Operating Systems (Honor Track)

Four fundamental OS concepts

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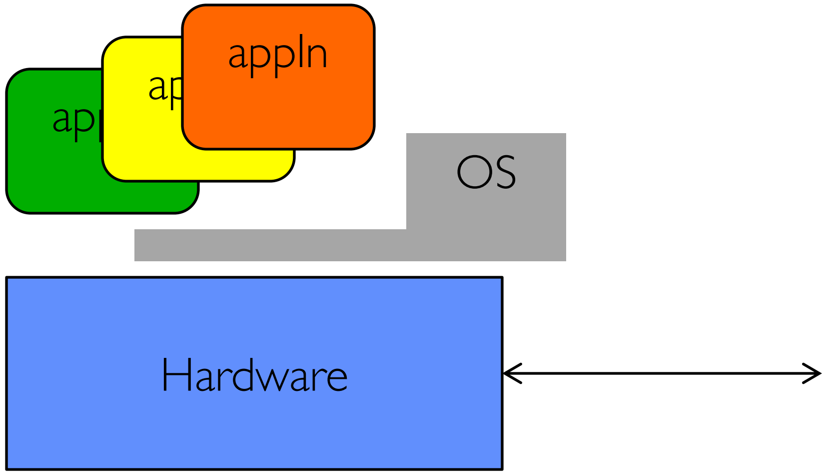
Acknowledgments: Ion Stoica, Berkeley CS 162

Announcements

- Course website: https://pkuos.systems/sp22/
  - You can access it if you currently do not have access to course.pku.edu.cn
- Lab 0 is out. Start to work on it now.
- Pintos: We have summer projects to extend Pintos labs to RISC-V and ARM.
  - Please contact us if you are interested.

Recall: What is an operating system?

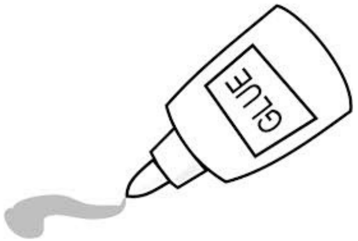
- Special layer of software that provides application software access to hardware resources
  - Convenient abstraction of complex hardware devices
  - Protected access to shared resources
  - Security and authentication
  - Communication amongst logical entities



Recall: What is an operating system?

- Referee
  - Manage protection, isolation, and sharing of resources
    - » Resource allocation and communication

- Illusionist
  - Provide clean, easy-to-use abstractions of physical resources
    - » Infinite memory, dedicated machine
    - » Higher level objects: files, users, messages
    - » Masking limitations, virtualization



- Glue
  - Common services
    - » Storage, Window system, Networking
    - » Sharing, Authorization
    - » Look and feel

Very Brief History of OS

- Several Distinct Phases:

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  - Hardware Expensive, Humans Cheap
    - » Eniac, … Multics

"I think there is a world market for maybe five computers." – *Thomas Watson, chairman of IBM, 1943*

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Thomas Watson was often called "the worlds greatest salesman" by the time of his death in 1956

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  - Hardware Cheaper, Humans Expensive
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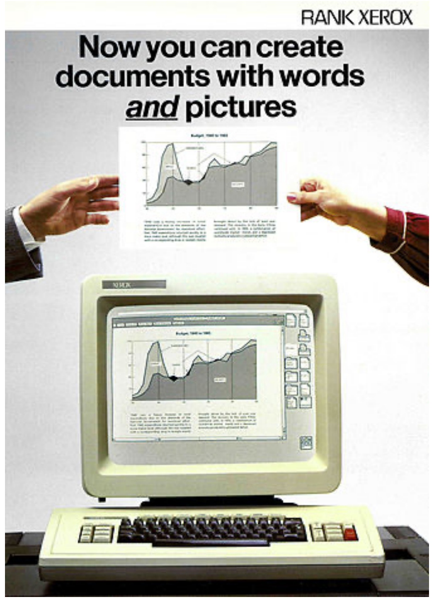

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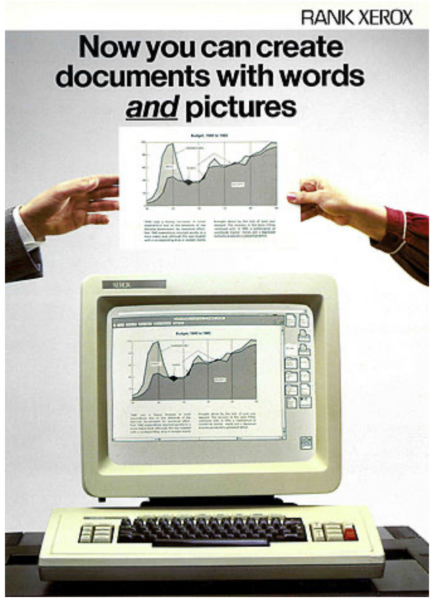
    - » Ubiquitous devices, widespread networking



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- Rapid change in hardware leads to changing OS
  - Batch $\Rightarrow$ Multiprogramming $\Rightarrow$ Timesharing $\Rightarrow$ Graphical UI $\Rightarrow$ Ubiquitous Devices
  - Gradual migration of features into smaller machines

- Today
  - Small OS: 100K lines / Large: 10M lines (5M browser!)
  - 100-1000 people-years

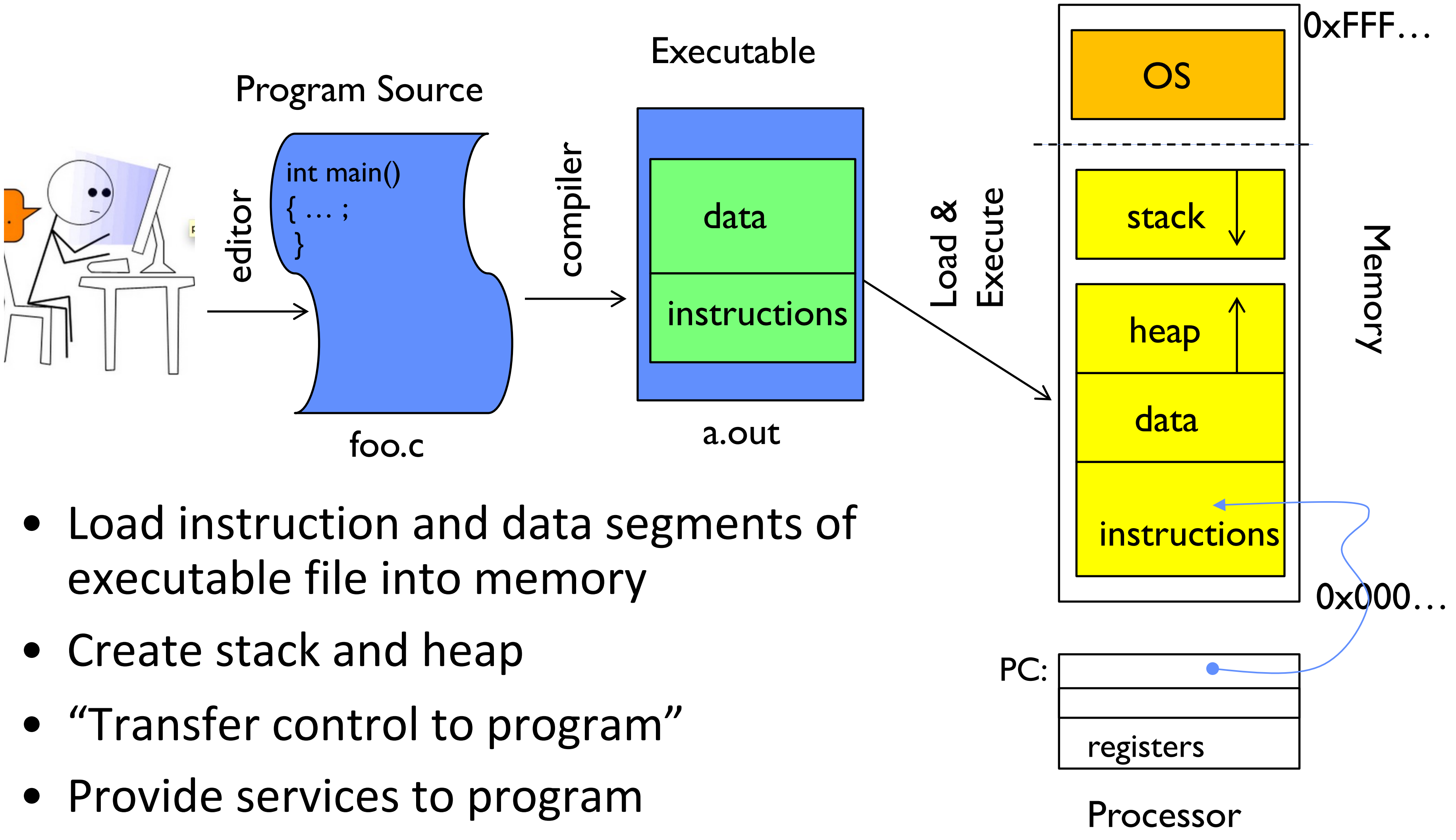
OS Archaeology

- Because of the cost of developing an OS from scratch, most modern OSes have a long lineage…
- Multics → AT&T Unix → BSD Unix → Ultrix, SunOS, NetBSD,…
- Mach (micro-kernel) + Unix BSD → NextStep → XNU → Apple OS X, iPhone iOS
- MINIX → Linux → Android OS, Chrome OS, RedHat, Ubuntu, Fedora, Debian, Suse,…
- CP/M → QDOS → MS-DOS → Windows 3.1 → NT → 95 → 98 → 2000 → XP → Vista → 7 → 8 → 10 → …

Today: Four Fundamental OS Concepts

- **Thread**
  - Single unique execution context: fully describes program state
  - Program Counter, Registers, Execution Flags, Stack
- **Address space** (with **translation**)
  - Programs execute in an *address space* that is distinct from the memory space of the physical machine
- **Process**
  - An instance of an executing program is *a process consisting of an address space and one or more threads of control*
- **Dual mode operation / Protection**
  - Only the "system" has the ability to access certain resources
  - The OS and the hardware are protected from user programs and user programs are isolated from one another by *controlling the translation* from program virtual addresses to machine physical addresses

