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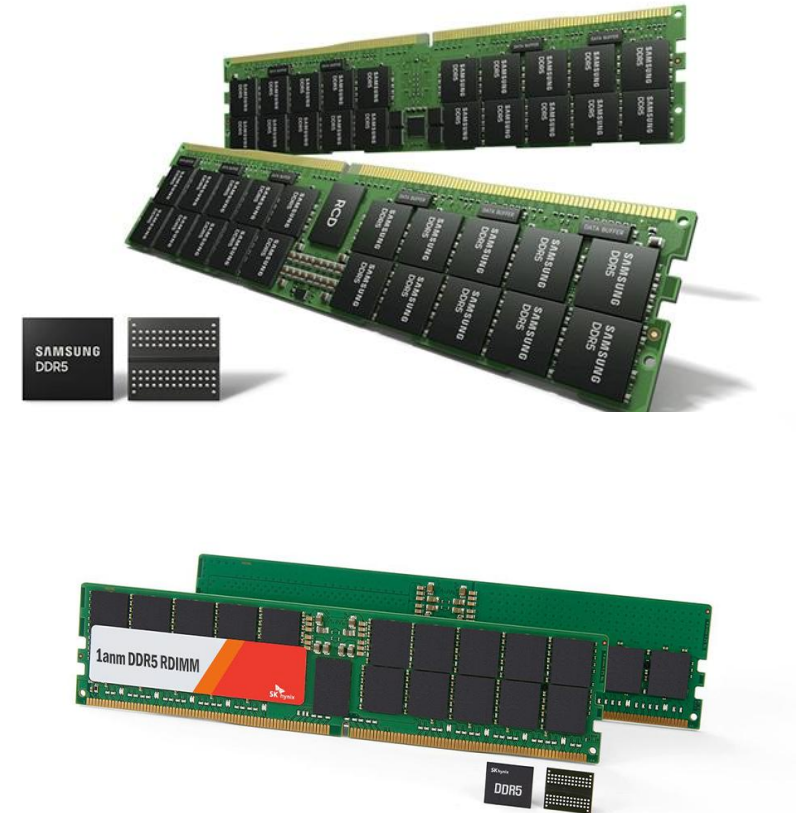
Fall 2026

Virtual Memory



Physical Memory Management

- Contiguous allocation with variable-sized segments
- Internal/external fragmentation
- Sharing
- Protection and isolation
- Limited capacity



Source: <https://semiconductor.samsung.com/news-events/news/samsung-starts-mass-production-of-most-advanced-14nm-euv-ddr5-dram/>
<https://news.skhynix.com/sk-hynix-obtains-industrys-first-validation-for-1anm-ddr5-dram-on-the-4th-gen-intel-xeon-scalable-processor/>

Virtual Memory: Goals

- **Transparency**

- Processes should not be aware that memory is shared
- Provide a convenient abstraction for programming (i.e., a large, contiguous memory space)

- **Efficiency**

- Minimize fragmentation due to variable-sized requests (space)
- Get some hardware support (time)

