GemRay for Windows
User's Guide

by Robert W. Strickland

Version 1.0.0

The purpose of *GemRay* is to predict what a faceted gemstone will look like when it is cut and to optimize its angles for the best optical performance. *GemRay* renders images of faceted gemstones created by *GemCad* using the technique of ray tracing. *GemCad for Windows* is a computer-aided design program for faceted gemstones. You can find *GemCad* at www.gemcad.com. *GemCad* is concerned chiefly with the geometry of the gemstone. Its output is a faceting diagram with angles that you can use to cut the gemstone with a commercial faceting machine. *GemRay* is concerned with the optical performance of a gemstone and how the stone will appear when cut. *GemRay* runs under Microsoft Windows® XP or later.

Table of Contents

Acknowledgements

I am indebted to Bob Long and Norm Steele for their pioneering contributions to the field of computer-aided facet design. Bob helped me understand the physics of ray tracing and shared their source code for ray tracing.

I am also indebted to Bruce Harding for his system of quantifying the optical performance of a gemstone. His work "Faceting Limits," *Gems and Gemology,* 1975 was the first to document the importance of head shadow and made a profound impact when I first saw it.

GemRay is based in part on the work of the FLTK project, the Fast Light Toolkit, http://www.fltk.org. Many thanks to its designer, Bill Spitzak, and all that contribute to this

project. I am also indebted to Colin Jones for his Gleam scheme patch to FLTK that gives FLTK widgets a nicer look.

Many thanks also to Tom Herbst for his Windows BOG program www.boghome.com. BOG is a front-end to my DOS *GemRay* program. Much of the optimization in *GemRay* is based on Tom′s ideas. The popularity of BOG in the faceting community is a testament to his many contributions.

If you want to print this *User′s Guide,* I recommend using the Google Chrome web browser. Other browsers split the figures between pages or even cut them off at the bottom.

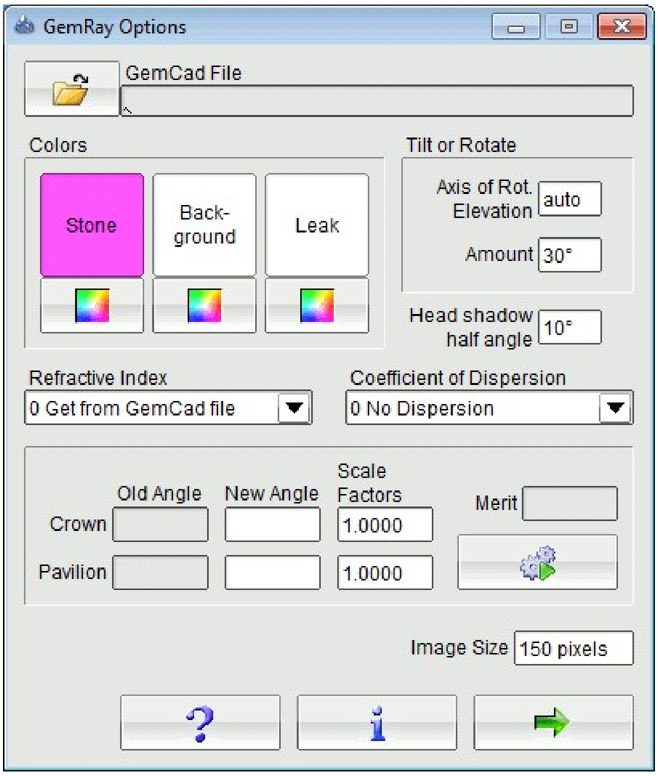
Ray Tracing Basics

Ray tracing is a technique of generating an image by following the paths of individual rays of light as they are refracted and reflected by objects. Light travels in straight lines. *GemRay* follows light rays backwards from the viewer′s eye through a pixel in the image plane and to the gemstone. When the ray hits the gemstone, part of the ray is reflected by the surface of the gemstone and part is refracted (bent) and continues inside the gemstone. The refracted ray travels inside the gemstone until it hits a second facet. This facet reflects all or part of the light ray back into the gemstone. If the ray is partially reflected, the remainder is refracted as it leaves the gemstone. The reflected ray continues until it hits a third facet, and the process repeats until its intensity dwindles to a small level. The software keeps track of the intensities, color and direction of every ray that exits the gemstone. The software combines all of the intensities of every split ray with the intensity of the light source in that direction and calculates a color value for that pixel.

Why trace light rays backwards? It is because many more light rays leave a light source than make it to the eye of the viewer. By tracing rays backwards through the stone *GemRay* only has to trace only the light rays that actually hit the viewer′s eye and the gemstone.

Unlike *GemRay* for DOS, *GemRay for Windows* models colored stones. It also models dispersion.

The *GemRay Options* Dialog



GemCad File:

Axis of Rot. Elevation: auto

Amount: 30°

Head shadow half angle: 10°

Refractive Index: 0 Get from GemCad file

Coefficient of Dispersion: 0 No Dispersion

	Old Angle	New Angle	Scale Factors
Crown			1.0000
Pavilion			1.0000

Image Size: 150 pixels

When you first run *GemRay*, it will display the *Options* dialog box. Typically, the first thing you will want to do is to press the *Open* 📂 button. This will bring up the standard Windows *File/Open* file chooser. After *GemRay* opens the file, it will fill in some of the fields. You will see the name of the file in the *GemCad File* box. Another way to open *GemRay* is to drag and drop a file onto *GemRay's* desktop icon.

