Introduction to Game Programming

Concurrency

CSC 329

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Concurrency – Topics

- Introduction
- Introduction to Subprogram-Level Concurrency
- Semaphores
- Monitors
- Message Passing
- Java Threads

Introduction

- Concurrency can occur at four levels:
  - Machine instruction level
  - High-level language statement level
  - Unit level
  - Program level
- Because there are no language issues in instruction- and program-level concurrency, they are not addressed here

Categories of Concurrency

- Categories of Concurrency:
  - Physical concurrency – Multiple independent processors (multiple threads of control)
  - Logical concurrency – The appearance of physical concurrency is presented by time-sharing one processor (software can be designed as if there were multiple threads of control)
- A thread of control in a program is the sequence of program points reached as control flows through the program
- Coroutines (quasi-concurrency) have a single thread of control

Introduction to Subprogram-Level Concurrency

- A task or process is a program unit that can be in concurrent execution with other program units
- Tasks differ from ordinary subprograms in that:
  - A task may be implicitly started
  - When a program unit starts the execution of a task, it is not necessarily suspended
  - When a task's execution is completed, control may not return to the caller
- Tasks usually work together

Two General Categories of Tasks

- Heavyweight tasks execute in their own address space
- Lightweight tasks all run in the same address space
- A task is disjoint if it does not communicate with or affect the execution of any other task in the program in any way

