The first spring 2021 assignment explained

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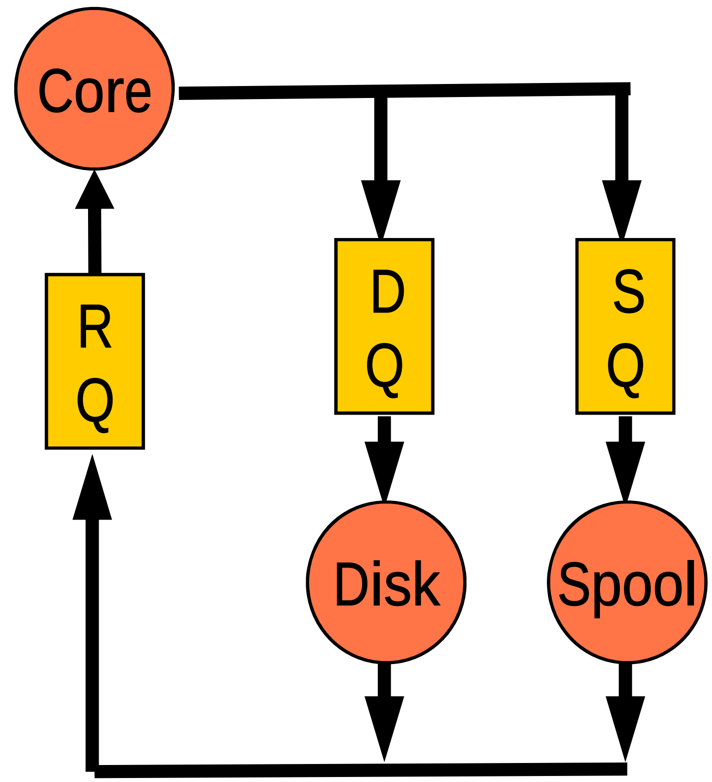
The model

We have

- One single core CPU
- One disk
- One print spooler
- Three queues
  - CPU (Ready queue)
  - Disk
  - Spooler



A deck of punched cards

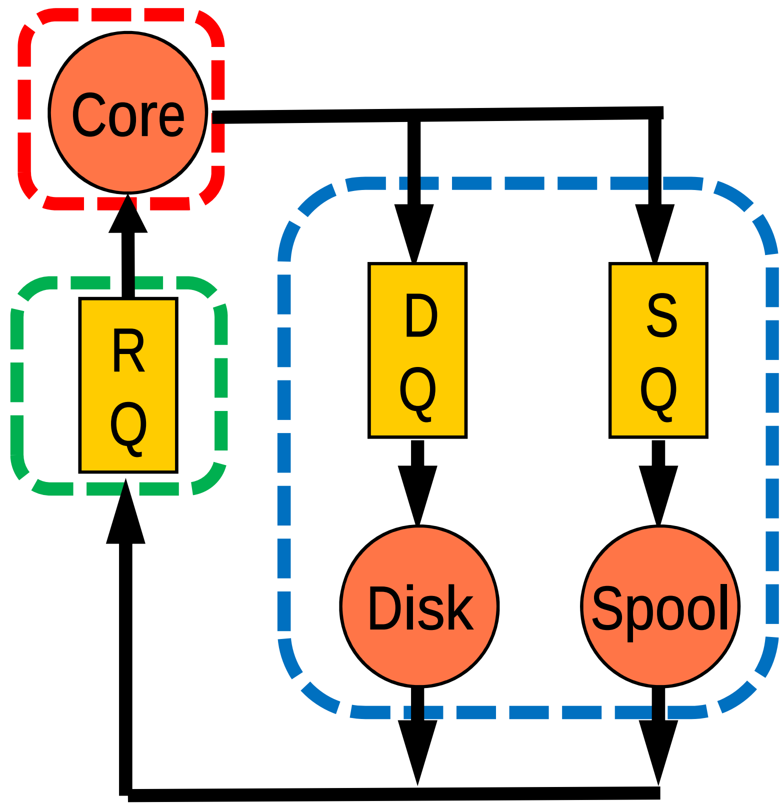
A very simple case

```
MPL    1          // no multiprogramming
JOB    1          // new job
CORE     100      // request CORE for 100ms
DISK     0        // no wait disk request
CORE     30       // request CORE for 30ms
DISK     7        // request DISK for 7ms
CORE     20       // request CORE for 20s
PRINT   1000      // print spooler request
CORE    20        // request CORE for 30ms
```

Job/process states

A job can be

- ***Running***
  - It *occupies* a core
- ***Ready***
  - It waits for a core
- ***Blocked***
  - It waits for the completion of a system request



Starting the simulation

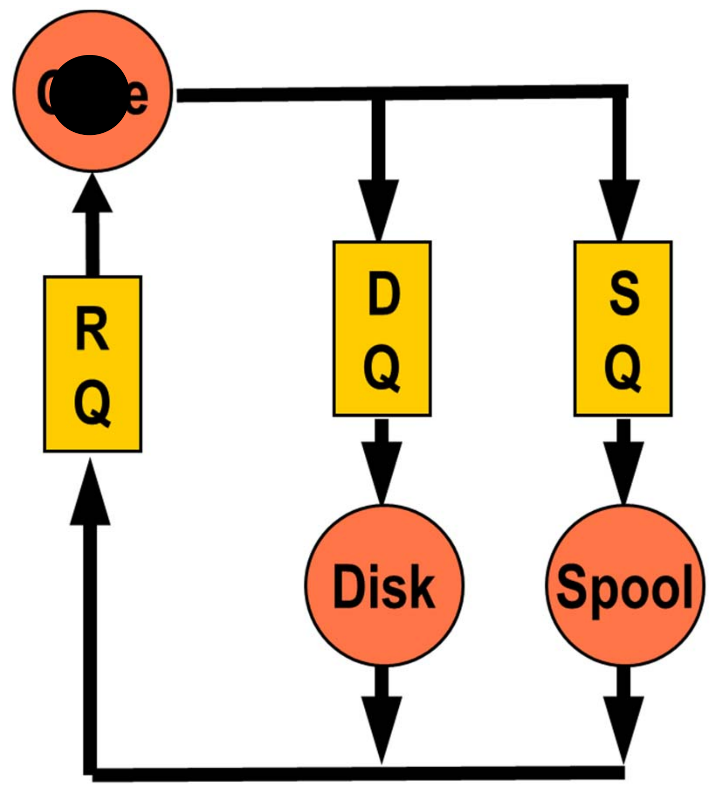
- **`MPL 1`**
  - Jobs are processed one by one
  - Set (simulated) time to zero
- **`JOB 1`**
  - Fetch and start processing job

