SPECIAL ISSUE

COMPUTERS IN VISION RESEARCH

Introduction

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It is a truism that what hitherto could only have been a thought or Gedanken experiment in vision research has now become a plausible and implementable experimental reality. This is, in large part, a result of the introduction of computer technology into this field of science. Computers have literally revolutionized vision research by providing new display, analytic, and data acquisition tools that permit us to carry out studies that were only dreams a few years ago. Complex visual stimuli varying spatially, temporally, chromatically, and intensively can now be manipulated with convenience and ease; data can be collected efficiently and automatically; and both statistical analyses and theoretical models can be constructed and tested nearly as fast as the data from an experiment becomes available. There has been, in the truest sense of Kuhn's (1962) phrase, a paradigm shift in visual science as powerful new information-processing and -presentation instruments have become ubiquitous in our laboratories.

As exciting as these changes have been, I must emphasize that it is not simply a matter of being able to do more quickly and better what we have always done; that would be a mere change in the time constant of visual experimentation. Rather, a major qualitative change has occurred in the nature of the experiments carried out and the theories generated. The prototypical visual stimulus is no longer a brief flash of a colored spot of light, but a scene in which the spatial attributes of the stimulus can be instantly transformed and modified in ways that would have brought joy and delight to the hearts of perceptual psychologists of earlier times. They could only dream then about what is commonplace now. They probably could not even have dreamed of some of the things that have happened to our understanding of visual processes.

Perceptual theory has also undergone some profound transformations as a result of the availability of general-purpose information processors. It has changed from more or less imprecise verbal models to precise computational

algorithms that can be verified or falsified in virtually microscopic detail. In my opinion (and this conjecture will probably meet with substantial disagreement) we are in the process of returning to a much more Gestalt or global context for our theories, simply because we can now manipulate form as a stimulus dimension in our experiments. New displays and software techniques have become available that allow us to generate with comparative ease representations of objects in motion; objects with projective, or even stereoscopic, depth; or surfaces with varying textural properties. New psychophysical techniques and statistical procedures that would have consumed the energies of armies of research assistants and months of time now can be carried out with great dispatch by an individual investigator.

In short, the computer has changed both the practice and the conceptualization of visual research and promises to continue to bring change as further innovations become available. As usual, psychologists and researchers in related fields have been among the first to make use of innovations in information-processing technology. There is, perhaps, no more compelling example of this assertion than some of the immediate applications of the first commercial parallel processing computers—devices that literally have become available only in the last few months—by computational vision researchers.

Thus, the impact of the introduction of computers into vision research has had some dramatic and overt effects. It also has had some subtle effects that are not always appreciated unless one has been around long enough to have seen the changes taking place. Two such subtle effects are the substantial increase in the experimental output of most automated laboratories and the substantial reduction in the lag between data collection and publication. Another is the reduction in the number of menial jobs for research assistants. The clipboard has virtually disappeared and has been replaced by the machine-readable code on a floppy disk. Thus, even the social structure of the vision laboratory has changed as a result of the introduction of small computers that can be committed to the work of the individual investigator. Most significantly, the change is evi-

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denced by the enhanced intellectual quality of the experiments and theories that currently characterize this field.

This revolution has not been without its difficulties, of course. At one time, as the editor of this journal once pointed out, most of the computers that had been installed in psychological laboratories were not being used or, as I once pointed out (Uttal, 1972), were being conceptually misused. It is still not an easy thing to abandon one's paradigm in midcareer and "computerize," and some of the adventures in so doing, as we shall see in this issue, are not without their humorous side, even if they were painful. But many of the early difficulties are behind us. New and better trained vision scientists have taken the place of their predecessors. (It is humbling to observe the enormous mathematical competence and sheer intellectual ability of some of the outstanding younger people in this field.)

Futhermore, computers have achieved a level of dependability that is close to that of any household appliance. People who did not experience it cannot appreciate some of the frustrations of working with some of the early equipment—including paper tape readers that could not read tapes, bootstrap loading programs that had to be inserted bit-by-bit by hand, microscopically small memories of 4,000 words or so, and, perhaps worst of all, a programming interface between the programmer and the computer that spoke only the bare-bones, binary language of the computer. We now can program in special-purpose languages particularized for formula manipulation, statistics, and even images. We can now simply plug in what is often a commercially available device to implement some necessary experimental function rather than laboriously construct a special electronic circuit that fulfills that function.

