MICROELECTRONIC COMPETITIVENESS: WHAT THE PRESIDENT'S COMMISSION ON INDUSTRIAL COMPETITIVENESS DIDN'T TELL US

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In October 1981 the Japanese outlined a bold plan for a Fifth Computer Generation based on artificial intelligence and utilizing parallel processing. This event marked the beginning of a deep and continuing concern about American competitiveness in the semiconductor and computer industries. Having already proved that they are the world's greatest engineers and manufacturers of everything from cameras to houses, the Japanese are now challenging our computer science community and computer industry. Our response has been to establish several research programs (e.g. DARPA's Strategic Computing Program and NSF's Supercomputer Program) which, in effect accepts the challenge for the race to the Fifth Generation. I believe that history will record that American and the rest of the world's science provided the initial ideas for the Fifth Generation, whatever it is, and that Japan delivered the products, got the major market share, and went on to complete the detailed, disciplined, hard-to-do science and engineering which remain after the initial rapid innovations that begin a field.

As a field such as semiconductors becomes more structured, the disciplined approach to science begins to take over. Note the change in scientific output as measured by the number of papers delivered at the International Solid State Circuits Conference (Table 1).

Table 1

U.S. SHARE OF PAPERS DELIVERED
AT THE ANNUAL ISSCC CONFERENCE

	1980	1981	1982	1983	1984	1985
North America	65%	61%	68%	49%	50%	37%
Japan	29	25	27	42	40	45
Other	6	14	5	9	10	18

Source: Richard A. Shaffer, Technologic Partners

*Based on a Keynote talk at MCNC's Conference on Industrial Competitiveness, March 26, 1985.

Since the US is in a zero-sum game, competing for fixed financial and technical human resources, the effect of accelerating science will probably be a further decline in manufacturing and engineering, and consequently, a decline in both the semiconductor and, ultimately, the computer industries.

Science is the acquisition of knowledge. Knowledge is like gold, but with a short half-life: it's pretty, but, until it's refined, useless. Overfunding those who mine the gold, relative to the refiners and craftsmen who will use it, is a waste, because others can just pick up the gold and freely use it. Similarly, overly outfitted, unqualified miners are likely to produce fool's gold. A good example is the case of fiber optics, a science-based invention from the UK. Fiber optics require the laser, a Bell Labs invention, but today's high-speed fiber optics are made, not in the UK or the US, but in Japan. In the US, we have no way to recover the cost of science, so it must be regarded as a luxury, not a necessity. In Japan, however, a policy of product and manufacturing domination based on world science and technology has allowed product and process supremacy. They can now afford science.

We spend Department of Commerce resources to measure and justify, rather than to assign responsibility for improvement, while the Office of Technology Assessment issues a thick, less-than-timely report with an unclear message to the unknowledgable corporate manager saying that competitive conditions aren't getting too bad too fast. At the MCNC microelectronic conference on competitiveness, Jim Moore, Deputy Assistant from the Department of Commerce, told us that "government" now understands that high technology industries including semiconductors and computers, are behind competitively--after at least a decade of early warning. The government must play a much stronger role in forcing our industries to be more competitive, including assigning responsibility to companies and to specific individuals within government.

Suggestion. In order to slow down our inevitable decline in industrial competitiveness, we must posit a balance of manufacturing, engineering and science as the cornerstone of US industrial policy. Let's accept the report of the President's Commission on Industrial Competitiveness, led by John Young, as a given, although the report understates the problem and its recommendations are not phrased as laws and specific enough actions. So far, the report has generated yawns.

We must accept the fact that nearly all US microelectronics technology is competitively behind in everything from research to manufacturing. The result is that we are losing our ability to make competitive electronic products from video records to supercomputers. For example, PCs are already a loss, because 70% of the components of an IBM PC are imported for low-technology, high-cost US assembly.

Table 2 shows the situation in a typical technology: semiconductor memories. It has taken five years for us to become major suppliers of 64K chips, and we have become major suppliers now only because the Japanese have moved on to larger, more expensive, and higher-technology memories. Already, US companies are withdrawing from the 256K market because the Japanese dominate it. A similar story can be told for high speed CMOS and ECL, the lifeblood of the computer industry.

TABLE 2

DYNAMIC RAM SALES

	1981	1982	1983	1984	1985
64K					
Japan	10	70	220	478	630
Other	4	30	140	360	550
% Japan	73	70	61	57	53
256K					
Japan*			1.7	31	180
Other			3	2	30
% Japan			86	93	86

* 6 Companies

Source: Hambrecht and Quist

Currently we may take solace only from the knowledge that we designed most of the micros (Table 3) and these have been copied or jointly manufactured by Japanese suppliers, but the situation may improve with the enforcement of patents and copyrights. This is long overdue. We respond faster to people sending dirty pictures in the mail--which is also illegal. It is simply more cunning and profitable to copy, even though it is illegal. The Japanese use tariffs, but we believe that it is un-American to enforce our own laws. Even if the Japanese will now be prevented from copying masks, I think that they will still give us an interesting race in producing micros, and perhaps even a better micro. The market still needs a great one.

