Paging and Midterm Review

Problem Solving Lab for CS111

Stanford CS111ACE, Spring 2026

Today

- Paging
- Dynamic Address Translation
  - Base and Bound
  - Multiple Segments
  - Paging
- Midterm Review

Virtual Memory

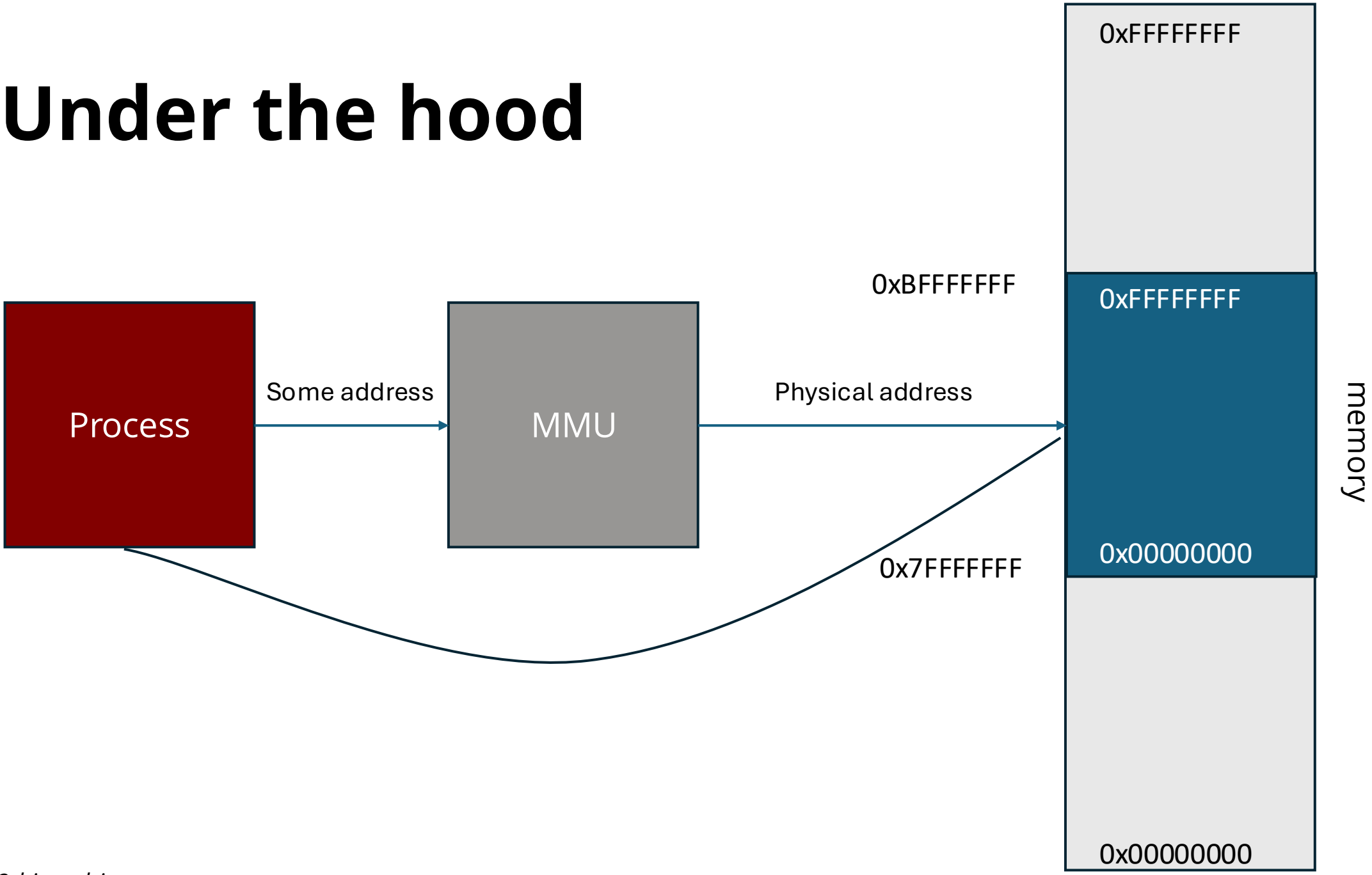

ILLUSION 100

What is virtual memory

- Allows many processes to make use of the memory
- Gives each process the *illusion* that it has *all* the memory
- Maps virtual addresses to physical addresses

