Virtual Memory – Remaining topics

Agenda

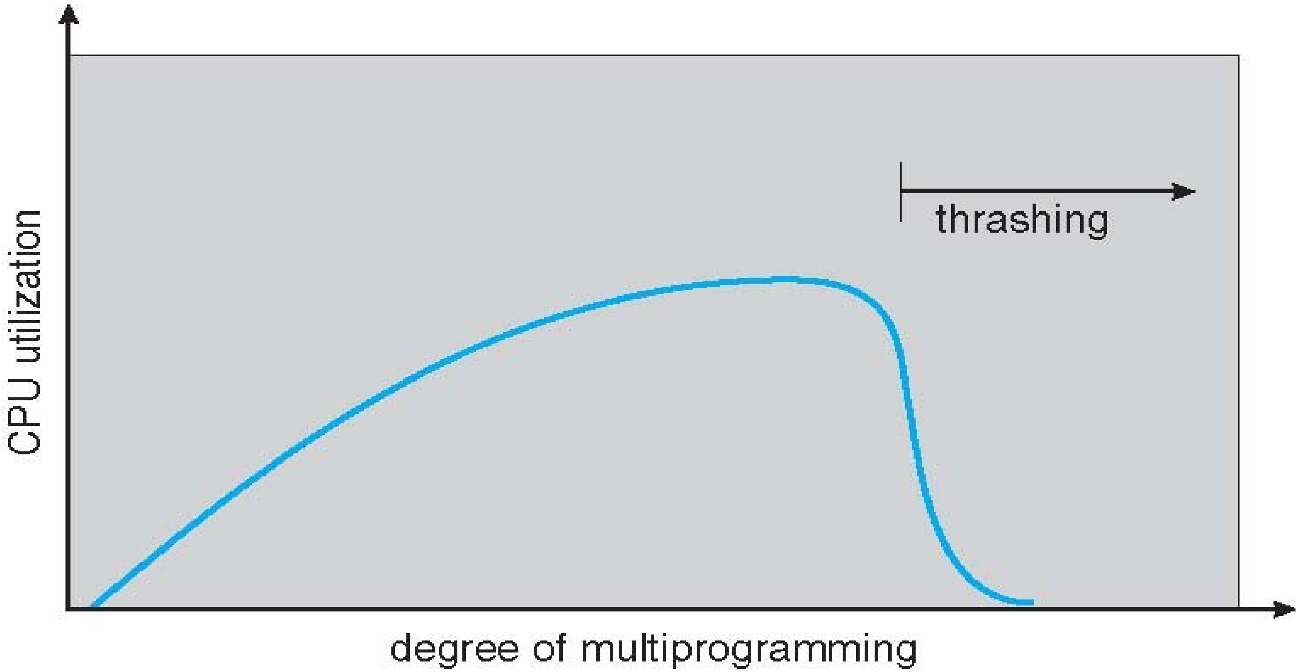
- Problem of Thrashing and possible solutions
- Mmap(), Memory mapped files
- Kernel Memory Management
- Other Considerations

