Operating Systems

Christopher Kruegel
Department of Computer Science
UC Santa Barbara
http://www.cs.ucsb.edu/~chris/

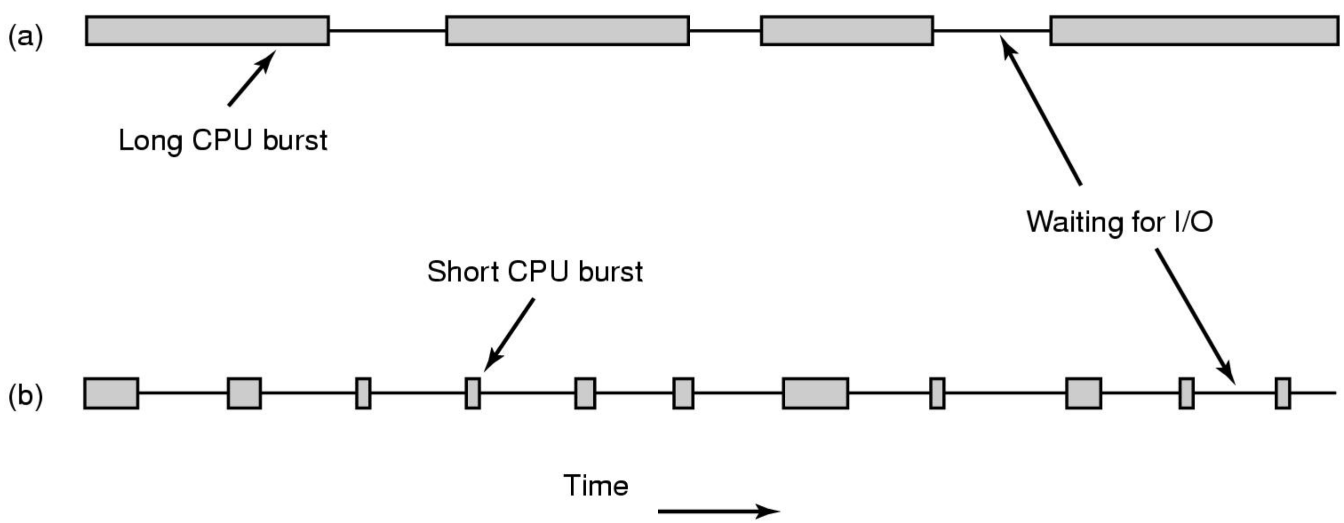
Scheduling

- Many processes to execute, but one CPU
- OS time-multiplexes the CPU by operating context switching
  - Between user processes
  - Between user processes and the operating system
- Operation carried out by *scheduler* following a *scheduling algorithm*

- Switching is expensive
  - Switch from user to kernel model
  - Save the state of the current process (including memory map)
  - Select a process for execution (scheduler)
  - Restore the saved state of the new process

CPU-bound and I/O-bound Processes

- Bursts of CPU usage alternate with periods of I/O wait
  - a CPU-bound process (a)
  - an I/O bound process (b)



When To Schedule

- Must schedule
  - a process blocks (I/O, semaphore, etc)
  - a process exits
- May schedule
  - new process is created (parent and child are both ready)
  - I/O interrupt
  - clock interrupt

Scheduling Algorithms

- Non-preemptive
  - CPU is switched when process
    - has finished
    - executes a yield()
    - blocks
- Preemptive
  - CPU is switched independently of the process behavior
    - A clock interrupt is required
- Scheduling algorithms should enforce
  - Fairness
  - Policy
  - Balance

Scheduling in Batch Systems

- Goals
  - Throughput:
    maximize jobs per hour
  - Turnaround time:
    minimize time between submission and termination
  - CPU utilization
    keep processor busy

- Examples
  - First-come first-served
  - Shortest job first
  - Shortest remaining time next

First-Come First-Served

- Processes are inserted in a queue
- The scheduler picks up the first process, executes it to termination or until it blocks, and then picks the next one
- Very simple

- Disadvantage
  - I/O-bound processes could be slowed down by CPU-bound ones

Shortest Job First

- This algorithm assumes that running time for all the processes to be run is known in advance
- Scheduler picks the shortest job first
- Optimizes turnaround time
  - a) Turnaround is A=8, B=12, C=16, D=20 (avg. 14)
  - b) Turnaround is B=4, C=8, D=12, A=20 (avg. 11)

- Problem: what if new jobs arrive?

(a) (b)

Shortest Remaining Time Next

- This algorithm also assumes that running time for all the processes to be run is known in advance
- The algorithm chooses the process whose remaining run time is the shortest
- When a new job arrive, its remaining run time is compared to the one of the process running
- If current process has more remaining time than the run time of new process, the current process is preempted and the new one is run

Scheduling in Interactive Systems

- Goals
  - Response time:
    minimize time needed to react to requests
  - Proportionality:
    meet user expectations

- Examples
  - Round robin
  - Priority scheduling
  - Lottery scheduling

Round Robin Scheduling

- Each is process is assigned a *quantum*
- The process
  - Suspends before the end of the quantum or
  - Is preempted at the end of the quantum
- Scheduler maintains a list of ready processes

(a) (b)

Round Robin Scheduling

- Parameters:
  - Context switch (e.g., 1 msec)
  - Quantum length (e.g., 25 msec)

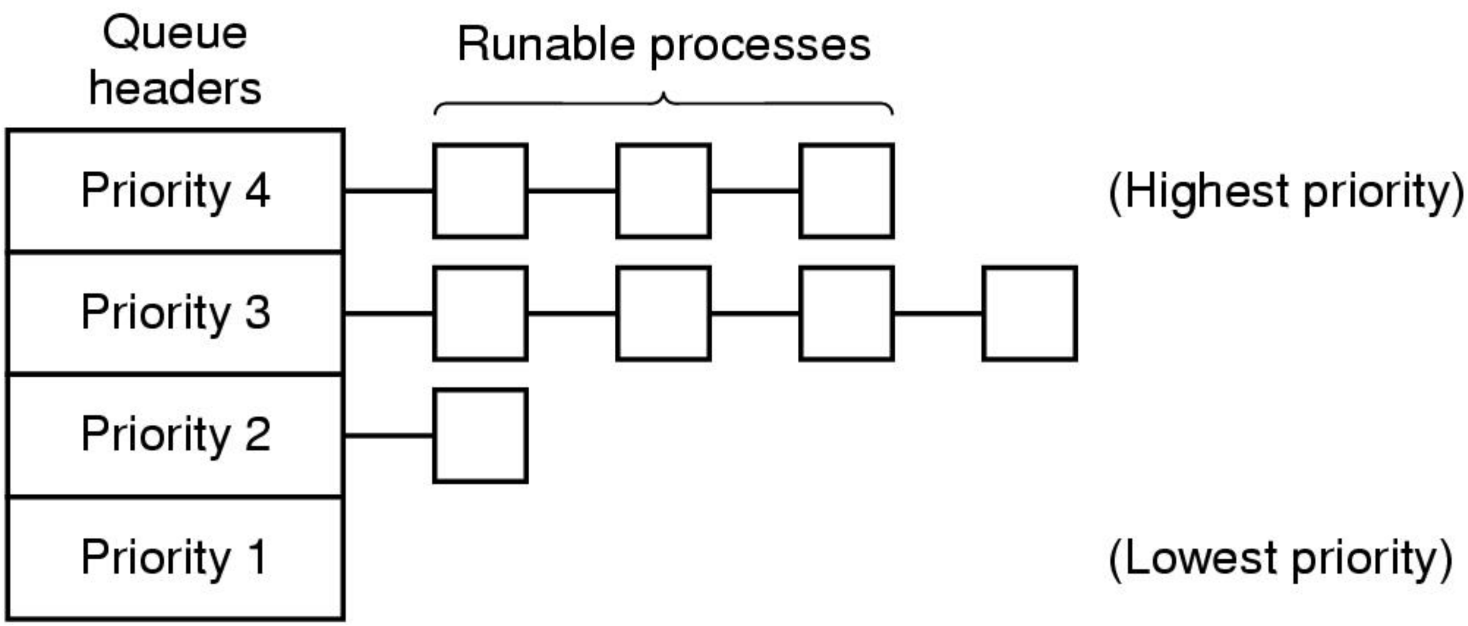
- If quantum is too small, a notable percentage of the CPU time is spent in switching contexts