Dynamic Address Translation

Under the hood

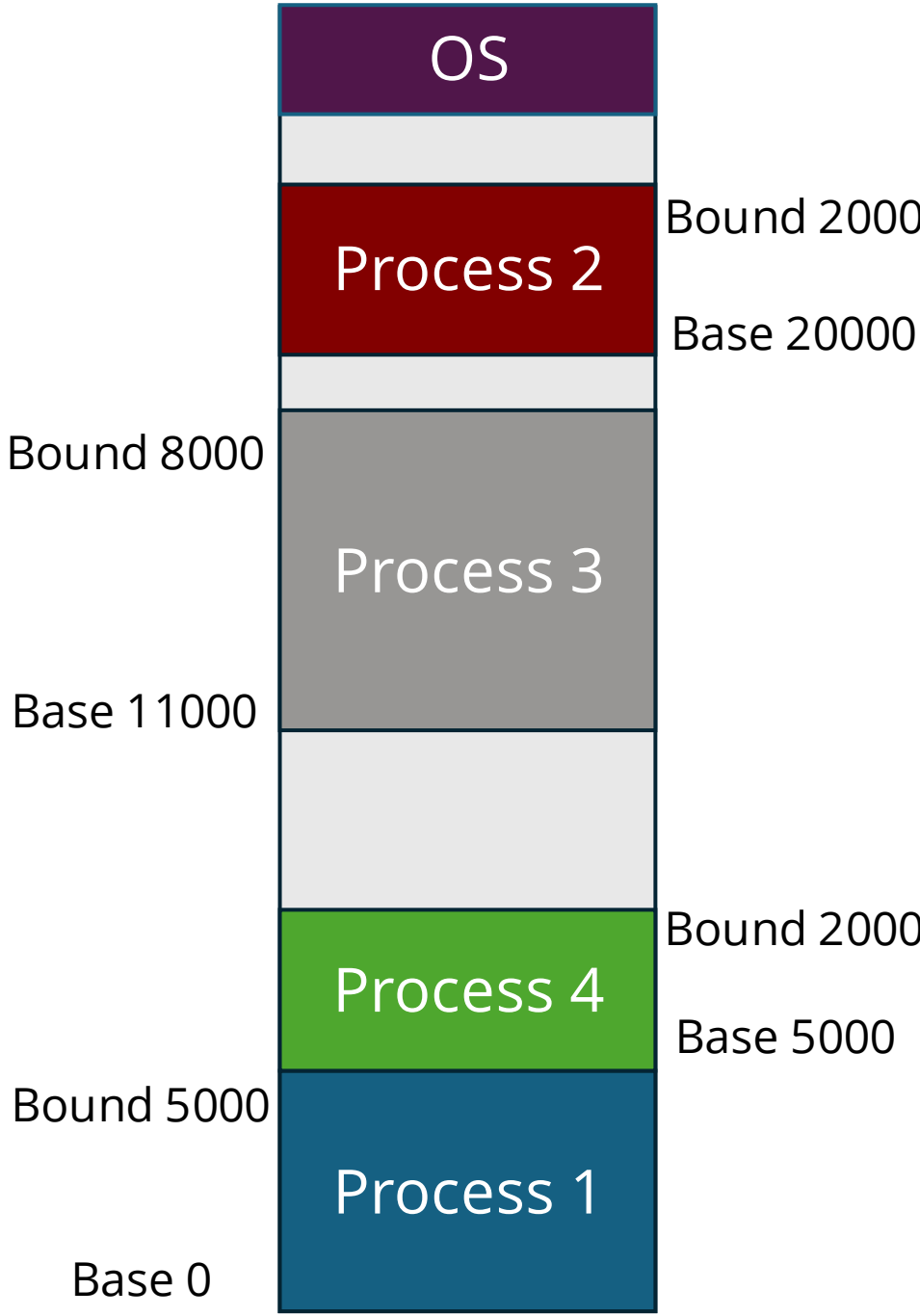


Assumes 32-bit architecture

Base and Bound

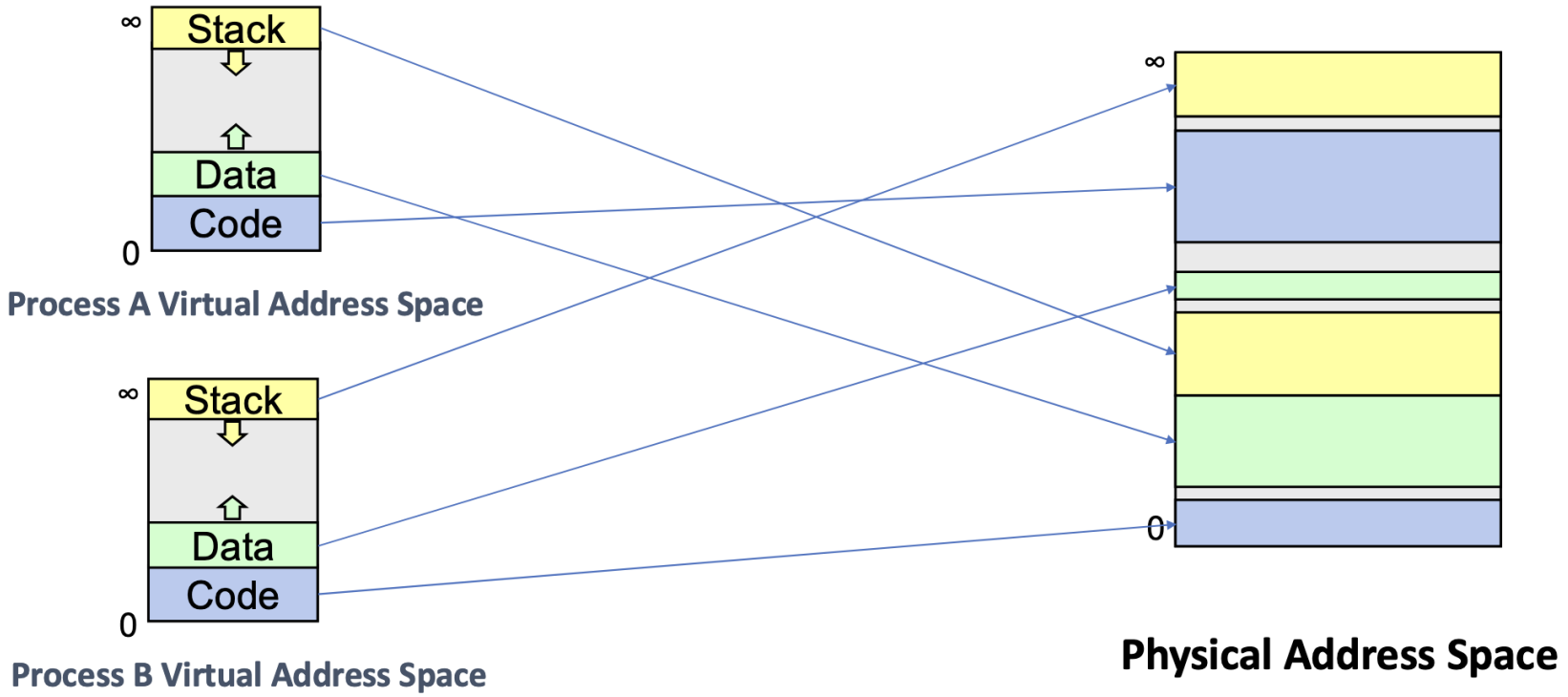
What is base and bound

- Physical address =
  - base + requested_addr
- The OS manages the base addresses, and the process has no knowledge of it!



