

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188	
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1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE 26.Jul.99	3. REPORT TYPE AND DATES COVERED THESIS	
4. TITLE AND SUBTITLE DESIGN, IMPLEMENTATION, AND EVALUATION OF A SHARED-MEMORY PARALLEL PROCESSING SYSTEM (SMPPS)			5. FUNDING NUMBERS	
6. AUTHOR(S) 2D LT STAUB ERIC H				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) NEW JERSEY INSTITUTE OF TECHNOLOGY			8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) THE DEPARTMENT OF THE AIR FORCE AFIT/CIA, BLDG 125 2950 P STREET WPAFB OH 45433			10. SPONSORING/MONITORING AGENCY REPORT NUMBER FY99-203	
11. SUPPLEMENTARY NOTES				
12a. DISTRIBUTION AVAILABILITY STATEMENT Unlimited distribution In Accordance With AFI 35-205/AFIT Sup 1			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words)				
14. SUBJECT TERMS			15. NUMBER OF PAGES 90	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT	

19990804213

P11 Redacted

**DESIGN, IMPLEMENTATION, AND EVALUATION OF A
SHARED-MEMORY PARALLEL PROCESSING SYSTEM
(SMPPS)**

**by
Eric H. Staub**

**A Thesis
Submitted to the Faculty of
New Jersey Institute of Technology
in Partial Fulfillment of the Requirements for the Degree of
Master of Science in Computer Engineering**

Department of Electrical and Computer Engineering

January 1999

APPROVAL PAGE

DESIGN, IMPLEMENTATION, AND EVALUATION OF A
SHARED-MEMORY PARALLEL PROCESSING SYSTEM
(SMPPS)

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ACKNOWLEDGMENT

The author wishes to express sincere thanks to my two advisors, Dr. Ziavras and Dr. Rosenstark, for their guidance, support, knowledge, and mentoring. I would also like to thank Dr. Hou for serving as a committee member.

I would like to give a special thanks to Rosalie Gaddala for her friendship and support throughout my academic career at NJIT and to Amy Sun who was an inspiration for me over the last few months of my graduate work.

Most of all, I would like to thank my Mother and the rest of my Family for the love and support that has gotten me this far.

I would like to thank all of the Electrical and Computer Engineering Department and all of the Faculty and Staff of NJIT that have been an integral part my academic career at NJIT. I would like to thank the numerous students that I had the opportunity to work and study with. I would like to thank the United States Air Force for giving me the opportunity to become an officer to serve my country and the Air Force Institute of Technology for giving me the opportunity to get my graduate degree at NJIT. I would like to thank the AFROTC Detachment 490 Staff, past and present, for their guidance and support while I have been at NJIT. Also, I would like to thank my brothers of Tau Delta Phi Fraternity. And finally, I would like to thank Altera's University Program for supplying hardware and software for this project.

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CHAPTER 1

INTRODUCTION

1.1 Parallel Processing

1.1.1 Importance of Parallel Processing

Even with ever changing technology, industry is always looking for ways to improve performance. Scientists are continually finding innovative ways to speed up the processing power of computers. Still, we need faster and more effective ways to accomplish a task. Now that advancements in technology are reaching their limits, industry must look for a new way to keep up with the demands. There is the old adage that two minds are greater than one. This theory can be applied to computer processing. With two processors, not only can more tasks be accomplished, but also tasks can be accomplished faster.

For example, the simple task of $\{g = (a+b)*(c+d)\}$ would take three steps (part a. of **Figure 1**) on one computer. On a system with two processors, that same task would take two steps (part b. of **Figure 1**). For simplicity sake, the time to pass information between the processors is not considered.

(a) System with one processor.

Step 1: Processor A adds 'a' to 'b' and places value in 'e'.
 Step 2: Processor A adds 'c' to 'd' and places value in 'f'.
 Step 3: Processor A multiplies 'e' and 'f', and places in 'g'.

(b) System with two processors.

Step 1: Processor A adds 'a' to 'b' and places value in 'e'.
 Processor B adds 'c' to 'd' and places value in 'f'.
 Step 2: Processor A or B multiplies 'e' and 'f', and places in 'g'.

Figure 1: Steps processors make to solve the equation $g = (a+b)*(c+d)$.

This is a 33% improvement in the time to accomplish a simple task. If the additional processor gives a 33% increase, why not add another processor? In this simple case the addition of more processors would not have any effect. This is because the task is made up of three subtasks, one of which requires information from the previous two. Even if the third processor was assigned the multiplication of 'e' and 'f' it would not be able to proceed until the additions were complete.

One might conclude that the improvement of processing time using multiple processors is limited. Actually the limit only exists for a particular task. As the task changes, the speedup factor changes. When multiple processor theory is applied to the task of $(a+b)*(c+d)*(e+f)*(g*h)$, the results are quite different. On one processor the task will take seven steps. On a two-processor system it would take four steps. This is over 40% decrease in processing time. On a four-processor system that same task would take only three steps. This is over 50% decrease. If the task is applied to a five-processor system, there is no improvement in processing time. Once again the processing time can only be improved to a certain limit.

Another factor to consider is that adding a fourth processor only increased the speedup by 10%. When one processor was added there was a gain of 40%, and only 10% more when adding two additional processors. Also, during some of the steps, some of the processors are not needed. Further complicating the matter is the movement of data between processors. This transfer will take additional time that will decrease the overall speedup of the system. Deciding what is the best possible design to obtain the best possible results is a topic that will not be discussed in detail and will be left to independent research. However, the focus of this paper will center on the design of a shared-memory parallel dual-processor system and the timing results of running algorithms on the system.

1.1.2 Classes of Parallel Processing

Before I get into the design of the system, I will discuss the different types of parallel computing systems. As one might guess, parallel systems are designed in different ways. In general, parallel systems are classified in to two major groups. The system I have designed falls into the shared-memory class and the other class consists of message passing systems. Each system has its pros and cons and the type of system needed is basically dependent on the task that needs to be accomplished. How parallel computers communicate with one another and how they share memory determines which one of the two major classes of parallel computers the systems belong to.

Systems that are considered inherent parallel computers are those which operate in the MIMD (multiple instruction stream over multiple data stream) mode. An example of a MIMD system is shown in **Figure 2**. Since parallel computers must share information, there has to be a way for them to access the shared information. In multiprocessor shared-memory systems this is accomplished by placing information in some variable and giving all systems access to that variable. In message-passing systems the information is passed between computers by using an interprocessor communication network.

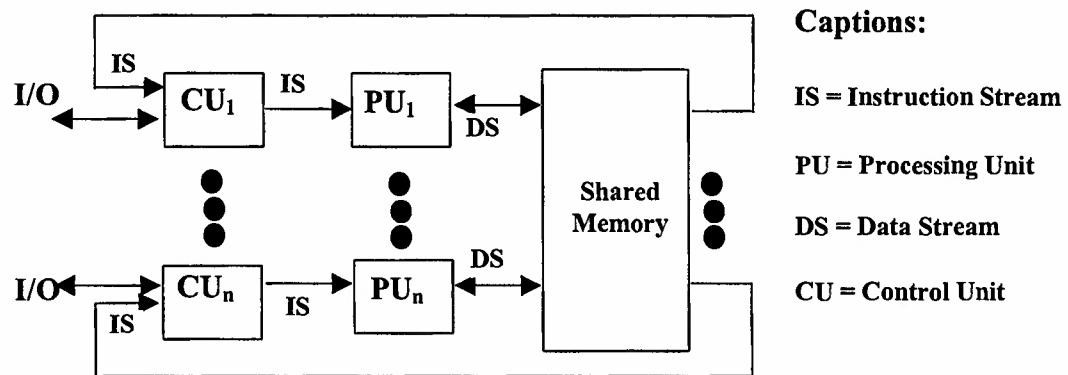


Figure 2: MIMD architecture (with shared-memory).

1.2 Existing Machines

1.2.1 Message-Passing

A system in the message-passing class consists of one or more multiple-computer networks. These networks connect together computer nodes. The computer nodes communicate information between one another through these networks. Hardware routers usually handle this communication. An example of a message-passing interconnection network is shown in **Figure 3**.

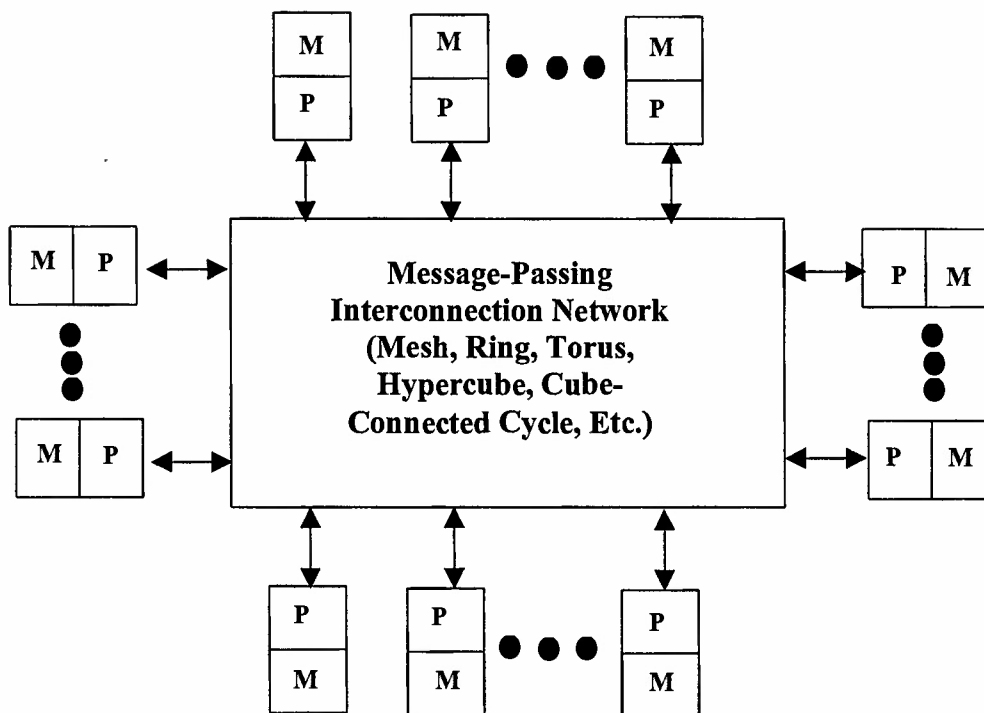


Figure 3: Generic model of a message-passing multicomputer (M=Memory, P=Processor).

Each network node is attached to a router. Based on the design and type of protocols that the router uses, information is then sent between the computer nodes via routing. This gives the designer the flexibility of creating multiple types of communications between the networks. By changing how the networks interact, the designer has the ability to use the same networks to accomplish numerous different tasks.

As with all technology, the scientist and engineer strive to improve the original design. Message-passing systems are now in their third stage of development. Development started in 1983 with systems like the Caltech Cosmic and the Intel iPSC/1. These systems were designed with software-controlled message-passing for the hypercube architecture.

Over the years of 1988-1992, systems such as the Intel Paragon and the Parsys SuperNode 1000 represented the next stage in the evolution of message-passing systems. The systems incorporated routing messages via hardware, utilizing software for medium-grain distributed computing, and using mesh-connected architectures.

The third stage of the development started in 1993 and consisted of machines that placed processing and communication devices on the same chip. Systems such as the MIT J-Machine and the Caltech Mosaic are based on this design.

Listed above are a few of the many systems that have been developed. Each system has its own unique design. What that design is and how each accomplishes its message passing can be found in numerous technical notes and publications. These systems were mentioned just to give a flavor of the type of systems and progression of the development of message-passing systems.

1.2.2 Shared-Memory

Shared-memory systems consist of multiple-processors, each of which has its own private memory, and information is shared through an independent memory that all of the processors have the ability to access. As with message-passing systems, I will give a brief description of shared-memory systems. I will briefly describe only three of the many models of shared-memory systems. Many other models incorporate one or more features of these three models.

The first model, **Figure 4**, is the uniform-memory-access (UMA). In this model all processors have equal access to all memory. These systems are for multiple processes for problems characterized by a high degree (that is fine-grain) parallelism. The system I designed falls under this model.

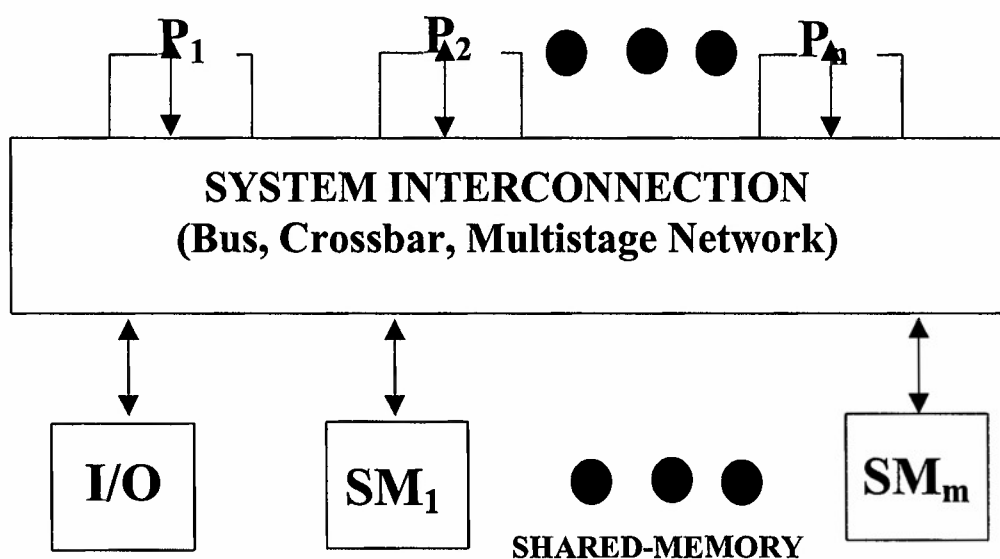


Figure 4: The UMA multiprocessor model (e.g., the Sequent Symmetry S-81)
 [P = Processor; SM = Shared-Memory; I/O = Input/Output].

The next model, **Figure 5**, is the non-uniform-memory-access (NUMA). NUMA systems consist of groups of multiple-processors that are connected by interconnection networks. There is local-shared-memory within each group and global-shared-memory between the groups. These systems share memory based on the location of the memory in relation to the processor needing access to that memory. Therefore, the access time to memory is not uniformly distributed among the processors.

