OPERATING SYSTEMS

MEMORY MANAGEMENT

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OPERATING SYSTEM
Memory Management

What Is In This Chapter?

Just as processes share the CPU, they also share physical memory. This chapter is about mechanisms for doing that sharing.

MEMORY MANAGEMENT

Just as processes share the CPU, they also share physical memory. This section is about mechanisms for doing that sharing.

EXAMPLE OF MEMORY USAGE:

Calculation of an **effective address**

- Fetch from instruction
- Use index offset

Example: (Here index is a pointer to an address)

```
loop:
        load            register, index
        add             42, register
        store           register, index
        inc             index
        skip_equal      index, final_address
        branch   loop
          ... continue ....
```

MEMORY MANAGEMENT

Definitions

- The concept of a logical *address space* that is bound to a separate *physical address space* is central to proper memory management.

  - **Logical address** – generated by the CPU; also referred to as *virtual address*
  - **Physical address** – address seen by the memory unit

- Logical and physical addresses are the same in compile-time and load-time address-binding schemes; logical (virtual) and physical addresses differ in execution-time address-binding scheme

MEMORY MANAGEMENT

Definitions

Relocatable Means that the program image can reside anywhere in physical memory.

Binding Programs need real memory in which to reside. When is the location of that real memory determined?

- This is called **mapping** logical to physical addresses.
- This binding can be done at compile/link time. Converts symbolic to relocatable. Data used within compiled source is offset within object module.

Compiler: If it's known where the program will reside, then absolute code is generated. Otherwise compiler produces relocatable code.

Load: Binds relocatable to physical. Can find best physical location.

Execution: The code can be moved around during execution. Means flexible virtual mapping.

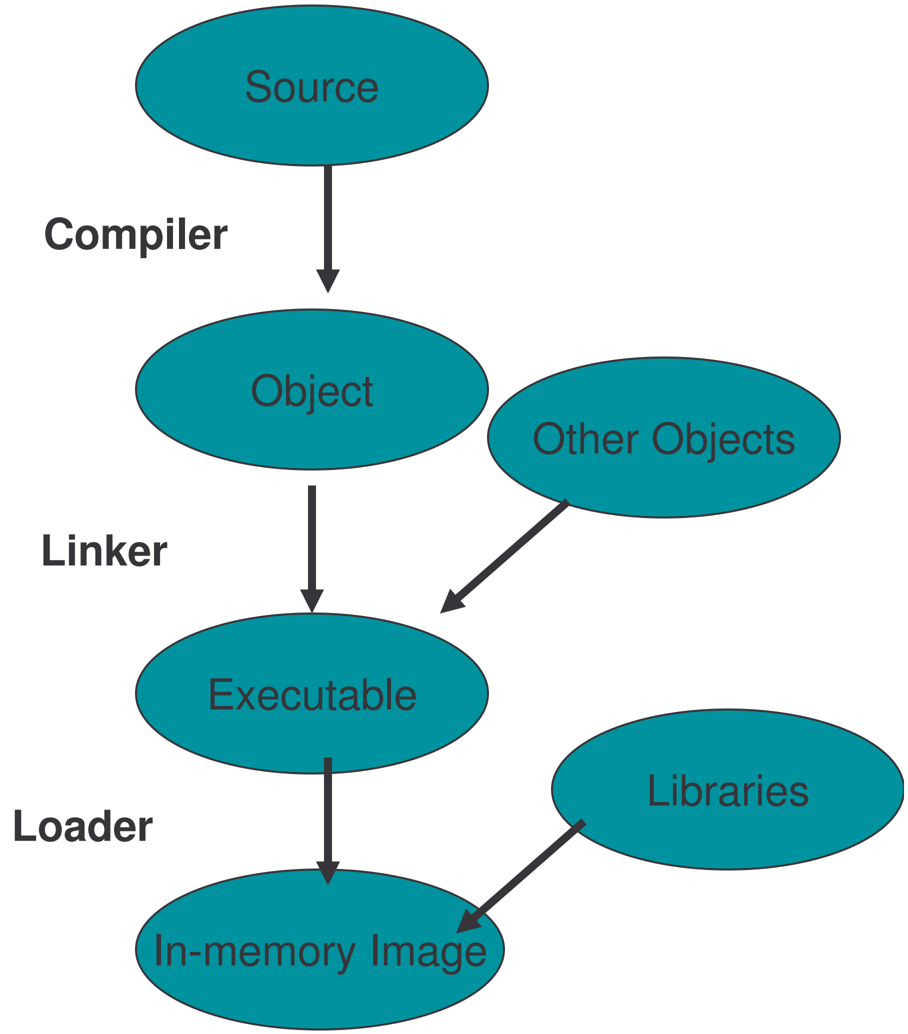
MEMORY MANAGEMENT

Binding Logical To Physical

This binding can be done at compile/link time. Converts symbolic to relocatable. Data used within compiled source is offset within object module.

- Can be done at load time. Binds relocatable to physical.
- Can be done at run time. Implies that the code can be moved around during execution.

The next example shows how a compiler and linker actually determine the locations of these effective addresses.



Binding Logical To Physical

```
void      main()
    {
    printf( "Hello, from main\n" );
    b();
}
voidb()
    {
    printf( "Hello, from 'b'\n" );
}
```

MEMORY MANAGEMENT

Binding Logical To Physical

ASSEMBLY LANGUAGE LISTING

```
000000B0: 6BC23FD9   stw        %r2,-20(%sp          ; main()
000000B4  37DE0080   ldo        64(%sp),%sp
000000B8  E8200000   bl         0x000000C0,%r1       ; get current addr=BC
000000BC  D4201C1E    depi      0,31,2,%r1
000000C0  34213E81   ldo        -192(%r1),%r1        ; get code start area
000000C4  E8400028   bl         0x000000E0,%r2       ; call printf
000000C8  B43A0040    addi      32,%r1,%r26          ; calc. String loc.
000000CC  E8400040   bl         0x000000F4,%r2       ; call b
000000D0  6BC23FD9    stw       %r2,-20(%sp)         ; store return addr
000000D4  4BC23F59   ldw        -84(%sp),%r2
000000D8  E840C000   bv         %r0(%r2)             ; return from main
000000DC  37DE3F81    ldo       -64(%sp),%sp
                                                              STUB(S) FROM LINE 6
000000E0: E8200000   bl         0x000000E8,%r1
000000E4  28200000    addil     L%0,%r1
000000E8: E020E002   be,n       0x00000000(%sr7,%r1)

000000EC  08000240   nop                                                void    b()
000000F0: 6BC23FD9   stw        %r2,-20(%sp)
000000F4: 37DE0080   ldo        64(%sp),%sp
000000F8  E8200000   bl         0x00000100,%r1         ; get current addr=F8
000000FC  D4201C1E    depi      0,31,2,%r1
00000100  34213E01   ldo        -256(%r1),%r1        ; get code start area
00000104  E85F1FAD   bl         0x000000E0,%r2       ; call printf
00000108  B43A0010    addi      8,%r1,%r26
0000010C  4BC23F59   ldw        -84(%sp),%r2
00000110  E840C000   bv         %r0(%r2)             ; return from b
00000114  37DE3F81    ldo       -64(%sp),%sp
```

MEMORY MANAGEMENT

Binding Logical To Physical

EXECUTABLE IS DISASSEMBLED HERE

```
00002000  0009000F                                      ; . . . .
00002004  08000240                                      ; . . . @
00002008  48656C6C                                      ; H e l l
0000200C  6F2C2066                                      ; o ,   f
00002010  726F6D20                                      ; r o m
00002014  620A0001                                      ; b . . .
00002018  48656C6C                                      ; H e l l
0000201C  6F2C2066                                      ; o ,   f
00002020  726F6D20                                      ; r o m
00002024  6D61696E                                      ; m a i n
000020B0  6BC23FD9  stw     %r2,-20(%sp)                ; main
000020B4  37DE0080  ldo     64(%sp),%sp
000020B8  E8200000  bl      0x000020C0,%r1
000020BC  D4201C1E  depi    0,31,2,%r1
000020C0  34213E81  ldo     -192(%r1),%r1
000020C4  E84017AC  bl      0x00003CA0,%r2
000020C8  B43A0040  addi    32,%r1,%r26
000020CC  E8400040  bl      0x000020F4,%r2
000020D0  6BC23FD9  stw     %r2,-20(%sp)
000020D4  4BC23F59  ldw     -84(%sp),%r2
000020D8  E840C000  bv      %r0(%r2)
000020DC  37DE3F81  ldo     -64(%sp),%sp
000020E0  E8200000  bl      0x000020E8,%r1               ; stub
000020E4  28203000  addil   L%6144,%r1
000020E8  E020E772  be,n    0x000003B8(%sr7,%r1)
000020EC  08000240  nop
```

