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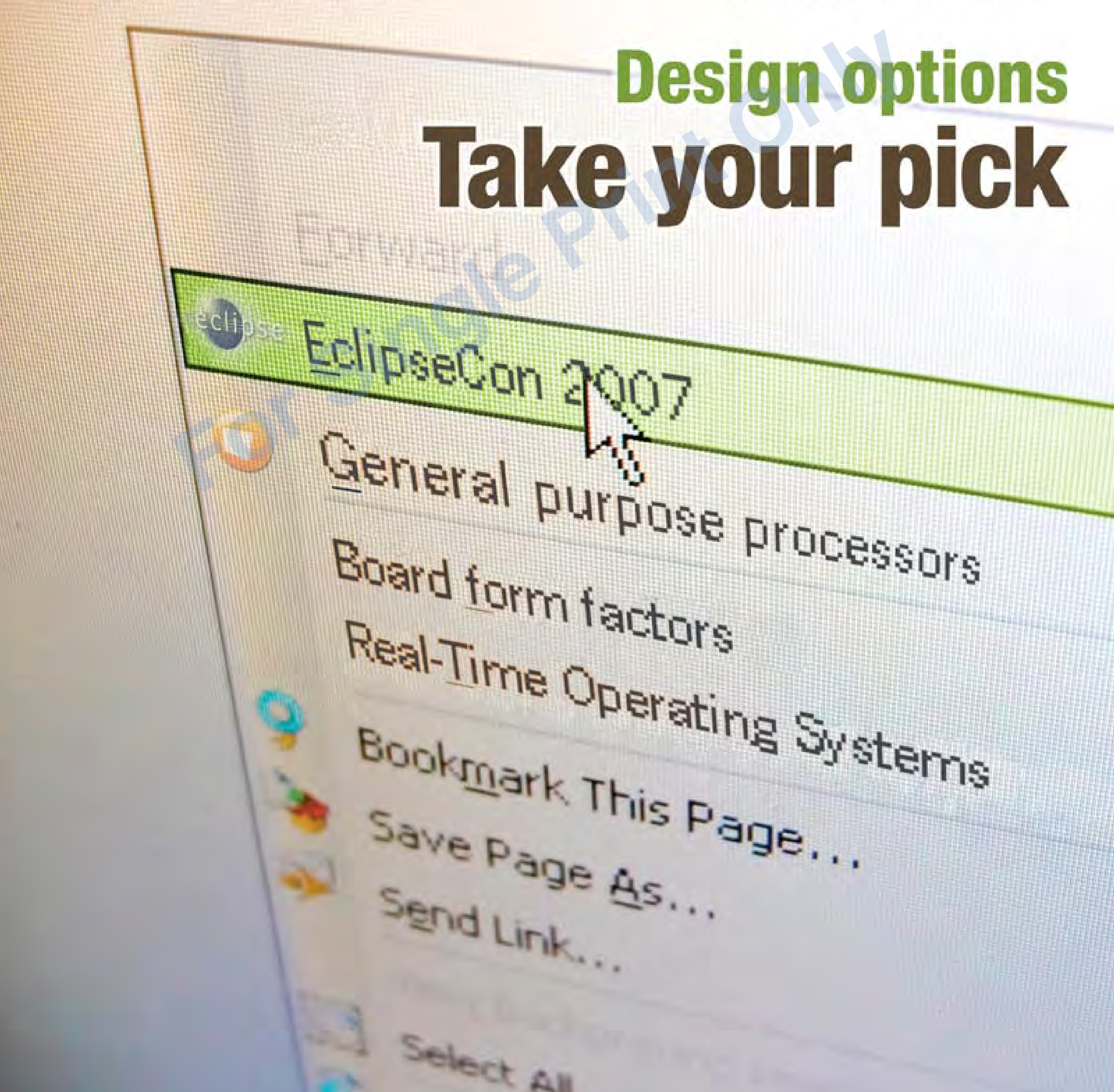

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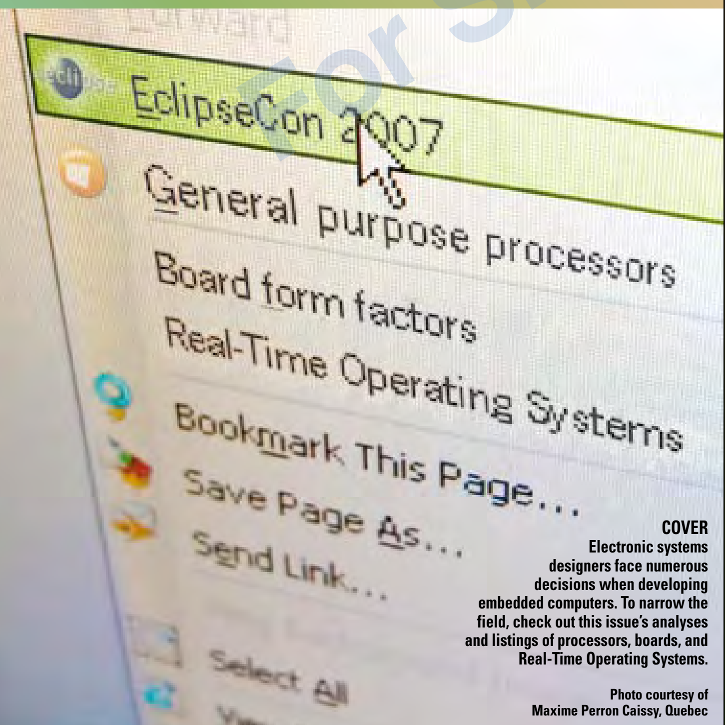

COVER
Electronic systems designers face numerous decisions when developing embedded computers. To narrow the field, check out this issue's analyses and listings of processors, boards, and Real-Time Operating Systems.

Photo courtesy of Maxime Perron Caissy, Quebec

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FEATURES

SPECIAL: General purpose processors

HARDWARE TECHNOLOGY: Board form factor review

SOFTWARE TECHNOLOGY: Real-Time Operating Systems roundup

E-CASTS

A Practical Guide to Implementing Open Standards-Based High Availability
March 22, 2 p.m. EST
www.opensystems-publishing.com/ecast

E-LETTER

March: **www.embedded-computing.com/eletter**
Embedded analysis from health to travel to dirt
By Hermann Strass

EVENTS

EclipseCon 2007
March 5-8 • Santa Clara, CA www.eclipsecon.org/2007

Semico Summit
March 11-13 • Phoenix, AZ www.semico.com/eventsummit/summit.asp

ESC Silicon Valley
April 1-5 • San Jose, CA www.embedded.com/esc/sv

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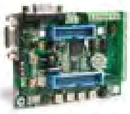
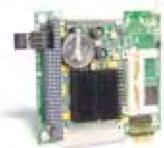
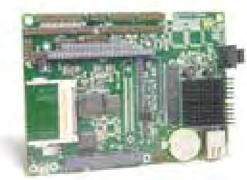


MCB58: Compact microcontroller with CAN, 32 DIO, 4PWM D/A, Temp. Sensor, RTC, 16K Serial EEPROM, 60K Flash, and 4K RAM. *Boots in 160 microseconds.*



SBC1586: Headless, Low-Power PC/104 Pentium with Compact Flash, 4 COM ports, USB, and Ethernet. *Boots in under 4 seconds.*

SBC1625: Low-Power ARM processor with Dual Ethernet, 4 COM ports and 24 Digital I/O on PC/104. *Boots in under 14 seconds to Linux Prompt.*



SBC4495: 486/586 EPIC CPU with GPS, Ethernet, 24 bit I/O, 14 bit A/D and D/A. *Boots in under 4 seconds.*

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A note to our readers

Those with sharp eyes may notice a small but ubiquitous change in this issue of *Embedded Computing Design*. Listed on every page you'll see www.embedded-computing.com/search, the URL for our new portal to articles, columns, special services and events, ads, and just about anything else embedded designers want to know. We've launched this service to give you instant access to our network of information, which can be gained easily using a search by category, company, event, or editorial. While you're checking out the latest news in the industry or researching upcoming trade shows, you don't have to worry about getting spammed – the system allows you to search freely without logging in or entering any personal information, so your privacy is protected. And if you can't find what you're looking for, special information can be requested via e-mail.

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Endless innovation keeps design choices evolving

Jerry Gipper

January for me was a hectic month of traveling to electronics shows and events. I started out the year attending the 40th Consumer Electronics Show in Las Vegas. As usual, it was packed with all the latest innovation in consumer electronics, and as usual, I couldn't even get to half of it in three days! From what I could tell browsing through the exhibits at the show, the electronics industry is looking as good as ever.

Factory-to-dealer sales of consumer electronics are projected to exceed $155 billion in 2007, showing 7 percent growth over last year, according to the semiannual industry forecast released by the Consumer Electronics Association (CEA). According to the study, American families now own an average of 26 electronic devices. I'm tipping the average at way beyond 100; where are you?

"The consumer electronics industry has outdone itself once again, with revenues totaling $145 billion in 2006, representing 13 percent growth over 2005, and we're on track for another year of healthy growth," said CEA President and CEO Gary Shapiro. "We surpassed original projections for the second year in a row, and the industry outlook is proof positive that Americans can't do without their beloved consumer electronics. Consumers are benefiting from our industry's innovations and only want to see more of them."

On the other end of the embedded computing spectrum, I stopped by Long Beach for the Bus&Boards Media Conference, where critical embedded systems took center stage as the focus of the annual event. Paul Zorfass, analyst for Venture Development Corporation, projected a solid 5 percent growth in sales of electronic components in these types of systems. An industry panel of executives all agreed that the forecast for 2007 looks very positive in all areas.

Factory-to-dealer sales of consumer electronics are projected to exceed $155 billion in 2007, showing 7 percent growth over last year.

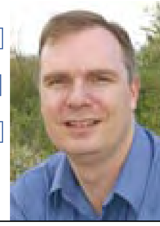
In this issue we examine the plethora of choices electronic system designers have when developing embedded computers. We have compiled much information on three key topics – general purpose processors, board form factors, and Real-Time Operating Systems (RTOSs) – that we hope you will find useful. As we were doing the research, it was interesting to note that these choices are constantly changing and evolving. There seems to be endless innovation to improve the technology that drives the embedded computing industry.

I apologize in advance if we missed something while compiling our research on processors, form factors, and RTOSs. It was difficult at best making determinations from the material available on which way to go with some of the technology that was reviewed. We plan to delve into more detail on processors that fall into the Systems-on-Chip and special function categories in the November issue, so we deferred a lot of material until that time. Send me your comments and we will consider them for the next update on this subject.

Best of luck as you make your choices and keep innovating!

Jerry Gipper, Editorial Director

jgipper@opensystems-publishing.com



By Don Dingee

The Phone of Next Tuesday

I figured with all the hype surrounding the launch of the Apple iPhone, now's the time – I've put together a marketing proposal and gone out in search of venture capital for a new mobile phone company. Our first project, code-named "The Phone of Next Tuesday" (TPoNT for short) would use or connect to everything I saw at the Consumer Electronics Show (CES) 2007. Great idea, huh?

Not just a phone

There's lots of embedded technology to choose from at CES; you just have to look for it carefully amid all the excitement. Here are a few of the great things I saw and touched that might show up in TPoNT (but I can't let on too much, our competitors are probably reading this).

Of course, every great phone starts with a great 3G chipset. Qualcomm's Snapdragon (www.qualcomm.com/snapdragon) combines a Scorpion 1 GHz core with a 600 MHz DSP to give connectivity to CDMA2000, WCDMA, HSDPA, and HSUPA networks, along with Bluetooth and Wi-Fi connectivity. It also has broadcast modem capability for DVB-H and other standards.

For the operating system, we'll run a Linux-based open source platform first appearing in the FIC Neo1973 called OpenMoko (www.openmoko.com). The features will be unlocked via biometrics using a Validity Sensors (www.validityinc.com) VFS201. This sensor is rugged enough to hit with a hammer due to its chip-on-flex packaging, yet highly accurate and small enough to fit. To add GPS, Global Locate (www.globallocate.com) has their new Hammerhead A-GPS chipset, providing much better indoor location capability at a really low cost, so we'll never be lost again.

With all the stuff to connect to, we'll need Ultra Wide band (UWB). WiLinx (www.wilinx.com) gets us connections from 3-10 GHz from a low-power CMOS chipset. And we'll need WiMax, so we'll add the Beceem Communications (www.beceem.com) BCS200 chipset. For near field communication, we'll go with the Innovision (www.innovision-group.com) chipset, which will give TPoNT the ability to read short-distance RFID tags from about an inch for applications like smart ticketing and e-wallet uses.

Got great content on the phone, but want to view it on your HDTV? We've got an answer that uses Wi-Fi capability. TPoNT will stream content from our device to a TV in HD using the PC2TV solution from Quartics (www.quartics.com). With just a simple driver, content is sent to a Wi-Fi box that does the heavy decoding work for HD formats.

Speaking of viewing our display, it will always be right side up and we'll know how fast it's moving because we'll have the ADXL 330MEMS sensor from Analog Devices (www.analog.com), the same one used in the Nintendo Wii-mote. And for an even bigger experience, we'll hook up the Icuiti (www.icuiti.com) AV920 video eyewear for an equivalent 62" screen.

We'll also have a battery with two charging options. We'll use the WildCharger (www.wildcharge.com) and set TPoNT on the pad to charge it – no cables. For road use, we'll connect a longer-life fuel cell – the Medis Technologies (www.medistechnologies.com) "24/7" Power Pack, enough power to recharge for three months.