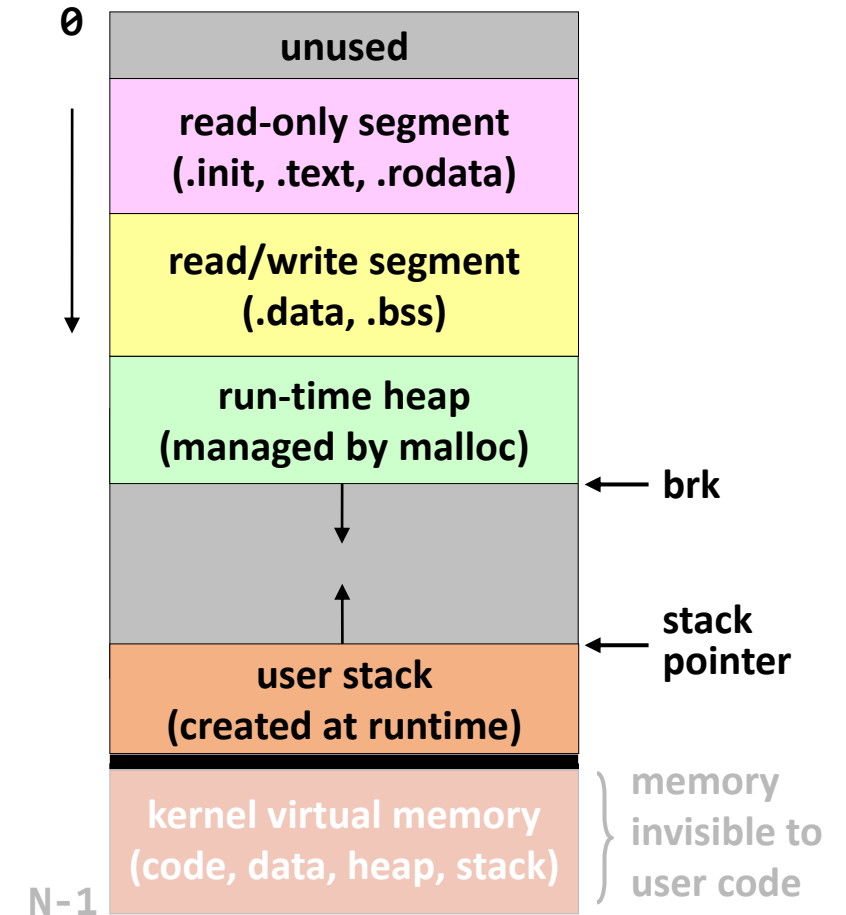
- **Protection**

- Protect processes and the OS from another process
- Isolation: a process can fail without affecting other processes
- Cooperating processes can share portions of memory

(Virtual) Address Space

■ Process' abstract view of memory

