NEW TRENDS IN COMPUTER TECHNOLOGY

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Summary

Computer technology has been rapidly advancing over the past two decades, mostly due to the high demand for personal and institutional computers. While this trend is expected to continue for a few years, Personal Computers (PCs) will slowly lose their position as the main driving factor behind the computer technology. This article starts by introducing the new devices that are likely to join or even replace PCs, maintaining the popularity of computers in the near future. These emerging devices, which include Internet appliances and smart vehicles, will pressure the computer industry to continue their current trend and deliver faster, denser and cheaper computers.

After explaining the demands that drive the computer technology, this article continues by focusing on the various trends that a responding industry might follow. Advancements in process technology are the most important reason that computer industry has been able to improve the speed and density of its devices over the past few years. Although such advances will continue for a number of years, scientists anticipate serious barriers that might be reached within the next decade. This article summarizes the trends, known barriers, and potential alternatives related to the process technology.

Another factor that improves computing performance independent of process technology is modifying the architecture and its supporting software to achieve higher *parallelism* in typical applications. Three major trends in extracting parallelism, known as Very Large Instruction Word (VLIW) processors, multiprocessors, and configurable computing are explained highlighting their advantages and drawbacks.

Finally, this article goes over the bolder anticipations and ideas in the scientific environment that can not be manufactured in the near future. These potential candidates for the next two decades include optical computing, molecular nanotechnology, and quantum computing.

1. Introduction

We have enjoyed explosive growth in the performance and capability of computer systems for over a decade. The theme of this dramatic success can be summarized in two words: *popularity* and *parallelism*. Application demand has led the industry to provide a wide range of computing solutions with increasing performance and capacity at an extra cost. Low end applications correspond to the highest volume machines with the greatest number of users, whereas the most demanding application at the high end, which are often an important minority, exert maximum performance of a computing system. Regardless of the type of applications, their number has been rapidly increasing over last few years and this trend is likely to continue into the future assuring rising popularity of computer systems. Type of popular applications, however, determines the direction for the next generation computing infrastructure. The demand for ever greater application performance is a familiar word to the ears of every computer designer. Responding to this demand, computers have evolved to perform multiple operations at once, in parallel, requiring a larger volume of resources on the same chip. Such parallelism has been made possible by advances in the underlying VLSI technology, which allow clock rates to increase and higher number of components to fit in a chip. Computer applications, architecture and technology have always been evolving together with very strong interaction and future will be no exception in this regard. To understand the trends in computer technology we need to analyze the directions in each of these three aspects of evolving computer technology.

According to a recent report released in the early months of year 2000, Personal Computers (PCs) continued to be the top consumers of semiconductors contributing 25% of total chip sales toward the end of last millennium. However, communication equipment makers, currently ranked second with consuming 22% of chip sales, showed a higher growth compared to PCs. As the new networking applications emerge, communications' share of chip sales is likely to overtake PCs later in the decade. Such a trend in popular applications will inevitably affect the next generation chips with stand-alone microprocessors at their leading edge. This article presents examples of these emerging applications and discusses the cost and performance demands that they might impose upon future computing systems.

As a highly diverse set of applications opens up, today's general-purpose computers are pressed to deliver higher throughput for a wider range of applications. This trend toward application diversification, as well as increased number of new applications is likely to set up a roadmap to various computer architectures. Despite this variety, however, all these new architectures will share a common goal of exploiting parallelism in their target application. Parallelism, which allows higher levels of performance for a given clock rate, is already used in microprocessors in various forms. For example, most modern processors take advantage of a fine-grained parallelism, called *pipelining,* which works by breaking an instruction into smaller tasks. These smaller tasks can execute concurrently, as long as they do not depend on each other (see *Processors*). While many past forms of exploiting the parallelism are likely to be used in future products, a number of new architectural approaches are emerging. This article summarizes three major trends that will be used, in combination or separately, to exploit parallelism in computer applications. These new trends, however, are extremely demanding in terms of the silicon technology that is needed for their implementation. Three major VLSI technology requirements are often area, delay, and power consumption of a computer chip or system. This article also discusses the trends, barriers and concerns that are related to the silicon technology used in computers.

