**LABWORK**

**COURSE: DISTRIBUTED SYSTEMS CHAPTER 6: SYNCHRONIZATION**

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**1. Deploy the synchronization for threads of a multithreaded process**

# 1.1. Contents

We consider now the problem in the Distributed Systems where multiple processes try to access the shared resource, however this resource can support only one (or only some processes) at a moment. Another problem is that multiple processes may sometimes need to agree on the ordering of events, such as whether message m1 from process P was sent before or after message m2 from process Q. These problems can be solved in using synchronization mechanism in Distributed Systems.

In this labwork, you will learn a synchronization technique in Java. In order to facilitate the things, you will work with threads instead of processes.

# 1.2. Requirements

**1.2.1. Theory**

* synchronization

**1.2.2. Hardwares**

* Laptop/PC on any OS

**1.2.3. Softwares**

* any Java IDE (Eclipse is recommended)

# 1.3. PRACTICAL STEPS

You will try to simulate an environment with a shared resource and several threads that want to access this resource.

Create a class, named *ResourcesExploiter*, which has a private variable *rsc* (type *int*) that is considered as the shared resource. Since this is a private variable so you do need two methods to set and get the value for it:

**public** **void** setRsc(**int** n){

rsc = n;

}

**public** **int** getRsc(){ **return** rsc;

}

The constructor method of this class takes only one input parameter to initialize the *rsc* variable.

**public** ResourcesExploiter(**int** n){

rsc = n;

}

You also create the *exploit()* method that increases the *rsc* variable by 1 unit.

**public** **void** exploit(){ setRsc(getRsc()+1);

}

Create a class named *ThreadedWorkerWithoutSync* that extends the *Thread* class (available in the Java library).

Create a private variable named *rExp* of type *ResourcesExploiter*.

In the *run()* method that you must override, you put a loop *for* of 1000 times calling the *exploit()* method of the variable *rExp*.

Create a class for the executable program (with the *main* method).

In the *main* method, follow these steps:

* Create an instance named *resource* of type *ResourcesExploiter* with the initial value of the input parameter is 0.

ResourcesExploiter resource = **new** ResourcesExploiter(0);

* Create 3 instances named *worker1*, *worker2*, and *worker3* of type *ThreadedWorkerWithoutSync* (don’t forget to put the instance *resource* as the input of the constructor method):

ThreadedWorkerWithoutSync worker1 = **new** ThreadedWorkerWithoutSync(resource);

ThreadedWorkerWithoutSync worker2 = **new** ThreadedWorkerWithoutSync(resource); ThreadedWorkerWithoutSync worker3 = **new** ThreadedWorkerWithoutSync(resource);

* Start these three *worker1-3* threads (by calling the *start()* method).
* Don’t forget to call the method *join()* for each thread to wait until this thread finishes its work.
* After, print the value of the *rsc* variable of the instance *resource*.

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| Question 1: Launch this program several times. What do you notice? Explain it!   * Chạy hàm main, mỗi lần sẽ ra một kết quả khác nhau do chưa có cơ chế đồng bộ hóa giữa các *ThreadedWorker*, các *ThreadedWorker dùng chung tài nguyên hay thứ tự các sự kiện =>* Kết quả sai lệch |

Now, it’s time to apply the synchronization mechanism to your program.

Create a class named *ThreadedWorkerWithSync* that is similar to the *ThreadedWorkerWithoutSync* class except that it now applies the ***synchronized*** on the *rExp* variable, and that's for the entire loop *for*.

**synchronized**(rExp){

**for**(**int** i=0;i<1000;i++){ rExp.exploit();

}

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| Question 2: Change the code of the general executable program by replacing *ThreadedWorkerWithoutSync* with *ThreadedWorkerWithSync* to initiate three instances *worker1-3*. What is the difference between the output of this program and that of question 1? Explain it!   * Kết quả luôn trả về 3000. Khi được áp dụng cơ chế đồng bộ hóa, các *ThreadedWorker*, mỗi *ThreadedWorker* tăng biên src lên 1000. Các *ThreadedWorker* được phân chia tài nguyên và quản lý thứ tự gửi các thông điệp |

Now, you’ll try the *lock* mechanism.

