Better by Design — The Solaris™ Operating Environment

A White Paper

THE NETWORK IS THE COMPUTER™

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Introduction

In today's increasingly competitive global market, organizations ranging from data centers to work groups are pressured to provide around-the clock, high-performance, and low-cost access to mission-critical applications:

- Information Technology (IT) organizations are responsible for mission-critical Enterprise Resource and Planning (ERP) systems, database management systems, data warehouses, and engineering applications. These applications demand a high degree of reliability and maturity. They require data centers that must continue to run while applications are added, Internet addresses changed, and when CPUs, I/O boards, and memory are replaced, upgraded, or dynamically reconfigured to meet changing demands. Large database management systems must often be reconfigured daily, supporting interactive applications during the day and compute-intensive batch jobs at night.
- Work groups require multi-user, multiprocessor servers that are easy to use, configure, and administer. They must seamlessly integrate with PC-based systems on heterogeneous networks, providing network file and directory services. Administration facilities must be graphical and easy to use — and must even manage PC clients.
- Engineering organizations must respond to market pressures demanding quick turn-around times for product designs. Long-running Mechanical Computer-Aided Design (MCAD) and Electronic Design Automation (EDA) simulations must execute on systems which simply don't crash.

- Internet Service Providers (ISPs) require high-performance, secure, networked systems which can be made impervious to attack. They must have resource management facilities enabling them to meet service level agreements and provide customers with the resources they have paid for. ISPs must have high-capacity DNS, mail and Web servers with the capacity for virtual hosting.

With such a diverse range of requirements, it is no wonder that organizations concerned with the bottom line are choosing the premier software operating environment from Sun Microsystems — the Solaris™ Operating Environment. The reason is that the Solaris environment is better by design. It is becoming increasingly clear that the Solaris Operating Environment delivers today what the competition promises for the future — and with its superior design, Solaris is well-poised to continue to stay in the lead. Good designs are good business, which is why the momentum behind the Solaris Operating Environment has been dramatically increasing:

- On July 27, 1998, International Data Corporation announced that Sun surpassed IBM and Hewlett-Packard to be number one in 1997 UNIX® server shipments — an astonishing 75 percent increase. With Sun winning more factory revenue than any NT-based competitor, Jay Bretzmann, IDC's Vice-President of Worldwide Systems Research predicts that "... Sun is likely to maintain this momentum in 1998 and will continue to gain share at the expense of its competitors."
- Amazon.com, one of the companies truly blazing the trail in electronic commerce, has selected the Solaris Operating Environment running on the Sun™ Enterprise 10000 (Starfire™) server for its strategic data warehousing needs.
- In an August 12, 1998 research note, Morgan Stanley Dean Witter reported on a Denver-based insurance company which cut costs by replacing 120 Windows NT systems with only two servers from Sun.
- In the last ten months, Sun has signed agreements with five major original equipment manufacturers to deliver Intel processor-based systems that run the Solaris Operating Environment — Amdahl, Fujitsu, NCR, Siemens, and Toshiba.
- On June 29, 1998, when Intel Corporation unveiled its Pentium II Xeon processor — designed specifically for high-performance workstations and multi-processor servers — Sun Microsystems announced Web server performance on the Intel platform surpassing by 146 percent that achievable on a Unisys platform running Microsoft Windows NT.

To understand an operating environment, it's important to consider the environment for which it was designed. Sun designed the Solaris Operating Environment to support reliable, scalable, multi-user and multi-platform network computing. In contrast, Microsoft Corporation built Windows NT for personal computing on the local-area network (LAN). The different operating environment design criteria have considerable impact. As the world embraces network computing, the Solaris Operating Environment is poised for the future while Microsoft Windows NT struggles to move a system designed for the LAN onto the Internet. Given Microsoft's legacy of code designed for single-user LAN computing, the transition involves a major paradigm shift and code re-writes. As a result, Microsoft

Windows NT 5.0 is late, and as the August 10, 1998 issue of *InformationWeek* reports, the Gartner Group now warns users not to adopt the long-promised 5.0 release until at least the year 2001. In the mean time, Sun Microsystems continues to diligently enhance software that was designed from the ground-up to support multi-platform, multi-user, multiprocessor, network computing.

Solaris Design Principles

Sun designed the Solaris Operating Environment for performance, and reliability; to scale and evolve as business needs change, and to easily support new hardware architectures as they become available. The Solaris Operating Environment is better by design, resulting in a system that grows and extends in an evolutionary fashion — not requiring error-prone major re-writes from one release to the next that decrease reliability. With less than five percent of its code platform and instruction set dependent, the Solaris Operating Environment easily ports to a wide range of platforms — giving users choice in computing infrastructure ranging from single and multiprocessor Intel systems to high-end products like the 64-processor Sun Starfire server. In the business of selling high-performance, networked systems Sun is motivated to unleash every ounce of processing power from its products, resulting in uniform scalability on platforms ranging from entry-level PCs and workstations to high-end multiprocessor servers and clusters.

Over the years that the Solaris Operating Environment has been providing the functionality, scalability, reliability, flexibility, and expandability that users, networks, mission-critical and enterprise applications demand, some have been waiting for other vendors to catch up. But while the competition makes promises for the future, the Solaris Operating Environment delivers on those promises today — and it will continue to be the operating environment of choice for those enterprises who wish to remain in the lead.

Designed to Evolve

Business requirements are constantly changing, and they require ease in adding new applications without disturbing existing ones, adding new devices and I/O capabilities, incorporating new and evolving network protocols, and flexibly managing storage without having to modify the applications that use it. The Solaris Operating Environment addresses these business needs because Sun designed it to evolve.

The Solaris Operating Environment begins with a core infrastructure that is constructed using modular, well-defined, stable interfaces that support the addition of new devices, software libraries, and even file systems (FIGURE 1). The operating

environment is built with a small kernel that provides the core set of features required by applications, the CDE windowing system, and their shared libraries. The kernel runs in protected mode and — by keeping its size small — Sun has limited the amount of software that can potentially cause the system to crash. This results in a system that is much more reliable than those which incorporate too many features in the operating system kernel itself. Microsoft Windows NT is designed for the desktop and LAN, and took a different approach by incorporating the windowing system into the kernel. Sun also designed the Solaris environment so that the instruction set and platform-specific code is isolated and easily-changed — one reason why the Solaris environment can quickly and flexibly adapt to and support many different processors and system architectures.

The Solaris architecture supports change through evolution — the ability to adapt to new environments — rather than revolutionary software re-writes that can cause existing applications to suddenly stop working. Sun has a highly-talented and well-disciplined software engineering staff, and therefore understands the plight of the software developer who must continually prepare major new releases of application software just to keep up with operating environment interface changes. Sun's engineers anticipated future needs, and they designed an operating environment that would support evolution from the very beginning. As a result, third-party software developers can count on a consistent, minimally-changing set of interfaces from release to release, allowing them to focus on developing superior applications.

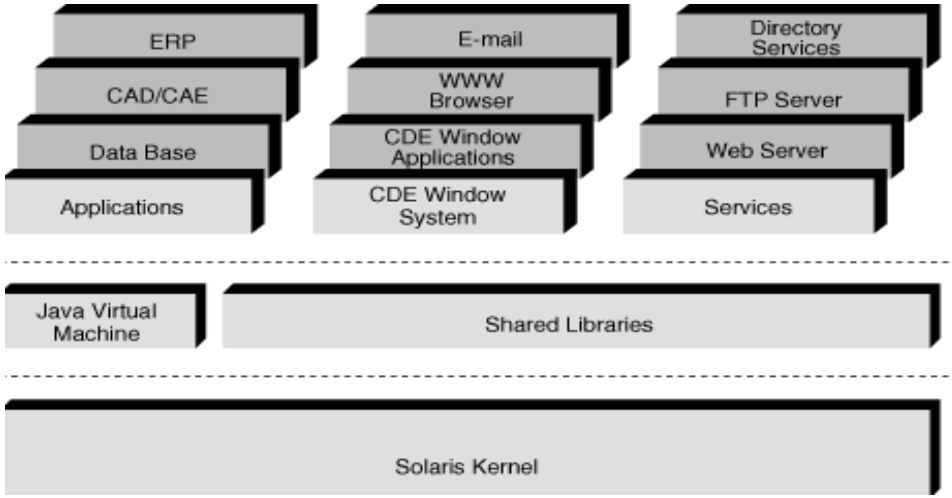

FIGURE 1 Sun designed the Solaris Operating Environment with a small, stable kernel that supports the needs of applications, the CDE windowing system, and their shared libraries — while at the same time isolating platform and instruction set dependencies to make it easy to support multiple platforms.

