# The Future of Computing Platforms

## Will PCs Rule the Future? What Does it Mean for Microprocessors?

**by Michael Slater**

With the rapid advances in personal computers over the past two decades, it is tempting to think that the industry has reached an advanced state, and that maybe it is even maturing. Although this is true in some limited respects, the design and use of computers is really in its infancy. The most significant gains from computing are yet to be realized, and advances in the next two decades will dwarf those of the past two.

Whatever the new world of computing will look like, one thing is certain: it will continue to fuel rapid growth in markets for microprocessors, memory, and support chips. But the success of various microprocessors will be significantly affected by how computing platforms—in the broadest sense of the term, including video games, set-top boxes, handheld computers, PDAs, and so forth—evolve. For chip and system developers alike, maintaining a clear vision of what the future will look like is key to long-term growth.

If we begin with where technology is today and extrapolate forward, we tend to get stuck in incremental thinking, resulting in shrunken PCs for handheld systems, super-fast PCs on desktops, and virtual reality game machines hooked up to TVs. A clearer view of the future can be seen by starting from what we'd like computing to do for us. We can then step back to see where today's technology falls short and what advances are needed to achieve the future vision.

### A Vision of the Future

The year is 2020. Computing has become so pervasive that I rarely think of it as computing any more. I have a dozen or so general-purpose computing devices, each optimized for a different environment but capable of many tasks. Another several dozen processors serve dedicated functions in various appliances, vehicles, and control systems, but these more constrained applications aren't full-fledged computing platforms.

My desktop system has a large display and a keyboard, making it the most productive to use for entering lots of text or manipulating large amounts of data. (All the systems have voice recognition, but I continue to prefer keyboards for writing.) The largest display of all is mounted on my living-room wall, but this unit has only a small remote control and no keyboard.

At the other extreme, my pocket system's display is only a couple of inches square. In between are various portable tablets—larger ones that sit around the house, and smaller ones for trips outside the home or office.

All my personal information—calendar, phone list, notes, documents I'm working on—is available on any of these systems, so I have access to the same information on whichever system I'm using. Each of the systems has wireless communication capabilities and can act as a telephone as well as an electronic-mail terminal or an access device for the worldwide information network.

The distinction among voice mail, e-mail, and faxes is blurred. A single in-box lists all my messages, whatever their type. Calls to my personal phone number ring on whatever device I currently have with me, unless I have instructed the system to do otherwise. Most of my systems are equipped with a built-in video camera, enabling them to serve as videophones as well.

Any system can also be used as an entertainment device, both for playing games and watching video content. The large-screen system at home is the most comfortable for watching movies and other video entertainment, but the tablets can serve this function as well.

The concept of television channels is largely gone. I program my video entertainment unit with a profile of the kinds of shows I want to see, and it captures them as they are broadcast. When I want something to watch, I select from the list of things that have been captured, freeing me from any concern about broadcasting schedules. And when I really want to explore, I can browse the entertainment servers on the worldwide network, where countless niche programs with which no broadcaster will take a chance are available. I can find material for every conceivable special interest, from koi to typography. On-demand movie archives offer every movie ever made.

Mail-order catalogs have all but disappeared. Direct-channel suppliers are more abundant than ever before, but their catalogs are on-line. I can search across multiple vendors for a particular type of product, and look at pictures and read customer reviews for any item. When I want to order, it takes only a few clicks. If I'm ordering software—which includes not just computer programs but also audio, video, and most books—it is delivered electronically over the network; for hard goods, Federal Express and UPS still reign.

Paper mail and fax volumes have dropped dramatically, as most communications have moved to e-mail. Printed encyclopedias, which began their decline in the late 1980s, are now sought only by antique collectors. Paper phone directories are also long gone. Video rental stores have disappeared, and music and book stores exist primarily as social centers.

 

## Fulfilling the Vision

This vision of the future is not particularly far-fetched, yet it describes a computing world that is significantly different from today's. In this future world, computing is enmeshed far deeper in the fabric of society and provides much greater utility than it does today. Pervasive electronic communications, the seamless integration of computing platforms with various form factors, and routine handling of rich media types are the central elements that make this new world different.

