Operating Systems

KAIST

18. Paging: Introduction

Concept of Paging

- Paging **splits up** address space into **fixed-zed** unit called a **page**.
  - Segmentation: variable size of logical segments(code, stack, heap, etc.)

- With paging, **physical memory** is also **split** into some number of pages called a **page frame**.

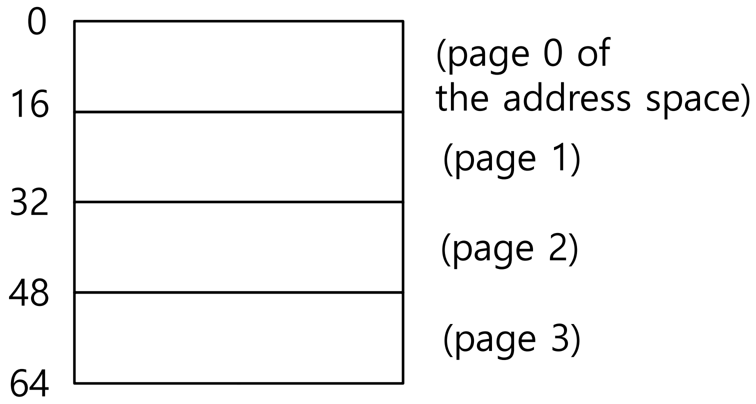
- **Page table** per process is needed **to translate** the virtual address to physical address.

Advantages Of Paging

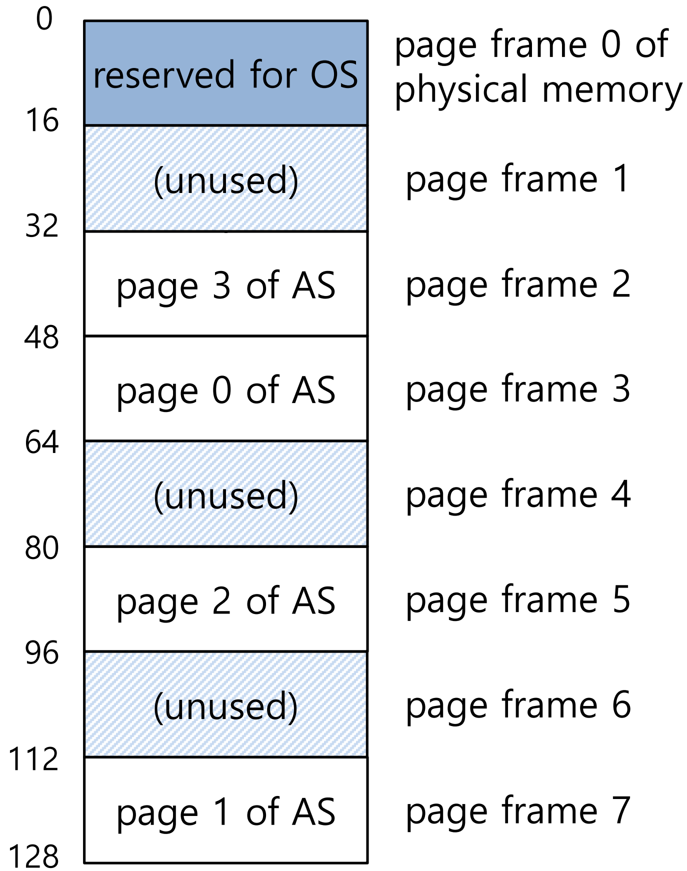
- **Flexibility:** Supporting the abstraction of address space effectively
  - Don't need assumption how heap and stack grow and are used.
- **Simplicity**: ease of free-space management
  - The page in address space and the page frame are the same size.
  - Easy to allocate and keep a free list

Example: A Simple Paging

- 128-byte physical memory with 16 bytes page frames
- 64-byte address space with 16 bytes pages



A Simple 64-byte Address Space



64-Byte Address Space Placed In Physical Memory

Address Translation

- Two components in the virtual address
  - VPN: virtual page number
  - Offset: offset within the page

