OSTEP
CPU Virtualization
Multiprocessor Scheduling (Advanced)

Multiprocessor Scheduling

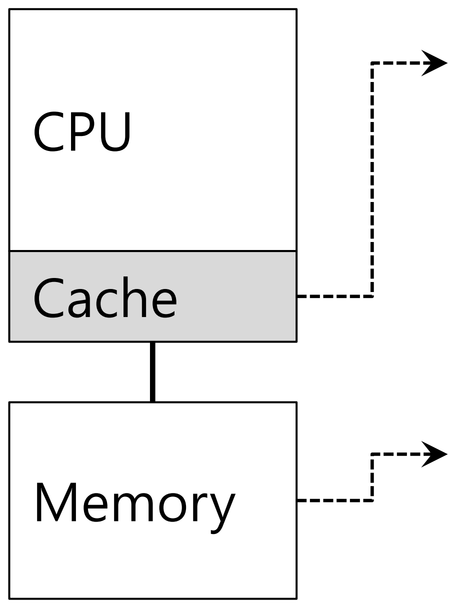
The rise of the multicore processor is the source of multiprocessor-scheduling proliferation.

- **Multicore**: Multiple CPU cores are packed onto a single chip.

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

How to schedule jobs on Multiple CPUs?

Single CPU with cache



Cache

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

Main Memory

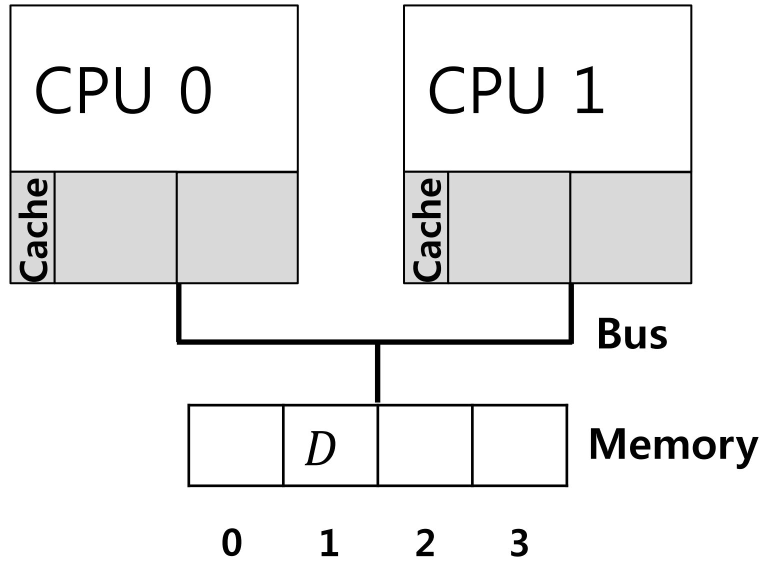
- Holds all of the data
- Access to main memory is slower than cache.

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

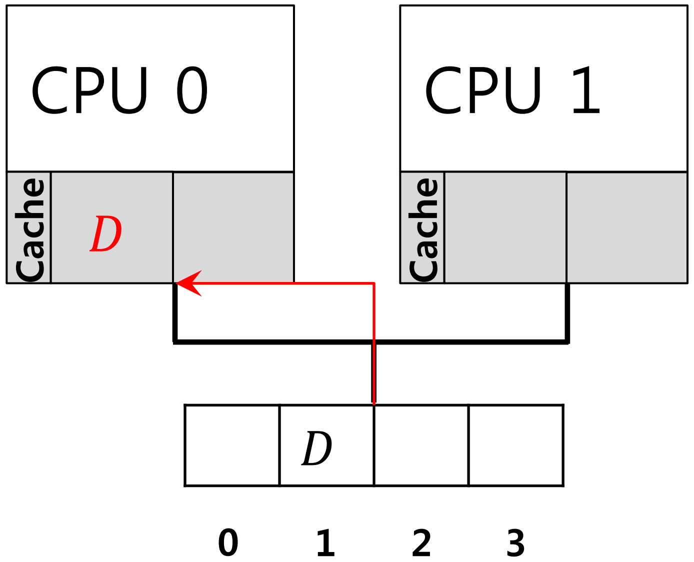
Cache coherence

Consistency of shared resource data stored in multiple caches.

