Operating Systems and Protection

Prof. David August

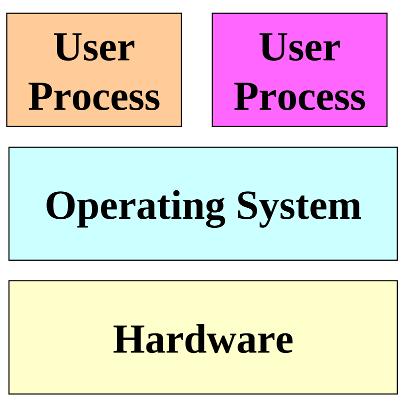
COS 217

Goals of Today's Lecture

- How multiple programs can run at once
  - Processes
  - Context switching
  - Process control block
  - Virtual memory
- Boundary between parts of the system
  - User programs
  - Operating system
  - Underlying hardware
- Mechanics of handling a page fault
  - Page tables
  - Process ID registers
  - Page faults

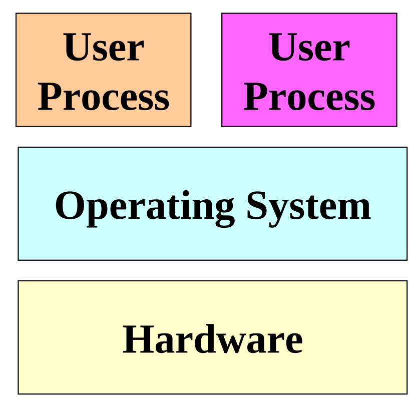
Operating System

- Supports virtual machines
  - Promises each process the illusion of having whole machine to itself
- Provides services:
  - Protection
  - Scheduling
  - Memory management
  - File systems
  - Synchronization
  - etc.

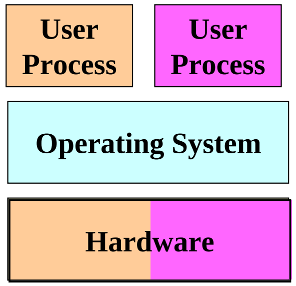


What is a Process?

- A process is a running program with its own …
  - Processor state
    - EIP, EFLAGS, registers
  - Address space (memory)
    - Text, bss, data, heap, stack
- Supporting the abstraction
  - Processor
    - Saving state per process
    - Context switching
  - Main memory
    - Sharing physical memory
    - Supporting virtual memory
  - Efficiency, fairness, protection

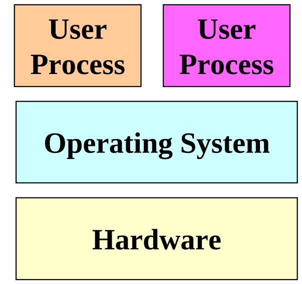


Divide Hardware into Little Pieces?



- Idea: registers, memory, ALU, etc. per process
  - Pro: totally independent operation of each process
  - Con: lots of extra hardware;
    some parts idle at any given time;
    hard limit on the number of processes

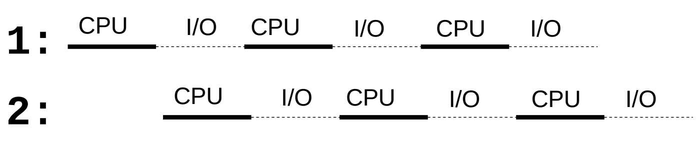
Indirection, and Sharing in Time?



- Idea: swap processes in and out of the CPU;
  map references into physical addresses
  - Pro: make effective use of the resources by sharing
  - Con: overhead of swapping processes;
    overhead of mapping memory references

When to Change Which Process is Running?

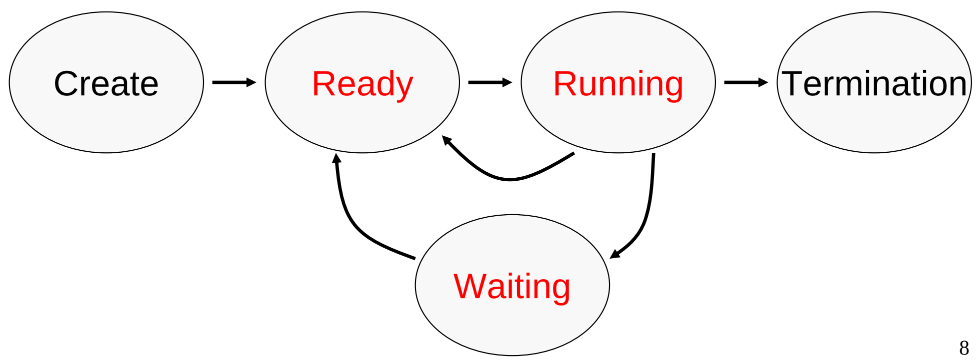
- When a process is stalled waiting for I/O
  - Better utilize the CPU, e.g., while waiting for disk access



