PERSPECTIVES

Computing goes embedded

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Even though computers may have become small enough to disappear, computing has continued to be a very *visible* task. However, this may change soon as the difference between the operating environments of appliances and traditional computing fades away, leading to a merger of the two. This merger will be a paradigm shift which *embeds* computing, making it ubiquitous.

EVER since the advent of programmable computing, the quest for a cheaper, smaller and yet more powerful computing device has continued unabated. However, even though *computers* may have become small enough to almost disappear, *computing* has continued to be a very *visible* task. This article is aimed at providing support for the hypothesis that the era of dominance of explicit computing may end soon and the future belongs to hidden and embedded computing. This can be argued to be an essential step in evolution towards truly *pervasive* or *ubiquitous* computing.

A typical middle-class home today contains many processors in addition to a personal computer (PC). These processors are embedded in home appliances and consumer goods such as television, video games, telephone, car, refrigerator, remote control, microwave oven, washing machine, etc. These are collectively referred to as *appliances* in the rest of this paper. The following are some of the major differences between the operating environment of these appliances and that of a typical home PC or desktop computer.

- *Programmability*: The programmable component of current appliances has grown over the years, but it is still very small compared to a desktop computer. Special-purpose hardware, application-specific integrated circuits (ASICs) and architectures with proprietary interfaces are still the dominant form of implementation for most appliances. As a result, the software/application development environment for appliances in terms of high-level debug, compiler and operating system support has been lacking in many aspects with respect to that for the desktops.
- *Connectivity*: A significant number of appliances such as a camera, car, refrigerator, etc. are stand-alone, or completely disconnected from other appliances. This is in contrast with the home computer, which, with the proliferation of internet, is a well-connected machine.
- *User interface*: In spite of the almost complete transition to graphical user interface, the user interface of these appliances is still more natural, simpler and friendlier than that of a PC.
- *Reliability*: The reliability of a PC, even with a powerful server back-end, cannot yet match that of many of the household goods.
- *Real-time vs deferred applications*: Embedded applications have always been primarily real-time. Whereas real-time applications, such as chat-rooms, are a recent phenomenon in the world of personal computers.

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Enabling trends

We next take a look at some of the enabling trends, which collectively provide the trigger for transition to the new era in computing:

1. *New level of processing cost-performance*: General-purpose programmable computing has now reached a cost-performance point for signal/image processing applications (referred to as *multimedia* applications) such that it is capable of offering many real-time solutions with good quality video and speech. The following are some of the examples:

Modems: Consider a fully programmable implementation of 28.8 kbps, V.34 modem standard. It requires 43%, or almost half of Pentium, 150 MHz processor. However, it should be only about 5% of a present-day version of the same processor family, namely a 600 MHz Pentium III.

CRC: Consider soft implementation of CRC-32, the most common error detection scheme. For data rates of 1 Gbps or more, soft CRC-32 requires close to a GHz implementation of Pentium-class processor! However, with the advent of new SIMD architectures, such as the AltiVec extension to PowerPC, the same can now be achieved with just a 200 MHz implementation!

TV broadcast: Processing/bandwidth needs for playing a TV broadcast range anywhere from 2 Mbps (low quality DVD) to almost 40 Mbps (high-quality HDTV). As a consequence of combined improvements in network bandwidth, compression technology and processing power, it will be possible to cover even the high-end of this processing spectrum on a fully-programmable general-purpose platform in the future.

2. *Next-generation connectivity*: The next enabler is the next-generation connectivity trends which can be categorized as:

Huge bandwidth: Bandwidth to a typical household is expected to grow 100- to 1000-fold (from few kilobits to a few million bits per second) in the not-so-distant future. With the help of fibre-optic and photonic switching enabled ease-of-routing, wireline backbone bandwidth would see an order-of-magnitude growth.

Mobility: Equally aggressive growth projection holds for wireless bandwidth also. Consider for example, the new 3G standard for long-range wireless, which is capable of providing ISDN class or better bandwidth while riding in a bus or in a car!

Merged traffic: Different traffic types, such as voice, data and video which have so far been carried into homes on separate channels are now merging into one.

3. *Convergence of software architecture models*: Finally, in addition to the technology trends listed above, a key enablement comes from the convergence of software architectural models from the appliances with that of traditional computers. Traditionally, software architecture model for appliances has been *vertical* whereas the same for desktops has been *horizontal*. For example, consider telephones and cable TV. Each is a vertical solution in terms of its own hardware, software and network infrastructure. Recent trend points to a convergence of these to a *horizontal* model, such as a *virtual operating system* layer (*Windows CE* or *Java OS*) on top of the hardware and the OS layers to provide inter-platform, inter-OS operability, with open horizontal interface, across the spectrum of embedded devices and back-end servers.

Implications

These trends will enable us to overcome the differences listed earlier between the operating worlds of appliances and traditional computing, leading to a merger of the two. Some of the early manifestations and other implications of this nascent merger are outlined below:

1. As a result of this new cost–performance potential for multimedia applications, processing environments of appliances, dominated by such applications, will move closer to that of traditional processing. Some of the visible trends in this direction are: a) multimedia solutions moving from fixed-function to programmable platforms; b) programmable multimedia solutions moving from special-purpose programmable to general-purpose programmable. Low-cost real-time adaptability to various connectivity standards is one of the critical driving forces behind programmable solutions.
2. Virtual OS layer had enabled development and *dynamic distribution of network applications* over the internet. Horizontal application layers can be built on top of this. One example of this is the *Wireless Application Protocol* (WAP) which has found wide acceptance with upcoming internet-enabled smart phones.
3. The merger of the two operating environments further implies that the software and application development environment for appliances will improve significantly in terms of ease-of-use, portability, and productivity. For example, desktop automatic parallelization and vectorization techniques can now be applied to soft (programmed) versions of home applications, such as video player/recorder. On the other hand, merger of these two environments also leads to new research directions, such as code and data size optimizations, power saving optimizations, and those related to real-time performance guarantees.
4. There is an important class of appliances, led by video games, for which combination of supercomputing-class performance at a cost lower than low-end desktops has been elusive until recently. This application segment requires classic supercomputing performance and optimizations, related to vector and matrix processing, to handle the computing needs of realistic next-generation media synthesis tasks, including emotions and behaviour synthesis. However, the research challenge is to make it all available at a cost affordable by the masses!
5. The new level of cost-performance also enables transition of traditional computers to next-generation user interface, more natural than before, further bridging the gap between the two environments. A good example would be a speech enabled natural language chat-session interface.

In summary, this merger of home appliances with the home computer will be a paradigm shift which *embeds* computing and makes it as pervasive as say, electricity is to modern-day living. It may be almost impossible to fathom the business implications of this paradigm shift. Consider, for example, the problem of estimating the revenue potential of the telecommunications industry on the basis of that of the postal industry. Estimating the potential of e-commerce in the context of this ubiquitous computing paradigm will be at least as difficult if not much more!