0. Two CPUs with caches sharing memory

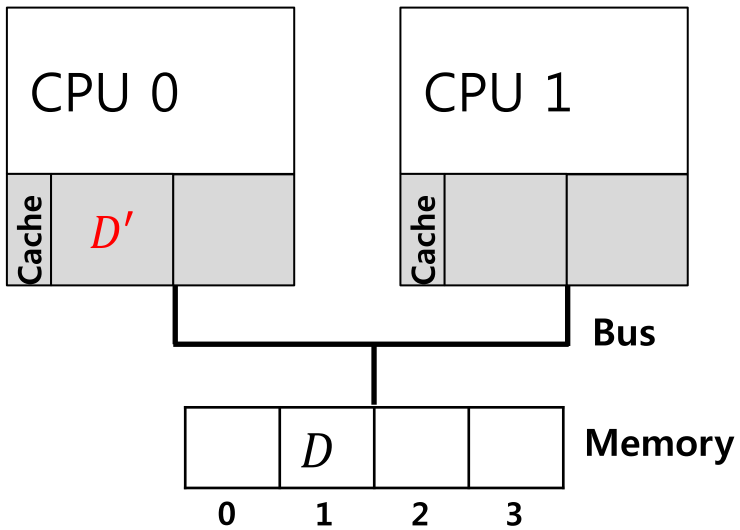


1. CPU0 reads a data at address 1.

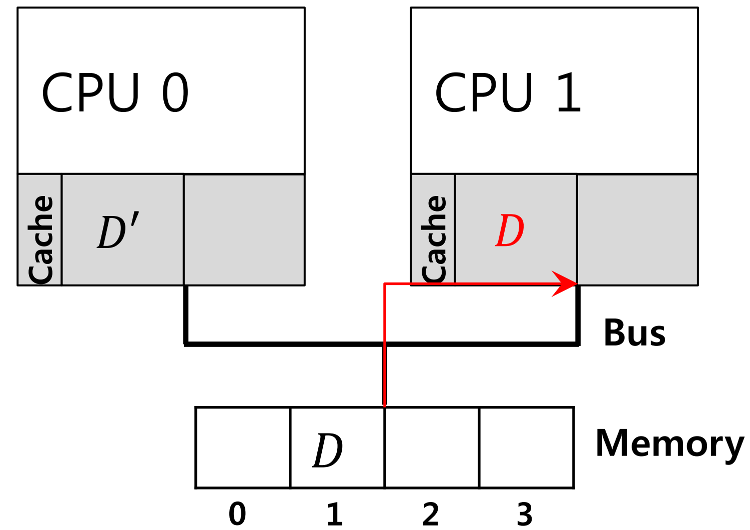


Cache coherence (Cont.)

2. D is updated and CPU1 is scheduled.



3. CPU1 re-reads the value at address A



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

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.

Don’t forget synchronization

When accessing shared data across CPUs, mutual exclusion primitives should likely be used to guarantee correctness.

```
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

Don’t forget synchronization (Cont.)

Solution

```
pthread_mtuex_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

Cache Affinity

Keep a process on the same CPU if at all possible

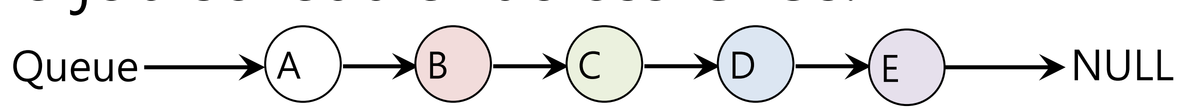
- A process builds up a fair bit of state in the cache of a CPU.
- The next time the process run, it will run faster if some of its state is *already present* in the cache on that CPU.

