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Opinion

The Opinion column offers mathematicians the opportunity to write about any issue of interest to the international mathematical community. Disagreements and controversy are welcome. An Opinion should be submitted to the Editor-in-Chief, Sheldon Axler.

Forum on Military Funding of Mathematics

William Browder, Jagdish Chandra, Morris Hirsch, Richard Karp, James Melcher, Michael Shub, and Robert Williams

Editor's note: *During the International Congress of Mathematicians at Berkeley in August 1986, a panel discussion on military funding of basic scientific research, particularly mathematics, was organized by Linda Keen, Keith Miller, and Barbara Simons, under the sponsorship of the Peace and Conflicts Studies program of the University of California, Berkeley. Although the discussion focused on the United States, the issues raised would be applicable to most other countries. What follows is a lightly edited transcript of the discussion, with some deletions of less relevant material. Richard Karp, professor of computer science at the University of California, Berkeley, was the moderator of the discussion.*

RICHARD KARP. For many decades the scientific research community of the United States has drawn a great deal of its support from military funding agencies. The mathematics community, while primarily dependent on the National Science Foundation (NSF), has benefited greatly from the support of such defense agencies as the Office of Naval Research (ONR). The greatest benefactor of computer science research over the past two decades has been the Defense Advanced Research Projects Agency (DARPA), an agency whose purpose is to promote research in areas relevant to military problems and to make advanced technology accessible to the military community. Physics research has drawn much of its support from the Department of Energy, the agency that operates the enormous weapons laboratories at Livermore and Los Alamos. It is clear that science in the United States could not have reached its present level of development without the support of military funding agencies.

In recent years the role of the Department of Defense (DOD) in the funding of research and development has grown steadily. Between 1970 and 1980 the DOD was responsible for 50 percent of the federal research and development budget; by 1986, that figure had grown to 72 percent. If we restrict attention to basic research the percentages are smaller, but DOD's role is very substantial and growing fast.

As the importance of DOD funding of basic research has expanded, disaffection against the Defense Department's policies has steadily mounted within the scientific community. There are numerous reasons for this disaffection, and, in order to set the stage for our discussion, I would like to briefly state what some of these reasons are.

First, some within the scientific community, although undoubtedly a minority, feel that all DOD money is tainted. They believe that our military-industrial complex has a vested interest in the continued escalation of the arms race, and they simply want no part of it, preferring to work for arms reduction and eventual disarmament.

Others do not make a blanket condemnation of our defense policies, but feel that specific programs such as the Strategic Defense Initiative (SDI) are not in our national interest. They see SDI, with its vision that defensive technologies can be developed to the point that they can eliminate the danger from nuclear weapons, as a dangerous technological fantasy that deters us from more realistic efforts to achieve peace in the world. And, even though they may grant that antiballistic missile research should be pursued at some level, they feel that the proposed levels of funding for SDI are grossly excessive.

The U.S. seems to be a society in which large projects for the common good can be mounted only in the name of defense.

Others do not contest the basic mission of the Defense Department, but do object to its massive size and budget, especially at a time when all other sectors of the government have tightened their belts. There is a sense that the Defense Department, in league with the many companies that depend on defense contracts, has been excessive in its appetite for money and cynical in concocting justifications for its projects.

A related objection is that the channeling of research funding through DOD distorts the distribution of scientific efforts in the United States. The U.S. seems to be a society in which large projects for the common good can be mounted only in the name of defense. As Pamela McCorduck points out in her interesting book, *The Universal Machine*, this tradition goes back at least to the presidency of Thomas Jefferson. When Lewis and Clark proposed to explore the new Louisiana Purchase, Congress, beset by Revolutionary War debts, refused to appropriate the necessary funds. Jefferson took matters into his own hands by promising that the army would contribute $15 to $20 for every civilian dollar raised. Our national practice of depending on the military to provide support for worthy national goals has persisted to this day. By comparison with the Defense Department, the contributions of the Commerce Department and the Department of Education to the support of basic research are minimal, even though it would seem that those agencies should also have a stake in the health of science and technology. The situation in Japan is quite different: the defense establishment is minimal there, and the Ministry of International Trade and Industry, their equivalent of the Commerce Department, is a major sponsor of research in engineering and computer science.

The imbalance in funding sources leads to distortions in the kind of basic science that gets done, the kinds of technology that get developed, and the kinds of skills and interests that our young scientists develop. As a rebuttal to this point, it is often argued that technology and expertise developed with military funding are easily adaptable to civilian purposes. This spin-off theory may be valid in some cases, but it is unlikely to be true for highly targeted projects such as SDI. Developing 5-megawatt lasers to be used as space weapons is certainly not a cost-effective way to promote the medical applications of lasers.

Yet another objection is that military and intelligence research cannot be conducted in the universities without restricting academic freedom. In general the defense agencies have been sensitive to this concern and have negotiated a reasonable modus vivendi, allowing university faculty to publish freely, to employ foreign students, to interact with scholars from Eastern European countries, and to exercise their political rights. But there have been a few unfortunate episodes in which the SDI office and the National Security Agency have attempted to restrict the dissemination of unclassified research results obtained under their sponsorship. And there was one infamous case in which an undersecretary of defense stated that scientists who oppose SDI should not receive federal research support. I'm happy to say that the statement was quickly repudiated by other Defense officials.

