Memory

2024 Semester 2 COMPSCI 340: Operating Systems

Lecture 1

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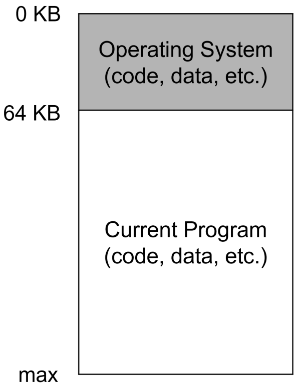
1.0.0

The early operating system



(Almost) No hardware abstraction.

OS is a set of routines (libraries).

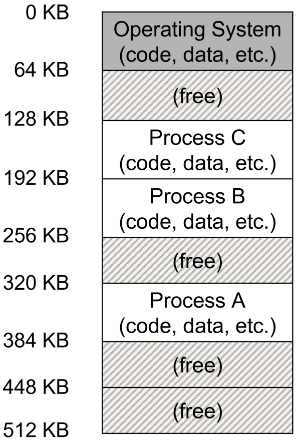
A single running program in physical memory.

Multiple people start sharing a computer

Timeshare: One user runs for a bit, saves everything to disk, then load another.

But it is very slow.

Writing from disk to memory is slow...but registers are fast

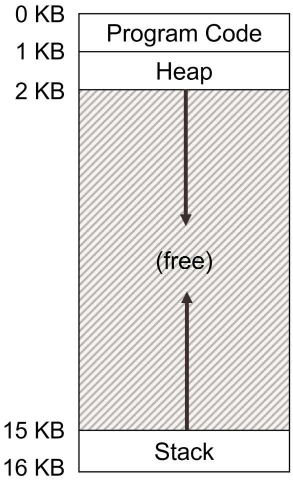


A second try - leaves everything in memory, but switch between them.

Each process gets 64 KB space from physical memory.

But there is no abstraction - any problems?

Create an abstraction – address space



An address space is the running program's view of memory in the system.

Code: where instructions live

Heap: dynamic data (malloc'd data)

Stack: local variables, arguments to routines, return values, etc.

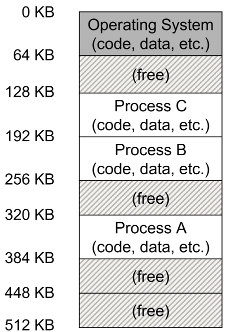
Create an abstraction – address space

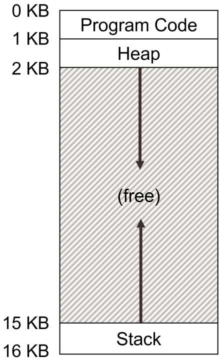
```c
#include <stdio.h>
#include <stdlib.h>
int main(int argc, char *argv[]) {
        printf("location of code : %p\n", main);
        printf("location of heap : %p\n", malloc(100e3));
        int x = 3;
        printf("location of stack: %p\n", &x);
        return x;
}
```

Virtual address or physical memory?

Create an abstraction – address space

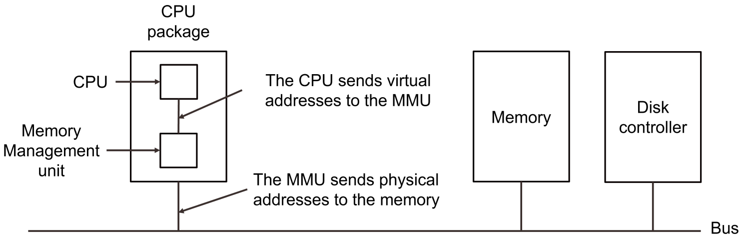
Difference?





How can the OS build this abstraction of a private, potentially large address space for multiple running processes (all sharing memory) on top of a single, physical memory?

The memory management unit (MMU)



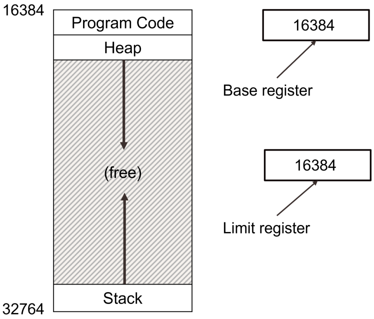
How Should We Implement Virtual Mapping?

What are your ideas for mapping a process's virtual memory to physical memory?

Virtual Memory Checklist

- Multiple processes must be able to co-exist
- Processes are not aware they are sharing physical memory
- Processes cannot access each others data (unless allowed explicitly)
- Performance close to using physical memory
- Limit the amount of fragmentation (wasted memory)

Base and limit registers



The simple solution: Each CPU has two special hardware registers: base and lmit.

When a process is run, the physical addresses are loaded to these registers.

An addition and a comparion on every memory reference.

