Processes - Part III

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CPU Scheduling

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- By switching the CPU among processes, the OS makes the computer more productive.

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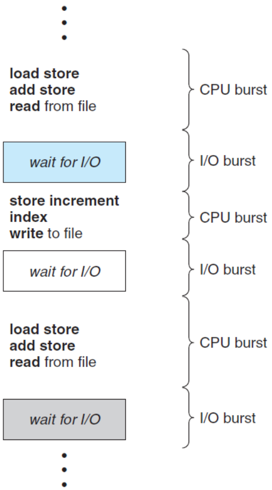
- Others must wait until the CPU is free and can be rescheduled.
- The objective of multiprogramming is to have some process running at all times, to maximize CPU utilization.

Basic Concepts

- CPU-I/O burst cycle: process execution consists of a cycle of CPU execution and I/O wait.



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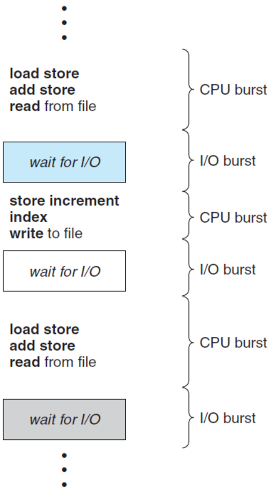

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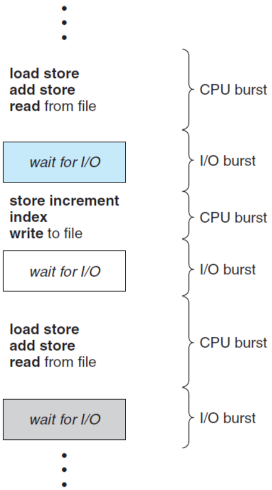
- CPU burst distribution is of main concern.



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- But, There is a choice, for situations 3 and 4 (preemptive).

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- Response time: amount of time it takes from when a request was submitted until the first response is produced (Min).

Scheduling Algorithms

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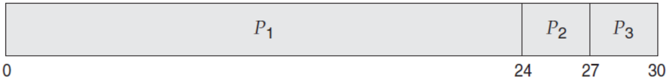
- First-Come, First-Served Scheduling
- Shortest-Job-First Scheduling
- Priority Scheduling
- Round-Robin Scheduling
- Multilevel Queue Scheduling

First-Come, First-Served (FCFS) Scheduling

FCFS Scheduling (1/2)

- Suppose that the processes arrive in the order: P_1, P_2, P_3

Process	Burst Time
P_1	24
P_2	3
P_3	3



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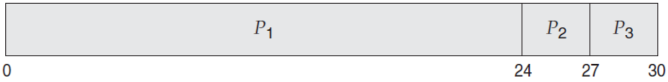

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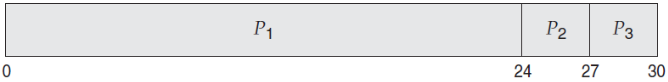

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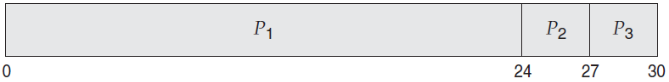

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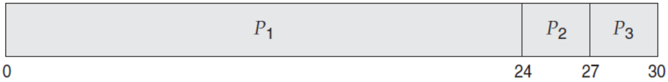

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- FCFS scheduling is non-preemptive: process keeps the CPU until it releases the CPU (either by terminating or by requesting I/O).
- Convoy effect: all the other processes wait for the one big process to get off the CPU.

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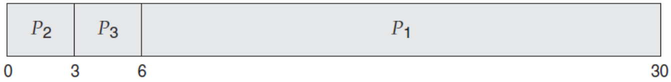

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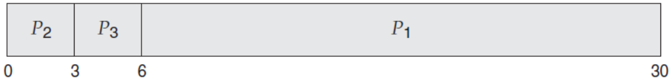

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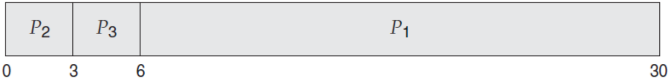

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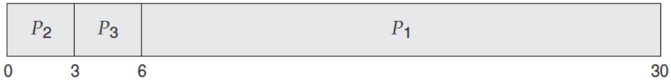

- Waiting time for $P_1 = 6$; $P_2 = 0$; $P_3 = 3$
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- Much better than previous case.

