Operating Systems

Scheduling and Deadlocks

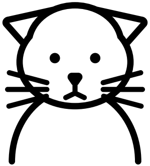
Daniel Gruss

2023-11-07

Scheduling

Time	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
07.00							
08.00							
09.00							
10.00							
11.00							
12.00							
13.00							
14.00							
15.00							
16.00							

Scheduling



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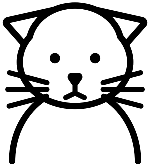

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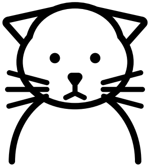
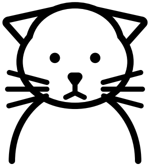


- No "right" answer



- No “right” answer
- always a trade-off

Some Scheduling Ideas Already

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... which are used in the real world!

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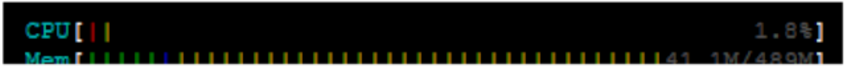
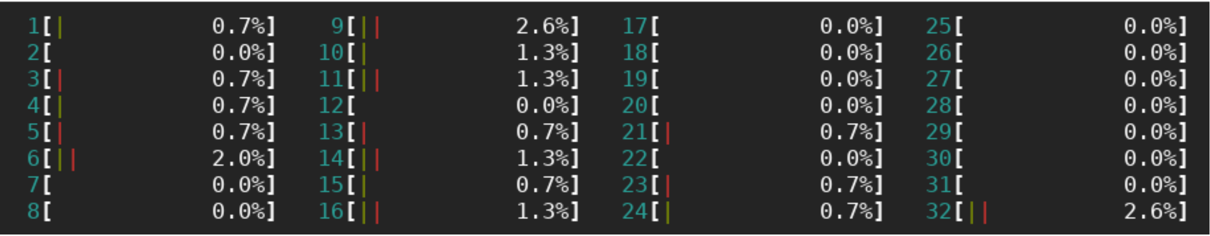
- Homework with earliest deadline next: **Earliest Deadline First (EDF)**
- 1 hour of this, then 1 hour of that, ... until everything is done: **Round Robin (RR)**
- Short homework first: **Shortest Job First (SJF)**

... which are used in the real world!


CPU[1.8%]
Mem[41.1M/489M]

VS


1[0.7%] 9[2.6%] 17[0.0%] 25[0.0%]
2[0.0%] 10[1.3%] 18[0.0%] 26[0.0%]
3[0.7%] 11[1.3%] 19[0.0%] 27[0.0%]
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7[0.0%] 15[0.7%] 23[0.7%] 31[0.0%]
8[0.0%] 16[1.3%] 24[0.7%] 32[2.6%]

Scheduling

Similar design challenges as with PRAs:

- latency
- throughput
- fairness


HAVING A TIRE BLOWOUT A WEEK AFTER HITTING A SIDECURB
PRINCIPLE OF LOCALITY

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- **Starvation**: task doesn't make any progress due to other tasks

Scheduling algorithm

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- Only **preemptive**, work-conserving schedulers to be considered

More terms

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  - **mixed**

First-In-First-Out (FIFO)

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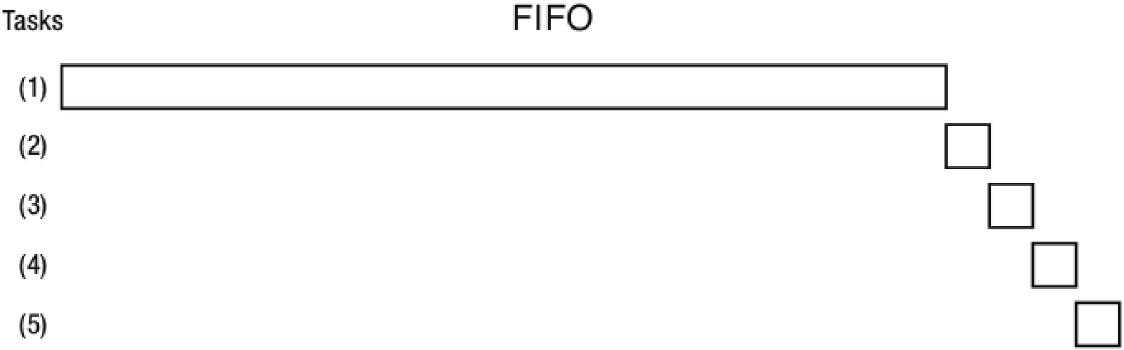
- Run tasks in order of arrival until they complete or yield


FIFO
Tasks
(1)
(2)
(3)
(4)
(5)

