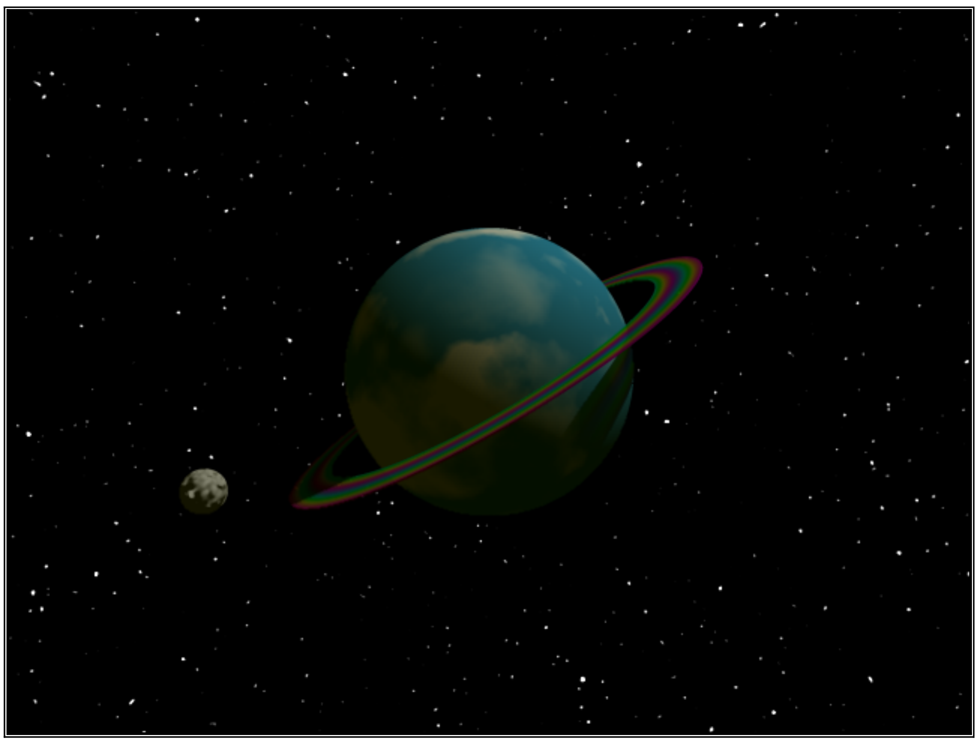
SIMPLE PHOTOREALISM USING PERSISTENCE OF VISION



A tutorial on making 3-D images for people who can't draw to save their life.

http://www.hoboes.com/NetLife/POV_Simple/

July 10, 2011

Persistence of Vision

The Persistence of Vision Raytracer, or POV-Ray, is 3-dimensional raytracing software that uses text files to tell it where to put objects and effects in a scene. Unlike most raytracing software, POV-Ray does not require you to be skilled at drawing. At its most basic, you tell POV that you want one shape here, another shape there, and you'd like to combine these two simple shapes into a more complex shape, and put it over there. But you do not have to draw the shapes yourself, and you don't have to draw them in perspective, draw their shadows, draw the light on them, or any of that stuff. The raytracer handles this for you.

You can download POV-Ray, and see the kinds of images it can produce, at the official website: *http://www.povray.org/*.

More Information

The Persistence of Vision web site at *http://www.povray.org/* has documentation, tips, tricks, and links to several wonderful resources. The POV-Ray Book Project at *http://book.povworld.org/* has a series of projects that guide you to more and more advanced use of POV-Ray. My own Persistence of Text at *http://www.hoboes.com/NetLife/POV/* has a handful of detailed projects that guide you through understanding specific concepts in POV-Ray.

If you want to be inspired by what raytracing can do, go to the Internet Raytracing Competition at *http://www.irtc.org/*. They hold several competitions every year, and keep an archive of past contests going back to 1996. Many of the images there were created using Persistence of Vision. Go there if you are easily inspired, but not if you are easily discouraged.

YOUR FIRST SCENE

LIGHTS, CAMERA, ACTION!

Your most basic scenes will consist of a light source, a camera, and an object. Raytracers such as POV-Ray work by sending "rays" from the camera and following the "rays" through reflection, refraction, and absorption until the rays reach a light source or are lost in shadow. See *http://en.wikipedia.org/wiki/Raytracing* for a more detailed explanation of what raytracing is. Now, let's create our first simple scene.

You should have already downloaded POV-Ray for your computer, and started it up. You will most likely have a blank document waiting for you to type your scene description. Scene descriptions in POV-Ray use a very formal "scene description language". I'll be using POV-Ray 3.6.1 for Mac OS X in the examples here. The location of menus and menu items will probably be slightly different if you are not using Mac OS X, but the scene description text will be exactly the same no matter what platform you are using.

Location, location, location!

Just about everything you put into a POV-Ray scene has to have a location. POV-Ray requires you to specify three numbers for each location. These numbers are the distance from an imaginary "origin" which might be thought of as the center of the universe.

A location of "5, 3, 6", for example, would be a distance of five to the right of the center, a distance of three above the center, and a distance of six behind the center.

If you need to place something to the left of center, below the center, or in front of the center, you'll use negative numbers: "-3, -9, -6", for example.

What do those numbers mean in actual distance? It's an important question, and one you'll want to think about before you start placing things in your scene. You can decide that the numbers mean meters, feet, inches, miles, or even light-years. I always try to place a note at the top of my scenes reminding me of what the numbers mean.

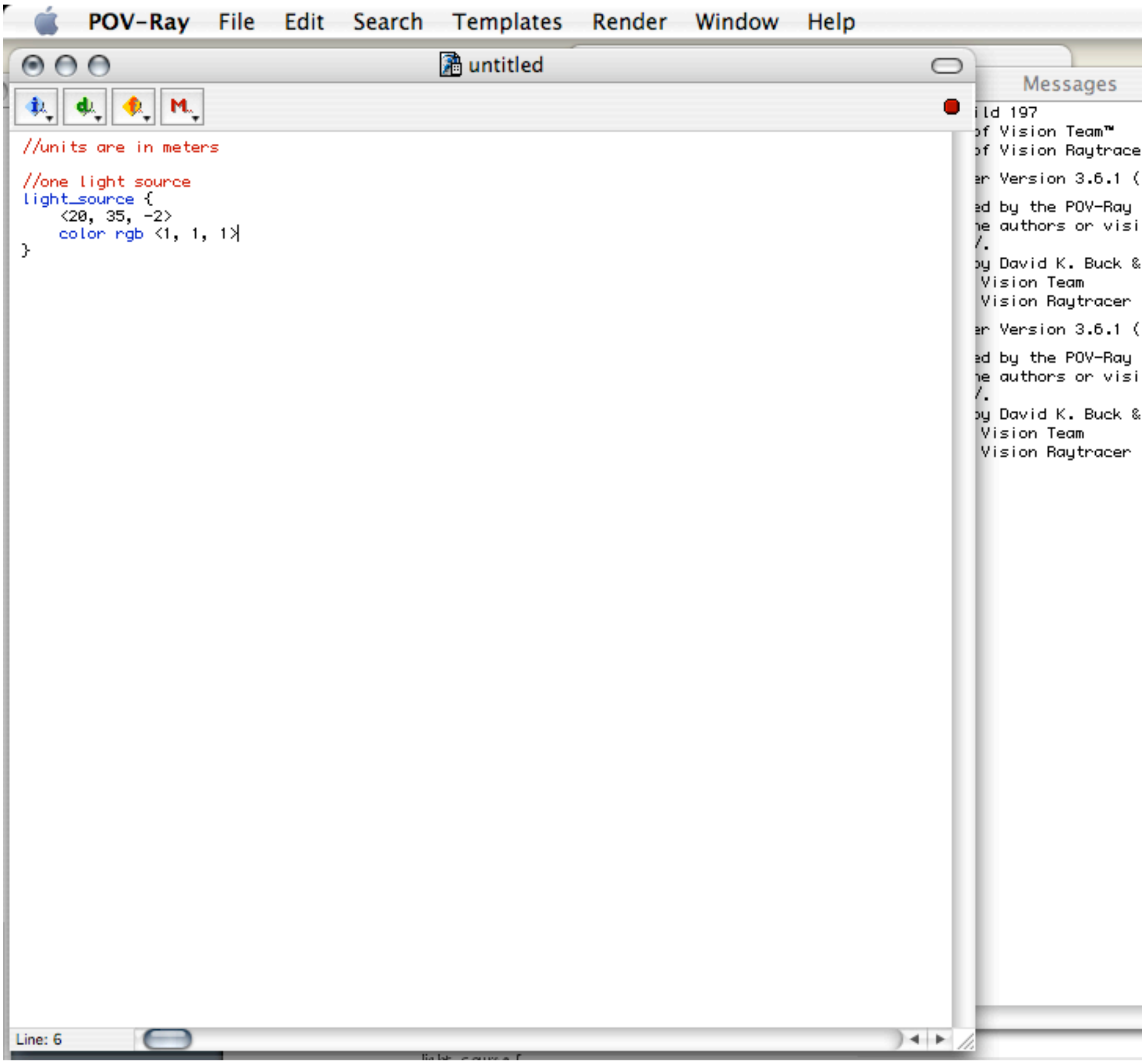
Because you can move the camera wherever you want, the "center of the universe" is usually not the center of your image.

Let there be light!

We need a light, a camera, and an object. Let's do the light first. The first line of our scene will be our reminder about what the numbers for locations mean. Let's go with meters. If you don't have an open blank document in POV-Ray, pull down the "File" menu and choose "New".

```
//units are in meters
```

Reminders and notes can be placed anywhere in your text, but must begin with two slashes. The two slashes tell POV-Ray that this line is not an instruction for it to place something within the scene.



You will usually want to put a note or reminder in front of every object, to remind of what their purpose is later.

Our light source is going to need a location and a color. You can have green lights, blue lights, chartreuse lights, if you want. Often, you'll be using white lights. Colors in POV-Ray are usually specified with specific amounts of red, green, and blue.

```
//one light source
light_source {
  <20, 35, -2>
  color rgb <1, 1, 1>
}
```

This is how most objects in your scene will look in your text. The first line tells POV-Ray what kind of an object it is, followed by an open curly-bracket. The rest of the lines, down to the matching closing curly-bracket, describe that object. Our light source has two lines in its description. The first line is its location, and the second line is its color.

Locations are surrounded by less-than and greater-than symbols. This light source is 20 meters to the right, 35 meters up, and 2 meters towards us.

Because colors are specified using three numbers also, they often will look like locations. Here, we are saying that our color in RGB format is 1 for red, 1 for green, and 1 for blue. Colors range from 0 to 1, so these are the maximum numbers for all three colors. If you remember your color mixes, this makes the color white.

You can have many light sources in your scene, each in different locations, with different colors, and different intensities. The more light sources you have, the longer it will take for POV-Ray to create an image from your scene description.

Light sources cast light on the scene, but they are not themselves visible to the camera.

Camera!

Our camera looks a lot like our light source.

```
//camera is at eye-level
camera {
  location  <0, 2, -10>
  look_at   <0, 0, 0>
}
```

This camera is two meters up and ten meters back. The camera is pointed straight towards the center of the universe: in the “look_at” location, each location number is zero.

While you can have many light sources in your scene, you can have only one camera.

ACTION!

Now comes the moment of truth. We're going to put something in our scene. At the center of the universe, we're going to put a big sphere.

```
//the center of the universe
sphere {
  <0, 0, 0>
  2
  pigment {
    color rgb <.2, .6, .8>
  }
}
```

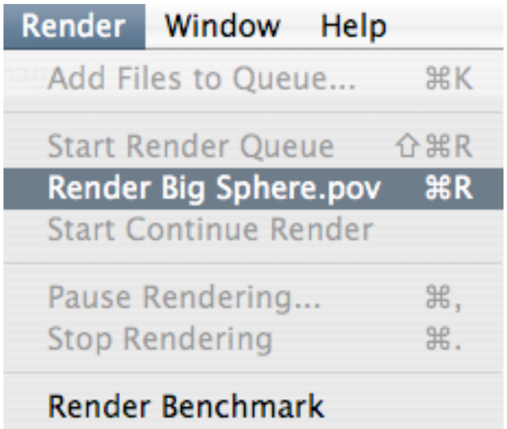
This sphere is at location <0, 0, 0>, which is the center of POV-Ray's universe. The next number, 2, is the *radius* of this sphere.

After that, we have a *pigment* section. A pigment section begins and ends with curly-brackets, just like objects do. Pigments can be quite complex, but in this case we're just setting the color of the object's pigment. The red is .2 (or 20% of maximum), the green is .6 (or 60% of maximum) and the blue is .8 (80% of maximum). This makes for a light blue.

