Computer animation for the academic community

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INTRODUCTION

The use of computer-graphic technology to produce low-cost films for education promises enormous educational benefit at modest cost. For educators, these technical developments are but a means to an end which has thus far received too little attention—the production of visual images that in their ability to communicate ideas are superior to traditional graphical images on paper or blackboard.

The printed word is symbolic, whereas the TV image is primarily iconic. New modes of iconic display may be needed to communicate with young people of the TV generation. Here, computer animation offers remarkable possibilities—instead of static images, words, and mathematical symbols, we may create dynamic signs that move about and develop in self-explanatory ways to express abstract relations and concepts.

Recent research emphasizes the importance of these possibilities. According to Bruner, intellectual development moves from enactive through iconic to symbolic representations of the world, with each level serving to define and give meaning to the next higher level. Education today primarily proceeds at the symbolic level; iconic modes of communication and instruction remain virtually untapped and warrant much more attention. In effecting this, computer animation is certain to play a major role.

The cost of showing

Major efforts to develop films for the classroom have been made during the past decade by various groups interested in improving education in fields such as mathematics, physics, and engineering. Most of these films have attempted to recreate in the classroom experiments and views of real phenomena that the student would otherwise miss. These films are of high quality and made by professionals at places such as the film studios of the Education Development Center, Newton, Mass., in cooperation with one or more principals from the academic community. They have been costly to produce (around $2,000 per minute of finished film). Because of the growing use of these visual materials in schools, however, they can be justified as a worthwhile investment that will reap educational benefits for years to come.

Recent advances in computer-graphic technology are obviously of great interest to educators. Of these graphical techniques, computer-generated film offers many attractive potentialities for the same reasons that studio-made films do. The production of elaborate visual sequences under interactive control of a human makes excellent economic sense for educational purposes provided the final product is recorded on film (or video-tape) for low-cost duplication and distribution to many other viewers. We consider the notion that these sequences should be produced individually under the interactive control of a single student for his sole benefit to be an economic absurdity at present. The realities of the high cost of computing are all too evident to those of us at schools struggling to support even batch-processing utilization of computers for education. Hence, to those wealthy few, who are fortunate to have such graphical displays available, we direct a plea that they should consider arrangements by which other interested members of the academic community can use their facilities for the very beneficial production of computer-animated films for the entire community.

In the remaining portion of this paper, we would like to discuss some aspects of computer animation that have received sparse attention and yet which are vital, we feel, to the ultimate success of films as an educational device. We have heard many papers and
much discussion of hardware and software for computer graphics at recent meetings, but virtually nothing concerning the design of appropriate symbols and conventions for portraying ideas and concepts. Enormously elaborate and costly equipment is used to produce images which are primitive and poorly designed to communicate the desired information. The technical apparatus of light-pens and data structures has so monopolized our attention that we have forgotten that all of this is but a means to an end—the production of visual images that are superior and more lucid than the traditional graphical images on paper or blackboard.

Perhaps it is unreasonable to expect those responsible for the development of the hardware and software to also be deeply concerned with the quality and properties of the graphical images that may be produced, but for those of us in education, this latter aspect is of ultimate importance. Some of us are making educational films without benefit of light-pens, online oscilloscopes or immediate access to microfilm plotters. Typically, these programs have been worked out on paper; the desired sequences translated into some appropriate assembly or compiler language; the program run on a machine such as an IBM-7094 which creates a magnetic tape that is then sent to an SC-4020 microfilm plotter located in another city where the actual film is produced and returned to the originator after a delay of 3 to 20 days or more! For those accustomed to using interactive graphical displays, such a tortuous process must appear intolerable. Yet, you may be surprised to learn that the long delay has not been as serious as one might expect because the conceptual design of the storyboard and the invention of appropriate conventions and schemes for showing the intended ideas and concepts in an accurate and perceptually clear way is even more time-consuming and difficult than the straightforward task of writing and processing the computer program to make the film.

It is in the art of showing ideas and concepts that educators can make their greatest contribution. Although computer-graphic terminals would be nice to have at every school, these elaborate and costly facilities are by no means essential. For instance, a high-school student, Garrett Jernigan in Raleigh, North Carolina, has written a short animated film to show the earth-moon system in true proportion, and to emphasize that the moon and the earth each revolves around the center of mass of the earth-moon system—a nice lesson in mechanics. The movie starts with a far-out view of our galaxy, then zooms into our solar system. After the earth-moon system is identified as one of the planets moving around the sun, the moon is shown revolving around the earth, with relative sizes and distances accurately portrayed. A further zoom toward the earth reveals on close view that it too is also nutating around the common center of mass. Jernigan didn't have even a computer, but he had the imaginative idea which enabled him to program these sequences in FORTRAN IV punched onto teletype tape. These tapes were mailed to Johns Hopkins where we ran the program on our IBM-7094 and then sent the magnetic tape containing the graphical instructions to Polytechnic Institute of Brooklyn for processing on their SC-4020.