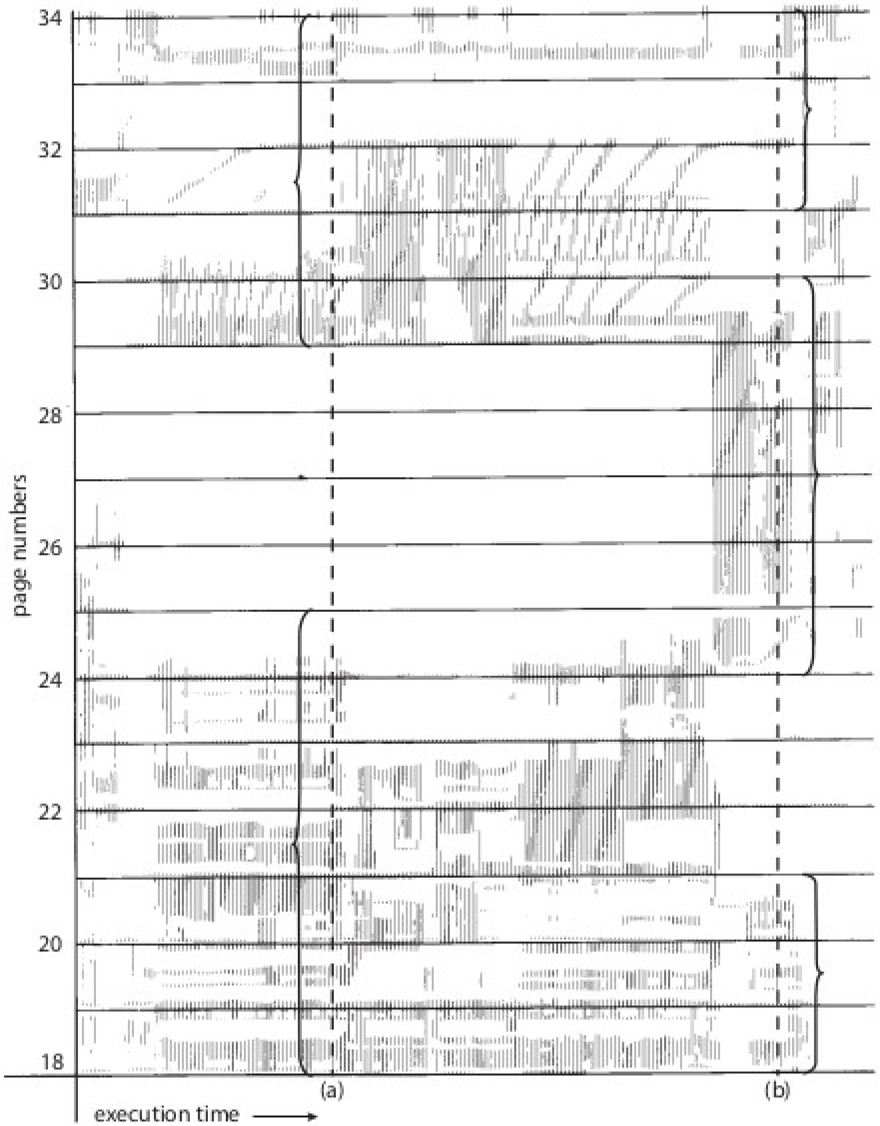
Thrashing

Thrashing

- If a process does not have “enough” pages, the page-fault rate is very high
  - Page fault to get page
  - Replace existing frame
  - But quickly need replaced frame back
- This leads to:
  - Low CPU utilization
  - Operating system thinking that it needs to increase the degree of multiprogramming
  - Another process added to the system
- Thrashing : a process is busy swapping pages in and out

