International Optical Design Conference 2010

Julie Bentley
Anurag Gupta
Richard N. Youngworth
Editors

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Introduction

The International Optical Design Conference (IODC) is a quadrennial time-capsule for the ever-evolving fields of optical design and illumination. The IODC has a rich history dating back to 1905. Recent meetings include:

Cherry Hills, New Jersey, USA (1986)
Monterey, California, USA (1990)
Rochester, New York, USA (1994)
Kona, Hawaii, USA (1998)
Tucson, Arizona, USA (2002)
Vancouver, British Columbia, Canada (2006).

The vibrant fields of optical and illumination design continue to have a significant impact on our world as the community partaking in the 2010 IODC once again witnessed.

The 2010 IODC took place in beautiful Jackson Hole, Wyoming, USA. The IODC always brings together an international group of experts and practitioners of optical and illumination design, research, and engineering. This year was no exception as we had an abundance of outstanding plenary, invited, and contributed talks in a wide variety of areas. Speakers came from many different parts of the world and work in diverse industries, government labs, and educational institutions. The program committee once again did an excellent job of promoting the conference, providing input on speakers, soliciting contributed papers, and reviewing submissions. Additionally, we were very pleased to be co-located with the Optical Fabrication and Testing (OF&T) Topical Meeting, which is a natural technical partner for our conference.

The 2010 IODC featured three plenary speakers. Dr. Greg Forbes from QED Technologies spoke on "Better ways to specify aspheric shapes can facilitate design, fabrication and testing alike." Dr. Kenny Kubala from Five Focal gave a talk on "Computational imaging technologies." The third plenary talk was presented by Professor Axel Scherer from Caltech on "The evolution from III-V opto-electronics to silicon nanophotonics and vertical cavity lasers to photonic crystal and surface plasmon devices."

Highlighted in this IODC were papers on surface representation in lens design, desensitizing and tolerancing optical systems, lighting and nonimaging system design, illumination system fabrication, beam shaping, polarization, and computational imaging. The illumination program had five full oral sessions and 10 invited talks and the imaging program consisted of 10 full oral sessions with 11 invited papers. There was a large joint poster session with OF&T that had a plethora of strong papers on Monday night.

Tuesday night the conference reception featured memorials to the influential community members who passed away since the last IODC. As a community, it was special to celebrate the lives and achievements of these great individuals:

Hans A. Buchdahl, honored by Greg Forbes
Juan Rayces, honored by Martha Rosete-Aguilar
Jim Palmer, honored by Jim Burge
Bob Hopkins, honored by David Shafer (with support from Doug Sinclair)
Bob Hilbert, honored by Kevin Thompson
Warren J. Smith, honored by Graham Brewis (with support from Bob Fischer).

We dedicate this proceedings volume to these six highly successful professionals who made such a strong contribution to the fields of optical and illumination design and engineering.

The results of the always-anticipated illumination and optical design problems were presented on Wednesday night. The winner of the illumination design contest, presented by Neri Shatz, was Bill Cassarly. The winner of the lens design contest, presented by Rick Juergens, was Rob Bates. The community appreciates the efforts of all of the people who contributed to the design problems: the subcommittee chairs Roland Winston and Rick Juergens, the presenters and writers of the articles, and of course all of the hardworking people who submitted solutions. The summaries of both of these design problems are included in these proceedings.

This IODC was fortunate to have a number of student awards at the conference. The winner of the prestigious Michael Kidger Memorial Scholarship was awarded on Monday to Braulio Fonseca Carneiro de Albuquerque. The Robert S. Hilbert Travel Grant Award winners were Amber M. Beckley, Joshua J. Kim, and Garam Yun. The winners of the best student paper award, sponsored by the Fabrication, Design and Instrumentation Division of OSA and announced by Dan Smith at the conclusion of the design problem sessions, were Garam Yun (best poster), Florian Fournier (best oral presentation), and Amber M. Beckley (best oral presentation runner-up). Congratulations to all student award winners. Also, thanks to the OSA Foundation and all of the volunteers for evaluating these different awards, once again showing that the optical and illumination design communities are very generous with their time.

We have been honored to serve as chairs for the community. We appreciate and thank the many people who continue to make the IODC a special event that captures the state of our exciting field. Special thanks go to CDGM, The College of Optical Sciences (University of Arizona), CREOL, College of Optics and Photonics (University of Central Florida), Institut d'Optique, The Institute of Optics (University of Rochester), Optical Research Associates, The Optical Society, The OSA Foundation, Schott, and SPIE. Thanks also go to all of our exhibitors and authors. Special appreciation is extended to Kristin Mirabal and Erin Richardson at OSA, and the SPIE staff for all of the hard work that went into producing this splendid conference and this proceedings volume.

Finally, thank you to everyone for taking the time and effort to travel to Wyoming, especially those who have traveled long distances, to interact and share your work and expertise with the community. We look forward to seeing you at future International Optical Design Conferences. For information on the IODC, please see the website graciously managed by Groot Gregory (www.iodc.info). This is an excellent place to check for the time and location of the next IODC.