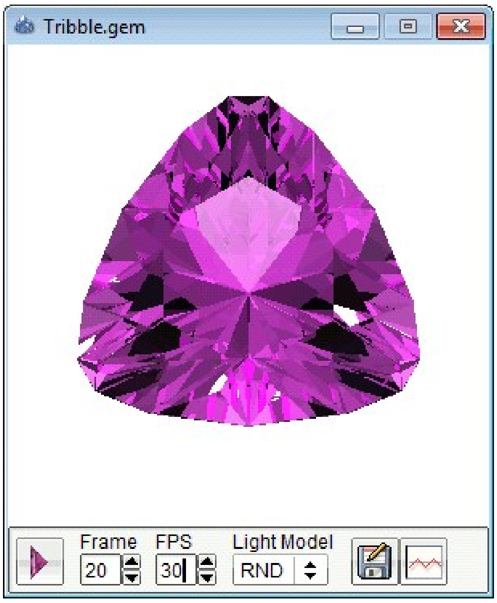
As you have already discovered, the ? button brings up this help file in your default web browser.

The i button pops up the *About* copyright and credit notice.

The *Image Size* is the size of the images *GemRay* renders. The size is in pixels and includes the background but not the Windows border. *GemRay* remembers this value. How big you should make this will depend on the speed of your computer.

After you set parameters, you can press the *Render* ➡ button.

The Animation Player



Frame: 20

FPS: 30

Light Model: RND

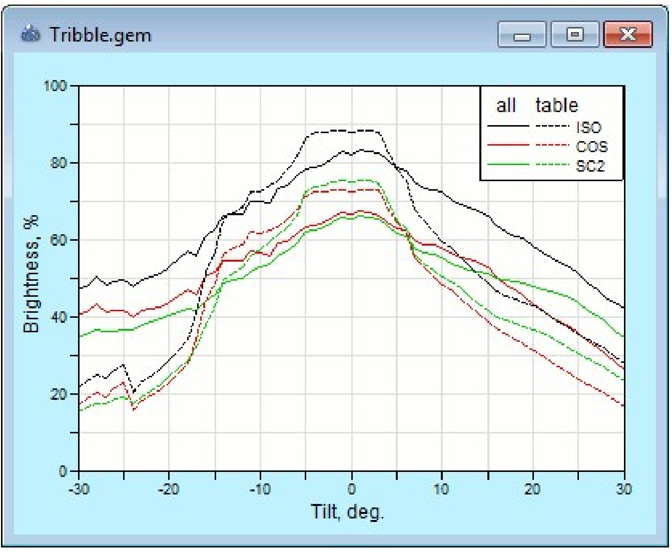
After you press the *Render* button, the *Options* dialog will hide itself, and *GemRay* will render a series of animation frames at the different tilt angles. If your computer has a multi-core processor, *GemRay* will render one frame in each core in parallel to speed up the calculation. While it renders the animation, you will see a progress bar. After *GemRay* finishes calculating the frames, it will play them back as an animation loop in its animation player. The player will automatically reverse to tilt the stone. (If your tilt amount was set to 180°, *GemRay* will play the animation as a seamless loop.)

At the bottom of the animation player are several controls. As you repeatedly press the *Pause/Play* button, its image will toggle between ⏸ and ▶ as the animation plays and pauses. You can change the speed with the control labeled *FPS,* frames per second. A larger number corresponds to a faster speed. You can use the up and down arrows to change the speed, or you can drag the mouse to select the text and type in a new number. You can use the *Light Model* control to select the lighting model (see below). When the animation is paused, you can select any single frame in the sequence. Tilt angle increment is one degree. Frame 0 is maximum tilt one direction and frame number equal to twice the tilt amount is the maximum tilt the other direction. Frame number equal to the tilt amount gives the face-up frame. You can use the arrows to increment the or decrement the frame number, or you can edit the number with the keyboard.

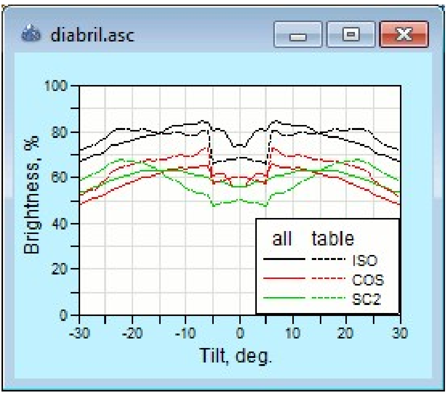
When the animation is paused, you can press the *Save As* button to save the current animation frame as a JPEG image file. *GemRay* will bring up the standard Windows *Save As* dialog to enter the file name. If you are preparing an image for publication or the web, you can use a trick to get a better-quality image. You can increase the image size by a factor of two or three. Then use an image processing program to scale the image down by 50% or 33%. This will reduce the "jaggies" and sharpen the image. There are also online image scaling services on the web that accomplish the same thing. Search the web for "image resize online" (without the quotes). The image at the right was made at a size of 900 pixels and scaled down to 300 pixels. Every pixel on the screen is an average of 9 pixels in the original image. Compare it to screen shot above, particularly the bottom edge of the stone.