Table 3

WORLDWIDE SALES OF MICROS

	4-BIT Microcontroller	8-BIT Microcontroller	16-BIT Microprocessor
1	NEC	NEC	Intel
2	Toshiba	Intel	Motorola
3	Matsushita	Nitachi	Zilog
4	National Semi.	Motorola	NEC
5	Hitachi	National Semi.	Fujitsu
Japanese Share	80%	35%	15%

Source: Hambrecht and Quist

The following sections look at three facets of microelectronic competitiveness:

1. our ability to manufacture goods, why our current course is doomed, and suggestions for improvement;
2. contrasting our behavior with the Japanese approach, gleaned as a student of their culture, processes, and products;
3. suggestions for what MCNC might do.

REGAINING MANUFACTURING COMPETITIVENESS

Eight factors will be described: manufacturing's very low professional status; engineering's low professional status; poor-performing large companies; overreliance on venture-capital-funded startups; the structure of the semiconductor industry; the military black hole; over-reliance on universities and individuals as our only hope.

MANUFACTURING PROFESSIONAL STATUS

Manufacturing is at the bottom of the intellectual ladder, outside of a few superficial courses in MBA schools, and it is not part of the basic intellectual schema defined by university training. I have hypothesized that the influx of MBA's into industry for the last 25 years is a major cause of our uncompetitiveness for many reasons, including the fact that 20-25% of our engineers, many of whom have not practiced engineering, go into business administration. Engineers are among the few who can do arithmetic well enough to understand the P&L and balance sheets that are the Maxwell's equations of business. It is unfortunate that engineering schools have to bother educating these students. Worse yet, their superficial understanding of engineering make MBAs especially dangerous when working with technology.

Manufacturing is physical, hard, and requires a deep knowledge, not only of products, but also of the processes by which they are manufactured. Many manufacturing managers are Cro-Magnon men, skilled in negotiation, who have risen from the ranks but lack a deep knowledge of both products and processes.

Suggestion. Engineers are needed to lead and manage a revolution in US manufacturing.

Manufacturing subsumes much of engineering, yet only two schools grant manufacturing-engineering degrees. Russel Jones, Vice President of Academic Affairs at Boston University, claims they are the first and only school with a manufacturing-engineering department. With IBM's equipment and cash grants a few years ago, 20 or so programs were established and we hope to see a deep interest that extends beyond the computers and the cash. Clearly MCNC has a great opportunity to offer a degree in this field--where it can make a great difference.

Let me address the standard assertion and question about the need for manufacturing:

> "Our expertise is software where the Japanese are weak. Let the Japanese manufacture everything and we'll dominate the programming of their computers and robots.
>
> Why do we need to manufacture anything ?"

This attitude is reinforced by the notion that we are prospering by becoming an information and service economy, and it is illustrated by the way we treat the farmers. This is a polite way of saying we are a colony of distributors and consumers that the world is now supporting.

Figure 1 shows the Three Island Disaster. We export agricultural products and import oil and manufactured goods. This behavior describes the function of a colony. We give paper called dollars. One who has little understanding of classical economics might ask why the dollars are worth anything, but just look at what the other islands can buy with these dollars: they can buy the colony! Also, note the military black hole in the middle, which just consumes resources. Since our system violates the second law of thermodynamics, it can operate only until the island is sold.

Becoming just a consumer island has problems from virtually every viewpoint:

1. A manufacturing industry cannot be rebuilt once it is destroyed and consequently cannot be sustained economically. Consumer electronics and optics are typical examples. In the US this industry is negligible, yet state-of-the-art optical system designs continue to come from our engineers. For example, Bausch and Lomb and American Optical rank far below Leitz and Canon in quality optics. Optics is one cornerstone of the equipment needed for semiconductor manufacturing.

2. There is no way to pay for manufactured goods with software. The sale of software is comparatively small even though the cost to produce it may be quite large. Like authoring books, which is inherently neither capital- nor labor-intensive, much of programming can be a cottage industry business.

3. The state of the art of Japanese software engineering appears to be ahead of us in building everything from operating systems to Pac Man. The Japanese make and program the best robots today. We have no alternative except to restore our lead in both hardware and software.

