Memory Reclamation

SWE3015

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This slide is based on Jaeho Hwang's lecture slide

Memory Overcommit

- Most OSes allow memory overcommit
  - Allocate more virtual memory than physical memory
- How does this work?
  - Physical pages allocated on demand only
  - Allocated pages are not reclaimed until it is actually needed
    - Even if it will never accessed.
  - If free space is low…
    - OS frees some pages non-critical pages (e.g., cache)
    - Worst case, page some stuff out to disk

Memory Overcommit

- To swap a page out…
  - Save contents of page to disk
  - What to do with page table entries pointing to it?
    - Clear the PTE_P bit
- If we get a page fault for a swapped page…
  - Allocate a new physical page
  - Read contents of page from disk
  - Re-map the new page (with old contents)

Reclaiming Pages

- When system runs out of memory
  - Kernel needs to reclaim physical pages for other uses
  - Doesn't necessarily mean we have zero free memory
    - Maybe just below a "uncomfortable" level
- Where to get free pages?
  - Goal: Minimal performance disruption
    - Should work on phone, supercomputer, and everything in between

Types of Pages

- Unreclaimable:
  - Free pages (obviously)
  - Pinned/wired pages
  - Locked pages

- Swappable: anonymous pages
- Dirty Cache: data waiting to be written to disk
- Clean Cache: contents of disk reads

General Principles

- Free harmless pages first
  - Consider dropping clean disk cache (can read it again)
  - Steal pages from user programs
    - Especially those that haven't been used recently
    - Must save them to disk in case they are needed again
  - Consider dropping dirty disk cache
    - But have to write it out to disk first
    - Doable, but not preferable
- When reclaiming page, remove all references at once
  - Removing one reference is a waste of time
  - Consider removing entire object (needs extra linked list)

Finding Candidates to Reclaim

- Try reclaiming pages not used in a while
  - All pages are on one of 2 LRU lists: active or inactive
  - Access causes page to move to the active list
  - If page not accessed for a while, moves to the inactive list
- How to know when an inactive page is accessed?
  - Remove PTE_PRESENT bit
    - Page fault is cheap compared to paging out bad candidate
- How to know when page isn't accessed for a while?
  - Would page fault too often on false candidates
  - Use PTE_ACCESSED bit (e.g., clock algorithm)