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

Single Queue Multiprocessor Scheduling (SQMS)

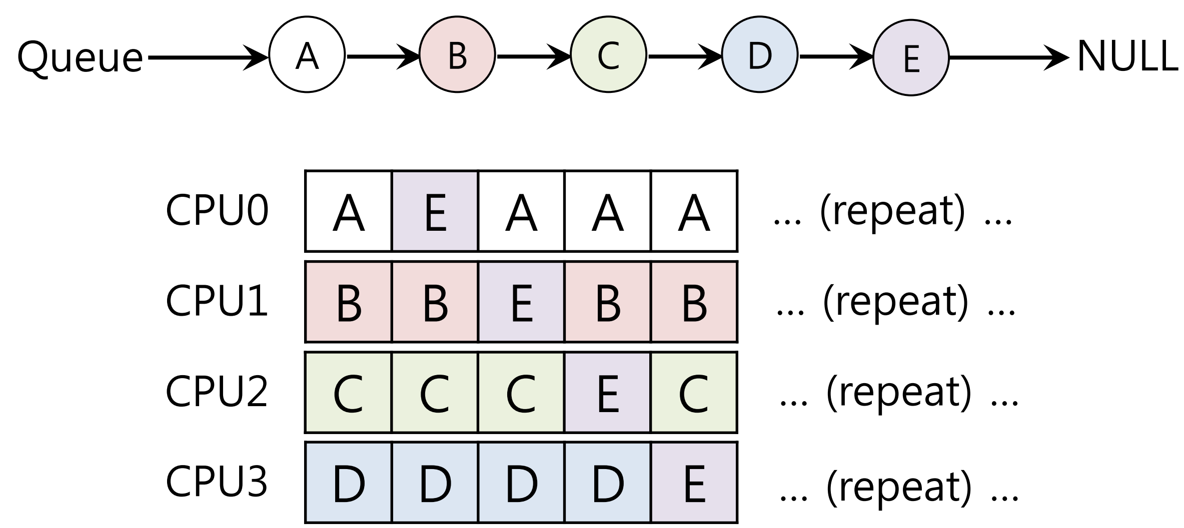
Put all jobs that need to be scheduled into a single queue.

- Each CPU simply picks the next job from the globally shared queue.
- Cons:
  - Some form of **locking** have to be inserted → Lack of scalability
  - Cache affinity
  - Example:
  - Possible job scheduler 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



Preserving affinity for most

- Jobs A through D are not moved across processors.
- Only job E Migrating from CPU to CPU.

Implementing such a scheme can be **complex**.

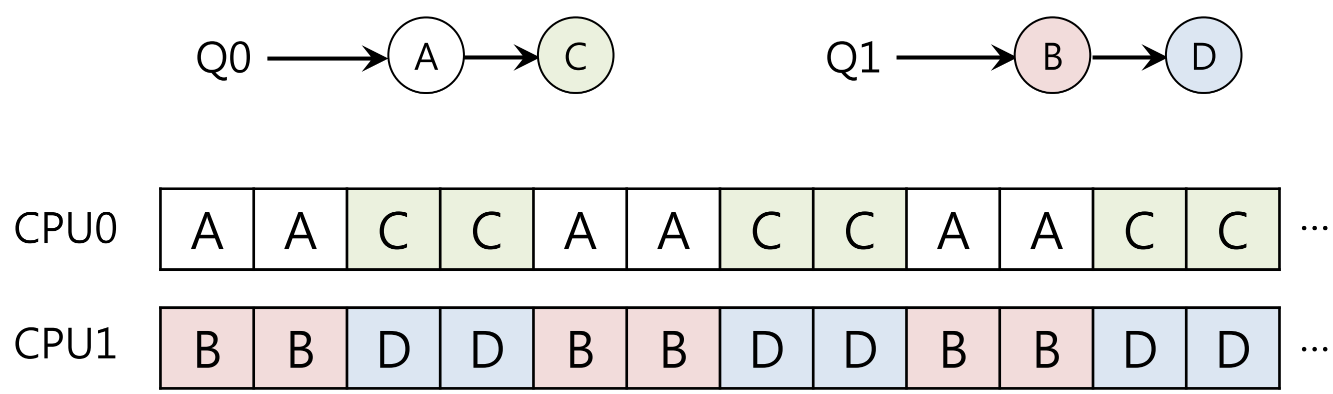
Multi-Queue Multiprocessor Scheduling (MQMS)

MQMS consists of multiple scheduling queues.

- Each queue will follow a particular scheduling discipline.
- When a job enters the system, it is placed on **exactly one** scheduling queue.
- Avoid the problems of <u>information sharing</u> and <u>synchronization</u>.

