Chapter 8
Main Memory

Images from Silberschatz

How does the OS manage memory?

- Allocation
- Swapping
- Hardware support
- Pentium + Linux

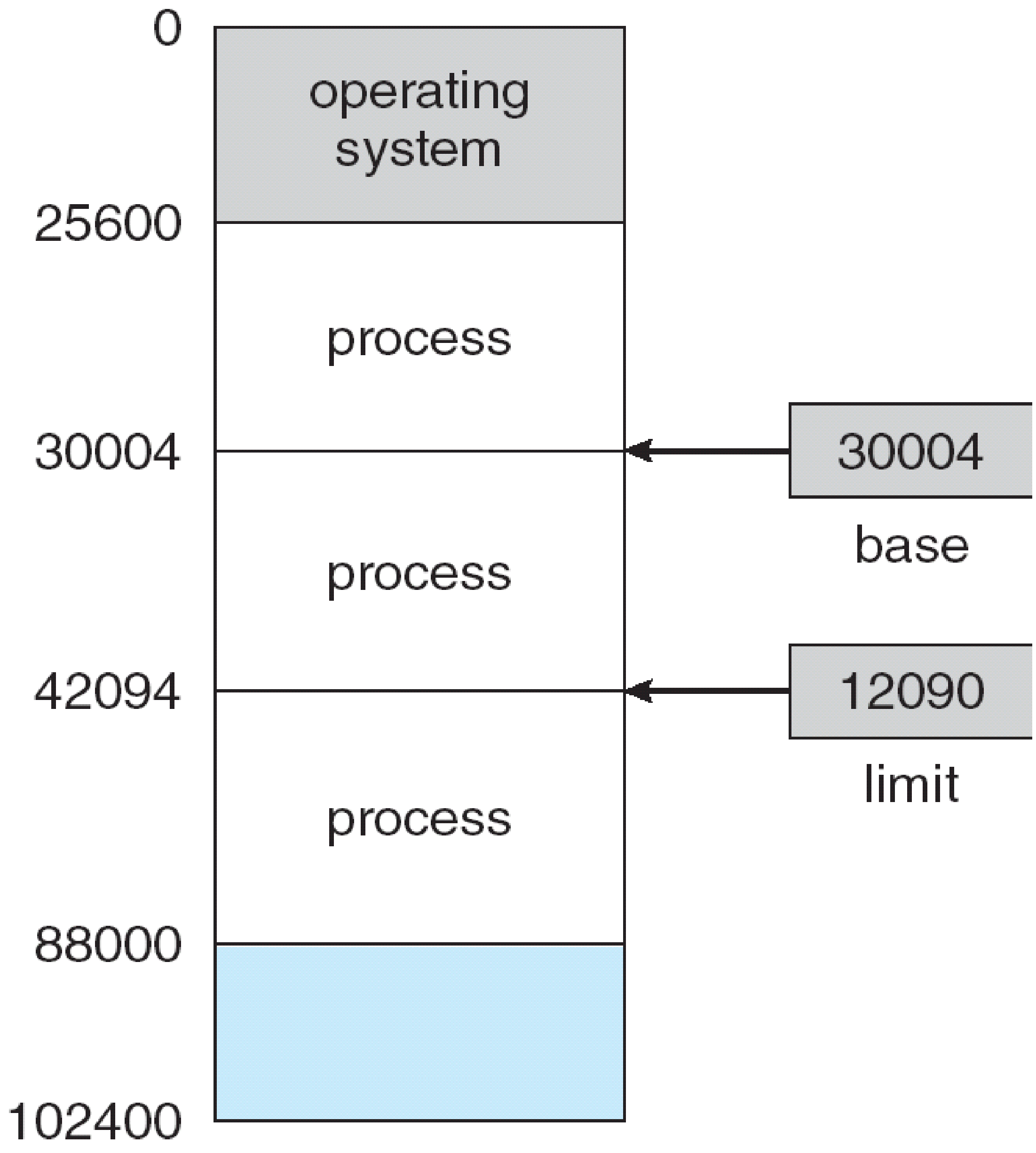
- Assume the entire process must be in memory!
  - Virtual Memory – chapter 9
  - Does not make this assumption

