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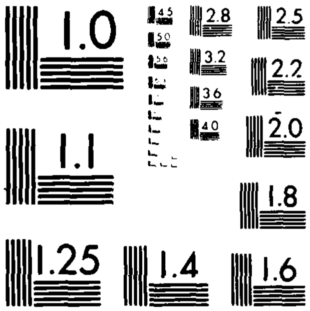

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The Naval Postgraduate School
SECURE ARCHIVAL STORAGE SYSTEM

Part II

- Segment and Process Management Implementation -

Lyle A. Cox, Roger R. Schell, and Sonja L. Perdue

March 1981

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Prepared for:

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Arlington, Virginia 22217

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Monterey, California

Rear Admiral J. J. Ekelund
Superintendent

D. A. Schrady
Acting Provost

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This report was prepared by:

Sonja L. Perdue

SONJA L. PERDUE
Adjunct Research Instructor of
Computer Science

Reviewed by:

GORDON H. BRADLEY
Department of Computer Science

Released by:

William M. Tolles

WILLIAM M. TOLLES
Dean of Research

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The security kernel technology has provided the technical foundation for highly reliable protection of computerized information. However, the operating system implementations face two significant challenges: providing (1) adequate computational resources for applications tasks, and (2) a clean, straightforward structure whose correctness can be easily reviewed. This paper presents the experience on an ongoing security kernel implementation using the Advanced Micro Devices 4116 single-board computer based on

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the Z8002 microprocessor. The performance issues of process switching, domain changing, and multiprocessor bus contention are explicityly addressed. The strictly hierarchical (i.e., loop-free) structure provides a series of increasingly capable, separately usable operating system subsets. Security enforcement is structured in two layers: the basic kernel rigorously enforces a non-discretionary (viz., lattice model) policy, while an upper layer provides the access refinements for a discretionary policy.

The Naval Postgraduate School

SECURE ARCHIVAL STORAGE SYSTEM

Part II

-Segment and Process Management Implementation-

by

Roger R. Schell, Lyle A. Cox, and Sonja L. Perdue

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THE STRUCTURE OF A SECURITY KERNEL FOR A Z8000 MULTIPROCESSOR

LYLE A. COX, Jr., and ROGER R. SCHELL, Col., USAF

Department of Computer Science
Naval Postgraduate School
Monterey, California

ABSTRACT

The security kernel technology has provided the technical foundation for highly reliable protection of computerized information. However, the operating system implementations face two significant challenges: providing (1) adequate computational resources for applications tasks, and (2) a clean, straightforward structure whose correctness can be easily reviewed. This paper presents the experience of an ongoing security kernel implementation using the Advanced Micro Devices 4116 single-board computer based on the Z8002 microprocessor. The performance issues of process switching, domain changing, and multiprocessor bus contention are explicitly addressed. The strictly hierarchical (i.e.,

loop-free) structure provides a series of increasingly capable, separately usable operating system subsets. Security enforcement is structured in two layers: the basic kernel rigorously enforces a non-discretionary (viz., lattice model) policy, while an upper layer provides the access refinements for a discretionary policy.

BACKGROUND

For the last two and a half years the Naval Postgraduate School has been conducting a research and development project involving security kernel based operating systems designed for multiple processor implementations. As this work continues we feel that it is important to report on our progress and experiences, especially in the area of microprocessor implementations.

This effort has come to be known as the "SASS" or Secure Archival Storage System project [1]. In fact, this is a misnomer, as SASS is but a single instance of a more general family of secure operating systems designed early in the project [2]. While SASS has been the object of the majority of the research reported it is not the only implementation. Another operating system of this family has also been written to support a signal processing system that uses multiple Intel 8086 processors [3].

SASS has been our principal testbed for exploring the implementation and performance issues related to these types of operating systems. SASS itself was designed to be a comprehensive multiuser, multilevel secure file storage system. As designed, it will consist of a small number of Z8000-based [4] single board computers sharing a single Multibus with storage devices and input/output devices. SASS will interface via bidirectional lines to a number of "host" systems, as illustrated in Figure 1. SASS will provide each host with a hierarchical file system. This system can be used to store and retrieve files, and share files with other hosts. This design will allow SASS to serve as a central hub of a data secure network of computers with diverse security authorization for sensitive information. SASS provides archival, shared storage while insuring that each interfaced host processor can access only that information appropriate to its security authorizations.

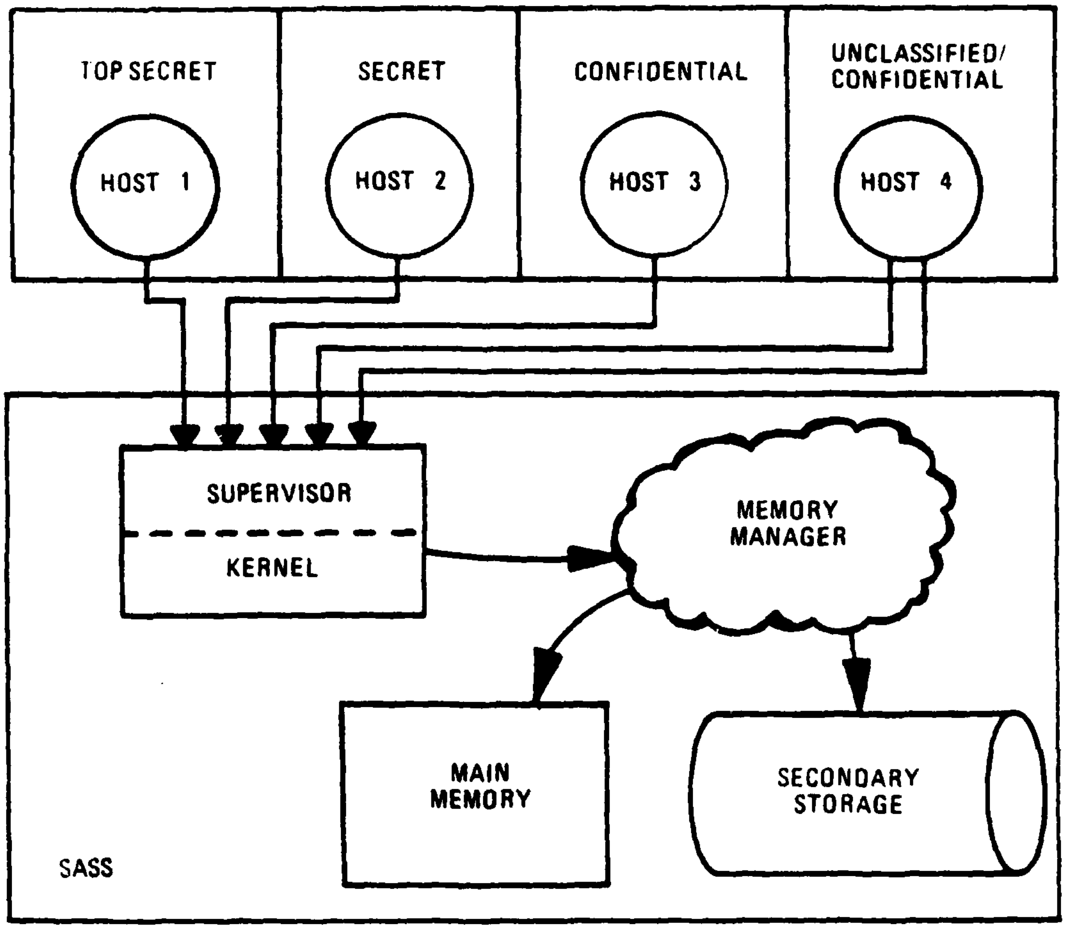

Figure 1: SASS System Interfaces

STRUCTURE

For this family of operating systems the security kernel technology has been used not only to effect security but also to provide the underlying organizational framework for the operating system. The SASS, one member of this family, is in the final stages of implementation. This development experience has highlighted the importance of several features that are key to this family:

- The pervasive, yet systematizing impact of the security kernel methodology [5].

- The design simplicity that accompanies a loop-free modularization that is highly compatible with the resource sharing and multiprogramming functions.

- The significance of a high degree of configuration independence, particularly for the ability to use the latest microprocessors for testbed implementation.

Independent of security, this particular kernel structure is attractive as a canonical operating system interface. It appears adequate for a wide range of functionality and capacity, and it evidences a high degree of independence from hardware idiosyncrasies. These operating system features will be discussed further below.

Security Kernel Approach

Members of this operating system family are organized with three distinct extended machine layers: (1) the security kernel, (2) the supervisor, and (3) the applications. This is illustrated in Figure 2. The concept of a hierarchy of extended machines is, to be sure, not new; however, the security kernel significantly constrains the organization. In particular, for reason of security all the management of physical resources must be within the kernel itself. Furthermore, confidence is increased by keeping the kernel as small and simple as possible. This means that much of what is commonly thought of as the operating system is provided outside the kernel in the supervisor layer. For this particular family member there is no major applications layer (viz., within SASS itself), since the applications are contained in the individual hosts.

The basic family of operating systems requires the kernels to provide extended virtual machines that specifically support both asynchronous processes and segmented address spaces. Within SASS, the kernel virtualizes processors, all levels of storage, and input/output. The kernel creates virtualized objects -- processes, segments, and devices. It is this "pure" virtual interface that is attractive as the

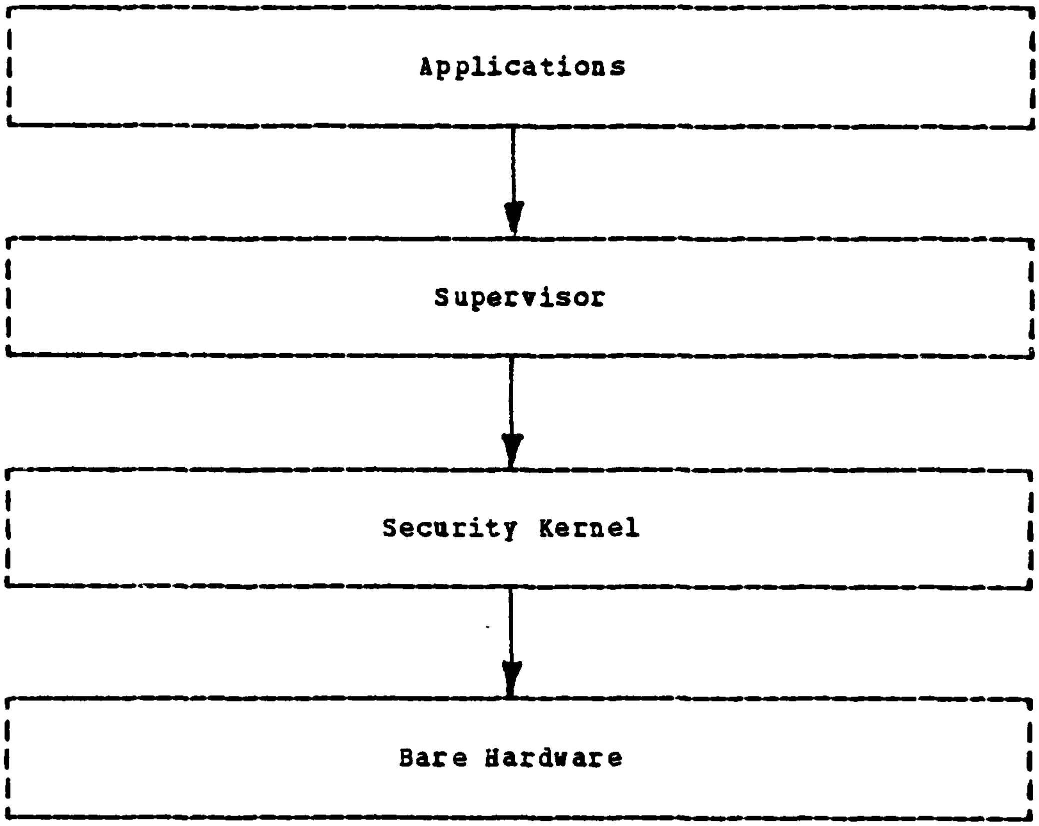

Figure 2: Extended Machine Layers

basis for canonical operating system features. The SASS supervisor is in turn built upon the kernel, using these virtualized objects to construct the file system.

Both the kernel and the supervisor have certain responsibilities for system security. The kernel manages all physical resources, and the kernel is distributed (i.e., included) in the address space of every process. At this level, isolation of the kernel -- protection from users and the supervisor -- must be provided by hardware enforced domains. The design of the system is strictly hierarchical (viz., the kernel is more privileged than the supervisor) so protection rings, as defined for Multics [6], are a satisfactory domain implementation.

The kernel has the responsibility for the enforcement of access limitations: that is, the kernel provides the mechanism for supporting non-discretionary security policy. The SASS kernel can support any such policy which can be expressed by a lattice of access classes [7]. Every object -- process, segment, or device -- has a non-forgable label that denotes its access class. This non-discretionary security has been parameterized in SASS such that exactly one module has knowledge of the interpretation of this label in terms of a specific policy. Thus, only this single module need be tailored to support a particular policy.

SASS provides discretionary security (shared access within the bounds of non-discretionary policy based on individual user identification) via the supervisor and the file structure. This discretionary security is completely outside of the kernel (in contrast with the KSOS [8] approach).

The supervisor handles the "Secure Reader-Writer Problem" with a non-exclusionary approach (one writer, retry on read) to provide synchronization between processes of different access classes. This control of interprocess communication is implemented via kernel primitives using Reed's eventcounts and sequencers [9].

The SASS supervisor capabilities are achieved by associating two processes with each host link. These processes access that portion of the SASS file structure associated with that host. One of these processes provides I/O transmission and link management, while the other, a file manager, is responsible for the file system structure of its associated host. Communication between these processes (as is communication between all processes) is achieved using shared segments -- a mailbox. Synchronization is provided by the kernel (with eventcounts and sequencers).

The complementary kernel/supervisor approach to security has several advantages for SASS: the size and the complexity of the kernel can be minimized, and, given reliable host authentication, any host weaknesses will not impact the reliable enforcement of the non-discretionary security policy.

The security kernel approach constrains not only the interface but also the detailed design and implementation of internal state variables. The problem is to prevent indirect information paths between processes with different access classes. We address this problem using essentially the approach detailed by Millen [10], although without the rigor of a proof. Internal state variables, e.g., shared resource tables, are assigned an access class, and it is confirmed that its values will not be reflected to processes of an inconsistent access class. The most apparent result is that the "success code" (returned in response to the invocation of kernel primitives) primarily reflects the state of the per-process virtual resources, not the shared physical resources.

Loop Free Organization

Another aspect of the design that has helped to keep the security kernel simple and understandable is the loop-free structure of SASS. The loop-free design supports the software engineering concept of "information hiding" [11], as there are really no global data structures within SASS. The kernel is internally organized into four distinct layers, as illustrated in Figure 3; these layers, that will be described below, are termed (1) segment and event managers, (2) traffic controller, (3) memory manager, and (4) inner traffic controller.

In practice we have been quite doctrinaire in enforcement of the loop-free structure for this organization. While many operating systems claim to be modular or well-structured, we empirically validate this claim. We "peel-off" the upper layers one at a time by literally removing the code and data, and then demonstrate that the remainder can be loaded and run as a functionally intact, but obviously limited, operating system subset. The function of each layer will now be described, proceeding from the bottom upward.

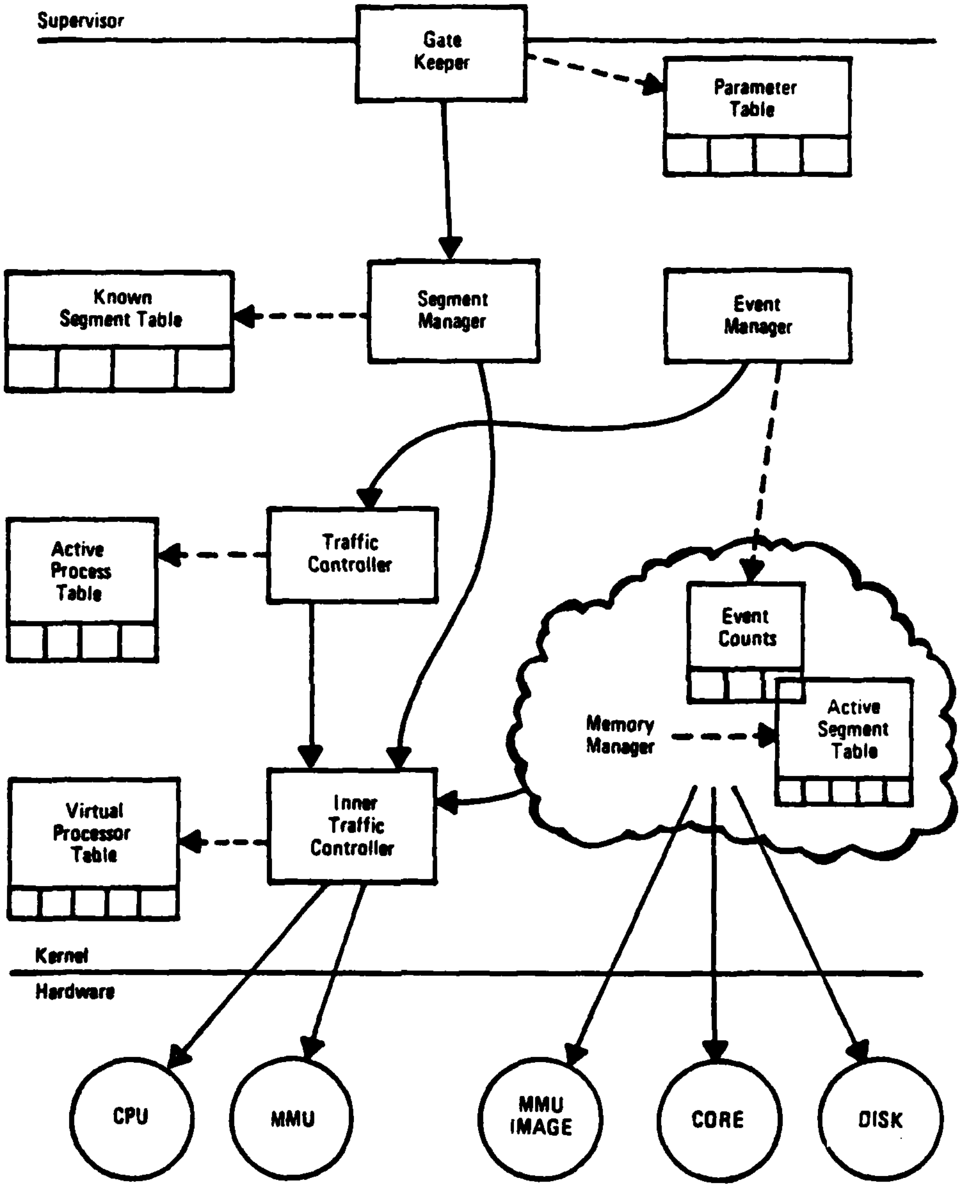

Figure 3: Internal Kernel Organization

Inner Traffic Controller. Processor multiplexing has two layers, similar to those proposed for Multics [12]. Each physical processor has a fixed number of "virtual processors" that are multiplexed onto it. Two of these virtual processors are dedicated to system services: an idle virtual processor and a memory manager process to manage the asynchronous access to secondary storage devices. The remaining virtual processors (currently two per physical processor) are available to the (upper level) traffic controller. The inner traffic controller provides signal and wait synchronization primitives that include a message that is passed between virtual processors. In terms of traditional jargon, the inner traffic controller provides multiprogramming by scheduling virtual processors to run on the CPU they are (permanently) associated with. Note that this structure implies that the security kernel is interruptible, viz., is not a critical section; however, the inner traffic controller itself is not interruptible. In addition, this layer provides all the multiprocessing interactions between individual physical processors, using a hardware "preempt" interrupt.

Memory Manager. This layer manages the multiplexing of the physical storage resources, viz., "disk" and "core". This layer also manages the segment descriptors in the memory management unit (MMU) image for each process. Most of the functions of this layer are executed by the per-CPU memory manager processes, with synchronization provided by inner traffic controller signal and wait primitives. The single board computers have per-processor, local memory; there is also additional global memory that is addressable by all processes. The memory manager insures that (only) shared segments are in global memory.

This policy can require some transfers between local and global memory; however, the low transaction rate of the archival storage system is not demanding, and this structure minimizes bus transfer requirements under expected operating conditions.

Traffic Controller. The variable number of processes (two per host) are multiplexed onto virtual processors defined by the inner traffic controller. Each process has an affinity to the physical processor whose local memory contains a portion of its address space at the time of the process scheduling decision. As indicated earlier, the traffic controller layer uses Reed's advance and await mechanism [9] to provide interprocess communication.

Segment and Event Managers. All entries into the kernel pass through the segment/event manager layer. The explicit non-discretionary security checks are made at this level by comparing the access class labels of subjects and objects. This layer uses a per-process known segment table to convert process local names (viz., segment number) for objects into system-wide names. Each segment has associated with it two eventcounts and a sequencer; thus, segment numbers also serve as their names. The segment manager provides for the creation and deletion of segments and their entry into and removal from a process address space.

Gate Keeper. A process invokes a security kernel function using the traditional trap mechanism. The Z8000 "system call" instruction causes a trap, and the gate keeper is merely the trap handler. All parameters and return values are "passed by value" in CPU registers; this simplifies security validation. The gate keeper merely calls the particular procedure that corresponds to the requested function.

Microprocessor Testbed

One important aspect of this research has been the actual implementation and testing of the concepts developed. Traditionally the implementation of multiple processor structures has been an expensive undertaking. Recently the development of sophisticated microprocessors that feature multiple operating modes, advanced addressing, support of multiple processor configurations, and a standard bus configuration with peripheral support have all made the implementation of advanced operating systems on microprocessor devices possible, and economically feasible.

The processors of SASS all share the same bus; each processor is a commercial single board computer with on-board random access memory. These processors also share a global memory, and certain peripheral devices. This configuration is illustrated in Figure 4.

In general, security kernel based operating systems find three processor-supported execution domains (operating states) highly desirable: for the kernel, supervisor, and applications. This is true of the operating system family discussed here. Currently there are no single chip processors that support three states. This is not a significant problem for SASS, since it is the hosts rather than the SASS system processors that execute user application programs. Under these circumstances a two mode (kernel and supervisor) machine is sufficient. Such architectures are currently available as microprocessors, in particular the Z8000.

Accordingly, we are implementing a multiple microprocessor system to test the SASS concept. The current hardware in use is the AMD 4116 single board computer [13] in a standard Multibus backplane. This configuration has a significant limitation: it does not include the hardware Memory Manager Unit, as described in [2].

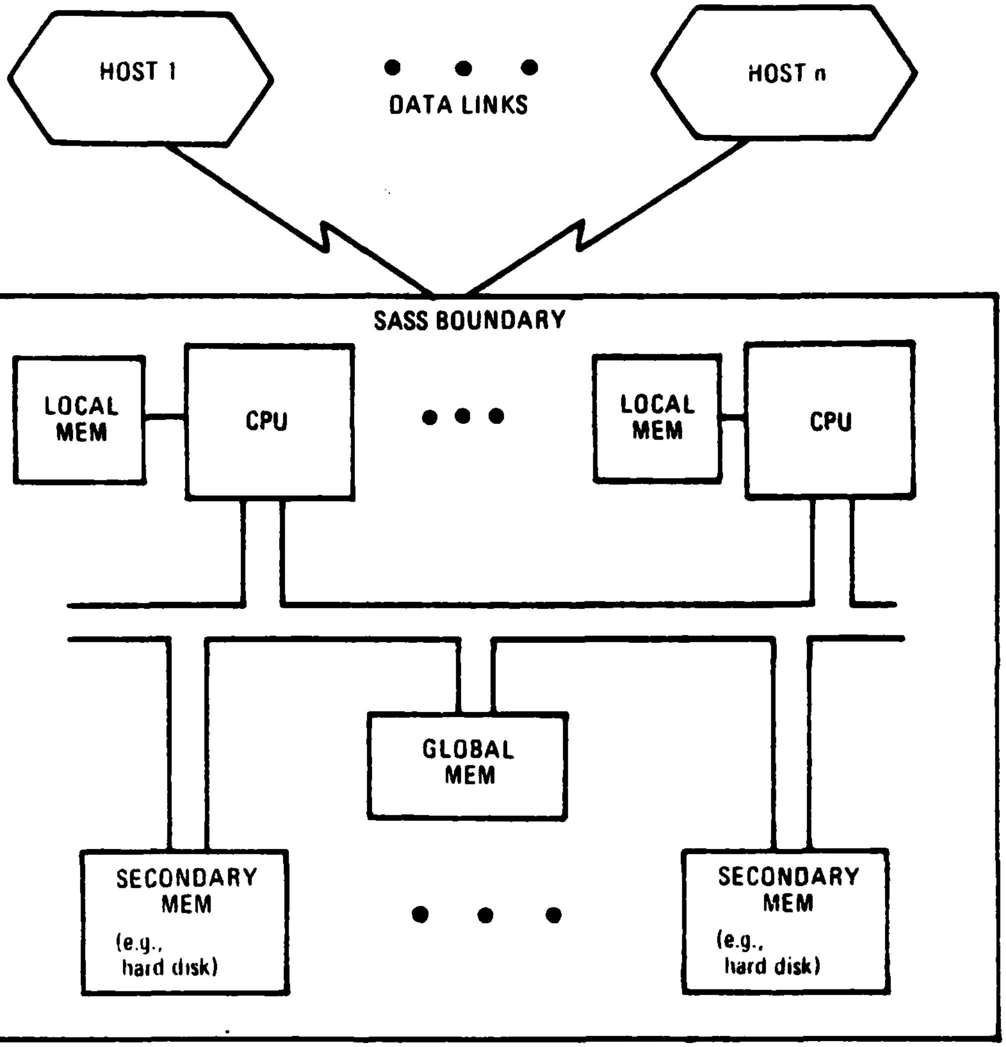

Figure 4: Multiprocessor Configuration

Currently we simulate in software the memory management unit, so the kernel is not protected from the supervisor as the original design specified. Hardware protection in the form of addressing limitations is available, and has been used in some of the experiments to assure the integrity of the kernel. In this configuration, the hardware protects one half of the local memory from any access when the CPU is operating in the normal mode. Any attempt to access memory which is thus protected generates an interrupt and the fault detection software traps the access. This is adequate for current tests, but a complete memory management system is clearly more desirable. Our experiences on this testbed in terms of performance and software development are discussed further below.

THE SASS EXPERIENCE

The lessons learned to this point fall into two broad categories: programming (software engineering) experiences, and performance experiences. We will discuss both of these issues below.

Programming Experiences

The nature of this research effort has been highly structured, emphasizing modularity at every opportunity. The software design is strictly "top-down". This has been a matter of good design practice, and of necessity. Since the majority of the work has been performed by a succession of Master's degree students [14,15,16,17,18,19] during their brief six to nine months of research each, the clear definition of software modules has been key to the success of the effort. We have found that the high degree of modularity has allowed the students to work on the project with a minimum of "start-up" time, and a maximum of productive effort and learning.

The actual implementation is proceeding in an essentially bottom up manner, with test harnesses and stubs being written as necessary for testing. The SASS modules were specified in a pseudo-language resembling current higher level languages. The SASS modules as implemented were coded in PLZ-ASM [20], the Z8000 structured assembly language. We found that the pseudo-code specifications of modules were adequate, and that the translation from this code to the structured assembly language was straightforward.

The structured assembly language of the Zilog Z8000 supported many of the constructs usually thought to be unique to higher level languages, including typed record structures, DO-loops, IF-THEN-ELSE, and CASE. In fact, our programmers think of this assembly language as a higher level language. Approximately 40 percent of the statements written in SASS are equivalent to statements in modern programming languages.

Despite the qualities of the structured assembler, it was selected by default. When the decision was made, the prototype hardware boards were just becoming available. There was virtually no software support available. In particular, no higher level language was available. The software environment was (by modern standards) very primitive, with no tools for operating system development available. Nevertheless, the progression from microprocessor development system to commercial single board computer system has been surprisingly smooth (an opinion that some students might dispute). The software development environment has grown slowly. Yet, this has not proved to be a handicap.

Performance Issues

In the programming for the SASS, we have generally treated performance as a secondary issue, in deference to more basic concerns such as security and modularity. However, we have addressed performance on a design level where performance is strongly related to architectural choices.

Obviously, one basic design choice is the use of multiprocessing as a way to increase processing capacity. However, bus contention is a major performance concern in the multiprocessor configurations, since all processors share a single Multibus. If, for example, all code and data were located in global memory, then even two or three processors would saturate the bus. However, in reality only shared, writable segments need be in global memory. Our use of a purely virtual, segmented memory permits the kernel to determine exactly which are the shared, writable segments. As noted before, the memory manager layer totally controls the allocation to global memory, and thus markedly controls bus contention.

In the current SASS implementation we use the "Normal" and "System" modes of the Z8000 hardware, with the system mode dedicated to the security kernel. The domain changes automatically generate a switch of the stack within the hardware. This is particularly important to the efficiency with which we can switch domains while maintaining the integrity of the kernel.

In SASS a process switch is achieved by switching the stack. SASS saves the process history in the stack, so a switch requires only the stack exchange. Preempt hardware interrupts can initiate scheduler changes, and associated virtual interrupts to the virtual processors. This sequence is relatively efficient given the Zilog architecture. The process switching performance question is more interesting in the context of processor multiplexing.

The multiprogramming time is the interval from the time the inner traffic controller signal primitive is invoked in one virtual processor until there is a return from a (pending) wait invocation in a different virtual processor. This includes both process switching and message passing operations.

For interprocess communication, the read and ticket calls (from the normal mode) include a system call though the gate keeper to the kernel, the non-discretionary security checks, and access to the eventcount or sequencer value; however, no process switch is involved. The synchronization time includes the interval from the invocation of the system call (in normal mode) for advance in one process until the return from a (blocking) await invocation in a different process. This includes the security checks and scheduling of both a virtual and a physical processor.

A set of measurements on the current implementation are summarized in Table 1. There has been no effort to "tune" the system to improve performance. We find these results within our range of expectations for a single chip microprocessor.

Function	Time (milliseconds)
Multiprogramming signal/wait pair	0.5
Synchronization advance/await pair	2.3
Read (Eventcount)	0.6
Ticket (Sequencer)	0.6

Table 1. Performance Measurements

SUMMARY

A modern operating system featuring kernel based security, segmented memory and multiple processors has been designed and is being implemented using modern microprocessors. To date our focus on methodical design has paid off: the implementation of a carefully designed, simple structure using elementary software development tools has proceeded well.

The initial testbed implementation is running and preliminary data is now available regarding the operating performance of such systems implemented on microprocessors of advanced architectures. Data gathered suggests that the security kernel is indeed an attractive structure for a modern operating system. There is a wide range of applications where sophisticated operating systems can be implemented upon microprocessors, and attractive performance can be achieved, particularly through the use of multiple processors.

ACKNOWLEDGMENTS

The authors would like to acknowledge the many long hours of work and dedicated effort contributed by E. E. Moore, A. V. Gary, S. L. Reitz, J. T. Wells, and A. R. Strickler, the students of the SASS project. Without their dedication, ideas and effort, this project would never have been able to progress. Specifically, we would like to acknowledge the contributions of Ms. C. Yamanaka and Ms. N. Seydel, whose typing and assistance were invaluable. This research was partially supported by grants from the Office of Naval Research, Project No. 427-001, monitored by Mr. Joel Trimble, and the Naval Postgraduate School Research Foundation.

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FOREWORD

This technical report contains edited segments of four masters' theses:

> The Design and Implementation of the Memory Manager for a Secure Archival Storage System by E. E. Moore and A. V. Gary
>
> An Implementation of Multiprogramming and Process Management for a Security Kernel Operating System by S. L. Reitz
>
> Implementation of Segment Management for a Secure Archival Storage System by J. T. Wells
>
> Implementation of Process Management for a Secure archival Storage System by A. R. Strickler

which describe the development and implementation of the Naval Postgraduate School Secure Archival Storage System (SASS). These theses are based upon the design outlined in the Naval Postgraduate School SECURE ARCHIVAL STORAGE SYSTEM Part I - Design - by R. R. Schell and L. A. Cox [17]. This design is updated and presented in detail.

Some sections of each thesis have been excluded in order to eliminate repetition and bulk. Similarly, the program listings in this report represent the current state of the project and do not pertain to any one thesis. An attempt has been made to footnote some discrepancies between the system described by these theses and the current state. However, there may be some details described herein which do not correspond to the current SASS system. Consequently, the reader is advised to consult the individual thesis if more detail on a particular phase of the development is required. A program description document, providing greater clarification of SASS organization and listings, is also available.

CONTENTS

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PART B -- SECURE ARCHIVAL STORAGE SYSTEM DESIGN

PART C -- THE DESIGN AND IMPLEMENTATION OF THE MEMORY MANAGER FOR A SECURE ARCHIVAL STORAGE SYSTEM

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PART D -- AN IMPLEMENTATION OF MULTIPROGRAMMING AND PROCESS MANAGEMENT FOR A SECURITY KERNEL OPERATING SYSTEM

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PART F -- IMPLEMENTATION OF PROCESS MANAGEMENT FOR A SECURE ARCHIVAL STORAGE SYSTEM

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LIST OF FIGURES

PART A

INTRODUCTION

Chapter I

BACKGROUND

This chapter is an updated excerpt from Implementation of Segment Management for a Secure Archival Storage System by J. T. Wells [20].

O'Connell and Richardson provided the design for a family of secure, distributed, multi-microprocessor operating systems from which the subset, SASS, was later derived [7]. In their work, two of the primary motivations were to provide a system that (1) effectively coordinated the processing power of microprocessors and (2) provided information security.

The basis for emphasis on utilization of microprocessors is not purely that of replacing software with more powerful (and faster) hardware (microprocessors) but is also an economic issue. Software development and computing operations are becoming more and more expensive, putting further pressure on system designers to increasingly utilize people solely for system functions that computers cannot perform in a cost effective manner. Microcomputers, on the other hand, are becoming less and less expensive and are, therefore, increasingly being used for more functions.

The need for information security has been gradually recognized as the uses of computers have expanded. As security needs for specific computer systems have been recognized, attempts have been made to modify the existing systems to provide the desired security. The results have been systems that could not be certified as secure and/or which have failed to resist penetration efforts, i.e. systems which, in effect, did not provide adequate information security. It has become clear that, in order to be certifiably secure, a computer system must have security designed in from first principles [10,11]. Such is the case with SASS. Information security was and continues to be a chief design feature. Integral to the design goal of information security were two related goals. One of these goals was to provide multilevel controlled access to a consolidated warehouse of data for a network of multiple host computers. The other key goal was to provide for controlled sharing among the computer hosts.

A brief background of prior work relative to SASS follows. O'Connell and Richardson originated the design of a secure family of operating systems. Their design provided two basic parts for their system -- the supervisor (to provide operating system services) and the kernel (to provide for physical resource management). The design of the SASS supervisor was completed by Parks [9]. No implementation or further design effort on the supervior has followed, to date. The initial design of the kernel was completed by Coleman [2]. That design described the kernel in terms of seven modules:

1. Gate Keeper Module -- provided for ring-crossing mechanism and thus isolation of the kernel.
2. Segment Manager Module -- provided for management of segmented virtual memory.
3. Traffic Controller Module -- multiplexed processes onto virtual processors and supports the inter- process communication primitives Block and Wakeup.
4. Non-Discretionary Security Module -- mediated non-discretionary security access attempts.
5. Inner Traffic Controller Module -- multiplexed virtual processors onto real processors and provided the Kernel synchronization primitives Signal and Wait.
6. Memory Manager Module -- managed main memory and secondary storage.
7. Input-Output Manager -- managed the moving of information to external devices outside the boundaries of the SASS.

Refinement of the kernel design and partial implementation was completed by Gary and Moore [5] in conjunction with Reitz [12]. The resultant description of the kernel as a result of their work was:

1. Gate Keeper Module
2. Segment Manager Module
3. Event Manager Module -- worked with the Traffic Controller to manage the event data associated with the IPC mechanism of eventcounts and sequencers.
4. Non-Discretionary Security Module
5. Traffic Controller Module -- replaced Block and Wakeup with Advance and Await (to implement Supervisor IPC mechanism of eventcounts and sequencers).
6. Memory Manager Module
7. Inner Traffic Controller Module

Reitz implemented the Traffic Controller Module and Inner Traffic Controller Module. Gary and Moore completed a detailed design of the Memory Manager, originated the Memory Manager code (written predominantly in PLZ/SYS), selected a thread of the code, hand compiled it into PLZ/ASM and ran it on the Z8000 developmental module. Wells provided the implementation of the Segment Manager and Non-Discretionary Security Modules as well as partial implementation of Distributed Memory Manager functions. Strickler refined and implemented the process management functions for the SASS (written in PLZ/ASM).

Chapter II

BASIC CONCEPTS/DEFINITIONS

This chapter is an excerpt from Implementation of Process Management for a Secure Archival Storage System by A. R. Strickler [19]. Minor changes have been made for integration into report.

This section provides an overview of several concepts essential to the SASS design. Readers familiar with SASS or with secure operating system principles may wish to skip to the next section.

A. PROCESS

The notion of a process has been viewed in many ways in computer science literature. Organick [8] defines a process as a set of related procedures and data undergoing execution and manipulation, respectively, by one of possibly several processors of a computer. Madnick and Donovan [6] view a process as the locus of points of a processor executing a collection of programs. Reed [10] describes a process as the sequence of actions taken by some processor. In other words, it is the past, present, and future "history" of the states of the processor. In the SASS design, a process is viewed as a logical entity entirely characterized by an address space and an execution point. A process' address space consists of the set of all memory locations accessible by the process during its execution. This may be viewed as a set of procedures and data related to the process. The execution point is defined by the state of the processor at any given instant of process execution.

As a logical entity, a process may have logical attributes associated with it, such as a security access class, a unique identifier, and an execution state. This notion of logical attributes should not be confused with the more typical notion of physical attributes, such as location in memory, page size, etc. In SASS, a process is given a security access class, at the time of its creation, to specify what authorization it possesses in terms of information access (to be discussed in the next section). It is also given a unique identifier that provides for its identification by the system and is utilized for interaction among processes. A process may exist in one of three execution states: 1) running, 2) ready, and 3) blocked. In order to execute, a process must be mapped onto (bound to) a physical processor in the system. Such a process is said to be in the "running" state. A process that is not mapped onto a physical processor, but is otherwise ready to execute, is in the "ready" state. A process in the "blocked" state is waiting for some event to occur in the system and cannot continue execution until the event occurs. At that time, the process is placed into the ready state.

B. INFORMATION SECURITY

There is an ever increasing demand for computer systems that can provide controlled access to the data it stores. In this thesis, "information security" is defined as the process of controlling access to information based upon proper authorization. The critical need for information security should be clear. Banks and other commercial enterprises risk the theft or loss of funds. Insurance and credit companies are bound by law to protect the private or otherwise personal information they maintain on their customers. Universities and scientific institutions must prevent the unauthorized use of their often over-burdened systems. The Department of Defense and other government agencies must face the very real possibility that classified information is being compromised or that weapon systems are being tampered with. In fact, security related problems can be found at virtually every level of computer usage.

The security of computer systems processing sensitive information can be achieved by two means: external security controls and internal security controls. In the first case, security is achieved by encapsulating the computer and all its trusted users within a single security perimeter establishe by physical means (e.g., armed guards, fences, etc.) This means of security is often undesirable due to its added cost of implementation, the inherent risk of error-prone manual procedures, and the problem of trustworthy but error-prone users. Also, since all security controls are external to the computer system, the computer is incapable of securely handling data at differing security levels or users with differing degrees of authorization. This restriction greatly limits the utility of modern computers. Internal security controls rely upon the computer system to internally distinguish between multiple levels of information classification and user authorization. This is clearly a more desirable and flexible approach to information security. This does not mean, however, that external security is not needed. The optimal approach would be to utilize internal security controls to maintain information security and external security controls to provide physical protection of our system against sabotage, theft, or destruction. The primary concern of this thesis is information security and will therefore center its discussion on the achievement of information security through implementation of the security kernel concept.

One might argue that a "totally secure" computer system is one that allows no access to its classified or otherwise sensitive information. Such a system would not be of much value to its users. Therefore, when we say that a system provides information security, it is only secure with respect to some specific external security policy established by laws, directives, or regulations. There are two distinct aspects of security policy: non-discretionary and discretionary. Each user (subject) of the system is given a label denoting what classification or level of access the user is authorized. Likewise, all information or segments (objects) within the system are labelled with their classification or level of sensitivity. The non-discretionary security mechanism is responsible for comparing the authorization of a subject with the classification of an object and determining what access, if any, should be granted. The DOD security classification system provides an example of the non-discretionary security policy and is the policy implemented in SASS. The discretionary security policy is a refinement of the non-discretionary policy. As such, it adds a higher degree of restriction by allowing a subject to specify or restrict who may have access to his files. It must be emphasized that the discretionary policy is contained within the non-discretionary policy and in no way undermines or substitutes for it. This prevents a subject from granting access that would violate the non-discretionary policy. An example of discretionary security is provided by the DOD "need to know" policy. In SASS, the discretionary policy is implemented within the supervisor [9] by means of an Access Control List (ACL). There is an ACL maintained for every file in the system, which provides a list of all users authorized access to that file. Every attempt by a user to access a file is first checked against the ACL and then checked against the non-discretionary security policy. The "least" or "most restrictive" access found in these checks is then granted to the user.

The relationship between the labels associated with the subject's access class (sac) and the object's access class (oac) is defined by a lattice model of secure information flow [12] as follows ("|" denotes "no relationship"):

1. sac = oac, read and write access permitted
2. sac > oac, read access permitted
3. sac < oac, write access permitted
4. sac | oac, no access permitted

In order to understand how these access levels are determined, it is necessary to gain an awareness of and consideration for several basic security properties.

The "Simple Security Property" deals with "read" access. It states that a subject may have read access only to those object's whose classification is less than or equal to the classification of the subject. This prevents a subject from reading any object possessing a classification higher than his own.

The "Confinement Property" (also known as "*-property") governs "write" access. It states that a user may be granted write access only to those objects whose classification is greater than or equal to the classification of the subject. This prevents a user from writing information of a higher classification (e.g., Secret) into a file of a lower classification (e.g., Unclassified). It is noted that while this property allows a user to write into a file possessing a classification higher than his own, it does not allow him access to any of the data in that file. The SASS design does not allow a user to "write up" to higher classified files. Therefore, in SASS, "sac < oac" denotes "no access permitted."

The "Compatibility Property" deals with the creation of objects in a hierarchical structure. In SASS, objects (segments) are hierarchically organized in a tree structure. This structure consists of nodes with a root node from which the tree eminates. The Compatibility Property states that the classification of objects must be non-decreasing as we move down the hierarchical structure. This prevents a parent node from creating a child node of a lower classification.

Several prerequisites must be met in order to insure that the security kernel design provides a secure environment. Firstly, every attempt to access data must invoke the Kernel. In addition, the Kernel must be isolated and tamperproof. Finally, the Kernel design must be verifiable. This implies that the mathematical model, upon which the Kernel is based, must be proved secure and that the Kernel is shown is to correctly implement this model.

C. SEGMENTATION

Segmentation is a key element of a security Kernel based system. A segment can be defined as a logical grouping of information, such as a procedure, file or data area [6]. Therefore, we can redefine a process' address space as the collection of all segments addressable by that process. Segmentation is the technique applied to effect management of those segments within an address space. In a segmented environment, all references within an address space require two components: 1) a segment specifier (number) and 2) the location (offset) within the segment.

A segment may have several logical and physical attributes associated with it. The logical attributes may include the segment's classification, size, or permissable access (read, write, or execute). These logical attributes allow a segment to nicely fit the definition of an object within the security kernel concept, and thus provide a means for the enforcement of information security. A segment's physical attributes include the current location of the segment, whether or not the segment resides in main memory or secondary storage, and where the segment's attributes are maintained by a segment descriptor. The segment descriptors for each segment in a process' address space are contained within a Descriptor Segment (viz., the MMU Image in SASS) to facilitate the memory management of that address space.

Segmentation supports information sharing by allowing a single segment to exist in the address spaces of multiple processes. This allows us to forego the maintenance of multiple copies of the same segment and eliminates the possibility of conflicting data. Controlled access to a segment is also enforced, since each process can have different attributes (read/write) specified in its segment descriptor. In the implementation of SASS, any segment which is shared, but has "read only" access by every process sharing it, is placed in the processor local memory supporting each of these processes rather than in the global memory. This implies the maintenance of multiple copies of some shared segments. It is noted that the problem of "conflicting data" is avoided since this only applies to read only segments. This apparent waste of memory and nonuse of existing sharing facilities is justified by a design decision to provide maximum reduction of bus contention among processors accessing global memory. This reduction in bus contention is considered to be of more importance than the saving of memory space provided by single copy sharing of read only segments. This decision is also well supported by the occurrence of decreasing memory costs, which we have experienced in terms of high speed bus costs.

D. PROTECTION DOMAINS

The requirement for isolating the Kernel from the remainder of the system is achieved by dividing the address space of each process into a set of hierarchical domains or protection rings [18]. O'Connell and Richardson [7] defined three domains in the family of secure operating systems: the user, the supervisor, and the kernel. Only two domains are actually necessary in the SASS design since it does not provide extended user applications. The Kernel resides in the inner or most privileged domain and has access to all segments in an address space. System wide data bases are also maintained within the Kernel domain to insure their accessibility is only through the Kernel. The Supervisor exists in the outer or least privileged domain where its access to data or segments within an address space is restricted.

While protection domains may be created through either hardware or software mechanisms, a hardware implementation provides much greater efficiency. Current microprocessor technology only provides for the implementation of two domains. This two domain restriction does not support O'Connell and Richardson's complete family design, but it is sufficient to allow hardware implementation of the ring structure required by the SASS subset.

E. ABSTRACTION

Dijkstra [4] has shown that the notion of abstraction can be used to reduce the complexity of a problem by applying a general solution to a number of specific cases. A structure of increasing levels of abstraction provides a powerful tool for the design of complex systems and generally leads to a better design with greater clarity and fewer errors.

Each level of abstraction creates a virtual hierarchical machine [6] which provides a set of "extended instructions" to the system. A virtual machine cannot make calls to another virtual machine at a higher level of abstraction and in fact is unaware of its existence. This implies that a level of abstraction is independent of any higher levels. This independence provides for a loop-free design. Additionally, a higher level may only make use of the resources of a lower level by applying the extended instruction set of the lower level virtual machine. Therefore, once a level of abstraction is created, any higher level is only interested in the extended instruction set it provides and is not concerned with the details of its implementation. In SASS, once a level of abstraction is created for the physical resources of the system, these resources become "virtualized" making the higher levels of the design independent of the physical configuration of the system.

PART B

SECURE ARCHIVAL STORAGE SYSTEM DESIGN

This section is an excerpt from *Implementation of Process Management for a Secure Archival Storage System* by A. R. Strickler [19]. Minor changes have been made for integration into this report.

Chapter III

BASIC SASS OVERVIEW

The purpose of the Secure Archival Storage System is to provide a secure "data warehouse" or information pool which can be accessed and shared by a variable set of host computer systems possessing differing security classifications. The primary goals of the SASS design are to provide information security and controlled sharing of data among system users.

Figure 5 provides an example of a possible SASS usage. The system is used exclusively for managing an archival storage system and does not provide any programming services to its users. Thus the users of the SASS may only create, store, retrieve, or modify files within the SASS. The host computers are hardwired to the system via the I/O ports of the Z8001 with each connection having a fixed security classification. Each host must have a separate connection for each security level it wishes to work on (It is important to note that Figure 5 only represents the logical interfacing of the system. Specifically, the actual connection with the host system must be interfaced with the Kernel as the I/O instructions for the port are privileged). In our example, Host #1 can create and modify only Top Secret files, but it can read files which are Top Secret, Secret, Confidential, or Unclassified. Likewise, Host #2 can create or modify secret files, using its secret connection or confidential files, using its confidential connection. Host #2 cannot create or modify Top Secret or Unclassified files.

In order to provide information security and controlled sharing of files, the SASS operates in two domains: (1) the Supervisor domain and (2) the Kernel domain. The SASS achieves this desired environment through a distributed operating system design which consists of two primary modules: the Supervisor and the Security Kernel. Each host system connected to the SASS has associated with it two processes within the SASS which perform the data transfer and file management on behalf of that host. The host computer communicates directly with its own I/O process and File Manager process within the SASS.

We can use our notion of abstraction to present a system overview of the SASS. The SASS consists of four primary levels of abstraction:

Level 3-The Host Computer Systems

Level 2-The Supervisor

Level 1-The Security Kernel

Level 0-The SASS Hardware

A pictorial representation of this abstract system overview is presented in Figure 6. This representation is limited to a dual host system for clarity and space restrictions. Note

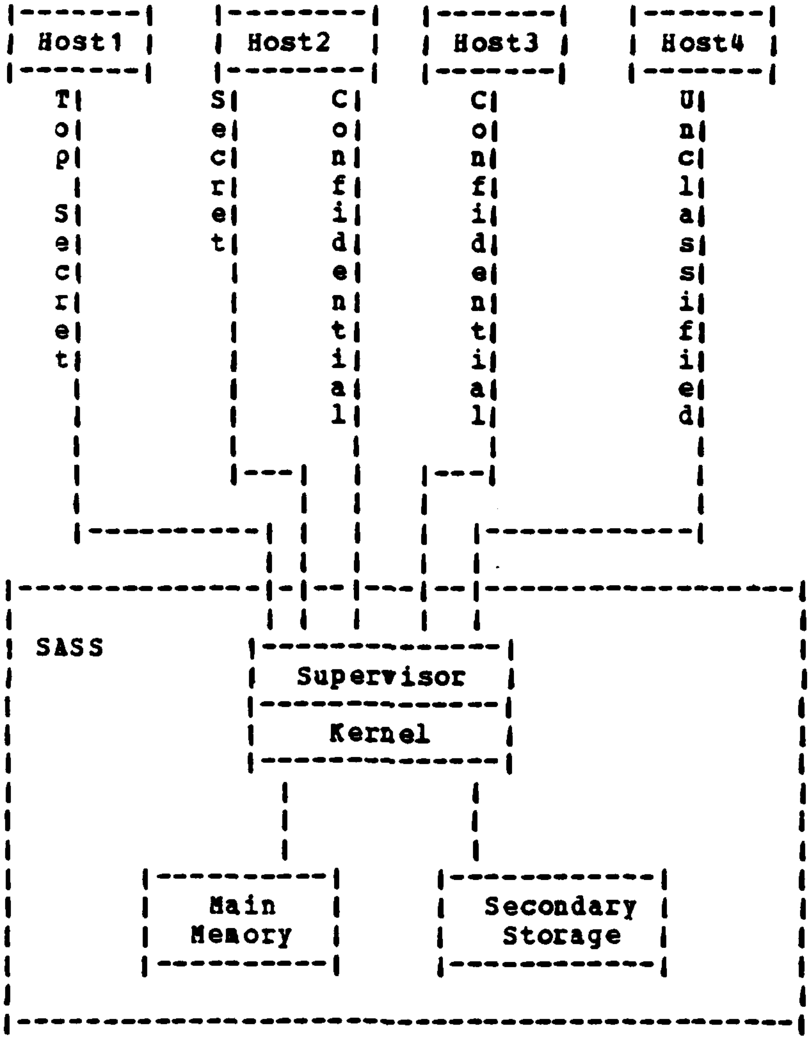

Figure 5: SASS System

that the Gate Keeper module is in actuality the logical boundary between levels one and two and as such will be described separately.

Level 3, the host computer systems, of SASS has already been addrassed. It should be noted that the SASS design makes no assumptions about the host computer systems. Therefore each host may be of a different type or size (i.e.- micro, mini, or maxi-computer system). Furthermore, the necessary physical security of the host systems and their respective data links with the SASS is assumed.

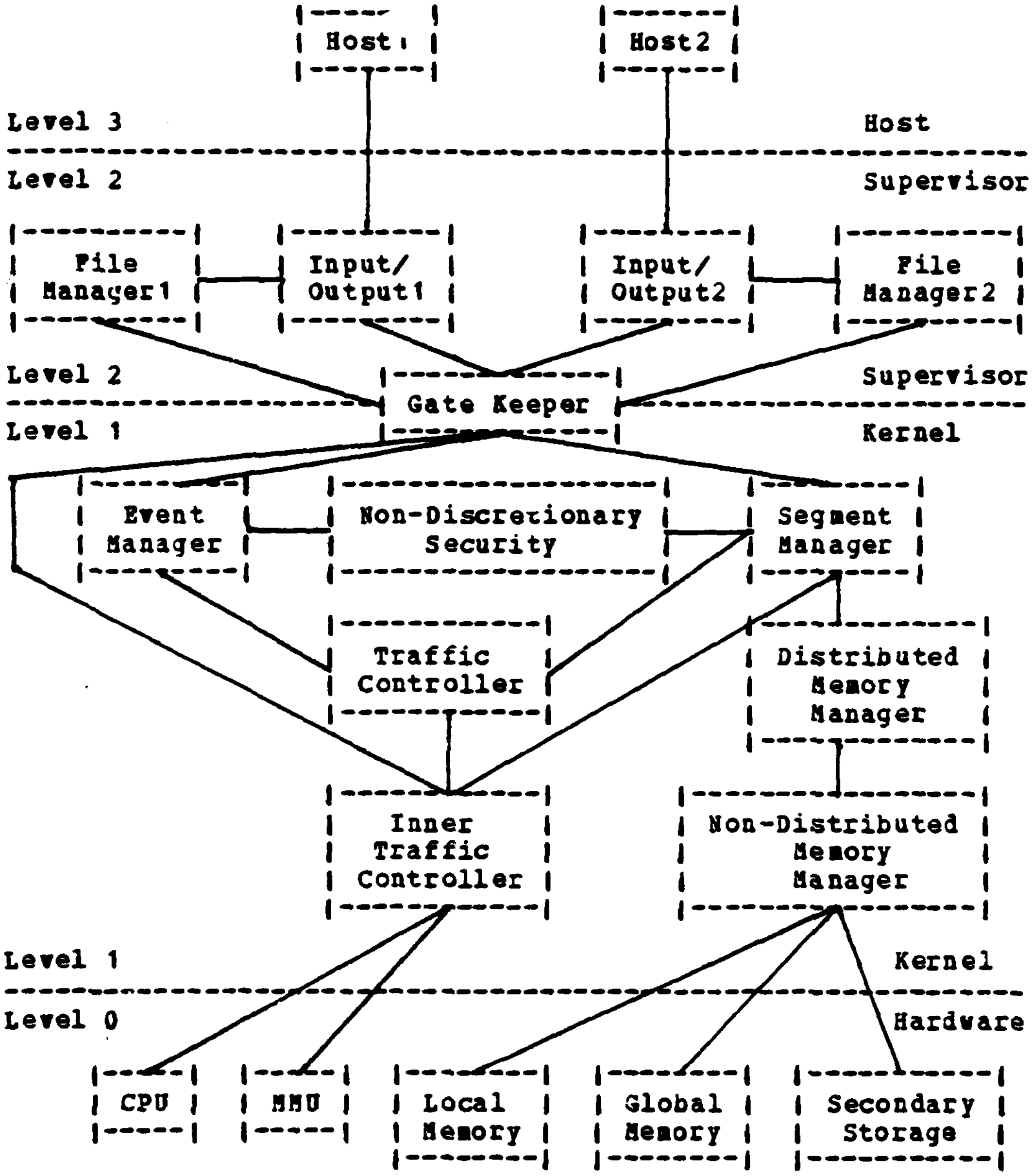

Figure 6: System Overview (Dual Host)

Chapter IV

SUPERVISOR

Level 2 of the SASS system is composed of the Supervisor domain. As already stated, the SASS consists of two domains. The actual implementation of these domains was greatly simplified since the Z8001 microprocessor provides two modes of execution. The system mode, with which the Kernel was implemented, provides access to all machine instructions and all segments within the system. The normal mode, with which the Supervisor was implemented, only provides access to a limited subset of machine instructions and segments within the system. Therefore, the Supervisor operates in an outer or less privileged domain than the Kernel.

The purpose of the Supervisor is to manage the data link between the host computer systems and the SASS by means of Input/Output control, and to create and manage the file hierarchy of each host within the SASS. These functions are accomplished via an Input/Output (I/O) process and a File Manager (FM) process within the Supervisor. A separate FM and I/O process are created and dedicated to each host at the time of system initialization.

A. FILE MANAGER PROCESS

The FM process directs the interaction between the host computer systems and the SASS. It interprets all commands received from the Host computer and performs the necessary action upon them through appropriate calls to the Kernel. The primary functions of the FM process are the management of the Host's virtual file system and the enforcement of the discretionary security policy.

The virtual file system of the Host is viewed as a hierarchy of files which are implemented in a tree structure. The five basic actions which may be initiated upon a file at this level are: 1) to create a file, 2) to delete a file, 3) to read a file, 4) to store a file, and 5) to modify a file. The FM process utilizes a FM Known Segment Table (FM_KST) as the primary database to aid in this management.

The FM process maintains an Access Control List (ACL) through which it enforces the discretionary security in SASS. The FM process initializes an ACL for every file in its Host's file system. The ACL is merely a list of all users that are authorized to access that file. The ACL is checked upon every attempt to access a file to determine its authorization. The user (host computer) directs the FM process as to what entries or deletions should be made in the ACL, and as such, specifies who he wishes to have access to his file. As noted earlier, discretionary security is a refinement to the Non-Discretionary Security Policy and therefore can only be utilized to add further access restrictions to those provided by the Non-Discretionary Security. This prevents a user from granting access to a file to someone who otherwise would not be authorized access.

B. INPUT/OUTPUT PROCESS

The I/O process is responsible for managing the input and output of all data between the host computer systems and the SASS. The I/O process is subservient to the FM process and receives all of its commands from it. Data is transferred between the SASS and Host Computer systems in fixed size "packets". These packets are broken up into three basic types: 1) a synchronization packet, 2) a command packet, and 3) a data packet. In order to insure reliable transmission and receipt of packets between the Host computer and the SASS, there must exist a protocol between them. Parks [9] provides a more detailed description of these packets, and a possible multi-packet protocol.

Chapter V

GATE KEEPER

The primary objective of the gate keeper is to isolate the Kernel and make it tamperproof. This goal is accomplished by reason of a software ring crossing mechanism provided by the gate keeper. In terms of SASS, this notion of "ring-crossing" is merely the transition from the Supervisor domain to the Kernel domain. As noted earlier, the gate keeper establishes the logical boundary between the Supervisor and the Kernel, and as a matter of course, it provides a single software entry point (enforced by hardware) into the Kernel. Therefore, any call to the Kernel must first pass through the gate keeper.

The gate keeper acts as a trap handler. Once it is invoked by a user (Supervisor) process, the hardware preempt interrupts are masked, and the user process' registers and stack pointer are saved (within the kernel domain). It then takes the argument list provided by the caller and validates these passed parameters to insure their correctness. To aid in the validation of these parameters, the gate keeper utilizes the Parameter Table as a database. The Parameter table contains all of the permitted functions provided by the Kernel. These relate directly to the extended instruction set (viz., Supervisor calls) provided by the Kernel (these extended instructions will be described in the next section). If an invalid call is encountered by the gate keeper, an error code is returned, and the Kernel is not invoked. If a valid call is encountered by the gate keeper, the arguments and control are passed to the appropriate Kernel module.

Once the Kernel has completed its action on the user request, it passes the necessary parameters and control back to the gate keeper. At this point, the gate keeper determines if any software virtual preempt interrupts have occurred. If they have, then the virtual preempt handler is invoked vice the Kernel being exited (virtual interrupt structure is discussed by Strickler [19]. Correspondingly, if a software virtual preempt has not occurred, then the return arguments are passed to the user process. The user process' registers and stack pointer (viz., its execution point) are restored and control returned to the Supervisor domain. A detailed description of the Gate Keeper interface and implementation is provided by Strickler [19].

Chapter VI

DISTRIBUTED KERNEL

Level 1 of our abstract view of SASS consists of two components: the distributed Kernel and the non-distributed Kernel. These two elements comprise the Security Kernel of the SASS. The Security Kernel has two primary objectives: 1) the management of the system's hardware resources, and 2) the enforcement of the non-discretionary security policy. It executes in the most privileged domain (viz., the system mode of the Z8001) and has access to all machine instructions. The following section will provide a brief description of the distributed Kernel, its components, and the extended instruction set it provides. A discussion of the non-distributed Kernel will be given in the next section.

The distributed Kernel consists of those Kernel modules whose segments are contained (distributed) in the address space of every user (Supervisor) process. Thus, in effect, the distributed Kernel is shared by all user processes in the SASS. The distributed Kernel is composed of the Segment Manager, the Event Manager, the Non-Discretionary Security Module, the Traffic Controller, the Inner Traffic Controller, and the Distributed Memory Manager Module. The Segment Manager and the Event Manager are the only "user visible" modules in the distributed Kernel. In other words, the set of extended instructions available to user processes invokes either the Segment Manager or the Event Manager.

A. SEGMENT MANAGER

The objective of the Segment Manager is the management of a process' segmented virtual storage. The Segment Manager is invoked by calls from the Supervisor domain via the gate keeper. Calls to the Segment Manager are made by means of six extended instructions provided by the segment manager. These extended instructions (viz., entry points) are: 1) CREATE_SEGMENT, 2) DELETE_SEGMENT, 3) MAKE_KNOWN, 4) TERMINATE, 5) SM_SWAP_IN, and 6) SM_SWAP_OUT. The extended instructions CREATE_SEGMENT and DELETE_SEGMENT add and remove segments from the SASS. MAKE_KNOWN and TERMINATE add and remove segments from the address space of a process. Finally, SM_SWAP_IN and SM_SWAP_OUT move segments from secondary storage to main storage and vice versa.

The primary database utilized by the Segment Manager is the Known Segment Table (KST). A representation of the structure of the KST is provided in Figure 7. The KST is a process local database that contains an entry for every segment in the address space of that process. The KST is indexed by segment number with each record of the KST containing descriptive information for a particular segment. The KST provides a mapping mechanism by which the segment number of a particular segment can be converted into a unique handle for use by the Memory Manager. The Memory Manager will be discussed in the next chapter.

```
|----Segment #
|    |----------|------|--------|------|-------|--------|--------|
|    |MM Handle | Size | Access | In   | Class | Mentor | Entry  |
|    |          |      | Mode   | Core |       | Seg No | Number |
|    |----------|------|--------|------|-------|--------|--------|
|    |          |      |        |      |       |        |        |
|    |----------|------|--------|------|-------|--------|--------|
|    |          |      |        |      |       |        |        |
V    |----------|------|--------|------|-------|--------|--------|
     |          |      |        |      |       |        |        |
     |----------|------|--------|------|-------|--------|--------|
     |          |      |        |      |       |        |        |
     |----------|------|--------|------|-------|--------|--------|
     |          |      |        |      |       |        |        |
     |----------|------|--------|------|-------|--------|--------|
     |          |      |        |      |       |        |        |
     |----------|------|--------|------|-------|--------|--------|
```

Figure 7: Known Segment Table (KST)

B. EVENT MANAGER

The purpose of the Event Manager is the management of event data which is associated with interprocess communications within the SASS. This event data is implemented by means of eventcounts (a synchronization primitive discussed by Reed [11]). The Event Manager is invoked, via the Gate Keeper, by user processes residing in the Supervisor domain. There are two eventcounts associated with every segment existing in the Supervisor domain. These eventcounts (viz., Instance 1 and Instance 2) are maintained in a database residing in the Memory Manager. The Event Manager provides its management functions through its extended instruction set READ, TICKET, ADVANCE, and AWAIT, and in conjunction with the extended instructions TC_ADVANCE and TC_AWAIT provided by the Traffic Controller (to be discussed next). These extended instructions are based on the mechanism of eventcounts and sequencers [11]. The Event Manager verifies the access permission of every interprocess communication request through the Non-Discretionary Security Module. The extended instruction READ provides the current value of the eventcount requested by the caller. TICKET provides a complete time ordering of possibly concurrent events through the mechanism of sequencers. The Event Manager will be discussed in more detail by Strickler [19].

C. NON-DISCRETIONARY SECURITY MODULE

The purpose of the Non-Discretionary Security Module (NDS) is the enforcement of the non-discretionary security policy of the SASS. While the current implementation of SASS represents the Department of Defense security policy, any security policy which may be represented through a lattice structure [3] may also be implemented. The NDS is invoked via its extended instruction set: CLASS_EQ and CLASS_GE. The NDS is passed two classifications which it compares and then analyzes their relationship. CLASS_EQ will return a true value to the calling procedure only if the two classifications passed were equal. The CLASS_GE instruction will return true if a given classification is analyzed to be either greater than or equal to another given classification. The NDS does not utilize a data base as it works only with the parameters it is passed.

D. TRAFFIC CONTROLLER

The task of processor scheduling is performed by the traffic controller. Saltzer [14] defines traffic controller as the processor multiplexing and control communication section of an operating system. The current SASS design utilizes Reed's [10] notion of a two level traffic controller, consisting of: 1) a Traffic Controller (TC) and 2) an Inner Traffic Controller (ITC).

The primary function of the Traffic Controller is the scheduling (binding) of user processes onto virtual processors. A virtual processor (VP) is an abstract data structure that simulates a physical processor through the preservation of an executing process' attributes (viz., the execution point and address space). Multiple VP's may exist for every physical processor in the system. Two VP's are permanently bound to Kernel processes (viz., Memory Manager and Idle) and as such are not in contention for process scheduling. These processes and their corresponding virtual processors are invisible to the TC. The remaining virtual processors are either idle or are temporarily bound to user processes as scheduled by the TC. The database utilized by the TC in process scheduling is the Active Process Table (APT). Figure 8 provides the structure of the APT.

The APT is a system-wide Kernel database containing an entry for every user process in the system. Since the current SASS design does not provide for dynamic process creation/deletion, a user process is active for the life of the system. Therefore, the size of the APT is fixed at the time of system generation. The APT is logically composed of three parts: 1) an APT header, 2) the main body of the APT, and 3) a VP table. The APT header includes: 1) a Lock to provide for a mutual exclusion mechanism, 2) a Running List indexed by VP ID to identify the current process running on each VP, 3) a Ready List, which points to the linked list of

```
            |-----------------------------|   ---|
            | Lock                        |      |
            |----------------|------------|      |
            | Running List   | APT Entry #|      |
            |                |------------|      |
            | VP ID----|     |------------|      |
            |          |     |------------|      |
            |          v     |------------|      |
            |----------------|------------|      |--- APT
            | Ready List Head| APT Entry #|      |    HEADER
            |                |------------|      |
            | Log_CPU_No--|  |------------|      |
            |             |  |------------|      |
            |             V  |------------|      |
            |-----------------------------|      |
            | Blocked List Head           |      |
            |-----------------------------|   ---|

|---APT Entry #
|
|  |----|------|------|--------|-----|-----|--|-------------|
|  |    |      |      |        |     |     |  |Awaited Event|
|  |    |      |      |        |     |     |  |-------------|
|  | AP | DBR  |Access|Priority|State|Affi-|VP|Handle       |
|  |Link|Handle|Class |        |     |nity |ID|  Instance   |
|  |    |      |      |        |     |     |  |   |    Count|
|  |----|------|------|--------|-----|-----|--|---|----|----|
|  |    |      |      |        |     |     |  |   |    |    |
|  |----|------|------|--------|-----|-----|--|---|----|----|
|  |    |      |      |        |     |     |  |   |    |    |
|  |----|------|------|--------|-----|-----|--|---|----|----|
|  |    |      |      |        |     |     |  |   |    |    |
V  |----|------|------|--------|-----|-----|--|---|----|----|
   |    |      |      |        |     |     |  |   |    |    |
   |----|------|------|--------|-----|-----|--|---|----|----|

          Log_CPU_No----------->
         |----------|-----|-----|-----|-----|   ---|
         |NR_OF_VP'S|     |     |     |     |      |  TC
         |----------|-----|-----|-----|-----|      |--VP
         |FIRST_VP  |     |     |     |     |      |  TABLE
         |----------|-----|-----|-----|-----|   ---|
```

Figure 8: Active Process Table (APT)

processes which are ready for scheduling, and 4) a Blocked List, which points to the linked list of processes which are in the blocked state awaiting the occurrence of some event.

