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A surge for solid state

Revitalization of the U.S. semiconductor industry may depend on supplying unconnected transistors and letting the buyer specify on-chip interconnections

BUSINESS

OPINION

The loss of leadership in the 256K RAM market to Japan is merely a symptom of the revolutionary upheaval in the U.S. semiconductor industry. Can the industry be rejuvenated? Ironically its greatest hope lies in a return to its roots: supplying unconnected transistors on integrated circuits so that users and algorithm designers can specify the on-chip connections according to the needs of the applications.

The causes of the U.S. semiconductor industry's troubles run deep. They include not only fierce competition from Japan but also such factors as changing patterns in the manufacturing and selling of chips, and rising demand for circuits tailored by buyers for specific uses.

A fast look at the evolution of the semiconductor industry's structure reveals the origin of some of its problems. When a chip held only a single transistor, semiconductor manufacturers and miconductor users were distinct. The manufacturers owned the ies, made the transistors, and sold them. Users bought the ps (the transistors) and assembled them into a hierarchy of logical circuits to form computers. Computers made with discrete transistors formed the second computer generation, in contrast to the first generation, based on vacuum tubes.

The third computer generation was based on small-scale integrated circuits (two to 64 transistors) and medium-scale ICs (64 to 2000 transistors). Although this development was seen as a hardware advance, it had another and ultimately even greater significance: for the first time, semiconductor manufacturers integrated the logic functions—the first step in blurring the distinction between manufacturer and user.

At the time, however, it was not the organizational change that captured the attention of the technical community, but the exciting application possibilities of the new technology. About 100 new companies—including Data General, of Southboro, Mass., Systems Electronics Laboratory, of Ft. Lauderdale, Fla., and Prime Computer Inc., Natick, Mass.—were formed to use these devices in building minicomputers. Digital Equipment Corp. (DEC), which was established during the second generation, had built the first PDP-8 minicomputer in 1965 using its own transistor circuits.

Changes in the industry's organizational structure accelerated with the fourth generation of computers, based on large-scale integrated circuits (2000 to 64 000 transistors). Many semiconductor manufacturers that provided simple processors, memory, and peripherals for controlling disks, CRTs, and communications lines transformed themselves into "semicomputer" companies. By 1980 the evolution of complex, powerful, inexpensive chip-based computer components led to new computer types—personal, portable, p, workstation, shared-micro, and multicomputers—and iora of new companies to make them.

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Three factors cutting U.S. market share

Three major factors have contributed to serious erosion of the customary markets served by traditional, large, full-line U.S. semiconductor manufacturers: competition from the Japanese semiconductor industry; the advent of specialized larger-scale parts; and reduced demand for traditional chips.

The Japanese government's policy of investing heavily in Japan's technical and industrial infrastructure continues to bear rich fruit. During 1983 and 1984 Japanese capital equipment investments for semiconductor manufacturing were 1.6 times those in the U.S. ($4.7 billion, compared with $3.1 billion). This investment, combined with the successful results of previous investments in the optics and microprecision industries, is a strong base on which Japan can now build its domination in semiconductors.

The results are already impressive. The Japanese industry leads in sales of 64K, 256K, and 1M RAMs, not to mention ECL RAMs and ECL and CMOS gate arrays. This dominant position in the market segment with largest sales and lowest manufacturing costs is a direct result of a well-conceived investment program of the Ministry of International Trade and Industry (MITI) in the late 1970s; it gave the Japanese industry a full two-year lead in CMOS processing.

This in turn has carried Japanese semiconductor makers two years farther down the cost-experience curve than their U.S. competitors—a real cost advantage, quite apart from any charges of predatory Japanese pricing and photographic copying of U.S. chips. [See "Solid state," *Spectrum*, January, p. 53.] The U.S. industry's investment in the design and tooling of the larger RAMs will earn a negligible return, because it was done too late to allow the industry to attain dominance and cost advantages in the technology. U.S. semiconductor manufacturers are completely withdrawing from the RAM market.

Because CMOS is the "crude oil" for virtually all chips, from simple gate arrays to microprocessors, the U.S. industry's future is not promising in these areas either. Japan has been exporting CMOS gate arrays to the United States for two years, both directly and through the LSI Logic Corp., Milpitas, Calif. In contrast, U.S. manufacturers have been slow to supply user-designed, application-specific ICs (ASICs) in any form.