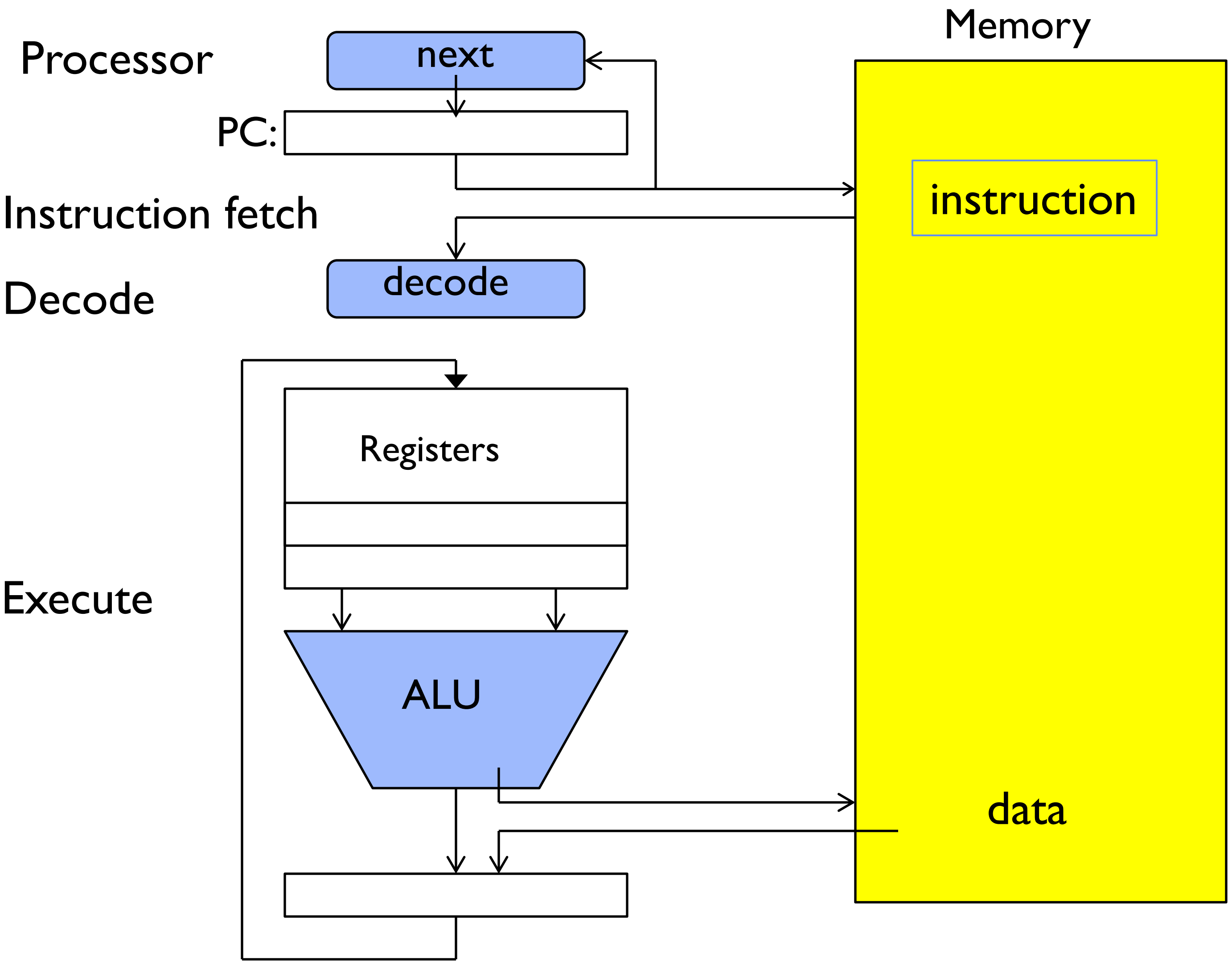
OS Bottom Line: Run Programs



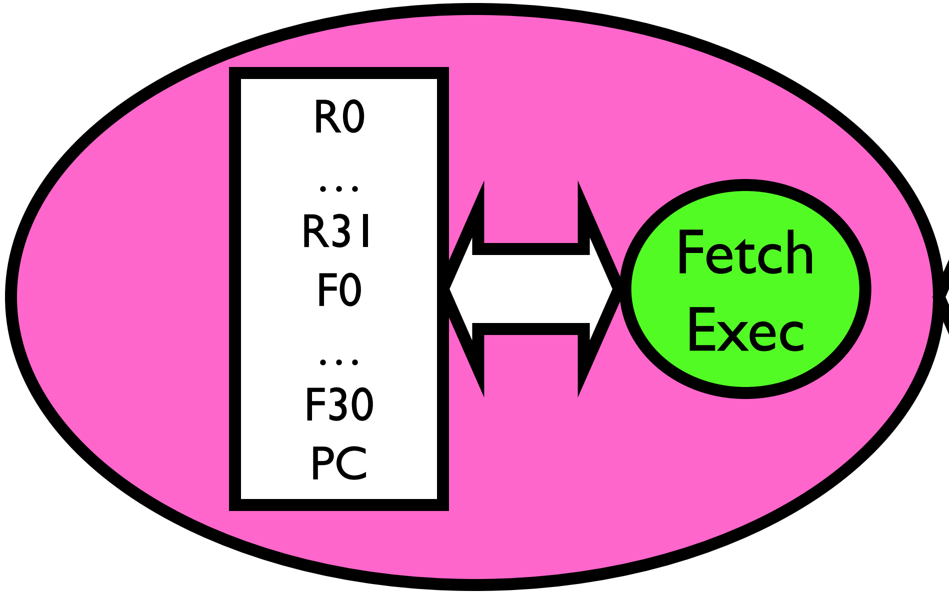
- Load instruction and data segments of executable file into memory
- Create stack and heap
- "Transfer control to program"
- Provide services to program
- While protecting OS and program

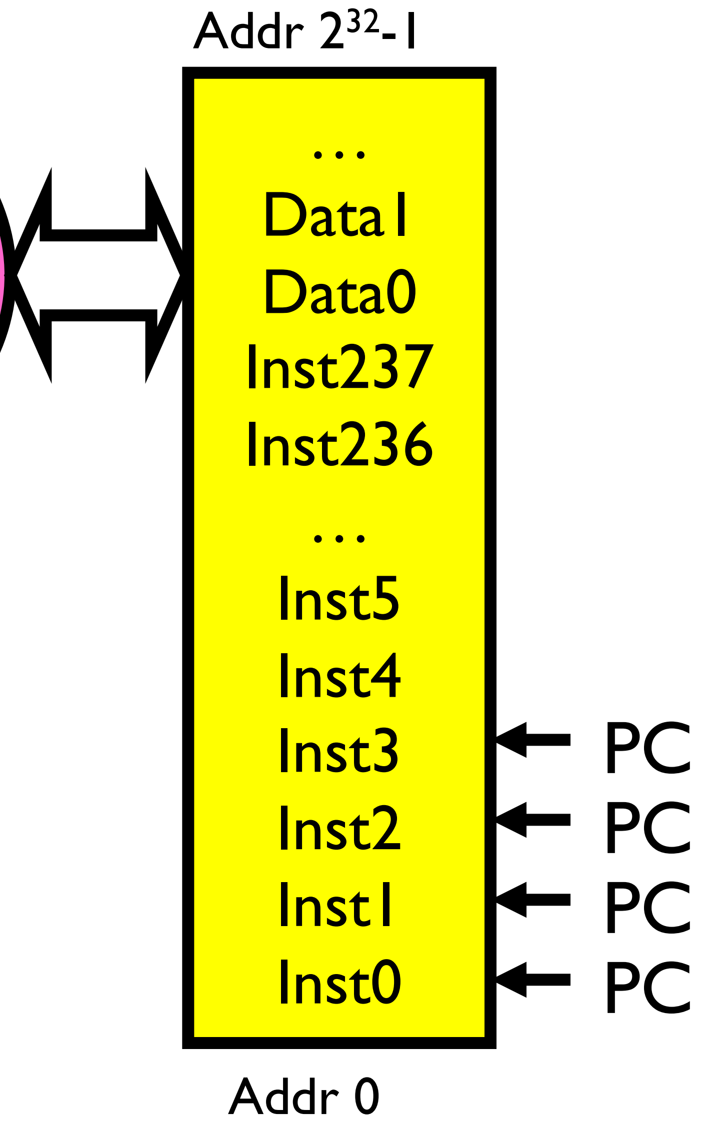
Recall (ICS): Instruction Fetch/Decode/Execute

The instruction cycle



Recall (ICS): What happens during program execution?





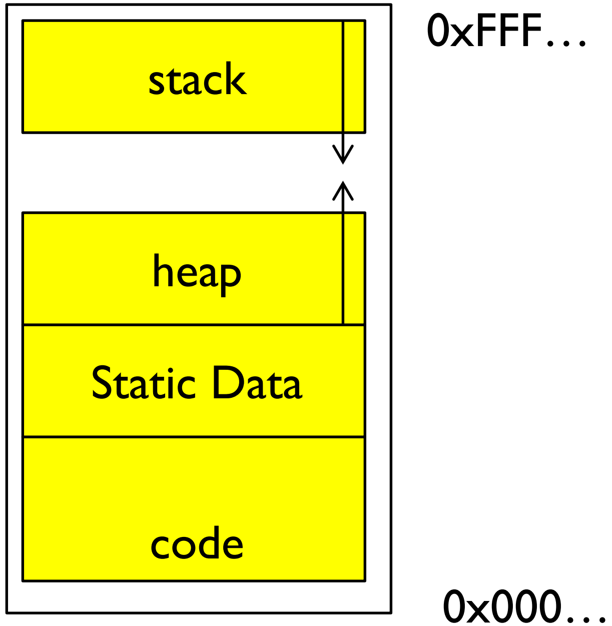
- Execution sequence:
  - Fetch Instruction at PC
  - Decode
  - Execute (possibly using registers)
  - Write results to registers/mem
  - PC = Next Instruction(PC)
  - Repeat

