Computer Science Research Funding

How much is too little?

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Executive Summary

A study of the historical and planned level of Department of Defense (DOD) funding in computer science (CS) research from the 2001–2011 DOD records has provided a top-level view of the current status of investment in this foundational technology. This study was triggered by university and Congressional concern that DOD has been reducing its investment in CS research. While the funding database provided by DOD agencies and components was limited, the study found that DOD maintains a significant and stable investment in CS and the related areas of information science (IS) and network and information technology (NIT). Overall, CS/IS/NIT constitutes 17.4 percent of the entire DOD science and technology (S&T) funding base.

While top-line DOD funding shows out-year growth, a primary finding of this study is that the focus of the DOD research investment in NIT has shifted from basic research to more applied DOD applications. It remains to be seen whether the shift from basic CS research funding to applied research and advanced technology development in NIT will result in the kind of fundamental advances in technology enabled by an earlier generation of funding in CS research. However, total funding in NIT research and development from all Federal agencies has grown to over three billion dollars in 2008, with DOD contributing about a third. Current hindrances to academic research in DOD-sponsored NIT research have had the effect of limiting university participation in some DOD contracts and grant programs. These obstacles include pre-publication review, International Traffic in Arms Regulations (ITAR) restrictions, and short milestones for go/no-go decisions for program continuation.

Introduction

In the 2005 Defense Authorization Act (Public Law 108-375), Congress noted with concern that DOD was reducing its investment in long-term CS research. Congress concluded that this reduced funding level put at risk next-generation systems for networking, information technology (IT), and information assurance (IA) technology. This concern was brought to the attention of Congress by several universities with histories of DOD-sponsored research that were concerned that CS was becoming underfunded relative to the level of worthwhile new proposals being submitted to DOD. In response to this Congressional concern, the Deputy Under Secretary of Defense for Science and Technology (DUSD(S&T)) asked The National Defense University (NDU) to undertake a study to determine the historical levels of DOD CS funding. The study focused on two issues. First, has DOD CS funding to universities changed substantially year-to-year? Second, what was the trend in DOD funding of CS (e.g., absolute funding and ratio of CS funding to total science and technology (S&T) funding)?

The purpose of this paper is to address these two issues and explore additional issues raised in the study. First, we summarize the findings and issues uncovered in the study. Second, we summarize historical funding of CS research and trends. Third, we formulate a taxonomy for CS. Fourth, we identify DOD CS funding agencies and categories of funding. Fifth, we comment on the quality of CS research funding data. Sixth, we summarize the results of a workshop of academic leaders in CS on these issues. Finally, we conclude by formulating key findings and recommendations.

While accurate data were limited, available existing funding data did not support the claim of a decrease in DOD CS investment. What has changed is increased focus on near-term applications, with the research increasingly mission-driven to solve current problems. Along these lines, the Defense Advanced Research Agency (DARPA) has shifted from block-funded university programs to funding mission-focused systems. Topics for research in CS continue to change, with new topics replacing old ones periodically. While basic research continues to provide the foundation, much current attention is focused on application-oriented research and IT development.

In the course of this study, several concerns were uncovered that transcend the concern over university funding of CS research. In particular, it was found that once-rigorous recording of data by DOD of its S&T database had significantly atrophied in the last several years, since the requirement for the Services to submit a standard data form (DD1498) for every S&T project had been relaxed. While DOD is currently instituting procedures in the Reliance-21 process to reestablish a meaningful database and to comply with the requirements of the E-Gov act of 2002,[1] the data to analyze the CS funding issue was in general incomplete, missing, and inconsistent among different sources of information. At a minimum, information at the individual project level needs to include the objective, approach, and progress of the project, in addition to funding and performer information. This information was difficult to obtain for the period FY00–FY06, in which funding trends for CS were examined.

[1] The E-Gov act of 2002 (Public Law 107-347) mandated that the U.S. Government promote greater use of the Internet to foster interagency collaboration, provide citizen-centric government information and services, promote better-informed decisionmaking, and promote citizen access to the government.

Different definitions of what should be considered CS also played a role in the analysis of CS funding. Traditionally, CS was the study of computers, including the theory of computation, algorithms, discrete mathematics, and computer hardware and software design. But over the years, CS has become part of the broader area of information science (IS). Recently, NIT has included the processing and communication of data and information, and the hardware, software, and systems that perform those functions. Complicating an analysis of funding of CS research is the fact that the terms *computer science*, *information science*, and *network and information technology* are sometimes used interchangeably. In addition, DOD characterizes the applied research (6.2) and advanced technology development (6.3) component of CS/IS/NIT as information systems technology (IST).

Finally, while DOD continues to be a major funding source of CS research, with a budget in this area comparable to that of the National Science Foundation (NSF), NIT research and development (NITRD) comprises a major multi-agency investment of roughly $3B a year coordinated by the National Coordinating Office (NCO)[2]. NSF continues to be the principal funding entity for university research.

An additional concern is the limited funding and programmatic data provided by DOD agencies and components, both to DOD and for the public record. This is due to both the limiting of distribution and the aggregation of data, which confuses attempts to separate CS from other research areas. While not directly related to the issue of funding CS, limited distribution of research results and technologies has a strong impact on the flow of ideas essential to innovation and progress in the research domain and inhibits the ability to build a database (such as was collected during this CS funding study) to provide understanding and oversight of DOD research programs.

Historical Funding of Computer Science Research and Trends

This report addresses the concerns that DOD was reducing its investment in long-term CS research, and that this reduced funding put at risk next-generation systems for networking, IT, and IA technology.[3] Specifically, we are attempting to determine historical levels of research funding to universities and how it changed year-to-year. Of particular interest is any unusual change in funding profiles to determine whether CS research funding has increased or decreased dramatically year-to-year, or whether it is trending up or down, both in absolute numbers and in relation to DOD S&T funding.