RENDER THE SCENE

Your scene should now have all three sections: lights, camera, and object.

```
//units are in meters

//one light source
light_source {
  <20, 35, -2>
  color rgb <1, 1, 1>
}

//camera is at eye-level
camera {
  location  <0, 2, -10>
  look_at   <0, 0, 0>
}


//the center of the universe
sphere {
  <0, 0, 0>
  2
  pigment {
    color rgb <.2, .6, .8>
  }
}
```



It is time to render so that we can see what our scene looks like. When POV-Ray renders an image, it uses raytracing to convert the text scene description into an image.

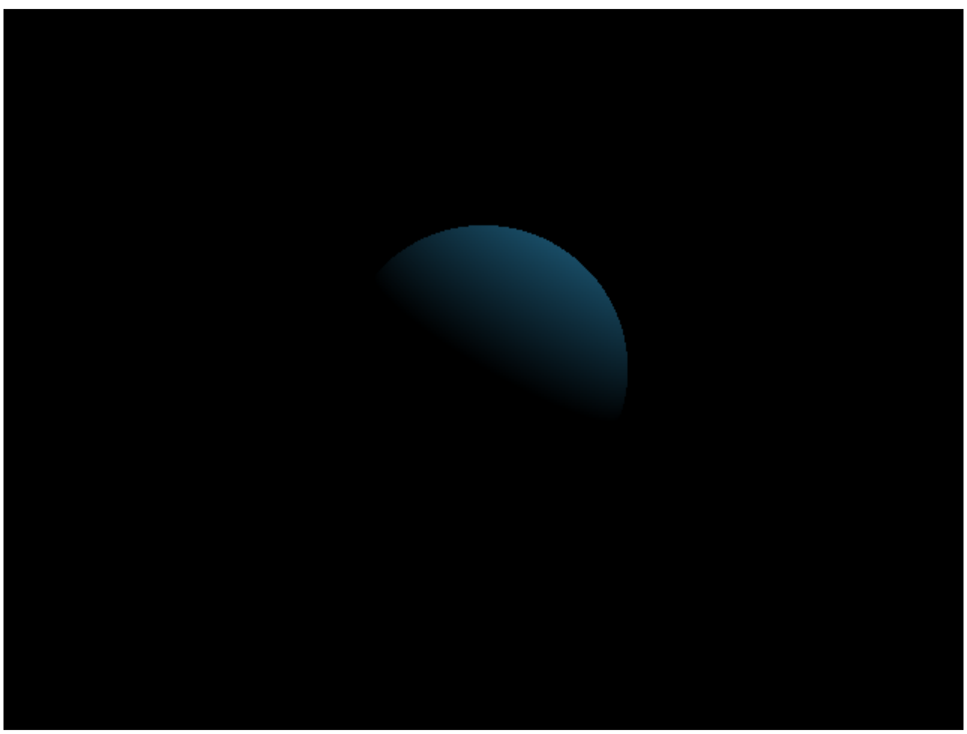
First, you need to save the document. POV-Ray will not render the file unless it is saved first. After you save it the first time, POV-Ray will automatically save it every time you re-render it.

We're rendering an image of a big sphere, so call it something like "Big Sphere.pov". You usually want your scene files to end in .pov so that POV-Ray will recognize that it owns those files.

After saving the scene, you can pull down the "Render" menu and choose "Render". POV-Ray will render your scene to an image file. Depending on your settings, it may also display a preview of the image on your display as it renders.

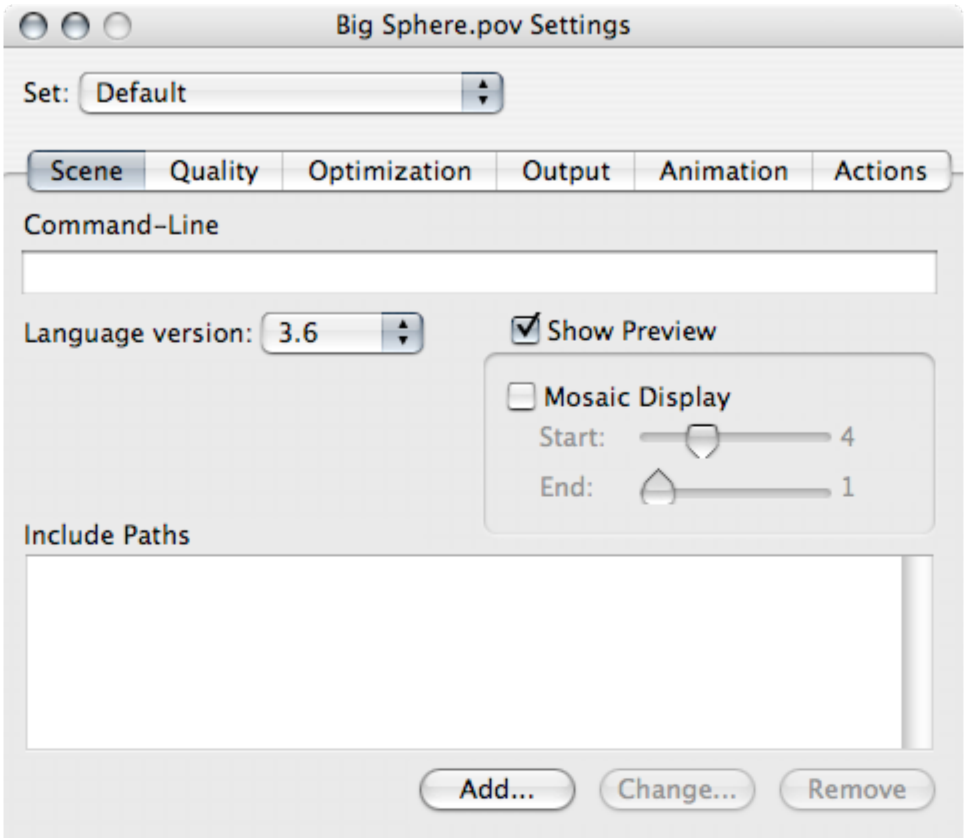
By default, POV-Ray places the image file in the same directory as the text scene file.

What we end up with is a blue sphere, with a light source up and to the right, against a black background.

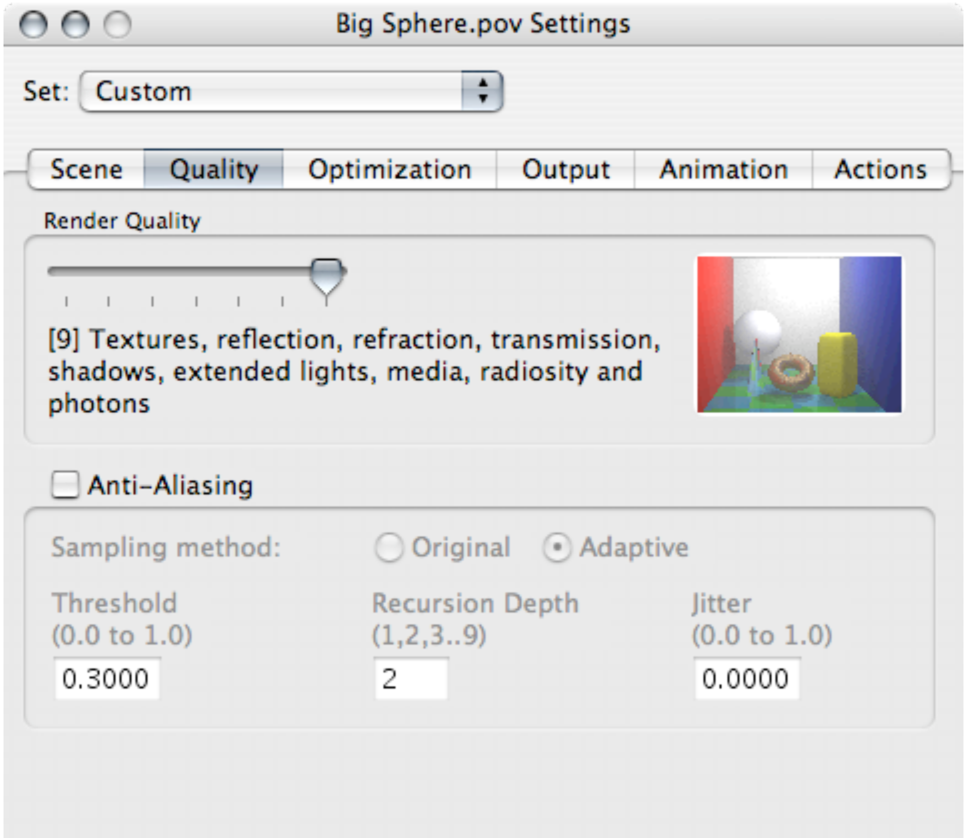


SETTINGS

You have several settings for what POV-Ray does while it renders. On Mac OS X, you can find the settings for your scene under the “Edit” menu. There are three important sections to the settings: the Scene, Quality, and Output panes.



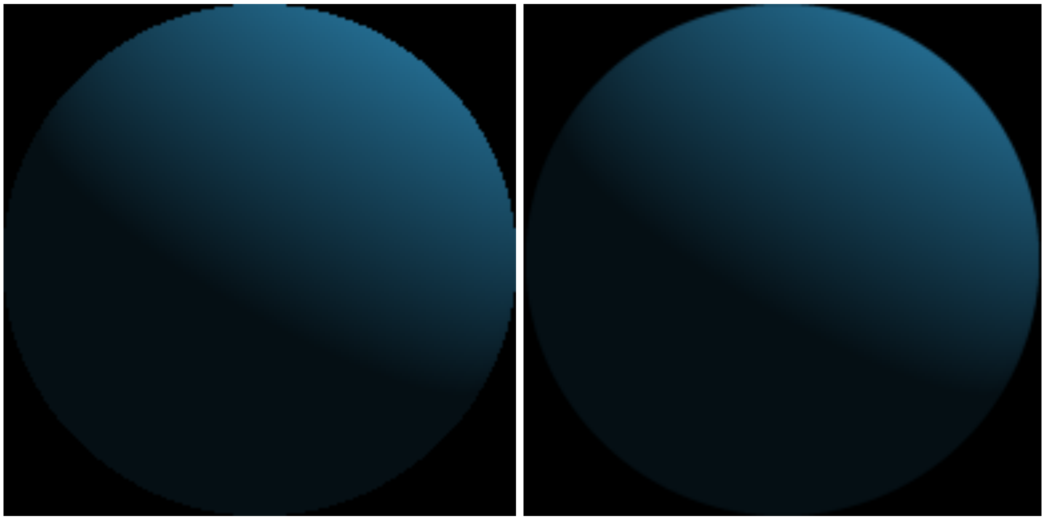
In the *Scene* pane, you’ll almost always want to have *Show Preview* checked. For scenes that take a long time to render, you might find *Mosaic Display* useful while testing the image. This renders the image in progressively smaller chunks, making it sort of “fade in” as it renders. This allows you to see potential mistakes without having to wait for the entire scene to render. Some complex scenes can take hours! None of the ones we’ll be working with here should take more than a few minutes, however.



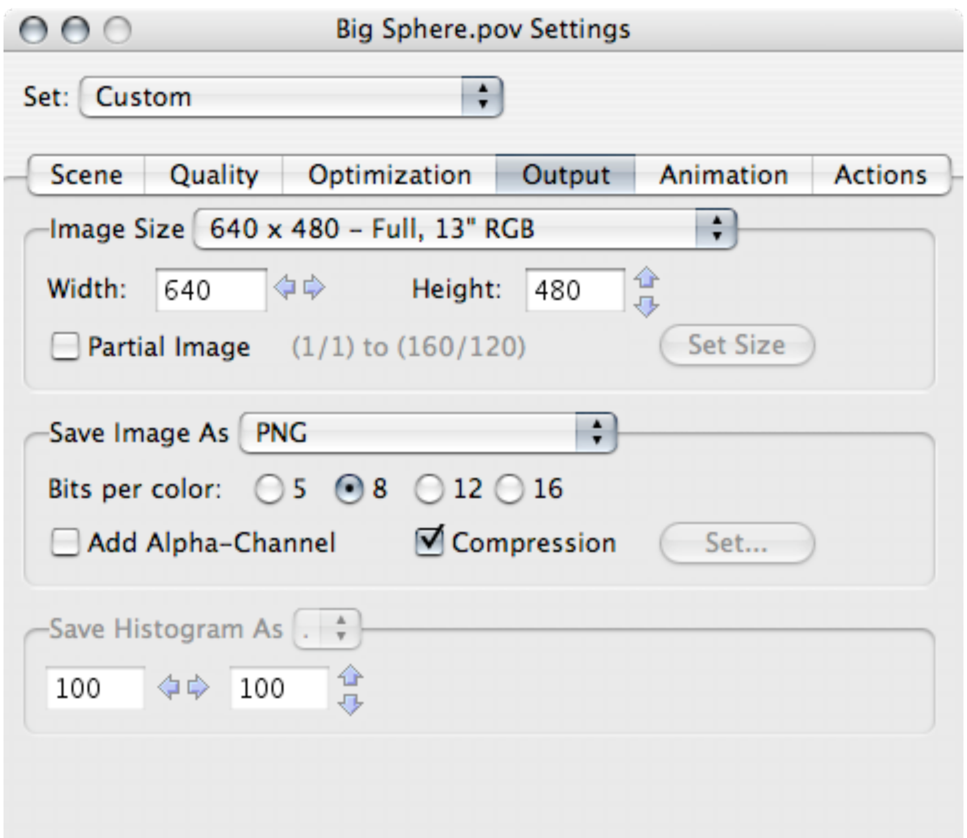
The *Quality* pane lets you specify the quality of your final image. If you reduce the quality, the render takes less time. Usually you will want to leave *Render Quality* at the maximum. When you reduce the quality you are actually removing information from the final image. Depending on the render quality, you may lose shadows, reflections, and even textures. A reduced-quality image often will not show you what you need to see to know whether your scene description is correct.

