AUSTRALIAN ACADEMY OF
TECHNOLOGICAL SCIENCES

Proceedings of the Tenth Invitation Symposium

Defence Science and Technology—A National Resource

This Symposium was held in
Adelaide, Australia, on
30th and 31st October 1986.

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Foreword

The Tenth Annual Invitation Symposium of the Australian Academy of Technological Sciences was held in Adelaide on 30th and 31st October, 1986 during the sesquicentennial celebrations of South Australia. The papers and addresses presented are in this volume. In addition, a day of field visits to South Australia's Technology Park, the Defence Science and Technology Centre at Salisbury, and the Edinburgh air base, was held on 1st November. At Technology Park an overview of operations was given by the Park Manager, Mr B. Orr, and visits were made to Austek Microsystems Ltd. and Vision Systems Ltd.

The full title of the Symposium was "Defence science and technology—a national resource". The topic was most timely in view of the release early in June of Mr Paul Dibb's "Review of Australia's Defence Capabilities" and of the ASTEC report on publicly-funded research with a review of defence research presently in hand. The interest of the armed services, government services, academia, and industry ensured an audience of 200 with most active participation. The interest of the defence scientists themselves can be gauged from the presence of two previous Chief Scientists, the present incumbent, and of the Chief Scientist elect (1987)!

The Hon. John Bannon, Premier of South Australia, opened the Symposium with a review of the supportive environment in the State for companies engaged in research and development, or the commercial application of high technology. He acknowledged the important part played in these developments by the establishment of the Defence Research Centre at Salisbury, 40 years earlier.

The keynote address by the Hon. Kim Beazley, Minister for Defence, reviewed Australia's new strategies of surveillance and mobility for quick response to minor incursions. The order of the remaining papers was to hear views from a large country (Dr W. J. Perry, USA) and a smaller country (Dr T. Gullstrand, Sweden) and then to proceed to general papers on the Australian scene by Dr R. Babbage (changing priorities) and Professor P. T. Fink (an assessment of science and technology).

The following day the papers addressed specific topics of the Australian activities; Mr W. Connick (materials research), Mr D. Roser (communications), Mr P. Rowland (electro-optics), and Mr B. Price (local industry).

A vigorous discussion panel was lead by Air Marshal R. G. Funnell on the interfaces of technology/industry/procurement and their influence on the value of defence science and technology as a national resource.

In addition to the panel papers, delegates had the good fortune to be stimulated, entertained, and led to reflect on the nature of defence by speeches by His Excellency the Governor-General; Dr J. L. Farrands, former Secretary of the Department of Science; and Professor Lynn Conway, University of Michigan.

Before the Symposium, the Academy held its Annual General Meeting which included the Eighth Annual Oration by Professor Ralph Slatyer, AO, Chairman of ASTEC, entitled "Innovation and competitiveness". This Oration is printed in this volume.

Grateful acknowledgement is made to the Symposium Committee (chaired by Sir Frank Espie) and to the other members of the Technical Programme Committee, particularly the Secretary, Professor Sam Luxton. Special thanks are due to Mr Milton Bridgland for efforts in obtaining financial support, and to those companies that responded to his efforts. Once again Mr J. T. Woodcock provided invaluable help,

despite tardy authors, in providing preprints where possible, and in overseeing the publication of this volume. Miss B. E. Jacka, the Executive Officer of the Academy, supervised the staff and multiplicity of "subcontracts" necessary for the success of the symposium. Her wealth of experience ensures the difficult is made easy.

NORTON JACKSON
Convener

Technical Programme

The technical programme was held at the
Hilton International Hotel, Adelaide, S.A.

30 October 1986

	Session	*Speaker*	*Chairman*
9.30 a.m.	Official opening	The Hon. John Bannon	Sir David Zeidler, CBE, FAA
10.00 a.m.	Keynote address	The Hon. Kim Beazley	
11.30 a.m.		Dr W. J. Perry	
12.45 p.m.	Luncheon address	Dr J. L. Farrands, CB	
2.15 p.m.		Dr Tore Gullstrand	Dr L. W. Davies, AO, FAA
3.15 p.m.		Dr R. Babbage	
4.00 p.m.		Prof. P. T. Fink, CB, CBE	
7.00 p.m.	Symposium dinner	His Excellency, Sir Ninian Stephen, AK, GCMG, GCVO, KBE	

