Building your own computer

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ABSTRACT

Microcomputer kits have changed the build-it-yourself hobby dramatically. Until the introduction of such kits, only about two dozen amateur computers of any real complexity were in operation; nearly all were built by engineers in the computer industry. Formidable problems exist when trying to use or rebuild obsolete vacuum-tube or transistor computers, such as the non-availability of schematics. Building from scratch is so complex that usually only electronics engineers achieve it. Building a machine that uses the instruction set of a commercial computer is popular. Microprocessors were introduced only a few years ago, and already two dozen microcomputer kits are available, ranging from inexpensive minimal machines using assembly language, to high-level-language systems costing several thousand dollars.

INTRODUCTION

Microcomputer kits have been available for only a little over two years, but they have changed the build-a-computer hobby quite dramatically. Up to the beginning of 1974, only about two dozen amateur computers of any real complexity were in operation, and nearly all had been built from scratch by engineers in the computer industry. Today two dozen different microcomputer kits are available, based on half-a-dozen different microprocessors, and about 7,000 have been sold, a great many to people with apparently little or no knowledge of electronics.

Despite all the activity in microkits, many computer hobbyists are still building machines of their own design, or copying a commercial machine (or its instruction set), or operating and/or rebuilding obsolete computers. Before looking at the microcomputer scene, let’s first examine what can be done, and has been done, in the more individualistic areas.

USING OBSOLETE COMPUTERS

Vacuum-tube computers are occasionally available, but most of the drawbacks in using them are formidable: many are so large that a barn is required to store them, they need a great deal of air-conditioning and electrical power, and tubes can be expensive to replace.

Schematics are needed to get the computer working and maintained, but they are almost never available. Even with the older transistor computers, schematics (and especially updated schematics) are usually impossible to obtain. Now and then the prototype of a recent computer can be bought cheaply, but again, usually without schematics, so the buyer has two choices: take months or years to trace out every connection, or rewire most or all of the machine.

Several hobbyists who have bought obsolete computers with ailing or missing magnetic-drum or core memories have tried replacing them with semiconductor memory, quite a task even for an electronics engineer, which not all of them are.

Despite all the problems, many hobbyists are still operating an old computer, or trying to get it into shape, including machines such as the LGP-30, RPC-4000, LGP-21, and G-15. The CDC 160A appeals to a number of amateurs, but few if any are in the hands of hobbyists, because the machine is still relatively expensive, and it has 1700 discrete transistors, leading one California amateur to note, “I look at this number as an indication of the problem I would have in keeping it running or even getting it going.” He bought an RPC-4000 “at a graveyard-type disposal sale,” and later noted, “My RPC is working but I can’t get an assembly program more than two-thirds loaded. This produces lots of messages telling me my programs are bad. I suspect some memory aberrations, but the memory print routine won’t print either. So I have been trying to write a simpler routine of my own in machine language. That is a drag. It is amazing how many ways you can make mistakes with 32-bit instructions.”

An Indiana hobbyist bought a Univac O File Computer as scrap, with arithmetic unit, program-control unit, 90-column reader/punch, sort-collate unit, tape-drive program controller, and six magnetic-tape units. The new owner says, “I had figured to use the outside winter air to get it turned on and see what I’ve got, and just close down in summer. As to space, not too bad:
only about 400 or 500 square feet, pretty compact. I'm presently having 220 V installed to begin to turn on some of it." The manufacturer told him they can't provide schematics for any machine this old. Each machine was somewhat different, various changes having been made to each during its life, and careful documentation had to be kept as to what was inside each. Many of the old schematics and documentation have been thrown out, and "no amount of money" could provide relevant schematics for most of these old machines, antiques at 19.

Manuals are (or were until recently) available for the Univac 1108: 20 to 30 of them, each costing $50. Some Univac Solid State computers were given away to schools; when the schools asked the manufacturer about documentation, the situation turned out to be "impossible," as there were no records available on updated blueprints. "Maintenance in those days was a tricky thing," said Univac, "and the man who did it has long since been assigned to newer equipment, so there is nobody available from us today who knows how to service the old machines."

One company was getting rid of its Univac I, and wanted to give it away. But Univac found that to take it apart carefully and reassemble it elsewhere would cost $100,000, so the machine was scrapped.

BUILDING FROM SCRATCH

As in amateur radio, many computer hobbyists would never think of buying a kit or an assembled machine; they must build one. Up until only a couple of years ago, this task was so difficult that only a couple of dozen computer hobbyists in this country had operating digital computers that could really be considered as computers, and nearly all were electronics engineers in the data-processing industry.

