

## Shared Pages

An advantage of paging is the possibility of *sharing* common code. This consideration is particularly important in a time-sharing environment

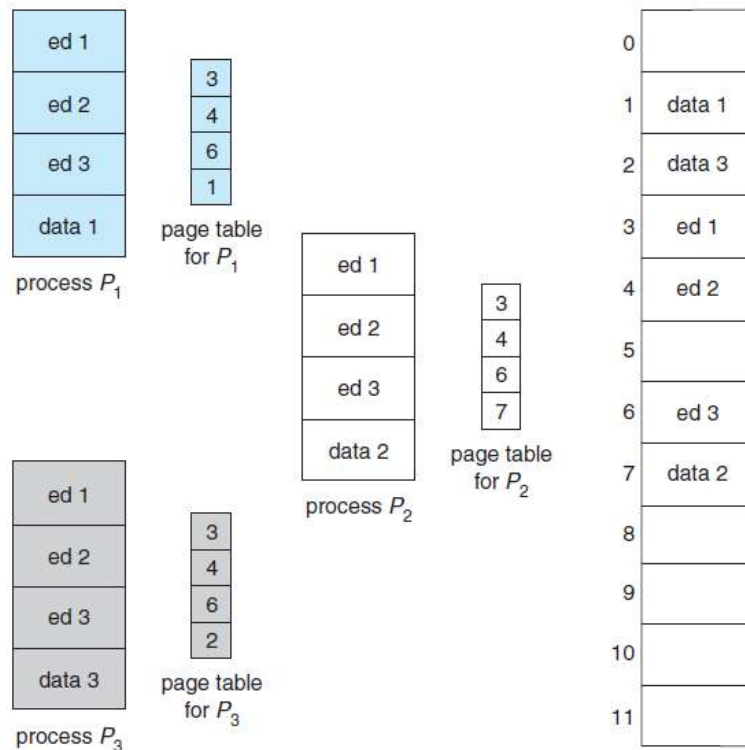
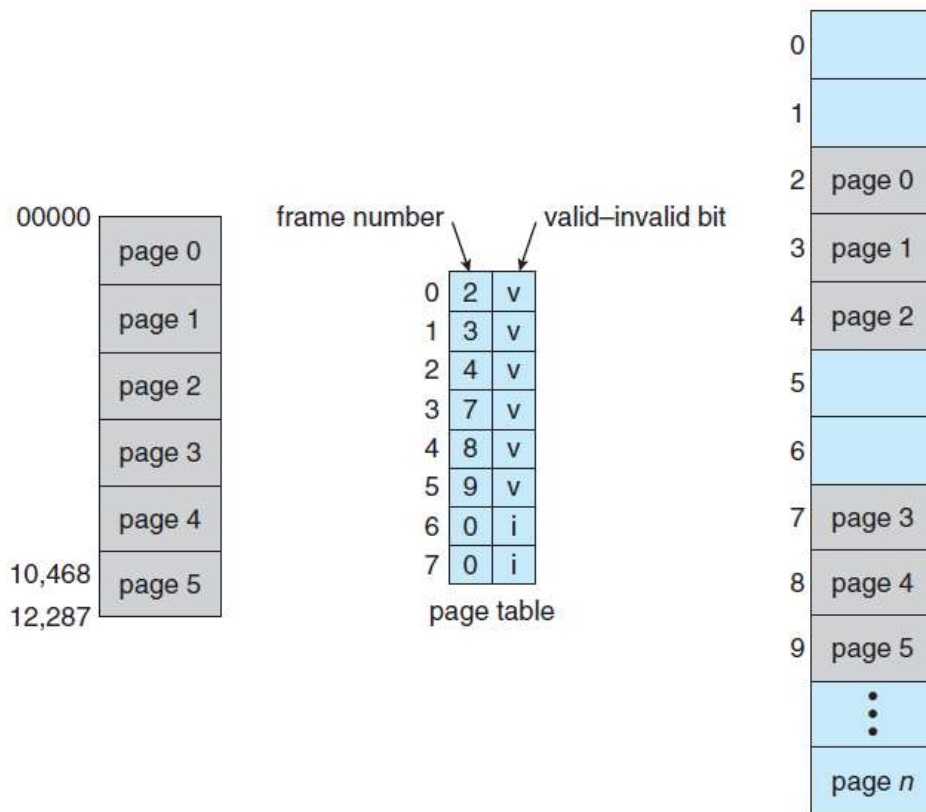


Figure 8.16 Sharing of code in a paging environment.

