1. a) Trap instruction is run in user mode, and privileged operation is run in kernel mode

Notes

- **Previliged Instructions**
  - Is the instruction that can run only in **kernel mode**
  - Attempt at execution in **user mode** → treated as an illegal operation & will not run.
- **Trap**
  - Is a special hardware instruction
  - Is a software generated interrupt [4]
  - Is a type of synchronous interrupt [1]
  - Is caused by an exceptional condition [1]
    1. Division by zero [1]
    2. Invalid memory access (segmentation fault) [1]
    3. Previleged instruction by **user mode** code [2]
  - Usually results in a switch to **kernel mode** → Operating system performs action → Returns control to oroginal process
- **Trap Instruction**
  - Is executed when a user wants to invoke a service from the operating system (i.e. reading hard drive) in **user mode**
  - Raise (the processor) privilege level to kernel mode
- **User Mode**
  - Is restricted
  - Executing code has no ability to *directly* access hardware or reference memory [3]
  - Crashes are always recoverable [3]
  - Is where most of the code on our computer / applications are executed [3]
- **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 [3]
  - Is fatal to crash; it will halt the entire PC (i.e the blue screen of death) [3]

References

1) Wikipedia, Trap (computing), link
2) University of Utah, CS5460: Operating Systems Lecture 3 - OS Organization, link
3) Coding Horror, Understanding User and Kernel Mode, link

4) ETH Zurich, Programming in Systems, link

b) No. Lock uses a variable with binary states 0 (acquired) and 1 (available), where as semaphore uses counter variable that can have value greater than 1 to keep track of the amount of resource remaining.

Notes

- **Locks**
  - Is a variable with two boolean states
    - 1 - (available/unlock/free)
    - 0 - (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;
}
```

  - Is put around critical section to ensure critical section executes as if it's a single atomic instruction

```
1  lock_t mutex; // some globally-allocated lock 'mutex'
2  ...
3  lock(&mutex);
4  balance = balance + 1;
5  unlock(&mutex);
```

  - Can only be released by the thread that acquired it
  - Is used to protect shared resource (e.g. from race condition in files and data structure) [2]
- **Semaphore**
  - Is an abstract data types suitable for synchronization problems [2]
  - Has variable `count` that allows arbitrary resource count [1]
  - Has two atomic operations
    1. (`wait/P/decrement`) - block until `count > 0` then decrement variable

```
wait(semaphore *s) {
        while (s->count == 0) ;
        s->count -= 1;
}
```

    2. (`signal/V/increment`) - increment `count`, unblock a waiting thread