SJF - Shortest Job First

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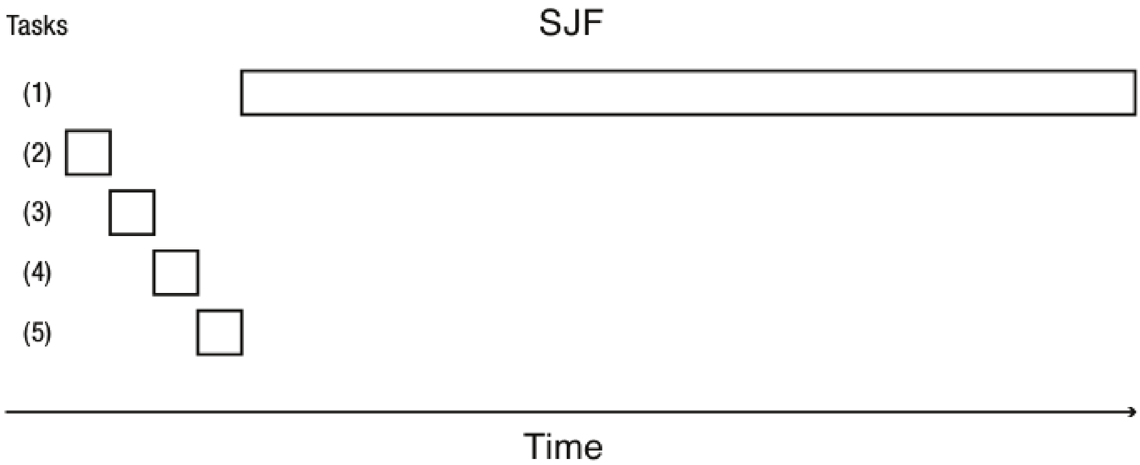
→ schedule the shortest job first (SJF)


SJF
Tasks
(1)
(2)
(3)
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Time

Example - Supermarket

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→ current customer interrupted

→ full basket - you have to wait...

Round Robin

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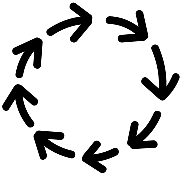

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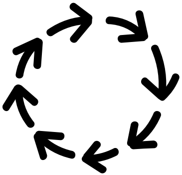

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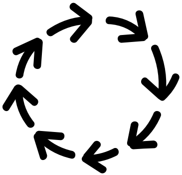

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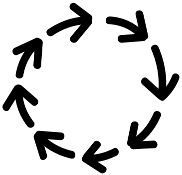

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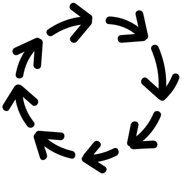

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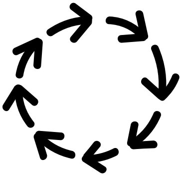
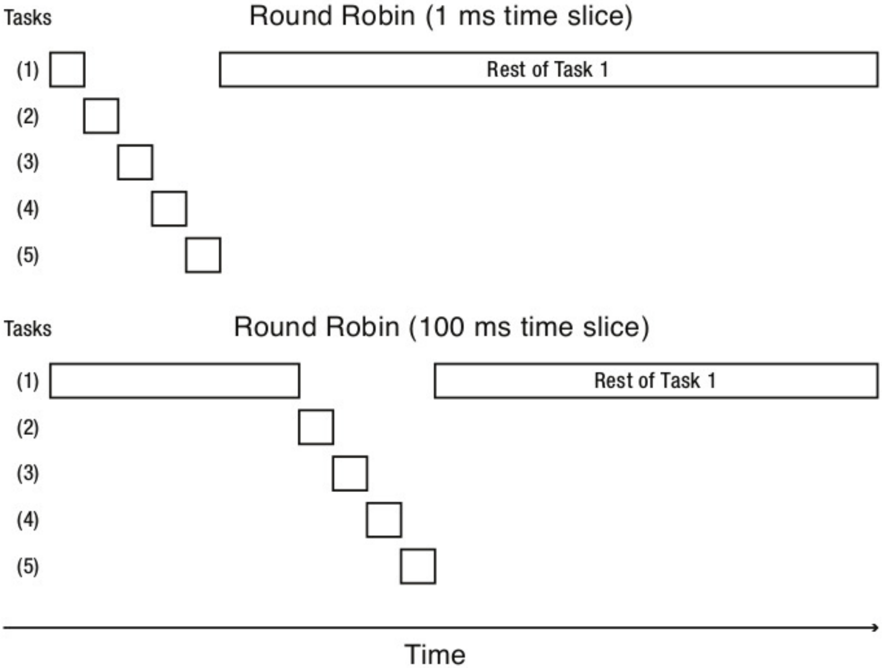
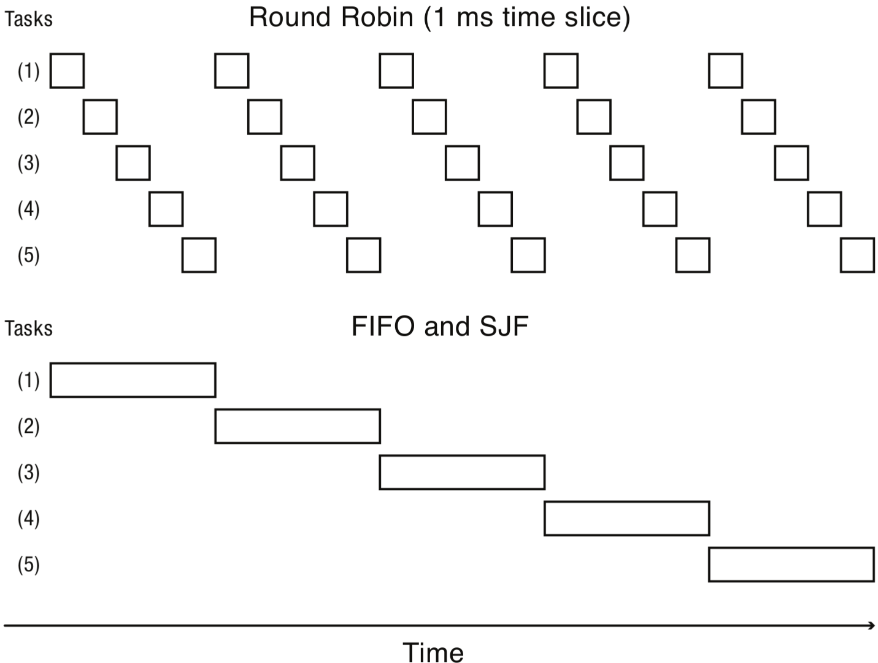


