Operating Systems: Virtual Memory – Part II

Neerja Mhaskar

Department of Computing and Software, McMaster University, Canada

Acknowledgements: Material based on the textbook Operating Systems Concepts (Chapter 10)

Page-Buffering Algorithms

- Used in *conjunction* with page replacement algorithms.
- Maintains a fixed minimum number of free frames called free-frame pool
  - Frame numbers in the pool can vary
- When page fault occurs
  - Select a victim frame (as before).
  - Read the new page into a free frame in the free frame pool,
  - Swap the victim page out when convenient.
    - Add its frame to the free frame pool.
- Advantage: Process causing the page fault restarted faster.
- Disadvantage: Fewer free frames available.

Allocation of Frames

- Various strategies/algorithms are available to allocate frames to processes (after allocating frames to OS)
  - **Equal allocation** - Allocate free frames equally among processes
  - **Proportional allocation** - Allocate frames to each process according to its size
  - **Priority allocation** - Higher priority processes get more frames.
- Each process needs ***minimum*** **number of frames** to execute.
  - This is defined by the computer architecture.

Global Vs. Local Replacement

- **Global Vs Local replacement**
- **Global replacement** - process selects a replacement frame from the set of all frames.
  - one process can take a frame from another process
- **Local replacement** – each process selects from only its own set of allocated frames

Thrashing

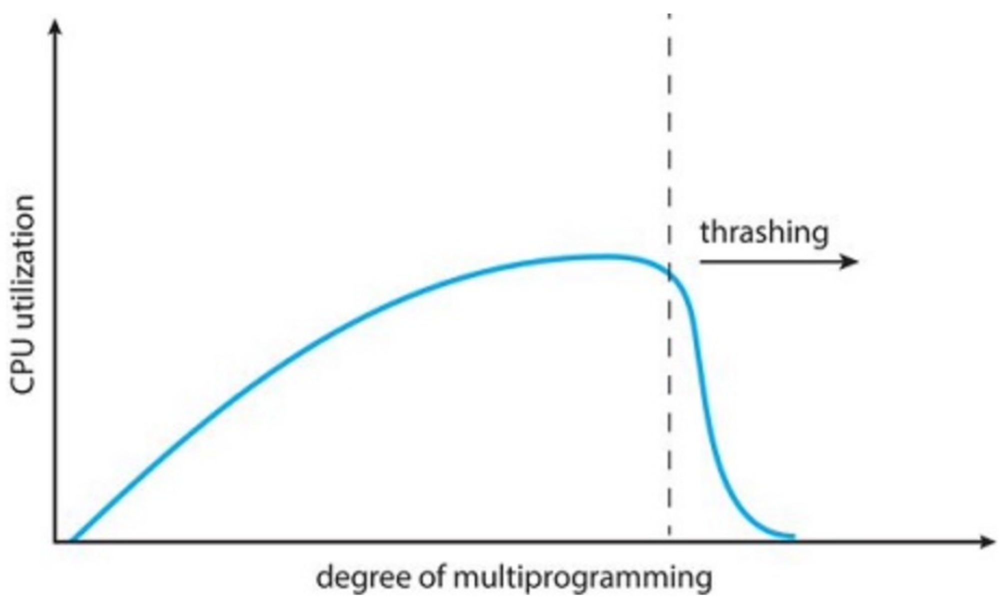
Thrashing – is a situation in which the system is busy swapping pages of a process in and out of memory, instead of executing its instructions on the CPU.

How does Thrashing occur in a system?

- A process needs a certain no. of frames to support the active pages.
- If it does not have the required number of frames, it will
  - page fault to get the desired page in memory
    - As a result, it will replace a page in an **existing frame**
  - But quickly needs to replace a page again from a frame to bring in the replaced page!

Thrashing Continued …

- As the thrashing processes wait for the pages to be swapped in and out, CPU utilization drops sharply.
- As CPU utilization plummets, OS thinking that it needs to increase the degree of multiprogramming.
- Another process added to the system, thus worsening the problem!