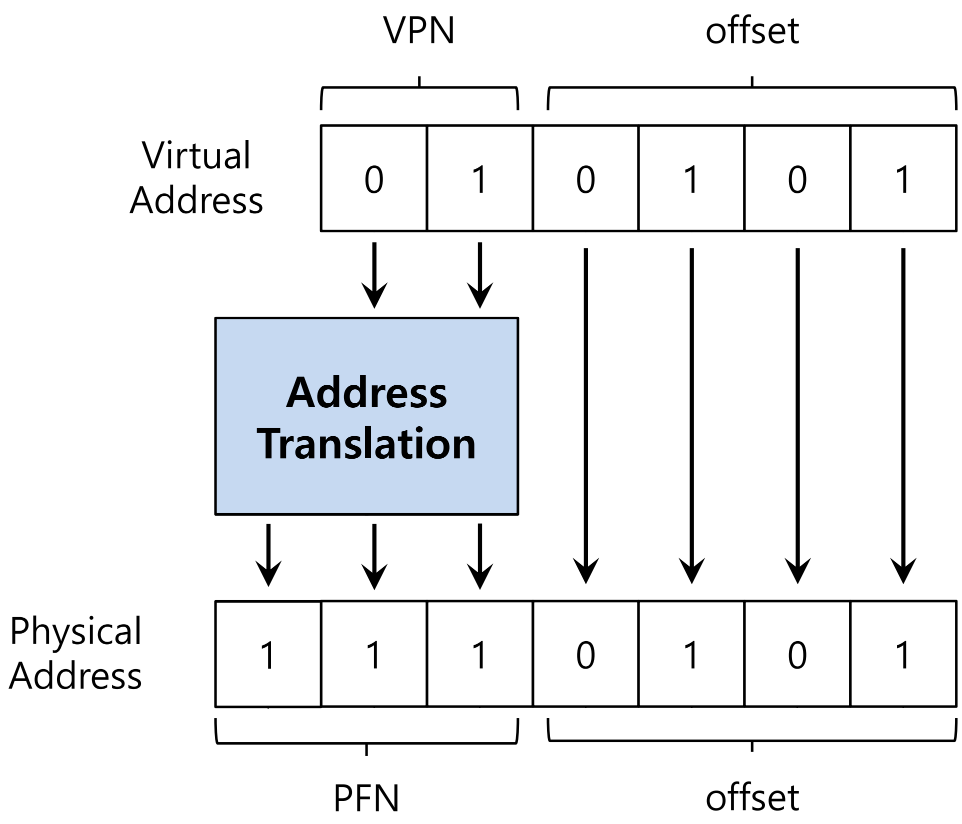
VPN		offset			
Va5	Va4	Va3	Va2	Va1	Va0

- Example: virtual address 21 in 64-byte address space

VPN		offset			
0	1	0	1	0	1

Example: Address Translation

- The virtual address 21 in 64-byte address space

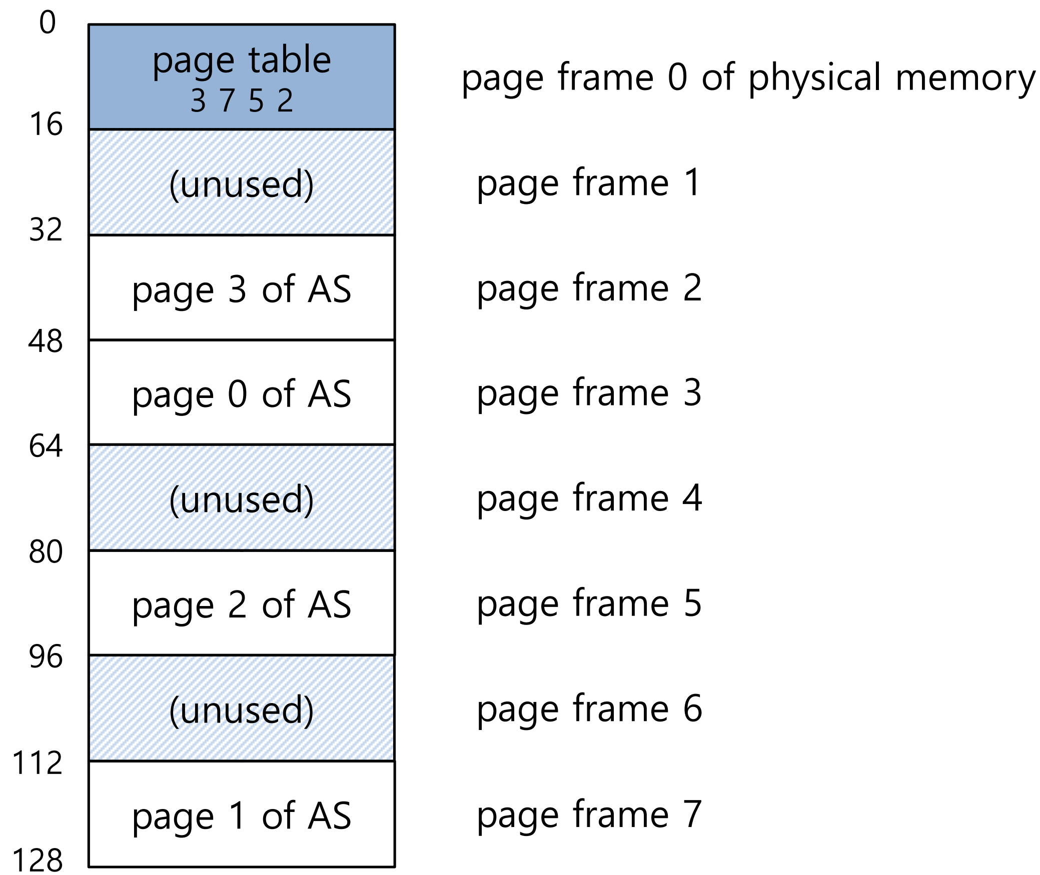


Where Are Page Tables Stored?

- Page tables can get awfully large.
  - 32-bit address space with 4-KB pages, 20 bits for VPN
    - Page offset for 4 Kbyte page: 20 bit
    - $4MB = 2^{20}\ entries\ * 4\ Bytes\ per\ page\ table\ entry$

- Page tables for each process are stored in memory.

Example: Page Table in Kernel Physical Memory



Physical Memory

What Is In The Page Table?

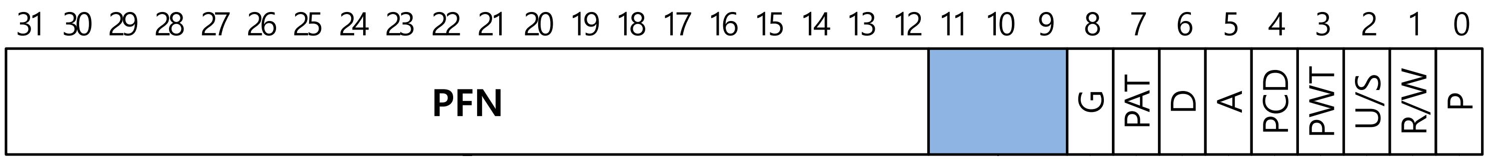
- The page table is a **data structure** that is used to map the virtual address to physical address.
  - Simplest form: a linear page table, an array

- The OS **indexes** the array by VPN, and looks up the page-table entry.

Common Flags Of Page Table Entry

- **Valid Bit**: Indicating whether the particular translation is valid.
- **Protection Bit**: Indicating whether the page could be read from, written to, or executed from
- **Present Bit**: Indicating whether this page is in physical memory or on disk(swapped out)
- **Dirty Bit**: Indicating whether the page has been modified since it was brought into memory
- **Reference Bit(Accessed Bit):** Indicating that a page has been accessed

Example: x86 Page Table Entry



