Department of Computer Science
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COMS20001 - Concurrent Computing

www.cs.bris.ac.uk/Teaching/Resources/COMS20001

Lecture 12

Sharing Memory, Locks and Critical Sections

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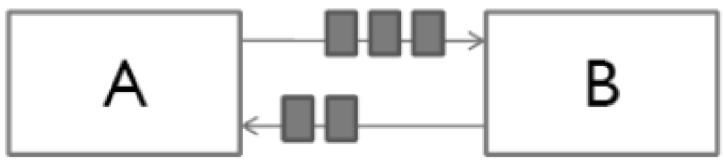
Paradigms of Concurrent Programming

so far covered: … **Message Passing**

- Analogy: two computers in a network, communicating only by network connections

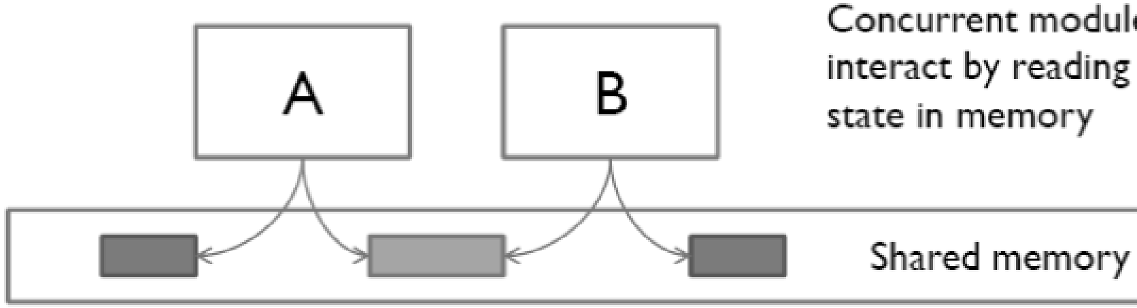


A and B interact by sending messages to each other through a communication channel

an alternative: … **Shared Memory**

- Analogy: two processors in a computer, sharing the same physical memory

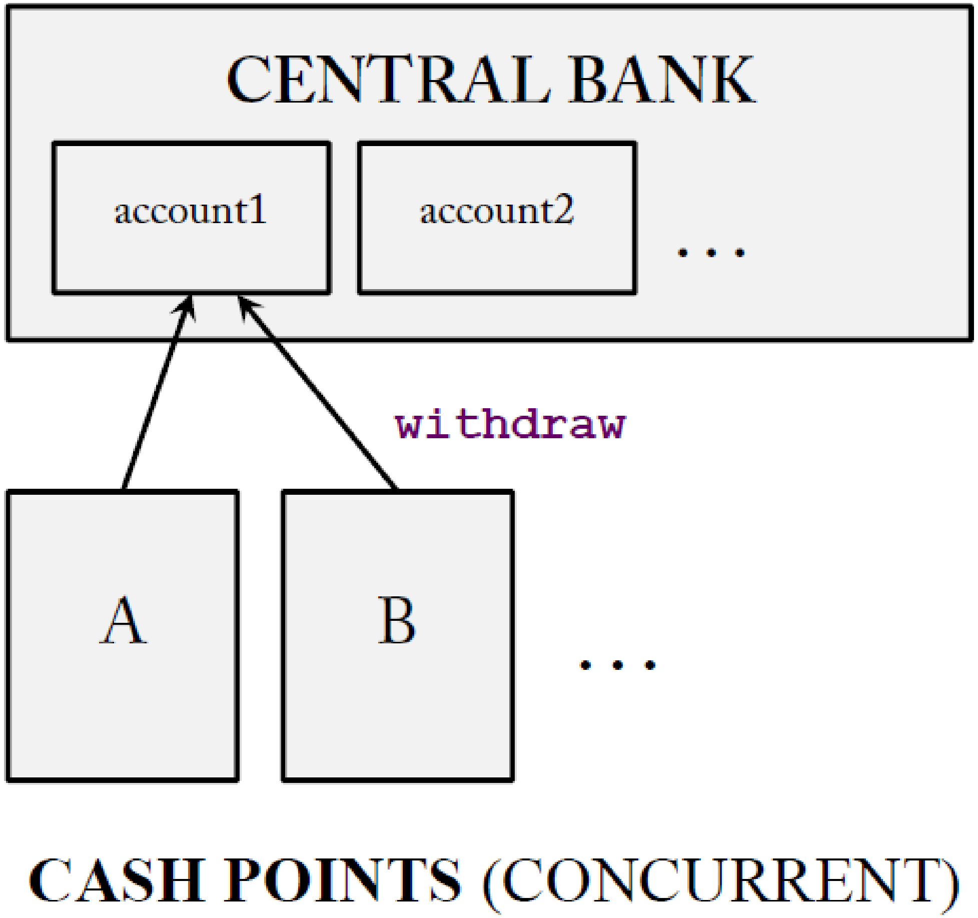
Concurrent modules A and B interact by reading & writing shared state in memory



