

NOT FOR PUBLICATION UNTIL RELEASED BY THE COMMITTEE

Multidisciplinary Research

by

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Committee on Science

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Mr. Chairman, Members, and staff. I am Tony Tether, the Director of the Defense Advanced Research Projects Agency (DARPA). I am pleased to be here today to talk about research at DARPA.

DARPA Funding for “Blue Sky” Research

Last month, an article appeared in the *New York Times* (April 2, 2005), “Pentagon Redirects Its Research Dollars.” The general message in the article is that DARPA has decided to shift away from basic research in favor of financing more classified work and narrowly defined projects that promise a more immediate payoff.

That simply is not correct.

There has been no decision to divert resources, as the article implies. DARPA’s commitment to seek new ideas, to include ideas that support research by bringing together new communities of research scientists, is the same as it has been, dating back to the Agency’s inception in 1958. You can see from my biography that I was at DARPA nearly 25 years ago, so I speak from years of personal experience.

Rather than go through a blow-by-blow rebuttal of the article, I am providing the Committee with my answers to specific questions from the *Times* reporter (Appendix A) and my response to a question from the Senate Armed Services Committee staff (Appendix B) which was used in the article. I urge you to read this information in order to better assess the claims made in the *New York Times* article itself, which is included in Appendix C for your convenience.

A mistaken impression that readers may get from the *New York Times* article is that DARPA is carelessly eliminating universities from research funding by requiring increased security classification. The case cited by the article is DARPA’s Network Embedded Systems Technology (NEST) program. NEST is developing technology for networks of small, low-power sensor nodes that can operate under extreme resource constraints of power, timing, memory, communication, and computation, while simultaneously being highly scalable and robust.

As you will see from Appendix A, NEST started in 2001 and was originally planned to end this fiscal year. DARPA extended the program for one year to focus on military applications of the technology. Contrary to the article, NEST funding to universities for research actually *increased* during the life of the program. From fiscal year FY 2001 through FY 2005, NEST program funding for university research increased from the original plan of \$18.8 million to \$26.1 million—an increase of \$7.3 million, or nearly 40 percent.

In addition, the article implies that DARPA is moving away from long-range “blue sky” research. Let me assure you that also is not the case. Appendix D is a list of representative

DARPA research programs that show DARPA is, indeed, funding radical ideas that involve long-range research.

When I first heard about the university funding concerns several months ago, I decided to investigate the claim. One of the first things I did was to determine whether a trend existed in DARPA's university funding over the past several years.

Figure 1, entitled "DARPA funding at selected universities, FY 1999 to FY 2004," shows the results from that investigation. For privacy reasons, I have not identified the universities, but I will provide the Committee the information on request.

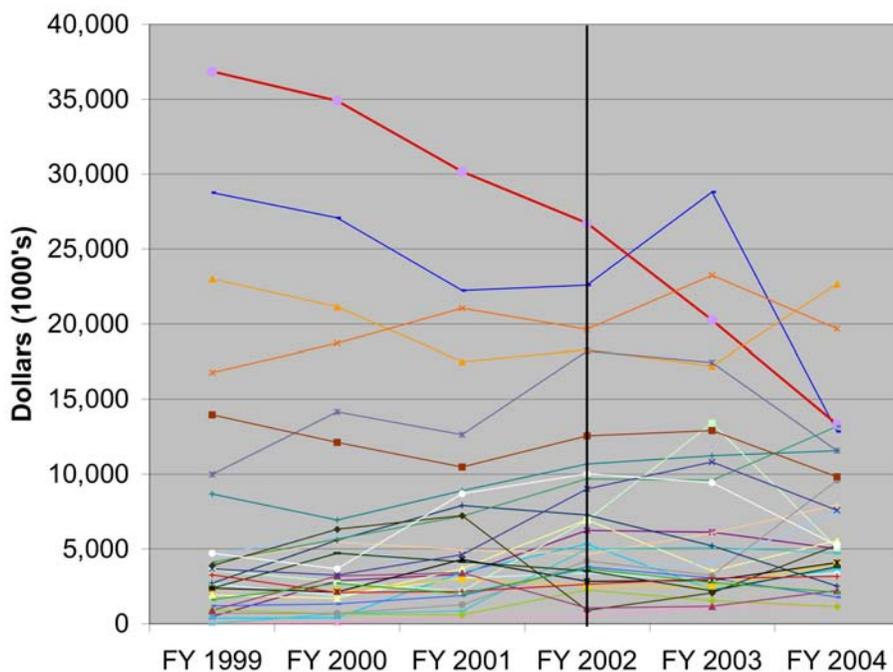


Figure 1: DARPA funding at selected universities, FY 1999 to FY 2004.

The graph shows that funding at individual universities varies over time; from year to year, funding typically goes up and down at any given school. However, with one notable exception¹, funding varies around a roughly constant level.²

The black vertical line in Figure 1 marks the period when I returned to DARPA as Director. Analyzing the data, I could not find any correlation between funding levels and trends since my

¹ After I saw the dramatic decrease in the university plotted as the red line, I contacted the president of the university. We are trying to figure out what is going on, and we plan to meet in June.

² The peculiar funding profile for the university plotted as the purple line, with a dramatic increase in FY 2003 followed by a sharp decrease in FY 2004, is the result of the timing of one contract; the funding for those two years should be averaged.

return to the Agency. Even the university with the large decrease was on this path long before I became Director.

Figure 1 leads to an interesting observation.

The major complaint about reduced university funding seems to be coming from one discipline—computer science. But if DARPA’s overall funding of universities is more or less constant, then other disciplines must be the recipients of DARPA’s research funding.

The key question becomes, “What other discipline has grown significantly over the past five years at the expense of computer science?”

As part of my investigation, I reviewed several dozen university websites to see if I could determine the new discipline that was on the rise.

The answer is surprising on the one hand and obvious on the other: no *single* discipline has been taking over.