- If quantum is too big, response time can be very bad

Priority Scheduling

- Each process is assigned a priority
- The process with the highest priority is allowed to run
- I/O bound processes should be given higher priorities
- Problem: low priority processes may end up starving...
- First solution: As the process uses CPU, the corresponding priority is decreased
- Second solution: Set priority as the inverse of the fraction of quantum used
- Third solution: Used priority classes (starvation is still possible)

Priority Scheduling



Lottery Scheduling

- OS gives “lottery tickets” to processes
- Scheduler picks a ticket randomly and gives CPU to the winner
- Higher-priority processes get more tickets

- Advantage:
  - processes may exchange tickets
  - it is possible to fine tune the share of CPU that a process receives
  - easy to implement

Scheduling

- Example
  - non-preemtive priority scheduling

Process	Start	Runtime	Priority
A	0	5	2
B	3	1	1
C	4	3	4
D	8	7	0
E	12	2	3

Scheduling

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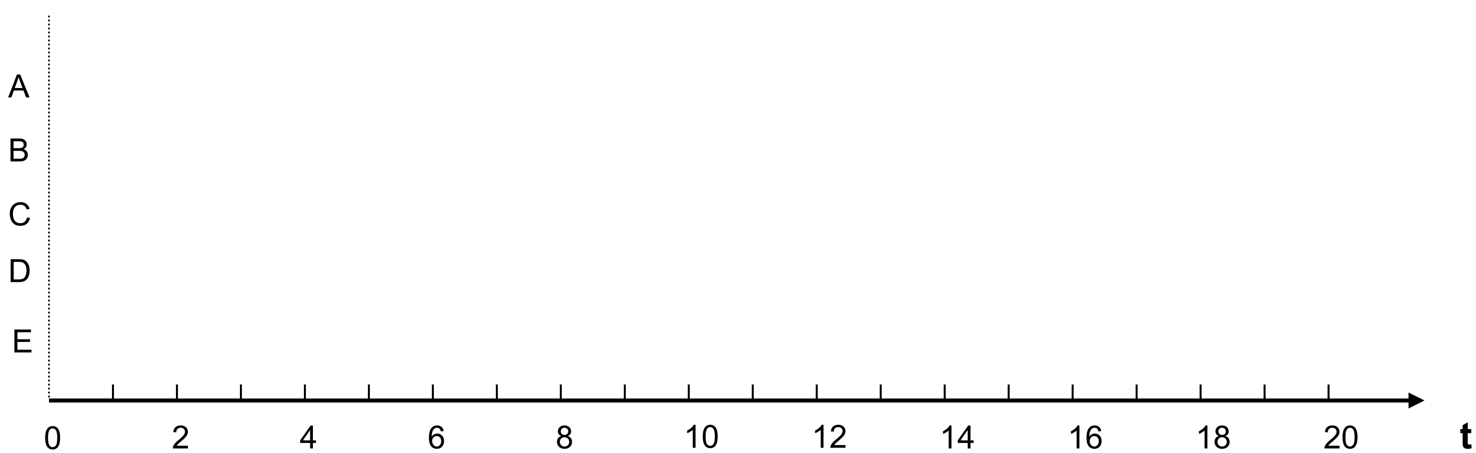

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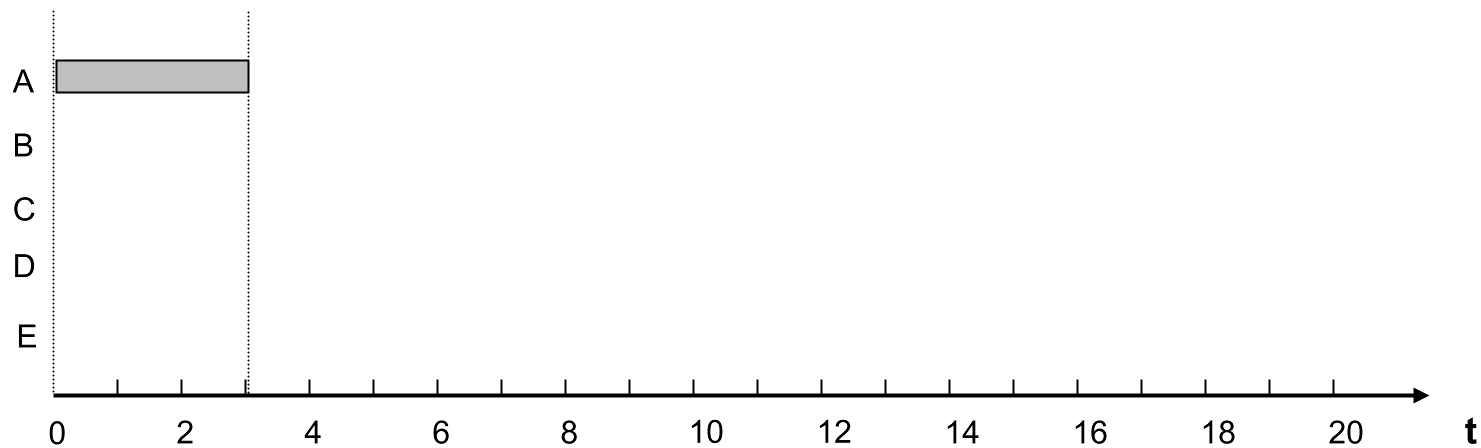