- fighting starvation: schedule tasks in a round robin fashion
- compromise between FIFO and SJF
- each task: fixed period of time (time quantum)
- not finished? $\rightarrow$ back in line


Tasks
Round Robin (1 ms time slice)
(1)
Rest of Task 1
(2)
(3)
(4)
(5)
Tasks
Round Robin (100 ms time slice)
(1)
Rest of Task 1
(2)
(3)
(4)
(5)
Time


Round Robin (1 ms time slice)
Tasks
(1)
(2)
(3)
(4)
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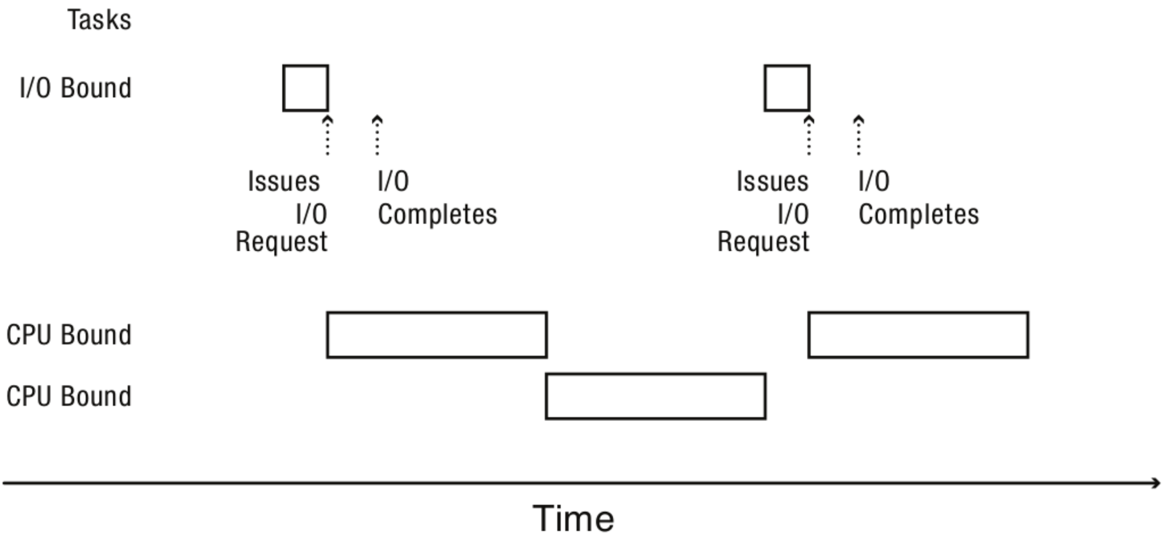
FIFO and SJF
Tasks
(1)
(2)
(3)
(4)
(5)
Time

