ROBOTICS

HEARINGS

BEFORE THE

SUBCOMMITTEE ON INVESTIGATIONS AND OVERSIGHT

OF THE

COMMITTEE ON SCIENCE AND TECHNOLOGY U.S. HOUSE OF REPRESENTATIVES

NINETY-SEVENTH CONGRESS

SECOND SESSION

JUNE 2, 23, 1982

[No. 148]

Printed for the use of the
Committee on Science and Technology

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ROBOTICS

WEDNESDAY, JUNE 2, 1982

House of Representatives,
Committee on Science and Technology,
Subcommittee on Investigations and Oversight,
Washington, D.C.

The subcommittee met, pursuant to call, at 9:45 a.m., in room 2325, Rayburn House Office Building, Hon. Albert Gore, Jr. (chairman of the subcommittee) presiding.

Mr. Gore. The subcommittee will come to order. It is a pleasure to welcome our witnesses and our guests today to the first indepth congressional hearing on robotics. Robot technology is growing rapidly and provides the United States with an excellent opportunity to improve our Nation's productivity and enhance our position in world markets. In fact, robotics will be in the forefront of the next industrial revolution which will be based on the use of intelligent machines in industrial processes. The United States spent $130 million on robots in 1981, and by 1990 the experts believe the United States will be spending $2 billion on robots or 40 percent of the expected worldwide expenditure of $5 billion.

A robotic system can be defined as "one capable of receiving communication, understanding its environment by the use of models, formulating plans, executing plans, and monitoring its operation." Most industrial robots today, including those with computers, have little or no sensory capabilities. In fact, these robots can function only in an environment where the objects to be manipulated are precisely located. But future robots will make significant contributions not only to manufacturing, but also to space activities, underwater exploration, medical surveillance, microsurgery, and many other areas.

In 1981, of the approximate 4,000 robots installed in the United States, almost one-third of these robots belonged to only six firms, and more than half of the robots were being used in the auto industry. Experts have forecast anywhere from 20,000 to 100,000 robots will be installed in the United States by the year 1990, and approximately 1 million by the turn of the century. Real gains in productivity, although presently difficult to quantify, will occur with the development of large robotic-based systems and eventually an automated factory.

Together with the issue of robotic technology, we as a nation must also plan for those who may be displaced as a result of this new technology. Other congressional committees will in the future be examining this important topic. My colleague from California, George Miller, will have a hearing next week, I believe.

The purpose of this hearing is twofold. First, the subcommittee will be assessing the current state of the art of robot technology, both internationally and in the United States. Secondly, we will be examining current areas of research and determining what research should be emphasized in the mid and long-term to improve our Nation's competitiveness in the world's market.

This hearing appears to be timely. Japan, as well as the other major economic powers, has taken aggressive steps to insure a strong robotics capability. The United States is currently behind Japan and the Soviet Union in the production of robots. In 1980, the United States only produced 1,269 industrial robots whereas Japan produced 4,493, and the Soviet Union produced between 2,000 and 3,000. The Ministry of Trade and Industry of Japan has embarked on two major projects. The first was an ambitious project started in 1977 to build an automated factory, or flexible manufacturing system (FMS) as it is also called.

Japan has made great technological strides in this area. MITI has recently announced a 7-year, 30 billion yen—approximately $150 million—national robot research program to develop Japanese robot technology so it does not have to rely on United States or European technology. Japan clearly recognizes the role of robotics to improve its productivity and insure preeminence in world markets.

Similarly, the Soviet Union has established a national plan for robotics development. Even though the Soviet Union is behind the United States generally in some robotics technology, it has made excellent progress in some important theoretical research areas.

To date, the United States has not articulated a national plan, but I am pleased to note the increasing amount of robotics research by companies, nonprofit labs, and major universities in the United States. Additional research will be needed to improve accuracy, dynamic performance, sensors, control systems, mobility and software programs. With the increased emphasis on research and the closer university/industry cooperation, these tough challenges can be met in a timely fashion to insure our competitiveness with other nations in the world marketplace.

Major issues to be examined today are:

One. The implications of robots on industrial and economic growth.

Two. How does the United States' robotic effort compare with other major industrialized countries?

Three. How will industry respond to advances in robotic technology?

Four. What research areas are being emphasized by industry and universities?

Five. Do we have sufficient scientifically trained manpower to meet the challenges of robot technology? and

Six. What role should the Government play?

Later this month we will have a second day of hearings when selected Government witnesses will be asked to testify about Federal initiatives to promote robot technology.

Today we will be hearing from three panels of experts. The first panel will be discussing the development of robotics in major countries other than the United States. The second panel will be discussing the current state of the art in the U.S. industry and what future research is needed to insure U.S. competitiveness. The third panel will be discussing the current university research and areas of research that need to be emphasized in the mid to long term.

In addition, we have a special expert panel from the National Science Foundation who will, at the conclusion of each panel's oral testimony, assist the members of the subcommittee with its inquiry to insure a comprehensive record on this important topic.

Our first panel of witnesses is made up of Mr. Paul H. Aron, Daiwa Securities America, Inc., and Mr. Joji Arai, manager of the U.S. Liaison Office of the Japan Productivity Center out in Arlington, Va.

Mr. Aron, we would like to begin with you. Without objection the entire text of your prepared statement will be put into the record and we would like to invite you to proceed in any manner that you see fit.

STATEMENTS OF PAUL H. ARON, DAIWA SECURITIES AMERICA, INC., BAYSIDE, N.Y.; AND JOJI ARAI, MANAGER, U.S. LIAISON OFFICE, JAPAN PRODUCTIVITY CENTER, ARLINGTON, VA.

Mr. ARON. Thank you, Mr. Chairman.

Mr. GORE. Before you do so let me just introduce our expert discussants who are going to have questions to assist the subcommittee in making a complete record on this difficult and new subject.

Dr. Jack Sanderson, who is Assistant Director of the Directorate of Engineering at the National Science Foundation. Welcome.

Dr. Bernard Chern, Program Director of Computer Engineering with the Division of Electrical, Computer and Systems Engineering at NSF.

And Dr. Alvin Strauss, with the Mechanical Engineering Department at NSF. We are delighted to have all three of you here and we welcome your participation.

Mr. Aron, welcome. Please proceed.

Mr. ARON. The United States has clearly been the pioneer in the area of industrial robots. In fact, it enjoyed at least a 15-year lead in research and an 8-year lead in production compared to Japan and compared to the Soviet Union.

The 1981 survey of robots in operation, conducted by the Robot Institute of America, a trade association, indicated, as of yesterday anyway, 4,700 operating robots in the United States. The Japanese reported 67,435, but that is using a Japanese definition, which includes as robots many machines which we do not include as robots. Using the American definition the figure would be 14,246 robots in operation.

The Soviet Union, the latest figures we have, somewhere between 6,000 and 7,000 by U.S. definition. This is a Soviet figure, not mine.

As far as production for the year 1981, the production of industrial robots in the United States was probably something in the neighborhood of 3,000. Production in Japan was somewhere between 8,000 and 9,000, and production in the Soviet Union is probably somewhere between 3,000 and 4,000. The 1985 figures for the number of robots in operation, as estimated by each country now, are as follows: in the United States the estimate for 1985 would be

STATEMENT OF GENERAL MOTORS CORP. ON INDUSTRIAL ROBOTICS USE AND FUTURE RESEARCH NEEDS

Good morning, Mr. Chairman and Members of the Subcommittee.

My name is Lothar Rossol. I am Assistant Head of the Computer Science Department with General Motors Research Laboratories. With me today is Richard Beecher, manager of Robotics, Perception and Team Study with General Motors Engineering Staff.

We are pleased to have this opportunity to present our views on the role of American industry in the development of robotics.

As you have recognized, there is a serious need to improve the economic well-being of our nation so that the United States may successfully compete in the world marketplace. We are also convinced also that robotics will play a major role in transforming GM and other industrial plant operations in the years to come.

You may be interested in knowing that, in 1961, GM pioneered the automotive use of this technology when a robot was placed in operation unloading a die casting machine. By 1980, we were using about 300 robots, primarily in one application -- spot welding. We now have approximately 1,600 robots on hand or on order. We expect this number to continue to increase.

At the GM Technical Center, an extensive robot laboratory has been established and it has had as many as 35 different experimental robots in operation at one time for evaluation or demonstration. In the past year, over 6,000 GM engineers and managers from around the world have visited the laboratory. We would be pleased if your committee or other government officials would visit our Technical Center to see this and other exhibits of advanced technology.

In addition, General Motors has led the industry in the development of visual sensor-based robot systems. These include:

- o CONSIGHT - a system which looks for randomly positioned parts on a moving conveyor belt and directs a robot to pick them up.
- o SIGHT-I - the first industrial application of computer vision in the United States. It is a vision system which inspects integrated circuit chips and automatically positions electrical probes to test the chips.
- o KEYSIGHT - a vision system that inspects engine heads for missing valve keys. It is the first system of this type installed in any U.S. plant.

In our comments, we'd like to touch briefly on the limitations of current robots, research areas that should be emphasized and the role, if any, to be played by the federal government.

Limitations of Today's Robots

The robots commercially available today are being successfully used in a variety of applications. They can perform relatively complex tasks -- such as component assembly -- and simpler ones, like material handling.

But there are many things today's robot is incapable of doing or is incapable of doing on a cost-effective basis.

In most installations, the robot is programmed to perform a certain repetitive routine. But the robot cannot become aware of, and thus cannot adapt to, changes in the workplace. As a result, we have failures which can result in damage to the robot, to the workpiece or to other tooling or fixtures.

Another deficiency is the robot's relatively slow speed. Many of our production operations require robots to complete a task in three seconds or less -- but the robots of today are simply not that fast.

Problem Areas Needing Underlying Basic Research

We have identified three problem areas requiring more underlying basic research to support the use of robotics in new applications. These problem areas are in sensor systems, robot control systems and robot programming technology -- which are all related. Let us look at each of them in somewhat more detail, starting with sensor systems.

In the future, many robots will be controlled by sensors. These sensors will provide information to the robot so that parts, surrounding equipment and the robot itself need not be precisely located or dimensioned; instead, the robot will adapt to changes in its environment. Additionally, sensor systems would provide general inspection capability.

The relevant sensors will be range, force (or touch) and, most importantly, vision. Although much can already be done with machine vision, we cannot yet claim that computers or robots can actually "see" in the usual meaning of the word.

In fact, most industrial vision tasks are not solvable today. This is because we do not understand vision -- biological or artificial. Each vision system we have developed to date can handle only one narrow class of problems. A better understanding of the basic processes of vision must therefore be achieved.

Additional understanding is also needed with respect to the other robot senses -- range and force. Although some experimental 3-dimensional vision machines can measure range, we do not yet have a good understanding of general range or force sensing systems.

The second major area where we lack basic knowledge is in robot control systems. Such systems now normally consist of several computers, some special purpose electronics and the software for the computers. Two issues are important hère -- robot speed and adaptive control.

Adaptive control involves the integration of information from vision, range and force sensors into the control software and electronics of the robot in order to adapt the motion of the robot arm to changes in its environment. Such control theory is an open research area today.

The third problem area is that of robot programming. Currently, a robot is taught by manually guiding it through pre-defined motions. The positional information must be stored in the robot's memory before it is able to repeat the motions.

Moreover, programming would have to change if a sensor-controlled robot were involved. There could be no predefined motions for use in programming because the path of the robot arm would vary according to its sensory inputs.

Generally, at programming time the robot itself would not be available, the part not yet built and the production line not yet set up. All the necessary information would likely exist, however, in computer-aided design data bases. The idea would be to program robots using such data. But this requires basic research in support of the programming issues because we do not even have concepts for off-line programming of conventional robots -- let alone sensor-controlled robots.

In our opinion, the three topics mentioned here constitute the most important areas for which new underlying scientific knowledge is required.

Role of the Federal Government

We believe basic research is the appropriate area for government involvement and that the underlying work in support of the three topics we have discussed is most important for the robot community.

Admittedly, the definition of basic research is not precise, but it can be roughly described as an effort to expand scientific knowledge and understanding rather than the application of such knowledge to the development of specific products. Government research that goes beyond the discovery of new knowledge unavoidably places the government on a parallel path with industry. Such unnecessary duplication is an inflationary waste of taxpayer dollars. In our view, the federal government should not be a competitor of industry, but rather a supportive ally. Long term policies and programs must be designed to foster increased productivity.

We have found the industrial affiliate programs -- as exemplified by those at SRI International and the University of Rhode Island -- to be useful. Such programs allow a synergistic relationship to be established between the research institution and private industry. This does not mean, however, that affiliate programs should be the sole mechanism for doing basic robotics research. Universities should also perform independent government-sponsored robotics research.

We hope the perspective we have offered on industrial robotics will prove useful to you.

Thank you.

Mr. GORE. Thank you very much.

Chairman Scheuer.

Mr. SCHEUER. Is this the time to ask questions?

Mr. GORE. Mr. Beecher, I take it, does not have a statement.

Mr. BEECHER. No, sir.

Mr. SCHEUER. Thank you, Mr. Chairman.

Mr. GORE. You are recognized for 5 minutes.

Mr. SCHEUER. It has been an extraordinarily interesting panel. All of you have given us much to chew on. There is very little you have said that I will take objection to, and very much that you have said that I think helps move our thinking along.

I would like to ask a couple of questions, addressing ourselves to the Japanese experience. First I would like to ask any of you what the proper role of the Federal Government is compared to MITI, which actually provides research and development funds, selects the industries in which they are going to make a quantum jump forward, provides research and development grants, takes two or three major companies, creates the consortia, funds the consortia, gives them the product or the industry they want to go. That has been their traditional pattern, of not only funding the research, but deciding the industry, almost defining the product, selecting the corporations. And then providing the research design and the funding. That is in the Japanese tradition.

It is not quite in our tradition. Let us pick and cull. What are the elements of the Japanese success that you think are applicable here, and what permanent mutations and combinations of change do we have to make to define what is a proper Federal Government role for this country? That is my first question.

My second question, I want to ask the two questions in my 5 minutes, at least, the second question is based on my feeling that industry is basically on the right track, that they are moving, the market forces are working. There is an absolute inevitability about our moving into this whole field of robotics and allied sophisticated applications of the computer.

I see the problem of labor unions, and I see the problem of the threat that will be perceived by individual workers to be a much greater problem in this country than it has been in Japan for some of the reasons we have already discussed. How do you all perceive this, and how do we meet the human needs of the workers who are not right on target and who are not ready to hit the deck running, and to participate in this whole computer revolution, who do not have the skills right now to be retrained? How do we include them in, as Samuel Goldwyn would have said? And what is the role that industry can play?

It is common knowledge that our education system, our elementary and secondary education system to some degree has turned off kids. Without trying to assay right and wrong and guilt, pointing the finger, the education system for a lot of our young people, a lot of our young minority people, has not involved them, it has not challenged them, it has turned them off. There are some people who say well, education at the traditional school site has failed. Maybe we ought to try education on the job site. Maybe we ought to design a work-study program that includes a lot of education, where they will be paid or released time, they will be compensated. That this turns the kids on.

It seems as you are doing computer applications, development and applications of more sophisticated robotics just as Mr. Radeke and Mr. Rosen have talked about, not only designing the computers but applying the computers to the roles that have to be accomplished, a very practical intervention, it seems to me we have to do some very practical thinking about how we defuse this potentially threatening situation, threatening the future application and acceptance of robotics and other computer applications.

How do we create an American labor movement, particularly among our young people, that will welcome it as the Japanese have, instead of feeling it as a direct threat to their futures, their psyches, their persona? How do we include them in and give them the literacy and numeracy tools so that they will accept it and welcome it? Does the corporation have a role in training and educating and providing the requisite skills to the workers during the 2- or 3-year period that you may have when you have once decided to eliminate a particular production line, and wipe out 300 or 400 jobs, and put in a computer so you will have 5 guys on 2 shifts and then the night watchman and maybe somebody watching a whole wall of computer panels? What role can industry play in that human retooling challenge?

Those are the two questions that I have: What is the proper role of the Federal Government in all of this? And what is a really creative and innovative role for industry and business itself to play in the human engineering or reengineering, as well as in the design of the computer hardware?

Have my 5 minutes expired, Mr. Chairman?

Mr. GORE. We will extend it for the answers.

Mr. RADEKE. I would like to address the second question. The first one is a much more complicated one, as you all are aware. I think as we look at that, I guess you would call that worker reluctance. That is a good term. To be very honest, we have not seen it at all in the industry. First we have the size of the industry. We are looking at 5,000 robots installed. They have not taken over the world, regardless of what Star Wars may want us to think. In general the worker reluctance has been zero. The jobs that they are now doing are much more rewarding than the ones they have done before. In fact, very few industries that I am aware of that have installed robots, in fact, have displaced people.

A worker now is controlling the cell that produces goods, as opposed to physically doing the work himself. There is an article that was done by a newspaper in Indiana on an installation, Cummins Diesel, which I have framed in my office, because the worker was doing a job, a similar one to the film here, moving parts, putting it in a machine, et cetera. He was then replaced with a robot. He now ran two machines and a robot. His comment to the press was when that thing goes down he is on the maintenance force 100 percent, because otherwise he has to do all that work physically himself. And it is so much more fun and enjoyable to run that cell and control that equipment, and be in charge of the production as opposed to being the production.

Mr. SCHEUER. Let me ask, what percentage of workers whose jobs will be replaced by computers are capable of managing and controlling that computer with how much additional skills upgrade?

Mr. RADEKE. I guess I have to start from a basic point. I heard a comment earlier that it is going to be very difficult to upgrade the U.S. workers in skills to handle this technology coming in. I do not personally agree with that. I happen to disagree with it. I have found very few workers that I have dealt with at any level within our company or the companies we deal with that are not eager to use the skills that God gave them. I think many times they have not had the opportunity to do that. We certainly have put them in jobs that deny them the opportunity to do that.

I think that in every case, and we have a great deal of training in our company for our customers and conjunctive with our customers like General Motors, the general reaction to that training is 95 percent favorable. Obviously there are some areas where the viewpoint is, "No, I do not want to be replaced, I do not want to do this job, I want to do that job, the one I have done all my life." Certainly that inertia exists, and there is no denying it. But in general when we go through the training programs, there is not a desire to thwart the task, but in fact a desire to participate and get retrained.

We have a program where we have donated robots to about 12–15 different universities and vocational colleges, along with curriculum help, again to solve the problem Mr. Rosen addressed earlier "of where are we going to get the manufacturing engineers, the technicians and self-supervisors and other people". I am very pleased these programs are being set up, vocational programs, particularly in Michigan, South Carolina, and other user States. They are taking these people who we might say are difficult to train and training them for this technology. They are finding great acceptance as far as finding jobs in a very tough marketplace. So I think there are a variety of roles there to be played on that issue.

I think certainly the industries themselves run a large number of retraining programs within their own companies. Certainly our company is involved in a variety of technologies, not just robots but machine tools, plastics equipment, and so on. We have the capability of retraining across any of those other disciplines. If, in fact, the displacement on putting a bolt onto an automobile gets done now by a robot, you certainly do not want to train that person to put a piece of trim on the automobile. You want to train him to do something totally different. Run a machine tool. Be a cell operator. Get involved in the other areas of the manufacture.