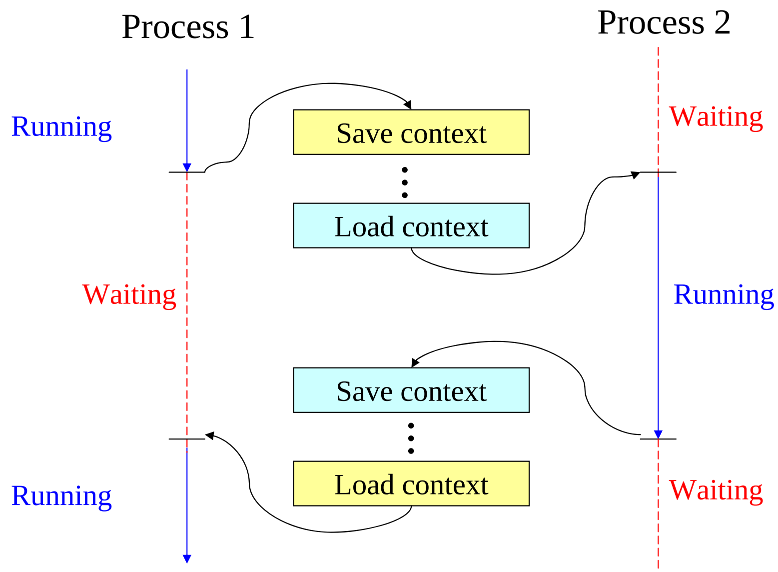
- When a process has been running for a while
  - Sharing on a fine time scale to give each process the illusion of running on its own machine
  - Trade-off efficiency for a finer granularity of fairness

Life Cycle of a Process

- Running: instructions are being executed
- Waiting: waiting for some event (e.g., I/O finish)
- Ready: ready to be assigned to a processor



Switching Between Processes

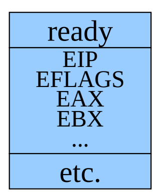


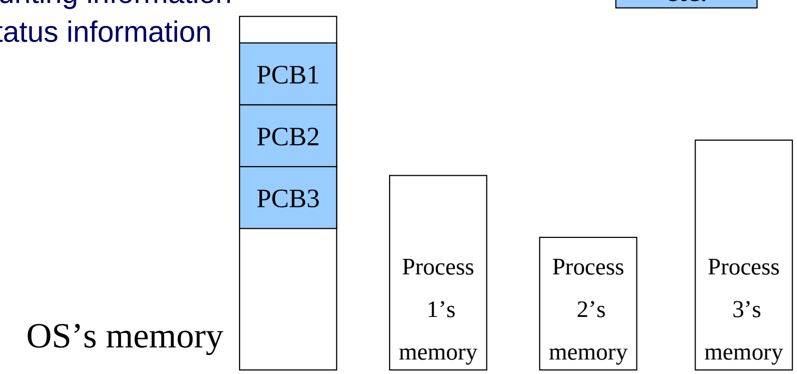
Context Switch: What to Save & Load?

- Process state
  - New, ready, waiting, halted
- CPU registers
  - EIP, EFLAGS, EAX, EBX, …
- I/O status information
  - Open files, I/O requests, …
- Memory management information
  - Page tables
- Accounting information
  - Time limits, group ID, ...
- CPU scheduling information
  - Priority, queues

Process Control Block

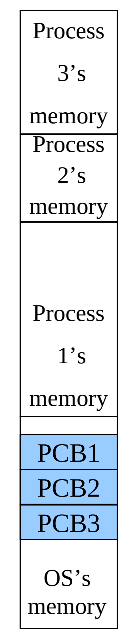
- For each process, the OS keeps track of ...
  - Process state
  - CPU registers
  - CPU scheduling information
  - Memory management information
  - Accounting information
  - I/O status information





