Systems and Networking I

Applied Computer Science and Artificial Intelligence

2023-2024

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Linear scan of all the pages to select the one to be removed

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Still too expensive as the OS must change multiple pointers on each memory access

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  - No total order of page access

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- The specific number of bits used and the frequency with which the reference byte is updated are adjustable

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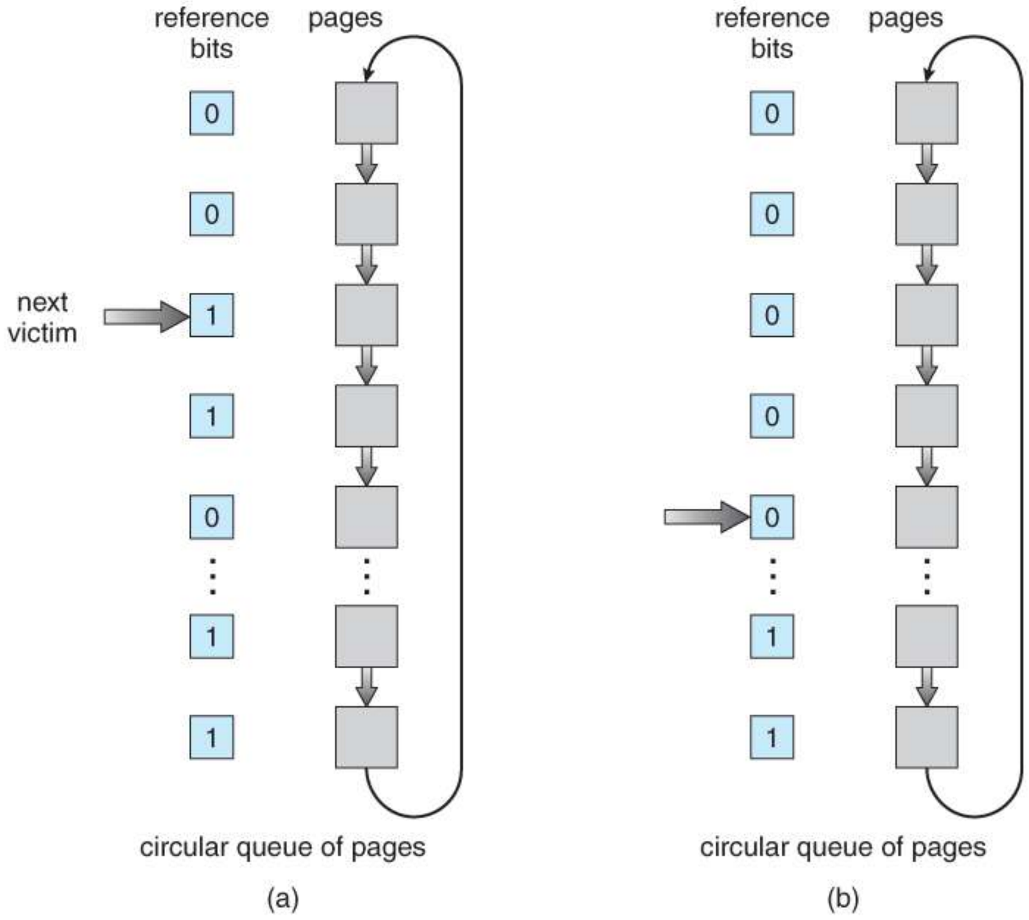
- OS keeps frames in a FIFO circular list
- On every memory access, the reference bit is set to 1
- On a page fault, the OS scans the list of frames, checking the reference bit of the frame:
  - If this is 0, it replaces the page and sets it to 1
  - If this is 1, it sets it to 0 (second chance) and move to the next frame

Second Chance Algorithm (Clock)



A raw partitioning into: young vs. old frames

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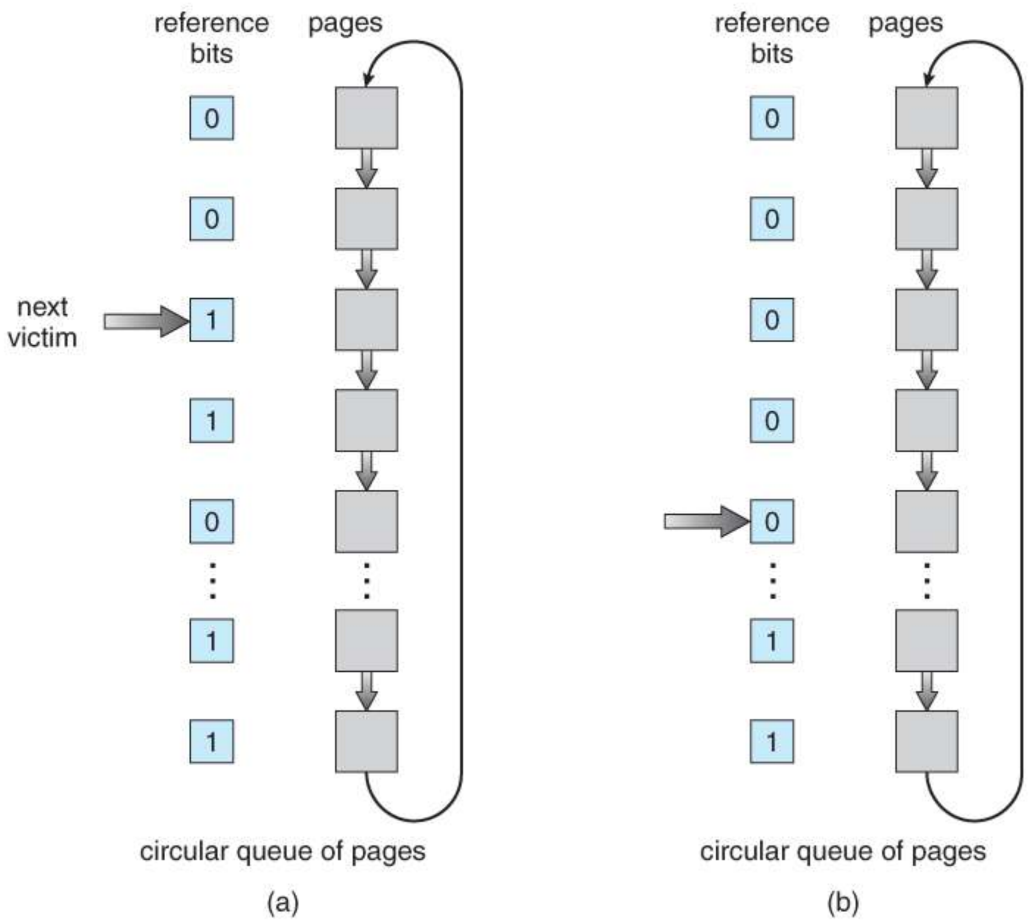