LEGENDS:

P: Processor

LM: Local Memory

GSM: Global Shared-Memory

CSM: Cluster Shared-Memory

CIN: Cluster Interconnection Network

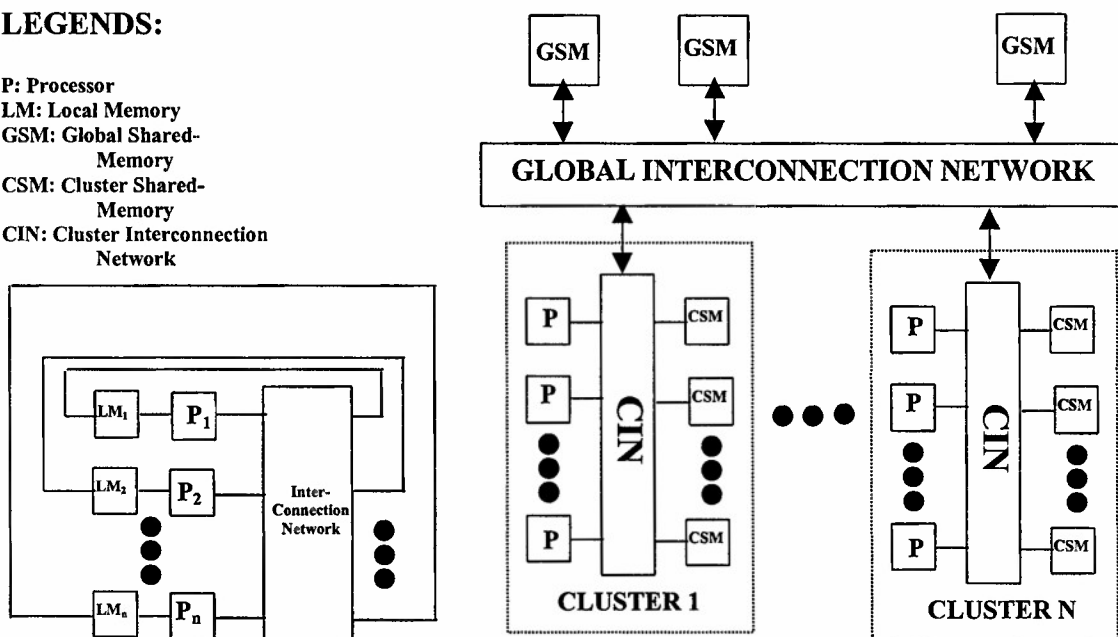


Figure 5: Two NUMA models for multiprocessor systems.

The last model, **Figure 6**, I will discuss, is the cache-only memory access (COMA). These systems are similar to NUMA systems, but the shared memories are replaced with cache memories. Processors wanting to access memory in another processor's cache memory must do so through cache directories.

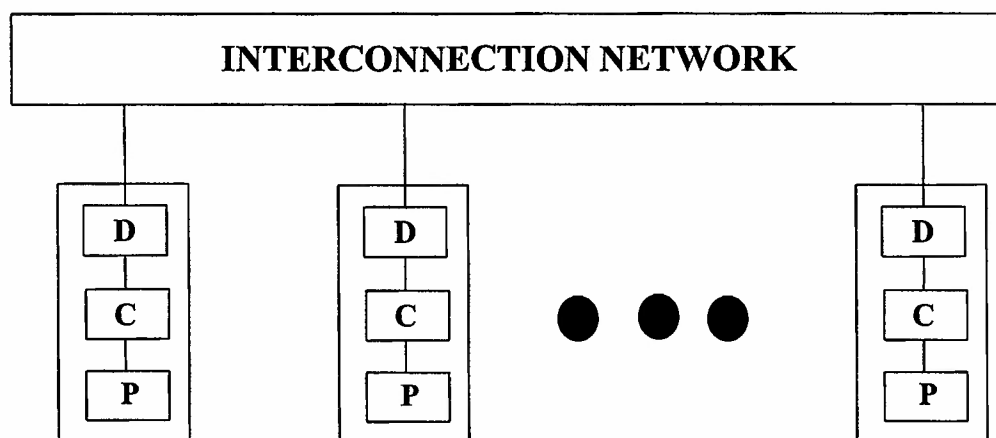


Figure 6: The COMA model of a multiprocessor (D: Directory, C: Cache, P: Processor; e.g., the KSR-1).

Numerous different sources, including the Internet, can be found for further information about parallel systems. This follow-on information is not necessarily needed to understand the design of my shared-memory system or the results of testing algorithms on that system.

CHAPTER 2

IMPLEMENTING A SHARED-MEMORY PARALLEL PROCESSING SYSTEM (SMPPS)

2.1 Objectives

There are three main objectives to this project. The first is the design of the shared-memory parallel processing system. Next is the implementation of that system. The final objective is the evaluation of the system for some algorithms.

2.2 A Dual-Processor Shared-Memory Parallel Processing System

2.2.1 Meeting Design Objectives

Since the evaluation of the system consisted of testing algorithms, I needed to design a system that could be implemented within time and monetary constraints. This system would have to show the effectiveness of running an algorithm on a parallel system as opposed to running that same algorithm on a single processor system.

I chose to develop a system with two processors and a single shared-memory. This would reduce the cost and complexity of the project. Also, it would help keep me within the time and monetary constraints. The next step was to determine which processor to use for the project.

I initially chose to use the TI TMS320C80 processor. The C80 processor consists of four DSPs and one RISC processor. I spent the next month gathering information about the C80. I considered how I would implement a system using two C80 processors

and what software would have to be developed to manage and test the interface between the two processors. After carefully considering the options that the information I collected presented to me, I determined that I would be unable to use the C80 for this project. Using the C80 would not only be cost prohibitive, but the complexity of implementing a dual processor system was extremely complex.

I then focused my attention on using TI's C40. Even though the cost was quite less, the complexity still remained quite high. After another month of investigations it was determined that using the C40 was not a viable solution. This left the Motorola 68000 series microprocessor. These processors would be much more cost effective and the complexity would be greatly reduced. Since I was familiar with this series of microprocessor, I determined that it would be the most promising candidate for a dual-processor system.

2.2.2 The Design

As an undergraduate, I was involved in many projects. The most significant was my senior project. In this project I developed a control system for a constant-pressure floodgate. I used the Motorola 68008 microprocessor as the control system processor. I used a micro-controller design that was developed by Dr. Rosenstark and is part of EE-393, Electrical Engineering Lab III. The micro-controller design and specifications are explained in detail in the EE-393 Lab Manual.^(Rosenstark 1998) The current version of the Lab Manual has the new micro-controller, Motorola 68EC000 microprocessor, in place of the Motorola 68008 microprocessor.

Once it was determined what microprocessor I should be using, the project was set in motion. The Electrical Engineering Laboratory III (EE 393 – Spring 98) was using the last of the MC68008 to build micro-controllers. Since the discontinuation of the processor, Dr. Rosenstark was seeking an alternative processor. The alternative was the MC68EC000. To test the feasibility of using this processor, Dr Rosenstark had one student build a micro-controller with the MC68EC000. The student was successful in using MC68EC000.

In order to accomplish the objectives I set, I needed to make modifications to the micro-controller in the EE-393 Lab Manual. The micro-controller has its own memory, which included DRAM and an EEPROM. The memory used in the EE-393 Lab Manual was 28C64 EEPROM and 6264 DRAM. Since my design required a larger memory space, I chose to use an ATMEL 28C256 EEPROM and a 62256 DRAM. This would give me two blocks, each 8K bytes, of addressable memory. This change in address space changed the addressing scheme of the micro-controller (see **Figure 7**).

	<u>28C64/6264</u>	<u>28C256/62256</u>
EEPROM	0000 - 1FFF	0000 0000 – 0000 7FFF
Private Memory	2000 - 3FFF	0000 8000 – 0000 FFFF
Shared Memory	N/A	0001 0000 – 0001 7FFF
Parallel Port	6000	0001 8000
Serial Port	4000	0002 0000
All values are in HEX		

Figure 7: Address location of devices.

Another benefit of using these chips is that they are 28-pin packages. This would allow me to use the original design while only changing two wires for each chip. The additional wires are address lines A13 and A14. These lines will be connected to pins that were originally no-connect pins on the EEPROM and will replace the nCE2 pin and a no-connect pin of the DRAM. This is shown in **Figure 8** and **Figure 9**.

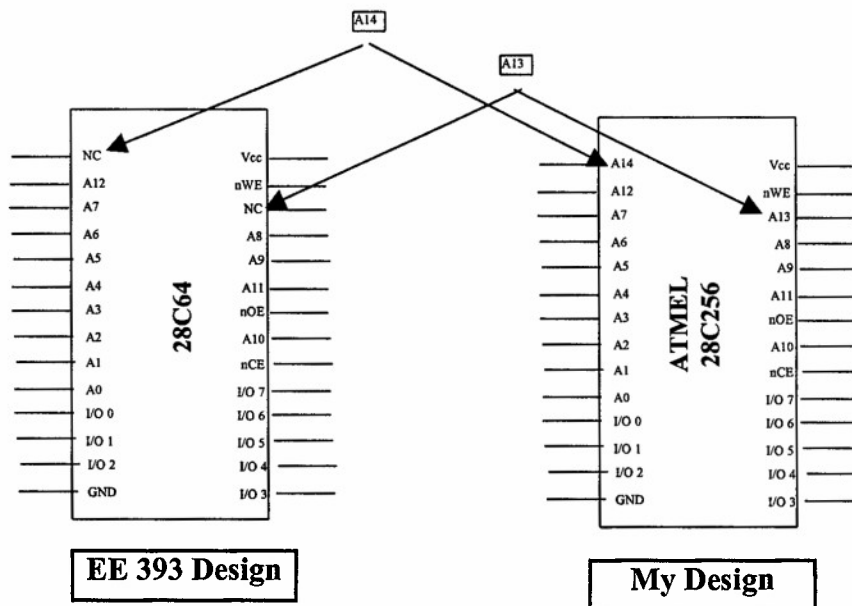


Figure 8: Differences between the 28C64 and the Atmel 28C256.

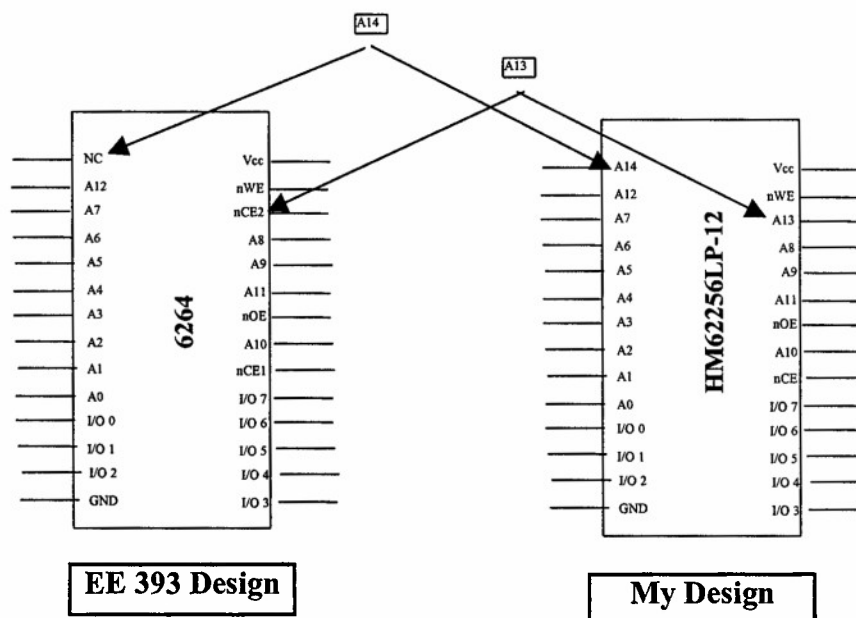


Figure 9: Differences between the 6264 and the HM62256LP-12.

Since I am using a larger address space, the address lines on the 74LS138 will have to change. Lines A13, A14, and A15 will be replaced with A15, A16, and A17 as shown in Figure 10.

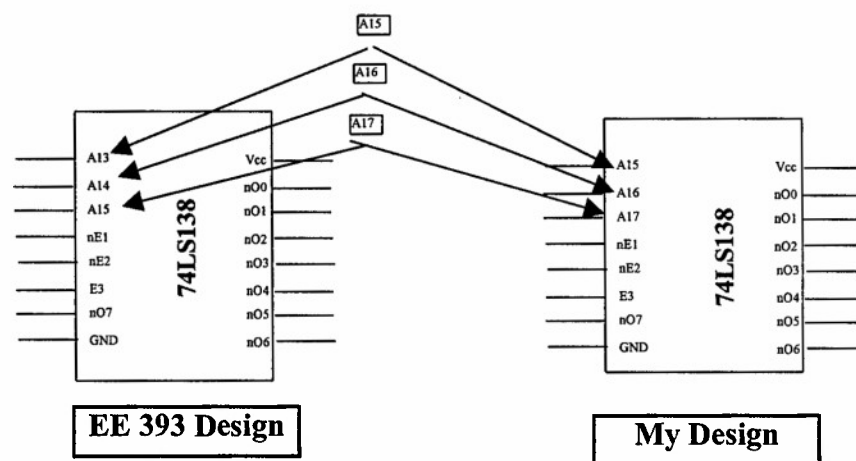


Figure 10: Differences in the wiring of the 74LS138.

Now that the major design decisions were out of the way I started to build the circuits around the microprocessor. I proceeded as far as possible with the parts that I had acquired up to this point. I was having difficulties acquiring some of the important components so I was unable to go any further. Due to lack of parts to complete the microprocessors I decided to work on the control logic and the 2-1 Mux.

After spending some time designing the control logic I received most of the components needed to finish the micro-controllers. After completing the first micro-controller, I ran into difficulties interfacing with the computer. Since I was only having trouble with communicating with the computer I started to build the second micro-controller. Once I completed this micro-controller, I ran into the same difficulties. After an exhaustive trouble shooting effort, I was only able to communicate with the computer on a simple level. I was still unable to run the Monitor program. I then changed my focus to the software and the assembler.

After more intense trouble shooting, Dr. Rosenstark and I determined that one of the problems was created by my larger address space. Specifically the range from 8000H to FFFFH. This problem was caused by the assembler when it sign extended. As a solution we decided not to use this address range. I moved the private memory to 0001 0000H – 0001 7000H and moved the shared-memory to 0002 0000H – 0002 7FFF. This solved some of the problems but I was still unable to get the monitor program to work.

While working on my project I was teaching EE393 over the second summer session. These students were using the MC68EC000. These students were using the smaller EPROMs and RAMs. They did not have the communication problems that I was having. This was very perplexing since it was the same program, except for the different

address scheme. Since I was able to communicate on a simple level it had to be a software problem. After using some unique debugging, I determined that the James L. Antonakos' Assembler was assembling addresses that used the LEA command with an offset of 6H. I also found another problem. The James L. Antonakos' assembler creates S1 records. This would not allow me to write a program to be loaded by the monitor in my memory location since my addressing scheme was a long word.

At this point I tried using another assembler. I found that Paragon's assembler was able to assemble the program, and I was able to run the monitor program. This created another problem. The Paragon assembler used S2 records in the Hex file. The monitor was not able to load S2 files, so I would not be able to load a program into memory.

Working with Dr. Rosenstark we came up with several solutions. The first was to change the LEA commands to MOVEA.L commands. This solved most of the problems but I would still be unable to use Antonakos' assembler for files to be loaded into the memory because my addressing scheme requires S2 records. Dr. Rosenstark's changing the monitor program to load S2 records solved this problem. Dr. Rosenstark has passed this information on to James L. Antonakos and he is currently working on a solution.

I now had two fully working micro-controllers. Now it was time to start to work on the shared-memory logic. For simplicity, I chose to make the shared-memory the same type as the private-memory of the micro-controllers. This way I would be able to use the same address and data bus as the micro-controllers.