More work to do

A few more details will have to be hammered out before TPoNT is launched. With all this stuff inside, TPoNT will probably retail in the range of the Bang & Olufsen Serene at $1,275. We'll need to make sure the carriers don't give it away for $20 with a two-year contract.

Let's see, what else is on the to-do list? Our CEO says to do a trademark search on "Cacophone." And great, I've been waiting for this e-mail with the customer focus group results – they say they want something easy to use, like that funny-looking broach they tap and say "Picard to Riker" on *Star Trek*. That's odd, I would have thought folks wanted more features like these packed into a small phone.

We've got our work cut out for us. I trust engineering can make all this stuff work together. I've got to run – John Kricfalusi is calling; he probably wants to invest in the company. As always, e-mail your thoughts and ideas to ddingee@opensystems-publishing.com.

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Embedded computing's all fun and games

By Hermann Strass

Conference and exhibition recap

Fun electronics like games, digital TV, streaming media, or navigation devices are big business these days, with sales in the billions of dollars. Embedded computers, microprocessors, or other electronic processing (such as an FPGA) and transmission electronics power these applications. Two large events last year that happened within a few weeks of each other and only a few miles apart showcased these technologies.

In September, the world's largest consumer electronics trade fair, Internationale FunkAusstellung (IFA) in Berlin, catered to more than 225,000 visitors, topping even the Consumer Electronics Show in Las Vegas. IFA, which started originally as a biannual event in 1924, featured more than 1,000 exhibitors from 32 countries. About 6,500 journalists from 74 countries and 1,300 TV and radio stations reported from the event. Highlights included HDTV and cell phone TV, or IPTV. A historical note: the MP3 player, invented in Germany, was first shown at the Science and Technology Forum during the IFA fair in 1997.

Juniper Research estimates that the world market for game products and services will reach about $35 billion in 2008. The Games Convention (GC) held last August in Leipzig, south of Berlin, saw attendance increase by a healthy rate of 36 percent over 2005. With 183,000 visitors, GC surpassed the Tokyo Games Show (160,000 attendees) in visitors and exhibitors as well as the Electronic Entertainment Expo in Los Angeles, which is currently restructuring because attendance was low last year.

GC hosted visitors from 33 different countries, 2,600 journalists from 43 countries, and 76 percent more exhibitors than in 2005. The new *GC family hall*, which allowed children and parents to have fun together playing with electronics, appeared to be an overwhelming success. Sony, Microsoft, and Nintendo each had their own hall at the convention center to distribute the masses of visitors more evenly.

Cell phones, stadiums, and "good vibrations"

It may not be a big surprise, but as of August 1, 2006, cell phones (called *handys* in German) in use in Germany outnumber the inhabitants, including infants.

In preparation for the month-long world football (soccer) championship last year in Germany, stadiums received updates with many new electronics. Upgrades included an emergency call system for the disabled and automatic heating of the natural grass lawns using multiple sensors placed in the soil near the grass roots. Computer-controlled primary power load balancing ensured floodlights only turned on when emergency diesel generators were active.

The International Broadcast Center (IBC) in Munich collected all communication from 12 stadiums spread throughout Germany and redistributed it to all corners of the world. For example, the world's largest audio router at that time distributed about 2,500 audio streams live and uncompressed from Munich. Modified europacPRO subracks from Schroff housed the switching equipment in the football stadiums. The subracks were extremely compact but still able to remove all excessive heat, avoiding hot spots and providing noise-free backplane circuits at gigabit rates. In addition to hot swap, these systems, which were equipped with electronic systems from Lawo AG, could accommodate live upgrading.

Using this [MEMS sensor], coaches in sports activities like golf, skiing, and baseball can analyze live graphics of 'good' or 'bad' movements.

In other invention news, the Technology Center Western Bavaria (TCW) in Noerdlingen, Germany, patented an electronic movement sensor coupled with a Bluetooth transmitter embedded in a walking stick or strapped to an arm or leg. The MicroElectronic Mechanical System (MEMS) device shown in Figure 1 includes a microprocessor that reduces the number of signals and shapes the signals to be transmitted. LabVIEW-based software in a nearby PC or notebook monitors movements and vibrations in real time. Using this technology, coaches in sports activities like golf, skiing, and baseball can analyze live graphics of "good" or "bad" movements. The device is especially helpful for people recovering from all kinds of muscular problems because the right type of movement and vibrations shortens recovery time dramatically.

Figure 1

For more information, contact Hermann at hstrass@opensystems-publishing.com.

Eclipse plugs-in for real-time development

By Rhoda Quate

Today, real-time software developers demand an efficient development environment that gives them access to the tools they need in a one-stop-shop framework. Due to its flexible nature and adaptable plug-in capability, Eclipse has become the development environment of choice for these developers.

Eclipse offers a smart and functional environment for software development and related tasks. As a programming environment, Eclipse provides the essentials and the aesthetic appeal to satisfy most programmers' needs, including visual shortcuts, dockable windows, navigation techniques, hierarchical views of software objects, and more.

But Eclipse is more than just another Integrated Development Environment (IDE) developers first see upon installation. Eclipse is based on an open source extensible framework into which other software tools can be plugged. Plug-ins can be created by following a standard Eclipse protocol. A common framework makes Eclipse plug-ins relatively easy to develop. Using plug-ins, Eclipse can be extended to include integration with a developer's favorite tools, including popular configuration management tools, Web development tools, software modeling tools, compiler tools, and even text editors.

Eclipse now offers valuable extensions for real-time developers such as integrations with real-time OS tools, cross compilers, and other real-time tool suites. An example of these extensions is in the Java arena. Eclipse started out as an environment for Java developers working on desktop and enterprise applications, but has now evolved to include support for real-time Java development as well. Tool suites supporting real-time Java developers such Aonix's PERC can now be plugged into Eclipse. Similarly, the ADT plug-ins from Aonix provide an Eclipse integration for Ada real-time development as shown in Figure 1.

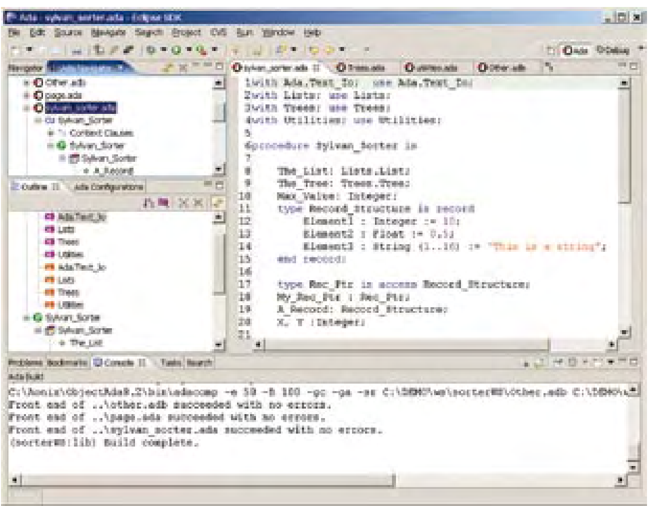

Figure 1

In the past, if Ada vendors, for example, wanted to add support for their tool within an environment, they had to spend a lot of energy to integrate it. Most development environments were difficult and time consuming to integrate with. At best, environments like CDE were easier to integrate with, but vendors were restrictive in platform availability. Also, for the platforms that were available, the customer depended on a relationship between the platform vendor and the tool provider to maintain compatibility with new releases. Eclipse provides a common framework that makes life easier for all.

The Eclipse popularity can be attributed to its powerful built-in features and, most of all, its plug-in capability. Hundreds of vendors and developers are contributing plug-ins, making Eclipse more powerful and usable every day. A myriad of Eclipse plug-ins is now available to satisfy developers' needs. Plug-ins are often free or available on a subscription basis. As the Eclipse plug-in community grows, the excitement escalates. Useful plug-ins quickly become popular as Eclipse users read ratings from colleagues on the Web.

Real-time developers are also now benefiting from the growing Eclipse environment by leveraging integrations with popular RTOS tools and other needed tool suites for real-time development. Developers can essentially build their own IDE by choosing the tools they use on a daily basis under one integrated environment. Whether the real-time development is in C/C++, Ada, or Java, Eclipse can integrate with the compiler technology and often with the RTOS tools' control of the target, including downloading, running, debugging, and analyzing target processor activity and state, all from within the Eclipse environment. In the case of PERC, Aonix's real-time Java tool suite, the Eclipse plug-in includes integration with the PERC Shell for communication with the target board within Eclipse.

Although Eclipse is a powerful tool, it has some downfalls. Eclipse runs on top of a Java Virtual Machine. On the upside, this makes it platform independent, meaning it runs identically on any platform that supports Java. The trade-off to this advantage is that the application is interpreted at runtime, which makes it slower to start up and resource intensive once it's running. While running Eclipse, developers might find that other large applications may not be able to acquire the resources they need to run simultaneously. Additionally, it is not uncommon to experience non-critical error messages when exiting, relating to problems saving the Eclipse workspace.

Despite these shortcomings, Eclipse has secured its own future by providing an open framework design. The open nature of the Eclipse framework has allowed the plug-in community to flourish, and this plug-in community will in turn work to ensure Eclipse's continued success. Real-time developers can look forward to this flexible and ever-improving Eclipse development environment well into the future.

Rhoda Quate *is an application engineer for Aonix. She has many years of experience in technical sales, training, and customer support with a variety of software development products in areas related to X/Motif, UML Modeling, Ada 95, and Java for real time. Rhoda received her BS in Electrical Engineering and Computer Science from the University of Colorado at Boulder and completed her MS in Software Engineering at National University in San Diego.*

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Navigating general purpose processor roadmaps

By Jerry Gipper and Don Dingee

Many high-end embedded computer systems use the same general purpose microprocessors found in laptop, desktop, or server computers. These processors are:

- Very high in performance
- Supported by the popular Windows, Linux, and Real-Time Operating Systems (RTOSs)
- Run a wide range of application software
- Relatively inexpensive for high-end applications

Consumer demand for more performance drives these microprocessors' roadmaps. The high volume of consumer usage assures a cost-effective solution with the trade-off of a shorter life cycle.

In the early days of microprocessors, product life cycles were relatively long; moving from significant speed to feature improvements could take two to three years. That has all changed in the past 10 years as new CPU clock speeds roll out almost every quarter and new processor families with improved features are released in less than 12 months. Consumer computer products have very short life cycles and do not require that the system be identical in functionality and configuration for multiple years.

Embedded computer designers are generally unable or unwilling to keep up with the faster and faster changes in semiconductor technology from the consumer markets, and the general purpose processor is no exception. In response, processor suppliers have started offering select models culled from the desktop market as "embedded" processors – the same device, but offered for a longer, more controlled life cycle.

Architecture consolidation

General purpose microprocessors tend to be used more frequently in embedded equipment designs that have a higher average selling price, typically in excess of $10,000. In applications below that price point, designers are using System-on-Chip (SoC) solutions and increasingly, specific purpose microprocessors.

While significant volumes of low- and mid-range embedded applications are driving increased SoC choices with many different core architectures, at the high end, consumer markets are driving selection. The mix of architecture choices for high-end processors has shrunk dramatically since 2000. As we entered this century, the options narrowed to x86, Power Architecture, and SPARC.

SPARC is no longer offered to embedded system designers as a microprocessor. It is only available on a few AdvancedTCA blades and servers from Sun Microsystems and on a handful of legacy products from other suppliers. Sun continues to drive their designs in the direction of Intel and AMD processor offerings, taking advantage of improving roadmaps, competitive costs, and increasing performance, making the future of SPARC unclear.

Power Architecture has undergone a shift driven by the Apple cutover to the Intel Architecture, and has disappeared in the desktop space from all but a few IBM desktop workstations. Without a desktop market driving it, Power Architecture better fits the mold of a specific purpose microprocessor for the embedded space. Power Architecture thrives with high-volume applications for gaming, networking, and other dedicated devices running RTOSs or Linux. Freescale Semiconductor continues to offer a select set of high-end processors such as the 8641D, but is moving in the direction of special purpose processors, embodied by the PowerQUICC families. Other evidence that confirms this trend is IBM's Cell processor, the P.A. Semi PWRficient processor, and AMCC's embedded PowerPC processors – devices with tuned interconnects, specialized execution units, and optimized I/O for embedded designs.

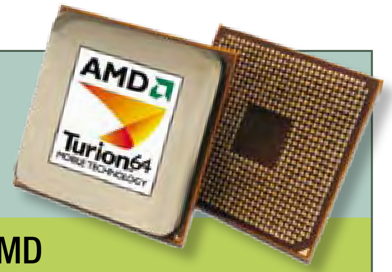
x86 left standing as "general purpose"

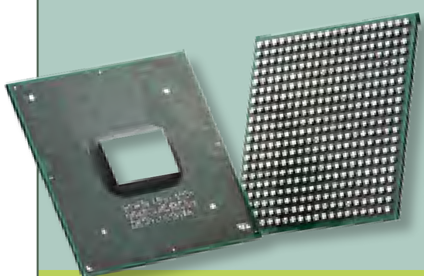
The only truly general purpose architecture with both desktop and embedded market appeal remaining is x86. The x86 variations led by Intel Architecture microprocessors have taken over the high ground in general purpose processing for both consumer and embedded markets. Intel, AMD, and VIA have developed processor roadmaps that support life-cycle management requirements by taking select processors from their laptop/desktop product lines and committing them to five-year or greater life cycles. They have improved the support for RTOSs by working closely with various RTOS suppliers while continuing to drive improvements in Windows and Linux for embedded applications.