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Startup companies a mixed blessing

New ventures are generally regarded as a U.S. triumph. Entrepreneurial, single-focused startup companies, financed by venture capital, usually outperform the large, functionally oriented companies. They hire top personnel from established large companies, have higher motivation through entrepreneurism, and make rapid and more relevant decisions. But the social and economic costs to the industry as a whole are usually overlooked.

The startup companies stimulate a pattern of job-hopping throughout the industry, and this churning causes inefficiency and delays in market development. The frequent observation that the Japanese industry lacks this entrepreneurial mechanism is misleading, because Japanese companies often invest in new, creative U.S. companies with few of the negative side effects for their own stable industries.

The U.S. semiconductor industry's "cash cow" has been highly functional, special-purpose chips that sell at high prices. Such chips are specified by an engineer-marketer who obtains buy-ins from several dozen customers. Only after enough customers have subscribed is the chip actually designed and produced. Inevitably some potential customers will buy in only if changes are made in the specifications. This procedure has worked reasonably well in the past, but fourth- and fifth-generation chips are too complex to be specified in this committeelike fashion.

Another aspect of the problem is that the semiconductor companies cannot hire enough designers capable of complex algorithms in silicon. Most of the qualified designers are at systems companies like DEC and IBM or at specialized software companies like Cullinet Software Inc., Westwood, Mass., or Relational Technology, Alameda, Calif., which produce database software. The absence of a microprocessor good enough to take on D recent MicroVAX II chip is typical.

Needed: a better microprocessor

Although microprocessors are absorbing a substantial portion of the U.S. semiconductor industry's intellectual and financial resources, they give the industry little in return. The pricing of these chips is based on manufacturing cost rather than total cost or value, so margins are bound to be low. The market is glutted with poor microprocessors, but there is a severe shortage of very good up-to-date ones.

The semiconductor industry has not yet produced any microprocessors having a modern architecture. Such a processor could replace nearly all other computer types, including minicomputers and mainframes. The proposed million-instructions-per-second (MIPS) instruction-set architecture of the U.S. Defense Advanced Research Projects Agency is an excellent first step. The ideal processor would have the following characteristics:

- A large virtual and physical address capability (equal to or greater than 32 bits).
- Paging.
- Support for the common "C" data types, including characters, floating-point numbers, and integers large enough to hold addresses.
- Compatibility with other language data types—for example, decimal if it is to excel in Cobol or vectors for scientific use. However, there is no need for backward compatibility with early, object-level machines.
- Availability with a choice of either VAX/Intel/National or IBM/Motorola byte orderings, to be compatible with several decades of user data.
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- Use in multiprocessors.

Such a chip, without floating point, need be no larger than 64K transistors—barely VLSI. —*C.G.B.*

DEC's chip effort began in 1972, and the effort has produced a number of 16-bit chips that have outperformed comparable commodity microprocessor chips. The 32-bit MicroVAX chip is the first high-quality microprocessor to become available—if only to DEC—that is complete with operating systems and languages. DEC has learned how to build semiconductors more rapidly than any of the semiconductor companies have learned to design microprocessors. And processors are the most trivial of system designs.

If this were not serious enough, many new companies are emerging to build chips in a single market niche. These companies are currently manufacturing read-only memories, programmable logic arrays, analog-digital converters, signal processors, and other high-performance custom chips. For example, Altera of Santa Clara, Calif., and Xilinx of San Jose, Calif., have introduced two alternative approaches to fully programmable chips to substitute for the fully random logic portion of systems.

User demand is shifting

Systems companies are designing more frequently with gate arrays and standard cells. This is a fundamental shift away from small-scale integration, medium-scale integration, and other, even more expensive chips, because chips are now being specified by the individual user. These chips are no longer a realization of compromises among several users in the characterization of products. Traditional semiconductor companies are ill-equipped to cope with virtually all forms of custom parts, including gate arrays. Ironically the largest U.S. supplier of gate arrays is LSI Logic, a five-year-old company that uses Toshiba's foundry in Japan.

Some systems companies are beginning to make full-fled custom parts by using tools ranging from simple gate-array to full silicon compilers. This not only reduces the dem d traditional integrated circuits, but also shifts overall demand from traditional semiconductor companies to custom foundries.

An unrelated reason for reduced demand is the tendency for U.S. manufacturers like Honeywell of Minneapolis, Minn., to become distributors, and for other manufacturers, including DEC and IBM, to move the manufacture or purchase of such items as disk drives, personal computers, and printed circuits from the United States to the Pacific rim—Singapore, Korea, Hong Kong, Taiwan, or Japan itself. When systems or subsystems are manufactured "on the rim," integrated circuits are supplied directly from Japan to the manufacturers.