MQMS Example

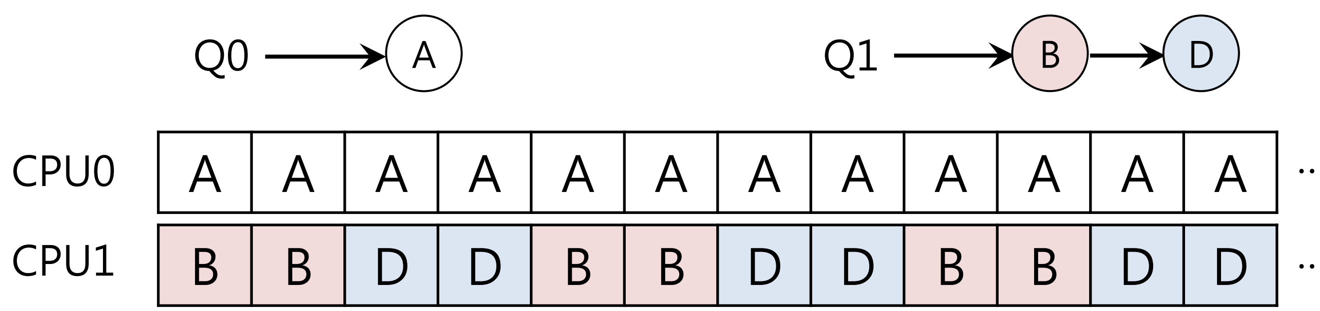
With **round robin**, the system might produce a schedule that looks like this:



MQMS provides more scalability and cache affinity.

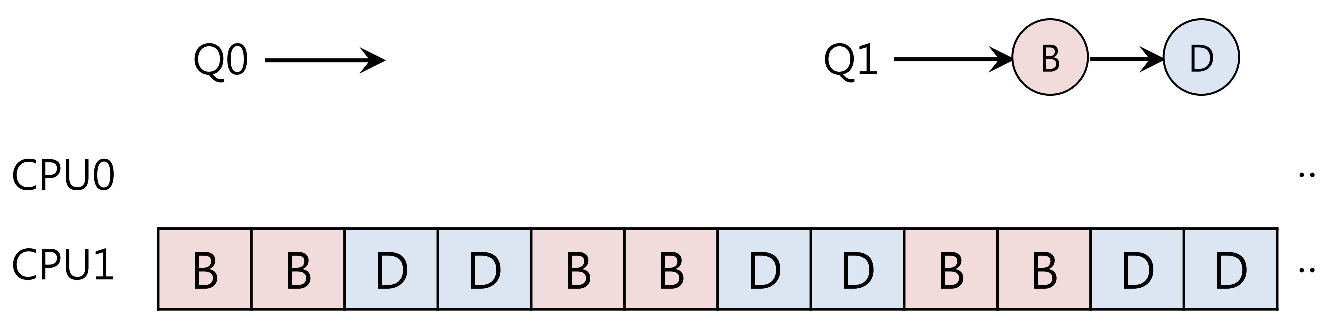
Load Imbalance issue of MQMS

- After job C in Q0 finishes:



A gets twice as much CPU as B and D.