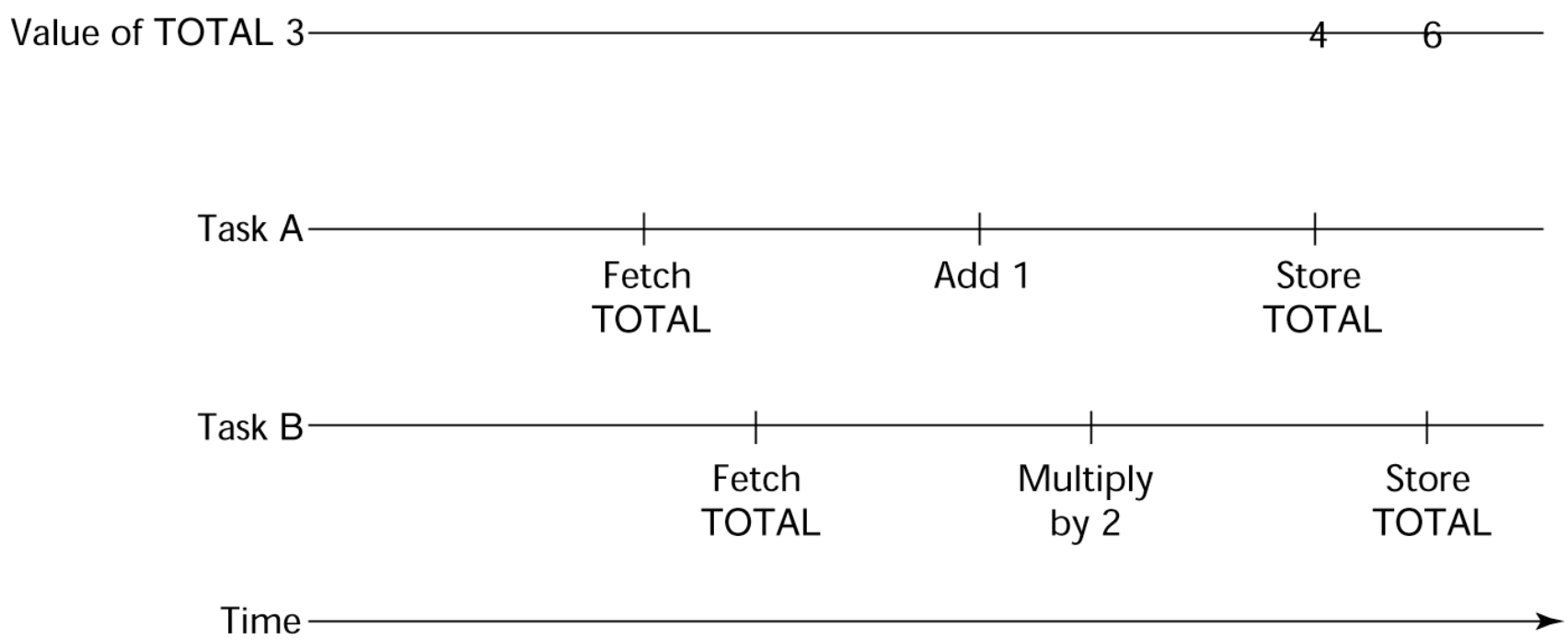
Task Synchronization

- A mechanism that controls the order in which tasks execute
- Two kinds of synchronization
  - Cooperation synchronization
  - Competition synchronization
- Task communication is necessary for synchronization, provided by:
  - Shared nonlocal variables
  - Parameters
  - Message passing

Kinds of synchronization

- Cooperation: Task A must wait for task B to complete some specific activity before task A can continue its execution, e.g., the producer-consumer problem
- Competition: Two or more tasks must use some resource that cannot be simultaneously used, e.g., a shared counter
  - Competition is usually provided by mutually exclusive access (approaches are discussed later)

Need for Competition Synchronization



Scheduler

- Providing synchronization requires a mechanism for delaying task execution
- Task execution control is maintained by a program called the scheduler, which maps task execution onto available processors

Task Execution States

- New – created but not yet started
- Ready – ready to run but not currently running (no available processor)
- Running
- Blocked – has been running, but cannot now continue (usually waiting for some event to occur)
- Dead – no longer active in any sense

Liveness and Deadlock

- Liveness is a characteristic that a program unit may or may not have
  - In sequential code, it means the unit will eventually complete its execution
- In a concurrent environment, a task can easily lose its liveness
- If all tasks in a concurrent environment lose their liveness, it is called deadlock

Methods of Providing Synchronization

- Semaphores
- Monitors
- Message Passing

Semaphores

- Dijkstra – 1965
- A semaphore is a data structure consisting of a counter and a queue for storing task descriptors
- Semaphores can be used to implement guards on the code that accesses shared data structures
- Semaphores have only two operations, wait and release (originally called P and V by Dijkstra)
- Semaphores can be used to provide both competition and cooperation synchronization

Cooperation Synchronization with Semaphores

- Example: A shared buffer
- Use two semaphores for cooperation: `emptyspots` and `fullspots`
- The semaphore counters are used to store the numbers of empty spots and full spots in the buffer
- The buffer is implemented as an ADT with the operations `DEPOSIT` and `FETCH` as the only ways to access the buffer

Cooperation Synchronization with Semaphores (continued)

- `DEPOSIT` must first check `emptyspots` to see if there is room in the buffer
- If there is room, the counter of `emptyspots` is decremented and the value is inserted
- If there is no room, the caller is stored in the queue of `emptyspots`
- When `DEPOSIT` is finished, it must increment the counter of `fullspots`

Cooperation Synchronization with Semaphores (continued)

- `FETCH` must first check `fullspots` to see if there is a value
  - If there is a full spot, the counter of `fullspots` is decremented and the value is removed
  - If there are no values in the buffer, the caller must be placed in the queue of `fullspots`
  - When `FETCH` is finished, it increments the counter of `emptyspots`
- The operations of `FETCH` and `DEPOSIT` on the semaphores are accomplished through two semaphore operations named wait and release

Semaphores: Wait Operation

```
wait(aSemaphore)
if aSemaphore's counter > 0 then
   decrement aSemaphore's counter
else
   put the caller in aSemaphore's queue
   attempt to transfer control to a ready task
     -- if the task ready queue is empty,
     -- deadlock occurs
end
```