A design decision was made to incorporate a single list of blocked processes instead of the more traditional notion of separate lists per eventcount because of its simplicity and its ease of implementation. This decision does not appreciably affect system performance or efficiency as the "blocked" list will never be very long. The VP table is indexed by logical CPU number and specifies the number of VP's associated with the logical CPU and its first VP in the Running List. The logical CPU number, obtained during system initialization, provides a simple means of uniquely identifying each physical CPU in the system. The main body of the APT contains the user process data required for its efficient control and scheduling. NEXT_AP provides the linked list threading mechanism for process entries. The DBR entry is a handle identifying the process' Descriptor Segment which is employed in process switching and memory management. The ACCESS_CLASS entry provides every process with a security label that is utilized by the Event Manager and the Segment Manager in the enforcement of the Non-Discretionary Security Policy. The PRIORITY and STATE entries are the primary data used by the Traffic Controller to effect process scheduling. AFFINITY identifies the logical CPU which is associated with the process. VP ID is utilized to identify the virtual processor that is currently bound to the process. Finally, the EVENTCOUNT entries are utilized by the TC to manage processes which are blocked and awaiting the occurrence of some event. HANDLE identifies the segment associated with the event, INSTANCE specifies the event, and COUNT determines which occurrence of the event is needed.

The Traffic Controller determines the scheduling order by process priority. Every process is assigned a priority at the time of its creation. Once scheduled, a process will run on its VP until it either blocks itself or it is preempted by a higher priority process. To insure that the TC will always have a process available for scheduling, there logically exists an "idle" process for every VP visible to the TC. These "idle" processes exist at the lowest process priority and, consequently, are scheduled only if there exists no useful work to be performed.

The Traffic Controller is invoked by the occurrence of a virtual preempt interrupt or through its extended instruction set: ADVANCE, AWAIT, PROCESS_CLASS, and GET_DBR_NUMBER. ADVANCE and AWAIT are used to implement the IPC mechanism envoked by the Supervisor. PROCESS_CLASS and GET_DBR_NUMBER are called by the Segment Manager to ascertain the security label and DBR handle, respectively, of a named process. A more detailed discussion of the TC is provided by Strickler [19].

E. INNER TRAFFIC CONTROLLER

The Inner Traffic Controller is the second part of our two-level traffic controller. Basically, the ITC performs two functions. It multiplexes virtual processors onto the actual physical processors, and it provides the primitives for which inter-VP communication within the Kernel is implemented. A design choice was made to provide each physical processor in the system with a small fixed set of virtual processors. Two of these VP's are permanently bound to the Kernel processes. The Memory Manager is bound to the highest priority VP. Conversely, the Idle Process is bound to the lowest priority VP and, as a result, will only be scheduled if there exists no useful work for the CPU to perform. The primary database utilized by the ITC is the Virtual Processor Table (VPT). Figure 9 illustrates the VPT.

The VPT is a system wide Kernel database containing entries for every CPU in the system. The VPT is logically composed of four parts: 1) a header, 2) a VP data table, 3) a message table, and 4) an external VP lis.. The header includes a LOCK (spin lock) that provides a mutual exclusion mechanism for table access, a RUNNING LIST (indexed by logical CPU #) that identifies the VP currently running on the corresponding physical CPU, a READY LIST (indexed by logical CPU #) which points to the linked list of VP's which are in the "ready" state and awaiting scheduling on that CPU, and a FREE LIST which points to the linked list of unused entries

```
                         |--------------|------------|   ---|
                         | Lock         |            |      |
                         |--------------|------------|      |
                         | Running_List |VPT Entry #|      |
                         |              |------------|      |
                         | CPU_No--|    |------------|      |
                         |         |    |------------|      |
                         |         V    |------------|      |
                         |--------------|------------|      |---VPT
                         | Ready_List   |VPT Entry #|      |  Header
                         |              |------------|      |
                         | CPU_No--|    |------------|      |
                         |         |    |------------|      |
                         |         V    |------------|      |
                         |--------------|------------|      |
                         | Free_List    |            |      |
                         |--------------|------------|   ---|

|-----VP_ID
|   |-----|---|-----|----|-------|---------|---|---|----|
|   |NEXT |   |     |    |       |         |   |EXT|    |
|   |READY|DBR|STATE|IDLE|VIRTUAL|PHYSICAL |PRI|VP |MSG |
|   | VP  |   |     |FLAG|PREEMPT|PROCESSOR|   |ID |LIST|
|   |-----|---|-----|----|-------|---------|---|---|----|
|   |     |   |     |    |       |         |   |   |    |
|   |-----|---|-----|----|-------|---------|---|---|----|
V   |     |   |     |    |       |         |   |   |    |
    |-----|---|-----|----|-------|---------|---|---|----|
    |     |   |     |    |       |         |   |   |    |
    |-----|---|-----|----|-------|---------|---|---|----|
    |     |   |     |    |       |         |   |   |    |
    |-----|---|-----|----|-------|---------|---|---|----|

|------MSG_INDEX
|   |----------|--------|-----|     EXT_VP_ID---------->
|   | NEXT_MSG | SENDER | MSG |    |--------------------|
|   |----------|--------|-----|    | VPT  |   |   |   |  |
|   |          |        |     |    |Entry|   |   |   |  |
|   |----------|--------|-----|    | No   |   |   |   |  |
|   |          |        |     |    |--------------------|
V   |----------|--------|-----|
    |          |        |     |    |--------------------|
    |----------|--------|-----|              |
                                          External
    |-----------|------------|               VP
                |                           List
          Message List
```

Figure 9: Virtual Processor Table (VPT)

in the message table. The VP data table contains the descriptive data required by the ITC to effectively manage the virtual processors. The DBR entry points within the MMU Image to the descriptor segment for the process currently running on the VP. PRI (Priority), STATE, IDLE_FLAG, and PREEMPT are the primary data used by the ITC for VP scheduling. PREEMPT indicates whether or not a virtual preempt is pending for the VP. The IDLE_FLAG is set whenever the TC has bound an "idle" process to the VP. Normally, a VP with the IDLE_FLAG set will not be scheduled by the ITC as it has no useful work to perform. In fact, such a VP will only be scheduled if the PREEMPT flag is set. This scheduling will allow the VP to be given (bound) to another process. PHYSICAL PROCESSOR contains an entry from the Processor Data Segment (PRDS) that identifies the physical processor that the VP is executing on. EXT_VP_ID is the identifier by which the VP is known by the Traffic Controller. A design choice was made to have the EXT_VP_ID equate to an offset into the External VP List. The External VP List specifies the actual VP ID (viz., VPT entry number) for each external VP identifier. This precluded the necessity for run time calculation of offsets for the EXT_VP_ID. NEXT_READY_VP provides the threading mechanism for the "Ready" linked list, and MSG_LIST points to the first entry in the Message Table containing a message for that VP. The Message Table provides storage for the messages generated in the course of

Inter-Virtual Processor communications. MSG contains the actual communication being passed, while SENDER identifies the VP which initiated the communication. NEXT_MSG provides a threading mechanism for multiple messages pending for a single VP.

The ITC is invoked by means of its extended instruction set: WAIT, SIGNAL, SWAP_VDBR, IDLE, SET_PREEMPT, and RUNNING_VP. WAIT and SIGNAL are the primitives employed in implementing the Inter-VP communication. SWAP_VDBR, IDLE, SET_PREEMPT, and RUNNING_VP are all invoked by the Traffic Controller. SWAP_VDBR provides the means by which a user process is temporarily bound to a virtual processor. IDLE binds the "Idle" process to a VP (the implication of this instruction will be discussed later). SET_PREEMPT provides the means of indicating that a virtual preempt interrupt is pending on a VP (specified by the TC) by setting the PREEMPT flag for that VP in the VPT. RUNNING_VP provides the TC with the external VP ID of the virtual processor currently running on the physical processor.

F. DISTRIBUTED MEMORY MANAGER

The Distributed Memory Manager provides an interface structure between the Segment Manager and the Memory Manager Process. This interfacing is necessitated by the fact that the Memory Manager Process does not reside in the Distributed Kernel and consequently is not included in the user process' address space. The primary functions performed in this module are the establishment of Inter-VP Communication between the VP bound to its user process and the VP permanently bound to the Memory Manager Process, the manipulation of event data, and the dynamic allocation of available memory. The Distributed Memory Manager Module is invoked by the Segment Manager through its extended instruction set: MM_CREATE_ENTRY, MM_DELETE_ENTRY, MM_ACTIVATE, MM_DEACTIVATE, MM_SWAP_IN, and MM_SWAP_OUT. These extended instructions are utilized on a one to one basis by the extended instruction set of the Segment Manager (e.g., SM_SWAP_IN utilizes (calls) MM_SWAP_IN). Wells [20] provides a more detailed description of this portion of the Distributed Memory Manager and the extended instruction set associated with it.

The Distributed Memory Manager is also invoked through its remaining extended instructions: MM_READ_EVENTCOUNT, MM_TICKET, MM_ADVANCE, and MM_ALLOCATE. These Distributed Memory Manager functions are discussed in detail by Strickler [19].

Chapter VII

NON-DISTRIBUTED KERNEL

The Non-Distributed Kernel is the second element residing in Level 1 of our abstract system view of the SASS. The sole component of the Non-Distributed Kernel is the Memory Manager Process.

A. MEMORY MANAGER PROCESS

The primary purpose of the Memory Manager Process is the management of all memory resources within the SASS. These include the local and global main memories, as well as the hard-disk based secondary storage. A dedicated Memory Manager Process exists for every CPU in the system. Each CPU possesses a local memory where process local segments and shared, non-writeable segments are stored. There is also a global memory, to which every CPU has access, where the shared, writeable segments are stored. It is necessary to store these shared, writeable segments in the global memory to ensure that a current copy exists for every access.

The Memory Manager Process is tasked by other processes within the Kernel domain (via Signal and Wait) to perform memory management functions. These basic functions include the allocation/deallocation of local and global memory and of secondary storage, and the transfer of segments between the local and global memory and between secondary storage and the main memories. The extended instruction set provided by the Memory Manager Process includes: CREATE_ENTRY, DELETE_ENTRY, ACTIVATE, DEACTIVATE, SWAP_IN, and SWAP_OUT. These instructions correspond one to one with those of the Distributed Memory Manager Module. The system wide data bases utilized by all Memory Manager Processes are the Global Active Segment Table (G_AST), the Alias Table, the Disk Bit Map, and the Global Memory Bit Map. The processor local databases used by each Memory Manager Process are the Local Active Segment Table (L_AST), and the Local Memory Bit Map. Gary and Moore [5] provide a detailed description of the Memory Manager, its extended instruction set, and its databases.

A summary of the extended instruction set created by the components of the Security Kernel is provided by Figure 10. One might question the prudence of omitting PHYS_PREEMPT_HANDLER and VIRT_PREEMPT_HANDLER (viz., the handler routines for physical and virtual interrupts) from the extended instruction set as both of these interrupts may be raised (viz., initiated) from within the Kernel. A decision was made to not classify these handlers as "extended instructions" since they are only executed as the result of a physical or virtual interrupt and as such cannot be directly invoked (viz., "called") by any module in the system.

A summary of the databases utilized by Kernel modules is presented in Figure 11.

MODULE	INSTRUCTION SET	
Segment Manager	Create_Segment*	Delete_Segment*
	Make_Known*	Terminate*
	SM_Swap_In*	SM_Swap_Out*
Event Manager	Read*	Ticket*
	Advance*	Await*
Non-Discretionary Security	Class_EQ	Class_GE
Traffic Controller	TC_Advance	TC_Await
	Process_Class	
Inner Traffic Controller	Signal	Wait
	Swap_VDBR	Idle
	Set_Preempt	Test_Preempt
	Running_VP	
Distributed Memory Manager	MM_Create_Entry	MM_Delete_Entry
	MM_Activate	MM_Deactivate
	MM_Swap_In	MM_Swap_Out
Non-Distributed Memory Manager	Create_Entry	Delete_Entry
	Activate	Deactivate
	Swap_In	Swap_Out

* Denotes user visible instructions

Figure 10: Extended Instruction Set

MODULE	DATABASE
Gate Keeper	Parameter Table
Segment Manager	Known_Segment_Table (KST)
Traffic Controller	Active_Process_Table (APT)
Inner Traffic Controller	Virtual_Processor_Table (VPT)
	Memory_Management_Unit Image (MMU)
Memory Manager	Global_Active_Segment_Table (G_AST)
	Local_Active_Segment_Table (L_AST)
	Disk_Bit_Map
	Global_Memory_Bit_Map
	Local_Memory_Bit_Map

Figure 11: Kernel Databases

Chapter VIII

SYSTEM HARDWARE

Level 0 of the SASS consists of the system hardware. This hardware includes: 1) the CPU, 2) the local memory, 3) the global memory, 4) the secondary storage (viz. hard disk), and 5) the I/O ports connecting the Host computer systems to the SASS. Since the SASS design allows for a multiprocessor environment, there may exist multiple CPU's and local memories. The target machine selected for the initial implementation of the system is the Zilog Z8001 microprocessor [22]. The Z8001 is a general purpose 16-bit, register oriented machine that has sixteen 16-bit general purpose registers. It can directly address 8M bytes of memory, extensible to 48M bytes. The Z8001 architecture supports memory segmentation and two-domain operations. The memory segmentation capability is provided externally by the Zilog Z8010 Memory Management Unit (MMU). The Z8010 MMU [23] provides management of the Z8001 addressable memory, dynamic segment relocation, and memory protection. Memory segments are variable in size from 256 bytes to 64K bytes and are identified by a set of 64 Segment Descriptor Registers, which supply the information needed to map logical memory addresses to physcal memory addresses. Each of the 64

Descriptor Registers contains a 16-bit base address field, an 8-bit limit field, and an 8-bit attribute field. Unfortunately, the Z8001 hardware was not available for use during system development. Therefore, all work to date has been completed through utilization of the Z8002 non-segmented version of the Z8000 microprocessor family [22]. The actual hardware used in this implementation is the Advanced Micro Computers Am96/4116 MonoBoard Computer [1] containing the AmZ8002 sixteen bit non-segmented microprocessor. This computer provides 32K bytes of on-board RAM, 8k bytes of PROM/ROM space, two RS232 serial I/O ports, 24 parallel I/O lines, and a standard INTEL Multibus interface. The general structure of the design has been preserved by simulation of the segmentation hardware in software. This software MMU Image (see Figure 12) is created as a database within the Inner Traffic Controller.

The MMU Image is a processor-local database indexed by DBR_No. Each DBR_No represents one record within the MMU Image. Each record is an exact software copy of the Segment Descriptor Register set in the hardware MMU. Each element of this software MMU Image is in the same form utilized by the special I/O instructions to load the hardware MMU. Each DBR record is indexed by segment number (Segment_No). Each Segment_No entry is composed of three fields: Base_Addr, Limit, and Attributes. Base_Addr is a 16-bit field which contains the base address of the segment in physcal memory.

```
                                               DBR_No------------>
              |---------------------------------------------------------|
              | Base_Addr | Limit | Attributes |                        |
              |-----------|-------|------------|                        |
    Segment   |           |       |            |                        |
      No.     |-----------|-------|------------|                        |
       |      |           |       |            |                        |
       |      |-----------|-------|------------|                        |
       |      |           |       |            |         . . .          |
       |      |-----------|-------|------------|                        |
       V      |           |       |            |                        |
              |-----------|-------|------------|                        |
              |           |       |            |                        |
              |-----------|-------|------------|                        |
              |           |       |            |                        |
              |-----------|-------|------------|------------------------|

              |----------------|---------------|
                               |
                               |
                               V
                    (entries for one DBR #)
```

Figure 12: Memory Management Unit (MMU) Image

Limit is an 8-bit field that specifies the number of contiguous blocks of memory occupied by the segment. Attributes is an 8-bit field representing the eight flags which specify the segment's attributes (e.g., "read", "execute", "write", etc.).

Chapter IX

SUMMARY

An extended overview of the current SASS design has been presented. The four major levels of abstraction comprising the SASS system have been identified, and the major components of each level have been discussed. The extended instruction set provided by the SASS Kernel was also defined. The actual details of this implementation are described by Strickler [19].

PART C

THE DESIGN AND IMPLEMENTATION OF THE MEMORY MANAGER FOR A SECURE ARCHIVAL STORAGE SYSTEM

This section contains updated excerpts from a Naval Postgraduaduate School MS Thesis by E. E. Moore and A. V. Gary [5]. The origins of these excerpts are:

INTRODUCTION	from Chapter I
MEMORY MANAGER PROCESS DETAILED DESIGN	from Chapter III
STATUS OF RESEARCH	from Chapter IV

Minor changes have been made for integration into this report.

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THE NAVAL POSTGRADUATE SCHOOL SECURE ARCHIVAL STORAGE SYSTEM. P--ETC(U)
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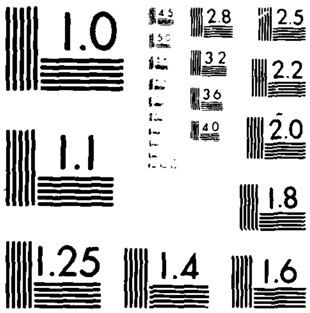
1.0
4.5
5.0
2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

Chapter X

INTRODUCTION

This thesis addresses the design and partial implementation of a memory manager for a member of the family of secure, distributed, multi-microprocessor operating systems designed by Richardson and O'Connell [7]. The memory manager is responsible for the secure management of the main memory and secondary storage. The memory manager design was approached and conducted with distributed processing, multiprocessing, configuration independence, ease of change, and internal computer security as primary goals. The problems faced in the design were:

1) Developing a process which would securely manage files in a multi-processor environment.

2) Ensuring that if secondary storage was inadvertantly damaged, it could usually be recreated.

3) Minimizing secondary storage accesses.

4) Proper parameter passing during interprocess communication.

5) Developing a process with a loop-free structure which is configuration independent.

6) Designing databases which optimize the memory management functions.

The proper design and implementation of a memory management process is vital because it serves as the interface between the physical storage of files in a storage system and the logical hierarchical file structure as viewed by the user (viz., the file system supervisor design by Parks [9]. If the memory manager process does not function properly, the security of that system cannot be guaranteed.

The secure family of operating systems designed by Richardson and O'Connell is composed of two primary modules, the supervisor and the security kernel. A subset of that system was utilized in the design of the Secure Archival Storage System (SASS). The design of the SASS supervisor was addressed by Parks [9], while the security kernel was addressed concurrently by Coleman [2]. The SASS security kernel design is composed of two parts, the distributed kernel and the non-distributed kernel. The design of the distributed kernel was conducted by Coleman [2], and processor management was implemented by Reitz [12]. This thesis presents the design and implementation of the non-distributed kernel. In the SASS design, the non-distributed kernel consists solely of the memory manager.

The design of the memory manager and its data bases was completed. The initial code was written in PLZ/SYS, but could not be compiled due to the lack of a PLZ/SYS compiler.

A thread of the high level code was selected, hand compiled into PLZ/ASM, and run on the Z8000 developmental module.

Chapter XI

MEMORY MANAGER PROCESS DETAILED DESIGN

A. INTRODUCTION

The memory manager is responsible for the management of both main memory (local and global) and secondary storage. It is a non-distributed portion of the kernel with one memory manager process existing per physical processor. The memory manager is tasked (via signal and wait) to perform memory management functions on behalf of other processes in the system. The major tasks of the memory manager are : 1) the allocation and deallocation of secondary storage, 2) the allocation and deallocation of global and local memory, 3) segment transfer from local to global memory (and vice versa), and 4) segment transfer from secondary storage to main memory (and vice versa). There are ten service calls (via signal) which task the memory manager Process to perform these functions. The ten service calls are:

```
CREATE_ENTRY
DELETE_ENTRY
ACTIVATE
DEACTIVATE
SWAP_IN
SWAP_OUT
DEACTIVATE_ALL*
MOVE_TO_GLOBAL*
MOVE_TO_LOCAL*
UPDATE*
```

Upon completion of the service request, the memory manager returns The results of the operation to the waiting process (via signal). It then blocks itself until it is tasked to perform another service. The hardware configuration managed by the memory manager process is depicted in Figure 13. The shared data bases used by all memory manager processes are the Global Active Segment Table (G_AST), the Alias Table, the Disk Bit Map, and the Global Memory Bit Map. The processor local data bases used by each process are the Local Active Segment Table (L_AST), the Memory Management Unit Images and the Local Memory Bit Map.

* In the current state these service calls are not implemented; therefore, there are currently six service calls.

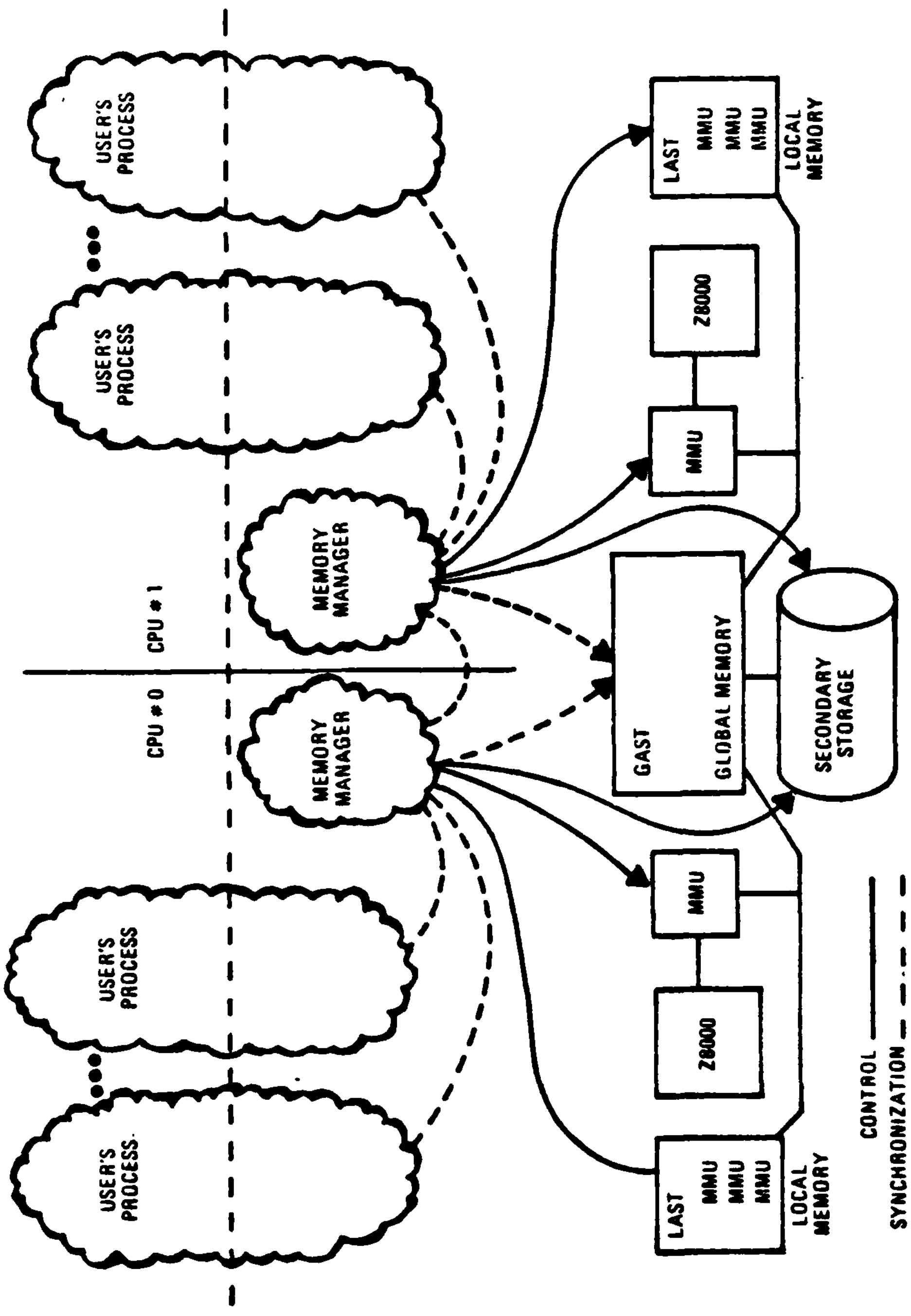

Figure 13: SASS H/W System Overview

B. DESIGN PARAMETERS AND DECISIONS

Several factors were identified during the design of the memory manager process that refined the initial kernel design of Coleman [2]. The two areas that were modified, were the management of the MMU images and the management of core memory. Both of these functions were managed outside of the memory manager in the initial design. The inclusion of these functions in the memory manager process significantly improved the logical structure of the overall system design. Additional design parameters were established to facilitate the initial implementation. These design parameters need to be addressed before the detailed design of the memory manager process is presented.

It was decided to make the block/page size of both main memory and secondary storage equal in size. This was to simplify the mapping algorithm from secondary storage to main memory (and vice versa). In the initial design the block/page size was set to 512 bytes.

The size of the page table for a segment was set at one page (non-paged page table). This was to simplify implementation, and had a direct bearing on the maximum segment size supported in the memory manager. For example, a page size of 256 bytes will address a maximum segment size of 32,768 bytes, while a page size of 512 bytes will address a segment size of 131,072 bytes.

The size of the alias table was set to one page (non-paged alias table). The number of entries that the alias table will support is limited by the size of the page table (viz., a page size of 512 bytes will support up to 42 entries in the Alias Table).

In the original design, the main memory allocation was external to the memory manager. This was due to the partitioned memory management scheme outlined by Parks [9] and Coleman [2]. In the current design, all address assignment and segment transfer are managed by the memory manager. This design choice enhanced the generality of the design, and provided support for any memory management scheme (either in the memory manager or at a higher level of abstraction). However, the current design still has a maximum core constraint for each process.

Dynamic memory management is not implemented in this design. Each process is allocated a fixed size of physical core. However, it is not a linear allocation of physical memory. The design supports the maximum sharing of segments in local and global memory. All segments that are not shared, or shared and do not violate the readers/writers problem will reside in local memory to eliminate the global bus contention. The need to compact the memory (because of fragmentation) should be minimal in this design due to the maximum sharing of segments. If contiguous memory is not available, the memory manager will compact main memory. After compaction, the memory can be allocated.

The design decision to represent memory as one contiguous block (not partitioned) was made to support a dynamic memory management scheme. Without dynamic memory management, the process' total physical memory can not exceed the systems main memory. The supervisor knows the size of the segments and the size of the process' virtual core, therefore it can manage the swap in and swap out to ensure that the process' virtual core has not been exceeded.

In the original design, the user's process inner-traffic controller maintained the software images of the memory management unit. This design required the memory manager to return the appropriate memory management data (viz.,segment location) to the kernel of the user's process. In the current design, the software images of the MMU are maintained by the memory manager. A descriptor base pointer is provided for the inner-traffic controller to multiplex the process address spaces. The MMU image data base does not need to be locked (to prevent race conditions) due to the fact that process interrupts are masked in the kernel. Thus, if the memory manager (a kernel process) is running then no other process can access the MMU image.

The system initialization process has not been addressed to date. However, this design has made some assumptions about the initial state of the system. Since the memory manager handles the transfer of segments from secondary storage to main memory, it is likely to be one of the first processes created. The memory manager's core image will consist of its pure code and data sections. The minimal initialization of the memory manager's data bases are entries for the system root and the supervisor's segments in the G_AST and L_AST(s), and the initializaton of the MMU images with the kernel segments. The current design does not call for an entry in the G_AST or L_AST for the kernel segments. However, when system generation is designed this will have to be readdressed.

The original [2] memory manager databases have been refined by this thesis to facilitate the memory management functions. The major refinements of the global and local active segment tables are outlined in the following section.

C. DATA BASES

1. Global Active Segment Table

The Global Active Segment Table (see Figure 14) is a system wide, shared data base used by memory manager processes to manage all active segments. A lock/unlock mechanism is utilized to prevent any race conditions from occurring. The signalling process locks the G_AST before it signals the memory manager. This is done to prevent a deadly embrace from occurring between memory manager processes, and also to simplify synchronization between memory managers. The entire G_AST is locked in this design to simplify the implementation (vice locking each individual entry).

```
Index_#
 |
 |
 |  ----------------------------------------------------------
 |  |      |      | *          |     Flag  Bits        |        /
 |  |Unique|Global|Processors  |-----------------------|G_ASTE_#/
 |  |  ID  | Addr | L_ASTE_#   | Written  | Writable   | Parent/
 |  |      |      |------------|   Bit    |    Bit     |       /
 |  |      |      | #0   |  #1 |          |            |       /
 |   ---------------------------------------------------------
 |  |      |      |      |     |          |            |       /
 |  |      |      |      |     |          |            |       /
 V  |      |      |      |     |          |            |       /
    |      |      |      |     |          |            |       /
    |      |      |      |     |          |            |       /
    |      |      |      |     |          |            |       /
    |      |      |      |     |          |            |       /
    |      |      |      |     |          |            |       /
    ----------------------------------------------------------
```

* Field indicates a two processor environment

```
 -----------------------------------------------------------------
 / # Active | No.      |    | Page| Alias| Seq-   |Inst-|Inst-|
 /In Memory | Active   |Size|Table| Table| uencer|ance1|ance2|
 /          | Depend.|    | Loc | Loc  |        |     |     |
 ----------------------------------------------------------------
 /          |          |    |     |      |        |     |     |
 /          |          |    |     |      |        |     |     |
 /          |          |    |     |      |        |     |     |
 /          |          |    |     |      |        |     |     |
 /          |          |    |     |      |        |     |     |
 /          |          |    |     |      |        |     |     |
 /          |          |    |     |      |        |     |     |
 /          |          |    |     |      |        |     |     |
 -----------------------------------------------------------------
```

Figure 14: Global Active Segment Table

The G_AST size is fixed at compile time. The size of the G_AST is the product of the G_AST record size, the maximum number of processes and the number of authorized known segments per process. Although the G_AST is of fixed size, it is plausible to dynamically manage the entries as proposed by Richardson and O'Connell [7]. The current memory manager design could be extended to include this dynamic management.

The Unique_Id field is a unique segment identification number in the G_AST. This field is four bytes wide and will provide over four billion identification numbers. A design choice was made not to manage the reallocation of the unique_id's. Thus when a segment is deleted from the system, the unique_id is not reused.

The Global_Address field is used to indicate if a segment resides in global or local memory. If not null, it contains the global memory base address of a segment. A null entry indicates that the segment might be in local memory(s).

The Processors_L_ASTE_# field is used as a connected processors list. The field is an array structure, indexed by Processor_Id. It identifies which L_AST the segment is active in, and provides the index into each of these tables. The design choice of maintaining an entry in the L_AST for all locally active segments implies that if all entries in the Processors_L_ASTE_# field are null, the segment is not active and can be removed from the G_AST (viz., no processors are connected).

The Flag_Bits field consists of the written bit, and the writable bit. The written bit is set when a segment is swapped out of memory, and the MMU image indicates that it has been written into. The writable bit is set during segment loading to indicate that some process has write access to that segment.

If an active segment is a leaf, the G_ASTE_#_Parent field provides a back pointer to the G_AST index of its parent. This back pointer to the parent is important during the creation of a segment. If a request is received to create a segment which has a leaf segment as its parent, then an alias table has to be created for that parent. Also, the alias table of the parent's parent needs to be updated to reflect the existence of the newly created alias table (see Figure 15). The indirect pointer shown is the back pointer to the parent via the G_AST.

The No_Active_In_Memory field is a count of the number of processes that have the segment in global memory. It is used during swap out to determine if the segment can be removed from global memory.

The No_Active_Dependents field is a count of the number of active leaf segments that are dependent on this entry (viz., require that this segment remain in the G_AST). Each time a process activates or deactivates a dependent segment this field is incremented or decremented.

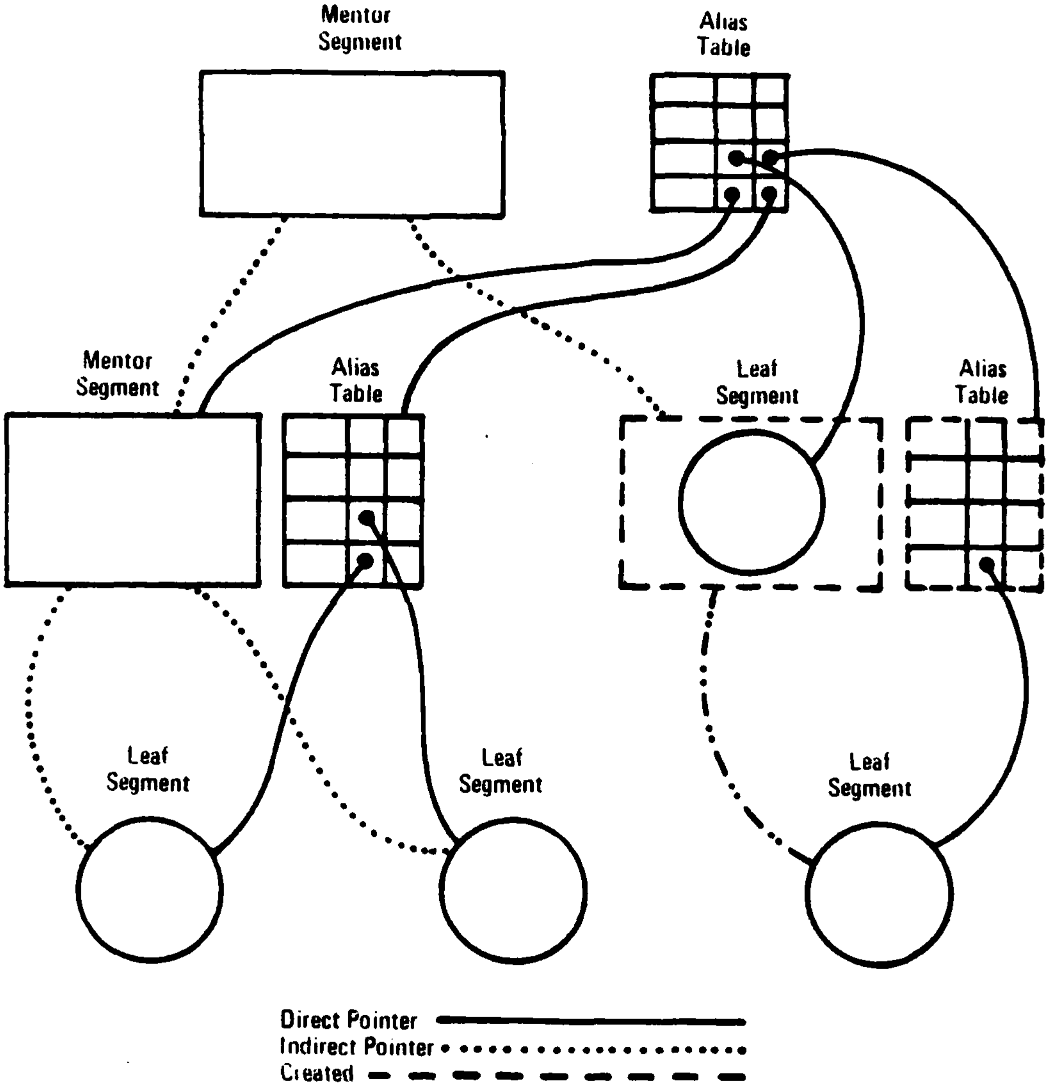

Figure 15: Alias Table Creation

The Size field is the size of the segment in bytes. The Page_Table_location field is the disk location of the page table for a segment, and the Alias_Table_Location field is the disk location of the alias table for the segment. The Alias_Table field can be null to indicate that no alias table exists for the segment.

The last three fields are used in the management of eventcounts and sequencers [12]. The Sequencer field is used to issue a service number for a segment. The Instance_1 field and Instance_2 field are eventcounts (i.e., are used to indicate the next number of occurances of some event).

2. Local Active Segment Table

The Local Active Segment Table (see Figure 16) is a processor local data base. The L_AST contains the characteristics (viz., segment number, access) of each locally active segment. An entry exists for each segment that is active in a process "loaded" on this CPU and in local memory. The first field of the L_AST contains the memory address of the segment. If the segment is not in memory, this field is used to indicate whether the L_AST entry is available or active. The Segment_No/Access field is a combination of segment number and authorized access. It is an array of records data structure that is indexed by DBR_#. The first record element (viz.,most significant bit) is used to indicate the access (read or read/write) permitted to that segment. The second record element (viz., the next seven bits) is used to indicate the segment number. A null segment number indicates that the process does not have the segment active.

Index_#

Memory Addr	Segment_#/Access_Auth					
	DBR_0	DBR_1	DBR_2	DBR_3	DBR_4	DBR_5

Figure 16: Local Active Segment Table

3. Alias Table

The alias table (see Figure 17) is a memory manager data base which is associated with each non leaf segment in the kernel. An aliasing scheme is used to prevent passing systemwide information (unique_id.) out of the kernel. Segments can only be created through a mentor segment and entry number into the mentor's alias table. When a segment is created, an entry must be made in its mentor segment's alias table. Thus the mentor segment must be known before that segment can be created.

```
Entry_#
|
|  ---------------------------------------------------------
|  | Unique_ID | Size |  Class  | Page Table | Alias Table |
|  |           |      |         |  Location  |  Location   |
|  |-------------------------------------------------------|
|  |           |      |         |            |             |
|  |           |      |         |            |             |
V  |           |      |         |            |             |
   |           |      |         |            |             |
   |           |      |         |            |             |
   |           |      |         |            |             |
   |           |      |         |            |             |
   |           |      |         |            |             |
   ---------------------------------------------------------
```

Figure 17: Alias Table

The alias table consists of a header and an array structure of entries. The header has two "pointers" (viz., disk addresses), one that links the alias table to its associated segment and one that links the alias table to the mentor segment's alias table. The header is provided to support the re-construction of the file system after a system crash due to device I/O errors. It is not used at all during normal operations. Each entry in the array structure consists of five fields for identifying the created segments. The Unique_Id field contains the unique identification number for the segment. The Size field is used to record the size of the segment. The Class field contains the appropriate security access class of the segment. The Page_Table_Location field has the disk address of the page table. A null entry indicates a zero-length segment. The Alias_Table_Location field has the disk address of the alias table for the segment. A null entry indicates that the segment is a leaf segment.

4. Memory Management Unit Image

The Memory Management Unit Image (MMU_Image) is a processor local data base. It is an array structure that is indexed by the DBR_#. Each MMU_Image (see Figure 18) includes a software representation of the segment descriptor registers (SDR) for the hardware MMU [23]. This is in exactly the format used by the special I/O instructions for loading/ unloading the MMU hardware. The SDR contains the Base_Address, Limit and Attribute fields for each loaded segment in the process' address space. The Base_Address field contains the base address of the segments in memory (local or global). The Limit field is the number of blocks of contiguous storage for each segment (zero indicates one block). The Attribute field contains eight flags. Five flags are used for protecting the segment against certain types of access, two encode the type of accesses made to the segment (read/write), and one indicates the special structure of the segment [23]. Five of the eight flags in the attribute field are used by the memory manager. The "system only" and "execute only" flags are used to protect the code of the kernel from malicious or unintentional modifications. The "read only" flag is used to control the read or write access to a segment. The "change" flag is used to indicate that the segment has been written into, and the "CPU-inhibit" flag is used to indicate that the segment is not in memory.

The last two fields of the MMU_Image are the Block_Used field and the Maximum_Available_Blocks field. These two fields are used in the mangement of each process' virtual core and are not associated with the hardware MMU.

```
                          DBR_#------------------->

        -------------------------------------------------
        | Blocks Used      |            |               |
        |------------------|------------|               |
        | Max Avail Blocks |            |               |
        |------------------|------------|               |
Segment | Base_Addr | Limit| Attributes |               |
  No.   |___________|______|____________|               |
   |    |           |      |            |               |
   |    |           |      |            |               |
   |    |           |      |            |               |
   |    |           |      |            |               |
   |    |           |      |            |               |
   |    |           |      |            |               |
   |    |           |      |            |               |
   |    |           |      |            |               |
   |    |           |      |            |               |
   V    |           |      |            |               |
        |           |      |            |               |
        |           |      |            |               |
        |           |      |            |               |
        |           |      |            |               |
        |           |      |            |               |
        |           |      |            |               |
        |           |      |            |               |
        |           |      |            |               |
        |           |      |            |               |

        -------------------------------------------------

        |-------------------------------|
                        |
               one record / DBR_#
```

Figure 18: Memory Management Unit Image

5. Memory Allocation/Deallocation Bit Maps

All of the memory allocation/deallocation bit maps (see Figure 19) are basically the same structure. Secondary storage, global memory and local memory are managed by memory bit maps. The Disk_Bit_Map is a global resource that is protected from race conditions via the locking convention for the G_AST. Each bit in the bit map is associated with a block of secondary storage. A zero indicates a free block of storage while a one indicates an allocated block of storage. The Global_Memory_Bit_Map is used to manage global memory. It is a shared resource that is protected from race conditions by the locking of the G_AST. The Local_Memory_Bit_Map is the same structure as the Global_Memory_Bit_Map and is used to manage local memory. The Local_Memory_Bit_Map is not locked since it is not a shared resource between memory managers.

```
                         Memory  Bit  Map

                                         2 2 2 2 2 2 2 2 2
Page  0 1 2 3 4 5 6 7 8 9 1 1 1 1 1 .... 4 4 4 5 5 5 5 5 5
                          0 1 2 3 4      7 8 9 0 1 2 3 4 5

     -----------------------------------------------------
     | | | | | | | | | | | | | | | |     | | | | | | | | | |
     | | | | | | | | | | | | | | | |     | | | | | | | | | |
     | | | | | | | | | | | | | | | |     | | | | | | | | | |
     | | | | | | | | | | | | | | | |.....| | | | | | | | | |
     | | | | | | | | | | | | | | | |     | | | | | | | | | |
     | | | | | | | | | | | | | | | |     | | | | | | | | | |
     | | | | | | | | | | | | | | | |     | | | | | | | | | |
     -----------------------------------------------------
```

Figure 19: Memory Allocation/Deallocation Map

D. BASIC FUNCTIONS

The detailed source code for the basic functions and main line of the memory manager is presented in Appendix J.

In the discussion of the memory manager design, a pseudo-code similar to PLZ/SYS is utilized. The rationale for using this pseudo-code was to provide a summary of the memory manager source code, and to facilitate the presentation of this design.

It is assumed that the memory manager is initialized into the ready state at system generation (as previously mentioned). When the memory manager is initially placed into the running state, it will block itself (via a call to the kernel primitive Wait). Wait will return a message from a signalling process. This message is interpreted by the memory manager to determine the requested function and its required arguments. The function code is used to enter a case statement, which directs the request to the appropriate memory manager procedure.

When the requested action is completed, the memory manager returns a success code (and any additional required data) to the signalling process via a call to the kernel primitive Signal. This call will awaken the process which requested the action to be taken, and place the returned message into that process' message queue. When that action is completed, the memory manager will return to the top of the loop structure and block itself to wait for the the next request. The main line pseudo-code of the memory manager process is displayed in Figure 20.

```
ENTRY
    INITIALIZE_PROCESSOR_LOCAL_VARIABLES
    DO
        !  CHECK_IF_MSG_QUEUE_EMPTY  !
        VP_ID, MSG := WAIT
        FUNCTION, ARGUMENTS := VALIDATE_MSG (MSG)
        IF  FUNCTION
            CASE  CREATE_ENTRY  THEN
                SUCCESS_CODE := CREATE_ENTRY (ARGUMENTS)
            CASE  DELETE_ENTRY  THEN
                SUCCESS_CODE := DELETE_ENTRY (ARGUMENTS)
            CASE  ACTIVATE  THEN
                SUCCESS_CODE := ACTIVATE (ARGUMENTS)
            CASE  DEACTIVATE  THEN
                SUCCESS_CODE := DEACTIVATE (ARGUMENTS)
            CASE  SWAP_IN  THEN
                SUCCESS_CODE := SWAP_IN (ARGUMENTS)
            CASE  SWAP_OUT THEN
                SUCCESS_CODE := SWAP_OUT (ARGUMENTS)
            CASE  DEACTIVATE_ALL  THEN
                SUCCESS_CODE := DEACTIVATE_ALL (ARGUMENTS)
            CASE  MOVE_TO_GLOBAL  THEN
                SUCCESS_CODE := MOVE_TO_GLOBAL (ARGUMENTS;
            CASE  MOVE_TO_LOCAL  THEN
                SUCCESS_CODE := MOVE_TO_LOCAL (ARGUMENTS)
            CASE  UPDATE  THEN
                SUCCESS_CODE := UPDATE (ARGUMENTS)
        FI
        SIGNAL (VP_ID, SUCCESS_CODE, ARGUMENTS)
    OD
END  MEMORY_MANAGER_PLZ/SYS  MODULE
```

Figure 20: Memory Manager Mainline Code

1. Create an Alias Table Entry

Create_Entry is invoked when a user desires to create a segment. A segment is created by allocating secondary storage, and by making an entry (unique_id, secondary storage location, size, classification) into it's mentor segment's alias table. This implies that the mentor segment must have an alias table associated with it, and that the mentor segment must be active in order to obtain the secondary storage location of the alias table.

The mentor segment can be in one of two states. It may have children (viz., have an alias table), or it may be a leaf segment (viz., not have an alias table). If the mentor segment has children, it has an alias table and this alias table can be read into core, secondary storage can be allocated, and the data can be entered into the alias table. If the mentor segment is a leaf, an alias table must be created for that segment before it (the alias table) can be read into core and data entered into it (see Figure 15).

The pseudo-code for CREATE_ENTRY PROCEDURE is presented in Figure 21. The arguments passed to Create_Entry are the index into the G_AST for the mentor segment, the entry number into its alias table, the size of the segment to be created, and the security access class of that segment. The return parameter is a success code, which would be "seg_created" for a successful segment creation.

```
CREATE_ENTRY PROCEDURE (PAR_INDEX  WORD, ENTRY_#  WORD,
                                SIZE   WORD, CLASS    BYTE)
    RETURNS (SUCCESS_CODE  BYTE)
    LOCAL  BLKS  WORD, PAGE_TABLE_LOC  WORD
    ENTRY
    IF  ALIAS_TABLE_DOES_NOT_EXIST   THEN
         SUCCESS_CODE := CREATE_ALIAS_TABLE
         IF  SUCCESS_CODE <> VALID  THEN  RETURN
         FI
    FI
    BLKS := CALCULATE_NO_BLKS_REQ (SIZE)
    SUCCESS_CODE := READ_ALIAS_TABLE (
                          G_AST[PAR_INDEX].ALIAS_TABLE_LOC)
    IF  SUCCESS_CODE  <>  VALID  THEN  RETURN
    FI
    SUCCESS_CODE := CHECK_DUP_ENTRY  ! in alias table !
    IF  SUCCESS_CODE  <>  VALID   THEN   RETURN
    FI
    SUCCESS_CODE, PAGE_TABLE_LOC := ALLOC_SEC_STORAGE (BLKS)
    IF  SUCCESS_CODE  <>  VALID   THEN   RETURN
    FI
    UPDATE_ALIAS_TABLE(ENTRY_#, SIZE, CLASS, PAGE_TABLE_LOC)
    SUCCESS_CODE := WRITE_ALIAS_TABLE (
                                G_AST[PAR_INDEX].ALIAS_TABLE_LOC)
    IF SUCCESS_CODE <>  VALID   THEN   RETURN
    ELSE  SUCCESS_CODE := SEG_CREATED
    FI

END CREATE_ENTRY
```

Figure 21: Create Entry Pseudo-code

When invoked, Create_Entry will determine which state the mentor segment is in (viz., if it has an alias table). If an alias table does not exist for the mentor segment, one is created and the alias table of the mentor segment's parent is updated. The alias table is read into core and a duplicate entry check is made. If no duplicate entry exists, the segment size is converted from bytes to blocks, and the secondary storage is allocated for non-zero sized segments. The appropriate data is entered into the alias table and the alias table is then written back to secondary storage.

2. Delete an Alias Table Entry

Delete_Entry is invoked when a user desires to delete a segment. A segment is deleted by deallocating secondary storage, and by removing the appropriate entry from the alias table of its mentor segment (the reverse logic of Create_Entry). This implies that the mentor segment must be active at the time of deletion. There are three conditions that can be encountered during the deletion of a segment: the segment to be deleted may be an inactive leaf segment, an active leaf segment, or a mentor segment.

If the segment to be deleted is an inactive leaf segment (viz., has been swapped out of core, and does not have an entry in the G_AST), the secondary storage can be deallocated and the entry deleted from the mentor segment's alias table. If the segment is an active leaf segment, the segment must first be swapped out of core and deactivated before it can be deleted. This entails signalling the memory manager of each processor, in which the segment is active, to swap out and deactivate the segment.

If the segment to be deleted is a mentor segment, an alias table exists for that segment . If the alias table is empty, the secondary storage for the alias table and the segment can be deallocated, and the entry for the deleted segment can be removed from its mentor's alias table. If the alias table contains any entries, the segment cannot be deleted because these entries would be lost. If this condition is encountered a success code of "leaf_segment_exists" is returned to the process which requested to delete the entry. Due to a confinement problem in "upgraded" segments, this Success_code cannot always be passed outside of the kernel. This implies that the segment manager must strictly prohibit deletion of a segment with an access class not equal to that of the process.

The pseudo-code for DELETE_ENTRY_PROCEDURE is presented in Figure 22. The parameters that are passed to this procedure are the parent's index into the G_AST and the entry number into the parent's alias table of the segment to be deleted. The alias_table_loc field is checked to determine the state of the mentor segment (either a leaf or a node), and the appropriate action is then taken. A success code is returned to indicate the results of this procedure.

```
DELETE_ENTRY PROCEDURE ( PAR_INDEX  WORD, ENTRY_#  WORD )
   RETURNS (SUCCESS_CODE  BYTE)
   LOCAL  PAR_INDEX  WORD
   ENTRY
 ! Check if the passed mentor segment has an alias table. !
   IF G_AST[ PAR_INDEX ].ALIAS_TABLE_LOC <> NULL
       SUCCESS_CODE := READ_ALIAS_TABLE (
                       G_AST[ PAR_INDEX].ALIAS_TABLE_LOC)
   ELSE
       SUCCESS_CODE := NO_CHILD_TO_DELETE
   FI
   IF  SUCCESS_CODE  <>  VALID    THEN   RETURN
   FI
 ! Determine if segment has children in alias table !
   IF  ALIAS_TABLE_NOT_EMPTY   THEN
       SUCCESS_CODE := LEAF_SEGMENT_EXISTS
       RETURN    ! Deletion will delete children !
   ELSE
! Search G_AST with UNIQUE_ID to verify segment inactive !
       IF  ACTIVE_IN_G_AST   THEN
           ! Check if active in AST !
           IF  ACTIVE_IN_L_AST  THEN
               DEACTIVATE_ALL (G_AST_INDEX, L_AST_INDEX)
           FI
! Check G_AST to verify segment inactive in other L_AST's !
           IF  ACTIVE_IN_OTHER_L_AST  THEN
               SIGNAL_TO_DEACTIVATE_ALL (G_AST_INDEX)
           FI
       FI
       FREE_SEC_STORAGE_OF_SEG_&_ALIAS_IF_EXISTS
       DELETE_ALIAS_TABLE_ENTRY
   FI
   DELETE_ALIAS_TABLE_ENTRY
   SUCCESS_CODE := WRITE_ALIAS_TABLE (
                     G_AST[ PAR_INDEX ].ALIAS_TABLE_LOC)
   IF  SUCCESS_CODE = VALID  THEN
        SUCCESS_CODE := SEG_DELETED
   FI
END DELETE_ENTRY
```

Figure 22: Delete Entry Pseudo-code

3. Activate a Segment

Activate is invoked when a user desires to make a segment known by adding a segment to his address space. A segment is activated by making an entry into the L_AST for that processor, and the G_AST. The activated segment could be in one of three states; it could have previously been activated by another process and have a current entry in both the G_AST and L_AST, it could have previously been activated by another process on a different processor and have an entry in the G_AST but not the L_AST, or it could be inactive and have an entry in neither the G_AST nor the L_AST.

If the segment to be activated already has entries in both the L_AST and G_AST, these entries need only be updated to indicate that another process has activated the segment. The segment number is entered into the Segment_No/Access_Auth field of the L_AST, and if the segment is a leaf, its mentor's No_Active_Dependents field in the G_AST is incremented. In this design, the G_AST is always searched to determine if the segment has been previously activated by another process.

If the segment to be activated has an entry in the G_AST but not the L_AST, an entry must be made in the L_AST and the G_AST must be updated. The L_AST is searched to determine an available index. The segment number is entered into the L_AST, and the index number is entered into the G_AST

Processors_L_ASTE_# field. If the segment to be activated is a leaf segment, its mentor's No_Active_Dependents field in the G_AST is incremented.

If the activated segment does not have an entry in either the G_AST or L_AST, an entry must be made in both. The G_AST is searched to find an available index, and the entry is made. The L_AST is then searched to find an available index, and the entry is made. The L_AST index is then entered into the G_AST Processors_L_ASTE_# field. If the activated segment is a leaf, the No_Active_Dependents field of its mentor's G_AST entry is incremented.

The pseudo-code for ACTIVATE PROCEDURE is presented in Figure 23. The parameters that are passed are the DBR_# of the signalling process, the mentor segment's index into the G_AST, the alias table entry number, and the segment number of the activated segment. The mentor segment is always checked to determine if it has an associated alias table. If it does not, the success code of "alias_does_not_exist" is returned. If the alias table does exist, it is read into core and the entry number is used as an index to obtain the activated segment's unique_id. The G_AST is then searched to determine if the segment has already been activated. If the unique_id is found, the G_AST is updated and the L_AST is either updated or an entry is made (depending on whether an entry existed or not). If the unique_id of the segment was not found during the search of the G_AST, an entry must be made in both the G_AST and L_AST. Activate returns the activated segment's classification, size, and handle to the signalling process.

```
ACTIVATE  PROCEDURE (DBR_#  BYTE, PAR_INDEX  WORD,
                      ENTRY_#  WORD, SEGMENT_NO  BYTE)
    RETURNS (SUCCESS_CODE  BYTE, RET_G_AST_HANDLE  HANDLE,
                       CLASS  BYTE, SIZE  WORD)
    LOCAL   G_INDEX  WORD,  L_INDEX  WORD
    ENTRY
  ! Verify that passed segment is a mentor segment !
    IF G_AST[PAR_INDEX].ALIAS_TABLE_LOC <> 0 THEN
        SUCCESS_CODE := READ_ALIAS_TABLE (
                          G_AST[PAR_INDEX].ALIAS_TABLE_LOC)
    ELSE
        SUCCESS_CODE := ALIAS_DOES_NOT_EXIST
    FI
    IF  SUCCESS_CODE <>  VALID  THEN   RETURN
    FI
  ! Check 3_AST to determine if active !
    SUCCESS_CODE,INDEX := SEARCH_G_AST (UNIQUE_ID)
    IF SUCCESS_CODE = FOUND THEN
        IF  SEGMENT_IN_L_AST  THEN
            UPDATE_L_AST (SEGMENT_NO)
        ELSE
            MAKE_L_AST_ENTRY (DBR_#, SEGMENT_NO)
            UPDATE_G_AST (L_INDEX)
            IF G_AST[INDEX].ALIAS_TABLE_LOC = NULL THEN
                G_AST[PAR_INDEX].NO_DEPENDENTS_ACTIVE += 1
            FI
        FI
    ELSE
        MAKE_G_AST_ENTRY (ENTRY_#)
        MAKE_L_AST_ENTRY (PAR_INDEX, ENTRY_#)
    FI
    SUCCESS_CODE := SEG_ACTIVATED
END ACTIVATE
```

Figure 23: Activate Pseudo-code

4. Deactivate a Segment

Deactivate is invoked when a user desires to remove a segment from his address space. To deactivate a segment, the memory manager either removes or updates an entry in both the L_AST and G_AST. Deactivate uses the reverse logic of activate. Once a segment is deactivated, it can only be reactivated via its mentor's alias table as discussed in activate. If a process requests to deactivate a segment which has not been swapped out of the process' virtual core, the memory manager swaps the segment out and updates the MMU image before the segment is deactivated. The segment to be deactivated could be in one of three states; more than one process could concurrently hold the segment active in the L_AST, the segment could be held active by one process in the L_AST and more than one in the G_AST, the segment could be held active by only one process in both the L_AST and the G_AST.

Deactivation of leaf segments and mentor segments are handled differently. If the segment is a mentor segment and has active dependents, it cannot be removed from the G_AST (even though no process currently has that segment active). This is based on the design decision which requires that the mentor of all active leaf segments remain in the G_AST to allow access to its alias table. The mentor's alias table must be accessible when an alias table is created for a dependent leaf segment. If a leaf segment is deactivated, the No_Active_Dependents field of its mentor's G_AST entry is decremented. A mentor segment can only be removed from the G_AST if no process holds it active, and it has no active dependents.

If more than one process concurrently hold a segment active in the L_AST, and one of them signals to deactivate that segment, the entry in the L_AST is updated. This is accomplished by nulling out the Segment_No/Access_Auth field of the L_AST for the appropriate process. If required, the No_Active_Dependents field of its mentor segment's G_AST entry is decremented.

If only one process holds the segment active in the L_AST, and that Process signals to deactivate the segment, the L_AST entry for that segment is removed. The Processors_L_ASTE_# is updated and checked to determine if there are other connected processors. If there are no other connected processors and the segment has no active dependents, the segment is removed from the G_AST. If there are other connected processors, the G_AST is updated. If the deactivated segment is a leaf, the mentor segment's No_Active_Dependents field in the G_AST is decremented.

The pseudo-code for DEACTIVATE PROCEDURE is presented in Figure 24. The parameters that are passed to the memory manager are the DBR_# of the signalling process, and the index into the G_AST for the segment to be deactivated. The procedure first updates the L_AST, and then removes the entry if no local process holds the segment active. The G_AST is then updated, and its mentor segment is checked (if the deactivated segment was a leaf), to determine if it can be removed. If no processes currently hold the segment active, and it has no active dependents, the segment is removed from the G_AST.

```
DEACTIVATE  PROCEDURE (DBR_#  BYTE, PAR_INDEX  WORD)
    RETURNS (SUCCESS_CODE  BYTE)
    LOCAL   INDEX   WORD
    ENTRY
  ! Check if segment is in core !
    IF G_AST[INDEX].NO_ACTIVE_IN_MEMORY <> 0 THEN
       ! Check MMU image to determine if in local memory !
        IF  IN_LOCAL_MEMORY  THEN
            SUCCESS_CODE := OUT (DBR_#, INDEX)
        FI
    FI
  ! Remove process segment_no entry in L_AST !
    L_AST[L_INDEX].SEGMENT_NO/ACCESS_AUTH[DBR_#] = 0
    CHECK_IF_ACTIVE_IN_L_AST (L_AST_INDEX)
    IF  NOT_ACTIVE_IN_L_AST  THEN
        L_AST[L_INDEX].MEMORY_ADDR := AVAILABLE
    FI
  ! Check if deleted segment was a leaf !
    IF G_AST[INDEX].G_ASTE_#_PAR <> 0  THEN
        G_AST[PAR_INDEX].NO_DEPENDENTS_ACTIVE -= 1
  ! Determine if parent can be removed !
        CHECK_FOR_REMOVAL (PAR_INDEX)
    FI
  ! Determine if deactivated segment can be removed !
    CHECK_FOR_REMOVAL (INDEX)
    SUCCESS_CODE := SEG_DEACTIVATED
END DEACTIVATE
```

Figure 24: Deactivate Pseudo-code

5. Swap a Segment In

SWAP_IN is invoked when a user desires to swap a segment into main memory (global or local) from secondary storage. A segment is swapped into main memory by obtaining the secondary storage location of its page table from the G_AST, allocating the required amount of main memory, and reading the segment into the allocated main memory. The segment must be active before it can be swapped into core, and the required main memory space must be available. Three conditions can be encountered during the invocation of SWAP_IN. The segment can already be located in global memory, the segment can already be located in one or more local memories, or the segment may only reside in secondary storage.

If the segment is not in local or global memory, local memory is allocated, the segment is read into the allocated memory, and the appropriate entries are made in the MMU image, the L_AST and the G_AST. If the segment is already in global memory, it can be assumed that the segment is shared and writable. In this case the only required actions are to update the G_AST and L_AST. The No_Active_In_Memory field of the G_AST entry is incremented, and the MMU image is updated to reflect the swapped in segment's core address and attributes.

If the segment already resides in one or more local memories, it must be determined if the segment is "shared" and "writable". A segment is "shared" if it exists in more than one local memory. A segment is "writable" if one process has write access to that segment. If the segment is not shared or not writable and in local memory, the appropriate entries are updated in the MMU image, the L_AST, and the G_AST. If the segment does not reside in local memory, the required amount of local memory is allocated, the segment is read into the allocated memory, and the appropriate entries are made in the MMU image, the L_AST, and the G_AST.

If the segment is shared, writable, and in local memory, the segment must be moved to global memory. If the segment is not in the memory manager's local memory, it signals another memory manager to move the segment to global memory. After the segment is moved to *global* memory, the memory manager signals all of the connected memory manager's to update their L_AST and MMU data bases. When all local data bases are current, the memory manager updates the G_AST and returns a success code of seg_activated.

The pseudo-code for SWAP_IN PROCEDURE is presented in Figure 25. The arguments passed to SWAP_IN are the G_AST_INDEX of the segment to be moved in, the process' DBR_#, and the access authorized. SWAP_IN will convert the segment size from bytes to blocks, and verify that the process' core will not be exceeded. If the virtual core will be exceeded, a success code of "core_space_exceeded" will be returned. If write access is permitted, the writable bit is set. Checks are then performed to determine the segment's storage location (local or global), and the appropriate action is taken.

```
SWAP_IN  PROCEDURE (INDEX  WORD, DBR_#  BYTE,
                  ACCESS_AUTH  BYTE)
    RETURNS (SUCCESS_CODE  BYTE)
    LOCAL  L_INDEX  WORD,  BLKS  WORD
    ENTRY
    BLKS := CALCULATE_NO._OF_BLKS (G_AST[INDEX].SIZE)
    SUCCESS_CODE := CHECK_MAX_LINEAR_CORE (BLKS)
    IF  SUCCESS_CODE = VIRTUAL_LINEAR_CORE_FULL  THEN
        RETURN
    FI
    G_AST[INDEX].NO_SEGMENTS_IN_MEMORY  +=  1
    IF   ACCESS_AUTH = WRITE   THEN
        G_AST[INDEX].FLAG_BITS := WRITABLE_BIT_SET
    FI
  ! Determine if segment can be put in local memory !
    IF G_AST[INDEX].FLAG_BITS  AND  WRITABLE_MASK = 0
    ORIF  G_AST[INDEX].NO_ACTIVE_IN_MEMORY <= 1  THEN
      ! Determine if already in local memory !
        CHECK_LOCAL_MEMORY (L_AST_INDEX)
        IF  NOT_IN_LOCAL_MEMORY  THEN
            ALLOCATE_LOCAL_MEMORY  (BLKS)
            READ_SEGMENT  (PAGE_TABLE_LOC, BASE_ADDR)
            L_AST[L_INDEX] := BASE_ADDR
        FI
    ELSE
        IF  NOT_IN_GLOBAL_MEMORY  THEN
            UPDATE_MMU
            UPDATE_L_AST
            RETURN
        ELSE
            ALLOCATE_GLOBAL_MEMORY (BLKS)
            IF  IN_LOCAL_MEMORY  THEN
              MOVE_TO_GLOBAL (L_INDEX, BASE_ADDR, SIZE)
            ELSE
              SIGNAL_OTHER_MEMORY_MANAGERS(INDEX,BASE_ADDR)
            FI
        FI
    FI
    UPDATE_MMU_IMAGE (DBR_#,SEG_#,BASE_ADDR,ACCESS,BLKS)
    UPDATE_L_AST_ACCESS (L_INDEX,ACCESS,DBR_#)
    SUCCESS_CODE := SWAPPED_IN
END   SWAP_IN
```

Figure 25: Swap_In Pseudo-code

6. Swap a Segment Out

SWAP_OUT is invoked when a user desires to move a segment out of core. A segment is swapped out of core by obtaining its secondary storage location, writing the segment to that location (if required), and deallocating the main memory used. The decision to write the segment is determined by the G_AST written bit. This bit is set whenever the segment has been modified. The segment to be swapped out can be in one of two states: the segment can be in local memory, or the segment can be in global memory.

If one process has the segment in local memory and the written bit is set, the segment is written into secondary storage and the local memory is deallocated. If the written bit is not set, the local memory need only be deallocated. If more than one process has the segment in the same local memory, the segment remains in core. The appropriate MMU image is updated to reflect the segments deletion and the G_AST No_Active_In_Memory field is decremented.

All segments in global memory are shared and writable. If a process requests the segment to be swapped out, the segment remains in memory. The MMU image is updated to reflect the segment's deletion, and the G_AST No_Active_In_Memory field is decremented. If the No_Active_In_Memory indicates that one process has the segment in core, its memory manager is signalled to move the segment to local memory.