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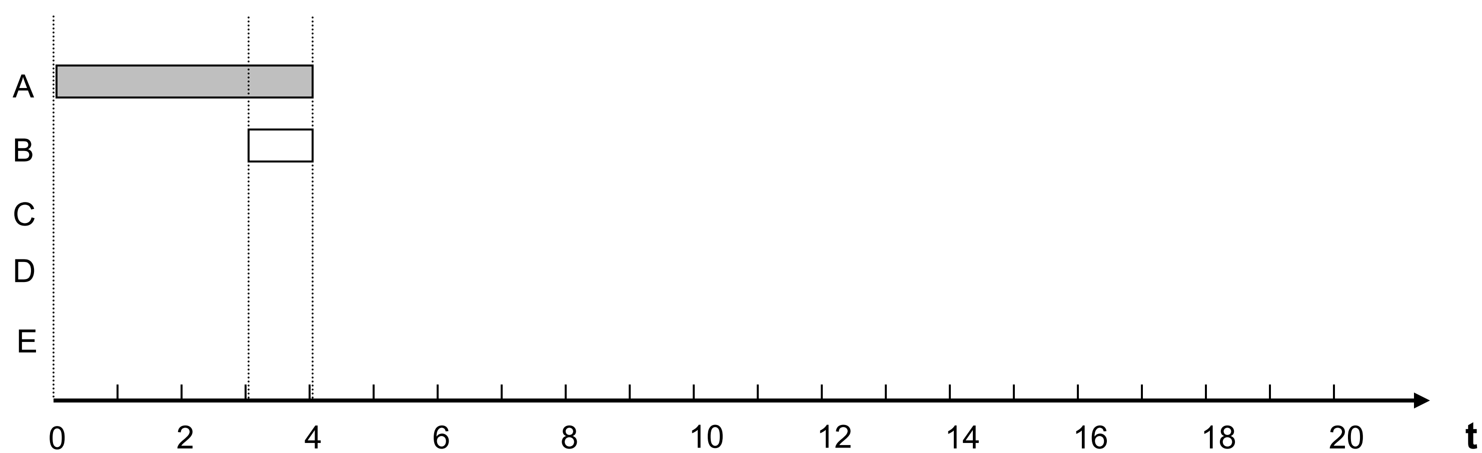

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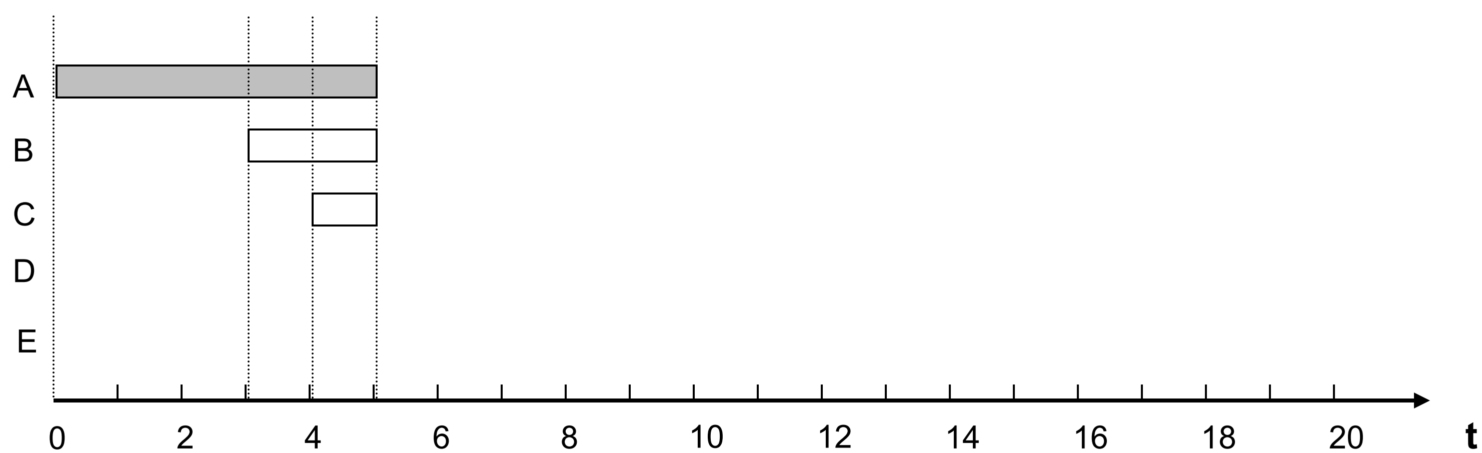

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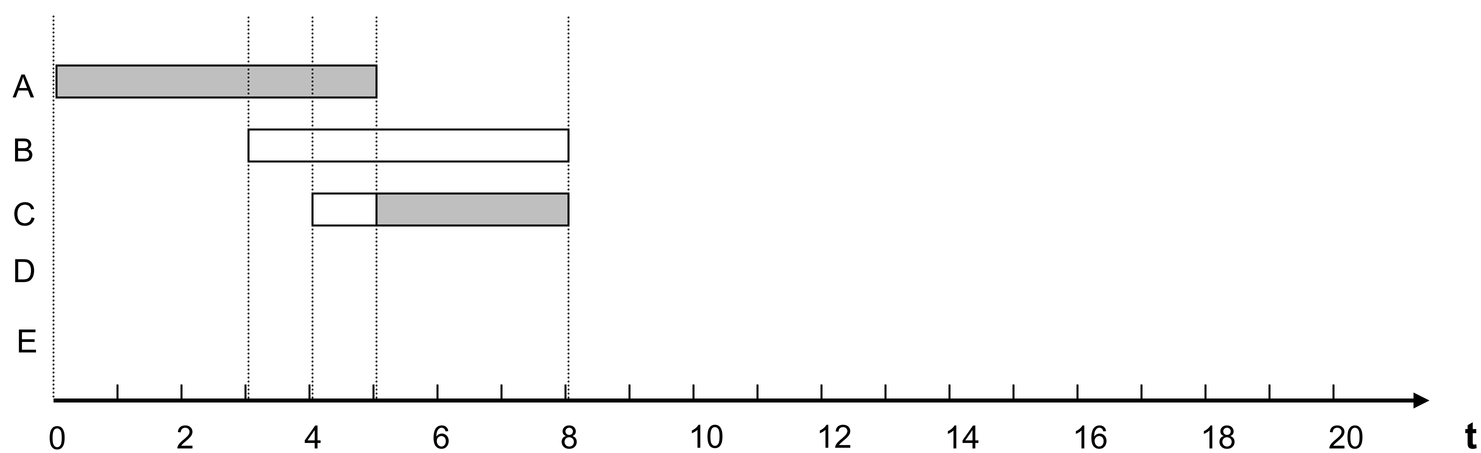

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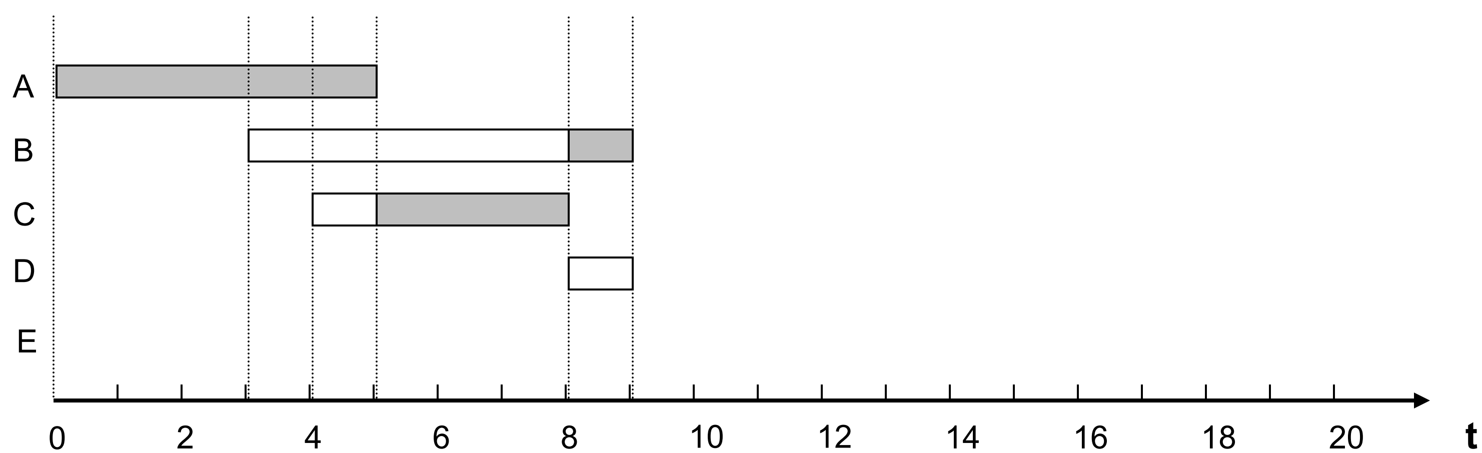