How to Prevent Thrashing?

To prevent thrashing, we must provide a process with as many frames as it needs for all its active pages.

How do we know how many frames it "needs"?

- Working-set Model
- Page Fault Frequency

Working Set Model

- **Locality** is a set of pages that are *actively* used together.
- During execution processes **move from locality to locality.**
- To avoid thrashing enough frames should be allocated to accommodate the size of the process's current locality.
- **Working-Set Model** – is a model of memory access based on tracking the set of most recently accessed pages.
  - Approximates the process's current locality.

Page Fault Frequency

- Thrashing has a high page fault rate.
- Page fault rate high => process needs more frames.
- Page-fault rate is too low => process may have too many frames
- To control page fault frequency rate, establish upper and lower limits on the desired page-fault rate
  - Page fault rate > upper limit – allocate more frames to the process
  - Page-fault rate < lower limit - remove a frame from process

Allocating Kernel Memory

- So far, we have discussed about process' memory.
- Kernel memory is often allocated from a **free-memory pool** as:
  - Certain hardware devices interact directly with physical memory and may require memory in contiguous pages.
  - Memory needed for kernel data structures is of varying sizes (some smaller than half a pages).
    - Kernel must ensure that minimum memory is wasted due to fragmentation.

Allocating Kernel Memory

- Two strategies adopted for managing free memory that is assigned to kernel processes:
  - Buddy System
  - Slab Allocation