So there is a whole task I think we face in this training area in the next decade as we go through the social transformation. And it will occur. The social transformation, if we are going to maintain ourselves competitively in a world marketplace, will occur. We must be prepared both as manufacturers of equipment, as users of equipment, as educational individuals, and as Government to make certain that looking downstream, we recognize that "threat and opportunity" and capitalize on the opportunity part.

Mr. SCHEUER. Mr. Rosen.

Mr. ROSEN. I would like to address both your questions. I already stated that the long-range research that goes on that keeps us competitive is not going to be done anywhere but in these universities and nonprofits that are looking toward 10-year improvements in basic science. I do not think that industry in general will put enough effort into it by themselves, because they have enough to do just to implement what there is. You have heard some of the problems my colleagues here have raised. The Government must, I believe, intercede in the basic research field. It must support that basic research in whatever way it can, and indirectly support the training of high-level professionals.

I just came from Carnegie yesterday. I saw an array of available computer facilities larger than I have seen anywhere except perhaps in one of our agencies that cannot be named. An enormous facility. They have 150 or so people working in robotics and allied automation funded by combined industrial-Government research grants. This is a very advanced artificial intelligence community, but one fact stood out. There are only 20 or 25 graduate students. This is one of the major university programs in this country. And only 20 or 25 graduate students going through that kind of training! It is ridiculous for a country this size. There are not more than a half dozen universities that are capable of doing this kind of work. So I want to see the Government intercede, at least in the educational field. By granting research grants and increasing grants sufficiently you will get both of these things to happen.

Mr. GORE. How many of the 20 or 25 were American?

Mr. ROSEN. You know, I do not know, but looking around, not all. Not all. That is right.

Mr. GORE. Go ahead.

Mr. ROSEN. The second thing of course, concerns these entrepreneurs, of which I am one. We need seed money. And we do have trouble getting seed money. That is why the small business bill is very important. I think that the near-term implementation of the technologies we have will be accelerated enormously if people who want to be entrepreneurs, people who want to start their businesses, can do so with a little help, not a lot. That is two. That is about all I would say the Government should do. I do not agree that Government should go in to help specific industries and pour enormous amounts of money into those industries. I think industry should take care of itself.

The second question perhaps is more important than the first one. I give talks to high school students about robots. The students are generally excited. Most of the kids who come are the ones who are playing around with these little personal computers related computer perpherals, that are in the high schools now. They are beginning to be widely available. Kids come in and play around. First they start with those damn computer games. Pretty soon they say, "Gee, maybe I can make some games." Soon afterwards they say, "Now what else can we do?" They have little equipment that is relevant to what we are discussing today to pursue that role. (Remember the radio amateurs in the previous generation.) If somehow these kids could be given some equipment and some teachers, which, of course, are woefully lacking, you would turn on a whole generation of kids who are inclined that way.

There is a technical fact that you must be aware of. My company and many others are trying to make equipment that is easy to set

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up and train and operate. In fact, the movie showed that with that little box, that you could train that robot to do its various things. I have never seen anybody in our laboratory or any visitor that could not learn how to operate that box in a half an hour. Once taught, he would begin to fool around making the robot do its tricks. The present robots have been designed so that a relatively untrained person can become a trained person quickly. Most people know how to work the box in a very short time, and then begin to learn how to make shortcuts.

For all the other equipments we are talking about, the sensors that are going to be attached to the robot, the more intelligent robot, the robot manufacturers and people supplying those equipments will have to make them extremely simple to use in the factory. The sophistication should be buried in the software programs that make the robots simple to be used in the factory. It is one of the great challenges to make a sophisticated robot that takes a kid to train. I am not worried about those people that have to be retrained, with the exception of just a few who are scared stiff. They do not want to do it. Or they are afraid they will never be able to do it. But the majority of them can.

Whether we will have enough jobs for these people is a separate issue. Whether you can train them I have no doubts. I think it is going to be the robot manufacturers and industrial people who will have to be forced to train these people, because they have nowhere else to go. As for the trade schools, there are just too few of them, there are too few teachers. You are going to have to teach the people right in the factories.

Mr. GORE. Mr. Rossol.

Mr. ROSSOL. There are two of us from General Motors and we will each take a question. Being first, I will take my choice.

On the idea of reluctance to retrain, there is a new "disease" which is afflicting some U.S. teenagers and that is their addiction to computers. They breathe, live, think computers all their waking hours. A sample is my teenage son. I bought him a computer, gave him the manuals and now there is only one thing in his universe—computers.

This gives you an indication that, at least in the long-term, the interest is there. I don't believe there is reluctance.

Mr. GORE. Mr. Beecher.

Mr. BEECHER. Just a brief statement with apologies to the academic side of the hearing. There are many, many jobs within the field of robotics, not all requiring a university education.

As Dr. Rosen said, the move is to make the industrial robot easier to program. The level of skills required to program them is therefore considerably lower than it has been in the past.

I have the robot laboratory to which Mr. Rossol referred earlier. One of the most frequent tasks in that laboratory is to give tours to visiting teenagers and grade school kids from the immediate area, Detroit, Warren and the environs.

These are very, very excited by robots and where possible, we give them hands-on experience with them.

With regard to what Mr. Scheuer referred to as the basic literary skills, that certainly is essential. They can't do much without it.

Mr. SCHEUER. Literacy skills.

Mr. BEECHER. I am sorry, I misspoke. Without them, we cannot do much.

Mr. GORE. Mr. Volkmer.

Mr. VOLKMER. I would like to direct my question more to some of the practical aspects of some of the previous testimony by the previous panel.

Mr. Radeke, do you find any problems with management in implementing robotics?

Mr. RADEKE. Yes, Mr. Volkmer, the answer is yes and no, how's that? Certainly when we deal with presidents and vice presidents of companies. Absolutely not.

They recognize the survival of their company as a viable economic unit is dependent upon them being competitive in domestic and foreign markets.

Therefore, from their view, the long-term investment in technology and automation is an important factor. I have to be honest and say that the place we normally have a reticence to install and use robots are at middle and lower management.

It represents to some degree a total change in what they manage. We have trained in this country a large number of managers that are very, very skilled in management of workers, of people.

We have not trained a large number of managers skilled in the management of equipment and the resources it represents.

So to that degree, it represents some sort of threat.

Mr. VOLKMER. Now, along that line, just to give me basic information, approximately—let me ask you first, about how many robots would your firm manufacture annually now?

Mr. RADEKE. We don't publish that information.

Mr. VOLKMER. All right, okay.

Mr. GORE. A bunch of them?

Mr. RADEKE. More than two.

Mr. VOLKMER. We realize that, but let me ask you this; do you feel that the field of robotics can be greatly expanded in this country?

Mr. RADEKE. Oh, absolutely.

Mr. VOLKMER. What is the reason that it is not at the present time?

Mr. RADEKE. I think there are several. One is the area I addressed, the area of applications.

Let me give you an example which may be helpful. I talked with my counterpart in a Japanese company several weeks ago and they manufacture and market in Japan and market those systems here in the United States.

In the course of our discussion, he said he has not been doing very well in the United States and he says: "I really don't understand why."

I thought about the question for a moment and I said: "Well, who do you sell to in Japan?" and he said: "Well, I sell to welding engineers."

Well, right there we have a basic problem.

The U.S. graduates in the range of 200 welding engineers, manufacturing engineers skilled in the welding arts, in a year. Japan is between 2,000 and 3,000, Western Europe is probably 4,000, if I remember, the Soviet Union is about 8,000.

So what he is trying to do is sell a high-technology project in an area where it is a very much "Missouri-kind" of atmosphere, show me it can do the job and I will buy it.

So if we look at our development expenditures in our company, we are looking at 50 percent of development of product, new product, new capabilities; and 50 percent of applications development, showing people how to use the robot, developing these applications for customers.

If there is one area I am concerned with, it is the one I directed my immediate discussion about, is getting a position where the risk to the user is reduced in introducing this new technology at whatever level the technology represents.

Mr. VOLKMER. In other words, the risk factor creates much of the resistance?

Mr. RADEKE. Yes.

Mr. VOLKMER. Mr. Rossol, on GM, do you manufacture your robots for your own use?

Mr. ROSSOL. Yes, sir, we do.

Mr. VOLKMER. You do not or do you manufacture for others?

Mr. ROSSOL. We do not manufacture for others.

Mr. VOLKMER. In other words, it is in-house.

Mr. ROSSOL. Yes.

Mr. VOLKMER. Do you ever plan or do you know if there is any plan for GM to manufacture for sale to others?

Mr. ROSSOL. I am not aware of any plan to manufacture robots for sale to others. There is the joint-venture company, of which GM is a part, that will, in fact, manufacture and sell to others.

Mr. VOLKMER. Right now, your program, then, is related to the automotive field explicitly and that is it?

Mr. ROSSOL. Yes.

Mr. VOLKMER. Mr. Rosen, can you tell me as far as what work is being done, if not you, anybody else; as far as I see as part of the problem as familiarizing other industries to the use of robots?

Mr. ROSEN. About 90 percent of American marketing effort is sending people out to factories and showing them, back to this Missouri—with hand-carried equipment how the stuff works, what it can do, walking through their plants and saying, here, here, here, here, here are places where it can be applied.

Then the second and much harder job occurs, they see they can use the equipment but it requires a whole system application group to work it up.

That is costly. If it is a small company like ours, we can just devote a small amount of our resources to that costly working up.

We then have to influence that company to pay the piper, like General Motors did at Lordstown for spot-welding.

That is, to make the first installation and make it work because there may be 10's, 20's, 30's, or hundreds of similar applications in that factory.

But that first breakthrough of getting that first system running and somebody paying for it, that is what it is all about.

Mr. VOLKMER. Is the cost factor—and I will conclude, Mr. Chairman—is the cost factor with smaller companies to bring them in, is that a resistant factor, also?

Mr. ROSEN. Oh, when—we rarely get a very small company, say a company that has 50 or 100 employees that will even begin to consider paying for that first installation.

They are going to follow a great deal what happens in the larger companies, whether it is spot-welding or material handling, they want to see it work and then get the money.

Mr. VOLKMER. Thank you, Mr. Chairman.

Mr. GORE. Thank you.

Let me ask you a few quick questions. Mr. Radeke, your film used a figure of $6 an hour for the P-3 robot. Does that mean $6 an hour for 24 hours a day? How do you figure that?

Mr. RADEKE. That is based on two shifts normally. Say that figure today is—that film is about 2 years old, it is $8 to $10 now.

Mr. GORE. $8 to $9 an hour based on what amortization period?

Mr. RADEKE. Looking at a 5-year amortization.

Mr. GORE. At what interest rates?

Mr. RADEKE. I think that was done, then, at 17 percent.

Mr. GORE. So if interest rates ever come down, you would expect to see an acceleration of the placement of robots?

Mr. RADEKE. Yes, if we look at any long-term investment, if the interest rates come down, we will see a major retooling.

Mr. GORE. You talked about social transformation, can you give me some way to assess the magnitude of the transformation you are talking about?

Mr. RADEKE. I think we can go back to Paul Aron's type of thinking, we are talking about 15,000 robots, six people, et cetera, so you are talking about 100,000 people.

When we look at that, we have to recognize we are talking across a decade, so the magnitude of the problem today is not significant.

If we look off 10 years from now and take no action today, we will have a significant problem. The key is to start programs today in industries like ourselves, General Motors, so on, universities, governmental areas, to start these things in the right direction, I think this is the area.

I don't know if you noticed this, but in the press recently, there have been comments concerning the unions getting together with MITI and so on to start discussing long-range social implications. It is not that the workers are resistant to the robots coming into their industries, because they see the benefits, but they want to formulate a long-range national policy on how social implications will be handled 5, 10, 20 years from now when we will have the problem, if we don't address it today.

Mr. GORE. Is it accurate to say that when one projects the social impact, one is dealing with an exponential curve?

Mr. RADEKE. I certainly hope so.

Mr. GORE. Well, if you——

Mr. RADEKE. If you look at the needs to be able to be competitive in the world markets, yes, we would hope to see a substantial increase in the types of automation we are talking about, plus, of course, that is cumulative.

If you ship the same amount of equipment, the sum total installed goes up exponentially.

Mr. GORE. When will industrial robots be able to adjust to errors in parts positioning in assembly operations?

Mr. RADEKE. I think GM has one operating today.
Mr. GORE. When will we have robots cooperating the same task?
Mr. RADEKE. We already do that.
Mr. GORE. So much for the futures question.
Mr. RADEKE. The point to make is with the capability of doing those things, and there are installations, yes, of doing that.
But how widespread is that technology, I would say it is very, very narrow.
Mr. GORE. You emphasized research into robot vision and interface with other systems, Mr. Rosen. Can robots see at the present time?
Mr. ROSEN. Well, the product we have is a vision system, very similar to the ones that Mr. Rossol has described in use now at GM. For many millions of jobs with a little rearrangement of the manufacturing process, these systems can be put to use now, but not with the kind of cost-effectiveness that will be available later when the newer systems—which are on the drawing boards right now—will reach the market.
Mr. GORE. Now, if you take one of the systems that are currently available, what would be the average initial investment cost per company desiring to purchase and install a robot?
Mr. ROSEN. Well, the robots of the complexity we have seen start out somewhere around $45,000, $50,000 apiece, and go up to $100,000, $125,000, depending on the application.
If you want a so-called intelligent robot integrated with other equipment, you may add another $25,000 to $30,000 to it, not counting other rearrangements of the manufacturing process.
Therefore you are in for an expenditure of about a $100,000 for a sophisticated task.
Mr. GORE. Both you, Mr. Rosen, and Mr. Radeke, in order to sell a robot to some manufacturing company, say, you have to first demonstrate to that company manager how the robot will help him out.
Mr. ROSEN. Yes.
Mr. GORE. Do you find that the manufacturers, you as manufacturers have to perform this systems engineering and analytical function for your customers?
Mr. ROSEN. Very few of them can. They don't have the personnel. It is only a few big fellows—GM, for instance—that have the personnel and the research and advanced development laboratories that can perform that function.
Most of the other manufacturers are just beginning to hire on their first people that know anything about it and they are trying to get robot manufacturers and other peripheral manufacturers to supply that expertise.
They don't know how to do it.
Mr. GORE. If a young person wanted to acquire that skill that will be in such enormous demand, where would he or she go to school for training?
Mr. ROSEN. There are only a few universities, very few that do undergraduate training at all.
It is just now that the engineering departments, rather than the computer science departments, are starting new teaching programs for this industrial engineering type of skill.

Mr. GORE. Could you name them, Carnegie-Mellon, who else?

Mr. ROSEN. MIT, Rhode Island, Stanford, University of Michigan, University of Illinois, and a few others. These are all just beginning.

Mr. GORE. Mr. Rossol, how many robots does GM use now today?

Mr. ROSSOL. GM has 1,600 robots, either installed or on order.

Mr. GORE. How many of them are being used for spot-welding?

Mr. ROSSOL. 400 to 500 of them.

Mr. GORE. And the others?

Mr. ROSSOL. Machine loading, unloading, material handling, painting.

Mr. GORE. Are you doing research in the flexible manufacturing system area which Japan emphasizes?

Mr. ROSSOL. We are doing research in computer-based manufacturing in general. We don't call it quite by the same name, but the answer is "Yes."

Mr. GORE. Now, you mentioned this joint venture. That is with the Japanese company, is it not?

Mr. ROSSOL. Yes.

Mr. GORE. Fujitsu FANUC.

Mr. ROSSOL. Yes.

Mr. GORE. It is a joint venture to design, manufacture, and sell robots. Do you think that arrangements of this kind are going to be commonplace?

Mr. ROSSOL. It is a departure from the way GM has historically done things, so perhaps it could be considered an experiment. If it works out well, then I think that in the future we will see more of this kind of thing.

Mr. ROSEN. Can I make a remark on that, Mr. Chairman?

Mr. GORE. Yes, sir.

Mr. ROSEN. My little company has just entered into a joint venture with a company in Japan for robots, so that we can put our equipment on their robots and sell an intelligent robot.

Maybe we are a small company that is one of the first to do so, however, IBM; GE, GM, Westinghouse, and others. Westinghouse, all of them have either engaged in joint ventures or cross-licensing as Unimate Corp. has for well over 20 years, and it is my impression that this will be the most common thing that happens to U.S. industry in this field in the next 10 years.

Mr. GORE. Why?

Mr. ROSEN. The Japanese have developed and implemented many applications and good high-quality robots and technology in robots.

We have very great computer and software capabilities in this country and the marriage is very good for both.

Mr. GORE. Well, it could be better if we could get partners in the United States.

Mr. ROSEN. It is very hard to do so.

Mr. GORE. Very hard to do so.

Mr. ROSEN. Yes, sir.

Mr. GORE. Well, OK.

Have there been any—this is my final question before turning to our discussants.

Have there been any significant studies of safety and health effects of robots? That may be premature.

Mr. ROSEN. Just safety. The Bureau of Standards is one of the few R&D establishments that is looking into safety aspects and developing devices so that the robot won't kill itself, people, or other equipment.

I think your company—Cincinnati-Milacron—has been interested in that as long as I have known your company.

Mr. RADEKE. Yes.

Mr. ROSEN. There are few research programs associated with that aspect.

As far as health is concerned, I don't know of any effects that would be unhealthy for workers.

Most of the newer robots are going to be electrical and even hydraulic machines; I don't think they present any health problems.

Mr. GORE. Probably very positive aspects.

Mr. ROSEN. Very much so.

Mr. GORE. Did you want to comment, Mr. Radeke?

Mr. RADEKE. Yes; just that the area of safety is addressed by the professional society, the Robotics International of the robot industry.

Mr. GORE. Is there a greater danger as we go to software-controlled robots as contrasted with the lead-through and walk-through approaches?

Mr. RADEKE. Our robot is computer-controlled and always has been, so I think the question is, if I look at off-line programing versus local programing—is that what you are asking?

I think there is no danger from the programing viewpoint, but if we look at automatically starting and programing those robots remotely; yes, that could pose a problem.

Mr. GORE. Who is looking at that?

Mr. RADEKE. Several people are looking at that and seeing how to solve that problem. We are addressing that with our customers. It is a difficult task.

Mr. GORE. Mr. Rosen.

Mr. ROSEN. I don't think hardly enough is being done in that field.

Mr. GORE. Well, very good.

Mr. VOLKMER. Mr. Chairman, just briefly.

Mr. GORE. Mr. Volkmer.

Mr. VOLKMER. I would like to ask, maybe one can answer and the rest can agree or not, how many hours do we operate a robot now without down time?

Mr. ROSEN. Maybe you have a figure?

Mr. VOLKMER. Number of hours.

Mr. RADEKE. I will let Dick answer that, he has done extensive testing.

Mr. VOLKMER. An average.

Mr. RADEKE. Let me say, again, it is something that is measured in the field. Our customers have fed back to us they are 99 percent up time. If you look at the automobile industry with robots installed on a line, if you are not looking at a robot with that up time, you don't have a product to sell.

Mr. VOLKMER. Do you agree on that?

Mr. BEECHER. Yes.

Mr. VOLKMER. Thank you, Mr. Chairman.

Mr. GORE. Mr. Rossol, just a couple more brief questions, how much of GM's automobile manufacturing capacity will be robotized by 1985?

Mr. ROSSOL. Our numbers show that we will have 14,000 robots in production by 1990. By 1985—do you know?