MEMORY MANAGEMENT

Binding Logical To Physical

EXECUTABLE IS DISASSEMBLED HERE

```
000020F0  6BC23FD9  stw       %r2,-20(%sp)          ; b
000020F4  37DE0080  ldo       64(%sp),%sp
000020F8  E8200000  bl        0x00002100,%r1
000020FC  D4201C1E  depi      0,31,2,%r1
00002100  34213E01  ldo       -256(%r1),%r1
00002104  E840172C  bl        0x00003CA0,%r2
00002108  B43A0010  addi      8,%r1,%r26
0000210C  4BC23F59  ldw       -84(%sp),%r2
00002110  E840C000  bv        %r0(%r2)
00002114  37DE3F81  ldo       -64(%sp),%sp

00003CA0  6BC23FD9  stw       %r2,-20(%sp)          ; printf
00003CA4  37DE0080  ldo       64(%sp),%sp
00003CA8  6BDA3F39  stw       %r26,-100(%sp)
00003CAC  2B7CFFFF  addil     L%-26624,%dp
00003CB0  6BD93F31  stw       %r25,-104(%sp)
00003CB4  343301A8  ldo       212(%r1),%r19
00003CB8  6BD83F29  stw       %r24,-108(%sp)
00003CBC  37D93F39  ldo       -100(%sp),%r25
00003CC0  6BD73F21  stw       %r23,-112(%sp)
00003CC4  4A730009  ldw       -8188(%r19),%r19
00003CC8  B67700D0  addi      104,%r19,%r23
00003CCC  E8400878  bl        0x00004110,%r2
00003CD0  08000258  copy      %r0,%r24
00003CD4  4BC23F59  ldw       -84(%sp),%r2
00003CD8  E840C000  bv        %r0(%r2)
00003CDC  37DE3F81  ldo       -64(%sp),%sp
00003CE0  E8200000  bl        0x00003CE8,%r1
00003CE8  E020E852  be,n      0x00000428(%sr7,%r1)
```

MEMORY MANAGEMENT

More Definitions

Dynamic loading

+ Routine is not loaded until it is called
+ 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 - implemented through program design.

Dynamic Linking

+ Linking postponed until execution time.
+ Small piece of code, *stub*, used to locate the appropriate memory-resident library routine.
+ Stub replaces itself with the address of the routine, and executes the routine.
+ Operating system needed to check if routine is in processes' memory address.
+ Dynamic linking is particularly useful for libraries.

Memory Management Performs the above operations. Usually requires hardware support.

MEMORY MANAGEMENT

SINGLE PARTITION ALLOCATION

BARE MACHINE:

- No protection, no utilities, no overhead.
- This is the simplest form of memory management.
- Used by hardware diagnostics, by system boot code, real time/dedicated systems.
- logical == physical
- User can have complete control. Commensurably, the operating system has none.

DEFINITION OF PARTITIONS:

- Division of physical memory into fixed sized regions. (Allows addresses spaces to be distinct = one user can't muck with another user, or the system.)
- The number of partitions determines the level of multiprogramming. Partition is given to a process when it's scheduled.
- Protection around each partition determined by
  bounds (upper, lower)
  base / limit.
- These limits are done in hardware.

MEMORY MANAGEMENT

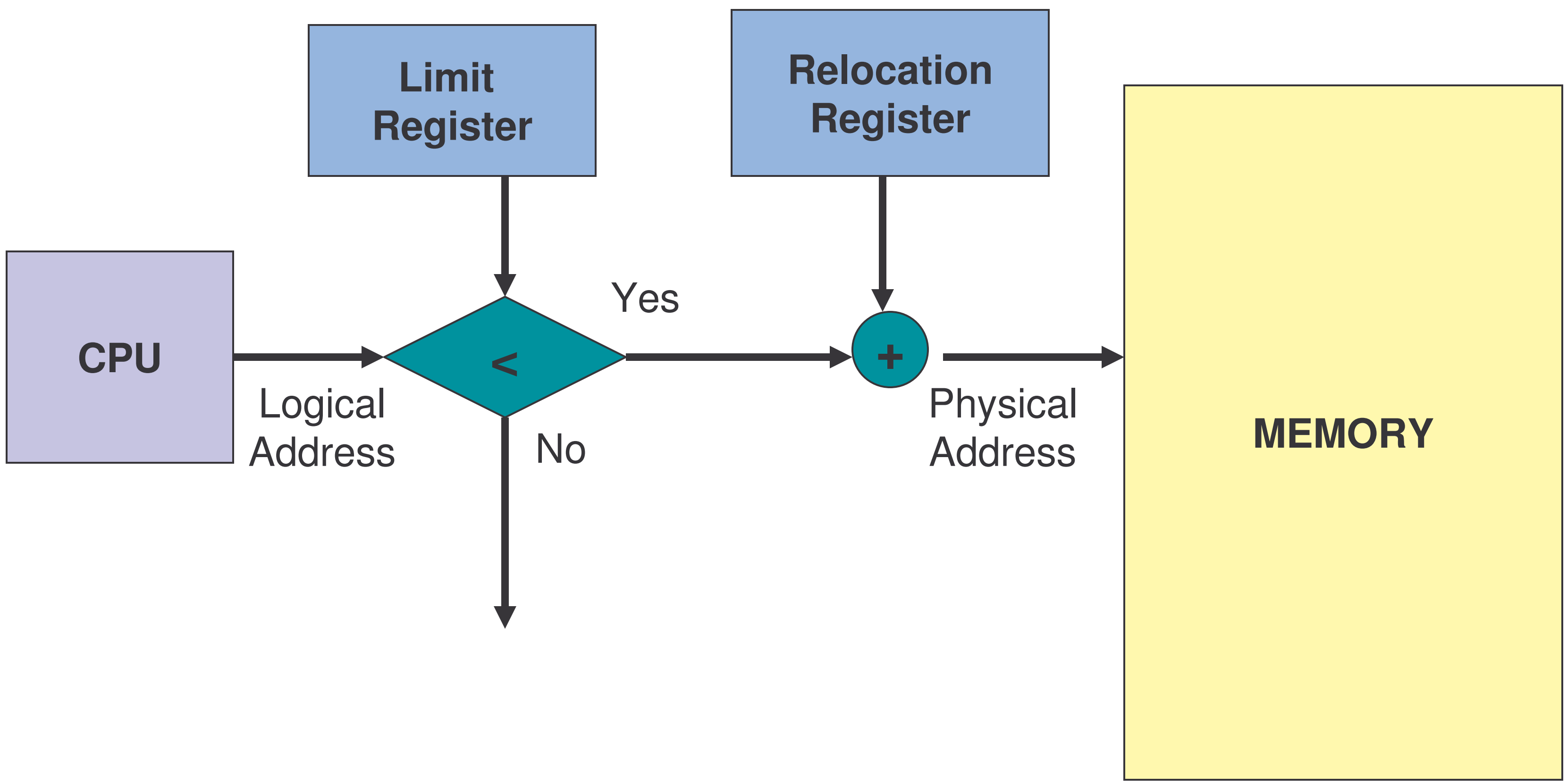
SINGLE PARTITION ALLOCATION

RESIDENT MONITOR:

- Primitive Operating System.
- Usually in low memory where interrupt vectors are placed.
- Must check each memory reference against fence (fixed or variable) in hardware or register. If user generated address < fence, then illegal.
- User program starts at fence -> fixed for duration of execution. Then user code has fence address built in. But only works for static-sized monitor.
- If monitor can change in size, start user at high end and move back, OR use fence as base register that requires address binding at execution time. Add base register to every generated user address.
- Isolate user from physical address space using logical address space.
- Concept of "mapping addresses” shown on next slide.

MEMORY MANAGEMENT

SINGLE PARTITION ALLOCATION



MEMORY MANAGEMENT

CONTIGUOUS ALLOCATION

All pages for a process are allocated together in one chunk.