SWE3015: Operating System Project

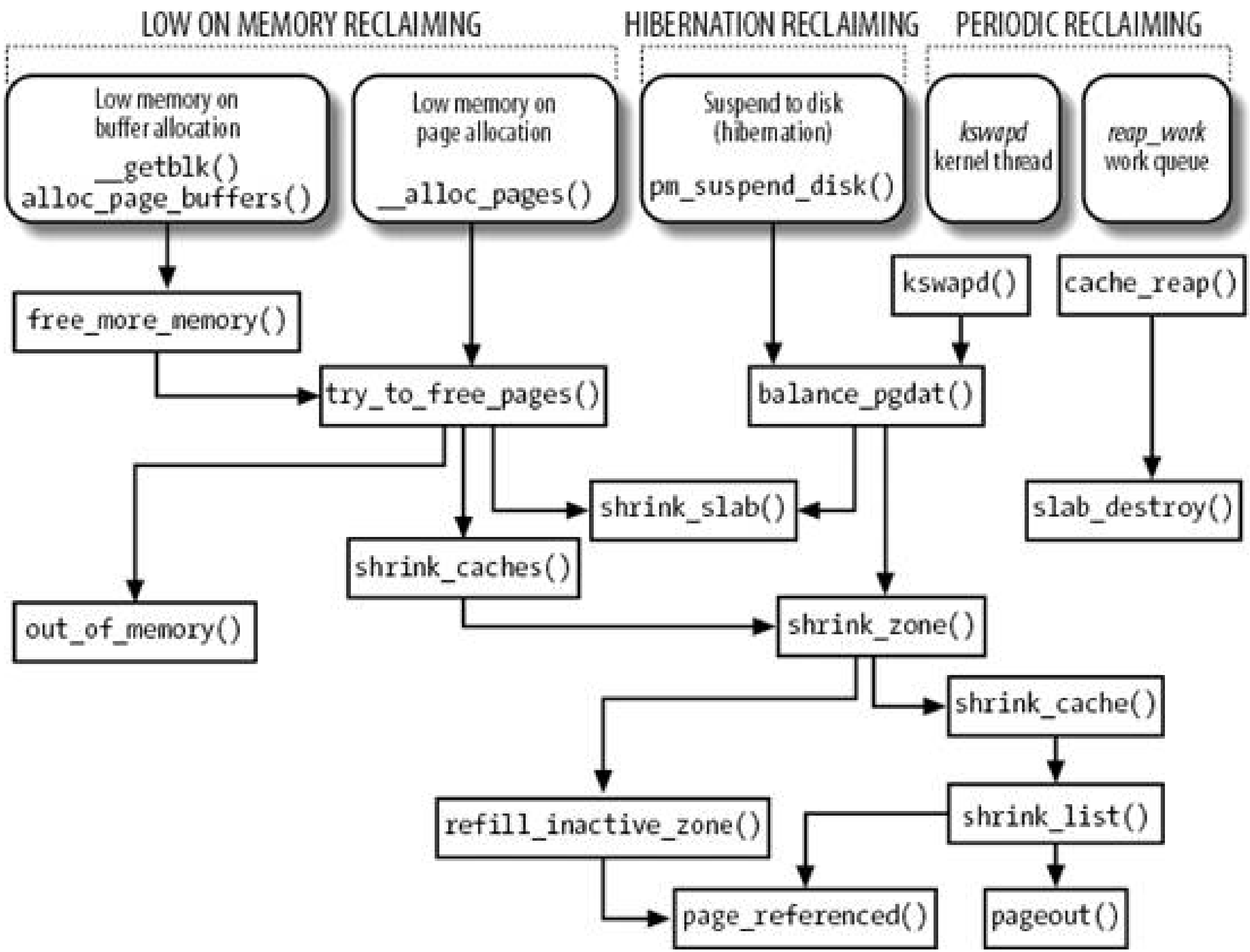
LINUX KERNEL IMPLEMENTATIONS FOR MEMORY RECLAMATION

/proc/meminfo

- http://www.reddit.com/r/linux/comments/1hk5ow/free_buffer_swap_dirty_procmeminfo_explained/

```
hahaman5@ubuntu: ~/linux-3.8.0
hahaman5@ubuntu:~/linux-3.8.0$ cat /proc/meminfo
MemTotal:        2051312 kB
MemFree:         1408160 kB
Buffers:           66084 kB
Cached:           468628 kB
SwapCached:            0 kB
Active:           266376 kB
Inactive:         293056 kB
Active(anon):      24884 kB
Inactive(anon):      164 kB
Active(file):     241492 kB
Inactive(file):   292892 kB
Unevictable:           0 kB
Mlocked:               0 kB
SwapTotal:        520188 kB
SwapFree:         520188 kB
Dirty:                 4 kB
Writeback:             0 kB
AnonPages:         24928 kB
Mapped:            10420 kB
Shmem:               328 kB
Slab:              60356 kB
SReclaimable:      50168 kB
SUnreclaim:        10188 kB
KernelStack:        1312 kB
PageTables:         2960 kB
NFS_Unstable:          0 kB
Bounce:                0 kB
WritebackTmp:          0 kB
```

When Reclamation Starts?



When Reclamation Starts?

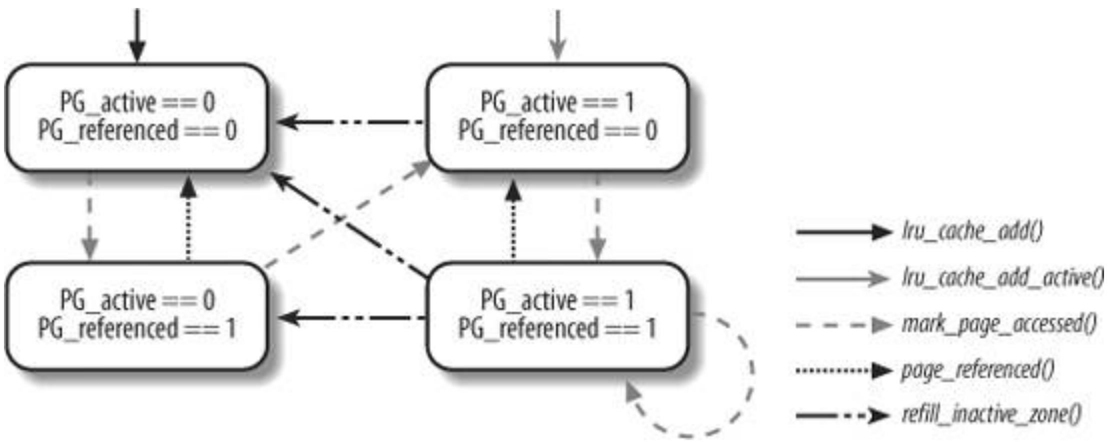
- Low on memory reclaiming
  - Failed to allocate a new buffer page
  - Failed to allocate the temporary buffer heads
  - __alloc_pages() failed to allocate contiguous pages
- Hibernation reclaiming
  - Must free memory for entering in the suspend-to-disk state
    - No more discussion for this class
- Periodic reclaiming
  - The kswapd kernel threads check *pages_high* watermark