When the animation is playing, the icon on the *Save As* button changes to . When you click it, you can save *all* of the animation files as individual JPEG files, one frame per file. *GemRay* will pop up the *Save As* dialog to prompt you for a file name. *GemRay* will take this file name, drop any extension and add an underscore, a three digit number and the `.jpg` extension. The number starts at 000 and goes to twice the *tilt amount*. For instance, if you enter `tribble` and the *tilt amount* is set to 10°, the files will be named `tribble_000.jpg` through `tribble_020.jpg`.

The *Graph* button will pop up a graph of brightness versus tilt angle. Here is an example for my Tribble design in quartz. The solid curves are for the whole stone outline, and the dashed lines are the brightness for the area outlined by the table facet. The angle range is chosen by the *Tilt Amount* parameter in the *Options* dialog. Note that for two-fold mirror-image symmetry and four-fold mirror-image symmetry, the negative tilt angles actually represent a different tilt direction than the positive tilt angles.



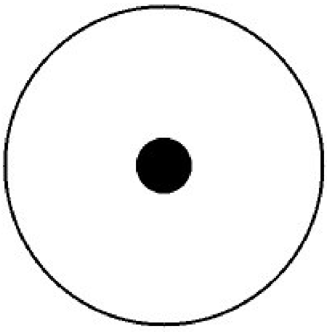
If you right click on the graph, *GemRay* will pop up a menu with two choices. The *Copy text* choice will copy the numerical values of brightness vs. tilt angle to the Windows clipboard. If you want to save this as a text file, you can paste it into Windows Notepad. The *Copy image* choice will copy the image window to the Windows clipboard. This has exactly the same effect as pressing `Alt-Print Screen`. You can then paste the image into a graphics program such as Windows Paint and save the image.



You can resize the graph. Here is an example of a graph of brightness for a standard round brilliant in diamond. I resized it before I copied it to the Windows clipboard with the right click and *Copy image* choice. Notice the dip from –5° to 5°. This is the cancellation of the surface reflection of the table facet due to the head shadow. The surface reflection is part of the brightness calculation. The table facet acts like a partially reflective mirror. When you tilt a mirror, the reflection moves through an angle twice the angle of tilt of the mirror. This is the reason why a 10° head shadow causes a dip at 5°. Notice also that the legend block repositions itself to try to avoid the curves.

You have to close the graph and the animation player to make the *Options* dialog reappear. Should you want to compare two graphs side-by-side, you can run two copies of *GemRay* and open the same design file. Leave one copy unchanged and do all of your editing on the other one.

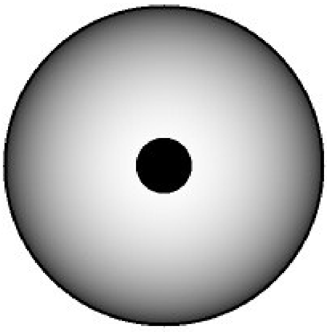
Lighting Models



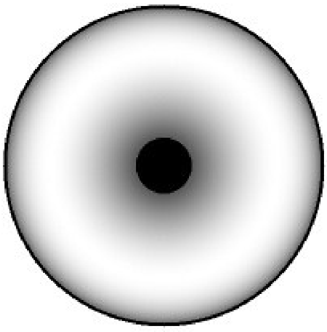
GemRay calculates images from several lighting models simultaneously. The best way to understand these models is to imagine that you are in a large dome-shaped room, like a planetarium. The stone is near the center of the spherical dome, and you are some distance above it. On the ceiling of the dome are projected various patterns of light and dark.

The simplest model to understand is the ISO model. ISO is short for isometric. Isometric means "equal measures." Light comes equally from everywhere on the dome. The black circle in the center is the head shadow. This is shared by all of the lighting models and is discussed below. The ISO model is similar to a room whose ceiling is completely covered with florescent light panels.

The next light model is the COS or cosine light model. Light intensity varies as the cosine of the elevation angle. It is completely dark on the horizon and white straight overhead (except for the head shadow disk) and smoothly varying between.

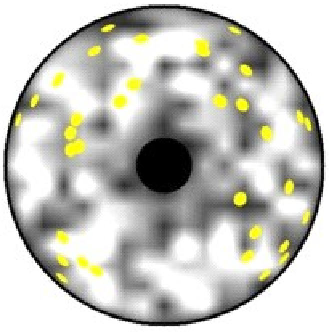


New in *GemRay for Windows* is the SC2 light model. SC2 stands for sine times cosine times two. It is white at a 45° elevation and black directly overhead and black on the horizon. It is sort of a fuzzy doughnut of light.



The ISO, COS, and SC2 light models don't allow any light from behind the stone, as if the room is carpeted with black carpet. In these three models, the stone is surrounded with a bezel that prevents any light from hitting the back of the gemstone. (What *GemRay* considers to be the "back" depends on how the stone is rotated.)

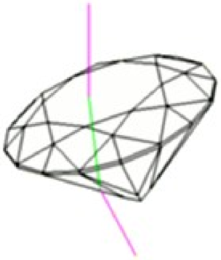
The RND light model is the random light model. It has a mottled pattern of light and dark on the dome. Like the SC2 model, it is darker above and towards the horizon. The mottled pattern makes it easier to see the scintillation of a gemstone.