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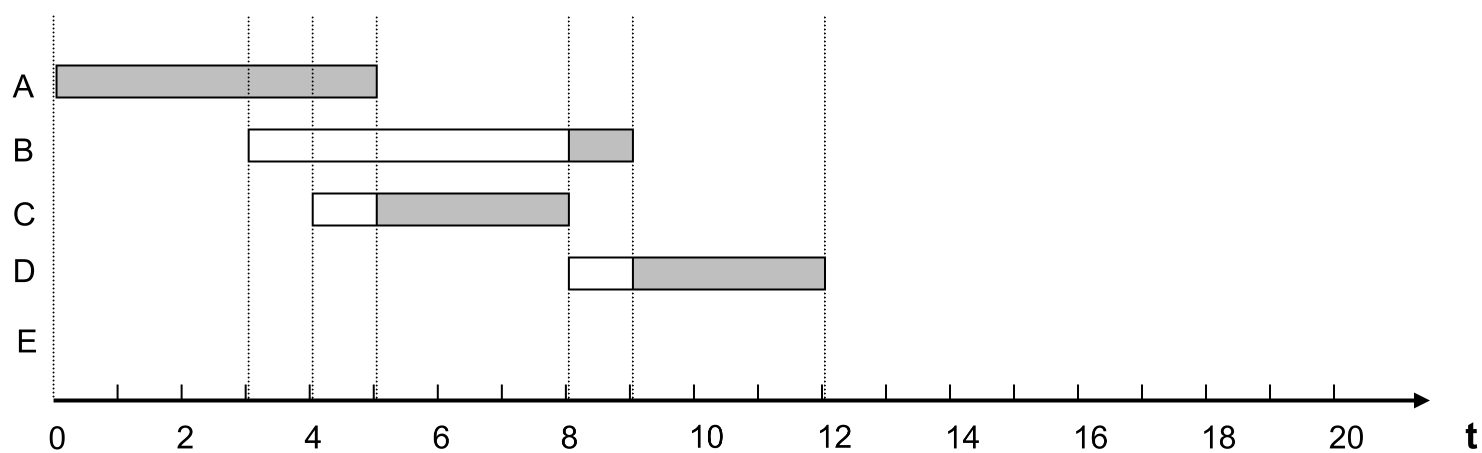

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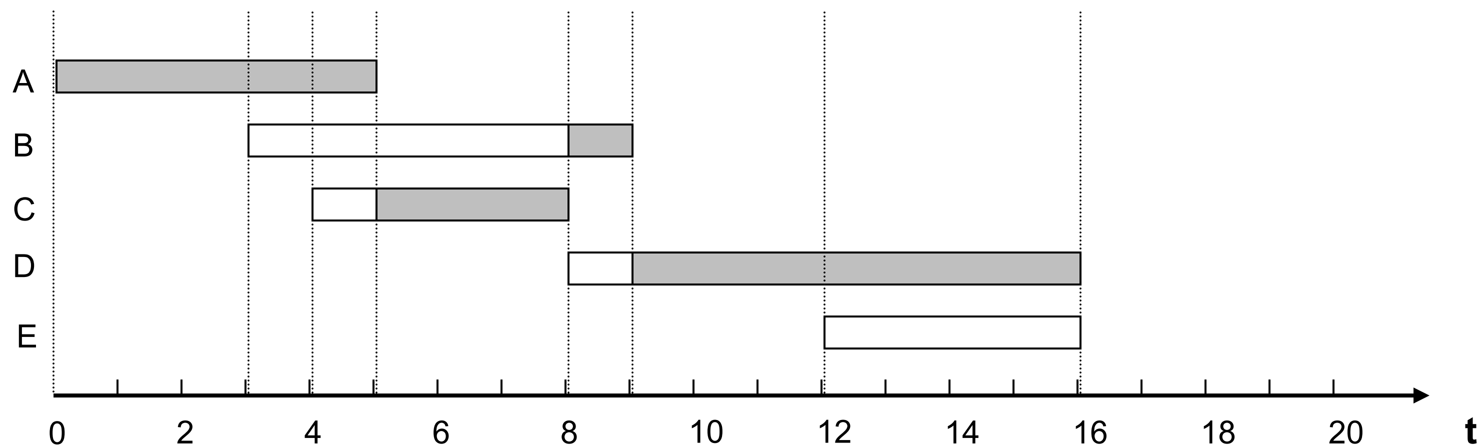

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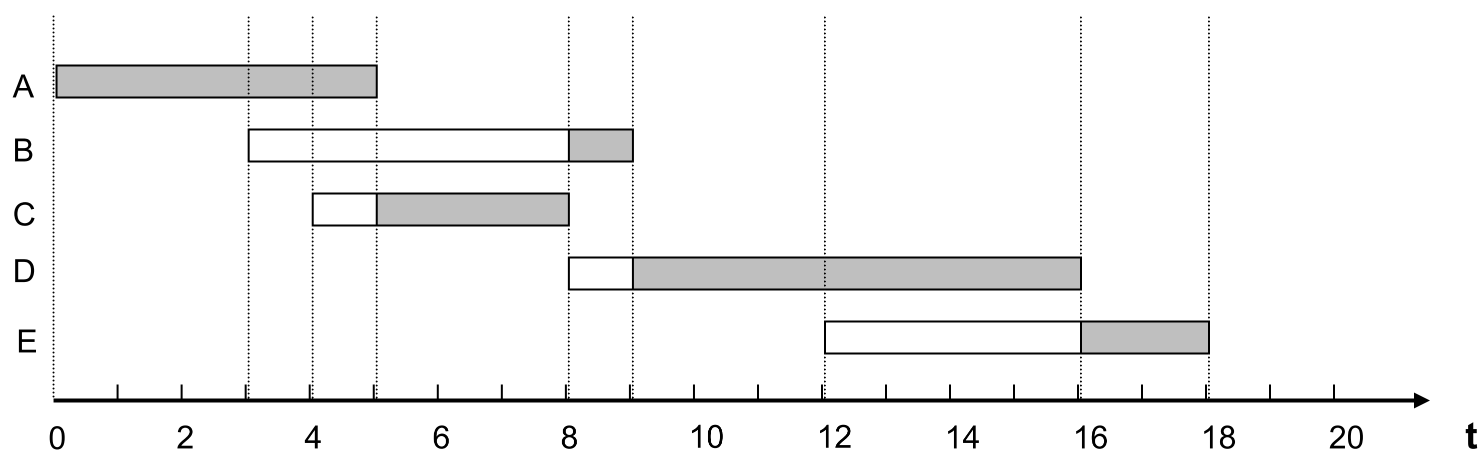