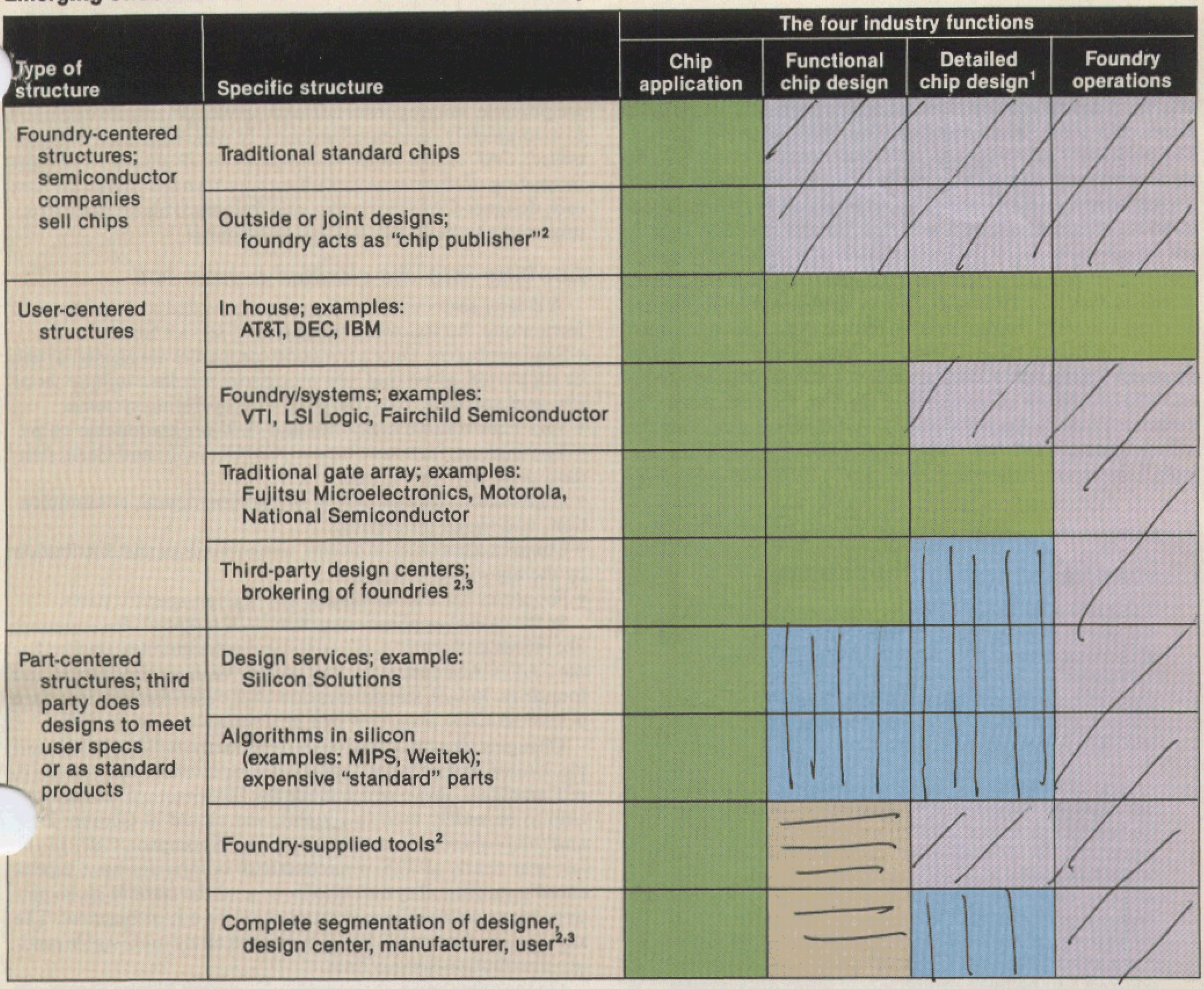
Finally, large companies such as AT&T, DEC, and IBM now satisfy a large part of their semiconductor needs through vertical, in-house manufacturing.

A new organizational model is emerging for the semiconductor industry's companies, based on the recently developed ability to translate functional designs into integrated circuits by use of silicon compilers such as that supplied by Silicon Compilers Inc., San Jose, Calif., and other high-level tools for designing fully custom VLSI. VLSI Technology Inc., San Jose, Calif., is the first company operating in this fashion to produce application-specific chips.

