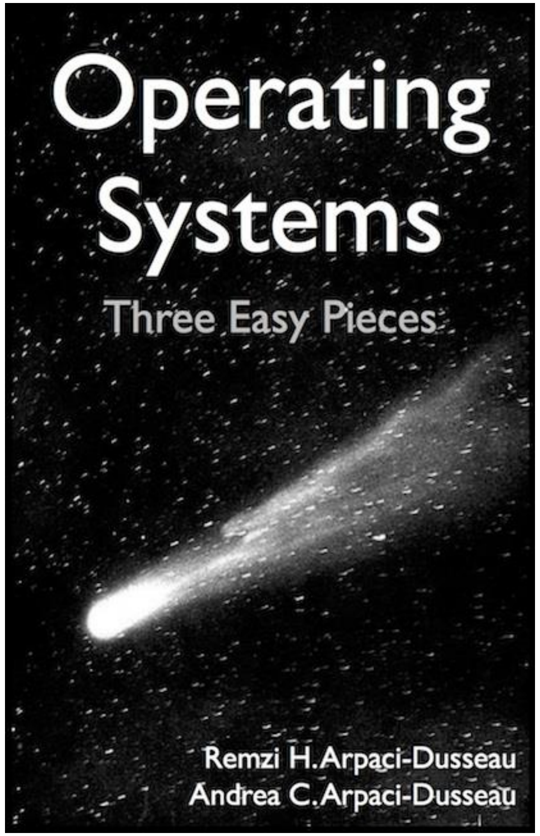
CMSC 125: Operating Systems

- Instructor: **Joseph Anthony C. Hermocilla**
- Email: jchermocilla@up.edu.ph
- Web: https://jachermocilla.org

Resources

Book: https://pages.cs.wisc.edu/~remzi/OSTEP/

Slides Template:
https://pages.cs.wisc.edu/~remzi/OSTEP/Educators-Slides/Youjip/



Acknowledgement

- This lecture slide set was initially developed for Operating System course in Computer Science Dept. at Hanyang University. This lecture slide set is for OSTEP book written by Remzi and Andrea at University of Wisconsin.

10. Multiprocessor Scheduling (Advanced)

Operating System: Three Easy Pieces

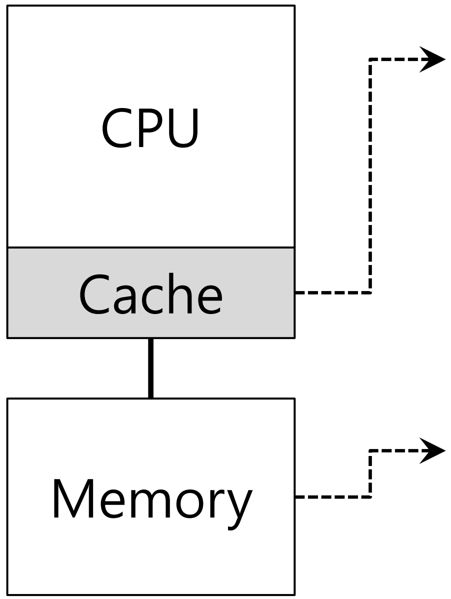
Multiprocessor Scheduling

- The rise of the multicore processor is the source of multiprocessor-scheduling proliferation
  - **Multicore**: Multiple CPU cores are packed onto a single chip

- Adding more cores does not make that single application run faster → You'll have to rewrite the application to run in parallel, using **threads**

How to schedule jobs on Multiple cores?

Background: Single CPU with Cache



Cache

- Small, fast memories
- Hold copies of popular data that is found in the main memory.
- Utilize *temporal* and *spatial* locality