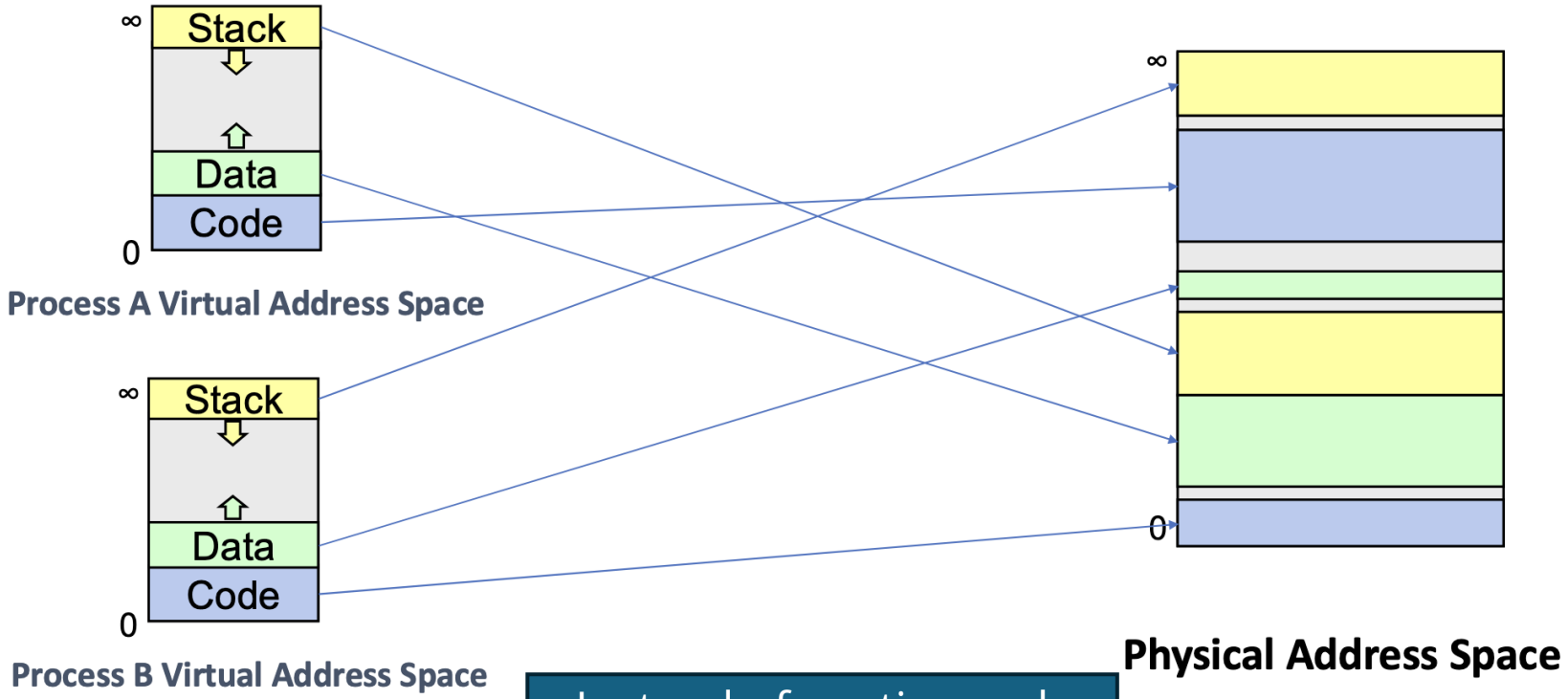
Multiple Segments

What are multiple segments?



From CS111 W26 lecture 22, slide 20

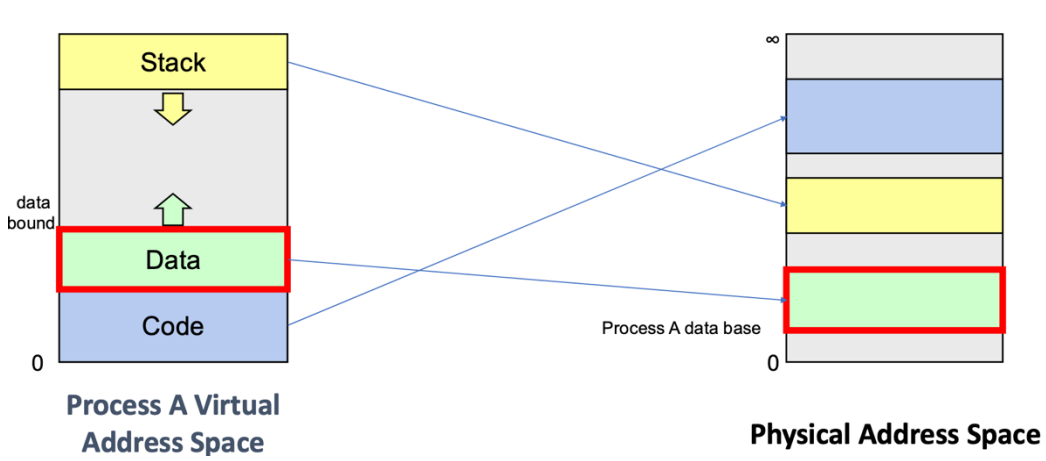
What are multiple segments?