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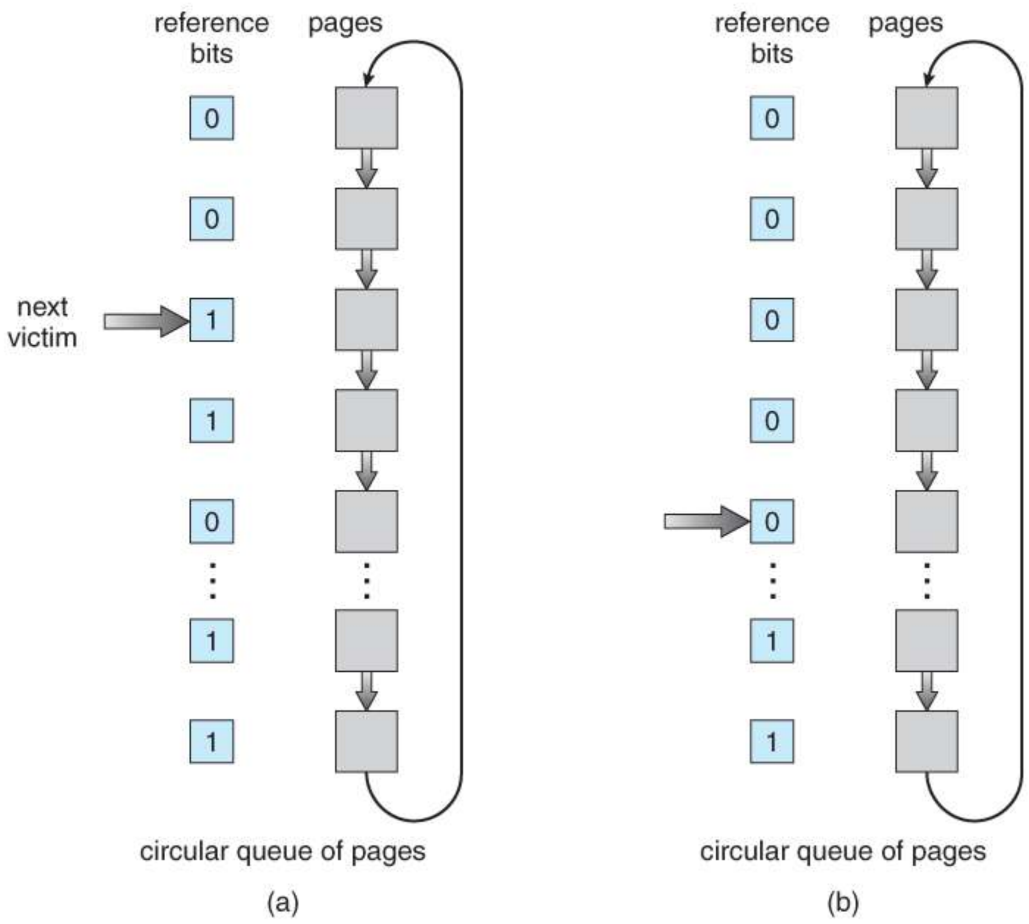

