

Technology and scientific thinking

Abstract

The following notes aim at naively discussing the impact of new information technologies on the development of scientific thinking. The discussion tries to underline the integration frontiers that computer technology is opening to us, mankind, in putting together all efforts that many people have done and are doing separately, in a possibly naive (but evolutionary) single world of knowledge.

A look at computer technology

The computer phenomenon can be seen from many points of view. We consider here the computer as a basic physical symbolic machine capable of reproducing data substitutions, following predetermined paths. Data can be paths as well as substitutions. Combining these possibilities with some ignorance on data, computers can be perceived in a rather large variety of ways, even non-deterministic ones. Behaviours of the physical world can be reproduced; mathematical computational problems can be solved; logical inferences of various kinds can be performed automatically; some human behaviour can be approximated, The technological improvements of the interface between computers and their users is extending the usability of computers even where the user is completely unaware of computer science or technology. This latter trend is essentially a consequence of the tremendous competition in computer technology due to the presence of countries, like Japan, which owe their economical survival to microelectronics and computers. The competition itself has consequences in all aspects of social behaviour. In fact, the increase in productivity that microelectronics and computers make possible, changes the economical equilibrium continually. The center of the world economy is moving toward the Far East; communication is more or less global today; political forces have to deal with a social issue modified by mass media, in the sense that social expectations from control technologies and sciences are probably beyond the will or the possibilities handled by governments.

Moreover, society is poisoned by subcultural attitudes that put science and technology exclusively at the service of special interests, and as such they are sometimes perceived as scarcely reliable. The incapability of official sciences to drive people to the defence of the environment and to the quality of life and food has been in the past probably one of the causes for the growth of those subcultures.

Computers and science

Scientific research is now completely dependent on computers. In research computers are used as observational tools combined with suitable sensors; they are used to drive actuators that enter into the experimentation; they are used to collect, store, retrieve and analyze data or knowledge, and to write, store, retrieve and communicate documents (formal or unformed); they are used to build and to make computations on models, to make predictions, to prove theorems, ... , and they are used to spread and teach results to people.

The case of expert systems

The paradigm of using computers differs slightly depending on the nature of the discipline considered. In the case of largely empirical disciplines, where a clearly understood set of rules or knowledge is not always available, as for example in medicine, computers are making their best appearance. In this case, in fact, the so-called "expert systems" are used: these are computers in which the path of data handling mimics deductive as well as inductive forms of reasoning, possibly with some degree of uncertainty or fuzziness. These systems, frequently considered as dirty entities by scientists, are playing an extremely important role in the development of a new scientific thinking. Expert systems are only an effort to build up axiomata from empirical observations. Obviously, they do not handle with well understood disciplines such as number or group theory, list or geometrical concepts, Rather frequently in a single expert system a variety of historically established disciplines are mixed with more local and circumscribed ones, whereby the scientific debate is occasionally rather poor. The practical success of expert systems is diffusing that technology in many fields where expert systems are used to increase the reliability of decisions or to substitute an expert person with a less competent one, and perhaps can be considered as "practical knowledge" (Hilary Putnam) handlers.

There are many problems which arise with expert systems. First of all, a better understanding of the phenomenon is needed, as it is developing its experiences essentially outside of the academy. Second, but not less important, is the publishing issue of expert systems. The problem is the following: expert systems are frequently rather complex entities and they are difficult to be described. Publications rarely permit a strong criticism on the projects reported. The only thing that can be judged is a rather vague idea of originality. Obviously, this situation is due also to the privatization of knowledge. If an expert system has to become a

commercial entity, it would be better to present it as a working tool, to give evidence of its external behaviour and to say as little as possible about its inside, in order to reduce the possibility of helping some competitor.

A large set of problems and a need for ethical behaviour result. A naive solution could be based on the following statements:

- a. Good documentation of the expert systems has to be developed in order that a scientist without technological competence can read its content clearly and judge the quality of the knowledge collected together with the references;
- b. The key ideas of expert systems have to be published clearly and left open to criticism
- c. The validation effort done on the expert system is to be considered part of the system itself precisely in the same sense in which the data collected represent an important part of any well-done physical sciences experiment.