JOB SCHEDULING

- Must take into account who wants to run, the memory needs, and partition availability. (This is a combination of short/medium term scheduling.)
- Sequence of events:
- In an empty memory slot, load a program
- THEN it can compete for CPU time.
- Upon job completion, the partition becomes available.
- Can determine memory size required (either user specified or "automatically").

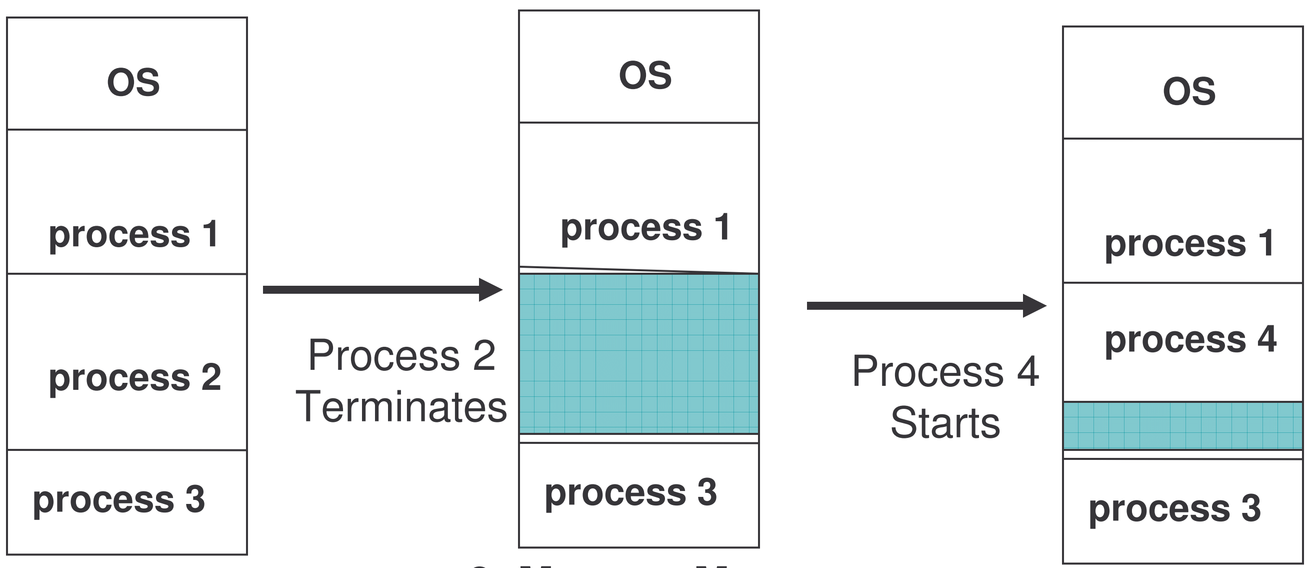
MEMORY MANAGEMENT

CONTIGUOUS ALLOCATION

DYNAMIC STORAGE

- (Variable sized holes in memory allocated on need.)
- Operating System keeps table of this memory - space allocated based on table.
- Adjacent freed space merged to get largest holes - buddy system.

ALLOCATION PRODUCES HOLES



MEMORY MANAGEMENT

CONTIGUOUS ALLOCATION

HOW DO YOU ALLOCATE MEMORY TO NEW PROCESSES?

First fit - allocate the first hole that's big enough.
Best fit - allocate smallest hole that's big enough.
Worst fit - allocate largest hole.

(First fit is fastest, worst fit has lowest memory utilization.)

- Avoid small holes (**external fragmentation**). This occurs when there are many small pieces of free memory.
- What should be the minimum size allocated, allocated in what chunk size?
- Want to also avoid **internal fragmentation.** This is when memory is handed out in some fixed way (power of 2 for instance) and requesting program doesn't use it all.

MEMORY MANAGEMENT

LONG TERM SCHEDULING

If a job doesn't fit in memory, the scheduler can

wait for memory

skip to next job and see if it fits.

What are the pros and cons of each of these?

There's little or no internal fragmentation (the process uses the memory given to it - the size given to it will be a page.)

But there can be a great deal of external fragmentation. This is because the memory is constantly being handed cycled between the process and free.

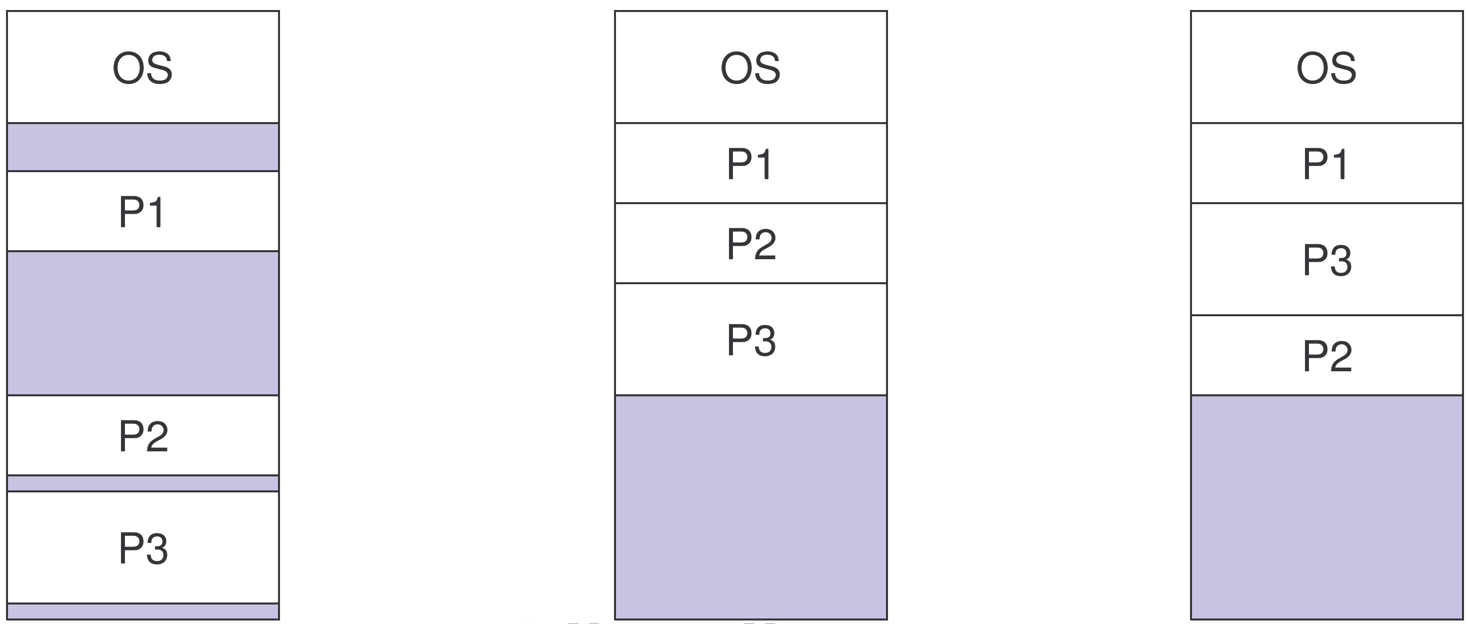
MEMORY MANAGEMENT COMPACTION

Trying to move free memory to one large block.

Only possible if programs linked with dynamic relocation (base and limit.)

There are many ways to move programs in memory.

Swapping: if using static relocation, code/data must return to same place. But if dynamic, can reenter at more advantageous memory.



MEMORY MANAGEMENT

PAGING

New Concept!!

- Logical address space of a process can be noncontiguous; process is allocated physical memory whenever that memory is available and the program needs it.
- Divide **physical** memory into fixed-sized blocks called **frames** (size is power of 2, between 512 bytes and 8192 bytes).
- Divide **logical** memory into blocks of same size called **pages**.
- Keep track of all free frames.
- To run a program of size *n* pages, need to find *n* free frames and load program.
- Set up a page table to translate logical to physical addresses.
- Internal fragmentation.

