1 User Mode

- Is restricted
- Executing code has no ability to *directly* access hardware or reference memory [1]
- Crashes are always recoverable [1]
- Is where most of the code on our computer / applications are executed [3]

2 Kernel Mode

- Is previleged (non-restricted)
- Executing code has complete and unrestricted access to the underlying hardware [3]
- Is generally reserved for the lowest-level, most trusted functions of the operating system [1]
- Is fatal to crash; it will halt the entire PC (i.e the blue screen of death) [3]

3 Interrupt

- i is a signals are sent by hardware (keyboardm mouse, etc.), or software (page fault, protection violation, system call)
- Tells the CPU to stop its current activities and execute the appropriate part of the operating system (**Interrupt Handler**). [2]
- Has three different types [2]

  1) **Hardware Interupts**
     - Are generated by hardware devices to signal that they need some attention from the OS.
     - May be due to receiving some data

       Examples

       * Keystrokes on the keyboard
       * Receiving data on the ethernet card

     - May be due to completing a task which the operating system previous requested

       Examples

       Transfering data between the hard drive and memory

2) **Software Interupts**
   - Are generated by programs when a system call is requested

3) **Traps**
   - Are generated by the CPU itself
   - Indicate that some error or condition occured for which assistance from the operating system is needed

4 Content Switch

- Is switching from running a user level process to the OS kernel and often to other user processes before the current process is resumed
- Happens during a timer interrupt or system call
- Saves the following states for a process during a context switch
  - Stack Pointer
  - Program Counter
  - User Registers
  - Kernel State
- May hinder performance

5 System Call

- Is the programmatic way in which a computer program requests a previleged service from the kernel of the operating system
- i.e. Reading from disk
- Is strictly a subset of software interrupts
- Steps
  1) Setup **trap tables** on boot
  2) Execute system call
  3) Save *Program Counter*, *CPU registers*, *kernal stack* (so process can resume after **return-from-trap** or **context switch**)
  4) Switch from **user mode** to **kernel mode**

5) Perform previleged operations
6) Finish and execute **return-from-trap** instruction
7) Return from **kernel mode** to **user mode** and resume user program

Example

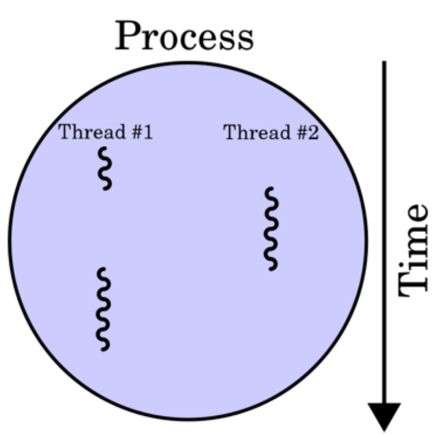
- `yield()`
  - Is a system call
  - Causes the calling thread to relinquish the CPU
  - Places the current thread at the end of the run queue
  - Schedules another thread to run