The main problem in building a computer from scratch, without resorting to a microprocessor, is that so many areas of specialization are involved: logic, input/output, memory, peripherals, and mechanical skills such as packaging, back-plane wiring, metalworking, plastics, and many others. To build one's own computer once required learning a great deal about each of these fields. Although some computer hobbyists are engineers who design their own circuits, most non-engineers must rely on published information, and although several dozen books and manuals contain computer schematics, they have serious limitations. A book may show schematics of various portions of a computer—arithmetic unit, memory, control circuits—but none show how to connect them together, and anyway, they are usually only partial schematics. Mini-computer manuals with full schematics can be bought, but many of the parts are identified only by the manufacturer's code number; copying such a machine would be no real hangup for a computer engineer, but it is indeed for the neophyte.

Even supposing that an amateur computer-builder did get hold of complete schematics and all the parts, the one big stumbling block that has thrown many is core memory. It is still expensive to buy when new, and when surplus it may contain broken cores, or perhaps it's surplus because it couldn't pass the manufacturer's quality control. Getting a core memory to work still separates the men from the boys, if there are still any who want to try it, now that semiconductor memory is so readily available and so cheap.

Surplus computer printed-circuit boards have been available for years, but most of them, especially the IBM SMS series, have had their "tab" ends broken off, to make sure the boards won't find their way back into commercial computers. Many of the 3800 different types of SMS boards are level-changing circuits, of little use to the amateur.

DESIGNING YOUR OWN

Computer engineers often like to design their own machines, perhaps for the challenge of making it work. One Pennsylvania engineer's pre-IC machine is 7 feet long, 1 1/2 feet deep, and 6 feet high; it took a year to build and "will take 10 years to program," according to the builder, who used NOR gates from a process-control system declared scrap, mounted on 120 circuit boards with 35-pin connectors.

One North Carolina hobbyist built 75 percent of his computer with IBM SMS cards, the rest with home-built cards, an IBM 1620 core memory, Selectric typewriter and paper-tape reader/punch for input/output. The six-register machine has 16 instructions, "I/O devices available but not connected: 384K-word drum, two 7330 tape drives, two 100-cpm card readers. . . . A home-built line printer is 1/2 complete; 52-character chain, about 200 lpm."

A letter published in the April 1969 issue of the Amateur Computer Society Newsletter, from an ACS member now in Israel, said, in part, "In past issues of the Newsletter, some rather ingenious instruction sets have been devised which either simplify hardware, decoding or subsequent programming. It should be borne in mind, however, that the use of an instruction set which is already implemented on a commercial machine means a great reduction in problems with software, which would then be readily available. Remember that commercial manufacturers also look for instruction sets which tend to optimize both hardware and software, and many machines have instructions worth copying. If you've never written an assembler or Fortran compiler, don't just laugh it off as an easy project; it may well take you longer than to build the machine itself. Coming up with a new, unique instruction set may be a thrilling idea, but getting someone else's instruction set to function with your hardware is no small feat either."
COPYING A COMMERCIAL MACHINE

The computer amateur who wants to make things easier on himself by copying has two choices: he can obtain the schematics of his favorite computer and try to duplicate it, or he can build a machine of his own design that will use the instruction set of a commercial machine; the latter choice is the most common.

Most of those who have borrowed an instruction set already in use are copying that of the PDP-8 family, because of the variety of programs available, and a simple yet powerful set of instructions.

An Arizona hobbyist has built two computers from scrap parts. "Both are 12-bit, 2-μsec machines patterned after the PDP-8 instruction set. The first was built from second-generation discrete-component DTL NAND logic. The memory was of my own design. My second computer was built to get around the power dissipation problem (1.5W) of the first machine. It gets expensive to operate and refrigerate that kind of system in Arizona. The second machine is made out of 7400-series TTL and has an 8K x 12 main core memory. . . . All the PDP-8 software works on my system. This has saved considerable time, as you can well imagine. I have used the following DEC software: compilers (Focal—8K, Basic—Poly, Fortran—8K); assemblers (Macro 8, Pal III, Saber); maintenance programs, disk monitor systems (my 32K core memory looks like a DF32 Disk System). . . . I have devoted most of my spare time for the last four years in accumulating the parts and developing my software."