First OS Concept: Thread of Control

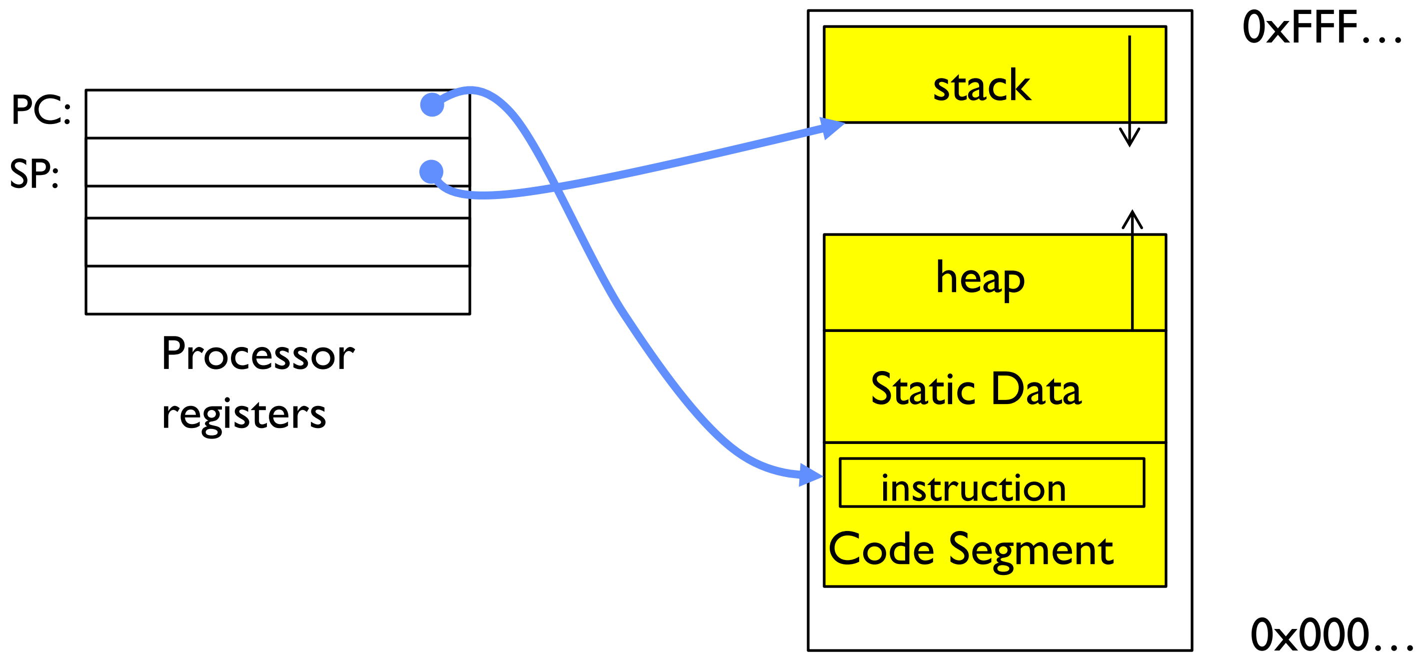
- **Thread**: Single unique execution context
  - Program Counter, Registers, Execution Flags, Stack
- PC holds the address of executing instruction in the thread
- Certain registers hold the *context* of thread
  - Stack pointer holds the address of the top of stack
    - » Other conventions: Frame pointer, Heap pointer, Data
  - May be defined by the instruction set architecture or by compiler conventions
- A thread is executing on a processor when it is resident in the processor registers
- Registers hold the root state of the thread.
  - The rest is “in memory”

Second OS Concept: Program's Address Space

- Address space ⇒ the set of accessible addresses + state associated with them:
  - For a 32-bit processor there are 2^{32} addresses
  - For a 64-bit processor there are 2^{64} addresses
- What happens when you read or write to an address?
  - Perhaps nothing
  - Perhaps acts like regular memory
  - Perhaps ignores writes
  - Perhaps causes I/O operation
    - » (Memory-mapped I/O)
  - Perhaps causes exception (fault)



Address Space: In a Picture

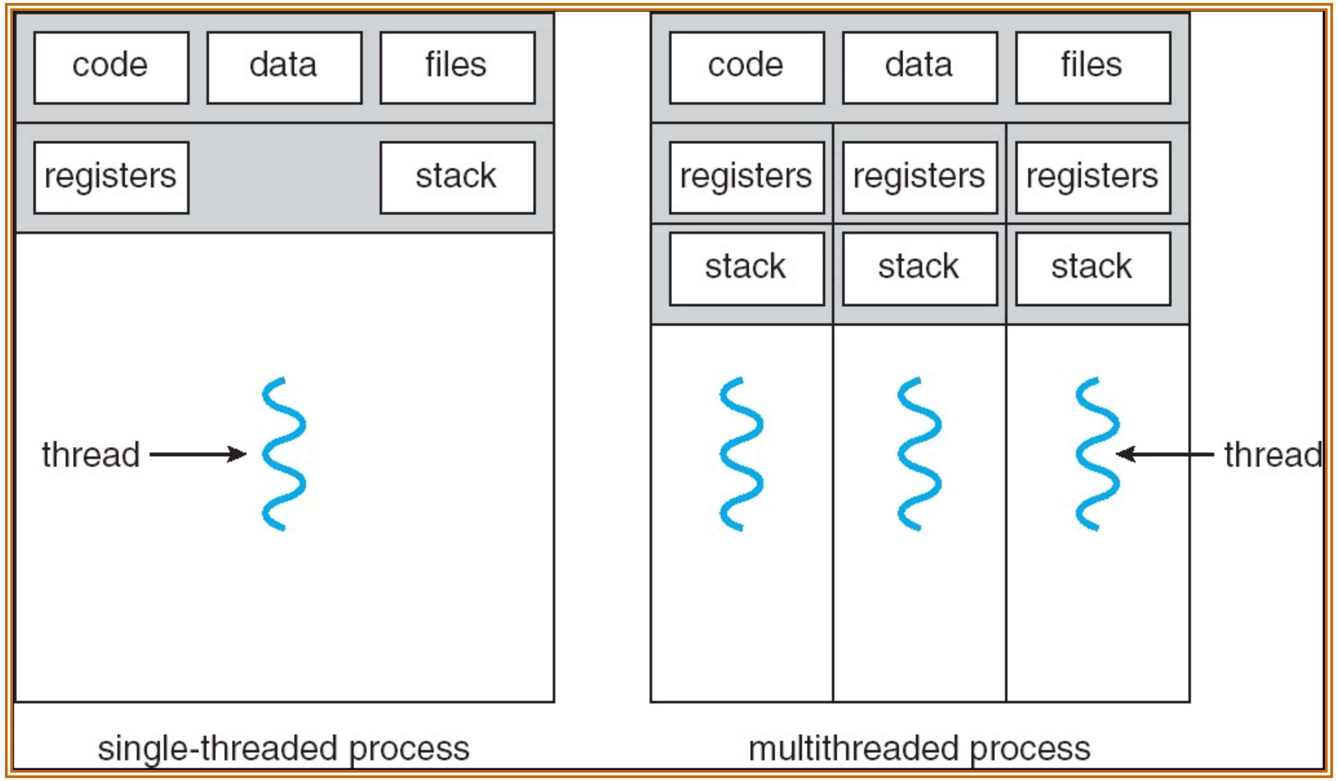


- What's in the code segment? Static data segment?
- What's in the Stack Segment?
  - How is it allocated? How big is it?
- What's in the Heap Segment?
  - How is it allocated? How big?

Third OS Concept: Process

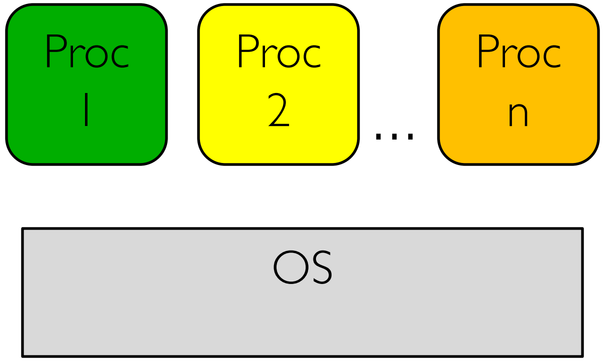
- Process: execution environment with Restricted Rights
  - Address Space with One or More Threads
  - Owns memory (address space)
  - Owns file descriptors, file system context, …
  - Encapsulate one or more threads sharing process resources
- Why processes?
  - Protected from each other!
  - OS Protected from them
  - Processes provides memory protection
  - Threads more efficient than processes (later)
- Fundamental tradeoff between protection and efficiency
  - Communication easier *within* a process
  - Communication harder *between* processes
- Application instance consists of one or more processes

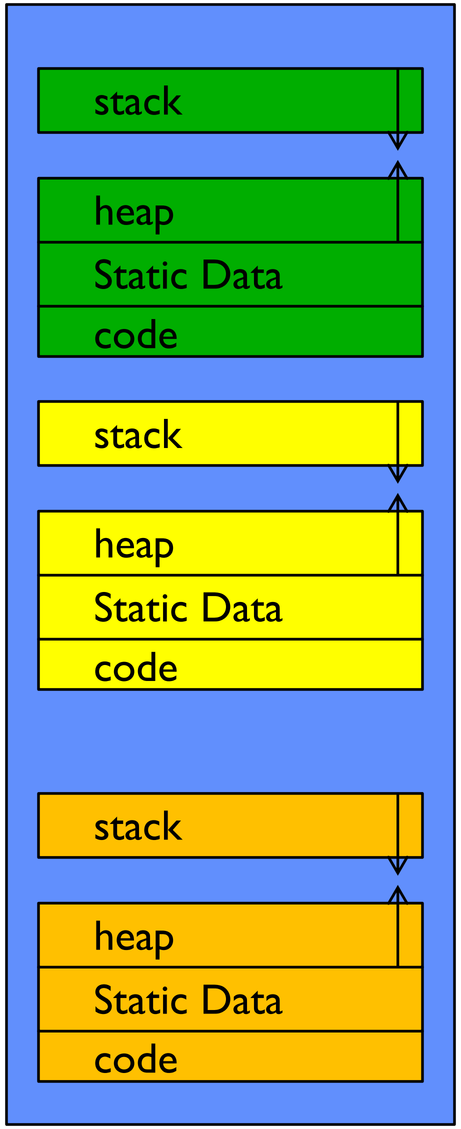
Single and Multithreaded Processes



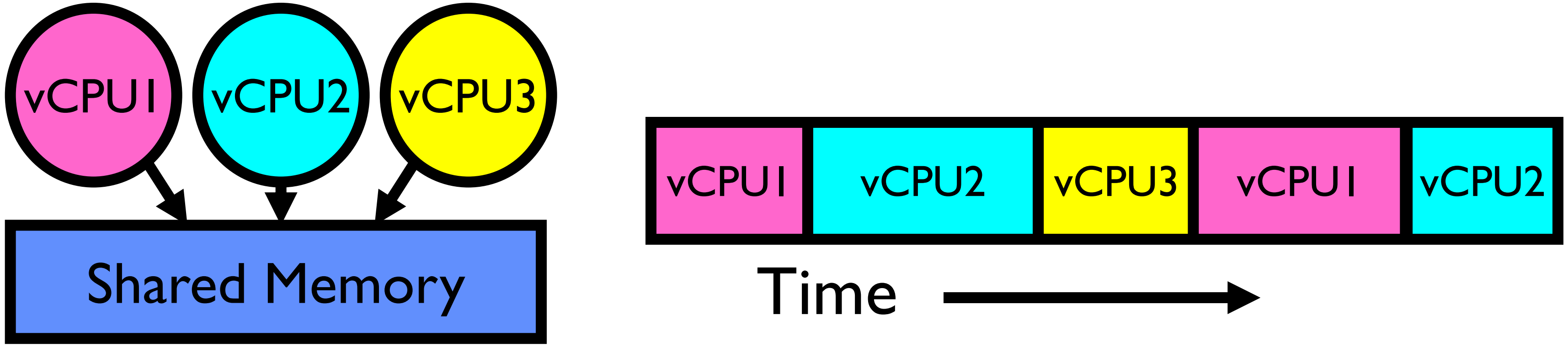
- Threads encapsulate concurrency
- Address spaces encapsulate protection
  - Keeps buggy program from trashing the system
- Why have multiple threads per address space?
- Do multiple threads share heap?