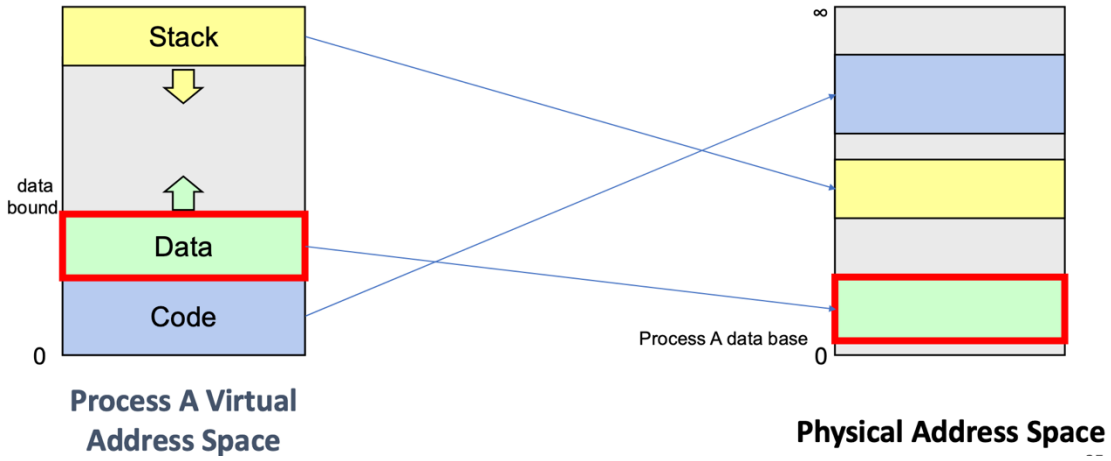


Instead of contiguously mapping processes, contiguously map the segments within processes

From CS111 W26 lecture 22, slide 20

Changing bounds with multiple segments





From CS111 W26 lecture 22, slide 24 & 25

Tradeoffs of multiple segments

Pros:

1. Segments are more easily moved to avoid segmentation

2. Can share segments
   - Why might this be useful?

Cons:

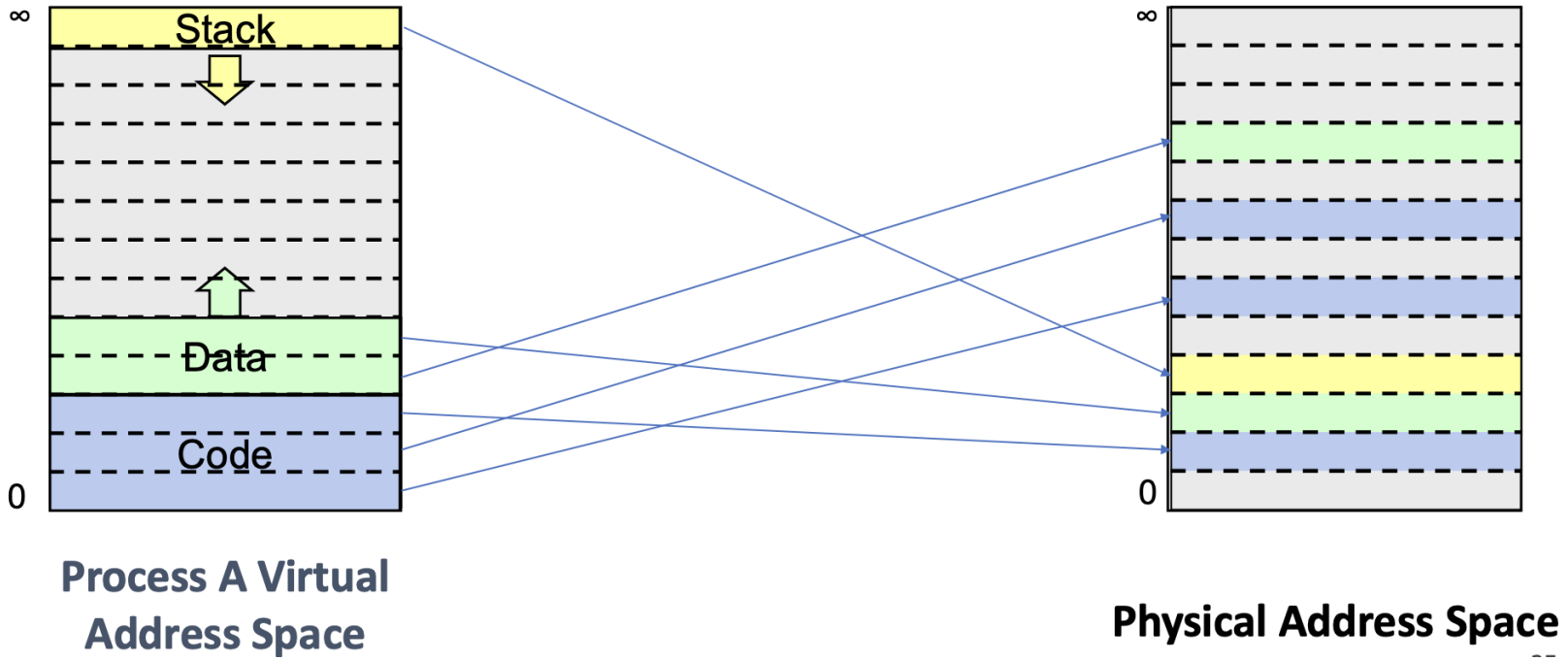
1. Can still only grow upwards with the bound

2. Can still have memory fragmentation

What questions can I answer?

