Memory Managment - Part I

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2022

Motivation

- Main memory is a large array of bytes, each with its own address.
- Program must be brought (from disk) into memory and placed within a process for it to be run.
  - Machine instructions may take memory addresses as arguments, but not disk addresses.
- The CPU fetches instructions from memory according to the value of the program counter.

Basic Hardware

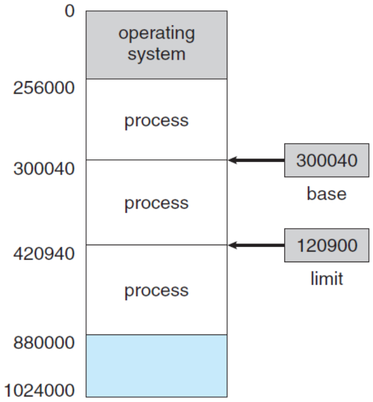
- Main memory and registers are the only storage that the CPU can access directly.
- Register access in one CPU clock (or less)
- Main memory can take many cycles, causing a stall.
- Cache sits between main memory and registers.

Address Protection

- We must protect the OS from access by user processes.
- We must protect user processes from one another.
- This protection is provided by the hardware.
- A separate memory space for each process.
  - Determining the range of legal addresses that the process may access.

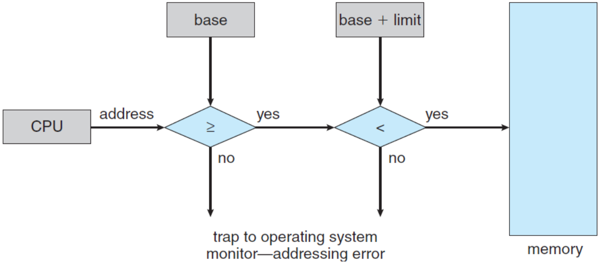
Base and Limit Registers

- A pair of base and limit registers define the logical address space.
- CPU must check every memory access generated in user mode to be sure it is between base and limit for that user.



Hardware Address Protection

- Any attempt by a user program to access OS memory or other users' memory results in a trap to the OS, which treats the attempt as a fatal error.



Address Binding

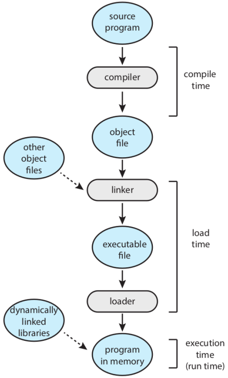
Address Binding

- Programs on disk, ready to be brought into memory to execute form an input queue.
- A user process can reside in any part of the physical memory.

Binding of Instructions and Data to Memory (1/3)

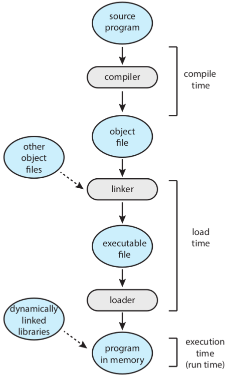
- Address binding of instructions and data to memory addresses can happen at three different stages.

- Compile time: if memory location known a priori, absolute code can be generated.
  - Must recompile code if starting location changes.



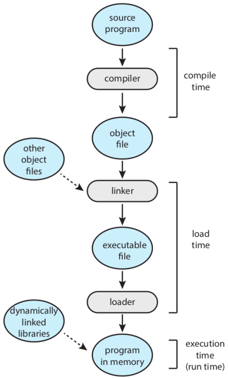
Binding of Instructions and Data to Memory (2/3)

- Load time: must generate relocatable code if memory location is not known at compile time.
  - Final binding is delayed until load time.
  - If the starting address changes, we need only reload the user code to incorporate this changed value.



Binding of Instructions and Data to Memory (3/3)

- Execution time: binding delayed until run time if the process can be moved during its execution from one memory segment to another.
  - Need hardware support

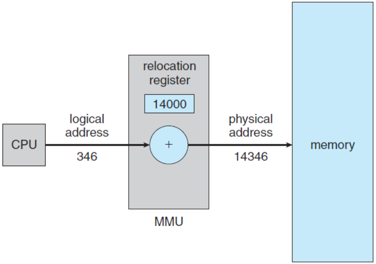


Logical vs. Physical Address Space

- Logical address (virtual address): address generated by the CPU.
  - Logical address space is the set of all logical addresses generated by a program.
- Physical address: address seen by the memory unit.
  - Physical address space is the set of all physical addresses generated by a program.

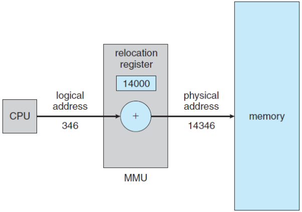
Memory-Management Unit (MMU) (1/2)

- Hardware device that maps virtual to physical address at run time.
- E.g., the value in the relocation register is added to every address generated by a user process at the time it is sent to memory.
    - Base register now called relocation register.



