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COMMUNICATION, SIMULATION, AND INTELLIGENT AGENTS: IMPLICATIONS OF PERSONAL INTELLIGENT MACHINES FOR MEDICAL EDUCATION

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Hardware advances in the next decade promise to make possible new medical educational technologies. New media for expressing, collecting, and sharing knowledge will provide students with means for coping with the increasing amounts of information. Novel means of graphically modelling physical phenomena--providing motivating and intuitively pleasing means for explorative interaction--could complement and sometimes replace traditional text material. Intelligent programs may serve as assistants, serving roles ranging from calculator to librarian to tutor, embracing a full range of secretarial and problem solving aids. This short paper outlines these opportunities, illustrating them with examples of existing prototypical artificial intelligence programs.

Introduction

Powerful personal computers can be expected to be widespread in the near future. Just as the expensive numerical calculators of the 60's evolved into nearly disposable, wafer-sized machines and the prototype 8-bit "home computer" of the late 70's, today's machines will be replaced by affordable, much more versatile intelligent computers. With the advent of 16-bit machines, a qualitatively new type of computing is possible. Much larger, more complex programs can be written, of the type that until recently required a million dollar, institutional, time-shared computer. These programs, with their evolving capabilities to teach and solve problems, will be the basis for widely available educational tools in the next few decades.

From their advent, computers have been used for educational purposes (1,2). Current applications include computerized library catalogs, interactive instructional programs, and, more recently, visual presentations made possible by the video disk. But this is just the beginning of what computers might do for us. Mass distribution of machines, simulation environments for exploratory learning, and programs serving as our intellectual assistants may make current computer applications seem as rigid and dry as the mechanical desk calculator appears to us today.

Educational applications of computer simulation

To people who only encounter a computer at a bank or through bill printouts, computers are merely numerical calculators. However, in the past year, millions of video games have been sold in the home market, demonstrating to everyone that graphical display and control of images is something computers can do, too. Simulation with a computer often connotes some medium of expression--an image or sound. On the other hand, the earliest computer simulations were of abstract processes such as traffic control or industrial production.

Simulation in a broad sense means imitative reproduction of any process--whether imagined or real, physical or mental. In medicine, computers have been used to simulate ambulatory care emergencies, anatomic and organic processes, the sound of a heart, and diagnostic reasoning. It is useful to characterize simulation applications broadly as: *macro prediction, cognitive modelling, experimental laboratories, exploratory environments,* and *media synthesis.* These are described briefly below. While there are implications for many areas of medicine, the focus here is on educational applications. No attempt is made to provide an historical survey of medical applications; the examples are chosen just to illustrate the ideas.

Macro prediction Simulation modelling at the macro level is a technique for discovering and exploring the effects of multiple parameters in a complex system. For example, one program, part of the PLATO system (3), helps a student to learn how to effectively treat malaria. He specifies a combination of hospital beds, spraying of DDT and draining swamps. The program uses its author-specified model to simulate the effects of the student's mix of solutions. Thus, the student is provided an engaging means for learning what could have just been a dry text-book presentation. However, the form of technology does not permit the student to easily specify his own models in an attempt to explain data. Simulation programs could be made more flexible in this way using artificial intelligence programming techniques.

Exploratory environments and graphical envisoning The idea of macro modelling can be generalized to allow exploration and discovery of any process. For example, a student could change the pH of fluids in a simulated body system graphically displayed before him, and watch the effect on body processes. The function of blood cells might be modelled in a way that allowed the student to experiment with and so discover the relation between chemical and geometric structure and physiological function.

Going a step further, a student could be provided with a workbench for assembling his own anatomical units and systems at the molecular or organ level. Given an appropriate level of primitives, he could build a circulation, nervous or digestive system and see how they interact. Or he might be given a working simulation and allowed to disassemble it to see how the system degrades, and so learn about its construction.

Prototypes of these ideas include the well-known LOGO programming system by which children are taught ideas like recursion and functional modularity by programming a "turtle" to draw pictures (4). More recently, instructional games like "Rocky's Boots" provide an electronic form of tinkertoys, by which a student can learn electronic logic design by building automata with "crocodile detectors" and "thrusters"(5).

Cognitive modelling Significant advances have been made in modelling cognitive processes in the past decade. A program like NEOMYCIN is an attempt to model knowledge structure and reasoning process in a way useful for teaching medical diagnosis. (6) Programs can be used as formal embodiements of theories, and possibly provide the means for better instruction through a better understanding of how people reason (7). In particular, advances in our understanding of analogical reasoning and mental models, as well as the errors that derive from incomplete models, (8) may help us choose explanations to facilitate understanding and avoid misconceptions.

Experimental Laboratory A computer can simulate situations (such as an emergency room encounter) and equipment in a way that enables a student to directly manage a problem, as if the real objects were before him. The SIM-1 medical simulated body (9) is one early example, but completely graphical presentations might be just as useful. A prototype is Brown's SOPHIE program, in which a student learns electronic diagnosis by taking measurements and replacing parts in a simulated faulty circuit (10). STEAMER allows a student to experimentally control and observe the propulsion plant of a ship (11). It makes use of color graphics, tied to a complex mathematical model--and runs on one of the new personal LISP machines.

Media synthesis It has always been important to convey the appearance and sounds of illnesses to a student. A programmable video disk, color displays, and sound synthesizer could be used with any of the applications mentioned above. These could all become more complex and useful as software is developed to exploit the computers with larger memories and processing power that will soon be available to students.

