Chapter 9 – Real Memory Organization and Management

Outline
9.1 Introduction
9.2 Memory Organization
9.3 Memory Management
9.4 Memory Hierarchy
9.5 Memory Management Strategies
9.6 Contiguous vs. Noncontiguous Memory Allocation
9.7 Single-User Contiguous Memory Allocation
9.7.1 Overlays
9.7.2 Protection in a Single-User System
9.7.3 Single-Stream Batch Processing
9.8 Fixed-Partition Multiprogramming
9.9 Variable-Partition Multiprogramming
9.9.1 Variable-Partition Characteristics
9.9.2 Memory Placement Strategies
9.10 Multiprogramming with Memory Swapping

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Objectives

• After reading this chapter, you should understand:
  – the need for real (also called physical) memory management.
  – the memory hierarchy.
  – contiguous and noncontiguous memory allocation.
  – fixed- and variable-partition multiprogramming.
  – memory swapping.
  – memory placement strategies.
9.1 Introduction

• Memory divided into tiers
  – Main memory
    • Relatively expensive
    • Relatively small capacity
    • High-performance
  – Secondary storage
    • Cheap
    • Large capacity
    • Slow
  – Main memory requires careful management
9.2 Memory Organization

• Memory can be organized in different ways
  – One process uses entire memory space
  – Each process gets its own partition in memory
    • Dynamically or statically allocated

• Trend: Application memory requirements tend to increase over time to fill main memory capacities
## 9.2 Memory Organization

**Figure 9.1** Microsoft Windows operating system memory requirements.

<table>
<thead>
<tr>
<th>Operating System</th>
<th>Release Date</th>
<th>Minimum Memory Requirement</th>
<th>Recommended Memory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Windows 1.0</td>
<td>November 1985</td>
<td>256KB</td>
<td></td>
</tr>
<tr>
<td>Windows 2.03</td>
<td>November 1987</td>
<td>320KB</td>
<td></td>
</tr>
<tr>
<td>Windows 3.0</td>
<td>March 1990</td>
<td>896KB</td>
<td>1MB</td>
</tr>
<tr>
<td>Windows 3.1</td>
<td>April 1992</td>
<td>2.6MB</td>
<td>4MB</td>
</tr>
<tr>
<td>Windows 95</td>
<td>August 1995</td>
<td>8MB</td>
<td>16MB</td>
</tr>
<tr>
<td>Windows NT 4.0</td>
<td>August 1996</td>
<td>32MB</td>
<td>96MB</td>
</tr>
<tr>
<td>Windows 98</td>
<td>June 1998</td>
<td>24MB</td>
<td>64MB</td>
</tr>
<tr>
<td>Windows ME</td>
<td>September 2000</td>
<td>32MB</td>
<td>128MB</td>
</tr>
<tr>
<td>Windows 2000 Professional</td>
<td>February 2000</td>
<td>64MB</td>
<td>128MB</td>
</tr>
<tr>
<td>Windows XP Home</td>
<td>October 2001</td>
<td>64MB</td>
<td>128MB</td>
</tr>
<tr>
<td>Windows XP Professional</td>
<td>October 2001</td>
<td>128MB</td>
<td>256MB</td>
</tr>
</tbody>
</table>
9.3 Memory Management

- **Strategies for obtaining optimal memory performance**
  - Performed by memory manager
    - Which process will stay in memory?
    - How much memory will each process have access to?
    - Where in memory will each process go?
9.4 Memory Hierarchy

- **Main memory**
  - Should store currently needed program instructions and data only

- **Secondary storage**
  - Stores data and programs that are not actively needed

- **Cache memory**
  - Extremely high speed
  - Usually located on processor itself
  - Most-commonly-used data copied to cache for faster access
  - Small amount of cache still effective for boosting performance
    - Due to temporal locality
9.4 Memory Hierarchy

Figure 9.2 Hierarchical memory organization.

- Storage access time decreases.
- Storage access speed increases.
- Storage cost per bit increases.
- Storage capacity decreases.

Cache memory

Primary memory

Secondary and tertiary storage

A processor may access programs and data directly.