**Protection.** If paging or segmentation is provided, different sections of a user program can be declared execute-only, read-only, or read-write. This restriction is necessary with shared code or data and is generally useful in any case to provide simple run-time checks for common programming errors.



**Figure 8.15** Valid (v) or invalid (i) bit in a page table.

### Demand Paging

Consider how an executable program might be loaded from disk into memory.

One option is to load the entire program in physical memory at program execution time. However, a problem with this approach is that we may not initially *need* the entire program in memory. Suppose a program starts with a list of available options from which the user is to select. Loading the entire program into memory results in loading the executable code for *all* options, regardless of whether or not an option is ultimately selected by the user. An alternative strategy is to load pages only as they are needed. This technique is known as **demand paging** and is commonly used in virtual memory systems.

With demand-paged virtual memory, pages are loaded only when they are demanded during program execution. Pages that are never accessed are thus never loaded into physical memory.

A demand-paging system is similar to a paging system with swapping (Figure 9.4) where processes reside in secondary memory (usually a disk).

When we want to execute a process, we swap it into memory. Rather than swapping the entire process into memory, though, we use a **lazy swapper**.

A lazy swapper never swaps a page into memory unless that page will be needed. In the context of a demand-paging system, use of the term “swapper” is technically incorrect. A swapper manipulates entire processes, whereas a **pager** is concerned with the individual pages of a process. We thus use “pager,” rather than “swapper,” in connection with demand paging.

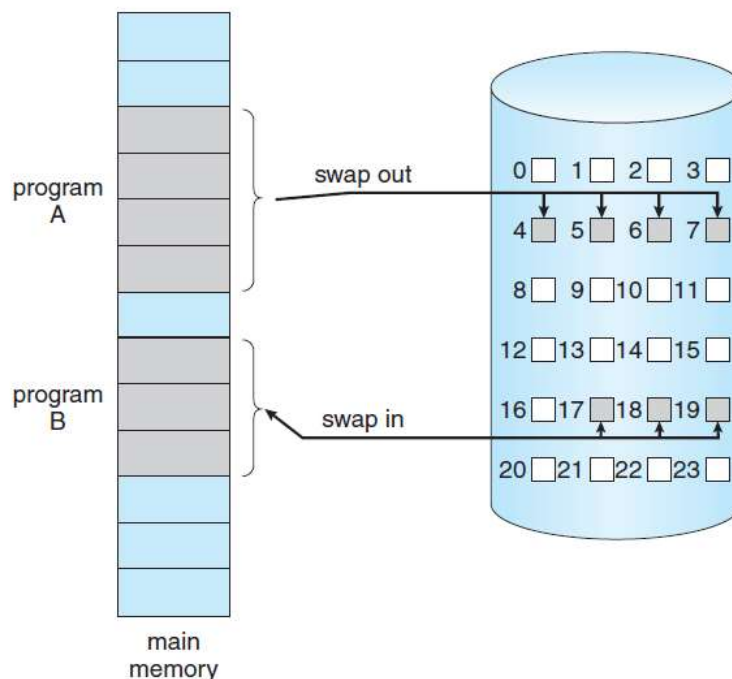


Figure 9.4 Transfer of a paged memory to contiguous disk space.

## Basic Concepts

When a process is to be swapped in, the pager guesses which pages will be used before the process is swapped out again. Instead of swapping in a whole process, the pager brings only those pages into memory. Thus, it avoids reading into memory pages that will not be used anyway, decreasing the swap time and the amount of physical memory needed.