Sharing Memory

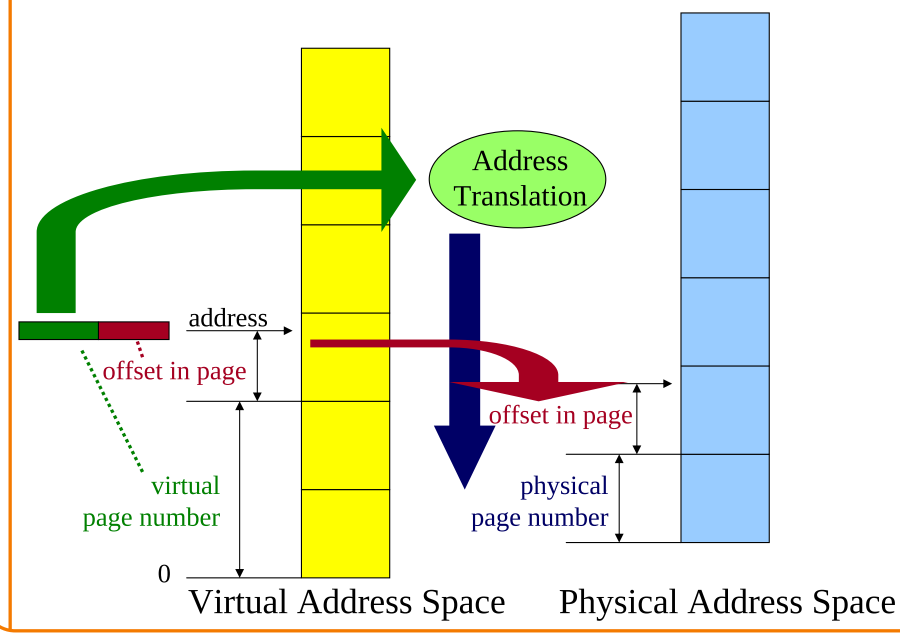
- In the old days…
  - MS-DOS (1990)
  - Original Apple Macintosh (1984)
- Problem: protection
  - What prevents process 1 from reading/writing process 3's memory?
  - What prevents process 2 from reading/writing OS's memory?
- In modern days, Virtual Memory protection
  - IBM VM-370 (1970)
  - UNIX (1975)
  - MS Windows (2000)



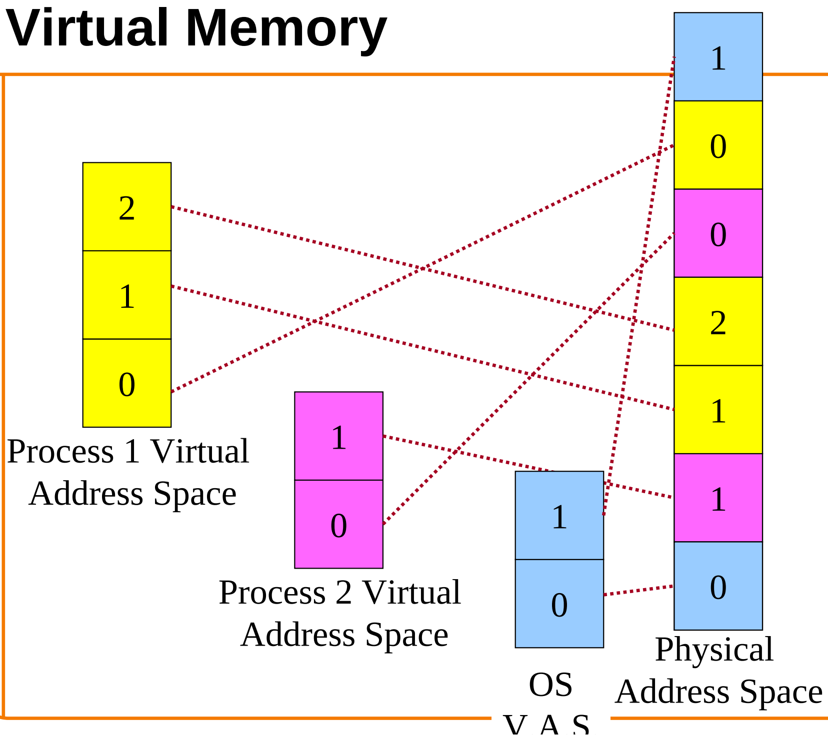
Virtual Memory

- Give each process illusion of large address space
  - E.g., 32-bit addresses that reference 4 Gig of memory
- Divide the physical memory into fixed-sized pages
  - E.g., 4 Kilobyte pages
- Swap pages between disk and main memory
  - Bring in a page when a process accesses the space
  - May require swapping *out* a page already in memory
- Keep track of where pages are stored in memory
  - Maintain a page table for each process to do mapping
- Treat address as page number and offset in page
  - High-order bits refer to the page
  - Low-order bits refer to the offset in the page