Shortest-Job-First (SJF) Scheduling

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- SJF is optimal: gives minimum average waiting time for a given set of processes.
- The difficulty is knowing the length of the next CPU request.

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Process	Burst Time
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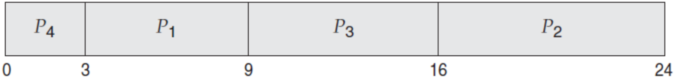

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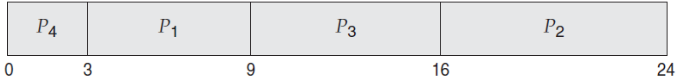

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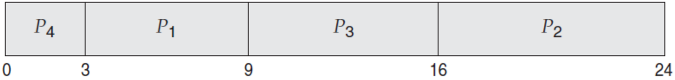

- Waiting time for $P_1 = 3$; $P_2 = 16$; $P_3 = 9$, $P_4 = 0$
- Average waiting time: $\frac{3+16+9+0}{4} = 7$

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- Commonly, α set to $\frac{1}{2}$

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- Preemptive version called shortest-remaining-time-first

Example of Shortest-Remaining-Time-First

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- Now we add the concepts of varying arrival times and preemption to the analysis.

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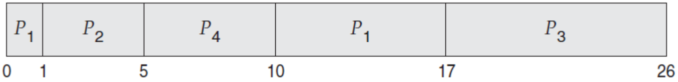

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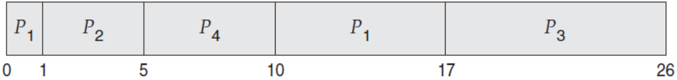

- Average waiting time: $\frac{(10-1)+(1-1)+(17-2)+(5-3)}{4} = \frac{26}{4} = 6.5$

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- Problem: starvation - low priority processes may never execute
- Solution: aging - as time progresses increase the priority of the process

Priority Scheduling (2/2)

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P_3	2	4
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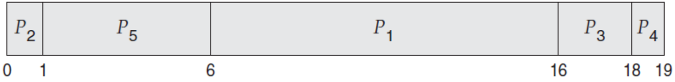

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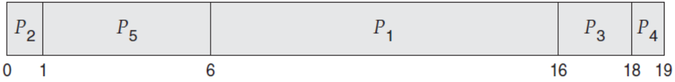

- Average waiting time: $\frac{0+1+6+16+18}{5} = 8.2$

Round-Robin (RR) Scheduling

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- No process waits more than $(n-1)q$ time units.

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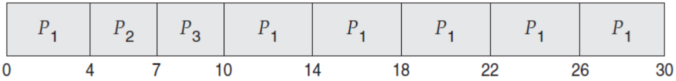

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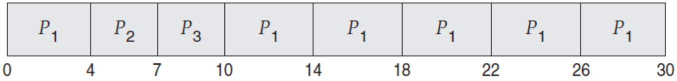

- Average waiting time: $\frac{(10-4)+4+7}{3} = 5.66$

Time Quantum and Context Switch Time (1/2)

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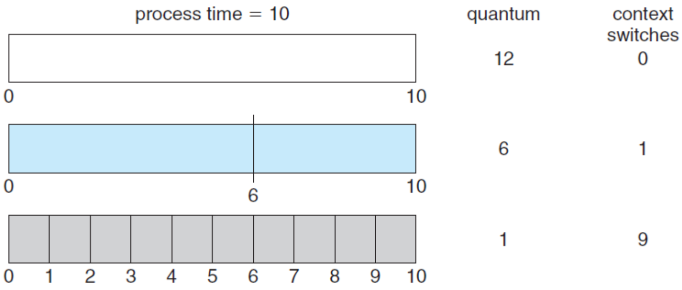
- Performance
  - q large $\Rightarrow$ FIFO
  - q small $\Rightarrow$ q must be large with respect to context switch, otherwise overhead is too high.

Time Quantum and Context Switch Time (2/2)

- q should be large compared to context switch time.



Multilevel Queue Scheduling

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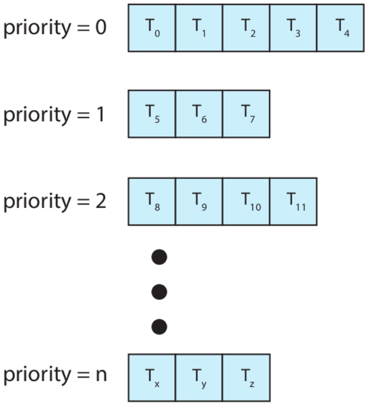
- Ready queue consists of multiple queues.