Designed to Evolve — Shared Libraries

IT organizations installing new applications simply want them to work, and new applications often require extensions to the operating system. Many operating systems support extension through shared libraries which allow multiple applications to share large amounts of system software. New applications sometimes provide new versions of shared libraries which must work side-by-side with existing shared libraries in order for all applications to work properly.

Nowhere else is superior design more evident than in the Solaris environment's implementation of shared libraries. The Solaris Operating Environment clearly separates shared libraries from protected kernel space and it supports multiple versions of the same shared library. For example, a 32-bit application can link to a 32-bit version of the C library while a 64-bit application links to a 64-bit version of the same library, while a third application links to an independent shared library (FIGURE 2).

- *Clear Separation of Shared Libraries and Kernel Space*

Sun designed the Solaris environment with a clear separation between the kernel and the applications that utilize shared libraries. In the Solaris environment, shared libraries are not part of the kernel; they are part of the user process — and thus an error in a shared library has the potential to bring down the applications which use it, but not the Solaris environment itself. Because of this clear separation, developers can examine, debug, and manipulate the use of Solaris shared libraries at run time — reducing costs and increasing reliability by facilitating the debugging of applications.

- *Multiple Shared Library Versions Supported*

  When a new version of a shared library is properly installed in the Solaris Operating Environment, only those applications which specify its use link to it. Sun has supported concurrent use of multiple versions of the same shared libraries since dynamic linking was introduced into the Solaris environment in 1987. New versions of shared libraries can be added by third-party applications, and multiple shared libraries can be used by different applications simultaneously. Conflicts do not exist in the Solaris Operating Environment because each shared library has a unique version number and well-defined scope of procedure call definitions. Each application simply specifies which version of a particular shared library it must use.

Because of the lack of version conflicts, Sun's shared library design enables IT organizations to consolidate many applications onto one server, resulting in lower capital costs and lower administration overhead. This is because the Solaris environment is designed for multi-user, network computing rather than personal computing on a local-area network.

In the Microsoft Windows NT environment, Dynamic Linked Libraries (DLLs) allow applications to inadvertently use un-managed, conflicting libraries, with unintended consequences that often result in system failures. Newly-installed applications can cause existing applications to crash the operating system because DLL versioning is not supported, and because the line between DLLs and the operating system is not clear. Unfortunately, according to Jim Allchin, Microsoft senior vice-president, "We haven't solved this problem" with NT 5.0 (*Computerworld*, August 24, 1998). As a result, IT organizations deploying applications in the Microsoft Windows NT environment will continue to find it easier — yet extremely costly — to deploy a separate server for each application and service to be supported.

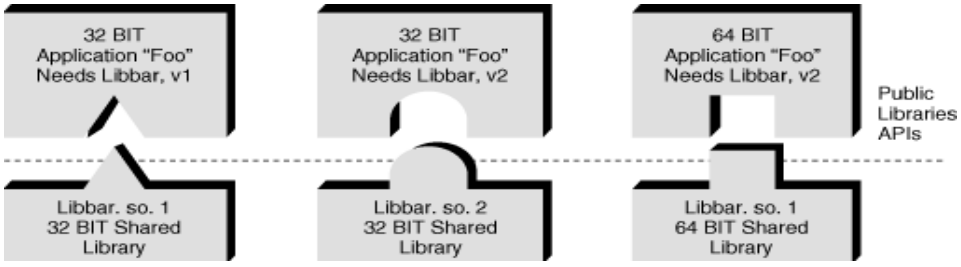

FIGURE 2 Sun designed shared libraries to be separate from kernel space and to allow multiple, concurrent use of different shared library versions.

Designed to Evolve — Drivers, Streams, and File Systems

With new devices, network protocols, and storage systems becoming available at a rapid pace, IT organizations need to flexibly change their configurations and use the operating environment in ways that were initially unforeseen — all without disrupting existing applications. These organizations need operating environments which can evolve with rapid changes in technology. The thoughtful design of the Solaris Operating Environment is evident in its ability to be extended with device drivers, streams modules, and file systems (FIGURE 3).

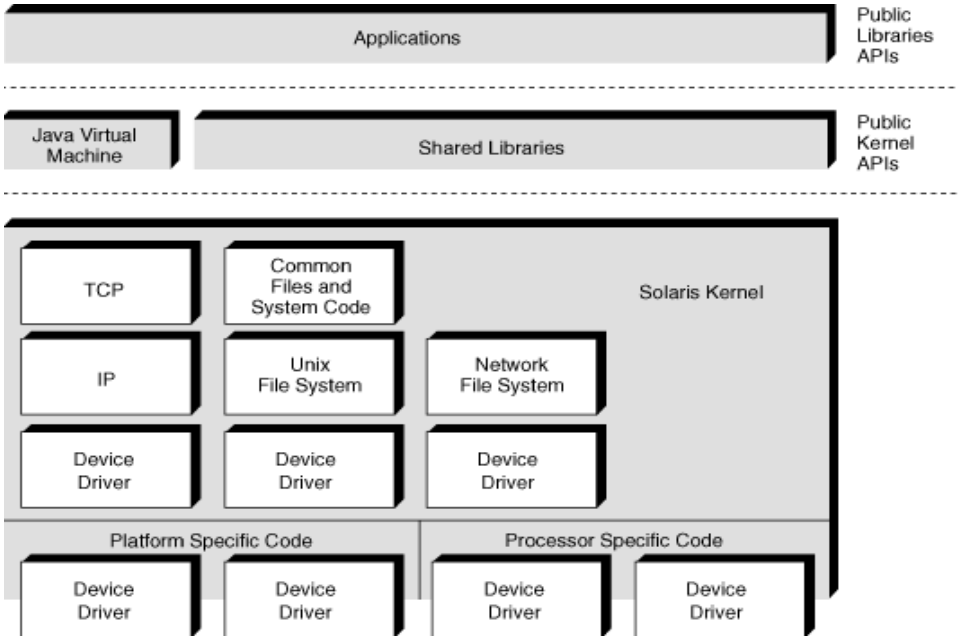

FIGURE 3 Sun designed the Solaris environment so that it can be extended in a modular fashion using device drivers, streams, and file systems.

- *Device Drivers*

  Device drivers are modules that plug into the Solaris kernel and provide access to I/O devices including disks, tapes, CD drives, serial ports, and networks. Sun designed the Solaris environment so that new drivers can be installed and removed on a running system without the need to reboot. In fact, on selected Sun servers, even the devices themselves may be hot-plugged in and out of the system without interruption. The ability to dynamically configure devices increases overall system availability. It also makes it possible to reconfigure running systems to accommodate changing resource demands and to meet service level agreements.

  One very useful way in which drivers are used in the Solaris Operating Environment is to manage large numbers of disks as a single volume. Using volume management software like Sun's Solstice™ DiskSuite™ or Veritas VxVM, software RAID arrays can be created, as well as disk mirrors, striping, and even the capability to add disk volumes to existing logical file systems. Data centers can layer volume management under whatever file system software they wish because the existence of the underlying driver is transparent.

Device drivers for the Solaris environment are written using published, stable interfaces to the operating system. These interfaces do not change from release to release, so when a vendor delivers a driver for one Solaris version, they will continue to work in the next release. Sun is careful to avoid any changes that might undermine the work of its internal and third-party device driver developers.

- *STREAMS*

  STREAMS provide a software backplane into which modules can be plugged in order to dynamically build higher-level services using low-level access like that provided by serial device drivers. STREAMS increase flexibility in the use of devices so that new and custom protocols and line disciplines can be configured using the same underlying physical device. They allow various modules to dynamically be pushed onto a stack. An underlying device driver passes data (using standard interfaces) to the next module in the stack which performs its unique processing and in turn passes data along to the next module and ultimately to a user process.

