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# THESIS

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

by

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June 1980

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The Design and Implementation  
of the Memory Manager for a  
Secure Archival Storage System

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## ABSTRACT

This thesis presents a detailed design and implementation of a memory manager for a kernel technology based secure archival storage system (SASS). The memory manager is part of the non-distributed portion of the Security Kernel, and is solely responsible for the proper management of both the main memory (random access) and the secondary storage (direct access) of the system. The memory manager is designed for implementation on the ZILOG Z8000 microprocessor in a multi-processor environment. The loop free design structure, based upon levels of abstraction, and a segment aliasing scheme for information confinement are essential elements of the overall system security provided by the SASS.



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## I. 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 [1]. 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, multi-processing, 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 inadvertently 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 [2]). 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 [2], while the security kernel was addressed concurrently by Coleman [3]. 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 [3], and processor management was implemented by Reitz [4]. 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.





The PIM/ASM thread listing is presented as a computer program appended to this thesis.

## A. BACKGROUND

Operating systems were initially developed during an era when hardware was a scarce and expensive resource, while software was relatively inexpensive. The initial system design technique was to begin with the hardware configuration and to build the operating system upon it. The "bottom up" design technique was practical, but it made the operating system extremely hardware dependent. Hardware configuration changes would often force a major software redesign, but as long as hardware costs were dominant, software modification was the logical alternative. As the functions required of the operating system increased, new procedures were haphazardly added to the operating system, often introducing new problems. Maintenance and debugging of the operating system became extremely cumbersome and time consuming.

The increased usage of computers in such fields as finance and sensitive information handling uncovered a serious problem with most operating systems. Information stored within a computer system was generally quite accessible to anyone who had a working knowledge of operating system design and structure, regardless of any



ad-hoc attempts to provide internal computer security. Data stored in information systems, with security added in, could not be certified as being totally secure[14].

Recent technological developments have reversed the economics of the computer design environment. Microprocessors have become abundant, powerful, and inexpensive. The relative cost of software, on the otherhand, has steadily increased until it now dominates the overall cost of a computer system. This reversal has two basic implications. First, software must be treated as the expensive commodity. Software developed should therefore be logical, easy to read, relatively maintenance free, and easy to debug. Second, more powerful hardware can be used to perform functions previously performed with software, and thus hardware (multiprocessors) can be utilized to achieve overall system speed goals.

The SASS was developed utilizing a "top down" design technique, with information security as a primary design issue. Security was designed into the system based upon the security kernel concept [5]. The security kernel provides a secure environment by ensuring that just one element of the system (the security kernel) is sufficient to provide the internal system security. All accesses of data stored within the computer system must be validated by the security kernel.



## B. BASIC CONCEPTS/DEFINITIONS

### 1. Process

Organick [6] 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. The process is a logical rather than a physical entity, and can be viewed as a set of related procedures and data (referred to as the process' address space) and a point of execution within that address space. Each process may have associated with it such logical attributes as a security class authorization and a unique identifier. In order to execute, the process must be mapped onto (bound to) a physical processor within the computer system.

A process may exist in one of three states: blocked, ready, or running. When in a blocked state, the process must wait for the occurrence of some event before execution can continue (for example, an access of secondary storage). When the event for which a blocked process is waiting occurs, the process is placed into the ready state which indicates that the process can run when a processor is available to be assigned to it. The process is in the running state when it is executing on a processor.



## 2. Process Switching

When a process is blocked, the physical processor upon which it is scheduled is idle. For efficiency reasons, it makes sense to freeze that process, save the execution point (program status registers, program counter, execution stack) and the address space, and then schedule another process to run on that processor. This is referred to as process switching (or multiprogramming), and is an important aspect of a distributed operating system. The overall system, such as SASS, can be viewed as a set of cooperating processes that interact to perform the intended functions.

Efficient process switching can only be achieved with the support of some hardware switching mechanism that will unload the blocked process' address space, and load the address space of the scheduled process. Some systems have a DFR (descriptor base register) which is used to point to a list of multiple address spaces (one per process) which exists in memory. Thus to change an address space, the DFR need only be changed. The SASS utilizes a Z-8000 supporting hardware device entitled a Memory Management Unit (MMU) to allow efficient process switching. The MMU consists of a set of registers (64 or 128 in the SASS design) which contain the process' address space. Thus process switching would involve the switching of control to another hardware MMU (if a hardware MMU were available for each process), or





alternately loading a software MMU image (which is always kept current) into the MMU whenever a process switch is required. The SASS currently maintains a software MMU image for each process.

### 3. Protection Domains

A user's process executing on a computer system has an address space which includes the user provided procedures and data, and also those portions of the distributed operating system which are required to support execution of his program. To maintain system integrity and security, it becomes mandatory to protect the operating system from being altered or manipulated by the user's procedures. To achieve this, the process' address space is divided into a set of hierarchical domains which ensure that the segments of the operating system are protected from the user. Since the top down design of the operating system provides a strict hierarchal structure, the domains of the operating system are also hierarchical in structure (viz., are protection rings). In the design of the secure operating system family, three domains were defined: the user, the supervisor, and the kernel.

Operating system segments which manage the actual shared physical resources reside in the kernel. The kernel is the most privileged domain of the address space. It can be envisioned as a mini-operating system that does all the



resource management. The security kernel segments (executable) can only be accessed within the kernel. Global (system wide) data bases are restricted to access by only the security kernel to prevent the possibility of an unauthorized inter-process leakage of information [7].

The supervisor domain resides between the most privileged kernel domain and the least privileged user domain. The supervisor contains those segments of the operating system which are required to provide such common services as creating a hierarchical file system. The supervisor deals with the logical entities (segments) as viewed by the user, and manages these segments by calls to the kernel. To preserve the integrity of the file system, the user is placed in the least privileged domain, and can communicate directly with the supervisor only.

Multiple protection domains may be implemented via either a hardware and/or a software ring structure. A hardware implementation is more efficient, however the VLSI microprocessors currently being manufactured provide for only two protection domains. The present design of the SASS requires two domains, separating the supervisor and the security kernel. The Z8000 microprocessor provides the SASS with the hardware ring structure by providing two execution modes, the system mode and the normal mode. The kernel executes in the system mode and thus has access to all segments, machine instructions, and hardware facilities. The



supervisor executes in the normal mode, and thus only has access to a subset of the instruction set and segments. The supervisor does not have access to those instructions which manipulate the system hardware, such as special I/O and execution mode control instructions.

#### 4. Segmentation

Segmentation is the key element of a secure system. A segment is a logical grouping of information such as a procedure, array, or data area [8]. The address space of a process consists of those segments that may be addressed by that process. Segmentation is the management of those segments within the address space. In order to address a specific location within a segment two dimensions are required, an identification of the segment (e.g., segment number) and an offset from the base of the segment.

Each segment may have several logical attributes associated with it. These attributes can include segment size, classification, and access permitted (read, write, execute). The physical attributes of a segment include the current base address, and whether or not the segment is "in core". The segment's attributes and its physical location in memory are contained in a segment descriptor. The segment descriptors for a process are often contained in a descriptor list (viz., an MMU image for the SASS) to facilitate the memory management of its address space.



Segmentation permits multiple processes to share a single segment and to avoid the requirement of maintaining duplicate copies in memory. This eliminates the possibility of having conflicting data when multiple copies of the same segment are maintained. Segmentation also enables the enforcement of controlled access to a particular segment, since each process can have different access (read/write) to stored segments. This capability of enforcing controlled access is crucial to security.

Segmentation provides a mechanism for the virtualization of memory (although not provided in the SASS). If a user requests access to a segment to which he has access rights, and that segment is not in main memory, a memory fault will occur which will cause that segment to be loaded into main memory (another segment may have to be moved to secondary storage to make room). Thus to the user, the size of main memory is virtualized into the size of the process' address space.

## 5. Information Security

As previously stated, there is an ever increasing demand for a computer system to provide for the secure storage of information. This security cannot be added to an existing operating system with a large degree of confidence that the resulting security system cannot be avoided or bypassed. In order to be demonstrably adequate, security





must be designed into the operating system, and must be part of the cornerstone upon which the operating system is built.

There are two basic aspects of information security, external security and internal security. External security prevents an infiltrator from getting to the object in which the desired information is stored. This can be of such form as a fence, a safe, a sentry, or a guard dog. If an infiltrator manages to penetrate these external security measures, he then has access to the desired information. Internal controls would consist of those security measures internal to the computer which impede and if effective, prevent a compromise of information. If the internal controls function properly, information is provided and exchanged only with the users who are explicitly authorized access to that information. Many information systems are required to store and access information of different security levels (e.g., secret files interspersed with confidential and unclassified). The internal security of such a "multilevel" system must permit users and information to exist simultaneously at different security levels, and also ensure that no unauthorized accesses (either intentional or unintentional) are permitted. The SASS was designed to provide a multilevel secure storage environment.

The data to be stored in a secure information system can be locked upon as a set of logical objects such as files or records. Associated with each of these objects is a set



of subjects which have access rights to that object. These access rights may include read access, write access, or a combination thereof. The non-discretionary security policy involves checking the object's access class (oac) with the subject's access class (sac) to ensure that they are compatible. The access permitted is defined in a lattice model of secure information flow [9] as follows:

sac = oac, read and write access permitted

sac > oac, read access permitted

sac < oac, no access permitted

The government security classification system provides an example of a non-discretionary security policy. A user with a security clearance of confidential is authorized read and write access to a confidential file (sac = oac), and he has read access (but not write) to an unclassified file (sac > oac). This restriction on write access is to prevent the inadvertent writing of confidential data into an unclassified file to which the subject may have simultaneous access (this property is often referred to as the \*-property [10]). Finally, the confidential subject does not have access to any secret files (sac < oac).

The discretionary security policy involves checking the subject against an object's access control list (ACL). The subject only has access to an object if he is included in its ACL. This policy is analogous with the government's "need to know" policy, which precludes a subject with a



secret clearance from having access rights to all secret information within the system. He may access only that for which he has a "need to know". The discretionary security policy thus allows the users of the system to specify who has access to their files. It is noted that the discretionary security policy is a refinement of the security policy, and never permits a violation of the non-discretionary security policy in effect.

The SASS was designed with the internal non-discretionary security to be provided by the security kernel. Discretionary security is provided by the supervisor file system. The security kernel is based upon a mathematical model which has been proven correct. This mathematical model implements the system's security policies.

The security kernel design has three prerequisites in order to provide a secure environment: 1) the kernel must be isolated to ensure that it cannot be modified either intentionally or inadvertently. This is to ensure that the behavior of the kernel cannot be modified. 2) Each and every attempt to access data within the system must invoke the kernel. 3) The kernel's correctness must be verifiable. This implies that the mathematical model must be proved and demonstrated as secure, and that the kernel implements this model.



## C. THESIS STRUCTURE

This thesis presents the detailed design of a memory management process for the SASS. The top down design technique was utilized, with levels of abstraction used to reduce the design complexity. The high level language utilized was PLZ/SYS, which was designed to be compatible with the Z8001 microprocessor. PLZ/SYS is a block structured language similar to PASCAL. The compiler which compiles from PLZ/SYS to the Z8001 instruction code is still in the developmental stage at ZILOG, INC. The PLZ/SYS code had to therefore be "hand compiled" (viz., translated to the PLZ/ASM assembly language) in order to run, test, and debug the code. Some of the procedures in the lower levels of design (those which use privileged instructions to directly manipulate the system hardware) must be directly coded using the assembly code PLZ/ASM. These procedures were declared external to the Memory\_Manager\_PLZ/SYS\_Module and are coded in the Memory\_Manager\_PLZ/ASM\_Module.

Chapter II of the thesis presents an overview of the SASS at its current stage of development. The design of the memory management process, and the concurrent implementation of the distributed kernel processor management by Peitz [4] refined the original design of Parks and Coleman. Future work in the SASS will most likely require some refinement of the present design.





Chapter III presents the detailed design of the memory manager module. This chapter emphasizes why certain design features were chosen, and how they were implemented in this design.

The final chapter presents the status of research to date, and attempts to identify what follow-on work is required. The PLZ/SYS code module and the PLZ/ASM code module are presented as appendices.



## II. SECURE ARCHIVAL STORAGE SYSTEM DESIGN

This chapter presents an overview of the SASS in its current state of development. It is a summation of the original design efforts, and reflects refinements of those original designs. This overview is necessary in order to fully understand the interrelationship between the memory manager and the overall system design. It also provides a current base for further SASS development.

### A. BASIC OVERVIEW

The purpose of the SASS is to provide a secure archival file storage medium for a variable number of host computers. The key design goals of the SASS were multi-level internal computer security and controlled sharing of data among authorized users.

Figure 1 provides an example of how the SASS could be used. In this example, there are four host computers which reside in four separate rooms (consider each of these computers to be microcomputers, although any computer could be utilized). Each of the four hosts are used to create and manipulate files of fixed predetermined security classification. For example, all files created by host #2 are classified secret. Host #2 cannot create top secret,



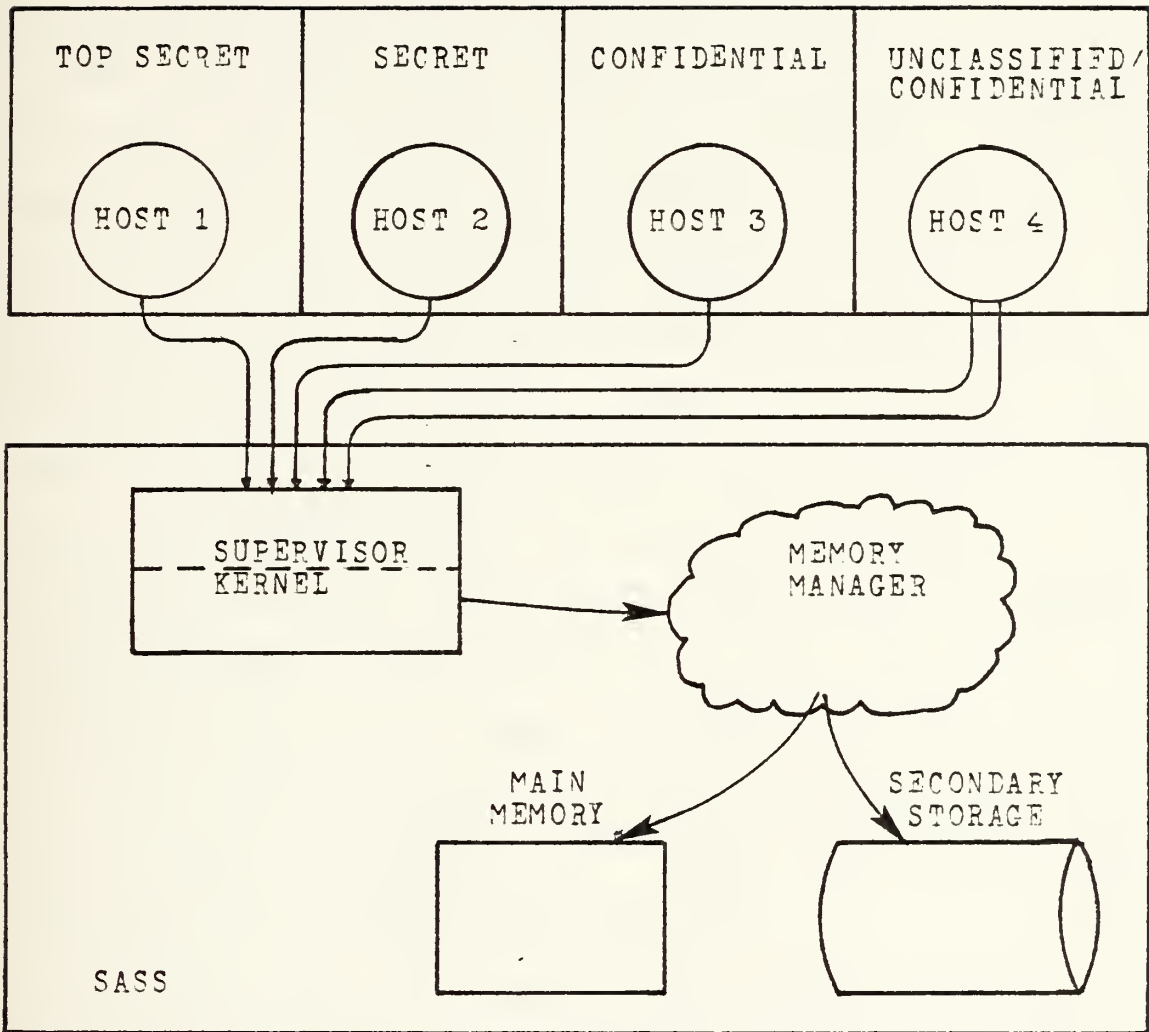


Figure 1. SASS System



confidential, or unclassified files (nor can he access top secret in this example). Access to each of these rooms is physically controlled to ensure that only personnel with the proper security clearance are authorized access. None of the host systems have a permanent local file storage device, and all are hard-wired to an I/O port of the SASS.

Each host controls the access to its I/O ports (host #4 illustrates the multi-level host connection currently required by the SASS). The physical protection of the hard-wire is assumed to be adequate to minimize the possibility of such malicious activities as wire tapping or emanations monitoring. Once a user of the host system completes his work, he can permanently store his file on the SASS, which is contained in the fifth room of figure 1 (view the SASS as an Z8001 microcomputer with access to secondary storage devices). To gain access to a file, the user or O/S of the host system must request the SASS to provide him with that file. This implies that if a malicious user gains access of the confidential host system, he still cannot access files of a higher classification.

The SASS must be capable of performing three basic functions in this environment. These functions are: 1) store a file for a host system, 2) retrieve a file for a host system, and 3) ensure that the the files are made available only to authorized users. The required capability of file storage and retrieval implies that processes must exist for





each host system to perform file management and data transfer on behalf of that host. To ensure the security of the stored information, the SASS must ensure that the user of a specific host system may only address the files to which he has access. The SASS achieves the desired environment through a distributed operating system design which consists of two primary modules, the supervisor and the security kernel (the security kernel actually consists of distributed and non-distributed portions). Each host system, which is hardwired to the SASS, communicates with its own I/O process and file manager process in the SASS itself.

The supervisor is responsible for the SASS-host system interface. It constructs and manages a hierarchical file system for its host, based upon the files which the host has submitted, and controls the actual I/O (both data and commands) between the SASS and the host system. The supervisor is built upon the security kernel and performs the host's requests (file storage, file retrieval, I/O) by calls to the security kernel. These calls must be validated (by a gate keeper module in the SASS design) before the security kernel function is invoked.

The SASS security kernel consists of a distributed and non-distributed kernel. The distributed kernel is distributed to (viz., is in the address space of) every process, and is responsible for the multiplexing of the



several processes onto the actual hardware processor(s), enforcing the non-discretionary security policy, and providing the synchronization primitives for inter-process communication. The non-distributed kernel consists of the memory manager process which is responsible for the secure management of both main memory and secondary storage. Each hardware processor must have its own memory manager (ergo, non-distributed kernel) in the SASS design.

An abstract system overview of the SASS is presented in figure 2. Four levels of abstraction were utilized to simplify the design and understandability of the system.

Level 1 consists of the system hardware which includes the Z8001 microprocessor, the local and global memories, and secondary storage. The SASS is designed to operate in a multi-microprocessor environment, therefore each CPU is assigned its own local memory (to which it alone has access) in which it can store process local segments. The system contains a global memory, which every CPU may access. Segments to which a user process has write access must be stored in global memory if more than one process has simultaneous access to that segment. This is to ensure that all processes access the current copy of that shared writable segment. The basic storage policy is to store every segment within local memory if at all possible. This is to keep bus contention between processors, which access global memory, to a minimum.



