

## Computers and creativity

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“The real danger is not that computers will begin to think like men, but that men will begin to think like computers.”—Sydney J. Harris

“Technical skill is mastery of complexity while creativity is mastery of simplicity.”—Christopher Zeeman

The essence of research is discovery. This activity is driven by two factors: a desire to know new things and a creative state of mind. The desire to discover is turned into exploration of the unknown by formulating the right questions, whereas a creative state of mind is indispensable in striking out in new directions.

It goes without saying that computers are invaluable tools in carrying out research. Computers have always been important in helping to formulate hypotheses and check theoretical calculations—even when a *computer* was a person. Prior to publishing their astonishing theorem on partitions, Hardy and Ramanujan benefited from the numerical results of an army of human computers who spent weeks calculating partitions by hand, while Feigenbaum, playing with a desktop calculator, discovered the universal behavior of period doubling bifurcations.

Computers have also had a profound impact in popularizing and disseminating mathematical insights that would be otherwise limited to a small community of scholars. For example, although Poincaré and Hadamard almost 100 years ago had a truly modern understanding of chaos and sensitive dependence on initial conditions, it wasn't until the widespread availability of computers allowed easy numerical simulations that these ideas led to a wholesale shift in our view of dynamical systems, deterministic chaos, and the loss of predictability. Similarly, although Cantor constructed the first fractal set in the 1870s, where would fractal science be today without high-resolution color graphics?

Large-scale (brute force) numerical modeling not only makes it possible to simulate experiments that cannot be carried out otherwise (e.g., observing the fine structure of wave propagation within complex media), but also opens up the opportunity to quantify the phenomena that one studies. Modern experimental science would be impossible without computers. Striking illustrations of this can be found in geophysics and

astrophysics, which involve the digital recording and processing of terrabyte data sets, and high-energy physics, where extremely rare events are buried within a staggering volume of less interesting “noise” and roomfuls of computers are needed to sort the data as they are acquired.

Data mining, visualization, cluster analysis, and exploratory data analysis are all computer-assisted ways of looking for features or correlations in data that are not apparent by ordinary human inspection. The resulting insights can be fundamentally new, and the scale of such problems currently being studied is driving much new research in computer science.

And last but not least, computers free our minds by alleviating the daily chores of writing (now with the word-processor—although it's remarkable how many more drafts we go through now than 20 years ago), making figures (using drawing programs), time management (with the electronic calendar), communication (with e-mail), information retrieval (through the Internet and database programs), and a large number of other tasks.

Nevertheless, the use of computers is not without its dangers, and three pitfalls can readily be identified.

- 1) Computers often are a sink of valuable human time. Every computer system requires a certain amount of effort to make it operate. In addition, researchers often spend an inordinate amount of time tailoring their computer to their taste at a level of detail that is not required by the work that needs to be carried out. Of course, the investment of time up front in customization can pay long-term benefits in efficiencies, but it's easy to go overboard. The worries of using the computer can actually clutter the mind to such an extent that it makes creative thinking impossible.
- 2) Computers are able to carry out well-defined tasks, but are of little use in solving the more vaguely defined problems common in research, or in the creative process generally (according to Littlewood, “Beethoven's notebooks show that—with some remote objective vaguely in view—he would start with deliberate crudities, and approach the final work through blunders and repeated alterations.”). As argued earlier, the ability to ask the

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right question is essential in doing innovative research. Computers can generate questions by drawing predefined questions from an existing database, but are unable to pose fundamentally new questions. The reason for this is that these machines can only carry out predefined numerical operations, whereas we do not have any algorithm that can translate our ability to ask exploratory questions into numerical operations. The over-intensive use of computers as a research tool may actually prevent us from posing the creative questions that drive innovation.

- 3) Presently, many researchers are overly preoccupied with the use of computers. This reflects itself even in the way we interact with each other. When a colleague does not answer a normal (paper) letter promptly we find this quite normal, but not responding to e-mail is definitely frowned upon in scientific circles. This preoccupation can be so extreme that some researchers feel that they are not doing anything useful unless they are located behind a computer terminal. This danger is especially acute when young and inexperienced researchers are working on projects that are not defined yet in great detail, a situation that is common among graduate students.

Some readers may find this description of the (ab)use of computers a caricature of the real situation. However, who has not experienced a breakdown of a computer system that has led to researchers wandering aimlessly through corridors instead of taking up an activity that does not require a computer (such as reading a journal, clearly formulating a problem and speculating about potential solutions, discussing a problem with a colleague, etc.).

The main problem is called in management jargon “the activity trap.” This is what happens when one confuses a goal with the means to reach this goal. A timetable of a bus service is a means to serve the goal to provide people with reliable transportation. When a bus driver does not stop to pick up passengers because he wants to stick to the timetable, he falls into the activity trap: driving the bus around according to the timetable then becomes his goal rather than a means to serve the goal to provide transportation. This example may appear to be farfetched, but a close scrutiny of your environment may reveal many examples of the activity trap. Many of

the problems that we face in making an optimal use of computers in research is related to the fact that the activity of using the computer for a task that we defined ourselves becomes the goal, rather than the means to serve a goal of making new discoveries.

What are the implications of this for the way we use computers and for the way in which we educate and train others? First, the message that computers in geophysics are nothing more than a means to reach a certain goal should be acknowledged by computer users. Educators and those who manage scientists should continuously make others aware that the use of computers is not our goal and that it is up to the researcher to formulate the questions that drive discovery. Second, our social code and the way we distribute tasks in our organizations should adapt more efficiently to a proper use of modern technology. For example, there is no reason why e-mail should get priority over other means of communication (such as face-to-face discussions). Presently, secretaries spend virtually no time anymore typing manuscripts, but at the same time scientists carry out many tasks on a computer (such as making websites) that could be done as well (or better) by a secretary who has received the proper training.

The problem of making good use of computers is especially acute for those of us who use computers in education. Computers are a wonderful interactive tool for making demonstrations. However, the danger is that the student only watches demonstrations without actively exploring the system that is simulated by the computer. The educational use of computers should be aimed at stimulating students to ask good questions that will help them in the adventure of discovery that good education should be. This is not a trivial task, and it requires a large amount of ingenuity to realize. Further, our experience is that no matter how realistic a computer simulation is, a physical demonstration, when feasible, is always far more effective as a teaching tool.

The reader may have obtained the impression that we are in some way opposed to using computers. Be assured that we actively use computers for our research, that we exchanged drafts of this column using electronic mail, and that we are avid users of the Internet and other tools that allow us to work more efficiently. However, we also have the impression that present-day researchers might be much more creative if they would switch off their computer one day per week . . .