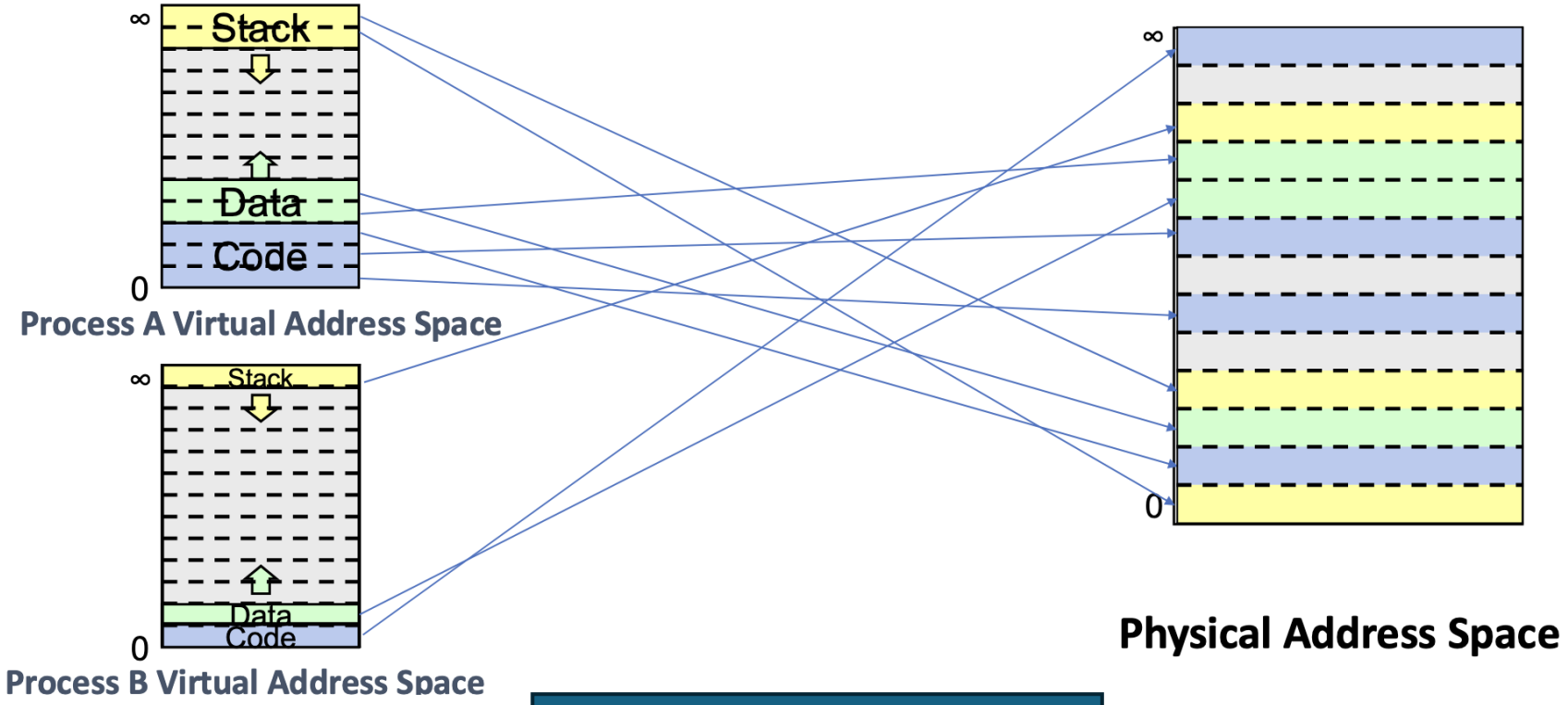
Paging

Reminder of *what* paging is



From CS111 W26 lecture 22, slide 35

With multiple processes



Instead of mapping each segment, map pages, typically 4 Kb

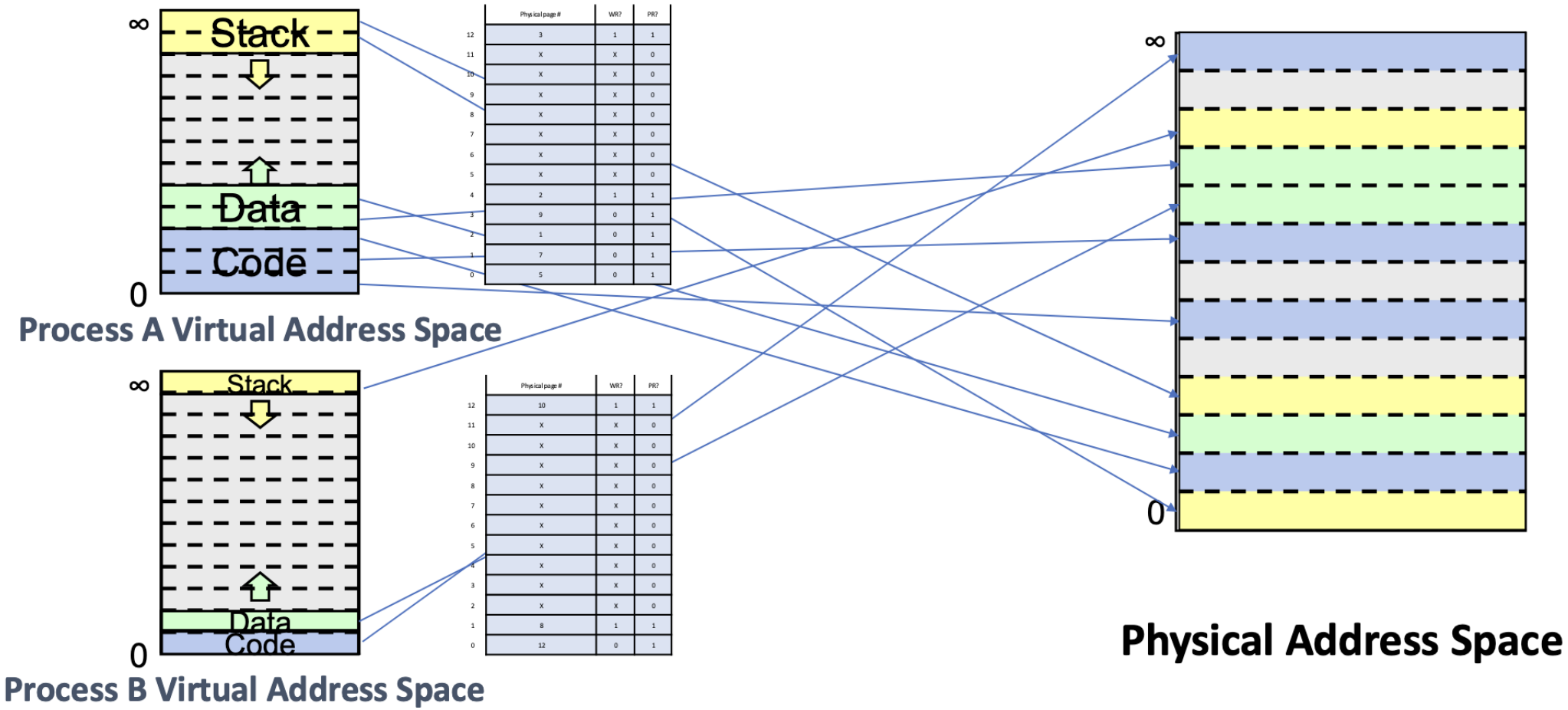
From CS111 W26 lecture 22, slide 35

About paging

- Each page is associated with a *page number*
- The virtual address is the virtual page # and offset in the page
- The physical address is the physical page # and offset in that page

How do we map virtual addresses to physical addresses?