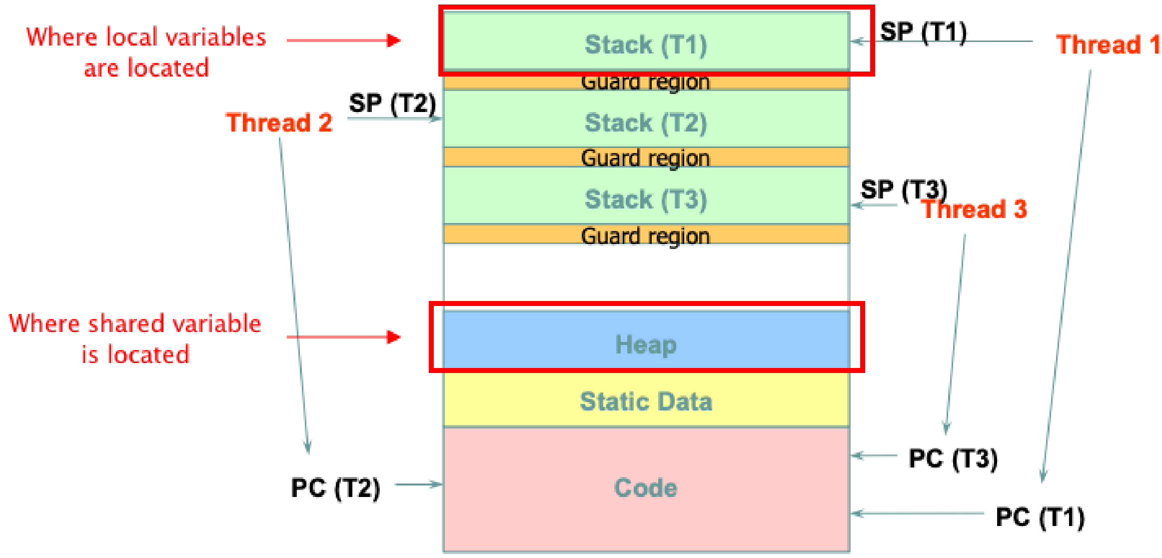
6 Critical Section

- Is a piece of code that accesses a *shared* resource, usually a variable or data structure

7 Thread

- Is a lightweight process that can be managed independently by a schdeduler [4]
- Improves the application performance using parallelism. (e.g peach)





- A thread is bound to a single process
- A process can have multiple threads
- Has two types
  - **User-level Threads:**
    * Are implemented by users and kernel is not aware of the existence of these threads
    * Are represented by a program counter(PC), stack, registers and a small process control block
    * Are small and much faster than kernel level threads
  - **Kernel-level Threads:**
    * Are handled by the operating system directly
    * Thread management is done by the kernel
    * Are slower than user-level threads

8 Thread API

- `pthread_cond_wait`
  - Puts the calling thread to sleep (a blocked state)
  - Waits for some other thread to signal it

Example

```
pthread_mutex_t lock = PTHREAD_MUTEX_INITIALIZER;
pthread_cond_t  cond = PTHREAD_COND_INITIALIZER;

Pthread_mutex_lock(&lock);
while (ready == 0)
    Pthread_cond_wait(&cond, &lock);
Pthread_mutex_unlock(&lock);
```

Puts calling thread cond to sleep

- `pthread_cond_signal`
  - Is used to unblocks at least one of the threads that are blocked on the specified condition variable cond

Example

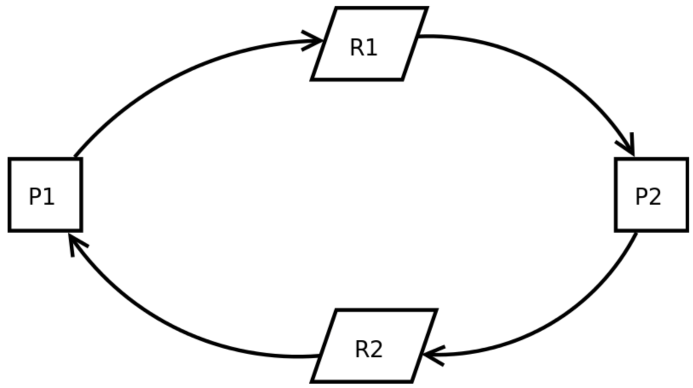
```
Pthread_mutex_lock(&lock);
ready = 1;
Pthread_cond_signal(&cond);
Pthread_mutex_unlock(&lock);
```