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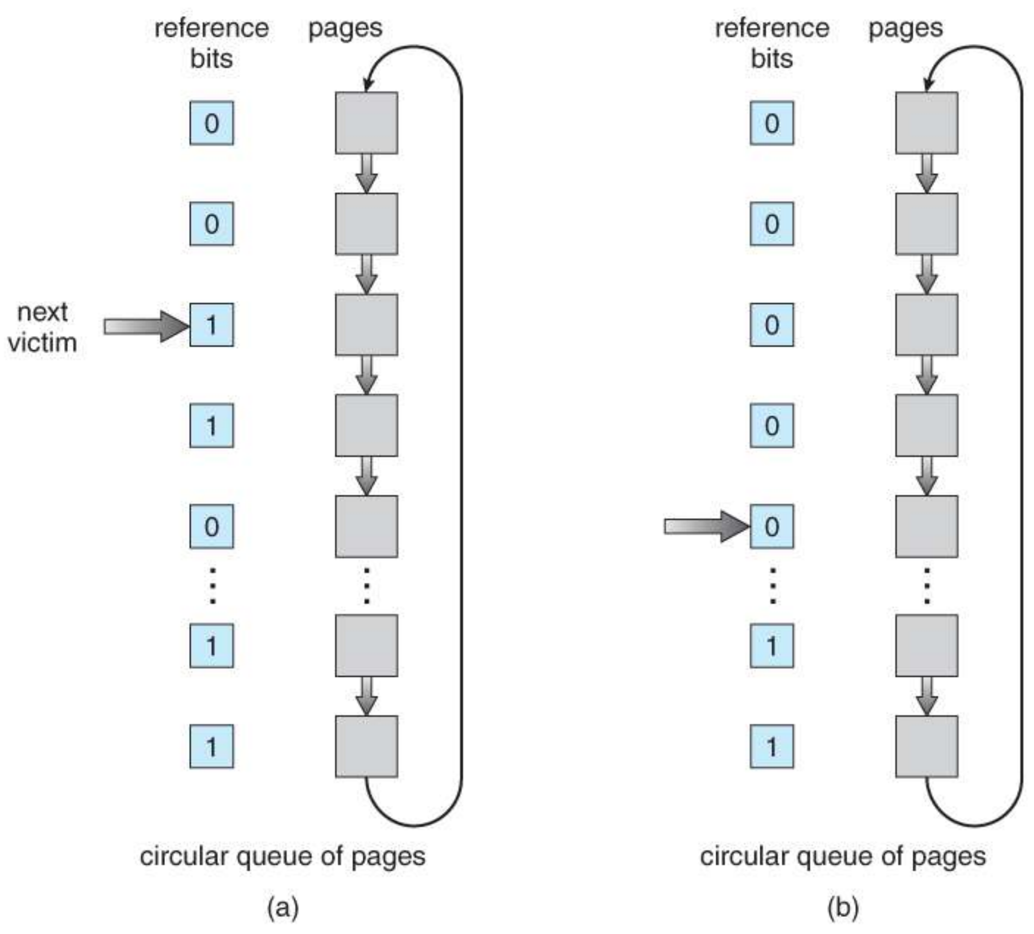

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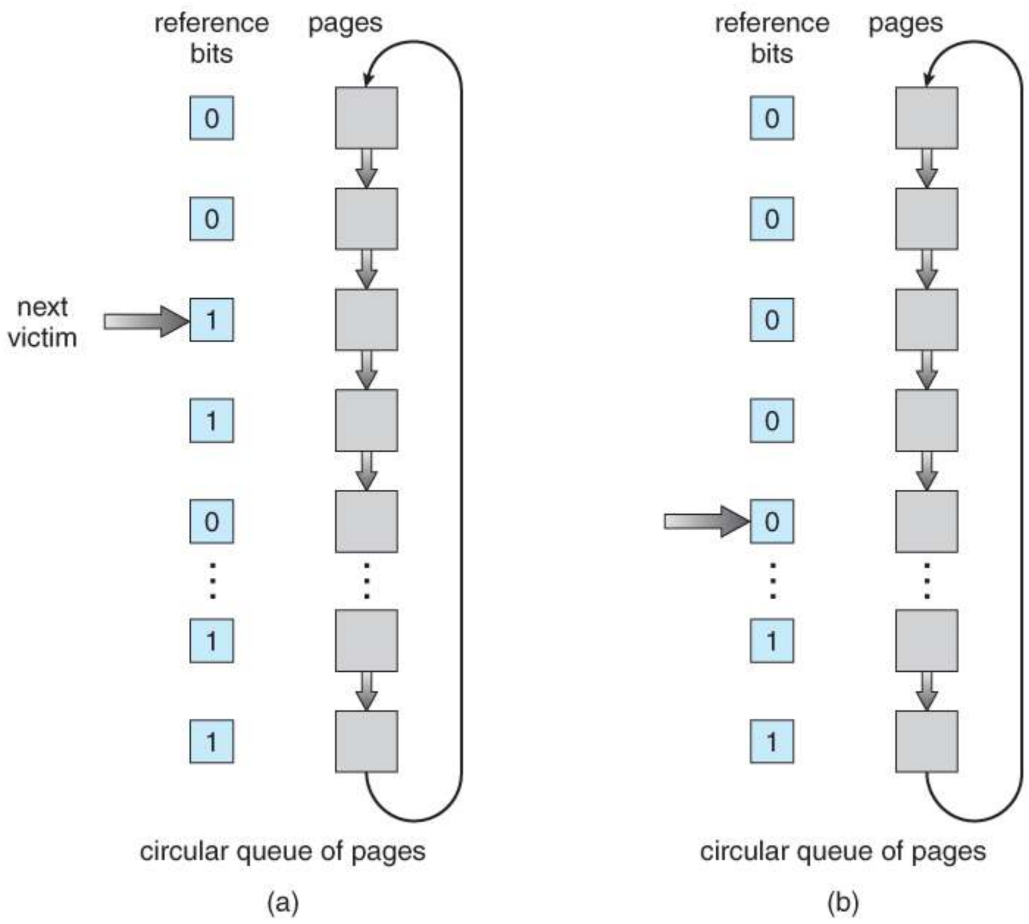

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This algorithm is also known as clock because it mimics the hands of a clock

Enhanced Second Chance Algorithm

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- Page replacement generally involves 2 I/O operations:
  - write the evicted page back to disk
  - read the newly referenced page from disk
- Intuition: It is cheaper to replace a page which has not been modified, since the OS does not need to write this back to disk