In Maryland, a computer amateur says, "Over the past four years, I have been in the process of building a computer. The actual hardware work got under way about three years ago. The machine really started working only a year ago. My machine uses the PDP-8 command set and runs at about the speed of a PDP-8/S (24-μsec cycle time). My memory is from an IBM 1620. . . . I have implemented only 4K at present, though I have designed the boards to allow easy expansion to 8K. . . . I have copies of the DEC software, which all seem to run: Focal, Editor, Pal III, etc. While I use the DEC software, I have made a point of never looking at their PDP-8 hardware diagrams, etc. I'm sure I learned more this way. After all, I'm supposed to be an EE."

A Floridian built a "Mininova 721," which he designed "to be a miniature Nova 1200. . . . I wanted to have a Nova for my very own, but couldn't afford it. I thought 'someday when the price of ICs comes down I'll design and build my own minicomputer, a small-scale version of the Nova.' Well, the prices of ICs came down tenfold or more in 1971-72, and this made my dream practical. The rest was innovation, enthusiasm, and a lot of careful planning. . . . I've incorporated very carefully the best features of the Nova instruction set and programmer's console, and designed the circuits to make a true stored-program, program-mable digital computer (complete with loads of integrated-circuit MOS-RAM memory) that would execute 16 different very carefully selected instructions. . . ."

TWO PRE-MICROPROCESSOR KITS

Back in the Sixties, the Tesla Research Foundation, with offices in Utah and Arizona, offered a variety of analog and digital computer kits, plans for digital gadgets, and home-study courses. The DI-TR5 digital computer, for instance, cost $365 in kit form, $440 assembled, used germanium transistor NAND logic and diode OR gates, and had two registers and 15 instructions. Input/output was with switches and lamps. The company didn't last long, and has vanished without a trace.

Beginning about five years ago, the National Radio Institute has been offering a course in computer electronics. The course includes building a simple desktop computer, which weighs 16 pounds. The Model 832 NRI Digital Computer contains 52 TTL ICs, 7400-type. The specifications include: 17 storage locations for 8-bit words, expandable to 32 words; over 15 basic instructions; input/output is with switches and lamps. For teaching purposes, the memory consists of slide switches.

THE MICROPROCESSOR REVOLUTION

All the previous quotes from amateurs building their own computers are from before 1974, the year in which hobbyist microcomputer kits first appeared on the market.

The avalanche started somewhat slowly, two years before, when Intel Corp. introduced two "Micro Computer Sets," the MCS-4 and MCS-8, sets of LSI chips for microprogrammable general-purpose computers. The MCS-4 was built around the 4-bit 4004 microprocessor, with 45 instructions; the MCS-8, around the 8-bit 8008, with 48 instructions. Although highly attractive to the hobbyist, both sets were expensive. The MCS-4 consisted of the 4001 programmable ROM memory, 4002 RAM data storage, 4003 I/O expansion, and the 4004 MPU. The last three were fairly cheap: $50, $10, and $100, respectively (in 1972), for 1 to 24. The catch was the 4001: the minimum order quantity was 25, at $25.50 each, plus mask charges of $600. The purchaser could have the ROMs programmed by Intel, or do it himself with the SIM-01 microcomputer (then $400), three control-program ROMs at $101 each, and an ASR33 Teletype.

The MCS-8 cost even more: the 8008 was then $200 for 1 to 24, and programming the ROMs required the SIM-01 at $900, plus the control ROMs and Teletype. Hobbyists soon seized upon these MPUs. A Connecticut computernik put it this way, "Enter the Intel 4004 and 8008 CPU on a chip! Both are complete.
CPU.s with quite a bit of power (45 instructions) and flexibility (internal address stack for subroutine nesting, etc.) The 4004 is not as desirable since it is more complicated to control and doesn't look as much like a typical computer. The 8008, however, is a beast!...The only drawback I see on these devices is their slow speed (about 1 MHz), yielding about 75K instructions per second. For amateur (and many commercial) uses this should be no real problem. Whether we wait 1 sec or 3 sec for the answer does not really matter. But a cost of $5K or $1K does matter!"

MICROPROCESSOR HOBBY KITS

In early 1974, Scelbi Computer Consulting offered the Scelbi-8H modular computer kit, based on the 8008 MPU. There was a starter set of five cards—CPU, DBB (data bus buffer) and output, input, front-panel card, and RAM card (256 8-bit words)—at $440. One step up, the standard card set, with 1024 words of RAM memory, was $565. A standard computer, with cards, chassis (console switches, card sockets, input/output and power connectors), and separate power supply, was $795 in kit form, $950 assembled. The 8H deluxe had 4096 words of RAM memory, and a higher-rated power supply; $1400 in kit, $1600 assembled. The memory could be expanded to 16K words, for about $2760 more.

