

CSC 252: Computer Organization

Spring 2023: Lecture 18

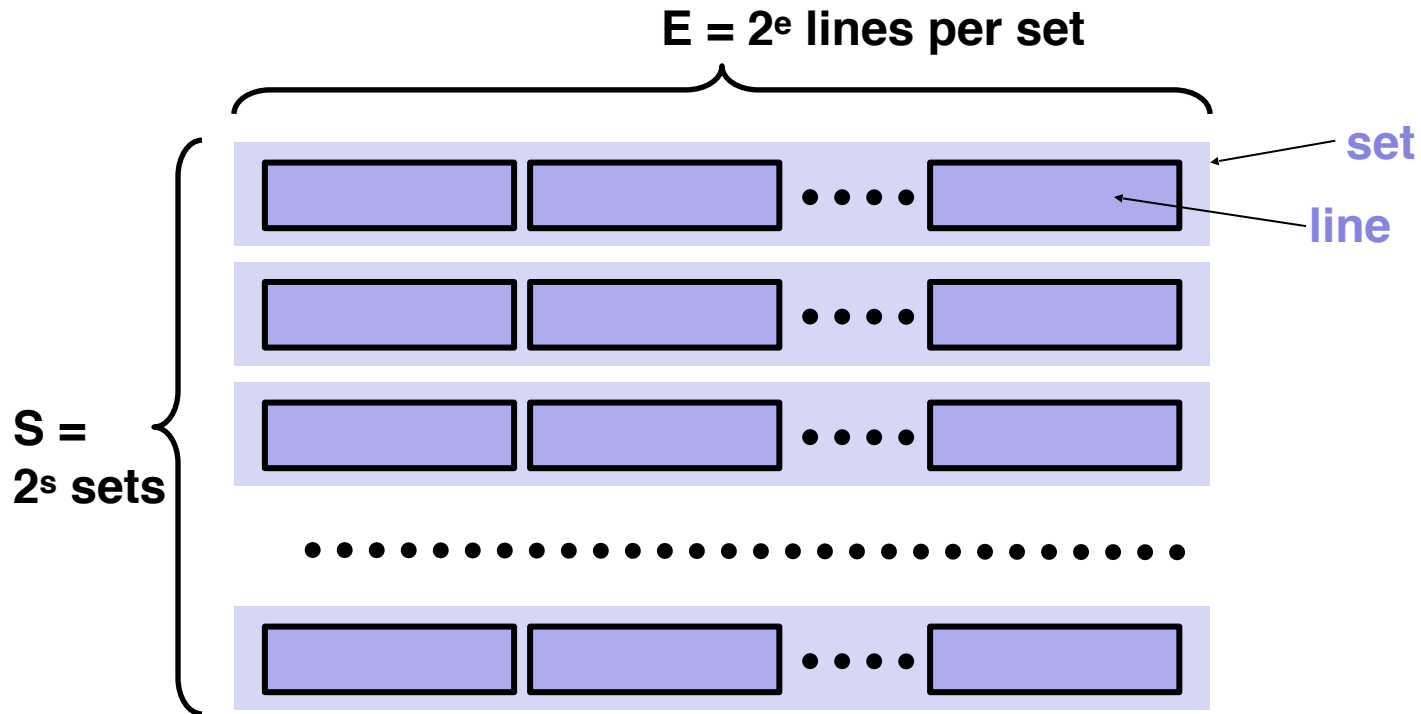
Instructor: Yuhao Zhu

Department of Computer Science
University of Rochester

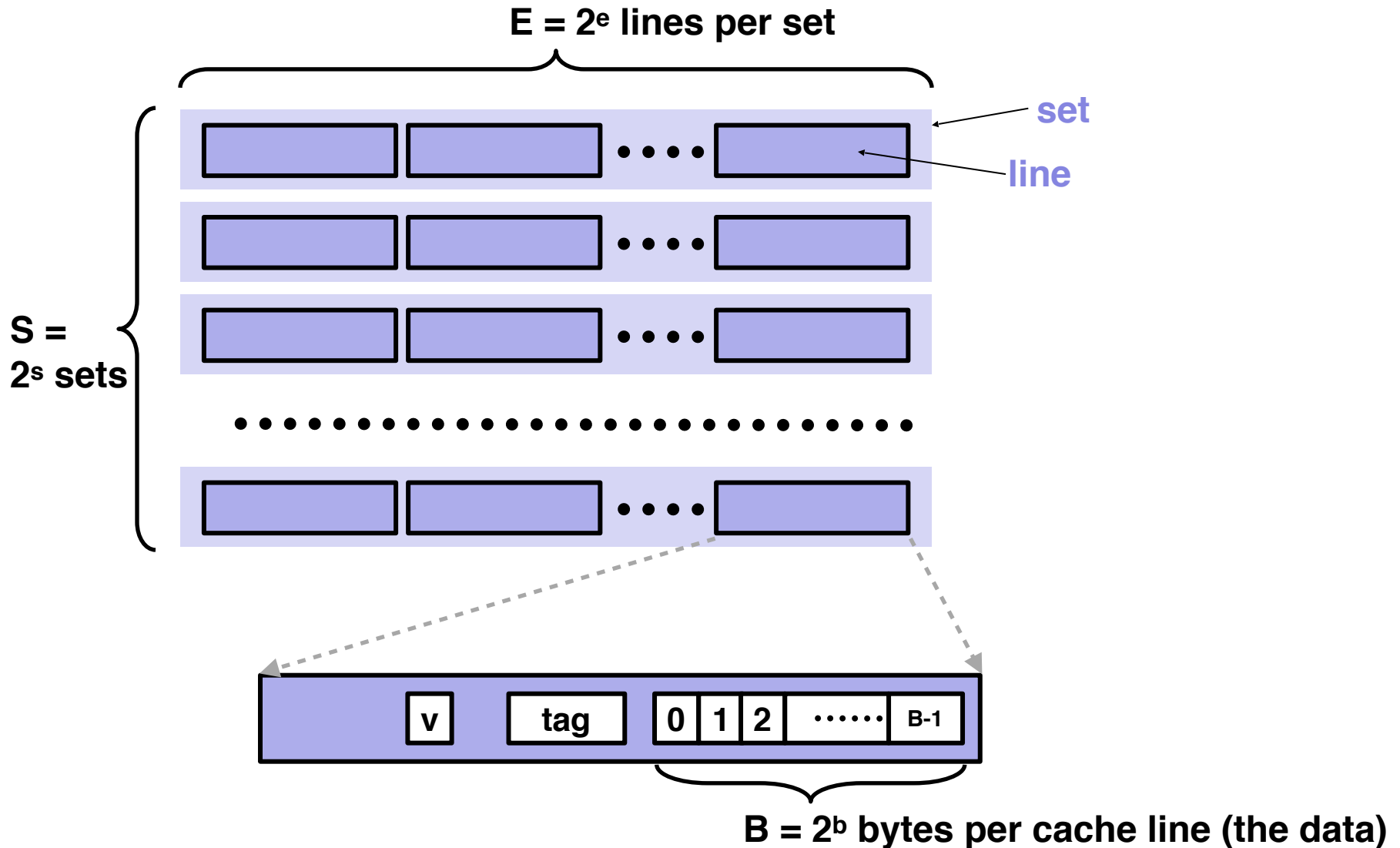
Announcements

- Cache problem set: <https://www.cs.rochester.edu/courses/252/spring2023/handouts.html>
- Not to be turned in. Won't be graded.
- Assignment 4 soon to be released later today.
 - Due April 6.
- I will not be here on Friday; watch the video from last year. More details later through Blackboard announcement.
- Mid-term solution posted: <https://www.cs.rochester.edu/courses/252/spring2023/handouts.html>

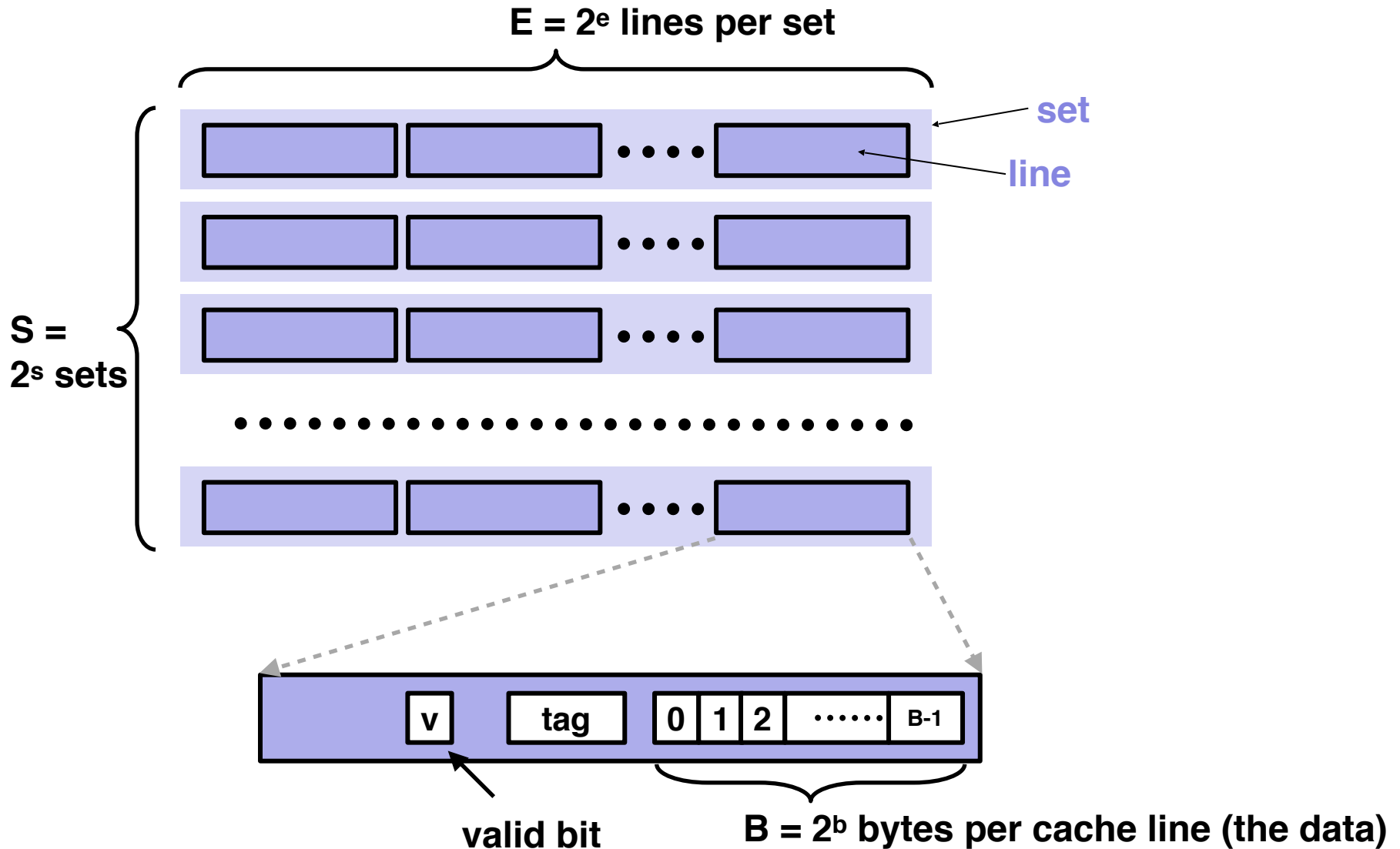
General Cache Organization (S, E, B)



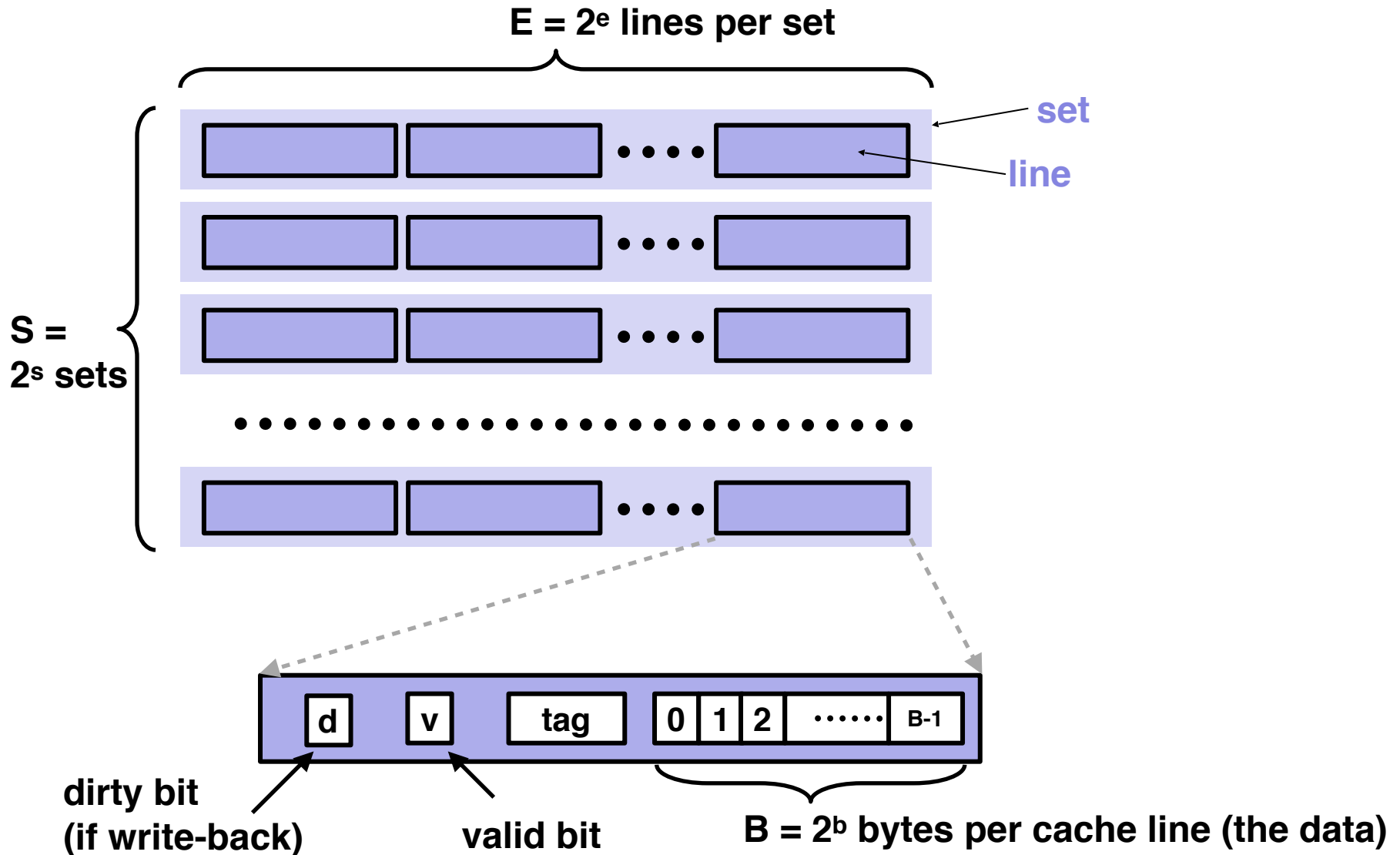
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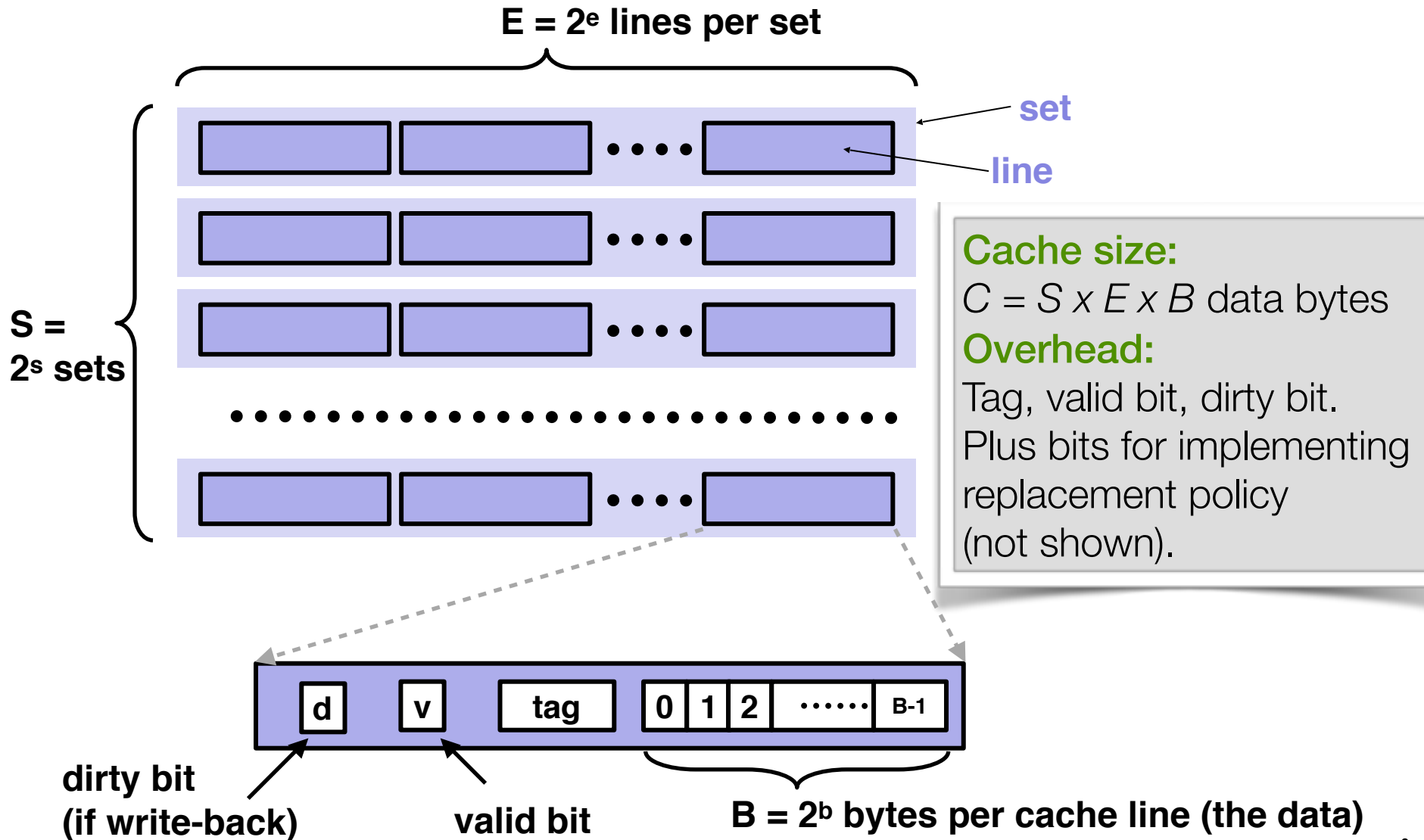
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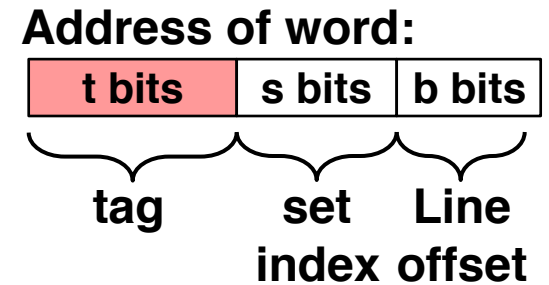
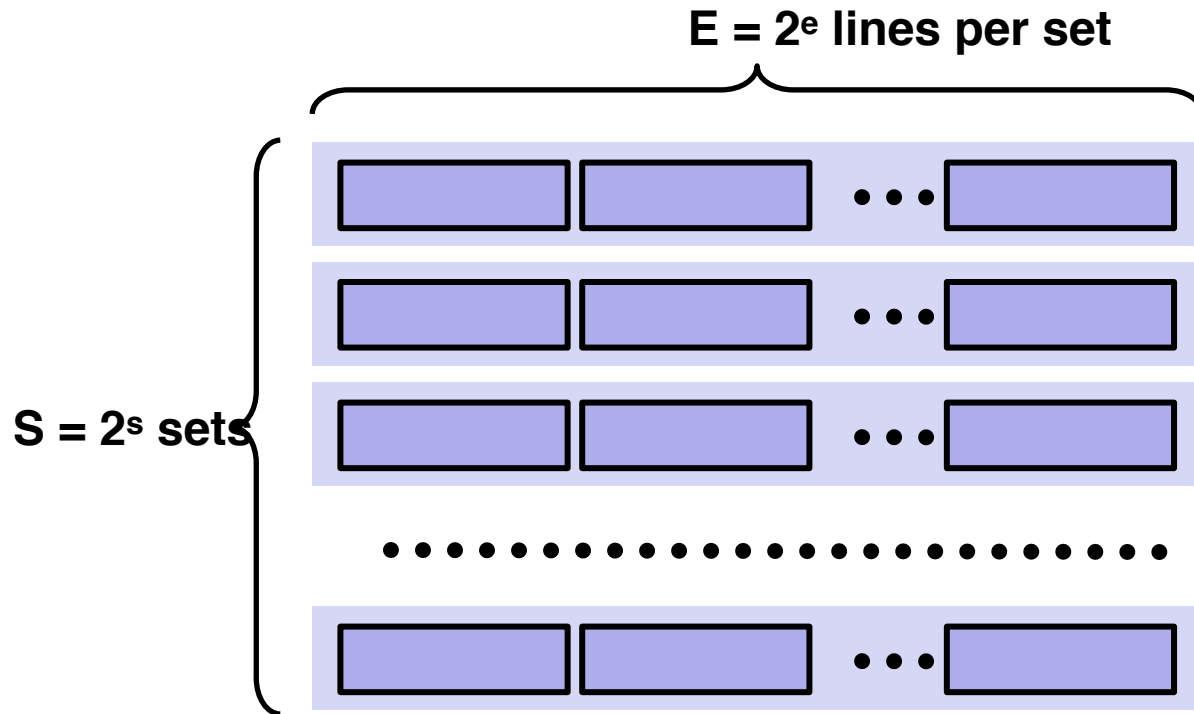
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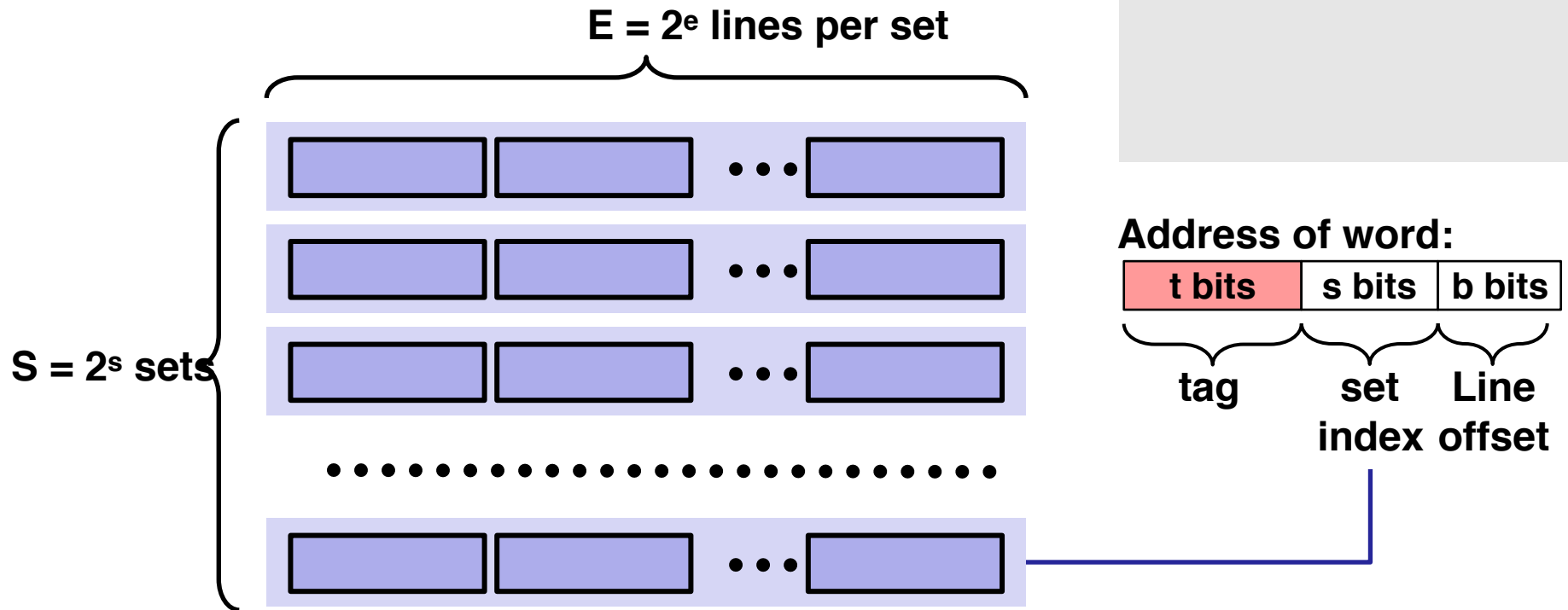