The technology to fulfill this vision all exists today, albeit in embryonic form in some cases. The gaps between the vision and today's reality are primarily in software, communications infrastructure, displays, memory—and cost. Note that microprocessors are not a primary limiting factor. While faster processors will be important for enabling better user interfaces, and costs need to be lower, there is little doubt that the microprocessors to make this scenario possible will exist long before the other technologies are in place. This gives microprocessor makers a powerful motivation to fuel the advancement of the supporting technologies, as Intel is doing with the PC platform and Motorola is doing with wireless communications.

At the heart of this vision is the central role of computing devices as communication tools. The recent spectacular rise of interest in the Internet is symbolic of this shift. Communication links will ultimately be nearly unlimited, with a matrix of wired and wireless networks channeling data into a fiber-optic web. Massive deployment of fiber-optic cables is leading to a bandwidth explosion that will dwarf increases in processor power.

At the moment, however, bandwidth still seems precious, and we are temporarily trapped in a counterproductive division into voice, data, and video networks. Eventually, all this will be melded. In the near-term evolution, however, much effort will be required to break down these barriers, which are deeply rooted in industrial history (see sidebar).

## What Happened to Interactive TV?

Today, we still think of computing and television as almost entirely separate realms. Interactive television seemed like an obvious opportunity for cable companies to merge computing and video capabilities, and many trials have been started. Lately, however, trials have been dropping like flies, and plans to roll out such services are moving further and further into the future. At the heart of the delay is the difficult business proposition: while interactive television offers services that seem valuable, it isn't clear how much consumers are willing to pay for them. The cost of upgrading the cable infrastructure to support these services, however, is enormous.

Video on demand, for example, is the most basic of interactive TV services. Just as in many hotel rooms today, you choose from a list of movies, and a short time later that movie begins playing on your TV.

Equipment vendors have flocked to this opportunity. Companies ranging from Oracle and Hewlett-Packard to Microsoft have developed hardware and software to act as video servers. Makers of cable set-top boxes are working to make the transition from analog to digital boxes, providing the support needed at individual televisions.

It is the cable companies that would have to buy all this equipment to deploy these services, however, and they seem to be getting cold feet about doing so. Video on demand will not pay for the wholesale upgrading of the cable network to two-way operation, installing of video servers, and deployment of digital set-top boxes. Cable companies seem to sense the opportunities but lack a clear vision of what to do. It is a terrifying thought that a critical part of the future information infrastructure is waiting on the people who brought us Home Shopping Network to clarify their vision.

The cable TV industry is likely to go digital, but at first it will be largely without shifting away from the antiquated "channel" paradigm. The biggest pressure pushing cable TV in this direction is the explosive success of direct-broadcast satellite receivers, which offer more channels and use digital transmission for superior quality. To compete with the DSS receivers, the cable industry will switch to digital transmission, enabling it to squeeze more channels into the same bandwidth. This will result in the widespread use of digital decoder boxes, but these boxes won't necessarily have any interactive capability and might use just an inexpensive microprocessor and an MPEG decoder chip.

It seems inevitable that the cable infrastructure will be upgraded to support two-way digital communication—something that DSS can't do easily—and that set-top boxes will have some intelligence, but just how quickly this will happen is a big question mark. The cable industry is struggling to come up with a package of services that will pay for this infrastructure.

The first major opportunity for cable systems to carry interactive digital data actually has nothing to do with television—it is the Internet. Using cable modems, which are currently being developed by Intel, Zenith, and others, data can be sent and received at speeds of tens of Mbits/s. The inertia of the cable TV industry, combined with the immaturity of cable modem hardware, has slowed this development. The cable infrastructure must also be upgraded to support a reverse data path. But once it takes off, it will probably grow far more quickly than what today is thought of as interactive TV. Because cable TV systems use a shared loop—not a point-to-point connection like a telephone system—careful design will be needed to support the bandwidth

 

## Melding the Communications Dichotomy

Today's communications infrastructure is anachronistic. We send digital data by modulating it into analog tones and sending it over copper lines that were designed for carrying voice. At the same time, we have a high-bandwidth coaxial connection to our television sets, in the form of cable TV, that is used almost exclusively for broadcasting multiple channels of analog television information to a passive receiver.