Peripherals for the 8H included an oscilloscope alphanumeric interface, audio cassette tape unit interface, ASCII keyboard, and bit-serial interface for Teletype.

The Scelbi 8H was manufactured from March 1974 to June 1975, and was superseded by the Scelbi-8B, manufactured from April to December 1975, and using Intel 2102 RAMs “which allow the 8B to be directly expanded up to 16,384 words of memory at a cost comparable to that of 4,096 words of memory in an 8H,” which used the Intel 1101 RAM. The 8B kit, with 8008 MPU and 1K memory, was $499; empty 4K RAM card, $49; eight 2102 RAMs, $59. Scelbi provided extensive assembly-language software for their machines.

Scelbi got out of the hardware business at the end of 1975, and has since devoted itself exclusively to software, and to publishing books such as the $19.95 "Machine Language Programming for the 8008 (and Similar Microprocessors)." (The book could just as well have been called "Assembly Language Programming, etc.," but the author felt that people with little or no knowledge of computers would be more likely to understand the title the book was given.) At this writing, Scelbi is working on software such as BASIC for the 8008 and the 8080, and is considering what other MPUs to write software for.

The July 1974 issue of Radio-Electronics heralded the debut of the Mark-8 microcomputer kit, based on the Intel 8008 and using 7400-series TTL ICs. A minimum Mark-8, with 256 8-bit words, was about $900. The Mark-8 was available from June 1974 to December 1975, and will be superseded this Spring by the Dyna-Micro kit, an 8080 "microcomputer learning system, not a number-cruncher," with a 1702A PROM that loads on reset, and a memory of 256 words, maximum 512 words; about $200.

The January and February 1975 issues of Popular Electronics heralded the debut of the Mark-8 microcomputer kit, based on the Intel 8080 MPU, an 8-bit-word/16-bit-address machine with 78 basic instructions. The 8080, through extensive advertising, has become the best-known and most widely sold hobby computer, with some 6,000 sold as of this writing. The basic Altair 8800, with CPU board, front panel, power supply and expander board, is $499 kit, $621 assembled. The 4K dynamic memory boards are $195 kit; the 2K static memory kit is $145; 1K static memory kit, $97; maximum memory is 65K. There are serial and parallel interface boards.

Altair hardware options include a terminal with built-in audio cassette interface, a floppy-disk system, and a line printer. Software includes 4K and 8K BASIC, 12K Extended BASIC, assembler, text editor, system monitor, debug and DOS.

Sphere, a Utah company, offers the 4K Sphere 1 computer kit, using the Motorola 6800 MPU, with 512-character TV terminal, keyboard and power supply, for $860 ($1400 assembled). Memory is expandable to 65K, at about $240 for a 4K board, $490 for 8K, $750 for a 16K memory-board kit. A mini-assembler, editor, debugger, and utility commands are built into 1K of PROM. Available software includes Extended BASIC (with string and matrix manipulation), machine-language subroutine calls, trig functions, and disk-file input/output, plus FDOS (flexible disk operating system). The Sphere 2 kit adds serial communications and audio-cassette capability, at $999. The Sphere 3 kit adds 16K more of memory, for $1765. The Sphere 4 kit includes a 65-lpm printer, two IBM-compatible floppy disks, and DOS, at $6100. Other Sphere products include a light pen, and both full-color and black-and-white video graphics systems.

The MITS Altair 680 kit, with the Motorola 6800 MPU, is less than a third the size of the Altair 8800. Software includes a monitor on PROM, assembler, debug and editor. The 680 has three interrupt levels (the 8800 has eight). A $345 kit includes 1K bytes of RAM; the price for the 12K RAM board kits has not been set as of this writing.

The SWTP 6800 kit, from Southwest Technical Products Corp., using the Motorola 6800 MPU, comes with serial interface, 128 words of static scratchpad RAM, and 2,048 words of main memory, at $450. Additional 4K memory boards are $125 each; interface cards are $35. The SWTP 6800 contains a "Mikbug" ROM with a program that allows data to be entered when power is turned on.

In addition to the Altair 8800 and 680, Sphere and
SWTP 6800 kits, over a dozen others are available, including the Mike 2 and Mike 3 (Martin Research), Mark 80 (E&L Instruments), MOD 8, MOD 80 and RM6800 (MiniMicroMart), 008A (RGS Electronics), “George” (Godbout Electronics), Micro 440 (Consultants), SRI-1000 (Systems Research Inc.), Imsai 8080 (IMS Associates), Jupiter II (Wave Mate), and Micro-68 (Electronic Products Assoc.).