Mr. BEECHER. 5,000.

Mr. GORE. 5,000 per year?

Mr. ROSSOL. No; a total of 5,000 robots installed.

Mr. GORE. What percentage of your auto manufacturing capacity would that represent?

Mr. ROSSOL. Well, we don't have any real numbers for you except to say that that number of six is considerably high.

Mr. GORE. Six what?

Mr. ROSSOL. Six people.

Mr. GORE. That is too high?

Mr. ROSSOL. Yes; by a factor of three at least.

Mr. GORE. Which means you think one robot replaces two people?

Mr. ROSSOL. At most.

Mr. GORE. What about 1995?

Mr. ROSSOL. We don't have any numbers that far in advance.

Mr. GORE. Is it fair to say that the percentage of your manufacturing capacity will be robotized by 1995 or 2000, that it will greatly exceed the percentage that is not robotized?

Mr. ROSSOL. It is fair to say that it will greatly exceed the percentage that is now robotized.

Mr. GORE. Do you—would it mean there would be some robotization on most or all of your assembly plants?

Mr. ROSSOL. We think assembly robots represent the biggest potential new robot market. Currently, they are not greatly used for assembly purposes.

They are used for spotwelding and other simpler applications. We think in the future, there will be assembly robots that we will use.

Mr. GORE. I know you have given a lot of thought to this, and I hope you can help the subcommittee in the exploration of this question, you have got to anticipate a lot of jobs being lost as a result of robots being introduced into the manufacturing process.

I know it is a sensitive subject, but one that the whole country is going to have to deal with. I don't want to put you on the spot, but if you would help us grapple with the problem.

How does GM grapple with it?

Mr. ROSSOL. We understand the question—it is a difficult one. We do spend a substantial amount of time looking at it.

We believe the relationship between automation and unemployment is tenuous at best. Our thinking is that the introduction of robots may well increase, rather than decrease, the number of jobs doing two things—making us more price-competitive and by helping us produce a higher-quality product.

Mr. GORE. Now, does that mean that you expect that the people, all of the people whose jobs are going to be done by robots will continue to be employed by GM?

Mr. ROSSOL. We have not, up to this point, seen any people lose their jobs because of robots and we don't expect it to happen in the future because of the relatively gradual introduction of robots.

Mr. GORE. Well, I wish we had other manufacturers here so we wouldn't all be exploring it within the context of GM and I don't want to put you on the spot, but I wonder if that is really an accurate analysis of what has happened, that no jobs have been taken by robots.

If one looks at the number of people laid off by GM, by your competitors as well, but if you look at the number of people laid off by GM and you look at the introduction of robotic manufacturing in the Japanese auto plants and the prospective reopening of some facilities that did employ lots of people with robots instead, can you really say that no people have been replaced by robots in GM?

Mr. ROSSOL. Again, I am a little out of my area of expertise, but the question I think that should be asked is, Is there unemployment because of automation or because of the lack of automation? I don't know if the answer is clear.

Mr. VOLKMER. Mr. Chairman.

Mr. GORE. Yes.

Mr. VOLKMER. If I can interrupt just to put it on a little personal note, at the present time, GM is building one of their newest plants at Wentzville in my district and it will have a lot of robots, as I understand it, and I am welcoming that because I would rather have a plant with a robot than not have a plant with robots.

I think that is part of it.

Mr. GORE. I think that is a useful addition to the record and I currently have a large plant being built in my district by Nisson that is utilizing a large number of robots as well.

We welcome that facility, too.

Mr. ROSEN. Mr. Chairman.

Mr. GORE. But the point I am getting at is this, instead of beating around the bush, it just seems to me reasonable to expect, however much we want to fuzz it over or pretend that for every job lost, there will be another one created, the fact is that the introduction of robots in a manufacturing operation like GM is probably going to mean elimination of a lot of jobs.

It may be a companion need by creation of an equal or greater number of jobs in other parts of the economy; it may be that a large percentage of those people whose jobs are affected can be employed by General Motors doing different tasks, overseeing the robots, whatever.

But to the extent that it is reasonable to suppose some jobs will be eliminated, does GM anticipate a retraining effort to anticipate that or what?

Mr. ROSSOL. Yes, we are aware of the problem, we are working with our people. We anticipate some retraining, and do whatever we can do.

Mr. GORE. Have you encountered any hostility from your work force as a result of the introduction of robots?

Mr. BEECHER. The answer to that question is no, we have not experienced hostility. I would like to address the previous question about the retraining.

We have had training programs for a number of years in various areas, obviously. We have programs in retraining for the application of robotics which continually grow more elaborate.

We have several rather sophisticated installations in several of our plants to train people in the use of robots and in the repair and care of them.

In other words, training has been underway for some time and we foresee a much higher growth in that area.

Mr. GORE. Thank you. I don't wish my questions to appear hostile and I will say to my colleague from Missouri, I agree absolutely that we have got to facilitate this trend rather than fight it.

Other countries are going to do it and we are going to lose out if we don't adopt the most modern techniques available.

The point I am making is large employers and other employers have to plan ahead to take care of the people who are most certainly going to be displaced in some numbers.

Mr. SCHEUER. Mr. Chairman, if I may add something. I think you have total unanimity here that we have to move into this area. We have no alternative.

What we are trying to do is anticipate some of the problems and roadblocks and see if we can't defuse them.

Taking the automobile industry, you have lost about 300,000 workers, between 300,000 and 400,000 workers now unemployed as a result of plants closing, as a result of lessening demand for this period of time we are going through, and probably as a result of some degree of automation, cybernation, robotics, whatever.

Assuming that the day, hopefully soon, that the automobile industry picks up, and assuming it does become competitive, more competitive than it is now, assuming that at some future date, more than half the cars bought in the State of California are not foreign cars; and assuming that they are now up to speed and assuming that there is a further introduction of robotics, what percentage of this 300,000 to 400,000 people who are unemployed will be brought back into the industry?

What I am trying to suggest is that I agree, looking at Japan's experience, it is quite possible that robotics increases unemployment, but getting it down to the personal level, me, there are some people who, through the introduction of robotics, are disadvantaged and others who are advantaged, and the guy that gets fired may not be the guy who is taken on to one of the jobs that are increasing global competitiveness.

So looking to the roadblocks, what will happen to those 300,000 people or even over the fairly long period when the industry gets back its muscle tone and what do we do about the profile of that industry if it looks as if there is a significant number of them—I don't want to put words in your mouth—but if the answer to that 300,000 is that most are not likely to be reemployed, what do we do about the profile of that typical worker who is unemployed and who is being disadvantaged and who is not likely to be advantaged?

What do we do to get him back in the mainstream and include him in on this surge of progress?

Mr. GORE. Mr. Rosen?

Mr. ROSEN. I think we have been concentrating a lot of time on looking at the motor industry and I would like to make a few comments, what my crystal ball tells me.

I don't believe we are going ever to get back to 10 or 12 million cars a year in this country again. I think it is a mature industry. I know you folks from General Motors don't agree with that, but that is my belief.

I think that the available cars from all the motor car industries all over the world that are competing are going to have much more capacity to produce motor cars than can be used by the general public at the prices that they are going to sell them at.

On the other hand, what do you do with all the huge plants, all the productive facilities, all the skilled people—and they are very skilled—some of the best work force in the world.

I have a crystal ball suggestion about that. These companies are going to have to make other products and maybe the products are going to be robot based. We have only been talking about replacing people in our industries with robots to manufacture goods.

We may follow the example of the agricultural industries where 4 or 5 percent of our working populace produce all our food and then some. It may happen that way in the manufacturing industries.

All the other people are in services, medical, sales, distribution, communications, so forth.

Mr. GORE. Government.

Mr. ROSEN. Government.

Those aren't services.

Mr. GORE. We will discuss striking that from the record.

Mr. ROSEN. Well, I have a feeling that you are going to see robot technology begin to enter the service field perhaps within 4 or 5 years, and require an enormous production of extra things that don't exist today, but will exist.

There is no reason why General Motors, that can produce a car for $5,000 to $10,000 can't produce a beautiful robot for $1,000 to $5,000, a simple one, that can be very useful other than in the manufacturing industries.

It is my prediction that they are going to survive, that is, the car industries, and the jobless people are going to be put back to work but change what they produce. They won't produce motor cars.

Mr. SCHEUER. Thank you very much.

Mr. GORE. One followup question; General Motors recently announced its intention to purchase 200,000 Isuzu automobiles for its U.S. market.

Is it fair to conclude—this goes back to your statement that what costs jobs, robotics or the failure to install robotics—to what extent did the Japanese advance in installation of robots influence that decision?

Mr. BEECHER. I am not sure I understand the question, sir.

Mr. SCHEUER. Well, this relates to the relationship between robotics and job loss. The larger question is if one country doesn't do it, another one will, and the desire to get away from looking at the problem just within the confines of the United States; is it fair to conclude that GM's decision to make this large Isuzu purchase arrangement was at least in part a result of the fact that the Japanese companies were further along in the installation of robots and their manufacturing facilities and as a result, it was more profitable and efficient for GM to get them there as opposed to here?

Mr. BEECHER. I think the most meaningful answer to that is that I, for one—I am sure Mr. Rossol, also—are not privy to that decisionmaking process.

Mr. GORE. Maybe it is an unfair question. I won't pursue it.

Let me——

Mr. SCHEUER. May I ask one further question?

Mr. GORE. Yes.

Mr. SCHEUER. Mr. Rosen, I asked you what percentage of these 300,000 people who are unemployed now, are going to be reemployed by that industry as we say in my district, irregardless of what they produce?

OK? What percentage of this—I am asking you to look at the profile of those 300,000 people in terms of their literacy skills, their numerous skills, ability to read simple job instructions, ability to adapt?

I hope I am overstating the problem and not understating it, but looking at the profile of those who lose their jobs, what percentage of them are going to be reemployed producing cars or producing robots or produce whatever that industry will produce?

They may produce telecommunications, I don't know, a lot of things. I am thinking of the unemployment and I am thinking of the lifetime employment prospects of the young people, particularly, who have been left off.

What are their prospects? How many of them will the industry likely take back, absent any intervention by us, by Government, in retraining, upgrading of skills and is there a role for Government to help?

Mr. ROSEN. There is only one thing one has to know, Mr. Scheuer, and that is how soon our car industry can get back from the 5 million cars up to somewhere where they were before, because in the near term, it will be zero if they can't increase their sales and marketing of the cars.

Mr. SCHEUER. I am asking you to assume they get back to that level of productivity or they produce something else.

Mr. ROSEN. In the near term, the next 10 years, most of them, if you get back to the same levels of sales, I think most of them. Automation won't remove enough people from the working rolls.

The key thing is how many cars are going to be sold in this year made by American manufacturers.

Mr. SCHEUER. Or how many robots are sold?

Mr. ROSEN. The number of robots that can be manufactured in this country in the next 5 years is very limited. No companies, not Cincinnati Millicron, Unimate or any of the new companies can suddenly increase their robot production overnight, they can't. It takes years to double up or triple up production.

Mr. SCHEUER. You are suggesting, as the automobile industry comes back selling to the public——

Mr. ROSEN. All of those people will come back.

Mr. SCHEUER [continuing]. Cars, robots, whatever?

Mr. ROSEN. I am not saying it will come back to 12 million production, though.

Mr. SCHEUER. But assuming they will be back at work, they will be using that plant and equipment in some way.

Mr. ROSEN. Yes, I think so.

Mr. SCHEUER. Will they absorb the 300,000 people that are out of work?

Mr. ROSEN. I think so.

Mr. GORE. The answer is we will have to have a massive job retraining.

Dr. Sanderson?

Dr. SANDERSON. I don't feel I am an expert on the manpower problem, but there were a couple of questions brought out in the program that I would like to have the panel elaborate on.

One of the major points was basically there are two areas of interaction where there is a recognized need for greater research.

One is in what I would call the basic components such as sensors, control systems, programing languages for the computer; another has been a statement that there is a major shortage of people who are really expert in systems, and in application of robots as part of a total manufacturing system.

The universities that we are familiar with are very active in many engineering areas looking at components.

Mr. Rosen named a few institutions that were active and very creative in the systems area. Most of those universities—at least the ones that I am most familiar with—have substantial university-industry collaborative programs, in which industry is actively working with the university to provide the scale of environment in which a system program can be developed.

To what extent do you think industry is going to actively expand its support and interaction with the universities in this area of systems development?

Mr. RADEKE. That is a difficult question. I certainly can't speak for all industry. Certainly from our viewpoint, we have expanded that on a continuing basis and we have even more aggressive plans in the future.

But when we look at the applications in systems, there are two pieces that have to come together. One is the process involved, whether it is metal cutting or joining of metals by spot-welding or arc-welding, one must understand the process being addressed first and then, second, how does the robot, how can it be applied to that process.

There are very few universities that I know that are addressing that type of training at this point.

We do see some training just beginning and when I say "just beginning," I mean within the last 6 months at the vocational school level, not at the engineering level, but it is a down-to-earth, pragmatic "I-am-going-to-use-this-technology" type of approach.

Mr. GORE. Any other witnesses?

Mr. ROSEN. There is damned little, really, in terms of the size of the problem. All the industry-university arrangements can be counted on one hand or two hands, at most.

Yes, they are doing excellent work and they are growing, but the effort has grown from practically nothing to a very, very substantial effort in that field in just a few years.

There are not many Carnegies, not many Stanfords, or MIT's. The size of the problem, you really need an order of magnitude more of that kind going on.

I can't say for sure that there will be the capabilities in the smaller universities that are just beginning to attract that kind of money and support from industry. There has to be a start.

In most cases, graduate schools of these universities have one or two professors who get interested, and they try to get grants from your organization—(NSF)—and from the DOD and that is how they begin. They then attract students and faculty and so on. Very often, they have no facilities.

Even at Carnegie you have to walk around a whole building to see the different projects. The program is not well-centralized; it is hard to acquire buildings and other facilities, let alone robots and other expensive equipment, to get going. So I say there is an order of magnitude less than desired for what is required for this kind of industry-university cooperation primarily because we don't have enough universities that have initiated programs.

Mr. GORE. Mr. Rossol?

Mr. ROSSOL. We work through grants or research work at Stanford, MIT, SRI International, Rhode Island, and a number of other places, and we will continue to do that work.

That may not be as much as Dr. Rosen would like, but we do a substantial amount.

In addition to working closely with a number of universities, we also hire professors as consultants. We get them involved.

Mr. GORE. Thank you very much.

Dr. Chern.

Dr. CHERN. Let me touch on a few points that have been raised.

Let me particularly mention what I call the technology infrastructure. This was not explicitly raised, but the argument goes something like the following.

If you really want to encourage basic research, say a 10-year time scale, the question could be posed that what would happen to the results of that research?

Are they likely to be picked up by other countries, Japan, West Germany, and others, and result in new products marketed by those countries?

Now, the answer in this area is interesting. What one has is a sophisticated technology infrastructure which has arisen in robotics.

There are a number of user and supplier industrial companies which are coming into the area. These companies have rather sophisticated research capabilities and existant R&D groups such as, Cincinnati Millicron, Unimation, IBM, General Electrics, GM, and others.

So you have a unique situation here where there exists the group which will make the machines and the group which will use the machines, as well as possibly make them, available and eager to really draw on the information which is to be developed.

Now, what is interesting is the fact that technology—by that I mean knowledge, understanding of particular things—is best transferred through people and there the role of universities becomes critical because if we are going to develop this type of research, there has to be a significant increase in the number of students that are involved in this in the universities, and will carry the knowledge into industry.

Now, you have coupled with this what is sometimes called the computer culture, a great interest on the part of the undergraduates, as you heard, and graduates in the use of the computer. The computer is going to play a central role in future intelligent robotic systems. So you have a nice system developing where Government-sponsored R&D in a 10-year time scale will propogate through to the industry in terms of products.

So I wanted to mention that explicitly.

Now, one comment. The business about systems of cooperating manipulators. In all fairness, one should say the following, when one asks does one have systems of cooperating manipulators, what you mean is can you get two or more manipulators to interact in real time doing something and modify their operations based on what they find? The answer is I don't think that exists today.

There are significant problems in one manipulator talking to another. You can approximate that problem and it's been done in clever ways. You can divide the work space into two parts and one arm stays in one part of the work space and the other in the other and they cooperate, but they don't cross the boundary.

There are other techniques that one can use.

But the general problem of you taking your two hands and working on something, and based on what is happening, the other arm automatically interacts, that has not been solved.

Except in rather limited circumstances, maybe.

One comment on the robot replacing end people. That is really a difficult problem in the following sense. A robot doesn't replace a person or two people or six people.

A robot is a very limited capability device. People are not.

People have all sorts of sophisticated sensors so when a human being does a job, he is using his eyes, hands, touch, all sorts of operations.

That does not occur when you use a robot. You have to really pre-plan the kind of operation. You have to recognize the fact you have to think it through as you have never done it before.

You can't wave your arms at a robot and tell it do what the guy on the line there is doing. It doesn't work.

You have to very explicitly today program that robot for all contingencies. So it is in a sense fictitious except on the basis of an ROI-type calculation, to say, I can have these robots do the following and this is what the costs will be. But they don't replace people in that particular sense.

I think that is all.

Mr. Gore. Thank you, that is a very helpful addition to the report.

Dr. Strauss.

Dr. Strauss. I would like to ask a question based on the hearing's outlined topics, that is, the first question limitations of present-day robots in relation to industry needs; and what robot capabilities are needed to allow you to penetrate the market.

I would like to pick a specific industry, machine tool industry. What we are seeing is the simple blades and milling machines are coming from places like India and Hungary, the larger machines coming from Italy and Japan, for example.

One problem is why hasn't the machine tool industry automated?

For example, right across the river from Cincinnati, there is a Japanese corporation with an automated machine tool factory which will make machining centers. Will Cincinnati Milacron be able to compete with the foreign machine tool company across the river without robotizing its own plant, and what will happen to the machine tool industry since we seem, for lack of capability of competing with the Third World countries in the central machines and the Europeans and Japanese in the sophisticated machines?

Mr. GORE. We bring these guys in to ask the questions and we are here to ask you to tell him the answer.

Mr. RADEKE. Yes.

It is a complex question, but let's address it.

First, the import of Japanese machine tools are primarily the lower cost units, but we see a trend in the more expensive machine tool areas. We think that will happen.

There are several issues we have to review, one is obviously our company has produced midrange-and-up type of equipment. I think if you look at our more recent product introductions, they are more down the line, as opposed to up the line, not necessarily in performance, but certainly in size.

I think there is no question that we have to robotize and make our operations automatic.

Let me just go back to that one particular Japanese company that you mentioned to give you a feel for what really occurred there.

I happened to visit it, the one you refer to is Yamisaki, and I went through their facility with the president of their company and what they found when they went to automation, the parts they selected which were machine tool bases, specifically in that limited range, although that represents a large part of the product, is that they could not do it.

They found out that they needed something like 600 different tools and there was no way to design any system automatically to manufacture that product. They then dedicated a large portion of their engineer staff to promptly redesign that portion of the product to allow it to be automated.

I think the thing we have to look at when we talk about applications is not only how you process it, but how is the design done to aid the process?

When we look at that issue, it is one that is not very simplistic, saying "I will automate this plant". Certainly those are very gut-level types of actions. They are actions that are current in our industry, certainly within our company.

