A Life in Color: Louis Silverstein's Contributions to Color Displays

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Abstract

Dr. Louis D. Silverstein was a pioneer in the human factors of electronic color displays and a leader and innovator of flat-panel display technology. During his short but active career, he published over 130 journal articles, book chapters and technical papers and was awarded over 30 patents for innovations in liquid crystal displays and liquid-crystal-based image-capture devices. He received many honors and awards, including the Macbeth Award from the Inter-Society Color Council in 2004 for his outstanding contributions in the field of full color electronic displays, and the Otto Schade Prize from SID in 2008 for outstanding contributions related to display image quality and performance. Dr. Silverstein was a man of great personal integrity and a mentor to many young scientists and engineers entering the field. His influence in the field of displays will be with us for many years to come.

Louis D. Silverstein died peacefully at his home on May 1, 2012. His death is a great loss to our community. In this talk, I describe some of Lou's contributions to color display engineering. I emphasize the word "some" because there are many important contributions that will not be mentioned today. I hope that other people will highlight these contributions in future talks.

Today, I will share some biographical information about Lou and I will say a few words about how I came to know him. But I urge you to go to http://louissilverstein.blogspot.com to read the comments of many of his friends and colleagues and to add your own memories. When you read the comments you will notice that everyone saw the same Lou. We write that he was a brilliant scientist, a pioneer in display engineering, an inventor, a teacher, a mentor and a very good friend. But mostly, we write about his generosity, his integrity, his wit, his humor and his modesty. We write about how we always looked forward to seeing him and how sad we are that he is gone from our lives.

Lou applied fundamental vision science to the design and evaluation of electronic displays. During his life, he published over 130 journal articles, book chapters, technical papers, and technical reports and was awarded over 30 patents for innovations in liquid crystal displays and liquid-crystal-based image-capture devices. He was an adjunct professor of engineering at the Georgia Institute of Technology and a visiting scholar in the Department of Medical Imaging at the University of Arizona. He received many honors and awards, including the Macbeth Award from the Inter-Society Color Council in 2004 for his outstanding contributions in the field of full color electronic displays, and the Otto Schade Prize from SID in 2008 for outstanding contributions related to display image quality and performance.

From the start of his undergraduate studies to the end of his postdoctoral training, Lou combined his interests in vision science with engineering. He received a BS, MS and PhD from the University of Florida. While studying psychophysics and vision science, he also earned master degrees in computer science and biomedical electronics. At the University of Wisconsin, Lou worked with Dr. Francis Graham, investigating the relationship between physiological measures (such as respiration, heart rate, brain EEG, eye blinks and eye movements) and different aspects of human behavior (such as sleep, attention and memory). In addition to his scientific research, Lou developed better engineering solutions for measuring EEG, eye blinks and eye movements. Throughout his career, Lou combined science and engineering.

Lou's first job in industry was with Rockwell International Corporation in Cedar Rapids, Iowa. Here he helped develop high-contrast, multi-color CRT displays for aircraft instrument applications. Lou used his expertise in color vision and human image processing to improve display symbology and computer-processed voice messages for aircraft advisory and warning signals. Lou used physiological measurements to quantify decreases in visual fatigue and operator workload. His improvements helped increase pilot acceptance of CRT displays in the cockpit and insure the safety of passengers in military and commercial aircraft.

From Rockwell, Lou move to Seattle Washington to work for the Boeing Airplane Company where he worked with a team of engineers developing the first aircraft "glass" cockpit using electronic color displays to replace mechanical avionic gauges. Lou's work in determining the visual requirements and measurement criteria for the displays drove the development of the Electronic Flight Instrument System color CRT hardware and display specifications and lead to the certification of CRTs on the 767 in 1982. Much of this work was captured in technical documents still referenced by the industry today. For this work, Lou and his colleague, Robin Merrifield, were awarded the Alexander C. Williams Jr. Award from the Human Factors Society in 1993 and an SID Special Recognition Award in 2004.

