Diamond Appearance: The Components of a Computer Model

By Barak Green, Mary Johnson, Ilene Reinitz, and James Shigley

There has been a tremendous increase in the application of computer modeling to complicated, real-world problems in the last few decades. As the processing power of computers has grown, so has our ability to mimic, and experiment with, a wide variety of real-life situations. These include weather patterns, financial markets, and biological processes such as cell growth or the spread of viruses in populations. Computer modeling allows researchers to experiment in areas, and with materials, that normally would be impossible to explore. This has been especially true in our research on diamond cut. Gem-quality diamonds are, by their nature, rare and costly. It would be prohibitively expensive — not to mention extremely difficult — to acquire or manufacture the hundreds of thousands of diamonds with specific proportion sets that we have examined in our desire to fully understand the effects that a diamond's cut has on its appearance. In this article, we will explore the components that are essential when using computer modeling, and more specifically computer ray tracing, for the scientific examination of diamond appearance.

Executive Summary:

- Computer modeling mimics the properties and behaviors of objects and their interactions with the environment.
- Diamond ray tracing has a long history, and has become more powerful with the use of computers to understand the interaction of light with a polished diamond.
- To understand how a diamond's proportions affect its appearance, we need to model the diamond, the environment (including lighting), and the observer.
- Metrics can be employed both to define the properties of the various components in the model (such as whether the observer views the diamond from a single location or many locations), and to provide a quantifiable (often numerical) result that can be used for comparison and analysis.
- Computer modeling must always be checked by real-world verification; this includes the precision of the model, the accuracy of the match between the model and the situation that is being examined, and the level at which fine points of distinction in the model are perceptible or meaningful in the real world.

HISTORY

Computer modeling allows us to explore and analyze the effect of hundreds of thousands of proportion sets on the appearance of a round brilliant cut (RBC) diamond. When a computer program models an object and its environment, it re-creates the properties and characteristics of that object, along with the key factors in its interaction with specified aspects of its environment. When this is done properly, the modeled object and environment act as they do in real life. For example, a computer could model the flight of a rock that was thrown into the air, by modeling the weight of the rock, the volume of the rock, the force with which the rock was thrown, the direction in which it was thrown, the air pressure, and the gravity of the Earth. In this way, the computer would be able to predict where the rock would land, and how long it would take to get there. In a similar way, researchers are able to model the geometric and optical properties of an RBC diamond, along with any light rays that strike that diamond. In this instance, we refer to the diamond as a modeled (or "virtual") diamond, and the light as modeled (or "virtual") light.

The history of modeling diamond optics — and more specifically, diamond ray tracing, which refers to the modeling of light rays as they travel through a polished diamond — began long before the invention of the modern computer. Max Bauer published examples of early drafted diamond ray tracing in his 1904 book *Precious Stones*. Over the next several decades, further examples of ray tracing were published in articles and books (see reference section at end of article). Perhaps the most famous example of early diamond ray tracing is that found in Marcel Tolkowsky's *Diamond Design*, published in 1919. Tolkowsky was one of the first to combine mathematical ray tracing within the field of optics, with examples of ray tracing specifically geared toward round brilliant diamonds. His work set the standard for modern diamond cutting throughout most of the century.

In 1989, researchers at GIA began to examine the effectiveness of computer ray tracing in the study of diamond cut and appearance. The increasing efficiency of computers and the advent of graphic software programs allowed us to model RBC diamonds in ways that were visually more realistic and accurate than any method used before[1].

Our first step was to model an RBC diamond so that the "virtual" diamond had many of the same attributes and properties as a real diamond. In 1991, we presented this virtual diamond at the Second Annual GIA International Gemological Symposium in Los Angeles (Manson, 1992). Our next step was to expand our proprietary computer model to include other variables, such as different lighting environments, and different observer positions. We published the results from the first part of this research, which dealt with the effects of proportions on brilliance in 1998 (Hemphill et al.). The most recent article on our findings, which explores the effect of proportions on the appearance aspect of fire, was published this October (Reinitz et al., 2001).

THE COMPONENTS OF COMPUTER MODELING

Computers allow the detailed modeling of diamonds and their environment by calculating the complex interactions between variables that occur when light interacts with diamond. However, a computer can accomplish this only after the essential components-such as diamond proportions and the laws of optics-have been programmed into its software.

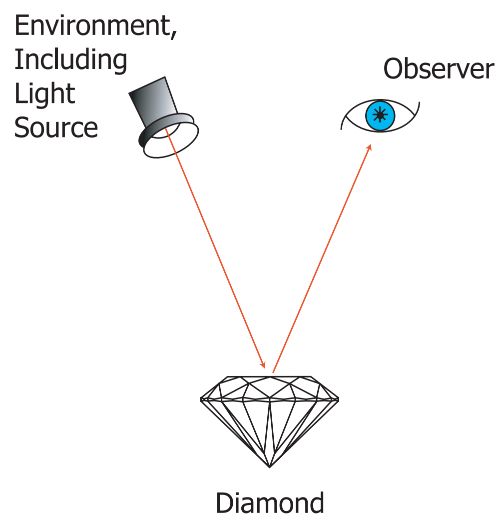

Figure 1. Three main components — the diamond, the environment (including light sources), and the observer — must be included in any accurate computer model of diamond appearance.