Along with offering processor devices, these companies have worked hard to develop industry-accepted board form factors. (See the related feature on board form factors on page 22.) These efforts have created an ecosystem of board and system suppliers to the embedded markets that further accelerates the adoption of these architectures. Each offers processors and chipsets that span the range from low power to scalable to high performance. Designers can choose the processor/chipset combination that best fits their design goals. New processors and chipsets are added to the roadmaps as they gain traction in the desktop, laptop, or server markets.

The processor family tree

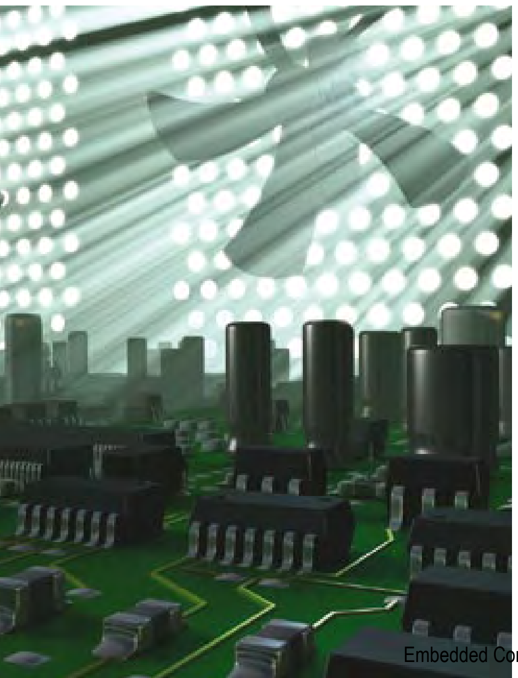
Table 1 shows the processor families included in each supplier's embedded processor product lines. Designers could try to use a current processor from the consumer roadmap such as the Intel Core 2 Extreme for embedded use, but would probably discover it doesn't guarantee availability, life-cycle, or design support. These families, while perhaps lacking the cutting edge in pure performance, provide power and I/O features more in-line with embedded computing applications and are well supported with design information and extended availability. ECD

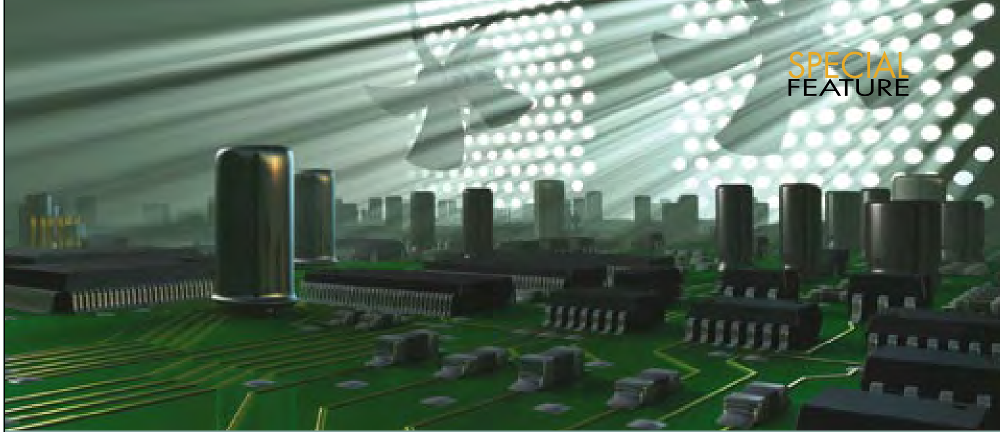




AMD www.amd.com	Opteron Dual-Core AMD Opteron Sempron Sempron Mobile model 3500+ Turion 64 Turion 64 X2 dual-core mobile TL-52
Intel www.intel.com/design/embedded	Pentium M Pentium M, Low Voltage Celeron D Celeron M Celeron M, Ultra Low Voltage Core Duo T2500 and L2400 Core 2 Duo E6400 and T7400 Pentium 4 with Hyper-Threading Technology Xeon Xeon, Low Voltage Dual-Core Xeon, Low Voltage Dual-Core Xeon, Ultra Low Voltage
VIA www.via.com.tw	C7 C7-Desktop C7-Mobile Eden CoreFusion Platform

Table 1





Intel and embedded markets

At the Boston Embedded Systems Conference last September, Joe Jensen, general manager of Marketing and Platform Programs, Intel Communications Infrastructure Group, made a bold statement as the chip maker announced the newest addition to its embedded processor roadmap. "For decades Intel has been a leader in embedded products, and today we have raised the bar for embedded performance while maintaining the low thermals and long life-cycle support that are critical to embedded applications," Jensen said. "The remarkable performance and energy efficiency that Intel Core 2 Duo processors offer desktop and laptop PCs are significant benefits now available to our embedded customers." Sounds good, but was this always the embedded processor story with Intel?

Intel microprocessors have been used in embedded applications since their debut – long before high-volume PC markets became the driving force in microprocessor design. Remember the 8080?

In the early years of microprocessing, Intel was truly an "embedded" supplier, offering processors with long life cycles and design information that embedded designers could use safely. Intel pioneered the Multibus architecture as a board form factor for embedded applications. Various other styles of cards were also available with Intel processors, such as STD, S-100, and others.

As PC markets began to accelerate in the late 1980s and early 1990s, the model began to change. Introductions of new processors, either faster clock speeds or entirely new models, became much quicker, approaching about one year for a major introduction. The now-famous Intel curve of introducing a processor, driving it to maturity, and obsoleting it in favor of higher-performance models within about two years began to take shape. This rate of introduction meant new parts were coming out too frequently for embedded designers to adopt and for Intel to continue supporting older devices. Embedded designers were caught in this vicious cycle and did not know which parts were safe to use.

In the late 1990s, Intel "rediscovered" embedded markets as a way to diversify and grow their processor business, and started listening to the feedback from numerous embedded customers struggling with choosing their parts. In 1997, Intel began a dedicated program for Embedded Intel Architecture products. For the first time, they launched formal roadmaps for Embedded Intel Architecture products – including processors near the high end of the performance curve. These were selected processors and chipsets from the laptop and desktop processor roadmaps that the Embedded Intel Architecture group would support for a minimum of five years.

At first, Intel wrestled with which parts should be moved to the longer life-cycle roadmaps. Predicting which parts would be best for the embedded roadmap and which would succeed with embedded design wins required building market knowledge. After several years, the embedded business unit started to make earlier and more accurate projections on which laptop and desktop parts should be carried forward, and the results have granted embedded designers more stable, robust roadmaps and support.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Off-the-shelf building blocks fit embedded systems

By Kristin Allen

Companies often develop their own electronics subsystems for products that require embedded computing elements. Many don't leverage standards-based modular embedded computer systems to significantly reduce time to market and costs for projects that have embedded electronic components. Kristin reviews the most compelling reasons for reconsidering the decision to build the system yourself.

Build or buy? Many companies face this question regarding embedded hardware when embarking on a new design project. The answer they choose can have a significant impact on the success and profitability of the venture.

Both proprietary design and the board-level approach have advantages and disadvantages. The build versus buy decision must be viewed in light of both technological and business considerations.

As hardware becomes more compact and feature rich, hardware design grows more complicated. And ever-shortening component life spans make designing products for long-term use challenging.

By using off-the-shelf modular boards, companies can save time and money through the following means:

- Eliminating component searches and qualification
- Avoiding long turnaround times from manufacturing facilities and hardware test processes
- Shortening design cycles and reducing late delivery risk
- Mitigating component obsolescence issues

Components

Qualifying and sourcing components in a complex project of any type can be a time-consuming task. But an embedded computer design project often requires components that feature long-term availability and reliability. Finding the right parts to meet those needs can be difficult.

Turnaround and design cycle time

Because designing an embedded computer is so complex, predicting how long the design work will take is challenging. One cannot foresee if a board will have to go back for rework or even be scrapped and redesigned because of a design flaw.

A relatively new factor in the design equation is designers' use of FPGAs to replace some super I/O chips. Because FPGAs typically have longer life cycles, they help mitigate obsolescence issues. On the other hand, they are more complicated and harder to engineer around. OEMs utilizing them usually encounter a more difficult learning curve and higher research and development costs. Recouping engineering costs when using an FPGA can stymie a company unless it can spread the costs over multiple customers and multiple boards. Off-the-shelf embedded computer manufacturers can do so, resulting in a cost-effective solution for many OEMs.

For a company considering whether to build or buy a board that utilizes an FPGA, the decision makers must also consider a risk. They may have to upgrade to a higher-capacity, significantly more expensive chip if they cannot fit all their code onto the same size FPGA as resides on the product they are considering.

Late delivery can also significantly reduce revenue opportunity. According to Venture Development Corporation (2002), 42 percent of embedded system designs are late and 18 percent are cancelled. Buying an embedded PC can help a company get a product to market faster and reduce the risks associated with project delays. "Serious" software debugging typically cannot begin until the prototype hardware is debugged to a certain stage. With a purchased embedded PC, the software can be prototyped and proof of concept verified even before the project is formally approved.

In reality, most OEM-initiated first-time development programs never end, and the ones that do rarely complete the product before the operating system increases by one or two revisions and the underlying components go obsolete. This tends to trap OEMs into a perpetual development cycle, never getting the product into mainstream, cash-generating production. By purchasing off-the-shelf products, a company avoids this risk and moves more directly into production.

Development time typically affects the speed of a product's market penetration and its eventual maximum sales rate. The "first mover" advantage is significant in most high-tech markets, and purchasing a proven system board can help an OEM achieve that advantage.

Obsolescence

An off-the-shelf manufacturer has the benefit of being able to devote individuals and even entire departments to planning for, studying, designing around, and mitigating obsolescence issues. For example, a board company will often select a component based on its long-term availability and replacement options roadmaps. Then the company will track product and process change notices and plan its form, fit, and function replacements accordingly. This practice enables the manufacturer to supply essentially the same board to an obsolescence-sensitive customer for a decade or more.

The cost factor

Companies may be tempted to compare a $600 SBC with a $300 bill of materials and conclude that building a proprietary board would be more economical. The total production cost, however, must include both parts and labor for the actual board plus the amortized costs for the nonrecurring development. These nonrecurring costs include the circuit design, board layout, prototyping/debugging, new part procurement/qualification, BIOS generation and compatibility testing, user/maintenance manuals, test fixtures, and all other associated costs. The labor rate must include an overhead rate, and the manufacturing operation required to handle new devices, such as manufacturing equipment, may incur additional nonrecurring costs.

Buying an embedded PC can help a company get a product to market faster and reduce the risks associated with project delays.

Another frequently overlooked cost factor, ongoing project and life-cycle management, takes a considerable amount of engineering and management labor.

Embedded PCs are more cost effective for moderate end-user quantities and are simpler and quicker to implement. Other advantages include their ability to conserve engineering time and talent, employ the latest components and design techniques, and afford maximum use of supporting software and peripherals.

A hybrid approach

Many companies use a hybrid approach, selecting an off-the-shelf standards-based SBC, then designing their own specialized I/O boards. SBCs with PC/104 expansion capability are well suited for this role since they are small, rugged, and PC compatible. They are also available in a wide range of configurations from a variety of vendors who have mastered the design expertise and manufacturing technology and can provide field-tested products. The OEM system designer choosing an off-the-shelf embedded PC can focus on the core competencies of the OEM's main business. To create a customized system, OEMs may wish to add their own I/O expansion to an off-the-shelf board such as the EPIC board from VersaLogic Corp. pictured in Figure 1.

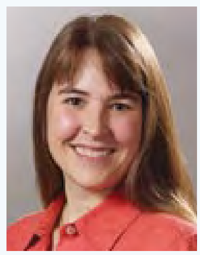
Staying competitive with standards-based systems

By using off-the-shelf components, OEMs can reduce the amount of work they have to do themselves. They can also have confidence in the product's ruggedness and quality standards because of the product's proven track record.

As development timelines shorten and systems become more complex, the predominance of the proprietary design is shrinking. By moving to outsource options, embedded systems developers are finding a way to become more efficient. Buying embedded PCs works because it saves both time and money and speeds up product design, development, and delivery, which helps with long-term competitiveness.

Figure 1

Other factors such as form, fit, function, power, survivability, service, and long-term availability tend to supersede the lowest price in industrial applications. Because these significant factors affect the project's total cost, time, and risk, companies often opt to purchase boards in quantities up to 1,000 units per year. **ECD**



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Embedded computer options in the PC/104 family

The PC/104 family of products offers a variety of options to OEMs looking for an off-the-shelf system. The family includes three form factors and six baseline CPU configurations. The PC/104 Embedded Consortium governs the specifications of each of these products. The following list explains the properties all the boards share, while Table 1 compares the differences between the boards.