Multiprogramming - Multiple Processes





How can we give the illusion of multiple processors?



- Assume a single processor. How do we provide the illusion of multiple processors?
  – Multiplex in time!
- Each virtual "CPU" needs a structure to hold:
  – Program Counter (PC), Stack Pointer (SP)
  – Registers
- How switch from one virtual CPU to the next?
  – Save PC, SP, and registers in current state block
  – Load PC, SP, and registers from new state block
- What triggers switch?
  – Timer, voluntary yield, I/O, other things

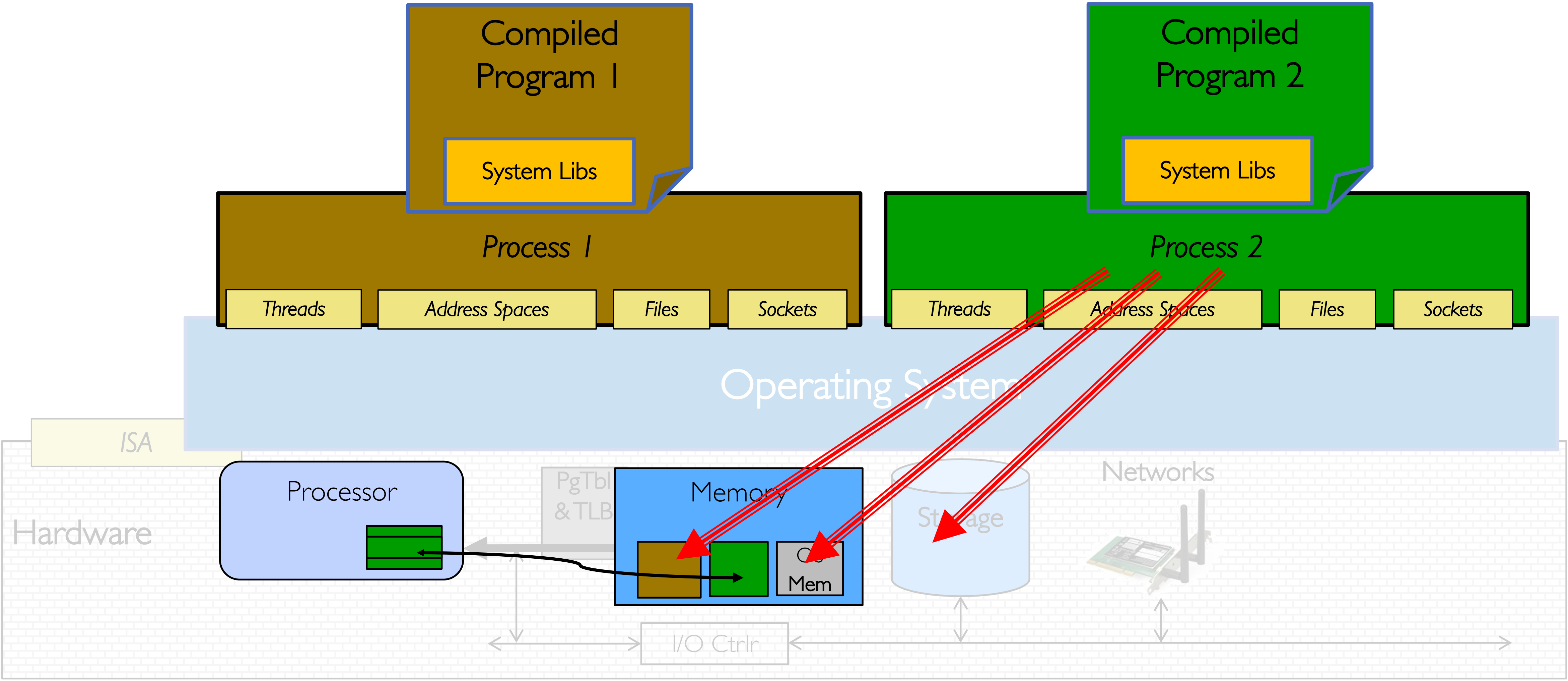
The Basic Problem of Concurrency

- The basic problem of concurrency involves resources:
  - Hardware: single CPU, single DRAM, single I/O devices
  - Multiprogramming API: processes think they have exclusive access to shared resources
- OS has to coordinate all activity
  - Multiple processes, I/O interrupts, …
  - How can it keep all these things straight?
- Basic Idea: Use Virtual Machine abstraction
  - Simple machine abstraction for processes
  - Multiplex these abstract machines
- Dijkstra did this for the “THE system”
  - Few thousand lines vs 1 million lines in OS 360 (1K bugs)

Properties of this simple multiprogramming technique

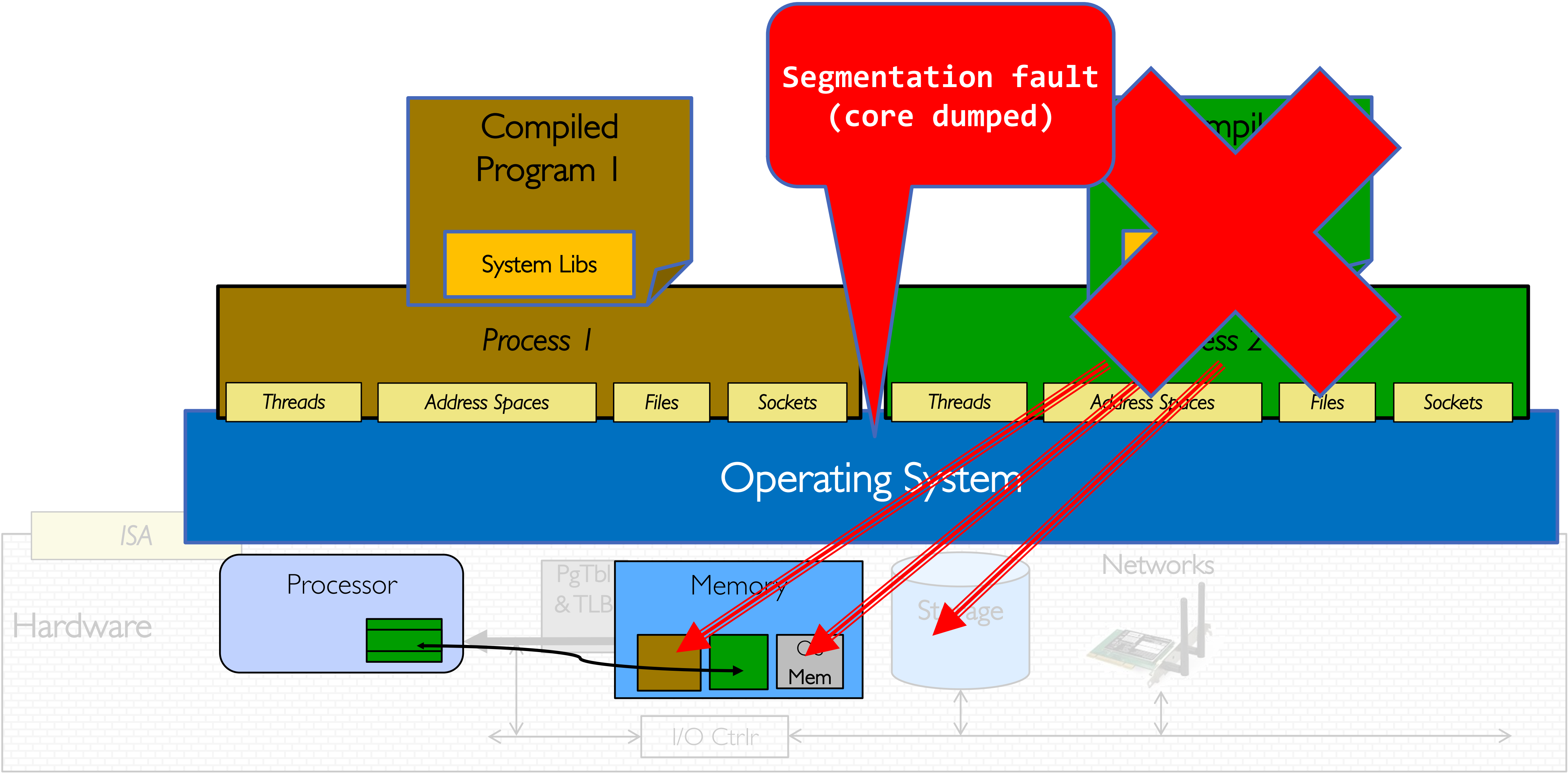
- All virtual CPUs share same non-CPU resources
  - I/O devices the same
  - Memory the same
- Consequence of sharing:
  - Each thread can access the data of every other thread (good for sharing, bad for protection)
  - Threads can share instructions
    (good for sharing, bad for protection)
  - Can threads overwrite OS functions?
- This (unprotected) model is common in:
  - Embedded applications
  - Windows 3.1/Early Macintosh (switch only with yield)
  - Windows 95—ME (switch with both yield and timer)