Each process has a Page Map



From CS111 W26 lecture 22, slide 66

How do you index into the page map?

- Assume that your pages are 4 KB

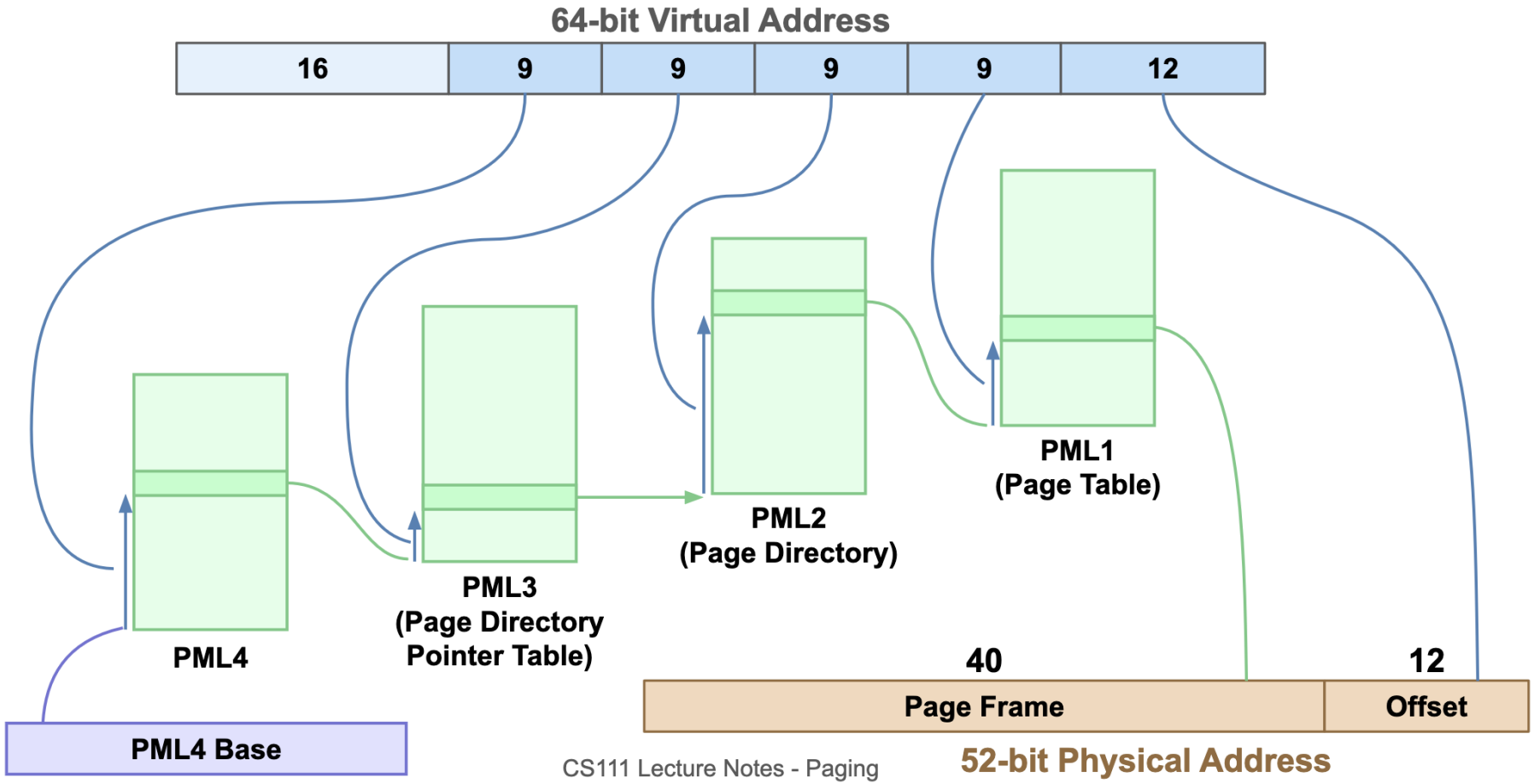
- How many bits do you need to represent 4 KB?
  - You need 12 bits to represent 0-4095

x86-64 with 4KB pages has 36-bit virtual page numbers and 40-bit physical page numbers.

From CS111 W26 lecture 22, slide 65

What questions can I answer?

How translation works in x86-64



From CS111 Spr26 lecture 15, slide 11

Demand Paging

Think-Pair-Share (3-min)

- How many possible virtual pages are there in our scheme?

x86-64 with 4KB pages has 36-bit virtual page numbers and 40-bit physical page numbers.

- How big is the page map?

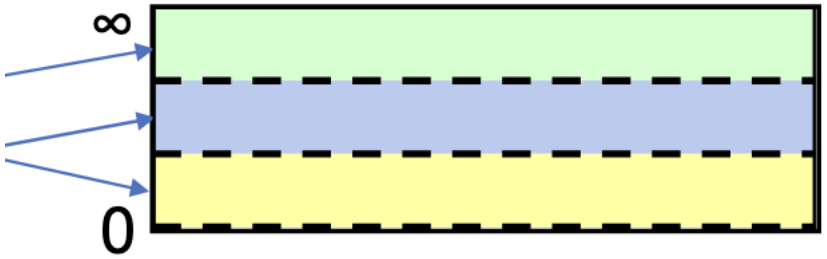
Keeping track of presence

- Our page map has a permissions bit and also a *present* bit.
- We must modify this every time that we move pages into our physical address space.

