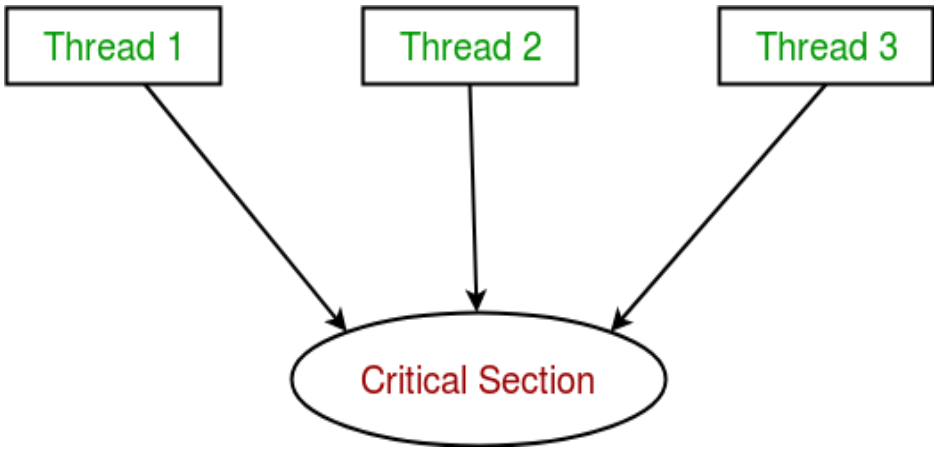
Multithreading in Python (Synchronization)

Synchronization between threads

Thread synchronization is defined as a mechanism which ensures that two or more concurrent threads do not simultaneously execute some particular program segment known as **critical section**.

Critical section refers to the parts of the program where the shared resource is accessed.

For example, in the diagram below, 3 threads try to access shared resource or critical section at the same time.



Concurrent accesses to shared resource can lead to **race condition**.

A race condition occurs when two or more threads can access shared data and they try to change it at the same time. As a result, the values of variables may be unpredictable and vary depending on the timings of context switches of the processes.

Consider the program below to understand the concept of race condition:

```
import threading
# global variable x
x = 0
def increment():
        """ function to increment global variable x """
        global x
        x += 1
def thread_task():
        """ task for thread calls increment function 100000 times. """
        for k in range(100000):
                increment()
def main_task():
        global x
        # setting global variable x as 0
        x = 0
        t1 = threading.Thread(target=thread_task)
        t2 = threading.Thread(target=thread_task)
        t1.start()
        t2.start()
        t1.join()
        t2.join()
for i in range(10):
            main_task()
            print("Iteration {0}: x = {1}".format(i,x))
```

Output:

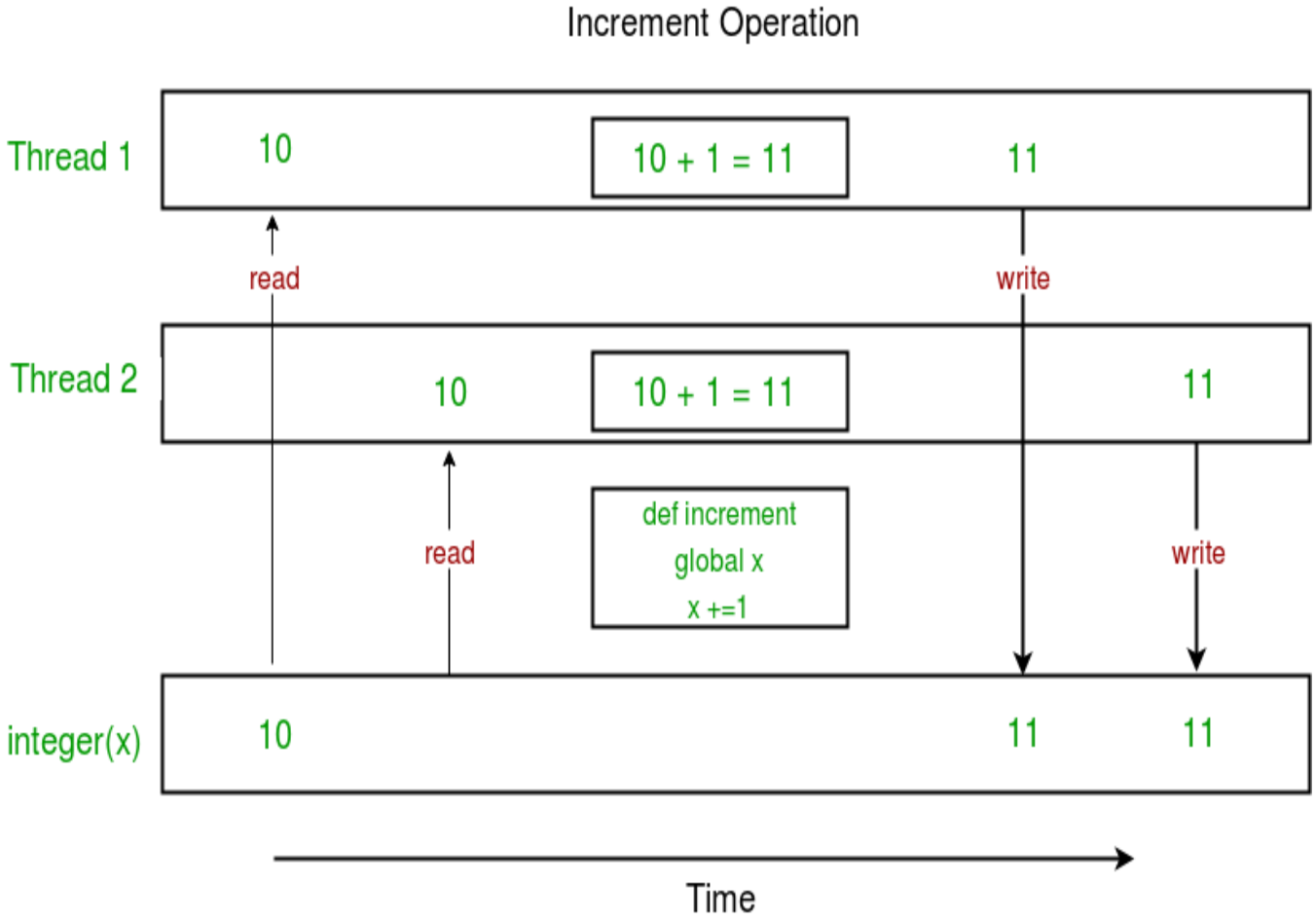
```
Iteration 0: x = 175005

Iteration 1: x = 200000

Iteration 2: x = 200000

Iteration 3: x = 169432

Iteration 4: x = 153316

Iteration 5: x = 200000

Iteration 6: x = 167322

Iteration 7: x = 200000

Iteration 8: x = 169917

Iteration 9: x = 153589
```

In above program:

- Two threads **t1** and **t2** are created in **main_task** function and global variable **x** is set to 0.
- Each thread has a target function **thread_task** in which **increment** function is called 100000 times.
- **increment** function will increment the global variable **x** by 1 in each call.

The expected final value of **x** is 200000 but what we get in 10 iterations of **main_task** function is some different values.
This happens due to concurrent access of threads to the shared variable **x**. This unpredictability in value of **x** is nothing but **race condition**.

Given below is a diagram which shows how can **race condition** occur in above program:



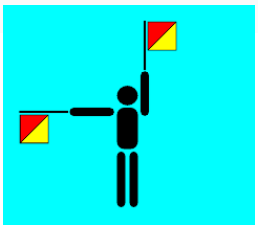
Notice that expected value of **x** in above diagram is 12 but due to race condition, it turns out to be 11!