The pseudo-code for SWAP_OUT PROCEDURE is presented in Figure 26. The arguments passed to SWAP_OUT are the DBR_# of the signalling process, and the G_AST_INDEX of the segment to be removed. The return parameter is a success code. SWAP_OUT removes the segment from the process's virtual core, deletes the segment from its MMU image, and decrements the No_Active_In_Memory field. If the segment can be removed from memory, it is determined which memory can be deallocated. If the segment has been modified, it is written back to secondary storage and the appropriate memory deallocated. If the segment has not been modified, the appropriate memory is deallocated. If after the deletion one process has the segment in global memory, its memory manager need only be signalled to move the segment to local memory. When SWAP_OUT successfully completes, it returns a success code of "swapped out".

```
SWAP_OUT  PROCEDURE (DBR_#  BYTE, INDEX  WORD)
    RETURNS (SUCCESS_CODE  BYTE)
    ENTRY
    BLKS := G_AST[INDEX].SIZE / BLK_SIZE
    FREE_PROCESS_LINEAR_CORE (BLKS)
    DELETE_MMU_ENTRY (DBR_#, SEG_#)
    G_AST[INDEX].NO_SEGMENTS_IN_MEMORY  -=  1
  ! Determine if segment has been written into !
    IF MMU_IMAGE[DBR_#].SDR[SEG_#].ATTRIBUTES=WRITTEN THEN
      ! If segment has been written into, update G_AST !
        G_AST[INDEX].FLAG_BITS := WRITTEN
    FI
  ! Determine if segment is in global memory !
    IF G_AST[INDEX].GLOBAL_ADDR <> NULL THEN
        IF  G_AST[INDEX].NO_SEGMENTS_IN_MEMORY = 0
        ANDIF  G_AST[INDEX].FLAG_BITS = WRITTEN  THEN
            WRITE_SEG (PAGE_TABLE_LOC, MEMORY_ADDR)
            FREE_LOCAL_BIT_MAP (MEMORY_ADDR,BLKS)
        ELSE
            IF G_AST[INDEX].NO_ACTIVE_IN_MEMORY = 0  THEN
                FREE_LOCAL_BIT_MAP (MEMORY_ADDR,BLKS)
            FI
        FI
    ELSE    ! If not in global memory !
        IF G_AST[INDEX].NO_ACTIVE_IN_MEMORY = 0
        ANDIF G_AST[INDEX].FLAG_BITS = WRITTEN  THEN
            WRITE_SEG (PAGE_TABLE_LOC, GLOBAL_ADDR)
            FREE_GLOBAL_BIT_MAP (GLOBAL_ADDR, BLKS)
        ELSE
            IF G_AST[INDEX].NO_ACTIVE_IN_MEMORY = 0  THEN
                FREE_GLOBAL_BIT_MAP (GLOBAL_ADDR, BLKS)
            FI
        FI
    FI
    SUCCESS_CODE := SWAPPED_OUT
END    SWAP_OUT
```

Figure 26: Swap_Out Pseudo-code

7. Deactivate All Segments

DEACTIVATE_ALL is invoked when it becomes necessary to remove a segment from every process' address space. Each process is checked to determine if the segment is active. If a process has the segment active, it is deactivated from its address space. The pseudo code for Deactivate_all is illustrated in Figure 27. The parameters passed to Deactivate_all are the deactivated segment's G_AST index and the L_AST index. The L_AST is searched by DBR_# to determine which process has the segment active. If the check reveals that the segment is active, it is deactivated by calling Deactivate. If the segment was successfully deactivated from all processes, a success_code of valid is returned.

```
DEACTIVATE_ALL PROCEDURE (INDEX  WORD, L_INDEX  WORD)
    RETURNS (SUCCESS_CODE  BYTE)
    ENTRY
    LOCAL  I  BYTE
       I := 0
       DO
          IF  I = MAX_DBR_#  THEN
            EXIT
          FI
          IF  L_AST[L_INDEX].SEGMENT_NO/ACCESS_AUTH[I]
                <> ZERO  THEN
             SUCCESS_CODE := DEACTIVATE (I, INDEX)
             IF  SUCCESS_CODE <> SEG_DEACTIVATED  THEN
                RETURN
             FI
          FI
          I += 1
       OD
       SUCCESS_CODE := VALID
END DEACTIVATE_ALL
```

Figure 27: Deactivate All Pseudo-code

8. Move a Segment to Global Memory

MOVE_TO_GLOBAL is invoked when it becomes necessary to move a segment from local to global memory. If a segment resides in one or more local memories, and a process with write access swaps that segment into core, or if a segment resides in in local memory (with write access) and another process with read access requests the segment swapped in, the segment is moved from a local to global memory to avoid a secondary storage access. If the segment resides in the running memory manager's local memory, it will affect the segment transfer, otherwise it will signal another memory manager of a connected processor to affect the transfer. Figure 28 illustrates the pseudo-code for MOVE_TO_GLOBAL. Once the segment has been moved to global memory, the signalled memory manager will update the MMU images for all connected processes, and deallocate the freed local memory. A success code of completed will be returned to the signalling memory manager. The parameters passed to the memory manager are the segment's L_AST index the global memory address of the move, and the size of the segment. This information is passed because the G_AST is locked during this request.

```
MOVE_TO_GLOBAL PROCEDURE (L_INDEX  WORD, GLOBAL_ADDR  WORD,
                          SIZE  WORD)
    RETURNS (SUCCESS_CODE  BYTE)
    ENTRY
  ! Move segment from local memory to global memory !
    DO_MEMORY_MOVE (MEMORY_ADDR, GLOBAL_ADDR)
    L_AST[INDEX].MEMORY_ADDR := AVAILABLE
  ! Update the MMU image to reflect new address !
    DO  FOR_ALL_DBR'S
      IF L_AST[L_INDEX].SEGMENT_NO/ACCESS_AUTH <> 0 ANDIF
      MMU_IMAGE[DBR_#].SDR[SEG_#].ATTRIBUTES=IN_LOCAL THEN
        MMU_IMAGE[DBR_#].SDR[SEG_#].BASE_ADDR:=GLOBAL_ADDR
      FI
    OD
    SUCCESS_CODE := VALID
END MOVE_TO_GLOBAL
```

Figure 28: Move To Global Pseudo-code

9. Move a Segment to Local Memory

MOVE_TO_LOCAL is invoked when it becomes necessary to move a segment from global to local memory. This occurs when one of two processes which hold a segment in global memory swaps the segment out. The segment is moved from global memory to the local memory of the remaining process. Figure 29 illustrates the pseudo-code for MOVE_TO_LOCAL. The parameters passed to the memory manager are the segment's L_AST index, the global address of the segment, and the size of the segment. The return parameter is a success code. The MMU images of the signalled process are updated after the move has been made, and the global memory is deallocated.

```
MOVE_TO_LOCAL PROCEDURE (L_INDEX  WORD, GLOBAL_ADDR  WORD,
                            SIZE  WORD)
    RETURNS  (SUCCESS_CODE  BYTE)
    ENTRY
    BLKS := SIZE / BLK_SIZE
    BASE_ADDRESS := ALLOCATE_LOCAL_MEMORY (BLKS)
  ! Move from global to local memory !
    MEMORY_MOVE (GLOBAL_ADDR, BASE_ADDRESS, SIZE)
    L_AST[L_INDEX].MEMORY_ADDR := BASE_ADDRESS
    DO  FOR_ALL_DBR'S
      IF LAST[L_INDEX].SEGMENT_NO/ACCESS_AUTH <> 0 ANDIF
      MMU_IMAGE[DBR_#].SDR[SEG_#].ATTRIBUTES=IN_LOCAL THEN
        MMU_IMAGE[DBR_#].SDR[SEG_#].BASE_ADDR:=BASE_ADDRESS
      FI
    OD
    SUCCESS_CODE := VALID
END  MOVE_TO_LOCAL
```

Figure 29: Move To Local Pseudo-code

10. Update the MMU Image

UPDATE is invoked following a MOVE_TO_GLOBAL operation. After a segment has been moved from local memory to global memory, it is necessary to signal the memory managers of all connected processors to update their MMU images and L_AST with the current location of the segment. They must also deallocate the moved segment's local memory. Figure 30 illustrates the pseudo-code of UPDATE. The parameters passed to the memory manager are the segment's L_AST index, the new global address for the segment, and the size of the segment. The return parameter is a success code.

```
UPDATE  PROCEDURE (L_INDEX  WORD, GLOBAL_ADDR  WORD,
                    SIZE  WORD)
    RETURNS (SUCCESS_CODE  BYTE)
    ENTRY
    DO  FOR_ALL_DBR'S
      IF  L_AST[L_INDEX].SEGMENT_NO/ACCESS_AUTH <> 0 ANDIF
      MMU_IMAGE[DBR_#].SDR[SEG_#].ATTRIBUTES=IN_LOCAL THEN
         MMU_IMAGE[DBR_#].SDR[SEG_#].BASE_ADDR :=
                                         GLOBAL_ADDR
      FI
    OD
    BLKS := SIZE / BLK_SIZE
    FREE_LOCAL_BIT_MAP (MEMORY_ADDR,BLKS)
    L_AST[L_INDEX].MEMORY_ADDR := ACTIVE
    SUCCESS_CODE := VALID
END UPDATE
```

Figure 30: Update Pseudo-code

E. SUMMARY

In this chapter the detailed design of the memory manager process has been presented. The purpose of the memory manager was outlined, followed by a detailed discussion of the memory manager's data bases. The design presented has identified ten basic functions for the memory manager. The success codes returned by the memory manager are presented in Figure 31.

This design has assumed that the kernel level inter-process synchronization primitives will be Saltzer's signal and wait primitives [14]. This fact dominated the design decision to lock the G_AST in the user's process before it signals the memory manager. In a multi-processor environment, the possibility of a deadly embrace exists if the memory manager processes lock the G_AST. Should follow on work implement eventcounts and sequencers as kernel level synchronization primitives, the locking of the G_AST and memory manager synchronization will need to be readdressed.

SYSTEM WIDE

INVALID
SWAPPED_IN
SWAPPED_OUT
SEG_ACTIVATED
SEG_DEACTIVATED
SEG_CREATED
SEG_DELETED
VIRTUAL_CORE_FULL
DUPLICATE_ENTRY
READ_ERROR
WRITE_ERROR
DRIVE_NOT_READY

MEMORY MANAGER LOCAL

VALID
INVALID
FOUND
NOT_FOUND
IN_LOCAL_MEMORY
NOT_IN_LOCAL_MEMORY
! + DISK ERRORS !

KERNEL LOCAL

LEAF_SEGMENT_EXISTS
NO_LEAF_EXISTS
ALIAS_DOES_NOT_EXIST
NO_CHILD_TO_DELETE
G_AST_FULL
L_AST_FULL
LOCAL_MEMORY_FULL
GLOBAL_MEMORY_FULL
SECONDARY_STORAGE_FULL

Figure 31: Success Codes

Chapter XII

STATUS OF RESEARCH

A. CONCLUSIONS

The memory manager design utilized state of the art software techniques and hardware devices. The design was developed based upon ZILOG'S Z8001 sixteen bit segmented microprocessor used in conjunction with the Z8010 Memory Management Unit [23]. A microprocessor which supports segmentation is required to provide access control of the stored data. The actual implementation of the selected thread was conducted upon the Z8002 non-segmented microprocessor without the Z8010 MMU.

While information security requires that the microprocessor support segmentation, the memory manager was developed to be configuration independent. The design will support a multi-processor environment, and can be easily implemented upon any microprocessor or secondary storage device. The loop free modular design facilitates any required expansion or modification.

Global bus contention is minimized by the memory manager. Segments are stored in global memory only if they are shared and writable. Secondary storage is accessed only if the segment does not currently reside in global memory or some local memory. The controlled sharing of segments optimizes main memory usage.

The storage of the alias tables in secondary storage supports the recreation of user file hierarchies following a system crash. The aliasing scheme used to address segments supports system security by not allowing the segment's memory location or unique identification to leave the memory manager.

The design of the distributed kernel was clarified by assigning the MMU image management to the memory manager. The transfer of responsibility for memory allocation and deallocation from the supervisor to the memory manager provides support for dynamic memory management.

In conclusion, the memory manager process will securely manage segments in a multi-processor environment. The process is efficient, and is configuration independent. The primitives provided by the memory manager will support the construction of any desired supervisor/user process built upon the kernel.

B. FOLLOW ON WORK

There are several possible areas in the SASS design that can be looked into for continued research. The complete implementation of the memory manager design (refine and optimize the current PLZ/SYS code) is one possibility. Other possibilities include the implementation of dynamic memory management, and modifying the interface of the memory manager with the distributed kernel using eventcounts and sequencers for inter-process communication.

The implementation of the supervisor has not been addressed to date. Areas of research include the implmentation of the file manager and input/output processes, and the complete design and implementation of the user-host protocols. The implementation of the gatekeeper, and system initialization are other possible research areas. Dynamic process creation and deletion, and the introduction of multi-level hosts could also prove interesting.

PART D

AN IMPLEMENTATION OF MULTIPROGRAMMING AND PROCESS MANAGEMENT FOR A SECURITY KERNEL OPERATING SYSTEM

This section contains updated excerpts from a Naval Postgraduate School MS Thesis by S. L. Reitz [12]. The origins of these excerpts are:

INTRODUCTION	from Chapter I
IMPLEMENTATION	from Chapter IV
CONCLUSION	from Chapter V

Minor changes have been made for integration into this report.

Chapter XIII

INTRODUCTION

The application of contemporary microprocessor technology to the design of large-scale multiple processor systems offers many potential benefits. The cost of high-power computer systems could be reduced drastically; fault tolerance in critical real-time systems could be improved; and computer services could be applied in areas where their use is not now cost effective. Designing such systems presents many formidable problems that have not been solved by the specialized single processor systems available today.

Specifically, there is an increasing demand for computer systems that provide protected storage and controlled access for sensitive information to be shared among a wide range of users. Data controlled by the Privacy Act, classified Department of Defence (DoD) information, and the transactions of financial institutions are but a few of the areas which require protection for multiple levels of sensitive information. Multiple processor systems which share data are well suited to providing such services - if the data security problem can be solved.

A solution to these problems - a multiprocessor system design with verifiable information security - is offered in a family of secure, distributed multi-microprocessor operating systems designed by O'Connell and Richardson [7]. A subset of this family, the Secure Archival Storage System (SASS) [9,5], has been selected as a testbed for the general design. SASS will provide consolidated file storage for a network of possibly dissimilar "host" computers. The system will provide controlled, shared access to multiple levels of sensitive information (Figure 32).

This thesis presents an implementation of a basic monitor for the O'Connell-Richardson family of operating systems. The monitor provides multiprogramming and process management functions specifically addressed to the control of physical processor resources of SASS. Concurrent thesis work [7] is developing a detailed design for a security kernel process, the Memory Manager, which will manage SASS memory resources.

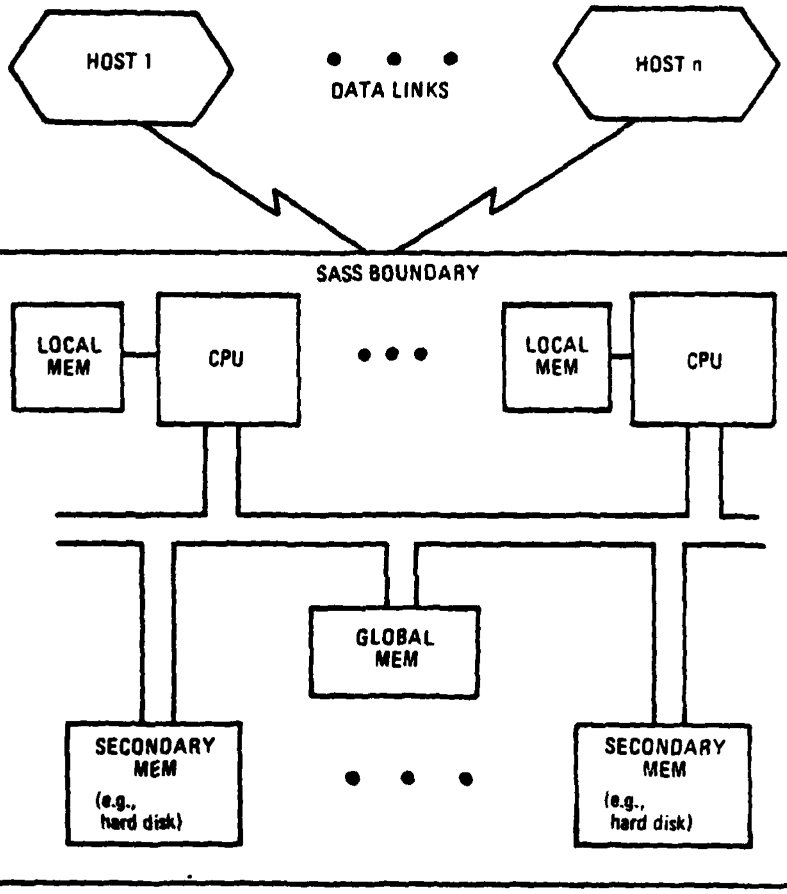

Figure 32: SASS SYSTEM

Chapter XIV

IMPLEMENTATION

Implementation of the distributed kernel was simplified by the hierarchical structure of the design for it permitted methodical bottom-up construction of a series of extended machines. This approach was particularly useful in this implementation since the bare machine, the Z8000 Developmental Module, was provided with only a small amount of software support.

A. DEVELOPMENTAL SUPPORT

A Zilog MCZ Developmental System provided support in developing Z8000 machine code. It provided floppy disk file management, a text editor, a linker and a loader that created an image of each Z8000 load module.

A Z8000 Developmental Module (DM) provided the necessary hardware support for operation of a Z8002 non-segmented microprocessor and 16K words (32K bytes) of dynamic RAM. It included a clock, a USART, serial and parallel I/O support, and a 2K PROM monitor.

The monitor provided access to processor registers and memory, single step and break point functions, basic I/O functions, and a download/upload capability with the MCZ system.

Since a segmented version of the processor was not available for system development, segmentation hardware was simulated in software as an MMU image (see Figure 33). Although this data structure did not provide the hardware support (traps) required to protect segments of the kernel domain, it preserved the general structure of the design.

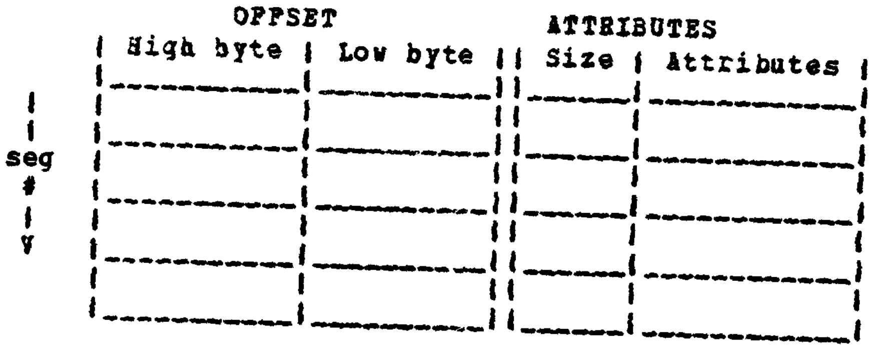

Figure 33: MMU_IMAGE

B. INNER TRAFFIC CONTROLLER

The Inner Traffic Controller runs on the bare machine to create a virtual environment for the remainder of the system. Only this module is dependent on the physical processor configuration of the system. All higher levels see only a set of running virtual processors. A kernel data base, the Virtual Processor Table is used by the Inner Traffic Controller to create the virtual environment of this first level extended machine. A source listing of the Inner Traffic Controller module is contained in Appendix G.

1. Virtual Processor Table (VPT)

The VPT is a data structure of arrays and records that maintains the data used by the Inner Traffic Controller to multiplex virtual processors on a real processor and to create the extended instruction set that controls virtual processor operation (see Figure 34). There is one table for each physical processor in the system. Since this implementation was for a uniprocessor system (the Z8000 DM), only one table was necessary.

The table contains a LOCK which supports an exclusion mechanism for a multiprocessor system. It was provided in this implementation only to preserve the generality of the design.

The Descriptor Base Register (DBR) binds a process to a virtual processor. The DBR points to an MMU_IMAGE contain-

```
     LOCK
     RUNNING_LIST
     READY_LIST
     FREE_LIST

---------|
      VP |DBR| PRI| STATE| IDLE_FLAG| CPU| NEXT_VP| MSG_LIST|
     INDEX|---|----|------|----------|----|--------|---------|
       |  |   |    |      |          |    |        |         |
       |  |---|----|------|----------|----|--------|---------|
       V  |   |    |      |          |    |        |         |
          |---|----|------|----------|----|--------|---------|
=========|
      MSG |__| MESSAGE | SENDER | NEXT_MSG |
       INDEX |---------|--------|----------|
         |   |         |        |          |
         |   |---------|--------|----------|
         V   |         |        |          |
             |---------|--------|----------|
```

Figure 34: Virtual Processor Table

ing the list of descriptors for segments in the process address space.

A virtual processor (VP) can be in one of three states: running, ready, and waiting (Figure 35). A running VP is currently scheduled on a real processor. A ready VP is ready to be scheduled when selected by the level-1 scheduling algorithm. A waiting VP is awaiting a message from some other VP to place it in the ready list. In the meantime it is not in contention for the real processor.

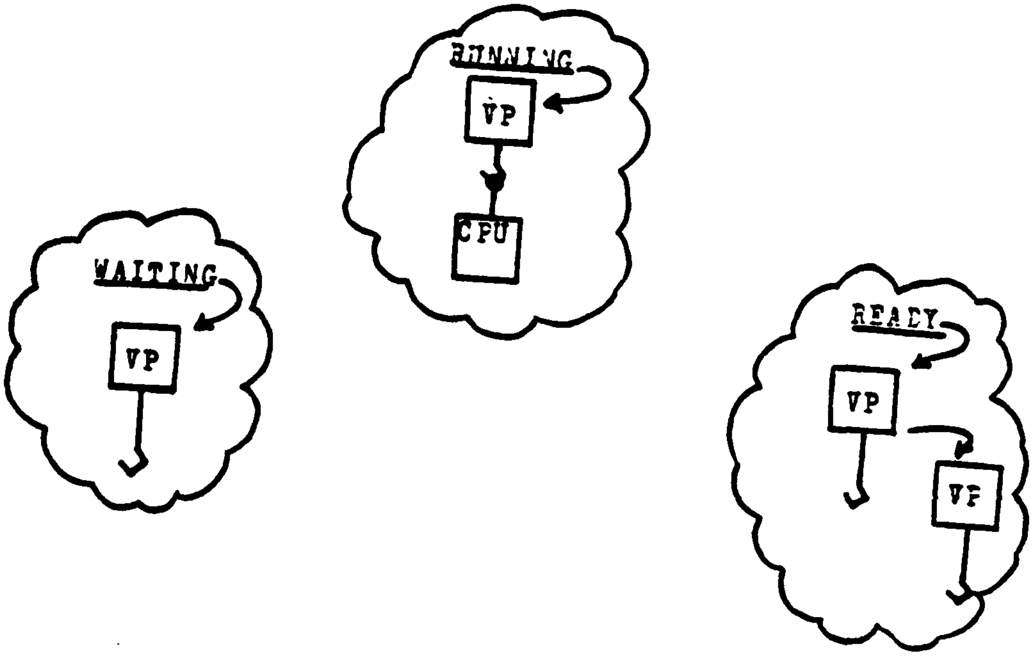

Figure 35: Virtual Processor States

2. Level-1 Scheduling

Virtual processor state changes are initiated by the inter-virtual-processor communication mechanisms, SIGNAL and WAIT. These level-1 instructions implement the scheduling policy by determining what virtual processor to bind to the real processor. The actual binding and unbinding is performed by a Processor switching mechanism called SWAP_DBR [14]. Processor switching implies that somehow the execution point and address space of a new process are acquired by the processor. Care must be taken to insure that the old process is saved and the new process loaded in an orderly manner. A solution to this problem, suggested by Saltzer [14], is to design the switching mechanism so that it is a common procedure having the same segment number in every address space.

In this implementation a processor register (R14) was reserved within the switching mechanism for use as a DBR. Processor switching was performed by saving the old execution point (i.e., processor registers and flag control word), loading the new DBR and then loading the new execution point. The processor switch occurs at the instant the DBR is changed (see Figure 36). Because the switching procedure is distributed in the same numbered segment in all address spaces, the "next" instruction at the instant of the switch will have the same offset no matter what address space the processor is in. This is the key to the proper operation of SWAP_DBR.

To convert this switching mechanism to segmented hardware it is necessary merely to replace SWAP_DBR with special I/O block-move instructions that save the contents of the MMU in the appropriate MMU_IMAGE and load the contents of the new MMU_IMAGE into the MMU.

a. Getwork

SWAP_DBR is contained within an internal Inner Traffic Controller procedure called GETWORK. In addition to multiplexing virtual processors on the CPU, GETWORK interprets the virtual processor status flags, IDLE and PREEMPT, and modifies VP scheduling accordingly in an attempt to keep the CPU busy doing useful work.

There are actually two classes of idle processes within the system. One class belongs to the Traffic Controller. Conceptually there is a ready level-2 idle process for each virtual processor available to the Traffic Controller for scheduling. When a running process blocks itself, the Traffic Controller schedules the first ready process. This will be an idle process if no supervisor processes are in the ready list.

The second class of idle process exists in the kernel. The kernel Idle process is permanently bound to the lowest priority virtual processor.

```
     Process #1             |             Process #2
   Address space            |           Address space
---------------------------|-----------------------------
         |                 |
         V                 |
   Call SWAP_DBR           |
         |                 |
         V                 |
   Save return point       |
   on call stack.          |
    (Process #1)           |
         |                 |
         V                 |
   Save execution point    |                  .
         |                 |                  .
         V                 |                  .
   Swap DBR (R14)  ------------------->  Swap DBR (R14)
         .               processor            |
         .                switch              V
         .                 |            Load new execution
                           |            point.
                           |                  |
                           |                  V
                                        Load return point
                                        from call stack
                                        (process #2)
                                              |
                                              V
                                              .
                                              .
                                              .
```

Figure 36: SWAP_DBR

The distinction is made between these classes because of the need to keep the CPU busy doing useful work whenever possible. There is no need for GETWORK to schedule a level-2 idle process that has been loaded on a virtual processor, because the idle process does no useful work. The virtual processor IDLE_FLAG indicates that a virtual processor has been loaded with a level-2 idle process. GETWORK will schedule this virtual processor only if the PREEMPT flag is also set. The PREEMPT flag is a signal from the Traffic Controller that a supervisor process is now ready to run.

When GETWORK can find no other ready virtual processors with IDLE and PREEMPT flags off, it will select the virtual processor permanently bound to the kernel Idle process. Only then will the Idle process actually run on the CPU.

Getwork contains two entry points. The first, a normal entry, resets the preempt interrupt return flag. (R0 is reserved for this purpose within GETWORK.) The second, a hardware interrupt entry point, contains an interrupt handler which sets the preempt interrupt return flag. The DBR (R14) must also be set to the current value by any procedure that calls GETWORK in order to permit the SWAP_DBR portion of GETWORK to have access to the scheduled process's address space. Upon completion of the processor switch, GETWORK examines the interrupt return flag to determine whether a normal return or an interrupt return is required.

The hardware interrupt entry point in GETWORK supports the technique used to initialize the system. Each process address space contains a kernel domain stack segment used by SWAP-DBR in GETWORK to save and restore VP states. For the same reason that SWAP-DBR is contained in a system wide segment number, the stack segment in each process address space will also have the same number (Segment #1 in this implementation). Each stack segment is initially created as though it's process had been previously preempted by a hardware interrupt. This greatly simplifies the initialization of processes at system generation time. The details of system initialization will be described later in this chapter. It is important to note here, however, that GETWORK must be able to determine whether it was invoked by a hardware preempt interrupt or by a normal call, before it can execute a return to the calling procedure. This is because a hardware interrupt causes three items to be placed on the system stack: the return location of the caller, the flag control word, and the interrupt identifier, whereas a normal call places only the return location on the stack. Therefore, in order to clean up the stack, GETWORK must execute an interrupt return (assembly instruction:IRET) if entry was via the hardware preempt handler (i.e., R0 set). This instruction will pop the three items off the stack and return to the appropriate location. If the interrupt return flag, R0, is off, a normal return is executed.

During normal operation, SWAP-DBR manipulates process stacks to save the old VP state and load the new VP state. This action proceeds as follows (Figure 37):

1. The Flag Control Word (FCW), the Stack Pointer (R15) and the preempt return flag (R0) are saved in the old VP's kernel stack.
2. The DBR (R14) is loaded with the new VP's DBR. This permits access to the address space of the new process.
3. The Flag Control Word (FCW), the Stack Pointer (R15) and the Interrupt Return Flag (R0), are loaded into the appropriate CPU registers.
4. R0 is tested. If it is set, GETWORK will execute an interrupt return. If it is off, a normal return occurs.

By constructing GETWORK in this way, both system initialization and normal operations can be handled in the same way. A high level GETWORK algorithm is given in Figure 38.

```
        Old VP Stack                        New VP Stack
        ------------                        ------------
        |    .     |                        |    .     |
        |    .     |                        |    .     |
        |    .     |                        |    .     |
        |----------|      ------            |----------|
   SP-> | RET ADDR |      |CPU |            | RET ADDR | <--SP
        |----------|      |REGS|            |----------|
        |    .     |      ------            |    .     |
        |    .     |                        |    .     |
        |    .     |                        |    .     |
   SB-> |----------|                        |----------| <--SB
        | SP: R15  |                        | SP: R15  |
        |----------|                        |----------|
        | IRET:R0  |                        | IRET:R0  |
        |----------|                        |----------|
        | FCW      |                        | FCW      |
        |----------|                        |----------|
        | HEADER   |                        | HEADER   |
        |__________|                        |__________|
```

Figure 37: Kernel Stack Segments

```
GETWORK Procedure (DBR = R14)

 Begin

  Reset Interrupt Return Flag (R0)

  Skip hardware preempt handler

 Hardware Preempt Entry:
    Set DBR
    Save CPU registers
    Save supervisor stack pointer
    Set Interrupt Return Flag (R0)

  Get first ready VP

  Do while not Select
   If Idle flag is set then
    if Preempt flag is set then
     select
    else
     get next ready VP
    end if
   else
    select
   end if
  end do

  SWAP_DBR:
   Save old VP registers in stack segment
   Swap dbr (R14)
   Load new VP registers in stack segment

   If Interrupt Return Flag is set then
    unlock VPT

    simulate GATEKEEPER exit:
     Call TEST_VPREEMPT
     Restore supervvisor registers
     Restore supervvisor stack pointer

    Execute Interrupt Return (IRET)
   end if

   Execute normal return

end GETWORK
```

Figure 38: GETWORK

3. Virtual Processor Instruction Set

The heart of the SASS scheduling mechanism is the internal procedure, GETWORK. It provides a powerful internal primitive for use by the virtual processors and greatly simplifies the design of the virtual processor instruction set. Virtual processor instructions perform three types of functions: multiprogramming, process management and virtual interrupts.

SIGNAL and WAIT provide synchronization and communication between virtual processors. They multiplex virtual processors on a CPU to provide multiprogramming. This implementation used a version of the signal and wait algorithms proposed by Saltzer [14]. In the SASS design each CPU is provided with a unique (fixed) set of virtual processors. The interaction among virtual processors is a result of multiprogramming them on the real processor. Only one virtual processor is able to access the VPT at a time because of the use of the VPT LOCK (SPIN_LOCK) to provide mutual exclusion. Therefore race and deadlock conditions will not develop and the signal pending switch used by Saltzer is not necessary.

This implementation also included message passing mechanism not provided by Saltzer. The message slots available for use by virtual processors are initially contained in a queue pointed to by FREE-LIST. When a message is sent from one VP to another, a message slot is removed from the free list and placed in a FIFO message queue belonging to the VP receiving the message. The head of each VP's message queue is pointed to by MSG-LIST. Each message slot contains a message, the ID of the sender, and a pointer to the next message in the list (either the free list or the VP message list.

IDLE and SWAP_VDBR provide the Traffic Controller with a means of scheduling processes on the running VP.

SET_VPREEMPT and TEST_VPREEMPT install a virtual interrupt mechanism in each virtual processor. When the Traffic Controller determines that a virtual processor should give up its process because a higher priority process is now ready, it sets the PREEMPT flag in that VP. Then, even if an idle process is loaded on the VP, it will be scheduled and will be loaded with the first ready process. Test_VPreempt is a virtual interrupt unmasking mechanism which forces a process to examine the preempt flag each time it exists from the kernel.

a. Wait

WAIT provides a means for a virtual processor to move itself from the running state to the waiting state when it has no more work to do. It is invoked only for system events that are always of short duration. It is supported by three internal Procedures.

SPIN_LOCK enables the running VP to gain control of the Virtual Processor Table. This procedure is only necessary in a multiprocessor environment. The running VP will have to wait only a short amount of time to gain control of the VPT. SPIN_LOCK returns when the VP has locked the VPT.

GETWORK loads the first eligible virtual processor of the ready list on the real processor. Before this procedure is invoked, the running VP is placed in the ready state. Both ready and running VP's are members of a FIFO queue. GETWORK selects the first VP in this ready list, loads it on the CPU, and places it in the running state. When GETWORK returns, the first VP of the queue will always be running and the second will be the first VP in the ready queue.

GET_FIRST_MESSAGE returns the first message of the message list (also managed as a FIFO queue) associated with the running VP. The action taken by WAIT is as follows:

```
WAIT Procedure (Returns: Msg, Sender_ID)
 Begin
  Lock VPT (call SPIN_LOCK)
  If message list empty (i.e., no work) Then
   Move VP from Running to Waiting state
   Schedule first eligible Ready VP (call GETWORK)
  end if
  (NOTE: process suspended here until
           it receives a signal and is
           selected by GETWORK.)
      Get first message from message list
          (call GET_FIRST_MSG)
      Unlock VPT
      Return
     end WAIT
```

If the running virtual processor calls WAIT and there is a message in its message list (placed there when another VP signaled it) it will get the message and continue to run. If the message list is empty it will place itself in the wait state, schedule the first ready virtual processor, and move it to the running state. The virtual processor will remain in the waiting state until another running VP sends it a message (via SIGNAL). It will then move to the ready list. Finally it will be selected by GETWORK, the next instructions of WAIT will be executed, it will receive the message for which it was waiting, and it will return to the caller.

b. Signal

Messages are passed between virtual processors by the instruction, SIGNAL, which uses four internal procedures, SPIN_LOCK, ENTER_MSG_LIST, MAKE_READY, and GETWORK.

SPIN_LOCK, as explained above insures that only one virtual processor has control of the Virtual Processor Table at a time.

ENTER_MSG_LIST manages a FIFO message queue for each virtual Processor and for free messages. This queue is of fixed maximum length because of the implementation decision to restrict the use of SIGNAL. A running VP can send no more than one message (SIGNAL) before it receives a reply (i.e., WAIT's for a message). Therefore if there are N virtual processors per real processors, the message queue length, L, is:

$$L = N - 1$$

MAKE_READY manages the virtual processor ready queue. If a message is sent to a VP in the waiting state, MAKE_READY wakes it up (it places it in the ready state) and enters it in the ready list. If a running VP signals a waiting VP of higher priority, it will place itself back in the ready state and the higher priority VP will be selected. The action taken by signal is as follows:

```
      SIGNAL Procedure (Message, Destination_VP)
        Begin
```

```
    Lock VPT  (call SPIN_LOCK)
    Send message (call ENTER_MSG_LIST)
    If signaled VP is waiting Then
     Wake it up and make it ready
        (call MAKE_READY)
    end if
    Put running VP in ready state.
    Schedule first elgible ready VP
        (call GETWORK)
    Unlock VPT
    Return (Success_code)
  End SIGNAL
```

c. SWAP_VDBR

SWAP_VDBR contains the same processor switching mechanism used in SWAP_DBR, but applies it to a virtual processor rather than a real processor. Switching is quite simple in this virtual environment because both processor execution point and address space are defined by the Descriptor Base

Register. SWAP_VDBR is invoked by the Traffic Controller to load a new process on a virtual processor in support of level-2 scheduling. It uses GETWORK to control the associated level-1 scheduling. The action taken by SWAP_VDBR is:

```
SWAP_VDBR Procedure (New_DBR)
 Begin
  Lock VPT (call SPIN_LOCK)
  Load running VP with New_DBR
  Place running VP in ready state
  Schedule first eligible ready VP
      (call GETWORK)
  Unlock VPT
  Return
 End SWAP_VDBR
```

In this implementation one restriction is placed upon the use of this instruction. If a virtual processor's message list contains at least one message, it can not give up its current DBR. This problem is avoided as the natural result of using SIGNAL and WAIT only for system events, and "masking" preempts within the kernel. If this were permitted, the messages would lose their context. (The messages in a VP_MSG_LIST are actually intended for the process loaded on the VP.)

d. IDLE

The IDLE instruction loads the Idle DBR on the running virtual processor. Only virtual processors in contention for process scheduling will be loaded by this instruction. (The Traffic Controller is not even aware of virtual processors permanently bound to kernel processes.)

IDLE has the same scheduling effect as SWAP_VDBR, but it also sets the IDLE_FLAG on the scheduled VP. The distinction is made between the two cases because, although the Traffic Controller must schedule an Idle process on the VP if there are no other ready processes, the Inner Traffic Controller does not wish to schedule an Idle VP if there is an alternative. This would be a waste of physical processor resources. The setting of the IDLE_FLAG by the Traffic Controller aids the Inner Traffic Controller in making this scheduling decision. Logically, there is an idle process for each VP; actually the same address space (DBR) is used for all idle processes for the same CPU, since only one will run at a time. As previously explained, virtual processors loaded by this instruction will be selected by GETWORK only to give the Idle process away for a new process in response to a virtual preempt interrupt. The action of IDLE is:

```
IDLE Procedure
 Begin
  Lock VPT  (call SPIN_LOCK)
  Load running VP with Idle DBR
  Set VP's IDLE_FLAG
  Place running VP in ready state
  Schedule first elgible ready VP
      (call GETWORK)
  Unlock VPT
  Return
 End IDLE
```

e. SET_VPREEMPT

SET_VPREEMPT sets the preempt interrupt flag on a specified virtual processor. This forces the virtual processor into level-1 scheduling contention, even if it is loaded with an Idle process. The instruction retrieves an idle virtual processor in the same way a hardware preempt retrieves an idle CPU by forcing the VP to be selected by GETWORK. The only difference between the two cases is the entry point used in GETWORK. The action of SET_VPREEMPT is:

```
SET_VPREEMPT Procedure (VP)
 Begin
  Set VP's PREEMPT flag
  If VP belongs to another CPU Then
   send hardware interrupt
  end if
  Return
 End SET_VPREEMPT
```

Since the action is a safe sequence, no deadlocks or race conditions will arise and no lock is required on the VPT.

f. TEST_VPREEMPT

Within the kernel of a multiprocessor system all process interrupts (which excludes system I/O interrupts) are masked. If process interaction results in a virtual preempt being sent to the running virtual processor by another CPU, it will not be handled since GETWORK has already been invoked. TEST_VPREEMPT provides a virtual preempt interrupt unmasking mechanism.

TEST_VPREEMPT mimics the action of a physical CPU when interrupts are unmasked. It forces the process execution point back down into the kernel each time the process attempts to leave the kernel domain, where the preempt flag of the running VP is examined. If the flag is off, TEST_VPREEMPT returns and the execution point exits through the Gatekeeper into the supervisor domain of the process address space as described above. However, if the PREEMPT flag is on, the TEST_VPREEMPT executes a virtual interrupt handler located in the Traffic Controller. This jump from the Inner Traffic Controller to the Traffic Controller (TC_PREEMPT_HANDLER) is a close parallel to the action of a CPU in response to a hardware interrupt, that is a jump to an interrupt handler. The Traffic Controller Preempt Handler forces level-2 and level-1 scheduling to proceed in the normal manner. The preempt handler forces the Traffic Controller to examine the APT and to apply the level-2 scheduling algorithm, TC_GETWORK. If the APT has been changed since the last invocation of this scheduler, it will be reflected in the scheduling selections. Eventually, when the running VP's preempt flag is tested and found to be reset, TEST_VPREEMPT will return to the Gatekeeper where the process execution point will finally make a normal exit into its supervisor domain. TEST_VPREEMPT performs the following action:

```
TEST_VPREEMPT Procedure
 Begin
  Do while running VP's PREEMPT flag is set
   Reset PREEMPT flag
   Call preempt handler
       (call TC_PREEMPT_HANDLER)
  End do
  Return
 End TEST_VPREEMPT
```

C. TRAFFIC CONTROLLER

The Traffic Controller runs in a virtual environment created by the Inner Traffic Controller. It sees a set of running virtual processor instructions: SWAP_VDBR, IDLE, SET_VPREEMPT, and RUNNING_VP, and provides a scheduler, TC_GETWORK, which multiplexes processes on virtual processors in response to process interaction. It also creates a level-2 instruction set: ADVANCE, AWAIT, and PROCESS_CLASS, which is available for use by higher levels of the design. The Traffic Controller uses a global data base, the ACTIVE PROCESS TABLE to support its operation.

1. Active Process Table (APT)

The Active Process Table is a system-wide kernel database containing entries for each supervvisor process in SASS (Figure 39). It is indexed by active process ID. The structure of the APT closely parallels that of the Virtual Processor Table. It contains a LOCK to support the implementation of a mutual exclusion mechanism, a RUNNING_LIST, and a READY_LIST_HEAD. The Traffic Controller is only concerned with virtual processors that can be loaded with supervisor processes. Since two VP's are permanently bound to kernel processes (the Memory Manager and the Idle Process), they cannot be in contention for level-2 scheduling; the Traffic Controller is unaware of their existence; since there are a number of available virtual processors, the

RUNNING_LIST was implemented as an array indexed by VP_ID. The READY_LIST_HEAD points to a FIFO queue that includes both running and ready processes. The running processes will be at the top of the ready list.

Because of their completely static nature, idle processes require no entries in the APT. Logically, there is an idle process at the end of the ready list for each VP available to the Traffic Controller. If the ready list is empty, TC_GETWORK loads one of these "virtual" idle processes by calling IDLE, and enters a reserved identifier, #IDLE, in the appropriate RUNNING_LIST entry. This identifier is the only data concerning idle processes that is contained in the APT. Idle process scheduling considerations are moved down to level-1, because the Inner Traffic Controller knows about physical processors, and can optimize CPU use by scheduling idle processes only when there is nothing else to do.

The subject access class, S_CLASS, provides each process with a label that is required by level-3 modules to enforce, the SASS non-discretionary security policy.

```
LOCK
-------------
RUNNING_LIST PROCESS_ID
             ------------
  VP_ID      |          |
    |        |----------|
    |        |          |
    V        |----------|

===============
READY_LIST_HEAD
===============
        DBR   ACCESS_CLASS   STATE   NEXT_AP  EVENTCOUNT
      |     |              |       |        |   HANDLE
      |     |              |       |        |   INSTANCE
      |     |              |       |        |   COUNT
  AP  |-----|--------------|-------|--------|-----------
Index |     |              |       |        |
  |   |     |              |       |        |
  V   |-----|--------------|-------|--------|-----------
```

Figure 39: Active Process Table

2. Level-2 Scheduling

Above the Traffic Controller, SASS appears as a collection of processes in one of the three states: running, ready, or blocked. Running and ready states are analogous to the corresponding virtual processor states of the Inner Traffic Controller. However, because of the use of eventcount synchronization mechanisms by the Traffic Controller, the blocked state has a slightly different connotation than the VP waiting state.

Blocked processes are waiting for the occurrence of a non-system event, e.g., the event occurrence may be signalled from the supervisor domain. When a specific event happens, all of the blocked processes that were awaiting that event are awakened and placed in the ready state. This broadcast feature of event occurrence is more powerful than the message passing mechanism of SIGNAL, which must be directed at a single recipient.

Just as SIGNAL and WAIT provide virtual processor multiplixing in level-1, the eventcount functions, ADVANCE and AWAIT, control process scheduling in level-2.

a. TC_GETWORK

Level-2 scheduling is implemented in the internal Traffic Controller procedure, TC_GETWORK. This procedure is invoked by eventcount functions when a process state change may have occurred. It loads the first ready process on the currently scheduled VP (i.e., the virtual processor that has been scheduled at level-1 and is currently executing on the CPU).

```
TC_GETWORK Procedure
 Begin
  VP_ID := RUNNING_VP
  Do while not end of ready list
   if process is running then
    get next ready process
   else
    RUNNING_LIST [VP_ID] := PROCESS_ID
    Process state := running
    SWAP_VDBR
   end if
  end do
 If end of running list (no ready processes) Then
  RUNNING_LIST := #IDLE
  IDLE
 end if
 Return
End TC_GETWORK
```

b. TC_PREEMPT_HANDLER

Preempt interrupts are masked while a process is executing in the kernel domain. As the process leaves the kernel, the gatekeeper unmasks this virtual interrupt by invoking TEST_VPREEMPT. This instruction tests the scheduled VP's PREEMPT flag. If this flag is off, the process returns to the Gatekeeper and exits from the kernel; but if the flag is set, TEST_VPREEMPT calls the Traffic Controller's virtual preempt interrupt handler, TC_PREEMPT_HANDLER. This handler invokes TC_GETWORK, which re-evaluates level-2 scheduling. Eventually, when the schedulers have completed their functions, the handler will return control to the preempted process, which will return to te Gatekeeper for a normal exit. This sequence of events closely parallels the action of a hardware interrupt, but in the environment of a virtual processor rather than a CPU. The virtualization of interrupts provides the ability for one virtual processor to interrupt execution of another that may, or may not, be running on a CPU at that time. This is provided without disrupting the logical structure of the system. This capability is particularly useful in a multiprocessor environment where the target virtual processor may be executing on another CPU. Because these interrupts will be virtualized, the operating system will retain control of the system. The action of the TC_PREEMPT_HANDLER is described in the procedure below.

```
TC_PREEMPT_HANDLER Procedure
 Begin
  Call WAIT_LOCK
  VP_ID := RUNNING_VP
  Process_ID := RUNNING LIST [VP_ID]
  If process is not idle  Then
   Process state := ready
  end if
  Call TC_GETWORK
  Call WAIT_UNLOCK
  RETURN
 End TC_PREEMPT_HANDLER
```

WAIT_LOCK and WAIT_UNLOCK provide an exclusion mechanism which prevents simultaneous multiple use of the APT in a multiprocessor configuration. This mechanism invokes WAIT and SIGNAL of the Inner Traffic Controller.

3. Eventcounts

An eventcount is a non-decreasing integer associated with a global object called an event [11]. The Event Manager, a level-3 module, controls access to event data when required and provides the Traffic Controller with a HANDLE, an INSTANCE, and a COUNT. The values for all eventcounts (and sequencers) are maintained at the Memory Manager level and are accessed by calls to the Memory Manager. The HANDLE provides the traffic controller with an event ID, associated with a particular segment. INSTANCE is a more specific definition of the event. For example, each SASS supervisor segment has two eventcounts associated with it, a INSTANCE_1 and a INSTANCE_2, that the supervisor uses keep track of read and write access to the segment [9]. Eventcounts provide information concerning system-wide events. They are manipulated by the Traffic Controller functions ADVANCE and AWAIT and by the Memory Manager functions, READ and TICKL. A proposed high level design for ADVANCE and AWAIT is provided by Reitz [12].

a. Advance

ADVANCE signals the occurrence of an event (e.g., a read access to a particular supervisor segment). The value of the eventcount is the number of ADVANCE operations that have been performed on it. When an event is advanced, the fact must be broadcast to all blocked processes awaiting it and the process must be awakened and placed on the ready list. Some of the newly awakened processes may have a higher priority than some of the running processes. In this case a virtual preempt, SET_VPREEMPT (VP_ID), must be sent to the virtual processors loaded with these lower priority processes.

b. **Await**

When a process desired to block itself until a particular event occurs, it invokes AWAIT. This procedure returns to the calling process when a specified eventcount is reached. Its function is similar to WAIT.

c. **Read**

READ returns the current value of the eventcount. This is an Event Manager (level three) function. This module calls the Memory Manager module to obtain the eventcount value.

d. **Ticket**

TICKET provides a complete time-ordering of possibly concurrent events. It uses a non-decreasing integer, called a sequencer, which is also associated with each supervisor segment. As with READ, this is an Event Manager function that calls the Memory Manager to access the sequencer value. Each invocation of TICKET increments the value of the sequencer and returns it to the caller. Two different uses of ticket will return two different values, corresponding to the order in which the calls were made.

D. SYSTEM INITIALIZATION

Because the Inner Traffic Controller's scheduler, GETWORK, can accommodate both normal calls and hardware interrupt jumps, the problem of system initialization is not difficult.

When SASS is first started at level-1, the Idle VP is running and the memory manager VP, which has the highest priority, is the first ready virtual processor in the ready list. All VP's available to the Traffic Controller for level-2 schedling are ready. Their IDLE_FLAG's and PREEMPT flags are set.

At level-2, all VP's are loaded with idle processes and all supervisor processes are ready.

The kernel stack segment of each process is initialized to appear as if it had been saved by a hardware Preempt interrupt (Figure 40).

All CPU registers and the supervisor stack pointer are stored on the stack. R15 is reserved as the kernel stack point; R14 contains the DBR. All other registers can be used to pass initial parameters to the process. The order in which these registers appear on the stack supports the PLZ/ASM block-move instructions.

```
                 Stack Segment
               |---------------|
               |               |
SP --->        | sup stack ptr |
               |---------------|
R0             |               |
               |       .       |
               |       .       |
               |       .       |
R15            |               |
               |---------------|
R14--->        |      DBR      |
               |---------------|
  .            |       .       |
  .            |       .       |
  .            |       .       |
R1             |               |
               |---------------|
               |    int ID     |
               |---------------|
               |   sup  FCW    |
               |---------------|
stack base->   | process entry |
               |---------------|
               | ker stack ptr |
               |-- ------------|
               |   IRET_FLAG   |
               |---------------|
               |   ker  FCW    |
               |---------------|
               |    header     |
               |               |
               -----------------
```

Figure 40: Initialized Stack

The status block contains the current value of the stack pointer, R15, and the preempt interrupt return flag. This flag is set to indicate that the process has been saved by a preempt interrupt. The first three items on the stack: the process entry point, the initial process flag control word, and an interrupt indentifier, are also initialized to support the action of a hardware interrupt.

To start-up the system, R14 (the DBR) is set to the Idle process DBR; the CPU Program counter is assigned the PREEMPT_ENTRY point in GETWORK; the CPU Flag Control Word (FCW) is initialized for the kernel domain; and the CPU is started. Because the Idle_VP is the lowest priority VP in the system, it will place itself back in the ready state and move the Memory Manager in the running state. The Memory Manager will execute an interrupt return because the interrupt return flag was set by system initialization. There will be no work for this kernel process so it will call WAIT to place itself in the waiting state. The next ready VP is idling, but since it's IDLE_FLAG and PREEMPT flag are set, GETWORK will select it. It too will execute an interrupt return, but because its PREEMPT flag is set, it will call TC_PREEMPT_HANDLER. This will cause the first ready process to be scheduled. Each time a supervisor process blocks itself, the next idle VP will be selected and the sequence will be repeated.

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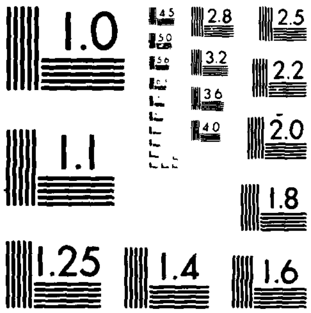

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The action described above is in accord with normal operation of the system. The only unique features of initialization are the entry point (PREEMPT-ENTRY: in GETWORK) and the values in the initialized kernel stack.

The implementation presented in this thesis has been run on a Z8000 developmental module. System initialization has been tested and executes correctly. At the current level of implementation, no process multiplexing function is available. There is no provision for unlocking the APT after an initialized process has been loaded as a result, a call to the Traffic Controller (viz., ADVANCE or AWAIT). In a process multiplexed environment this would cause a system deadlock. Once the process left the kernel domain with a locked APT, no process would be able to unlock it. The Traffic Controller must handle this system initialization problem.

Chapter XV

CONCLUSION

The implementation presented in this thesis created a security kernel monitor that runs on the Z8000 Developmental Module. This monitor supports multiprogramming and process management in a distributed operating system. The process executes in a multiple virtual processor environment which is independent of the CPU configuration.

This monitor was designed specifically to support the Secure Archival Storage System (SASS) [2, 9, 5]. However, the implementation is based on a family of Operating Systems [7] designed with a primary goal of providing multilevel security of information. Although the monitor currently runs on a single microprocessor system, the implementation fully supports a multiprocessor design.

A. RECOMMENDATIONS

Because the Zilog MMU is not yet available for the Z8000 Developmental Module, it was necesary to simulate the segmentation hardware. As Reitz explained [12], this was accomplished by reserving a CPU register, R14, as a Descriptor Base Register (DBR) to provide a link to the loaded addresss space. When the MMU becomes available, this simulation must be removed. This can be done in two steps.

First, the addressing format must be translated to the segmented form. This requires no system redesign.

Second, the switching mechanism most be modified to accomodated to use the MMU. This can be done by modifying the SWAP_DBR portion of GETWORK to multiplex the MMU_IMAGE onto the MMU hardware and this can be accomplished by changing about a dozen lines of the existing code.

B. FOLLOW ON WORK

Although the monitor appears to execute correctly, it has not been rigorously tested. Before higher levels of the system are added, it is essential that the monitor be highly reliable. Therefore a formal test and evaluation plan should be developed.

An automated system generation and initialization mechanism is also required if the monitor to be is a useful tool in the development of higher levels of the design.

Once the monitor has been proven reliable and can be loaded easily, work on the implementation of the Memory Manager kernel process and the remainder of the kernel can continue.

PART E

IMPLEMENTATION OF SEGMENT MANAGEMENT FOR A SECURE ARCHIVAL STORAGE SYSTEM

This section contains excerpts from a Naval Postgraduate School MS Thesis by J. T. Wells [20]. The origins of these excerpts are:

INTRODUCTION	from Chapter I
SEGMENT MANAGEMENT FUNCTIONS	
SEGMENT MANAGER	
NON-DISCRETIONARY SECURITY MODULE	
MEMORY MANAGER	
SUMMARY	from Chapter II
SEGMENT MANAGEMENT IMPLEMENTATION	from Chapter III
CONCLUSIONS AND FOLLOW ON WORK	from Chapter IV

Minor changes have been made for integration into this report.

Chapter XVI

INTRODUCTION

This thesis addresses the implementation of the segment management functions of an operating system known as the Secure Archival Storage System or SASS. This system, with full implementation, will provide: (1) multilevel secure access to information (files) stored in a "data warehouse" for a network of multiple host computers, and (2) controlled data sharing among authorized users. The correct performance of both of these features is directly dependent upon the proper implementation of the segment management functions addressed in this thesis. The issue of access to sensitive information is addressed by the Non-Discretionary Security Module, which mediates all non-discretionary access to information. Sharing of information is accomplished chiefly through the properties of segmentation, the SASS memory management scheme that is supported by the Memory Manager Module and the Segment Manager Module. The implementation of segment management for SASS is thus integral to the attainment of the two key goals that SASS was designed to achieve. This implementation addresses the Non-Discretionary Security, Distributed Memory Manager (the interface to the Memory Manager Process), and Segment Manager modules.

Chapter XVII

SEGMENT MANAGEMENT FUNCTIONS

A. SEGMENT MANAGER

1. Function

The Segment Manager is the focal point of the segment management function. Using the per-process Known Segment Table as its database and the Memory Manager and Non-Discretionary Security Module in strongly supportive roles, it is responsible for managing the segmented virtual memory for a process. Its role can be viewed as somewhat intermediary in nature (viz., between the Supervisor modules and the Memory Manager modules). The extended instruction set created in the Segment Manager includes the following instructions: CREATE_SEGMENT, DELETE_SEGMENT, MAKE_KNOWN, TERMINATE SM_SWAP_IN, and SM_SWAP_OUT (note that the names for SWAP_IN and SWAP_OUT have been modified by preceding each with SM_; this is strictly for clarity because the Memory Manager also creates two instructions called SWAP_IN and SWAP_OUT). These instructions are invoked by the Supervisor domain of the process (viz., calls are made from the Supervisor domain via the Gatekeeper to the Segment Manager in the Kernel domain) to provide SASS support to the Host.

In general, when the Segment Manager receives these calls, it performs certain checks to ensure the validity and security compliance (when required) of the request (call). These checks are performed using its own database (the KST) and by calls to the Non-Discretionary Security Module (when required). The Segment Manager invokes one of six Memory Manager (more specifically, the Distributed Memory Manager Module) created instructions. These instructions include: MM_CREATE_ENTRY, MM_DELETE_ENTRY, MM_ACTIVATE, MM_DEACTIVATE, MM_SWAP_IN, and MM_SWAP_OUT. These invoked instructions (procedures) in turn perform interprocess communciations with the non-distributed memory manager process (where actual memory management functions are accomplished). These interprocess invocations and returns are accomplished through the use of the IPC primitives Signal and Wait. The Segment Manager returns the required arguments to the Supervisor by value (as passed back to it by the Memory Manager and/or determined within itself). The Segment Manager performs actual segment number assignment when a segment is made known to a process' address space. It also performs any further database (KST) updating as may be required.

2. Database

The Known Segment Table (KST) is the database used to manage segments. The KST is described in its tabular form and PLZ/SYS structured representation in Figure 41. There are several basic and pertinent facts to be noted of the KST:

1. It is a process local database; that is, each process has its own KST.
2. The KST is indexed by segment number; each record of the KST consists of a set of fields (description information) regarding a particular segment.
3. Entering information into the fields of a segment is called "making a segment known". This simply refers to adding a segment to a process' address space (viz., making a segment accessible to a process).
4. In SASS, a correspondence exists between making a segment "known" and making a segment "active"; i.e., when a segment is added to the address space of a process, this action results in an entry in the KST (making "known") by the Segment Manager and an entry in the Global Active Segment Table (G_AST) by the Memory Manager process (making it "active"). The G_AST will be described later in this chapter.

A proper description of the structure and fields of the KST is necessary at this point. Using the representation of the PLZ/SYS language structure, the KST is described as an array of records of fields of varying types. The fields are described separately below. Although the KST index is not in itself a field in the record, it does perform a rather significant role. The KST index is an integer closely related to the segment number of the segment described in that KST entry (viz., it is the subscript into the array of records). This segment number also corresponds to the MMU descriptor register (number) for that segment.

The MM_Handle is the first field in a KST record. The MM_Handle is a system wide unique number that is assigned to each segment with an entry in the G_AST (viz., every active segment). This "handle" is the instrument of controlled single copy sharing of information (segments). It allows a segment to exist under one unique handle but be accessible in the address space of more than one process (with different segment numbers in each address space). The MM_Handle is returned to the Segment Manager by the Memory Manager during the execution of the Make_Known instruction.

The Size field is an integer value (of language structure type "word") which represents the number of 256 byte blocks composing a segment.

The Access_Mode field is used to describe the process' access to the segment (i.e., null or read and/or write).

The In_Core field is used to indicate if the segment is or is not in main memory (i.e., this field is a flag or true/false boolean switch).

The Class field is a long word field used to represent the degree of information sensitivity (viz., access class) assigned to the segment. This field (for example) would be used to numerically describe a classification label (as described above).

```
---Segment_#
|
|
|-------------------------------------------------------------------------
V|           |       | Access_| In_  |      |   M_    | Entry_  |
 |MM_Handle  | Size  | Mode   |Core  |Class |  Seg_No | Number  |
 |-----------|-------|--------|------|------|---------|---------|
 |           |       |        |      |      |         |         |
 |           |       |        |      |      |         |         |
 |           |       |        |      |      |         |         |
 |           |       |        |      |      |         |         |
 |           |       |        |      |      |         |         |
 |           |       |        |      |      |         |         |
 |           |       |        |      |      |         |         |
 |           |       |        |      |      |         |         |
 |           |       |        |      |      |         |         |
 |           |       |        |      |      |         |         |
 |           |       |        |      |      |         |         |
 |           |       |        |      |      |         |         |
 |           |       |        |      |      |         |         |
 |           |       |        |      |      |         |         |
 |           |       |        |      |      |         |         |
 |           |       |        |      |      |         |         |
 |           |       |        |      |      |         |         |
 |           |       |        |      |      |         |         |
 |           |       |        |      |      |         |         |
 |           |       |        |      |      |         |         |
 -------------------------------------------------------------------------
```

```
KST     Array [4    KST_REC]

KST_REC     Record [MM_Handle   Array  [3 Word]
                    Size        Word
                    Access_Mode Byte
                    In_Core     Byte
                    Class       Long
                    M_Seg_No    Short_Integer
                    Entry_Number Short_Integer]
```

Figure 41: Known Segment Table

The Mentor_Seg_Nr field is a number representing the segment number of a segment's parent or "mentor" segment. Its importance will discussed shortly.

The Entry_Nr field is a number representing a segment's index number into its parent or mentor segment's Alias Table (not yet discussed).

The Alias Table is a Memory Manager database and will be described later. The aliasing scheme provided via the alias tables is used to prevent passing system wide information out of the Kernel (i.e., the Unique_ID of a segment). The "alias" of a segment is the concatenation of the Mentor_Seg_Nr with the segment's Entry_Nr (index) into the mentor segment's Alias Table. It is clear that the last two fields of a KST record are the "alias" of that segment.

B. NON-DISCRETIONARY SECURITY MODULE

The key in protection of secure information using internal controls was identified as the security kernel concept. The basic idea within this concept is to prove the hardware part of the Kernel correct and, similarly, to keep the software part small enough so that proving it correct is feasible. A central component of the kernel software is the Non-Discretionary Security Module (hereafter referred to as the NDS Module). The NDS Module is concerned only with the non-discretionary aspect of the security policy in effect; since the discretionary aspect is subservient in nature to the non-discretionary aspect, it is then sufficient that the Kernel contain only the software representing the non-discretionary aspect of the security policy. The discretionary security is provided outside the kernel in the SASS supervisor. Every attempt to access information must result in an invocation of the NDS Module.

The function of the NDS Module is to compare two classifications (viz., compare two labels), make a decision as to their relationship (i.e., =,>,<,|), and return a true/false interpretive answer relative to the query of the calling procedure. The mechanism used as a basis is the lattice model abstraction previously discussed. The NDS Module does not require a database since the labels it compares are stored in (passed from) other Kernel databases.

C. MEMORY MANAGER

1. Function

The Memory Manager process is the only component of the non-distributed kernel. It is responsible for managing the real memory resources of the system -- main (local and global) memory and secondary storage. It is tasked by other processes within the Kernel domain (via Signal and Wait) to perform memory management functions. This thesis will address the Memory Manager in terms of two components: (1) the Memory Manager Process (also called the nondistributed kernel and the Memory Manager Module), and (2) the distributed

Memory Manager (also called the Distributed Memory Manager Module). The former is the "true" memory manager while the latter is the interface with other processes, that is, it resolves the issue of interprocess communication with the "true" memory manager.

The Distributed Memory Manager Module creates the following extended instruction set: MM_CREATE_ENTRY, MM_DELETE_ENTRY, MM_ACTIVATE, MM_DEACTIVATE, MM_SWAP_IN, and MM_SWAP_OUT. The instructions form the mechanism of communication between the Segment Manager of a process and a memory manager process (where the actual memory management functions are performed). The Memory Manager Process instruction set corresponds one to one with that of the Distributed Memory Manager; the set consists of: CREATE_ENTRY, DELETE_ENTRY, ACTIVATE, DEACTIVATE, SWAP_IN, and SWAP_OUT. The basic functions performed by the Memory manager are allocation/deallocation of global and local memory and of secondary storage, and segment transfers from local to global memory (and vice-versa) and from secondary storage to main memory (and vice-versa).

2. Databases

A detailed and descriptive discussion of the Memory Manager databases is presented in the work of Gary and Moore [5], and the reader may refer to it for memory manager database details. This thesis addresses the implementation of the distributed Memory Manager but not the Memory Manager Process, thus brief descriptions are provided of the latter's databases.

The Global Active Segment Table (G_AST) is a system wide (i.e., shared by all memory manager processes) database used to manage all active segments. A lock/unlock mechanism is used to prevent race conditions from occurring. The distributed memory manager of the signalling process locks the G_AST before it signals the memory manager process.

The Local Active Segment Table (L_AST) is a processor local database which contains an entry for each segment active in a process currently loaded in local memory.

The Alias Table is a system wide database associated with each nonleaf segment in the Kernel. It is a product of the aliasing scheme used to prevent passing system wide information out of the Kernel. The alias table header (provided for file system reconstruction after system crashes) has two pointers, one linking the alias table to its associated segment, the other linking the alias table to the mentor segment's alias table. The fields in the alias table are Unique_ID, Size, Class, Page_Table_Loc, and Alias_Table_Loc. The index into the alias table is Entry_No.

The Memory Management Unit Image (MMU_Image, Figure 42) is a processor local database indexed by DBR_No (viz., for each DBR_No there is a MMU_Image record, with each record containing a software image of the segment descriptor regis-

ters of the hardware MMU). The MMU_Image is an exact image of the MMU. Each record is indexed by Segment_No (segment number) and each Segment_No entry contains three fields. The Base_Addr field contains the segment's base address in memory. The Limit field contains the number of blocks of contiguous storage for the segment (zero indicates one block). The Attributes field contains 8 flags including 5 which relate to the memory manager. The Blks_Used field and the Max_Blks (available) fields are per record (not per segment entry) and are used in the management of
each process' virtual core.

The Memory Bit Maps (Disk_Bit_Map, Global_Memory_Bit_Map, and Local_Memory_Bit_Map) are memory block usage maps that use true/false flags (bits) to indicate the use or availability of storage blocks.

The only database in the Distributed Memory Manager is the Memory Manager CPU Table (Figure 43). It is an array of memory manager VP_ID's (MM_VP_ID) indexed by CPU number. This table enables a signalling process to identify the appropriate memory manager process (virtual processor) to signal.

```
                                      DBR_NO ------------->

                   ----------------------------------------------------------
                   | Blocks Used       |           |                        |
                   |-------------------|-----------|                        |
                   | Max Avail Blocks  |           |                        |
                   |-------------------|-----------|                        |
        Segment    |Base Addr | Limit  |Attributes |                        |
          No.      |----------|--------|-----------|                        |
           |       |          |        |           |                        |
           |       |          |        |           |                        |
           |       |          |        |           |                        |
           |       |          |        |           |                        |
           |       |          |        |           |                        |
           |       |          |        |           |                        |
           |       |          |        |           |                        |
           |       |          |        |           |                        |
           |       |          |        |           |                        |
           V       |          |        |           |                        |
                   |          |        |           |                        |
                   |          |        |           |                        |
                   |          |        |           |                        |
                   |          |        |           |                        |
                   |          |        |           |                        |
                   |          |        |           |                        |
                   ----------------------------------------------------------
```

```
MMU_Image      Array  [Max_DBR_No   MMU]
MMU            Record [SDR       Array [No_Seg_Desc_Reg
                                        Seg_Desc_Reg]
                       Blks_Used  Word
                       Max_Blks   Word]
Seg_Desc_Reg   Record [Base_Addr  Address
                       Limit      Byte
                       Attributes Byte]
Address        Word
```

Figure 42: Memory Management Unit Image

```
            MM_VP_ID
  CPU  ------------
   |   |          |
   |   |----------|
   |   |          |
   V   |---------->|
       |          |
       |    .     |
       |    .     |
       |    .     |
       |----------|
       |          |
       |----------|
       |          |
       |----------|
```

Figure 43: Memory Manager-CPU Table

D. SUMMARY

The segment management functions and key related concepts (such as segmentation) were discussed in this chapter. The importance of segmentation to data sharing and information security was emphasized as were key information security concepts. With this background, the implementation of segment management and a non-discretionary security policy will be described in the following chapter.

Chapter XVIII

SEGMENT MANAGEMENT IMPLEMENTATION

The implementation of segment management functions and a non-discretionary security policy is presented in this chapter. Paramount to this implementation were several key issues that affected the implementation. These issues are discussed first. The implementation is discussed in terms of the Segment Manager, Non-Discretionary Security (NDS), and Distributed Memory Manager modules.

A. IMPLEMENTATION ISSUES

Segment management for the SASS was provided through the implementation of the Segment Manager Module, the NDS Module, and the Distributed Memory Manager Module. Additionally, since a demonstration/testbed was integral to the testing and verification of the implementation, it was necessary to complete other supportive tasks. Reitz [12] provided a demonstration of the operation of the Inner Traffic Controller primitives SIGNAL and WAIT (for interprocess communication). Integral to this demonstration was the correct performance of the Inner Traffic Controller VP scheduling mechanism and a "stub" of the Traffic Controller and its process scheduling mechanism (the TC support and use of the mechanism of eventcounts and sequencers was not a part of the demonstration). The Segment management demonstration (hereafter referred to as "Seg_Mgr.Demo") was "built on top of" Reitz' ITC synchronization primitive demonstration (hereafter referred to as "Sync. Demo"). Thus, an immediate issue was to resolve the feasibility of adding on to Sync.Demo and also to refine the present design of the Sync. Demo to facilitate its integration into the Seg_Mgr.Demo. One aspect of this effort was in resolving the problem of how to pass (i.e., in interprocess communication) a larger message.

1. Interprocess Messages

The Sync.Demo passed "word" (16 bit) messages. To provide the mechanism for the distributed memory manager to signal the memory manager process with a command function identification code and the arguments needed to perform that function (e.g., CREATE-ENTRY and its input arguments), a message size of at least eight words (16 bytes) was necessary. An obvious answer was to signal with an array of eight words as the message. PLZ/SYS, however, does not allow passing arrays in its procedure calls (a procedure call is analogous to a subroutine call). Another alternative was to signal with a pointer to the array of words, since PLZ/SYS does allow passing pointers in procedure calls (thus the message would be a pointer to the real message). This, however, would be invalid in the segmented implementation (on the Z8000 segmented microprocessor) since identical segment numbers in different processes may not refer to identical segments. For example, a pointer in a process (e.g., file management) points to an array (i.e., provides its address) by segment number and offset; passing this pointer to another process (e.g., memory manager) would provide this same segment number and offset which, of course, may be a different object in the second process's address space).