The art of showing

We shall always be grateful to J. C. R. Licklider for bringing to our attention nearly 5 years ago a remarkable book by Gombrich. Until then, we had not been fully aware of how important is cultural conditioning in altering the perception of visual images. Gombrich examines in depth the notion that all art (and visual communication, generally) involves illusion and he shows that a "realistic" representation always incorporates unrealistic conventions that must first be learned and then ignored. In our own culture, where photographic-like representations have been so highly developed, most people would regard a photographic portrait of a human head in profile as a more realistic representation than a Picasso drawing showing both eyes in a profile view. Yet, if you were to show the two representations to a visually illiterate aborigine, he might select the Picasso as the more realistic because the photograph shows only one eye, whereas most people have two eyes (as realistically represented by Picasso). The conventions of perspective, which seem so natural and absolute to us, are quite unnatural to the savage who may, in fact, not even recognize a photograph as a picture but see it simply as a blotchy, discolored piece of paper (which it is!). (Incidentally, although visually illiterate people may not perceive the content of a still photograph, they always perceive the moving images in a motion picture. This observation emphasizes the likely advantage of computer-animated presentations, particularly for elementary and secondary-school education.)

Unlike the aborigine, nearly all school children in this country today are extremely literate visually. It is estimated that on the average they will have spent between 10,000 to 15,000 hours watching TV by the time they finish school. The impact of TV on our culture today is hard to evaluate, but there is little doubt that it is enormous. For instance, one of us has found that disadvantaged first-graders of the Baltimore inner-city schools have better developed abili-
ties to associate and use common words than the more privileged children of corresponding age in suburban schools. Furthermore, by the time children finish elementary school their verbal associative structures appear to be much further developed than students of the same age who lived 50 years ago or than students who today are members of cultural groups in which TV is little used. That these effects are a direct consequence of television seems very likely; slum children spend much more time watching TV than children in middle-class homes where a larger part of their time is directed by parents and teachers toward other activities.

These young people of the TV generation seem to have developed a different kind of visual literacy than those of us who grew up prior to TV, and new modes of visual display may be needed to communicate effectively with them. The printed word is symbolic, whereas the TV image is primarily iconic. Yet our traditional modes of communication in science and engineering are still dominated by symbols rather than by the icons to which the TV generation is habituated. Here, computer animation offers remarkable possibilities that have never before existed—instead of static images and mathematical equations on the printed page, we may now create dynamic signs that move about and develop in self-explanatory ways to express abstract relations and concepts. These potentialities for iconic communication of the quantitative ideas central to science and engineering are only now beginning to be exploited; most of the imagery that we have seen produced by computer graphics in CAI and other applications has merely transferred the traditional static signs and symbols from the printed page to the cathode-ray tube. A dynamic dimension is now available that requires the invention and development of new conventions and a visual syntax appropriate to this new medium if it is to be fully used for communication and education. (These possibilities are suggested by the computer pantomimes which communicate quantitative concepts without using words or equations.)

The technical advantages of computer-animated films have been discussed elsewhere. Not only is animation produced in this way likely to be much less costly than traditional animation, but one person can do the whole thing, from conception of the idea through programming and production of the final film. It thus becomes feasible to study alternate schemes for displaying certain ideas by developing at low cost a wide range of visual materials useful for empirical tests with student subjects for evaluating the effectiveness of these different schemes.

In making a computer-animated film, if one deliberately avoids the use of traditional words and mathematical symbols and attempts instead to portray all abstract ideas iconically, he quickly learns that “one word is worth a thousand pictures!” He also soon discovers that many of the signs traditionally used in science and engineering are inadequate for conveying many familiar concepts without first introducing irrelevant details freighted with erroneous artifacts and implications. For instance, in some recent research on the design of symbols for representing electric circuits, we found it very difficult to indicate cause-effect relations. (We finally used an inelegant anthropomorphic symbol shaped like a human hand to change the value of the source signal.)

Another unsolved problem is how to portray a continuum field, such as the electric potential around a set of charges. The portrayal of a vector field using the familiar stream lines (or lines of force) leaves much to be desired because the direction of the lines is not easily shown, (e.g., arrowheads introduce broken-line segments which violate the portrayal of smooth continuity of the field). Furthermore, when one attempts to superimpose two such fields, as in demonstrating the superposition of forward- and backward-traveling waves on a transmission line, a whole host of spurious effects result as field lines cross each other or vanish and reappear from nowhere, and perform other atrocities. These difficulties arise even in showing simple, two-dimensional fields; traditional conventions are completely inadequate for portraying general vector fields in three dimensions. New ideas are badly needed for representational schemes that will be free of these bothersome artifacts.