If you don't do those things it is clear no matter how much you automate or try to automate the process, if the product is not designed to take advantage of the automation you are still in a no-win situation.

The answer is absolutely those are the directions we are going. That does require a great deal of capital, not only in the sense of money, but human resources, to accommodate those problems.

Dr. STRAUSS. Thank you.

Mr. GORE. Do you have other questions?

We are running short on time, but if you have another quick question, Dr. Sanderson?

Dr. SANDERSON. Just one quick one and I think it was prompted by my own visits to some of the Japanese robotics factories and a comment made by one of the earlier witnesses. The comment was that by the time the Japanese put a robot on the market, they have used it for a number of years, know its strengths, weaknesses and know how to design a product so the robot can manufacture it.

In that sense, maybe General Motors is in a better position than Cincinnati Milacron to make a major effort in this direction.

But the other thing that impressed me was the dedicated move toward a fully automated factory which Fujitsu Fannon, for example, had in their own plants.

I am not aware of any similar move towards the automated factory in the United States. That may be beyond the current capability, but that, in fact, does force one to begin to think about designing for manufacturing, the types of actual sensors needed and provides a feedback into the system which the Japanese seem to be generating and we are not.

I don't know who would like to comment.

Mr. RADEKE. I happened to visit that plant, also.

I think there is something you have to look at in reviewing the automation of factories. I think Paul Aron's put his finger on it accurately in the previous testimony.

But in the Japanese production, they take a very pragmatic approach. They rate their speeds and feeds where they get into production like the auto industry which says the issue is how many parts do I put on the floor that are good parts per shift, as opposed to how many seconds it takes to produce this part?

It is a totally different way of viewing the problem. Those systems, and I certainly do not in any way mean to detract from their capability and their capacity for producing good solid products, certainly they are not ultrasophisticated systems in the way we would view them.

There is no question that that is the direction they are going. They are doing heavy work in the area of sensors to be incorporated. But what they did not do was say "I am going to wait for the final panacea before taking my first step."

They have taken a pragmatic approach and I consider a successful approach.

Mr. GORE. Mr. Rossol, Mr. Beecher?

Mr. BEECHER. No, sir, I agree with that entirely.

Mr. GORE. Well, thank you very much, gentlemen.

I appreciate your testimony. The subcommittee thanks you. Thank you very much.

Mr. RADEKE. Thank you very much, Mr. Chairman.

Mr. GORE. Our final panel is Dr. Daniel Berg of Provost for Science and Technology at Carnegie-Mellon in Pittsburgh; Dr. Bertholt Horn with the Artificial Intelligence Laboratory in Cambridge, Massachusetts; and Dr. Delbert Tesar, director of the Center for Intelligent Machines and Robotics, Mechanical Engineering Department of the University of Florida in Gainesville.

Dr. Berg, we would like to begin with you. I notice several references have been made to Carnegie-Mellon already, you may wish to correct or modify some of those, but we are most interested in your testimony.

Please proceed.

STATEMENTS OF DR. DANIEL BERG, PROVOST FOR SCIENCE AND TECHNOLOGY, CARNEGIE-MELLON, PITTSBURGH, PA.; BERTHOLT HORN, ARTIFICIAL INTELLIGENCE LABORATORY, CAMBRIDGE, MASS.; AND DELBERT TESAR, DIRECTOR, CENTER FOR INTELLIGENT MACHINES AND ROBOTICS, MECHANICAL ENGINEERING DEPARTMENT, UNIVERSITY OF FLORIDA

Dr. BERG. I hope I have time to rebut everything that was said. Thank you, Mr. Chairman, and members of the subcommittee. I am Dan Berg, provost at Carnegie-Mellon. I am also professor of science and technology and cofounder of our own Robotic Institute. Perhaps most importantly, I am an active researcher in the sensory part of our institute's work.

I want to make just a few points based on our experience.

First of all, the kind of robots that we work with at our university are the intelligent robots, what we call the see, think, and act robots. They have sensory capacity; they have the "ability" to think; that is, they can take the data that the sensors have accumulated, and can make some sense out of it. They can make some perception of what is going on, and can actually make decisions based on the information they receive. Based on the decision, there will be an action on the part of the robot. With some of our major advanced robots, the robot will actually learn from the action it took whether that action made sense; it will put it in its data base and remember it for the future.

Now, this kind of robot with sensory capacity does not necessarily have to be an arm, nor does it have to be an R2D2 kind of robot. That is, the sensing, intelligence, and action functions can be separate. It can be a distributive robot. The sensor can be in one city, the intelligence can be in another city, and the action can take place in yet a third city thousands of miles away.

To highlight and respond to the subcommittee's questions, the areas of basic research that we think are vital include: artificial intelligence techniques, primarily in the areas of knowledge representation and acquisition; planning and problem solving, model analysis, and use interphases; contact-sensing and recognition on the part of the robots; autonomous and semiautonomous rover robots for working in hazardous environments; and robotic approaches to the assembly of batch-produced parts and materials processing and manufacturing.

From a different perspective, basic research is needed on the societal impacts of and policy issues surrounding robotics. In that regard, I do want to state that in combination with our Robotics Institute, we recently established an industry supported center at Carnegie-Mellon which has the function of bringing together our engineering and public policy groups, our social scientists, business school, et cetera, to focus on the societal impacts of and policy issues surrounding robotics and industrial automation.

To turn to the question of the role of universities, as we all understand, there are a variety of different kinds of universities. I think perhaps all of them do play a role in the training and education of a variety of people, some technical, some scientists and engineers, some managers, some social scientists, and the public in general.

As an aside, I want to point out in response to what was said before that at Carnegie-Mellon, we have established a dual option in manufacturing in belated recognition of a great lack in the educational process. In our mechanical engineering department, we have established an undergraduate manufacturing option. At the same time, in our business school, we are providing an option in manufacturing to our master's students.

The universities fulfill other roles besides those of training and education. Clearly, there are a variety of universities involved with research, a topic which we will discuss in more detail later. Another role, one that Dr. Chern touched on, involves technology transfer. CMU has found that effective robotics research requires not only Federal, industrial, and internal financial support, but also the active operational involvement of sponsors. This latter need derives from the necessity for workplace testing of ideas and developments evolving from our research. Consequently, we have found it to be absolutely necessary to involve industry in this technology-transfer mechanism, not only because industry is a source of resources, but also because they are a test bed for the kinds of things we are working on.

At CMU we have industrial people spend time at our Robotics Institute and have our researchers spend time at industrial sites. It is really more of a partnership in much of what we do, rather than the normal grant arrangement. Our industrial agreements also reflect several levels of cooperative arrangements with industry and with other significant supporters of the research. We have in some cases given up patent rights and software rights to industrial funders. At the same time, in order for the university to function in its proper mode, the industrial groups have let us maintain the rights to publish the material we develop in this work. Consequently, we, as a university, think we have retained what is crucial to us, and given to the industrial group what is crucial to them.

Finally, with regard to the question of the role of the Government, I think the role is multifold. I think, clearly, just as this subcommittee is serving a very useful function in creating public awareness, understanding and support, I think the Federal Government can clearly play a role in leadership, in research and development strategy, and in grants and contracts to support key areas of research. Also, I think the Federal Government can play a crucial role in establishing public policy and focussing on societal issues. I want to support the point that I believe was made this morning by Congressman Scheuer, that it is absolutely critical in this country that we have a scientifically and technically educated citizenry. I do not mean scientists and engineers, but I mean a citizenry that appreciates and understands the role of science and technology.

I think I will stop at this point. Thank you.

[The prepared statement of Dr. Berg follows:]

Proposed Testimony of Dr. Daniel Berg, Provost for Science and Technology, Carnegie-Mellon University, before the Committee on Science and Technology, U.S. House of Representatives, June 2, 1982.

My name is Daniel Berg. I am Provost of Carnegie-Mellon University (CMU).

As we've just heard, robotics and advanced information systems can play - will play - a central role in our future. The size, shape and impact of that role is still being determined by the groups represented here today. The research and development needed to support this process requires a long term, coherent, multidisciplinary approach. The university has both the ability and responsibility to develop new technologies, and to step back and look at them whole: to see how they can be developed and implemented, and to explore if they should be. If up until the recent past the potential of robotics has not been realized in the United States, part of the blame must rest with universities in creating neither research centers to produce the new technologies and to explore their impacts, nor training centers to produce the trained work force.

That is not true currently. With government and industry, universities are developing a research agenda and implementation priorities. In the process, we have also explored the most effective way to support and structure our on-going collaborative efforts.

The Research Agenda

The research agenda is a complex, multifaceted one. It includes basic and applied research and the actual implementation of robotic systems. Its potential impact on areas of our lives extends from manufacturing through office automation, undersea exploration, mining, space exploration and medical applications.

In basic research we must investigate and develop

1. robotic related soft and hardware including:
   - artificial intelligence techniques, primarily in the areas of knowledge representation and acquisition, planning and problem solving, model analysis, and user-interfaces;
   - techniques for visual non-contact sensing and recognition on the part of robots, primarily through reflected light sources (infra-red, x-ray and other electromagnetic radiation) and other sensor systems (tactile sensors, laser sensors, acoustic sensors, and chemical sensors);
   - techniques and hardware for autonomous and semi-autonomous robot rovers; and
   - robotic approaches to the assembly of batch-produced parts and materials processing and manufacturing;
2. impact and policy studies, and supporting analytic techniques:
   - to guide technology choice and implementation;
   - to investigate the robotic related problems faced by individuals;
   - to investigate human resource issues in manufacturing;
   - to investigate alternative organizational structure;
   - to identify institutional options and devise policy strategies;
   - to analyze broader economy-wide issues;
   - to study technology, trade and international competition; and
   - to conduct technology assessments of advanced robotic applications.

CMU Robotic Research Priorities

At Carnegie-Mellon University, the priorities of and unifying elements in our robotic research are artificial intelligence, computer science and sensor based systems. Artificial intelligence research began at Carnegie-Mellon in the 1950's with research into the processes of reasoning and decision making. Current research priorities in artificial intelligence include knowledge representation and acquisition, planning and problem solving, model analysis and expert systems. Carnegie-Mellon University's Computer Science Department, one of the top three in the nation, works jointly with the Robotics Institute in the areas of developing more graceful interactions between men and machines in programs approaching natural language, in developing new languages well suited to programming complex processes with multiple machines, and in developing programs that vastly increase the speed of information anlysis. Carnegie-Mellon University's robotic related sensor based systems research involves the development of novel uses of multiple sensors to monitor the environment and performance of machines; and the development of sensor based systems that enables adaptive control of the machines.

It is of vital importance that this research agenda be joined to an educational program that will produce the work force necessary to enhance and sustain it. Engineers, scientists, managers, technicians, policy analysts, and social scientists are needed. Of equal importance is a diversified, skilled labor force to maintain robotic systems. An important part of this work force must be people who, through a combination of sound fundamental knowledge and skills, and hands-on field experience, understand and can manage technological change.

University/Industry/Government Cooperation

It becomes increasingly obvious as we talk that none of us can do this alone. Each of us by ourselves do not have the comprehensive insight, skills, data, analytical tools, and insititutional environment, that will allow us to develop and improve robotic technology, and to anticipate, understand and learn how to manage the economic and social impacts of robotic and advanced information system technologies. Industry has experience in the practical problems of undertaking and managing technological change in the production environment. Industry and labor organizations have their respective experience with the human resource and organizational aspects of implementing these changes. Universities have the technical expertise, the knowledge, analytical tools and institutional environment that are necessary to generalize such specific industry experience into broader understanding. Government has the power to affect public and private sector policies through its own social and economic statistical data and mechanisms for distributing information. To repeat, none of us will be very successful without the others.

What are effective ways to carry out what is inherently a collaborate effort? We at Carnegie-Mellon University have developed both internal administrative arrangements and an external system of linkages that has proven worthwhile. Internally, our key concerns were to create an organization that encouraged collaboration and free exchange between faculty and students and among the disciplines, and that integrated the various functions that had to be performed (basic and applied research, systems development, teaching, and hands-on implementation). To this end, the Robotics Institute was created. Its objectives are to solve fundamental and applied problems of robotics science through scientific and engineering research; to encourage and assist the transfer of robotics from the laboratory to industry; and to train engineers and scientists for the further development of the field. Institute staff include both CMU faculty and full time researchers. The faculty involved are primarily from Engineering and Science, though faculty from the Social Sciences, Industrial Administration and Operations Research also play a significant role. All faculty retain departmental and college affiliation. Departmental and cross departmental courses have been developed that reflect the research on-going at the Institute. Both undergraduate and graduate students study and do research at RI while maintaining membership in the University department from which their degree will be granted.

Externally, our concerns were to create linkages with government and industry that would promote and protect the exchange of ideas, knowledge and experience; that would produce research relevant to the needs of industry; that would be economically fair and potentially profitable to all parties; and that would provide the level and length of support necessary to carry out robotics research. We approach research relevancy and information

The Government's Role

A successful program in robotic research and development will require a nucleus of continuing support around which a long term coherent program of investigation can be built and to which separately funded studies can be selectively added as opportunities arise. We are approaching multiple sponsors in both government and industry for both long and short term funding.

We believe government can be most supportive in achieving our joint goals:

- by creating general public awareness, understanding and support of the potentials of robotics;
- by creating a network of both legislative and agencies policies and regulations that encourage the growth and development of the robotic industry; and
- by providing individual grants and contracts to support key areas of research, perhaps not readily applicable to specific industries or concerning public policy or societal issues.

I look forward to our continuing discussion.

Mr. GORE. Thank you very much. Dr. Bertholt Horn is from the Artificial Intelligence Laboratory in Cambridge.

Dr. Horn, we are most pleased to have you. Please proceed.

Dr. HORN. I am, as you stated, from the Artificial Intelligence Laboratory, which has been engaged in robotics research for about 17 years. There have been many ups and downs in those 17 years.

One of the points I would like to make is that research funding is needed, but we have lost a good number of researchers as a result of the fact we only had three short periods of strong interest in robotics.

Altogether, I would like to make five points. One is that robots are not applied widely, in part because they are not widely applicable. Their current capabilities are limited.

The second point is that further progress is not just a matter of engineering development, not something that can be carried out by modifying an electric motor or attaching a micro processor.

The third point is that there are deep scientific issues we have to raise in robotics. I think the universities can play a role in addressing those scientific issues.

The fourth point is the one I have mentioned, that I feel that only steady support of the basic research can encourage progress in that area.

The final point, I think there should be ways of supporting the development of application of robotics in industry by various mechanisms such as perhaps reform of the patent laws. I would like to review the state of the art in robotics and along with Dr. Berg, point out that the kind of robot I am interested in has three subsystems, one of which is the mechanical factor; one of which is the reasoning part, or planning part; and one of which is the sensors which allow it to adapt to changes in the environment.

It is certainly true that we can do more in applying the technology we already have, but we must make a firm basis for future applications. The kind of things that are being put into use now are things which were developed in research laboratories like SRI–10, 15 years ago.

We have to continue to supply a stream of new ideas and new concepts by working on basic research in the universities. The present day robot as far as the mechanical part is concerned, has a multi manipulator as you saw in the film, which has either electric or hydraulic actuators. Invariably, it has special purpose groups which have to be redesigned for each application.

Control systems are very simple, they are based on traditional industrial control systems. The nature of programing them is typically to teach by showing method, which is fine if all you want to do is have the robot repeat indefinitely the same motion. There are now a few simple programing languages which allow you an alternative means of programing the robot.

On the sensing side at the moment, all we have are simple switches which allow you to take where the part has arrived at the feeder and maybe some scanners which allow you to follow a seam in welding. But the vision side is highly deficient. There is a lot that needs to be done.

As was pointed out earlier, vision is a very difficult process. And it is certainly going to take some time to tackle the deep issues of inverting the process of imaging the three-dimensional world on to the two-dimensional image.

The current research area we are engaged in, first on the manipulator side, include designing manipulators for assembly. Present day manipulators are very good at picking up a part and putting it down somewhere else. For this they need to have position and velocity controls.

In assembly, the parts interact and a force is created. What is more important than position control is control of the appliance, how the manipulators adjust to the forces created. This has implications for the programing and for the design of the manipulator.

Secondly, we would like to get away from the need to design it for every task. Part of the robot's beauty is that it is supposed to be easily reprogramable for a new task. Yet, at the moment we are faced with making a new gripper for every job. So we and other universities are interested in studying dextrous multifingered hands with tendons much like our own hands.

One of the shortcomings of today's robots is that they are too slow, was mentioned by a previous witness. Part of the reason is that the control systems that are used are very simplistic. They are not too slow because the strength of the materials is not there, they are not too slow because the motors are not powerful.

They are too slow because the control systems fail at high speeds. We have done some work on improving that, using computational methods. On the thinking third of the robot, we have been interested in developing systems which can reason about objects and space. At the moment, the way you teach a robot is either to lead it through the motions or to program it by detailed analysis, saying move 1 inch to the right and 2 inches down.

It is clear that this will be an obstacle in reprograming at the end of the year. When a new model comes in you will spend a month just trying to reprogram the manipulator. One way out is to program in terms of the task rather than detailed manipulator motions. You might say test part A on part B. Assuming the computer has representations for these parts, it can then figure out where to pick one part up so it can place it on the other part and also determine its trajectory, where it would not bump into something else.

In terms of the thinking about objects and space is quite hard, even though we have no trouble with it. So it is a little bit confusing.

For example, it is very hard to understand why vision should be hard. We are so good at it. We find the same problem in spacial reasoning. It is quite difficult to teach a computer to think about paths and objects. We also find a need to deal with inaccurate parts positioning. That can be dealt with in a number of ways.

One is to have, giving the compliant manipulator, which has springiness built into it, so it will adjust to a certain degree to inaccurate parts positioning. Another way is to use sensing techniques, in particular vision. As Mr. Rossol pointed out, we have systems which can look on conveyor belts and determine exactly where a part is. Or in our case, we developed a system 7 years ago which allows you to look at a circuit chip and orient it so you can automatically bond the leads to it.

There are yet other methods. For example, if I had this ash tray coming down a conveyor belt, I could alien it simply by having a gage across the belt. As the belt pushes it, it will automatically achieve a certain position of orientation. I can do the same with a manipulator hand.

So in some cases, I can avoid the need for sensing simply by looking at the problem of the interaction of the part with the manipulator.

This kind of scientific approach has been neglected. People have mostly felt that, well, we take a mechanical system, hook up some motors to it, and add several microcomputers and away we go. I think future progress will depend on analyzing the physics of these interactions and of the image formation, then building mathematical models based on that and building algorithms on the mathematical models.

I think that is somewhat obliterated by the typical Businessweek article where it looks like you take your home computer and hook up a vacuum cleaner motor and you have robotics. In fact, we find this a problem in attracting students because they do not yet understand that there is real science to be done in robotics.

Some of the problems we have had in the field related to this difficulty of uneven funding, we have been interested in robotics for a long time. Only in a few spurts have we been able to attract funding. The result is that some of the better people have gone off to do other things.

The result now is that the country has a very small number of knowledgeable people. I think this is one of the big differences with Japan. There are a very large number of people, perhaps not in the most sophisticated technology, but people who are used to working with robots. We do not have that.