The distinction between telephony and television networks is rooted in history but makes no sense for current technology. There is no good reason to send digital data over telephone lines when a much higher bandwidth connection is available in the living room. And there is no good reason why the cable company cannot provide voice telephony as well as video and digital data transport.

Of course, the telephone and cable companies have long recognized this collision of their industries and have been trying to get into each other's businesses. So far, the barriers to this competition have been largely regulatory. The landmark Telecommunications Act, which is expected to become law this year, promises to sweep away most of these barriers. Some consumer advocates express dismay at the price increases that are likely to follow in some sectors as regulation is stripped away, and the Act may have gone further than necessary in dropping price controls and limits on ownership of multiple TV and radio stations. But dramatic reductions in legislative barriers are essential if we are going to allow the industry to deliver the potential of the technology. There may be some short-term pain, but in the long run, consumers will benefit greatly as telephone and cable companies all compete to offer telephony, video, and data services.

Each type of company has some unique advantages and some unique limitations. The telephone companies have the largest number of customers and a much higher revenue base, but they have a relatively low bandwidth connection to each house. Of course, this can change; telephone companies are laying fiber at a breakneck pace. Another disadvantage telephone companies face is that they know nothing about entertainment programming.

Cable companies, while they have the high-bandwidth pipe to many homes and know the entertainment business, don't have nearly as great a penetration into homes—and they have a horrible reputation for customer service. So far, cable networks have been mainly unidirectional, although they can be readily upgraded to two-way interaction. Whether cable companies can find a way to woo many subscribers to use them as their telephony supplier remains to be seen, but you will see many of them giving it a shot soon after the legislative barriers are removed.

Ultimately, both the telephone and television system architectures are doomed. As George Gilder illustrates so well in his landmark book *Life After Television* (W. W. Norton, 1990), both of these old systems are designed around completely centralized intelligence, with dumb, memoryless nodes at the periphery. In a future world where every node is intelligent, massive amounts of storage are pervasive, and huge amounts of bandwidth are cheap, the antiquated paradigms of both the telephone and television systems will give way to network architectures.

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demands if nonbroadcast use of the system becomes widespread. But the bandwidth of fiber cables is so massive that many users can be supported.

### PCs As Interactive TVs

Indeed, maybe the successful form of interactive TV *is* a PC (of any variety, Windows or Macintosh) hooked to the Internet via a cable modem. There is a tremendous near-term opportunity to use the cable network as a connection for Internet traffic, giving every cable TV subscriber a high-bandwidth digital network connection. Having a high-speed connection makes a qualitative difference in the kinds of things that can be done effectively using the net. Live audio, and even compressed video, becomes practical, and still images appear in a flash instead of like watching someone paint.

One application that has already been demonstrated, using a small fraction of this bandwidth, is a virtual music store (will people still call them record stores?). After browsing album covers, you can pick any album and hear sample cuts. In the next few years, if you decide to buy it, the CD would be mailed to you. Eventually, the music can be downloaded to your system, where it might be stored on a hard drive, or on a writable CD-ROM, or some other medium. In the long run, the concept of albums may even disappear. And it might not be necessary to store the music in your home at all, if it is available on demand over the network.

It is not out of reason—though it would require considerable upgrading of Internet bandwidth—to extend this to a video rental store on the net, and we would have, in essence, video on demand.

Suppose now that the hardware and software to implement these audio and video servers—A/V Web sites, in effect—were to become widely available at moderate costs. Now anyone on the net can be a music and video publisher, and the entire television paradigm of an all-powerful broadcaster, taking a tiny sliver of the available content and pushing it to the masses, becomes obsolete. We may not want to watch other people's home movies, but there are countless films from small producers that could find new audiences. The number of "videos" available to "rent" would be orders of magnitude greater than in the biggest video store today.

