L5: Operating Systems

Frans Kaashoek
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MASSACHUSETTS
INSTITUTE OF
TECHNOLOGY

Operating systems

- Today: organization
- Next week: techniques for managing multiple activities
- Week after: virtual machines and performance

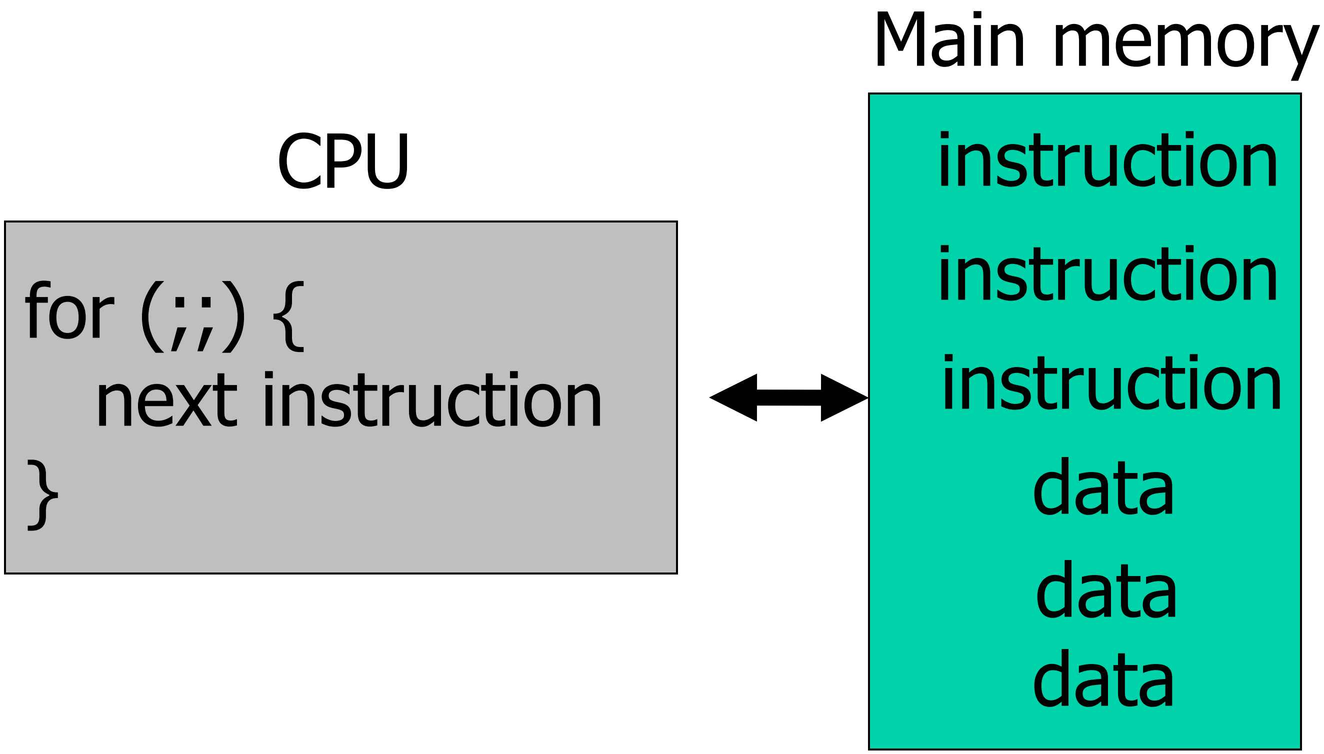
OS challenge and goals

- Challenge:
  - one computer, many programs
- Goals:
  - Multiplexing
  - Protection
  - Cooperation
  - Portability
  - Performance