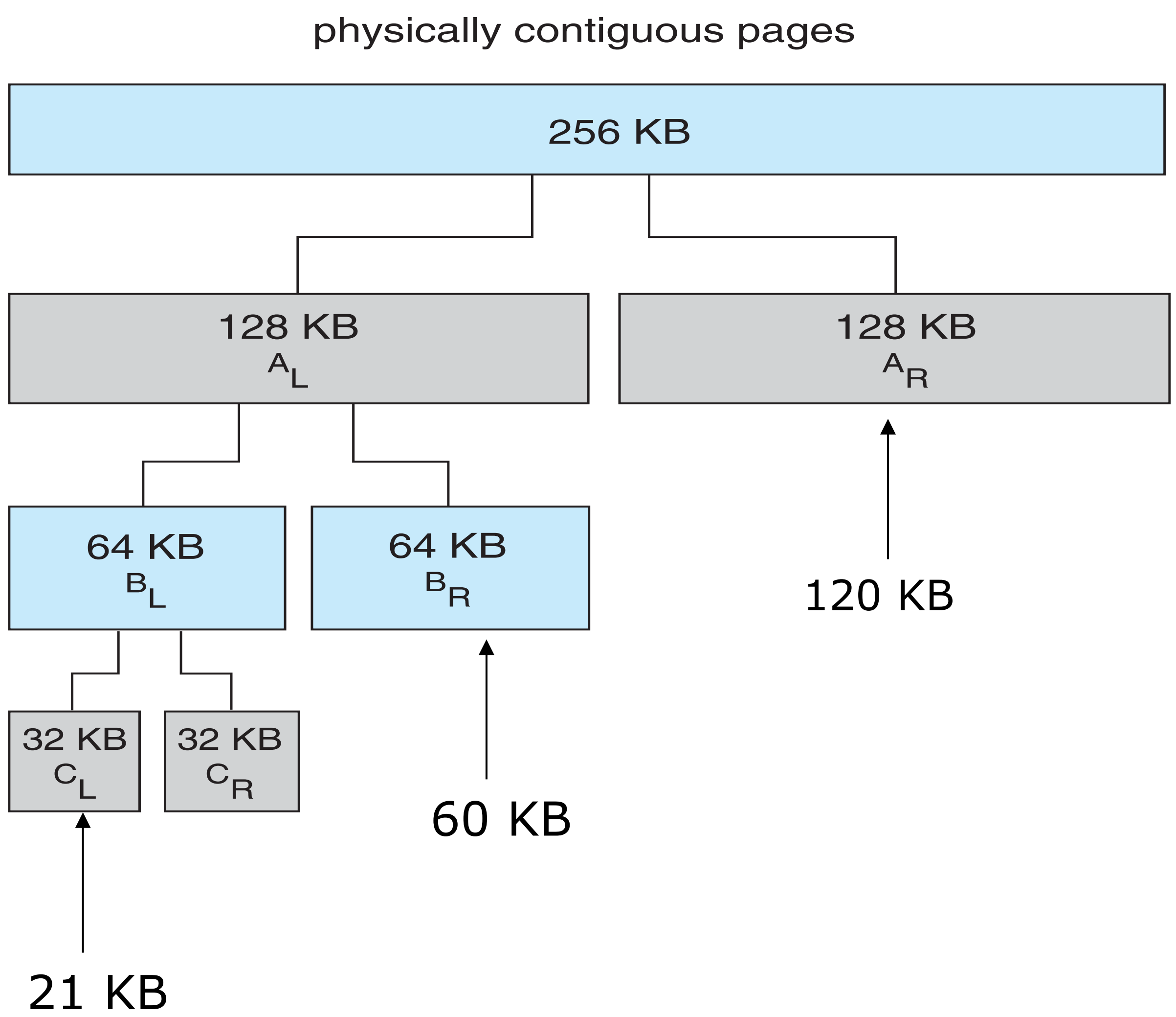
Buddy System

- 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 appropriately sized chunk available
- Advantage – quickly coalesce unused chunks into larger chunk (**note that only buddies can be coalesced**)
- **Disadvantage – internal fragmentation**

Buddy System Example

- For example, assume 256KB chunk available, kernel makes the following requests
  - request 21KB,
  - request 60 KB, and
  - request 120KB
- Rounding the request of 21KB to the closest power of 2 > 21, we get segment of size 32KB. Therefore, request 21KB is satisfied by memory segment C_L (see the tree in next slide).
- Other requests (60KB and 120KB) are satisfied in a similar way.
- If request 60KB and 120KB are released, we cannot coalesce, these segments as they were not buddies – that is they did not result from the same partition.
- However, if request 21KB is released later, then all the segments can coalesce to form the original 256KB segment.