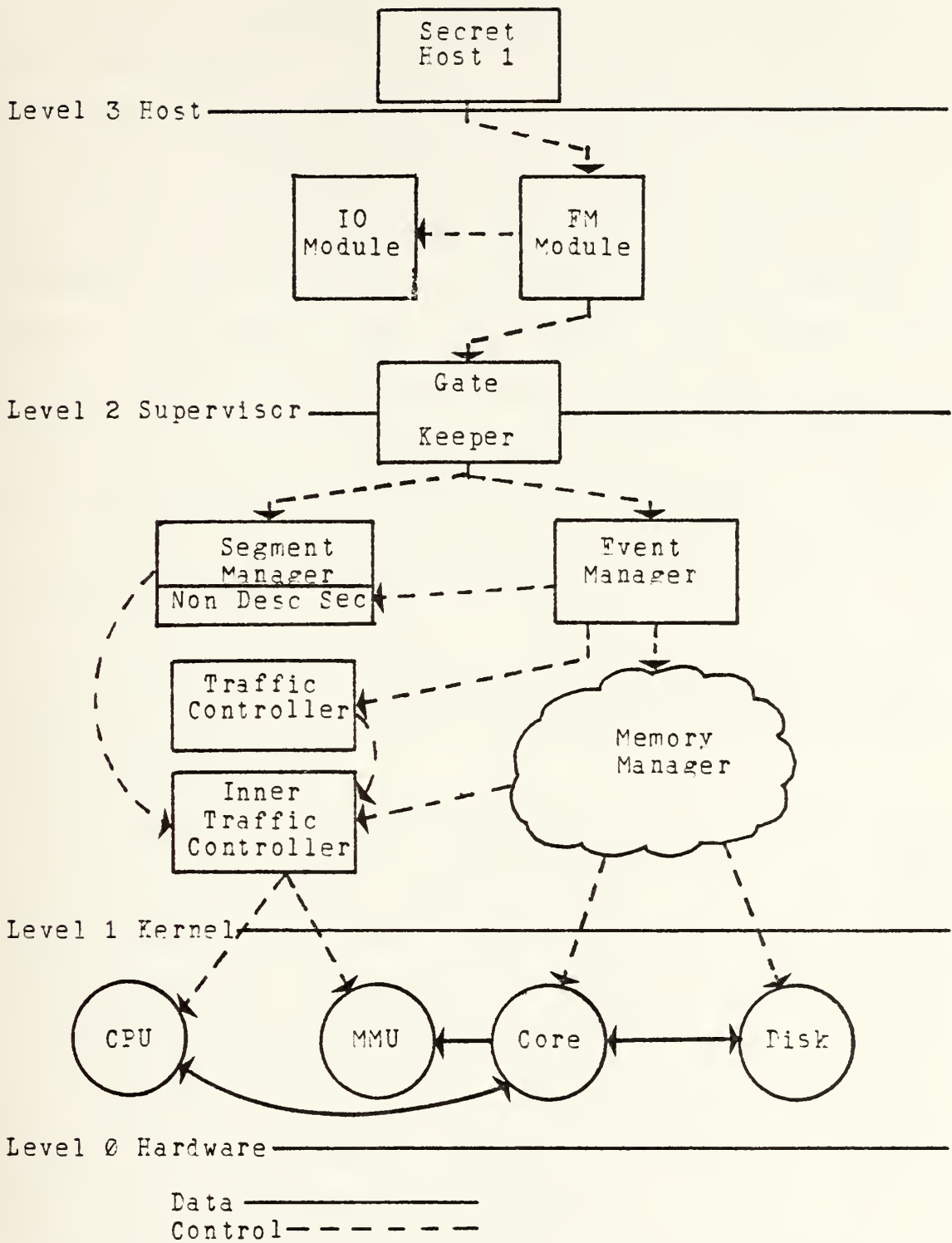


Figure 2. SASS Abstract System Overview



Level 1 consists of the distributed and non-distributed kernel. The kernel is placed in (executes in) the most privileged domain (system mode) of the Z8001 to ensure that it is protected from any manipulation (either malicious or inadvertant). The kernel controls all access to the system hardware by maintaining all privileged machine instructions within its domain. Only the kernel may access these instructions. The distributed kernel is responsible for creating a virtual processor environment and enforcing the non-discretionary security policy. It multiplexes processes onto virtual processors and then multiplexes these virtual processor(s) onto the actual hardware processors. The non-distributed kernel consists of the memory manager and is responsible for the secure management of both main memory and secondary storage.

Level 2 consists of the supervisor, which resides in the less privileged domain (normal mode) of the Z8001 microprocessor. It has access to all the machine instructions with the exception of those which manipulate the system hardware. The supervisor must request the kernel to move segments into and out of memory and secondary storage via the gate keeper (a software assisted ring-crossing mechanism). The supervisor consists of two surrogate processes for each host, the I/O (input/output) process and the FM (file management) process. By utilizing the I/O and FM processes the supervisor is able to provide





and manage a virtual file hierarchy for each host system. Each host system has I/O and FM processes created and assigned at system generation. They are not dynamically created or deleted. The supervisor ensures that each segment's discretionary security is enforced.

Level 3 consists of the host computer systems. These systems are hardwired to the I/O ports of the Z8000. The hosts communicate with the SASS via system protocols over a communication link. Any computer system could serve as a host, with each host supporting multiple users.

### B. SUPERVISOR

Each host system is assigned the dedicated services of a pair of supervisor processes at system generation. These processes are the I/O and FM processes. The FM process and the I/O process communicate with each other via a shared segment entitled the "mailbox". This communication is synchronized via the kernel synchronization primitives which act upon eventcounts and sequencers [10]. A virtual file system is created and maintained for each host by its FM and I/O processes.

#### 1. File Management Process

The FM process is responsible for the management of the host's virtual file system within the SASS. The FM



process interprets all the host commands and acts upon them in conjunction with the I/O process.

The user of the host system views his stored data (within the SASS) as a hierarchy of files. Figure 3 provides an example of such a hierarchical file structure. To specify a particular file, a pathname is required. The pathname is simply a concatenation of the file names (given to each file by the user at its creation) starting at the "root" directory and proceeding sequentially to the desired file. The user is required to submit a pathname with each command sent to the SASS. The five basic actions to be performed upon files at this level are: 1) to create a file (data or directory), 2) to delete a file, 3) to read a file (data or directory), 4) to initiate or modify file attributes (size, classification, access permitted), and 5) to store (write) a file.

The FM process is required to convert the pathname provided by the user, into one or more segment numbers. This is necessary because the notion of a file is not known within the kernel. All files are composed of segments, and must be referenced as segments within the kernel for manipulation and management. The FM process must also provide appropriate command handlers to ensure that the user's requested action is properly carried out.

The SASS permits a host to read or write the files of another host, at the same security level, if



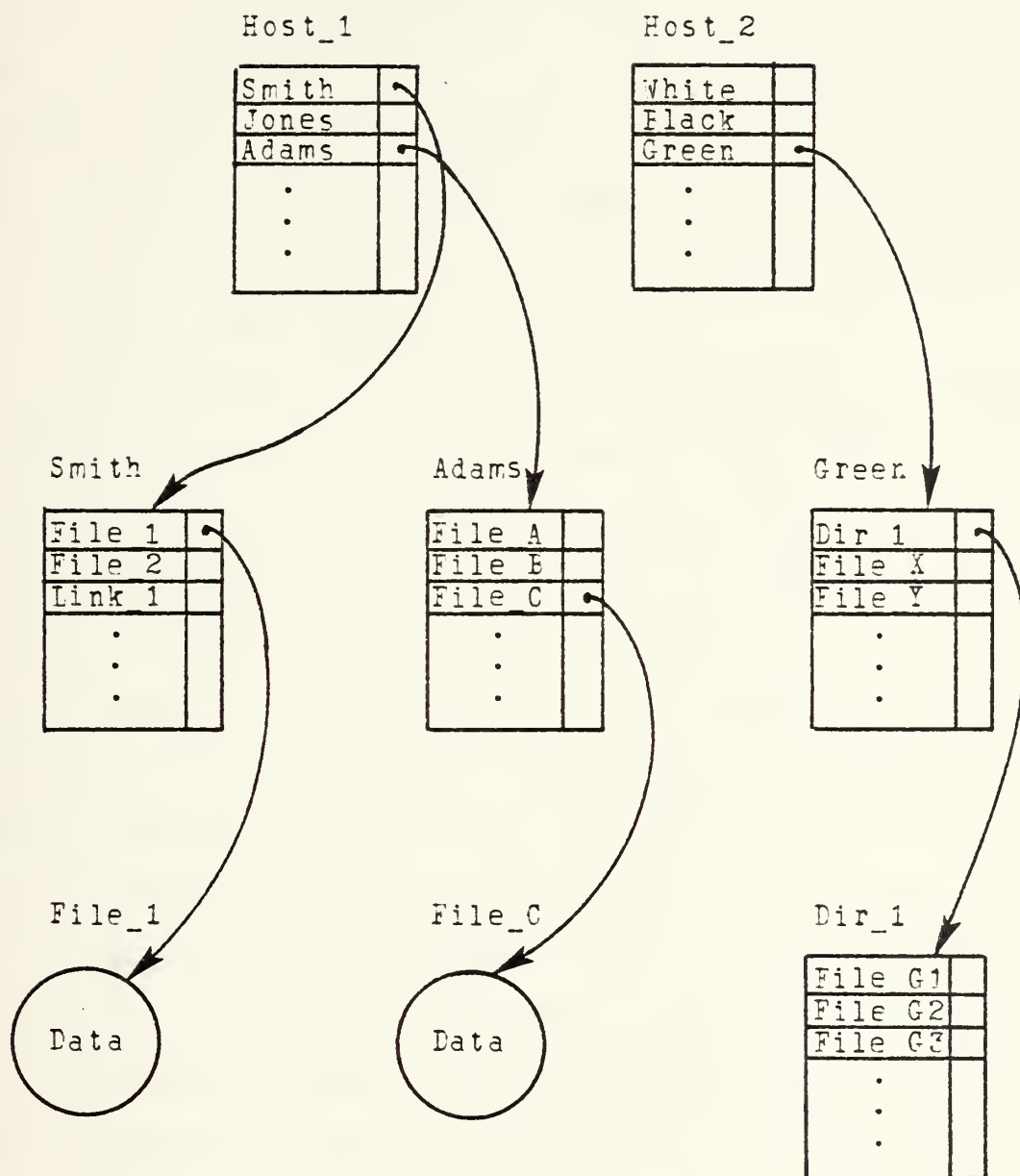


Figure 3. Virtual File Hierarchy



discretionary access is permitted. Files of a lower classification may be read only (if discretionary access is permitted). This file sharing is achieved by creating a link between the two file hierarchies. This link is entered into a directory file of the host, and is constructed in the same manner as a pathname (viz., it is a concatenation of filenames). The kernel enforces a read only access to the lower classified files, which prevents the possibility of writing data (through a link) of a higher classification into a file of lower classification.

The database utilized by the FM process to manage the host's files is the FM Known Segment Table (FM\_KST). The FM\_KST is a list of those segments which are known to (viz., within the address space of) the FM process. Figure 4 provides an example of the FM\_KST structure.

Whenever a user of a host system requests access to a specific file, the FM\_KST is searched to determine if that pathname (segment) is already known. If it is known, the request is passed to the kernel, via the gate\_keeper, with the appropriate segment number, for the desired action. If the pathname is not known, the segment number of the desired file's directory (parent) file and an entry number are sent to the kernel with the request to make that segment known. If the request is authorized by the kernel, a segment number and access mode authorized are returned. The returned segment number and mode are then entered into the FM\_KST





| Path Name           | Seg_# | Access Mode | Use |
|---------------------|-------|-------------|-----|
| Host_1>Adams>File_C | 50    | R           | N   |
| Host_2>Green>Dir_1  | 44    | W           | Y   |
| Host_1>Smith>File_1 | 22    | W           | N   |
| Host_1>Smith>Link_1 | 44    | R           | Y   |
|                     | .     |             |     |
|                     | .     |             |     |
|                     | .     |             |     |
|                     | .     |             |     |
|                     | .     |             |     |

Figure 4. File Manager Known Segment Table.



with that segment's pathname. Once the segment is known, the desired user action can be carried out.

The user requests to create or delete files are simply passed to the appropriate kernel procedure, via the gate keeper, by the FM process (after a discretionary security check). No entries are added or deleted from the FM\_KST during create or delete requests (they invoke kernel primitives which add or delete entries from a kernel data base).

Should the FM process request that a segment be swapped into memory and memory is full, an error code will be returned to the FM process from the kernel (it is noted that this is a per process memory allocation, thus the memory state cannot be affected by its use by other processes). The FM process will then select a segment to be removed from core to make room for the desired segment. The current design calls for the invocation of a least recently used algorithm (LRU) which makes use of the FM\_KST "used" field to determine the least recently used segment for swap out.

Discretionary security is enforced in the discretionary security module of the FM process. An access control list (ACL) is maintained for each file within the file hierarchy. The ACL is simply a list of authorized users (a refinement of non-discretionary security) which is checked for each access to that file. The discretionary



security module also performs the housekeeping functions for the file's ACL. These functions include the addition of a ACL entry, the deletion of an ACL entry, and the initialization of an ACL for a new file.

It is noted that the original design of the FM process contained a memory manager procedure. This was necessary because the original SASS design called for the partitioning of memory such that each supervisor maintained his own core. The FM memory manager managed this virtual core by calls to the kernel via the gate keeper (swap\_in, swap\_out). The current design of the non-distributed kernel includes memory allocation and thus has removed the need for the supervisor to manage its own virtual core. Because of this, a FM memory manager is not required.

## 2. Input/Output Process

The I/O process is responsible for all the input and output between the supervisor and the host computer system. The I/O process receives its commands from the FM process via the shared mailbox segment.

Data is transferred between the host systems and the SASS in fixed size "packets". There are three basic types of packets, a synchronization packet, a command packet, and a data packet. Protocols exist for the reliable transmission and receipt of the packets by both the SASS and the host systems. The current design calls for the use of



multi-packet protocols, which allows the sender to send several packets before he receives a receipt.

The original design of the I/O process contained a Memory Manager procedure for the same reasons as the FM process. This procedure is no longer required due to the design of the non-distributed kernel.

### C. DISTRIBUTED KERNEL

The initial design of the security kernel as presented by Coleman [3], has been developed by Reitz [4] and the work presented here. The primary refinements have been the replacement of block/wakeup [3] by eventcounts, the inclusion of an event manager which contains the synchronization primitives, and the transfer of MMU management to the memory manager. Figure 5 provides an overview of the security kernel design.

#### 1. Gate Keeper

The gate keeper is a software ring crossing mechanism which is utilized to ensure that the security kernel is isolated and tamperproof. The major issues of the gatekeeper design are: 1) to provide a mode switching mechanism for switching from normal (supervisor) mode to system (kernel) mode, 2) to mask hardware preempt interrupts in the kernel, and 3) to check for "virtual"





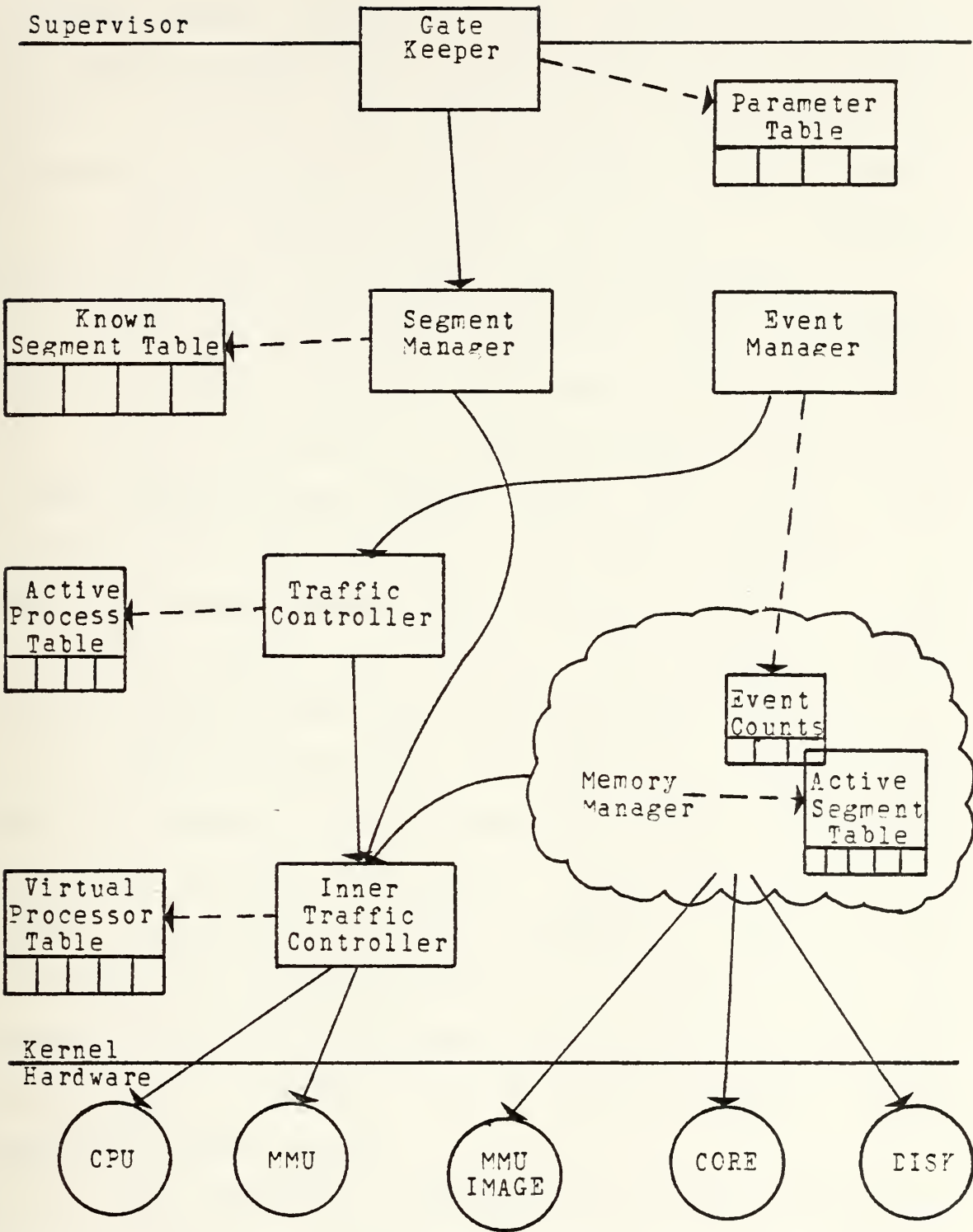


Figure 5. Security Kernel Design.



software preempt interrupts when leaving the kernel. The gate keeper provides the sole entry point into the kernel domain, validates the request and its arguments, and transfers the request to the appropriate kernel procedure. If the gate keeper encounters an error, it returns an appropriate error code without invoking the kernel.

The gate keeper uses a parameter table to validate the user's request (call by value only). This table contains the number of parameters required by each kernel function (create\_segment, delete\_segment, etc.), the type of each parameter, and the type of each return parameter. If an error is discovered during the validation process, it sets the return message to an error code. If the request is valid, the gate keeper calls the appropriate kernel module.

The gate keeper is a trap handler. The supervisor puts an argument list and space for a return message in a segment (or processor registers) within the supervisor's domain. When the gate keeper is invoked, it must first save the supervisor processor registers and then retrieve the argument list (via an argument list pointer register). The arguments are validated and if correct, passed to the appropriate kernel module.

When the kernel completes action taken upon the user request, it returns to the gate keeper. The gate keeper then copies a return message into the return argument (that is returned to the supervisor's domain), restores the



supervisor's environment, unmask the interrupts, and makes a trap return back to the supervisor (viz., changes the mode back to normal).

## 2. Segment Manager

The segment manager is responsible for the management of the segmented virtual memory. There are six functions which the segment manager is called upon to perform. These functions are: 1) to create a segment, 2) to delete a segment, 3) to make a segment known, 4) to make a segment unknown (terminate), 5) to swap a segment into core, and 6) to swap a segment out of core.

The segment manager uses the Known Segment Table (KST) as its data base to manage segments. The KST is a process local kernel data base which contains entries for all the segments which the process has made known. Figure 6 provides an example of the KST structure. The KST size is fixed at system generation. It is indexed by segment numbers which are assigned by the segment manager. When a segment is made known, a "handle" (the concatenation of the Global Active Segment Table (G\_AST) index and the segment's unique identification) is returned to the segment manager by the memory manager. The handle is a system wide unique identification that is assigned to each active segment (viz., active in the G\_AST). The KST provides the mapping mechanism for converting the segment number into the



Segment\_#



| MM_Handle | Size | Access Mode | In Core | Class |
|-----------|------|-------------|---------|-------|
|           |      |             |         |       |

Figure 6. Known Segment Table.





segment's unique handle. The use of the unique handle by the memory manager is what permits the controlled sharing of segments by concurrent processes. Any process which requests to make a specific segment active will always be returned that segment's unique handle. Thus any one segment may exist within the address space of several processes (with a different segment number in each process) while residing in one location in memory.