In 1983, Lou joined General Physics and shortly thereafter the Sperry/Honeywell Corporation's Technology Center in Phoenix. While he continued to work on color avionic displays, he also applied his expertise in vision research and human factors to simulate, design and evaluate new display technologies, including active matrix liquid crystal displays (AMLCD), laser projection displays and stereoscopic displays.

I first met Lou in the mid-80s when he was working at Honeywell. At that time Lou and his colleagues were developing methods for simulating and evaluating liquid crystal and plasma color matrix displays [1, 2]. Lou built a physical device to prototype and evaluate their ideas for new types of color displays. Lou's device was designed to create virtual images that would appear to be generated by different simulated displays. This was accomplished by displaying a magnified version of images on high resolution color CRT displays and then passing the images through a binocular optical system to create a minified virtual image. Lou could manipulate the virtual viewing distance by varying optical focus and binocular disparity and he could measure subjects' accommodation to make sure that they were focusing at the distance of the virtual image. Using this device, Lou and his colleagues measured the limits of fusion and depth discrimination in stereoscopic displays and the effects that different color sub-pixel patterns have on the visibility of sampling artifacts.

Lou helped me make a monocular version of his device at HPLabs so that I could study grayscale-resolution tradeoffs for inkjet and laser printers. I found, as Lou had found, that grayscale filtering improved the image quality of text and that there was little benefit of using more than 16 levels of gray[3, 4]. Using Lou's device to simulate printed text was the first of many ideas that I borrowed from Lou. Lou was very generous with his ideas and he gave me many free hours of consultation.

In 1990, Lou left Honeywell to start his own consulting company called VCD Sciences. As a consultant, Lou was able to work with many different companies working at the cutting-edge of display technologies, pushing forward inventions in thin crystal films, holographic polymer dispersed liquid crystals (H-PDLC), polymer-stabilized cholesteric texture liquid crystals (PSCT), field emissive displays (FEDs), full-color subtractive light valve displays, super-twisted nematic displays, near-to-eye virtual displays and many other new display devices. Not only did Lou understand and contribute to these technologies, he also believed that human vision was the key to understanding the engineering tradeoffs that would result in the best possible display given the limits of technology and manufacturing.

Lou's ideas about color-temporal synthesis [5] is an excellent example of how he was able to invent new color display technologies by combining his knowledge about human vision with the practice of testing ideas using computer simulation, physical prototypes and visual psychophysical measurements. I would like to take a few minutes to describe those ideas now to illustrate Lou's breadth and creativity.

The basic insight behind color-temporal synthesis is that by combining color matrix displays with two alternating backlights one can expand the color gamut of displays and minimize the visibility of color breakup artifacts that can arise with present-day field sequential displays. Figure 1 shows one possible combination of color backlights and filters. In this example, the backlights switch rapidly between long (yellow) and short (blue) wavelengths. The color filters in the display are cyan and magenta. When the yellow backlight is on (Field 1), the display is a checkerboard of red and green subpixels because the cyan filters only transmit the green light and the magenta filters only transmit the red light. When the blue light is on (Field 2), the subpixels are all blue because both the cyan and magenta filters transmit the blue light. The human visual system integrates the two fields over time and the display appears to have the full color gamut of an rgb display. Depending on the spectrum of the two alternating backlights, it is also possible to expand the color gamut of the display.