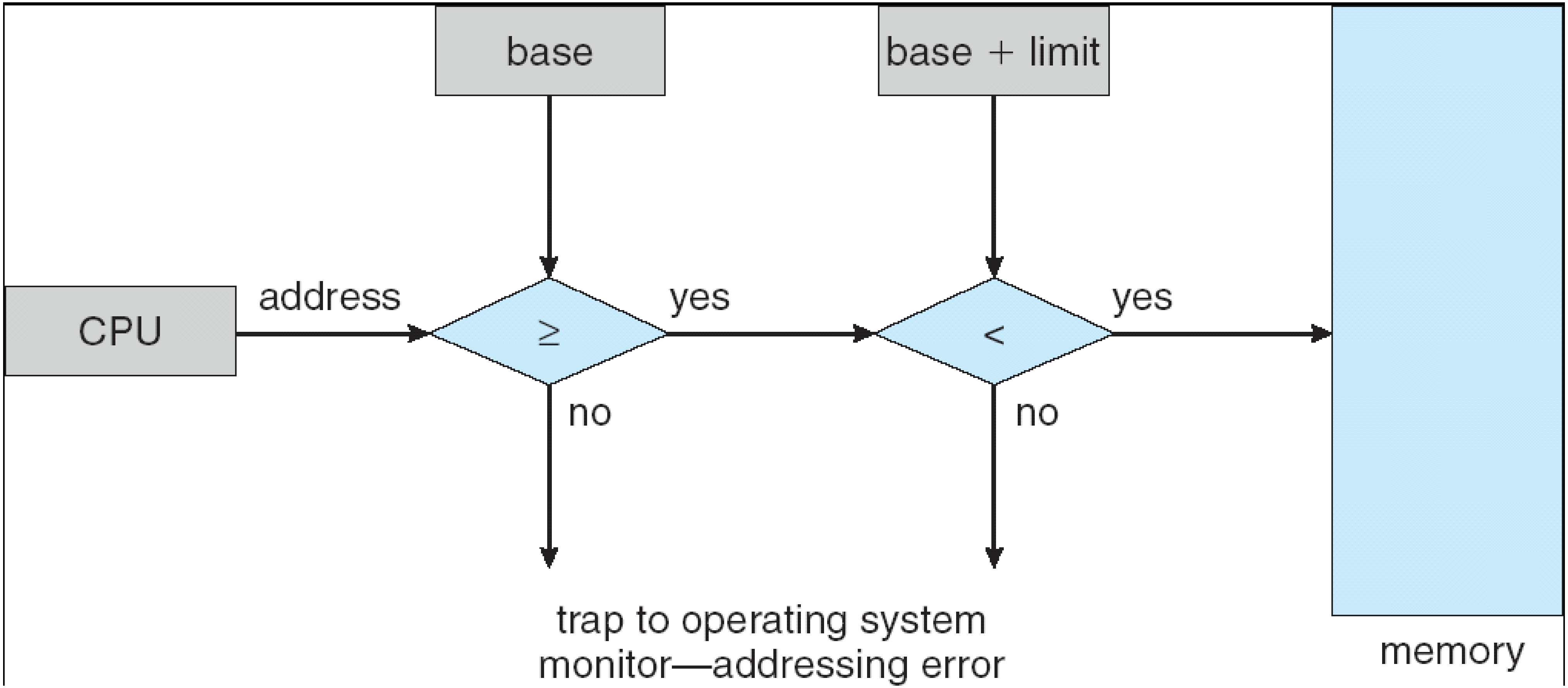
Memory Access Basics

- Register
- Cache
  - Stall
- Main Memory
- Disk
- Protection

(Basic) Mapping + Protection

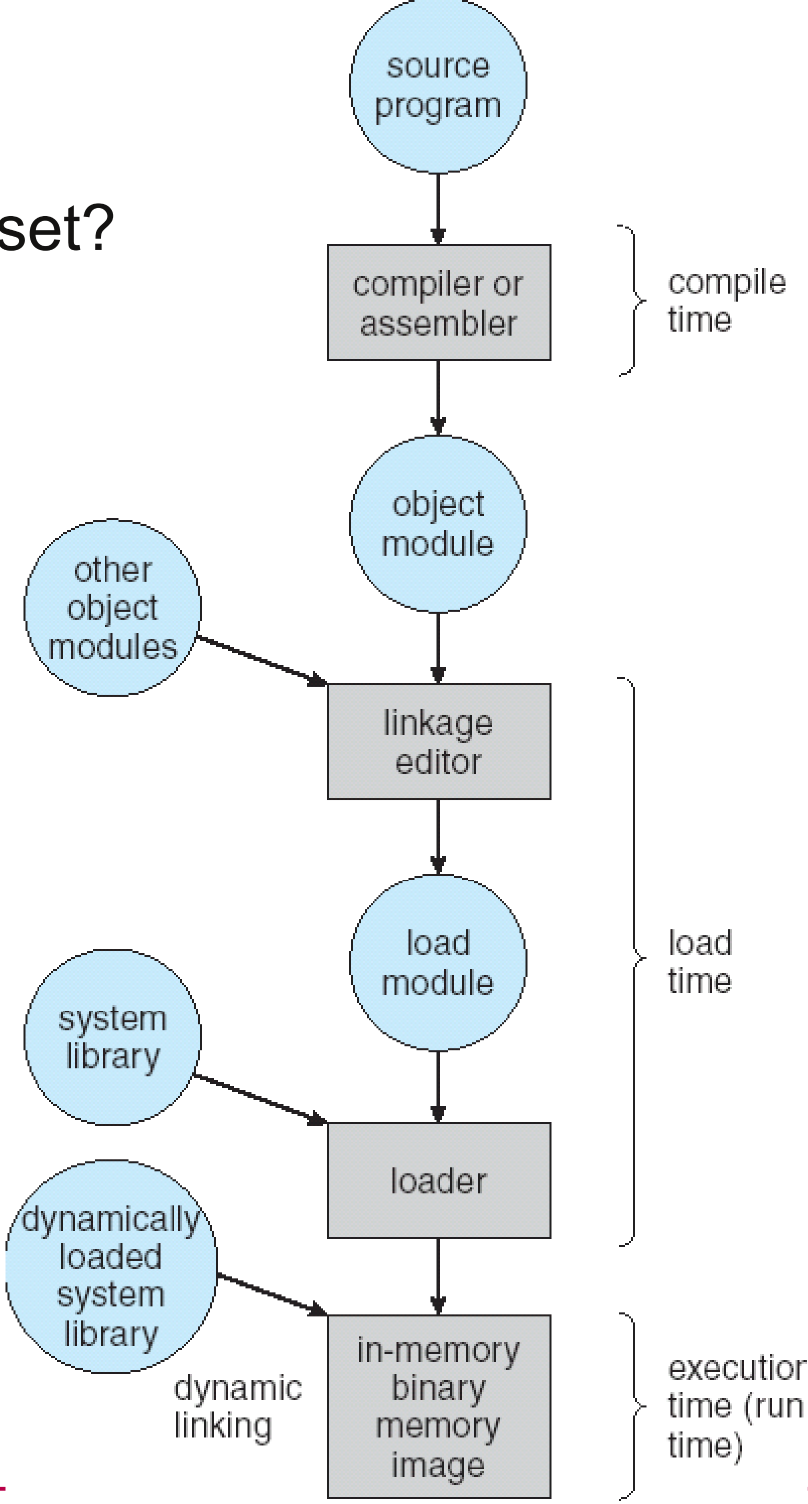
- Software
  - Thinks it can access address zero to limit
- Hardware
  - Two registers
    - Base
    - Limit
  - Privileged instructions
    - Kernel mode!
  - On error
    - Trap!




base
base + limit
CPU
address
≥
yes
<
yes
no
no
trap to operating system
monitor—addressing error
memory