Every university website I visited advertised that they had created centers for multidisciplinary research and professed that these centers were the harbinger of the future. What must be happening is that, while computer science is always part of the multidisciplinary efforts, its past dominance and, hence, respective share must be decreasing in relationship to the other disciplines involved in the effort.

In this same vein, last month Dr. Arden Bement, Director of the National Science Foundation, remarked that, “Evolving in concert with the new [scientific] tools are different ways of working within science, such as collaboration across large, multidisciplinary, often international teams. These new modes of working are essential to meeting the grand scientific challenges of our era-- those overarching goals that require a concerted, large-scale effort.”³

Multidisciplinary research is the foundation for creating the innovations of the future.

I agree.

In fact, DARPA has been leading that trend for almost 50 years. And we are continuing that tradition.

Let me give you some examples:

Material Science: In the early 1960s, universities had departments in metallurgy, chemistry, physics, mining, and engineering, but there was no “material science” discipline to solve the burgeoning problems of space vehicles, ballistic missile nose cones, and hypervelocity impact.

³ Dr. Arden L. Bement, Jr., “The Shifting Plate Tectonics of Science,” American Ceramic Society, Frontiers of Science and Society Rustom Roy Lecture, Baltimore, MD, April 10, 2005

We needed advanced materials like plastics, composites, thermoelectrics, semiconductors, ceramic windows for high power microwave devices, lightweight armor, and other materials for space applications. All this required multidisciplinary laboratories to provide the science, technology, and the cadre of “material scientists” to develop the materials the nation would need for its Defense technologies. DARPA funded the formation and growth of the Interdisciplinary Materials Laboratories through the 1960s. By 1989, there were about 100 materials science departments in U.S. universities—much of this stemming from DARPA’s funding of multidisciplinary university activities.

Computer Science: In the 1960s, there was no “computer science” discipline *per se*. DARPA funded electrical engineering and mathematics ideas, along with ideas from other areas, combined them, and began to focus on the problems and opportunities of human-machine interface and networks. This effort led to the personal computer and the Internet. Today, the multidisciplinary outcome is what we call “computer science.” A recent survey of 335,000 computer science publications⁴ shows that DARPA is second only to the National Science Foundation in funding this multidisciplinary group of researchers.

More recently, DARPA’s High Performance Computing Systems (HPCS) program is aimed at filling the gap between today’s late-80s high performance computing technology and the quantum/bio-computing systems of the future. HPCS involves new materials, new microelectronics architectures, and revolutionary software engineering—it is a quintessential multidisciplinary computer program.

Stealth: In the 1970s, DARPA wanted to make an aircraft invisible to radar. To achieve stealthy aircraft such as today’s F-117 and B2, DARPA assembled research teams in radar absorbent materials, infrared shielding, heat dissipation, reduced visual signature technology, low-probability-of-intercept radar, active signature cancellation, inlet shielding, exhaust cooling and shaping, and windshield coatings. Physicists, aeronautical engineers, material scientists, and electrical, thermal and structural engineers were brought together to solve the problem. To achieve this, DARPA did not post specific requirements for academic disciplines to be gathered to solve stealth. Instead, we focused on the problem of how to build an airplane not only according to the Navier-Stokes equation, but also according to Maxwell’s equations, and then brought together the necessary disciplines to solve the tough technical challenges.

Analog, Optical, and Radio Frequency Electronics: In the 1980s and 1990s, DARPA pioneered advances in digital silicon microelectronics and analog gallium arsenide microwave circuits critical to military information superiority. Since 2000, DARPA has opened a new range of capabilities by leading the development of Integrated Microsystems—complete “platforms on a chip” with the ability to sense, process, and act on data. DARPA programs have driven

⁴ Giles, L. and Council, I., “Who gets acknowledged: Measuring scientific contributions through automatic acknowledgement indexing,” *Proceedings of the National Academy of Sciences* **101**, 51 (2004)

combinations of electronics, photonics, microelectromechanical systems (MEMS), algorithms, and architectures to give the DoD an unparalleled ability to sense, process, and act on data.

Bio:Info:Micro: A few years ago, we saw opportunity in the convergence of biology, information technology, and microsystems. That led to our current work to combine neuroscience, biology, computers, actuators, sensors, and power systems in a multidisciplinary program to revolutionize prosthetics. Our goal is to dramatically improve the quality of life for amputees and allow them to return to a normal life with no limits whatsoever by developing limb prostheses that are fully functional, neurologically controlled limb replacements that have normal sensory abilities.

As I mentioned earlier, Appendix D shows a sample of more than 75 DARPA programs we're working on today. If you look over that list, you can't help but see the tremendous amount of multidisciplinary work being done to solve Defense technology problems.

Developing completely new multidisciplinary research is at the heart of many DARPA success stories that are reported often in the press.

DARPA's focus on national security problems and opportunities naturally leads to multidisciplinary research because most problems or opportunities do not come neatly packaged in disciplines.

We do not emphasize advancing progress in established disciplines. Instead, we bring together teams from diverse institutions and disciplines to solve a particular problem.

This does lead to significant changes in the disciplines and institutions that are involved with DARPA at any given time, but it also results in a great deal of progress.

It is also highly likely that the funding varies considerably for specific established academic disciplines—but these funding variations, like in computer science, are hard to track since DARPA does not specifically fund disciplines, as explained earlier.

Thus, our funding of people, disciplines, universities, and institutions increases and decreases as a result of the constantly changing mix of problems that DARPA is working to solve. The mix does change, but the overall effort is robust.

This change, while occasionally discomfoting, is very healthy. It is exactly how problems are solved and ensures DARPA remains open to entirely new ideas. Many, perhaps most, of our solutions are multidisciplinary and, as you saw above, we even occasionally foster entirely new disciplines this way.

More often than not, revolutionary technological progress—which is distinct from scientific progress—is not a product of continuing, secure funding of established disciplines. Crucial steady progress is made within disciplines, but many would agree that truly major technical

revolutions often occur outside or in between disciplines. Real technology breakthroughs come from the multidisciplinary problem-solving approach that DARPA has been relying on for decades.

