Operating Systems and Concurrency

Memory Management 1

COMP2007

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Remember

Subjects We Will Discuss

Subject	#Lectures	By
Introduction to operating systems/computer design	3	GDM/DM
Processes, process scheduling, threading, ...	4	DM
Concurrency (deadlocks)	6	DM
Memory management, swapping, virtual memory, ...	6	GDM
File Systems, file structures, management, ...	5	GDM
Revision	1	GDM

Table: Course structure

Goals for Today

Overview

1. **Introduction** to memory management
2. **Modelling** of multi-programming
3. Memory management based on **fixed partitioning**

Memory Management

Memory Hierarchies

- Computers typically have memory hierarchies:
  - **Registers**, L1/L2/L3 **cache**
  - **Main memory** (RAM)
  - **Disks**
- "**Higher memory**" is faster, more expensive and volatile, "**lower memory**" is slower, cheaper, and non-volatile
- The operating system provides a **memory abstraction**
- Memory can be seen as one **linear array** of bytes/words

Memory Management

OS Responsibilities

- **Allocate/deallocate** memory when requested by processes
- Keep track of **used/unused** memory
- **Distribute memory** between processes and simulate an **“infinitely large”** memory space
- **Control access** when multiprogramming is applied
- **Transparently** move data from **memory** to **disk** and vice versa

Memory Management

History of Memory Management

- Memory management has **evolved** over time
- **History repeats** itself:
  - Modern **consumer electronics** often require **less complex memory management** approaches
  - Many of the **early ideas underpin** more **modern memory management** approaches (e.g. relocation)

Partitioning

Approaches: Contiguous vs. Non-Contiguous

Figure: contiguous

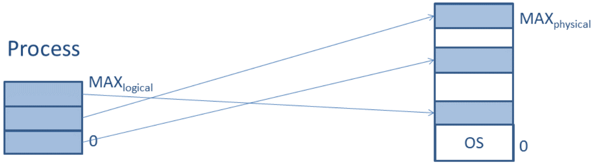


Figure: non-contiguous

Models

Approaches: Contiguous vs. Non-Contiguous

- **Contiguous memory management models** allocate memory in **one single block** without any **holes** or **gaps**
- **Non-contiguous memory management models**:
  - Allocate memory in **multiple blocks**, or **segments**
  - May be **placed anywhere in physical memory** (i.e., not necessarily next to each other)

Partitioning

Contiguous Approaches

- **Mono-programming**: one single partition for user processes
- **Multi-programming** with **fixed partitions**
  - Fixed **equal** sized partitions
  - Fixed **non-equal** sized partitions
- **Multi-programming** with **dynamic partitions**

Mono-Programming

No Memory Abstraction

- Only **one single user process** is in memory/executed at any point in time (no multi-programming)
- A fixed region of memory is allocated to the **OS/kernel**, the remaining memory is reserved for a **single process** (MS-DOS worked this way)
- This process has **direct access** to **physical memory** (i.e. no address translation takes place)

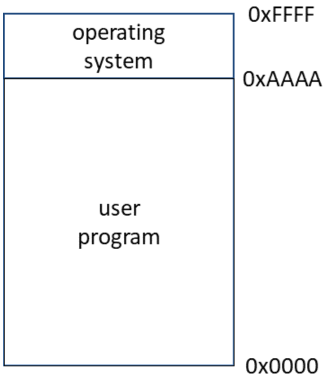


Figure: Mono-programming

Mono-Programming

No Memory Abstraction: Properties

- Every process is allocated **contiguous block of memory**, i.e. it contains no "holes" or "gaps"
- **One process** is allocated the **entire memory space**
- The process is **always located in the same address space**
- **No protection** between different user processes required (one process)
- **Overlays** enable the programmer to use more memory than available (burden on programmer)

Mono-Programming

No Memory Abstraction: Properties (Cont'ed)

- **Shortcomings** of mono-programming:
  - Since a process has **direct access to the physical memory**, it may have **access to OS** memory
  - The operating system can be seen as a process - so we have **two processes anyway**
  - **Low utilisation** of hardware resources (CPU, I/O devices, etc.)
  - **Multiprogramming is expected** on modern machines
- Direct memory access and mono-programming are common in basic **embedded systems** and **modern consumer electronics**, e.g. washing machines, microwaves, car's ECUs, etc.

Mono-Programming

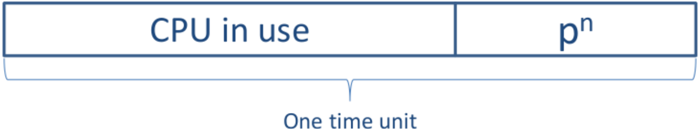
Simulating Multi-Programming

- Simulate multi-programming through **swapping**
  - **Swap process** out to the disk and load a new one (context switches would become **time consuming**)
  - Apply **threads** within the same process (limited to one process)
- Assumption that **multiprogramming** can **improve CPU utilisation**?
  - Intuitively, this is true
  - How do we model this?