The SIZE field of the KST represents that segment's size. Segments exist in multiples of 256 bytes due to Z-8000 MMU hardware constraints. An upper bound upon the segment size is fixed at system generation by the design parameter max\_segment\_size. This is limited to 65K bytes by hardware. The ACCESS\_MODE field states the access authorized to the segment (read, write) by this process. The IN\_CORE field is set when a process successfully requests the segment to be swapped into core. The CLASS field is used to give the access class (e.g., secret, confidential) of the segment.

The usual sequence of invoking the segment manager functions (by the supervisor) would be as follows: 1) Create\_Segment (this will invoke the memory manager to assign a unique identification to the created segment), 2) Make\_Known, which will place the segment into the KST, and 3) Swap\_In, which will move the segment from secondary storage to main memory. To remove a segment from main memory



to secondary storage, the order would be 1) Swap\_Out, 2) Make\_Unknown, and 3) Delete\_Segment.

### 3. Event Manager

The event manager provides the kernel synchronization primitives that are used for the synchronization of concurrent processes in the supervisor of the present SASS design. The synchronization mechanism used is that of eventcounts and sequencers, first proposed by Reed and Kanodia [12]. The use of eventcounts and sequencers allows the ordering of events to be controlled directly by the processes involved, rather than to depend upon mutual exclusion mechanisms such as semaphores. The actual eventcounts are maintained in the memory manager module as they are a system wide entity and are not process local.

Reed and Kanodia define an eventcount as an object that keeps a count of the number of events in a particular class that have occurred so far in the execution of the system. The event observed can be anything from the input of data to the system, to writing a particular segment. The eventcount can be viewed as an integer value, which is incremented with each occurrence of the observed event. The primitive ADVANCE(X) is used to signal the occurrence of a particular event, and causes the eventcount X, associated with that event, to be incremented. The primitive READ(X) will return the value of the eventcount X. The primitive



AWAIT(X,n) will suspend the calling process until the value of eventcount X is greater than or equal to the integer value n.

A sequencer can be defined as an abstract object that can be utilized to totally order the events of a particular class. The basic purpose of the sequencer is to provide a means to determine an ordering of a set of occurrences of a particular event. Like the eventcount, the sequencer can be viewed as an integer value which is incremented each time the primitive TICKET(S) is called. The TICKET primitive is based upon the ticket machines often used in barbershops and ice cream stores. When a customer enters, he takes a ticket, from which the order of who arrived first and whom will be served next can be determined.

The use of eventcounts and sequencers by the SASS supervisor can be illustrated as follows. Suppose that segment A is currently being updated by process one. Eventcount A currently has the value of 9 (the eventcount associated with the reading of segment A). Process two desires to read segment A, so he obtains a ticket by utilizing the TICKET primitive associated with segment A. The value returned by TICKET is 10. Process two now calls upon the primitive, AWAIT(A,10), which will suspend process two until eventcount A is valued at 10. When process one completes his update, he will execute ADVANCE(A), which will



increment eventcount A to the value of 10. This will allow the WAIT(A,10) to return to process two, which will then be allowed to read segment A.

#### 4. Traffic Controller

The traffic controller performs the function of scheduling processes to run on virtual processors. The traffic controller could be designed to schedule processes to run directly on the hardware processors, but in this design, Reed's [11] notion of a two level traffic controller was utilized. Thus the processes are first multiplexed onto virtual processors by the traffic controller. The virtual processors are then multiplexed onto the actual hardware processors by the inner traffic controller.

A virtual processor is an abstract data structure which preserves all the attributes of a process in execution on a processor (i.e., an execution point and an address space). Multiple virtual processors may exist for a single physical processor. The Active Process Table (APT) is the data base utilized by the traffic controller to control and manage the multiplexing of processes onto virtual processors. Figure 7 provides an example of the the APT.

The APT is a fixed sized table which contains an entry for each process of the SASS (the processes are created at system generation). Because of the design decision not to create or destroy processes after system





Process\_Index

| DER | Priority | State | Next_Ready<br>Active_Process |
|-----|----------|-------|------------------------------|
|     |          |       |                              |

Figure 7. Active Process Table.



generation, the initial entries into the APT will be active for the life of the system. The index into the APT is the PROCESS\_ID.

The traffic controller uses the PRIORITY field of the APT to determine which process to schedule for execution on each virtual processor. The STATE field contains that process' current state (running, blocked, or ready). The DPR (descriptor base register) field of the APT provides the address of the MMU image for that process. The Next\_Ready\_AP field is a pointer which contains the index of the next process which is in the ready state.

The design simplification choice of always having a process running on the virtual processors, introduced the notion of an idle process for each virtual processor. The idle process is loaded onto a virtual processor and placed into the running state whenever the number of available virtual processors exceeds the number of ready or running processes (excluding the idle process). The idle process is of the lowest priority, and will only run if no other process can be loaded. It is incapable of blocking itself, and thus must always be in either the running or ready state.

When a virtual processor becomes available, the traffic controller will be invoked to schedule the highest priority ready process which may run on that particular virtual processor. If no process is ready, the Idle process



is scheduled. The Idle process provides a means to guarantee that a ready process will always be found, and that the Traffic Controller cannot be exited without scheduling a process.

## 5. Inner Traffic Controller

The purpose of the inner traffic controller is to provide the multiplexing of the virtual processors onto the actual system processor(s), and to provide the kernel primitives for inter-process communication within the kernel (Signal and Wait). In the SASS design, each physical processor has a fixed set of virtual CPU's that it multiplexes. The primary data base utilized by the inner traffic controller is the Virtual Processor Table (VPT). Figure 8 provides an example of the VPT.

The VPT is indexed by the Virtual\_Processor\_ID. The DBR, PRI, and the STATE fields are used in the same manner as those fields in the APT. The Idle\_Flag simply indicates that the idle process is loaded on that virtual processor. The Preempt flag indicates that a virtual preempt interrupt has been directed to that virtual processor. The Phys\_Processor is a fixed field that indicates which hardware processor that virtual processor is scheduled to run on. The Next\_Ready\_VP is a pointer to the index of the next ready virtual processor in the VPT for this CPU.

In his original design, Coleman [3] tasked the inner



VP\_ID

| DBF | Pri | State | Idle<br>Flag | Preempt<br>Flag | Phys<br>Proc | Next<br>Rdy_VP | Msg<br>List |
|-----|-----|-------|--------------|-----------------|--------------|----------------|-------------|
|     |     |       |              |                 |              |                |             |

Figure 8. Virtual Processor Table.





traffic controller with the management of the hardware Memory Management Units (which contain the process' address space and its attributes) and the MMU software images. In the present design, this function has been assigned to the memory manager. When the inner traffic controller unloads a processor, it simply writes the MMU into the MMU image in order to save the segment usage information. To load a process, it writes the MMU image into the MMU. The memory manager insures that the MMU image is kept current by updating the images whenever a segment is swapped in or swapped out of memory.

The kernel synchronization primitives of SIGNAL and WAIT are maintained within the inner traffic controller. These primitives are used by virtual processors within the kernel domain to synchronize with other virtual processors within the kernel domain.

#### D. NON-DISTRIBUTED KERNEL

The SASS non-distributed kernel is composed solely of the memory manager process. Each physical processor has associated with it, its own dedicated memory manager process. The purpose of the process is the proper and secure management of the main memory (both local and global), and secondary storage. The actual transfer of segments from main memory to secondary storage and vice-versa, is controlled by



the memory manager process. The primary data base utilized by the process is the Active Segment Table. Chapter 3 provides a detailed description of the process' functions and data bases.



### III. 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 9. 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.

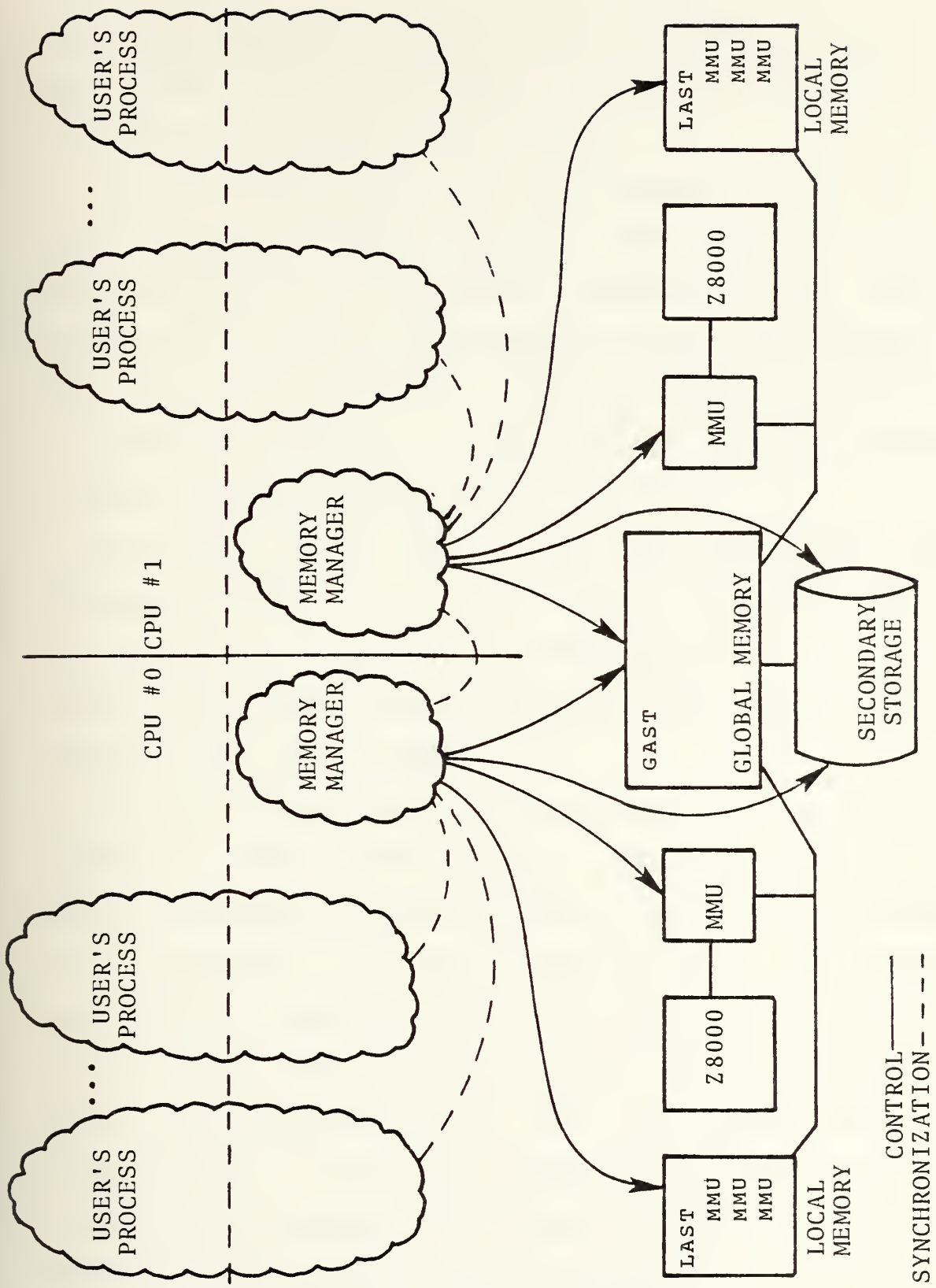
#### F. DESIGN PARAMETERS AND DECISIONS

Several factors were identified during the design of the memory manager process that refined the initial kernel design of Coleman[3]. 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







CONTROL ———  
 SYNCHRONIZATION - - - -

Figure 9. SASS H/W System Overview.



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 46 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[2] and Coleman[3]. 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 initialization 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[3] memory manager data bases 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 10) 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).

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[1]. 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



Index\_#

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

\* Field indicates a two processor environment

| # Active In Memory | No. Active Depend. | Size | Page Table Loc | Alias Table Loc | Sequencer | Inst-ance1 | Inst-ance2 |
|--------------------|--------------------|------|----------------|-----------------|-----------|------------|------------|
|                    |                    |      |                |                 |           |            |            |

Figure 10. Global Active Segment Table.



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 11). 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.

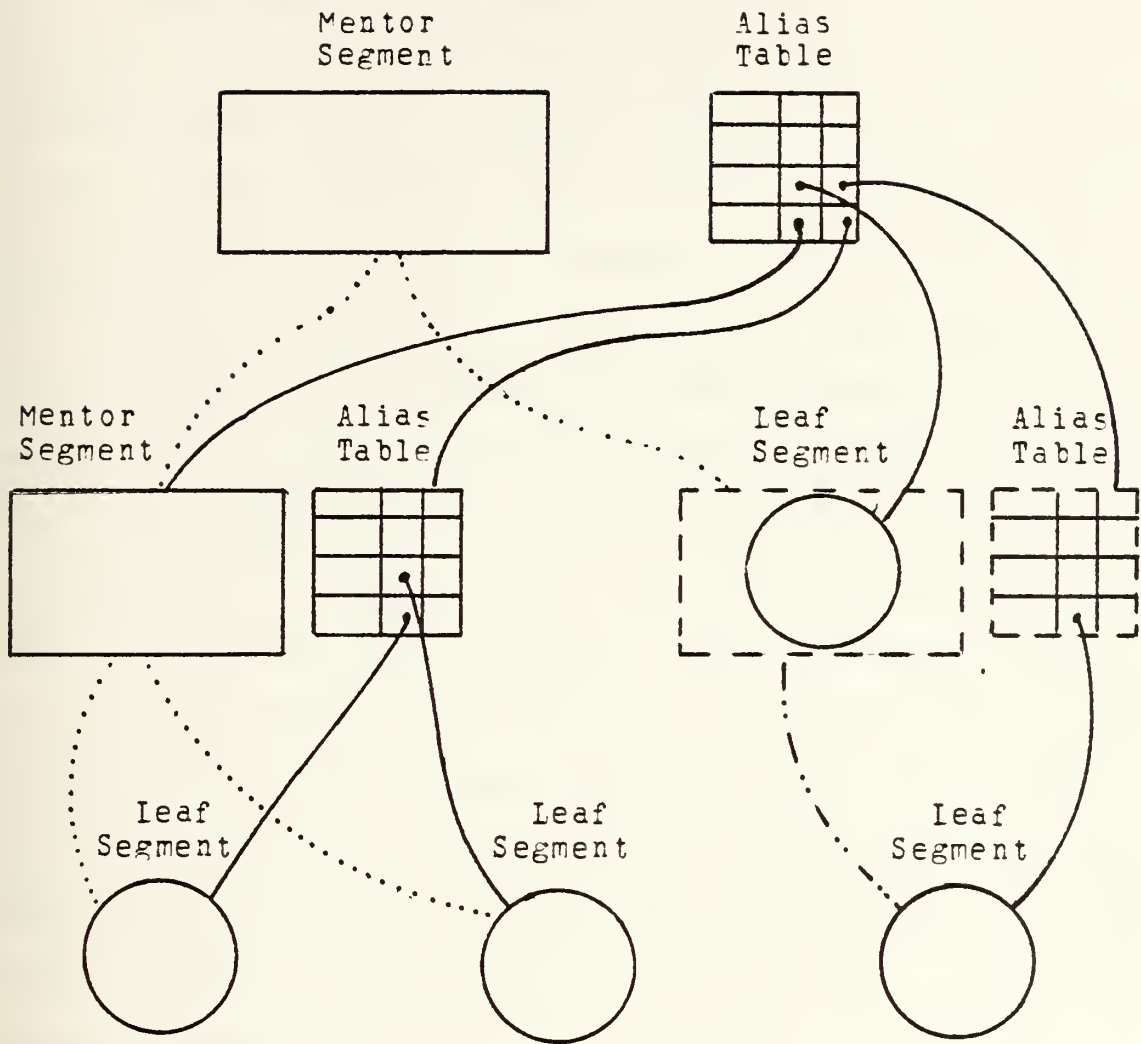
The No\_Active\_Dependents field is a count of the number of active leaf segments that are dependent on this entry (viz., require that this segment remain in the G\_AST). Each time a process activates or deactivates a dependent segment this field is incremented or decremented.

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 [4]. 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 occurrences of some event).







Direct Pointer —————  
 Indirect Pointer .....  
 Created - - - - -

Figure 11. Alias Table Creation.



## 2. Local Active Segment Table

The Local Active Segment Table (see figure 12) 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.

## 3. Alias Table

The alias table (see figure 13) 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



Index\_#

| Memory<br>Addr | Segment_#/Access_Auth |       |       |       |       |       |
|----------------|-----------------------|-------|-------|-------|-------|-------|
|                | DBR_0                 | DBR_1 | DBR_2 | DBR_3 | DBR_4 | DBR_5 |
|                |                       |       |       |       |       |       |

Figure 12. Local Active Segment Table.



Entry\_#

| Unique_ID | Size | Class | Page Table Location | Alias Table Location |
|-----------|------|-------|---------------------|----------------------|
|           |      |       |                     |                      |

Figure 13. Alias Table.





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.

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 14) includes a software representation of the segment descriptor registers (SDR) for the hardware MMU [12]. 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 [12]. 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 management of each process' virtual core and are not associated with the hardware MMU.



DBR\_# →

Segment  
No. ↓

|                  |       |            |  |
|------------------|-------|------------|--|
| Blocks Used      |       |            |  |
| Max Avail Blocks |       |            |  |
| Base_Addr        | Limit | Attributes |  |
|                  |       |            |  |

one record / DBR\_#

Figure 14. Memory Management Unit Image



## 5. Memory Allocation/Deallocation Bit Maps

All of the memory allocation/deallocation bit maps (see figure 15) 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.

### D. BASIC FUNCTIONS

The detailed source code for the basic functions and main line of the memory manager are presented in appendices A and B. Appendix A lists the procedures which are coded in PLZ/SYS, while Appendix B lists the lower level hardware dependent procedures which are coded in PLZ/ASM.

PLZ/SYS is a high level modular structured language which produces a machine-independent Z-code similar to





Memory Bit Map

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

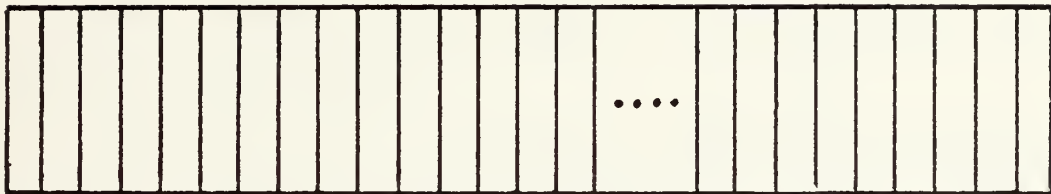


Figure 15. Memory Allocation/Deallocation Map.



PASCAL'S P-code. The translator from Z-code to Z-8000 machine code is currently under development at ZILOG Inc., thus the PLZ/SYS module could not be compiled on the Z8000 [13]. PLZ/ASM is a symbolic assembly language that is used to program the Z-8000. The assembler supports Structured programming and produces a relocatable Z-8000 object module.

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 16.

### 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 11).

The pseudo-code for CREATE\_ENTRY PROCEDURE is presented in figure 17. The arguments passed to Create\_Entry



```

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)
CD
END MEMORY_MANAGER_PIZ/SYS MODULE

```

Figure 16. Memory Manager Mainline Code.





```

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 17. Create Entry Pseudo-code.



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.

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 18. 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.

### 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





```

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_IOC <> NULL
    SUCCESS_CODE := READ_ALIAS_TABLE (
      G_AST[PAR_INDEX].ALIAS_TABLE_IOC)
  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_IOC)
  IF SUCCESS_CODE = VALID THEN
    SUCCESS_CODE := SEG_DELETED
  FI
END DELETE_ENTRY

```

Figure 18. Delete Entry Pseudo-code.



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 19. The parameters that are passed are the DPR\_# 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



```

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 G_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_DEPENDENTIS_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 19. Activate Pseudo-code.



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.

#### 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\_I\_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 22. 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.