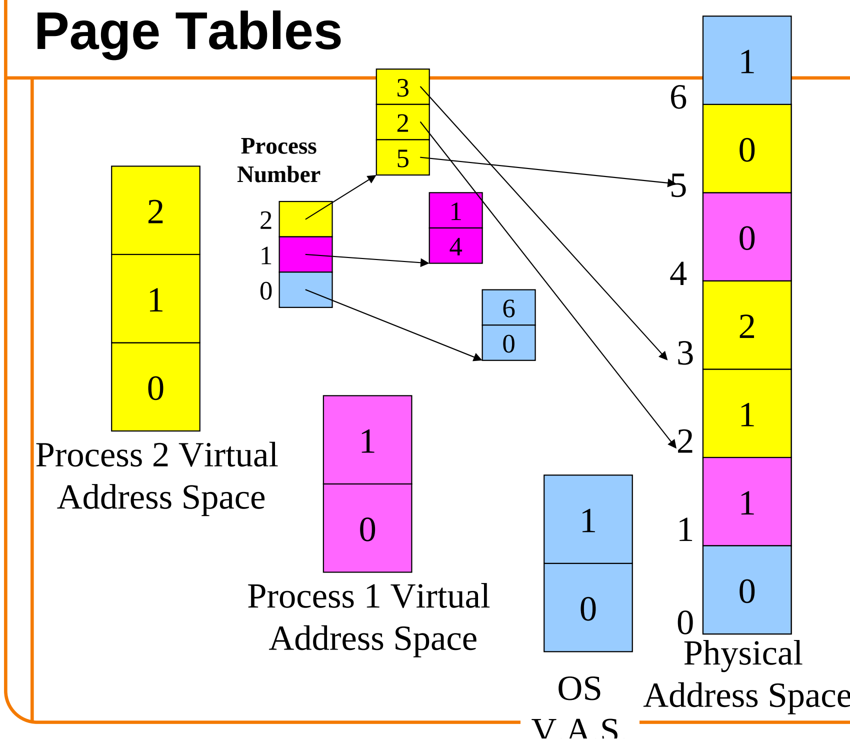
Virtual Memory for a Process



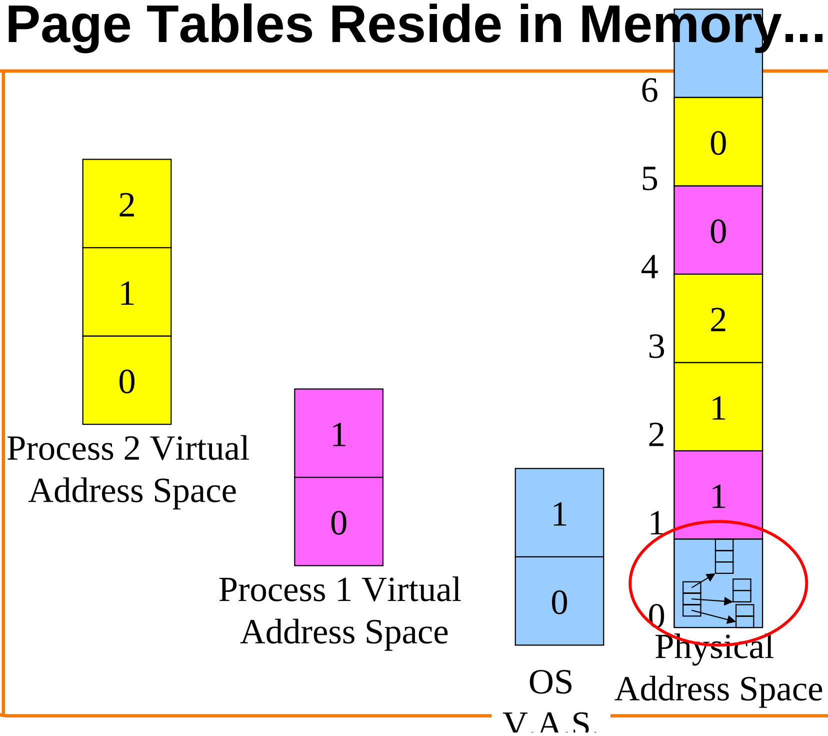
Virtual Memory



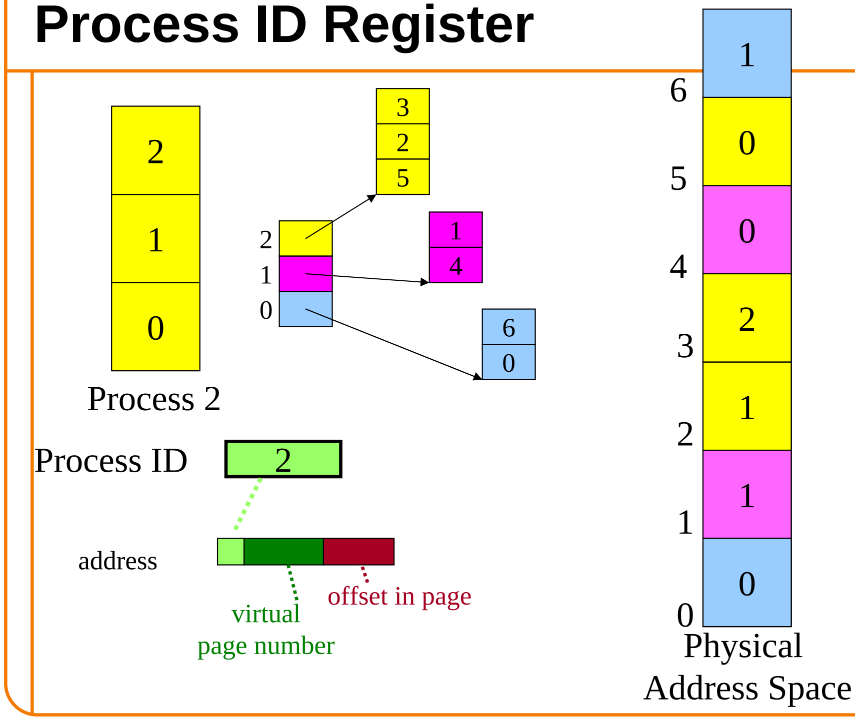
Page Tables



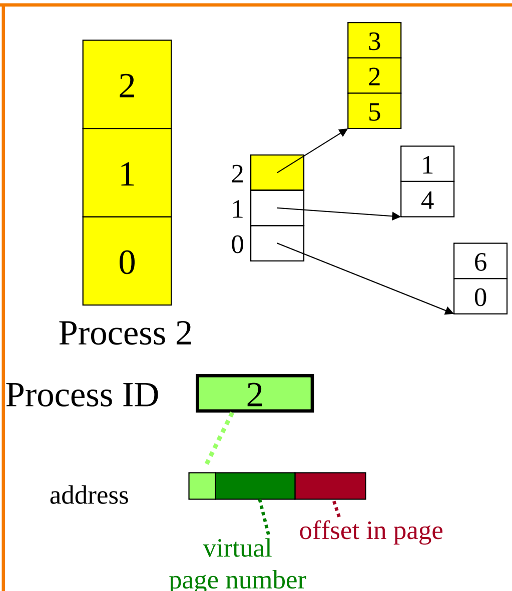
Page Tables Reside in Memory...