Semaphores: Release Operation

```
release(aSemaphore)
if aSemaphore's queue is empty then
   increment aSemaphore's counter
else
   put the calling task in the task ready queue
   transfer control to a task from aSemaphore's queue
end
```

Producer Consumer Code

```
semaphore fullspots, emptyspots;
fullstops.count = 0;
emptyspots.count = BUFLEN;
task producer;
   loop
   -- produce VALUE --
   wait (emptyspots); {wait for space}
   DEPOSIT(VALUE);
   release(fullspots); {increase filled}
   end loop;
end producer;
```

Producer Consumer Code

```
task consumer;
   loop
   wait (fullspots);{wait till not empty}}
   FETCH(VALUE);
   release(emptyspots); {increase empty}
   -- consume VALUE --
   end loop;
end consumer;
```

Competition Synchronization with Semaphores

- A third semaphore, named `access`, is used to control access (competition synchronization)
  - The counter of **`access`** will only have the values 0 and 1
  - Such a semaphore is called a binary semaphore
- Note that wait and release must be atomic!

Producer Consumer Code

```
semaphore access, fullspots, emptyspots;
access.count = 0;
fullstops.count = 0;
emptyspots.count = BUFLEN;

task producer;
   loop
   -- produce VALUE --
   wait(emptyspots); {wait for space}
   wait(access);     {wait for access)
   DEPOSIT(VALUE);
   release(access); {relinquish access}
   release(fullspots); {increase filled}
   end loop;
end producer;
```

Producer Consumer Code

```
task consumer;
   loop
   wait(fullspots);{wait till not empty}
   wait(access);   {wait for access}
   FETCH(VALUE);
   release(access); {relinquish access}
   release(emptyspots); {increase empty}
   -- consume VALUE --
   end loop;
end consumer;
```

Evaluation of Semaphores

- Misuse of semaphores can cause failures in cooperation synchronization, e.g., the buffer will overflow if the wait of `fullspots` is left out
- Misuse of semaphores can cause failures in competition synchronization, e.g., the program will deadlock if the release of `access` is left out

Monitors

- The idea: encapsulate the shared data and its operations to restrict access
- A monitor is an abstract data type for shared data
- Java

Competition Synchronization

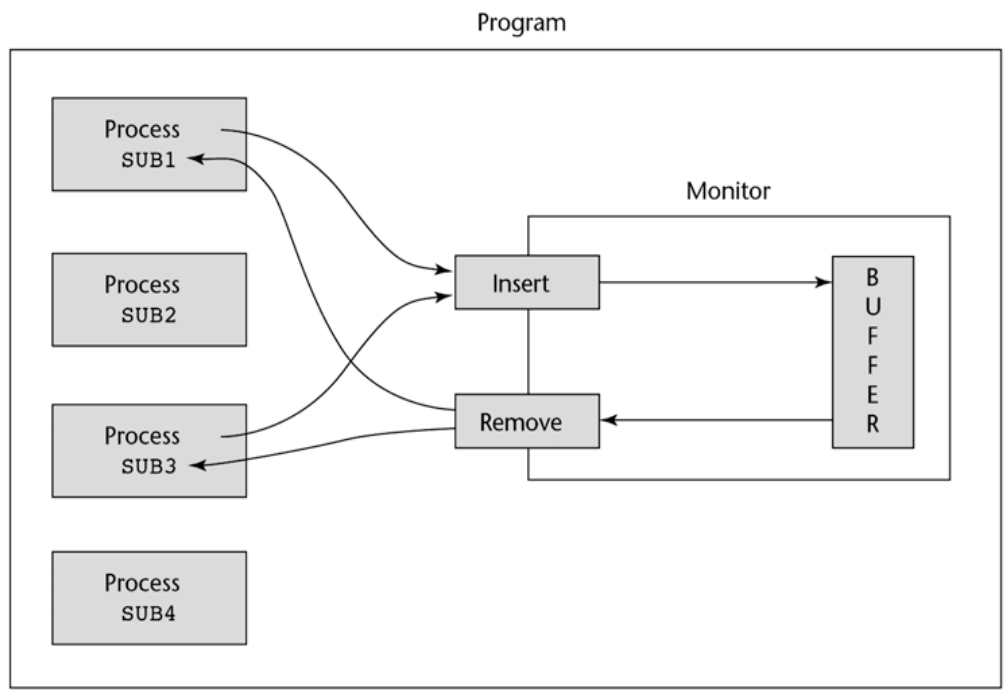
- Shared data is resident in the monitor (rather than in the client units)
- All access resident in the monitor
  - Monitor implementation guarantee synchronized access by allowing only one access at a time
  - Calls to monitor procedures are implicitly queued if the monitor is busy at the time of the call