The next step was to design the interface between the micro-controllers and the shared-memory. My design called for single-port access of the memory. Also, access of the shared-memory should not interfere with the independent processing of the other processor unless both processors try to access the shared-memory at the same time. In order to accomplish that, I needed to separate the address and data buses of the individual processor while allowing access to those buses when shared-memory is accessed.

Diagram I in Appendix A shows the initial block diagram for the system. I separated the address buses with 2-1 multiplexors and the data buses with bus-transceivers. I used a bus-transceiver on the data bus because of the bi-directional nature of the data bus. After further evaluation of my design I found that I had unnecessary logic.

Diagram II in Appendix A shows that I removed two bus-transceiver blocks and two 2-1 MUX blocks. The DRAM chip has an enable pin on it. This enable pin would only be activated when a processor requires access to the shared-memory. This allowed me to remove the MUX blocks. The bus-transceiver is bi-directional so it can be placed in the direction of the shared memory while a processor is accessing its private memory. Since the shared-memory is not enabled during this time, the data on the data lines of the shared-memory chip is ignored. This allowed me to remove the bus-transceiver blocks.

Now that the design for the address and data bus was complete I needed to design the shared-memory control logic. The problem that needed to be solved was how to access the shared-memory with interrupting independent processing of the other processor. I used one of the features of the MC68EC000 to build my design.

I used the MC68EC000 A/S pin and the /DTACK pin. When an instruction is executed the MC68 places a signal on the A/S pin. In order for the processor to continue to the next instruction, a signal must be placed on the /DTACK pin. Once the state on the /DTACK pin has gone from high to low and then back to high, the processor will continue on to the next instruction. If the transition is not completed the processor will not continue.

Since my design requires that a second processor wait till the first processor is done when both processors try to access shared-memory, I can use these pins to my advantage. In the EE 393 design the two pins are connected directly together. If I could separate the pins during shared-memory access, I would have solved my problem. Now that I had a possible solution to this problem, I had to consider the other chips that needed to be controlled by this logic.

The shared-memory had to be enabled when accessed and whether the operation is a read or write must be handled. The bus-transceiver on the data bus must be enabled and the direction set. And finally the multiplexor on the address bus must be set correctly. This design would require large amounts of logic and testing would become a nightmare. Luckily, as part of my undergraduate work I used a software package by Altera called MAX+plus II.

I decided to use ALTERA programmable chips for the control logic and the 2-1 Mux. Using the Altera chips would be much more cost effective and would reduce the area required for the shared-memory system. Also these chips would allow flexibility in the design of the logic. The design could be easily modified and reprogrammed onto the chip.

MAX+plus II can be used to design entire logic devices from those as simple as a gate to those as advanced as microcomputers. The designs can be created in text format or in graphical format. Once the design is complete, it can be thoroughly tested. If it does not meet the specifications needed, then it can be easily changed and tested again. This eliminates the need to build the circuits, test them, and then throw them away because they did not meet the specifications you had planned. Another advantage was that the design could be placed on a single chip the size of a computer processor. Not only would I save time and money, but also the space I needed for my control logic would be reduced.

Diagram III in Appendix A shows one of the preliminary designs. The final design for the most part was similar to this design. One of the features of MAX+plus II that is very useful is the ability to create default symbols. This allows the use of the same sub-design in multiple places. This became particularly useful when testing a specific point of the design.

I used this feature in two places in my design. One place was the point that became the focal point of fault with my original design. This will be explained as I describe the final design of the control logic. The second place is the 1-2 de-multiplexor I created. I would have had to create a third default symbol, but this symbol had already been created. This was the 2-1 multiplexor.

The 1-2 DEMUX is shown in Diagram IV in Appendix A. I created it using tri-state buffers. This design allows one signal to be sent over a different line based on what is selected by the select pin. The drawback to this design is the high 'Z' output that is created when a line is not selected. This would be a problem when a processor is

working with its own memory. Then the input to the shared-memory logic would be high 'Z'. Since my design of this control logic requires a high or low signal to be present, I had to come up with another solution.

The simple solution was an open-collector buffer. Since the chip that I will be placing the design on does not support open-collector buffers in the design, I chose to route the 1-2 DEMUX output out of the chip and then back into the chip via an input pin. The signal would then go through the open-collector buffer and then back into the design on the chip. This would require an additional chip. Since I had saved large amounts of space by using the Altera chip, I didn't mind adding one additional chip.

In order to save additional space, I chose to design the 2-1 multiplexors for the address bus with the MAX+plus II software. Diagram V in Appendix A shows this design. This would require the use of two Altera MAX EPM7128SLC84-7 chips. Using two MAX chips still required less space than using 2-1 multiplexor chips. After running the control design through many simulations, I programmed the design into the second MAX chip. I then proceeded to wire the chip into the micro-controller. Before I could actually test the design, I had to wire the bus-transceivers for the data bus and the second MAX chip, which has the 2-1 Multiplexors for the address bus.

Once the wiring was complete, I started testing the design. The design did not work the way it was expected to. After days of testing and troubleshooting, I narrowed the problem down to a specific area in the design. I removed this area from the design and created a default symbol for this area. It is shown as default symbol 'ctest' in Diagram VI in Appendix A. This would allow me to redesign and test the problem area of the design.

After many days of testing and modifications, I determined that I would have to redesign this portion of the control logic. Any modifications I made to the design would either introduce a race condition into the logic or give total control of the shared-memory to one processor. Just before starting from scratch, I asked Scott Margo, an NJIT Electrical Engineering Ph.D. student what he thought might solve the problem. After evaluating the design, he came to the same conclusion that I should start over from the truth tables. The resulting truth table is shown in **Figure 11**.

Ain	Bin	Aout	Bout	A'out	B'out
0	0	0	0	0	0
0	0	0	1	0	0
0	0	1	0	0	0
0	0	1	1	Invalid	Invalid
0	1	0	0	0	1
0	1	0	1	0	1
0	1	1	0	0	1
0	1	1	1	Invalid	Invalid
1	0	0	0	1	0
1	0	0	1	1	0
1	0	1	0	1	0
1	0	1	1	Invalid	Invalid
1	1	0	0	1	0
1	1	0	1	0	1
1	1	1	0	1	0
1	1	1	1	Invalid	Invalid

Figure 11: Truth table for the shared-memory control logic.

Using the Karnaugh Maps in **Figure 12 (a)** and **(b)** the following equations emerged:

$$A'out = (Ain / Bin) + (Ain / Bout) + (/Ain Bin / Aout / Bout)$$

$$B'out = (/Ain Bin) + (Bin / Aout Bout)$$

A'out	00	01	11	10
00	0	0	1	1
01	0	0	0	1
11	0	0	0	1
10	0	0	1	1

(a)

B'out	00	01	11	10
00	0	1	0	0
01	0	1	1	0
11	0	1	0	0
10	0	1	0	0

(b)

Figure 12: Karnaugh Maps for the shared-memory control logic.

The resulting logic is shown in Diagram VII in Appendix A.

I tested this design by running it through several simulations. The results of these simulations were very promising. After compiling the control design with this new design, I programmed it into the MAX chip. This began the testing phase of the new control logic. I used the monitor program on each micro-controller to manually access the shared-memory. I was able to edit and display the shared-memory from both micro-controllers. This confirmed that the hardware design was complete.

The next step was to write a program that used software semaphores to lock the shared-memory. The program I wrote is in Appendix B. The program ran flawlessly on both processors. Not only did the hardware design work, but also the software-controlled locks were executing properly.

2.2.3 Timer Configuration

Before I could move on to the algorithms, I had to decide how I would track the execution times. The most effective way is to interface directly with the micro-controllers. This would allow the software to directly control the timer. Not only would this be more efficient, but it would also produce more accurate times.

I chose the Intel 8253-5 programmable interval timer to accomplish the task of timing the execution of the algorithms. The 8253 timer is a 24-pin dual in-line package with three 16-bit counters, each with a count rate of up to 2 MHz. The timer has five different modes of operation and four different ways of obtaining count values. I will be using mode 0, interrupt on terminal count, and will use 'Read/Load least significant byte first, then most significant byte' for obtaining the count value. The timer counts down from $2^{16}-1$. This produces a 16-bit number.

The timer has an eight-bit data bus that can be easily interfaced with the micro-controller's eight-bit data bus. This data bus is used to read the count value in the count register. As stated before this is done with two reads of the chip. The first read is stored in one register and the second read is stored in another register. The final result is the combination of the two values, which is a 16-bit number.

Once I completed the interface of the chip to the micro-controller, I conducted preliminary tests on the timer chip. These tests were done to ensure the timer was working properly. Even though I chose to operate the timers at 1.2 MHz, I noticed that the timer was counting completely down several times. I was getting valid count values but had no way of telling how many times the counter started over. This could cause a problem when determining the speed up of the algorithms that I would be testing on the project.

In order to solve this problem I had to find a way to track how many times the counter reaches zero. This was one of the main reasons I chose to operate the timer in mode 0. In mode 0 the timer would count down to zero, and once zero was reached a high signal would be placed on the out1 pin of the timer chip. Now I had a way to keep

track of how many times the timer reached zero. Of course, it was not as simple as I thought.

Once the timer reached zero, the signal would be placed on the out1 pin. The timer would then continue to count down again. The problem with this is that the signal on the out1 pin was not reset. The only way to reset the out1 pin was to reset the entire timer and then restart the timer. This presented another problem. All of these actions would take time. Even though it was a very small amount of time, it was still enough to reduce the accuracy of the execution times of the algorithms.

The solution to this problem brought about the final design for the interface of the timer. Since the resetting of the timer would take time, I needed to halt the execution of the algorithm while I was resetting the timer. I accomplished this by using the external interrupts on the MC68EC000.

Using the 68's interrupts I could reset the timer and count the number of times the timer reached zero. This was accomplished by adding an interrupt service routine to the monitor program. The routine, which is written in assembly, is shown in **Figure 13**.

Using the interrupts also required some additional hardware design.

```

        ORG      $6300

; This is Interrupt #4 Service Routine

        move.b   #$44, ($18000)
        addi.l   #$01, (ICNT)      ; # times counter counts down
        move.b   #$30, (LCW)       ; Initializes the counter to mode 0
        move.b   #$00, (WC1LB)     ; Loads the count value
        move.b   #$00, (WC1MB)
        RTE

```

Figure 13: Timer Interrupt Service Routine (written in assembly).

While designing the hardware interface between the timer and micro-controller, I developed a way to totally automate the resetting of the timer and the reading of the final count value. This would require additional interrupts and logic for the interface. After a few weeks of testing designs, I decided just to use the interrupt for the resetting of the timer and keeping track of how many times the timer reached zero. I made this decision based on the fact that these additional features of automation were not really necessary and the fact that I would not be able to work out the bugs in the design in the time allocated for the timer design.

Since I was not using automation for the stopping and reading of the timer, I had to create a design that would allow the software to stop and read the timer. In the micro-controller design the 74LS138 is used to select different chips. This is accomplished by having three upper address lines connected to the 74LS138. By executing a read/write at the address location specified by the address lines that are connected to the 74LS138, a particular chip will be enabled. Since I was not using all of the locations available on the 74LS138, I decided to use it to help with the stopping and reading of the timer.

Now that my new design for the timer required additional logic, I decided to use the MAX+plus II software. I designed the logic and then added it to the design for the address bus multiplexors. This is shown in Diagram VIII in Appendix A. The logic would allow for the interrupt for the tracking of the number of times the counter reaches zero, the software-controlled stopping and reading of the timer.

The timer will be initialized and started by software-control. When the timer reaches zero, the execution of the algorithm will be interrupted, a count variable will be incremented, the timer will be reset and restarted, and then the execution of the algorithm

will resume. This will be done without any software-control. When the algorithm is complete, software will stop the timer and read the count value. The software-control will be additional lines of code that will be added to the code for the algorithms. This code will not affect the results of the execution time of the algorithms. After running several tests, I determined the design was sufficient to give effective timing results for the algorithms I would be testing on the SMPPS.

This concluded the hardware design of the system. Now it was time to move on to the development of the algorithms for the system. For this project I will be testing two algorithms. The first will be matrix multiplication and the second would be parallel sorting.

CHAPTER 3

IMPLEMENTATION OF PARALLEL ALGORITHMS

3.1 Matrix Multiplication

3.1.1 Demonstrating a [4x4], [8x8], and [16x16] with [4x4] Matrix

For the matrix-multiplication algorithm (MMA), I wanted to use several different sized matrices to show the effective speed up of using a SMPPS. I would multiply two matrices and place the results in a third matrix. The three matrix sizes I chose were 4x4, 8x8, and a 16x16. This would give me speed up values for simple matrix multiplication that is time-consuming.

I would also produce results for computing the matrix-multiplication on one processor and on the SMPPS. The multiplication of the matrices on the SMPPS would be done in two different ways. One way would be just utilizing the two processors, and the second would utilize the shared-memory. I will be expecting a speed up of almost two for the dual processor system without shared data, and considerably less of a speed up for the shared-memory implementation. This would be caused by the overhead involved in using the SMPPS. The transfer of data through the shared-memory is considerably slower than using registers of a single micro-controller. I do, however, expect a reasonable speed up over the single processor.

I will use 4x4 matrices to demonstrate the different ways I will do the matrix-multiplication algorithm. I will be multiplying matrices A and B, and placing the results in matrix C as shown in **Figure 14**.

Matrix A					Matrix B					Matrix C			
A ₀₀	A ₀₁	A ₀₂	A ₀₃	*	B ₀₀	B ₀₁	B ₀₂	B ₀₃	=	C ₀₀	C ₀₁	C ₀₂	C ₀₃
A ₁₀	A ₁₁	A ₁₂	A ₁₃		B ₁₀	B ₁₁	B ₁₂	B ₁₃		C ₁₀	C ₁₁	C ₁₂	C ₁₃
A ₂₀	A ₂₁	A ₂₂	A ₂₃		B ₂₀	B ₂₁	B ₂₂	B ₂₃		C ₂₀	C ₂₁	C ₂₂	C ₂₃
A ₃₀	A ₃₁	A ₃₂	A ₃₃		B ₃₀	B ₃₁	B ₃₂	B ₃₃		C ₃₀	C ₃₁	C ₃₂	C ₃₃

Figure 14: [4x4] Matrix Multiplication on a single processor.