##### 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



```

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 20. Deactivate Pseudo-code.



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 I\_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 I\_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 21. The arguments passed to SWAP\_IN are the G\_AST\_INDEX of the segment to be moved in, the process' DEB\_#, 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
ENTPY
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
OR IF 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 21. 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 segment's 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 22. The arguments passed to SWAP\_OUT are the DER\_# 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".

## 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 23. The parameters passed to





```

SWAP_OUT PROCEDURE (DER_#  BYTE, INDEX  WORD)
  RETURNS (SUCCESS_CODE  BYTE)
  ENTRY
  BLKS := G_AST[INDEX].SIZE / BIK_SIZE
  FREE_PROCESS_LINEAR_CORE (BLKS)
  DELPTE_MMU_ENTRY (DER_#, SEG_#)
  G_AST[INDEX].NO_SEGMENTS_IN_MEMORY -= 1
  ! Determine if segment has been written into !
  IF MMU_IMAGE[DER_#].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
    AND IF 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
    AND IF 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 22. Swap\_Out Pseudo-code.



```

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 I_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 23. Deactivate All Pseudo-code.



Deactivate\_all are the deactivated segment's G\_AST index and the L\_AST index. The I\_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.

### 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 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 24 illustrates the pseudo-code for MOVE\_TO\_GLOBAL. Once the segment has been moved to global memory, the signalled memory manager will update the MMJ 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



```

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_#].SDP[SEG_#].ATTRIBUTES=IN_LOCAL THEN
    MMU_IMAGE[DBR_#].SDP[SEG_#].BASE_ADDR:=GLOBAL_ADDR
  FI
OD
SUCCESS_CODE := VALID
END MOVE_TO_GLOBAL

```

Figure 24. Move To Global Pseudo-code.





memory address of the move, and the size of the segment. This information is passed because the G\_AST is locked during this request.

#### 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 25 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.

#### 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 26 illustrates the pseudo-code of UPDATE. The parameters passed to the memory manager are the segment's



```

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)
  I_LAST[I_INDEX].MEMORY_ADDR := BASE_ADDRESS
  DO FOR_ALL_DBR'S
    IF LAST[I_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 25. Move To Local Pseudo-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 AND IF
  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 26. Update Pseudo-code.



L\_AST index, the new global address for the segment, and the size of the segment. The return parameter is a success 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 implementation details of these functions are presented in Appendix A. The success codes returned by the memory manager are presented in figure 27.

This design has assumed that the kernel level inter-process synchronization primitives will be Saltzer's signal and wait primitives[15]. 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

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

MEMORY MANAGER LOCAL

VALID  
INVALID  
FOUND  
NOT\_FOUND  
IN\_LOCAL\_MEMORY  
NOT\_IN\_LOCAL\_MEMORY  
! + DISK ERRORS !

Figure 27. Success Codes



#### IV. 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 ZILCO'S Z8001 sixteen bit segmented microprocessor used in conjunction with the Z8010 Memory Management Unit[12]. 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 FLZ/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 implementation 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.





APPENDIX A - PLZ/SYS SOURCE LISTINGS

MEMORY\_MANAGER\_PLZ\_SYS MODULE

! \* \* \* \* VERS. 1.0 \* \* \* \* !

CONSTANT

```

FALSE           := 0
TRUE            := 1
AVAILABLE       := 0 ! AST ENTRY AVAIL. !
ACTIVE         := 1 ! AST ENTRY ACTIVE !
ZERO           := 0
NULL           := %0000
NULL_PAGE      := 0
    
```

! SUCCESS CODES !

```

INVALID        := 0
VALID          := 1
FOUND          := 2
NOT_FOUND      := 3
SWAPPED_IN    := 4
SWAPPED_OUT   := 5
SEG_ACTIVATED := 6
SEG_DEACTIVATED := 7
SEG_CREATED   := 8
SEG_DELETED   := 9
LEAF_SEGMENT_EXISTS := 10
NO_LEAF_EXISTS := 11
G_AST_FULL    := 12
L_AST_FULL    := 13
IN_LOCAL_MEMORY := 14
NOT_IN_LOCAL_MEMORY := 15
LOCAL_MEMORY_FULL := 16
GLOBAL_MEMORY_FULL := 17
VIRTUAL_CORE_FULL := 18
DUPLICATE_ENTRY := 19
NO_CHILD_TO_DELETE := 20
    
```

! ATTRIBUTE MASKS !

```

READ_MASK      := %(2)11111110
WRITE_MASK     := %(2)00000001
CHANGED_MASK   := %(2)01000000
IN_MEMORY_MASK := %(2)00000100
CLEARED       := ? ! CLEAR ATTRIBUTES !
    
```

! AUTHORIZED\_ACCESS !

```

READ          := 0
    
```



```

WRITE                := 1
EXECUTE              := 2

! G_AST FLAG BITS MASKS !
WRITABLE_MASK       := %(2)00000010
WRITTEN_MASK        := %(2)00000100

! DESIGN PARAMETERS    !
BIK_SIZE             := 256
MAX_PAGE_SIZE       := BIK_SIZE / 2
MAX_MSG_SIZE        := 16
C_MEM_SIZE          := ? ! SIZEOF GLOBAL MEM !
L_MEM_SIZE          := ? ! SIZEOF LOCAL MEMORY !
NO_OF_PROCESSORS    := 1
! MAX NUMBER OF DPR #'S !
MAX_DPR_NO          := 4
! MAX ENTRIES IN G_AST !
G_AST_LIMIT         := 100
! MAX ENTRIES IN L_AST !
L_AST_LIMIT         := 100
! SIZE OF ALIAS TABLE !
MAX_ENTRY_NO        := 32
! # OF SEGMENTS PER PROCESS !
NO_SEG_DESC_REG     := 64
FIRST_POSS_FREE_BLOCK := 1
! PROCESSOR LOCAL DATA !
PROCESSOR_ID        := 0

```

```

TYPE      ADDRESS      WORD

ALIAS_HEADER RECORD [ SEG_PAGE_TABLE_LOC  WORD
                      PAR_ALIAS_TABLE_LOC WORD ]

ALIAS      RECORD [ UNIQUE_ID  LONG WORD
                    SIZE      WORD
                    CLASS     WORD
                    PAGE_TABLE_LOC  WORD
                    ALIAS_TABLE_LOC WORD ]

SEG_DESC_REG RECORD [ BASE_ADDR  ADDRESS
                      LIMIT     BYTE
                      ATTRIBUTES BYTE ]

MMU          RECORD [ SDR_ARRAY[NO_SEG_DESC_REG
                              SEG_DESC_REG]
                    BIKS_USED  WORD
                    MAX_BIKS   WORD := ??? ]

G_AST_REC    RECORD [ UNIQUE_ID1  LONG WORD
                      GLOBAL_ADDR ADDRESS
                      PROCESSORS_L_AST_NO ARRAY

```



```

        [NO_OF_PROCESSORS  WORD]
FLAG_BITS  BYTE
G_AST_NO_FAR  WORD
NO_ACTIVE_IN_MEMORY  WORD
NO_ACTIVE_DEPENDENTS  WORD
SIZE1  WORD
PAGE_TABLE_LOC1  WORD
ALIAS_TABLE_LOC1  WORD
SEQUENCER  WORD
INSTANCE1  WORD
INSTANCE2  WORD ]

```

```

I_AST_REC  RECORD [ MEMORY_ADDR  ADDRESS
                    SEGMENT_NO_ACCESS_AUTH
                    ARRAY [MAX_DBR_NO  BYTE] ]

```

```

HANDLE  RECORD [ UNIQUE_ID2  LONG WORD
                  H_INDEX  WORD ]

```

```

!*****
*
*  VARIABLE DECLARATIONS
*
*****!

```

\$SECTION G\_DATA

```

GLOBAL  G_AST  ARRAY [G_AST_LIMIT  G_AST_REC]
        GLOBAL_MEM_BIT_MAP  ARRAY[G_MEMORY_SIZE/16 WORD]

```

\$SECTION I\_DATA

```

MMU_IMAGE  ARRAY [MAX_DBR_NO  MMU]
I_AST  ARRAY [I_AST_LIMIT  I_AST_REC]
ALIAS_TABLE  RECORD [ HEADER  ALIAS_HEADER
                      ALIAS_ENTRY  ARRAY
                        [MAX_ENTRY_NO  ALIAS] ]
LOCAL_MEM_BIT_MAP  ARRAY [L_MEM_SIZE/16  WORD]
DISK_BIT_MAP_BUFF  ARRAY [????  BYTE]
PAGE_TABLE_BUFFER  ARRAY [PLK_SIZE  BYTE]

```



EXTERNAL

```
!*****  
*  
* The following procedures are coded in PLZ/ASM and are *  
* contained in a separate PLZ/ASM module. *  
*  
*****!
```

```
REAL_PAGE PROCEDURE (DISK_IOC WORD , MEMORY_ADDR ADDRESS )  
  RETURNS ( SUCCESS_CODE BYTE )
```

```
READ_SEGMENT PROCEDURE (PAGE_TABLE_LOC WORD , MEMORY_ADDR  
  ADDRESS)  
  RETURNS ( SUCCESS_CODE BYTE )
```

```
WRITE_PAGE PROCEDURE (DISK_IOC WORD , FROM_ADDR ADDRESS )  
  RETURNS ( SUCCESS_CODE BYTE )
```

```
WRITE_SEGMENT PROCEDURE (PAGE_TABLE_LOC WORD , FROM_ADDR  
  ADDRESS)  
  RETURNS ( SUCCESS_CODE BYTE )
```

```
READ_DISK_BIT_MAP PROCEDURE  
  RETURNS ( SUCCESS_CODE BYTE )
```

```
WRITE_DISK_BIT_MAP PROCEDURE  
  RETURNS ( SUCCESS_CODE BYTE )
```

```
SEARCH_DISK_BIT_MAP PROCEDURE (START_SRCF_LOC WORD)  
  RETURNS ( SUCCESS_CODE BYTE, BIK_IOC WORD )
```

```
CLEAR_DISK_BIT_MAP PROCEDURE ( BLK_IOC WORD )
```

```
FREE_GLOBAL_BIT_MAP PROCEDURE (ADDR ADDRESS, BIKS WORD)
```

```
FREE_LOCAL_BIT_MAP PROCEDURE (ADDR ADDRESS, BIKS WORD)
```

```
ALLOC_LOCAL_MEMORY PROCEDURE (BIKS WORD)  
  RETURNS ( SUCCESS_CODE BYTE , BASE_ADDR ADDRESS )
```

```
ALLOC_GLOBAL_MEMORY PROCEDURE (BIKS WORD)  
  RETURNS ( SUCCESS_CODE BYTE , BASE_ADDR ADDRESS )
```

```
GET_UNIQ_ID PROCEDURE  
  RETURNS ( ID LONG WORD, SUCCESS_CODE BYTE )
```

```
MEMORY_MOVE PROCEDURE (TO ADDRESS, FROM ADDRESS, SIZE WORD)
```

```
VALIDATE_MSG PROCEDURE (MSG ARRAY [MAX_MSG_SIZE BYTE])  
  RETURNS ( FUNCTION BYTE, ARGUMENTS ARRAY [6 WORD] )
```





```
VALIDATE_WAIT_MSG PROCEDURE (MSG ARRAY [MAX_MSG_SIZE BYTE])
  RETURNS ( SUCCESS BYTE )
```

INTERNAL

```
!*****
*
* The READ_ALIAS_TABLE Procedure is called from the
* Create_entry procedure and Delete_entry procedure.
* The procedure will read the requested alias table
* from secondary storage to main memory.
*
*****!
```

```
READ_ALIAS_TABLE PROCEDURE ( ALIAS_DISK_LOC WORD,
                             MEMORY_ADDR ADDRESS )
  RETURNS ( SUCCESS_CODE BYTE )
  ENTRY
  SUCCESS_CODE := READ_PAGE(ALIAS_DISK_LOC, MEMORY_ADDR)
END READ_ALIAS_TABLE
```

```
!*****
*
* The WRITE_ALIAS_TABLE Procedure is called from the
* Create_entry and Delete_entry procedures. The pro-
* cedure will write the appropriate alias table from
* main memory to secondary storage.
*
*****!
```

```
WRITE_ALIAS_TABLE PROCEDURE ( ALIAS_DISK_LOC WORD,
                              MEMORY_ADDR ADDRESS )
  RETURNS ( SUCCESS_CODE BYTE )
  ENTRY
  SUCCESS_CODE := WRITE_PAGE(ALIAS_DISK_LOC, MEMORY_ADDR)
END WRITE_ALIAS_TABLE
```



```

!*****
*
* The SEARCH_ALIAS_TABLE Procedure is called from the
* Create_alias_table procedure. The procedure will step
* through the alias table until it matches the passed
* unique_id with a table entry, or the table has been
* exhausted. The procedure returns a success code of
* either found or not_found, and the appropriate index
* into the alias table.
*
*****!

```

```

SEARCH_ALIAS_TABLE PROCEDURE ( UNIQUE_ID LONG WORD )
  RETURNS ( SUCCESS_CODE BYTE, INDEX BYTE )
  ENTRY
    INDEX := 0
    SUCCESS_CODE := NOT_FOUND
  DO
    IF INDEX > MAX_ENTRY_NO THEN EXIT
  FI
    IF ALIAS_TABLE.ALIAS_ENTRY[INDEX].UNIQUE_ID =
      UNIQUE_ID THEN
      SUCCESS_CODE := FOUND
      EXIT
  FI
    INDEX += 1
  OD
END SEARCH_ALIAS_TABLE

```

```

!*****
*
* The UPDATE_MMU_IMAGE Procedure is called from the In
* procedure. The procedure will update the MMU image of
* the appropriate process with the memory location,
* limit, and access authorization for the passed segment
* number.
*
*****!

```

```

UPDATE_MMU_IMAGE PROCEDURE ( DER_NO BYTE, SEGMENT_NO BYTE,
  ADDR ADDRESS, ACCESS BYTE, LIMIT BYTE )
  LOCAL ATTR BYTE
  ENTRY
    MMU_IMAGE[DER_NO].SDR[SEGMENT_NO].BASE_ADDR := ADDR
    MMU_IMAGE[DER_NO].SDR[SEGMENT_NO].LIMIT := LIMIT
    ATTR := MMU_IMAGE[DER_NO].SDR[SEGMENT_NO].ATTRIBUTES
    ! CLEAR PREVIOUS ACCESS !
    IF ACCESS = READ OR IF ACCESS = WRITE THEN
      ATTR := ATTR AND %(2)11111110
    END IF
  END ENTRY

```



```

ELSE      ! EXECUTE ONLY ACCESS      !
      ATTR := ATTR AND %(2)11110111
FI
MMU_IMAGE[DER_NO].SDR[SEGMENT_NO].ATTRIBUTES :=
      ATTR OR ACCESS
END UPDATE_MMU_IMAGE

```

```

!*****
*
* The DELETE_MMU_ENTRY Procedure is called from the Out *
* procedure. The procedure will null out the MMU image *
* of the appropriate process for the passed segment *
* number. *
*
*****!

```

```

DELETE_MMU_ENTRY PROCEDURE ( DER_NO BYTE, SEGMENT_NO BYTE )
  ENTRY
  MMU_IMAGE[DER_NO].SDR[SEGMENT_NO].BASE_ADDR := NULL
  MMU_IMAGE[DER_NO].SDR[SEGMENT_NO].LIMIT := ZERO
  MMU_IMAGE[DER_NO].SDR[SEGMENT_NO].ATTRIBUTES := CLEARED
END DELETE_MMU_ENTRY

```

```

!*****
*
* The FIND_SEC_SECONDARY_STORAGE Procedure is called from *
* the Alloc_sec_storage procedure. The procedure will *
* search the secondary storage bit map to find a con- *
* tiguous storage location in secondary storage for the *
* required number of blocks passed. The procedure will *
* return a success code of either valid or invalid. *
*
*****!

```

```

FIND_SEC_STORAGE PROCEDURE ( BLKS WORD )
  RETURNS (SUCCESS_CODE BYTE, TABLE ARRAY [BLK_SIZE WORD] )
  LOCAL INDEX WORD
        I WORD

  ENTRY
  SUCCESS_CODE := READ_DISK_BIT_MAP
  IF SUCCESS_CODE <> VALID THEN
    RETURN

  FI
  INDEX := FIRST_POSS_FREE_BLK
  I := 0
  DO
    SUCCESS_CODE, INDEX := SEARCH_DISK_BIT_MAP (INDEX)
  
```



```

IF SUCCESS_CODE <> VALID THEN
  DO
    CLEAR_DISK_BIT_MAP ( TABLE[I] )
    IF I = 0 THEN EXIT
    FI
    I --= 1
  OD
  SUCCESS_CODE := SEC_STOR_FULL
  RETURN
FI
TABLE [I] := INDEX
I += 1
IF I = BLKS THEN EXIT
FI
OD
SUCCESS_CODE := VALID
END FIND_SEC_STORAGE

```

```

!*****
*
* The ALLOC_ONE_PAGE Procedure is called from the Create *
* alias_table procedure. The procedure will find one *
* page of secondary storage for the creation of an alias *
* table. This procedure will return a success code of *
* either valid or invalid. *
*
*****!

```

```

ALLOC_ONE_PAGE PROCEDURE
  RETURNS ( SUCCESS_CODE BYTE, PAGE_LOCATION WORD )
  LOCAL TABLE ARRAY[BLK_SIZE WORD]
  ENTRY
    SUCCESS_CODE, TABLE := FIND_SEC_STORAGE ( 1 )
    IF SUCCESS_CODE <> VALID THEN
      RETURN
    FI
    PAGE_LOCATION := TABLE[0]
END ALLOC_ONE_PAGE

```





```

!*****
*
* The ALLOC_SEC_STORAGE Procedure is called from the
* Create_entry procedure. The procedure will create a
* page table from the allocated secondary storage, and
* write this page to secondary storage. This procedure
* will return a success code of valid or invalid.
*
*****!

```

```

ALLOC_SEC_STORAGE PROCEDURE ( BLKS WORD )
  RETURNS ( PAGE_TABLE_LOC WORD, SUCCESS_CODE BYTE )
  LOCAL TABLE ARRAY [BLK_SIZE WORD]
  ENTRY
  SUCCESS_CODE, TABLE := FIND_SEC_STORAGE ( BLKS + 1 )
  IF SUCCESS_CODE <> VALID THEN
    RETURN
  FI
  PAGE_TABLE_LOC := TABLE [0]
  I := 1
  DO
    PAGE_TABLE_BUFFER [I-1] := TABLE [I]
    IF I = BLKS THEN EXIT
  FI
  I += 1
OD
DO
  IF I = MAX_PAGE_SIZE THEN
    EXIT
  FI
  PAGE_TABLE_BUFFER [I-1] := NULL_PAGE
  I += 1
OD
SUCCESS_CODE := WRITE_PAGE ( PAGE_TABLE_LOC,
                             #PAGE_TABLE_BUFFER )
END ALLOC_SEC_STORAGE

```

```

!*****
*
* The CREATE_ALIAS_TABLE Procedure is called by the
* Create_entry procedure. The procedure will allocate
* secondary storage for the creation of an alias table
* and update the mentor segment's alias table to reflect
* the created alias table's secondary storage location.
* The procedure returns a success code of either valid
* or invalid.
*
*****!

```



```

CREATE ALIAS_TABLE PROCEDURE ( PAR_INDEX WORD )
  RETURNS ( SUCCESS_CODE BYTE )
  LOCAL PARENT BYTE
        ALIAS_TABLE_LOC WORD
        ENTRY_NO BYTE

ENTRY
  SUCCESS_CODE , ALIAS_TABLE_LOC := ALLOC_ONE_PAGE
  PARENT := G_AST[PAR_INDEX].G_AST_NO_PAF
  SUCCESS_CODE := READ_ALIAS_TABLE(G_AST[PARENT].
    ALIAS_TABLE_LOC1, #ALIAS_TABLE )
  IF SUCCESS_CODE <> VALID THEN
    RETURN
  FI
  SUCCESS_CODE, ENTRY_NO := SEARCH_ALIAS_TABLE(
    G_AST[PAR_INDEX].UNIQUE_ID1 )
  IF SUCCESS_CODE = NOT_FOUND THEN
    RETURN
  FI
  ALIAS_TABLE.ALIAS_ENTRY[ENTRY_NO].ALIAS_TABLE_LOC :=
    ALIAS_TABLE_LOC
  G_AST[PAR_INDEX].ALIAS_TABLE_LOC1 := ALIAS_TABLE_LOC
  SUCCESS_CODE := WRITE_ALIAS_TABLE ( ALIAS_TABLE_LOC,
    #ALIAS_TABLE )

END CREATE_ALIAS_TABLE

```

```

!*****
*
* The CHECK_MAX_VIRTUAL_CORE Procedure is called *
* by the In_procedure. The procedure will verify that *
* the addition of the segment requested to be swapped in *
* will not cause the process' allocated virtual core to *
* be exceeded. If the virtual core is not exceeded, a *
* success code of valid is returned, otherwise a success *
* code of no_memory is returned. *
*
*****!