- **Stackable:** All CPU boards in the PC/104 family accommodate a variety of stacking modules.
- **Rugged design:** PC/104 eliminates the backplane and replaces it with a rugged pin and socket expansion bus. Boards are held together with a rigid four-corner mounting system. The combination of these features results in an extremely rigid multiboard system that can withstand shock and vibration, making PC/104 particularly popular in vehicle and military applications.
- **PC technology:** PC/104 is based on popular PC technology, including processors, support chips, expansion buses, operating systems, and software development tools. PC/104 board designers can easily take advantage of the latest and most popular technologies, in turn making these technologies available to PC/104 users. In addition, most engineers today have experience with PC hardware and software and are already familiar with the technology of PC/104, so implementing a PC/104 system is relatively fast and easy.
- **Low cost:** PC/104 systems cost substantially less than other embedded computing standards because of their smaller size and backplane elimination. PC/104 makes embedded computing technology accessible to a larger number of applications.
- **Multivendor support:** With more than 75 companies offering compatible PC/104 boards and accessories, PC/104 provides a reliable platform for embedded systems designers concerned with long product life and feature availability. OEMs can mix and match boards from multiple vendors and upgrade processors to achieve higher performance when needed.

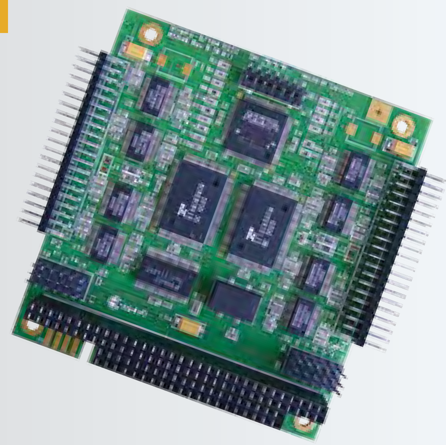


Figure 2a

Figure 2b

PC/104 and PC/104-*Plus* modules such as those from Connect Tech pictured in Figures 2a and 2b offer stacking technology in a very small footprint.

The PC/104 Embedded Consortium consists of members worldwide who have joined together to disseminate information about PC/104 and provide a liaison function between PC/104 and standards organizations. Members help shape the future of embedded market standards and gain early access to new developments in the industry.

To learn more, contact:

PC/104 Embedded Consortium
505 Beach Street, Suite 130 • San Francisco, CA 94133
Tel: 415-674-4504 • Fax: 415-674-4539
info@pc104.org • www.pc104.org

Form Factor	Size	Bus	Relative cost	Ease of maintenance	Advantages
PC/104	Small 90 x 96 mm	ISA	Low	High	Least expensive of the compact form factors.
PC/104-*Plus*	Small 90 x 96 mm	ISA + PCI	Highest	High	Small size, fast bus speed, more expansion options.
PCI-104	Small 90 x 96 mm	PCI	Medium	High	Small size, fast bus speed.
EBX	Large 146 x 203 mm	ISA + PCI	Lowest	Low	Large enough to enable additional circuitry and features. Room for higher-performance processors with heat sinks and fans without interference of add-on modules.
EPIC	Medium 115 x 165 mm	ISA + PCI	Low	Low	Supports use of consumer I/O connectors along one edge, which reduces cabling and enables quick assembly in enclosures. Room for higher-performance processors with heat sinks and fans without interference of add-on modules.
EPIC Express	Medium 115 x 165 mm	ISA + serial PCI Express	High	High	Same advantages as EPIC, plus adds the high-speed PCI Express bus.

Table 1

Factor this: board selection criteria

By Jerry Gipper and Don Dingee

In the past decade, we have seen an explosion of options for board form factors – some driven by the PC market but suitable for embedded applications and some created specifically for the embedded market. To help you choose from the many options, we'll take a look at the range of popular standard form factors available today and share a list of important criteria to evaluate.

PC market developments

Standards aren't new to the PC market, but for years we lived with limited choices like Baby AT motherboards, ISA cards, and a variety of custom to semicustom industrial-strength boards like STD, VME, and Multibus. At some point in the mid 1990s, the PC industry started looking for better solutions. Several new form factors such as ATX, BTX, and ITX succeeded the venerable Baby AT motherboard. Today, Intel, VIA, Microsoft, and others collaborate on the evolution of many PC motherboard form factors and help drive these new configurations for the PC market – but embedded designers often find these useful for embedded computing designs as well.

PC market motherboards are often installed in what many refer to as "pizza box" chassis. These 1U and 2U chassis can be stacked in racks and offer a very high computing density in a small space. They can be connected quickly via Ethernet and replaced without disrupting the entire system. However, pizza box stacks have cooling and density issues that some applications cannot tolerate.

Blade configurations have emerged to better address cooling, density, interconnect, and expansion issues. The blade concept has been around for many years in the form of slot cards, but the big breakthrough has been improvement in Ethernet performance to the point where it has become a reasonable alternative to parallel buses. Ethernet is ubiquitous, inexpensive, and easy to use.

With the emergence of PCI Express, vendors are sure to develop even higher-performance motherboard and blade configurations.

Embedded market developments

At the same time PC market boards have improved, embedded system designers have optimized various form factors to make them more appropriate for embedded applications. Some are stackable like the various PC/104 configurations. Some are modular and provide stand-alone capability. Certain form factors depend on PCI cards for expansion, and others address height limitations and use mezzanine modules like PMCs.

While most embedded boards are smaller than their PC market siblings, in some cases embedded designs have gone larger and more rugged to fill a specific role. Emerging form factors like AdvancedTCA and VPX address the power requirements of today's processors and grant users choices in interconnects and I/O management. These form factors are more open than the PC market blade architectures and offer many of the same benefits, with some differences in cost and life cycle.

The PCI or PCI Express card is common in the PC market, but in the embedded market mezzanine boards have been all over the map. Most board companies have several options. We continue to see small custom modules on most any design where functional density is a challenge. Board designers gain real estate by using small modules that fit in any available space. At the same time, PCI boards and PMCs have become more standardized. PCI boards are used in cost-sensitive applications where space is not a major issue while PMCs are used on boards with severe height restrictions. Most slot cards and many blades allow for the addition of a PMC or AdvancedMC form factor.

Choosing the right form factor

With these developments as background, what should a designer look for when selecting a form factor? Consider the following issues:

- **Size**: Size is always important. Some applications are very space constrained. Every square centimeter is prime real estate, and its use must be optimized. Larger boards tend to be less costly because they present fewer manufacturing challenges, but they do consume valuable space. Do some space studies to determine which trade-offs make sense for your project.
- **Expansion**: Will you need to add more functionality later? How that decision is handled can dramatically influence the form factor choice. Does it use a standard interface that already has a large selection of add-in options, or is it proprietary or limited in choices? Some expansion options take a large chunk of valuable real estate while others are low profile and space efficient. Be sure to check how well accepted the expansion option is if you think you need or will need it. Expansion options are a great way to add functionality to an already deployed system, improving chances to gain revenue from upgrades.

- **I/O management**: Some form factors are better than others on I/O management. Improvements in the location, number, and type of I/O have shaped the evolution of PC motherboards. As new types of I/O such as USB, flash cards, SATA, and IEEE 1394 have taken over the serial and parallel connections of the past, board designers have made appropriate changes in the way I/O is brought to the board. Many smaller form factors for embedded applications have even more unique choices better suited for such applications.
- **Power**: Something seemingly as straightforward as getting power to the board can be a huge obstacle. Backplane-based boards have power pinouts as part of the standard, but motherboard-based solutions are all over the map. Some are better than others when it comes to defining the power connectors and required voltages. The best solutions allow designers to use commonly available power supplies and connectors. It can be frustrating to have a "paperweight" that can't be conveniently powered for lab development, so be sure the power solution is understood beforehand.
- **Cooling**: How does a particular form factor handle cooling? For some applications this is a minor concern, but the majority will have some issues to consider, especially if you are using high-end processors for the project. Some form factors give you the choice of air, conduction, or even liquid cooling. Some are built into the board specification while others require some pretty creative mechanical design and plumbing.
- **Ruggedness**: What type of environment is your product going to be deployed in? Standard PC market boards do well in a home or office but are not so hot in mobile, industrial, or military applications. Picking a form factor that can handle your environment is high on the list of items to consider. Some form factors have extreme shock and vibration options. Again, form factors designed for embedded applications tend to do a much better job managing rugged requirements.
- **Standards**: Form factors endorsed and managed by a standards organization can be very important to many applications. A standard-supported form factor is more stable, well thought out, qualified, and usually has a planned evolution path. All this can help you manage future life-cycle issues as you improve and evolve your design. PC market boards tend to give life-cycle management a much lower priority than form factors targeted at embedded applications.
- **Support**: Who is the real target audience of the source you choose? PC market board suppliers are by definition focused primarily on the PC market. In choosing these boards for embedded use, you may be stuck with difficult revision management issues with these suppliers. Many companies with an embedded computing focus offer PC-style motherboards, providing support and life-cycle management while still leveraging PC motherboard technology. This comes at a slight cost premium, but the ROI can be beneficial farther down the road.
- **Number of suppliers**: Having choices in suppliers is just as important as choice in form factors. While our focus is mostly on *de facto* and true standards-based form factors, many are proprietary to a single company. This is less of a risk for one-off products that have a limited life span, but having a solution supported by several suppliers gives you options for prices, support, and life-cycle management.
- **Chassis choices**: Selecting a form factor is not the only step. What will you be doing for an enclosure and power supply? Do you need one or will you be managing that as part of your project? Many form factors have a great selection of chassis. The slot card and blades are dependent on the chassis to provide the mechanical support they need for good selections. PC-style motherboards are also well supported, but they may not be as appropriate for embedded applications. Some of the smaller embedded form factors leave most of the chassis decisions and design up to you.
- **Backplane versus motherboard**: This is a key decision. Factors to consider include I/O management, expansion, cooling, and ruggedness. Many of the newer backplane solutions, commonly called *blades*, use serial networking interconnects so that single boards can operate in physically separated boxes or in a larger chassis with several boards together. Larger systems that require a lot of expansion capability tend to lean toward the backplane choice. Smaller, more constrained applications will use a motherboard of some style. Sometimes a large product line will use motherboards at the low end and backplane style for the high end. Be sure to understand the range of your product needs.

What's out there

Table 1 (page 24) lists most of the popular options for standard form factors with specifications openly available. Many other form factors exist, but they tend to be proprietary to specific suppliers. To find form factor suppliers, visit the *Embedded Computing Design* website at www.embedded-computing.com, click on the product search feature, and enter the key words. You can also read more about small form factor boards in our sister publication, *PC/104 and Small Form Factors* (www.smallformfactors.com).

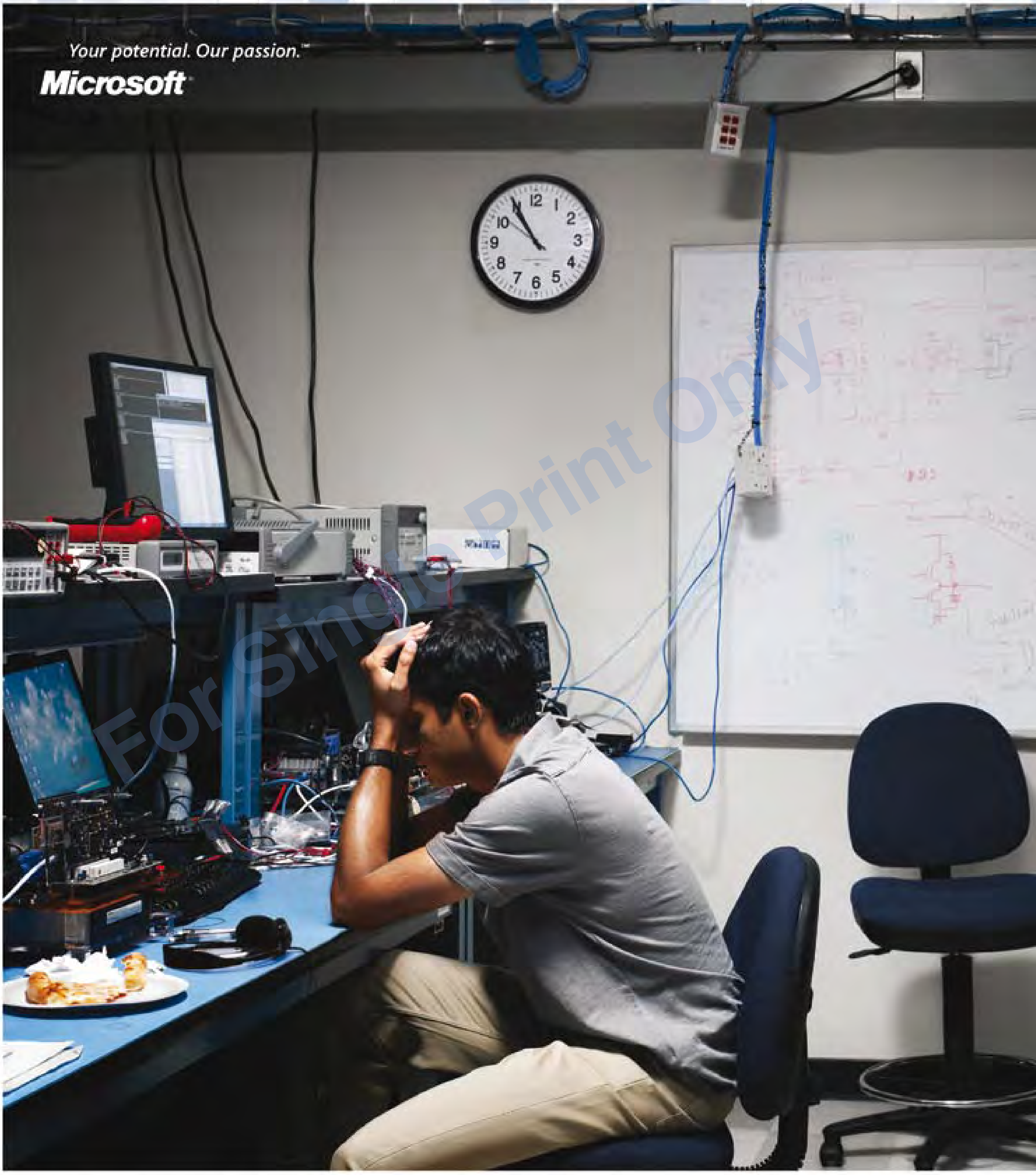
As you can see, the choices abound. If all else fails, many of the vendors also will customize a board leveraging an existing design and adding features and sizes suitable to your application. In fact, many of the "standard" form factors emerge from such projects. Choose wisely. ECD