Anti-Aliasing smooths out the edges of your objects. More specifically, it smooths out the edges of any adjacent colors. Anti-aliasing almost always makes the resulting image look nicer. It makes the render take more time, however, so I will often leave anti-aliasing off until I'm finished. I'll do the final render with anti-aliasing turned on.

Here's a close-up of our blue sphere, with anti-aliasing turned off and anti-aliasing turned on. Notice the "staircase" effect on upper part of the left image.



The more sharp transitions from one color to another, the more you'll need anti-aliasing for your final render. Anti-aliasing and mosaic preview do not work well together, so when you do your final, anti-aliased render you'll want to turn mosaic preview off.



In the *Output* pane, you'll set the size of the image, the kind of the image, and whether or not to add an alpha channel. I've been rendering this image at 640 by 480.

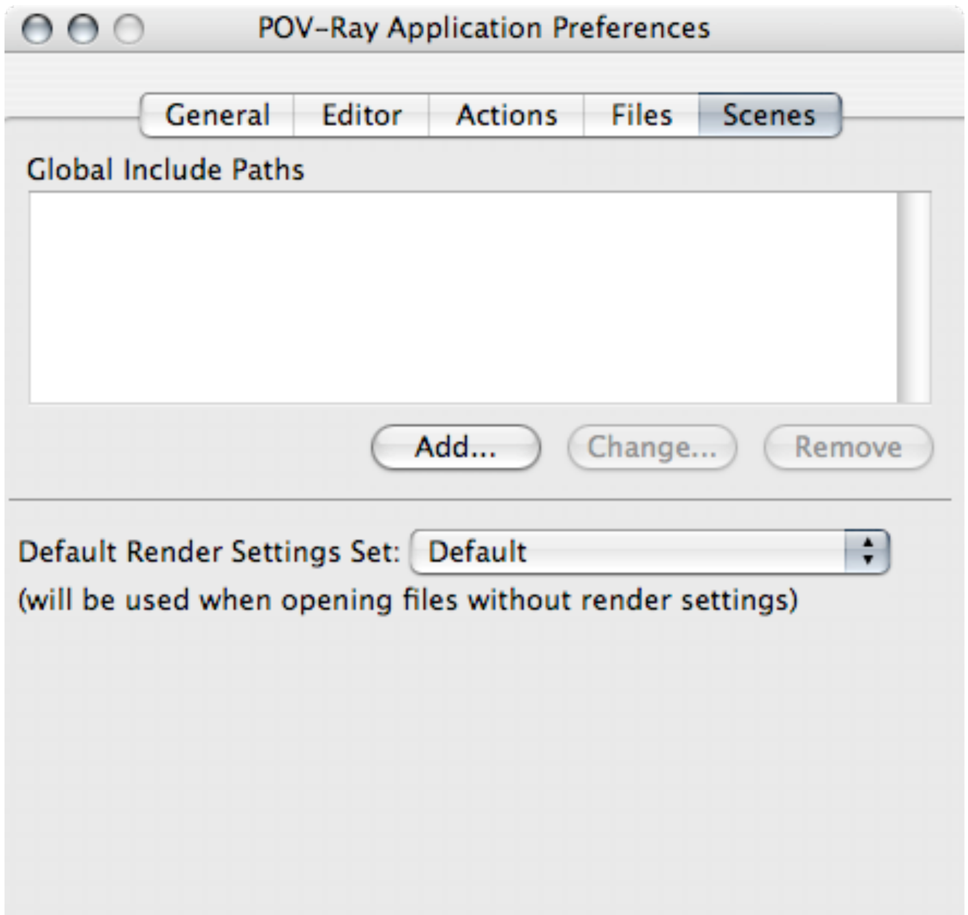
I prefer to save my rendered images as PNG, because it is a fairly universal format. From PNG, I can use image software such as *GraphicConverter*, *GIMP*, or Photoshop to convert the image to JPEG, GIF, or compressed PNG as needed. But I keep the original POV-Ray PNG so that I don't have to re-render to get a higher quality image.

The alpha channel is very useful for creating web images and for merging POV-Ray images into photographs. Turning on the alpha channel makes the image transparent where nothing exists. In our current image, there is only one object, the sphere. If we turned the alpha channel on, every other part of the image would be transparent. This makes the image useful as, say, a button or icon on a web page. If your page is white and you put the blue sphere there, it will appear as a blue sphere on a white background: the black is transparent because nothing is there. The alpha channel is especially useful for anti-aliased images. In an anti-aliased image, the smoothed sections will have varying degrees of transparency, removing the halo effect you often see when trying to match smoothed images to a web page's background color.

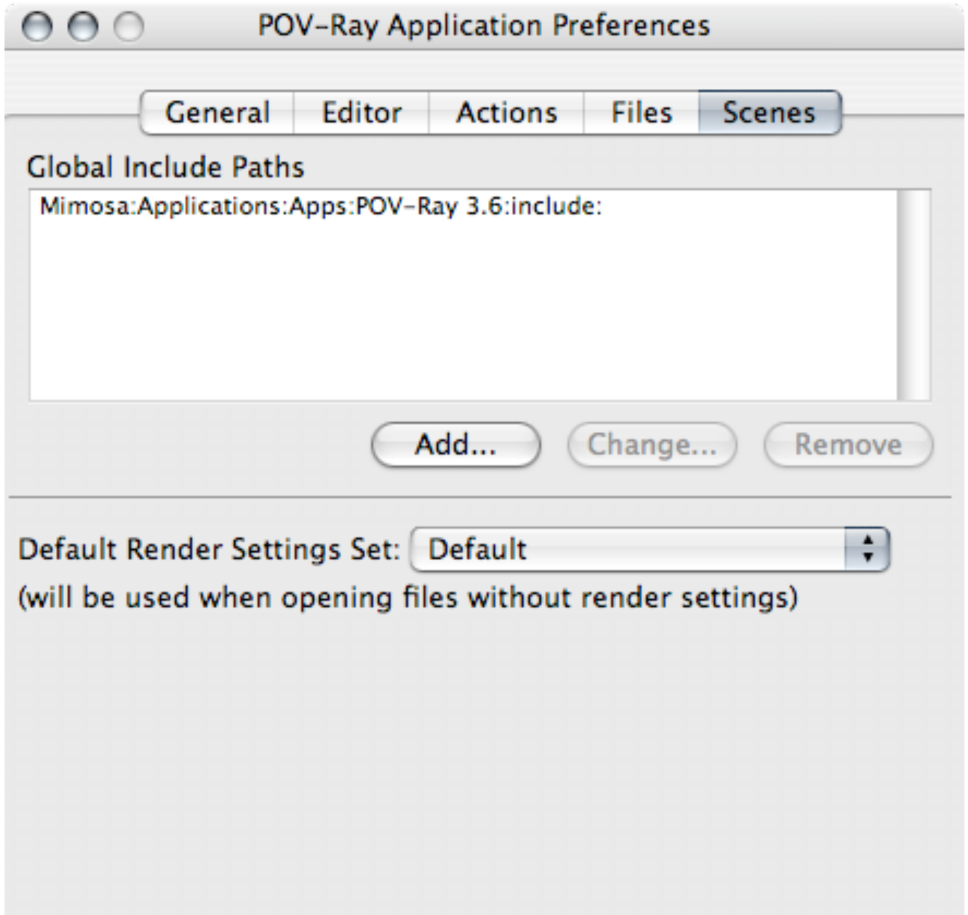
INCLUDE FILES

I hope I haven't scared you with all these numbers because, at least for some of them, there is an easier way. POV-Ray comes with several files that contain useful objects and numbers. One of those files will let you specify your colors in English rather than as a series of red, green, and blue numbers.

In order to use this color file, you have to "include" it. In order to include it, you need to make sure that POV-Ray knows where your include files are. Under the "Edit" menu, choose "Preferences…".



You want to add to the *Global Include Paths*. In your POV-Ray folder, there will be a folder called "include". Click on the "Add…" button and choose that folder. Its path will appear in the *Global Include Paths* box.



Once you’ve told POV-Ray where to find your include files, we can use color names instead of RGB numbers in our scene. First, tell POV-Ray to include the “colors” file. Most include files will end in “.inc”.

```
//get some colors
#include "colors.inc"
```

Then, replace the color in the light_source:

```
//one light source
light_source {
  <20, 35, -2>
  color White
}
```

And the color in the sphere:

```
//the center of the universe
sphere {
  <0, 0, 0>
  2
  pigment {
    color SkyBlue
  }
}
```

When you render this scene, it will look exactly as the other scene did.

You can mix RGB colors and color names throughout your scene as necessary.

THE PLANE TRUTH

There are two basic kinds of objects in POV-Ray: objects that have a definite end, and objects that go on forever. POV-Ray calls these *finite* objects and *infinite* objects. A sphere is a finite object. A plane is an infinite one. Let's add a plane to our scene.

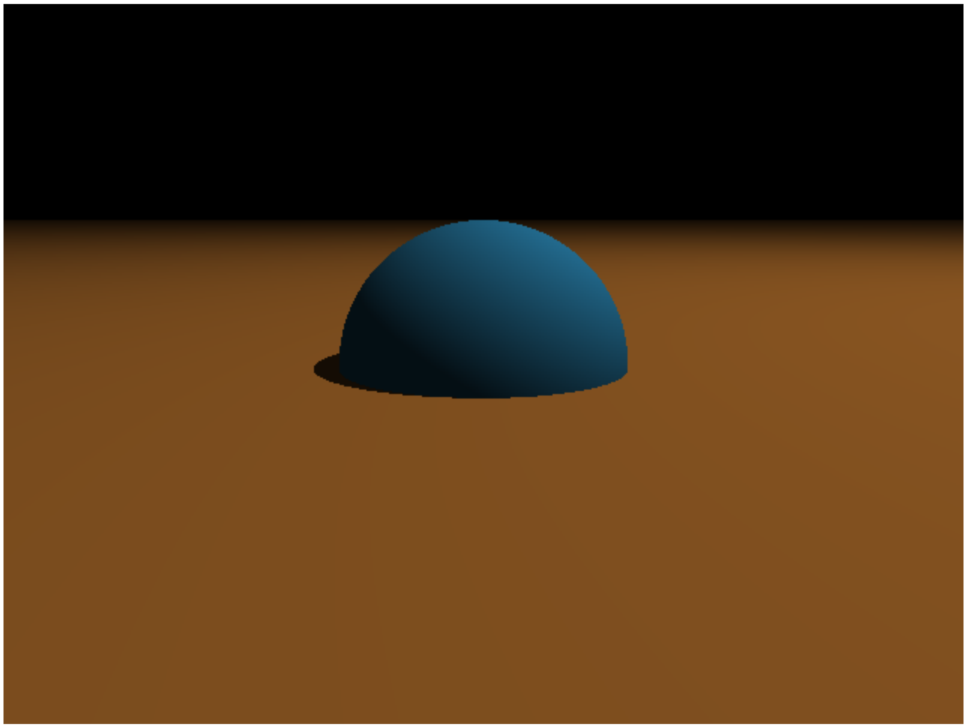
```
//it's Magrathea!
plane {
  y, 0
  pigment {
    color Gold
  }
}
```

Render this one and you've got half of a sphere protruding from a golden plane. A plane goes on forever in two directions. This plane goes on forever left and right, and forward and back. You specify which directions it goes on forever by telling POV-Ray which direction it *does not* go on forever.

Rather than using left, right, up, down, forward, and back, POV-Ray uses x, y, and z as its directions. What we've been calling left and right is 'x'. What we've been calling up and down is 'y', and what we've been calling forward and back is 'z'. From now on, we're going to use x, y, and z as well. Left, right, up, down, forward, and back don't make much sense when we start moving the camera around.

