Memory Virtualization: Swapping and Demand Paging Mechanisms

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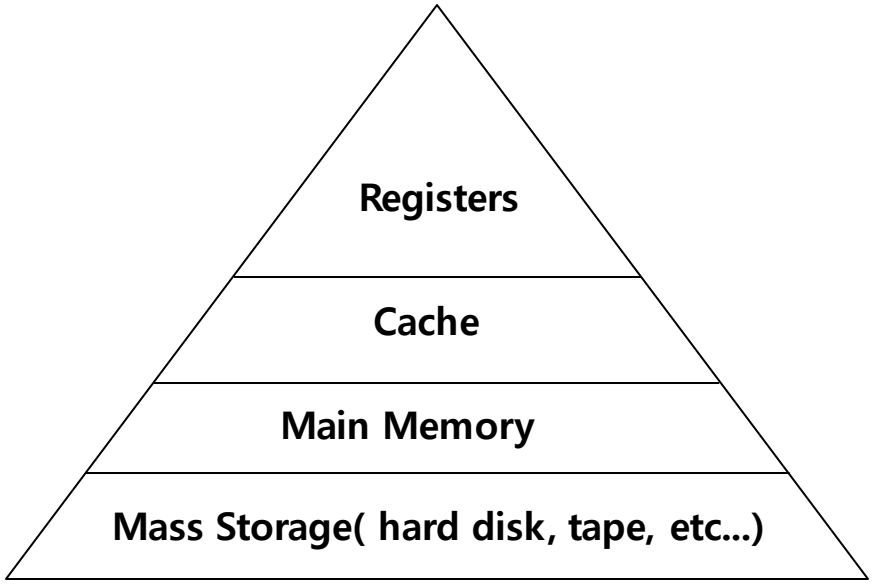
Beyond Physical Memory: Mechanisms

- **Require an additional level in the memory hierarchy.**
  - OS need a place to stash away portions of address space that currently aren't in great demand.
  - In modern systems, this role is usually served by a hard disk drive



Memory Hierarchy in modern system

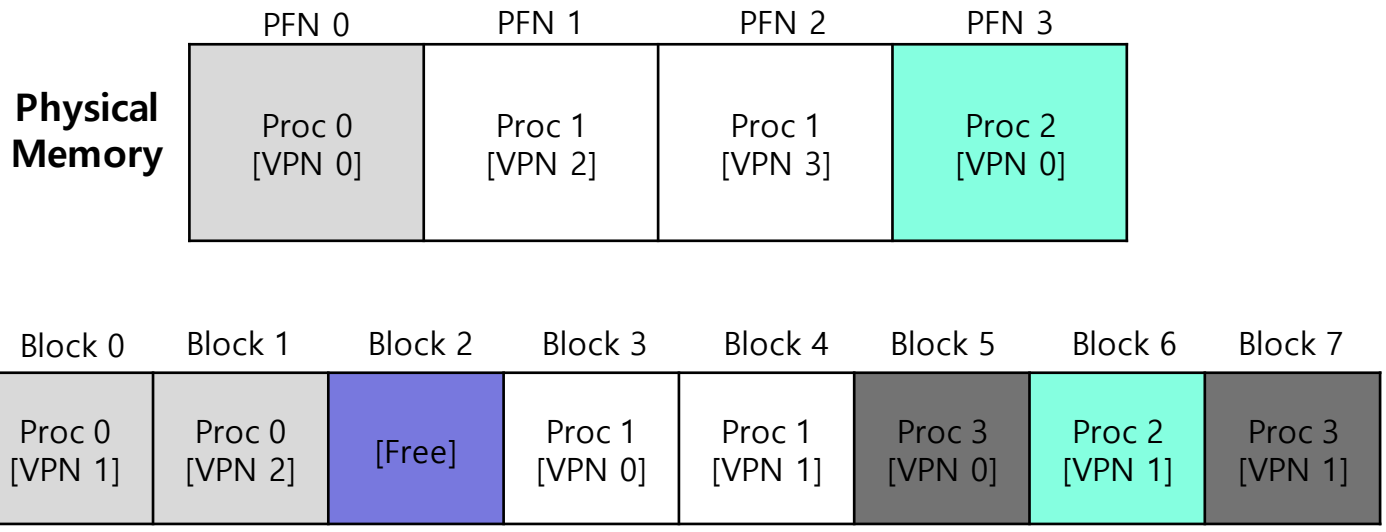
Single large address for a process

- **Always need to first arrange for the code or data to be in memory when before calling a function or accessing data.**