Some kits are based on the Intel 8080 (Mike 2, MOD 8, 008A), or 8080 (Altair 8800, Mike 3, Mark 80, MOD 80, Imsai 8800), others on the Motorola 6800 (Altair 680, Sphere, SWTP 6800, RM6800), National Semiconductor PACE (“George,” SRI-1000), or Intel 4040 (Micro 440).

Many microprocessors are available as part of a PC-board kit marketed for engineering evaluation, usually with a minimum of memory, and without power supply, chassis or case. Some of these are being bought by hobbyists, including the JOLT from Pehaco Corp., built around a MOS Technology 6502, at $249; a Mostek F8 Evaluation Kit, using the Mostek F8550; three evaluation kits from Cramer Electronics, based on the Intel 8080A, Texas Instruments 8080, Motorola 6800, $495 each. Cramer has planned later evaluation kits based on the AMD 6900, Mostek F8, RCA COSMAC, and bipolar MPUs such as the Intel 3001, AMD 2901, TI C400, Motorola 10800.

KIT PROBLEMS

Building a computer kit is not all that simple for a beginner. One kit manufacturer says, “For every person who can wire a computer kit, there are ten who can’t.” But those ten do try. Another manufacturer says, “Half the people buying kits are not qualified to build them. From the ones that are sent back, it’s obvious that most people don’t know how to solder, don’t even know how to put components on boards. Even resistors get all jumbled up. Our literature says the builder should have a couple of years experience in electronics, but people just don’t believe that.”

Because of these problems, Sphere is now offering the Micro-Sphere 200, in assembled form only. Built around the 6800 MPU, the basic 200 comes with 4K RAM, cassette loader, cassette operating system, 12-line by 21-character alphanumeric character generator, and “Monte Carlo games package,” at $860. A second 4K of memory is $180; an Extended Business BASIC ROM, $400; floating-point and trig ROM, $130.

The latest hobbyist computer offered by Systems Research is the SRI-F8, sold as a wired unit only, not a kit, because “too many people building computers have blown CPU chips. It’s too dangerous.” Quite a few beginners (and some professionals too) have destroyed sensitive ICs with static electricity, and have also put ICs in the wrong sockets or wrong-way-around, and burned them out. The SRI-F8, with the Mostek F8, 1K words, Teletype interface and debug program in ROM, is $325. Options are power supply, cassette interface, keyboard interface, video interface, keyboard, and enclosure.

Not all marketers of microkits are altruistic to the point of really trying to provide a top-quality product with adequate assembly and operating instructions. A few kits are little more than a box of parts, delivery of some kits is on an uncertain schedule, and some manuals that are supposed to be for beginners, would be understood only by a computer-design engineer. Surely many beginners are buying kits with no knowledge of what is involved in writing programs in assembly language, which many will find to be tedious, uninspiring and error-prone. And there are only a couple of books or manuals that teach the tyro how to use microprocessor assembly language; nearly all the manufacturers’ publications are meant for the engineer or the professional programmer. Of course some computer enthusiasts thrive on assembly language, but many beginners are likely to soon find that what they really want is a high-level language such as BASIC. So far, BASIC is available on only a few hobby computers, including the Altair 8080, Sphere, and Jupiter II.

AMATEUR COMPUTER CLUBS AND PUBLICATIONS

A variety of amateur computer clubs and newsletters exists. The Amateur Computer Society, the oldest, has been publishing a newsletter since 1966 (all the quotations regarding hobbyist computers are taken from the ACS Newsletter). The other newsletters, and the clubs, came into being after the introduction of microprocessor kits, and include the Micro-S Newsletter (Lompoc, Calif.), Homebrew Computer Club Newsletter (Menlo Park, Calif.), Interface (Studio City, Calif.), and The Computer Hobbyist (Cary, N.C.). The Amateur Computer Club Newsletter first appeared in England in March 1973; the newsletter of the Association Francaise des Amateurs Constructeurs d’Ordinateurs was first published in the Spring of 1974.

THE LAST QUESTION

One big question remains for the amateur: after you’ve gotten tired of playing games on your kit computer, what are you going to do with it? The discussion of this question opens up a whole new area, so large that another paper should be devoted to it.

From the collection of the Computer History Museum (www.computerhistory.org)