

Memory Allocation

Now we are ready to turn to memory allocation. One of the simplest methods for allocating memory is to divide memory into several fixed-sized **partitions**. Each partition may contain exactly one process. Thus, the degree of multiprogramming is bound by the number of partitions. In this **multiple partition method**, when a partition is free, a process is selected from the input queue and is loaded into the free partition. When the process terminates, the partition becomes available for another process. In the **variable-partition** scheme, the operating system keeps a table indicating which parts of memory are available and which are occupied. Initially, all memory is available for user processes and is considered one large block of available memory, a **hole**. Eventually, as you will see, memory contains a set of holes of various sizes. As processes enter the system, they are put into an input queue. The operating system takes into account the memory requirements of each process and the amount of available memory space in determining which processes are allocated memory. When a process is allocated space, it is loaded into memory, and it can then compete for CPU time. When a process terminates, it releases its memory, which the operating system may then fill with another process from the input queue.

At any given time, then, we have a list of available block sizes and an input queue. The operating system can order the input queue according to a scheduling algorithm. Memory is allocated to processes until, finally, the memory requirements of the next process cannot be satisfied—that is, no available block of memory (or hole) is large enough to hold that process. The operating system can then wait until a large enough block is available, or it can skip down the input queue to see whether the smaller memory requirements of some other process can be met. In general, as mentioned, the memory blocks available comprise a **set** of holes of various sizes scattered throughout memory. When a process arrives and needs memory, the system searches the set for a hole that is large enough for this process. If the hole is too large, it is split into two parts. One part is allocated to the arriving process; the other is returned to the set of holes. When a process terminates, it releases its block of memory, which is then placed back in the set of holes. If the new hole is adjacent to other holes, these adjacent holes are merged to form one larger hole. At this point, the system may need to check whether there are processes waiting for memory and whether this newly freed and recombined memory could satisfy the demands of any of these waiting processes.

This procedure is a particular instance of the general **dynamic storage allocation problem**, which concerns how to satisfy a request of size n from a list of free holes. There are many solutions to this problem. The **first-fit**, **best-fit**, and **worst-fit** strategies are the ones most commonly used to select a free hole from the set of available holes.

- **First fit.** Allocate the first hole that is big enough. Searching can start either at the beginning of the set of holes or at the location where the previous first-fit search ended. We can stop searching as soon as we find a free hole that is large enough.
- **Best fit.** Allocate the smallest hole that is big enough. We must search the entire list, unless the list is ordered by size. This strategy produces the smallest leftover hole.
- **Worst fit.** Allocate the largest hole. Again, we must search the entire list, unless it is sorted by size. This strategy produces the largest leftover hole, which may be more useful than the smaller leftover hole from a best-fit approach. Simulations have shown that both first fit and best fit are better than worst fit in terms of decreasing time and storage utilization. Neither first fit nor best fit is clearly better than the other in terms of storage utilization, but first fit is generally faster.

Fragmentation

Both the first-fit and best-fit strategies for memory allocation suffer from **external fragmentation**. As processes are loaded and removed from memory, the free memory space is broken into little pieces. External fragmentation exists when there is enough total memory space to satisfy a request but the available spaces are not contiguous: storage is fragmented into a large number of small holes. This fragmentation problem can be severe. In the worst case, we could have a block of free (or wasted) memory between every two processes. If all these small pieces of memory were in one big free block instead, we might be able to run several more processes.

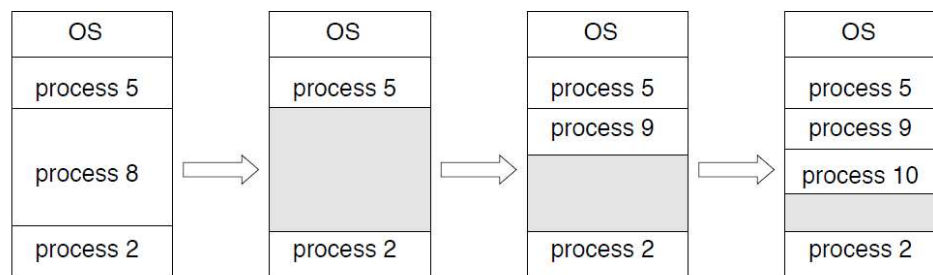
Whether we are using the first-fit or best-fit strategy can affect the amount of fragmentation. (First fit is better for some systems, whereas best fit is better for others.) Another factor is which end of a free block is allocated. (Which is the leftover piece—the one on the top or the one on the bottom?) No matter which algorithm is used, however, external fragmentation will be a problem.