DARPA's focus is to agilely pursue national security problems and opportunities.

Funding for the Future

As I think about the issues this Committee is dealing with, I have an observation to make.

First, the major complaints about decreased funding seem to be coming from one specific discipline—computer science.

The complaints, I also note, never clearly identify the specific research that is not being done, the problems that are not being solved, or the progress that is impeded as a result of decreased funding in the discipline. The message of the complaints seems to be that the computer science community did good work in the past and, therefore, is entitled to be funded at the levels to which it has become accustomed.

I want to strongly emphasize that I do believe individual research disciplines are important. They provide the scientific foundation for multidisciplinary research, and they need to be funded at healthy levels to keep the pipeline full and allow for multidisciplinary work to occur.

However, it may be appropriate to have funding for specific established disciplines such as computer science, and this Committee may reach that decision. However once such funding is started, it would be reasonable to expect that other disciplines such as chemistry, physics, and math would expect similar consideration.

But rigidly funding specific, established disciplines would severely limit the flexibility DARPA needs to be successful. DARPA needs the ability to promote multidisciplinary work to solve important national security problems, to include forming completely new disciplines.

We at DARPA are always interested in hearing about good ideas that we can accelerate into use for our national security no matter where they come from. This is inherently multidisciplinary work, just as the universities are emphasizing, and we believe it is to the great benefit of our military and nation.

Appendix A

Q and A's Asked by *New York Times* Reporter Regarding University Interactions with DARPA

1. Is it true that there has been a shift in DARPA funding away from universities during the past two to three years? How significant has the shift been?

A: The claim that DARPA funding has shifted away from universities is incorrect.

However, University funding requires an understanding of how the DoD budgets. There are several Budget Activities ranging from 6.1 to 6.7. Science and Technology (S&T) funding is defined as the 6.1 through 6.3 Budget Activities.

The 6.1 Budget Activity is termed Basic Research and is defined as systematic study directed toward greater knowledge or understanding of the fundamental aspects of phenomena and of observable facts without specific applications in mind. The activity in this account is almost always unclassified and ITAR (International Traffic in Arms Regulations, i.e., export control) restrictions do not apply since specific applications are not in mind. Hence these funds are ideally suited to the operations of universities.

The 6.2 Budget Activity is termed Applied Research and is defined as systematic study to understand the means to meet a recognized and specific need. The activity in this account tends to require classification and/or be subject to ITAR restrictions far more often than 6.1 research. Hence, not all the programs under this account are suitable for universities, or even possible for universities that refuse to do classified research. However universities do submit proposals for programs funded from this account, and receive the largest absolute value of their funding from DARPA from this account. That said, as programs in this account progress, they may require classification and/or have ITAR restrictions, meaning that normal university operating practices make participation in the program less desirable and feasible.

The 6.3 Budget Activity is termed Advanced Technology Development and includes development of subsystems and components and efforts to integrate them into system prototypes for field experiments and/or tests in a simulated environment. This type of work is rarely a good fit with universities. Universities do propose to efforts in this account but the efforts are typically incidental, specific investigations and do not last the duration of the effort.

There has NOT been a shift away from universities. The DARPA 6.1 Basic Research account has increased since 1999 both in absolute terms and as a percentage of the DARPA budget. And, since 1999, the percentage of that 6.1 funding going to universities has also increased.

DARPA 6.1 funding has averaged 8.7 percent of DoD's total 6.1 investment over the last 10 years. DARPA's share of the total 6.1 funding increased noticeably over the past several years. Our 6.1 program was 13.4 percent of the DoD 6.1 program in 2004 and 11.2 percent of the 6.1 total in FY 2005 – well above the 10-year average.

Within DARPA's budget, the percentage devoted to 6.1 averaged approximately 4.4 percent over the past 10 years. In this area too, the percentage has been on the rise over this timeframe, and the 6.1 percentage has increased to 5.8 percent of the overall DARPA budget.

In absolute terms, the 6.1 budget has more than tripled, from \$54.9 million in FY 1999 to \$169.9 million in FY 2005.

The percentage of the DARPA university 6.1 budget in FY 1996-2000 was 52 percent, while the FY 2001-2004 percentage was 59 percent (where FY 2004 stands today). This is in line with the findings of the National Academy of Sciences' *Assessment of Department of Defense Basic Research* study published in 2005 that 60 percent of DoD's overall 6.1 program went to universities.

2. What is the reason for the shift? What are the DARPA priorities and have they changed significantly?

A: The only shift since 1999 in our basic research has been towards MORE funding and MORE funding at universities.

DARPA currently has eight strategic thrusts (see list below) chosen based on a strategic assessment of national security threats and technological opportunities facing the U.S:

- Detection, precision identification, tracking, and destruction of elusive targets
- Location and characterization of underground structures
- Networked manned and unmanned systems
- Robust, secure self-forming tactical networks
- Cognitive computing
- Assured use of space
- Bio-revolution
- Urban area operations

In addition to these eight strategic thrusts, DARPA's research also emphasizes core technology areas that are independent of current strategic circumstances, but important to future technical opportunities and successes.

These core technology foundations are the investments in fundamentally new technologies, particularly at the component level, that historically have been the technological feedstock enabling quantum leaps in U.S. military capabilities. Core investment areas include: materials, microsystems, information technology and other technologies and sciences, including in recent years biology and mathematics.

Many of DARPA's university performers are funded to develop breakthroughs in the core technology investment areas. However, many universities are also funded to achieve technological breakthroughs in the eight strategic thrust areas.

Details on these thrusts are provided in the DARPA document "Bridging the Gap" which can be downloaded from our website www.darpa.mil.