The RND light model also has randomly distributed spotlights. These are many times brighter than the areas between the lights. These are shown schematically by the yellow dots. The lights are actually colorless white, not yellow. From the top view of the dome, they look like ellipses, but actually all are circular. The spotlights are all identical but randomly distributed. The spotlights are crucial for identifying dispersion. The spotlights also cause surface reflections on the facets as well as bright sparkling reflections in the body of the stone.

The RND lighting model is the only one that allows light to enter the back of the stone.

All of the lighting models allow you to select the color of the background. This is the color of the floor visible outside of the perimeter of the stone.

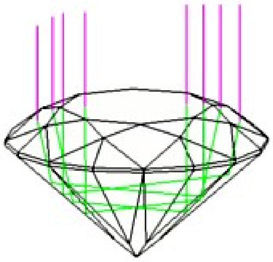


Most, if not all, faceted gemstones will window or "leak" as they are tilted. Windowing occurs when light rays enter the pavilion of the gemstone from the back and travel through the stone. The round brilliant pictured at the right shows one of these ray paths. Objects behind the gemstone can be seen from the front of the gemstone. As an aid to identify windowing, the RND light model has a separate color for light that enters the back of the stone from the floor and returns to the viewer. It is as if the stone is placed in a bezel, and the inside of the bezel mounting is painted with the windowing or "leak" color.

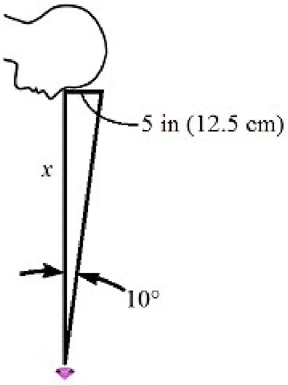
Head Shadow

All of the light models include a circular head shadow. *GemRay* lets you adjust the half-angle of this disk. The angle is measured down from the zenith to the perimeter of the circle. Head shadow is the reflection of the viewer's head in a gemstone. The word *shadow* is perhaps not the best word for the phenomenon. Certainly the viewer does cast a shadow on a gemstone. Whether this actually affects how the stone looks from the viewer's point of view depends on the optics of the gemstone. Only light rays that hit the viewer's eye that entered the stone nearly parallel to the viewer's line of sight can cause a head shadow. A well-designed gemstone has few such problem areas. With poorer designs, there are areas in the stone where the only place from which light could have come to your eye is from your own body. It is not as if you can see a reflection of yourself in the same way that you can identify your reflection in a mirror, rather it is more like looking at a picture of yourself in a kaleidoscope.

With an actual gemstone, you can often identify areas of head shadow with the following procedure. Hold the stone with one hand using tweezers or a stone grabber. Place your free hand just in front of your face and wiggle your fingers or wave your hand. If you see motion in the reflection pattern of the gemstone that is in sync with the movement of your fingers, you have located head shadow. Repeat with your fingers in front of your forehead and body.



The sources of the problem are light rays that leave a gemstone in a direction opposite but nearly parallel to the direction they entered the stone. Such rays have to come from near the viewer′s eye to be seen by the viewer′s eye. Consider a round brilliant in quartz, shown at right. Pretend your line of sight is looking down a light ray on the left side of the stone. From where did this light ray come? Since the rays on the right side of the stone are nearly parallel to the rays on the left side of the stone, the only place from which they could have come is your head!



GemRay′s black circle is an approximation to a disembodied head above the gemstone. *GemRay*′s head shadow half-angle is by default 10°. How significant is this? Well, how big is your head? My head is about 10 inches (25 cm) from chin to the top of my head, so let′s say it has a radius of 5 inches (12.5 cm). To what viewing distance does this correspond?

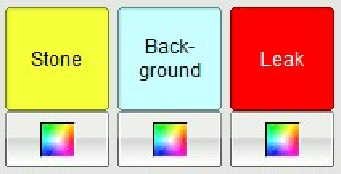
We can draw a right triangle with one leg 5 inches (12.5 cm) and the opposite angle of 10°. The gemstone is at the tip of the triangle. How long is the other leg of the right triangle labeled *x*? If you do the trig, you′ll discover it′s about 29 inches (74 cm). I got out my yardstick, and I can′t comfortably hold a gemstone 29 inches from my eye. If the ratio of your head height to arm length is about the same as mine, you can assume that a 10° head shadow is about as far from your eye as you can hold a stone with arm outstretched. Closer viewing distance means bigger head shadow half-angle.

Head shadow is too important to be ignored, and *GemRay*′s default 10° shadow is not very large. If you still don′t believe in the head shadow effect, you can set the head shadow half-angle to zero, and *GemRay* will leave out the head shadow in all of the models.

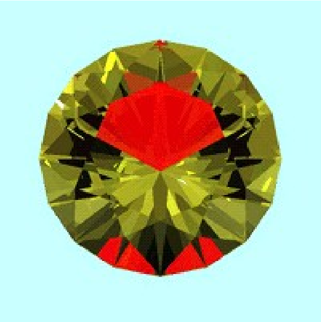
Head shadows are common with lower refractive index materials in designs with conical pavilions. A triangular pyramidal pavilion can eliminate head shadow *and* give a better tilt performance.

Sometimes head shadow is used as a visual effect in gemstone design. The star in the Lone Star cut is cut at 45° and makes a head shadow. A Portuguese cut has concentric rings of head shadow that are visually appealing.