Create a class named *ResourcesExploiterWithLock* that extends the

*ResourcesExploiter* class. First, you have to import two classes as follows:

**import** java.util.concurrent.TimeUnit; **import** java.util.concurrent.locks.ReentrantLock;

This class has a *lock* variable of type *ReentrantLock*:

**private** ReentrantLock lock;

For the constructor, you have to use *super* method to use the constructor of the class *ResourcesExploiter*:

**public** ResourcesExploiterWithLock(**int** n){

**super**(n);

lock = **new** ReentrantLock();

}

In its *exploit()* method, use the *lock.tryLock* method to block the variable's increase operation:

**try**{

**if**(lock.tryLock(10, TimeUnit.***SECONDS***)){ setRsc(getRsc()+1);

}

} **catch** (InterruptedException e) { e.printStackTrace(); }**finally**{ //release lock lock.unlock();

}

Create a class named *ThreadedWorkerWithLock* that extends the *Thread* class. This class looks like the class *ThreadedWorkerWithoutSync* except that the type of its variable *rExp* is *ResourcesExploiterWithLock*.

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| Question 3: Change the code of the general executable program by replacing *ThreadedWorkerWithSync* with *ThreadedWorkerWithLock* to initiate three instances *worker1-3*. What is the difference between the output of this program and the output in question 1? Explain it!  Phương thước:  tryLock(long timeout, TimeUnit unit):  timeout – Thời gian chờ khóa  unit – Đơn vị thời gian   * Chỉ giữ lock khi không có bất kỳ luồng nào khác đang giữ lock. Nếu luồng đã giữ khóa này -> true. Không trả về false   Kết quả luôn trả về 3000. Vì khi đó các *ThreadedWorker* sẽ được quản lý và không bị dùng chung tài nguyên |

**2. Parallel Programming with Critical Sections**

# 2.1. Contents

In the *Chapter 3: Processes and Threads*, we explored threads and their usefulness for concurrent programming. Threads are a way to divide the resources of a process so that individual parts can be scheduled independently. We also described this as user level parallelism, as oppose to O.S. level parallelism that is provide by processing.

There are many benefits to user level parallelism, such as simpler programming structure and design. User level parallelism also means that each thread shares the same resources, including memory. However, using shared resources comes at a cost. Imagine we have multiple threads trying to manipulate a single memory address. You might think that each thread will be able to act without interference, but computers are finicky and the thread scheduling routine is not transparent. A thread may be just in the middle of an operation and then be interrupted by another thread that is also operating on the same data. The result is that the data can become inconsistent and neither thread has the true representation of the data.

To solve these problems, we need a new mechanism to ensure that all critical operations are atomic or mutually exclusive, that is, an operation completes full within one thread without the possibility of another thread preempting that process. This mechanism is called Critical Section. In the 2nd part of this labwork, we are going to learn how to add mutual exclusion to our programs to avoid inconsistencies and how to avoid using these tools in ways to hamper program progress.

# 2.2. Requirements

**2.2.1. Theory**

* Parallel programming with critical sections

**2.2.2. Hardwares**

* Laptop/PC on any OS (recommended on Linux)

**2.2.3. Softwares**

* gcc

# 2.3. PRACTICAL STEPS

You begin with a very simple multi-threaded program.

Create a file *simple.c* with the content as below:

#include <stdio.h>

#include <stdlib.h>

#include <unistd.h> #include <sys/types.h> #include <pthread.h>

int shared = 10;

void \* fun(void \* args){

time\_t start = time(NULL);

time\_t end = start+5; //run for 5 seconds

**YOUR-CODE-HERE**

return NULL;

} int main(){

pthread\_t thread\_id;

pthread\_create(&thread\_id, NULL, fun, NULL);

pthread\_join(thread\_id, NULL);

printf("shared: %d\n", shared);

return 0;

}

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| Question 4: Complete this file above (in the part **YOUR-CODE-HERE**) with a loop to increase the variable shared by 1 for 5 seconds.  (hint: time(NULL) will return the present system time in second).  for(i=0;i<100;i++){ while(lock > 0); lock = 1; shared++; lock = 0; } |

Compile and run this program with the command:

$gcc –pthread simple.c –o simple

$./simple

The main thread will block on the function pthread\_join and print the result of variable *shared*. This is only possible because both threads, the worker thread and the main thread, share memory.

Now, you will develop a program with more than 2 threads (multi-threaded program). So, the program has to manage the shared resource in using the *Locking* method. The concept of resource locking is a huge area of study in computer and operating system research. The big idea is that when a program enters a *critical section* or a set of code that must fully complete without interruption, the program holds a *lock* that only one program (or thread) can hold a time. In this way only one thread can ever be in the critical section at any time.

Now, first you develop a multi-threaded program without using *locking* method.

Create a file *without-lock.c* to simulate a simple banking service.