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9.00 a.m.		Mr Wynford Connick	Dr J. C. Mudge
9.30 a.m.		Mr Douglas Roser	
10.00 a.m.		Mr P. Rowland	
11.15 a.m.		Mr Peter Smith	Dr W. J. McG. Tegart
11.45 a.m.		Mr I. J. Bettison	
12.45 p.m.	Luncheon address	Professor Lynn Conway	Sir David Zeidler, CBE, FAA
2.30 p.m.		Mr B. Price	Dr W. J. McG. Tegart
3.15 p.m.	Panel discussion	Air Vice Marshal I. T. Sutherland Mr F. Bennett Professor R. I. Tanner	Air Marshal R. G. Funnell
4.45 p.m.	Symposium rapporteur	Professor G. A. Rigby	
5.00 p.m.	Close of Symposium	Sir David Zeidler, CBE, FTS, FAA	

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ADDRESS AT SECOND SYMPOSIUM LUNCHEON

U.S. defense advanced research—causes and effects

Lynn Conway[1]

INTRODUCTION

My talk today will discuss methods for conducting advanced research aimed at producing new technologies and transitioning those technologies into commercial or military usage. I am going to focus in particular on the causes and effects of activity in the US advanced defense research community. I will speculate about some directions that such research itself might take in the future. But the heart of my discussion is about the nature of the new methods for conducting research that have evolved within the US defense research community.

In outline the talk will proceed as follows. First, I will provide some historical perspective to establish a context for better communication of the major ideas. Then I will give a sketch of the key US government agency concerned with advanced technology exploration, namely the Defense Advanced Research Projects Agency (DARPA), discussing why it was formed and how it works. We will survey some of the results of DARPA activities, and sketch some of the new programs now getting underway. We will then reflect on these events, and develop insights into and derive implications of the novel methods of the DARPA research community.

HISTORICAL PERSPECTIVES

First some historical perspectives. In the United States, perhaps even more than elsewhere in the world, there has been a very long intertwining of military enterprise and technological and cultural change [SM185]. Two short stories may help you visualize the depth and the subtlety of these interactions. First, let's think back to the development of muskets and artillery in the period between the war of 1812 and the Civil War in the United States. If you examine the technical artifacts (the muskets and artillery) that were produced during that period, you will find some revolutionary changes such as the introduction of percussion primers, but mainly lots of

[1]Professor of Electrical Engineering and Computer Science, and Associate Dean of Engineering, University of Michigan, USA.

orderly, inventive evolution of basic designs within those technologies. That is what you would see if you looked at a musket or an artillery piece of that period.

But at the same time, the US Army Ordnance Corps pioneered a really phenomenal new technology that isn't immediately apparent from an examination of the ordnance itself, namely the new techniques, tools, and technology for mass production of systems composed of interchangeable standard parts. This technical phenomenon was created under the guidance of a few visionaries in the Ordnance Corps and yielded what became later known as the American System of Manufactures - a whole system of methods of using patterns and techniques for insuring interchangeability of mass produced parts, and the connection of that system with methods of design and methods of manufacturing. It is quite a remarkable, abstract, complex system of technology.

A similar story surrounds the activities of the US Army Corps of Engineers during the early generation and propagation of railroad technology. Army engineers were involved in much of the early railroad building in the US. They applied military-like methods for "deploying" railroads, in order to deal with the complex problems of logistics and of the management of large, dispersed enterprises. They also used the emerging railroad infrastructure and the associated telegraphic communications media to support its own propagation and to cope with the problems of managing large quantities of material and large numbers of people scattered over time and space. The Corps of Engineers thus created a uniquely American System of Management, which was propagated widely, into the commercial railroad enterprises and beyond, during the latter part of the 19th century.

These stories suggest that observed activities may consist of more than is initially apparent. By analogy such situations are similar to looking at a sports game that is unfamiliar. One of the first things I saw on television here in Australia was a game of cricket. While I could clearly see the objects being manipulated in the game, and could see the people running around, nevertheless I couldn't interpret what was going on. And I am sure that visitors to United States have similar difficulties interpreting an American football game. The thing to keep in mind is that observed events themselves don't necessarily reveal the human roles, the methods, the system of recruitment, the way people become heroes and leaders, the overall aspects of the behaviors, and the deeper cultural patterns surrounding a game or a technology. Such things are not usually visible to outsiders, to the uninitiated. And in the case of new and emergent cultural forms, they are sometimes not even obvious to the players!