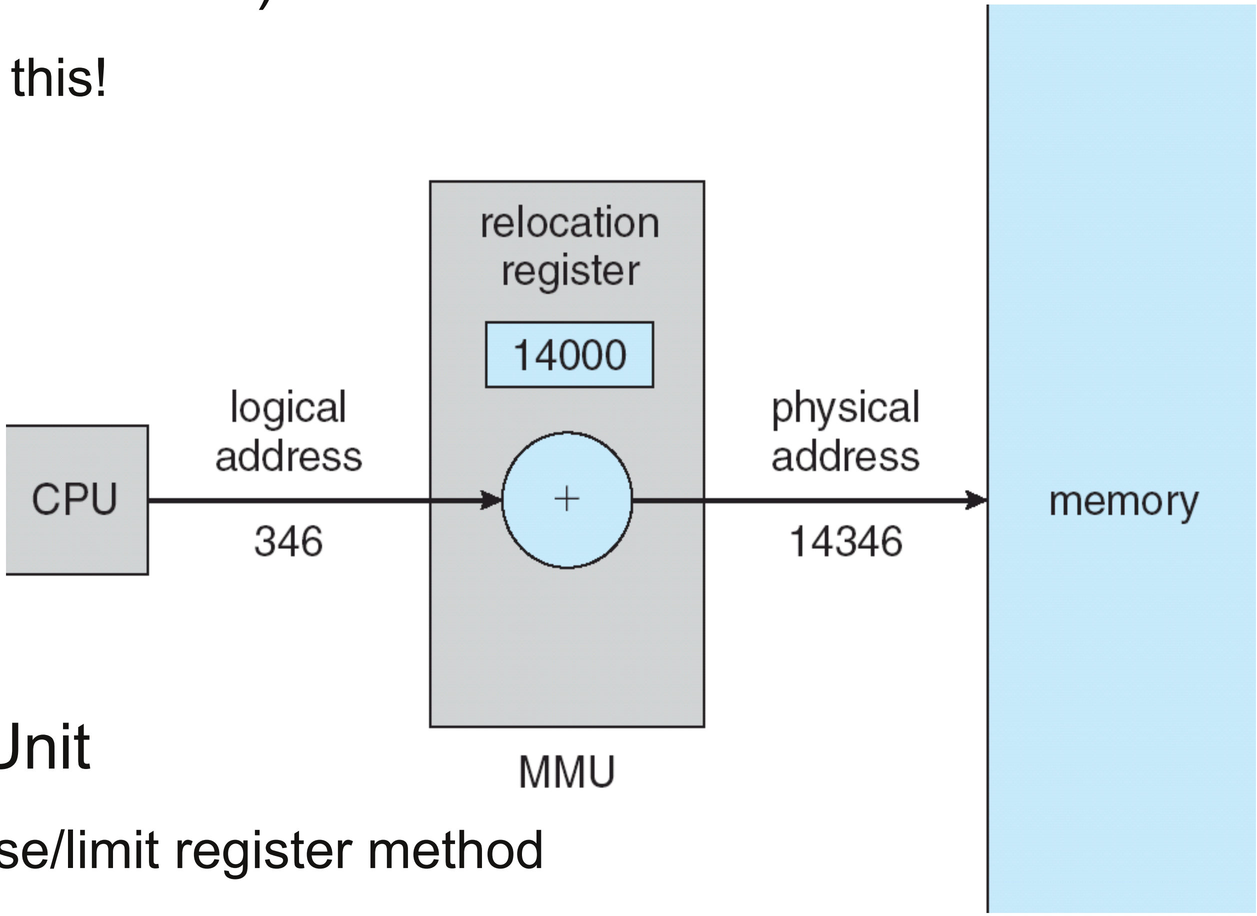
Address Bind Time

- When are addresses in the executable set?
  - Compile time
    - Must always be in the same location
  - Load time
    - Can be loaded anywhere
  - Execution time
    - Can be *moved* during execution!



Logical vs Physical Addresses

- Logical Address (Virtual Address)
  - Software only ever sees this!
- Physical Address
- Memory Management Unit
  - Generalization of the base/limit register method
  - Relocation register



Dynamic Linking

- Linking at execution time
- Static linking
- stub
- Shared libraries
  - .dll or .so

Swapping

- Not all processes fit in physical memory
  - Chapter 9: not all of a *single process* will fit into physical memory
- Physical memory <==> Backing store
- Swap back into memory
  - Same location
  - Different location
- Context Switch Time
  - Size * Transfer rate
  - How does this affect time slices?

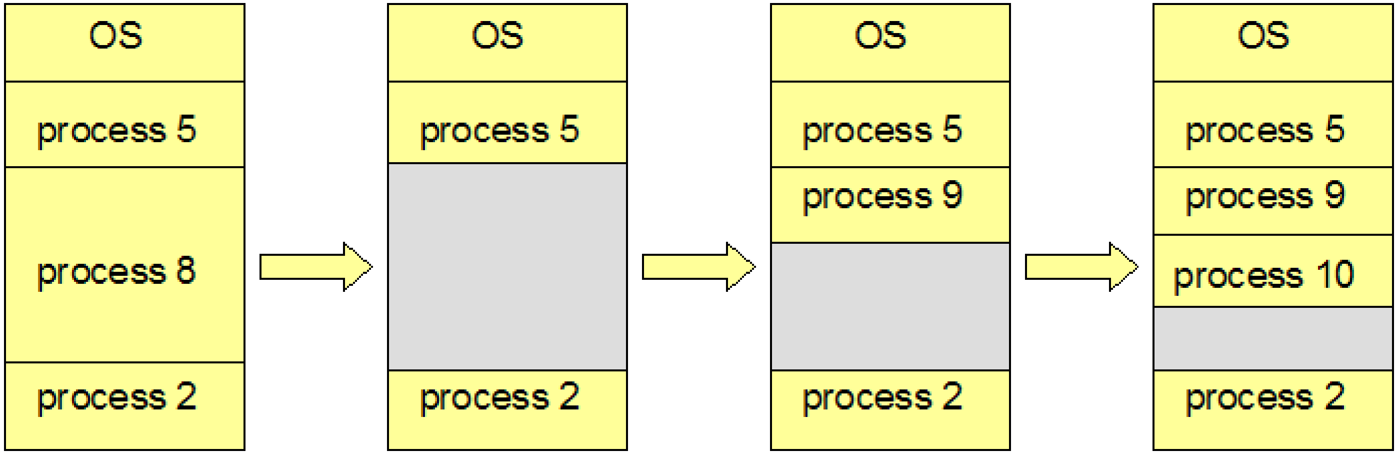
Contiguous Memory Allocation

- Two Partitions
  - OS
  - User Processes

Allocation of Memory

- Allocate part of User Space partition to each process
- Hole (technical term)

- First Fit
- Best Fit
- Worst Fit



- Best Fit/First Fit found (experimentally) to be better than Worst Fit in terms of time and memory utilization

- What happens if 5 & 2 terminate?

Fragmentation

- External

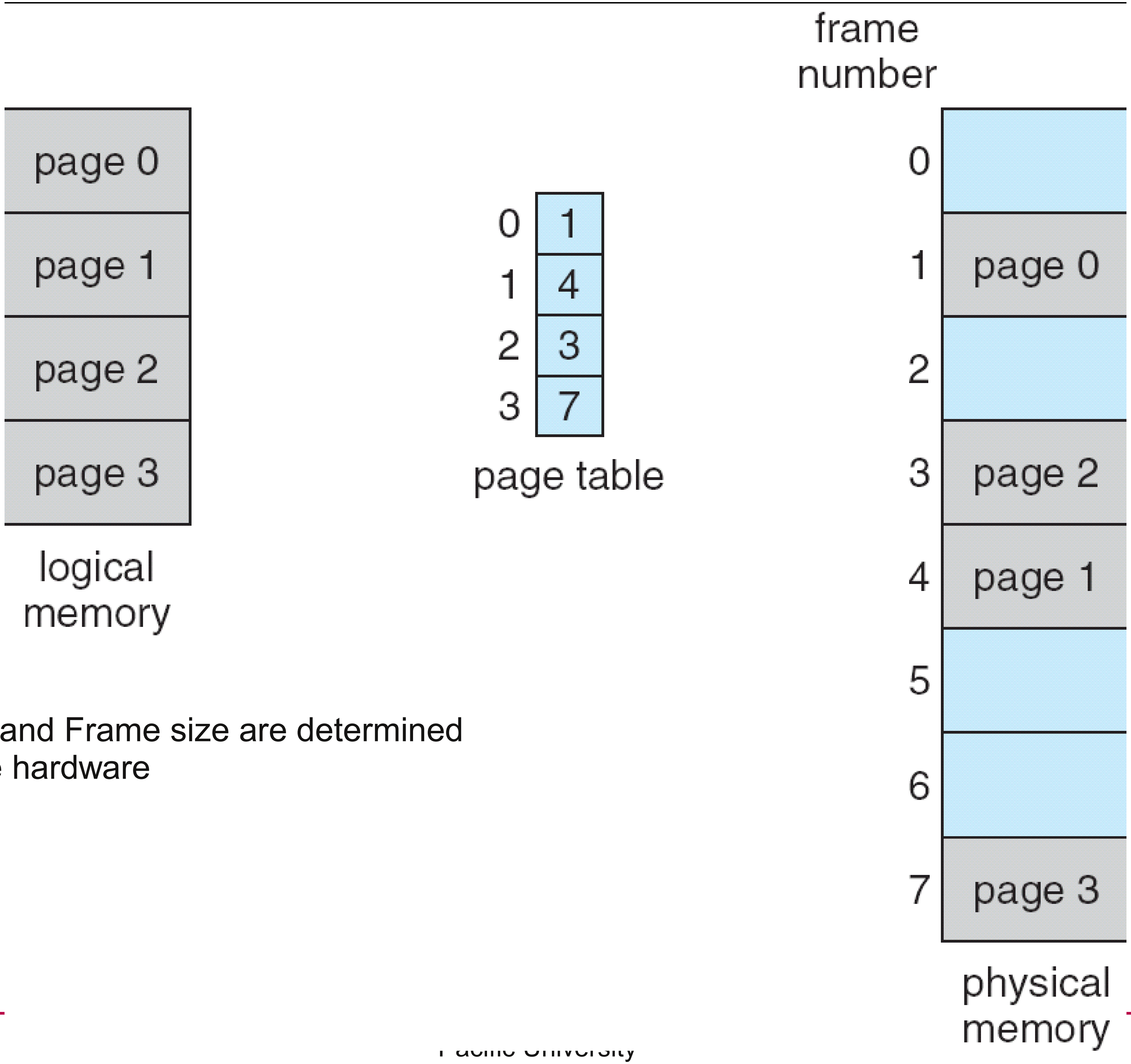
- Internal

- Compaction

- 50% Rule

Paging!