The LRU Lists

- Active/inactive list
  - All user mode pages or page caches are belonged one of the m.
    - Current implementation divides each list for anon. and file.
  - Unreferenced pages in active list are moved to inactive list.
  - Referenced pages in inactive list are move to active list.
  - Unreferenced pages in inactive list are opt to be reclaimed.

The LRU Lists

- Active/inactive list
  - Refer to mm/swap.c/__activate_page
    - del_page_from_lru_list(zone, page, lru)
    - add_page_to_lru_list(zone, page, lru)
    - Argument "lru" indicates INACTIVE or ACTIVE



Low On Memory Reclaiming

- free_more_memory()
  - wakeup_pdflush(): write back some dirty pages
  - Calls try_to_free_pages()
- try_to_free_pages()
  - Does loop from priority 12 to 0
    - Priority means portion of scanning area in zone
    - Call shrink_zones()
    - Call shrink_slab()
    - If got the goal (reclaiming 32 pages) exit the loop

Low On Memory Reclaiming

- shrink_zones()
  - Calls shrink_zone for each zone
- shrink_zone()
  - Extracts LRU list and calls shrink_list()
  - Determines how aggressively the lists should be scanned
    - nr_to_scan
  - Fore each LRU list, calls shrink_list
    - Repeat until obtaining the scan count

Low On Memory Reclaiming

- shrink_list()
  - If the list is an active list, calls shrink_active_list
    - Only if the inactive list has insufficient pages
    - Return 0 because nothing reclaimed
  - If the list is an inactive list, calls shrink_inactive_list
- shrink_active_list()
  - Scans inactive and evictable pages in the active list
    - And moves them to the inactive list
- shrink_inactive_list()
  - Isolates maximum 32 evictable pages to local list
  - Calls shrink_page_list and pass the local list as an argument
  - Reassigns failed-to-reclaim pages to the (in)active lists
  - Return the number of actually reclaimed pages

Low On Memory Reclaiming

- shrink_page_list()
  - Determines whether it is currently to be activated, kept, or re claimable
  - Do actual page reclaiming process
    - Reclaim only reclaimable pages