#include <time.h>

#include <stdio.h> #include <stdlib.h> #include <unistd.h> #include <sys/types.h>

#include <pthread.h>

#define INIT\_BALANCE 50

#define NUM\_TRANS 100

int balance = INIT\_BALANCE;

int credits = 0; int debits = 0;

void \* transactions(void \* args){ int i,v;

for(i=0;i<NUM\_TRANS;i++){

//choose a random value srand(time(NULL)); v = rand() % NUM\_TRANS;

//randomnly choose to credit or debit if( rand()% 2){

//credit

balance = balance + v; credits = credits + v;

}else{

//debit

balance = balance - v; debits = debits + v;

}

}

return 0;

}

int main(int argc, char \* argv[]){

int n\_threads,i; pthread\_t \* threads;

//error check if(argc < 2){

fprintf(stderr, "ERROR: Require number of threads\n"); exit(1);

}

//convert string to int n\_threads = atol(argv[1]);

//error check if(n\_threads <= 0){

fprintf(stderr, "ERROR: Invalivd value for number of threads\n"); exit(1);

}

//allocate array of thread identifiers threads = calloc(n\_threads, sizeof(pthread\_t));

//start all threads for(i=0;i<n\_threads;i++){

pthread\_create(&threads[i], NULL, transactions, NULL);

}

//wait for all threads finish its jobs for(i=0;i<n\_threads;i++){ pthread\_join(threads[i], NULL);

} printf("\tCredits:\t%d\n", credits); printf("\t Debits:\t%d\n\n", debits);

printf("%d+%d-%d= \t%d\n", INIT\_BALANCE,credits,debits, INIT\_BALANCE+credits-debits); printf("\t Balance:\t%d\n", balance);

//free array free(threads);

return 0;

}

Now, build and run the above program. Try it with 5 additional threads

$gcc –pthread without-lock.c –o without-lock

$./without-lock 5

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| Question 5: Try to increase the value of threads and the value of the constant NUM\_TRANS after each execution time until you obtain the different results between *Balance* and *INIT\_BALANCE+credits-debits.* Explain why do you get this difference.  Khi đó các giá trị nhận được về credits, debits sẽ sai lệch do các tiến trình dùng chung tài nguyên |

To solve the problem in Question 2, you have to identify the critical sections of the program, that is, sections of code that only one thread can execute at a time. Once a critical section is identified, we use a shared variables to *lock* that section. Only one thread can hold the *lock*, so only one thread executes the critical section at the time.

You first try a Naive Lock method in using a variable lock like the program below. You create a program called *naive-lock.c* with the content as follows:

#include <time.h>

#include <stdio.h>

#include <stdlib.h>

#include <unistd.h> #include <sys/types.h>

#include <pthread.h>

int lock = 0; //0 for unlocked, 1 for locked

int shared = 0; //shared variable

void \* incrementer(void \* args){ int i;

for(i=0;i<100;i++){

//check lock

while(lock > 0); //spin until unlocked

lock = 1; //set lock

shared++; //increment

lock = 0; //unlock

}

return NULL;

}

int main(int argc, char \* argv[]){ pthread\_t \* threads; int n,i; if(argc < 2){

fprintf(stderr, "ERROR: Invalid number of threads\n"); exit(1);

}

//convert argv[1] to a long if((n = atol(argv[1])) == 0){

fprintf(stderr, "ERROR: Invalid number of threads\n"); exit(1);

}

//allocate array of pthread\_t identifiers threads = calloc(n,sizeof(pthread\_t));

//create n threads for(i=0;i<n;i++){

pthread\_create(&threads[i], NULL, incrementer, NULL); }

//join all threads for(i=0;i<n;i++){

pthread\_join(threads[i], NULL);

}

//print shared value and result printf("Shared: %d\n",shared); printf("Expect: %d\n",n\*100);

return 0;

}

Question 6: Try to build and run this program. Launch it repeatedly until you see the difference between *Shared* and *Expect* values. Analyze the source code to understand the problem that leads to this difference.

Giá trị Shared và Expect như nhau

Now, you’ll try another way, called *mutex lock*, to realize the lock method. The term *mutex* stands for a mutually exclusion, which is a fancy name for lock. A *mutex* is not a standard variable; instead, it is guaranteed to be atomic in operation. The act of acquiring a lock cannot be interrupted.

