Monitors

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Programming Concepts using Java

Week 10

Atomic test-and-set

- Test-and-set is at the heart of most race conditions
- Need a high level primitive for atomic test-and-set in the programming language
- Semaphores provide one such solution
- Solutions based on test-and-set are low level and prone to programming errors

Monitors

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- Monitor is like a class in an OO language
  - Data definition — to which access is restricted across threads
  - Collections of functions operating on this data — all are implicitly mutually exclusive

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monitor bank_account{
  double accounts[100];

  boolean transfer (double amount,
                          int source,
                          int target){
    if (accounts[source] < amount){
      return false;
    }
    accounts[source] -= amount;
    accounts[target] += amount;
    return true;
  }

  double audit(){
    // compute balance across all accounts
    double balance = 0.00;
    for (int i = 0; i < 100; i++){
      balance += accounts[i];
    }
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Monitors

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- Monitors — Per Brinch Hansen and CAR Hoare
- Monitor is like a class in an OO language
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- Monitor guarantees mutual exclusion — if one function is active, any other function will have to wait for it to finish

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Monitors: external queue

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Monitors: external queue

- Monitor ensures `transfer` and `audit` are mutually exclusive
- If `Thread 1` is executing `transfer` and `Thread 2` invokes `audit`, it must wait
- Implicit queue associated with each monitor
  - Contains all processes waiting for access
  - In practice, this may be just a set, not a queue

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Making monitors more flexible

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- If these calls are reordered and `accounts[j] < 400` initially, this will fail

Making monitors more flexible

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transfer(500.00,i,j);
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```

- This should always succeed if `accounts[i] > 500`
- If these calls are reordered and `accounts[j] < 400` initially, this will fail
- A possible fix — let an account wait for pending inflows

```
boolean transfer (double amount, int source, int target){
  if (accounts[source] < amount){
    // wait for another transaction to transfer money
    // into accounts[source]
  }
  accounts[source] -= amount;
  accounts[target] += amount;
  return true;
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Monitors — wait()

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- All other processes are blocked out while this process waits!

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- Need a mechanism for a thread to suspend itself and give up the monitor
- A suspended process is waiting for monitor to change its state
- Have a separate internal queue, as opposed to external queue where initially blocked threads wait
- Dual operation to notify and wake up suspended processes

Monitors — notify()

```
boolean transfer (double amount, int source, int target){
  if (accounts[source] < amount){  wait();  }
  accounts[source] -= amount;
  accounts[target] += amount;
  notify();
  return true;
}
```

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Monitors — notify()

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- Signal and exit — notifying process immediately exits the monitor
  - notify() must be the last instruction

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- Signal and wait — notifying process swaps roles and goes into the internal queue of the monitor

Monitors — `notify()`

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- What happens when a process executes `notify()`?
- Signal and exit — notifying process immediately exits the monitor
  - `notify()` must be the last instruction
- Signal and wait — notifying process swaps roles and goes into the internal queue of the monitor
- Signal and continue — notifying process keeps control till it completes and then one of the notified processes steps in

Monitors — `wait()` and `notify()`

- Should check the `wait()` condition again on wake up
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  - Change of state may not be sufficient to continue — e.g., not enough inflow into the account to allow transfer
- A thread can be again interleaved between notification and running
  - At wake-up, the state was fine, but it has changed again due to some other concurrent action
- `wait()` should be in a `while`, not in an `if`

```
boolean transfer (double amount, int source, int target){
  while (accounts[source] < amount){  wait();  }
  accounts[source] -= amount;
  accounts[target] += amount;
  notify();
  return true;
}
```

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- After transfer, notify() is only useful for threads waiting for target account of transfer to change state
- Makes sense to have more than one internal queue
- Monitor can have condition variables to describe internal queues

```
monitor bank_account{
  double accounts[100];
  queue q[100];  // one internal queue
                 // for each account
  boolean transfer (double amount,
                    int source,
                    int target){
    while (accounts[source] < amount){
      q[source].wait();  // wait in the queue
                         // associated with source
    }
    accounts[source] -= amount;
    accounts[target] += amount;
    q[target].notify();  // notify the queue
                         // associated with target
    return true;
  }

  // compute the balance across all accounts
  double audit(){ ...}
}
```

Summary

- Concurrent programming with atomic test-and-set primitives is error prone
- Monitors are like abstract datatypes for concurrent programming
  - Encapsulate data and methods to manipulate data
  - Methods are implicitly atomic, regulate concurrent access
  - Each object has an implicit external queue of processes waiting to execute a method
- `wait()` and `notify()` allow more flexible operation
- Can have multiple internal queues controlled by condition variables