MEMORY MANAGEMENT

PAGING

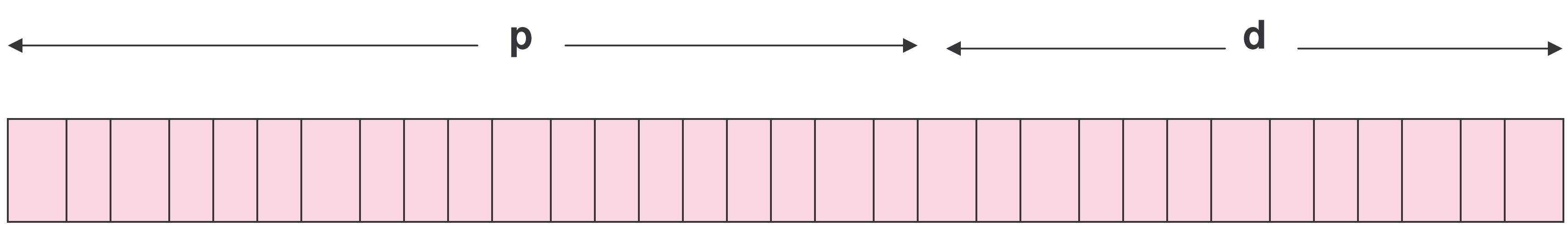
Address Translation Scheme

Address generated by the CPU 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)* – combined with base address to define the physical memory address that is sent to the memory unit.

4096 bytes = 2^12 – it requires 12 bits to contain the Page offset



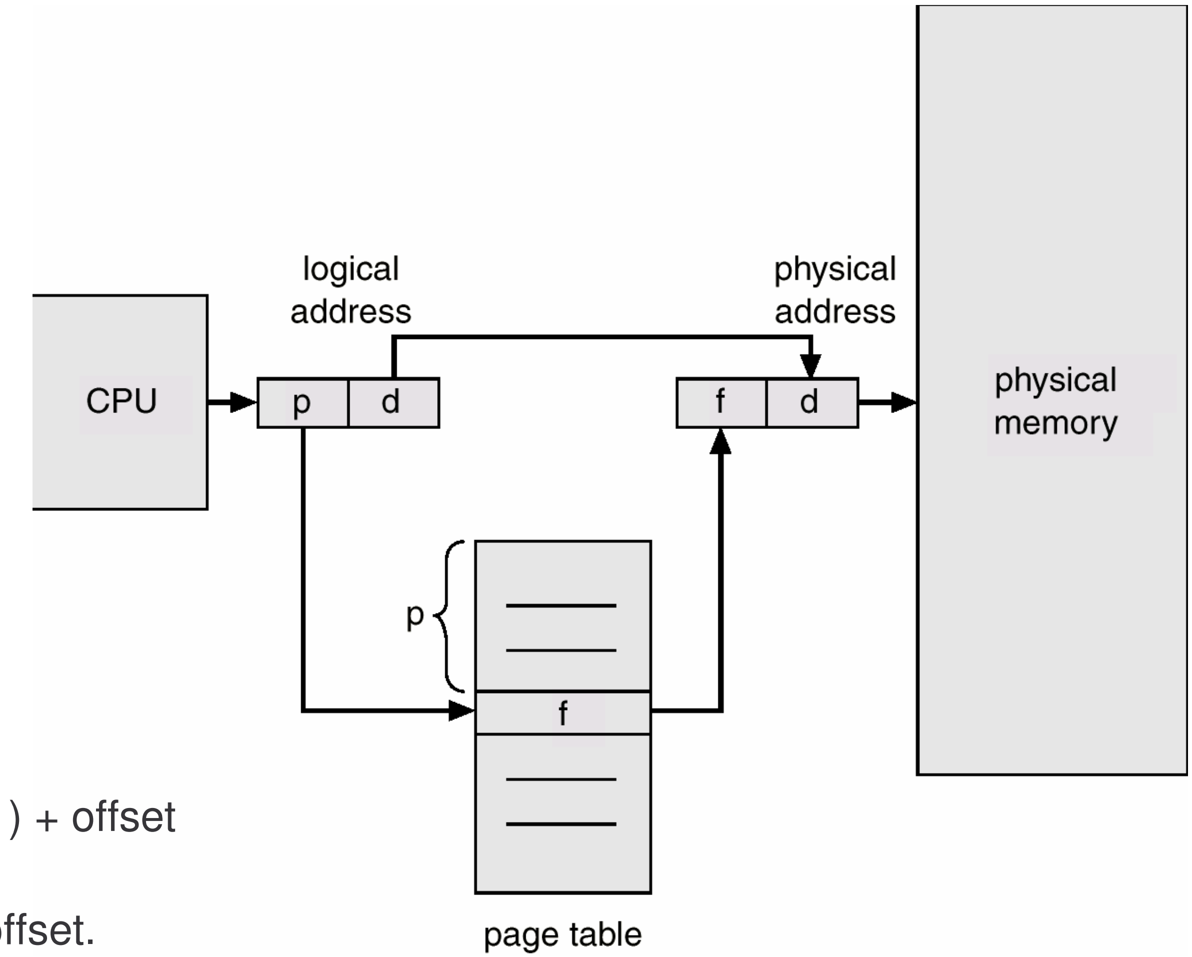
MEMORY MANAGEMENT

PAGING

Permits a program's memory to be physically noncontiguous so it can be allocated from wherever available. This avoids fragmentation and compaction.

Frames = physical blocks
Pages = logical blocks

Size of frames/pages is defined by hardware (power of 2 to ease calculations)



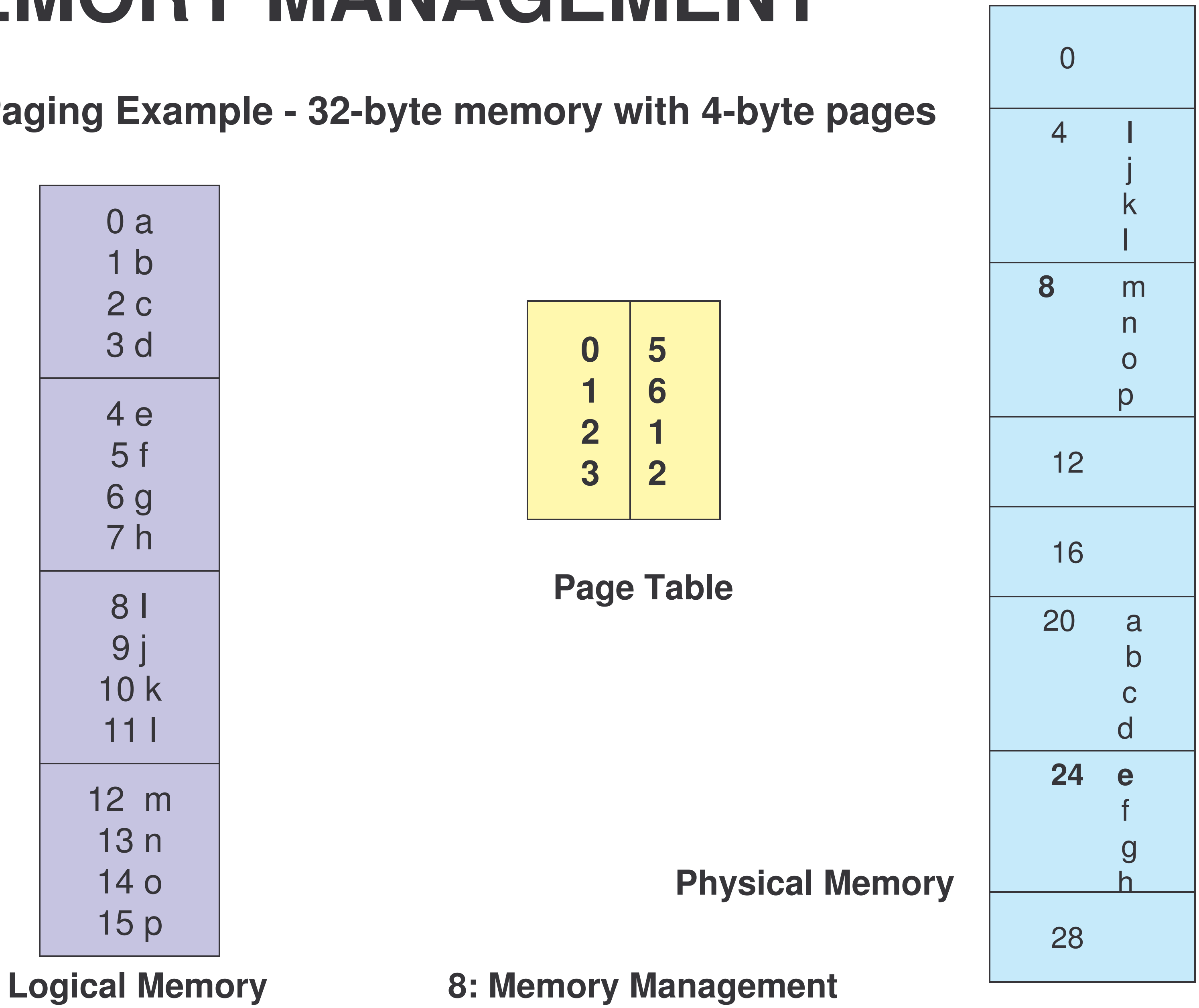
HARDWARE

An address is determined by:

page number (index into table) + offset
---> mapping into --->
base address (from table) + offset.