To put all these recommendations together is now almost a question of will, it is no longer a technological problem. Particularly large optical memories are an ideal tool for putting together software, rules, data, documentation and knowledge validation sequences...

But there is much more on expert systems as a consequence of the research done by Herbert Simon and others. Simon and his coworkers have been able to make an important rediscovery by using expert systems that were programmed on the knowledge of the time when the discovery being considered was made. These results have to be considered as an evidence of the possibility that expert systems not only are the ideal tools for practical knowledge, but rather can incorporate the "practical set of rules" that can improve research productivity and lead to new results. In this sense expert systems are just tools that enter into the methodology of doing science.

Automated theorem provers

There are some research laboratories that are beginning to consider as feasible some integration of results from logic and artificial intelligence into working software embedded in suitable computers, whereby some theorem proving can be done almost automatically with some interactive human guidance. The experiences publicized are beginning to be many, and it is not rare now that some important theorem is rediscovered with a daily effort due to a single person instead of many people working for tens of years. Nevertheless, the art of computer automated theorem proving is still improving; and a large war against undecidability

problems and resource limitation because of complexity is undertaken by those pioneers who hope to help humans in proving theorems not only with negative results, but by battling against those negative results and showing that "practically" automated theorem proving is perfectly feasible.

Unfortunately the excessive amount of logic developed is plaguing the field: this discourages many people from seriously considering the tools developed.

Fortunately in these latter times many researchers are concentrating on predicate calculus, one of the very few standards in human communication. The impetus on development of theorem proving techniques comes from various fields, particularly from the need for developing bug-free electronic circuits and computer software. The scientific mathematical world is prone to consider unfeasible the use of theorem proving, and sometimes simply rejects the idea even when developing researches in fields related to automated theorem proving.

With the advent of submicron electronics, however, it will be feasible to significantly reduce the cost of developing extremely powerful computers based on parallelism: excellent centers for theorem proving will appear, and new results from theoretical disciplines will depend on creativity combined with the quality of the theorem prover employed.

If these considerations prove to be true (as it is likely), then we have to consider quite carefully the direction to which young researchers are directed by the current management of sciences. In less than ten years theorem proving will be certainly useful in improving the research ability of scientists and in deepening results. The philosophical debate of the acceptability of theorem provers has to be considered with common sense. The request that proofs be understood by humans is nevertheless certainly very important. Research in human understanding of proofs certainly has to be done. Doing these researches requires theorem prover capabilities.

So the directions in theorem proving will probably be followed by more human-centered times where aids in understanding theorem proofs will be provided. These tools will range from some naive set of theoretic help in understanding proofs, as well as assistance in knowledge representation: both entities could make the meaning of proofs understandable.

According to the above point of view, it is probably correct to ask young researchers to extend the range of their investigation rather than to focus on strong specialization. It is to be noted that many advantages in scientific communication would be drawn from a different attitude:

communication among different and distant disciplines would gain in deepening good results, and the distance between society and science would not increase. Moreover, the commercial availability of theorem provers will spread logic and formal attitudes in many technical and scientific applications.

Publishing

Paper uses natural resources, and the process of producing paper is a polluting one. Many new countries want to become first-class countries in developing scientific cultures. This will increase significantly the need for communication and publishing. There are now many scientific journals which support the great amount of researchers' results. Some of those journals are considered rather arbitrarily as the best channels for communication. Nevertheless, there is some truth in this: it is probably true that those communication channels are just a way of underlying results from important people, and sometimes important results. They, in fact, publish results with great delay, and corrections (if any) obviously appear later.

Meanwhile, scientists maintain links in very restricted and distant groups through electronic mail, reinforcing the appearance of international recognition of results to all people outside to the above kens. The easiness of communication has a strong consequence: when extended electronic mail immediately overrides the human capability of reading and managing concepts; the same goes for human relations. In a world where many new countries want to communicate, this enforces closed elitist relations, underlining even more people with solid traditions in the field.

