INTERCONNECTION STRATEGIES FOR SINGLE_BOARD COMPUTERS

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ABSTRACT

Blade servers and embedded computer systems are among the technology innovations requiring advanced connectivity. A discussion of applications and interconnection alternatives for single-board computers (SBC) frames the decision faced by system designers. A regression analysis of current product alternative variables suggests the strategic direction of the market.

INTRODUCTION

A single board computer is a computer processor and supporting components mounted on a single card. These systems are designed to operate like individual computers, but occupy much less space. They were originally developed about 20 years ago as embedded systems for application-specific computing power in the control industry [3], such as a single-board computer system for monitoring and logging temperatures at various points in plastic extrusion and other similar processes [1].

At the low-end of the computational spectrum, embedded systems have deployed application specific microcontrollers. This paper focuses on the higher end of embedded systems and other applications with the processing requirements of single-board computers.

Single-board computers are finding their way into more aeronautics, security, and military applications. The Predator, the high-altitude unmanned aerial vehicle that served U.S. military operations in Iraq and Afghanistan relies on single-board computers for many of its systems. [4]

Blade Servers About the size of a network card, Blade Servers are single board computers that can be packed tightly together. In the company data center, they offer the promise of higher computing density at lower cost and power consumption. Without blades, about 40 processors can be housed in a 72 inch rack, while 200 blades occupy the same space. The typical processor consumes 100 watts of power, but blades require only 15 to 40 watts each. Only about one fourth as many connecting wires are required. The high density of blades, however, increases the problem of heat dissipation. Nevertheless, blades are expected to significantly replace rack based computing over the next few years.

An industry web site, embedded-pc.com, includes information on the applications of single-board computers listed in Table 1, as well as information on other applications. [6] Grabowski and Sanborn provide a review of some of these systems and the associated evaluation problems. [2]

Table 2 summarizes the major interconnection technologies. The gray area indicates where these technologies are most common in current designs. The table is organized by network distance, declining from left to right and including: Wide Area Network (WAN), Metropolitan Area Network (MAN), Local Area Network (LAN), Input and Output (I/O), Computer System Bus, Processor Architecture. This paper focuses on standards for bus alternatives, the most pressing current problem faced in embedded system deployment. A summary of these alternatives follows.

Table 1: Some Current Applications of Single-Board Computers

Banking	Cash dispensers & automated teller machines (ATMs), Telephone call monitoring and recording
Communications	Mobile data networks, wide & local area networks, voice systems
Defense	Military communications, secure systems, simulators
Government	Security and administration
Industry	Rugged systems, pipeline monitoring., process control, visual inspection systems
Medicine	ECM & ECG monitors, cell scanning, MRI body scanners
Transport	Ticket machines, test equipment
Retailing	Point of sale terminals, cash registers. Environmental control.

ISA (Industry Standard Architecture) The original personal computer PC bus, this 8-bit version evolved to a 16-bit backward compatible EISA (Extended Industry Standard Architecture. The original ISA standard was a local bus, meaning that it was processor specific, represented in Table 2 as some shading in the Processor column. To accommodate the smaller space requirements of embedded systems, the ISA electrical specifications were migrated to a smaller form factor (the physical shape of the connection) known as PC104.

PC104 Refers to a personal computer standard with 104 pins in the connector, using the ISA electrical specification. Although ISA has been replaced by PCI among personal computers in an effort to improve performance, the ISA standard is adequate for low performance embedded applications. Since it is inexpensive and well known to designers, it presents a good bus strategy where cost considerations overshadow performance issues.

VME Originally developed by Motorola in 1979 around the MC68000 processor, the VME standard combines the VERSAbus electrical specification with the Modular Eurocard packaging system. Like PC104, VME defines a small form factor designed for space saving embedded systems. The standard was quickly migrated to higher performance, rugged, higher cost environments such as military, industrial, and communications applications. VME offers larger data paths and support for complex systems, but since mainstream personal computer applications have migrated away from the Motorola processors, it is more difficult to take advantage of the lower costs and wider variety of products that have been developed for personal computers.

PCI (Peripheral Component Interconnect) Developed by Intel and part of the plug and play standard, PCI is a mezzanine card, independent of the CPU, making it a good cross platform technology. This independence is reflected in Table 2 by a lack of shading in the processor columns. PCI replaced ISA as the personal computer standard in an effort to improve system performance. Since gains in processor speeds have outpaced bus speeds, improving bus performance is a current focus of computer systems developer. An advanced PCI standard, PCI-X, has been widely accepted as the emerging standard in personal computer design. Economies of scale in personal computer products result in low component prices for PCI based embedded systems. Software compatibility with the mainstream personal computer market also allows for lower costs than competing standards, such as VME.

CPCI (Compact PCI) In order to migrate the PCI specification into a more compact size for embedded systems, the Compact PCI standard was developed using the VME form factor and the PCI electrical specification. The recent introduction of the CPCI standard has been stalled by the drastic decline in telecommunications investment where CPCI was expected to gain rapid acceptance.