Protection



Compiled
Program 1
System Libs
Compiled
Program 2
System Libs
Process 1
Threads
Address Spaces
Files
Sockets
Process 2
Threads
Address Spaces
Files
Sockets
Operating System
ISA
Processor
PgTbl
& TLB
Memory
OS
Mem
Storage
Networks
Hardware
I/O Ctrlr

Protection



Segmentation fault
(core dumped)
Compiled
Program I
System Libs
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Files
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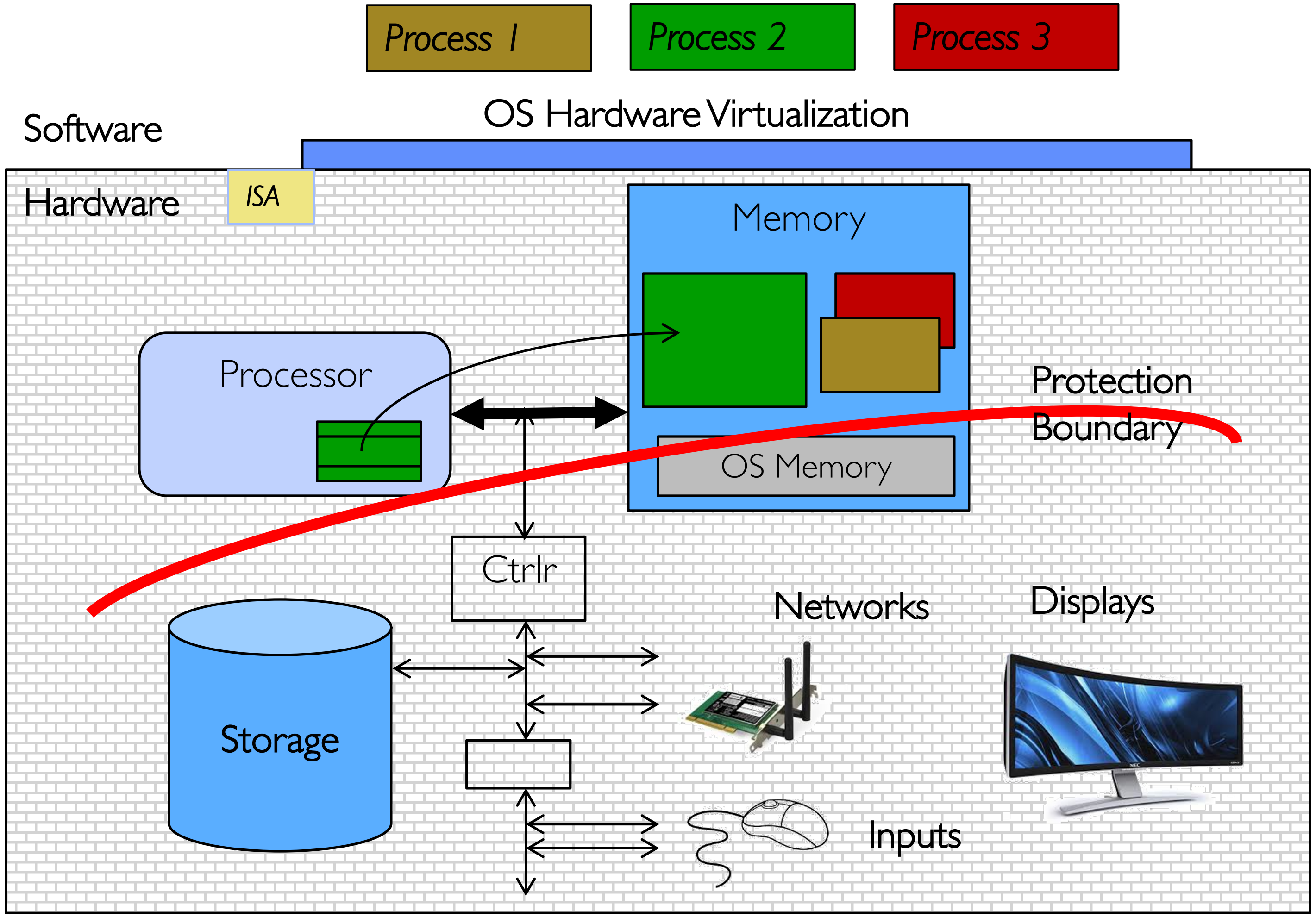


- OS *isolates* processes from each other
- OS *isolates* itself from other processes
- … even though they are actually running on the same hardware!

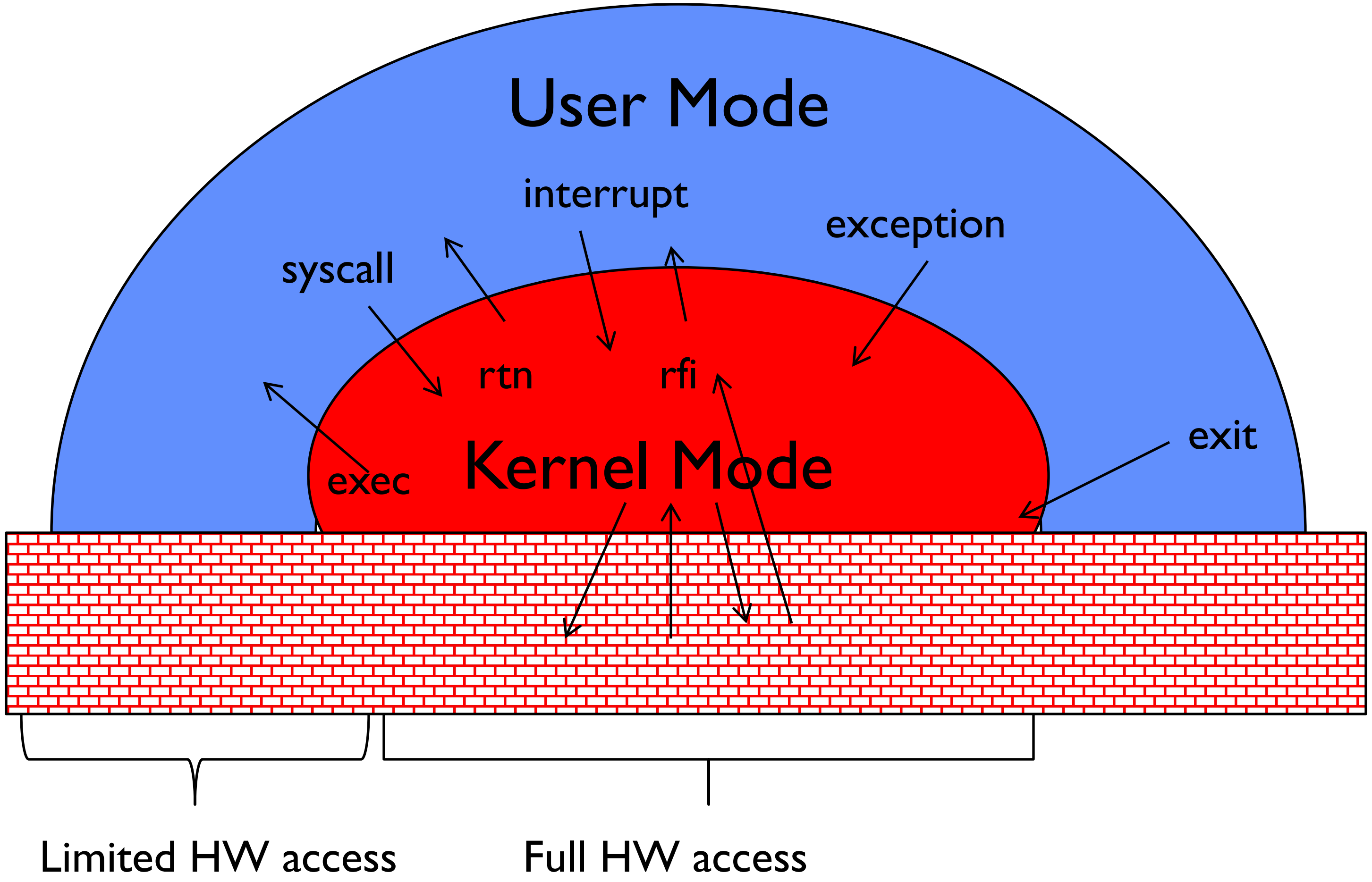
Protection

- Operating System must protect itself from user programs
  - Reliability: compromising the operating system generally causes it to crash
  - Security: limit the scope of what processes can do
  - Privacy: limit each process to the data it is permitted to access
  - Fairness: each should be limited to its appropriate share of system resources (CPU time, memory, I/O, etc)
- It must protect user programs from one another
- Primary Mechanism: limit the translation from program address space to physical memory space
  - Can only touch what is mapped into process *address space*
- Additional Mechanisms:
  - Privileged instructions, I/O instructions, special registers
  - syscall processing, subsystem implementation
    - (e.g., file access rights, etc)