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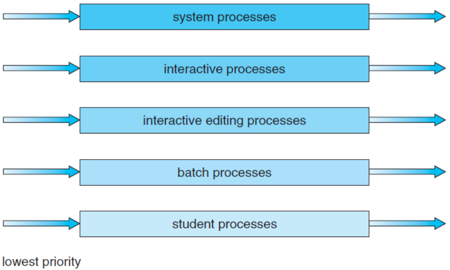

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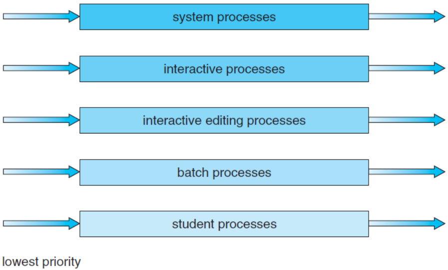

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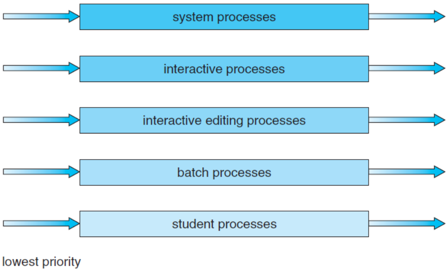

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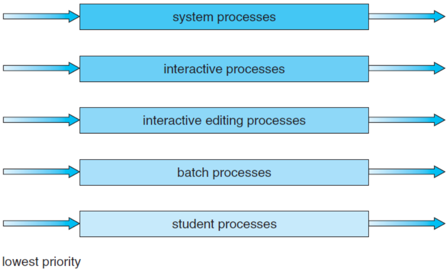
  - Scheduling algorithms for each queue



Multilevel Queue Scheduling (2/2)

- A process can move between the various queues.
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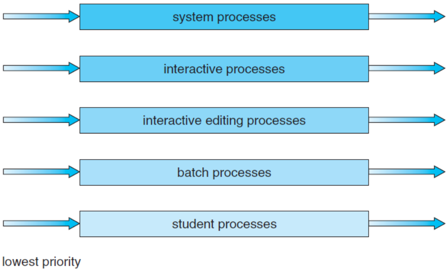

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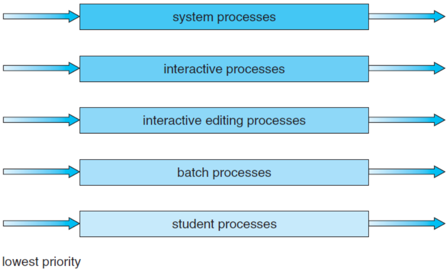
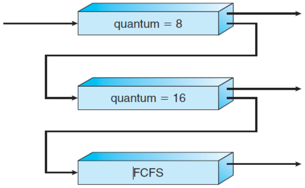


Multilevel Queue Scheduling - Example

- For example, three queues:
  - Q_0: RR with time quantum 8 milliseconds
  - Q_1: RR time quantum 16 milliseconds
  - Q_2: FCFS



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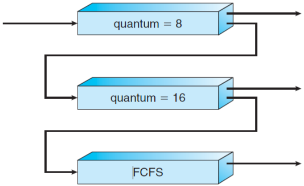

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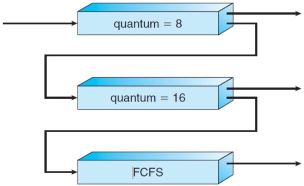

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- A new job enters queue Q_0 which is served RR:
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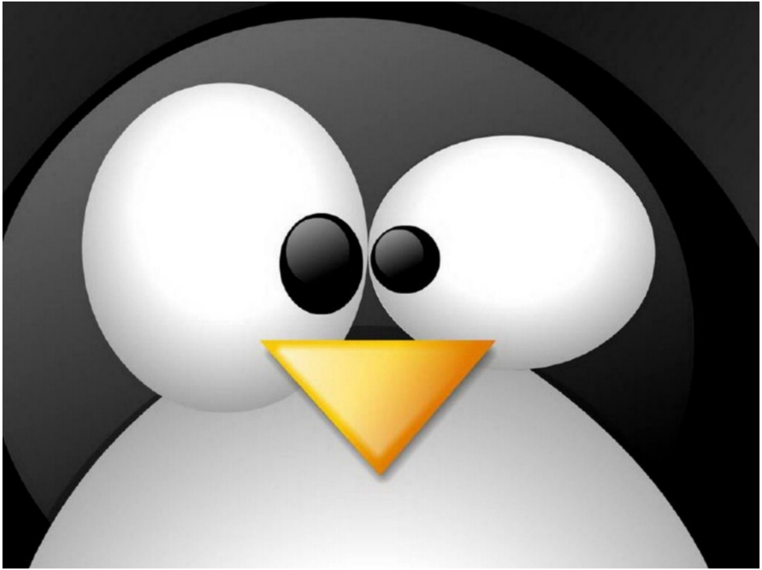
- At Q_1 job is again served RR and receives 16 additional milliseconds.
  - If it still does not complete, it is preempted and moved to queue Q_2.