The remaining interconnection strategies listed in Table 2 have yet to be widely developed for single-board computers or embedded systems applications, although they may play a role in the future strategies, particularly Fibre Channel and Ethernet.

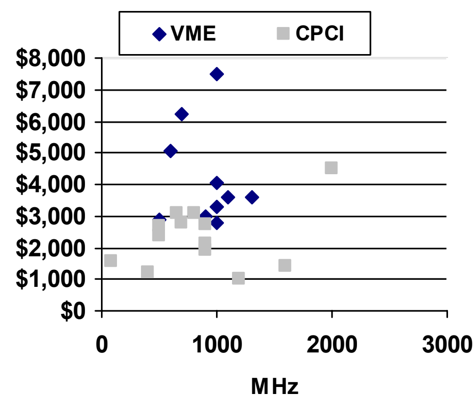
Table 2: Summary of Primary Interconnection Standards by Application Organized over Distance

Standard	WAN				MAN				LAN				I/O				Bus				Processor			
ISA															■	■	■	■	■	■	■			
PC104															■	■	■	■	■	■	■			
VME															■	■	■	■	■	■	■			
PCI															■	■	■	■	■	■				
CPCI															■	■	■	■	■	■				
PCMCIA														■	■	■	■	■	■	■				
SCSI													■	■	■	■	■	■	■					
Fibre Channel											■	■	■	■	■	■	■	■	■					
USB												■	■	■	■	■								
Firewire												■	■	■	■	■								
Ethernet							■	■	■	■	■	■	■	■										
FDDI								■	■	■	■	■												
ATM	■	■	■	■	■	■	■	■	■															

THE DECISION VARIABLES AND DATA ANALYSIS

Factors to be considered in evaluating alternative interconnection strategies will vary by application. Price will always be an issue, but other factors include speed, reliability, size, power consumption, distance, scalability, portability, and compatibility. The price, processor speed measured in Megahertz, and processor architecture for the two dominant single-board computer interconnection standards, VME and CPCI, were collected from the COTS Journal [5]. Figure 1 illustrates the data scattered by price, processor speed, and interconnection standard.

Figure 1: Single-Board Computer Price by Processor Speed



The regression equation summarized in Table 3 was estimated from this data using the price of the single-board computer as the dependent variable. The independent variables were processor speed, interconnection standard, and processor type. The equation was estimated using dummy variables for all variables except speed and can be interpreted as a price estimate based on the cost of a single-board computer using the CPCI and X86 architecture. The results summarize how the price of a single-board computer changes with an increase in processor speed, the choice of VME instead of CPCI, and the choice of PowerPC or UltraSparc processors instead of X86.

The analysis suggests that price rises with processor speed (confidence level of about 89%). This relationship is no surprise but the relatively low statistical significance is somewhat counterintuitive. It can be explained as some independent variable intercorrelation. The more expensive and older VME standard is more commonly used in combination with the slower (measured in Megahertz) PowerPC and UltraSparc processors. As the equation suggestions, choosing VME over CPCI adds about $1905 to the cost of the single-board computer; using PowerPC instead of X86 adds about 1109.72 to the price; using UltraSparc instead of X86 adds about $2382.09 to the price.

Table 3: Forecast of Single Board Computer Price Compared to Base System: CPCI, X86

R Square	0.747		
Observations	23		
	Coefficient	t-Stat	P-Value
Intercept	439.26	0.43	0.67
Speed	1.3448	1.66	0.115
VME	1905.077	3.64	0.0019
PowerPC	1109.72	1.75	0.097
UltraSparc	2382.09	2.28	0.0348

FUTURE INTERCONNECTION STRATEGIES

As the equation in Table 3 suggestions, single-board computers built on X86 and CPCI technology offer price and perhaps a performance advantage. Since processor speed measured in Megahertz is not the only aspect of processor performance, the case for a performance advantage is not solidly supported by the data. Even the price advantage is not absolute since for some legacy applications support for VME products is substantial whereas CPCI is relatively new can be subject to higher development costs.

In general, the advantage goes to the X86 and CPCI combination. The market concurs with this conclusion by rewarding this technology combination with higher growth rates and wider acceptance in new designs. Blade servers are almost exclusively CPCI. Both VME and CPCI are bus standards and this paper might have been titled "Bus Strategies for Single-Board Computers", except for an issue mentioned earlier: processor speed advancements have outpaced processor speeds. Neither VME nor CPCI bus standards will be able to keep up with the rapid pace of processor development for high-end applications. Likely technical models of future development can be drawn from other interconnection evolutions. For example, when traffic began to overwhelm the Ethernet bus in local area networks, a switched topology developed. Fibre Channel began as a fast connection between processors and hard drives that has been successfully extended to support Storage Area Networks (SAN). New interconnection standards have been proposed by companies such as Dell.

Some form of switched fabric is expected to emerge as a dominant standard in the next five or ten years. The wide acceptance and low cost of Ethernet make it a good candidate for the basis of the new standard. The performance advantages of Fibre Channel also make it a contender. Both technologies offer a future of smaller, faster, and cheaper computing.

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