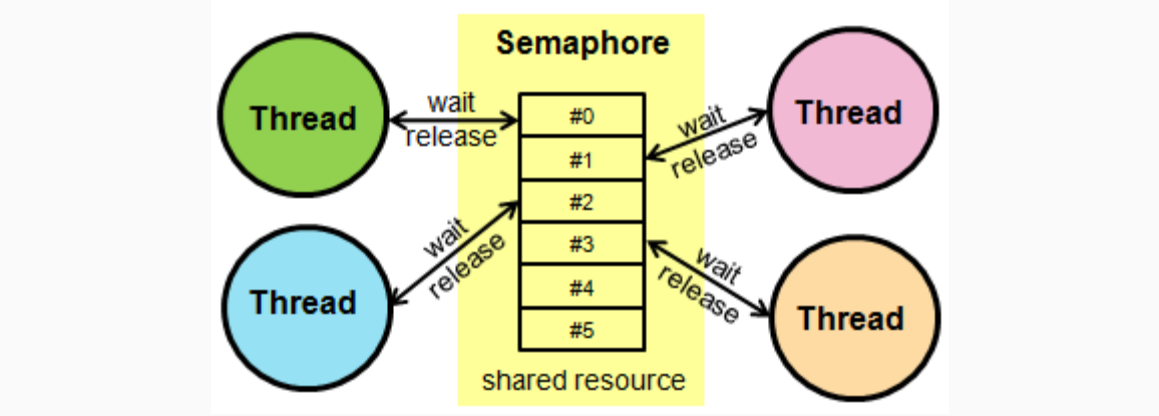
Hence, we need a tool for proper synchronization between multiple threads.

Using Locks

threading module provides a **Lock** class to deal with the race conditions. Lock is implemented using a **Semaphore** object provided by the Operating System.

A semaphore is a synchronization object that controls access by multiple processes/threads to a common resource in a parallel programming environment. It is simply a value in a designated place in operating system (or kernel) storage that each process/thread can check and then change. Depending on the value that is found, the process/thread can use the resource or will find that it is already in use and must wait for some period before trying again. Semaphores can be binary (0 or 1) or can have additional values. Typically, a process/thread using semaphores checks the value and then, if it using the resource, changes the value to reflect this so that subsequent semaphore users will know to wait.





Lock class provides following methods:

- **acquire([blocking]) :** To acquire a lock. A lock can be blocking or non-blocking.
  - When invoked with the blocking argument set to **True** (the default), thread execution is blocked until the lock is unlocked, then lock return **True**.
  - If thread execution is not blocked. The lock is set to **False** .
- **release() :** To release a lock.
  - When the lock is locked, reset it to unlocked, and return. If any other threads are blocked waiting for the lock to become unlocked, allow exactly one of them to proceed.
  - If lock is already unlocked, a **ThreadError** is raised.

Consider the example given below:

```
import threading
# global variable x
x = 0
def increment():
        """ function to increment global variable x """
        global x
        x += 1
def thread_task(lock):
        """ task for thread calls increment function 100000 times. """
        for _ in range(100000):
                lock.acquire()
                increment()
                lock.release()
def main_task():
        global x
        # setting global variable x as 0
        x = 0
        # creating a lock
        lock = threading.Lock()
```

```
# creating threads
        t1 = threading.Thread(target=thread_task, args=(lock,))
        t2 = threading.Thread(target=thread_task, args=(lock,))
        t1.start()
        t2.start()
        t1.join()
        t2.join()
for i in range(10):
        main_task()
        print("Iteration {0}: x = {1}".format(i,x))
```

Output:

```
Iteration 0: x = 200000

Iteration 1: x = 200000

Iteration 2: x = 200000

Iteration 3: x = 200000

Iteration 4: x = 200000

Iteration 5: x = 200000

Iteration 6: x = 200000

Iteration 7: x = 200000

Iteration 8: x = 200000

Iteration 9: x = 200000
```