Cache Access



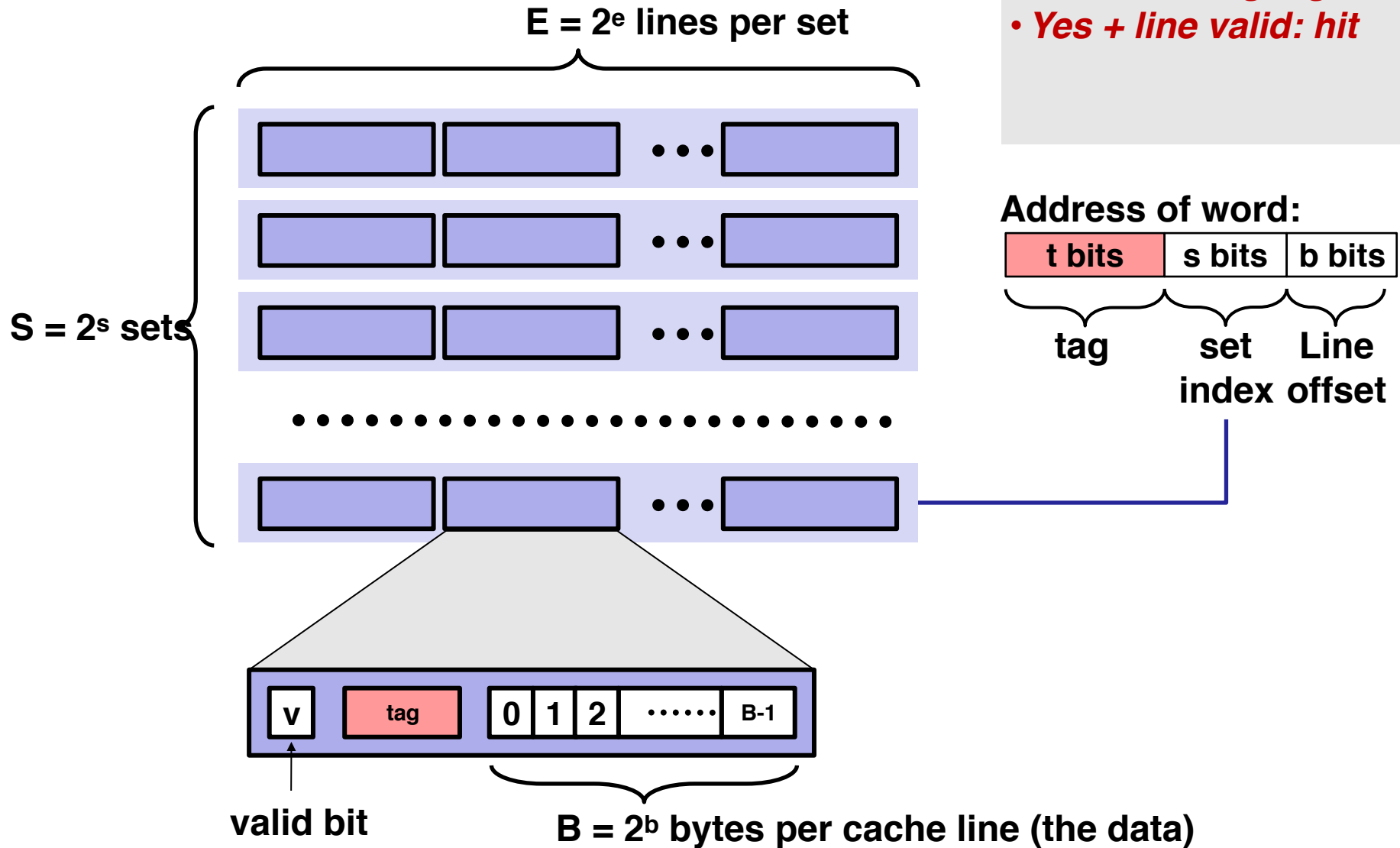
Cache Access

- *Locate set*



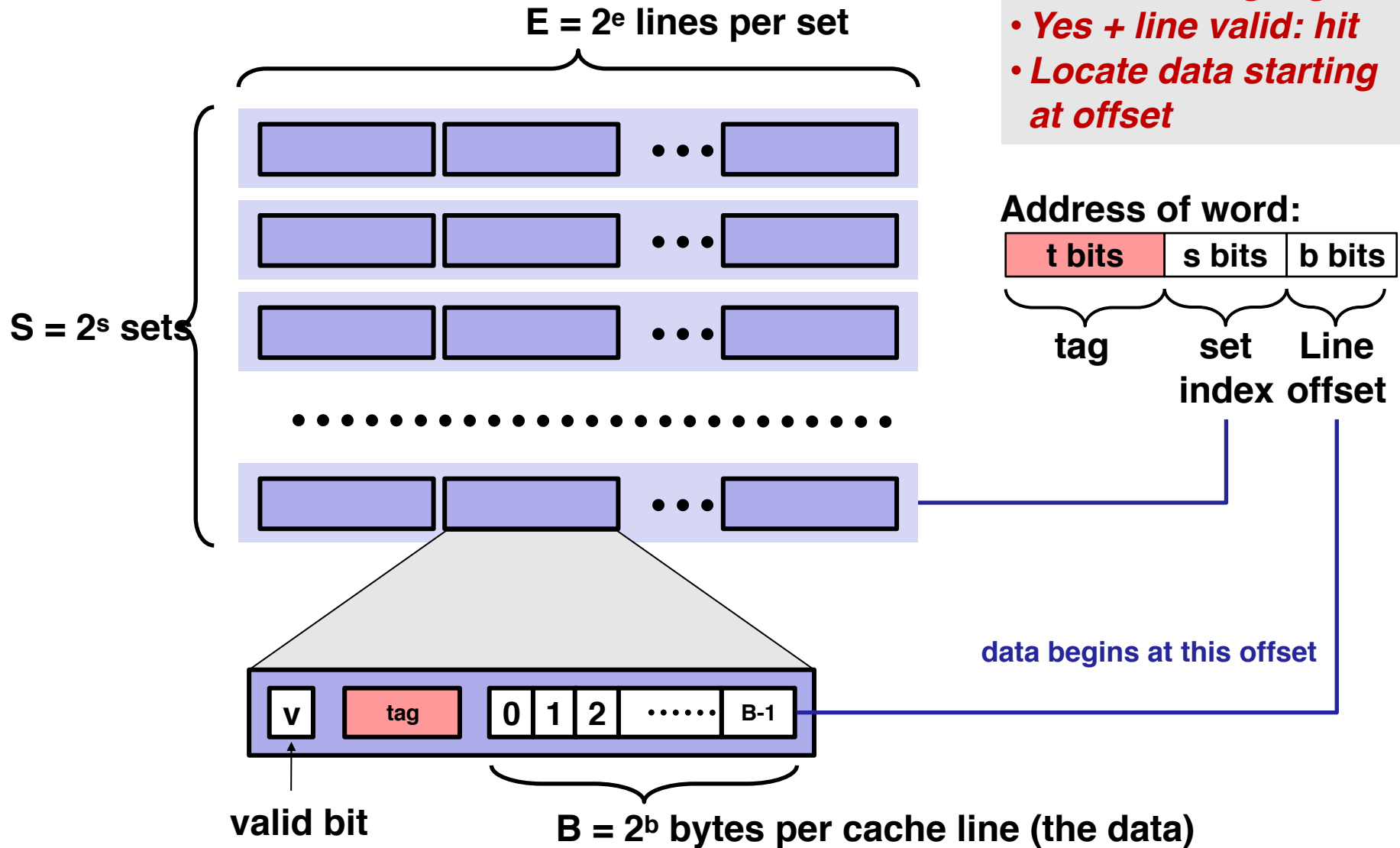
Cache Access

- *Locate set*
- *Check if any line in set has matching tag*
- *Yes + line valid: hit*



Cache Access

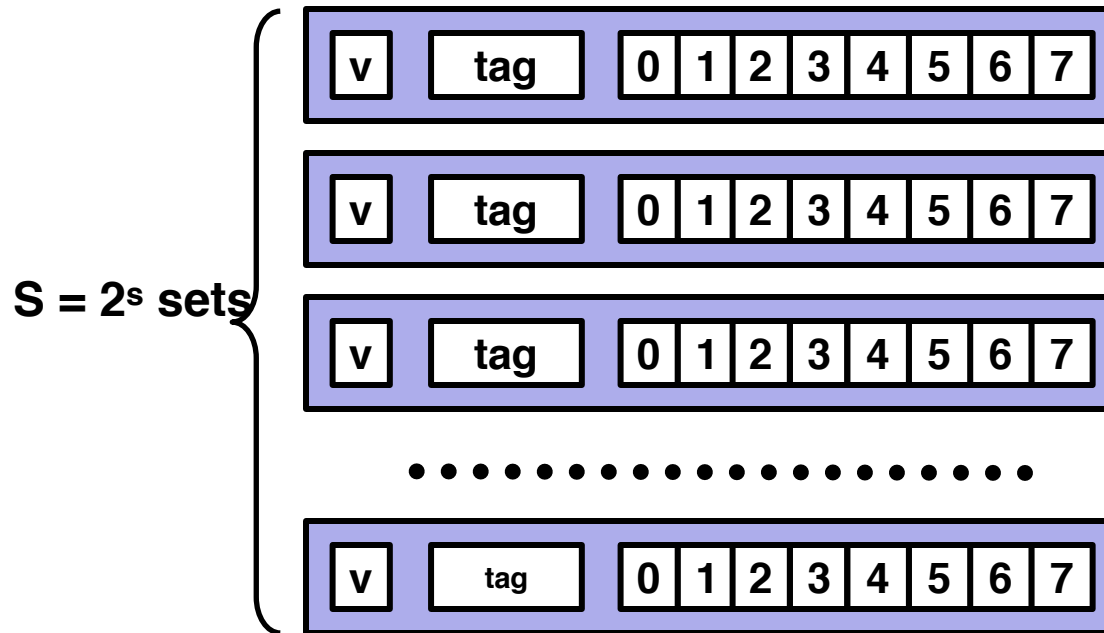
- *Locate set*
- *Check if any line in set has matching tag*
- *Yes + line valid: hit*
- *Locate data starting at offset*