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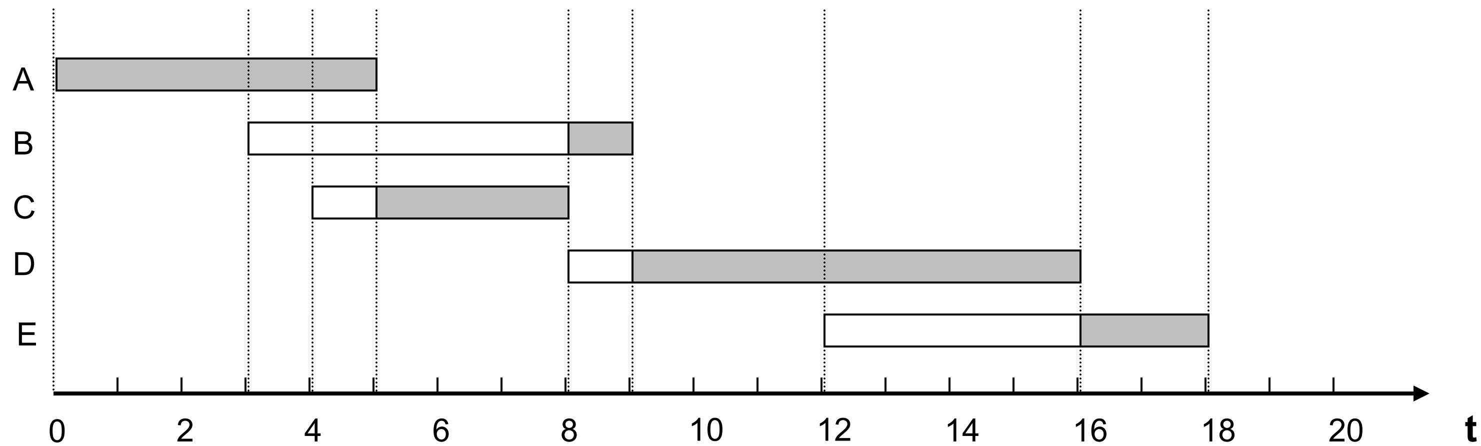

Process	A	C	B	D	E
Time (RUNNING)	0	5	8	9	16

Scheduling

- Example
  - *preemtive* priority scheduling

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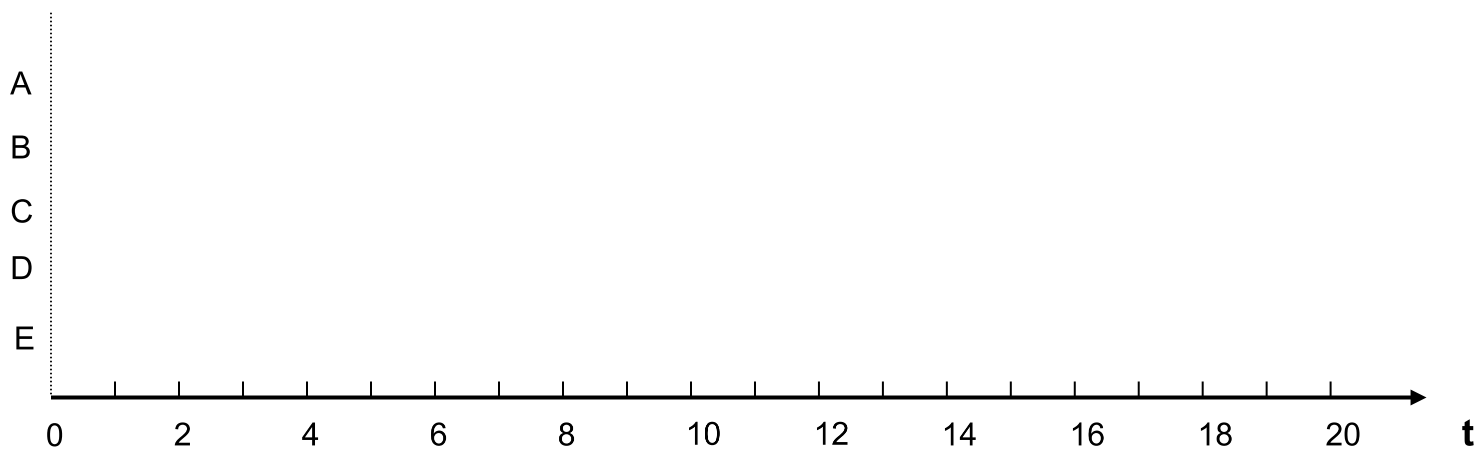

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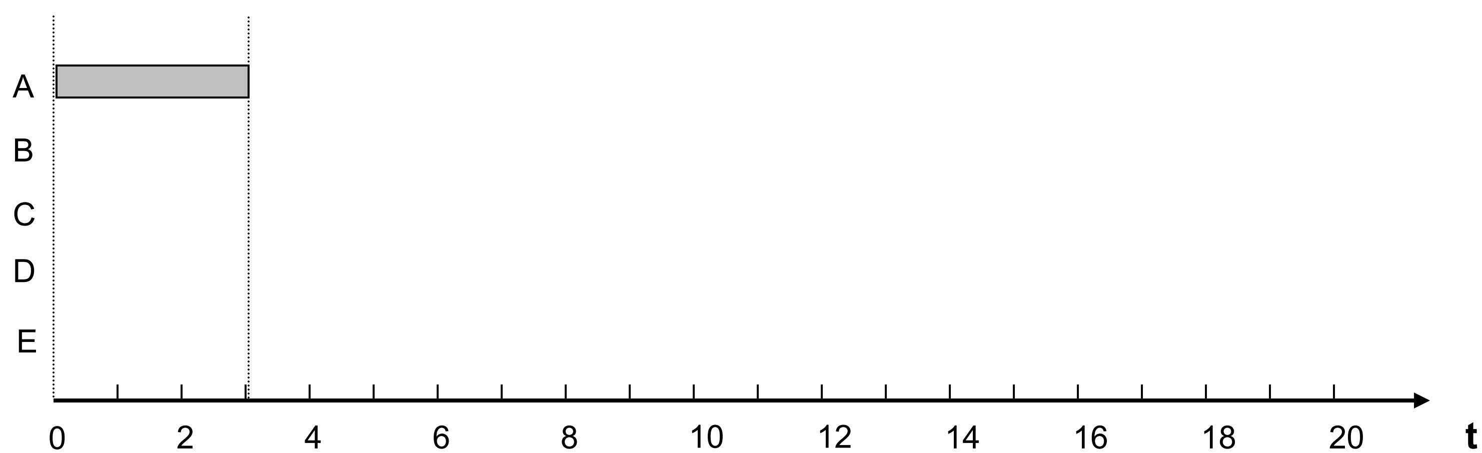