Julie Bentley
Anurag Gupta
Richard N. Youngworth

In Memoriam, a tribute to

Hans Adolf Buchdahl
1919-2010

Father of high-order aberration analysis and champion of Hamiltonian methods in optics

Born in Mainz, Hans Buchdahl had the tragic misfortune of being a young member of a German-Jewish family as Germany self-destructed in the 1930s. He was sent by his parents to boarding school in England. After completing high school and then a first degree at the Royal College of Science (a constituent of Imperial College London) he was interned as a German national in reaction to the widespread fear that followed the evacuation of Dunkirk in 1940. His parents had escaped Germany in 1939. Hans and his brother Gerd were among those bundled from the internment camp to an overcrowded ship, the Dunera, and sent on a hellish two-month journey to an undisclosed destination. It turned out to be Australia. When the conditions on the ship were seen in Sydney, criminal proceedings were initiated against those in charge. One faced court martial and another received a prison term. To add to the ordeal, the internees were directly sent on an overnight train into central New South Wales to an internment camp in the barren outback. It is hard to imagine that the stark, empty plains and sky could be seen as anything but a continuation of their hellish experience. To Hans, however, they exclaimed the promise of a new life far from the collapse of his homeland. It was his 21st birthday, and he immediately began creating opportunities and contributing to his newly adopted country, where he lived and worked for the rest of his life.

It is no surprise that Hans' mathematical and scientific abilities were soon appreciated. In late 1941, he was released under a guarantor arrangement to work at the University of Tasmania in Hobart to "assist with the teaching load of particular physics staff heavily involved in the local optical munitions work." He lived for nine years in a hut behind the house of Prof. A.L. McAulay in Hobart. Interestingly, McAulay's father had worked on Hamilton's quaternions, but I do not know if this seeded Hans's interest in Hamilton's methods. McAulay led the Tasmanian component of the Optical Munitions Panel, a group that coordinated optics-related war-time research and development around Australia. At the time that Hans was transferred to Hobart, the panel was overseeing Australia's first large-scale production of optical glass at ICI Ltd, in Sydney. Capabilities for design and optical fabrication were hurriedly being created around the nation to produce prisms, lenses, and multi-component systems such as telescopes and camera lenses. By developing analytical methods to facilitate optical design on mechanical calculating machines, Hans contributed to this broad effort.

His works from that era ultimately led to the publication of his first book, *Optical Aberration Coefficients* (Oxford University Press, 1954 and reprinted by Dover in 1968). In it, he says "Once again, I ask the reader's forbearance with regard to the bewildering multiplicity of symbols, type, and affixes of all kinds." The painstaking attention to detail in this work was essential to its successful development, but also contributed to Hans' reputation for texts that were hard going for the reader. He knew this all too well. Aside from his powerful methods that supported optical design, another notable contribution in this book was the introduction of a spectral parameter for use in modelling the chromatic dependence of optical performance. Hans called it the "chromatic coordinate". Although it is a simple change of variables from wavelength, it insightfully enabled a power series to account for colour dependence across the full visible spectrum with far fewer terms than was required when wavelength itself was used. As this became better appreciated, Paul Robb of Lockheed (Palo Alto, 1983) wrote to Hans that, "Having the chromatic coordinate turned out to be exactly like having the key to a room full of gold."

In 1950, Hans married Pamela Wann, whom he had met at his brother Gerd's wedding to Pamela's sister. By this time, he was a research physicist and lecturer at the University of Tasmania, which had awarded him a DSc for his contributions to three major areas: geometrical optics, general relativity, and classical thermodynamics. He also received a DSc from Imperial College in 1956. After serving as a Reader at the University of Tasmania, Hans became the inaugural Professor of the Department of Theoretical Physics in 1963 within the new School of General Studies at the Australian National University (ANU) in Canberra. Before moving to the ANU, his research had led to visits to Imperial College and to the

Institute for Advanced Studies at Princeton. His children Tanya, Nick, and Kate were born in 1953, 1956, and 1964.

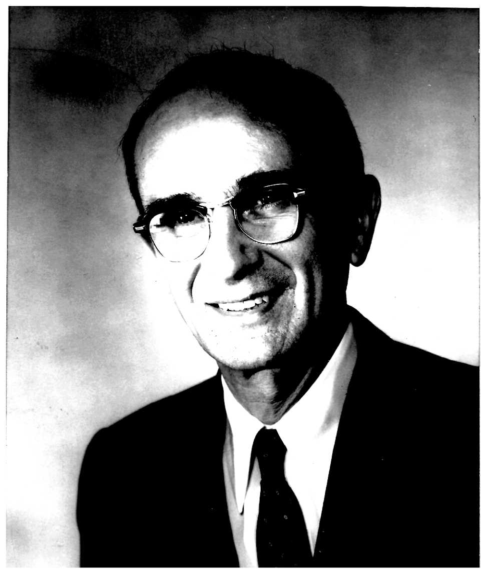
During a visit to The Institute of Optics at the University of Rochester, he completed his second book in optics, namely, *An Introduction to Hamiltonian Optics* (Cambridge University Press, 1970 and reprinted by Dover in 1993). This work brought new attention to the important methods that Hamilton first developed within the field of optics and later generalized to mechanics. Much of the work in Hamiltonian optics over the last 40 years can be traced to Hans. He also contributed to the general theory of relativity during what was known as its 'Golden Age', and to the discipline of thermodynamics. His three other books in these areas, together with his over 160 technical papers, are testament to his intellectual creativity.

