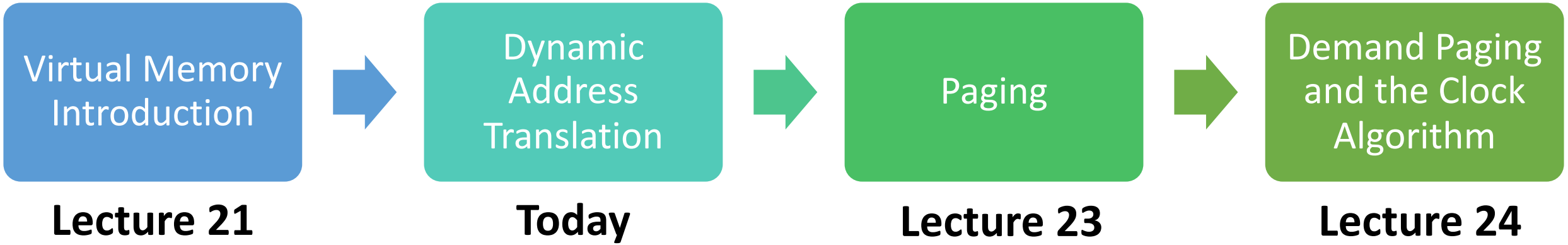
CS111, Lecture 22
Dynamic Address Translation

Topic 4: Virtual Memory - How can one set of memory be shared among several processes? How can the operating system manage access to a limited amount of system memory?

CS111 Topic 4: Virtual Memory



assign6: implement *demand paging* system to translate addresses and load/store memory contents for programs as needed.

Learning Goals

- Understand the benefits of dynamic address translation
- Reason about the tradeoffs in different ways to implement dynamic address translation

Plan For Today

- **Recap:** virtual memory and dynamic address translation
- Approach #1: Base and Bound
- Approach #2: Multiple Segments

Plan For Today

- **Recap: virtual memory and dynamic address translation**
- Approach #1: Base and Bound
- Approach #2: Multiple Segments

Virtual memory is a mechanism for multiple processes to simultaneously use system memory.

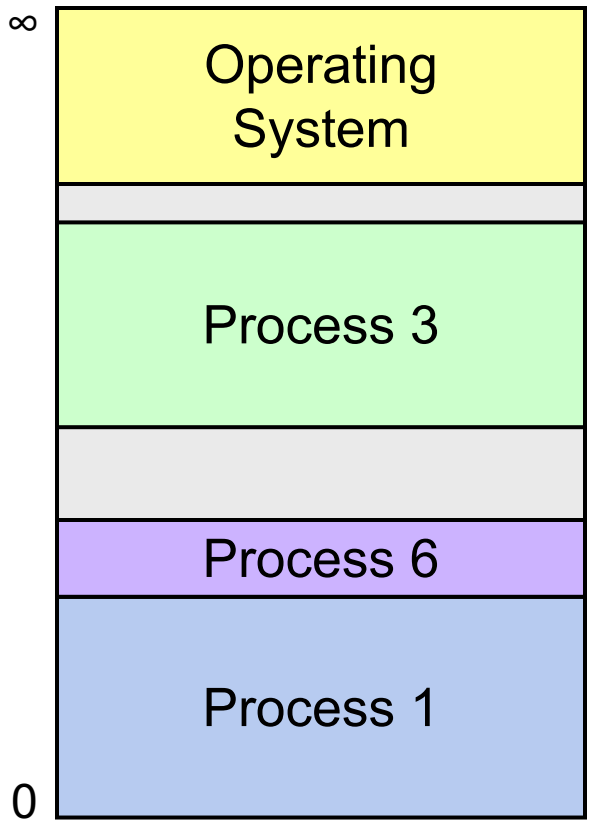
Sharing Memory

We want to allow multiple processes to simultaneously use system memory. Our goals are:

- **Multitasking** – allow multiple processes to be memory-resident at once
- **Transparency** – no process should need to know memory is shared. Each must run regardless of the number and/or locations of processes in memory.
- **Isolation** – processes must not be able to corrupt each other
- **Efficiency** (both of CPU and memory) – shouldn't be degraded badly by sharing

Load-Time Relocation

- When a process is loaded to run, place it in a designated memory space.
- That memory space is for everything for that process – stack/data/code
- Interesting fact – when a program is compiled, it is compiled assuming its memory starts at address 0. Therefore, we must update its addresses when we load it to match its real starting address.
- Use first-fit or best-fit allocation to manage available memory.
- **Problems:** isolation, deciding memory sizes in advance, fragmentation, updating addresses when loading



Idea: What if, instead of translating addresses when a program is loaded, the OS intercepted every memory reference and translated it?