Example: Direct Mapped Cache

Direct mapped: One line per set

Assume: cache line size 8 bytes



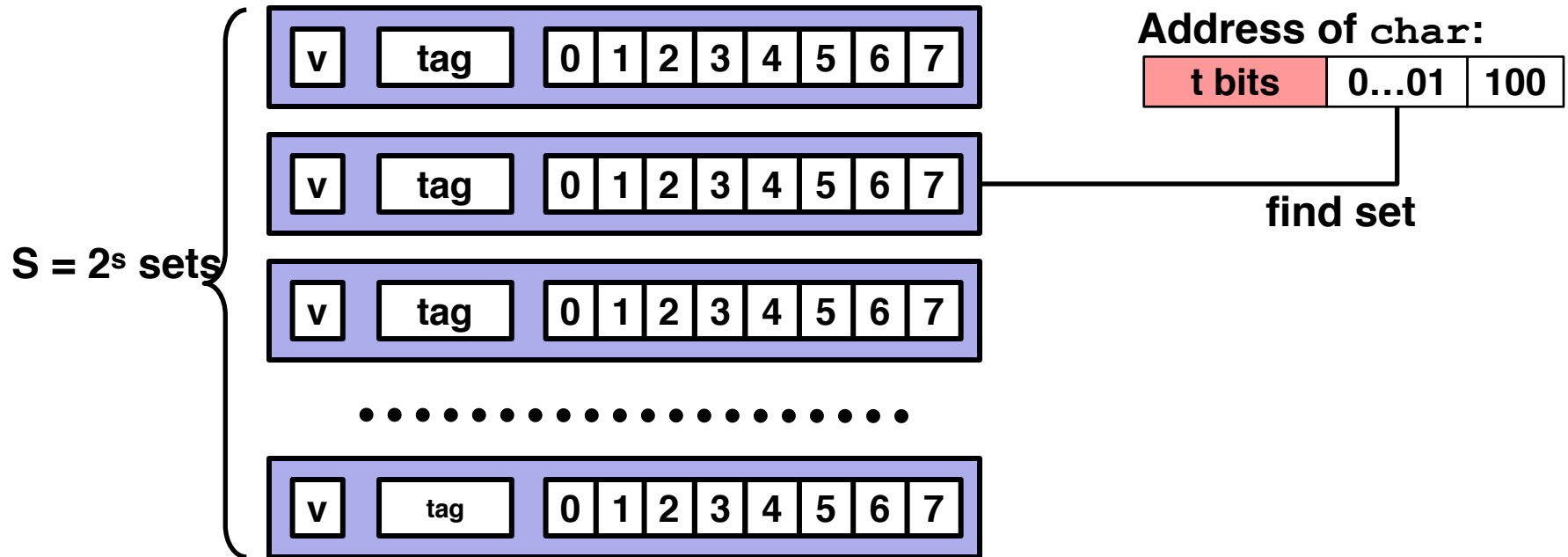
Address of char:

t bits	0...01	100
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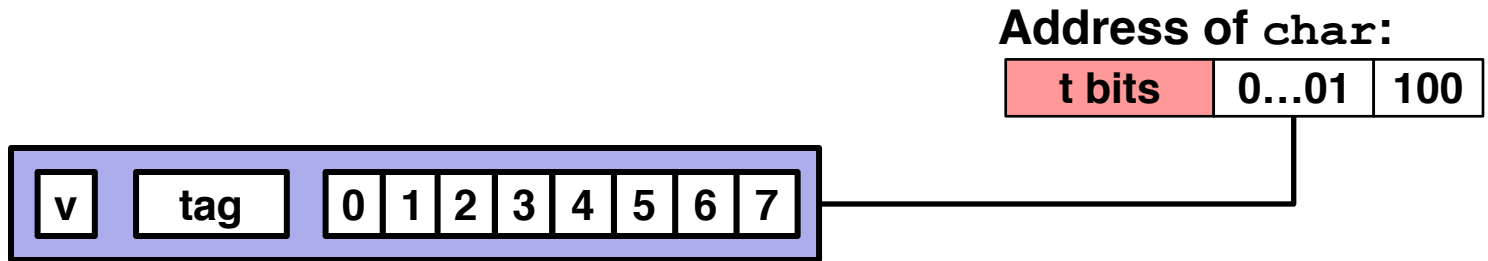
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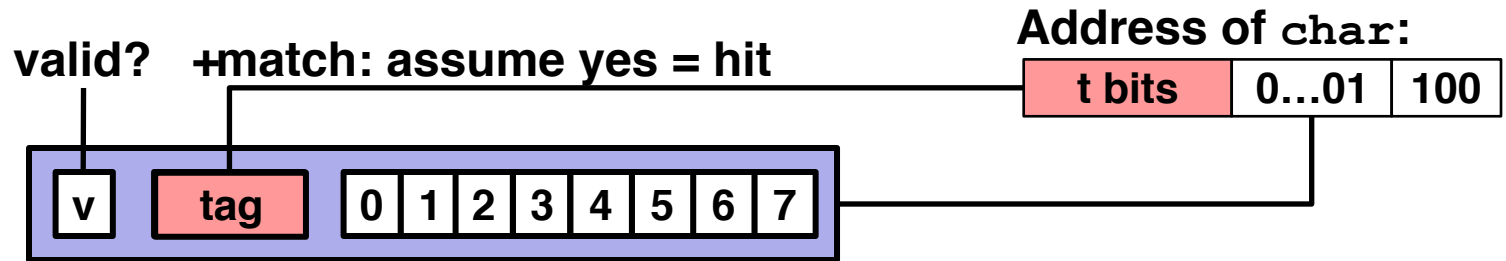
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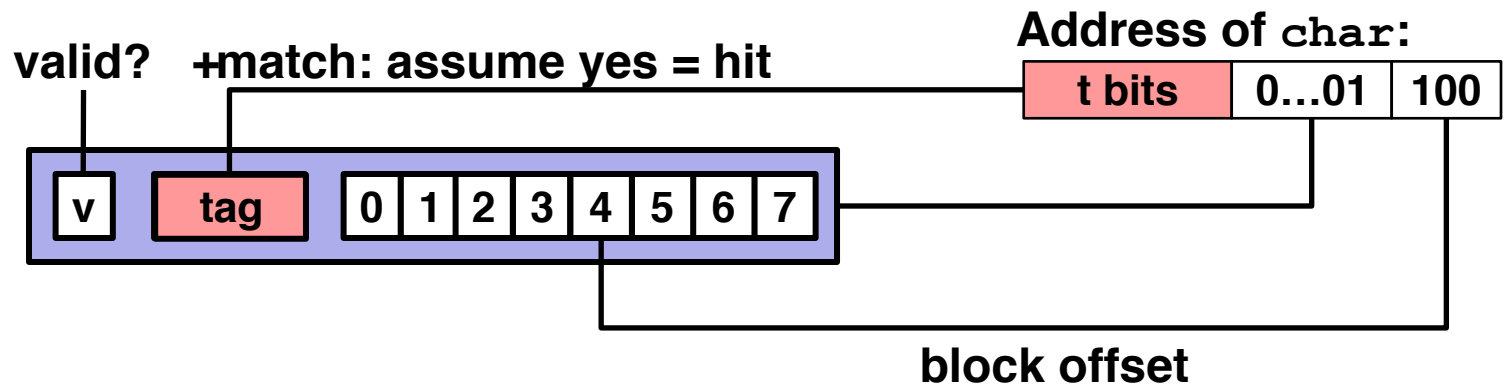
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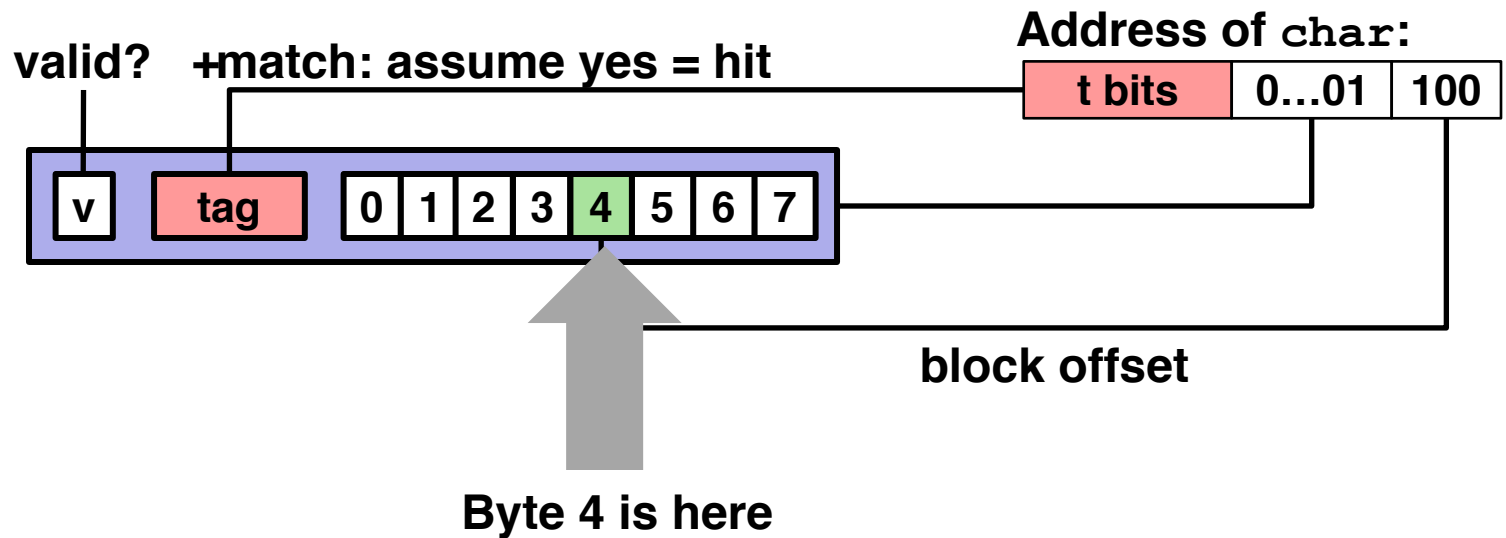
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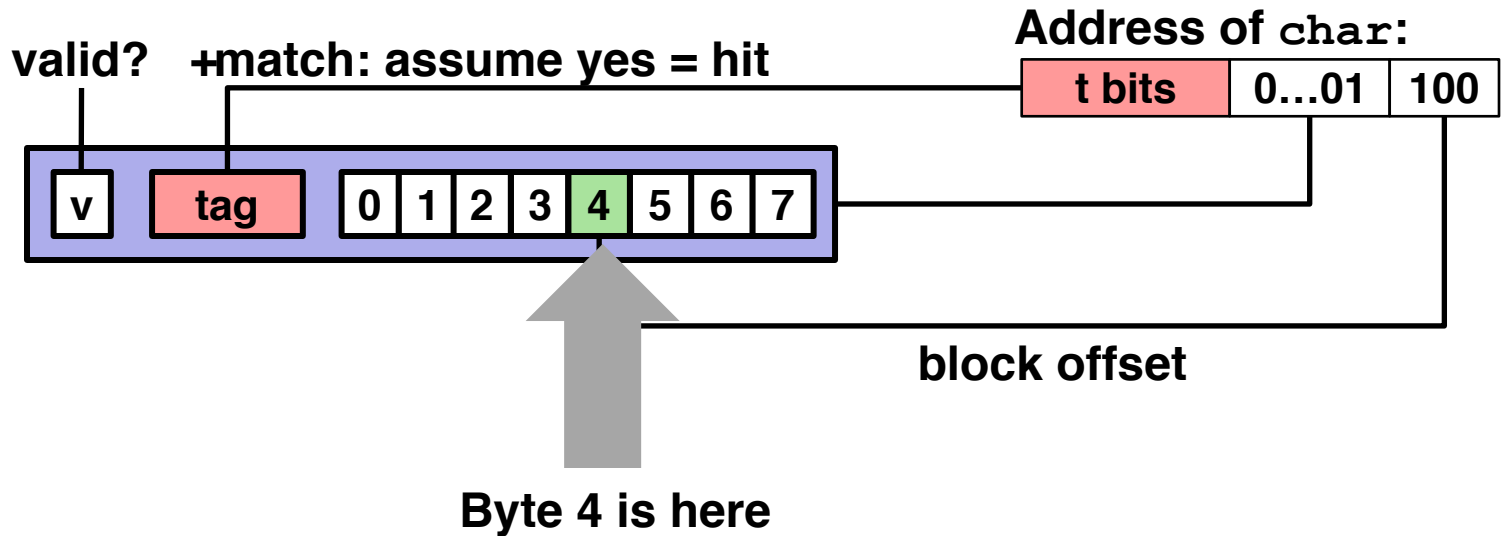
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If tag doesn't match: old line is evicted and replaced

Direct-Mapped Cache Simulation

t=1	s=2	b=1
x	xx	x

4-bit address space, i.e., Memory = 16 bytes

B=2 bytes/line, S=4 sets, E=1 line/set

Address trace (reads, one byte per read):

0 [0000]₂,
 1 [0001]₂,
 7 [0111]₂,
 8 [1000]₂,
 0 [0000]₂

	v	Tag	Line
Set 0	0	?	?
Set 1			
Set 2			
Set 3			

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← The two bytes at memory address 0 and 1

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	v	Tag	Line	
Set 0	1	1	M[8-9]	← The two bytes at memory address 8 and 9
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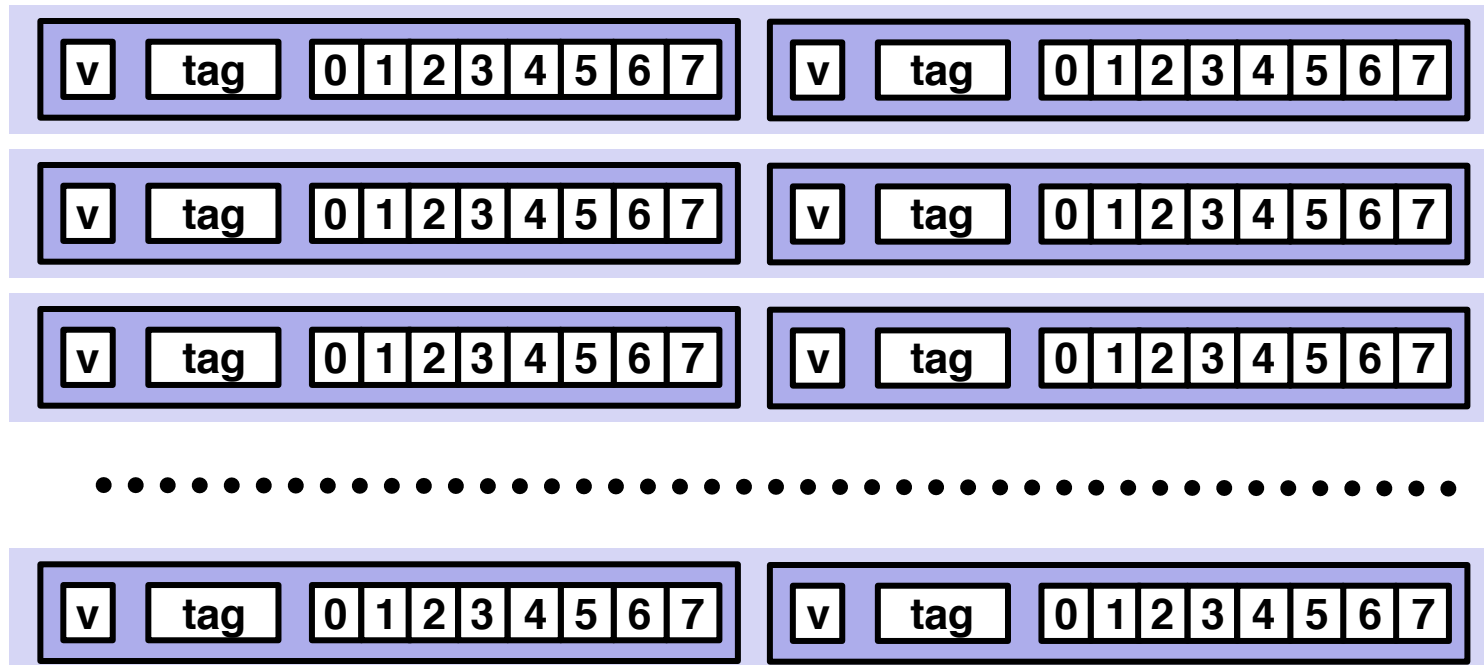
E-way Set Associative Cache (Here: E = 2)

E = 2: Two lines per set

Assume: cache line size 8 bytes

Address of short int:

