The Mini and Micro Industries

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Market pressures have forced marginal computer firms out of business. Looking to compatibles, wary customers are helping create de facto standards.

With today's multitiered, overlapping set of programmable computer classes, where and how computing can be done and how much it will cost can vary considerably. Computing costs can be anywhere from $100 to $10 million (Figure 1). In addition, computing devices can include electronic typewriters with built-in communication capability, further increasing the choices to be made and the complexity of the information processing market.

What is happening to mini and mainframe companies as the micro continues to pervade the industry? One thing is that several traditional mainframe suppliers, Burroughs, Univac, NCR, CDC, and Honeywell (or BUNCH, for brevity's sake), are experiencing a declining market share as mainframe customers select IBM-compatible hardware as a standard and turn to other forms of computing. Fujitsu, Hitachi, Mitsubishi, and NEC supply commodity mainframes, which are distributed through Amdahl, National, Univac, and Honeywell.

The microprocessor-based systems are the newest alternative for distributed computation. New companies are forming to develop these products; Burroughs and NCR have distribution agreements with new microprocessor suppliers such as Convergent Technology. As microprocessor technology continues to be substituted for that of traditional minicomputers, these suppliers find themselves in a situation similar to BUNCH's dilemma. For example, SEL and Prime, minicomputer manufacturers, have marketing/distribution agreements with Convergent Technology, but mini companies must compete with systems built from high-performance, commodity-oriented, 32-bit MOS-based microprocessors—processors that provide the same performance as the traditional TTL-based processors at a small fraction of the cost.

In short, the forecast could be gloomy for mini companies. Just as the mainframe companies were unable to respond to the mini, the mini companies will have difficulty moving to meet the micro challenge

Table 1. Minicomputer technology circa 1970.

BASIC COMPONENT INDUSTRIES	MINICOMPUTER SYSTEM COMPANIES
Power Supplies	Optional
Packaging	Essential
Core Memory	Optional
Semiconductors (MSI)	CPU and Memories
Disks and Tapes	Peripheral Controllers
Terminals	—
	Operating Systems
	Languages
	Applications
	System Integration

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because of the large installed bases, proprietary standards, and large functional organizations.

The minicomputer generation

In the beginning of the minicomputer industry, a product took two years to reach the market. This period began with the start of hardware design and went through writing an assembler, a minioperating system, and utility routines for the sophisticated users. A relatively wide range of technology (Table 1) was required to design logic, core memories, and power supplies; to interface peripherals and do packaging; and to write system software, such as operating systems, compilers, assemblers, and all types of applications software such as message switching. Clearly, this industry was high-tech.

The early minicomputer, characterized by a 16-bit word length and 4K-word memory, sold for about $10,000. It was small and could be embedded in larger systems (for example, electronic circuit testers and machine tools); it could be evolved to large system configurations; and it was used for departmental timesharing. Applications varied from factory control to laboratory collection and data analysis, and communications to computing in the office and small business. The original equipment manufacturer, or OEM, concept was established so that hardware and software and software-only applications could be designed and marketed in two applications, thereby increasing the market for what was basically a general-purpose computer. Many more markets were created than could be reached by a single organization with a limited view of applications.

From 1968 to 1972, about 100 minicomputer efforts were started by four different kinds of organizations (see box on following page). At least 50 new companies were formed by individuals who came from established companies or research laboratories. Some of these later merged with other companies. Established small and mainframe computer companies such as Scientific Data Systems and CDC attempted to develop a line of minis, and other electronics-related companies looked at the opportunity to enter the computer business.

No significant minicomputer companies were established after 1972. In the late 1970's, IBM decided that distributed departmental computing, using multichannel distribution (OEM/end user), was not a fad and introduced the Series 1. Several companies, Floating Point Systems, for one, were started up to build special signal- and image-processing "niche to supply high-availability and cluster-expandable minicomputer systems.

We can make several conclusions from the data on the minicomputer companies:

- Seven successful minicomputer companies—or eight percent of all tries—survived to enter and

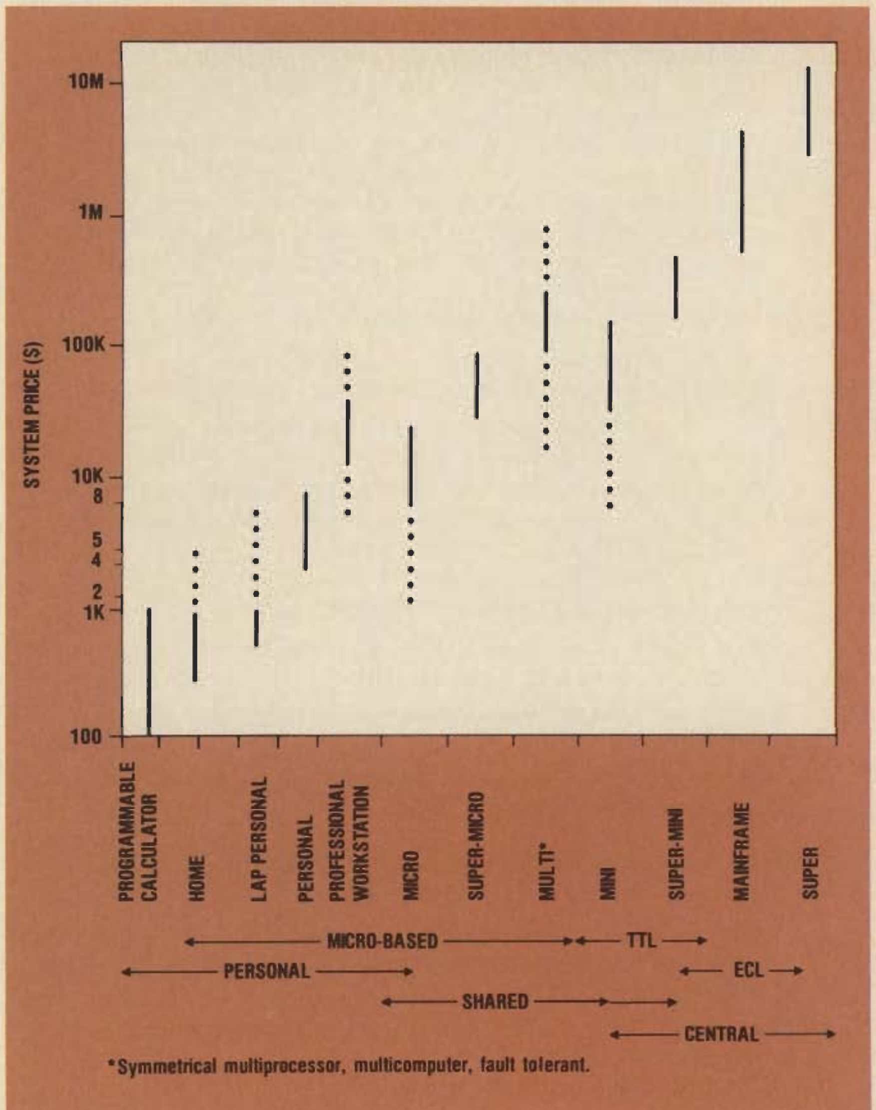

Figure 1. 1984 system price versus machine class. The dots on the ends of the lines signify the uncertainty of price range. Because these classes are relatively new, prices are changing rapidly. Also the class has a broad definition; that is, a number of products of varying complexity can go by the same name. Products within a class can be anything from boards to complete systems.

91 US minicomputer company attempts from 1968 to 1972

The following list includes all general- and special-purpose minicomputers for real-time, communicatons, business, etc., sold through OEMs, end users, and bundled for process control and testing, for example. It does not include scores of military, AT&T, European, and Japanese computers. At a later time, Tandem formed and array processing systems were developed for niche markets.

