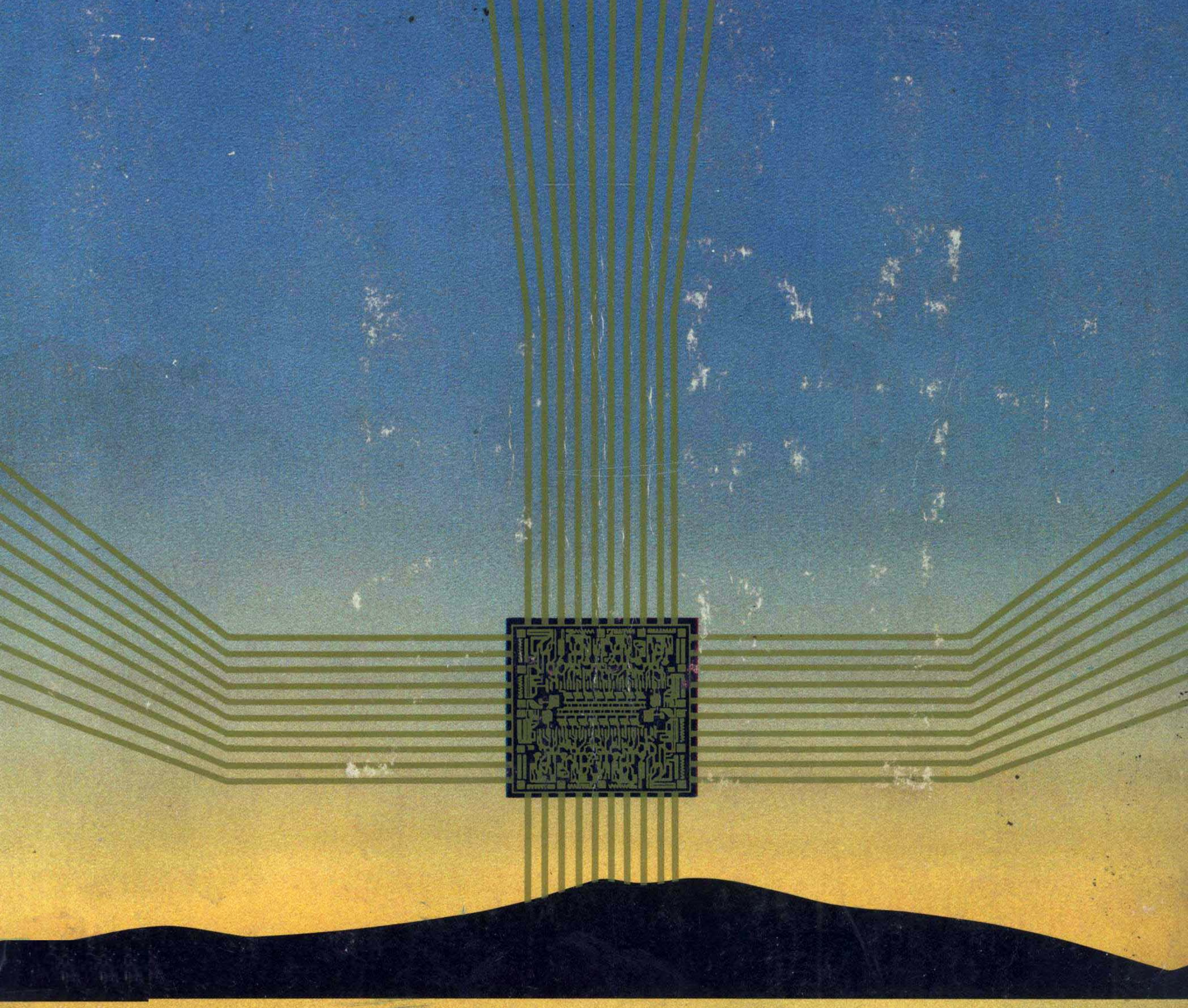
8086/8088
16-Bit Microprocessor Primer

By Christopher L. Morgan and Mitchell Waite

Featuring Intel's 8088 as used in the IBM Personal Computer



- General Purpose, Numeric and I/O Coprocessors
- 11 Sample Programs Based on the 8088 Microprocessor
- Covers 8086, 8088, 8087, 8089, PLUS 186, 286, and 432 Processors