A side issue there is that there is a huge salary disparity between the universities and industry, which causes the few people we have to be siphoned off. The few groups which have attained critical mass to do research are being disbanded.

Now we have a number of companies that have perhaps one roboticist who is able to educate management about robotics, but not actually able to do any real research. The relationship between universities and industries I see as follows.

First I think the university is the appropriate place to carry out the basic research, not tied to next year's model. And with the wonderful resource of bright, young students coming in, able to work on these problems.

A second problem we have is in educating students. These will be the future users of systems, and in some cases, designers of systems. The interest is enormous. My undergraduate course which has been going for 7 years has 80 percent enrollment this year. However, six or so universities teaching 60 students each is nothing compared to what we need.

There is a real need to rapidly expand education at more and more universities in this area. We also run short summer courses attended by engineers who are the current users to try to fill the gap. These are also very well attended.

I guess other roles are things like writing textbooks and editing journals. Only recently are there good journals in the field where you do not find yourself looking through 20 different publications to try to find research on robotics.

Industry's role includes carrying out applied research, and identifying real problems for us. In many cases, universities end up working on things which are toy problems, which are not really significant. On the other hand, in other cases we find industry gives us conflicting signals.

For example, the famous bin of parts problem which was mentioned earlier. In some industries, this is considered the ultimate, the most important thing to work on. If you can take a bin which has parts lying on top of each other, all of the same type, say, and you can pick things out of there with the robot, then you have done a great service to them.

Yet other industries say, well, this is not a problem because we can palletize them and keep them precisely oriented. I think it is a little bit a matter of semantics. Namely, if you can throw them all in the box the way we do now for people, you have a cheaper system. Sure, you can palletize them but the pallet will cost you a fortune, and take up a lot of space and not be nearly as convenient.

Another role of industry is to take the methods that have been proposed and see whether they really are robust enough to apply in practice. As was pointed out, we are not really in a position to work on these things. Among other things, students would like to develop theses which are typically more cost-related to research than they are to developing a particular solution.

Interaction between universities and industry is quite strong. It includes visitor exchange programs. For example, at the moment we have a program which we call the "Year of the Robot" where in order to again rapidly increase our research in robotics, we have invited industrial visitors to come in and work with us for a year on problems of mutual interest.

I have mentioned the intensive short courses that we provide, and also Lothar Rossol mentioned the intense consulting interactions between industry and universities which are very useful in keeping us on the straight and narrow as far as working on real problems is concerned. And in some cases, industry of course has helped fund the research.

As far as the role of the Federal Government is concerned, I think the most important is in terms of steady funding of the research. I think that the sort of on and off again funding we have seen in the past is not really conducive to developing the field very well. It needs to be somehow organized and kept at a steady level.

Then, also to encourage industrial application, there are many ways to do it. Obviously I am the wrong person to talk about it, but many things come to mind. Obviously there are tax incentives, writeoffs. For example, at the moment most of the inventions in the field are hidden, buried in side products because there is no way of protecting them in the patent field. Therefore this knowledge is not fully developed.

There are many cases in which I have come across systems which include really innovative ideas, but I could not use those results because they were part of some proprietary product. If it was possible to patent some such products, I think it would be much better for everyone.

Well, I think that the point I want to end on is my feelings when I visited Japan. I found that in terms of share numbers they are ahead. But what was the most startling thing to me was the way we have embraced this technology. They are not arguing about it any more.

I have spent years arguing about it. They have just decided let's go with it. There is a spirit out there that you go ahead and even applied in cases where it does not make economic sense right away, just so you can learn.

In many ways they have gained an advantage on us just because of that. Thank you.

[The biographical sketch and attachments of Dr. Horn follow:]

1. Full Name: Berthold K. P. Horn

2. Date of Birth: 1943 December 8

3. Citizenship: German

4. Immigration Status: Permanent resident

5. Education:

School	Degree	Date
University of the Witwatersrand	B. Sc. (Eng.)	Dec. 1965
M. I. T.	S. M.	June 1968
M. I. T.	Ph. D.	June 1970

6. Principal Fields of Interest:

(1) Machine Vision & Visual Perception.
(2) Machine Manipulation & Productivity Technology.
(3) Spatial Reasoning & Expert Problem Solving.

7. Employment prior to M. I. T.:

Employer	Position	Beginning	Ending
University of the Witwatersrand	Junior Lecturer	Jan. 1966	Aug. 1967
University of the Witwatersrand	Lecturer	Jan. 1971	Dec. 1971
Perseus Computing	Software Manager	Feb. 1972	June 1972

8. History of M. I. T. Appointments:

Rank	Beginning	Ending
Instructor (Mathematics)	Aug. 1970	Dec. 1970
Research Associate	July 1972	Jan. 1973
Assistant Professor	Jan. 1973	June 1976
Associate Professor (without tenure)	July 1976	June 1979
Associate Professor (with tenure)	July 1979	---

9. Consulting Record:

Firm	Beginning	Ending
Randfontein Estate Mining, R. S. A.	Nov. 1963	Feb. 1964
Institute of Oceanography, R. S. A.	Dec. 1965	Aug. 1966
H. H. O. Civil Engineering, R. S. A.	Dec. 1966	May 1967
Aircraft Operating Company, R. S. A.	Jan. 1967	June 1967
Anglo American Corporation, R. S. A.	Apr. 1967	June 1967
University of Sussex, U. K.	Sep. 1972	Nov. 1972
National Retail Food Stores	Oct. 1972	Mar. 1973
Schlumberger	Dec. 1972	Mar. 1973
General Motors Research Laboratories	Dec. 1974	---
Mass. General Hospital	June 1975	July 1976
Texas Instruments	July 1975	Jan. 1976
Applicon	Sep. 1975	Nov. 1976
Butler	Jan. 1976	Dec. 1978
Federal Highway Administration	Apr. 1977	June 1977
Information International Incorporated	May 1977	Nov. 1977
N. A. S. A.	June 1977	Sept. 1979
Optronics	Dec. 1977	Mar. 1978
Jet Propulsion Laboratory	Nov. 1978	Nov. 1979
Texas Instruments	July 1979	Dec. 1979
Elscint	July 1979	July 1981
Textron	Feb. 1980	Mar. 1980
Stocker & Yale	Nov. 1980	Nov. 1981
National Enterprise Board, U. K.	Dec. 1980	Mar. 1981
ASEA	Feb. 1981	Dec. 1981
Automatics	Sep. 1981	---
Bridgeport	Oct. 1981	---

10. Awards Received:

Award	Date
First Prize: Individual Student Project. South African Association for the Advancement of Science.	Dec. 1961
Gold Medal & Scholarship: Best non-mining Student. South African Chamber of Mines.	Dec. 1965

11. Current Organization Membership:

Organization	Offices Held	Dates
Society for the Protection of Wildlife	Jan. 1966	---
SIGMA XI	Aug. 1968	---
S.W.A. Wissenschaftliche Gesellschaft	Jan. 1979	---
Boston Mycological Society	Sep. 1981	---

12. Patents and Patent Applications Pending:

1. B. K. P. Horn, "Tomography X-ray Detector," U. S. Patent 4,110,621. 1978 August 29.

Publications of Berthold K. P. Horn:

1. Books

(1) P. H. Winston & B. K. P. Horn, *LISP*, Addison-Wesley, Reading, Massachusetts, 1981.

2. Papers in Refereed Journals

(1) Horn, B. K. P., "Fitting non-harmonically related sinusoids" Appendix I of "Recent Developments in Tidal Analysis in South-Africa," by A. M. Shipley, *International Hydrographic Review*, Monaco, April 1967, pp. 66–70.

(2) Horn, B. K. P., "Artificial Intelligence — a little vision on the real world," *Systems/Stelsels — Bulletin of the Computer Society of South Africa*, Johannesburg, Vol. 1, No. 4, March/April 1971, pp. 10–15.

(3) Leigh, R. A., Van Blerk, P. J. P. & Horn, B. K. P., "Lymphocytic Infiltration in Bladder Cancer," *South African Medical Journal*, Capetown, February 1973, pp. 192–194.

(4) Horn, B. K. P., "A New Machine Organization — something to look forward to," *Systems/Stelsels — Bulletin of the Computer Society of South Africa*, Johannesburg, Vol. 3, No. 4, July/August 1973, pp. 6–12.

(5) Horn, B. K. P., "The Legacy of a Poor Formalism — a tree is not the key," *Systems/Stelsels — Bulletin of the Computer Society of South Africa*, Johannesburg, Vol. 3, No. 5, September/October 1973, pp. 6–10.

(6) Horn, B. K. P., "Determining Lightness from an Image," *Computer Graphics and Image Processing*, Vol. 3, No. 1, December 1974, pp. 277–299.

(7) Horn, B. K. P., "A Problem in Computer Vision: Orienting Silicon Integrated Circuit Chips for Lead Bonding," *Computer Graphics and Image Processing*, Vol. 4, No. 1, September 1975, pp. 294–303.

(8) Horn, B. K. P., "Circle Generators for Display Devices," *Computer Graphics and Image Processing*, Vol. 5, No. 1, June 1976, pp. 280–288.

(9) Hinder, R. A., Horn, B. K. P. & Bremmer, D. G., "The Volumetric Measurement of Gastric Emptying and Gastric Secretion by a Radio-Isotope Method," *The American Journal of Digestive Diseases,"* Vol. 21, No. 11, November 1976, pp. 940–945.

(10) Horn, B. K. P., "Understanding Image Intensities," *Artificial Intelligence,* Vol. 8, No. 2, April 1977, pp. 201–231.

(11) Horn, B. K. P., "Rational Arithmetic for Minicomputers," *Software Practice and Experience,* Vol. 8, No. 2, March/April 1978, pp. 171–176.

(12) Horn, B. K. P., "Density Reconstruction Using Arbitrary Ray Sampling Schemes," *Proc. of the I. E. E. E.,* Vol. 66, No. 5, May 1978, pp. 551–562.

(13) Raibert, M. H. & Horn, B. K. P., "Manipulator Control using the Configuration Space Method," *Industrial Robot,* Vol. 4, No. 2, June 1978, pp. 69–73.

(14) Horn, B. K. P. & Bachman, B. L., "Using Synthetic Images to Register Real Images with Surface Models," *Comm. of the A. C. M.,* Vol. 21, No. 11, November 1978, pp. 914–924.

(15) Horn, B. K. P. & Woodham, R. J., "Destriping LANDSAT MSS Images using Histogram Modification," *Computer Graphics and Image Processing,* Vol. 10, No. 1, May 1979, pp. 69–83.

(16) Horn, B. K. P. & Sjoberg, R. W., "Calculating the Reflectance Map," *Applied Optics,* Vol. 18, No. 11, June 1979, pp. 1770–1779.

(17) Horn, B. K. P., "Fan-Beam Reconstruction Methods," *Proc. of the I. E. E. E.,* Vol. 67, No. 12, December 1979, pp. 1616–1623.

(18) Horn, B. K. P., "Hill-Shading and the Reflectance Map," *Proc. of the I. E. E. E.,* Vol. 69, No. 1, January 1981, pp. 14–47.

(19) Ikeuchi, Katsushi & Horn, B. K. P., "Numerical Shape from Shading and Occluding Boundaries," *Artifical Intelligence,* Vol. 16, No. 1-3, August 1981, pp. 141-184.

(20) Horn, B. K. P. & Schunck, B. G., "Determining Optical Flow," *Artificial Intelligence*, Vol. 16, No. 1-3, August 1981, pp. 185-203.

3. Proceedings of Refereed Conferences

(1) Horn, B. K. P., "Towards a Science of Image Understanding," *Proc. 5th Int. Joint Conf. on Artificial Intelligence*, Cambridge, Massachusetts, 1977 August 22–25, pg 648.

(2) Horn, B. K. P., "What is Delaying the Manipulator Revolution," *Proc. of the N. S. F. Workshop on the Impact on the Academic Community of Required Research Activity for Generalized Robotic Manipulators*, Gainesville, Florida, 1978 February 8–10, pp. 260–265.

(3) Horn, B. K. P., "VISION," *Proc. AISB/GI Conference 1978*, Hamburg, West-Germany, 1978 July 16–20, pp. 147–163.

(4) Horn, B. K. P. & Woodham, R. J., "Landsat MSS Coordinate Transformations," *Proc. Conf. on Machine Processing of Remotely Sensed Data*, Purdue University, West Lafayette, Indiana, 1979 June 27–29, pp. 59–68.

(5) Ikeuchi, Katsushi & Horn, B. K. P., "An Application of Photometric Stereo," *Proc. 6th Int. Joint Conf. on Artificial Intelligence*, Tokyo, Japan, 1979 August 20–23 pp. 413–415.

(6) Horn, B. K. P., "Derivation of Invariant Scene Characteristics from Images," *AFIPS Conference Proc.*, Vol. 49, National Computer Conference, Anaheim, California, 1980 May 19–22, pp. 371–376.

(7) Schunck, B. G. & Horn, B. K. P., "Constraints on Optical Flow," *Pattern Recognition and Image Processing Conference*, Dallas, Texas, 1981 August 3–4.

4. Other Major Publications:

(1) Horn, B. K. P., "Three Dimensional Reconstruction from Two Dimensional Brightness Distribution," Section 8.5 in *Foundations of Cyclopean Vision*, Julesz, B., Univ. of Chicago Press, Chicago, 1971, pp. 283–285.

(2) Horn, B. K. P., "Determining Shape from Shading," Chapter 4 in *The Psychology of Computer Vision*, Winston, P. H. (Ed.), McGraw-Hill, New York, April 1975, pp. 115–155.

(3) Horn, B. K. P. & Winston, P. H., "Personal Computers — end of the time-sharing era?" *DATAMATION*, May 1975, pp. 111–115.

(4) Horn, B. K. P., "Death is a four gene mutation," *Journal for Irreproducible Results*, Vol. 22, No. 3, 1976, pg 23.

(5) Horn, B. K. P., "Artificial Intelligence and the Science of Image Understanding," pp. 69–77, in *Computer Vision and Sensor-Based Robots*, G. G. Dodd & L. Rossol (Eds.), Plenum Press, 1979.

(6) Horn, B. K. P. & Bachman B. L., "Registering Real Images Using Synthetic Images," pp. 129–160, in *Artificial Intelligence: An MIT Perspective*, Vol. 2, P. H. Winston & R. H. Brown (Eds.), MIT Press, 1979.

(7) Horn, B. K. P., "Kinematics, Statics, and Dynamics of Two-dimensional Manipulators," pp. 273–310, in *Artificial Intelligence: An MIT Perspective*, Vol. 2, P. H. Winston & R. H. Brown (Eds.), MIT Press, 1979.

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THE UNIVERSITY'S ROLE IN THE DEVELOPMENT OF ROBOTICS

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STATE OF THE ART IN ROBOTICS

Industrial robots have not yet fulfilled there apparent promise of greatly improving industrial productivity. Why? The answer is that they are still very limited in their capabilities.

Today's industrial robots are mechanical manipulators consisting of rigid links attached to each other at joints driven by electrical or hydraulic motors. At the business end of the manipulator there is usually a special purpose gripper. Joint angles and velocities are relayed back to simple control systems, one per joint.

The manipulator is taken through a sequence of motions by a person using push buttons on a teaching pendant. These motions can then be repeated indefinitely. More recently, simple programming languages have been intrdouced which provide alternate means of specifying the tasks to be performed.

Sensing of the presence of a part in a feeder may be performed using a simple switch, and the sequence of motions delayed if necessary. The outputs of other such binary sensors may cause the manipulator to follow different sequences of motion depending on the type of part. Special purpose scanners may allow the manipulator to follow a feature on the surface of an object, as is required in seam welding. Images of high contrast between object and background, in which the information is essentially two-dimensional, can be processed by binary image processing systems to determine the position and orientation of an object. In this way, a manipulator can pick a part from a conveyor belt even when it is not exactly in the pre-programmed position.

Typically the industrial robot is limited to repeating exactly the sequence of moves taught, unable to adjust to errors in parts positioning or small errors in its own motion. While suitable for transferring parts from one place to another, it is not good at assembly operations. Present day hands are specialized devices which are usually able to grip only certain classes of objects. Often an industrial robot is also limited by its simple control system to speeds of motion lower than its mechanical structure would allow.

PRESENT RESEARCH AREAS

EFFECTORS:

In parts transfer the ability of a manipulator control system to follow a trajectory through space is of paramount importance. In assembly however the detailed motion after parts meet must be determined by how they conform. In this situation control of forces is more appropriate than control of position. One wants to be able to adjust the springiness or compliance of the gripper. This has implications for the design of the manipulator as well as the system controlling it and the way it is programmed.

A big advantage of the industrial robot is the fact that it can be easily reprogrammed for another task. Something which runs counter to this is that the specialized grippers now used have to be designed afresh for each application. Dextrous multi-finger hands with tendon actuation are needed.

Present day manipulators cannot deal with errors in parts position and must therefore have accurate parts feeding mechanisms. These special purpose devices again run counter to the otherwise easy reprogrammability of robotics systems. One way to deal with uncertainty in the positioning of the parts being manipulated, is to sense where the part lies in the hand. A sense of touch requires more than simple on-off switches however. The tactile sensor must have spatial resolution and be able to measure the forces applied.

For rapid moves, interactions between the rigid bodies constituting the manipulator become important, as do centrifugal and Coriolis forces. Manipulators with one simple control system per joint cannot deal with these effects. The speed of operation is therefore artifically restricted to one which the control system can handle. A manipulator able to perform a move more rapidly can carry out more operations per year and will be correspondingly more attractive to the user.

PLANNING:

Today industrial robots are programmed by specifying their motions. If a different manipulator is used for the same task a totally different program is needed. A great deal of effort goes into specifying detailed motions in terms of distances and angles. It would be much more convenient if these devices could be programmed in terms of the task to be accomplished. The programming languages needed for this are entirely different from the simple ones existing now. It would be very useful if the programming system could carry out some of the spatial reasoning operations associated with path planning for example.

Existing methods also do not provide for the programmed application of forces, since they concentrate entirely on position. For assembly operations the compliance of the arm must be controlled. Another difficult issue is the control of two manipulators cooperating on some task. Often, for example, a fastener, to be used for holding parts of an assembly together, has two parts which can only be brought into position using two manipulators.

One need not always sense where a part is to deal with uncertainty in its postion. One can employ a motion which automatically aligns the part relative to the hand just by sliding the part on its supporting surface. Work is needed to automatically come up with such alignment strategies.

SENSORS:

Measuring the forces when the hand touches an object is not enough. The information has to be interpreted to determine what it implies about the position of the object within the hand.

Vision is our most powerful sense. It is also the most complex. It is not surprising then that only very crude vision systems have been developed so far. The simple binary image processing systems now available work only in very restricted situations. Much needs to be done to further develop methods which allow manipulator systems to deal with uncertainty in parts position. Machine vision also holds promise for certain inspection tasks, such as for surface finish and to check for the presence of a componenet of an assembly.

Systems which reason about the motion of objects through space need to represent these object and the space between them. Sometimes suitable models for the objects can be derived from the computer-aided-design (CAD) systems used to design those objects. In other cases it may be more convenient to develop the model based on showing the object to a machine vision system.

