CS161: Operating Systems

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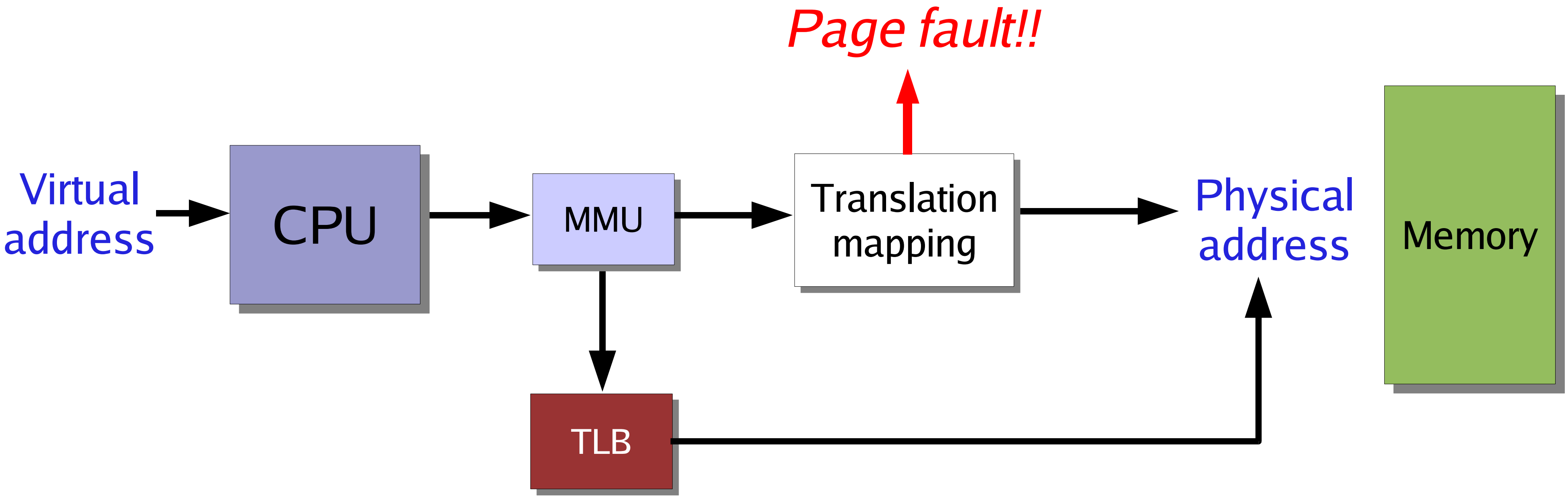
Lecture 10: Demand Paging and Multi-level Page Tables
March 8, 2007

Topics for today

What happens when a page is not in memory?

How do we prevent having page tables take up a huge amount of memory themselves?

Page Faults



When a virtual address translation cannot be performed, it's called a *page fault*

Page Faults

Recall the PTE format:

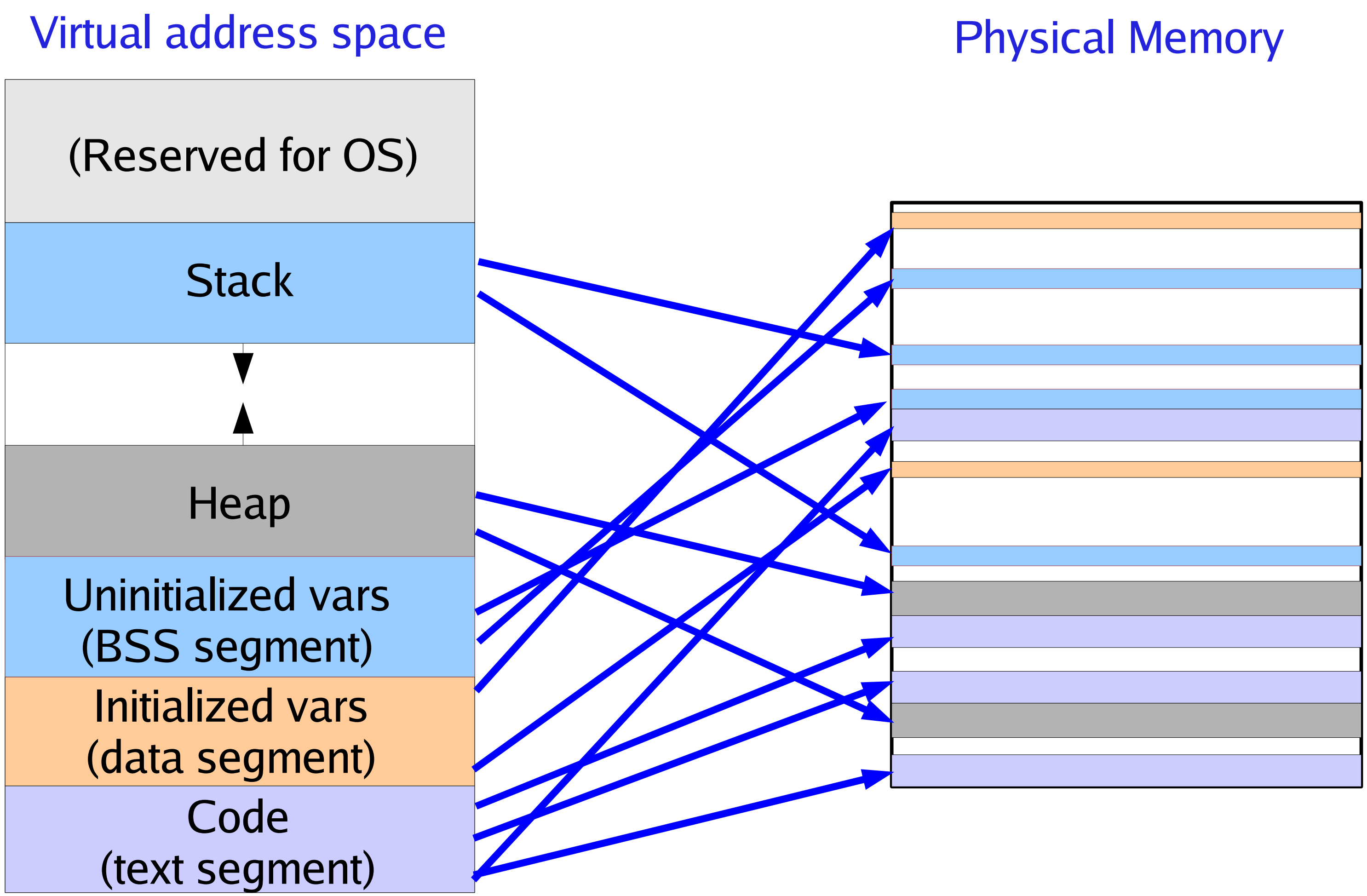
V	M	R	prot	page frame number

- Valid bit indicates whether a page translation is valid
- If Valid bit is 0, then a page fault will occur
- Page fault will also occur if attempt to write a read-only page (based on the Protection bits, not the valid bit)
    - *This is sometimes called a protection fault*

Demand Paging

Does it make sense to read an entire program into memory at once?

- No! Remember that only a small portion of a program's code may be used!
- For example, if you never use the "save as PDF" feature in OpenOffice...



