Memory Management

Disclaimer: some slides are adopted from book authors' slides with permission

Recap: Performance of Demand Paging

- Memory access time = 200 nanoseconds
- Average page-fault service time = 8 milliseconds
- EAT = (1 – p) x 200 + p (8 milliseconds)

  = (1 – p) x 200 + p x 8,000,000

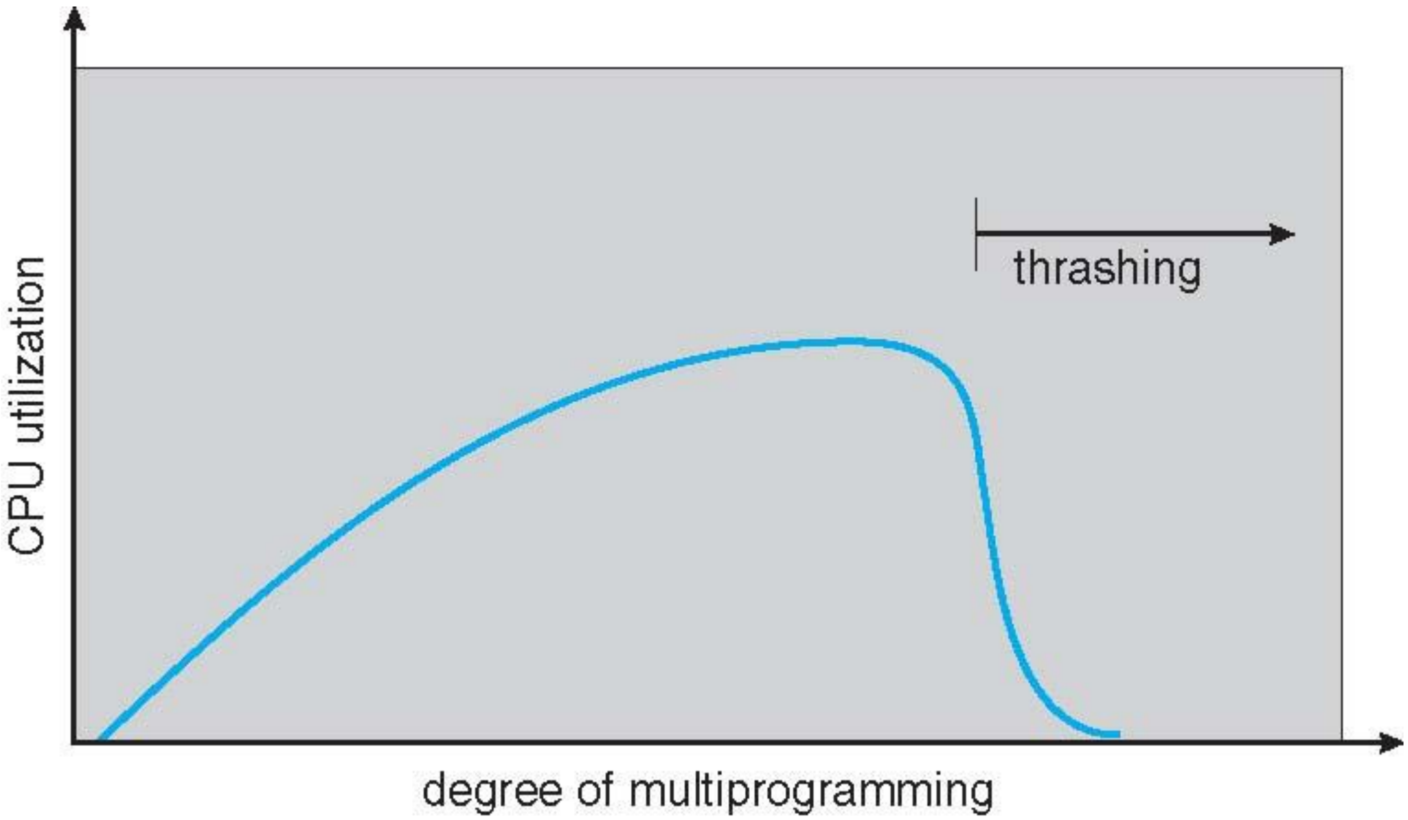
  = 200 + p x 7,999,800
- If one access out of 1,000 causes a page fault, then

  EAT = 8.2 microseconds. → This is a slowdown by a factor of 40!!
- If want performance degradation < 10 percent
  - 220 > 200 + 7,999,800 x p
    20 > 7,999,800 x p
  - p < .0000025
  - < one page fault in every 400,000 memory accesses

Thrashing

- A process is busy swapping pages in and out
  - Don’t make much progress
  - Happens when a process do not have “enough” pages in memory
  - Very high page fault rate
  - Low CPU utilization (why?)
  - CPU utilization based admission control may bring more programs to increase the utilization → more page faults