In Federal funding, the term *NIT* is used by several agencies to describe investment in computer sciences and information systems, including processing and communication of data and information, and the hardware, software, and systems that perform those functions. Since the

[2] The NCO reports through to the cabinet-level National Science and Technology Council (NSTC) through the subcommittee on Networking and Information Technology R&D of the NSTC Committee on Technology. See <http://www.nitrd.gov/about/about_nco.htm>.

[3] It is important to note that DOD investment in CS research was a significant factor in developing the technologies that underpin today's computing and networking infrastructure, including the Internet and basic networking architectures.

terms *CS*, *IS*, and *NIT* are sometimes used interchangeably in Federal funding documents, funding are listed as CS/IS/NIT in the tables below.

Public sources of published data on Federal investment in CS, IS, and NIT were investigated to determine both historical funding data and future funding as planned in out years of the Federal and Defense budgets. It is important to note here that deficiencies in published data created an incomplete picture of total funding of CS research. Principal causes of the sparseness of data essential for information exchange between researchers and for program oversight are that:

- Requirements for DOD components to provide detailed funding and programmatic information were significantly relaxed several years ago. The consequent shortfall in collection is being addressed by DDR&E as part of the Reliance-21 process and the E-gov initiative; however, shortfalls in collection persist.
- Restrictions on distribution of research information limit the utility of the research.
- Currently, data are supplied at too high an aggregate level to separate projects into a meaningful taxonomy.
- CS is now incorporated in many multi-discipline projects, and partitioning and extracting its financial contribution are difficult.
- Funding of projects in multiple program elements creates redundancies in budget data.

Despite the limitations that plagued the assessment, the data collected were sufficient to reach the following broad conclusions.

- The data from different sources showed fairly consistently that funding for CS/IS/NIT was flat or slightly depressed from FY00 through FY04, then increased steadily from FY04 through FY07. In other words, the published budgetary numbers did not show any significant, long-term decrease in CS/IS/NIT funding. Over the fiscal years FY04 through FY07, funding for CS/IS/NIT increased, and projected (programmed) funding from FY08 through FY11 continues to increase. These budget numbers are then-year dollars, without any inflation adjustments, and may result in relatively flat funding over the decade.
- The concerns raised by Congress in the 2005 Defense Authorization Act do not seem warranted. However, it is important to point out that the numbers combine CS research funding with IS and NIT. The latter two categories are very broad categories of applied CS. It is unclear whether funding in IS and NIT will result in the kind of fundamental advances in technology enabled by an earlier generation of funding in CS research.
- Another key point of consideration is that the proportion of funding of basic research (6.1) remains a small fraction of the total investment in CS/IS/NIT funding. Since most 6.1 basic research funding goes to universities, Service laboratories, and national laboratories, it is unclear whether this level of support is sufficient to enable the next generation of global technical innovation and leadership.

In the following section we develop a taxonomy of CS research to aid future collection of data on CS research funding, with a current chart showing the DOD focus areas in CS/IS/NIT that formed the basis of this report. Following the taxonomy and chart are a listing of the DOD funding agencies for CS/IS/NIT and charts and tables that show historic and programmed funding levels of CS/IS/NIT.

Computer Science Taxonomy

To assist in our study, a top-level taxonomy of CS research was developed by researchers in the CS community:

- Systems and languages (S&L)
- Artificial intelligence (AI)
- Theory (THEORY)
- Scientific computing (SC)
- Multi-disciplinary (MD)

Because CS research encompasses a broad range of topics, these fields were further broken down into the sub-levels in table 1.

Table 1. Computer Science Research Taxonomy and Sub-levels

Systems and Languages (S&L)	**Artificial Intelligence (AI)**
Command and Control	Planning
Compilers	Knowledge representation
Computer architecture	Game theory
Databases	Machine learning
Data mining	Vision
Decision support systems	Speech
Dependable systems	Natural languages
Distributed systems	**Theory (THEORY)**
Graphics	Algorithms
Grid computing	Complexity
High-performance computing	Formal methods
Human-Computer Interaction	Technology, society, economics
Image processing	Quantum computing
Mobile and pervasive computing	Quantum computing
Modeling and simulation	**Scientific Computing (SC)**
Operating systems	Bioinformatics
Parallel computing	Computational biology
Principles of programming	Computational neuroscience
Real-time and embedded systems	Scientific computation
Search	Scientific computation
Software engineering	**Multi-Disciplinary (MD)**
Software testing	Networking
Virtual reality	Security
	Robotics
	Other

The current taxonomy of focus areas that incorporates IS and NIT, as well as CS research as applied to defense network centric warfare systems, is provided in figure 1. These five focus areas—knowledge and information management, information security, communications and networking, modeling and simulation, and computing and software technology—are the basis of the funding charts listing DOD CS/IS/NIT investment shown in tables below.