49 started up and retained autonomy

- 2 grew at significant rates and continue to grow
  Data General, Prime
- 8 grew at diminished or declining rates, or found small niches
  Adage, Basic 4, Computer Automation, Four Phase, General Automation, Macrodata, Microdata, Modcomp
- 39 ceased to manufacture
  American Computer Tech., Atron, BIT, Cascade, Compiler Systems, Computer Development Corp., Computer Logic Systems, Computer Property, Datamate, Data Technology Corp., Datac, Decade, Digital Electronics, Digital Computer Corp. (ultimately merged with DG), Digital Scientific, Dresser, Electronic Engineering, Foto-Mem, GRI, Hetra, Information Technology Inc., Infotronics, Linolex, Minicomp, Monitor Data, Multidata, Nanodata, Northeast Data, Nuclear Data, Omnicomp Computer, Omnus, Redcor, Scientific Control Corp., Standard Computer Corp., Spiras Systems, TEC, Unicom Inc., Unicomp, Inc., Viatron

10 started up and merged with larger companies

- 2 grew at significant rates and continue to grow
  Interdata → Perkin Elmer, SEL → Gould
- 2 continued and now manufacture niche products
  Comten → NCR, Datacraft → Harris
- 6 stopped manufacturing minicomputers in the merged division
  ASI/EMR (Schlumberger), CCC/Honeywell, DMI/Varian/Univac, PDS/EAI, SDS/Xerox/Honeywell, Tempo/GTE

8 existing computer companies built minicomputers

- 2 made successful minicomputers and grew rapidly
  Digital Equipment Corporation, IBM
- 2 continued with diminishing success in minis
  Bunker-Ramo, CDC
- 4 stopped manufacturing minicomputers
  GE, Packard-Bell, Recomp, Victor

25 existing non-computer companies built minicomputers for backward integration or special system niches

- 1 acquired an embryonic company in the design state and formed a division to become a highly successful supplier
  HP acquired Dymec
- 3 continued to build and now supply minicomputers for niche markets
  Hughes, Raytheon, Texas Instruments
- 21 discontinued building minicomputers
  AC Electronics, Bailey Meter, Beckman Instruments, Cincinnati Milling, Clary, Collins, EAI, Fabritek, Fairchild, Foxboro, GTE, Interstate Electronics, Lockheed, International Telephone and Telegraph, Litton, Motorola, Philco-Ford, RCA, Singer, Teradyne, Westinghouse

defend themselves in the microprocessor market.

- Another 16 companies succeeded to a lesser degree and still exist in either diminished or niche segments of the market.
- Of all organizations, 23 (25%) were successful. While virtually all companies built working computers, 75 percent did not build organizations with any longevity for a variety of reasons, including failure in engineering, failure in marketing, faulty manufacturing, or insufficient product depth or breadth.
- Only two of 50 (4%) start-ups succeeded and remained independent, although nine of 50 (18%) continued in some fashion.
- For start-ups, merging increased the chance of survival; four of 60 (7%) could be considered winners.
- The probability of a successful merger was 50-50.
- An organization that is part of a larger body in some other business is pretty likely to fail; only HP—one of 23—really made it. A start-up within a large existing company may as well be a stand-alone start-up.
- Companies selling in a different market or price band were unable to make the transition. Only DEC made it, but we can argue that DEC was already in the mini business and simply maintained its market when everyone else started making minis.
- IBM eventually started making traditional minis in the late 1970's with the Series 1 and began claiming a significant market share. The System 3 (circa 1972) was the most successful "business minicomputer."
- Companies that differentiated their products by using specialized hardware and software were prone to failure. Vendors

that made special computers for an application such as communications or testing (real-time control) *always* failed to make successful minis and often failed or fell behind in developing their main product. Specialized hardware limited the market instead of broadening it; although specialized software could sometimes leverage sales, it was typically inadequate when used with limited hardware for a single market.

- In the mini generation having a high-performance, low-cost, general-purpose minicomputer suitable for broad application ensured getting the largest market share. DEC, for example, had a variety of operating systems aimed at the real-time, single user (which laid the foundation for the CP/M operating system for personal computers) and provided communications, real-time control, and timesharing. The real-time system was ultimately extended for transaction processing. Minis became especially useful for business applications because they were designed for high throughput. Although business computers weren't useful for real time, minis designed for real time were very good for business and timesharing uses.

DG and Prime—the first market successes. The initial Data General and Prime products were unique and had a relatively long time to find a place before the established leader, DEC, reacted to the threat. DG was established by engineers who had built successful products at DEC (in contrast to many start-ups that had little or no experience in designing products). DG had a simple-to-build, yet modern, 16-bit minicomputer based on integrated circuits that enabled it to be priced below all existing products despite its late entrance into the market. In fact, the late entry was a benefit, since more modern parts could be used and the experience of others could be taken into account. The simplicity of the DG product allowed rapid understanding, production, and distribution, especially to OEMs. The OEM form of distribution is particularly suited to start-up companies because a product is not used in any volume until one to two years after the first shipment.

Prime, another successful start-up minicomputer company, arose under different circumstances. Before the company was established, Bill Poduska, its founder, had built the breadboard of a large, virtual memory in a NASA laboratory. Prime was thus able to introduce the first of the "32-bit (address) minis" in 1973. With this new technology, programs such as CAD could be run. DEC didn't provide a large, virtual memory capability until 1978 when it introduced Vax.

The start-up of both DG and Prime were characterized by superb marketing followed by the establishment of a large organization to build and service in accordance with demand.

DEC—a steady force in the mini market. After several false starts, DEC was able to compete with DG and other start-ups because of its momentum in three other basically mini product lines. Thus, its fundamental business from its inception in 1957 was small computers, and while it produced the first large-scale timesharing computer in 1966, it also produced the first mini, the PDP-8 in 1965.

With the onslaught of minicomputer start-ups (including DG, which you will recall was formed by former DEC engineers in 1968), DEC finally responded with a competitive 16-bit minicomputer, the PDP-11, in 1970. The 11, which was comparatively complex, sold as a premium product and allowed DEC to quickly regain the market. With the PDP-11's Unibus, interconnection of OEM products was easy, and extensive hardware facilitated the construction of complex software. By 1975, several different operating systems were available for the various market segments.

DEC converted the PDP-11 to a multichip set relatively early and entered the board market to compete with microprocessors to some degree. Until just recently, it led the 16-bit micro market, but now chip-based micros are commodity parts, and the assembly of personal computers has become trivial. DEC failed to license the PDP-11 chips or make them available for broad use, including the transition to personal computers, so unfortunately the PDP-11 today is merely another interesting machine that failed to make the generation transition.

DEC introduced Vax-11, a 32-bit mini, about six years after Prime introduced its model, but at a time when physical memories were large enough to support virtual memories and provide optimum cost and performance. Because it had much larger manufacturing and marketing divisions, DEC quickly regained the market it had lost to smaller manufacturers including Prime.

IBM—a consistent winner. IBM always responds to mainline computing styles and needs, even though it sometimes enters the market late; for example, it didn't realize early on that the minicomputer had broad market appeal.

IBM sometimes innovates with radical new technology such as the disk, chain printer, and Fortran, but often follows pioneers in computing styles as evidenced by its development of the minicomputer, timesharing, the PC, local area networks, and home computers.

Some of its low-cost computers admittedly were nearly minis: the 1130 (1965) for technical computing, the 1800 (1966) for real-time and process control, and the System 3 (1971) for business. In fact, while the minicomputer was forming, IBM was preoccupied with introducing the 360. However, we should remember that the antitrust suit against IBM

Patterns of computer industry growth and change

Several phenomena have been repeated with the evolution of each new generation. Corporate winners of one generation have generally not been big winners in the next, with one exception—IBM always eventually wins. New companies have been required to implement computer structures using new technology, and while many innovators have been successful, the overall probability of success is low, especially when viewed over a 10-year period.

Established companies have generally been slow or unable to adopt new technology to implement old architectures. This strategy locks existing customers into a vendor with proprietary architectures and software, and the resulting price/performance penalty is costly to the user.

The cost of extending old architectures is inherently higher than the cost of building computing structures with new technology. Users end up having computer facilities comprising products from many vendors because it is cheaper to maintain their software investment in old applications while building new applications on the more cost-effective new generation systems. The pattern of minis taking over mainframe applications is now being repeated with micro-based structures such as PCs taking over mini and mainframe applications. At the same time, the total amount of computing continues to rise sharply.

First generation—1950-1959. In the first computer generation, centralized, batch-mode mainframes sold for $250,000 to $10,000,000. Using vacuum-tube technology, the major vendors, IBM and Remington Rand Univac, had a combined market share of approximately 90 percent in 1959. However, high cost, small primary and secondary memories, and difficulty of programming from the lack of high-level languages greatly constrained the market.

Second generation—1960-1968. The second generation of mainframes was based on transistors and brought the cost down sufficiently for large organizations such as the government and large businesses to use computing for commercial applications. Smaller computers were introduced, further broadening applications to encompass smaller organizations.