Approach

- Virtualization
- Abstractions

One program per computer



Main memory

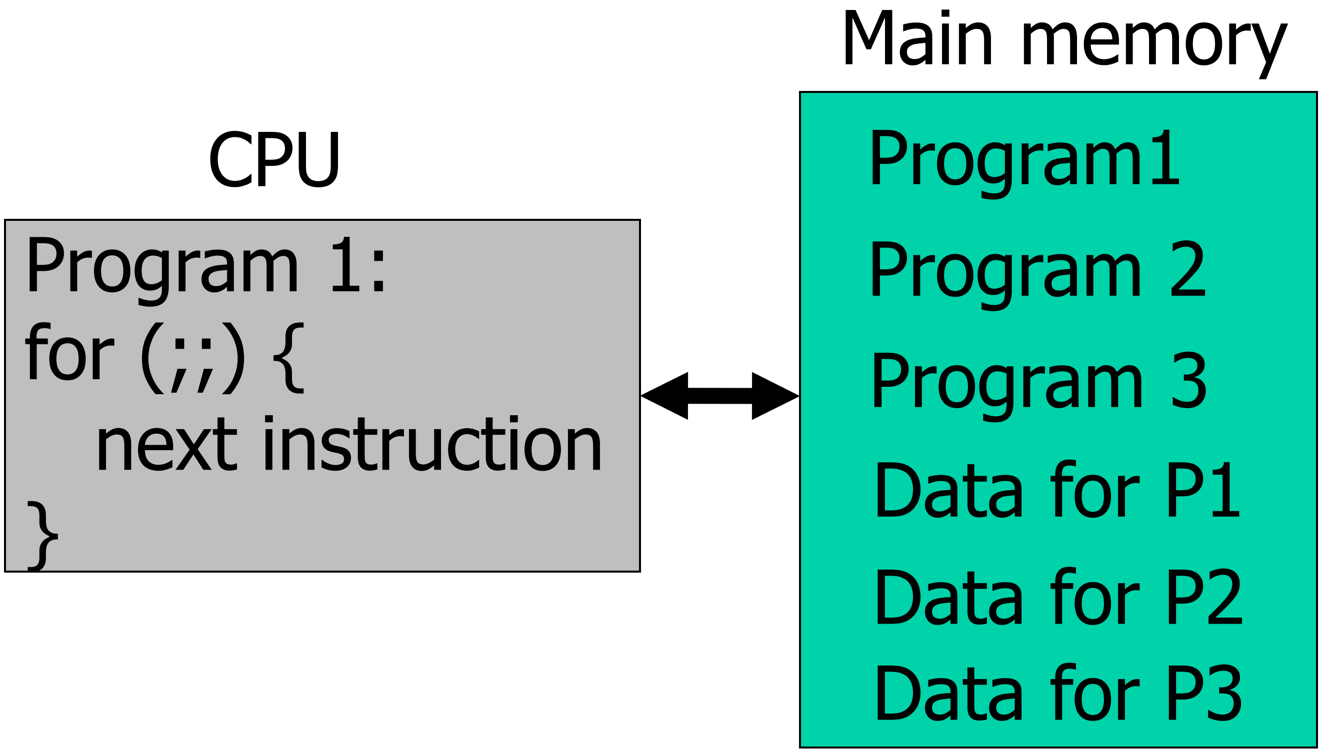
CPU

```
for (;;) {
   next instruction
}
```