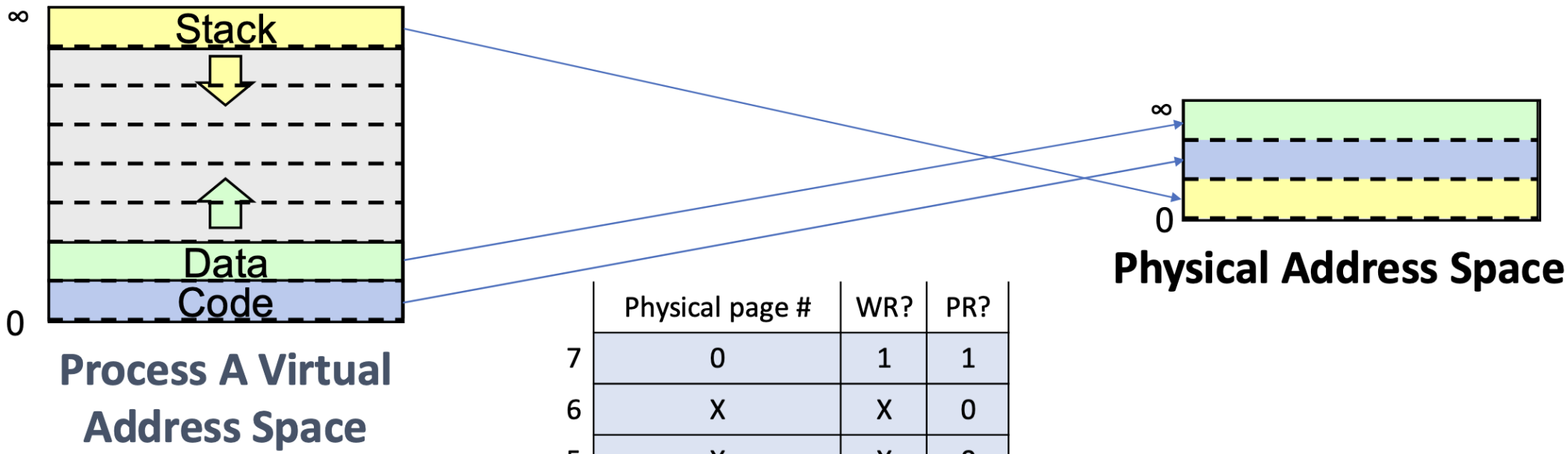
	Physical page #	WR?	PR?
7	0	1	1
6	X	X	0
5	X	X	0
4	X	X	0
3	X	X	0
2	X	X	0
1	2	0	1
0	1	0	1

In lecture

We only had three physical pages, so we had to use this technique track which pages were present in our page map

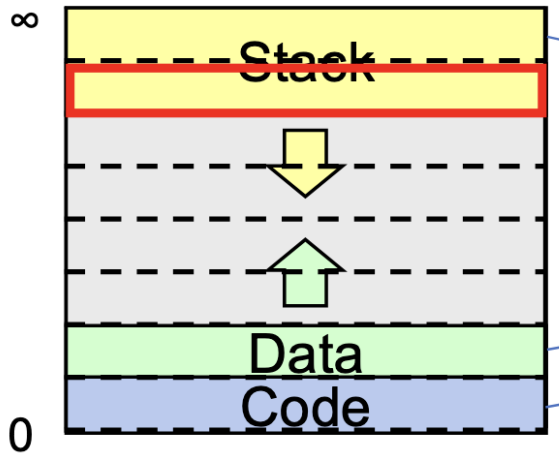


A quick review of the lecture example

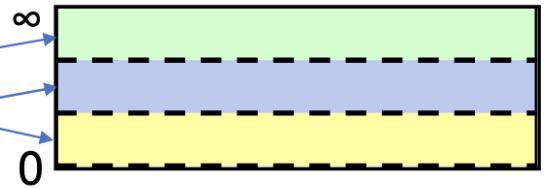


	Physical page #	WR?	PR?
7	0	1	1
6	X	X	0
5	X	X	0
4	X	X	0
3	X	X	0
2	X	X	0
1	2	0	1
0	1	0	1

From CS111 W26 lecture 23, slide 44



Process A Virtual Address Space

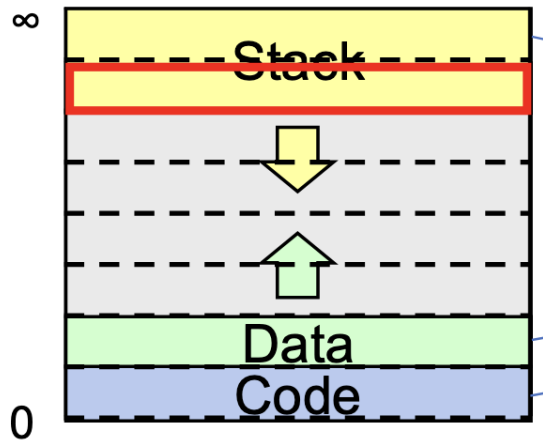


Physical Address Space

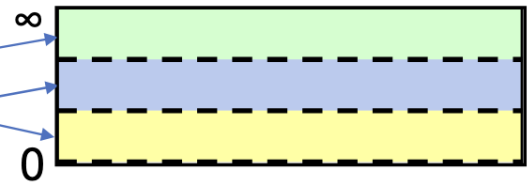
	Physical page #	WR?	PR?
7	0	1	1
6	X	X	0
5	X	X	0
4	X	X	0
3	X	X	0
2	X	X	0
1	2	0	1
0	1	0	1