The mainframe winners in the first two generations included IBM, Burroughs, NCR, Honeywell, and Control Data. Univac continued to lose the market share for its mainframe, focusing on its existing installed base—not seeking to build new structures or broaden applications. The merger of GE's computer division with Honeywell in 1970 combined GE's technical strength and Honeywell's marketing and service capabilities to strengthen Honeywell's position in the market for a brief period. During this generation, mainframe companies were entirely vertically integrated, manufacturing everything from circuits, peripherals, computer systems, and all system and application software. Today, the non-IBM mainframe industry is predicated on running its highly evolved software on technology-improved mainframes.

Third generation and minicomputers—1969-1977. The integrated circuit was the basis of the third generation (and subsequent ones). The principal new product to spring from this technology was the minicomputer, which cost much less than a mainframe ($10,000 to $100,000) and opened up many new applications. Minicomputers were used as embedded components within a larger system, such as a telephone switch; as a small mainframe for small organizations; and as a shared, interactive computer for a group or team within an organization. The mini made a particularly strong impact in technical, factory, engineering, and scientific applications. It pioneered distributed processing environments because to proliferate such environments required extensive communication facilities for interactive use and for connection of other minis and mainframes. By the late 1970's, the mini had evolved to the supermini, a model with higher performance and a price of up to $500,000.

By the early 1970's, about 100 US minicomputer efforts were started, and all used the concept of placing many logic circuits on a single chip. The dominant technology was medium-scale-integration components called TTL, short for transistor-transistor logic. In addition to circuits supplied by the developing semiconductor industry, peripherals and software components were being supplied by another industry developed to furnish expertise at various levels of integration. Only a handful of companies, including Digital, Data General, and Prime, were building sustained-growth minicomputer companies. Others, including SEL and Interdata, merged with larger companies. None of the established mainframe companies were successful in the minicomputer industry until IBM entered the picture in the late 1970's.

Fourth generation—1978-?. The fourth generation was based on large-scale integrated circuits, permitting a large number of circuits such as a processor to be built as a single component on a single chip. By 1978, single-user, personal computers were configured around these microprocessors with CRTs, keyboards, low-cost primary memory, and file memory such as floppy disks—and, by 1982, small Winchester disks. (P. Hazan's article on personal computers in this issue offers more detail.) These personal computing devices have brought computer resources to desktop systems for about $1000 (home computers) to $100,000 (specialized, professional workstations).

Hundreds of unique information-processing products can be built using VLSI microprocessors and their associated semiconductor, networking, and electromechanical components. These systems have a broad price range, from several hundred to several hundred thousand dollars. Advances in standard software products and networking (especially local area) technology have come together to allow multiple computer systems to be linked together to form a single computing environment, or cluster.

started in January 1969 and may account for its lack of aggressiveness during this time.

IBM waited until PCs were established before it entered the market and established the standard. Now, only two years after entering the market, it has the largest market share. Today, IBM is tackling the difficult problems presented by home computing. Thus, because of its size, IBM can dominate *any* (and perhaps all) market segments of information processing in just a few years.

If we look at computing in the simplest way—that is, in terms of substituting alternative price and performance levels—we can say that a low cost means more people can decide to buy a product whether they are small company presidents or department heads in a large company. The cost per user, then, determines the product's attractiveness when weighed against other forms of computation. By both measures, IBM missed the minicomputer market until it introduced the Series 1 in 1977.

In short, IBM will consistently win, not only because of its size, but also because it aggressively views all forms of computing and possibly communication as part of its market.

HP—the only established company to succeed. Hewlett-Packard purchased a small start-up called Dymec to enter the minicomputer business, and thus might be considered a merger even though it integrated the product into its organization right from the start. HP's fundamental business was to produce information from instrumentation equipment, and it regarded computing as fundamental. For most companies outside the computer field, computers were too much of a diversion from what they understood and could manage.

The success of HP alone only underlines a concept that usually holds: Leaders in a market segment of an industry usually remain leaders, unless too much evolutionary change is required. Technology transition, which typifies the generations, requires much change including a new computer, a new market, and a new way of computing. Since existing companies are unlikely to address a new market, new companies are required.

The microprocessor generation

The micro-based information-processing industry is composed of thousands of independent, entrepreneurial-oriented companies that are stratified by levels of integration and segmented by product function—whether microprocessor, memory, floppy, monitor, or keyboard—within a level.

The first computer companies built the whole system from circuits to tape drives through end-user applications in a totally vertically integrated fashion. A stratified industry, on the other hand, is a set of industries within an industry, each building on successive product layers. Each company designs and builds only a single product within each level. Systems companies then integrate collections of the segmented products to produce a system for final use.

Three factors have caused this industry structure: (1) entrepreneurial energy released by venture capital; (2) standards,[1] which become constraints for the products and create product divisions, or strata; and (3) the establishment of clearly defined target product segments—so many in fact that we are forced to ask "What part of the industry *is* high-tech?"

Entrepreneurial energy. Companies form in an entrepreneurial fashion and are able to participate in every level of integration in a single product or through the integration of products into a complete system. The amount of energy released to build products through entrepreneurial self-determinism is truly incredible; improvements in productivity by a factor of several hundred have been observed in a single, large monolithic functional organization.

The industry formation process, expressed in a style similar to Pascal language dialect, is shown below.

```
procedure Entrepreneur_Venture_Cycle
    begin
    while Frustration > Reward {Push
            from Old_co} and
          Greed > Fear {Pull to New
            company} do
          begin
          get (PC, spreadsheet);
          IF System_Company then
            write  (Beat_Vax_Plan)_
            ELSE
            write (Plan)_
               New_Company
          get (Venture_capital);
            {from Old_Venture_Co}
          exit {job};
            start (New_Company);
          get (Vax, development_tools);
          build (product); sell (product);
          sell (New_Company);
            {@ 100 × sales}
          venture_funds := Co._Sale
          start (New_Venture_Co.);
          end
    end
```

The "push and pull" concept. The WHILE clause in the above (the start-up) is evoked by two conditions: the "push" of an old company and the "pull" of a new company or product idea. Throughout each generation, we've seen the "push." Bill Norris led a group (including Seymour Cray) from Remington Rand's Minneapolis group (originally Engineering Research Associates) to form CDC in 1957. Cray left CDC in the early 1970's to form Cray Research. Gene Amdahl could not build high-performance 360's within the IBM environment, so he left to form Amdahl Corporation. Later, he left Amdahl to form Trilogy for similar reasons. Bill Poduska, who founded Prime in the early 1970's, came from a NASA laboratory where he had built a prototype of a minicomputer with a virtual memory. Later, he left Prime to found Apollo Corporation and build clustered workstations. Bob Noyce left the Schockley Transistor Company to form Fairchild (where he was a major inventor of the IC) and then left Fairchild with

Grove and Moore to form Intel to develop the first MOS memories and microprocessors. By most accounts, all these transitions were made with at least 50 percent push from the parent company.

Two business plans, separated by the IF clause in the entrepreneur-venture capital cycle, are (1) a component plan to enter and address one segment of the market, such as a new spreadsheet package, and (2) a plan to build a computing system that will win against Vax or some part of the IBM PC market.

Money is secured from one or more venture capital companies. The founders leave their jobs and start the New_Company in almost a single step. In some instances, "seed" financing is acquired whereby founders actually leave their jobs before the first business plan for the new company is written.

Building and selling the company. The company proceeds to get a Vax for use as a development computer. They develop and sell a product. After the first profitable quarter the company goes public and the valuation is placed at multiples of up to 100 times the annualized sales of the company. (A multiple of slightly over one is not uncommon for mature but still profitable companies.) With the funds from the public sale, New_Venture_Co. can be formed to invest in new high-tech companies.

The start-up and two alternatives. A PC running Lotus 1-2-3 is required to write the plan and address the financial aspects (i.e., profit and loss and balance sheet). Poduska's elements in a successful business plan, which *must* be less than 10 pages, include[2]

- summary—one page;
- market brief, a synopsis of who will buy and why;
- product brief, the what, why, and how of product building;
- people, the rule being use only Grade A, experienced people; and
- financial projection, characterized by the desire for a practical strategy that would yield high yet realizable returns and that could be used as an operational "yardstick."

Standards. Formal standards developed by international standards groups established many of the standards (constraints) observed by today's designers. These restrictions have gradually caused industrial layers to form, which have clearly defined limits. The following eight levels of integration form the industrial strata, the bottom four being hardware and the top four being software and applications.