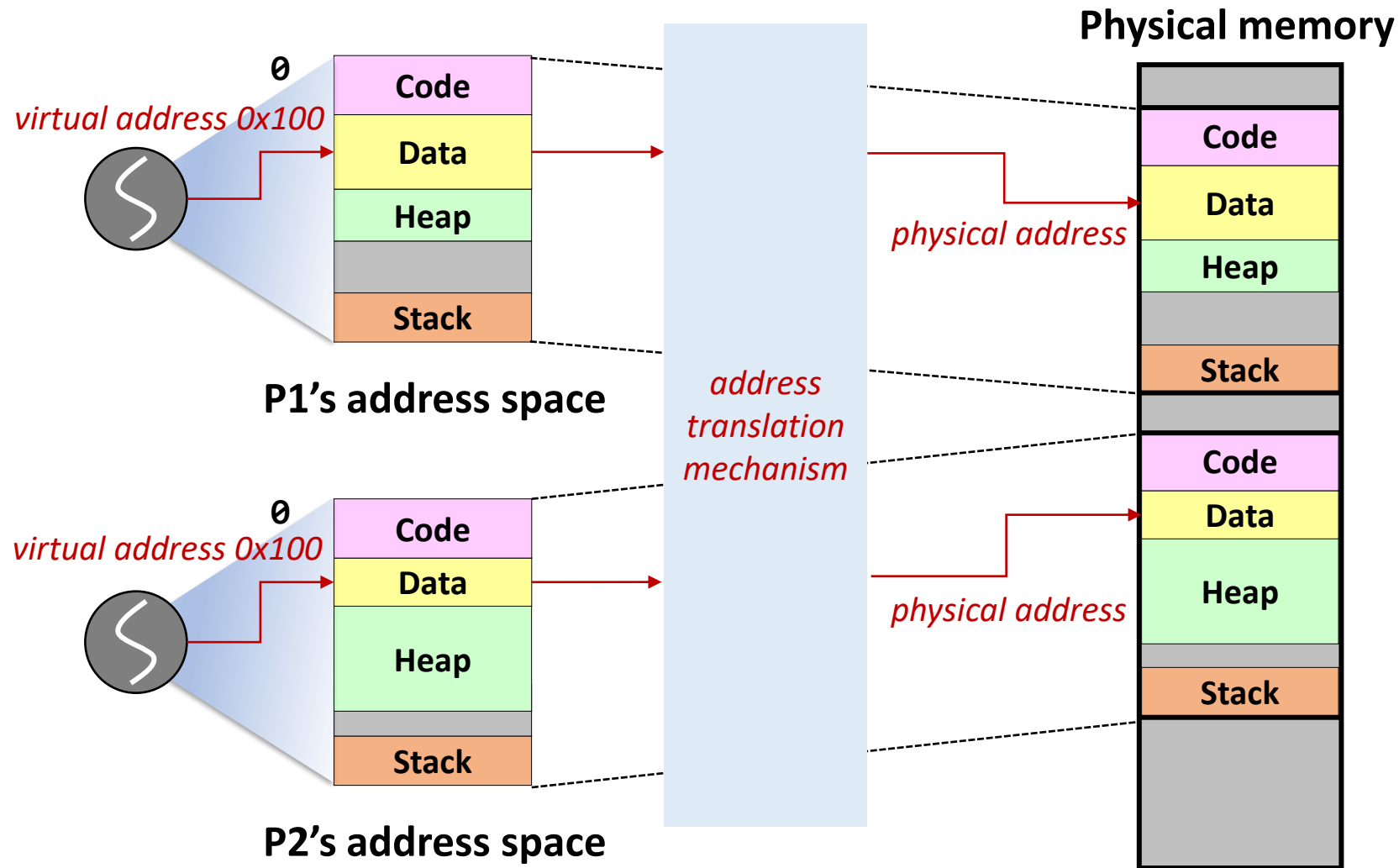
- OS provides illusion of private address space to each process
- Contains all of the memory state of the process
- Static area
 - Allocated on `exec()`
 - Code & Data
- Dynamic area
 - Allocated at runtime
 - Can grow or shrink
 - Heap & Stack