The operations required to compute Matrix C are shown in Figure 15.

$$\begin{aligned}
 C_{00} &= (A_{00} * B_{00}) + (A_{01} * B_{10}) + (A_{02} * B_{20}) + (A_{03} * B_{30}) \\
 C_{01} &= (A_{00} * B_{01}) + (A_{01} * B_{11}) + (A_{02} * B_{21}) + (A_{03} * B_{31}) \\
 C_{02} &= (A_{00} * B_{02}) + (A_{01} * B_{12}) + (A_{02} * B_{22}) + (A_{03} * B_{32}) \\
 C_{03} &= (A_{00} * B_{03}) + (A_{01} * B_{13}) + (A_{02} * B_{23}) + (A_{03} * B_{33}) \\
 \\
 C_{10} &= (A_{10} * B_{00}) + (A_{11} * B_{10}) + (A_{12} * B_{20}) + (A_{13} * B_{30}) \\
 C_{11} &= (A_{10} * B_{01}) + (A_{11} * B_{11}) + (A_{12} * B_{21}) + (A_{13} * B_{31}) \\
 C_{12} &= (A_{10} * B_{02}) + (A_{11} * B_{12}) + (A_{12} * B_{22}) + (A_{13} * B_{32}) \\
 C_{13} &= (A_{10} * B_{03}) + (A_{11} * B_{13}) + (A_{12} * B_{23}) + (A_{13} * B_{33}) \\
 \\
 C_{20} &= (A_{20} * B_{00}) + (A_{21} * B_{10}) + (A_{22} * B_{20}) + (A_{23} * B_{30}) \\
 C_{21} &= (A_{20} * B_{01}) + (A_{21} * B_{11}) + (A_{22} * B_{21}) + (A_{23} * B_{31}) \\
 C_{22} &= (A_{20} * B_{02}) + (A_{21} * B_{12}) + (A_{22} * B_{22}) + (A_{23} * B_{32}) \\
 C_{23} &= (A_{20} * B_{03}) + (A_{21} * B_{13}) + (A_{22} * B_{23}) + (A_{23} * B_{33}) \\
 \\
 C_{30} &= (A_{30} * B_{00}) + (A_{31} * B_{10}) + (A_{32} * B_{20}) + (A_{33} * B_{30}) \\
 C_{31} &= (A_{30} * B_{01}) + (A_{31} * B_{11}) + (A_{32} * B_{21}) + (A_{33} * B_{31}) \\
 C_{32} &= (A_{30} * B_{02}) + (A_{31} * B_{12}) + (A_{32} * B_{22}) + (A_{33} * B_{32}) \\
 C_{33} &= (A_{30} * B_{03}) + (A_{31} * B_{13}) + (A_{32} * B_{23}) + (A_{33} * B_{33})
 \end{aligned}$$

Figure 15: [4x4] Matrix Multiplication.

To obtain the execution time for running the algorithm on one processor, I gave the processor access to all of matrix A and matrix B. The program I developed for this algorithm is in Appendix B. I started out by writing individual programs for each of the three different sized matrices and each of the three different ways. While developing the first few programs, it occurred to me that this might affect the results for the execution times of the algorithm. What I needed was a program that accomplished the three

different types of matrix-multiplication on all three of the matrix sizes. Also, the program must accomplish it with as little different overhead as possible.

As I developed the program, I would test it numerous times. I started to get count values for the different matrices. The values I was getting were very close to the speedups I expected. The problem I was having was that I could not get the program to work exactly like I wanted it to. It would give me results for one matrix size and not the others. As I made changes to correct the problem, another problem would be introduced. Rather than spend tremendous amount of time on trying to resolve these problems. I chose to continue with the writing of the thesis. **Figure 16** shows the results of the execution times.

Matrix Size	One Processor	Dual Processor	Dual Processor Using Shared-Memory
[4x4] Matrix	418	273	386
[8x8] Matrix	1909	1018	1493
[16x16] Matrix	12397	6219	8414

Figure 16: Matrix-Multiplication Execution Times (clock cycles).

The flowchart for the one-processor matrix multiplication algorithm is shown in Diagram IX in Appendix A. In the program the micro-controller would have access to all of matrix A and matrix B. The program would be loaded into the memory of one micro-controller. The program is then started. After the program went through its initializations and loading of variables, the timer would start and it would simply calculate the results for matrix C by the previously stated equations. Once the results were calculated they were moved to shared-memory and the timer was stopped. The last step of the program was to read the values in the timer.

The next step was the program that used two processors to do the matrix multiplication. This was accomplished by giving Processor A access to the first half of matrix A (half of the rows) and access to all of matrix B. Processor A computes the results for the first half of the C matrix. Processor B was given access to the second half of matrix A and all of matrix B. Processor B computes the results for the second half of the C matrix. The dashed line in **Figure 17** shows the separation for the 4x4 matrices:

Matrix A				*	Matrix B				=	Matrix C			
A ₀₀	A ₀₁	A ₀₂	A ₀₃		B ₀₀	B ₀₁	B ₀₂	B ₀₃		C ₀₀	C ₀₁	C ₀₂	C ₀₃
A ₁₀	A ₁₁	A ₁₂	A ₁₃		B ₁₀	B ₁₁	B ₁₂	B ₁₃		C ₁₀	C ₁₁	C ₁₂	C ₁₃
A ₂₀	A ₂₁	A ₂₂	A ₂₃		B ₂₀	B ₂₁	B ₂₂	B ₂₃		C ₂₀	C ₂₁	C ₂₂	C ₂₃
A ₃₀	A ₃₁	A ₃₂	A ₃₃		B ₃₀	B ₃₁	B ₃₂	B ₃₃		C ₃₀	C ₃₁	C ₃₂	C ₃₃

Figure 17: [4x4] Matrix Multiplication on dual processors.

The flowchart for this program is shown in Diagram X in Appendix A. Since the only difference between the program in each processor is what portion of matrix A is accessible, I developed the program to load on the correct portion of the matrix that the individual processor needed. I accomplished this by using a subroutine that required a start and finish location for the values of the matrix. The start and finish locations were determined by which processor was using the program. This was all controlled by the settings placed in the beginning of the program. To gain a better understanding of what I did, a review of the program in Appendix B will be necessary.

In order to obtain the most accurate times as possible, I chose to have the processor control the start and stop of the timer. I accomplished this by using semaphores. These semaphores would be used to signal the other processor when it could continue with its operations. This would allow the initialization and loading of variables by both processors without having to include these operations in the execution times.

Processor A would start by loading its start values and then would enter into a wait state. It would exit that Wait State when Processor B signaled that it had finished loading variables and was now in its own wait state. Now Processor A would start the timer, signal Processor B to start executing, and then start its own execution. Once Processor A completed its execution it would check to see if Processor B was complete. If Processor B were complete, Processor A would stop and read the count value of the timer. Otherwise, Processor A would enter a wait state until Processor B completed its execution.

The final program would give timing results for using shared memory as well as the dual processors. The flowchart for this process is shown in Diagram XI in Appendix A. In this program, both the A matrix and the B matrix are split up. The separation of the matrices is shown in **Figure 18**.

$$\begin{array}{|c|c|c|c|} \hline \text{Matrix A} & & & \\ \hline A_{00} & A_{01} & A_{02} & A_{03} \\ \hline A_{10} & A_{11} & A_{12} & A_{13} \\ \hline A_{20} & A_{21} & A_{22} & A_{23} \\ \hline A_{30} & A_{31} & A_{32} & A_{33} \\ \hline \end{array} * \begin{array}{|c|c|c|c|} \hline \text{Matrix B} & & & \\ \hline B_{00} & B_{01} & B_{02} & B_{03} \\ \hline B_{10} & B_{11} & B_{12} & B_{13} \\ \hline B_{20} & B_{21} & B_{22} & B_{23} \\ \hline B_{30} & B_{31} & B_{32} & B_{33} \\ \hline \end{array} = \begin{array}{|c|c|c|c|} \hline \text{Matrix C} & & & \\ \hline C_{00} & C_{01} & C_{02} & C_{03} \\ \hline C_{10} & C_{11} & C_{12} & C_{13} \\ \hline C_{20} & C_{21} & C_{22} & C_{23} \\ \hline C_{30} & C_{31} & C_{32} & C_{33} \\ \hline \end{array}$$

Figure 18: [4x4] Matrix Multiplication on dual processors using shared-memory.

In this program, Processor A has access to the first half of matrix A and the first half of matrix B. Processor A computes the results for the first half of the C matrix. Processor B has access to the second half of matrix A and the second half of matrix B. Processor B computes the results for the second half of the C matrix.

The difference between the program and the dual processor program is that each processor does not have all of the data to complete the computations for the C matrix. For instance, for Processor A to compute the value of C_{00} it would need access to B_{20} and B_{30} . Since Processor B has access to these locations, the data in these locations must be transferred to Processor A through the shared-memory. During the computation portion of the program, each processor must finish the calculations that are possible and wait until it is given the needed data.

I tried to develop the program in a fashion that would allow one processor to make its possible calculations while the other processor was sending and receiving data from the shared-memory. To ensure that a processor did not retrieve the data before it was placed in shared-memory, I used the semaphores to place the processor into a wait state until the required data was available. Once again, a better understanding can be obtained by reviewing the program in Appendix B.

I gave a description on how I implemented the different programs by showing how it was done on a $[4 \times 4]$ matrix. I developed the program to compute the results for the $[8 \times 8]$ matrix. To get the results for the $[4 \times 4]$ case, I added code to reduce the number of loops in the matrix-multiplication routines. I increased the number of loops in the matrix-multiplication routines to get the results for the $[16 \times 16]$. In order to produce valid timing results, I tried to do this in a way that makes the overall operation of the program

to remain the same for all size matrices. The theory of adding and subtracting loops was sound, but the code to keep the operations the same became quite complex. This is what is causing the delay in the development of a fully operational program.

CHAPTER 4

PERFORMANCE EVALUATIONS

4.1 Matrix Multiplication

As I stated earlier, I am getting consistent results from the current program. However, I am still unable to remove all of the bugs from the program to produce results for all of the program operations. I noticed that overall the results I obtained do not change as I make changes to the program. When I make changes to the program I am able to get results for different size matrices. Several times I was able to get results for more than one size matrix and the results were quite similar to the ones I was getting when I was only able to produce results for one size matrix. Since I am getting results like I expected, I could continue to troubleshoot the current program. With time, I expect to have all the problems worked out of the program. The speedups, based on the results in **Figure 16** are:

Matrix Size	One Processor	Dual Processor	Dual Processor Using Shared-Memory
[4x4] Matrix	418	273	386
[8x8] Matrix	1909	1018	1493
[16x16] Matrix	12307	6219	8414

Figure 16: Matrix-Multiplication Execution Times (clock cycles).

CHAPTER 5

CONCLUSIONS

Based on the results I achieved with the matrix multiplication algorithm, I am concluding that there is an overall effective speedup in using a SMPPS. Overall I would rate this project as a success. I accomplished the first two objectives and made significant progress on the third objective. This project gave me the opportunity to work on a project from the design phase to the testing phase and the opportunity to apply the knowledge I acquired while at NJIT as well as hone my engineering skills.

During the project, I conquered many hurdles and had the chance to have an impact on the curriculum of undergraduate students. Many of the discoveries I made while designing and implementing the micro-controller were beneficial to the EE 393 Lab. Teaching the EE 393 Lab over the summer session was equally rewarding. Not only was I able to increase my understanding of the micro-controller, but I was enabled to impart to the students the knowledge I had gained while working on the project.

The SMPPS project leaves the door open for future areas of study and research. Basing a new system with more processors on this design would present an interesting challenge. Also, developing more parallel algorithms for the system would present an equally challenging obstacle. The possibilities that can be pursued are virtually limitless.

APPENDIX A

DIAGRAMS

Appendix A has the following diagrams:

Dual-Processor Shared-Memory Block Diagram (I)

Dual-Processor Shared-Memory Block Diagram (II)