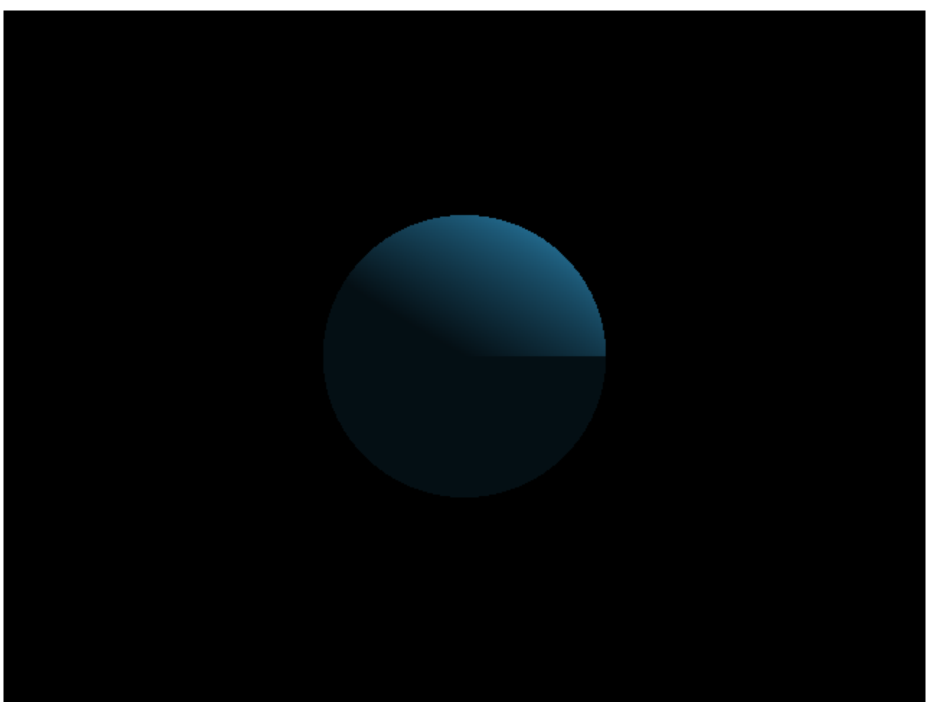
The center of the universe is zero x, zero y, and zero z.

When we tell POV that our plane is "y, 0", we are saying that the y axis is *perpendicular* to the plane. And the plane is zero units away from y's origin (or, zero units away from zero y).



Where planes go on to infinity in two directions, they are infinitely thin in the other direction. Temporarily change your camera's location from a y of 2, to a y of 0:

```
//camera is at eye-level
camera {
  location  <0, 0, -10>
  look_at   <0, 0, 0>
}
```



The plane disappears completely! All you can see now is the shadow that it casts on the lower half of the sphere. This is because the plane is infinitely thin, and we are looking at the plane straight on. If we were even slightly above it or slightly below it, we would see the plane, but we're not. Go ahead and try a 'y' location of .0001 or -.0001 for the camera and see what happens. In both cases, you'll seen the plane and either the top or bottom half of the sphere.

Before going further, restore the camera's y to 2 and re-render it to make sure it is still half of a blue sphere on a gold plane.

Ambient light

If you've been paying attention to the description of raytracing, you might be asking why the plane casts a shadow onto a visible sphere. The light source is above the plane. The plane goes on to infinity in the x and z directions. How does *any* light get below the plane? We shouldn't be able to see the lower half of the sphere *at all*.

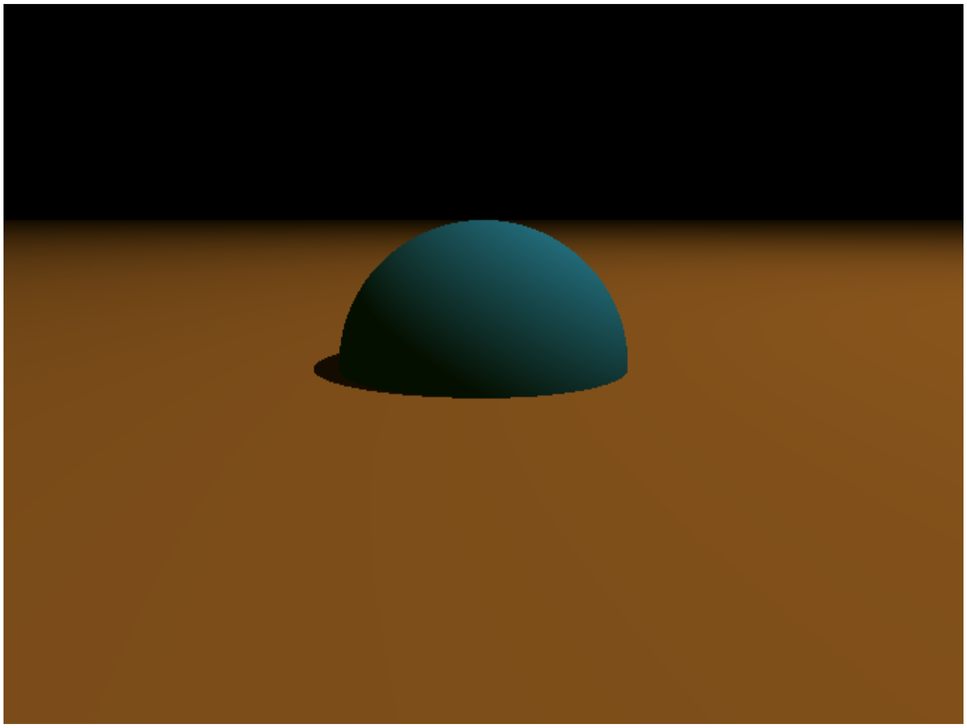
The reason it does show up is that POV-Ray assumes by default that there is "ambient light" throughout the scene. You can control this. There are two places to set the ambient light.

First, you have the *global* ambient. Add the following to the top of your scene:

```
global_settings {
  ambient_light Black
}
```

This sets the general ambient light to zero. If you render the scene with the ambient light set to zero, the shadows will all become much sharper. If you change the camera's location to below the plane, the whole scene will become black. That's because there is no ambient light, and the one light source can't illuminate below the plane.

By default, ambient_light is White. Often, you'll set it to white, black, or some gray in-between. You can get some interesting effects by changing its color to something else, however. Go ahead and change it to Yellow in this scene and re-render it.



Notice how the shadows on the blue sphere have a yellowish tint? That’s from the ambient light.

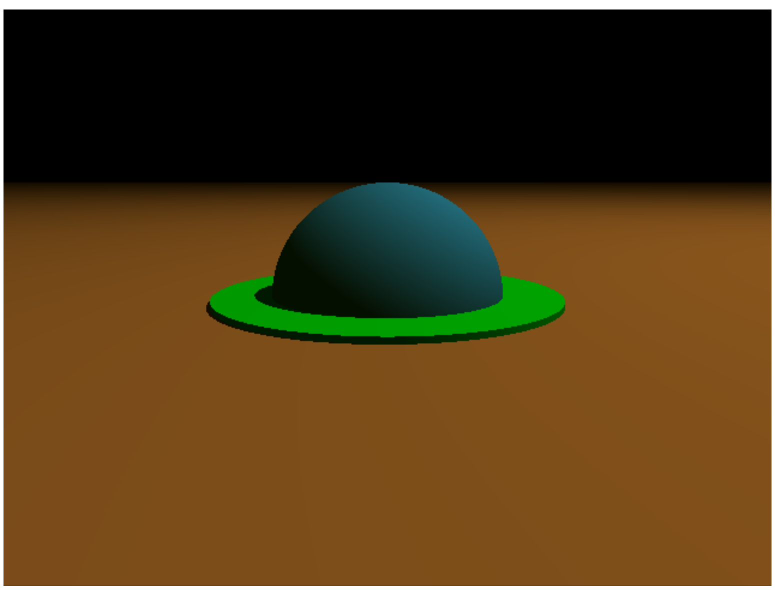
Constructing objects

POV-Ray gives you several simple objects that you can place in your scene. If you want more complex objects there are several ways of getting them. One of these ways is using *constructive solid geometry*, or CSG. With CSG you take simple objects and combine them into more complex objects. You can merge objects, unite them, cut them, and intersect them.

Once you've created a CSG object, CSG objects are themselves able to be used in merges, unions, differences, and intersections.

Let's add a ring to our sphere. There is no such thing as a flat ring in POV-Ray (it does have a torus, but that's a kind of donut shape). But it does have a cylinder. Below the sphere, add a cylinder object.

```
//ring around the sphere
cylinder {
  <0, -.01, 0>, <0, .01, 0>, 3.2

  pigment {
    color Green
  }
}
```

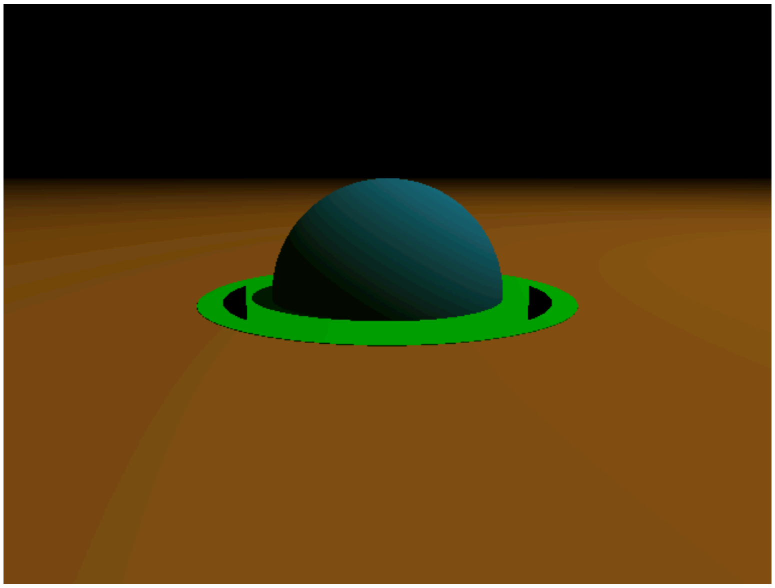


Cylinders are defined by their starting location, their ending location, and their radius. This cylinder starts at -.01 meters below the origin, ends at .01 meters above the origin, and is 3.2 meters in radius. It's really more of a disc than a cylinder.

You should end up with a blue sphere with a green puddle around it on the plane.

We want this to be a ring, like a ring around a planet, so we don't want the ring to go right up to the surface of the sphere. Let's add another, smaller cylinder where we want the empty space to be.

```
cylinder {
  <0, -.01, 0>, <0, .01, 0>, 2.8
}
```

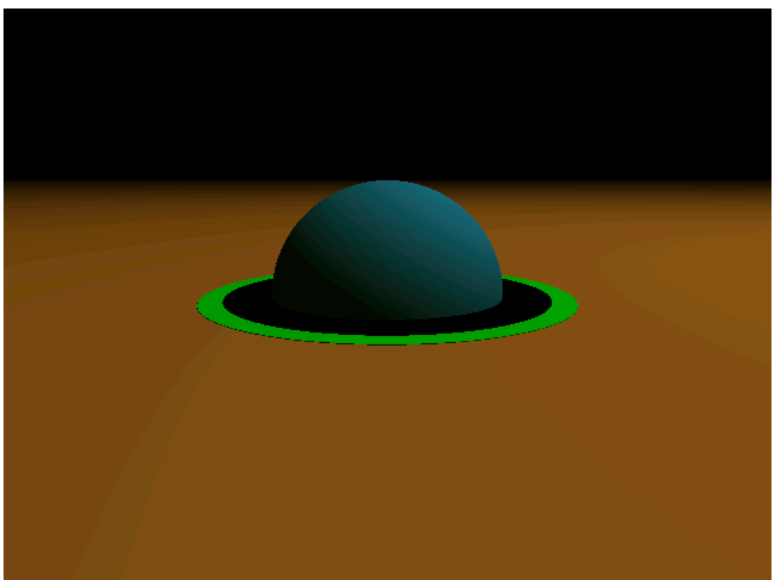


This looks strange. There's green all the way to the center, but little black semicircles on the edge. It might even look different on yours than it does in this picture.

This is happening because we have two *coincident surfaces*. We have a black plane and a green plane whose surfaces are *exactly the same* once you get inside the radius of 2.8. Both of those cylinders start at y -.01 and end at y .01. POV-Ray has no idea which surface to use as the "real" surface at those points.

This is similar to the problem of looking at a plane straight-on. Because these numbers are exact numbers, we can tell POV-Ray to put things or look at things at exactly the same locations.

In this case, the solution is to make the inner cylinder start at slightly lower and higher points than the outer cylinder does.