Enhanced Second Chance Algorithm

- OS should give preference to paging-out un-modified frames
- Yet, it can proactively write to disk modified frames for later

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- HW keeps a modify bit (in addition to the reference bit)
  - 1 means the page has been modified (different from the copy on disk)
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- HW keeps a modify bit (in addition to the reference bit)
  - 1 means the page has been modified (different from the copy on disk)
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- Use both the reference and modify bits (r, m) to classify pages into:
  - (0, 0): neither recently used nor modified;
  - (0, 1): not recently used, but modified;
  - (1, 0): recently used, but clean
  - (1, 1): recently used and modified

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- Prioritize replacement of clean pages if possible

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- Multiple processes can however run concurrently on a single-CPU system
- The degree of multiprogramming is not fixed apriori, yet it is driven by the locality reference (a.k.a. 90÷10 rule)
- This allows a system to load the **working set** (i.e., few pages) of many processes, thereby increasing the degree of multiprogramming

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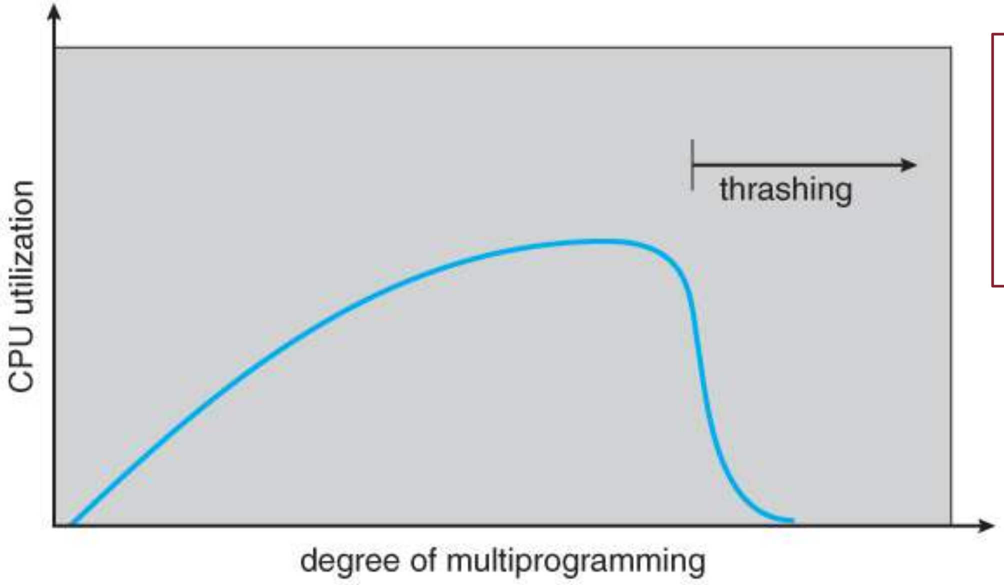
- When the degree of multiprogramming is too high, active working sets of running processes may saturate the whole memory capacity
- **Thrashing** → Memory is over-committed and pages are continuously tossed out while they are still in use
  - Memory access time approaches disk access time due to many page faults
  - Drastic degradation of performance

Multiprogramming and Thrashing



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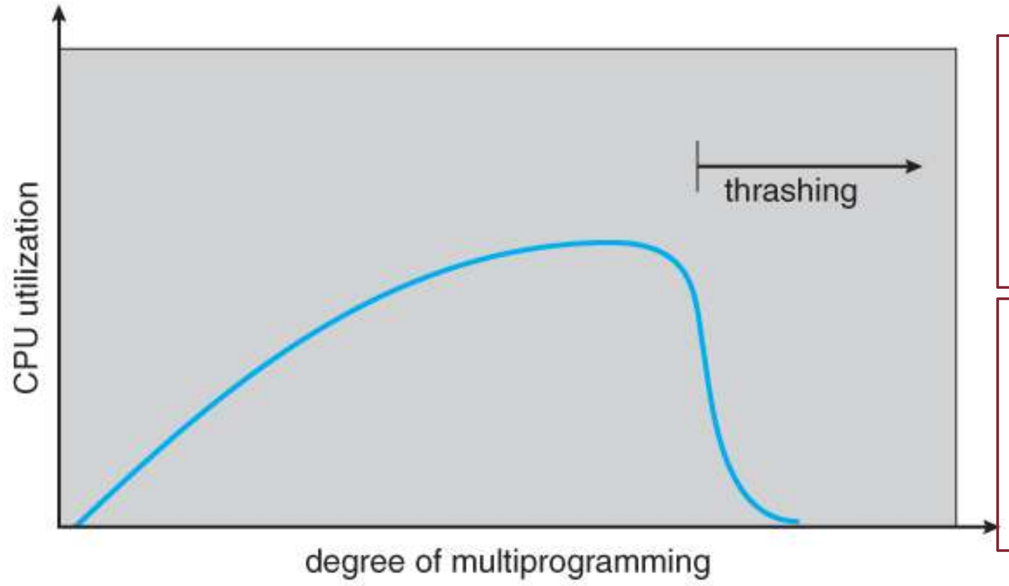