- *Discipline and profession-specific vertical applications.* CAD for logic design and circuit design and small business accounting.
- *Generic application.* Word processing, electronic mail, spreadsheets.
- *Third-generation programming languages and databases.*

Semiconductor technology (mainly) determines computer class

Density and resulting clock rate. MOS semiconductor memory density has increased by roughly a factor of four every three years, or 60 percent per year. Increased chip density reduces overall system costs but increases performance with lower interchip delays. (The article in this issue by R. Burger et al. on the impact of IC development gives more details.) MOS-based microprocessor performance is likely to evolve at the current rate of 50 percent per year. Thus, micros will compete with TTL- and ECL-based minicomputers and ECL-based mainframes because these technologies evolve at less than 20 percent per year.

The cycle time of the AMD 2901 bipolar bit-slice family has decreased by roughly a factor of four since its introduction in 1975 (or 15 percent per year). In 1985, the simple 32-bit bipolar bit slice datapath using standard integrated circuits will likely operate at 20 MHz. A similar, standard ECL-based datapath can be expected to operate at roughly 40 MHz. For comparison, the speed of the Motorola 6800/68000 family has increased by a factor of 50 since 1975, and by 1985, the internal datapath should operate at 16 MHz. The table below shows the clock rate evolution over 10 years for various datapaths.

SYSTEM	TECHNOLOGY	YEAR	CLOCK RATE (MHz)
Cray-3	GaAs?	—	—
Cray-2	ECL	1985?	250
Cray X-MP	ECL	1984	105
Cray-1	ECL	1976	80
AMD 2901	TTL-bit slice	1975	5
—	TTL-bit slice	1985	20
68000	MOS	1980	8
68020	MOS	1984	16
6800	MOS	1975	0.4*
—	CMOS	1985?	30†

*Effective clock rate based on performance
†Postulated to be possible based on fast CMOS

System performance. Microprocessor performance is now measured in terms of the 1978 Vax-11/780 super-minicomputer. In 1985, the micro

Fortran, Basic → Pascal → (evolution).

- *Operating system.* Base systems, communication gateways, databases/integrated Basic → CP/M → MS/DOS → Unix (evolution).
- *Electromechanical.* Disks, monitors, power supplies, enclosures/8″ → 5″ → 3″(?) floppy; 5″ Winchester (evolution).
- *Printed circuit board.* Buses synchronized to micro and memory intros/S100 → PC bus, Multibus → Multibus II and VME.
- *Standard chip.* Micros, micro peripherals and memories/evolution of Intel and Motorola architectures synchronized to the evolution of memory chip sizes—8080 [S100](4K) → Z80, 6502 (16K) → 8086 [Multibus, PC Bus] and 68000 [VME] (64K) → 286 [Multibus II], 68020 and NS32032 (256K).
- *Silicon wafer.* Bipolar and evolving CMOS technologies (proprietary, corporate process standards...require formalization to realize a silicon-foundry-based industry).

Signal transmission, physical environment, communications links, and language standards have played a key role in defining these strata. De facto standards by various manufacturers, which provide the most important standards, are microprocessor architectures, buses, peripherals, operating systems, and application software file formats. Regrettably, we often misunderstand and underestimate the importance of these and other standards.[1,3]

and 11/780 are likely to become equal in performance for simple, non-floating-point and non-data-processing (Cobol record-oriented) applications, but the cost of the microprocessor will be almost a factor of 100 less. A large number of systems have been measured and compared for Fortran benchmarks (see table below). The performance of the Cray X-MP compared with that of the Sun workstation is about a factor of 3500 higher while the clock rate is a factor of 13 slower. The Cray produces results at roughly 1/15 of its maximum 470-Mflop rate. The performance of the Cray X-MP compared with that of the Vax-11/780 is a factor of 100 higher, whereas the clock rate is a factor of 21 slower. The discrepancy factors of 270 and 4.8 for the 68000 and Vax-11/780 can be partially explained by the lack of floating point in the 68000. The IBM PC with built-in floating point is only a factor of 5 to 7.5 slower than Vax-11/780 despite Vax's slower 5-MHz clock. (These benchmarks are taken from J. J. Dongarra, "Performance of Various Computers Using Standard Linear Equation Software in a Fortran Environment," *Computer Architecture News*, Vol. 11, No. 5, Dec. 1983, pp. 22-27.)

COMPUTER	YEAR	CLASS	PERFORMANCE* (Mflops)	IMPLEMENTATION†
Cray X-MP	1984	Super	21-33‡	h
Cray 1/S	1976	Super	12-18‡	h
CDC 7600	1970	Super	33-4.6‡	h
FPS-164	1983	Array Proc.	1.3-2.6‡	h
IBM 3081K	1983	Mainframe	2.2-2.4	m
CDC 6600	1964	Super	0.36-0.48	h
Vax 11/780	1978	Supermini	0.21-0.33	m
Ridge 32	1983	Mini‡	0.20-0.31	h
Vax 11/750	1981	Mini	0.14-0.22	m
Apollo (68000)	1981	Micro	0.037-0.069	m§
IBM PC/8087	1982	Micro	0.04	m
Sun (68000)	1981	Micro	0.0095	m‖

*range for two- and one-dimensional access
†h = hardwired, instruction-set interpretation; m = microprogrammed
‡double precision
§floating point hardware
‖no floating point hardware

Four computers can be grossly compared for this benchmark in terms of performance/price. A $5 million Cray X-MP supercomputer delivers 6.6 floating point operations per second per dollar, whereas a $4 million IBM 3081 K, a $200,000 Vax-11/780, and a $6000 IBM PC with floating point will deliver 0.6, 1.65, and 6.7 floating point operations per second per dollar, respectively.

Product segmentation. The number of clear product segments in the industry is a major determinant of its present structure. To understand that structure, we need to isolate which products are worthy of the title "high tech." Advanced technology is characterized by significant investment, highly skilled personnel who understand the technology, and often high project risk.

Products evolve at a rapid rate and demonstrate continued performance and price improvements, together with innovative structures. The resulting products demand a premium. High-density semiconductor and magnetic recording products fit the definition, but most systems assembled from these components, such as IBM-compatible PCs, are clearly *not* high-tech because they are simply a system formed from high-tech components.

The barriers for entering an end-user, OEM, or system-level business with a generic product are not very imposing (Table 2 shows the technology requirements), especially when they are compared with the complexity of the engineering needed to produce early mainframes and minis (Table 1). A micro-based system company can be formed by a part-time president, someone with a PC and Lotus 1-2-3 to do the business plan, someone who can buy and assemble the various circuit boards into a Multibus backplane, a pro-

Table 2. Microcomputer-based technology circa 1978.

BASIC COMPONENT INDUSTRIES	MICROCOMPUTER SYSTEM COMPANIES
Power Supplies	Optional
Packaging	Optional
Semiconductors (micros, memory, peripherals)	—
CRTs and Terminals	—
Disks and Tapes	—
Board Options (displays)	Optional
Unix & Diagnostics	Optional
Languages & Databases	Optional
LANs and Communication	Optional
Applications	Optional System Integration

grammer to buy and load a version of Unix, and one or two helpers.

The point I am making here is that the single, most important measure of the high-tech portion of the micro industry is semiconductor improvement. That is, semiconductor technology mainly determines the computer class (see box on previous page). Clearly, many more issues are involved in accounting for performance, price and relative performance/price, including machine age; hardwired versus microprogrammed control and associated instruction times; memory speed; Vax's cache performance (neither the Cray nor the IBM PC uses a cache); floating point speed; degree of parallelism for both vectors and scalars; the relative goodness of the Fortran compilers; and actual use versus a single benchmark to typify a computer's workload.

Micro and mini computing structures

Hundreds more products can be built from the micro than can be built from the mini because of the micro's low cost, small size, and ease of programming. Personal computers, terminals, typewriters, and computing PABXs are all lower cost alternatives to larger computers that provide relatively the same performance as their larger computer ancestors. In addition, micro-based products can be interconnected in a vast array, forming a much larger range than ever before. The most important structure to emerge is the local area network, because it permits the formation of a much larger, potentially single system.