These stories reveal unexpected, major side effects of the early activities of Army Ordnance Corps and the Army Corps of Engineers. I think that this idea of side-effects is useful to keep in mind as we explore the activities of the US Defense Advanced Research Projects Agency. I hypothesize that a modern, uniquely "American system of technology-creation" is the unexpected side effect of the activities of the DARPA community.

THE FORMATION OF DARPA

Let's jump ahead from the nineteenth century to the year 1958. By then the US had a vast technology enterprise, and there was a national sense of technology preeminence. And then there was the dramatic surprise of Sputnik. Sputnik led to the realization that our defense and political leaders had no coordinated access to the nation's technological knowledge of that time. Our leaders were not well informed about what it was possible to do, and thus were quite open to surprises such as Sputnik. This challenge lead directly to the formation of Defense Advanced Research Projects Agency (DARPA). In concept DARPA was formed as a "corporate research group for the Department of Defense", having the general charter to explore what it is possible to do so as to prevent surprises (and perhaps cause surprises!) [LER83].

A SKETCH OF DARPA AND ITS METHODS

What kind of organization appeared? Under the pressure of rapidly moving events during an unusual period of time, DARPA emerged as an unusual organization. It is a relatively small organization, having in total about eighty professionals. These professionals are highly qualified and carefully selected for technical and managerial skills. They do not themselves conduct DARPA research, but instead serve as program managers of research activities contracted out to the best talent that can be identified. This relatively small staff at DARPA has considerable leverage, and can have large impact both as individuals and in groups. The DARPA budget is now approximately US $800 million. Thus the average program manager has a research budget of US $10 million per year. The DARPA budget supports a research community of approximately ten thousand investigators, and perhaps an equal number of associated students, technicians, and support staff. When you think of DARPA, it is important to keep in mind is that game you are observing is not what happens at the agency, but what happens in the overall DARPA research community.

When interacting with this large community of investigators and potential investigators, the individual program managers operate something like venture capitalists. They invest risk money in order to form new knowledge production enterprises in new areas of knowledge (in a pattern similar to investing risk money to form new product production enterprises in areas of possible products).

Most DARPA program managers spend two to five year tours of duty at the agency, rather than being permanent employees of the agency. Most come to the agency from the communities that they serve. Many are originally senior researchers or research managers from universities or an industrial firms, and return to such positions following their DARPA tour. About one third of the program managers are technically educated military officers (PhDs) who work at DARPA during one of their regular tours of their military career. These officers help provide DARPA with the military services' perspectives concerning applications of emergent technologies.

The functioning of DARPA contains another analogy to the world of venture capitalists and entrepreneurs. The most talented, most creative, high-rollers and risk-takers of the research world come to DARPA with their best ideas. DARPA program managers compete to outperform each other in identifying winning people and ideas, in knowledge produced, communities built, and knowledge propagated. Program managers who produce better results for the funds invested, can better argue for enlarged budgets for their communities' activities. In that way, score is kept within the agency, and competition among program managers stimulates the production of new knowledge.

SOME DETAILS OF DARPA METHODS

I'll now go through a list of detailed observations of DARPA in action. Such observations are not often made, so I lack the opportunity to gain perspective by comparing my observations with those of others. I will do what I can here to play ethnographer and convey what I see. View this list as a collection of facts about the "sports game" of DARPA program management and research. Although the list may not convey deep concepts of the game, it may at least suggest that a complicated game is underway.

As a group, DARPA program managers can be visualized as coordinating an overall new-technology knowledge-market, much like groups of venture capitalists manage enterprise markets or product markets. Let's suppose a program manager is given the mission of forming a new program. The first critical challenge is to find or stimulate production of some really good "business plans", i.e. some exciting research concept proposals, and then attracting a following of investigators to the area of activity, leading to the building a community of players.

Such research activities invariably are required to produce working demonstrations of new concepts related to their new area of knowledge. A great deal of emphasis is placed on creating concept demonstrations in order to make the new ideas visible and understandable. In addition, considerable emphasis is placed on building and creating tools to allow others to create designs or systems involving the new technology.

We often observe an intense kind of high risk "can-do" enthusiastic atmosphere surrounding these activities. It is not the sort of formal, scholarly atmosphere usually associated with academic research, instead it has more the flavor of adventurous amateurs pioneering the technology and plays of a new sport form. Thus a new technology would be generated in the DARPA research community almost in the style that you might imagine generated and propagated the sport of wind-surfing.