Virtual Memory

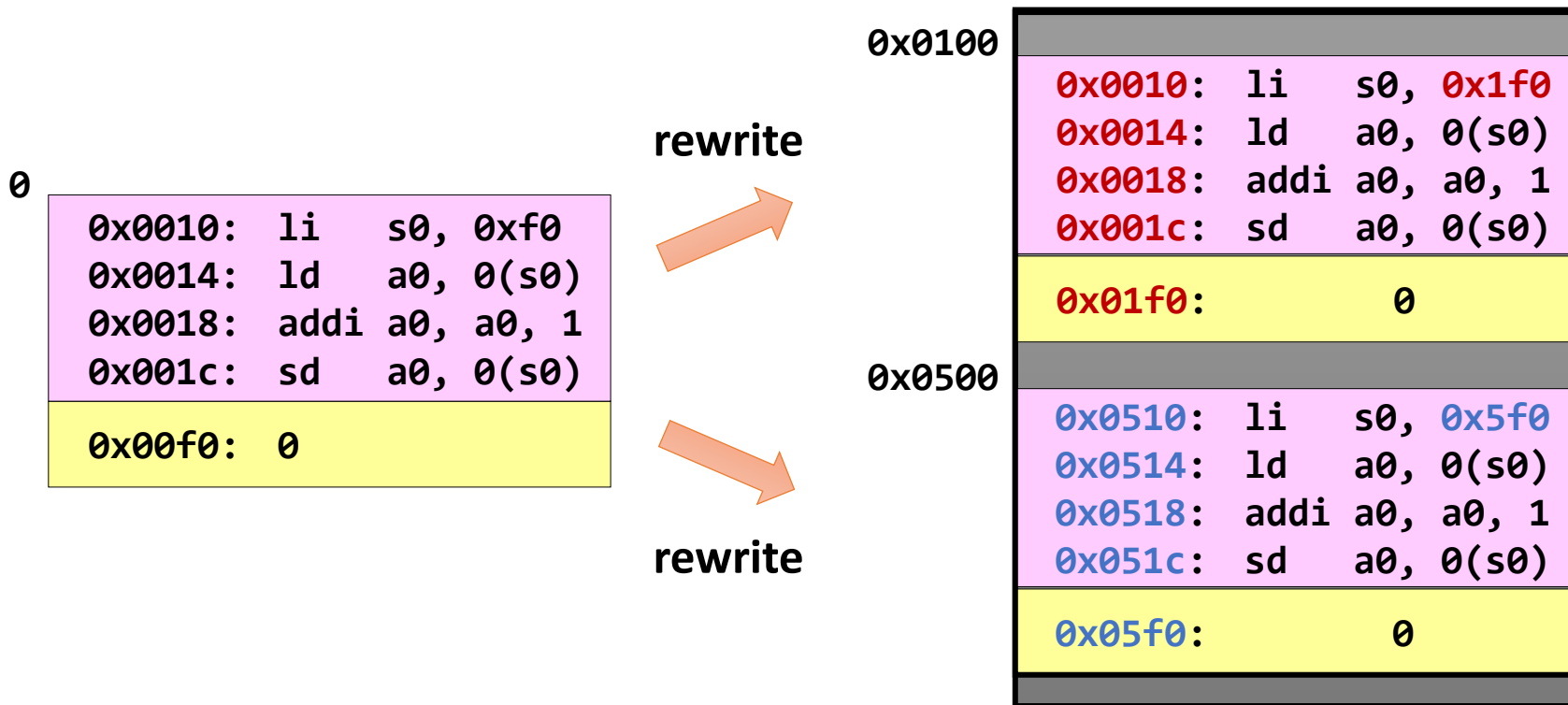
- Each process has its own **virtual address space**
 - Large and contiguous
 - Use virtual addresses for memory references
 - Virtual addresses are **private** to each process
- **Address translation** is performed at run time
 - From a virtual address to the corresponding physical address
- Supports lazy allocation
 - Physical memory is dynamically allocated or released on demand
 - Programs execute without requiring their entire address space to be resident in physical memory

Virtual Memory



Static Relocation (I)

- Software-based relocation
 - OS rewrites each program before loading it into memory
 - Changes addresses of static data and functions



Static Relocation (2)

■ Pros

- No hardware support is required

■ Cons

- No protection enforced
 - A process can destroy memory regions of the OS or other processes
 - No privacy: can read any memory address
- Cannot move address space after it has been placed
 - May not be able to allocate a new process due to external fragmentation