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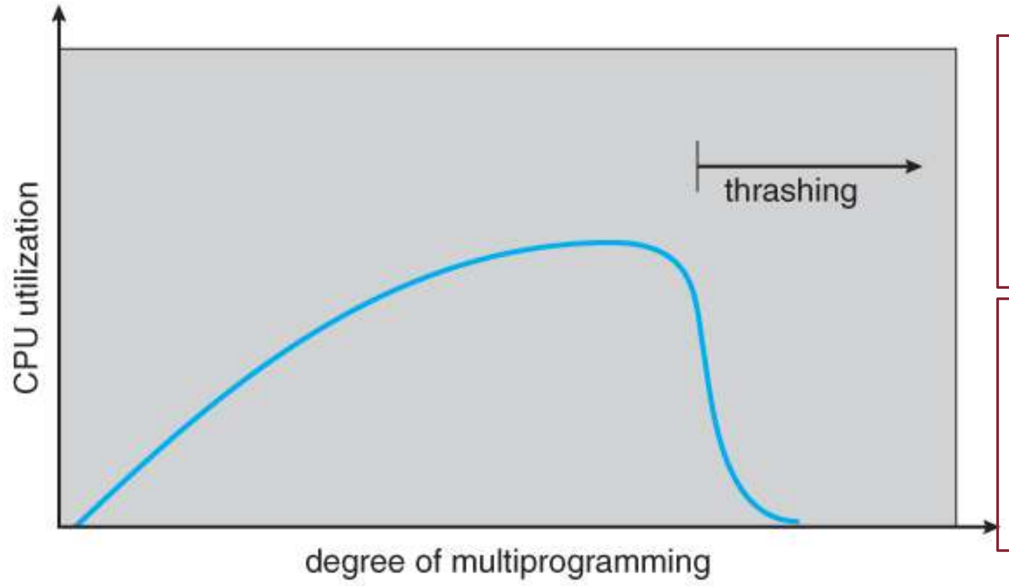

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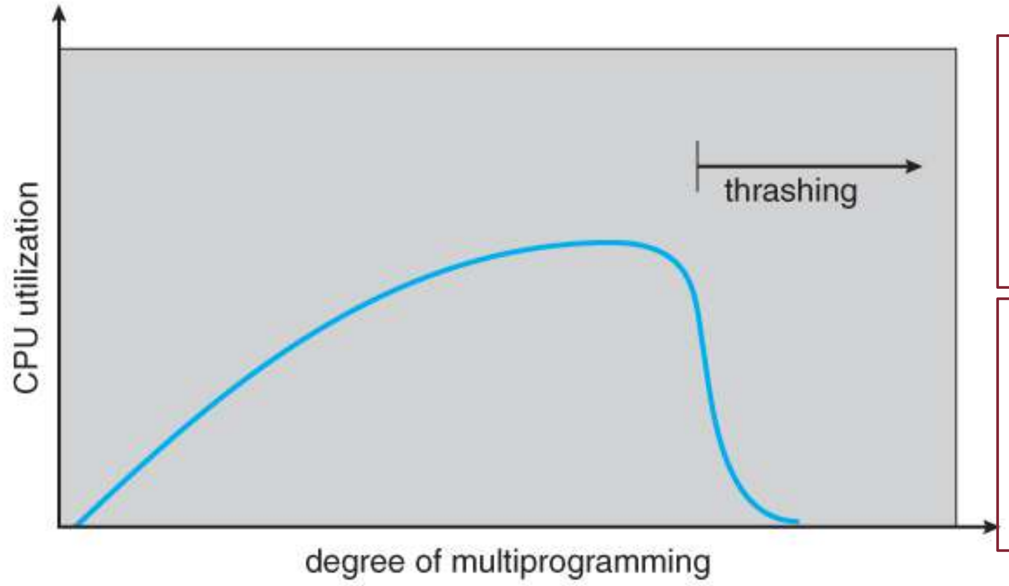

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Fixing the degree of multi-programming apriori may be a too inflexible option

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- All pages from all processes are in a single pool (single LRU queue)
- Upon page replacement, any page may be a potential victim, whether it currently belongs to the process seeking a free frame or not
- PRO: flexibility
- CON: thrashing more likely (no isolation)

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Local Allocation/Replacement

- Each process has its own fixed pool of frames
- Run only group of processes that fits in memory
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As allocations fluctuate over time, so does m (processes must be swapped out or not started if not enough frames)

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- However, there might be cases where this is not true
  - e.g., a process allocates a 1GB array but only uses a small portion of it
- In other words, the working set of a process may not be correlated with its memory footprint

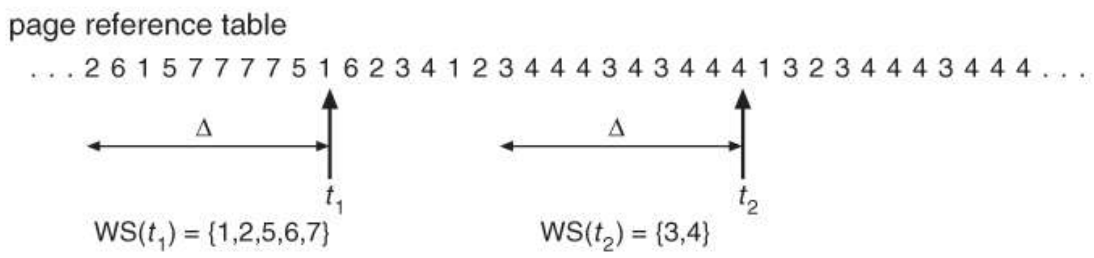
Matching the Working Set

- **Goal** → Give each process enough frames to contain its working set
  - Informally, the working set is the set of pages the process is using "right now"
  - More formally, it is the set of all pages that the process has referenced during the past T units of time (e.g., seconds)