Figure 1

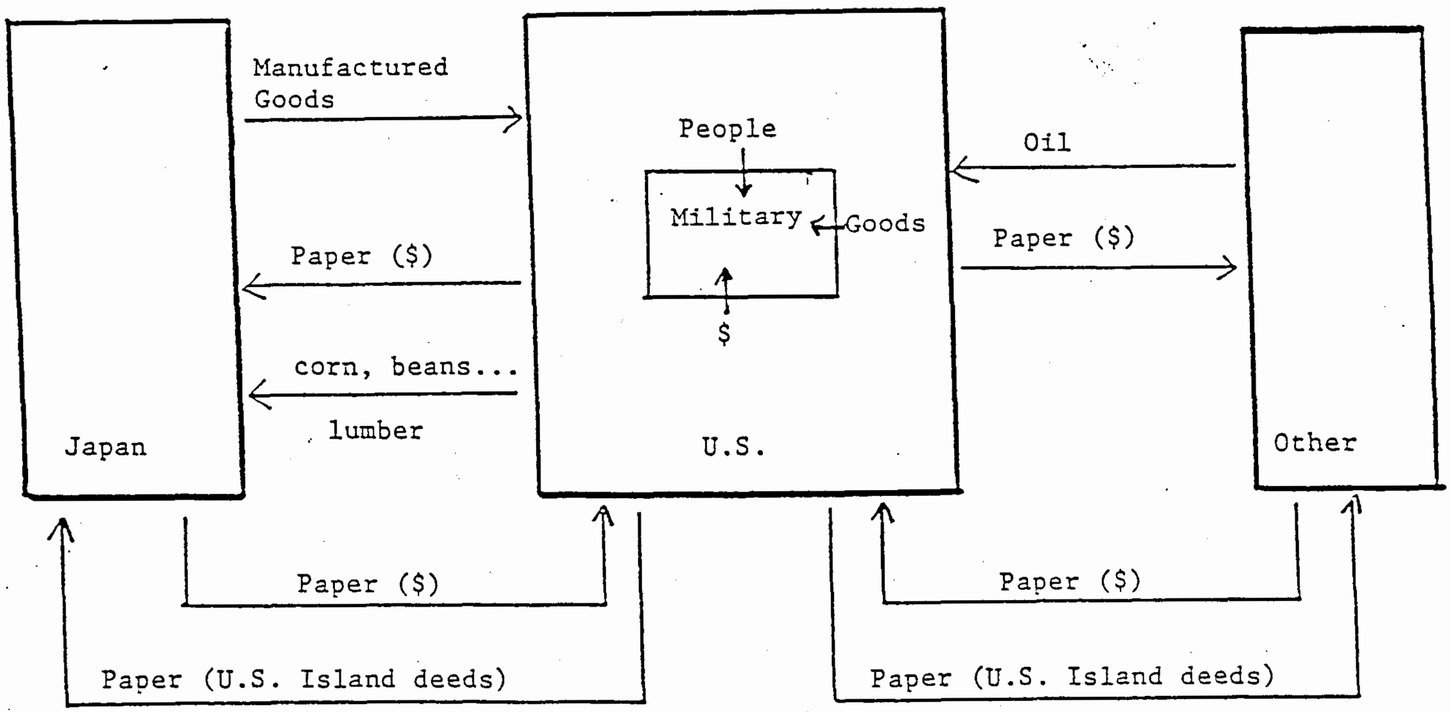

FIGURE 1 The three island disaster showing U.S. consumption of other island resources and manufactured goods in exchange for U.S. dollars. Other islands exchange U.S. dollars for U.S. Island deeds.

Statistics that show a rise in the number of engineering graduates are misleading, because they include graduates in software engineering. Our focus on teaching software to the exclusion of the physical sciences may create a nation of hackers, focused on symbol manipulation, and this will further exacerbate the manufacturing resource problem. We must treat computing as a tool and a component for other systems, rather than as an end in itself! We already have a ten-times overkill in home computer games, spread sheets, CAD/CAE/CAM systems, and compilers.

ENGINEERING PROFESSIONAL STATUS

Moving upward in the intellectual and professional order, engineering is only slightly above manufacturing as a profession. This situation, relative to science and the other so-called professions, has several bad effects:

1. Poor coupling between science and engineering exists. The result is a complete reinvention of ideas when they are transferred from the lab. I can't tell whether the Not-Invented-Here (NIH), syndrome is discipline related or whether it is a general American trait. My favorite story is one that escaped IBM:

   Gene Amdahl suggested that bonuses would be given to groups that used the work of others, to which one of his colleagues replied, "That's un-American..." and the bonus scheme was rejected.

2. The Japanese are better coupled to American and world research and are able to incorporate research results into products. They are also patient and willing to invest in the long term. My own career started 25 years ago as a member of MIT's Speech Research Laboratory, using one of the first transistorized computers, the TX-0. I worked on the speech problem a year and helped write the first paper on one of the basic techniques of voice recognition. Then I left the field, because I only like to work on a problem 3 to 6 years and I predicted this one would take 20. It has, in fact, taken about 25 years to develop useful speech recognition products. In contrast to me, two visiting Japanese researchers also worked at the lab. One is now a professor of speech at Tokyo University, patiently extending the technique we worked on 25 years ago. The other researcher spends, alternatively, time at Bell Labs and at Nippon Telephone and Telegraph. The NEC recognizer, one of the first products on the market, was developed by a Japanese alumnus of the lab.