Cooperation Synchronization

- Cooperation between processes is still a programming task
  - Programmer must guarantee that a shared buffer does not experience underflow or overflow

Figure 13.2

A program using a monitor to control access to a shared buffer



Evaluation of Monitors

- A better way to provide competition synchronization than are semaphores
- Semaphores can be used to implement monitors
- Monitors can be used to implement semaphores
- Support for cooperation synchronization is very similar as with semaphores, so it has the same problems

Message Passing

- Message passing is a general model for concurrency
  - It can model both semaphores and monitors
  - It is not just for competition synchronization
- Central idea: task communication is like seeing a doctor--most of the time she waits for you or you wait for her, but when you are both ready, you get together, or rendezvous

Java Threads

- The concurrent units in Java are methods named `run`
  - A `run` method code can be in concurrent execution with other such methods
  - The process in which the `run` methods execute is called a thread

```
Class myThread extends Thread
  public void run () {… }
}
…
Thread myTh = new MyThread ();
myTh.start();
```

Controlling Thread Execution

- The `Thread` class has several methods to control the execution of threads
  - The `yield` is a request from the running thread to voluntarily surrender the processor
  - The `sleep` method can be used by the caller of the method to block the thread
  - The `join` method is used to force a method to delay its execution until the run method of another thread has completed its execution

Thread Priorities

- A thread's default priority is the same as the thread that create it
  - If `main` creates a thread, its default priority is `NORM_PRIORITY`
- Threads defined two other priority constants, `MAX_PRIORITY` and `MIN_PRIORITY`
- The priority of a thread can be changed with the methods `setPriority`

Competition Synchronization with Java Threads

- A method that includes the `synchronized` modifier disallows any other method from running on the object while it is in execution

```
…
public synchronized void deposit( int i) {…}
public synchronized int fetch() {…}
…
```

- The above two methods are synchronized which prevents them from interfering with each other
- If only a part of a method must be run without interference, it can be synchronized using the `synchronized` statement

```
synchronized (expression)
   statement
```

Cooperation Synchronization with Java Threads

- Cooperation synchronization in Java is achieved via `wait`, `notify`, and `notifyAll` methods
  - All methods are defined in `Object`, which is the root class in Java, so all objects inherit them
- The `wait` method must be called in a loop
- The `notify` method is called to tell one waiting thread that the event it was waiting has happened
- The `notifyAll` method awakens all of the threads on the object's wait list

Creating and Running Threads in Java

- There are three basic ways to use Threads in Java
  - Extend the Thread Class
  - Implement the Runnable Interface
  - Use anonymous inner classes

Extending the Thread Class

Extend the thread class and override the run() method

```
public class MyThread extends Thread
{
   public static void run()
   {
      System.out.println("Do something cool here.");
   }
}
```

Then create and start the thread:

```
Thread myThread = new MyThread();
myThread.start();
```

Using Anonymous Inner Classes

An anonymous inner class can be used to start a Thread when inheriting the Thread class or implementing the Runnable interface is not desirable.

```
new Thread() {
   public void run() {
      System.out.println("Do something cool here.");
   }
}.start();
```

This piece of code creates an instance of a nameless class that inherits the Thread class and overrides the run() method.