The quality of researches obviously improves significantly. Unfortunately, the improvements are frequently concurrent with language specialization. This state of the art requires some rethinking and possibly new technologies.

Paradoxically, the first step to be taken is probably to increase the availability of both scientific literature and good information retrieval tools. This can be achieved through data networks and/or large optical memories. One consequence of this approach seems to be the possibility of making the process public. According to this hypothesis, the evaluations of results could change, and probably the number of people who will conduct the scientific researches in new frontiers will increase. Today if one young person has to advance in his career, he has to publish papers in some professional journals or other which satisfies certainly important but otherwise arbitrary criteria. This has significantly

negative consequences on his professional freedom and scientific curiosity.

Ted Nelson, in his visions on hypertext technology, suggested that all the world literature should be linked together in a unique system where references, ownerships, criticisms, readers and payments due for reading would be connected together by suitable links. This system is certainly not far from feasible, taking into account the development of the optical stores that will manage many terabytes of data in small-size low-cost systems.

Before that time, some trial situations are appearing: some scientific societies are building optical computable proceedings. The advantages of using the computer as a medium for communication are rather evident: if results are related to computational concepts these will be directly inspectionable; easy accesses using hypertext concepts are feasible and have positive consequences on scientific productivity...

The integration of these systems with a better electronic mailing system (as John McCarthy claims, the current one is under risk of failure) could really introduce a rational form of scientific communication.

The importance of improving productivity in researches through the speedy availability of documents of a given discipline on a single work station cannot be forgotten in those fields where time is playing an important role in human survival, as in the cases of AIDS, of atmospheric pollution, or in the human genome project.

Obviously, this state of affairs immediately opens a new and very interesting problem related to the possibility of integrating knowledge (as well as documents). It will become particularly important experience in knowledge representation, as well as in tools that will help in building models, doing deductive, inductive, abductive systems, or analogical reasoning, representing text content pictorially, improving readability, and changing the language representation of contents,

The importance of metatheoretical concepts (even naive ones) will significantly improve all cases in which metatheory will be capable of practically enhancing the control over a large set of documents, formal or informal. Slowly, this will make us accept the idea that "formal" only means "partially treatable by computers", just as any real formal document where aspects of conventional signs can be computed, while others can not.

In the frame of this chapter it is important to recognize the efforts done by D. Knuth in trying to standardize the typography of mathematics through the development of the TEX system, now inserted in almost all

publishing companies having to do with mathematics. It is just one step in the right direction.

Software as a carrier

The advent of software as a product along with the computer has led out new and important ways of distributing (and selling) results of scientific or technological research.

This is particularly true in computational mathematics, statistics and in design (electronic, mechanics, mathematics,...).

Computer-Aided Computation (CAC) and Computer Aided Design (CAD) tools are spreading and are changing the work organization and the communication of results. While scientific literature is becoming quite difficult to read and quite disperse, software is learning how to reach its users, thus assuring the diffusion of scientific results and incentives to its builders.

One consequence of this state of affairs is the relative independence of judgements from scientific production. A result could be valid for publishing but not for selling, or vice versa. Since this is the state of affairs in every field, the standard scientific literature is changing its role from communication to prestige making. In the long run, the quality of scientific literature could decrease, if this has not already happened, as a consequence of the pressure in obtaining results.

In scientific research software plays many important roles: communicating that software among cooperating people is still a custom. Whenever such a custom will spread further, all the software connected with research will become a publishing entity. As a consequence the distribution of those tools will not be limited to the cooperating people, but will be extended to the competing ones with synergistic consequences.

The strong knowledge integration force represented by the computer could suggest many new ways for making scientific results cooperate directly, with a minimum human effort, leading naturally to a new form of thinking support for scientific communication, one whereby results are part of a unique world of science in which the beauty of the whole will not be lost in favour of details.