks jaggy, try using interpolation instead of going to a higher resolution image. The results can be very good.

7.7 Atmospheric Effects

Atmospheric effects are a loosely-knit group of features that affect the background and/or the atmosphere enclosing the scene. POV-Ray includes the ability to render a number of atmospheric effects, such as fog, haze, mist, rainbows and skies.

7.7.1 Atmosphere

Computer generated images normally assume a vacuum space that does not allow the rendering of natural phenomena like smoke, light beams, etc. A very simple approach to add fog to a scene is explained in section 7.7.3 on page 351. This kind of fog does not interact with any light sources though. It will not show light beams or other effects and is therefore not very realistic.

The atmosphere effect overcomes some of the fog's limitations by calculating the interaction between light and the particles in the atmosphere using volume sampling. Thus shaft of light beams will become visible and objects will cast shadows *onto* smoke or fog.

The syntax of the atmosphere is:

```
atmosphere {
  type TYPE
  distance DISTANCE
  [ scattering SCATTERING ]
  [ eccentricity ECCENTRICITY ]
  [ samples SAMPLES ]
  [ jitter JITTER ]
  [ aa_threshold AA_THRESHOLD ]
  [ aa_level AA_LEVEL ]
  [ colour <COLOUR> ]
}
```

The `type` keyword determines the type of scattering model to be used. There are five different phase functions representing the different models: isotropic, Rayleigh, Mie (haze and murky atmosphere) and Henyey-Greenstein. The different scattering functions are shown in figure 7.22.

Isotropic scattering is the simplest form of scattering because it is independent of direction. The amount of light scattered by particles in the atmosphere does not depend on the angle between the viewing direction and the incoming light.

Rayleigh scattering models the scattering for extremely small particles such as molecules of the air. The amount of scattered light depends on the incident light angle. It is largest when the incident light is parallel or anti-parallel to the viewing direction and smallest when the incident light is perpendicular to the viewing direction. You should note that the Rayleigh model used in POV-Ray does not take the dependency of scattering on the wavelength into account.

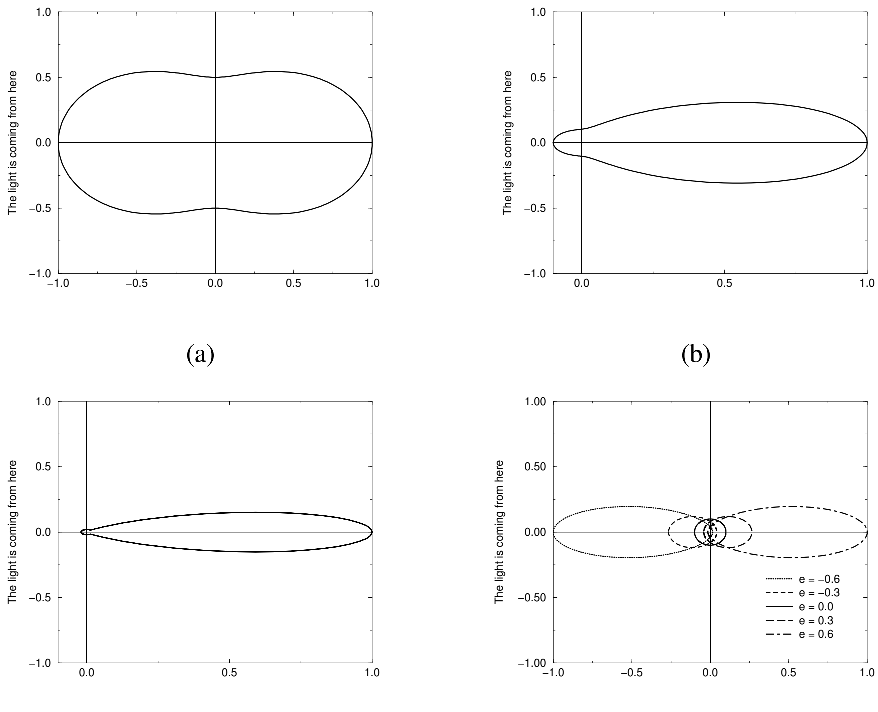


Figure 7.22: The different atmospheric scattering functions: (a) Rayleigh, (b) Mie ”haze”, (c) Mie ”murky”, and (d) Heyney-Greenstein

.

Mie scattering is used for relatively small particles such as miniscule water droplets of fog, cloud particles, and particles responsible for the polluted sky. In this model the scattering is extremely directional in the forward direction i. e. the amount of scattered light is largest when the incident light is anti-parallel to the viewing direction (the light goes directly to the viewer). It is smallest when the incident light is parallel to the viewing direction. The haze and murky atmosphere models differ in their scattering characteristics. The murky model is much more directional than the haze model.

The *Henyey-Greenstein scattering* is based on an analytical function and can be used to model a large variety of different scattering types. The function models an ellipse with a given eccentricity e. This eccentricity is specified by the optional keyword `eccentricity` which is only used for scattering type five. An eccentricity value of zero defines isotropic scattering while positive values lead to scattering in the direction of the light and negative values lead to scattering in the opposite direction of the light. Larger values of e (or smaller values in the negative case) increase the directional property of the scattering.

The easiest way to use the different scattering types will be to declare some constants and use those in your atmosphere definition:

```
#declare ISOTROPIC_SCATTERING         = 1
#declare MIE_HAZY_SCATTERING          = 2
#declare MIE_MURKY_SCATTERING         = 3
#declare RAYLEIGH_SCATTERING          = 4
#declare HENYEY_GREENSTEIN_SCATTERING = 5
```

The `distance` keyword is used to determine the density of the particles in the atmosphere. This density is constant for the whole atmosphere. The distance parameter works in the same way as the fog distance.

With the `scattering` keyword you can change the amount of light that is scattered by the atmosphere, thus increasing or decreasing the brightness of the atmosphere. Smaller scattering values decrease the brightness while larger values increase it.

The `colour` or `color` keyword can be used to create a colored atsosphere, i. e. it can be used to get particles that filter the light passing through. The default color is black.

The light passing through the atmosphere (either coming from light sources or the background) is filtered by the atmosphere's color if the specified color has a non-zero filter value. In other words, the amount by which the light is filtered by the atmosphere's color is given by the filter value (pretty much in the same way as it is done for the fog). Using a color of `rgbf` $\langle 1,0,0,0.25\rangle$ will result in a slightly reddish atmosphere because 25% of the light passing through the atmosphere is filtered by (multiplied with) the color of the atmosphere, i. e. rgb $\langle 1,0,0\rangle$ (and that's red).

The transmittance channel of the atmosphere's color is used to specify a minimum translucency. If a value larger than zero is used you'll always see that amount of the background through the atmosphere, regardless of how dense the atmosphere is. This works in the same way as it does for fogs.

Since the atmosphere is calculated by sampling along the viewing ray and looking for contributions from light sources, it is prone to aliasing (just like any sampling technique). There are four parameters to minimize the artifacts that may be visible: samples, jitter, aa_level and aa_threshold.

The samples keyword determines how many samples are calculated in one interval along the viewing ray. The length of the interval is either the distance as given by the distance keyword or the length of the *lit* part of the viewing ray, whichever is smaller. This lit part is a section of the ray that is *most likely* lit by a light source. In the case of a spotlight it is the part of the ray that lies in the cone of light. In other cases it becomes more difficult. The only thing you should keep in mind is that the actual sampling interval length is variable but there will never be fewer than the specified samples in the specified distance.

One technique to reduce the visibility of sampling artifacts is to jitter the sample points, i. e. to add random noise to their location. This can be done with the jitter keyword.

Another technique is super-sampling (an anti-aliasing method). This helps to avoid missing features by adding additional samples in places were high intensity changes occur (e. g. the edge of a shadow). The anti-aliasing is turned on by the aa_level keyword. If this is larger than zero super-sampling will be used. The additional samples will be recursively placed between two samples with a high intensity change. The level to which subdivision takes places is specified by the aa_level keyword. Level one means one subdivision (one additional sample), level two means two subdivisions (up to three additional samples), etc.