Output

- ```
  Job 1 starts at time 0 ms
  Job Table:
  There are no other active jobs
  ```
  ```

Allocate core to job 1 for 100ms at *t* = 0ms

- MPL 1
JOB 1
<u>CORE 100</u>
DISK 0
CORE 30
DISK 7
CORE 20
PRINT 1000
CORE 20



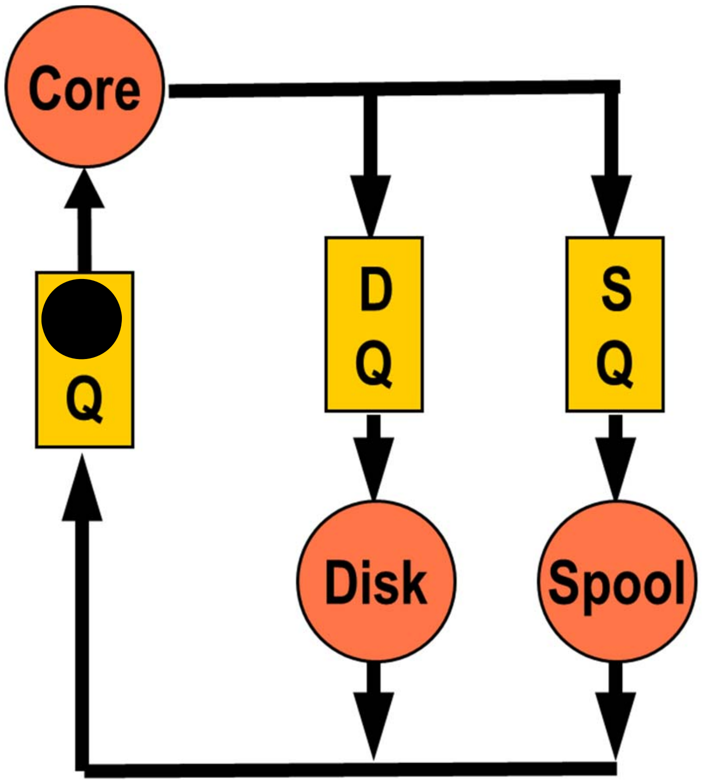
What’s next?

- Must wait end of core step at t = 100ms
- Can then perform the next step

- **Set t = 100ms**

Zero-time disk access at t = 100ms

- MPL 1
  JOB 1
  CORE 100
  DISK 0
  CORE 30
  DISK 7
  CORE 20
  PRINT 1000
  CORE 20



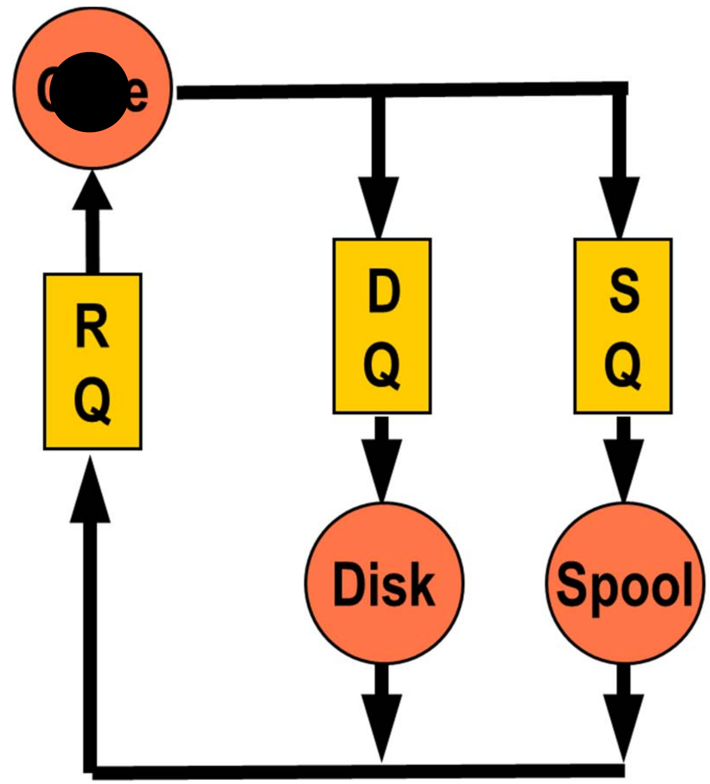
What's next?

- Immediately perform the next step
- At ***t* = 100ms**

A zero-delay disk request (DISK 0)
- ***Always bypasses*** the disk
- ***Never waits*** for it

Allocate core to job 1 for 30ms at t = 100ms

- MPL 1
  JOB 1
  CORE 100
  DISK 0
  CORE 30
  DISK 7
  CORE 20
  PRINT 1000
  CORE 20



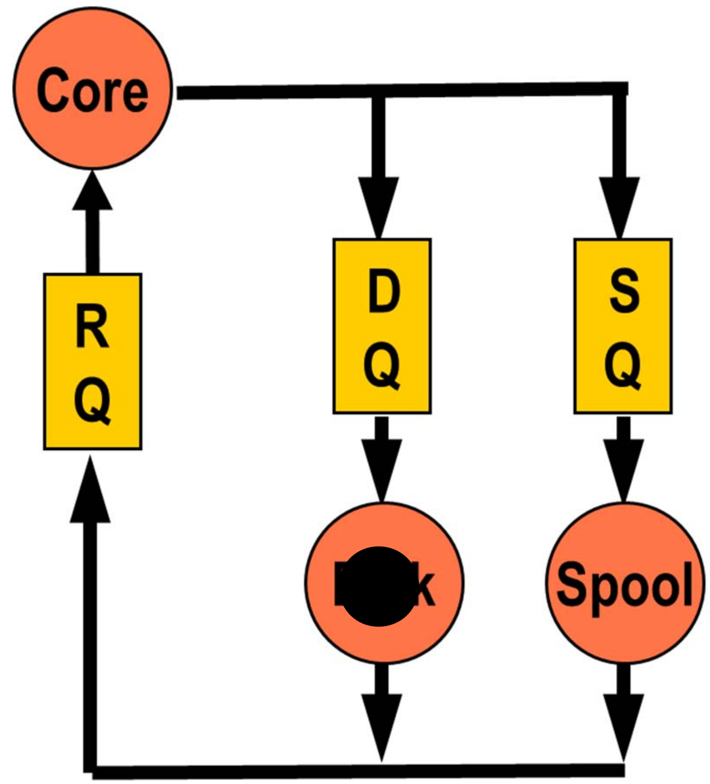
What’s next?

- Must wait end of core step at t = 100ms + 30ms = 130ms
- Can then perform the next step

- **Set *t* = 130ms**

Allocate disk to job 1 for 7ms at t = 130ms

- MPL 1
  JOB 1
  CORE 100
  DISK 0