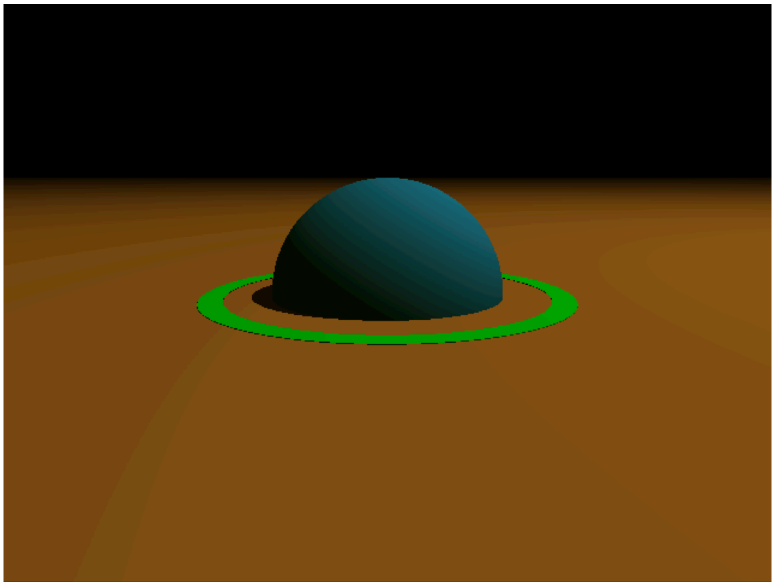
```
cylinder {
 <0, -.02, 0>, <0, .02, 0>, 2.8
}
```

That's better. This gives our green cylinder the basic shape we want, but we still have that black cylinder inside. We really want there to be *nothing* there. We want the cylinder to be, not a cylinder, but a ring.

This is what CSG is for. In CSG, we have a difference object that takes the *difference* between two other objects. We want the difference between our green cylinder and our inner cylinder. Surround the two cylinders with *difference*:

```
difference {
  cylinder {
    <0, -.01, 0>, <0, .01, 0>, 3.2

    pigment {
      color Green
    }
  }
```

```
cylinder {
  <0, -.02, 0>, <0, .02, 0>, 2.8
  }
}
```



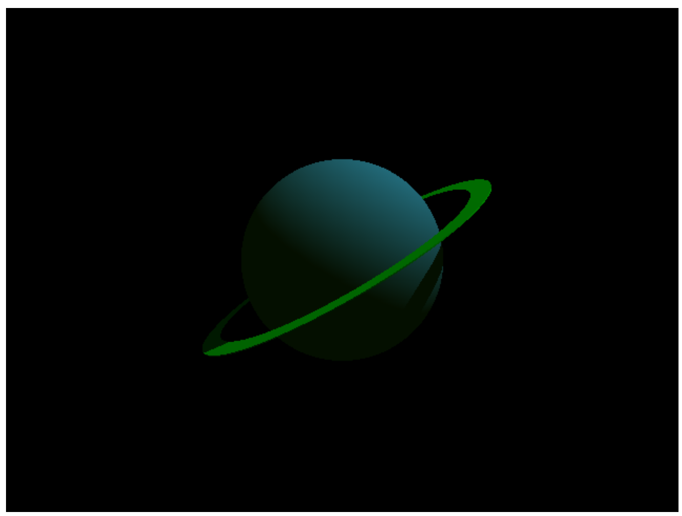
Okay, this is what we want. The ring circles the sphere with space between the sphere and the inner edge of the ring. Let's add a little more "action" to the scene. We can rotate the ring so that it is on an angle.

First, remove the plane from the scene so that we'll be able to see the whole ring when we angle it. It was a nice plane, but we won't be needing it any more.

Then, add a "rotate" line to the difference section, just above the final curly bracket:

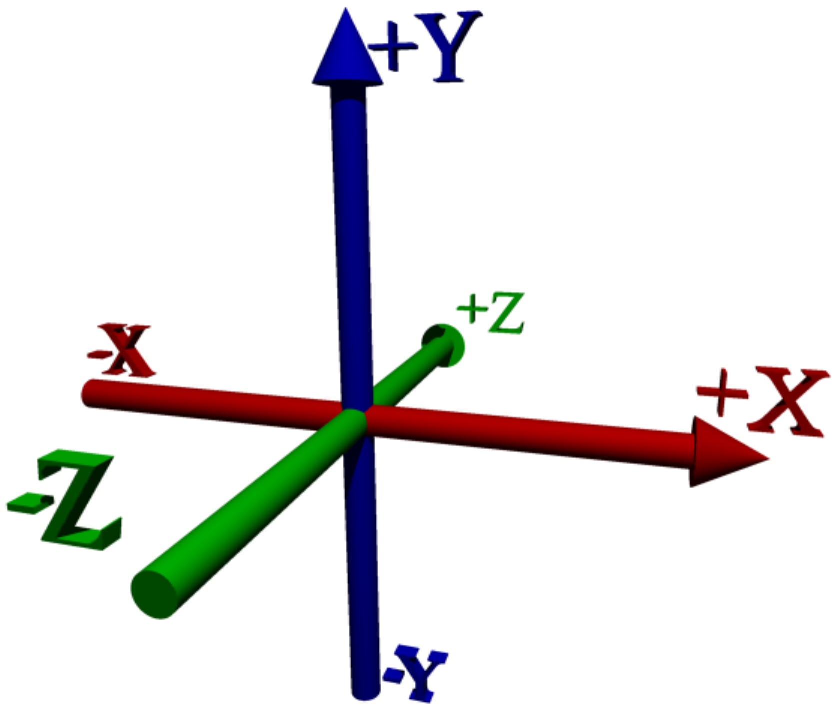
```
rotate <0, 0, 30>
```

The complete difference section should be:



```
//ring around the sphere
difference {
  cylinder {
    <0, -.01, 0>, <0, .01, 0>, 3.2

    pigment {
      color Green
    }
  }

  cylinder {
    <0, -.02, 0>, <0, .02, 0>, 2.8
  }

  rotate <0, 0, 30>
}
```

The "rotate" line has a set of three numbers that look a lot like our other sets of three numbers. In this case, we're rotating a number of degrees around the "pole" that we've specified. The numbers are still x, y, and z. We've told it to rotate 30 degrees around z. You can imagine z as a pole situated on zero x and zero y. It moves from front to back. Here's a diagram (you can see how this diagram was made at *The Persistence of Text*).



Rotating the ring <0, 0, 30> is like resting it on the green pole and rotating it 30 degrees, with the right side moving up. We could also rotate it around x and y. In this case rotating the ring solely around y wouldn't change anything in the image. No matter how much you rotate it around y, it is still a green ring circling the sphere, flat on the other two poles. Now, having rotated it around z first, we could rotate it around y and that would move the lower end either towards or away from us. Go ahead and add another rotate after the current rotate, and play around with rotating it around x and y.

When you're done, remove that second rotate.

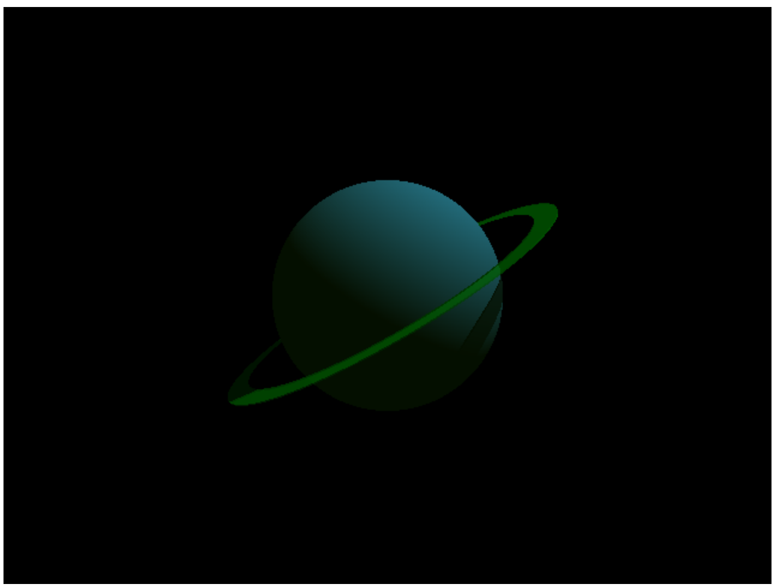
More about pigments

That pigment statement has been standing out like a sore thumb, because we haven't really talked about it yet. What's the point of having a whole section for pigment if the only thing we can put in there are colors? In fact, we can do quite a bit more. Pigments can contain *patterns*.

Tinted transparency

Let's start with something simple first. Our colors have so far contained three numbers: one for red, one for green, and one for blue. There is a fourth number in colors as well. It stands for filter and is assumed to be zero if it isn't specified. Change your "color green" to:

```
color Green filter .5
```



When you add a "filter" to a color, the color will let some light through. In this case, the color is green and the filter is .5, so any green light is let through at 50% of its normal strength. Take a look at the shadow that the ring is casting on the sphere. Where it was black, it now has a greenish tint to it.

Our light source is fully white, and white contains 100% red, green, and blue. When the filter on the ring was zero, the ring didn't let any light through, thus casting a dark shadow onto the sphere. By specifying a filter of 50% for our green, we're still not letting any red or blue light through, but any green gets dropped to half strength and continues on.

If you are specifying "rgb" values as we did before using the colors.inc include file, you can specify rgbf to add a fourth value for filter.

Patterns

Pigment sections truly come into their own when we start using *patterns* with them. Patterns allow you to have the color vary from point to point according to, well, a pattern. There is a checkered pattern, a brick pattern, an onion pattern, as well as stranger patterns such as a bozo pattern and a crackle pattern. There are, in fact, many different patterns you can use. We're going to look at two right now. The first is the *cylindrical* pattern, and the second will be the *bozo* pattern.

Cylindrical pattern

Patterns can sometimes be a lot easier to show than they are to explain. Go ahead and make a new scene document, and copy everything except the objects into it. Keep only our original cylinder. Your scene file should look like this:

```
//units are in meters

//get some colors
#include "colors.inc"

// place all settings of globally influenced features here
global_settings {
  ambient_light Yellow
}

//one light source
light_source {
  <20, 35, -2>
  color White
}

//camera is at eye-level
camera {
  location <0, 2, -10>
  look_at <0, 0, 0>
}

cylinder {
  <0, -.01, 0>, <0, .01, 0>, 3.2
  pigment {
    color Green
  }
}
```

And when you render it you should see a bright green disc in the center of your image.

What we'd like this disc to do is have a rainbow-like range of colors in bands circling it. The pattern that will help us do this is the cylindrical pattern. Replace the pigment section with:

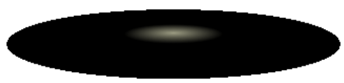
```
  pigment {
    cylindrical
  }
```

When you render it, our disc becomes quite smaller, a tiny dot in the background radiating from white to black.

However, because our default background is black and our disc is turning black, we may not be seeing everything. Let's tell POV-Ray to use a different color for the background.

```
background {
  color White
}
```

Just put that at the end of your scene, and then re-render.



As you can see, the disc is the same size as it always was, but only the tiny center has the cylindrical pattern applied to it. Everything else is black.

This happens because the cylindrical pattern, like many patterns, expects to see what is called a “unit-sized” object. That is, an object that goes from zero to one. Change the radius of the disc to 1 by replacing “3.2” with “1”.

```
cylinder {
  <0, -.01, 0>, <0, .01, 0>, 1
  pigment {
    cylindrical
  }
}
```

Now when you re-render, the pattern goes out to the edge of the disc, but that’s because we’ve made the disc smaller. We now need to make the disc large while making the pattern larger as well. We do this by scaling the cylinder after we apply the cylindrical pigment.

```
cylinder {
  <0, -.01, 0>, <0, .01, 0>, 1
  pigment {
    cylindrical
  }
  scale <3.2, 1, 3.2>
}
```

We’ve added one line: “scale <3.2, 1, 3.2>”. Scale changes the size of the object. And yet again we’re seeing a group of three numbers. These are our familiar x, y, and z. The first number makes the disc larger in the x directions: it multiplies x by 3.2. The second number applies to the y direction, but because we made it 1 the y size (the height) will not change. Multiplying y by 1 leaves us with the same height as before. The third number multiplies z by 3.2.

When applying patterns of this type, it will often be useful to make your object be “unit-sized” before applying the pigment, and then scale it after applying the pigment.

Frequency

That’s nice. We’ve got the disc sized correctly again, but the pattern is not exactly what we want for a planetary-style ring. It needs to go through the cycle of light to dark several times. We can change the number of cycles by adding a *frequency* line to the pigment.