  High-level services can be dynamically configured with STREAMS without rebooting the kernel. For example, a point-to-point (PPP) protocol stack can be built using a serial device driver and layering in modules to support PPP network control protocols and the TCP/IP protocol itself. No major operating environment updates or changes to the code are necessary.

- *File Systems*

  File systems provide another way in which the capabilities of the Solaris Operating Environment can be dynamically configured and extended to meet business needs such as managing disk volumes and files. Any third party who writes software that uses the VFS interfaces can provide file systems that integrate with the Solaris environment. Examples of the supported extensions include the high-performance UNIX File System (UFS), the PC file system (PCFS) with long file name support, the ISO 9660 CD-ROM file system known as the High Sierra File System (HSFS), and the Veritas file system VxFS.

Designed to Evolve — Binary Compatibility

Software is one of the most costly investments that an IT organization makes. Operating environments which force frequent application software upgrades due to operating system interface changes can result in skyrocketing costs. Sun understands the need to preserve investments in third-party applications, device drivers, and hardware peripherals. In order to minimize the impact of interface changes, Sun has

established a certification program which developers can use to help ensure that their applications, once written, will continue to run on future versions of the Solaris environment.

Sun's *Appcert* application certification program utilizes Solaris dynamic linking to evaluate an application's proper use of Solaris APIs. Appcert warns developers about the use of potentially unstable interfaces and the use of static linking to shared libraries which will be updated in future Solaris Operating Environment releases. Applications which pass Appcert's evaluation are highly likely to run on future versions of Solaris without modification — whether on the SPARC or the Intel platforms.

In addition to certifying applications, Sun has established programs that evaluate compatibility with third-party SPARC and Intel platform devices as well as their device drivers.

Multi-Platform for Choice

Forward-looking organizations know that computing technology is constantly changing, and that business needs dictating the use of one technology today may require a different one in the future. Any factor that preserves choice in hardware platform is one that will put them ahead in the future. That is one reason why Sun provides a single Solaris Operating Environment that runs exactly the same on any hardware platform.

Whereas DEC, HP, and IBM are just now attempting ports to the Intel architecture, the Solaris environment has always been a multi-platform operating environment — and has the agility to move easily between platforms because it has been designed for this purpose since the beginning. Sun believes that users should not be locked into the use of any hardware platform — which is one reason why the Solaris environment is available today on both Intel and SPARC processors, as well as being licensed to Solaris System Partners including Amdahl, Fujitsu, NCR, Siemens, and Toshiba.

Sun has refined portability into a science, having completed ports to 32- and 64-bit SPARC™ processors, the Motorola 68000 and PowerPC processor families, and 32-bit Intel 386, 486, and Pentium processors. Solaris is fully 64-bit compatible on SPARC platforms, and has supported the 32-bit Intel platform for years. With a well-established track record for both 64-bit and Intel architectures, Sun is far beyond other vendors in the experience that is needed to port to the first 64-bit Intel architecture processor known as Merced. In order to ensure that no processor dependencies are inadvertently added, Sun builds the core Solaris operating system from the same source code base.

Sun has accomplished this high degree of portability by reducing and isolating the platform and instruction set-dependent operating environment code into the smallest possible footprint — today, the software requiring modification to support a new architecture is less than 5 percent of the core Solaris code base (FIGURE 4). The small portion of processor-specific code is divided into modules which handle platform-specific features like the bus architecture and access to I/O devices, and modules which handle instruction set-specific features like the UltraSPARC™ VIS instruction set and processor-specific synchronization primitives (FIGURE 5). The use of processor-specific modules in the Solaris Operating Environment allows it to exploit the most advanced features of each architecture without making changes which permeate the code base.

The result is highly-optimized and efficient software that is extremely capable in adapting to and using different platforms — and can be ported to support new processor platforms —like Merced — quite easily. The Solaris Operating Environment is endian-neutral, moving gracefully and transparently to 64-bit processors, and providing a high degree of interoperability through its use of open standards.

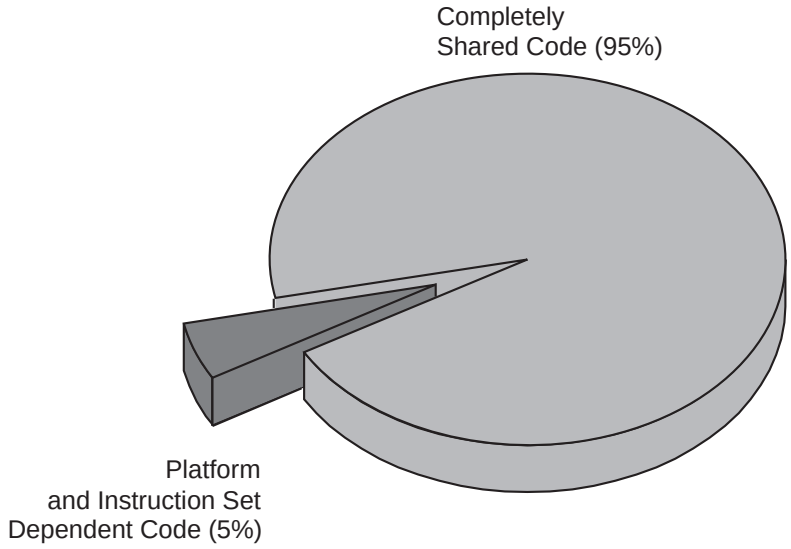

FIGURE 4 95 percent of the Solaris Operating Environment (measured by lines of code) is completely shared code that only requires recompilation when the operating system is ported.

Multi-Platform for Choice — Solaris is Endian-Neutral

One of the strengths of the Solaris Operating Environment is that it handles the endianness issue so well that customers do not need to be concerned about how quickly their applications will be available on new platforms. The Solaris Operating Environment can port easily because its byte-ordering dependencies are so confined that Sun can switch the operating environment between big- and little-endian architectures with only the change of a set of compilation variables — no re-engineering by Sun or customers is needed.

The Solaris Operating Environment is endian-neutral, and has been supporting big- and little-endian processors, applications, and networks for years. This enables customers to freely choose processor architectures and insulates them from the details of byte-ordering conventions. The Solaris environment supports the natural byte-ordering of the underlying processor and has experimentally been ported both ways on processors which support both byte ordering conventions. Historically, Sun has supported big-endian byte ordering on the SPARC, IBM, MIPS, and PA-RISC platforms, and little-endian on the Intel, Alpha, and VAX processors.

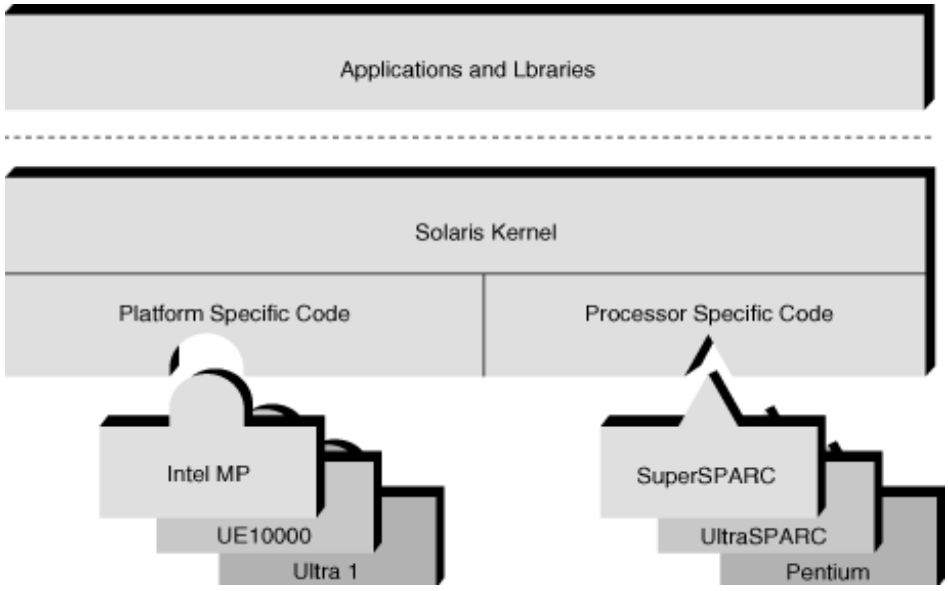

FIGURE 5 The use of platform and instruction set-specific modules localizes and minimizes the amount of software that must change when the Solaris Operating Environment is ported to new architectures.