  CORE 30
  <u>DISK 7</u>
  CORE 20
  PRINT 1000
  CORE 20



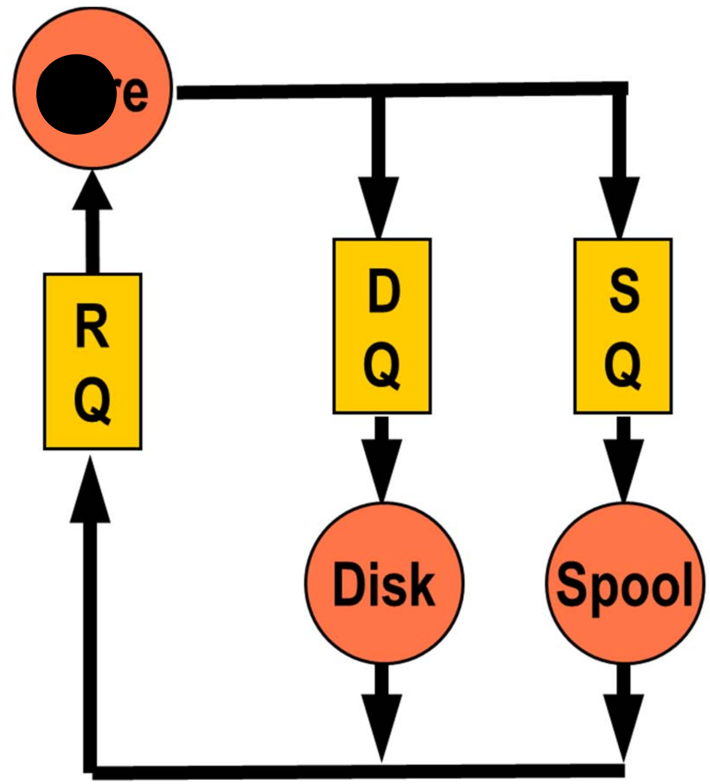
What’s next?

- Must wait end of disk step at *t* = 130ms + 7ms = **<u>137ms</u>**
- Can then perform the next step

- **Set *t* = 137ms**

Allocate core to job 1 for 20ms at t = 137ms

- MPL 1
  JOB 1
  CORE 100
  DISK 0
  CORE 30
  DISK 7
  <u>CORE 20</u>
  PRINT 1000
  CORE 20



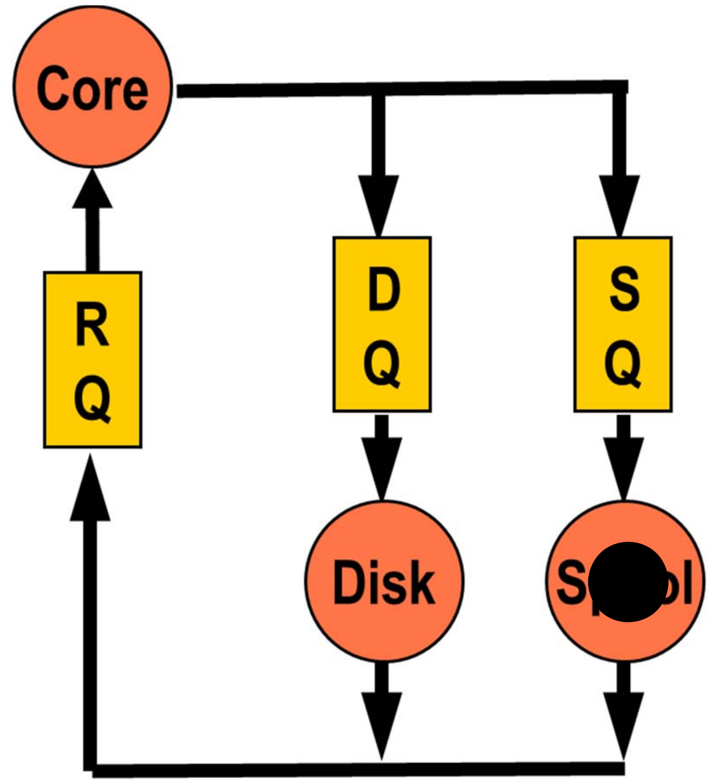
What's next?

- Must wait end of core step at t = 137ms + 20ms = **157ms**
- Can then perform the next step

  - **Set t = 157ms**

Allocate spooler to job 1 for 1000ms at t = 157ms

- MPL 1
  JOB 1
  CORE 100
  DISK 0
  CORE 30
  DISK 7
  CORE 20
  <u>PRINT 1000</u>
  CORE 20



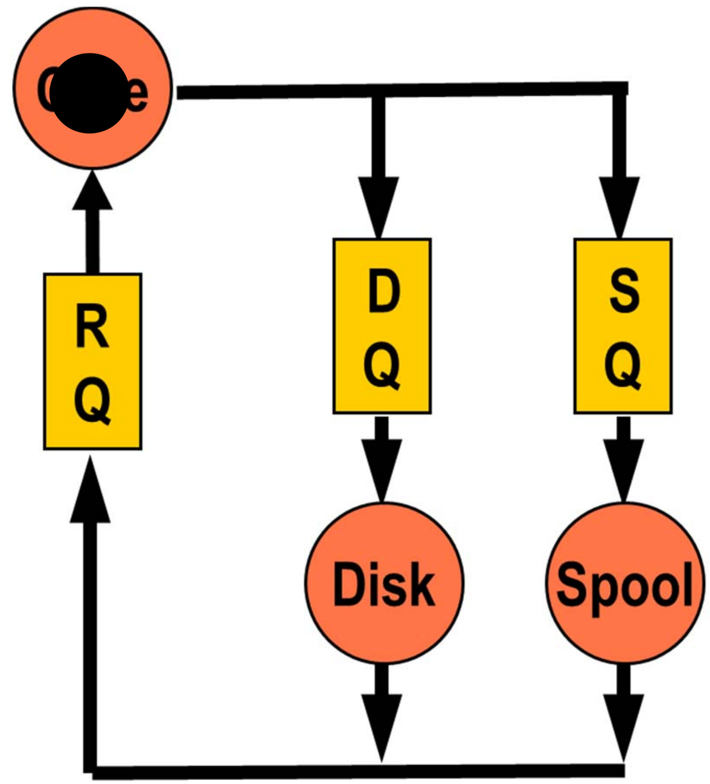
What's next?

- Must wait end of spooler step at t = 157ms + 1000ms = **<u>1157ms</u>**
- Can then perform the next step

- **Set *t* = 1157ms**

Allocate core to job 1 for 20ms at t = 1157ms

- MPL 1
  JOB 1
  CORE 100
  DISK 0
  CORE 30
  DISK 7
  CORE 20
  PRINT 1000
  CORE 20



What’s next?

- Job 1 has terminated
- Print the required output

Output