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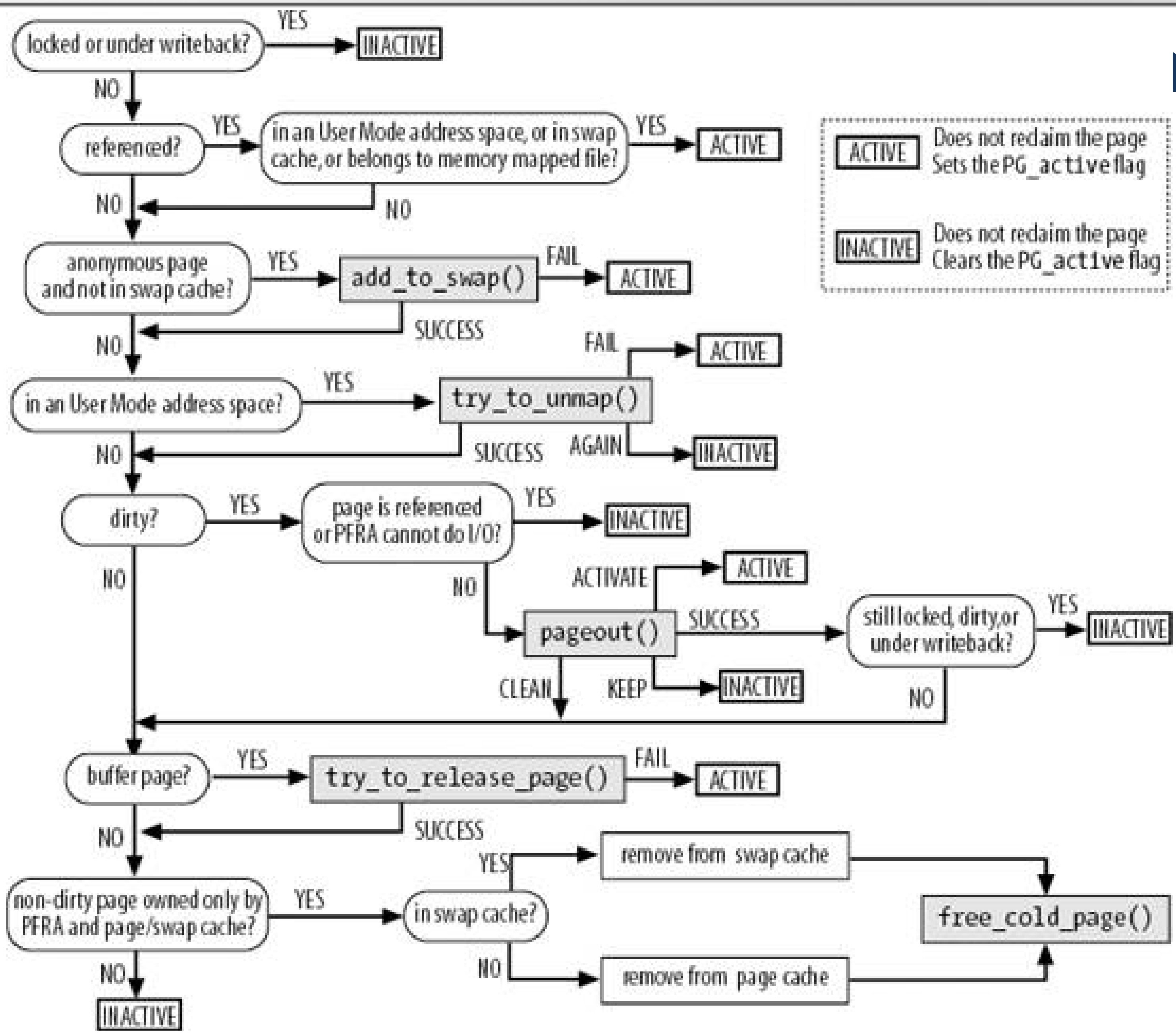

locked or under writeback?
YES
INACTIVE
NO
referenced?
YES
in an User Mode address space, or in swap cache, or belongs to memory mapped file?
YES
ACTIVE
NO
NO
anonymous page and not in swap cache?
YES
add_to_swap()
FAIL
ACTIVE
SUCCESS
NO
FAIL
ACTIVE
in an User Mode address space?
YES
try_to_unmap()
SUCCESS
AGAIN
INACTIVE
NO
dirty?
YES
page is referenced or PFRA cannot do I/O?
YES
INACTIVE
NO
NO
ACTIVATE
ACTIVE
pageout()
SUCCESS
still locked, dirty, or under writeback?
YES
INACTIVE
CLEAN
KEEP
INACTIVE
NO
buffer page?
YES
try_to_release_page()
FAIL
ACTIVE
NO
SUCCESS
YES
remove from swap cache
non-dirty page owned only by PFRA and page/swap cache?
YES
in swap cache?
free_cold_page()
NO
NO
remove from page cache
INACTIVE
ACTIVE
Does not reclaim the page
Sets the PG_active flag
INACTIVE
Does not reclaim the page
Clears the PG_active flag

Periodic Reclaiming

- kswapd kernel thread
  - Wakes up periodically and checks free memory for each zone
    - To guarantee enough free pages.
    - To leverage cpu power during idle
  - Starts reclamation if less free pages are in some zones
    - Same mechanism to previous explanation
  - __alloc_pages() could wake it up
    - When the free page rate is over its threshold (WMARK_LOW)