LAN-based computing. The information processing structure within a large organization is driven by newly emerging computer structures, computing nodes, and local area networks, or communication links (Figure 2). The LAN is critical to computer evolution during the next few years, and the lack of standards is greatly impeding progress.[3]

The multiprogrammable operating systems introduced in the mid 1960's allowed a machine to be shared by a number of users, if each had a "virtual" computer (Figure 2a). Since overloading is common in shared systems, users enjoyed having their own personal computers when reasonably powerful, reasonably cheap

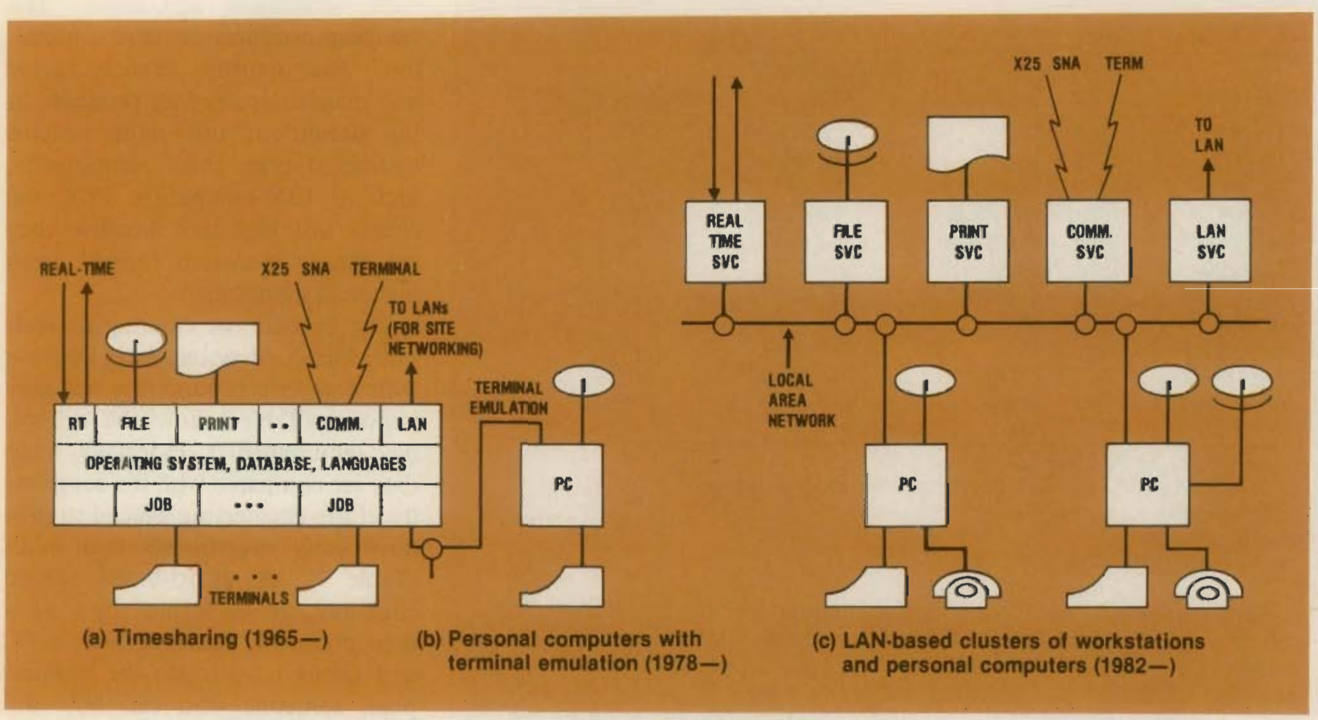

Figure 2. Evolution from timeshared central computers to LAN-based clustered workstations and personal computers.

models were introduced in 1978 by Apple and then in 1981 by IBM (Figure 2b). PCs proliferated in large organizations. The need to obtain data from the shared computers meant that programs had to be developed that would allow PCs to emulate dumb terminals. Increased PC usage, coupled with greater expectation of response time, provided a demand for increased shared computation at minis and mainframes. Because users wanted access to specialized and central data, the demand for mainframes has resurged, and this trend is likely to continue until a fully distributed, LAN-based system (Figure 2c) is built.

Xerox Palo Alto Research Center invented the LAN-based cluster concept in the mid-1970's using Ethernet, the basis of IEEE 802.3, the LAN standard. For powerful workstations such as the Xerox Star or Apollo Domain, the LAN must permit the sharing of files and intercommunication of work. Functional services such as filing and printing of the shared system (Figure 2a) are decomposed into specialized "servers" (Figure 2c) and connected along a LAN. A LAN, then, must address several needs:

- Large, shared systems must be "decomposed" for improved locality, lower cost, physical security, communication with a single resource, and incremental evolution.
- Personal computers or workstations must be "aggregated" into a single system to share resources such as printers and files to intercommunicate.
- Networks of minis and mainframes, which have relied on poor wide-area, data communications facilities for local communications, require high-speed intercommunication.
- The connection of minis and mainframes to terminals must be completely flexible, and incremental upgrades must be possible.
- Gateways must be done once for a network or protocol instead of for each system, thereby limiting the number of communications protocols.

The computing nodes. Figure 3 is a taxonomy of common mini- and micro-based computer structures, which illustrate the plethora of new computer structures made possible by the micro. (For more details on specific structures, see the appendix to this article, "Specific Microcomputer and Minicomputer Structures.") These range from the simple PC to the LAN, omitting the wide-area network. (A WAN is usually not used as a single system, but as a communication network among several systems, including LANs.)

The combination of micros, higher level performance, wide-scale use, and higher reliability can be offered for the price of a mini or supermini. Complete new structures have emerged, including functional multiprocessors, symmetric multiprocessors for performance and high availability, fault-tolerant computers, and multicomputer clusters. In addition, microcomputers are combined in fixed structures to provide high-performance, close-area-network

Single C (10-100us.) (1 cabinet)	1 Pc (uniprocessor)	1 Bus	Pc + nK's	Unibus-type (PDP-11, LSI-11*, Vax-11)
		P-M/P-K Bus	Pc + nK's	traditional mini IBM PC* structure
		:attached P|C	C + Pf|Cf*	eg. attch'd array proc. (Vax-11 + Floating Point Systems FPS-164)
	n Pc (multi-P)	1 bus (eg. Multibus)	1 Pc + nCf	NCR Tower*, Plexus*
		Symmetric.mP (for perf. & high avail.)	ssmP (2-6)	Arete*, Elexsi
			msmP (10-100)	Synapse*
			lsmP (100-1K)	Cm*, Sequoia*
			vlmP (1K-10K)	
			ulmP (>10K)	NYU Ultracomputer* (paper)
	multi-instr/data		Dataflow architectures	
Close Area Net (.1-1ms.) (1 room)	reg. connect	memory	grid	
		links	tree	Columbia DADO*
			binary n-cube	Caltech 64 computer*
	ad hoc connect	via P or M	closenets	functional simulators*
	switched	bus	CAN high avail. cluster	Tandem Auragen*
			backpanel cluster	Convergent Technology Megaframe*
Local Area Net (1-100ms.) (1 building or campus)	spanning tree, ring, central topologies		LAN cluster, fmC/functional	multiC Cambridge Ring Computer*
			homogeneous cluster	Xerox Star Apollo Domain*, SUN Workstations*
Wide Area Net (.1-10s) (global)				

*Micro-based computer structures.

Figure 3. Taxonomy of common mini- and micro-based computer structures. C = computer; P = processor; K = controller; Cluster = collection of C's acting as a single C—Interprocessor communication times determine parallel processing grain size; and function = arithmetic, array processor, signal processor, communication (front end), database (back end), display, simulation.

computer clusters. If a method can be found to use a large number of essentially zero-cost microprocessors in various multiple-processor structures to work on a single job stream, then micros can potentially compete with all forms of computers including mainframes. Fox[4] has used an array of 64 Intel 8086/8087-based computers for particular theoretical physics calculations to show that this structure can approach supercomputer performance.

Figure 4 illustrates the variation in processor types for common computer types. Micros have followed the traditional mini evolution and are today microprogrammed with the exception of the MIPS chip at Stanford[5] and the RISC chip at the University of California, Berkeley.[6] Given the current speed of logic relative to memory, it is again time to return to direct (versus microprogrammed) execution of the instruction set when performance is a consideration.

The systems industry

Virtually all microprocessor-based systems supply a single information processing market. Micros allowed the PC to form but also to attack the traditional minicomputer, the high-availability mini, and possibly the mainframe. Now with the standard operating system, complete product segmentation may occur to eliminate vanity architectures at all levels of integration.