In the interests of even-handedness, it must be mentioned that another kind of abridgement of academic freedom occurs when scientists opposed to certain military projects exert pressure to inhibit their colleagues from participating in those projects. This use of peer pressure to tyrannize one's colleagues is also unacceptable, and it deserves to be repudiated.

Another objection to military funding in the universities arises from the mission-oriented nature of military research and the power that is concentrated in the hands of those who set the goals and dispense the money. In my own field, computer science, the Information Processing Techniques Office of DARPA has been the dominant funding source for experimental computer science in the universities. DARPA by itself has the ability to make or break a computer science department. The top computer science departments are, with one or two exceptions, precisely those that have large DARPA grants.

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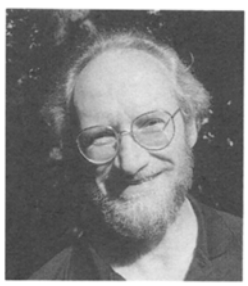
Many of the DARPA program directors have had great vision, and DARPA-sponsored research has led to great advances in fields such as computer networking and the automatic design of very large-scale digital in-

tegrated circuits. Nevertheless, one must realize that negotiating a grant with DARPA is quite a different matter from making a proposal to NSF. A DARPA proposer must establish the relevance of the proposed work to rather specific goals dictated by the military through DARPA, and must make a commitment to reach those well-defined milestones by specified dates. If these milestones are not achieved then, regardless of the intrinsic merit of the work, the project may abruptly get the axe; this was the case with the speech-understanding projects that DARPA supported at several universities about a decade ago.

At a time when NSF budgets are frozen and large pots of DARPA money are available, there will inevitably be a strong temptation for investigators to dance to DARPA's tune.

In the case of DARPA's recently announced Strategic Computing Initiative, the general goal is to advance the state of machine-intelligence technology through the fulfillment of certain specific military tasks: the development of an autonomous land vehicle, a pilot's associate, and an aircraft-carrier battle-management system. In the case of DARPA's new mathematics program, the research areas are less linked to military tasks, but still fairly tightly defined. They are: dynamical systems, harmonic analysis, computational algorithms, data compression, and neural networks. At a time when NSF budgets are frozen and large pots of DARPA money are available, there will inevitably be a strong temptation for investigators to dance to DARPA's tune. Whether this mission-oriented approach will promote the health of basic science and mathematics remains unclear.

I will now turn the floor over to our panelists, who will state their own views on some of these complex issues.



I would like to begin with Bill Browder. Bill is the youngest of three mathematician brothers; he graduated from MIT in 1954, and earned a Ph.D. in Princeton in 1958. After a year at Rochester and five years at Cornell he returned to Princeton in 1963, where apart from visiting appointments he has been ever since, serving as department chair in the early 1970s. Bill has held a number of posts in the American Mathematical Society, the National Academy of Sciences, and other organizations. He works in various areas of algebraic and differential topology and probably is best known for his contributions to surgery theory. He is a member of the National Academy of Sciences and the American Academy of Arts and Sciences.

WILLIAM BROWDER. The involvement of defense agencies in funding of scientific research dates from the end of WWII when the Office of Naval Research began a program of contracts or grants for basic research in many branches of science, including mathematics. For some years it was the only governmental source of research support, but with the establishment of NSF in the early 1950s the major civilian source of funds entered the picture.

In the early 1960s, the spectrum of core mathematical research supported by DOD narrowed considerably to areas in and around applied mathematics. This basic research support was justified by program officers by scenarios of mission relatedness. Great pressures existed to divert more funds to specific mission-oriented research and less to mathematical areas.

This tendency is now modified partly because of DOD interest in broader areas of mathematics and partly because of closer relations between pure mathematics and areas of applied mathematics and computation. The DOD budget in core mathematics is now the same order of magnitude as the NSF mathematical budget, around $50 million, but covering a narrower area of mathematics. There's little prospect politically of major congressional increases in the NSF appropriation. So even with the friendliest disposition in the NSF administration, which in fact seems to exist, any major increases in mathematical funding must be found elsewhere.

If the disastrous erosion of mathematical research support of the last 20 years is to be repaired, DOD must play a major role. The conditions of DOD grantees in mathematics are not significantly worse than those of NSF grantees—in fact, significantly better. Budgets are more generous, restrictions more flexible, and no onerous restrictions, such as prior review, have been imposed. Attempts at such restrictions in other areas have been successfully repelled. Strong and independent-minded grantees should have a good chance of resisting any possible such future attempts.

If the disastrous erosion of mathematical research support of the last 20 years is to be repaired, DOD must play a major role.

At a time when the cutoff level for NSF grants has reached an alarmingly high level with productive people being refused grants in greater numbers, these new DOD funds can play an important role in preserving and enlarging support for mathematical research if people will look without prejudice at these possibilities. The DOD after all is spending *our* tax money. It is an institution of the United States government, and whether we approve of its policies or not, we must deal with the government agencies to keep mathematical research healthy.