SUMMARY:

While further work is needed on the hardware of manipulators, grippers and sensors, the key problems are in the area of software. The programs cannot be written however until the basic algorithms are developed. This in turn requires a thorough understanding of the physics of the interaction of the effectors and sensors with the environment.

BASIC SCIENTIFIC ISSUES

EFFECTOR:

In order to properly use mechanical manipulators it is necessary to understand how their geometry or kinematics affects their use. It is also important to understand the relationship between the torques produced by the actuators and the forces exerted by the hand on the environment. For control at high speeds, the equations of motion must be developed. The interaction between the hand, the part being held, and the environment must be modelled.

PLANNING:

Methods for representing objects and space in a computer need to be further explored. Motion sequences can then be planned provided the system can reason about the trajectories. Flexible objects will present particular difficulties in manipulation. Systems must be developed which can react in a robust manner to a variety of events not anticipated by the person programming the manipulator.

SENSORS:

In order to extract information form images it is necessary to first understand the transformation from the three dimensional world to the image. Then, under favourable circumstances, one can go about undoing this transformation. The shape of an object may be recovered and its attitude in space. Surface properties and shape may be used in recognition.

Machine vision is difficult. In the industrial automation context however, it is possible to use specialized lighting arrangments and other methods to simplify this task. Thus progress can be made long before we have an adequate theory of how human vision might work.

SOME PROBLEMS

Funding for robotics research has been sporadic. One result is that some researchers went on to other things in the lean years. This means that there are not that many people with more than a superficial knowledge of the research areas. There is heavy competition between the companies scrambling to get into robotics for these people. This creates a huge salary disparity between university and industrial research establishments. It also tend to tear apart the few groups which have become large enough to be effective. Many companies then end up with less than a critical mass. Perhaps they have only a token roboticist who is engaged in educating management rather than carrying out research.

Another difficulty is that it has not become apparent to many that robotics is more than a study of how to hook a micro-computer to an electric motor driving a joint on a multi-link mechanical device. There are deep scientific issues and the methods of physics, mathematics and computer science must be brought to bear.

RELATIONSHIP BETWEEN UNIVERSITIES AND INDUSTRY

UNIVERSITY ROLE:

The university's role is primarily in the area of basic research and education. The long-range effort needed to lay the ground-work for the more applications-oriented research is best carried out away from the immediate demands of next year's product. It is preferable that much of the basic research be carried out in the open, to avoid it being buried by competitive secrecy. There is a desparate need to educate students who will be tomorrow's users and designers of robotic systems. There is a similar need to educate engineers using and designing robotics systems now. Then also, texts must be developed which make information more easily available. This is a little tricky in an area which is changing so rapidly. Research articles should be published in journals dedicated to this area.

INDUSTRY ROLE:

Industry's role is primarily to carry out research oriented more towards applications. The line between what is basic and what is applied research is hard to draw of course. Only industry can identify problems which are really worth solving. Here too, methods which have been proposed can be tested. Often what works in the friendly environment of the laboratory fails to work in the real world. It is in industrial research laboratories where the successful ideas can be transformed into the robust systems which can be put to practical use.

INTERACTION:

Students of robotics courses at universities transfer knowledge to the companies that they are employed by. Similarly, short intense courses can bring the professional in the field up to date. Very helpful in ensuring that researcher in the universities are aware of real problems is a program encouraging visitors from industry to stay for some time. The visitor has the oppportunity to work with bright and eager students during his stay. Another conduit of information to industry is provided by the consulting relationships between individual faculty members and companies. In some cases companies may elect to fund research at a university rather than in their own research department.

ROLE OF THE FEDERAL GOVERNMENT

SUPPORT BASIC RESEARCH:

Steady support of research on advanced automation and robotics will ensure a supply of ideas and people able to improve productivity. There is no substitute for this type of funding.

ENCOURAGE INDUSTRIAL APPLICATION:

Companies should be encouraged to participate in research themselves by means of suitable tax incentives. The application of this new technology should be similarly encouraged. Cooperation in research between different companies should be permitted. It would be advantageous if the patent system was more receptive to methods used in robotics systems. Measures should be taken to encourage the formation of small firms with promising new ideas in the robotics area.

ALSO:

An effort should be made to try and anticipate possible problems created by advanced automation.

STATE OF THE ART IN ROBOTICS

MECHANICAL:

- Multi-link Manipulators
- Electrical or Hydraulic Actuators
- Special Purpose Grippers

CONTROL:

- P. D. I. Control Systems
- Teach by Showing
- Simple Programming Languages

SENSING:

- Limit Switches
- Special Purpose Scanners
- Binary Image Processing

PRESENT RESEARCH AREAS

EFFECTORS:

- o Manipulators Design for Assembly
- o Dextrous Multi-Fingered Hands
- o Imaging Tactile Sensors
- o High Speed Control

PLANNING:

- o Spatial Reasoning
- o Task Level Languages
- o Compliant Manipulation
- o Alignment Operations

SENSORS:

- o Interpreting Tactile Information
- o Vision for Alignment
- o Vision for Inspection of Surface Properties
- o Acquiring Object Models

BASIC SCIENTIFIC ISSUES

EFFECTOR:

- o Kinematics and Statics
- o Dynamics
- o Modelling of Interaction

PLANNING:

- o Representing Objects and Space
- o Automatic Motion Planning
- o Reasoning about Flexible Objects

SENSORS:

- o Understand Image Formation
- o Recover Shape and Attitude
- o Recognition

SOME PROBLEMS

- Uneven Funding Profile
- Lack of Knowledgable People
- Large Salary Disparity
- Not Considered Science

RELATIONSHIP BETWEEN UNIVERSITIES AND INDUSTRY

UNIVERSITY ROLE:

- o Carry out Basic Research
- o Educate Students - Future Users
- o Educate Engineers - Current Users
- o Write Text-Books and,Edit Journals

INDUSTRY ROLE:

- o Carry out Applied Research
- o Identify Real Problems
- o Evaluate Utility of Proposed Methods
- o Bring Laboratory Methods to Practical Use

INTERACTION:

- o Visitor Exchange Program
- o Intensive Short Courses
- o Consulting
- o Fund Research

ROLE OF THE FEDERAL GOVERNMENT

- o Support Basic Research
- o Encourage Industrial Application

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ARTIFICIAL INTELLIGENCE LABORATORY

The primary goal of the Artificial Intelligence Laboratory is to understand how computers can be made to exhibit intelligence. Two corollary goals are to make computers more useful and to understand certain aspects of human intelligence. Current research includes work on English-language understanding, learning, common-sense reasoning, distributed problem-solving, expert engineering problem-solving, computer vision and manipulation, manufacturing productivity, computer architecture, human development, and human education.

Professor Patrick H. Winston, Director of the Artificial Intelligence Laboratory, heads the research effort in learning and reasoning by analogy. Professor Berthold K. P. Horn and Professor Shimon Ullman direct work in computer vision. Dr. J. Michael Brady, Dr. John M. Hollerbach, and Professor Tomas Lozano-Perez lead research on computer-controlled, multiple-joint manipulators and other aspects of Robotics. Professor Randall Davis and Professor Carl E. Hewitt work with distributed problem-solving and parallel computation. Professor Marvin Minsky develops general theories of artificial and natural intelligence. Professor Gerald J. Sussman, Dr. Howard E. Shrobe, and Mr. Thomas F. Knight work on the problems of integrated circuit design. Dr. Charles Rich and Dr. Richard C. Waters explore the creation of intelligent programming environments. Mr. Richard D. Greenblatt does research on memory and heuristic control. Professor Seymour Papert leads efforts concerned with education through the use of computers.

The Laboratory's 80 members include 10 faculty, 35 research and support staff, and 30 graduate students involved in research activities funded by the Defense Advanced Research Projects Agency, the Office of Naval Research, the Air Force Office of Sponsored Research, the National Science Foundation, the Olivetti Corporation, the Xerox Corporation, the Jet Propulsion Laboratory, and IBM.

Image Understanding

Professor Horn's group studies the problems associated with the relationship between the shapes of visible surfaces and their gray-level shading. In particular, Professor Horn formulated the image-irradiance equation, which relates surface orientation to brightness values, and he developed the reflectance map, which graphically displays the constraint implied by the image-irradiance equation.

One application of the image-irradiance equation and the reflectance-map representation is centered on the development of albedo maps, in which ground slope and sun position are factored out so that intensity is solely a function of ground cover. A crucial step in this application, the generation of high-quality synthetic images, is difficult because of atmospheric scattering. Professor Horn and Mr. Robert J. Sjoberg have demonstrated that although understanding the effects of the atmosphere is a difficult task, the adoption of even simple models can provide substantial improvement over results obtained with no model. In particular, they have showed how the abundance of shadows cast in mountainous regions can aid in the determination of path radiance. Professor Horn and Mr. Sjoberg are extending the models in order to extract calibration data from multichannel images and from multiple images taken a few days apart.

In general, the image-irradiance equation has an infinite number of solutions, each corresponding to a surface. Thus shading alone is not sufficient to determine a surface uniquely. Working with Professor Horn, Dr. Anni R. Bruss has examined the use of supporting information from silhouettes, edges, and rotational symetry, showing how to arrive at unique solutions in some cases. In particular, she has showed when the images captured by scanning electron microscopes determine surface shape uniquely.

Professor Horn and Mr. Brian G. Schunk continute to investigate the use of the image-irradiance equation in determining with the instantaneous positional velocity field which is generated on the image plane by moving in a textured environment. One important application is in navigation where it is desirable to determine camera motion from noisy image sequences. Professor Horn and Dr. Bruss have devised a least-squares approximation technique to handle the special case of pure rotation. An implementation is in progress.

Natural Vision

A model of two important aspects of retinal function has been proposed by Professor Shimon Ullman and Dr. Jacob Richter. Their computational theory addresses the role of the retinal ganglion X- and Y-cells. The X-cells implement in human vision what has been modelled mathematically as the convolution of the Laplacian of a Gaussian filtered image. These cells provide the visual cortex with information about the location of rapid intensity changes, from which intensity features such as edges, bars, and blobs can be detected. The X-cells constitute the basic input for much of later visual processing such as stereo, texture, and contours. The Y-cells, which appear to be the primary input for perceiving visual motion, are modelled as the time derivative of the Laplacian of the Gaussian filtered image. Professor Ullman and Dr. Richter show how these two mathematical functions can be implemented by the neural architecture of the retina, particularly by synaptic interactions.

Dr. Richter has continued this research into the next stage of visual processing, wherein X-cell input to the visual cortex is used to detect the location and orientation of intensity edges. That current line of work dovetails with a theory of edge detection developed by the late Professor David C. Marr in collaboration with Ms. Ellen C. Hildreth.

The processing of retinal intensity information is therefore becoming better understood, and allows the generation of specific computational models for various later processes. In particular, a theory of human stereo has been developed by the late Professor Marr and Professor Tomaso Poggio. A computer implementation by Dr. W. Eric L. Grimson has allowed a quantitative comparison of this model with the known psychophysics of human stereopsis. During the past year, Dr. Grimson also explored several computational issues regarding the process of deriving a representation of a smooth surface given the incomplete sort of information that stereopsis naturally provides.

Other computational problems that are under investigation regard the representation of continuous curves or contours from local edge or line information by Dr. Kent A. Stevens, the detection of texture discontinuities by Mr. Michael D. Riley, and the modelling of directional selectivity to visual motion by Ms. Hildreth.

Finally Dr. H. Keith Nishihara and Mr. Noble G. Larson have developed hardware for processing images with Gaussian filters, thereby working toward a real-time stereopsis machine.

Robotics

Ordinary human abilities, such as the planning of motions in a world of obstacles to reach some goal without collision, are difficult to automate. Professor Lozano-Perez developed a system of wide generality which constructs a hierarchical tesselation of space and efficiently computes grasping positions and paths for a polyhedral object in terms of the space of allowable configurations. Professor Lozano-Perez is now designing a high-level manipulator language in which his spatial reasoning system will be embedded.

In addition to an ability to reason about space, a high-level manipulator language must have an ability to reason about the interaction of manipulators and objects. Mr. Matthew T. Mason has uncovered some simple rules governing the collisions which occur when a manipulator grasps or pushes objects.

Working together, Professor Lozano-Perez and Mr. Mason implemented new software that enables a minicomputer to perform time-critical functions while a LISP-oriented computer does task planning and supervision. This software drives a manipulator designed by Mr. John A. Purbrick, which uses an innovative stepping-motor control system developed by Messrs. Larson, Mason, and Purbrick.

Mr. William M. Silver has worked on another aspect of manipulator control, extending some previous results on manipulator dynamics worked out by Dr. Hollerbach. Dr. Hollerbach had used a Lagrangian approach to obtain an especially simple form of the equations of motion. Mr. Silver demonstrated that Dr. Hollerbach's Lagrangian approach is equivalent to results obtained using a Newton-Euler approach.

A three degree-of-freedom tendon-driven shoulder, designed by Dr. Hollerbach, and two high-resolution touch sensors, one designed by Mr. Purbrick and one designed by Mr. William D. Hillis, continued to receive attention, with emphasis on experiment.

During the past year, a great deal of effort went into preparation for expansion of the Laboratory's work in Robotics. This preparation included the development of ties with other laboratories and centers and with the Department of Electrical Engineering and Computer Science, the Department of Mechanical Engineering, and the Department of Psychology.

Learning from Experience and Natural Language Understanding

Professor Winston's theory of reasoning by analogy has led to a system with the following parts: a hypothesizer that searches memory for precedents likely to be useful in analyzing a new problem; a matcher that finds the most useful correspondence between a retrieved precedent and the given problem using the causal framework found in the precedent; and a reasoning system that reaches conclusions about the problem using the precedent. During the past year, Professor Winston has developed a technique for generating abstract rules as a byproduct of the problem-solving effort. These abstract rules are similar to those that appear in systems developed elsewhere for medical diagnosis and oil-well log analysis. Professor Winston expects his work to lead to learning systems that acquire expert knowledge from experience, reducing the need for expensive and unreliable acquisition from human experts.

Mr. Boris Katz produced an English input module for Professor Winston's analogy system using the same approach he developed for generating English text from semantic representations. His generation system subdivides into three relatively independent steps: the first generates a set of kernel sentences from the semantic representation; the second uses syntactic and thematic considerations to determine the set of transformations to perform on each kernel; the third executes the specified transformations, combines the altered kernels into a sentence, performs a pronominalization process, and produces the appropriate English word string.

Expert Problem-Solving in Programming

Drs. Rich and Waters analyze the logical structure of programs in order to create intelligent programming environments.

They have devised a representation called a *plan*, a language-independent representation for a program that stands above the syntactic details of the programming language and represents control flow and data directly. The central idea is that typical programs are built up in a small number of stereotyped ways by what are called plan-building methods.

The power of the program-analysis system is demonstrated by the fact that it can produce plans for COBOL programs as well as for LISP and FORTRAN programs. Dr. Waters also constructed a coding module which produces LISP code from a plan. It has been tested on several dozen plans, including some which were produced by automatically analyzing COBOL and FORTRAN programs. The LISP programs produced range from several lines to several pages long.

VLSI

Professor Sussman and his associates work on design tools for Very Large Scale Integration (VLSI) and on innovative ways to exploit VLSI hardware.

During the past year, Professor Sussman and Mr. John D. Batali continued to develop the Design Procedure Language (DPL) for describing a hierarchical abstract wiring diagram for a device. Messrs Batali, Edmund Goodhue, and Christopher Hanson have developed software for translating control-unit function into a form accepted by the DPL system.

Dr. Shrobe continued to develop the Daedalus system, a graphics interface to the DPL system. One new feature allows fracture lines to be placed, describing places where a circuit may be stretched. Another allows the conditional interpretation of standard cell parts, allowing proper display even though the use and the precise form of a cell vary.

Mr. Knight has designed and fabricated a prototype silicon image sensor which includes image processing implemented through a hybrid analog/digital approach. The operation of the chip relies on interconnections that make it behave like a finite-element approximation to a distributed transmission line governed by the diffusion equation. The resulting computations are Gaussian convolutions which can be differenced to form approximations to the operations that are required in early vision processing.

Mr. Hillis is currently leading an investigation into the possibility of building a concurrent computing machine for searching data bases with 10,000 times more facts than those in today's expert systems. The proposed machine, called the connection machine, is a locally-connected array of cells. In contrast to the memory cells in ordinary serial machines, each cell in the connection machine is to have not only the hardware necessary to hold an item of data but also the hardware necessary to manipulate it.

Distributed Problem Solving and Computing

Professor Davis studies some of the fundamental issues that must be faced in distributed planning and problem solving. Motivations for distributed planning and problem solving include both economic forces (which suggest connecting many small computers together to work on a common goal), as well as arguments based on reliability and graceful degradation in performance if one of many machines stops functioning. Professor Davis has begun studying planning strategies that make sense in a world populated by multiple agents, none of which has complete knowledge, and is exploring techniques for producing plans that produce robust, cooperative, and cautious behavior.

Professor Hewitt investigates the issues surrounding the creation of multiprocessor systems. A central problem in any multiprocessor system concerns the topology of interconnections between the individual processors, and this in turn determines the lengths of the wires between processors. Some researchers have suggested placing processors at the vertices of an n-dimensional cube so that the maximum number of hops between processors is the logarithm of the number of processors. This topology has the disadvantage that almost all the wires are extremely long, which is disadvantageous in VLSI systems. In order to deal with this problem Professor Hewitt, in collaboration with Professors Robert H. Halstead, Jr. and Richard E. Zippel, developed the idea of using a folded n-dimensional hypertorus, which can be visualized as wrapping opposite sides of the n-cube to make them adjacent. Mr. Jeffrey I. Schiller has constructed a test-bed implementation based on three of the Laboratory's LISP Machines, and a simulator for a 64-node system using the folded Cartesian hypertorus geometry of interconnections. This has enabled pilot studies of the important idea of work sharing and dynamic load balancing to be started. Recently Ms. Phyllis A. Koton constructed a communications VLSI chip called PORTAL-0 to facilitate further experimentation with the Apiary.

The Computing Environment

Several years ago Mr. Greenblatt conceived of the LISP Machine, a computer that gives its users more symbol-manipulation and list-processing power than had ever been available before. During the past year the number of these machines in the Laboratory increased to 14, enabling research that otherwise could not be done. All of the LISP Machines, five PDP10s, two ETHERNET gateways, and miscellaneous computers and terminal concentrators are linked together with an eight-megabit packet-oriented cable system known as the CHAOSNET.

Basic Theory

Professor Minsky continues work on his *society of minds* theory, in which intelligence emerges from the interaction of large societies of rather simple individual agents, in a parallel computational structure. Because each agent is relatively simple, communication between agents must be restricted in amount and in complexity.

Professor Minsky's approach may illuminate the psychological theories of Piaget and Freud, as well as give coherence to Artificial Intelligence theories that do not consider the kinds of problems inherent in the representation of a personality. The limitations of inter-agent communication make it necessary for the mind to develop hierarchies of control structures that may be similar to developmental stages. The censors and critics of the hierarchy settle conflicts by referring to early-developed self-images.

Professor Minsky's work has led to new ways to organize very large knowledge-based computer programs, such as the building of large, active computer memories, useful for dealing with the representation of common-sense knowledge.

Education

The LOGO Group, under the direction of Professor Papert, applies theoretical and technological developments in Computer Science to education. All of the group's activities are done in collaboration with the Division for Study and Research in Education.