Another alternative considered was that of a shared "Mailbox" segment with an associated eventcount acted on by the Kernel Inner Traffic Controller primitives TICKET,ADVANCE and AWAIT. A design for using this concept in the supervisor ring is provided by Parks [9]. This alternative was not deeply considered since these primitives are not included in the current Inner Traffic Controller.

The method ultimately used to signal the new length messages is based on the fact that the ITC is in both the signalling and the receiving (memory manager) processes' address space. The message is loaded into an array in process #1 and a pointer to the array is passed in the call SIGNAL; the VPT, the ITC's database, is then updated by (using the pointer) putting the message into its MSG_Q section. The message is retrieved by process #2 by execution of Reitz' WAIT primitive with only one refinement. That refinement is for the "waiting" process to provide as an argument (in the

WAIT primitive) a pointer to its own message array so that the message in the VPT can be copied to it. This refinement provides for passing a long message essentially "by value" between processes.

2. Structures as Arguments

Another issue concerned the use of pointers in the implementation of segment management. This necessary "evil" is a result of the need to pass linguistically "complex" data types in procedure calls. Complex types refer to array and record structures in PLZ/SYS (as opposed to the "simple" types--byte, word, integer, short-integer, long, and pointer). In managing databases (e.g., KST, G_AST) which consist of arrays of records (which in turn contain records and/or arrays), it was frequently necessary to reference data as an array or record. Within a process, the use of pointers was not a problem (i.e., not a problem such as would be encountered in IPC passing of pointers).

3. Reentrant Code

The issue of code reentrancy was addressed at the assembly language level through the use of a stack segment and registers for storage of local variables. PLZ/SYS (high level language) does not address reentrant procedures and thus the segment management high level code is not automatically reentrant. The problem of reentrancy can be seen by looking at a shared procedure that is not reentrant; such a procedure has storage for its variables allocated statically in memory. Suppose a procedure (e.g., in the Kernel) can be activated by more than one process. While the procedure is executing in one process, a process switch occurs (e.g., to wait for a disk transfer) and its execution is suspended. The second process is activated, and while it is running it invokes the procedure. While the procedure is executing for the second process it uses the same storage space for variables as it did when executing for the first process. Eventually, it relinquishes the processor. However, when the procedure resumes its execution for the first process, the variable values that were in use by it originally have been changed during its execution in the second process. Thus, incorrect results are now inevitable.

4. Process Structure of the Memory Manager

References to the "Memory Manager" in past works have generally meant the memory manager process (non-distributed kernel). This work references two distinct components of the "memory manager module". The Distributed Memory Manager is an interface provided to the Memory Manager Process. It is, in fact, distributed in the address space of each Supervisor process. In contrast, the Memory Manager Process clearly is not distributed and its address space is contained entirely in the Kernel.

5. Per-Process Known Segment Table

Another key issue was that of the per process Segment Manager database, the KST. Since each process has its own KST, it cannot be linked to the (shared) segment manager procedures. To implement the KST as a per process database, it was convenient to establish, by convention, a KST segment number that is consistent from process to process. That segment in each process is the KST segment for that process. Implementation is then accomplished by using the segment number to construct a pointer to the base of the appropriate KST. It is then easy to calculate an appropriate offset to index any desired entry in the KST data.

6. DBR Handle

In Reitz's implementation of the multilevel scheduler and the IPC primitives, references to "DBR" (descriptor base register) are references to an address. That address value represents a pointer to an MMU_IMAGE record containing the list of descriptors for segments in the process address space. Gary and Moore [5] reference a "DBR_NO" that is essentially a handle used within the memory manager as an index within the MMU_IMAGE to a particular MMU record. The base address of the MMU record indexed by DBR_NO is then equivalent to the concept of DBR value used in Reitz' work. The effect of this inconsistency on the segment management implementation was minor and will be further discussed later in this chapter.

B. SEGMENT MANAGER MODULE

The Segment Manager Module consists of six procedures representing the six extended instructions it provides. These are based on the design of Coleman [2]. Only calls from external to the Kernel (via the Gate Keeper) may be made to the Segment Manager (per the loop-free structure of the SASS). The normal sequence of invocation of the Segment Manager functions to allow referencing a segment is: (1) CREATE_SEGMENT--allocate secondary storage for the segment and update the mentor segment's Alias Table, (2) MAKE_KNOWN--add the segment to the process address space (segment number is assigned), (3) SWAP_IN--move the segment from secondary storage into the process's main memory. The normal sequence of invocation to "undo" the above is: (1) SWAP_OUT--move the segment from main memory to secondary storage, (2) TERMINATE--remove the segment from the process's address space, (3) DELETE_SEGMENT--deallocate secondary storage and remove the appropriate entry from the alias table of its mentor segment. The six Supervisor entries into the Segment Manager (viz., the six extended instructions) will be discussed individually below. The PLZ/ASM listings for the Segment Manager are in Appendix H.

1. Create a Segment

The function that creates a segment (i.e., adds a new segment to the SASS) is CREATE_SEGMENT. This function validates the correctness of the Supervisor call by checking the parameters and making certain security checks. The distributed memory manager is then called to accomplish interprocess communication with the Memory Manager Process, where segment creation is realized through secondary storage allocation and alias table updating.

CREATE_SEGMENT is passed as arguments: (1) Mentor_Seg_No--the segment number of the mentor segment of the segment to be created, (2) Entry_No--the desired entry number in the alias table of the mentor segment, (3) Class--the access class (label) of the segment to be created, and (4) Size--the desired size of the segment (in blocks of 256 bytes). The initial check is to verify that the desired size does not exceed the designed maximum segment size. If this check is satisfactory, a conversion of the Mentor_Seg_No to a KST index is necessary. This is because the Kernel segments use the first several segment numbers available but do not have entries in the KST. Thus if there were 10 Kernel segments and a system segment had segment number 15, then its index in the KST would actually be 5 (i.e.,the Kernel segments would use numbers 0-9, and this segment would be the sixth segment in the KST and its index would be 5). A call is then made to the procedure

ITC_GET_SEG_PTR with the constant KST_SEG_NO passed as a parameter. This procedure will return a pointer to the base of this process' KST. This pointer is then the basis for addressing entries in the KST. The next check is to see if the mentor segment is known (viz., is in the address space of the process, and thus, in the KST). The key to determining if any segment is known is the mentor segment entry (M_SEG_No) for that segment in the KST. If not known, this entry in the segment's KST record will be filled with the constant NULL_SEG. The basis for checking to see if the segment's mentor segment is known is the aliasing scheme implication that a mentor segment must be known before a segment can be created. The process classification must next be obtained from the Traffic Controller. The process classification is checked to ensure that it is equal to the classification of the mentor segment since write access to its alias table is needed to create a segment. The NDS module's CLASS_EQ procedure is called and returns a code of true or false. The last check is the ccmpatibility check to ensure that the classification of the segment to be created is greater than or equal to the classification of the mentor segment. This is accomplished by calling the NDS Module's CLASS_GE procedure which returns a code of true or false. If any of these checks are unsatisfactory, an appropriate error code is generated and the Segment Manager returns to its calling point. If all checks are satisfactory, then a pointer to the mentor segment's MM_Handle array is derived (HPTR). Note that in the current memory manager design [5] the actual MM_Handle contents are a Unique_ID (a long word, viz., two words concatenated), and an Index_No (index into the G_AST, a word); thus together these two fields are a total of three words. Since the Segment Manager does not interpret this handle, it is considered a three word array at this level. For this reason, the entire uninterpreted MM_Handle array will be passed by passing its pointer. This pointer and Entry_No, Size, and Class are then passed in a call to the distributed memory manager procedure MM_CREATE_ENTRY. This procedure, in turn, performs IPC with the memory manager process where segment creation ultimately is accomplished. A success code is returned in an IPC message from the memory manager process via the distributed memory manager to the CREATE_SEGMENT procedure to indicate success or failure as appropriate. This success code is checked by the Segment Manager to ensure confinement would not be violated if it is returned to the calling process' supervisor domain. Only after the success code has been returned can the action of segment creation be considered complete. Segment creation does not imply the ability to reference that segment; MAKE_KNOWN will accomplish that.

2. Delete a Segment

The function that deletes a segment (i.e., deletes a segment from SASS) is DELETE_SEGMENT. Validation of parameters and security checks are performed here similar to (but fewer than) the CREATE_SEGMENT checks. The distributed memory manager is then called to cause IPC with the memory manager process, where segment deletion is realized through secondary storage deallocation and alias table entry deletions. DELETE_SEGMENT is passed as arguments: (1) Mentor_Seg_No and (2) Entry_No. Conversion of the Mentor_Seg_No to a KST index is accomplished first. The pointer tc the base of the KST is located and returned, as before. The mentor segment is checked to ensure it is known, again, by verifying that its own M_SEG_No (mentor segment number) entry in the KST is not the NULL_SEG. The process classification is obtained from the TC and checked (by a call to CLASS_EQ) to ensure it is equal to the mentor segment classification, since deleting an entry requires write access to the alias table. If all checks are satisfactory, then the mentor segment's MM_Handle pointer is derived. This pointer and the mentor segment alias table entry number are passed in a call to the distributed memory manager procedure MM_DELETE_ENTRY. It then performs IPC with the memory manager process where segment deletion is accomplished and a success code is returned as before.

3. Make a Segment Known

The function that makes a segment known (i.e., adds that segment to the process' address space by assigning a segment number, updating the KST, and causing the memory manager process to "activate" the segment (that is, add it to the AST)) is MAKE_KNOWN. Making a segment known is the way the Supervisor declares its intention to use a segment. MAKE_KNOWN is passed as arguments: (1) Mentor_Seg_No, (2) Entry_No, and (3) Acess_Desired (e.g., write, read, or null). It returns (1) a success code, (2) the access allowed to the segment, and (3) the segment number. Conversion of the mentor segment number to a KST index, finding the KST pointer, and verifying that the mentor segment is known occur as previously discussed.

There are three basic cases that may occur in MAKE_KNOWN: (1) the segment is already known (has an entry in the KST), (2) the segment is not known and there is a segment number available, or (3) the segment is not known and there is no segment number available.

A search is made of the KST using each record's (segment's) M_SEG_No (mentor segment number) and Entry_Number fields as the search key. If these two fields match the input values Mentor_Seg_No and Entry_No, then the record indexed is that of the desired segment; thus the segment to be made known is already known. In this case, all that need be done is to return the success code, segment number (converted from the index by adding to it the number of kernel segments), and the access allowed (equal to the Access_Mode entry in the KST for the already known segment).

During the search of the KST, the M_SEG_No field is also checked to see if it contains the NULL_SEG entry (this implies that the segment number associated with the record is "available"). The first time this is noted, the index is saved. Note the first available index is saved since it is desired to assign segment numbers at the "top" of the KST to keep it dense there. When the search does not find that the segment is already known, the index for the available segment number is retrieved and converted to segment number by adding to it the number of kernel segments. If this index is the NULL_SEG entry, then there is no segment number available. In this event, the success code is set to NO_SEG_AVAIL, the segment number is assigned NULL_SEG, and access allowed is set to NULL_ACCESS (this is the third case mentioned). If the index is not equal to NULL_SEG and conversion to segment number has occurred then the Traffic Controller is called to provide the DBR_No (descriptor base register number) for the current process. The DBR_No is used by the memory manager process as an index in the MMU_Image and the local AST. The distributed memory manager procedure MM_Activate is called; it is passed the DBR number, the pointer to the mentor segment's MM_Handle entry, the mentor segment alias table Entry_No, and the segment number. MM_Activate performs the normal interface function (performs IPC with the memory manager process procedure that updates the local and global AST's) and also updates the KST entry for the new segment's MM_Handle entry (returned from the memory manager process). It also returns to the Segment Manager the success code, the segment classification, and the segment size from the memory manager process. If the success code is "succeeded" then the issue of access to be granted must be resolved. The process classification is obtained from the TC and passed with the segment classification to the NDS Module procedure CLASS_GE. If the CONDITION_CODE returned is FALSE then access allowed is NULL_ACCESS, the segment number is NULL_SEG, and MM_DEACTIVATE is called to deactivate the segment. An appropriate error code is returned. If it is greater than or equal then the access allowed is assigned as follows: (1) the two classifications are compared again--this time to see if equal; (2) If they are equal, then the access allowed is either read or write per the access desired; (3) if they are not equal (i.e., the process class is greater than the segment class) then the access allowed is read. Finally the KST entries for that segment number (more accurately for its index in the KST) are filled with the appropriate information (e.g., IN_CORE is false, etc.). If the success code returned from the memory manager process via the distributed memory manager is not "succeeded", then the segment number is set to NULL_SEG and the access allowed is set to NULL_ACCESS.

4. Make a Segment Unknown (Terminate)

The function that makes a segment unknown (i.e., removes that segment from the process' address space--by updating the KST and causing the memory manager process to "deactivate" the segment) is TERMINATE. It results in removal of the M_SEG_No (mentor segment number) entry from that segment's KST record. Terminate is passed the segment number of the segment to be terminated as an argument. It returns a success code. Conversion of the segment number to a KST index, finding the KST pointer, and verifying that the segment is known occurs in the same manner as previously discussed. The next check is to verify that the segment is not still loaded in the process' virtual core (viz., it has been "swapped-out"). If not, an error code is returned and the user must cause the Segment Manager extended instruction SM_SWAP_OUT to be executed. The next check is to ensure that the user is not attempting to terminate a Kernel segment. The first several segment numbers in a process' address space will be used by Kernel procedures and data (though they will not be entries in the KST). Thus if there were 10 Kernel segments, then the segment number to be terminated must be greater than or equal to #10 (since the Kernel segments used #'s 0-9). Thus a check is made to ensure that the segment number is not less than the number of Kernel segments; otherwise an error code is returned. Next, the segment number is checked to ensure that it is not larger than the maximum segment number allowable (if so, an error code is returned). If all checks are satisfactory, then the segment's MM_Handle pointer and the process DBR_No are obtained (as discussed before) and passed in a call to the MM_Deactivate procedure. It calls the memory manager process procedure DEACTIVATE which removes or updates (as appropriate) the entries in the local and global AST's.

5. Swap a Segment In

The function that swaps a segment from secondary storage to main memory (global or local) is SM_SWAP_IN. It is passed the segment number of the segment to be swapped in as an argument and returns a success code. Conversion of the segment number to a KST index, finding the KST pointer, and verifying that the segment number is known are accomplished as previously discussed. If the check is satisfactory, then the segment's MM_Handle pointer and the process DBR number are obtained. They are passed with the segment's access mode (from the KST) as arguments in the call to MM_SWAP_IN. It performs normal interface (IPC) functions and returns a success code from the memory manager process' SWAP_IN procedure (where, if not already in core, allocation of main memory space and reading the segment into main memory occurs).

If the success code is "succeeded" then the segment's IN_CORE entry in the KST is updated to show that the segment is in main memory for this process (i.e., the entry is now "true").

6. Swap a Segment Out

The function that swaps a segment from main memory to secondary storage is SM_SWAP_OUT. It is passed the segment number of the segment to be swapped out as an argument and returns a success code. The behavior of SM_SWAP_OUT is exactly analogous to that of SM_SWAP_IN except that the segment's KST IN_CORE entry is updated to reflect that the segment has been removed from main memory for this process (i.e., the new entry is "false").

C. NON-DISCRETIONARY SECURITY MODULE

The Non-Discretionary Security Module implements the non-discretionary security policy for the SASS. The NDS module contains two procedures: CLASS_EQ and CLASS_GE; both compare two labels (classifications) and determine if their relationship meets that of the procedure's name (i.e., equal, or greater than or equal). Although the type of checks being made are, in fact, compatibility checks, Simple Security Condition checks, etc, the NDS Module does not recognize or need to recognize this. It simply uses an algorithm to determine if classification #1 = classification #2 or if classification #1 >= classification #2, as appropriate. It then returns a condition code of true or false in accordance with the particular case. The earlier discussion of label comparison in accordance with a partially ordered lattice structure is relevant in discussing the NDS Module's algorithm. Consider the same "totally ordered" relationship TS > S > C > U of levels and the "disjoint" relationship Cy | N | Nu | % of categories. Comparison of levels will be numerical comparisons while comparison of categories will use set theory comparison as a basis. If TS=4, S=3, C=2, U=1 are level numerical assignments, then the totally ordered relationship is maintained (i.e., TS>S>C>U is still true). Now consider the categories and make the following assignments: Cy=1, N=2, Nu=4, %=0. Note that a classification may have only one level and one category set (the category set may contain several categories). Consider this example: (TS, Cy,N . The level is TS (=4). The category is the set Cy,N and numerically is formed by performing a logical OR with the categories Cy and N. Sixteen bit representation of this is:

Cy OR N

(0000 0000 0000 0001) OR (0000 0000 0000 0010)

= 0000 0000 0000 0011 = Cy,N

If (TS, Cy,N) is considered label #1 and (S, N) as label #2 then a comparison of the two labels would be:

(1) Compare level #1 with level #2 -- 4 > 3?

Clearly, the answer is yes.

(2) Compare category #1 with category #2 -- is (0000 0000 0000 0011) a superset of (0000 0000 0000 0010), or more clearly is the latter a subset of the former?

The answer is yes, and one way to show that is true is by performing a logical OR of category #1 with category #2 and comparing the result to category #1. If the result of the OR operation equals category #1 then category #1 is a superset (not necessarily proper) of category #2. Since usage of the term subset is more frequent than that of superset, this relationship will typically be stated as "category #2 is a subset of category #1. To illustrate the above:

Cy,N OR N :
(0000 0000 0000 0011) OR (0000 0000 0000 0010)
= 0000 0000 0000 0011 = category #1.

This means , in this example, that category #2 is a subset (not necessarily proper) of category #1. Since level #1 > level #2 and category #2 subset category #1 then label #1 > label #2. Thus, a call to the CLASS_EQ procedure with these two labels as the input classifications would return a condition code of false while CLASS_GE would return true. The decision to have the classifications as long word (32 bits) supports the requirement of some DoD specifications for eight levels and sixteen categories. This module uses sixteen bits for the level and sixteen bits for the category. Appendix I is the PLZ/ASM listings for the NDS Module.

1. Equal Classification Check

The CLASS_EQ procedure performs comparison of two classifications (labels) and returns a condition code of true if they are equal (an exact match of the two long words bit per bit) or false if they are not.

2. Greater or Equal Classification Check

The CLASS_GE procedure performs comparison of two classifications (labels) and returns a condition code true if classification #1 is greater than or equal to classification #2 or a condition code of false otherwise. For classification #1 to be greater than or equal to classification #2, the following must be true: (1) level #1 >= level #2 (determine this by simple numerical comparison of values) and (2) category #2 subset category #1 (determine this by performing a logical OR with the categories and comparing the result to category #1 -- if they are equal then category #2 is a subset of category #1).

Since PLZ/SYS allows passing only "simple" types in calls, the labels were passed as long words (as opposed to each being word arrays of length two). An access class label is never interpreted outside the NDS Module. However, within the NDS Module it is necessary to address the classification's components separately (viz., level and category). Thus, an "overlay" of the logical view of the classification was created. This overlay was a record of type ACCESS_CLASS and it consisted of two fields: level -- 16 bit integer and category -- 16 bit integer. A pointer type CPTR was declared to be of type pointer to ACCESS_CLASS. Two other pointers CLASS1_PTR and CLASS2_PTR were declared to be of type CPTR and were set equal to the base address of CLASS1 and CLASS2 respectively. This "overlay" of the record frame over the two classification labels passed as arguments allowed the desired component addressibility. Futhermore, the non-discretionary policy enforced by SASS can be changed from the current DoD policy to another lattice policy by changing (only) the NDS Module.

D. DISTRIBUTED MEMORY MANAGER MODULE

The Distributed Memory Manager Module performs as an interface between the Segment Manager and the Memory Manager Process. As its name implies, it is distributed in the kernel domain of each Supervisor process. The key role performed in this module is to arrange and perform interprocess communication between its process (actually the VP) and the memory manager process (VP). The module consists of eight procedures. Six of the procedures are called directly by Segment Manager procedures; they are MM_CREATE_ENTRY, MM_DELETE_ENTRY, MM_ACTIVATE, MM_DEACTIVATE, MM_SWAP_IN, and MM_SWAP_OUT. The other two procedures are "service" procedures called by multiple procedures; they are: MM_GET_DBR_VALUE and PERFORM_IPC. The logic used in the first six procedures is somewhat uniform (except for MM_ACTIVATE). Thus, the general logic will be explained (with MM_CREATE_ENTRY as an example) and it should suffice as a description for all (except MM_ACTIVATE) procedures. The service procedures will be described separately.

1. Description of Procedures

Each procedure is invoked (and returns) on a one to one basis with a corresponding procedure in the Segment Manager. For example, CREATE_SEGMENT invokes MM_CREATE_ENTRY which signals the CREATE_ENTRY procedure in the Memory Manager Process Module. Associated with each procedure is an IPC message "frame" to describe the unique format of the contents of the message to be signalled to the memory manager process. Similarly, there must be a message "frame" for return messages from the memory manager process; this frame is the same for all but the MM_ACTIVATE procedure. Consider the message frame for MM_CREATE_ENTRY; it consists of: (1) a code to describe which function is to be performed (e.g., CREATE_CODE indicates that the CREATE_ENTRY procedure is the intended recipient of the message), (2) MM_Handle (an array of three words), (3) Entry_No, (4) Size, and (5) Class. The message frame has a filler (in this case) of one byte to ensure that it is of length 16 bytes. The purpose of this frame is to provide an overlay onto the actual message array to be signalled and to facilitate loading the arguments into the message array. This is accomplished by having a pointer of the type that points to the frame but by converting its address so that it actually points to the base of the message array. Consider these lines of PLZ/SYS code:

```
CE_MSGPTR := CE_PTR COM_MSGPTR
CE_MSGPTR¬.CREATE_CODE := CREATE_ENTRY_CODE
```

This code is putting a value into the structure pointed to by CE_MSGPTR at entry CREATE_CODE. The key point is that the frame of that structure is, in fact, CREATE_MSG (as described before), but the physical location pointed to is the message array. This is assured by having the pointer CE_MSGPTR (which points to a structure of type CREATE_MSG) set equal to a pointer (COM_MSGPTR) to the actual message array (COM_MSGBUF). This is accomplished by the first line of code. The message array itself is never directly referenced, but rather the message array that is overlayed by the message frame is filled in the format of the CREATE_MSG frame. In this example, the first two bytes of the message array now contain the value of the constant CREATE_ENTRY_CODE. The remainder of the message array is filled in the same manner (all procedures use the same notion of a frame, although the frames have different formats). The PERFORM_IPC (perform interprocess communication) procedure is called by all procedures at this point in their execution. The key is that the argument passed is the message array pointer not the pointer to the CREATE_MSG record (after all it is only an overlay frame -- linguistically, it is only a type and is never declared as a structure requiring memory storage allocation). When PERFORM_IPC returns, the message array contains a return message. This message consists of only a success code and filler space in all cases but MM_ACTIVATE. Interpretation of the return message is performed in the same manner as loading the message array. The retrieved success code is returned to the calling Segment Manager procedure. For MM_ACTIVATE, the return message must be interpreted and values for success code, segment size, and segment classification retrieved and returned to the Segment Manager MAKE_KNOWN procedure. The value for the MM_Handle (called the G_AST_Handle by the memory manager process) must be retrieved and entered in the KST record for this segment.

2. Interprocess Communication

The final arrangements and actual performance of IPC is completed by the internal procedure PERFORM_IPC. By locating the identity of the current physical processor (CPU) and using that identity to index into the MM_CPU_TABLE, the VP_ID of the current memory manager is resolved, so that the memory manager process dedicated to this physical processor is signalled. The call to K_LOCK is, in fact, a disguised call to the SPIN_LOCK procedure (since K_LOCK calls SPIN_LOCK). K_LOCK represents an ultimate (as yet unimplemented) goal of a Kernel locking (wait-lock) system. In any event, the G_AST lock must be set prior to signalling the memory manager process. After SIGNAL has been called, a call is made to WAIT with the pointer to the message array as the argument. The synchronization cycle that results is: (1) PERFORM_IPC calls the ITC procedure SIGNAL with the memory manager VP_ID and message array pointer as arguments; PERFORM_IPC then calls WAIT with the message array as the argument, (2) SIGNAL causes the message array to be copied into the message queue (in the VPT) of the appropriate VP_ID, (3) ultimately, the signalled VP is scheduled; it had previously called WAIT, passing a pointer to its own local message array; the action of WAIT is to copy the message from the VPT to the signalled process' local message array; there it is interpreted by the memory manager process main procedure and the appropriate procedure is called for action (e.g., CREATE_ENTRY), (4) when action is completed the memory manager process fills its local message array with the appropriate return message and calls SIGNAL with a pointer to the message and the original signalling process' VP_ID as arguments, (5) SIGNAL causes the memory manager process' message to be copied into the VPT message queue for the appropriate VP_ID, (6) that VP is eventually scheduled and through the action of WAIT has the return message copied from its message queue in the VPT to its local message array; WAIT then returns to PERFORM_IPC. The G_AST lock is unlocked and

PERFORM_IPC returns to the appropriate distributed memory manager procedure.

The last procedure in the distributed memory manager is MM_GET_DBR_VALUE. This procedure simply provides the service of translating a DBR_NO (DBR number) into its appropriate DBR address. It is called by the TC_GETWORK procedure to allow it to call the ITC procedure SWAP_VDBR (remember that presently the Inner Traffic Controller deals with the DBR as the address of the appropriate MMU record in the MMU_IMAGE while the Traffic Controller uses DBR as a DBR number which indexes to the appropriate MMU record).

E. SUMMARY

The implementation of segment management functions and a non-discretionary security policy for the SASS has been presented in this chapter. The implementation of the Segment Manager Module, Non-Discretionary Security Module, and Distributed Memory Manager management demonstration was described.

Chapter XII

CONCLUSIONS AND FOLLOW ON WORK

The implementation of segment management for the security kernel of a secure archival storage system has been presented. The implementation was completed on Zilog's Z8002 sixteen bit nonsegmented microprocessor. Segmentation hardware (Zilog's Z8010 Memory Management Unit) was not available, therefore it was simulated in software as described by Reitz [12]. The loop free modular construction used in the implementation facilitates ease of expansion or modification.

A non-discretionary security policy was implemented using a partially ordered lattice structure as a basis. Enforcement was realized through an algorithm that compared two labels and determined if their relationship was equal to a desired relationship. Although the DoD security classification system was represented, any non-discretionary security policy that may be represented by a lattice structure may similarly be implemented. This implementation has shown that by having the non-discretionary security policy enforced in one module, changing to another policy requires changing only this one module.

Software engineering techniques used in previous work emphasized the advantages of working with code that is well structured, well documented, and well organized. Despite being written in assembly language, Reitz' implementation of multiprogramming and process management proved to be consistent in style, clarity and documentation. This enhanced the construction of a segment management demonstration which was built onto his synchronization demonstration. Further, refinements made to his code (not necessitated by any failures of his code) were relatively easily accomplished.

While the segment management implementation appears to perform properly, it has not been subjected to a formal test plan. Such a test plan should be developed and implemented.

The Memory Manager Process has been designed but not implemented. Segment management implementation, provision for IPC using more practical size messages, and the detailed design of the memory manager by Moore and Gary [5], provide a sound foundation for memory manager implementation. A framework of the mainline code needed is provided in the Memory Manager Module of the demonstration code in Appendix J. Prior to this implementation, formal testing of the segment management implementation herein and the monitor implemented by Reitz [12] should be completed.

PART F

IMPLEMENTATION OF PROCESS MANAGEMENT FOR A SECURE ARCHIVAL STORAGE SYSTEM

This section contains excerpts from a Naval Postgraduate School MS Thesis by A. R. Strickler [19]. The origins of these excerpts are:

INTRODUCTION	from Chapter I
IMPLEMENTATION ISSUES	from Chapter III
PROCESS MANAGEMENT IMPLEMENTATION	from Chapter IV
CONCLUSION	from Chapter V

Minor changes have been made for integration into this report.

Chapter II

INTRODUCTION

This thesis addresses the implementation of process management functions for the Secure Archival Storage System or SASS. This system is designed to provide multilevel secure access to information stored for a network of possibly dissimilar host computer systems and the controlled sharing of data amongst authorized users of the SASS. Effective process management is essential to insure efficient use and control of the system.

The major accomplishments of this thesis effort include the provisions for efficient process creation and management. These functions are provided through the establishment of a system Traffic Controller and the creation of a virtual interrupt structure. An effective mechanism for inter-process communication and synchronization is realized through an Event Manager that makes use of uniquely identified segments supported by eventcount and sequencer primitives. A hardware controlled two domain operational environment is created with the necessary interfacing between domains provided by a software "gate" mechanism. Additional support is provided through considerable work in the area of database initialization and a technique for limited dynamic memory allocation.

This implementation was completed on the commercial AMC Am96/4116 MonoBoard Computer with a standard Multibus interface.

Chapter XXI

IMPLEMENTATION ISSUES

Issues bearing on the implementation of process management and refinements made to existing modules are presented in this chapter. Process management for the SASS was provided through the implementation of the Traffic Controller Module, the Event Manager Module, the Distributed Memory Manager Module, and a Gate Keeper Stub (system trap). Additionally, since a demonstration/testbed was integral to the testing and verification of the implementation, it was necessary to complete other supportive tasks. These supportive tasks included limited Kernel database initialization, revised preempt interrupt handling mechanisms, Idle process definition and structure, and additional refinements to existing modules.

A. DATABASE INITIALIZATION

Previous work on SASS has relied on statically built databases, which proved to be sufficient for demonstration of a single processor, single host supported system. In the current demonstration, multiple hosts are simulated, and the Kernel data structures have been refined to represent a multiprocessor environment. Since a multiprocessor system was unavailable at the time of this demonstration, several "runs" were made and traced, using different logical CPU numbers, to show the correctness of this structure. Due to this multiprocessor representation and simulation of multiple hosts, the use of statically built Kernel databases was no longer convenient. Therefore, it became necessary to provide initialization routines for the dynamic creation of those Kernel databases required for this implementation. While it was not the intent of this effort to implement system initialization, care was taken in the writing of these initializing routines so that they might be utilized in the system intialization implementation with, hopefully, minimal refinement. Database initialization was restricted to those databases existing in the Inner Traffic Controller and the Traffic Controller. Limited elements of the Known Segment Table (KST) and Global Active Segment Table (G_AST) were also created for demonstration purposes.

1. Inner Traffic Controller Initialization

A "Bootstrap Loader" Module, which logically exists at a higher level of abstraction within the Kernel, was created to initialize the databases of the Inner Traffic Controller. This initialization includes the creation of: 1) the Processor Data Segment (PRDS), 2) an MMU Map, 3) Kernel domain stack segments for Kernel processes, 4) allocation and updating of MMU entries for Kernel processes, and 5) Virtual Processor Table (VPT) entries.

The PRDS was loaded with constant values that specify the physical CPU ID, logical CPU ID, and number of VP's allocated to the CPU. A design decision was made to allocate logical CPU ID's in increments of two (beginning with zero) so that they could be used to directly access lists indexed by CPU number. The MMU map, constructed as a "byte" map, was created to specify allocated and free MMU Image entries.

A separate procedure, CREATE_STACK, was created to establish the initial Kernel domain stack conditions for Kernel processes. A discussion and diagram of these initial stack conditions is presented in the next section. ALLOCATE_MMU checks the MMU Map and allocates the next availabe MMU entry to the process being created. The PRDS is inserted in the allocated MMU entry and the DBR number is returned to the calling procedure. The DBR number (handle) is merely the offset of the DBR in the MMU Image. Since the ITC deals with an address rather than a handle, a procedure, GET_DBR_ADDR, was created to convert this offset into a physical address. UPDATE_MMU_IMAGE is the procedure which creates or modifies MMU Image entries. UPDATE_MMU_IMAGE accepts as arguments the DBR number, segment number, segment attributes, and segment limits. To facilitate process switching and control, various process segments must possess the same segment number system wide. This is accomplished during initialization through the use of the UPDATE_MMU_IMAGE procedure. In the ITC, these segments include the PRDS (segment number zero) and the Kernel stack segment (segment number one).

The final task required in ITC intialization is the creation of the VPT. The VPT header is initialized with the "running" and "ready" lists pointers set to a 'nil' state, and the "free" list pointer set to the first entry in the message table. Virtual Processor entries are inserted in the main body of the VPT by the UPDATE_VP_TABLE procedure. Entries are first made for the VP's permanently bound to the Memory Manager and Idle processes. The VP bound to the MM process is given a priority of 2 (highest), and the VP bound to the Idle process is given a priority of 0 (lowest). The External VP ID for both of these VP's is set to "nil" as they are not visible to the Traffic Controller. The remaining VP's allocated to the CPU (viz., TC visible VP's) are then entered in the VPT with a priority of 1 (intermediate), and their "idle" and "preempt" flags are set. The preempt flag is set for these TC visible VP's to insure proper scheduling by the Traffic Controller. The DBR for these remaining VP's is initialized with the Idle process DBR. A discussion of "idle" processes and VP's will be provided later in this chapter. The External VP ID for each TC visible VP is merely the offset of the next available entry in the EXTERNAL VP LIST. This External VP ID is entered in the VPT, and the corresponding VP ID (viz., VPT Entry #) is entered in the EXTERNAL VP LIST.

Once these VPT entries have been made, it is necessary to set the state of each VP to "ready" and thread them (by priority) into the appropriate ready list. A VPT threading mechanism was provided by Reitz [12] in procedure MAKE_READY. However, it was desired to have a more general threading mechanism that could be used for other lists. Procedure LIST_INSERT was created to provide this general threading mechanism. LIST_INSERT is logically a "library" function that exists at the lowest level of abstraction in the Kernel. This function threads an object into a list (specified by the caller) in order of priority, and then sets its state as specified by the calling parameters.

Once the "Bootstrap Loader" has completed ITC initialization, it passes control to the ITC GETWORK procedure to begin VP scheduling.

2. Traffic Controller Initialization

The initialization routines for the TC include TC_INIT, CREATE_PROCESS, and CREATE_KST. These routines are called from the Memory Manager process. The MM process was chosen to initiate these routines as it is bound to the highest priority VP and will begin running immediately after the Inner Traffic Controller is initialized. Procedure MM_ALLOCATE was written to allocate memory space for data structures during initialization (viz., Kernel stacks, user stacks, and KST's). Memory space is allocated in blocks of

100 (hex) bytes. MM_ALLOCATE is merely a stub of the memory allocating procedure designed by Moore and Gary [5].

It was necessary to pass long lists of arguments to the TC for initialization purposes. To aid in this passing of parameters, a data structure template was used. This template was created by declaring the parameters as a data structure in both the sending and receiving procedures, and then imaging this structure at absolute address zero. The process' stack pointer was then decremented by the size of the parameter data structure, and the parameters were loaded into this data structure indexed by the stack pointer. This template made it very easy to send and receive long argument lists using the process' stack segment.

TC_INIT initializes the APT header and virtual interrupt vector (discussed later). Each element of the running list is marked "idle", the ready and blocked lists are set to "nil", and the number of VP's and first VP for each CPU are entered in the VP table. The address of the virtual preempt handler is then passed to the ITC procedure CREATE_INT_VEC for insertion in the virtual interrupt vector.

CREATE_PROCESS intializes user processes and creates entries in the APT. ALLOCATE_MMU is called to acquire a DBR number, and an APT entry is created with the process descriptors (viz., parameters). The process is then declared "ready" and threaded into the approciate ready list by calling the threading function, LIST_INSERT. A user stack is allocated and UPDATE_MMU_IMAGE is called to include the user stack in the MMU as segment number three. The user stack contains no information or user process initialization parameters (viz., execution point and address space) as all processes are initialized and begin execution from the Kernel domain. Next, a Kernel domain stack is allocated and included in the MMU Image. A design decision was made to initialize the Kernel stacks for user processes with the same structure as the Kernel process' stacks. The rationale for this decision is presented in the next section. As a result of this decision, it became possible to use the CREATE_STACK procedure in building Kernel domain stacks for both Kernel and user prosesses. CREATE_STACK was therefore used as a library function and placed in the library module with LIST-INSERT.

Finally, a Known Segment Table (KST) stub is created to provide a means of demonstrating the mechanism provided by the eventcounts and sequencers for interprocess communication (IPC) and mutual exclusion. Space for the process' KST is created by calling MM_ALLOCATE. The KST is then included in the process' address space, as segment number two, by UPDATE_MMU_IMAGE. Initial entries are made in the Known Segment Table by procedure CREATE_KST. CREATE_KST makes an entry in the KST for the "root" and marks the remaining KST entries as "available." The Unique_ID portion of the root's handle (viz., upper two words) is initialized as -1 (for convenience) and the G_AST entry number portion of the handle (viz., lowest word) is initialized with zero.

3. Additional Initialization Requirements

As already mentioned, the Memory Manager Process prepares the arguments utilized by TC_INIT, CREATE_PROCESS, and CREATE_KST for TC initialization and user process creation. Additionally, the MM process creates a Global Active Segment Table (G_AST) stub utilized fcr demonstration of event data management. The G_AST stub is declared in a separate module (viz., the DEMO_DATABASE Module) with the format prescribed by Moore and Gary [5]. However, the only fields initialized and utilized by this implementation are UNIQUE_ID, SEQUENCER, INSTANCE 1, and INSTANCE 2. The eventcounts and sequencer fields are initialized as zero whenever an entry is created in the G_AST. The UNIQUE_ID is created just to support this demonstration and does not reflect the segment's unique identifier as specified by Moore and Gary [5]. In this demonstration, UNIQUE_ID is built with the parameters passed to MM_ACTIVATE. The first word in UNIQUE_ID is the G_AST entry number of the segment's parent, and the second word is the segment's entry number into the alias table. The UNIQUE_ID together with the offset of the segment's entry in the G_AST comprise the segment HANDLE maintained in the KST. The first entry in the G_AST is reserved for the root, and is initialized with an Unique_ID of minus one

(-1). It should be noted that any call to MM_ACTIVATE for a segment already possessing an entry in the G_AST will not effect any changes to that entry. This is to insure that a single G_AST entry exists for every segment as specified by Moore and Gary [5].

B. PREEMPT INTERRUPTS

Various refinements were made in the handling of both physical (hardware) and virtual (software) preempt interrupts. A hardware preempt is a non-vectored interrupt that invokes the virtual processor scheduling mechanism (viz., ITC GETWORK). A virtual preempt is a software vectored interrupt that invokes the user process scheduling mechanism (viz., TC_GETWORK). This implementation provides the notion of a virtual interrupt that closely mirrors the behavior of a hardware interrupt. In particular, there are similar constructs for initialization of a handler, invokation of a handler, masking of interrupts, and return from a handler. As with most hardware interrupts, a virtual interrupt can occur only at the completion of execution for an "instruction," where each kernel entry and exit for a process delimit a single "virtual instruction."

1. Physical Preempt Handler

The physical preempt handler resides in the virtual processor manager (viz., Inner Traffic Controller). The functions it perform are: 1) save the execution point, 2) invoke ITC GETWORK, 3) check for virtual preempt interrupts, 4) restore the execution point, and 5) return control via the IRET instruction. Reitz [12] included the hardware preempt handler in ITC GETWORK by establishing two entry points and two exit points, one for a regular call to GETWORK and another for the preempt interrupt. He had a separate procedure, TEST_PREEMPT, that was used to check for the occurrence of virtual preempt interrupts. This structure works nicely, but it requires some means of determining how GETWORK was invoked so that the proper exiting mechanism is used. This was resolved by incorporating a preempt interrupt flag in the status register block of every process' Kernel domain stack segment. A design decision was made to restructure the hardware preempt handler into a single and separate procedure, PHYS_PREEMPT_HANDLER. This allowed ITC GETWORK to have a single entry and exit point, and it did away with the necessity of maintaining a preempt interrupt flag in the process stacks. PHYS_PREEMPT_HANDLER was constructed from the preempt handling code in GETWORK and procedure TEST_PREEMPT. TEST_PREEMPT was deleted from the ITC as its functions were performed by PHYS_PREEMPT-HANDLER.

A further refinement was made to the hardware preempt handler dealing with the method by which the virtual preempt handler was invoked. Reitz [12] invoked the virtual preempt handler from TEST_PREEMPT by means of the "call" instruction. Since the virtual preempt handler logically exists at a higher level of abstraction than the ITC, this invocation violated our notion of only allowing "calls" to lower or equal abstraction levels. However, this deviation was necessitated by the absence of a virtual interrupt structure. This problem was alleviated by creating a virtual interrupt vector in the ITC that is used in the same way as the hardware interrupt vector. The virtual preempt was given a virtual interrupt number (zero). The virtual interrupt handler is then invoked by means of a "jump" through the virtual interrupt vector for virtual interrupt number 0. This invocation occurs in the same manner that the handlers for hardware interrupts are invoked. The virtual interrupt vector is created by procedure CREATE_INT_VEC. CREATE_INT_VEC accepts as arguments a virtual interrupt number and the address of the interrupt handler. The creation of the virtual preempt entry in the virtual interrupt vector is accomplished at the time of the Traffic Controller initialization by TC_INIT.

2. Virtual Preempt Handler

The virtual preempt handler (VIRT_PREEMPT_HANDLER) resides in the user process manager (viz., the Traffic Controller). The functions performed by VIRT_PREEMPT_HANDLER are: 1) determine the VP ID of the virtual processor being preempted, 2) invoke the process scheduling mechanism (viz., TC_GETWORK), and 3) return control via a virtual interrupt return. The correct VP ID is obtained by calling RUNNING_VP in the ITC. The Active Process Table is then locked, and the state of the process running on that VP is changed to "ready." At this time, process scheduling is effected by calling TC_GETWORK. Once process s heduling is completed, the APT is unlocked and control is returned via a virtual interrupt return. This virtual interrupt return is merely a jump to the PREEMPT_RET label in the hardware preempt handler (This jump emulates the action of the IRET instruction for a hardware interrupt return). This label is the point at which the virtual preempt interrupts are unmasked.

All Kernel processes are initialized to appear as though they are returning from a hardware preempt interrupt. All user processes initially appear to be returning from a virtual preempt interrupt. Therefore, the initial conditions of a process' Kernel domain stack is largely influenced by the stack manipulation of the preempt handlers. Figure 44 illustrates the initial Kernel domain stack structure for all system processes.

```
Base-->|-----------------------|
Address|           .           |  ^
   of  |           .           |  | Stack
Segment|           .           |  | "grows"
       |                       |  | this
       |-----------------------|  | way
SP|--->| Preempt Return Point  |  |
  |    |-----------------------|  |
  |    |         N_S_P         |
  |    |-----------------------|
  |    |      Register 1       |
  |    |-----------------------|
  |    |           .           |
  |    |           .           |
  |    |           .           |
  |    |-----------------------|
  |    |      Register 15      |
  |    |-----------------------|
  |    |      Register 0       |
  |    |-----------------------|
  |    |     Interrupt ID      | ---|
  |    |-----------------------|    |IRET
  |    |      Initial PCW      |    |---
  |    |-----------------------|    |Frame
  |    |      Initial IC       | ---|
  |    |-----------------------|
  |----| Current Stack Pointer|
       |-----------------------|
       |      Kernel PCW       |
       |-----------------------|
```

Figure 44: Initial Process Stack

The initial Kernel Flag Control Word (FCW) value is "5000", indicating non-segmented code, system mode of operation, non-vectored interrupts masked, and vectored interrupts enabled. The Current Stack Pointer value is set to the first entry in the stack (viz., SP). The IRET Frame is the portion of the Kernel stack affected by the IRET instruction. The first element, Interrupt ID (set to "FFFF") is merely popped off of the stack and discarded. The next element, Initial FCW, is popped and placed in the system Flag Control Word. Initial FCW is set to "5000" for Kernel processes and "1800" (indicating normal mode with all interrupts enabled) for user processes. The final element of the IRET frame, Initial IC is popped off of the stack and placed in the program counter (PC) register. This value is initialized as the entry address of the process in question.

The "register" entries on the stack represent the initial register contents for the process at the beginning of its execution. Since the Kernel processes (viz., MM and Idle) do not require any specific initial register states, their entries reflect the register contents at the time of stack creation. Initial register conditions are used to provide initial "parameters" required by the user processes. This will depend largely upon the parameter passing conventions of the implementation language. The means for register initialization was provided through CREATE_PROCESS; however, the only initial register condition used for the user processes in this demonstration was register #13. Register #13 was used to pass the user ID/Host number of the process created. This value is utilized by the user process in activating the segment used for inter-process communication between a Host's File manager and I/O processes. Another logical parameter passed to the user processes is the root segment number. This did not require a register for passing in the demonstration as it is known to be the first entry in the KST for all processes. The N_S_P entry on the stack represents the initial value of the normal stack pointer. For user processes, this value is obtained when the Supervisor domain stack for that process is created. For Kernel processes, this value is set to "FFFF" since they execute solely in the Kernel domain and have no Superivsor domain stack. The Preempt Return Point specifies the address where control will be passed once the process' VP is scheduled and the "return" from ITC GETWORK is executed. For Kernel processes, this is the point within the hardware preempt handler where the virtual processor table is unlocked. For user processes, this is the point within the virtual preempt handler where the Active Process Table is unlocked.

It is important to note that if the APT was not unlocked when a user process began its initial execution, the system would become deadlocked and no further process scheduling could occur. It should be further noted that the initial stack conditions for user processes do not reflect a valid history of execution. The "normal" history of a user process returning from ITC GETWORK after a virtual preempt interrupt would reflect the passing of control through SWAP_VDBR and TC_GETWORK to the point in the virtual preempt handler where the APT is unlocked. Another "possible" history could reflect the occurrence of a hardware preempt interrupt at the point in the virtual preempt handler where the APT is unlocked. Such a history would be depicted by replacing the current top of the stack with the return point into the hardware preempt handler (viz., at the point of virtual preempt interrupt unmasking) and an additional hardware preempt interrupt frame whose IC value in the IRET frame is the point in the virtual preempt handler where the APT is unlocked. The current initial stack condition for user processes was chosen for its ease of understanding and its clear depiction of the fact that the structure of a Kernel domain stack is the same for both Kernel and user processes.

C. IDLE PROCESSES

In the SASS design, there logically exists a Kernel domain "Idle" process for every physical processor in the system and a Supervisor domain "Idle" process for every "TC visible" virtual processor in the system. These processes are necessary to insure that both the VP scheduler (viz., ITC GETWORK) and the process scheduler (TC_GETWORK) will always have some object ͻ schedule, hence precluding any CPU or VP from ever having an undefined execution point. Since the Kernel domain Idle process performs no useful work, it could be included within the ITC by means of an infinite looping mechanism. The Kernel Idle process was maintained separately, however, as it is hoped that future work on SASS will provide this Idle process with some constructive purpose (e.g., performing maintenance diagnostics).

The Supervisor domain Idle processes (hereafter referred to as TC Idle processes) are scheduled (bound) on VP's when there are no user processes awaiting scheduling. Since a TC Idle process performs no user constructive work, we do not want any VP executing a TC Idle process to be bound to a physical processor. In other words, a VP bound to a TC Idle process assumes the lowest system priority (represented by the "idle flag"). Therefore, any such VP will have its idle flag set and will not be scheduled unless it receives a virtual preempt interrupt. Such an interrupt will allow the VP to be rescheduled by the Traffic Controller. It should be obvious, at this point, that a TC Idle process will never actually begin execution on a real processor. This knowledge allowed a design decision to be made to only simulate the existence of TC Idle processes. At the TC level, this was accomplished by a constant value, IDLE_PROC, that was used as a process ID in the APT running list, thus precluding the necessity of any "Idle" entries in the APT. At the

ITC level, any VP marked "Idle" (viz., the idle flag set) was given the DBR number (viz., address space) of the Kernel Idle process solely to provide the use of a Kernel domain stack for rescheduling of the VP.

D. ADDITIONAL KERNEL REFINEMENTS

In addition to those already discussed, several other refinements to existing Kernel modules were effected in this implementation. One of these refinements deals with the way virtual processors are identified by the Traffic Controller. In the current implementation, all TC visible virtual processors are given an External VP ID which corresponds to its entry number in an External VP List. This required a modification to the ITC procedure RUNNING_VP. The benefits derived from this refinement included the ability to directly access the External VP ID in the Virtual Processor Table vice the requirement of a run time division to compute its value and the ability to use the External VP ID as an index into the TC running list.

Refinements were also made to the existing Memory Manager, File Manager and IO process stubs used for demonstration purposes. These refinements were largely associated with the eventcount and sequencer mechanisms utilized in this implementation. The current status of these processes is provided in this report.

The remaining refinements deal largely with the MMU Image. In Moore and Gary's [5] design, the MMU Image was managed by the Memory Manager process. This was largely because the MMU Image is a processor local database and would seem well suited for management by the non-distributed Kernel. In fact, the MMU Image is utilized mainly by the ITC for the multiplexing of process address spaces. Therefore, in the current design, the MMU Images are maintained by the Inner Traffic Controller. However, the MMU header proposed by Moore and Gary (viz., the BLOCKS_USED and MAXIMUM_AVAILABLE_BLOCKS fields) was retained in the Memory Manager as it is used strictly in the management of a process' virtual core and is not associated with the hardware MMU.

In Wells' design [20], the Traffic Controller used the linear ordering of the DBR entries in the MMU Image as the DBR handle (viz., 1,2,3...). This required a run time division operation to compute the DBR number, and a run time multiplication operation, by MM_GET_DBR_VALUE, to recompute the DBR address for use by the ITC. In the current design, the offset of the DBR entry in the MMU Image (obtained at the time of MMU allocation) is used as the DBR handle in the Traffic Controller. Furthermore, SWAP_VDBR was refined to accept a DBR handle rather than a DBR address to preclude the necessity of the Traffic Controller having to deal with MMU addresses. DBR addresses are computed only within the

ITC (viz., by procedure GET_DBR_ADDR) by adding the value of the DBR handle to the base address of the MMU Image. Since DBR addresses are now used solely within the ITC, procedure MM_GET_DBR_VALUE was no longer needed and was deleted from the Memory Manager.

E. SUMMARY

The primary issues addressed in this thesis effort have been presented in this chapter. Aside from the process management functions, this description included a mechanism for limited Kernel database initialization, a revised preempt interrupt handling mechanism, the creation of a virtual interrupt structure, a definition of "idle" processes and their structure, and a discussion of the minor refinements effected in existing SASS modules. A detailed description of the implementation of process management functions for the SASS is presented in the next chapter.

Chapter XXII

PROCESS MANAGEMENT IMPLEMENTATION

The implementation of process management functions and a gate keeper stub (system trap) is presented in this chapter. The implementation is discussed in terms of the Event Manager, Traffic Controller, Distributed Memory Manager, User Gate, and Kernel Gate Keeper modules. A block diagram depicting the structure and interrelationships of these modules is presented in Figure 45. Support in developing the Z8000 machine code for this implementation was provided by a Zilog MCZ Developmental System operating under the RIO operating system. The Developmental System provided disk file management for a dual drive, hard sectored floppy disk, a line oriented text editor, a PLZ/ASM assembler, a linker and a loader that created an executable image of each Z8000 load module. An upload/download capability with the Am96/4116 MonoBoard computer was also provided. This capability, along with the general interfacing of the Am96/4116 into the SASS systam, was accomplished in a concurrent thesis endeavor by Gary Baker. Baker's work relating to hardware initialization in SASS, will be published upon completion of his thesis work in June 1981.

```
                     |-------------|
                     | Kernel Gate |
                     |-------------|
Gate Keeper
------------------------------------------------------------
 |------|    |-------|            |---------|    |----------|
 | Read |    | Await |            | Ticket |    | Advance |
 |------|    |-------|            |---------|    |-------->|

                       |---------|
                       | Convert |
                       |   and   |
                       | Verify  |
                       |---------|
                     Event   Manager
------------------------------------------------------------
     |----------|      |---------|           |------------|
     | TC_Await |      | Process |           | TC_Advance |
     |----------|      |  Class  |           |------------|
                       |---------|

         |------------|   |----------|
         | TC_Getwork |   | Virt Int |
         |------------|   | Handler  |
                          |----------|
                    Traffic Controller
------------------------------------------------------------
|--------------------|          |-----------| |------------|
| MM_Read_Eventcount |          | MM_Ticket | | MM_Advance |
|--------------------|          |-----------| |------------|
                Distributed Memory Manager
------------------------------------------------------------
```

Figure 45: Implementation Module Structure

A. EVENT MANAGER MODULE

The eventcount and sequencer primitives [11], which are system-wide objects, collectively comprise the event data of SASS. As mentioned earlier, this event data is tied directly to system segments and is stored in the Global Active Segment Table. There are two eventcounts and one sequencer for every segment in the system. These objects are identified to the Kernel in user calls by specification of a segment number. Once this segment number is identified by the Kernel, the segment's handle can be obtained from the process' Known Segment Table. The segment handle identifies the particular entry in the G_AST containing the event data desired.

The Event Manager module manages the event data within the system and provides the mechanism for interprocess communication between user processes. The Event Manager consists of six procedures. Four of these (Advance, Await, Read, and Ticket) represent the four user extended instructions provided by the Event Manager. The remaining two procedures provide internal computational support to include necessary security checking. The Event Manager is invoked solely by user processes, via the Gate Keeper, through utilization of the extended instruction set provided. For every Event Manager extended instruction invoked by a user process, the non-discretionary security is verified by comparing the security access classification of the process invoking the instruction with the classification of the object (segment) being accessed. Access to the user process' Known Segment Table is required by the module in order to ascertain the segment handle and security class for a given segment number. The PLZ/ASM assembly language listing for the Event Manager module is provided in Appendix A. A more detailed discussion of the procedures comprising the Event Manager follows.

1. Support Procedures

The procedures GET_HANDLE and CONVERT_AND_VERIFY provide internal support for the Event Manager and are not visible to the user processes. Procedure CONVERT_AND_VERIFY is invoked by the four procedures representing the instruction set of the Event Manager. The input parameters to CONVERT_AND_VERIFY are a segment number and a requested mode of access (viz., read or write). CONVERT_AND_VERIFY returns a pointer to the segment's handle and a success code. Procedure GET_HANDLE is invoked solely by CONVERT_AND_VERIFY. The input parameter to GET_HANDLE is the segment number received as input by CONVERT_AND_VERIFY. GET_HANDLE returns a pointer to the segment's handle, a pointer to the segment's security classification, and a success code. A discussion of the functions provided by these support procedures follows.

Procedure GET_HANDLE translates the segment number, received as input, into a KST index number and verifies that the resulting index number is valid. Next the base address of the process' KST is obtained from procedure ITC_GET_SEG_PTR. The KST index number is then converted into a KST offset value and added to the base address to obtain the appropriate KST entry pointer for the segment in question. A verification is then made to insure that the referenced segment is "known" to the process. If the segment is not known, an errcr message is returned to CONVERT_AND_VERIFY. Otherwise, a pointer to the segment's handle is obtained to identify the segment to the memory manager. A pointer to the segment's security class entry in the KST is also returned for use in appropriate security checks.

Procedure CONVERT_AND_VERIFY provides the necessary non-discretionary security verification for the extended instruction set of the Event Manager. Procedure GET_HANDLE is invoked for segment number verification and to obtain pointers to the segment's handle and security class. If GET_HANDLE returns with a successful verification, the process' security class is compared to the segment's security class to verify the mode of access requested. A request for "write" access causes invocation of the CLASS_EQ function in the Non-Discretionary Security Module to insure that the security classification of the process is equal to the classification of the eventcount or sequencer, which is the same as that of the segment. Otherwise, the CLASS_GE function is called to verify that the process has read access. If the appropriate security check is unsuccessful, an error code is returned by CONVERT_AND_VERIFY. Otherwise, the segment handle is returned along with a success code of "succeeded" indicating that the user process possesses the necessary security clearance to complete execution of the extended instruction.

2. Read

Procedure READ ascertains the current value of a user specified eventcount and returns its value to the caller. The input parameters to READ are a segment number and an instance (viz., an event number). CONVERT_AND_VERIFY is invoked with a "read" access request to obtain the segment's handle and necessary verification. "Read" access is sufficient for this operation as it only requires observation of the current eventcount value and performs no data modification. If verification is successful, procedure MM_READ_EVENTCOUNT is called to obtain the eventcount value.

3. Ticket

Procedure TICKET returns the current sequencer value for the segment specified by the user. CONVERT_AND_VERIFY is called with a request for write access to obtain verification and the segment handle. Write access is required because once the sequencer value is read it must be incremented in anticipation of the next ticket request. Once verification is complete, MM_TICKET is invoked to obtain the sequencer value that is returned to the user process. It is noted that every call to TICKET for a particular segment number will return a unique and time ordered sequencer value. This is because the sequencer value may only be read within MM_TICKET while the G_AST is locked, thereby preventing simultaneous read operations. Futhermore, once the sequencer value is read it is incremented before the G_AST is unlocked.

4. Await

Procedure AWAIT allows a user process to *block* itself until some specified event has occurred. The parameters to AWAIT include a segment number and instance, which identify a particular event, and a user specified value which identifies a particular occurrence of the event. Verification of read access and a pointer to the segment's handle is obtained from procedure CONVERT_AND_VERIFY. Procedure TC_AWAIT is invoked to effect the actual waiting for the event occurrence. TC_AWAIT will not return to AWAIT until the requested event has occurred. It is noted that AWAIT makes no assumptions about the event value specified by the user. Therefore, the Kernel cannot guarantee that the event specified by the user will ever occur; this is the responsibility of other cooperating user processes.

5. Advance

Procedure ADVANCE allows a user process to broadcast the occurrence of some event. This is accomplished by incrementing the value of the eventcount associated with the event that has occurred. The parameters to ADVANCE include a segment number and instance which identify a particular event. The calling process must have write access to the identified segment as modification of the eventcount is required. Verification of write access and a pointer to the segment's handle is obtained through procedure CONVERT_AND_VERIFY. Procedure TC_ADVANCE is invoked to perform the actual broadcasting of event occurrence.

B. TRAFFIC CONTROLLER MODULE

The primary functions of the Traffic Controller module are user process scheduling and support of the inter-process communication mechanism. The Traffic Controller is invoked by the occurrence of a virtual preempt interrupt and by the Event Manager and the Segment Manager through the extended instruction set: TC_Advance, TC_Await, Process_Class, and Get_DBR_NUMBER. The Traffic Controller module is comprised of nine procedures. Four of these procedures represent the extended instruction set of the Traffic Controller. A detailed discussion of six of the procedures contained in the Traffic Controller module is presented below. The remaining three procedures (viz., TC_INIT, CREATE_PROCESS, and CREATE_KST) were described in chapter three. The PLZ/ASM assembly language source code listings for the Traffic Controller module is provided in Appendix B.

1. TC_Getwork

Procedure TC_GETWORK provides the mechanism for user process scheduling. The input parameters to TC_GETWORK are the VP ID of the virtual processor to which a process will be scheduled and the logical CPU number to which the virtual processor belongs. The determination of which process to schedule is made by a looping mechanism that finds the first "ready" process on the ready list associated with the current logical CPU number. Processes appear in the ready list by order of priority. This looping mechanism is required as both "running" and "ready" processes are maintained on the ready list. This ready list structure was chosen to simplify the algorithm provided in procedure TC_Advance. If a ready process is found, its state is changed to "running" and its process ID (viz., the APT entry number) is inserted in the running list entry associated with the current virtual processor. Procedure SWAP_VDBR is then invoked in the Inner Traffic Controller to effect the actual process switch. If a ready process was not found (viz., the ready list was empty or comprised solely of "running processes"), then the running list entry associated with the current virtual processor is marked with the constant "Idle_Proc" and procedure IDLE is invoked in the Inner Traffic Controller.

2. TC_Await

The primary function of TC_AWAIT is the determination of whether some user specified event has occurred. If the event has occured, control is returned to the caller. Otherwise, the process is blocked and another process is scheduled. The input parameters to TC_AWAIT are a pointer to a segment handle, an instance (event number), and a user specified eventcount value. TC_AWAIT initially locks the Active Process Table and obtains the current value of the eventcount in question by calling procedure MM_READ_EVENTCOUNT. The determination of event occurrence is made by comparing the user specified eventcount value with the current eventcount. If the user value is less than or equal to the current eventccunt, the awaited event has occurred and control is returned to the caller. Otherwise, the awaited event has not yet occurred and the process must be blocked.

If the process is to be blocked, procedure RUNNING_VP is invoked to ascertain the VP ID of the virtual processor bound to the process. The process' ID (viz., APT entry number) is then read from the running list. The input parameters to TC_AWAIT (viz., Handle, Instance, and Value) are then stored in the Event Data portion of the process' APT entry. The process is removed from its associated ready list by redirecting the appropriate linking threads (pointers). Once removed from the ready list, the process is threaded into the blocked list and its state changed to "blocked" by invocation of the library function LIST_INSERT. Procedure TC_GETWORK is then called to schedule another process for the current virtual processor.

3. TC_Advance

The primary purpose of TC_ADVANCE is the broadcasting of some event occurrence. This entails incrementing the eventcount associated with the event, awakening all processes that are waiting for the event, and insuring proper scheduling order by generating any necessary virtual preempt interrupts. The high level design algorithm for TC_ADVANCE is provided in Figure 46. The input parameters to TC_ADVANCE are a pointer to a segment's handle and an instance (event number). Initially, TC_ADVANCE locks the APT to prevent the possibility of a race condition. The eventcount identified by the input parameters is then incremented by calling MM_ADVANCE. MM_ADVANCE returns the new value of the eventcount. Once the eventcourt has been advanced, TC_ADVANCE awakens all processes awaiting this event occurrence. This is accomplished by checking all processes that are currently in the blocked list. The process' HANDLE and INSTANCE entries are compared with the handle and instance identifying the current event. If they are the same, then the process is awaiting some occurrence of the current event. In such a case, the process' VALUE entry in the APT is compared with the current value of the eventcount. If the process' VALUE is less than or equal to the current eventcount value, the awaited event has occurred and the process is removed from the blocked list and threaded into the appropriate ready list by the library function LIST_INSERT.

Once the blocked list has been checked, it is necessary to reevaluate each ready list to insure that the highest priority processes are running. It is relatively simple to determine if a virtual preempt interrupt is necessary, however, it is considerably more difficult to determine which virtual processor should receive the virtual preempt. To assist in this evaluation, a "count" variable (number of preempts needed) is zeroed and a preempt vector is created on the Kernel stack with an entry for every virtual processor associated with the logical CPU being evaluated. Initially, every entry in the preempt vector is marked "true" indicating that its associated virtual processor is a candidate for preemption. Once the preempt vector is initialized, the first "n" processes on the ready list (where n equals the number of VP's associated with the current logical CPU) are checked for a determination of their state. If

```
  TC_ADVANCE   Procedure (HANDLE, INSTANCE)

Begin

 ! Get new eventcount !
 COUNT := MM_ADVANCE (HANDLE, INSTANCE)

 Call  WAIT_LOCK (APT)

 ! Wake up processes !
 PROCESS := BLOCKED_LIST_HEAD

 Do while not end of BLOCKED_LIST
   If (PROCESS.HANDLE = HANDLE) and
      (PROCESS.INSTANCE = INSTANCE) and
      (PROCESS.COUNT <= COUNT)
    then
      Call  LIST_INSERT(READY LIST)
   end if

   PROCESS := PROCESS.NEXT_PROCESS
 end do

 ! Check all ready lists for preempts !
 LOGICAL_CPU_NO := 1

 Do while LOGICAL_CPU_NO <= #NR_CPU
   ! Initialize preempt vector !
   VP_ID := FIRST_VP(LOGICAL_CPU_NO)

   Do for LOOP := 1 to NR_VP(LOGICAL_CPU_NO
     RUNNING_LIST[VP_ID].PREEMPT := #TRUE

     VP_ID := VP_ID + 1
   end do

   ! Find preempt candidates !
   CANDIDATES := 0

   PROCESS := READY_LIST_HEAD(LOGICAL_CPU_NO)
```

Figure 46: TC_ADVANCE Algorithm

```
    VP_ID := FIRST_VP(LOGICAL_CPU_NO)

    Do (for CYCLE = 1 to NR_VP(LOGICAL_CPU_NO) and
       not end of READY_LIST(LOGICAL_CPU_NO)
      If  PROCESS = #RUNNING
       then
        RUNNING_LIST[VP_ID].PREEMPT := #FALSE
       else
        CANDIDATES := CANDIDATES + 1
      end if

      VP_ID := VP_ID + 1
      PROCESS := PROCESS.NEXT_PROCESS
    end do

    ! Preempt appropriate candidates !
    VP_ID := FIRST_VP(LOGICAL_CPU_NO)

    Do for CHECK := 1 to NR_VP(LOGICAL_CPU_NO)
      If (RUNNING_LIST[VP_ID].PREEMPT = #TRUE) and
         (CANDIDATES > 0)
       then
        Call  SET_PREEMPT(VP_ID)

        CANDIDATES := CANDIDATES - 1
      end if

      VP_ID := VP_ID + 1
    end do

    LOGICAL_CPU_NO := LOGICAL_CPU_NO + 1
  end do

  Call  UNLOCK(APT)

  Return

End TC_ADVANCE
```

Figure 46: TC_ADVANCE Algorithm (Continued)

a process is found to be "running" then it should not be preempted as processes appear in the ready list in order of priority. When a running process is found, its associated entry in the preempt vector is marked "false." If a process is encountered in the "ready" state then it should be running and the "count" variable is incremented. When the first "n" processes have been checked or when we reach the end of the current ready list (whichever comes first), the entries in the preempt vector are "popped" from the stack. If an entry from the preempt vector is found to be "true", this indicates that its associated virtual processor is a candidate for preemption since it is either bound to a lower priority process, or it is "idle." In such a case, the "count" variable is evaluated to determine if the virtual processor associated with the vector entry should be preempted. If the count exceeds zero, a virtual preempt interrupt is sent to the VP and the count is decremented. Otherwise, no preempt is sent as there is no higher priority process awaiting scheduling.

This preemption algorithm is completed for every ready list in the Active Process Table. Once all ready lists have been evaluated, the APT is unlocked and control is returned to the caller. It is noted that it is not necessary to invoke TC_GETWORK before exiting ADVANCE. If the current VP requires rescheduling, it will have received a virtual preempt interrupt from the preemption algorithm. If this has occurred, the VP will be rescheduled when its running process attempts to leave the Kernel domain and the virtual preempt interrupts are unmasked.

4. Virtual Preempt Handler

VIRTUAL_PREEMPT_HANDLER is the interrupt handler for virtual preempt interrupts. The entry address of VIRTUAL_PREEMPT_HANDLER is maintained in the virtual interrupt vector located in the Inner Traffic Controller. Once invoked, the handler locks the Active Process Table and determines which virtual processor is being preempted by calling RUNNING_VP. The process running on the preempted VP is then set to the "ready" state and TC_GETWORK is invoked to reschedule the virtual processor. When TC_GETWORK returns to VIRTUAL_PREEMPT_HANDLER, the APT is unlocked and a virtual interrupt return is executed. This return is simply a jump to the point in the hardware preempt handler where the virtual interrupts are unmasked. This effects a virtual interrupt return instruction.