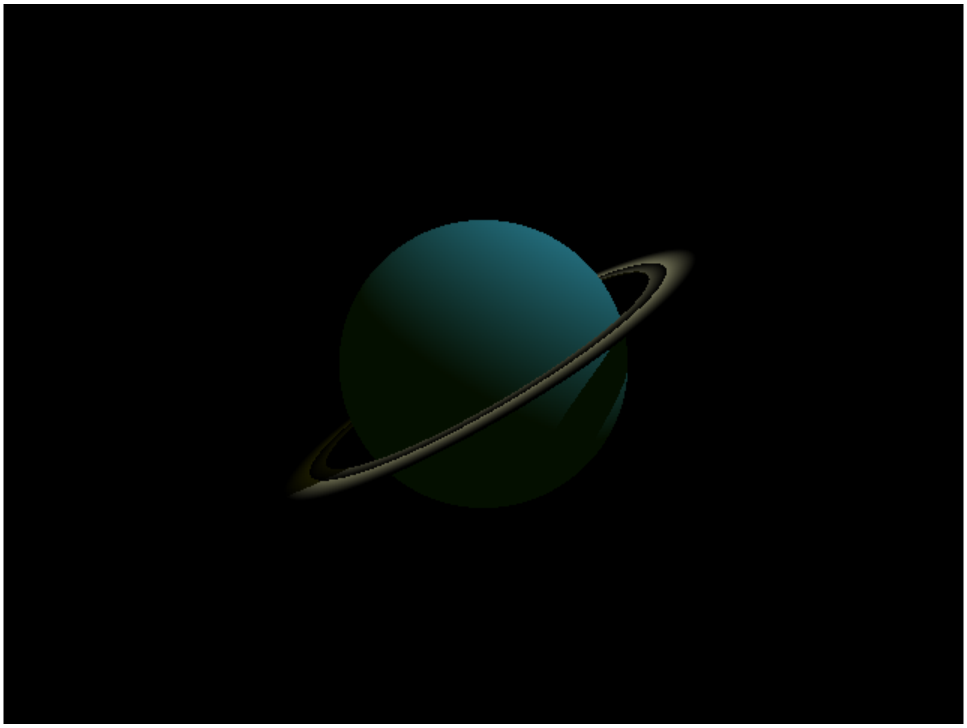
```
pigment {
  cylindrical
  frequency 2
}
```

Frequency 2 tells it to cycle through the pattern two times. We’re getting closer. Try changing the frequency from 2 to 8.

That’s looking a lot nicer, so let’s bring that pigment back into our main scene. Remember to change the size of your cylinders: change the outer cylinder to radius 1, and the inner cylinder to radius .8:

```
//ring around the sphere
difference {
  cylinder {
    <0, -.01, 0>, <0, .01, 0>, 1

  }

  cylinder {
    <0, -.02, 0>, <0, .02, 0>, .8
  }

  pigment {
    cylindrical
    frequency 8
  }

  scale <3.2, 1, 3.2>

  rotate <0, 0, 30>
}
```

The sphere is now circled by a set of grey rings.



Color maps

There are a couple of problems. First, we've lost our transparency, and second, we'd really like those rings to be in color. This is where things get tricky. A pattern in POV-Ray almost always has a range of possibilities from zero to one. That's why we changed our rings to have a radius of 1 first, and then scaled them. We can tell POV-Ray what colors go at which points.

In the case of the cylindrical pattern, the center of the pattern is 1, and the outside of the pattern is 0. Beyond the outside—as in our original disc where the disc was larger than one unit—the pattern continues to be 0.

We can map colors to various points from 0 to 1. We always start at zero and move upwards to one. In the case of our cylindrical pattern, this means that the first color we choose will be at the outer edge, and the last color at the inner edge.

Often when using frequencies greater than one, or when using patterns that repeat, you'll want the same color at each ends of the "map". This creates a smooth transition between repetitions.

Here is our color map:

```
color_map {
  [0.00 Magenta filter .5]
  [0.30 Yellow filter .5]
  [0.45 Green filter .5]
  [0.60 Cyan filter .5]
  [1.00 Magenta filter .5]
}
```

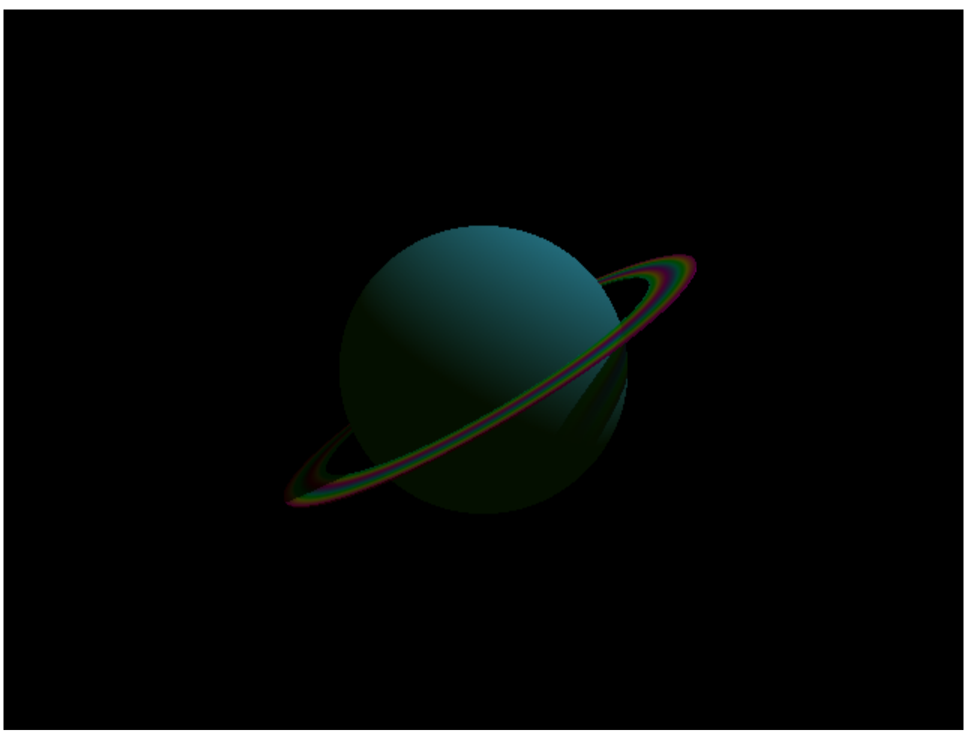
Add that to the ring's pigment section.

At 0 and at 1 (at the outer edge and the inner edge) the ring will be Magenta. Inside, moving from the outer edge to the inner edge, it will transition from Magenta to Cyan to Green to Yellow and back to Magenta. Since we've set a frequency of 8, it will do this eight times from the center of the disc to the edge.

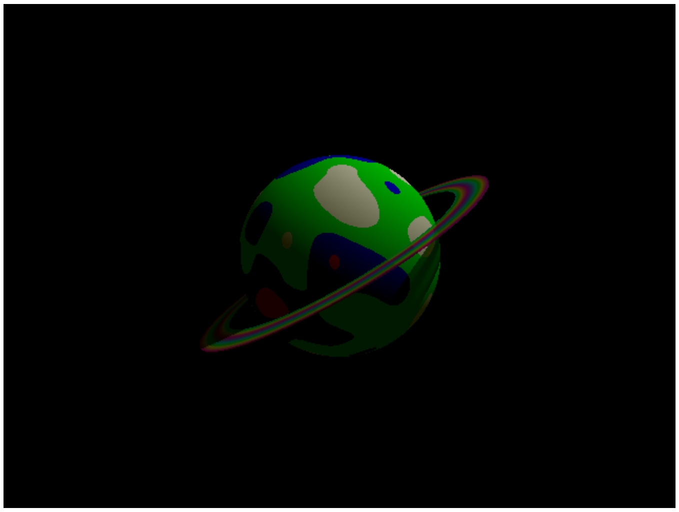
Remember that since we're only looking at a portion of the disc—we took out the center by using a *difference*—we don't see all eight repetitions.

For all colors, we've set the filter to 50%. This is what the pigment section of the rings should look like:

```
pigment {
  cylindrical
  frequency 8
  color_map {
    [0.00 Magenta filter .5]
    [0.30 Yellow filter .5]
    [0.45 Green filter .5]
    [0.60 Cyan filter .5]
    [1.00 Magenta filter .5]
  }
}
```



Bozo pattern

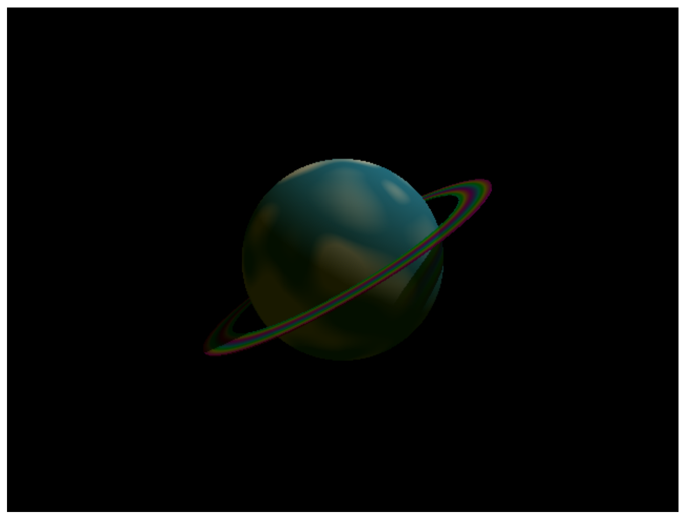


Patterns are important enough that we are going to look at another one. The *bozo* pattern is meant to resemble things that are random when far from each other but that have similar values when close to each other. One of the things that bozos are great for are making cloud-like patterns over a surface. Change the SkyBlue sphere to a bozo pattern.

```
pigment {
 bozo
}
```

That's certainly something, isn't it? Let's add our own color map instead of using the default.

```
pigment {
  bozo
  color_map {
    [0.00 White]
    [0.45 SkyBlue]
    [0.55 SkyBlue]
    [0.70 White]
    [1.00 White]
  }
}
```



That is a lot nicer. But we can do even better. Every pattern can be *warped* to change the shape of its contours. The most commonly-used feature of a warp, and the only one we're going to use here, is *turbulence*. Turbulence adds random variation to a pattern.

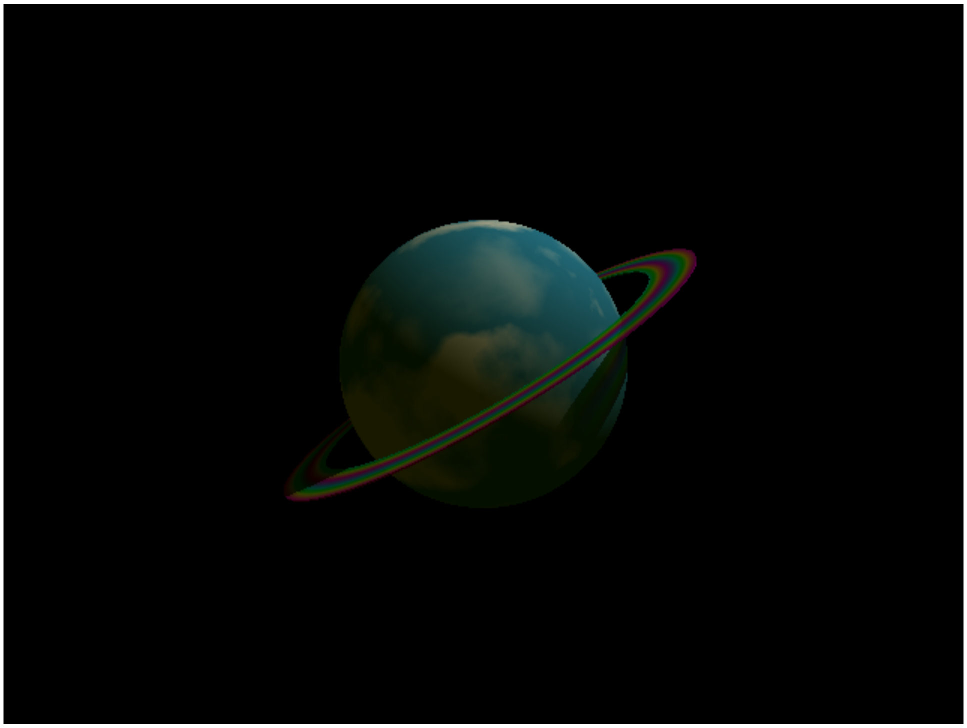
Add:

```
warp {
  turbulence .5
}
```

to your pigment, so that it reads:

```
pigment {
  bozo
  color_map {
    [0.00 White]
    [0.45 SkyBlue]
    [0.55 SkyBlue]
    [0.70 White]
```

```
    [1.00 White]
  }
  warp {
    turbulence .5
  }
}
```



This is beginning to look like a place we'd like to visit.

A LITTLE BACKGROUND

While we were working on the cylindrical pattern, we added a *background* section to the test scene. Backgrounds tie into what we talked about earlier with alpha channels. The background is what POV-Ray shows when there is nothing in the scene. By default, POV-Ray shows black when there is nothing in the scene, but we can tell POV-Ray to show something else.