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16-Bit MICROPROCESSOR PRIMER

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Christopher L. Morgan and Mitchell Waite

Preface

The new, powerful 16-bit microprocessor units from Intel — the 8086 and the 8088 — represent the latest magic in solid-state integrated circuits. These new microprocessors are expected to eclipse the popular 8-bit microprocessor units of the past as the best choice for a microcomputer-based product. This is because the processing throughput of the 8086 16-bit chip may be from 2 to 4000 times more than that of its 8-bit predecessors. The lower figure would occur when the 8086 is performing ordinary 16-bit integer arithmetic computations and the higher figure could easily happen when the 8086 CPU is teamed up with the 8087 number-crunching coprocessor on double-precision, floating-point calculations. Furthermore, the amount of code needed for equivalent programs is up to 50 percent less. In fact, these new 16-bit microprocessors have built-in integer multiply and divide routines, string instructions, and so many other features that the instruction set is almost like a high-level language.

In addition, the 8086 and 8088 general-purpose processors use such advanced architectural concepts as memory management, multi-level vectored interrupts, and coprocessing — concepts explained in this book. These features give the new 16-bit chips a great lead over the early 8-bit microprocessors, allowing them to be used in synergistic combinations in which the final processor complex is greater in power than the sum of the individual parts would imply.

Besides covering the basic concepts of 16-bit microprocessors, this book details how special coprocessors can work with the 8086 and 8088 to enhance performance manyfold. In particular, it covers the incredible 8087 Numeric Data Processor and the highly flexible 8089 Input/Output Processor. The 8087 and 8089 coprocessing chips enhance the 8086 by performing certain time-consuming tasks for it. The 8087 number cruncher can execute powerful math instructions in hardware much faster than the same functions performed in software by the 8086 alone. The 8087 NDP actually extends the instruction set of the 8086 CPU, giving the programmer the equivalent of a built-in scientific calculator with trigonometric, logarithmic, and other transcendental functions. The 8087 can represent numbers as large as 10 to the 4000th power! The 8089, for example, can perform intelligent dual-channel interleaved I/O operations while the 8086 hums along with the main program. With the addition of these coprocessor chips an 8086 or 8088 may have up to 100 times the throughput of an 8086 alone!

Using a down-to-earth primer approach, this book is the first to explain how the incredible 8086 and 8088 16-bit microprocessors and their coprocessors work. The book also is the first to explain the Intel 186 (an enhanced and updated 8086), the Intel 286 (an 8086 with built-in memory management), and the upcoming Intel 432 (an ultimate super-powerful, 32-bit microprocessor).

The first chapter begins with an explanation of what 16-bit microprocessors are all about and then gives an overview of the book. It then details what makes the 16-bit microprocessors so special, explores the kinds of products possible with 16-bits and gives a sneak preview of the 8086 and 8088. A software overview and a description of the book's organization are also included.

The book then covers basic 16-bit concepts and mechanisms such as the makeup of a typical 16-bit microcomputer with graphics peripherals, data types and numbers, physical memory organization, memory management, multi-processing and coprocessing, and how the 8086 and 8088 differ. The different levels of programming, from high-level languages to assembly language to microcode and finally to nanocode are described as is the development of assembly language programs on 16-bit microprocessors.

