Lecture 5 – Memory Management

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Administration

- **There WILL be a lecture this Friday**
  - **In MFLT, 11:00**
- **Lecture Notes**
  - **Are available at http://www.cs.rhul.ac.uk/~karl**
  - **Formats**
    - **Original Powerpoint 2000 slides**
    - **PDF files, A4 2 slides per page, colour**
    - **Let me know if you would like other formats**

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Objectives

- In this class we will discuss:
  - Why manage memory
  - Memory allocation
  - Virtual memory
  - Paged memory
  - Page replacement algorithms

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The Memory Manager

- In our discussion of processes we have assumed that all concurrent processes fit simultaneously into memory
- This is not typically the case
  - (It may be on desktop or personal systems, but still need a memory manager)
- The memory manager is responsible for:
  - Recording which parts of memory are in use or free
  - Where to allocate memory for new processes
  - How to manage swapping between main memory and disk storage

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Memory Considerations

- **Swapping processes out to disk may be slow**
  - **therefore frequent swaps are inefficient**
- **We aim to keep the CPU busy**
  - **But if in-memory processes have a lot of I/O wait time CPU utilisation may be poor**
- **The longer the I/O wait time, the more processes should be in memory so at least one is ready to run**
  - **Assume processes spend a fraction *p* of time in I/O wait**
  - **There are *n* processes in memory at once**
  - **The probability that <u>all</u> processes are waiting is p^n**
  - **CPU utilisation is $1 - p^n$**

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Examples

- **Assume 100M of RAM, 20M for OS, user programs of 20M each**
  - **If each process spends 80% of its time in I/O wait:**
    - **CPU Utilisation = $1 - 0.8^4 = 59\%$**
  - **What if we had 90% I/O wait?**
    - **CPU Utilisation = $1 - 0.9^4 = 34\%$**
  - **If we add another 100M of memory (at 80% I/O)?**
    - **CPU Utilisation = $1 - 0.9^8 = 86\%$**
  - **If we add another 100M of memory (at 90% I/O)?**
    - **CPU Utilisation = $1 - 0.9^9 = 61\%$**
  - **A further 100M of memory?**
    - **80% I/O = 95%** **90% I/O = 77%**

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Memory Allocation Algorithms

- **The process of allocating main memory to processes**
  - **New processes and existing processes which need additional stack or data space**
- **Fixed size memory allocation**
  - **May not make best use of memory**
  - **Easy to manage**
- **Variable size memory allocation**
  - **Makes better use of memory**
  - **More complicated to manage**
- **In either case we need to track what is allocated and what is free**

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Bit Maps For Memory Allocation

- **Memory is divided in *allocation units***
  - **Can be a few words or several kilobytes**
- **For each allocation unit there is a bit in the map**
  - **The bit is 1 if the unit is occupied, 0 if it is free**
- **Simple way to keep track of memory**
  - **The size of the bit map depends only the size of the memory and the size of the allocation unit**
- **Main problem is searching the bit map for *k* consecutive bits**
  - **These may cross CPU word size boundaries**

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Linked Lists For Memory Allocation

- Maintain a linked list of memory segments
- Each segment is either allocated to a process
- List maintained in address order
- Updating list is straightforward
- Adjacent holes must be merged (to combine them into a single larger hole)
- Therefore it is easier if the list is doubly linked

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Link List Algorithms

- It is easy to find all available holes in the list
  - Which of them should be allocated?
- First Fit
  - Scan the list until one is found sufficiently large
- Next Fit
  - As first fit, but starting from where you left off
- Best Fit
  - Allocate smallest hole that the process fits in
- Worst Fit
  - Allocate largest available hole
- Quick Fit
  - Maintain separate lists for common sizes

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Buddy System For Memory Allocation

- The buddy system takes advantage of computers using binary numbers for addressing
- The manager maintains a list of free blocks of size 1, 2, 4, 8, 16, etc. bytes up to size of memory
- Initially, one hole the size of the whole memory
- To allocate space for a process which needs *x* bytes, find a hole of size 2^k, where $2^{k-1} < x <= 2^k$
- If necessary bigger holes are divided into two holes half as big