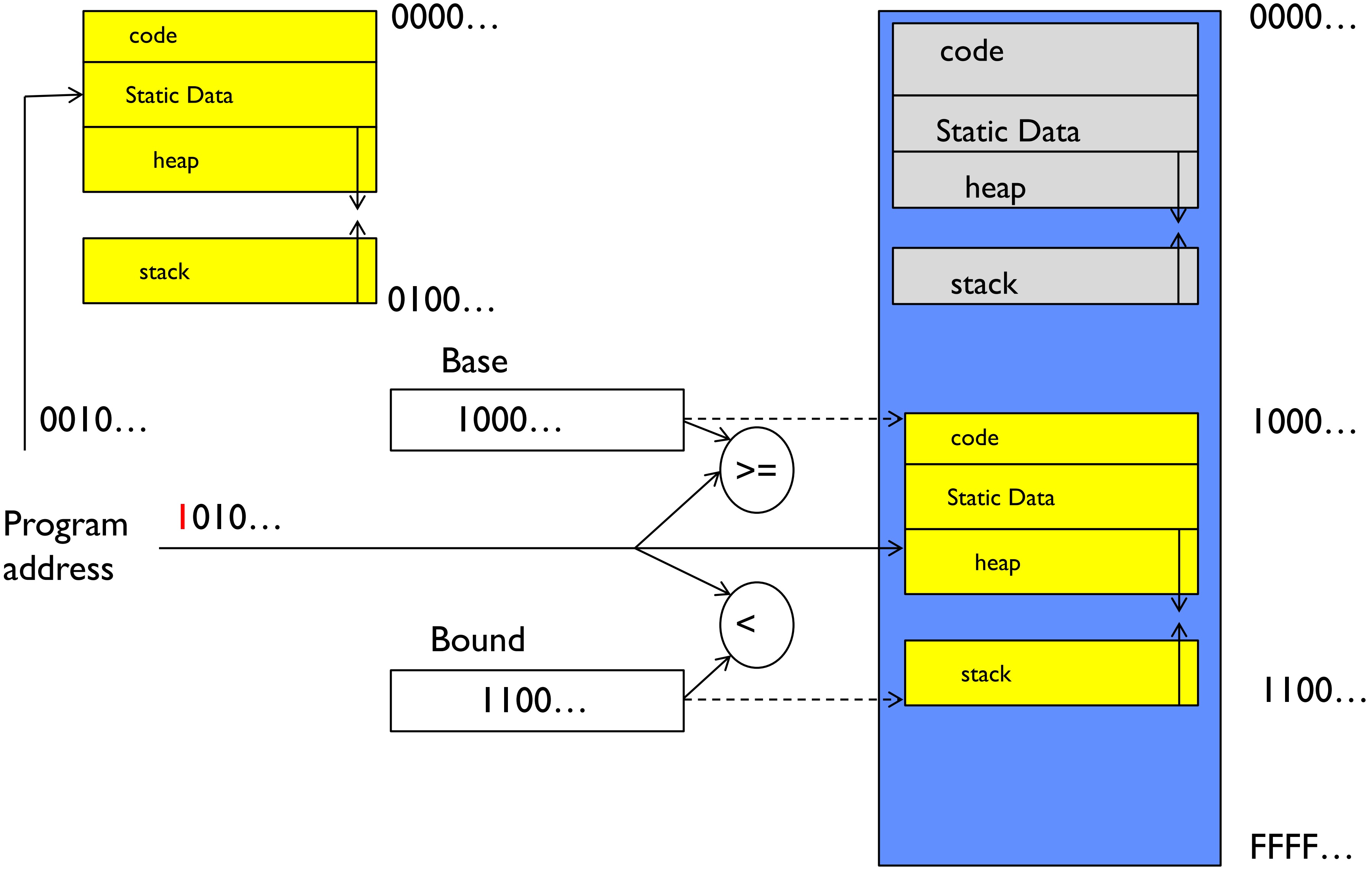
Fourth OS Concept: Dual Mode Operation

- Hardware provides at least two modes:
  - "Kernel" mode (or "supervisor" or "protected")
  - "User" mode: Normal programs executed
- What is needed in the hardware to support "dual mode" operation?
  - A bit of state (user/system mode bit)
  - Certain operations / actions only permitted in system/kernel mode
    - » In user mode they fail or trap
  - User → Kernel transition *sets* system mode AND saves the user PC
    - » Operating system code carefully puts aside user state then performs the necessary operations
  - Kernel → User transition *clears* system mode AND restores appropriate user PC
    - » return-from-interrupt

User/Kernel (Privileged) Mode



Simple Protection: Base and Bound (B&B)



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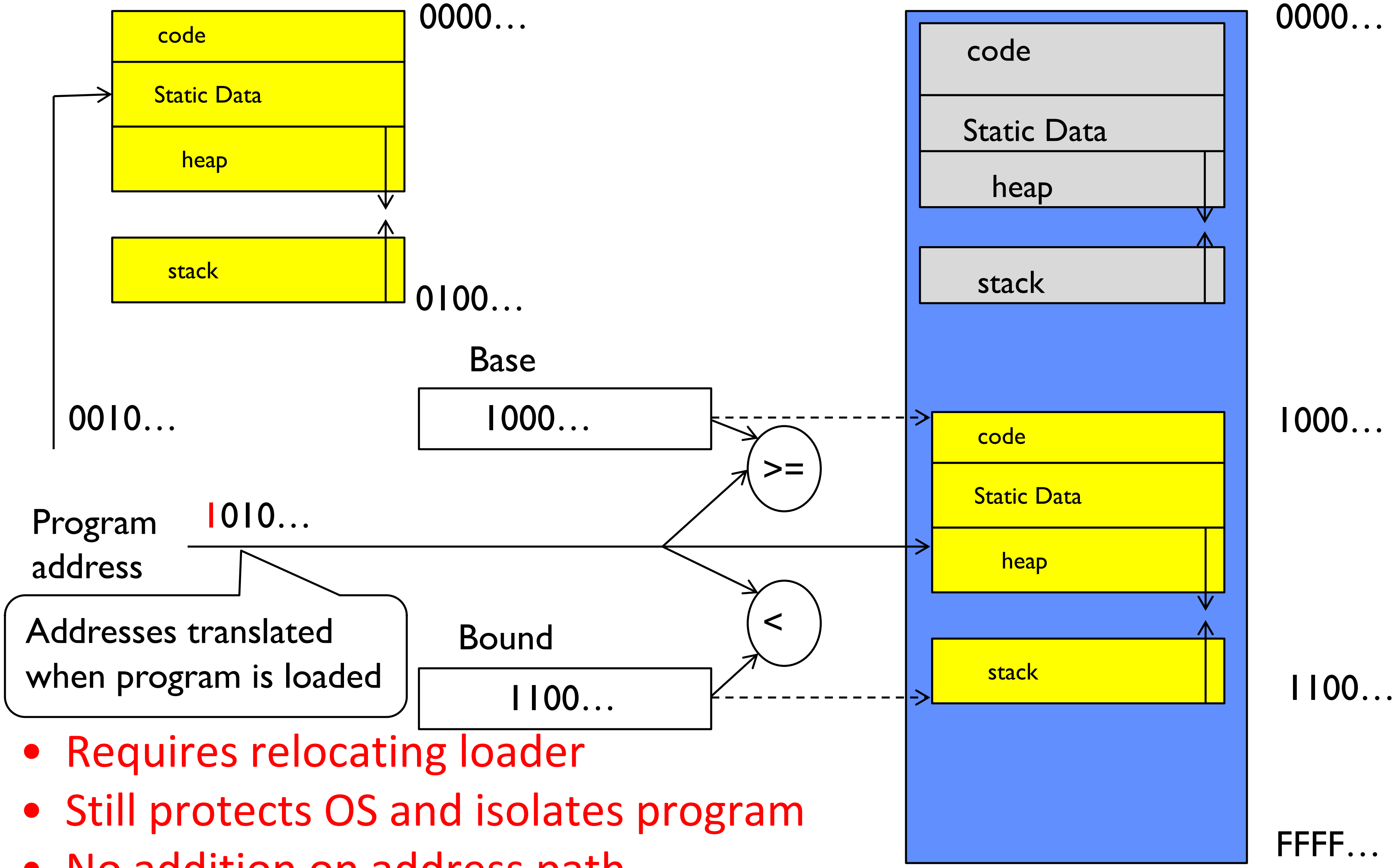
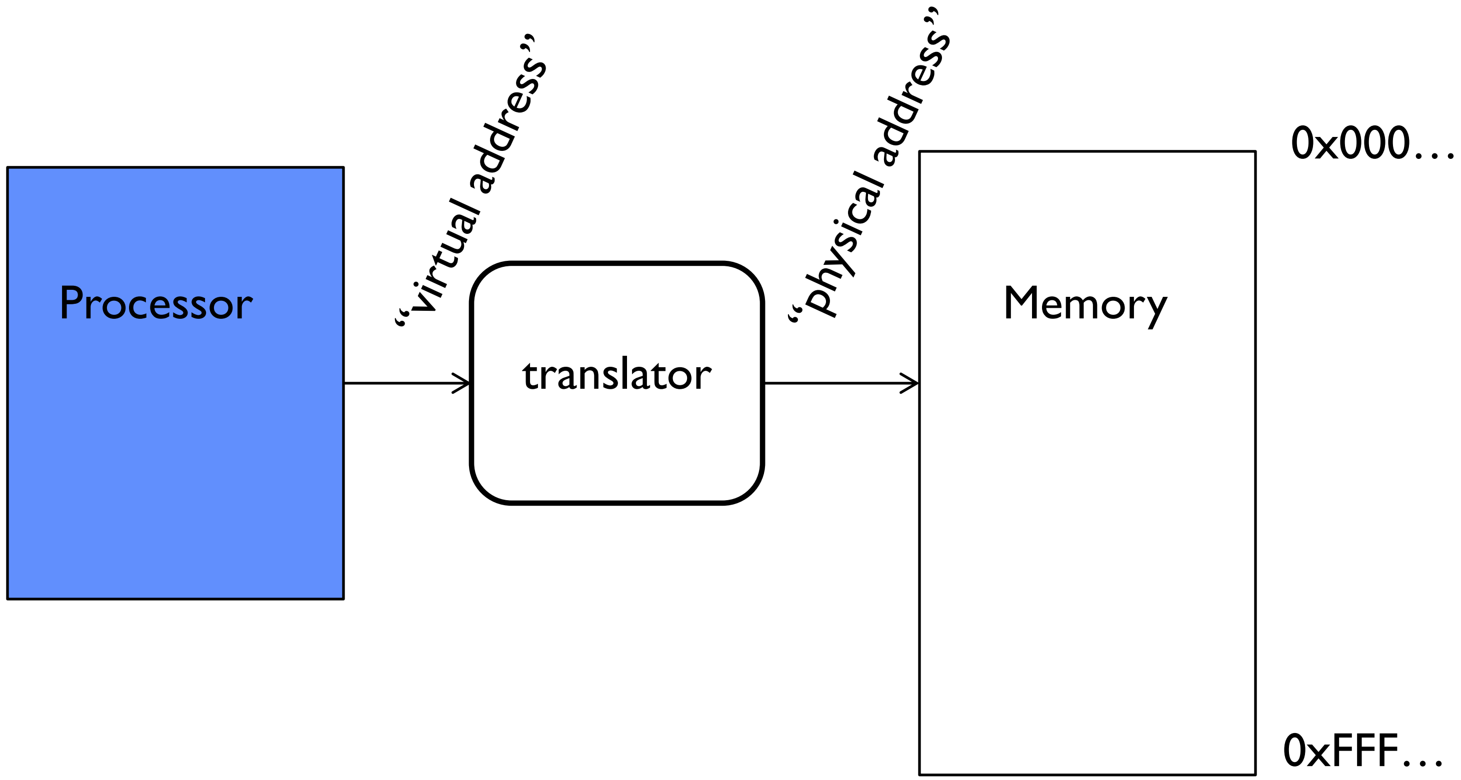