```

```

CHECK_MAX_VIRTUAL_CORE PROCEDURE ( DER_NO BYTE,
  BIK_NO_REC WORD )
  RETURNS ( SUCCESS_CODE BYTE )

ENTRY
  MMU_IMAGE[DER_NO].BIKS_USED += BIK_NO_REC
  IF MMU_IMAGE[DER_NO].BIKS_USED >
    MMU_IMAGE[DER_NO].MAX_BIKS THEN
    MMU_IMAGE[DER_NO].BIKS_USED -= BIK_NO_REC
    SUCCESS_CODE := VIRTUAL_CORE_FULL
  ELSE

```



```

        SUCCESS_CODE := VALID
    FI
END CHECK_MAX_VIRTUAL_CORE

```

```

!*****
*
*   The FREE_PROCESS_VIRTUAL_CORE Procedure is called from
*   the Out procedure. The procedure will subtract the
*   size of the segment which has been swapped out from
*   the virtual linear core allocated to that process.
*
*****!

```

```

FREE_PROCESS_VIRTUAL_CORE PROCEDURE ( BLK_NO   WORD )
    ENTRY
    MMU_IMAGE [ DER_NO ].BLKS_USED -= BLK_NO
END FREE_PROCESS_VIRTUAL_CORE

```

```

!*****
*
*   The FREE_SECONDARY_STORAGE Procedure is called from
*   the Delete_seg procedure. The procedure will read the
*   page table of the segment to be deleted and the
*   secondary storage bit map into main memory. The bit
*   map will be cleared to reflect the deallocation of
*   secondary storage, and the page table location will be
*   cleared. The procedure returns a success code of
*   valid or invalid.
*
*****!

```

```

FREE_SEC_STORAGE PROCEDURE ( PAGE_TABLE_LOC WORD )
    RETURNS ( SUCCESS_CODE BYTE )
    LOCAL   I WORD
            TABLE1 ARRAY [ BLK_SIZE WORD ]
    ENTRY
    SUCCESS_CODE := READ_PAGE ( PAGE_TABLE_LOC , #TABLE1 )
    IF SUCCESS_CODE <> VALID THEN
        RETURN
    FI
    SUCCESS_CODE := READ_DISK_BIT_MAP
    IF SUCCESS_CODE <> VALID THEN
        RETURN
    FI
    I := 0
    DO
        IF TABLE1[I] = NULL ORIF I >= BLK_SIZE THEN

```



```

        EXIT
    FI
    CLEAR_DISK_BIT_MAP ( TABLE1[I] )
    I += 1
OD
CLEAR_DISK_BIT_MAP ( PAGE_TABLE_LOC )
SUCCESS_CODE := VALID
END FREE_SEC_STORAGE

```

```

!*****
*
* The DELETE_SEG Procedure is called from the Delete
* entry procedure. The procedure will free secondary
* storage for the deleted segment, and null out the
* entry in its mentor segment's alias table. The pro-
* cedure returns a success code of either valid or in-
* valid.
*
*****!

```

```

DELETE_SEG PROCEDURE ( ENTRY_NO WORD )
    RETURNS ( SUCCESS_CODE BYTE )
    ENTRY
    SUCCESS_CODE := FREE_SEC_STORAGE(
        ALIAS_TABLE.ALIAS_ENTRY[ENTRY_NO].PAGE_TABLE_LOC )
    IF SUCCESS_CODE <> VALID THEN
        RETURN
    FI
    IF ALIAS_TABLE.ALIAS_ENTRY[ENTRY_NO].ALIAS_TABLE_LOC
        <> NULL THEN
        CLEAR_DISK_BIT_MAP(
            ALIAS_TABLE.ALIAS_ENTRY[ENTRY_NO].ALIAS_TABLE_LOC )
    FI
    ALIAS_TABLE.ALIAS_ENTRY[ENTRY_NO].UNIQUE_ID := NULL
END DELETE_SEG

```

```

!*****
*
* The CHECK_IF_ALIAS_EMPTY Procedure is called by the
* Delete_entry procedure. The procedure will search the
* alias table to determine if the table is empty. If the
* alias table is empty, the variable Alias_table_empty
* is set equal to true and returned. If the table is not
* empty, Alias_table_empty is set equal to false.
*
*****!

```





```

CHECK_IF_ALIAS_EMPTY PROCEDURE
  RETURNS ( ALIAS_TABLE_EMPTY BYTE )
  LOCAL I BYTE
  I := 0
  DO
    IF I = ALIAS_TABLE_LIMIT THEN
      ALIAS_TABLE_EMPTY := TRUE
      EXIT
    ELSE
      IF ALIAS_TABLE.ALIAS_ENTRY[I].UNIQUE_ID <> 0 THEN
        ALIAS_TABLE_EMPTY := FALSE
        EXIT
      ELSE
        I += 1
      FI
    FI
  OD
END CHECK_IF_ALIAS_EMPTY

```

```

!*****
*
* The CHECK_LOCAL_MEMORY Procedure is called from the In *
* procedure. The procedure determines if the segment is *
* in the processor's local memory by examining the MMU *
* image for each connected process. If the segment is in *
* the local memory, the variable Test is set equal to *
* true, otherwise it is set equal to false. *
*
*****!

```

```

CHECK_LOCAL_MEMORY PROCEDURE ( INDEX WORD )
  RETURNS ( TEST BYTE )
  LOCAL I BYTE
        SEG_NO BYTE
  I := 0
  DO
    IF I = MAX_DBR_NO THEN
      TEST := NOT_IN_LOCAL_MEMORY
      RETURN
    FI
    SEG_NO := ( I_LAST[INDEX].SEGMENT_NO_ACCESS_AUTH[I]
              AND %(2)01111111 )
    IF SEG_NO <> 0 THEN
      IF (MMU_IMAGE[I].SDR[SEG_NO].ATTRIBUTES AND
          IN_MEMORY_MASK) <> 0 THEN
        TEST := IN_LOCAL_MEMORY
        RETURN
      FI
    FI
  OD

```



```

        I += 1
    OD
END CHECK_LOCAL_MEMORY

```

```

!*****
*
* The CHECK_FOR_REMOVAL Procedure is called by the Deact-
* ivate procedure. The procedure will determine if the
* segment is active in any I_AST and if it has any active
* dependents. If the segment is not active and does not
* have any active dependents, the G_AST entry is removed.*
*
*****!

```

```

CHECK_FOR_REMOVAL PROCEDURE ( INDEX WORD )
    LOCAL I BYTE
           TEST BYTE
    ENTRY
    TEST := FALSE
    I := 0
    DO
        IF I = NO_OF_PROCESSORS ORIF TEST = TRUE THEN
            EXIT
        FI
        IF G_AST[INDEX].PROCESSORS_I_AST_NO[I] <> 0 THEN
            TEST = TRUE
        FI
        I += 1
    OD
    IF G_AST[INDEX].NO_ACTIVE_DEPENDENTS=0
        ANDIF TEST = FALSE THEN
            G_AST[INDEX].UNIQUE_ID1 := AVAILABLE
        FI
END CHECK_FOR_REMOVAL

```

```

!*****
*
* The CHECK_IF_OTHERS_ACTIVE Procedure is called by the
* Delete_entry procedure. The procedure will check to
* determine if a segment is active in any I_AST. If the
* segment is active, the variable Others_active is set
* equal to true, otherwise it is set equal to false.*
*
*****!

```

```

CHECK_IF_OTHERS_ACTIVE PROCEDURE ( INDEX WORD )

```



```

RETURNS ( OTHERS_ACTIVE BYTE )
LOCAL I BYTE
ENTRY
I := 0
DO
  IF I = NO_OF_PROCESSORS THEN
    OTHERS_ACTIVE := FALSE
    RETURN
  FI
  IF G_AST[INDEX].PROCESSORS_LAST_NO[I] <> 0 THEN
    OTHERS_ACTIVE := TRUE
    RETURN
  FI
  I += 1
OD
END CHECK_IF_OTHERS_ACTIVE

```

```

!*****
*
* The ACTIVE_IN_I_AST Procedure is called by the React- *
* ivate procedure. The procedure will search the Seg- *
*  ment#/Access_auth field of a segment to determine if *
*  the segment is active in the I_AST. If the segment is *
*  active, the variable Check will be set equal to True *
*  and returned. *
*
*****!

```

```

ACTIVE_IN_I_AST PROCEDURE ( INDEX WORD )
RETURNS ( CHECK BYTE )
LOCAL I BYTE
ENTRY
I := 0
CHECK := FALSE
DO
  IF I = MAX_DBR_NO ORIF CHECK = TRUE THEN
    RETURN
  FI
  IF I_AST[INDEX].SEGMENT_NO_ACCESS_AUTH <> 0 THEN
    CHECK := TRUE
  FI
  I += 1
OD
END ACTIVE_IN_I_AST

```

```

!*****
*

```



```

*   The UPDATE_L_AST_ACCESS Procedure is called by the In   *
*   procedure. The procedure will set the read/write bit   *
*   of the appropriate segment#/access_auth field of the   *
*   L_AST to a one if the process has write access or to a   *
*   zero if the process has read access.                     *
*

```

```

*****!

```

```

UPDATE_L_AST_ACCESS  PROCEDURE(INDEX  WORD,ACCESS_AUTH BYTE,
                               DBR_NO  BYTE )
  LOCAL  SEG_NO  WORD
  ENTRY
  SEG_NO := L_AST[INDEX].SEGMENT_NO_ACCESS_AUTH[DBR_NO]
  IF ACCESS_AUTH = WRITE THEN
    L_AST[INDEX].SEGMENT_NO_ACCESS_AUTH[DBR_NO] :=
      SEG_NO OR  %(2)10000000
  ELSE
    L_AST[INDEX].SEGMENT_NO_ACCESS_AUTH[DBR_NO] :=
      SEG_NO AND  %(2)01111111
  FI
END  UPDATE_L_AST_ACCESS

```

```

!*****!

```

```

*
*   The SEARCH_G_AST Procedure is called by the Activate   *
*   procedure. The procedure will search the G_AST to      *
*   determine if a passed segment's unique_id exists in    *
*   the G_AST. If the unique_id is found, a success code   *
*   of found and the G_AST index are returned. If the      *
*   segment is not found, a success code of not_found is   *
*   returned.                                               *
*

```

```

*****!

```

```

SEARCH_G_AST  PROCEDURE (SEG_ID  LONGWORD)
  RETURNS (SUCCESS  BYTE, INDEX  WORD)
  LOCAL  I  WORD
  ENTRY
  I := 0
  ILOOP: DO
    IF I => G_AST_LIMIT THEN
      SUCCESS := NOT_FOUND
      INDEX := NULL
      RETURN
    FI
    IF G_AST[I].UNIQUE_ID1 = SEG_ID THEN

```





```

        SUCCESS := FOUND
        INDEX := I
        RETURN
    FI
    I += 1
OD
END SEARCH_G_AST

```

```

!*****
*
* The GET_L_AST_INDEX Procedure is called by the Make_
* L_AST_entry procedure. The procedure will search the
* L_AST from top down until an available index is found.
* If an index is not found, a success_code of L_AST_full
* is returned. If an index is found, the index, and a
* success_code of valid are returned.
*
*****!

```

```

GET_L_AST_NO_INDEX      PROCEDURE
    RETURN ( SUCCESS_CODE BYTE , L_INDEX      WORD )
    LOCAL  I      WORD
    ENTRY
    SUCCESS_CODE := VALID
    I := 0
    ILOOP: DO
        IF I => I_AST_LIMIT THEN
            SUCCESS_CODE := L_AST_FULL
            RETURN
        FI
        IF I_AST[I].MEMORY_ADDR = AVAILIABLE THEN
            I_INDEX := I
            L_AST[I].MEMORY_ADDR := ACTIVE
            RETURN
        FI
        I += 1
    OD
END GET_L_AST_NO_INDEX

```



```

!*****
*
* The GET_G_AST_INDEX Procedure is called from the Make_ *
* G_AST_entry procedure. The procedure will search the *
* G_AST from the top down until an available index is *
* found. If an index is not found, a success_code of *
* G_AST_full is returned. If an index is found, the index *
* and a success_code of valid are returned. *
*
*****!

```

```

GET_G_AST_INDEX    PROCEDURE
RETURN ( SUCCESS_CODE BYTE , INDEX WORD )
LOCAL I WORD
ENTRY
SUCCESS_CODE := VALID
I := 0
ILOOP: DO
  IF I => G_AST_LIMIT THEN
    SUCCESS_CODE := G_AST_FULL
    RETURN
  FI
  IF G_AST[I].UNIQUE_ID1 = NULL THEN
    INDEX := I
    RETURN
  FI
  I += 1
OD
END GET_G_AST_INDEX

```

```

!*****
*
* The MAKE_G_AST_ENTRY Procedure is called from the *
* Activate procedure. The procedure will obtain an *
* index into the G_AST and enter the appropriate data *
* from the alias table. The flag bits are set to not *
* written and not writable. The eventcounts and ticket *
* fields are set to zero. The processor_L_ASTE_# fields *
* are set to null. If the entry is successfully made, *
* a success_code of valid will be returned. *
*
*****!

```

```

MAKE_G_AST_ENTRY  PROCEDURE ( PAR_INDEX WORD , ENTRY_NO WORD )
RETURNS ( SUCCESS_CODE BYTE , INDEX WORD )
LOCAL I WORD

ENTRY
SUCCESS_CODE, INDEX := GET_G_AST_ENTRY

```



```

IF SUCCESS_CODE = VALID THEN
  G_AST[INDEX].UNIQUE_ID1 := ALIAS_TABLE.ALIAS_ENTRY[
                                ENTRY_NO].UNIQUE_ID
  G_AST[INDEX].GLOBAL_ADDR := ACTIVE
  G_AST[INDEX].FLAG_BITS := G_AST[INDEX].FLAG_BITS
                                AND ( NOT WRITTEN_MASK )
  G_AST[INDEX].FLAG_BITS := G_AST[INDEX].FLAG_BITS
                                AND ( NOT WRITABLE_MASK )
  G_AST[INDEX].G_ASTE_NO_PAR := PAR_INDEX
  G_AST[INDEX].NO_ACTIVE_IN_MEMORY := 0
  G_AST[INDEX].NO_ACTIVE_DEPENDENTS := 0
  G_AST[INDEX].SIZE1 := ALIAS_TABLE.ALIAS_ENTRY[
                                ENTRY_NO ].SIZE
  G_AST[INDEX].PAGE_TABLE_LOC1 :=
    ALIAS_TABLE.ALIAS_ENTRY[ENTRY_NO].PAGE_TABLE_LOC
  G_AST[INDEX].ALIAS_TABLE_LOC1 :=
    ALIAS_TABLE.ALIAS_ENTRY[ENTRY_NO].ALIAS_TABLE_LOC
  G_AST[INDEX].INSTANCE1 := 0
  G_AST[INDEX].INSTANCE2 := 0
  G_AST[INDEX].SEQUENCER := 0
  I := 0
  ILOOP: DO
    IF I = NO_OF_PROCESSORS THEN
      EXIT
    FI
    G_AST[INDEX].PROCESSORS_L_ASTE_NO[I] := NULL
    I += 1
  OD

  SUCCESS_CODE := VALID
FI
END MAKE_G_AST_ENTRY

```

```

!*****!
*
* The MAKE_L_ASTE_ENTRY Procedure is called from the
* activate procedure. The procedure will obtain an
* index into the L_ASTE and enter the appropriate data.
* The memory_addr field is set to active, the segment_
* #/access_auth fields are initialized to zero, and
* the passed segment number is entered into the ap-
* propriate location. If the entry is successfully
* made, a success_code of valid is returned.
*
*****!

```

```

MAKE_L_ASTE_ENTRY PROCEDURE (DBR_NO BYTE, SEGMENT_NO WORD)
  RETURNS ( SUCCESS_CODE BYTE, L_INDEX WORD )
  LOCAL I BYTE

```



```

                SEG_NO   WORD
ENTRY
  SUCCESS_CODE, L_INDEX := GET_L_AST_INDEX
  IF SUCCESS_CODE <> VALID THEN RETURN
  FI
  L_AST[L_INDEX].MEMORY_ADDR := ACTIVE
  I := 0
  DO
    L_AST[L_INDEX].SEGMENT_NO_ACCESS_AUTH[I] := 0
    I += 1
    IF I >= MAX_DBR_NO THEN EXIT
  FI
  OD
  I_AST[I_INDEX].SEGMENT_NO_ACCESS_AUTH[DBR_NO] := SEGMENT_NO
END MAKE_I_AST_ENTRY

```

```

!*****
*
* The DEACTIVATE_ALL Procedure is called by the
* Detete_entry procedure and by the Main_line
* procedure. The procedure will deactivate the
* deleted segment from all connected process'
* address space. The G_AST index and the I_AST
* index for the deleted segment are passed to the
* procedure. If the segment was successfully
* deactivated from all connected processes, a
* success_code of valid is returned.
*
*****!

```

```

DEACTIVATE_ALL PROCEDURE ( INDEX WORD, L_INDEX WORD )
  RETURNS ( SUCCESS_CODE BYTE )
  LOCAL I BYTE
  ENTRY
    I := 0
    DO
      IF I = MAX_DBR_NO THEN EXIT
      FI
      IF L_AST[L_INDEX].SEGMENT_NO_ACCESS_AUTH[I]
        <> ZERO THEN
        SUCCESS_CODE := DEACTIVAE ( I, INDEX )
        IF SUCCESS_CODE <> SEG_DEACTIVATED THEN
          RETURN
        FI
      FI
      I += 1
    OD
    SUCCESS_CODE := VALID
  END DEACTIVATE_ALL

```





```

!*****
*
* The SIGNAL_OTHER_MEMORY_MANAGER Procedure is called
* by the In procedure. The procedure will signal
* a memory manager to move a segment from its local
* memory to global memory. When the segment is moved
* to global memory the procedure will signal all other
* connected memory managers to update their local
* databases. The global address for the transfer
* is passed. A success_code is returned to indicate
* the success of the operation.
*
*****!

```

```

SIGNAL_OTHER_MEMORY MANAGERS PROCEDURE (
    SEG_INDEX WORD, ADDR WORD )
RETURNS ( SUCCESS_CODE BYTE )
LOCAL
    PROCESSOR_NO BYTE
    FIRST BYTF
    L_ENTRY_NO WORD
    VALID_MSG BYTE
    MSG ARRAY [MAX_MSG_SIZE BYTE]
ENTRY
    FIRST := TRUE
    PROCESSOR_NO := 0
    DO
        IF PROCESSOR_NO = PROCESSOR_ID THEN
            PROCESSOR_NO += 1
        FI
        IF PROCESSOR_NO >= NO_OF_PROCESSORS THEN
            EXIT
        FI
        L_ENTRY_NO := G_AST[SEG_INDEX].PROCESSOR_I_ASTE_NO[
            PROCESSOR_ID ]
        IF L_ENTRY_NO <> NULL THEN
            IF FIRST = TRUE THEN
                FIRST := FALSE
                IF PROCESSOR_NO
                    CASE 0 THEN
                        SIGNAL ( VP_ID, MEMORY_MANAGER_0, MOVE,
                            L_ENTRY_NO, ADDR, G_AST[SEG_INDEX].SIZE,
                            VP_ID, MSG := WAIT
                    )
            ! **** CHECK IF VALID MSG *** !
                VALID_MSG := VALIDATE_WAIT_MESSAGE (MSG)
            FI
        ELSE

```



```

        IF PROCESSOR_NO
        CASE 0 THEN
            SIGNAL( VP_ID, MEMORY_MANAGER 0, UPDATE,
                L_ENTPY_NO, ADDR, G_AST[SEG_INDEK].SIZE \
                VP_ID, MSG := WAIT
    |      ***** CHECK IF VALID MSG ***** |
            VALID_MSG := VALIDATE_WAIT_MESSAGE(MSG)
            FI
            FI
            FI
            PROCESSOR_NO += 1
    OD
    IF VALID_MSG THEN
        SUCCESS_CODE := VALID
    ELSE
        SUCCESS_CODE := INVALID
    FI
END SIGNAL_OTHER_MEMORY MANAGERS

```

```

!*****
*
* The CREATE_ENTRY Procedure is called by the
* Main_line procedure. The procedure will create
* an entry into the alias table and allocate sec-
* ondary storage for the created segment. If the
* alias table does not exist, the procedure will
* create an alias table on secondary storage.
* A unique_id is assigned to the segment and the
* appropriate data is entered into the table.
* If the function is successfully completed, a
* success_code of segment_created is returned.
*
*****!