If minicomputer history is a good indicator, fallout in the micro-based industry will be even more legendary. For example, of the 100+ workstation companies, we can expect fewer than 10 to survive, let alone prosper. A similar statement can be made about the PC market. The following criteria will determine success:

- Economy of scale in distribution and service is most important.
- Economy of scale in manufacturing is critical for a few focused products such as the PC but less important for larger products. Here, systems integration costs dominate. For example, the Japanese are likely to dominate the PC market in much the same way they dominate consumer electronics.
- Time to market is far more important than economy of scale in engineering or manufacturing.
- Since there are few technological challenges in a start-up, companies will form if they get venture capital; later entrants will be less successful.
- Specialized, or niche, products are rarely "sacred" enough or large enough to serve as main products very long.
- Generic and unique software applications like CAD that run on a few standardized structures (PCs, workstations, and supermicros) will fuel this generation.
- Truly unique structures like home robots are rarely sufficiently protected by patents, processes, or practice to avoid becoming displaced by an established supplier entering the market. Remember how quickly IBM became a dominant force in the PC market?

The applications challenge

Now that we have examined the bewildering number of products and services available, we need to look at ways to supply them. A number of strategies are possible, from selling a purely general-purpose base system to offering customized hardware and software. In the latter case, however, the resulting function may scarcely resemble a computer. Economy of scale may occur in the widespread sales, distribution, installation, and service of hardware products.

An OEM approach usually requires a product range, not just a point product. An OEM customer often requires service and always requires high-level applications and field support. An end-user approach requires both a wide product range and complete sales/service.

A new application software company, such as one offering CAD or typesetting, that has to invent its own hardware system is likely either to become obsolete because of its hardware or to fall behind in its software development. The company is limited because investment has to be divided between its unique vanity hardware and its specialty, added-value software. In most cases, large hardware vendors, such as AT&T, DEC, and IBM, can surpass the small hardware/software supplier by using packaged software from the applications software industry.

single instr-single data	hardwired	simple	minimal	PDP-8, NOVA minis
			complex	
		pipelined	load/store	RISC*, MIPS*, Ridge 32
			" + multifunction units	6600
	microprog.		simple	8086*
			CIS	360, Vax, 68000*
			P. language	Symbolics 3600 (LISP)
single instruction, single data, high availability			vote (detect only)	
			vote (det./corr.)	Stratus*
			TMR (det./corr.)	
single instruction, multi-data		open microprog	array processor	FPS-164
		hardwired	vector	CRAY 1

*Microprocessor

Figure 4. Taxonomy of common processor types.

Supplying the basic computer. Figure 5a shows the simplest form of distribution for what is fundamentally a computer sold with some general-purpose software. A base system would typically include generic software such as languages, utilities, editors, communications interfaces, and database programs. The system is built by a hardware manufacturer or system integrator; it is sold (S) directly or through another distribution channel of some sort; and eventually, the system is installed (I), the user is trained (T), and the system is serviced (S).

Supplying the basic computer with applications software. As users require more specialized applications for particular professional environments, such as the computer-aided design of electrical circuits, various industries will supply these programs, creating a product development and distribution structure (Figures 5b, 5c, and 5d).

The base-system manufacturer and an independent software industry can coordinate the introduction of applications programs into the distribution network (Figure 5b). Special software can be integrated with the base system by the hardware supplier, the application supplier, the distribution channel (store or systems installer), or the final user.

A system manufacturer can acquire a variety of packages and transform what is a general-purpose system into a variety of special-purpose systems. The software suppliers are likely to be the best obtainable for the application selected because they have focused on the particular, vertical professional application, be it mechanical or electrical CAD, architectural drawing, office automation, or actuarial or statistical analysis. The software suppliers have the largest market because a program can be transformed to run on many different base systems. Mentor is an example of a CAD company with a flexible approach to systems integration. A total system can be purchased from Mentor Apollo (and the hardware supplier of the workstation) or it can be bought a la carte and integrated by the customer.

Supplying applications software as part of a system. Since the perceived (and often actual) price of software is low, a company marketing a software product and wishing to enhance its sales volume may buy hardware for resale as a complete system (Figure 5c). In effect, a company potentially competes with the hardware's main manufacturer by supplying a similar, but greatly enhanced product. While the gross sales are up, the costs can easily outrun the sales, since the once-software-only company must now support hardware too. In addition, the software company doesn't usually market the range of products of a mainline hardware supplier. Offering a total system, therefore, is likely to be less profitable—when measured by return on investment—than offering software only, even though the total revenue of the company would be much larger in the former case. Furthermore, the supplier is cut off from the large number of distribution channels possible when a basic software package is tailored for operation on many different base systems. Computer Vision is an example of a company that now buys products on an OEM basis from Apple and IBM, integrates them, and supplies them as turnkey

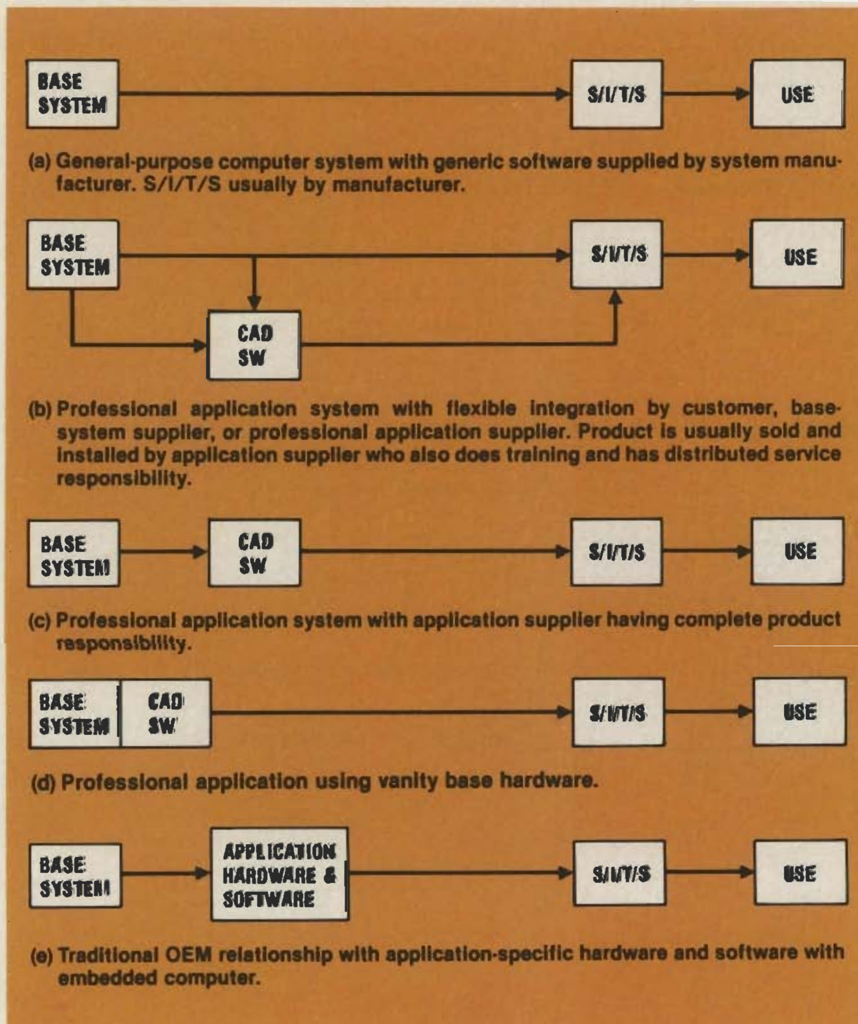

Figure 5. Alternative industry structures for supplying base, application and hardware-embedded computer systems (S/I/T/S = sell, install, train, service).

