

## Memory Management - 1

## Memory Management Unit

- memory is a critical resource
  - efficient use
  - sharing
- memory management unit

### Memory Management Unit: Main Aims

- relocation
  - physical memory assigned to process may be different during each run
  - physical and absolute addresses should not be used
- protection
  - process cannot access another process' memory area
- sharing
  - code / data sharing

### Memory Management Unit: Main Aims

- logical organization
  - in traditional systems: linear address space (0→max)
  - programs: written as modules / procedures
- physical organization
  - transfers among main memory and secondary storage

## Memory Management Functions

- naming (N)
  - user defined variable → actual location referenced
- memory (M)
  - variables → physical adres
- contents (C)
  - obtain contents of memory locations from address

user variable  $\xrightarrow{N}$  system variable  $\xrightarrow{M}$  memory address  $\xrightarrow{C}$  value

## Memory Management Functions

- functions performed at different times
  - N during link phase
  - M during load phase
  - C changes during assignment to memory

## Linkers and Loaders

- aim: binding abstract names to concrete names
- actions performed:
  - symbol resolution
  - relocation
  - program loading

## Symbol Resolution

- references from one subprogram to another made through symbols
- linker resolves symbol
  - notes location assigned to called function
  - patch caller's object code
  - e.g. "main" function calls "sqrt" function defined in math library
    - linker finds location assigned to "sqrt"
    - modifies "main" object code so call instruction references location

## Relocation

- compilers and assemblers generate object code starting at 0
  - all subprograms loaded at non-overlapping locations
- linker creates linked output starting at 0
  - subprograms relocated to locations within complete program
- loader picks actual load address
  - linked program relocated as a whole

## Program Loading

- loader copies program from secondary storage into main memory
  - allocate storage
  - copy data from disk to memory
  - set protection bits
  - arrange virtual memory maps

## Final Address Binding

- before OS
  - each program had entire memory
  - assembled and linked for fixed memory addresses
- with OS
  - programs share memory with OS and other programs
  - actual addresses not known until program is loaded
  - final address binding is deferred to load time

## Dividing Work

- linker does part of address binding
  - assigns relative addresses within each program
- loader does final relocation step
  - assigns actual addresses

## Multiple Programs

- computers run more than one program
  - frequently copies of same program
  - some parts of program are same among all running instances
  - other parts unique to each instance
- separate same and different parts
  - use single copy of same parts

## Linking Multiple Sections

- compilers and linkers generate object code in multiple sections
  - read-only code section
  - writable data section
- linker combines all
  - all read-only codes together
  - all writable data together

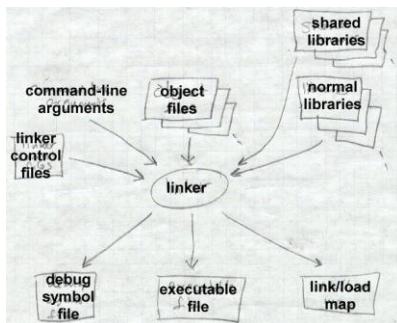
## Shared Libraries

- different programs share a lot of common code
  - library routines
    - e.g. printf, fopen in C
- modern systems provide shared libraries
  - all programs share same copy of library
    - improves runtime performance
    - saves disk/memory space

## Two-Pass Linking

- input: set of object files
  - each input file contains a set of segments
  - libraries
  - command files
- output: executable object file
  - load map, debugger symbols, ...

## Linker Input and Output



## Symbol Table

- each input file contains a symbol table
- exported symbols
  - defined within file for use in other files
  - names of routines within file that may be called from elsewhere
- imported symbols
  - used in file but defined elsewhere
  - names of routines called but not present in file

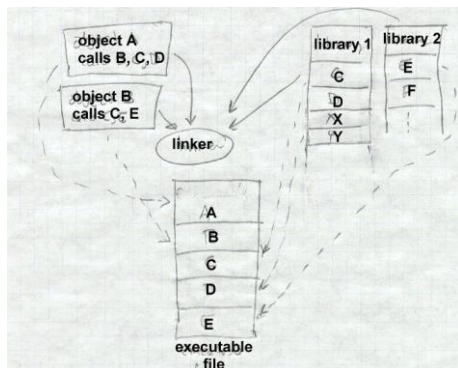
## First Pass

- scan input files
  - find size of segments
  - collect definition and references of all symbols
- create:
  - segment table: all segments defined in all input files
  - symbol table: all imported and exported symbols

## Second Pass

- use data from first pass:
  - assign numeric locations to symbols
  - determine size and location of segments in the output address space
  - substitute numeric addresses for symbol references
  - adjust memory addresses in code to reflect relocated segment addresses
  - after all regular input files processed, if any imported names remain undefined
    - run through libraries
    - link required libraries

### Linking Libraries



## Allocating Memory

- memory allocation: allocate memory to program
- not required to have whole program in memory
  - load as required
  - more efficient memory usage
  - more costly

## Static / Dynamic Memory Allocation

- programs with absolute addresses
  - give absolute addresses when writing program (M and N together)
- symbolic programming
  - compiler / linker generates memory addresses from symbolic names

## Static / Dynamic Memory Allocation

- |  |   |  |
|--|---|--|
| static:<br>addresses<br>fixed<br>when loading<br>into memory | { | – memory allocation: <ul style="list-style-type: none"> <li>• generate fixed absolute addresses             <ul style="list-style-type: none"> <li>– linking and loading together with compiling → fast)</li> </ul> </li> <li>• use relocatable addresses             <ul style="list-style-type: none"> <li>– loader determines absolute addresses</li> <li>– addresses remain fixed during execution</li> <li>– code remains constant in memory after loading</li> </ul> </li> </ul> |
| dynamic  | { | <ul style="list-style-type: none"> <li>• use relocatable addresses             <ul style="list-style-type: none"> <li>– gets absolute address when referenced</li> </ul> </li> </ul>   |