This picture of an intensely involved amateur is as appropriate for the early stages of evolution of a new technology as it is for an art of sport form. During this phase, there are exciting possibilities available for creating and doing something new, and by definition there are no "professionals" or "experts" yet. One has to be an amateur because the field is not a real field yet. So some amateurs go off, and create and evolve the form, and in the process try to make it into something that propagates out into the world.

There is a sense of passionate amateurism surrounding much of the DARPA community research work. On the other hand, such work attracts the very hardest "hard-ball" players, people who are driven to bring their talents to bear to create some new area of knowledge, and who compete to outperform all others in leaving their mark on the new fields.

The program managers work to orchestrate the process of building and stimulating their communities, encouraging healthy competition among investigators, but also encouraging collaborations to generate an overall area of activity. Program managers make extensive use of workshops, meetings, and information technology to stimulate interactions within their communities, communities that are often geographically quite dispersed around the country. DARPA programs often involve researchers from many institutions, and yet they usually manage to develop a feeling of being a tight-knit, interactive community.

We also observe a lot of talent scouting going on. At all levels people have a keen interest in developing knowledge of "who's who" in their communities, what they now doing and what they might contribute. Program managers and research leaders are always discussing "who are the bright students", and looking for people who get good ideas. This openness to new people and new ideas may be an important part of the culture of an agency having the mission of insuring against surprises. A related phenomena we sometime observe is the deliberate encouragement of "outsiders", the occasional betting on a few mavericks in order to provoke, stimulate and test some area of research activity.

Another observation is that since the DARPA communities are often new interdisciplines that as yet have no clear identity, members of these communities display considerable concern and interest in building an image of what their discipline is about. There is considerable preoccupation with naming things and with trying to make things explainable to other people. These behaviors are an important part of the social process of reification of a new technology. The cumulative effect is that people in the larger technical community eventually hear about the new technology in ways that lead them to think about it as a natural part of the cultural landscape.

It is interesting to contrast this picture with the traditional National Science Foundation (NSF) model of funding scientific research in the US. NSF primarily funds individual researchers to operate in areas of basic research, patterning on long-standing science funding models. NSF funding thus goes to people who have a good reputation and have an interest in an important problem area, and who are passed on by their peers as being credible people to get funding to work in that area. In contrast, at DARPA the funding is based primarily on ideas. It is like orienting around a business plan; you do not get funding from venture capitalists just because you are a good manager, you have to come up with a business plan containing interesting concepts for a profitable new business.

Because of the emphasis on demonstration and on the production of things, and also because of the avant-grade "amateur" style of pioneering new areas, there's a down-to-earth "what works, works" style for evaluating success in the DARPA community. There is also considerable openness to criticism, and this is a key part of the competitiveness built into the culture. Useless projects and hoaxes are avoided by having things be rather open and subject to continual ongoing criticism. Researchers tainted by involvement in really bogus projects may find it impossible to regain the respect and support of the DARPA community. On the other hand, there is respect for those who may have reached a bit too far and didn't succeed. Occasional failure is not only tolerated, it is expected, because of the level of challenges undertaken.

A lot of subtle in-fighting occurs among the program managers in the agency concerning whose programs are "real" and are going to work and all that sort of thing. An atmosphere is created that encourages questioning and competition. There is always a certain tension in the air, exerting pressure on the program managers to get things to happen out in the world.

DARPA programs often create new interdisciplines of considerable impact. Part of the process of creating new interdisciplines is the expectation that any important new research communities will begin to hold conferences in their area (like VLSI design or artificial intelligence), and the communities will receive DARPA support to initiate conferences. As a byproduct, we will begin to see new journals, new magazines, and other media surrounding the new technical field. Again by analogy, if you are going to have wind-surfing, you have to have a wind-surfing magazine--that is just part of the process. These conference formation and media production phenomena are firmly embedded in the "genes" of the DARPA system.

Another important community mechanism is the structuring of interfaces between the research community and the community of venture capitalists and entrepreneurs that might take things to the product market. Many of the new domains of knowledge produced by DARPA researchers have been quickly commercialized by entrepreneunial businesses supported by venture capital. Stories surrounding such start-ups provide an atmosphere in which researchers are interested in commercial exploitation of new knowledge. Key members of the research community often participate in these businesses as founders or early investors.

Another interesting community habit is career rotation. This is especially noticeable among the more competitive community members, who will cycle through various roles and assignments in universities, industry, government, and in new start-up businesses, rather than spend their whole career in just one of those institutional sectors.