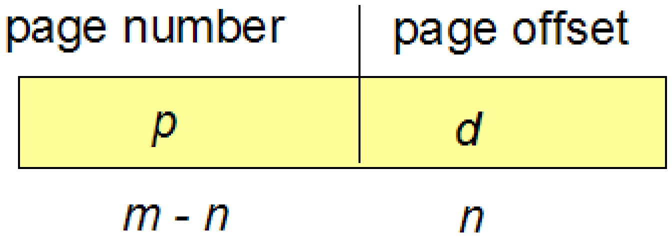
- Noncontiguous memory allocation
- Frame
  - Physical memory
- Page
  - Logical memory
  - Allocate an entire page at a time
- Page table
- Internal Fragmentation



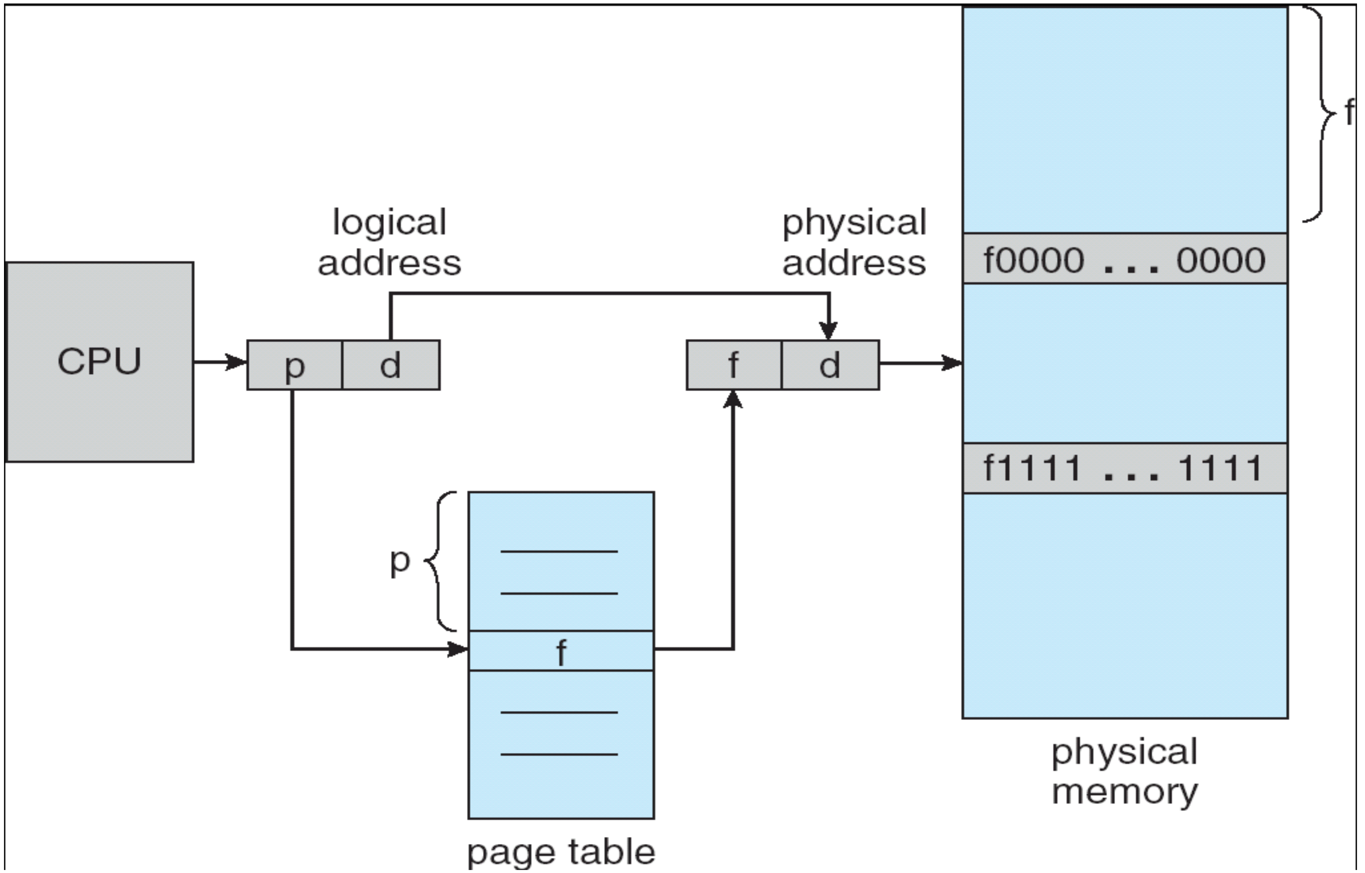
Page and Frame size are determined
by the hardware