5. Remaining Procedures

The remaining two procedures in the Traffic Controller module represent the extended instructions: PROCESS_CLASS and GET_DBR_NUMBER. Both procedures lock the Active Process Table and call RUNNING_VP to determine which virtual processor is executing the current process. The process ID (viz., APT entry Number) is then extracted from the running list. PROCESS_CLASS reads and returns the current process' security access classification from the APT. GET_DBR_NUMBER reads and returns the current process' DBR handle. It should be noted that in general the DBR number provided by procedure GET_DBR_NUMBER is only valid while the APT is locked. Particularly, in the current SASS implementation, the Segment Manager invokes GET_DBR_NUMBER and then passes the obtained DBR number to the Distributed Memory Manager for utilization at that level. In a more general situation, the process associated with the DBR number may have been unloaded before the DBR number was utilized, thus making it invalid. This problem does not arise in SASS as all processes remain loaded for the life of the system.

C. DISTRIBUTED MEMORY MANAGER MODULE

The Distributed Memory Manager module provides an interface between the Segment Manager and the Memory Manager process, manipulates event data in the Global Active Segment Table (G_AST), and dynamically allocates available memory. A detailed description of the Distributed Memory Manager interface to the Memory Manager process was presented by Wells [20]. The remaining extended instruction set is discussed in detail below. The complete PLZ/ASM source listings for the Distributed Memory Manager module is provided in Appendix C.

1. MM_Read_Eventcount

MM_READ_EVENTCOUNT is invoked by the Event Manager and the Traffic Controller to obtain the current value of the eventcount associated with a particular event. The input parameters to this procedure are a segment handle pointer and an instance (event Number), which together uniquely identify a particular event.

The G_AST is locked and the entry offset of the segment into the G_AST is obtained from the segment's handle. The instance parameter is then validated to determine which eventcount is to be read. If an invalid instance is specified, control is returned to the caller specifying an error condition. Otherwise, the current value of the specified eventcount is read. The G_AST is then unlocked, and the current eventcount value is returned to the caller.

2. MM_Advance

MM_ADVANCE is invoked by the Traffic Controller to reflect the occurrence of some event. The input parameters to MM_ADVANCE are a pointer to a segment's handle and a particular instance (event number).

The Global Active Segment Table is locked to prevent a race condition, and the offset of the segment's entry into the G_AST is obtained from the segment handle. The instance parameter is then validated to determine which eventcount is to be advanced. If an invalid instance is specified, an error condition is returned to the caller and no data entries are affected. If the instance value is valid, the appropriate eventcount is incremented, and its new value is returned.

3. MM_Ticket

MM_TICKET is invoked by the Event Manager to obtain the current value of the sequencer associated with a specified segment. The input parameter to MM_TICKET is a pointer to a segment's handle.

Initially, MM_TICKET locks the Global Active Segment Table to prevent a race condition. Next the offset of the segment's entry into the G_AST is obtained from the segment handle. The current value of the sequencer for the specified segment is then read and saved as a return parameter to the caller. The sequencer value is then incremented in anticipation of the next ticket request. Once this is complete, the G_AST is unlocked and control is returned to the caller.

4. MM_Allocate

The MM_ALLOCATE procedure provided in this implementation is a stub of the MM_ALLOCATE described in the Memory Manager design of Moore and Gary [5]. The primary function of MM_ALLOCATE is the dynamic allocation of fixed size blocks of available memory space. It is invoked in the current implementation by the initialization routines in BOOTSTRAP_LOADER and TC_INIT for the allocation of memory space used in the creation of the Kernel domain and Supervisor domain stack segments and the creation of the Known Segment Tables for user processes. Dynamic reallocation of previously used memory space (viz., garbage collection) is not provided by the MM_ALLOCATE stub in this implementation. All memory allocation required in this implementation is for segments supporting system processes that remain active, and thus allocated, for the entire life of the system. Memory is allocated in blocks of 256 (decimal) bytes of processor local memory (on-board RAM). In this stub allocatable memory is declared at compile time by a data structure (MEM_POOL) that is accessible only by MM_ALLOCATE.

The input parameter to MM_ALLOCATE is the number of blocks of requested memory. This parameter is converted from a block size to the actual number of bytes requested. This computation is made simple since memory is allocated in powers of two. The byte size is obtained by logically shifting left the input parameter eight times, where eight is the power of two desired (viz., 256). Once the size of the requested memory is computed, it is necessary to determine the starting address of the memory block(s) to be allocated. To assist in this computation, a variable (NEXT_BLOCK) is used to keep track of the next available block of memory in MEM_POOL. NEXT_BLOCK, which is initialized as zero, provides the offset into the memory being allocated. Once the starting address is obtained, the physical size of the memory allocated is added to NEXT_BLOCK so that the next request for memory allocation will begin at the next free byte of memory in MEM_POOL. This new value of NEXT_BLOCK is saved and the starting address of the memory for this request is returned to the caller.

D. GATE KEEPER MODULES

The SASS Gate Keeper provides the logical boundary between the Supervisor and the Kernel and isolates the Kernel from the system users, thus making it tamperproof. This is accomplished by means of the hardware system/normal mode and the software ring-crossing mechanism provided by the Gate Keeper. The Gate Keeper is comprised of two separate modules: 1) the USER_GATE module, and 2) the KERNEL_GATE_KEEPER module. These modules are disjoint, with the USER_GATE module residing in the Supervisor domain and the KERNEL_GATE_KEEPER module residing in the Kernel domain. It is important to note that the USER_GATE is a separately linked component in the Supervisor domain and is not linked to the Kernel. The only thing in common between these two modules is a set of constants identifying the valid extended instruction set which the Kernel provides to the users.

The Gate Keeper modules presented in this implementation are only stubs as they do not provide all of the functions required of the Gate Keeper. However, the only task not provided in this implementation is the validation of parameters passed from the Supervisor to the Kernel. A detailed description of this parameter validation design is provided by Coleman [2]. In the process management demonstration, the Supervisor stubs are written in PLZ/ASM with all parameters passed by CPU registers. A detailed description of the Gate Keeper modules and the nature of their interfaces is presented below. The PLZ/ASM source listings for the two Gate Keeper modules are provided in Appendix D.

1. User_Gate Module

The USER_GATE module provides the interface structure between the user processes in the Supervisor domain and the Kernel. The USER_GATE is comprised of ten procedures (viz., entry points) that correlate on a one to one basis with the ten "user visible" extended instructions (listed in Figure 10) provided by the Kernel. The only action performed by each of these procedures is the execution of the "system call" instruction (SC) with a constant value, identifying the particular extended instruction invoked, as the source operand.

The SC instruction is a system trap that forces the hardware into the system mode (Kernel domain) and loads register 15 with the system stack pointer (Kernel domain stack). The current instruction counter value (IC) is pushed onto the Kernel stack along with the current CPU flag control word (FCW). In addition, the system trap instruction is pushed onto the Kernel stack with the upper byte representing the SC instruction and the lower byte representing the SC instruction's source operand (viz., the Kernel extended instruction code). Together, these operations form an interrupt return (IRET) frame as illustrated in Figure 44. Once this is complete, the FCW is loaded with the FCW value found in the System Call frame of the Program Status Area (viz., the hardware "interrupt vector"). The structure of the Program Status Area is illustrated in Figure 47. The instruction counter is then loaded with the address of the SC instruction trap handler. This value is also located in the SC frame of the Program Status Area.

```
OFFSET

 0   |--------------------| --|
     |      Reserved      |   |--Frames
 4   |--------------------| --|
     |   Unimplemented    |
     |    Instruction     |
     |        Trap        |
 8   |--------------------|
     |     Privileged     |
     |    Instruction     |
     |        Trap        |
12   |--------------------| --|
     |     Kernel FCW     |   |System
     |--------------------|   |--Call
     | Kernel Gate Keeper |   |Instruction
     |      Address       |   |
16   |--------------------| --|
     |      Segment       |
     |        Trap        |
20   |--------------------|
     |    Non-Maskable    |
     |     Interrupt      |
24   |--------------------| --|Hardware
     |     Kernel FCW     |   |Preempt
     |--------------------|   |--
     |PHYS_PREEMPT_HANDLER|   |(Non-
     |      Address       |   | Vectored
28   |--------------------| --| Interrupt)
     |    Vectored Int    |
32   |--------------------|
     |         .          |
     |         .          |
     |         .          |
     |--------------------|
```

* NOTE: Offsets represent Program Status Area structure for non-segmented Z8002 microprocessor.

Figure 47: Program Status Area

2. Kernel Gate Keeper Module

The system trap handler for the System Call instruction is the KERNEL_GATE_KEEPER. The address of the KERNEL_GATE_KEEPER and the Kernel FCW value are placed in the System Call frame of the Program Status Area by the BOOTSTRAP_LOADER module during initialization. The KERNEL_GATE_KEEPER fetches the extended instruction code from the trap instruction entry in the IRET frame on the Kernel stack. This value is then decoded by a "case" statement to determine which extended instruction is to be executed. If the extended instruction code is valid, the appropriate Kernel procedure is invoked. Otherwise, an error condition is set and no Kernel procedures are not invoked. Once control returns to the KERNEL_GATE_KEEPER, the CPU registers and normal stack pointer (NSP) value are pushed onto the Kernel stack in preparation for return to the Supervisor domain. It is noted that this operation would normally occur immediately upon entry into the KERNEL_GATE_KEEPER. In this implementation, however, parameter validation is not accomplished and the CPU registers are used to pass parameters to and from the Kernel only for use by the process management demonstration. In an actual SASS environment, all parameters would be passed in a separate argument list and the CPU registers would appear exactly the same upon leaving the Kernel as they did upon entering the Kernel. This is important to insure that no data or information is leaked from the Kernel by means of the CPU registers.

Control is returned to the Supervisor by means of the return mechanism in the hardware preempt handler. This mechanism is utilized to preclude the necessity of building a separate mechanism for the KERNEL_GATE_KEEPER that would actually perform the very same function. To accomplish this, the KERNEL_GATE_KEEPER executes an unconditional jump to the PREEMPT_RET label in PHYS_PREEMPT_HANDLER. This "jump" to the hardware preempt handler represents a "virtual IRET" instruction providing the same function as the virtual interrupt return described in the discussion of the virtual preempt handler. At this point, the virtual preempt interrupts are unmasked, the normal stack pointer and CPU registers are restored from the stack, and control is returned to the Supervisor by execution of the IRET instruction.

E. SUMMARY

The implementation of process management functions for the SASS has been presented in this chapter. The implementation was discussed in terms of the Event Manager, Traffic Controller, Distributed Memory Manager, and Gate Keeper modules.

Chapter XXIII

CONCLUSION

The implementation of process management for the security Kernel of a secure archival storage system has been presented. The process management functions presented provide a logical and efficient means of process creation, control, and scheduling. In addition, a simple but effective mechanism for inter-process communication, based on the eventcount and sequencer primitives, was created. Work was also completed in the area of Kernel database initialization and a Gate Keeper stub to allow for dual domain operation.

The design for this implementation was based on the Zilog Z8001 sixteen bit segmented microprocessor [22] used in conjunction with the Zilog Z8010 Memory Management Unit [23]. The actual implementation of process management for the SASS was conducted on the Advanced Micro Computers Am96/4116 MonoBoard Computer [1] featuring the AmZ8002 sixteen bit non-segmented microprocessor. Segmentation hardware was simulated by a software Memory Management Unit Image.

This implementation was effected specifically to support the Secure Archival Storage System (SASS) [17]. However, the implementation is based on a family of Operating Systems

[7] designed with a primary goal of providing multilevel information security. The loop free modular design utilized in this implementation easily facilitates any required expansion or modification for other family members. In addition, this implementation fully supports a multiprocessor design. While the process management implementation appears to perform correctly, it has not been subjected to a formal test plan. Such a test plan should be developed and implemented before kernel verification is begun.

A. FOLLOW ON WORK

There are several possible areas in the SASS design that would be immediately suitable for continued research. In the area of hardware, this includes, the establishment of a multiprocessor environment, hardware initialization, and interfacing to the host computers and secondary storage. Further work in the Kernel includes the actual implementation of the memory manager process, and the refinement of the Gate Keeper and Kernel intialization structures. The implementation of the Supervisor has not been addressed to date. Its areas of research include the implementation of the File Manager and Input/Output processes, and the final design and implementation of the SASS-Hosts protocols.

Other areas that could also prove interesting in relation to the SASS include the implementation of dynamic memory management, the support of multilevel hosts, dynamic pro-

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THE NAVAL POSTGRADUATE SCHOOL SECURE ARCHIVAL STORAGE SYSTEM. P--ETC(U)
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UNCLASSIFIED NPS52-81-001 NL

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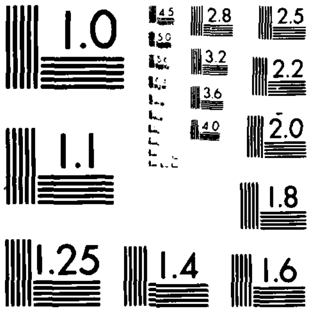

MICROCOPY RESOLUTION TEST CHART
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cess creation and deletion, and the provision of constructive work to be performed by the Idle process.

Appendix A

EVENT MANAGER LISTINGS

```
Z8000ASM  2.02
LOC    OBJ CODE    STMT SOURCE STATEMENT

        $LISTON $TTY

        EVENT_MGR       MODULE

        CONSTANT
          TRUE                      := 1
          FALSE                     := 0
          READ_ACCESS               := 1
          WRITE_ACCESS              := 0
          SUCCEEDED                 := 2
          SEGMENT_NOT_KNOWN         := 28
          ACCESS_CLASS_NOT_EQ       := 33
          ACCESS_CLASS_NOT_GE       := 41
          KST_SEG_NO                := 2
          NR_OF_KSEGS               := 10
          MAX_NO_KST_ENTRIES        := 54
          NOT_KNOWN                 := %FF

        TYPE
          H_ARRAY       ARRAY[3 WORD]

          KST_REC    RECORD
           [MM_HANDLE   H_ARRAY
            SIZE        WORD
            ACCESS_MODE BYTE
            IN_CORE     BYTE
            CLASS       LONG
            M_SEG_NO    SHORT_INTEGER
            ENTRY_NUMBER SHORT_INTEGER]

        EXTERNAL
          MM_TICKET                 PROCEDURE
          MM_READ_EVENTCOUNT        PROCEDURE
          TC_ADVANCE                PROCEDURE
          TC_AWAIT                  PROCEDURE
          PROCESS_CLASS             PROCEDURE
          CLASS_EQ                  PROCEDURE
          CLASS_GE                  PROCEDURE
          ITC_GET_SEG_PTR           PROCEDURE
          INTERNAL

          $SECTION EM_KST_DCL
          ! NOTE: THIS SECTION IS AN "OVERLAY"
            OR "FRAME" USED TO DEFINE THE
            FORMAT OF THE KST.  NO STORAGE IS
            ASSIGNED BUT RATHER THE KST IS
            STORED IN A SEPARATELY OBTAINED
            AREA. (A SEGMENT SET ASIDE FOR IT)!

            $ABS 0
0000        KST   ARRAY[MAX_NO_KST_ENTRIES KST_REC]
```

```
          GLOBAL
          $SECTION EM_GLB_PROC

0000        READ                  PROCEDURE
           !*******************************
            * READS SPECIFIED EVENTCOUNT *
            * AND RETURNS IT'S VALUE TO  *
            * THE CALLER                 *
            ******************************
            * PARAMETERS:                *
            *  R1: SEGMENT #             *
            *  R2: INSTANCE              *
            ******************************
            * RETURNS:                   *
            *  R0: SUCCESS CODE          *
            *  RR4: EVENTCOUNT           *
            *******************************!

            ENTRY
             ! SAVE INSTANCE !
0000 93F2    PUSH   @R15, R2

             ! "READ" ACCESS REQUIRED !
0002 2102    LD      R2, #READ_ACCESS
0004 0001
             ! GET SEG HANDLE & VERIFY ACCESS !
0006 5F00    CALL   CONVERT_AND_VERIFY !R1:SEG #
0008 0000'
                                         R2:REQ. ACCESS
                                         RETURNS:
                                         R0:SUCCESS CODE
                                         R1:HANDLE PTR!
000A 0B00    CP      R0, #SUCCEEDED
000C 0002
             IF EQ !ACCESS PERMITTED!
000E 5E0E     THEN  !READ EVENTCOUNT!
0010 001C'
               !RESTORE INSTANCE!
0012 97F2      POP  R2, @R15
0014 5F00      CALL MM_READ_EVENTCOUNT !R1:HPTR
0016 0000*
                                         R2:INSTANCE
                                         RETURNS:
                                         R0:SUCCESS CODE
                                         RR4:EVENTCOUNT!
0018 5E08     ELSE  !RESTORE SP!
001A 001E'
001C 97F2      POP  R2, @R15
             FI
001E 9E08    RET
0020        END READ
```

```
0020        TICKET                 PROCEDURE
           !********************************
            * RETURNS CURRENT VALUE OF     *
            * TICKET TO CALLER AND INCRE-  *
            * MENTS SEQUENCER FOR NEXT     *
            * TICKET OPERATION             *
            ********************************
            * PARAMETERS:                  *
            *  R1: SEGMENT #               *
            ********************************
            * RETURNS:                     *
            *  R0: SUCCESS CODE            *
            *  RR4: TICKET VALUE           *
            ********************************!

            ENTRY
             ! GET SEG HANDLE & VERIFY ACCESS !
             ! "WRITE" ACCESS REQUIRED !
0020 2102    LD    R2, #WRITE_ACCESS
0022 0000
0024 5F00    CALL  CONVERT_AND_VERIFY !R1:SEG #
0026 0000'
                                        R2:ACCESS REQ
                                        RETURNS:
                                        R0:SUCCESS CODE
                                        R1:HANDLE PTR!
0028 0B00    CP    R0, #SUCCEEDED
002A 0002
             IF EQ !ACCESS PERMITTED!
002C 5E0E     THEN  ! GET TICKET !
002E 0038'
0030 5F00      CALL  MM_TICKET !R1:HANDLE PTR
0032 0000*
                                 RETURNS:
                                 RR4:TICKET!
               ! RSTORE SUCCESS CODE !
0034 2100      LD    R0, #SUCCEEDED
0036 0002
             FI
0038 9E08    RET
003A        END TICKET
```

```
003A        AWAIT                      PROCEDURE
           !*******************************
            * CURRENT EVENTCOUNT VALUE IS *
            * COMPARED TO USER SPECIFIED  *
            * VALUE. IF USER VALUE IS     *
            * GREATER THAN CURRENT EVENT- *
            * COUNT VALUE THEN PROCESS IS *
            * "BLOCKED" UNTIL THE DESIRED *
            * EVENT OCCURS.               *
            *******************************
            * PARAMETERS:                 *
            *  R1: SEGMENT #              *
            *  R2: INSTANCE (EVENT #)     *
            *  RR4: SPECIFIED VALUE       *
            *******************************
            * RETURNS:                    *
            *  R0: SUCCESS CODE           *
            *******************************!

            ENTRY
             ! SAVE DESIRED EVENTCOUNT VALUE !
003A 91F4    PUSHL  @R15, RR4
             ! SAVE INSTANCE !
003C 93F2    PUSH   @R15, R2
             ! "READ" ACCESS REQUIRED !
003E 2102    LD     R2, #READ_ACCESS
0040 0001
             ! GET SEG HANDLE & VERIFY ACCESS !
0042 5F00    CALL   CONVERT_AND_VERIFY !R1:SEG #
0044 0000'
                                         R2:ACCESS REQ
                                         RETURNS:
                                         R0:SUCCESS CODE
                                         R1:HANDLE PTR!
0046 0B00    CP     R0, #SUCCEEDED
0048 0002
             IF EQ ! ACCESS PERMITTED !
004A 5E0E     THEN ! AWAIT EVENT OCCURRENCE !
004C 005A'
               ! RESTORE INSTANCE !
004E 97F2      POP  R2, @R15
               ! RESTORE SPECIFIED VALUE !
0050 95F4      POPL RR4, @R15
0052 5F00      CALL TC_AWAIT !R1:HANDLE PTR
0054 0000*
                               R2:INSTANCE
                               RR4:VALUE
                               RETURNS:
                               R0:SUCCESS CODE!
```

```
0056 5E08        ELSE !RESTORE STACK!
0058 005E'
005A 95F4          POPL  RR4, @R15
005C 97F2          POP   R2, @R15
                 FI
005E 9E08        RET
0060            END AWAIT
```

```
0060        ADVANCE                 PROCEDURE
           !********************************
            * SIGNALS THE OCCURRENCE OF    *
            * SOME EVENT.  EVENTCOUNT IS   *
            * INCREMENTED AND THE TRAFFIC  *
            * CONTROLLER IS INVOKED TO     *
            * AWAKEN ANY PROCESS AWAITING  *
            * THE OCCURRENCE.              *
            ********************************
            * PARAMETERS:                  *
            *  R1: SEGMENT #               *
            *  R2: INSTANCE (EVENT #)      *
            ********************************
            * RETURNS:                     *
            *  R0: SUCCESS CODE            *
            ********************************!

            ENTRY
             ! SAVE INSTANCE !
0060 93F2    PUSH  @R15, R2

             ! GET SEG HANDLE & VERIFY ACCESS !
             ! "WRITE" ACCESS REQUIRED !
0062 2102    LD    R2, #WRITE_ACCESS
0064 0000
0066 5F00    CALL  CONVERT_AND_VERIFY !R1:SEG #
0068 0000'
                                        R2:ACCESS REQ
                                        RETURNS:
                                        R0:SUCCESS CODE
                                        R1:HANDLE PTR!
006A 0B00    CP    R0, #SUCCEEDED
006C 0002
             IF EQ ! ACCESS PERMITTED !
006E 5E0E     THEN ! ADVANCED EVENTCOUNT !
0070 007C'
               ! RESTORE INSTANCE !
0072 97F2      POP   R2, @R15

0074 5F00      CALL  TC_ADVANCE !R1:HANDLE PTR
0076 0000*
                                  R2:INSTANCE
                                  RETURNS:
                                  R0:SUCCESS CODE!
0078 5E08     ELSE !RESTORE STACK!
007A 007E'
007C 97F2      POP   R2, @R15
             FI
007E 9E08    RET
0080        END ADVANCE
```

```
          INTERNAL
          $SECTION EM_INT_PROC

0000        CONVERT_AND_VERIFY          PROCEDURE
           !****************************************
            * CONVERTS SEGMENT NUMBER TO KST INDEX*
            * AND EXTRACTS SEGMENT'S HANDLE FROM  *
            * KST. IF SUCCESSFUL, THEN ACCESS     *
            * CLASS OF SUBJECT IS CHECKED AGAINST *
            * ACCESS CLASS OF OBJECT TO INSURE    *
            * THAT ACCESS IS PERMITTED.           *
            ***************************************
            * PARAMETERS:                         *
            *  R1: SEGMENT NUMBER                 *
            *  R2: ACCESS REQUESTED               *
            ***************************************
            * RETURNS:                            *
            *  R0: SUCCESS CODE                   *
            *  R1: HANDLE POINTER                 *
            ***************************************!

            ENTRY
             ! SAVE REQUESTED ACCESS !
0000 93F2    PUSH  @R15, R2
             ! GET SEGMENT HANDLE !
0002 5F00    CALL  GET_HANDLE !R1:SEG #
0004 0062'
                               RETURNS:
                               R0:SUCCESS CODE
                               R4:HANDLE PTR
                               R5:CLASS PTR!
0006 0B00    CP    R0, #SUCCEEDED
0008 0002
             IF EQ  ! SEGMENT IS KNOWN !
000A 5E0E     THEN  ! VERIFY ACCESS !
000C 005E'
               ! SAVE HANDLE & CLASS PTR !
000E 91F4      PUSHL @R15, RR4
               ! GET SUBJECT'S SAC !
0010 5F00      CALL  PROCESS_CLASS !RETURNS:
0012 0000*
                                    RR2:PROC CLASS!
               ! RETRIEVE SEG CLASS POINTER !
0014 95F0      POPL  RR0, @R15
               ! GET SEGMENT'S CLASS !
0016 1414      LDL   RR4, @R1
               ! RETRIEVE REQUESTED ACCESS !
0018 97F1      POP   R1, @R15
               ! SAVE HANDLE POINTER !
001A 93F0      PUSH  @R15, R0
               ! CHECK ACCESS CLEARANCE !
001C 0B01      CP    R1, #WRITE_ACCESS
001E 0000
               IF EQ ! WRITE ACCESS REQUESTED !
```

```
0020 5E0E       THEN
0022 0040'
0024 5F00        CALL  CLASS_EQ !RR2:PROCESS CLASS
0026 0000*
                                 RR4:SEGMENT CLASS
                                 RETURNS:
                                 R1: CONDITION CODE!
0028 0B01        CP    R1, #FALSE
002A 0000
                 IF EQ !ACCESS NOT PERMITTED!
002C 5E0E         THEN
002E 0038'
0030 2100          LD  R0, #ACCESS_CLASS_NOT_EQ
0032 0021
0034 5E08         ELSE !ACCESS PERMITTED!
0036 003C'
0038 2100          LD  R0, #SUCCEEDED
003A 0002
                 FI
003C 5E08       ELSE ! READ ACCESS REQUESTED !
003E 0058'
0040 5F00        CALL  CLASS_GE !RR2:PROCESS CLASS
0042 0000*
                                 RR4:SEGMENT CLASS
                                 RETURNS:
                                 R1:CONDITION CODE!
0044 0B01        CP    R1, #FALSE
0046 0000
                 IF EQ !ACCESS NOT PERMITTED!
0048 5E0E         THEN
004A 0054'
004C 2100          LD  R0, #ACCESS_CLASS_NOT_GE
004E 0029
0050 5E08         ELSE !ACCESS PERMITTED!
0052 0058'
0054 2100          LD  R0, #SUCCEEDED
0056 0002
                 FI
               FI
               ! RETRIEVE HANDLE POINTER !
0058 97F1      POP   R1, @R15
005A 5E08    ELSE
005C 0060'
               ! RESTORE STACK !
005E 97F2      POP   R2, @R15
             FI
0060 9E08    RET
0062        END CONVERT_AND_VERIFY
```

```
0062        GET_HANDLE            PROCEDURE
           !*******************************
            * CONVERTS SEGMENT NUMBER TO  *
            * KST INDEX AND DETERMINES IF *
            * SEGMENT IS KNOWN.  IF KNOWN *
            * POINTER TO SEGMENT HANDLE   *
            * AND POINTER TO SEGMENT CLASS*
            * ARE RETURNED.               *
            *******************************
            * PARAMETERS:                 *
            *  R1: SEGMENT NUMBER         *
            *******************************
            * RETURNS:                    *
            *  R0: SUCCESS CODE           *
            *  R4: HANDLE POINTER         *
            *  R5: CLASS POINTER          *
            *******************************!

            ENTRY
             ! CONVERT SEGMENT # TO KST INDEX # !
0062 0301    SUB   R1, #NR_OF_KSEGS
0064 000A
             ! VERIFY KST INDEX !
0066 2100    LD    R0, #SUCCEEDED
0068 0002
006A 0B01    CP    R1, #0
006C 0000
             IF LE !INDEX NEGATIVE!
006E 5E0A     THEN
0070 007A'
0072 2100      LD    R0, #SEGMENT_NOT_KNOWN
0074 001C
0076 5E08     ELSE !INDEX POSITIVE!
0078 0086'
007A 0B01      CP    R1, #MAX_NO_KST_ENTRIES
007C 0036
               IF  GT !EXCEEDS MAXIMUM INDEX!
007E 5E02       THEN  !INVALID INDEX!
0080 0086'
0082 2100        LD    R0, #SEGMENT_NOT_KNOWN
0084 001C
               FI
             FI
0086 0B00    CP    R0, #SUCCEEDED
0088 0002
             IF EQ  !INDEX VALID!
008A 5E0E     THEN
008C 00BE'
               ! SAVE KST INDEX !
008E 93F1      PUSH  @R15, R1
               ! GET KST ADDRESS !
0090 2101      LD    R1, #KST_SEG_NO
0092 0002
0094 5F00      CALL  ITC_GET_SEG_PTR !R1:KST_SEG_NO
```

```
0096 0000*
                                      RETURNS:
                                      R0:KST ADDR!
               ! RETRIEVE KST INDEX # !
0098 97F3      POP   R3, @R15

               ! CONVERT KST INDEX # TO KST OFFSET !
009A 1902      MULT  RR2, #SIZEOF KST_REC
009C 0010
               ! COMPUTE KST ENTRY ADDRESS !
009E 8103      ADD   R3, R0
               ! SEE IF SEGMENT IS KNOWN !
00A0 4D31      CP    KST.M_SEG_NO(R3), #NOT_KNOWN
00A2 000E
00A4 00FF
               IF EQ !SEGMENT NOT KNOWN!
00A6 5E0E       THEN
00A8 00B2'
00AA 2100        LD  R0, #SEGMENT_NOT_KNOWN
00AC 001C
00AE 5E08       ELSE !SEGMENT KNOWN!
00B0 00BE'
00B2 2100        LD  R0, #SUCCEEDED
00B4 0002
                 ! GET HANDLE POINTER !
00B6 7634        LDA   R4, KST.MM_HANDLE(R3)
00B8 0000
                 ! GET CLASS POINTER !
00BA 7635        LDA   R5, KST.CLASS(R3)
00BC 000A
               FI
             FI
00BE 9E08    RET
00C0        END GET_HANDLE
           END EVENT_MGR
```

Appendix B

TRAFFIC CONTROLLER LISTINGS

```
Z8000ASM  2.02
LOC    OBJ CODE    STMT SOURCE STATEMENT

        $LISTON $TTY
        TC MODULE

         CONSTANT

         ! ******** SYSTEM PARAMETERS ******** !
                NR_PROC          := 4
                VP_NR            := 2
                NR_CPU           := 2
                NR_KST           := 54

          ! ******** SYSTEM CONSTANTS ******** !
               RUNNING      := 0
               READY        := 1
               BLOCKED      := 2
               IDLE_PROC    := %DDDD
               NIL          := %FFFF
               INVALID      := %EEEE
               KERNEL_STACK := 1
               USER_STACK   := 3
               KST_SEG      := 2
               KST_LIMIT    := 1
               USER_FCW     := %1800
               WRITE        := 0
               !INDICATES LOWEST SYSTEM
                SECURITY CLASS!
               SYSTEM_LOW   := 0
               STK_OFFSET   := %FF
               REMOVED      := %ABCD
               TRUE         := 1
               FALSE        := 0
               SUCCEEDED    := 2

         TYPE
          AP_PTR      WORD
          VP_PTR      WORD
          ADDRESS     WORD
          H_ARRAY     ARRAY[3  WORD]
```

```
 AP_TABLE RECORD
      [NEXT_AP              AP_PTR
       DBR                  WORD
       SAC                  LONG
       PRI                  INTEGER
       STATE                INTEGER
       AFFINITY             WORD
       VP_ID                VP_PTR
       HANDLE               H_ARRAY
       INSTANCE             WORD
       VALUE                LONG
       FILL_2               ARRAY[2 WORD]
      ]

 RUN_ARRAY     ARRAY[VP_NR  AP_PTR]
 RDY_ARRAY     ARRAY[NR_CPU AP_PTR]
 AP_DATA       ARRAY[NR_PROC AP_TABLE]
 VP_DATA       RECORD
   [NR_VP      ARRAY[NR_CPU WORD]
    FIRST      ARRAY[NR_CPU VP_PTR]
   ]

 KST_REC       RECORD
  [MM_HANDLE   H_ARRAY
   SIZE        WORD
   ACCESS      BYTE
   IN_CORE     BYTE
   CLASS       LONG
   M_SEG_NO    SHORT_INTEGER
   ENTRY_NUM   SHORT_INTEGER
  ]

EXTERNAL
   K_LOCK                   PROCEDURE
   K_UNLOCK                 PROCEDURE
   SET_PREEMPT              PROCEDURE
   SWAP_VDBR                PROCEDURE
   IDLE                     PROCEDURE
   RUNNING_VP               PROCEDURE
   CREATE_INT_VEC           PROCEDURE
   LIST_INSERT              PROCEDURE
   ALLOCATE_MMU             PROCEDURE
   MM_ALLOCATE              PROCEDURE
   UPDATE_MMU_IMAGE         PROCEDURE
   CREATE_STACK             PROCEDURE
   MM_ADVANCE               PROCEDURE
   MM_READ_EVENTCOUNT       PROCEDURE
   G_AST_LOCK               WORD
   PREEMPT_RET              LABEL
```

```
         $SECTION TC_DATA
         INTERNAL
0000      APT        RECORD
            [ LOCK             WORD
              RUNNING_LIST     RUN_ARRAY
              READY_LIST       RDY_ARRAY
              BLOCKED_LIST     AP_PTR
              FILL_3           LONG
              VP               VP_DATA
              FILL             ARRAY[4 WORD]
              AP               AP_DATA
            ]

         !THESE VARIABLES ARE USED DURING TC
          INITIALIZATION TO SPECIFY AVAILABLE
          ENTRIES IN THE APT, AND ARE INITIAL-
          IZED BY TC_INIT IN THIS IMPLEMENTATION!
00A0     NEXT_VP    WORD
00A2     APT_ENTRY  WORD

        $SECTION  TC_LOCAL
        $ABS 0
        !NOTE: USED AS OVERLAY ONLY!
0000     ARG_LIST      RECORD
           [REG          ARRAY[13 WORD]
            IC           WORD
            CPU_ID       WORD
            SAC1         LONG
            PRI1         WORD
            USR_STK      WORD
            KER_STK      WORD
            KST1         LONG
           ]

        $ABS 0
        !NOTE: USED AS STACK FRAME FOR
         STORAGE OF TEMPORARY VARIABLES
         FOR CREATE_PROCESS.!
0000     CREATE     RECORD
           [ARG_PTR   WORD
            DBR_NUM   WORD
            LIMITS    WORD
            SEG_ADDR  ADDRESS
            N_S_P     WORD
           ]

        $ABS 0
0000     HANDLE_VAL    RECORD
             [HIGH   LONG
              LOW   WORD
             ]

        !THE FOLLOWING DECLARATION IS UTILIZED
         AS A STACK FRAME FOR STORAGE OF
         TEMPORARY VARIABLES UTILIZED BY
         TC_ADVANCE AND TC_AWAIT.!
        $ABS 0
0000     TEMP     RECORD
           [HANDLE_PTR    WORD
            EVENT_NR      WORD
            EVENT_VAL     LONG
            ID_VP         WORD
            CPU_NUM       WORD
            HANDLE_HIGH   LONG
            HANDLE_LOW    WORD
           ]

        $SECTION TC_KST_DCL
         !NOTE: KST DECLARATION IS USED HERE
          TO SUPPORT KST INITIALIZATION FOR
          THIS DEMONSTRATION ONLY.  THIS
          DECLARATION AND INITIALIZATION
          SHOULD EXIST AT THE SEGMENT MANAGER
          LEVEL AND THUS SHOULD BE REMOVED
          UPON IMPLEMENTATION OF SYSTEM
          INITIALIZATION.!
            $ABS 0
0000         KST  ARRAY[NR_KST KST_REC]
```

```
          $SECTION TC_INT_PROC
0000        TC_GETWORK          PROCEDURE
           !******************************
            * PROVIDES GENERAL MANAGE-   *
            * MENT OF USER PROCESSES BY  *
            * EFFECTING PROCESS SCHEDU-  *
            * LING ON VIRTUAL PROCESSORS*
            ******************************
            * PARAMETERS:                *
            *  R1: CURRENT VP ID         *
            *  R3: LOGICAL CPU #         *
            ******************************
            * LOCAL VARIABLES:           *
            *  R2: NEXT READY PROCESS    *
            *  R4: AP PTR                *
            ******************************!

            ENTRY
             ! FIND FIRST READY PROCESS !
0000 6132    LD    R2, APT.READY_LIST(R3)
0002 0006'
             GET_READY_AP:
             DO  !WHILE NOT (END OF LIST OR READY)!
0004 0B02     CP   R2, #NIL
0006 FFFF
0008 5E0E     IF EQ !NO READY PROCESS! THEN
000A 0010'
000C 5E08      EXIT FROM GET_READY_AP
000E 0026'
              FI
0010 4D21     CP   APT.AP.STATE(R2), #READY
0012 002A'
0014 0001
0016 5E0E     IF EQ !PROCESS READY! THEN
0018 001E'
001A 5E08      EXIT FROM GET_READY_AP
001C 0026'
              FI
              ! GET NEXT AP FROM LIST !
001E 6124     LD   R4, APT.AP.NEXT_AP(R2)
0020 0020'
0022 A142     LD   R2, R4
0024 E8EF    OD
0026 0B02    CP   R2,#NIL
0028 FFFF
002A 5E0E    IF EQ ! IF NO PROCESSES READY ! THEN
002C 003C'
              ! LOAD IDLE PROCESS !
002E 4D15     LD   APT.RUNNING_LIST(R1), #IDLE_PROC
0030 0002'
0032 DDDD
0034 5F00     CALL IDLE
0036 0000*
0038 5E08    ELSE
```

```
003A 0052'
               ! LOAD FIRST READY AP !
003C 6F12      LD   APT.RUNNING_LIST(R1), R2
003E 0002'
0040 4D25      LD   APT.AP.STATE(R2), #RUNNING
0042 002A'
0044 0000
0046 6F21      LD   APT.AP.VP_ID(R2), R1
0048 002E'
004A 6121      LD   R1, APT.AP.DBR(R2)
004C 0022'
004E 5F00      CALL SWAP_VDBR  !(R1:DBR)!
0050 0000*
              FI
0052 9E08     RET
0054        END TC_GETWORK
```

```
0054      VIRTUAL_PREEMPT_HANDLER    PROCEDURE
            !***************************
             * LOADS FIRST READY AP    *
             * IN RESPONSE TO PREEMPT  *
             * INTERRUPT               *
             ***************************!

             ENTRY
              !** CALL WAIT_LOCK (APT¬.LOCK) **!
              !** RETURNS WHEN PROCESS HAS LOCKED APT **!
0054 7604     LDA   R4, APT.LOCK
0056 0000'
0058 5F00     CALL  K_LOCK
005A 0000*
              ! GET RUNNING_VP ID !
005C 5F00     CALL  RUNNING_VP  !RETURNS:
005E 0000*
                                   R1:VP_ID
                                   R3:CPU #!

              ! GET AP !
0060 6112     LD      R2, APT.RUNNING_LIST(R1)
0062 0002'

              ! IF NOT AN IDLE PROCESS, SET IT TO READY !
0064 0B02     CP      R2, #IDLE_PROC
0066 DDDD
0068 5E06     IF NE ! NOT IDLE !  THEN
006A 0072'
006C 4D25      LD     APT.AP.STATE(R2), #READY
006E 002A'
0070 0001
              FI

              ! LOAD FIRST READY PROCESS !
0072 5F00     CALL TC_GETWORK  !R1:VP_ID
0074 0000'
                                  R3:CPU #!

             !NOTE: THIS IS THE INITIAL POINT OF
              EXECUTION FOR USER PROCESSES.!
             VIRT_PREEMPT_RETURN:
              !** CALL UNLOCK (APT¬.LOCK) **!
              !** RETURNS WHEN PROCESS HAS UNLOCKED APT **!
              !** AND ADVANCED ON THIS EVENT **!
0076 7604     LDA   R4, APT.LOCK
0078 0000'
007A 5F00     CALL  K_UNLOCK
007C 0000*
              ! PERFORM A VIRTUAL INTERRUPT RETURN !
              !NOTE: THIS JUMP EFFECTS A VIRTUAL
               IRET INSTRUCTION.!
007E 5E08     JP   PREEMPT_RET
0080 0000*
```

```
END VIRTUAL_PREEMPT_HANDLER
```

```
            GLOBAL
            $SECTION TC_GLB_PROC
0000            TC_INIT               PROCEDURE
               !*****************************
                * INITIALIZES APT HEADER    *
                * AND VIRTUAL INT VECTOR    *
                *****************************
                * PARAMETERS:               *
                *  R1: CPU_ID               *
                *  R2: NR_VP                *
                *****************************!

                ENTRY
                 ! NOTE: THE NEXT FOUR VALUES ARE
                   ONLY TO BE INITIALIZED ONCE. !
0000 4D05        LD   EXIT_VP, #0
0002 00A0'
0004 0000
0006 4D05        LD   APT_ENTRY, #0
0008 00A2'
000A 0000
000C 4D05        LD   APT.BLOCKED_LIST, #NIL
000E 000A'
0010 FFFF
0012 4D08        CLR  APT.LOCK
0014 0000'
                 !****************************************
                  NOTE: THE FOLLOWING CODE IS INCLUDED
                  ONLY FOR SIMULATION OF A MULTIPROCESSOR
                  ENVIRONMENT.  THIS IS TO INSURE THAT THE
                  READY LIST(S) AND VP DATA OF THE SIMULATED
                  CPU(S) ARE PROPERLY INITIALIZED.  IN AN
                  ACTUAL MULTIPROCESSOR ENVIRONMENT, THIS
                  BLOCK OF CODE SHOULD BE REMOVED.
                  ****************************************!
0016 2104              LD    R4, #0
0018 0000
                       DO
001A 0B04               CP    R4, #NR_CPU*2
001C 0004
                        IF EQ !ALL LISTS INITIALIZED!
001E 5E0E                THEN EXIT
0020 0026'
0022 5E08
0024 0036'
                        FI
                        ! INITIALIZE READY_LISTS AS EMPTY !
0026 4D45               LD    APT.READY_LIST(R4), #NIL
0028 0006'
002A FFFF
                        ! INITIALLY MARK ALL LOGICAL CPU'S
                          AS HAVING 1 VP.  THIS IS NECESSARY
                          TO INSURE TC_ADVANCE WILL FUNCTION
                          PROPERLY, AS IT EXPECTS EVERY CPU
```

```
                      TO HAVE AT LEAST 1 VP. !
002C 4D45           LD    APT.VP.NR_VP(R4), #1
002E 0010'
0030 0001
0032 A941           INC   R4, #2
0034 E8F2          OD
             ! END MULTIPROCESSOR SIMULATION CODE.
              *****************************************!
0036 6F12    LD   APT.VP.NR_VP(R1), R2
0038 0010'
003A 6103    LD   R3, NEXT_VP
003C 00A0'
003E 6F13    LD   APT.VP.FIRST(R1), R3
0040 0014'
            ! RECOMPUTE NEXT_VP VALUE FOR TC
              INITIALIZATION OF NEXT LOGICAL
              CPU. !
0042 A125    LD   R5, R2
0044 1904    MULT RR4, #2
0046 0002
0048 8153    ADD  R3, R5
004A 6F03    LD   NEXT_VP, R3
004C 00A0'
             ! INITIALIZE RUNNING LIST !
004E 6113    LD   R3, APT.VP.FIRST(R1)
0050 0014'
             DO
0052 0B02     CP  R2, #0
0054 0000
0056 5E0E     IF EQ THEN EXIT FI
0058 005E'
005A 5E08
005C 006A'
005E 4D35     LD   APT.RUNNING_LIST(R3), #IDLE_PROC
0060 0002'
0062 DDDD
0064 A931     INC  R3, #2
0066 AB20     DEC  R2, #1
0068 E8F4    OD
006A 4D15    LD   APT.READY_LIST(R1), #NIL
006C 0006'
C06E FFFF
0070 2101    LD   R1, #0
0072 0000
             ! ENTRY ADDRESS !
0074 7602    LDA  R2, VIRTUAL_PREEMPT_HANDLER
0076 0054'
0078 5F00    CALL   CREATE_INT_VEC
007A 0000*
                    !R1:VIRTUAL INTERRUPT #
                     R2:INTERRUPT HANDLER ADDRESS!
007C 9E08    RET
007E        END TC_INIT
```

```
007E           CREATE_PROCESS  PROCEDURE
              !*************************
               * CREATES USER PROCESS  *
               * DATABASES AND APT     *
               * ENTRIES               *
               *************************
               * PARAMETERS:           *
               *  R14: ARGUMENT PTR    *
               *************************!

               ENTRY
                !NOTE: THIS PROCEDURE IS A STUB TO ALLOW
                 PROCESS INITIALIZATION FOR THIS
                 DEMONSTRATION.!
                ! ESTABLISH STACK FRAME FOR LOCAL
                  VARIABLES. !
007E 030F       SUB   R15, #SIZEOF CREATE
0080 000A
                ! STORE INPUT ARGUMENT POINTER !
0082 6FFE       LD    CREATE.ARG_PTR(R15), R14
0084 0000
                ! LOCK APT !
0086 7604       LDA   R4, APT.LOCK
0088 0000'
008A 5F00       CALL  K_LOCK
008C 0000*
                ! RETURNS WHEN APT IS LOCKED !
                ! CREATE MMU ENTRY FOR PROCESS !
008E 5F00       CALL  ALLOCATE_MMU !RETURNS:
0090 0000*
                                        R0: DBR #!
                ! GET NEXT AVAILABLE ENTRY IN APT !
0092 6101       LD    R1, APT_ENTRY
0094 00A2'
                ! COMPUTE APT OFFSET !
3096 2102       LD    R2, #SIZEOF AP_TABLE
0098 0020
009A 8112       ADD   R2, R1
                ! SAVE NEXT AVAILABLE APT ENTRY !
009C 6F02       LD    APT_ENTRY, R2
009E 00A2'
                ! CREATE APT ENTRY FOR PROCESS !
00A0 4D15       LD    APT.AP.NEXT_AP(R1), #NIL
00A2 0020'
00A4 FFFF
0CA6 6F10       LD    APT.AP.DBR(R1), R0
00A8 0022'
                ! GET PROCESS CLASS !
00AA 54E2       LDL   RR2, ARG_LIST.SAC1(R14)
00AC 001E
00AE 5D12       LDL   APT.AP.SAC(R1), RR2
00B0 0024'
                ! GET PROCESS PRIORITY !
00B2 61E2       LD    R2, ARG_LIST.PRI1(R14)
```

```
00B4 0022
00B6 6F12    LD    APT.AP.PRI(R1), R2
00B8 0028'
             ! GET LOGICAL CPU # !
00BA 61E2    LD    R2, ARG_LIST.CPU_ID(R14)
00BC 001C
00BE 6F12    LD    APT.AP.AFFINITY(R1), R2
00C0 002C'
             !THREAD IN LIST AND MAKE READY!
00C2 7623    LDA   R3, APT.READY_LIST(R2)
00C4 0006'
00C6 7604    LDA   R4, APT.AP.NEXT_AP
00C8 0020'
00CA 7605    LDA   R5, APT.AP.PRI
00CC 0028'
00CE 7606    LDA   R6, APT.AP.STATE
00D0 002A'
00D2 2107    LD    R7, #READY
00D4 0001
00D6 AD21    EX    R1, R2
             ! SAVE DBR # !
00D8 6FF0    LD    CREATE.DBR_NUM(R15), R0
00DA 0002
00DC 5F00    CALL  LIST_INSERT
00DE 0000*
                   !R2: OBJ ID
                    R3: LIST HEAD PTR
                    R4: NEXT OBJ PTR
                    R5: PRIORITY PTR
                    R6: STATE PTR
                    R7: STATE!
             ! UNLOCK APT !
00E0 7604    LDA   R4, APT.LOCK
00E2 0000'
00E4 5F00    CALL  K_UNLOCK
00E6 0000*
             !CREATE USER STACK!
             ! RESTORE ARGUMENT POINTER !
00E8 61FE    LD    R14, CREATE.ARG_PTR(R15)
00EA 0000
00EC 61E3    LD    R3, ARG_LIST.USR_STK(R14)
00EE 0024
             ! SAVE LIMITS !
00F0 6FF3    LD    CREATE.LIMITS(R15), R3
00F2 0004
00F4 5F00    CALL  MM_ALLOCATE !R3: # OF BLOCKS
00F6 0000*
                                RETURNS:
                                R2: START ADDR!
             !COMPUTE & SAVE NSP!
00F8 A128    LD    R8, R2
             ! ESTABLISH INITIAL SP VALUE
               FOR USER STACK. !
00FA 0108    ADD   R8, #STK_OFFSET
```

```
00FC 00FF
00FE 6FF8   LD    CREATE.N_S_P(R15), R8
0100 0008
            ! RESTORE LIMITS !
0102 61F4   LD    R4, CREATE.LIMITS(R15)
0104 0004
0106 AB40   DEC   R4  !SEG LIMITS!
            ! RESTORE DBR !
0108 61F0   LD    R0, CREATE.DBR_NUM(R15)
010A 0002
010C 2101   LD    R1, #USER_STACK
010E 0003
0110 2103   LD    R3, #WRITE   !ATTRIBUTE!
0112 0000
0114 5F00   CALL  UPDATE_MMU_IMAGE
0116 0000*
                  !R0: DBR #
                   R1: SEGMENT #
                   R2: SEG ADDRESS
                   R3: SEG ATTRIBUTES
                   R4: SEG LIMITS!
            !CREATE KERNEL STACK!
            ! RESTORE ARGUMENT POINTER !
0118 61FE   LD    R14, CREATE.ARG_PTR(R15)
011A 0000
011C 61E3   LD    R3, ARG_LIST.KER_STK(R14)
011E 0026
0120 5F00   CALL  MM_ALLOCATE !R3: # OF BLOCKS
0122 0000*
                             RETURNS
                             R2: START ADDR!
            !MAKE MMU ENTRY!
            ! RESTORE DBR # !
0124 61F0   LD    R0, CREATE.DBR_NUM(R15)
0126 0002
0128 2101   LD    R1, #KERNEL_STACK
012A 0001
012C A134   LD    R4, R3
012E AB40   DEC   R4
0130 2103   LD    R3, #WRITE
0132 0000
            ! SAVE START ADDRESS !
0134 6FF2   LD    CREATE.SEG_ADDR(R15), R2
0136 0006
0138 5F00   CALL  UPDATE_MMU_IMAGE
013A 0000*
                  !R0: DBR #
                   R1: SEGMENT #
                   R2: SEG ADDRESS
                   R3: SEG ATTRIBUTES
                   R4: SEG LIMITS!
            !ESTABLISH ARGUMENTS!
            ! RESTORE ARGUMENT POINTER !
013C 61FE   LD    R14, CREATE.ARG_PTR(R15)
```

```
013E 0000
             ! RESTORE STACK ADDRESS !
0140 61F1    LD     R1, CREATE.SEG_ADDR(R15)
0142 0006
0144 2103    LD     R3, #USER_FCW
0146 1800
0148 61E4    LD     R4, ARG_LIST.IC(R14)
014A 001A
             ! RESTORE INITIAL NSP !
014C 61F5    LD     R5, CREATE.N_S_P(R15)
014E 0008
0150 7606    LDA    R6, VIRT_PREEMPT_RETURN
0152 0076'
0154 030F    SUB    R15, #8
0156 0008
0158 1CF9    LDM    @R15, R3, #4
015A 0303
             ! LOAD ARGUMENT POINTER FOR
               CREATE_STACK CALL !
015C A1F0    LD     R0, R15
015E 93F1    PUSH   @R15, R1
0160 A1E1    LD     R1, R14
             ! LOAD INITIAL REGISTER VALUES TO
               BE PASSED TO USER PROCESS AS
               INITIAL PARAMETERS. !
0162 5C11    LDM    R2, ARG_LIST.REG(R1), #13
0164 020C
0166 0000
0168 97F1    POP    R1, @R15
016A 5F00    CALL   CREATE_STACK
016C 0000*
                   !R0: ARGUMENT PTR
                    R1: TOP OF STACK
                    R2-R14: INITIAL
                     REG STATES!
             !NOTE: THE ABOVE INITIAL REG STATES
              REPRESENT THE INITIAL PARAMETERS
              (VIZ., REGISTER CONTENTS) THAT A
              USER PROCESS WILL RECEIVE UPON
              INITIAL EXECUTION. !
016E 010F    ADD    R15, #8  !OVERLAY PARAMETERS!
0170 0008
             ! ALLOCATE KST !
0172 2103    LD     R3, #KST_LIMIT
0174 0001
0176 5F00    CALL   MM_ALLOCATE !R3:# OF BLOCKS
0178 0000*
                                 RETURNS
                                 R2:START ADDR!
             ! RESTORE DBR !
017A 61F0    LD     R0, CREATE.DBR_NUM(R15)
017C 0002
             ! SAVE KST ADDRESS !
017E 6FF2    LD     CREATE.SEG_ADDR(R15), R2
```

```
0180 0006
              !MAKE MMU ENTRY FOR KST SEG!
0182 2101     LD     R1, #KST_SEG
0184 0002
0186 2103     LD     R3, #WRITE !ATTRIBUTE!
0188 0000
018A 2104     LD     R4, #KST_LIMIT-1
018C 0000
018E 5F00     CALL   UPDATE_MMU_IMAGE
0190 0000*
                     !R0: DBR #
                      R1: SEGMENT #
                      R2: SEG ADDRESS
                      R3: SEG ATTRIBUTES
                      R4: SEG LIMITS!
              ! RESTORE KST ADDRESS !
0192 61F2     LD     R2, CREATE.SEG_ADDR(R15)
0194 0006
              ! CREATE INITIAL KST STUB !
0196 5F00     CALL   CREATE_KST !R2:KST ADDR!
0198 01A0'
              ! REMOVE TEMPORARY VARIABLE
                STACK FRAME. !
019A 010F     ADD    R15, #SIZEOF CREATE
019C 000A
019E 9E08     RET
01A0         END CREATE_PROCESS
```

```
01A0        CREATE_KST     PROCEDURE
           !************************
            * CREATES KST STUB FOR *
            * PROCESS MANAGEMENT   *
            * DEMO.  INSERTS ROOT  *
            * ENTRY IN KST.  NOT   *
            * INTENDED TO BE FINAL *
            * PRODUCT.             *
            ************************
            * PARAMETERS:          *
            *  R2: KST ADDRESS     *
            ************************!

            ENTRY
             !NOTE: THIS PROCEDURE IS A STUB USED
              FOR INITIALIZATION IN THIS IMPLEMENTATION
              ONLY.  THE ACTUAL INITIALIZATION CODE
              FOR THE KST WILL RESIDE AT THE SEGMENT
              MANAGER LEVEL ONCE IMPLEMENTATION OF
              SYSTEM INITIALIZATION IS EFFECTED. !

             ! CREATE ROOT ENTRY IN KST !
01A0 1406    LDL    RR6, #-1  !ROOT HANDLE!
01A2 FFFF
01A4 FFFF
01A6 5D26    LDL    KST.MM_HANDLE(R2), RR6
01A8 0000
             !SET ROOT ENTRY # IN G_AST !
01AA 4D25    LD     KST.MM_HANDLE[ 2](R2), #0
01AC 0004
01AE 0000
             ! SET ROOT CLASSIFICATION !
01B0 1406    LDL    RR6, #SYSTEM_LOW
01B2 0000
01B4 0000
01B6 5D26    LDL    KST.CLASS(R2), RR6
01B8 000A
             !SET MENTOR SEG #!
01BA 4C25    LDB    KST.M_SEG_NO(R2), #0
01BC 000E
01BE 0000
             !INITIALIZE FREE KST ENTRIES
              FOR DEMO. NOT FULL KST!
01C0 2101    LD     R1, #10
01C2 000A
             DO
01C4 0B01     CP    R1, #0
01C6 0000
01C8 5E0E     IF EQ THEN EXIT FI
01CA 01D0'
01CC 5E08
01CE 01DE'
01D0 0102     ADD  R2, #SIZEOF KST_REC
01D2 0010
```

```
01D4 4C25        LDB  KST.M_SEG_NO(R2), #%FF
01D6 000E
01D8 FFFF
01DA AB10        DEC  R1
01DC E8F3       OD
01DE 9E08       RET
01E0           END CREATE_KST
```

```
01E0          TC_ADVANCE            PROCEDURE
             !********************************
              * EVENTCOUNT IS ADVANCED BY    *
              * INVOCATION OF MM_ADVANCE.    *
              * PROCESSES THAT ARE AWAITING  *
              * THIS EVENT OCCURRENCE ARE    *
              * REMOVED FROM THE BLOCKED LIST*
              * AND MADE READY.  THE READY   *
              * LISTS ARE THEN CHECKED TO    *
              * INSURE PROPER SHEDULING IS   *
              * EFFECTED.  IF NECESSARY VIR- *
              * TUAL PREEMPTS ARE SENT TO ALL*
              * THOSE VP'S BOUND TO LOWER    *
              * PRIORITY PROCESSES.          *
              ********************************
              * PARAMETERS:                  *
              *  R1: HANDLE POINTER          *
              *  R2: INSTANCE (EVENT #)      *
              ********************************
              * RETURNS:                     *
              *  R0: SUCCESS CODE            *
              ********************************!

              ENTRY
               ! ESTABLISH TEMPORARY VARIABLE
                 STACK FRAME. !
01E0 030F      SUB   R15, #SIZEOF TEMP
01E2 0012
               ! SAVE INPUT ARGUMENTS !
01E4 6FF1      LD     TEMP.HANDLE_PTR(R15), R1
01E6 0000
01E8 6FF2      LD     TEMP.EVENT_NR(R15), R2
01EA 0002
               ! LOCK APT !
01EC 7604      LDA    R4, APT.LOCK
01EE 0000'
01F0 5F00      CALL   K_LOCK
01F2 0000*
               ! RETURNS WHEN APT IS LOCKED !
               ! ANNOUNCE EVENT OCCURRENCE BY
                 INCREMENTING EVENTCOUNT IN G_AST!
01F4 5F00      CALL   MM_ADVANCE !R1:HANDLE PTR
01F6 0000*
                                  R2:INSTANCE
                                  RETURNS:
                                  R0:SUCCESS CODE
                                  RR2:EVENTCOUNT!
01F8 0B00      CP     R0, #SUCCEEDED
01FA 0002
01FC 5E0E      IF EQ THEN
01FE 0372'
               ! SAVE EVENTCOUNT !
0200 5DF2      LDL    TEMP.EVENT_VAL(R15), RR2
0202 0004
```

```
                ! RESTORE INSTANCE !
0204 61F0       LD     R0, TEMP.EVENT_NR(R15)
0206 0002
                ! RESTORE HANDLE POINTER !
0208 61F1       LD     R1, TEMP.HANDLE_PTR(R15)
020A 0000
                ! SAVE HANDLE !
020C 5414       LDL    RR4, HANDLE_VAL.HIGH(R1)
020E 0000
0210 5DF4       LDL    TEMP.HANDLE_HIGH(R15), RR4
0212 000C
0214 6114       LD     R4, HANDLE_VAL.LOW(R1)
0216 0004
0218 6FF4       LD     TEMP.HANDLE_LOW(R15), R4
021A 0010
                ! AWAKEN ALL PROCESSES AWAITING
                  THIS EVENT OCCURRENCE !
                ! GET FIRST BLOCKED PROCESS !
021C 6101       LD     R1, APT.BLOCKED_LIST
021E 000A'
0220 7606       LDA    R6, APT.BLOCKED_LIST
0222 000A'
               WAKE_UP:
                DO
                 ! DETERMINE IF AT END OF BLOCKED LIST !
0224 0B01        CP     R1, #NIL
0226 FFFF
                 IF EQ ! NO MORE BLOCKED PROCESSES !
0228 5E0E         THEN EXIT FROM WAKE_UP
022A 0230'
022C 5E08
022E 02B4'
                 FI
                 ! SAVE NEXT ITEM IN LIST !
0230 6117        LD     R7, APT.AP.NEXT_AP(R1)
0232 0020'
                 ! DETERMINE IF PROCESS IS ASSOCIATED
                   WITH CURRENT HANDLE !
0234 54F4        LDL    RR4, TEMP.HANDLE_HIGH(R15)
0236 000C
0238 5014        CPL    RR4, APT.AP.HANDLE(R1)
023A 0030'
                 IF EQ !HIGH HANDLE VALUE MATCHES!
023C 5E0E        THEN
023E 02A2'
0240 61F4        LD     R4, TEMP.HANDLE_LOW(R15)
0242 0010
0244 4B14        CP     R4, APT.AP.HANDLE[2](R1)
0246 0034'
                 IF EQ ! HANDLE'S MATCH !
0248 5E0E         THEN ! CHECK FOR INSTANCE MATCH !
024A 029C'
024C 61F0          LD     R0, TEMP.EVENT_NR(R15)
024E 0002
```

```
0250 4B10                CP    R0, APT.AP.INSTANCE(R1)
0252 0036'
                         IF EQ ! INSTANCE MATCHES !
0254 5E0E                 THEN !DETERMINE IF THIS IS THE
0256 0296'
                                OCCURRENCE THE PROCESS
                                WAITING FOR !
0258 54F2                  LDL    RR2, TEMP.EVENT_VAL(R15)
025A 0004
025C 5012                  CPL    RR2, APT.AP.VALUE(R1)
025E 0038'
                           IF GE !AWAITED EVENT HAS OCCURRED!
0260 5E01                   THEN ! AWAKEN PROCESS !
0262 0290'
                              ! REMOVE FROM BLOCKED LIST !
0264 2F67                     LD    @R6, R7
                              ! SAVE LOCAL VARIABLES !
0266 91F6                     PUSHL @R15, RR6
                              !SET LIST THREADING ARGUMENTS!
0268 6112                     LD    R2, APT.AP.AFFINITY(R1)
026A 002C'
026C 7623                     LDA   R3, APT.READY_LIST(R2)
026E 0006'
0270 7604                     LDA   R4, APT.AP.NEXT_AP
0272 0020'
0274 7605                     LDA   R5, APT.AP.PRI
0276 0028'
0278 7606                     LDA   R6, APT.AP.STATE
027A 002A'
027C 2107                     LD    R7, #READY
027E 0001
0280 A112                     LD    R2, R1
0282 5F00                     CALL  LIST_INSERT
0284 0000*
                               !R2: OBJ ID
                                R3: LIST HEAD PTR
                                R4: NEXT OBJ PTR
                                R5: PRIORITY PTR
                                R6: STATE PTR
                                R7: STATE VALUE !
                              ! RESTORE LOCAL VARIABLES !
0286 95F6                     POPL  RR6, @R15
0288 210B                     LD    R11, #REMOVED
028A ABCD
028C 5E08                    ELSE !PROCESS STILL BLOCKED!
028E 0292'
0290 8DB8                     CLR   R11
                            FI ! END VALUE CHECK !
0292 5E08                  ELSE !PROCESS STILL BLOCKED!
0294 0298'
0296 8DB8                   CLR   R11
                          FI ! END INSTANCE CHECK !
0298 5E08                ELSE  !PROCESS STILL BLOCKED!
029A 029E'
```

```
029C 8DB8         CLR   R11
                FI ! END HANDLE CHECK !
029E 5E08       ELSE !PROCESS STILL BLOCKED!
02A0 02A4'
02A2 8DB8        CLR   R11
                FI ! END HIGH HANDLE CHECK !
                ! RESET AP POINTER REGISTERS !
02A4 0B0B       CP     R11, #REMOVED
02A6 ABCD
                IF NE ! PROCESS IS STILL BLOCKED !
02A8 5E06        THEN
02AA 02B0'
02AC 7616         LDA   R6, APT.AP.NEXT_AP(R1)
02AE 0020'
                FI
02B0 A171       LD     R1, R7
02B2 E8B8      OD
               ! DETERMINE IF ANY VIRTUAL PREEMPT
                 INTERRUPTS ARE REQUIRED !
02B4 8D28      CLR   R2
              PREEMPT_CHECK:
               DO
02B6 0B02       CP     R2, #NR_CPU * 2
02B8 0004
02BA 5E0E       IF EQ !ALL READY LISTS CHECKED! THEN
02BC 02C2'
02BE 5E08        EXIT FROM PREEMPT_CHECK
02C0 0366'
                FI
                ! CREATE PREEMPT VECTOR FOR VP'S !
02C2 8D18       CLR   R1
                DO !FOR R1=1 TO NR_VP'S!
02C4 A910        INC    R1
02C6 4B21        CP     R1, APT.VP.NR_VP(R2)
02C8 0010'
                 IF GT ! PREEMPT VECTOR COMPLETED !
02CA 5E02         THEN EXIT
02CC 02D2'
02CE 5E08
02D0 02D8'
                 FI
02D2 0DF9        PUSH  @R15, #TRUE
02D4 0001
02D6 E8F6       OD
                ! # TO PREEMPT !
02D8 8D38       CLR    R3
02DA 6124       LD     R4, APT.VP.NR_VP(R2)
02DC 0010'
                ! # OF VP'S !
                ! GET FIRST READY PROCESS !
02DE 6121       LD     R1, APT.READY_LIST(R2)
02E0 0006'
               CHECK_RDY_LIST:
                DO
               ! SEE IF READY LIST IS EMPTY !
02E2 0B01      CP    R1, #NIL
02E4 FFFF
               IF EQ !LIST IS EMPTY!
02E6 5E0E       THEN EXIT FROM CHECK_RDY_LIST
02E8 02EE'
02EA 5E08
02EC 0324'
               FI
02EE 4D11      CP    APT.AP.STATE(R1), #RUNNING
02F0 002A'
02F2 0000
               IF EQ !PROCESS IS RUNNING!
02F4 5E0E       THEN !DON'T PREEMPT IT!
02F6 030C'
02F8 6115        LD    R5, APT.AP.VP_ID(R1)
02FA 002E'
                 !COMPUTE LOCATION IN PREEMPT VECTOR!
02FC 4325        SUB   R5, APT.VP.FIRST(R2)
02FE 0014'
0300 74F6        LDA   R6, R15(R5)
0302 0500
0304 0D65        LD    @R6, #FALSE
0306 0000
0308 5E08       ELSE ! PREEMPT IT !
030A 030E'
030C A930        INC   R3
               FI
030E AB40      DEC   R4
0310 0B04      CP    R4, #0
0312 0000
               IF EQ  !ALL VP'S VERIFIED!
0314 5E0E       THEN
0316 031C'
0318 5E08        EXIT FROM CHECK_RDY_LIST
031A 0324'
               FI
               ! GET NEXT AP IN READY LIST !
031C 6110      LD    R0, APT.AP.NEXT_AP(R1)
031E 0020'
0320 A101      LD    R1, R0
0322 E8DF     OD  !END CHECK_RDY_LIST!
              ! SET NECESSARY PREEMPTS !
0324 6124     LD    R4, APT.VP.NR_VP(R2)
0326 0010'
0328 6121     LD    R1, APT.VP.FIRST(R2)
032A 0014'
             SEND_PREEMPT:
              DO
032C 97F0      POP   R0, @R15
               ! CHECK TEMPLATE !
032E 0B00      CP    R0, #TRUE
0330 0001
               IF EQ !CAN BE PREEMPTED!
```

```
0332 5E0E          THEN
0334 0350'
0336 0B03           CP    R3, #0
0338 0000
                    IF GT !PREEMPTS REQUIRED!
033A 5E02            THEN !PREEMPT IT!
033C 0350'
                      !SAVE ARGUMENTS!
033E 93F1             PUSH  @R15, R1
0340 91F2             PUSHL @R15, RR2
0342 93F4             PUSH  @R15, R4
0344 5F00             CALL  SET_PREEMPT
0346 0000*
                       !R1: VP ID!
                      ! RESTORE ARGUMENTS !
0348 97F4             POP   R4, @R15
034A 95F2             POPL  RR2, @R15
034C 97F1             POP   R1, @R15
034E AB30             DEC   R3
                    FI
                  FI
0350 A911         INC   R1, #2
0352 AB40         DEC   R4
0354 0B04         CP    R4, #0
0356 0000
                  IF EQ !STACK RESTORED!
0358 5E0E          THEN
035A 0360'
035C 5E08           EXIT
035E 0362'
                  FI
0360 E8E5        OD !END SEND_PREEMPT!
                 ! CHECK NEXT READY LIST !
0362 A921        INC   R2, #2
0364 E8A8       OD !END PREEMPT_CHECK!
                ! UNLOCK APT !
0366 7604       LDA   R4, APT.LOCK
0368 0000'
036A 5F00       CALL  K_UNLOCK
036C 0000*
                ! RESTORE SUCCESS CODE !
036E 2100       LD    R0, #SUCCEEDED
0370 0002
                FI
                ! RESTORE STACK !
0372 010F       ADD   R15, #SIZEOF TEMP
0374 0012
0376 9E08       RET
0378           END TC_ADVANCE
```

```
0378        TC_AWAIT                 PROCEDURE
           !********************************
            * CHECKS USER SPECIFIED VALUE  *
            * AGAINST CURRENT EVENTCOUNT   *
            * VALUE. IF USER VALUE IS LESS *
            * THAN OR EQUAL EVENTCOUNT THEN*
            * CONTROL IS RETURNED TO USER. *
            * ELSE USER IS BLOCKED UNTIL   *
            * EVENT OCCURRENCE.            *
            ********************************
            * PARAMETERS:                  *
            *  R1: HANDLE POINTER          *
            *  R2: INSTANCE (EVENT #)      *
            *  RR4: SPECIFIED VALUE        *
            ********************************
            * RETURNS:                     *
            *  R0: SUCCESS CODE            *
            ********************************!

            ENTRY
             ! ESTABLISH STACK FRAME FOR
              TEMPORARY VARIABLES. !
0378 030F    SUB   R15, #SIZEOF TEMP
037A 0012
             ! SAVE INPUT PARAMETERS !
037C 6FF1    LD     TEMP.HANDLE_PTR(R15), R1
037E 0000
0380 6FF2    LD     TEMP.EVENT_NR(R15), R2
0382 0002
0384 5DF4    LDL    TEMP.EVENT_VAL(R15), RR4
0386 0004
             ! LOCK APT !
0388 7604    LDA    R4, APT.LOCK
038A 0000'
038C 5F00    CALL   K_LOCK
038E 0000*
             ! RETURNS WHEN APT IS LOCKED !
             ! GET CURRENT EVENTCOUNT !
0390 5F00    CALL   MM_READ_EVENTCOUNT
0392 0000*
                   !R1:HANDLE POINTER
                    R2:INSTANCE
                   RETURNS:
                    R0:SUCCESS_CODE
                    RR4: EVENTCOUNT!
0394 0B00    CP     R0, #SUCCEEDED
0396 0002
0398 5E0E    IF EQ THEN
039A 0440'
             ! DETERMINE IF REQUESTED EVENT
               HAS OCCURRED !
039C 54F6    LDL    RR6, TEMP.EVENT_VAL(R15)
039E 0004
03A0 9046    CPL    RR6, RR4
```

```
                  IF  GT  !EVENT HAS NOT OCCURRED!
03A2 5E02          THEN  !BLOCK PROCESS!
03A4 0440'
                    ! IDENTIFY PROCESS !
03A6 5F00           CALL  RUNNING_VP  !RETURNS:
03A8 0000*
                                          R1:VP ID
                                          R3:CPU #!
                    ! SAVE RETURN VARIABLES !
03AA 6FF1           LD     TEMP.ID_VP(R15), R1
03AC 0008
03AE 6FF3           LD     TEMP.CPU_NUM(R15), R3
03B0 000A
03B2 6118           LD     R8, APT.RUNNING_LIST(R1)
03B4 0002'
                    ! RESTORE REMAINING ARGUMENTS !
03B6 61F2           LD     R2, TEMP.EVENT_NR(R15)
03B8 0002
03BA 61F1           LD     R1, TEMP.HANDLE_PTR(R15)
03BC 0000
                    ! SAVE EVENT DATA !
03BE 5414           LDL    RR4, HANDLE_VAL.HIGH(R1)
03C0 0000
03C2 5D84           LDL    APT.AP.HANDLE(R8), RR4
03C4 0030'
03C6 6114           LD     R4, HANDLE_VAL.LOW(R1)
03C8 0004
03CA 6F84           LD     APT.AP.HANDLE[2](R8), R4
03CC 0034'
03CE 6F82           LD     APT.AP.INSTANCE(R8), R2
03D0 0036'
03D2 54F6           LDL    RR6, TEMP.EVENT_VAL(R15)
03D4 0004
03D6 5D86           LDL    APT.AP.VALUE(R8), RR6
03D8 0038'
                    ! REMOVE PROCESS FROM READY LIST !
03DA 6181           LD     R1, APT.AP.AFFINITY(R8)
03DC 002C'
03DE 6112           LD     R2, APT.READY_LIST(R1)
03E0 0006'
                    ! SEE IF PROCESS IS FIRST
                      ENTRY IN READY LIST !
03E2 8B82           CP     R2, R8
                    IF EQ !INSERT NEW READY LIST HEAD!
03E4 5E0E            THEN
03E6 03F4'
03E8 6183             LD     R3, APT.AP.NEXT_AP(R8)
03EA 0020'
03EC 6F13             LD     APT.READY_LIST(R1), R3
03EE 0006'
03F0 5E08            ELSE !DELETE FROM LIST BODY!
03F2 040E'
                      DO
03F4 6123              LD     R3, APT.AP.NEXT_AP(R2)
```

```
03F6 0020'
03F8 8B83        CP    R3, R8
                 IF EQ !FOUND ITEM IN LIST!
03FA 5E0E         THEN
03FC 040A'
03FE 6183          LD    R3, APT.AP.NEXT_AP(R8)
0400 0020'
0402 6F23          LD    APT.AP.NEXT_AP(R2), R3
0404 0020'
0406 5E08          EXIT
0408 040E'
                 FI
040A A132        LD    R2, R3
040C E8F3       OD
              FI
              !THREAD PROCESS IN BLOCKED LIST!
040E A182     LD    R2, R8
0410 7603     LDA   R3, APT.BLOCKED_LIST
0412 000A'
0414 7604     LDA   R4, APT.AP.NEXT_AP
0416 0020'
0418 7605     LDA   R5, APT.AP.PRI
041A 0028'
041C 7606     LDA   R6, APT.AP.STATE
041E 002A'
0420 2107     LD    R7, #BLOCKED
0422 0002
0424 5F00     CALL  LIST_INSERT !R2:OBJ ID
0426 0000*
                                  R3:LIST HEAD PTR
                                  R4:NEXT OBJ PTR
                                  R5:PRIORITY PTR
                                  R6:STATE PTR
                                  R7:STATE !
              ! GET CURRENT VP ID !
0428 61F1     LD    R1, TEMP.ID_VP(R15)
042A 0008
042C 61F3     LD    R3, TEMP.CPU_NUM(R15)
042E 000A
              ! SCHEDULE FIRST READY PROCESS !
0430 5F00     CALL  TC_GETWORK  !R1:VP_ID
0432 0000'
                                  R3:CPU #!
              ! UNLOCK APT !
0434 7604     LDA   R4, APT.LOCK
0436 0000'
0438 5F00     CALL  K_UNLOCK
043A 0000*
              ! RESTORE SUCCESS CODE !
043C 2100     LD    R0, #SUCCEEDED
043E 0002
            FI
           FI
            ! RESTORE STACK !
```

```
0440 010F    ADD   R15, #SIZEOF TEMP
0442 0012
0444 9E08    RET
0446        END TC_AWAIT
```

```
0446          PROCESS_CLASS      PROCEDURE
             !****************************
              * READS SECURITY ACCESS    *
              * CLASS OF CURRENT PROCESS *
              * IN APT.  CALLED BY SEG   *
              * MGR AND EVENT MGR        *
              ****************************
              * LOCAL VARIABLES:         *
              *  R1: VP ID               *
              *  R5: PROCESS ID          *
              ****************************
              * RETURNS:                 *
              *  RR2: PROCESS SAC        *
              ****************************!

              ENTRY
0446 7604      LDA   R4,APT.LOCK
0448 0000'
044A 5F00      CALL  K_LOCK   !R4:¬APT.LOCK!
044C 0000*
044E 5F00      CALL  RUNNING_VP  !RETURNS:
0450 0000*
                                   R1:VP_ID
                                   R3:CPU #!
0452 6115      LD    R5,APT.RUNNING_LIST(R1)
0454 0002'
0456 5452      LDL   RR2,APT.AP.SAC(R5)
0458 0024'
               ! UNLOCK APT !
045A 7604      LDA   R4, APT.LOCK
045C 0000'
045E 5F00      CALL  K_UNLOCK
0460 0000*
0462 9E08      RET
0464          END PROCESS_CLASS
```

```
0464         GET_DBR_NUMBER          PROCEDURE
            !*********************************
             * OBTAINS DBR NUMBER FROM APT   *
             * FOR THE CURRENT PROCESS.      *
             * CALLED BY SEGMENT MANAGER     *
             *********************************
             * LOCAL VARIABLES:              *
             *  R1: VP ID                    *
             *  R5: PROCESS ID               *
             *********************************
             * RETURNS:                      *
             *  R1: DBR NUMBER               *
             *********************************!

             ENTRY
              !NOTE: DBR # IS ONLY VALID WHILE PROCESS
               IS LOADED.  THIS IS NO PROBLEM IN SASS
               AS ALL PROCESSES REMAIN LOADED.  IN A
               MORE GENERAL CASE, THE DBR # COULD ONLY
               BE ASSUMED CORRECT WHILE THE APT IS LOCKED!
0464 7604      LDA   R4,APT.LOCK
0466 0000'
0468 5F00      CALL  K_LOCK  !R4:¬APT.LOCK!
046A 0000*
046C 5F00      CALL  RUNNING_VP  !RETURNS:
046E 0000*
                                   R1:VP_ID
                                   R3:CPU #!
0470 6115      LD    R5,APT.RUNNING_LIST(R1)
0472 0002'
0474 6151      LD    R1,APT.AP.DBR(R5)
0476 0022'
               ! UNLOCK APT !
0478 7604      LDA   R4, APT.LOCK
047A 0000'
047C 5F00      CALL  K_UNLOCK
047E 0000*
0480 9E08      RET
0482          END GET_DBR_NUMBER

            END TC
```