3. Does DARPA publicly break out the university component of its funding?

A: Yes, the following provides average funding for the past three fiscal years:

FY02 to FY04	Avg. \$ univ. performers*	Avg. overall DARPA \$	Univ. percentage
6.1 Basic Research	\$90.1M	\$150.3M	60%
6.2 Applied Research	\$270.4M	\$1,128M	24%
6.3 Adv Tech Devel	\$92.3M	\$1,076.3M	8.6%
Total	\$452.8M	\$2,354.3M	19.2%

*This is funding that goes directly to a university and does not count the funding that goes to universities through subcontracts to industry.

Universities receive a significant percentage of dollars from DARPA. In fact, the table shows that universities receive nearly 4 times more of their dollars from DARPA's 6.2 and 6.3 accounts, even though the research funded in these accounts is less suited to universities' operational practices.

4. A number of university researchers have told me that the DARPA Network Embedded Systems Technology (NEST) research has largely been removed from universities and classified. Is that true? Is that because there is an operational need for the technology?

A: Yes, there is an operational need for the technology and this is a specific case where the original 6.2 effort was successful to the point that further efforts became classified..

DARPA's NEST program started in 2001, and was scheduled to end in FY05 (this year). DARPA is extending the program for an additional year to focus on military applications of the technology. In order to protect the U.S. advantage in this technology, it is necessary to classify and protect aspects of the technology.

Previous NEST university performer work is all unclassified, and university researchers can publish information on their concept, findings, algorithms, and other basic research academic material. Under the terms of their NEST contracts, university researchers provide their source code to the Government as a deliverable. DoD does plan to protect the source code and military applications of the technology appropriately.

DARPA expects to involve the defense contractor community in the next phase of the NEST program. It is also expected that many of the university researchers will become subcontractors to the defense contractors.

In addition, all of the current NEST university efforts are continuing. Some individual university NEST activities were reduced, but other university NEST activities were increased. Overall, there was increased funding for universities in NEST over what was originally planned.

5. There was a specific effort to remove the NEST Tiny OS research at the University of California at Berkeley. Do you know why DARPA attempted to classify that research? Is it true

that there was a prior contract that stipulated that the research results would be available as open source?

A: TinyOS research is not classified. In fact, all basic level fundamental research in sensor network systems is unclassified. The DARPA NEST program is funding University of California at Berkeley to continue their research work through FY05. However, DoD does plan to protect the source code and military applications of the technology by taking the deliverable software from all such researchers to further develop it with other defense contractors.

6. Was research being done by Jack Stankovic at the University of Virginia on sensor networks classified?

A: All university research on the NEST program, including that of Professor Stankovic, was unclassified. University researchers, including Professor Stankovic, will continue to be funded for unclassified basic research in FY 2005 as well. In addition, the program plans to support classified work to be done by defense contractors.

7. A November 2004 report by the President's Information Technology Advisory Committee states that DARPA has departed from its historical support of longer term research. Is this accurate?

A: This is not accurate, DARPA has always supported a mix of longer and shorter term research.

DARPA mines fundamental discoveries and accelerates their development and lowers their risks until they prove their promise and can be adopted by the Services. The key is a focus on high-risk, high-payoff research.

DARPA has two fundamental types of technical offices. Technology offices focus on new knowledge and component technologies that might have significant national security applications, which often involved longer term research. System offices focus on technology development programs leading to products that more closely resemble a specific military end-product.

During periods of active conflict, DARPA adds an additional type of activity – quick reaction projects that take the fruits of previous science and technology investment and very quickly move the technology into a prototype, fieldable system and into the hands of deployed forces. There have been many published articles on some of these technologies.

Quick reaction projects are done in addition to DARPA's usual activities, not instead of.

The PITAC report addresses specifically cybersecurity research for commercial applications and seems to think that if research is classified, it is by definition short-term.

DARPA expects that its information assurance research will have a broad, beneficial impact on the commercial world, as commercial networks move toward the mobile, ad hoc, peer-to-peer features common to today's military networks.

Recall that the Internet, which came from DARPA research, progressed in the 1970s for DoD reasons, not commercial reasons. There are many other commercial products available today to protect the Nation's computer networks that are the result of DARPA research on information assurance for military networks having a fixed infrastructure similar to those encountered in the civilian community.

Network centric warfare involves networks that must assemble and reassemble on-the-fly on an ad hoc basis without having a fixed or set infrastructure in-place. The military must achieve what has been called "critical infrastructure protection" without infrastructure. In the most advanced cases, these are peer-to-peer or "infrastructureless" networks. There is no fixed, in-place network equipment – the whole network architecture is fluid and reassembles dynamically.

In the long term, commercial networks will acquire some of these features. Why? Because the cost of these networks will be considerably less than today's networks, in which fixed assets such as towers, etc., have to be built and maintained.

8. The report also states that DARPA programs are increasingly classified, thereby excluding most academic institutions. Is that accurate?

A: DARPA follows Executive Branch guidelines when classifying its programs – classification is only used to protect information that, if subjected to unauthorized disclosure, could reasonably be expected to cause damage to the national security.

It is true that some universities are not able to perform classified or ITAR research. But many DARPA programs are not classified and university researchers are often involved in them. 6.1 programs are defined as programs without a specific application in mind and are very seldom classified or have ITAR restrictions.

DARPA's programs are developing technologies to benefit the warfighter. DoD has an ongoing effort to streamline and shorten the amount of time necessary for advanced technology to be incorporated into new weapons systems and become operational. DARPA's role is to transition technology into military applications and demonstrations.

It should not be a surprise that, as the programs mature, they move from research that is unclassified to research that is either classified and/or ITAR restricted. In addition, as technology development moves along this continuum, it tends to increasingly involve industry performers who can actually produce the product.

This progression, which results in either classification as the application becomes focused, or ITAR restrictions at the component level, or the increasing involvement of industry, seems to account for the decrease in university performers in DARPA's 6.2 and 6.3 research. However as the answer to an earlier question showed, Universities receive nearly 4 times more resources from the 6.2 and 6.3 accounts as they do from 6.1

9. The report also asserts that DARPA's new mission is to incorporate pre-existing technology into products for the military rather than funding basic research. Is that accurate?