Address Translation

- Logical Address to Page Number + Offset

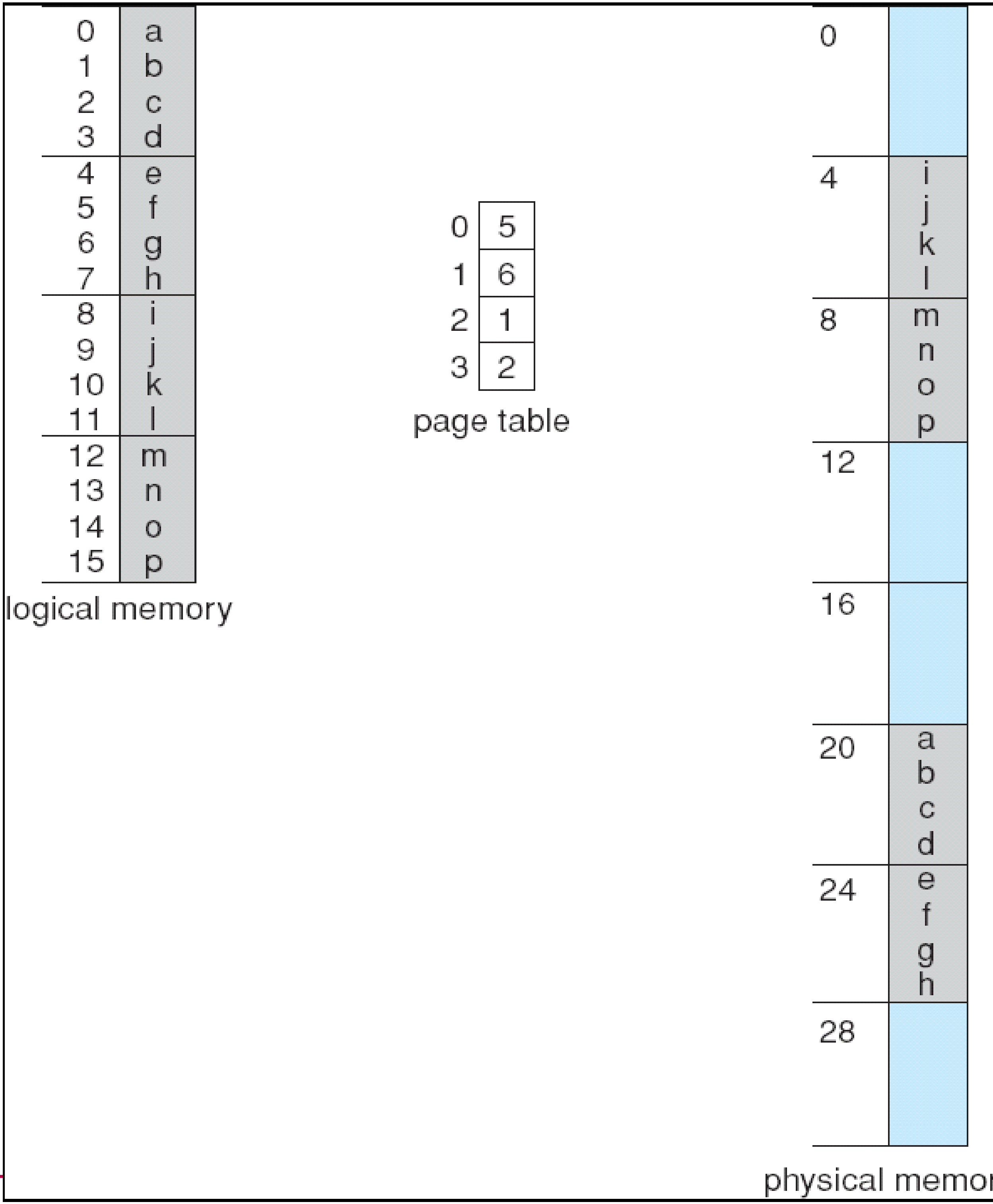


  - Logical address space 2^m and page size 2^n



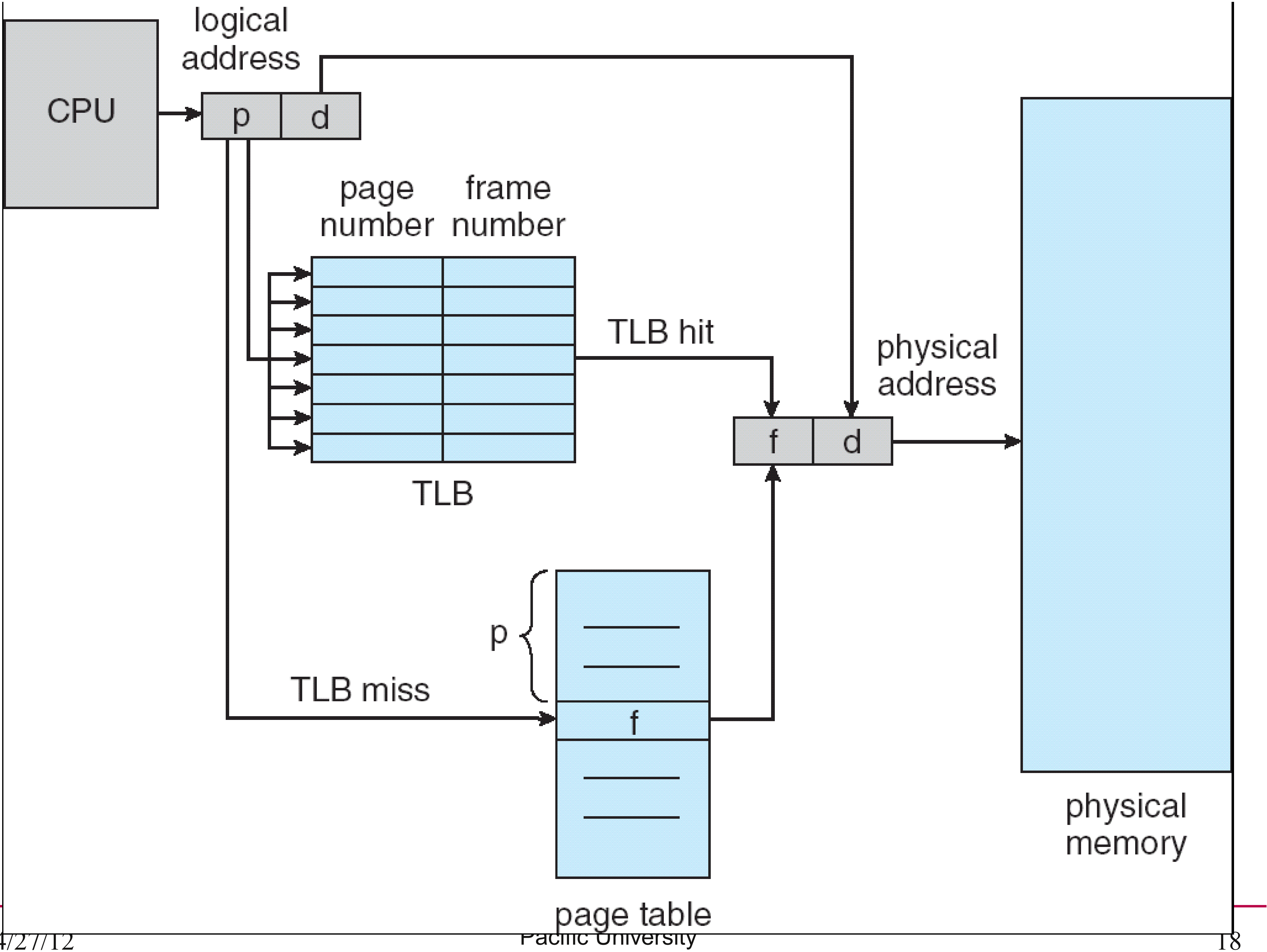
- 32 byte memory
- 4 byte pages
- No guarantee of ordering
- What happens

```
char *pChar = 0x7;
pChar ++;
print pChar;
```



Page Table

- Pages are not always reloaded to the same frame
  - ??
- Contains base address of each page in physical memory
  - Per process (usually)
  - Which frame is it in
  - In main memory
- Hardware (not per process)
  - Page table base register (PTBR)
  - Page table length register (PRLR)
  - Translation look-aside buffers (TLBs)
    - Address space identifiers (ASIDs)
    - protection


logical address
CPU
p
d
page number
frame number
TLB hit
physical address
f
d
TLB
p
TLB miss
f
page table
physical memory