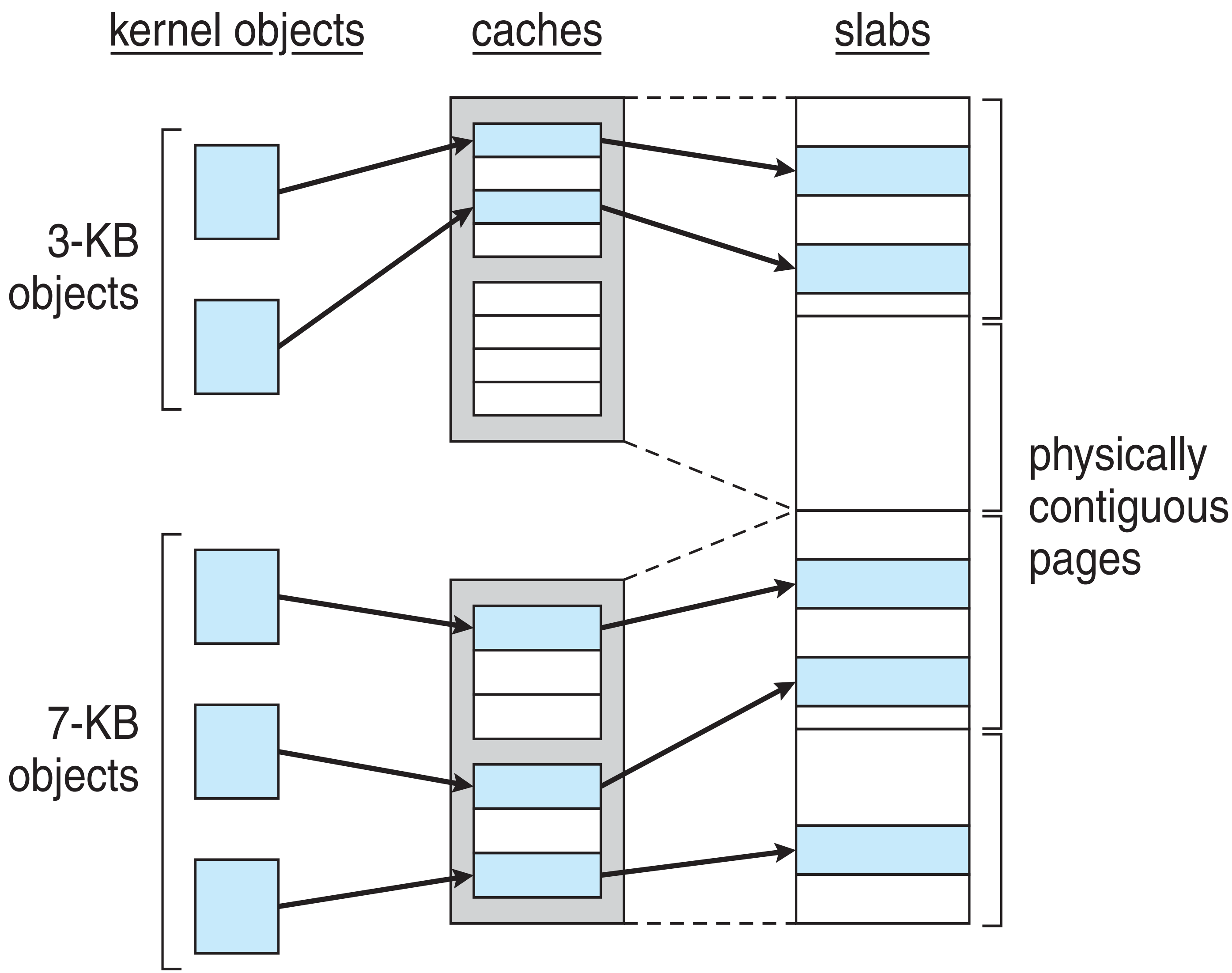
Buddy System Example Cont…



Slab Allocation

- **Slab** is one or more physically contiguous pages
- **Cache** consists of one or more slabs.
  - Single cache for each unique kernel data structure (e.g.: separate cache for program descriptors, semaphores, file objects etc.)
  - Each cache is filled with **object** instantiations of the kernel data structure the cache represents.
  - Objects are marked as free or used.

Slab Allocation



Slab Allocation Illustration continued…

- When cache is created it is filled with objects marked as `free`
- Objects assigned from cache are marked as `used`.
- If a slab is full of used objects, the next free object is allocated first from a partial slab (if available), otherwise it is allocated from an empty slab.
  - If no empty slabs, then new slab allocated from contiguous physical pages and assigned to a cache, and
  - memory for the object is allocated from this slab.

Slab Linux Example

- Suppose kernel requests memory from the slab allocator for an object representing a PCB (process control block) which requires around 1.7 KB of memory.
- Kernel creates a new task; it requests the necessary memory for the PCB object from its cache.
- The cache will fulfill the request using a task_struct object that has already been allocated in a slab and is marked as free.