instruction
instruction
instruction
data
data
data

- Memory holds *instructions* and *data*
- CPU *interprets* instructions

Strawman solution



Main memory

CPU

```
Program 1:
for (;;) {
   next instruction
}
```

Program1

Program 2

Program 3

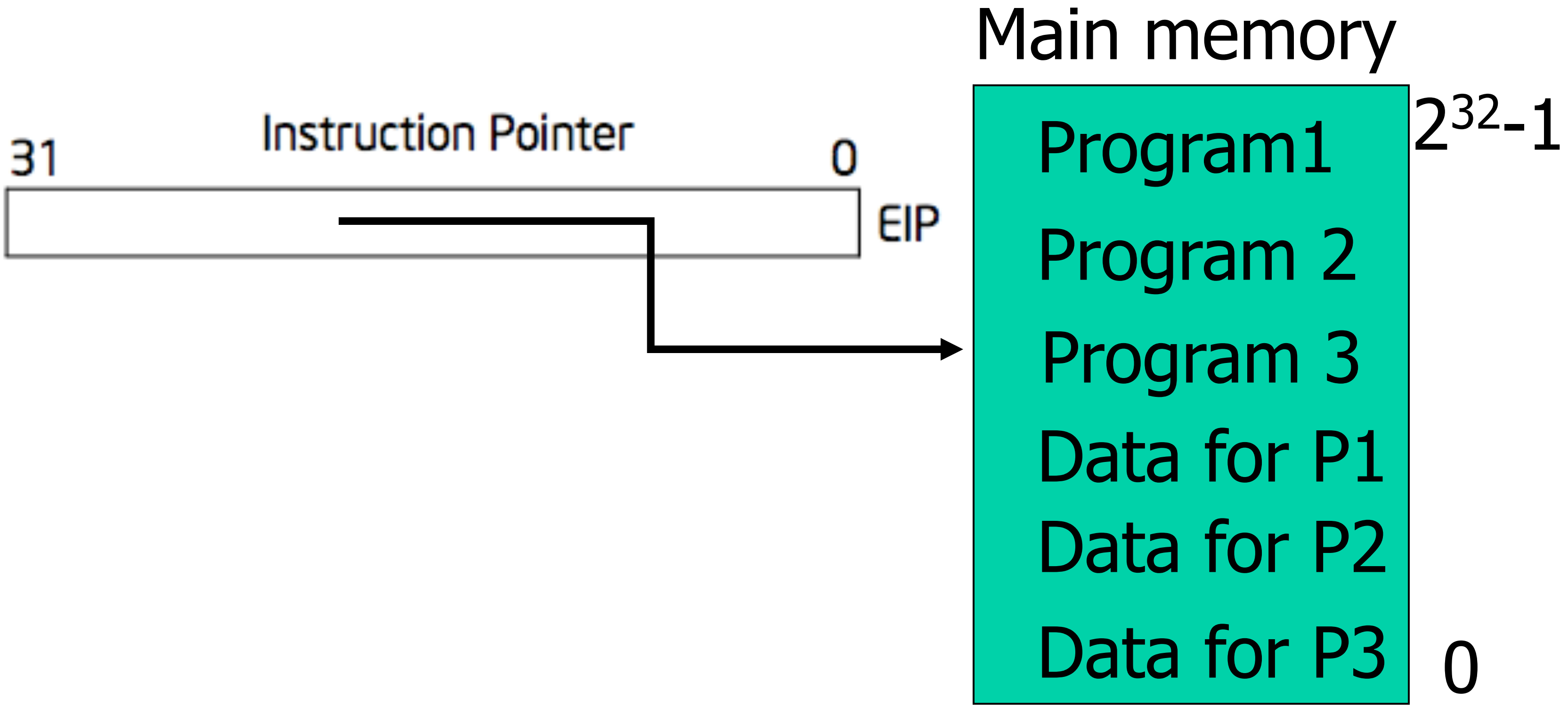
Data for P1

Data for P2

Data for P3

- OS switches processor(s) between programs

Problem: no boundaries



Main memory

2^{32}-1

Program1
Program 2
Program 3
Data for P1
Data for P2
Data for P3

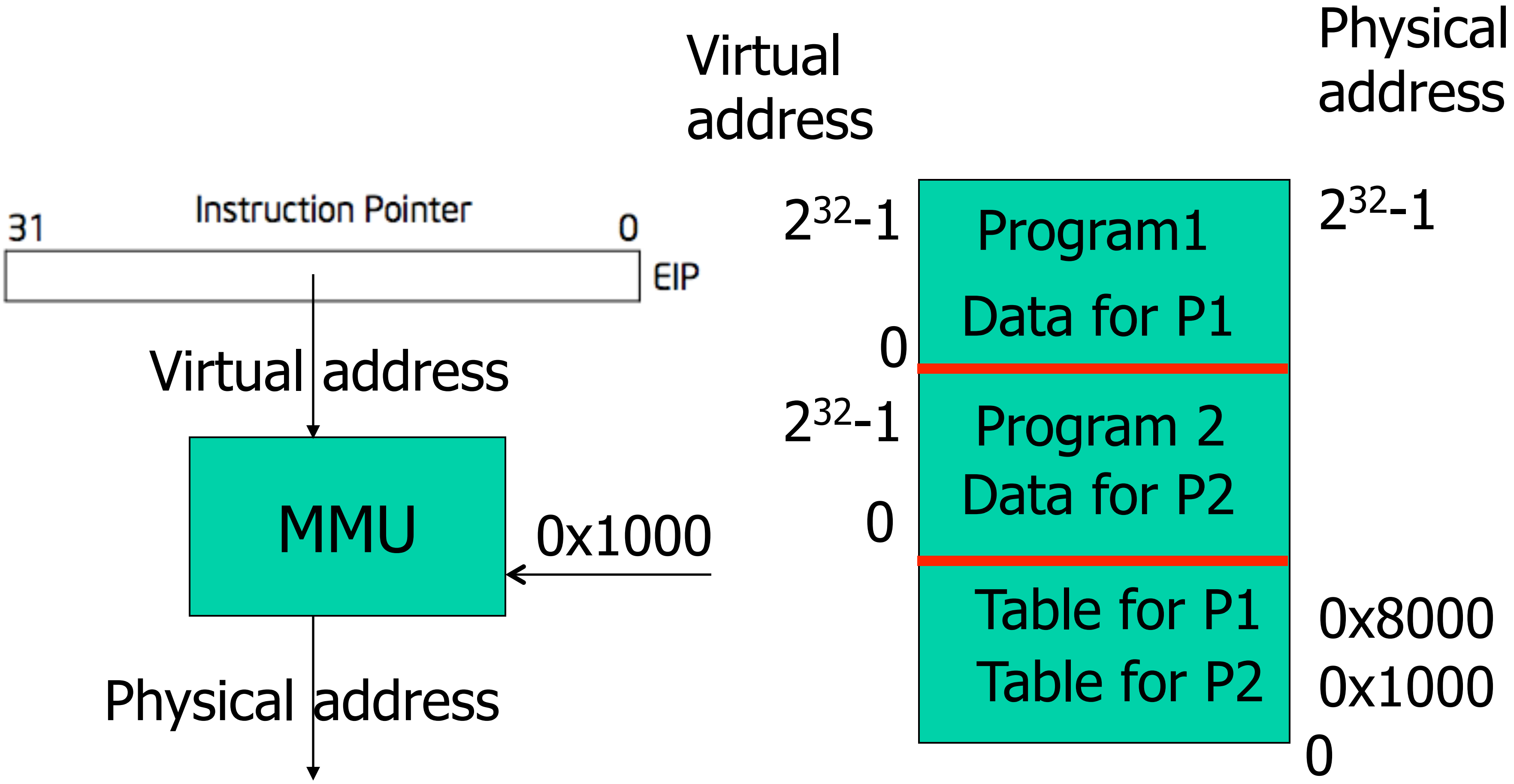
0

- A program can modify other programs data
- A program jumps into other program’s code
- A program may get into an infinite loop