Process ID Register

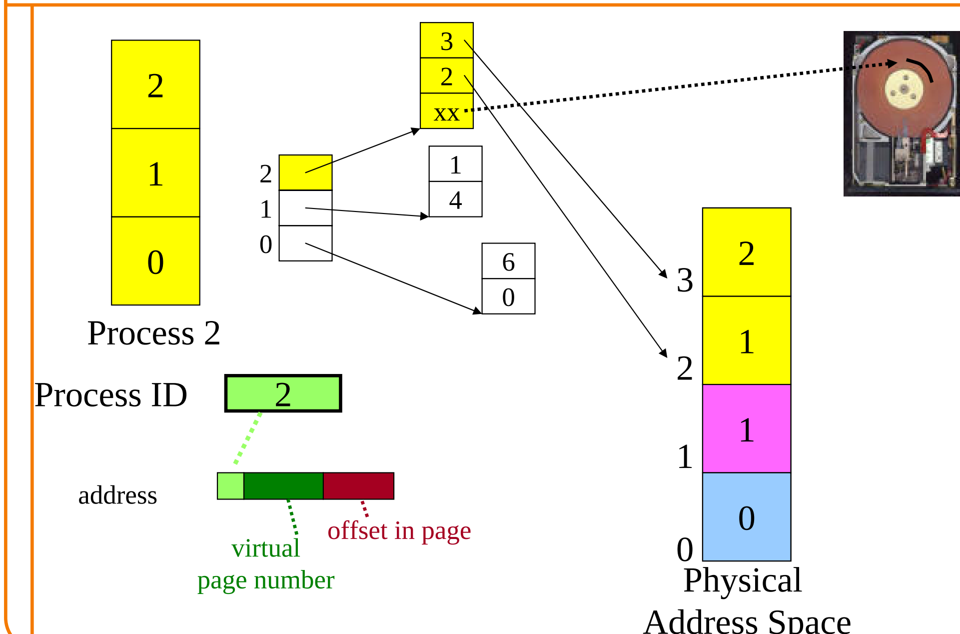


Protection Between Processes

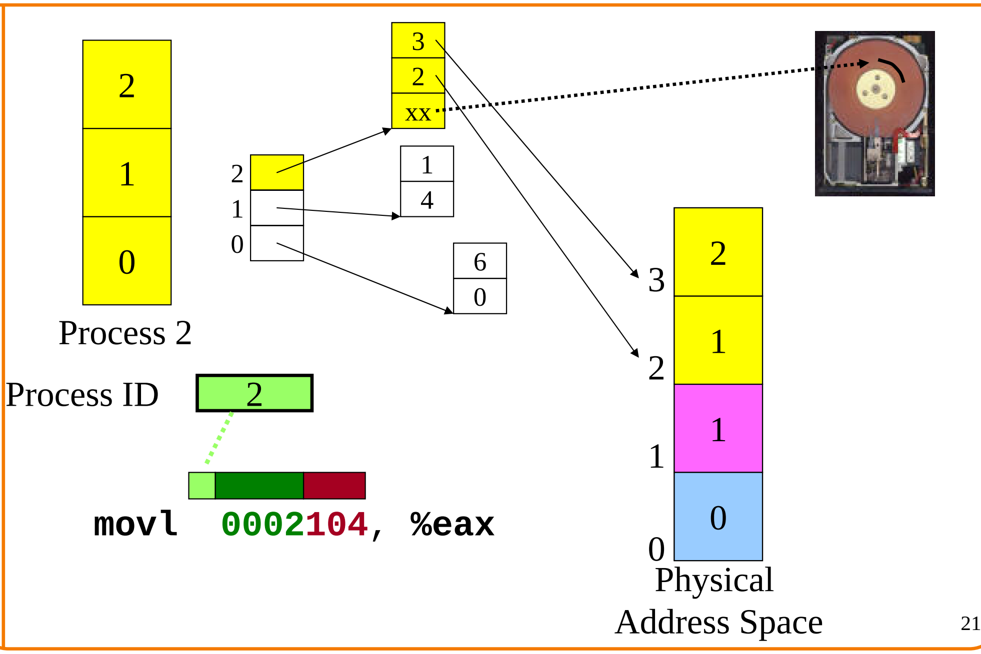


- User-mode (unprivileged) process *cannot* modify Process ID register