Hans had passions for classical music and bushwalking. During his earlier years in Australia, for example, he walked the wilderness of southwestern Tasmanian as often as he could. Hans remained at the Australian National University until his retirement in 1984. Tragically, the loss of his younger daughter to Hodgkin's disease in 1992 took the wind from the sails of his extraordinary and continuing professional life. To be near their son, he and his wife moved to Adelaide in 2001. It was Hans's remarkable talent that enabled him to be so successful through his life, even in what would appear to be overwhelming adversity. Through teaching and mentoring, he generously created opportunities for the careers of others. The Buchdahl name is indelibly stamped on our discipline, and our community is deeply indebted to Hans for his many contributions.

Greg Forbes

In Memoriam, a tribute to

Juan L. Rayces
1918–2009



An enthusiastic scientist with great passion for optical design who inspired men and women of all ages working in this field.

I am sad to inform you that we have lost one of the greatest optical designers of our time, Juan Rayces. He passed away 6 December 2009, at the age of 91. He was not only a great gentleman, but also the quintessential Great Thinker. A memorial service was performed on 17 April 2010, at Arizona Inn with friends from around the world paying the tribute to Juan for his lifetime contributions to optics, and for nurturing the next generation of optical designers.

Juan was born in Bahia Blanca, Argentina on Persian New Year's day, the first day of spring, in 1918. His passion in optics started in his early life. In an interview with SPIE for his A. E. Conrady Award, he recalled making a simple telescope as a teenager out of a rolled up newspaper, a discarded pair of his mother's eye glasses and a magnifier lens.

Juan attended the Argentina Navy Academy at Rio Santiago. Besides required naval science subjects, he excelled in mathematics, physics, chemistry, mechanics and electricity. He was commissioned in 1940. As a junior officer, in 1943, he gained quite a reputation in the Navy after he developed a nomogram for azimuth verification.

Juan graduated from Imperial College of Science and Technology in 1946 with an M. Sc. in Technical Optics. He studied under Professors L. Martin, W. D. Wright and lecturer B. K. Johnson. After the graduation, he returned to Argentina and the Navy. He retired from the Navy due to his loss in hearing with the rank of Lieutenant in 1950. He transitioned from the Navy to La Plata Observatory as the manager of the optics section. In the meantime, he was appointed to a lecturer position in optics for optometrists and opticians. He decided to emigrate to the United States due to the unchallenging job in the Observatory, and the political turmoil during the Juan Peron era.

His first job in the United States was with Bausch & Lomb, where he introduced algebraic ray-tracing, as opposed to trigonometric ray-tracing, with desk calculators. The algebraic method requires two square roots per ray-surface. He developed a simple method to interpolate square roots that required only one sheet table and one keystroke in the calculator to work with six-place accuracy.

Subsequently, Juan worked for David White Company between 1952 to 1954, developing a 35mm stereoscopic camera and theodolite optics. From 1954 to 1957, Juan worked for American Optical Research Laboratory in Southbridge, Massachusetts, where he started his use of computers in optical design.

After 1957, Juan mainly worked for Perkin-Elmer Company in Norwalk, Connecticut from 1958 to 1964, and Perkin-Elmer in Costa Mesa, California from 1965 to 1983, where he made significant contributions both in developing optical design software and in innovative lens design. After his retirement from Perkin-Elmer, he continually devoted his life to advancing both optical design algorithms software and lens design to the very last days of his life. Juan was inducted as an OSA fellow in 1995, and won the SPIE 2004 A. E. Conrady Award for his life time achievements in optics. Here, I would like to recite his achievements from the Conrady Award:

> During more than 50 years in the field of optics, Rayces has been responsible for many developments in lens design and optimization methods in software. Prior to his own consulting company in 1983, he was a chief optical designer for 24 years. In 1960, as an optical design engineer at Perkin-Elmer, he developed a numerical convolution method for the computation of optical transfer functions, which he used to write the first computer program in the U.S. used to evaluate lens systems in the design stage." The mathematical framework Juan developed for the optical transfer function computation turned out to be the "Canonical system coordinates" as called by H. H. Hopkins. As cited by A. Offner, Juan was the first in developing "Canonical system coordinates" for optical transfer function computation.
>
> In 1970 Juan developed the optical design program Eikonal, which was the first program in the U.S. to trace rays through holograms and the first to use Zernike coefficients for optimization.

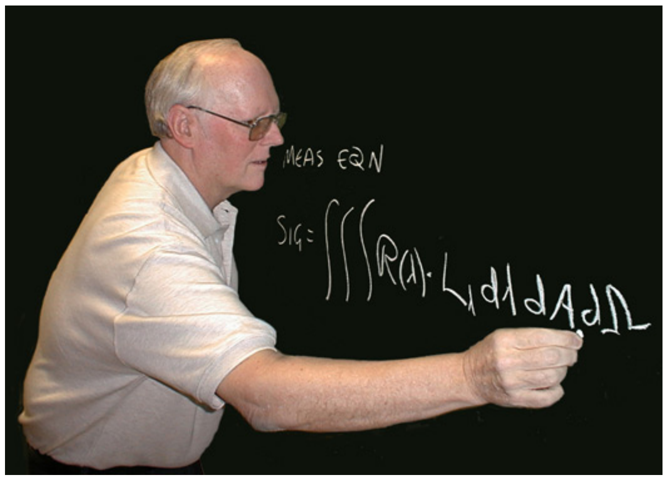
> These are just two highlights in a career filled with innovations. They include a modified Glatzel's adaptive correction method, general solution of paraxial ray angles, inside-out method of null lens design and contributions to lens design theory such as the exact relation between wave and ray aberrations. The innovations were implemented in many applications, including a wide-angle periscope for the Mercury Space Project, NIMS spectrograph for Galileo Saturn Mission, Fourier lenses for SAR images, a family of solid catadioptric lenses for Vivatar, and a catadioptric system for simulation of HST primary mirror flawed wavefronts.