Dynamic Relocation

- **Hardware-based relocation**

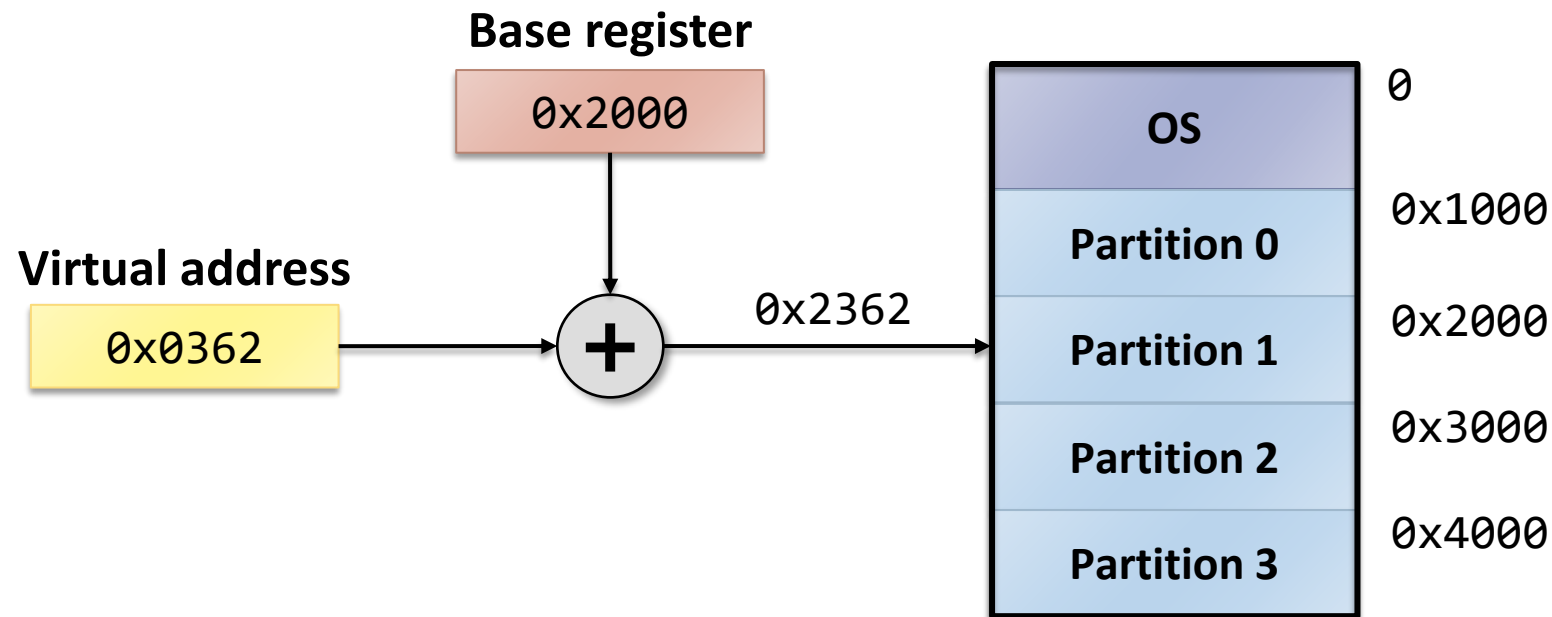
- Hardware performs address translation on every memory reference instructions
- Protection is enforced by hardware: if the virtual address is invalid, the hardware raises an exception
- OS passes the information about the valid address space of the current process to the hardware

- **Implementations**

- Fixed or variable partitions
- Segmentation
- Paging

Fixed Partitions (I)

- Physical memory is broken up into fixed partitions
 - Size of each partition is the same and fixed
 - The number of partitions = degree of multiprogramming



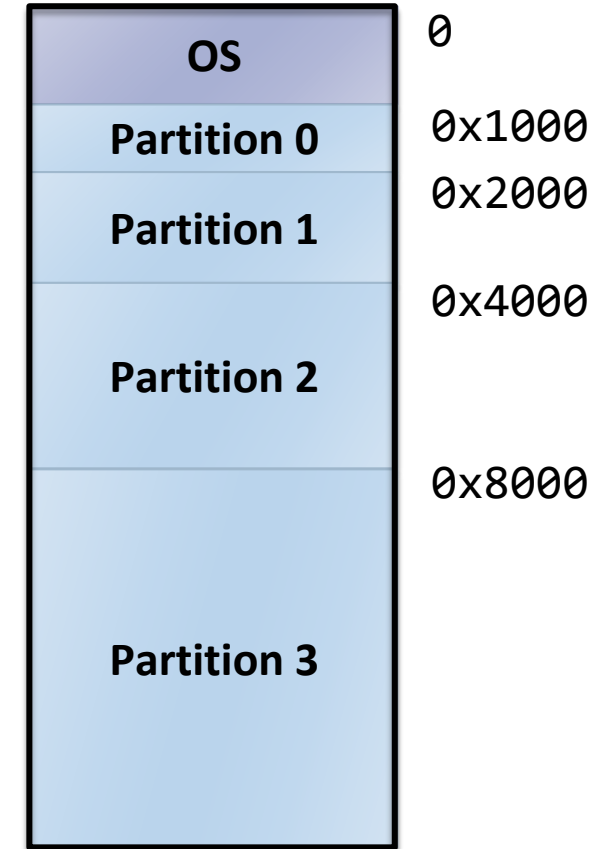
Fixed Partitions (2)