MEMORY MANAGEMENT

Paging Example - 32-byte memory with 4-byte pages



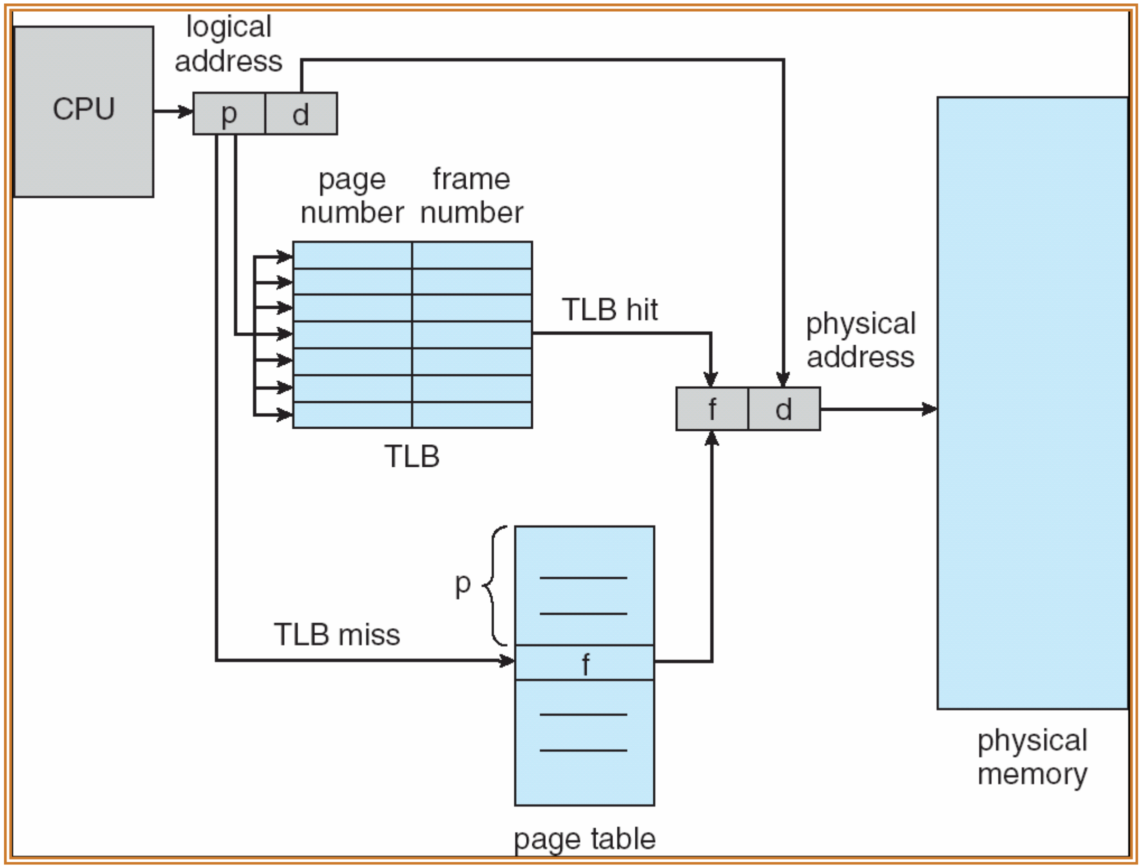
MEMORY MANAGEMENT

PAGING

- A 32 bit machine can address 4 gigabytes which is 4 million pages (at 1024 bytes/page). WHO says how big a page is, anyway?
- Could use dedicated registers (OK only with small tables.)
- Could use a register pointing to table in memory (slow access.)
- Cache or associative memory
- (TLB = Translation Lookaside Buffer):
- simultaneous search is fast and uses only a few registers.

IMPLEMENTATION OF THE PAGE TABLE

TLB = Translation Lookaside Buffer



MEMORY MANAGEMENT

PAGING

IMPLEMENTATION OF THE PAGE TABLE

Issues include:

key and value
hit rate 90 - 98% with 100 registers
add entry if not found

Effective access time = %fast * time_fast + %slow * time_slow

Relevant times:

2 nanoseconds to search associative memory – the TLB.
20 nanoseconds to access processor cache and bring it into TLB for next time.

Calculate time of access:

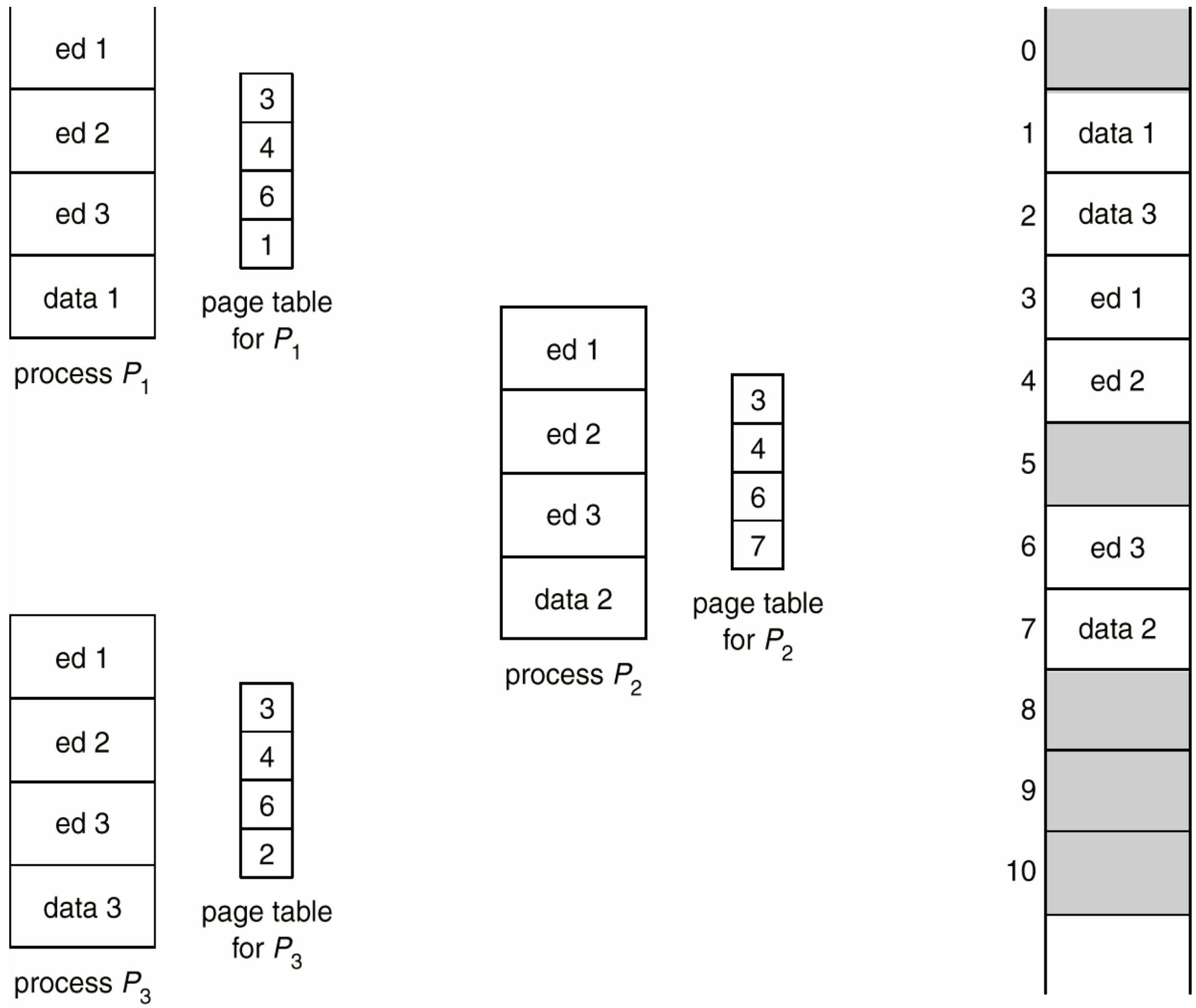
hit = 1 search + 1 memory reference
miss = 1 search + 1 mem reference(of page table) + 1 mem reference.

