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**OPHTHALMOLOGY NEWS**

**Computer program simulates visual perception**

by **Matt Young** EyeWorld Contributing Editor

*Tool attempts to simulate conditions that arise from aspheric surfaces*

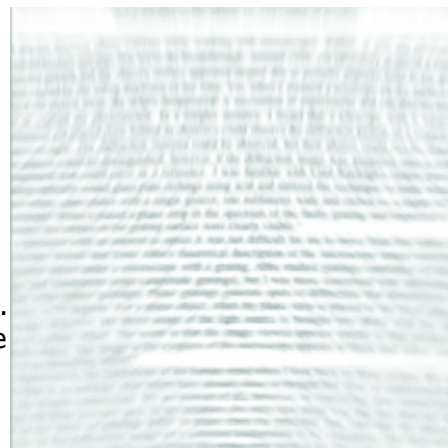
**A**n experimental vision model that simulates the visual conditions of various diseases could someday help ophthalmologists better communicate with their patients.

SimEye is a new computer-based simulation of visual perception using Zernike polynomials. SimEye provides both still images and animated movies. Wolfgang Fink, Ph.D., visiting associate in physics, Visual and Autonomous Exploration Systems Research Laboratory, California Institute of Technology, Pasadena, Calif., described this new software tool in the September/October 2006 issue of the Journal of Biomedical Optics together with co-author Daniel Micol. Some ophthalmologists have welcomed the idea as a potentially helpful addition to their patient consultations.

Dr. Fink, indeed, has high hopes for simEye—although it does not yet have a manufacturer—because he sees its potential applications in science, optics, and education.

**What is simEye?**

SimEye certainly isn't the first model



**SimEye simulation of irregular astigmatism. Source: Wolfgang Fink, Ph.D.**

Reprinted courtesy from Dr. Zernike's Nobel Prize address delivered in 1953 in Stockholm, Sweden, and published in the March 11, 1953 issue of Science.

In optical devices, phase control while working with microscopes. Before, it was an experiment with diffraction gratings that led to the breakthrough. Around 1935, our laboratory acquired a small objective grating and the object's surface appeared striped due to periodic imperfections in the grating caused by the ruling machines of the time. Yet, when I focused a microscope on the surface, the stripes disappeared! A succession of experiments and calculations enabled us to explain the phenomenon. In a simpler instance, I found that a microscope with a certain lens, whenever it is placed close behind its objective could observe the diffraction pattern of a certain set of lines of light. The diffraction pattern could be observed, but their phases could not be discussed. The phases could be distinguished, however, if the diffraction image was projected onto a coherent background that could serve as a reference. I was familiar with Lord Rayleigh's simple process of using specially ruled glass plate gratings using acid and utilized the technique to make what is now simply glass plates with a single groove; one reflector was used and etched to a depth of half-wavelength. When I placed a phase step on the spectrum of the facts grating and imaged it with a microscope, the stripes on the grating surface were clearly visible.

For a reference with an incoherent object it was not difficult for me to move from this system to a microscope. Recall that Franz Abbe's theoretical development of the microscope image formation of an incoherent object under a microscope with a grating. I also studied gratings consisting of alternate opaque and transparent strips (comparable gratings) but I was more concerned with obtaining the diffraction pattern of phase gratings. Phase gratings generate spots of diffraction that demonstrate a phase difference of 90 degrees. For a phase object, when my phase step is placed in the focal plane of a microscope objective, the direct image of the light source is brought into phase with the diffraction image of a phase object. The result is that the image viewed appears similar to that produced by a transparent object. The image in the eyepiece of the microscope appears in black and white contrast. I will note an absorbing object.

I am reminded by the limitations of the human visual when I look back on these events. We are often reminded to, to estimate what others have already done as though has done to understand that is, I believe the human connection. We are almost all of it, however, in connecting new connections and getting old ideas to new ones. In my situation, the only new points were the fact that the diffraction pattern of the lines of gratings differ in phase from the principal line, and that the phase itself (incoherence of the diffraction image on a coherent background) to be visualized. The full title of the

to attempt simulating visual perception. But it is new in that it attempts such simulation of visual conditions that arise from aspheric surfaces.

Dr. Fink noted that the Gullstrand exact schematic eye model has been used previously to study visual perception under various eye conditions including myopia, hyperopia, cataract caused by microvacuoles, and dislocated IOLs.

"Gullstrand's exact schematic eye model also has its limitations, predominantly because of the sphericity of its surfaces and, resulting from that, a very limited customizability," Dr. Fink reported. "To obtain more realistic and quantitative results, aspheric surfaces must be considered."

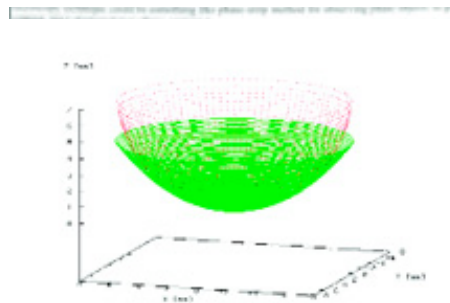
That's exactly what simEye does. Using ray-tracing techniques, simEye can, for example, imitate visual perception characterized by emmetropia, regular astigmatism, irregular astigmatism, and central symmetric keratoconus—which are all marked by aspheric corneal surfaces. It's also quite customizable. Even the diameter of the pupil is user-adjustable in simEye.