If one does not approve of many ways in which DOD money is spent or the government policies it supports, it seems rational to welcome and encourage instances where the money is well spent. In a word, if DOD agencies will fund the research you want to do with no strings attached, I say, take it.

KARP. *The next speaker is Michael Shub. Mike received his A.B. degree from Columbia College in 1964 and his Ph.D. from the University of California at Berkeley in 1967 with Steve Smale. His research has been in dynamical systems and geometric complexity theory. He has just left his position of 13 years at the City University of New York for IBM's Thomas J. Watson Research Center. He has been elected to the council and the nominating committee of the American Mathematical Society. He wants me to mention that he represents no one but himself today.*

MICHAEL SHUB. I have no doubt that mathematicians can use a lot more support for their research. But I think that a certain amount of cynicism and dishonesty is being encouraged for the sake of dollars available from the Defense Department agencies. I will not apply for those funds, and my reasons are both political and professional.

First the political. The Reagan government has been escalating the arms race enormously through programs such as the Strategic Computing Initiative and the Strategic Defense Initiative, which we know as Star Wars. Moreover, I think that, in fact, all DOD funding, even basic research, is part of the arms race, and I'm going to try and justify that by a few quotes from the things I have been reading in the *Notices of the American Mathematical Society* and a few other places.

Admiral J. B. Mooney, Jr. writes in the March 1985 issue of the *Notices*. He is Chief of Naval Research at the ONR. He says: "I am hopeful. I am looking forward to better things in our immediate future, not only for the mathematical sciences but for all the scientific activities within the Office of Naval Research." And then he says: "In return, I ask for your assistance. For you as citizen scholars play a vital role. First, the mathematics and university communities can play a vital role in increasing congressional understanding of the ONR role. ONR funds basic academic research. This fact is not always understood in the halls of Congress."

Well, what is this basic research Admiral Mooney of the ONR would have us lobby for? SDI is limited to research, people say, and in *Physics Today* in July 1985, we have this report: "On the shopping list also are supercomputers that far exceed the capabilities of today's fastest Crays and Cybers as well as software that contains 10 million lines of error-free code. 'We don't want a few lines of bad code mistakenly setting off a nuclear weapon or causing a laser to miss a target,' said Edwin Redman, Chief of the Mathematical Sciences Division of the Office of Naval Research." I was wondering if this is the research, these 10 million lines of code, that Admiral Mooney wants us to lobby for?

Then there's DARPA. DARPA is probably even worse. This Strategic Computing Initiative is theirs. One of their accomplishments is the Butterfly, a multiprocessor machine that is supposed to work fast.

There's one thing wrong with these multiprocessors. They want to use them, first of all, for the following purposes (this comes from a report prepared by the Advisory Committee to the Undersecretary of Defense for Research and Development): "autonomous vehicles, air, land, and sea; battle assessment, battle management; intelligent adaptive electronic warfare; ballistic missiles defense; warfare simulation." There's only one problem with all this. They don't know how to program these machines. So, one of the main recommendations of this report to the undersecretary is university involvement. "The academic community should be encouraged to participate in basic and applied research which is directly applicable to military programs. To accomplish this, research projects must be given the minimum classification level possible."

I would hope that my colleagues would join me and decide not to apply for DOD money. Even if people's political evaluations differ from mine, I would still hope that the harmful effects of funding, and I'm going to get to that now, would cause our professional organizations to reverse their call for ever more defense money.

I would hope that my colleagues would join me and decide not to apply for DOD money.

Military funding poses danger to basic research. I'm not the only person who says that. I just thought I would read you a couple of quotes from the David committee report. They studied these problems at some greater length and they have a lot of experienced people. "Much (but not all) mathematical research has long-term payoffs. Thus, the field will be strongly affected by federal policy shifts which emphasize mission relevance of immediate applicability to technologies."

The David committee quotes Senator Mansfield on his 1969 amendment. "Senator Mansfield said: In essence it (the amendment) emphasizes the responsibility of the civilian agencies for the long-term basic research. It limits the research sponsored by the De-

fense Department to studies and projects that directly and apparently relate to defense needs."

Helena Wisniewski, at DARPA, seems to understand this very well. From the *SIAM News* of March 1986, we have: "According to Dr. Helena Wisniewski, who has a Ph.D. in dynamical systems, the overriding objective of the program is to provide significant mathematical results to solve critical scientific problems in the Department of Defense." And more. "In addition, specific areas of application have been established. According to Wisniewski, NIMMP [National Intelligence Mathematics and Multiprocessor Program] sponsored mathematics research will lead to new and improved capabilities for radar processing, crystallography and aircraft design. Also, the program will provide the methodology to solve currently intractable problems in turbulence, robotics, and will aid in the design of high-speed memory devices for optical computers." And, maybe, I don't know, God help them, if they don't; funding will disappear. The article says that Wisniewski believes strict direction and goal orientation, while a departure from the traditional approach to support of mathematics research within the government agencies, will enhance the new program's effectiveness.

Military funding poses danger to basic research.