- If page tables are set up correctly, process #1 can access *only* its own pages in physical memory
- The operating system sets up the page tables

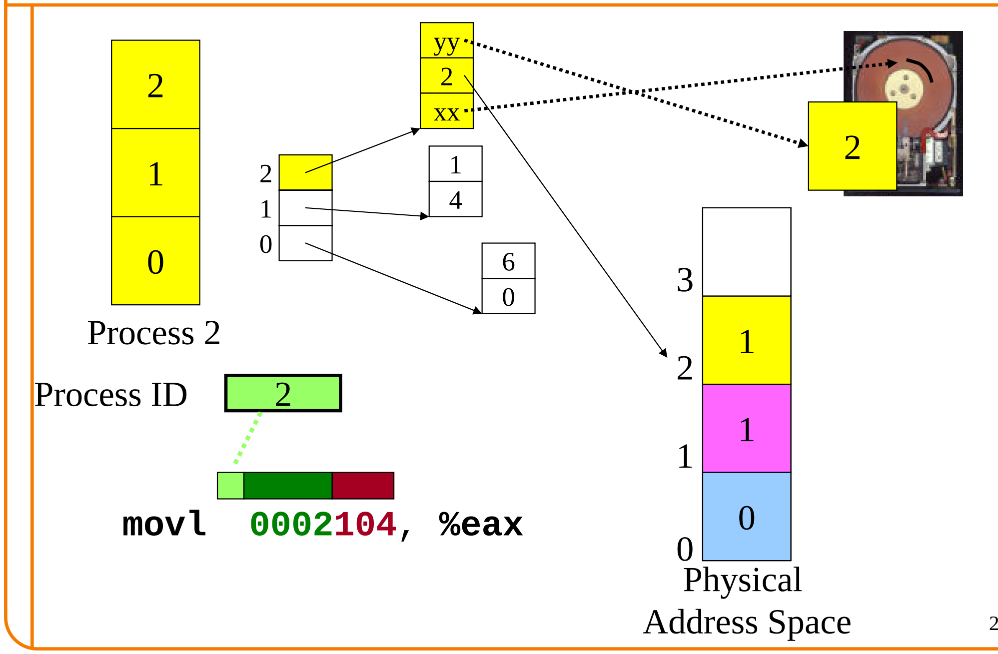
Paging



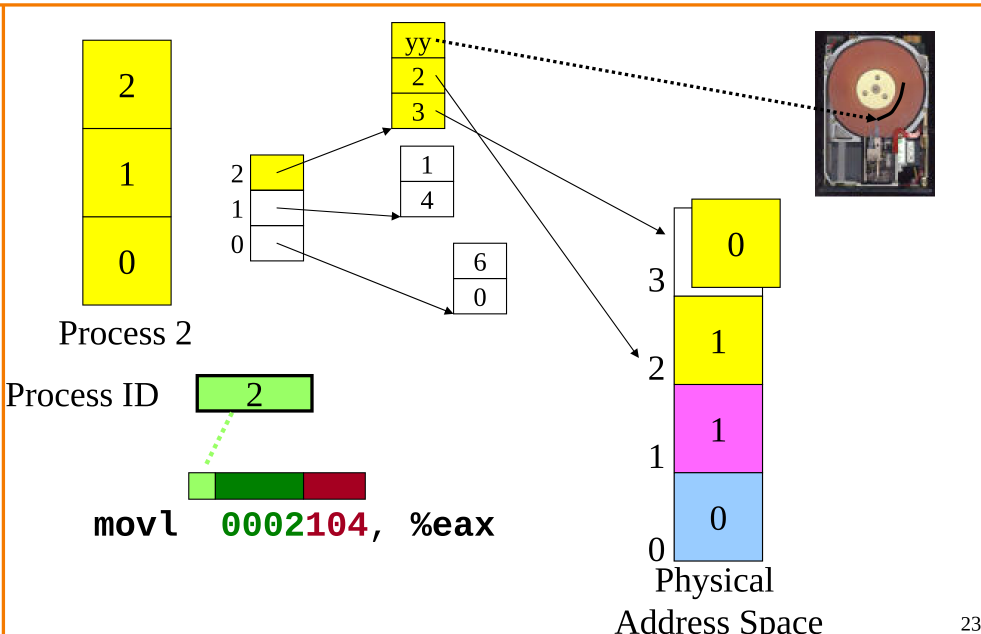
Page Fault!