Race Conditions: Bank Example (in C)

```
...
// shared global memory
// at bank
int account1 = 99;
int account2 = ...
...
```

```
...
// code fragment for
// withdrawing cash
...
int withdraw1( int amount ) {
  if (amount <= account1) {
    account1 -= amount;
    return 1;
  } else return 0;
}
...
```



Race Conditions: Concurrent Withdrawels 1

```
// shared global memory held at bank
int account1 = 99;
```

```
// started from CASH POINT A
 withdraw1(20);
```

```
// started from CASH POINT B
 withdraw1(90);
```

```
...
// THREAD AT CASH POINT A

  if (amount <= account1) {
    account1 -= amount;
    return 1;
  } else return 0;
...
```

```
// THREAD AT CASH POINT B

...
  if (amount <= account1) {
    account1 -= amount;
    return 1;
  } else return 0;
...
```

runtime

£20 withdrawn, £90 payout rejected, new balance is £79 – *ok*

Race Conditions: Concurrent Withdrawels 2

```
// shared global memory held at bank
int account1 = 99;
```

```
// started from CASH POINT A
 withdraw1(20);
```

```
// started from CASH POINT B
 withdraw1(90);
```

```
...
// THREAD AT CASH POINT A

  if (amount <= account1) {


    account1 -= amount;




    return 1;
  } else return 0; ...
```

```
...
// THREAD AT CASH POINT B



  if (amount <= account1) {



    account1 -= amount;
    return 1;
  } else return 0;

...
```

runtime

£110 withdrawn

Race Conditions: Critical Section

Critical Sections are…

code fragments that interact with a shared resource and should not be accessed by more than one thread at any one time.

```
...
// shared global memory held at bank
int account1 = 99;
int account2 = ...
...
// code fragment for withdrawing cash
...
int withdraw1( int amount ) {
  if (amount <= account1) {
    account1 -= amount;
    return 1;
  } else return 0;
}
...
```

Demands on Critical Sections

(SECURITY)

no two threads can be within the critical section at the same time (mutual exclusion)

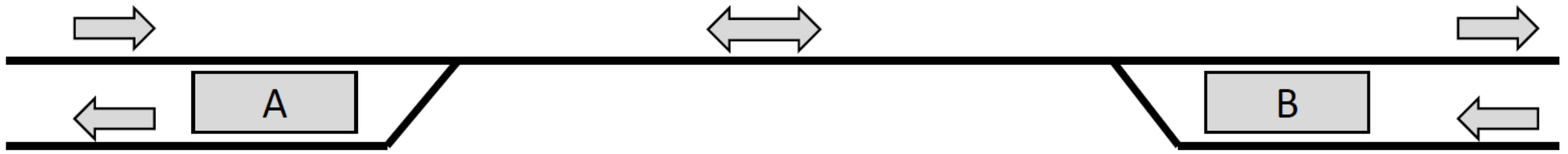
(LIVENESS / NO STARVATION)

any thread attempting to enter the critical section is able to enter it after some finite time

(FAIRNESS)

any thread has a fair chance of entering the critical section

Trains sharing a single line analogy



Between stations A and B there is only a single line. How can we stop trains from accidentally crashing into each other?

Obvious safety requirement: at most one train can be on the single line section at any one time.

One Solution ...

This is a “train staff”. Rule: you can only go onto the single line if you have the train staff with you.

At the other end you pass it to the stationmaster or to the next train wanting to travel in the opposite direction.

Mutual Exclusion

Principles: a train must never enter the single line section unless it has a token.

The token machines must never allow more than one token out at any time.

Procedure for train:

1. Wait until you get a token.
2. Proceed to the other end of the section.
3. Give back the token.

Data Races

A data race happens when

- two or more threads have access to the same data
- at least one of them is writing to this data
- there is no synchronization

Like two trains on the same line, data races are BAD, and our job as programmers is to ensure that they can NEVER happen.

Insecure Implementation for Locks

```
...
// UNSUCCESSFUL LOCKING ATTEMPT
...
int Lock = 0;
//Lock == 0: free
//Lock == 1: locked

void lock(int *Lock) {
  while (*Lock != 0);
  //busy waiting
  //CRITICAL SECTION EXPOSED HERE
  *Lock = 1;
}

void unlock(int *lock) {
  *Lock = 0;
}
```

- Why does this attempt fail in a concurrent system?
- Which atomic operation would solve the problem?

NO MUTUAL EXCLUSION!

Insecure Implementation for Locks

- bus logic implements atomic operations:
  - read
  - write
  - read <u>and</u> write

```
test_and_set R, lock
//write to a memory location and
//return its old value, i.e.
//R = lock; lock = 1;

exchange R, lock
//X = lock; lock = R; R = X;
```

Implementation for Locks using Atomic `test_and_set`

```
...
// SUCCESSFUL LOCKING ATTEMPT
// (to LOCK spin until lock
//  is found to be 0, write 1
//  to lock after any test)

LOCK:
  test_and_set R, lock
  //atomic: R = lock; lock = 1;
  cmp R, #0
  //compare result R to zero
  jnz LOCK
  //if (R != 0) goto lock
  ret
  //return

UNLOCK:
  mov lock, #0
  //set lock to zero
  ret
  //return
```

achieves mutual exclusion

Disadvantages:

- requires HW support
  (What happens if two threads are on same processor?)
- busy waiting
- heavy bus load
- thread starvation possible (no fairness)

Mutual Exclusion via Peterson's Algorithm

```
...
// THREAD 0
...

  // register interest
  interested[0] = true;

  // secure next available turn
  turn = 0;

  while (
     (interested[1]==true) &&
     (turn == 0)) {
    // busy wait
  }

  // CRITICAL SECTION

  interested[0] = false;
```

```
...
// THREAD 1
...

  // register interest
  interested[1] = true;

  // secure next available turn
  turn = 1;

  while (
     (interested[0]==true) &&
     (turn == 1)) {
    // busy wait
  }

  // CRITICAL SECTION

  interested[1] = false;
```

achieves mutual exclusion

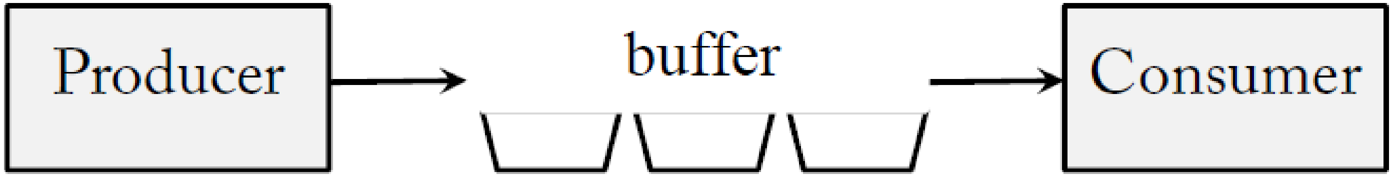
Busy Waiting vs. Suspension

- **'Busy Waiting' (also known as Spinning) …**
  a thread repeatedly checks to see if a condition is true

- Peterson's Algorithm uses 'Busy Waiting'

```
...
  while (
     (interested[1]==true) &&
     (turn == 0)) {
     // busy wait
  }
...
```

- **Consider a Producer-Consumer System with Limited Buffer and Permanent Operation**



→ explore suspension instead of busy waiting

Semaphore Implementation using Scheduling

```
class SemaphoreT {
  int        count;
  QueueType queue;
  public:
  SemaphoreT(int howMany);
  void P();
  void V();
}

SemaphoreT::SemaphoreT(
  int howMany) {
  count = howMany;
}

SemaphoreT::P() {
  if (count <= 0)
    sleep(queue);
  count--;
}

SemaphoreT::V() {
  count++;
  wakeup(queue);
}
```

- Need to implement all these methods as Critical Sections themselves !!!!

- **sleep(queue)**
  ```
  thread_current.state = sleeping;
  queue.enter(thread_current);
  schedule;
  ```

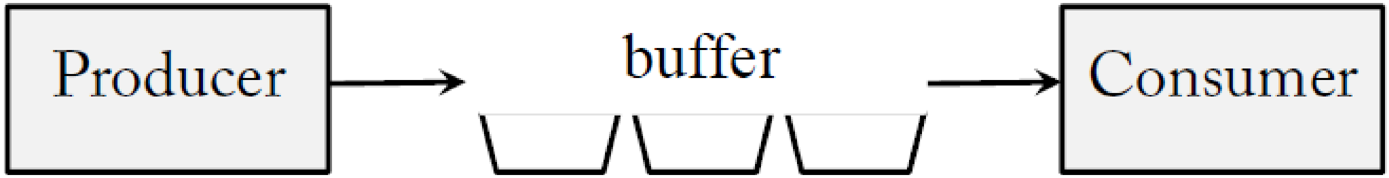
- **wakeup(queue)**
  ```
  thread_current.state = ready;
  switch_to(queue.take);
  ```

Producer-Consumer System using Semaphores

achieves mutual exclusion

```
...
// PRODUCER FRAGMENT
...

void produce() {
  while (true) {
    item = produce_item();
    noOfEmpty.P(); //wait&decr buffer
    critSec.P();   //enter critSec

    // send to buffer
    enter_item(item);

    critSec.V();   //leave critSec
    noOfFull.V();  //incr items
  }
}
```

```
...
// CONSUMER FRAGMENT
...

void consume() {
  while (true) {
    noOfFull.P(); //wait&decr item
    critSec.P();  //enter critSec

    // receive from buffer
    item = remove_item();

    critSec.V();   //leave critSec
    noOfEmpty.V(); //incr free buffer
    consume_item(item);
  }
}
```



Deadlocking Producer-Consumer Implementation

```
...
// PRODUCER FRAGMENT
...

void produce() {
  while (true) {
    item = produce_item();
    noOfEmpty.P();
    critSec.P();

    // send to buffer
    enter_item(item);

    critSec.V();
    noOfFull.V();
  }
}
```

```
...
// CONSUMER FRAGMENT
...

void consume() {
  while (true) {
    critSec.P();
    noOfFull.P();

    // receive from buffer
    item = remove_item();

    noOfEmpty.V();
    critSec.V();
    consume_item(item);
  }
}
```

DEADLOCK POSSIBLE!