t bits	0...01	100
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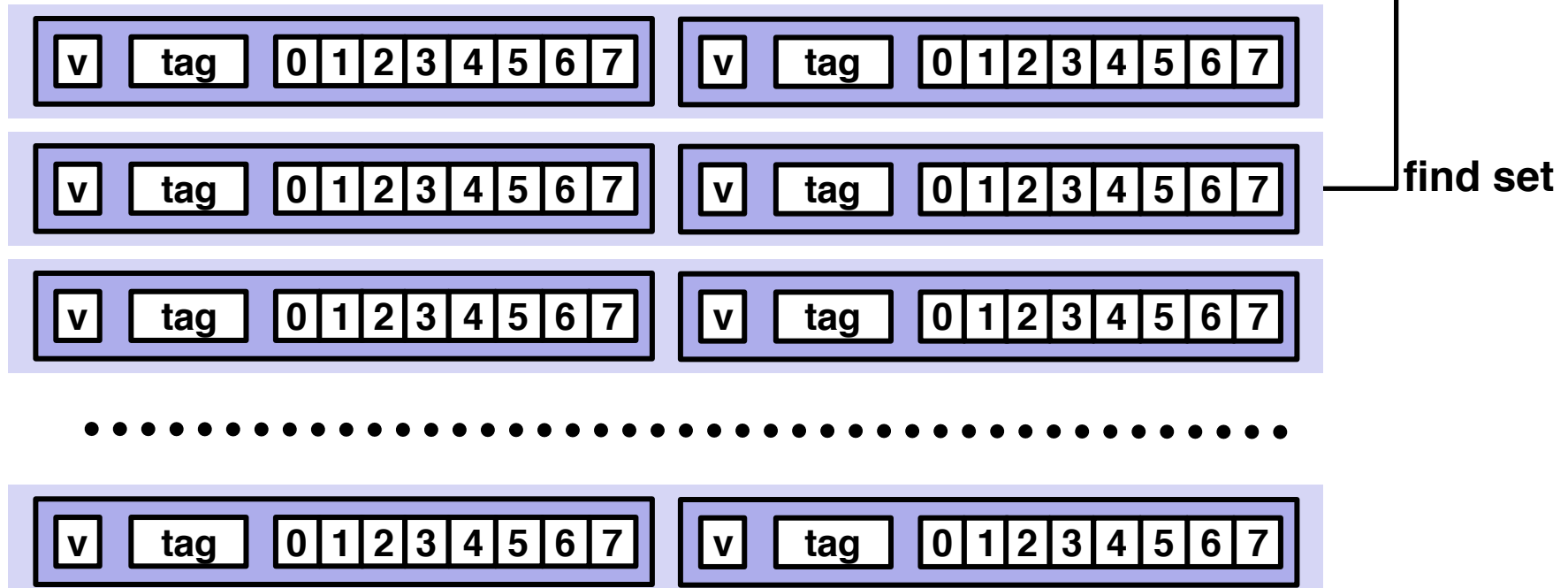
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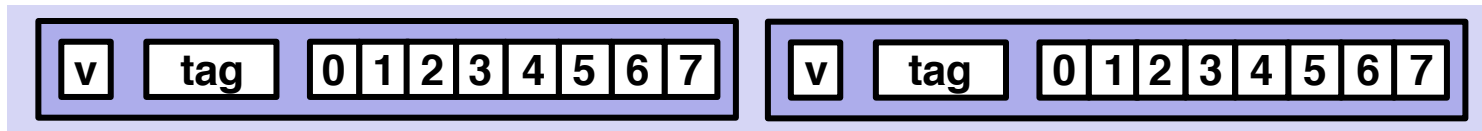
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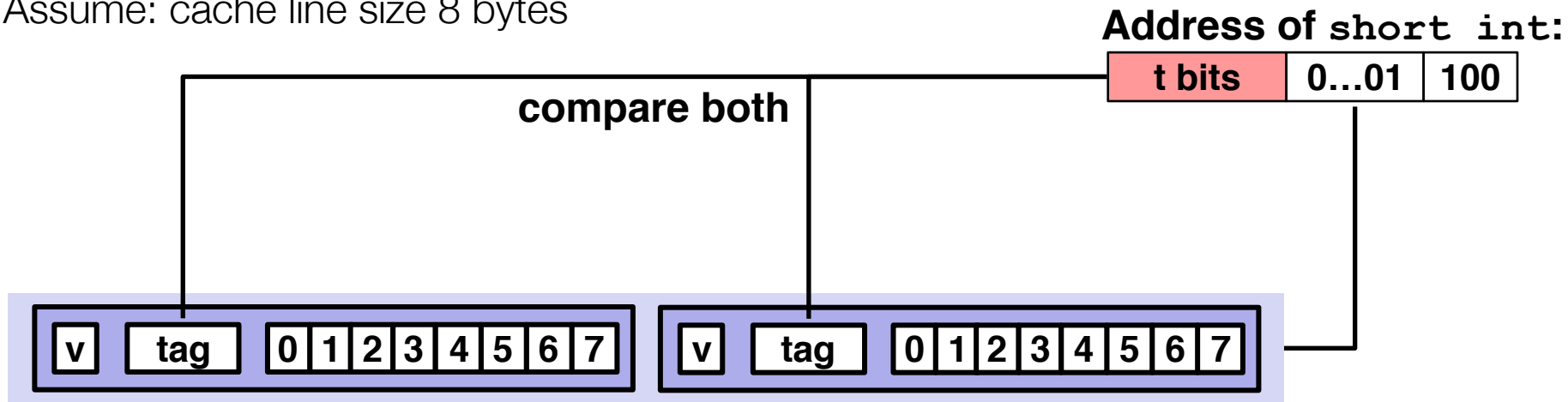
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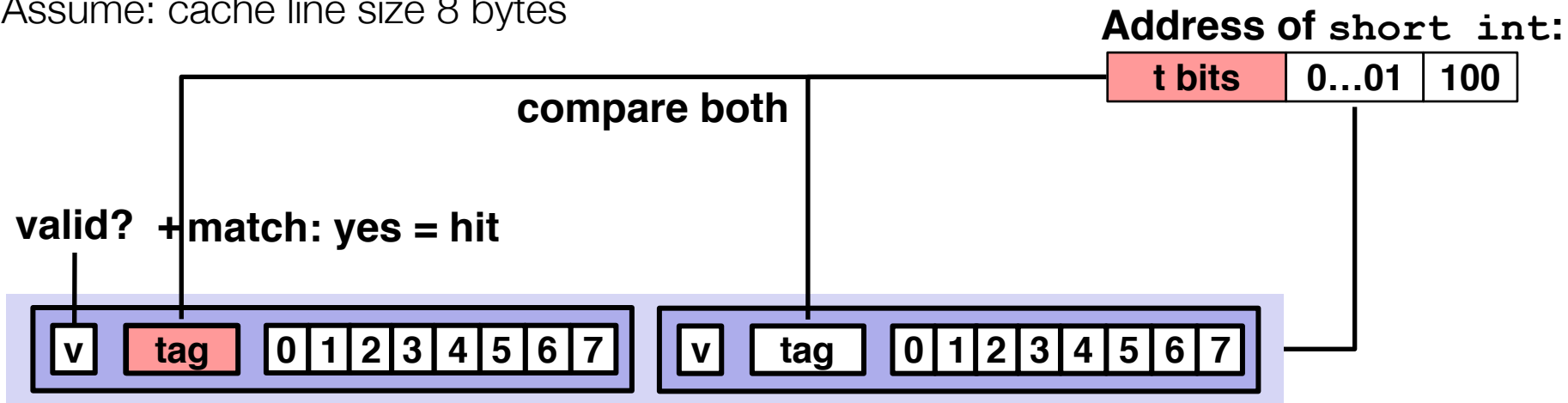
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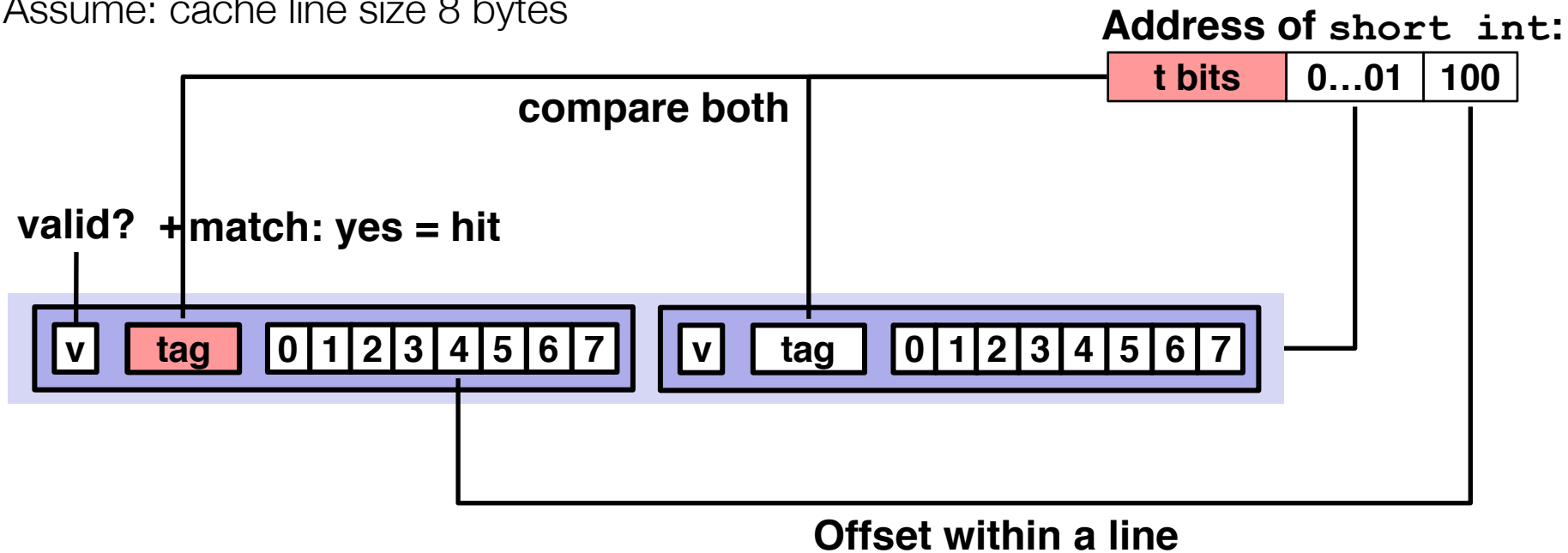
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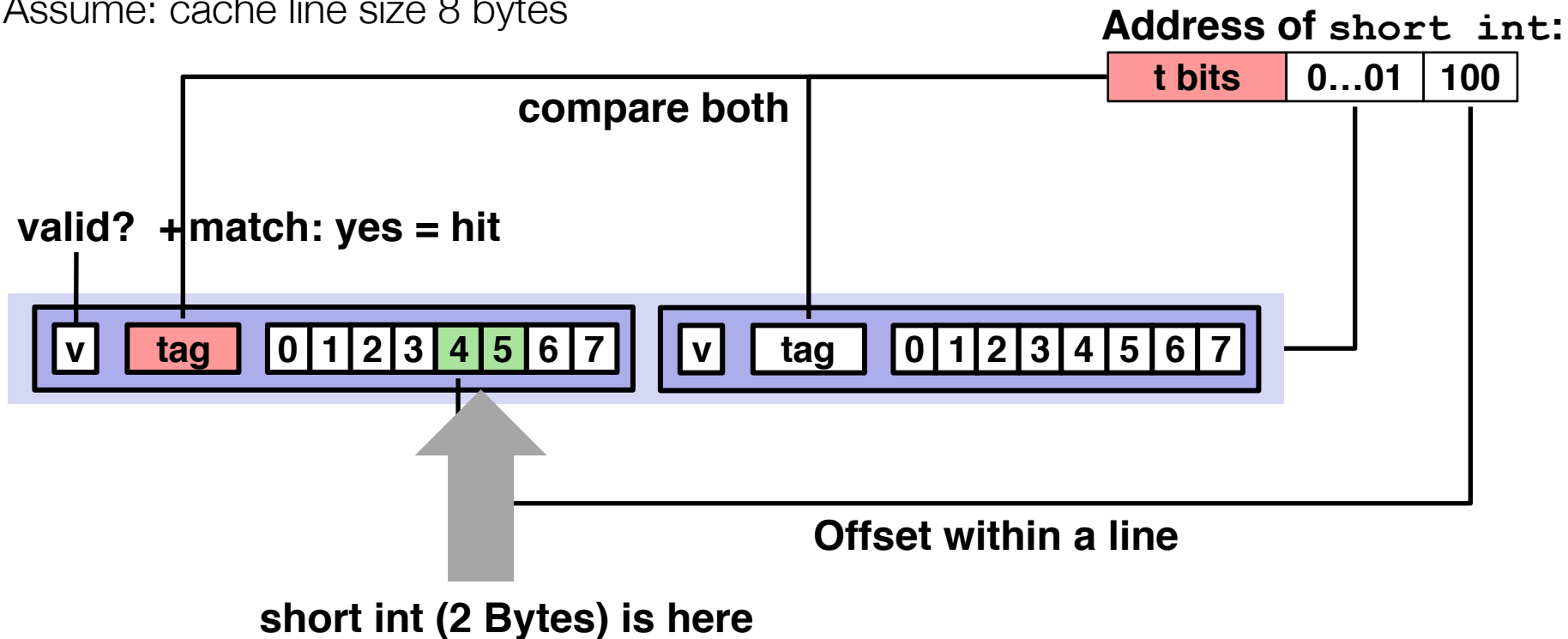
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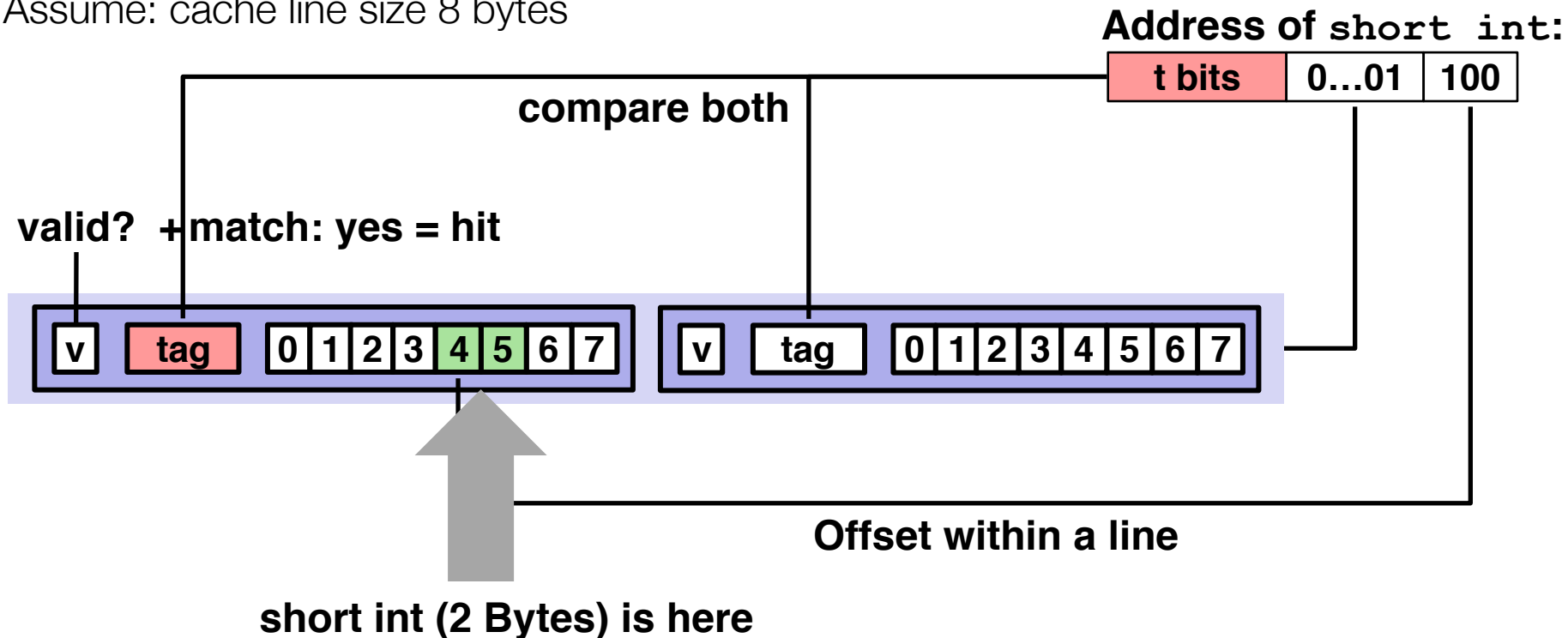
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No match:

- One line in set is selected for eviction and replacement
- Replacement policies: random, least recently used (LRU),

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Today

- Processes and Signals: running multiple programs concurrently
 - Processes
 - Process Control
 - Signals

Processes

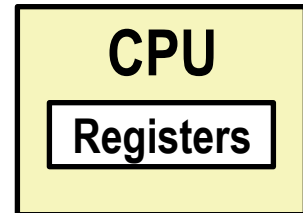
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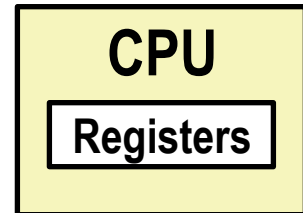
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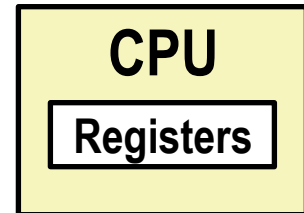
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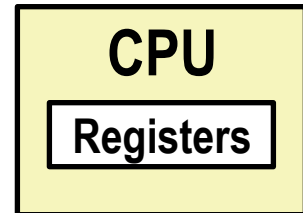
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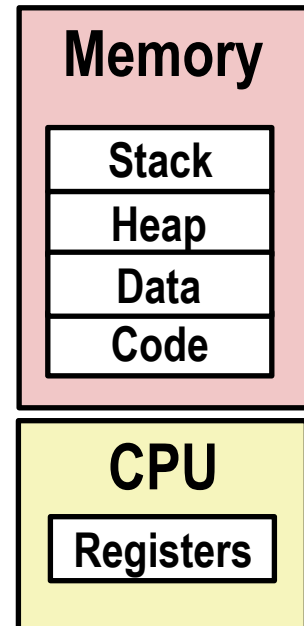
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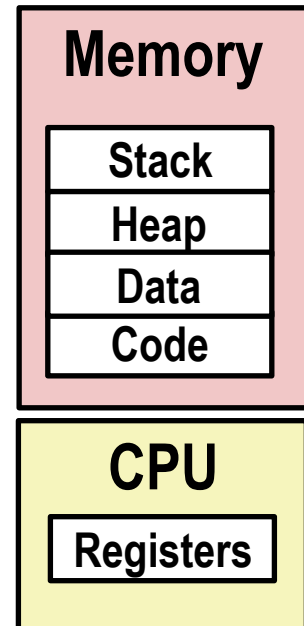
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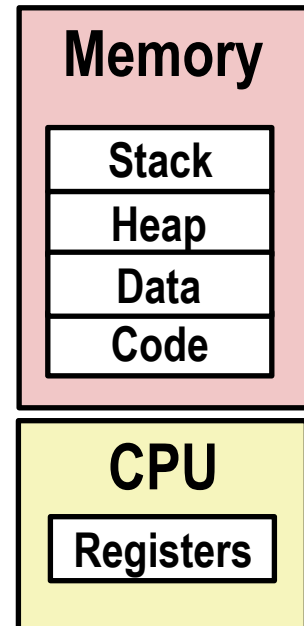
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 - One of the most profound ideas in computer science
 - Not the same as “program” or “processor”
- Process provides each program with two key abstractions:
 - *“Owns” the CPU*
 - Each program seems to have exclusive use of the CPU
 - Done by the OS kernel through “context switching”
 - *Private address space*
 - Each program seems to have exclusive use of main memory.