Thrashing





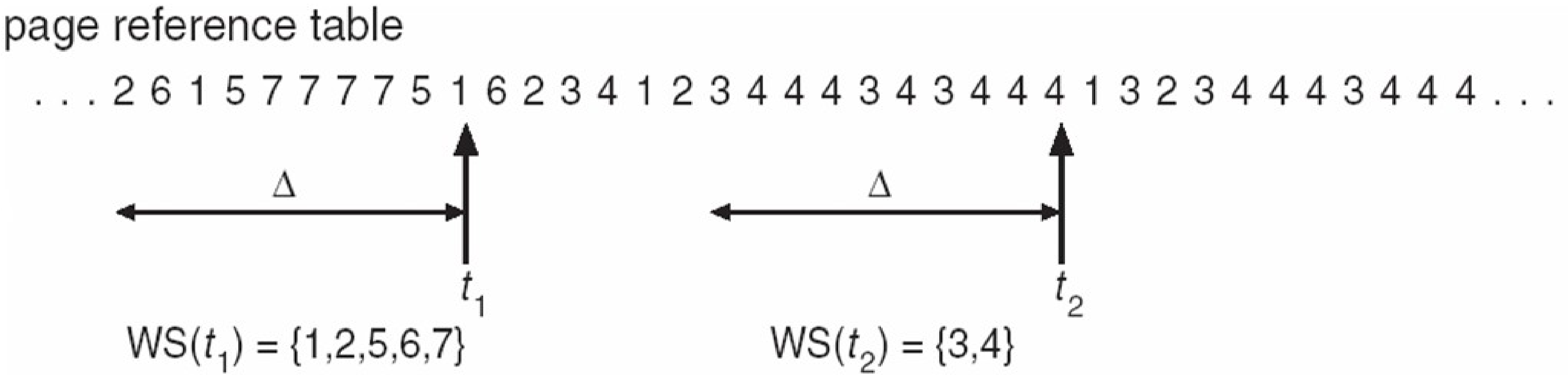
Locality In A Memory-Reference Pattern

Demand paging and thrashing

- Why does demand paging work?
  - Locality model
  - Process migrates from one locality to another
  - Localities may overlap
- Why does thrashing occur?
  - size of locality > total memory size
  - Limit effects by using local or priority page replacement

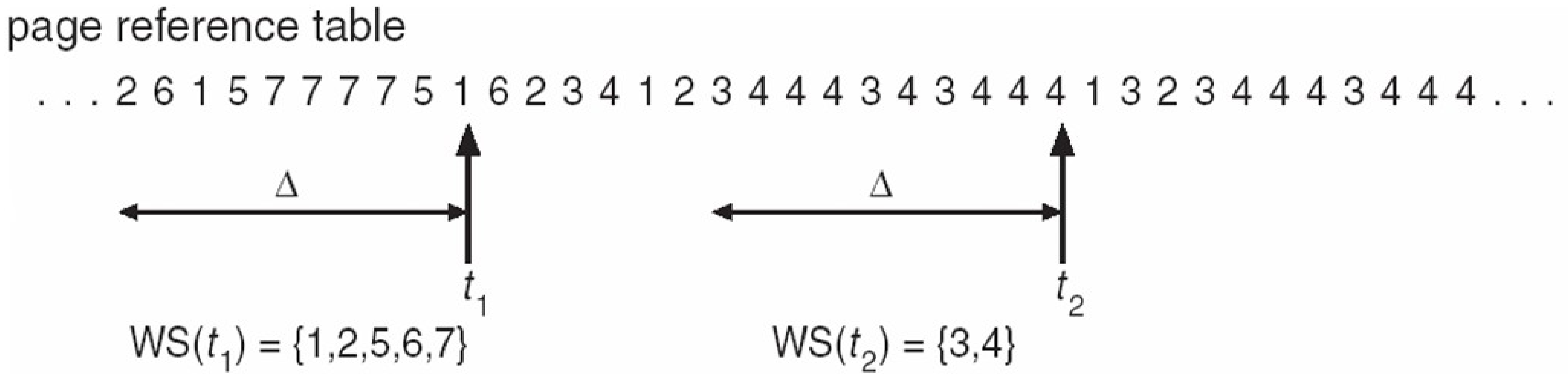
Working set model

- $\Delta \equiv$ working-set window $\equiv$ a fixed number of page references
  - Example: 10,000 instructions
- Working Set Size, WSS_i (working set of Process P_i) =
  - total number of pages referenced in the most recent Δ (varies in time)
  - if Δ too small will not encompass entire locality
  - if Δ too large will encompass several localities
  - if $\Delta = \infty \Rightarrow$ will encompass entire program



Working set model

- $D = \Sigma\ WSS_i \equiv$ total demand frames
  - Approximation of locality
- if D > m (total available frames) ⇒ Thrashing
- Policy if D > m, then suspend or swap out one of the processes