Goal: enforcing modularity

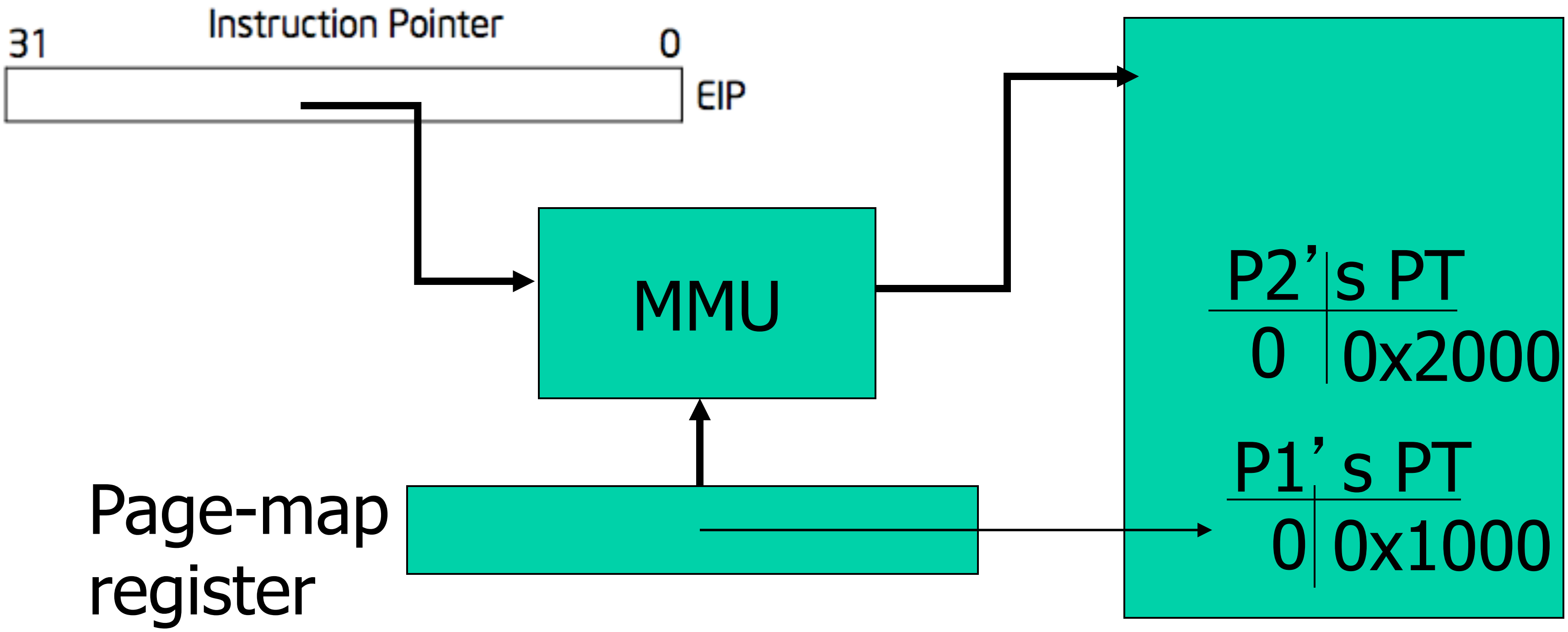
- Give each program its private memory for code, stack, and data
- Prevent one program from getting out of its memory
- Allowing sharing between programs when needed
- Force programs to share processor