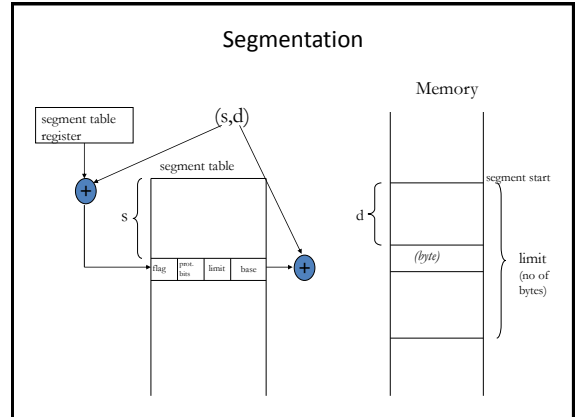
modern operating systems use  
(segmentation + paging)

## Segmentation

- programs composed of logical parts
- segmentation reflects logical structure of programs
- program divided into segments
  - segment sizes may be different
  - e.g.
    - data area as a segment
    - a procedure / function as a segment
- $$\text{address} = \text{segment start address} + \text{offset in segment}$$
- program segments may be in different memory locations
  - may be on disk too (loaded when required)
  - address calculation requires special hardware

## Segmentation

- address: (s,d)
  - s: segment name
  - d: offset
- each process has a segment table
  - flag: is segment in memory?
  - base address of segment
  - segment length (limit)
  - protection bits
- starting address of segment table kept in a register



## Segmentation

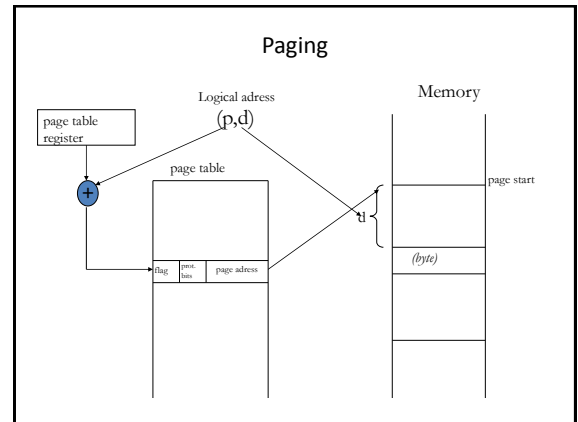
- check flag before address calculation
- “segment fault” if not in memory
  - interrupt
- segment loaded into memory
  - if no room in memory, remove another segment from memory
    - segment sizes may be different → fragmentation in memory
  - segment table register points to start of segment table of running process

## Paging

- memory divided into equal sized blocks
  - page frame
- program and data also divided into same sized logical blocks
  - page
- a page is loaded into a page frame
- address: (p,d)
  - p: page name
  - d: offset in page

## Paging

- info on page in page table
- page table entry:
  - flag: is page in memory ?
  - page location (memory/secondary storage address)
  - protection bits
- page table register
  - points to start of page table of running process



## Paging

- check flag before address calculation
  - “page fault” if not in memory
  - fetch page from secondary storage
- check protection bits
- operating system keeps list of free page frames
- main memory  $\leftrightarrow$  secondary storage page transfers = **page traffic**

## Paging

- memory allocation easier than in segmentation
  - fixed page size
- problem: page size may be smaller than a program logical block
  - more than one page
  - fragmentation

## Paging

- external fragmentation
  - empty spaces between blocks
- internal fragmentation
  - empty spaces within blocks
- no external fragmentation with paging

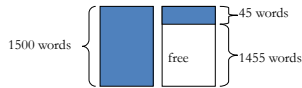
## Paging

- criteria for page size selection:
    - page traffic
    - internal fragmentation
  - large page sizes
    - easier main memory  $\leftrightarrow$  secondary storage transfers
    - process has less pages  $\Rightarrow$  less page traffic
    - more internal fragmentation
  - small page sizes
    - more page traffic
    - less internal fragmentation
- Result:** balance internal fragmentation and page traffic costs

## Paging

- Example (internal fragmentation): process size 1545 words

– if page size = 1500 words: process has 2 pages

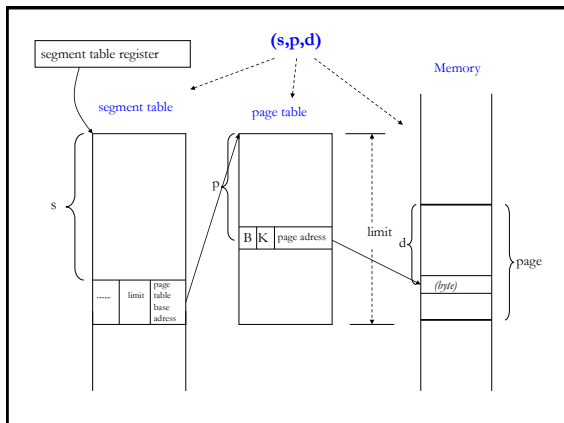


– if page size = 500 words: process has 4 pages



## Segmentation with Paging

- segments divided into pages
- each segment has page table
- address: (s,p,d)
  - s: segment name
  - p: page table access info for segment
  - d: offset in page



## Segmentation with Paging

- 3 step address calculation
- time consuming even when hardware used
  - associative registers used  $\Rightarrow$  **TLB (Translation Lookaside Buffer)**

## Segmentation with Paging

- has advantages of both segmentation and paging
- easy memory allocation due to paging
- no external fragmentation
- through TLB use, address calculation times become acceptable