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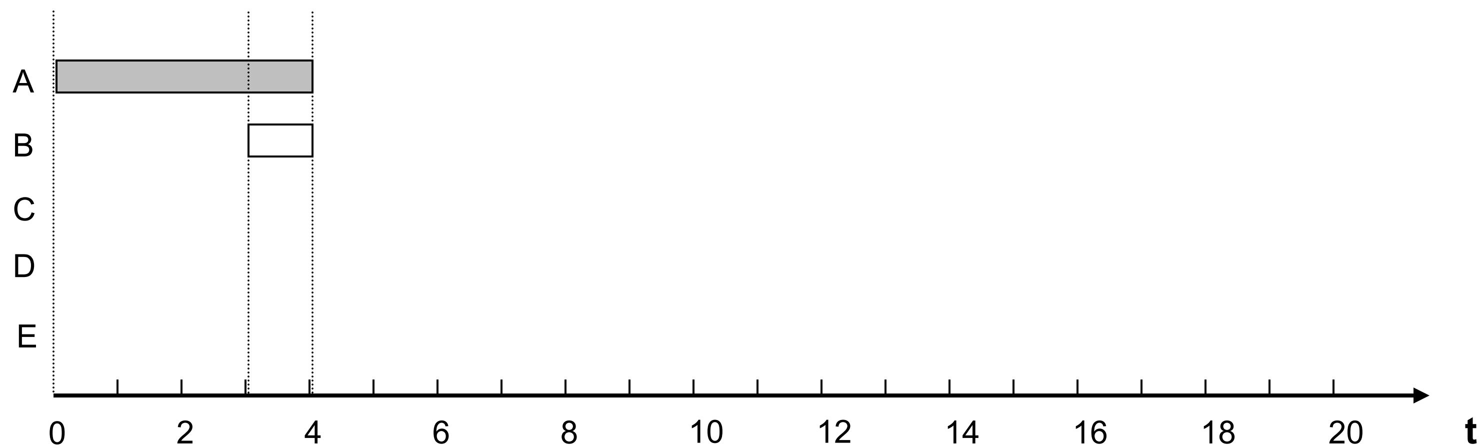

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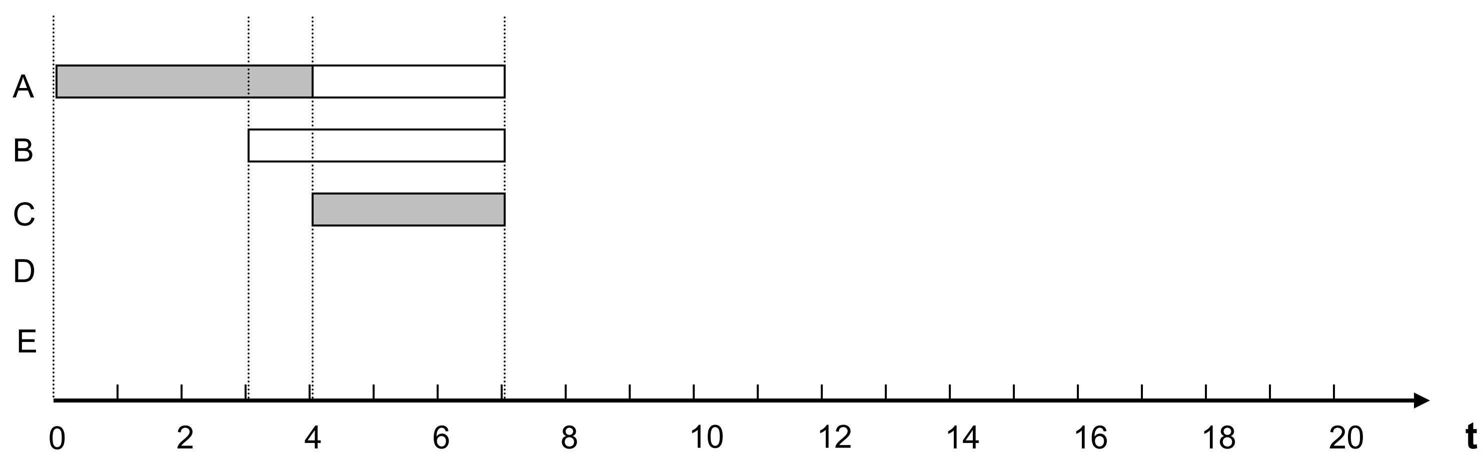

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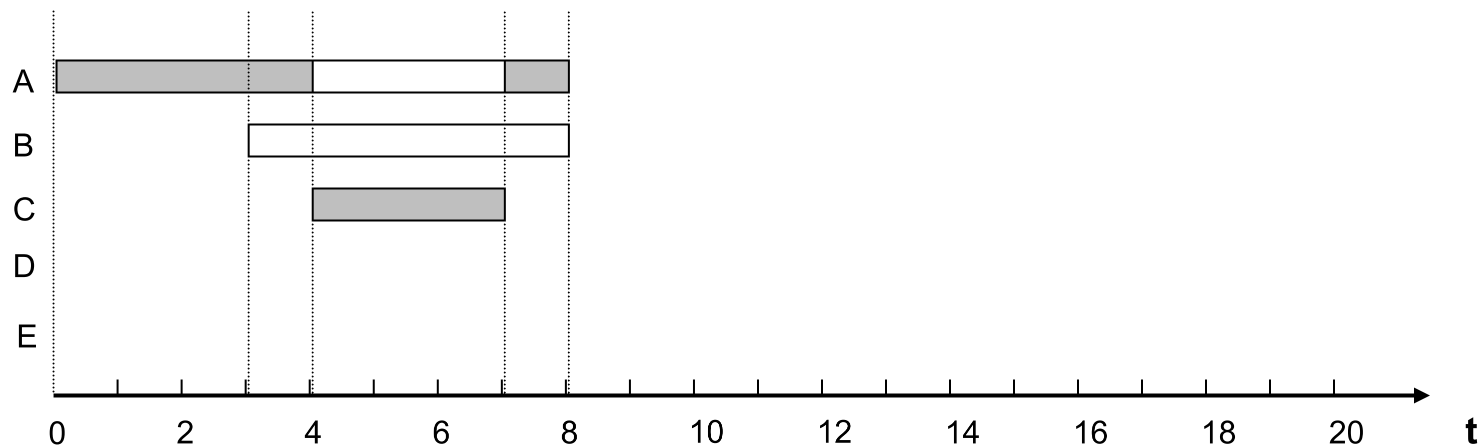

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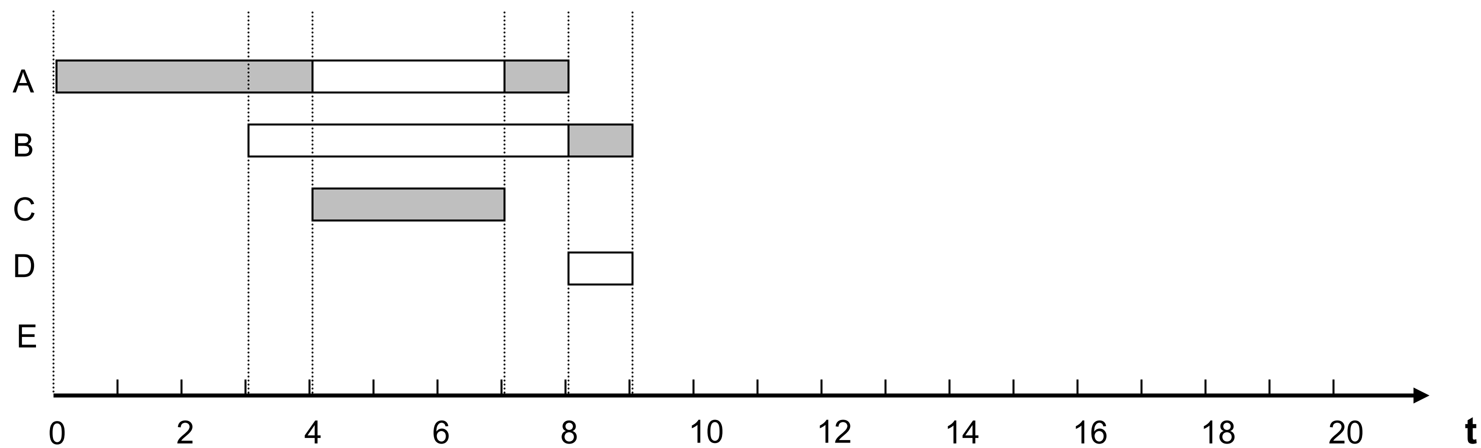