```

```

CREATE_ENTRY PROCEDURE ( PAR_INDEX WORD, ENTRY_NO WORD,
    SIZE WORD, CLASS BYTE )
    RETURNS ( SUCCESS_CODE BYTE )

    LOCAL PAGE_TABLE_LOC WORD
           BLKS WORD

    ENTPY
        BLKS := SIZE / BIK_SIZE
        IF G_AST[PAR_INDEX].G_ASTE_NO_PAR <> ZERO THEN
            SUCCESS_CODE := CREATE_ALIAS_TABLE( PAR_INDEX )
            IF SUCCESS_CODE <> VALID THEN
                RETURN
            FI
        FI

```



```

FI
SUCCESS_CODE := READ_ALIAS_TABLE(
    G_AST[PAR_INDEX].ALIAS_TABLE_LOC1, #ALIAS_TABLE)
IF SUCCESS_CODE <> VALID THEN
    RETURN
FI
IF ALIAS_TABLE.ALIAS_ENTRY[ENTRY_NO].UNIQUE_ID <> 0
THEN
    SUCCESS_CODE := DUPLICATE_ENTRY
    RETURN
FI
PAGE_TABLE_LOC, SUCCESS_CODE := ALLOC_SEC_STORAGE(
    EKS )
IF SUCCESS_CODE <> VALID THEN
    RETURN
FI
ALIAS_TABLE.ALIAS_ENTRY[ENTRY_NO].UNIQUE_ID,
    SUCCESS_CODE := GET_UNIQUE_ID
IF SUCCESS_CODE <> VALID THEN
    RETURN
FI
ALIAS_TABLE.ALIAS_ENTRY[ENTRY_NO].SIZE := SIZE
ALIAS_TABLE.ALIAS_ENTRY[ENTRY_NO].CLASS := CLASS
ALIAS_TABLE.ALIAS_ENTRY[ENTRY_NO].PAGE_TABLE_LOC :=
    PAGE_TABLE_LOC
ALIAS_TABLE.ALIAS_ENTRY[ENTRY_NO].ALIAS_TABLE_LOC := 2
SUCCESS_CODE := WRITE_ALIAS_TABLE(G_AST[PAR_INDEX].
    ALIAS_TABLE_LOC, #ALIAS_TABLE )
IF SUCCESS_CODE = VALID THEN
    SUCCESS_CODE := SEG_CREATED
FI
END CREATE_ENTRY

```

!\*\*\*\*\*

```

*
* The DELETE_ENTRY Procedure is called by the Main-
* line procedure. The procedure will remove a segment
* from secondary storage by deleting its entry in its
* mentor segment's alias table and deallocating its
* allotted secondary storage. Before the segment is
* deleted, the G_AST is checked to ensure that no other
* process holds the segment active, and that the segment
* is not a mentor segment. If the segment is a mentor
* segment, deletion is not allowed. If the segment is
* active, those processes will be signaled to deactivate
* the procedure. When the segment is deactivated, it
* will be deleted. If the deletion is successful, a
* success_code of seg_deleted will be returned.
*

```



\*\*\*\*\*!

```
DELETE_ENTRY PROCEDURE ( PAR_INDEX WORD , ENTRY_NO WORD )
  RETURNS ( SUCCESS_CODE BYTE )
  LOCAL I_INDEX WORD
         INDEX WORD
         I BYTE
         ALIAS_TABLE_EMPTY BYTE
         OTHERS_ACTIVE BYTE

ENTRY
  IF G_AST[PAR_INDEX].ALIAS_TABLE_LOC1 <> NULL THEN
    SUCCESS_CODE := READ_ALIAS_TABLE ( G_AST[PAR_INDEX].
                                       ALIAS_TABLE_LOC1, #ALIAS_TABLE )
  ELSE
    SUCCESS_CODE := NO_CHILD_TO_DELETE
  FI
  IF SUCCESS_CODE <> VALID THEN
    RETURN
  FI
  ALIAS_TABLE_EMPTY := CHECK_IF_ALIAS_EMPTY
  IF ALIAS_TABLE_EMPTY = TRUE THEN
    SUCCESS_CODE, INDEX := SEARCH_G_AST (
      ALIAS_TABLE.ALIAS_ENTRY[ENTRY_NO].UNIQUE_ID )
    IF SUCCESS_CODE = FOUND THEN
      I_INDEX := G_AST[PAR_INDEX].PROCESSORS_I_ASTE_NO[
        PROCESSOR_ID]
      IF I_INDEX <> NULL THEN
        SUCCESS_CODE := DEACTIVATE_ALL(INDEX, I_INDEX)
        IF SUCCESS_CODE <> VALID THEN
          RETURN
        FI
      FI
      OTHERS_ACTIVE := CHECK_IF_OTHERS_ACTIVE
      IF OTHERS_ACTIVE = TRUE THEN
        SIGNAL_OTHERS_TO_DEACTIVATE_ALL
      FI
    FI
    DELETE_SEG ( ENTRY_NO )
    ALIAS_TABLE.ALIAS_ENTRY[ENTRY_NO].UNIQUE_ID := 0
    SUCCESS_CODE := WRITE_ALIAS_TABLE ( G_AST[PAR_INDEX].
                                       ALIAS_TABLE_LOC1, #ALIAS_TABLE )
    IF SUCCESS_CODE = VALID THEN
      SUCCESS_CODE := SEG_DELETED
    FI
  ELSE
    SUCCESS_CODE := DEPENDENTS_EXIST
  FI
END DELETE_ENTRY
```





```

!*****
*
* The ACTIVATE Procedure is called by the Main_line
* procedure. The purpose of activate is to add a
* segment to the user's address space. The procedure
* is passed the segment_#, the parent's handle, and
* the entry number into the alias table for the
* segment. The procedure returns the size,
* class., and the handle for the activated segment
* The G_AST is searched to determine if the segment
* is already active. If the segment is active and
* not in the L_AST, an entry is made in the L_AST
* and the G_AST is updated. If the segment is active
* in both the G_AST and the L_AST, the entries are
* updated. If the segment was not active, entries
* are made in both the G_AST and the L_AST.
* If the operation was successfully completed, a
* success_code of seg_activated is returned.
*
*****!

```

```

ACTIVATE PROCEDURE (DBR_NO BYTE, PAR_INDEX WORD,
                    ENTRY_NO WORD, SEGMENT_NO BYTE )
RETURNS ( SUCCESS_CODE BYTE , G_AST_HANDLE HANDLE ,
          CLASS BYTE, SIZE WORD )
LOCAL L_INDEX WORD
       INDEX WORD
ENTRY
  IF G_AST[PAR_INDEX].ALIAS_TABLE_LOC1 <> ZERO THEN
    SUCCESS_CODE := READ_ALIAS_TABLE(G_AST[PAR_INDEX].
                                     ALIAS_TABLE_LOC1. #ALIAS_TABLE)
  ELSE
    SUCCESS_CODE := NO_LEAF_EXIST
  FI
  IF SUCCESS_CODE <> VALID THEN
    RETURN
  FI
  SUCCESS_CODE , INDEX := SEARCH_G_AST (
    ALIAS_TABLE.ALIAS_ENTRY[ENTRY_NO].UNIQUE_ID )
  IF SUCCESS_CODE = FOUND THEN
    L_INDEX := G_AST[INDEX].PROCESSORS_L_AST_NO[
      PROCESSOR_ID]
    IF L_INDEX <> NULL THEN
      L_AST[L_INDEX].SEGMENT_NO_ACCESS_AUTH[DBR_NO] :=
        SEGMENT_NO
    ELSE
      SUCCESS_CODE, L_INDEX := MAKE_L_AST_ENTRY (
        DBR_NO, SEGMENT_NO )
    IF SUCCESS_CODE <> VALID THEN
      RETURN
    FI
  FI

```



```

        G_AST[INDEX].PROCESSORS_L_ASTE_NO[PROCESSOR_ID]
            := L_INDEX
    FI
    IF G_AST[INDEX].ALIAS_TABLE_LOC1 = NULL THEN
        G_AST[PAR_INDEX].NO_DEPENDENTS_ACTIVE -= 1
    FI
ELSE
    SUCCESS_CODE, INDEX := MAKE_G_AST_ENTRY(ENTRY_NO)
    IF SUCCESS_CODE = G_AST_FULL THEN
        RETURN
    FI
    SUCCESS_CODE, L_INDEX := MAKE_L_AST_ENTRY (
        PAR_INDEX, ENTRY_NO )
    IF SUCCESS_CODE = L_AST_FULL THEN
        RETURN
    FI
    G_AST[INDEX].PROCESSORS_L_ASTE_NO[PROCESSOR_ID] :=
        L_INDEX
FI
SUCCESS_CODE := SEG_ACTIVATED
SIZE := ALIAS_TABLE.ALIAS_ENTRY[ENTRY_NO].SIZE
CLASS := ALIAS_TABLE.ALIAS_ENTRY[ENTRY_NO].CLASS
G_AST_HANDLE.UNIQUE_ID2 := G_AST[INDEX].UNIQUE_ID1
G_AST_HANDLE.INDEX := INDEX
END ACTIVATE

```

```

!*****
*
* The SWAP_OUT Procedure is called by the Main_line
* procedure or the Deactivate procedure. The
* procedure will remove a segment from main memory
* and store it on secondary storage. The procedure
* is passed the process' DER_# and the G_AST index
* for the segment to be swapped out of memory.
* A success_code is returned to indicate the success
* of the operation. The procedure removes the
* segment from the process' MMU_Image and if not
* shared, it is returned to secondary storage
* and memory deallocated. Shared segments remain in
* memory until all processes have swapped the segment
* out of main memory.
*
*****!

```

```

SWAP_OUT PROCEDURE ( DER_NO BYTE, INDEX WORD )
    RETURNS ( SUCCESS_CODE BYTE )
    LOCAL BIKS WORD
        L_INDEX WORD
        SEG_NO WORD

```



```

ENTRY
BLKS := G_AST[INDEX].SIZE1 / BIK_SIZE
L_INDEX := G_AST[INDEX].PROCESSOR_L_ASTE_NO[PROCESSOR_ID]
SEG_NO := I_AST[L_INDEX].SEGMENT_NO_ACCESS_AUTH[DEP_NO]
FREE_PROCESS_VIRTUAL_CORE ( BLKS )
DELETE_MMU_ENTRY ( DEP_NO, SEG_NO )
G_AST[INDEX].NO_ACTIVE_IN_MEMORY -= 1
IF (MMU_IMAGE[DEP_NO].SDR[SEG_NO].ATTRIBUTES AND
      WRITTEN_MASK) <> 0 THEN
  G_AST[INDEX].FLAG_BITS := G_AST[INDEX].FLAG_BITS OR
      WRITTEN_MASK
FI
IF G_AST[INDEX].GLOBAL_ADDR = NULL THEN
  IF G_AST[INDEX].NO_ACTIVE_IN_MEMORY = 0 ANDIF
    (G_AST[INDEX].FLAG_BITS AND WRITTEN_MASK) <> 0
  THEN
    SUCCESS_CODE := WRITE_SEGMENT ( G_AST[INDEX].
      PAGE_TABLE_LOC, L_AST[L_INDEX].
      MEMORY_ADDR )
    IF SUCCESS_CODE <> VALID THEN
      RETURN
    FI
    FREE_LOCAL_BIT_MAP ( I_AST[L_INDEX].MEMORY_ADDR,
      BLKS )
  ELSE
    IF G_AST[INDEX].NO_ACTIVE_IN_MEMORY = 0 THEN
      FREE_LOCAL_BIT_MAP ( I_AST[L_INDEX].
        MEMORY_ADDR, BLKS )
    FI
  FI
ELSE
  IF G_AST[INDEX].NO_ACTIVE_IN_MEMORY = 0 ANDIF
    (G_AST[INDEX].FLAG_BITS AND WRITTEN_MASK) <> 0 THEN
    SUCCESS_CODE := WRITE_SEGMENT ( G_AST[INDEX].
      PAGE_TABLE_LOC1, G_AST[INDEX].GLOBAL_ADDR )
    IF SUCCESS_CODE <> VALID THEN
      RETURN
    FI
    FREE_GLOBAL_BIT_MAP ( G_AST[INDEX].GLOBAL_ADDR,
      BLKS )
  ELSE
    IF G_AST[INDEX].NO_ACTIVE_IN_MEMORY = 0 THEN
      FREE_GLOBAL_BIT_MAP ( G_AST[INDEX].GLOBAL_ADDR,
        BLKS )
    FI
  FI
FI
SUCCESS_CODE := SWAPPED_OUT
END SWAP_OUT

```



```

!*****
*
* The DEACTIVATE Procedure is called by the
* the Main_line procedure, the Deactivate_all
* procedure, or the Delete_entry procedure.
* The purpose of deactivate is to remove a segment
* from a process' address space. The segment is
* removed by deleting the segment number from the
* L_AST. If no other processes have the segment
* active and no children are active, the entry
* is removed from the L_AST and the G_AST.
* The process' DBR_# and the deactivated segment's
* G_AST index are passed to the procedure. A
* success_code is returned to indicate the success
* of the operation.
*
*****!

```

```

DEACTIVATE PROCEDURE ( DBR_NO BYTE, INDEX WORD )
  RETURNS ( SUCCESS_CODE BYTE )
  LOCAL L_INDEX WORD
         SEG_NO BYTE
         CHECK BYTE
         PAR_INDEX WORD

  ENTRY
  PAR_INDEX := G_AST[INDEX].G_ASTE_NO_PAR
  L_INDEX := G_AST[INDEX].PROCESSOR_L_ASTE_NO[PROCESSOR_ID]
  SEG_NO := L_AST[L_INDEX].SEGMENT_NO_ACCESS_AUTH[DBR_NO]
  IF G_AST[INDEX].NO_ACTIVE_IN_MEMORY <> 0 THEN
    IF (MMU_IMAGE[DBR_NO].SDR[SEG_NO].ATTRIBUTES AND
        IN_MEMORY_MASK) = ZERO THEN
      SUCCESS_CODE := SWAP_OUT ( DBR_NO, INDEX )
      IF SUCCESS_CODE <> SWAPPED_OUT THEN
        RETURN
    FI
  FI
  L_AST[L_INDEX].SEGMENT_NO_ACCESS_AUTH[DBR_NO] := 0
  CHECK := ACTIVE_IN_L_AST( L_INDEX )
  IF CHECK = 0 THEN
    L_AST[L_INDEX].MEMORY_ADDR := AVAILABLE
  FI
  IF PAR_INDEX <> 0 THEN
    G_AST[PAR_INDEX].NO_ACTIVE_DEPENDENTS -= 1
    CHECK_FOR_REMOVAL ( PAR_INDEX )
  FI
  CHECK_FOR_REMOVAL ( INDEX )
  SUCCESS_CODE := SEG_DEACTIVATED
END DEACTIVATE

```





```

!*****
*
*   The MOVE_TO_GLOBAL Procedure is called by the
*   Main_line procedure. The procedure is called to
*   to move a shared and writable segment to global
*   memory. The procedure is passed the L_AST index,
*   the size, and the global address for the move.
*   A success_code is returned to indicate the
*   success of the operation. The procedure locates
*   the segment in its local memory, transfers the
*   segment to global memory, and deallocates the
*   local memory.
*
*****!

```

```

MOVE_TO_GLOBAL PROCEDURE ( L_INDEX WORD, GLOBAL_ADDR
                          ADDRESS, SIZE WORD )
  RETURNS ( SUCCESS_CODE BYTE )
  LOCAL  SEG_NO  BYTE
         I       BYTE
  ENTRY
  MEMORY_MOVE ( L_AST[L_INDEX].MEMORY_ADDR, GLOBAL_ADDR,
               SIZE )
  L_AST[L_INDEX].MEMORY_ADDR := ACTIVE
  I := 0
  DO
    IF I = MAX_DER_NO THEN EXIT
    FI
    SEG_NO := L_AST[L_INDEX].SEGMENT_NO_ACCESS_AUTF[I]
              AND  %(2)01111111
    IF SEG_NO <> 0 ANDIF (MMU_IMAGE[I].SDR[SEG_NO].
                        ATTRIBUTES AND IN_MEMORY_MASK) = 0 THEN
      MMU_IMAGE[I].SDR[SEG_NO].PAGE_ADDR := GLOBAL_ADDR
    FI
    I += 1
  OD
  FREE_LOCAL_BIT_MAP ( L_AST[L_INDEX].MEMORY_ADDR, BLKS )
  SUCCESS_CODE := VALID
END MOV_TO_GLOBAL

```



```

!*****
*
* The SWAP_IN Procedure is called by the Main_line
* procedure. The procedure will transfer a segment
* from secondary storage to main memory. The procedure
* is passed the process' DEB_#, the segment's G_AST
* index, and the authorized access to the segment.
* A success_code is returned to indicate the
* success of the operation. ( successful = swapped_in )
* If the segment is not already in memory, the appro-
* priate memory is allocated and the segment is trans-
* ferred to the allocated memory. If the segment is
* writable and shared, the segment is transferred into
* global memory.
*
*****!

```

```

SWAP_IN PROCEDURE(INDEX WORD,DEB_NO BYTE,ACCESS_AUTH BYTE)
RETURNS ( SUCCESS_CODE BYTE )
LOCAL BLKS WORD,
TEST BYTE
SEG_NO BYTE
I_INDEX WORD
BASE_ADDR ADDRESS

ENTRY
BLKS := G_AST[INDEX].SIZE / BLK_SIZE
I_INDEX:=G_AST[INDEX].PROCESSOR_L_ASTE_NO[PROCESSOR_ID]
SEG_NO := I_AST[I_INDEX].SEGMENT_NO_ACCESS_AUTH[DEB_NO]
SUCCESS_CODE := CHECK_MAX_VIRTUAL_CORE ( DEB_NO, BLKS )
IF SUCCESS_CODE = VIRTUAL_CORE_FULL THEN
RETURN
FI
G_AST[INDEX].NO_ACTIVE_IN_MEMORY += 1
IF ACCESS_AUTH = WRITE THEN
G_AST[INDEX].FLAG_BITS := G_AST[INDEX].FLAG_BITS OR
WRITABLE_MASK
FI
IF (G_AST[INDEX].FLAG_BITS AND WRITABLE_MASK) = 0
OPIF G_AST[INDEX].NO_ACTIVE_IN_MEMORY <= 1 THEN
TEST := CHECK_LOCAL_MEMORY ( I_INDEX )
IF TEST <> IN_LOCAL_MEMORY THEN
SUCCESS_CODE,BASE_ADDR := ALLOC_LOCAL_MEMORY(BLKS)
IF SUCCESS_CODE = LOCAL_MEMORY_FULL THEN
RETURN
FI
SUCCESS_CODE := READ_SEGMENT ( G_AST[INDEX].
PAGE_TABLE_LOC1, BASE_ADDR )
IF SUCCESS_CODE <> VALID THEN
FREE_LOCAL_BIT_MAP ( BASE_ADDR, BLKS )
RETURN
FI

```



```

        L_AST[L_INDEX].MEMORY_ADDR := BASE_ADDR
    ELSE
        BASE_ADDR := L_AST[L_INDEX].MEMORY_ADDR
    FI
ELSE
    IF G_AST[INDEX].GLOBAL_ADDR = NULL THEN
        SUCCESS_CODE, BASE_ADDR := ALLOC_GLOBAL_MEMORY(
                                        ELKS )
        IF SUCCESS_CODE = GLOBAL_MEMORY_FULL THEN
            RETURN
        FI
        IF TEST = IN_LOCAL THEN
            SUCCESS_CODE := MOVE_TO_GLOBAL ( L_INDEX,
                                            BASE_ADDR, G_AST[INDEX].SIZE1 )
            IF SUCCESS_CODE <> VALID THEN
                FREE_GLOBAL_BIT_MAP ( BASE_ADDR, ELKS )
                RETURN
            FI
        ELSE
            SUCCESS_CODE :=
                SIGNAL_OTHER_MEMORY MANAGERS ( INDEX, BASE_ADDR )
            IF SUCCESS_CODE <> VALID THEN
                RETURN
            FI
        ELSE
            BASE_ADDR := G_AST[INDEX].GLOBAL_ADDR
        FI
    FI
    UPDATE_MMU_IMAGE ( DER_NO, SEG_NO, BASE_ADDR, ACCESS_AUTH,
                                        ELKS )
    UPDATE_I_AST_ACCESS ( L_INDEX, ACCESS_AUTH, DER_NO )
    SUCCESS_CODE := SWAPPED_IN
END SWAP_IN

```

```

!*****
*
* The MOVE_TO_LOCAL Procedure is called by the Main_
* line procedure. The procedure is called when
* a segment no longer needs to be in global memory
* and can be moved to local memory. The procedure
* is passed the L_AST index, size, and global address
* of the segment to be moved. A success_code is returned
* to indicate the success of the operation.
*
*****!