The threshold for the intensity change is given by the aa_threshold keyword. If the intensity change is greater than this threshold anti-aliasing will be used for those two samples.

With spotlights you'll be able to create the best results because their cone of light will become visible. Pointlights can be used to create effects like street lights in fog. Lights can be made to not interact with the atmosphere by adding atmosphere off to the light source. They can be used to increase the overall light level off the scene to make it look more realistic.

You should note that the atmosphere feature will not work if the camera is inside a non-hollow object (see 7.5.1 on page 229 for a detailed explanation).

7.7.2 Background

A background color can be specified if desired. Any ray that doesn't hit an object will be colored with this color. The default background is black. The syntax for background is:

```
background { colour <COLOUR> }
```

7.7.3 Fog

Fog is defined by the following statement:

```
fog {
  fog_type FOG_TYPE
  distance DISTANCE
  colour <COLOUR>
  [ turbulence <TURBULENCE> ]
  [ turb_depth TURB_DEPTH ]
  [ omega OMEGA ]
  [ lambda LAMBDA ]
  [ octaves OCTAVES ]
  [ fog_offset FOG_OFFSET ]
  [ fog_alt FOG_ALT ]
  [ up <FOG_UP> ]
  [ TRANSFORMATION ]
}
```

The optional `up` vector specifies a direction pointing up, generally the same as the camera's up vector. All calculations done during the ground fog evaluation are done relative to this up vector, i. e. the actual heights are calculated along this vector.

The up vector can also be modified using any of the known transformations described in 7.3.1 on page 214. Though it may not be a good idea to scale the up vector — the results are hardly predictable — it is quite useful to be able to rotate it. You should also note that translations do not affect the up direction (and thus don't affect the fog).

Currently there are two fog types, *constant fog* and *ground fog*. The constant fog has a constant density everywhere while the ground fog has a constant density for all heights below a given point on the up axis and thins out along this axis. The height below which the fog has constant density is specified by the `fog_offset` keyword. The `fog_alt` keyword is used to specify the rate by which the fog fades away. At an altitude of $fog\_offset + fog\_alt$ the fog has a density of 25%. The density of the fog at a given height y is calculated by the formula:

$$density = \begin{cases} \dfrac{1}{\left(1 + \dfrac{y - fog\_offset}{fog\_alt}\right)^2}, & y > fog\_alt \\ 1, & y \leq fog\_alt \end{cases} \tag{7.46}$$

The total density along a ray is calculated by integrating from the height of the starting point to the height of the end point.

Two constants are defined for easy use of the fog types in the file CONST.INC:

```
// FOG TYPE CONSTANTS
#declare Constant_Fog = 1
#declare Ground_Fog   = 2
```

The color of a pixel with an intersection depth d is calculated by

$$Color_{pixel} = e^{\frac{-d}{D}}\, Color_{object} + \left(1 - e^{\frac{-d}{D}}\right) Color_{fog} \tag{7.47}$$

where D is the fog distance. At depth 0 the final color is the object's color. If the intersection depth equals the fog distance the final color consists of 64% of the object's color and 36% of the fog's color.

The fog color that is given by the `color` keyword has three purposes. First it defines the color to be used in blending the fog and the background. Second it is used to specify a translucency threshold. By using a transmittance larger than zero one can make sure that at least that amount of light will be seen through the fog. With a transmittance of 0.3 you'll see at least 30% of the background. Third it can be used to make a filtering fog. With a filter value larger than zero the amount of background light given by the filer value will be multiplied with the fog color. A filter value of 0.7 will lead to a fog that filters 70% of the background light and leaves 30% unfiltered.

Fogs may be *layered*. That is, you can apply as many layers of fog as you like. Generally this is most effective if each layer is a ground fog of different color, altitude and with different turbulence values. To use multiple layers of fogs, just add all of them to the scene.

You may optionally stir up the fog by adding turbulence. The `turbulence` keyword may be followed by a float or vector to specify an amount of turbulence to be used. The `omega`, `lambda` and `octaves` turbulence parameters may also be specified. See section 7.6.8 on page 332 for details on all of these turbulence parameters.

Additionally the fog turbulence may be scaled along the direction of the viewing ray using the `turb_depth` amount. Typical values are from 0.0 to 1.0 or more. The default value is 0.5 but any float value may be used.

You should note that the fog feature will not work if the camera is inside a non-hollow object (see 7.5.1 on page 229 for a detailed explanation).

7.7.4 Sky Sphere

The sky sphere is used create a realistic sky background without the need of an additional sphere to simulate the sky. Its syntax is:

```
sky_sphere {
  pigment { PIGMENT1 }
  pigment { PIGMENT2 }
  pigment { PIGMENT3 }
  ...
  [ TRANSFORMATION ]
}
```

The sky sphere can contain several pigment layers with the last pigment being at the top, i. e. it is evaluated last, and the first pigment being at the bottom, i. e. it is evaluated first. If the upper layers contain filtering and/or transmitting components lower layers will shine through. If not lower layers will be invisible.

The sky sphere is calculated by using the direction vector as the parameter for evaluating the pigment patterns. This leads to results independent from the view point which pretty good models a real sky where the distance to the sky is much larger than the distances between visible objects.

If you want to add a nice color blend to your background you can easily do this by using the following example.

```
sky_sphere {
  pigment {
    gradient y
    color_map {
      [ 0.5  color CornflowerBlue ]
      [ 1.0  color MidnightBlue ]
    }
    scale 2
    translate -1
  }
}
```

This gives a soft blend from *CornflowerBlue* at the horizon to *MidnightBlue* at the zenith. The scale and translate operations are used to map the direction vector values, which lie in the range from $\langle -1,-1,-1\rangle$ to $\langle 1,1,1\rangle$, onto the range from $\langle 0,0,0\rangle$ to $\langle 1,1,1\rangle$. Thus a repetition of the color blend is avoided for parts of the sky below the horizon.

In order to easily animate a sky sphere you can transform it using the known transformations described in 7.3.1 on page 214. Though it may not be a good idea to translate or scale a sky sphere — the results are hardly predictable — it is quite useful to be able to rotate it. In an animation the color blendings of the sky can be made to follow the rising sun for example.

You should note that only one sky sphere can be used in any scene. It also will not work as you might expect if you use camera types like the orthographic or cylindrical camera. The orthographic camera uses parallel rays and thus you'll only see a very small part of the sky sphere (you'll get one color skies in most cases). Reflections in curved surface will work though, e. g. you will clearly see the sky in a mirrored ball.

7.7.5 Rainbow

The rainbow is a fog-like, circular arc that can be used to create rainbows. The syntax is:

```
rainbow {
  direction <DIR>
  angle ANGLE
  width WIDTH
  distance DISTANCE
  color_map { COLOUR_MAP }
  [ jitter JITTER ]
  [ up <UP> ]
  [ arc_angle ARC_ANGLE ]
  [ falloff_angle FALLOFF_ANGLE ]
}
```

The `direction` vector determines the direction of the (virtual) light that is responsible for the rainbow. Ideally this is an infinitely far away light source like the sun that emits parallel light rays. The position and size of the rainbow are specified by the `angle` and `width` keywords. To understand how they work you should first know how the rainbow is calculated.

For each ray the angle between the rainbow's direction vector and the ray's direction vector is calculated. If this angle lies in the interval from $ANGLE - WIDTH/2$ to $ANGLE + WIDTH/2$ the rainbow is hit by the ray. The color is then determined by using the angle as an index into the rainbow's colormap. After the color has been determined it will be mixed with the background color in the same way like it is done for fogs.

Thus the angle and width parameters determine the angles under which the rainbow will be seen. The optional `jitter` keyword can be used to add random noise to the index. This adds some irregularity to the rainbow that makes it look more realistic.

The `distance` keyword is the same like the one used with fogs. Since the rainbow is a fog-like effect it's possible that the rainbow is noticeable on objects. If this effect is not wanted it can be avoided by using a large distance value. By default a sufficiently large value is used to make sure that this effect does not occure.