SHARED PAGES

Data occupying one physical page, but pointed to by multiple logical pages.

Useful for common code - must be write protected. (NO write-able data mixed with code.)

Extremely useful for read/write communication between processes.



MEMORY MANAGEMENT PAGING

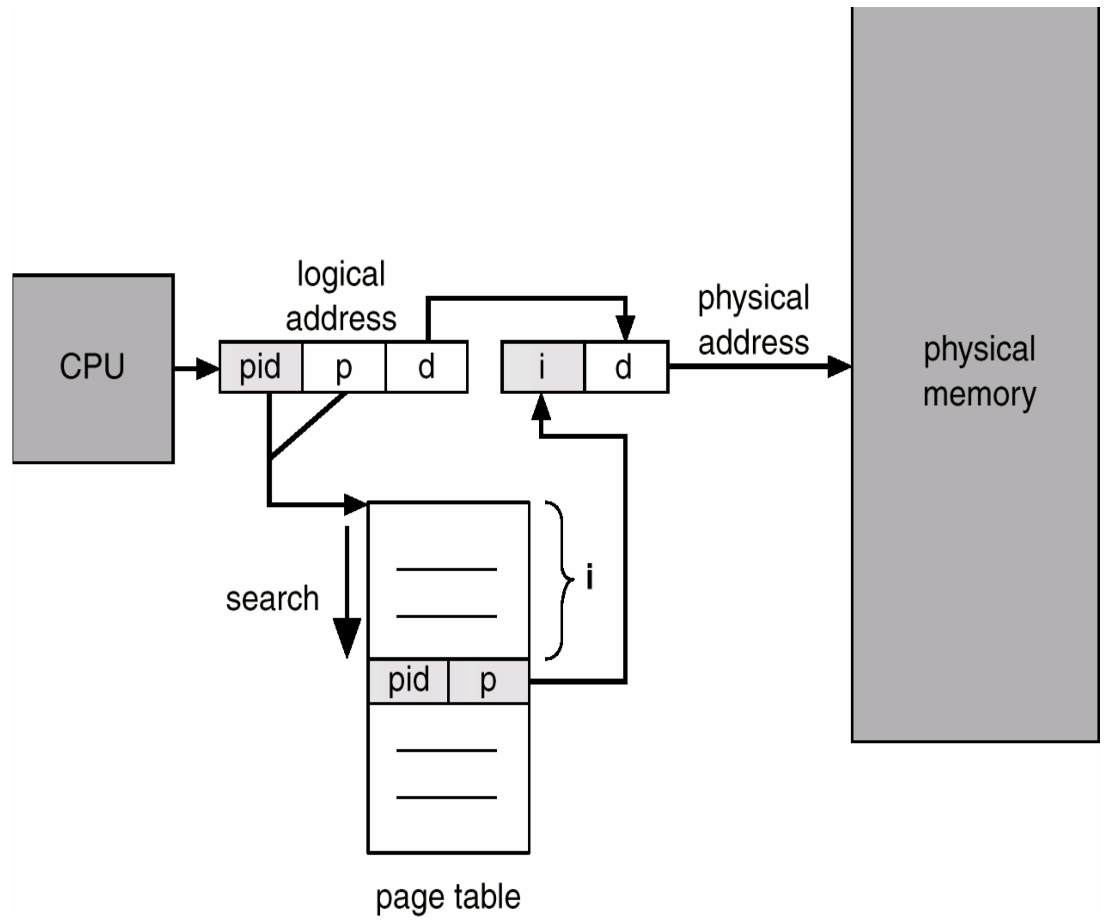
INVERTED PAGE TABLE:

One entry for each real page of memory.

Entry consists of the virtual address of the page stored in that real memory location, with information about the process that owns that page.

Essential when you need to do work on the page and must find out what process owns it.

Use hash table to limit the search to one - or at most a few - page table entries.



MEMORY MANAGEMENT

PAGING

PROTECTION:

- Bits associated with page tables.
- Can have read, write, execute, valid bits.
- Valid bit says page isn't in address space.
- Write to a write-protected page causes a fault. Touching an invalid page causes a fault.

ADDRESS MAPPING:

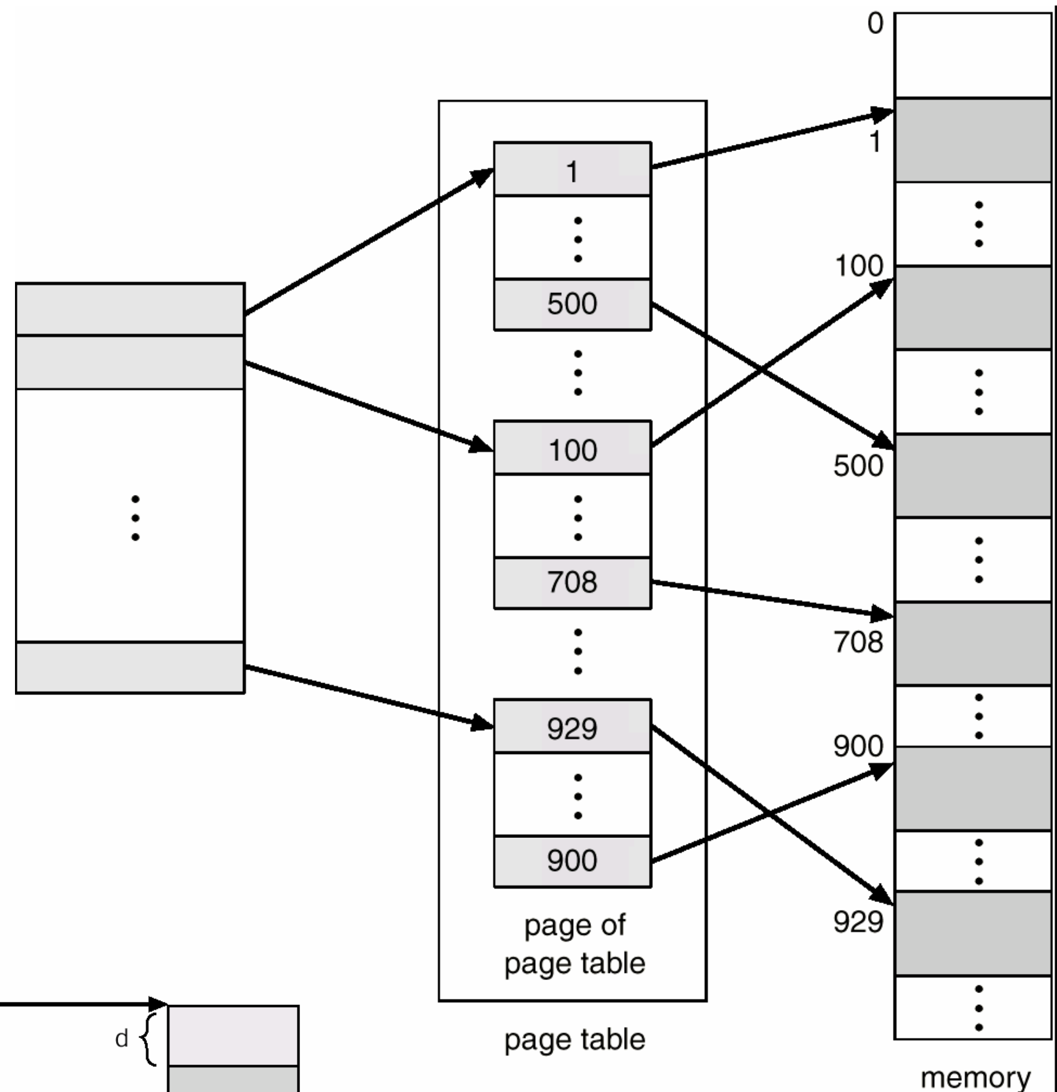
- Allows physical memory larger than logical memory.
- Useful on 32 bit machines with more than 32-bit addressable words of memory.
- The operating system keeps a frame containing descriptions of physical pages; if allocated, then to which logical page in which process.