- ```
  Job 1 terminates at time 1177ms
  Job Table:
  There are no active jobs
  ```
- ```
  SUMMARY:
  Total elapsed time: 1177ms
  Number of jobs that have completed: 1
  Total number of disk accesses: 2
  Core utilization: 0.13
  ```

Things become interesting

```
MPL   2          // memory can hold 2 jobs
JOB   1          // new job
CORE    100      // request CORE for 100ms
DISK    9        // request DISK for 9ms
CORE    30       // request CORE for 30ms
JOB    5         // new job
CORE    20       // request CORE for 20s
DISK    8        // request DISK for 8ms
CORE   20        // request CORE for 30ms
```

Starting the simulation

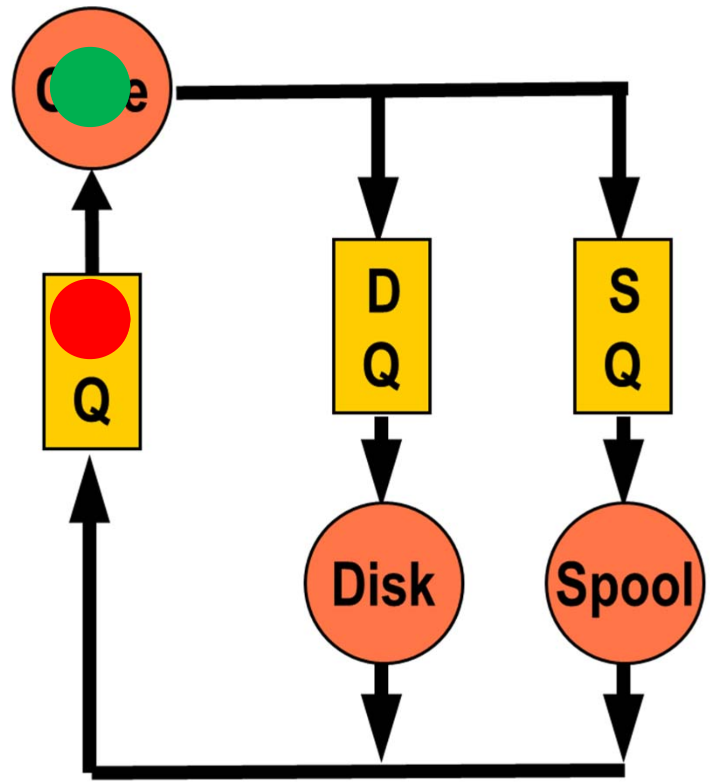
- `MPL   2`
  - Two jobs now compete for system resource
    - Better utilization of CPU, disk, …
    - Price to pay is ***queuing delays***
  - Set (simulated) time to zero
- `JOB 1`
  - Fetch and start processing job 1
- `JOB 5`
  - Fetch and put on hold job 5 in ready queue

Output

- `Job 1 starts at time 0 ms`
  `Job Table:`
  `There are no other active jobs`
- `Job 5 starts at time 0 ms`
  `Job Table:`
  `Job 1 is RUNNING` (Will also accept `Job 1 is READY`)

Allocate core to job 1 for 100ms at *t* = 0ms
Note job 5 requests core

- MPL 2
  JOB 1
  CORE 100
  DISK 9
  CORE 30
  JOB 5
  CORE 20
  DISK 8
  CORE 20



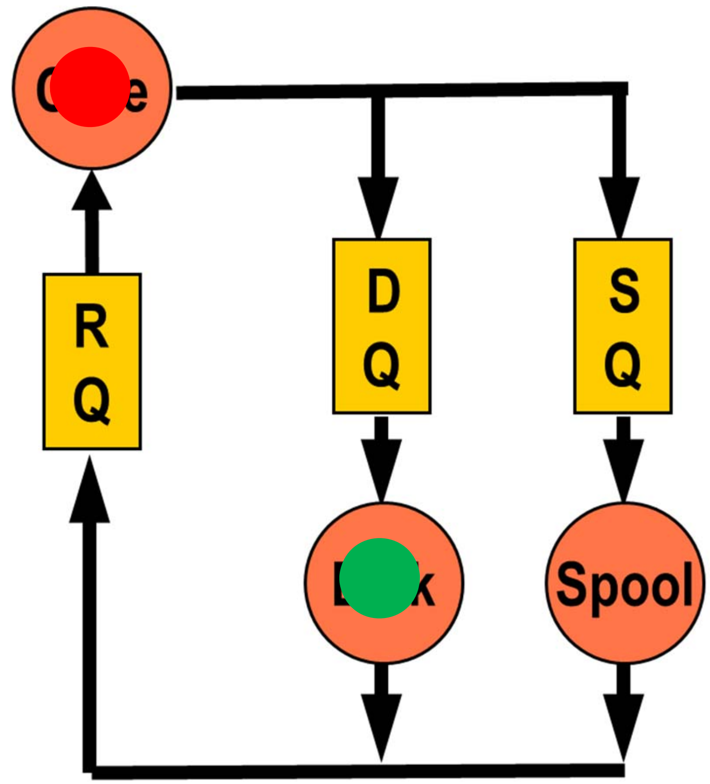
What’s next?

- Must wait end of core step at t = 0ms + 100ms = **<u>100ms</u>**
- Can then perform the next step

- **Set t = 100ms**

Allocate disk to job 1 for 9ms at *t* = 100ms
Allocate core to job 5 for 20ms

- MPL 2
  JOB 1
  CORE 100
  DISK 9
  CORE 30
  JOB 5
  CORE 20
  DISK 8
  CORE 20



What's next

- Must wait for the first task to complete:
  - Disk I/O for job 1 ending at t = 100ms + 9ms = <u>**109ms**</u>