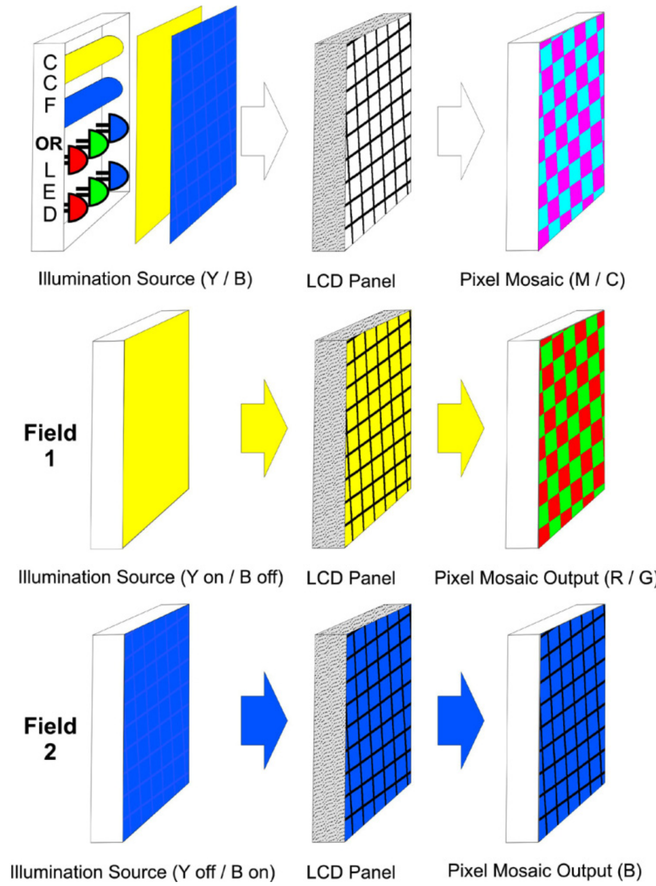

***Figure 1**: A display design using color-temporal synthesis. In this example design, the backlights switch rapidly between long (yellow) and short (blue) wavelengths. The color filters in the display are cyan and magenta. When the yellow backlight is on (Field 1), the display is a checkerboard of red and green subpixels because the cyan filters transmit the green light and the magenta filters transmit the red light. When the blue light is on (Field 2), the subpixels are all blue because both the cyan and magenta filters transmit the blue light. The human visual system integrates the two fields over time and the display appears to have the full color gamut of an rgb display. (Figure reproduced with permission from IS&T[6].*

This type of display reduces the visibility of color fixed pattern noise because a color filter array made with only two different filters (cyan and magenta) samples an image with higher spatial frequency than a color filter array made with three different filters (cyan, magenta and yellow). This display also mitigates the problem of color break up since the red and green pixels are presented in the same instant in time. To minimize the visibility of flicker, one needs a frame rate around 80 Hz which is considerably lower than the typical frame rate of today's field sequential displays. Lou explored many combinations of backlights and filters to find practical engineering solutions that expanded color gamut and minimized the visibility of flicker and color breakup.

Lou's ideas about color-temporal synthesis exemplify how his insights about human vision and his understanding of display engineering enabled him to invent displays with better color image quality. Many companies benefited from Lou's insights and expertise. I am tempted to list those companies now, but the list is much too long. I will point out, however, that Xerox holds 18 patents, Optiva holds 10 patents, and Qualcomm and Dolby Laboratories each hold two patents that include Lou as an inventor. In addition to the people who co-authored patents and publications with Lou, there are many more people, like me, who he advised and mentored during his lifetime.

During his too short but very active career, Lou always looked for ways to bring engineers and vision scientists together, whether it was at SID or CIC. He recruited young promising scientists and engineers to become active in the industry and on the SID and CIC program committees. He was on the SID program committee since 1984 and he became a Fellow of the SID in 1997. Lou chaired the annual International SID Symposium in 1993 and was the technical program chair in 1991. He was also one of the leaders in creating the Color Imaging Conference (CIC). Co-sponsored by SID and IS&T, this year CIC celebrates its 20th anniversary.

For many years Lou taught courses at SID and CIC on how to apply basic color vision science to display engineering issues. An excellent example of Lou's teaching style is represented in an article published in the IST Reporter in 2006[6] . In this article, which I highly recommend, Lou succinctly summarizes the state of the art in display technologies and how knowledge about human vision can be used to optimize the image quality of color displays. Lou was able to bridge the gap between the disciplines of vision science and display engineering and, in so doing, greatly improve the quality of color displays.

Lou was a man of great personal integrity, a wonderful friend, and a mentor to many young engineers and scientists entering the field. For those of us who were lucky enough to know Lou, his absence is strongly felt. His influence in the field of displays will be with us for many years to come.

References

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Author Biography

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