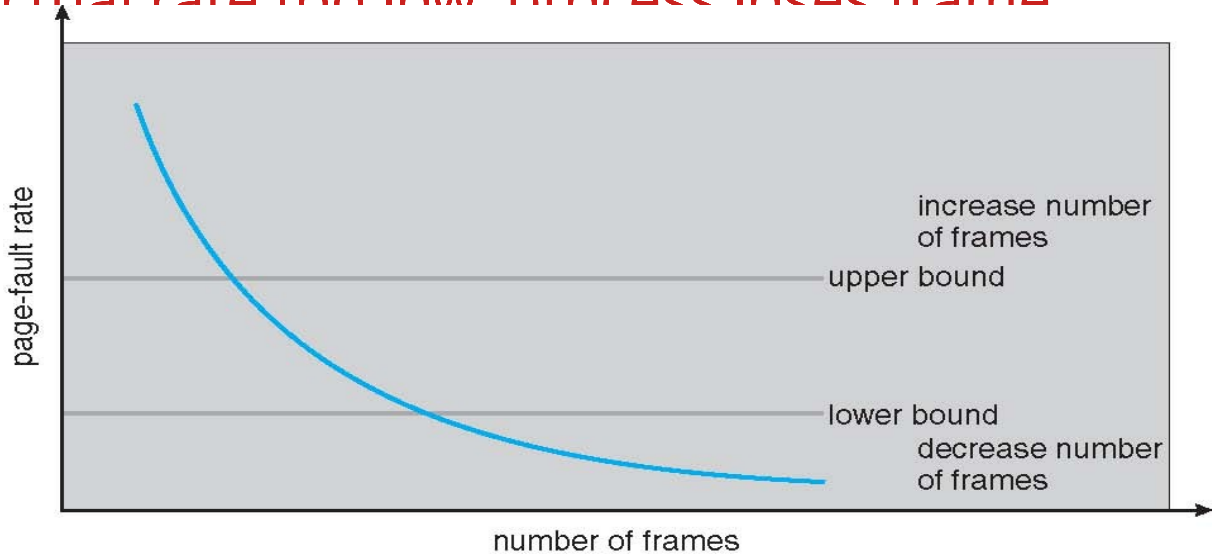


Keeping Track of the Working Set

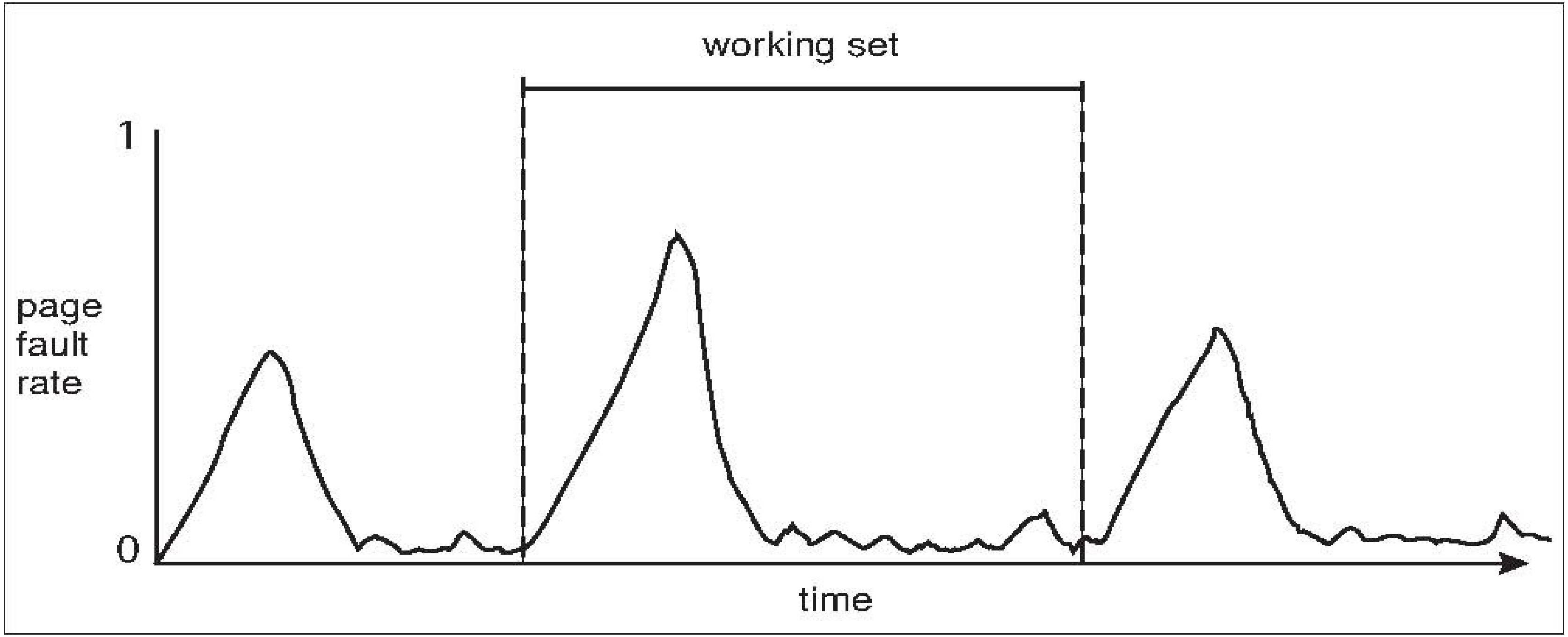
- Approximate with interval timer + a reference bit
- Example: Δ = 10,000
  - Timer interrupts after every 5000 time units
  - Keep in memory 2 bits for each page
  - Whenever a timer interrupts copy (to memory) and sets the values of all reference bits to 0
  - If one of the bits in memory = 1 $\Rightarrow$ page in working set
- Why is this not completely accurate?
- Improvement = 10 bits and interrupt every 1000 time units