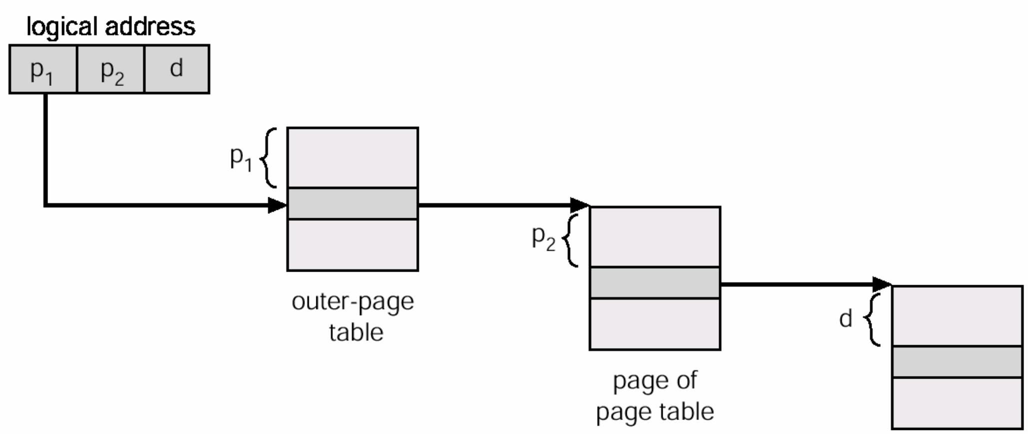
MEMORY MANAGEMENT

PAGING

MULTILEVEL PAGE TABLE

A means of using page tables for large address spaces.





Segmentation

USER'S VIEW OF MEMORY

A programmer views a process consisting of unordered segments with various purposes. This view is more useful than thinking of a linear array of words. We really don't care at what address a segment is located.

Typical segments include

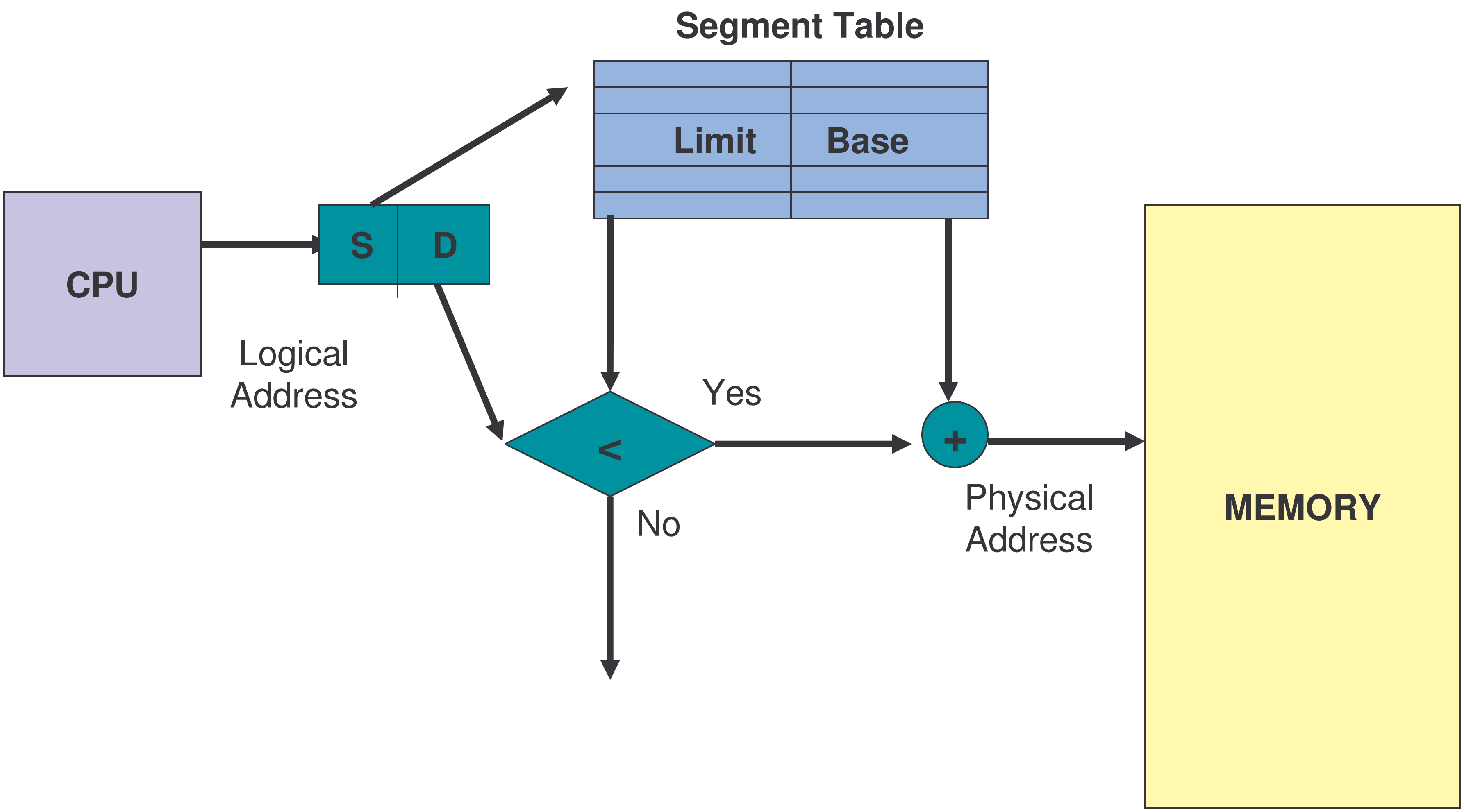
- global variables
- procedure call stack
- code for each function
- local variables for each
- large data structures

Logical address = segment name (number) + offset

Memory is addressed by both segment and offset.

MEMORY MANAGEMENT **Segmentation**

HARDWARE -- Must map a dyad (segment / offset) into one-dimensional address.

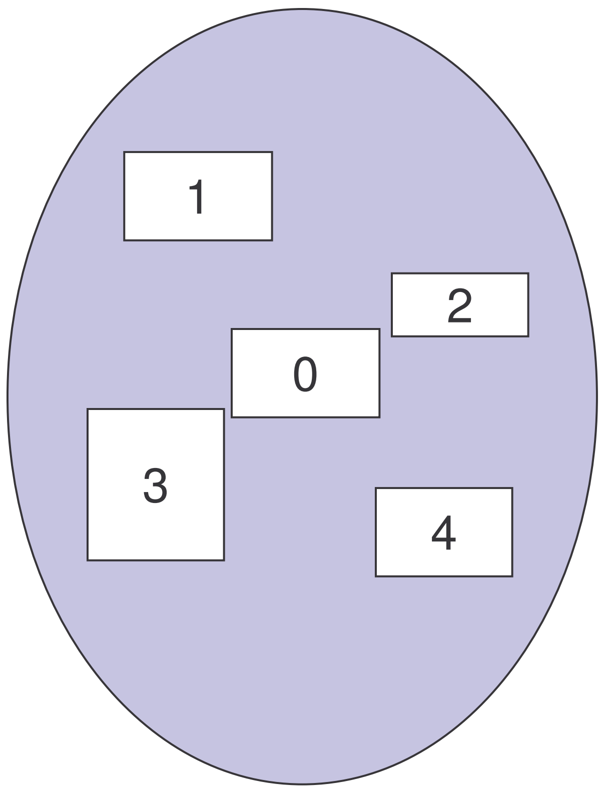


MEMORY MANAGEMENT

Segmentation

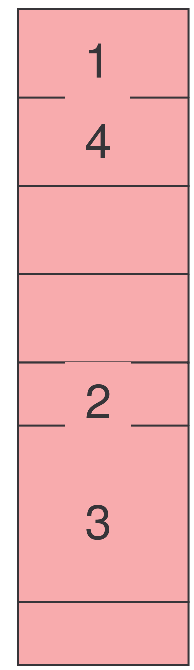
HARDWARE

base / limit pairs in a segment table.