Approach: memory virtualization



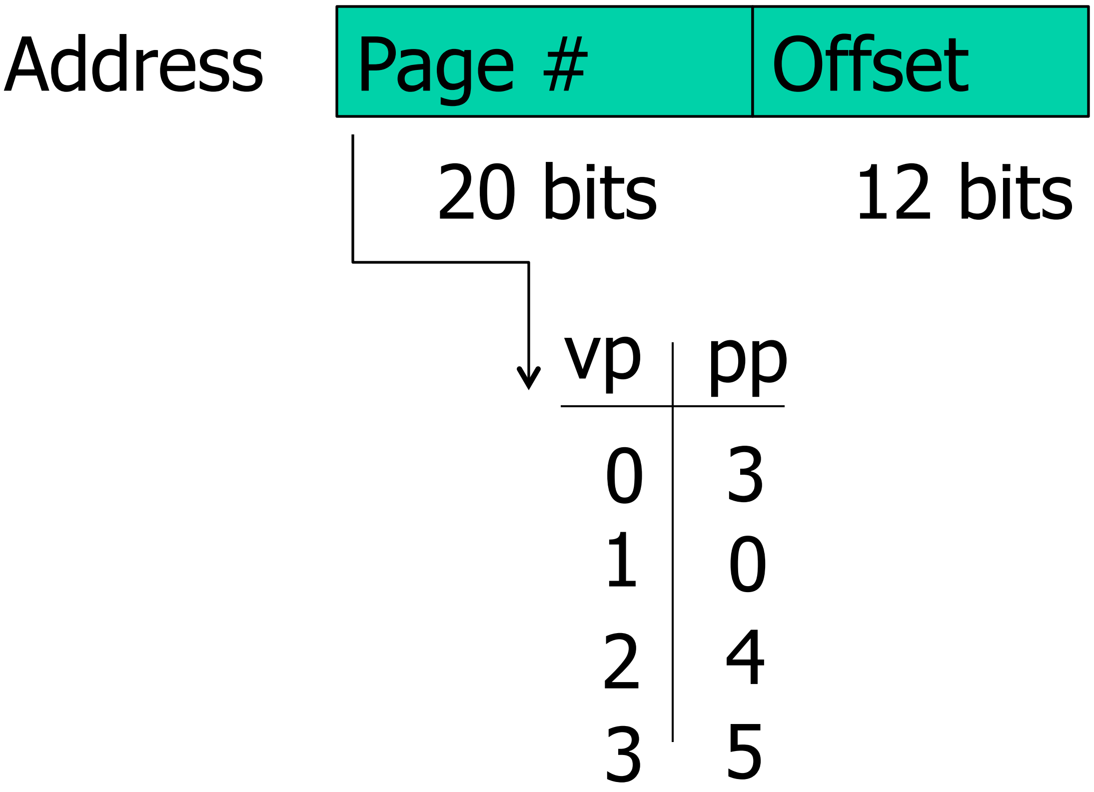
- Modify processor to support virtual addresses

Table records mapping



- Each program has its own translation map
  - Physical memory doesn't have to be contiguous
- When switching program, switch map
- Maps stored in main memory