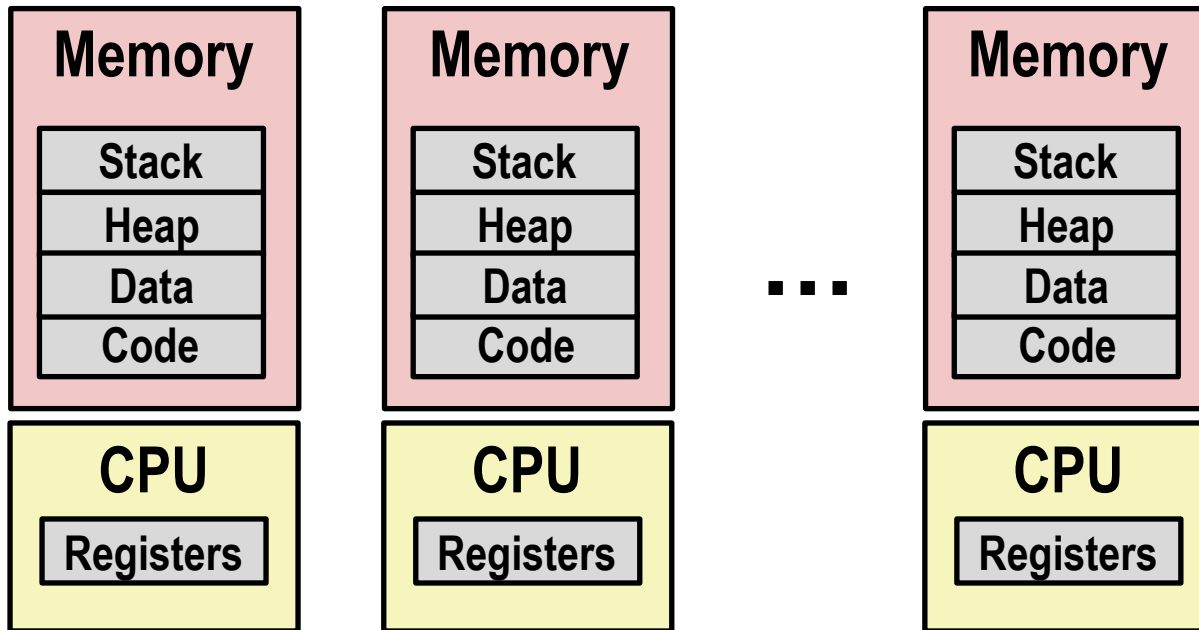


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 - Each program seems to have exclusive use of main memory.
 - Provided by OS through “virtual memory”



Multiprocessing: The Illusion



- Computer runs many processes simultaneously
 - Applications for one or more users
 - Web browsers, email clients, editors, ...
 - Background tasks
 - Monitoring network & I/O devices

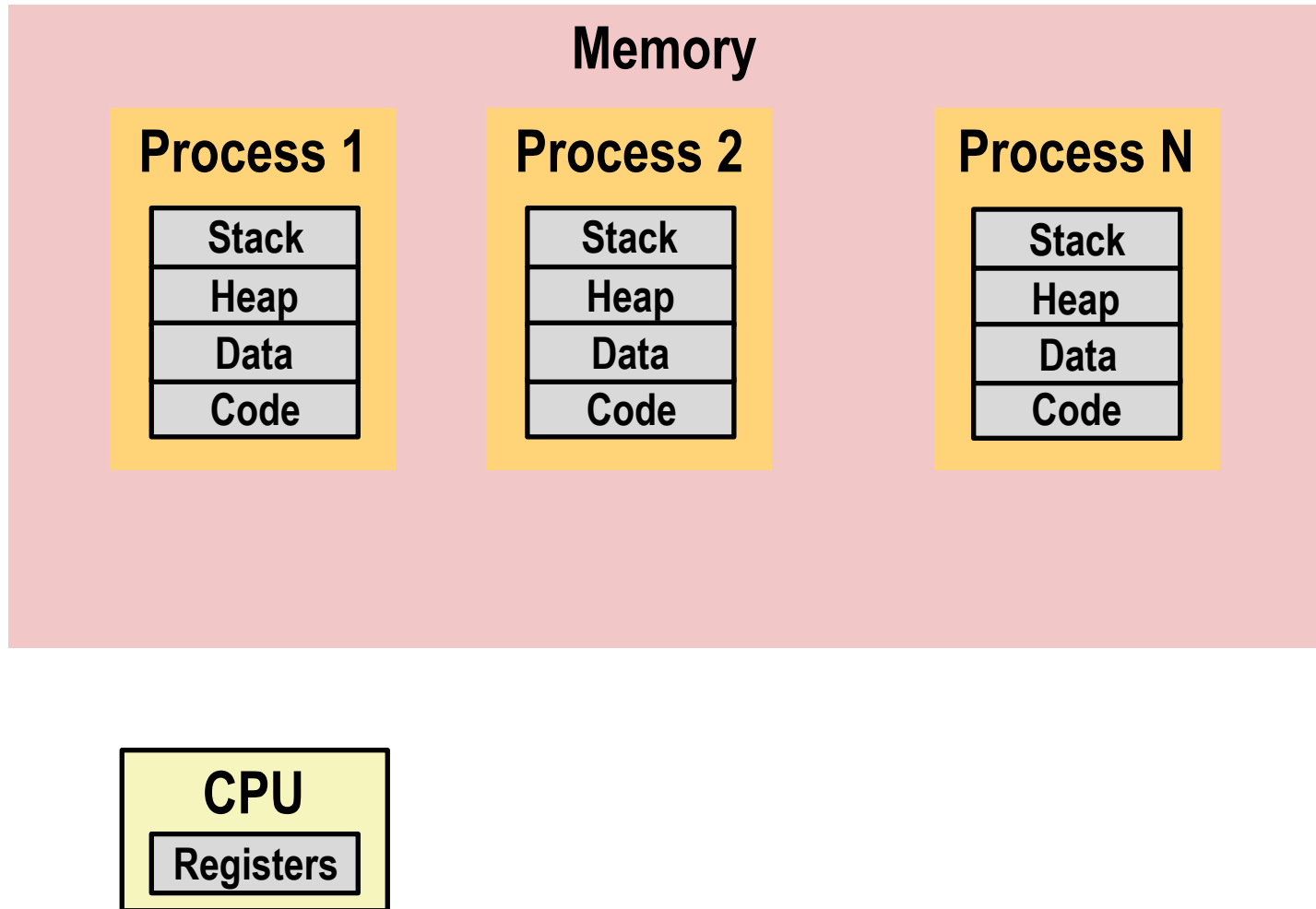
Multiprocessing Example

```
Processes: 123 total, 5 running, 9 stuck, 109 sleeping, 611 threads
Load Avg: 1.03, 1.13, 1.14  CPU usage: 3.27% user, 5.15% sys, 91.56% idle
SharedLibs: 576K resident, 0B data, 0B linkedit.
MemRegions: 27958 total, 1127M resident, 35M private, 494M shared.
PhysMem: 1039M wired, 1974M active, 1062M inactive, 4076M used, 18M free.
VM: 280G vsize, 1091M framework vsize, 23075213(1) pageins, 5843367(0) pageouts.
Networks: packets: 41046228/11G in, 66083096/77G out.
Disks: 17874391/349G read, 12847373/594G written.

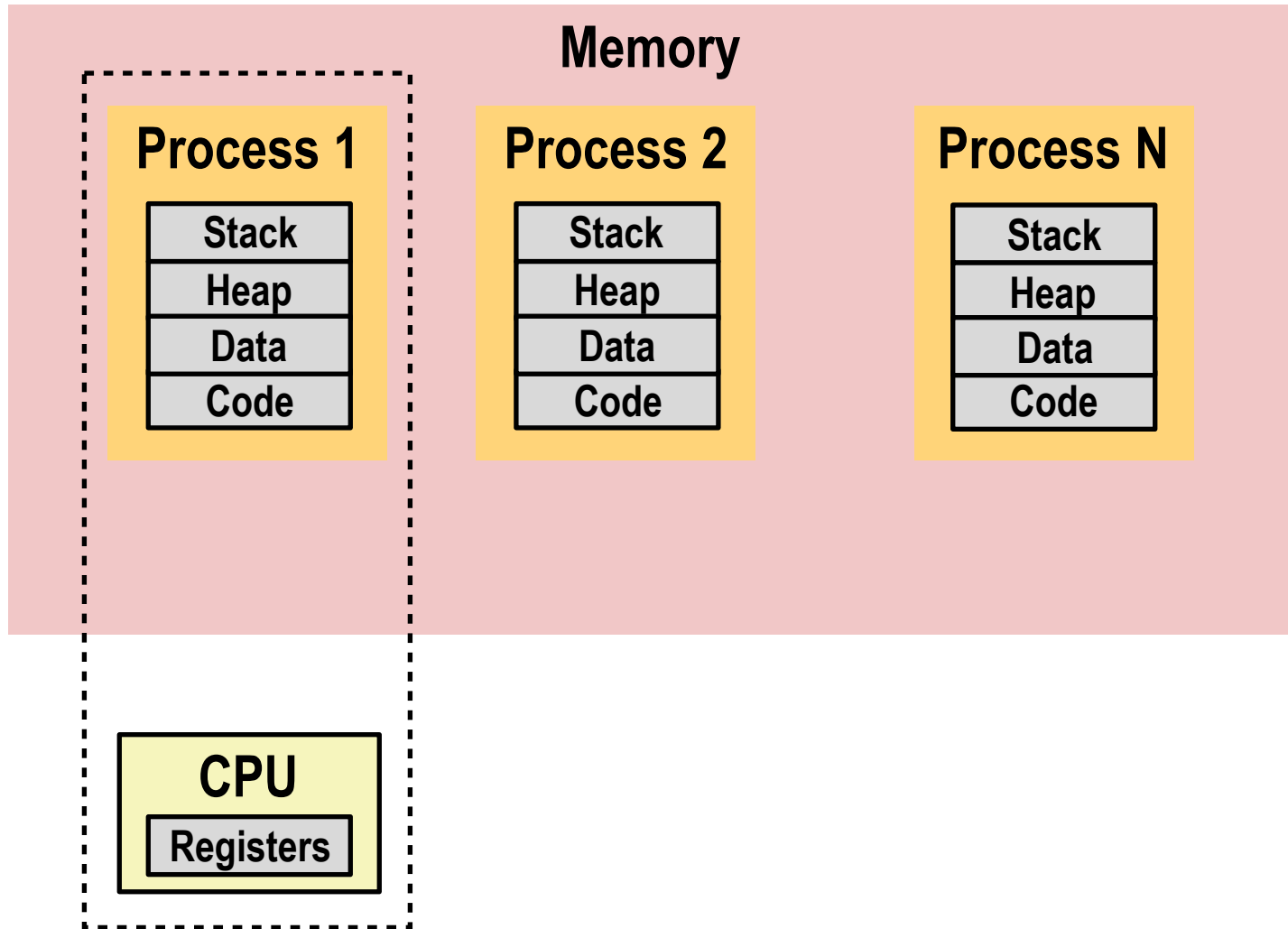
PID    COMMAND      %CPU TIME    #TH    #WQ    #PORT #MREG RPRVT  RSHRD  RSIZE  VPRVT  VSIZE
99217-  Microsoft Of 0.0 02:28.34 4      1      202  418   21M   24M   21M   66M   763M
99051   usbmuxd      0.0 00:04.10 3      1      47    66    436K  216K  480K  60M   2422M
99006   iTunesHelper 0.0 00:01.23 2      1      55    78    728K  3124K 1124K 43M   2429M
84286   bash         0.0 00:00.11 1      0      20    24    224K  732K  484K  17M   2378M
84285   xterm        0.0 00:00.83 1      0      32    73    656K  872K  692K  9728K 2382M
55939-  Microsoft Ex 0.3 21:58.97 10     3      360   954   16M   65M   46M   114M  1057M
54751   sleep        0.0 00:00.00 1      0      17    20    92K   212K  360K  9632K 2370M
54739   launchdadd   0.0 00:00.00 2      1      33    50    488K  220K  1736K 48M   2409M
54737   top          6.5 00:02.53 1/1    0      30    29    1416K 216K  2124K 17M   2378M
54719   automountd   0.0 00:00.02 7      1      53    64    860K  216K  2184K 53M   2413M
54701   ocspd        0.0 00:00.05 4      1      61    54    1268K 2644K 3132K 50M   2426M
54661   Grab         0.6 00:02.75 6      3      222+  389+  15M+  26M+  40M+  75M+  2556M+
54659   cookied      0.0 00:00.15 2      1      40    61    3316K 224K  4088K 42M   2411M
53919   sshd         0.0 00:00.07 1      1      50    81    7696K 7448K 46M   48M   2470M
```

- Running program “top” on Unit/Linux
 - System has 123 processes, 5 of which are active
 - Identified by Process ID (PID)