Page fault frequency

- More direct approach than WSS
- Establish “acceptable” page-fault frequency rate and use local replacement policy
  - If actual rate too low, process loses frame
  - If a



Working Sets and Page Fault Rates

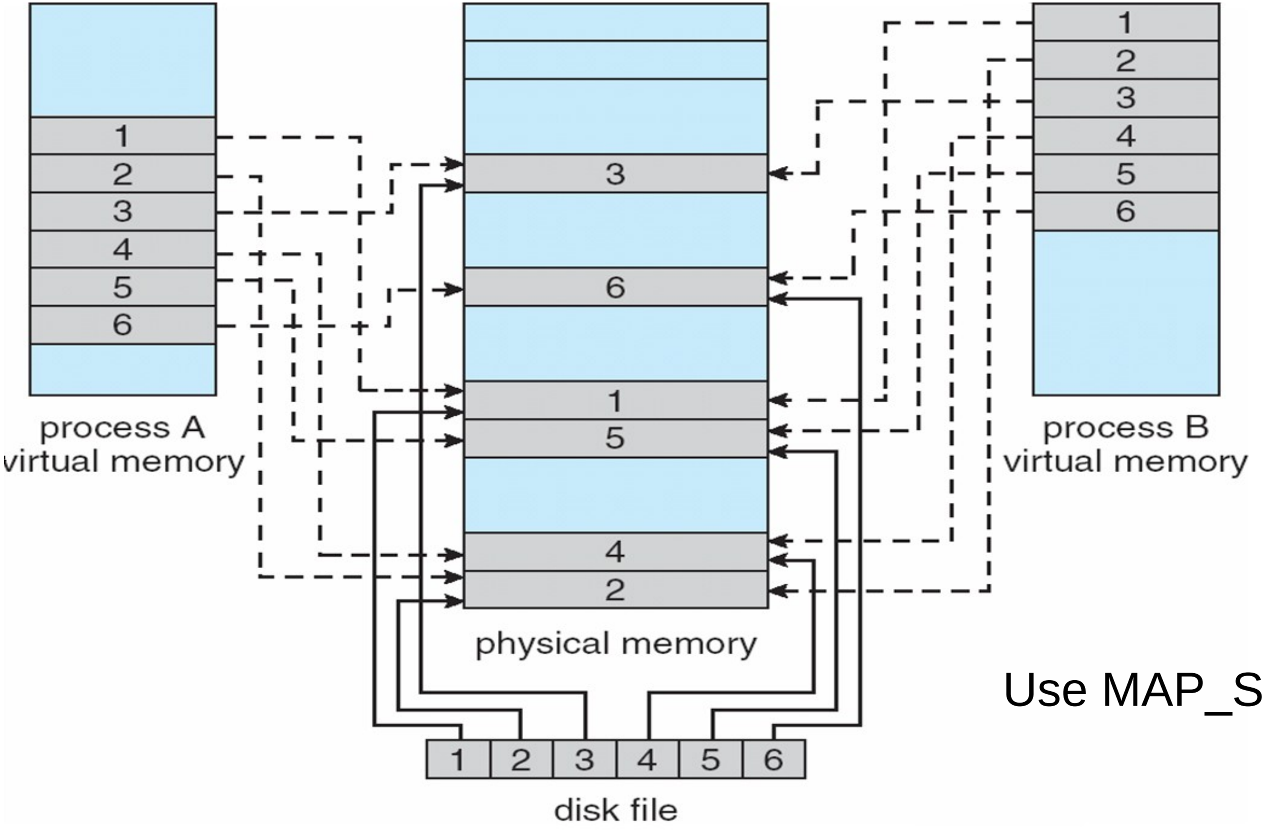


Memory Mapped Files

Memory-Mapped Files

- First, let's see a demo of using mmap()