3. Engineering training must address industrial competitiveness. This includes processes and the effect of errors on them--the basis of quality control. We have not yet learned that most product quality problems are the result of poor engineering.

Suggestion. A general course for all engineers on the Theory and Structure of Processes might help. It would deal with the analysis and synthesis of VLSI, general digital systems, and software. The course would cover the processes that create each of these systems, as well as the description, structure, mathematics, and other tools which explain behavior (i.e. performance), especially in light of unreliable and faulty components. Understanding economics and quality would be by-products.

Suggestion. A directed, professional manufacturing engineering education program could increase the number and quality of input from essentially zero; raise professional standards; cut down the obsolescence and narrowness of existing engineers; and create broad, interdisciplinary engineers for manufacturing--perhaps just focusing on semiconductors. Universities could start right now and have a prototype program operating within a year. This program would grant a professional degree in manufacturing engineering. It would be designed for the engineers who might otherwise mistakenly stumble into MBA school. Its purpose would be to immerse students in manufacturing environments in the same way as professional schools immerse them in professional environments. Were it to take on the manufacturing challenge, MCNC would be an excellent place to intern. As in other professional schools, the case-study method would be used and tools would be introduced as needed, instead of concentrating on the teaching of tools as we now do in each of the continually narrowing engineering disciplines. An engineering degree without a particular discipline may be the best approach to avoiding technical obsolescence. Complex products and processes require an interdisciplinary approach to design. Physics departments once trained engineers on an interdisciplinary basis, including mechanics, electricity, magnetism, and optics. Today, none of these are taught with much depth, and we have no optics industry.

INEFFECTIVE, LARGE INDUSTRIAL ORGANIZATIONS

Our large industrial organizations are not meritocracies, nor are they committed to excellence and dominance in manufacturing. Distributing Japanese goods, establishing offshore manufacturing, and buying plants from Japan (e.g. the Toyota/GM Saturn plant) are all much easier than doing the hard work necessary to design a competitive, fully automated plant. Auto industry competitiveness appears to be tied to trade barriers, not good management. With unrestricted auto imports, the auto industry will again return to unprofitability, reduce their capital spending, and hasten the next recession. Industrial ills are attributed to poor government and investment policies, but the reality is that industrial leaders simply do not have an understanding of products and manufacturing. Consequently large-organization politics is their main output. I believe investors would welcome and support any manufacturer that is committed to being Number One.

The better large organizations such as Xerox fund research and contribute ideas and people for venture-capitalist-funded startups, but this does not solve the manufacturing problem.

Suggestion. Every corporation must be made accountable for trade and manufacturing competitiveness. The simplest solution is to impose and enforce stiff tariffs on imports, but a progressive incentive scheme to encourage manufacturing human and capital investment might help more.

UNREALISTIC RELIANCE ON VENTURE CAPITAL (VC) AND ENTREPRENEURIAL STARTUPS

We have accepted the proposition that large organizations cannot bring innovations to the marketplace. For every innovative product or aggressive automated manufacturing plan, at least two committees are determined to prevent its implementation in a large company.

Thus, we believe that small entrepreneurial companies such as Apple are the only way to save American industry, by inventing new products and establishing new industries. Unfortunately, for every Apple there are tens of crabapples, because the underlying motivation, getting filthy rich, is not a sound foundation for a company. The entrepreneur is quite overrated, as nearly all of them are unqualified to actually run a business. They possess only the notion that a product is needed in the market and that they should be rich.

Too much venture capital is available as overvalued companies are sold to the public at over 100 times their sales values. While new companies may appear to be the ONLY source of new product innovation, their net effect is generally deleterious, because new and well-formed industries become quickly overfunded and people who could work on the hard problem of manufacturing are diverted to the easy problem of a new-product startup.

Adam Osborne commented that... "There are a few very bright, very good venture capitalists, but most are what you get when you cross sheep with lemmings."

At least half of the venture capitalists are completely unqualified to fund or be part of the operation of any company, simply because they are composed of lawyers and MBAs with neither operational management or technical skills. I did a study (published in the October 1984 Computer Magazine) on the 92 US companies that were formed to build minicomputers in the period around 1972, using small and medium-scale integrated circuits (which lowered the barrier to building computers). Today only 7 are profitably building computers. Another 16 still exist, either in niches or to torture their user base, and the failure rate would be lower if the financial infrastructure needs to sustain the marginal companies in order to sustain high valuations. The situation will be much worse in companies building PCs, micros, and workstations, which are now numbered in the 100's.