The terms big- and little-endian refer to the way a processor orders bytes into words. Either way is equally efficient. A *byte* is a set of eight bits that represent a character or an integer value between 0 and 255. A *word* is a set of 32 bits that is assembled from four bytes. Depending on the processor architecture, four bytes *a0...a3* are fetched from sequential memory locations and stored internally as a word with the lowest byte used as the left-most eight bits (little-endian convention), or as the right-most bits (big-endian convention, FIGURE 6).

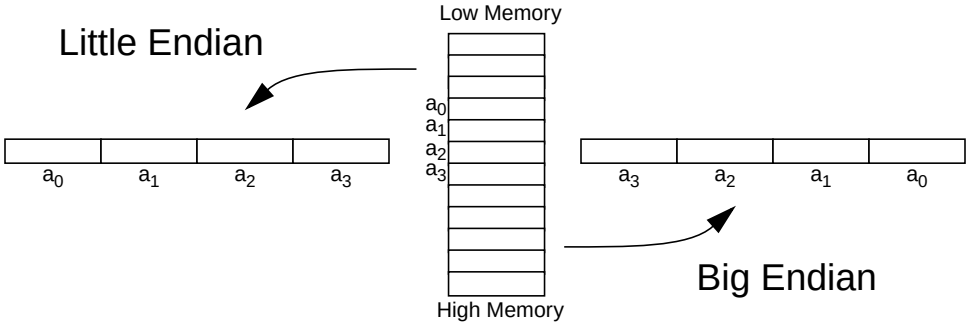

FIGURE 6 The Solaris Operating Environment is endian-neutral, and supports both big-endian (SPARC, IBM, PowerPC, MIPS, PA-RISC) and little-endian (Intel, Alpha, VAX) byte-ordering conventions so that they are not issues for customers.

With processors like Merced supporting both big- and little-endian conventions, there has been some controversy as to which convention operating systems should support. Sun has chosen to continue supporting big-endian byte ordering on its SPARC processor line and the natural little-endian byte ordering on all 32- and 64-bit Intel processor sets. In fact, all vendors except HP have decided to support little-endian byte ordering on the Intel Merced processor — making HP-UX the odd one out. This can potentially result in mixed-endian issues because theirs is the only big-endian environment in an all little-endian world on Intel.

More than 3,200 applications run on the Solaris Operating Environment on heterogeneous networks in both big-endian and little-endian modes — testimony to the fact that endianness has not been a significant issue in the real world. Sun handles byte-ordering issue in all three areas where it has an impact: application execution, network interoperability, and application data storage.

- *Application Execution*

  With the Solaris Operating Environment, applications can execute in big- or little-endian mode because both the operating system application programming interfaces and the application itself are consistent in their use of big- or little-endian byte ordering. This is the simple result of the Solaris Operating Environment and its applications being compiled using a consistent byte-ordering scheme.

- *Network Interoperability*

  Solaris applications interoperating with other processes and other systems use standard network protocols which for years have enabled communication between big- and little-endian systems. This is fortunate for companies with networks, because the endianness interoperability issues have been solved long ago. The FTP protocol, for example, has provided a standard way to transfer files between big- and little-endian systems since 1969.

Modern protocols like the Open Network Computing (ONC) Remote Procedure Call (RPC) protocol incorporate an External Data Representation (XDR) layer which byte-swaps data if needed during transfers. Simply re-compiling software that uses XDR configures it for the appropriate endianness of the processor. Many other protocols are built on ONC/RPC, including the Network File System (NFS™) protocol, which realizes the benefits of ONC/RPC's underlying byte-ordering compatibility.

- *Application Data Storage*

  Applications storing data which can be shared between platforms already handle the endianness issue in one of two ways. One is to store data in an application-defined, endian-neutral format using text files and strings. Another is to choose either the big- or little-endian convention and do byte-swapping (potentially using enabling technology such as XDR) when necessary.

  The need for cross-platform compatibility is so well-understood that major applications have been available on big- and little-endian Solaris environment implementations for years without problems. They range from personal productivity applications like Adobe FrameMaker to major database management systems including Oracle, Informix, and Sybase. Sun's experience with porting applications between architectures is sufficient to allow them to state that endianness issues are well understood, and problems are rarely encountered.

Sun continues to facilitate application independence from byte-ordering issues with the Java™ programming language. The Java platform is designed from the ground up to have no byte-ordering dependencies and is one of the reasons why the same compiled Java software can run on any architecture without change.

Multi-Platform for Choice — Full 64-Bit Support

With the price of memory continuing to tumble, organizations are reaping the performance advantages of keeping more application data in main memory rather than on disk. Although few applications require an entire 64-bit address space, the impact of more than 32 bits of address space benefits database servers, Web search engines and Web server caches, mechanical computer-aided design, electronic design automation, and high-performance computing applications.

Sun has designed Solaris 7 to support both 32- and 64-bit applications on the same system. This design enables users to reap the advantages of increased memory space for those applications which can utilize it — while providing equal support for 32-bit applications. The Solaris Operating Environment is UNIX 98 certified, which allows applications to be portable between 32- and 64-bit environments of Solaris and other certified vendors. This preserves customer investments by not forcing them to upgrade to 64-bit applications.

The Solaris environment has been making a graceful transition to a full 64-bit operating system by incrementally adding stable, well-tested features. Solaris 2.5 supported Sun's 64-bit UltraSPARC processors; Solaris 2.5.1 introduced 64-bit math; and Solaris 2.6 supported files with offsets as large as 64 bits. With the release of Solaris 7, the operating system interfaces themselves will be fully 64-bit compatible, with a 64-bit address space available to any application. Along with the operating system interfaces, Sun has expanded many of the operating system limits in Solaris 7, giving applications significantly more room to grow. Applications can now have as many file pointers, devices, file systems and as many disk blocks as can fit into a 64-bit integer.

Developers can make the transition to 64-bit interfaces easily, and at their leisure. Sun designed the Solaris environment to deliver exactly the same Application Programming Interfaces (APIs) to both 32-bit and 64-bit applications. The behavior of each interface is exactly the same in 32-bit and 64-bit modes because they use common code; only the initial system call processing differs. As a result, the transition to 64-bit processing for almost all applications requires only some code modifications to match the industry-standard 64-bit C programming language data model, and a change to a compiler flag.

Multi-Platform for Choice — Solaris uses Open Standards

Portability of applications between UNIX platforms is enhanced even further by Sun's endorsement and support of open standards. Sun adheres to X/Open, POSIX, UNIX 98, and POSIX threads standards for interoperability between UNIX implementations on both SPARC and Intel platforms. As of the release date of this paper, only three certifications had been issued for the UNIX 98 standard, with two of them Sun's Solaris 7 on the SPARC architecture, and Sun's Solaris 7 on NCR's Intel-based platform. Sun conforms to industry standards and is active in their design as well — the Solaris threads design is the basis of the POSIX standard.

For Internet and World Web interoperability, Sun adheres to Internet Engineering Task Force (IETF) and WWW Consortium standards, respectively. Even for innovations that originate at Sun — like the Network File System (NFS) — the philosophy is to make interfaces public and stable, and to compete with other vendors based on Sun's superior implementations.

Scalability to Support Growth

Scalability is critical to companies needing to make the most cost-effective use of their computing resources, gracefully handle peak workloads, and grow their computing environment as their business grows. There are three aspects to scalability:

- How the system responds to increasing workloads, i.e., what performance it provides, and, as the workload increases, whether it crashes or provides gracefully-degrading performance.
- How easy it is to add processors, CPUs, storage, and I/O resources to a system or network that must serve increasing demands from users.
- Whether the same environment can support applications as they grow from low-end systems to mid-range servers and mainframe-class systems.

The Solaris Operating Environment is superior in all aspects of scalability, providing rock-solid reliability as workloads increase, and delivering the most processing power available for applications. The Solaris environment provides the ability to add resources to supported systems without requiring a system shutdown. And as business needs grow, applications can continue to use the Solaris Operating Environment with binary compatibility from low-end desktop servers and PCs to multiprocessor workgroup servers like the Sun Enterprise 450 server, and on to 64-processor Sun Starfire servers and clusters. On the Intel platform, the Solaris environment supports systems ranging from single-processor personal computers to large systems like NCR's WorldMark server. Among Microsoft, IBM, DEC, and HP, the Solaris environment supports four times more processors than the nearest competitor, and is ready to support even larger servers as they become available (FIGURE 7).