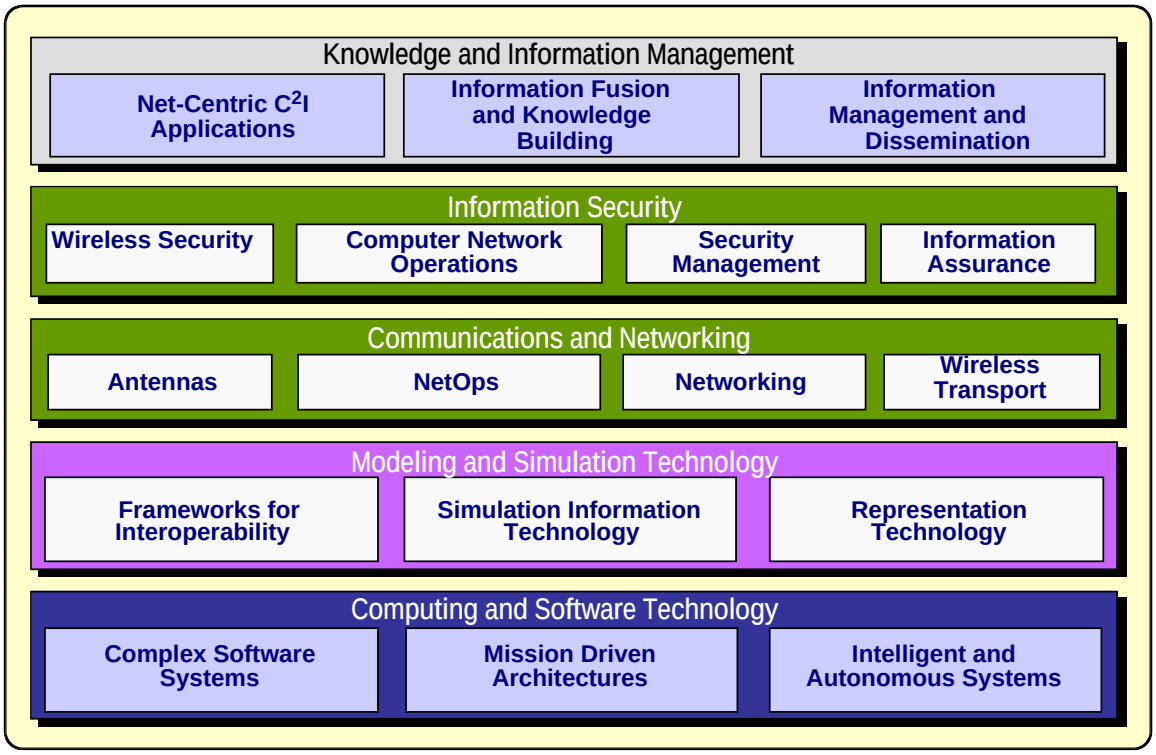
DOD Funding Agencies and Support

CS research in DOD is funded by several different agencies and components, including:

- Office of the Secretary of Defense through the Director of Defense Research and Engineering (DDR&E)
- Armed Services laboratories
    - Army Research Laboratory (ARL), including Army Research Office (ARO)

- Office of Naval Research (ONR), including Naval Research Laboratory (NRL)
- Air Force Research Laboratory (AFRL), including Air Force Office of Scientific Research (AFOSR)

Figure 1. DOD CS/IS/NIT Focus Areas



- Defense Advanced Research Projects Agency (DARPA)
- National Security Agency (NSA)
- Missile Defense Agency (MDA) and others

The various research programs have been coordinated through the DDR&E Reliance process (currently the Reliance-21 process) to minimize redundancy and provide visibility of research within each agency to all agencies. The programs are coordinated through multi-Service and multi-agency DOD program reviews. Federal-wide, program directors from NSF, the National Institute of Standards and Technology (NIST), and the Department of Energy (DOE) serve on DOD program review panels to facilitate coordination and dissemination of CS research. Similarly, DOD program managers serve tours of duty in NSF and other Federal agencies. Finally, DOD actively participates in the Federal NITRD program responsible for coordinating CS/IS/NIT R&D programs across Federal agencies.

DOD CS/IS/NIT research funds are included in the following programs:

- Defense Research Sciences (Basic Research (6.1))
- University Research Initiatives (URI) (6.1)

- Army University and Industry Research Centers, Collaborative Technology Alliance (6.1)
- Small Business Innovative Research (SBIR) and Small Business Technology Transfer (STTR)
- Computing and Software Technology (Applied Research (6.2))
- Information Technology–Decision Making (6.2)
- Information Systems–Information Assurance (6.2/Advanced Technology Development (6.3))
- Modeling and Simulation Technology (6.2/6.3)
- Network Communication Technology (6.2/6.3)
- Information and Communication Technology (DARPA 6.2)
- Cognitive Computing Systems (DARPA 6.2)
- Command, Control and Communication Systems (DARPA 6.3)
- Network-Centric Warfare Technology (DARPA 6.3)

Research funding through DOD is allocated according to Basic Research (6.1), Applied Research (6.2), and Advanced Technology Development (6.3). The following documents were used to obtain funding information.

- Technology Area Review and Assessment (TARA) Info Sys Tech Review, 2006
- Defense Technology Area Plans (DTAP) spreadsheet, 2007
- RDT&E Budget Item Justification Sheet (R-2 Exhibit) for relevant CS/IS/NIT Program Elements (e.g. PE0602304E).
- DOD Basic Research Plans, 1999, 2001, 2003, 2005, 2006.
- DDR&E Strategic Plan, 2007.
- Quadrennial Defense Review Report, February 6, 2006.
- PCAST, Leadership under Challenge: Information Technology R&D in a Competitive World, August 2007.
- Networking and Information Technology Research and Development, Supplement to the President's Budget, August 2007.

Table 2 shows historic DOD funding in CS/IS/NIT from FY00–FY06 in then-year millions of dollars. Notice that funding was relatively level over the period FY00–FY05, with a 13 percent surge in FY06. The table reports Basic Research funding from only the Armed Services Defense Research Sciences (PE 06011102A, PE 0601153N, PE 0601102F), but does not include the URI and In-house Laboratory Independent Research (ILIR) programs. Applied Research (6.2) and Technology Development (6.3) funding includes PEs in the Defense Technology Area Information Systems Technology. DARPA funding includes basic research (PE 0601101E) and relevant CS/IS/NIT programs (PE 0601303E, PE 0602304E, PE 0603760E, PE 0603766E, PE

0602301E, PE 0602302E, PE 0602110E, and PE 0602708E).[4] Other CS/IS/NIT related projects embedded in other programs are not reported in table 2.