- **Hardware requirements: base register**
 - Physical address = virtual address + base register
 - Base register loaded by OS on context switch
- **Pros**
 - Easy to implement
 - Fast context switch
- **Cons**
 - Internal fragmentation: unused area in a partition is wasted
 - Partition size: one size does not fit all

Fixed Partitions (3)

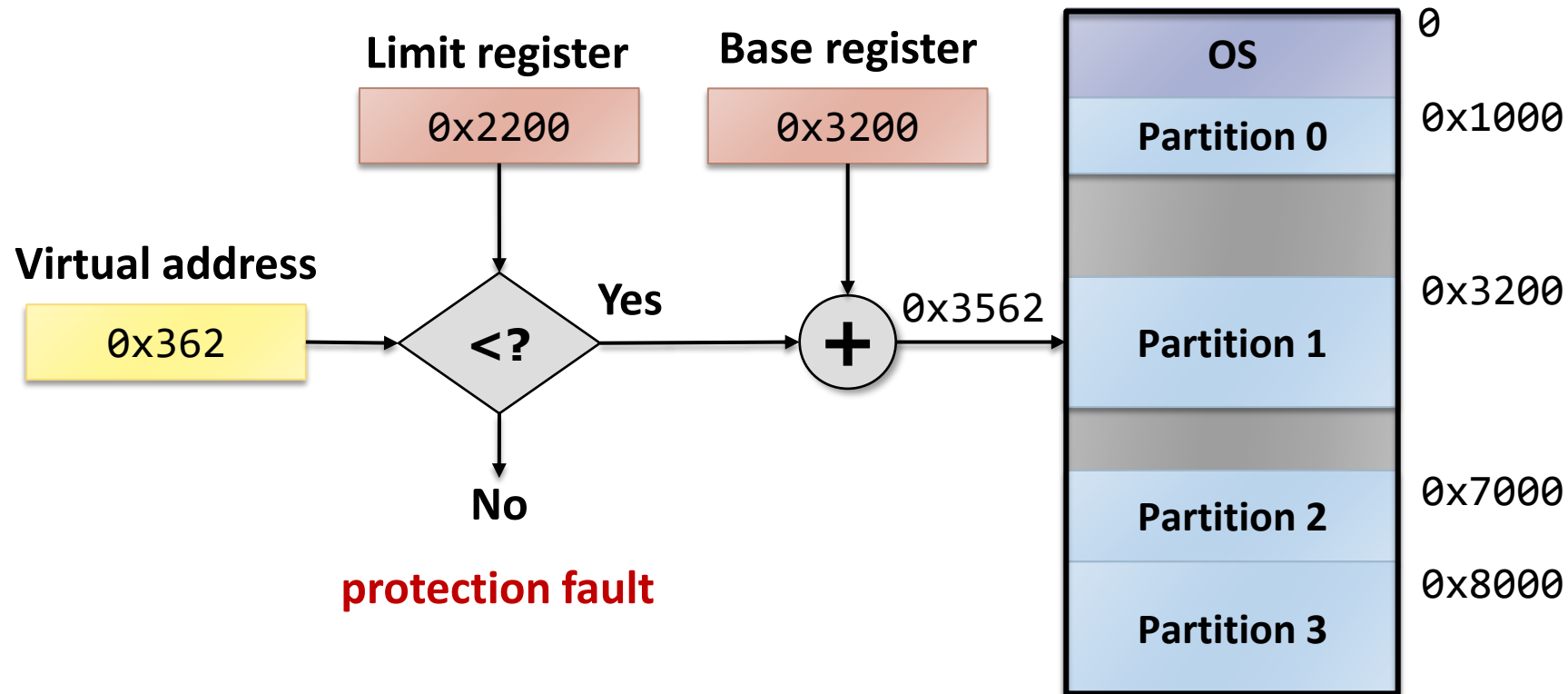
■ Improvement

- Partition size needs not be equal
- Allocation strategies
 - A separate queue for each partition size
 - A single queue + first fit
 - A single queue + best fit
- Used in IBM OS/MFT
(Multiprogramming with a
Fixed number of Tasks)