Juan's contributions to the world of optics were tremendous. But it was clear at his memorial service that his impact was much broader than that. He was not only a committed scientist, but a devoted mentor to optical scientists, friends and family members all of his life. His love of design and derivation was contagious as he inspired men and women of all ages. He spent countless hours showing his homemade stereoscopic viewer to children of colleagues. But Juan's passion was not limited to the world of optics. He was an enthusiastic student of different cultures, arts and religion; a connoisseur of classical music and Asian art. He was a true Renaissance man and a gentleman. But most importantly, he was a loving husband, father, grandfather and friend. Juan Rayces contributed a great deal to the world around him and will be much missed.

Martha Rosete-Aguilar

In Memoriam, a tribute to

James M. Palmer
1937-2007



James M. Palmer dedicated his career to advancing state-of-the-art in photometry, radiometry, and detector calibration. He was research professor emeritus of optical sciences at The University of Arizona. His research interests ranged from radiometric standards and instrumentation to making high-accuracy radiometric measurements, sensor system calibration, self-calibrating quantum efficient photodiodes, and even to radiometric properties of the Moon.

Jim also dedicated his career to teaching. He was one of the faculty members who helped establish the BS undergraduate program in optical sciences and engineering at The University of Arizona, and taught a variety of courses in electronics, radiometry, sources and detectors. He taught these subjects at the undergraduate, graduate, and professional level for over 25 years. Essentially, Jim was instrumental in bringing the study of radiometry into mainstream optics education.

Jim was born in Saginaw, Michigan on September 3, 1937. He earned an AB in physics from Grinnell College in 1959. After graduation, he left the family's home in Chicago and drove to his new job in southern California, following the complete Route 66 path. He worked at Hoffman Electronics as a senior engineer from 1959-1987, where he optically tested the world's first space-qualified solar cells. He earned an MS in optical sciences in 1973, and a PhD in optical sciences in 1975 both from the University of Arizona, the latter of which he earned under Bill Wolfe. His PhD project was "Pioneer Venus Solar Flux Radiometer," which was a 12-band narrow-field radiometer to measure net solar flux versus altitude in the Venerian atmosphere. His radiometer was carried aboard the Pioneer 13 Mission to Venus and its data is still relevant to studying global warming here on Earth.

Besides Jim's love of optics, he took great pleasure in singing with choral groups, notably the William Hall Master Chorale based in Los Angeles. With them he traveled to perform in 15 countries in many venues, including Carnegie Hall as well as before the Pope in the Sistine Chapel. Jim's list of performances also include gigs with Herbie Hancock and Dave Brubeck.

Jim passed away on January 4, 2007, after a lengthy and courageous battle with cancer. His legacy lives on, in the form of his book *The Art of Radiometry*, published posthumously in 2009 by SPIE Press. According to SPIE:

> The material from this book was derived from a popular first-year graduate class taught by James M. Palmer for over 20 years at the University of Arizona, College of Optical Sciences. This text covers topics in radiation propagation, radiometric sources, optical materials, detectors of optical radiation, radiometric measurements, and calibration. Radiometry forms the practical basis of many current applications in aerospace engineering, infrared systems engineering, remote sensing systems, displays, visible and ultraviolet sensors, infrared detectors of optical radiation, and many other areas. While several texts individually cover topics in specific areas, this text brings the underlying principles together in a manner suitable for both classroom teaching and a reference volume that the practicing engineer can use.

SOCIETY AFFILIATIONS

- Optical Society of America (Member, 1962)
- Institute of Electrical and Electronic Engineers (Life Member, 1962)
- Council for Optical Radiation Measurements (Member, 1972)
- SPIE (Member, 1975; Fellow 2003)
- U.S. National Committee, Commission Internationale De l'Eclairage (CIE)
- CIE Technical Committee TC2-29, Measurement of detector linearity (member)
- CIE Technical Committee TC2-51, Calibration of multi-channel spectrometers (member)
- CIE Technical Committee TC2-48, Spectral responsivity measurement of detectors, radiometers, and photometers. (member)

AWARDS, HONORS

- EDN Award for Excellence (Feature Article), 1970
- NASA Group Achievement Award, Pioneer Venus, 1979
- Tau Beta Pi Teacher of the Year, University of Arizona, 1992
- University of Arizona Non-Traditional Student Teaching Award, 1993
- SPIE Fellow, 2003

Jim Burge

In Memoriam, a tribute to

Robert E. Hopkins
1915-2009

Robert E. Hopkins, former director of the University of Rochester's Institute of Optics, passed away July 4th, 2009, at the age of 94. Hopkins, known as the "Father of Optical Engineering," was honored as an SPIE Fellow in 1978. He served on the SPIE Board of Governors from 1982 to 1984, and won the Gold Medal of the Society in 1983.