Original Control Logic Design

1-2 DeMultiplexor Logic

2-1 Multiplexor Logic

Final Shared-Memory Control Logic Design

Default Symbol CTEST Logic

Timer Control Logic

Flow Chart I – One Processor Operation

Flow Chart II – Dual-Processor Operation

Flow Chart III – Dual-Processor Operation using Shared-Memory

Diagram 1

**Dual-Processor Shared-Memory
Block Diagram (I)**

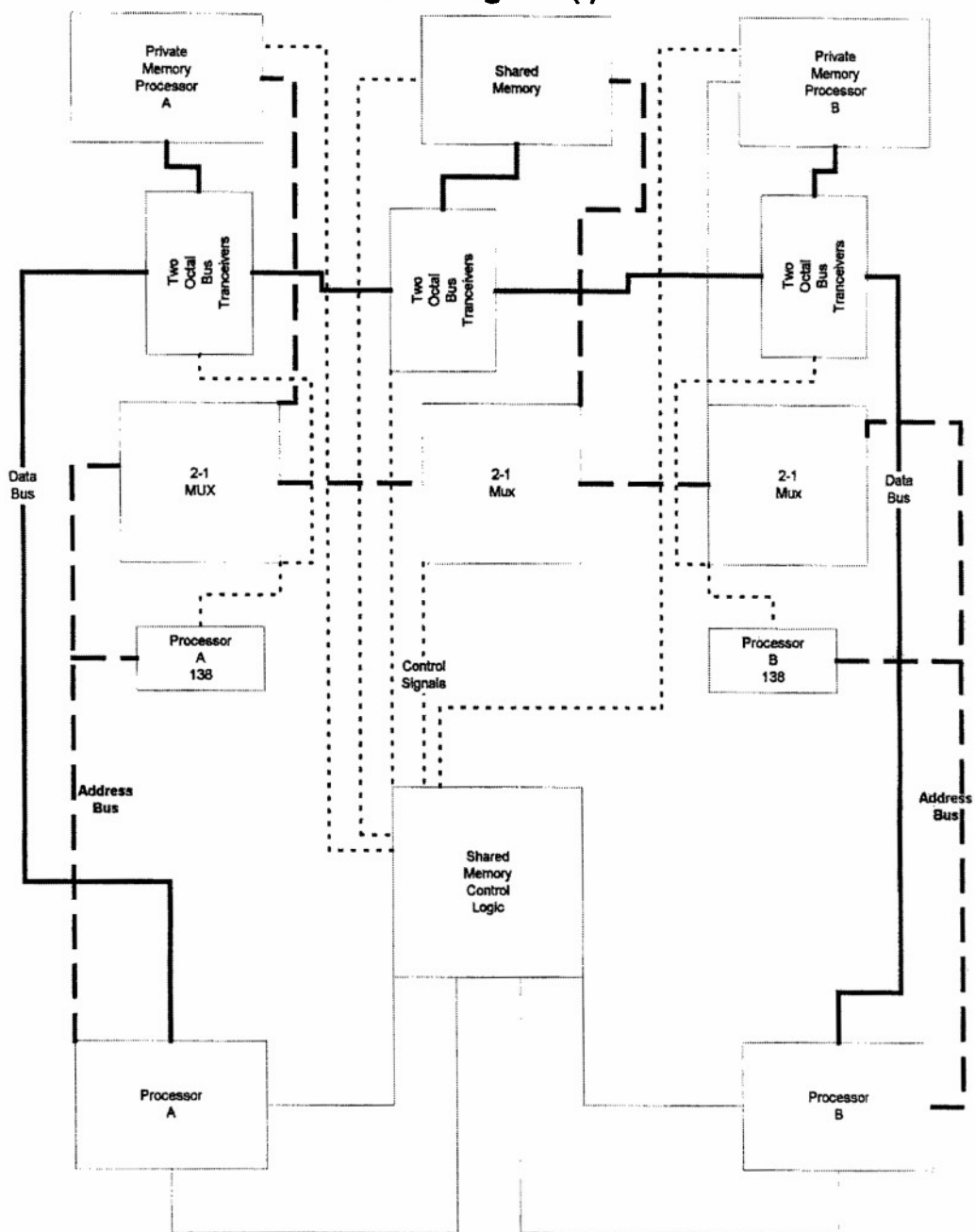


Diagram 2

**Dual-Processor Shared-Memory
Block Diagram (II)**

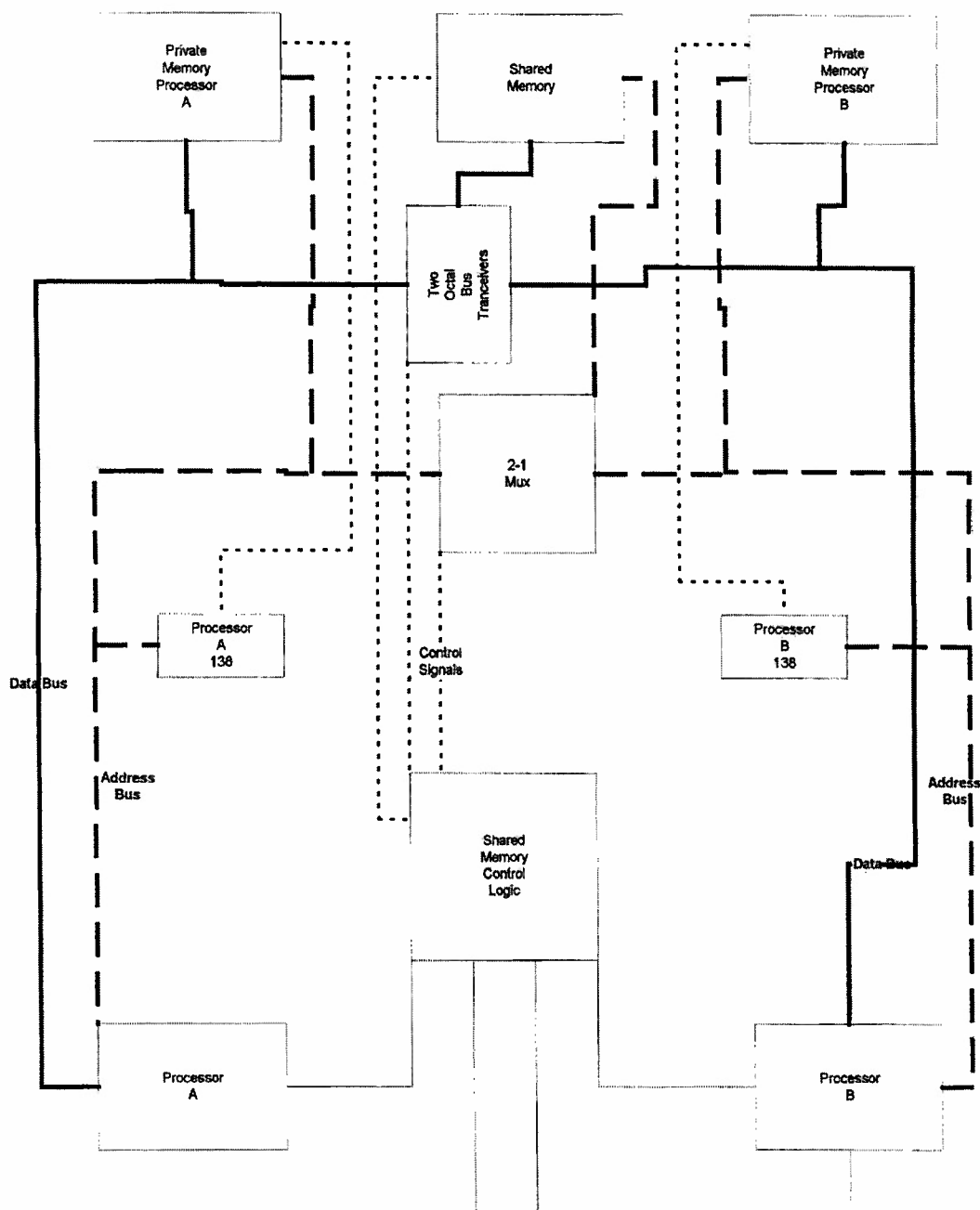
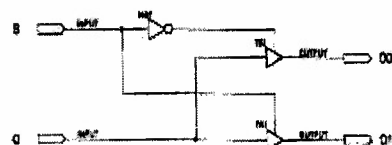


Diagram 4



1-2 DEMUX

TITLE Shared Memory Logic				
COMPANY N&T CDE Masters				
DESIGNER Eric W. Stoud				
SEE	REV	DATE	NUMBER	REV
0	1	5.10.88	1	1
0	1	5.10.88	1	1
0	1	5.10.88	1	1
0	1	5.10.88	1	1

Diagram 5

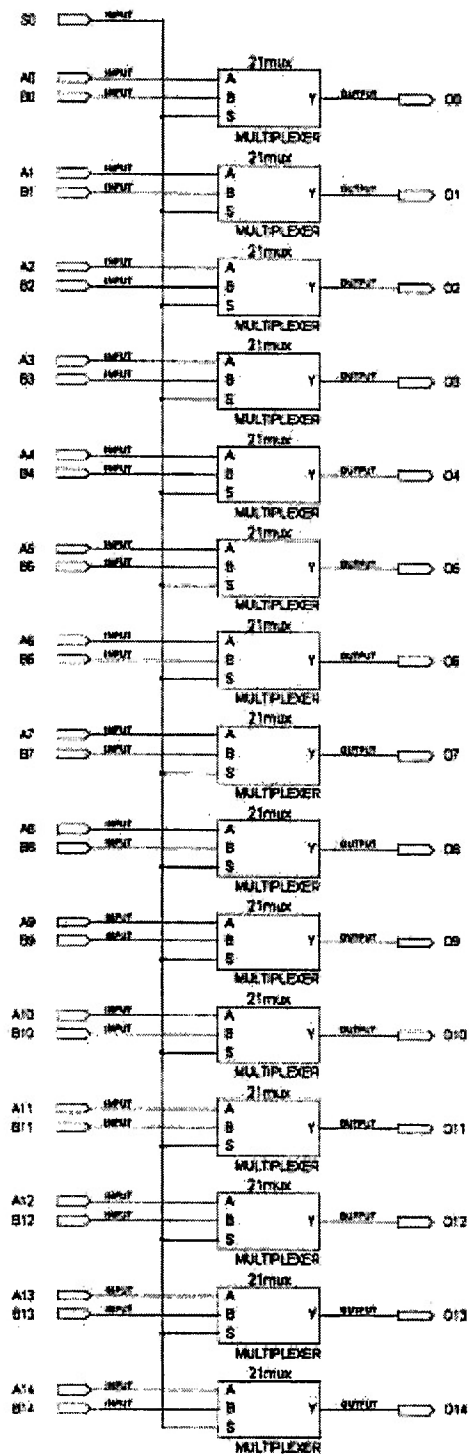
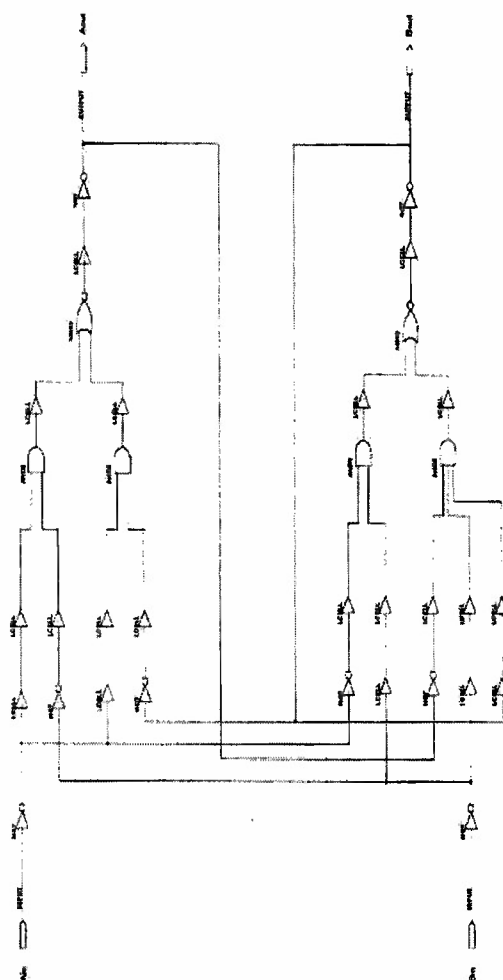


Diagram 7



**A/S & /DTACK
Control Logic**

NAME	Shore Memory Logic
DESCRIPTION	NYT CDE Masters
ADDRESS	E's - 1 - 1000
DATA	1 - 1000
CONTROL	1 - 1000
STATUS	1 - 1000
OUTPUT	1 - 1000