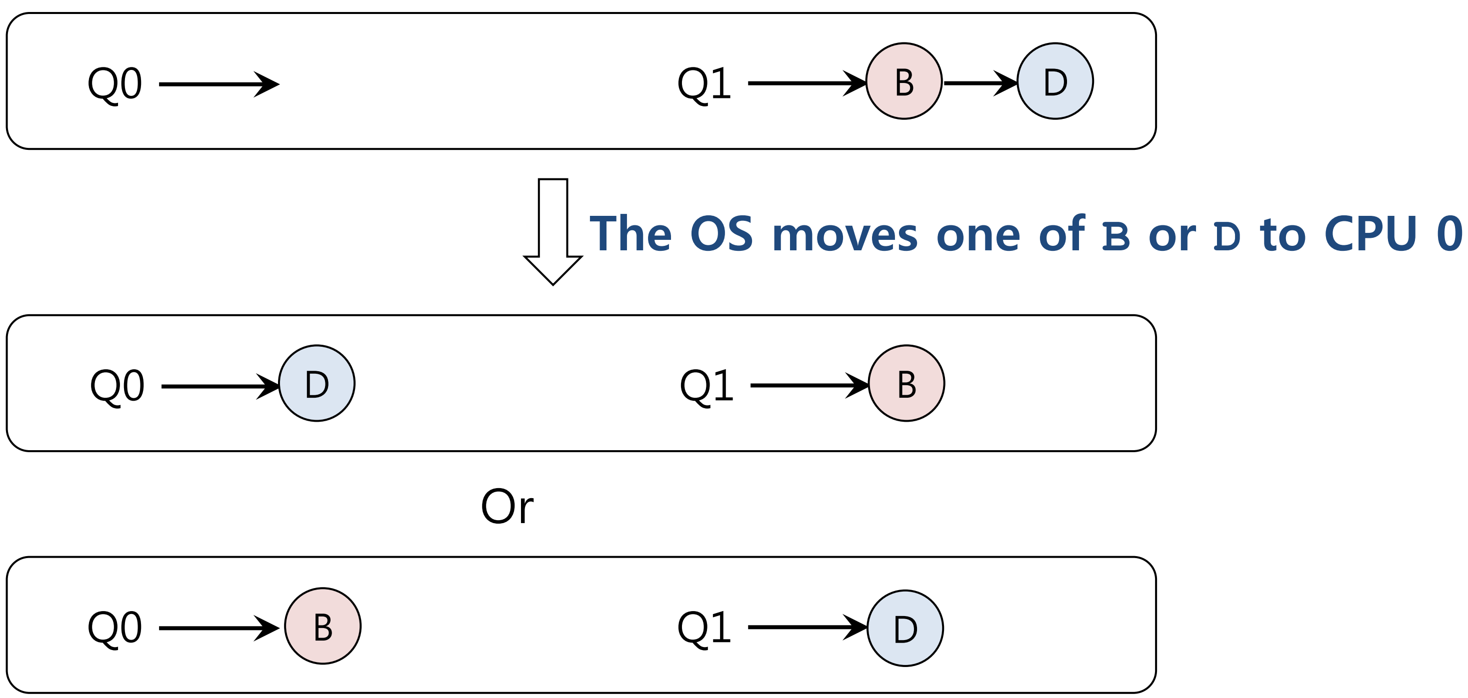
- After job A in Q0 finishes:



CPU0 will be left idle!

How to deal with load imbalance?

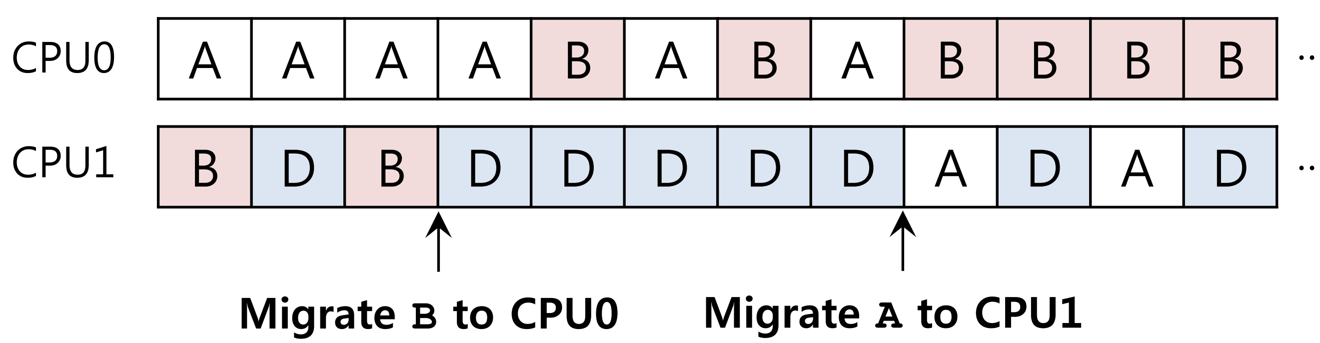
- The answer is to move jobs (**Migration**).
  - Example:



How to deal with load imbalance? (Cont.)

- A more tricky case:

- A possible migration pattern:
  - Keep switching jobs



Work Stealing

Move jobs between queues

Implementation:

- A source queue that is low on jobs 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 jobs 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

BF Scheduler (BFS)

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