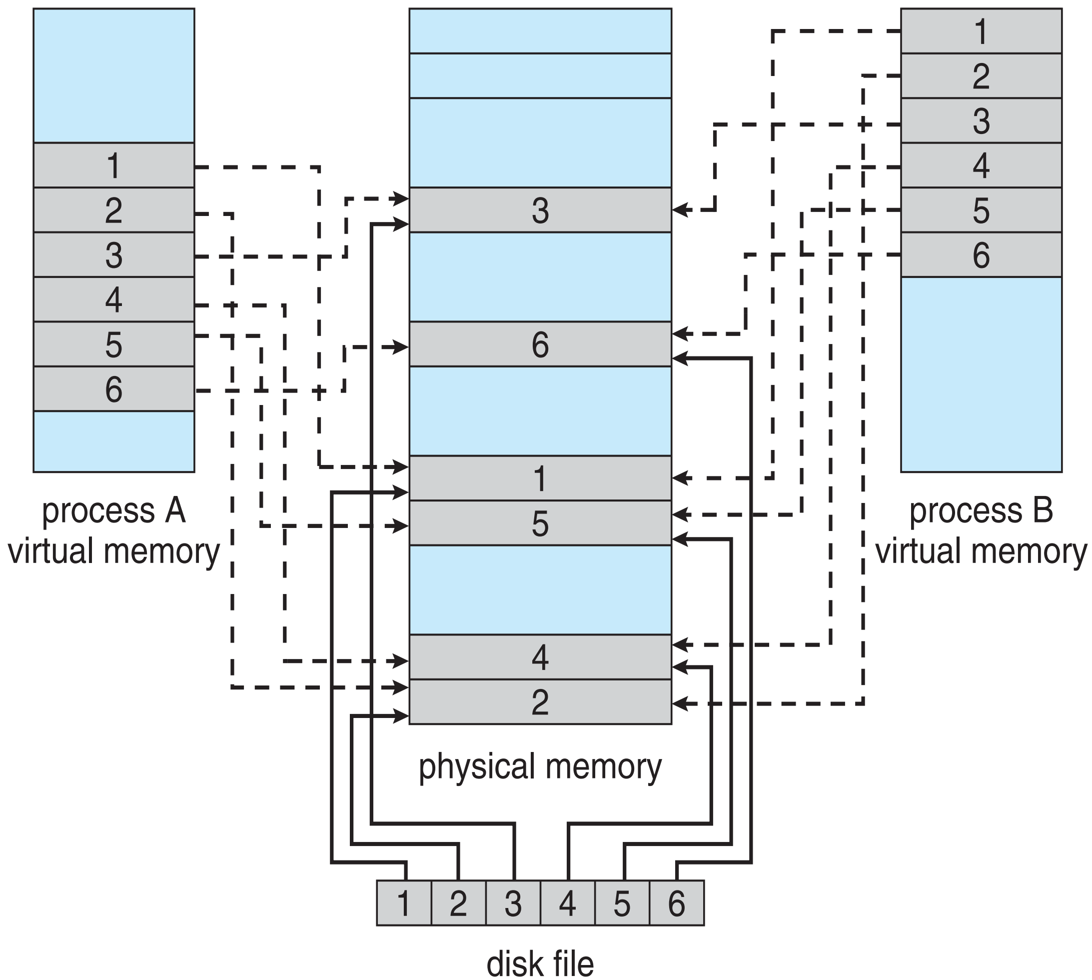
Slab Allocation Advantanges

- No fragmentation
- Fast memory request satisfaction (as no allocation and deallocation of memory)
- Slab Allocation used in Solaris, and now used by various Operating Systems (e.g., Linux)

Memory-Mapped Files

- Memory-mapped file 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 frame in memory
  - 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 to the same file allowing the pages in memory to be shared
- Data written back to disk periodically and/or at file `close()` time
- Some operating systems (e.g Solaris) use memory mapped files for standard I/O.

Memory Mapped Files



Copy-on-Write

- Consider the fork() system call to create a new child process.
  - It creates a copy of the parent's address space for the child.
  - As most fork() calls are followed by exec() system, the above steps is unnecessary.
- **Copy-on-Write** (COW) allows both parent and child processes to initially ***share*** the same pages in memory
  - If either process modifies a shared page, only then is the page copied
- COW allows more efficient process creation as only modified pages are copied.