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Computer Controlled Color Displays in Vision Research: Possibilities and Problems

Extended Abstract

The recent general availability of display processors with enough memory to represent raster-based images in color on a pixel-by-pixel basis removes some technical obstacles that have significantly constrained color-vision research up until now. The paper summarized here will discuss (1) recent work (much of it as yet unpublished) by various investigators using this new technology; (2) its likely effect on future research directions; and (3) its associated difficulties and limitations.

Even the most straightforward experiments on color vision, for instance the measurement of color-discrimination thresholds along various directions in color space, have been cumbersome to implement because of the need to control and monitor separately the excitation of each of the three cone receptor types that are the basis of trichromatic vision. A computer-controlled color monitor affords improved convenience and flexibility in such studies, as illustrated in recent work by J. Krauskopf and L. Fallowfield[1] and by P. E. King-Smith and associates;[2] the techniques promise to be fruitfully applicable to diagnostic testing in the clinic.

A much-sought-after but elusive goal in the study of visual sensitivity is to be able to apply a test stimulus selectively to one color mechanism, while holding constant the excitation of the others. Because spectral stimuli typically excite all three cone mechanisms (and the rods as well), the desired test stimulus must be a "silent substitution" of one spectral radiance distribution for another. Computer-controlled displays make it easy to produce such substitutions, and the results of using them have sometimes been enlightening: For example, M. D'Zmura and P. Lennie[3] have shown that with a high-enough light level and suitable stimulus configuration rods (with the cones kept silent) exhibit a differential sensitivity close to that of the cones, with a differential threshold as low as two percent.

Another classical problem to which the new displays have made a contribution is that of heterochromatic brightness matching. The minimum-motion procedure of S. Anstis and P. Cavanagh,[4] described elsewhere[5] at this meeting, exposes the observer to superimposed red-green gratings drifting in opposite directions. Motion is seen in the direction of whichever grating has the greater modulation in luminance. Luminance nulls can be set in this way very easily and with remarkable precision. This precision could perhaps be carried over into conventional flicker photometry by fixing the intensity of the standard a few percent lower on one side of the flicker photometric field than on the other, the observer's task being to set the test intensity so the two halves of the field flicker equally. But the moving stimuli provide a uniquely vivid directional indication of matching error, and they also allow new questions to be raised. For instance, the luminance null turns out to vary by about 0.1 log units across the observable range of spatial frequency, with greater short-wavelength sensitivity when the spatial frequency is low. While this could suggest a contribution of the poorly resolving short-wave cones to the low-frequency nulls, experiments with selective adaptation do not support that interpretation. Instead it appears that the central fovea is more important at higher spatial frequencies and is less sensitive to short wavelengths, presumably because it has a higher density of macular pigment than the foveal fringe.[6]

A major contribution of computer-controlled displays is that by allowing easy control of pattern and movement they make it easy to examine the visual system's use of color in supporting spatial perception. Recent observations of P. Cavanagh and O. Favreau[7] agree with earlier ones of Ramachandran and Gregory[8] in showing that purely chromatic stimuli have very little capacity (although they do have some) to excite motion-sensing mechanisms. Form perception, too, is curiously degraded when objects are portrayed using purely chromatic contrast without any luminance variation; apparently the chromatic information cannot be used in the construction of three-dimensional shape from shading.[9] More than this is involved, though, as shown by the extinction or near-extinction of "subjective contours" and related illusions at isoluminance. The partial or complete exclusion of chromatic signals from various kinds of visual processing can now be examined much more readily, and the results should be fundamental for our understanding of the organization of the visual system as well as of how color is and is not used in vision.

Color appearance and color discrimination have typically been studied with quite simple displays, but interesting questions involving complex displays are now more approachable. One instance is recent work on the effects of discrete spatial sampling on chromatic and achromatic sensitivity: When a test waveform is viewed as if through a regular lattice of small windows, sensitivity is impaired to a degree that depends strongly on the luminance and color of the background separating the lattice elements, as well as on test and lattice spatial frequencies.[10,11] A second example is color constancy, which has resisted elucidation partly, perhaps, because of the difficulty of controlling experimentally many of the potentially relevant cues, such as the relation between specular and diffuse reflection, or between primary and multiple diffuse reflections. These effects are now much more open to investigation and though little work appears to have been done as yet, we can surely look forward to a renaissance of interest in these important but previously intractable questions.

Several more-or-less obvious limitations restrict the usefulness of these displays in vision research:

1. A uniform screen may be difficult to achieve. And, if a large field is used, retinal inhomogeneity also needs to be considered (just as with "natural" stimuli), especially in silent-substitution experiments.

2. Compensation for the eye's chromatic aberration is not as easy as with optical systems, and with broad-band phosphors perfect compensation at the screen is not possible.

3. Convergence (registration of the three chromatic components of the image) can be a problem. Experiments vary in their demands in this respect, depending, for instance, on whether central fixation is maintained.

4. Temporal control is limited by frame rate, and in some cases by phosphor persistence.[12]

5. Phosphor bandwidths are broad, and calibration can be problematical.[13] A linearizing table must generally be introduced to compensate for nonlinearity in light output from the phosphors. This is also a possible recourse in dealing with the fairly pervasive problem of interactions between the CRT guns. Equally common, occasionally important, and almost completely intractable, is the problem that, due to loading of the power supply, the phosphor intensity at one point will vary slightly depending on the intensities called for in other regions of the image.

6. Artifacts of spatial sampling by the raster are a recognized danger when the image has significant components at spatial frequencies exceeding half the pixel frequency.[12] With lower-frequency stimuli, sampling artifacts could arise from the interaction of the raster with the receptor mosaic in the retina. This is precluded, for foveal vision with the long-wave or mid-spectral cones, by the eye's optical low-pass filtering action, which limits the retinal image to frequencies that are very adequately sampled by the cone mosaic. For the more-coarsely spaced short-wave cones, or for peripheral vision, raster–receptor interactions might be expected at moderate viewing distances, but they have not yet been demonstrated.

7. With the use of one 8-bit digital-to-analog converter per CRT gun (as is typical), quantization errors can be enough to interfere seriously with many standard experiments (notably, sine-wave contrast-sensitivity measurements). If high contrast is not needed simultaneously with low contrast, the contrast range can be reduced by attenuating the DAC voltages or by optically adding a uniform field using front illumination of the CRT screen or by interposing a beamsplitter. If dichromatic or monochromatic vision is acceptable, a double-precision specification of radiance can be arranged by using suitably colored filters to attenuate the light from the "less significant" phosphor and make it more-or-less similar in appearance to the light from the "more significant" phosphor—a technique introduced by J. B. Mulligan. Alternatively, if some sacrifice in spatial fidelity is acceptable, the quantization errors can be reduced by halftoning.[14]

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