I think that's just simply the opposite of anything that we've ever believed about theoretical mathematical funding. We say: we fund people, they're good mathematicians, we want to give them the money so that they can follow where they think the research is best going. You are not supposed to be told what to do. And that's the question. Do we want, as a mathematical community, to accept Helena Wisniewski's direction and orientation for 9% of all the money? Moreover, these grants are large, and the recipients are likely to exert a force in their departments and an influence in their universities.

The programs certainly will include some theoretical core mathematics—good mathematics, excellent mathematics without question. Lots of the results will undoubtedly be of interest to the theoretical mathematics community. But, unfortunately, we're going to have new criteria for success in mathematics. That's because the funding agencies are defense agencies, and any reasonable accounting that they will give of how they spent their money has to be that the money is being spent on defense. It is just reasonable; it is almost impossible to think that it's not like this.

Here is another quote from the David committee report: "An example of the possible enormous payoffs of improved statistical methods is the test-firing program for the MX missile. With conventional statistical techniques a minimum acceptable confidence level of 72% would require 36 test firings in phase one, and the total sample size in all phases would have to be greater than twice the planned deployment size. With a new and different statistical approach based on Bayesian techniques in reliability, the phase-one test-firing size has been reduced to 25, with an increase in reliability from 72% to 93% and an estimated direct-cost saving of 250 million dollars." That's a really new criterion for mathematics. And in fact, in the long run, these types of military applications will govern DOD funding.

There's one more issue that I would like to consider. Is this money for DOD research really additional money for basic research? I say, in the short run, maybe it is. But I don't think it really is.

One reason is that already you can see in the *Notices of the American Mathematical Society* that there is a budget for all federal support of basic mathematical sciences.

There is one budget. How it's divided up between the agencies will vary from year to year, but I think

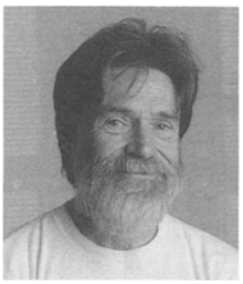
Federal Support of Basic Academic Research in Mathematical Sciences (FY)
(in $millions)

	1982	1983	1984	1985	1986[a]
NSF[b]	34.2	37.2	45.6	52.7	57.2
DOD[c] (AFOSR, ARO, ONR, DARPA)	23.3	26.5	29.9	32.3	42.4
Other[c] (DOE, NASA, NIH)	4.3	4.8	4.9	5.5	5.9
Total	61.8	68.4	80.4	90.5	104.5

[a] These are pre-Gramm–Rudman, SDI, and University Research Initiative figures. Their eventual effects may cancel each other.
[b] Division of Mathematical Sciences represents about 90%.
[c] This is based on estimates of the mathematics extramural component of some programs.

you can see that there's a total on the bottom, and anybody that has to allocate funds will watch the progression of the total. Right now, the division of the funds is NSF 58%, DOD 35%; it doesn't quite add up to 100%. There are some other agencies involved in funding of mathematics, but by comparison I want to tell you what happened to computer science.

In 1976 the computer science breakdown was 61% NSF, 30% DOD. In 1985 it was shifted to 37% NSF, 53% DOD. The initial figures in 1976 were a little bit more toward the civilian side than we now see in mathematics; where do you think we're going to be in 1994? In short, far from being good, more defense money seems bad to me.



KARP. *Robert Williams received his Ph.D. in mathematics at the University of Virginia in 1954 with G. T. Whyburn. He has had positions at Florida State University, the University of Wisconsin, Purdue University, the Institute for Advanced Study, Princeton, the University of Chicago, and has been at Northwestern University since 1963. He has given invited addresses at the International Congress of Mathematicians in 1970 and at the AMS meeting in Las Vegas in 1971. He was one of the original group supported by Helena Wisniewski at DARPA.*

ROBERT WILLIAMS. I'm talking for myself, like Michael Shub. And I'm talking only about my involvement with DARPA. I have not been involved with SDI, Star Wars, and I wouldn't want to be.

I have been involved with Helena Wisniewski now for some two-and-a-half years since she first phoned me and told me that there was money available and that DARPA wanted for the first time ever to support mathematics research.

Now DARPA is something we've all heard of as ARPANET. DARPA was called ARPA at one point—the Advanced Research Projects Administration. Now as the Advanced Research Projects Administration arm of the Defense Department, ARPA has supported basic research in computer science for many years.

On the one hand that's good, because we need computers. But on the other hand, that's bad. It's been attacked by distinguished computer scientists tonight. It's interesting that we're finally starting to talk about this subject. If it has been bad for these 20 years, I'm glad that we're finally starting to talk about it.

DARPA has been supportive in supplying us with a computing machine. Two members of my department are involved in our grant. We asked for a certain amount of money, which amounts to a lot. If you say $200,000 for three years, that sounds like a lot. Now, of that, approximately $80,000 has gone for a computing machine, something like $40,000 spread over two people for three years for academic support, then on top of this you add overhead. Now, the National Science Foundation has been willing to buy computers for some of us, but my university would much rather have 40% overhead than pay 20% up front. The National Science Foundation has been unwilling or unable, and I'm sure it's unable, to give computers to mathematicians.