There are many other observations that I could provide given more time, but this sample is sufficient to suggest that there is a novel, complex form of enterprise going on here that may be quite worthy of study in itself. We'll now look at some of the results of the community's research, and then go on to discuss the implications of this research enterprise.

SOME RESULTS OF DARPA PROGRAMS

DARPA historically has made investments and operated research communities to support two general areas of militarily related technology: ordnance and aerospace. There have been many important results in those areas: from M16 prototypes, all the way through to Cruise missiles and stealth aircraft. DARPA has also funded basic research programs in the broad areas of materials science, process technologies and systems technologies to support the ordnance and aerospace domains.

In addition, DARPA has long funded basic research in computer science and information technology. It is in the area of computer science and information technology research that I observe the new research methods occurring in their purest form, and in sketching DARPA research I draw primarily upon examples from the information technology community. I hypothesize that one important factor in this community's rapid emergence is that it exploits its own results to provide new infrastructure to support its research activities.

Let me list some major information technologies that you can trace directly to DARPA community activities. First, there was the pioneering of time-sharing technology; the early methods for linking many terminals to a single processor, which for the first time really broadened the use of computers a very, very small handful of people. And then there was the DARPA work in packet network technology to better support communications between different computers. That computer networking research evolved over time and yielded the ARPAnet infrastructure, which at an early point in time began to interconnect the researchers, and their information technology, at all the elite universities and research labs that were participating in DARPA information technology programs.

DARPA also supported many in the community of people who generated the early forms of interactive computer graphics. The combination of networking technology and interactive computer graphics then led to the spawning of the modern personal interactive computing technology, with several industrial laboratories such as Xerox Palo Alto Research Center building upon work that had originated in the DARPA community, and bringing the technology to the point of entrepreneurial commercialization.

Another area of information technology activity that was supported and guided by DARPA, was the work of the group of visionaries who created the field of artificial intelligence. DARPA, in cooperation with the Office of Naval Research, was the sole support for this community over many years, including years when the general technical community felt that the work was unsound. And in the end, this support has paid off handsomely through the generation of an important new array of programming tools and methods.

Another area that DARPA supported was the rapid evolution of modern VLSI design methods, the associated computer-aided design tools, and the propagation of a new form of rapid silicon-chip prototyping called the MOSIS implementation service (MOSIS is an electronically accessible prototyping service used by the DARPA community). That DARPA supported research created much of the new technology called "application-specific integrated circuits" (ASIC). (ASIC design and manufacturing is now a major fraction of semiconductor industry activity). I was heavily involved in that work as a researcher, and those experiences helped me form these visualizations of DARPA community practices [CON80].

SETTING NEW DIRECTIONS AND FORMING NEW PROGRAM: THE STRATEGIC COMPUTING EXAMPLE

One question you might ask is: "How do new programs ad initiatives get started at DARPA? Sometimes scientific and technology break-throughs open up and suggest an obvious new line of research. In that case, the appropriate office in the agency recruits a knowledgeable person to form a program in that area, working as a program manager using the methods given above. Sometimes a group of DARPA programs evolves to the point of suggesting a restructuring of funding, with perhaps some new lines of research now separately spelled out. In all such cases, the new offerings of restructurings are initiated with considerable co-ordination across research and defense community advisory groups.

A more complex set of funding structurings surround the formation of a new DARPA office, or the formation of a major new research initiative. DARPA's Strategic Computing Initiative provides an example of how a major initiative can get underway.

Back around 1981-82, an awareness began to surface in the advanced research community that information technology had become a major and dominant technological arena in its own right, and was emerging as co-equal to the traditional ordnance and aerospace technologies in the overall portfolio of defense technologies. There was also a sense of increased research opportunities. Many of the separate DARPA supported information technology research fields (such as AI, VLSI, computer architecture, networking, etc) were becoming visible successes, but these emergent fields had yet to interact highly with one another.

Thus in 1983 DARPA formed the Strategic Computing Initiative (SCI) to broaden the base of computing research activities in the DARPA community [DAR83] [DAV85]. The period from 1983 to the present time has seen a substantial increase, due to SCI, in the fraction of the overall DARPA budget that is invested in information technology research (increasing from one-seventh to one-third of the total).