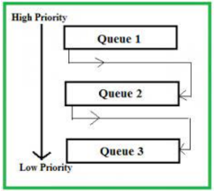

Tasks
I/O Bound
Issues I/O Request
I/O Completes
Issues I/O Request
I/O Completes
CPU Bound
CPU Bound
Time

Multi-level Feedback Queue (MFQ)

- Goals:
  - Latency
  - Low overhead
  - Starvation freedom
  - Some tasks are high/low priority
  - Fairness (among equal priority tasks)
- Not perfect at any of them!
  - Used in Linux (and probably Windows, MacOS)

MFQ

MFQ



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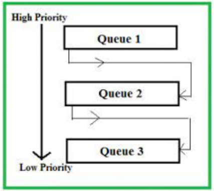

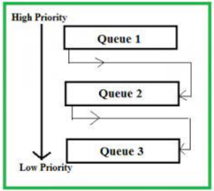

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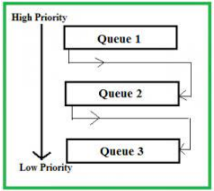
MFQ



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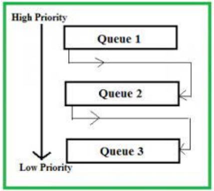

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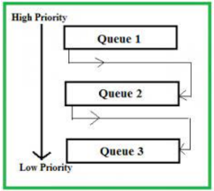

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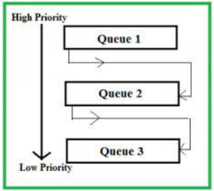

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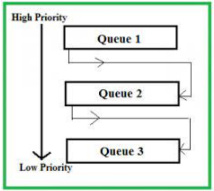

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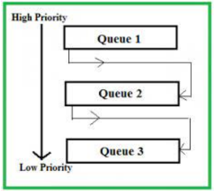

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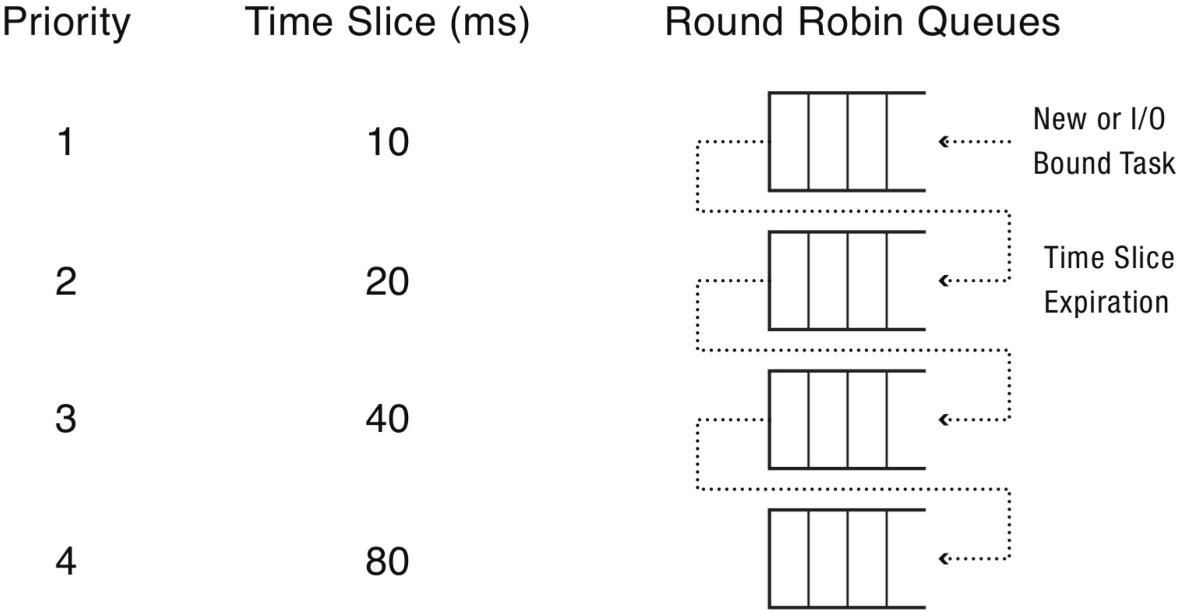
- If time slice expires, task drops one level


Priority
Time Slice (ms)
Round Robin Queues
1
10
2
20
3
40
4
80
New or I/O
Bound Task
Time Slice
Expiration

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→ CPU and I/O mixed → SJF > RR

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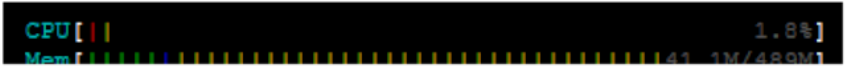
$\rightarrow$ CPU and I/O mixed $\rightarrow$ SJF $>$ RR