Matching the Working Set

- How does the OS pick T?
  - 1 page fault takes order of 10 msecs to be served
  - 10 msecs ~ 10 million instructions
  - T needs to account for a lot more than 10 million instructions

Determining the Working Set



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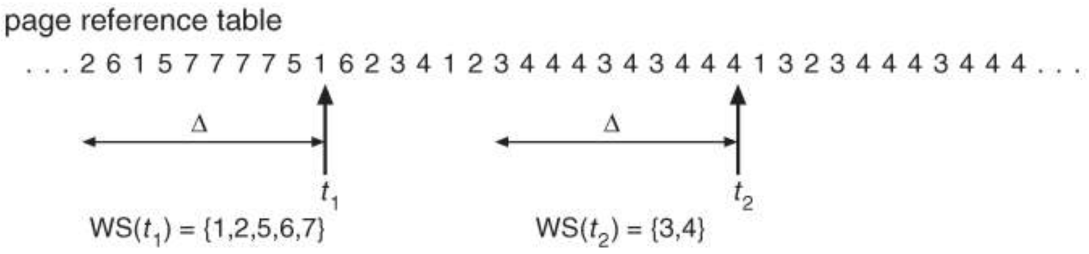

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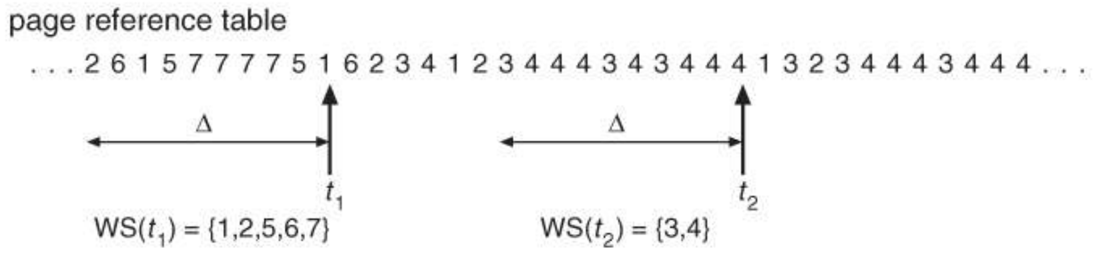

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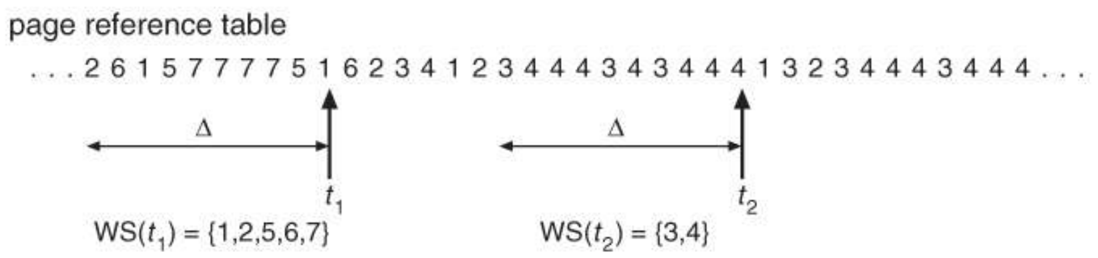

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Exact tracking is expensive: update the working set at each memory access

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- To avoid the overhead of keeping a list of the last Δ referenced pages, the working set is often implemented with **sampling**
- Every k memory references (e.g., k = 1,000), consider the working set to be all pages referenced within *that* period of time

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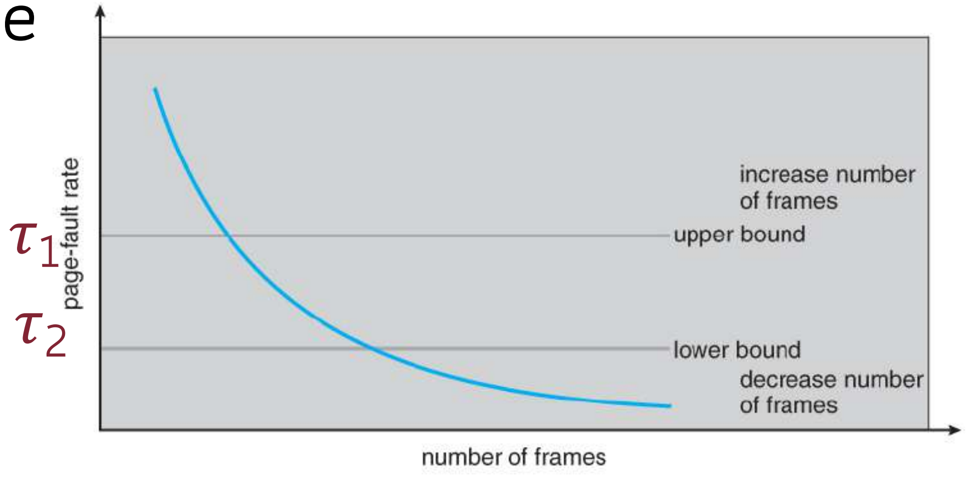