The Strategic Computing Initiative aims at recruiting ideas and building a multiplicity of programs to cross-leverage and exploit the earlier created disciplines of artificial intelligence, multi-processor computer architecture, and VLSI microelectronics. For example, the advances in artificial intelligence technology has been laboratory curiosities that ran too slowly and weren't scalable so as to be useful in advanced military systems. But by enabling those programs to run on very high-performance multi-processors, performance and scaling could be brought within range of the requirements. This in turn has affected the thinking in parallel architectures, which now developed to support the avant-garde requirements of AI systems. But those architectures were too large in size, power requirements, and cost when built with off-the-shelf parts. So, the SCI programs crossed the work in architecture with that in with advanced VLSI microelectronics, enabling the new architectures to be implemented at a reasonable scale of size and cost.

So the Strategic Computing Initiative amounts to a mixing and reintegrating of past results across a large array of emergent information technology in order to produce a new generic machine intelligence technology. The program will also yield prototypes of a new generation of embeddable intelligent systems. Such systems may eventually be proliferated throughout ordnance and aerospace technology, while the underlying machine intelligence technology is likely to have a wide range of commercial spinoffs.

One image I have of the Strategic Computing Initiative is that the overall research community has seen new ways to combine and reinvest the successes of the past to generate new areas of research activity. But how exactly is this done? Well, one result of the earlier DARPA successes (in AI, VLSI, etc) is the production of people (research thought leaders who played major roles in earlier successes) who are now advisors to DARPA. These folks are called upon to brainstorm and advise DARPA on how their maturing areas might be mixed and matched with other maturing areas of emergent technology to generate yet newer areas.

And so we observe a large array of earlier research pioneers serving as informal advisors, interacting with DARPA in the role of "elders". This observation provides a nice closure on our set of observations of the DARPA "game" of new technology generation.

INTERPRETATIONS AND IMPLICATIONS OF THESE DARPA ACTIVITIES

If we look at the DARPA community activities as a "system of technology generation", we will notice this system produces more than just new "technology things" or "new technology knowledge". The activities also produce new infrastructure and methods for the further evolution of the particular new technologies. For example, the DARPA VLSI research program not only supported the creation of new VLSI design methods and tools, but also supported the MOSIS rapid prototyping infrastructure.

I've mentioned the customs of emphasizing the generation of new names and terminology, and the focus on conducting "concept demonstrations". These customs stimulate the reification of new human roles associated with a new technology, thus greatly helping in the process of technology transition into the larger engineering community. For example, when electronics engineers heard about things like the "MOSIS implementation service" and "silicon foundries", and saw demos that clarified the various human roles surrounding these new technological phenomena, they were able to imagine how to exploit the new technology and find roles in it far better than if they had just read technical papers about it. An important product of DARPA community activities is the production of tangible new human roles associated with designing and using the new technologies.

The research activities also produce a talent-scouted community of players, from graduate students, to young investigators, to principal investigators, to research managers, to potential program managers, and on to potential elder advisors. Thus the DARPA research community activities automatically provide the US with an identifiable, demographically-structured, technology leadership community associated with any important new technology. For example, as artificial intelligence research knowledge began to mature, so did general knowledge within that DARPA research community about who everybody was, and what roles they had played and might potentially play in the future. Just as in windsurfing, the community knew who the heroes were, who had done what, and who might be up to leading the community in new directions.

It is quite common for highly extended communities of researchers who are not under contract with DARPA to nevertheless coalesce around and interact with DARPA program communities. The visibility, avant-garde nature and infrastructure creation aspects of DARPA research communities, forms a powerful "recuitment" force to attract the attention of others to the new technologies. Thus the process of knowledge generation and propagation often involves many more people than those directly under contract, and this is especially true within the larger university research community. The effect is something like that when you first saw somebody wind-surfing and you think "My God, look at that". And then you think "That sure looks like it would be fun to do". Well, that same thing often happens in the universities as new DARPA program begin to produce visable results. A small number of people may be funded by DARPA to be involved in a new knowledge generation and propagation wave. Many others then see what is going on, and want to be involved so badly that they start doing it whether they're funded or not. They make time to get involved, in the hope they will think of ideas that will lead to support from some sponsor. Sponsors other than DARPA then often follow up with support for work in these "exciting new technology areas". Overall this produces a vital knowledge generation and propagation marketplace. The new technology movements compete for support, attention and followers. Step-by-step, any demonstrable successes of a movements tends to bring it further attention, leading to further support in resources and numbers of followers.