Write Some Other Page to Disk



Fetch Current Page, Adjust Page Tables



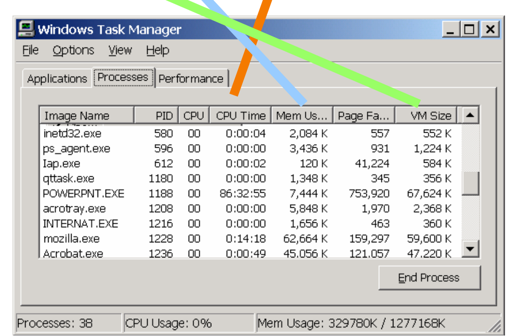
Measuring the Memory Usage

Virtual memory usage
Physical memory usage (“resident set size”)
CPU time used by this process so far

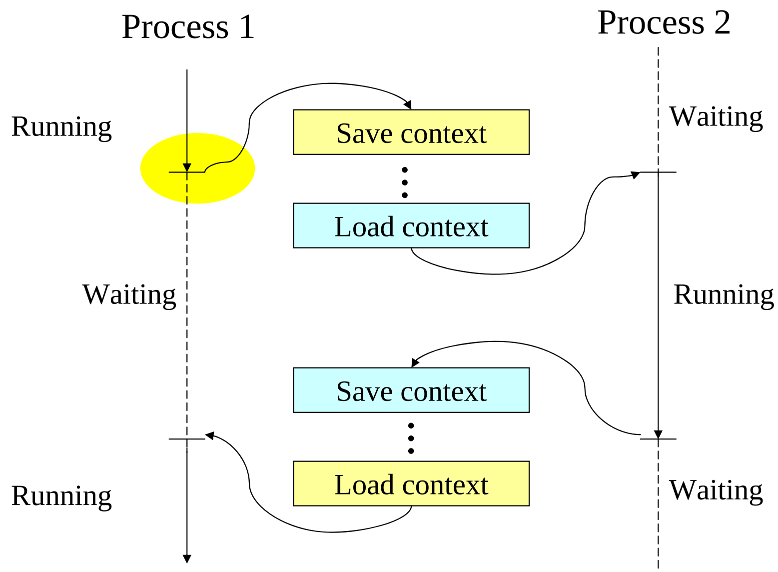
Unix

```
% ps l
F  UID   PID  PPID PRI   VSZ   RSS STAT  TIME COMMAND
0  115  7264  7262  17  4716  1400  SN   0:00 -csh
0  115  7290  7264  17 15380 10940  SN   5:52 emacs
0  115  3283  7264  23  2864   812  RN   0:00 ps l
```