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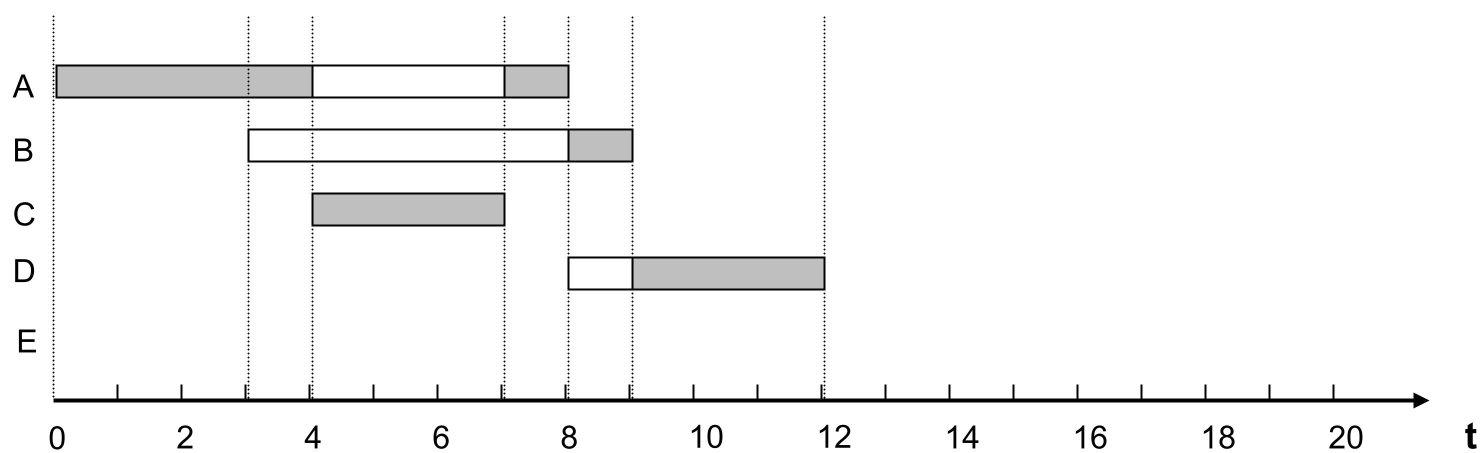

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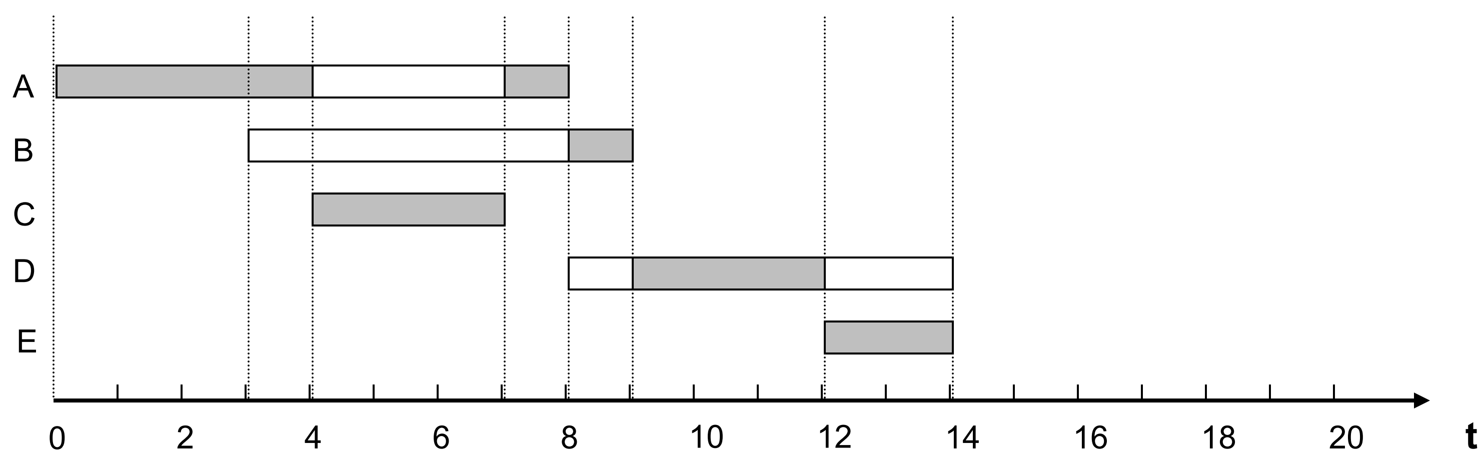

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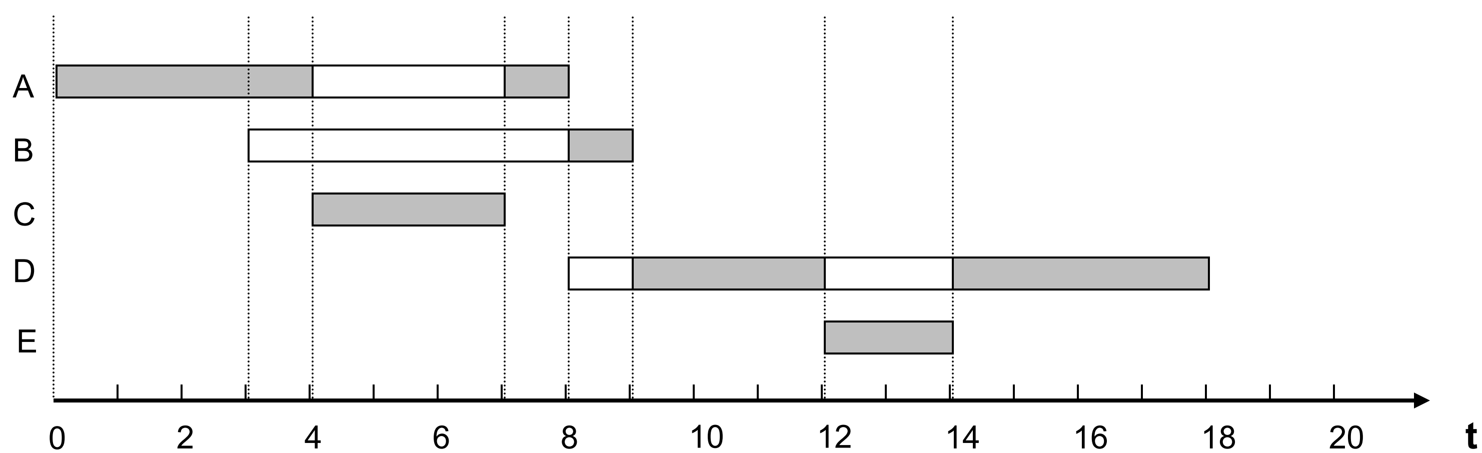