Working for and with Bob Hopkins, 1960–1990

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I first met Bob Hopkins when I was an undergraduate at MIT. I was working in the Strobe Lab, for Dr. Harold Edgerton, taking pictures of exploding dynamite caps, using a Schlieren optical system. Hopkins came to MIT because he was helping Doc Edgerton design an underwater camera where the imagery was important. I got to meet Hopkins at that time, and was impressed with his knowledge of optics, a subject that I had recently become interested in, because of the Schlieren system. Doc Edgerton suggested that I should go to the Institute of Optics for graduate school, because it was the only place where I could specifically study optics. So I did.

When I arrived at the University of Rochester in the fall of 1960, I went to meet with Hopkins to find out what academic program he would recommend for me, to learn lens design. Surprisingly, he told me that he would not recommend that I go into lens design, because it was a subject that had been extensively studied, and I might have trouble finding a suitable thesis topic. Instead, he recommended that I should study lasers. The first ruby laser had just been demonstrated by Ted

Maiman, and Hopkins had been able to get a research contract to study lasers from DARPA and was looking for graduate students to work in this area. Mike Hercher and I signed up. We first got a ruby laser from Edgerton, Germeshausen and Grier, and began to study the optics of the output beam. Later, Mike developed several ruby lasers on his own, and I switched over to gas lasers.

Hopkins agreed to be my thesis advisor. Of course, gas lasers weren't his specialty, but I got a lot of help from workers in the field that he introduced me to, including Don Herriott of Bell Labs, co-inventor of the gas laser, and several scientists from Spectra Physics, the leading manufacturer of gas lasers. Because I was working in lasers, I never took any courses from Hopkins, nor from Kingslake either. My account of Hopkins teaching career is based on what others have told me, as well as what I learned from him after I joined the faculty.

Bob Hopkins teaching career lasted from the end of World War II to the mid-1960s. He had come to the Institute of Optics in the late 1930s and studied lens design with Rudolf Kingslake. When Kingslake left the Institute of Optics in 1940 to work full-time at Kodak, Hopkins became the principal lens designer on the faculty. Actually, Kingslake continued part-time at the Institute of optics for the rest of his career, teaching his lens design course on Wednesday nights. Hopkins taught a Saturday laboratory section of the course. It was a synergistic relationship. Kingslake was a superb lecturer, with a set of notes (later published as a book) that have become a standard in the field of lens design. Hopkins excelled in one-on-one teaching, being able to explain to students how to use the material that they learned in lectures to solve practical problems.

Hopkins learned practical lens design during the war, when he and Don Feder were the principal lens designers at the Institute of Optics. The Institute at that time served primarily as the applied optics research arm of the National Defense Research Council. Under director Brian O'Brien, a wide variety of optical instruments were designed, ranging from conventional visual systems to high-resolution photogrammetric lenses, night vision devices, and a high-speed streak camera that was used for atomic weapons testing. Graduate teaching was deemphasized, but the undergraduate program continued, since there was a national need for people trained in applied optics. Occasionally conflicts arose, such as when equipment needed for laboratory teaching was used for classified research. Warren Smith, an undergraduate at the time, told me that O'Brien had once gotten security clearances for the entire senior class, so that they could continue their studies without restriction.

Brian O'Brien was a strong leader who should probably be considered the founder of the Institute of Optics as we know it today. His own background was in physiological optics, but he realized that for the Institute to maintain its preeminent position in optics, its scope needed to be enlarged to accommodate all activities in the field. He made two important faculty appointments: Parker Givens, who became one of the Institute's great teachers, and David Dexter, a physicist who established the Institute's solid state research program, and later ran the graduate program.

Jack Evans, a faculty member with an interest in mechanical design, who worked at the Institute during the war, told me that O'Brien was a dominating personality, and that he (Jack) was terrified when he needed to describe his work to O'Brien. Nevertheless, Hopkins seems to have gotten along with O'Brien well, and became his assistant. When O'Brien left the Institute of Optics to take an industrial position, Hopkins was his logical successor as director, a position that he assumed in 1954.

As director, Hopkins continued the policy established by O'Brien and appointed a number of additional faculty, the most important being Emil Wolf. He also continued his teaching, and started a joint consulting practice with Jack Evans. Later, with Jim Anderson, they founded the company that eventually became Tropel. John Buzawa, a lens designer who graduated from the Institute, soon joined the company and later became its president. Over the years, Tropel has maintained close contact with the Institute of Optics, and has employed dozens of their graduates (including me, for a summer). Initially, the company concentrated on the design and fabrication of a variety of precision optical systems, together with a series of aluminum slides (called Unislides) that had been developed by Jack Evans. They also got an early start in the design of lenses for microlithography. Buzawa's talents for lens design, and Anderson's unique ability to assemble precision optical systems, gave Tropel an important competitive advantage.

At the Institute of Optics, the period from the mid 1950s to about 1970 was the golden age of computer-aided lens design. During the war, Hopkins and Feder designed lenses using computers, but the computers at that time were people. The primary computer at the Institute of Optics was a woman named Louise. According to Hopkins, she could trace about one ray per minute, using equipment that he and Evans developed to work with logarithm tables. After the war, Marchant calculators came in to common use in optical design. In addition, the first digital computers were developed. Hopkins recognized immediately that digital computers would be a requirement for modern lens design, and set about to get one at the university. It took a while to persuade the university to buy a computer, but in the meantime Hopkins arranged to use an IBM computer at Cornell.