Table 2. DOD CS/IS/NIT Program Funding FY00-06

DoD CS/IS/NIT ($M)	FY00	FY01	FY02	FY03	FY04	FY05	FY06
6.1 Basic Research	96	109	116	141	103	111	116
6.2 Applied Research	174	207	198	212	212	207	210
6.3 Tech Development	568	585	621	599	596	615	656
DARPA 6.1/6.2/6.3	625	600	625	566	591	603	748
Total	1,463	1,501	1,560	1,518	1,503	1,536	1,731

Figure 2 shows a historical perspective of NITRD funding from 1993 through the 2008 President's Budget Request (PBR) in millions of dollars. NITRD uses a strict set of definitions for the component areas, such as High End Computing R&D, whereas CS/IS/NIT includes a much broader set of programs. Prior to FY06, DOD funding included only DARPA and OSD programs. FY07 and FY08 PBR funding included DARPA, NSA, some of the Services' basic and applied research program, and a small portion of technology development programs. Based on the limited definitions, the DOD/DARPA/NSA funding number in NITRD represents about half of the total DOD CS/IS/NIT budget number. For example, DARPA's 6.3 programs are not included because they do not fit the NITRD definition. Similarly, some of the C^3 programs and discrete mathematics programs are not included.

DOD funding contributes roughly one-third of the Federal NITRD research funding, with NSF funding another third. Funding numbers do not include Service and OSD programs prior to FY06. In the 2008 PBR, total Federal NITRD funding exceeds $3B. Federal NITRD investment is augmented by industry.

The FY08 PBR by Agency and CS/IS/NIT component area is shown in table 2. The top two requested areas in CS/IS/NIT are High-End Computing Infrastructure and Applications and Human Computer Interaction and Information Management. Cyber Security and Information Assurance is relatively low in terms of requested FY08 funding at $217M.[5]

[4] Program elements (PE's) are funding line budget items in an appropriation. The first four digits signify the funding category, e.g., PE 06011102A is category 6.1 funding. The concluding letter is for the Service or agency, i.e., A for Army, N for Navy, F for Air Force, and E for a DOD agency, in this case, DARPA.

[5] This amount may have been changed subsequently by the administration's cyber security initiative at NSF and DARPA.

Figure 2. Federal National Information Technology Research and Development (NITRD) Program Funding Historical Perspective

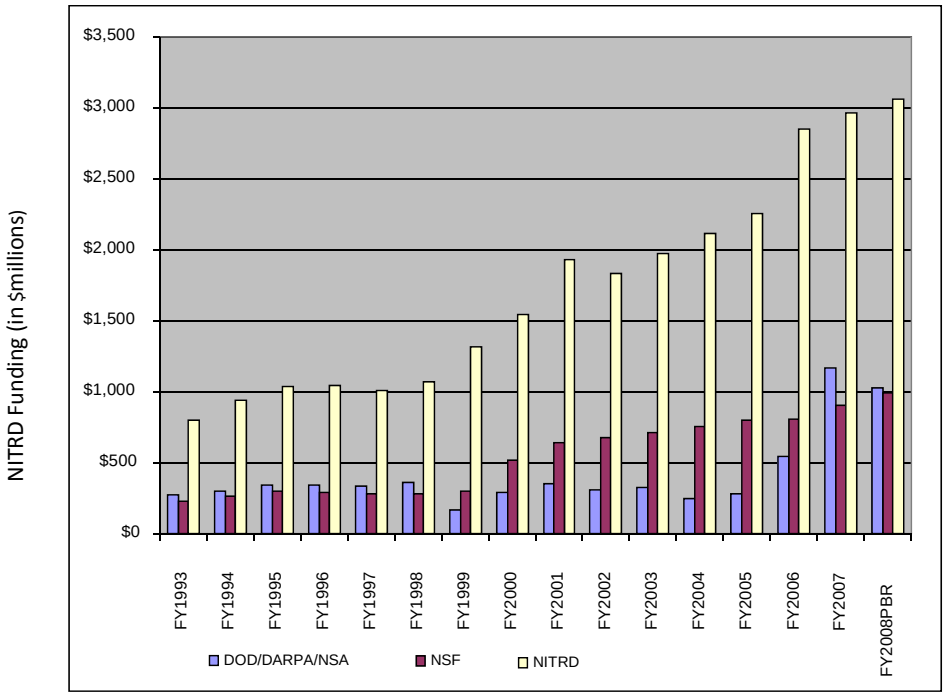
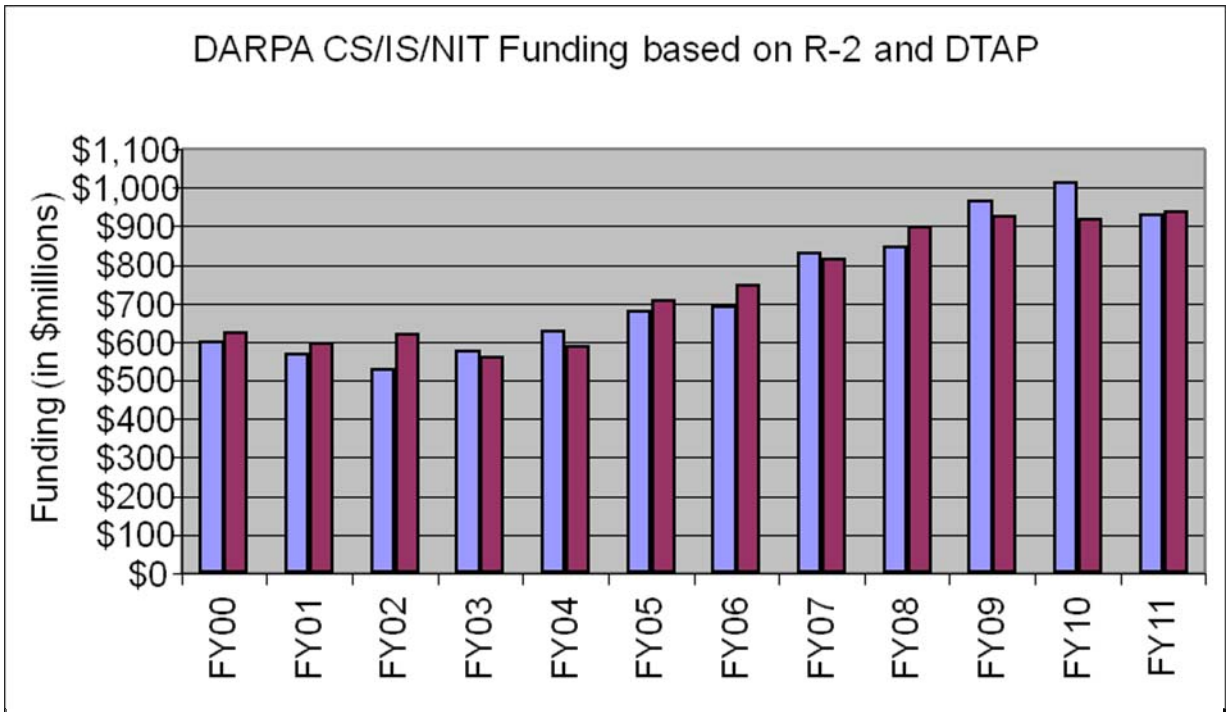