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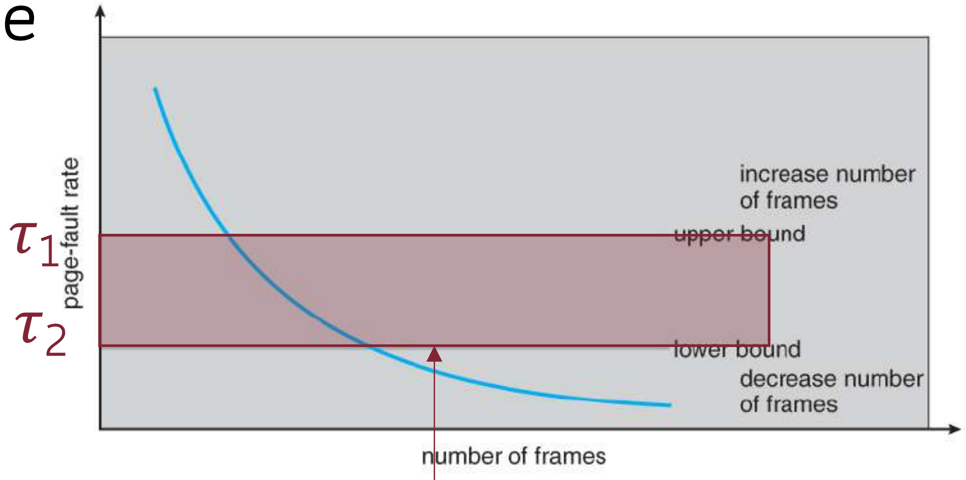

Dynamically adjust allocated frames so as to keep processes in this area

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- But kernel needs memory to store things too: code and data structures like PCB, page tables, etc.
- Kernel does not use any of the advanced mechanisms seen so far
  - No paging → what if a page fault occurs for the kernel?

Kernel Memory: Buddy Allocator

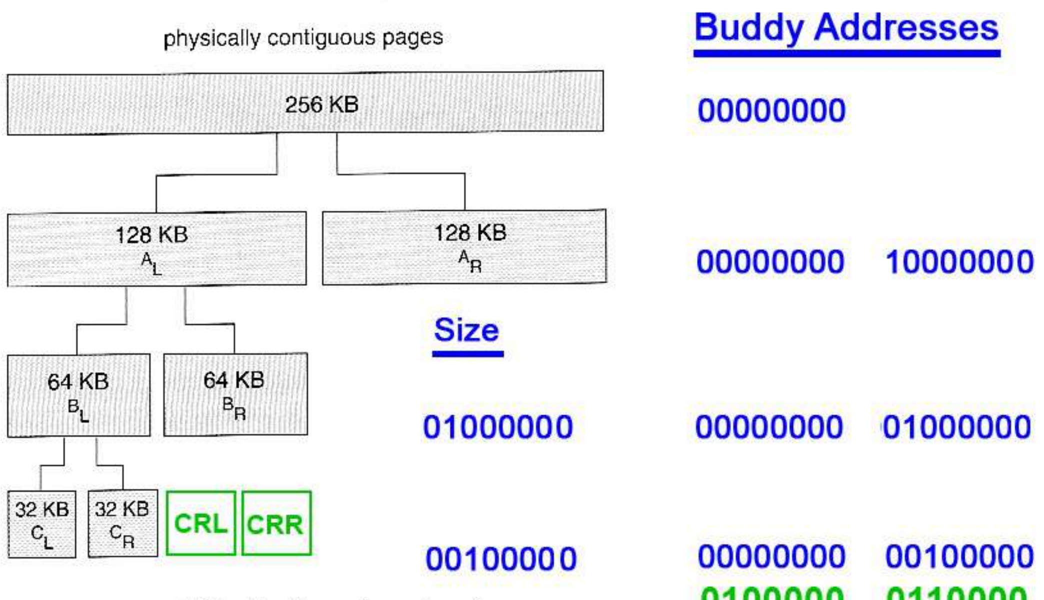

Figure 9.27 Buddy system allocation.

- Allocates memory using a power of 2 allocator (e.g., 4KiB, 8KiB, 16KiB), rounding up to the next nearest power of two if necessary

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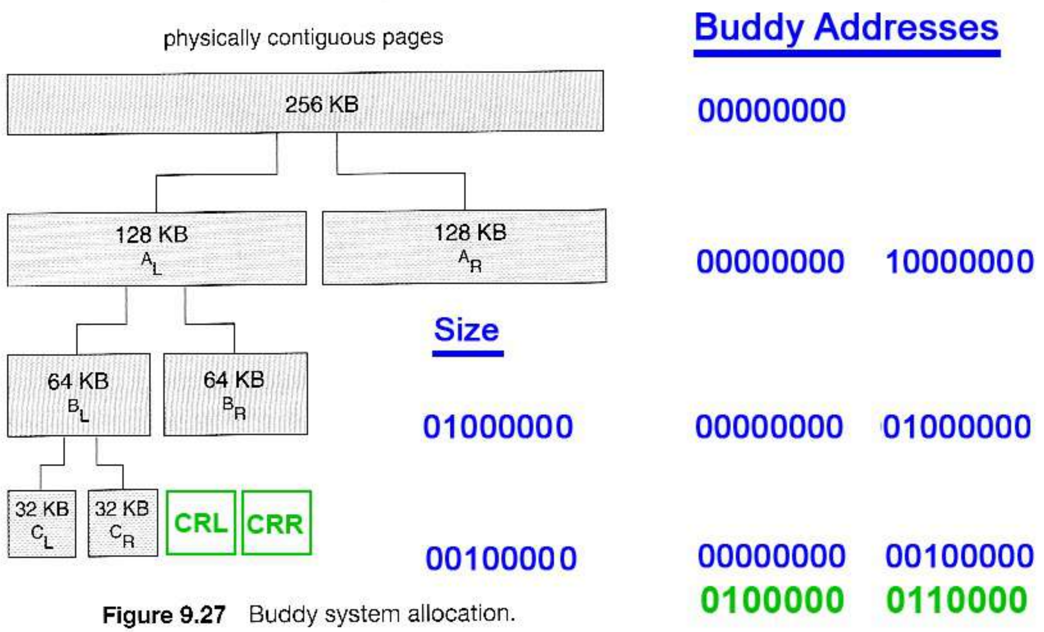