Dynamic Address Translation

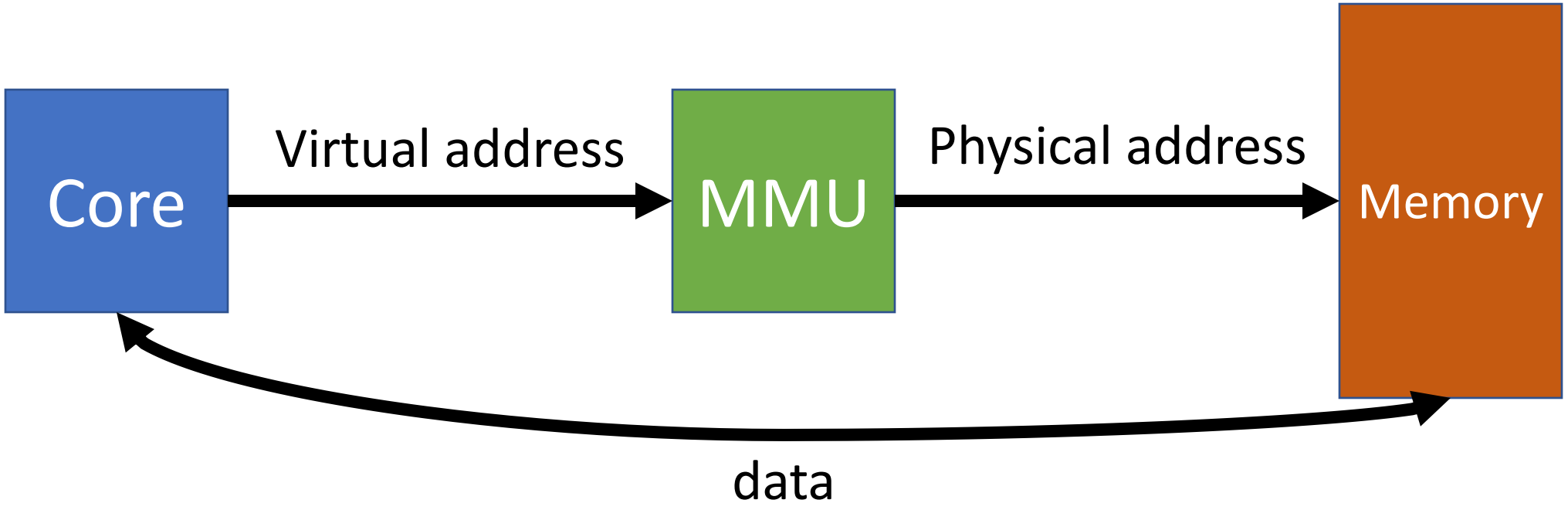
Let's have the OS intercept every memory reference a process makes.

- The OS can prohibit processes from accessing certain addresses (e.g. OS memory or another process's memory)
- Gives the OS lots of flexibility in managing memory
- Every process can now think that it is located starting at address 0
- The OS will translate each process's address to the real one it's mapped to

Dynamic Address Translation

We will add a *memory management unit* (MMU) in hardware that changes addresses dynamically during every memory reference.

- *Virtual address* is what the program sees
- *Physical address* is the actual location in memory