1. Pick an existing physical page and swap it to disk.

From CS111 W26 lecture 23, slide 45



Process A Virtual Address Space

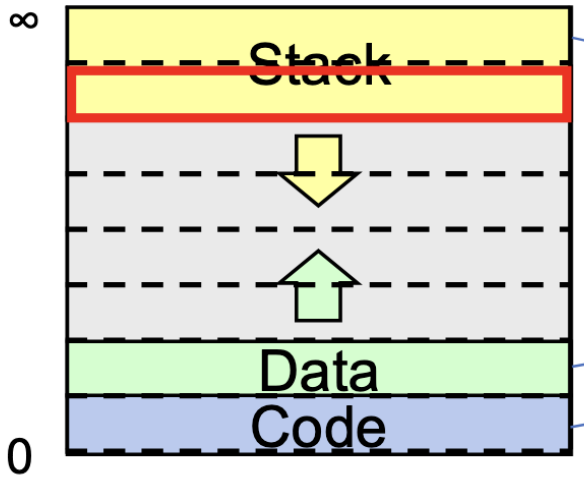


Physical Address Space

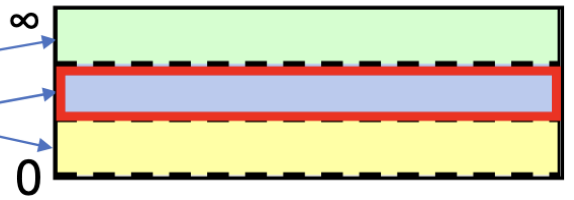
	Physical page #	WR?	PR?
7	0	1	1
6	X	X	0
5	X	X	0
4	X	X	0
3	X	X	0
2	X	X	0
1	2	0	1
0	1	0	1

1. Pick an existing physical page and swap it to disk.

From CS111 W26 lecture 23, slide 46

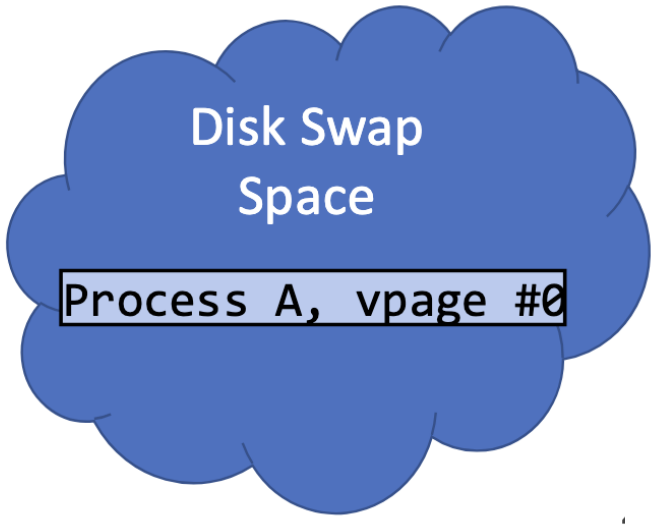


Process A Virtual Address Space



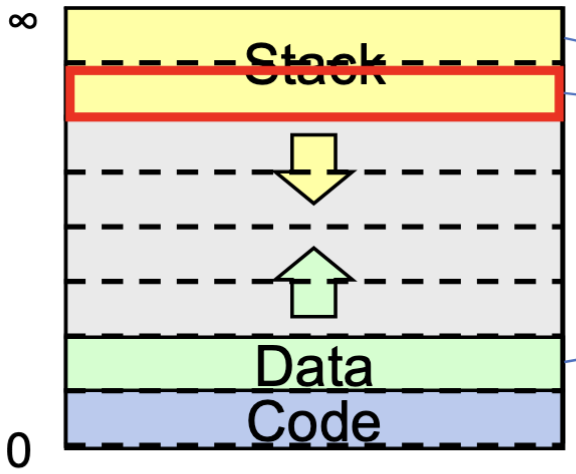
Physical Address Space

	Physical page #	WR?	PR?
7	0	1	1
6	X	X	0
5	X	X	0
4	X	X	0
3	X	X	0
2	X	X	0
1	2	0	1
0	1	0	0

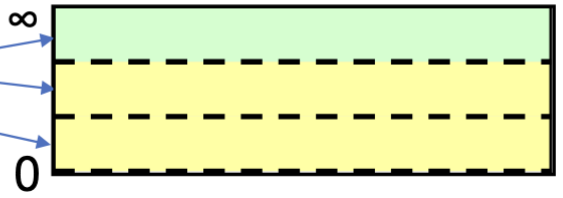


1. Pick an existing physical page and swap it to disk, mark not present.

From CS111 W26 lecture 23, slide 47



Process A Virtual Address Space



Physical Address Space

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6	1	1	1
5	X	X	0
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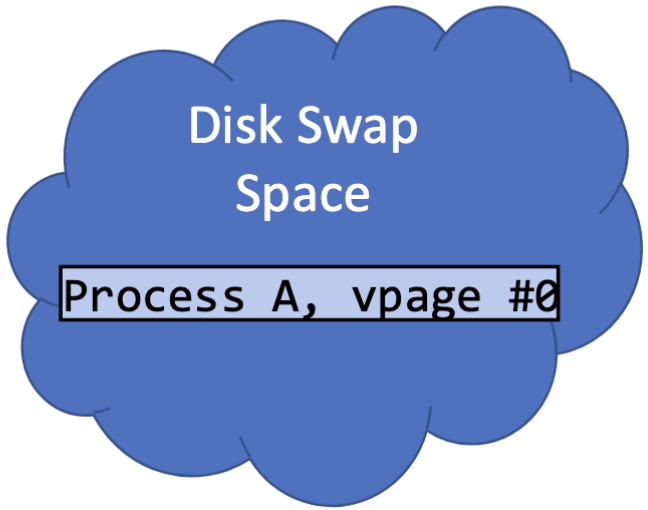
3	X	X	0
2	X	X	0
1	2	0	1
0	1	0	0



2. Map this physical page to the new virtual page.

From CS111 W26 lecture 23, slide 48

What questions can I answer?

Kahoot time!