Space-efficient map



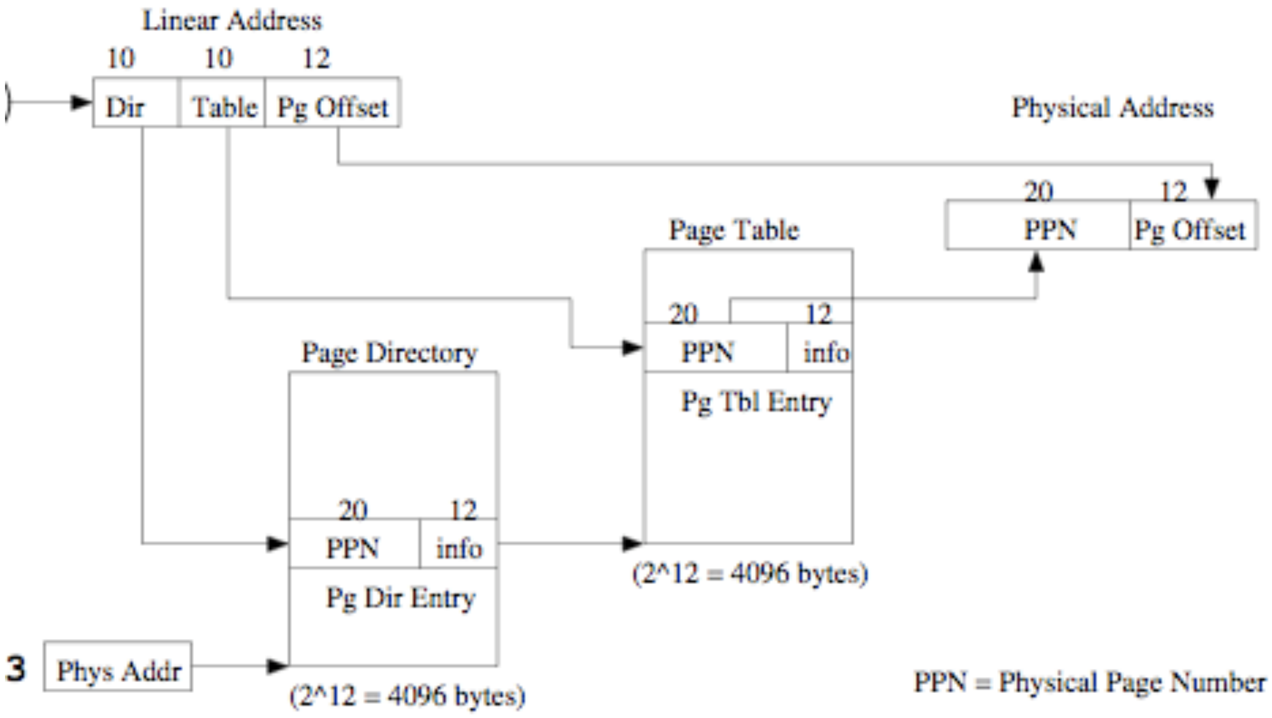
Address

Page #	Offset
20 bits	12 bits

vp	pp
0	3
1	0
2	4
3	5

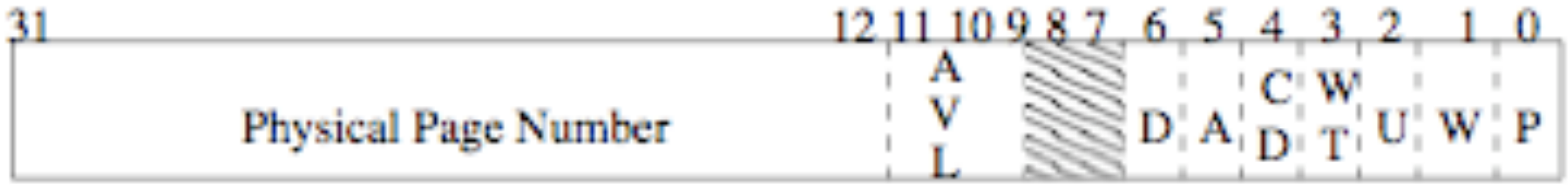
- 0x02020 -> 4 * 4096 + 0x20 = 0x4020

Intel x86-32 two-level page table



- Page size is 4,096 bytes
  - 1,048,576 pages in 2^{32}
  - Two-level structure to translate

x86 page table entry



- W: writable?
  - Page fault when W = 0 and writing
- U: user mode references allowed?
  - Page fault when U = 0 and user references address
- P: present?
  - Page fault when P = 0

Page fault

- Switches processor to a predefined handler in software
  - Handler can stop program and raise error
  - Handler can update the page map and resume at faulted instruction

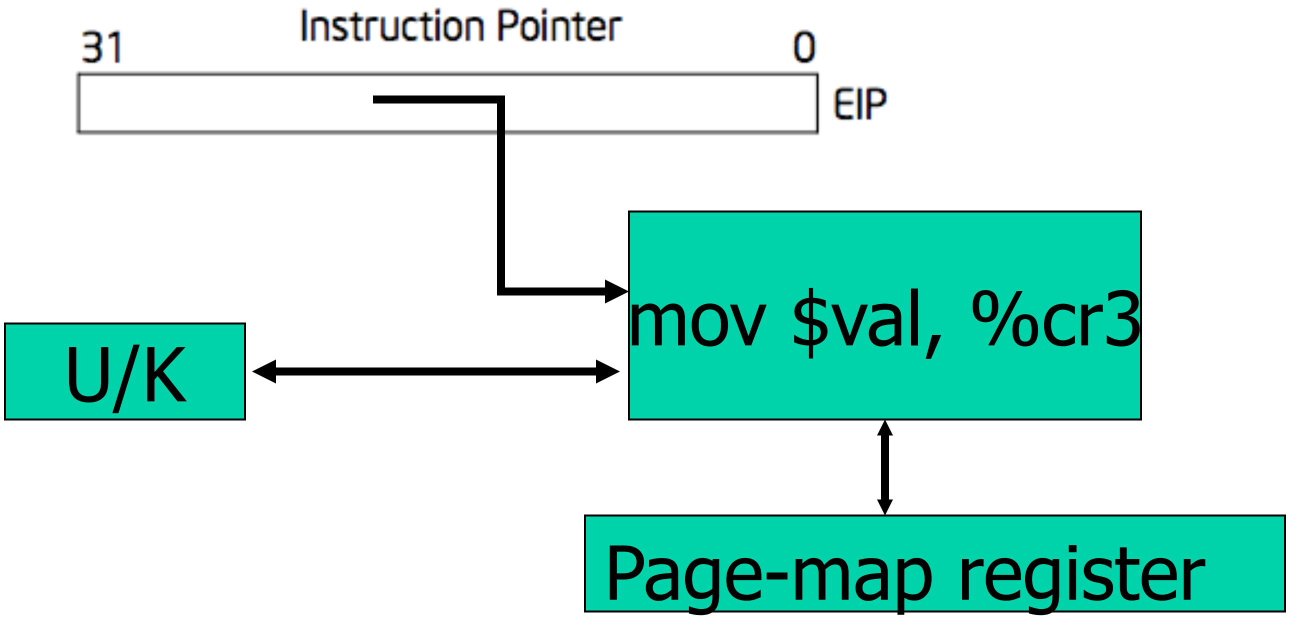
Naming view

- Apply naming model:
  - Name = virtual address
  - Value = physical address
  - Context = Page map
  - Lookup algorithm: index into page map
- Naming benefits
  - Sharing
  - Hiding
  - Indirection (demand paging, zero-fill, copy-on-write, …)

Threat: page map address is unprotected

- If program can modify page map, then it can access any physical address
- Must protect page table!