Bolder, software issues.

2. Application Trends

Understanding computer application trends is crucial to predicting where computer technology is heading in the future. The broad diversity of future computer applications prevents a thorough classification, but this article focuses on the main aspects of the application trends by presenting three examples. The first example set is tomorrow's most popular computer applications that will substitute or even increase today's PC popularity. This prediction is based on the phenomenal growth of *Internet* (see *Networking*) in recent years. The second sample application is electronic design tools, which can be considered as a high-end computer application in the future. Finally, this article touches upon future smart vehicles, as an example of how the dependency of human typical daily life on computing devices will increase in the future.

2.1. Internet Appliances

While billions of microprocessors are at work in intelligent computing devices worldwide, less than 1% of them exchange data with other computers. Perhaps the most common networked device is desktop PC, but the trend is on the course for a world in which even the smallest embedded processors have Internet access. These new emerging devices are often referred as Internet or Web appliances. In reality, Internet appliances are simple computers designed for common tasks such as surfing the Web or checking email. The premise behind Internet appliances is that today's PCs are too complicated and costly for beginning users or people who just want to access the Internet. In spite of the explosive growth of the Internet these past few years, there are still millions of people, intimidated to merge onto the information superhighway, because learning to use a standard computer is too complicated. Figure 1 shows examples of Internet appliances that will let you get on the web just by hitting a button or two. The appliance on the left is an actual phone with touch screen web-browsing and email capabilities, and the one on the right is a web surfing device. Beside simplicity, these devices offer a cost advantage over the PC, which in turn adds to their popularity.

The networking technology behind an Internet appliance is one of the most important factors in determining its usefulness and ease of use. Most of today's networking uses wired infrastructure such as already existing phone cable lines, or dedicated lines. However, wireless networking is becoming less expensive and more affordable; therefore next generation of mass-market personal computing equipment will be some form of small internet-connected mobile device. The main effect of these mobile devices on their internal embedded processor will be the power requirements as will be discussed shortly.

Regardless of the networking choice, future Internet appliances will be based on embedded computing systems (see *Embedded Systems*). Traditionally, embedded systems have been designed using very minimal hardware with slow or even obsolete 8-bit microprocessors. All that is changing, and the next generation of devices will probably sport fast, full-featured, up to 128-bit processors. There is a unanimous feeling in the computer industry that the driving engine of the Internet appliances in the next decade will provide a success similar to what microprocessors in PCs did for Intel, the largest semiconductor company, in the last decade. There are many processors battling for this market, including some established players such as PowerPC or Intel's StrongArm, and a promising new processor, called (Transmeta's) Crusoe, which has specifically targeted mobile applications and Internet appliances.

Figure 1. Examples of Internet Appliances.

The main effect of Internet appliances on computer technology is simply demanding stringent requirement in terms of area, speed, and power. Due to high popularity, the devices will be more cost-sensitive than PCs and their processors should take less silicon area for the same functionality to be cost-effective. Moreover, a small mobile Internet device will be expected to process image and voice at real-time speed. Finally the low power requirements in the wireless appliances will impose rigorous limit on the power consumption of their driving engine. PCs are often equipped with heat sinks and a cooling system to alleviate the high power consumption of the microprocessors. A portable device that works on a battery life has a much tighter power budget than the microprocessors in PCs. Section 3 and 4 discuss the technology and architecture trends that might help the industry to overcome the obstacles imposed by future applications.

2.2. Electronic CAD Tools

Perhaps the most apparent application reliance on increasing levels of performance is well established in the fields of computational science and engineering. In these fields computers are used to simulate phenomena that are either impossible or too costly to observe through empirical methods. Typical examples include modeling global climate change over a long period, the evolution of galaxies, and genetic analysis of human biology. Computational modeling allows reasonably accurate analysis to be performed on hypothetical design through computer simulation.