Memory fragmentation can be internal as well as external. Consider a multiple-partition allocation scheme with a hole of 18,464 bytes. Suppose that the next process requests 18,462 bytes. If we allocate exactly the requested block, we are left with a hole of 2 bytes. The overhead to keep track of this hole will be substantially larger than the hole itself. The general approach to avoiding this problem is to break the physical memory into fixed-sized blocks and allocate memory in units based on block size. With this approach, the memory allocated to a process may be slightly

larger than the requested memory. The difference between these two numbers is **internal fragmentation**—unused memory that is internal to a partition.

One solution to the problem of external fragmentation is **compaction**. The goal is to shuffle the memory contents so as to place all free memory together in one large block. Compaction is not always possible, however. If relocation is static and is done at assembly or load time, compaction cannot be done. It is possible only if relocation is dynamic and is done at execution time. If addresses are relocated dynamically, relocation requires only moving the program and data and then changing the base register to reflect the new base address. When compaction is possible, we must determine its cost. The simplest compaction algorithm is to move all processes toward one end of memory; all holes move in the other direction, producing one large hole of available memory. This scheme can be expensive.

Another possible solution to the external-fragmentation problem is to permit the logical address space of the processes to be noncontiguous, thus allowing a process to be allocated physical memory wherever such memory is available. Two complementary techniques achieve this solution: segmentation and paging. These techniques can also be combined. Fragmentation is a general problem in computing that can occur wherever we must manage blocks of data.



External Fragmentation – total memory space exists to satisfy a request, but it is not contiguous"

Internal Fragmentation – allocated memory may be slightly larger than requested memory; this size difference is memory internal to a partition, but not being used"

Segmentation

As we've already seen, the user's view of memory is not the same as the actual physical memory. This is equally true of the programmer's view of memory. Indeed, dealing with memory in terms of its physical properties is inconvenient to both the operating system and the programmer. What if the hardware could provide a memory mechanism that mapped the programmer's view to the actual physical

memory? The system would have more freedom to manage memory, while the programmer would have a more natural programming environment. Segmentation provides such a mechanism.

Basic Method

Do programmers think of memory as a linear array of bytes, some containing instructions and others containing data? Most programmers would say “no.” Rather, they prefer to view memory as a collection of variable-sized segments, with no necessary ordering among the segments (Figure 8.7). When writing a program, a programmer thinks of it as a main program with a set of methods, procedures, or functions. It may also include various data structures: objects, arrays, stacks, variables, and so on. Each of these modules or data elements is referred to by name. The programmer talks about “the stack,” “the math library,” and “the main program” without caring what addresses in memory these elements occupy. She is not concerned with whether the stack is stored before or after the Sqrt() function. Segments vary in length, and the length of each is intrinsically defined by its purpose in the program. Elements within a segment are identified by their offset from the beginning of the segment: the first statement of the program, the seventh stack frame entry in the stack, the fifth instruction of the Sqrt(), and so on.

Segmentation is a memory-management scheme that supports this programmer view of memory. A logical address space is a collection of segments.

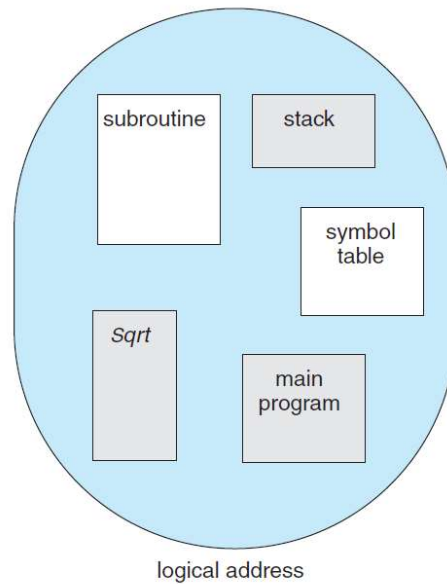


Figure 8.7 Programmer's view of a program.

Each segment has a name and a length. The addresses specify both the segment name and the offset within the segment. The programmer therefore specifies each address by two quantities: a segment name and an offset. For simplicity of implementation, segments are numbered and are referred to by a segment number, rather than by a segment name. Thus, a logical address consists of a *two tuple*: $\langle \text{segment-number}, \text{offset} \rangle$.

Normally, when a program is compiled, the compiler automatically constructs segments reflecting the input program.