Diagram 8

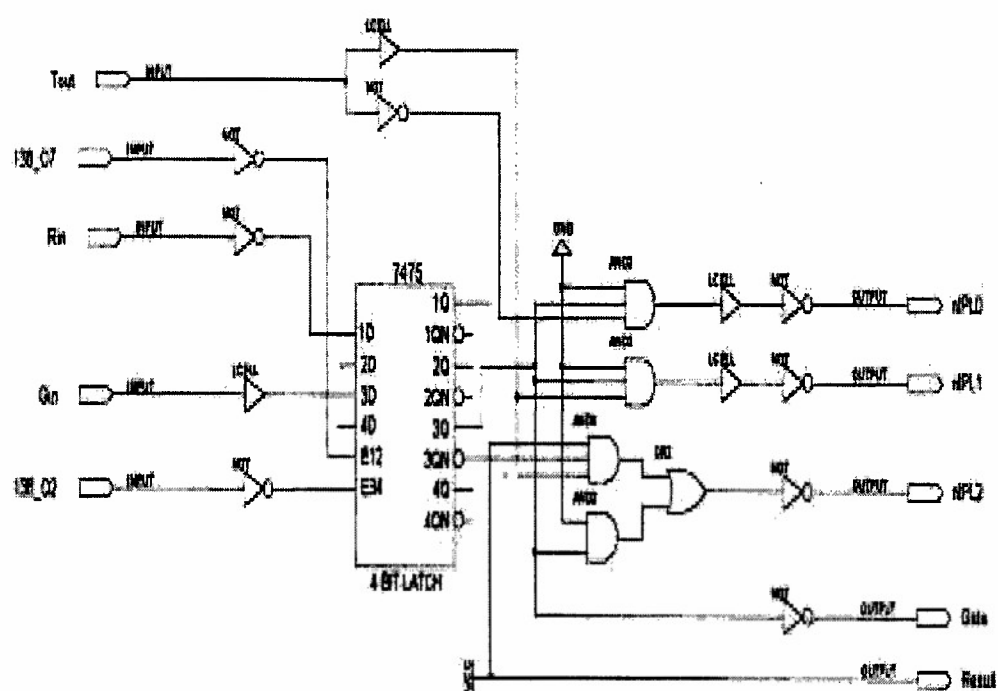


Diagram 9

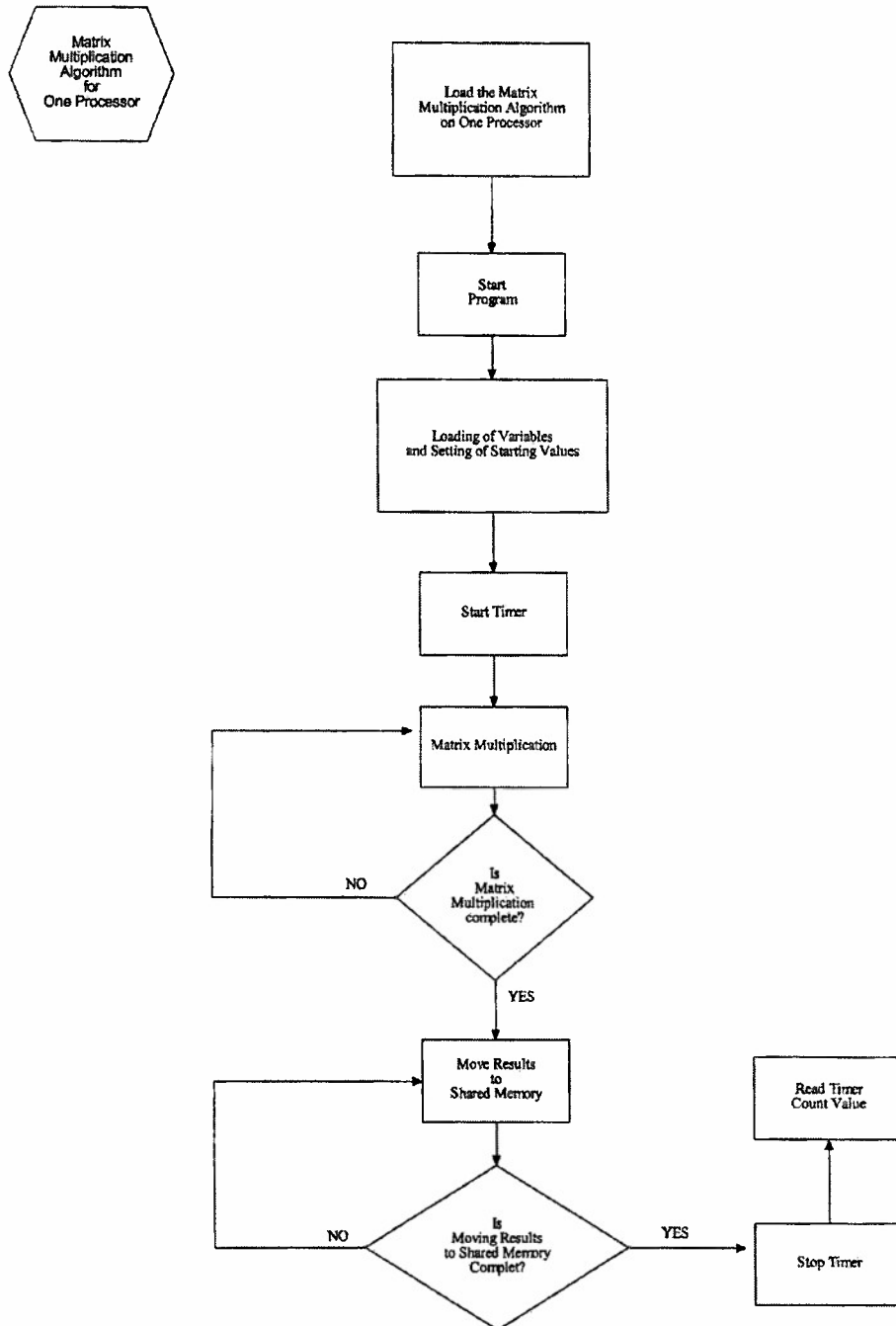


Diagram 10

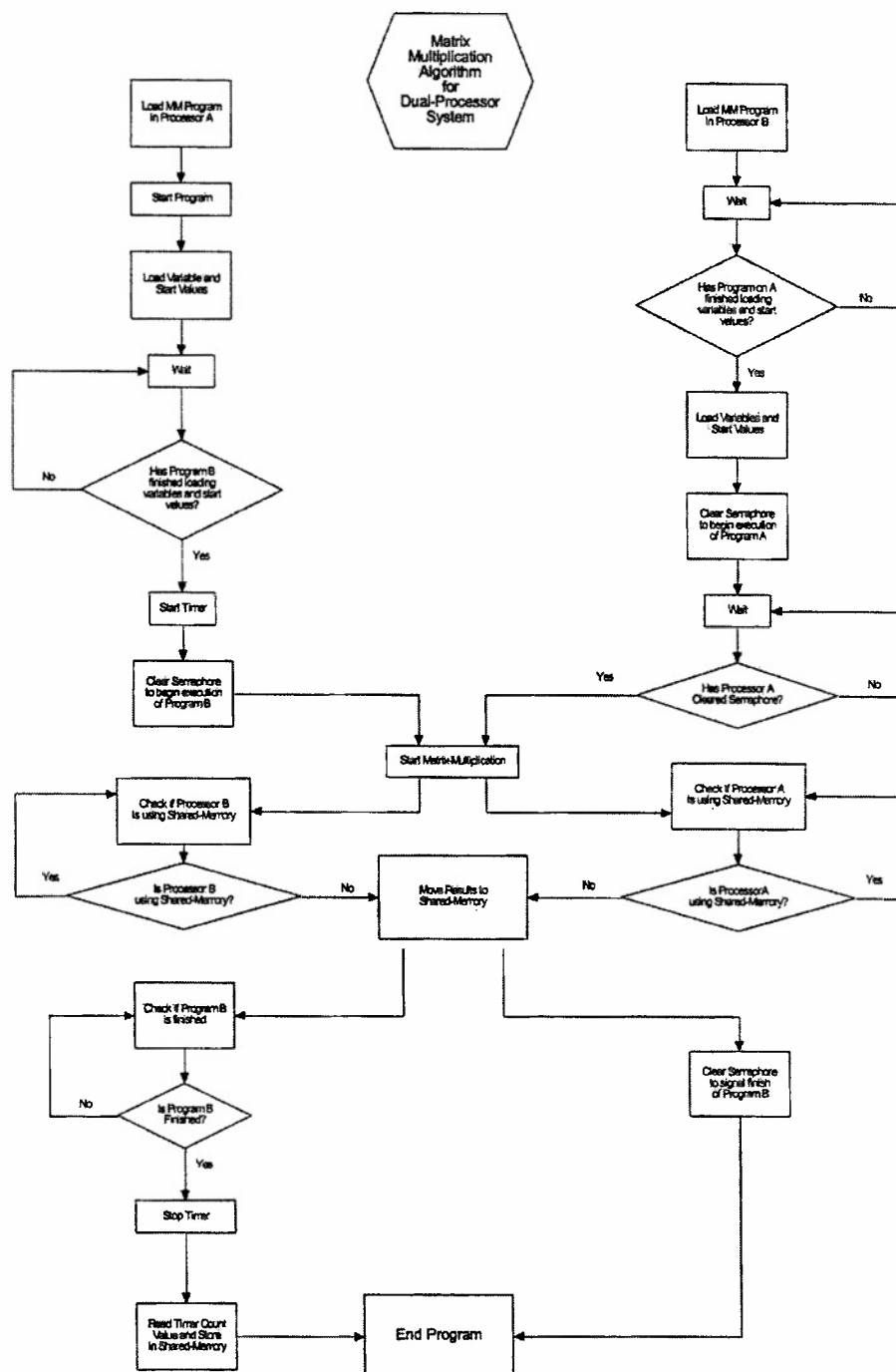
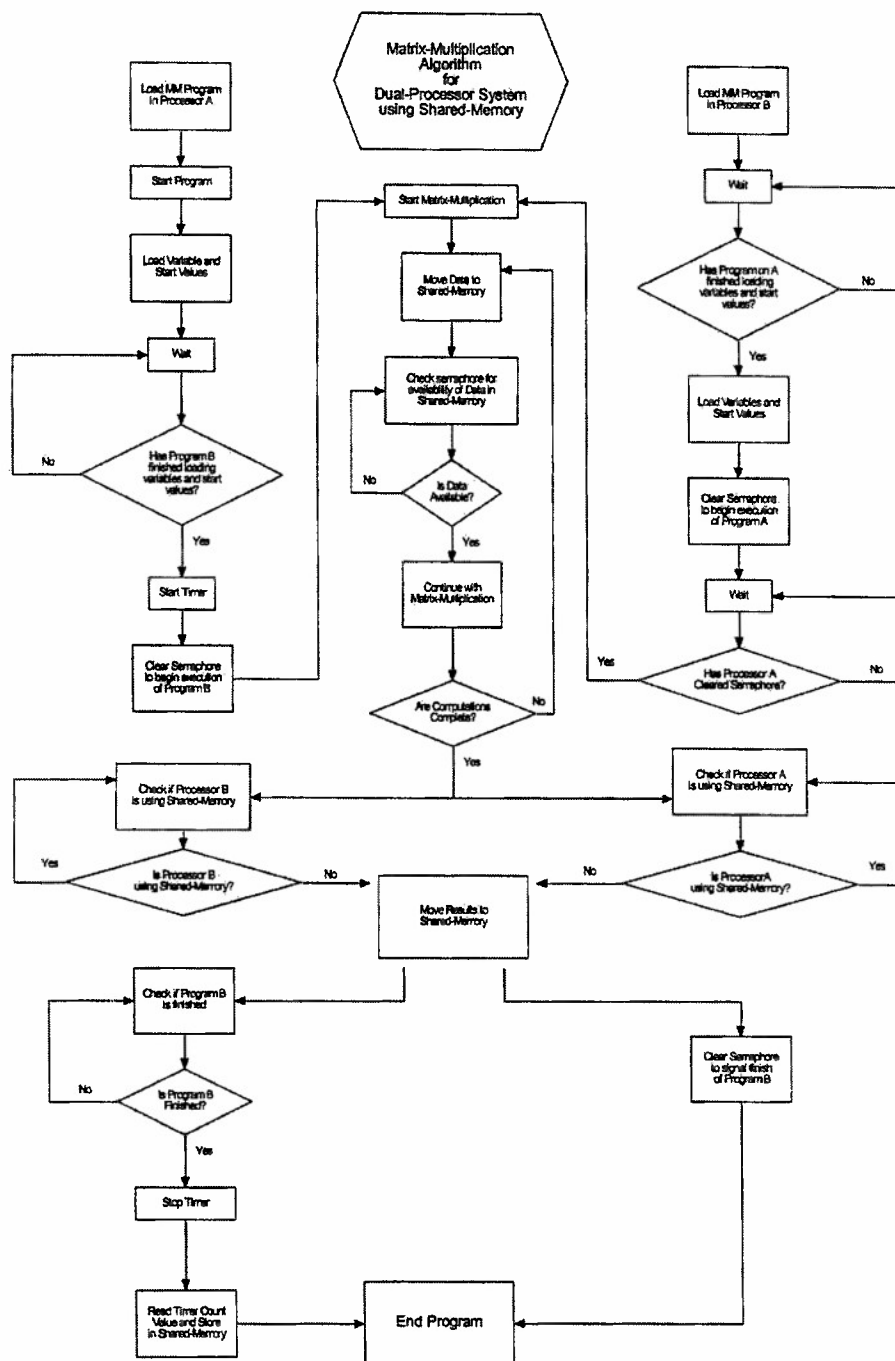


Diagram 11



APPENDIX B

Programs

This is the program for a [4x4], [8x8], and [16x16] Matrix-Multiplication on One Processor System, a Dual-Processor System, and a Dual-Processor System using Shared-Memory.

```

; This is a Matrix Multiplication Algorithm
;
;   PA: Processor A
;   PB: Processor B
;
;   PA[ A11 A12 A13 A14 A15 A16 A17 A18 ]
;   PA[ A21 A22 A23 A24 A15 A16 A17 A18 ]
;   PA[ A31 A32 A33 A34 A15 A16 A17 A18 ]
;   PA[ A41 A42 A43 A44 A15 A16 A17 A18 ]
;   PB[ A51 A52 A53 A54 A15 A16 A17 A18 ]
;   PB[ A61 A62 A63 A64 A15 A16 A17 A18 ]
;   PB[ A71 A72 A73 A74 A15 A16 A17 A18 ]
;   PB[ A81 A82 A83 A84 A15 A16 A17 A18 ]
;
;   PA[ B11 B12 B13 B14 B15 B16 B17 B18 ]
;   PA[ B21 B22 B23 B24 B25 B26 B27 B28 ]
;   PA[ B31 B32 B33 B34 B35 B36 B37 B38 ]
;   PA[ B41 B42 B43 B44 B45 B46 B47 B48 ]
;   PB[ B51 B52 B53 B54 B55 B56 B57 B58 ]
;   PB[ B61 B62 B63 B64 B65 B66 B67 B68 ]
;   PB[ B71 B72 B73 B74 B75 B76 B77 B78 ]
;   PB[ B81 B82 B83 B84 B85 B86 B87 B88 ]
;
; Matrix Type (1)4x4,(2)8x8,(4)16x16
MMT      EQU      $02
; Matrix Shared (0)NO,1(YES)
MMTS      EQU      $01
; Matrix B Shared (0)NO,(1)YES
MMTSA     EQU      $00
; Program (0)A,(1)B
PROC      EQU      $00
; Matrix Starting Values
ASRT      EQU      $14000
BSRT      EQU      $14100
CSRT      EQU      $14200
LMAVal    EQU      $03
LMBVal    EQU      $03
LMBVla    EQU      $02
; Moving Shared Memory (Start) (End)
MRVA      EQU      $14200
MRVB      EQU      $14240

; Variable Equates
A00      EQU      $14000
A01      EQU      $14001
A02      EQU      $14002
A03      EQU      $14003
A04      EQU      $14004
A05      EQU      $14005
A06      EQU      $14006
A07      EQU      $14007
A08      EQU      $14008
A09      EQU      $14009
A0A      EQU      $1400A
A0B      EQU      $1400B

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A0D	EQU	\$1400D
A0E	EQU	\$1400E
A0F	EQU	\$1400F
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A1B	EQU	\$1401B
A1C	EQU	\$1401C
A1D	EQU	\$1401D
A1E	EQU	\$1401E
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A26	EQU	\$14026
A27	EQU	\$14027
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A29	EQU	\$14029
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A2D	EQU	\$1402D
A2E	EQU	\$1402E
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A3A	EQU	\$1403A
A3B	EQU	\$1403B
A3C	EQU	\$1403C
A3D	EQU	\$1403D
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A41	EQU	\$14041
A42	EQU	\$14042
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A45	EQU	\$14045
A46	EQU	\$14046
A47	EQU	\$14047
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A49	EQU	\$14049
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A4B	EQU	\$1404B
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AC7	EQU	\$140C7
AC8	EQU	\$140C8
AC9	EQU	\$140C9
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ACC	EQU	\$140CC
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ACE	EQU	\$140CE
ACF	EQU	\$140CF
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AD1	EQU	\$140D1
AD2	EQU	\$140D2
AD3	EQU	\$140D3
AD4	EQU	\$140D4
AD5	EQU	\$140D5
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AD7	EQU	\$140D7
AD8	EQU	\$140D8
AD9	EQU	\$140D9
ADA	EQU	\$140DA
ADB	EQU	\$140DB
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ADF	EQU	\$140DF
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AE5	EQU	\$140E5
AE6	EQU	\$140E6
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AF4	EQU	\$140F4
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BA0	EQU	\$1410A
BB0	EQU	\$1410B
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B32	EQU	\$14123
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B62	EQU	\$14126
B72	EQU	\$14127

B82	EQU	\$14128
B92	EQU	\$14129
BA2	EQU	\$1412A
BB2	EQU	\$1412B
BC2	EQU	\$1412C
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BE2	EQU	\$1412E
BF2	EQU	\$1412F
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B13	EQU	\$14131
B23	EQU	\$14132
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BC5	EQU	\$1415C
BD5	EQU	\$1415D
BE5	EQU	\$1415E
BF5	EQU	\$1415F
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B16	EQU	\$14161
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B66	EQU	\$14166
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BC6	EQU	\$1416C
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BE6	EQU	\$1416E
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C5C	EQU	\$1425C
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C6D	EQU	\$1426D
C6E	EQU	\$1426E
C6F	EQU	\$1426F
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C79	EQU	\$14279
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C7C	EQU	\$1427C

C7D	EQU	\$1427D
C7E	EQU	\$1427E
C7F	EQU	\$1427F
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SC33	EQU	\$28233
SC34	EQU	\$28234
SC35	EQU	\$28235
SC36	EQU	\$28236
SC37	EQU	\$28237
SC38	EQU	\$28238
SC39	EQU	\$28239
SC3A	EQU	\$2823A
SC3B	EQU	\$2823B
SC3C	EQU	\$2823C
SC3D	EQU	\$2823D
SC3E	EQU	\$2823E
SC3F	EQU	\$2823F
SC40	EQU	\$28240
SC41	EQU	\$28241
SC42	EQU	\$28242
SC43	EQU	\$28243
SC44	EQU	\$28244
SC45	EQU	\$28245
SC46	EQU	\$28246
SC47	EQU	\$28247
SC48	EQU	\$28248
SC49	EQU	\$28249
SC4A	EQU	\$2824A
SC4B	EQU	\$2824B
SC4C	EQU	\$2824C
SC4D	EQU	\$2824D
SC4E	EQU	\$2824E
SC4F	EQU	\$2824F
SC50	EQU	\$28250
SC51	EQU	\$28251
SC52	EQU	\$28252
SC53	EQU	\$28253
SC54	EQU	\$28254
SC55	EQU	\$28255
SC56	EQU	\$28256
SC57	EQU	\$28257
SC58	EQU	\$28258
SC59	EQU	\$28259
SC5A	EQU	\$2825A
SC5B	EQU	\$2825B
SC5C	EQU	\$2825C
SC5D	EQU	\$2825D
SC5E	EQU	\$2825E

SC5F	EQU	\$2825F
SC60	EQU	\$28260
SC61	EQU	\$28261
SC62	EQU	\$28262
SC63	EQU	\$28263
SC64	EQU	\$28264
SC65	EQU	\$28265
SC66	EQU	\$28266
SC67	EQU	\$28267
SC68	EQU	\$28268
SC69	EQU	\$28269
SC6A	EQU	\$2826A
SC6B	EQU	\$2826B
SC6C	EQU	\$2826C
SC6D	EQU	\$2826D
SC6E	EQU	\$2826E
SC6F	EQU	\$2826F
SC70	EQU	\$28270
SC71	EQU	\$28271
SC72	EQU	\$28272
SC73	EQU	\$28273
SC74	EQU	\$28274
SC75	EQU	\$28275
SC76	EQU	\$28276
SC77	EQU	\$28277
SC78	EQU	\$28278
SC79	EQU	\$28279
SC7A	EQU	\$2827A
SC7B	EQU	\$2827B
SC7C	EQU	\$2827C
SC7D	EQU	\$2827D
SC7E	EQU	\$2827E
SC7F	EQU	\$2827F
SC80	EQU	\$28280
SC81	EQU	\$28281
SC82	EQU	\$28282
SC83	EQU	\$28283
SC84	EQU	\$28284
SC85	EQU	\$28285
SC86	EQU	\$28286
SC87	EQU	\$28287
SC88	EQU	\$28288
SC89	EQU	\$28289
SC8A	EQU	\$2828A
SC8B	EQU	\$2828B
SC8C	EQU	\$2828C
SC8D	EQU	\$2828D
SC8E	EQU	\$2828E
SC8F	EQU	\$2828F
SC90	EQU	\$28290
SC91	EQU	\$28291
SC92	EQU	\$28292
SC93	EQU	\$28293
SC94	EQU	\$28294
SC95	EQU	\$28295
SC96	EQU	\$28296
SC97	EQU	\$28297

SC98	EQU	\$28298
SC99	EQU	\$28299
SC9A	EQU	\$2829A
SC9B	EQU	\$2829B
SC9C	EQU	\$2829C
SC9D	EQU	\$2829D
SC9E	EQU	\$2829E
SC9F	EQU	\$2829F
SCA0	EQU	\$282A0
SCA1	EQU	\$282A1
SCA2	EQU	\$282A2
SCA3	EQU	\$282A3
SCA4	EQU	\$282A4
SCA5	EQU	\$282A5
SCA6	EQU	\$282A6
SCA7	EQU	\$282A7
SCA8	EQU	\$282A8
SCA9	EQU	\$282A9
SCAA	EQU	\$282AA
SCAB	EQU	\$282AB
SCAC	EQU	\$282AC
SCAD	EQU	\$282AD
SCAE	EQU	\$282AE
SCAF	EQU	\$282AF
SCB0	EQU	\$282B0
SCB1	EQU	\$282B1
SCB2	EQU	\$282B2
SCB3	EQU	\$282B3
SCB4	EQU	\$282B4
SCB5	EQU	\$282B5
SCB6	EQU	\$282B6
SCB7	EQU	\$282B7
SCB8	EQU	\$282B8
SCB9	EQU	\$282B9
SCBA	EQU	\$282BA
SCBB	EQU	\$282BB
SCBC	EQU	\$282BC
SCBD	EQU	\$282BD
SCBE	EQU	\$282BE
SCBF	EQU	\$282BF
SCC0	EQU	\$282C0
SCC1	EQU	\$282C1
SCC2	EQU	\$282C2
SCC3	EQU	\$282C3
SCC4	EQU	\$282C4
SCC5	EQU	\$282C5
SCC6	EQU	\$282C6
SCC7	EQU	\$282C7
SCC8	EQU	\$282C8
SCC9	EQU	\$282C9
SCCA	EQU	\$282CA
SCCB	EQU	\$282CB
SCCC	EQU	\$282CC
SCCD	EQU	\$282CD
SCCE	EQU	\$282CE
SCCF	EQU	\$282CF
SCD0	EQU	\$282D0

SCD1	EQU	\$282D1
SCD2	EQU	\$282D2
SCD3	EQU	\$282D3
SCD4	EQU	\$282D4
SCD5	EQU	\$282D5
SCD6	EQU	\$282D6
SCD7	EQU	\$282D7
SCD8	EQU	\$282D8
SCD9	EQU	\$282D9
SCDA	EQU	\$282DA
SCDB	EQU	\$282DB
SCDC	EQU	\$282DC
SCDD	EQU	\$282DD
SCDE	EQU	\$282DE
SCDF	EQU	\$282DF
SCE0	EQU	\$282E0
SCE1	EQU	\$282E1
SCE2	EQU	\$282E2
SCE3	EQU	\$282E3
SCE4	EQU	\$282E4
SCE5	EQU	\$282E5
SCE6	EQU	\$282E6
SCE7	EQU	\$282E7
SCE8	EQU	\$282E8
SCE9	EQU	\$282E9
SCEA	EQU	\$282EA
SCEB	EQU	\$282EB
SCEC	EQU	\$282EC
SCED	EQU	\$282ED
SCEE	EQU	\$282EE
SCEF	EQU	\$282EF
SCF0	EQU	\$282F0
SCF1	EQU	\$282F1
SCF2	EQU	\$282F2
SCF3	EQU	\$282F3
SCF4	EQU	\$282F4
SCF5	EQU	\$282F5
SCF6	EQU	\$282F6
SCF7	EQU	\$282F7
SCF8	EQU	\$282F8
SCF9	EQU	\$282F9
SCFA	EQU	\$282FA
SCFB	EQU	\$282FB
SCFC	EQU	\$282FC
SCFD	EQU	\$282FD
SCFE	EQU	\$282FE
SCFF	EQU	\$282FF

;

; Semaphores

SML1A	EQU	\$28300
SML2A	EQU	\$28301
SML1B	EQU	\$28302
SML2B	EQU	\$28303
SMLC	EQU	\$28304
SM1S	EQU	\$28305
SM2F	EQU	\$28306
SM2S	EQU	\$28307