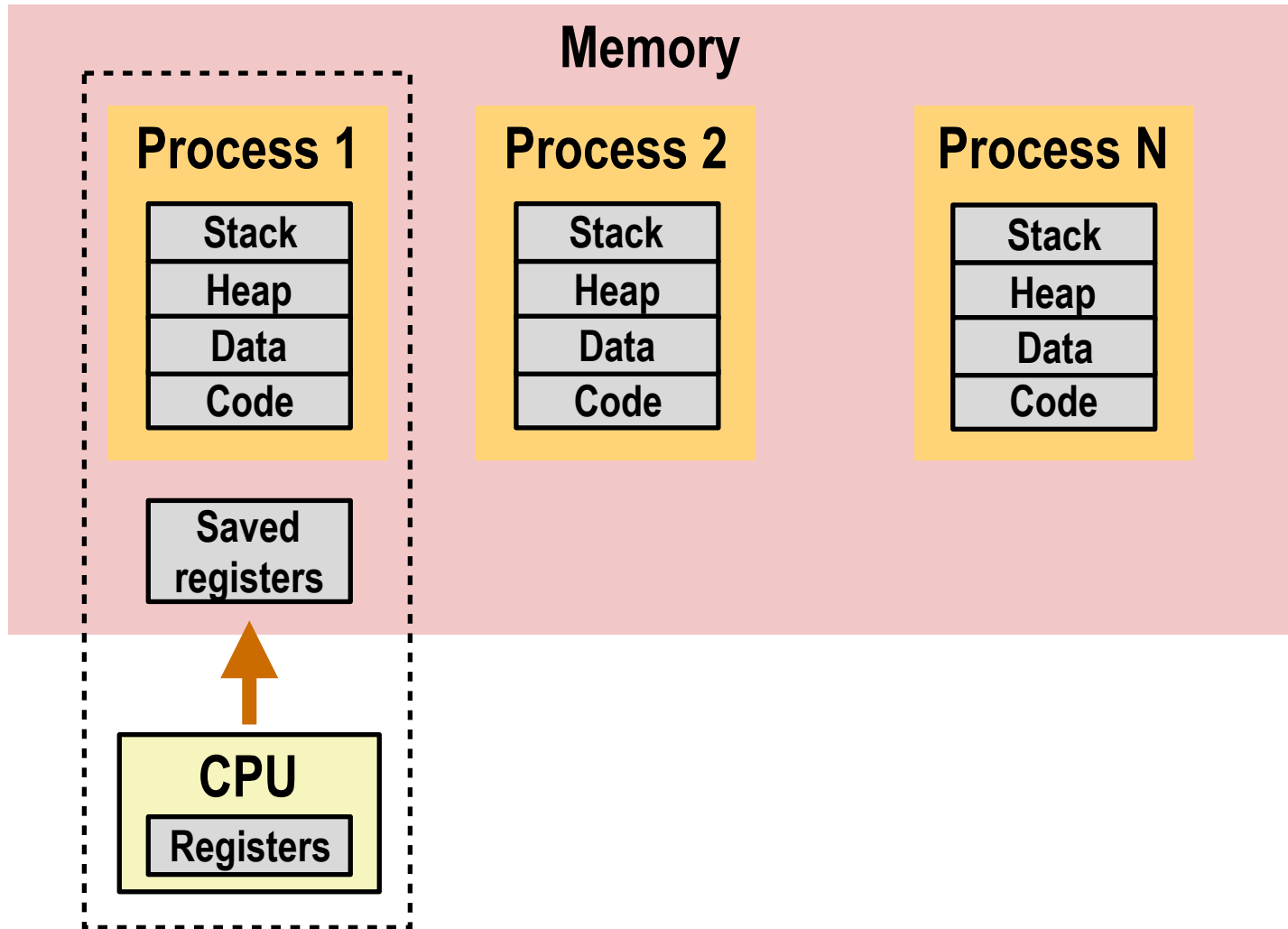
Multiprocessing Illustration



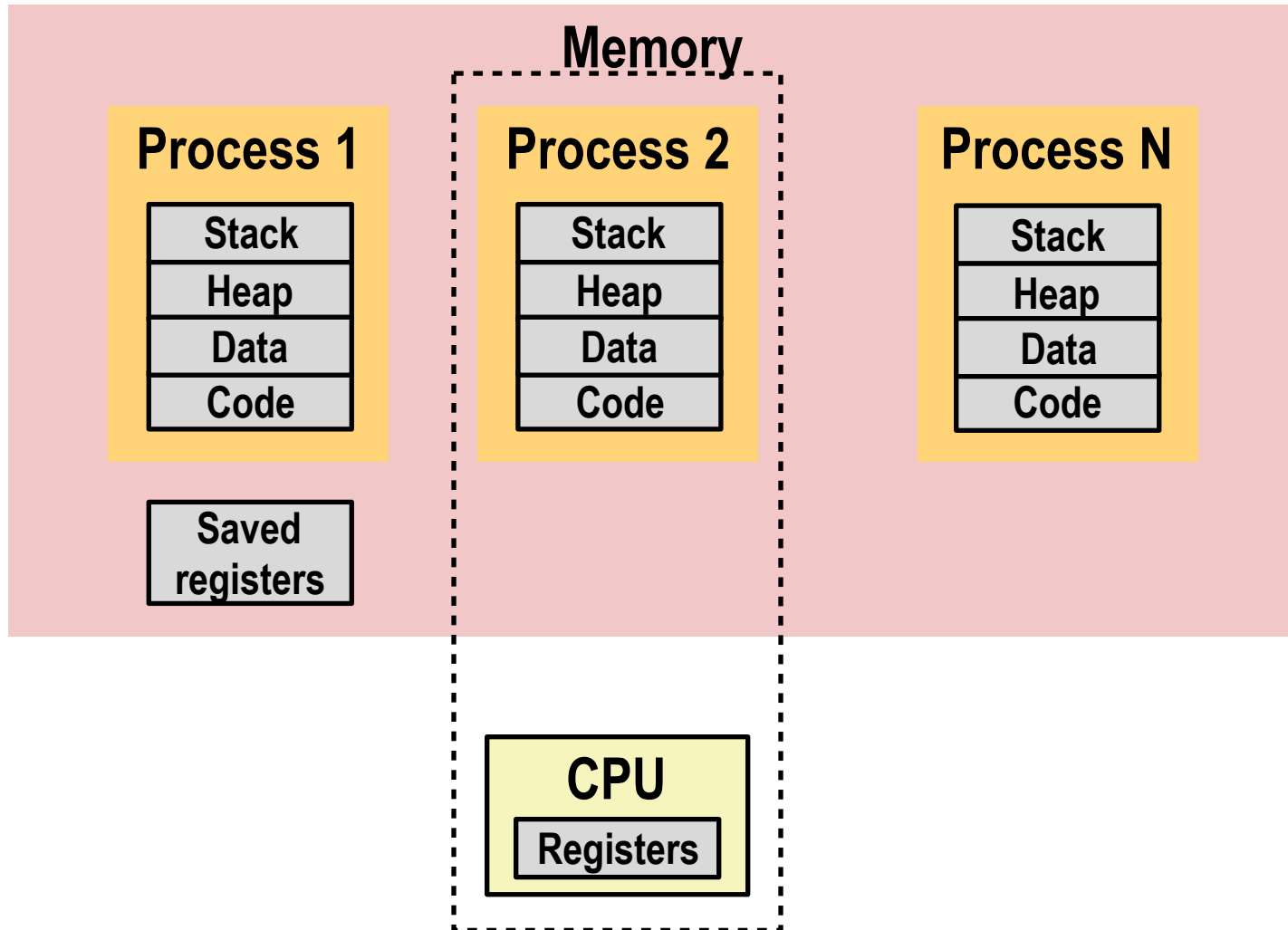
Multiprocessing Illustration



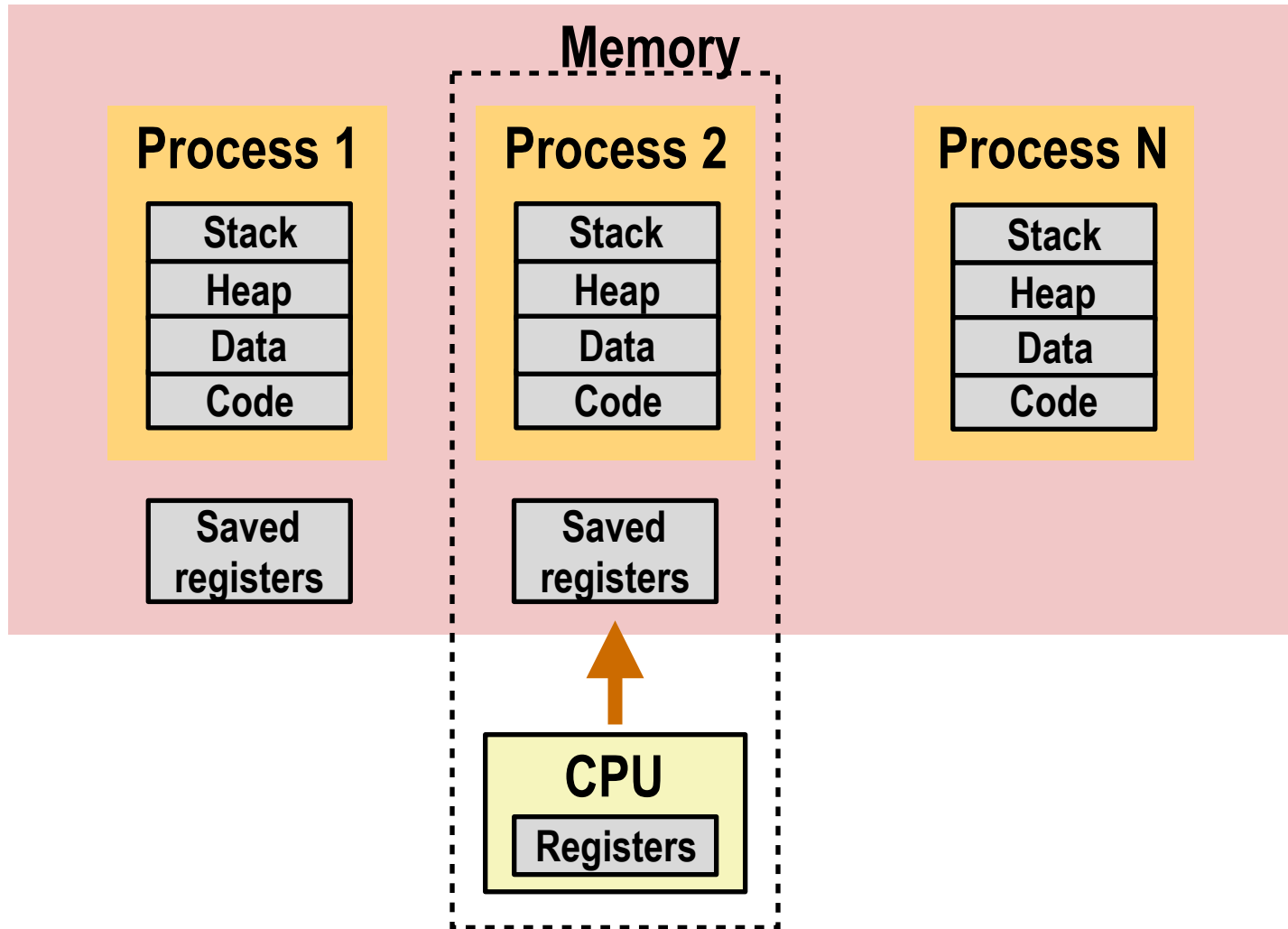
Multiprocessing Illustration



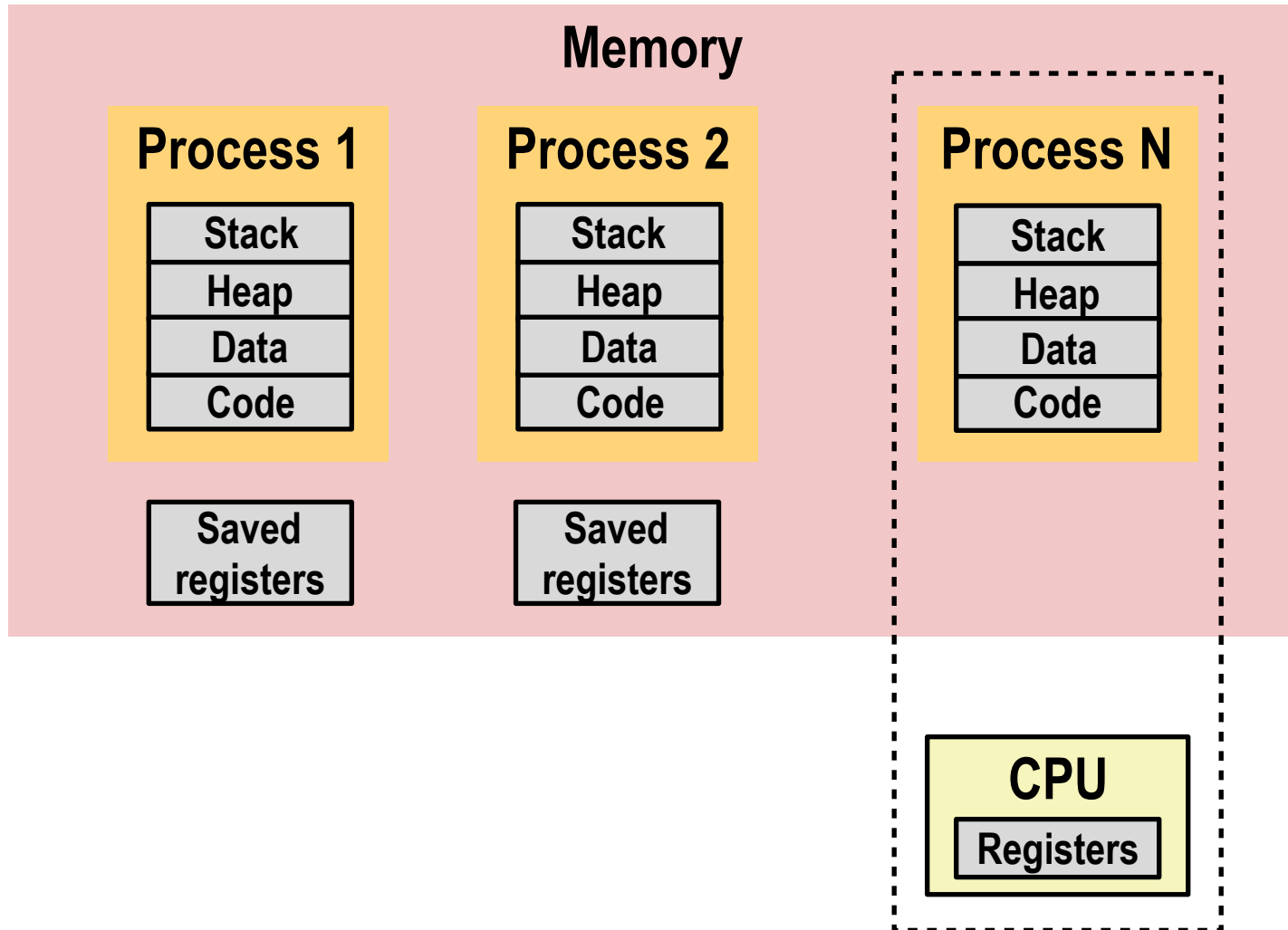
Multiprocessing Illustration



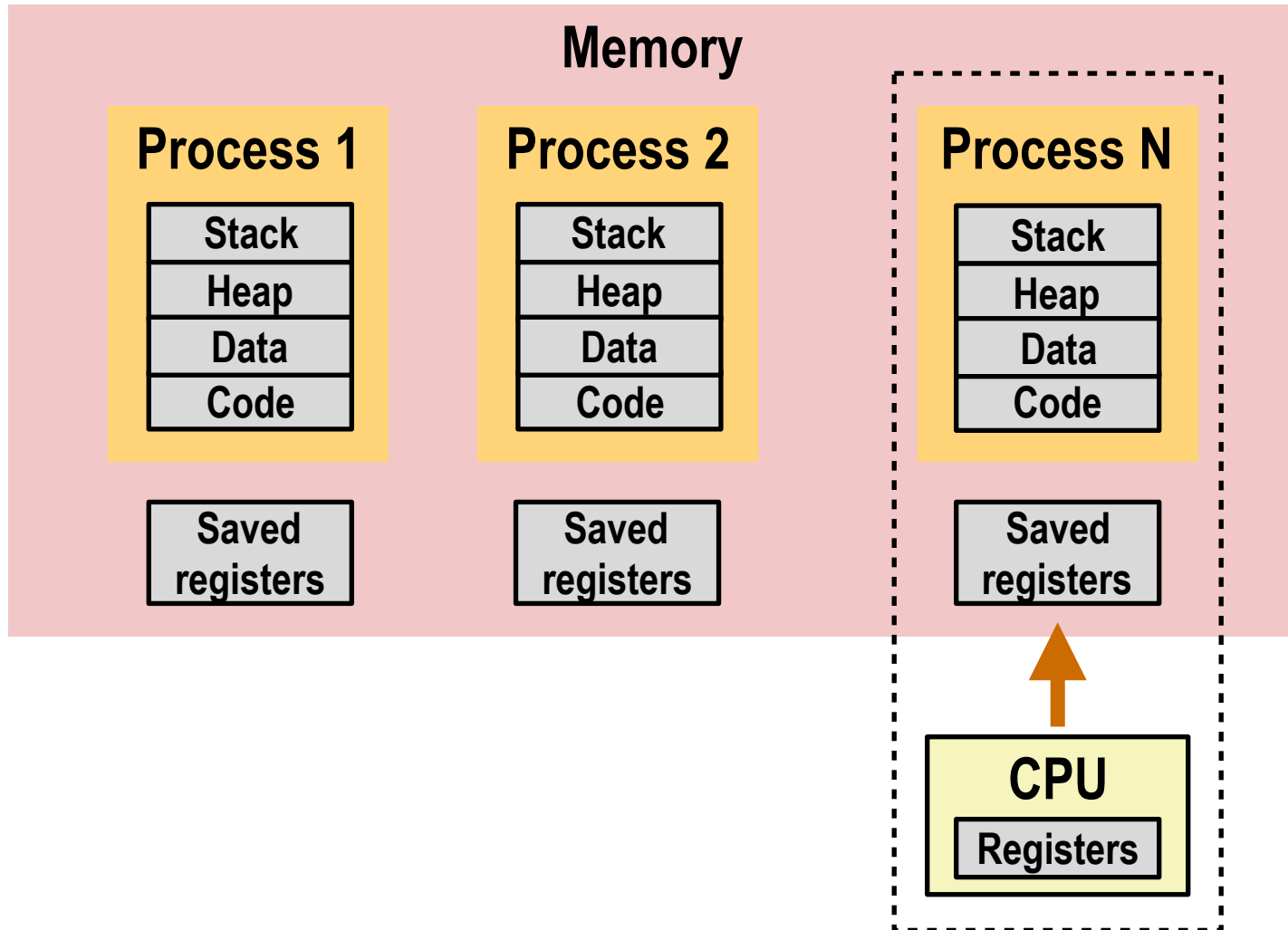
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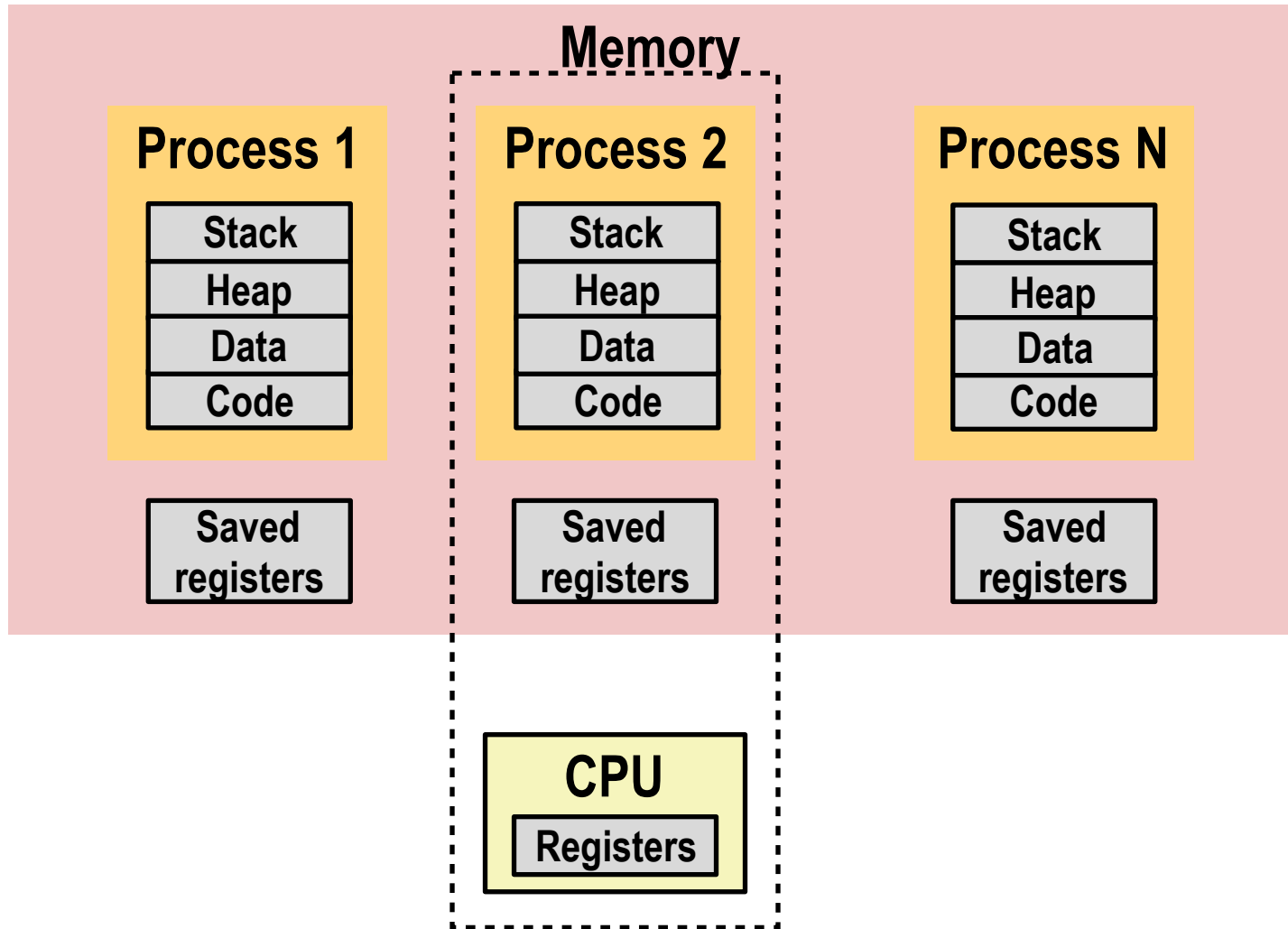
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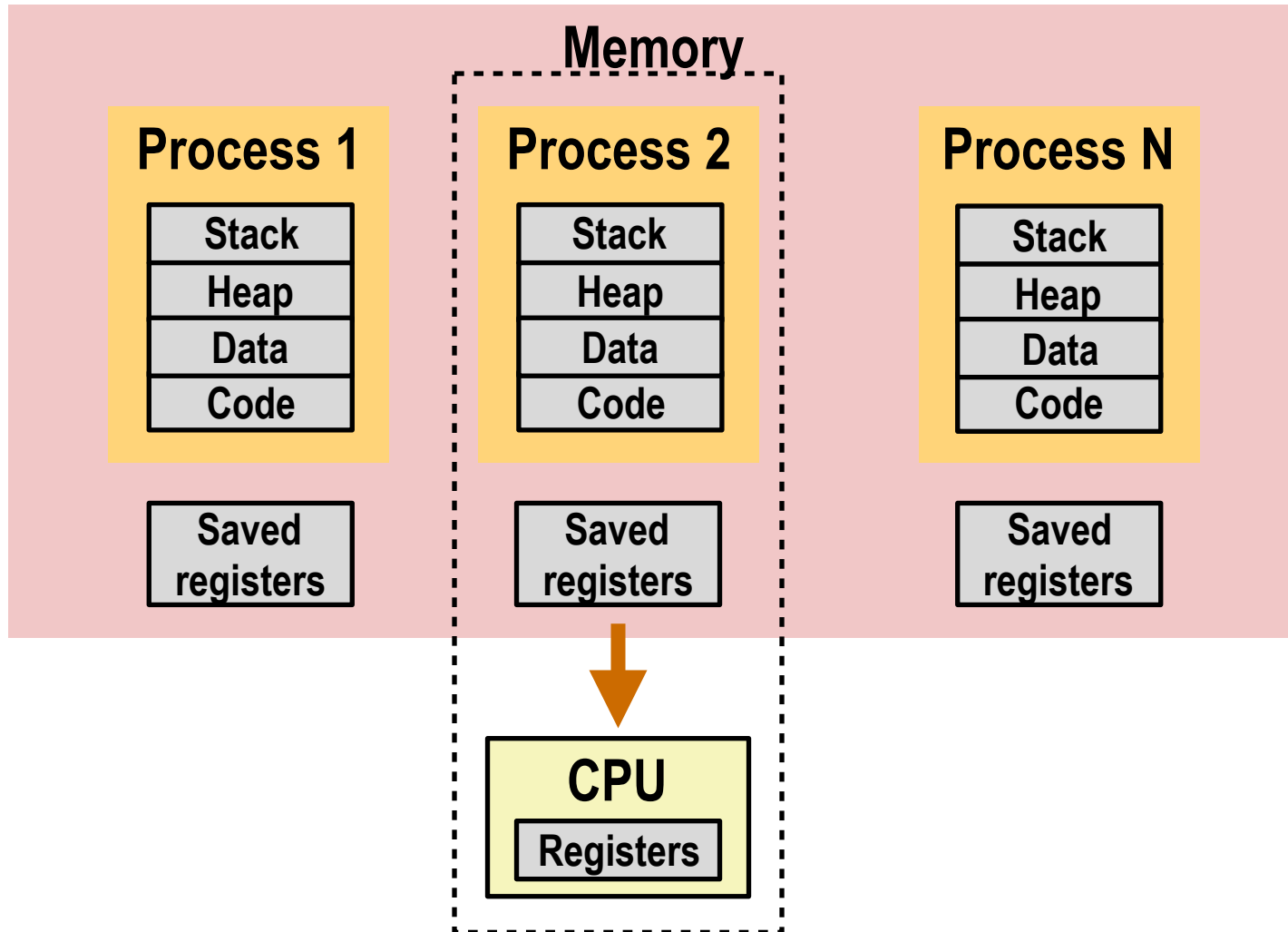
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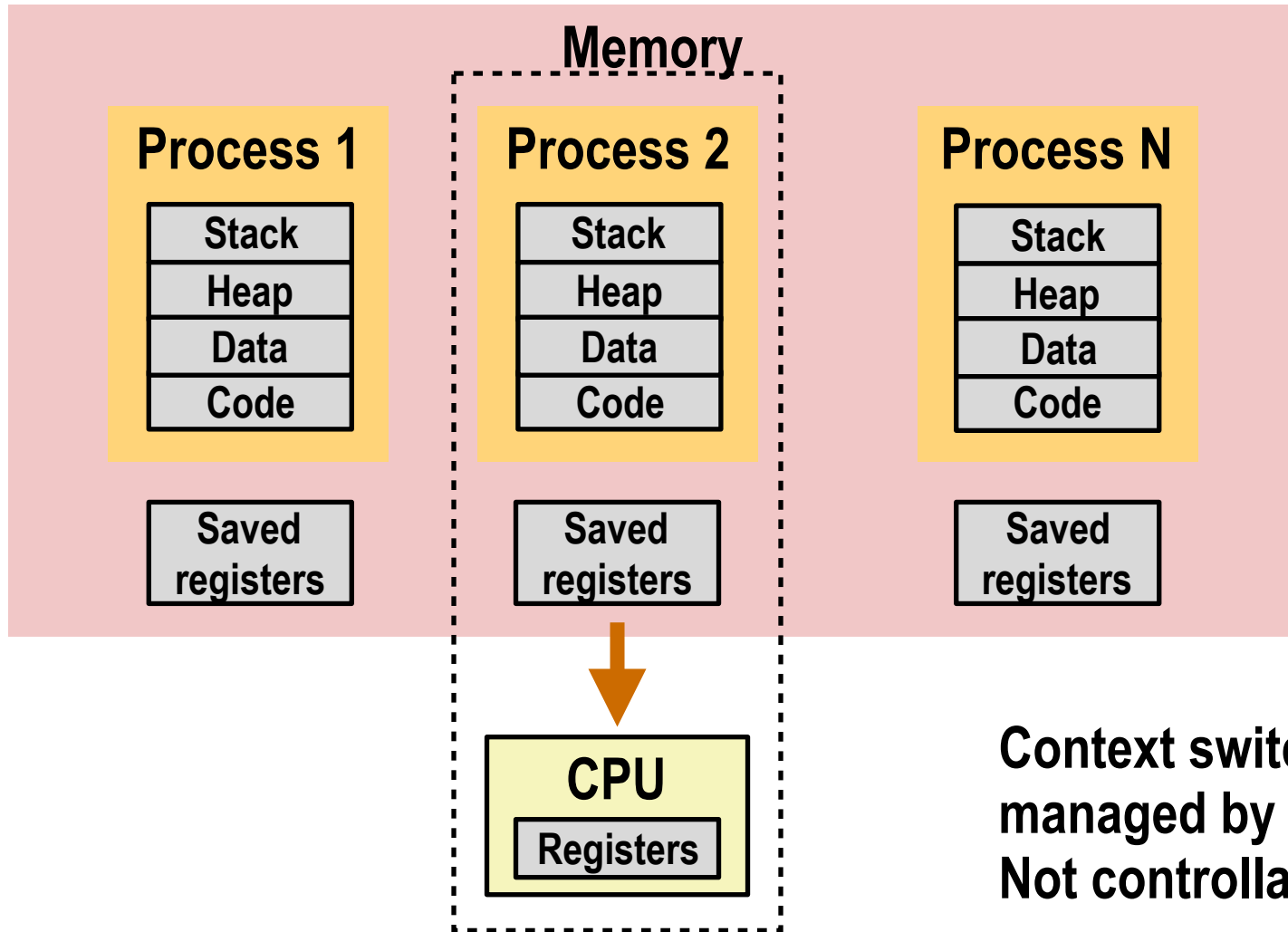
Multiprocessing Illustration