Colors

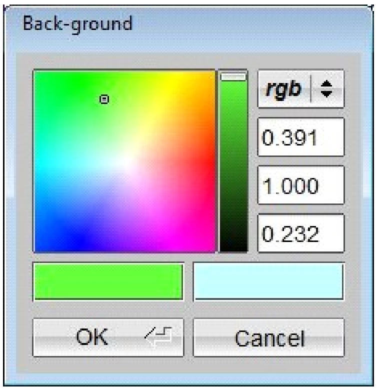


GemRay allows you to choose three different colors: the *Stone* color, the *Background* color and the *Leak* color. Consider the rather ugly combination of colors at the right. The body of the stone is yellow. The background outside of the stone is a pale blue. The leak color is bright red.



Here is the result of these color choices with a stone tilted to the north. The red areas are places where the stone windows or "leaks." The *Leak* color only applies to the RND light model. The leaks will be shown in black in the other lighting models. The black areas are where there is a head shadow. The primary purpose of the *Leak* color is to identify where the stone windows and clearly distinguish these from reflections of the head shadow. Note that there is still some detail visible in the red areas. These are partial internal reflections.

The stone color you chose is close to the final color of the gemstone after it is faceted. It will usually be darker than the color of a stone when viewed with a white card behind it. The color you pick is translated into three absorption coefficients for the three primary colors of light. Light decays exponentially inside a gemstone. If a ray travels twice the distance through a stone, it will decay twice as much.



Back-ground

rgb

0.391

1.000

0.232

GemRay's color chooser is part of the FLTK toolkit. The color in the left box is the new color you are editing. The box on the left contains the previous color. You can drag the little dot around the map to choose a color. You can also drag the individual red, green, and blue numbers with the mouse by clicking in a number box, holding down the mouse button and dragging left and right. The chooser uses the HSV model that allows you to select the *hue, saturation* and *value* of the color. The little dot controls the hue (angle) and saturation (distance from the center). The vertical slider controls the *value* of the color. A value of zero for the value is black for any hue or saturation. To get shades of brown, move the dot to the orange sector and move the value slider down. To get white (clear stone or white background) click near the center and then individually drag the numbers until they are all 1.000. There is no easy way to save a color. You can copy and paste the individual red, green, and blue numbers to an external file.

The spinner at the top allows you to choose how the color is displayed numerically. A color is still selected exactly the same way, but its numerical values are displayed differently. The default *rgb* setting allows you to specify the numerical proportion for the red, green and blue components from zero to one. The *hex* setting is similar, but the numbers are displayed in hexadecimal from 00 to FF corresponding to 0 to 255. The hex values can be used to match a color used in other programs. The *hsv* setting display shows the hue, saturation and value directly.

Angles

GemRay can scale the pavilion and crown independently. You can enter either a *Scale Factor* or a *New Angle*. The scale factors and the angles are linked: if you enter or change a scale factor, *GemRay* will change the corresponding *New* angle. If you change the *New* angle, *GemRay* will change the corresponding scale factor. The scale factor is the ratio of the tangents of the angles

scale factor = tan(new angle) / tan(old angle)

The *Old* angle is the angle of a key facet. But which angle? There are lots of them! *GemRay* automatically chooses a *key* facet for the pavilion and the crown using simple rules. It displays these as the *Old* angles. For the pavilion, *GemRay* chooses the facet with the lowest elevation angle (but not the culet facet). This is often the angle of one of the facets at the point of the bottom of the stone. For the crown, *GemRay* chooses the facet with the largest area as viewed from above (but not the table facet).

For many designs, you can figure out easily which facets *GemRay* picks for the key facets. For others the process is not so easy. After *GemRay* optimizes the angles, you need a way to edit the table of angles. To do this, you need to use the process of *tangent ratio* scaling. To do this manually with a calculator, you take the tangent of the angle, multiply it by the scale factor and then take the inverse tangent (arctan).

Transferring the Angles to GemCad

There are three ways to transfer the angle information from *GemRay* to *GemCad*. The first is the most natural way *if* you can visually identify which facet *GemRay* selected to be the key facet. Click in the key facet to bring up the Facet dialog box. Double check that the angle in *GemCad*'s *New angle* box matches the angle in *GemRay*'s *Old angle* box. Type in (or paste in) *GemRay*'s new angle and press the *Apply* button.

The second way is to locate the key facet angle in the *Cutting Instructions* view and click on that line. In the dialog box that pops up, you can then type (or paste) in the new angle in the *New Angle box* and click the *Apply Edit* button.

If you cannot figure out which facet is the key facet, there is an alternative method that will *always* work. It takes a few more steps, but it's a turn-the-crank procedure that doesn't require you to find the key facet. To scale the crown, in *GemCad*, do

Edit → Scale → Z

Type (or paste) the crown scale factor in the *Numerator* box. Leave the default value of one in the *Denominator* box. Press the *OK* button. If *GemCad* asks you about rounding indices, click the *No* button.

For the pavilion, repeat the above steps with

Edit → Scale → –Z

and new pavilion angle in the *Numerator* box and leave a value of one in the *Denominator* box.