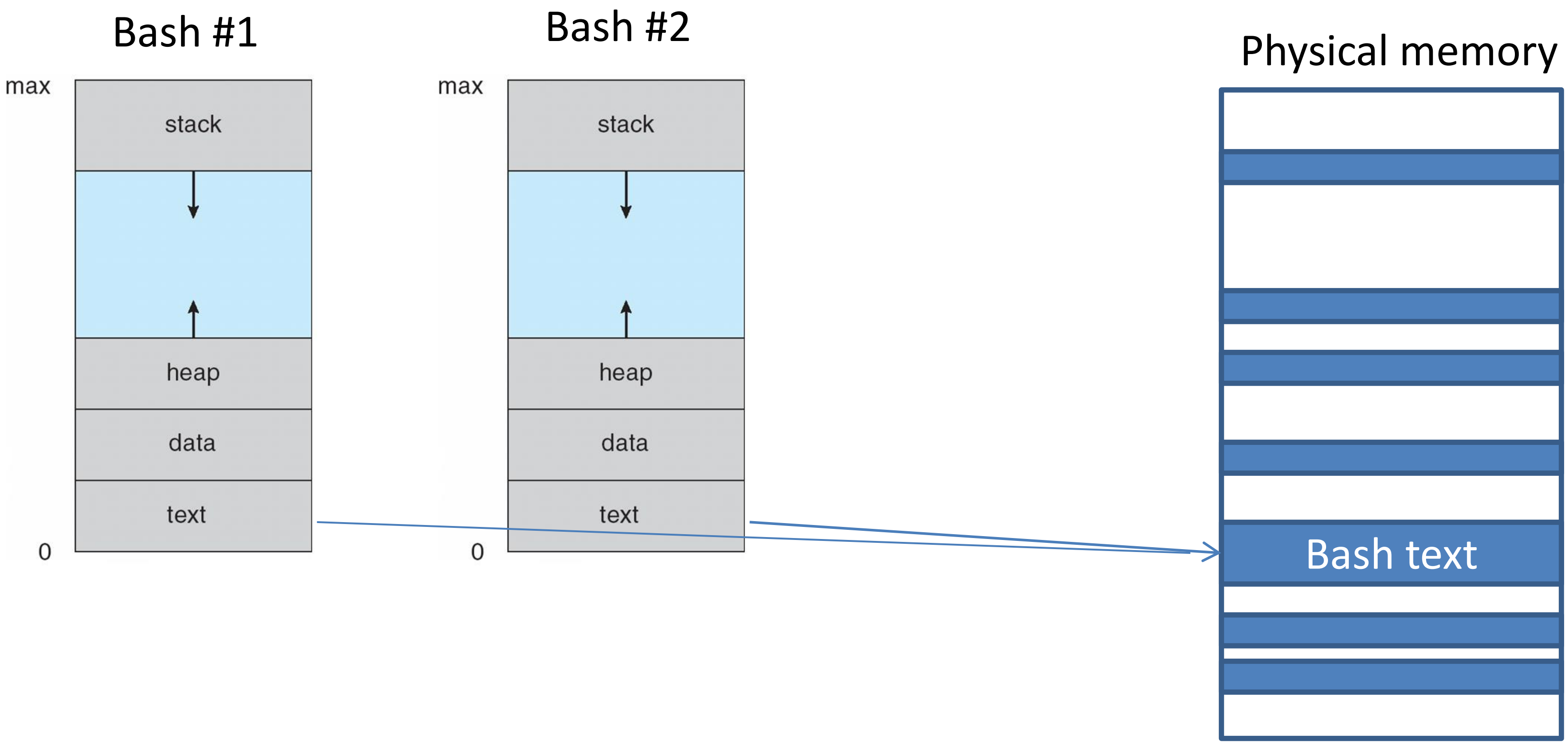
Thrashing



Concepts to Learn

- Memory-mapped I/O
- Copy-on-Write (COW)
- Memory allocator

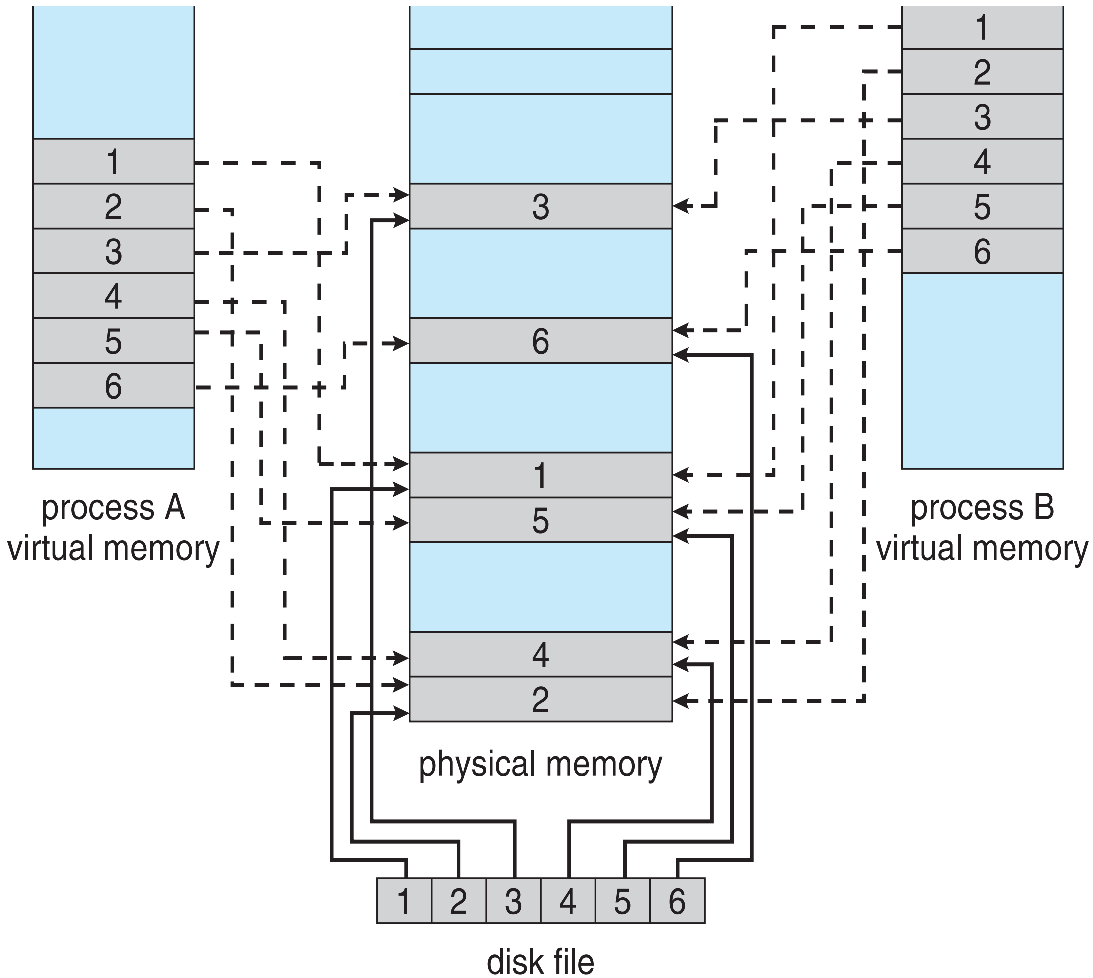
Recap: Program Binary Sharing



- Multiple instances of the same program
  - E.g., 10 bash shells

Memory Mapped I/O

- Idea: map a file on disk onto the memory space



Memory Mapped I/O