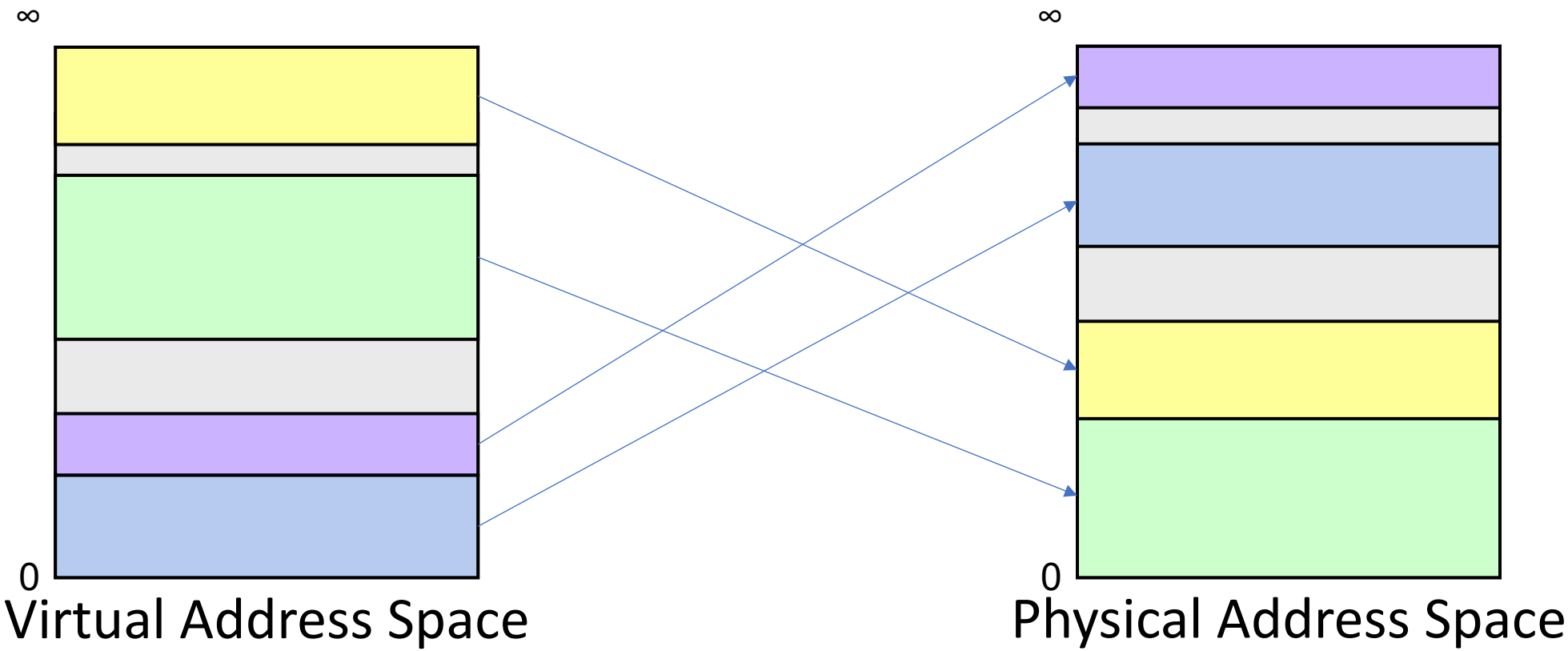
Dynamic Address Translation

- Every process can think it starts at address 0 and is the only process in memory
- Behind the scenes, the OS can choose how it maps each process's virtual addresses to real ("physical") addresses
- As a result, a process's virtual address space may look very different from how the memory is really laid out in the physical address space.

Dynamic Address Translation

Key Idea: there are now *two views of memory,* and they can look very different:

- **Virtual address space** is what the program sees
- **Physical address space** is the actual allocation of memory



Key Question: How do the MMU/OS translate from virtual addresses to physical ones?

Plan For Today

- **Recap:** virtual memory and dynamic address translation
- Approach #1: Base and Bound
- Approach #2: Multiple Segments
- Approach #3: Paging

Plan For Today

- **Recap:** virtual memory and dynamic address translation
- **Approach #1: Base and Bound**
- Approach #2: Multiple Segments

Approach #1: Base and Bound

Key Idea: Let's use the **load-time relocation** idea of contiguous allocation, but with the MMU.

- Every process's virtual address space is mapped to a contiguous region of physical memory.
- When a program accesses a virtual address, translate it by adding the ***base*** for that process – the physical address its memory really starts at.
- We specify the process's memory size by setting a ***bound*** for it; if a process accesses an an invalid virtual address above the bound, OS triggers an error.

Approach #1: Base and Bound

- “base” is physical address starting point – corresponds to virtual address 0
- “bound” is highest allowable **virtual** memory address
- Each process has own base/bound. Stored in PCB and loaded into two registers when running.