The first step in this process is to separate components into larger groups and then define the specific attributes of each component in that group. Diamond appearance relies primarily on the interaction of three main groups: the diamond, the environment (especially lighting), and the observer (figure 1).

Each must be modeled to explore how a diamond's proportions affect its appearance. Also, it is important to verify at each step throughout the research project that the computer model is accurately reproducing reality.

Diamonds. Since diamonds are the main focus of our study, we decided to model their attributes first. We identified two main categories that needed to be considered in order to model a virtual diamond for the purpose of this research. The first category encompasses all the properties of diamond *as a material*. This includes properties such as diamond's refractive index (which determines its external and internal reflectance), its critical angle (which determines when light can "escape" from a diamond), and the amount that diamond refracts different wavelengths of light.

The second category includes the characteristics of each individual diamond, such as color and clarity. Each diamond's *cut proportions* also needed to be considered. These include facet lengths and facet angles (which make up most proportion information), along with the diamond's symmetry and the condition of its polish[2]. Other attributes in this category are a diamond's shape and cutting style. So far, we have limited our research to a virtual diamond that is colorless and flawless, and mimics the shape and cutting style of a round brilliant (with the standard 58-facet arrangement, counting the culet)[3].

Environment and Lighting. Everything that surrounds a diamond (the light source, the observer, the color of the observer's clothing, shadows, dark bookshelves, etc.) is considered part of its environment. Lighting is the most important factor. The interaction of different types of light with a diamond is another main focus of our research. There are two important lighting categories that need to be considered when modeling diamond appearance: *the properties of light* itself, and the particular *lighting environment* (which includes lighting types and other environmental factors) that we are interested in studying. Remember that each ray of light has its own wavelength, direction of travel, and intensity (or amplitude; see "Diamond Optics: Part 2").

Each of these must be included in the computer model, along with the associated optical behavior. Each light ray also has its own polarization state, which affects how that light ray behaves in a diamond. Computer modeling allows us to track each individual light ray as it travels through the virtual diamond, adjusting its direction, polarization state, and amplitude. In addition, computer modeling allows us to calculate these rays in *all three dimensions*, rather than in only the two dimensions to which hand-drafted ray tracing on paper is restricted. Often, millions of light rays are traced for each set of diamond proportions we model. This would be extremely time-consuming — if even possible — if we were forced to do all of the calculations "by hand."

The type of lighting that is modeled as part of a diamond's environment (e.g., diffuse, directed, fluorescent, incandescent, daylight) has a critical effect on the results of the computer ray tracing. For example, diffuse lighting — that is, even and non-directional lighting, such as that usually seen in office buildings or outside on an overcast day — brings out the brightness of a diamond, but offsets the spread (dispersion) of wavelengths that cause the appearance of fire. Yet, directional lighting — such as that from candlelight or a spotlight — accentuates the spread of wavelengths, thereby strengthening the appearance of fire. The advantage of computer modeling is that we can control these lighting environments in very exact ways to study the effect that each type will have on the appearance of a diamond cut to a specific set of proportions.

In addition to lighting, there are several other aspects of the environment that need to be considered when modeling diamond appearance. These mostly have to do with objects in the environment (e.g., bookshelves, the observer, clothing color) that potentially can affect the quality of the light that interacts with the diamond. Through *observer effect*, we attempt to model all those ways in which an observer might block or otherwise affect the light that is entering the diamond. Because most diamonds are relatively small, and most observers by comparison are relatively large, the person viewing the diamond can strongly affect the lighting environment. For example, the observer's head and shoulders sometimes might block part of the light that is entering the diamond. Another effect that might be just as important occurs when most of the surrounding environment is dark and the only light that strikes the diamond is being reflected off the observer. This, in effect, turns the observer into an indirect light source. The color of an observer's clothing, along with other objects in the diamond's immediate vicinity, also potentially can affect the appearance of the diamond. With detailed computer modeling, all of these components can be factored in to better understand how they help determine diamond appearance.

The Observer. The third group of components consists of everything related to how the light that exits the diamond is *detected* by an observer. This aspect of diamond appearance may be the most difficult to model accurately. This is because it involves the human visual system, which is much more complex than mechanical detectors, such as photometers. The components related to the observer can also be broken into two categories: observer position and observer thresholds.

When we model *observer position*, we attempt to mimic the location from which the person looks at the diamond. Specifically, we model whether the person will be viewing the diamond from directly overhead or from an angle (also called a tilted view). For example, if we were modeling an overhead observer, we would count only those light rays that exit straight out of the diamond crown (i.e., those rays that exit in a direction perpendicular to the diamond table). Similarly, we can choose to count only those light rays that exit at particular angles from the crown. We chose to ignore all light rays that exit through the pavilion, since an observer is very rarely looking at a mounted diamond from its back.

