Lecture 12

Concepts of Programming Languages

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Topics

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

Introduction

- Concurrency can occur at many 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

Multiprocessor Architectures

- Late 1950s - one general-purpose processor and one or more special-purpose processors for input and output operations
- Early 1960s - multiple complete processors, used for program-level concurrency
- Mid-1960s - multiple partial processors, used for instruction-level concurrency
- **Single-Instruction Multiple-Data (SIMD)** machines
- **Multiple-Instruction Multiple-Data (MIMD)** machines
  - Independent processors that can be synchronized (unit-level concurrency)

Categories of Concurrency

- A *thread of control* in a program is the sequence of program points reached as control flows through the program
- 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)
- Coroutines (*quasi-concurrency) have a single thread of control*

Motivations for Studying Concurrency

- Involves a different way of designing software that can be very useful - many real-world situations involve concurrency
- Multiprocessor computers capable of physical concurrency

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

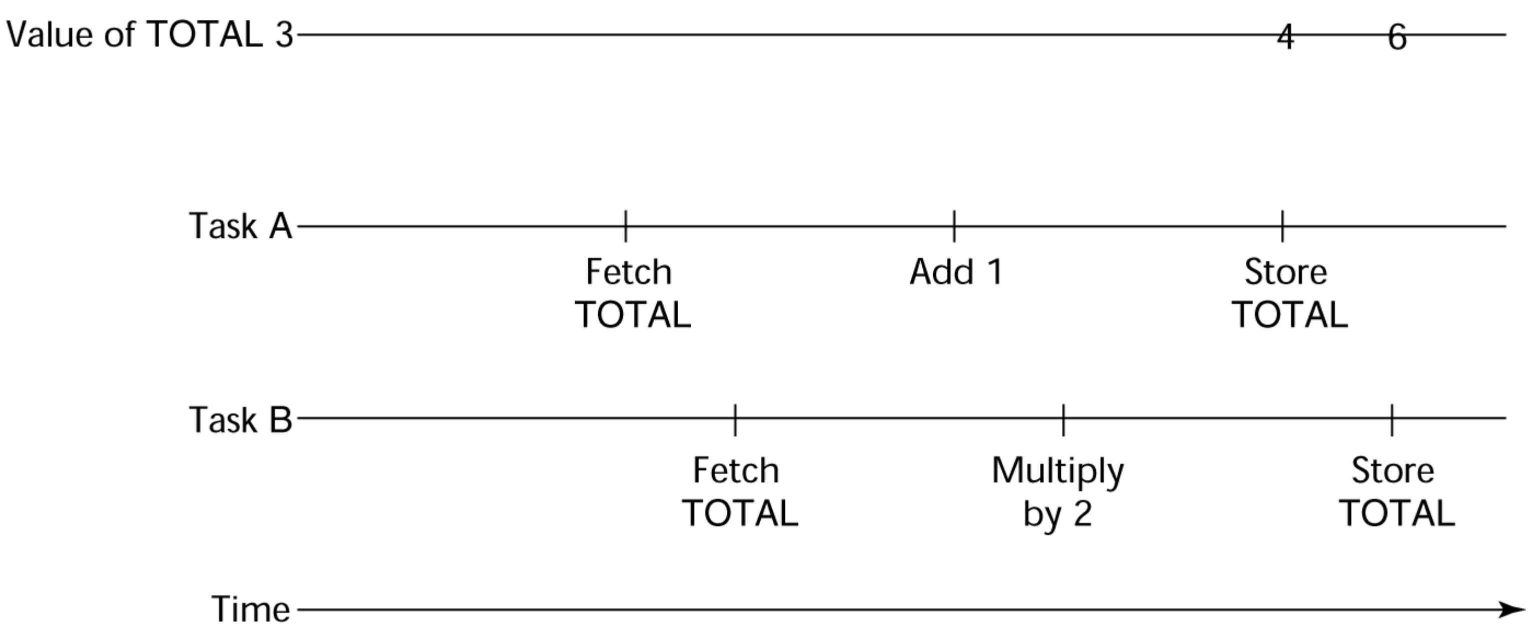
Task Synchronization

- 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*

Design Issues for Concurrency

- Competition and cooperation synchronization
- Controlling task scheduling
- How and when tasks start and end execution
- How and when are tasks created