```

;
LCW          EQU      $30003
WC1LB        EQU      $30000
WC1MB        EQU      $30000
RC1LB        EQU      $30000
RC1MB        EQU      $30000
GtRd         EQU      $8000
GtRda        EQU      $38000
ICNT         EQU      $17000
RCNT         EQU      $17004
;
;
; Matrix Control Equates
;   Byte equates
ACNT          EQU      $17010
MMWL          EQU      $17011
MMTA          EQU      $17012
LMASB         EQU      $17013
LMBSB         EQU      $17014
ZERO          EQU      $17015
PROCa         EQU      $17016
MMTSB         EQU      $17017
MMTSC         EQU      $17018
PrBa          EQU      $17019
PrBb          EQU      $17020
MMTB          EQU      $17021
;   Word equates
BCNT          EQU      $17040
BSCNT         EQU      $17042
;   Long Equates
MCSVb         EQU      $17050
LMAS          EQU      $17054
LMBS          EQU      $17058
ACRT          EQU      $1705C
BCRT          EQU      $17060
CCRT          EQU      $17064
ACRTa         EQU      $17068
BCRTa         EQU      $1706C
CCRTa         EQU      $17070
ACRTb         EQU      $17074
BCRTb         EQU      $17078
CCRTb         EQU      $1707C
ACRTc         EQU      $17080
BCRTc         EQU      $17084
CCRTc         EQU      $17088
SD5           EQU      $1708C
SD6           EQU      $17090
; Matrix A Load Values
LMAVA         EQU      $1708C
LMAVB         EQU      $17090
; Matrix B Load Values
LMBVA         EQU      $17070
LMBVB         EQU      $17074
;ASCNT
;CSCNT
;CCNT
;

```

```

                                ORG      $10000
; Step A1
; Clearing of Registers
;
START      clr.l   D0
           clr.l   D1
           clr.l   D2
           clr.l   D3
           clr.l   D4
           clr.l   D5
           sub.l   A1,A1
           sub.l   A2,A2
           sub.l   A3,A3
           sub.l   A4,A4
           sub.l   A5,A5
;
;
; Routine for clearing $14000-$140C0,$28000-$280C0,$28100-$28106
;
           move.l   #$17000,A5
           move.l   #$17100,A4
           BSR      MCLR
           move.b   #PROC,(PROCa)
           cmpi.b   #$01,(PROCa)
           beq      MC0
           move.l   #$28000,A5
           move.l   #$28300,A4
           BSR      MCLR
           move.l   #$28300,A5
           move.l   #$28308,A4
           BSR      MCLR
MC0         move.l   #$14000,A5
           move.l   #$14300,A4
           BSR      MCLR
;
; Matrix Load variable
           move.l   #ASRT,(LMAVA)
           move.l   #ASRT,(LMAVB)
           move.l   #ASRT,(LMAS)
           move.l   #BSRT,(LMBVA)
           move.l   #BSRT,(LMBVB)
           move.l   #BSRT,(LMBS)
           move.b   #LMBVAL,D0
           move.b   #$00,(ZERO)
           move.b   #MMTS,(MMTSC)
           move.b   #MMTSA,(MMTSB)
           cmpi.b   #$01,(MMTSB)
           beq      LVA
           move.b   #MMT,(MMTA)
           move.b   #MMT,(MMTB)
           bra      LVB
LVA         cmpi.b   #$04,(MMTA)
           beq      LVA1
           move.b   #$01,(MMTA)
           bra      LVA2
LVA1        move.b   #$02,(MMTA)
LVA2        move.b   #$01,(MMTB)

```

```

LVB      cmpi.b  #$01, (MMTA)
         beq     LM4
         cmpi.b  #$02, (MMTA)
         beq     LM8
         cmpi.b  #$04, (MMTA)
         beq     LM16
LM4       cmpi.b  #$01, (MMTB)
         beq     LM4b
         addi.l  #$04, (LMAS)
         addi.l  #$04, (LMBS)
         move.b  #$04, (MASB)
         move.b  #$04, (MBSB)
         cmpi.b  #$01, (MTSC)
         beq     LM4a
         addi.l  #$40, (MAVB)
         move.w  #$0010, (BSCNT)
         BRA     LM4a3
LM4a      cmpi.b  #$01, (PROCa)
         beq     LM4a1
         addi.l  #$20, (MAVB)
         bra     LM4a2
LM4a1     addi.l  #$20, (MAVA)
         addi.l  #$20, (MAS)
         addi.l  #$40, (MAVB)
LM4a2     move.w  #$0010, (BSCNT)
LM4a3     addi.l  #$40, (MBVB)
         move.b  #$20, (PrBb)
         BRA     LMO
LM4b      cmpi.b  #$01, (PROCa)
         beq     LM4b1
         addi.l  #$08, (MAS)
         addi.l  #$04, (MBS)
         move.b  #$08, (MASB)
         move.b  #$04, (MBSB)
         addi.l  #$40, (MAVB)
         addi.l  #$80, (MBVB)
         bra     LM4d
LM4b1     addi.l  #$08, (MAS)
         addi.l  #$08, (MBS)
         move.b  #$08, (MASB)
         move.b  #$08, (MBSB)
         addi.l  #$40, (MAVA)
         addi.l  #$04, (MBVA)
         addi.l  #$40, (MAS)
         addi.l  #$04, (MBS)
         addi.l  #$80, (MAVB)
         addi.l  #$84, (MBVB)
         move.b  #LMBVla, D0
LM4d      move.b  #$04, (PrBa)
         move.b  #$40, (PrBb)
         move.w  #$0010, (BSCNT)
         bra     LMO
LM8       cmpi.b  #$01, (MMTB)
         beq     LM8b
         addi.l  #$08, (MAS)
         addi.l  #$08, (MBS)
         move.b  #$08, (MASB)

```

```

                                move.b    #$08, (LMBSB)
                                cmpi.b    #$01, (MMTSC)
                                beq        LM8a
                                addi.l     #$80, (LMAVB)
                                move.w     #$0040, (BSCNT)
                                BRA        LM8a3
LM8a                            cmpi.b    #$01, (PROCa)
                                beq        LM8a1
                                addi.l     #$40, (LMAVB)
                                bra        LM8a2
LM8a1                          addi.l     #$40, (LMAVA)
                                addi.l     #$40, (LMAS)
                                addi.l     #$80, (LMAVB)
LM8a2                          move.w     #$0020, (BSCNT)
LM8a3                          addi.l     #$80, (LMBVB)
                                move.b     #$40, (PrBb)
                                BRA        LMO
LM8b                            cmpi.b    #$01, (PROCa)
                                beq        LM8b1
                                addi.l     #$10, (LMAS)
                                addi.l     #$08, (LMBS)
                                move.b     #$10, (LMASB)
                                move.b     #$08, (LMBSB)
                                addi.l     #$80, (LMAVB)
                                addi.l     #$100, (LMBVB)
                                bra        LM8d
LM8b1                          addi.l     #$10, (LMAS)
                                addi.l     #$10, (LMBS)
                                move.b     #$10, (LMASB)
                                move.b     #$10, (LMBSB)
                                addi.l     #$80, (LMAVA)
                                addi.l     #$08, (LMBVA)
                                addi.l     #$80, (LMAS)
                                addi.l     #$08, (LMBS)
                                addi.l     #$80, (LMAVB)
                                addi.l     #$108, (LMBVB)
                                move.b     #LMBVla, D0
LM8d                            move.b     #$08, (PrBa)
                                move.b     #$80, (PrBb)
                                move.w     #$0020, (BSCNT)
                                bra        LMO
;LM8                            addi.l     #$08, (LMAS)
;                                addi.l     #$08, (LMBS)
;                                move.b     #$08, (LMASB)
;                                move.b     #$08, (LMBSB)
;                                addi.l     #$80, (LMBVB)
;                                cmpi.b     #MMTS, (ZERO)
;                                bne        S2
;                                move.w     #$0040, (BSCNT)
;                                addi.l     #$80, (LMAVB)
;                                BRA        S3
;S2                             move.w     #$0020, (BSCNT)
;                                cmpi.b     #$01, (PROCa)
;                                beq        S2a
;                                addi.l     #$40, (LMAVB)
;                                bra        LMO
;S2a                            move.b     #$40, (PrBb)

```

```

;          addi.l  #$40, (LMAVA)
;          addi.l  #$40, (LMAS)
;          addi.b  #$40, (LMASB)
;          addi.l  #$80, (LMAVB)
;S3        bra      LMO
LM16       addi.l  #$00, (LMAS)
           addi.l  #$00, (LMBS)
           addi.b  #$00, (LMASB)
           addi.b  #$00, (LMBSB)
           addi.l  #$100, (LMBVB)
           cmpi.b  #MMTS, (ZERO)
           bne     S4
           move.w  #$0100, (BSCNT)
           addi.l  #$100, (LMAVB)
           move.b  #$80, (PrBb)
           BRA     LMO
S4         move.w  #$0080, (BSCNT)
           cmpi.b  #$01, (PROCa)
           beq     S4a
           addi.l  #$80, (LMAVB)
           move.b  #$80, (PrBb)
           bra     LMO
S4a       addi.l  #$80, (LMAVA)
           addi.l  #$100, (LMAVB)
           move.b  #$80, (PrBb)
; Loading Variables
LMO        move.b  #$00, (ACNT)
           move.w  #$00, (BCNT)
           move.b  #$00, (MMWL)
           move.l  #$00, (ACRT)
           move.l  #$00, (BCRT)
           move.l  #$00, (CCRT)
; Initializing the Counter
           move.b  #$30, (LCW)
;
; Loading of Matrix Value
;          BSR      Lmat      ; Testing
; Matrix A
           movea.l (LMAVA), A3
           movea.l (LMAVB), A2
           BSR     LMA
;
; Matrix B
           movea.l (LMBVA), A3
           movea.l (LMBVB), A2
           BSR     LMB
;
; Check for Single Processor
           cmpi.b  #$01, (MMTSC)
           bne     SG
;
; Check if Prog A or Prog B
           cmpi.b  #$01, (PROCa)
           beq     ASWT
; Locking Semaphores
           BSR     LS
;

```