The first computer at the university that was able to handle any significant optical work was an IBM 650. Together with a graduate student named Charlie McCarthy, Hopkins developed a series of routines to automate the third order correction process that he and Feder had used during the war. Hopkins kept pressing the university to get a bigger computer that could be used for scientific computing, but the best he could get approval for was an IBM 7070, a machine that the university could also use for payroll processing. The computer was not really suitable for scientific work, being programmed in assembly language.

Nevertheless, it was better than the 650, so Hopkins set about to develop a new program called ORDEALS that had the capability for ray and higher-order aberration optimization.

Interestingly, Hopkins himself never wrote a line of programming code, to my knowledge. I asked him about this, and he told me that he had watched Feder get involved with computers so much that he didn't do any more lens design. Hopkins decided that he wanted to remain an active designer, and to do this, he should get other people to write the programs. He got three students, Gordon Spencer, Chuck Rimmer, and Pat Hennessy, to work on software, and he continued to teach lens design.

During the 1960s it became apparent to Hopkins that the university was not keeping up with progress in scientific computing, so he put together a consortium between the University, Bausch and Lomb, and Tropel to buy time on CDC computers, which were the leading high-performance machines at the time. A new company, Genesee Computer Center, was formed to provide time-shared access to the machines from their office in Rochester. At Genesee, Bill Peck developed a lens design program called GENII, and the company also provided access to David Grey's lens design programs.

As I said before, Hopkins was an excellent one-on-one teacher. He liked to work with individuals, or small groups. He was able to take the formal material taught in Kingslake's lectures and show students how to put it to work in practical designs. He talked about tweaking a design, the term he used to describe the incremental process that lens designers used, to go from a preliminary to a final design solution. He gave them advice such as "If you find that your lens is performing much better than you expected, sit on your hands until you figure out what you've done wrong." By the end of the 1950s, Hopkins had taught probably most of the lens designers in the United States how to ply their trade.

A shortcoming of Hopkins teaching, however, was that there was little to no documentation of the material that he taught. Lens design, even today, is an intensely personal activity, carried out in private by adults. It is the centerpiece of what Gordon Spencer called hard-core optics. Lens designers know better than to write down how they work. On the other hand, by the end of the 1950s so many optical systems had been designed for the government that military contractors wanted to have some documentation that could be used by future designers to understand the process. This led to the creation of the Military Handbook for Optical Design, MIL-HDBK-141. Hopkins agreed to prepare several chapters on lens design, and hired Richard Hanau to help him with the writing. For many years following its publication, the Military Handbook was the standard reference for practical lens design; on the shelf of virtually all lens designers in the United States.

Students found that Hopkins loved to discuss things, but was often quite absent-minded. This led to the circulation of many "Hoppy" stories recounting episodes of forgetfulness. Some of these are described in Carlos Stroud's "Jewel in the Crown" book. My favorite, which may be apocryphal, concerns the time that Hopkins flew to an out-of-town meeting in the winter. He rented a car, attended the meeting, and then rented a motel room for the night, since it was late in the day. The next morning, when he tried to start his rental car, he had a great deal of difficulty getting the key to turn in the ignition lock. It was cold, so he persisted, and eventually got the car to start. However, when he got to the airport, the rental agent said "Dr. Hopkins, this is not the car that we rented to you!"

Hopkins' topics were not all related to lens design. He was a social activist, and I remember a lot of discussions in the faculty club where he railed against the automobile. Cars were too inefficient, he argued, and could never be a solution to the nation's transportation needs. He cited the pollution in Los Angeles, which already was a problem, and recommended that high-speed rail systems were a better solution. Considering the present interest in such systems, it appears that his arguments were prescient.

Outside of his university duties, Hopkins was an active family man, with several children. He was an athlete of considerable ability in sports such as sailing, skiing, and later in life, horseshoes. He was an initial investor in Swain, for which he received a lifetime ski pass, which he used extensively. I used to go skiing with him occasionally, but he was far better than I was, so I could not really keep up with him, particularly in deep powder. However, I remember an incident during a ski trip that changed my life. We were riding the chairlift together at Swain in 1968, and he asked me to teach his course in geometrical optics the following term. I reminded him that he had previously told me that I should not go into geometrical optics, that I had never taken a course in geometrical optics, so obviously I couldn't teach it. He said, "Well, you're the only one there who could do it. You can learn it." That's how I wound up in geometrical optics. I started by taking Kingslake's course when I was an associate professor. Later, I became interested in desktop computers, and spent the rest of my career working on lens design software.

1961 was an epochal year for the Institute of Optics. That was the year when the institute was demoted from an independent Institute at the University to a department in the College of Engineering. It came at a time when it was obvious that digital computers and lasers would create a burgeoning renaissance in optics that would last for many, many years. I can assure you that Hopkins had nothing to do with it. He was on sabbatical leave at the time, and could not make effective arguments against it. In any case, it did happen, and the story of its effect on the Institute is much too long to be described here. Hopkins resigned as Director a few years later.