Ironically, one example of such high-end applications is the electronic Computer Aided Design (CAD) tools, which are essential in design of the chips that are the driving engine of a computer system. As the number of components on the chip increases the need for modeling activity rises and clearly there is more to simulate. In addition, the increasing complexity of VLSI chips makes the verification task much tougher, mainly because complex designs require more test vectors and each vector must run for a larger number of clock cycle to cover for the extra levels of chip functionality. Furthermore, the cost of chip fabrication is rapidly increasing, resulting in lower levels of tolerance for design mistakes. This leads to a requirement for higher levels of confidence in design, emphasizing the importance of a complete verification. The cumulative effect is that the computational demand for both chip design and verification of each new generation is increasing at an even faster rate than the speed of the microprocessors themselves.

The bottom line is that many of today's high-end applications will be tomorrow's high-end applications as well. Even with dramatic increases in processor performance, very large parallel architectures are needed to address these problems in near future. The trend for such applications shows that, as always, they will strive for higher speed in the next decade. Unlike the high-volume applications in Subsection 2.1, these high-end applications can tolerate greater costs due to their low volume. Also, the driving engines for these high-end computer systems are likely to tolerate some reasonable higher power consumption, for the sake of higher speeds. Based on the technology advances that are discussed in Section 3, the silicon area will probably not be a concern for high-end computer systems.

2.3. Smart Vehicles

Our last example will represent a set of future computer applications that will cause deeper penetration of computer systems in people's daily life. While a low percentage of world population deals with high-end computer applications and Internet is mostly available to people in developed countries, the majority of people are already exposed to automobiles. Automotive industry is currently one of the smaller semiconductor consumers (with only 6% of total sales), but this is likely to change in near future. People around the globe expect to be able to receive information even when they are on a commute in their cars, public train, or buses. Providing such high levels of connectivity in the vehicles will require the vehicles to be equipped with a greater amount of computing devices. Another piece of consumer electronic, which will soon invade cars, is an in-vehicle navigation display based on a Global Positioning System (GPS) and a pre-loaded map. GPS helps the driver locate the car by exchanging information in high frequency signals with satellites. Voice recognition is also a future possibility in automobile features. Drivers will be able to dial phone, check email, control the radio and interior climate, set cruise control speeds, and even ask for direction from a voice-activated GPS.

Convenience is not the only motive for further integration of embedded computer systems in future vehicles. For example, GPS and satellite communication could also play a significant role in the transport of hazardous materials. By tracking the carrier by means of real-time GPS transmission, the drivers can be alerted to conditions ahead, to avoid accidents. Safety is already one of major considerations in design of a new car, and computer technology is contributing in achieving the safety goals. United States federal government has set a goal of reducing crash fatalities by 20% and truck-related fatalities by 50% in less than ten years. Since approximately 75% of crashes are caused by driver error, incorporating intelligent vehicle technology in the next generation cars can significantly reduce the accidents by preventing the errors. These advances that are based on computer technologies include adaptive cruise control, vision enhancement, vehicle stability monitoring, drowsiness warnings, and collision avoidance for lane changes or intersection crossings. The systems are designed to warn drivers of dangerous situations, recommend actions, or even assume partial control of a vehicle to avoid collisions.

Increasing computing electronics in the cars can contribute to their efficiency as well as convenience and safety. Hybrid cars, which combine an electric motor and an internal combustion engine, are growing in importance to auto makers and government agencies because they are more appealing to consumers than pure electric vehicles and offer greater fuel efficiency than conventional vehicles. While today’s hybrid cars claim fuel efficiencies in excess of 70 miles per gallon, those figures can drop dramatically under real-world conditions. To maintain high fuel efficiency, the engineers must create sophisticated control systems that adapt to driver’s habits. Such systems would know how hard the drivers accelerate or brake; what type of road and traffic congestion they experience; and at what speeds they often drive. Adaptive controller system could effectively manage the electrical charge by acting on such information. Hybrids are particularly well suited for such techniques, because they use their internal combustion engine only to store charge in the batteries. Electrical current is then released to the electric motor, as it is needed. To be successful in such control schemes, the researchers believe that vehicles need more computer power.