The "silicon algorithms" used in these compilers are a kind of software, and the design and organizational styles of the companies or company units using silicon compilation to design complete chip systems are more like those seen in software companies than those in semiconductor or systems companies. Ultimately, large software houses with proprietary software may produce proprietary chips for added value and performance.

Based on the new model, a new silicon foundry and s algorithm industry is springing up and displacing the traditio industry from portions of its historical market. Several application-specific chips are emerging from companies that have neither factories nor proprietary tools; the chips are based instead on

Emerging structures of the U.S. semiconductor industry



Type of structure	Specific structure	The four industry functions			
		Chip application	Functional chip design	Detailed chip design[1]	Foundry operations
Foundry-centered structures; semiconductor companies sell chips	Traditional standard chips	🟩	▨	▨	▨
	Outside or joint designs; foundry acts as "chip publisher"[2]	🟩	▨	▨	▨
User-centered structures	In house; examples: AT&T, DEC, IBM	🟩	🟩	🟩	🟩
	Foundry/systems; examples: VTI, LSI Logic, Fairchild Semiconductor	🟩	🟩	▨	▨
	Traditional gate array; examples: Fujitsu Microelectronics, Motorola, National Semiconductor	🟩	🟩	🟩	▨
	Third-party design centers; brokering of foundries [2,3]	🟩	🟩	▥	▨
Part-centered structures; third party does designs to meet user specs or as standard products	Design services; example: Silicon Solutions	🟩	▥	▥	▨
	Algorithms in silicon (examples: MIPS, Weitek); expensive "standard" parts	🟩	▥	▥	▨
	Foundry-supplied tools[2]	🟩	▤	▨	▨
	Complete segmentation of designer, design center, manufacturer, user[2,3]	🟩	▤	▥	▨

1. With CAD tools or silicon compiler
2. Structure does not yet exist
3. CAD system prices will affect existence of design centers

🟩 User
▤ Designer of chip functions
▥ Design center (converter of functional design into detailed chip design)
▨ Foundry or manufacturer

Color indicates who controls or owns the various functions under each structure

the ability to convert an application or algorithm into silicon. These chips, with their sole or typical suppliers, include:

- A fast, powerful microprocessor (Mips Computer Systems, Sunnyvale, Calif.).
- Fast floating-point and graphics processors (Weitek, Sunnyvale, Calif.).
- A picture transformation workstation (Silicon Graphics, Sunnyvale, Calif.).
- Text-string search and database processors.
- Signal processors (Kurzweil AI, Waltham, Mass.).
- Communication, LANs and protocol conversion chips.
- Chip simulators (Silicon Solutions Corp., Menlo Park, Calif.).

Restructured industry in the offing

The advent of silicon compilers and independent silicon foundries has opened the possibility of new structures for the semiconductor industry. The alternative ways in which chips can be ed, designed, supplied, and used can determine how the try's basic activities are apportioned among users, designers, suppliers of computer-aided-design tools, and foundries. The four basic activities can be organized into 10 different structures of three basic types: foundry-centered, user-centered, and part-centered [see table]. The three types are indicated in the first column of the table. The specific structures, with examples, appear in the second column. The last four columns indicate the four basic chip-producing activities, and the color coding shows who controls each basic activity for each possible structure. The two traditional industry structures are represented by the semiconductor company that controls the entire design and fabrication process and then sells the chips (Row 1), and the in-house operation that makes chips for internal use (Row 3). The most interesting new structure is forming around independent design services (Row 7).

There were formerly only two basic structures: (1) the traditional semiconductor industry, with product design and foundry owned by the manufacturer, which sells to users that connect the products to form computer systems; and (2) the vertically integrated in-house organization, with use, design, and foundry within a single, user-dominated organization.

With the cost of designing chips dropping dramatically, the seven additional industry structures become feasible, because detailed knowledge of a circuit's intended function—that is, the silicon algorithm—becomes the significant asset and may dominate in determining the value of the chip. One possibility that varies only slightly from the traditional structure is for traditional semiconductor manufacturers simply to pay a user chip royalties when the user defines a chip that is made by the manufacturer. In this structure, the manufacturer would function much as a book publisher does. This analogy is valuable because it can lead to exploration of the various ways in which publishers have been restructuring themselves, which might serve as models. For instance, most publishers no longer operate their own printing plants (foundries), and many assign the copy editing and typographic design (the actual chip design based on silicon compilation) to free-lancers. The publisher's key functions are selecting manuscripts (silicon algorithms) and distributing the finished works (selling chips).