The theory of showing

In his recent important book, Bruner (who is the country’s leading cognitive theorist) has suggested that the acquisition and understanding of information generally proceeds through three stages:

1. Manipulative — personal action
2. Iconic — perceptual organization and imagery.

These stages occur in the development of every child. In the beginning, the child manipulates and experiences things surrounding him in a most intimate and direct way. Later, he recognizes things by their appearance, and the images in his environment acquire an autonomous status as he explores the similarities
and differences among the concrete objects around him. The child begins to observe that things are related to other things in more or less predictable ways. As he becomes aware of geometrical and other invariants in his environment, he is able to make predictions and extrapolations from what he perceives on any single occasion and to further refine his internalized model of the world. A major advance occurs when he gives symbolic names to these perceptions and relationships and gradually begins to use words to stand for objects not present. Finally, through absorbing a generalized syntax and semantics, he learns to use words and other symbols to deal with ideas and thoughts for which there are no direct referents in immediate experience.

As intellectual development moves from enactive through iconic to symbolic representations of the world, each level serves to define the elements of the next higher level. Like nested macro instructions in a compiler, the abstract symbols expand into more primitive instructions that are often iconic so that the abstract symbols will have concrete meaning. If the learner has a well-defined symbolic system, it may be possible to bypass the first two stages and communicate with him purely at the symbolic level. But too often, the learner may not possess the imagery to fall back on when his symbolic transformations fail to solve the problem, and for many persons it may be impossible to rely entirely on a completely symbolic mode.

We wish to draw an analogy between the process of programming a computer and the process of instructing a student that may (like most analogies) be of questionable value, but it will serve to emphasize a worthy point. A source program in a high-level language, like FORTRAN, is purely symbolic and, by itself, has no meaning to the computer until expanded into a more primitive set of assembly instructions which are recognizable by the machine. Insofar as the computer is concerned, these assembly instructions are iconic. But they, in turn, must be defined in terms of actual manipulative actions performed by the built-in operations of the machine.

In terms of this analogy, the major task of instruction is to provide the computer with a useful compiler, rather than with a multitude of FORTRAN source decks. Certainly no one would attempt to read a FORTRAN program into the computer before a working FORTRAN compiler had been entered into its memory. Yet, the analog of this is attempted every day in the instruction of students. No, that is not quite correct: a FORTRAN compiler is, in fact, first entered—but it, too, is written in FORTRAN!

In his closing paragraph of Chapter 3, (page 72), Bruner states:

"Finally, a theory of instruction seeks to take account of the fact that a curriculum reflects not only the nature of knowledge itself but also the nature of the knower and of the knowledge-getting process. It is the enterprise par excellence where the line between subject matter and method grows necessarily indistinct. A body of knowledge, enshrined in a university faculty and embodied in a series of authoritative volumes, is the result of much prior intellectual activity. To instruct someone in these disciplines is not a matter of getting him to commit results to mind. Rather, it is to teach him to participate in the process that makes possible the establishment of knowledge. We teach a subject not to produce little living libraries on that subject, but rather to get a student to think mathematically for himself, to consider matters as an historian does, to take part in the process of knowledge-getting. Knowing is a process, not a product."

CONCLUSION

What, then, may be concluded from all of this? We believe that there is tremendous untapped potential in the use of iconic modes of communication to give fuller definition to the symbols that so dominate the classroom today. There is a paucity of experimental evidence on this issue. Nevertheless, we have prepared a self-instructing text for use at the early college level to teach the major concepts of modern system theory by using the highly iconic notation of signal-flow graphs. Judging from student response this approach has been very effective. In another vein, the studies of Rohwer show that pictorial presentation of pairs of objects to elementary-school children leads to better association between the objects than verbal presentation of pairs of words representing the objects. At the college level, this difference vanishes, reflecting probably the greater symbolic competence of the older person.

What may be true is that the iconic stage, largely ignored, has had an aborted development. Who knows what the potentialities may be? Young children, adults, people who have never been "hooked" on reading, are those most addicted to TV—it is as if there is a vast starvation for meaningful communication that has never been met by the standard media using printing. Instead of bemoaning this, one could exploit it. What would happen, for instance, if even modest sums from Headstart were diverted to producing TV programs of educational use to four-year-olds?

We agree with Bruner when he states (page 34) "that principal emphasis in education should be placed upon skills—skills in handling, in seeing and imaging, and in symbolic operations, particularly as these relate..."
to the technologies that have made them so powerful in their human expression." He mentions the increased visual power and subtlety of students exposed to courses in visual design, and the experiments by Holton and Purcell at Harvard with instruction in visual patterns as a mode of increasing the ability of physics students to represent events visually and non-metrically. He believes "that we have not begun to scratch the surface of training in visualization—whether related to the arts, to science, or simply to the pleasures of viewing our environment more richly."

We believe these theoretical considerations justify much more effort toward the development of iconic modes of communication, and that computer animation can play a major role in these developments, both at the research level and in the classroom. In particular, the subject matter of system theory offers many interesting opportunities for visualizing the topological and dynamic relationships that occur in models of many fields. It is a stimulating and challenging area for study. We commend it to you.

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