

The changing art of Computer Science Research¹

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1 The feelings

Computer Science researchers should be ecstatic, but they are not. Their area is *à la mode*. The daily news are filled with stories about computers, communication and the media. The economy as a whole is not only affected but it is spearheaded by new technology. It is not a revolt, it is a revolution. On the other hand, the visions are promoted not by scientists but by modern entrepreneurs. The new ideas are coming from the small companies and not from the research groups. The bright students do not dream of scientific valor but of commercial success. Something is changing profoundly. Thirty years ago we were fighting for acceptance and independence as scientists. Now the area is becoming so big and so dynamic that we are fighting for position and attention inside our own field.

The traditional researchers still write papers, still meet in conferences, still produce Ph D theses. They are as a whole a little bit frustrated. Their quasi monopole as modern day prophets is gone. They still have great ideas. The ideas, however, are fast, too fast, overrun by commercial developments. Not only they don't have a chance to set the trends. Sometimes they do not even have the podium to explain or comment. The technical journalists do it more effectively. Never before so many non-computer scientists knew so much about computers. One does not need to ponder about new directions or discuss the hot topics. One can get everything on Internet or in the morning paper.

At the same time, research funds are cut, the large companies phase out their research departments and everybody is questioning the role of research. The current day developments from Internet to microprocessors and PC's were research projects not too long ago. Why did everybody forget? What is so dramatically different today that research is being threatened from its own successful intellectual results. Governments in the past were directing great amounts of funds for exotic fields and vague promises. Now the projects are concrete, and the demand is great. Visions and ideas are fast translated into economic activity. The chances of success were never greater. At the same time laboratory equipment is affordable. One can do great things with little budgets. One would expect more Research funding not less. Success brought penury and not extra grants.

2 The trends

There are a number of trends which are at play. Each one separately is significant . All of them at the same time are not only important, they are critical.

1. Most of our remarks also apply to other scientific areas.

- There are two fundamental ways to approach research. In the first way we can pose a fundamental question and provide an answer. We seek a basic truth. In the second way we attack an existing or anticipated problem and provide a solution. The first way is supply driven and the second is demand driven. One of the major trends in our research is that it is turning from supply driven to demand driven. There is no basic truth in Internet, or the Web, or PC's. They create a demand for the solution of many problems.
- There are two ways to manage research. In one way we get very good people and leave them free. Management only means that we cater to their needs, material or psychological. This is the way all great Research Labs were managed. In the second way, we actively co-ordinate and influence what they are doing. Research is turning increasingly from free to directed. The managers, the sponsors, the bureaucrats everybody wants to have a say on what and how is researched.
- There are two kinds of research: theoretical and applied. The quality of theoretical research is measured by its depth and of applied research by its relevance. There is an overall trend from theoretical research to applied research. Before, you could not get a thesis or tenure without some theoretical research. Applications were considered time consuming and dirty. Now, they are at the forefront of research activity.
- Research can be targeted in only one domain. The goal is to advance the state of the art in that domain. Alternatively research can try to combine different domains and seek an integrated solution. There is a trend from targeted to integrated research. Before, mixing domains was considered a sign of weakness. If you were not strong in any one field, you try the combinations. Now, all interesting problems are attacked with combinations of tools.
- Research can be contained in one branch of science, let's call it mono-color. In another way research can draw results, methods, and paradigms from different branches of science, let's call it interdisciplinary. There is a trend from mono-color to interdisciplinary research. Before, specialization was the only way to success. People or groups who were interdisciplinary were considered queer ducks. Now, all the exciting results come in boundaries between sciences.
- Research can be set up to produce identifiable results. In this way each quantum can correspond nicely to a paper and be attributed to some person(s). In another way research can proceed incrementally without any care of packaging. There is a trend from identifiable to incremental research. Before, incremental research, or ameliorating an existing result, would produce zero credit. Now it is hardly possible to identify the specific contribution of many well known researchers.
- Research can be organised in large projects or in small projects loosely but dynamically co-ordinated. There is a trend from large, heavy, difficult to manage projects to small dynamic projects communicating with each other. Large projects were visible at the beginning and hardly visible in the end. People now want results not big promises. Importing and exporting results between small projects gets more impact as a whole.