This technique should be used carefully because it can easily become hard to read.

Implementing the Runnable Interface

Any object that implements the Runnable Interface can be passed as a parameter to the constructor of a Thread object.

```
public class MyClass extends SomeOtherClass implements Runnable{
  public MyClass(){
    Thread thread = new Thread(this);
    thread.start();
  }

  public void run(){
    System.out.println("Do something cool here.");
  }
}
```

The MyClass class implements Runnable, passes itself into a new thread, then starts that thread which executes MyClass.run() .

The join() and sleep() Methods

- Thread.join();
  - If you are in one Thread and you want to wait for another Thread to finish then call the other Thread object's join() method. The current Thread will remain inactive until the outside Thread finishes its run() method.
- Thread.sleep(int);
  - The sleep(int) method causes a Thread to be inactive for the specified number of milliseconds during which it will take up no clock cycles.

Avoiding Deadlock

Deadlock is the result of two threads that stall because they are waiting on each other to do something. For example:

Fig 1

- Thread A acquires lock 1
- Thread B acquires lock 2

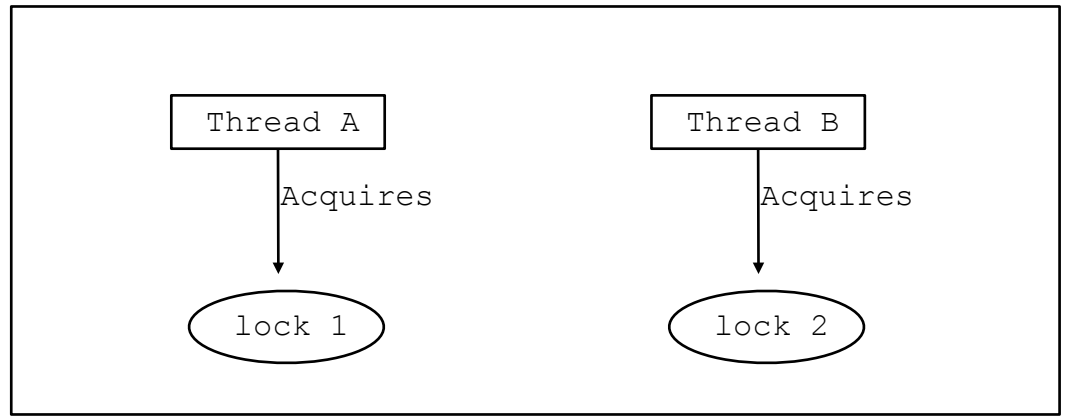
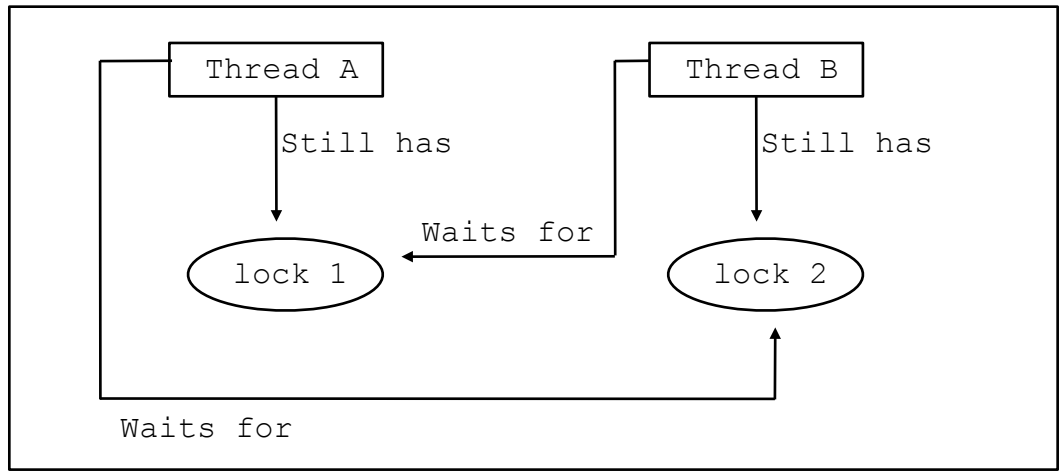