I decided to give up my faculty position in 1980 to work full-time on my lens design program. After I left the Institute, I had to confront the possibilities for commercial lens design software. I reviewed the work of Hopkins and his students, and concluded that their view of what optical software should do was the best one. It was based on an extension of his original "tweaking" approach, using the computer to extend a human lens designer's capabilities. The alternate approach at that time assumed that computers would eventually be so powerful that the designer could merely enter the specifications for a lens and let the computer do all the design work. This approach was advocated by Don Feder, and later by Berlyn Brixner. A completely automatic approach has never really worked well, since the design process involves trade-offs between what the designer would like to do, and what can actually be accomplished.

Hopkins' concept of lens design software was reduced to practice by Gordon Spencer, first in his PhD thesis, and later in the program called ACCOS. I studied and used ACCOS quite a bit, and decided that what I should do was to develop a program similar to ACCOS, but meant for desktop computers. Early versions of the program did little more than compute aberration coefficients and provide basic ray tracing. Later, we were able to implement full ray optimization on a desktop computer that traced only 10 ray surfaces per second. When desktop computers with 16 and 32-bit CPUs became available, the lid was off, and we were able to develop OSLO software with capabilities that exceeded the original ACCOS program. Fortunately, for this work I was able to hire Gordon Spencer to help with the program development. Major contributions to the program were also made by Institute of optics graduates Paul McLaughlin, Dale Buralli, and Andrew Jones.

A lens design program more towards the Feder approach was developed by Tom Harris, an Institute of optics graduate who had started an optical design business in Los Angeles. This was very early in the 1960s, when commercial lens design software was not available. Harris and his partner Daryl Gustafson also recognized the importance of the computer in lens design, and made large investments in computer technology to support their business. Harris developed a lens design program that later became Code V. The basic technology in the program was similar to ACCOS, but Code V contained an extensive number of default conditions that would produce a pretty good lens with minimal user input. Although it was initially designed for internal use, in the mid-1970s the program was offered to the public. It was well accepted, and today is one of the principal lens design programs.

During the 1970s and 1980s, Hopkins gave me a tremendous amount of help in establishing Sinclair Optics as a supplier of lens design software. He worked with our early programs, and gave us great deal of useful feedback on our user interface. Later, he and I designed a few lenses together, the most interesting of which was one called the Non-Lens. This was a lens design project suggested by Peter Clark for an International Lens Design Conference. The task was to develop a real lens that was invisible when you looked through it. That is, rays entering one end of the lens should emerge from the other end with no deviation. The object was to maximize the aperture of the lens. It turns out that this was not an easy job. Hopkins came up with a number of interesting design approaches. I took these and optimized them using OSLO. The best solution that we found incorporated a lens within the lens, and we submitted this as our entry. About a week before the conference, I was talking with Jarus Quinn, Executive Director of the Optical Society, asking him if he had received many entries to the lens design contest. He said yes, he had, and that our solution was significantly better than any of the others. I was very pleased with this news, since our design had been developed using a desktop computer that could only trace about 10 ray-surfaces/sec.

However, when I arrived at the conference the next week, I was surprised to learn that David Grey had submitted a design at the last minute that was substantially better than anything that Hopkins and I had been able to produce. It was full of tenth-order aspherics, and would be impossible to build, but that was not a requirement, according to the contest rules. Clearly, Grey's solution could only be obtained using Grey's program, and could not be found using commercial lens design software such as ACCOS/OSLO or Code V. His solution brought to the forefront a fact that I am not sure many people realize: namely, that there is still lots of room for improvement in lens design software. I hope that this topic will be addressed in the future at the Hopkins Center.

During the 1990s, my interaction with Hopkins became less and less. When I last saw him about five years ago, he could barely recognize me. But no matter. The memory of our friendship over the years is something I will always cherish. He taught me lots about optics, and even more about life.

In Memoriam, a tribute to

Robert S. Hilbert
1941-2008

Robert S. Hilbert passed away on December 11, 2008, in Pasadena, California. He was 67. Bob was a dynamic and respected leader at Optical Research Associates, where he was actively involved in all aspects of ORA business, from shaping important CODE V® and *LightTools®* software features to supporting key optical design and engineering initiatives.

Bob joined ORA in 1975, initially as Vice President, leading the optical engineering services business. In 1991, he was named the company's President and Chief Operating Officer. He was elevated to CEO in 2000 and additionally appointed as the Chairman of the Board in 2006.

"Bob was an important member of our team for more than 30 years, and was instrumental in the growth that ORA has enjoyed both in our optical design software and engineering services offerings," said Thomas Harris, Founder and former CEO of ORA. "Most importantly, Bob understood the core values that have always driven ORA, and emphasized customer success as our highest goal. Bob cared deeply about the staff at ORA and the feeling was reciprocated."

Bob started his 50-year career in optics by receiving the Future Scientist of America Award for a 360° camera design in 1957, at age 16. He received BS and MS degrees in optics from the University of Rochester in 1962 and 1964, respectively. His master's thesis presented a study of concentric and Schmidt type catadioptric systems, and was later referenced by Duncan T. Moore in a 1977 paper published with the Optical Society of America titled, "Catadioptric system with a gradient-index corrector plate" (J. Opt. Soc. Am. 67, 1143-1146).

From 1963 to 1975, Bob worked for Itek Corporation, which pioneered satellite-borne, photo- optical reconnaissance systems and high-altitude strategic reconnaissance systems. He was a member of the engineering team assigned to the then-classified Corona program, to design the spaceborne cameras used in the United States' first photoreconnaissance satellites. The Corona camera system is currently on display at the Smithsonian National Air and Space Museum. Derivatives of this camera system were later used in the Apollo mission to map the moon.