The system must first move programs and data to main memory before a processor may reference them.
9.5 Memory Management Strategies

- Strategies divided into several categories
  - Fetch strategies
    - Demand or anticipatory
    - Decides which piece of data to load next
  - Placement strategies
    - Decides where in main memory to place incoming data
  - Replacement strategies
    - Decides which data to remove from main memory to make more space
9.6 Contiguous vs. Noncontiguous Memory Allocation

- **Ways of organizing programs in memory**
  - **Contiguous allocation**
    - Program must exist as a single block of contiguous addresses
    - Sometimes it is impossible to find a large enough block
    - Low overhead
  - **Noncontiguous allocation**
    - Program divided into chunks called segments
    - Each segment can be placed in different part of memory
    - Easier to find “holes” in which a segment will fit
    - Increased number of processes that can exist simultaneously in memory offsets the overhead incurred by this technique
9.7 Single-User Contiguous Memory Allocation

- One user had control of entire machine
  - Resources did not need to be shared
  - Originally no operating systems on computer
    - Programmer wrote code to perform resource management
  - Input-Output Control Systems (IOCS)
    - Libraries of prewritten code to manage I/O devices
    - Precursor to operating systems
9.7 Single-User Contiguous Memory Allocation

Figure 9.3 Single-user contiguous memory allocation.
9.7.1 Overlays

• **Overlays**: Programming technique to overcome contiguous allocation limits
  – Program divided into logical sections
  – Only place currently active section in memory
  – Severe drawbacks
    • Difficult to organize overlays to make efficient use of main memory
    • Complicates modifications to programs
  – Virtual memory accomplishes similar goal
    • Like IOCS, VM shields programmers from complex issues such as memory management
9.7.1 Overlays

**Figure 9.4** Overlay structure.

- **Operating system**
- **User program with memory requirement larger than available portion of main memory**

1. Load initialization phase at $b$ and run.
2. Then load processing phase at $b$ and run.
3. Then load output phase at $b$ and run.
9.7.2 Protection in a Single-User Environment

- Operating system must not be damaged by programs
  - System cannot function if operating system overwritten
  - Boundary register
    - Contains address where program’s memory space begins
    - Any memory accesses outside boundary are denied
    - Can only be set by privileged commands
    - Applications can access OS memory to execute OS procedures using system calls, which places the system in executive mode
9.7.2 Protection in a Single-User Environment

**Figure 9.5** Memory protection with single-user contiguous memory allocation.

The system prevents the user from accessing the addresses less than $a$. 
9.7.3 Single-Stream Batch Processing

• Early systems required significant setup time
  – Wasted time and resources
  – Automating setup and teardown improved efficiency

• Batch processing
  – Job stream processor reads job control languages
    • Defines each job and how to set it up
9.8 Fixed-Partition Multiprogramming

- I/O requests can tie up a processor for long periods
  - Multiprogramming is one solution
    - Process not actively using a processor should relinquish it to others
    - Requires several processes to be in memory at once
9.8 Fixed-Partition Multiprogramming

Figure 9.6 Processor utilization on a single-user system. [Note: In many single-user jobs, I/O waits are much longer relative to processor utilization periods indicated in this diagram.]
9.8 Fixed-Partition Multiprogramming

- **Fixed-partition multiprogramming**
  - Each active process receives a fixed-size block of memory
  - Processor rapidly switches between each process
  - Multiple boundary registers protect against damage
9.8 Fixed-Partition Multiprogramming

Figure 9.7 Fixed-partition multiprogramming with absolute translation and loading.
9.8 Fixed-Partition Multiprogramming

• **Drawbacks to fixed partitions**
  – Early implementations used absolute addresses
    • If the requested partition was full, code could not load
    • Later resolved by relocating compilers
9.8 Fixed-Partition Multiprogramming

Figure 9.8 Memory waste under fixed-partition multiprogramming with absolute translation and loading.
9.8 Fixed-Partition Multiprogramming

Figure 9.8 Fixed-partition multiprogramming with relocatable translation and loading.

A job may be placed in any available partition in which it fits.
9.8 Fixed-Partition Multiprogramming

• Protection
  – Can be implemented by boundary registers, called base and limit
    (also called low and high)
9.8 Fixed-Partition Multiprogramming

Figure 9.10 Memory protection in contiguous-allocation multiprogramming systems.
9.8 Fixed-Partition Multiprogramming

- Drawbacks to fixed partitions (Cont.)
  - Internal fragmentation
    - Process does not take up entire partition, wasting memory
  - Incurs more overhead
    - Offset by higher resource utilization
9.8 Fixed-Partition Multiprogramming

Figure 9.11 Internal fragmentation in a fixed-partition multiprogramming system.
9.9 Variable-Partition Multiprogramming

- System designers found fixed partitions too restrictive
  - Internal fragmentation
  - Potential for processes to be too big to fit anywhere
  - Variable partitions designed as replacement
9.9 Variable-Partition Multiprogramming

Figure 9.12 Initial partition assignments in variable-partition programming.
9.9.1 Variable-Partition Characteristics

- Jobs placed where they fit
  - No space wasted initially
  - Internal fragmentation impossible
    - Partitions are exactly the size they need to be
  - External fragmentation can occur when processes removed
    - Leave holes too small for new processes
    - Eventually no holes large enough for new processes
9.9.1 Variable-Partition Characteristics