Memory-Management Unit (MMU) (2/2)

- Two different types of addresses:
  - Logical addresses: range 0 to max
  - Physical addresses: range R + 0 to R + max for a base value R
- The user program generates only logical addresses and thinks that the process runs in locations 0 to max.
- These logical addresses must be mapped to physical addresses before they are used.



Dynamic Loading and Linking

Dynamic Loading (1/2)

- Routine/library is not loaded until it is called.
- The main program is loaded into memory and is executed.
- When a routine is needed, if it has not been loaded, the loader loads the desired routine into memory and updates the program's address tables to reflect this change.
- Then control is passed to the newly loaded routine.

Dynamic Loading (2/2)

- Better memory-space utilization; unused routine is never loaded.
- Useful when large amounts of code are needed to handle infrequently occurring cases.
- No special support from the OS is required.
- OS can help by providing libraries to implement dynamic loading.

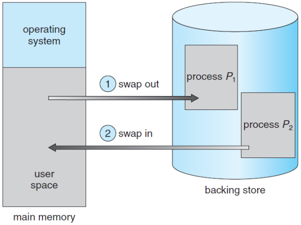
Dynamic Linking

- Static linking: system libraries and program code combined by the loader into the binary program image.
- Dynamic linking: linking postponed until execution time.
  - Useful for shared libraries.

Swapping

Swapping

- A process can be swapped temporarily out of memory to a backing store, and then brought back into memory for continued execution.
- Backing store: fast disk large enough to accommodate copies of all memory images for all users.



Swapping Cost

- Major part of swap time is transfer time; which is proportional to the amount of memory swapped.
- If next processes to be put on CPU is not in memory, need to swap out a process and swap in target process.
- Example:
  - 100MB process swapping to hard disk with transfer rate of 50MB/sec.
  - Swap out time of 2s + swap in of same sized process.
  - Total context switch swapping component time of 4s.

Swapping on Mobile Systems (1/2)

- Not typically supported.
- Flash memory based
  - Small amount of space
  - Limited number of write cycles
  - Poor throughput between flash memory and CPU on mobile platform

Swapping on Mobile Systems (2/2)

- Instead use other methods to free memory if low.
- iOS asks apps to voluntarily relinquish allocated memory.
- Read-only data thrown out and reloaded from flash if needed.
- Failure to free can result in termination.
- Android terminates apps if low free memory, but first writes application state to flash for fast restart.

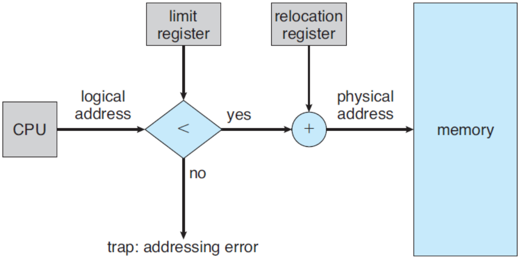
Contiguous Memory Allocation

Contiguous Allocation (1/2)

- Main memory must support both OS and user processes.
- Limited resource, must allocate efficiently.
- Contiguous allocation is an early method.
- Main memory usually into two partitions:
  - Resident OS and user processes memory address.
  - Each process contained in single contiguous section of memory.

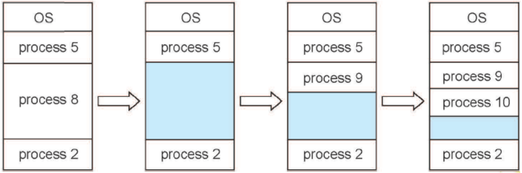
Contiguous Allocation (2/2)

- Relocation registers used to protect user processes from each other, and from changing OS code and data.
  - Base register contains value of smallest physical address.
  - Limit register contains range of logical addresses.
  - MMU maps logical address dynamically.



Multiple-Partition Allocation (1/2)

- Memory is divided into several fixed-sized partitions.
- Each partition may contain exactly one process.
- Degree of multiprogramming limited by number of partitions.
- When a partition is free, a process is selected from the input queue and is loaded into the free partition.



Multiple-Partition Allocation (2/2)

- Variable-partition sizes for efficiency (sized to a given process' needs).
- Hole: block of available memory.
- When a process arrives, it is allocated memory from a hole large enough to accommodate it.
- Process exiting frees its partition, adjacent free partitions combined.
- OS maintains information about: allocated partitions and free partitions (holes).