Table 3. NITRD FY08 PBR Funding Broken out by Agency and Program Component Areas

$M	High End Computing Infrastructure & Applications	High End Computing Research & Development	Cyber Security & Information Assurance	Human Computer Interaction & Information Management	Large Scale Networking	High Confidence Software & Systems	Social, Economic, & Workforce Implications of IT	Software Design & Productivity	
Agency	HEC I&A	HEC R&D	CSIA	HCI&IM	LSN	HCSS	SEW	SDP	Total
NSF	303.1	67.1	69.2	225.6	106.7	57.4	109.3	55.3	993.7
OSD & DOD Service Research Organizations	234.1	2.0	23.3	78.7	137.4	31.5		4.3	511.4
DARPA		68.9	96.9	204.3	42.4				412.5
NSA		60.3	15.8		1.4	25.2			102.6
NIH	131.7	1.8	1.2	194.5	65.4	8.2	11.9	2.9	417.6
DOE/SC	250.5	67.0			47.3		5.0		369.8
NASA	71.4		0.3	8.0	1.5	3.5		2.0	102.6
NIST	2.4	1.8	11.1	8.4	1.5	3.5		2.0	86.7
AHRQ				39.8	5.0				44.8
DOE/NNSA	9.9	17.9			1.2		4.8		33.8
NOAA	16.4	1.9		0.5	2.9			1.6	23.3
EPA	3.3			3.0					6.3
NARA				4.5					4.5
Total FY2008 PBR	1022.8	288.6	217.7	767.3	416.5	145.6	131.0	71.3	3061.0

A more detailed look at DARPA's CS/IS/NIT research funding from FY00 through out years to FY11 based on congressional PE submissions and the Defense Technology Area Plan (DTAP) is shown in figure 3.

Figure 3. DARPA CS/IS/NIT Funding Profile Based on R-2 (left bar) and DTAP Data (right bar), in Then-year $M



A historical look at DARPA's funding in CS/IS/NIT shows funding was relatively flat, if not slightly depressed, from FY00 through FY03, but then increased through FY07. Requested budgets for FY08 through FY10 show further increases to over $1B, though it is important to remember that out-year funding is not binding but just an indication of program planning.

Figure 4 shows CS/IS/NIT funding DOD-wide (Services 6.1 bottom bar, 6.2 second bar, 6.3 third bar, DARPA top bar) from DTAP reporting plus 6.1-6.3 funding reported from R-2s from the armed services. Figure 4 shows total DOD CS/IS/NIT funding relatively level from FY00 through FY05, then increasing steadily through FY07. Out-year program planning shows increases to over $2B, with the caveat these are projections (estimates) only, not commitments.

Figure 4 shows the breakout of planned funding (from the POM) for CS/IS/NIT funding for FY07 through FY11 from the Armed Services (6.1, 6.2, and 6.3) and DARPA funding. Again, budget numbers include only DARPA and the Services' research efforts. CS/IS/NIT funding in SBIR/STTR, NSA, and other agencies are not included. Basic research funding includes the Services' Defense Research Sciences (PE0601102A, PE0601153N, and PE0601102F), as well as DOD MURI and Army's CTAs. Services applied research (6.2) and technology development (6.3) funding includes PEs in the Defense Technology Area, Information Systems Technology. DARPA funding includes basic research (PE0601101E), and the relevant CS/IS/NIT programs based on PE0601101E (DRS), 0602303E (Information and Communications Technology), 0602304E (Cognitive Computing Systems), 0603760E (Command, Control, and Communication

Systems), 0603766E (Network-Centric Warfare Technology). CS/IS/NIT projects embedded in other PEs are not included here. Actual DOD CS/IS/NIT funding should be higher than these numbers.