Wakes a thread that's been put to sleep
on cond variable

9 Livelock

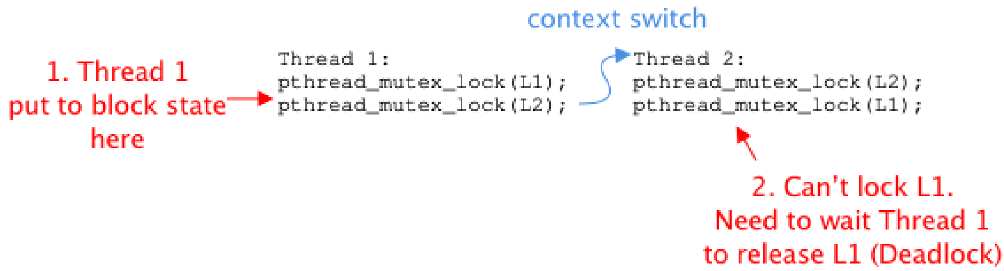
- Two or more threads reapeatedly attempting this code over and over (e.g acquiring lock), but progress is not being made (e.g acquiring lock)
- Solution: Add a random delay before trying again (decrease odd of livelock)

10 Deadlock



- Is a state in which each member of a group is waiting for another member including itself, to take action (e.g. releasing lock)
- Conditions for Deadlock (All four must be met)
  - **Mutual Exclusion**
    - Occurs when threads claim exclusive control of resources that they require (e.g. thread grabing a lock)
  - **Hold-and-wait**
    - Occurs when threads hold resources allocated to them (e.g locks that they have already acquired) while waiting for additional resources (e.g. locks that they wish to acquire)
  - **No Preemption**
    - Occurs when resource cannot be forcibly removed from threads that are holding them
  - **Circular Wait**
    - Occurs when there exists a circular chain of threads such that each threads hold one or more resources (e.g. locks) that are being requested by the next thread in the chain.

Example



- Preventions
  - **Circular Wait**
    - Write code such that circular wait is never induced
    - Is the most practical prevention technique
    - Requires deep understanding of the code base
    - **Total Ordering** (Most starightforward)

      <u>**Example**</u>

      Given two locks in the system (`L1` and `L2`), always acuiqure `L1` before `L2`
    - **Partial Ordering** (Applied to complex systems)

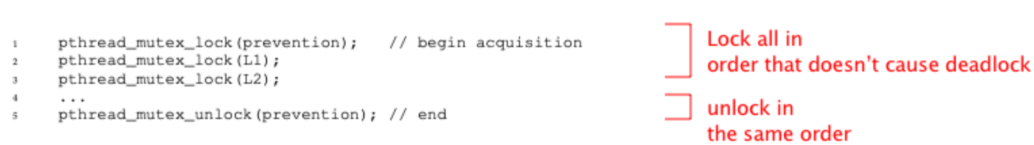
      <u>**Example**</u>

      Memory mapping code in Linux (has then different groups).

      (Simple) `i_mutex` before `i_mmap_mutex`

      (More complex) `i_mmap_mutex` before `private_lock` before `swap_lock` before `mapping->tree_lock`
  - **Hold-and-wait**
    - Can be avoided by acquiring all locks at once
    - Can be problematic
    - Must know which lock must be held and acquire ahead of time
    - Is likely to decrease concurrency (since all need to be acquired over their needs)

      <u>**Example**</u>



- **No Preemption**
  - Can be avoided by adding code that force unlock if not available

Thread 1

```
top:
  pthread_mutex_lock(L1);
  if (pthread_mutex_trylock(L2) != 0) {
    pthread_mutex_unlock(L1);
    goto top;
  }
```

1. Check if L2 is locked or not available

2. Unlock L1 forcibly (to avoid deadlock)

Thread 2

```
top:
  pthread_mutex_lock(L2);
  if (pthread_mutex_trylock(L1) != 0) {
    pthread_mutex_unlock(L2);
    goto top;
  }
```

  - `pthread_mutex_trylock` tries to lock the speicied mutex.
  - `pthread_mutex_trylock` returns 0 if lock is available
  - `pthread_mutex_trylock` returns the following error if occupied