With this scheme, we need some form of hardware support to distinguish between the pages that are in memory and the pages that are on the disk.

The valid–invalid bit scheme described in Section 8.5.3 can be used for this purpose. This time, however, when this bit is set to “valid,” the associated page is both legal and in memory. If the bit is set to “invalid,” the page either is not valid (that is, not in the logical address space of the process) or is valid but is currently on the disk. The page-table entry for a page that is brought into memory is set as usual, but the page-table entry for a page that is not currently in memory is either simply marked invalid or contains the address of the page on disk. This situation is depicted in Figure 9.5. Notice that marking a page invalid will have no effect if the process never attempts to access that page. Hence, if we guess right and page in all pages that are actually needed and only those pages, the process will run exactly as though we had brought in all pages. While the process executes and accesses pages that are **memory resident**, execution proceeds normally.

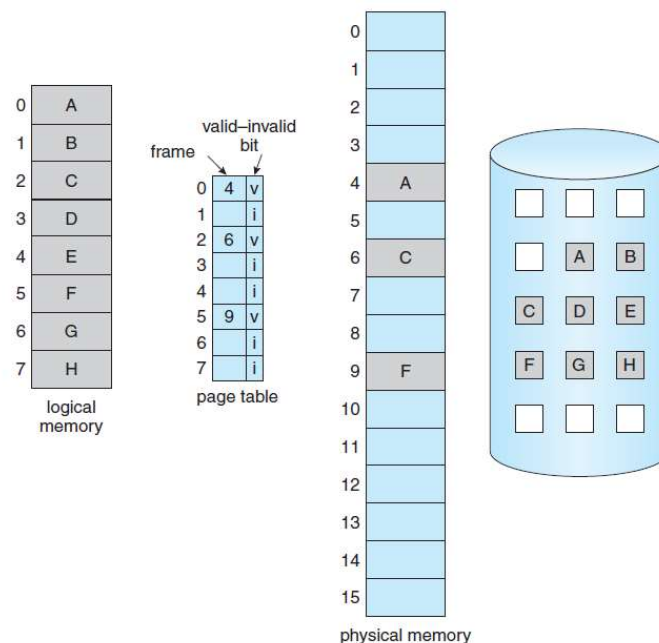


Figure 9.5 Page table when some pages are not in main memory.

But what happens if the process tries to access a page that was not brought into memory? Access to a page marked invalid causes a **page fault**. The paging hardware, in translating the address through the page table, will notice that the invalid bit is set, causing a trap to the operating system. This trap is the result of the operating system’s failure to bring the desired page into memory.

The procedure for handling this page fault is straightforward (Figure 9.6):

1. We check an internal table (usually kept with the process control block) for this process to determine whether the reference was a valid or an invalid memory access.
2. If the reference was invalid, we terminate the process. If it was valid but we have not yet brought in that page, we now page it in.
3. We find a free frame (by taking one from the free-frame list, for example).
4. We schedule a disk operation to read the desired page into the newly allocated frame.
5. When the disk read is complete, we modify the internal table kept with the process and the page table to indicate that the page is now in memory.
6. We restart the instruction that was interrupted by the trap. The process can now access the page as though it had always been in memory.

In the extreme case, we can start executing a process with *no* pages in memory.

### Page Replacement

In our earlier discussion of the page-fault rate, we assumed that each page faults at most once, when it is first referenced. This representation is not strictly accurate, however. If a process of ten pages actually uses only half of them, then demand paging saves the I/O necessary to load the five pages that are never used. We could also increase our degree of multiprogramming by running twice as many processes. Thus, if we had forty frames, we could run eight processes, rather than the four that could run if each required ten frames (five of which were never used).

If we increase our degree of multiprogramming, we are **over-allocating** memory. If we run six processes, each of which is ten pages in size but actually uses only five pages, we have higher CPU utilization and throughput, with ten frames to spare. It is possible, however, that each of these processes, for a particular data set, may suddenly try to use all ten of its pages, resulting in a need for sixty frames when only forty are available.