This "Internet takes over the world" scenario may be extreme, and commercial considerations may keep much of the video entertainment traffic on private networks. But the potential for a massive shift in the entertainment and communications infrastructure is clearly present. And note one critical feature of the end-user equipment—it is no longer a TV, but a computer.

Just what this computer looks like is open to question. It could be a grown-up set-top box, but it seems more likely that an evolution of today's desktop computers will take on this role. This is an opportunity for the Macintosh, as well as for Windows-based PCs. Indeed, the market for computer-based entertainment systems will be even more diverse than today's PC market.

## Video-Game Boxes an Endangered Species?

While digital set-top boxes for cable TV remain in their infancy, there is one type of digital box that already sits on tens of millions of TVs—the video game. Ideally, the set-top box could serve as a game player as well. The problem is one of software standards: video-game systems each have a proprietary architecture, and set-top boxes are not being built in a compatible fashion.

Cable companies like the idea of downloading games over the cable connection, running games from a server in the cable head-end, and providing multiplayer games. But until they develop a substantial installed base of set-top boxes following a single standard, they will have a hard time getting much support from game developers, who already face a plethora of platforms to support. So far, there is little standardization among proposed set-top box designs, and they lack the graphics horsepower being incorporated into next-generation video games *(see **090704.PDF**)* and the CD-ROM drives to read existing game media.

The biggest threat to video-game machines is not set-top boxes but personal computers. As the popularity of home PCs has skyrocketed, they have become an increasingly attractive target for game developers *(see **0911MSB.PDF**)*. Next-generation video games have a potential advantage in graphics performance, since they include custom silicon designed specifically for games graphics. PC graphics chips are following suit, however, so the gap may not be sustained. PCs have the additional advantages of having more memory and higher-resolution displays. And while it looked a little while ago as if the game machines were going to have faster processors than PCs, delays in the shipment of game systems combined with an accelerating increase in PC microprocessor performance have eliminated this edge.

The big advantage game machines have, of course, is price. Systems that cost only a few hundred dollars are accessible to far more families than are PCs. As you would expect, PC penetration into homes is far higher in high-income households. Lower-income households often purchase game machines instead. And in a higher-income household where mom and dad don't want to abdicate the PC to the kids, game machines make popular additions to the home computing arsenal. This economic fact ensures the video game's place in the ecology of computing—unless something else can take over its ecological niche.

## Merging PCs, Set Tops, and Video Games

Since PCs are going to rapidly catch up with video games in graphics performance and game software availability, price remains the key barrier blocking the PC from the video-game space.

Today, game machines are getting more CPU power per dollar by using microprocessors that carry neither the architectural baggage nor the premium profit margins associated with PC-compatible microprocessors. This is one point of differentiation that could survive for a while; with the PC microprocessor makers focused on higher price points, there is an opportunity for other processor vendors to take away markets that don't care about PC compatibility. As the x86 market becomes heavily oversupplied, however, which we expect to occur over the next few years, there may be an ample supply of bargain-priced yet PC-compatible microprocessors.

The most fundamental cost factor is the display itself: computers have displays with higher resolution and faster refresh rates than televisions, and these displays are more expensive. Video games share the TV's display, eliminating this cost entirely from the purchase decision. But there is no reason that a computer cannot be built to use a TV, as long as the limited resolution is acceptable—remember the wildly successful Commodore 64? And as computer monitors become nearly as widespread as TV screens, the cost differential will drop. If HDTV ever takes off, this will give the TV a display with a resolution suitable for computer applications.

The next barrier is the amount of RAM required. Today, RAM remains frustratingly expensive, having stubbornly refused to follow historical price curves because of a supply/demand imbalance. For now, cutting a PC down to a video-game price point means giving up the ability to run today's more sophisticated software. Eventually, memory prices will come down to a point where this is less of a barrier.

Mass storage (typically a hard disk) is a major cost component in today's PCs, and video games dispense with it entirely. Most next-generation video games include CD-ROM drives, giving them lots of read-only memory but little writable storage. This is acceptable for game playing and for some communication and computing applications. Eventually, the solution will be the home network; individual computing devices won't need mass storage because they'll be connected via a network to a few tens of gigabytes of disk storage in the closet.