Computers have gone more or less to those other people who need them. In the other sciences they've been able to get computers. Mathematicians have not.

I would like to say that there's no peer review at DARPA. When I first heard the DARPA pep talk on the lack of peer review, I was quite surprised. I was stunned. There was a period to ask questions afterward, and I didn't ask any questions, I was so dumbfounded. But I've thought about that since, and perhaps I've found rationalizations, if you wish. It seems to me that it's not bad to have several different ways of deciding upon things. Maybe after all that's not as bad as having a complete monopoly on how these things are decided. I know that peer review, when it works well (and I personally think that it works very well in the mathematics section of the National Science Foundation), is still a little bit conservative.

Now with this I come to three institutions that we deal with: the universities, the American Mathematical Society (AMS), and the NSF. I think of the three, the National Science Foundation is the most progressive.

Our universities, because of the need for tenure, are very conservative, slow-moving outfits. Now, tenure is a fairly good thing. Those of us who have it like it, and those who don't would like to have it; at least some would. But with the National Science Foundation there is no tenure, and since there is no tenure I think they're more capable of moving and changing and doing different kinds of mathematics. They are more receptive to new subcorners, subfields of mathematics than universities are. I think that our society, the AMS, lies somewhere in between, as being less conservative than the universities, but more conservative than the National Science Foundation.

I want to close with remembering when my colleague and I decided to apply for our DARPA grant. All of us worried about the DARPA grant. As you know, or perhaps will understand better toward the end of the evening, DARPA does not write contracts. DARPA money must be contracted through other agencies. The ONR is one example, the Air Force, the Army. The agency we got our money through first, the agency that Helena Wisniewski was working for, was the Central Intelligence Agency (CIA).

I think that all the initial group of people that got

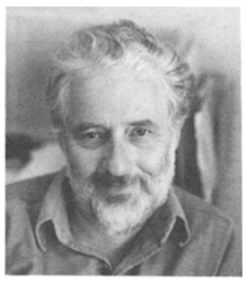
these contracts were concerned about this. We talked together; our friends like Michael Shub phoned us and talked to us. All of us thought about it and worried about it a lot. But I would just like to remember that the day that my colleague and I decided to apply for a contract was the day we heard from our sponsor, Dr. Al Thaler from the NSF.

Northwestern University, my university, has been involved many years with young people in dynamical systems. I've made a list of 20 people whom we have supported in their beginning careers in dynamical systems. These are good people. We had applied for a special year: some funding for a special year—not very much money, $25,000—and we didn't get it. I'm sure Al Thaler would have given it to us, but instead there are pressures. The NSF has been very good in deciding these things, but there are pressures. Northwestern University in the guise of algebraic topology had gotten such a grant the year before. Therefore, there were pressures for us not to get it.

Our universities, because of the need for tenure, are very conservative, slow-moving outfits.

I know something about one of the institutions that got it and they got it primarily because there were five people, they are people I know and like because they are friends of mine, but they are big shots who came to the university each for about a week. Well, I just wanted to share that thought with you.

These 20 people in dynamical systems have been at Northwestern for mostly a year or two, and I think that's a good way to support research in mathematics.



KARP. *Morris W. Hirsch received his Ph.D. from the University of Chicago in 1958 with Ed Spanier. He also studied with Steve Smale. He has been at the University of California at Berkeley since 1960 and was chair of the mathematics department from 1981 to 1983. He is the author or coauthor of four books in topology and dynamical systems, which have been translated into Spanish, Russian, Japanese, and, without permission, into Vietnamese and also pirated in Taiwan.*

MORRIS HIRSCH. I think two things happened almost at the same time. One: the United States mathematical community formally and publicly made a very strong case for increased federal funding of mathematics. The other thing that happened was that Star Wars became the official policy of the United States. As a result, much of the new funding for American mathematics, computer science, and in fact all science, is coming from military agencies, and I think this has changed things. I don't think that things are going to go on exactly as they have up to now; if I thought they were, I wouldn't be here.

Mathematics is in a very unusual position right now, because we have traditionally relied on NSF funding or no funding, rather than (as in many branches of science and engineering) military agencies. So we have very strong tradition of civilian funding. But I think what looks like an avalanche of military money coming to the scientific community may change that. And that's what I'm worried about.

I would agree that up to now nothing bad has happened from military funding of mathematics. I was militarily supported once. I had a post-doc 26 years ago, I forget whether it was Air Force or Army, through the Institute for Advanced Study, and I even had military orders. To get on the military air transport system when I went to Europe, I had orders: You shall, it said, you shall proceed to Bonn, Germany, where you shall contact Prof. F. Hirzebruch for the purpose of discussing topology. I had 30 copies of that. One of them was my ticket on the airplane, another was a ticket for my hotel room in Frankfurt or someplace. It was very nice. But I don't think the situation is the same now as it was then. I don't think it is the same now as it was before Star Wars. Because money is not only a good thing, money can be a bad thing. It can greatly deform the agencies and the institutions that it strikes, and I'm very worried about that happening in mathematics.