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

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
```

Cooperation Synchronization with Semaphores

- Example: A shared buffer
- The buffer is implemented as an ADT with the operations `DEPOSIT` and `FETCH` as the only ways to access the 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

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*

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(emptyspots)`** of **`producer`** 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

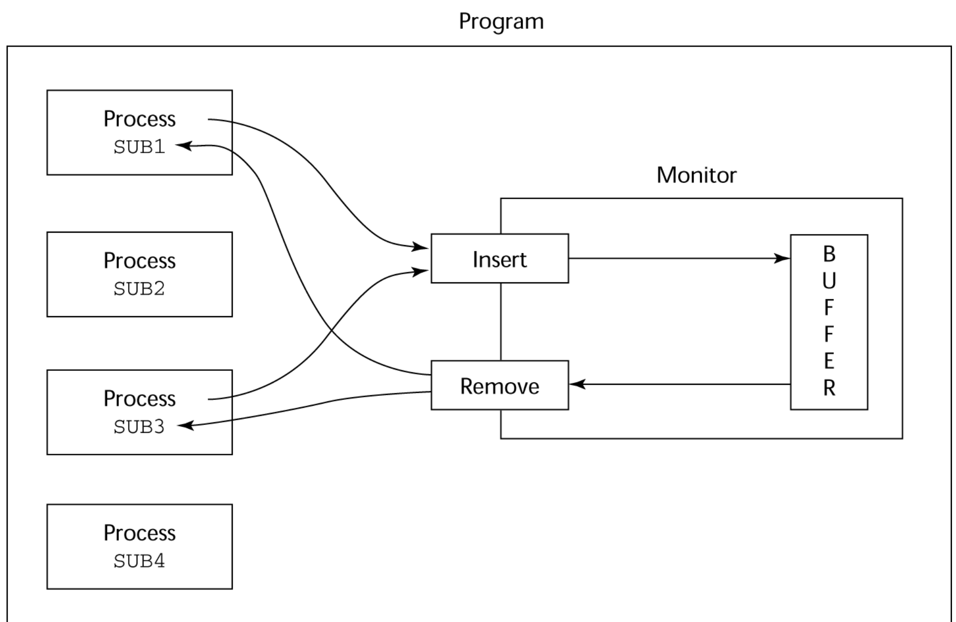
- Ada, Java, C#
- The idea: encapsulate the shared data and its operations to restrict access
- A monitor is an abstract data type for shared data

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



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*

Message Passing Rendezvous

- To support concurrent tasks with message passing, a language needs:

  - A mechanism to allow a task to indicate when it is willing to accept messages

  - A way to remember who is waiting to have its message accepted and some “fair” way of choosing the next message

- When a sender task’s message is accepted by a receiver task, the actual message transmission is called a *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 thru `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

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 but there are significant differences
- Basic thread operations
  - Any method can run in its own thread
  - A thread is created by creating a `Thread` object
  - Creating a thread does not start its concurrent execution; it must be requested through the `Start` method
  - A thread can be made to wait for another thread to finish with `Join`
  - A thread can be suspended with `Sleep`
- A thread can be terminated with `Abort`

Synchronizing Threads

- Three ways to synchronize C# threads
  - The `Interlocked` class
    - Used when the only operations that need to be synchronized are incrementing or decrementing of an integer
  - The `lock` statement
    - Used to mark a critical section of code in a thread

      lock (expression) {… }
  - The `Monitor` class
    - Provides four methods that can be used to provide more sophisticated synchronization

C#'s Concurrency Evaluation

- An advance over Java threads, e.g., any method can run its own thread
- Thread termination is cleaner than in Java
- Synchronization is more sophisticated

Statement-Level Concurrency

- Objective: Provide a mechanism that the programmer can use to inform compiler of ways it can map the program onto multiprocessor architecture
- Minimize communication among processors and the memories of the other processors