While venture capital and entrepreneurial greed appear to be a key motivation in the formation of a new company, an equally strong motivation is the frustration encountered in large organizations which push people out. They are only the catalysts of change. Venture capital money could be applied to automated manufacturing, but it is not, because large companies and universities, the source of new ideas, are not generating the technology which is the basis for most startups. Small companies are not the saviours.

A recent startup has an elegant disk design. It is going to be manufactured on an automatic line in Japan, because the people and investment are not available here. This will further hurt the floundering disk industry while making a few folks in Silicon Valley rich and famous as entrepreneurs. Both startups and large corporations are doing more joint projects in the Far East because the manufacturing technology is there, because labor costs are lower there, and because it is too hard and too dirty (or too clean) to do ourselves.

STRUCTURE AND BEHAVIOR OF THE SEMICONDUCTOR INDUSTRY.

The US semiconductor industry is unable to meet the needs of the next generation which will be based on fully custom-integrated circuits as required by users. Furthermore, all signs point to the beginning of a rapid decline in this industry. Because I am so close to this industry, I do not believe that the problem is the simple incompetence of large, established organizations. The leaders, many of whom have come from a science and engineering background, are among the brightest people in US industry. The Silicon Valley environment, with its focus on starting new companies, has enormous turnover. This environment values only short-term, high-payoff products and not long-term processes.

Clearly, the US position in semiconductors has slipped, and this is only the beginning (Table 4).

Table 4

SEMICONDUCTOR MARKET SHARE
DATA BY COUNTRIES

	Worldwide Production ($ Millions)	U.S.	Japan	Europe
1980	$14,130	47%	27%	23%
1981	14,250	43	34	19
1982	14,064	44	36	18
1983	17,767	44	37	17
1984	25,463	43	40	15

Source: Hambrecht and Quist

The Japanese accept less profitability and this is directly linked to the fact that US investors can get higher returns by investing in distributor companies such as Sears. (Table 5)

Table 5

NET PROFIT MARGIN COMPARISON
OF SEMICONDUCTOR COMPANIES

	1976	1978	1980	1982	1983	AVERAGE
JAPANESE COMPANIES						
Nippon Electric Co.	1.2%	1.0%	2.1%	2.3%	2.5%	1.8%
Toshiba	0.2	1.3	2.4	1.6	2.2	1.5
Fujitsu	2.8	2.4	3.9	5.0	5.5	3.6
Hitcahi	3.2	3.8	3.9	3.8	3.8	3.7
U.S. COMPANIES						
Motorola	6.0%	5.8%	5.8%	4.5%	5.6%	5.6%
Texas Instruments	5.9	5.5	5.2	3.3	(3.2)	3.8
Intel	11.2	11.1	1.3	3.3	10.3	9.2
Advanced Micro Devices	4.2	5.5	10.3	3.2	5.9	6.5
National Semiconductor	5.8	4.6	4.9	(1.0)	(1.2)	3.0

Source: Hambrecht and Quist

The concern now is for the future, where last year's investments will directly result in new, lower-cost processes (Table 6).

Table 6

SEMICONDUCTOR COMPANY CAPITAL SPENDING
($ Billions)

	1981	1982	1983	1984
U.S. (10 companies*)	1.1	1.0	1.1	2.0
% Sales	18.0	16.0	14.0	19.0
Japan (9 companies)	.8	1.0	1.5	3.2
% Sales	17.0	19.0	21.0	30.0

* not including IBM

Source: Hambrecht and Quist

Companies have become enamoured with building computer components in what is now fundamentally a semicomputer industry and have given up the base technologies, including large and fast memories and very fast logic, together with the infrastructure. By building only microprocessors, companies neglect all of the customers who build either noncomputers or computers bigger than PCs or workstations. For example, it took startups to establish a source of custom and gate arrays. The constant stream of startups (Table 7) further churns the supply of available talent who should be able to innovate within large companies in Silicon Valley--but who, for some reason, cannot.

Table 7

U.S. SEMICONDUCTOR STARTUPS BY TECHNOLOGY '80-'83

	CUSTOM	LEAPFROG	NEW HI GROWTH	MATURE
1980	4	1	-	-
1981	2	1	2	2
1982	5	2	1	1
1983	5	3	7	3

A major problem is the instability due to economic cycles that the Japanese do not face because their semiconductor companies are part of larger, integrated corporations. Furthermore, companies such as NEC and Hitachi support major material and semiconductor manufacturing research. The challenge for SRC and MCNC is to see whether they can make a difference in semiconductors, an industry that has traditionally shunned research and depended for change on equipment improvements and process evolution through manufacturing learning.