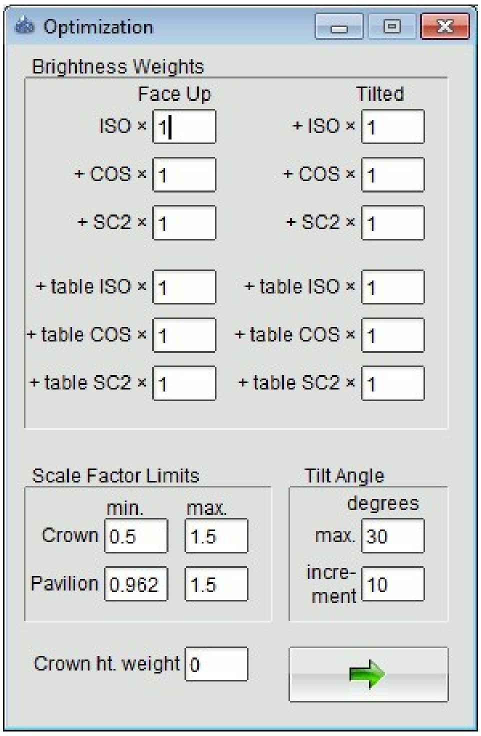
How to copy and paste from *GemRay* to *GemCad*? Click in a text entry box. Do `ctrl-A` (or drag the mouse) to select the text. Then do `ctrl-C` to copy the text to the Windows clipboard. Then go to *GemCad*, click in a text entry box, do `ctrl-A` (or drag the mouse) to select what is there and do `ctrl-V` to paste over it. These steps work with just about any Windows application.

Optimization

GemRay can automatically choose the angles to optimize the optical performance of a gemstone. *GemRay* uses an algorithm called the Downhill Simplex Method to find the “best” angles. This method also called Nelder-Mead method, after its discoverers. Sometimes it’s called the Amoeba method. The Siplex method searches for a minimum of a function of several variables. We want a maximum instead of a minimum, but the problem is mathematically equivalent, since you can just take the reciprocal of the objective function. Let’s call the function to be maximized the *merit* function and the function to be minimized the *objective* function. Our merit function is just a weighted average of the brightness percentages from the different lighting models at different tilt angles.

Our problem has two dimensions: the pavilion and crown scale factors. For our two-dimensional problem, the simplex of the Downhill Simplex Method is just a triangle. The method starts off with a small right triangle with the right angle vertex on the pavilion and crown scale factors you have entered. For the other two vertices, it just offsets a small amount in pavilion and crown scale factors. *GemRay* calculates the relative merits of the three vertices. Using the relative heights of the three vertices it uses a simple set of rules to transform or move the triangle to find a new triangle that is nearer the minimum. It might move one or all of the vertices. For each new point, the method calculates the objective function. From the relative heights of the objective function, it decides how to transform the triangle for the next step. The process repeats until, at the final stage, the triangle shrinks to a single point at the minimum.

When you press the *Optimize* button, *GemRay* will pop up the *Optimization* dialog so you can select the values that control the optimization. The *Tilt Angle* maximum and increment set the maximum tilt for the optimization. At the default setting of 30 for the maximum and 10 for the increment, *GemRay* will tilt the stone −30°, −20°, −10°, 0, 10°, 20°, and 30° and calculate a small 100 pixel image for each tilt angle. The brightness values are then multiplied by the weight factors in the upper portion of the dialog.


Optimization

Brightness Weights

Face Up		Tilted	
ISO ×	1	+ ISO ×	1
+ COS ×	1	+ COS ×	1
+ SC2 ×	1	+ SC2 ×	1
+ table ISO ×	1	+ table ISO ×	1
+ table COS ×	1	+ table COS ×	1
+ table SC2 ×	1	+ table SC2 ×	1

Scale Factor Limits

	min.	max.
Crown	0.5	1.5
Pavilion	0.962	1.5

Tilt Angle

	degrees
max.	30
incre-ment	10

Crown ht. weight 0

With the default settings, the optimization gives a great deal of weight to tilt performance since there are six tilted images and only one face-up image. For this reason, you might want to increase the weight value for one or more of the face-up brightnesses. When you make changes in the weights, make *big* changes, say a factor of 5 or 10. A 10% change in one of the weights is unlikely to change the outcome. Another trick is to change one of the weights to 1000 to optimize for just that parameter. This is quicker than zeroing out the other weights. The weights are relative weights, so if you double all of the weights, the optimizer will converge on exactly the same answer, and the same merit value will be displayed.

It is important to note that the tilt angle in the optimization is separate from the tilt amount in the main *GemRay Options* dialog. The tilt direction however is the same and is chosen automatically based on the symmetry of the design. If you want to ignore the tilt performance in favor of the face-up performance, the simplest way is to set the *Tilt Angle max.* to zero.

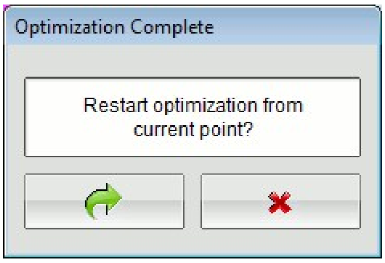
Tilt				Table	Table	Table
Ang.	ISO	COS	SC2	ISO	COS	SC2
–30°	47.5	40.7	34.8	21.6	17.2	15.5
–20°	52.6	43.2	40.0	28.7	23.1	24.5
–10°	69.5	56.3	52.6	73.3	62.2	57.8
0°	81.2	66.1	65.0	87.1	71.9	74.4
10°	72.3	58.0	55.3	59.0	47.9	49.9
20°	58.5	43.2	47.6	42.8	30.9	36.4
30°	42.2	26.6	35.0	27.6	16.2	22.8