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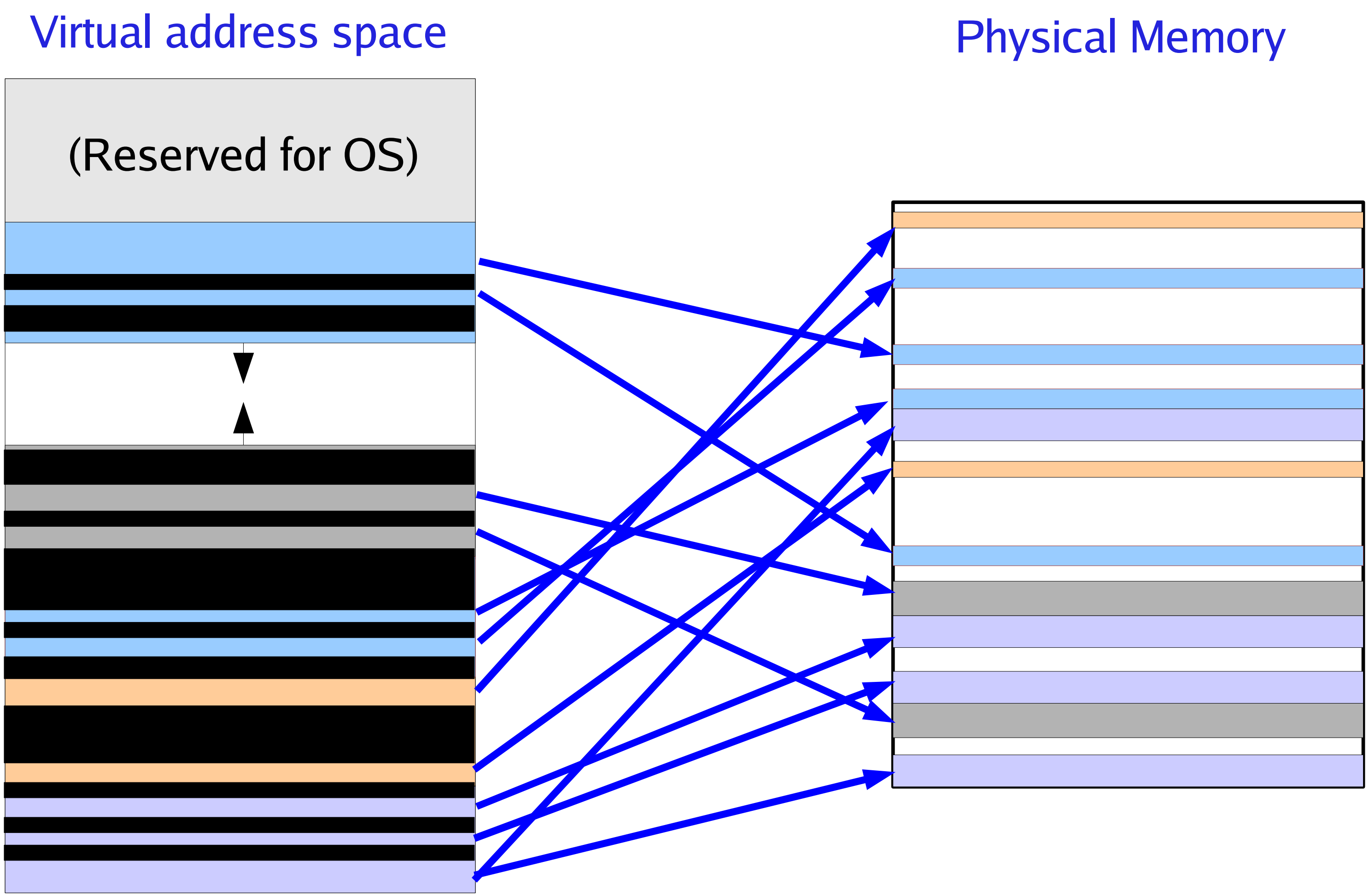

What are these “holes” ??

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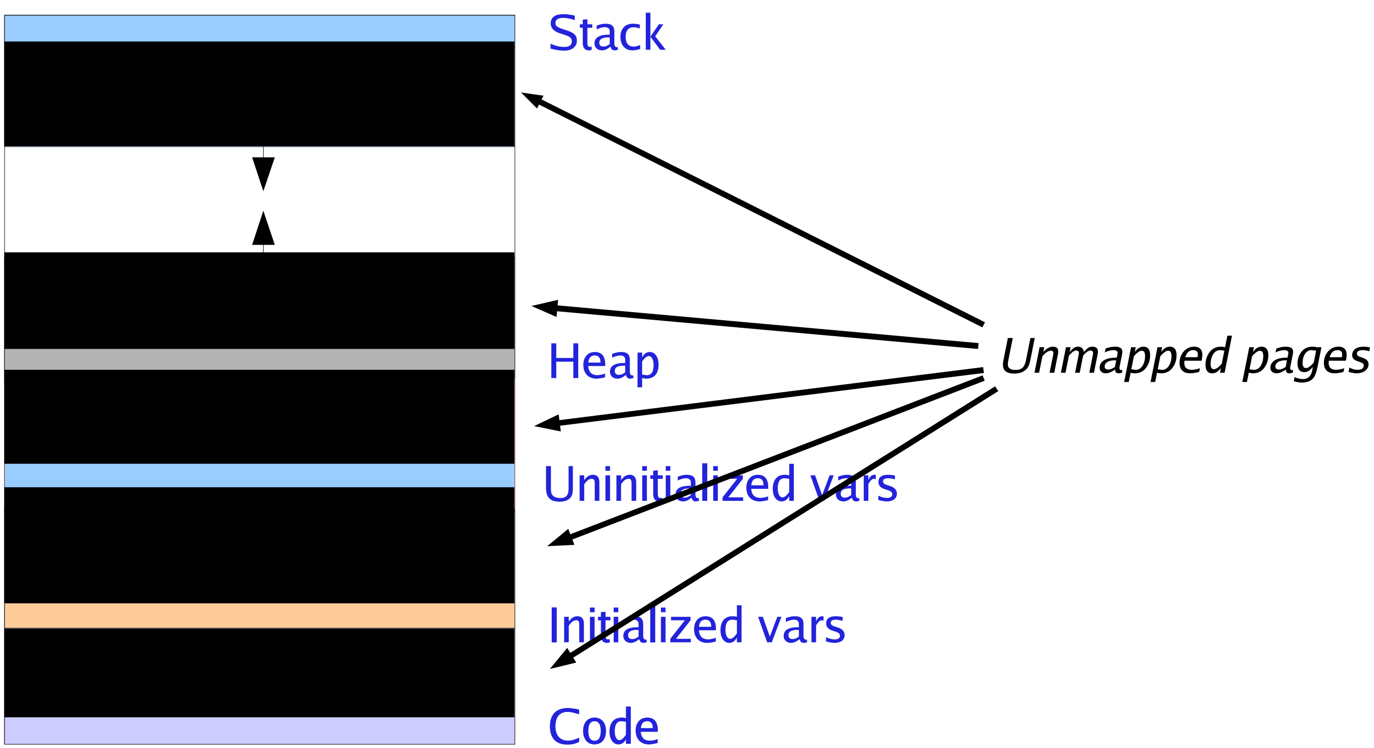
Three kinds of “holes” in a process's page tables:

1. Pages that are on disk
   - Pages that were swapped out to disk to save memory
   - Also includes code pages in an executable file
     - *When a page fault occurs, load the corresponding page from disk*
2. Pages that have not been accessed yet
   - For example, newly-allocated memory
     - *When a page fault occurs, allocate a new physical page*
   - What are the contents of the newly-allocated page???
3. Pages that are invalid
   - For example, the “null page” at address 0x0
     - *When a page fault occurs, kill the offending process*

Starting up a process

What does a process's address space look like when it first starts up?



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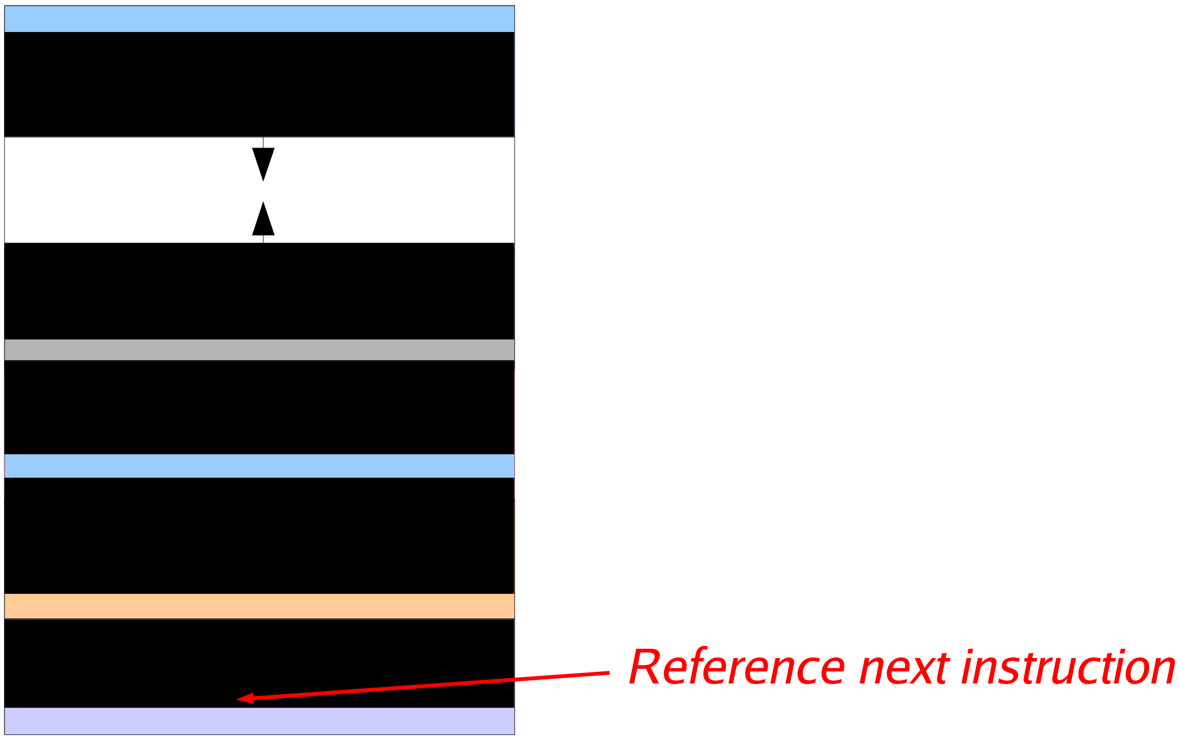