Next, in Chapter 3, the book introduces the 8086 and 8088 general-purpose processors, covering them in depth, describing their electrical nature, structure, instruction sets, and so forth. Chapters then follow on the 8087 Numeric Data Processor and the 8089 Input/Output Processor. There is also a chapter on the complete 8086 family of support chips so you can maximize the use of chips from a single source. Chapter 7 goes on to demonstrate 8086 programming by presenting 11 short sample programs you can type in and try. These have been optimized for simplicity and cover putting the letters "HI" on the computer screen, counting on the screen, a quick memory test, dumping EU registers, typing in a line, and single stepping the 8086. Finally, there is a chapter on the current hardware and software available for these processors and a look at the new IBM Personal Computer. Appendices cover the larger and more sophisticated 32-bit 432 from Intel, as well as the new 186 and the 286.

Throughout the book are numerous diagrams and sample programs that help to illustrate the operations. The three-dimensional drawings also make them more interesting. We have avoided complex timing diagrams and reference information of the type found in manufacturers' manuals and some of the more advanced books. We have taken a more visual approach and presented the subject of 16-bit microprocessors in an interesting, readable, and learnable text. All programs used in this book (except the last) are short and to the point. An entire sequence was developed on an 8085/8088 Dual Processor board for the S-100 bus using the CP/M operating system and the Microsoft cross-assembler. The programs for the 8087 coprocessor were debugged at Intel.

The 8086 and the 8088 are the first of a remarkable breed of third-generation, high-power 16-bit microprocessor chips. Comparatively speaking, they make the first microprocessors look like Model T Fords. You can be certain that the products born from these new chips will cause a giant leap in the capability of low-cost computers. The authors hope that this book will help you to understand and harness the awesome power of these 16-bit devices and the products they spawn.

Christopher L. Morgan, Ph.D.
Mitchell Waite

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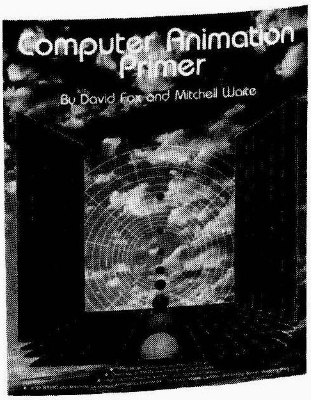
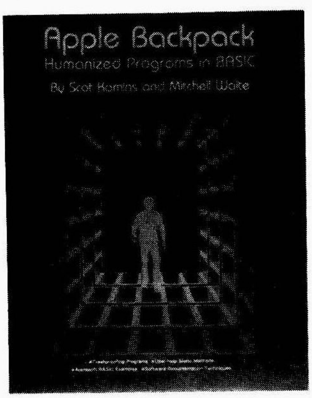
More BYTE Books Coauthored by Mitchell Waite

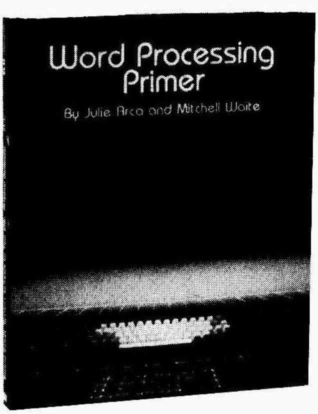
This is just one of four books coauthored by Mitchell Waite and published by BYTE/McGraw-Hill. You'll find the same friendly, easy-to-follow style and user-centered approach in each of the titles listed below. If you enjoyed and learned from this book, you'll certainly find the others in the Waite series equally helpful.



Computer Animation Primer, by Mitchell Waite and David Fox. Another in the ever-popular "Primer" computer book series, this engaging book introduces the exciting world of computer-animated graphics and presents the tools and techniques for creating original animated graphics on your personal computer. The book first describes the theory of animation and the potentials of various products, and then the authors go on to detail the actual programming techniques used in animation, focusing on character set, plotting, player-missile, and scrolling graphics. *Computer Animation Primer* features full-color illustrations and program listings in Atari BASIC and 6502 assembly language.



APPLE BACKPACK: Humanized Programming in BASIC, by Scot Kamins and Mitchell Waite. This book aids all computer users by establishing the "user-friendly" approach to programming in BASIC. The authors present concrete methods for developing programs that are not only easy to use, but also hard to misuse. Specific topics include clear screen formatting, crashproofing programs, developing built-in verifications and validations, presenting directions on the video display, and writing helpful, thorough documentation. Appendices feature an educational game program embodying the authors' user-centered approach and a humanized telephone-message-recording program with model documentation, both with complete Applesoft BASIC listings.