Dynamic Storage-Allocation Problem

- How to satisfy a request of size n from a list of free holes?
- First-fit: allocate the first hole that is big enough
- Best-fit: allocate the smallest hole that is big enough
  - Must search entire list, unless ordered by size.
  - Produces the smallest leftover hole.
- Worst-fit: allocate the largest hole
  - Must also search entire list.
  - Produces the largest leftover hole.
- First-fit and best-fit better than worst-fit in terms of speed and storage utilization.

Fragmentation

- External fragmentation: total memory space exists to satisfy a request, but it is not contiguous.
- Internal fragmentation: allocated memory may be slightly larger than requested memory; this size difference is memory internal to a partition, but not being used.

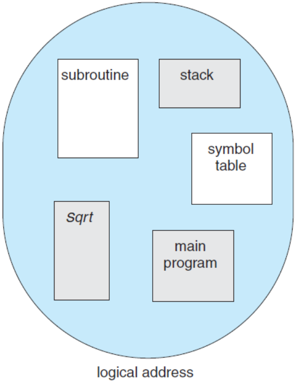
External Fragmentation

- Compaction: a solution to the problem of external fragmentation.
- Shuffle memory contents to place all free memory together in one large block.
- Another possible solution to the external fragmentation problem: permit the logical address space of the processes to be noncontiguous.
- Two techniques:
  - Segmentation
  - Paging

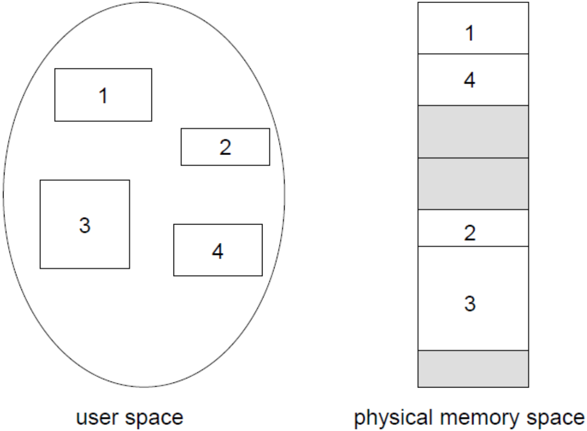
Segmentation

Segmentation

- Memory-management scheme supports user view of memory.
- A program is a collection of segments.
- A segment is a logical unit such as:
  - Main program
  - Procedure
  - Function
  - Object
  - ...



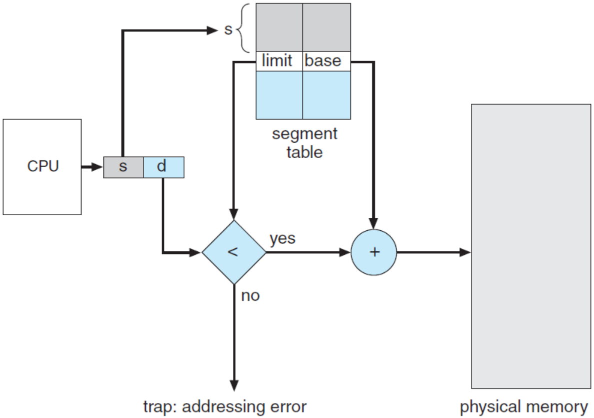
Logical View of Segmentation



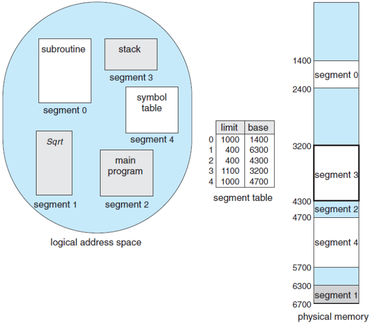
Segmentation Architecture

- Logical address consists of a tuple: $\langle \texttt{segment\_number}, \texttt{offset} \rangle$
- Segment table: maps two-dimensional user-defined addresses into one-dimensional physical address.
- Each table entry has:
  - Base: contains the starting physical address where the segments reside in memory.
  - Limit: specifies the length of the segment.

Segmentation Hardware



Segmentation Example



- A reference to byte 53 of segment 2: $4300 + 53 = 4353$
- A reference to byte 852 of segment 3: $3200 + 852 = 4052$
- A reference to byte 1222 of segment 0: trap to OS

Summary

Summary

- Main memory
- Address protection: base + limit
- Address binding: compile time, load time, execution time
- Logical and physical address, MMU
- Swapping: backing store, swapping cost
- Contiguous memory allocation: partitions, holes, first-fit, best-fit, worst-fit
- External and internal fragmentation: compaction, segmentation, paging
- Segmentation: noncontiguous address, user view of memory

Questions?

Acknowledgements

Some slides were derived from Avi Silberschatz slides.