Most Popular Form Factor Options

Form Factor	Style	Standard	Spec URL
5.25" Mini Module	Embedded Motherboard	*de facto*	
AdvancedMC	Blade	PICMG AMC.x	www.picmg.com
AdvancedTCA	Blade	PICMG 3.x	www.picmg.com
ATX	PC Motherboard	ATX 2.2	www.formfactors.org
ATX, FlexATX	PC Motherboard	flexATX 1.0	www.formfactors.org
ATX, microATX	PC Motherboard	microATX 1.2	www.formfactors.org
ATX, Mini-ATX	PC Motherboard	ATX 2.2	www.formfactors.org
Biscuit	Embedded Motherboard	*de facto*	
Biscuit, Half	Embedded Motherboard	*de facto*	
BTX	PC Motherboard	BTX 1.0b	www.formfactors.org
BTX, microBTX	PC Motherboard	BTX 1.0b	www.formfactors.org
BTX, nanoBTX	PC Motherboard	BTX 1.0b	www.formfactors.org
BTX, picoBTX	PC Motherboard	BTX 1.0b	www.formfactors.org
COM Express	Embedded Motherboard	PICMG COM.x	www.picmg.com
CompactPCI Express, 3U	Slot Card	PICMG EXP.x	www.picmg.com
CompactPCI Express, 6U	Slot Card	PICMG EXP.x	www.picmg.com
CompactPCI, 3U	Slot Card	PICMG 2.0	www.picmg.com
CompactPCI, 6U	Slot Card	PICMG 2.0	www.picmg.com
DIMM PC	Module	*de facto*	
EBX	Embedded Motherboard	EBX 2.0	www.pc104.org
ePCI-X	Embedded Motherboard	PICMG 1.2	www.picmg.com
EPIC	Embedded Motherboard	EPIC 2.0	www.pc104.org
EPIC Express	Embedded Motherboard	EPIC 2.0	www.pc104.org
ETX	Embedded Motherboard	ETX 3.0	emea.kontron.com/downloads/white_papers/ETXSpecV3.pdf
ETXexpress	Embedded Motherboard	PICMG COM.x	www.etx-express.com
ITX, Mini-ITX	PC Motherboard	*de facto*	www.via.com.tw
ITX, Nano-ITX	PC Motherboard	*de facto*	www.via.com.tw
MicroTCA, Double	Blade	PICMG MTCA.x	www.picmg.com
MicroTCA, Single	Blade	PICMG MTCA.x	www.picmg.com
Mini PCI	Mezzanine	Mini PCI 1.0	www.pci-sig.com
M-Module	Mezzanine	ANSI/VITA 12	www.vita.com
NLX	PC Motherboard		www.formfactors.org
PC/104	Embedded Motherboard	PC/104	www.pc104.org
PC/104-*Plus*	Embedded Motherboard	PC/104-*Plus*	www.pc104.org
PCI-104	Embedded Motherboard	PCI-104	www.pc104.org
PIM (PMC Interface Module)	Mezzanine	VITA 36	www.vita.com
PrPMC	Mezzanine	ANSI/VITA 32	www.vita.com
PXI	Slot Card	PXI 2.2	www.pxisa.org
PXI Express	Slot Card	PXI Express 1.0	www.pxisa.org
SHB Express, Long	Slot Card	PICMG 1.3	www.picmg.com
SHB Express, Short	Slot Card	PICMG 1.3	www.picmg.com
SOM-ETX	Embedded Motherboard	*de facto*	
STX	Module	STX 1.0	www.stx-consortium.com
VMEbus, 3U	Slot Card	ANSI/VITA 1.x	www.vita.com
VMEbus, 6U	Slot Card	ANSI/VITA 1.x	www.vita.com
VPX, 3U	Slot Card	VITA 46	www.vita.com
VPX, 6U	Slot Card	VITA 46	www.vita.com
XMC	Mezzanine	VITA 42	www.vita.com
XTX	Embedded Motherboard	XTX 1.1	www.xtx-standard.org

Table 1

Width (mm)	Depth (mm)	Area (cm²)	Expansion Bus	Notes
203	146	296	ISA	
72	185	133	PCI Express, Serial RapidIO, Ethernet, Fibre Channel	
311	280	871	PCI Express, Serial RapidIO, Ethernet, Fibre Channel	
305	244	744	PCI	Baby AT motherboard rotated 90 degrees
229	191	437	PCI	Smaller, ATX
244	244	595	PCI	Referred to as *EmbATX* or *Embedded ATX*
284	208	591	PCI	Smaller version of the ATX Motherboard
146	203	296	ISA	
146	102	149	ISA	
325	266	865	PCI, PCI Express	Balanced Technology Extended, 7 Expansion Slots
264	267	705	PCI, PCI Express	Balanced Technology Extended, 4 Expansion Slots
224	267	598	PCI, PCI Express	Balanced Technology Extended, 2 Expansion Slots
203	267	542	PCI, PCI Express	Balanced Technology Extended, 1 Expansion Slot
125	95	119	PCI Express	
100	160	160	PCI Express	
233	160	373	PCI Express	
100	160	160	PCI	
233	160	373	PCI	
68	40	27	Self-contained	
146	203	296	ISA, PCI	
203	146	296	PCI/PCI-X bus	Embedded PCI eXtended
115	165	190	ISA, PCI	Embedded Platform for Industrial Computing
115	165	190	ISA, PCI Express	EPIC with PCI Express
95	112	106	ISA, PCI	Embedded Technology eXtended
90	125	113	PCI Express	Embedded Technology eXtended with PCI Express
170	170	289	PCI, PCI Express	
120	120	144	PCI, PCI Express	
149	182	270	PCI Express, Serial RapidIO, Ethernet, Fibre Channel	Double; 3HP, 4HP, or 6HP
74	182	134	PCI Express, Serial RapidIO, Ethernet, Fibre Channel	Single; 3HP, 4HP, or 6HP
60	44	26	PCI	
148	53	78	PCI	
228	345	787	PCI	
90	96	86	ISA	
90	96	86	ISA, PCI	
90	96	86	PCI	
74	69	51	User-defined	
74	149	110	PCI	
233	160	373	PCI	PCI eXtensions for Instrumentation
233	160	373	PCI Express	PCI eXtensions for Instrumentation
126	339	427	PCI Express, PCI, PCI-X	
126	168	212	PCI Express, PCI, PCI-X	
114	95	108	Self-contained	System On Module - ETX
96	90	86	ISA, PCI	Smarter Technology eXtension
100	160	160	VMEbus	
233	160	373	VMEbus	
100	160	160	PCI Express, Serial RapidIO, Ethernet, InfiniBand	
233	160	373	PCI Express, Serial RapidIO, Ethernet, InfiniBand	
74	149	110	PCI, Serial RapidIO, PCI Express	
95	112	106	PCI Express	eXpress Technology for ETX



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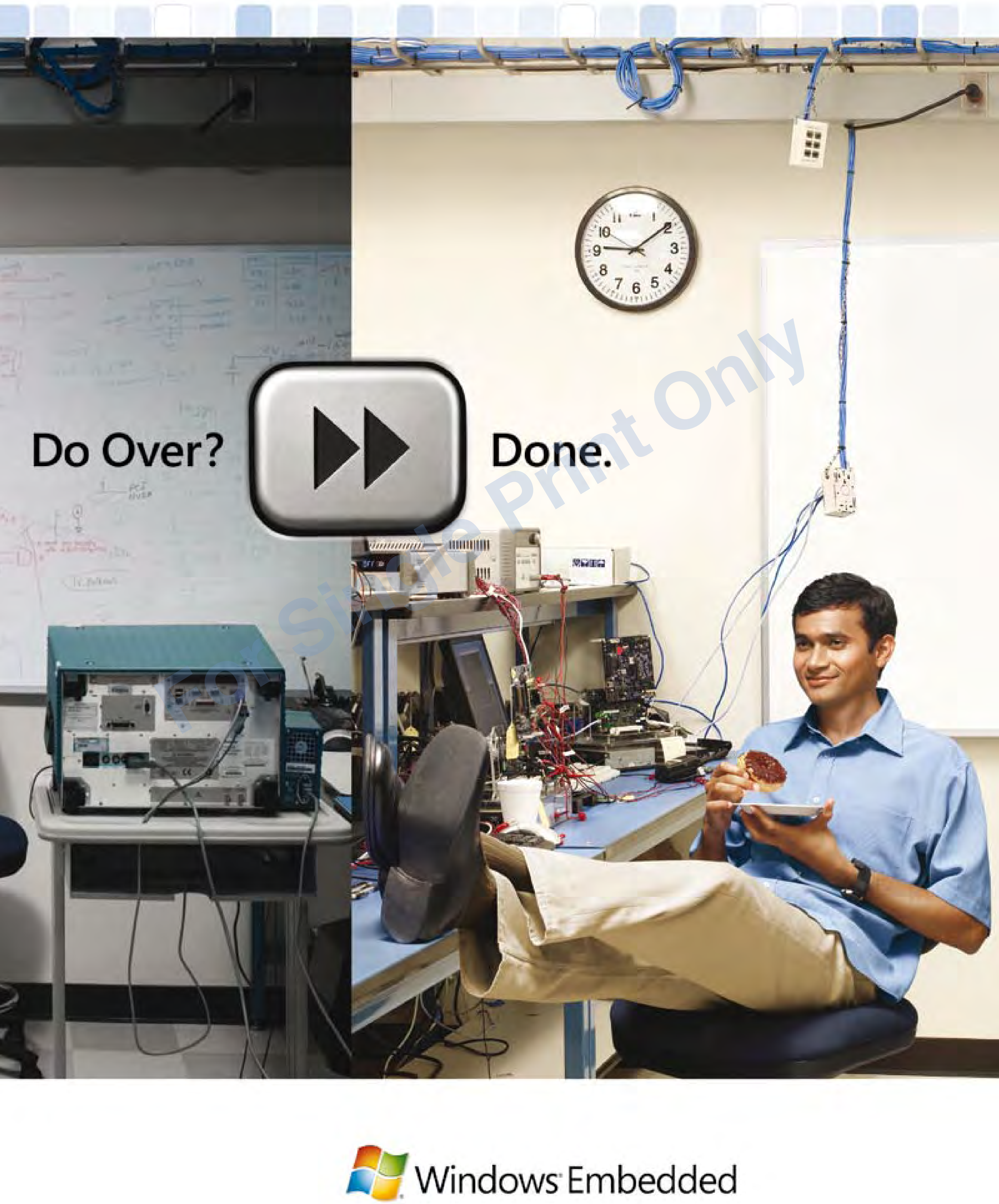
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Multicore communication: today and the future

By Tony Trawick

With the ever-increasing demands for embedded devices, multicore solutions are becoming more prevalent. The use of multiple cores increases the complexity of software design in many aspects, one of those being the communication between the different cores. How the communication will be used, what it should support, and how it should be implemented are all questions multicore systems software developers will ask. The majority will require a straightforward, simple approach to accomplishing the task.

Increased move to multicore platforms

If you have looked around the embedded hardware landscape lately, you may have noticed hardware vendors are offering a growing number of multicore development platforms. With increasing demands on embedded devices, it is no wonder that more processing power is needed. The move to multicore platforms is the natural evolution for embedded devices considering the convergence of functionality being placed on what have traditionally been known as single purpose devices. Take the phone for example. It has evolved from a device whose main purpose was to place a simple point-to-point call to a device that functions as a mobile phone, gaming unit, camera, media server, Web browser, and more, all in one, as illustrated by Figure 1.

While the convergence of functionality being placed on embedded devices in and of itself may not necessitate the move to multicore, additional considerations such as footprint, energy consumption, heat dissipation, and other aspects of driving a single processor at higher and higher frequencies demand the transition. The move toward multiple cores requires that the software be allocated in some fashion among the different and sometimes specialized processor cores.

The addition of multiple cores also creates the need for communication and synchronization. Software developers want an easy-to-use mechanism that allows them to take advantage of multicore systems efficiently. They also want that method to be extensible in the future. With this in mind, the need for a communication system, what it should support, and how it should be implemented will be explored.

Considerations and assumptions

Communication among multiple cores involves many aspects. However, it should be noted that this discussion does not address a distributed system that communicates over a network. This mechanism is intended for embedded devices and should be as simple as possible, while providing the needed abilities to accomplish its goal: to allow different cores to send data to each other through an easy-to-use API. In the embedded world, developers will typically know how many cores they have available, the data and applications that will be used, and how each specialized core will be utilized.

Today, in most cases, the cores are tightly coupled, sharing a block of memory. With a few notable exceptions, cores are limited to a small number per chip/processor. However, the number of cores contained within a processor is continually growing, making it necessary for the communication scheme to be easily scalable. Also, some situations involve multiple processors on

Figure 1

a single board that could be connected using a type of high-speed interconnect, creating a need for the scheme to support more than shared memory.