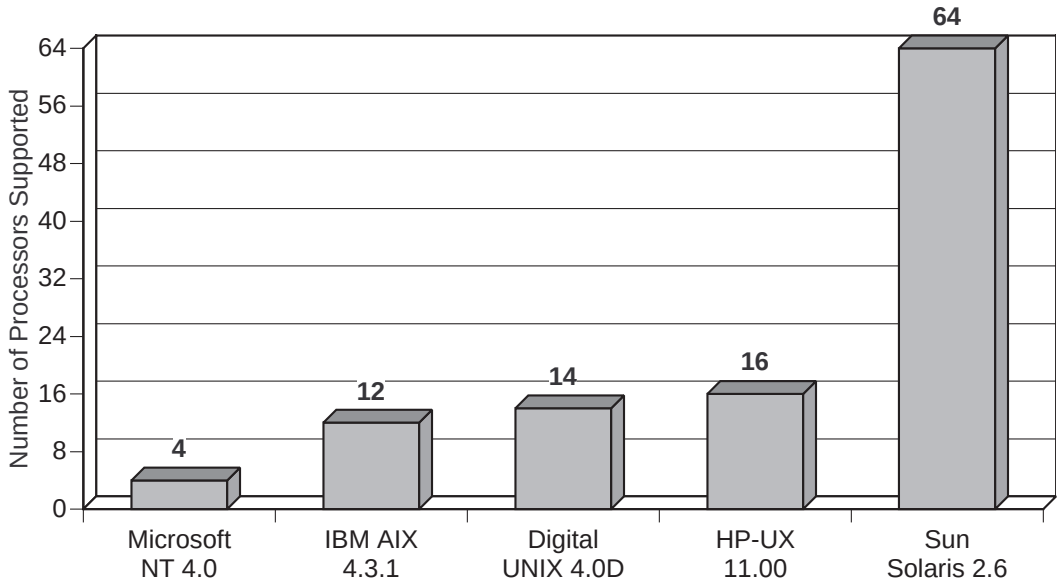

FIGURE 7 Among Microsoft, IBM, DEC, and HP, the Solaris environment supports four times more processors in SMP configurations than the nearest competitor (source: IDC Operating System Functionality Matrix, 1998).

Binary compatibility means that the same application can move up the product line as business needs grow, and any training and support costs continue to provide benefit regardless of the server environment. This is not the case with IBM, where each step in an application's growth requires a costly change in the operating environment — IBM begins with PCs running Microsoft Windows, moves up to the AS/400 operating system for mid-range servers, then to the UNIX operating system on high-end servers such as the IBM RS/6000, and finally to MVS on IBM's mainframes. Each step requires application upgrades, additional training, and support costs.

Scalability to Support Growth — Objective Scalability Measures

An objective measure of scalability is to determine how much processing power is provided to applications with the addition of each new CPU. In an ideal world, each CPU added to a symmetric multiprocessing server would contribute 100 percent of

its processing power to additional application performance. For example, adding a second processor would double the processing capability of a system, and adding a four processors would quadruple the original capability.

Consider the difference in Web server scalability between the Solaris environment and Microsoft Windows NT 4.0, with Solaris hosting the Sun WebServer on a Sun Enterprise 450 server and Windows NT hosting IIS 3.0 on an HP LX Pro system. As more processors are added to the Sun server, performance measured with the SPECweb96 benchmark increases to the point where four processors deliver 82 percent of the theoretical maximum (FIGURE 8). With Microsoft Windows NT running four processors, only 58 percent of the maximum processing power is utilized. This translates into significant costs for organizations requiring favorable return on investment. An additional processor in the Microsoft Windows NT environment delivers only 58 percent of its full capacity, compared to 82 percent in the Solaris Operating Environment. One can only speculate as to the return on investment if Windows NT could support 64 processors.

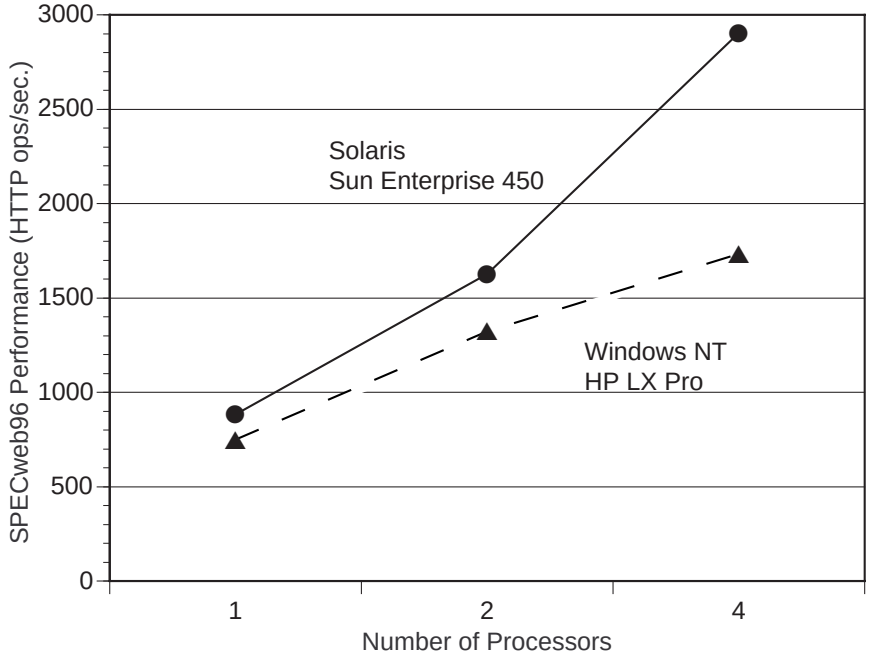

FIGURE 8 Scalability on Solaris-based Web servers is much closer (82% with four processors) to the theoretical maximum than with Windows NT-based Web servers (only 58% with four processors).

On August 12, 1998, a Morgan Stanley report asked the question: “Are Wintel servers pulling away from UNIX servers?” And they responded: “The answer was more than no.” Morgan Stanley reported that the scalability gap between UNIX and Windows NT systems is widening, not narrowing, with overall UNIX scalability growing at a rate two and a half times that of Microsoft Windows NT.

Microsoft Windows NT responds to the need for scalability beyond four processors by clustering up to two four-way PCs. Unlike Sun Clusters, where global storage, file systems, and networking will be provided, clustering under Windows NT can be difficult to manage.

In the Solaris environment, clustering is used primarily when hardware redundancy is needed for high-availability applications because scaling for performance is more effective in a single SMP server environment. The Solaris environment can scale up to the ability of the application to utilize multiple processors. For example, Sun has tested NFS servers up to 24 processors, and the results show almost linear scalability (FIGURE 9).

The Solaris environment is highly scalable on servers up to 64 processors, and will support even larger systems when they become available. If more than 64 processors are needed, Sun Clusters can support up to four 64-processor servers today, and up to sixteen in the near future.

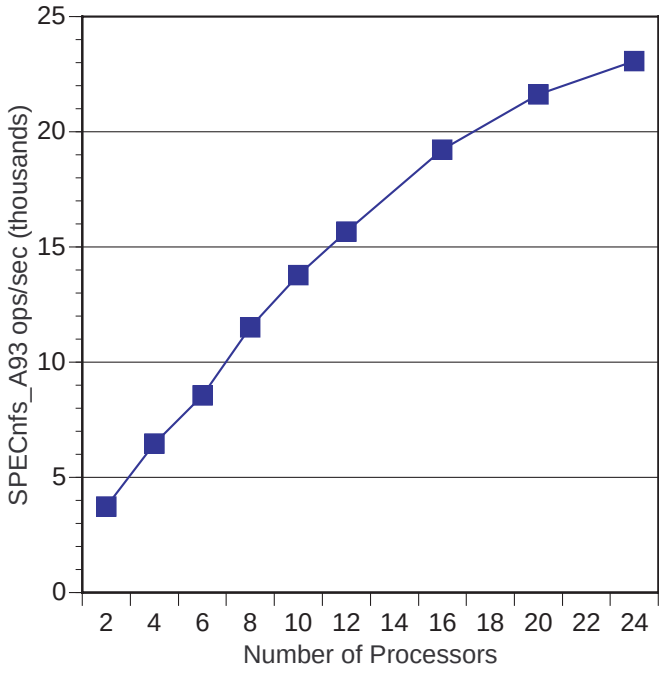

FIGURE 9 On Sun servers, the Solaris Operating Environment can provide near-linear scalability from 1 to 24 processors.