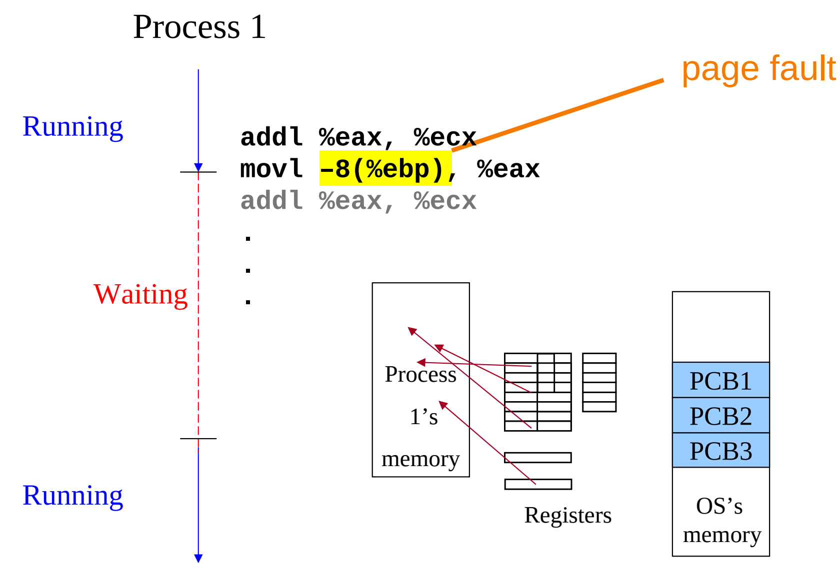
Windows



Context Switch, in More Detail

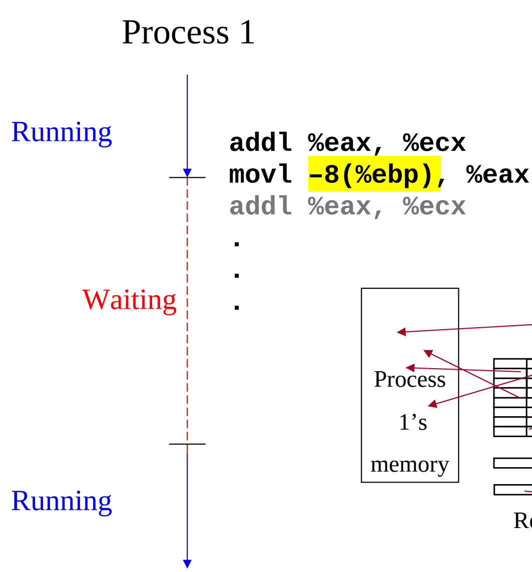


Context Switch, in More Detail




```
addl %eax, %ecx
movl -8(%ebp), %eax
addl %eax, %ecx
.
.
.
```


Context Switch, in More Detail

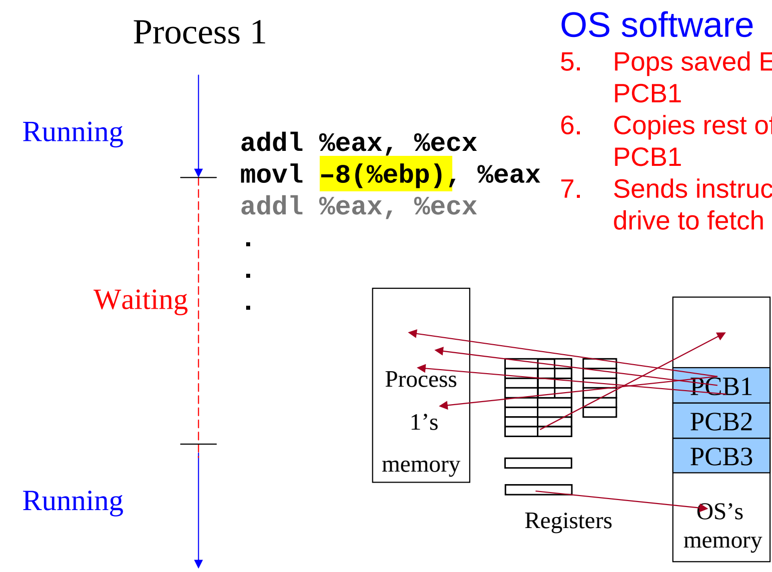



```
addl %eax, %ecx
movl -8(%ebp), %eax
addl %eax, %ecx
.
.
.
```

Fault-handler hardware

1. Enters privileged mode
2. Sets EIP to specific location in operating system
3. Sets ESP to operating-system stack in OS memory
4. Pushes old (process 1) EIP and ESP on OS stack

Context Switch, in More Detail




```
addl %eax, %ecx
movl -8(%ebp), %eax
addl %eax, %ecx
.
.
.
```

OS software

5. Pops saved EIP,ESP into PCB1
6. Copies rest of registers into PCB1
7. Sends instructions to disk drive to fetch page

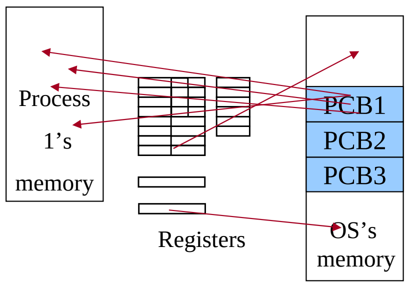
Resuming Some Other Process

OS software

8. Sets process-ID register to 2
9. Pushes saved EIP,ESP from PCB2 onto OS stack
10. Copies rest of registers from PCB2
11. Executes “return from interrupt” instruction

Hardware

12. Pops EIP,ESP into registers
13. Switches back to unprivileged mode
14. Resumes where process 2 left off last time

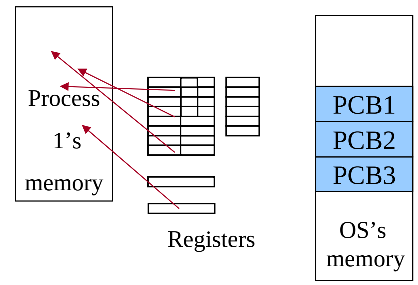


System call, just another kind of fault

Process 1


```
mov     $4,%eax
int     $0x80
addl %eax, %ecx
.
.
.
```

system call
(privileged instruction)



Summary

- Abstraction of a “process”
  - CPU: a share of CPU resources on a small time scale
  - Memory: a complete address space of your own
- OS support for the process abstraction
  - CPU: context switch between processes
  - Memory: virtual memory (VM) and page replacement
  - Files: open/read/write, rather than “move disk head”
  - Protection: ensure process access only its own resources
- Hardware support for the process abstraction
  - Context switches, and push/pop registers on the stack
  - Switch between privileged and unprivileged modes
  - Map VM address and process ID to physical memory