  - CORE request from job 5 ending at t = 100ms + 20ms = 120ms

- Disk I/O for job 1 completes first
  - **Set t = 109ms**

Event list

- Tells your program decide what step to take next
- Each record describes a completion event
  - Expected time
  - Type of event
  - Job ID

t = 109ms
DISK
Job 1

t = 120ms
CORE
Job 5

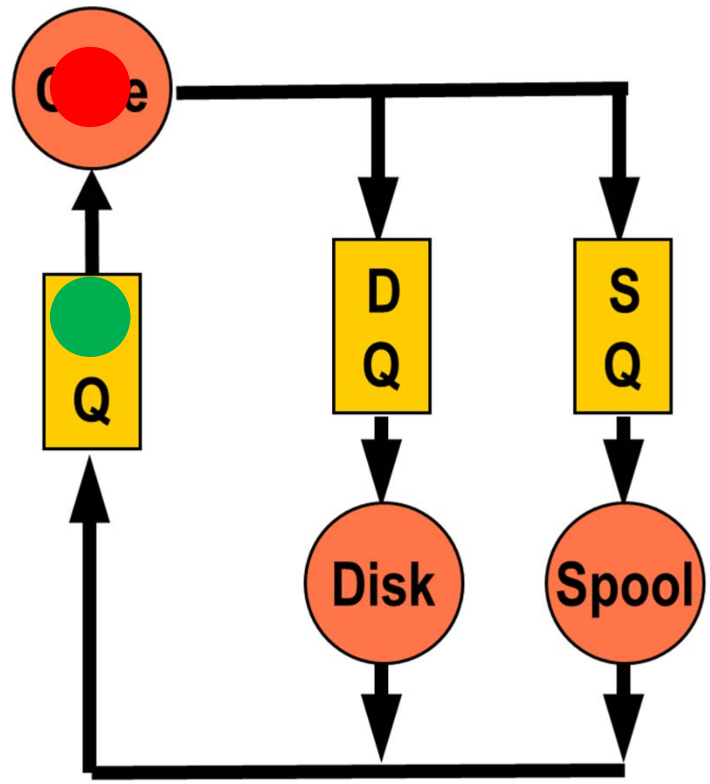
Using the event list

- When deciding which step to take,
  must always pick the one associated with the next event

***t* = 109ms** **DISK** **Job 1**	***t* = 120ms** **CORE** **Job 5**

Job 1 requests a core at t = 109ms

- MPL 2
  JOB 1
  CORE 100
  DISK 9
  <u>CORE 30</u>
  JOB 5
  <u>CORE 20</u>
  DISK 8
  CORE 20



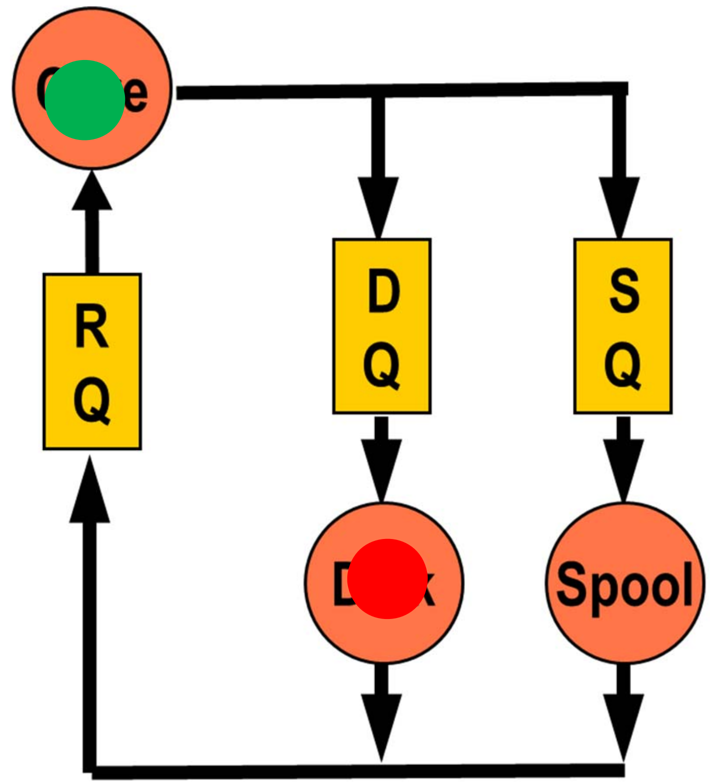
The new event list

- Only one entry
- **Set *t* = 120ms**

t **= 120ms**
CORE
Job 5

Allocate core to job 1 for 30ms at t = 120ms
Allocate disk to job 5 for 8ms

- MPL 2
JOB 1
CORE 100
DISK 9
<u>CORE 30</u>
JOB 5
CORE 20
<u>DISK 8</u>
CORE 20



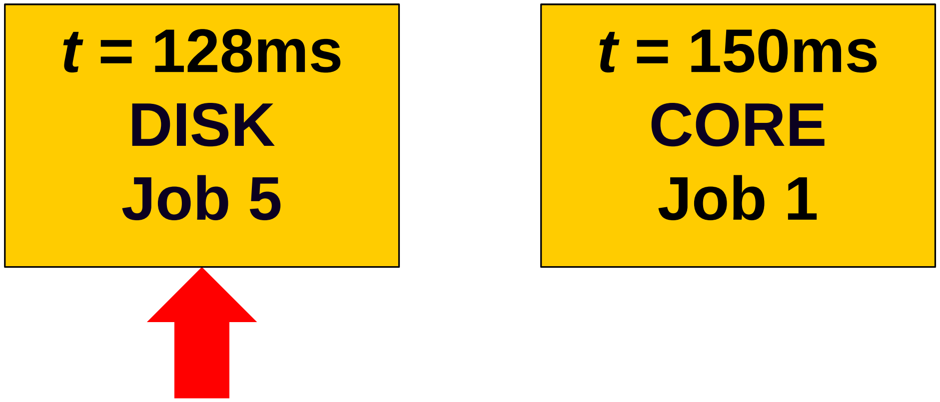
What's next

- Must wait for the first task to complete:
  - Disk I/O for job 5 ending at t = 120ms +8ms = **<u>128ms</u>**
  - CORE request from job 1ending at t = 120ms + 30ms = 150ms

- Disk I/O for job 5 completes first
  - **Set *t* = 128ms**

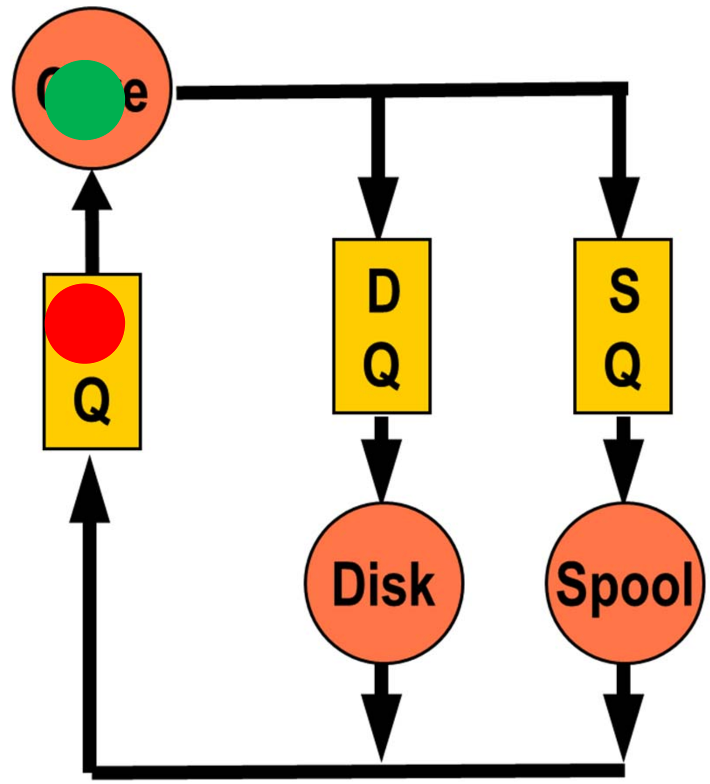
The new event list

- When deciding which step to take,
  must always pick the one associated with the next event



Job 5 requests CORE at t = 128ms

- MPL 2
  JOB 1
  CORE 100
  DISK 9
  CORE 30
  JOB 5
  CORE 20
  DISK 8
  CORE 20

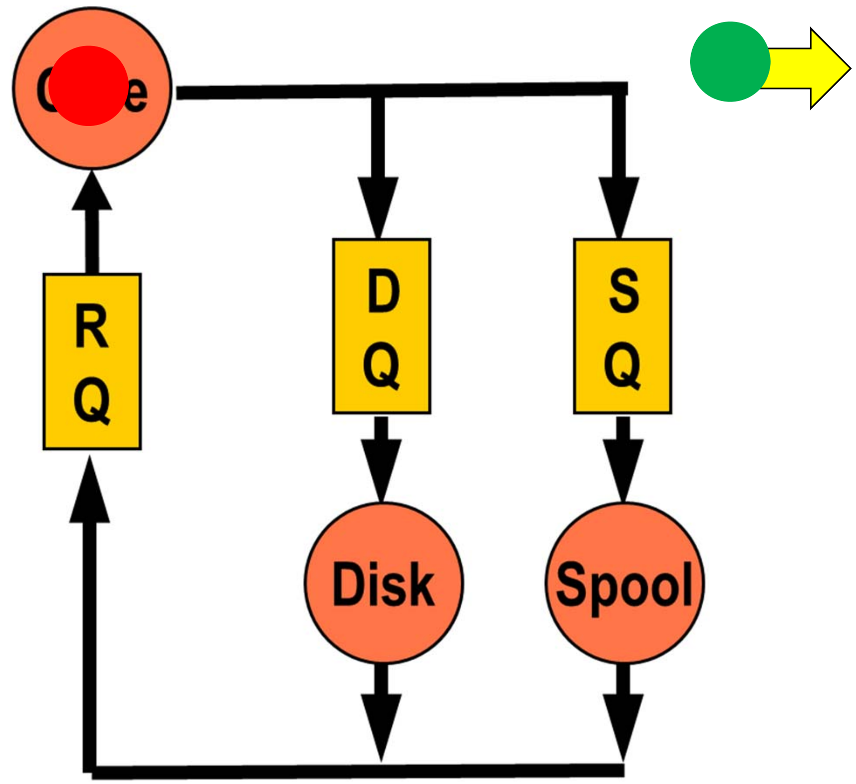


The new event list

***t* = 150ms**
CORE
Job 1

Job 1 terminates at *t* = 150ms
Allocate core to job 5 for 20ms

- MPL 2
  JOB 1
  CORE 100
  DISK 9
  CORE 30
  JOB 5
  CORE 20
  DISK 8
  <u>CORE 20</u>



Output