SOME IMPLICATIONS FOR AUSTRALIA

These observations lead me to hypothesize that it may be quite important for the Australian technology community to visualize and track these knowledge generation processes, and then finds ways to get into them and participate in the processes, rather than just interacting with the "technology things" that are produced by the processes. My point here is that such participation by some members of your community can lead to a deep cultural integration of the new technology, rather than just a surface consumption of its artifacts.

Let me give you a specific example to clarify why I think those early interactions are important. As a result of progress in microelectronics, some amazingly complex, intelligent, systems can be implemented on single chips of silicon. Such a chip can be sealed in a small package, embedded into a complex mechanical assemblage, and then perform rather elaborate functions such as sensing its environment, planning an action, and then effecting that action through a transducer.

In the past, such an electronic system was sure to have many chips in it, with the chips attached to boards, the boards mounted in a cage, etc. In the past, the production of such a system could be divided up among different people and firms in a number of ways. If your mental model of "what a chip is" is based on past methods of designing and making integrated circuits, then you might think that these new single chip systems can't be "divided into parts". You might think that "whoever makes it, makes it". From that viewpoint, there is no way you can share any piece of that action, as compared to the older period where there were ways of dividing up design and manufacturing responsibility for electronic systems.

Ah, but if you were "inside the VLSI community" and really knew how these new chips are actually designed, and grasped the cultural phenomena surrounding the way silicon is done now, you would see it is now even easier now to share and divide up design and manufacturing activities than it was before.

You would think of that chip as being something like a page of a newspaper. There could be lots of different articles printed here. While they might interact in some ways, they could have different origins, from different places, and were communicated and merged together electronically, prior to printing. So in fact, the system on a chip is just that: it is a system that can have many parts, some out of chip libraries, some produced and designed in the past, some new ones added. The chip can be manufactured by any "silicon foundry" that is tied into the computer networks so as to receive electronically transmitted chip layout specifications. Finally, it could be marketed and sold somewhere else. Thus you would notice that there are remarkable new opportunities for participation and sharing in commercial enterprises related to the conception, making and marketing of products that are enabled by silicon-based information technology.

It is important to note that in this particular case a number of very brilliant Australian engineers happened to be in the United States and participated in the DARPA community research behind this silicon chip design revolution. Therefore, Australia got on the inside of this technology community right at its beginning. And one of those participants, Dr Craig Mudge, returned to Australia to lead the new VLSI program at CSIRO, going on to found Austek Microsystems. Thus he is playing a key role in the propagation and diffusion and enhancement of that technology here in Australia. Because of the direct, early involvement of Dr Mudge and other Australians in the US VLSI research, the Australian community is well positioned to participate in the important new industrial arena of "application-specific integrated-circuit technology".

I would guess that many other Australian have in the past, and are now, involved in DARPA research programs in the US. Such participation could lead to interesting opportunities for joint US-Australian benefits in both the defense and commercial arenas, by opening up a wider set of alternatives for trade and offset structuring. However, if the technology community in Australia doesn't have an effective model of the US advanced research process, you might not collectively derive the full benefits of such participation. There could be ways to stimulate more stories such as Austek to occur in the future. I believe that there is considerable interest in the United States in encouraging such mutually beneficial interactions with our friends and allies.

Another possibly important interpretation concerning DARPA activities is that information technology is the key infrastructure that enables the geographically dispersed communities to collaborate, to share access to expensive fabrication or prototyping facilities, to announce and share their results. As information technology evolves, this infrastructure becomes even more effective. Thus geographical remoteness is an ever decreasing constraint against participation. In the United States, researchers especially value two things; first, an ability to plug into the DARPA information infrastructure, and secondly to have some kind of contractual involvement in DARPA research; size of contract is not as important as is just being "in the community" and having access to (and an effect upon) the flow of advanced research knowledge. These facts suggest that involvement by geographically remote groups in Australia is quite feasible. And, the key thing may be involvement, even if only on a small scale.

THE CHALLENGE OF HIGH RATES OF CHANGE AND CULTURE GAPS

In thinking about some of the implications of all this, I've become interested in the challenges associated with high rates of technological and cultural change. Think about the stories of all these different technology communities and their formation, and their competitive vying for attention, and their recruitment of talented people to participate in the work. The result is wave after wave of new technical phenomena that are increasingly difficult for the larger technical and business community to transition through. There is on the one hand the advanced research community, having access to the infrastructure, involved in spawning and evolving the new things. Then there is the larger technical community not "in the network", and not yet familiar with the latest emergent technologies. In between these camps, a large "technical culture gap" has formed. Perhaps the DARPA research community methods, of recruitment and initiation, and of the use of information technology for interaction can provide means for people in the larger community to better access these new technologies.