```

```

MOVE_TO_LOCAL PROCEDURE ( L_INDEX WORD, GLOBAL_ADDR
                        ADDRESS, SIZE WORD )

```



```

RETURNS ( SUCCESS_CODE  BYTE )
LOCAL   BASE_ADDRESS  ADDRESS
        SEG_NO        BYTE
        I              BYTE
        BLKS          BYTE

ENTRY
BLKS := SIZE / BLK_SIZE
SUCCESS_CODE, BASE_ADDRESS := ALLOC_LOCAL_MEMORY(BLKS)
IF SUCCESS_CODE <> VALID THEN
    RETURN
FI
MEMORY_MOVE ( GLOBAL_ADDR, BASE_ADDRESS, SIZE )
L_AST[L_INDEX].MEMORY_ADDR := BASE_ADDRESS
I := 0
DO
    IF I = MAX_DER_NO THEN EXIT
    FI
    SEG_NO := L_AST[L_INDEX].SEGMENT_NO_ACCESS_AUTH[I]
              AND  %(2)01111111
    IF SEG_NO <> 0 ANDIF (MMU_IMAGE[I].SDR[SEG_NO].
              ATTRIBUTES AND IN_MEMORY_MASK) = 0 THEN
        MMU_IMAGE[I].SDR[SEG_NO].BASE_ADDR:=BASE_ADDRESS
    FI
    I += 1
OD
SUCCESS_CODE = VALID
END MOVE_TO_LOCAL

```

```

!*****
*
* The UPDATE Procedure is called by the Main_line
* procedure. The procedure is called to update the
* MMU images of process' connected to a segment
* that was moved to global memory by the Move_to_global
* procedure. The procedure is passed the L_AST index,
* the size, and the global address of the segment
* that was moved to global address. A success_code
* is returned to indicate the success of the operation.
*
*****!

```

```

UPDATE PROCEDURE ( I_INDEX  WORD, GLOBAL_ADDR  ADDRESS,
                  SIZE      WORD )
RETURNS ( SUCCESS_CODE  BYTE )
LOCAL   SEG_NO        BYTE
        BLKS          BYTE
        I              BYTE

ENTRY
I := 0

```





```

DO
  IF I = MAX_DER_NO THEN EXIT
  FI
  SEG_NO := L_AST[L_INDEX].SEGMENT_NO_ACCESS_AUTH[I]
           AND %(2)01111111
  IF SEG_NO <> 0 AND IF (MMU_IMAGE[I].SDR[SEG_NO].
    ATTRIBUTES AND IN_MEMORY_MASK) = 0 THEN
    MMU_IMAGE[I].SDR[SEG_NO].BASE_ADDR := GLOBAL_ADDR
  FI
  I += 1
OD
BLKS := SIZE / BLK_SIZE
FREE_LOCAL_BIT_MAP( L_AST[L_INDEX].MEMORY_ADDR, BLKS )
L_AST[L_INDEX].MEMORY_ADDR := ACTIVE
SUCCESS_CODE := VALID
END UPDATE

```

```

|          ***** MAIN LINE CODE          ***** |

```

```

$SECTION MAIN

```

```

MAIN_LINE PROCEDURE
  LOCAL FUNCTION BYTE
            ARGUMENTS ARRAY [ ??? BYTE]
            MSG         ARRAY [MAX_MSG_SIZE BYTE]
            VP_ID       BYTE
            SUCCESS_CODE BYTE
ENTRY
  INITIALIZE_PROCESSOR_LOCAL_VARIABLES
  DO
    CHECK_MSG_QUEUE
    VP_ID, MSG := WAIT
    |          *** VALIDATE THE MSG FROM 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, HANDLE, CLASS, SIZE :=
                      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 MOVE_TO_LOCAL THEN SUCCESS_CODE :=  
        MOVE_TO_LOCAL(ARGUMENTS)  
    CASE MOVE_TO_GLOBAL THEN SUCCESS_CODE :=  
        MOVE_TO_GLOBAL(ARGUMENTS)  
    CASE UPDATE          THEN SUCCESS_CODE :=  
        UPDATE(ARGUMENTS)  
    CASE DEACTIVATE_ALL THEN SUCCESS_CODE :=  
        DEACTIVATE_ALL(ARGUMENTS)  
FI  
    SIGNAL ( VP_ID, SUCCESS_CODE, ARGUMENTS )  
OD  
END MAIN_LINE  
END MEMORY_MANAGER_PLZ_SYS MODULE
```



APPENDIX B - PLZ/ASM SOURCE LISTINGS

```
!*****!
! THE PLZ/ASM MODULE WAS WRITTEN TO PROVIDE SUPPORT FOR !
! THE SWAP_IN TEREAD [APPENDIX 3]. THE VALIDITY OF THE !
! CODE HAS NOT BEEN THOROUGHLY TESTED, NOR HAS IT BEEN !
! OPTIMIZED. THE CODE SIMULATES SECONDARY STORAGE IN !
! MAIN MEMORY, AND WAS NOT INTENDED TO BE USED IN AN !
! ACTUAL SYSTEM IMPLEMENTATION. !
!*****!
```

M\_MGR\_2 MODULE

! \* \* \* \* VERS. 1.0 \* \* \* \* !

CONSTANT

```
FALSE := 0
TRUE := 1
AVAILABLE := 0 ! AST ENTRY AVAILABLE !
ACTIVE := 1 ! AST ENTRY ACTIVE !
ZERO := 0
NULL := %0000
NULL_PAGE := 0
HBUG := %A900
MONITOR := %059A
```

```
! SUCCESS CODES !
INVALID := 0
VALID := 1
FOUND := 2
NOT_FOUND := 3
SWAPPED_IN := 4
SWAPPED_OUT := 5
SEG_ACTIVATED := 6
SEG_DEACTIVATED := 7
SEG_CREATED := 8
SEG_DELETED := 9
LEAF_SEG_EXISTS := 10
NO_LEAF_EXISTS := 11
G_AST_FULL := 12
L_AST_FULL := 13
IN_LOCAL_MEMORY := 14
NOT_IN_LOCAL_MEM := 15
LOCAL_MEMORY_FULL := 16
GLOBAL_MEM_FULL := 17
VIRTUAL_CORE_FULL := 18
DUPLICATE_ENTRY := 19
```



```

NO_CHILD_TO_DEL := 20
SEC_STOR_FULL := 21
DISK_ERROR := 22
ALIAS_DOES_NOT_EXIST := 23
! ATTRIBUTE MASKS !
READ_MASK := %(2)11111110
WRITE_MASK := %(2)00000001
CHANGED_MASK := %(2)01000000
IN_MEMORY_MASK := %(2)00000100
CLEARED := 0 ! CLEAR ATTR !
! AUTHORIZED ACCESS !
READ := 0
WRITE := 1
EXECUTE := %(2)00001000

! G_AST FLAG BITS FIELD MASKS !
WRITABLE_MASK := %(2)00000010
WRITTEN_MASK := %(2)00000100

! DESIGN PARAMETERS !
BLK_SIZE := 128
MAX_PAGE_SIZE := BLK_SIZE/2
NO_OF_PROCESSORS := 1
MAX_DBR_NO := 4 ! EVEN NO. OF DBR #'S !
G_AST_LIMIT := 16 ! MAX ENTRIES IN G_AST !
L_AST_LIMIT := 16 ! MAX ENTRIES IN L_AST !
MAX_ENTRY_NO := 10 ! SIZE OF ALIAS TABLE !
NO_SEG_DESC_REG := 3 ! NO. OF SEGMENT/PROCESS!
FST_POSS_FREE_BLK := 1
DISK_MEM_BASE := %9000
MAX_POSS_D_BLK := 96
GLOBAL_MEM_BASE := %8000
MAX_POSS_G_BLK := 32
LOCAL_MEM_BASE := %5000
MAX_POSS_L_BLK := 64
DISK_BIT_MAP_LOC := 0

```

TYPE

```

ADDRESS WORD
ALIAS_HEADER RECORD [
    SEG_PAGE_TABLE_LOC WORD
    PAR_ALIAS_TABLE_LOC WORD ]

SEG_DESC_REG RECORD [
    BASE_ADDR ADDRESS
    LIMIT BYTE
    ATTRIBUTE BYTE ]

ALIAS RECORD [
    UNIQUE_ID WORD
    CLASS WORD
    SIZE WORD

```





PAGE TABLE LOC WORD  
ALIAS\_TABLE\_LOC WORD ]

MMU

RECORD [  
SDR ARRAY [NO\_SEG\_DESC\_REG  
SEG\_DESC\_REG]  
BLKS\_USED WORD  
MAX\_BLKs WORD]

GLOBAL

!\$SECTION G\_DATA !

GLOBAL\_MEM\_BIT\_MAP ARRAY [MAX\_POSS\_G\_BLKs/16 WORD]  
G\_AST\_LOCK BYTE

! \$SECTION L\_DATA !

MMU\_IMAGE ARRAY [MAX\_DBR\_NO MMU]  
LOCAL\_MEM\_BIT\_MAP ARRAY [MAX\_POSS\_L\_BLKs/16 WORD]  
ALIAS\_TABLE RECORD [ HEADER ALIAS HEADER  
ALIAS\_ENTRY ARRAY  
[MAX\_ENTRY\_NO ALIAS] ]  
DISK\_BIT\_MAP\_BUFF ARRAY [6 BYTE]  
PAGE\_TABLE\_BUFFER ARRAY [BLK\_SIZE BYTE]

INTERNAL

COMPACT\_L PROCEDURE  
ENTRY  
END COMPACT\_L

COMPACT\_G PROCEDURE  
ENTRY  
END COMPACT\_G

GLOBAL

ALLOC\_LOCAL\_MEMORY PROCEDURE

!\*\*\*\*\*!  
! PASSED PARAMETER !  
! R0 = BLKS OF MEMORY !  
! RETURNED PARAMETERS !  
! R0 = SUCCESS\_CODE !  
! R1 = BASE\_ADDR !  
! LOCAL VARIABLES !  
! R0 = BLKS !  
! R10 = BIT\_MAP\_INDEX !  
! R11 = COUNTER FOR BIT !  
! R12 = BIT\_MAP WORD !  
! R13 = WORKING REGISTER !



!\*\*\*\*\*!\*\*\*\*\*!\*\*\*\*\*!\*\*\*\*\*!\*\*\*\*\*!\*\*\*\*\*!\*\*\*\*\*!\*\*\*\*\*!\*\*\*\*\*!\*\*\*\*\*!

LOCAL BLKS WORD  
IS\_COMPACTED BYTE  
FILLER2 BYTE

ENTRY

LD BLKS, R0

LDB IS\_COMPACTED, #FALSE

LD R10, #ZERO

DO

CP R10, #(MAX\_POSS\_L\_BLK/16)

IF EQ THEN

CPB IS\_COMPACTED, #FALSE

IF EQ THEN

CALL COMPACT\_L

LD R10, #ZERO

LDB IS\_COMPACTED, #TRUE

ELSE

LD R0, #LOCAL\_MEMORY\_FULL

RET

FI

FI

LD R11, #ZERO

LD R12, LOCAL\_MEM\_BIT\_MAP(R10)

DO

BIT R12, R11

IF Z THEN

DEC R0, #1

ELSE

LD R0, BLKS

FI

CP R0, #ZERO

IF EQ THEN

LD R1, R10

MULT RR0, #16

ADD R1, R11

SUB R1, BLKS

MULT RR0, #BLK\_SIZE

ADD R1, #LOCAL\_MEM\_BASE

LD R0, #INVALID

LD R13, BLKS

DO

LD R12, LOCAL\_MEM\_BIT\_MAP(R10)

DO

SET R12, R11

DEC R13, #1

DEC R11, #1

CP R13, #ZERO

IF EQ THEN

LD LOCAL\_MEM\_BIT\_MAP(R10), R12

RET

FI



```

                                CP R11, #ZERO
                                IF EQ THEN
                                    LD LOCAL_MEM_BIT_MAP(R10), R12
                                    LD R11, #15
                                    DEC R10, #1
                                    EXIT
                                FI
                            OD
                    OD
            FI
            INC R11, #1
            CP R11, #16
            IF EQ THEN
                LD R11, #ZERO
                EXIT
            FI
        OD
        INC R10, #1
    OD
END ALLOC_LOCAL_MEMORY

```

```

FREE_LOCAL_BIT_MAP PROCEDURE
!*****!
! PASSED PARAMETERS !
! R0 = BASE_ADDR !
! R1 = BLKS !
! LOCAL VARIABLES !
! R10 = COUNTER FOR BIT RESET !
! R11 = BIT_MAP INDEX !
! R12 = BIT_MAP WORD !
!*****!
ENTRY
CLR R10
LD R11, R0
SUB R11, #LOCAL_MEM_BASE
DIV RR10, #BLK_SIZE*16
DO
    LD R12, LOCAL_MEM_BIT_MAP(R11)
    DO
        RES R12, R10
        DEC R1, #1
        CP R1, #ZERO
        IF LT THEN
            LD LOCAL_MEM_BIT_MAP(R11), R12
            RET
        FI
        INC R10, #1
        CP R10, #16
        IF EQ THEN
            LD LOCAL_MEM_BIT_MAP(R11), R12

```



```

                LD R10, #ZERO
                EXIT
            FI
        OD
        INC R11, #1
    OD
END FREE_LOCAL_BIT_MAP

```

FREE\_GLOBAL\_BIT\_MAP PROCEDURE

```

!*****!
! PASSED PARAMETERS !
! R0 = BASE_ADDR !
! R1 = BLKS !
! LOCAL VARIABLES !
! R10 = COUNTER FOR BIT RESET !
! R11 = BIT_MAP INDEX !
! R12 = BIT_MAP WORD !
!*****!
ENTRY
CLR R10
LD R11, R0
SUB R11, #GLOBAL_MEM_BASE
DIV RR10, #BLK_SIZE*16
DO
    LD R12, GLOBAL_MEM_BIT_MAP(R11)
    DO
        RES R12, R10
        DEC R1, #1
        CP R1, #ZERO
        IF LT THEN
            LD GLOBAL_MEM_BIT_MAP(R11), R12
            RET
        FI
        INC R10, #1
        CP R10, #16
        IF EQ THEN
            LD GLOBAL_MEM_BIT_MAP(R11), R12
            LD R10, #ZERO
            EXIT
        FI
    OD
    INC R11, #1
OD
END FREE_GLOBAL_BIT_MAP

```





```

ALLOC GLOBAL MEMORY PROCEDURE
!*****!
! PASSED PARAMETER !
! R0 = BLKS OF MEMORY !
! RETURNED PARAMETERS !
! R0 = SUCCESS_CODE !
! R1 = BASE_ADDR !
! LOCAL VARIABLES !
! R0 = BLKS !
! R10 = BIT_MAP INDEX !
! R11 = COUNTER FOR BIT !
! R12 = BIT_MAP WORD !
! R13 = WORKING REGISTER !
!*****!

```

```

LOCAL BLKS WORD
      IS_COMPACTED BYTE
      FILLER3 BYTE

```

```

ENTRY
LD BLKS, R0
LDB IS_COMPACTED, #FALSE
LD R10, #ZERO
DO
  CP R10, #(MAX_POSS_G_BLK/16)
  IF EQ THEN
    CPB IS_COMPACTED, #FALSE
    IF EQ THEN
      CALL COMPACT_G
      LD R10, #ZERO
      LDB IS_COMPACTED, #TRUE
    ELSE
      LD R0, #GLOBAL_MEM_FULL
      RET
  FI
  LD R11, #ZERO
  LD R12, GLOBAL_MEM_BIT_MAP(R10)
  DO
    BIT R12, R11
    IF Z THEN
      DEC R0, #1
    ELSE
      LD R0, BLKS
  FI
  CP R0, #ZERO
  IF EQ THEN
    LD R1, R10
    MULT RR0, #16
    ADD R1, R11
    SUB R1, BLKS
    MULT RR0, #BLK_SIZE

```



```

ADD R1, #GLOBAL_MEM_BASE
LD R0, #VALID
LD R13, BLKS
DO
    LD R12, GLOBAL_MEM_BIT_MAP(R10)
    DO
        SET R12, R11
        DEC R13, #1
        DEC R11, #1
        CP R13, #ZERO
        IF EQ THEN
            LD GLOBAL_MEM_BIT_MAP(R10), R12
            RET
        FI
        CP R11, #ZERO
        IF EQ THEN
            LD GLOBAL_MEM_BIT_MAP(R10), R12
            LD R11, #15
            DEC R10, #1
            EXIT
        FI
    OD
OD
FI
INC R11, #1
CP R11, #16
IF EQ THEN
    LD R11, #ZERO
    EXIT
FI
OD
INC R10, #1
OD
END ALLOC_GLOBAL_MEMORY

```

READ PAGE PROCEDURE

```

!*****!
! PASSED PARAMETERS !
! R0 = BLK NO !
! R1 = BASE_ADDR !
! RETURNED PARAMETER !
! R0 = SUCCESS CODE !
! LOCAL VARIABLES !
! R10 = COUNTER FOR BLOCK MOVE !
! R11 = SIMULATED DISK ADDRESS !
!*****!
ENTRY
LDL RR10, #BLK_SIZE
MULT PR10, R0
ADD R11, #DISK_MEM_BASE

```



```

LD R10, #MAX_PAGE_SIZE
LDIR @R1, @R11, R10
LD R0, #VALID
END READ_PAGE

```

WRITE\_PAGE PROCEDURE

```

!*****!
! PASSED PARAMETERS !
! R0 = BLK_NO !
! R1 = FROM_BASE_ADDR !
! RETURNED PARAMETR !
! R0 = SUCCESS_CODE !
! LOCAL VARIABLES !
! R10 = COUNTER FOR BLOCK MOVE !
! R11 = SIMULATED DISK ADDRESS !
!*****!

```

```

ENTRY
LDL RR10, #BLK_SIZE
MULT RR10, R0
ADD R11, #DISK_MEM_BASE
LD R10, #MAX_PAGE_SIZE
LDIR @R11, @R1, R10
LD R0, #VALID
END WRITE_PAGE

```

READ\_SEGMENT PROCEDURE

```

!*****!
! PASSED PARAMETERS !
! R0 = PAGE_TABLE_LOC (BLK_#) !
! R1 = MEMORY_ADDR !
! RETURNED PARAMETER !
! R0 = SUCCESS CODE !
! LOCAL VARIABLES !
! R2 = INDEX FOR PAGE_TABLE_ARRAY !
! R10 = COUNT FOR BLOCK MOVE !
! R11 = DISK_BLK_# CONV TO MEM ADDR !
! R13 = DISK_ADDRESS !
!*****!