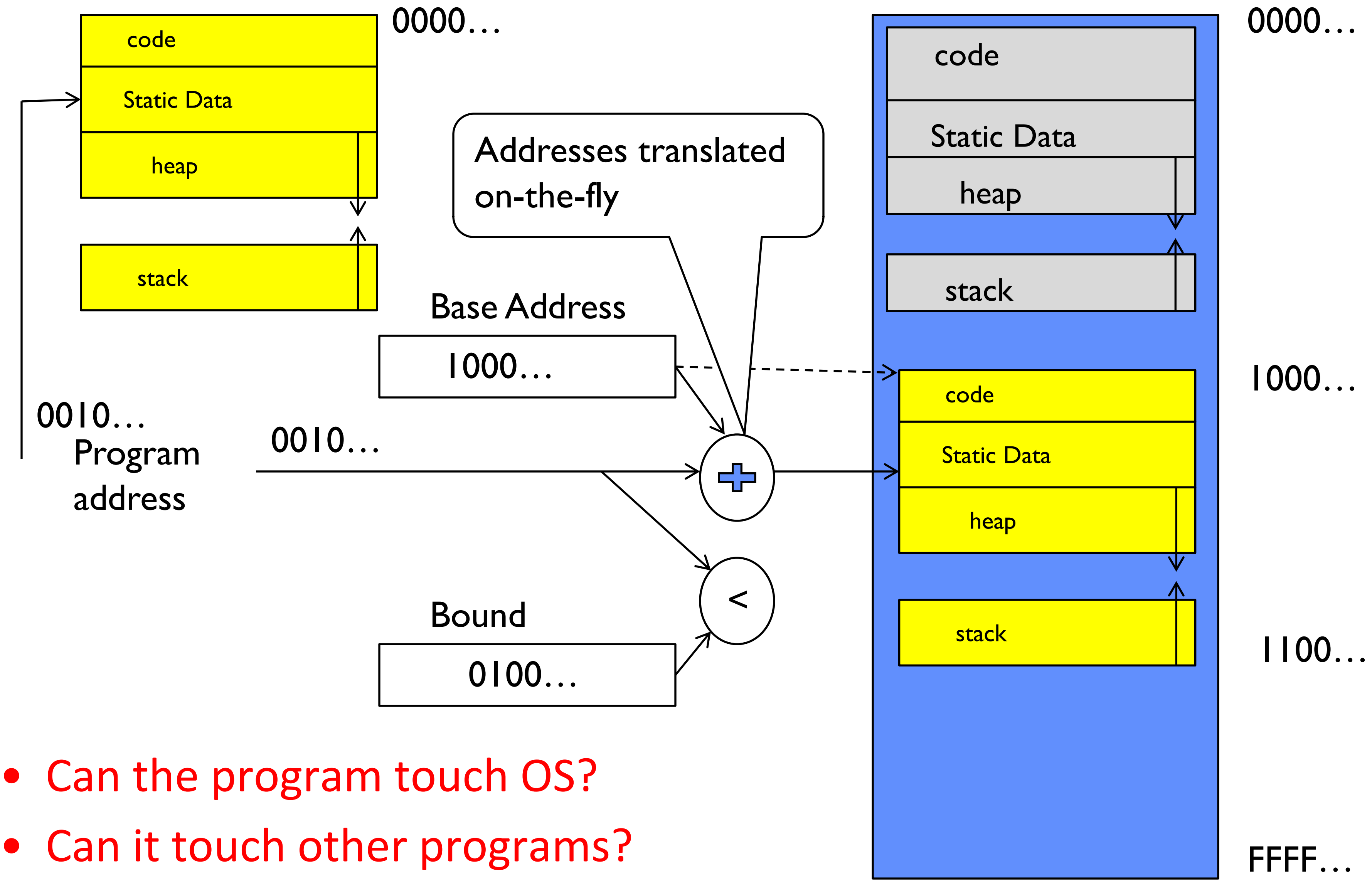
- Requires relocating loader
- Still protects OS and isolates program
- No addition on address path

Another idea: Address Space Translation

- Program operates in an address space that is distinct from the physical memory space of the machine