Main Memory

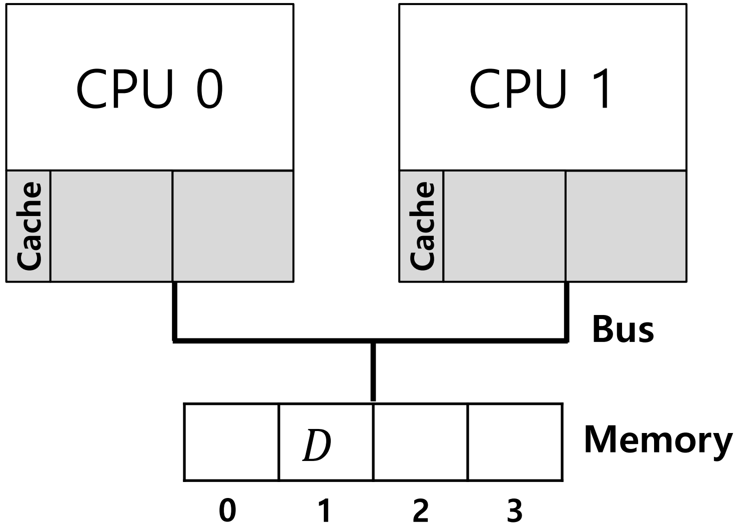
- Holds all of the data
- Access to main memory is slower than cache

By keeping data in cache, the system can make slow main memory access appear to be a fast one

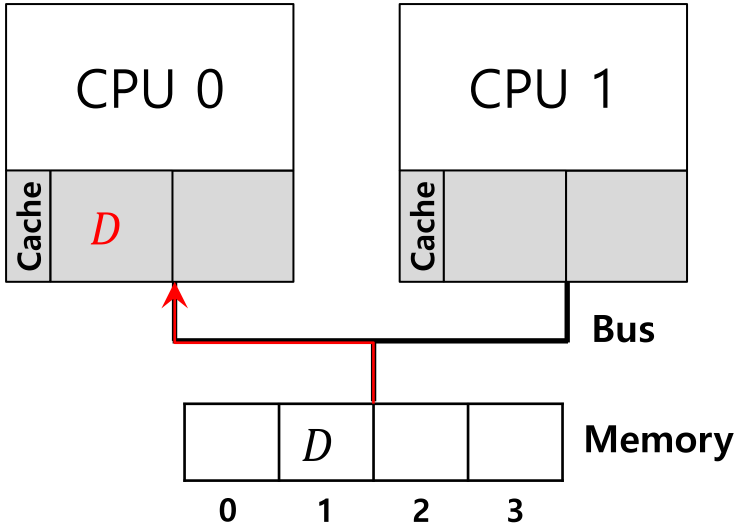
Issue #1: Cache Coherence

- Consistency of shared resource data stored in multiple caches.