The `color_map` keyword is used to assign a color map that will be mapped onto the rainbow. To be able to create realistic rainbows it is important to know that the index into the color map increases with the angle between the ray's and rainbow's direction vector. The index is zero at the innermost *ring* and one at the outermost *ring*. The filter and transmittance values of the colors in the color map have the same meaning as the ones used with fogs (see section 7.7.3 on page 351).

The default rainbow is a 360 degree arc that looks like a circle. This is no problem as long as you have a ground plane that hides the lower, non-visible part of the rainbow. If this isn't the case or if you don't want the full arc to be visible you can use the optional keywords `up`, `arc_angle` and `falloff_angle` to specify a smaller arc.

The `arc_angle` keyword determines the size of the arc in degrees (from 0 to 360 degrees). A value smaller than 360 degrees results in an arc that abruptly vanishes. Since this doesn't look nice you can use the `falloff_angle` keyword to specify a region in which the rainbow will smoothly blend into the background making it vanish softly. The falloff angle has to be smaller or equal to the arc angle.

The up keyword determines were the *zero angle* position is. By changing this vector you can *rotate* the rainbow about its direction. You should note that the arc goes from $-ARC\_ANGLE/2$ to $+ARC\_ANGLE/2$. The soft regions go from $-ARC\_ANGLE/2$ to $-FALLOFF\_ANGLE/2$ and from $+FALLOFF\_ANGLE/2$ to $+ARC\_ANGLE/2$.

The following example generates a 120 degrees rainbow arc that has a falloff region of 30 degrees at both ends:

```
rainbow {
  direction <0, 0, 1>
  angle 42.5
  width 5
  distance 1000
  jitter 0.01
  color_map { Rainbow_Color_Map }
  up <0, 1, 0>
  arc_angle 120
  falloff_angle 60
}
```

It is possible to use any number of rainbows and to combine them with other atmospheric effects.

7.8 Global Settings

The global_settings statement is a *catch-all* statement that gathers together a number of global parameters. The statement may appear anywhere in a scene as long as its not inside any other statement. You may have multiple global_settings statements in a scene. Whatever values were specified in the last global_settings statement override any previous settings. Regardless of where you specify the statement, the feature applies to the entire scene.

Note that some items which were language directives in previous versions of POV-Ray have been moved inside the global_settings statement so that it is more obvious to the user that their effect is global. The old syntax is permitted but generates a warning.

```
global_settings {
  adc_bailout FLOAT
  ambient_light COLOR
  assumed_gamma FLOAT
  hf_gray_16 BOOLEAN
```

```
  irid_wavelength COLOR
  max_intersections INTEGER
  max_trace_level INTEGER
  number_of_waves INTEGER
  radiosity { RADIOSITY_ITEMS... }
}
```

Each item is optional and may appear in and order. If an item is specified more than once, the last setting overrides previous values. Details on each item are given in the following sections.

7.8.1 ADC_Bailout

In scenes with many reflective and transparent surfaces, POV-Ray can get bogged down tracing multiple reflections and refractions that contribute very little to the color of a particular pixel. The program uses a system called *Adaptive Depth Control* (ADC) to stop computing additional reflected or refracted rays when their contribution is insignificant.

You may use the global setting `adc_bailout` keyword followed by float value to specify the point at which a ray's contribution is considered insignificant.

```
global_settings { adc_bailout FLOAT }
```

The default value is 1/255, or approximately 0.0039, since a change smaller than that could not be visible in a 24 bit image. Generally this setting is perfectly adequate and should be left alone. Setting `adc_bailout` to 0 will disable ADC, relying completely on `max_trace_level` to set an upper limit on the number of rays spawned.

See 7.8.6 on page 360 for details on how ADC and `max_trace_level` interact.

7.8.2 Ambient Light

Ambient light is used to simulate the effect of interdiffuse reflection that is responsible for lighting areas that partially or completely lie in shadow. POV-Ray provides an ambient light source to let you easily change the brightness of the ambient lighting without changing every ambient value in all finish statements. It also lets you create interesting effects by changing the color of the ambient light source. The syntax is:

```
global_settings { ambient_light COLOR }
```

The default is a white ambient light source set at $\texttt{rgb}\langle 1,1,1\rangle$. The actual ambient used is:

$$ambient = ambient_{finish}\ ambient_{light\_source} \tag{7.48}$$

See section 7.6.3.1 on page 295 for more information.

7.8.3 Assumed_Gamma

Many people may have noticed at one time or another that some images are too bright or dim when displayed on their system. As a rule, Macintosh users find that images created on a PC are too bright, while PC users find that images created on a Macintosh are too dim.

The `assumed_gamma` global setting works in conjunction with the Display_Gamma INI setting (see section 6.2.2.2.1 on page 158) to ensure that scene files render the same way across the wide variety of hardware platforms that POV-Ray is used on. The assumed gamma setting is used in a scene file by adding

```
global_settings { assumed_gamma FLOAT }
```

where the assumed gamma value is the correction factor to be applied before the pixels are displayed and/or saved to disk. For scenes created in older versions of POV-Ray, the assumed gamma value will be the same as the display gamma value of the system the scene was created on. For PC systems, the most common display gamma is 2.2, while for scenes created on Macintosh systems should use a scene gamma of 1.8. Another gamma value that sometimes occurs in scenes is 1.0.

Scenes that do not have an `assumed_gamma` global setting will not have any gamma correction performed on them, for compatibility reasons. If you are creating new scenes or rendering old scenes, it is strongly recommended that you put in an appropriate `assumed_gamma` global setting. For new scenes, you should use an assumed gamma value of 1.0 as this models how light appears in the real world more realistically.

The following sections explain more thoroughly what gamma is and why it is important.

7.8.3.1 Monitor Gamma

The differences in how images are displayed is a result of how a computer actually takes an image and displays it on the monitor. In the process of rendering an image and displaying it on the screen, several gamma values are important, including the POV scene file or image file gamma and the monitor gamma.

Most image files generated by POV-Ray store numbers in the range from 0 to 255 for each of the red, green and blue components of a pixel. These numbers represent the intensity of each color component, with 0 being black and 255 being the brightest color (either 100% red, 100% green or 100% blue). When an image is displayed, the graphics card converts each color component into a voltage which is sent to the monitor to light up the red, green and blue phosphors on the screen. The voltage is usually proportional to the value of each color component.

Gamma becomes important when displaying intensities that aren't the maximum or minimum possible values. For example, 127 should represent 50% of the maximum intensity for pixels stored as numbers between 0 and 255. On systems that don't do gamma correction, 127 will be converted to 50% of the maximum voltage, but because of the way the phosphors and the electron guns in a monitor work, this may be only 22% of the maximum color intensity on a monitor with a gamma of 2.2. To display a pixel which is 50% of the maximum intensity on this monitor, we would need a voltage of 73% of the maximum voltage, which translates to storing a pixel value of 186.

The relationship between the input pixel value and the displayed intensity can be approximated by an exponential function

$$obright = ibright^{display\_gamma} \tag{7.49}$$

where *obright* is the output intensity and *ibright* is the input pixel intensity. Both values are in the range from 0 to 1 (0% to 100%). Most monitors have a fixed gamma value in the range from 1.8 to 2.6. Using the above formula with $display\_gamma$ values greater than 1 means that the output brightness will be less than the input brightness. In order to have the output and input brightness be equal an overall system gamma of 1 is needed. To do this, we need to gamma correct the input brightness in the same manner as above but with a gamma value of $1/display\_gamma$ before it is sent to the monitor. To correct for a display gamma of 2.2, this pre-monitor gamma correction uses a gamma value of $1.0/2.2$ or approximately 0.45.

How the pre-monitor gamma correction is done depends on what hardware and software is being used. On Macintosh systems, the operating system has taken it upon itself to insulate applications from the differences in display hardware. Through a gamma control panel the user may be able to set the actual monitor gamma and MacOS will then convert all pixel intensities so that the monitor will appear to have the specified gamma value. On Silicon Graphics machines, the display adapter has built-in gamma correction calibrated to the monitor which gives the desired overall gamma (the default is 1.7). Unfortunately, on PCs and most UNIX systems, it is up to the application to do any gamma correction needed.