The decline in instrumentation, product test, and semiconductor manufacturing equipment industries continues. The most advanced equipment comes from Canon and Nikon--large, integrated manufacturers. Furthermore, this equipment is available 1 to 3 years sooner in Japan than in the United States. In contrast, our semiconductor CAD/CAM industry software is transported almost instantaneously to Japan. Also, since the CAD/CAM industry is another industry overfunded by venture capital and with too many suppliers, the Japanese only utilize software produced by the stronger, more viable companies and are not tempted to waste time with software from marginal startups.

Suggestion. We must ask:

- How can we rebuild the semiconductor instrument and equipment manufacturing base, given the inherent cycle of capital equipment spending?
- Is it better to have strong, integrated companies like Hitachi and possibly IBM's evolving ownership of Intel?
- How can we have a completely stratified and segmented industry composed of entrepreneurs who:
  - process wafers of each speed and applications segment?
  - design and have built chips for each segmented set of products?
  - distribute?

DEFENSE VERSUS COMMERCE--THEY NEED NOT CONFLICT: AN INDUSTRIAL POLICY

Our most qualified resources are going into defense, without a coupling to the commercial sector which must ultimately provide the funds through taxes. On the other hand, many companies would not move without certain incentives such as DARPA's Very High Speed Integrated Circuit (VHSIC) program. A recent visit to a VHSIC contractor who was building CMOS chips with 1 micron feature size showed only that the commercial side wasn't using it yet, because their decoupled, duplicate effort was not yet operational.

Suggestion. The only way we can afford military funding and provide state-of-the-art parts for defense is by a very strong, synergistically coupled commercial sector.

The notion of an industrial policy was raised in the Young report. We need one which everyone understands. It could become our driving goal, focusing all sectors to operate within a common framework.

> Industrial competitiveness should be our number one goal, followed by defense. The only way to accomplish both goals must be through massive cooperation and common goals. The reason for the prioritization is that, without competitive technology and a solid tax base, there is no way to have and pay for defense. This must be understood by the Defense Department (spenders), Commerce Department (facilitators) and organizations (workers) responsible for US economic viability.

Suggestion. Our national laboratories have been underutilized for 20 years. The Young report mentions that these 700 laboratories spend 1/6 of our R&D money, and suggests that they be given a vital role in fostering industrial competitiveness. Japan's labs do a significant amount of the front-end, gatekeeping research that makes them vital. In a recent review of a defense group, I commented that the work could be done in less time and with less effort by using a particular modern method which would result in a nearly two-orders-of-magnitude decrease in cost. The main rebuttal was, "Why change such a good business?" I thought that their job was defense. Just as our commercial manufacturers (e.g. GM) have become purchasing agents and distributors for Japanese goods, the military has become purchasing agents. General Dynamics, Martin-Marietta, and the plethora of beltway bandits who merely integrate technology in unreadable proposals for unworkable specs should be fully nationalized! Why should there be any concept of profit in building military systems?

Suggestion. The fact that high quality bombs are successfully researched and produced by national facilities argues for nationalization. Let's nationalize defense production at General Dynamics, Martin-Marietta and others who have no way of helping commerce today because their sole business is with their military hostages. The goal is higher productivity versus the current system, which is founded on and reinforces waste and incompetence by underbidding, a formula-driven approach to R&D, and profit. Much of the current effort in defense goes into contracting with and auditing vendors.

Suggestion. My fourth suggestion for industrial/military cooperation stems from a goal of having completely automatic factories by 2001. The manufacture of quality products required for industrial competitiveness and for defense requires significant automation. Industry is both unwilling to risk this investment and not qualified to automate. Robotics and a substantially better computing network structure have to be developed. Universities would have a major role in the automatic world, a world not unlike the Japanese vision of the Fifth Generation.

While factory automation will undoubtedly create concerns regarding unemployment, the other three alternatives are much poorer and generally unacceptable:

1. buy the factories from Japan like GM and Apple did. Since 80% of the components in Apple's MAC are Japanese semiconductors, one can simply look at the MAC as a package for Japanese parts.

2. give up and buy automatically assembled goods directly from Japan as we do with all consumer electronics, the IBM PC and non-IBM mainframes (from Hitachi, Fujitsu and NEC). By 2001, virtually all goods will be made automatically, whether we build them, buy them, or buy the factories from Japan which produce the parts and then package the final products here.

3. establish a trade barrier.

A concerted effort aimed at competitiveness through complete automation would aid both American industry and defense.

WILL THE UNIVERSITIES SAVE US?

As we work on the problem of competitiveness, the universities are again asked to help. A recent conference on Continuing Education at MIT criticized universities as being both obsolete in what they teach and unable to meet the requirements of continuing education. A university has evolved into unmanageable complexity while at the same time forcinig the most talented and critical resources to leave.

1. The faculty is organized into departments. Some faculty members whose interests are difficult to codify into departmental lines have joint appointments among departments. Laboratories crossing departmental lines are formed to carry out projects. Institutes are created for interdisciplinary projects, crossing schools (or "deanships"). Often, "hot" technical fields, such as engineering, "support" other departments covering the "overhead" of the entire institution. Until recently, faculty salaries were governed by rank and tenure, not market

conditions. The "industrial affiliates" program is used to raise incremental departmental money and to provide some coupling to industry.