User-centered designs can be accommodated by the traditional in-house organization, by a separate foundry that may or may not supply tools, or by the introduction of a third-party design center. If the user goes to the design center to manage the project as well as design it, the result could be the brokering of foundry services. The MOS Implementation System (MOSIS) center, operated by the Information Science Institute of the University of Southern California in Marina del Rey, provides this service for universities and for contractors of the U.S. Defense Advanced Research Projects Agency (Darpa), and it is now extending the service to companies [see "The one-month chip: business outlook," *Spectrum*, September 1984, p. 47]. If the user takes a design to the foundry for project management, the design center could be hired by the foundry, much as a free-lance typographic designer is hired by a publisher.

Industry representatives comment

Spectrum *asked several leading representatives of the U.S. semiconductor industry to comment on this article of C. Gordon Bell's. There was both agreement and disagreement; some of those questioned preferred not to enter into a public debate. We have therefore selected some of the dissenting opinions for presentation here without identifying the sources.* —Ed.

- "Lost-cost design is here. Bell speculates on a number of ways in which this new capability can be used. He seems to prefer a 'boutique' approach—algorithm boutiques, design boutiques, foundry boutiques—and indeed this trend is already apparent and perhaps irreversible. One difficulty with this approach is that our primary competitors, the Japanese, are going to address the problem with very large vertically integrated companies with vast financial resources. These resources can be used effectively in integrated *design* price wars just as effectively as they can in integrated circuit price wars. When will we have our first *design* dumping case?"
- "The problems cited are real ones for the semiconductor industry and for the small equipment manufacturers. Solving these problems will help but it won't save the semiconductor industry. The questions for the semiconductor industry are 'Do we want to be in the major leagues or do we want to be relatively small-volume manufacturers?' and 'How to we get the financial muscle to compete with the Japanese?' Volume is vital. Without it we'll lose the leading edge of design capability. Until you get to a volume of 1 million or 2 million per month, you're still in the pilot stage. Custom products (or application-specific ICs as they're now being called) is not where the money is to be made. Money is made in commodity products when there's a product shortage."
- "Advanced design techniques have been pioneered in the United States, not Japan. This should lead to American advantage as the restructuring envisaged by Bell occurs. But that will not happen if the prospect for return on the necessary investment is bleak, as it is today."
- "Higher segmentation of the market will not occur if there is significant advantage in participating in many segments. This is true in semiconductors, as the design and manufacturing technology has much in common and the output is delivered to the same customers, in large part."

Another newly emerging type of structure is based on knowledge of the algorithm. At least four alternative industry structures are possible, ranging from a design service (surrogate engineer) to a completely segmented industry in which the user, designer (seller), CAD design center, and foundry are all separate. The most interesting of these structures has three separate organizations: user, designer-CAD-marketing, and foundry. This industry structure seems to be in the process of forming.

Looking into the clouded crystal ball

A clearer segmentation of markets is needed and perhaps will form along the following product and service lines:

- Semicomputers. Only a few good companies are needed or can be supported, given that new processors require a unique set of low-level software, like compilers and operating systems.
- Very high-volume memories and field-programmable chips.
- Very high-performance bipolar, CMOS, ECL, and GaAs standard parts and gate arrays.
- High-volume special niches, like analog-digital, communication, and signal processing.
- Complex algorithms in silicon, using foundries and distribution by the algorithm designers.
- Foundries for user-designed, application-specific parts.

In the case of application-specific ICs, a central clearinghouse like the MOSIS center could establish the design rules, standardize the CAD-CAM databases, and broker the mask production and foundries. In fact, standardization of the user-foundry interface is vital so CAD programs can be developed more rapidly.

Change is already occurring throughout the industry. For example, United Technologies' semiconductor division, Mostek Corp. of Carrollton, Texas, which made the first practical 4K memor chip to be widely used in systems, was closed in October 19 and then sold to a European company, Thompson CSF. In the last year nearly all U.S. semiconductor companies have experienced unprofitability and layoffs beyond the normal cyclic pattern. Many companies will retrench or go out of business. The key to retrenchment will be segmentation along more stable product-distribution-service lines.

On the other hand, the company European Silicon Structures is starting up in France and the United Kingdom to produce ASICs by direct writing on the wafer, with two-week turnaround and volumes suitable for most system applications.