**Life-like vision**

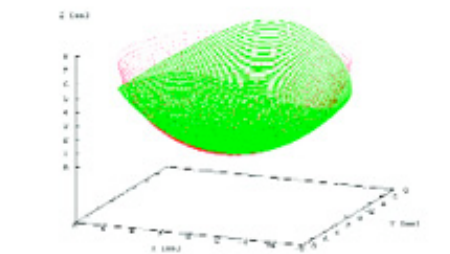
Indeed, Dr. Fink put those four conditions to a test with simEye. To do this, Dr. Fink adapted the simEye ray-tracing procedure to Gullstrand's exact schematic eye model. He fitted the spherical refractive surfaces—except for the anterior corneal surface—and the spherical retina with Zernike polynomials for both distance viewing and maximal accommodation.

"We would like to emphasize that any of these surfaces can be replaced by surfaces that are fitted to more elaborate and realistic eye models, otherwise modeled data, or to actual biometric data," Dr. Fink said in his study.

During his test, Dr. Fink set the



**A SimEye simulation of aspheric astigmatism.**



**"How I Discovered Phase Gratings"**  
 Modified excerpt from Dr. Fink's "Natural Focus" address, delivered in 1976 to the American Society of Opticians and published in the March 11, 1991 issue of Science.

"I did not discover phase gratings while working with microscopes. Rather, it was my involvement with diffraction gratings that led to the breakthrough. As usual, I had one laboratory assigned a variable concave grating and the object surface appeared inverted due to periodic imperfections in the grating lines caused by the ruling machines of the time. Yet, when I focused a microscope on the surface from about six inches away, the stripes disappeared! A succession of experiments and calculations culled me to explain the phenomenon. In a simple instance, I found that a telescope with a vertical 2-millimeter slit placed close behind its objective could observe the diffraction pattern of a vertical line source of light. The diffraction maxima could be observed, but their phases could not be discerned. The phases could be distinguished, however, if the diffraction image was projected onto a coherent background that could serve as a reference. I was familiar with Lord Rayleigh's simple process of making optically sound glass plate gratings using acid and utilized the technique to make what I call phase strips. Glass plates with a single groove, one reflective side and ruled on a slope at both a wavelength. When I placed a phase strip in the spectrum of the faulty grating and inspected it with a telescope, the stripes on the grating surface were clearly visible."

"As a physicist with an interest in optics it was not difficult for me to move from this subject to the microscope. Recall that Ernst Abbe's theoretical development of the microscope image formation for a microscope object under a microscope with a grating. Abbe realized gratings consisting of alternating opaque and transparent strips (amplitude gratings), but I was more concerned with alternating dark and thin strips (phase gratings). Phase gratings generate orders of diffraction that demonstrate a phase difference of 90 degrees. For a phase object when my phase strip is placed in the focal plane of the microscope objective, the direct image of the light source is brought into phase with the diffracted image of a phase object. The result is that the image view of opaque circles is due produced by an amplitude object. The image in the eyepiece of the microscope appears in black and white contrast, as if it were an amplitude object."

"I am impressed by the limitations of the human mind when I look back on these events. We are quick to know that is, to consider what others have already done or thought but slow to understand that is, to make the deeper connections. We are slow of all, however, in conceiving new connections and in applying old ideas in a new way. In my opinion, the only new path was the fact that the diffraction pattern of the lines of gratings differ in phase from the principal line, and that the phase might produce an image of the diffraction image into a coherent background to be contrasted. The full name of the microscopically technique could be something like phase-strip method for observing phase objects in good contrast, but I discovered it in phase contrast."

**SimEye can simulate what it looks like to have irregular astigmatism and other eye**

diameter of the pupil to 4 mm.

In the test of emmetropia, or normal vision, simEye produced an image clear in the center as opposed to the periphery, which is the result of the

assumed sphericity of the cornea (which leads to spherical aberration). "It resembles the naturally occurring blurry perception in our peripheral vision due to the reduced retinal receptor density," Dr. Fink reported. Under one particular instance of regular astigmatism, the produced simEye image shows an arc-like, structural image distortion along the vertical y axis with the horizontal x axis being the symmetry axis. Under one particular instance of irregular astigmatism, Dr. Fink reported: "The resulting visual perception exhibits five distinct areas: the upper left and right are characterized by a more arc-like, structural image distortion akin to the visual perception under regular astigmatism, whereas the lower left and right are characterized by a more Gaussian-type, fuzzy blur without any apparent structure to it. In the image center, a relatively undistorted viewing channel is visible." Finally, visual perception under one particular instance of central symmetric keratoconus shows just the kind of detail that simEye can achieve.

The image produced three areas of varying amounts of distortion. "In the central region, image blurriness paired with slight image enlargement is exhibited because of the increased central corneal thickness due to the central symmetric keratoconus compared to the 'normal' central corneal thickness," Dr. Fink reported. "This central region is surrounded by an annular region of image blurriness because of the reduced corneal thickness due to the central symmetric keratoconus compared to the normal corneal thickness in that region. Surrounding this annular region is a peripheral region where the regular image blurriness due to the spherical aberration of the anterior corneal surface is exhibited."

### **Ophthalmologists imagine uses**

"I could see a significant role" for simEye, said Eric D. Donnenfeld, M.D., Rockville Centre, N.Y. "Patients would be able to visualize possible complications of surgery."

Dr. Donnenfeld said that understanding the experiences of glare and halo with multifocal lenses or corneal refractive procedures would be particularly useful, although Dr. Fink did not test those conditions specifically in his study.

"Anything that gives the physician a better tool to explain surgical outcomes is going to be a benefit for patients," Dr. Donnenfeld said. Mark Packer, M.D., clinical associate professor, ophthalmology, Casey Eye Institute, Oregon Health and Science University, Portland, Ore., also was fairly optimistic about simEye's potential benefits in private clinics.

If a clinician can show a patient what astigmatism or other visual defects are like in a movie, "That's very interesting," he said.

"It is a useful educational idea," he said.

**Editors' note:** *Dr. Fink reported no financial interests related to his study. Drs. Donnenfeld and Packer have no financial interests related to their comments.*

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