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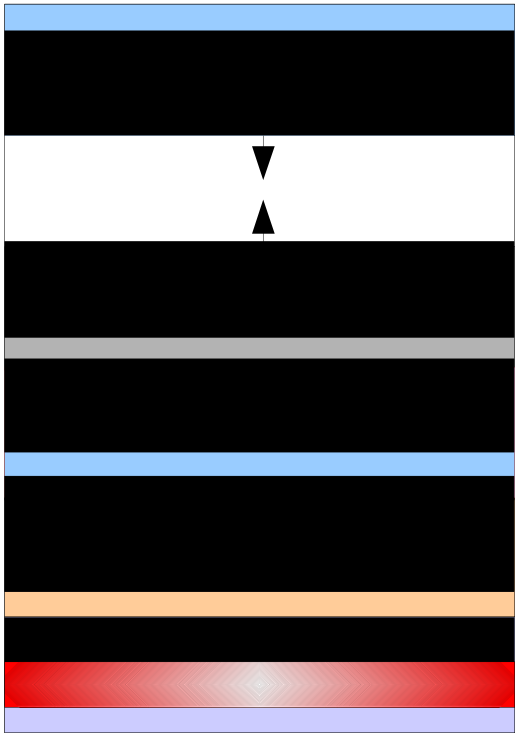

Page fault!!!

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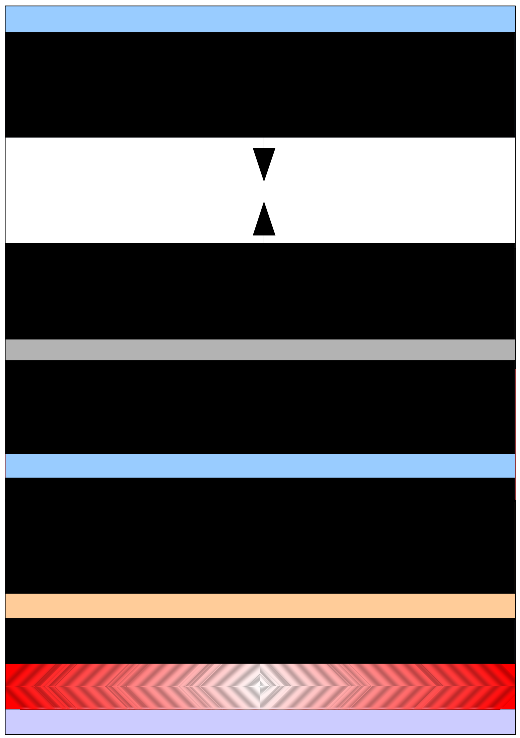
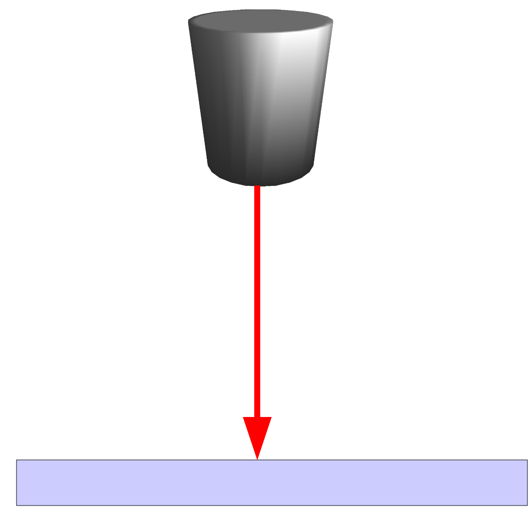


OS reads missing page from executable file on disk



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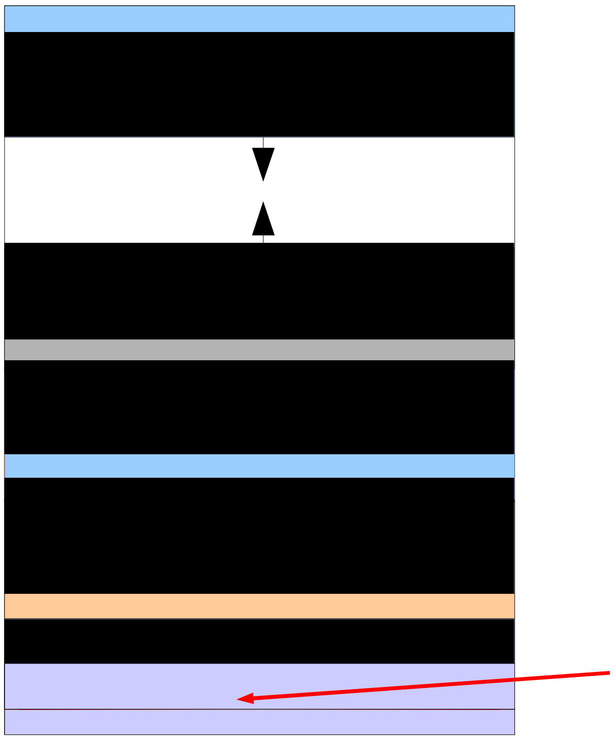

Process resumes at the next instruction

Starting up a process

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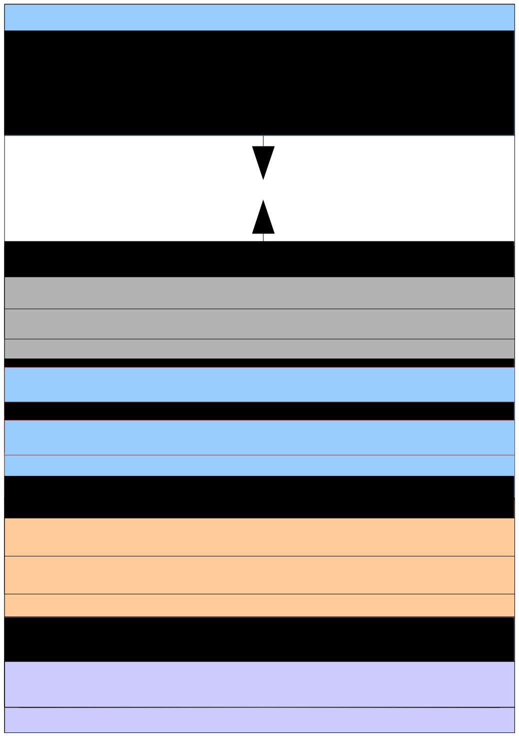

Over time, more pages are
brought in from the executable as needed

Uninitialized variables and the heap

Page faults bring in pages from the executable file for:

- Code (text segment) pages
- Initialized variables

What about uninitialized variables and the heap?

Say I have a global variable "`int c`" in the program ... what happens when the process first accesses it?

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What about uninitialized variables and the heap?

Say I have a global variable "`int c`" in the program ... what happens when the process first accesses it?