Scalability to Support Growth — Committed to Scalability

Sun builds scalability into the Solaris Operating Environment from the outset. Solaris achieves superior scalability by using *threads* as the fundamental unit on which processors are allocated. A thread is an independent stream of instructions that can be executed by a processor, with many threads executed in parallel by separate processors. The Solaris environment responds to interrupts, driver activities, and application requests using threads, and the number of possible threads is only limited by the virtual address space of the processor. Delays due to synchronization and locking are minimized by designing locks on fine-grained data objects. Deadlocks are avoided by not allowing locks to be held when the flow of control moves from one kernel subsystem to another.

Sun unleashes the power of threads for use by applications so that they can utilize multiple processors simultaneously, enabling scalable multiprocessing applications and increasing performance. Sun has designed the Solaris environment with an *M* by *N* threading paradigm, where a number of user threads are multiplexed on a smaller number of kernel threads, increasing performance. Both HP-UX and Microsoft Windows NT use a lower-performance *M* by *M* paradigm, which uses more kernel threads and reduces efficiency.

There are two ways in which Solaris threads unleash the full power of a system's processors to applications (FIGURE 10):

- *Multi-threaded applications* such as databases by Informix and Sybase use a small number of processes with many threads, which allows many CPUs to execute in each process, speeding execution for parallelizable code.

  The Java programming language facilitates multi-threaded programming. Sun's implementation of the Java virtual machine allows Java applications to utilize as many processors as necessary to speed execution. The ability to fully utilize the multiprocessing capabilities of a server from the Java language is another mark of a good design — and another reason why organizations deploying three-tier applications using Java technology middleware choose the Solaris Operating Environment.
- *Single-threaded applications* such as database management systems by Oracle and the popular Apache Web server are built using many single-threaded processes, utilizing many CPUs by creating multiple processes which can execute in parallel.

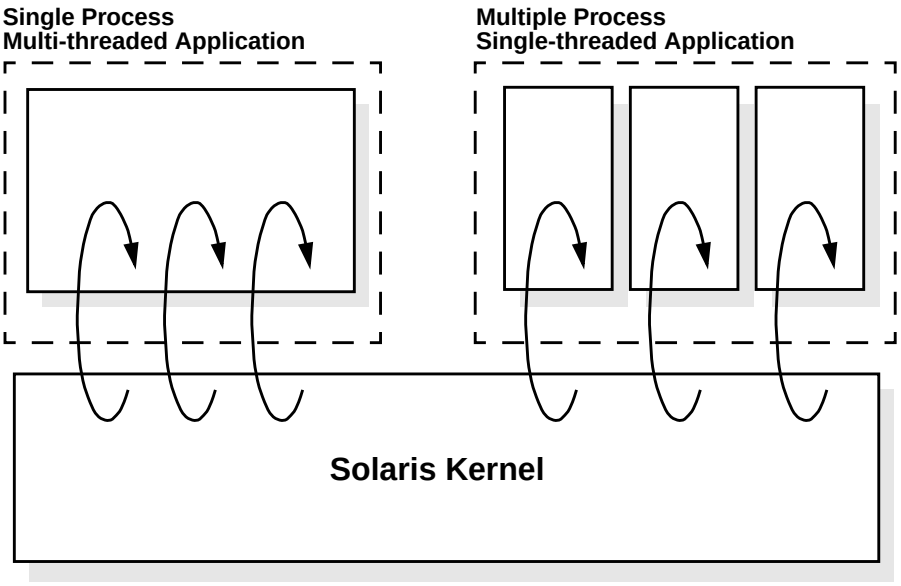

FIGURE 10 Applications can utilize multiple processors using a single, multi-threaded process, or with multiple, single-threaded processes. Not shown are multi-process, multi-threaded applications.

Scalability to Support Growth — Unleashing Hardware Capabilities

The Solaris Operating Environment delivers the maximum capabilities of the hardware on which it executes, whether it is based on 32- or 64-bit processors:

- On 32-bit SPARC and Intel processors, Solaris supports virtual address spaces up to 4 GB in size. On 32-bit processors with physical addressing extensions — like Intel's Pentium II Xeon processor — up to 8 GB of physical memory is supported.
- On UltraSPARC-equipped Sun servers, the Solaris Operating Environment currently supports 64 GB of physical memory, and with Solaris 7, up to 16 *terabytes* of virtual memory per process.

Delivering the power of the underlying system to the application is especially important for large database management systems, where large Shared Global Areas (SGAs) are often used to enhance performance by increasing the sharing of database tables.

Leveraging Reliability and Availability

Today's economy is changing rapidly, with ever-increasing competition fostered by the emergence of global markets, deregulation, and reduction in trade barriers. In order to maintain competitiveness, companies must have 24-hour access to their data and applications. Enterprise data stored in on-line transaction processing systems and data warehouses must be available to users during the day and to batch processing at night. Engineering applications executing long-running EDA and MCAD simulations must be hosted on systems which can be trusted not to crash — delays in critical product development can have a direct effect on time-to-market and profitability.

Leveraging Reliability and Availability — Reliability by Design

The Solaris Operating Environment provides a level of reliability that gives users confidence that their long-running and resource-intensive applications will execute without interruption. There is no secret as to the source of reliability in the Solaris Operating Environment — Solaris is reliable by design. Sun designed the Solaris Operating Environment with a small, compact kernel that limits the exposure to errors that can bring a system down. Sun designed the Solaris environment with a clear distinction between the kernel, shared libraries, and applications which further limits the impact of application failures. Companies with critical computing needs like the *San Francisco Chronicle* know of Solaris' reliability — one of their servers has not crashed in more than two years. When even this level of reliability and availability is insufficient, Sun Clusters can be deployed to provide an integrated, general purpose, high-availability environment.

Leveraging Reliability and Availability — Reliability through Maturity

Even the best designs in the world must still endure the test of time — and a significant part of the reliability of the Solaris Operating Environment is due to its maturity. Software gains maturity through years of use by many different users in many different environments, backed up with the hard work of eliminating bugs over time:

- The Solaris Operating Environment capitalizes on a history of UNIX systems employed by millions of users on a wide variety of platforms for more than 25 years. This experience accrues to Solaris in terms of standard, well-defined interfaces which have long had any inconsistencies and inadequacies ironed out — and in terms of modifications and extensions which have withstood the test of time and have become part of UNIX today.
- Sun does the hard work of compiling and testing the Solaris environment for each supported platform every night when the operating environment is developed, resulting in the highest degree of test coverage for the kernel code. Isolating and debugging deadlocks and race conditions is one of the most difficult classes of problems to isolate and debug in operating environments. With load testing performed on large 64-processor Sun Enterprise servers and clusters, Sun can speed up time to maturity by increasing the likelihood of such problems occurring long before they would have been found on four-processor systems — and well before the software is released for customer use.
- Reliability and maturity accrue from a small and stable code base. The core Solaris kernel — the part that could possibly cause a system to crash — is modular and manageable at 400,000 lines of code. Sun manages complexity by building a kernel that delivers a small, core set of facilities, with more complex features built in shared libraries, STREAMS modules, and application software. New releases of the Solaris Operating Environment have small incremental changes in code size which limits exposure to problems.
- In the event of system failures, Sun is there with 24-by-7 support, 365 days a year. Sun provides worldwide service, and can coordinate the escalation of problems through time zones, so there is always someone working on critical issues.

Adding a large number of lines of code in a short time increases the exposure of customers to unforeseen problems because large amounts of code are more difficult to test than small amounts of code. Microsoft Windows NT has demonstrated a growth curve that suggests a dramatic increase in exposure to bugs (FIGURE 11). With major parts of the windowing system included in the kernel, the exposure to system crashes is dramatically increased. In September 1998, NT 5.0 stood at 40 million lines of code, making it no surprise that *PC Week* (September 8, 1997) declared that “Solaris is one of the most powerful operating systems around and far easier to keep running on a continual basis than Windows NT.” And it is no wonder why the Gartner Group (August 1998) recommends holding off on NT 5.0 adoption until at least the year 2001.