0. Two CPUs with caches sharing memory

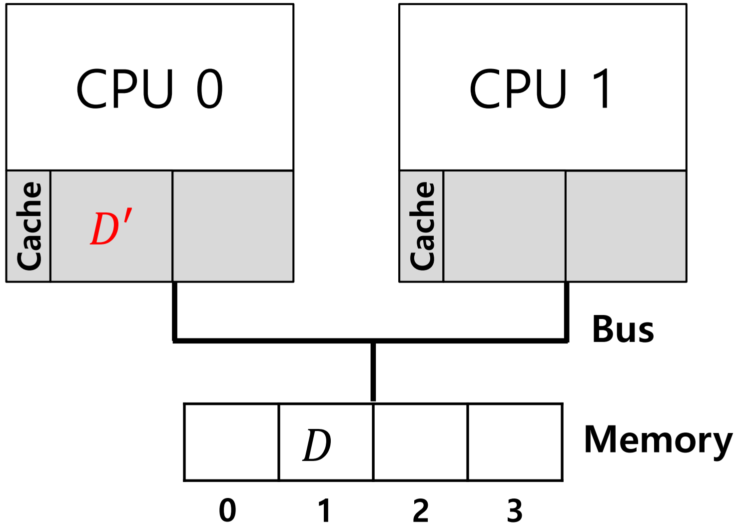


1. CPU0 reads a data at address 1

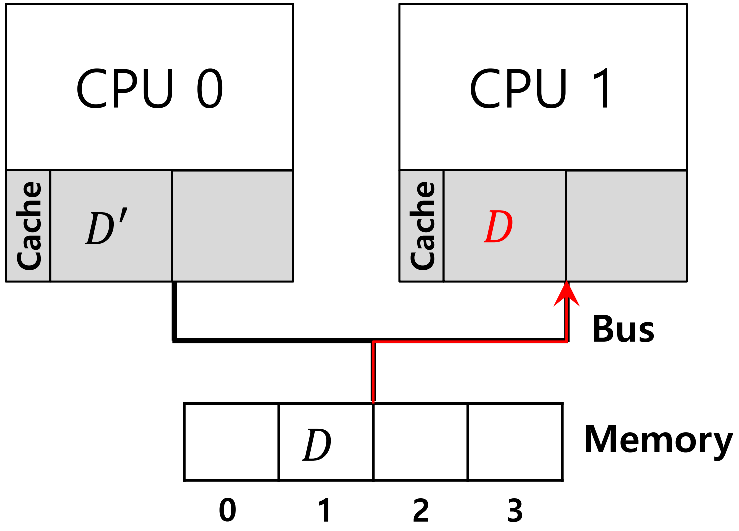


Issue #1: : Cache coherence (Cont.)

2. D is updated (D') and CPU1 is scheduled



3. CPU1 re-reads the value at address 1



CPU1 gets the old value D instead of the correct value D'

Issue #1 : Cache Coherence

- **Solution: Bus snooping**
  - Each cache pays attention to memory updates by **observing the bus**
  - When a CPU sees an update for a data item it holds in its cache, it will notice the change and either <u>invalidate</u> its copy or <u>update</u> it

Issue #2: Don't forget synchronization

- When accessing shared data across CPUs, mutual exclusion primitives should likely be used to <u>guarantee correctness</u>

```
typedef struct __Node_t {
     int value;
     struct __Node_t *next;
} Node_t;

int List_Pop() {
     Node_t *tmp = head;           // remember old head ...
     int value = head->value;      // ... and its value
     head = head->next;            // advance head to next pointer
     free(tmp);                    // free old head
     return value;                 // return value at head
}
```

Simple List Delete Code

Issue #2: Don’t forget synchronization (Cont.)

- Solution

```
pthread_mutex_t m;
typedef struct __Node_t {
        int value;
        struct __Node_t *next;
} Node_t;

int List_Pop() {
        lock(&m);
        Node_t *tmp = head;         // remember old head ...
        int value = head->value;    // ... and its value
        head = head->next;          // advance head to next pointer
        free(tmp);                  // free old head
        unlock(&m);
        return value;               // return value at head
}
```

Simple List Delete Code with lock

Issue #3: Cache Affinity

- Keep a process on the same CPU if at all possible
  - A process builds up a fair bit of state in the cache of a CPU
  - The next time the process run, it will run faster if some of its state is *already present* in the cache on that CPU

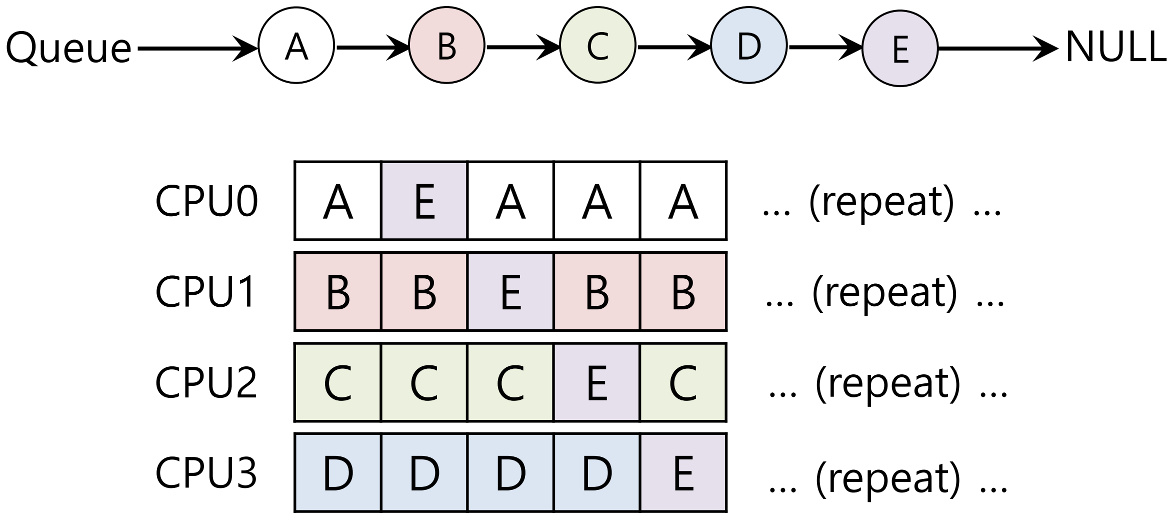
A multiprocessor scheduler should consider cache affinity when making its scheduling decision.