- Page fault occurs
- OS looks at the page and realizes it corresponds to a *zero page*
- Allocates a new physical frame in memory **and sets all bytes to zero**
  - *Why???*
- Maps the frame into the address space
  - *What do I mean by this?*

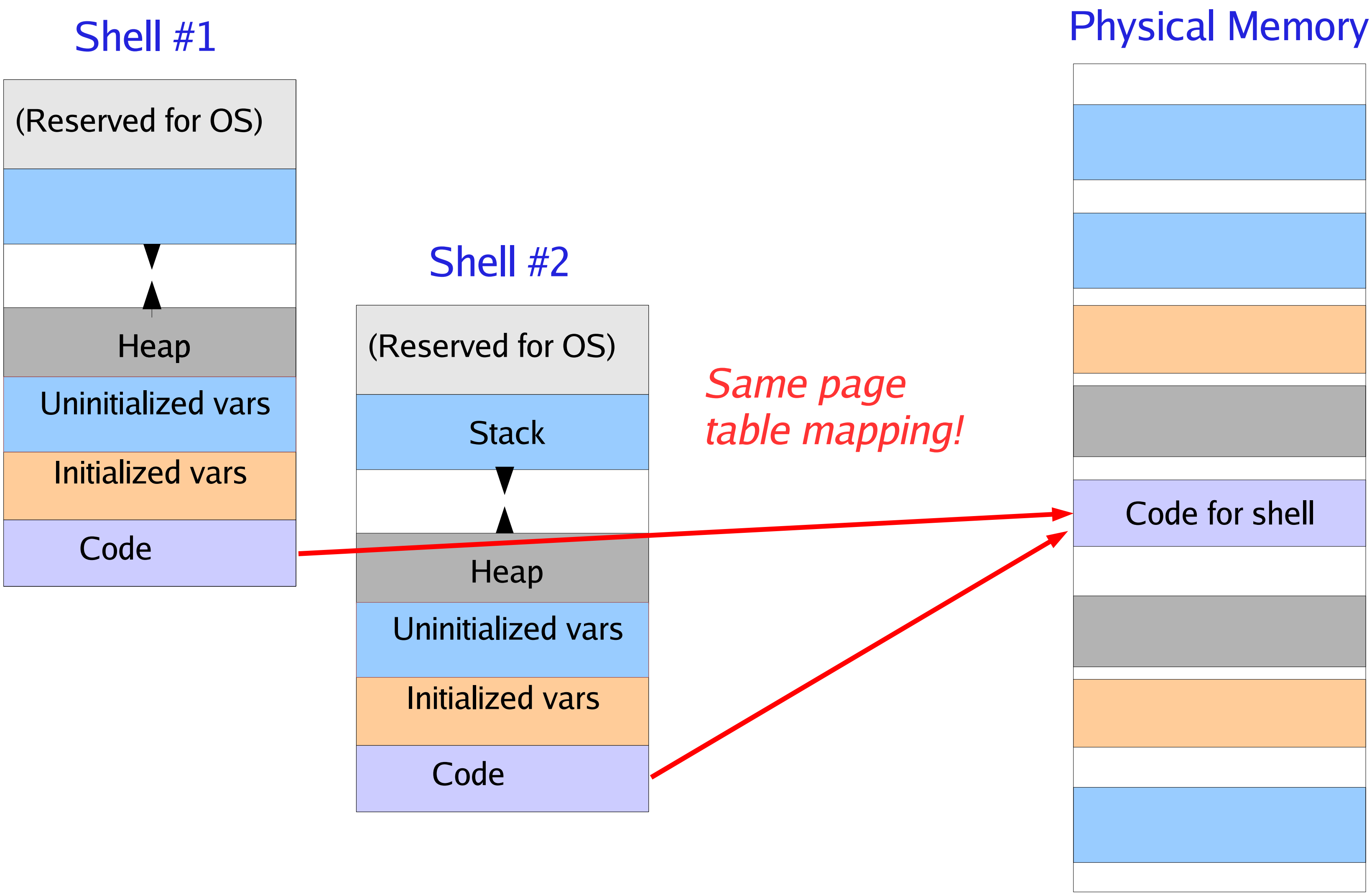
What about the heap?

- `malloc()` just asks the OS to map new zero pages into the address space
- Page faults allocate new empty pages as above

More Demand Paging Tricks

Paging can be used to allow processes to share memory

- A significant portion of many process's address space is identical
- For example, multiple copies of your shell all have the same exact code!



More Demand Paging Tricks

This can be used to let different processes share memory

- UNIX supports shared memory through the `shmget/shmat/shmdt` system calls
- Allocates a region of memory that is shared across multiple processes
- Some of the benefits of multiple threads per process, but the rest of the processes address space is protected
  - *Why not just use multiple processes with shared memory regions?*

Memory-mapped files

- Idea: Make a file on disk look like a block of memory
- Works just like faulting in pages from executable files
  - *In fact, many OS's use the same code for both*
- One wrinkle: Writes to the memory region must be reflected in the file
- **How does this work?**

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- One wrinkle: Writes to the memory region must be reflected in the file
- How does this work?
  - *When writing to the page, mark the "modified" bit in the PTE*
  - *When page is removed from memory, write back to original file*

Remember fork()?

fork() creates an exact copy of a process

- What does this imply about page tables?

When we fork a new process, does it make sense to make a copy of all of its memory?

- Why or why not?

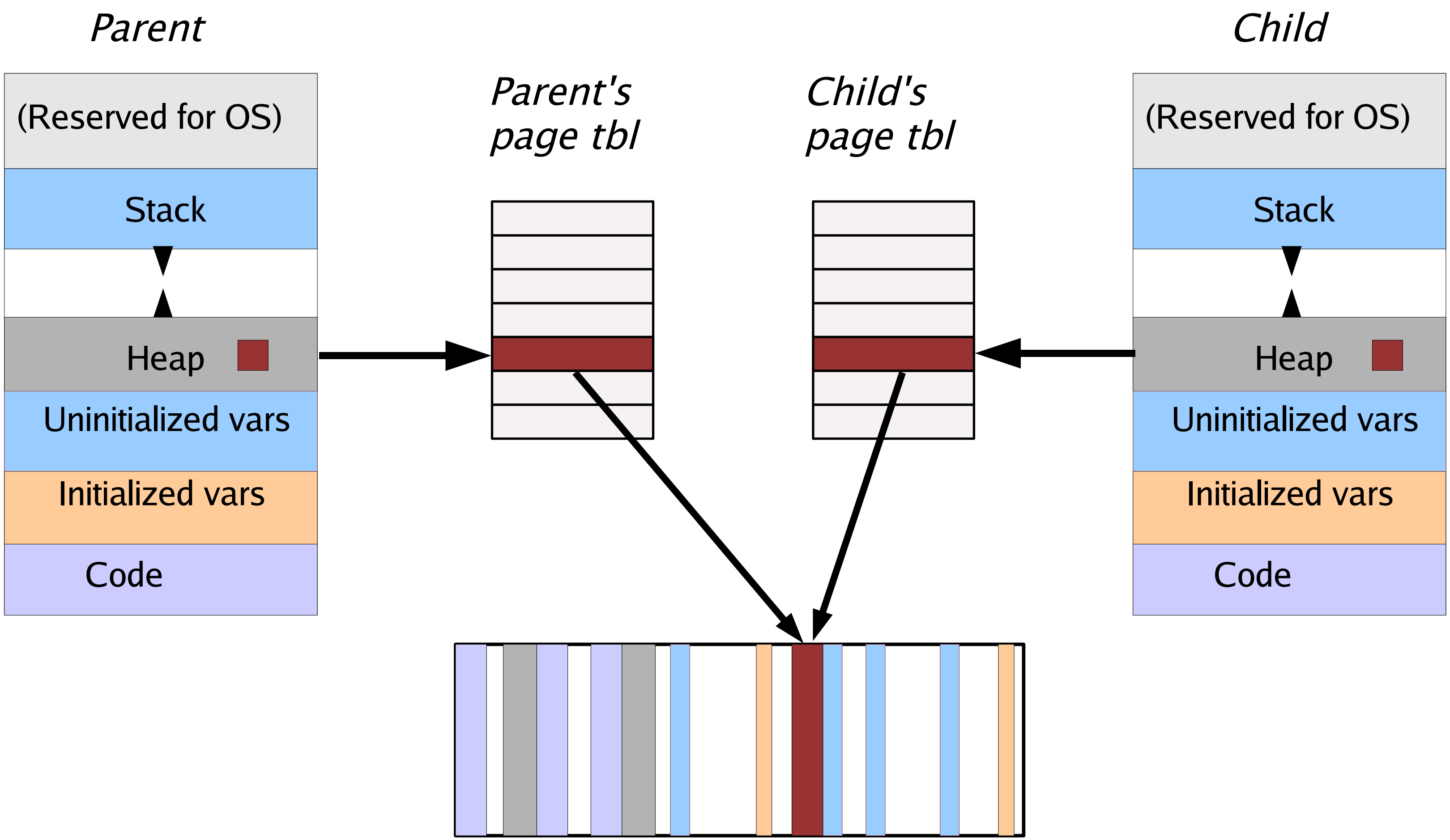
What if the child process doesn't end up touching most of the memory the parent was using?