Consider the table of brightness value percentages vs. tilt angle for the Tribble design in the table at the right. (You can compare these numerical values with the brightness vs. tilt graph for the Tribble above.) Note that the maximum tilt is 30° and the tilt increment is 10°, so the table has seven rows. How does *GemRay* calculate the relative merit from these values? For the 0° center row of the table, it uses the weights in the left column labeled *Face Up*. It multiplies the top *ISO* weight by the number in the first column labeled *ISO*. To that it adds the product of the *COS* weight times the *COS* brightness. To that it adds the product of the next weight down the *Face Up* column times the next brightness value from the next column to the right. It continues the process until it finishes the 0° row. Then it repeats the process for each tilt angle using the weights in the right column labeled *Tilted*. To that total it adds the product of the *Crown height weight* times the tangent of the crown angle times 100%. Next it divides the grand total by the sum of all the weights used in the above tally. The result is a number that has to be less than 100% and is the weighted average brightness. Note that if you double all the weights, the result is exactly the same since the grand total is divided by the sum of the weights. The weighted average is the *Merit* value for this design. For this example with the weights above and the brightnesses in the table, the merit has a value of 42.1%. Since the weights are all one, this is just the mean of all the brightness values in the table.

GemRay doesn't know anything about aesthetics of design or the economics of yield. Sometimes it will want to lower the crown more that you might like. To prevent this, you can change the value of the *Crown Height Weight* from its default value of zero. A reasonable starting value is 10. *GemRay* uses the tangent of the crown key facet angle times 100% as the crown height merit. A crown angle of 45° is capped at a perfect 100%. This makes crown height part of the merit function. Another way to prevent *GemRay* from lowering the crown is to raise the minimum crown scale factor limit from its default value to 0.8 or even 1.0. If the design has a table facet, the pavilion scale factor limit defaults to the scale factor that corresponds to a minimum pavilion angle of 0.5° above the critical angle. If the design does not have a table facet, its minimum limit is set to 0.5.

The achilles heel of any minimization method is the presence of local minima. If we roll a marble down a slope, the marble can come to rest in a hole, but there is no guarantee that it will come to rest in the deepest hole. The results you get can often depend on the starting point you enter.

After *GemRay* finishes the optimization, it is often a good idea to restart the optimization from the best answer that it just found. Sometimes there is a slight minimum near a better one. When you restart, it will leave one vertex on the previous minimum and enlarge the triangle again. Sometimes this will allow the method to dislodge from a local minimum and find a better answer. When *GemRay* finishes with the optimization, it will pop up the dialog titled *Optimization Complete.* This serves as a visual cue that the optimization is complete and gives you a chance to restart the optimization from the current best combination of angles. The *Cancel* ✖ button simply dismisses the dialog. The *Restart* ↪ button restarts the optimization. Often, you will want to restart several times until *GemRay* no longer changes the angles.


Optimization Complete

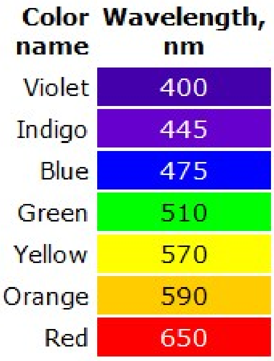
Restart optimization from current point?

After *GemRay* optimizes the angles, you may transfer the angles to *GemCad*.

Refractive Index and Dispersion

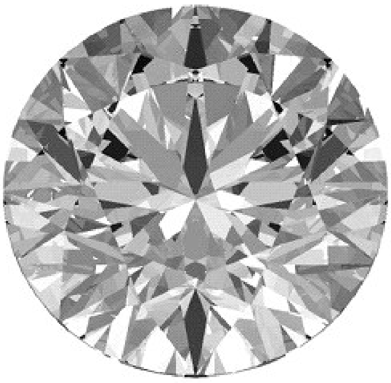
The refractive index is a measure of the speed of light in a gemstone as compared to the speed of light in a vacuum. The higher the refractive index, the slower light travels in the material. Gemology texts give the refractive index at a specific wavelength, the yellow-orange 589.3 nm *D* line of the sodium spectrum. This is the predominant color of low-pressure sodium lights. This is near the peak in our eye's sensitivity to light.

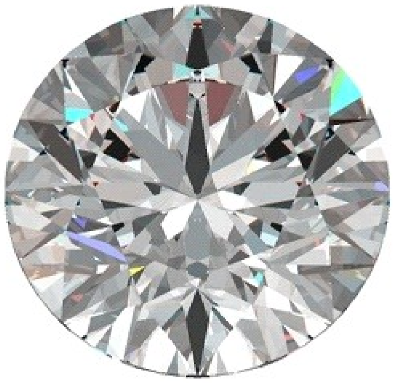
Dispersion is the splitting of white light into its component colors by a gemstone. There are two types of dispersion in gemstones: the dispersion of diffraction and the dispersion of refraction. Diffraction is what gives fire opals, DVDs and iridescent feathers their colors. It is caused by repeated features spaced on the order of a wavelength of light. In transparent materials we commonly facet, we are usually more concerned with dispersion due to refraction, and that is what *GemRay* models. A gemstone that is dispersive has a refractive index that varies with the wavelength (color) of light. Refraction and dispersion only happens when light hits a facet at an angle. Light rays that hit perpendicular to a facet are neither refracted nor dispersed.