- **Beyond just a single process.**
  - The addition of swap space allows the OS to support the illusion of a large virtual memory for multiple concurrently-running process

Swap Space

- Reserve some space on the disk for moving pages back and forth.
- OS need to remember to the swap space, in page-sized unit



Physical Memory and Swap Space

Present Bit

- **Add some machinery higher up in the system in order to support swapping pages to and from the disk.**
  - When the hardware looks in the PTE, it may find that the page is not present in physical memory.

Value	Meaning
1	page is present in physical memory
0	The page is not in memory but rather on disk.

What If Memory Is Full ?

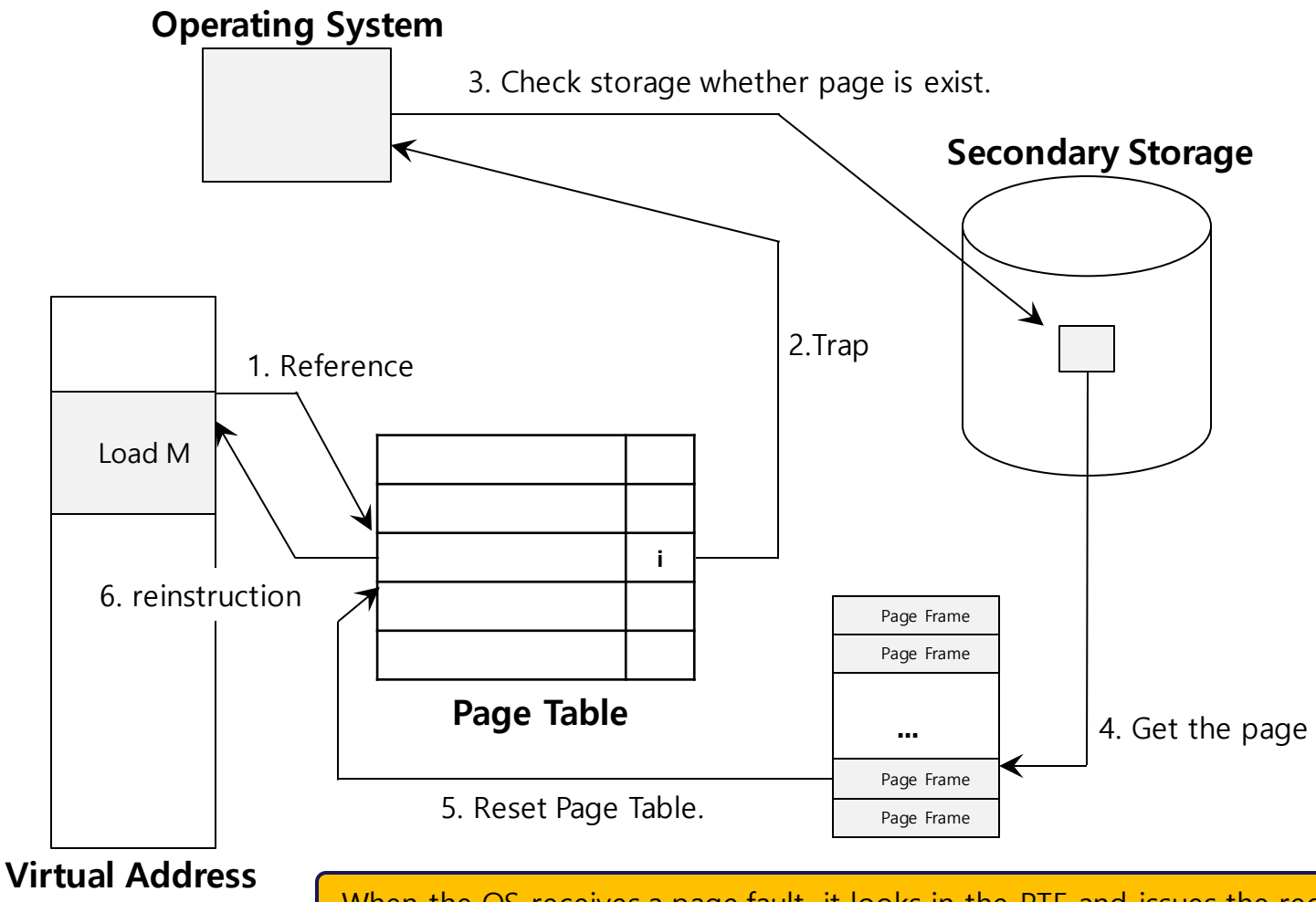
- **The OS like to page out pages to make room for the new pages the OS is about to bring in.**
  - The process of picking a page to kick out, or replace is known as page-replacement policy