For example, General Motor’s Percept, a hybrid concept car, now uses 47 microcontrollers and 12 networks, which is based on a 266 MHz, 32-bit Motorola system with integrated I/O. (see Motorola or delete?) In addition to higher computer power, future hybrid vehicles might need fiber-optic network bus link instead of copper, because of greater bandwidth, lighter weight and superior electromagnetic interference shielding.

The effects of this application trend on future computer systems will be similar to that of Internet appliances in terms of cost sensitivity and speed requirements. However, vehicle electronics is likely to impose much higher quality standards on both hardware and software of future computing system. Today's VLSI technology allows for production of chips with acceptable quality, but such a need will be even more pronounced in the future. Unlike computer hardware, the commercial software quality is not quite ready for the next generation consumer products such as smart vehicles. PC users have often experienced a system crash due to a software bug. While these software faults may only cause some frustration for PC users and can often be rectified by resetting the system, they will probably lead to fatal results if they occur in the computer system of future cars. Therefore, as a result of trends similar to that of applications in future intelligent vehicles, the focus of software in computer systems will shift from functionality to quality for certain products. This will also emphasize the need for fault-tolerant systems in both aspects of hardware and software.

3. VLSI Technology Trends

Without a doubt, the advances in VLSI technology have been the main contributing factor behind improvements of computer industry. Since the 1970s, VLSI technology has paced a famous law, known as Moore's Law, to achieve higher performance and device density. According to the Moore's law, the chip capacity doubles every 18 months for the same price. The primary technology advance is a steady reduction in basic VLSI *feature size*, making the transistors, gates and circuits faster and smaller. The core of a VLSI chip, called *die*, consists of a large number of transistors and metal wires that connect them to implement a desired circuit.

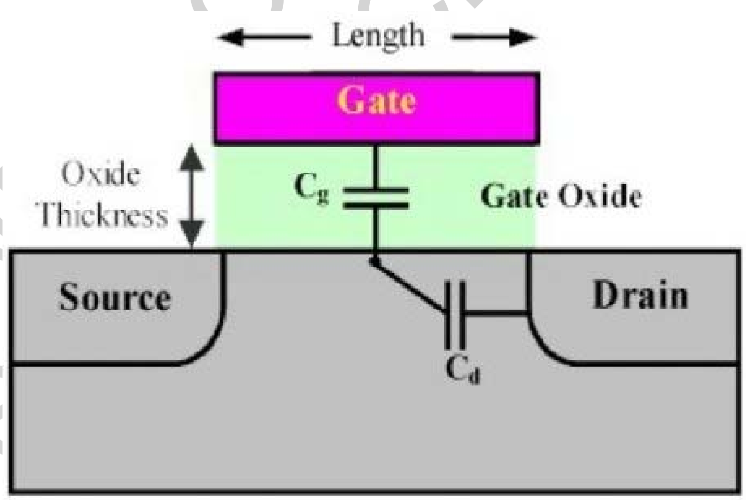

Figure 2. A Simplified Transistor.

Figure 2 depicts a simplified CMOS transistor with three terminals, called source, gate, and drain. (See reference for transistors?) Minimum feature size in each process generation determines the maximum density of transistors and wires in the chip die. Although die density depends on the wire geometry as well as the size of transistors, this article refers to the gate length, shown in Figure 2, as the minimum feature size for the sake of simplicity. The past trend in VLSI technology shows that the minimum feature size has been shrinking at a rate of 12% a year, since the 1960s. Shrinking along with continuous increase in the die size has resulted in an annual 38% to 50% increase in the number of transistors per chip, depending on the type of semiconductor family.

In this section, we examine various aspects of VLSI technology to understand the likelihood of the past trend continuing in the future. We discuss the most important barriers that currently interfere with the objective of attaining the desired density and speed for future computer systems. As discussed in Section 2, the application trends present an increasing demand for higher density and speed, and lower power and cost for future computer systems. These application demands can all be translated into a need for reducing the minimum feature size as it is explained shortly.

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