Virginia Tech’s System X Supercomputer

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In November of 2003, Virginia Polytechnic and State University grabbed the attention of computing enthusiasts around the world with the creation of the System X supercomputer. It was built as a cluster of 1100 of the newly-introduced Apple PowerMac G5 computers for amazingly low total cost of 5.8 million dollars, a tenth of the cost of any comparable supercomputer. Another thing that makes System X unique is that it was created and tested all within a six-month period. We will compare this machine with other current supercomputers by discussing System X’s architecture, the applications that can be run on this machine, and the performance of some common benchmarks.

We will start our look at System X by looking at the architecture of the G5 processor it uses. The G5 CPU features a fast 1.25 GHz front side bus (or FSB) allowing for a larger number of tasks that can run 215 simultaneous instructions. When compared to various other processors commonly used in supercomputing, the G5’s FSB is almost double the speed of the next fastest CPU (see Figure 1 below). In addition to the fast front side bus, the G5 processor has dual channels. Having dual channels allows for every processor to have its own dedicated connection to the system. Without it, all processors on a single system have to share a single channel when sending and receiving information.

![Figure 1](image-url)
The G5 processor has a 64-bit architecture allowing for a large number of improvements over previous 32-bit processors. Using a 64-bit processor allows for a wider data path, allowing for larger, more precise 64-bit numbers to be calculated in a single clock cycle. To make this increase easier to understand, imagine the largest number a 32-bit processor can compute is the size of a post card. Now with a 64-bit processor you can compute information 4.3 billion times larger. So when being compared to a 32-bit post card, this new size would be about the size of Manhattan Island. Such an increase in size allows for numbers to be computed with a single pass instead of having to be broken up into several parts causing reduced overall performance.

The next advantage of a 64-bit processor is the amount of memory the processor can address. Since memory addresses are unique integers, the more memory you have the more memory addresses you have you need to be able to calculate. Currently, 32-bit processors are only capable of addressing a limit of 4 gigabytes of memory that must be shared between the processor and system components. Now with a 64-bit processor the number of memory addresses it’s capable of addressing increases exponentially from $2^{32}$ to $2^{64}$ allowing up to 4 terabytes of system memory. Keeping so much information in physical memory allows access to data forty times faster than if it was read from a hard drive.

All this fancy architecture is worthless if the computer has no applications to run. Fortunately, being based off the PowerMac G5, System X has a bevy of applications at its disposal. We will discuss some of these applications next.
In order to run 64-bit processors an operating system and software must be created that supports it. System X uses the Mac OS X operating system that is designed for 64 bit computers. The unique thing about using OS X is that it has a Graphical User Interface (GUI) which most others systems don’t. The majority of supercomputers use a Unix-based OS that can be modified to meet operating needs but still requires a command line shell to run code. OS X has the advantage of being built on top of a version of FreeBSD (Darwin) so that the same code used on the non-GUI supercomputers will run on OS X. Windows currently is not an option at this time for complete 64-bit support but a compatible version is in development.

The software that System X supports is very similar to what you would find running on various other super computers. To begin, compilers that you will find supported on System X are IBM XL Fortran, IBM XLC, and gcc 3.3, all of which are available for Mac OS X. When compared to other supercomputers such as Seaborg, at Nersc, and Thunder, at the Lawrence Livermore National Laboratory, System X’s selection of compilers is pretty similar.

There are many common tasks that supercomputers are used for and software has been developed to do these specific tasks. With this in mind, System X (like any other supercomputer) will come with these special-use programs preinstalled. These applications cover a multitude of uses in fields of study, such as chemistry, climate, visualization, and physics. It opens the door for more potential system users. Applications provided by System X include Gamess (used for quantum chemistry), Charmm and Amber (used for molecular dynamics), and Wrf (used for weather modeling). All of these software applications can be
found on various other supercomputers. Other important software that can be run on System X includes Maple and Matlab (for mathematics) and Avs and Idl (for visualization).