Another important development is that the computer power available to the individual experimenter is so enormous that the difficulties of time-sharing large computers for real-time experiments are, for all practical purposes, no longer an issue in this field. Individuals now own computers that are the equivalent in sheer processing power of entire computer centers only a few years ago. Indeed, it is probably the case that very few vision researchers are in need of any greater computer power or response time than that available off the shelf in what is becoming a very small package. This is evidenced by the fact that virtually all of the responses to my invitation to present an article dealt with techniques that utilize independent computers rather than time-shared systems.

The idea for this special issue arose at the annual meeting of the editorial board of *Behavior Research Methods, Instruments, & Computers* in 1985. An increasing flow of papers had been coming to the editor dealing with the various ways in which the computer was having an impact on vision research. Editor Sidowski, as usual, had the insight to appreciate that this particular field of application of computers is especially mature, and that the applications of computer technology to the study of vision are general enough to represent a tutorial for other fields

of behavioral research as well. When he suggested to me that I organize this special issue, I was excited by the concept and promptly accepted. It was only later that I realized that it was going to be a very difficult job to make up the list of invitees who would be asked to make a contribution to this special issue. There are many investigators who have productively used computers in their laboratories, and the list of vision researchers whom I approached obviously does not include all of them. I selected a group that I thought might provide a relatively broad cross section of accomplishments. The authors were asked to emphasize the applications of and the influences exerted by the computer, but not to exclude substance. Their responses ranged from those that are purely methodological to those in which the problem holds center stage.

The organization of this issue was determined by the nature of the responses and, I believe, correctly reflects the state of the field. Most contributions were concerned with software, a category within which I include theory and statistics. The first section contains papers that discuss software techniques for generating visual stimuli of one kind or another on several different kinds of displays. Virtually all of them use the cathode ray tube (CRT) (in either a raster or point-plotting mode) as the display of choice. The CRT has become the magic slate of vision researchers, but only because of the computer's ability to manipulate images on it. All of the papers in this first section deal with the generation of stimuli that possess complex spatial, temporal, or spatiotemporal attributes—a class of stimulus material that had been nearly completely missing from the media of visual experiments in the 1940s, 1950s, and 1960s. It cannot be overemphasized how these dynamic displays, producing percepts as elaborate as three-dimensional colored forms in complex motion, have substantially changed the face of our science; as one can see from surveying the articles in this issue, vision scientists are not only doing the same things their predecessors did only a few years ago; they also are attacking entirely new problems.

The second section consists of three papers concerned with the hardware of computers and computer-driven displays. Technological innovations are obviously on the way, including what is essentially an instantaneous, random-access, scene-storage unit. The tutorial on that topic and the other useful hardware papers remind us that there is much more yet to come and that the necessity for developing new techniques for properly utilizing these innovations will constantly be with us.

I, personally, am impressed by the impact of the new computer technology on theory even more than I am by its impact on experimentation. The three papers in the third section demonstrate how computers have sharpened and strengthened the theoretical enterprise by introducing entirely new concepts into the explanations we generate of the phenomena we measure.

Statistical techniques have evolved in recent years that are impossible to implement without computer power. The fourth section presents papers describing two of these.

Finally, we have had the good luck to have two senior vision researchers present two very personal anecdotes describing some of their experiences as they went through the transformation from the precomputer to the computer laboratory. These two nontechnical papers are extremely informative about the pains and pleasures of undergoing this change and are also enjoyable reading.

As the special issue editor, I had one previously held opinion strongly reinforced. Joe Sidowski, the editor of *Behavior Research Methods, Instruments, & Computers*, has made a major contribution to psychology by his dedicated service to this journal. Joe was of enormous help to me in processing these papers in what was to turn out to be an extraordinarily short publication lag. The authors of the various articles and I owe him an enormous debt for his sharp editorial pen and organizational skills. The extent to which this issue achieves its purpose—spreading knowledge about the use of computers to other behavioral scientists—will largely be of his doing.

I would also like to express my appreciation to the authors. There was an overwhelming positive response

to the invitations that I sent out, and almost everyone met what even I thought at the beginning was a very optimistic deadline.

We are witnesses to a true paradigm shift in vision research, largely attributable to the introduction of computers. There is currently a special excitement and vigor to the field that makes it extremely satisfying to be a participant in this enterprise. It is also stirring to step back and look at some of the effects this technological development is having on our science. A collection of papers of this sort helps to achieve that broad perspective. The one thing that is absolutely certain, however, is that we are only at the beginning: There is much more to come.

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