Variable Partitions (I)

- Physical memory is broken up into variable-sized partitions
 - Used in IBM OS/MVT



Variable Partitions (2)

- Hardware requirements: base register + limit register
 - The role of limit register: protection
- Pros
 - Simple, inexpensive implementation
 - No internal fragmentation
- Cons
 - Each process must be allocated contiguously in physical memory
 - External fragmentation:
 - Holes are left scattered throughout physical memory
 - Compaction can be used to reduce external fragmentation
 - No partial sharing: cannot share parts of address space

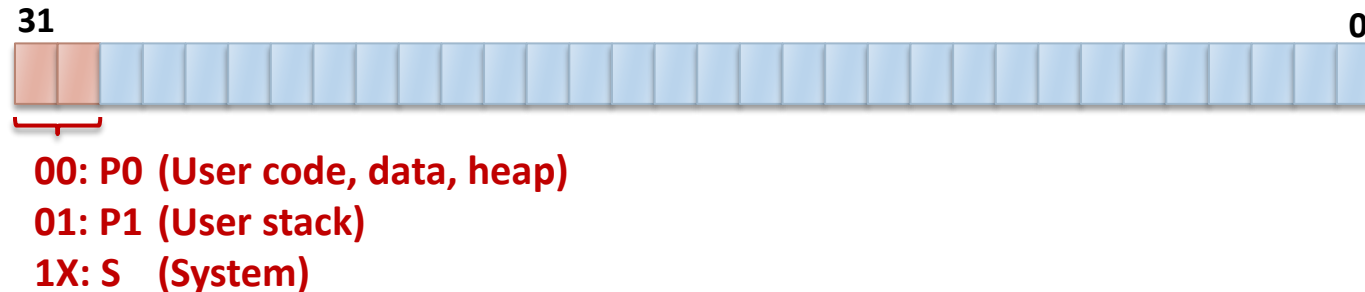
Segmentation

- Divide address space into logical segments
 - Each segment corresponds to logical entity in address space
 - Code, data, stack, heap, etc.
 - Users view memory as a collection of variable-sized segments, with no necessary ordering among them
 - Virtual address: <Segment #, Offset>
 - Each segment can independently
 - be placed in physical memory
 - grow or shrink
 - be protected (separate read/write/execute protection bits)
 - Natural extension of variable partitions
 - Variable partitions: 1 segment / process
 - Segmentation: many segments / process

Segmentation: Addressing

■ Explicit approach

- Use a part of virtual address as a segment number
- The remaining bits mean the offset within the segment
- e.g., VAX/VMS system