- Extreme example: What happens if a process does an exec() immediately after fork()?

Copy-on-write

Idea: Give the child process access to the same memory, but don't let it write to any of the pages directly!

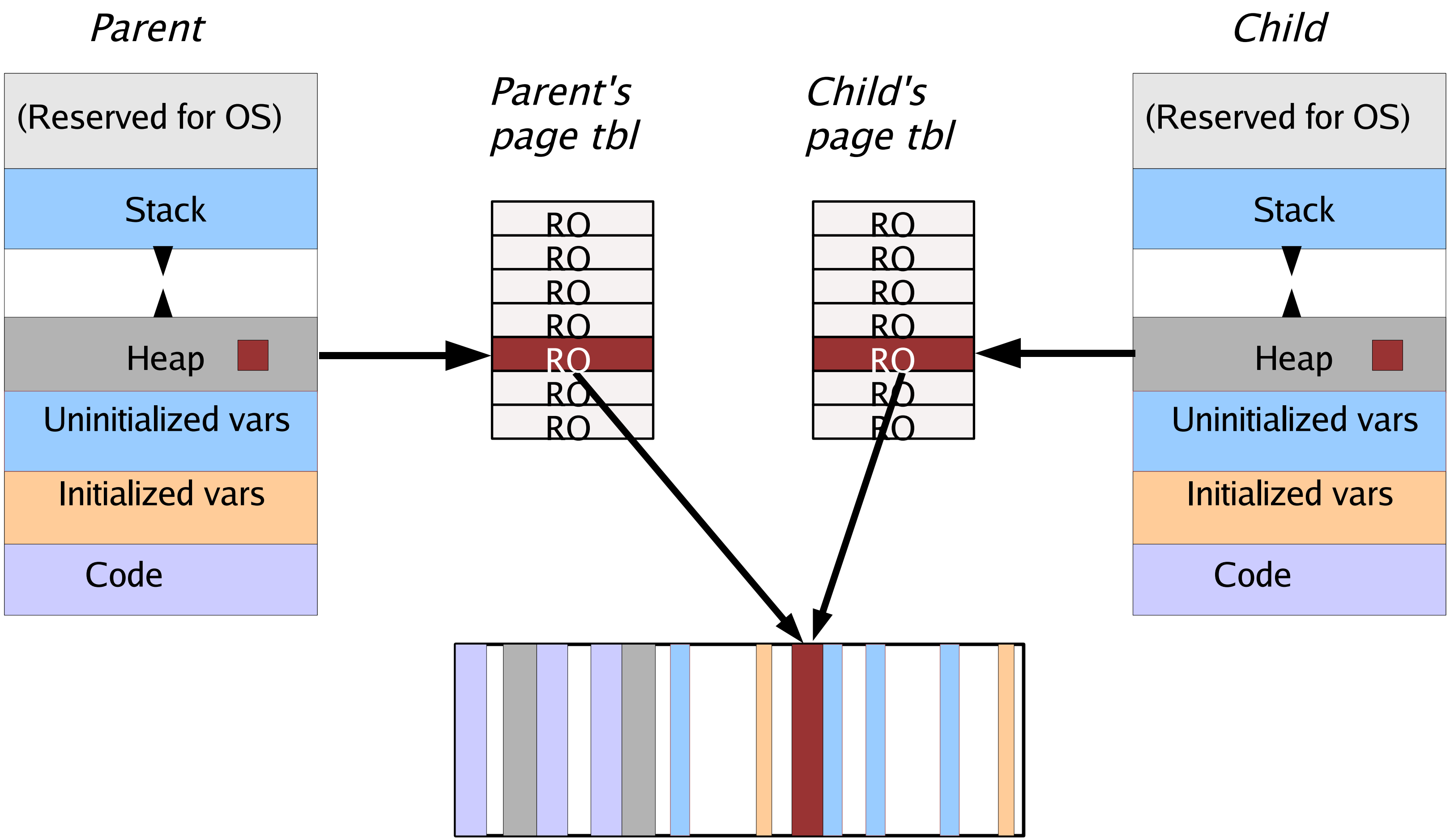
- 1) Parent forks a child process
- 2) Child gets a copy of the parent's page tables
  - *They point to the same physical frames!!!*



Copy-on-write

All pages (both parent and child) marked read-only

- Why???



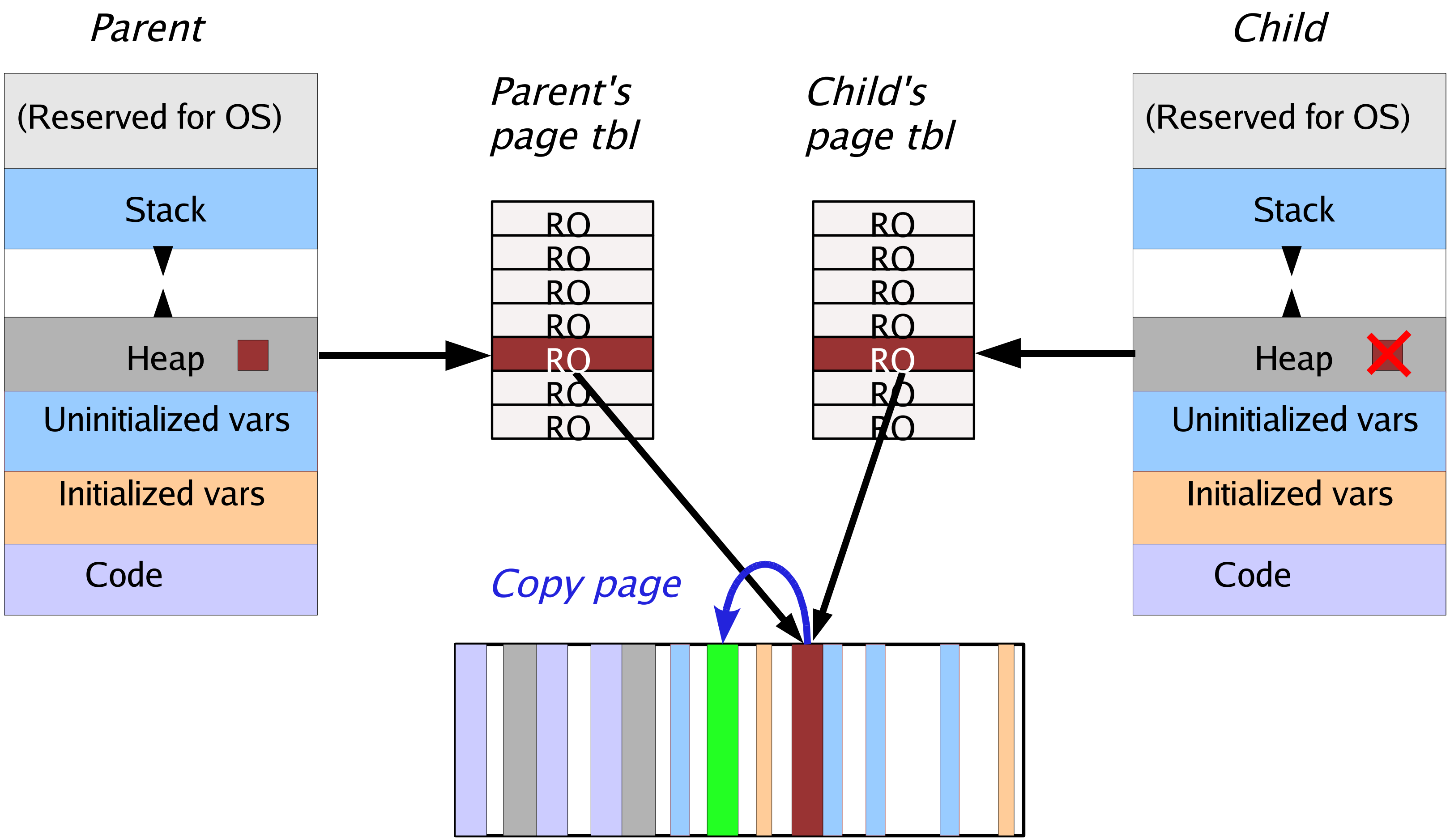
Copy-on-write

What happens when the child *reads* the page?