Apple Computer has taken the first step toward a low-cost PC/game system with its Pippin game/education player, initially to be produced by Japan's Bandai.

 

Essentially a stripped-down Power Mac that uses a TV for display and has a CD-ROM drive but no hard disk, Pippin in its initial version will have a hard time competing against video games that have lower prices and much faster graphics. With the addition of accelerated 3D graphics and aggressive pricing, however, Pippin could become an interesting point of overlap between video games and personal computers.

It is possible to do the same for the DOS/Windows PC world, but so far no company has announced plans to pursue such a venture. Intel and Microsoft have both investigated the idea, but the compromises needed to bring the price point down are hard to accept. Fortunately for Intel and Microsoft, they have the luxury of time; the chance of the game machines building up enough of a software base to move up and threaten the PC is nil, so the game machines will be patiently waiting for PCs to attack when the technology and price/point are right. Ultimately, set-top boxes and video games may represent a useless kind of specialization that gets eaten by more flexible big brothers.

## Handheld Computing Grows Up

A much-expanded role for handheld computers is inevitable. Handhelds have suffered because of their hardware and software limitations, but as technology advances, the tablet form factor will become compelling. Indeed, the tablet is an essential part of ubiquitous computing because of the natural, paper-like interface it offers. If I am ever going to read my morning newspaper on a computer, it will have to be a tablet that is as easy to read and carry around as today's paper newspaper. If I am ever going to use a digital wallet and notepad in place of my conventional one, it will have to be of comparable size and weight, and just as easy to use.

Thanks to the inexorable pace of semiconductor advancements, these changes are not fantasies; they are safe predictions. Flat-panel technology is improving at a steady pace, memory densities are increasing, and much is being learned about creating good pen-based interface software. The ability to handle high-quality video is emerging now on desktop systems, and it won't take long for it to move down into notebooks and ultimately into tablets. Tablets will be the ubiquitous computers of the future; it is only a matter of when. (As companies such as Go, Eo, Momenta, and others found out all too painfully, the time is not now, but this is a comment on the timing, not on the underlying concepts.)

## The Evolving Desktop

The rise of the tablet does not mean that desktop systems will go away. While speech recognition and handwriting will ultimately be important forms of input, writing an article such as this one is most likely to be done with a keyboard for many years to come. Speech recognition will play a role, especially for issuing commands, but keyboards will continue to be widely used. Keyboards are a remarkably high bandwidth mechanism for conveying information to the computer. To be sure, they could be greatly improved; if the horrible inertia of standardization can be overcome, chording keyboards (where each finger remains on one button and combinations of buttons produce characters) could make the keyboard even better.

Desktop systems also will have bigger displays than most portable systems. As the cost of displays comes down, the popularity of larger models will skyrocket. CRT technology has proven remarkably resilient, but it is likely that one flat-panel technology or another will ultimately take over, finally relegating the last vestige of the vacuum tube to the scrap heap.

As computers become communication and entertainment vehicles, desktop systems will also include better sound systems and video cameras. Because they generally stay in a fixed spot, they will have access to the highest-bandwidth, direct-wired communication links. Desktop systems will become much less central than today's PCs, and more and more users may choose to do without them entirely, but for the power user's home base they will remain the high-performance connection.

## Integrating Communications

An integral part of ubiquitous computing is the availability of wireless communications. As personal computers have been connected over the past decade, first into LANs and more recently into WANs, we have all learned that their value is increased dramatically by their connections. Today, travelers with notebook computers must generally give up their connections to gain mobility—a conflict poignantly illustrated by the countless executives scurrying for a phone jack to suck up their next fix of live data. Wireless data communication is possible but not yet practical for most users.

In the past decade, cellular telephones have made wireless audio communication commonplace. A massive investment is now being made to implement several different types of wide-area wireless digital communications. Just how all the conflicting schemes will sort out is a puzzle of great significance to those who have to place their bets, but for our future computing vision, it really doesn't matter; in one form or another, wireless communication will be widely available probably, within five, and certainly within ten, years.