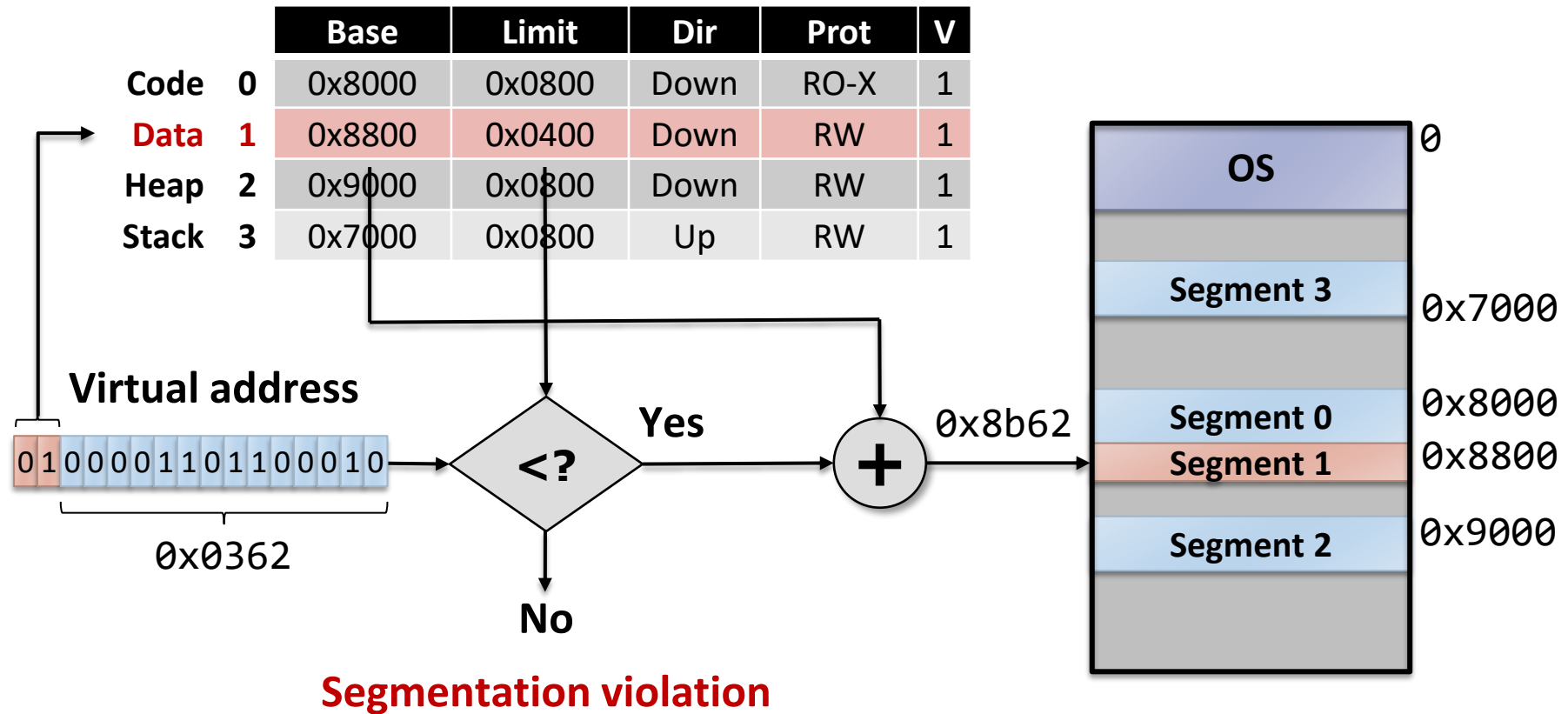


■ Implicit approach

- Determines the segment by the type of memory reference
 - PC-based addressing: code segment
 - SP- or BP-based addressing: stack segment

Segmentation: Implementation

- Segment registers or table (per process)



Segmentation: Pros

- Enables sparse allocation of address space
 - Stack and heap can grow independently
- Easy to protect segments
 - Valid bit
 - Different protection bits for different segments
 - e.g., Read-only status for code, Kernel-mode-only for system segment
- Easy to share segments
 - Put the same translation into base/limit pair
 - Code/data sharing at segment level (e.g., shared libraries)
- Supports dynamic relocation of each segment

Segmentation: Cons

- Each segment must be allocated contiguously
 - External fragmentation
 - May not have sufficient physical memory for large segments
- Large segment table
 - Keep in main memory
 - Use hardware cache for speed
- Cross-segment addresses
 - Segments need to have same segment number for pointers to them to be shared among processes
 - Otherwise, use indirect addressing only

Summary

- Separates user's virtual memory from physical memory
 - Abstracts main memory into a large, uniform array of bytes
 - Frees programmers from the concerns of memory limitations
 - Physical memory locations can be moved transparently
- The virtual address space is overcommitted
 - Allows the execution of processes that may not be completely in memory
 - Physical memory is allocated on demand
 - Views the physical memory as a cache for the disk
- Easy to protect and share memory regions among processes