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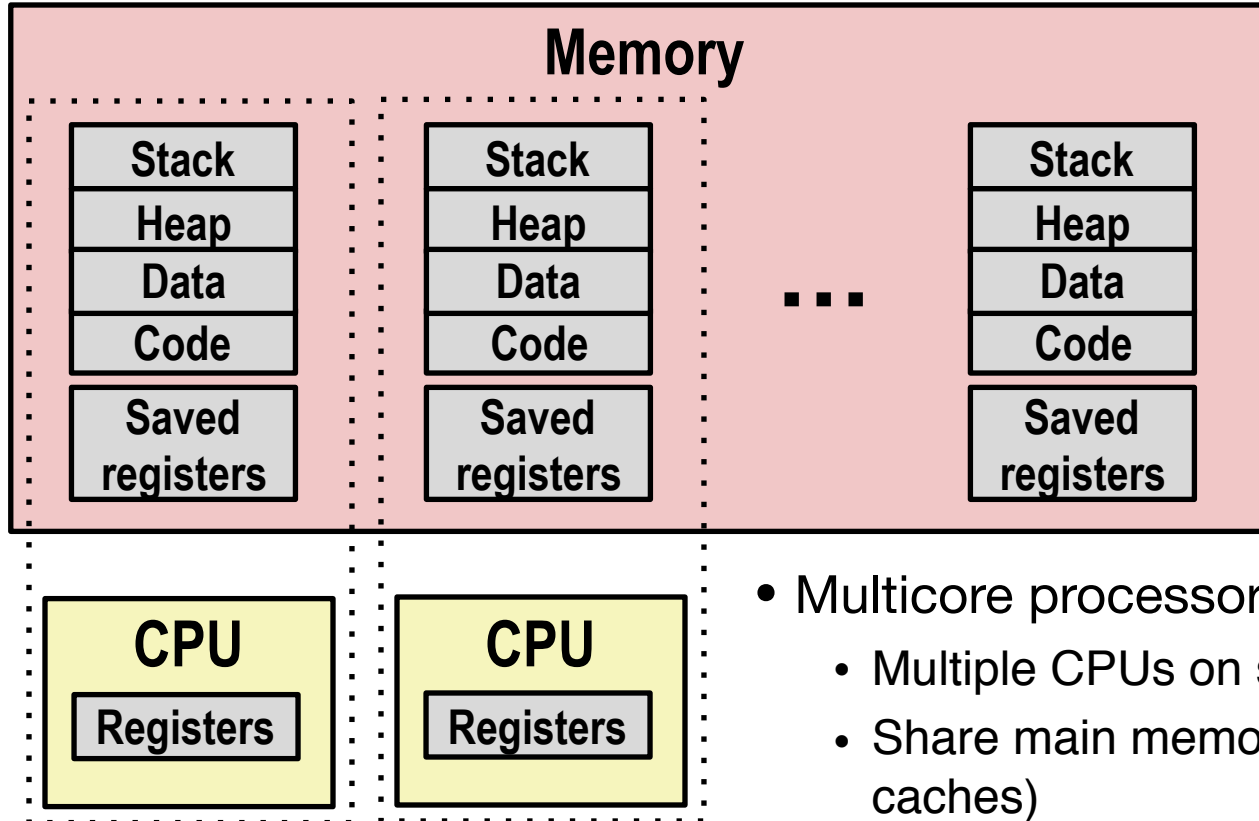


Multiprocessing Illustration



**Context switch
managed by the OS.
Not controllable by
programmers.**

Multiprocessing: The Multi-Core Case



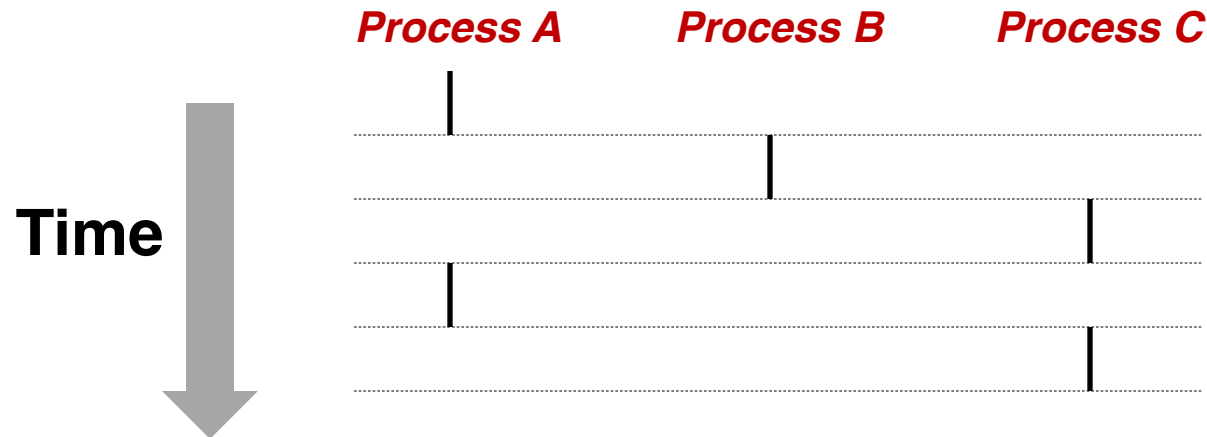
- Multicore processors
 - Multiple CPUs on single chip
 - Share main memory (and some of the caches)
 - Each can execute a separate process
 - Scheduling of processors onto cores done by kernel

Concurrent Processes

- Each process is a logical control flow.
- Two processes *run concurrently* (*are concurrent*) if their flows overlap in time
- Otherwise, they are *sequential*

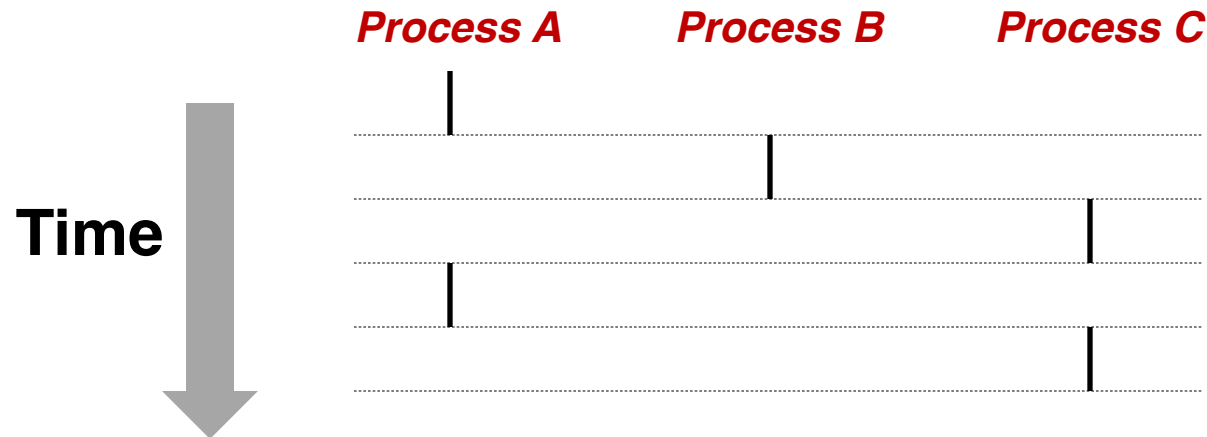
Concurrent Processes

- Each process is a logical control flow.
- Two processes *run **concurrently*** (*are concurrent*) if their flows overlap in time
- Otherwise, they are ***sequential***
- Examples (running on single core):



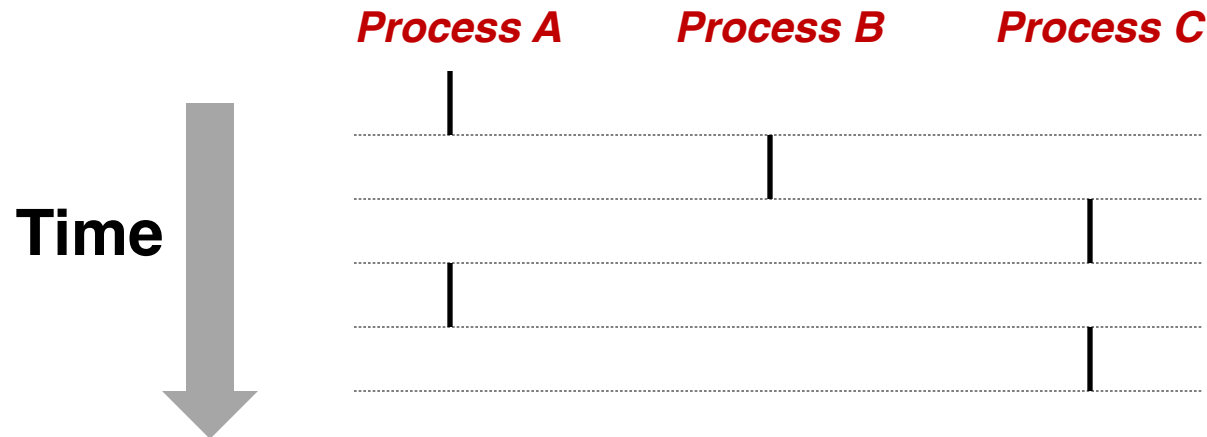
Concurrent Processes

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 - Concurrent: A & B, A & C



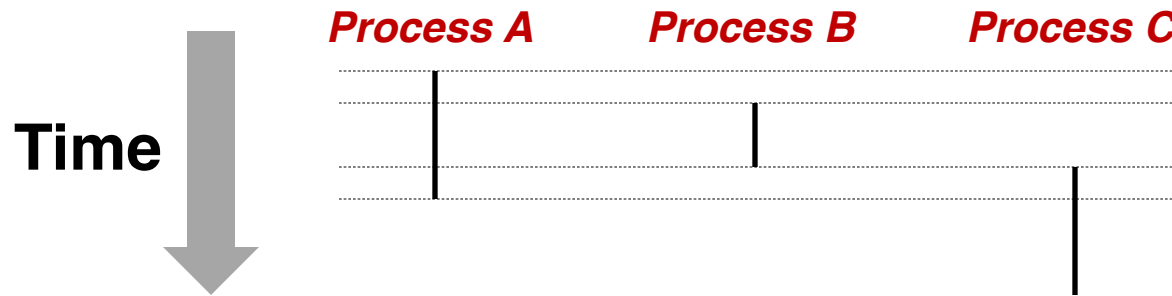
Concurrent Processes

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 - Concurrent: A & B, A & C
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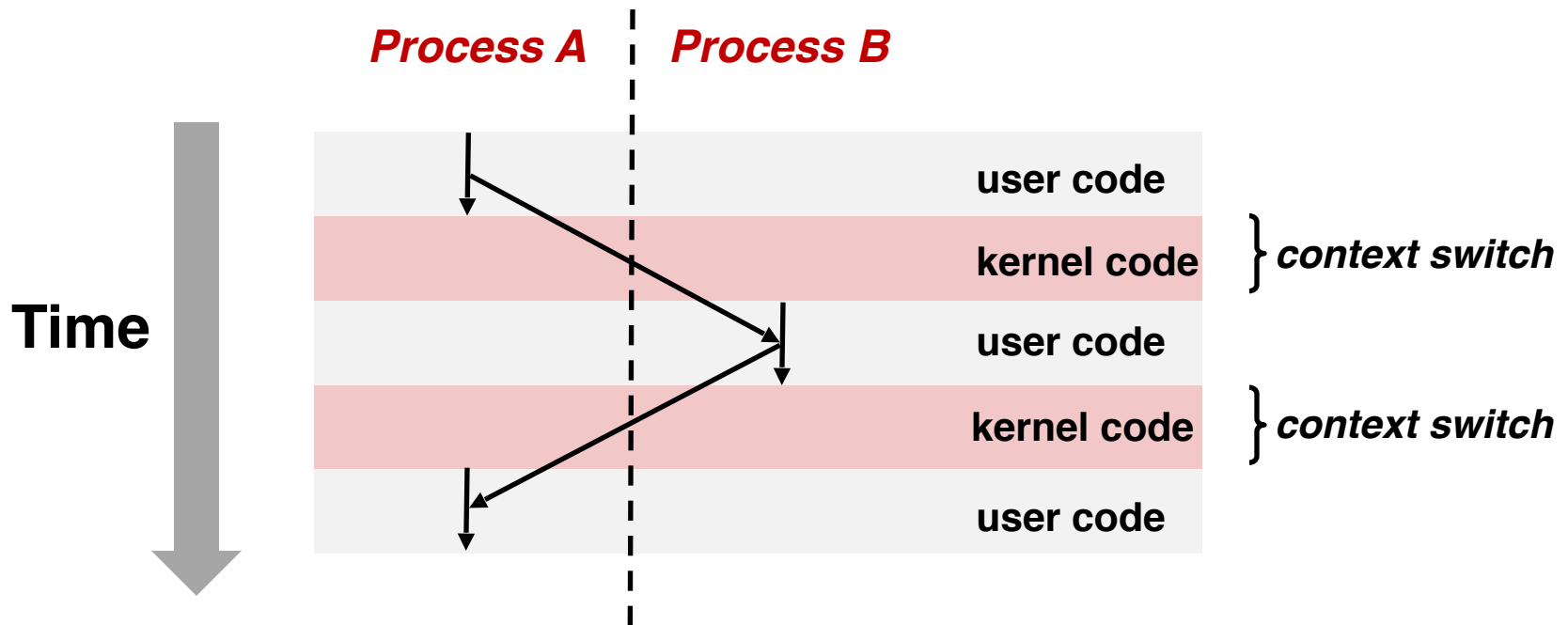
User View of Concurrent Processes

- Control flows for concurrent processes are physically disjoint in time
- However, we can think of concurrent processes as running in parallel with each other



Context Switching

- Processes are managed by a shared chunk of memory-resident OS code called the *kernel*
 - Important: the kernel is not a separate process, but rather runs as part of some existing process.
- Control flow passes from one process to another via a *context switch*



Today

- Processes and Signals: running multiple programs concurrently
 - Processes
 - Process Control
 - Signals

Obtaining Process IDs

- `pid_t getpid(void)`
 - Returns PID of current process
- `pid_t getppid(void)`
 - Returns PID of parent process

Creating and Terminating Processes

From a programmer's perspective, we can think of a process as being in one of three states

- Running
 - Process is either executing, or waiting to be executed and will eventually be *scheduled* (i.e., chosen to execute) by the kernel
- Stopped
 - Process execution is suspended and will not be scheduled until further notice (through something call **signals**)
- Terminated
 - Process is stopped permanently

Terminating Processes

- Process becomes terminated for one of three reasons:
 - Receiving a signal whose default action is to terminate
 - Returning from the `main` routine
 - Calling the `exit` function
- `void exit(int status)`
 - Terminates with an *exit status* of `status`
 - Convention: normal return status is 0, nonzero on error
 - Another way to explicitly set the exit status is to return an integer value from the main routine
- `exit` is called **once** but **never** returns.