Memory-Mapped Files



Use MAP_SHARED flag

Memory-Mapped Files

- Memory-mapped file I/O allows file I/O to be treated as routine memory access by mapping a disk block to a page in memory
- A file is initially read using demand paging
  - A page-sized portion of the file is read from the file system into a physical page
  - Subsequent reads/writes to/from the file are treated as ordinary memory accesses
- Simplifies and speeds file access by driving file I/O through memory rather than read() and write() system calls
- Also allows several processes to map the same file allowing the pages in memory to be shared
- But when does written data make it to disk?
  - Periodically and / or at file close() time
  - For example, when the pager scans for dirty pages

Memory-Mapped Files

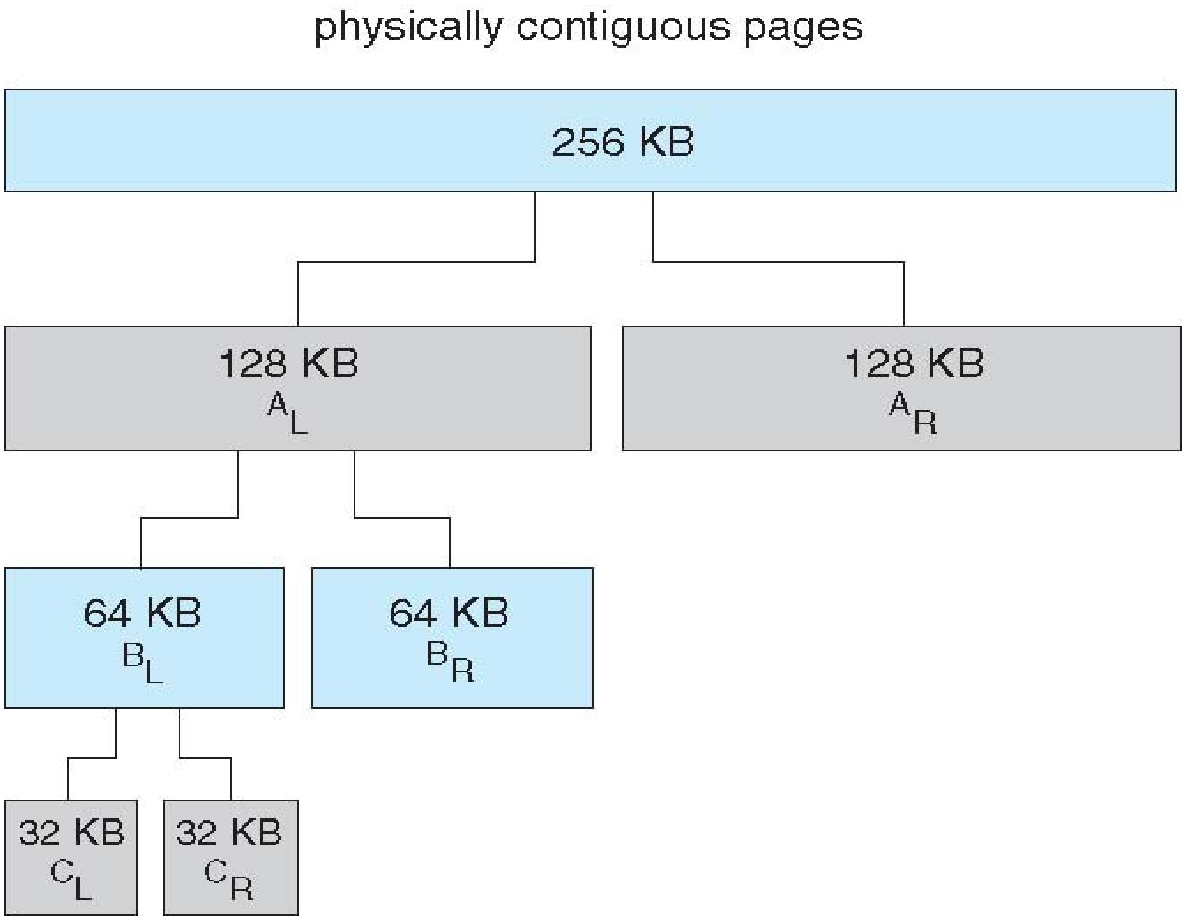
- Some OSes uses memory mapped files for standard I/O
- Process can explicitly request memory mapping a file via mmap() system call
  - Now file mapped into process address space
- For standard I/O (open(), read(), write(), close()), mmap anyway
  - But map file into kernel address space
  - Process still does read() and write()
    - Copies data to and from kernel space and user space
  - Uses efficient memory management subsystem
    - Avoids needing separate subsystem
- COW can be used for read/write non-shared pages
- Memory mapped files can be used for shared memory (although again via separate system calls)