- ```
  Job 1 terminates at time 150ms
  Job Table:
  Job 5 is RUNNING
  ```
  ```

Output

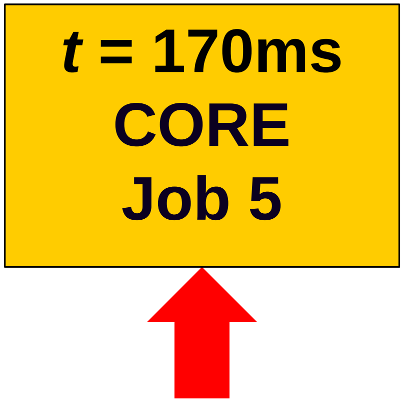
- ```
  Job 1 terminates at time 150ms
  Job Table:
  Job 5 is RUNNING
  ```
  ```

What's next

- Must wait for the completion of core request for job 5 ending at t = 150ms +20ms = **170ms**

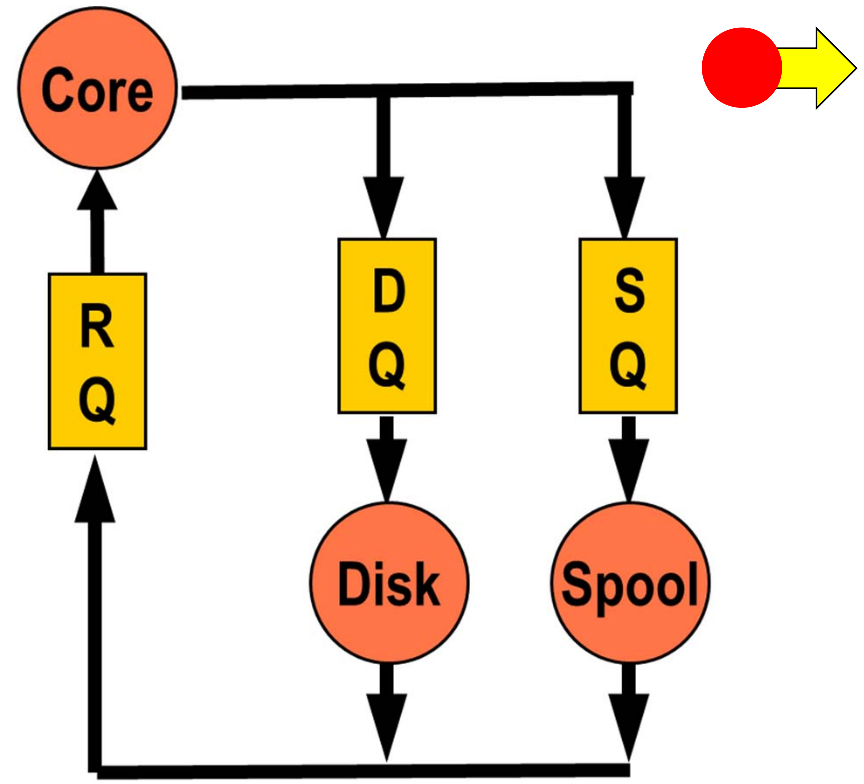
- **Set t = 170ms**

The new event list



Job 5 terminates at *t* = 170ms

- MPL 2
  JOB 1
  CORE 100
  DISK 9
  CORE 30
  JOB 5
  CORE 20
  DISK 8
  CORE 20



Output

- ```
  Job 5 terminates at time 170ms
  Job Table:
  There are no active jobs
  ```
- ```
  SUMMARY:
  Total elapsed time: 170ms
  Number of jobs that have completed: 2
  Number of disk accesses: 2
  Core utilization: 1.00
  ```

Computing core utilization

- $$\frac{\text{Sum of all CORE times}}{\text{Simulated elapsed time}}$$
- (100 + 30 + 20 + 20)/170 = 1.00
  - *The CPU was always busy*

Handling parallel activities

- We only need to consider start times and completion times of each computational step
- Completion times are the most important
  - Release a device
  - Initiate the next request
    - Can be immediately satisfied if requested device is free
    - May require job to wait for device
      - Ready queue, disk queue, spooler queue

The simulated time

- Imaginary clock keeping track of simulated time
  - Never ticks
  - Only updated each time we process a new event

ENGINEERING THE SIMULATION

Simulating time

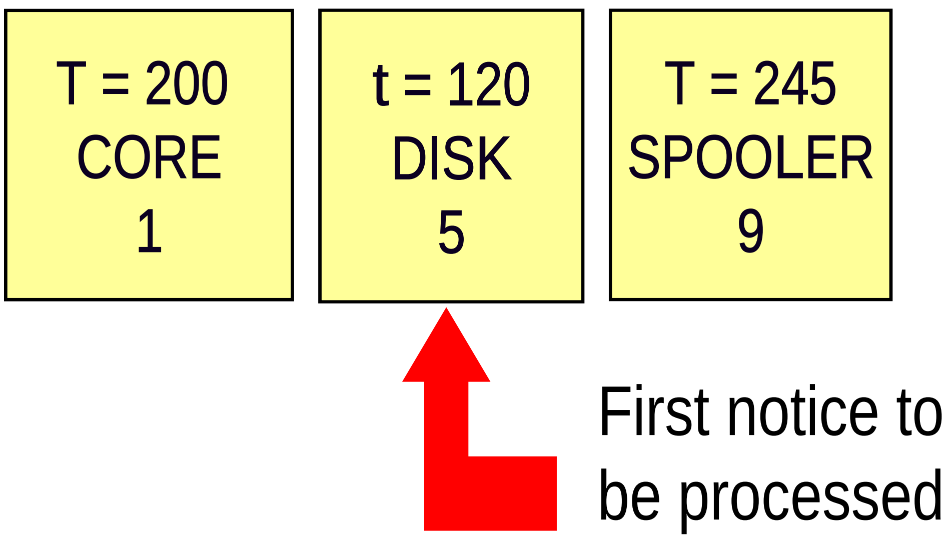
- ***Absolutely nothing happens to our model between two successive "<u>events</u>"***
- ***Events are***
  - Completion of a computing step
  - Completion of a disk access
  - Completion of a spooler request
- We associate an ***event routine*** with each event

Organizing our program (I)

- Most steps of simulation involve scheduling future completion events
- Associate with each completion event an event notice
  - ***Time of event***
  - ***Device (core, disk, spooler)***
  - ***Job ID***

Organizing our program (II)

- Process all event notices in chronological order



Organizing our program (III)

- Overall organization of main program