2. Many government and industry funding sources force present conflicting projects in science, engineering, and near-term work. If a university is very good, a company may set up a lab on the premise, complete with industrial-level security to develop and transfer technology rapidly, forcing a short-term focus and conflict with their basic charter of open knowledge production and science. Individuals also work for companies on a consulting basis.

3. If a good idea starts to form in a laboratory, a venture-capital conduit will carry students and faculty out to start up companies. When industry really gets behind technically, or when an area requires much capital, external consortia are set up to carry out people and to couple with the faculty.

5. Since fields are evolving more rapidly, technical obsolescence is more prevalent. Industry asks for continuing education programs which further strain the limited facilities.

While the need for all of these activities is clear, we must question the overall effect in terms of increased complexity and availability of finite resources. Are we getting more research, engineering, or whatever done? Organizational complexity is one of the greatest forms of nonproductivity today. As part of a small startup operation, I see how much a few, dedicated individuals with clear goals can accomplish, compared to a cast-of-thousands, complex-interaction, conflicting-goals approach.

Suggestion. We must ask what industry can do to help in the problem of growing complexity and the strained resources. Are we asking universities for too much already? Are we asking for education based on the latest technology rather than on fundamentals?

THE INDIVIDUAL

The single individual contributor or leader is probably our greatest strength, (even though we do not follow through and maintain market share as a field matures). A few individuals completely establish an industry. Today, the United States is number one in being able to generate graphics and images, the basis of CAD/CAM--even though this area is greatly overfunded. The mechanical computer-aided-manufacturing idea came out of the Automatic Programmed Tools Project headed by Doug Ross at MIT in the 50's. Virtually all of today's graphics came from the work of students of Evans and Sutherland at the University of Utah in the late 60's and early 70's. Cray builds the world's supercomputers. Larry Roberts and Bob Kahn brought about ARPAnet and packet switching. Surely someone can take on the fully automatic semiconductor factory.

WHY THE JAPANESE WIN

Table 8 lists the technologies that the Japanese now dominate as measured by price, performance, and quality. The reasons for this excellence in engineering and manufacturing are varied, but a list, compiled from my first visit to Japan in 1978, includes:

- Teamwork, including government (especially MITI) sets goals.
- Government management of trade barriers supports domination--despite the fact that we believe this is un-American. Trade barriers must go up in order to restore our fundamental ability to manufacture.
- Company loyalty promotes risk taking versus individual freedom and entrepreneurism.
- Quality is understood and managed throughout an organization.
- Time and quality are compulsively measured and managed.
- The Japanese live to work and learn. They are also smarter by 10 IQ points and rank highest in mathematics and science achievement tests.
- Their resources go for trade instead of Nobel prizes. We also spend several hundred billion dollars per year of nonproduction for defense.
- With egoless designers, they zealously acculturate world science, engineering and designs. They are now beginning to do science. They balance their investment in basic and applied research, development and manufacturing. (Science is a luxury, not a necessity.)
- They understand materials, manufacturing and process investments, including the capital investment strategy for domination, and they understand our greed need as marketers and distributors.
- In general, management objectives look toward long-term industrial growth instead of toward short-term market advantages.
- Japanese products are sophisticated and of high-quality, not low-cost throw-aways.
- They have a commitment to computers and especially to robotics.
- Instead of MBAs and lawyers, they have trained engineers who can design products and operate factories.

- Japan has invested its savings in industry with a single-minded commitment to quality and export.
- They are fundamentally a closed society and, by our rules, don't play fair.

TABLE 8

JAPNESE TECHNOLOGY DOMINATION*

- Generic materials, processes and quality
- Displays: crt, lcd, electroluminescent
- Printing: impact, xerography
- Memories: magnetic disks, electro-optical disks, video recorders
- Voice and audio products
- Communications and fiber optics
- Packaging including ceramic substrates and printed circuit boards
- Semiconductors: bipolar ram, bipolar gate arrays, MOS/CMOS ram and gate arrays, small microprocessors.
  Products...research results
- Computers: large and PC
- Robotics and automated factories

*As measured by state-of-the-art or market share

The Japanese strategy for industry domination has traditionally followed a four-step process:

1. Development of a domestic Japanese industry.
   a. Market control by limiting imports
   b. Borrowing and licensing technology
   c. Vertical integration of manufacturing and manufacturing processes
   d. Major, planned investments in manufacturing, research and development
2. Establishment of an export market base.
   Sales, market research, quality products and limited focus to gain acceptance
3. Major market penetration.
   a. Cooperation with other Japanese manufacturers to segment markets
   b. Focus on mainstream market
   c. Lower initial prices to gain market share

4. Market exploitation after the local industry has been eliminated.

With the goal and capability of complete automation, their strategy may have already changed. Automatic factories may be established to serve "local" markets through joint ventures such as Apple and GM.