Word Processing Primer, by Mitchell Waite and Julie Arca. The first book of its kind, *Word Processing Primer* focuses on the newly available microcomputer-based text-editing programs. The authors begin with a review of the field, giving a working knowledge of the equipment and programs that make text editors work. A section on text formatting shows you how to control the final appearance of your printed copy, and a review of ancillary software, such as programs that check grammar or spelling and those that generate indexes or personalized form letters, shows the potential for customized applications. The book goes on to tell you what to look for when choosing a word processor, and a mini-catalog compares features, capabilities, limitations, and prices of many of the most popular pieces of software and equipment.

Contents

Chapter 1

Perspectives

WHAT IS A 16-BIT MICROPROCESSOR?

The 16-bit microprocessors are a new generation of computer chips from the wizards of silicon, the integrated-circuit chip makers. The 16-bit microprocessors are larger, more powerful devices designed to replace or supplement the 8-bit microprocessors of the seventies that started the microcomputer revolution. These new 16-bit microprocessors are important because in certain configurations and on certain calculations they are up to 4000 times more powerful than the older 8-bit chips and yet will cost about the same. This awesome power is about to be unleashed in the form of intelligent products that will make an incredible impact on society. This is because 16-bit microprocessors allow products to have significant intelligence. Thus, they make it extremely likely that we will see a revolution in end products, such as machines that talk and listen, three-dimensional color displays, advanced communication networks allowing you to access giant data bases via your telephone, intelligent, computerized automobiles, and smart houses that follow the inhabitants' movements in the house and adjust for maximum energy utilization.

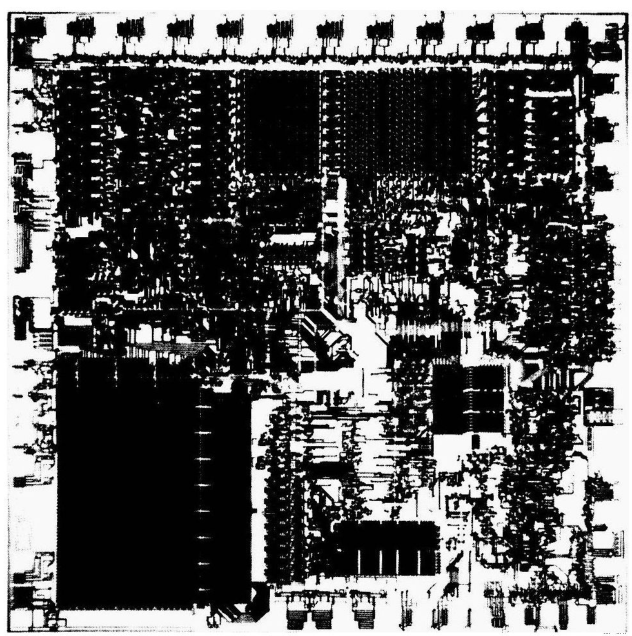


Figure 1.1a: Magnified photo of the 8086 chip.