Approach #1: Single Queue Multiprocessor Scheduling (SQMS)

- Put all jobs that need to be scheduled into a single queue.
  - Each CPU simply picks the next job from the globally shared queue.
  - Pros: Simple
  - Cons:
    - (1) Lack of scalability - Some form of **locking** needs to be inserted
    - (2) Cache affinity issue
      - Example: Queue → A → B → C → D → E → NULL
      - Possible process schedules across CPUs:

CPU0	A	E	D	C	B	... (repeat) ...
CPU1	B	A	E	D	C	... (repeat) ...
CPU2	C	B	A	E	D	... (repeat) ...
CPU3	D	C	B	A	E	... (repeat) ...

Scheduling Example with Cache affinity



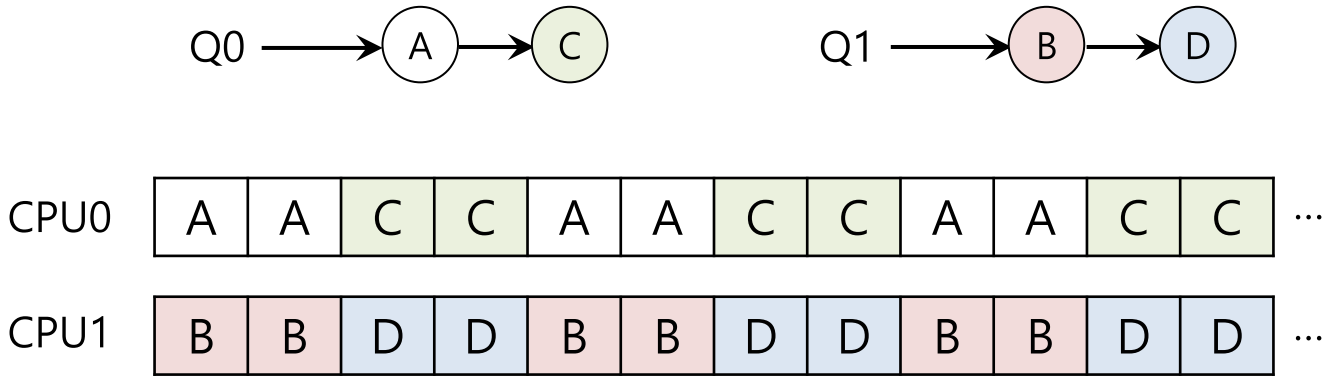
- <u>Solution: Preserve affinity for most processes</u>
  - Process A through D are not moved across processors
  - Only process E migrates from CPU to CPU
- Implementing such a scheme can be **complex**

Approach #2: Multi-Queue Multiprocessor Scheduling (MQMS)

- MQMS consists of multiple scheduling queues
  - Each queue will follow a particular scheduling discipline
  - When a process enters the system, it is placed on **exactly one** scheduling queue
  - Avoids the problems of information sharing and synchronization.

MQMS Example

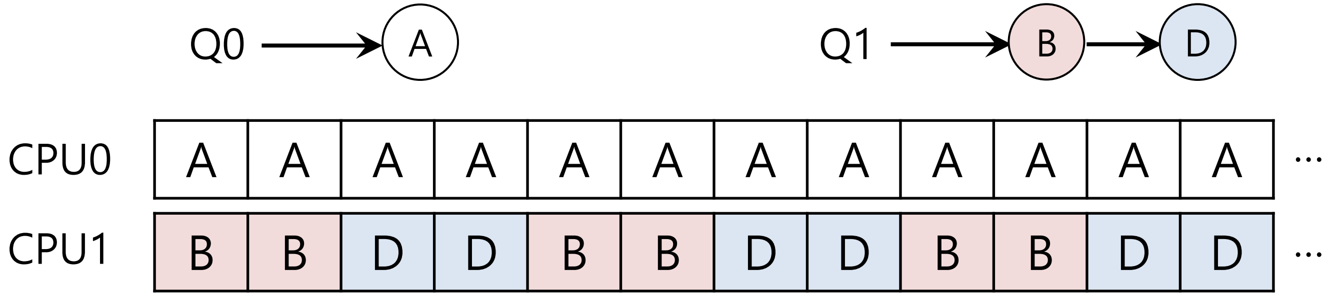
- With **round robin**, the system might produce a schedule that looks like this:



MQMS provides more scalability and cache affinity.