Remember That Memory is Byte Addressable

The smallest unit you can use to address memory is one byte

You can read or write one byte at a time at minimum

Each “address” is like an index of an array

Segmentation or Segments are Coarse Grained

Divide the virtual address space into segments for: code, data, stack, and heap

Each segment is a variable size, and can be dynamically resized

- This is an old legacy technique that's no longer used

Segments can be large and very costly to relocate

- It also leads to fragmentation (gaps of unused memory)

No longer used in modern operating systems

Segmentation Details

Each segment contains a: base, limit, and permissions

- You get a physical address by using: `segment selector:offset`

The MMU checks that your offset is within the limit (size)

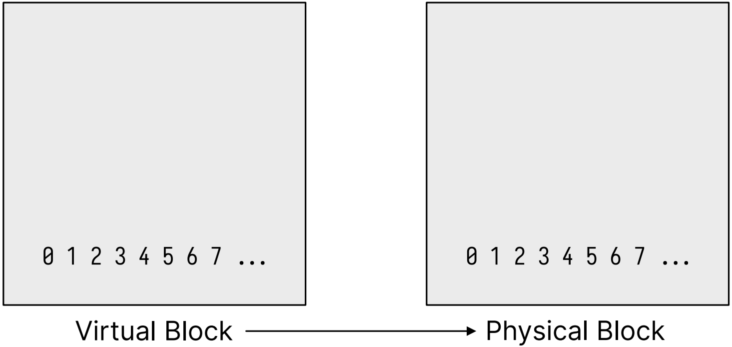
- If it is, it calculates base + offset, and does permission checks
  - Otherwise, it's a segmentation fault

For example 0×1:0xFF with segment 0×1 base = 0×2000, limit = 0×1FF

- Translates to 0×20FF

Note: Linux sets every base to 0, and limit to the maximum amount

First Insight: Divide Memory into Fixed-Sized Chunks



Paging

One technique is to divide memory up into fixed-size pages (typically 4096 bytes or 4 KB)

- A page in virtual memory is called a page
- A page in physical memory is called a frame

You Typically Do Not Use All 64 Virtual Address Bits

CPUs may have different levels of virtual addresses you can use

- Implementation ideas are the same

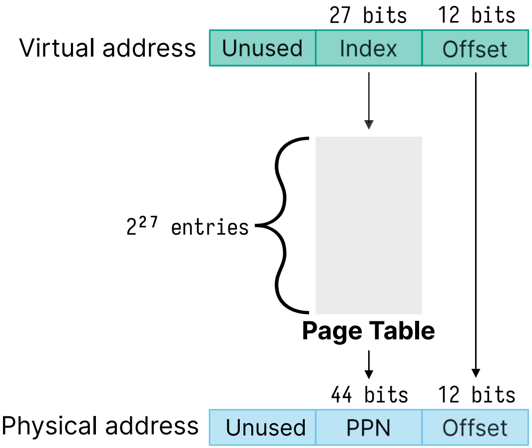
We'll assume a 39 bit virtual address space used by RISC-V and other architectures

- Allows for 512 GiB of addressable memory (called Sv39)

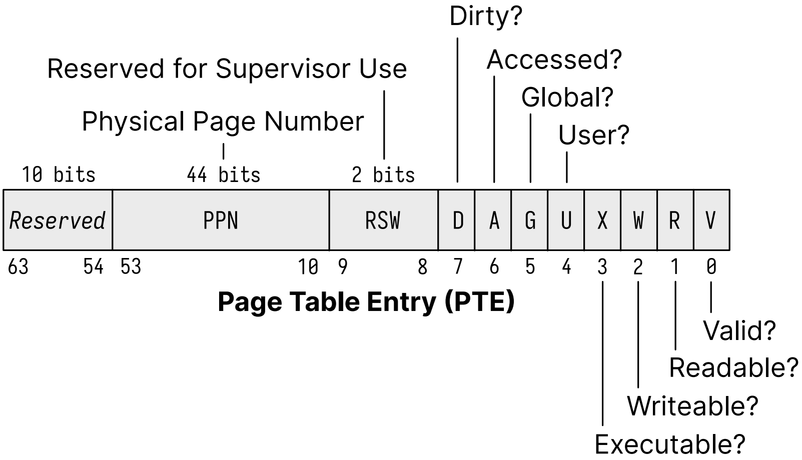
Implemented with a page table indexed by Virtual Page Number (VPN)

- Looks up the Physical Page Number (PPN)

The Page Table Translates Virtual to Physical Addresses



The Page Table Entry (PTE) Also Stores Flags in the Lower Bits



The Kernel Handles Translating Virtual Addresses

Considering the following page table:

VPN	PPN
0x0	0x1
0x1	0x4
0x2	0x3
0x3	0x7

We would get the following virtual $\rightarrow$ physical address translations:

0x0AB0 $\rightarrow$ 0x1AB0
0x1FA0 $\rightarrow$ 0x4FA0
0x2884 $\rightarrow$ 0x3884
0x32D0 $\rightarrow$ 0x72D0

Page Translation Example Problem

Assume you have a 8-bit virtual address, 10-bit physical address and each page is 64 bytes

- How many virtual pages are there?
- How many physical pages are there?
- How many entries are in the page table?
- Given the page table is `[0x2, 0x5, 0x1, 0x8]` what's the physical address of `0xF1`?

Page Translation Example Problem

Assume you have a 8-bit virtual address, 10-bit physical address and each page is 64 bytes

- How many virtual pages are there? $\frac{2^8}{2^6} = 4$
- How many physical pages are there? $\frac{2^{10}}{2^6} = 16$
- How many entries are in the page table? 4
- Given the page table is `[0x2, 0x5, 0x1, 0x8]` what's the physical address of `0xF1`?
  `0x231`

Each Process Gets Its Own Page Table

When you `fork` a process, it will copy the page table from the parent
- Turn off the write permission so the kernel can implement copy-on-write

The problem is there are 2^{27} entries in the page table, each one is 8 bytes
- This means the page table would be 1 GiB

Note that RISC-V translates a 39-bit virtual to a 56-bit physical address
- It has 10 bits to spare in the PTE and could expand
- Page size is 4096 bytes (size of offset field)

We Use Pages for Memory Translation

Divide memory into blocks, so we only have to translate once per block

Use page tables (array of PTEs) to access the PPN (and flags)

New problem: these page tables are always huge!