A: This is not true, there has been NO change in DARPA's core mission.

Our mission, established in 1958 in response to Sputnik, is to prevent technological surprise for the U.S. and create technological surprise for our adversaries. Our focus is and has always been solely on research and development for national security, and therefore portions of DARPA's research have always been classified or subject to ITAR restrictions.

Please read the answers to the previous questions and download "Bridging the Gap" from our website to find out what we are doing.

10. Reporter would like an interview w/ Dr. Tether or other DARPA official to discuss these questions.

A: DARPA will provide written answers in lieu of an interview.

Appendix B

Senate Armed Services Committee Staff Request for DARPA Investment in Computer Science and Opportunities for University Participation

Introduction: DARPA was requested by the SASC staff to provide an historical estimate of DARPA funding for Computer Science (CS), and the amount of that funding given to Universities.

The following material provides data to answer the questions

For the purposes of this discussion, Computer Science (CS) is defined as:

The systematic study of computing systems and computation. The body of knowledge resulting from this discipline contains theories for understanding computing systems and methods; design methodology, algorithms, and tools; methods for the testing of concepts; methods of analysis and verification; and, knowledge representation and implementation.

However it is doubtful that any accurate assessment whether or not DARPA interest in Computer Science has increased or decreased can be made.

Why is this true?

First of all, DARPA does not directly seek efforts in Computer Science; that is, DARPA does not publish Broad Agency Announcements (BAA's) requesting ideas to advance the field of Computer Science as a discipline.

Instead, DARPA publishes BAA's to solicit ideas for obtaining a particular capability, such as achieving 24 by 7 situational awareness, or developing a new High Performance computer based upon productivity as a goal rather than raw speed as measured by instructions per second.

Whether or not Computer Science was needed to achieve these capabilities is a consequence of the effort and not a prime reason in its own right.

Because of this, it required significant effort to compile the numbers in this report. Each of DARPA's 400-plus efforts had to be examined individually to determine whether or not Computer Science was an ingredient.

In order to avoid having almost every effort classified as such, only those where Computer Science as defined above was a significant ingredient were included.

Hence the following funding data should be considered as a low estimate of the actual funding.

In addition, due to database constraints, the university participation funding data is limited to those instances where the university is identified as the prime (or sole) performer on the contract or grant. The database records the amounts obligated and disbursed to the performer of record on each contracting vehicle; subsequent funding distributions made by the prime contractor to subcontractors, which could include Universities, is not captured in the database.

Overall Computer Science Funding trends:

DARPA conducted a review of FY 1994-2004 funding for computer science research. The following table summarizes CS research funding for those years (\$, Millions).

FY 94	FY 95	FY 96	FY 97	FY 98	FY 99	FY 00	FY 01	FY 02	FY 03	FY 04
471	546	536	512	523	557	525	546	571	613	583

These funds support a vast array of information research including basic (6.1) research, traditional software and high performance computing programs, information assurance and security, and applications of the technology for warfighter requirements in such areas as language translation, advanced networking, robotic systems control, and command and control systems.

Increasingly, DARPA funding is being applied to long term research that is exploring cognitive computing, which is the quest for computers that are interactive with the user and capable of learning as opposed to the current generation of machine tools; the use of advanced quantum theory and biological based computer science; and, Defense applications of computer science research. Universities are not excluded from any of these research areas and are welcome to participate to the extent they are willing to comply with basic DoD oversight and security requirements and ITAR restrictions.

The years following the FY 1995 budget (\$546 million) reflected completion of a number of software (architectures, persistent object bases), hardware programs (completion of the first high performance computing initiative) and applications (global grid communications, defense simulation internet, transition of the advanced simulation program to the Defense Simulation Systems Office).

As a consequence, funding declined in FY 1996-98 in comparison to the FY 1995 level.

The decline in computer science funding in the late 1990s would have been far more severe had it not been for the significant funding increases for information assurance programs (all of which had computer science as a significant part), and DARPA's participation in the Next Generation Internet program, a multi-agency, term limited (five year) effort to explore network bandwidth expansion and quality of service initiatives.

Information assurance programs increased five fold between FY 1995 and FY 1999. In FY 1995, Information Assurance programs were only \$10 million or less than 2 percent of computer science funding. By FY 1999, Information Assurance funding had increased to \$55 million or 10 percent of the computer science total.

After a temporary lull in FY 2000, increases in middleware research and expanded emphasis on information tools for Asymmetric Threat prediction and prevention fueled the major expansion of IT funding in FY 2001-2003.

From FY 2000 to FY 2003 computer science funding rose \$88 million or 17 percent. Yet even as the budget was increasing, the portfolio mix was changing. Agent based software, Quality of Service programs, and high performance computing architectures transitioned into DoD

applications programs, and the Software Engineering Institute was transferred from DARPA's accounts to OSD.