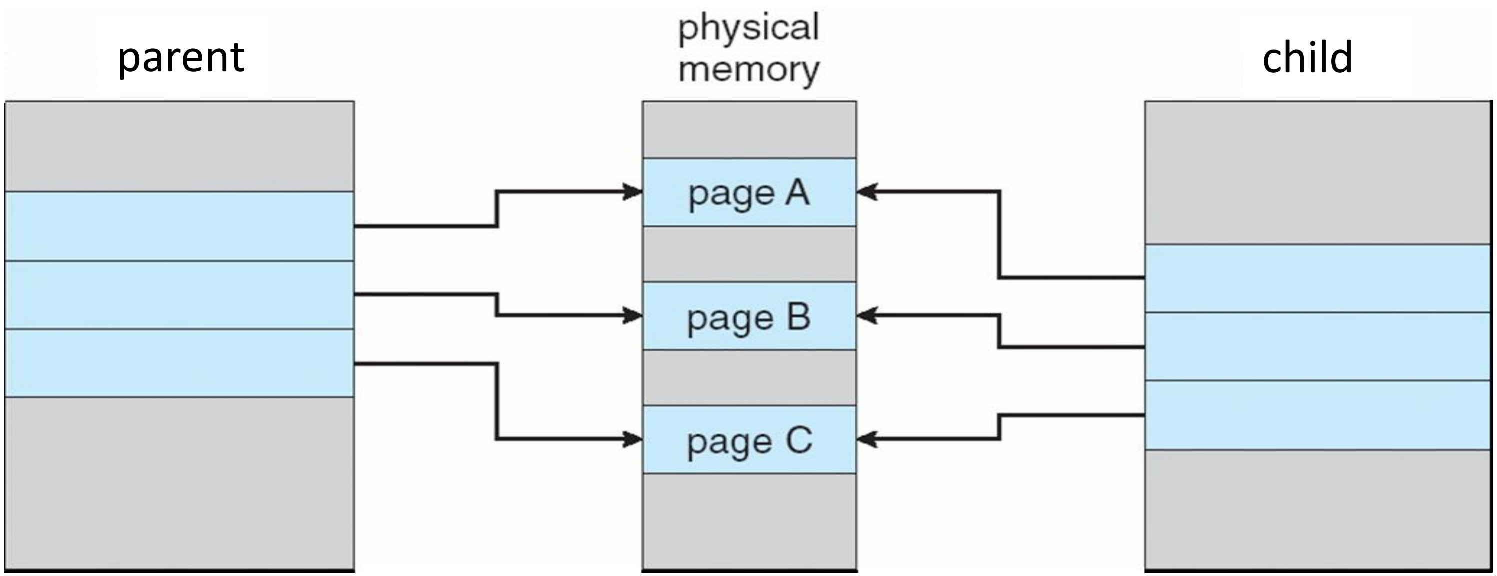
- Benefits: you don't need to use read()/write() system calls, just directly access data in the file via memory instructions
- How it works?
  - Just like demand paging of an executable file
  - What about writes?
    - Mark the modified (M) bit in the PTE
    - Write back the modified pages back to the original file