To say that it hasn't happened up until now is not an answer to my concern, because I agree it hasn't happened. But I think a lot of things *may* happen. Here are some of the things that might happen. I think our scientific and academic freedom will be constricted. If not de jure, then de facto. These agencies, military agencies, have the duty to consider whether publication is in the security interest of the United States. By law, they must consider that, and then if they decide that it's not in the security interest of the United States, by law, they must so inform the researcher. Now, I don't think they can prevent someone from publishing, except perhaps in very specialized areas, but imagine the effect it will have on, say, a young research scientist who is worried about whether his or her grant will be renewed, and is told by the head of the agency giving the grant, "We really don't think you should publish this research; you can if you want to, you're free to do that." But that's not exactly the kind of freedom that we're used to, and I worry about that. And, today, everything is security.

With the new cryptography methods involving fac-

toring of large numbers, I suppose it would be a "breach of security" to publish the factorization of certain large numbers! Or to invent a fast method for testing for primality. You would immediately destroy all these codes if you can do that. This is a very serious matter. So, that is one of the bad things that might happen.

Another bad thing that might happen is that the direction of scientific research, especially of mathematics, will inevitably be distorted. Now, I really can't argue that that is necessarily bad, but I don't think it's good.

If you're faced with a choice of applying to one agency or another, and the one doesn't have any money and the other has oodles of money, and the one with oodles of money is interested in possible military applications, and you have already been turned down by the other agency: which one are you going to apply to?

Suppose you want to support a number of graduate students, or you want to buy a computer, or you merely want to get your papers typed by somebody else. The NSF is very stingy on those things. The other agencies are not. If you think about applying to different agencies, as I've thought, it goes through your head: "Well, maybe I should think a little more about practical applications of this. Maybe dynamical systems are useful for tracking missiles?" These things go through people's heads. So, that's one of the things that might happen.

With the new cryptography methods involving factoring of large numbers, I suppose it would be a "breach of security" to publish the factorization of certain large numbers!

Another thing that *will* happen is that universities will be increasingly reliant on military research programs for their funding. In many fields of science and engineering, a professor at a university must bring in a contract. They say when you apply for a job, "Yeah, we'll hire you, but you have to get 20% of your salary from a federal contract." This hasn't happened yet in mathematics. It's happened in many other fields. Why should we think it's not going to happen in mathematics?

The fourth thing that will happen—may happen, is happening—is that absolutely crazy research programs, and I use the word *crazy* in a precise sense, will be legitimized by our association with them and will be funded and will be relied on by the military; I am thinking, of course, of Star Wars.

Why is DARPA suddenly investing in dynamical systems and mathematics? They didn't do it before Star Wars. It's because Helena Wisniewski convinced the CIA that dynamical systems could contribute to Star Wars. That's why they are doing it.

Now, people say, "Well, so what if this money comes from military agencies. If they are crazy enough to pay me to do the same research I'm doing anyway, if I can get a computer, increase my salary, support my students, why should I care who pays? Take the money. I would gladly take NSF support, but if they aren't supporting my work, and DARPA does, why should I care where the dollar comes from?"

Well, there are a couple of answers to that. One answer is a parable—and I apologize for the inherent sexism in it, but this is the way it goes—about the rich man who asked the young woman if she would marry him, if he gave her one million dollars in her own name. She said, "At once!" He said, "Well, how much do you charge for one night?" She said, "Sir, what do you think I am?" And he said, "We've already settled that; now we're haggling about the price."

So that's one answer.

Another answer is that the heads of the military agencies that are supporting our research and the congressional committees who oversee them are not stupid. They are much more experienced in giving out money than we are in accepting it. They have to see where this money goes. They're not going to go around for many years saying, "Oh, yes, this guy has convinced us that research in large cardinals is very useful for military application."

It's very naive to think that we can just take the money and nothing will happen. They will inevitably want to know what are we contributing to national defense. They must ask that by law. And if that's a few years down the road, what will happen if we're all relying on that money for supporting our graduate students, buying our computers, paying the rent? We're going to worry about the direction our research takes.

I think it *does* matter what agency our money comes from. I don't think this is primarily a question of individual responsibility or morality. I think it is very unfortunate that so many of us are faced with a choice of mathematical poverty or accepting funding from military agencies.

But if we say only that the correct thing to do is just to refuse such funding, then a lot of people will refuse such funding and will never be heard of again in this discussion, if that's the end of our reaction.

In fact, this is a question for our scientific organizations, and right now is a very crucial time within mathematics, more so than other organizations, because we are relatively new to this game.

The AMS and other math organizations in the United States have hired a full-time lobbyist to lobby Congress for more money for mathematics. Apparently

Kenneth Hoffman was instructed: get the money, don't worry about where it comes from, don't worry that it's going to deform mathematics, which they have said publicly.

Relying on military funding is insufficient for the future development of mathematics. What we have to do is tell the AMS and the Society for Industrial and Applied Mathematics (SIAM) and whatever other agencies are relevant that they are to instruct their lobbyist, they are to instruct their staff members who testify before Congress, to tell Congress: We want civilian funding of mathematics, not military funding; we don't want prior review; we want freedom to consult with any colleague in the world in mathematics, to offer them the use of our computers, to invite them into our offices to discuss our projects, and to read our papers. Our mathematical societies must say that mathematics can prosper only with this kind of funding. Thank you.