A C compiler might create separate segments for the following:

1. The code
2. Global variables
3. The heap, from which memory is allocated
4. The stacks used by each thread
5. The standard C library

Libraries that are linked in during compile time might be assigned separate segments. The loader would take all these segments and assign them segment numbers.

Segmentation Hardware

Although the programmer can now refer to objects in the program by a two-dimensional address, the actual physical memory is still, of course, a one dimensional sequence of bytes. Thus, we must define an implementation to map two-dimensional user-defined addresses into one-dimensional physical addresses. This mapping is effected by a **segment table**. Each entry in the segment table has a **segment base** and a **segment limit**. The segment base contains the starting physical address where the segment resides in memory, and the segment limit specifies the length of the segment.

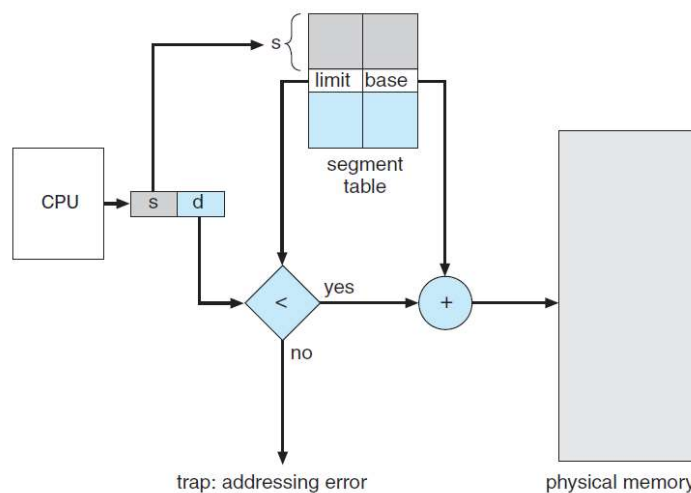


Figure 8.8 Segmentation hardware.

The use of a segment table is illustrated in Figure 8.8. A logical address consists of two parts: a segment number, *s*, and an offset into that segment, *d*. The segment number is used as an index to the segment table. The offset *d* of the logical address must be between 0 and the segment limit. If it is not, we trap to the operating system (logical addressing attempt beyond end of segment). When an offset is legal, it is added to the segment base to produce the address in physical memory of the desired byte. The segment table is thus essentially an array of base–limit register pairs.

As an example, consider the situation shown in Figure 8.9. We have five segments numbered from 0 through 4. The segments are stored in physical memory as shown. The segment table has a separate entry for each segment, giving the beginning address of the segment in physical memory (or base) and the length of that segment (or limit). For example, segment 2 is 400 bytes long and begins at location 4300. Thus, a reference to byte 53 of segment 2 is mapped onto location $4300 + 53 = 4353$. A reference to segment 3, byte 852, is mapped to 3200 (the base of segment 3) + 852

= 4052. A reference to byte 1222 of segment 0 would result in a trap to the operating system, as this segment is only 1,000 bytes long.

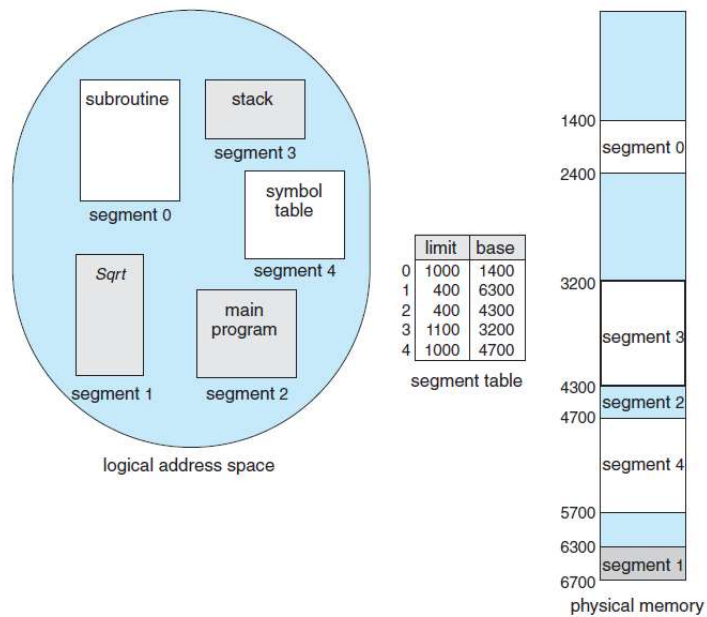


Figure 8.9 Example of segmentation.