Copy-on-Write (COW)

- Fork() creates a copy of a parent process
  - Copy the entire pages on new page frames?
    - If the parent uses 1GB memory, then a fork() call would take a while
    - Then, suppose you immediately call exec(). Was it of any use to copy the 1GB of parent process's memory?

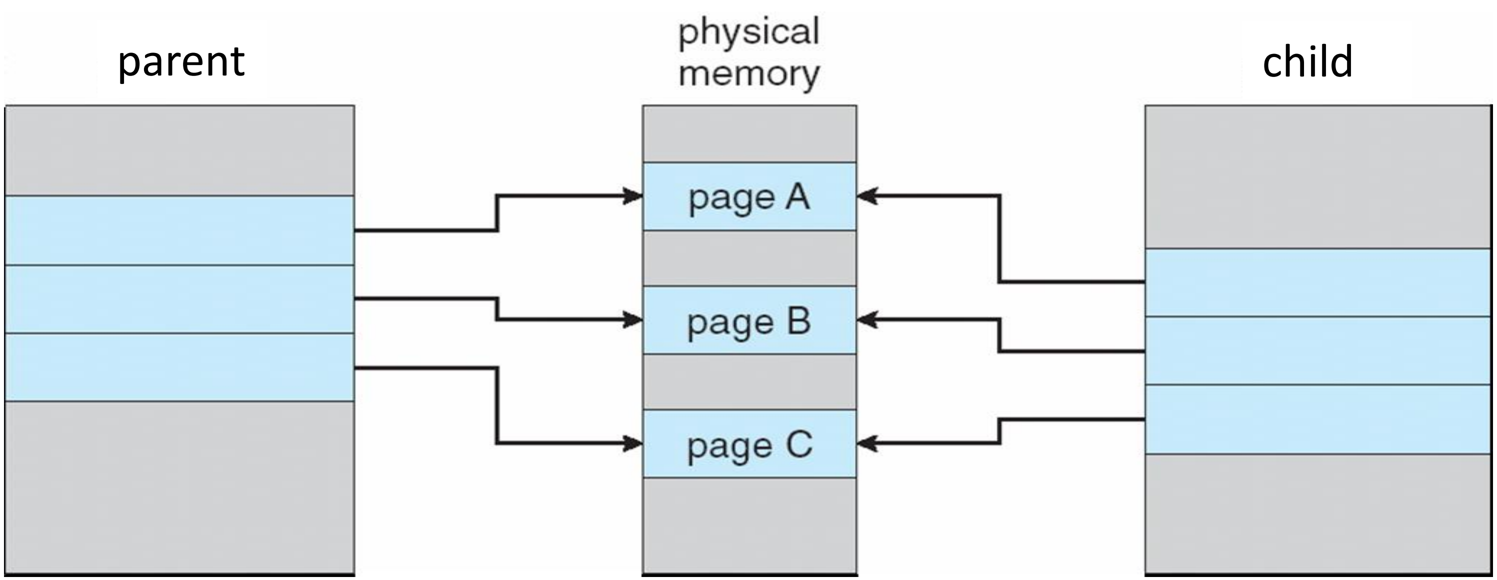
Copy-on-Write

- Better way: copy the page table of the parent
  - Page table is much smaller (so copy is faster)
  - Both parent and child point to the exactly same physical page frames



Copy-on-Write

- What happens when the parent/child reads?
- What happens when the parent/child writes?
  - Trouble!!!