Bob held a variety of management positions at ITEK, including Director of Optics, Manager of the Optical Engineering Department, Chief Optical Engineer, and Supervisor of Optical Design. As Director of Optics, he was responsible for all engineering and manufacturing necessary to design and produce mounted optics including optical design, opto-mechanical design, optical fabrication, assembly, and test.

As an optical engineer at ITEK and ORA, Bob contributed to the development of new concepts and designs for a wide spectrum of systems. This included visible, IR and UV sensors, the optical design of a broad variety of fabricated optics such as a wide angle projection lens for 35 mm slides, optical systems for High Energy Lasers and for Ballistic Missile Defense, an important advance in star tracker objective optical design, a Raman Spectrograph relay lens, an f/0.62 low light level catadioptric TV lens, the objective for the Air Force KA-80 panoramic camera, a zoom system for visual use, an 80° field cos3 falloff objective, a one-meter aperture wide field telescope, a finite multi-conjugate relay lens for rectifying Corona panoramic photography, a zoom lens for SLR use, and many others. Bob had a key role in identifying the initial configuration and developing a preliminary optical design for the very successful Wide Field and Planetary Cameras that were recovered from space during the Hubble Servicing Mission 1, which he was actively involved in with Kevin Thompson of ORA.

In addition to working as a detailed optical designer, Bob often took on a broader optical engineering role, including developing qualification and acceptance test procedures as well as performing component and system-level tests (both Hartmann and interferometric tests and data reduction of massive optics), and radiometric tests of electro-optical systems. Early in his career as a precision optician, Bob fabricated high-quality spherical and aspheric surfaces through figuring of 2-inch to 20-inch aperture optics to fractional wave tolerances.

Bob was elected SPIE fellow in 1992, received an American Optical Company Fellowship from the University of Rochester in 1962, and held seven U.S. Patents in the field of optics. These patents include innovative designs for three-dimensional reflex lens systems, a high-speed projection lens, and a composite photography system used for scanning probes for simulators.

Bob served as Chairman of the SPIE Fellows Committee in 1998, and was a longtime member of the Optical Society of America, where he served in many positions, including Vice Chairman and Chairman of the Optical Design Technical Group.

In Memoriam, a tribute to

Warren J. Smith
1922-2008

A leader in the global optics community who contributed to the field with his books, papers, and perhaps most importantly through teaching

Warren Smith's professional career spanned over six decades beginning with a role in the Manhattan Project when he first graduated from the University of Rochester in 1944, to finishing the editing of the fourth edition of his textbook in optics, *Modern Optical Engineering*, first published in 1966. Warren served as president of OSA in 1980 and president of SPIE in 1983. He was a Fellow of both the OSA and SPIE. Among the companies that Warren worked for during his career was Panavision of motion picture fame. But perhaps how most people came to know Warren was through his classes. He taught a one week class in optical design that used a program called GENII and to his credit the class was more heavily weighted to the fundamentals of design than using the program. Later Warren taught the class using OSLO when GENII was no longer available. During the annual meetings of SPIE held for the most part in San Diego, he taught short courses in optical design which were always well attended.

Warren wrote two other books besides *Modern Optical Engineering*; *Modern Lens Design*, and *Practical Optical System Layout: And Use of Stock Lenses*. Each of his books was based on detailed notes that he took while working on different projects throughout his career. And so, for the most part his writings are based on first hand design experience.

Warren was issued five patents. In an interview with Robert E. Fischer in 2003 he said that the most fun design that he worked on was a railroad track leveling device which is represented in U.S. Patent 3,107,168 granted in 1963. U.S. Patent 3,255,664 granted in 1966 was for the design of a Petzval type objective. U.S. Patents 3,363,963 granted in 1968 and 3,540,804 granted in 1970 were for the design of precision optical micrometers. And U.S. Patent 3,497,695 was for the design of an infrared tracker.

A number of stories abound about Warren. One of these pertains to his resemblance to the comic book character Clark Kent (Superman's alter ego) and how some of Duncan Moore's students at the Institute of Optics made a Superman outfit which he actually wore to a Lens Design Technical Group session in 1979. There are a number of photographs of him in the costume and he does make a rather convincing Superman.

In 1987 Warren left Santa Barbara Applied Optics and joined Kaiser Electro-Optics in Carlsbad, California, where he had the title of chief scientist. As he was emptying out his office at Santa Barbara Applied Optics and putting the boxes in his car he was approached by a representative of the University of Rochester with an offer to become a professor at the Institute of Optics. He said the timing could not have been worse since he had accepted the position in Carlsbad. He did comment that going back to the winters in Rochester might have been a bit much.

Warren did have his opinions on a few things. Concerning the well known textbook *Fundamentals of Optics* by Jenkins and White he commented "You can tell that they never traced a ray in their lives." His books, chapters in handbooks, and articles, in contrast to *Fundamentals of Optics*, are written from the point of view of the lens designer and as such are very accessible.

With Warren's long career and presence at optical society meetings both locally and nationally he became a familiar and welcome site at these events. He was always willing to share his knowledge when asked technical questions and not just about optics but even mundane subjects such as termite damage and health issues (he had had a few surgeries). Right until the end his mind was sharp and his memory excellent and he will be missed.

Graham Brewis