    `EBUSY` - Mutex is already locked

    `EINVAL` - Is not initialized mutex

    `EFAULT` - Is in valid pointer
  - May result in **live lock**
- **Mutual Exclusion**
  - Idea: Avoid the mutual exclusion at all
  - Use **lock-free/wait-free** approach: building data structures in a manner that does not require explicit locking using hardware instructions

    Example

```
int CompareAndSwap(int *address, int expected, int new) {
  if (*address == expected) {
    *address = new;
    return 1; // success
  }
  return 0; // failure
}
```

- Avoidance
  - **Banker's Algorithm**

11 Process

- Is a program in execution
- Is named by it's process ID or PID
- Can be described by the following states at any point in time
  - Address Space
  - CPU Registers
  - Program Counter
  - Stack Pointer
  - I/O Information

  (wait. this is PCB)
- Exists in one of many different **process states**, including
  1. Running
  2. Ready to Run
  3. Blocked

  - Different events (Getting Scheduled, descheduled, or waiting for I/O) transitions one of these states to the other

12 Signals

- Provides a way to communicate with the process
- Can cause job to stop, continue, or terminate
- Can be delivered to an application
  - Stops the application from whatever its doing
  - Runs Signal handler (some code in application to handle the signal)
  - When finished, the process resumes previous behavior

13 Spinlock

- Is the simplest lock to build
- Uses a lock variable
  - 0 - (available/unlock/free)
  - 1 - (acquired/locked/held)
- Has two operations
  1. `acquire()`

```
boolean test_and_set(boolean *lock)
{
      boolean old = *lock;
      *lock = True;
      return old;
}
boolean lock;

void acquire(boolean *lock) {
       while(test_and_set(lock));
}
```

  2. `release()`

```
void release(boolean *lock) {
       *lock = false;
}
```

- Allows a single thread to enter critical section at a time
- Spins using CPU cycles until the lock becomes available.
- May spin forever

14 Deadlock

-

---

15 Response Time

- **Formula** $T_{response} = T_{firstrun} - T_{arrival}$
- measures the interactive performance between users and the system

16 Turnaround Time

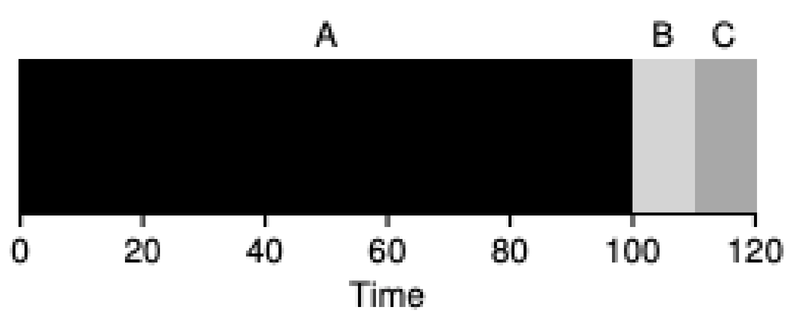
- **Formula** $T_{turnaround} = T_{completion} - T_{arrival}$
- measures the amount of time taken to complete a process

17 Starvation

- Is the problem that occurs when high priority processes keep executing and low priority processes get blocked for indefinite time [1]

18 Convoy Effect

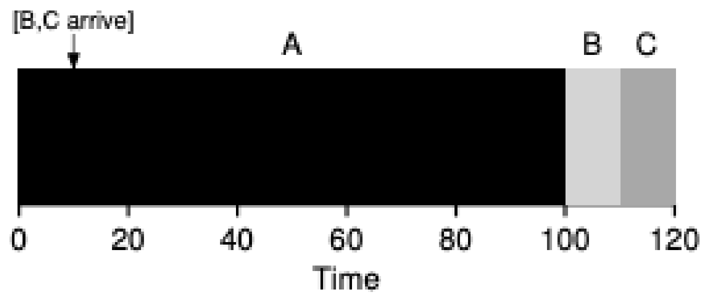
- Is the problem where number of relatively-short potential consumers of a resource get queued behind a heavy weight consumer