Fig 2

- Thread B waits for lock 1 to be released
- Thread A waits for lock 2 to be released



Both threads are now waiting for the other to finish so neither will continue. To avoid deadlock write your synchronization code so that deadlock will not occur.

There are no blanket fixes for deadlock, but there are detectors.

The Java Event Model

- When your program operates in a graphical environment it can be accessed by at least two threads even if you are not using threads explicitly.
- The two threads are the main thread that runs your program and the AWT event dispatch thread which handles user input in order to allow event driven program design.
- Because of this you should always keep synchronization in mind even if you are not creating and using threads of your own.

When to Use Threads

- For the purpose of game design threads are useful to prevent lengthy operations from hindering the playing experience. (The player will not be happy if hitting the quick-save button causes the game to freeze for several seconds)
- Other examples of smart thread use include:
  - Loading files from the disk
  - Network communication, such as sending high scores to a server
  - Massive calculations, such as terrain generation

When not to use Threads

- In games there are often many things happening at the same time. This does not mean that every bullet, spaceship, and flake of snow should have it's own thread. In fact such a design would be very problematic and slow. Later in the book we will see different methods for "lots of stuff happening".

Thread Pools

A thread pool is used to limit the number of threads being used at a time.

Here we have an example ThreadPool class and a test program for that class.

Java's Thread Evaluation

- Java's support for concurrency is relatively simple but effective
- Not as powerful as Ada's tasks

C# Threads

- Loosely based on Java Threads but significant differences
- Basic operations
  - Any C# method can run in an own thread
  - Thread is created by making a `Thread` object
  - `Thread` constructor needs an instantiation of a pre-defined delegate class `ThreadStart`
- Example:

```
public void MyRun1(){ … }
Thread myThread = new Thread(new ThreadStart(MyRun1));
myThread.Start();
```

C# Threads, basic operations

- Like Java we can use `Join`
- Suspend a thread with `Sleep`
- Unlike Java C#'s `Sleep` does not rise any exceptions, thus it needs to be called in a **`try`** block
- Terminate a thread with the `abort` method

C# Threads, Synchronizing

- Three different ways
  - `Interlock class`: used when the only operations that need to be synchronized are incrementing/ decrementing integers;
  - `lock statement`: used to mark a critical section of code in a thread; `lock(expression){…}`
  - `Monitor class`: has 4 methods: `enter, wait, pulse, exit`. Used to provide more sophisticated synchronization of threads

C# Threads, Synchronizing

- Three different ways
  - Monitor class: has 4 methods: enter, wait, pulse, exit. Used to provide more sophisticated synchronization of threads
    - `Enter`: takes object reference and marks beginning
    - `Wait`: suspends execution of thread and instructs CLR of .NET that the thread wants to resume next time
    - `Pulse`: takes object reference, notifies waiting threads that they can run (similar to NotifyAll in Java)
    - `Exit`: marks end of critical section

C#'s Thread Evaluation

- Slightly more effective than Java
  - Each method can have own thread
  - Termination is cleaner than Java (Java sets pointer to NULL)
  - Synchronization is more sophisticated
- Not as powerful as Ada's tasks

Summary

- Concurrent execution can be at the instruction, statement, or subprogram level
- Physical concurrency: when multiple processors are used to execute concurrent units
- Logical concurrency: concurrent united are executed on a single processor
- Two primary facilities to support subprogram concurrency: competition synchronization and cooperation synchronization
- Mechanisms: semaphores, monitors, rendezvous, threads