Using AMP or SMP solutions

Asymmetric MultiProcessing (AMP) and *Symmetric MultiProcessing* (SMP) are terms used to describe a Real-Time Operating System (RTOS) and hardware architecture of the device. Many detailed papers and books have been written on the subjects of AMP and SMP, so for the purposes of this discussion, analysis will focus on the high-level advantages and disadvantages of each system in a multicore environment and why the need for a simple communication scheme exists no matter which architecture is used.

SMP RTOSs are characterized as having a single image of the RTOS shared by many cores. They also offer the developer many advantages. SMP RTOSs handle the load balancing between the cores, which allows SMP systems to easily scale, but only up to a certain point. Another benefit is that all of the data is available for all of the cores and tasks, so any type of external communication mechanism between cores is not needed. All communication is handled within the SMP RTOS. The major disadvantage to SMP systems is the inability for the SMP RTOSs to operate in heterogeneous environments. This causes problems for the majority of embedded systems in which specialized cores are used in conjunction with general-purpose cores.

AMP RTOSs differ from SMPs in that instead of sharing cores with one image, AMPs have one image per core. The main advantage to an AMP system is that it can be used in a heterogeneous environment. However, AMP systems with large numbers of cores can become unwieldy, creating problems with scalability. AMP systems also will most likely require some type of mechanism to communicate among the cores to realize the full potential of the multicore system.

While it seems advantageous that an SMP system can handle communication by the RTOS, the future may require both architectures to have some type of communication mechanism outside the RTOS. In the not too distant future, a group of general-purpose cores will be able to replace a single general-purpose core, and a group of DSP cores will be able to replace a single specialized DSP core. Each group will have an SMP RTOS, but the two groups will still need to communicate with each other just as AMP systems do today. For current situations, it appears an AMP system is optimal, but whether it or an SMP system is used, a communication method between heterogeneous groups will be needed, as depicted in Figure 2.

Communication system details

After determining that a communication mechanism is necessary, developers need to concern themselves with the implementation details. Factors such as the physical interface supported, availability of guaranteed communication, protection, and configurability of the mechanism are all important factors that affect the overhead, speed, complexity, and scalability of the communication mechanism.

Today, communicating over shared memory handles the majority of cases needed, but as mentioned earlier, developers want a system that is extensible. Communication over other types of interconnects will be necessary in the future, and it is imperative to have the ability to add future interconnects interchangeably, providing transparency to the applications.

Guaranteeing that data be sent and received correctly between cores is very important and can also be a source of tremendous overhead to the system. In tightly coupled systems, the transport mechanisms such as shared memory are stable and can be trusted to send and receive data correctly. When receive notification is needed, a simple low-overhead protocol can be developed, taking advantage of the system being tightly coupled.

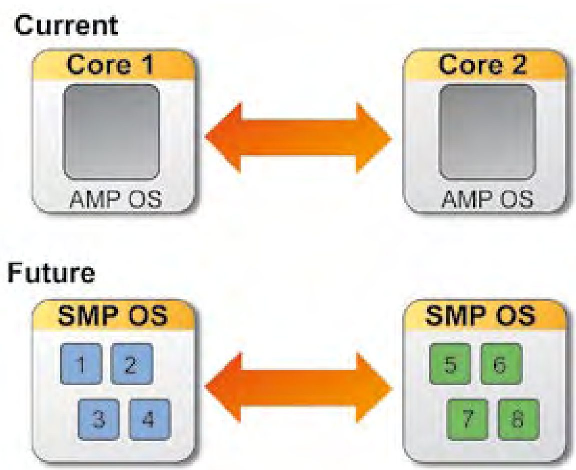

Figure 2

Typically in shared memory implementations, spin locks will be used for the protection mechanism. A spin lock usually takes advantage of a hardware atomic test and set operation. It operates by basically locking out other operations from using the protected entity. Waiting operations just spin in a loop until the protection is removed. The granularity of these spin locks greatly affects the speed and usability of the system. A very coarse granularity would have a single spin lock controlling the entire shared memory region. A very fine granularity would have a spin lock covering every single structure and object in the shared memory region. Each has its advantages and disadvantages, but the most efficient granularity will be between these extremes.

It is a tricky balancing act in the embedded world to provide configurability without creating burdensome overhead. For embedded devices, the developer will typically have a good idea of the amount of data to be communicated at one time and how often the data will be sent. This allows, for the most part, configuration to be done at compile time, removing the overhead of dynamic allocation but still allowing the developer to customize to any particular needs.

Scalability of the communication mechanism is also an important factor to consider, especially with the growing number of cores per chip expected in the future. Having to change communication mechanisms because more cores were added to the system is not very appealing and could be very expensive.

Multicore platforms are here to stay

Multicore solutions for embedded devices are here to stay and will only become more prevalent in the future. Multicore solutions today mostly contain two to four cores on a chip/processor, but this number has the potential to grow very large in the near future. Some cores today have upwards of 300 DSPs per chip. This number will continue to grow and be accompanied by combinations of different specialized cores.

Whether one opts for an AMP or SMP RTOS architecture, an external communication mechanism between cores or groups of cores will be necessary. The details of this mechanism should also be very important to the developer. The overhead, speed, and complexity should be considered, as well as the ability to support future additions with scalability. To ignore these factors could prove very costly. **ECD**

__Tony Trawick__ is a software engineer for Mentor Graphics, working in the Nucleus PLUS kernel development group. He has worked in the embedded industry for more than four years, and his embedded experience includes kernel porting, device driver writing, multicore/processor support, and kernel development. Tony is a graduate of the University of South Alabama with a BS in Computer Science and Physics as well as an MBA from Spring Hill College in Mobile, Alabama.

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Real-time Linux, past and present

By Daniel Walker

Linux traditionally has been considered a general-purpose server or desktop Operating System (OS), and as a result is often viewed as incapable of true real-time functionality. However, this assumption has proven false on multiple occasions. In fact, various Linux approaches begin with a dual OS, Linux, and Real-Time Operating System (RTOS) and continue down the path of low latency, resulting in Linux as the RTOS. Typical real-time approaches entail running an application on bare hardware or using a small OS, which is considered tightly bounded and specifically created for use in real-time applications.

With more than nine million lines of code in today's Linux kernel, many programmers often struggle envisioning how to approach Linux. Additionally, programmers are fearful of the Linux community and the General Public License (GPL). These concerns have led to the creation of the dual OS real-time approach, which primarily entails ignoring the existing Linux code base and using a second OS for real-time purposes. Subsequently, the two OSs are combined using one of the flavors of "glue code," such as Opersys's Adaptive Domain Environment for Operating Systems (ADEOS, see Figure 1). From the end user's perspective, the two kernels appear as a single OS. From a high-level perspective, the real-time kernel appears as a high-priority process and the Linux kernel appears as the low-priority process. FSMLabs and the Real-Time Application Interface (RTAI) use this now-common approach.

Although the dual OS real-time approach has become prevalent, Linux code is fully capable of being developed into an RTOS. TimeSys, the first to create soft real time based solely on the Linux kernel, deserves credit for breaking new ground with the single Linux kernel method, but did not disclose the majority of its changes to the Linux community. Additionally, the changes it released were not considered for inclusion in the vanilla Linux kernel.

The Linux-based RTOS movement continued to make significant advances with Robert Love's changes, which created preemption inside the Linux kernel as well as a constant time scheduler. Linux community members including Ingo Molnar (Red Hat) and others rewrote or heavily reviewed both of these changes and then incorporated them into the kernel. Next, Molnar began work on Voluntary Preemption, a polling preemption process mainly useful in server environments. Over the course of several months, the Voluntary Preempt patch matured, putting a Linux RTOS within reach.

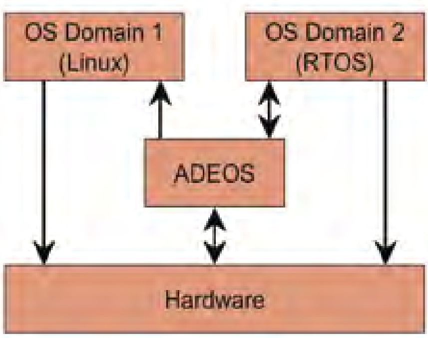

Figure 1

During subsequent Voluntary Preemption development, Sven Dietrich and I (to a lesser extent) created and released a set of changes for Linux 2.6 that paralleled those TimeSys created with Linux 2.4. In the ripe environment of advances in latency reduction, this code release became a channel for the community to finally solve the real-time Linux dilemma. Molnar, the most experienced real-time community member, rewrote/created and maintained all real-time Linux features in the newly formed real-time Linux branch that evolved from Voluntary Preempt. Molnar's involvement played a vital role in getting Linux real time to the point it's at today. This flurry of activity endowed the real-time Linux branch with preemption rates that approach the hardware context switching cost.

The Linux real-time kernel uses the following key features:

- ***Priority Inheriting Mutex:*** A mutual exclusion object (mutex) allowing the highest priority of all the waiters on a

The days of Linux considered as only a general-purpose OS are ending.

mutex to increase the process priority of the mutex owner.

- ***Spin locks seamlessly converted to the new mutex:*** Spin locks in Linux disable preemption; consequently, one of the keys to lower preemption rates is removing spin locks through a noninvasive process.
- ***Interrupts in threads:*** The process of servicing interrupts in thread context instead of interrupt context. Linux also disables interrupts (and thereby preemption) when in interrupt context. Interrupts can lock the new mutex, meaning they need to be in process context so they may sleep.

Embedded solutions companies such as MontaVista and others have created products based on these changes. The real-time patch to the Linux kernel is openly available at http://people.redhat.com/mingo/realtime-preempt/.

The features in the current real-time branch represent a culmination of the ideas from prior real-time approaches. Using these changes, the Linux kernel can handle hard real time. The significance of this is astounding, but has not been fully realized. As companies and individuals begin to leverage these changes, the days of Linux considered as only a general-purpose OS are ending. **ECD**

Daniel Walker *is a real-time architect at MontaVista Software. In addition to his active open source community involvement for seven years, Daniel has been involved in Linux real-time development for more than two years. He graduated with a BS in Computer Science from the University of California Santa Cruz.*

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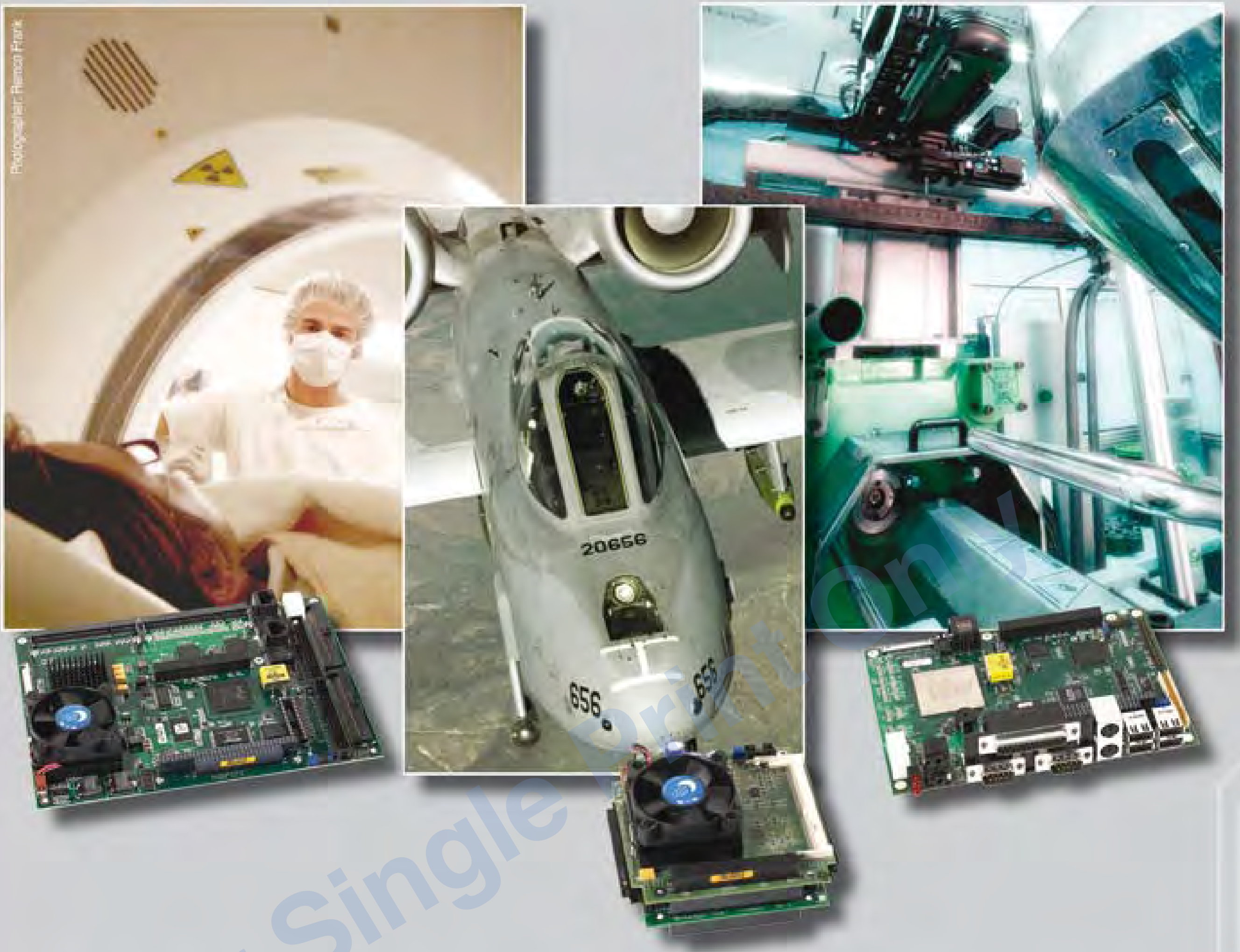
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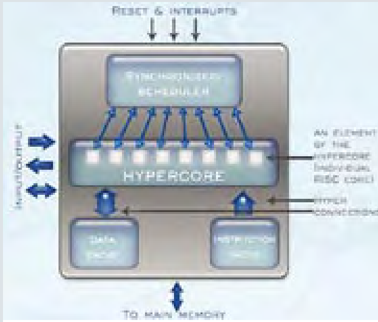
64 cores and more

We've been hearing about bigger numbers of cores lately, and now FGPA designs and tools are showing up to enable custom processor designs with many cores possible.