To use the emerging matrix of connections effectively, devices will have to be agile. When I'm working intensely in my office, I might choose to make a hardwired connection for the greatest possible bandwidth. When roaming in my office, my tablet would use a private, in-building wireless system. Such a system would offer higher bandwidth than public, wide-area wireless systems while eliminating all usage time charges.

When I leave my home or office, my tablet would automatically detect that it was out of range of my private wireless system and connect to the best available wide-area wireless carrier. As I travel, this connection would probably change, not only from one cell to another but from one type of system to another. Other than a varying bandwidth, this should all be invisible to me.

## Realizing the Vision

For the purpose of this article, I'll assume that all the underlying technologies—communications infrastructure, memory chips, processors, batteries, and displays—make the necessary advancements over the next ten years. I think this is a safe prediction; any one technology may stumble, but there are enough alternatives, a large enough base of investment, and a rapid enough pace of advancement that the technology foundation seems secure, given a sufficient time horizon.

Let's look first at the home environment. For competitive reasons, there is a strong desire on the part of the government and public interest groups to support both cable company and telephone company connections to the home. Either could service all the needs of the home, but having both of them will provide the competition that will drive both to offer more innovative services at lower prices. But the current dichotomy of which devices each connection serves will disappear.

One natural design is for both communications links to feed a household server. This system, which could reside in a closet, would have interchangeable modules for connecting to twisted-pair, coax, or fiber communication feeds using various modulation schemes. It would also serve as the central storage device, with tens or maybe even hundreds of Gbytes of disk storage and possibly with a tape or other medium for even larger amounts (or perhaps some form of solid-state storage will finally become more cost-effective than rotating disks). This server could handle telephony, data, video, or fax traffic using either of the communication pipes.

The server would connect to various devices around the home. There would be large-screen computers, anachronistically called televisions, and one or more desktop units. A local-area wireless communication link would connect the server to the tablets and pocket telephones used within, or near, the house. The cost of the server would be covered by the savings in all the individual devices, which would be diskless.

These devices would automatically pick up a wide-area wireless signal if taken far from the house. The home server would store all your personal information, such as your calendar, address book, letters, and so forth. When roaming, your portable tablet, connecting through a wireless service, could traverse the networks to find your home server, making personal data available wherever you are.

The server would capture video programs that met the user's profile, storing them for later viewing. In this way, it would replace the VCR, with some form of off-line storage for archiving. On-demand video would also be available, but for programs of widespread interest, the broadcast-and-capture approach makes far more effective use of the network bandwidth. The server could also store digitized music, replacing the CD player.

Note that the distinction between the set-top box, the video-game player, and the personal computer is gone. All of these devices are equally inexpensive because they all share the storage and communication capacity of the server; the bandwidth of the interconnect eliminates the need for local storage. Siblings will then argue over who gets the bigger screen, but it is just a matter of size; playing games, crunching spreadsheets, surfing the net, or watching a video can all be done from any display.

In an office environment, the scenario could be much the same, except that the server would have to handle many more local device connections. The biggest difference would be in the style of the terminal devices and the software used. Because office environments already have WAN connections, however, along with a host of servers and other equipment, they will evolve more slowly than the home.

## What It All Means for Microprocessors

At the heart of this scenario is a universality of computing devices and services. An essential part of the vision is that any device can be used for any purpose, subject to the limits of its I/O capabilities, and that information is available wherever you are with whatever device you are using.

Software incompatibility, and the associated issue of CPU instruction sets, is the Achilles' heel of this utopian scenario. If, in this future world, only certain types of computing devices can talk with certain brands of servers, or some data is inaccessible from some tablets because of compatibility issues, then the seamlessness that is critical to ease of use will be terribly compromised.

An essential part of making computing a universal tool rather than a challenge, enabling it to serve as part of the social fabric, is that ease of use becomes dramatically better. And since a major function of computing devices will be to serve as communications vehicles, and since most users will have multiple devices, seamless integration among diverse products is essential to their widespread success.