7.8.3.2 Image File Gamma

Since most PC and UNIX applications and image file formats don't understand display gamma, they don't do anything to correct for it. As a result, users creating images on these systems adjust the image in such a way that it has the correct brightness when displayed. This means that the data values stored in the files are made brighter to compensate for the darkening effect of the monitor. In essence, the 0.45 gamma correction is built in to the image files created and stored on these systems. When these files are displayed on a Macintosh system, the gamma correction built in to the file, in addition to gamma correction built into MacOS, means that the image will be too bright. Similarly, files that look correct on Macintosh or SGI systems because of the built-in gamma correction will be too dark when displayed on a PC.

The new PNG format files generated by POV-Ray 3.0 overcome the problem of too much or not enough gamma correction by storing the image file gamma (which is

$1.0/display\_gamma$) inside the PNG file when it is generated by POV-Ray. When the PNG file is later displayed by a program that has been set up correctly, it uses this gamma value as well as the current display gamma to correct for the potentially different display gamma used when originally creating the image.

Unfortunately, of all the image file formats POV-Ray supports, PNG is the only one that has any gamma correction features and is therefore preferred for images that will be displayed on a wide variety of platforms.

7.8.3.3 Scene File Gamma

The image file gamma problem itself is just a result of how scenes themselves are generated in POV-Ray. When you start out with a new scene and are placing light sources and adjusting surface textures and colors, you generally make several attempts before the lighting is how you like it. How you choose these settings depends upon the preview image or the image file stored to disk, which in turn is dependent upon the overall gamma of the display hardware being used.

This means that as the artist you are doing gamma correction in the POV-Ray scene file for your particular hardware. This scene file will generate an image file that is also gamma corrected for your hardware and will display correctly on systems similar to your own. However, when this scene is rendered on another platform, it may be too bright or too dim, regardless of the output file format used. Rather than have you change all the scene files to have a single fixed gamma value (heaven forbid!), POV-Ray 3.0 allows you to specify in the scene file the display gamma of the system that the scene was created on.

The `assumed_gamma` global setting, in conjunction with the Display_Gamma INI setting lets POV-Ray know how to do gamma correction on a given scene so that the preview and output image files will appear the correct brightness on any system. Since the gamma correction is done internally to POV-Ray, it will produce output image files that are the correct brightness for the current display, regardless of what output format is used. As well, since the gamma correction is performed in the high-precision data format that POV-Ray uses internally, it produces better results than gamma correction done after the file is written to disk.

Although you may not notice any difference in the output on your system with and without an `assumed_gamma` setting, the assumed gamma is important if the scene is ever rendered on another platform.

7.8.4 HF_Gray_16

The `hf_gray_16` setting is useful when using POV-Ray to generate heightfields for use in other POV-Ray scenes. The syntax is ...

```
global_settings { hf_gray_16 BOOLEAN }
```

The boolean value turns the option on or off. If the keyword is specified without the boolean value then the option is turned on. If `hf_gray_16` is not specified in any `global_settings` statement in the entire scene then the default is off.

When `hf_gray_16` is on, the output file will be in the form of a heightfield, with the height at any point being dependent on the brightness of the pixel. The brightness of a pixel is calculated in the same way that color images are converted to grayscale images:

$$height = 0.3\ red + 0.59\ green + 0.11\ blue. \tag{7.50}$$

Setting the `hf_gray_16` option will cause the preview display, if used, to be grayscale rather than color. This is to allow you to see how the heightfield will look because some file formats store heightfields in a way that is difficult to understand afterwards. See section 7.5.2.5 on page 236 for a description of how POV-Ray heightfields are stored for each file type.

7.8.5 Irid_Wavelength

Iridescence calculations depend upon the dominant wavelengths of the primary colors of red, green and blue light. You may adjust the values using the global setting `irid_wavelength` as follows …

```
global_settings { irid_wavelength COLOR }
```

The default value is `rgb`$\langle 0.25, 0.18, 0.14\rangle$ and any filter or transmit values are ignored. These values are proportional to the wavelength of light but they represent no real world units.

In general, the default values should prove adequate but we provide this option as a means to experiment with other values.

7.8.6 Max_Trace_Level

In scenes with many reflective and transparent surfaces POV-Ray can get bogged down tracing multiple reflections and refractions that contribute very little to the color of a particular pixel. The global setting `max_trace_level` defines the maximum number of recursive levels that POV-Ray will trace a ray.

```
global_settings { max_trace_level INTEGER }
```

This is used when a ray is reflected or is passing through a transparent object and when shadow rays are cast. When a ray hits a reflective surface, it spawns another ray to see what that point reflects. That is trace level one. If it hits another reflective surface another ray is spawned and it goes to trace level two. The maximum level by default is five.

One speed enhancement added to POV-Ray in version 3.0 is *Adaptive Depth Control* (ADC). Each time a new ray is spawned as a result of reflection or refraction its contribution to the overall color of the pixel is reduced by the amount of reflection or the filter value of the refractive surface. At some point this contribution can be considered to be insignificant and there is no point in tracing any more rays. Adaptive depth control is what tracks this contribution and makes the decision of when to bail out. On scenes that use a lot of partially reflective or refractive surfaces this can result in a considerable reduction in the number of rays fired and makes it *safer* to use much higher `max_trace_level` values.

This reduction in color contribution is a result of scaling by the reflection amount and/or the filter values of each surface, so a perfect mirror or perfectly clear surface will not be optimizable by ADC. You can see the results of ADC by watching the *Rays Saved* and *Highest Trace Level* displays on the statistics screen.

The point at which a ray's contribution is considered insignificant is controlled by the `adc_bailout` value. The default is 1/255 or approximately 0.0039 since a change smaller than that could not be visible in a 24 bit image. Generally this setting is perfectly adequate and should be left alone. Setting `adc_bailout` to 0 will disable ADC, relying completely on `max_trace_level` to set an upper limit on the number of rays spawned.

If `max_trace_level` is reached before a non-reflecting surface is found and if ADC hasn't allowed an early exit from the ray tree the color is returned as black. Raise `max_trace_level` if you see black areas in a reflective surface where there should be a color.

The other symptom you could see is with transparent objects. For instance, try making a union of concentric spheres with a clear texture on them. Make ten of them in the union with radius's from 1 to 10 and render the scene. The image will show the first few spheres correctly, then black. This is because a new level is used every time you pass through a transparent surface. Raise `max_trace_level` to fix this problem.

Note that raising `max_trace_level` will use more memory and time and it could cause the program to crash with a stack overflow error, although ADC will alleviate this to a large extent. Values for `max_trace_level` are not restricted, so it can be set to any number as long as you have the time and memory. However, increasing its setting does not necessarily equate to increased image quality unless such depths are really needed by the scene.

7.8.7 Max_Intersections

POV-Ray uses a set of internal stacks to collect ray/object intersection points. The usual maximum number of entries in these *I-Stacks* is 64. Complex scenes may cause these stacks to overflow. POV-Ray doesn't stop but it may incorrectly render your scene. When POV-Ray finishes rendering, a number of statistics are displayed. If you see *I-Stack Overflows* reported in the statistics you should increase the stack size. Add a global setting to your scene as follows:

```
global_settings { max_intersections INTEGER }
```

If the *I-Stack Overflows* remain increase this value until they stop.

7.8.8 Number_Of_Waves

The wave and ripples pattern are generated by summing a series of waves, each with a slightly different center and size. By default, ten waves are summed but this amount can be globally controlled by changing the `number_of_waves` setting.

```
global_settings { number_of_waves INTEGER }
```

Changing this value affects both waves and ripples alike on all patterns in the scene.

7.8.9 Radiosity

Radiosity is an extra calculation that more realistically computes the diffuse interreflection of light. This diffuse interreflection can be seen if you place a white chair in a room full of blue carpet, blue walls and blue curtains. The chair will pick up a blue tint from light reflecting off of other parts of the room. Also notice that the shadowed areas of your surroundings are not totally dark even if no light source shines directly on the surface. Diffuse light reflecting off of other objects fills in the shadows. Typically ray-tracing uses a trick called *ambient* light to simulate such effects but it is not very accurate.