KARP. *Our next speaker is Jag Chandra. He received his Ph.D. in 1965 from RPI. He is adjunct professor of mathematics at Duke University and director of the Mathematical Sciences Division of the Army Research Office. His area of personal research is non-linear analysis.*

JAGDISH CHANDRA. I have heard this evening that there's a lot of money in defense research, and when I go back Monday morning to my office I'm going to look for it. There have been several statements made here, some of them may be correct, but on the whole I don't think they make total sense, and I'll tell you why.

Here we have discussion going on, on military funding and basic research. We heard some of the speakers giving their personal experiences about the support that they got and what they know about defense research. They have also indicated the fact that something like 30 to 40% of basic research is being funded by DOD agencies. They did not, however, give any appreciation of what kind of work is being supported.

I think one has to go back to basics. The funding of basic research, for that matter research of any kind in this country, is fortunately or unfortunately done in a certain way. Namely, there are multiple federal agencies involved in this enterprise. NSF is one such federal agency, and the Defense Department is another; they have specific responsibilities for supporting research, both applied and basic research, in several areas, and there's no secret about it.

The Department of Defense, by definition, and also by the will of Congress, is supposed to support research which has potential relevance to DOD's mission. The Department of Agriculture has the same responsibility and so does the Human and Health Services. There is nothing secret about that, and nobody is forced to do anything against their will.

The Department of Defense has been in the business of supporting research for a long time, it is not a new phenomenon that you are discussing here. The Defense Department, in fact, was the first federal agency of the U.S. government after the Second World War to initiate research programs. It was in subsequent years that the National Science Foundation was born for the purpose of supporting research. The Defense Department supports only that part of science for which it can establish potential relevance to defense needs.

Now that word *potential* is a very important one. The question is, what is potentially relevant? The only explanation I can give in this regard is what kind of people have been supported, what kind of research has been supported, and what has been the outcome.

Statements have been made about certain areas of research being relevant to one kind or another of technology and so on, and I would like to go back to certain historical facts.

Even before the National Science Foundation decided to establish large mathematical activities like the Berkeley center or the Minnesota center, it was the Defense Department through the Army Research Office which established and continued to support a very large activity in mathematical sciences at the University of Wisconsin, which now has moved to Cornell University. The Defense Department considers the support of basic research, and in this case mathematics, physics, chemistry, and other basic sciences, as a necessary step because it believes that DOD is the user of the knowledge of these basic disciplines and needs to make the necessary investments to strengthen these areas. I wish the large industrial organizations in this country could see things in a similar way.

The question that comes up is: has this support of research distorted the funding of research? That's a very good question. As far as the Defense Department is concerned, I am somewhat familiar with the three agencies, Army, Navy, and Air Force. I don't know much about DARPA; it's something that is new on the scene in mathematical sciences. The principal criteria used by these agencies for support of research are as follows.

First, the necessary condition for support of research is quality. You can determine quality in different ways. In the case of the Navy and Air Force, they have their own ways. In the case of the Army, we

have a peer review system which is in many ways much superior to NSF because the majority of the proposals are not only subjected to peer review; they are also subjected to a blind peer review system. The program managers do not pick the referees; they are picked by an advisory panel appointed by the National Academy advisers. So whatever may be the mechanics, the first criterion that these Defense agencies use is the quality of the research.

Not all the proposals will be funded because there is not enough money despite all the statements about huge funds. Other considerations are brought into account, namely certain areas we wish to emphasize, because we are not in the business of supporting all branches of sciences—this is the business of the National Science Foundation. So one has to look at the programs of the National Science Foundation, the Department of Defense, and the Department of Energy (DOE) as contributing to the total support of scientific research in this country.

The second thing which is very important from our point of view, and I can vouch for it with my experience for many years in the Defense agency, is that we do not force anyone to do a particular thing. In other words, there is nothing in support of basic research by DOD that will direct a person to solve a specific problem. It is your ideas submitted to us as unsolicited proposals that we respond to. I agree, only one in six, or one in ten, proposals may be funded because we don't have that much money.

A third factor, which is very important for support of basic research, and we pursue it religiously, is to give stability to support of research. This you can see through the pattern of support that we have provided to a variety of places.

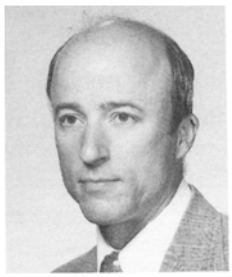
There's one more point that has not been brought up so far, I'd like to bring it up, namely, the nature of support. Since most of the audience here is in mathematics and mathematical sciences, we tend to think in very small terms, specifically individual investigators, summer support, etc.

The Defense Department supports only that part of science for which it can establish potential relevance to defense needs.

We are going through a phase where we may have to make some hard choices. Certain areas of research need much larger investments of resources. We need to consider newer modes of support, especially involving interdisciplinary groups.

But that does not mean that everything should be done in large projects. It is an important topic for discussion, therefore, to consider what should get the most support. Should there be individual investigators, or should there be large contracts? I think there should be a good balance of support for both individual and group activities. And I think these are the kinds of issues that should be discussed more thoroughly.

