CS 423
Operating System Design: Virtual Memory Mgmt

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Goals for Today

- **Learning Objective:**
  - Explore historical strategies for memory management

- **Announcements, etc:**
  - MP1 is out! Due **TODAY**
  - Midterm Exam — Wednesday March 6th (in-class)
  - C4 Readings! Due **FRIDAY**

**Reminder:** Please put away devices at the start of class
Storage Hierarchy

CPU Registers

Cache

Memory

Secondary Storage

Performance

Size

32-64 bits

4-128 words

512-16k words
We have limited amounts of fast resources, and large amounts of slower resources…

*How to create the illusion of an abundant fast resource?*
History: Mem Overlays

Used when process memory requirement exceeded the physical memory space
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History: Mem Overlays

- **Main Program**: 0K
- **Overlay Manager**: 5k
- **Overlay Area**: 7k
- **Secondary Storage**:
  - Overlay 1
  - Overlay 2
  - Overlay 3

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Used when process memory requirement exceeded the physical memory space
• Approach: Multiprogramming with fixed memory partitions
• Divides memory into $n$ fixed partitions (possibly unequal)
• Problem?
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• Divides memory into \( n \) fixed partitions (possible unequal)
• Problem?
  • **Internal Fragmentation**

**History: Fixed Partition Allocation**

- Program 1: 4k
- Program 2: 16k
- Program 3: 64k
- Free Space: 128k

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CS 423: Operating Systems Design
History: Fixed Partition Allocation

- Separate input queue for each partition
  - Sorting incoming jobs into separate queues
  - Inefficient utilization of memory
    - when the queue for a large partition is empty but the queue for a small partition is full. Small jobs have to wait to get into memory even though plenty of memory is free.

- One single input queue for all partitions.
  - Allocate a partition where the job fits in.
History: Relocation

- Correct starting address when a program should start in the memory
- Different jobs will run at different addresses
  - When a program is linked, the linker must know at what address the program will begin in memory.
- Enter “Logical addresses”
  - Logical address space, range (0 to max)
  - Physical addresses, Physical address space range (R+0 to R+max) for base value R.
  - User program never sees the real physical addresses
- Relocation register
  - Mapping requires hardware with the base register
History: Relocation Register

CPU Instruction Address

Logical Address
MA

Base Register
BA

Physical Address
MA+BA

Memory

+
History: Variable Partition Allocation

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Monitor | Job 1 | Job 2 | Job 3 | Job 4 | Free

Memory wasted by **External Fragmentation**
History: Storage Placement Strategy

- **Best Fit?**
  - Use the hole whose size is equal to the need, or if none is equal, the hole that is larger but closest in size.
  - Problem: Creates small holes that can’t be used

- **First Fit?**
  - Use the first available hole whose size is sufficient to meet the need.
  - Problem: Creates average size holes.

- **Next Fit?**
  - Minor variation of first fit: search from the last hole used.
  - Problem: slightly worse performance than first fit.

- **Worst Fit?**
  - Use the largest available hole.
  - Problem: Gets rid of large holes making it difficult to run large programs.
Virtual Memory

- Provide user with virtual memory that is as big as user needs
- Store virtual memory on disk
- Cache parts of virtual memory being used in real memory
- Load and store cached virtual memory without user program intervention

ITS AN ILLUSION
Paging

Request Page 3...

Virtual Memory Stored on Disk

Memory

Page Table
VM Frame

1 2 3 4

1 2 3 4

3 1

2

3

4
Paging

Request Page 1…

Memory

Page Table

VM

Frame

Virtual Memory Stored on Disk
Paging

Request Page 6…
Paging

Request Page 2…

Memory

Page Table
VM Frame

Virtual Memory Stored on Disk
Paging

Request Page 8. Swap Page 1 to Disk First…

Virtual Memory Stored on Disk

Memory

Page Table
VM Frame

1 2 3 4
3 1
2 2
6 3
2 4

Virtual Memory Stored on Disk

1 2 3 4 5 6 7 8
Paging

Request Page 8. ... now load Page 8 into Memory.
Note: Virtual Memory also supports shared pages.
Page Mapping Hardware

Virtual Address (P,D)

Page Table

0 0
1 0
0 1
1 1
1 0
1 1

Physical Address (F,D)

Virtual Memory

Contents(P,D)

Physical Memory

Contents(F,D)
Page size 1000
Number of Possible Virtual Pages 1000
Number of Page Frames 8
- Occur when we access a virtual page that is not mapped into any physical page
  - A fault is triggered by hardware
- Page fault handler (in OS’s VM subsystem)
  - Find if there is any free physical page available
    - If no, evict some resident page to disk (swapping space)
  - Allocate a free physical page
  - Load the faulted virtual page to the prepared physical page
  - Modify the page table
Reasoning about Page Tables

- On a 32 bit system we have $2^{32}$ B virtual address space
  - i.e., a 32 bit register can store $2^{32}$ values
- # of pages are $2^n$ (e.g., 512 B, 1 KB, 2 KB, 4 KB...)
- Given a page size, how many pages are needed?
  - e.g., If 4 KB pages ($2^{12}$ B), then $2^{32}/2^{12}=...$
    - $2^{20}$ pages required to represent the address space
- **But!** each page entry takes more than 1 Byte of space to represent.
  - suppose page size is 4 bytes (Why?)
  - $(2\times2) \times 2^{20} = 4$ MB of space required to represent our page table in physical memory.
- What is the consequence of this?