Further, consider that system memory is not used only for holding program pages. Buffers for I/O also consume a considerable amount of memory. This use can increase the strain on memory-placement algorithms. Deciding how much memory to allocate to I/O and how much to program pages is a significant challenge. Some systems allocate a fixed percentage of memory for I/O buffers, whereas others allow both user processes and the I/O subsystem to compete for all system memory.

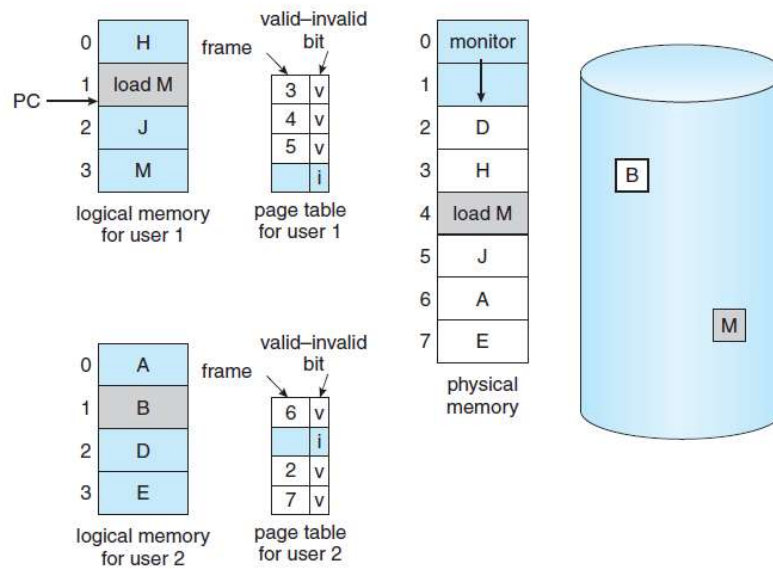


Figure 9.9 Need for page replacement.

Over-allocation of memory manifests itself as follows. While a user process is executing, a page fault occurs. The operating system determines where the desired page is residing on the disk but then finds that there are **no** free frames on the free-frame list; all memory is in use (Figure 9.9).

The operating system has several options at this point. It could terminate the user process. However, demand paging is the operating system's attempt to improve the computer system's utilization and throughput. Users should not be aware that their processes are running on a paged system—paging should be logically transparent to the user. So this option is not the best choice.

The operating system could instead swap out a process, freeing all its frames and reducing the level of multiprogramming. Here, we discuss the most common solution: **page replacement**.

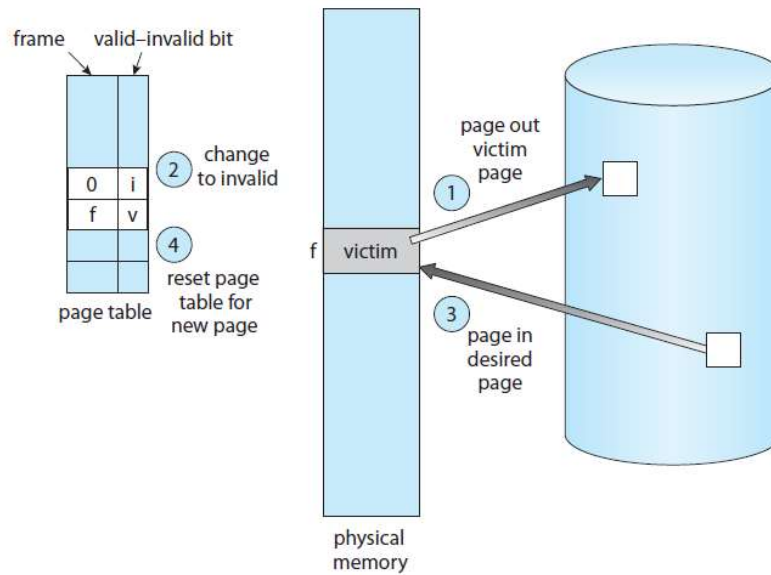


Figure 9.10 Page replacement.