There have been some statements made here about the support by the Defense Department. Like the review process, there is some misinformation about the right to publish. There are no such restrictions. I would like to challenge here, especially with respect to my agency: is there any mathematician who was supported with the Army Research Office who was at any time stopped from publishing any paper? Tell me if there was any mathematician who was stopped from collaborating with any scientist, whether from the Eastern European bloc or a Western European country? Or, was there any time that we sort of stopped anyone from hiring a particular faculty member or supporting a particular faculty member? If there are any such instances, I would like to know, and I am pretty sure that my sister agencies have a similar story to tell.



KARP. *James Melcher is the Stratton Professor of Electrical Engineering on the faculty of the Department of Electrical Engineering and Computer Science at MIT. He serves as the director of the Laboratory for Electromagnetics and Electronic Systems at MIT; he is a Fellow of the Institute of Electrical and Electronics Engineers and a member of the National Academy of Engineering.*

JAMES MELCHER. In the background in all of our discussions is a very much larger issue than the one we have so far brought up. It is not just the issue of mathematics and the funding of mathematics, but whether or not the human race is going to be around in a decade . . . or two decades . . . or three decades.

I would like to make a further point. What we are doing economically won't go on forever, either. There are trends afoot that make our situation today very different than ever before.

Recently, I have been a member of a faculty committee reviewing MIT's Lincoln Laboratory. This has given me the opportunity to see this trend from the perspective of the past forty years. The laboratory began with the end of the Second World War. At the end of that war we were comfortable with military funding of research. However, we had warnings from farsighted people like Eisenhower that problems would evolve. And indeed they have. Now we have

reached the point in this evolution where we have to contend with Star Wars, of all things. I use the word *crazy* often to describe the political thrust of Star Wars. In this context, it is not a description of someone who is mentally sick. It is the description of a state where fantasy and fact are thoroughly confused.

What are we coming to? Just how long will this last? Is SDI any more a solution to the problem of obtaining long-term support for mathematics than it is to providing a meaningful defense for my country? Mathematics will not go very far on a horse that is going to be dead. (Better the horse than us.)

Many of us are academics. Our students watch as we deal with this matter. If they learn the wrong lessons, our problems are compounded. After all, they are our future. At MIT, we have a committee (resulting from an initiative led by Vera Kistiakowski, bless her soul) that was established to provide a faculty review of the influence of the military on the campus. During the past two terms I have been a member of that committee as it has reviewed the attitudes of faculty and students toward matters concerning the military presence on campus in general and SDI in particular. By way of emphasizing our responsibility to our students, let me share just a couple of findings from that review.

Perhaps for the mathematician the answer is to also grow up, to recognize that the times demand that the right to do basic mathematics should be earned by taking part in the processes that justify the use of resources.

First, in regard to the strategic, economic, and political desirability of SDI, the faculty was asked if they felt it would be an asset to the strategic position of the United States: 16% agreed, 58% disagreed, and 26% were unsure. Asked if they felt it would have a good effect on the U.S. economy, 13% agreed, 57% disagreed.

Even though one-third of our students at MIT are currently choosing electrical engineering and computer science as a major, 73% put "intellectual excitement" as their main criterion for choice of department. Far fewer indicated that their choice was made because of their ability to make money. When asked to rate (one to five) the influence on their career choice of their desire to make contributions of "social value," 34% indicated the highest rating of a five, while 4% indicated a one. We found that students really do not want to be involved with making weapons.

By way of emphasizing the contrast between these preferences and the available job opportunities, I brought along an issue of *Spectrum*, a publication of the professional society to which I belong. Open the advertisement pages and see the world through the eyes of a student seeking a job. Examples that you can see are advertisements from Lockheed, MIT's Lincoln Lab, and General Motors (GM). The last is in three pages, featuring a tracked military vehicle. That one really hurts because I do research aimed at improving the painting of GM automobiles, to help them be more competitive. I even own a Cavalier. GM is one of the biggest SDI contractors. Is that really the way to get better at making automobiles? Given U.S. government policies, can GM be faulted for responding to our government's guarantees of quick returns on investments aimed at military markets?

These are questions akin to the one we face here. How can we keep our professional commitments and not promulgate policies that lead toward economic disaster and the ultimate insecurity? For me, the professional commitment is to the advancement of engineering science. For many of you, it is to mathematics. For many of us, it is also to the education of the next generation. We cannot keep our commitments and meet our responsibilities without undergoing some change.

What changes am I experiencing? As a laboratory director, I am trying my damnedest to find industrial support from industries that, like the electric utilities and automobile manufacturers, want to keep people warm, to clothe people, to feed people, and maybe in the process to balance our payments. Don't tell anyone, but I am now so frustrated as to be willing to take on the most applied of problems if it will help some industrial group be viable and competitive in the private sector. Indeed, as an engineer and educator, I find it professionally fulfilling to attempt to meet practical demands and in the process make progress with the basic engineering science.

Perhaps for the mathematician the answer is to also grow up, to recognize that the times demand that the right to do basic mathematics should be earned by taking part in the processes that justify the use of resources.

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