Plurality's Hypercore Processor design is implemented on an Altera Stratix II-180 FPGA and incorporates 16 32-bit RISC cores managed by a high flow rate Synchronizer/Scheduler, sharing a common memory. The FPGA design comprises a 4 Mb data cache, a 2 Mb instruction cache, four 32-bit multipliers, and four 64-bit dividers. Also available is a cycle-accurate graphic simulator for Hypercore Processors of up to 256 cores.



Plurality Ltd. • Hypercore processor

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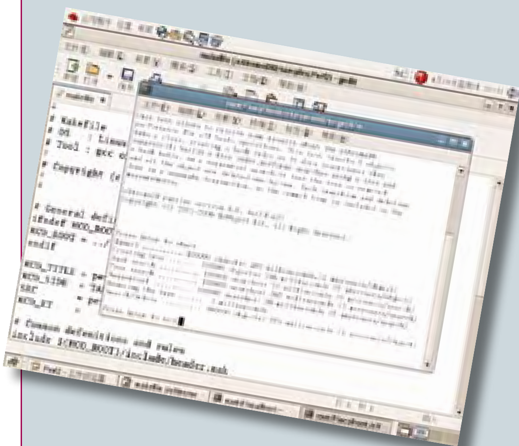
Database gets extremely embedded

Embedded databases usually can't just be tossed on high-performance RAID hardware to get needed performance. They must optimize memory and disk transactions very efficiently and give designers a space-conserving approach.



*eXtreme*DB Fusion from McObject enables developers to combine both database paradigms – in-memory and on-disk – in a single database instance. It allows some data to be specified as transient (managed in memory) while choosing on-disk storage for other data. Simple schema declarations and built-in optimized caching strategies help develop fast applications quickly.

McObject • *eXtreme*DB Fusion

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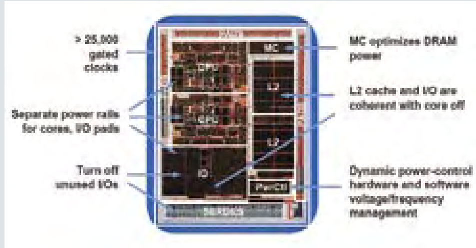
More Power takes a lot less power

The Power Architecture scales from low-end microcontrollers to high-end processors, and a recent development at the high end is grabbing attention.

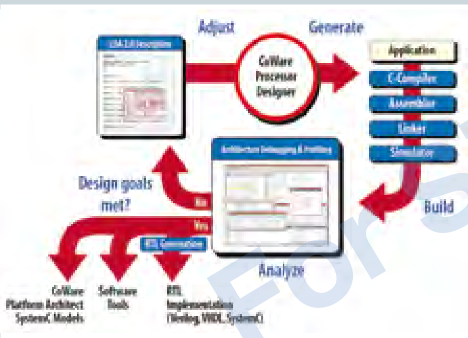


The new 64-bit dual-core PA6T-1682M PWRficient processor from P.A. Semi is based on the Power Architecture technology, but that's not the big news. Power consumption is the first order of business: the System-on-Chip (SoC) consumes just 5-13 W of power (typical) at 2 GHz, with high-performance processing and onboard I/O such as Gigabit Ethernet and PCI Express.

P.A. Semi • PA6T-1682M PWRficient processor

Long words? No problem

Cutting the time for complex architecture exploration from months to hours, new electronic system-level tools are targeting development of next-generation Very Long Instruction Word (VLIW) processors for high-end video, multimedia, and wireless devices.



The latest version of CoWare's Processor Designer lets users explore a large design space and look at interconnect infrastructure to achieve needed performance. Users can parameterize the processor architecture with the number of VLIW slots, optimizing and customizing slots individually for a specific application.

CoWare • Processor Designer

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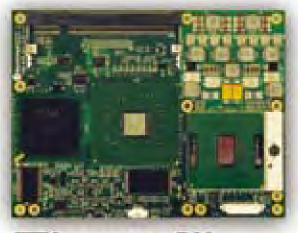

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Optimizing device data processing and management

By Jan Liband

Editor's note: Learn more about device data management

Encirq is taking a bold step to improve the acceptance of device data management with their DeviceSQL Quick Start Suite. Available for free download at www.encirq.com, the Quick Start Suite combines device data management technology with an interactive, self-paced tutorial that steps users through a primer on device data management, exercises with example code, and a demo application, teaching users to employ advanced, resource-efficient techniques for manipulating and managing device data. The self-contained environment provides everything needed to design and build device applications with the DeviceSQL framework and run them in a Windows environment.

Requirements for increased software functionality and device connectivity are driving changes in embedded software development. To address the data explosion in embedded devices, a new breed of device data management technologies is emerging to help developers take advantage of higher-level, data-centric methods while maintaining the control and performance of hand-coded implementations.

Not too long ago, embedded systems were largely stand-alone, nonconnected devices with limited user-interface features. By contrast, today's embedded devices are far more connected, feature rich, and intelligent. Many now feature multiple connectivity options, more integrated peripherals, and a growing number of input sensors. And in systems ranging from industrial control equipment to consumer electronics devices to automotive "infotainment" systems, many must now meet requirements for a far more sophisticated user interface. At the heart of it all, today's systems must process and manage growing amounts of complex data from an increasing variety of sources both inside and outside the device.

The impact of this trend on embedded software and development teams has been huge. In the past 10 years, both the complexity and the amount of software going into embedded devices have exploded. According to Venture Development Corporation (VDC), the size of embedded software applications has been growing at a rate of 46 percent per year while the growth rate of embedded developers has been merely 7.5 percent (see Figure 1). This increasing disparity between application size and available talent has made engineering shortages and individual developer productivity critical business concerns. Of course, the growing size and complexity of embedded applications is also driving up software development costs and risk.

Data management is at the core

Related research has shown that, on average, 54 percent of application code in embedded devices is used for processing and managing data, that is, code for acquiring, filtering, aggregating, storing, and accessing device data through dynamic and tabular data structures together with linked lists, indices, pointers, and so on. Despite recurring patterns in device data management infrastructure, the vast majority of device data management programming is still being done manually in C or C++. Without higher-level, data-centric design and development methods, opportunities for designing or discovering better data models and optimal implementation schemes are routinely missed. Consequences include slower system performance, increased memory requirements, and higher hardware costs. They also include longer development cycles and higher development costs as software teams manually reimplement their system's data management infrastructure on project after project.

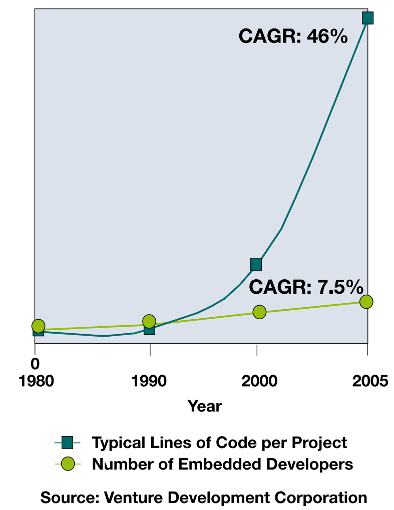

Figure 1

Fortunately, new solutions to the software development challenges of device data management are starting to appear. Some of the more advanced solutions, such as DeviceSQL from Encirq, come in the form of domain-specific software development frameworks rather than packaged embedded database technologies. Regardless of the solution, when tackling the data explosion in embedded devices, it helps to build on best practices based on decades of enterprise data management experience.

Lessons from the enterprise

In enterprise software development, data management is a central, well-honed practice. Developing complex applications that process and manage enormous volumes of data from disparate sources has become routine. Thus, important lessons can be learned from enterprise software development that can be applied to building the software for managing data in today's embedded devices. The key is understanding which techniques and technologies make sense given the challenging hardware constraints, performance requirements, and unique characteristics of device data.

For many years, enterprise software developers have benefited from higher-level, data-centric software design and development approaches for managing data. The most popular data management languages today are the Structured Query Language (SQL) and its procedural cousins, such as Oracle's PL/SQL. These languages enable software architects and developers to define, manipulate, and manage data from a higher level of abstraction. According to Software Productivity Research, data management languages like SQL are 10 times more expressive than C, allowing developers to get more done with far fewer lines of code.

Using these higher-level languages is usually predicated upon the use of an underlying database. The most popular database model today is the relational database. Most databases such as Oracle, DB2, MySQL, and others are architected in a client-server fashion. They reside on one or more servers and manage (or serve) data to multiple clients and applications. Databases, together with the use of higher-level data management languages such as SQL, make it easier to define and manipulate data by abstracting physical data sources, reducing development complexity, and providing numerous data management features such as indexing for more rapid data search and retrieval.

Embedded system realities

While databases and higher-level data management methods have provided tremendous productivity and application flexibility benefits to enterprise software developers, the harsh constraints of embedded systems have limited their use for device software development.

First, most embedded systems have stringent performance and deterministic response requirements. While the performance of embedded databases has improved over the years, they typically offer poorer performance than hand-coded data management routines.

Second, embedded systems typically have limited memory. Unfortunately, embedded database technologies usually increase memory requirements by several hundred kilobytes to several megabytes. While some designs can tolerate the extra memory costs, many cannot.

Third, embedded developers need the flexibility to store and access system data in ways that optimize available hardware resources. Many designs do not include a hard drive, thus using many disk-oriented databases is not an option. A few databases support in-memory operation only and a handful of others support storage in flash, but none offer the ability to store and access data across the full spectrum of persistent storage media that may be found in advanced systems.

Finally, the *store, then process* model supported by database technologies is a poor fit for the dynamic processing and management of data in most embedded applications. While data is relatively static in a traditional server environment, in products ranging from portable wireless devices to automotive systems to industrial automation systems, the application must operate on data with many of the following unique characteristics:

- Device data is acquired and/or generated by the device, for the device and is often temporal in nature
- Device data often comes in the form of dynamic data streams, such as streams of structured data from environmental sensors or network I/O
- Data often enters the device from diverse sources and in multiple formats
- When device data is stored it is often processed, stored, and then reprocessed locally, rather than being processed and then "warehoused" on a remote server
- Device data is derived from and/or stored in a wide variety of media such as ROM, NVRAM, flash, mini hard drives, and so on
- Device data processing is subject to immediate power-off and/or disconnection conditions, coupled with requirements for fast restoration upon power-up or reconnection
- Device data processing and management must be extremely reliable as system uptime requirements may be stringent
- Device data processing is extremely deterministic; almost all operations with and on the data are determined during design, with little need for *ad hoc* operations
- Device data must be processed using an ever-changing variety of CPU architectures and operating systems as appropriate to the design, economics, or intended purpose of the device

As a result of the unique characteristics of device data management, embedded database technologies remain a poor fit for most designs. Leveraging the many benefits of higher-level, data-centric methods and tools in a way that works in an embedded environment is a must. Developers need the abstraction provided by a database while maintaining the control, design flexibility, and performance of hand-coded data management implementations.

A new approach for managing device data

Fortunately, a new breed of device data management technologies has emerged. These technologies extend the power of relational data management concepts normally reserved for tables and apply them to data streams. This allows the benefits

Programming abstraction minus the overhead

DeviceSQL is a software development framework that enables developers to take a higher-level approach for managing device data. It features an SQL-based language, DeviceSQL, for manipulating and managing data, offering developers the programming abstraction of a database without the associated overhead. As a framework, it includes the necessary tools and runtime services needed for building high-performance data management components optimized for the exacting requirements and resource constraints of embedded designs. Unlike embedded databases, DeviceSQL supports the wide range of storage media that may be present in any given device, making it easier for developers to optimize data processing and management within available hardware resources.

of relational data models to be directly applied to dynamic data stream sources. In many cases, a stream-based approach uses less memory and offers significant performance advantages because data does not first need to be stored, retrieved, and then processed. Instead, data can be filtered and aggregated on-the-fly, regardless of its original source.