On each memory reference:

- Compare virtual address to bound, trap if >= (invalid memory reference)
- Otherwise, add base to virtual address to produce physical address

Approach #1: Base and Bound

Example: let's say process A has **base = 1000**, **bound = 5000.** What happens if:

- It accesses virtual address **6000**?
- It accesses virtual address **0**?

Approach #1: Base and Bound

Example: let's say process A has **base = 1000**, **bound = 5000.** What happens if:

- It accesses virtual address **6000**? Invalid memory reference.
- It accesses virtual address **0**? Accesses physical address **1000**.

Process B has base = 6000, bound = 2000. What happens when it accesses virtual addresses 1) 6000 and 2) 1000?

- Accesses 1) physical address 12000 and 2) physical address 7000
- Accesses 1) physical address 0 and 2) physical address 3000
- 1) Invalid memory reference and 2) physical address 7000
- Gets memory errors for both references

Process B has base = 6000, bound = 2000. What happens when it accesses virtual addresses 1) 6000 and 2) 1000?

Accesses 1) physical address 12000 and 2) physical address 7000

Accesses 1) physical address 0 and 2) physical address 3000

1) Invalid memory reference and 2) physical address 7000

Gets memory errors for both references

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Gets memory errors for both references	

Approach #1: Base and Bound

- Key idea: each process appears to have a completely private memory whose size is determined by the bound register.
- The only physical address is in the base register, controlled by the OS. Process sees only virtual addresses!
- OS can update a process's base/bound if needed! E.g. it could move physical memory to a new location or increase bound.

Approach #1: Base and Bound

What are some benefits of this approach?

- Inexpensive translation – just doing addition
- Doesn't require much additional space – just per-process base + bound
- The separation between virtual and physical addresses means we can move the physical memory location and simply update the base, or we could even *swap* memory to disk and copy it back later when it's actually needed.

What are some drawbacks of this approach?

- One contiguous region per program
- Fragmentation
- Growing can only happen upwards with the bound
- Doesn't support read-only regions of memory within a process

Idea: what if we broke up the virtual address space into segments and mapped each segment independently?

Plan For Today

- **Recap:** virtual memory and dynamic address translation
- Approach #1: Base and Bound
- **Approach #2: Multiple Segments**

Approach #2: Multiple Segments

Key Idea: Each process is split among several variable-size areas of memory, called segments.

- E.g. one segment for code, one segment for data/heap, one segment for stack.
- The OS maps each segment individually – each segment would have its own base and bound, and these are stored in a *segment map* for that process
- We can also store a *protection* bit for each segment; whether the process is allowed to write to it or not in addition to reading
- Now each segment can have its own permissions, grow/shrink independently, be swapped to disk independently, be moved independently, and even be shared between processes (e.g. shared code).

Approach #2: Multiple Segments

On each memory reference:

- Look up info for the segment that address is in
- Compare virtual address to that segment's bound, trap if >= (invalid memory reference)
- Add segment's base to virtual address to produce physical address

Problem: how do we know which segment a virtual address is in?

Approach #2: Multiple Segments

Problem: how do we know which segment a virtual address is in?

One Idea: make virtual addresses such that the top bits of the address specify its segment, and the low bits of the address specify the offset in that segment.

Another possibility: deduce from machine code instruction executing

Approach #2: Multiple Segments

What are some benefits of this approach?

- Flexibility – can manage each segment independently
- Can share segments between processes
- Can move segments to compact memory and eliminate fragmentation

What are some drawbacks of this approach?

- Variable-length segments result in memory fragmentation – can move, but creates friction
- Typically small number of segments
- Encoding segment + offset rigidly divides virtual addresses (how many bits for segment vs. how many for offset?)

Idea: what if we broke up the virtual address space not into variable-length segments, but into fixed-size chunks?

Recap

- **Recap:** virtual memory and dynamic address translation
- Approach #1: Base and Bound
- Approach #2: Multiple Segments

Next time: approach #3 - paging

Lecture 22 takeaway:
Dynamic Address translation means that the OS intercepts and translates each memory access. Initial approaches to this include base+bound per process, and then expanding that to be base+bound per variable-length segment.