Basic Memory Management

CS 256/456
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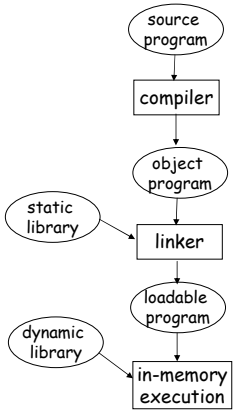
Basic Memory Management

- Program must be brought into memory and placed within a process for it to be run.
- Mono-programming
  - running a single user program at a time
- Need for multi-programming
  - overlapping I/O with CPU
- Memory management task #1:
  - Allocate memory space among user programs (keep track of which parts of memory are currently being used and by whom).

Running a user program

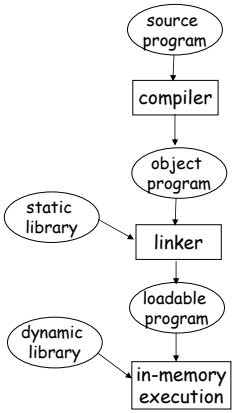
- User programs go through several steps before being run.



Address Binding

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

- Compile time:
  - If memory location known a priori, absolute code can be generated;
  - Must recompile code if starting location changes.
- Load time:
  - Must generate *relocatable* code if memory location is not known at compile time.
- Execution time:
  - Binding delayed until run time.
- Compare them on flexibility & protection & overhead

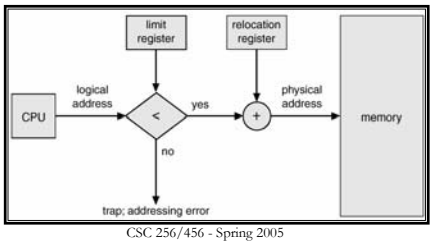


Logical vs. Physical Address Space

- Two different addresses for execution-time addressing binding:
  - *Logical address* – those in the loaded user program; seen directly by the CPU; also referred to as *virtual address*.
  - *Physical address* – address seen by the memory unit.
- Address translation from logical addresses and physical addresses must be (mostly) done in hardware
  - Why?
  - Memory-mapping unit: hardware device that maps virtual to physical address.
- Memory management task #2:
  - address translation and protection.

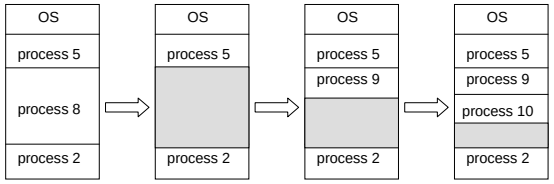
Contiguous Allocation

- Contiguous allocation
  - allocate contiguous memory space for each user program
  - Logical address always starts from 0.
- MMU: address translation and protection
  - Relocation register contains starting physical address;
  - Limit register contains range of logical addresses – each logical address must be less than the limit register.



Contiguous Allocation (Cont.)

- Memory space allocation
  - Available memory blocks of various size are scattered throughout memory.
  - When a process arrives, it is allocated memory from a free block large enough to accommodate it.
  - Operating system maintains information about:
    a) allocated partitions b) free partitions (hole)



Track Free Space

- Keep track of free space:
  - bitmaps
    - 2GB physical memory, 4KB basic allocation unit ⇒ size of the bitmap?
  - free block chain
- Compare them on the space overhead and the performance.

Space Allocation Strategies

How to satisfy a request of size *n* from a list of free memory blocks (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.

Compare them on space 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 minimal allocation unit, but not being used.
- Reduce external fragmentation by compaction
  - Shuffle memory contents to place all free memory together in one large block.
  - Issues:
    - overhead
    - problems with programs currently doing I/O

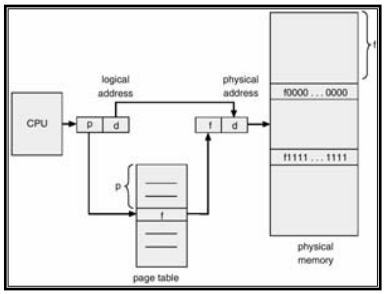
Paging (non-contiguous allocation)

- Physical address space of a process can be noncontiguous; process is allocated physical memory whenever the latter is available.
- Divide physical memory into fixed-sized blocks called **frames** (typically 4KB).
- Divide logical memory into blocks of same size called **pages**.
- To run a program of size *n* pages, need to find *n* free frames and load program.
- Internal fragmentation.

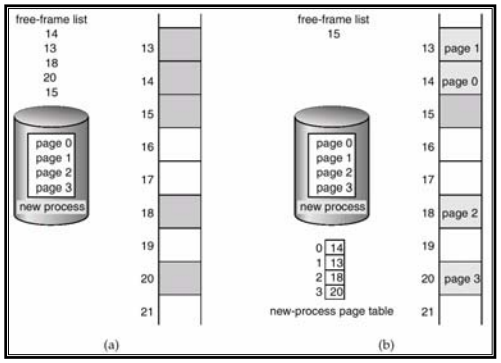
Paging: Address Translation Scheme

A logical address is divided into:

- *Page number (p)* – used as an index into a *page table* which contains base address of each page in physical memory.
- *Page offset (d)* – the offset address with each page/frame. The same for both logical address and physical address.



Load A User Program: An Example

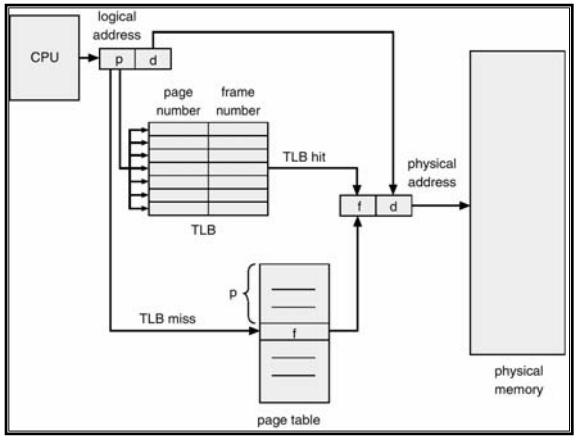


Before loading After loading

Implementation of Page Table

- Page table is (usually) kept in main memory
  - why not in registers?
  - kernel or user space?
- Hardware MMU:
  - *Page-table base register* points to the page table.
  - *Page-table length register* indicates size of the page table.
- In this scheme every data/instruction access requires two memory accesses. One for the page table and one for the data/instruction.
- Solution:
  - A special fast-lookup hardware cache called *translation look-aside buffers (TLBs)*

Paging MMU With TLB



Effective Access Time

- Assume
  - TLB Lookup = 1 ns
  - Memory cycle time is 100 ns
- Hit ratio (α)– percentage of times that a page number is found in the TLB.
- Effective memory Access Time (EAT)

$$EAT = 101 \times \alpha + 201 \times (1 - \alpha)$$

Memory Protection

- How is memory protection achieved?
  - protecting the page tables in the kernel memory space.
- Parts of the logical address space may not be mapped
  - *Valid-invalid* bit attached to each entry in the page table:
    - "valid" indicates that the associated page is in the process' logical address space, and is thus a legal page.
    - "invalid" indicates that the page is not in the process' logical address space.
  - Software exception if attempting to access an invalid page.

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