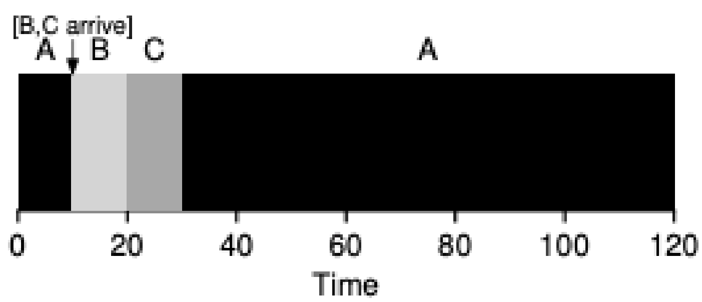
19 Scheduling policies

- Are algorithms for allocating CPU resources to concurrent tasks deployed on (i.e., allocated to) a processor (i.e., computing resource) or a shared pool of processors [5]

- Are sometimes called **Discipline**
- Covers the following algorithms in textbook
  - **First In First Out**
    - Is the most basic scheduling algorithm
    - Is vulnerable to **convoy effect**
    - No **starvation** as long as every process eventually completes
  - **Shortest Job First**
    - Improves average **turnaround time** given processes of uneven length
    - Is a general scheduling principle useful in situation where turnaround time per process matters
    - Is vulnerable to **convoy effect**



    - Is vulnerable to **starvation**
      - When only short-term jobs come in while a long term job is in queue
  - **Shortest Time-to-completion First**
    - Addresses **convoy effect** in **Shortest Job First**
    - Determines which of the remaining+new jobs has least time left, and schedule accordingly at <u>any time</u>

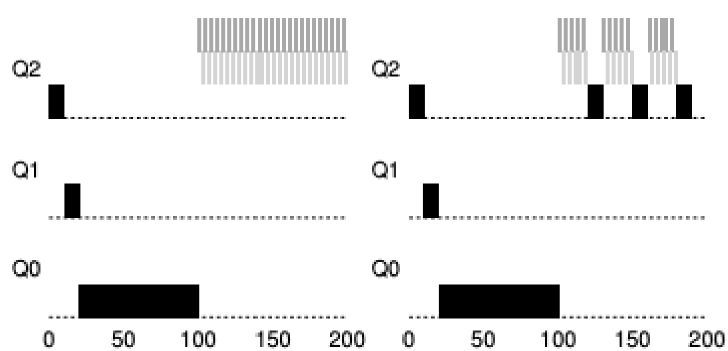


    - Is vulnerable to **starvation**
      - When only short-term jobs come in while a long term job is in queue
  - **Round Robin**
    - Has good **response time** but terrible **turnaround time**

* Runs job for a **time slice** or **quantum**
* Each job gets equal share of CPU time
* Is clock-driven [6]
* Is starvation-free [7]
* Must have the length of a time slice (**quantum**) as multiple of timer-interrupt period

```
void release(boolean *lock) {
        *lock = false;
}
```

– **Multi-level Feedback Queue**
  * Is the most well known approaches to shceduling
  * Optimizes **turnaround time**, and minimizes **response time**
  * Observees the execution of a job and priortizes accordingly without prior knowledge
  * Rules
    · **Rule 1:** If Priority(A) > Priority(B), A runs (B doesn't)
    · **Rule 2:** If Priority(A) = Priority(B). A & B run in round-robin fashion using the time slice (quantum length) of the given queue
    · **Rule 3:** When a job enters the system, it is placed at the highest priority(the top most queue)
    · **Rule 4:** Once a job uses up its time allotment at a given level (regardless of how many times it has given up the CPU), its priority is reduced (it moves down on queue)
    · **Rule 5:** After some time period S, move all the jobs in the system to the topmost queue.



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