Figure 4. Total DOD CS/IS/NIT Reported Funding

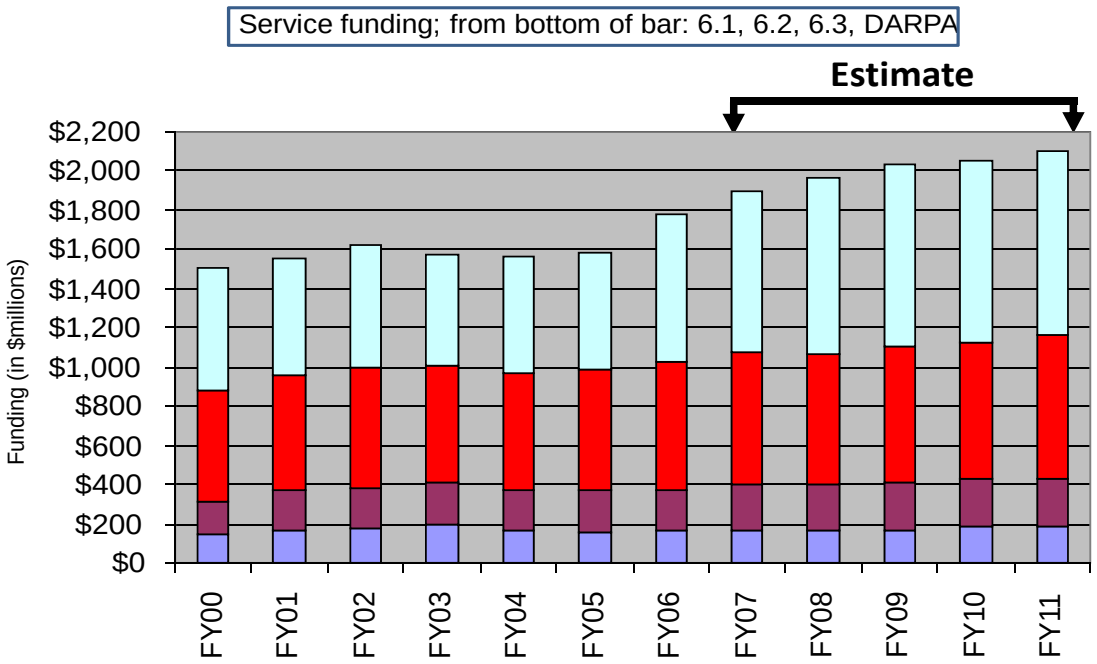


Table 4. FY07–FY11 CS/IS/NIT POM Budget of Planned Funding

Planned CS/IS/NIT ($M)	FY07	FY08	FY09	FY10	FY11
6.1 Basic Research	168	164	171	190	183
6.2 Applied Research	228	240	241	242	243
6.3 Tech Development	683	665	691	696	736
DARPA 6.1/6.2/6.3	817	900	927	920	938
Total	1,896	1,969	2,030	2,049	2,100

The role of DARPA in CS research is important to highlight because DARPA has been a traditional source of funding in this area and has funded technologies that underpin today's

computing and networking infrastructure, including the Internet and basic networking architectures. Changes in the philosophy of DARPA funding in CS were a principal cause of the Congressional concern in 2005 about the levels of funding in CS research.

An analysis of the data leads to the following conclusions about the DARPA funding in CS research:

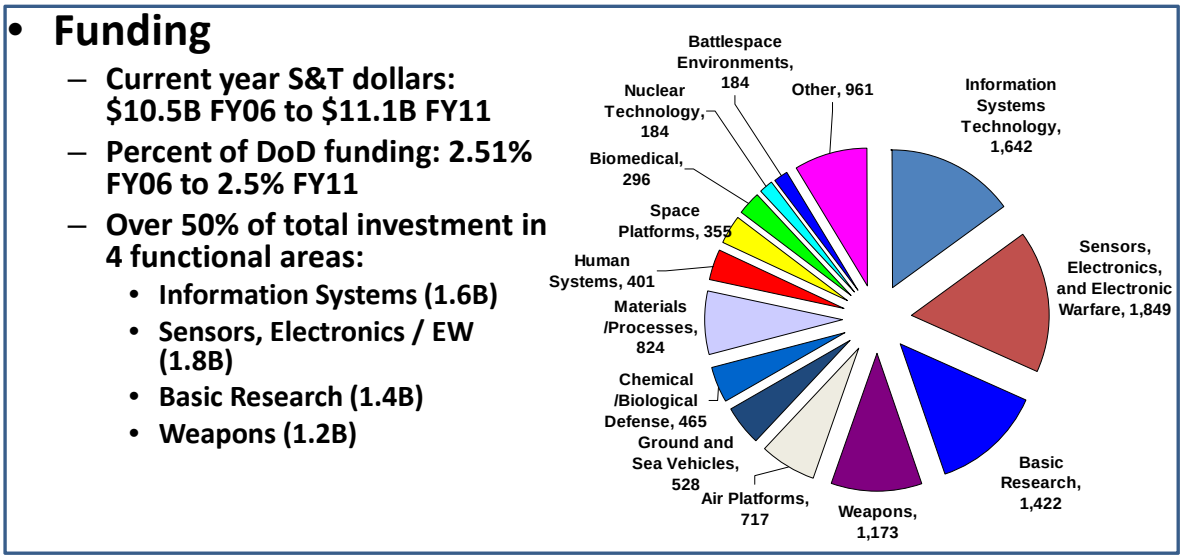
- DARPA CS funding to universities is steady and is not decreasing. However, the thrust of the DARPA program has moved from basic research to more applied problems, such as Internet security.
- The historical model of DARPA CS funding (block-grants to major universities) is gone. This means that universities must now compete for funding on individual projects.
- Difficulties in assessing DARPA investment in CS exist because:
  - DARPA makes little distinction between 6.1, 6.2 and 6.3.
  - DARPA programs are idea-driven and capability driven, and are not sorted by disciplines such as CS.
  - CS/IS/NIT research is embedded in various multidisciplinary programs because it is so pervasive in addressing many of DOD's needs.
- DOD's and DARPA's role in funding CS research is to focus on DOD's needs that are not met by other federal agencies (e.g., NSF) and commercial industry (e.g. Microsoft and Google).

In addition to the objective of an investigation of the absolute value of the historical level of funding in CS was a comparison of the ratio of the DOD CS/IS/NIT investment to the total DOD investment in S&T. In figure 5, a breakout of the entire S&T program is shown by functional areas. The chart lists IST which is the 6.2 and 6.3 component of CS/IS/NIT. If an additional 12 percent (the 6.1 percent of S&T funding in FY06) is added for 6.1, the total CS/IS/NIT S&T funding for FY06 is $1,839M. This figure is close to the figure $1,731M in table 1 for CS/IS/NIT S&T funding accounting for the slight differences in taxonomy between IST and the 6.2 and 6.3 components of CS/IS/NIT. Assuming that the relative funding in CS/IS/NIT of 6.1 to the entire program is the same as the ratio of 6.2 and 6.3 to the entire program, from figure 5, CS/IS/NIT is 17.4 percent of the entire S&T program. With the exception of Sensors, Electronics and Electronic Warfare, IST is the largest single technology area in the technology base.