Appendix C

DISTRIBUTED MEMORY MANAGER LISTINGS

```
Z8000ASM  2.02
LOC    OBJ CODE    STMT SOURCE STATEMENT

        $LISTON $TTY
        DIST_MM MODULE

        CONSTANT

        CREATE_CODE          := 50
        DELETE_CODE          := 51
        ACTIVATE_CODE        := 52
        DEACTIVATE_CODE      := 53
        SWAP_IN_CODE         := 54
        SWAP_OUT_CODE        := 55
        NR_CPU               := 2
        NR_KST_ENTRY         := 54
        MAX_SEG_SIZE         := 128
        MAX_DBR_NO           := 4
        KST_SEG_NO           := 2
        NR_OF_KSEGS          := 10
        BLOCK_SIZE           := 8
        MEM_AVAIL            := %F00
        G_AST_LIMIT          := 10
        INSTANCE1            := 1
        INSTANCE2            := 2
        INVALID_INSTANCE     := 95
        SUCCEEDED            := 2

      TYPE
        H_ARRAY          ARRAY [3   WORD]
        COM_MSG          ARRAY [16  BYTE]
        ADDRESS          WORD

        G_AST_REC       RECORD
         [UNIQUE_ID     LONG
          GLOBAL_ADDR   ADDRESS
          P_L_ASTE_NO   WORD
          FLAG          WORD
          PAR_ASTE      WORD
          NR_ACTIVE     WORD
          NO_ACT_DEP    BYTE
          SIZE1         BYTE
          PG_TBL        ADDRESS
          ALIAS_TBL     ADDRESS
          SEQUENCER     LONG
          EVENT1        LONG
          EVENT2        LONG
         ]

        MM_VP_ID         WORD

        SEG_ARRAY       ARRAY [MAX_SEG_SIZE    BYTE]

        $SECTION D_MM_DATA
        GLOBAL

0000    MM_CPU_TBL ARRAY [NR_CPU MM_VP_ID]

        $SECTION AVAIL_MEM
        INTERNAL
        ! NOTE: MEM_POOL IS LOCATED IN
          CPU LOCAL MEMORY. !
0000    MEM_POOL     ARRAY [MEM_AVAIL BYTE]

      GLOBAL
        ! NOTE: NEXT_BLOCK IS USED IN THE MM_ALLOCATE
          STUB AS AN OFFSET POINTER INTO THE BLOCK
          OF ALLOCATABLE MEMORY.  IT IS INITIALIZED
          IN BOOTSTRAP LOADER. !
0F00    NEXT_BLOCK      WORD
        $SECTION MSG_FRAME_DCL
      INTERNAL
        !NOTE: THESE RECORDS ARE "OVERLAYS" OR "FRAMES" USED
         TO DEFINE MESSAGE FORMATS. NO MEMORY IS ALLOCATED !
        $ABS 0
0000    CREATE_MSG       RECORD [CR_CODE       WORD
                                 CE_MM_HANDLE  H_ARRAY
                                 CE_ENTRY_NO   SHORT_INTEGER
                                 CE_FILL       BYTE
                                 CE_SIZE       WORD
                                 CE_CLASS      LONG]

        $ABS 0
0000    DELETE_MSG       RECORD [DE_CODE       WORD
                                 DE_MM_HANDLE  H_ARRAY
                                 DE_ENTRY_NO   SHORT_INTEGER
                                 DE_FILL       ARRAY[7 BYTE]]

        $ABS 0
0000    ACTIVATE_MSG     RECORD [ACT_CODE      WORD
                                 A_DBR_NO      WORD
                                 A_MM_HANDLE   H_ARRAY
                                 A_ENTRY_NO    SHORT_INTEGER
                                 A_SEGMENT_NO  SHORT_INTEGER
                                 A_FILL        LONG]
        $ABS 0
0000    DEACTIVATE_MSG    RECORD[ DEACT_CODE    WORD
                                  D_DBR_NO        WORD
                                  D_MM_HANDLE     H_ARRAY
                                  D_FILL          ARRAY[ 3 WORD ]]

        $ABS 0
0000    SWAP_IN_MSG       RECORD [ S_IN_CODE      WORD
                                  SI_MM_HANDLE    H_ARRAY
                                  SI_DBR_NO       WORD
                                  SI_ACCESS_AUTH  BYTE
                                  SI_FILL1        BYTE
                                  SI_FILL         ARRAY[ 2 WORD ]]
        $ABS 0
0000    SWAP_OUT_MSG      RECORD [ S_OUT_CODE     WORD
                                  SO_DBR_NO       WORD
                                  SO_MM_HANDLE    H_ARRAY
                                  SO_FILL         ARRAY[ 3 WORD ]]

        $ABS 0
0000    RET_SUC_CODE      RECORD[SUC_CODE       BYTE
                                  SC_FILL         ARRAY[ 15 BYTE ]]

        $ABS 0
0000    R_ACTIVATE_ARG    RECORD [ R_SUC_CODE     BYTE
                                  R_FILL          BYTE
                                  R_MM_HANDLE     H_ARRAY
                                  R_CLASS         LONG
                                  R_SIZE          WORD
                                  R_FILL1         WORD ]

        $ABS 0
0000    MM_HANDLE       RECORD
          [ ID        LONG
           ENTRY_NO WORD
          ]

        EXTERNAL

                G_AST_LOCK          WORD

                G_AST   ARRAY[G_AST_LIMIT G_AST_REC ]

                K_LOCK              PROCEDURE

                K_UNLOCK            PROCEDURE

                GET_CPU_NO          PROCEDURE

                SIGNAL              PROCEDURE

                WAIT                PROCEDURE
          GLOBAL
          $SECTION D_MM_PROC

0000           MM_CREATE_ENTRY         PROCEDURE
              !**********************************
               * INTERFACE BETWEEN SEG MGR      *
               * (CREATE_SEG PROCEDURE) AND     *
               * MMGR PROCESS (CREATE_ENTRY     *
               * PROCEDURE). ARRANGES AND       *
               * PERFORMS IPC.                  *
               **********************************
               * REGISTER USE:                  *
               * PARAMETERS                     *
               *  R0:SUCCESS_CODE (RET)         *
               *  R1:HPTR (INPUT)               *
               *  R2:ENTRY_NO (INPUT)           *
               *  R3:SIZE (INPUT)               *
               *  RR4:CLASS (INPUT)             *
               * LOCAL USE                      *
               *  R6:MM_HANDLE ARRAY ENTRY      *
               *  R8:¬COM_MSGBUF                *
               *  R13:¬COM_MSGBUF               *
               **********************************!
               ENTRY
                !USE STACK FOR MESSAGE!
0000 030F       SUB   R15,#SIZEOF COM_MSG
0002 0010
0004 A1FD       LD    R13,R15   ! ¬COM_MSGBUF !

                !FILL COM_MSGBUF (LOAD MESSAGE). CREATE MSG
                 FRAME IS BASED AT ADDRESS ZERO.  IT IS
                 OVERLAID ONTO COM_MSGBUF FRAME BY INDEXING
                 EACH ENTRY (I.E. ADDING TO EACH ENTRY) THE
                 BASE ADDRESS OF COM_MSGBUF!

0006 4DD5       LD    CREATE_MSG.CR_CODE(R13),#CREATE_CODE
0008 0000
000A 0032
000C 3116       LD    R6,R1(#0)   !INDEX TO MM_HANDLE ENTRY!
000E 0000
0010 6FD6       LD    CREATE_MSG.CE_MM_HANDLE[0](R13),R6
0012 0002
0014 3116       LD    R6,R1(#2)
0016 0002
0018 6FD6       LD    CREATE_MSG.CE_MM_HANDLE[1](R13),R6
001A 0004
001C 3116       LD    R6,R1(#4)
001E 0004
0020 6FD6       LD    CREATE_MSG.CE_MM_HANDLE[2](R13),R6
0022 0006
0024 6FD2       LD    CREATE_MSG.CE_ENTRY_NO(R13),R2
0026 0008
0028 5DD4       LDL   CREATE_MSG.CE_CLASS(R13),RR4
002A 000C
```

```
002C 6FD3     LD     CREATE_MSG.CE_SIZE(R13),R3
002E 000A
0030 A1D8     LD     R8,R13
0032 5F00     CALL   PERFORM_IPC  !R8: ¬COM_MSGBUF!
0034 018C'
              !RETRIEVE SUCCESS_CODE FROM RETURNED MESSAGE!

0036 8D08     CLR    R0
0038 60D8     LDB    RL0,RET_SUC_CODE.SUC_CODE(R13)
003A 0000
003C 010F     ADD    R15,#SIZEOF COM_MSG  !RESTORE STACK STATE!
003E 0010
0040 9E08     RET
0042      END MM_CREATE_ENTRY
```

```
0042          MM_DELETE_ENTRY          PROCEDURE
             !**********************************
              * INTERFACE BETWEEN SEG MGR      *
              * (DELETE_SEG PROCEDURE) AND     *
              * MMGR (DELETE_ENTRY PROCEDURE).*
              * ARRANGES AND PERFORMS IPC.     *
              **********************************
              * REGISTER USE:                  *
              * PARAMETERS                     *
              *   R0:SUCCESS_CODE(RET)         *
              *   R1:HPTR(INPUT)               *
              *   R2:ENTRY_NO(INPUT)           *
              * LOCAL USE                      *
              *   R6:MM_HANDLE ARRAY ENTRY     *
              *   R8:¬COM_MSGBUF               *
              *   R13:¬COM_MSGBUF              *
              **********************************!
              ENTRY
               !USE STACK FOR MESSAGE!
0042 030F      SUB    R15,#SIZEOF COM_MSG
0044 0010
0046 A1FD      LD     R13,R15    ! ¬COM_MSGBUF !
          !FILL COM_MSGBUF (LOAD MESSAGE). DELETE_MSG FRAME
           IS BASED AT ADDRESS ZERO. IT IS OVERLAID ONTO
           COM_MSGBUF FRAME BY INDEXING EACH ENTRY (I.E. ADD-
           ING TO EACH ENTRY) THE BASE ADDRESS OF COM_MSGBUF!
0048 4DD5      LD     DELETE_MSG.DE_CODE(R13),#DELETE_CODE
004A 0000
004C 0033
004E 3116      LD     R6,R1(#0)  !INDEX TO MM_HANDLE ENTRY!
0050 0000
0052 6FD6      LD     DELETE_MSG.DE_MM_HANDLE[0](R13),R6
0054 0002
0056 3116      LD     R6,R1(#2)
0058 0002
005A 6FD6      LD     DELETE_MSG.DE_MM_HANDLE[1](R13),R6
005C 0004
005E 3116      LD     R6,R1(#4)
0060 0004
0062 6FD6      LD     DELETE_MSG.DE_MM_HANDLE[2](R13),R6
0064 0006
0066 6FD2      LD     DELETE_MSG.DE_ENTRY_NO(R13),R2
0068 0008
006A A1D8      LD     R8,R13
006C 5F00      CALL   PERFORM_IPC  !R8: ¬COM_MSGBUF!
006E 018C'
               !RETRIEVE SUCCESS_CODE FROM RETURNED MESSAGE!
0070 8D08      CLR    R0
0072 60D8      LDB    RL0,RET_SUC_CODE.SUC_CODE(R13)
0074 0000
0076 010F      ADD    R15,#SIZEOF COM_MSG  !RESTORE STACK STATE!
0078 0010
007A 9E08      RET
007C       END MM_DELETE_ENTRY
```

```
007C          MM_ACTIVATE            PROCEDURE
             !**********************************
              * INTERFACE BETWEEN SEG MGR      *
              * (MAKE_KNOWN PROCEDURE) AND     *
              * MMGR   (ACTIVATE PROCEDURE).   *
              * ARRANGES AND PERFORMS IPC.     *
              **********************************
              * REGISTER USE:                  *
              * PARAMETERS                     *
              *   R1:DBR_NO(INPUT)             *
              *   R2:HPTR(INPUT)               *
              *   R3:ENTRY_NO                  *
              *   R4:SEGMENT_NO                *
              *   R12:RET_HANDLE_PTR           *
              * LOCAL USE                      *
              *   R8:¬COM_MSGBUF               *
              *   R13:¬COM_MSGBUF              *
              * RETURNS:                       *
              *   R0:SUCCESS CODE              *
              *   RR2:CLASS                    *
              *   R4:SIZE                      *
              **********************************!

              ENTRY
               !USE STACK FOR MESSAGE!
007C 030F      SUB   R15,#SIZEOF COM_MSG
007E 0010
0080 A1FD      LD    R13,R15   ! ¬COM_MSGBUF !
               ! SAVE RETURN HANDLE POINTER !
0082 93FC      PUSH  @R15, R12

            !FILL COM_MSGBUF (LOAD MESSAGE). ACTIVATE_MSG FRAME
             IS BASED AT ADDRESS ZERO. IT IS OVERLAID ONTO
             COM_MSGBUF FRAME BY INDEXING EACH ENTRY (I.E. ADD-
             ING TO EACH ENTRY) THE BASE ADDRESS OF COM_MSGBUF!
0084 4DD5      LD    ACTIVATE_MSG.ACT_CODE(R13),#ACTIVATE_CODE
0086 0000
0088 0034
008A 6FD1      LD    ACTIVATE_MSG.A_DBR_NO(R13),R1
008C 0002
008E 3126      LD    R6,R2(#0)
0090 0000
0092 6FD6      LD    ACTIVATE_MSG.A_MM_HANDLE[ 0 ](R13),R6
0094 0004
0096 3126      LD    R6,R2(#2)
0098 0002
009A 6FD6      LD    ACTIVATE_MSG.A_MM_HANDLE[ 1 ](R13),R6
009C 0006
009E 3126      LD    R6,R2(#4)
00A0 0004
00A2 6FD6      LD    ACTIVATE_MSG.A_MM_HANDLE[ 2 ](R13),R6
00A4 0008
00A6 6EDB      LDB   ACTIVATE_MSG.A_ENTRY_NO(R13),RL3
00A8 000A
```

```
00AA 6EDC     LDB   ACTIVATE_MSG.A_SEGMENT_NO(R13),RL4
00AC 000B
00AE A1D8     LD    R8,R13
00B0 5F00     CALL  PERFORM_IPC !(R8:¬COM_MSGBUF!
00B2 018C'
              ! RESTORE RETURN HANDLE POINTER !
00B4 97FC     POP   R12, @R15

              ! UPDATE MM_HANDLE ENTRY !
00B6 54D6     LDL   RR6, R_ACTIVATE_ARG.R_MM_HANDLE(R13)
00B8 0002
00BA 5DC6     LDL   MM_HANDLE.ID(R12), RR6
00BC 0000
00BE 61D6     LD    R6,R_ACTIVATE_ARG.R_MM_HANDLE[2](R13)
00C0 0006
00C2 6FC6     LD    MM_HANDLE.ENTRY_NO(R12), R6
00C4 0004
              !RETRIEVE OTHER RETURN ARGUMENTS!
00C6 8D08     CLR   R0
00C8 60D8     LDB   RL0,R_ACTIVATE_ARG.R_SUC_CODE(R13)
00CA 0000
00CC 54D2     LDL   RR2,R_ACTIVATE_ARG.R_CLASS(R13)
00CE 0008
00D0 61D4     LD    R4,R_ACTIVATE_ARG.R_SIZE(R13)
00D2 000C
00D4 010F     ADD   R15,#SIZEOF COM_MSG !RESTORE STACK STATE!
00D6 0010
00D8 9E08     RET
00DA       END MM_ACTIVATE
```

```
00DA         MM_DEACTIVATE           PROCEDURE
            !**********************************
             * INTERFACE BETWEEN SEG MGR      *
             * (TERMINATE PROCEDURE) AND      *
             * MMGR (DEACTIVATE PROCEDURE).   *
             * ARRANGES AND PERFORMS IPC.     *
             **********************************
             * REGISTER USE:                  *
             * PARAMETERS                     *
             *  R0:SUCCESS_CODE(RET)          *
             *  R1:DBR_NO(INPUT)              *
             *  R2:HPTR(INPUT)                *
             * LOCAL USE                      *
             *  R6:MM_HANDLE ARRAY ENTRY      *
             *  R8:¬COM_MSGBUF                *
             *  R13:¬COM_MSGBUF               *
             **********************************!

             ENTRY
              !USE STACK FOR MESSAGE!
00DA 030F     SUB   R15,#SIZEOF COM_MSG
00DC 0010
00DE A1FD     LD    R13,R15    ! ¬COM_MSGBUF !

           !FILL COM_MSGBUF (LOAD MESSAGE). DEACTIVATE_MSG FRAME
            IS BASED AT ADDRESS ZERO. IT IS OVERLAID ONTO
            COM_MSGBUF FRAME BY INDEXING EACH ENTRY (I.E. ADD-
            ING TO EACH ENTRY) THE BASE ADDRESS OF COM_MSGBUF!

00E0 4DD5     LD    DEACTIVATE_MSG.DEACT_CODE(R13),
00E2 0000                          #DEACTIVATE_CODE
00E4 0035
00E6 6FD1     LD    DEACTIVATE_MSG.D_DBR_NO(R13),R1
00E8 0002
00EA 3126     LD    R6,R2(#0)   !INDEX TO MM_HANDLE ENTRY!
00EC 0000
00EE 6FD6     LD    DEACTIVATE_MSG.D_MM_HANDLE[0](R13),R6
00F0 0004
00F2 3126     LD    R6,R2(#2)
00F4 0002
00F6 6FD6     LD    DEACTIVATE_MSG.D_MM_HANDLE[1](R13),R6
00F8 0006
00FA 3126     LD    R6,R2(#4)
00FC 0004
00FE 6FD6     LD    DEACTIVATE_MSG.D_MM_HANDLE[2](R13),R6
0100 0008
0102 A1D8     LD    R8,R13
0104 5F00     CALL  PERFORM_IPC  !R8: ¬COM_MSGBUF!
0106 018C'

              !RETRIEVE SUCCESS_CODE FROM RETURNED MESSAGE!

0108 8D08     CLR   R0
010A 60D8     LDB   RL0,RET_SUC_CODE.SUC_CODE(R13)
```

```
010C 0000
010E 010F    ADD    R15,#SIZEOF COM_MSG !RESTORE STACK STATE!
0110 0010
0112 9E08    RET
0114      END MM_DEACTIVATE
```

```
0114          MM_SWAP_IN              PROCEDURE
             !*********************************
              * INTERFACE BETWEEN SEG MGR (SM_*
              * SWAP_IN PROCEDURE) AND MMGR   *
              * (SWAP_IN PROCEDURE). ARRANGES *
              * AND PERFORMS IPC.             *
              *********************************
              * REGISTER USE:                 *
              * PARAMETERS                    *
              *  R0:SUCCESS_CODE(RET)         *
              *  R1:DBR_NO(INPUT)             *
              *  R2:HPTR(INPUT)               *
              *  R3:ACCESS      (INPUT)       *
              * LOCAL USE                     *
              *  R6:MM_HANDLE ARRAY ENTRY     *
              *  R8:¬COM_MSGBUF               *
              *  R13:¬COM_MSGBUF              *
              *********************************!
              ENTRY
               !USE STACK FOR MESSAGE!
0114 030F      SUB   R15,#SIZEOF COM_MSG
0116 0010
0118 A1FD      LD    R13,R15   ! ¬COM_MSGBUF !

           !FILL COM_MSGBUF (LOAD MESSAGE). SWAP_IN_MSG FRAME
            IS BASED AT ADDRESS ZERO. IT IS OVERLAID ONTO
            COM_MSGBUF FRAME BY INDEXING EACH ENTRY (I.E. ADD-
            ING TO EACH ENTRY) THE BASE ADDRESS OF COM_MSGBUF!

011A 4DD5      LD    SWAP_IN_MSG.S_IN_CODE(R13),#SWAP_IN_CODE
011C 0000
011E 0036
0120 3126      LD    R6,R2(#0)  !INDEX TO MM_HANDLE ENTRY!
0122 0000
0124 6FD6      LD    SWAP_IN_MSG.SI_MM_HANDLE[0](R13),R6
0126 0002
0128 3126      LD    R6,R2(#2)
012A 0002
012C 6FD6      LD    SWAP_IN_MSG.SI_MM_HANDLE[1](R13),R6
012E 0004
0130 3126      LD    R6,R2(#4)
0132 0004
0134 6FD6      LD    SWAP_IN_MSG.SI_MM_HANDLE[2](R13),R6
0136 0006
0138 6FD1      LD    SWAP_IN_MSG.SI_DBR_NO(R13),R1
013A 0008
013C 6EDB      LDB   SWAP_IN_MSG.SI_ACCESS_AUTH(R13),RL3
013E 000A
0140 A1D8      LD    R8,R13
0142 5F00      CALL  PERFORM_IPC  !R8: ¬COM_MSGBUF!
0144 018C'
               !RETRIEVE SUCCESS_CODE FROM RETURNED MESSAGE!
0146 8D08      CLR   R0
0148 60D8      LDB   RL0,RET_SUC_CODE.SUC_CODE(R13)
```

```
014A 0000
014C 010F    ADD   R15,#SIZEOF COM_MSG !RESTORE STACK STATE!
014E 0010
0150 9E08    RET
0152     END MM_SWAP_IN
```

```
0152          MM_SWAP_OUT              PROCEDURE
             !*********************************
              * INTERFACE BETWEEN SEG MGR (SM_*
              * SWAP_OUT PROCEDURE) AND MMGR  *
              * (SWAP_OUT PROCEDURE). ARRANGES*
              * AND PERFORMS IPC.             *
              *********************************
              * REGISTER USE:                 *
              * PARAMETERS                    *
              *  R0:SUCCESS_CODE(RET)         *
              *  R1:DBR_NO(INPUT)             *
              *  R2:HPTR(INPUT)               *
              * LOCAL USE                     *
              *  R6:MM_HANDLE ARRAY ENTRY     *
              *  R8:¬COM_MSGBUF               *
              *  R13:¬COM_MSGBUF              *
              *********************************!
              ENTRY
               !USE STACK FOR MESSAGE!
0152 030F      SUB    R15,#SIZEOF COM_MSG
0154 0010
0156 A1FD      LD     R13,R15   ! ¬COM_MSGBUF !

            !FILL COM_MSGBUF (LOAD MESSAGE). SWAP_OUT_MSG FRAME
             IS BASED AT ADDRESS ZERO. IT IS OVERLAID ONTO
             COM_MSGBUF FRAME BY INDEXING EACH ENTRY (I.E. ADD-
             ING TO EACH ENTRY) THE BASE ADDRESS OF COM_MSGBUF!

0158 4DD5      LD     SWAP_OUT_MSG.S_OUT_CODE(R13), #SWAP_OUT_CODE
015A 0000
015C 0037
015E 3126      LD     R6,R2(#0)  !INDEX TO MM_HANDLE ENTRY!
0160 0000
0162 6FD6      LD     SWAP_OUT_MSG.SO_MM_HANDLE[ 0](R13),R6
0164 0004
0166 3126      LD     R6,R2(#2)
0168 0002
016A 6FD6      LD     SWAP_OUT_MSG.SO_MM_HANDLE[ 1](R13),R6
016C 0006
016E 3126      LD     R6,R2(#4)
0170 0004
0172 6FD6      LD     SWAP_OUT_MSG.SO_MM_HANDLE[ 2](R13),R6
0174 0008
0176 6FD1      LD     SWAP_OUT_MSG.SO_DBR_NO(R13),R1
0178 0002
017A A1D8      LD     R8,R13
017C 5FC'      CALL   PERFORM_IPC  !R8: ¬COM_MSGBUF!
017E 018C'
               !RETRIEVE SUCCESS_CODE FROM RETURNED MESSAGE!
0180 8D08      CLR    R0
0182 60D8      LDB    RL0,RET_SUC_CODE.SUC_CODE(R13)
0184 0000
0186 010F      ADD    R15,#SIZEOF COM_MSG !RESTORE STACK STATE!
0188 0010
```

```
018A 9E08    RET
018C     END MM_SWAP_OUT
```

```
018C          PERFORM_IPC                    PROCEDURE
             !*************************************
              * SERVICE ROUTINE TO ARRANGE AND    *
              * PERFORM IPC WITH THE MEM MGR PROC *
              *************************************
              * REGISTER USE:                     *
              * PARAMETERS                        *
              *  R8: ¬COM_MSG(INPUT)              *
              * LOCAL USE                         *
              *  R1,R2: WORK REGS                 *
              *  R4: ¬G_AST_LOCK                  *
              *  R13: ¬COM_MSGBUF                 *
              *************************************!

              ENTRY
018C 93FD      PUSH  @R15,R13  !¬COM_MSGBUF!
018E 5F00      CALL  GET_CPU_NO !RET-R1:CPU_NO!
0190 0000*
0192 A112      LD    R2,R1
0194 6121      LD    R1,MM_CPU_TBL(R2)  !MM_VP_ID!
0196 0000'
0198 7604      LDA   R4,G_AST_LOCK
019A 0000*
019C 5F00      CALL  K_LOCK
019E 0000*
01A0 5F00      CALL  SIGNAL  !R1:MM_VP_ID,R8:¬COM_MSGBUF!
01A2 0000*
01A4 97FD      POP   R13,@R15
01A6 A1D8      LD    R8,R13  !¬COM_MSGBUF!
01A8 93FD      PUSH  @R15,R13
01AA 5F00      CALL  WAIT  !R8:¬COM_MSGBUF!
01AC 0000*
01AE 7604      LDA   R4,G_AST_LOCK
01B0 0000*
01B2 5F00      CALL  K_UNLOCK
01B4 0000*
01B6 97FD      POP   R13,@R15
01B8 9E08      RET
01BA        END PERFORM_IPC
```

```
01BA         MM_ALLOCATE     PROCEDURE
            !**************************
             * ALLOCATES BLOCKS OF CPU*
             * LOCAL MEMORY.  EACH    *
             * BLOCK CONTAINS 256     *
             * BYTES OF MEMORY.       *
             **************************
             * PARAMETERS:            *
             *  R3: # OF BLOCKS       *
             * RETURNS:               *
             *  R2: STARTING ADDR     *
             * LOCAL:                 *
             *  R4: BLOCK POINTER     *
             **************************!
             ENTRY
              ! NOTE: THIS PROCEDURE IS ONLY A STUB
                OF THE ORIGINALLY DESIGNED MEMORY
                ALLOCATING MECHANISM.  IT IS USED
                BY THE PROCESS MANAGEMENT DEMONSTRATION
                TO ALLOCATE CPU LOCAL MEMORY FOR ALL
                MEMORY ALLOCATION REQUIREMENTS. IN AN
                ACTUAL SASS ENVIRONMENT, THIS WOULD
                BE BETTER SERVED TO HAVE SEPARATE
                ALLOCATION PROCEDURES FOR KERNEL AND
                SUPERVISOR NEEDS. (E.G., KERNEL_ALLOCATE
                AND SUPERVISOR_ALLOCATE). !
              ! COMPUTE SIZE OF MEMORY REQUESTED !
01BA B331     SLL    R3, #BLOCK_SIZE
01BC 0008
              ! COMPUTE OFFSET OF MEMORY THAT IS
                TO BE ALLOCATED !
01BE 6104     LD     R4, NEXT_BLOCK  !OFFSET!
01C0 0F00'
01C2 7642     LDA    R2, MEM_POOL(R4) !START ADDR!
01C4 0000'
01C6 8134     ADD    R4, R3  !UPDATE OFFSET!
              ! UPDATE OFFSET IN SECTION OF AVAILABLE
                MEMORY TO INDICATE THAT CURRENTLY
                REQUESTED MEMORY IS NOW ALLOCATED !
01C8 6F04     LD     NEXT_BLOCK, R4  !SAVE OFFSET!
01CA 0F00'
01CC 9E08     RET
01CE         END MM_ALLOCATE
```

```
01CE        MM_TICKET           PROCEDURE
           !******************************
            * RETURNS CURRENT VALUE OF  *
            * SEGMENT SEQUENCER AND     *
            * INCREMENTS SEQUENCER VALUE*
            * FOR NEXT TICKET OPERATION *
            *****************************
            * PARAMETERS:               *
            *  R1: SEG HANDLE PTR       *
            * RETURNS:                  *
            *  RR4: TICKET VALUE        *
            * LOCAL VARIABLES:          *
            *  RR6: SEQUENCER VALUE     *
            *  R8: G_AST ENTRY #        *
            ******************************!
            ENTRY
             ! SAVE HANDLE PTR !
01CE 93F1    PUSH    @R15, R1
             ! LOCK G_AST !
01D0 7604    LDA   R4, G_AST_LOCK
01D2 0000*
01D4 5F00    CALL  K_LOCK
01D6 0000*
             ! RESTORE HANDLE PTR !
01D8 97F1    POP   R1, @R15
             ! GET G_AST ENTRY # !
01DA 6118    LD    R8, MM_HANDLE.ENTRY_NO(R1)
01DC 0004
             ! GET TICKET VALUE !
01DE 5486    LDL   RR6, G_AST.SEQUENCER(R8)
01E0 0014*
             ! SET RETURN REGISTER VALUE !
01E2 9464    LDL   RR4, RR6
             !ADVANCE SEQUENCER FOR NEXT
              TICKET OPERATION!

01E4 1606    ADDL  RR6, #1
01E6 0000
01E8 0001
             ! SAVE NEW SEQUENCER VALUE IN G_AST !
01EA 5D86    LDL   G_AST.SEQUENCER(R8), RR6
01EC 0014*
             ! UNLOCK G_AST !
             ! SAVE RETURN VALUES !
01EE 91F4    PUSHL @R15, RR4
01F0 7604    LDA   R4, G_AST_LOCK
01F2 0000*
01F4 5F00    CALL  K_UNLOCK
01F6 0000*
             ! RETRIEVE RETURN VALUES !
01F8 95F4    POPL  RR4, @R15
01FA 9E08    RET
01FC        END  MM_TICKET
```

```
01FC         MM_READ_EVENTCOUNT    PROCEDURE
            !********************************
             * READS CURRENT VALUE OF THE   *
             * EVENTCOUNT SPECIFIED BY THE  *
             * USER.                        *
             ********************************
             * PARAMETERS:                  *
             *  R1: SEG HANDLE PTR          *
             *  R2: INSTANCE (EVENT #)      *
             ********************************
             * RETURNS:                     *
             *  RR4: EVENTCOUNT VALUE       *
             ********************************
             * LOCAL VARIABLES:             *
             *  RR6: SEQUENCER VALUE        *
             *  R8: G_AST ENTRY #           *
             ********************************!

             ENTRY
              ! SAVE INPUT PARAMETERS !
01FC 93F1     PUSH  @R15, R1
01FE 93F2     PUSH  @R15, R2
              ! LOCK G_AST !
0200 7604     LDA    R4, G_AST_LOCK
0202 0000*
0204 5F00     CALL  K_LOCK
0206 0000*
              ! RESTORE INPUT PARAMETERS !
0208 97F2     POP    R2, @R15
020A 97F1     POP    R1, @R15
              ! GET G_AST ENTRY # !
020C 6118     LD     R8, MM_HANDLE.ENTRY_NO(R1)
020E 0004
              ! READ EVENTCOUNT !
              ! CHECK WHICH EVENT # !
              IF  R2
0210 0B02      CASE  #INSTANCE1 THEN
0212 0001
0214 5E0E
0216 0224'
0218 5484       LDL   RR4, G_AST.EVENT1(R8)
021A 0018*
021C 2100       LD    R0, #SUCCEEDED
021E 0002
0220 5E08      CASE  #INSTANCE2 THEN
0222 023C'
0224 0B02
0226 0002
0228 5E0E
022A 0238'
022C 5484       LDL   RR4, G_AST.EVENT2(R8)
022E 001C*
0230 2100       LD    R0, #SUCCEEDED
0232 0002
```

```
0234 5E08     ELSE   !INVALID INPUT!
0236 023C'
0238 2100      LD    R0, #INVALID_INSTANCE
023A 005F
             FI
             ! NOTE: NO VALUE IS RETURNED IF
               USER SPECIFIED INVALID EVENT #!
             ! SAVE RETURN VALUES !
023C 91F4    PUSHL @R15, RR4
             ! UNLOCK G_AST !
023E 7604    LDA    R4, G_AST_LOCK
0240 0000*
0242 5F00    CALL   K_UNLOCK
0244 0000*
             ! RESTORE RETURN VALUES !
0246 95F4    POPL   RR4, @R15
0248 9E08    RET
024A        END  MM_READ_EVENTCOUNT
```

```
024A         MM_ADVANCE                  PROCEDURE
            !**********************************
             * DETERMINES G_AST OFFSET FROM    *
             * SEGMENT HANDLE AND INCREMENTS   *
             * THE INSTANCE(EVENT #) SPECIFIED *
             * BY THE CALLER.  THIS IN EFFECT  *
             * ANNOUNCES THE OCCURRENCE OF THE *
             * EVENT.  THE NEW VALUE OF THE    *
             * EVENTCOUNT IS RETURNED TO THE   *
             * CALLER.                         *
             ***********************************
             * PARAMETERS:                     *
             *  R1: HANDLE POINTER             *
             *  R2: INSTANCE (EVENT #)         *
             ***********************************
             * RETURNS:                        *
             *  RR2: NEW EVENTCOUNT VALUE      *
             ***********************************!

             ENTRY
              ! SAVE INPUT PARAMETERS !
024A 93F1     PUSH  @R15, R1
024C 93F2     PUSH  @R15, R2
              ! LOCK G_AST !
024E 7604     LDA   R4, G_AST_LOCK
0250 0000*
0252 5F00     CALL  K_LOCK
0254 0000*
              ! RESTORE INPUT PARAMETERS !
0256 97F2     POP   R2, @R15
0258 97F1     POP   R1, @R15
              ! GET G_AST OFFSET !
025A 6114     LD    R4, MM_HANDLE.ENTRY_NO(R1)
025C 0004
              ! DETERMINE INSTANCE !
              IF  R2
025E 0B02      CASE  #INSTANCE1  THEN
0260 0001
0262 5E0E
0264 027C'
0266 5442       LDL   RR2, G_AST.EVENT1(R4)
0268 0018*
026A 1602       ADDL  RR2, #1
026C 0000
026E 0001
                ! SAVE NEW EVENTCOUNT !
0270 5D42       LDL   G_AST.EVENT1(R4), RR2
0272 0018*
0274 2100       LD    R0, #SUCCEEDED
0276 0002
0278 5E08      CASE  #INSTANCE2  THEN
027A 029E'
027C 0B02
027E 0002
```

```
0280 5E0E
0282 029A'
0284 5442      LDL   RR2, G_AST.EVENT2(R4)
0286 001C*
0288 1602      ADDL  RR2, #1
028A 0000
028C 0001
               ! SAVE NEW EVENTCOUNT !
028E 5D42      LDL   G_AST.EVENT2(R4), RR2
0290 001C*
0292 2100      LD    R0, #SUCCEEDED
0294 0002
0296 5E08     ELSE  !INVALID INPUT!
0298 029E'
029A 2100      LD    R0, #INVALID_INSTANCE
029C 005F
             FI
             ! NOTE: AN INVALID INSTANCE VALUE
               WILL NOT AFFECT EVENT DATA !
             ! UNLOCK G_AST !
029E 7604    LDA   R4, G_AST_LOCK
02A0 0000*
02A2 5F00    CALL  K_UNLOCK
02A4 0000*
02A6 9E08    RET
02A8        END MM_ADVANCE
           END DIST_MM
```

Appendix D

GATE_KEEPER LISTINGS

```
Z8000ASM  2.02
LOC    OBJ CODE    STMT SOURCE STATEMENT

       KERNEL_GATE_KEEPER       MODULE

       $LISTON $TTY

       CONSTANT
         ADVANCE_CALL           := 1
         AWAIT_CALL             := 2
         CREATE_SEG_CALL        := 3
         DELETE_SEG_CALL        := 4
         MAKE_KNOWN_CALL        := 5
         READ_CALL              := 6
         SM_SWAP_IN_CALL        := 7
         SM_SWAP_OUT_CALL       := 8
         TERMINATE_CALL         := 9
         TICKET_CALL            := 10
         WRITE_CALL             := 11
         WRITELN_CALL           := 12
         CRLF_CALL              := 13
         WRITE                  := %0FC8 !PRINT CHAR!
         WRITELN                := %0FC0 !PRINT MSG!
         CRLF                   := %0FD4 !CAR RET/LINE FEED!
         MONITOR                := %A902
         REGISTER_BLOCK         := 32
         TRAP_CODE_OFFSET       := 36
         INVALID_KERNEL_ENTRY   := %BAD

       GLOBAL
         GATE_KEEPER_ENTRY      LABEL

       EXTERNAL
         ADVANCE                PROCEDURE
         AWAIT                  PROCEDURE
         CREATE_SEG             PROCEDURE
         DELETE_SEG             PROCEDURE
         MAKE_KNOWN             PROCEDURE
         READ                   PROCEDURE
         SM_SWAP_IN             PROCEDURE
         SM_SWAP_OUT            PROCEDURE
         TERMINATE              PROCEDURE
         TICKET                 PROCEDURE
         KERNEL_EXIT            LABEL
```

```
          INTERNAL
          $SECTION KERNEL_GATE_PROC

0000           GATE_KEEPER_MAIN        PROCEDURE

               ENTRY
               GATE_KEEPER_ENTRY:
                 ! SAVE REGISTERS !
0000 030F        SUB   R15, #REGISTER_BLOCK
0002 0020
0004 1CF9        LDM   @R15, R1, #16
0006 010F
                 ! SAVE NSP !
0008 93F2        PUSH  @R15, R2
000A 7D27        LDCTL R2, NSP
                 ! RESTORE INPUT REGISTERS !
000C 2DF2        EX    R2, @R15
                 ! SAVE REGISTER 2 !
000E 93F2        PUSH  @R15, R2
                 ! GET SYSTEM TRAP CODE !
0010 31F2        LD    R2, R15(#TRAP_CODE_OFFSET)
0012 0024
                 ! REMOVE SYSTEM CALL IDENTIFIER FROM
                   SYSTEM TRAP INSTRUCTION !
0014 8C28        CLRB  RH2
                 ! NOTE: THIS LEAVES THE USER VISIBLE
                   EXTENDED INSTRUCTION NUMBER IN R2 !
                 ! DECODE AND EXECUTE EXTENDED INSTRUCTION !
                 IF  R2
                 ! NOTE: THE INITIAL VALUE FOR REGISTER 2
                   WILL BE RESTORED WHEN THE APPROPRIATE
                   CONDITION IS FOUND !
0016 0B02         CASE  #ADVANCE_CALL  THEN
0018 0001
001A 5E0E
001C 0028'
001E 97F2           POP   R2, @R15
0020 5F00           CALL  ADVANCE
0022 0000*
0024 5E08         CASE  #AWAIT_CALL  THEN
0026 010C'
0028 0B02
002A 0002
002C 5E0E
002E 003A'
0030 97F2           POP   R2, @R15
0032 5F00           CALL  AWAIT
0034 0000*
0036 5E08         CASE  #CREATE_SEG_CALL  THEN
0038 010C'
003A 0B02
003C 0003
003E 5E0E
```

```
0040 0C   '
0042 97F2         POP    R2, @R15
0044 5F00         CALL   CREATE_SEG
0046 0000*
0048 5E08      CASE  #DELETE_SEG_CALL  THEN
004A 010C'
004C 0B02
004E 0004
0050 5E0E
0052 005E'
0054 97F2         POP    R2, @R15
0056 5F00         CALL   DELETE_SEG
0058 0000*
005A 5E08      CASE  #MAKE_KNOWN_CALL  THEN
005C 010C'
005E 0B02
0060 0005
0062 5E0E
0064 0070'
0066 97F2         POP    R2, @R15
0068 5F00         CALL   MAKE_KNOWN
006A 0000*
006C 5E08      CASE  #READ_CALL  THEN
006E 010C'
0070 0B02
0072 0006
0074 5E0E
0076 0082'
0078 97F2         POP    R2, @R15
007A 5F00         CALL   READ
007C 0000*
007E 5E08      CASE  #SM_SWAP_IN_CALL  THEN
0080 010C'
0082 0B02
0084 0007
0086 5E0E
0088 0094'
008A 97F2         POP    R2, @R15
008C 5F00         CALL   SM_SWAP_IN
008E 0000*
0090 5E08      CASE  #SM_SWAP_OUT_CALL  THEN
0092 010C'
0094 0B02
0096 0008
0098 5E0E
009A 00A6'
009C 97F2         POP    R2, @R15
009E 5F00         CALL   SM_SWAP_OUT
00A0 0000*
00A2 5E08      CASE  #TERMINATE_CALL  THEN
00A4 010C'
00A6 0B02
00A8 0009
00AA 5E0E
```

```
00AC 00B8'
00AE 97F2           POP   R2, @R15
00B0 5F00           CALL  TERMINATE
00B2 0000*
00B4 5E08         CASE  #TICKET_CALL  THEN
00B6 010C'
00B8 0B02
00BA 000A
00BC 5E0E
00BE 00CA'
00C0 97F2           POP   R2, @R15
00C2 5F00           CALL  TICKET
00C4 0000*
00C6 5E08         CASE  #WRITE_CALL   THEN
00C8 010C'
00CA 0B02
00CC 000B
00CE 5E0E
00D0 00DC'
00D2 97F2           POP   R2, @R15
00D4 5F00           CALL  WRITE
00D6 0FC8
00D8 5E08         CASE  #WRITELN_CALL  THEN
00DA 010C'
00DC 0B02
00DE 000C
00E0 5E0E
00E2 00EE'
00E4 97F2           POP   R2, @R15
00E6 5F00           CALL  WRITELN
00E8 0FC0
00EA 5E08         CASE  #CRLF_CALL   THEN
00EC 010C'
00EE 0B02
00F0 000D
00F2 5E0E
00F4 0100'
00F6 97F2           POP   R2, @R15
00F8 5F00           CALL  CRLF
00FA 0FD4
00FC 5E08         ELSE !INVALID KERNEL INVOCATION!
00FE 010C'
                    ! RETURN TO MONITOR !
                    ! NOTE: THIS RETURN TO MONITOR IS
                      FOR STUB USE ONLY.  AN INVALID
                      KERNEL INVOCATION WOULD NORMALLY
                      RETURN TO USER. !
0100 7601           LDA   R1, $
0102 0100'
0104 2100           LD    R0, #INVALID_KERNEL_ENTRY
0106 0BAD
0108 5F00           CALL  MONITOR
010A A902
                 FI
```

```
                      ! SAVE REGISTERS ON KERNEL STACK !
                      ! SAVE R1 !
0 10C 93F1            PUSH  @R15, R1
                      ! GET ADDRESS OF REGISTER BLOCK !
010E 34F1             LDA    R1, R15(#4)
0110 0004
                      ! SAVE REGISTERS IN REGISTER BLOCK
                        ON KERNEL STACK. !
0112 1C19             LDM    @R1, R1, #16
0114 010F
                      ! RESTORE R1 BUT MAINTAIN ADDRESS
                        OF REGISTER BLOCK !
0116 2DF1             EX     R1, @R15
                      ! SAVE R1 ON STACK !
0118 33F1             LD     R15(#4), R1
011A 0004
                      ! RESTORE REGISTER BLOCK ADDRESS !
011C 97F1             POP    R1, @R15
                      ! SAVE VALID EXIT SP VALUE !
011E 33F1             LD     R15(#30), R1
0120 001E
                      ! EXIT KERNEL BY MEANS OF HARDWARE
                        PREEMPT HANDLER !
0122 5E08             JP     KERNEL_EXIT
0124 0000*
0126                END  GATE_KEEPER_MAIN
                  END  KERNEL_GATE_KEEPER
```

```
Z8000ASM  2.02
LOC    OBJ CODE    STMT SOURCE STATEMENT

          USER_GATE       MODULE

          $LISTON  $TTY

          CONSTANT
            ADVANCE_CALL           := 1
            AWAIT_CALL             := 2
            CREATE_SEG_CALL        := 3
            DELETE_SEG_CALL        := 4
            MAKE_KNOWN_CALL        := 5
            READ_CALL              := 6
            SM_SWAP_IN_CALL        := 7
            SM_SWAP_OUT_CALL       := 8
            TERMINATE_CALL         := 9
            TICKET_CALL            := 10
            WRITE_CALL             := 11
            WRITELN_CALL           := 12
            CRLF_CALL              := 13

          GLOBAL
          $SECTION USER_GATE_PROC

0000        ADVANCE        PROCEDURE
            !************************
             * PARAMETERS:           *
             *  R1:SEGMENT #         *
             *  R2:INSTANCE (ENTRY#)*
             ************************
             * RETURNS:              *
             *  R0:SUCCESS CODE      *
             ************************!
             ENTRY
0000 7F01      SC    #ADVANCE_CALL
0002 9E08      RET
0004         END  ADVANCE

0004         AWAIT          PROCEDURE
            !************************
             * PARAMETERS:           *
             *  R1:SEGMENT #         *
             *  R2:INSTANCE          *
             *  RR4:SPECIFIED VALUE *
             ************************
             * RETURNS:              *
             *  R0:SUCCESS CODE      *
             ************************!
             ENTRY
0004 7F02      SC    #AWAIT_CALL
0006 9E08      RET
0008         END  AWAIT
```

```
0008       CREATE_SEG     PROCEDURE
          !************************
           * PARAMETERS:          *
           *  R1:MENTOR_SEG_NO    *
           *  R2:ENTRY_NO         *
           *  R3:SIZE             *
           *  RR4:CLASS           *
           ************************
           * RETURNS:             *
           *  R0:SUCCESS CODE     *
           ************************!
           ENTRY
0008 7F03    SC    #CREATE_SEG_CALL
000A 9E08    RET
000C       END  CREATE_SEG

000C       DELETE_SEG     PROCEDURE
          !************************
           * PARAMETERS:          *
           *  R1:MENTOR_SEG_NO    *
           *  R2:ENTRY_NO         *
           ************************
           * RETURNS:             *
           *  R0:SUCCESS CODE     *
           ************************!
           ENTRY
000C 7F04    SC    #DELETE_SEG_CALL
000E 9E08    RET
0010       END  DELETE_SEG

0010       MAKE_KNOWN     PROCEDURE
          !************************
           * PARAMETERS:          *
           *  R1:MENTOR_SEG_NO    *
           *  R2:ENTRY_NO         *
           *  R3:ACCESS DESIRED   *
           ************************
           * RETURNS:             *
           *  R0:SUCCESS CODE     *
           *  R1:SEGMENT #        *
           *  R2:ACCESS ALLOWED   *
           ************************!
           ENTRY
0010 7F05    SC    #MAKE_KNOWN_CALL
0012 9E08    RET
0014       END  MAKE_KNOWN

0014       READ           PROCEDURE
          !************************
           * PARAMETERS:          *
           *  R1:SEGMENT #        *
           *  R2:INSTANCE         *
           ************************
```

```
              * RETURNS:              *
              *  R0:SUCCESS CODE      *
              *  RR4:EVENTCOUNT       *
              ************************!
              ENTRY
0014 7F06       SC     #READ_CALL
0016 9E08       RET
0018          END  READ

0018          SM_SWAP_IN     PROCEDURE
             !************************
              * PARAMETERS:           *
              *  R1:SEGMENT #         *
              ************************
              * RETURNS:              *
              *  R0:SUCCESS CODE      *
              ************************!
              ENTRY
0018 7F07       SC     #SM_SWAP_IN_CALL
001A 9E08       RET
001C          END  SM_SWAP_IN

001C          SM_SWAP_OUT    PROCEDURE
             !************************
              * PARAMETERS:           *
              *  R1:SEGMENT #         *
              ************************
              * RETURNS:              *
              *  R0:SUCCESS CODE      *
              ************************!
              ENTRY
001C 7F08       SC     #SM_SWAP_OUT_CALL
001E 9E08       RET
0020          END  SM_SWAP_OUT

0020          TERMINATE      PROCEDURE
             !************************
              * PARAMETERS:           *
              *  R1:SEGMENT #         *
              ************************
              * RETURNS:              *
              *  R0:SUCCESS CODE      *
              ************************!
              ENTRY
0020 7F09       SC     #TERMINATE_CALL
0022 9E08       RET
0024          END  TERMINATE

0024          TICKET         PROCEDURE
             !************************
              * PARAMETERS:           *
              *  R1:SEGMENT #         *
              ************************
              * RETURNS:              *
```

```
                     *  R0:SUCCESS CODE     *
                     *  RR4:TICKET VALUE    *
                     ************************!
                     ENTRY
0024 7F0A              SC     #TICKET_CALL
0026 9E08              RET
0028                 END  TICKET

0028                 WRITE              PROCEDURE
                     ENTRY
0028 7F0B              SC     #WRITE_CALL
002A 9E08              RET
002C                 END  WRITE

002C                 WRITELN            PROCEDURE
                     ENTRY
002C 7F0C              SC     #WRITELN_CALL
002E 9E08              RET
0030                 END  WRITELN

0030                 CRLF               PROCEDURE
                     ENTRY
0030 7F0D              SC     #CRLF_CALL
0032 9E08              RET
0034                 END  CRLF
```