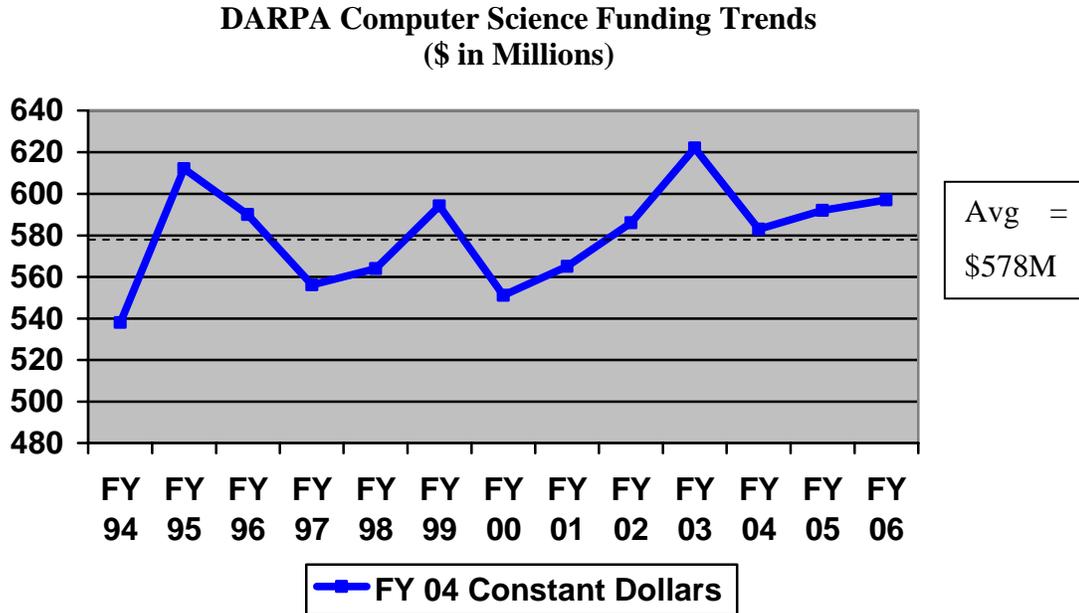
Between FY 2003 and FY 2004, overall funding for computer science research declined slightly, by \$30 million or 5 percent, from \$613 million to \$583 million. A number of ongoing embedded software programs transitioned to major applications efforts such as the Future Combat Systems. Like FY 2000, the FY 2004 decrease is more an anomaly than a significant trend.

All computer science research activities associated with Asymmetric Threats programs were eliminated by congressional decree in FY 2004, thus further reducing the FY 2004 computer science budget by nearly \$80 million, and also reduced outyear outlays. Funding increases in cognitive computing, language translation efforts, and classified applications partially offset the congressional action.

The FY 2005-06 budgets have held computer science funding constant at the FY 2004 level. The following table displays the budgets for FY 2004-2006 as reflected in the FY 2006 President's budget.

FY 04	FY 05	FY 06
583	583	584

Another way to look at the computer science trends, without the masking effect of inflation, is to covert and display the data in constant dollars. The following graph does just that.



When expressed in constant dollars, it becomes clear that the trend in DARPA computer science funding was downward from FY1995 to FY2000. The downward trend stopped in FY2000 and has been increasing since then.

University Involvement in DARPA Computer Science Research: Data constraints limited the evaluation of university research funding to the FY 2001-2004 period. The following table shows university funding for those years.

	FY 2001	FY 2002	FY 2003	FY 2004
Total Comp Science	546	571	613	583
University Funding	214	207	173	123

There are factors for the decline, some of which were beyond DARPA's control. They are:

1. High Performance Computing (HPC): In FY 2001, over 50 percent of HPC funding (\$67 million) went to universities. However, the program focus shifted from pure research to super computer construction. This change in emphasis resulted in the major CS vendors—Sun, IBM, Cray, etc—receiving the bulk of the funding and as a result, universities received only 14 percent of the HPC funding in FY 2004 (\$14 million). But, they are included in the program through sub-contract relationships
2. Information Assurance (IA): University research comprised \$20 million of the \$70 million applied to IA efforts in FY 2001. During the subsequent years, the IA program classification increased. By FY 2004, the unclassified budget for IA was less than half of the FY 2001 program, and the amount issued to universities had dropped to \$4 million.
3. Asymmetric Threats: Universities received a consistent \$11-12 million per year for asymmetric threat program research. This ended with congressional cancellation of the program in FY 2004.
4. Intelligent Software: Much of the intelligent software research in FY 2001 was oriented towards proving and refining the use of software agents and control architectures. As the research matured, many of the tools developed were integrated into network command and control application programs. While the universities continued involvement with these efforts after transition to applications, the amount they received (approximately \$8 million in FY 2004) was only about one third the amount they received in FY 2001 (approximately \$28 million) when the programs were still in the early stages of research.
5. Classified programs: Classified funding for computer science-related programs increased markedly between FY 2001 and FY 2004. Universities received none of this funding.

Appendix C

Please refer to:

<http://query.nytimes.com/gst/abstract.html?res=F00E10FA3A5B0C718CDDAD0894DD404482&incamp=archive:search>

Appendix D

Typical DARPA Research Efforts

1. **3-Dimensional Integrated Circuits:** Three dimensional stacked integrated circuits to achieve “human brain-like” complexity in digital circuits.
2. **Adaptive Focal Plane Array:** Tunable microelectromechanical (MEMS) etalons at each pixel of an infrared focal plane array for chip-scale hyperspectral imaging.
3. **Advanced Soldier Sensor Information System and Technology:** Methods that will allow machines to automatically parse multimodal sensory input into meaningful “experiences” and support intelligent indexing and retrieval of useful episodes.
4. **Architectures for Cognitive Information Processing:** Radically new computer architectures that are a better match to cognitive information processing algorithms than conventional Von Neumann machines.
5. **Biological Sensory Structure Emulation:** Fundamental understanding of biological sensory structures, and emulating this knowledge to create superior synthetic sensors.
6. **Biologically-Inspired Cognitive Architectures:** Relatively complete models of the brain’s functioning mapped to brain structures; models for cognition, as well as understanding memory models used by people for everyday reasoning.
7. **Bio-Magnetic Interfacing Concepts:** Novel capabilities for integrating nanomagnetism with biology as a powerful new tool for manipulation and functional control of large numbers of cells and biomolecules, including magnetically actuated, on/off control of cellular functions, and magnetic filtration of pathogens.
8. **Canard Rotor Wing:** Aircraft capable of transforming from a helicopter into a jet—and retaining all the advantages of either.
9. **Chip Scale Atomic Clock:** Atomic time precision in devices smaller than a dime that will revolutionize modern networking and communications.
10. **Close Combat Lethal Reconnaissance:** A new weapon approach that allows long-range indirect fire to occur at the individual soldier level.
11. **Computational Fluid Dynamics:** Incorporation of underlying physics will enable advances in CFD for building ships with greatly reduced friction drag, and building extraordinarily quiet helicopter blades.
12. **Coordination Decision-Support Assistants:** Personalized machine-based cognitive coordination agents to assist commanders in adapting complex plans in real time to changing situations.
13. **Cormorant:** Unmanned aircraft that can be launched from a submarine and retrieved at the end of a mission.
14. **Data in Optical Domain – Network:** All-optical communications with optical coding, storage, multiplexing, and routing.