Quality of Computer Science Research Funding Data

Significant shortfalls exist in the funding data for the period 2000–2006. Issues with the data include incomplete reporting of data, large inconsistencies between sources of data (e.g. the funding listed in the component Program Elements does not match the Congressional Appropriation), and data are provided at too high a level of aggregation to determine

Figure 5. Characterization of the DOD S&T Program by Technology Area



programmatic content. Redundancy of data issues arise when projects are funded in multiple Program Elements. In addition, a different definition of what constitutes CS (different taxonomies) leads to significant differences in funding estimates. For example the restricted definition of CS shown in figure 2 for Federal NITRD funding represents only about a half of the DOD CS/IS/NIT budget numbers shown in table 2.

Significant issues arise in trying to reconcile the multiple sources of funding data listed in table 2 and figure 2. A significant part of the problem exists in the period of interest for this study. Prior to 2000 funding and programmatic data for the DOD S&T programs were provided by the DOD S&T agencies and components in a standard form (DD1498) that provided detailed program information. Under the Service Reliance program, the requirement for the standard form was relaxed and data were provided to DDR&E through the Basic Research Review and the TARA IST Review as well as the Program Element submissions. These documents did not provide a detailed funding picture. In 2005, as part of the E-gov initiative, and in an effort to improve the DOD reliance process, DDR&E established the Research and Engineering Database as the centerpiece of the Reliance-21 process. The purpose of the R&E Database is to provide a reliable, agile, complete, and accurate database to provide insight into all of DOD's funded efforts. Since its inception, the Defense Technical Information Center (DTIC) has collected data on DOD funded efforts in FY2005, 2006, and 2007. On April 28, 2008 DDR&E issued a data

call for the FY2008 R&E Database. However, a preliminary examination of 2007 data by one of the authors showed little improvement in data quality over the 2005 and 2006 data. To date, the DOD S&T agencies and components have been slow in complying with the requirements of the Research and Engineering data base.

Restrictions on distribution of research information limit the utility of the research. If multiple projects are listed together and labeled with a single restrictive distribution code such as “for government agencies only” the entire data fields and research results are not available to the public.

Currently data are supplied at too high an aggregate level to separate projects into a meaningful taxonomy. As mentioned previously, CS, IS, and NIT are often combined into a single taxonomy. Aggregation of projects under a single data submission obscures the details of the effort and often blurs distinctions between basic and applied research. The detailed taxonomy given at the beginning of this report would assist future data collection in CS.

CS is now incorporated in many multi-disciplinary projects and it is difficult to extract its financial contribution. While basic research in CS is a relatively well defined discipline as defined by the expanded taxonomy reproduced in this report applied research CS, expanded to include IS and NIT, is a pervasive science that has become an element of many disciplines such as communications. This can lead to either under-counting CS if its contribution in a multi-discipline project is not counted or even over-counted if a project is funded from multiple funding lines (Program Elements) and the CS contribution in each line is reported redundantly.

Table 5 lists a data call set of fields. Incorporation of this set of fields in future data calls would provide the detailed data needed to assess programmatic efforts in depth. This data call is issued by DDR&E to collect data to input the DTIC Research and Engineering database.

Workshop of Academic Leaders in Computer Science

To better understand the concerns on computer science research funding, we held a workshop of leading computer science researchers from renowned computer science universities in June 2006. Academic participants included Cornell, Stanford, and Harvard Universities, the Universities of Texas, Washington, California (Berkeley), and North Carolina, the California Institute of Technology, and the Massachusetts Institute of Technology.

As a result of this meeting, the professors at these universities put forward their concerns over several recent issues in DOD funding. A key finding of the meeting was broad agreement that no single entity had full knowledge of the “ground-truth” of actual funding of CS research. All agreed that being able to capture this ground truth was a necessary foundational task in understanding and analyzing CS research funding issues. It was agreed that DUSD-S&T would attempt to gather this information from the DOD Services and agencies and the results of that study would form the basis of this report. While the overall funding level for CS was an issue, discussions at the workshop uncovered related issues of concern to the Universities that appeared to be of more concern than bottom line funding. These issues are highlighted below.

The universities were concerned that Basic Research is being ignored in favor of Applied Research at the expense of the next generation of innovation. The actual data shown in tables 2 and 4 for Basic Research indicated that Basis Research funding was relatively level over the

Table 5. Proposed Data Call Set

1. Program Element
2. Project Number
3. Contract/Grant Number
4. Title of Project
5. Scientific or Technology Subject Areas
6. Start Date
7. Estimated Completion Date
8. Award Status (new, renewal, incremental funding)
9. Type (Firm Fixed Price, Cost Plus, Purchase Order, MIPR)
10. Kind of Award (grant, contract, in-house)
11. Amount (in thousands $) by Fiscal Year
12. Cumulative/Total Funding (in thousands $)
13. Funding Organization Name, Office, Address, Phone
14. Funding Organization Program Manager Name, email, Phone, Address
15. Responsible (Contracting) DOD Organization Name, Office, Address
16. Name, email, phone of responsible DOD Individual
17. Performing Organization Name, Address, Phone
18. Principal Investigator Name, Email, Phone, Address
19. Associate Investigator Name, Email, Phone, Address
20. Sub-Award Principal Investigator Name, Email, Phone, Address
21. Sub-Award Amount by FY
22. Keywords
23. Technical Objective
24. Abstract/Approach
25. Accomplishments

period of the study at more than $100M a year with some planned growth in FY10. The study did confirm that more funding and attention is being given to CS applied research and advanced technology development. It is again important to point out that the numbers combine CS with IS and NIT. The latter two categories tend to incorporate more applied than basic research. From the university point of view it is unclear if funding in IS and NIT will result in the kind of fundamental advances in technology enabled by an earlier generation of funding in CS research. To counter- balance this, the NSF funding in CS basic research is comparable in size to the DOD investment and has continued to grow (see figure 2).