- MFQ balances latency, overhead and fairness


CPU[1.8%]
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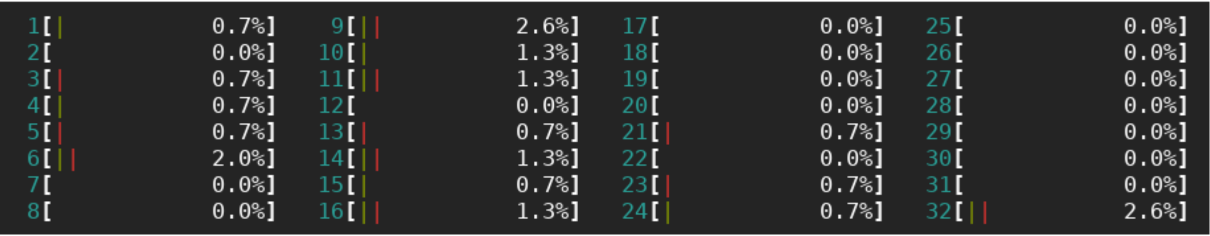
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Multi-Core Scheduling

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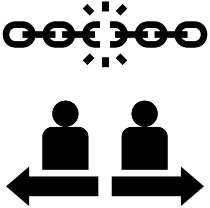
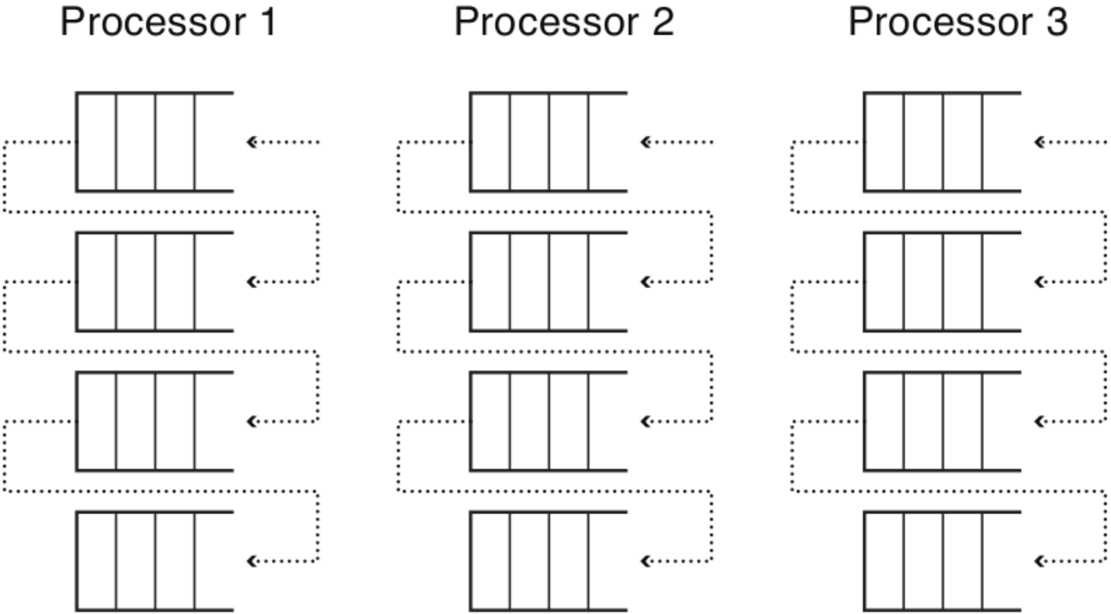
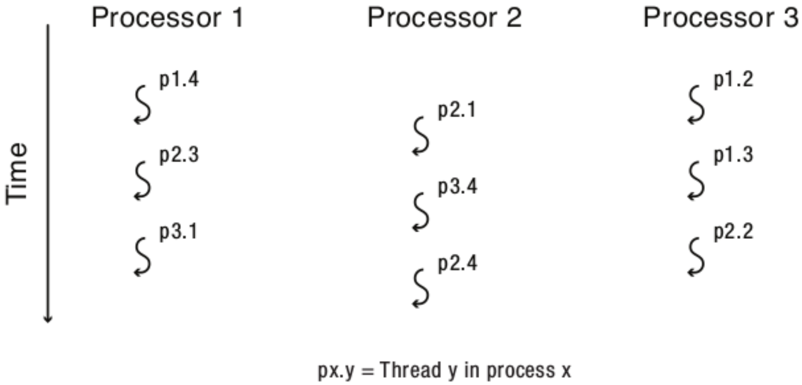
  - Cache slowdown (write access on one core → slower read on other core)
  - Limited cache reuse: thread's data from last time could still be in the cache (of another core!)