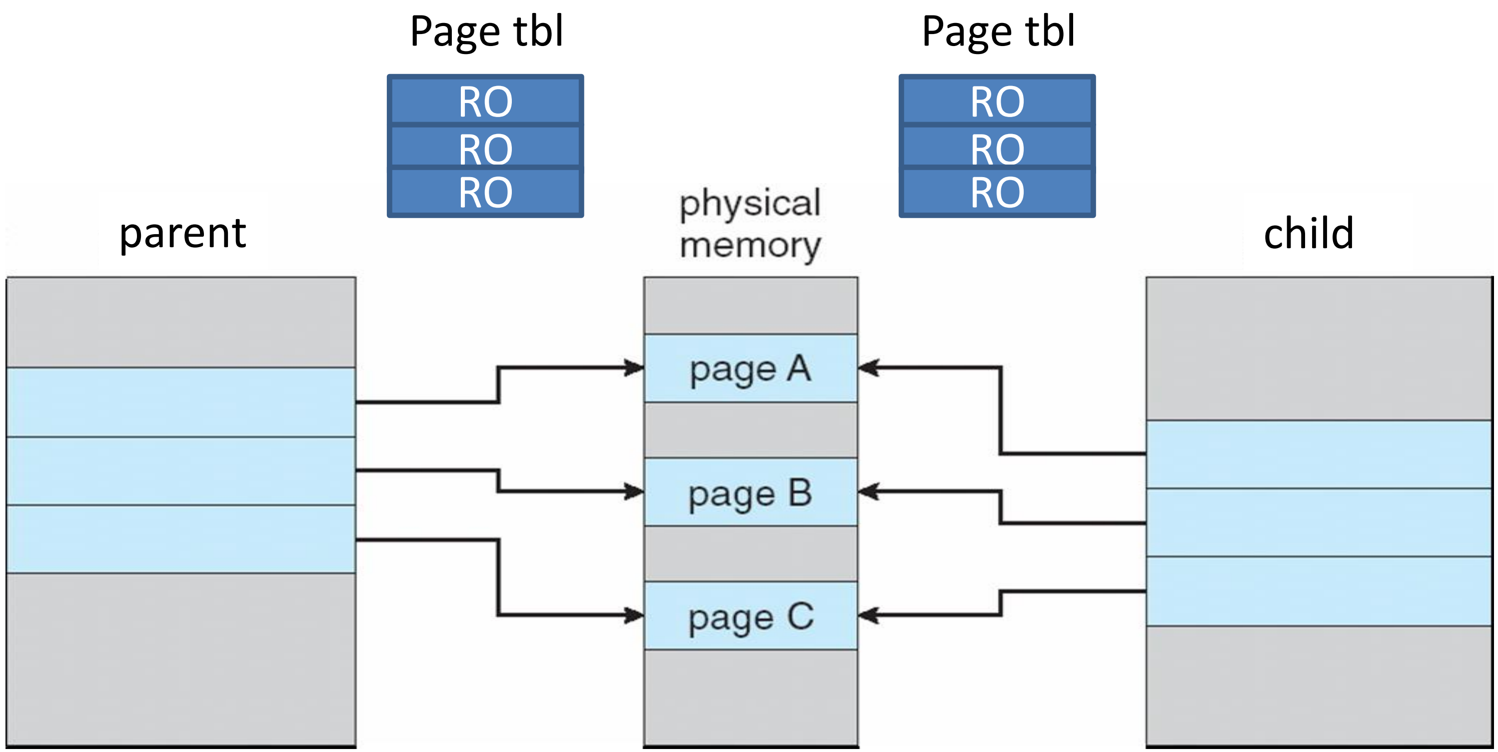
Page Table Entry (PTE)

- PTE format (architecture specific)

  - Valid bit (V): whether the page is in memory
  - Modify bit (M): whether the page is modified
  - Reference bit (R): whether the page is accessed
  - **Protection bits(P): readable, writable, executable**