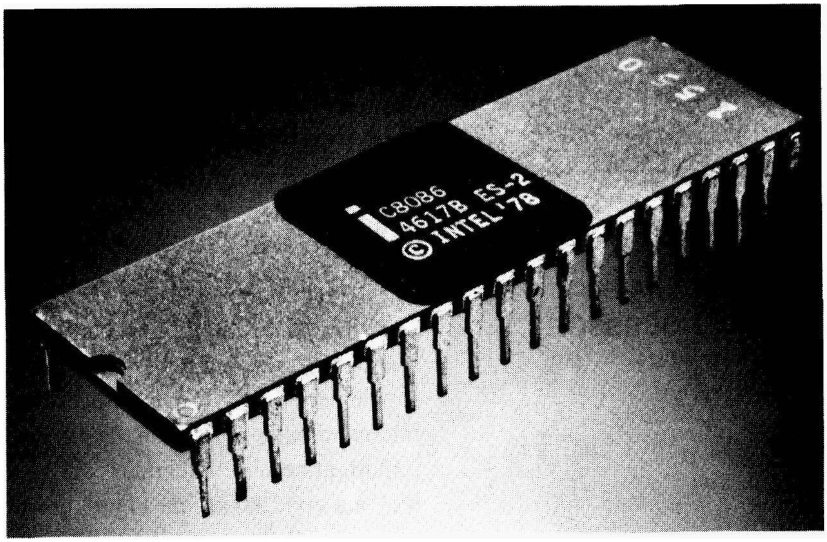


Figure 1.1b: The 8086 in an IC package.

WHAT IS THIS BOOK ABOUT?

This book is about one of the first, most powerful, and most popular of the 16-bit microprocessors — the Intel 8086. (The book is also about the 8086's cousin, the 8088. When we say 8086, we normally mean both.) This book will show you how the 8086 works, how it fits together, and how to take advantage of its power. The powerful 8086 16-bit chip was the first on the market and has, therefore, established the largest following of users and manufacturers of support products. It is also the least expensive of the major 16-bit chips on the market.

This book is designed to teach you in a simple down-to-earth fashion about the 8086, along with its entire family of support chips, and its sister chips (the 186, 286, and 432). If you are familiar with the older and extremely popular 8080 chip from Intel, then you will certainly want to know all about the more powerful 8086. Since the 8086 is a logical extension of the 8080, it is easy for 8080-oriented people to assimilate. This introductory book uses a visual primer approach to cover the basics of the 8086 and family. It is not a reference manual, but rather a basic book for the beginner who has already been exposed to the 8-bit world and wants to know about the new 16-bit technology.

WHAT IS SPECIAL ABOUT 16-BIT MICROPROCESSORS?

What makes the new 16-bit microprocessors stand out is the fact that they can deal with information in multiples of 16 bits instead of 8 bits. Actually, these newer processors can deal with data in various basic sizes including both 8 bits and 16 bits, but the underlying mechanisms of the 16-bit processor are twice as large as those in their 8-bit counterparts. Also, because each piece of data can be twice as large, the processor can be many times more accurate. The largest number that can be represented with 8 bits is 255; with 16 bits you can represent a number as large as 65535, which is about 256 times larger! Thus, the range and/or the accuracy can be greatly increased in the various number representation formats. It is interesting to note that the 8086/8088 still uses a byte-oriented instruction set. That is, a machine language instruction for the 8086/8088 takes up from 1 to 6 bytes of memory. On the older 8080-type processors a machine language instruction takes from 1 to 3 bytes, and so a newer processor will have a much richer and more versatile instruction set. At the same time, by dealing with 16-bit data chunks, the processor grabs its instructions at the faster rate of 2 bytes at a time. The 16-bit capability also leads to a much faster microprocessor in other ways. For example, the 16-bit device can send and receive a 16-bit data value in one transfer, whereas the 8-bit device often requires two separate operations to do this. Furthermore, software can be more efficient because it is easy to represent and operate upon larger 16-bit values in the registers of the CPU. In an 8-bit microprocessor you must often do 16-bit operations in two steps, often taking as many as four times the number of instructions to do the job of one 16-bit instruction.

But the 16-bit basis of the microprocessor is only a small part of the whole story. The manufacturers of these devices decided to let out all the stops and increase the computing power beyond what a doubling of the data word would imply. To do this, they used more complex circuitry on the chip. Keep in mind that microprocessors are nothing more than computers made of thousands of tiny transistors (transistors are tiny amplifiers that allow the flow of electronics to be precisely controlled) housed in a tiny chip. The transistors are *etched* onto thin crystal slabs, using photographic techniques of miniaturization. The crystal slabs are *cooked* in an electrical chemical environment and then cut and packaged into lots of computer chips.