Logical Address Space

	Limit	Base
0	1000	1400
1	400	6300
2	400	4300
3	1100	3200
4	1000	4700



Physical Memory

MEMORY MANAGEMENT

Segmentation

PROTECTION AND SHARING

Addresses are associated with a logical unit (like data, code, etc.) so protection is easy.

Can do bounds checking on arrays

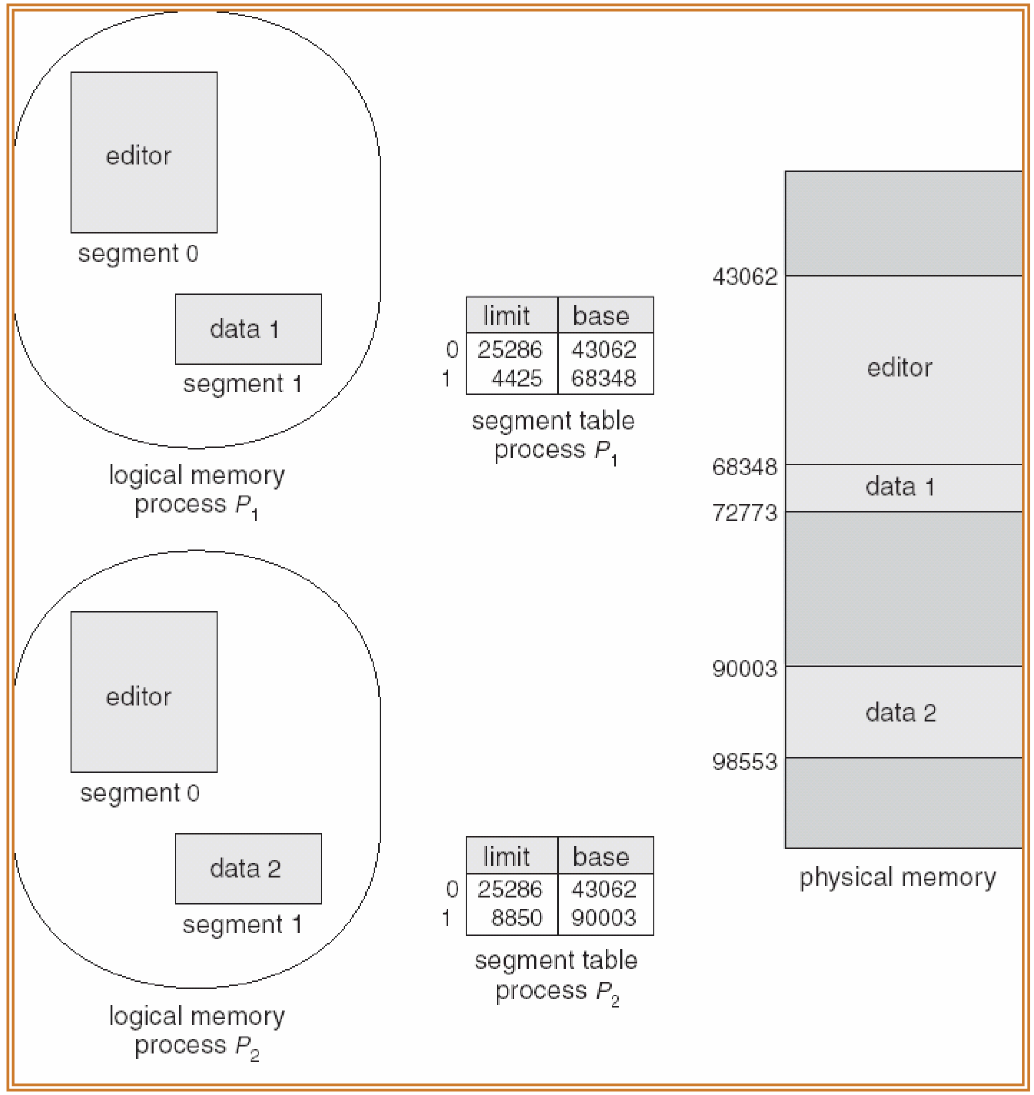
Sharing specified at a logical level, a segment has an attribute called "shareable".

Can share some code but not all - for instance a common library of subroutines.

FRAGMENTATION

Use variable allocation since segment lengths vary.

Again have issue of fragmentation; Smaller segments means less fragmentation. Can use compaction since segments are relocatable.



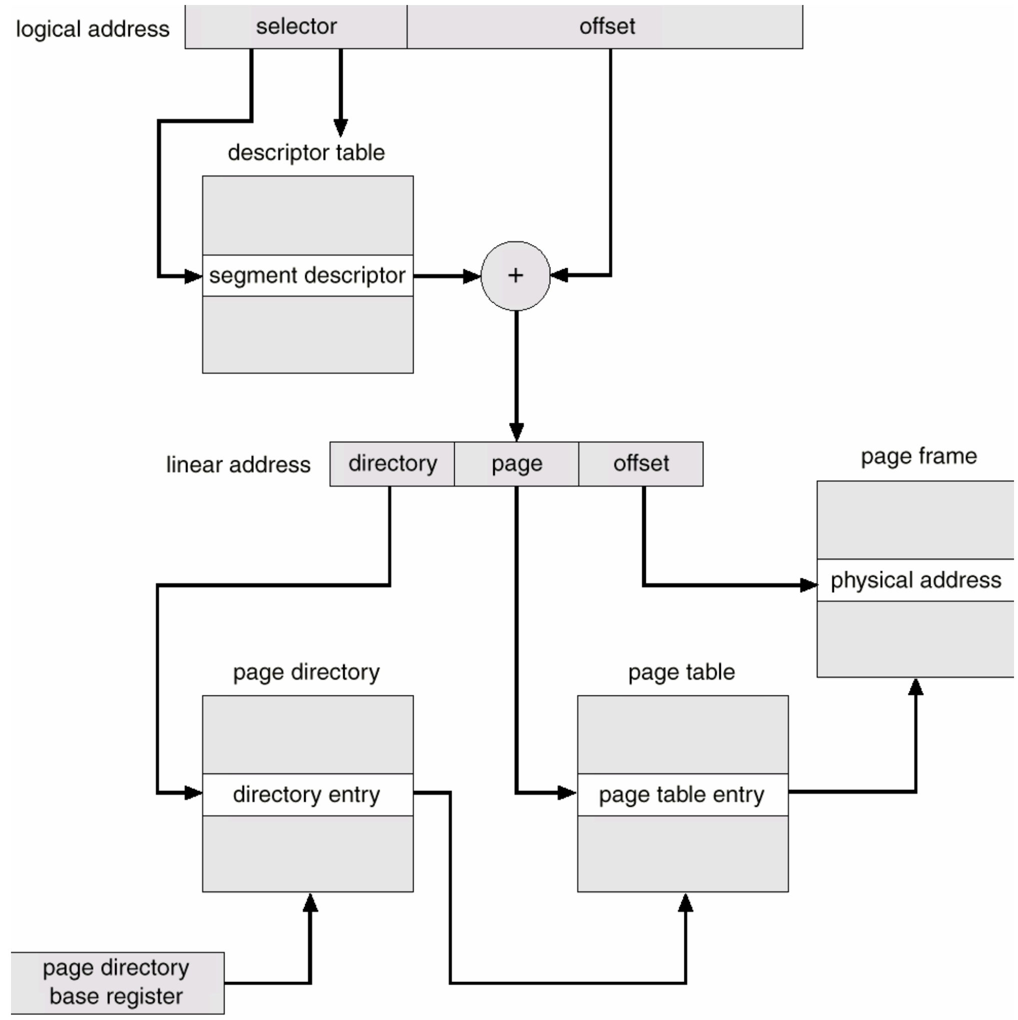
Segmentation

PAGED SEGMENTATION

Combination of paging and segmentation.

address =
  frame at (page table base for segment
  + offset into page table)
  + offset into memory

Look at example of Intel architecture.



MEMORY MANAGEMENT

WRAPUP

We've looked at how to do paging - associating logical with physical memory.

This subject is at the very heart of what every operating system must do today.