This company and the many others emerging to exploit ultra-large-scale integration are examples of a semiconductor industry restructuring, not a semiconductor recession. Whether the traditional industry will play a part in the new market, other than as a supplier of trained people, is unclear.

To probe further

The September 1984 *Spectrum* contains an in-depth, multipart report, "The one-month chip," which describes the development of user-designed chips and custom foundries.

VLSI System Design's November 1985 issue contains "Silicon Compilation," a survey by Daniel D. Gajski [p. 48]. The same magazine's January 1986 issue contains the reasonably comprehensive "Survey of ASIC Design Centers" [p. 60], which shows how quickly design centers are developing.

The U.S. semiconductor industry and U.S.-Japanese competition was sketched recently by *Business Week* [Jan. 13, 1986, p. 90].

About the author

C. Gordon Bell (F) is chief scientist for the Dana Group in S nyvale, Calif. He was most recently vice chairman for techno at Encore Computer Corp. Prior to joining Encore, he was vice president for engineering at Digital Equipment Corp. Bell earned his B.S. and M.S. degrees in electrical engineering at the Massachusetts Institute of Technology. ◆

Views: ① Software w/ chips ~ eg. comm, mm, vga.
② No software publishing i.e. royalty for designers and marketing/mfg. done as a book publisher — Cirrus, C+T, Adaptec, ...
③ Paradox: SW has higher value added than (hw)
→ Cypress — A wholly owned sub of designers,

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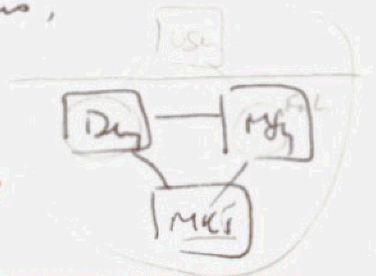

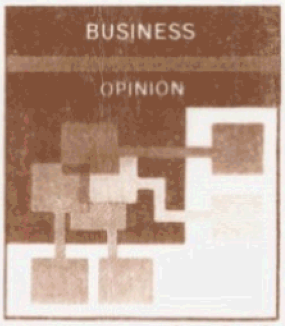

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Such a chip, without floating point, need be no larger than 64K transistors—barely VLSI. —*C.G.B.*

User demand is shifting

Systems companies are designing more frequently with gate arrays and standard cells. This is a fundamental shift away from small-scale integration, medium-scale integration, and other, even more expensive chips, because chips are now being specified by the individual user. These chips are no longer a realization of compromises among several users in the characterization of products. Traditional semiconductor companies are ill-equipped to cope with virtually all forms of custom parts, including gate arrays. Ironically the largest U.S. supplier of gate arrays is LSI Logic, a five-year-old company that uses Toshiba's foundry in Japan.

Some systems companies are beginning to make full-fledg custom parts by using tools ranging from simple gate-array lay to full silicon compilers. This not only reduces the demand traditional integrated circuits, but also shifts overall demand from traditional semiconductor companies to custom foundries.

An unrelated reason for reduced demand is the tendency for U.S. manufacturers like Honeywell of Minneapolis, Minn., to become distributors, and for other manufacturers, including DEC and IBM, to move the manufacture or purchase of such items as disk drives, personal computers, and printed circuits from the United States to the Pacific rim—Singapore, Korea, Hong Kong, Taiwan, or Japan itself. When systems or subsystems are manufactured "on the rim," integrated circuits are supplied directly from Japan to the manufacturers.

Finally, large companies such as AT&T, DEC, and IBM now satisfy a large part of their semiconductor needs through vertical, in-house manufacturing.

A new organizational model is emerging for the semiconductor industry's companies, based on the recently developed ability to translate functional designs into integrated circuits by use of silicon compilers such as that supplied by Silicon Compilers Inc., San Jose, Calif., and other high-level tools for designing fully custom VLSI. VLSI Technology Inc., San Jose, Calif., is the first company operating in this fashion to produce application-specific chips.

The "silicon algorithms" used in these compilers are a kind of software, and the design and organizational styles of the companies or company units using silicon compilation to design complete chip systems are more like those seen in software companies than those in semiconductor or systems companies. Ultimately, large software houses with proprietary software may produce proprietary chips for added value and performance.