BACKGROUND

The simplest way to change the background is with the background section. You'll often want to change the background to something other than black if you need a specific background color to match a web page or document's background color. You will also sometimes want to change the background color if you are unsure where shadows end and the background begins. Changing the background to other than black will more clearly show what part of the image is shadow and what part is nothing.

Often, white is a good color for the background in both of the above cases.

```
background {
  color White
}
```

Backgrounds cannot have patterns. They must be solid colors. They can, however, be any color. Also, it makes no sense for a background to be transparent, since a background means there is nothing in the scene to show.

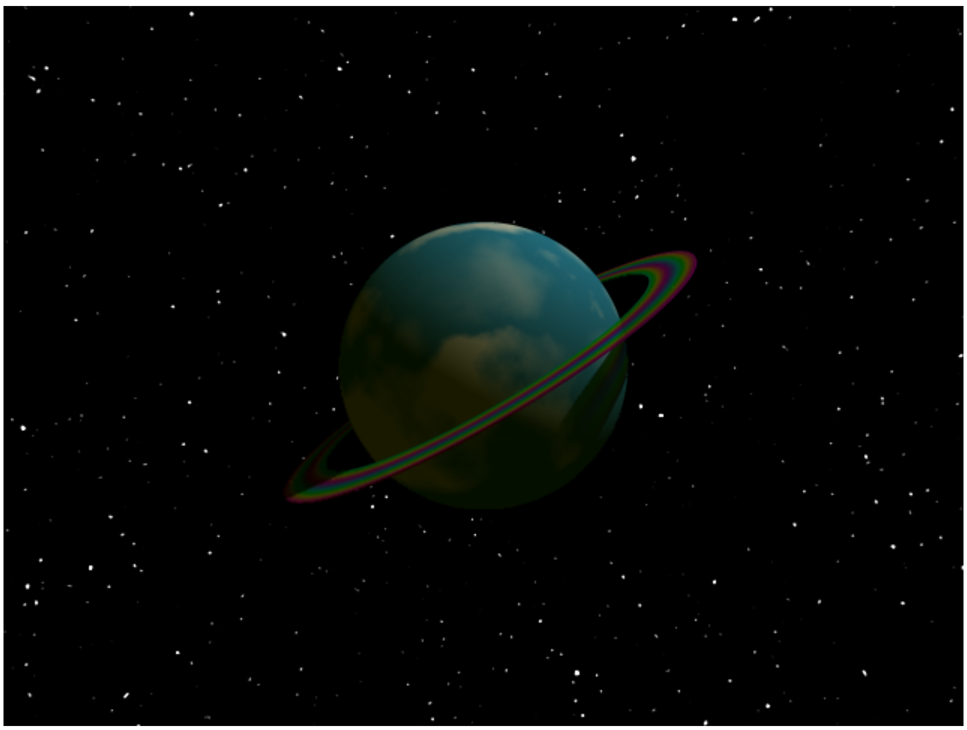
SKY SPHERE

The sky sphere is a more complex form of background. You can use it when you want to simplify your scene: it allows you to place a pigment pattern into the scene, at an infinite distance, wherever nothing is. Often, you'll use it to place a sky in your image or to place a star field.

Any pigment that you can place on an object, you can place on the sky sphere. There are some commonly-used pigments in the skies.inc include file for creating cloudy skies. We'd like to have a starry night, however, so we'll need to make our own up.

A web search is often useful when you're looking for some patterns for a specific purpose. A search on "povray starfield sky_sphere" found a couple of nice options: one using the *crackle* pattern and one galaxy include file. Because *crackle* is a very complex pattern to describe, I'm going to pretend we didn't find anything useful, however, and go with what we know. The bozo pattern makes for a nice distribution of values that might work out well as a star field. Since we want the stars to be tiny points on a mostly black background, our color map will be a tiny section of white near one end, and the rest all black.

```
sky_sphere {
  pigment {
    bozo
    color_map {
      [0.0 White*3]
      [0.2 Black]
      [1.0 Black]
    }
    scale .006
  }
}
```



As you can see above, pigments can be scaled just like objects can. We scaled it down so that there are many more white points in view. That is, so that more stars are visible. Play around with the scale, bringing it up towards 1, to see what happens as the scale effect is reduced. You can get some interesting effects that way.

Another interesting line above is in the color map. Our first color is White, multiplied by 3. Remember that the color names are just textual representations of the rgb colors. For white, the rgb colors are <1, 1, 1>. When you multiply it by 3, you get <3, 3, 3>. Didn't I write earlier that color numbers go from zero to one? I did, and it's true. But that doesn't stop you from using higher numbers when necessary. It is often possible to tell POV-Ray to go outside its normal bounds to achieve a special, unnatural result. In this case, we're trying to get bozo dots to look like stars. Making them ultra-bright helps.

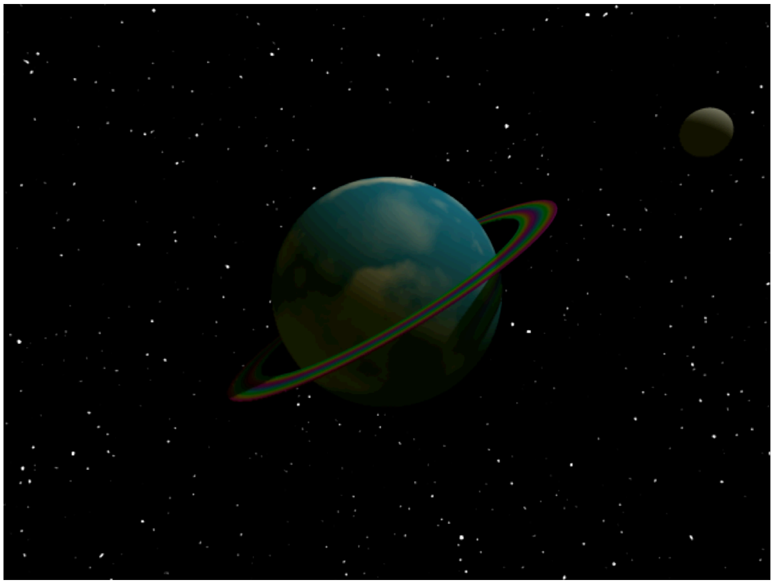
It is important to remember that even when you are using a sky sphere, the sky sphere is just another background, and it is still what gets shown when there is nothing in the scene. If you turn on the alpha channel, for example, you won't see the sky sphere.

As an example of that, I took the same image, turned the alpha channel on, and brought it into GIMP as a layer on top of a picture of a pond in Michigan.

GIMP recognized the alpha channel automatically, and all I had to do was drag the planet to where in the photograph I wanted it. The sky (because it is in a lower layer in GIMP) shows through everywhere that the POV-Ray image has nothing in it.

THE MOON IS A HARSH NORMAL

Our planetary model needs a moon. Let's add a smaller sphere orbiting our big blue sphere. We'll make this one gray, and angle it just a bit less than we angled the planet's rings.

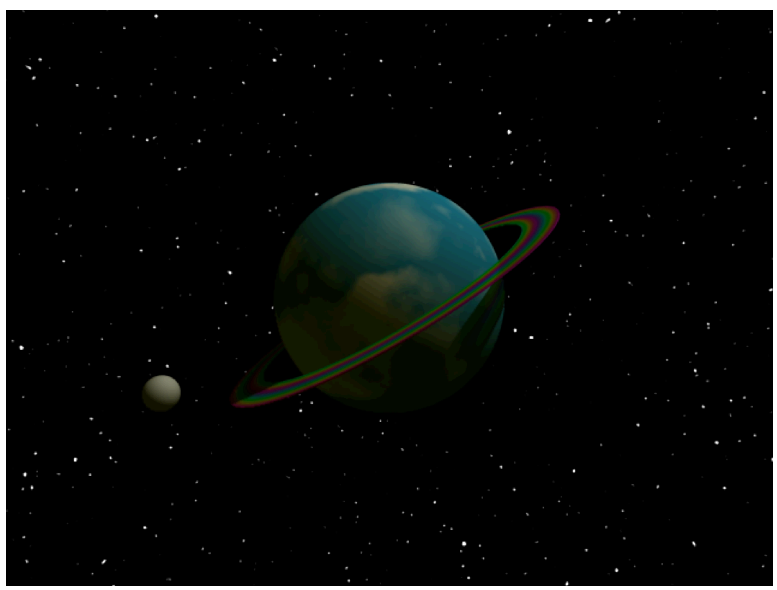


```
//the moon
sphere {
 <6, 0, 0>
 .4
 pigment {
   color Grey
 }
 rotate <0, 0, 27>
}
```

We've put this moon out six units (six meters? we may want to rethink our scale) from the center of the universe. Remember that our central sphere has a radius of 2 units. So the moon will be about 4 units away from the planet's surface.

Then we rotate it just 27 degrees around z. Rather than having it stick all the way off the edge like that, though, let's put it on the other side of the planet. Make that rotate line be:

```
rotate <0, 200, 27>
```



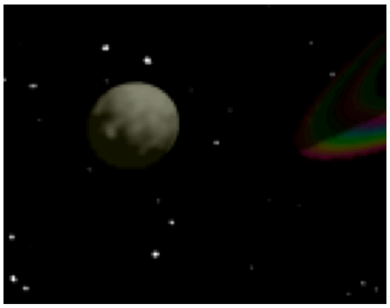
to rotate it 200 degrees around y first, before rotating it around z. This puts the moon down along the lower left, just above the rings.

Which is all fine and good, except that this is the most boring moon I've ever seen. It is completely smooth. We could try to add some pigment to it, but we really do want it to be grey, we just need some bumps on the surface.

There is a related section for objects, similar to pigment but which modifies the surface of the object. This is the *normal* section. It is called "normal" because that is a mathematical term for, basically, a pole that is perpendicular to the surface of an object. By altering the normal, we alter the appearance of the surface.

The normal section uses patterns just as the pigment section does. In fact, the same patterns will generally work in both places. Here, we are going to use the “bump” pattern to add bumps to the moon. Add, below the moon’s pigment:

```
normal {
  bumps
  scale .1
}
```

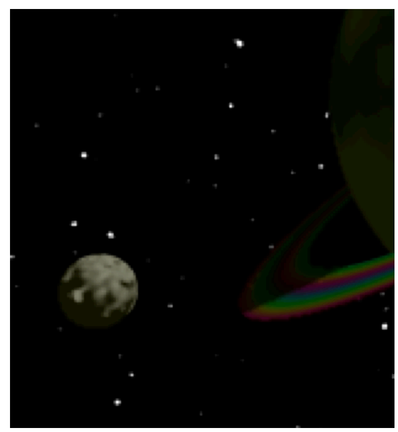


We have to scale the bumps because the moon is smaller than one unit in radius. In fact, it’s smaller than one unit in diameter: its radius is .4, so its diameter is .8. Patterns tend not to be as visible if they are larger than the object they are applied to, so we are scaling this pattern down to 10% of its default size.

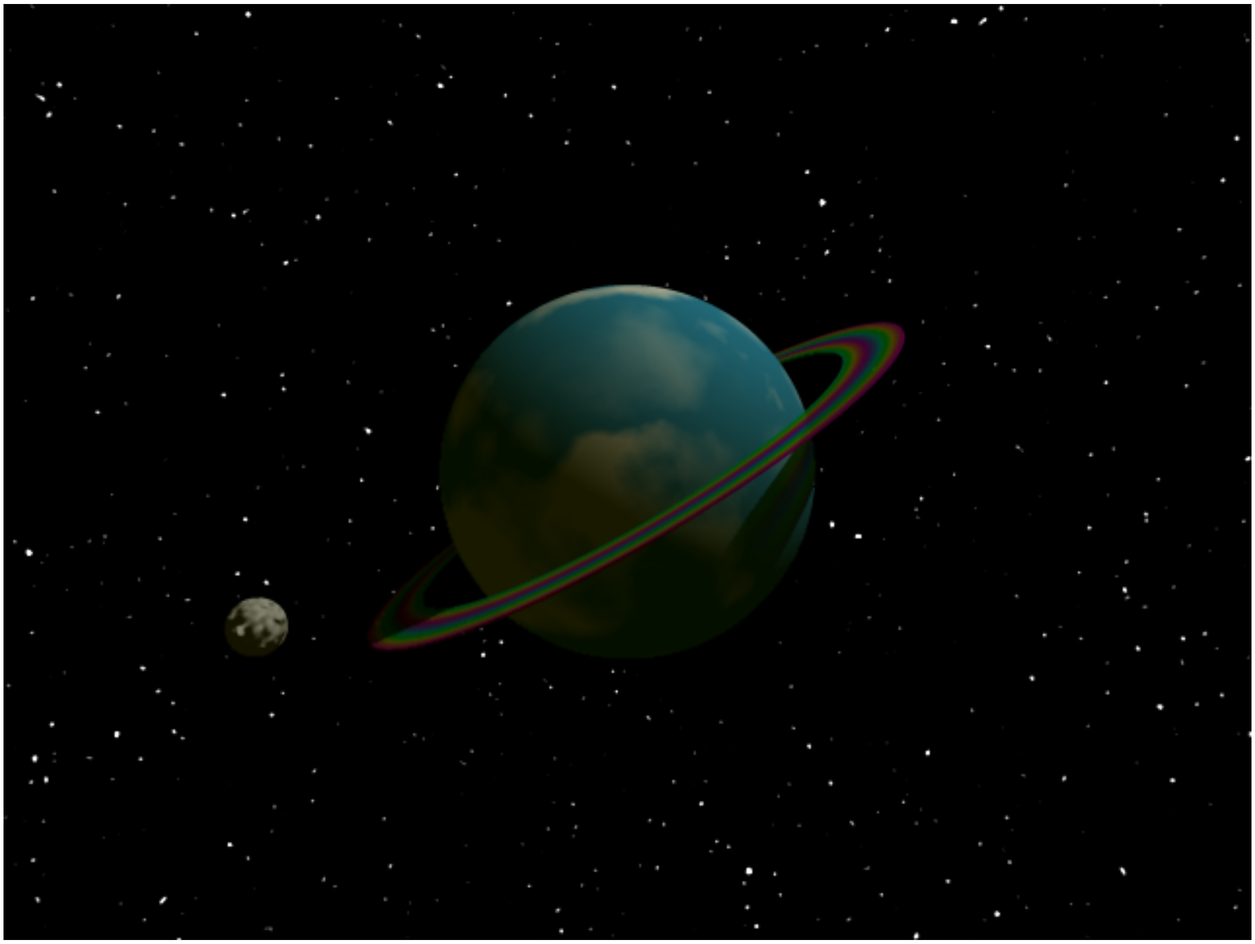
The moon is now bumpy, but it isn’t bumpy enough. Some patterns will let us increase their strength. We can change the size of the bumps by adding a number after the word bumps. The default is .5. Change it to 1.5:

```
normal {
  bumps 1.5
  scale .1
}
```