Allocating Kernel Memory

Allocating kernel memory

- Treated differently from user memory
- Often allocated from a free-memory pool
  - Kernel requests memory for structures of varying sizes
  - Some kernel memory needs to be contiguous
  - I.e. for device I/O
-

Buddy Allocator



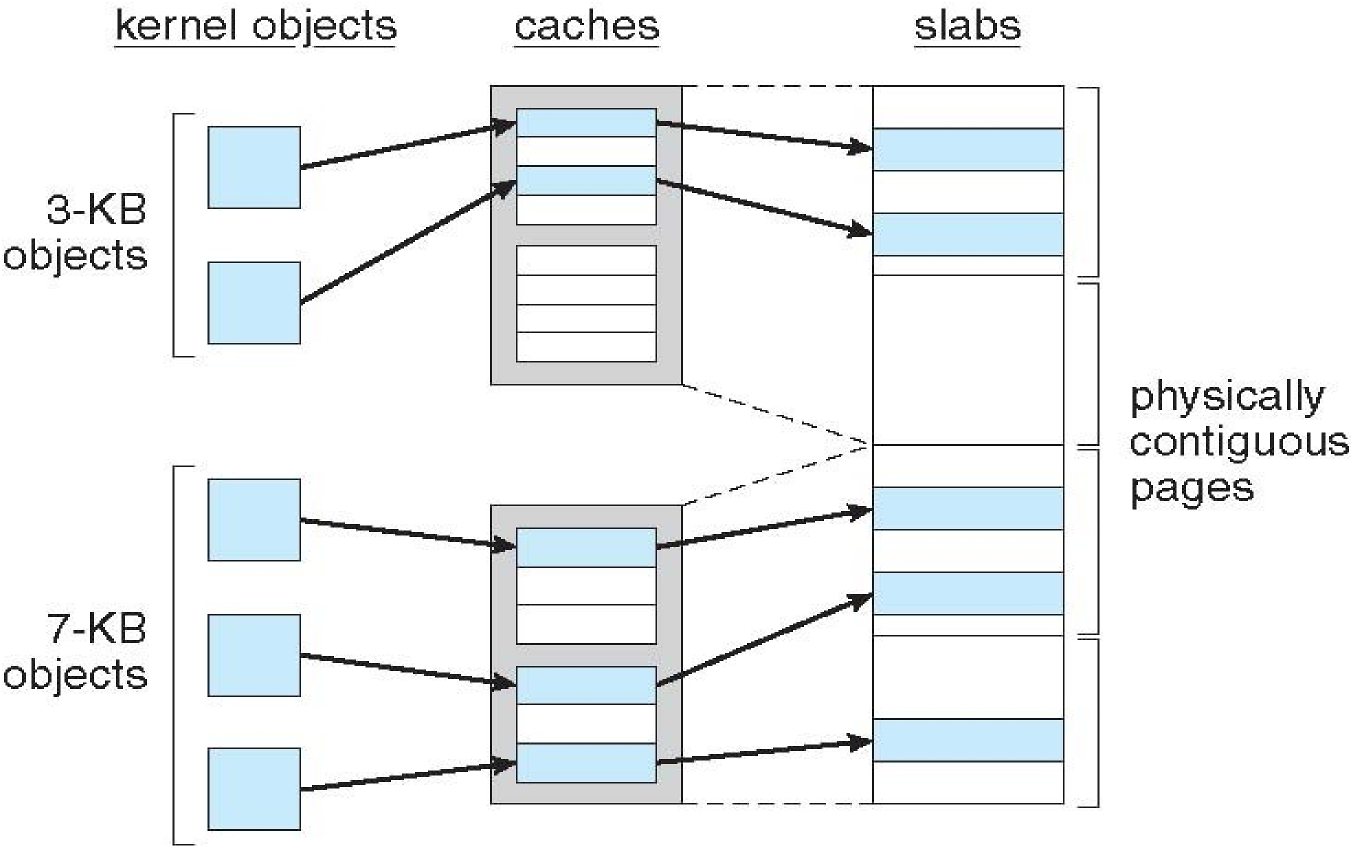
Buddy Allocator

- Allocates memory from fixed-size segment consisting of physically-contiguous pages
- Memory allocated using power-of-2 allocator
  - Satisfies requests in units sized as power of 2
  - Request rounded up to next highest power of 2
  - When smaller allocation needed than is available, current chunk split into two buddies of next-lower power of 2
  - Continue until appropriate sized chunk available

Buddy Allocator

- Continue until appropriate sized chunk available
- For example, assume 256KB chunk available, kernel requests 21KB
  - Split into AL and Ar of 128KB each
    - One further divided into BL and BR of 64KB
      - One further into CL and CR of 32KB each – one used to satisfy request
- Advantage – quickly coalesce unused chunks into larger chunk
- Disadvantage - fragmentation

Slab Allocator



Slab Allocator

- Alternate strategy
- **Slab** is one or more physically contiguous pages
- **Cache** consists of one or more slabs
- Single cache for each unique kernel data structure
  - Each cache filled with **objects** – instantiations of the data structure
- When cache created, filled with objects marked as **free**
- When structures stored, objects marked as **used**
- If slab is full of used objects, next object allocated from empty slab
  - If no empty slabs, new slab allocated
- Benefits include no fragmentation, fast memory request satisfaction

Other considerations

Other Considerations -- Prepaging

- To reduce the large number of page faults that occurs at process startup