- Research can be thought as long range providing results in decades, or as short range providing results in years or months. There is a strong trend from long range to short range research. Before, people would work for years in one project or idea. Now, people, groups, and institutions need to report on progress not only every year in a conference but every day in their web pages.
- Research can be organized according to strict time frames, or it can be considered completely open ended. There is a growing trend from open ended to time critical research. Before, time was relative. You needed to advance as fast or faster than other experts in the field. Everybody would meet yearly in a conference to synchronize their watches. Now, the impact of a result can depend completely on its timing.
- Research can be very strictly orchestrated by assigning tasks, or it can proceed in a more chaotic way by advancing while also monitoring both internal results and external influences. Research is turning more from managed to chaotic. Before, a research group or project would work according to a predefined plan. Now, such a plan is only a recipe for disaster unless it is continuously updated and sometimes even totally modified.
- Finally, research can be considered as an individual or a team activity. There is an increasing trend from individual to team research. Before, if all your publications were with co-authors it would be a sign that you were not capable to produce something on your own. Now, hardly anything substantial comes from individuals. Most progress is by teams which are also very dynamic in their composition.

One can argue against some of these trends, or argue about their independence. Rather than going into a detailed analysis it is better to look for some overall pattern. What is influencing all these trends? Why so many accepted practices are changing all at the same time?

3 The causes

Since our area is becoming key for economic development and social change, we cannot escape the major influences of our times. If we live in an Information Society, then we can expect that research will be influenced from the society we help (are responsible?) creating. The trends discussed in the previous paragraphs are all related to some major shifts in the environment we live. These shifts affect much more than research and not only research in Computer Science. Computer Science Research is, however, at the forefront of these changes, hence it is affected faster and deeper than other areas.

The first cause is purely economic. The globalization, the fast pace, the dynamics and the instability of our economy all affect the nature and the organization of research. We do not research in a vacuum. There are major economic interests related to the results of this research. Research is becoming demand driven, directed, applied, small project oriented, short ranged and time critical because the economic activity based of this research is exploding. If we try to go against the trends we are bypassed by the commercial developments. On the other hand if we follow the trends we can take part and deliver jobs and wealth to our region. Research is needed to innovate our products and processes. Information technology products have a very volatile

and competitive market. Innovation and the research associated with it is of major importance for survival for existing companies and the creation of new ones. One can say that research is becoming a too important activity to be left only to the researchers.

The second influence is intellectual. We are experiencing a big bang of research activity in our area. There is simply too much going on. Most of the activity is not centred in the traditional research institutions, Universities and Research Centers. Most of it is encapsulated inside companies who integrate research, development, production and marketing. All this research going on simultaneously cannot either be free or over-managed. If it were absolutely free it will create intellectual dust in the knowledge cosmos. Over-managed it simply can not be. The trends of integrated, interdisciplinary, incremental, team oriented and chaotic is an attempt to provide some intellectual discipline. If we go against these trends we will be isolated or overrun by the sheer avalanche of intellectual activity. If we are flexible and go fast forward we can participate in a gigantic development. The hyper-interaction between the researchers creates a very dynamic environment. Before, researchers needed weeks to prepare and days to assist in a meeting. Now, they need minutes to prepare and seconds to interact through Internet. The quantum of progress one can have in-between interaction is too small to make research effort identifiable and attributed to an individual. Everything is progressing too fast and in a continuous manner.

These major influences are not fads. They will continue for the foreseeable future for as long as there is a rapid expansion of the knowledge based economy. Hence we should expect these trends in Computer Science research to be irreversible. We do not see a temporary change but a major shift of the environment in which we do research. If this is the case in what ways does this change our instruments, our goals and our habits? In short what is a research career in our time.

4 Research careers

A few years ago a research career was considered a normal job and it was a common goal for people with strong interest in science. In addition, it was rather straightforward to plan. You do a PhD in a good University. This involved some preparation work and a Thesis. Duration could vary from 3 to 6 years. You then join a University or a Research Lab. In both the research was supposed to be your main activity. Teaching in a University and some administration and Technology Transfer in a Research Lab were considered auxiliary activities. You were supposed to produce a couple of publications per year, where a publication was very well defined. Every 10-15 publications you could get some kind of promotion. You slowly could get involved in editorial boards for journals and program committees for conferences. You became known in one area. You go in a natural progression from contributed papers to invited papers to books to editorials and you end up with dinner speeches. In a career of 30 years you may change a couple of times between organizations and you could slide in and out some related scientific areas. From beginning to the end your salary would approximate double in real terms and you would expect to have tenure. One could not imagine a much more stable and well planned career. If the environment of research is changing we can expect that many of the hypotheses for a research career are also changing.

A Ph D Thesis is usually a document with a form: preamble - abstraction - model - results - experimental system - conclusion. It is supposed to demonstrate originality and maturity. There are other ways to demonstrate originality for instance by producing original code to solve a problem. Maturity can be demonstrated through presence as outlined in home pages. The notion of a thesis should be reviewed to fit current developments. A thesis is not a document but a demonstration of intellectual achievement.

A publication is considered a paper in a journal, book or refereed conference Proceedings. This notion is becoming irrelevant in many ways. First, much effort is team oriented and incremental. It does not lend itself to quantum publications. Second, software, demos, web sites are also publications but of a different kind. Third, paper publications are read only by a few and their impact is minimal. We need to redefine the notion of publication according to its impact and not its form.