OOM Killer

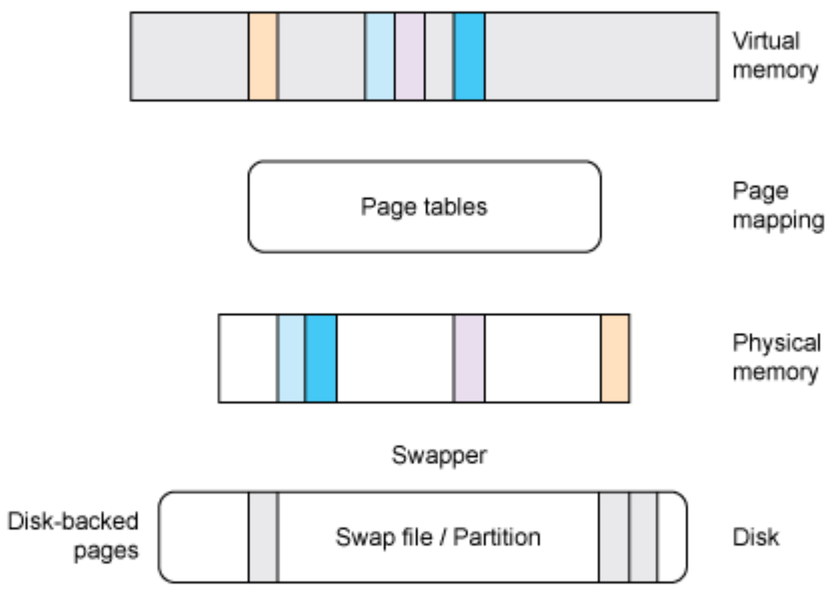
- If reclamation is failed?
  - __alloc_pages calls out_of_memory() (OOM).
  - determines a victim process which
    - Owns a large number of page frames
    - Might lose a small amount of work
    - Is a low static priority process
    - Is not a root process
    - Does not directly access hardware devices
    - Is not neither swapper nor init
  - Sends SIGKILL to the victim

Summary

- Memory pages are reclaimed if
  - No sufficient pages to allocate
  - The number of free pages is under the threshold
- Simple (in)active LRU list is maintained
  - A page has been referenced since the last check is active.
  - Pages to be evicted are collected in inactive lists.
  - If a page to be evicted becomes active or is being written bac k, it is reassigned to its list.
  - During eviction, some pages can be swappable, and written t o the swap device.
- Almost all flow is done in mm/vmscan.c

Swapping

- introduced to offer a backup on disk for unmapped pag es
  - Three kinds of pages that must be handled by the swapping
    - But we know/talk only one: anonymous pages



Swap Area

- Stores the swapped-out pages
  - Either as a disk partition or as a file
  - Multiple swap area can be defined (MAX_SWAPFILES)

- Each swap area consists of a sequence of page slots
  - 4KB blocks: PAGE_SIZE
  - Slot 0 has info structure including magic number
    - “SWAPSPACE2”

Creating a swap area

```
hahaman5@ubuntu: ~
hahaman5@ubuntu:~$ dd bs=4096 count=10 if=/dev/zero of=swap
10+0 records in
10+0 records out
40960 bytes (41 kB) copied, 0.000397511 s, 103 MB/s
hahaman5@ubuntu:~$ sudo mkswap swap -L os_project
Setting up swapspace version 1, size = 36 KiB
LABEL=os_project, UUID=ab2b6bef-11cc-4af5-a1cc-c11dde2827c5
hahaman5@ubuntu:~$ sudo swapon swap
hahaman5@ubuntu:~$ cat /proc/swaps
Filename                                Type            Size    Used    Priority
/dev/dm-1                               partition       520188  56      -1
/home/hahaman5/swap                     file            36      0       -2
hahaman5@ubuntu:~$ sudo swapoff swap
hahaman5@ubuntu:~$ cat /proc/swaps
Filename                                Type            Size    Used    Priority
/dev/dm-1                               partition       520188  56      -1
hahaman5@ubuntu:~$
```

Swapping Out Pages

- Inserting the page frame in the swap cache
  - In shrink_page_list(), if a victim page is anonymous and not swap cache, add_to_swap() is called to allocate a new slot in a swap area
- Writing the page into the swap area
  - Invoked in pageout() called in shrink_page_list()
  - pageout() invokes *writepage* method of the page's *address_space* strcture.
    - The implementation is swap_writepage().
      - See the code if you are interested.

Swapping Out Pages

- Removing the page frame from the swap cache
  - shrink_list( ) verifies that no process has tried to access the page frame.
    - Then invokes delete_from_swap_cache() to reclaim the physical page frame.

Swapping in Pages

- The page fault handler triggers a swap-in operation if
  - The page for the fault is a valid one.
  - The page is not present in memory.
  - The pte for the page is not null but the Dirty bit is clear.
  - Then handle_ptd_fault() invokes do_swap_page()
    - Also refer the code if you are interested.