Radiosity is more accurate than simplistic ambient light but it takes much longer to compute. For this reason, POV-Ray does not use radiosity by default. Radiosity is turned on using the Radiosity INI file option or the **+QR** command line switch.

The following sections describes how radiosity works, how to control it with various global settings and tips on trading quality vs. speed.

7.8.9.1 How Radiosity Works

The problem of ray-tracing is to figure out what the light level is at each point that you can see in a scene. Traditionally, in ray tracing, this is broken into the sum of these components:

Diffuse The effect that makes the side of things facing the light brighter.

Specular	The effect that makes shiny things have dings or sparkles on them.
Reflection	The effect that mirrors give.
Ambient	The general all-over light level that any scene has, which keeps things in shadow from being pure black.

POV's radiosity system, based on a method by Greg Ward, provides a way to replace the last term — the constant ambient light value — with a light level which is based on what surfaces are nearby and how bright in turn they are.

The first thing you might notice about this definition is that it is circular: the light of everything is dependent on everything else and vice versa. This is true in real life but in the world of ray-tracing, we can make an approximation. The approximation that is used is: the objects you are looking at have their *ambient* values calculated for you by checking the other objects nearby. When those objects are checked during this process, however, a traditional constant ambient term is used.

How does POV-Ray calculate the ambient term for each point? By sending out more rays, in many different directions, and averaging the results. A typical point might use 200 or more rays to calculate its ambient light level correctly.

Now this sounds like it would make the ray-tracer 200 times slower. This is true, except that the software takes advantage of the fact that ambient light levels change quite slowly (remember, shadows are calculated separately, so sharp shadow edges are not a problem). Therefore, these extra rays are sent out only *once in a while* (about 1 time in 50), then these calculated values are saved and reused for nearby pixels in the image when possible.

This process of saving and reusing values is what causes the need for a variety of tuning parameters, so you can get the scene to look just the way you want.

7.8.9.2 Adjusting Radiosity

As described earlier, radiosity is turned on by using the Radiosity INI file option or the **+QR** command line switch. However radiosity has many parameters that are specified in a `radiosity { ... }` statement inside a `global_settings { ... }` statement as follows:

```
global_settings {
  radiosity {
    brightness FLOAT
    count INTEGER
    distance_maximum FLOAT
    error_bound FLOAT
    gray_threshold FLOAT
    low_error_factor FLOAT
    minimum_reuse FLOAT
```

```
    nearest_count INTEGER
    recursion_limit INTEGER
  }
}
```

Each item is optional and may appear in and order. If an item is specified more than once the last setting overrides previous values. Details on each item is given in the following sections.

7.8.9.2.1 brightness

This is the degree to which ambient values are brightened before being returned upwards to the rest of the system. If an object is red $\langle 1,0,0\rangle$, with an ambient value of 0.3, in normal situations a red component of 0.3 will be added in. With radiosity on, assume it was surrounded by an object of gra color $\langle 0.6,0.6,0.6\rangle$. The average color returned by the gathering process will be the same. This will be multiplied by the texture's ambient weight value of 0.3, returning $\langle 0.18,0.18,0.18\rangle$. This is much darker than the 0.3 which would be added in normally. Therefore, all returned values are brightened by the inverse of the average of the calculated values, so the average ambient added in does not change. Some will be higher than specified (higher than 0.3 in this example) and some will be lower but the overall scene brightness will be unchanged.

The default value is 3.3.

7.8.9.2.2 count

The number of rays that are sent out whenever a new radiosity value has to be calculated is given by `count`. Values of 100 to 150 make most scenes look good. Higher values might be needed for scenes with high contrast between light levels or small patches of light causing the illumination. This would be used only for a final rendering on an image because it is very compute intensive. Since most scenes calculate the ambient value at 1% to 2% of pixels, as a rough estimate, your rendering will take 1% to 2% of this number times as long. If you set it to 300 your rendering might take 3 to 6 times as long to complete (1% to 2% times 300).

When this value is too low, the light level will tend to look a little bit blotchy, as if the surfaces you're looking at were slightly warped. If this is not important to your scene (as in the case that you have a bump map or if you have a strong texture) then by all means use a lower number.

The default value is 100.

7.8.9.2.3 distance_maximum

The `distance_maximum` is the only tuning value that depends upon the size of the objects in the scene. This one **must** be set for scenes to render properly … the rest can be ignored for a first try. It is difficult to describe the meaning simply but it sets the distance in model units from a sample at which the error is guaranteed to hit 100% (`radiosity_error_bound` ≥ 1): no samples are reused at a distance larger than this from their original calculation point.

Imagine an apple at the left edge of a table. The goal is to make sure that samples on the surface of the table at the right are not used too close to the apple and definitely not underneath the apple. If you had enough rays there wouldn't be a problem since one of them would be guaranteed to hit the apple and set the reuse radius properly for you. In practice, you must limit this.

We use this technique: find the object in your scene which might have the following problem: a small object on a larger flatter surface that you want good ambient light near. Now, how far from this would you have to get to be sure that one of your rays had a good chance of hitting it? In the apple-on-the-table example, assuming I used one POV-Ray unit as one inch, I might use 30 inches. A theoretically sound way (when you are running lots of rays) is the distance at which this object's top is 5 degrees above the *horizon* of the sample point you are considering. This corresponds to about 11 times the height of the object. So, for a 3-inch apple, 33 inches makes some sense. For good behavior under and around a 1/3 inch pea, use 3 inches etc. Another VERY rough estimate is one third the distance from your eye position to the point you are looking at. The reasoning is that you are probably no more than 90 inches from the apple on the table, if you care about the shading underneath it.

The default value is 0.

7.8.9.2.4 error_bound

The `error_bound` is one of the two main speed/quality tuning values (the other is of course the number of rays shot). In an ideal world, this would be the **only** value needed. It is intended to mean the fraction of error tolerated. For example, if it were set to 1 the algorithm would not calculate a new value until the error on the last one was estimated at as high as 100%. Ignoring the error introduced by rotation for the moment, on flat surfaces this is equal to the fraction of the reuse distance, which in turn is the distance to the closest item hit. If you have an old sample on the floor 10 inches from a wall, an error bound of 0.5 will get you a new sample at a distance of about 5 inches from the wall. 0.5 is a little rough and ready, 0.33 is good for final renderings. Values much lower than 0.3 take **forever**.

The default value is 0.4.

7.8.9.2.5 gray_threshold

Diffusely interreflected light is a function of the objects around the point in question. Since this is recursively defined to millions of levels of recursion, in any real life scene, every point is illuminated at least in part by every other part of the scene. Since we can't afford to compute this, we only do one bounce and the calculated ambient light is very strongly affected by the colors of the objects near it. This is known as color bleed and it really happens but not as much as this calculation method would have you believe. The `gray_threshold` variable grays it down a little, to make your scene more believable. A value of .6 means to calculate the ambient value as 60% of the equivalent grey value calculated, plus 40% of the actual value calculated. At 0%, this feature does nothing. At 100%, you always get white/grey ambient light, with no hue. Note that this does not change the lightness/darkness, only the strength of hue/grayness (in HLS terms, it changes H only).

The default value is 0.5

7.8.9.2.6 low_error_factor

If you calculate just enough samples, but no more, you will get an image which has slightly blotchy lighting. What you want is just a few extra interspersed, so that the blending will be nice and smooth. The solution to this is the mosaic preview: it goes over the image one or more times beforehand, calculating radiosity values. To ensure that you get a few extra, the radiosity algorithm lowers the error bound during the pre-final passes, then sets it back just before the final pass. This tuning value sets the amount that the error bound is dropped during the preliminary image passes. If your low error factor is 0.8 and your error bound is set to 0.4 it will really use an error bound of 0.32 during the first passes and 0.4 on the final pass.

The default value is 0.8.