A related issue to DOD's move toward more applied than basic research relates to DOD programmatic requirements. Since new discoveries are difficult to plan in advance, basic research operates best under relaxed milestones and is generally funded to produce gradual advances under a best level of effort. Applied research, and in particular advanced technology development, on the other hand needs to provide deliverables with milestones and go/no-go decisions. As DOD, and in particular DARPA, have moved toward more applied efforts in CS, universities with a basic research focus have found it difficult to take on contracts with short milestones, deliverables, and go/no-go decisions.

The universities also raised two additional issues that they felt significantly limits their ability to contribute to DOD contracted research. The first issue deals with the universities right to publish unclassified material in the open literature without government pre-approval. Because of pre-publication review requirements written into DOD grants and contracts, it makes it difficult, if

not impossible, for many universities to participate in DOD funding. Many universities have explicit policies prohibiting research on campus that is not automatically eligible for publishing.

The second issue relates to the fact that a significant percentage of CS graduate students in the US are foreign nationals. Many of these students remain in the US after they receive their degrees and contribute greatly to US expertise in CS as well as other areas of science and engineering. Others return to their home countries and take their expertise with them. In many cases, International Traffic in Arms Regulation (ITAR) restrictions apply to CS research and make it difficult, if not impossible, to undertake CS research grants and contracts with foreign nationals having access to the work.

A related issue to the ability of universities to publish results and to incorporate foreign nationals in research teams is that of security classification of basic research. Appropriate classification of research is essential for national security but over classification is detrimental to the sharing of information essential for progress and excludes researchers without clearances. A National Research Council Study chaired by Jacques Gansler and Alice Gast[6] expressed concern about apparent over-classification, particularly of basic research. An article by Lee Hamilton[7] pointed out the downsides of over-classification including the fact that "by classifying less information, we can focus resources on the secrets that must be kept". If too much is stamped classified, the value of the stamp is debased. An indication that over-classification has become a significant problem was presented in an article by Graeme Wood," who graphed the growth in classification of papers from 1980 till 2006. [8] During 2001, about 8 million pages were classified; during 2006 more than 20 million pages were classified.

Conclusions

The relatively poor quality of historical data on DOD funding in CS does not show a decreasing funding base for this critical area. However, this study has brought to light several concerns about DOD funding policy and oversight, including those expressed by members of American universities with renowned CS departments.

A comprehensive data base is needed with a detailed taxonomy that would permit a reliable understanding of the ground truth in CS (and presumably other critical science and technology areas) with funding levels, programmatic content, performer base, and accomplishments for information exchange between performers and for programmatic understanding and oversight. While DOD has instituted a revamped approach to data collection and sharing under the E-gov initiative and the Reliance-21 process, DOD agency and component response still appears to be spotty, in part because data is aggregated at too high a level to determine accurate information on the S&T areas of the project. The high level of aggregation also places many unlimited distribution projects into a data field of limited distribution not available to the public. In particular, unclassified fundamental CS research at universities should not be restricted, as

[6] "Science and Security in a Post 9/11 Word," (Washington, DC: National Academies Press, 2007).
[7] "When stamping 'secret' goes too far," Lee Hamilton, *Christian Science Monitor*, February 22, 2006.
[8] "Classify This", Greame Wood, *The Atlantic Monthly*, September 2007; 44.

determined in NSDD 189,[9] and only appropriate levels of classification should be applied to research.

As the field of CS has expanded, IS and NIT have overlapped to the point of being used interchangeably in the database. Another manifestation of the growth of CS and IT is the fact that many multi-disciplinary programs embed these technologies because they are so pervasive in addressing many of DOD's needs. While these changes are a fact of life, they increase the need for a well articulated taxonomy to provide an overview of the entire investment. While funding for CS and NIT has shown growth, a residual concern is the underfunding of basic research in CS at the expense of growth in applied research and advanced technology development to meet the current requirements of mission-focused systems.

To enable future, unpredictable significant advances in technology, as a matter of policy DOD should balance basic, long-range fundamental CS research and near-term application-oriented research to meet the current defense needs, while not mistaking one for the other. While DOD has a role in maintaining this balance it is also true that DOD's role in funding CS research is to focus on DOD needs that are not met by other federal agencies such as the NSF as well as commercial industry (e.g., IBM, Microsoft, and Google). Accordingly, DARPA no longer funds a historical model in CS funding of block-grants to major universities but has focused its efforts in CS/IS/NIT in four of their nine strategic thrusts. These four thrusts are:

- Robust, Secured, Self-Forming Networks
- Detection, Precision ID, Tracking, and Destruction of Elusive Targets
- Increasing the Tooth-to-Tail Ratio
  - Cognitive Computing
  - High Productivity Computing Systems
  - Machine-Enabled Language Translation
- Core Technologies
  - Information Technology

This list highlights the reality of the more applied focus of the DOD effort and also the broadening of CS in including IS and NIT as major thrust areas.

While the concerns above are real and should be addressed, we conclude that the level of DOD investment in CS does not constitute a crisis. Funding levels appear to show some level of growth both in the past and in out-year planning. As a ratio of the entire DOD S&T investment, CS/IS/NIT funding appears to be level at about 17 percent of the entire S&T budget. Future efforts are aimed at DOD needs, which is the appropriate role for DOD investment in the sciences. The two principal recommendations from this study are that:

- DOD must maintain accurate and appropriately detailed records of its funding investments in S&T to provide understanding, sharing and oversight of these investments.

- DOD greatly benefits from university contributions to CS and should move to reduce current obstacles to university participation in its contracts and grants. These obstacles include restrictions on publications and over-classification of basic research.

[9] NSDD 189, September 21, 1985, is the National Policy on the Transfer of Scientific, Technical and Engineering Information. Its stated policy is that "to the maximum extent possible, the products of fundamental research remain unrestricted."