Linux Scheduling (1/2)

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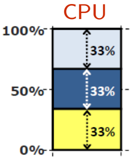
- n users want to share a resource, e.g., CPU.
  - Solution: allocate each $\frac{1}{n}$ of the shared resource.



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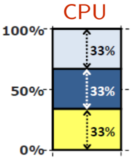

- Generalized by max-min fairness.
  - Handles if a user wants less than its fair share.
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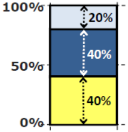

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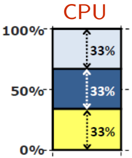

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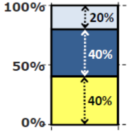
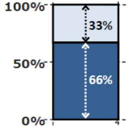
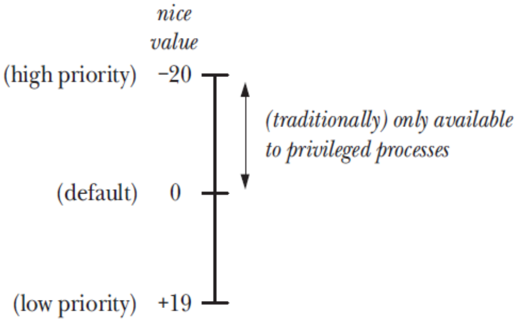


- Generalized by weighted max-min fairness.
  - Give weights to users according to importance.
  - E.g., user 1 gets weight 1, user 2 weight 2.



Linux Scheduling (2/2)

- Quantum calculated based on nice value from -20 to +19.



Modifying the Nice Value

- `nice()` increments a process's nice value by `inc` and returns the newly updated value.
- Only processes owned by root may provide a negative value for inc.

```c
#include <unistd.h>

int nice(int inc);
```

Retrieving and Modifying Priorities

- The `getpriority()` and `setpriority()` system calls allow a process to retrieve and change its own nice value or that of another process.

```c
#include <sys/resource.h>

int getpriority(int which, id_t who);

int setpriority(int which, id_t who, int prio);
```

Thread Scheduling

Thread Scheduling (1/2)

- Distinction between user-level and kernel-level threads.

- Process-Contention Scope (PCS)
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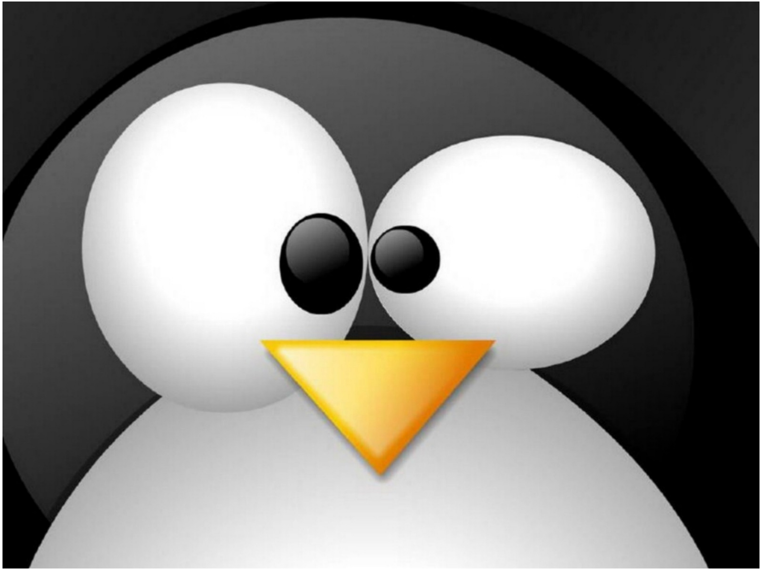
- System-Contention Scope (SCS)
  - In one-to-one model.
  - Scheduling competition among all threads in system.