With the tremendous growth in the size and complexity of embedded software, forward-thinking developers are searching for ways to reduce complexity and increase productivity. When they look closely at their systems and applications, many are finding that what used to be a control problem solvable through procedural application logic has morphed into a complex data processing and management challenge. Thus, engineering teams today face the difficulty of designing and building the software to process, integrate, and manage growing amounts of data from diverse sources and in multiple formats while achieving the following goals:

- Maximum performance and reliability
- Using minimal hardware resources across changing hardware and software platforms
- Short development time

New technologies for processing and managing device data are tackling this problem head on. By using these new technologies together with more data-centric design approaches, developers are better able to address the most challenging device software issues today. **ECD**

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Know your OS options

OS OPTIONS

By Jerry Gipper and Don Dingee

As a natural outgrowth of the trend for more and more software content in products, software often leads the decision on which hardware to choose for an embedded applications design. For projects tightly coded in a small microcontroller, designers may be able forgo an Operating System (OS) altogether. But for most projects, an off-the-shelf OS offers benefits, most of which become stronger the larger the project gets. The right choice of an OS can make or break a project.

If you get to choose which OS you use in your next project, there's good news – many software alternatives are available to sort through. Evaluating and selecting an OS can be a fun and challenging exercise for those who know what to look for.

We've examined the range of OSs from simple to complex with some real-time characteristics and separated them into three basic classes:

- Linux (and its near cousin, BSD)
- Real-Time Operating Systems (RTOSs)
- RTOS extensions that work with Windows

Evaluation criteria

Which questions should designers ask when evaluating OS choices? Let's run through some of the areas to consider. (Note: We didn't attempt to tabulate these in our list, so consult individual vendors for current information.)

- **Distribution rights, runtime royalties, and development seat costs.** Some OSs are free and others are licensed on a per-copy, per-seat, or per-project basis or a hybrid cost model. Consider this up front: For small projects, development seat costs can be prohibitive, and for medium to large volume projects, be sure to include any royalties in the total cost of your application. The licensed models usually come with some form of vendor support, while the free models usually have support from a community that contributes fixes and new development.
- **Processors supported.** Designers should review which processor architectures and models are supported when reviewing RTOS choices. Hardware and software teams should coordinate closely to ensure the OS and processor architecture are compatible. Look for OS suppliers that have a strong working relationship with the processor vendors – most list these relationships in formal partnering programs. A long track record with a processor family is a huge plus. You want the OS to be able to leverage the features of the processor to your advantage.
- **Features.** These OSs were usually developed for a specific job and have varying strengths and weaknesses. Features are numerous and differ widely among OSs. With an understanding of your application and its requirements, prioritize required features to narrow the search. Items to consider include kernel size, interrupt response, context switching time, memory management, networking protocol support, development language support, debugging, and others.
- **Customer support.** To some developers, this can be a decisive factor. How big is your project? How familiar are you with the RTOS you are using? Answers to questions like these can point to a supplier with a solid and well-established support team that can assist you through some difficult design issues and save much time and effort. Sometimes, communities can be very helpful, especially if you're a contributor in good standing. But generally, timely and experienced customer support is not going to be free – expect to pay to get priority response.
- **Development tools supported.** Development tools can be a major decision, especially on large projects with numerous developers. Many companies have corporate-wide mandates for certain tool chains, thus limiting your RTOS choices. Some smaller RTOS suppliers don't have much in the way of development tools, a good compiler may be all you get. Other suppliers offer fully featured development environments. Your development team will be spending a lot of time with the tools so be sure you choose wisely. Consider Eclipse-based tools so they can be customized to meet current and future requirements. (For more insight direct from industry experts on this topic, read the Eclipse Perspective and News column, one of our regular features, on page 11.)
- **Source code access.** Access to source code can be very important to some programs. Open source OSs by definition come with this. Linux again provides a great example of a community of developers that has kept the source code in the public domain and harvested the "best of the best" to provide a solid OS. Vendors of proprietary code often provide snippets to help with driver development or configuration, but licensing source is a different story – it's usually quite

expensive. Many defense programs require access as sort of an insurance policy to business disruptions and emergency maintenance. Some developers like access to source so they can fully understand the RTOS's underpinnings. Be sure you understand the vendor's policy on source code.

- **Supplier reputation.** "Let the buyer beware" applies here. The big suppliers have been around for a long time for good reason – customers have succeeded in using their products. A number of small suppliers, some backed by only a single software person, provide OSs. Look deep and see what's there. Ask for references if necessary. Consider what kind of risks you are willing and able to accept. Some great solutions come from the smallest of suppliers, but your project could face huge risks if the supplier fails or you get in over your head and can't get the right support.

The RTOS roll call

Table 1 lists some of the choices available today. Many you may recognize, while others may be unfamiliar. While conducting our research, we tried to find a wide range of options from the simplest OSs to the most complex. Numerous individual university research projects could add more depth to the choices; we included choices supported by a community of researchers.

This list fluctuates as new alternatives emerge, old ones fall out of favor, and ongoing mergers and acquisitions change the landscape of the industry. Many did not make the list if we were could not confirm continued OS support. Some websites were dated and showed very few signs of life.

If you enjoy digging into the history of OSs, you can find some interesting reading at www.answers.com/topic/list-of-operating-systems, which captures some of the background on a long list of OSs that have come and gone and provides the roots to the popular choices of today.

Do your homework. Ask questions. Demo some code. Make informed decisions. **ECD**

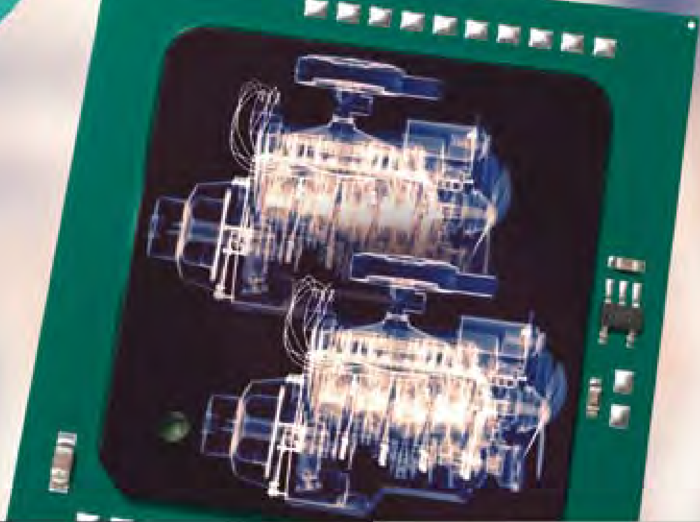
OS OPTIONS

Table 1

Operating System	Company	URL	Model	Type
µCLinux	Community	www.uclinux.org	Open source	Linux
µITRON	Community	www.assoc.tron.org	Open source	RTOS
µnOS	Miray Software	www.miray.de	Proprietary	RTOS
AMX	KADAK Products Ltd.	www.kadak.com	Proprietary	RTOS
BlueCat Embedded Linux	LynuxWorks, Inc.	www.lynuxworks.com	Proprietary	Linux
C EXECUTIVE	JMI Software Systems, Inc.	www.jmi.com	Proprietary	RTOS
CapROS	Community	www.capros.org	Proprietary	RTOS
Certified BSD	Wasabi Systems	www.wasabi.com	Proprietary	Linux
CEWin	Kuka Controls	www.kuka-controls.com	Proprietary	RTOS Extension
CMX-RTX	CMX Systems	www.cmx.com	Proprietary	RTOS
CMX-Tiny+	CMX Systems	www.cmx.com	Proprietary	RTOS
Contiki	Community	www.sics.se/contiki	Open source	RTOS
Coyotos	Community	www.coyotos.org	Open source	RTOS
E/OS LX	Community	http://meos.sourceforge.net	Open source	Linux
eCos	Community	http://ecos.sourceware.org	Open source	RTOS
ELinOS	SYSGO AG	www.sysgo.com	Proprietary	Linux
Emb OS	SEGGER Microcontroller Systems	www.segger.com	Proprietary	RTOS
Embedded Linux	Neoware	www.neoware.com	Proprietary	Linux
EPOC	Symbian	www.symbian.com	Proprietary	RTOS
ESF OS	EmINENT Microsystems Inc.	www.eminentmicro.com	Proprietary	RTOS
FreeRTOS	Community	www.freertos.org	Open source	RTOS
Fusion	Unicoi Systems Inc.	www.unicoi.com	Proprietary	RTOS
Haiku	Community	http://haiku-os.org	Open source	RTOS
Inferno	Vita Nuova Holdings Ltd.	www.vitanuova.com	Proprietary	RTOS
INTEGRITY	Green Hills Software, Inc.	www.ghs.com	Proprietary	RTOS
InTime	TenAsys Corporation	www.tenasys.com	Proprietary	RTOS Extension
iRMX III	TenAsys Corporation	www.tenasys.com	Proprietary	RTOS
Javaloution	Community	www.javaloution.org	Proprietary	RTOS
Linux 2.6	Community	www.kernel.org	Open source	Linux
LinuxDA	Empower Technologies Corporation	www.linuxda.com	Proprietary	Linux
LinuxLink	TimeSys Corporation	www.timesys.com	Open source	Linux
LynxOS	LynuxWorks, Inc.	www.lynuxworks.com	Proprietary	RTOS
MaRTE OS	University of Cantabria	http://marte.unican.es	Open source	RTOS

continued on page 48

Operating System	Company	URL	Model	Type
MC/OS	Mercury Computer Systems	www.mc.com	Proprietary	RTOS
MicroC/OS-II	Micrium	www.micrium.com	Proprietary	RTOS
MontaVista Linux	MontaVista Software Inc.	www.mvista.com	Proprietary	Linux
MQX	MQX Embedded (ARC International)	www.metaware.com	Proprietary	RTOS
NetBSD	The NetBSD Foundation, Inc.	www.netbsd.org	Open source	RTOS
Neutrino	QNX Software Systems	www.qnx.com	Proprietary	RTOS
NicheTask Embedded OS	InterNiche Technologies, Inc.	www.freertos.com	Open source	RTOS
Nimble	Eddy Solutions	www.eddysolutions.com	Proprietary	RTOS
Nucleus OS	Mentor Graphics Corporation	www.mentor.com	Proprietary	RTOS
Nut/OS	Community	www.ethernut.de	Open source	RTOS
On Time RTOS-32	On Time Informatik GmbH	www.on-time.com	Proprietary	RTOS
OpenMoko	OpenMoko	www.openmoko.com	Open source	Linux
OS-9	RadiSys Corporation	www.radisys.com	Proprietary	RTOS
OSE	Enea	www.enea.com	Proprietary	RTOS
OSEK-OS	OSEK.org	http://portal.osek-vdx.org	Proprietary	RTOS
PERC	Aonix	www.aonix.com	Proprietary	RTOS
Phar Lap ETS	Ardence (Citrix Systems, Inc.)	www.ardence.com	Proprietary	RTOS
PikeOS	SYSGO AG	www.sysgo.com	Proprietary	RTOS
Prex	Community	http://prex.sourceforge.net	Open source	RTOS
PSX	JMI Software Systems, Inc.	www.jmi.com	Proprietary	RTOS
ROM-DOS	Datalight	www.datalight.com	Proprietary	RTOS
RT Linux	FSMLabs, Inc.	www.fsmlabs.com	Proprietary	Linux
RTA OSEK-OS	ETAS Group – LiveDevices	http://en.etasgroup.com	Proprietary	RTOS
RTAI	RTAI.org	www.rtai.org	Open source	RTOS Extension
RTCoreBSD	FSMLabs, Inc.	www.fsmlabs.com	Proprietary	RTOS
RTEMS	On-Line Applications Research Corporation	www.rtems.com	Open source	RTOS
RTOS-UH	Institute for Automatic Control	www.irt.uni-hannover.de	Proprietary	RTOS
RTX	Ardence (Citrix Systems, Inc.)	www.ardence.com	Proprietary	RTOS Extension
RTXC Quadros	Quadros Systems, Inc.	www.quadros.com	Proprietary	RTOS
Rubus OS	Arcticus Systems AB	www.arcticus-systems.com	Proprietary	RTOS
Salvo	Pumpkin	www.pumpkininc.com	Proprietary	RTOS
SCIOPTA	SCIOPTA Systems AG	www.sciopta.com	Proprietary	RTOS
simpleRTJ	RTJ Computing	www.rtjcomputing.com	Proprietary	RTOS
smx	Micro Digital Inc.	www.smxinfo.com	Proprietary	RTOS
Solaris	Sun Microsystems, Inc.	www.sun.com	Open source	Linux
SUSE Linux Enterprise Real-Time	Novell	www.novell.com	Proprietary	Linux
TargetOS	Blunk Microsystems	www.blunkmicro.com	Proprietary	RTOS
T-Engine	T-Engine Forum	www.t-engine.org	Proprietary	RTOS
ThreadX	Express Logic, Inc.	www.rtos.com	Proprietary	RTOS
TTP-OS	TTTech Computertechnik AG	www.tttech.com	Proprietary	RTOS
VelOSity	Green Hills Software, Inc.	www.ghs.com	Proprietary	RTOS
VLX	VirtualLogix	www.virtuallogix.com	Proprietary	RTOS Extension
VxWorks	Wind River	www.windriver.com	Proprietary	RTOS
VxWin	Kuka Controls	www.kuka-controls.com	Proprietary	RTOS Extension
Wind River Linux	Wind River	www.windriver.com	Open source	Linux
Windows CE Platform Builder	BSQUARE	www.bsquare.com	Proprietary	RTOS Extension
Windows Embedded CE	Microsoft Corporation	www.microsoft.com/windows/embedded	Proprietary	RTOS
Windows XP Embedded	Microsoft Corporation	www.microsoft.com/windows/embedded	Proprietary	RTOS
Xenomai	Community	www.xenomai.org	Open source	RTOS



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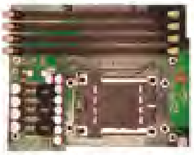

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