- Each core has its own thread list
- Protected by a per-core lock
- Idle cores can “steal” threads from other cores

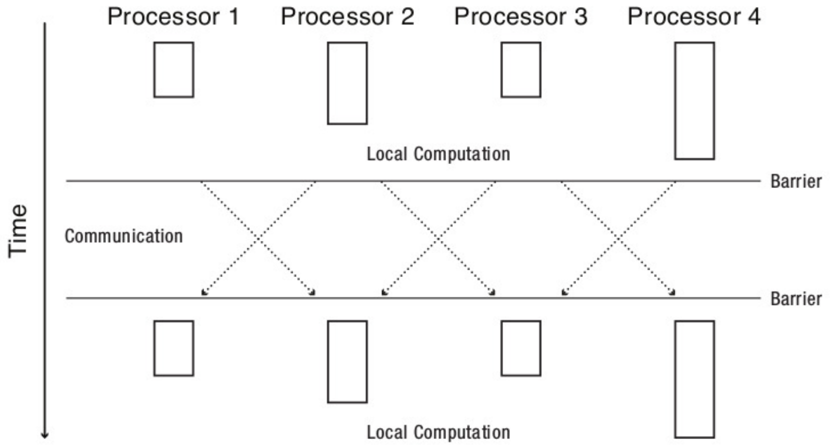

Processor 1
Processor 2
Processor 3

Scheduling Multi-threaded Programs



"Just schedule threads" – yes, but ...

Bulk Synchronous Parallelism



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- Examples:
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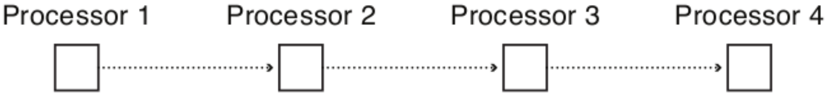
  - Most parallel algorithms can be recast in BSP
    - Sacrificing a small constant factor in performance

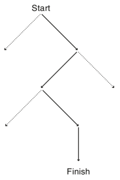
Producer-Consumer-Delay



- preempting one thread stalls all others

Other issues

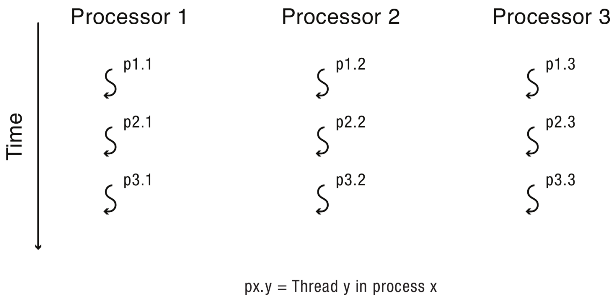
- Critical Path Delay
  - Preempting a thread on a critical path will slow down end result



- Preemption of lock holder

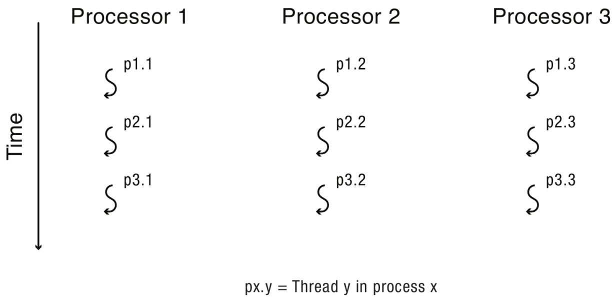
Gang Scheduling

- Application splits work into threads



Gang Scheduling

- Application splits work into threads
- threads always run together (if possible)



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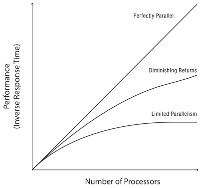
- system reserves subset of cores to other applications
- today: also relevant for security