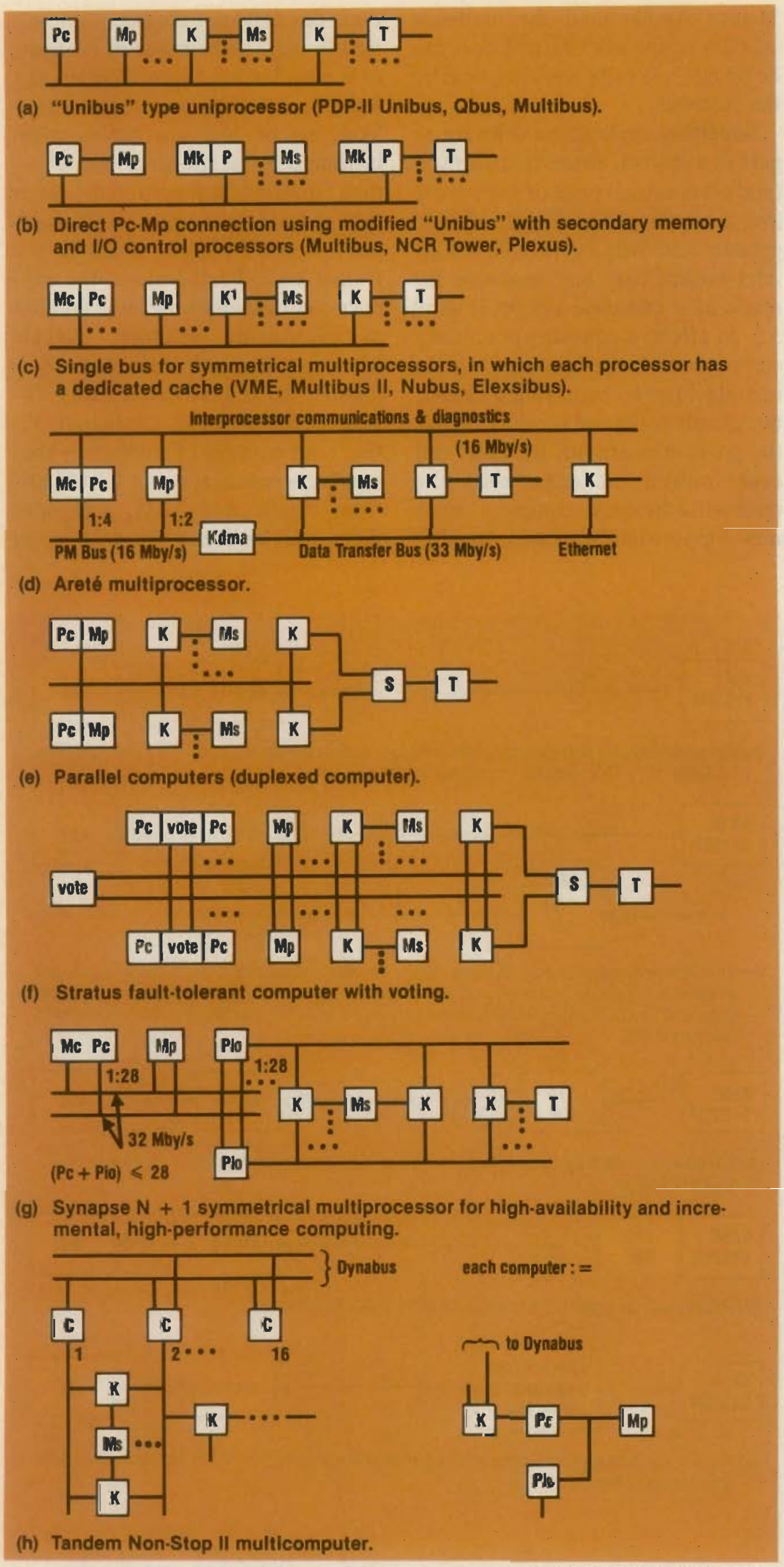

Figure A-1. Common micro- and mini-computer structures. Pc = central processor; Pio = I/o processor; K = control; Mp = primary memory; Mc = cache; Ms = secondary memory; and T = transduce (terminal).

products. Computer Vision formerly manufactured its own base system.

Supplying unique hardware and application programs. The traditional approach of catering to OEMs, which DEC established with the minicomputer, is shown in Figure 5e. A company skilled in a particular technology—computed axial tomography is a good example—or in logic board testing can build a highly complex instrument. A computer may constitute up to half the cost of the system. Products of this nature are *not* basic, general-purpose computers, and as such, the customer will not require other software beyond the control of the device. A specialized field organization is required to sell, install, and service the system and to train users. This support is hardly possible with a conventional computer company.

A final word about applications. Applications that involved minicomputers are likely to be a good history lesson. Companies that tried to backward integrate and build their own minicomputer, such as Cincinnati Milling, failed in the market, often neglecting their mainline business. The applications system winners combined the use of a general-purpose mini with their expertise in the application. Companies that use high-cost, vanity hardware or who distribute someone else's hardware will be at a disadvantage because the value of the product is completely in the software.

New professional software application products will come from those in existing companies and institutions such as universities who have expertise in particular problem domains. Applications industries will form and evolve through the strata model discussed earlier in "Standards" to software-only companies that create the professional application (a form of "expert" system) and use standard systems supplied by hardware vendors such as IBM.

Thus, we have an opportunity not available in industry—to build generic, basic hardware systems in a crowded field, resulting in an almost unlimited set of professional application products as experts encode their "knowledge" into programs for machine interpretation and personal use. These will constitute the real expert systems of the fifth generation, as they run on evolutionary microprocessor-based computers and clusters of computers connected by local area networks.

New technology, especially VLSI, has provided powerful, low-cost microprocessors and memory which, in turn, have acted as standards and permitted a new industrial structure to emerge. The structure, which is typical of a cottage industry and is almost the antithesis of a vertically integrated industry, is stratified by eight hardware and software levels of integration and segmented by a vast array of component products. Companies are funded by a vast array of venture capital companies formed from the profits of selling previous companies. The resulting products are integrated into an equally large array of system products by traditional system suppliers, such as IBM; companies that add value by distribution, service, and training; conventional, retail distribution channels; and even the final user.

The micro industry offers a much wider range of computing products at a lower cost ($500 to $500,000) than the mini ($20,000 to $500,000) or mainframe ($250,000 to $5,000,000) industries can afford, and the micro offers comparable performance. The results? A continued shakeout of all types of products and companies and changing roles for all parts of the industry, including the users. ☰

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Appendix: Specific Minicomputer and Microcomputer Structures

Figure A-1 illustrates a wide range of microcomputers, from the common, single-processor, "Unibus" structure (Figure A-1a), to computer clusters for high availability (Figure A-1b). Since microprocessors require memory access at a higher rate than the first DEC Unibus and Intel Multibus (2M and 4M bytes per second), the common adaptation is to provide a direct connection between the processor and primary memory (Figure A-1b). Performance can be increased for these systems by having functional multiprocessors serve disks and terminals, including the migration of software for file access.

A completely symmetrical multiprocessor can be made using more recent buses such as the Multibus II or VME bus (Figure A-1c), if a cache is used to reduce processor/memory traffic. The Areté quad processor, which uses this principle, is shown in Figure A-1d.

A variety of approaches are used to increase system availability. Parallel computers (Figure A-1e) use the Multibus for intercommunicating among distinct, redundant computers (Pc-Mp) and among redundant controllers for secondary memory (Ms) and terminals. Of course, much software is required to provide true high-availability computing with this structure. The structure is a vastly scaled down version of the Tandem (Figure A-1h).

Stratus provides a fault-tolerant system (Figure A-1f) that is completely transparent to its software. Any hardware component can fail and the system will continue to operate without affecting the basic software. The single point of failure is system and application software. Stratus systems require four processors and two memories to provide a single, effective processor.

Synapse N + 1 (Figure A-1g) uses a second bus for both performance and redundancy in a true symmetric multiprocessor version of the single bus system. By having all resources in a single pool, users can trade off performance and reliability. Since work can be run on any processor, load leveling is automatic.

Tandem (Figure A-1h) pioneered high-availability computing when it introduced its multicomputer system in the mid-1970's using minicomputer technology. Sixteen computers are connected in a cluster via a dual, high-speed message-passing bus. Complete redundancy is provided, including computers, control units, and mass storage. Operating systems and applications are run in two computers in a backup fashion. Information is forwarded to the backup process using the intercomputer bus. A key use of the Tandem structure is to permit incremental addition of performance. Since processes and files are assigned to specific processors, load balancing is less dynamic than that in the multiprocessor. Several microprocessor versions of the Tandem structure have been introduced, including models by Auragen and Computer Consoles Inc.

The price range of micros from $500 for a lap PC to nearly $500,000 for a fully configured multimicroprocessor is much greater than that for any previous generation or computer class (see Figure 1 in main article). Table A-1 illustrates the range of several Motorola 68000/Unix-based computers that compete with the minicomputer.[1]

Winners and losers in products, organization, and marketing may already be established.[2] However, many micro-based products are still to be invented outside the computer classes previously described. The box on the following page contains questions about each structure in terms of competitiveness, long-term stability, and substitution with other structures.