```
read in input file
start first MPL jobs
while (event list is not empty) {
      process next event in list
} // while
print simulation results
```

Organizing our program (IV)

- Processing next event in list

```
pop event from list
clock = event.time
if (event.type is core) {
    core(event.time, event.jobID)
else if (event.type is disk) {
    disk(event.time, event.jobID)
```

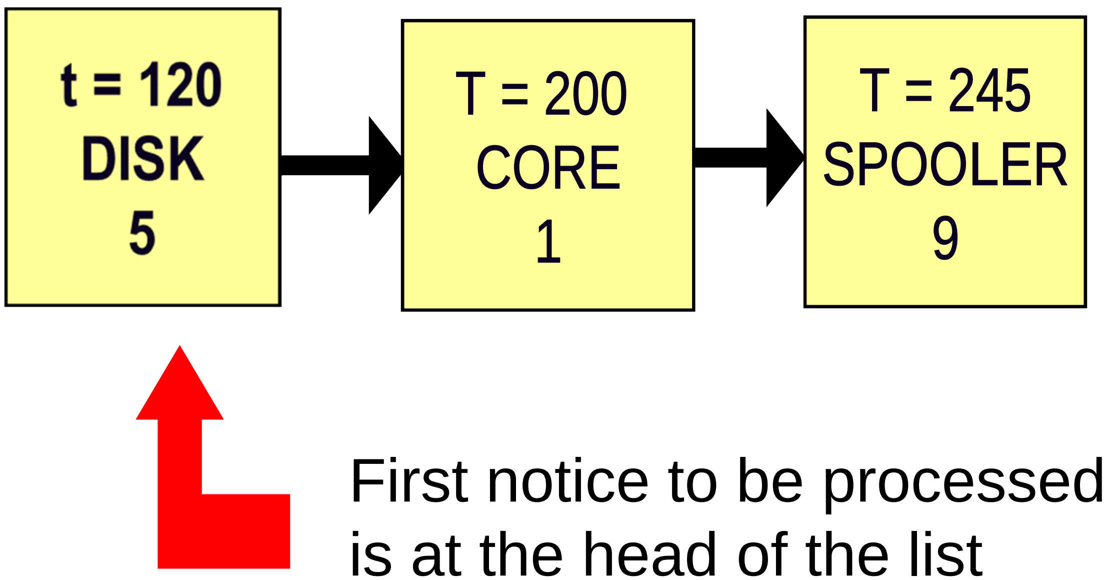
Organizing our event list (I)

- As a priority queue

- Associating a completion time
  - With each core request
  - With each disk request
  - With each spooler request

Organizing our event list

- Process all event notices in time order



First notice to be processed
is at the head of the list

Core request routine

```
core_request(how_long, jobID){
     if (core == FREE) {
          core = BUSY;
          schedule CORE completion at time
          current_time + how_long for job jobID;
     } else {
          queue jobID in readyQueue
     }  // if
} // core_request
```

Core completion routine

```
core_release (jobID){
     if (readyQueue is not empty) {
          pop first core request in readyQueue
          schedule its completion at
          current_time + how_long
     } else {
          core = FREE;
     } //if
     process next job request for job jobID
} // core_release
```

Disk request routine

```
disk_request(how_long, jobID){
     if (how_long == 0) {
          perform next job request
     } else if (disk == FREE) {
          disk = BUSY;
          schedule DISK completion event at time
          current_time + how_long for job jobID
     } else {
          queue job jobID in diskQueue;
     }  // if
} // disk_request
```

Disk completion routine

```
disk_release (jobID){
     if (disk queue is not empty) {
          pop first request in disk queue
          schedule its completion at
          current_time + how_long;
     } else {
          disk = FREE;
     } // if
     process next job request for job jobID
} // disk_release
```

Spooler request routine

```
spooler_request(how_long, jobID){
     if (spooler == FREE) {
          disk = BUSY;
          schedule SPOOLER completion event at time
          current_time + how_long for job jobID
     } else {
          queue job jobID in spoolerQueue;
     }  // if
} // spooler_request
```

Spooler completion routine

```
spooler_release (jobID){
     if (spooler queue is not empty) {
          pop first request in spooler queue
          schedule its completion at
          current_time + how_long;
     } else {
          spooler = FREE;
     } // if
     process next job request for job jobID
} // disk_release
```

Overview (I)

- ***Input module***
  - Read in all input data
    - Store them in a jobList
  - Start first MPL jobs
- ***Main loop***
  - Pops next event from event list
    - CORE completion
    - DISK completion
    - SPOOLER completion

Overview (II)

- ***Starting a job***
  - Will always be a Core request
- ***Handling job termination***
  - ```
    if (jobList is empty) {
        break;  //  then print summary
    } else  {
        pop next job from jobList
    } // if
    ```
    ```

Overview (III)

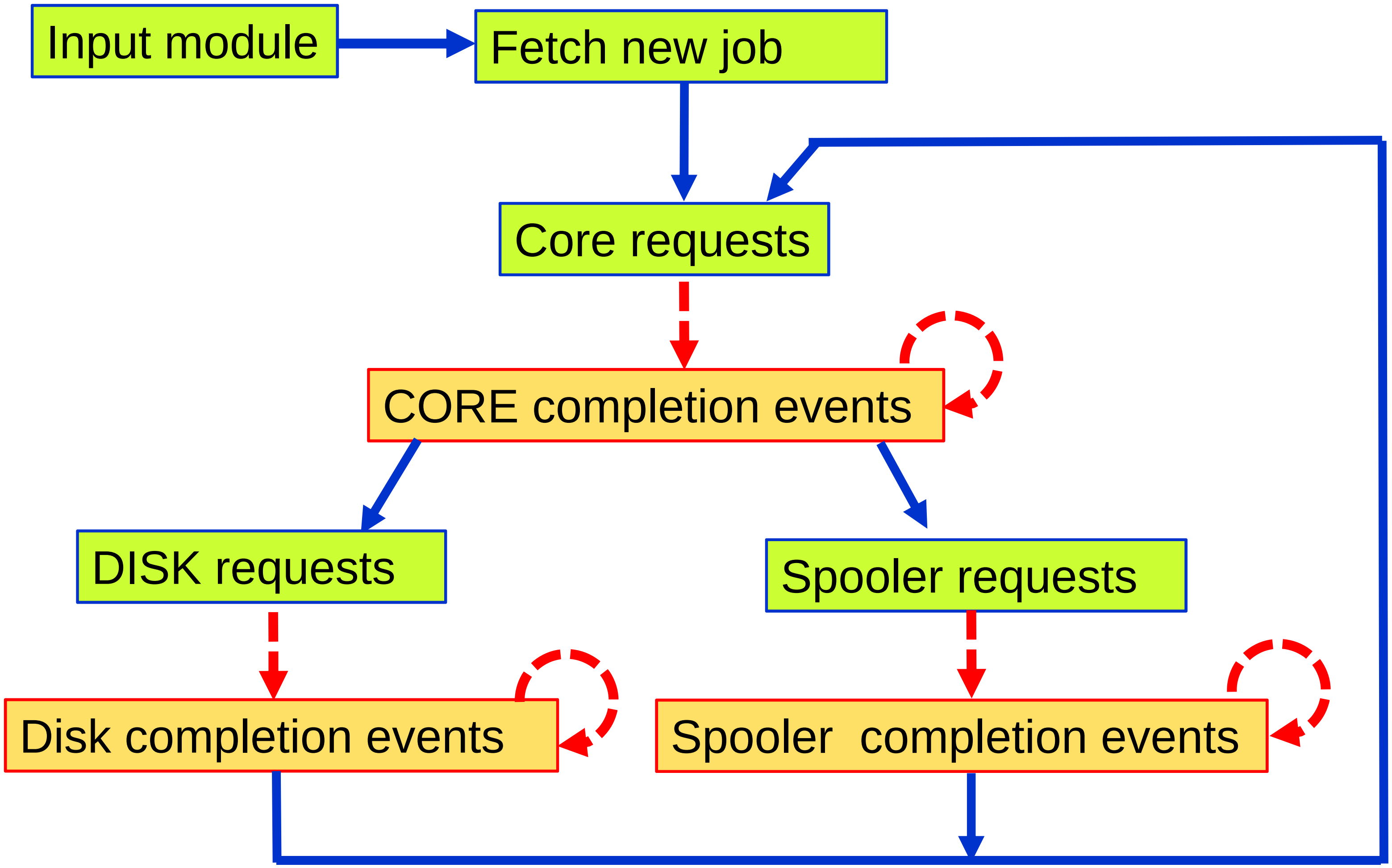
- ***Core request***
  - If a core is free
    - Schedules a CORE completion event
- ***CORE completion event***
  - May schedule a CORE completion event
  - Starts next request
    - DISK or SPOOLER