- Just accesses same memory as parent .... niiiiiice

What happens when the child *writes* the page?

- Protection fault occurs (page is read-only!)
- OS copies the page and maps it R/W into the child's addr space



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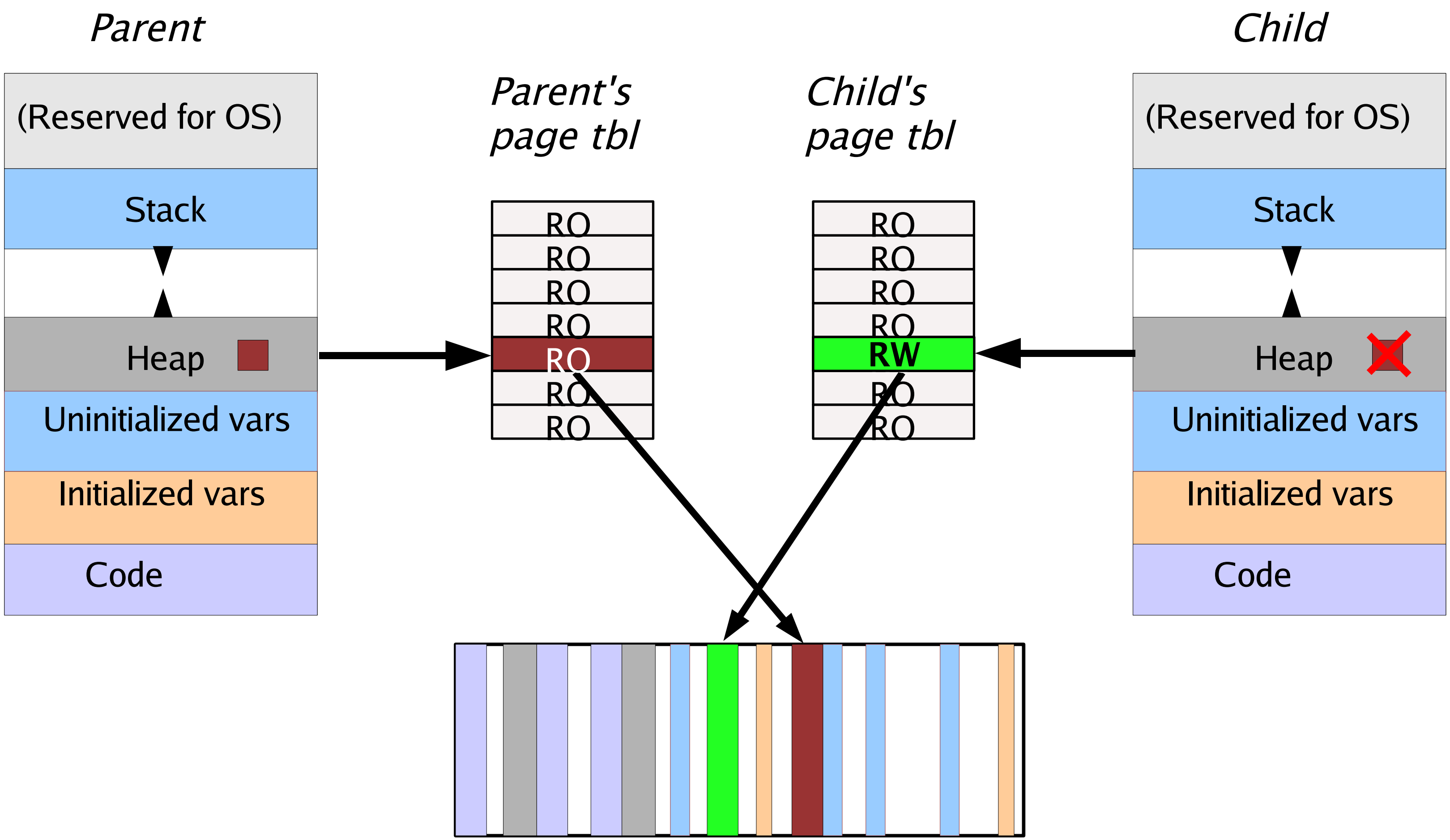
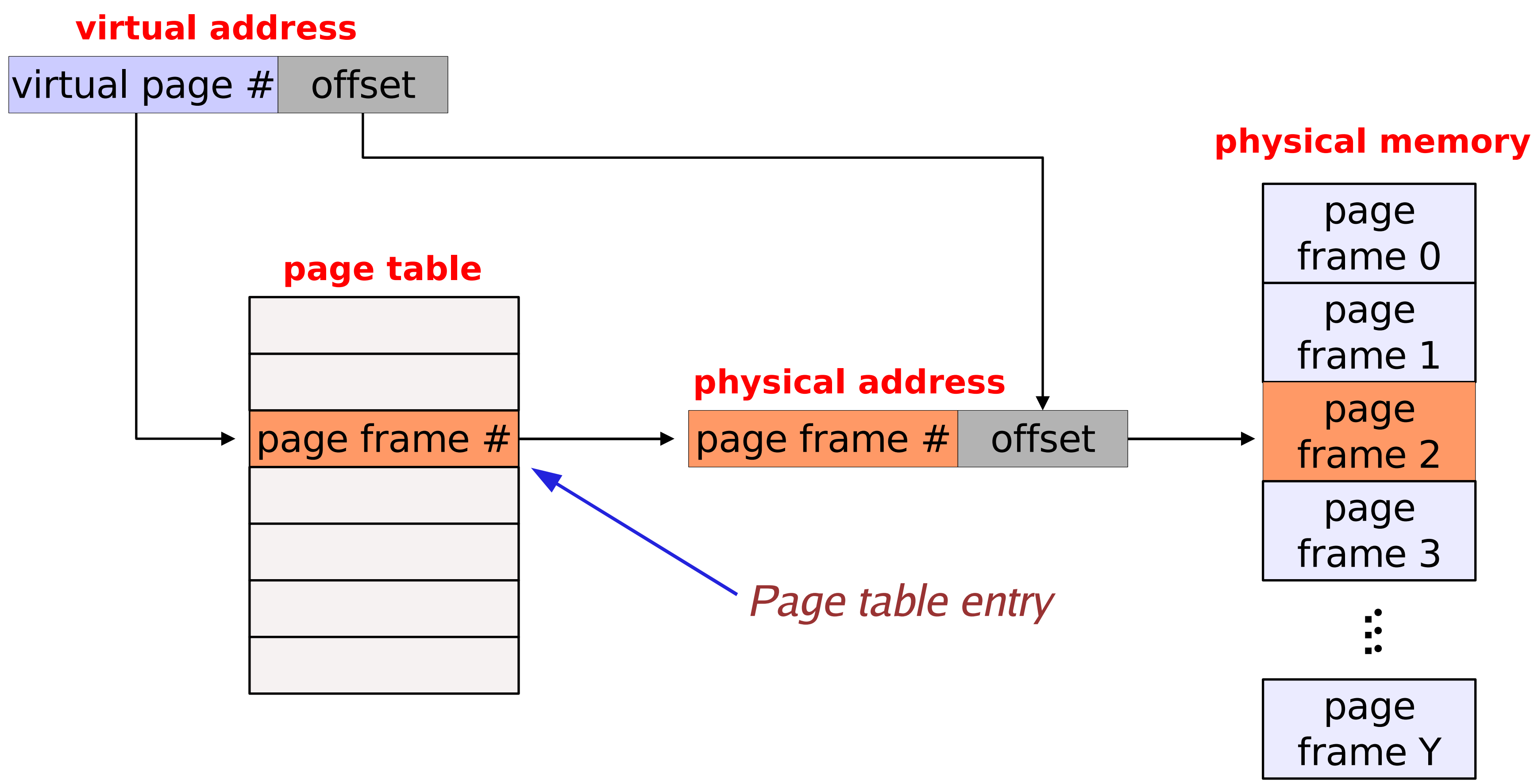


Page Tables

Remember how paging works:



Recall that page tables for one process can be very large!