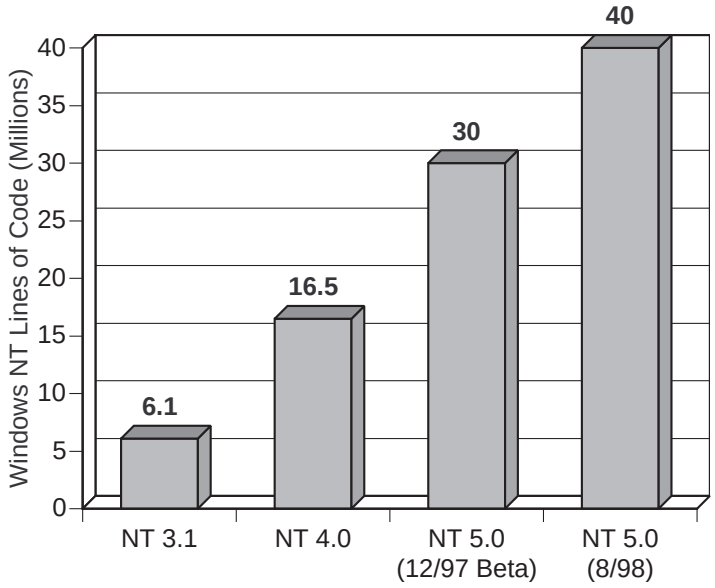

FIGURE 11 The Microsoft Windows NT code base increases dramatically each release, with NT 5.0 currently standing at 40 million lines of code. Sources: *LanTimes*, December 8, 1997, first three estimates, *ZDNet* (quoting Steve Ballmer), September 11, 1998, last estimate.

Leveraging Reliability and Availability — Availability with Sun Clusters

Many organizations require applications that are always available, and Sun Clusters provide a highly-available computing environment for running general-purpose applications and those specifically tailored for the high availability environment. Sun Clusters — developed in Sun's Full Moon Cluster program — enable two or more servers to work together as a single entity to provide high-availability applications, system resources, and data to users. Sun Clusters integrate servers using redundant high-speed interconnects, redundant networking, and redundant connections to mirrored disk systems so that no single failure can interfere with application availability (FIGURE 12).

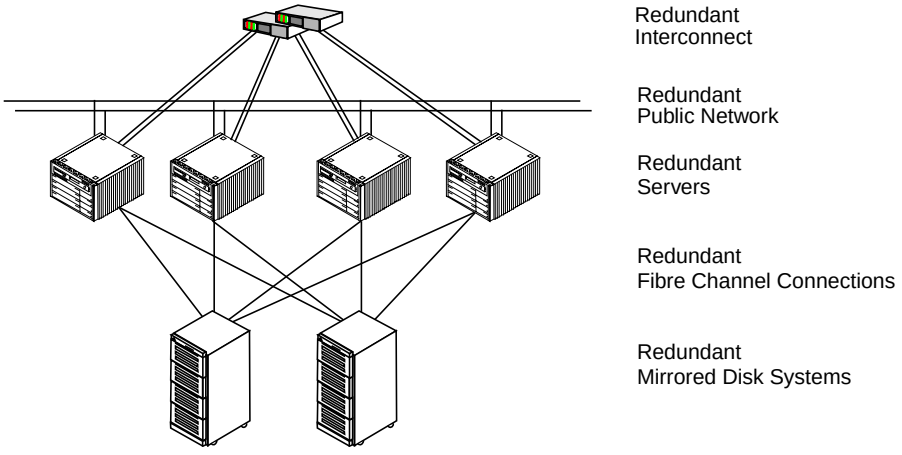

FIGURE 12 Example of a four-server cluster based on Sun Enterprise 4500 servers and Sun Enterprise storage systems.

Today, Sun Clusters support up to four Sun servers with up to 64 processors, with sixteen processor support in a future release. Sun Clusters are designed to be hardware-neutral, with support for Intel architecture-based clusters to be provided in the future. Sun will protect customer investments by allowing the mixing of server types within the same cluster, so long as processors with the same architecture are used.

The next phase of Full Moon Clusters will be integrated with the Solaris Operating Environment, and will allow a large pool of resources to be managed as one. Sun Clusters will provide a global cluster file system which will deliver uniform, highly-available access to files and devices regardless of the location of the data, device, or the application. Sun Clusters will also provide a single, global networking environment where the cluster can be addressed with a single IP address — providing clients with uniform access to applications regardless of the actual server hosting the software.

Leveraging Reliability and Availability — Availability with Dynamic Configuration

Data centers running mission-critical applications require systems that don't go down, and Solaris dynamic configuration delivers the support that is demanded by enterprise applications. At boot time, the Solaris environment automatically adapts to the underlying system hardware, and can be reconfigured as needed without rebooting. The Solaris Operating Environment is self-scaling, from 1 to 64 CPUs per node, from one to four nodes per cluster. It is self-configuring, recognizing all memory, devices, networks, and software at boot time. Rebooting is not required when applications are added, or even when Internet addresses are changed — a key feature that allows one server in a cluster to transparently take over another server's identity and services in the event of a failure.

Sun is committed to driving the technology curve from high-end systems down to the desktop, and the Solaris Operating Environment is prepared to support sophisticated configuration features of Sun and Intel servers as they work their way into increasing numbers of systems:

- *Hot-Pluggable Components*

  On supported multiprocessor servers like the Enterprise 6500 and 10000 servers, and Intel systems utilizing the PCI bus, the Solaris Operating Environment supports hot-pluggable disks, CPUs, memory, and I/O boards which can be connected to a variety of high-capacity storage devices and cluster interfaces. Sun understands that when data centers dynamically reconfigure servers, they must have the ability to hot *unplug* as well as hot plug their devices — another feature of the Solaris environment that supports dynamic reconfiguration

- *Processor Sets*

  In order to help IT organizations to meet their service guarantees, processor sets can be defined using the Solaris Operating Environment. Processor sets allow certain processors to be assigned to particular applications so that other activities on the server do not impact the performance of mission-critical applications.

- *Solaris Domains*

  Domains on high-end systems like the Sun Enterprise 10000 (Starfire) server allow groups of processors, memory, and I/O devices to be configured as physically separate servers, delivering the superior reliability, availability, and serviceability of the Starfire server while allowing resources to be configured as needed to meet application demands. An additional benefit of Solaris domains is the ability to reconfigure resources as needed in response to an un-predicted failure, or in response to scheduled changes in demand. For example, processors and memory can be easily re-allocated at night from lightly-loaded on-line transaction processing applications and moved to support long-running batch queries in a data warehousing domain.

Leveraging Reliability and Availability — Availability through Resource Management

One of the critical objectives of IT organizations is to build economies of scale by controlling costs and centralizing control. The model of hosting one application per server for more predictable performance and availability is outmoded and expensive, and has resulted in a proliferation of servers that are costly to administer. Solaris Resource Manager™ software enables server consolidation by providing fine-grained control over the resources used by multiple applications on a single server. It enables control over resources such as number of CPUs, memory, number of processes, users, and even facilitates the setting of scheduling policies.

The Solaris Resource Manager provides tremendous benefits to organizations ranging from data centers to Internet service providers. In data centers, multiple enterprise applications can share the same server and have resources allocated so that service level agreements are always met. Internet service providers can host hundreds of Web servers on the same server with each customer guaranteed the use of the resources that they have purchased.

Designed for the Internet

The Internet is the way of life for businesses today. Networked systems enable companies to extend their reach and forge better relationships with large numbers of customers — while at the same time enhancing communication with consultants, partners, suppliers, and employees working in the office, home, and on the road. Companies that provide goods and services on the Internet find that they can reduce the cost of doing business while at the same time dramatically increasing sales. And many businesses are starting from the ground-up as Internet-only companies, ranging from the bookstore Amazon.com to the Security First Network Bank.