Appendix E

BOOTSTRAP_LOADER LISTINGS

```
Z8000ASM  2.02
LOC    OBJ CODE    STMT SOURCE STATEMENT

             BOOTSTRAP_LOADER   MODULE

      $LISTON $TTY
      CONSTANT

              ! ******** SYSTEM PARAMETERS ******** !
              NR_CPU              := 2
              NR_VP               := NR_CPU*4
              NR_AVAIL_VP         := NR_CPU*2
              MAX_DBR_NR          := 10
              STACK_SEG           := 1
              STACK_SEG_SIZE      := %100
              STACK_BLOCK         := STACK_SEG_SIZE/256

                ! * * OFFSETS IN STACK SEG * * !
              STACK_BASE          := STACK_SEG_SIZE-%10
              STATUS_REG_BLOCK:= STACK_SEG_SIZE-%10
              INTERRUPT_FRAME     := STACK_BASE-4
              INTERRUPT_REG       := INTERRUPT_FRAME-34
              N_S_P               := INTERRUPT_REG-2
              F_C_W               := STACK_SEG_SIZE-%E

             ! ****** SYSTEM CONSTANTS ****** !
              ON                  := %FFFF
              OFF                 := 0
              READY               := 1
              NIL                 := %FFFF
              INVALID             := %EEEE
              KERNEL_FCW          := %5000
              AVAILABLE           := 0
              ALLOCATED           := %FF
              SC_OFFSET           := 12

       TYPE

              MESSAGE  ARRAY [16    BYTE]
              ADDRESS  WORD
              MM_VP_ID WORD
              VP_INDEX        INTEGER
              MSG_INDEX       INTEGER
```

```
    MSG_TABLE RECORD
     [ MSG          MESSAGE
       SENDER       VP_INDEX
       NEXT_MSG     MSG_INDEX
       FILLER       ARRAY [6, WORD]
     ]

    VP_TABLE RECORD
    [  DBR   ADDRESS
       PRI             WORD
       STATE           WORD
       IDLE_FLAG       WORD
       PREEMPT         WORD
       PHYS_PROCESSOR  WORD
       NEXT_READY_VP VP_INDEX
       MSG_LIST        MSG_INDEX
       EXT_ID          WORD
       FILLER_1        ARRAY[ 7, WORD]
    ]

EXTERNAL
    GET_DBR_ADDR    PROCEDURE
    CREATE_STACK    PROCEDURE
    LIST_INSERT     PROCEDURE
    ALLOCATE_MMU    PROCEDURE
    UPDATE_MMU_IMAGE PROCEDURE
    MM_ALLOCATE     PROCEDURE
    MM_ENTRY        LABEL
    IDLE_ENTRY      LABEL
    PREEMPT_RET     LABEL
    BOOTSTRAP_ENTRY LABEL
    GATE_KEEPER_ENTRY LABEL
    NEXT_BLOCK      WORD
    MM_CPU_TBL ARRAY[NR_CPU MM_VP_ID]

   VPT      RECORD
    [ LOCK         WORD
      RUNNING_LIST ARRAY[NR_CPU WORD]
      READY_LIST   ARRAY[NR_CPU WORD]
      FREE_LIST    MSG_INDEX
      VIRT_INT_VEC ARRAY[1, ADDRESS]
      FILLER_2     WORD
      VP        ARRAY [NR_VP, VP_TABLE]
      MSG_Q        ARRAY [NR_VP, MSG_TABLE]
    ]
```

```
              EXT_VP_LIST    ARRAY[NR_AVAIL_VP WORD]
              NEXT_AVAIL_MMU  ARRAY[MAX_DBR_NR  BYTE]

              PRDS    RECORD
                 [PHYS_CPU_ID WORD
                  LOG_CPU_ID  INTEGER
                  VP_NR       WORD
                  IDLE_VP     VP_INDEX]

          INTERNAL
          $SECTION LOADER_DATA

         ! NOTE: THESE DECLARATIONS WILL NOT WORK
           IN A TRUE MULTIPROCESSOR ENVIRONMENT AS
           THEY ARE SUBJECT TO A "CALL."  THEY MUST
           BE DECLARED AS A SHARED GLOBAL DATABASE
           WITH "RACE" PROTECTION (E.G., LOCK). !

0000     NEXT_AVAIL_VP   INTEGER
0002     NEXT_EXT_VP     INTEGER
```

```
      $SECTION  LOADER_INT
         INTERNAL
0000             BOOTSTRAP                PROCEDURE
                !*********************************
                 * CREATES KERNEL PROCESSES AND *
                 * INITIALIZES KERNEL DATABASES.*
                 * INCLUDES INITIALIZATION OF   *
                 * VIRTUAL PROCESSOR TABLE,     *
                 * EXTERNAL VP LIST, AND MMU    *
                 * IMAGES.  ALLOCATES MMU IMAGE *
                 * AND CREATES KERNEL DOMAIN    *
                 * STACK FOR KERNEL PROCESSES.  *
                 *********************************!

                 ENTRY
                 ! INITIALIZE PRDS AND MMU POINTER !
                 ! NOTE: THE FOLLOWING CONSTANTS ARE
                   ONLY TO BE INITIALIZED ONCE.  THIS
                   WILL OCCUR DURING SYSTEM INITIALIZATION!
0000 4D05        LD          PRDS.PHYS_CPU_ID, #%FFFF
0002 0000*
0004 FFFF
                  ! NOTE: LOGICAL CPU NUMBERS ARE ASSIGNED
                    IN INCREMENTS OF 2 TO FACILITATE INDEXING
                    (OFFSETS) INTO LISTS SUBSCRIPTED BY
                    LOGICAL CPU NUMBER. !
0006 4D05        LD          PRDS.LOG_CPU_ID, #2
0008 0002*
000A 0002
                  ! SPECIFY NUMBER OF VIRTUAL PROCESSORS
                    ASSOCIATED WITH PHYSICAL CPU. !
000C 4D05        LD          PRDS.VP_NR, #2
000E 0004*
0010 0002
0012 4D08        CLR         NEXT_BLOCK
0014 0000*
0016 4D08        CLR         NEXT_AVAIL_VP
0018 0000'
001A 4D08        CLR         NEXT_EXT_VP
001C 0002'
                 ! ESTABLISH GATE KEEPER AS SYSTEM CALL
                   TRAP HANDLER !
                 ! GET BASE OF PROGRAM STATUS AREA !
001E 7D15        LDCTL       R1, PSAP

                 ! ADD SYSTEM CALL OFFSET TO PSA BASE ADDR !
0020 0101        ADD         R1, #SC_OFFSET
0022 000C
                 ! STORE KERNEL FCW IN PSA !
0024 0D15        LD          @R1, #KERNEL_FCW
0026 5000
                 ! STORE ADDRESS OF GATE KEEPER IN PROGRAM
                   STATUS AREA AS SYSTEM TRAP HANDLER !
0028 A911        INC         R1, #2
```

```
002A 0D15     LD         @R1, #GATE_KEEPER_ENTRY
002C 0000*
002E 8D18     CLR        R1  ! NEXT_AVAIL_MMU INDEX !

              ! INITIALIZE ALL MMU IMAGES AS AVAILABLE !
           SET_MMU_MAP:

               DO
0030 4C15       LDB      NEXT_AVAIL_MMU(R1), #AVAILABLE
0032 0000*
0034 0000
0036 A910       INC      R1, #1
                ! CHECK FOR END OF TABLE !
0038 0B01       CP       R1, #MAX_DBR_NR
003A 000A
003C 5E0E       IF EQ THEN EXIT FROM SET_MMU_MAP  FI
003E 0044'
0040 5E08
0042 0046'
0044 E8F5     OD

              ! CREATE MEMORY MANAGER PROCESS !
0046 2103     LD         R3, #STACK_BLOCK
0048 0001
              ! ALLOCATE AND INITIALIZE KERNEL
                DOMAIN STACK SEGMENT !
004A 5F00     CALL       MM_ALLOCATE  !R3: # OF BLOCKS
004C 0000*
                                      RETURNS
                                      R2: START ADDR!
004E A121     LD         R1, R2
0050 2103     LD         R3, #KERNEL_FCW
0052 5000
0054 7604     LDA        R4, MM_ENTRY
0056 0000*
0058 6105     LD         R5, %FFFF  !NSP!
005A FFFF
005C 7606     LDA        R6, PREEMPT_RET
005E 0000*
0060 93F1     PUSH       @R15, R1 !SAVE STACK ADDR!
0062 030F     SUB        R15, #8
0064 0008
0066 1CF9     LDM        @R15, R3, #4
0068 0303
006A A1F0     LD         R0, R15

              ! NOTE: ARGLIST FOR CREATE_STACK INCLUDES
                KERNEL_FCW, INITIAL IC, NSP, AND INITIAL
                RETURN POINT. !
006C 5F00     CALL       CREATE_STACK   ! (R0: ARGUMENT PTR
006E 0000*
                                           R1: TOP OF STACK
                                           R2-R14: INITIAL
                                           REG.STATES !
```

```
0070 010F     ADD       R15, #8  !OVERLAY ARGUMENTS!
0072 0008
              ! ALLOCATE MMU_IMAGE !
0074 5F00     CALL      ALLOCATE_MMU    !RETURNS:
0076 0000*
                                         (R0: DBR #) !
0078 2101     LD        R1, #STACK_SEG    ! SEGMENT NO. !
007A 0001
007C 97F2     POP       R2, @R15  !GET STACK ADDR!
007E 2103     LD        R3, #0    ! WRITE ATTRIBUTE !
0080 0000
              ! SPECIFY NUMBER OF BLOCKS. COUNT STARTS
                FROM ZERO. (I.E.,1 BLOCK=0, 2=1, ETC.)!
0082 2104     LD        R4, #STACK_BLOCK-1
0084 0000
              ! SAVE DBR # !
0086 93F0     PUSH      @R15, R0

              ! CREATE MMU ENTRY FOR MM STACK SEGMENT !
0088 5F00     CALL      UPDATE_MMU_IMAGE  !(R0: DBR #
008A 0000*
                                          R1: SEGMENT #
                                          R2: SEG ADDRESS
                                          R3: SEG ATTRIBUTES
                                          R4: SEG LIMITS)   !
              ! RESTORE DBR # !
008C 97F0     POP        R0, @R15

              ! GET ADDRESS OF MMU IMAGE !
008E 5F00     CALL      GET_DBR_ADDR  ! (R0: DBR #)
0090 0000*
                                         RETURNS:
                                         (R1: DBR ADDRESS) !
              ! PREPARE VP TABLE ENTRIES FOR MM !
0092 2102     LD        R2, #2     ! PRIORITY !
0094 0002
0096 2105     LD        R5, #OFF    ! PREEMPT !
0098 0000
009A 2106     LD        R6, #OFF  ! KERNEL PROCESS !
009C 0000

              ! UPDATE VPT !
009E 5F00     CALL      UPDATE_VP_TABLE  !(R1: DBR
00A0 01CA'
                                          R2: PRIORITY
                                          R5: PREEMPT FLAG
                                          R6: EXT_VP FLAG)
                                          RETURNS:
                                          R9: VP_ID !
              ! INITIALIZE MM_CPU_TBL IN DISTRIBUTED MEMORY
                MANAGER WITH VP ID OF MM PROCESS !
              ! GET LOGICAL CPU # !
00A2 610A     LD R10, PRDS.LOG_CPU_ID
00A4 0002*
```

```
00A6 6FA9     LD          MM_CPU_TBL(R10), R9
00A8 0000*
              ! CREATE IDLE PROCESS !
00AA 2103     LD         R3, #STACK_BLOCK
00AC 0001
00AE 5F00     CALL       MM_ALLOCATE !R3: # OF BLOCKS
00B0 0000*
                                   RETURNS
                                   R2: START ADDR!
00B2 A121     LD         R1, R2
00B4 2103     LD         R3, #KERNEL_FCW
00B6 5000
00B8 7604     LDA        R4, IDLE_ENTRY
00BA 0000*
00BC 2105     LD         R5, #%FFFF !NSP!
00BE FFFF
00C0 7606     LDA        R6, PREEMPT_RET
00C2 0000*
00C4 93F1     PUSH       @R15, R1 !SAVE STACK ADDR!
00C6 030F     SUB        R15, #8
00C8 0008
00CA 1CF9     LDM        @R15, R3, #4
00CC 0303
00CE A1F0     LD         R0, R15

              ! INITIALIZE IDLE STACK VALUES !
00D0 5F00     CALL       CREATE_STACK  ! (R0: ARGUMENT PTR

                                      R1: TOP OF STACK
                                      R2-R14: INITIAL
                                      REG. STATES !
00D4 010F     ADD        R15, #8 !OVERLAY ARGUMENTS!
00D6 0008

              ! ALLOCATE MMU IMAGE FOR IDLE PROCESS !
00D8 5F00     CALL       ALLOCATE_MMU  ! RETURNS R0:DBR # !
00DA 0000*

              ! PREPARE IDLE PROCESS MMU ENTRIES !
00DC 2101     LD         R1, #STACK_SEG  ! SEG # !
00DE 0001
00E0 97F2     POP        R2, @R15  !GET STACK ADDR!
00E2 2103     LD         R3, #0           ! WRITE ATTRIBUTE !
00E4 0000
00E6 2104     LD         R4, #STACK_BLOCK-1  ! BLOCK LIMITS !
00E8 0000
              ! SAVE DBR # !
00EA 93F0     PUSH       @R15, R0

              ! CREATE MMU IMAGE ENTRY !
00EC 5F00     CALL       UPDATE_MMU_IMAGE  !(R1: SEGMENT #
00EE 0000*
                                       R2: SEG ADDRESS
                                       R3: SEG ATTRIBUTES
```

```
                                                R4: SEG LIMITS ) !
                  ! RESTORE DBR # !
00F0 97F0         POP         R0, @R15

                  ! GET MMU ADDRESS !
00F2 5F00         CALL        GET_DBR_ADDR  ! (R0: DBR #)
00F4 0000*
                                               RETURNS
                                               (R1: DBR ADDRESS) !
                  ! PREPARE VPT ENTRIES FOR IDLE PROCESS !
00F6 2102         LD          R2, #0          ! PRIORITY !
00F8 0000
00FA 2105         LD          R5, #OFF        ! PREEMPT !
00FC 0000
00FE 2106         LD          R6, #OFF        ! KERNEL PROC !
0100 0000

                  ! CREATE VPT ENTRIES !
0102 5F00         CALL        UPDATE_VP_TABLE  !(R1: DBR
0104 01CA'
                                                R2: PRIORITY
                                                R4: IDLE_FLAG
                                                R5: PREEMPT
                                                R6: EXT_VP FLAG)
                                                RETURNS:
                                                R9: VP_ID !
                  ! ENTER VP ID OF IDLE PROCESS IN PRDS !
0106 6F09         LD          PRDS.IDLE_VP, R9
0108 0006*
                  ! INITIALIZE IDLE VP'S !
010A 2102         LD          R2, #1          ! PRIORITY !
010C 0001
010E 2105         LD          R5, #ON         ! PREEMPT !
0110 FFFF
0112 2106         LD          R6, #ON         !NON-KERNEL PROC!
0114 FFFF
0116 6100         LD          R0, PRDS.VP_NR
0118 0004*
                  ! INITIALIZE VP VALUES !
                  DO
011A 5F00         CALL        UPDATE_VP_TABLE  !(R1: DBR
011C 01CA'
                                                R2: PRIORITY
                                                R4: IDLE_FLAG
                                                R5: PREEMPT
                                                R6: EXT_VP FLAG)
                                                RETURNS:
                                                R9: VP_ID !
011E AB00         DEC         R0, #1
0120 0B00         CP          R0, #0
0122 0000
0124 5E0E         IF EQ !ALL VP'S INITIALIZED! THEN
0126 012C'
0128 5E08            EXIT
```

```
012A 012E'
               FI
012C E8F6     OD

              ! INITILIZE VPT HEADER !
              ! GET LOGICAL CPU NUMBER !
012E 6102     LD          R2, PRDS.LOG_CPU_ID
0130 0002*
0132 4D05     LD          VPT.LOCK, #OFF
0134 0000*
0136 0000
0138 4D25     LD          VPT.RUNNING_LIST(R2), #NIL
013A 0002*
013C FFFF
013E 4D25     LD          VPT.READY_LIST(R2), #NIL
0140 0006*
0142 FFFF
0144 4D08     CLR         VPT.FREE_LIST  !HEAD OF MSG LIST!
0146 000A*

          !THREAD VP'S BY PRIORITY AND SET STATES TO READY !
0148 8D28     CLR         R2  !START WITH VP #1!

           THREAD:
              DO
014A 610D        LD       R13, PRDS.LOG_CPU_ID
014C 0002*
014E 76D3        LDA      R3,VPT.READY_LIST(R13)
0150 0006*
0152 7604        LDA      R4,VPT.VP.NEXT_READY_VP
0154 001C*
0156 7605        LDA      R5,VPT.VP.PRI
0158 0012*
015A 7606        LDA      R6,VPT.VP.STATE
015C 0014*
015E 2107        LD       R7,#READY
0160 0001
                 ! SAVE OBJ ID !
0162 93F2        PUSH     @R15, R2
0164 5F00        CALL     LIST_INSERT !R2: OBJ ID
0166 0000*
                                        R3: LIST_HEAD_PTR ADDR
                                        R4: NEXT_OBJ PTR
                                        R5: PRIORITY_PTR
                                        R6: STATE_PTR
                                        R7: STATE    !
                 ! RESTORE OBJ ID !
0168 97F2        POP      R2, @R15
016A 0102        ADD      R2, #SIZEOF VP_TABLE
016C 0020
016E 0B02        CP       R2, #(NR_VP * (SIZEOF VP_TABLE))
0170 0100
0172 5E0E        IF EQ THEN EXIT FROM THREAD FI
0174 017A'
```

```
0176 5E08
0178 017C'
017A E8E7    OD

             ! INITIALIZE VP MESSAGE LIST !
             ! NOTE: ONLY THE THREAD FOR THE MESSAGE
               LIST NEED BE CREATED AS ALL MESSAGES
               ARE INITIALLY AVAILABLE FOR USE. THE
               INITIAL MESSAGE VALUES WERE CREATED
               FOR CLARITY ONLY TO SHOW THAT THE
               MESSAGES HAVE NO USABLE INITIAL VALUE!
017C 8D18    CLR        R1

         MSG_LST_INIT:
             ! NOTE: R1 REPRESENTS CURRENT ENTRY IN
               MSG_LIST, R2 REPRESENTS CURRENT POSITION
               IN MSG_LIST ENTRY, AND R3 REPRESENTS
               NEXT ENTRY IN MSG_LIST. !
              DO
017E A112      LD       R2, R1
0180 A123      LD       R3, R2
0182 0103      ADD      R3, #SIZEOF MESSAGE
0184 0010
              FILL_MSG:
                DO
0186 4D25       LD      VPT.MSG_Q.MSG(R2), #INVALID
0188 0110*
018A EEEE
018C A921       INC     R2, #2
018E 8B32       CP      R2, R3
0190 5E0E       IF EQ THEN EXIT FROM FILL_MSG FI
0192 0198'
0194 5E08
0196 019A'
0198 E8F6      OD
019A 4D15      LD       VPT.MSG_Q.SENDER(R1), #NIL
019C 0120*
019E FFFF
01A0 A112      LD       R2, R1
01A2 0101      ADD      R1, #SIZEOF MSG_TABLE
01A4 0020
01A6 0B01      CP       R1, #SIZEOF MSG_TABLE*NR_VP
01A8 0100
                IF EQ
01AA 5E0E       THEN
01AC 01BC'
01AE 4D25        LD     VPT.MSG_Q.NEXT_MSG(R2), #NIL
01B0 0122*
01B2 FFFF
01B4 5E08        EXIT FROM MSG_LST_INIT
01B6 01C2'
01B8 5E08       ELSE
01BA 01C0'
01BC 6F21        LD     VPT.MSG_Q.NEXT_MSG(R2), R1
```

```
01BE 0122*
                  FI
01C0 E8DE    OD

             ! GET LOGICAL CPU # FOR USE
               BY ITC GETWORK. !
01C2 610D    LD           R13, PRDS.LOG_CPU_ID
01C4 0002*
             ! BOOTSTRAP COMPLETE !
             ! START SYSTEM EXECUTION AT PREEMPT ENTRY !
             ! POINT IN ITC GETWORK PROCEDURE !
01C6 5E08    JP         BOOTSTRAP_ENTRY
01C8 0000*
01CA        END BOOTSTRAP
```

```
01CA              UPDATE_VP_TABLE       PROCEDURE
                  !********************************
                  * INITIALIZES VPT ENTRIES       *
                  *********************************
                  * REGISTER USE:                 *
                  *  PARAMETERS:                  *
                  *   R1: DBR ADDRESS             *
                  *   R2: PRIORITY                *
                  *   R5: PREEMPT FLAG            *
                  *   R6: EXTERNAL VP FLAG        *
                  *  RETURNS:                     *
                  *   R9: ASSIGNED VP ID          *
                  *  LOCAL VARIABLES:             *
                  *   R7: LOGICAL CPU #           *
                  *   R8: EXT_VP_LIST OFFSET      *
                  *   R9: VPT OFFSET              *
                  ********************************!

                  ENTRY
                  ! GET OFFSET IN VPT FOR NEXT ENTRY !
01CA 6109         LD        R9, NEXT_AVAIL_VP
01CC 0000'
01CE 6F91         LD        VPT.VP.DBR(R9), R1
01D0 0010*
01D2 6F92         LD        VPT.VP.PRI(R9), R2
01D4 0012*
01D6 6F96         LD        VPT.VP.IDLE_FLAG(R9), R6
01D8 0016*
01DA 6F95         LD        VPT.VP.PREEMPT(R9), R5
01DC 0018*
01DE 6107         LD        R7, PRDS.LOG_CPU_ID
01E0 0002*
01E2 6F97         LD        VPT.VP.PHYS_PROCESSOR(R9), R7
01E4 001A*
01E6 4D95         LD        VPT.VP.NEXT_READY_VP(R9), #NIL
01E8 001C*
01EA FFFF
01EC 4D95         LD        VPT.VP.MSG_LIST(R9), #NIL
01EE 001E*
01F0 FFFF

                  ! CHECK EXTERNAL VP FLAG !
01F2 0B06         CP        R6, #ON
01F4 FFFF
                   IF EQ !EXTERNAL VP!
01F6 5E0E          THEN  ! VP IS TC VISIBLE !
01F8 0210'
01FA 6108           LD      R8, NEXT_EXT_VP
01FC 0002'
                    ! INSERT ENTRY IN EXTERNAL VP LIST !
01FE 6F89           LD      EXT_VP_LIST(R8), R9
0200 0000*
0202 6F98           LD      VPT.VP.EXT_ID(R9), R8
0204 0020*
```

```
0206 A981       INC     R8, #2
0208 6F08       LD      NEXT_EXT_VP, R8
020A 0002'
020C 5E08      ELSE  !VP DOUND TO KERNEL PROCESS!
020E 0216'
0210 4D05       LD      VPT.VP.EXT_ID, #NIL
0212 0020*
0214 FFFF
              FI
0216 A19A     LD        R10, R9
0218 010A     ADD       R10, #SIZEOF VP_TABLE
021A 0020
021C 6F0A     LD        NEXT_AVAIL_VP, R10
021E 0000'
0220 9E08     RET
0222        END UPDATE_VP_TABLE
         END BOOTSTRAP_LOADER
```

Appendix F

LIBRARY FUNCTION LISTINGS

```
Z8000ASM  2.02
LOC    OBJ CODE    STMT SOURCE STATEMENT

                 LIBRARY_FUNCTION  MODULE

        $LISTON $TTY

        CONSTANT
          KERNEL_FCW       := %5000
          STACK_SEG_SIZE   := %100
          STACK_BASE       := STACK_SEG_SIZE-%10
          STATUS_REG_BLOCK:= STACK_SEG_SIZE-%10
          INTERRUPT_FRAME := STACK_BASE-4
          INTERRUPT_REG    := INTERRUPT_FRAME-34
          N_S_P            := INTERRUPT_REG-2
          NIL              := %FFFF
        $SECTION LIB_PROC
        GLOBAL

0000         LIST_INSERT             PROCEDURE
            !***********************************
             * INSERTS OBJECTS INTO A LIST     *
             * BY ORDER OF PRIORITY AND SETS   *
             * ITS STATE                       *
             ***********************************
             * REGISTER USE:                   *
             *  PARAMETERS:                    *
             *   R2: OBJECT ID                 *
             *   R3: HEAD_OF_LIST_PTR ADDR     *
             *   R4: NEXT_OBJ_PTR ADDR         *
             *   R5: PRIORITY_PTR ADDR         *
             *   R6: STATE_PTR ADDR            *
             *   R7: OBJECT STATE              *
             *  LOCAL VARIABLES:               *
             *   R8: HEAD_OF_LIST_PTR          *
             *   R9: NEXT_OBJ_PTR              *
             *   R10: CURRENT_OBJ PRIORITY     *
             *   R11: NEXT_OBJ PRIORITY        *
             ***********************************!

             ENTRY
             ! GET FIRST OBJECT IN LIST !
0000 2138    LD              R8, @R3
0002 0B08    CP              R8, #NIL
0004 FFFF
0006 5E0E    IF EQ !LIST IS EMPTY! THEN
0008 0018'
              ! PLACE OBJ AT HEAD OF LIST !
000A 2F32     LD             @R3, R2
000C 7449     LDA            R9, R4(R2)
000E 0200
0010 0D95     LD             @R9, #NIL
0012 FFFF
0014 5E08    ELSE
0016 005A'
              ! COMPARE OBJ PRI WITH LIST HEAD PRI !
0018 715A     LD             R10, R5(R2) !OBJ PRI!
001A 0200
001C 715B     LD             R11, R5(R8) !HEAD PRI!
001E 0800
0020 8BBA     CP             R10, R11
0022 5E02     IF GT !OBJ PRI>HEAD PRI! THEN
0024 0030'
0026 2F32      LD            @R3, R2  !PUT AT FRONT!
0028 7348      LD            R4(R2), R8
002A 0200
002C 5E08     ELSE ! INSERT IN BODY OF LIST !
002E 005A'

          SEARCH_LIST:
              DO
0030 0B08       CP          R8, #NIL
0032 FFFF
0034 5E0E       IF EQ !END OF LIST! THEN
0036 003C'
0038 5E08        EXIT FROM SEARCH_LIST
003A 0052'
                FI
003C 715B       LD          R11, R5(R8) !GET NEXT PRI!
003E 0800
0040 8BBA       CP          R10, R11
0042 5E02       IF GT !CURRENT PRI>NEXT PRI! THEN
0044 004A'
0046 5E08        EXIT FROM SEARCH_LIST
0048 0052'
                FI

                ! GET NEXT OBJ !
004A A189       LD          R9, R8
004C 7148       LD          R8, R4(R9)
004E 0900
0050 E8EF      OD   ! END SEARCH_LIST !

               ! INSERT IN LIST !
0052 7348      LD           R4(R2), R8
0054 0200
0056 7342      LD           R4(R9), R2
0058 0900
              FI
             FI

             ! SET OBJECT'S STATE !
005A 7367    LD             R6(R2), R7
005C 0200
005E 9E08    RET
0060        END LIST_INSERT
```

```
0060            CREATE_STACK           PROCEDURE
               !*********************************
                * INITIALIZES KERNEL STACK      *
                * SEGMENT FOR PROCESSES         *
                *********************************
                * REGISTER USE:                 *
                *  PARAMETERS:                  *
                *   R0: ARGUMENT POINTER        *
                *   (INCLUDES:FCW,IC,NSP, AND   *
                *    RETURN POINT. SEE LOCAL    *
                *    VARIABLES BELOW.)          *
                *   R1: TOP OF STACK            *
                *   R2-R14: INITIAL REGISTER    *
                *    STATES. (NOTE: IN DEMO, NO*
                *    SPECIFIC INITIAL REGISTER *
                *    VALUES ARE SET, EXCEPT R13*
                *    (USER ID) FOR USER PRO-    *
                *    CESSES.)                   *
                *********************************
                *  LOCAL VARIABLES              *
                *  (FROM ARGUMENTS STORED ON    *
                *   STACK.)                     *
                *   R3: FCW                     *
                *   R4: PROCESS ENTRY POINT(IC)*
                *   R5: NSP                     *
                *   R6: PREEMPT RETURN POINT    *
                *********************************!

                ENTRY
0060 93F0       PUSH      @R15, R0 !SAVE ARGUMENT PTR!
0062 ADF0       EX        R0, R15  !SAVE SP!
0064 341F       LDA       R15, R1(#INTERRUPT_REG)
0066 00CA
0068 1CF9       LDM       @R15, R1, #16  !INITIAL REG. VALUES!
006A 010F
                ! NOTE: ONLY REGISTERS R2-R14 MAY CONTAIN
                  INITIALIZATION VALUES !
006C A10F       LD        R15, R0  !RESTORE SP!
006E 97F0       POP       R0, @R15 !RESTORE ARGUMENT PTR!
0070 A1FE       LD        R14, R15 !SAVE CALLER RETURN POINT!
0072 A10F       LD        R15, R0  !GET ARGUMENT PTR!
0074 1CF1       LDM       R3, @R15, #4 !LOAD ARGUMENTS!
0076 0303
0078 341F       LDA       R15, R1(#INTERRUPT_FRAME)
007A 00EC
007C 1CF9       LDM       @R15, R3, #2 !INIT IRET FRAME!
007E 0301
0080 341F       LDA       R15, R1(#N_S_P)
0082 00C8
0084 2FF5       LD        @R15, R5  !SET NSP!
0086 030F       SUB       R15, #2
0088 0002
008A 2FF6       LD        @R15, R6 !PREEMPT RET POINT!
008C 3418       LDA       R8, R1(#STACK_BASE)
```

```
008E 00F0
              ! INITIALIZE STATUS REGISTER BLOCK !
0090 2100     LD         R0, #KERNEL_FCW
0092 5000
0094 1C89     LDM        @R8, R15, #2  !SAVE SP & FCW!
0096 0F01
0098 A1EF     LD         R15, R14  !RESTORE RETURN POINT!
009A 9E08     RET
009C        END CREATE_STACK
        END LIBRARY_FUNCTION
```

Appendix G

INNER TRAFFIC CONTROLLER LISTINGS

```
Z8000ASM  2.02
LOC    OBJ CODE    STMT SOURCE STATEMENT

            INNER_TRAFFIC_CONTROL MODULE

       $LISTON $TTY

    !**1. GETWORK:
          A. NORMAL ENTRY DOES NOT SAVE REGISTERS.
          ( THIS IS A FUNCTION OF THE GATEKEEPER ).
          B. R14 IS AN INPUT PARAMETER TO GETWORK THAT
           SIMULATES INFO THAT WILL EVENTUALLY BE ON
           THE MMU HARDWARE.  THIS REGISTER MUST BE
           ESTABLISHED AS A DBR BY ANY PROCEDURE
           INVOKING GETWORK.
        C. THE PREEMPT INTERRUPT ENTRY HANDLER DOES
           NOT USE THE GATEKEEPER AND MUST PERFORM
           FUNCTIONS NORMALLY ACCOMPLISHED BY IT
           PRIOR TO NORMAL ENTRY AND EXIT.
         ( SAVE/RESTORE: REGS, NSP; UNLOCK VPT, TEST INT)

       2. GENERAL:
        A. ALL VIOLATIONS OF VIRTUAL MACHINE INSTRUCTIONS
           ARE CONSIDERED ERROR CONDITIONS AND WILL RETURN
           SYSTEM TO THE MONITOR WITH AN ERROR CODE IN R0
           AND THE PC VALUE IN R1.
        B. ITC PROCEDURES CALLING GETWORK PASS DBR
           (REGISTER R14) AND LOGICAL CPU NUMBER
           (REGISTER R13) AS INPUT PARAMETERS.
           (INCLUDES: SIGNAL, WAIT, SWAP_VDBR,
            PHYS_PREEMPT_HANDLER, AND IDLE).  !

        CONSTANT
             ! ********** ERROR CODES ********** !
           U_L       := 0      ! UNAUTHORIZED LOCK !
           M_L_EM    := 1      ! MESSAGE LIST EMPTY !
           M_L_ER    := 2      ! MESSAGE LIST ERROR !
           R_L_E     := 3      ! READY LIST EMPTY !
           M_L_O     := 4      ! MESSAGE LIST OVERFLOW !
           S_N_A     := 5      ! SWAP NOT ALLOWED !
           V_I_E     := 6      ! VP INDEX ERROR !
           M_U       := 7      ! MMU UNAVAILABLE !
```

```
   ! ******** SYSTEM PARAMETERS ******** !
   NR_SDR          := 64   !LONG WORDS!
   NR_CPU          := 2
   NR_VP           := NR_CPU*4
   NR_AVAIL_VP     := NR_CPU*2
   MAX_DBR_NR      := 10  !PER CPU!
   STACK_SEG       := 1
   PRDS_SEG        := 0
   STACK_SEG_SIZE  := %100

   ! ***** OFFSETS IN STACK SEG ***** !
   STACK_BASE      := STACK_SEG_SIZE-%10
   STATUS_REG_BLOCK:= STACK_SEG_SIZE-%10
   INTERRUPT_FRAME := STACK_BASE-4
   INTERRUPT_REG   := INTERRUPT_FRAME-34
   N_S_P           := INTERRUPT_REG-2
   F_C_W           := STACK_SEG_SIZE-%E

   ON      := %FFFF
   OFF     := 0
   RUNNING := 0
   READY   := 1
   WAITING := 2
   NIL     := %FFFF
   INVALID := %EEEE
   MONITOR  := %A900        ! HBUG ENTRY !
   KERNEL_FCW  := %5000
   AVAILABLE   := 0
   ALLOCATED   := %FF

TYPE
   MESSAGE  ARRAY [ 16   BYTE]
   ADDRESS  WORD
   VP_INDEX         INTEGER
   MSG_INDEX        INTEGER

   SEG_DESC_REG  RECORD
                [
                 BASE      ADDRESS
                 ATTRIBUTES        BYTE
                 LIMITS            BYTE
                ]

   MMU              ARRAY[ NR_SDR SEG_DESC_REG]

   MSG_TABLE RECORD
    [ MSG           MESSAGE
      SENDER        VP_INDEX
      NEXT_MSG      MSG_INDEX
      FILLER        ARRAY [6, WORD]
    ]
```

```
               VP_TABLE RECORD
               [  DBR   ADDRESS
                  PRI           WORD
                  STATE         WORD
                  IDLE_FLAG     WORD
                  PREEMPT       WORD
                  PHYS_PROCESSOR  WORD
                  NEXT_READY_VP VP_INDEX
                  MSG_LIST      MSG_INDEX
                  EXT_ID        WORD
                  FILLER_1      ARRAY[ 7, WORD ]
                ]

           EXTERNAL
             LIST_INSERT       PROCEDURE

           GLOBAL
             BOOTSTRAP_ENTRY   LABEL

           $SECTION ITC_DATA

0000         VPT      RECORD
               { LOCK         WORD
                 RUNNING_LIST ARRAY[NR_CPU WORD]
                 READY_LIST   ARRAY[NR_CPU WORD]
                 FREE_LIST    MSG_INDEX
                 VIRT_INT_VEC ARRAY[1, ADDRESS]
                 FILLER_2     WORD
                 VP         ARRAY [NR_VP, VP_TABLE]
                 MSG_Q        ARRAY [NR_VP, MSG_TABLE]
               ]
0210         EXT_VP_LIST  ARRAY[NR_AVAIL_VP  WORD]

          $SECTION MMU_DATA

0000         MMU_IMAGE       RECORD
                 [
                   MMU_STRUCTURE       ARRAY[MAX_DBR_NR  MMU]
                 ]
0A00         NEXT_AVAIL_MMU  ARRAY[MAX_DBR_NR  BYTE]
0A0A         PRDS    RECORD
                  [PHYS_CPU_ID WORD
                   LOG_CPU_ID  INTEGER
                   VP_NR       WORD
                   IDLE_VP     VP_INDEX]
          $SECTION ITC_INT_PROC
            INTERNAL
0000         GETWORK                 PROCEDURE
            !*******************************
             * SWAPS VIRTUAL PROCESSORS    *
             * ON PHYSICAL PROCESSOR.      *
             *******************************
             * PARAMETERS:                 *
             *  R13: LOGICAL CPU #         *
             * REGISTER USE:               *
             *  STATUS REGISTERS           *
             *   R14: DBR (SIMULATION)     *
             *   R15: STACK_POINTER        *
             *  LOCAL VARIABLES:           *
             *   R1: READY_VP (NEW)        *
             *   R2: CURRENT_VP (OLD)      *
             *   R3: FLAG CONTROL WORD     *
             *   R4: STACK_SEG BASE ADDR   *
             *   R5: STATUS_REG_BLOCK ADDR *
             *   R6: NORMAL STACK POINTER  *
             *******************************!
             ENTRY

             ! GET STACK BASE !
0000 31E4    LD         R4, R14(#STACK_SEG*4)
0002 0004
0004 3445    LDA        R5, R4(#STATUS_REG_BLOCK)
0006 00F0
             ! * * SAVE SP * * !
0008 2F5F    LD         @R5, R15
             ! * * SAVE FCW * * !
000A 7D32    LDCTL      R3, FCW
000C 3343    LD         R4(#F_C_W), R3
000E 00F2

         BOOTSTRAP_ENTRY:         ! GLOBAL LABEL !
             ! GET READY_VP LIST !
0010 61D1    LD         R1, VPT.READY_LIST(R13)
0012 0006'

            SELECT_VP:
             DO  ! UNTIL ELGIBLE READY_VP FOUND !
0014 4D11     CP VPT.VP.IDLE_FLAG(R1), #ON
0016 0016'
0018 FFFF
001A 5E0E     IF EQ  ! VP IS IDLE ! THEN
001C 0030'
001E 4D11      CP VPT.VP.PREEMPT(R1), #ON
0020 0018'
0022 FFFF
0024 5E0E      IF EQ  ! PREEMPT INTERRUPT IS ON !  THEN
0026 002C'
0028 5E08        EXIT FROM SELECT_VP
002A 003C'
```

```
               FI
002C 5E08     ELSE ! VP NOT IDLE !
002E 0034'
0030 5E08       EXIT FROM SELECT_VP
0032 003C'
              FI
              ! GET NEXT READY_VP !
0034 6113     LD  R3, VPT.VP.NEXT_READY_VP(R1)
0036 001C'
0038 A131     LD  R1, R3
003A E8EC    OD

            ! NOTE: THE READY_LIST WILL NEVER BE EMPTY SINCE
                THE IDLE VP, WHICH IS THE LOWEST PRI VP,
                WILL NEVER BE REMOVED FROM THE LIST.
                IT WILL RUN ONLY IF ALL OTHER READY VP'S ARE
                IDLING OR IF THERE ARE NO OTHER VP'S ON
                THE READY_LIST. ONCE SCHEDULED, IT
                WILL RUN UNTIL RECEIVING A HDWE INTERRUPT. !

            ! NOTE: R14 IS USED AS DBR HERE. WHEN MMU
                IS AVAILABLE THIS SERIES OF SAVE AND LOAD
                INSTRUCTIONS WILL BE REPLACED BY SPECIAL I/O
                INSTRUCTIONS TO THE MMU. !
            ! PLACE NEW_VP IN RUNNING STATE !
003C 4D15    LD    VPT.VP.STATE(R1), #RUNNING
003E 0014'
0040 0000
0042 6FD1    LD    VPT.RUNNING_LIST(R13), R1
0044 0002'
             ! * * SWAP DBR * * !
0046 611E    LD    R14, VPT.VP.DBR(R1)
0048 0010'

             ! LOAD NEW_VP SP !
004A 31E4    LD    R4, R14(#STACK_SEG*4)
004C 0004
004E 3445    LDA   R5, R4(#STATUS_REG_BLOCK)
0050 00F0
0052 215F    LD    R15, @R5

             ! * * LOAD NEW FCW * * !
0054 3143    LD    R3, R4(#F_C_W)
0056 00F2
0058 7D3A    LDCTL  FCW, R3
005A 9E08    RET
005C       END GETWORK
```

```
005C        ENTER_MSG_LIST          PROCEDURE
           !*********************************
            * INSERTS POINTER TO MESSAGE    *
            * FROM CURRENT_VP TO SIGNALED_VP*
            * IN FIFO MSG_LIST              *
            *********************************
            * REGISTER USE:                 *
            *  PARAMETERS:                  *
            *   R8(R9):MSG (INPUT)          *
            *   R1: SIGNALED_VP (INPUT)     *
            *   R13: LOGICAL CPU NUMBER     *
            *  LOCAL VARIABLES:             *
            *   R2: CURRENT_VP              *
            *   R3: FIRST_FREE_MSG          *
            *   R4: NEXT_FREE_MSG           *
            *   R5: NEXT_Q_MSG              *
            *   R6: PRESENT_Q_MSG           *
            *********************************!
            ENTRY
005C 61D2    LD  R2, VPT.RUNNING_LIST(R13)
005E 0002'

             ! GET FIRST MSG FROM FREE_LIST !
0060 6103    LD  R3, VPT.FREE_LIST
0062 000A'

                 ! * * * * DEBUG * * * * !
0064 0B03        CP R3, #NIL
0066 FFFF
0068 5E0E        IF EQ THEN
006A 0078'
006C 7601         LDA R1, $
006E 006C'
0070 2100         LD R0, #M_L_O! MESSAGE LIST OVERFLOW !
0072 0004
0074 5F00         CALL MONITOR
0076 A900
                 FI
                 ! * * * END DEBUG * * * !

0078 6134    LD  R4, VPT.MSG_Q.NEXT_MSG(R3)
007A 0122'
007C 6F04    LD  VPT.FREE_LIST, R4
007E 000A'
             ! INSERT MESSAGE LIST INFORMATION !
0080 763A    LDA       R10,VPT.MSG_Q.MSG(R3)
0082 0110'
0084 2107    LD        R7,#SIZEOF MESSAGE
0086 0010
0088 BA81    LDIRB     @R10,@R8,R7
008A 07A0
008C 6F32    LD  VPT.MSG_Q.SENDER(R3), R2
008E 0120'
```

```
             ! INSERT MSG IN MSG_LIST !
0090 6115    LD  R5, VPT.VP.MSG_LIST(R1)
0092 001E'

0094 0B05    CP  R5, #NIL
0096 FFFF
0098 5E0E    IF EQ  ! MSG LIST IS EMPTY !  THEN
009A 00A4'
              ! INSERT MSG AT TOP OF LIST !
009C 6F13     LD VPT.VP.MSG_LIST(R1), R3
009E 001E'

00A0 5E08    ELSE  ! INSERT MSG IN LIST !
00A2 00BC'
             MSG_Q_SEARCH:
             DO  ! WHILE NOT END OF LIST !
00A4 0B05     CP         R5, #NIL
00A6 FFFF
00A8 5E0E     IF EQ  ! END OF LIST !  THEN
00AA 00B0'
00AC 5E08      EXIT FROM MSG_Q_SEARCH
00AE 00B8'
              FI

              ! GET NEXT LINK !
00B0 A156     LD       R6, R5
00B2 6165     LD       R5, VPT.MSG_Q.NEXT_MSG(R6)
00B4 0122'
00B6 E8F6    OD
             ! INSERT MSG IN LIST !
00B8 6F63    LD        VPT.MSG_Q.NEXT_MSG(R6), R3
00BA 0122'
             FI
00BC 6F35    LD         VPT.MSG_Q.NEXT_MSG(R3), R5
00BE 0122'
00C0 9E08    RET
00C2      END ENTER_MSG_LIST
```

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THE NAVAL POSTGRADUATE SCHOOL SECURE ARCHIVAL STORAGE SYSTEM. P--ETC(U)
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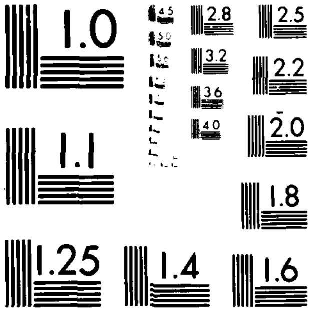

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```
00C2            GET_FIRST_MSG                PROCEDURE
               !*************************************
                * REMOVES MSG FROM MSG_LIST         *
                * AND PLACES ON FREE LIST.          *
                * RETURNS SENDER'S MSG AND          *
                * VP_ID                             *
                *************************************
                *REGISTER USE:                      *
                * PARAMETERS:                       *
                *  R8(R9): MSG POINTER (INPUT)      *
                *  R13: LOGICAL CPU NUMBER (INPUT)  *
                *  R1: SENDER VP (RETURNED)         *
                * LOCAL VARIABLES                   *
                *  R2: CURRENT_VP                   *
                *  R3: FIRST_MSG                    *
                *  R4: NEXT_MSG                     *
                *  R5: NEXT_FREE_MSG                *
                *  R6: PRESENT_FREE_MSG             *
                *************************************!
                ENTRY
00C2 61D2       LD          R2, VPT.RUNNING_LIST(R13)
00C4 0002'

                ! REMOVE FIRST MSG FROM MSG_LIST !
00C6 6123       LD          R3, VPT.VP.MSG_LIST(R2)
00C8 001E'

                            ! * * * * DEBUG * * * * !
00CA 0B03                   CP R3, #NIL
00CC FFFF
00CE 5E0E                   IF EQ THEN
00D0 00DE'
00D2 2100                    LD R0, #M_L_EM  ! MSG LIST EMPTY !
00D4 0001
00D6 7601                    LDA R1, $
00D8 00D6'
00DA 5F00                    CALL MONITOR
00DC A900
                            FI
                            ! * * * END DEBUG * * * !
00DE 6134       LD          R4, VPT.MSG_Q.NEXT_MSG(R3)
00E0 0122'
00E2 6F24       LD          VPT.VP.MSG_LIST(R2), R4
00E4 001E'
                          ! INSERT MESSAGE IN FREE_LIST !
00E6 6105       LD          R5, VPT.FREE_LIST
00E8 000A'
00EA 0B05       CP          R5, #NIL
00EC FFFF
00EE 5E0E       IF EQ    ! FREE_LIST IS EMPTY !   THEN
00F0 0100'
                 ! INSERT AT TOP OF LIST !
00F2 6F03        LD         VPT.FREE_LIST, R3
00F4 000A'
```

```
00F6 4D35      LD        VPT.MSG_Q.NEXT_MSG(R3), #NIL
00F8 0122'
00FA FFFF
00FC 5E08    ELSE  ! INSERT IN LIST !
00FE 011C'
            FREE_Q_SEARCH:
               DO

0100 0B05       CP       R5, #NIL
0102 FFFF
0104 5E0E       IF EQ  ! END OF LIST !  THEN
0106 010C'
0108 5E08         EXIT FROM FREE_Q_SEARCH
010A 0114'
                FI
                ! GET NEXT MSG !
010C A156       LD       R6, R5
010E 6165       LD       R5, VPT.MSG_Q.NEXT_MSG(R6)
0110 0122'
0112 E8F6      OD

             ! INSERT IN LIST !
0114 6F63      LD        VPT.MSG_Q.NEXT_MSG(R6), R3
0116 0122'
0118 6F35      LD        VPT.MSG_Q.NEXT_MSG(R3), R5
011A 0122'
             FI
             ! GET MESSAGE INFORMATION:
               (RETURNS R1: SENDING_VP)  !
011C 6131    LD          R1, VPT.MSG_Q.SENDER(R3)
011E 0120'
0120 763A    LDA         R10,VPT.MSG_Q.MSG(R3)
0122 0110'
0124 2107    LD          R7,#SIZEOF MESSAGE
0126 0010
0128 BAA1    LDIRB       @R8,@R10,R7
012A 0780
012C 9E08    RET
012E        END GET_FIRST_MSG
```

```
                  !   * * INNER TRAFFIC CONTROL ENTRY POINTS * * !

                  ! NOTE: ALL INTERRUPTS MUST BE MASKED WHENEVER
                    THE VPT IS LOCKED.  THIS IS TO PREVENT AN
                    EMBRACE FROM OCCURRING SHOULD AN INTERRUPT
                    OCCUR WHILE THE VPT IS LOCKED. !

                  GLOBAL
                  $SECTION ITC_GLB_PROC

                  PREEMPT_RET LABEL
                  KERNEL_EXIT LABEL
0000              CREATE_INT_VEC          PROCEDURE
                 !*********************************
                  * CREATES ENTRY IN VIRTUAL INT-*
                  * ERRUPT VECTOR WITH ADDRESS   *
                  * OF THE VIRTUAL INTERRUPT HAN-*
                  * DLER.                        *
                  ********************************
                  * PARAMETERS:                  *
                  *  R1: VIRTUAL INTERRUPT #     *
                  *  R2: INTERRUPT HANDLER ADDR  *
                  ********************************!

                  ENTRY
                   ! COMPUTE OFFSET IN VIRTUAL
                     INTERRUPT VECTOR !
0000 1900          MULT       RR0, #SIZEOF ADDRESS
0002 0002
                   ! SAVE ADDRESS OF VIRTUAL INTERRUPT
                     HANDLER IN INTERRUPT VECTOR !
0004 6F12          LD         VPT.VIRT_INT_VEC(R1), R2
0006 000C'
0008 9E08          RET
000A             END CREATE_INT_VEC
```

```
000A        GET_DBR_ADDR           PROCEDURE
           !*********************************
            * CALCULATES DBR ADDRESS FROM   *
            * DBR NUMBER                    *
            *********************************
            * REGISTER USE:                 *
            *  PARAMETERS:                  *
            *   R0: DBR #                   *
            *  RETURNS:                     *
            *   R1: DBR ADDRESS             *
            *********************************!
            ENTRY
             ! GET BASE ADDRESS OF MMU IMAGE !
000A 7601    LDA       R1, MMU_IMAGE
000C 0000'
             ! ADD DBR HANDLE (OFFSET) TO MMU BASE
               ADDRESS TO OBTAIN DBR ADDRESS !
000E 8101    ADD       R1, R0
0010 9E08    RET
0012       END GET_DBR_ADDR
```

```
0012        ALLOCATE_MMU            PROCEDURE
           !********************************
            * ALLOCATES NEXT AVAILABLE MMU *
            * IMAGE AND CREATES PRDS ENTRY *
            ********************************
            * REGISTER USE:                *
            *  RETURNS:                    *
            *    R0: DBR #                 *
            *  LOCAL VARIABLES:            *
            *    R1: SEGMENT #             *
            *    R2: PRDS ADDRESS          *
            *    R3: PRDS ATTRIBUTES       *
            *    R4: PRDS LIMITS           *
            ********************************!
            ENTRY
              ! GET NEXT AVAILABLE DBR # !
0012 8D08    CLR        R0
0014 8D18    CLR        R1
              ! NOTE: THE FOLLOWING IS A SAFE SEQUENCE
               AS NEXT_AVAIL_MMU AND MMU ARE CPU LOCAL!
         GET_DBR:
             DO
0016 4C11      CPB      NEXT_AVAIL_MMU(R1), #AVAILABLE
0018 0A00'
001A 0000
               IF EQ  !MMU ENTRY IS AVAILABLE!
001C 5E0E        THEN
001E 002E'
0020 4C15         LDB  NEXT_AVAIL_MMU(R1), #ALLOCATED
0022 0A00'
0024 FFFF
0026 5E08         EXIT FROM GET_DBR
0028 004A'
002A 5E08        ELSE  !CURRENT ENTRY IS ALLOCATED!
002C 0048'
002E A910         INC  R1, #1
0030 0100         ADD  R0, #SIZEOF MMU
0032 0100
                   ! * * * * DEBUG * * * * !
0034 0B01          CP  R1, #MAX_DBR_NR
0036 000A
0038 5E0E          IF EQ THEN
003A 0048'
003C 2100            LD         R0, #M_U  !MMU UNAVAILABLE!
003E 0007
0040 7601            LDA        R1, $
0042 0040'
0044 5F00            CALL       MONITOR
0046 A900
                   FI
                   ! * * * END DEBUG * * * !

               FI
0048 E8E6    OD
```

```
004A 2101     LD         R1, #PRDS_SEG    ! SEGMENT NO. !
004C 0000
004E 7602     LDA        R2, PRDS         ! PRDS ADDR   !
0050 0A0A'
0052 2103     LD         R3, #1 ! READ ATTR    !
0054 0001
0056 2104     LD         R4, #((SIZEOF PRDS)-1)/256
0058 0000
              ! PRDS LIMITS !

             ! CREATE PRDS ENTRY IN MMU IMAGE !
005A 5F00     CALL       UPDATE_MMU_IMAGE  !(R1: SEGMENT #
005C 0060'
                                              R2: SEG ADDRESS
                                              R3: ATTRIBUTES
                                              R4: SEG LIMITS)!
005E 9E08     RET
0060         END ALLOCATE_MMU
```

```
0060           UPDATE_MMU_IMAGE       PROCEDURE
              !********************************
               * CREATES SEGMENT DESCRIPTOR   *
               * ENTRY IN MMU IMAGE           *
               ********************************
               * REGISTER USE:                *
               *  PARAMETERS:                 *
               *    R0: DBR #                 *
               *    R1: SEGMENT #             *
               *    R2: SEGMENT ADDRESS       *
               *    R3: SEGMENT ATTRIBUTES    *
               *    R4: SEGMENT LIMITS        *
               *  LOCAL VARIABLES:            *
               *    R10: MMU BASE ADDRESS     *
               *    R13: OFFSET VARIABLE      *
               ********************************!
               ENTRY
0060 210A       LD  R10, #MMU_IMAGE ! MMU BASE ADDRESS !
0062 0000'
0064 810A       ADD  R10, R0
0066 210D       LD  R13, #SIZEOF SEG_DESC_REG
0068 0004
006A 991C       MULT  RR12, R1 ! COMPUTE SEG_DESC OFFSET !
006C 81DA       ADD  R10, R13 !ADD OFFSET TO BASE ADDRESS!
                ! INSERT DESCRIPTOR DATA !
006E 2FA2       LD  @R10, R2
0070 A9A1       INC  R10, #2
0072 0DA8       CLR  @R10
0074 2EAC       LDB  @R10, RL4
0076 A9A0       INC  R10, #1
0078 20AC       LDB  RL4, @R10
007A 0A0B       CPB  RL3, #%(2)00001000 ! EXECUTE !
007C 0808
007E 5E0E       IF  EQ  THEN
0080 008A'
0082 060C           ANDB  RL4, #%(2)11110111  ! EXECUTE MASK !
0084 F7F7
0086 5E08       ELSE
0088 008E'
008A 060C           ANDB  RL4, #%(2)11111110  ! READ MASK !
008C FEFE
                FI
008E 84BC       ORB  RL4, RL3
0090 2EAC       LDB  @R10, RL4
0092 9E08       RET
0094          END UPDATE_MMU_IMAGE
```

```
0094         WAIT                       PROCEDURE
            !************************************
             * INTRA_KERNEL SYNC/COM PRIMATIVE *
             * INVOKED BY KERNEL PROCESSES     *
             ***********************************
             * PARAMETERS                      *
             *  R8(R9): MSG POINTER (INPUT)    *
             *  R1: SENDING_VP (RETURN)        *
             * GLOBAL VARIABLES                *
             *  R14: DBR (PARAM TO GETWORK)    *
             * LOCAL VARIABLES                 *
             *  R2: CURRENT_VP (RUNNING)       *
             *  R3: NEXT_READY_VP              *
             *  R4: LOCK_ADDRESS               *
             *  R13: LOGICAL CPU NUMBER        *
             ***********************************!
             ENTRY
              ! MASK INTERRUPTS !
0094 7C01     DI    VI
              ! LOCK VPT !
0096 7604     LDA        R4, VPT.LOCK
0098 0000'
009A 5F00     CALL       SPIN_LOCK  ! (R4:¬VPT.LOCK) !
009C 0282'
             ! NOTE: RETURNS WHEN VPT IS LOCKED BY THIS VP !
             ! GET CPU NUMBER !
009E 5F00     CALL       GET_CPU_NO  !RETURNS:
00A0 02C8'
                                      R1:CPU #
                                      R2:# VP'S!
00A2 A11D     LD         R13, R1

00A4 61D2     LD         R2, VPT.RUNNING_LIST(R13)
00A6 0002'
00A8 6123     LD         R3, VPT.VP.NEXT_READY_VP(R2)
00AA 001C'

00AC 4D21     CP         VPT.VP.MSG_LIST(R2), #NIL
00AE 001E'
00B0 FFFF
00B2 5E0E      IF EQ ! CURRENT VP'S MSG LIST IS EMPTY ! THEN
00B4 00EA'
               ! REMOVE CURRENT_VP FROM READY_LIST !
                         ! * * * * DEBUG * * * * !
00B6 0B03                CP       R3, #NIL
00B8 FFFF
00BA 5E0E                IF EQ  THEN
00BC 00CA'
00BE 2100                 LD  R0, #R_L_E  ! READY LIST EMPTY !
00C0 0003
00C2 7601                 LDA R1, $
00C4 00C2'
00C6 5F00                 CALL MONITOR
00C8 A900
```

```
                        FI
                        ! * * * END DEBUG * * * !
00CA 6FD3      LD       VPT.READY_LIST(R13), R3
00CC 0006'
00CE 4D25      LD       VPT.VP.NEXT_READY_VP(R2), #NIL
00D0 001C'
00D2 FFFF

               ! PUT IT IN WAITING STATE !
00D4 4D25      LD VPT.VP.STATE(R2), #WAITING
00D6 0014'
00D8 0002
               ! SET DBR !
00DA 612E      LD       R14, VPT.VP.DBR(R2)
00DC 0010'
               ! SCHEDULE FIRST ELGIBLE READY VP !
00DE 93F8      PUSH       @R15,R8
               ! SAVE LOGICAL CPU # !
00E0 93FD      PUSH     @R15, R13
00E2 5F00                CALL    GETWORK  !R13:CPU #
00E4 0000'
                                           R14:DBR!
               ! RESTORE CPU # !
00E6 97FD      POP      R13, @R15
00E8 97F8      POP        R8,@R15
             FI
             ! GET FIRST MSG ON CURRENT VP'S MSG LIST !
00EA 5F00    CALL GET_FIRST_MSG  ! COPIES MSG IN MSG ARRAY!
00EC 00C2'
                                 ! R13: LOGICAL CPU # !
                                 !RETURNS R1:SENDER_VP !

             ! UNLOCK VPT !
00EE 4D08    CLR  VPT.LOCK
00F0 0000'
             ! UNMASK VECTORED INTERRUPTS !
00F2 7C05    EI    VI

             ! RETURN: R1:SENDER_VP !
00F4 9E08    RET
00F6      END WAIT
```

```
00F6         SIGNAL                        PROCEDURE
            !*************************************
             * INTRA_KERNEL SYNC /COM PRIMATIVE *
             * INVOKED BY KERNEL PROCESSES      *
             ************************************
             * REGISTER USE:                    *
             *  PARAMETERS:                     *
             *   R8(R9): MSG POINTER (INPUT)    *
             *   R1: SIGNALED VP_ID (INPUT)     *
             * GLOBAL VARIABLES                 *
             *  R13: CPU # (PARAM TO GETWORK)   *
             *  R14: DBR (PARAM TO GETWORK)     *
             *  LOCAL VARIABLES:                *
             *   R1: SIGNALED VP                *
             *   R2: CURRENT_VP                 *
             *   R4: VPT.LOCK ADDRESS           *
             ************************************!
             ENTRY
              ! SAVE VP ID !
00F6 93F1     PUSH    @R15, R1
              ! MASK INTERRUPTS !
00F8 7C01     DI    VI
              ! LOCK VPT !
00FA 7604     LDA        R4, VPT.LOCK
00FC 0000'
00FE 5F00     CALL       SPIN_LOCK  ! (R4:¬VPT.LOCK) !
0100 0282'
             !NOTE: RETURNS WHEN VPT IS LOCKED BY THIS VP. !
              ! GET LOGICAL CPU # !
0102 5F00     CALL       GET_CPU_NO !RETURNS:
0104 02C8'
                                    R1:CPU #
                                    R2:# VP'S!
0106 A11D     LD         R13, R1
              ! RESTORE VP ID !
0108 97F1     POP        R1, @R15

              ! PLACE MSG IN SIGNALED_VP'S MSG_LIST !
010A 5F00     CALL ENTER_MSG_LIST !(R8:MSG POINTER
010C 005C'                          R1:SIGNALED_VP
                                    R13:LOGICAL CPU #)!

010E 4D11     CP         VPT.VP.STATE(R1), #WAITING
0110 0014'
0112 0002
0114 5E0E     IF EQ  ! SIGNALED_VP IS WAITING !  THEN
0116 0148'

                ! WAKE IT UP AND MAKE IT READY !
0118 A112       LD       R2, R1
011A 76D3       LDA      R3, VPT.READY_LIST(R13)
011C 0006'
011E 7.)4        )A      R4, VPT.VP.NEXT_READY_VP
0120 0[illegible]
```

```
0122 7605      LDA     R5, VPT.VP.PRI
0124 0012'
0126 7606      LDA     R6, VPT.VP.STATE
0128 0014'
012A 2107      LD      R7, #READY
012C 0001
               ! SAVE LOGICAL CPU # !
012E 93FD      PUSH    @R15, R13
0130 5F00      CALL    LIST_INSERT  !R2: OBJ ID
0132 0000*
                                     R3: LIST_PTR ADDR
                                     R4: NEXT_OBJ_PTR
                                     R5: PRIORITY_PTR
                                     R6: STATE_PTR
                                     R7: STATE  !
               ! RESTORE LOGICAL CPU # !
0134 97FD      POP     R13, @R15
              ! PUT CURRENT_VP IN READY_STATE !
0136 61D2     LD       R2, VPT.RUNNING_LIST(R13)
0138 0002'
013A 4D25     LD       VPT.VP.STATE(R2), #READY
013C 0014'
013E 0001
              ! SET DBR !
0140 612E     LD       R14, VPT.VP.DBR(R2)
0142 0010'

             ! SCHEDULE FIRST ELGIBLE READY VP !
0144 5F00     CALL    GETWORK  !R13:LOGICAL CPU #
0146 0000'
                                R14:DBR !
             FI

             ! UNLOCK VPT !
0148 4D08    CLR  VPT.LOCK
014A 0000'
             ! UNMASK VECTORED INTERRUPTS !
014C 7C05    EI    VI

014E 9E08    RET
0150      END SIGNAL
```

```
0150            SET_PREEMPT          PROCEDURE
               !****************************
                * SETS PREEMPT INTERRUPT ON*
                * TARGET_VP. CALLED BY TC_ *
                * ADVANCE.                 *
                ****************************
                * REGISTER USE:            *
                * PARAMETERS:              *
                *  R1:TARGET_VP_ID (INPUT) *
                * LOCAL VARIABLES          *
                *  R1: VP_INDEX            *
                ****************************!
                ENTRY
                 ! NOTE: DESIGNED AS SAFE SEQUENCE SO VPT NEED
                   NOT BE LOCKED. !

                 ! CONVERT VP_ID TO VP_INDEX !
0150 6112        LD           R2, EXT_VP_LIST(R1)
0152 0210'

                 ! TURN ON TGT_VP PREEMPT FLAG !
0154 4D25        LD           VPT.VP.PREEMPT(R2), #ON
0156 0018'
0158 FFFF

                 ! ** IF TARGET VP NOT LOCAL
                      ( NOT BOUND TO THIS CPU )
                 [IE, IF <<CPU_SEG>>CPU_ID<>VPT.VP.PHYS_CPU(R1) ]
                 THEN SEND HARDWARE PREEMPT INTERRUPT TO
                   VPT.VP.CPU(R1). ** !

015A 9E08        RET
015C            END SET_PREEMPT
```

```
015C          IDLE            PROCEDURE
             !*************************
              * LOADS IDLE DBR ON     *
              * CURRENT VP. CALLED BY *
              * TC_GETWORK.           *
              *************************
              * REGISTER USE          *
              *  GLOBAL VARIABLE      *
              *    R13: LOG CPU #     *
              *    R14: DBR           *
              *  LOCAL VARIABLES:     *
              *    R2: CURRENT_VP     *
              *    R3: TEMP VAR       *
              *    R4: VPT.LOCK ADDR  *
              *    R5: TEMP           *
              *************************!
              ENTRY
               ! GET LOGICAL CPU # !
015C 5F00      CALL       GET_CPU_NO  !RETURNS:

               ! LOAD IDLE DBR ON CURRENT VP !
0174 6103      LD         R3, PRDS.IDLE_VP
0176 0A10'
0178 6135      LD         R5, VPT.VP.DBR(R3)
017A 0010'
017C 6F25      LD         VPT.VP.DBR(R2), R5
017E 0010'

               ! TURN ON CURRENT VP'S IDLE FLAG !
0180 4D25      LD         VPT.VP.IDLE_FLAG(R2), #ON
0182 0016'
0184 FFFF
               ! SET VP TO READY STATE !
0186 4D25      LD         VPT.VP.STATE(R2), #READY
0188 0014'
018A 0001

               ! SCHEDULE FIRST ELIGIBLE READY VP !
018C 5F00      CALL    GETWORK  !R13:LOGICAL CPU #
018E 0000'
                                 R14:DBR !

               ! UNLOCK VPT !
0190 4D08      CLR  VPT.LOCK
0192 0000'
               ! UNMASK VECTORED INTERRUPTS !
0194 7C05      EI    VI

0196 9E08      RET
0198          END IDLE
```

```
0198          SWAP_VDBR        PROCEDURE
             !*************************
              * LOADS NEW DBR ON       *
              * CURRENT VP. CALLED BY  *
              * TC_GETWORK.            *
              **************************
              * REGISTER USE           *
              *  PARAMETERS            *
              *   R1: NEW_DBR (INPUT)  *
              *  GLOBAL VARIABLES      *
              *   R13: LOGICAL CPU #   *
              *   R14: DBR             *
              *  LOCAL VARIABLES       *
              *   R2: CURRENT_VP       *
              *   R4: VPT.LOCK ADDR    *
              **************************!
              ENTRY
               ! SAVE NEW DBR !
0198 93F1      PUSH      @R15, R1
               ! MASK INTERRUPTS !
019A 7C01      DI    VI
               ! LOCK VPT !
019C 7604      LDA       R4, VPT.LOCK
019E 0000'
01A0 5F00      CALL      SPIN_LOCK  ! (R4:¬VPT.LOCK) !
01A2 0282'
               ! NOTE: RETURNS WHEN VPT IS LOCKED BY THIS VP.!
               ! GET CPU # !
01A4 5F00      CALL      GET_CPU_NO  !RETURNS:
01A6 02C8'
                                      R1: CPU #
                                      R2:# VP'S!
01A8 A11D      LD        R13, R1
               ! GET CURRENT VP !
01AA 61D2      LD        R2, VPT.RUNNING_LIST(R13)
01AC 0002'
                         ! * * * DEBUG * * * !
01AE 4D21                CP VPT.VP.MSG_LIST(R2), #NIL
01B0 001E'
01B2 FFFF
01B4 5E06                IF NE ! MSG WAITING !  THEN
01B6 01C4'
01B8 2100                 LD  R0, #S_N_A  ! SWAP NOT ALLOWED !
01BA 0005
01BC 7601                 LDA R1, $   !PC!
01BE 01BC'
01C0 5F00                 CALL MONITOR
01C2 A900
                         FI
                         ! * * END DEBUG * * !
               ! SET DBR !
01C4 612E      LD        R14, VPT.VP.DBR(R2)
01C6 0010'
               ! RESTORE NEW DBR !
```

```
01C8 97F0    POP       R0, @R15
01CA 5F00    CALL      GET_DBR_ADDR   ! (R0: DBR #)
01CC 000A'
                                         RETURNS
                                        (R1: DBR ADDR) !

             ! LOAD NEW DBR ON CURRENT VP !
01CE 6F21    LD        VPT.VP.DBR(R2), R1
01D0 0010'

             ! TURN OFF IDLE FLAG !
01D2 4D25    LD        VPT.VP.IDLE_FLAG(R2), #OFF
01D4 0016'
01D6 0000

             ! SET VP TO READY STATE !
01D8 4D25    LD        VPT.VP.STATE(R2), #READY
01DA 0014'
01DC 0001

             ! SCHEDULE FIRST ELGIBLE READY VP !
01DE 5F00    CALL   GETWORK  !R13:LOGICAL CPU #
01E0 0000'
                              R14:DBR !

             ! UNLOCK VPT !
01E2 4D08    CLR  VPT.LOCK
01E4 0000'
             ! UNMASK VECTORED INTERRUPTS !
01E6 7C05    EI     VI

01E8 9E08    RET
01EA       END SWAP_VDBR
```

```
01EA        PHYS_PREEMPT_HANDLER   PROCEDURE
           !********************************
            * HARDWARE PREEMPT INTERRUPT    *
            * HANDLER.  ALSO TESTS FOR      *
            * VIRTUAL PREEMPT INTERRUPT     *
            * FLAG AND INVOKES INTERRUPT    *
            * HANDLER IF FLAG IS SET.       *
            * INVOKED UPON EVERY EXIT FROM *
            * KERNEL.  KERNEL FCW MASKS     *
            * NVI INTERRUPTS TO PREVENT     *
            * SIMULTANEOUS PREEMPT INTERR. *
            * HANDLING.                     *
            ********************************
            * REGISTER USE                  *
            *  LOCAL VARIABLES              *
            *   R1: PREEMPT_INT_FLAG        *
            *   R2: CURRENT_VP              *
            * GLOBAL VARIABLES              *
            *   R13:LOGICAL CPU #           *
            *   R14:DBR                     *
            ********************************!

            ENTRY

             ! * * PREEMPT_HANDLER * * !

             ! SAVE ALL REGISTERS !
01EA 030F    SUB      R15, #32
01EC 0020
01EE 1CF9    LDM      @R15, R1, #16
01F0 010F

             ! SAVE NORMAL STACK POINTER (NSP) !
01F2 7D67    LDCTL    R6, NSP
01F4 93F6    PUSH     @R15, R6
             ! GET CPU # !
01F6 5F00    CALL    GET_CPU_NO !RETURNS:
01F8 02C8'
                                R1: CPU #
                                R2:# VP'S!
01FA A11D    LD      R13, R1
             ! MASK INTERRUPTS !
01FC 7C01    DI    VI
             ! LOCK VPT !
01FE 7604    LDA   R4, VPT.LOCK
0200 0000'
0202 5F00    CALL  SPIN_LOCK
0204 0282'
             !RETURNS WHEN VPT IS LOCKED!
             ! SET DBR !
0206 61D2    LD       R2, VPT.RUNNING_LIST(R13)
0208 0002'
020A 612E    LD       R14, VPT.VP.DBR(R2)
020C 0010'
```

```
                ! PUT CURRENT PROCESS IN READY STATE !
020E 4D25       LD       VPT.VP.STATE(R2), #READY
0210 0014'
0212 0001
0214 5F00       CALL     GETWORK  !R13:LOG CPU #
0216 0000'
                                   R14:DBR !
              PREEMPT_RET:
                ! UNLOCK VPT !
0218 4D08       CLR    VPT.LOCK
021A 0000'
                ! UNMASK VECTORED INTERRUPTS !
021C 7C05       EI     VI
              KERNEL_EXIT:
                ! *** UNMASK VIRTUAL PREEMPTS *** !
                ! ** NOTE: SAFE SEQUENCE AND DOES NOT REQUIRE
                         VPT TO BE LOCKED. ** !

                ! GET CURRENT_VP !
021E 610D       LD     R13, PRDS.LOG_CPU_ID
0220 0A0C'
0222 61D2       LD R2, VPT.RUNNING_LIST(R13)
0224 0002'

                ! TEST PREEMPT INTERRUPT FLAG !
0226 4D21       CP       VPT.VP.PREEMPT(R2), #ON
0228 0018'
022A FFFF
022C 5E0E       IF EQ  !  PREEMPT FLAG IS ON !  THEN
022E 0240'

                  ! RESET PREEMPT FLAG !
0230 4D25         LD   VPT.VP.PREEMPT(R2), #OFF
0232 0018'
0234 0000
                  ! SIMULATE VIRTUAL PREEMPT INTERRUPT !
0236 2101         LD   R1, #0
0238 0000
023A 6112         LD   R2, VPT.VIRT_INT_VEC(R1)
023C 000C'
023E 1E28         JP   @R2
              !NOTE: THIS JUMP TO TRAFFIC_CONTROL
               IS USED ONLY IN THE CASE OF A PREEMPT INTERRUPT,
               AND SIMULATES A HARDWARE INTERRUPT. ** !

               ! *** END VIRTUAL PREEMPT HANDLER *** !
               FI

              ! NOTE: SINCE A HDWE INTERRUPT DOES NOT EXIT
                  THROUGH THE GATE, THOSE FUNCTIONS PROVIDED
                    BY A GATE EXIT TO HANDLE PREEMPTS MUST BE
                    PROVIDED HERE ALSO. !
                ! RESTORE NSP !
0240 97F6       POP R6, @R15
0242 7D6F       LDCTL   NSP, R6
                ! RESTORE ALL REGSTERS !
0244 1CF1       LDM       R1, @R15, #16
0246 010F
0248 010F       ADD       R15, #32
024A 0020

                ! EXECUTE HARDWARE INTERRUPT RETURN !
024C 7B00       IRET

024E     END PHYS_PREEMPT_HANDLER
```

```
024E       RUNNING_VP            PROCEDURE
           !*********************************
            * CALLED BY TRAFFIC CONTROL.     *
            * RETURNS VP_ID. RESULT IS VALID*
            * ONLY WHILE APT IS LOCKED.      *
            *********************************
            * REGISTER USE                   *
            *  PARAMETERS                    *
            *   R1: EXT_VP_ID  (RETURNED)    *
            *   R3: LOG CPU # (RETURNED)     *
            *  LOCAL VARIABLES               *
            *    R2: VP INDEX                *
            *********************************!
            ENTRY
             ! MASK INTERRUPTS !
024E 7C01    DI    VI
             ! LOCK VPT !
0250 7604    LDA       R4, VPT.LOCK
0252 0000'
0254 5F00    CALL      SPIN_LOCK  ! (R4:¬VPT.LOCK) !
0256 0282'
             ! NOTE: RETURNS WHEN VPT IS LOCKED BY THIS VP !
             ! GET LOGICAL CPU # !
0258 5F00    CALL      GET_CPU_NO  !RETURNS:
025A 02C8'
                                    R1: CPU #
                                    R2:# VP'S!
025C A113    LD        R3, R1
025E 6132    LD        R2, VPT.RUNNING_LIST(R3)
0260 0002'
             ! CONVERT VP_INDEX TO VP_ID !
0262 6121    LD        R1, VPT.VP.EXT_ID(R2)
0264 0020'
                       ! * * * DEBUG * * * !
0266 0B01              CP  R1, #NIL
0268 FFFF
026A 5E0E              IF EQ  ! KERNEL PROC !  THEN
026C 027A'
026E 2100               LD R0, #V_I_E  ! VP INDEX ERROR !
0270 0006
0272 7601               LDA R1, $
0274 0272'
0276 5F00               CALL MONITOR
0278 A900
                       FI
                       ! * * END DEBUG * * !
             ! UNLOCK VPT !
027A 4D08    CLR       VPT.LOCK
027C 0000'
             ! UNMASK VECTORED INTERRUPTS !
027E 7C05    EI    VI
0280 9E08    RET
0282       END RUNNING_VP
```

```
0282           SPIN_LOCK   PROCEDURE
              !*************************
               * USES SPIN_LOCK MECH.  *
               * LOCKS UNLOCKED DATA   *
               * STRUCTURE (POINTED TO *
               * BY INPUT PARAMETER).  *
               *************************
               *REGISTER USE           *
               * PARAMETERS            *
               *  R4: LOCK ADDR (INPUT)*
               *************************!
               ENTRY
               !  NOTE: SINCE ONLY ONE PROCESSOR CURRENTLY
                         IN SYSTEM, LOCK NOT NECESSARY. ** !
                    ! * * * DEBUG * * * !
0282 0D41      CP  @R4, #0FF
0284 0000
0286 5E06      IF NE ! NOT UNLOCKED !  THEN
0288 0296'
028A 2100       LD  R0, #U_L     ! UNAUTHORIZED LOCK !
028C 0000
028E 7601       LDA R1, $
0290 028E'
0292 5F00       CALL MONITOR
0294 A900
                         FI
                         ! * * END DEBUG * * !
                       TEST_LOCK:
                        !  DO WHILE STRUCTURE LOCKED !
0296 0D46    TSET       @R4
0298 E5FE    JR MI, TEST_LOCK
                         ! ** NOTE SEE PLZ/ASM MANUAL
                                   FOR RESTRICTIONS ON
                                   USE OF TSET. ** !
029A 9E08    RET

029C        END SPIN_LOCK
```

```
029C          ITC_GET_SEG_PTR          PROCEDURE
             !**********************************
              * GETS BASE ADDRESS OF SEGMENT   *
              * INDICATED.                     *
              **********************************
              * REGISTER USE:                  *
              *  R0:SEG BASE ADDRESS(RET)      *
              *  R1:SEG NR (INPUT)             *
              *  R2:RUNNING_VP (LOCAL)         *
              *  R3:DBR_VALUE (LOCAL)          *
              *  R4:VPT.LOCK                   *
              *  R13:LOGICAL CPU #             *
              **********************************!