If several observer positions are being modeled, it is helpful to *weight the light return* so that it takes into account these positions at the same time. An example of this might be if we were to give all light rays exiting directly up from the crown (and therefore presumably toward the observer) a certain weight in the overall computed value, while giving all other light rays that exit the crown at other angles a lower weight (i.e., less value). This allows us to examine how the diamond might look to the direct observer, as well as to those observers who are looking at it from the side.

The question of *observer thresholds* (i.e., the acuity of human vision) is extremely difficult to answer. As previously stated, this is because the human visual system is much more complex than any mechanical detector (such as a photometer). There are many aspects of human vision, especially in relation to its ability to process aspects of visual appearance in diamonds, that still need to be explored. One area that we have attempted to model is the ability of the eye to see appearance aspects above and below certain threshold levels. With regard to our research on fire, for example, we had to determine at what levels the human eye can discern colored light (as well as changes in colored light).

To arrive at a threshold level for our fire model, we asked individuals to compare actual patterns of fire with computer generated fire-patterns (set at various threshold levels) from diamonds with the same proportions (see Reinitz et al., 2001).

METRICS: THE END RESULT

Once an accurate computer model is developed, the next stage is to use it to create a useful end product, such as a number that can be compared when different variables are changed in the model. When researching the effects of diamond proportions on the appearance aspects of brilliance and fire, we developed two measurement standards (or metrics) that provided numerical results we could use for analysis. Each metric incorporates the components that will be held constant as well those that can be varied (the variables). For example, in our brilliance study, our WLR (weighted light return) metric incorporates a constant lighting environment and weighted observer positions, while it varies the different proportions of the virtual diamond.

CONCLUSION

Because computers can efficiently and accurately calculate millions of light rays through thousands of diamond proportion sets, they allow much more latitude in diamond cut research. Computer modeling-incorporating components of diamond, environment, lighting, and observer properties — allows us to explore a wider variety of proportion possibilities than ever before.

We hope that you found this article useful, and invite any feedback or comments that you may have. You may contact us by e-mail at DiamondCut@gia.edu. ■

Originally published: September 27, 2002
GIA on Diamond Cut

Bibliography

Bauer M. (1904) *Precious Stones*. Charles Griffin and Company, Ltd., London, 647 pp.

Hemphill T.S., Reinitz I.M., Johnson M.L., Shigley J.E. (1998) Modeling the appearance of the round brilliant cut diamond: An analysis of brilliance. *Gems & Gemology*, Vol. 34, No. 3, pp. 158-183; available through subscription services at 760-603-4595 ext. 7142, or at https://www.gia.edu/gandg/ggOrderform/ggOrderform.cfm.

Manson D. (1992) Proportion considerations in round brilliant diamonds. *Proceedings of the International Gemological Symposium 1991 – Facing the Future*, Gemological Institute of America, Santa Monica, CA, p. 60.

Reinitz I.M., Johnson M.L., Hemphill T.S., Gilbertson A.M., Geurts R.H., Green B.G., Shigley J.E. (2001) Modeling the appearance of the round brilliant cut diamond: An analysis of fire, and more about brilliance. *Gems & Gemology*, Vol. 37, No. 3, pp. 174-197; available through subscription services at 760-603-4595 ext. 7142, or at https://www.gia.edu/gandg/ggOrderform/ggOrderform.cfm.

Tolkowsky M. (1919a) *Diamond Design*. Spon & Chamberlain, New York, 104 pp.

Previous Examples of Ray Tracing

Astric B., Merigoux H., Zecchini P. (1992) Etude de la variation de l'aspect de pierres taillées à l'aide d'images de synthèse. *La Gemmologia*, Vol. 17, No. 1, pp. 7-31.

Bauer M. (1904) *Precious Stones*. Charles Griffin and Company, Ltd., London, 647 pp.

Chester C. (1910) *The Science of Diamonds*. Chester & Bergman, Chicago, 56 pp.

Dodson J. (1979) The statistic brilliance, sparkliness and fire of the round brilliant-cut diamond. *Diamond Research*, pp. 13-17.

Tognoni C. (1990) An automatic procedure for computing the optimal cut proportions of gems. *La Gemmologia*, Vol. 25, No. 3-4, pp. 23-32.

Wade F. (1916) *Diamonds: A Study of the Factors that Govern Their Value*. G.P. Putnam's Sons, New York, London, 150 pp.

Wade F. (1917) Why the diamond is cut with a culet. *The Jewelers' Circular-Weekly*, May, p. 49.

Whitlock H. (1917a) The evolution of the brilliant cut diamond. *The Jewelers' Circular-Weekly*, February, pp. 115-120.

Whitlock H. (1917b) The proportions of the brilliant cut. *The Jewelers' Circular-Weekly*, May, p. 45.

[1] Other researchers have also explored the computer modeling of diamond appearance (see, e.g., Dodson, 1979; Tognoni, 1990; and Astric et al., 1992). Dodson's is perhaps the closest model to ours, although he limited his research to 120 proportions sets of various pavilion angles, crown heights, and table sizes.

[2] Researchers at GIA currently assume conditions of perfect symmetry and polish in their RBC diamond computer models.

[3] The culet in the virtual diamond is counted as a facet since it can vary in size from "none" (i.e., no culet) to "extremely large."

