15-440 Distributed Systems Recitation 6

Laila Elbeheiry

Slides Adopted From:

Zeinab Khalifa

Carnegie Mellon University Qatar

Logistics

- Quiz 2 Graded (Average: 16.88, Stdev: 2.3, Max: 19.5, Median: 17.5)
- P1 Due Next Monday
- PS3 Released (Due next Thursday)

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In this Recitation..

- Study concurrent programming
  - Using Java as a language
  - Using an abstract shared memory model
- In a future lecture
  - Use C/C++ primitives (MPI)
  - Using a distributed memory machine

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What is concurrency?

- Sequential Programs
  - Single thread of control
  - Executes one instruction at a time
  - (- pipelining + SIMD)

Not accurate

- Concurrent Programs
  - Multiple autonomous sequential threads, executing (logically) in parallel
- The implementation (i.e. execution) of the threads can be:
  - Multiprogramming – Threads multiplex their executions on a single processor.
  - Multiprocessing – Threads multiplex their executions on a multiprocessor or a system
  - Distributed Processing – Processes multiplex their executions on several different machines

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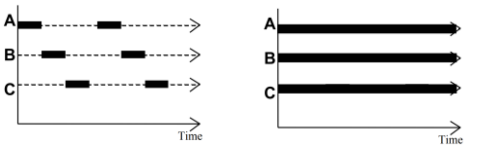
Concurrency and Parallelism

- Concurrency doesn't imply parallelism ← Why?



Concurrency in Java

Bank use case

Concurrency in Java

- Java has a predefined class `java.lang.Thread`

```
public class MyThread extends Thread {
    public void run() {
    }
}
```

What's the diff?

- Java also provides a standard interface

```
public interface Runnable {
    public void run();
}
```

- Any class which wishes to express concurrent execution must implement this interface and the `run` method
- Threads do not begin their execution until the `start` method in the `Thread` class is called

Activity Trace 1 of ATMs

Time

Account ID > Laila	Account ID > Mohammed
Password > 1234	Password > 0000
your account balance is 200	your account balance is 250
Deposit or withdraw amount > -150	Deposit or withdraw amount > -50
your balance is 50	your balance is 200

Activity Trace 2 of ATMs

Time

Account ID > Laila	Account ID > Laila
Password > 1234	Password > 1234
Your account balance is 200	Your account balance is 200
Deposit or withdraw amount > -150	Deposit or withdraw amount > -150
your balance is 50	your balance is 50

200 – 150 – 150 = 50!!!

Synchronization

- Threads can be arbitrarily interleaved
- Some interleavings are NOT correct
- Java provides synchronization mechanism to restrict the interleavings
- Synchronization serves two purposes:
  - Ensure safety for shared updates – Avoid race conditions
  - Coordinate actions of threads – Parallel computation – Event notification

Safety of Concurrent Execution

- Multiple threads access shared resource simultaneously
  - Safe only if:
    - All accesses have no effect on resource, – e.g., reading a variable
    - All accesses are atomic
    - Only one access at a time: mutual exclusion

Mutual Exclusion

- Prevent more than one thread from accessing critical section at a given time
- Once a thread is in the critical section, no other thread can enter that critical section until the first thread has left the critical section.
- No interleavings of threads within the critical section
- Serializes access to section

```
synchronized int getbal() { return balance; }
synchronized void post(int v) { balance = balance + v; }
```

Good enough?

Activity Trace 2 of ATMs Zoom in

Time

```
int val = in.readLine();

if (acc.getbal() + val > 0)

        post(val);

out.println("your balance is " +
        acc.getbal());
```

your balance is 50

```
int val = in.readLine();

if (acc.getbal() + val > 0)

        post(val);

out.println("your balance is " +
        acc.getbal());
```

your balance is 50

Negative Bank Balance!

Atomicity

- Synchronized methods execute the body as an atomic unit
- May need to execute a code region as the atomic unit
- Block Synchronization is a mechanism where a region of code can be labeled as synchronized
- The `synchronized` keyword takes as a parameter an object whose lock the system needs to obtain before it can continue

```
synchronized (acc) {
    if (acc.getbal() + val > 0)
        acc.post(val);
    else
        throw new Exception();
    out.print("your balance is " + acc.getbal());
}
```

Good enough?

Activity Trace 2 of ATMs Zoom in

Time

```
out.println("your balance is " + acc.getbal());
your balance is 200

out.print("Deposit or withdraw amount > ");
Deposit or withdraw amount > -150

int val = in.readLine();

synchronized(acc)
if (acc.getbal() + val > 0) acc.post(val);
out.println("your balance is " +
        acc.getbal());
```

your balance is 50

```
out.println("your balance is " + acc.getbal());
your balance is 200
out.print("Deposit or withdraw amount > ");
Deposit or withdraw amount > -150

int val = in.readLine();

synchronized(acc)


if (acc.getbal() + val > 0)
throw new Exception();
```

Balance shows 200 but couldn't withdraw!!

Activity Trace 2 of ATMs Zoom in

Time

```
Account ID > Laila
Password > 1234
synchronized(acc)
out.println("your balance is " + acc.getbal());
your balance is 200
Deposit or withdraw amount >
```

```
                    Account ID > Laila
                    Password > 1234
                    synchronized(acc)
```

NO RESPONSE!!!

Account Transfer Execution Trace

Mohammed wants to transfer 10 riyals to Ammar
Ammar wants to transfer 20 riyals to Mohammed
Will our code always work?

Time

Mohammed -> Ammar

```
synchronized(from) {
if (from.getbal() > val)
from.post(-val);

synchronized(to)
```

DEADLOCKED!!!!

Ammar -> Mohammed

```
synchronized(from) {
if (from.getbal() > val)

from.post(-val);

synchronized(to)
```

How to fix?

Avoiding deadlocks

- Cycle in locking graph = deadlock
- Standard solution: canonical order for locks
  - Acquire in increasing order
  - Release in decreasing order
- Ensures deadlock-freedom, but not always easy to do

Other types of synchronization in Java

- Semaphores
- Blocking & non-blocking queues
- Concurrent hash maps
- Copy-on-write arrays
- Exchangers
- Barriers
- Futures
- Thread pool support

Potential Concurrency Problems

- Deadlock
  - Two or more threads stop and wait for each other
- Livelock
  - Two or more threads continue to execute, but make no progress toward the ultimate goal.
- Starvation
  - Some thread gets deferred forever.
- Lack of fairness
  - Each thread gets a turn to make progress.
- Race Condition
  - Some possible interleaving of threads results in an undesired computation result

Interesting Ongoing Research on Concurrency

- Automatic parallelizers (e.g. Parsynt)
- Verification of concurrent programs (e.g. Duet)
- Concurrent program testing (e.g. Penelope)
- PL approached to deadlock freedom

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Conclusion

- Concurrency and Parallelism are important concepts in Computer Science
- It can be very hard to understand and debug concurrent programs
- Parallelism is critical for high performance
  - From Supercomputers in national labs to Multicores and GPUs on your desktop
- Concurrency is the basis for writing parallel programs
- Next Recitation: Project 2

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Credits

- The bank use case code and some slides are taken from 6.189 IAP 2007 MIT concurrent programming lecture

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