MCNC'S ROLE IN COMPETITIVENESS

Suggestion. Do things that are unique to a $100M semiconductor facility that can support research. MCNC is one of the few places outside of Bell Labs and IBM to research the manufacturing process and train scientists and engineers.

Suggestion. Do not work on CAD tools. These are easy grist for universities, existing or venture-capital-based companies, and the software cottage industry, where there is no highly capitalized semiconductor facility.

Suggestion. If you want to accelerate CAD/CAM, catalyze standards across the myriad of existing tools. Focus on interoperability for the behavioral and physical hierarchies, together with CAD, CAM and CAT. A recent issue of VLSI Design listed 23 incompatible logic simulators for sale, not counting the myriad available within each company or the many efforts sponsored by DARPA's Very High Speed Integrated Circuit (VHSIC) program. A similar statement may soon be made about automatic layout tools, including silicon compilers.

Suggestion. If you have developed a variety of CAD tools, such as VIVID, sell them and use the proceeds to fund the institution. Recognize that MCNC is an alternative form of venture capital for low risk, high payoff to the developers! The resources going into MCNC software could be better spent in the process development area. Software is technology and, because it can be transferred easily, benefits producers more rapidly than any other sector.

Suggestion. Computer Aided Manufacturing (CAM) is another matter. Do it if it leverages and utilizes your facility and no one else can do it. Make partnerships with existing CAM companies to test and enhance their software.

Suggestion. Do not focus on product designs which will absorb even more software resources. The existing MOSIS infrastructure can handle university designs. Your $100M facility isn't needed to do this, and building with vanity chips may only get in the way of attaining higher densities.

Suggestion. Take on the hard, multilevel interconnect structure that will let anyone build high-performance systems. This means the chips and the packages. Don't stop at the chip interface, because we now lose at least 2/3 of the on-chip performance in the physical interconnect. A radical wafer-scale integration or silicon interconnect would leverage the facility. This is a hard, but fertile, area of research. Make alliances with those who would use your foundry and, if there is something worthy of a radical process, be prepared to exploit it. None of the chips being designed in your universities have this capability!

Suggestion. The highest priority is the complete automation of the semiconductor factory for quality and for the fallout in learning to do it--that is, the training of interdisciplinary engineers. The low, varied, 100-wafer-per-week rate will challenge the understanding of yield and manufacturing learning. Innovation in the 90's will be in designing, building, and running automated factories for the devices and interconnects, rather than innovative devices and processes. Communication will be electronic--which MCNC must catalyze, or the silicon founderies will be in Japan.

Suggestion. Infrastructure becomes very high priority. Infrastructure is a collection of standards which allow a set of industries to form and build a complex system such as a computer system or a semiconductor chip. MOSIS at the USC's Information Sciences Institute has a process from design to complete system test, under a formal set of protocols and completely automatic. The status of MOSIS, 1983, is given in Table 9. This will allow an industry restructuring which will segment design from manufacturing, letting us build completely automatic founderies, while at the same time unleashing our creativity on a geography-independent basis for new designs. This will benefit smaller groups who are the source of most innovative products. MCNC can play a vital part by segmenting its own work, improving MOSIS standards, and utilizing the infrastructure for both designs and as a foundry.

Table 9

MOSIS, USC'S/ISI (1983)

- 1200 LSI/VLSI designs processed from 50 institutions at $3,000 per design
- 10 foundries and 4 mask shops
- 3-4 micron, MNOS, CMOS, CMOS/SOS
  1-3 micron (scaleable), double metal, CMOS
- Printed circuit boards

The Fifth Generation may just be the ability to put arbitrary algorithms into silicon on VLSI (>2M transistor) chips. It is what Carver Mead calls the silicon foundry--a merger of software, semiconductor and systems. Various companies have emerged to utilize this industry structure. Table 10 lists some of the areas and companies that are involved in silicon algorithms. With this true Fifth Generation identified, we can reach it. The Japanese Fifth Generation based on artificial intelligence and a high degree of parallelism is most likely the Sixth Generation. Let them work on it and then we'll use their ideas to produce the products and regain manufacturing supremacy.

Table 10

SILICON FOUNDRY/SILICON ALGORITHM INDUSTRY
(Software in Silicon)

- Fast, microprocessors (MIPS)
- Arithmetic and High Performance Graphics (Weitek)
- Picture Transformation Workstation (Silicon Graphics)
- Text String Search and Database Operations
- Signal Processing (TI, Kurzweil Applied AI)
- Communications, LANs, Protocol conversion
- Simulation, Routing, Placement, etc. Engines

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