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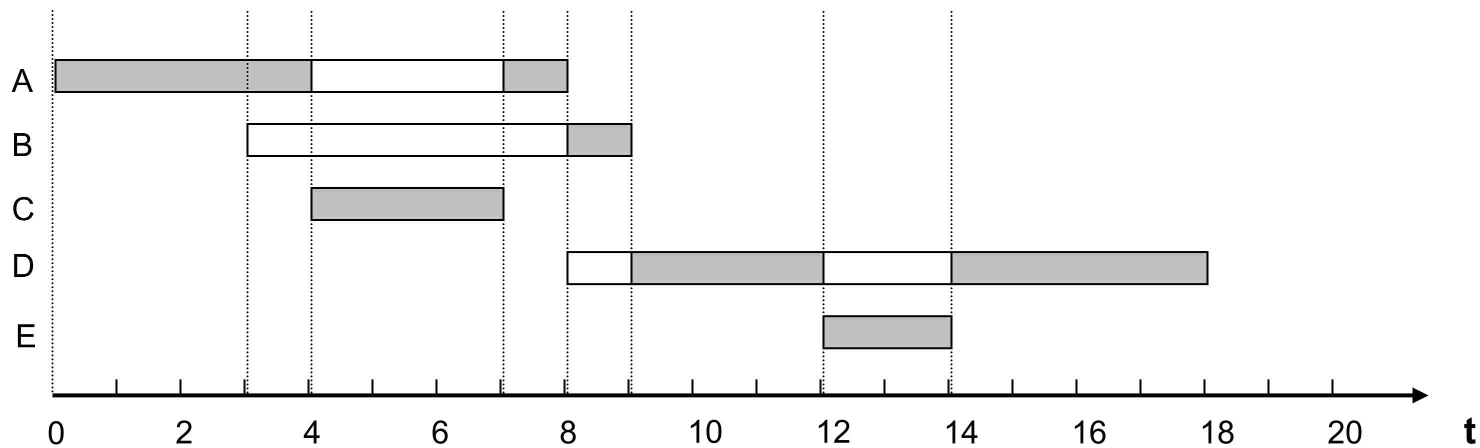
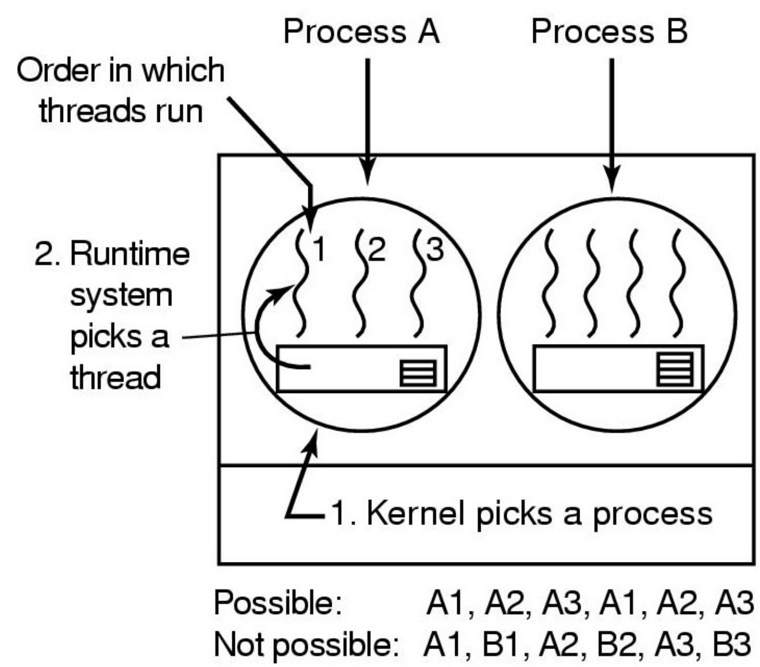


Process	A	C	A	B	D	E	D
Time (RUNNING)	0	4	7	8	9	12	14

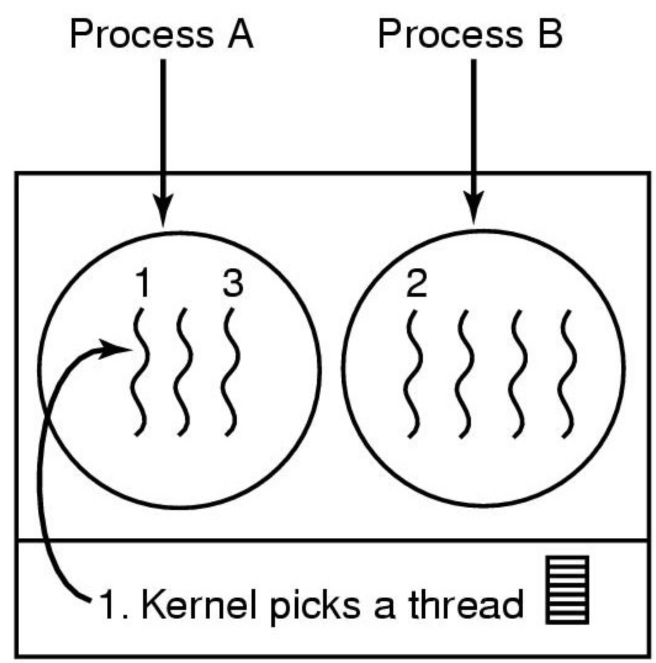
Thread Scheduling

- If threads are implemented in user space, only one process' threads are run inside a quantum
- Possible scheduling of user-level threads
  - 48-msec process quantum
  - Threads run 8 msec/CPU burst



Thread Scheduling

- If threads are implemented in the kernel, threads can be interleaved
- Kernel may decide to switch to a thread belonging to the same process for efficiency reasons (memory map does not change)



Possible: A1, A2, A3, A1, A2, A3
Also possible: A1, B1, A2, B2, A3, B3

Policy versus Mechanism

- Sometimes an application may want to influence the scheduling of cooperating processes (same user, or children processes) to achieve better overall performance

- Separate what is <u>allowed</u> to be done with <u>how</u> it is done
  - process knows which of its children threads are important and need priority

- Scheduling algorithm parameterized
  - Mechanism in the kernel

- Parameters filled in by user processes
  - Policy set by user process

Linux - CFS

- Completely fair scheduler (CFS)

```
Ingo Molnar:
80% of CFS's design can be summed up in a single sentence:
CFS basically models an "ideal, precise multi-tasking CPU"
on real hardware.

On real hardware, we can run only a single task at once, so
while that one task runs, the other tasks that are waiting
for the CPU are at a disadvantage - the current task gets
an unfair amount of CPU time. In CFS this fairness
imbalance is expressed and tracked via the per-task
p->wait_runtime (nanosec-unit) value. "wait_runtime" is the
amount of time the task should now run on the CPU for it to
become completely fair and balanced.
```