System X also supports many parallelization libraries, including the three we have used in class, OpenMP, pthreads, and MPI. Therefore, any of the code we have developed this semester could potentially be compiled on run on this supercomputer.

When making direct comparisons between other super computers we will use Thunder and Seaborg to get an idea of how System X compares to the competition. Take into consideration that all three systems were built at different times. Comparisons can be made based on the hardware, which includes processors and memory, and performance, based on details such as system performance using the Linback benchmark, number of processors, and system cost.

The Linpack benchmark is a set of Fortran subroutines that analyze and solve linear equations, general, symmetric, and banded matrices. Introduced by Jack Dongarra, it doesn’t reflect the overall performance of a system; it just reflects how well it performs when calculating multiple complex matrices. When running these routines an \( R_{\text{max}} \) score is calculated based on the time to compute the given matrices, along with a theoretical \( R_{\text{peak}} \) score guessing the potential the system has.

Beginning with hardware comparisons, System X uses the 2.3 GHz PowerPC 970FX processor that was described in more detail earlier. Thunder uses a 1.4 GHz Intel Itanium processor that is 64-bit but has less cache, a lower clock speed, and a slower system bus than the PowerPC.
970FX. Seaborg uses the 64-bit Power3 processor that runs at 375 MHz, but it also has a much lower cache, clock speed and system bus than the processors found in System X (see Figure 2 below). At first glance it’s easy to see that the processors in System X are better but overall system performance comes down to sheer performance based on the number of overall processors in the system.

When comparing memory, the speed of the memory is important but at this time such details for Thunder were not available so total amount of accessible memory will be used. Now physical memory is very important to computing because it tends to run forty times faster than if read from a hard drive. The more full memory the processors have to access the faster the information can be computed. Virginia Tech’s System X has a total of 4.4TB of system memory. Seaborg has 7.8TB of system memory, while Thunder has a total of 8.2TB of system memory (see Figure 3 below). At first glance, you would think Thunder has it better off than System X but System X is using memory running at 400 MHz, whereas the memory Thunder is running has only a speed of 133 MHz. With memory more than twice as fast as Thunder, System X is on par when it comes to memory. Currently System X is also only at half of its memory capacity. It has the potential to use 8.8TB of system memory. Another important
feature that System X has is the ECC memory that contains “Error-Correcting Code” to ensure the accuracy of data as it passes in and out of memory. Use of such memory reduces the amount of error correction that needs to be taken into consideration when developing high performance code.

The last area of comparison that we will do is based on system performance. All supercomputers listed on top500.org are ranked based on the LINPACK benchmark. Using the LINPACK benchmark, you have a systems $R_{\text{max}}$ speed in Gigaflops, and its $R_{\text{peak}}$ speed, also given in Gigaflops. For our comparison we will use $R_{\text{max}}$.

System performance is proportional to speed and number of processors a system has. Seaborg has a benchmark score of 7304 Gigaflops using a total of 6656 processors. Thunder scored 19940 Gigaflops using 4096 processors. And finally System X scored 12240 with 2200 processors (see Figure 4 on the next page).
The unique parts of System X are the computers that make up each node of the system. All of the computers are standard off the shelf systems that anyone can purchase at their local computer store. With such a simple construction, it’s easy to acquire any needed components quickly. Because of this, the overall system cost of $5.8 million was much lower than other supercomputers such as Thunder’s $13 million total and Seaborg’s $33 million total (see Figure 5 below). When it comes to other supercomputers you will find that many are built with proprietary parts specific to the engineers’ design. Having such a system tends to be expensive because of production cost that goes into developing the system.
In conclusion, the Virginia Tech System X computer is a revolutionary system built with off the shelf computer systems at a small price point without sacrificing performance. We have pointed out the details of the advantages of using the Apple Xserver computers beginning with the PowerPC 970FX processor and its 64-bit architecture. With brute speed, fast system bus, and wide data path the processor outperforms individual processors from other systems. Then we spoke on the system performance in relation to the number of processors the system has showing how System X outperforms other systems.