```

; Unlocking Semaphores
        BSR      US
;
; Waiting for PB initialization
        movea.l  #SM1S,A3          ; PA Only
        BSR      SC
;
; Routine to Start Time
SG      BSR      TSTR              ; PA only
;
; Starting Processor B
        clr.b    (SM2S)           ; PA only
        bra      SG1
;
; PB Initialization
ASWT     clr.b    (SM1S)           ; PB only
; Processor B Start
        movea.l  #SM2S,A3          ; PB Only
        BSR      SC              ; PB Only
;
; Matrix Multiplication
;
; [Segment A0]
;
SG1      move.l   #ASRT, (ACRT)
        move.l   #BSRT, (BCRT)
        move.l   #CSRT, (CCRT)
        clr.l    D5
        clr.l    D6
        move.b    (PrBa), D5
        move.b    (PrBb), D6
        cmpi.b    #$01, (PROCa)
        bne      SA1
; Start Locations for Proc B
        add.l    D6, (ACRT)
        cmpi.b    #$01, (MMTSB)
        bne      PB0
        add.l    D5, (BCRT)
PB0      add.l    D6, (CCRT)
        move.l    (ACRT), (ACRTb)
        move.l    (BCRT), (BCRTb)
        move.l    (CCRT), (CCRTb)
        bra      SA2
; Location Start for Block Proc A
;
SA1      move.l    (ACRT), (ACRTa)
        move.l    (BCRT), (BCRTa)
        move.l    (CCRT), (CCRTa)
SA2      cmpi.b    #$01, (MMTSB)
        bne      PA
        cmpi.b    #$01, (PROCa)
        bne      PA
        movea.l    (BCRT), A5
        BSR      MTSM
        clr.b     (SML1A)
        movea.l    (BCRT), A5
        adda.l     D6, A5

```

```

BSR      MTSM
clr.b    (SML2A)
add.l    D5, (ACRTb)
movea.l  (ACRTb), A4
movea.l  (BCRT), A5
movea.l  (CCRT), A3

BSR      Block
movea.l  (ACRTb), A4
movea.l  (BCRT), A5
movea.l  (CCRT), A3
adda.l   D6, A5
adda.l   D5, A3
BSR      Block
sub.l    D5, (BCRTb)
movea.l  (BCRTb), A5

;

movea.l  #SML1B, A3
BSR      SC

;

BSR      GFSM
movea.l  (ACRT), A4
movea.l  (BCRTb), A5
movea.l  (CCRT), A3
BSR      Block
add.l    D6, (BCRTb)
movea.l  (BCRTb), A5

;

movea.l  #SML2B, A3
BSR      SC

;

BSR      GFSM
movea.l  (ACRT), A4
movea.l  (BCRTb), A5
movea.l  (CCRT), A3
adda.l   D5, A3
BSR      Block
bra      MMC
PA      cmpi.b  #$01, (PROCa)
        beq     PA0
        movea.l (ACRTa), A4
        movea.l (BCRTa), A5
        movea.l (CCRTa), A3
        bra     PA1
PA0     movea.l  (ACRTb), A4
        movea.l (BCRTb), A5
        movea.l (CCRTb), A3
PA1     BSR      Block
        cmpi.b  #$01, (MMTSB)
        bne     MMC
        movea.l (ACRT), A4
        movea.l (BCRT), A5
        movea.l (CCRT), A3
        adda.l  D6, A5
        adda.l  D5, A3
        BSR      Block
        movea.l (BCRT), A5

```

```

        BSR      MTSM
        clr.b    (SML1B)
        move.l   (BCRT), (BCRTa)
        movea.l  (BCRTa), A5
        adda.l   D5, A5
;
        movea.l  #SML1A, A3
        BSR      SC
;
        BSR      GFSM
        movea.l  (ACRT), A4
        movea.l  (BCRTa), A5
        movea.l  (CCRT), A3
        adda.l   D5, A4
        adda.l   D5, A5
        BSR      Block
        movea.l  (BCRT), A5
        adda.l   D6, A5
        BSR      MTSM
        clr.b    (SML2B)
        movea.l  (BCRTa), A5
        adda.l   D6, A5
        adda.l   D5, A5
;
        movea.l  #SML2A, A3
        BSR      SC
;
        BSR      GFSM
        movea.l  (ACRT), A4
        movea.l  (BCRTa), A5
        movea.l  (CCRT), A3
        adda.l   D5, A4
        adda.l   D6, A5
        adda.l   D5, A5
        adda.l   D5, A3
        BSR      Block
;
;
; [Segment A9]
;
; Checking SMLC Semaphore
MMC      movea.l  #SMLC, A3
        BSR      SC
;
; Move Results to Shared Memory
        movea.l  #CSRT, A5
        BSR      MRTSM
;
; Clearing SMLC Semaphore
        clr.b    (SMLC)
;
; [Segment A10]
;
        cmpi.b   #$01, (PROCa)
        beq      DSWT
        cmpi.b   #$01, (MMTSC)
        bne      CSWT

```

```

; Checking if Processor 2 is finished
        movea.l #SM2F,A3
        BSR     SC
;
; Routine to Stop Timer
CSWT          BSR     TSTP
;
        bra     ESWT
;
; Processor 2 is finished
DSWT          clr.b (SM2F)
; Routine to Get Time information
ESWT          BRA     ENDING
;
;
; Subroutines
TSTR          move.b #$00,(WC1LB)
              move.b #$00,(WC1MB)
              move.b #$00,(GtRd)
              RTS
TSTPA         move.b #$01,(GtRd)
              move.b #$03,(GtRda)
              RTS
TSTP          move.b #$01,(GtRd)
              move.b #$00,(LCW)
              clr.l D1
              clr.l D2
              move.b (RC1LB),D1
              move.b (RC1MB),D2
              ASL    #$8,D2
              add.l D2,D1
              move.l D1,(RCNT)
              RTS
;
;SC          subi.b #$01,D7
;            cmpi.b #$00,D7
;            bne    SC
SC           TAS     (A3)
            BNE     SC
;            clr.b (A3)
            RTS
;
BLOCK        move.l D5,(SD5)
            move.l D6,(SD6)
            movea.w (BSCNT),A2
            move.l A4,(ACRTc)
            move.l A5,(BCRTc)
            move.l A3,(CCRTc)
BLA          BSR     MMW
            addi.b #$01,(MMWL)
            move.b (MMTB),D3
            cmp.b (MMWL),D3
            bne    BLA
BLB          addi.w #$01,BCNT
            cmpa.w (BCNT),A2
            beq    BLEND
;            move.w #$01,CCNT

```

```

                                addi.b  #$01,ACNT
                                adda.l  #$01,A3
                                cmpi.b  #$01,(MMWL)
                                beq      MMW4
                                cmpi.b  #$02,(MMWL)
                                beq      MMW8
MMW16                          move.b  #$00,MMWL
                                cmpi.b  #$10,(ACNT)
                                beq      ADJA16
                                BRA      BLCNT
MMW8                           move.b  #$00,MMWL
                                cmpi.b  #$08,(ACNT)
                                beq      ADJA08
                                adda.l  #$08,A5
                                BRA      BLCNT
MMW4                           move.b  #$00,MMWL
                                cmpi.b  #$04,(ACNT)
                                beq      ADJA04
                                adda.l  #$0C,A5
                                BRA      BLCNT
ADJA16                         addi.l  #$10,(ACRTc)
                                movea.l (BCRTc),A5
                                move.b  #$00,(ACNT)
                                BRA      BLCNT
ADJA08                         addi.l  #$10,(ACRTc)
                                addi.l  #$10,(CCRTc)
                                movea.l (BCRTc),A5
                                movea.l (CCRTc),A3
                                move.b  #$00,(ACNT)
                                BRA      BLCNT
ADJA04                         addi.l  #$10,(ACRTc)
                                addi.l  #$10,(CCRTc)
                                movea.l (ACRTc),A4
                                movea.l (BCRTc),A5
                                movea.l (CCRTc),A3
                                move.b  #$00,(ACNT)
                                BRA      BLCNT
BLCNT                         movea.l (ACRTc),A4
;                               move.w  #$01,CCNT
                                BRA      BLA
BLEND                          move.b  #$00,MMWL
                                move.b  #$00,ACNT
                                move.w  #$00,BCNT
                                move.l  (SD5),D5
                                move.l  (SD6),D6
                                RTS
;
MMW                             move.b  (A4)+,D0
                                move.b  (A5)+,D1
                                move.b  (A4)+,D2
                                move.b  (A5)+,D3
                                move.b  (A4)+,D4
                                move.b  (A5)+,D5
                                move.b  (A4)+,D6
                                move.b  (A5)+,D7
                                mulu    D1,D0
                                mulu    D3,D2

```

```

        add.b    D0,D2
        mulu     D5,D4
        mulu     D7,D6
        add.b    D4,D6
        add.b    D6,D2
        clr.l    D5
        move.b   (A3),D5
        add.b    D5,D2
        move.b   D2,(A3)
        clr.l    D1
        clr.l    D2
        clr.l    D3
        clr.l    D4
        clr.l    D5
        clr.l    D6
        clr.l    D7
;        sub.l   A3,A3
RTS

;
MTSM        clr.l    D0
            clr.l    D1
            clr.l    D2
            move.b   (PrBa),D1
            move.b   (PrBb),D2
            movea.l  A5,A2
            movea.l  A5,A3
            adda.l   D1,A2
            adda.l   D2,A3
            move.l   A5,D0
            addi.l   #$14000,D0
            move.l   D0,A1
MT1         move.b   (A5)+,(A1)+
            cmpa.l   A5,A2
            bne      MT2
            adda.l   #$10,A2
            adda.l   #$0C,A1
            adda.l   #$0C,A5
MT2         cmpa.l   A5,A3
            bne      MT1
            sub.l    A1,A1
            sub.l    A2,A2
            sub.l    A3,A3
            sub.l    A5,A5
RTS

;
GFSM        clr.l    D0
            clr.l    D1
            clr.l    D2
            move.b   (PrBa),D1
            move.b   (PrBb),D2
            movea.l  A5,A2
            movea.l  A5,A3
            adda.l   D1,A2
            adda.l   D2,A3
            move.l   A5,D0
            addi.l   #$14000,D0
            move.l   D0,A1

```

```

MT4      move.b   (A1)+, (A5)+
        cmpa.l   A5,A2
        bne     MT5
        adda.l   #$10,A2
        adda.l   #$0C,A1
        adda.l   #$0C,A5
MT5      cmpa.l   A5,A3
        bne     MT4
        sub.l    A1,A1
        sub.l    A2,A2
        sub.l    A3,A3
        sub.l    A5,A5
        RTS

;
MRTSM    clr.l    D1
        movea.l  A5,A2
        movea.l  A5,A3
        cmpi.b   #$01,(MMTA)
        beq      MT5a
        cmpi.b   #$02,(MMTA)
        beq      MT5b
        cmpi.b   #$04,(MMTA)
        beq      MT5c
MT5a      cmpi.b   #$01,(MMTB)
        beq      MT5a5
        cmpi.b   #$01,(MMTSC)
        beq      MT5a2
        adda.l   #$40,A3
        bra      MT5a4
MT5a2     cmpi.b   #$01,(PROCa)
        beq      MT5a3
        adda.l   #$20,A3
        bra      MT5a4
MT5a3     adda.l   #$20,A5
        adda.l   #$40,A3
MT5a4     adda.l   #$04,A2
        move.l   #$04,D1
        bra      MT5d
MT5a5     cmpi.b   #$01,(PROCa)
        beq      MT5a6
        adda.l   #$40,A3
        bra      MT5a7
MT5a6     adda.l   #$40,A5
        adda.l   #$40,A2
        adda.l   #$80,A3
MT5a7     adda.l   #$08,A2
        move.l   #$08,D1
        bra      MT5d
MT5b      cmpi.b   #$01,(MMTB)
        beq      MT5b5
        cmpi.b   #$01,(MMTSC)
        beq      MT5b2
        adda.l   #$80,A3
        bra      MT5b4
MT5b2     cmpi.b   #$01,(PROCa)
        beq      MT5b3
        adda.l   #$40,A3

```

```

bra      MT5b4
MT5b3    adda.l  #$40,A5
          adda.l  #$80,A3
MT5b4    adda.l  #$08,A2
          move.l  #$08,D1
          bra     MT5d
MT5b5    cmpi.b  #$01,(PROCa)
          beq     MT5b6
          adda.l  #$80,A3
          bra     MT5b7
MT5b6    adda.l  #$80,A5
          adda.l  #$80,A2
          adda.l  #$100,A3
MT5b7    adda.l  #$10,A2
          move.l  #$10,D1
          bra     MT5d
MT5c     cmpi.b  #$01,(MMTSC)
          beq     MT5c2
          adda.l  #$100,A3
          bra     MT5c4
MT5c2    cmpi.b  #$01,(PROCa)
          beq     MT5c3
          adda.l  #$80,A3
          bra     MT5c4
MT5c3    adda.l  #$80,A5
          adda.l  #$100,A3
MT5c4    adda.l  #$10,A2
          move.l  #$10,D1

;
MT5d     move.l  A5,D0
          addi.l  #$14000,D0
          move.l  D0,A1
MT6      move.b  (A5)+,(A1)+
          cmpa.l  A5,A2
          bne     MT7
          cmpi.b  #$04,(MMTA)
          beq     MT7
          adda.l  #$10,A2
          adda.l  D1,A1
          adda.l  D1,A5
MT7      cmpa.l  A5,A3
          bne     MT6
          sub.l   A1,A1
          sub.l   A2,A2
          sub.l   A3,A3
          sub.l   A5,A5
          RTS

;
;
MCLR     clr.b   (A5)+
          cmpa.l  A4,A5
          BNE     MCLR
          sub.l   A5,A5
          sub.l   A4,A4
          RTS

;
LS       move.b  #$80,(SML1A) ; PA only

```

```

        move.b #$80, (SML2A) ; PA only
        move.b #$80, (SML1B) ; PA only
        move.b #$80, (SML2B) ; PA only
        move.b #$80, (SM1S)  ; PA only
        move.b #$80, (SM2F)  ; PA only
        move.b #$80, (SM2S)  ; PA only
        RTS

;
US      move.b #$00, (SMLC)  ; PA only
        RTS

;
LMA     cmpa.l   (LMAS), A3
        bne     LMAC
        cmpi.b  #$08, (MASB)
        beq     LMAA
        cmpi.b  #$04, (MASB)
        beq     LMAB
        BRA     LMAC
LMAA    adda.l   #$08, A3
        addi.l   #$10, (MAS)
        BRA     LMAC
LMAB    adda.l   #$0C, A3
        addi.l   #$10, (MAS)
LMAC    cmpa.l   A2, A3
        beq     LMAE
        move.b  #LMAVal, (A3) +
        BRA     LMA
LMAE    RTS

;
LMB     cmpa.l   (LMBS), A3
        bne     LMBC
        cmpi.b  #$08, (LMBSB)
        beq     LMBA
        cmpi.b  #$04, (LMBSB)
        beq     LMBB
        BRA     LMBC
LMBA    adda.l   #$08, A3
        addi.l   #$10, (LMBS)
        BRA     LMBC
LMBB    adda.l   #$0C, A3
        addi.l   #$10, (LMBS)
LMBC    cmpa.l   A2, A3
        beq     LMBE
        move.b  D0, (A3) +
        BRA     LMB
LMBE    RTS

;
;
ENDING  Trap      #9
        END      START

```

REFERENCES

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******The following references have been included as further reading to help with****
the understanding of the material, figures, and programs contained in this thesis.**

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