1. Find the location of the desired page on the disk.
2. Find a free frame:
  - a. If there is a free frame, use it.
  - b. If there is no free frame, use a page-replacement algorithm to select a **victim frame**.
  - c. Write the victim frame to the disk; change the page and frame tables accordingly.
3. Read the desired page into the newly freed frame; change the page and frame tables.
4. Continue the user process from where the page fault occurred.

## Replacement algorithms:

### 1. FIFO Page Replacement

The simplest page-replacement algorithm is a first-in, first-out (FIFO) algorithm. A FIFO replacement algorithm associates with each page the time when that page was brought into memory. When a page must be replaced, the oldest page is chosen. Notice that it is not strictly necessary to record the time when a page is brought in. We can create a FIFO queue to hold all pages in memory.

We replace the page at the head of the queue. When a page is brought into memory, we insert it at the tail of the queue. For our example reference string, our three frames are initially empty. The first three references (7, 0, 1) cause page faults and are brought into these empty frames. The next reference (2) replaces page 7, because page 7 was brought in first. Since 0 is the next reference and 0 is already in memory, we have no fault for this reference. The first reference to 3 results in replacement of page 0, since it is now first in line. Because of this replacement, the next reference, to 0, will fault. Page 1 is then replaced by page 0. This process continues as shown in Figure 9.12. Every time a fault occurs, we show which pages are in our three frames. There are fifteen faults altogether.

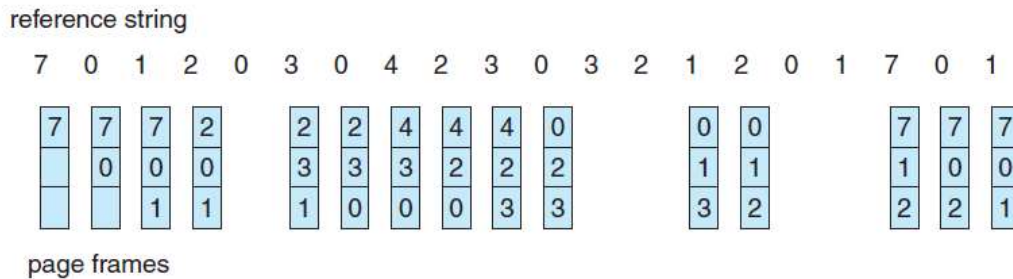


Figure 9.12 FIFO page-replacement algorithm.

The FIFO page-replacement algorithm is easy to understand and program. However, its performance is not always good. On the one hand, the page replaced may be an initialization module that was used a long time ago and is no longer needed. On the other hand, it could contain a heavily used variable that was initialized early and is in constant use.

Notice that, even if we select for replacement a page that is in active use, everything still works correctly. After we replace an active page with a new one, a fault occurs almost immediately to retrieve the active page. Some other page must be replaced to

bring the active page back into memory. Thus, a bad replacement choice increases the page-fault rate and slows process execution. It does not, however, cause incorrect execution. To illustrate the problems that are possible with a FIFO page-replacement algorithm, consider the following reference string:

1, 2, 3, 4, 1, 2, 5, 1, 2, 3, 4, 5

the curve of page faults for this reference string versus the number of available frames. Notice that the number of faults for four frames (ten) is **greater** than the number of faults for three frames (nine)! This most unexpected result is known as **Belady's anomaly**: for some page-replacement algorithms, the page-fault rate may **increase** as the number of allocated frames increases. We would expect that giving more memory to a process would improve its performance.

The disadvantage of FIFO is that it may significantly increase the time it takes for a process to execute because it does not take into consideration the principle of locality and consequently may replace heavily used frames as well as rarely used frames with equal probability. For example, if an early frame contains a global variable that is in constant use, this frame will be one of the first to be replaced. During the next access to the variable, another page fault will occur, and the frame will have to be reloaded, replacing yet another page.