```

```

ENTRY
LDL RR10, #BLK_SIZE
MULT RR10, R0
ADD R11, #DISK_MEM_BASE
LD R2, #ZERO
DO
LD R10, #MAX_PAGE_SIZE
LD R13, R11(R2)
MULT RR12, #BLK_SIZE
ADD R13, #DISK_MEM_BASE
LDIR @R1, @R13, R10
INC R2, #1

```



```

        CP R2, #MAX_PAGE_SIZE
        IF EQ THEN
            EXIT
        FI
        LD R0, R11(R2)
        CP R0, #ZERO
        IF EQ THEN
            EXIT
        FI
    OD
    LD R0, #VALID
END READ_SEGMENT

```

WRITE\_SEGMENT PROCEDURE

```

!*****!
! PASSED PARAMETERS !
! R0 = PAGE_TABLE_LOC (BLK_#) !
! R1 = MEMORY_ADDR !
! RETURNED PARAMETER !
! R0 = SUCCESS_CODE !
! LOCAL VARIABLES !
! R10 = PAGE_TABLE_ARRAY_INDEX !
! R11 = DISK_BLK_NO CONV TO MEM_ADDR !
! R13 = DISK_ADDR !
!*****!
ENTRY
LDL RR10, #BLK_SIZE
MULT RR10, R0
ADD R11, #DISK_MEM_BASE
LD R2, #ZERO
DO
LD R10, #MAX_PAGE_SIZE
LD R13, R11(R2)
MULT RR12, #BLK_SIZE
ADD R13, #DISK_MEM_BASE
LDIR @R13, @R1, R10
INC R2, #1
CP R2, #MAX_PAGE_SIZE
IF EQ THEN
    EXIT
FI
LD R0, R11(R2)
CP R0, #ZERO
IF EQ THEN
    EXIT
FI
OD
LD R0, #VALID
END WRITE_SEGMENT

```





```

READ_DISK_BIT_MAP PROCEDURE
!*****!
! RETURNED PARAMETERS !
! R0 = SUCCESS_CODE !
! LOCAL VARIABLES !
! R10 = DISK_BIT_MAP_BUFF_ADDR !
! R11 = COUNTER FOR BLK MOVE !
! R13 = BIT_MAP_DISK_ADDR !
!*****!
ENTRY
LD R10, #DISK_BIT_MAP
LD R13, #DISK_BIT_MAP_LOC
CLR R12
MULT RR12, #BLK_SIZE
ADD R13, #DISK_MEM_BASE
LD R11, #(MAX_POSS_D_BLK/16)
LDIR @R13, @R10, R11
LD R0, #VALID
END READ_DISK_BIT_MAP

```

```

WRITE_DISK_BIT_MAP PROCEDURE
!*****!
! RETURNED PARAMETER !
! R0 = SUCCESS_CODE !
! LOCAL VARIABLES !
! R10 = DISK_BIT_MAP_BUFF_ADDR !
! R11 = COUNTER FOR BIT MAP !
! R13 = BIT_MAP_ADDRESS !
!*****!
ENTRY
LD R10, #DISK_BIT_MAP
LD R13, #DISK_BIT_MAP_LOC
CLR R12
MULT RR12, #BLK_SIZE
ADD R13, #DISK_MEM_BASE
LD R11, #(MAX_POSS_D_BLK/16)
LDIR @R10, @R13, R11
LD R0, #VALID
END WRITE_DISK_BIT_MAP

```

```

SEARCH_DISK_BIT_MAP PROCEDURE
!*****!
! PASSED PARAMETER !
! R0 = START_SRCH_BLK_# !
! RETURNED PARAMETERS !
! R0 = SUCCESS_CODE !
! R1 = FREE_BLK_# !
! LOCAL VARIABLES !
! R10 = BIT_COUNTER !
! R11 = BIT_MAP_INDEX !
! R12 = BIT_MAP_WORD !

```



```

!*****!
ENTRY
CLR R10
LD R11, R0
DIV RR10, #16
! R10 = REM, R11 = QUOT !
DO
LD R12, DISK_BIT_MAP(R11)
DO
BIT R12, R10
IF Z THEN
SET R12, R10
LD DISK_BIT_MAP(R11), R12
LD R1, R11
MULT RR0, #16
ADD R1, R10
LD R0, #VALID
RET
FI
INC R10, #1
CP R10, #16
IF EQ THEN
LD R10, #ZERO
EXIT
FI
OD
INC R11, #1
CP R11, #(MAX_POSS_D_BLK/16)
IF EQ THEN
LD R0, #SEC_STOR_FULL
RET
FI
OD
LD R0, #VALID
END SEARCH_DISK_BIT_MAP

```

```

CLEAR_DISK_BIT_MAP PROCEDURE
!*****!
! PASSED PARAMETER !
! R0 = BLK_NO TO CLEAR !
! LOCAL VARIABLES !
! R10 = BIT COUNTER !
! R11 = BIT MAP INDEX !
! R12 = BIT MAP WORD !
!*****!
ENTRY
CLR R10
LD R11, R0
DIV RR10, #16
! R10 = REM, R11 = QUOT !

```



```

LD R12, DISK_BIT_MAP(R11)
RES R12, R10
LD DISK_BIT_MAP(R11), R12
END CLEAR_DISK_BIT_MAP

```

MEMORY\_MOVE PROCEDURE

```

!*****!
! PASSED PARAMETERS !
! R0 = TO_ADDR !
! R1 = FROM_ADDR !
! R2 = SIZE IN BYTES !
!*****!
ENTRY
CLR R12
LD R13, R2
RR R13, #1
LD R12, R0
LDIRB @R12, @R1, R13
END MEMORY_MOVE

```

GET\_UNIQ\_ID PROCEDURE

```

!*****!
! RETURNED PARAMETERS !
! R0 = SUCCESS_CODE !
! R1 = UNIQUE_ID !
! NOTE: WILL BE STORED ON SEC STOR !
!*****!
LOCAL WORK_SPACE_BLK ARRAY [MAX_PAGE_SIZE WORD]
UNIQ_ID WORD
ENTRY
LD R0, #SYSTEM_DATA_LOC
LD R1, #WORK_SPACE_BLK
CALL READ_PAGE
CP R0, #VALID
IF NE THEN
RET
FI
LD R10, #ZERO ! UNIQ_ID INDEX !
LD R13, WORK_SPACE_BLK(R10)
LD UNIQ_ID, R13
INC R13, #1
LD WORK_SPACE_BLK(R10), R13
LD R0, #SYSTEM_DATA_LOC
LD R1, #WORK_SPACE_BLK
CALL WRITE_PAGE
LD R1, UNIQ_ID
END GET_UNIQ_ID

```



```
MAIN_LINE PROCEDURE
  ENTRY
  CALL ALLOC_LOCAL_MEMORY
  CALL HBUG
END MAIN_LINE
END M_MGR_2
```





APPENDIX C - SWAP\_IN PLZ/ASM CODE

MEM\_MGR MODULE

! \* \* \* \* VERS. 1.0 \* \* \* \* !

CONSTANT

```

FALSE           := 0
TRUE            := 1
AVAILABLE       := 0  ! AST ENTRY AVAILABLE !
ACTIVE          := 1  ! AST ENTRY ACTIVE !
ZERO            := 0
NULL            := %0000
NULL_PAGE      := 0
HBUG            := %A900
MONITOR        := %059A
    
```

! SUCCESS CODES !

```

INVALID         := 0
VALID           := 1
FOUND           := 2
NOT_FOUND       := 3
SWAPPED_IN     := 4
SWAPPED_OUT    := 5
SEG_ACTIVATED  := 6
SEG_DEACTIVATED := 7
SEG_CREATED     := 8
SEG_DELETED    := 9
LEAF_SEG_EXISTS := 10
NO_LEAF_EXISTS := 11
G_AST_FULL     := 12
L_AST_FULL     := 13
IN_LOCAL_MEMORY := 14
NOT_IN_LOCAL_MEM := 15
LOCAL_MEMORY_FULL := 16
GLOBAL_MEM_FULL := 17
VIRTUAL_CORE_FULL := 18
DUPLICATE_ENTRY := 19
NO_CHILD_TO_DEL := 20
SEC_STOR_FULL  := 21
DISK_ERROR     := 22
ALIAS_DOES_NOT_EXIST := 23
    
```

! ATTRIBUTE MASKS !

```

READ_MASK      := %(2)11111110
WRITE_MASK     := %(2)00000001
    
```



```

        CHANGED_MASK      := %(2)01000000
        IN_MEMORY_MASK    := %(2)00000100
        CLEARED           := 0                ! CLEAR ATTR !
!   AUTHORIZED ACCESS    !
        READ              := 0
        WRITE             := 1
        EXECUTE          := %(2)00001000

!   G_AST FLAG BITS FIELD MASKS    !
        WRITABLE_MASK     := %(2)00000010
        WRITTEN_MASK      := %(2)00000100

!   DESIGN PARAMETERS            !
        BLK_SIZE          := 128
        NO_OF_PROCESSORS := 1
        MAX_DBR_NO        := 4 ! EVEN NO. OF DBR #'S !
        G_AST_LIMIT       := 16 ! MAX ENTRIES IN G_AST !
        L_AST_LIMIT       := 16 ! MAX ENTRIES IN L_AST !
        MAX_ENTRY_NO      := 21 ! SIZE OF ALIAS TABLE !
        NO_SEG_DESC_REG   := 8 ! NO. OF SEGMENT/PROCESS !
        FST_POSS_FREE_BLK:= 1

```

TYPE

```

ADDRESS      WORD
ALIAS_HEADER RECORD [
                SEG_PAGE_TABLE_LOC  WORD
                PAR_ALIAS_TABLE_LOC  WORD ]

```

```

SEG_DESC_REG RECORD [
                BASE_ADDR  ADDRESS
                LIMIT      BYTE
                ATTRIBUTE   BYTE ]

```

```

ALIAS      RECORD [
                UNIQUE_ID      WORD
                CLASS           WORD
                SIZE            WORD
                PAGE_TABLE_LOC  WORD
                ALIAS_TABLE_LOC WORD ]

```

```

MMU      RECORD [
                SDR_ARRAY [NO_SEG_DESC_REG
                           SEG_DESC_REG]
                BLKS_USED  WORD
                MAX_BLKs   WORD]

```

```

G_AST_REC RECORD [
                UNIQUE_ID1  WORD
                GLOBAL_ADDR  ADDRESS

```

! ONLY ONE PROCESSOR !



```

PROCESSORS L_ASTE NO WORD
! WRITTEN BIT AND WRITABLE BIT !
FLAG_BITS WORD
G_ASTE_NO_PAR WORD
NO_ACTIVE_IN_MEMORY WORD
NO_ACTIVE_DEPENDENTS WORD
PAGE_TABLE_LOC1 WORD
SIZE1 WORD
ALIAS_TABLE_LOC1 WORD
SEQUENCER WORD
INSTANCE1 WORD
INSTANCE2 WORD ]

```

```

L_AST_REC RECORD [
    MEMORY_ADDR ADDRESS
    SEGMENT_NO_ACCESS_AUTH ARRAY
    [MAX_DBR_NO BYTE] ]
HANDLE RECORD [
    UNIQUE_ID2 WORD
    H_INDEX WORD ]

```

GLOBAL

!\$SECTION G\_DATA !

```

G_AST ARRAY [G_AST_LIMIT G_AST_REC]
G_AST_LOCK BYTE
DISK_BIT_MAP_LOCK BYTE

```

! \$SECTION L\_DATA !

```

MMU_IMAGE ARRAY [MAX_DBR_NO MMU]
L_AST ARRAY [L_AST_LIMIT L_AST_REC]
ALIAS_TABLE RECORD [ HEADER ALIAS_HEADER
    ALIAS_ENTRY ARRAY
    [MAX_ENTRY_NO ALIAS] ]
DISK_BIT_MAP_BUFF ARRAY [6 BYTE]
PAGE_TABLE_BUFFER ARRAY [BLK_SIZE BYTE]

```

EXTERNAL

```

ALLOC_LOCAL_MEMORY PROCEDURE
    ENTRY
END ALLOC_LOCAL_MEMORY

```

```

READ_SEGMENT PROCEDURE
    ENTRY
END READ_SEGMENT

```



```

FREE_LOCAL_BIT_MAP  PROCEDURE
  ENTRY
END FREE_LOCAL_BIT_MAP

```

```

ALLOC_GLOBAL_MEMORY  PROCEDURE
  ENTRY
END ALLOC_GLOBAL_MEMORY

```

```

MOVE_TO_GLOBAL  PROCEDURE
  ENTRY
END MOVE_TO_GLOBAL

```

```

SIGNAL_OTHER_MEMORY_MANAGERS  PROCEDURE
  ENTRY
END SIGNAL_OTHER_MEMORY_MANAGERS

```

```
INTERNAL
```

```

UPDATE_MMU_IMAGE  PROCEDURE
  !*****!
  ! PASSED PARAMETERS !
  !  R0 = DBR_#       !
  !  R1 = SEGMENT_#   !
  !  R2 = ADDR        !
  !  R3 = ACCESS      !
  !  R4 = LIMIT       !
  ! LOCAL VARIABLES  !
  !  R10 = WORKING REGISTER !
  !  R13 = WORKING REGISTER !
  !*****!
  ENTRY
  LD  R10, #MMU_IMAGE
  LD  R13, #SIZEOF MMU
  MULT RR12, R0
  ADD  R10, R13
  LD  R13, #SIZEOF SEG_DESC_REG
  MULT RR12, R1
  ADD  R10, R13
  LD  @R10, R2
  INC  R10, #2
  LDB  @R10, RL4
  INC  R10, #1
  LDB  RL4, @R10
  CPB  RL3, #EXECUTE
  IF  EQ THEN
    ANDB  RL4, #(2)11110111
  ELSE
    ANDB  RL4, #(2)11111110
  FI

```





```

ORB  RL4, RL3
LDB  @R10, RL4
RET
END UPDATE_MMU_IMAGE

```

UPDATE\_L\_AST\_ACCESS PROCEDURE

```

!*****!
! PASSED PARAMETERS !
! R0 = INDEX !
! R1 = ACCESS_AUTH !
! R2 = DBR_# !
! LOCAL VARIABLES !
! R5 = WORKING REGISTER !
! R7 = WORKING REGISTER !
!*****!
ENTRY
LD R5, #L_AST
LD R7, #SIZEOF L_AST_REC
MULT RR6, R0
ADD R7, #2
ADD R7, R2
ADD R5, R7
LDB RL3, @R5
CPB RL1, #WRITE
IF EQ THEN
ORB RL3, #(2)10000000
LDB @R5, RL3
ELSE
ANDB RL3, #(2)01111111
LDB @R5, RL3
FI
RET
END UPDATE_L_AST_ACCESS

```

CHECK\_LOCAL\_MEMORY PROCEDURE

```

!*****!
! PASSED PARAMETERS !
! R0 = INDEX !
! RETURNED PARAMETER !
! R0 = TEST !
! LOCAL VARIABLES !
! R2 = I !
! R3 = SEG_NO !
! RH3 = ATTRIBUTES !
! R10 = ADDR OF MMU_IMAGE.SDR[SEG#] !
! R11 = ADDR OF L_AST[R0].SEG/ACC[I] !
! R12,13 = WORKING REGISTERS !
!*****!
ENTRY

```



```

LD R2, #ZERO
DO
  CP R2, #MAX_DBR_NO
  IF EQ THEN
    LD R0, #NOT_IN_LOCAL_MEM
    RET

  FI
  LD R11, #L_AST
  LD R13, #SIZEOF L_AST_REC
  MULT RR12, R0
  ADD R11, R13
  ADD R11, #2 ! SEGMENT NO OFFSET !
  ADD R11, R2
  LDB RL3, QR11
  CLR B RH3
  ANDB RL3, %(2)01111111
  CPB RL3, #ZERO
  IF NE THEN
    LD R10, #MMU_IMAGE
    LD R13, #SIZEOF MMU
    MULT RR12, R2
    ADD R10, R13
    ADD R10, R3
    ADD R10, #3 ! ATTRIBUTES OFFSET !
    LDB RH1, QR10
    ANDB RH1, #IN_MEMORY_MASK
    CPB RH1, #ZERO
    IF NE THEN
      LD R0, #IN_LOCAL_MEMORY
      RET
    FI
  FI
  INC R2, #1
OD
END CHECK_LOCAL_MEMORY

```

#### CHECK\_MAX\_VIRTUAL\_CORE PROCEDURE

```

!*****!
! PASSED PARAMETERS !
! R0 = DBR_# !
! R1 = BLKS !
! RETURNED PARAMETER !
! R0 = SUCCESS_CODE !
! LOCAL VARIABLES !
! R10,R12 = WORKING REGISTERS !
!*****!
ENTRY
LD R10, #MMU_IMAGE
LD R13, #SIZEOF MMU

```



```

MULT  RR12, R0
ADD   R10, R13
LD    R13, #SIZEOF SEG_DESC_REG
MULT  RR12, #NO_SEG_DESC_REG
ADD   R10, R13
LD    R12, @R10
ADD   R12, R1
INC   R10, #2
CP    R12, @R10
IF    GT THEN
      SUB  R12, R1
      LD  R0, #VIRTUAL_CORE_FULL
ELSE
      LD  R0, #VALID
FI
DEC   R10, #2
LD   @R10, R12
RET
END CHECK_MAX_VIRTUAL_CORE

SWAP_IN PROCEDURE
!*****!
! PASSED PARAMETERS !
! R0 = INDEX !
! R1 = DBR # !
! R2 = ACCESS !
! RETURNED PARAMETER !
! R0 = SUCCESS CODE !
!*****!
LOCAL      INDEX      WORD
           DBR_NO     WORD
           ACCESS     WORD
           G_AST_BASE  ADDRESS

ENTRY
LD  INDEX, R0
LD  DBR_NO, R1
LD  ACCESS, R2
LD  R5, #G_AST
LD  R13, #SIZEOF G_AST_REC
MULT RR12, R0
ADD  R5, R13
LD  G_AST_BASE, R5
ADD  R5, #16      ! SIZE OFFSET !
CLR  R6
LD  R7, @R5
DIV  RR6, #BLK_SIZE
LD  R6, R7
DEC  R5, #12      ! L_AST INDEX OFFSET !
LD  R7, @R5
LD  R0, R1
LD  R1, R6

```



```

CALL CHECK_MAX_VIRTUAL_CORE
CP R0, #VIRTUAL_CORE_FULL
IF EQ THEN
    RET
FI
INC R5, #4      ! NO_ACTIVE_IN_MEMORY CFFSET !
INC @R5, #1
LD R8, @R5
CP ACCESS, #WRITE
IF EQ THEN
    DEC R5, #4      ! OFFSET TO FLAG_BITS !
    LD R4, @R5
    OR R4, #WRITABLE_MASK
    LD @R5, R4
FI
LD R0, R7
CALL CHECK_LOCAL_MEMORY
AND R4, #WRITABLE_MASK
CP R4, #0
IF NE THEN
    CP R8, #1
    IF GT THEN
        CP R0, #IN_LOCAL_MEMORY
        IF NE THEN
            LD R0, R6
            CALL ALLOC_LOCAL_MEMORY
            CP R0, #LOCAL_MEMORY_FULL
            IF EQ THEN
                RET
            FI
            LD R9, R1
            INC R5, #8      ! PAGE_TABLE_LOC OFFSET !
            LD R0, @R5
            CALL READ_SEGMENT
            CP R0, #VALID
            IF NE THEN
                LD R0, R9
                LD R1, R6
                CALL FREE_LOCAL_BIT_MAP
                RET
            FI
            LD R10, #L_AST
            LD R13, #SIZEOF L_AST_REC
            MULT RR12, R7
            ADD R10, R13 !MEMORY_ADDR OFFSET INTO L_AST!
            LD @R10, R9
        ELSE
            LD R10, #L_AST
            LD R13, #SIZEOF L_AST_REC
            MULT RR12, R7
            ADD R10, R13

```





```

                LD R9, @R10
            FI
        FI
    ELSE
        LD R8, R0
        LD R5, G_AST_BASE
        INC R5, #2 ! GLOBAL_ADDR OFFSET !
        LD R12, @R5
        CP R12, #NULL
        IF EQ THEN
            LD R0, R6
            CALL ALLOC_GLOBAL_MEMORY
            CP R0, #GLOBAL_MEM_FULL
            IF EQ THEN
                RET
            FI
            LD R9, R1
            CP R8, #IN_LOCAL_MEMORY
            IF EQ THEN
                LD R0, R7
                INC R5, #14 ! SIZE OFFSET !
                LD R2, @R5
                CALL MOVE_TO_GLOBAL
                CP R0, #VALID
                IF NE THEN
                    RET
                FI
            ELSE
                LD R0, R1
                LD R1, INDEX
                CALL SIGNAL_OTHER_MEMORY MANAGERS
                CP R0, #VALID
                IF NE THEN
                    RET
                FI
            FI
        ELSE
            LD R5, G_AST_BASE
            ADD R5, #2 ! GLOBAL_ADDR OFFSET !
            LD R9, @R5
        FI
    FI
    LD R0, DBR_NO
    LD R10, #L_AST
    LD R13, #SIZEOF L_AST_REC
    MULT RR12, R7
    ADD R10, R13
    ADD R10, R0
    INC R10, #2
    LDB RL1, @R10
    LD R2, R9

```



```
LD R3, ACCESS
LD R4, R6
CALL UPDATE_MMU_IMAGE
LD R0, R7
LD R1, ACCESS
LD R2, DBR_NO
CALL UPDATE_LAST_ACCESS
LD R0, #SWAPPED_IN
END SWAP_IN
```

```
MAIN_LINE PROCEDURE
ENTRY
CALL SWAP_IN
CALL HBUG
END MAIN_LINE
END MEM_MGR
```



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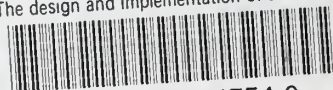
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