Creating Processes

- Parent process creates a new running child process by calling `fork`
- `int fork(void)`
 - Returns 0 to the child process, child's PID to parent process
 - Child is almost identical to parent:
 - Child get an identical (but separate) copy of the parent's (virtual) address space (i.e., same stack copies, code, etc.)
 - Child gets identical copies of the parent's open file descriptors
 - Child has a different PID than the parent
- `fork` is interesting (and often confusing) because it is called **once** but returns **twice**

fork Example

```
int main()
{
    pid_t pid;
    int x = 1;

    pid = Fork();
    if (pid == 0) { /* Child */
        printf("child : x=%d\n", ++x);
        exit(0);
    }

    /* Parent */
    printf("parent: x=%d\n", --x);
    exit(0);
}
```

fork.c

```
linux> ./fork
parent: x=0
child : x=2
```

fork Example

- Call once, return twice

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fork.c

- Call once, return twice
- Concurrent execution
 - Can't predict execution order of parent and child

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fork.c

- Call once, return twice
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 - Can't predict execution order of parent and child
- Duplicate but separate address space
 - x has a value of 1 when fork returns in parent and child
 - Subsequent changes to x are independent

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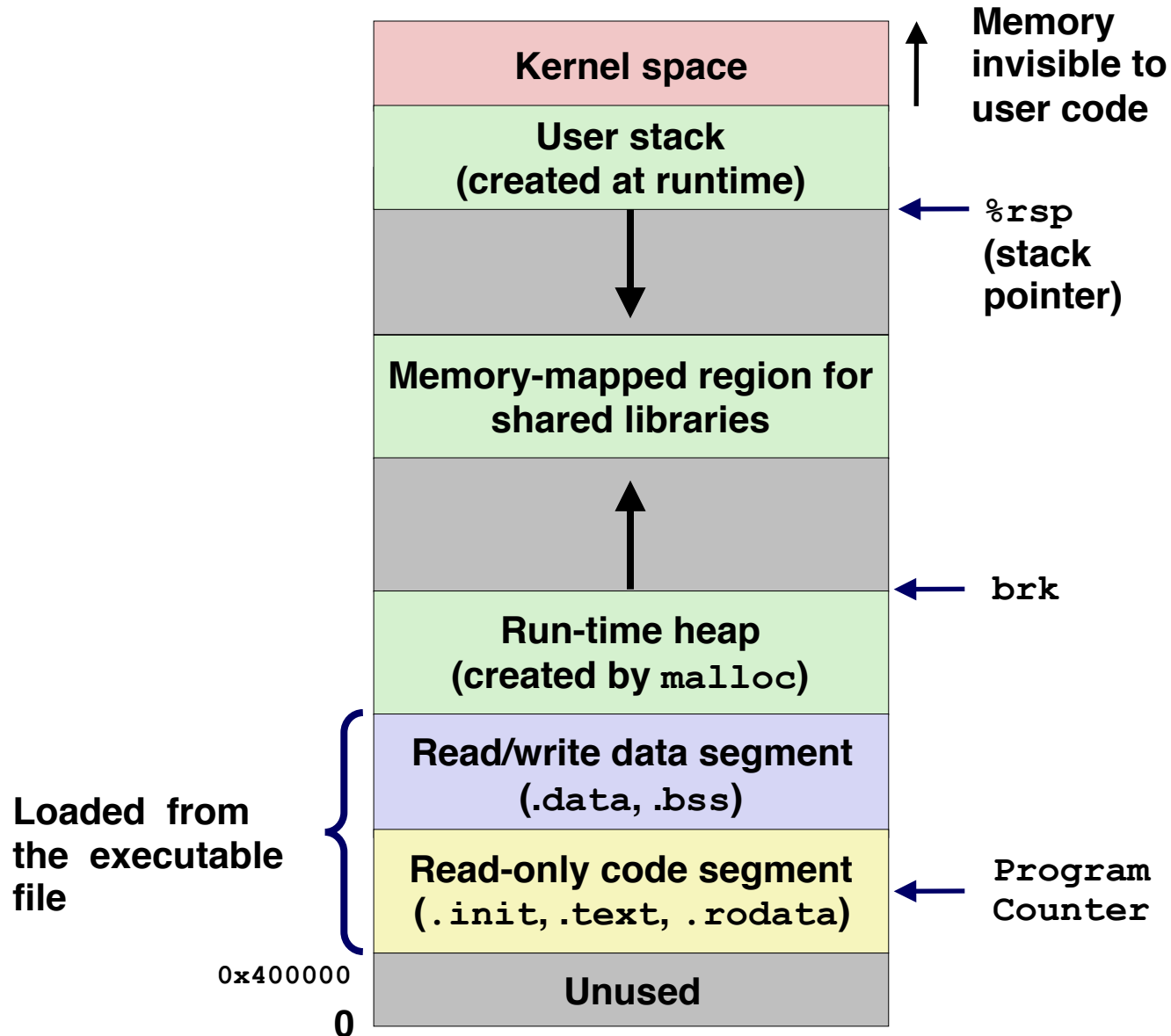
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fork.c

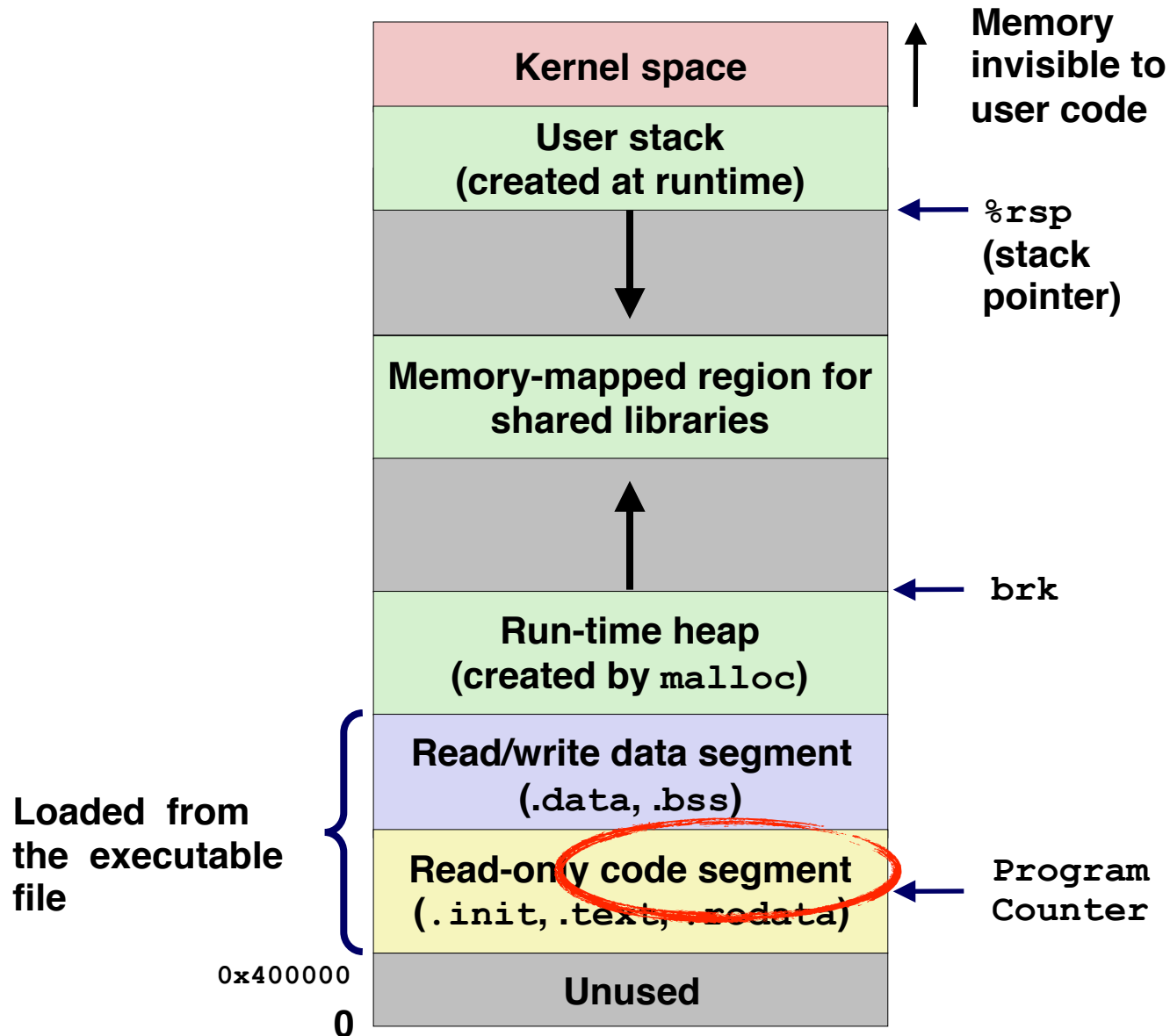
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- Concurrent execution
 - Can't predict execution order of parent and child
- Duplicate but separate address space
 - x has a value of 1 when fork returns in parent and child
 - Subsequent changes to x are independent
- Shared open files
 - stdout is the same in both parent and child

Process Address Space



Process Address Space



What Happens at `fork()` ?

Code Segment

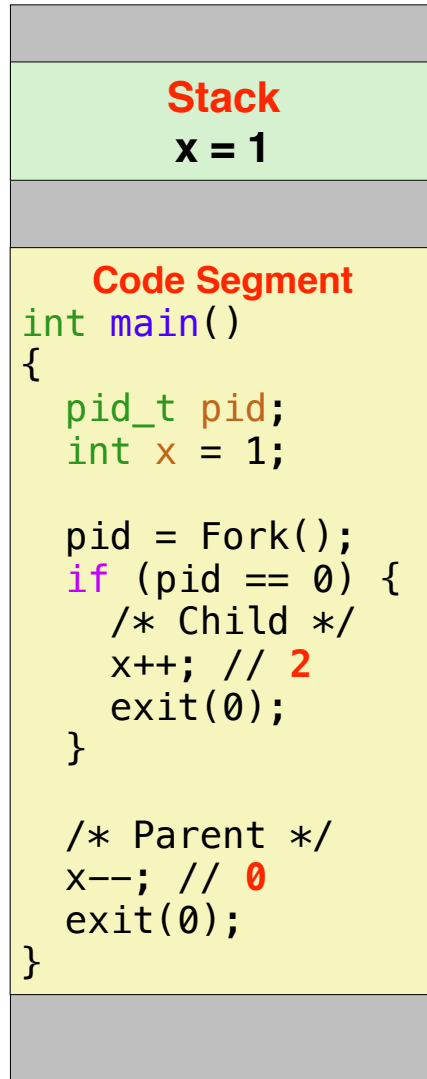
```
int main()
{
    pid_t pid;
    int x = 1;

    pid = Fork();
    if (pid == 0) {
        /* Child */
        x++; // 2
        exit(0);
    }

    /* Parent */
    x--; // 0
    exit(0);
}
```

What Happens at `fork()` ?

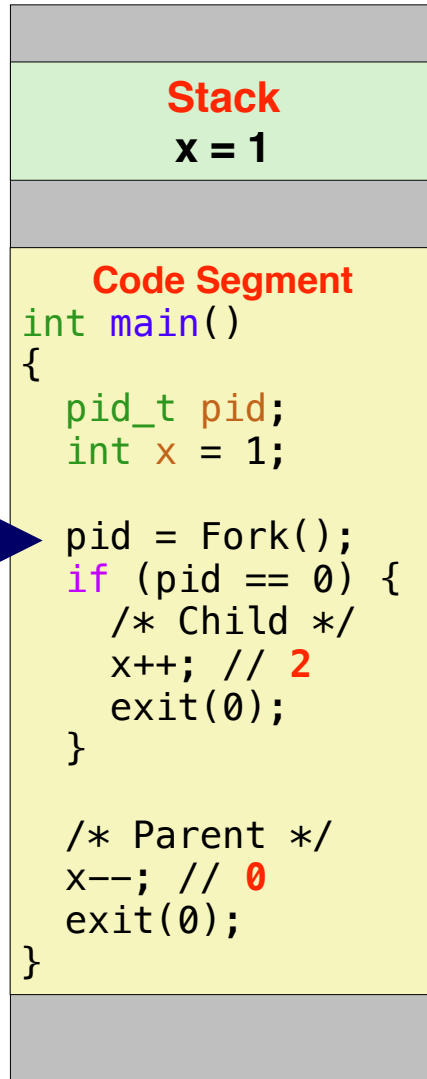
Parent Address Space



What Happens at `fork()` ?

Parent Address Space

Parent
Process
Program
Counter

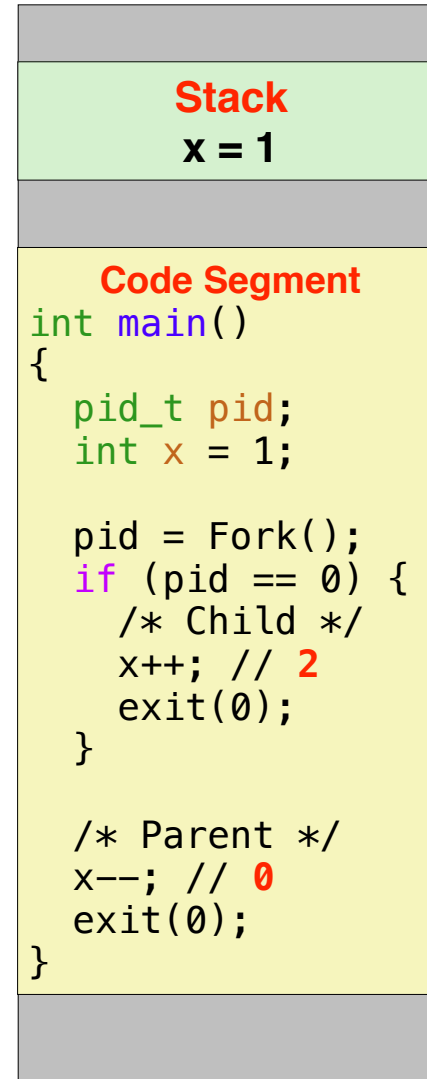
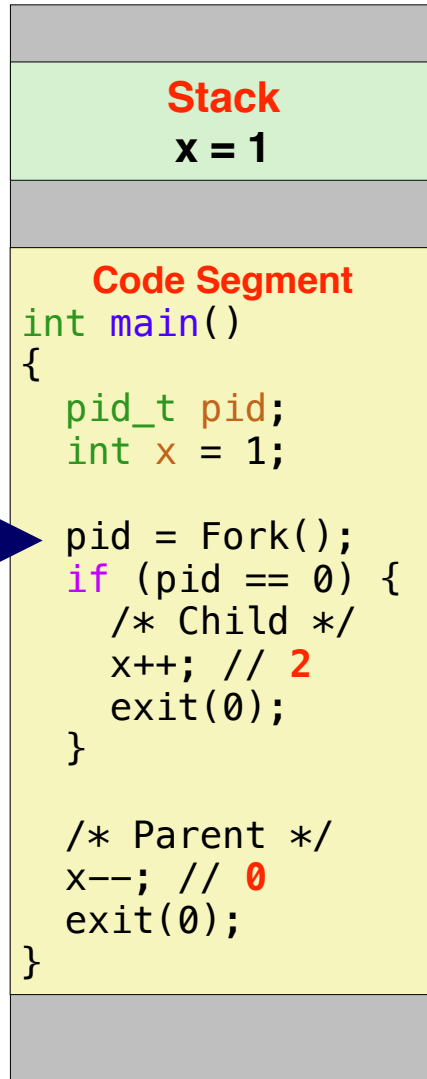


What Happens at `fork()` ?

Parent Address Space

Child Address Space

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Process
Program
Counter

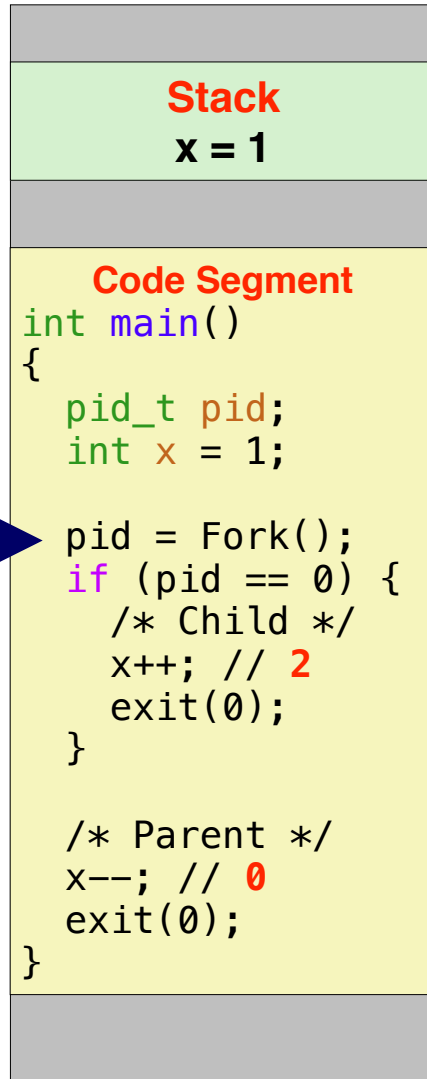


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Child Address Space

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Program
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Child
Process
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Counter