7.8.9.2.7 minimum_reuse

The minimum effective radius ratio is set by `minimum_reuse`. This is the fraction of the screen width which sets the minimum radius of reuse for each sample point (actually, it is the fraction of the distance from the eye but the two are roughly equal). For example, if the value is 0.02 the radius of maximum reuse for every sample is set to whatever ground distance corresponds to 2% of the width of the screen. Imagine you sent a ray off to the horizon and it hits the ground at a distance of 100 miles from your eyepoint. The reuse distance for that sample will be set to 2 miles. At a resolution of 300×400 this will correspond to (very roughly) 8 pixels. The theory is that you don't want to calculate values for every pixel into every crevice everywhere in the scene, it will take too long. This sets a minimum bound for the reuse. If this value is too low, (which is should be in theory) rendering gets slow, and inside corners can get a little grainy. If it is set too high, you don't get the natural darkening of illumination near inside edges, since it reuses. At values higher than 2% you start getting more just plain errors, like reusing the illumination of the open table underneath the apple.

Remember that this is a unitless ratio.

The default value is 0.015.

7.8.9.2.8 nearest_count

The nearest_count value is the maximum number of old ambient values blended together to create a new interpolated value. It will always be the *n* geometrically closest reusable points that get used. If you go lower than 4, things can get pretty patchy. This can be good for debugging, though. Must be no more than 10, since that is the size of the array allocated.

The default value is 6.

7.8.9.2.9 radiosity_quality

This feature is not yet implemented.

7.8.9.2.10 recursion_limit

This value determines how many recursion levels are used to calculate the diffuse inter-reflection. Valid values are one and two.

The default value is 1.

7.8.9.3 Tips on Radiosity

If you want to see where your values are being calculated set radiosity_count down to about 20, set radiosity_nearest_count to 1 and set radiosity_grey to 0. This will make everything maximally patchy, so you'll be able to see the borders between patches. There will have been a radiosity calculation at the center of most patches. As a bonus, this is quick to run. You can then change the radiosity_error_bound up and down to see how it changes things. Likewise modify radiosity_reuse_dist_min and max.

One way to get extra smooth results: crank up the sample count (we've gone as high as 1300) and drop the low_error_factor to something small like 0.6. Bump up the reuse_count to 7 or 8. This will get better values, and more of them, then interpolate among more of them on the last pass. This is not for people with a lack of patience since it is like a squared function. If your blotchiness is only in certain corners or near certain objects try tuning the error bound instead. Never drop it by more than a little at a time, since the run time will get very long.

If your scene looks good but right near some objects you get spots of the right (usually darker) color showing on a flat surface of the wrong color (same as far away from the object), then try dropping reuse_dist_max. If that still doesn't work well increase your ray count by 100 and drop the error bound just a bit. If you still have problems, drop reuse_nearest_count to about 4.

Part IV

Appendix

Appendix A

Copyright

The following sections contain the legal information and license for the Persistence of Vision™ Ray-Tracer, also called POV-Ray™.

Before you use this program you have to read the sections below.

A.1 General License Agreement

THIS NOTICE MUST ACCOMPANY ALL OFFICIAL OR CUSTOM PERSISTENCE OF VISION FILES. IT MAY NOT BE REMOVED OR MODIFIED. THIS INFORMATION PERTAINS TO ALL USE OF THE PACKAGE WORLDWIDE. THIS DOCUMENT SUPERSEDES ALL PREVIOUS GENERAL LICENSES OR DISTRIBUTION POLICIES. ANY INDIVIDUALS, COMPANIES OR GROUPS WHO HAVE BEEN GRANTED SPECIAL LICENSES MAY CONTINUE TO DISTRIBUTE VERSION 2.x BUT MUST RE-APPLY FOR VERSION 3.00 OR LATER.

This document pertains to the use and distribution of the Persistence of Vision™ Ray-Tracer a. k. a POV-Ray™. It applies to all POV-Ray program source files, executable (binary) files, scene files, documentation files, help file, bitmaps and INI files contained in official POV-Ray Team™ archives. All of these are referred to here as *the software*.

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The user is also granted the right to use the scenes files, fonts, bitmaps, and include files distributed in the INCLUDE, TEXSAMPS and POV3DEMO sub- directories in their own scenes. Such permission does not extend to files in the POVSCN sub-directory. POVSCN files are for your enjoyment and education but may not be the basis of any derivative works.

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The permission to distribute this package under certain very specific conditions is granted in advance, provided that the following conditions are met.

These archives must not be re-archived using a different method without the explicit permission of the POV-Team. You may rename the archives only to meet the file name conventions of your system or to avoid file name duplications but we ask that you try to keep file names as similar to the originals as possible (for example: POVSRC.ZIP to POVSRC30.ZIP)

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You must distribute a *full package* of files as described in the next section. No portion of this package may be separated from the package and distributed separately other than under the conditions specified in the provisions given below.

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Teachers and educational institutions may also distribute the material to students and may charge minimal copying costs if the software is to be used in a course.

A.4 Definition of *Full Package*

POV-Ray is contained in two sets of archives for each hardware platform. A *full package* consists of either:

End user executable archives containing an executable program, documentation, and sample scenes but no source.

or

Programmer archives containing full source code but no executable. Also you must include an archive containing documentation, and sample scenes. On some platforms, the documentation and sample scenes are archived separately from the source. Source alone is not sufficient. You must have docs and scenes.

POV-Ray is officially distributed for MS-Dos; Windows 32-bit; Linux for Intel x86 series; Apple Macintosh; Apple PowerPC; SunOS; and Amiga. Other systems may be added in the future.

Distributors need not support all platforms but for each platform you support you must distribute a full package. For example a Macintosh only BBS need not distribute the Windows versions.

This software may **only** be bundled with other software packages according to the conditions specified in the provisions below.

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You must notify us that you are distributing POV-Ray and must provide us with information on how to contact you should any support issues arise.

No more than five dollars U.S. ($5) can be charged per disk for the copying of this software and the media it is provided on. Space on each disk must be used as fully as possible. You may not spread the files over more disks than are necessary.

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No portion of the POV-Ray source code may be incorporated into another program unless it is clearly a custom version of POV-Ray that includes all of the basic functions of POV-Ray.

All executables, documentation, modified files and descriptions of the same must clearly identify themselves as a modified and unofficial version of POV-Ray. Any attempt to obscure the fact that the user is running POV-Ray or to obscure that this is an unofficial version expressly prohibited.

You must provide all POV-Ray support for all users who use your custom version. You must provide information so that user may contact you for support for your custom version. The POV-Ray Team is not obligated to provide you or your users any technical support.

Include contact information in the DISTRIBUTION_MESSAGE macros in the source file OPTOUT.H and insure that the program prominently displays this information. Display all copyright notices and credit screens for the official version.

Custom versions may only be distributed as freeware. You must make all of your modifications to POV-Ray freely and publicly available with **full source code** to the modified portions of POV-Ray and must freely distribute full source to any new parts of the custom version. The goal is that users must be able to re-compile the program themselves and to be able to further improve the program with their own modifications.

You must provide documentation for any and all modifications that you have made to the program that you are distributing. Include clear and obvious information on how to obtain the official POV-Ray.

The user is encouraged to send enhancements and bug fixes to the POV-Ray Team, but the team is in no way required to utilize these enhancements or fixes. By sending material to the team, the contributor asserts that he owns the materials or has the right to distribute these materials. He authorizes the team to use the materials any way they like. The contributor still retains rights to the donated material, but by donating, grants unrestricted, irrevocable usage and distribution rights to the POV-Ray Team. The team doesn't have to use the material, but if we do, you do not acquire any rights related to POV-Ray. The team will give you credit as the creator of new code if applicable.

Include a copy of the POVLEGAL.DOC document.

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Vendors wishing to bundle POV-Ray with commercial software (including shareware) or with publications must first obtain explicit permission from the POV-Ray Team. This includes any commercial software or publications, such as, but not limited to, magazines, cover-disk distribution, books, newspapers, or newsletters in print or machine readable form.

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- Purchasers of your product must not be led to believe that they are paying for POV-Ray. Any mention of the POV-Ray bundle on the box, in advertising or in instruction manuals must be clearly marked with a disclaimer that POV-Ray is free software and can be obtained for free or nominal cost from various sources.
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- Include contact and support information for your product.
- Include a full user package as described above.