Educational applications of intelligent agents

In contrast with simulation programs, intelligent agents are programs with problem solving capabilities for assisting in some intellectual task. These are the programs we usually associate with artificial intelligence.

Calculation Perhaps the most common form of intellectual assistance we receive from a computer is in numerical calculation. It is quite possible that the day will come when students are taught how to apply mathematics, such as calculus, before they learn how to perform the calculations themselves. Already complex programs, such as MACSYMA, shoulder some of the burden of symbolic integration that previously required hours of scientists' time (12). Programs could calculate and display graphically relations such as loading attenuation of antibiotics during renal failure (13), freeing students from having to learn the details of the mathematical models. Our cognitive research may help us discover just what qualititative level of understanding will be useful for students so they can retain the responsibility for applying and monitoring these tools.

Secretary and Librarian The use of word processors is now widespread; these are surely a boon for students for preparing reports. Students with access to more complex computing facilities use the computer to assemble reading lists and bibliographies. While a great deal of tedious online entry is required, it is inevitable that library indices will be accessible some day to every computer terminal, just as we now go to the library today to access special citation databases, such as via MEDLARS. Advances in programs that can read and summarize text (14) suggest that a computerized librarian, knowledgeable about all journals and texts, as well as our interests, will help students and researchers sift through and digest the huge amount of printed material that is growing exponentially in the world today.

Facilitator One problem with simulation programs is that their usefulness is limited by the imagination of the student. Just as a child might never think to build a certain kind of structure from his tinker toy set, or not know how to use a certain component, a student may not make use of all of the computational facilities that a simulation or intelligent agent program makes available. A facilitator or "coach" is a program that watches silently in the background, observing the patterns of a student's behavior. Interrupting non-obtrusively, or only upon request, the facilitator points out how a student can enrich his interaction with the program, perhaps by setting goals for the student such as constructive tasks and experiments to try. A prototypical example is the WEST Coach by Burton and Brown which helps a student to learn mathematics while playing a game (15).

Tutor In contrast with a coach, a tutor directly interacts with the student, constantly testing his understanding, setting tasks, and generally defining the instructional sequence that the student will follow. The GUIDON tutorial program is a prototypical artificial intelligence system for teaching medical diagnosis (16,17,18). This kind of program, termed an "intelligent tutoring system", has an internal representation of the knowledge to be taught. This knowledge is used by the program to solve problems in parallel with the student, to evaluate his partial solutions, and to generate questions. Since teaching knowledge is represented in a similar manner, independently of the knowledge to be taught, these programs are very flexible. Without reprogramming, any medical case in a library of cases can be discussed. In addition, the same teaching knowledge can be used for mulitiple problem domains. In essence, the "authoring problem" of CAI reduces to constructing the knowledge base to be used by the teaching program, an extreme gain in efficiency and important step towards formally evaluating teaching procedures.

Diagnostician A number of diagnostic intelligent agents have been constructed in the past decade (19). These programs, like those that perform calculations, might some day act as routine problem-solving aids. Today students can use them to stimulate their own thinking, or learn indirectly by instructing the systems. The NEOMYCIN research indicates that these programs are not necessarily good models for students to emulate, for human ways of organizing knowledge and reasoning must be respected.

A different kind of diagnostician can be used to model a student's reasoning and characterize the cause of his errors. A facilitator or tutor can then intervene to correct the student. Brown and Burton's BUGGY system is a prototype of this kind for diagnosing subtraction errors. Designing instructional sequences to elucidate and correct student misconceptions is an important educational approach. (20).

Scientist, Designer, Planner We can imagine that many human intellectual functions might be assisted by intelligent programs, just as human specialists are in demand today. Rather than replacing specialists, these aids could raise their level of concern beyond the routine and easily solvable to the level of planning, conception, and discovery. Some prototype artificial intelligence programs suggest that these tasks, too, can be performed to some extent by computers.

A student interested in medical discovery might work with the RX system to learn how to perform empirical studies of causal relations using large data bases (22). A biomedical engineer could benefit from computer aided design tools that helped him visualize new devices and their operation. Planning is basic to most problem solving; intelligent agents that can plan will act as facilitators for other instructional systems, research assistants for scientific experiments (23), and so on. In each case, the intelligent agent brings the student to a higher level of problem-solving capability more quickly, replacing part of the routine and setting up the student to focus on the tasks that need to be mastered.

The benefits of enhanced communication

The mass distribution of computational systems like those described above can be expected to have a profound impact on education. To begin with, these systems will be *engaging* through their realism and the high level of attention they will demand. They will be *expressive* through their computational and graphic complexity, allowing high fidelity simulation and hence communication of scientific models. By their affordablility, the systems will bring about a *distribution of knowledge* and pedagogical methodology that has only been foreshadowed by television by its ubiquity and potential to spread ideas.

Distribution will make possible a *sharing of ideas and products* through computer networks (24) that will enable individual schools and teachers to extend contact beyond annual conventions. Similarly, *data collection* and the study of educational alternatives will be facilitated by these networks, so research on teaching will be facilitated.

Perhaps most importantly, *knowledge will accumulate* in a way that will make books seem inert and one-dimensional. Knowledge bases as "dynamic books" (25) can be explored and modified by the student, "run" as models to simulate phenomena, applied to solve problems (diagnosticians, designers, scientists, or planners), or used as the basis of active instructional systems.

Conclusion

This paper is deliberately speculative, but every possibility described here has a concrete realization in some computer network, simulation, or intelligent agent program in operation today. The benefits for medicine of course go well beyond education, to include all forms of patient care and physical aids, such as intelligent prosthetics.

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