Protecting page maps: kernel and user mode



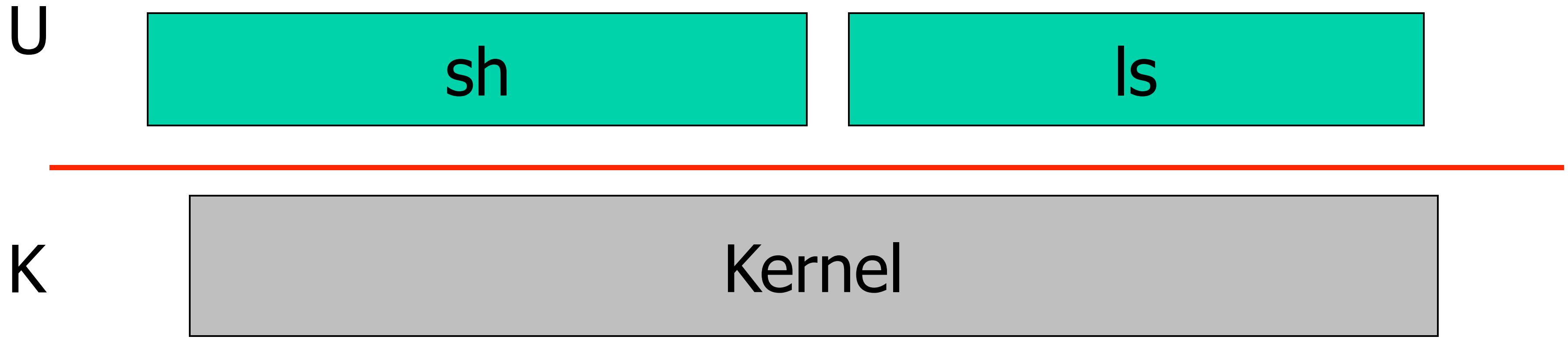
mov $val, %cr3

U/K

Page-map register

- Kernel mode: can change page-map register, U/K
- In user mode: cannot
- Processor starts in kernel mode
- On interrupts, processor switches to kernel mode

What is a kernel?



- The code running in kernel mode
  - Trusted program: e.g., sets page-map, U/K register
  - All interrupt handlers (e.g. page fault) run in kernel mode

How transfer from U to K, and back?

- Special instruction: e.g., int #
- Processor actions on int #:
  - Set U/K bit to K
  - Lookup # in table of handlers
  - Run handler
- Another instruction for return (e.g., reti)
  - Kernel sets U/K bit to U
  - Calls reti

Process: a virtual processor

- Kernel sets up a hard timer to deliver interrupt every, say, 100 msec
- Interrupts transfers control to kernel
    - Kernel saves current program state
        - Program counter, stack pointer, pmap reg, etc.
    - Kernel choses a runnable program
    - Kernel loads saved program state
    - Kernel returns from interrupt
    - Processors resumes execution w. new state
- No processs can hog processor

Abstractions

- Pure virtualizing is often not enough
  - E.g., Portability
  - E.g., Cooperation
- Example OS abstractions:
  - Disk -> FS
  - Display -> Windows
  - DRAM -> heap w. allocate/deallocate
- Design of abstraction important

```
main() {
  int fd, n;
  char buf[512];

  chdir("/usr/rtm");

  fd = open("quiz.txt", 0);
  n = read(fd, buf, 512);
  write(1, buf, n);
  close(fd);
}
```

Where do abstractions live?

- Library in user space?
  - No! Program must use disk only through abstraction
- Use kernel to enforce abstractions
- Methods of abstraction are system calls
  - E.g., int 33

How does kernel read user memory?