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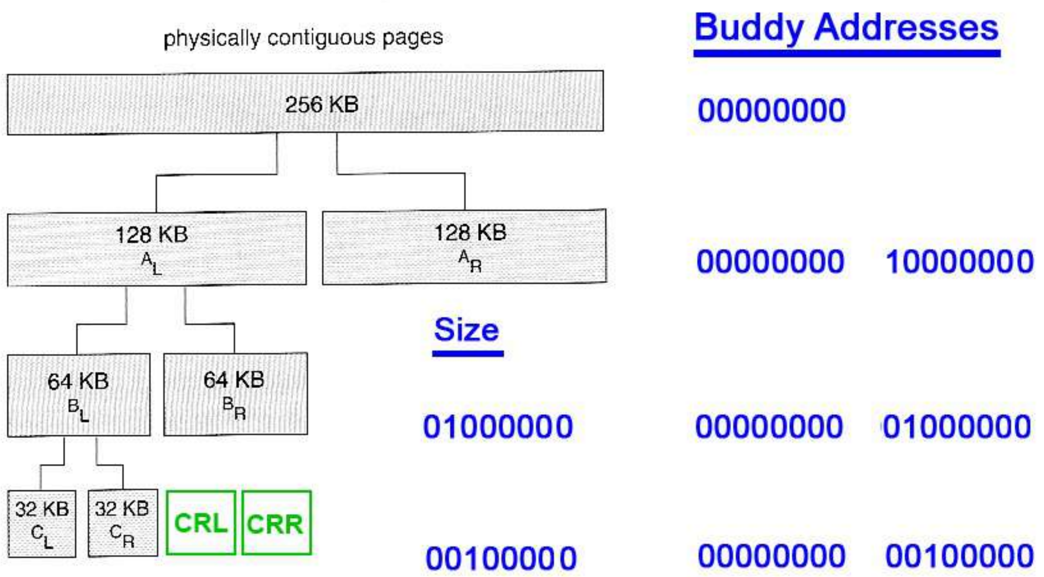

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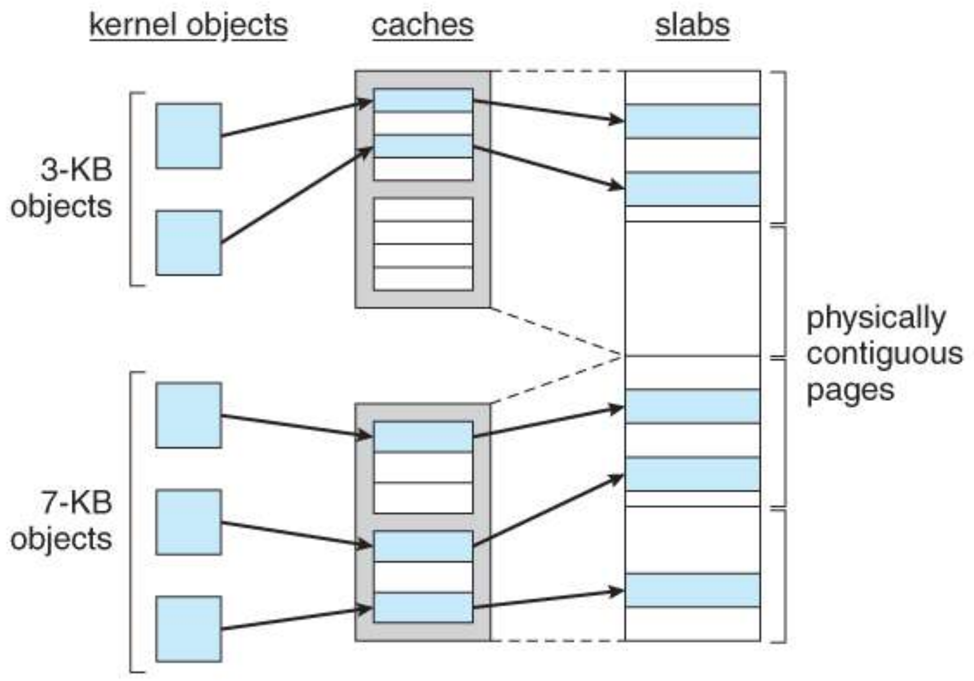
- If a block of the correct size is not available, then one is formed by (repeatedly) splitting the next larger block in two
- Can lead to internal fragmentation

Kernel Memory: Slab Allocator



- Group of objects of the same size in a **slab**
- Object cache points to one or more slabs
- Separate cache for each kernel data structure (e.g., PCB)
- No internal fragmentation
- Used in Solaris and Linux

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- Reasons for large pages?
  - Smaller page table size (i.e., smaller number of page table entries)
  - Fewer page faults (locality reference)
  - Amortizes disk overhead (reading a 1KiB page from disk takes approximately the same as reading an 8KiB one)

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  - All algorithms approach to the optimum as the physical memory allocated to a process approaches to the virtual memory size
- The more processes running concurrently, the less physical memory each one can have
- The OS must choose how many processes (and the number of frames per process) can share memory