Dr. Sylvia Weir, Professor Papert, Mr. Jose Valente, and Mr. Gary Drescher, use computer-based techniques to address the diagnostic and educational needs of children with physical, learning, and emotional handicaps. Work with the learning disabled involves the isolation of a spatially gifted subcategory of the population, using the computer as a source of formal spatial reasoning. This work links recent brain-behavior correlation research with computer-based spatial learning environments that have been generated by the application of Artificial Intelligence to education.

Mr. GORE. Dr. Horn, thank you very much.

Our final witness is Dr. Delbert Tesar, director of the Center for Intelligent Machines and Robotics at the Mechanical Engineering Department of the University of Florida.

Let me welcome you on behalf of the chairman of our full committee, Don Fuqua, who speaks very highly of you and your colleagues there. We are delighted to have you.

Please proceed.

Dr. TESAR. Thank you.

I would like to first describe our center. We have 10 faculty, 25 students, $2.5 million funding over the last 2 years, three-quarter million dollar laboratory. We do have major interactions with industry, and we are keen to maintain a high level of development activity.

I personally have been involved in a position paper development in the areas of innovation, productivity, robotics policy, manpower policy, nuclear reactor maintenance questions over the last 5 to 8 years.

I have traveled essentially in every major institution in the world in the robotics technology under discussion today, including Russia, Europe, Japan, and Australia. So I would like to address the highlights of my formal presentation which has been submitted for the record by means of a few slides.

Realizing of course that I cannot provide an in-depth presentation, I would enjoy doing it at this time. I would like to highlight the fact that I do believe that the robot technology of the next generation does not exist, and there are grave dislocations you might say between need and available feasible technology today.

By means of these slides, I would like to illustrate some of those issues. First we have to be aware of the fact of the magnitude of the problem we are facing. Manufacturing is 24 percent of the GNP and outranks all the other wealth generators in the United States by a large amount.

Mechanical technology represents 75 percent of our manufacturer's trade. Which means it is dominant and we should have policy in proportion to that.

Yet 20 of the most negative deficits in the manufacturing area which are mechanicals produced a $34 billion loss in 1978. This is the same loss we had in oil. We have no aggregate policy or technology to defend that particular issue.

So——

Mr. GORE. Before you move to the next slide, could we get that focused, and let me make certain I understand the slide.

Dr. TESAR. Fine.

Mr. GORE. Where is it?

You have got a total of 36 percent.

Dr. TESAR. That is right. The other 63 percent is service, of which 50 percent is from industry and 13 from government.

Mr. GORE. Now why do you—is service not a wealth generator?

Dr. TESAR. Not in the sense of raising the standard of living. There is a distinction between these four primary wealth generators: agriculture, construction, extraction, and manufacturing versus service industries.

Mr. GORE. What is tribology?

Dr. TESAR. Friction aware and lubrication.

Mr. GORE. Well, that is fascinating testimony. Thank you very much.

Mr. Scheuer is recognized for 5 minutes.

Mr. SCHEUER. Yes. Just a brief question for starters, Mr. Tesar. Are you familiar with the computer center in Paris?

Dr. TESAR. No, I am sorry I am not.

Mr. SCHEUER. The World Micro Computer Center. You are not.

Dr. TESAR. I just admit I am a mechanics engineer and tend to gravitate toward that.

Mr. BERG. The director of our institute, Professor Reddy, is a member of the institute.

Mr. GORE. He was a witness here before the subcommittee last week. A fascinating fellow.

Mr. SCHEUER. I would simply ask if either of you would like to address the questions I asked before: First, what is the role of Government in moving us forward and do we have a problem of acceptance of the whole role of robotics by members of the labor force who feel threatened by it, and if we have, what do we do?

Dr. TESAR. I will like to address the Government role question. I have dealt with this quite a bit, interacted with policy people as well as industry people extensively.

I believe that our biggest failing in this area is first organization, sense of purpose and sense of urgency.

Second, recognizing management of the task. In the United States, it is very high, management level is very low. We have to get industry, universities, and Government active so that things actually happen on a negotiated basis. That means all universities would have to be involved to a certain extent and not be an isolated few.

That is one of our biggest problems, that an isolated few are involved. There are a lot of wonderful universities that get left out, underutilized to our great deficit in this country.

Mr. SCHEUER. Thank you.

Mr. BERG. I would like to make a few comments.

I think my experience with labor indicates to me that they are scared, and I don't blame them. We don't know what is going to happen; they don't know. They see tremendous world competitive pressures; it is a time of transition, obviously. As a result, of our concerns, we have enlisted labor unions in our societal impact study, but that is really only a start.

I guess I will repeat what I said before: labor uneasiness clearly is an issue: labor is scared; there is much more in this area that we must understand and much more that we must do.

Mr. SCHEUER. We didn't get the feeling from the other panels and issues that it was an issue.

I asked the question in several different ways, and we got repeated answers that labor is happy with robotics, no apprehension, all systems are go. You are the first witness today who seems to indicate that there may be a problem of acceptance and anxiety or anxiety and therefore reluctance to see it move ahead.

Dr. BERG. We talk about going to a different kind of society where the labor force is working perhaps a few hours a day, perhaps even a few hours a week. Clearly, there will be tremendous dislocations and reorientations. How we get from here to there, no one at this point knows.

Mr. SCHEUER. Thank you very much, Mr. Chairman.

Mr. GORE. Dr. Horn, would you want to respond?

Dr. HORN. No.

Mr. GORE. Mr. Volkmer.

Mr. VOLKMER. I would just like to inquire of Dr. Tesar to expand—do you envision that we get the direction we need in this country by the combination of Government and industry and the universities?

Dr. TESAR. Well, I think, first of all——

Mr. VOLKMER. We have no central organization.

Dr. TESAR. That is correct, we do not have a central policy. That is essentially the case. If you look at the NASA/Science Foundation as the representative agency, that covers a broad spectrum of technologies.

One would have to admit that they don't have the resources to carry out that broad mission. It would be impossible for anyone to suggest that NASA/NSF is powerful enough in the area of engineering to carry out a mission that would be equivalent to that of some of the Japanese missions that have come along with cooperation of industries and universities.

The Japanese missions are very structured by comparison, and they forecast what they will do and stay on target, and there is an urgency to do so.

I really wished that we could take advantage of our resources. This country has unbelievable resources in universities and manpower in teaching, education, and distributive industrial research bases, but they don't seem to get together.

It has to be done by negotiated distributive response through incentives, through sense of urgency and purpose. I don't see that coming from any place else but from the Government.

Mr. VOLKMER. You have had some success, as I understand, in being able to solicit industry to——

Dr. TESAR. Nominal success, yes. From industry.

Mr. VOLKMER. Not that great?

Dr. TESAR. You have to be aware of the fact that only 2 or 3 percent of the R&D money in the universities comes from industry, only 2 or 3 percent.

Mr. VOLKMER. You see no fear in having that enlarged?

Dr. TESAR. I have no reservation whatever. I feel my priorities are established by industry. I have a better sense of purpose in direction than I would get otherwise.

Mr. VOLKMER. All right.

Do you think that Government should try and focus on the problem of trying to centralize it through the Congress or through a Presidential commission or something like this?

Dr. TESAR. Yes, sir. I think that the country should say this is our purpose, we want industry and the universities and other laboratories to get together, we will provide sufficient incentives to allow negotiated distributed response and if you look at the way industry responds to policy and with that policy industry will respond in a positive way with a good policy.

If the Government says we will let certain dying industries die, the signal is very clear.

Mr. SCHEUER. Will my colleague yield?

Mr. VOLKMER. Go ahead and I have one more question.

Mr. SCHEUER. We have a recently appointed Commission on Productivity. Would that be the engine that Congressman Volkmer is looking to to focus our concern?

Mr. VOLKMER. That was my next question—not exactly that, but go ahead.

Mr. SCHEUER. No, no, there is one possibility there.

Dr. TESAR. Yes.

Mr. SCHEUER. Or are there reasons we need something else?

Dr. TESAR. I have watched this for some years, and most of you have, but it seems every time we have a new Commission or study, we don't seem to bite the bullet. The Commissioners went through this last year—in the last administration, I suspect it went on before that.

So I think that we have got to get over this. We have to get to the sense of urgency.

Mr. VOLKMER. Let me ask you one last question, and it would be a hypothetical, it is one of those "if" things, you know, a little word. But let's assume the United States had manufactured mechanical robots, was in the same position to use the robotics as they are in Japan.

Would you tell us where we would be as far as manufacturing and the cost of manufacturing, et cetera?

Anybody want to try that?

Dr. TESAR. I suspect the major benefit would be improved quality of product.

Mr. VOLKMER. More in quality than in costs?

Dr. TESAR. That was my first reaction, yes.

Mr. VOLKMER. Anybody else?

Dr. HORN. Well, I agree with Dr. Tesar, that somehow we have got to elevate this to the status of a national need, so that it is recognized that we should be working on it, and that something that will be supported for a substantial amount of time, so there is some security in its future.

As far as where we would be if we had the widespread introduction of simple robots as we do in Japan, I agree that perhaps the primary interface would be in quality. On the other hand, improved quality usually also means reduced cost, because if you make 100 things and 70 aren't right——

Mr. VOLKMER. You don't have the recalls and you don't have to go back over and redo.

Dr. HORN. Right.

Mr. VOLKMER. Thank you, Mr. Chairman.

Mr. GORE. Well, I get the impression that the Government effort in this area is akin to one of your first-generation robots. It is pretty awkward, it doesn't get feedback, it doesn't move in very many degrees, not very sophisticated.

Dr. TESAR. I love that analogy.

Mr. VOLKMER. Very slow moving.

Mr. GORE. That is right. You have to walk it through.

Mr. ROSEN. And it shakes a lot.

Mr. GORE. Yes, it shakes a lot. This year, it will shake a lot of heads.

I won't torture that metaphor any more. Seriously, we do have to improve the function and role of the Government in this area rather quickly if we are going to compete with Japan and other countries.

Let me start in a slightly different place. Dr. Horn, and maybe the other two witnesses would like to respond to this, I don't know to what extent you gentlemen feel expert in artificial intelligence.

Dr. Horn, you are from the Artificial Intelligence Laboratory; let me ask you the extent to which you believe artificial intelligence will advance in the balance of this century.

Dr. HORN. Well, I think that as far as robotics is concerned, we don't really look for tremendous advances in AI, even if we use what is available now.

Also, robotics seems to require new things. For example, it was felt for a long time that the special reasoning problems I talked about could be solved by traditional AI methods that are now used in other problem-solving contexts until we tried it and found that special reasoning was something we had to address on our own.

I think that artificial intelligence and its application to robotics will make great advances. It has done so already in areas where people have built expert problem-solving systems for specific domains such as geologic explorations and disease contexts.

It has made natural language interfaces for other systems, so they are more widely available. There are systems which allow you to retrieve information, management information-type systems which would not otherwise be used because managers do not like to learn the programing language.

By providing the natural language interfaces now, they are more widely accessible and frequently, in fact, the natural language interface is the most expensive component, and the largest part of the system.

But it is making a great impact already, whereas, for many years, AI was just a glint in our eyes and far off into the future. It has gotten to the point where it is commercially feasible to exploit some of these ideas. Companies are being formed.

Mr. GORE. Dr. Berg?

Dr. BERG. I would like to endorse what has been said and give a slightly different perception of it.

There is a tremendous wealth of basic research involving AI already developed and just beginning to be used. I think that research relates to the kind of robotics we have talked about; namely, there are a number of companies that are using artificial intelligence for maintenance systems. They are planning to put sensor-based systems on machinery which will use the information collected. Initially, humans will look at that information, then get access to the artificial intelligence system to tell it how that machinery has to be maintenanced. Eventually, however, the sensor based system will act on its own.

So there are a lot of things just coming to the fore based on past research in AI. In addition, I have to mention that one of my colleagues has said he likens what is going on to what happened in the British industrial revolution in that the driving force for the development of steam engines was the pumping of water out of the coal mines. It was the study of steam engines that in time led to the real development of the science of thermodynamics. So, the driving force for a lot of basic research is practical problems; the same is happening now in AI.

Mr. GORE. Well, complete the analogy, what is the driving force?

Dr. BERG. He is predicting that because of the driving force of using these AI systems to respond to practical problems, the whole field of artificial intelligence will develop a deeper scientific underpinning.

Mr. GORE. That is the larger question precisely that I am getting at. Is it theoretically impossible for a machine to become conscious?

Dr. BERG. Well, there are great debates in this area of what thinking means and I guess I am not qualified to judge. I might note that the machines appear as to go through some reasoning process which is different than what humans do. It is—in terms of the machine operation—different, but it has gone through some kind of process which enables it to make a decision, which makes it appear it has intelligence, but it is of a different kind.

Mr. GORE. Dr. Horn?

Dr. HORN. Well, I think that perhaps I would like to concentrate rather on those uses of AI which don't go quite that far. There are many things we can do which don't involve——

Mr. GORE. I know it is a tangential question, but one I was interested in.

Dr. HORN. I would like to answer by saying it is difficult to define something that is "conscious" just as it is difficult to be sure what is "live" in the sense that to external stimuli, something reacts in what appears to be an intelligent way, you might conclude it is intelligent in the same way you conclude something is conscious.

I don't think there is a good answer to that. As far as the research is concerned, I guess the hope is that one would continue and develop science fiction-type creatures, but I am not interested in that.

I think we can do a lot of really neat things in the closer term with the techniques we have developed.

Mr. GORE. Has any research been done on the relationship between energy use and robotics, specifically, the improvement or lack of improvement in energy use compared to a human system?

Dr. TESAR. May I mention something about that? Generally speaking, robotics themselves, if that is all you are looking at, are extremely energy-intensive. They are almost without a doubt the most energy-intensive machines you could have.

On the other hand, if you look at the total system, part of the system has support to the more complex system, it may be much more energy-efficient.

So I could say a robot could be 1,000 times less efficient as far as energy use than a direct machine. I would have no reservation about that kind of number.

Mr. GORE. Dr. Horn, Dr. Berg?

Research has not really been done on this question.

Dr. TESAR. That is right.

Mr. GORE. If we stand, as some Americans believe, on the verge of a third energy shock, that question could become a significant one.

Dr. Berg, how has the arrangement between Carnegie, Mellon and Westinghouse worked out? Are you satisfied with that arrangement?

Dr. BERG. I can't speak for Westinghouse, but based on all we have seen, I think the agreement has worked very well for both parties. I should mention that Westinghouse is not the only participant in our Robotics Institute. They were the first major one. Since then, we have had at least two more major supporters, Digital Equipment Corp. and the Office of Naval Research. We also have about 15 industrial affiliates, so we have a varying degree of participation. Westinghouse happened to be the first and the largest. From what they tell us, in fact, they are going to continue to fund us and to work closely with us. I would say it has worked out very well for them as it has for us.

Mr. GORE. You haven't felt your institutional priorities have been changed in a detrimental way?

Dr. BERG. Not at all. If I can take a moment, I'll tell you how we operate. We have selected the problems that we work on by asking Westinghouse to come up with a list of about 25 things that they would like to see solved, 25 problems that they felt were significant. Out of that 25, we have selected 3 or 4 that we felt were important and that we could do.

Subsequently, we have been able to do research relevant to us both that can be shared with their people. The research has led to developments that are being incorporated into their production facilities. In addition, as I stated before, they have gotten the patent rights to significant numbers of patents and software copyrights already, and we have published papers fulfilling our function.

Mr. GORE. Dr. Tesar, let's suppose for a moment that your 10 centers are not set up and that the U.S. Government's effort remains relatively small and uncoordinated. What is the concern—what is the problem with that?

What I am getting at is, how big a threat is there that the use of robotics in other manufacturing countries will deprive us of many millions of those jobs now available?

Dr. TESAR. I think the crucial question is jobs, and as you know, the policy, I should say perhaps, business climate, in the Northeast is not as attractive as it is in the Southeast.

So there has been very rapid movement of jobs from the Northeast to the Southeast over the last decade.

Now, it should be possible to recognize that international competition has the same influence and impact, that if you do not have a vital atmosphere, that means people and technology at all levels, industry which has to take the position of survival will make the most effective decision at a different moment to maintain that survival.

Whether it has to do with national interest or not is not really the crucial question.

Their survival is the prudent question. So if the national Government does not establish policy where the vitality of people in technology is available so industry, when it needs those resources, can absorb them and move with opportunity and urgency, it will take the secondary road which is to lose the jobs, transmit the more expensive task to other countries and in many ways maintain marketing capability in this country, and not a manufacturing capability.

I am very concerned about that. I think the vitality of the technology and the growth of the people is a Government responsibility.

Mr. GORE. I certainly appreciate the amount of thought you have given that question, and as I said earlier, I think we have to rapidly improve our Nation's ability to perform this task.

Dr. Horn, my final question, do you believe that the U.S. robotics research effort has fallen behind the Japanese?

Mr. HORN. No, it has not, because the strength of the Japanese is in the mechanical side, and widespread use of the robot, they are weak at the moment in computer science and development of algorithms.

However, on my last visit, I saw disturbing signs where they developed CADCAM systems comparable to our own. I think they could catch up on us particularly with these large Government projects like PIPS and the problem sponsored by MITI now.

At the moment, we may feel safe, but that is not going to last long.

Dr. TESAR. May I comment, when I was in Japan last week, there was a newspaper article saying they are going to put $400 million in the next 10 years into software development.

Mr. GORE. Well, to draw another analogy, I have done a lot of work in strategic arms and you see the payoff in research effort and deployment of new equipment altering the strategic balance. When you look at the balance of trade and the balance of manufacturing capability, the deployment of robots is a critical factor in affecting that trade and the allocation of research money and the focus of research effort on areas that have the ability to confer a dramatic trade advance is something that this country can't sit back on and take in a blythe way what is happening.

We have to compete. In order to compete, we have to recognize, in my judgment, that we have to work together and that that means often we have to work together through the Government focusing intelligent efforts to make the transition which lies directly ahead.

Did you want to ask another question before we go to our discussants?

Mr. SCHEUER. No.

Mr. GORE. Dr. Sanderson

Dr. SANDERSON. This panel has emphasized the need for continuity and for a level of resources to be focused on this problem area. One issue of interest to me, is the resource limitations which exist. This of course, is a budgetary issue which has to be examined by each Congress and by each administration in terms of national priorities.

Many of the areas which have been discussed are areas that the Foundation or other Federal agencies have been actively working in.

Certainly, in the engineering directorate, we place a lot of emphasis on the support of fundamental research activities.

We have also sponsored the development of some centers in robotics or in other technologies. We have actively encouraged formation of industry-wide cooperative programs such as the cooperative program in the chemical industry and many of the centers now being established in microelectronics.

Where do you think the priorities should be placed in the Federal Government in terms of achieving the greatest forward momentum in this area of robotics and the implementation of robotics into our economy?

Dr. TESAR. Why don't you go ahead?

Dr. BERG. Well, Dr. Sanderson, at least what I think is happening is that a lot of the DOD related agencies are getting very active in this area. If I look at our own experience, I think the support that we have received for pattern recognition work from the Defense Advanced Research Projects Agency has been key in giving us a firm scientific foundation for the work we are doing.