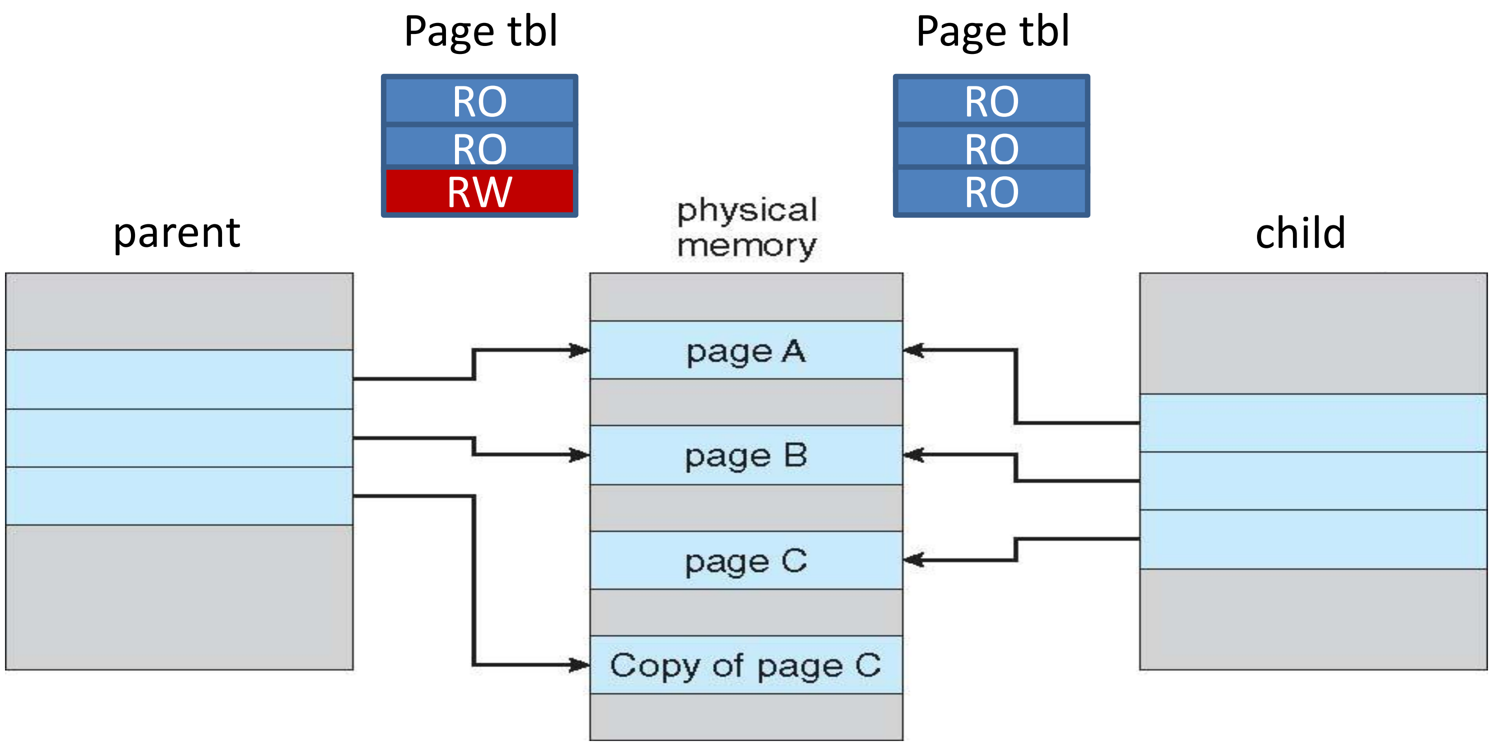
Copy-on-Write

- All pages are marked as read-only



Copy-on-Write

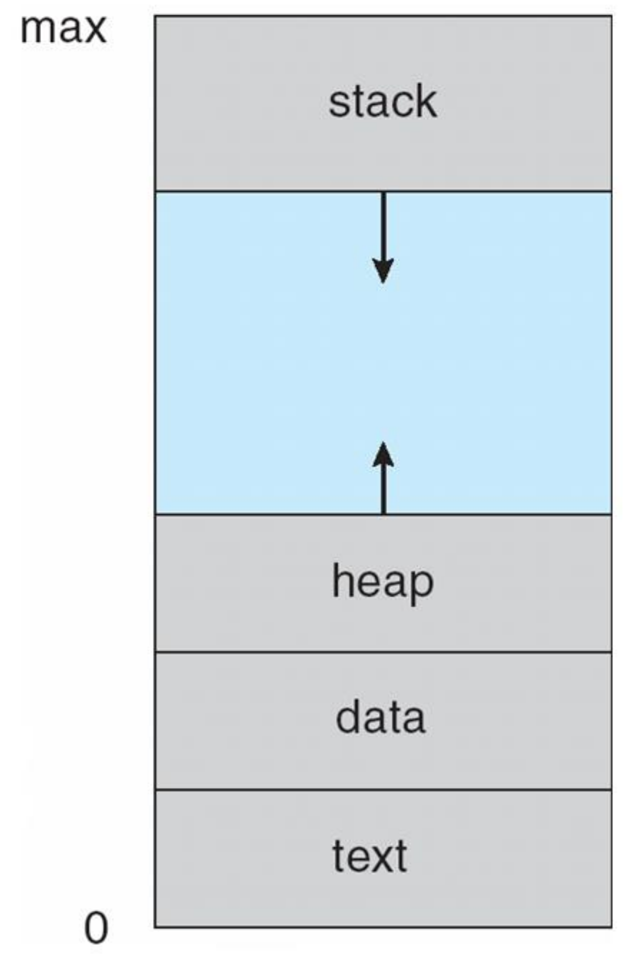
- Up on a write, a page fault occurs and the OS copies the page on a new frame and maps to it with R/W protection setting



User-level Memory Allocation

- When a process actually allocate a memory from the kernel?
  - On a page fault
  - Allocate a page (e.g., 4KB)

- What does **malloc**() do?
  - Manage a process's heap
  - Variable size objects in heap