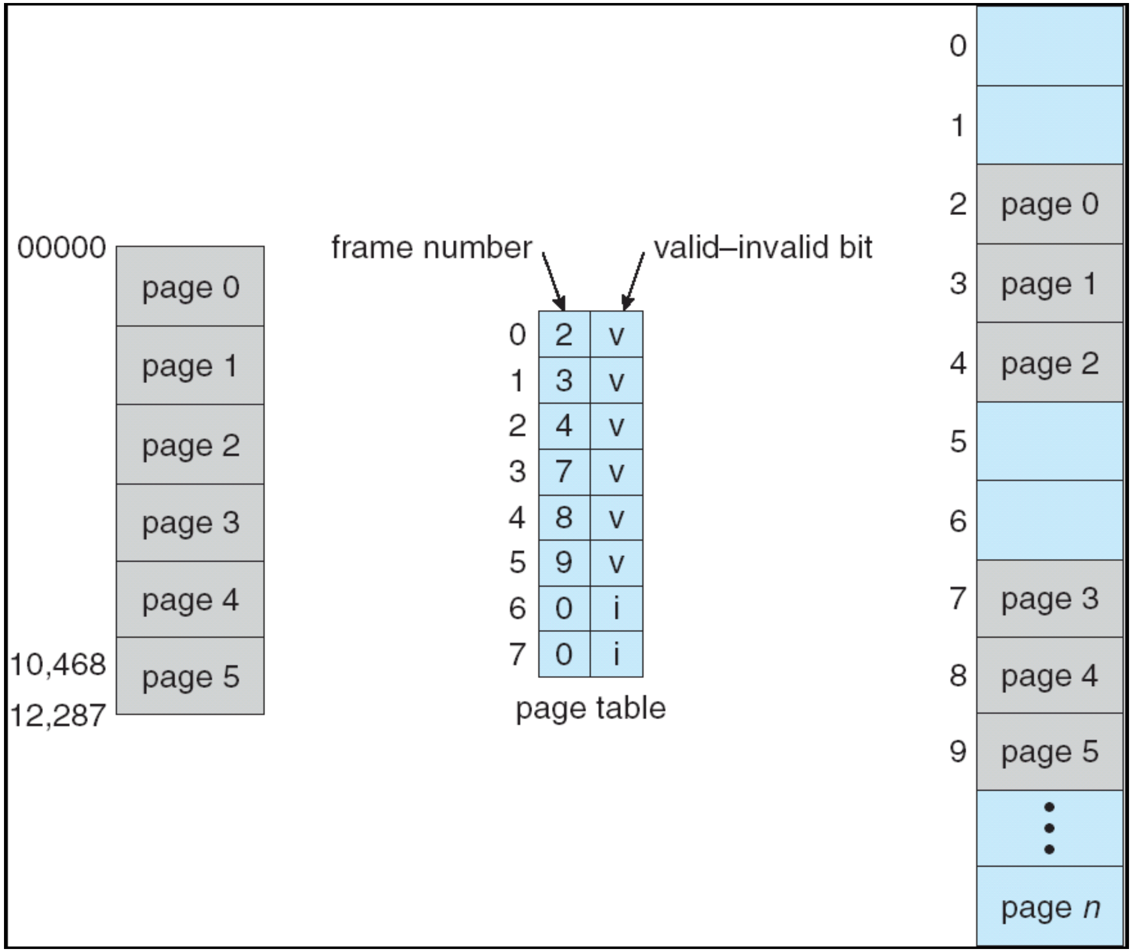
Logical -> Physical Address

- What do we need to do to get a physical address?
  - How long will it take?

Protection

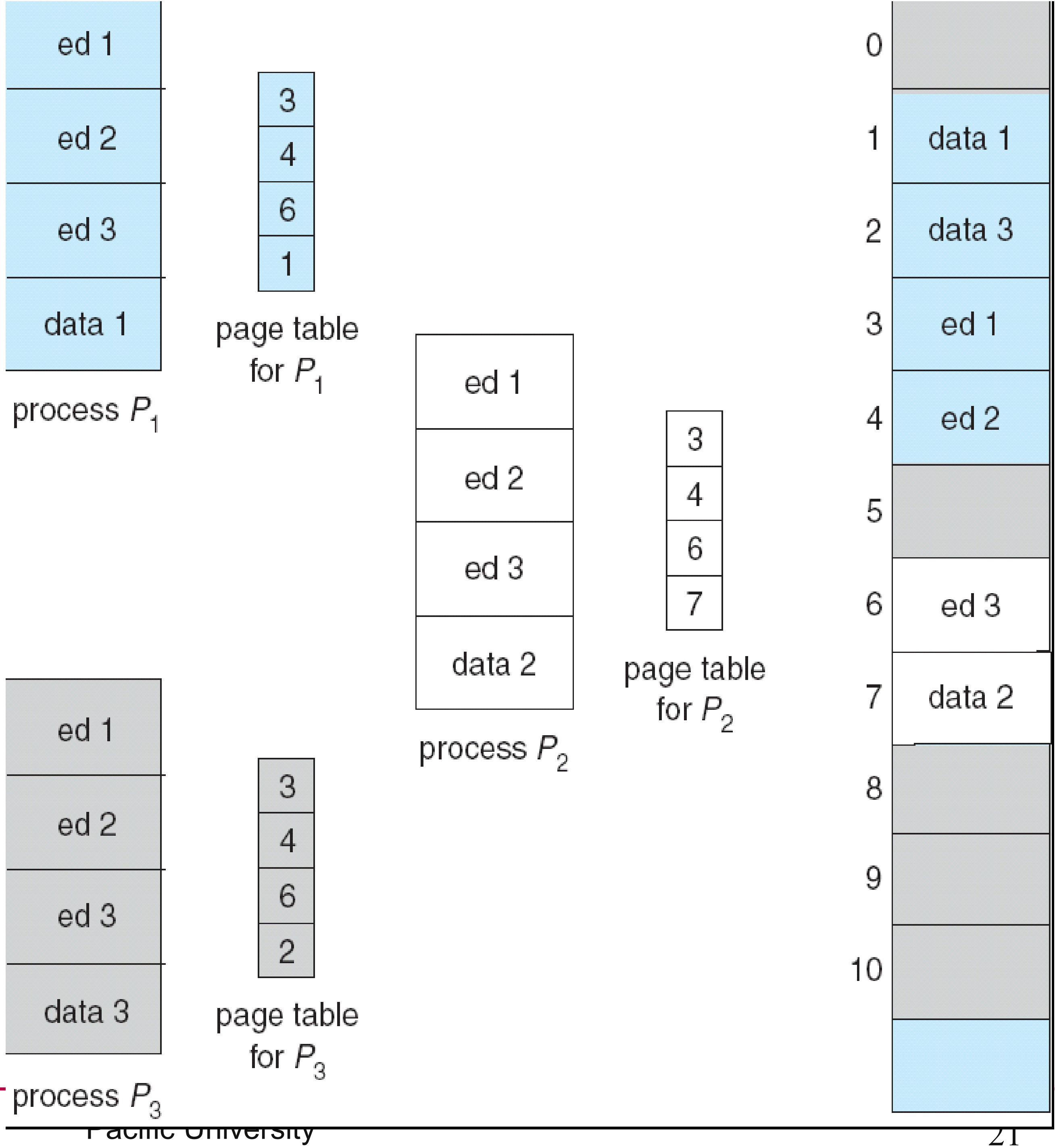
- Add valid/invalid bit to each page table entry