- Prepage all or some of the pages a process will need, before they are referenced
- But if prepaged pages are unused, I/O and memory was wasted
- Assume s pages are prepaged and α of the pages is used
  - Is cost of $s * \alpha$ save pages faults > or < than the cost of prepaging
    $s * (1- \alpha)$ unnecessary pages?
  - α near zero --> prepaging loses

Page Size

- Sometimes OS designers have a choice
  - Especially if running on custom-built CPU
- Page size selection must take into consideration:
  - Fragmentation
  - Page table size
  - **Resolution**
  - I/O overhead
  - Number of page faults
  - Locality
  - TLB size and effectiveness
- Always power of 2, usually in the range 2^{12} (4,096 bytes) to 2^{22} (4,194,304 bytes)
- On average, growing over time

TLB Reach

- TLB Reach - The amount of memory accessible from the TLB
- TLB Reach = (TLB Size) X (Page Size)
- Ideally, the working set of each process is stored in the TLB
  - Otherwise there is a high degree of page faults
- Increase the Page Size
  - This may lead to an increase in fragmentation as not all applications require a large page size
- Provide Multiple Page Sizes
  - This allows applications that require larger page sizes the opportunity to use them without an increase in fragmentation

Program Structure

- Program structure
- `Int[128,128] data;`
- Each row is stored in one page
- Program 1

```
for (j = 0; j <128; j++)
    for (i = 0; i < 128; i++)
        data[i,j] = 0;
```

128 x 128 = 16,384 page faults

- Program 2

```
for (i = 0; i < 128; i++)
    for (j = 0; j < 128; j++)
        data[i,j] = 0;
```

128 page faults

I/O Interlock

- **I/O Interlock** – Pages must sometimes be locked into memory
- Consider I/O - Pages that are used for copying a file from a device must be locked from being selected for eviction by a page replacement algorithm