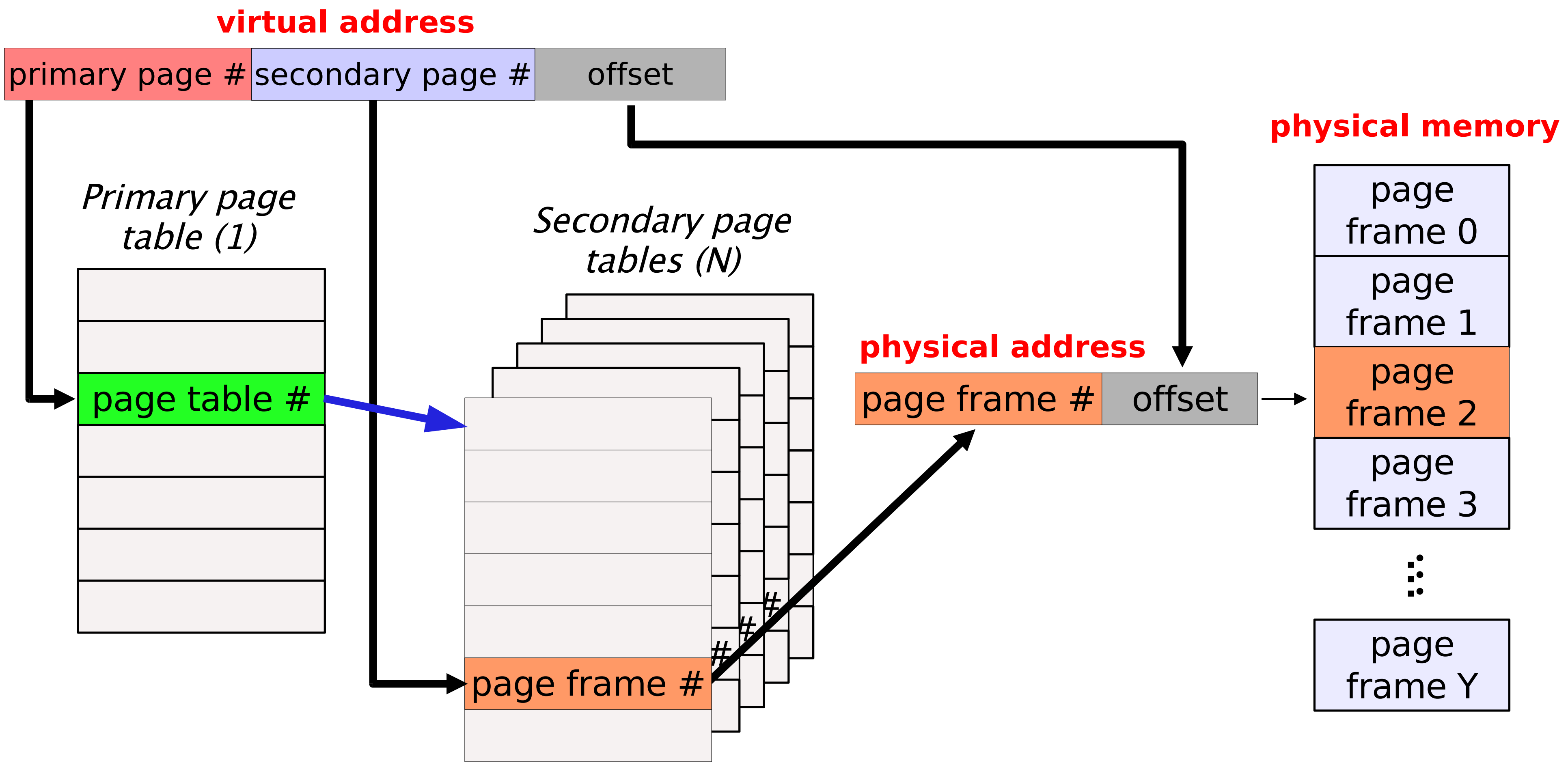
- 2^20 PTEs * 4 bytes per PTE = 4 Mbytes per process

Multilevel Page Tables

Problem: Can't hold all of the page tables in memory

Solution: Page the page tables!

- Allow portions of the page tables to be kept in memory at one time



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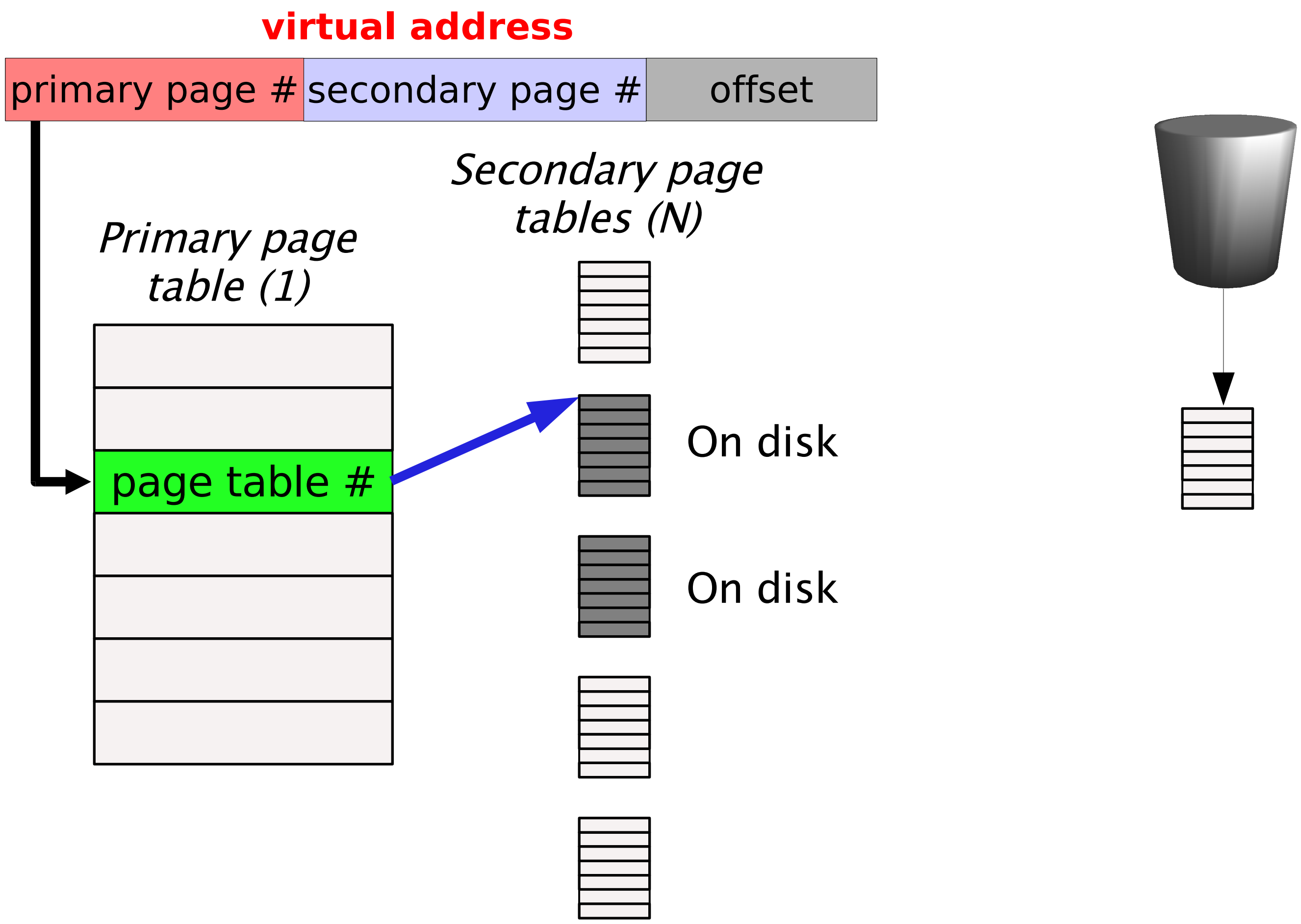