- ASIDs in TLBs denote which process owns each frame



Shared Pages

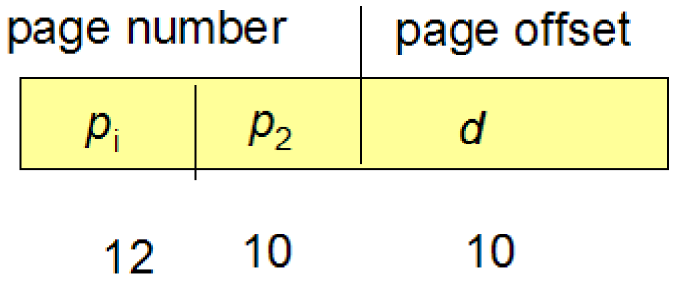
- .dll / .so
  - Share read only code pages
- Shm
  - Shared read/write data pages



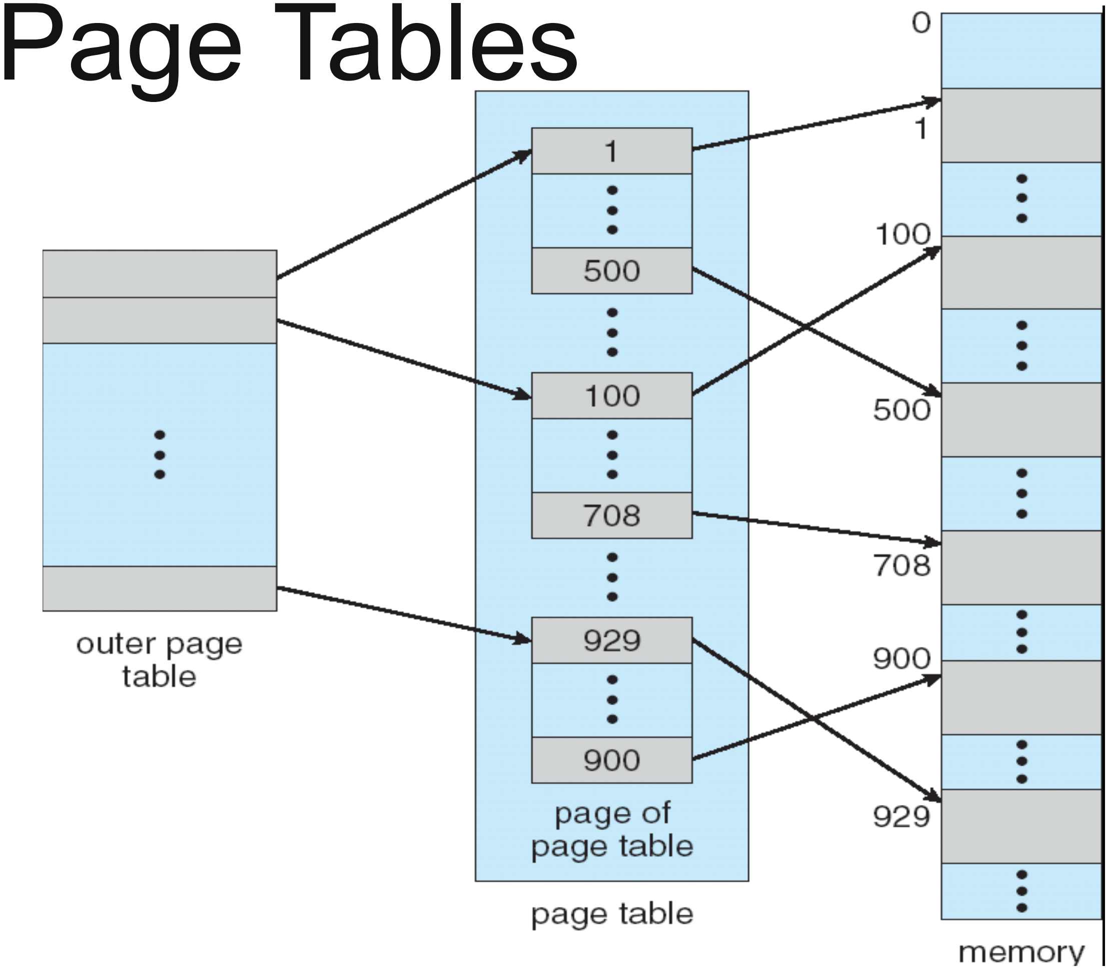
Problems with page tables

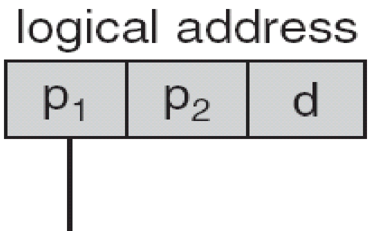
- What do you think?