An x86 Page Table Entry(PTE)

- P: present
- R/W: read/write bit
- U/S: supervisor
- A: accessed bit
- D: dirty bit
- PFN: the page frame number

Paging: Too Slow

- To find a location of the desired PTE, the **starting location** of the page table is **needed**.

- For every memory reference, paging requires the OS to perform one **extra memory reference**.

Accessing Memory With Paging

```
// Extract the VPN from the virtual address
VPN = (VirtualAddress & VPN_MASK) >> SHIFT

// Form the address of the page-table entry (PTE)
PTEAddr = PTBR + (VPN * sizeof(PTE))

// Fetch the PTE
PTE = AccessMemory(PTEAddr)

```

Accessing Memory With Paging

```
    // Check if process can access the page
    if (PTE.Valid == False)
        RaiseException(SEGMENTATION_FAULT)
    else if (CanAccess(PTE.ProtectBits) == False)
        RaiseException(PROTECTION_FAULT)
    else
        // Access is OK: form physical address and fetch it
        offset = VirtualAddress & OFFSET_MASK
        PhysAddr = (PTE.PFN << PFN_SHIFT) | offset
        Register = AccessMemory(PhysAddr)
```

A Memory Trace

```
int array[1000];
...
for (i = 0; i < 1000; i++)
      array[i] = 0;
```

```
prompt> gcc -o array array.c -Wall -o
prompt>./array
```

Memory access

```
0x1024 movl $0x0,(%edi,%eax,4) //[edi+eax*4]= 0
0x1028 incl %eax
0x102c cmpl $0x03e8,%eax //0000 0011 1110 1000₂ = 1000₁₀
0x1030 jne 0x1024
```

A Virtual(And Physical) Memory Trace