Multi-Programming

A Probabilistic Model

- There are n **processes in memory**
- A process spends p percent of its time **waiting for I/O**
- **CPU Utilisation** is calculated as 1 minus the time that all processes are waiting for I/O: e.g., $p = 0.9$ then CPU utilisation = 1 - 0.9 $\Rightarrow$ 0.1 $(1 - p)$
- The probability that **all** n **processes are waiting for I/O** (i.e., the CPU is idle) is p^n, i.e. $p \times p \times p \ldots$
- The **CPU utilisation** is given by $1 - p^n$



Multi-Programming

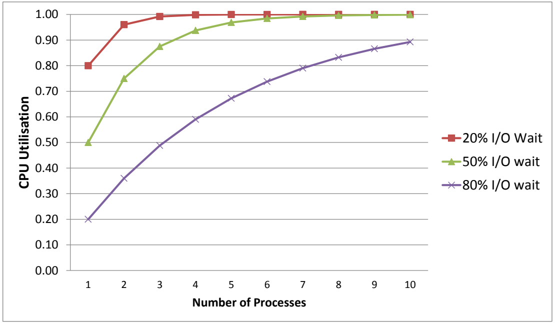
A Probabilistic Model

- With an **I/O wait time of 20%**, almost **100% CPU utilisation** can be achieved with four processes $(1 - 0.2^4)$
- With an **I/O wait time of 90%**, 10 processes can achieve about **65% CPU utilisation** $(1 - 0.9^{10})$
- CPU **utilisation goes up** with the **number of processes** and **down** for **increasing levels of I/O**

Multi-Programming

A Probabilistic Model

	I/O Ratio		
# Processes	0.2	0.5	0.8
1	0.80	0.50	0.20
2	0.96	0.75	0.36
3	0.99	0.88	0.49
4	1.00	0.94	0.59
5	1.00	0.97	0.67
6	1.00	0.98	0.74
7	1.00	0.99	0.79
8	1.00	1.00	0.83
9	1.00	1.00	0.87
10	1.00	1.00	0.89



CPU utilisation as a function of the I/O ratio and the number of processes

Multi-Programming

A Probabilistic Model

- Assume that:
  - A computer has **1 MB** of memory
  - The **OS takes up 200KB**, leaving room for **four 200KB processes**
- Then:
  - If we have an **I/O wait time of 80%**, then we will achieve just under **60% CPU utilisation** $(1-0.8^4)$
  - If we add **1 MB of memory**, it would allows us to run another **five processes**
  - We can achieve about **87% CPU utilisation** $(1-0.8^9)$
  - If we add another **megabyte of memory** (fourteen processes) we will find that the CPU utilisation will increase to **about 96%** $(1-0.8^{14})$

Multi-Programming

A Probabilistic Model

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  - If we add another **megabyte of memory** (fourteen processes) we will find that the CPU utilisation will increase to **about 96%** ($1 - 0.8^{14}$)
- **Multi-programming** does enable to **improve resource utilisation**
  - $\Rightarrow$ memory management should provide support for multi-programming

Multi-Programming

A Probabilistic Model

Caveats:

- This model assumes that **all processes are independent**, this is not true
- More complex models could be built using **queueing theory**, but we can still use this simplistic model to **make approximate predictions**

Partitioning

Fixed Partitions of equal size

- Divide memory into **static**, **contiguous** and **equal sized partitions** that have a **fixed size** and **fixed location**
  - Any process can take **any** (large enough) **partition**
  - Allocation of **fixed equal sized partitions** to processes is **trivial**
  - Very **little overhead** and **simple implementation**
  - The OS keeps a track of which partitions are being **used** and which are **free**

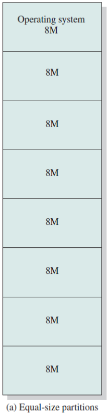

Figure: From Stallings

Partitioning

Fixed Partitions of equal size

- **Disadvantages** of **static equal-sized partitions**:
  - **Low memory utilisation** and **internal fragmentation**: partition may be unnecessarily large
  - **Overlays** must be used if a program does not fit into a partition (burden on programmer)

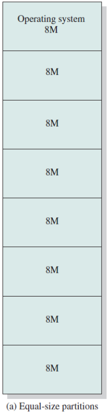

Figure: From Stallings

Partitioning

Fixed Partitions of non-equal size

- Divide memory into **static** and **non-equal sized partitions** that have a **fixed size** and **fixed location**
  - **Reduces internal fragmentation**
  - The **allocation** of processes to partitions must be **carefully considered**

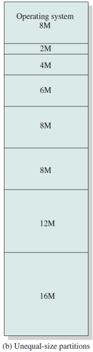

Figure: From Stallings

Partitioning

Fixed Partitions (Allocation Methods)

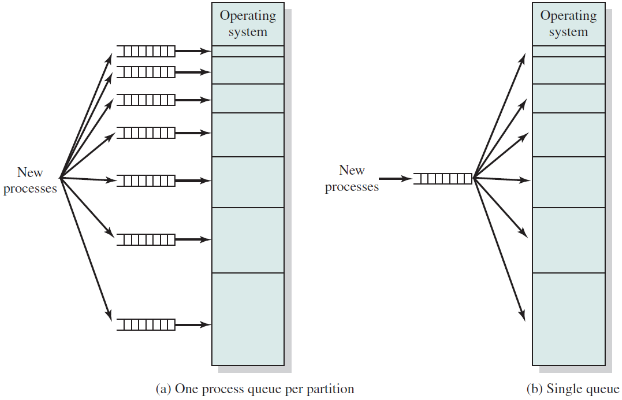

Figure: From Stallings

Partitioning

Fixed Partitions (Allocation Methods)

- One **private queue** per partition:
    - Assigns each process to the **smallest partition** that it would fit in
    - Reduces **internal fragmentation**
    - Can **reduce memory utilisation** (e.g., lots of small jobs result in unused large partitions) and result in **starvation**
- A single **shared queue** for all partitions can allocate small processes to **large partitions** but results in **increased internal fragmentation**

Test Your Understanding

- The compiler allocates **memory addresses**
- What is **the issue**?
- How would you **resolve it**?

Recap

Take-Home Message

- **Mono-programming** and **absolute addressing (no memory abstraction)**
- Why multi-programming: CPU utilisation modelling
- Memory management for **multi-programming**: fixed (non-)equal **partitions**