Figure 9.13 Memory “holes” in variable-partition multiprogramming.
9.9.1 Variable-Partition Characteristics

• Several ways to combat external fragmentation
  – Coalescing
    • Combine adjacent free blocks into one large block
    • Often not enough to reclaim significant amount of memory
  – Compaction
    • Sometimes called garbage collection (not to be confused with GC in object-oriented languages)
    • Rearranges memory into a single contiguous block of free space and a single contiguous block of occupied space
    • Makes all free space available
    • Significant overhead
9.9.1 Variable-Partition Characteristics

Figure 9.14 Coalescing memory “holes” in variable-partition multiprogramming.
9.9.1 Variable-Partition Characteristics

Figure 9.15 Memory compaction in variable-partition multiprogramming.

Operating system
In use
Free
In use
Free
In use
Free

Operating system places all “in use” blocks together leaving free memory as a single large hole.
9.9.2 Memory Placement Strategies

- Where to put incoming processes
  - First-fit strategy
    - Process placed in first hole of sufficient size found
    - Simple, low execution-time overhead
  - Best-fit strategy
    - Process placed in hole that leaves least unused space around it
    - More execution-time overhead
  - Worst-fit strategy
    - Process placed in hole that leaves most unused space around it
    - Leaves another large hole, making it more likely that another process can fit in the hole
9.9.2 Memory Placement Strategies

Figure 9.16 First-fit, best-fit and worst-fit memory placement strategies (Part 1 of 3).

(a) First-fit strategy
Place job in first memory hole on free memory list in which it will fit.

Free Memory List (Kept in random order.)

<table>
<thead>
<tr>
<th>Start address</th>
<th>Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>16MB</td>
</tr>
<tr>
<td>e</td>
<td>5MB</td>
</tr>
<tr>
<td>c</td>
<td>14MB</td>
</tr>
<tr>
<td>g</td>
<td>30MB</td>
</tr>
</tbody>
</table>

0

Operating system

<p>| |</p>
<table>
<thead>
<tr>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>16MB hole</td>
</tr>
<tr>
<td>In use</td>
</tr>
<tr>
<td>14MB hole</td>
</tr>
<tr>
<td>In use</td>
</tr>
<tr>
<td>5MB hole</td>
</tr>
<tr>
<td>In use</td>
</tr>
<tr>
<td>30MB hole</td>
</tr>
</tbody>
</table>

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9.9.2 Memory Placement Strategies

Figure 9.16 First-fit, best-fit and worst-fit memory placement strategies (Part 2 of 3).
9.9.2 Memory Placement Strategies

Figure 9.16 First-fit, best-fit and worst-fit memory placement strategies (Part 3 of 3).

(c) Worst-fit strategy
Place process in the largest possible hole in which it will fit.

<table>
<thead>
<tr>
<th>Free Memory List</th>
<th>(Kept in descending order by hole size.)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Start address</strong></td>
<td><strong>Length</strong></td>
</tr>
<tr>
<td>g</td>
<td>30MB</td>
</tr>
<tr>
<td>a</td>
<td>16MB</td>
</tr>
<tr>
<td>c</td>
<td>14MB</td>
</tr>
<tr>
<td>e</td>
<td>5MB</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>0</th>
<th>Operating system</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>16MB hole</td>
</tr>
<tr>
<td>b</td>
<td>In use</td>
</tr>
<tr>
<td>c</td>
<td>14MB hole</td>
</tr>
<tr>
<td>d</td>
<td>In use</td>
</tr>
<tr>
<td>e</td>
<td>5MB hole</td>
</tr>
<tr>
<td>f</td>
<td>In use</td>
</tr>
<tr>
<td>g</td>
<td>30MB hole</td>
</tr>
<tr>
<td>h</td>
<td></td>
</tr>
</tbody>
</table>

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9.10 Multiprogramming with Memory Swapping

• Not necessary to keep inactive processes in memory
  – Swapping
    • Only put currently running process in main memory
      – Others temporarily moved to secondary storage
      – Maximizes available memory
      – Significant overhead when switching processes
  • Better yet: keep several processes in memory at once
    – Less available memory
    – Much faster response times
    – Similar to paging
9.10 Multiprogramming with Memory Swapping

Figure 9.17 Multiprogramming in a swapping system in which only a single process at a time is in main memory.

1. Only one process at a time resides in main memory.
2. That process runs until
   a) I/O is issued,
   b) timer runs out or
c) voluntary termination.
3. System then swaps out the process by copying the swapping area (main memory) to secondary storage.
4. System swaps in next process by reading that process's main memory image into the swapping area. The new process runs until it is eventually swapped out and the next user is swapped in, and so on.