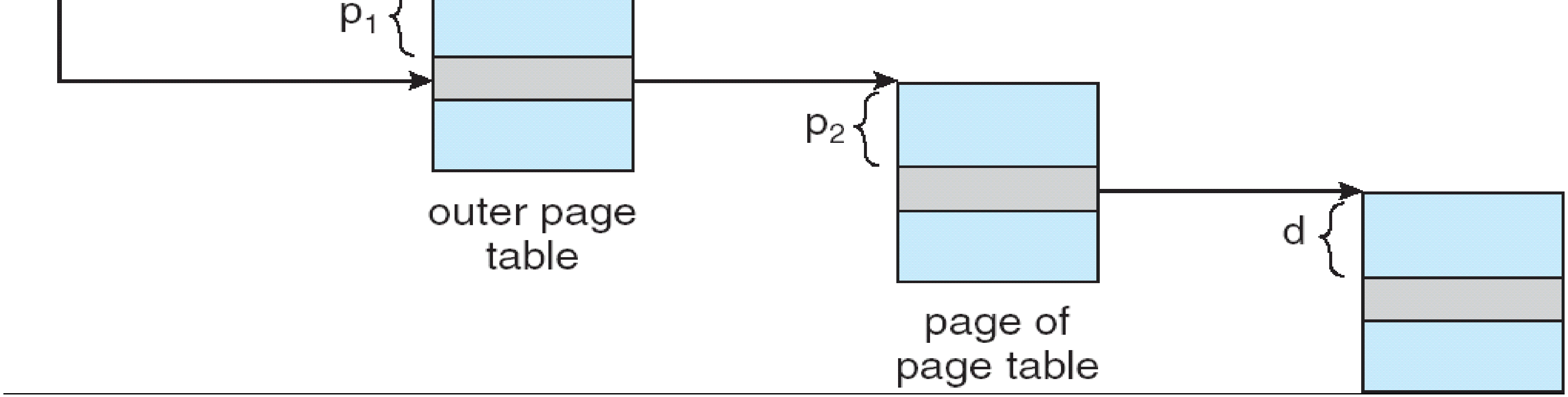
Multilevel Page Tables



- Page the page table
- Forward mapped page table

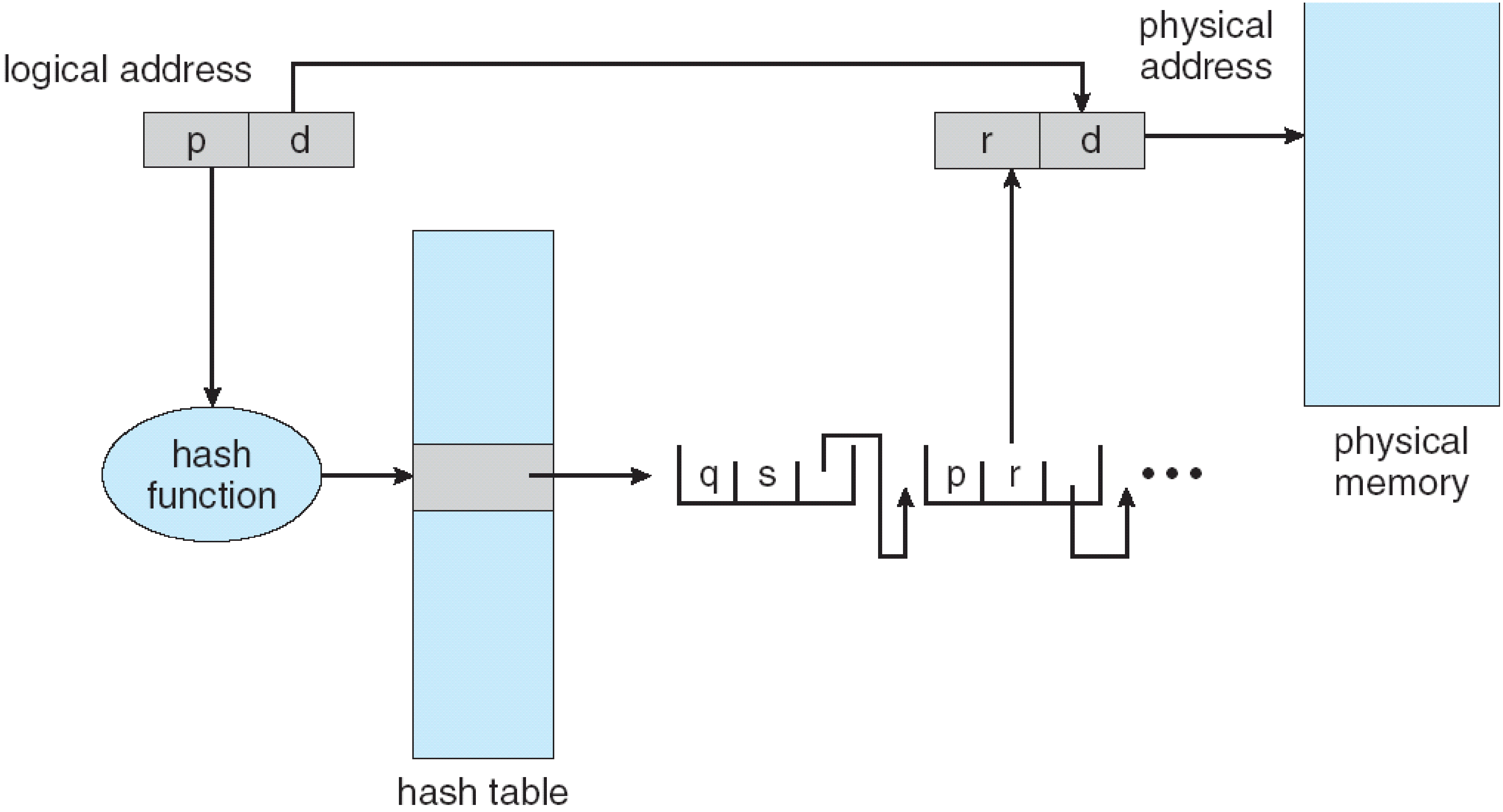






Hashed Page Tables

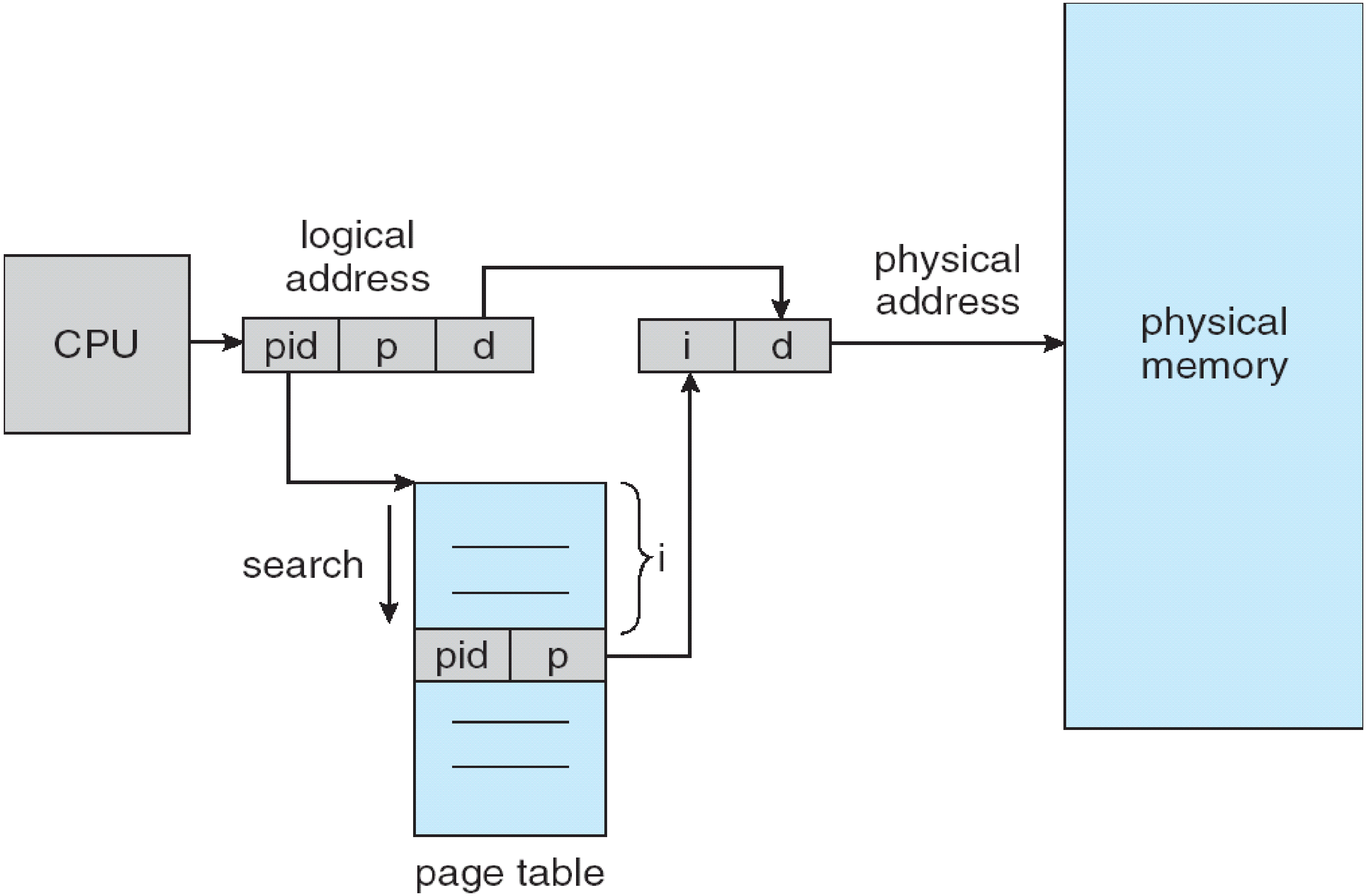
- Address spaced > 32 bits
- Use Virtual address to hash into the table



Inverted Page Table

- One entry per ***frame*** in physical memory
- One page table for the entire system
- Track pid in the table
- Problem?

- Solution?


CPU
logical address
pid
p
d
search
pid
p
i
page table
i
d
physical address
physical memory