Pthread Scheduling

- API allows specifying either PCS or SCS during thread creation.
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- pthread_attr_setscope and pthread_attr_getscope set/get contention scope attribute in thread attributes object.

```
#include <pthread.h>

int pthread_attr_setscope(pthread_attr_t *attr, int scope);

int pthread_attr_getscope(const pthread_attr_t *attr, int *scope);
```

Pthread Scheduling API

```c
int main(int argc, char *argv[]) {
  pthread_t t1, t2;
  pthread_attr_t attr;

  pthread_attr_init(&attr);
  pthread_attr_setscope(&attr, PTHREAD_SCOPE_SYSTEM);

  pthread_create(&t1, &attr, thread_func, NULL);
  pthread_create(&t2, &attr, thread_func, NULL);

  pthread_join(t1, NULL);
  pthread_join(t2, NULL);
}

void *thread_func(void *param) {
  /* do some work ... */
  pthread_exit(0);
}
```

Multi-Processor Scheduling

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- Symmetric multiprocessing (SMP)

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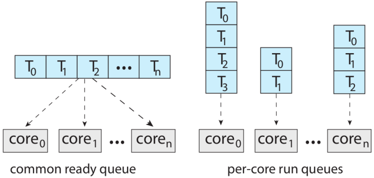
- Symmetric multiprocessing (SMP)
  - Each processor is self-scheduling
  - All processes in common ready queue, or each has its own private queue of ready processes.



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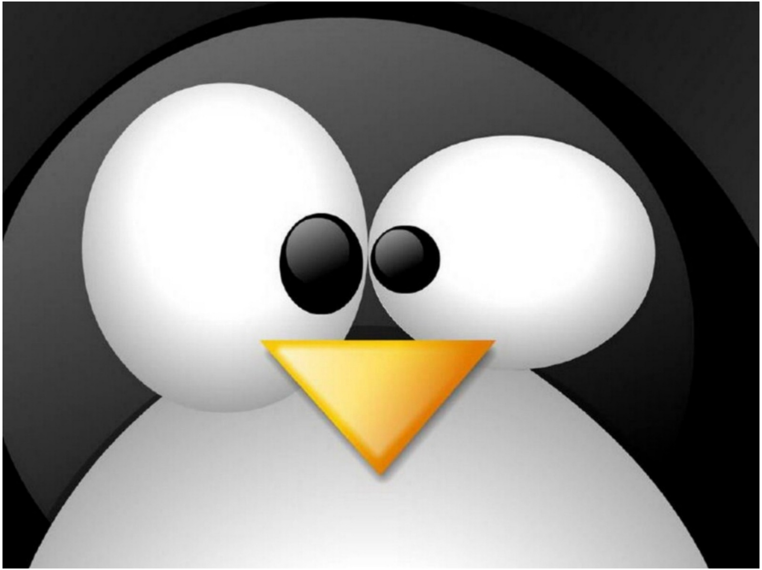
- Hard affinity: allowing a process to specify a subset of processors on which it may run.



CPU Affinity

- `sched_setaffinity()` and `sched_getaffinity()` sets/gets the CPU affinity of the process specified by `pid`.

```
#define _GNU_SOURCE
#include <sched.h>

int sched_setaffinity(pid_t pid, size_t len, cpu_set_t *set);

int sched_getaffinity(pid_t pid, size_t len, cpu_set_t *set);
```

CPU Affinity Macros

- `CPU_ZERO()` initializes set to be empty.
- `CPU_SET()` adds the CPU cpu to set.
- `CPU_CLR()` removes the CPU cpu from set.
- `CPU_ISSET()` returns true if the CPU cpu is a member of set.

```
#define _GNU_SOURCE
#include <sched.h>

void CPU_ZERO(cpu_set_t *set);
void CPU_SET(int cpu, cpu_set_t *set);
void CPU_CLR(int cpu, cpu_set_t *set);
int CPU_ISSET(int cpu, cpu_set_t *set);
```

CPU Affinity Macros

- The process identified by pid runs on any CPU other than the first CPU of a four-processor system.

```
cpu_set_t set;

CPU_ZERO(&set);
CPU_SET(1, &set);
CPU_SET(2, &set);
CPU_SET(3, &set);

sched_setaffinity(pid, sizeof(set), &set);
```

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Questions?

Acknowledgements

Some slides were derived from Avi Silberschatz slides.