Sun has long believed that all systems should be networked. This is one reason why Sun invested in Internet technology beginning more than fifteen years ago. Sun designed the Solaris Operating Environment for network computing and based its strategy on the TCP/IP protocol. TCP/IP packets are routed from local-area networks on to the Internet, which is why one common networking architecture can operate in both environments without change. Because the TCP/IP protocol is the backbone of the Internet, Sun customers can count on Solaris networking capabilities to remain stable for quite some time. Sun *built* the Internet — and today, *Dataquest* reports that 10 of the top 12 worldwide Internet Service Providers (ISPs) use Sun servers.

In contrast to the Solaris environment, Microsoft Windows NT was designed for local-area network computing. This has resulted in a system built around proprietary protocols, proprietary name registries, and proprietary network file systems. Microsoft Corporation has only recently realized the importance of the Internet, which is resulting in an unstable base of network protocols which must be retrofitted in order to interoperate using standard network protocols.

There are several important advantages of systems that are designed for the Internet. They are designed for use by many users at the same time, which may be located anywhere on the network. They are built to industry standards, and are therefore available from a number of suppliers. They can interoperate with any other system or network, and they provide security solutions which have withstood the test of time.

Designed for the Internet — Supporting Multiple Simultaneous Users

Effective networked operating systems must inherently support multiple users so that they can share resources in a secure way without interfering with each other or with the underlying system. The Solaris Operating Environment is a multi-user operating system at its very core, which means that — with the support of integrated TCP/IP networking — many applications located anywhere on the network can safely, securely, and simultaneously access a system, whether it is a workstation or a server. Sun continues to refine its implementation of TCP/IP, which is now multi-threaded to enable many users utilizing multiple processors to simultaneously access the network with even higher performance. In addition, Solaris 7 provides each application with the capability to maintain up to 65,536 simultaneous network connections.

Multi-user systems result in more cost-effective computing because the resources of networked systems can be shared remotely. Authorized users can log in and access files and start applications as needed. Client systems can access a host of facilities on servers, including file, print, and name services, as well as Web pages, and database services. Administrators can manage networked systems remotely, resulting in significantly lower costs of ownership. Solaris Operating Environment servers are easily configured to provide multiple services — such as mail, file, and Web services — to many simultaneous users. Features such as these are not available on systems where multi-user support is an add-on.

Designed for the Internet — Interoperability in Multi-Vendor Environments

The Solaris Operating Environment is designed to operate in multi-vendor environments. Built to industry standards, the Solaris environment can interoperate with any vendor which supports the TCP/IP protocol set. And since the protocols are open, free competition is possible among vendors of network systems, providing users and customers a wide choice of products.

TCP/IP is a routable protocol which works across sub-nets, corporate intranets, and wide-area networks. There is no distinction between local-area networks and wide area networks in TCP/IP, which means systems can provide uniform services whether they are accessed locally, or over the Internet by customers, suppliers, partners, and employees working remotely. Remote access to graphical applications has been supported for more than a decade with the X Window System, another TCP/IP based technology.

Microsoft Windows NT was designed as the next generation of the personal computer operating system, and is still based on a set of proprietary protocols — NetBEUI, NetBT, and Exchange. The legacy of these design choices includes protocols which limit users' choices and tend to lock them into a single vendor. In order to interoperate with other systems over the Internet, Microsoft has layered standard protocols — TCP/IP, DNS, and SMTP — over their proprietary layer, providing interoperability, but creating a second set of networking facilities that must be configured and managed. Because of its late arrival into network computing, Microsoft is often shifting network strategies. Users must beware, for example, that Windows NT 5.0 will no longer be based on domains. Rather, the Windows NT 5.0 primary domain controller will be based on Active Directory, which incorporates industry-standard LDAP and DNS. This change will once again force IT organizations based on Windows NT 4.0 to undergo a complete network re-design.

In contrast, Sun has spent years refining their implementation of TCP/IP so that it provides the high-performance networking support demanded of Internet, client-server, and three-tier networked applications. Rather than keeping their innovations proprietary, Sun has turned control of the Network File System (NFS) protocol for standardization by the Internet Engineering Task Force (IETF), which is the body responsible for maintaining standards for network computing.

Designed for the Internet — Integrating with Higher Level Services

Because the Solaris Operating Environment is based on TCP/IP, layering in new services is as easy as modifying configuration tables. Well-known services such as File Transfer Protocol (FTP), Telnet, Hyper-Text Transfer Protocol (HTTP), Domain Name Service (DNS), Post Office Protocol (POP), Internet Mail Access Protocol (IMAP), and Simple Mail Transfer Protocol (SMTP) are either already provided as part of Solaris 7, or can be added by installing third-party software packages and configuring the service. Because of the extensibility that Sun designed into the Solaris environment, even protocols supporting proprietary, non-standard network file services — such as Microsoft's CIFS — can easily be configured.

Designed for the Internet — Providing Solid Security Solutions

From the time users log into a server and access files and applications on the system, to when they venture out onto the Internet, they can be assured of the industry's strongest security when they use the Solaris Operating Environment. The Solaris environment supports the IETF-standard Kerberos for user authentication, resulting in superior security when compared to Windows NT proprietary challenge-response authentication. Denial-of-service attacks that were prevented in the Solaris environment years ago have been exploited in Windows NT as recently as December 1997 — testimony to the benefit brought by well-tested, mature, standard approaches to networking. Sun is committed to implementing the recently-standardized IPsec security protocol that prevents the viewing of any data transmitted over insecure networks like the Internet.

Ahead Today, Ahead Tomorrow

Good architectural choices result in systems which enable businesses to grow. They result in multi-user, multi-platform network operating environments which are reliable, and can scale and grow as business grows. Bad architectural choices result in systems which do not extend well beyond support for single users; they lock customers into one platform, are error-prone, and have limited scalability. As a result of being designed for single-user LAN computing, the momentum for Microsoft Windows NT is slowing, with a creeping feature list, rapidly-increasing code base, and with only guesses as to whether the release date will precede the year

2000. With code size more than double the previous release, the level of maturity and reliability of the system is in question — this it is no surprise that the Gartner Group recommends waiting until at least the year 2001 for deployment.

While Microsoft Windows NT 5.0 continues to be delayed, Sun's Solaris Operating Environment is quickly gaining recognition as the premier operating environment. International Data Corporation measures the 1997 growth in Solaris to be almost 43 percent, with sales of Sun servers having increased 75 percent. With Sun's strong Solaris System Partner Program, more than 12,000 applications are available for the Solaris Operating Environment on SPARC platforms, and more than 3,200 are available on both SPARC and Intel platforms. While HP, IBM, Digital/Compaq, and SGI promise Intel architecture support in the future, the Solaris environment has been running on Intel platforms for years, with a stable, mature, portable, and compact code base.

For those companies wishing to take and maintain a competitive edge, the Solaris Operating Environment is ahead today, and will remain ahead tomorrow — one reason why companies are utilizing Solaris more and more frequently for mission-critical applications like ERP, SAP, supply chain management, on-line transaction processing systems, data warehouses, and key engineering applications.

Solaris 7 delivers today what enterprise, workstation, and network applications demand — including features such as full 64-bit support, scalable symmetric multiprocessing, and high-availability clusters. And while Microsoft struggles to deliver this functionality in the next few years, the Solaris Operating Environment continues to innovate and move ahead with an operating environment that is better by design.

The Solaris Operating Environment is better because it is based on a carefully-designed architecture that is compact and built to grow and extend in an evolutionary manner. It is better because it supports both SPARC and Intel architectures, not locking customers into any one processor architecture. The Solaris environment is better because it is scalable on platforms with 1 to 64 processors — and with Morgan Stanley estimating the growth in UNIX scalability at 2.5 times that of Windows NT, Solaris will remain ahead in the future.

The maturity that comes from a stable, well-tested code base results in a high degree of reliability, and features such as dynamic configuration and hot-pluggable CPUs, memory, and I/O devices can only be built on a mature code base. Finally, the Solaris Operating Environment was built from day one to be networked, using industry standard protocols that provide the interoperability that is the cornerstone of the Internet. With the most evolvable, scalable, mature, reliable, portable, easily-configured and networked operating environment available, enterprises that wish to maintain their competitive edge today and in the future are choosing the Solaris Operating Environment.

References

Sun Microsystems posts complete information on Sun's hardware and software products and service offerings in the form of data sheets, specifications, and white papers on its Internet Web page at *http://www.sun.com/*.

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