A promotion is based on written output, e.g. papers, books. There are many other ways to advance the state of the art. Presence in the net, value of e-mail contributions in a forum, participation in successful companies are new way in obtaining status. Promotion should be based on peer acceptance and intellectual achievement and not on number of successfully written pages.

A research career used to be considered as a life time job. One spends his life in a stable position going deep in his specialty and fitting it to different projects. A research career has now many discontinuities. One should be prepared to go from research to development to management to consulting from large to small companies and universities. It is de facto an unstable career based on competence and drive and not seniority. Tenure in such an environment has no sense. Most people will enter a research activity probably at the beginning of their careers but then move to something else. The ability to question, to propose, to experiment, to innovate which is associated with research is all too important, but it should not be the privilege only of the researchers. All persons should be doing that. Research or most of it should be ubiquitous and not only concentrated. Research will never be the same. We are getting to the situation as it used to be a century ago. Research was/will be not an isolated activity. It is a part of a whole scheme to promote innovation in our lives.

All these developments are not necessarily bad. It is the result of the success of our own ideas. We need, however, to update both our research environment and our expectations. If we fail to do it quickly, we run the risk to see our whole effort bypassed. That would be terrible. Not because we will be irrelevant. The real danger is we would waste our most precious resource: our own intellectual cycles.

If research is changing in terms of goals, nature and results then the organizations dealing with research should also adopt. We will discuss the necessary changes for Companies, Research organizations and Research funding agencies.

5 Company Research

Companies (at least sizable ones) had before an identifiable separate Research Division. This division was running Laboratories whose main function was to stay ahead in Research and to try

to respond to or influence the rest of the company. The Research Labs (like Bell Labs, IBM Research Lab, Xerox Parc) were very independent and long range in their attitude and produced many of the technological developments in current high tech products. It was well accepted that such a Lab had very substantial and measurable costs but it was impossible to measure its worth in output. This situation has dramatically changed. Companies are under tremendous pressure for shareholder value and they cannot afford to show sizable units with big budgets without any direct benefits. In addition, the technology transfer to the rest of the company from its own Research Division was always debatable. The operating Divisions had no time for discussion with the researchers. Anyway they felt that what they needed was always different and available from outside. The researchers always considered a burden to relate to the operating Divisions filled with people with different preoccupations. The companies are reacting to this problems with different solutions, all of them having one effect: the dissolution of identifiable Research Divisions.

The first solution is to dissolve the Research Division and distribute the people to other operating Divisions. The research people can bring some innovation (at least temporarily) and added manpower for development. The net effect is that the Research budget is distributed and hence not so visible. In the best possible way some Research islands are kept alive in the operating divisions for a short period of time.

The second solution is to spin-off the Research Division as a separate company and ask it to get its budget in the market. This situation is not viable in the long term unless the new company is transformed to advanced development. Since Research Divisions were not accustomed to win contracts from outside, it is a very difficult process. Parent companies help the process by directing the operating Divisions to give some preference to the research company but this special treatment cannot last for ever. The operating Divisions need their freedom of action. The research company needs to amortize its costs by leveraging its results to many more customers.

The third solution is to split the Research Division in many small Labs and associate each one of them with some Operating Division. Each Lab needs to specialize as a competence center and be directly responsible for some innovative area for the benefit of its Division. This solution solves again the cost visibility problem. In addition, the operating Divisions get some direct control and some needed new ideas. The coordination of all these Labs and the crossfertilization of the ideas coming between them become an issue.

If a company has no more Research Division, it does not mean they do not need or get innovation. There are three main vehicles. First, they can organize their own internal Research projects or can enter cooperative Research projects with other companies or Research Institutions. Second, they can outsource research projects to Research organizations or companies. Third, they can buy directly the research results they need at the appropriate time. Increasingly, Companies find that outsourcing or buying research results is more flexible and cheaper than participating in projects themselves. This situation creates an open research market where small companies and research organizations compete globally. It implies that research organizations have to orient themselves according to the needs actual or prospective of this market.

If companies buy their needed research in the market they obviously lose two privileges. First, they cannot single-handedly direct the goals of the research. Second, they do not get ex-

clusivity in the results. These problems are not in reality so dramatic. First, the needs of a company cannot easily be anticipated in a very fast and dynamic product market. It is therefore very difficult to set company research goals. In addition, because of globalization and the sheer avalanche of research results the chances are pretty high to find what you need at the appropriate time. Second, exclusivity can be negotiated through licences, patent-acquisition, or even buying outright into the organizations that have the results. Finally, exclusivity gives only a temporal advantage in a dynamic market and its importance should not be overestimated.