Overview (IV)

- ***Disk request***
  - If disk is free
    - Schedules an DISK completion event
- ***Disk completion event***
  - May schedule a DISK completion event
  - Starts next request
    - Always a CORE request

Overview (V)

- ***Spooler request***
  - Schedules a SPOOLER completion event
- ***Spooler completion event***
  - May schedule a SPOOLER completion event
  - Starts next request
    - Always a CORE request


Input module
Fetch new job
Core requests
CORE completion events
DISK requests
Spooler requests
Disk completion events
Spooler completion events

Explanations

- Green boxes represent conventional functions
- Amber boxes represent events and their associated functions
- Continuous blue arrows represent regular function calls
- Red dashed lines represent the scheduling of specific events

Finding the next event

- If you do not use a priority list for your events, you can find the next event to process by searching the **lowest value** among the times
  - The CPU will be done with the current job
  - The disk will complete a disk I/O
  - The spooler will be done with the current job

AN IMPLEMENTATION

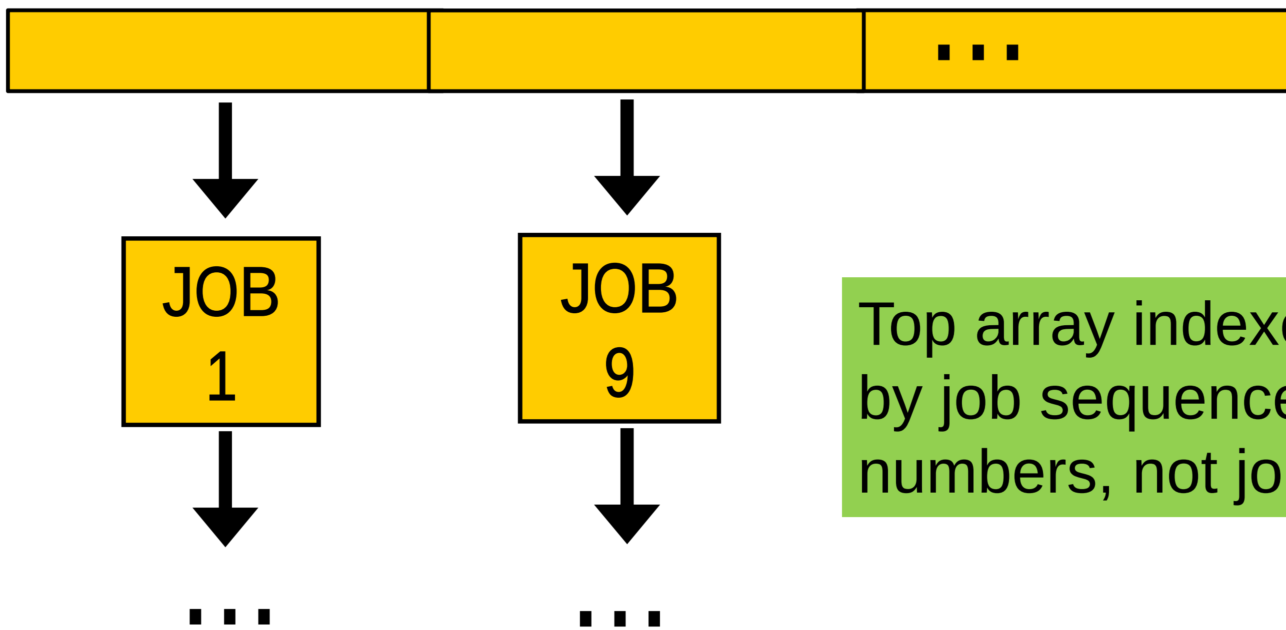
- My main data structures would include:
  - An input table
  - A job/process table
  - A device table

The input table

- Stores the input data
- Line indices are used in job table

Operation	Parameter
MPL	5
JOB	3
CORE	20
DISK	0
CORE	20
JOB	42
CORE	4
…	…

A more elegant input table



Top array indexed by job sequence numbers, not job ID

The job table/process table (I)

Job ID	First Line	Last Line	Current Line	State
3	1	4	varies	varies
4	5	…	…	
	…	…	…	

The job table/process table (II)

- One line per job
  - ***Line index is job sequence number*!**
- First column has start time of job
- First line, last line and current line respectively identify first line, last line and current line of the process in the input table
- Last column is for the current state of the process (READY, RUNNING or BLOCKED)

The device table (I)

Device	Status	Busy times total
CPU	P0	15
disk	-	--

The device table (II)

- One line per device
  - ***Line index identifies the device***
- First column has status of device
  - Number of free cores for CPU
  - Free/busy for disk
- Last column is for the total of all busy times

Reading your input

- You must use I/O redirection
  - **`assign1 < input_file`**
- ***Advantages***
  - Very flexible
  - Programmers write their code as if it was reading from standard input
    - No need to mess with **`fopen()`**, **`argc`** and **`argcv`**

Detecting the end of data

- The easiest ways to do it
- If you use **`scanf()`**
  - **`scanf(…)`** returns **`0`** once it reaches the end of data
    - **`while(scanf(…)) { … }`**
- If you use **`cin`**
  - **`cin`** returns **`0`** once it reaches the end of data
    - **`while (cin >> keyword >> argument)  { … }`**