Color name	Wavelength, nm
Violet	400
Indigo	445
Blue	475
Green	510
Yellow	570
Orange	590
Red	650

The colors of the visible spectrum and their approximate wavelengths are given in the table at the right. Gemology textbooks define dispersion as the *difference* in refractive index at two specific wavelengths, the blue 430.8 nm *G* line of iron and the red 687.0 nm *B* line of oxygen. This is commonly called the *G-B* dispersion, or just *d*. It is a direct measure of how much a material can split light into colors. So how does *GemRay* calculate the refractive index for each color? The refractive index at optical frequencies varies linearly with the inverse square of the wavelength. From the refractive index at the sodium *D* line and the *G-B* dispersion, *GemRay* can calculate the refractive index for any wavelength (color) of light.



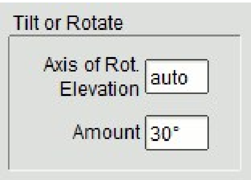


When modeling dispersive materials, *GemRay* follows the paths of three different colors of light rays. The specific colors that *GemRay* uses are red 650 nm, green 510 nm and blue 475 nm. When modeling gemstones without dispersion, *GemRay* still keeps track of the intensities of three colors, but all three sets of rays follow exactly the same path through the stone. If the dispersion is set to zero, the brightness calculations are done at the refractive index for the *D* yellow-orange sodium wavelength. If dispersion is not zero, the brightness calculations for the optimization and graph are calculated at the refractive index for red light. If dispersion is not zero, it takes *GemRay* about three times longer to calculate the images. The images at the right are diamonds rendered without and with dispersion. You might note on the green patch that there is a distinct line of transition from cyan to green. Since *GemRay* only follows three different colors of light, the spectrum of light is limited to the primary and secondary colors.

If you select a material from the common materials in the refractive index list, *GemRay* will automatically select the corresponding dispersion for the material. When *GemRay* reads a *GemCad* file, the refractive index is read from the file (set by *GemCad's Raytrace->Properties* command), and the dispersion is set to zero. (The *GemCad* file does not store the dispersion.) You can then pick material from the dropdown list, and *GemCad* will set the corresponding value of the dispersion. If the material has low dispersion or is a material that is commonly strongly colored, *GemRay* will set the dispersion to zero. Dispersion in these materials makes little difference, so *GemRay* sets the dispersion to zero to speed up the calculation by a factor of three.

You are not limited to the values in the short dropdown lists. These combo boxes allow you to type in values not present in the list. To do this, highlight the value in the box by dragging with the mouse (or do `ctrl-A`) and type in the value you want. In this way you could, for example, model corundum with its actual value of dispersion, 0.018. *GemRay's* table of dispersions sets the dispersion to zero if the actual dispersion is less than 0.020.

Tilt and Rotation



Tilt or Rotate

Axis of Rot. Elevation: auto

Amount: 30°

GemRay lets you adjust two parameters that determine how it rotates the stone. One parameter, the tilt axis *Elevation,* controls which direction the tilt axis points. The other parameter, the tilt *Amount,* controls how far the stone is rotated about this axis.

If you enter 0 in the *Tilt Elevation* box, *GemRay* will use the *auto* setting and tilt the stone based on the axis of symmetry. This is the default setting for the *Tilt Elevation.* In the *auto* mode, stones with no symmetry or 1-fold mirror are tilted north and south. Stones with 2-fold mirror symmetry (emeralds, ovals, marquises, etc.) are tilted towards the north and east. Stones with a multiple of 4-fold, mirror image, symmetry are tilted towards the north and southeast. In all three symmetry cases, the axis of rotation remains on the *x-y* plane.

You can set the tilt *Elevation* to an angle larger than zero to rotate the stone about a different axis. The most common setting is 45°, although you can choose any angle up to 90°. Imagine that while looking down on the gemstone, we spear it with a skewer that lies somewhere on the *y-z* plane. The skewer passes through the center of the stone. The tilt elevation controls the angle of the skewer in relation to the gemstone. A small elevation sets the skewer so that it is parallel to the table and skewers the stone through its center with the skewer pointing toward the bottom of the screen. An elevation of 90° skewers the stone straight down through the center along our line of sight perpendicular to the table. The skewer then rotates about its axis to rotate the stone. The tilt amount controls the rotation angle of the skewer about its axis.

A tilt elevation of 45° and rotation amount of 180° gives the illusion of the stone resting at the center of a spinning turntable. The result is similar to the image at the right, but the animation is much smoother. The viewer's eye is also at an elevation of 45°, so the line of sight is perpendicular to the table when the stone faces the viewer.

Tutorials

I will occasionally post tutorial videos on YouTube about using *GemCad* and *GemRay*. Go there and type *GemCad tutorial* or *GemRay tutorial* in the search box, or just click here for *GemCad* or here for *GemRay* .

Bugs

GemRay will get confused if it tries to tangent-ratio scale a design whose girdle line zig-zags. In such designs, the bottom of the crown extends below the level of top of the pavilion. It won't complain, but the images it generates may not be accurate. Any tangent ratio scaling should be treated with great suspicion. The only real work-around is to do the scaling in *GemCad*, do an Edit→ReGenerate and then make sure the girdle facets are still there. Then save the design and open it with *GemRay*

Table of Contents