Based on the new model, a new silicon foundry and s algorithm industry is springing up and displacing the traditio industry from portions of its historical market. Several application-specific chips are emerging from companies that have neither factories nor proprietary tools; the chips are based instead on

Emerging structures of the U.S. semiconductor industry

Type of structure	Specific structure	The four industry functions: Chip application	Functional chip design	Detailed chip design[1]	Foundry operations
Foundry-centered structures; semiconductor companies sell chips	Traditional standard chips	■	▨	▨	▨
	Outside or joint designs; foundry acts as "chip publisher"[2]	■	▨	▨	▨
User-centered structures	In house; examples: AT&T, DEC, IBM	■	■	■	■
	Foundry/systems; examples: VTI, LSI Logic, Fairchild Semiconductor	■	■	▨	▨
	Traditional gate array; examples: Fujitsu Microelectronics, Motorola, National Semiconductor	■	■	■	▨
	Third-party design centers; brokering of foundries[2,3]	■	■	▥	▨
Part-centered structures; third party does designs to meet user specs or as standard products	Design services; example: Silicon Solutions	■ specs	▥	▥	▨
	Algorithms in silicon (examples: MIPS, Weitek); expensive "standard" parts	■	▥	▥	▨
	Foundry-supplied tools[2]	■	☰	▨	▨
	Complete segmentation of designer, design center, manufacturer, user[2,3]	■	☰	▥	▨

[1] With CAD tools or silicon compiler

[2] Structure does not yet exist

[3] CAD system prices will affect existence of design centers

■ User

☰ Designer of chip functions

▥ Design center (converter of functional design into detailed chip design)

▨ Foundry or manufacturer

Color indicates who controls or owns the various functions under each structure

the ability to convert an application or algorithm into silicon. These chips, with their sole or typical suppliers, include:

- A fast, powerful microprocessor (Mips Computer Systems, Sunnyvale, Calif.).
- Fast floating-point and graphics processors (Weitek, Sunnyvale, Calif.).
- A picture transformation workstation (Silicon Graphics, Sunnyvale, Calif.).
- Text-string search and database processors.
- Signal processors (Kurzweil AI, Waltham, Mass.).
- Communication, LANs and protocol conversion chips.
- Chip simulators (Silicon Solutions Corp., Menlo Park, Calif.).

Restructured industry in the offing

The advent of silicon compilers and independent silicon foundries has opened the possibility of new structures for the semiconductor industry. The alternative ways in which chips can be ed, designed, supplied, and used can determine how the try's basic activities are apportioned among users, designers, suppliers of computer-aided-design tools, and foundries. The four basic activities can be organized into 10 different structures of three basic types: foundry-centered, user-centered, and part-centered [see table]. The three types are indicated in the first column of the table. The specific structures, with examples, appear in the second column. The last four columns indicate the four basic chip-producing activities, and the color coding shows who controls each basic activity for each possible structure. The two traditional industry structures are represented by the semiconductor company that controls the entire design and fabrication process and then sells the chips (Row 1), and the in-house operation that makes chips for internal use (Row 3). The most interesting new structure is forming around independent design services (Row 7).

There were formerly only two basic structures: (1) the traditional semiconductor industry, with product design and foundry owned by the manufacturer, which sells to users that connect the products to form computer systems; and (2) the vertically integrated in-house organization, with use, design, and foundry within a single, user-dominated organization.

With the cost of designing chips dropping dramatically, the seven additional industry structures become feasible, because detailed knowledge of a circuit's intended function—that is, the silicon algorithm—becomes the significant asset and may dominate in determining the value of the chip. One possibility that varies only slightly from the traditional structure is for traditional semiconductor manufacturers simply to pay a user chip royalties when the user defines a chip that is made by the manufacturer. In this structure, the manufacturer would function much as a book publisher does. This analogy is valuable because it can lead to exploration of the various ways in which publishers have been restructuring themselves, which might serve as models. For instance, most publishers no longer operate their own printing plants (foundries), and many assign the copy editing and typographic design (the actual chip design based on silicon compilation) to free-lancers. The publisher's key functions are selecting manuscripts (silicon algorithms) and distributing the finished works (selling chips).

User-centered designs can be accommodated by the traditional in-house organization, by a separate foundry that may or may not supply tools, or by the introduction of a third-party design center. If the user goes to the design center to manage the project as well as design it, the result could be the brokering of foundry services. The MOS Implementation System (MOSIS) center, operated by the Information Science Institute of the University of Southern California in Marina del Rey, provides this service for universities and for contractors of the U.S. Defense Advanced Research Projects Agency (Darpa), and it is now extending the service to companies [see "The one-month chip: business outlook," *Spectrum*, September 1984, p. 47]. If the user takes a design to the foundry for project management, the design center could be hired by the foundry, much as a free-lance typographic designer is hired by a publisher.