The degree of miniaturization that can be achieved controls how many transistors can be packed into the computer. And the more transistors, the more sophisticated things can be done. At the time the 8086 was developed, a better manufacturing technique was needed to allow smaller dimensions for the transistors. A new silicon manufacturing process called HMOS (pronounced h-moss) was implemented for the 8086 family. HMOS allowed putting up to 70,000 (or more) transistors on a single micro chip. With this many transistors manufacturers could include extensive hardware circuits. For example, they could now include on-chip multiply and divide instructions. Since multiply and divide are now built into the chip and not simulated in software, math operations can be performed much faster. With so many transistors there can be sophisticated interrupt structures (some with built-in priority circuitry) right on the chip. This allows the controlling of many I/O devices in efficient ways with little additional hardware.

There are other things about 16-bit chips that extend them far beyond their 8-bit little brothers. For example, the size of memory that the 16-bit chips can use is huge compared to that of the 8-bitters. The 8086 and 8088, for example, can access over a million bytes of read/write memory. Contrast this to the maximum of about 64,000 bytes for most 8-bit microprocessors. With such large memory, programmers can design much more powerful and sophisticated computer programs. It is possible with memory sizes of about 256,000 bytes to run advanced operating systems which can support the very best of computer products. Having lots of memory also means it's easy to have several users sharing the same computer. It is reasonable to imagine a word processor with 1 megabyte of memory serving 16 users. Each user would have a terminal with its own built-in 8088 that communicates with a central 8086.

But perhaps the most relevant, mysterious and trend-setting aspect of the new 16-bit microprocessors is the way in which their designers have distributed their intelligent features. The new 16-bit chips have mechanisms that support much more powerful computing structures than a single processor doing a single task. Whereas older microprocessors usually did all the computing in a system, the new 16-bit micros have divided up the computing into subfunctions available in *optional* special-purpose chips. That is, you don't need these chips for simple operations, but they are available for you when you want to add them. Today there are special chips for doing floating-point mathematics including computation of trigonometric functions. There are also chips for doing specialized I/O automatically, without the use of the main processor.

These supplemental processors, or coprocessors, are not just simple support chips. They are really complete microprocessors dedicated to special purposes that previously would have required many large circuit boards to contain. In fact, sometimes they are called special-purpose processors. An example is the Intel 8087 Math Chip. It is a very powerful microprocessor itself, with its own programming language. It can perform high-precision computations in an incredibly short time. Whereas a computation of a double-precision square root (53 bits of accuracy) executed on the 16-bit processor in software might take almost 20 milliseconds, with a math chip it takes about 36 microseconds, more than 500 times faster! (Of course, you should not expect to sustain such a performance ratio over the long range during typical operations.) Such a high-speed math chip eliminates the need for lengthy, memory-intensive emulation routines. Using such a chip with a language like BASIC or Pascal means that the language will not only run very fast but use up much less memory space and be cheaper and more reliable.

These math chips,, or coprocessors, are not limited to use in scientific processing or in extending high-level language instruction sets. It is possible, for example, to build a low-cost very high-performance industrial controller using the math chip and the 8088. This allows complex equations to be performed in real time. Digital recording, spectrum analysis, music synthesis, speech recognition, communications, and so on are all untapped applications for this new speed.

In addition to giving the 16-bit microprocessor creative connections, the designers have performed several neat tricks with it. With the dropping cost of computer hardware, it is the programming of computers, a complex and time-consuming chore, that is the most expensive development aspect of any microprocessor-based product, be it for a process controller, business machine, or personal computer. Designers have incorporated features in the new 16-bit chips that allow programs to be easily moved around memory without a lot of difficulty. Moving programs around easily in memory is important if you want powerful software. This ability, for example, allows a program to reconfigure itself on the fly, creating a custom version for the amount of memory available in each unique application. It is likely that because numerous programs for the new 16-bit microprocessors can easily relocate programs, they will also be quite able to work in harmony with programs from different manufacturers.