The moon is now nicely bumpy.



To be more precise, the normal section does not modify the surface of the object. It modifies the way that light bounces off of the surface of the object. If you look closely at this bumpy moon you’ll see that its outline remains completely spherical. What we’re really creating here is the illusion of bumpiness. But life is an illusion, raytracing doubly so. Modifying the normal to a surface rather than the surface itself is a shortcut that makes it easier for us to create basically sphere-like objects without having to draw out every bump and crack. It also makes it easier for POV-Ray to render the image of our scene. Because it is easier, POV-Ray takes less time to render the scene to an image.

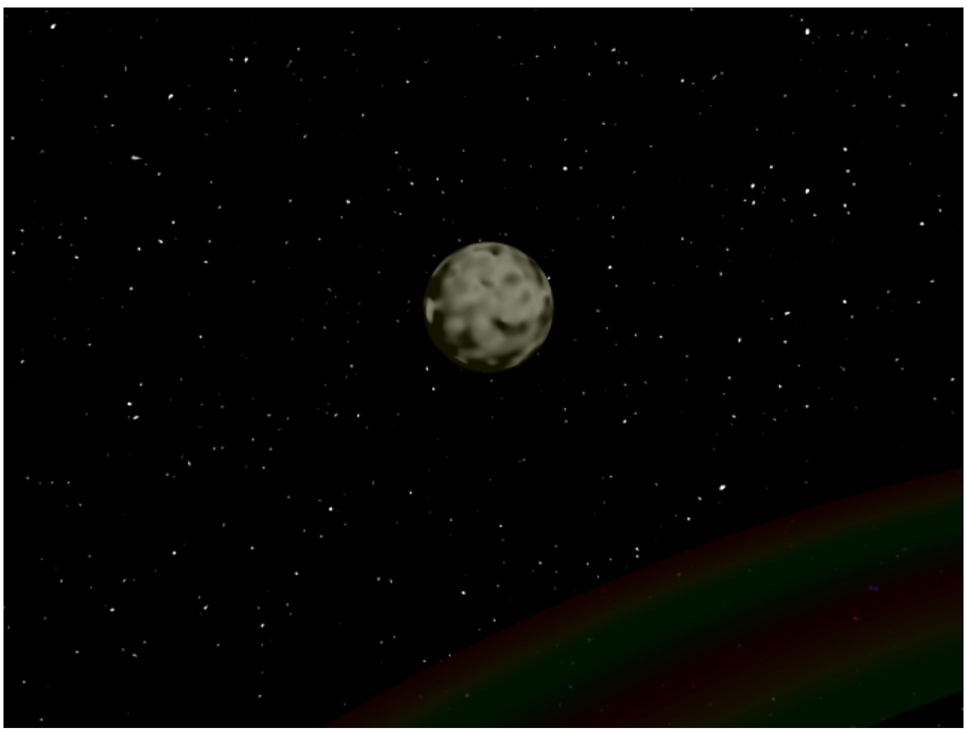


CAMERAS

CAMERA DIRECTION

We haven't moved the camera at all in this tutorial, but you can put the camera wherever you want. For example, if you want to be on the surface of your planet looking up at the moon, replace the current camera section with:

```
//camera is on the surface looking out
camera {
  location  <-2, 0, 0>
  look_at   <-5, -3, 2>
}
```



Moving the camera can often be useful to track down problems with your scenes, or simply to gain a new perspective.

THE CAMERA IS ALWAYS RIGHT

Put your camera *location* and *look_at* back to what we've been using.

```
  location  <0, 2, -10>
```

```
  look_at   <0, 0, 0>
```

All of the images we've made so far have been in "television format". The width and the height are at an *aspect ratio* of 4 to 3, like a television set and like many computer monitors. As you'll recall, I've been using 640 pixels wide by 480 pixels tall. Multiply 480 by 4/3 and you get 640.

This is a reasonable aspect ratio to work in, but it is not always what you want. Many computers now come with widescreen displays, and if you want to make a desktop background you'll need to use a height and width that are not at a 4/3 aspect ratio.

For example, one common display size on widescreen displays is 1,680 pixels wide by 1,050 pixels tall. Go into the scene's settings, go to the "Output" pane, and change the width to 1680 and the height to 1050. When you render the scene at this size, it will be oddly out of shape. The spheres will be stretched horizontally. That's because our width and our height no longer match our aspect ratio.

We need to tell our camera to use the aspect ratio that matches the width and height we want. You can determine the aspect ratio by pulling out a calculator and dividing the width by the height. For 1,680 by 1,050, that's an aspect ratio of 1.6.

The aspect ratio is the *width* divided by the *height* of the resulting image. In POV-Ray, you can tell the camera to use specific *right* and *up* triplets to determine the aspect ratio. The defaults that we've been using are:

```
right x*1.33
up y
```

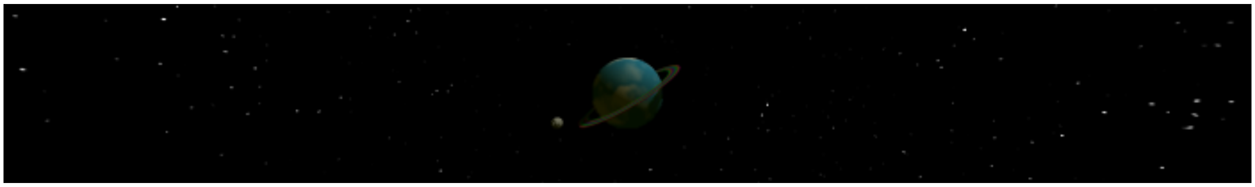
The horizontal number (x) is 1.33. The vertical number (y) is unchanged at 1. This is the default aspect ratio of 4 to 3: four (horizontal) divided by three (vertical) is 1.33.

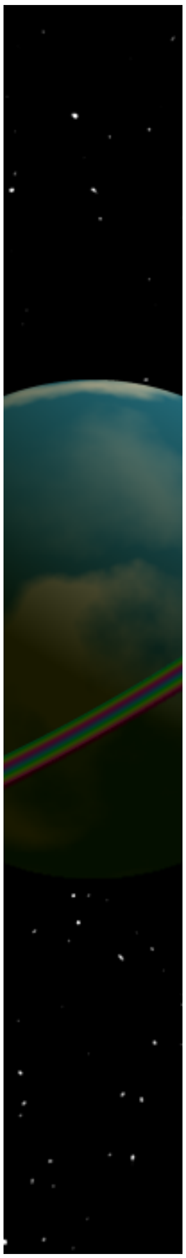
The *up*, with its unchanged y, is almost always what we want, so we can leave it at the default. What we'll change is the right, which has the aspect ratio in it. We could change the 1.33 to 1.6 in this case, but we can also tell POV-Ray to calculate the aspect ratio automatically. POV-Ray has its own built-in calculator that you can use when you give it numbers. The built-in calculator also has some default values that depend on your scene. It has, for example, values for the image_width and the image_height. We can use those. The aspect ratio will be the image_width divided by the image_height.

```
camera {
  location  <0, 2, -10>
  look_at   <0, 0, 0>
  right x*image_width/image_height
}
```

If you add that *right* line to your camera, you can experiment with rendering the scene in all sorts of shapes.

Try making a banner with a width of 700 pixels and a height of 100 pixels.





Once you've got the aspect ratio automatic, you don't need the width to be larger than the height. Switch the width and height around so that your banner is 100 pixels wide and 700 pixels tall, and you'll get a nice side-banner. Changing the aspect ratio is like reshaping the window on which you view the scene.

Take another look at those two banners. The wide one (700 by 100) shows the entire planet, tiny. The thin, tall one (100 by 700) shows only a portion of the planet, at about the same size as we've come to expect in our normal renderings.

The reason for the difference is that, in both cases, we are applying the aspect ratio change to the x, or right. When that change is large (700 divided by 100) we get a small image. When the change is tiny (100 divided by 700, we get a larger image.

If you want your vertical banner to show the entire planet in the same way it does in the horizontal banner, you can get that effect by applying the reverse change to the up, or y direction.

Remember that the default in POV-Ray is for *right* to be x*1.33 and for *up* to be y. If we choose to modify y instead of x, we have to tell POV-Ray to make *right* be just x.

```
camera {
location  <0, 2, -10>
look_at   <0, 0, 0>
//right x*image_width/image_height
right x
up y*image_height/image_width
}
```

Remember that when we put two slashes in front of a line, POV-Ray ignores that line. Look at the old *right* line and the new *up* line. What we're doing to y in the *up* line is the opposite of what we did to the x in the *right* line. Instead of image_width divided by image_height, it is image_height divided by image_width. This produces the same size for the objects in the image as in our horizontal banner.

Resolution

Let's talk a little about the *resolution* of your image. You might, for example, need a high-resolution image for printing on an 8.5 by 11 inch paper. Your computer screen usually displays 72 pixels per inch. So when we create a 640 by 480 pixel image, that ends up being about 8.8 inches by 6.7 inches *on the screen*.

Printers, however, usually require a much higher resolution. For an image to appear high quality on a printer, you'll need it to be 300 pixels per inch, or up to 600 pixels per inch for professional printing. For most basic purposes, *resolution* is the number of pixels per inch. The higher the resolution, the more pixels per inch.

This is where you need to pull out your computer's built-in calculator. If you want an 8.5 inch by 11 inch image and you want 300 pixels per inch, this will be 2,550 pixels wide and 3,300 pixels tall. That's 8.5 inches times 300 pixels, and 11 inches times 300 pixels.

Go to the Output pane and change width to 2550 and height to 3300. This will give you a huge, high-resolution image shaped for an 8.5 by 11 inch page.

This image will take a lot longer to render than our other examples. The larger you make the image, the longer it takes to render. This is a fairly simple scene and it has rendered nearly instantly for me at 640 by 480. At 2,550 pixels by 3,300 pixels it took almost a minute to render on my computer. When using rendering software, you will often need to be patient.

You will almost always want to render your test images at smaller sizes, and only do the full-size, high-resolution image when you are ready to wait.

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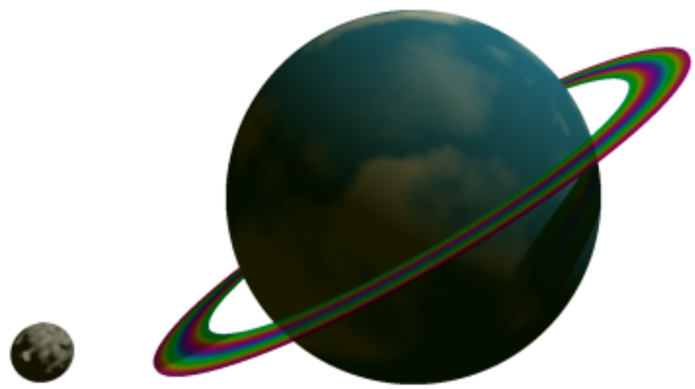

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