6 Research organizations

Research organizations, whether government research centers, universities, or private research think-tanks were mainly organized to respond to the needs of their sponsors. Their funding sponsors were government institutional funding, government project funding agencies and corporate sponsors. All three categories of sponsors are changing their attitude. Governments are overexposed after a long expansion in institutional research funding and they are now cutting back. Since the research organizations are semi-governmental they cannot be cut too brutally. At the same time it is very difficult to cut non-uniformly since the processes of establishing priorities are too complex. This leaves research organizations with a clear perspective: uniform and durable cuts in institutional funding. This situation gives advantages (unfortunately) to the fattest and not necessarily the best organizations.

Government project funding agencies used to fund visible long range research projects. They are increasingly moving closer to precompetitive industrial research, much more closer to the market. They also favour commercial companies rather than research institutions. In this way, they feel there is a better chance that research results can move to products. In addition, large long range projects have produced disasters as they are very difficult to properly manage. The result is that research organizations need to participate in many consortia and write many proposals to get a reasonable level of research project financing. Writing proposals and lobbying for projects is sidetraking the research effort and it is diluting any clear direction or purpose.

Corporate sponsors are also changing their attitude. They are not any more interested in long range cooperation contracts or projects. They are willing to finance short projects, or personnel training programs. They are also interested in corporate participation programs which give them a chance to follow research developments and occasionally pick up some needed expertise.

The changing environment is forcing research organisations to a very different structure and operations. First, they need to be very lean, they need to rationalize. Second, they have to operate in a decentralized way in terms of relative independent Institutes, which operate as cost centers. Third, the Institutes need to define and promote a very clear profile as competence centers. Each Institute has to worry about its own project mix and corporate sponsorship. Research Institutes have to dynamically reorient themselves according to the needs of their research market. Finally, they need a heavy turn over of personell to ensure dynamism and flexibility.

Needless to say that research organizations cannot survive without some direct or indirect institutional financing. The level depends on the legacy of an institution (how many past mis-

takes it carries) on the flexibility it is allowed from its supervisors, and from the amount of fundamental research it is supposed to carry.

7 Funding Agencies

Research funding agencies used to finance long range research according to people's reputation and peer reviews. Under pressure to become more relevant they have switched to project financing according to proposals with regular reporting and expert reviews. In the end they finance according to promises and not results.

The research topics or themes have become extremely important. First, because funding agencies need good hot themes to defend their budgets. Second, the themes have to be preannounced in programs to guide proposers in their project applications. As the funded research is getting closer to development of marketable products, themes have to be very actual to what seems to be the market developments. Influencing theme definition, project architecture, proposal writing and lobbying has taken tremendous proportions. Organisations and companies which can play well this game can be successful. Unfortunately nothing guarantees quality of results or chances of success in the real market. Research funding sometimes creates its own market which has nothing to do with any real need. Themes which seem to be good and actual today maybe completely irrelevant by the time the project is completed and the results are available. At the same there is no post evaluation. Projects are not judged by their input.

Research funding agencies have also the tendency to strive for very visible large projects. Such a large project may be merely possible in one well run organization with superior project management capacity. It is unrealistic when it is implemented by a consortium of partners with no clear management lines.

In order to be more effective funding agencies have different options. They can concentrate on long range research and go back to funding people according to reputation and peer reviews. They can fund institutionally a good group or organization around a top person for a determined time period. They can fund an existing institution again over a determined period. Finally, they can fund a network of institutions over a determined period. Evaluation is not based on themes or promises - but on close monitoring of work and post evaluations. Themes, directions, projects can be very dynamic, only the results count. Results can be measured by publications, patents, software used, spin-off companies or any other measure seems appropriate. The main goal is impact.

8 Concluding remarks

Research is in a rapidly changing environment. There are new trends, caused by very deep and long lasting influences Research careers, as we know them, are disappearing. Company research is melting down. Research organizations are in a corner. Research funding agencies are in a bind. Does this mean that research is in a crisis? Certainly not. There was never so much research going on. All companies large and small, institutions, even governments, need innovation in a rapidly changing world. This innovation comes from research activity going on everywhere. The

ability to question existing knowledge, to propose something new, to experiment, to integrate new ideas and to evaluate the results is a cornerstone to innovation.

Today innovation in terms of ideas products and processes is becoming the basis for fast economic development. Restructuring, reengineering and cost cutting provide temporary relief but nothing durable. Only innovation can provide a durable basis for the economy. Innovation comes from research mentality and activity which is distributed and paramount.

It is very interesting that at the same time that research as it is operating today is under the most criticism it also carries the most promise for the future. All we need to do is to be flexible and retarget our careers, our procedures and our institutions. As a first step we should be persuaded that we are not a problem but part of the solution.