A related observations and concern, looking at the scene from the DARPA community point of view, is that it is usually very difficult to initiate paradigm shifts, to stimulate the required shifts in viewpoint needed to culturally integrate a new technology. Here again information technology infrastructure may provide a boost. New information technology is now diffusing rapidly. There is an increasing rate of acceptance of new forms of information technology. Many people have experienced several generations in personal computing systems. In the process, information technology has become a subtle vehicle for propagating cultural change. If people perceive that there is going to be a generational change in information technology, many people will just take it, as if it were the inevitable next step in scientific knowledge. Therefore, new technologies (for example, things like methods for artificial intelligence) can be rapidly propagated during a generational change in an organization's information technology.

Interesting stories are already emerging about how technology revolutionaries can exploit information technology in order to propagate new technological-cultural forms [CON80]. I would draw an analogy with the period of the latter half of the last century when France went through a remarkable cultural transition. The transition was to a large extent centrally planned and manipulated. Within a short period of time, a common form of the French language, a postal system, well-graded roads, and an extensive railroad infrastructure were driven deeply and widely through all parts of the country. For the first time lots of widely separated, unique local cultural groups were connected through a new common infrastructure. As all of these groups separtely began to interact with what they saw "coming down the local road" and what they could "learn about via the postal system", a modern, common cultural form coalesced throughout France.

I think we see something analogous to the France story happening as information technology infrastructure propagates today. The technology to some extent determines the style of interaction of folks in the DARPA community, and the style of research results produced by that community. It then plays a role in enabling the resulting styles to be propagated along with the spreading, evolving information technology.

Along with all of these interesting, positive things come some problems. I have already mentioned the problem of cultural disconnect. We also observe that many outside the DARPA research community believe that it is an elitist community, and "old-boy network", that is quite exclusive of outsiders. That's largely because folks outside the community often don't have a good model of how to participate. Those not already in the community can feel very left out, and there are no easy fixes for this. For example, recent efforts to make the contracting processes more competitive (and thus distribute contracts over a wider community) may have had the reverse effect by greatly lengthening contracting process times, thus demoralizing groups not already familiar with the contracting process and confident of eventual contract success.

Another problem has surfaced around the gap that has arisen between the relatively small advanced research community and the larger technical community in their knowledge of what it is possible to do, what things that are known to work and can be demonstrated, and how these things are actually implemented. The Defense procurement system sometimes interprets literally the notion that certain new technologies are in hand, once they are demonstrated by the advanced research community (but before they are well integrated in to the knowledge of the larger engineering community). This leads to increased risk that defense contractors may propose systems that are technically unsound or infeasible on the one hand, or delay development for many years beyond the point of feasibility to reduce such risks. One solution is to develop methods for quickly producing prototypes of avant-garde military systems. DARPA has just formed an office that will focus on such system prototyping.

One final observation. An additional piece of evidence that a new "system of technology generation" has been produced by DARPA is found in the National Science Foundation's application of many DARPA methods in the new directorates recently formed in the areas of engineering and computer science research. In contrast with funding patterns in the traditional science areas at NSF, patterns that emphasize a hands-off style of support to people who pass the review of their peers, NSF is now applying more of a program management style of interaction with its engineering and computer science research communities. NSF has also undertaken to build new infrastructure to better support the work of its research communities. A new NSF program called EXPRES will deploy a system based on "collaboration technology", to provide the widely dispersed NSF research community with information technology support for collaborative production of proposals, conduct of research, writing of papers, and so forth. This also follows the DARPA method of applying the latest advances in information technology to further build the research community's infrastructure.

SUMMARY

In this talk I have sketched some of the practices of the US Defense Advanced Research Projects Agency and its research community. I have suggested that, as in earlier activities in Army Ordnance and Army Engineering, some very interesting side effects have been produced by DARPA programs over the years, namely the production of a "system for generating technology". We have discussed some of the details of the DARPA methods, and then some of the possible implications of this system of methods. I hope that these sketches will prove useful to you and your technology community by providing some new viewpoints for interpreting and interacting with US advanced research. I also hope that as our friends and allies you can increasingly join with us further expand our knowledge generation enterprise for our mutual benefit.

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