Another area of enhancement in the 16-bit microprocessors is in error checking. Error checking is a subject largely overlooked by the microcomputer industry, and a program that doesn't handle errors properly can create major operation problems. For example, if the error checking is poor on your computer, the error may not be detected and the results of the program may become suspect. Or if the error recovery is poor, you may find your computer program ''dead in the water'' and unable to be restarted without destroying lots of your work. On the other hand if the recovery process is good and an error occurs, the program may be able to fix itself and continue automatically. All the new 16-bit units have strengthened error checking. This is especially true for the new math processor. For example, if there is an error in the divide instruction, such as an overflow or divide by zero, the microprocessor notices this and causes an interruption of the processing. Your program can deal with this interruption in a smooth and logical fashion, sending a message to the console, returning control to the program, inserting more realistic values, or whatever you desire. With such sound error-recovery mechanisms, it is possible to design programs that just can't be hung up or crash the system.

With such sophistication you can be sure you will see many high-level languages and operating systems such as C, UNIX, Pascal, Forth, and Ada becoming available on low-cost computers that use these fantastic 16-bit chips.

The 8086 provides the potential for a host of consumer products which use its ability to quickly and efficiently execute complicated programs. Any particular product that currently uses a computer chip is subject to the enhancing effects of the 16-bit microprocessor. Consumer products that are most likely to use the first 8086-type chips are high-performance personal computers (such as small business machines with graphics), video arcade games, automobiles, kitchen machines, typewriters, answering machines, and radios.

Because of the power of the 16-bit chips, it is certain that voice communications will become the bottom line for the computerized products of the 1980s. For example, personal computers will soon feature programs that ask you questions and listen to your answers. Vending machines will have no buttons, just a coin entrance and a heavily grilled speaker and microphone. The sight of people talking with these intelligent boxes will become as commonplace as the sight of someone using a drinking fountain.

Because the 8086 doesn't cost much more than the 8080, and will eventually cost even less, it is possible to use it in places where weight, cost, and superior intelligence are critical, such as in aircraft, and, unfortunately, weapons. With the various subsystems of an airplane controlled independently by 8086's in a *slave* mode, the entire aircraft could operate more precisely, quickly, and reliably than ever before. The math processor would allow navigation control so the 8086 could tie into the auto-pilot system. It is easy to imagine that with enough of these processors the jet fighter itself could be given so much intelligence that a pilot could be on the ground in a simulation cockpit, dogfighting via the computers.

But the first appearance of the 8086 will no doubt be in the personal and home computer market, an increasingly competitive market. In August of 1981, IBM announced their first Personal Computer. Besides shocking the world by going out and making a computer that could run much of the existing 8-bit software on the market, the IBM designers also used the powerful 8088 chip. The 8088 is exactly like the 8086 internally, but externally it uses an 8-bit data bus. This allows it to easily use current, inexpensive, 8-bit I/O and memory chips. With IBM using the 8088, it is clear that its computer will be among the most powerful on the market. By using an 8088 in the computer, the IBM people will be able to develop and use extremely powerful software. Moreover, the IBM Personal Computer has a socket for an 8087 number-cruncher chip, and in typical IBM fashion this socket will be filled and utilized to the hilt to make the IBM Personal Computer a mathematical wizard.

It is not too likely that the 8086 will show up in low-cost TV games, but it may appear in top-of-the-line telephone-answering machines. With the 8086, a number-cruncher chip, and an I/O processor, you could store your messages in random-access memory (RAM) inside the machine rather than on tape. With the 8086's powerful language structure, it is easy to imagine that the answering machine would incorporate more than just the message-taking computer system, and will probably include an appointment reminder program, as well as electronic mail capability.

Another place where the 8086 will probably be used in conjunction with the telephone is the digital private branch exchange (PBX). A PBX is a device that allows the many telephones of a business to be connected to the outside and monitored by one or more attendants. Some PBX's turn each telephone in the system into an intelligent station. Most PBX's