In addition to these questions about word processing, workstations, supermicros, and clusters of micros and high-

Questions about the micro-based computer market

Typewriters	Are these alternatives to terminals and word processors?
Terminals	What will happen when the market demands personal computers instead of terminals?
Computers on a Desk	
Home (and game)	Aren't Atari, Mattel, and TI setbacks the leading edge? Can IBM market a home computer? What about television-based computers?
Word processing	First shakeouts and mergers occurring. Won't this market be completely eroded by PCs (with word-processing software), smart typewriters, telephones, and workstations?
PCs	A general-purpose structure will dominate special devices. Is it possible to have a standard outside the IBM PC? Are the Osborne and Computing Devices failures in portable PCs the leading edge?
Workstations	Are 100 microprocessor-based Unix companies needed? Won't the finale be from evolving high-performance, 286-based, IBM-compatible PCs?
Shared micro (table/pedestal)	Won't a shareable PC alter this market?
Departmental and Group-Level Computers	
Supermicros (multi)	Another name for shared, one-processor micro with functional I/O processor? A mini replacement usually at lower cost... but what about the minicomputer suppliers?
Symmetrical multiprocessor	Can these "multis" be built to compete with all minis? Mainframes?
Special Products	
High availability (multi)	Is this a niche or an important requirement? Are Tandem, the current (Stratus, Computer Consoles, Digital), and the emerging (August, Auragen, IBM, No Halt, Parallel, Sequoia, Synapse, Tolerant Systems) companies overcrowding the field?
Special processors	Can an infinity of types—signal processing, high-performance, reduced instruction set (not necessarily micro-based)—be unique enough to compete with the micros? Will there be adequate resources or time to develop the system software?
High-Performance, Mainframe Computing	
Clustered micros (multi)	Can't zero-cost multiprocessor micros deliver the best performance/cost? How much parallelism is possible and can it be a competitor for the non-IBM 370 mainframes? Will multiple microcomputers for special applications such as simulation emerge?
Communication and Networking	
Voice/data PABX	Aren't too many companies in the field? Or will the market expand as AT&T ignores communications to be a computer supplier?
LANs	Ethernet is now the de facto standard for high-performance LANs. There is still concern for too many options, including lack of IBM standard.
LAN Servers	A plethora of small systems is required: concentrators, gateways, file service, print service, and real time. Are these unique or just a requirement for all small systems?
Smart telephones	Isn't an attachment to a PC the best way to provide terminal access, telephone database, and control?
Other Products	
Robots, voice I/O, vision modules	Multitudes of products and industries are possible based on the microprocessor and specialized hardware and software.

availability computers is the most important question: that of standards, especially Unix.

Unix. For awhile, Unix appeared to be suitable only for a particular class of experimental uses, but now it promises to be a constraint for the whole market. Interactive computing with Unix is the product constraint future users are all hastening to demand, or at least specify. Just as the PC market has standardized on the IBM PC (8086, MS/DOS, PC bus, graphics interface, file formats, etc.), the market for systems larger than a PC appears to be standardizing on Unix. IBM has shown its flexibility in adopting industry standards especially when the time to market is crucial and the market demands it. If customers want a product, IBM will likely supply it. IBM has already announced Unix on the PC and will probably respond with Unix on its 4300 and mainframes.

In a similar fashion, every minicomputer and microcomputer supplier appears to be offering Unix in a commodity-like fashion. While the combined market is large, the fundamental market has *not* been expanded, but merely made more accessible by every manufacturer. The result will be that more small manufacturers who have inadequate marketing and manufacturing organizations will fail to compete with mainframe and mini suppliers.

Unix has been an opiate that hundreds of companies have used as an excuse to form and assemble—quite trivially—a product from boards, Unix ports, or general-purpose software. Perhaps the entry cost for computer systems should be higher.

Office and word-processing systems. Historically, general-purpose computers have won in the marketplace over equivalent special-purpose machines. The IBM PC standard is the unique structure to watch as conventional word-processing software becomes available and replaces simple editors. Terminals, including typewriters with built-in modems or computing telephones, can be connected to desktop and pedestal-sized, shared micros running Unix or to large systems for the casual users. Professionals who already have large workstations use them for text processing.

Workstations. Over 100 workstation vendors value themselves at up to $100 billion for a commodity-like product with a limited market to engineers, scientists, and business analysts. All have enough organizational overhead to start, but few have the critical mass or ability to raise the next round of capital to gain a significant market share except those well on the way—Apollo, Apple (with Macintosh), Convergent Technology, and Sun—or those with unique high-performance products such as Silicon Graphics.[3]

Workstation design consists of "assembling" the following:

- boards with microprocessors, disk, CRT, and communication controllers that use one of several standard buses, such as Multibus, Qbus, or VME/Versabus;
- appropriate disks and CRTs;
- standard or custom enclosures;
- a licensed version of Unix available from myriad suppliers; and
- generic software, including word processing and spreadsheet.

Each start-up company believes its product and business plan will beat Apollo, the first entrant into the high-performance, clustered workstation market. In fall 1983, just after going public, Apollo was valued at $1 billion with annualized sales of less than $100 million and with fewer than 1000 employees. At the same time, Digital had a valuation of about $4 billion with sales of $4 billion and a work force of over 70,000.

A typical workstation start-up company compares itself with Apollo on two points: the start-up date (usually one to two years after Apollo when systems were easier to build) and the current month's annualized shipments. In this context, within two years, each of 100+ companies will be valued at $1 billion dollars, giving a valuation of workstation companies of $10 to $100 billion...at least one order of magnitude greater than any optimistic projection of the market.

This valuation doesn't include established companies. The workstation is a *mainline* product for large suppliers such as AT&T (via new teletype computing terminals), DEC, HP, and IBM. Also, the 32-bit personal computers circa 1984-85, led by IBM using 256K chips and the Intel 286, will provide the power of emerging 68000-based Unix workstations at a lower price.

Table A-1. Selected 68000/Unix computer systems.

SYSTEM	BUS	STRUCTURE	FIRST DELIVERY	ENTRY PRICE (K$)	MAXIMUM USERS
Apple Macintosh	Ext. serial	PC	1/84	2.7	1
Corvus Uniplex	Backplane	Micro, LAN serve	6/82	6†	8
Altos 586-10	Multibus	Shared micro	3/82	8†	4
Wicat 150WS	Backplane	PC, shared	11/81	9.5†	1-5
NCR Tower 1632	Multibus + PcMp bus	Shared	12/82	14.6†	8
Plexus P/60	Multibus + PcMp bus	Supermicro	8/83	32†	40
SUN Workstation	Multibus	Workstation		17	1
ONYX C8002	None	Shared micro	8/80	17†	8
Areté 1000	Single prop. bus	Symmetric mP	—/84	52.6	64
Synapse*	Dual	Symmetric high avail mP—:multi	6/83	330-1M‡	50-1K
Stratus/32*	Dual voting bus	Fault tolerant	2/82	115	64
Auragen 4000	Modified VME dual inter C	Multiprocessor Multicomputer, Tandem type cluster	1/84	140†	96

*Operating system kernel LS not Unix-based.
†*UNIX Review*, June/July 1983.
‡Degree of range for a multiprocessor

Super-micro and clustered supermicro systems. Basically this structure competes with old-line mini *and* mainframe makers, both of which are beginning to distribute supermicros (the Convergent Technology distribution model, for example). CT supplies hardware to traditional manufacturers who use only their distribution capability. Neither group will let its base erode without resistance, and both are ultimately capable of backwardly integrating OEM hardware.

High-availability computer systems. High-availability computing, pioneered by Tandem, may no longer be treated as a niche, but rather something a user should be able to trade off. Tandem's product line is based on mini technology and as such now has about 20 companies targeting its base using microprocessors. DEC has introduced the Vax clusters in the "Tandem-price" market, but VLSI will reduce the cost. An IBM product is long overdue.

Because a somewhat different structure is involved in building high-availability computers, especially with respect to software, there is a clear market. As the overall reliability of computers increases, the demand and price premium for high-reliability or high-availability computing is unclear.

There is still interest in making a self-diagnosable, self-repairing computer that *never* fails, however. While this feat is possible for the CPU portion of a system, the peripherals and software do not permit the ultimate machine to be built for some time.

The most important aspect of high-availability computers is that they can be designed for incremental upgrades using both the multiprocessor and multicomputer structures. This capability is why many computers are sold, regardless of their availability. With much lower priced machines, a broader range, and the introduction of fully distributed computing in LAN clusters, the need for high-availability computers for incremental expansion may decline.

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Bell led the team that conceived the Vax architecture, established Digital Computing Architecture, and was one of the principal architects of C.mmp (16 processors) and Cm* (50 processors) at Carnegie-Mellon. He is widely published in computer architecture and computer design.

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