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The team permits and encourages the creation of programs, including commercial packages, which import, export or translate files in the POV-Ray Scene Description Language. There are no restrictions on use of the language itself. We reserve the right to add or remove or change any part of the language.

”POV-Ray”, ”Persistence of Vision”, ”POV-Ray Team” and ”POV-Help” are trademarks of the POV-Ray Team.

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In this regard, ”PC Format”, a magazine published by Future Publishing, Ltd. in the United Kingdom, distributed incomplete versions of POV-Ray 1.0 in violation the license which was effect at the time. They later attempted to distribute POV-Ray 2.2 without prior permission of the POV-Ray Team in violation the license which was in effect at the time. There is evidence that other Future Publishing companies have also violated our terms. Therefore ”PC Format”, and any other magazine, book or CD-ROM publication owned by Future Publishing is expressly prohibited from any distribution of POV-Ray software until further notice.

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This software is provided as is without any guarantees or warranty. Although the authors have attempted to find and correct any bugs in the package, they are not responsible for any damage or losses of any kind caused by the use or misuse of the package. The authors are under no obligation to provide service, corrections, or upgrades to this package.

A.13 Technical Support

We sincerely hope you have fun with our program. If you have any problems with the program, the team would like to hear about them. Also, if you have any comments, questions or enhancements, please contact the POV-Ray Team on the CompuServe Information Service in the GO GRAPHICS forums, GRAPHDEV forum. Also check us out on the internet at `http://www.povray.org` or `ftp.povray.org`. The USENET group `comp.graphics.rendering.raytracing` is a great source of information on POV-Ray and related topics.

License enquiries should be made via email and limited technical support is available via email to:

Chris Young
POV-Ray Team Coordinator
CIS: 76702,1655
Internet: 76702.1655compuserve.com

The following postal address is only for official license business and only if email is impossible.

We do not provide technical support via regular mail, only email. We don't care if you don't have a modem or online access. We will not mail you disks with updated versions. Do not send money.

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The other authors' contact information may be found in section B on the next page (see also D on page 387).

Appendix B

Authors

Following is a list in alphabetic order of all people who have ever worked on the POV-Ray Team or who have made a note-worthy contribution. If you want to contact or thank the authors read the sections C on page 385 and D on page 387.

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Appendix C

Contacting the Authors

The POV-Team is a collection of volunteer programmers, designers, animators and artists meeting via electronic mail on Compuserve's GRAPHDEV forum (GO GRAPHDEV).

The POV-Team's goal is to create freely distributable, high quality rendering and animation software written in C that can be easily ported to many different computers.

If you have any questions about POV-Ray, please contact

We love to hear about how you're using and enjoying the program. We also will do our best try to solve any problems you have with POV-Ray and incorporate good suggestions into the program.

If you have a question regarding commercial use of, distribution of, or anything particularly sticky, please contact Chris Young, the development team coordinator. Otherwise, spread the mail around. We all love to hear from you!

The best method of contact is e-mail through CompuServe for most of us. America On-Line and Internet can now send mail to CompuServe, also, just use the Internet address and the mail will be sent through to CompuServe where we read our mail daily.

Please do not send large files to us through the e-mail without asking first. We pay for each minute on CompuServe and large files can get expensive. Send a query before you send the file, thanks!

Appendix D

Postcards for POV-Ray Team Members

If you want to personally thank some of the POV-Ray Team members you can send them a postcard from wherever you are. To avoid invalid addresses from floating around (in case some of us move) the addresses listed below (in alphabetical order) are only valid until the given date.

Dieter Bayer Taeublingstr. 26 91058 Erlangen Germany	 (until 31. July 1997)
Chris Cason PO Box 407 Williamstown Victoria 3016 Australia	(Windows version) (until 31. December 1998)
Joel NewKirk 255-9 Echelon Rd Voorhees, NJ, USA, 08043	 (until —)
Eduard Schwan 1112 Oceanic Drive Encinitas, California, USA, 92024-4007	(Macintosh version) (until 30. June 1998)

You should also be aware that we do not answer any questions asked by regular mail or phone, we only reply to e-mails. Send any questions you have to the e-mail address mentioned in section C on page 385.

Appendix E

POV-Ray Output Messages

STILL BEING WRITTEN

E.1 Options in Use

STILL BEING WRITTEN

E.2 Warning Messages

STILL BEING WRITTEN

E.2.1 Warnings during the Parsing Stage

STILL BEING WRITTEN

E.2.2 Other Warnings

STILL BEING WRITTEN

E.3 Error Messages

STILL BEING WRITTEN

E.3.1 Scene File Errors

STILL BEING WRITTEN

E.3.2 Other Errors

STILL BEING WRITTEN

E.4 Statistics

STILL BEING WRITTEN [DB]

Appendix F

Tips and Hints

F.1 Scene Design Tips

There are a number of excellent shareware CAD style modelers available on the DOS platform now that will create POV-Ray scene files. The online systems mentioned elsewhere in this document are the best places to find these.

Hundreds of special-purpose utilities have been written for POV-Ray: data conversion programs, object generators, shell-style *launchers* and more. It would not be possible to list them all here, but again, the online systems listed will carry most of them. Most, following the POV-Ray spirit, are freeware or inexpensive shareware.

Some extremely elaborate scenes have been designed by drafting on graph paper. Ray-tracer Mike Miller recommends graph paper with a grid divided in tenths, allowing natural decimal conversions.

Start out with a *boilerplate* scene file, such as a copy of BASICVUE.POV, and edit that. In general, place your objects near and around the *origin* with the camera in the negative z-direction, looking at the origin. Naturally, you will break from this rule many times, but when starting out, keep things simple.

For basic, boring, but dependable lighting, place a light source at or near the position of the camera. Objects will look flat, but at least you will see them. From there, you can move it slowly into a better position.

F.2 Scene Debugging Tips

To see a quick version of your picture, render it very small. With fewer pixels to calculate the ray-tracer can finish more quickly. **–W**160 **–H**100 is a good size.

Use the **+Q** *quality* switch when appropriate.

If there is a particular area of your picture that you need to see in high resolution, perhaps with anti-aliasing on (perhaps a fine-grained wood texture), use the **+SC**, **+EC**, **+SR** and **+ER** switches to isolate a *window*.

If your image contains a lot of inter-reflections, set `max_trace_level` to a low value such as 1 or 2. Don't forget to put it back up when you're finished!

Turn off any unnecessary lights. Comment out extended light keywords when not needed for debugging. Again, don't forget to put them back in before you retire for the night with a final render running!

If you've run into an error that is eluding you by visual examination it's time to start bracketing your file. Use the block comment characters `/* ... */` to disable most of your scene and try to render again. If you no longer get an error the problem naturally lies somewhere within the disabled area. Slow and methodical testing like this will eventually get you to a point where you will either be able to spot the bug, or go quietly insane. Maybe both.

If you seem to have *lost* yourself or an object (a common experience for beginners) there are a few tricks that can sometimes help:

1. Move your camera way back or increase the viewing angle to provide a long range view. This may not help with very small objects which tend to be less visible at a distance but it's a nice trick to keep up your sleeve.
2. Try setting the ambient value to 1.0 if you suspect that the object may simply be hidden from the lights. This will make it self-illuminated and you'll be able to see it even with no lights in the scene.
3. Replace the object with a larger, more obvious *stand-in* object like a large sphere or box. Be sure that all the same transformations are applied to this new shape so that it ends up in the same spot.

F.3 Animation Tips

When animating objects with solid textures, the textures must move with the object, i. e. apply the same rotate or translate functions to the texture as to the object itself. This is now done automatically if the transformations are placed **after** the texture block like the following example

```
shape { ...
  pigment { ... }
  scale < ... >
}
```

will scale the shape and pigment texture by the same amount.

```
shape { ...
  scale < ... >
  pigment { ... }
}
```

will scale the shape but not the pigment.

Constants can be declared for most of the data types in the program including floats and vectors. By writing these to include files you can easily separate the parameters for an animation into a separate file.