Industry representatives comment

***Spectrum asked several leading representatives of the U.S. semiconductor industry to comment on this article of C. Gordon Bell's. There was both agreement and disagreement; some of those questioned preferred not to enter into a public debate. We have therefore selected some of the dissenting opinions for presentation here without identifying the sources.** —Ed.*

- **"Lost-cost design is here. Bell speculates on a number of ways in which this new capability can be used. He seems to prefer a 'boutique' approach—algorithm boutiques, design boutiques, foundry boutiques—and indeed this trend is already apparent and perhaps irreversible. One difficulty with this approach is that our primary competitors, the Japanese, are going to address the problem with very large vertically integrated companies with vast financial resources. These resources can be used effectively in integrated *design* price wars just as effectively as they can in integrated circuit price wars. When will we have our first *design* dumping case?"**
- **"The problems cited are real ones for the semiconductor industry and for the small equipment manufacturers. Solving these problems will help but it won't save the semiconductor industry. The questions for the semiconductor industry are 'Do we want to be in the major leagues or do we want to be relatively small-volume manufacturers?' and 'How to we get the financial muscle to compete with the Japanese?' Volume is vital. Without it we'll lose the leading edge of design capability. Until you get to a volume of 1 million or 2 million per month, you're still in the pilot stage. Custom products (or application-specific ICs as they're now being called) is not where the money is to be made. Money is made in commodity products when there's a product shortage."**
- **"Advanced design techniques have been pioneered in the United States, not Japan. This should lead to American advantage as the restructuring envisaged by Bell occurs. But that will not happen if the prospect for return on the necessary investment is bleak, as it is today."**
- **"Higher segmentation of the market will not occur if there is significant advantage in participating in many segments. This is true in semiconductors, as the design and manufacturing technology has much in common and the output is delivered to the same customers, in large part."**

Another newly emerging type of structure is based on knowledge of the algorithm. At least four alternative industry structures are possible, ranging from a design service (surrogate engineer) to a completely segmented industry in which the user, designer (seller), CAD design center, and foundry are all separate. The most interesting of these structures has three separate organizations: user, designer-CAD-marketing, and foundry. This industry structure seems to be in the process of forming.

Looking into the clouded crystal ball

A clearer segmentation of markets is needed and perhaps will form along the following product and service lines:

- Semicomputers. Only a few good companies are needed or can be supported, given that new processors require a unique set of low-level software, like compilers and operating systems.
- Very high-volume memories and field-programmable chips.
- Very high-performance bipolar, CMOS, ECL, and GaAs standard parts and gate arrays.
- High-volume special niches, like analog-digital, communication, and signal processing.
- Complex algorithms in silicon, using foundries and distribution by the algorithm designers.
- Foundries for user-designed, application-specific parts.

In the case of application-specific ICs, a central clearinghouse like the MOSIS center could establish the design rules, standardize the CAD-CAM databases, and broker the mask production and foundries. In fact, standardization of the user-foundry interface is vital so CAD programs can be developed more rapidly.

Change is already occurring throughout the industry. For example, United Technologies' semiconductor division, Mostek Corp. of Carrollton, Texas, which made the first practical 4K memo chip to be widely used in systems, was closed in October 19 and then sold to a European company, Thompson CSF. In th last year nearly all U.S. semiconductor companies have experienced unprofitability and layoffs beyond the normal cyclic pattern. Many companies will retrench or go out of business. The key to retrenchment will be segmentation along more stable product-distribution-service lines.

On the other hand, the company European Silicon Structures is starting up in France and the United Kingdom to produce ASICs by direct writing on the wafer, with two-week turnaround and volumes suitable for most system applications.

This company and the many others emerging to exploit ultra-large-scale integration are examples of a semiconductor industry restructuring, not a semiconductor recession. Whether the traditional industry will play a part in the new market, other than as a supplier of trained people, is unclear.

To probe further

The September 1984 *Spectrum* contains an in-depth, multipart report, "The one-month chip," which describes the development of user-designed chips and custom foundries.

VLSI System Design's November 1985 issue contains "Silicon Compilation," a survey by Daniel D. Gajski [p. 48]. The same magazine's January 1986 issue contains the reasonably comprehensive "Survey of ASIC Design Centers" [p. 60], which shows how quickly design centers are developing.

The U.S. semiconductor industry and U.S.-Japanese competition was sketched recently by *Business Week* [Jan. 13, 1986, p. 90].

About the author

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