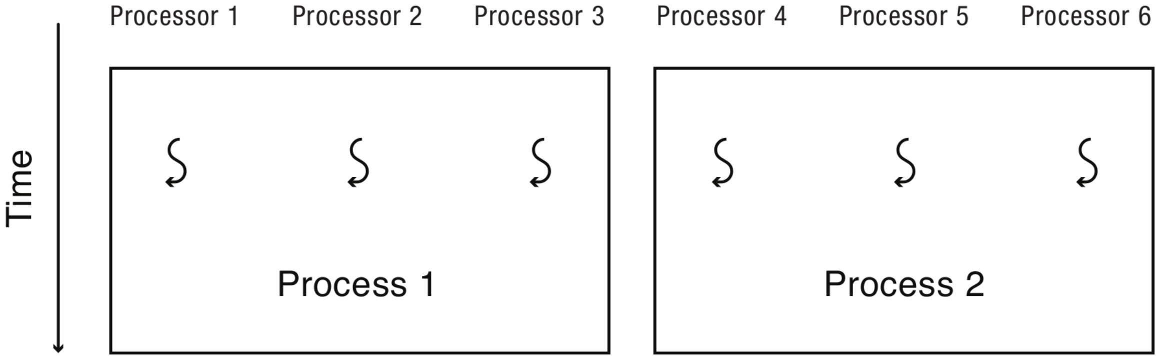
Gang Scheduling

- Some make efficient use of many cores
- some have diminishing return



Space Sharing

- give two parallel programs each half of the cores → **space sharing**
- minimizes context switches for each core
- what we discussed before was: **time sharing, time slicing** (single core to multiple tasks)



Time
Processor 1
Processor 2
Processor 3
Processor 4
Processor 5
Processor 6
Process 1
Process 2

Deadlocks

Classic Deadlock Example

```
wait(Resource_1);
wait(Resource_2);
use_Resource();
signal(Resource_2);
signal(Resource_1);
```

```
wait(Resource_2);
wait(Resource_1);
use_Resource();
signal(Resource_2);
signal(Resource_1);
```

Deadlock

Formal definition

A set of processes is deadlocked if each process in the set is waiting for an event that only another process in the set can cause.

Assumptions: processes, threads - both may be deadlocked. Number of threads, types of resources relevant.

Conditions for deadlocks (1)

Mutual Exclusion condition

Each resource is either currently assigned to exactly one process or is available.

Conditions for deadlocks (2)

Hold-and-wait condition

Processes currently holding resources that were granted earlier can request new resources

Conditions for deadlocks (3)

No-preemption condition

Resources previously granted cannot be forcibly taken away from a process. They must be explicitly released by the process holding them

Conditions for deadlocks (4)

Circular wait condition

There must be a circular list of two or more processes, each of which is waiting for a resource held by the next member of the chain

Conditions for deadlocks

All four conditions must be present for a deadlock to occur

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Strategies to deal with deadlocks

- Ignore it (maybe it ignores us too...)

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- Avoidance

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- Prevention

Ignoring - the "Ostrich Algorithm"

Mathematical Approach

We MUST prevent deadlocks!

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Engineering Approach

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- How expensive is it to solve?

Ignoring - the “Ostrich Algorithm”

Mathematical Approach

We MUST prevent deadlocks!

Engineering Approach

- How often does the problem occur?
- How expensive is it to solve?
- Let’s do a cost-benefit analysis!

Ignoring as Best Practice

- Unix, Windows: the problem is ignored

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- Unix, Windows: the problem is ignored
- Cost to prevent deadlocks too high
- Prevention may not be possible at all
- Even detection is too expensive
- Weigh “comfort” versus “correctness”

Example

- Resources in OS are limited
- limited number of processes or open files at any time
- assume: all active process need to do another fork or open one more file
- None are available → deadlock!
- Now how likely is that?

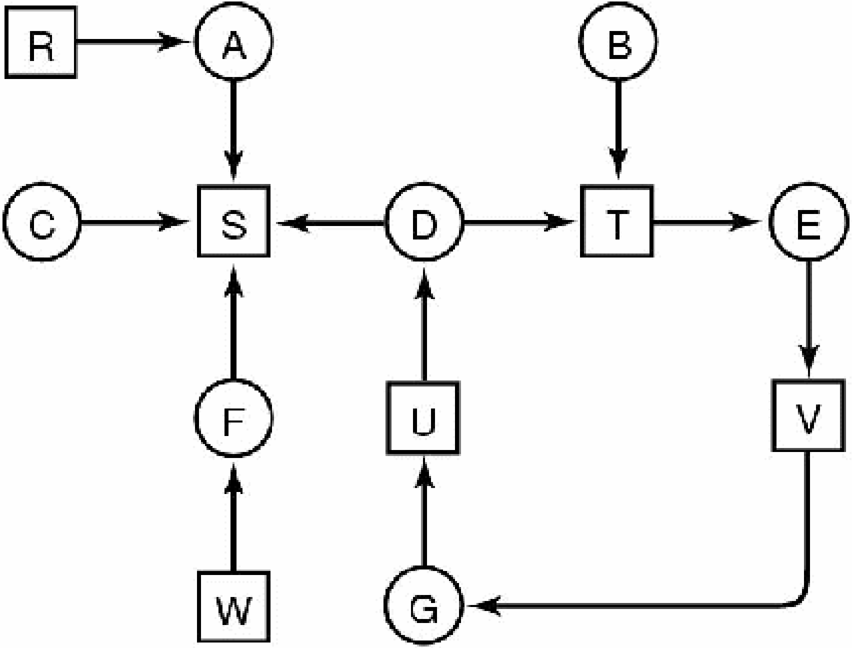
Detection and Recovery

- Don't prevent occurrence
- try to detect occurrence and deal with it when it happens
- how can we do that?
- e.g.: "draw" resource-graphs and detect circles