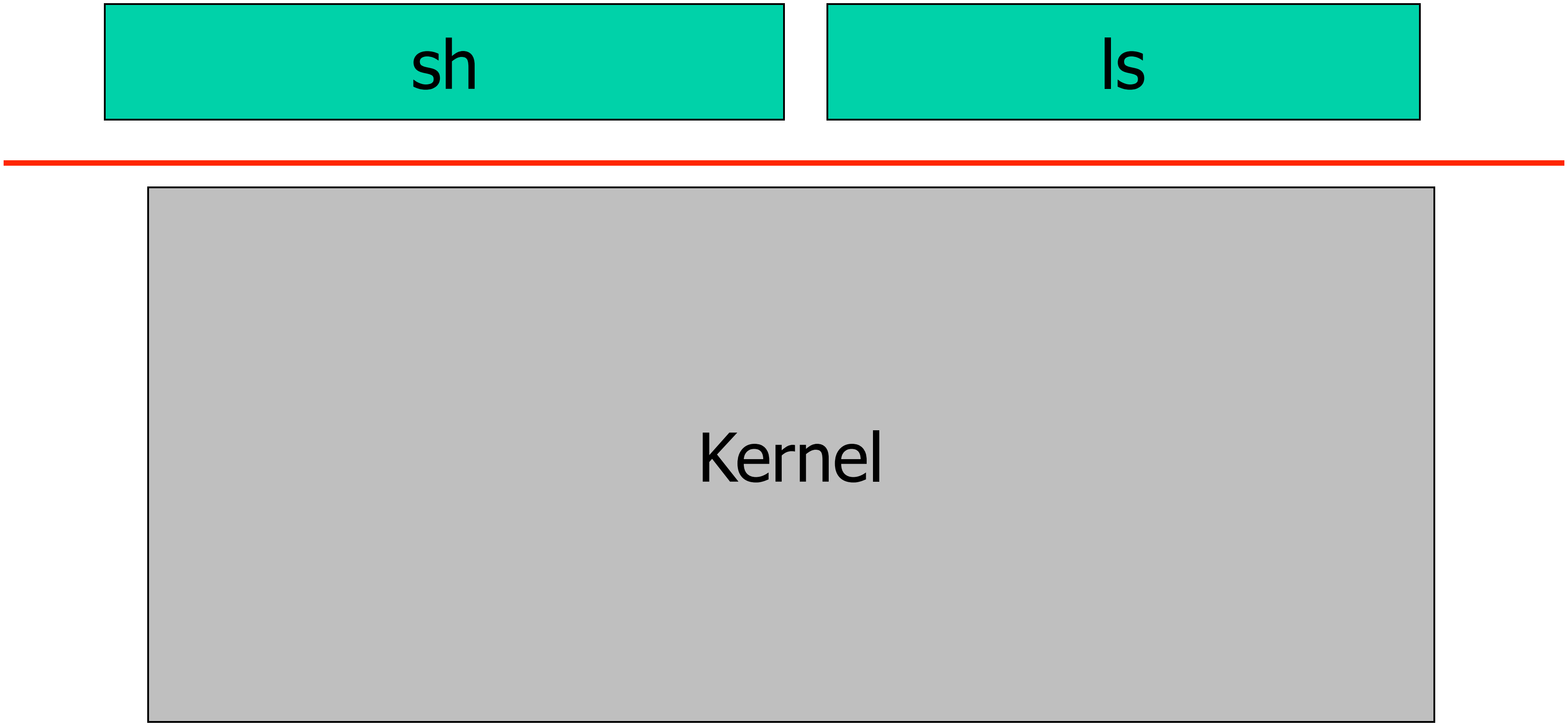
- read(fd, buf, 512)
- kernel and user share page map
  - E.g., user program in low addresses
  - E.g., kernel in high addresses
  - Page map entry has U/K bit
    - Set U bit only for low addresses

Kernel complexity

- 1975 Unix kernel: 10,500 lines of code
- 2008 Linux 2.6.24 line counts:

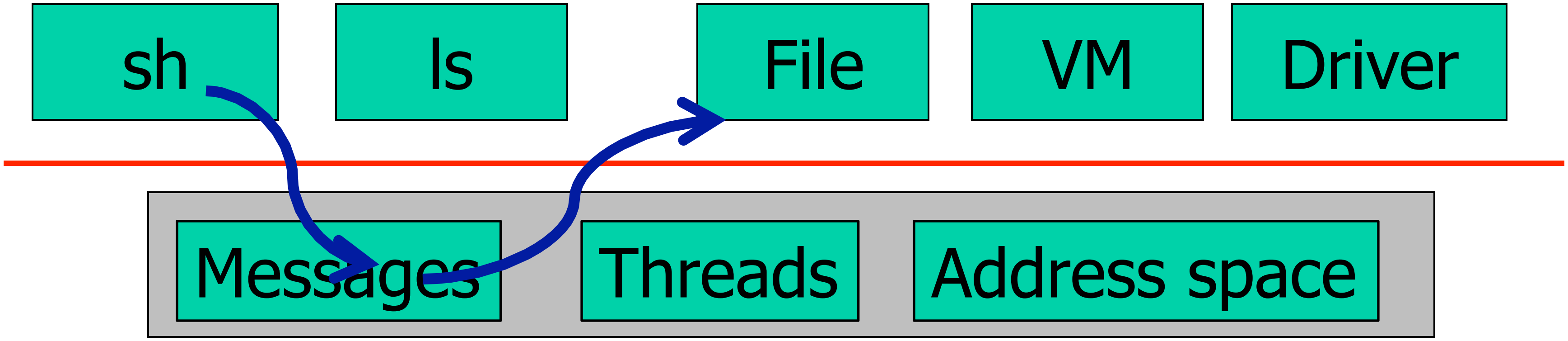
85,000	processes
430,000	sound drivers
490,000	network protocols
710,000	file systems
1,000,000	different CPU architectures
4,000,000	drivers
7,800,000	Total

Monolithic kernel



- Avoiding chaos:
  - Internal interfaces simplify
  - Loadable kernel modules

Microkernel



- Apply client/server to OS
- Kernel maps devices into driver's address space

Micro versus monolithic

- Many kernels are monolithic
- Why change a working kernel?
- Microkernel benefits not that easy to get
  - Message more costly then function calls
  - Sharing between servers not that easy
  - What do you do if file server is down?
- Easy to have servers on monolithic too

Summary

- OS virtualizes for sharing/multiplexing
- Abstract for portability and cooperation
- Provides enforced modularity:
  - Program versus programs
  - Program versus kernel