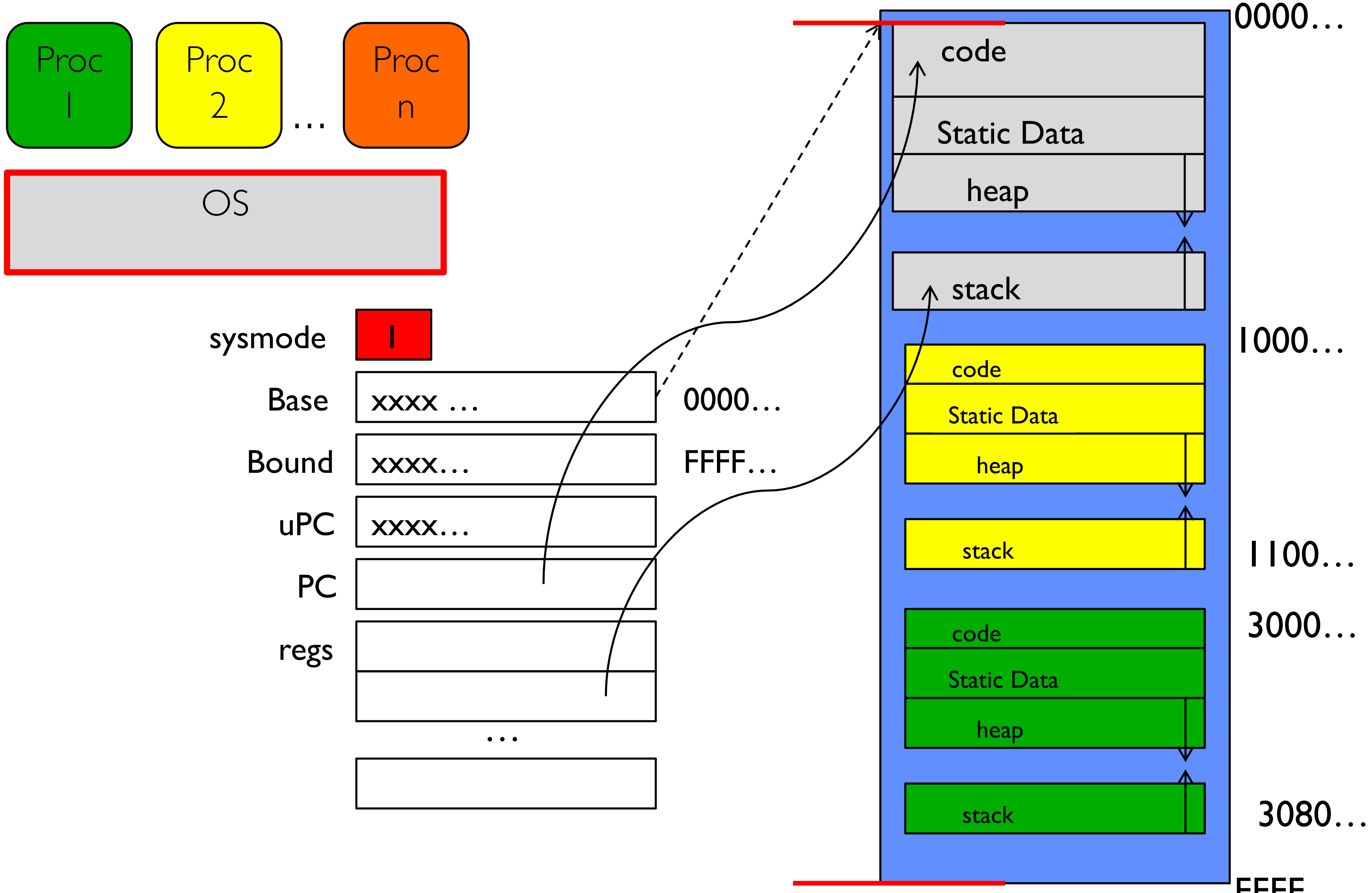


A simple address translation with Base and Bound

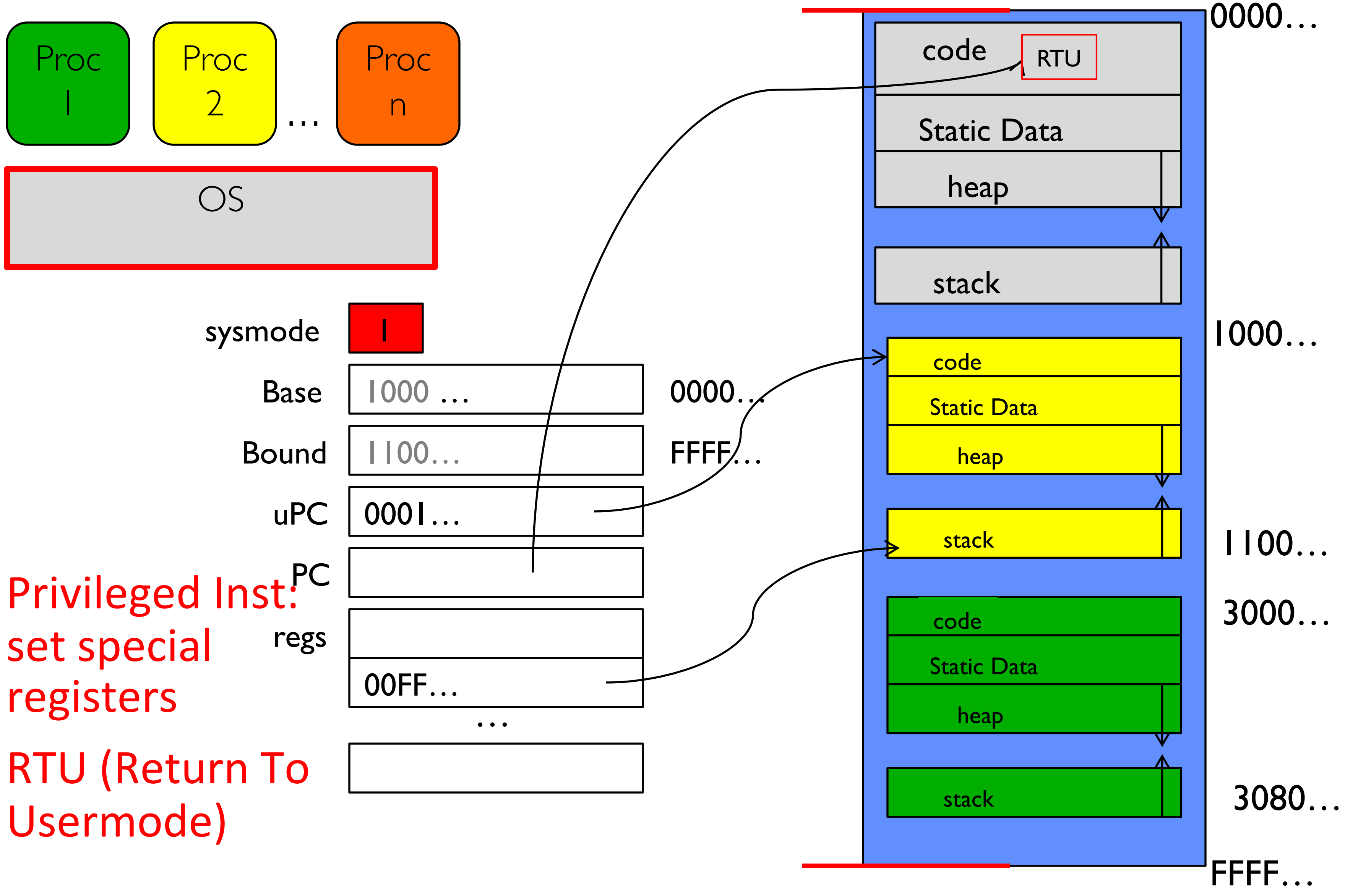


- Can the program touch OS?
- Can it touch other programs?

Tying it together: Simple B&B: OS loads process

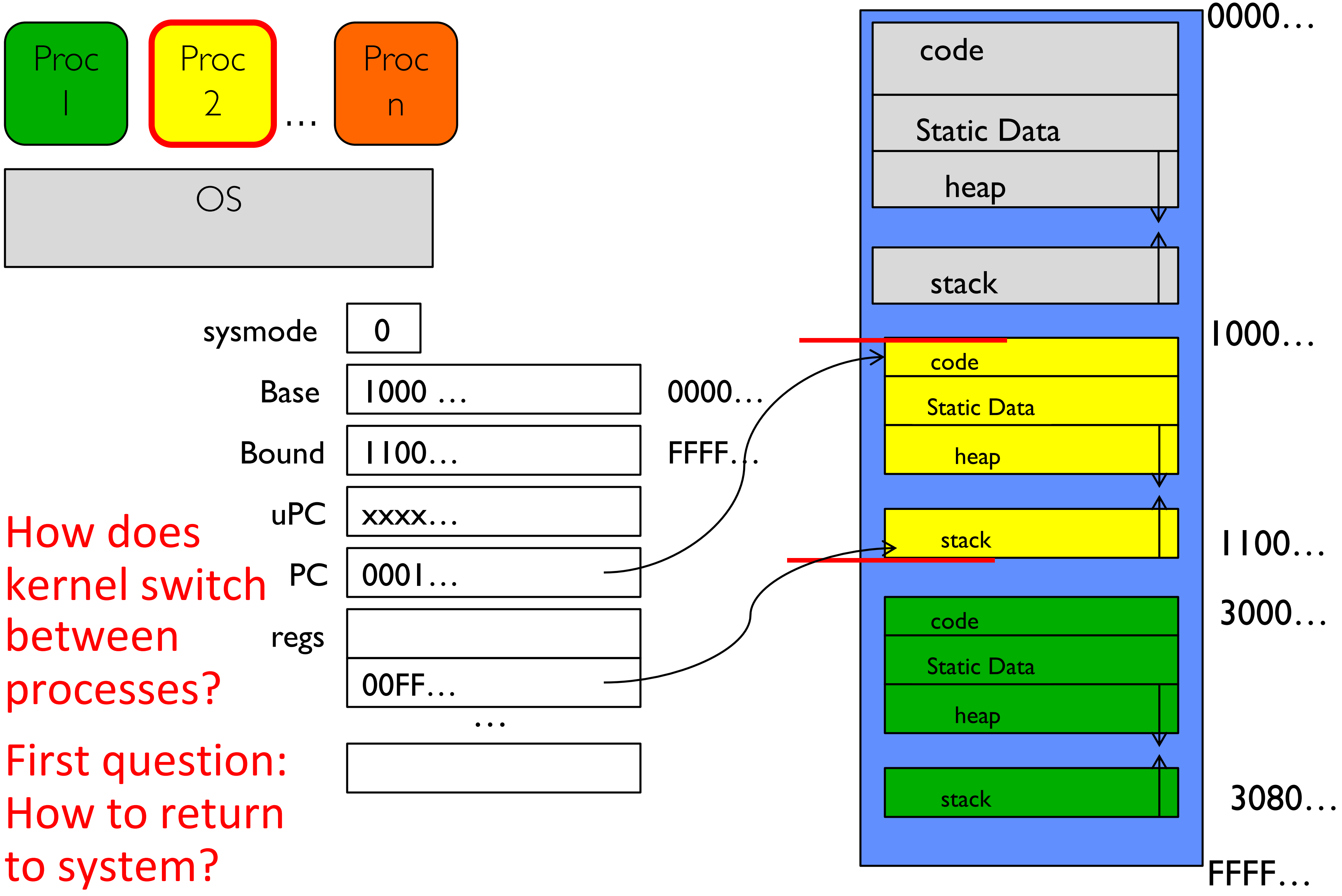


Simple B&B: OS gets ready to execute process



- Privileged Inst: set special registers
- RTU (Return To Usermode)

Simple B&B: User Code Running



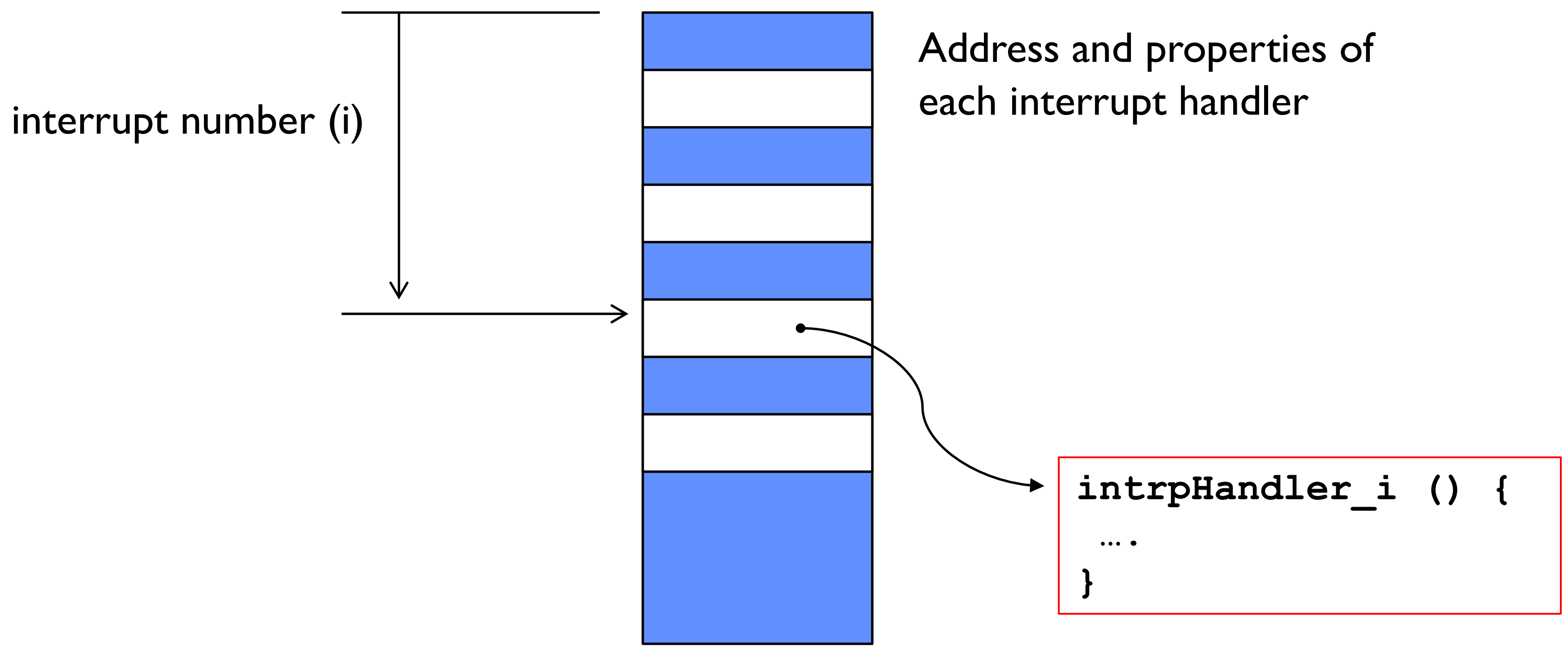
- How does kernel switch between processes?
- First question: How to return to system?

3 types of Mode Transfer

- Syscall
  - Process requests a system service, e.g., exit
  - Like a function call, but “outside” the process
  - Does not have the address of the system function to call
  - Like a Remote Procedure Call (RPC) – for later
  - Marshall the syscall id and args in registers and exec syscall
- Interrupt
  - External asynchronous event triggers context switch
  - e. g., Timer, I/O device
  - Independent of user process
- Trap or Exception
  - Internal synchronous event in process triggers context switch
  - e.g., Protection violation (segmentation fault), Divide by zero, …
- All 3 are an UNPROGRAMMED CONTROL TRANSFER
  - Where does it go?

How do we get the system target address of the "unprogrammed control transfer?"

Interrupt Vector



Group Discussion

- Topic: Base and Bound (B&B)
  - What are the pros and cons of Base and Bound?
  - What are the pros and cons of the two approaches to implement Base and Bound?

- Discuss in groups of two to three students
  - Each group chooses a leader to summarize the discussion
  - In your group discussion, please do not dominate the discussion, and give everyone a chance to speak

Conclusion: Four fundamental OS concepts

- **Thread**
  - Single unique execution context
  - Program Counter, Registers, Execution Flags, Stack
- **Address Space** with **Translation**
  - Programs execute in an *address space* that is distinct from the memory space of the physical machine
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