The steps to deploy *mutex lock* are described as follows:

* First, you declare the variable mutex: pthread\_mutext\_t mutex;

* After, you must first initialize a mutex before you can use it (the second parameter is always *NULL*): pthread\_mutex\_init(&mutex, NULL);

* You then can acquire and unlock a mutex:

pthread\_mutex\_lock(&mutex);

/\* critical section here \*/

pthread\_mutex\_unlock(&mutex);

* Finally, creating a *mutex* allocates memory. So we have to deallocate the *mutex*, or destroy it:

pthread\_mutex\_destroy(&mutex);

// Mutex lock là một cấu trúc dữ liệu, được Linux kernel xây dựng theo nguyên tắc mutual exclusion, dùng để ngăn chặn race condition xảy ra trên các cấu trúc dữ liệu khác. Nói nôm na, mutex lock đảm bảo rằng: tại một thời điểm bất kì, chỉ có tối đa một thread truy cập vào critical resource.

Question 7: Now, you have to modify the code of the file *without-lock.c* in implementing the *mutex lock* above (you can name it differently like *mutex-lockbanking.c*). Try to launch it repeatedly and evaluate the obtained output. What is the improvement after using *mutex lock*?

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Khởi chạy nhiều lần có những lần cùng số lượng thread, có lúc giá trị đúng, có lúc giá trị bị lệch

There are two strategies for locking critical sections: **Coarse Locking** and **Fine Locking**.

Coarse Locking locks a program in using a single lock for the critical section to protect the entire critical section. It’s what you’ve done in the Question 4. While Coarse Locking is a reasonable choice, it is inefficient. You look some parallelism because not all parts of the critical section are critical to each other. For example, consider the banking service program you are working on: the variable *credits* and *debits* are used exclusively of each other; each thread only performs a credit or debit but not both. Maybe it would be worthwhile to do more fine grain locking: it’s called Fine Locking.

Now you’ll modify the code of your banking program (it’s better if you create a copy of that and name it differently like *fine-locking-bank.c*).

Instead of using only one variable mutex, you now declare three variables:

pthread\_mutex\_t b\_lock,c\_lock,d\_lock;

where b\_lock is for variable balance, c\_lock for variable credits, and d\_lock for variable debits.

In the loop *for*: for(i=0;i<NUM\_TRANS;i++), you put each statement in a correspondent lock. For example:

pthread\_mutex\_lock(&b\_lock); balance = balance + v;

pthread\_mutex\_unlock(&b\_lock);

You do the same thing with other statements for *credits* and *debits*.

Question 8: compare the run times of the two strategies to prove that Fine Locking is faster and much faster on larger load sets.

Khi sử dụng Fine Locking cho số lượng lên 10000 thread thì thấy thời gian chạy nhanh hơn so với Coarse Locking ở câu trên (các khoản tín dụng và ghi nợ có thể thay đổi được sử dụng riêng cho nhau; mỗi luồng chỉ thực hiện một tín dụng hoặc ghi nợ nhưng không thực hiện cả hai)

Make attention while using Fine Locking method because there is a risk of having **deadlocks**. Try to run the program below (name it *deadlocks-test.c*):

#include <stdio.h>

#include <stdlib.h>

#include <pthread.h>

int a=0,b=0;

pthread\_mutex\_t lock\_a, lock\_b;

void \* fun\_1(void \* arg){ int i;

for (i = 0 ; i< 10000 ; i++){

pthread\_mutex\_lock(&lock\_a); //lock a then b pthread\_mutex\_lock(&lock\_b);

//CRITICAL SECTION a++; b++;

pthread\_mutex\_unlock(&lock\_a); pthread\_mutex\_unlock(&lock\_b);

}

return NULL;

} void \* fun\_2(void \* arg){ int i;

for (i = 0 ; i< 10000 ; i++){

pthread\_mutex\_lock(&lock\_b); //lock b then a pthread\_mutex\_lock(&lock\_a);

//CRITICAL SECTION a++; b++;

pthread\_mutex\_unlock(&lock\_b); pthread\_mutex\_unlock(&lock\_a); }

return NULL;

}

int main(){

pthread\_t thread\_1,thread\_2;

pthread\_mutex\_init(&lock\_a, NULL); pthread\_mutex\_init(&lock\_b, NULL);

pthread\_create(&thread\_1, NULL, fun\_1, NULL); pthread\_create(&thread\_2, NULL, fun\_2, NULL);

pthread\_join(thread\_1, NULL); pthread\_join(thread\_2, NULL);

printf("\t a=%d b=%d \n", a,b);

return 0;

}

Question 9: Run this program and what do you get as output? Explain what the *deadlock* is.

Giá trị

Giá trị a và b trả về <20 000 do số lượng thread quá lớn dẫn đến 1 vài lock sẽ không được xử lý sinh ra deadlock