15. **Defense Against Cyber Attacks on Mobile Ad Hoc Network Systems:** Cognitive, autonomous, information assurance tools for next-generation, yet-to-be-deployed, tactical military networks.
16. **Disruption Tolerant Networking:** Replacing the connection oriented philosophy of today's Internet with protocols that guarantee message delivery, even when connections are disrupted.
17. **Dynamic Quarantine of Computer-Based Worms:** Computer defenses that operate "faster-than-worm-speed" against zero-day worms.
18. **Electronic and Photonic Integrated Circuits:** Ubiquitous photonics produced on the same wafer as silicon microelectronics.
19. **Engineered Bio-Molecular Nano-Devices/Systems:** Engineered bio-molecular nano-scale devices that emulate the behavior of membrane ion channels to enable real-time observation and analysis of bio-molecular signals, enabling single-molecule sensitivity.
20. **Exploitation of 3D Data:** New methods to describe and analyze shape signatures from advanced 3D sensors that can recognize specific targets from a vast array of alternatives; e.g., finding a specific terrorist vehicle in urban clutter.
21. **Focus Areas in Theoretical Mathematics:** New mathematical foundations for conformal field theory in physics.
22. **Global Autonomous Language Exploitation:** Ultimately replace human language translators and human analysts with machine language processing that leads directly from source natural language (speech or text) to actionable intelligence.
23. **Global Reach With Global Endurance:** Novel aircraft and propulsion concepts to enable aircraft to launch from the United States and reach anywhere in the world—and stay aloft for weeks at a time.
24. **Heterogeneous Urban Reconnaissance Teams:** System to provide real-time reconnaissance, surveillance, targeting, and acquisition services directly to warfighters in complex urban environments.
25. **High-Productivity Computing Systems:** Viable peta-scale processor to be available (in small numbers) by 2010.
26. **Handheld Isothermal Silver Standard Sensor:** Develop a handheld sensor for biological warfare agents that brings laboratory-quality assays into the field.
27. **Human Assisted Neural Devices:** Fundamental research to enable the understanding and use of brain activity to control external prosthetic devices, using sensory feedback and memory.
28. **Hypersonic Aircraft And Missiles:** Controlled flight at higher speeds than ever before, exploring the uncharted territory of flight at 6 to 20 times the speed of sound.
29. **Immune Buildings:** Buildings to actively defend against chemical and biological warfare agent releases inside or near them.

30. **Improving Warfighter Information Intake Under Stress:** A machine that recognizes a human's cognitive state (especially under stress) and adapts its mode of information presentation based on the state.
31. **Indoor and Underground Navigation:** GPS-like capability to navigation inside and underground.
32. **Innovative Space-Based Radar Antenna Technology:** Components, deployment technologies, and active calibration methods to enable affordable, tactical-grade targeting from space, thereby enabling true persistent surveillance of all moving ground vehicles.
33. **Integrated Sensor Is Structure:** Integrate the world's largest radar into a station keeping airship, to enable uninterrupted, persistent surveillance of all air and ground targets, including dismounted troops.
34. **Intelligence, Surveillance, and Reconnaissance (ISR) for Building Internals:** Extend the range of our ISR capabilities to include determining building layout and occupancy from outside, prior to entry.
35. **Laser Weapons:** Tactical and practical laser weapons that can be carried in a HMMWV or fighter jet and are capable of shooting any tactical threat out of the air—from missiles to mortars.
36. **Low Power Micro Cryogenic Coolers:** Local refrigerators machined into regions of highly sensitive circuits to increase the performance of the electronics without appreciable increases in the direct current power.
37. **Machines That Mimic Nature:** Nano-flapping winged vehicles, vehicles that flare to land like birds, and snake-like robots.
38. **Mission-Adaptable Chemical Spectrometer:** A man-portable, chemical identification system with a sensitivity of 10 parts per trillion.
39. **Mobile Integrated Sustainable Energy Recovery:** Novel mechanical and chemical approaches to allow the processing of military waste into logistics fuels.
40. **Negative Index Materials:** Novel microwave materials that have a negative refractive index ("left handed") behavior, and extending this behavior to the optical regime.
41. **New Concepts For Logistics:** Novel, heavy lift aircraft concepts capable of moving an entire army brigade from fort to fight—eliminating any need for bases outside the United States.
42. **Novel Satellite Communications:** Jam-proof communications satellites.
43. **Ocean Wave Energy Harvesting:** High efficiency harvesting of electrical energy from wave motion.
44. **Opto-Electronics for Coherent Optical Transmission And Signal Processing:** Exploit phase control of photons to realize coherent optical free-space communications.
45. **Persistent Operational Surface Surveillance and Engagement:** Persistent surveillance system that can respond rapidly to a rapidly evolving insurgent threat.
46. **Personalized Assistant that Learns:** Integrated, enduring personalized cognitive assistant that perceives, reasons, and learns.