The Page Fault

- **Accessing page that is not in physical memory.**
  - If a page is not present and has been swapped disk, the OS need to swap the page into memory in order to service the page fault.

Page Fault Control Flow

- PTE used for data such as the PFN of the page for a disk address.



When the OS receives a page fault, it looks in the PTE and issues the request to disk.

Page Fault Control Flow – Hardware

```
1:      VPN = (VirtualAddress & VPN_MASK) >> SHIFT
2:      (Success, TlbEntry) = TLB_Lookup(VPN)
3:      if (Success == True) // TLB Hit
4:      if (CanAccess(TlbEntry.ProtectBits) == True)
5:              Offset = VirtualAddress & OFFSET_MASK
6:              PhysAddr = (TlbEntry.PFN << SHIFT) | Offset
7:              Register = AccessMemory(PhysAddr)
8:      else RaiseException(PROTECTION_FAULT)
```

Page Fault Control Flow – Hardware

```
9:      else // TLB Miss
10:     PTEAddr = PTBR + (VPN * sizeof(PTE))
11:     PTE = AccessMemory(PTEAddr)
12:     if (PTE.Valid == False)
13:             RaiseException(SEGMENTATION_FAULT)
14:     else
15:     if (CanAccess(PTE.ProtectBits) == False)
16:             RaiseException(PROTECTION_FAULT)
17:     else if (PTE.Present == True)
18:     // assuming hardware-managed TLB
19:             TLB_Insert(VPN, PTE.PFN, PTE.ProtectBits)
20:             RetryInstruction()
21:     else if (PTE.Present == False)
22:             RaiseException(PAGE_FAULT)
```

Page Fault Control Flow – Software

```
1:        PFN = FindFreePhysicalPage()
2:        if (PFN == -1) // no free page found
3:                PFN = EvictPage() // run replacement algorithm
4:                DiskRead(PTE.DiskAddr, pfn) // sleep (waiting for I/O)
5:                PTE.present = True // update page table with present
6:                PTE.PFN = PFN // bit and translation (PFN)
7:                RetryInstruction() // retry instruction
```

- The OS must find a physical frame for the soon-be-faulted-in page to reside within.
- If there is no such page, waiting for the replacement algorithm to run and kick some pages out of memory.

When Replacements Really Occur

- **OS waits until memory is nearly full, and only then replaces a page to make room for some other page**
  - This is a little bit unrealistic, and there are many reason for the OS to keep a small portion of memory free more proactively.
  - Generally keep a low water mark and a high water mark on number of free physical pages desired

- **Swap Daemon, Page Daemon**
  - There are fewer than LW pages available, a background thread that is responsible for freeing memory runs.
  - The thread evicts pages until there are HW pages available.