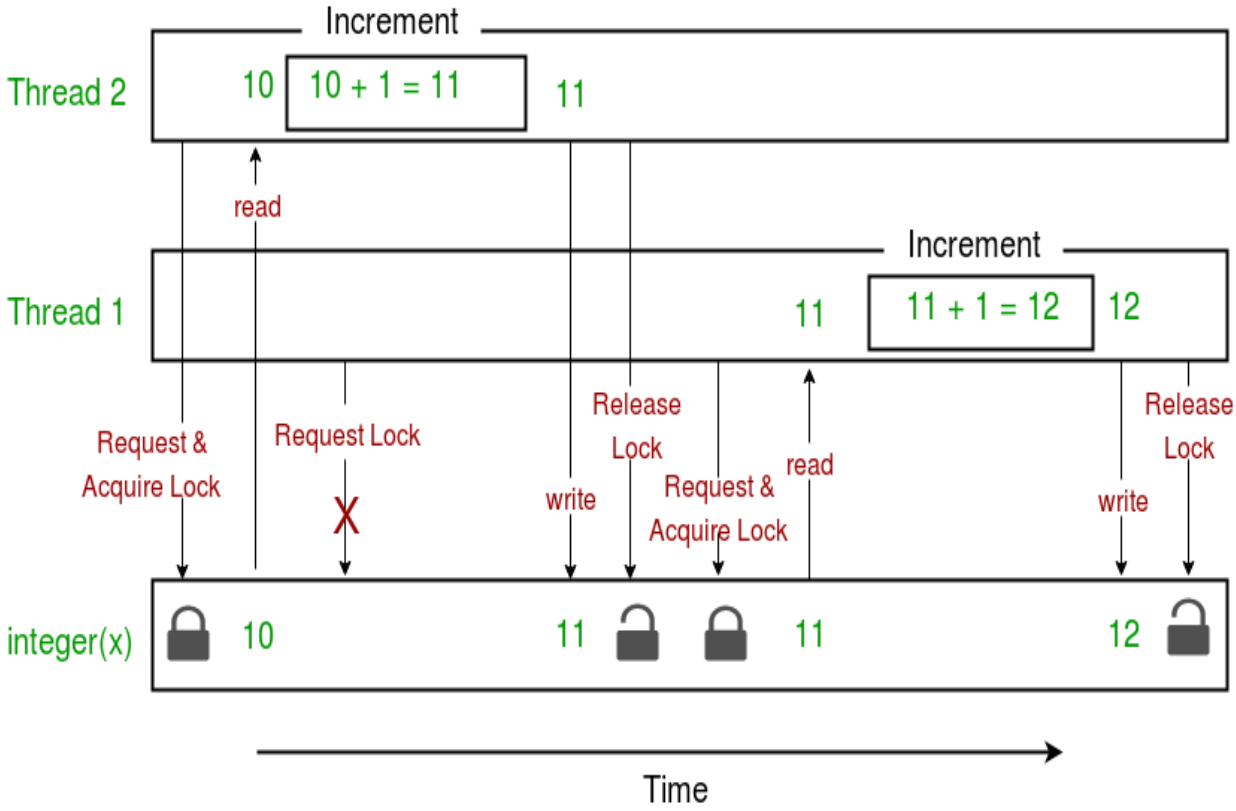
Let us try to understand the above code step by step:

- Firstly, a **Lock** object is created using:
- `lock = threading.Lock()`
- Then, **lock** is passed as target function argument:
- `t1 = threading.Thread(target=thread_task, args=(lock,))`
- `t2 = threading.Thread(target=thread_task, args=(lock,))`
- In the critical section of target function, we apply lock using **lock.acquire()** method. As soon as a lock is acquired, no other thread can access the critical section (here, **increment** function) until the lock is released using **lock.release()** method.

```
lock.acquire()

increment()

lock.release()
```

As you can see in the results, the final value of **x** comes out to be 200000 every time (which is the expected final result).

Here is a diagram given below which depicts the implementation of locks in above program:



Finally, here are are a few advantages and disadvantages of multithreading:

Advantages:

- It doesn't block the user. This is because threads are independent of each other.
- Better use of system resources is possible since threads execute tasks parallely.
- Enhanced performance on multi-processor machines.
- Multi-threaded servers and interactive GUIs use multithreading exclusively.

Disadvantages:

- As number of threads increase, complexity increases.
- Synchronization of shared resources (objects, data) is necessary.
- It is difficult to debug, result is sometimes unpredictable.

Difference between Multi-tasking and Multi-threading