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Not Enough Memory

- **The previous discussion assumed that processes would fit into the available memory**
  - **Not always the case**
- **An early solution – Overlays**
  - **Overlay 0 runs first**
  - **When done calls next overlay into memory**
  - **Overlay splitting was done by the programmer**
  - **Performance depended on how well (how modular) the split was**
- **Replaced by the concept of virtual memory**

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Virtual Memory

- The combined size of the program, data, and stack may exceed the amount of physical memory available
- The operating system keeps those parts of the program currently in use in the main memory
- The rest is kept on disk
- Applicable to all the processes in a multi-programming system

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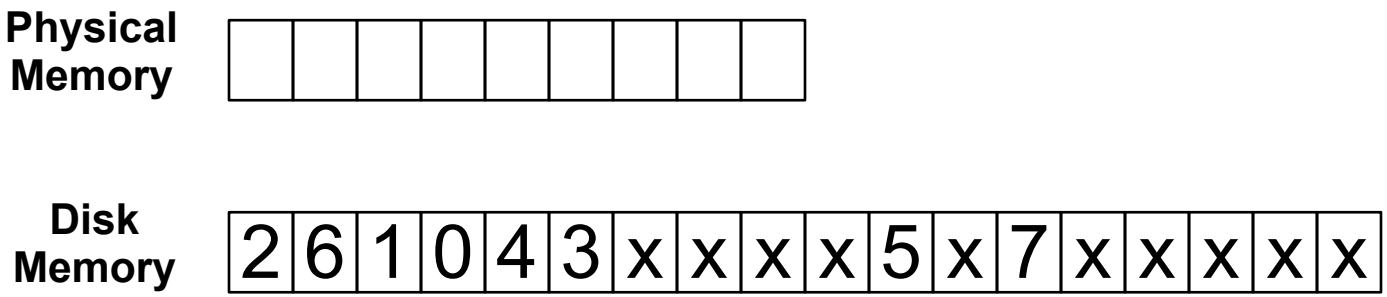
Paging

- Virtual memory systems use the technique Paging
- On a computer there exists a set of memory addresses that programs can produce
- They are called virtual addresses
- They form the virtual address space
- These addresses go to a memory management unit (MMU)
- The MMU hardware maps the virtual addresses onto the physical memory address

Pages and Page Frames

- **The virtual space is divided into fixed sized pages**
- **The physical memory is divided into page frames of the same size**
- **Transfers between the two memories are always in units of a page**



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Page Faults

- Since the virtual memory is bigger than the physical memory not every page is mapped onto a page frame
- A present / absent bit in each entry keeps track of whether a page is mapped or not
- When the program tries to use an unmapped page it causes a trap to the operating system
- This trap is called a page fault
- The OS chooses one page frame, writes the contents back to disk and fetches the called page into the page frame, then updates the MMU map

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Page Tables

- **Page Tables are used for the mapping (virtual address → physical address) in the MMU**
- **The virtual address is split into a virtual page number and offset**
  - **Virtual page number = index into page table**
  - **Offset = last part of (virtual and physical) address**

- **The major issues:**
  - **The page table can be extremely large**
  - **The mapping must be fast**

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Multilevel Page Tables

- To avoid keeping all page tables in memory
  - Uses a top level page table
  - And second level page tables
- The virtual address is now partitioned into:
  - PT1 field (e.g. 10 bits)
  - PT2 field (e.g. 10 bits)
  - Offset field (e.g. 12 bits)
- The PT1 field indexes the top level page table
- There we get the address of the second level page table (indexed by the PT2 field)
- This table contains the physical address

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Associative Memory

- Most programs tend to make a large number of references to a small number of pages
- Therefore computers are equipped with a small hardware device for mapping virtual addresses to physical addresses without using page tables
- This device is called an associative memory
- Has a small number of entries, each about 1 page
- The OS looks up the page in the associative memory first
- If not present then the normal page tables are consulted

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Summary

- **We wish to have multiple processes in memory**
  - **So that at least one is ready to run**
- **Therefore memory must be shared between processes**
  - **Need to keep track of which memory is used by what**
- **We would also like to let processes run that need more memory than physically available**
  - **We use virtual paged memory to achieve this**

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Next Lecture

- **On Friday, MFLT**
- **We will talk about about page replacement algorithms**
- **Lecture Notes: http://www.cs.rhul.ac.uk/~karl**