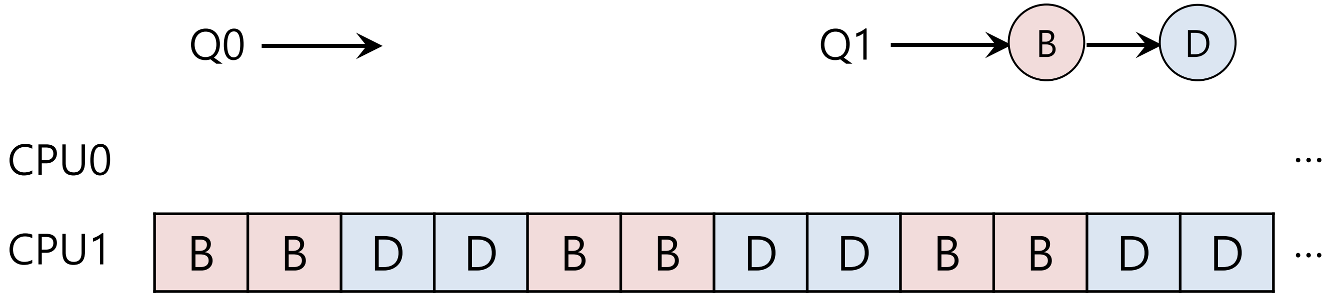
Load Imbalance Issue of MQMS

- After process C in Q0 finishes:



A gets twice as much CPU as B and D.

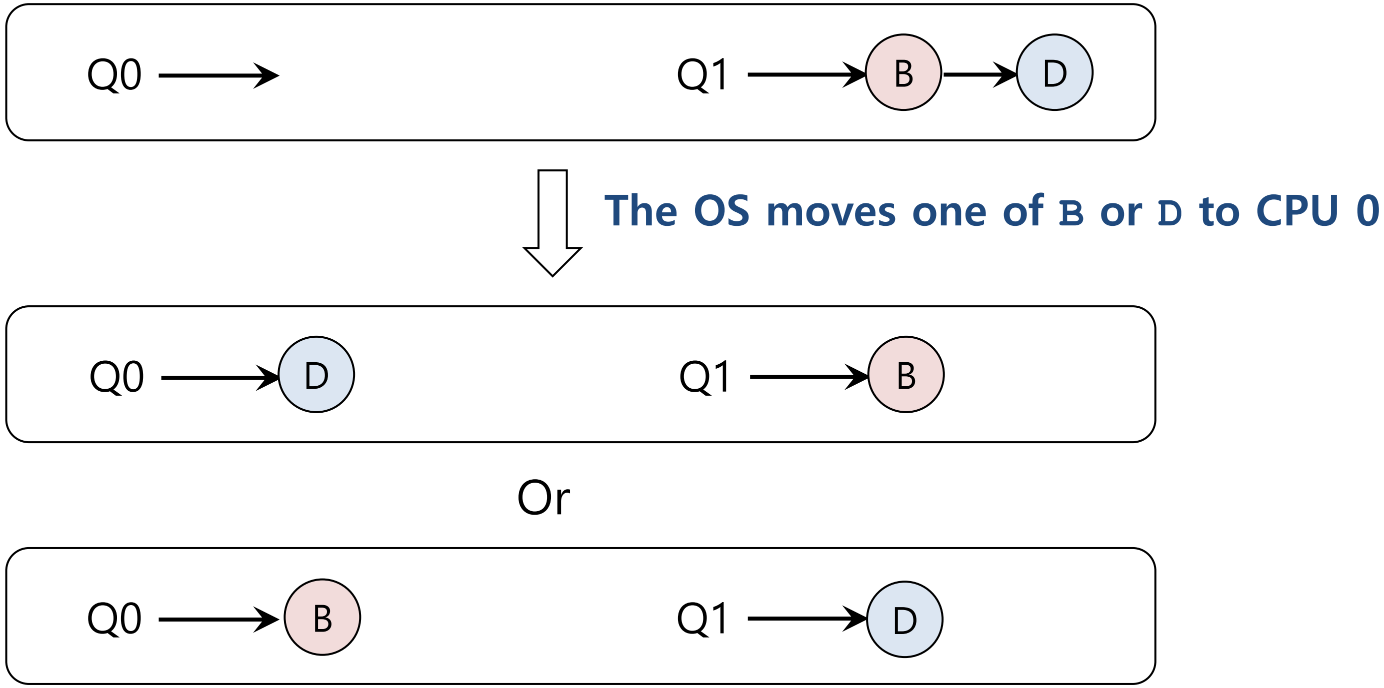
- After process A in Q0 finishes:



CPU0 will be left idle!

How to deal with load imbalance?

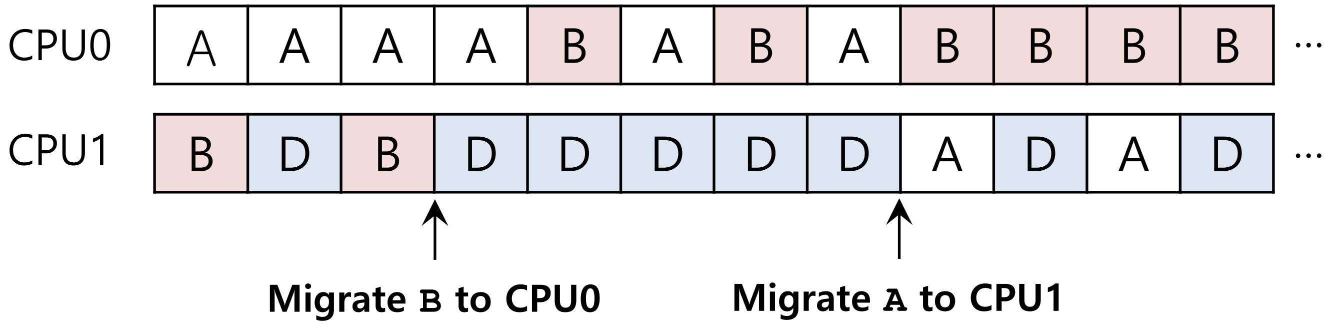
- The answer is to move processes (**Migration**)
  - Example:



How to deal with load imbalance? (Cont.)

- A more tricky case: Single process migration will not solve the problem

- A possible migration pattern:
  - Keep switching processes (continuously)



Work Stealing

- Move processes between queues
  - Implementation:
    - A source queue that is low on processes is picked
    - The source queue occasionally peeks at another target queue
    - If the target queue is more full than the source queue, the source will "**steal**" one or more processes from the target queue
  - Cons:
    - *High overhead* and trouble *scaling*

Linux Multiprocessor Schedulers

- O(1)
  - A Priority-based scheduler
  - Use Multiple queues
  - Change a process’s priority over time
  - Schedule those with highest priority
  - Interactivity is a particular focus

- Completely Fair Scheduler (CFS)
  - Deterministic proportional-share approach
  - Multiple queues

Linux Multiprocessor Schedulers (Cont.)

- BF Scheduler (BFS)
  - A single queue approach
  - Proportional-share
  - Based on Earliest Eligible Virtual Deadline First(EEVDF)

Useful linux commands related to scheduling

- `cat /proc/sched_debug            #show sched stats for system`
- `` cat /proc/`pidof threads`/sched     #show scheduling stats for process ``
- `` ps -o thcount,nlwp `pidof threads`   #show the number of threads ``
- `` ps -L -p `pidof threads`             #show thread/LWP ids ``
- `` ps -mo pid,tid,%cpu,psr `pidof threads`    #show which core a thread is running ``
- `taskset -c 1 ./threads 1000000       # pin all threads to a core`