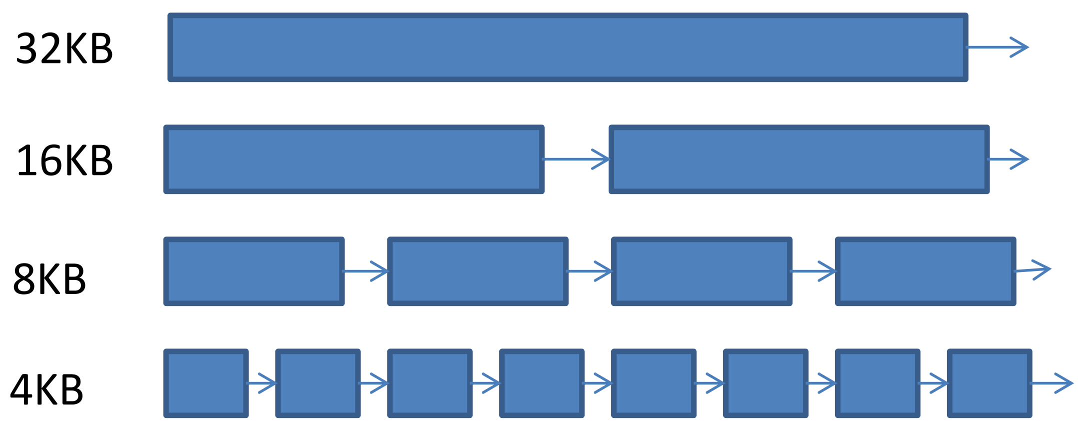
Kernel-level Memory Allocation

- Page-level allocator
  - Page frame allocation/free (fixed size)
  - Users: page fault handler, kernel-memory allocator

- Kernel-memory allocator (KMA)
  - Typical kernel object size << page size
    - File descriptor, inode, task_struct, …
  - KMA ← kernel-level malloc
  - In Linux: buddy allocator, SLAB

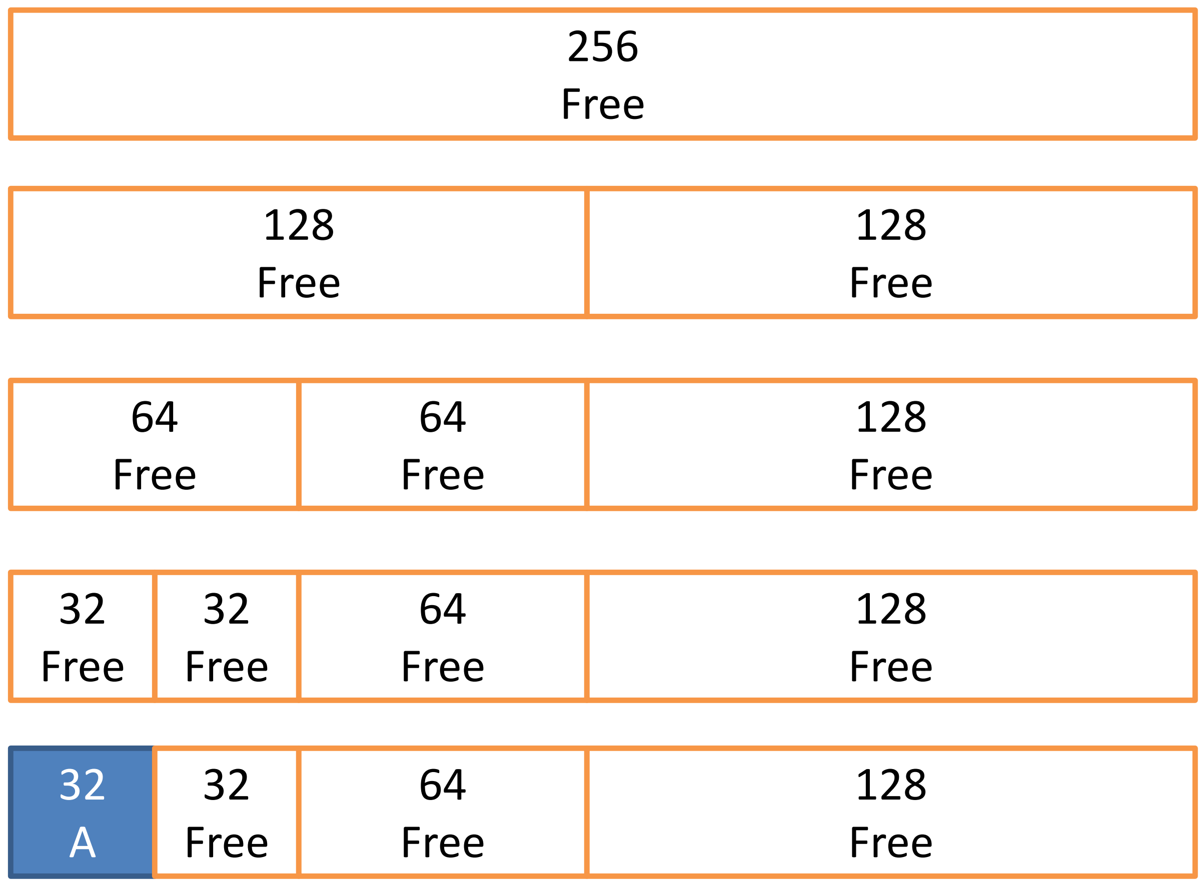
Buddy Allocator

- Allocate physically contiguous pages
  - 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
  - Quickly expand/shrink across the lists