In some respects, the cleanest—and sometimes, it seems, the most commercially likely—way to solve this problem is to simply have Intel microprocessors and Microsoft software rule the world. But the laws of competition will prevent this from happening, at least in a comprehensive sense. And while customers might benefit in many ways from the resulting uniformity and compatibility, such a scenario would surely lead to many missed opportunities, as two fat and happy duopolists will never be as creative and aggressive as lots of hungry, eager challengers—and the duopolists will run faster in the presence of this hungry mob.

First and foremost, data formats must be universal. It is nice, but not essential, to be able to move programs from one system to another; it is the data that must be able to move. The creation of cross-platform standards for a wide range of data types, from rich text documents to video, and including structures such as address and calendar databases, is essential. This standardization is likely to occur, driven primarily not by standards organizations but by the de facto standards created by successful products. Users must be vociferous in their rejection of proprietary data formats, the scourge of the computing world.

If we assume such standardization of data formats, opportunities for microprocessors with any instruction-set architecture appear—if the needed application software to access the data is created. For certain form factors, such as small tablets, a relatively narrow range of applications is needed, and these applications are quite different in character from those on the desktop because of the radically different user interface. As many companies have noted, this makes handheld devices an exceptional opportunity for processor architectures that don't conform to the desktop standard.

Today, this opportunity is limited because the infrastructure is not in place. Today's handhelds are tiny islands with occasional links to other, larger, islands. In the future, handheld tablets will be the ubiquitous point of access into a pervasive web of digital connections. For those who can survive the journey, the handheld computer market will ultimately be a gold mine—but there may well be few, if any, survivors among the pioneers.

## The Television Becomes a Computer

In this vision of the future, video games and set-top boxes occupy only a moment in time—just like the analog telephone, though its moment has been considerably longer. Taking the long view, set-top boxes and video games are nothing more than transitional products on the way to the television as a computing device. These applications represent a tactical opportunity today for fast, aggressively priced microprocessors, but as a long-term strategy they fail. These devices must either grow up to be flexible computing devices, or they will be forced out by their more adaptable cousins.

The desktop PC, which reigns supreme today, will suffer a gradual erosion of its importance as other computing formats become more pervasive. But the overwhelming value of the software produced for it will cause it to bleed over into many other areas. As computing capabilities move into televisions, for example, having the compatibility to run games developed for personal computers will be highly desirable.

The home server represents a fascinating opportunity, as it is potentially a high-volume market—though still some distance in the future—that does not necessarily need PC compatibility and thus could be open to other processor architectures. Even here, however, there would be some value in PC compatibility, and alternatives will have to work hard to earn a place and hold back the momentum of the PC architecture.

## Opportunities for New Architectures

Ultimately, computing must break free from the bounds of machine-language instruction sets as a determinant of compatibility. As computing power continues to skyrocket, the need for close ties to the processor's architecture will fade. For computing to achieve its full potential, artificial barriers must be eliminated. Eventually, some form of intermediate software layer will emerge as a distribution standard, decoupling software and microprocessor design.

At this point, microprocessor competition will become more of a pure design and manufacturing game, and Intel's ability to milk its architectural franchise will disappear. This certainly does not spell doom for Intel, though it may mean a considerable reduction in its profit margins. By then, Intel will have such dominance in its manufacturing and design capability that it will be well positioned to sustain its leadership.

For makers of PowerPC and other microprocessors, this vision holds considerable promise. Much new software must be created, and the new software will be portable. Processor architectures that can show a significant edge in price, performance, or power consumption may be able to find a niche, such as in the home server or wallet-sized tablet. Portability of software may wash away instruction-set barriers even on the desktop.

That the technology will exist to fulfill this vision—or any of countless possible alternatives—is not, I believe, seriously in doubt. I am equally convinced that, although there are formidable challenges to overcome and the risk of our world becoming even more disjunct from the natural world is real, individuals and society will benefit. It is hard not to be enthusiastic about a vision that includes the end of television as we know it.

We must always keep in mind, however, that a clear vision must not be mistaken for a short distance. It is easier to see where we can end up than it is to see how we will get there, as the path is littered with obstacles. But what lies ahead is an unprecedented shift in how people communicate, work, and entertain themselves, and there will be many fortunes to be made—not the least of them among microprocessor makers. ♦

 