I don't think that commitment has a broad enough impact on our industrial base. I think that it encourages only a certain group of industrials to get involved in robotics research. I guess the question that I am not sure I am qualified to answer is how do you get a broad range of companies in this country to become aware of and committed to incorporating the results of robotics research into their own operations.

I guess I don't know the answer.

Dr. HORN. Well, I think related to the problem of a lot of robotics research having been funded by DOD is the similar situation that occurred with NASA, where certainly robotics and artificial intelligence would be of great value to them, but they have had not the resources to do it themselves, but worked on the basis of others doing it.

This has not materialized because problems were different. Similarly, the problems of industrial robotics are just a little different than we raise in our research funded by DARPRA and RNR. I think there is a need to strengthen the civilian component for funding for robotics. I think NSF would be the appropriate place to do that, both in terms of strengthening existing centers working in robotics and in establishing new ones.

We don't have the number of people being trained now that we need and that will only happen if new places also start.

Dr. TESAR. Well, that is a very difficult question to answer. But, obviously, I think if I had my choices, first of all, NSF does not have enough research dollars. It is clear they don't have the money for the job.

We have to be aware of the fact that 250 engineers schools which represents perhaps 2,500 departments, is spending $90 million over 2,500 departments representing about $30,000 a department.

I appreciate the fact you don't put salt on top of salt or grains on grains of sand on top of the beach. The management of the problem is significant just in engineering.

I think we have to face the issue that the very best way is create incentives for industry to interact, not only with Government labs, but the universities have to be in the picture.

I think it fits beautifully into the present administration's philosophy. I think it can be done. There are certain significant barriers at every State line that allows industry and the universities in that particular State to want to cooperate with each other and I think we can enhance that by having properly established incentives from the Federal Government.

If you have only 2 or 3 percent of all your R&D money now coming from industry, you do have a decoupled system which is not working together, the customer is not being listened to and the university is not establishing priorities in concert with the needs.

Dr. SANDERSON. I am glad you emphasized that point. There have been a number of changes in the tax laws in the last year or two. There have been a number of States that have grown increasingly concerned with their own economically competitive capability and in which the State governments or the industries within the States have begun to take action.

It has been most visible in microelectronics. Are you seeing any similar signs in the area of robotics? And if so, do you think this is the beginning of the solution?

Mr. TESAR. I think Carnegie-Mellon is a good example, but the fact is that the State of Florida is one of those emerging States which is becoming more conscious of how you bring industry in and how you make yourself more attractive.

Right now, the State of Florida has the best business climate in the United States.

Mr. GORE. No; the second best.

Dr. TESAR. Oh, OK. We are similar in our natural resources to Japan, so therefore, we have to structure ourselves in many ways that Japan has. The State authority is now acting to take those steps.

Dr. HORN. Just one last comment, I think it would be advantageous if it were possible for companies to cooperate on research than we can under current law. I don't know how you change that.

Mr. SCHEUER. May I?

Mr. GORE. Sure.

Mr. SCHEUER. There is thinking going on along those lines. As a matter of fact, there was a meeting recently between several Members of Congress and Department of Justice officials, the head of the Antitrust Branch, the top official of the Office of Management and Budget, somebody representing the President from the White House, and an Under Secretary of Treasury, on just that question.

How can companies pool resources and pool capital for R&D and not come afoul of the antitrust laws.

There is a growing perception that that is absolutely necessary for us to compete, especially with the Japanese where that cooperation between enormous corporate entities in Japan is not only permitted but encouraged and funded by their Government.

At least in R&D I think there is a growing perception that we have to permit that cooperative action in R&D and there is a lot of ferment going on, as I said, along that line.

Dr. SANDERSON. Mr. Scheuer, that is an area that is also under considerable discussion in the National Science Foundation.

Indeed, there are questions about the ways that one can encourage cooperative R&D activities and there is discussion going on with the Justice Department and the executive branch as well.

Mr. SCHEUER. One simple way to encourage it is to say that it is legal instead of illegal.

Mr. SANDERSON. There are questions going even further than that, and that is that many of our antitrust laws were put in around the turn of the century, when the United States was very much an insular economy and when the cost of transporting manufactured goods often exceeded the value added in the manufacture.

Today you can pick up an integrated circuit chip and mail it from here to Japan for the cost of a postage stamp. As long as one is maintaining a free-market economy, the antitrust issue takes on a very different complexity because we are no longer as worried about the same internal cartel formation.

Mr. SCHEUER. What we are worried about is not just competition in the United States, not just where we can maintain an economy with three or four automobile companies, but rather in terms of a global way, whether any automobile company will be able to survive or whether any telecommunications manufacturer will survive in the face of global competition.

One of the ways in which we may enable our automobile industry and our steel industry and our telecommunications industry to survive at all in this now-global market is to enable them to pool resources.

So, the whole thrust—this is not to reflect on Al Gore and my predecessor of almost a century ago, I don't suppose today we are any more omniscient of what conditions will be in 2080 or 2090 than they were at the turn of the century about conditions today—but the form that the antitrust laws take today are totally archaic and anachronistic and irrelevant and harmful to the sharply tuned analysis of what our industrial problems are today, and what our real problems are in the sense of America surviving as a major factor in a global economy.

That, as I said before, that thinking is permeating this Government, and there is considerable ferment.

Mr. GORE. I don't want to break the harmony, but in my opinion a lot of the concerns which led to the formation of the antitrust laws around the turn of the century and for decades after that still exist, and although some of the applications of the antitrust laws have caused difficulties, I think the problem of concentrating power in the economy is still a very keen problem that has to be faced.

I think some of the antitrust laws need to be strengthened rather than weakened. All of them need to be made more efficient and more relevant.

Certainly, that is a ground on which we can agree. But I, for one, want the record to reflect some concern that we not abandon the protections that were important then and are still important today.

Dr. SANDERSON. Mr. Gore, certainly I cannot speak as an expert in the antitrust area, and the concerns for concentration of power are very real, but at the same time, I think the mechanism by which we prevent undue concentration of power may be inhibiting our ability to cooperate in areas where cooperation would be beneficial.

Certainly, the ability to cooperate in R&D could enable a great deal of forward advancement in our technical capability, by not looking at internal competition of the United States and Japan, but their ability to compete against one another in Third World markets.

One point made is that the Japanese are often able to provide a much more integrated package of all the capabilities needed to deliver the end products than the United States because of our real or imagined concerns with antitrust.

Many of them I suspect are imagined concerns.

Mr. GORE. We are going to have to move along. Dr. Berg, you wanted to react to—you don't?

Dr. BERG. No, thank you.

Mr. GORE. Dr. Chern?

Dr. CHERN. I guess the only comment I would like to make is to try to set things a little bit in perspective.

It is true that the robot is a system which performs mechanical activities but I think we should view robotics in many ways as an application area of which many disciplines come to play a role, areas like computer science, electrical engineering, mechanical engineering, people who build actuators, and various groups and individuals.

I think what is interesting about the robotics is that many of the problems which will occur when we go toward automated manufacturing, begin to occur in a more constrained way that can be perhaps more easily encompassed and handled in the robotics area.

So, we have talked about robotics and automated manufacturing. They are quite different. Robots are a form of automata, and there are many forms of automata. The problems arise in integrating those things into systems and the problems are formidable. They are not easily solved.

In fact, if you had to really build truly flexible automated manufacturing systems today, we couldn't do it.

We can approximate it so you have a transfer machine in a mechanical sense an automated manufacturing system. There are various degrees of automation, and you have heard about the experiments. I think what is interesting in robotics is it is an area where enormous progress can be made and where there, in a sense, is this competition between the various disciplines which is healthy, I think, and very useful.

So you may get people who look at computer science and computer engineering and they look at it from the point of view of the semiconductor revolution of what we can do in terms of gaining precision by use of feedback and different types of control.

You get the mechanical engineers who look more traditionally at it. They may wish to obtain this type of precision through use of different types of actuators and different types of mechanical structures.

It is an interesting combination that different people view the problem from different perspectives. It is that sort of joining together which I think will yield some very interesting advances.

Mr. GORE. Thank you very much.

Dr. Strauss.

Dr. STRAUSS. No.

Mr. GORE. Let me thank all of our witnesses and let me thank this last panel for an excellent job. I would like to also thank our expert discussants, Dr. Sanderson, Dr. Chern, Dr. Strauss. You have certainly contributed to the record today, and helped the subcommittee.

I think it has been a fascinating hearing, and I just want to thank, again, all the witness here today. We have our work cut out for us in focusing the Government's effort in this area, and it is an urgent and important task.

Thank you all for your helping us address it.

[Whereupon, at 2:25 p.m., the subcommittee adjourned subject to the call of the Chair.]

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ROBOTICS

WEDNESDAY, JUNE 23, 1982

HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE AND TECHNOLOGY,
SUBCOMMITTEE ON INVESTIGATIONS AND OVERSIGHT,
Washington, D.C.

The subcommittee met, pursuant to recess, at 9:45 a.m., in room 2325, Rayburn House Office Building, Hon. Albert Gore, Jr. (chairman of the subcommittee) presiding.

Present: Representatives Gore and Walker.

Mr. GORE. The subcommittee will come to order.

I would like to welcome all of our witnesses on this giant panel and all of our guests. This is our second hearing on robotics and the implications of robotics. At our hearing on June 2, we heard from three panels of experts who discussed the projections of foreign industry, U.S. industry, and universities for the use of robots and their perspectives on the development of robotics technology. It was a fascinating hearing but the record would not be complete without the Government witnesses who will be testifying today.

In order to put today's testimony in perspective, I would like to very briefly highlight some of the testimony from our subcommittee's June 2 hearing. We learned that there are approximately 14,000 robots in Japan, 6,000 to 7,000 in the Soviet Union, and 3,000 in the United States. By 1985 there are expected to be 85,000 to 100,000 in Japan, 40,000 to 42,500 in the Soviet Union, and only 15,000 in the United States.

The importance of robots lies in their ability to increase productivity. Unlike humans, they do not need coffee breaks, vacation, or sleep, as many of our witnesses noted. They can work continuous shifts, doing monotonous work without tiring. Extensive use of robots will have major impacts on productivity. Indeed, those impacts are already evident. It could create jobs but of course they also have great potential to displace millions of workers. The extent of such displacement is not clear but what is clear is that robots will dramatically alter employment patterns in at least the basic industries like the automotive industry. Any plans for increased use of robots, therefore, needs to be extremely sensitive to such concerns.

As we learned in our hearing earlier this month, the Japanese have embarked on an aggressive program to develop a preeminent position in the development of robotic technology. Back in 1977, Japan launched an ambitious project to develop an automated factory or automated manufacturing system, or FMS. They have made excellent progress, apparently, and they appear to be much further along than the United States in the development of an automated factory.

This past year the Japanese Ministry of Trade and Industry or MITI initiated a 7-year national robot research program to develop Japanese self-sufficiency in robotics technology. I saw on television two nights ago the robot pilot of one of their ships. I do not know if anybody saw that, where the captain of the ship spoke commands in English and the computer and robot controls made the ship do whatever he said.

Strong support by the Japanese Government of robotics has included development of the Japan Leasing Corp., established to assist companies who want to lease robots; second, provision of low-interest loans to small- and medium-size firms to encourage the use of robots; and, three, allowance of an extra depreciation for use of robots. Similar efforts have been made in some European nations.

United States industry and major U.S. universities are actively conducting robotic research but, as we have heard, their efforts are not nearly as coordinated or as well financed as are those of the Japanese and other industrialized countries. Clearly more can and should be done.

Earlier this month the subcommittee's witnesses suggested ways to improve the U.S. robotics effort. Suggestions included the development of a national robotics plan; incentives for improved Goverment-industry-university coordination; and establishment of robotics centers. The purpose of today's hearing is to examine these and other suggestions in order to determine what role the Federal Government can best play in this area.

It is, therefore, appropriate that today we hear from robotics experts in the National Science Foundation, the National Aeronautics and Space Administration, the National Bureau of Standards, the Department of Defense, and the Office of Technology Assessment, to assist in further assessing the following questions: One, is there a need for a national plan to promote robotics technology? Two, what is the Federal role in the development and application of robotics technology? Three, what is the Federal role in evaluating the potential employment impacts from the widespread use of robotics technology and in stimulating programs to reduce adverse impacts? Four, what is the nature of robotics research being conducted and/or funded by the Federal Government? Five, what are long-range research projects that should be funded by the Federal Government? And, six, what efforts are being made to coordinate Federal robotics research?

I look forward to a vigorous discussion of the feasibility of developing a national plan and on the other suggestions that encourage closer cooperation between industry, universities, and the Government.

I would like to ask unanimous consent at this point that the record be held open for the inclusion of the opening statement of the ranking minority member, Mr. Walker.

[The opening remarks of Mr. Walker follow:]

Opening Remarks of Robert S. Walker

Mr. Chairman, I would like to join you in welcoming the witnesses here today. This area is one in which the role of government is not yet clear.

For many years America's leadership in world markets was taken for granted in this country. But we are now learning that our leadership has been seriously eroded in many areas.

In our first hearing on this matter we learned that the Japanese have taken a clear and commanding lead in the field of robotics. And, what may be even more serious, is that the Japanese lead is rapidly increasing.

One of the most serious problems facing American industry is the relatively high cost of skilled American labor. In many other parts of the world labor costs are so much lower that there is a competitive advantage for goods produced overseas.

But, we have learned from our own limited experience with robotics, and seen in a much larger scale in the Japanese experience, that robots can replace manpower in many repetitive applications. So far, the general experience has been that the introduction of robots has considerably increased productivity and freed human labor for other applications in the production process.

Today, we will hear from a number of government witnesses who will discuss robotics in the government. Perhaps, after having heard from the government we may be able to determine what the proper role of government in this area will be.

There are a number of possible areas in which the government might become involved, including: Research on basic robotics, development of particular techniques and equipment, implementation of robotics technology through tax incentives or other incentives, education in basic robotics and possible retraining assistance.

We have learned a great deal about the ability of man to design machines to do complex tasks in all possible environments. We merely have to look about this room to see a number of the most spectacular applications. Now that we have the basic technology, we can and should be ready to utilize it for the good of all mankind.

Mr. GORE. I would like to welcome our witnesses today. We just have one large panel. Only five of the witnesses at the table have prepared statements, I am informed, and others are present to respond to questions and to assist in the presentation of the various departments and agencies here represented.

I would like to welcome to represent and speak on behalf of the National Science Foundation, Dr. Jack Sanderson, Assistant Director of the Directorate of Engineering; to represent NASA, Lee Holcomb, Manager of the Computer Science and Electronics Division of the Office of Aeronautics and Space Technology, who is accompanied by Dr. William B. Gevarter, Manager of Robotics Research, and Dr. Larsen, Manager of Automation and Computer Science; representing the National Bureau of Standards, Dr. John W. Lyons, Director of the National Engineering Laboratory, accompanied by Dr. James S. Albus, Acting Chief of the Industrial Systems Division; representing the Department of Defense, Dr. Edith W. Martin, who is Deputy Under Secretary of Defense for Research and Advanced Technology, accompanied by Dr. Lloyd Lehn, Assistant for Manufacturing Technology in the Office of the Under Secretary; and, finally, representing the Office of Technology Assessment, D. Frederick Weingarten, Program Manager for Communications and Information Technologies.

Ladies and gentlemen, without objection the entire text of your prepared statements will be put into the record in full at this point. We will invite you to go ahead with your testimony at this point. If you want to read your testimony, that is OK. If you prefer to summarize the highlights, that is fine, too.

We would like to begin with Dr. Jack Sanderson from the National Science Foundation.

STATEMENT OF DR. JACK SANDERSON, ASSISTANT DIRECTOR, DIRECTORATE OF ENGINEERING, NATIONAL SCIENCE FOUNDATION

Dr. SANDERSON. Thank you, Congressman Gore.

In the interest of time I would like to have my formal statement put in the record and to just briefly highlight a few points which I think are important.

The National Science Foundation, as you are aware, has as its primary concern the long-range health of U.S. science and technology, and we support that, in general, through funds for fundamental or longer term research activities and through funds designed to encourage some of our best graduating students to continue their careers in science and engineering.

The area of robotics broadly defined to include automated manufacturing and related activities is one that the Foundation has been concerned with for a number of years. We have had for some time a program concentrated on production research. That program has produced a number of significant results on individual projects and I have some material which I will be glad to supply to you and your staff. This material highlights some of the research activities in production research which looks at the longer-term applications of science and technology to robotics and manufacturing.

We have experimented with the problem of transferring some of this technology into use. For example, we funded a joint university/industry cooperative activity at Westinghouse a few years ago which was designed to pull together the basic research results from some half-dozen projects that we had funded earlier to create an automated assembly system designed to assemble major components of electric motors. This product was selected because many of the steps involved in assembly represent typical manufacturing steps. That particular project is just about reaching completion and we hope to begin publicizing the final results in the near future.

More fundamentally, we have been concerned for several years about the need to build on America's strength in the robotics and automated manufacturing area, that is, the high technology end of the spectrum. We have spent about half a year looking at the opportunities for robotics research, the problems in sensors, controls, computing, and the areas of fundamental research where we believed NSF could make the greatest contribution. We have now produced a program plan to emphasize those activities where we already have fundamental research going on and have begun to pull these activities together so that we can get the interchange of ideas and the interdisciplinary approach that will be needed to really make robotics advance over the long term.

I have a few documents which I have included in the record as part of my formal testimony, highlighting some of those activities. One was prepared by a contractor about 3 months ago which looked at the robotics research and research needs in the United States and attempted to identify not only what the research needs are but also those laboratories currently actively involved in this type research.

A second area of concern, in addition to building the fundamental technology, is the problem of skilled manpower that will be required to operate the factory of the future. In this area, the Foundation has taken two steps, both of which are pointed out in my testimony. First, we have assigned a very high priority to the engineering research programs for which I am responsible and to the related mathematics and physical science programs, so that those are the fastest-growing parts of the Foundation at present. We are also trying to build the research capability of the universities in order to produce better students and to produce a stronger base of fundamental research in the universities.

Wherever possible we are encouraging the universities to work collaboratively with U.S. industry in joint university-industry activities which tend to strengthen the transfer of the fundamental research going on in the university and move it more quickly into use.

Second, we, like many of you here in the Congress, have been concerned with the falling test scores, the declining scientific aptitude, of many of our secondary school students. As a result, we announced about a month and a half ago the establishment of a special Commission on Precollege Education in Mathematics, Science and Technology. That Commission has been charged with producing an action report within the next 12 to 18 months in an attempt to identify key steps that can be taken by the Federal Government, by local school systems, and by State systems, to reverse the downward trend in test scores and to try to improve the scientific and engineering aptitude of the high school student so that he or she has a greater range of career options.

I will be glad to respond to questions, and I would like to provide your staff with much of the documentation which we have developed in this area.

[The prepared statement of Dr. Sanderson follows:]

ROBOTICS

HEARINGS

BEFORE THE

SUBCOMMITTEE ON
INVESTIGATIONS AND OVERSIGHT

OF THE

COMMITTEE ON
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U.S. HOUSE OF REPRESENTATIVES

NINETY-SEVENTH CONGRESS

SECOND SESSION

JUNE 2, 23, 1982

[No. 148]

Printed for the use of the
Committee on Science and Technology

U.S. GOVERNMENT PRINTING OFFICE
99-916 O WASHINGTON : 1983