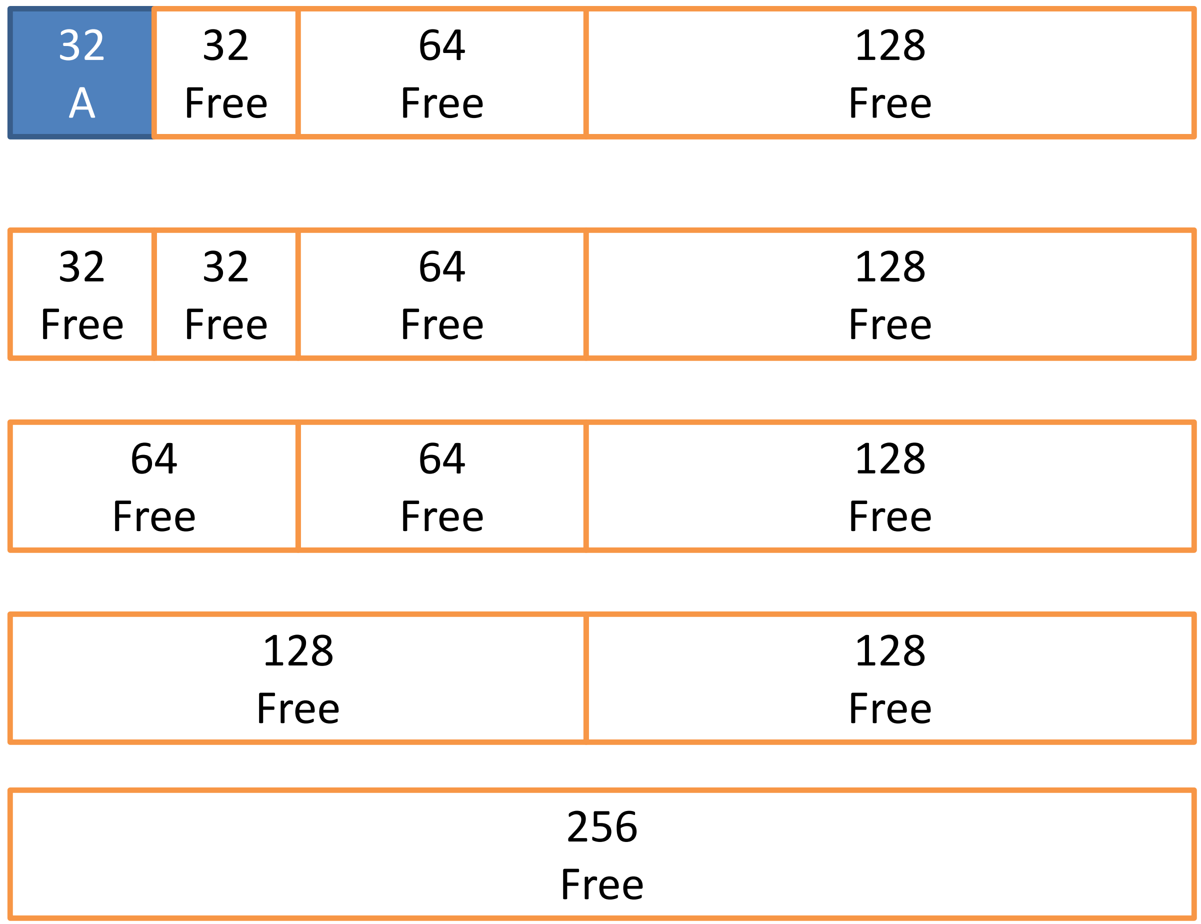
Buddy Allocator

- Example
  - Assume 256KB chunk available, kernel requests 21KB



Buddy Allocator

- Example
  - Free A



Virtual Memory Summary

- MMU and address translation
- Paging
- Demand paging
- Copy-on-write
- Page replacement

Quiz: Address Translation

8 bits	8 bits	8 bits
1^{st} level	2^{nd} level	offset

Virtual address format (24bits)

4 bits	3	1
Frame #	Unused	V

Page table entry (8bit)

Vaddr: 0x0703FE
Paddr: 0x3FE

Vaddr: 0x072370
Paddr: **???**

Vaddr: 0x082370
Paddr: **???**

Page-table base address = 0x100

Addr	+0	+1	+2	+3	+4	+5	+6	+7	+8	+A	+B	+C	+D	+E	+F
0x000				31											
0x010															
0x020				41											
..															
0x100	**00**	**01**						**01**	**00**			**01**			
..															
0x200															

Quiz: Address Translation

8 bits	8 bits	8 bits
1st level	2nd level	offset

Virtual address format (24bits)

4 bits	3	1
Frame #	Unused	V

Page table entry (8bit)

Vaddr: 0x0703FE
Paddr: 0x3FE

Vaddr: 0x072370
Paddr: **0x470**

Vaddr: 0x082370
Paddr: **invalid**

Page-table base address = 0x100

Addr	+0	+1	+2	+3	+4	+5	+6	+7	+8	+A	+B	+C	+D	+E	+F
0x000				31											
0x010															
0x020				41											
..															
0x100	**00**	**01**						**01**	**00**			**01**			
..															
0x200															