Some examples of declared constants would be:

```
#declare Y_Rotation = 5.0 * clock
#declare ObjectRotation = <0, Y_Rotation, 0>
#declare MySphere = sphere { <0, 0, 0>, 1.1234 }
```

Other examples can be found scattered throughout the sample scene files.

A tip for MS-Dos users: Get ahold of DTA.EXE (Dave's Targa Animator) for creating .FLI/.FLC animations. AAPLAY.EXE and PLAY.EXE are common viewers for this type of file.

When moving the camera in an animation (or placing one in a still image, for that matter) avoid placing the camera directly over the origin. This will cause very strange errors. Instead, move off center slightly and avoid hovering directly over the scene.

F.4 Texture Tips

Wood is designed like a *log* with growth rings aligned along the *z*-axis. Generally these will look best when scaled down by about a tenth (to a unit-sized object). Start out with rather small value for the turbulence too (around 0.05 is good for starters).

The marble texture is designed around a pigment primitive that is much like an *x*-gradient. When turbulated, the effect is different when viewed from the *side* or from the *end*. Try rotating it by 90 degrees on the *y*-axis to see the difference.

You cannot get specular highlights on a totally black object. Try using a very dark gray, say *Gray10* or *Gray15* (from COLORS.IN), instead.

F.5 Height Field Tips

Try using POV-Ray itself to create images for height fields:

```
camera { location <0, 0, -2> }
plane { z, 0
   finish { ambient 1 }     // needs no light sources
   pigment { bozo }         // or whatever.  Experiment.
}
```

That's all you'll need to create a `.TGA` file that can then be used as a height field in another image!

F.6 Converting "Handedness"

If you are importing images from other systems you may find that the shapes are backwards (left-to-right inverted) and no rotation can make them correct.

Often, all you have to do is negate the terms in the right vector of the camera to flip the camera left-to-right (use the *right-hand* coordinate system). Some programs seem to interpret the coordinate systems differently, however, so you may need to experiment with other camera transformations if you want the *y*- and *z*-vectors to work as POV-Ray does.

Appendix G

Frequently Asked Questions

This is a collection of frequently asked questions and their answers taken directly from messages posted in the Graphic Developer's Forum on Compuserve and the `comp.graphics.raytracing` newsgroup.

This version of the FAQ is heavily biased towards the CompuServe user of the IBM PC version of POV-Ray. Hopefully later revisions will remove some of this bias, but at present time, that is the largest audience.

G.1 General Questions

Q: When will POV-Ray 3.0 be released?

A: It is already available.

Q: When will the source code be released?

A: The soruce code available too.

G.2 POV-Ray Option Questions

Q: How can I set mosaic preview to go from $8\times$ straight to final render without going to $4\times$ and then $t\times$ first?
A: Use the **+SP**n or Preview_Start_Size option to set the starting resolution and the **+EP**n or Preview_End_Size option to set the ending resolution. With **+SP**8 and **+EP**8 it will go from 8×8 down to 8×8 (just one pass) then immediately drop into the final pass at 1×1.

Q: Should the **+MB** switch be used in very small scenes, i. e. with a low number of objects.

A: That depends on the number of objects and their type. Normally it doesn't hurt to always use the bounding box hierarchy (**+MB**0). If you have just one or two objects it may be better to not use automatic bounding.

Q: Does the **+MB** switch affect the quality of the image? **A:** No. It only affects the speed of the intersection tests.

G.3 Atmosphere Questions

Q: Why is the atmosphere I added not visible?
A: The most common error made when adding an atmosphere to a scene is the missing hollow keyword in all objects the camera currently is in. If you are inside a box that is used to model a room you'll have to add the hollow keyword to the box statement. If a plane is used to model the ground you'll have to make it hollow (only if you are inside the plane, but to be sure you can always do it).

If this doesn't help there may be other problems you'll have to verify. The distance and scattering values of the atmosphere have to be larger than zero. Light sources that shall interact with the atmosphere mustn't contain an `atmosphere off` statement.

Q: Why can't I see any atmosphere through my translucent object?
A: If you have a translucent object you (almost) always have to make it hollow by adding the `hollow` keyword. Whenever an intersection is found and the ray is inside a solid object no atmospheric effects will be calculated.

If you have a partially transparent plane for example the atmosphere on the other side of the plane will only be visible through the plane if this plane is hollow.

Q: Why do the lit parts of the atmosphere amplify the background?

A: First, they don't.

Second, whenever parts of the background are visible through the atmosphere and those areas of the atmosphere are lit by any light source, the scattered light is added to the light coming from the background. This is the reason why the background seems to be amplified by the atmosphere. Just imagine the followoing example: you have a blue background that is attenuated be the atmosphere in a way that the color reaching the viewer is $\langle 0,0,0.2\rangle$. Now some light coming from a light source is attenuated and scattered by the atmosphere and finally reaches the viewer with a color of $\langle 0.5,0.5,0.5\rangle$. Since we already have light coming from the background, both colors are added to give $\langle 0.5,0.5,0.7\rangle$. Thus the light gets a blue hue. As a result you think that the background light is amplified but it isn't as the following scene clearly shows.

```
ersion 3.0
camera {
  location <0, 6, -20>
```

```
  look_at <0, 6, 0>
  angle 48
}

atmosphere {
  type 1
  samples 10
  distance 20
  scattering 0.3
  aa_level 3
  aa_threshold 0.1
  jitter 0.2
}

light_source { <0, 15, 0> color red .7 green .7 blue .7 shadowless }

light_source {
  <-5, 15, 0> color rgb <1, 0, 0>
  spotlight
  point_at <-5, 0, 0>
  radius 10
  falloff 15
  tightness 1
  atmospheric_attenuation on
}

light_source {
  <0, 15, 0> color rgb <0, 1, 0>
  spotlight
  point_at <0, 0, 0>
  radius 10
  falloff 15
  tightness 1
  atmospheric_attenuation on
}

light_source {
  <5, 15, 0> color rgb <0, 0, 1>
  spotlight
  point_at <5, 0, 0>
  radius 10
  falloff 15
  tightness 1
  atmospheric_attenuation on
}

plane { z, 10
  pigment { checker color rgb<1, 0, 0> color rgb<0, 1, 0> }
  hollow
}
```

In the background you see a red/green checkered plane. The background color visible through the atmosphere is added to the light scattered from the spotlights. You'll notice that even though the red squares behind the red spotlight's cone are brighter than those outside the cone the green ones are not. For the green spotlight the situation is turned around: the green squares seem to be amplified while the red are not. The blue spotlight doesn't show this effect at all.

Appendix H

Suggested Reading

Beside the POV-Ray specific books mentioned in 2.4.6 on page 20 there are several good books or periodicals that you should be able to locate in your local computer book store or your local university library.

An Introduction to Ray-Tracing
Andrew S. Glassner (editor)
ISBN 0-12-286160-4
Academic Press
1989

3D Artist Newsletter
(The Only Newsletter about Affordable PC 3D Tools and Techniques)
Publisher: Bill Allen
P.O. Box 4787
Santa Fe, NM 87502-4787
(505) 982-3532

Image Synthesis: Theory and Practice
Nadia Magnenat-Thalman and Daniel Thalmann
Springer-Verlag
1987

The RenderMan Companion
Steve Upstill
Addison Wesley
1989

Graphics Gems
Andrew S. Glassner (editor)
Academic Press
1990

Fundamentals of Interactive Computer Graphics
J. D. Foley and A. Van Dam
ISBN 0-201-14468-9
Addison-Wesley
1983

Computer Graphics: Principles and Practice (2nd Ed.)
J. D. Foley, A. van Dam, J. F. Hughes
ISBN 0-201-12110-7
Addison-Wesley
1990

Computers, Pattern, Chaos, and Beauty
Clifford Pickover
St. Martin's Press

SIGGRAPH Conference Proceedings
Association for Computing Machinery
Special Interest Group on Computer Graphics

IEEE Computer Graphics and Applications
The Computer Society
10662, Los Vaqueros Circle
Los Alamitos, CA 90720

The CRC Handbook of Mathematical Curves and Surfaces
David von Seggern
CRC Press
1990

The CRC Handbook of Standard Mathematical Tables
CRC Press
The Beginning of Time

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