Detection

- Example: is the following system deadlocked?

```
Process A holds R and wants S
Process B holds nothing but wants T
Process C holds nothing but wants S
Process D holds U but wants S and T
Process E holds T but wants V
Process F holds W but wants S
Process G holds V but wants U
```


R
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V
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G

Detection

- easy - visually

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Detection

- easy - visually
- but there is an algorithm too
- many algorithms for detecting cycles in directed graphs

Simple Algorithm (useful for `pthread_join`)

Depth-first search in a tree

- take each node as the root of a tree
- do a depth-first search
- if we ever come back to a node we have already been to: cycle found
- when we have visited all arcs from a node: backtrack one level up
- back to start: no deadlock found
- need to try for all nodes as roots

not quite optimal

Detection

- When do we check for deadlock?

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- When do we check for deadlock?
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- And what do we do?? Preemption, roll back, kill processes?

Recovery/Preemption

- Take resource away from process

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- manual intervention may be required

Rollback

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- When deadlock occurs, select process and set it back checkpoint before deadlocked resource was assigned

Kill Processes

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- best to kill one which can easily start again (like a compiler)
- killing processes that e.g. changed databases not a great idea

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- is there an algorithm that can do this?
- Yes, if certain information is available in advance

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- Prevent - by excluding one of the requirements

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    - try to make sure that as few processes as possible may actually claim the resource

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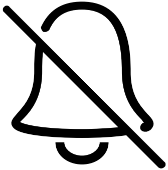

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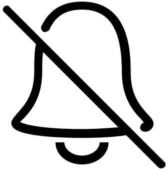

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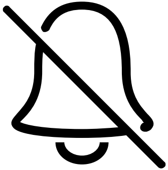

- Very difficult. Rarely possible.

Circular Wait

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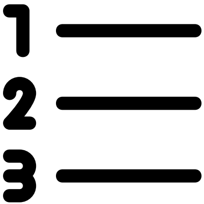

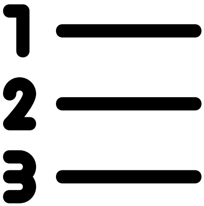

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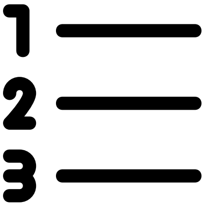

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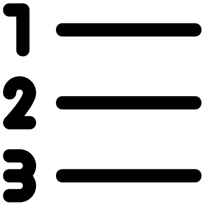

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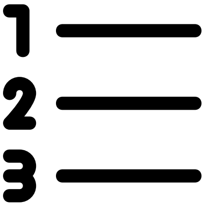

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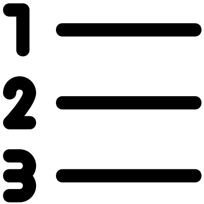

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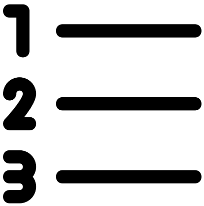

- Easy way: allow only one resource to be held. Not very practical though.
- Better way: **Provide global numbering of all resources.**
- Processes can request resources, but only in numerical order.
- No cycle can exist.
- Problem: It can be difficult to find a working numbering scheme. What to do if resources are dynamic?

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- multiple processes: real danger of a deadlock

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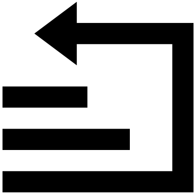

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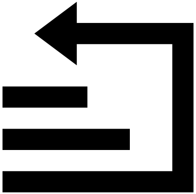

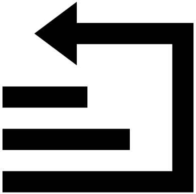

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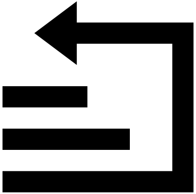

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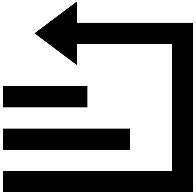

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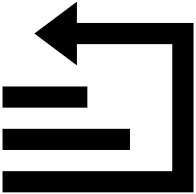

- Phase 1: try to get locks for all records
- successful:
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- unsuccessful:
  - release locks and start again with Phase 1

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- policies decide who gets which resource when
- may lead to the situation that some process never gets service even if they are not deadlocked
- can e.g. be avoided by a first-come-first-served basis