47. **Protein Design Processes:** Approaches to radically transform the protein design process by developing new mathematical and biochemical approaches to the *in silico* design of proteins.
48. **Quantum Information Science and Technology:** Fundamental technology and ideas that could ultimately lead to a quantum computer.
49. **Rad Decontamination:** First methods to decontaminate buildings after release of radiological dispersal device; provides a clean-up option other than rubble-ization.
50. **Radiation Hard By Design:** Putting Moore's Law into space by exploiting commercial integrated circuit fabrication of military-critical circuits for satellites.
51. **Rapid Vaccine Assessment:** Interactive and functional *in vitro* human immune system that will replicate the *in vivo* human immune response.
52. **Real-time Adversarial Intelligence and Decision-making:** Methods that model an adversary's likely course of action in different urban combat scenarios.
53. **Real-World Reasoning:** Fundamental research in machine reasoning, trying to drastically improve the scale at which certain types of reasoning can be done.
54. **Restorative Injury Repair:** Fundamental understanding of the behavior of cells as they recover from injury, and learning how to control their regeneration in order to regrow the original structure (skin, muscle, etc.), rather than scar.
55. **Robotic Ground Vehicles:** Ground vehicles that can sense and react to complex terrain—negotiating obstacles, discovering paths, avoiding detection, and conducting military missions.
56. **Robotic Space Assembly Concepts:** Revolutionary space capabilities on orbit—systems too complex and fragile to be constructed anywhere but in zero-G.
57. **Robotic Spacecraft:** Autonomously repairing, upgrading, and refueling other satellites—completely changing the paradigm and economics of “disposable” military spacecraft.
58. **Satellite Navigation:** Using pulsing neutron stars as GPS-like sources.
59. **Self Forming Constellations Of Tiny Intelligent Spacecraft:** Spacecraft that are cheap, easy to launch, and swarm together to provide entirely new capabilities beyond current space systems.
60. **Self-Regenerative Systems:** Revolutionary capabilities for computer systems under cyberattack to heal themselves, create immunity to future attack, and recognize and stop insider threats.
61. **Semiconductor Ultra Violet Optical Sources:** New region of the photon spectrum with wide bandgap semiconductor lasers and light emitting diodes.
62. **Slow Light:** Fundamental physics and new solid-state materials that slow, store, and process light pulses, i.e., optical information, in optical components.
63. **Standoff Precision Identification in Three Dimensions:** New long-range lidar that can acquire entire scenes in a single frame, rather than by scanning.

64. **Statistical and Perturbation Methods in Partial Differential Equation (PDE) Systems:** Stochastic treatment of fundamental PDEs modeling physical systems; e.g., Maxwell, Navier-Stokes, Helmholtz, Poisson, and Laplace.
65. **Surviving Blood Loss:** Fundamental understanding of the mechanisms of oxygen use in cells and the mechanisms of hibernation in order to increase the time before onset of hemorrhagic shock.
66. **Sustained Littoral Presence:** Using the chemistry of the undersea environment to generate electrical power.
67. **Swarming Robotic Flyers For Urban Reconnaissance:** Controlling every intersection and rooftop and reporting directly back to the soldier on the ground.
68. **Technology for Frequency Agile Digitally Synthesized Transmitters:** 500 GHz transistors with large dynamic range to support circuits for direct digital generation of microwave waveforms.
69. **Terahertz Imaging Focal Plane Array Technology:** Bridging the terahertz gap with sources and detectors in the 300 to 3,000 GHz (3 THz) frequency range.
70. **Triangulation Identification for Genetic Evaluation of Biological Risk:** The first, truly broadband sensor for detecting biological warfare agents, as well as diagnosing human disease, including agents/diseases never before seen or sequenced.
71. **Tiny Bullets And Grenades:** Munitions capable of steering themselves in flight to hit the hardest targets at the farthest ranges.
72. **Topological Data Analysis:** Mathematical concepts and techniques necessary to determine the fundamental geometric structures underlying massive data sets.
73. **Traction Control:** Nonlethal force multiplier to develop capability to adjust traction on surfaces to allow traction by U.S. forces, but deny it to the enemy.
74. **Transfer Learning:** New methods for learning that ultimately will allow the transfer of knowledge learned on one problem to many others not anticipated when the initial learning was done.
75. **Untouchable Aircraft:** Giving aircraft the capability to shoot down modern missile threats with high power beam weapons.
76. **Very High Efficiency Solar Collectors:** Engineered biomolecules to guide the assembly of inorganic molecules to create solar cells that are 50 percent efficient.
77. **Wide Bandgap Semiconductors for RF Applications:** High power, high frequency transistors based on wide bandgap semiconductors for future radar, electronic warfare, and communications systems.

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DIRECTOR
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Dr. Anthony J. Tether was appointed as Director of the Defense Advanced Research Projects Agency (DARPA) on June 18, 2001. DARPA is the principal Agency within the Department of Defense for research, development, and demonstration of concepts, devices, and systems that provide highly advanced military capabilities. As Director, Dr. Tether is responsible for management of the Agency's projects for high-payoff, innovative research and development.

Until his appointment as Director, DARPA, Dr. Tether held the position of Chief Executive Officer and President of The Sequoia Group, which he founded in 1996. The Sequoia Group provided program management and strategy development services to government and industry. From 1994 to 1996, Dr. Tether served as Chief Executive Officer for Dynamics Technology Inc. From 1992 to 1994, he was Vice President of Science Applications International Corporation's (SAIC) Advanced Technology Sector, and then Vice President and General Manager for Range Systems at SAIC. Prior to this, he spent six years as Vice President for Technology and Advanced Development at Ford Aerospace Corp., which was acquired by Loral Corporation during that period. He has also held positions in the Department of Defense, serving as Director of DARPA's Strategic Technology Office in 1982 through 1986, and as Director of the National Intelligence Office in the Office of the Secretary of Defense from 1978 to 1982. Prior to entering government service, he served as Executive Vice President of Systems Control Inc. from 1969 to 1978, where he applied estimation and control theory to military and commercial problems with particular concentration on development and specification of algorithms to perform real-time resource allocation and control.

Dr. Tether has served on Army and Defense Science Boards and on the Office of National Drug Control Policy Research and Development Committee. He is a member of the Institute of Electrical and Electronics Engineers (IEEE) and is listed in several Who's Who publications. In 1986, he was honored with both the National Intelligence Medal and the Department of Defense Civilian Meritorious Service Medal.

Dr. Tether received his Bachelor's of Electrical Engineering from Rensselaer Polytechnic Institute in 1964, and his Master of Science (1965) and Ph.D. (1969) in Electrical Engineering from Stanford University.