              ENTRY
               ! SAVE SEGMENT # !
029C 93F1      PUSH    @R15, R1
               ! MASK INTERRUPTS !
029E 7C01      DI    VI
               ! LOCK VPT !
02A0 7604      LDA      R4,VPT.LOCK
02A2 0000'
02A4 5F00      CALL     SPIN_LOCK  !R4:¬VPT.LOCK!
02A6 0282'
               ! GET CPU # !
02A8 5F00      CALL     GET_CPU_NO  !RETURNS:
02AA 02C8'
                                     R1: CPU #
                                     R2:# VP'S!
02AC A11D      LD       R13, R1
               ! RESTORE SEGMENT # !
02AE 97F1      POP      R1, @R15
02B0 61D2      LD       R2,VPT.RUNNING_LIST(R13)
02B2 0002'
02B4 6123      LD       R3,VPT.VP.DBR(R2)
02B6 0010'
               ! UNLOCK VPT !
02B8 4D08      CLR      VPT.LOCK
02BA 0000'
               ! UNMASK VECTORED INTERRUPTS !
02BC 7C05      EI    VI
02BE 1900      MULT     RR0,#4
02C0 0004
02C2 7130      LD       R0,R3(R1)
02C4 0100

02C6 9E08      RET
02C8          END ITC_GET_SEG_PTR
```

```
02C8          GET_CPU_NO      PROCEDURE
             !*************************
              * FIND CURRENT CPU_NO    *
              * CALLED BY DIST MMGR    *
              * AND MM                 *
              *************************
              * RETURNS                *
              * R1: CPU_NO             *
              * R2: # OF VP'S          *
              *************************!

              ENTRY
02C8 6101      LD       R1, PRDS.LOG_CPU_ID
02CA 0A0C'
02CC 6102      LD       R2, PRDS.VP_NR
02CE 0A0E'
02D0 9E08      RET
02D2        END GET_CPU_NO


02D2        K_LOCK                  PROCEDURE
             !*************************
              *  STUB FOR WAIT LOCK    *
              *************************
              *  R4:¬LOCK (INPUT)      *
              *************************!

              ENTRY
02D2 5F00      CALL  SPIN_LOCK
02D4 0282'
02D6 9E08      RET
02D8        END K_LOCK

02D8        K_UNLOCK                PROCEDURE
             !*************************
              *  STUB FOR WAIT UNLOCK *
              *************************
              *  R4:¬LOCK (INPUT)      *
              *************************!

              ENTRY
02D8 0D48      CLR   @R4
02DA 9E08      RET
02DC        END K_UNLOCK

          END INNER_TRAFFIC_CONTROL
```

Appendix M

SEGMENT MANAGER LISTINGS

```
Z8000ASM  2.02
LOC    OBJ CODE    STMT SOURCE STATEMENT

        $LISTON $TTY

        SEG_MGR           MODULE


        CONSTANT
          NULL_SEG               := -1
          NULL_ACCESS            := 4
          MAX_SEG_NO             := 64
          MAX_NO_KST_ENTRIES     := 54
          MAX_SEG_SIZE           := 128
          KST_SEG_NO             := 2
          NR_OF_KSEGS            := 10
          TRUE                   := 1
          FALSE                  := 0
          READ                   := 1
          WRITE                  := 0
        ! ****    SUCCESS_CODES      **** !
          SUCCEEDED              := 2
          MENTOR_SEG_NOT_KNOWN   := 22
          ACCESS_CLASS_NOT_EQ    := 33
          NOT_COMPATIBLE         := 24
          SEGMENT_TOO_LARGE      := 25
          NO_SEG_AVAIL           := 27
          SEGMENT_NOT_KNOWN      := 28
          SEGMENT_IN_CORE        := 29
          KERNEL_SEGMENT         := 30
          INVALID_SEGMENT_NO     := 31
          NO_ACCESS_PERMITTED    := 32
          LEAF_SEG_EXISTS        := 10
          NO_LEAF_EXISTS         := 11
          ALIAS_DOES_NOT_EXIST   := 23
          NO_CHILD_TO_DELETE     := 20
          G_AST_FULL             := 12
          L_AST_FULL             := 13
          PROC_CLASS_NOT_GE_SEG_CLASS := 41
          LOCAL_MEMORY_FULL      := 16
          GLOBAL_MEMORY_FULL     := 17
          SEC_STOR_FULL          := 21
          MONITOR               := %059A

        TYPE
          H_ARRAY     ARRAY  [ 3   WORD ]

          KST_REC     RECORD
           [MM_HANDLE       H_ARRAY
            SIZE            WORD
            ACCESS_MODE     BYTE
            IN_CORE         BYTE
            CLASS           LONG
            M_SEG_NO        SHORT_INTEGER
            ENTRY_NUMBER    SHORT_INTEGER
           ]

          ADDRESS     WORD

          SEG_ARRAY   ARRAY [MAX_SEG_SIZE   BYTE]


        INTERNAL

        $SECTION SM_KST_DCL
        ! NOTE: THIS SECTION IS AN "OVERLAY"
          OR "FRAME" USED TO DEFINE THE
          FORMAT OF THE KST. NO STORAGE
          IS ASSIGNED BUT RATHER THE KST IS
          STORED IN A SEPARATELY OBTAINED
          AREA (A SEGMENT SET ASIDE FOR IT) !
        $ABS 0
0000    KST   ARRAY  MAX_NO_KST_ENTRIES   KST_REC

        EXTERNAL
          CLASS_EQ PROCEDURE
          CLASS_GE PROCEDURE
          MM_CREATE_ENTRY PROCEDURE
          MM_DELETE_ENTRY PROCEDURE
          MM_ACTIVATE PROCEDURE
          MM_DEACTIVATE PROCEDURE
          MM_SWAP_IN PROCEDURE
          MM_SWAP_OUT PROCEDURE
          PROCESS_CLASS PROCEDURE
          ITC_GET_SEG_PTR PROCEDURE
          GET_DBR_NUMBER PROCEDURE
        $SECTION SM_PROC
        GLOBAL

0000       CREATE_SEG           PROCEDURE

          !*******************************!
          ! CHECKS VALIDITY OF CREATE     !
          ! REQUEST AND                   !
          ! CALLS MM_CREATE IF VALID.     !
          !*******************************!
          ! REGISTER USE:                 !
          !  PARAMETERS                   !
          !  R1: MENTOR_SEG_NO(INPUT)     !
          !  R2: ENTRY_NO(INPUT)          !
          !  R3: SIZE(INPUT)              !
          !  RR4: CLASS (INPUT)           !
          !  R0: SUCCESS_CODE (RETURNED)  !
          !  LOCAL USE                    !
          !  R9: KST REC INDEX            !
          !  R6,R7 VARIOUS USES           !
          !  R13: ¬KST                    !
          !*******************************!

           ENTRY
0000 0B03   CP  R3,#MAX_SEG_SIZE
0002 0080
0004 5E02   IF  GT  THEN
0006 0010'
0008 2100     LD  R0,#SEGMENT_TOO_LARGE
000A 0019
000C 5E08   ELSE
000E 00A2'
0010 030F     SUB   R15,#10  !STACK AREA FOR
                                INPUT REGS!
0012 000A
0014 1CF9     LDM   @R15,R1,#5
0016 0104
0018 2101     LD    R1,#KST_SEG_NO
001A 0002
001C 5F00     CALL  ITC_GET_SEG_PTR  !R1: KST_SEG_NO!
001E 0000*
                    !RET:R0:¬KST!
0020 A10D     LD    R13,R0  !KST BASE ADDRESS
                             (IE ¬KST)!
0022 1CF1     LDM   R1,@R15,#5  !RESTORE NEEDED REGS!
0024 0104
0026 A119     LD    R9,R1  !COPY OF MENTOR_SEG_NO!
0028 0309     SUB   R9,#NR_OF_KSEGS  !CONVERT
                                      MENTOR_SEG_NO
002A 000A
                                      KST_REC INDEX!
002C 1908     MULT  RR8,#SIZEOF KST_REC
                                  !OFFSET TO KST_REC!
```

```
002E 0010
0030 819D     ADD   R13,R9  !ADD OFFSET TO KST
                                  BASE ADDRESS!
0032 2106     LD    R6,#NULL_SEG
0034 FFFF
0036 4ADE     CPB   RL6,KST.M_SEG_NO(R13)
0038 000E
003A 5E0E     IF  EQ  THEN  !MENTOR SEG NOT KNOWN!
003C 0046'
003E 2100       LD    R0,#MENTOR_SEG_NOT_KNOWN
0040 0016
0042 5E08     ELSE
0044 009E'
0046 93FD       PUSH  @R15,R13
0048 5F00       CALL  PROCESS_CLASS !RR2:PROC_CLASS!
004A 0000*
004C 97FD       POP   R13,@R15
004E 54D4       LDL   RR4,KST.CLASS(R13)
0050 000A
0052 93FD       PUSH  @R15,R13
0054 5F00       CALL  CLASS_EQ  !RR2: PROC_CLASS!
0056 0000*
                          !RR4: MENTOR SEG CLASS!
                          !R1:(RET)CONDITION_CODE!
0058 97FD       POP   R13,@R15
005A A116       LD    R6,R1

005C 1CF1       LDM   R1,@R15,#5 !RESTORE INPUT REGS!
005E 0104
0060 0B06       CP    R6,#FALSE
0062 0000
0064 5E0E       IF  EQ  THEN
0066 0070'
0068 2100         LD    R0,#ACCESS_CLASS_NOT_EQ
006A 0021
006C 5E08       ELSE
006E 009E'
0070 93FD         PUSH  @R15,R13  !SAVE ¬KST!
0072 9442         LDL   RR2,RR4  !CLASS!
0074 54D4         LDL   RR4,KST.CLASS(R13)
0076 000A
0078 5F00         CALL  CLASS_GE  !RR2:CLASS!
007A 0000*
                          !RR4:MENTOR CLASS!
                          !RET:R1:COND_CODE!
007C 97FD         POP   R13,@R15  !RESTORE PTR!
007E 0B01         CP    R1,#FALSE
0080 0000
0082 1CF1         LDM   R1,@R15,#5
0084 0104
0086 5E0E         IF  EQ  THEN
0088 0092'
008A 2100           LD    R0,#NOT_COMPATIBLE
```

```
008C 0018
008E 5E08          ELSE
0090 009E'
0092 76D1            LDA    R1,KST.MM_HANDLE(R13)
0094 0000
0096 5F00            CALL   MM_CREATE_ENTRY
0098 0000*
                     !R1:PTR TO MM_HANDLE!
                     !R2:ENTRY_NO!
                     !R3:SIZE!
                     !RR4:CLASS!
                     !R0:(RETURNED)SUCCESS_CODE!
009A 5F00            CALL CONFINEMENT_CHECK
009C 0428'

                       !(R0:SUCCESS_CODE)!
                   FI
                 FI
               FI
009E 010F      ADD    R15,#10
00A0 000A
             FI
00A2 9E08    RET
00A4       END CREATE_SEG
```

```
00A4        DELETE_SEG          PROCEDURE
           !*****************************!
           ! CHECKS VALIDITY OF DELETE   !
           ! REQUEST AND                 !
           !  CALLS MM_DELETE IF VALID.  !
           !*****************************!
           !  REGISTER USE:              !
           !  PARAMETERS                 !
           !   R1:MENTOR_SEG_NO(INPUT)   !
           !   R2:ENTRY_NO(INPUT)        !
           !   R0:SUCCESS_CODE(RET)      !
           !  LOCAL USE                  !
           !   R6:VARIOUS LOCAL USES     !
           !*****************************!

            ENTRY
00A4 93F1    PUSH  @R15,R1  !SAVE NEEDED REGS!
00A6 93F2    PUSH  @R15,R2
00A8 2101    LD    R1,#KST_SEG_NO
00AA 0002
00AC 5F00    CALL  ITC_GET_SEG_PTR  !R1:KST_SEG_NO!
00AE 0000*
00B0 A10D    LD    R13,R0  !¬KST!
00B2 97F2    POP   R2,@R15  !RESTORE INPUT REGS!
00B4 97F1    POP   R1,@R15
00B6 0301    SUB   R1,#NR_OF_KSEGS  !CONVERT
                              MENTOR_SEG_NO TO
00B8 000A
                                 KST REC INDEX!
00BA 1900    MULT  RR0,#SIZEOF KST_REC  !OFFSET
                                 TO DESIRED REC!
00BC 0010
00BE 811D    ADD   R13,R1  !ADD OFFSET TO KST BASE
                                       ADDRESS!
00C0 2106    LD    R6,#NULL_SEG
00C2 FFFF
00C4 4ADE    CPB   RL6,KST.M_SEG_NO(R13)
00C6 000E
00C8 5E0E    IF    EQ   THEN  !MENTOR SEGMENT
                                 NOT KNOWN!
00CA 00D4'
00CC 2100      LD    R0,#MENTOR_SEG_NOT_KNOWN
00CE 0016
00D0 5E08    ELSE
00D2 010E'
00D4 93F1      PUSH  @R15,R1  !SAVE NEEDED REGS!
00D6 93F2      PUSH  @R15,R2
00D8 93FD      PUSH  @R15,R13
00DA 5F00      CALL  PROCESS_CLASS
00DC 0000*
                     !(RETURNS RR2:PROC_CLASS)!
00DE 97FD      POP   R13,@R15
00E0 54D4      LDL   RR4,KST.CLASS(R13) !MENTOR
```

```
                                    SEG CLASS!
00E2 000A
00E4 93FD     PUSH  @R15,R13
00E6 5F00     CALL  CLASS_EQ !RR2:PROCESS CLASS!
00E8 0000*
                         !RR4:MENTOR SEG CLASS!
                         !R1: (RET) CONDITION_CODE!
00EA A116     LD    R6,R1
00EC 97FD     POP   R13,@R15
00EE 97F2     POP   R2,@R15  !RESTORE NEEDED REGS!
00F0 97F1     POP   R1,@R15
00F2 0B06     CP    R6,#FALSE
00F4 0000
00F6 5E0E     IF   EQ   THEN
00F8 0102'
00FA 2100       LD    R0,#ACCESS_CLASS_NOT_EQ
00FC 0021
00FE 5E08     ELSE
0100 010E'
0102 76D1       LDA   R1,KST.MM_HANDLE(R13)
0104 0000
0106 5F00       CALL  MM_DELETE_ENTRY
0108 0000*
              !R1:¬MM_HANDLE!
              !R2:ENTRY_NO!
              !R0: (RET) SUCCESS_CODE!
010A 5F00           CALL CONFINEMENT_CHECK
010C 0428'
              ! (R0:SUCCESS_CODE)!
              FI
            FI
010E 9E08   RET
0110       END DELETE_SEG
```

```
0110         MAKE_KNOWN          PROCEDURE
             !*******************************!
             ! CHECKS VALIDITY OF MAKE KNOWN !
             ! REQUEST AND CALLS MM_ACTIVATE !
             ! IF VALID. ASSIGNS SEG         !
             ! NUMBER AND UPDATES KST.       !
             !*******************************!
             ! REGISTER USE:                 !
             ! PARAMETERS:                   !
             !  R1:MENTOR_SEG_NO(INPUT)      !
             !  R2:ENTRY_NO(INPUT)           !
             !  R3:ACCESS_DESIRED(INPUT)     !
             !  R0:SUCCESS_CODE(RET)         !
             !  R1:SEGMENT_NO(RET)           !
             !  R2:ACCESS_ALLOWED(RET)       !
             ! LOCAL USE                     !
             !  IDENTIFIED AT POINT OF USAGE !
             !*******************************!
              ENTRY
0110 93F1      PUSH  @R15,R1  !SAVE INPUT REGS!
0112 91F2      PUSHL @R15,RR2
0114 2101      LD    R1,#KST_SEG_NO
0116 0002
0118 5F00      CALL  ITC_GET_SEG_PTR !(R1:KST_SEG_NO,
                                       RET:R0:¬KST)!
011A 0000*
011C A10D      LD    R13,R0  !¬KST!
011E 95F2      POPL  RR2,@R15
0120 97F1      POP   R1,@R15
0122 A115      LD    R5,R1  !COPY OF MENTOR_SEG_NO!
0124 0305      SUB   R5,#NR_OF_KSEGS !CONVERT TO
                                          INDEX!
0126 000A
0128 1904      MULT  RR4,#SIZEOF KST_REC !KST OFFSET
                                        TO SEG REC!
012A 0010
012C 815D      ADD   R13,R5  !ADD OFFSET TO ¬KST!
012E 2104      LD    R4,#NULL_SEG
0130 FFFF
0132 4ADC      CPB   RL4,KST.M_SEG_NO(R13)
0134 000E
0136 5E0E      IF EQ THEN
0138 014A'
013A 2100        LD    R0,#MENTOR_SEG_NOT_KNOWN
013C 0016
013E 2101        LD    R1,#NULL_SEG
0140 FFFF
0142 2102        LD    R2,#NULL_ACCESS
0144 0004
0146 5E08      ELSE
0148 02C8'
014A 2107        LD    R7,#0  !KST INDEX!
014C 0000
```

```
014E 2108      LD    R8,#NULL_SEG  !AVAIL SEG INDEX!
0150 FFFF
0152 A109      LD    R9,R0  !¬KST!
0154 210A      LD    R10,#NULL_SEG !SEG KNOWN INDICATOR!
0156 FFFF
            SEE_IF_KNOWN:
            DO
0158 4A99      CPB   RL1,KST.M_SEG_NO(R9)
015A 000E
015C 5E0E      IF EQ THEN
015E 017C'
0160 4A9A        CPB   RL2,KST.ENTRY_NUMBER(R9)
0162 000F
0164 5E0E        IF EQ THEN  !CASE: SEG KNOWN!
0166 017C'
0168 2100          LD    R0,#SUCCEEDED
016A 0002
016C 0107          ADD   R7,#NR_OF_KSEGS
016E 000A
0170 A171          LD    R1,R7  !SEG#!
0172 609A          LDB   RL2,KST.ACCESS_MODE(R9)
0174 0008
0176 A11A          LD    R10,R1  !SET SEG KNOWN
                                     INDICATOR!
0178 5E08          EXIT FROM SEE_IF_KNOWN
017A 01A6'
                 FI
               FI

017C 4A9C      CPB   RL4,KST.M_SEG_NO(R9)
                     !SEE IF SEG # AVAIL!
017E 000E
0180 5E0E      IF EQ THEN
0182 0192'
0184 0B08        CP    R8,#NULL_SEG
0186 FFFF
0188 5E0E        IF EQ THEN
018A 0192'
018C A178          LD    R8,R7 !SAVE FIRST
                           AVAIL SEG INDEX!
018E 0108          ADD   R8,#NR_OF_KSEGS
                            !CONVERT TO SEG #!
0190 000A
                 FI
               FI
0192 A970      INC   R7
0194 0109      ADD   R9,#SIZEOF KST_REC
                            !INCREMENT ONE REC!
0196 0010
0198 0B07      CP    R7,#MAX_NO_KST_ENTRIES
019A 0036
019C 5E02      IF GT THEN
019E 01A4'
```

```
01A0 5E08       EXIT FROM SEE_IF_KNOWN
01A2 01A6'
              FI
01A4 E8D9   OD
            !SEE_IF_KNOWN!
01A6 0B0A   CP     R10,#NULL_SEG
01A8 FFFF
01AA 5E0E     IF EQ THEN  !SEG KNOWN
                            INDICATOR NOT SET!
01AC 02C8'
01AE 0B08       CP     R8,#NULL_SEG
01B0 FFFF
01B2 5E06       IF NE THEN  !CASE:SEG UNKNOWN
                               AND SEG# AVAIL!
01B4 02BC'
01B6 91F0          PUSHL @R15,RR0  !¬KST AND
                                     MENTOR_SEG_NO!
01B8 91F2          PUSHL @R15,RR2 !ENTRY_NO
                                   &ACCESS_DESIRED!
01BA 93F8          PUSH  @R15,R8 !AVAIL SEG
                                   INDEX IN KST!
01BC 93FD          PUSH  @R15,R13 !MENTOR SEG REC PTR!
01BE 5F00          CALL  GET_DBR_NUMBER
                   !(RET:RL1:DBR_NO)!
01C0 0000*
01C2 A11A          LD    R10,R1  !DBR_NO!
01C4 97FD          POP   R13,@R15
01C6 97F8          POP   R8,@R15
01C8 95F2          POPL  RR2,@R15
01CA 95F0          POPL  RR0,@R15
            !MUST REARRANGE REGS FOR PASSING AND
             RETURN CONSISTENCY OF LOCATION!
01CC A135     000D
047C 5E0E          LD    R5,R3  !ACCESS_DESIRED!
01CE A123          LD    R3,R2  !ENTRY_NO!
01D0 76D2          LDA   R2,KST.MM_HANDLE(R13) !HPTR!
01D2 0000
01D4 A116          LD    R6,R1  !MENTOR_SEG_NO!
01D6 A181          LD    R1,R8  !SEGMENT_NO (SAVE)!
01D8 A184          LD    R4,R8  !SEGMENT_NO
                               (PASSING ARG)!
01DA A109          LD    R9,R0  !¬KST!
01DC 030F          SUB   R15,#20
01DE 0014
01E0 1CF9          LDM   @R15,R1,#10 !SAVE REGS 1-10!
01E2 0109
01E4 A1A1          LD    R1,R10  !DBR_NO PASSED
                                  IN R1!
01E6 A18B          LD    R11, R8
01E8 030B          SUB   R11, #NR_OF_KSEGS
01EA 000A
01EC 190A          MULT  RR10, #SIZEOF KST_REC
01EE 0010
```

```
01F0 A1BC          LD    R12, R11
01F2 819C          ADD   R12, R9
01F4 5F00          CALL  MM_ACTIVATE
01F6 0000*
             !(R1:DBR_NO,R2:HPTR,R3:ENTRY_NO,
               R4:SEGMENT_NO,R12:RET_HPTR)!
             !(RET:R0:SUCCESS_CODE,RR2:CLASS,
               R4:SIZE)!
01F8 5F00          CALL CONFINEMENT_CHECK
                        !(R0:SUCCESS_CODE)!
01FA 0428'
01FC 942A          LDL   RR10,RR2  !CLASS!
01FE A14C          LD    R12,R4  !SIZE!
0200 1CF1          LDM   R1,@R15,#9 !RESTORE REGS 1-9!
0202 0108
0204 A187          LD    R7,R8  !SEG #!
0206 0307          SUB   R7,#NR_OF_KSEGS
0208 000A
020A 1906          MULT  RR6,#SIZEOF KST_REC
                             !OFFSET TO REC!
020C 0010
020E A17D          LD    R13,R7
0210 819D          ADD   R13,R9 !ADD ¬KST TO OFFSET!
0212 5DDA          LDL   KST.CLASS(R13),RR10 !CLASS!
0214 000A
0216 6FDC          LD    KST.SIZE(R13),R12 !SIZE!
0218 0006
021A 0A08          CPB   RL0,#SUCCEEDED
021C 0202
021E 5E0E          IF EQ THEN
0220 02AC'
0222 93FD            PUSH  @R15,R13
0224 5F00            CALL  PROCESS_CLASS
0226 0000*
                     !(RET:RR2:PROC_CLASS)!
0228 97FD            POP   R13,@R15
022A 54D4            LDL   RR4,KST.CLASS(R13)
022C 000A
022E 93FD            PUSH  @R15,R13
0230 91F2            PUSHL @R15,RR2
0232 91F4            PUSHL @R15,RR4
0234 5F00            CALL  CLASS_GE
0236 0000*
                !(RR2:PROC_CLASS,RR4:SEG CLASS,RET:
                    R1:CONDITION_CODE)!
0238 95F4            POPL  RR4,@R15
023A 95F2            POPL  RR2,@R15
023C 97FD            POP   R13,@R15
023E 0B01            CP    R1,#FALSE
0240 0000
0242 5E0E            IF EQ THEN !NO ACCESS
                                POSSIBLE--DEACT.!
0244 0266'
```

```
0246 1CF1             LDM    R1,@R15,#10
0248 0109
024A A1A1             LD     R1,R10  !DBR_NO!
024C 76D2             LDA    R2,KST.MM_HANDLE(R13)
                                       !HPTR!
024E 0000
0250 5F00             CALL   MM_DEACTIVATE
                          !RET:R0:S_CODE!
0252 0000*
0254 5F00             CALL   CONFINEMENT_CHECK
                                    !R0:S_CODE!
0256 0428'
0258 21F1             LD     R1,@R15 !SEG #!
025A 2102             LD     R2,#NULL_ACCESS
025C 0004
025E 2100             LD     R0,
                        #PROC_CLASS_NOT_GE_SEG_CLASS
0260 0029
0262 5E08           ELSE
0264 02A8'
0266 93FD             PUSH   @R15,R13
0268 5F00             CALL   CLASS_EQ !(RR2:PROC_CLASS,
026A 0000*
                                      RR4:SEG CLASS,
                             RET:R1:CONDITION_CODE)!
026C 97FD             POP    R13,@R15
026E A1:0             LD     R0,R1 !CONDITION_CODE!
0270 1CF1             LDM    R1,@R15,#9
0272 0108
0274 0B00             CP     R0,#TRUE
0276 0001
0278 5E0E             IF EQ THEN
027A 0290'
027C 0B05               CP     R5,#WRITE
027E 0000
0280 5E0E               IF   EQ THEN
0282 028A'
0284 CA00                 LDB   RL2,#WRITE
0286 5E08               ELSE
0288 028C'
028A CA01                 LDB   RL2,#READ
                        FI
028C 5E08             ELSE
028E 0292'
0290 CA01               LDB   RL2,#READ
                      FI
0292 4CD5             LDB    KST.IN_CORE(R13),#FALSE
0294 0009
0296 0000
0298 6EDE             LDB    KST.M_SEG_NO(R13),RL6
029A 000E
029C 6EDB             LDB    KST.ENTRY_NUMBER(R13),RL3
029E 000F
```

```
02A0 6EDA             LDB   KST.ACCESS_MODE(R13),RL2
02A2 0008
02A4 2100             LD    R0,#SUCCEEDED
                                    !SUCCESS_CODE!
02A6 0002
                    FI
02A8 5E08         ELSE
02AA 02B4'
02AC 2101           LD    R1,#NULL_SEG
02AE FFFF
02B0 2102           LD    R2,#NULL_ACCESS
02B2 0004
                  FI
02B4 010F         ADD   R15, #20
02B6 0014
02B8 5E08       ELSE
02BA 02C8'
02BC 2100         LD    R0,#NO_SEG_AVAIL
02BE 001B
02C0 2101         LD    R1,#NULL_SEG
02C2 FFFF
02C4 2102         LD    R2,#NULL_ACCESS
02C6 0004
                FI
              FI
            FI
02C8 9E08   RET
02CA       END MAKE_KNOWN
```

```
02CA       TERMINATE          PROCEDURE

          !******************************!
          ! CHECKS VALIDITY OF TERMINATE !
          ! REQUEST AND CALLS            !
          ! MM_DEACTIVATE IF VALID       !
          !******************************!
          ! REGISTER USE                 !
          ! PARAMETERS                   !
          !  R1:SEGMENT_NO(INPUT)        !
          !  R0:SUCCESS_CODE(RET)        !
          ! LOCAL USE                    !
          !  R3:KST REC INDEX            !
          !  R6:CONSTANT STORAGE         !
          !  R13:¬KST                    !
          !******************************!

           ENTRY
02CA A113   LD    R3,R1  !COPY OF SEG #!
02CC 0303   SUB   R3,#NR_OF_KSEGS
             !CONVERT SEG# TO KST INDEX!
02CE 000A
02D0 1902   MULT  RR2,#SIZEOF KST_REC
02D2 0010
02D4 93F1   PUSH  @R15,R1
02D6 93F3   PUSH  @R15,R3
02D8 2101   LD    R1,#KST_SEG_NO
02DA 0002
02DC 5F00   CALL  ITC_GET_SEG_PTR
                  !(R1:KST_SEG_NO)!
02DE 0000*
                 !(RETURNS:R0:KST_SEG_PTR)!
02E0 A10D   LD    R13,R0
02E2 97F3   POP   R3,@R15
02E4 97F1   POP   R1,@R15
02E6 813D   ADD   R13,R3  !ADD OFFSET TO ¬KST!
02E8 2106   LD    R6,#NULL_SEG
02EA FFFF
02EC 4ADE   CPB   RL6,KST.M_SEG_NO(R13)
02EE 000E
02F0 5E0E   IF    EQ    THEN
02F2 02FC'
02F4 2100         LD    R0,#SEGMENT_NOT_KNOWN
02F6 001C
02F8 5E08   ELSE
02FA 0346'
02FC 2106         LD    R6,#TRUE
02FE 0001
0300 4ADE         CPB   RL6,KST.IN_CORE(R13)
0302 0009
0304 5E0E     IF    EQ    THEN
0306 0310'
0308 2100           LD    R0,#SEGMENT_IN_CORE
```

```
030A 001D
030C 5E08     ELSE
030E 0346'
0310 0B01           CP    R1,#NR_OF_KSEGS
0312 000A
0314 5E09       IF    LT    THEN
0316 0320'
0318 2100         LD    R0,#KERNEL_SEGMENT
031A 001E
031C 5E08       ELSE
031E 0346'
0320 93FD         PUSH  @R15,R13
0322 5F00         CALL  GET_DBR_NUMBER
0324 0000*
                  !(RETURNS:RL1:DBR_NO)!
0326 97FD         POP   R13,@R15
0328 76D2         LDA   R2,KST.MM_HANDLE(R13)
032A 0000
032C 93FD         PUSH  @R15,R13
032E 5F00         CALL  MM_DEACTIVATE !(R1:DBR_NO)!
0330 0000*
                           !(R2:¬MM_HANDLE)!
                      !(RET:R0:SUCCESS_CODE)!
0332 5F00         CALL CONFINEMENT_CHECK
0334 0428'
            !(R0:SUCCESS_CODE)!
0336 97FD         POP   R13,@R15
0338 0A08         CPB   RL0,#SUCCEEDED
033A 0202
033C 5E0E         IF    EQ    THEN !UPDATE KST!
033E 0346'
0340 4CD5           LDB   KST.M_SEG_NO(R13),
0342 000E
0344 FFFF
                                #NULL_SEG
                  FI
                FI
              FI
            FI
0346 9E08   RET
0348       END TERMINATE
```

```
0348       SM_SWAP_IN        PROCEDURE

           !****************************!
           ! CHECKS VALIDITY OF SWAP IN !
           ! REQUEST AND CALLS          !
           ! MM_SWAP_IN IF VALID        !
           !****************************!
           ! REGISTER USE               !
           ! PARAMETERS                 !
           !  R1:SEGMENT_NO(INPUT)      !
           !  R0:SUCCESS_CODE(RET)      !
           ! LOCAL USE                  !
           !  R7:KST REC INDEX          !
           !  R3:ACCESS_MODE            !
           !  R6:CONSTANT STORAGE       !
           !  R13:¬KST                  !
           !****************************!

            ENTRY
0348 A117   LD     R7,R1  !COPY OF SEG #!
034A 0307   SUB    R7,#NR_OF_KSEGS
            !CONVERT SEG# TO KST INDEX!
034C 000A
034E 1906   MULT   RR6,#SIZEOF KST_REC
                   !OFFSET TO KST_REC!
0350 0010
0352 93F1   PUSH   @R15,R1  !SAVE SEGMENT#!
0354 93F7   PUSH   @R15,R7
0356 2101   LD     R1,#KST_SEG_NO
0358 0002
035A 5F00   CALL   ITC_GET_SEG_PTR  !R1:KST_SEG_NO!
035C 0000*
035E A10D   LD     R13,R0  !¬KST!
0360 97F7   POP    R7,@R15
0362 97F1   POP    R1,@R15 !RETRIEVE SEGMENT#!
0364 817D   ADD    R13,R7  !ADD OFFSET TO KST BASE ADDR!
0366 2106   LD     R6,#NULL_SEG
0368 FFFF
036A 4ADE   CPB    RL6,KST.M_SEG_NO(R13)
036C 000E
036E 5E0E   IF     EQ   THEN
0370 037A'
0372 2100     LD     R0,#SEGMENT_NOT_KNOWN
0374 001C
0376 5E08   ELSE
0378 03B8'
037A 2106     LD     R6,#TRUE
037C 0001
037E 4ADE     CPB    RL6,KST.IN_CORE(R13)
0380 0009
0382 5E0E     IF EQ THEN
0384 038E'
0386 2100       LD     R0,#SUCCEEDED
```

```
0388 0002
038A 5E08     ELSE
038C 03B8'
038E 93FD       PUSH  @R15,R13 !SAVE KST REC ADDR!
0390 5F00       CALL  GET_DBR_NUMBER !R1:(RET)DBR_NO!
0392 0000*
0394 97FD       POP   R13,@R15
0396 76D2       LDA   R2,KST.MM_HANDLE(R13)
0398 0000
039A 60DB       LDB   RL3,KST.ACCESS_MODE(R13)
039C 0008
039E 93FD       PUSH  @R15,R13 !SAVE SEG KST REC ADDR!
03A0 5F00       CALL  MM_SWAP_IN  !R1:DBR_NO  !
03A2 0000*
                !R2:¬MM_HANDLE!
                !R3:ACCESS_MODE!
                !R0: (RET)SUCCESS_CODE!
03A4 5F00       CALL CONFINEMENT_CHECK
                     !(R0:SUCCESS_CODE)!
03A6 0428'
03A8 97FD       POP   R13,@R15
03AA 0A08       CPB   RL0,#SUCCEEDED
03AC 0202
03AE 5E0E       IF    EQ    THEN
03B0 03B8'
03B2 4CD5         LDB   KST.IN_CORE(R13),#TRUE
03B4 0009
03B6 0101
                FI
              FI
            FI
03B8 9E08   RET
03BA       END SM_SWAP_IN
```

```
03BA        SM_SWAP_OUT          PROCEDURE

            !******************************!
            ! CHECKS VALIDITY OF SWAP OUT !
            ! REQUEST AND CALLS            !
            ! MM_SWAP_OUT IF VALID         !
            !******************************!
            ! REGISTER USE                 !
            ! PARAMETERS                   !
            !  R1:SEGMENT_NO               !
            !  R0:SUCCESS_CODE(RET)        !
            ! LOCAL USE                    !
            !  R7:KST REC INDEX            !
            !  R6:CONSTANT STORAGE         !
            !  R13:¬KST                    !
            !******************************!

            ENTRY
03BA A117    LD     R7,R1  !COPY OF SEG #!
03BC 0307    SUB    R7,#NR_OF_KSEGS
              !CONVERT SEG# TO KST INDEX!
03BE 000A
03C0 1906    MULT   RR6,#SIZEOF KST_REC
              !OFFSET TO KST_REC!
03C2 0010
03C4 93F1    PUSH   @R15,R1  !SAVE SEGMENT#!
03C6 93F7    PUSH   @R15,R7
03C8 2101    LD     R1,#KST_SEG_NO
03CA 0002
03CC 5F00    CALL   ITC_GET_SEG_PTR  !R1:KST_SEG_NO!
03CE 0000*
03D0 A10D    LD     R13,R0  !¬KST!
03D2 97F7    POP    R7,@R15
03D4 97F1    POP    R1,@R15  !RETRIEVE SEGMENT#!
03D6 817D    ADD    R13,R7  !ADD OFFSET TO KST
                                      BASE ADDR!
03D8 2106    LD     R6,#NULL_SEG
03DA FFFF
03DC 4ADE    CPB    RL6,KST.M_SEG_NO(R13)
03DE 000E
03E0 5E0E    IF     EQ    THEN
03E2 03EC'
03E4 2100      LD     R0,#SEGMENT_NOT_KNOWN
03E6 001C
03E8 5E08    ELSE
03EA 0426'
03EC 2106      LD     R6,#FALSE
03EE 0000
03F0 4ADE      CPB  RL6,KST.IN_CORE(R13)
03F2 0009
03F4 5E0E      IF EQ THEN
03F6 0400'
03F8 2100        LD    R0,#SUCCEEDED
```

```
03FA 0002
03FC 5E08     ELSE
03FE 0426'
0400 93FD       PUSH  @R15,R13 !SAVE KST REC ADDR!
0402 5F00       CALL  GET_DBR_NUMBER !R1: (RET) DBR_NO!
0404 0000*
0406 97FD       POP   R13,@R15
0408 76D2       LDA   R2,KST.MM_HANDLE(R13)
040A 0000
040C 93FD       PUSH  @R15,R13 !SAVE SEG KST REC ADDR!
040E 5F00       CALL  MM_SWAP_OUT !R1:DBR_NO!
0410 0000*
                !R2:¬MM_HANDLE!
                !R0: (RET) SUCCESS_CODE!
0412 5F00       CALL CONFINEMENT_CHECK
                ! (R0:SUCCESS_CODE) !
0414 0428'
0416 97FD       POP   R13,@R15
0418 0A08       CPB   RL0,#SUCCEEDED
041A 0202
041C 5E0E       IF    EQ    THEN
041E 0426'
0420 4CD5         LDB   KST.IN_CORE(R13),#FALSE
0422 0009
0424 0000
                FI
              FI
            FI
0426 9E08   RET
0428       END SM_SWAP_OUT
```

```
0428          CONFINEMENT_CHECK         PROCEDURE
              !*********************************!
              ! SERVICE ROUTINE TO VERIFY       !
              ! CONFINEMENT IS NOT VIOLATED     !
              ! WHEN MEM MGR SUCCESS_CODE IS    !
              ! RETURNED TO SUPERVISOR.         !
              !*********************************!
              ! REGISTER USE:                   !
              ! PARAMETERS                      !
              !  R0:SUCCESS_CODE                !
              !*********************************!
              ENTRY
               IF R0
0428 0B00        CASE #LEAF_SEG_EXISTS THEN
                   CALL MONITOR
042A 000A
042C 5E0E
042E 0438'
0430 5F00
0432 059A
0434 5E08        CASE #NO_LEAF_EXISTS THEN
                   CALL MONITOR
0436 04B4'
0438 0B00
043A 000B
043C 5E0E
043E 0448'
0440 5F00
0442 059A
0444 5E08        CASE #ALIAS_DOES_NOT_EXIST THEN
                   CALL MONITOR
0446 04B4'
0448 0B00
044A 0017
044C 5E0E
044E 0458'
0450 5F00
0452 059A
0454 5E08        CASE #NO_CHILD_TO_DELETE THEN
                   CALL MONITOR
0456 04B4'
0458 0B00
045A 0014
045C 5E0E
045E 0468'
0460 5F00
0462 059A
0464 5E08        CASE #G_AST_FULL THEN
                   CALL MONITOR
0466 04B4'
0468 0B00
046A 000C
```

```
046C 5E0E
046E 0478'
0470 5F00
0472 059A
0474 5E08       CASE #L_AST_FULL THEN
                  CALL MONITOR
0476 04B4'
0478 0B00
047A 000D
047C 5E0E
047E 0488'
0480 5F00
0482 059A
0484 5E08       CASE #LOCAL_MEMORY_FULL THEN
                  CALL MONITOR
0486 04B4'
0488 0B00
048A 0010
048C 5E0E
048E 0498'
0490 5F00
0492 059A
0494 5E08       CASE #GLOBAL_MEMORY_FULL THEN
                  CALL MONITOR
0496 04B4'
0498 0B00
049A 0011
049C 5E0E
049E 04A8'
04A0 5F00
04A2 059A
04A4 5E08       CASE #SEC_STOR_FULL THEN
                  CALL MONITOR
04A6 04B4'
04A8 0B00
04AA 0015
04AC 5E0E
04AE 04B4'
04B0 5F00
04B2 059A
              FI
04B4 9E08     RET
04B6         END CONFINEMENT_CHECK

        END SEG_MGR
```

Appendix I

NON-DISCRETIONARY SECURITY LISTINGS

```
Z8000ASM  2.02
LOC    OBJ CODE    STMT SOURCE STATEMENT

        $LISTON $TTY
        NDS MODULE

        CONSTANT
          TRUE             :=1
          FALSE            :=0
        INTERNAL
          $SECTION ACC_CLASS_DCL !NOTE: IS AN OVERLAY,
                                   IE NO ALLOCATION
                                   OF MEMORY!
          $ABS 0
0000      ACCESS_CLASS       RECORD [LEVEL   INTEGER
                                     CAT     INTEGER]

        GLOBAL
        $SECTION NDS_PROC

0000       CLASS_EQ              PROCEDURE
          !********************************!
          ! PASSED PARAMETERS              !
          !  RR2 = CLASS1                  !
          !  RR4 = CLASS2                  !
          ! RETURNED                       !
          !  R1 = CONDITION_CODE           !
          !********************************!

           ENTRY
0000 9042   CPL     RR2,RR4
0002 5E0E   IF      EQ      THEN
0004 000E'
0006 2101           LD      R1,#TRUE
0008 0001
000A 5E08   ELSE
000C 0012'
000E 2101           LD      R1,#FALSE
0010 0000
            FI
0012 9E08   RET
0014       END CLASS_EQ
```

```
0014        CLASS_GE              PROCEDURE
           !******************************!
           ! PASSED PARAMETERS            !
           !  RR2 = CLASS1                !
           !  RR4 = CLASS2                !
           ! RETURNED PARAMETER           !
           !  R1 = CONDITION_CODE         !
           !******************************!

            ENTRY
0014 91F2    PUSHL @R15,RR2 !PUSH CLASS1 ON STACK-
                                   -REFER BY ADDR!
0016 A1FD    LD     R13,R15  ! CLASS1 ADDR !
0018 91F4    PUSHL @R15,RR4
001A A1FE    LD     R14,R15  ! CLASS2 ADDR !
001C 31E7    LD     R7,R14(#ACCESS_CLASS.CAT)
                           ! CAT2 IN R7 !
001E 0002
0020 45D7    OR     R7,ACCESS_CLASS.CAT(R13)
                        !CAT1 OR CAT2, R7!
0022 0002
0024 4BD7    CP     R7,ACCESS_CLASS.CAT(R13)
                       !CAT1=(CAT1 OR CAT2)?!
0026 0002
0028 5E0E    IF EQ THEN
002A 0048'
002C 61D6      LD   R6,ACCESS_CLASS.LEVEL(R13)
                                       !LEVEL1!
002E 0000
                 ! COMPARE LEVEL1 WITH LEVEL2 !
0030 4BE6      CP   R6,ACCESS_CLASS.LEVEL(R14)
0032 0000
0034 5E01      IF   GE      THEN  !LEVEL1 GE LEVEL2!
0036 0040'
0038 2101           LD      R1,#TRUE
003A 0001
003C 5E08      ELSE
003E 0044'
0040 2101           LD      R1,#FALSE
0042 0000
               FI
0044 5E08    ELSE
0046 004C'
0048 2101      LD   R1,#FALSE
004A 0000
             FI
004C 95F4    POPL   RR4,@R15
004E 95F2    POPL   RR2,@R15  !RESTORE STACK!
0050 9E08    RET
0052        END CLASS_GE
         END NDS
```

Appendix J

MEMORY MANAGER LISTINGS

```
Z8000ASM  2.02
LOC    OBJ CODE    STMT SOURCE STATEMENT

              $LISTON $TTY
              MM_PROCESS      MODULE

              ! VERS. 1.9  !

              CONSTANT
                RETURN_TO_MONITOR  := %A902  !MBUG REENTRY!

                COUNT := 10
                TIME  := 500

                NR_OF_HOSTS    := 2
                G_AST_LIMIT    := 10
                G_AST_FULL     := 12
                FREE_ENTRY     := %EEEEEEEE
                TRUE           := %BBBB
                FALSE          := %CCCC
                SPACE          := %20
                DASH           := %2D

                IO_MGR         :=%60
                FILE_MGR       := %40
                MEM_MGR        := %00
                FM_ENTRY       := %4A00
                IO_ENTRY       := %4E00
                CREATE_ENTRY_CODE  := 50
                INVALID_MMGR_CODE  := 60
                DELETE_ENTRY_CODE  := 51
                ACTIVATE_SEG_CODE  := 52
                DEACTIVATE_SEG_CODE:= 53
                SWAP_IN_SEG_CODE   := 54
                SWAP_OUT_SEG_CODE  := 55
                SUCCEEDED          := 2
                STK_SIZE           := 1
                TOP_SECRET         := 4
                SECRET             := 3
                CONFIDENTIAL       := 2
                UNCLASS            := 1
                EMPTY              := 0
                CRYPTO             := 1
```

```
  NATO                 := 2
  NUCLEAR              := 4

TYPE
  ADDRESS        WORD
  M_ARRAY        ARRAY[3  WORD]

  G_AST_REC      RECORD
   [UNIQUE_ID      LONG
    GLOBAL_ADDR    ADDRESS
    P_L_ASTE_NO    WORD
    FLAG_BITS      WORD
    G_ASTE_PAR     WORD
    NO_ACT_IN_MEM  WORD
    NO_ACT_DEP     BYTE
    SIZE1          BYTE
    PG_TBL_LOC     ADDRESS
    ALIAS_TBL_LOC  ADDRESS
    SEQUENCER      LONG
    EVENT1         LONG
    EVENT2         LONG
   ]

EXTERNAL
  SIGNAL           PROCEDURE
  WAIT             PROCEDURE
  TC_INIT          PROCEDURE
  GET_CPU_NO       PROCEDURE
  CREATE_PROCESS   PROCEDURE
  SNDCHR           PROCEDURE
  SNDMSG           PROCEDURE
  SNDCRLF          PROCEDURE

  G_AST_LOCK       WORD
  G_AST ARRAY[G_AST_LIMIT G_AST_REC]
GLOBAL
$SECTION MM_DATA
   MM_ENTRY     LABEL
```

```
              INTERNAL

                              ! * * * * MESSAGES * * * * !
0000 08   28   IO     ARRAY [* BYTE] := '%08(FOR IO)'
0002 46   4F
0004 52   20
0006 49   4F
0008 29
0009 08   28   FM     ARRAY [* BYTE] := '%08(FOR FM)'
000B 46   4F
000D 52   20
000F 46   4D
0011 29
0012 12   4B   MM_MSG_1
                 ARRAY [* BYTE] := '%12KERNEL = SIGNALLER'
0014 45   52
0016 4E   45
0018 4C   20
001A 3D   20
001C 53   49
001E 47   4E
0020 41   4C
0022 4C   45
0024 52
0025 10   4D   CREATE_MSG
                 ARRAY [* BYTE]:= '%10MM: CREATE_ENTRY'
0027 4D   3A
0029 20   43
002B 52   45
002D 41   54
002F 45   5F
0031 45   4E
0033 54   52
0035 59
0036 10   4D   DELETE_MSG
                 ARRAY [* BYTE] := '%10MM: DELETE_ENTRY'
0038 4D   3A
003A 20   44
003C 45   4C
003E 45   54
0040 45   5F
0042 45   4E
0044 54   52
0046 59
```

```
0047 0C   4D    ACTIVATE_MSG
                  ARRAY [* BYTE] := '%0CMM: ACTIVATE'
0049 4D   3A
004B 20   41
004D 43   54
004F 49   56
0051 41   54
0053 45
0054 0E   4D    DEACTIVATE_MSG
                  ARRAY [* BYTE] := '%0EMM: DEACTIVATE'
0056 4D   3A
0058 20   44
005A 45   41
005C 43   54
005E 49   56
0060 41   54
0062 45
0063 0B   4D    SWAP_IN_MSG
                  ARRAY [* BYTE] := '%0BMM: SWAP_IN'
0065 4D   3A
0067 20   53
0069 57   41
006B 50   5F
006D 49   4E
006F 0C   4D    SWAP_OUT_MSG
                  ARRAY [* BYTE] := '%0CMM: SWAP_OUT'
0071 4D   3A
0073 20   53
0075 57   41
0077 50   5F
0079 4F   55
007B 54
007C 0C   49    ERROR_MSG
                  ARRAY [* BYTE] := '%0CINVALID CODE'
007E 4E   56
0080 41   4C
0082 49   44
0084 20   43
0086 4F   44
0088 45
0089 02   00    RET_VALUES
                  ARRAY [* B'TE] := [2,0,0,0,0,16,0,17,0,3,0,
008B 00   00
008D 00   10
008F 00   11
0091 00   03
0093 00   01
0095 00   30
0097 00   00
                                                  1,0,48,0,0]
099A            MM_MSG_ARRAY     ARRAY  [ 8 WORD ]
00AA            SENDER           WORD
```

```
             $ABS 0
              !NO MEMORY ALLOCATED; USED
               FOR PARAMETER TEMPLATE ONLY!

0000          ACTIVATE_ARG   RECORD
           [  CODE        WORD
              DBR         WORD
              HANDLE      H_ARRAY
              ENTRY_NO    BYTE
              SEG_NO      BYTE
           ]

             $ABS 0
              !NO MEMORY ALLOCATED; USED
               FOR PARAMETER TEMPLATE ONLY!

0000          RET_VAL        RECORD
           [  CODE1       BYTE
              FILLER      BYTE
              MM_HANDLE   H_ARRAY
              CLASS       LONG
              SIZE        WORD
              FILLER1     WORD
           ]
             $ABS 0
0000          ARG_LIST   RECORD
           [  REG        ARRAY[13 WORD]
              IC         WORD
              CPU_ID     WORD
              SAC        LONG
              PRI        WORD
              USR_STK    WORD
              KER_STK    WORD
           ]
```

```
        $SECTION MM_PROC

0000          MM_MAIN            PROCEDURE
             ENTRY
             MM_ENTRY:
              ! INITIALIZE G_AST !
0000 4D08     CLR   G_AST_LOCK
0002 0000*
0004 2102     LD    R2, #1
0006 0001
0008 2101     LD    R1, #0
000A 0000
000C 1404     LDL   RR4, #FREE_ENTRY
000E EEEE
0010 EEEE
              DO
0012 5D14       LDL  G_AST.UNIQUE_ID(R1), RR4
0014 0000*
0016 A920       INC  R2, #1
0018 0B02       CP   R2, #G_AST_LIMIT
001A 000A
001C 5E02       IF GT !END OF G_AST! THEN
001E 0024'
0020 5E08       EXIT FI
0022 002A'
0024 0101       ADD  R1, #SIZEOF G_AST_REC
0026 0020
0028 E8F4     OD

                    ! RESERVE FIRST ENTRY IN
                              G_AST FOR ROOT !
002A 2101     LD    R1, #0
002C 0000
002E 1404     LDL   RR4, #-1
0030 FFFF
0032 FFFF
0034 5D14     LDL   G_AST.UNIQUE_ID(R1), RR4
0036 0000*
0038 5F00     CALL  GET_CPU_NO !RETURNS:
003A 0000*
                              R1: CPU #
                              R2: # VP'S!
003C 93F1     PUSH  @R15, R1 !SAVE CPU #!
003E 5F00     CALL  TC_INIT
0040 0000*

               ! USER/HOST # !

0042 210D     LD    R13, #0
0044 0000
              ! INITIALIZE USERS !
              DO
0046 A9D0       INC  R13, #1
```

```
0048 0B0D      CP   R13, #NR_OF_HOSTS
004A 0002
               IF GT !ALL HOSTS INITIALIZED!
004C 5E02      THEN EXIT
004E 0054'
0050 5E08
0052 00B8'
               FI

                ! CREATE FM PROCESS !

0054 21F0      LD   R0, @R15 !RESTORE CPU #!
0056 030F      SUB  R15, #SIZEOF ARG_LIST
0058 0028
               !SETS ARGUMENT LIST IN STACK!
005A A1F1      LD   R1, R15
005C 6F10      LD   ARG_LIST.CPU_ID(R1), R0
005E 001C

               !LOAD INITIAL REGISTER PARAMETERS
                FOR FM PROCESS (SIMULATED)
                R13 DENOTES USER # !
0060 5C19      LDM  ARG_LIST.REG(R1), R2, #13
0062 020C
0064 0000
0066 2102      LD   R2, #FM_ENTRY
0068 4A00
006A 6F12      LD   ARG_LIST.IC(R1), R2
006C 001A
006E 2102      LD   R2, #SECRET
0070 0003
0072 8D38      CLR  R3
0074 0503      OR   R3, #CRYPTO
0076 0001
0078 5D12      LDL  ARG_LIST.SAC(R1), RR2
007A 001E
007C 4D15      LD   ARG_LIST.PRI(R1), #2
007E 0022
0080 0002
0082 4D15      LD   ARG_LIST.USR_STK(R1), #STK_SIZE
0084 0024
0086 0001
0088 4D15      LD   ARG_LIST.KER_STK(R1), #STK_SIZE
008A 0026
008C 0001
008E A11E      LD   R14, R1
0090 93FD      PUSH @R15, R13
0092 5F00      CALL CREATE_PROCESS !R14: ARG PTR!
0094 0000*
0096 97FD      POP  R13, @R15

                ! CREATE IO PROCESS !
```

```
0098 A1F1     LD   R1, R15 !RESTORE ARGUMENT PTR!

               !LOAD INITIAL REGISTER PARAMETERS
                FOR IO PROCESS (SIMULATED)
                R13 DENOTES USER # !
009A 5C19     LDM  ARG_LIST.REG(R1), R2, #13
009C 020C
009E 0000
00A0 2102     LD   R2, #IO_ENTRY
00A2 4E00
00A4 6F12     LD   ARG_LIST.IC(R1), R2
00A6 001A
00A8 A11E     LD   R14, R1
00AA 93FD     PUSH @R15, R13
00AC 5F00     CALL CREATE_PROCESS !R14: ARG PTR!
00AE 0000*
00B0 97FD     POP  R13, @R15
00B2 010F     ADD  R15, #SIZEOF ARG_LIST
00B4 0028
00B6 E8C7   OD
            ! REMOVE CPU # FROM STACK !
00B8 97F0   POP   R0, @R15
            DO !** DO FOREVER **!
00BA 7608     LDA     R8,MM_MSG_ARRAY 0
00BC 009A'
00BE 5F00     CALL    WAIT
00C0 0000*
00C2 6F01     LD      SENDER, R1 !SAVE SIGNALING PROC #!
00C4 00AA'
00C6 2103     LD      R3,#50
00C8 0032
00CA 5F00     CALL    MM_PRINT_BLANKS
00CC 030C'
00CE 2102     LD      R2,#MM_MSG_1
00D0 0012'
00D2 5F00     CALL    SNDMSG
00D4 0000*
00D6 6101     LD      R1,SENDER
00D8 00AA'
              IF      R1
00DA 0B01       CASE #IO_MGR THEN LD R2,#IO
00DC 0060
00DE 5E0E
00E0 00EE'
00E2 2102
00E4 0000'
00E6 5F00         CALL SNDMSG
00E8 0000*
00EA 5E08       CASE #FILE_MGR THEN LD R2,#FM
00EC 00FE'
00EE 0B01
00F0 0040
00F2 5E0E
```

```
00F4 00FE'
00F6 2102
00F8 0009'
00FA 5F00           CALL SNDMSG
00FC 0000*
              FI
00FE 5F00     CALL      MM_DELAY
0100 02D8'
0102 5F00     CALL      SNDCRLF
0104 0000*
0106 2103     LD        R3,#50
0108 0032
010A 5F00     CALL      MM_PRINT_BLANKS
010C 030C'
010E 6101     LD        R1,MM_MSG_ARRAY 0
0110 009A'
```

```
                 IF        R1
0112 0B01          CASE #CREATE_ENTRY_CODE THEN
0114 0032
0116 5E0E
0118 0122'
011A 5F00             CALL   CREATE_ENTRY
011C 019E'
011E 5E08          CASE #DELETE_ENTRY_CODE THEN
0120 0176'
0122 0B01
0124 0033
0126 5E0E
0128 0132'
012A 5F00             CALL  DELETE_ENTRY
012C 01AC'
012E 5E08          CASE #ACTIVATE_SEG_CODE THEN
0130 0176'
0132 0B01
0134 0034
0136 5E0E
0138 0142'
013A 5F00             CALL  ACTIVATE
013C 01BA'
013E 5E08          CASE #DEACTIVATE_SEG_CODE THEN
0140 0176'
0142 0B01
0144 0035
0146 5E0E
0148 0152'
014A 5F00             CALL  DEACTIVATE
014C 029E'
014E 5E08          CASE #SWAP_IN_SEG_CODE THEN
0150 0176'
0152 0B01
0154 0036
0156 5E0E
0158 0162'
015A 5F00             CALL SWAP_IN
015C 02AC'
015E 5E08          CASE #SWAP_OUT_SEG_CODE THEN
0160 0176'
0162 0B01
0164 0037
0166 5E0E
0168 0172'
016A 5F00             CALL SWAP_OUT
016C 02CA'
016E 5E08        ELSE
0170 0176'
0172 2102          LD         R2,#ERROR_MSG
0174 007C'
                 FI
```

```
0176 5F00      CALL    SNDMSG
0178 0000*
017A 5F00      CALL    MM_DELAY
017C 02D8'
017E 5F00      CALL    SNDCRLF
0180 0000*
0182 2103      LD      R3,#75
0184 004B
0186 5F00      CALL    MM_PRINT_LINE
0188 02F4'
018A 5F00      CALL    SNDCRLF
018C 0000*
               ! ** SIGNAL (SENDER, 'DONE') ** !
018E 6101      LD      R1, SENDER
0190 00AA'
0192 7608      LDA     R8,MM_MSG_ARRAY 0
0194 009A'
0196 5F00      CALL SIGNAL
0198 0000*
019A E88F   OD ! ** REPEAT FOREVER ** !
019C 9E08   RET
019E       END MM_MAIN

019E       CREATE_ENTRY              PROCEDURE

           ENTRY
019E 7608   LDA   R8,MM_MSG_ARRAY 0
01A0 009A'
01A2 0C85   LDB   @R8,#SUCCEEDED
01A4 0202
01A6 2102   LD       R2,#CREATE_MSG
01A8 0025'
01AA 9E08   RET
01AC       END CREATE_ENTRY

01AC       DELETE_ENTRY              PROCEDURE

           ENTRY
01AC 7608   LDA   R8,MM_MSG_ARRAY 0
01AE 009A'
01B0 0C85   LDB   @R8,#SUCCEEDED
01B2 0202
01B4 2102   LD    R2,#DELETE_MSG
01B6 0036'
01B8 9E08   RET
01BA       END DELETE_ENTRY
```

```
01BA        ACTIVATE                 PROCEDURE
                     ! R8: ARGUMENT PTR !

            ENTRY
01BA 7608    LDA  R8, MM_MSG_ARRAY 0
01BC 009A'
01BE 6182    LD    R2, ACTIVATE_ARG.HANDLE 2 (R8)
                                         !UNIQUE ID!
01C0 0008
01C2 8D38    CLR   R3
01C4 608B    LDB   RL3, ACTIVATE_ARG.ENTRY_NO(R8)
01C6 000A
01C8 030F    SUB   R15, #SIZEOF RET_VAL
01CA 0010
01CC A1F8    LD    R8, R15
01CE 2100    LD    R0, #FALSE
01D0 CCCC
01D2 2101    LD    R1, #0 !G_AST INDEX!
01D4 0000
01D6 2104    LD    R4, #1 !NR OF ENTRIES SEARCHED!
01D8 0001

             SEARCH_G_AST:
             DO
01DA 5012      CPL  RR2, G_AST.UNIQUE_ID(R1)
01DC 0000*
01DE 5E0E      IF EQ !SEGMENT IS ACTIVE! THEN
01E0 01EA'
01E2 2100       LD  R0, #TRUE
01E4 BBBB
01E6 5E08       EXIT FROM SEARCH_G_AST
01E8 01FE'
               FI
01EA A940      INC  R4, #1
01EC 0B04      CP   R4, #G_AST_LIMIT
01EE 000A
01F0 5E02      IF GT !END OF G_AST! THEN
01F2 01F8'
01F4 5E08       EXIT FROM SEARCH_G_AST
01F6 01FE'
               FI
01F8 0101      ADD  R1, #SIZEOF G_AST_REC
01FA 0020
01FC E8EE    OD

01FE 0B00    CP    R0, #FALSE
0200 CCCC
             IF EQ !SEGMENT NOT ACTIVE!
0202 5E0E      THEN
0204 0266'
0206 2100      LD   R0, #1
0208 0001
020A 2101      LD   R1, #0
```

```
020C 0000
               FIND_FREE_ENTRY:
                 DO
020E 1404          LDL   RR4, #FREE_ENTRY
0210 EEEE
0212 EEEE
0214 5014          CPL   RR4, G_AST.UNIQUE_ID(R1)
0216 0000*
0218 5E0E          IF EQ !ENTRY IS AVAILABLE! THEN
021A 0220'
021C 5E08            EXIT FROM FIND_FREE_ENTRY
021E 0234'
                   FI
0220 A900          INC   R0, #1
0222 0B00          CP    R0, #G_AST_LIMIT
0224 000A
0226 5E02          IF GT !END OF G_AST! THEN
0228 022E'
022A 5E08           EXIT FROM FIND_FREE_ENTRY
022C 0234'
                   FI
022E 0101          ADD   R1, #SIZEOF G_AST_REC
0230 0020
0232 E8ED        OD

0234 0B00        CP      R0, #G_AST_LIMIT
0236 000A
                 IF  LE !FOUND FREE ENTRY!
0238 5E0A           THEN
023A 025C'
023C 5D12            LDL G_AST.UNIQUE_ID(R1), RR2
023E 0000*
                  !  ZERO ALL EVENT DATA ENTRIES !
0240 1404          LDL RR4, #0
0242 0000
0244 0000
0246 5D14          LDL G_AST.SEQUENCER(R1), RR4
0248 0014*
024A 5D14          LDL G_AST.EVENT1(R1), RR4
024C 0018*
024E 5D14          LDL G_AST.EVENT2(R1), RR4
0250 001C*
0252 4C85          LDB RET_VAL.CODE1(R8), #SUCCEEDED
0254 0000
0256 0202

0258 5E08        ELSE
025A 0262'
025C 4C85          LDB RET_VAL.CODE1(R8), #G_AST_FULL
025E 0000
0260 0C0C
                 FI
0262 5E08       ELSE !SEGMENT ACTIVE!
```

```
0264 026C'
0266 4C85     LDB    RET_VAL.CODE1(R8), #SUCCEEDED
0268 0000
026A 0202
            FI
026C 5D82   LDL    RET_VAL.MM_HANDLE 0 (R8), RR2
026E 0002
0270 6F81   LD     RET_VAL.MM_HANDLE 2 (R8), R1
0272 0006
0274 1404   LDL    RR4, #%30001
0276 0003
0278 0001
027A 5D84   LDL    RET_VAL.CLASS(R8), RR4
027C 0008
027E 4D85   LD     RET_VAL.SIZE(R8), #1
0280 000C
0282 0001
0284 7689   LDA    R9, RET_VAL(R8)
0286 0000
0288 7608   LDA    R8, MM_MSG_ARRAY 0
028A 009A'
028C 2102   LD     R2, #16
028E 0010
0290 BA91   LDIRB  @R8, @R9, R2
0292 0280
0294 2102   LD     R2, #ACTIVATE_MSG
0296 0047'
0298 010F   ADD    R15, #SIZEOF RET_VAL
029A 0010
029C 9E08   RET
029E       END ACTIVATE
```

```
029E        DEACTIVATE                PROCEDURE

            ENTRY
029E 7608    LDA    R8,MM_MSG_ARRAY 0
02A0 009A'
02A2 0C85    LDB    @R8,#SUCCEEDED
02A4 0202
02A6 2102    LD     R2,#DEACTIVATE_MSG
02A8 0054'
02AA 9E08    RET
02AC        END DEACTIVATE

02AC        SWAP_IN                   PROCEDURE

            ENTRY
02AC 2102    LD     R2, #%FF30
02AE FF30
02B0 3B26    OUT    %FFD2, R2
02B2 FFD2
02B4 7608    LDA    R8, MM_MSG_ARRAY
02B6 009A'
02B8 5F00    CALL   WAIT  !R8:MSG ARRAY!
02BA 0000*
02BC 7608    LDA    R8,MM_MSG_ARRAY 0
02BE 009A'
02C0 0C85    LDB    @R8,#SUCCEEDED
02C2 0202
02C4 2102    LD     R2,#SWAP_IN_MSG
02C6 0063'
02C8 9E08    RET
02CA        END SWAP_IN
```

```
02CA        SWAP_OUT                 PROCEDURE

            ENTRY
02CA 7608    LDA   R8,MM_MSG_ARRAY 0
02CC 009A'
02CE 0C85    LDB   @R8,#SUCCEEDED
02D0 0202
02D2 2102    LD    R2,#SWAP_OUT_MSG
02D4 006F'
02D6 9E08    RET
02D8        END SWAP_OUT


02D8        MM_DELAY                 PROCEDURE
           !*********************************!
           ! PRODUCES 2 SEC DELAY            !
           !*********************************!
            ENTRY
02D8 2102    LD      R2, #COUNT
02DA 000A
02DC 2101    LD      R1, #TIME
02DE 01F4
             DO
02E0 0B02      CP      R2, #0
02E2 0000
02E4 5E0E      IF EQ THEN EXIT FI
02E6 02EC'
02E8 5E08
02EA 02F2'
02EC AB20      DEC     R2
02EE 7B1D      MREQ    R1
02F0 E8F7    OD
02F2 9E08    RET
02F4        END MM_DELAY
```

```
02F4       MM_PRINT_LINE           PROCEDURE
          !*********************************!
          ! PRINTS LINE LENGTH              !
          ! SPEC IN R3.                     !
          !*********************************!
           ENTRY
02F4 C82D   LDB     RL0, #DASH
            DO
02F6 0B03     CP      R3, #0
02F8 0000
02FA 5E0E     IF EQ THEN EXIT FI
02FC 0302'
02FE 5E08
0300 030A'
0302 5F00     CALL SNDCHR
0304 0000*
0306 AB30     DEC     R3
0308 E8F6   OD
030A 9E08   RET
030C       END MM_PRINT_LINE

030C       MM_PRINT_BLANKS         PROCEDURE
          !*********************************!
          ! PRINTS NUMBER OF                !
          ! BLANKS SPEC IN R3.              !
          !*********************************!
           ENTRY
030C C820   LDB     RL0, #SPACE
            DO
030E 0B03     CP      R3, #0
0310 0000
0312 5E0E     IF EQ THEN EXIT FI
0314 031A'
0316 5E08
0318 0322'
031A 5F00     CALL SNDCHR
031C 0000*
031E AB30     DEC     R3
0320 E8F6   OD
0322 9E08   RET
0324       END MM_PRINT_BLANKS
        END MM_PROCESS
```

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Honeywell Plaza
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Research and Developement
Digital Equipment Corp.
146 Main Street
Maynard, Mass. 01754

20. David P. Reed 1
MIT Lab for Computer Science
545 Tech Sq
Cambridge, Mass. 02139

21. Capt. Anthony R. Strickler 1
HQ Command,
US Army Signal Center & Ft. Gordon (WOU5AA)
Ft. Gordon, Georgia 30905

22. Lt. W. J. Wasson 1
Naval Electronics Systems Command
Headquarters, PME 124
Washington D. C. 20360

23. S. H. Wilson 1
Code 7590
Naval Research Lab
Washington D. C. 20375

24. Maj. Robert Yingling 1
Box 6227
APO New York, New York 09012

25. LCDR William R. Shockley 40
Code 52Sp
Department of Computer Science
Naval Postgraduate School
Monterey, California 93940

26. LCDR Ronald W. Modes 5
Code 52Mf
Department of Computer Science
Naval Postgraduate School
Monterey, California 93940

27. S. L. Perdue 5
Code 52
Department of Computer Science
Naval Postgraduate School
Monterey, California 93940