```
signal(semaphore *s) {
        s->count += 1;
        ......                  //unblock one waiter
}
```

  - Can be signaled by any thread [2]

References

1) Wikipedia, Semaphore (programming), link
2) Stack Overflow, Difference between binary semaphore and mutex, link

c) If both access are read, then concurrency error will not occur.

Notes

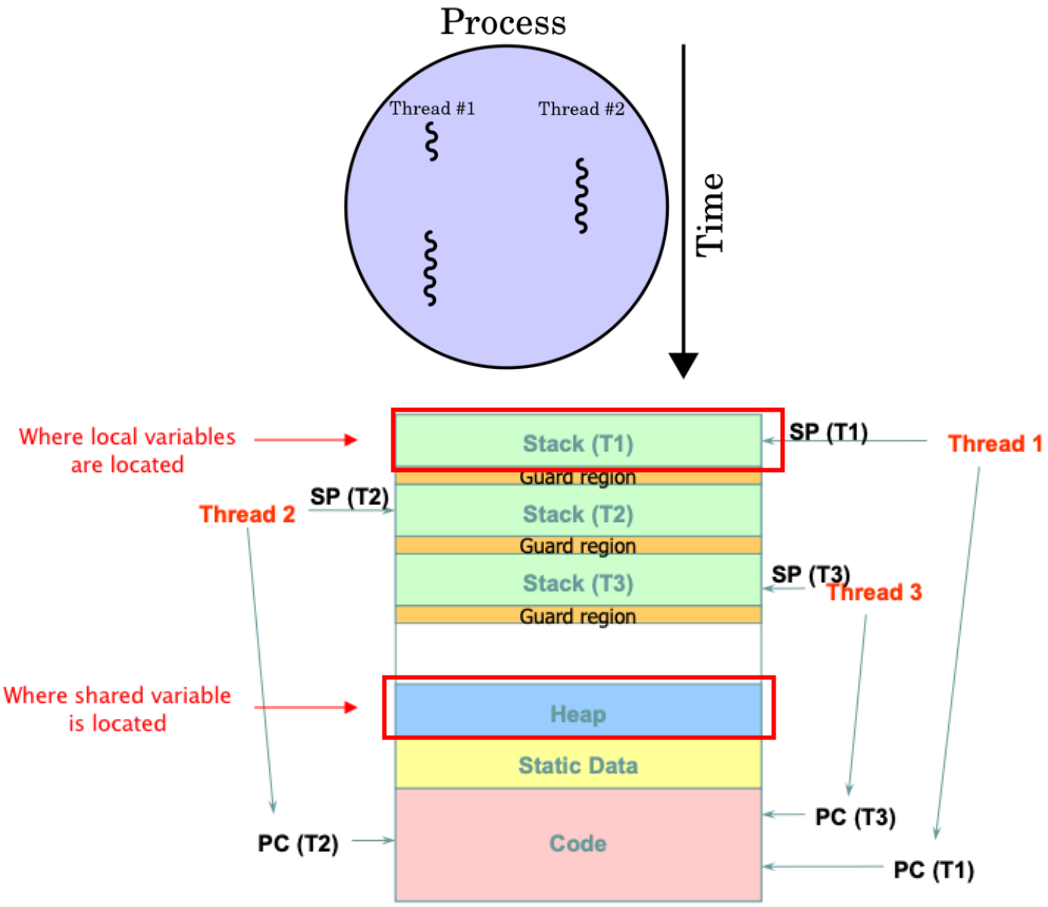
- What is concurrency error? Where and when does it occur?
- **Concurrency**
  - Is the ability of different parts or units of a program, algorithm, or problem to be executed out of order, without affecting the final outcome. [1]
- **Concurrency Error**
  - Two types of concurrency errors [3]
    1. **Deadlock:** A situation wherein two or more processes are never able to proceed because each is waiting for the others to do something

       Key: Circular wait

    2. **Race Condition:** a timing dependent error involving shared state

  - **Data Race:** Concurrent accesses to a shared variable and at least one access is a write
  - **Atomicity Bugs:** Code does not enforce the atomicity programmers intended for a group of memory access
  - **Order Bugs:** Code does not enforce the order programmers intended for a group of memory access

- **Thread**
  - Is the smallest sequence of programmed instructions that can be managed independently by a schdeduler [2]



  - A thread is bound to a single process
  - A process can have multiple threads

References

1) Wikipedia, Concurrency (computer science), link
2) Wikipedia, Thread, link
3) Columbia University, Concurrency Errors, link

d) No, limited execution limits what a process can do without OS assistance by restricting access to hardwares, setting up interrupt timer, and trap handlers.

Notes

- **Virtualization of CPU**
  –
- **Limited Direct Execution**
  – Idea: Just run the program you want to run on the CPU, but first make sure to set up the hardware so as to limit what process can do without OS assistance
  – baby proofs the CPU by

    1. Setting up trap handlers
    2. Starts an interrupt timer
    3. Run processes in a restricted mode

    Example

    Baby proofing a room:

    * Locking cabinets containing dangerous stuff and covering electrical sockets.
    * When room is readied, let your baby roam free in knowledge that all the dangerous aspect of the room is restricted
- **Trap Handlers**
  – Is instruction that tells the hardware what to run when certain exceptions occur

    Example

    What code to run when

    1. Hard disk interrupt occurs
    2. Keyboard interrupt occrs
    3. Program makes a system call?
- **Timer Interrupt**
  – Is a hardware mechanism that ensures the user program does not run forever
  – Is emitted at regular intervals by a timer chip [1]

References

1) Wikibooks, Operating System Design/Processes/Interrupt, link

e) **Notes**

- **Inode**
  – Is a short form for **index node**
  – Contains disk block location of the object's data [1]

- **Index-based File System**
  –
- **External Fragmentation**
  – Is various free holes that are generated in either your memory or disk space. [2]
  – Are available for allocation, but may be too small to be of any use [2]
- **Internal Fragmentation**
  – Is wasted space within each allocated block [2]
  – Occurs when more computer memory is allocated than is needed

References

1)
2) Washington University, Explain the difference between external fragmentation and internal fragmentation, link