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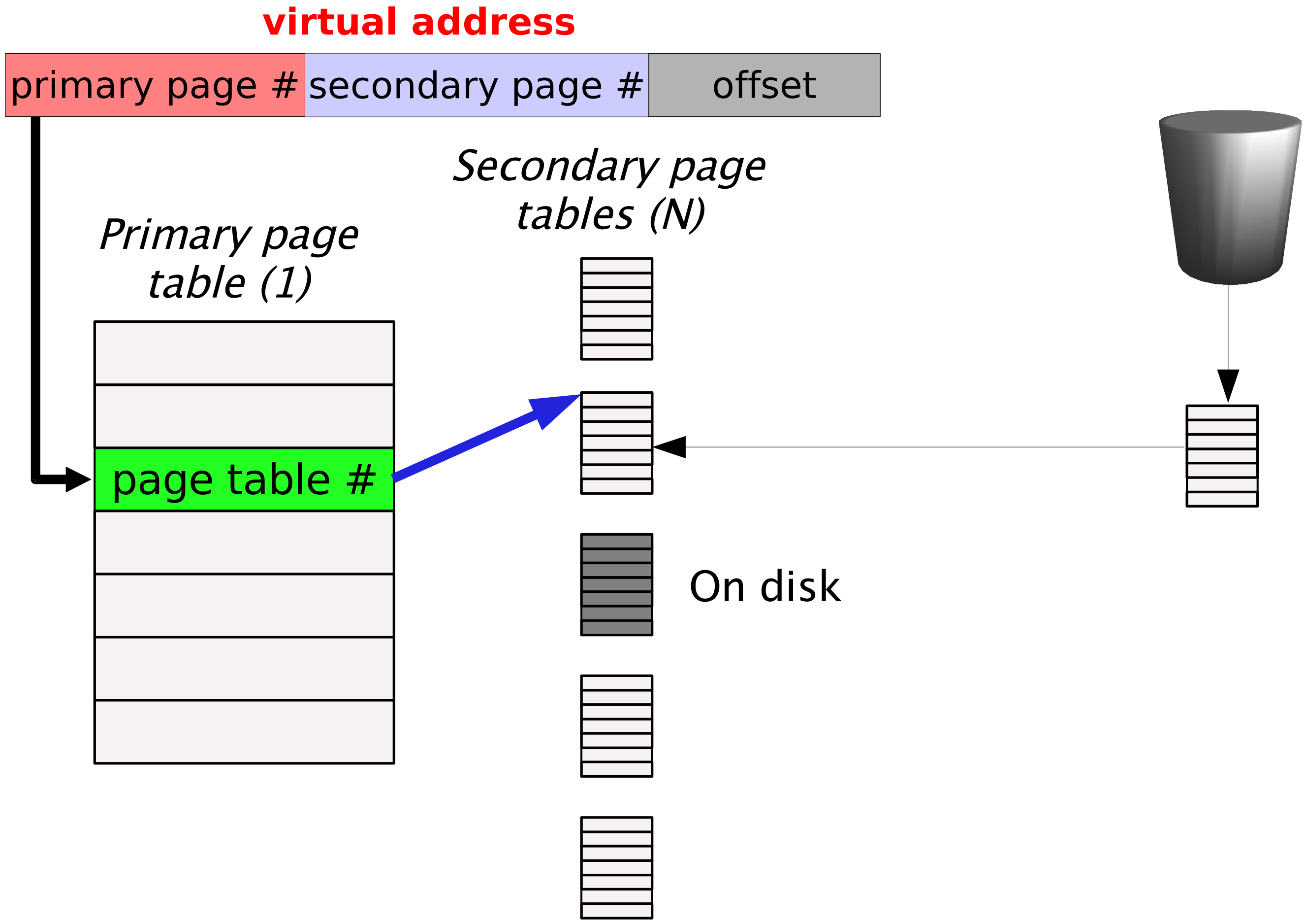

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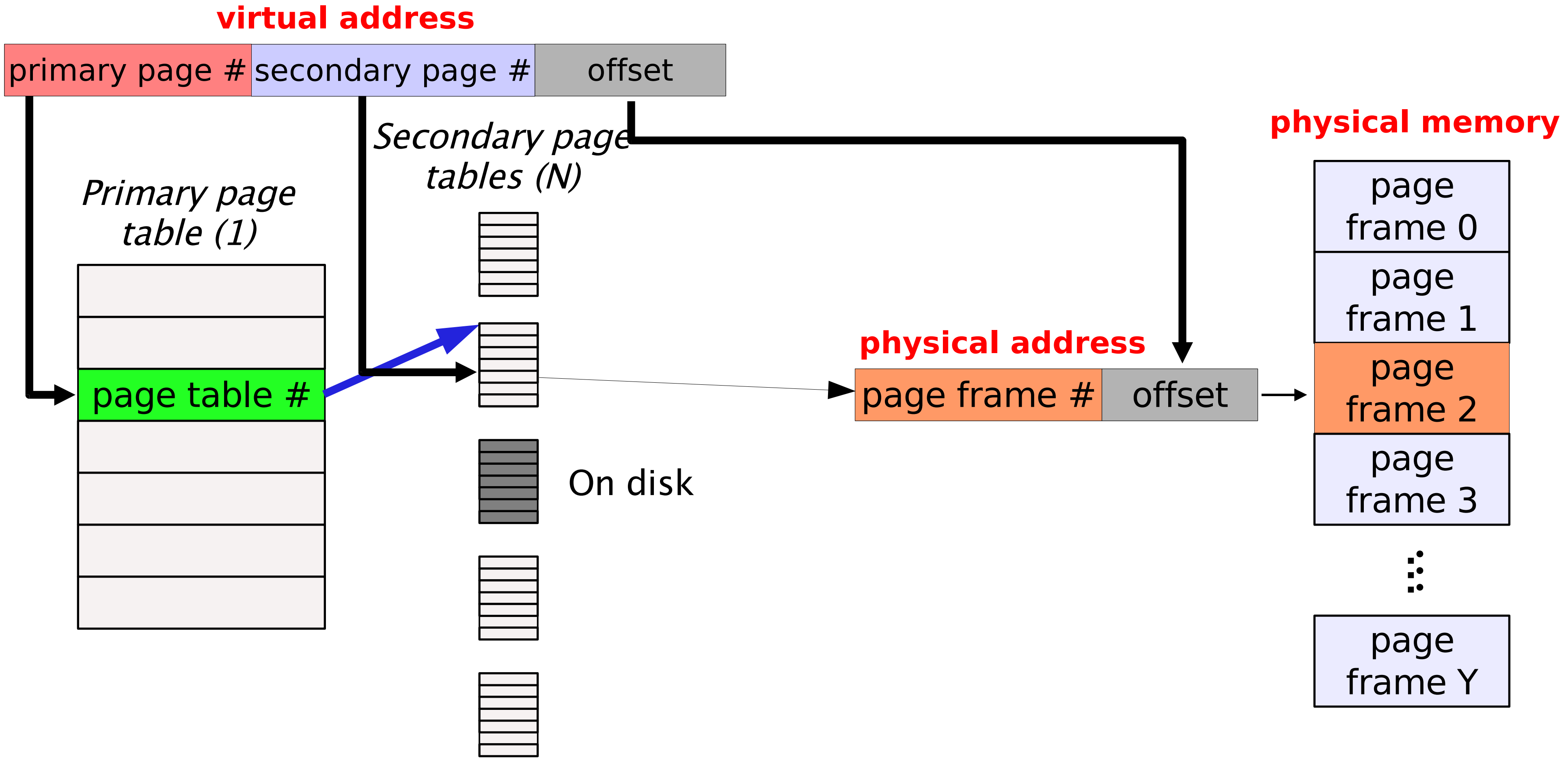

Multilevel page tables

With two levels of page tables, how big is each table?

- Say we allocate 10 bits to the primary page, 10 bits to the secondary page, 12 bits to the page offset
- Primary page table is then 2^10 * 4 bytes per PTE == 4 KB
- Secondary page table is also 4 KB
  - *Hey ... that's exactly the size of a page on most systems ... cool*

What happens on a page fault?

- MMU looks up index in primary page table to get secondary page table
  - *Assume this is “wired” to physical memory*
- MMU tries to access secondary page table
  - *May result in another page fault to load the secondary table!*
- MMU looks up index in secondary page table to get PFN
- CPU can then access physical memory address

Issues

- Page translation has very high overhead
  - *Up to three memory accesses plus two disk I/Os!!*
- TLB usage is clearly very important.

Next Lecture

Page Replacement Policies

- How do we decide which pages to kick out to disk?
- How do we bring kicked out pages back into memory?