The University of North Carolina at Chapel Hill

COMP 144 Programming Language Concepts

Spring 2002

Lecture 38: Implementing Concurrency

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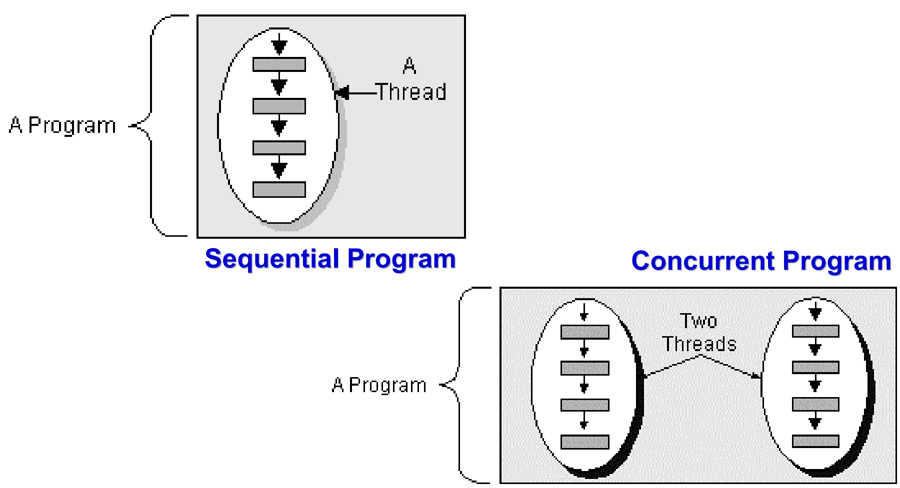
April 26

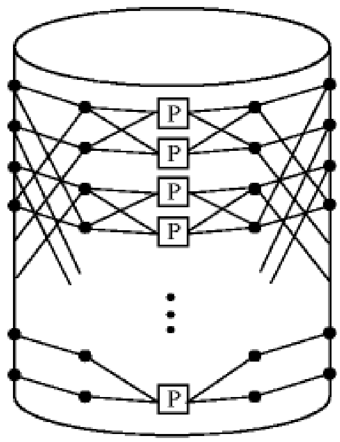
Concurrent Programming

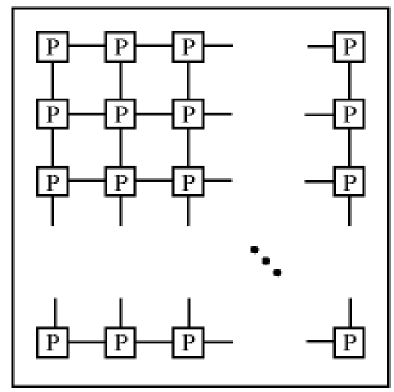


Sequential Program

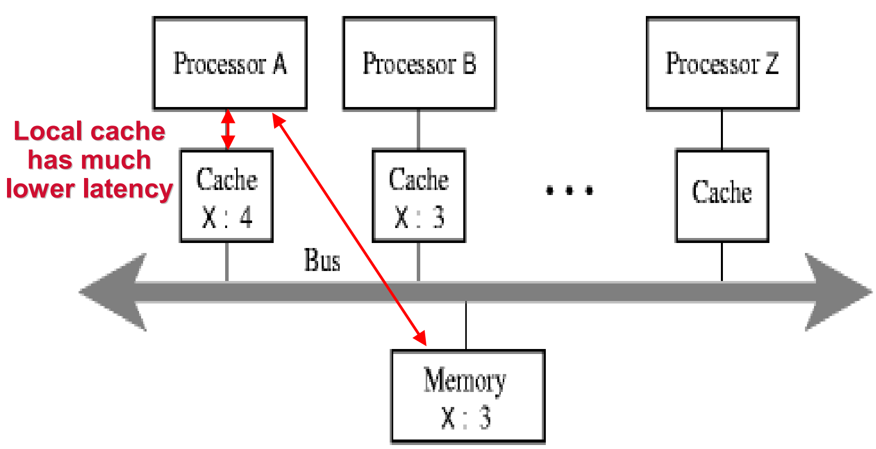
Concurrent Program

Multiprocessors

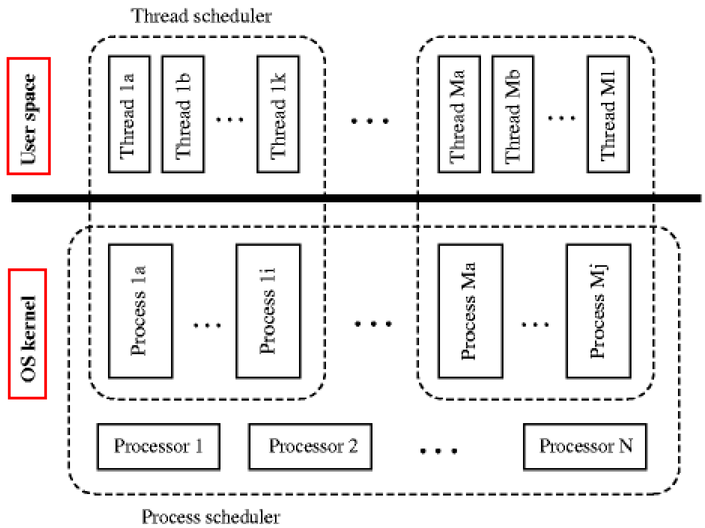




Shared-Memory Multiprocessor



Threads and Processes
OS Space versus User Space



Threads and Processes
Tradeoffs

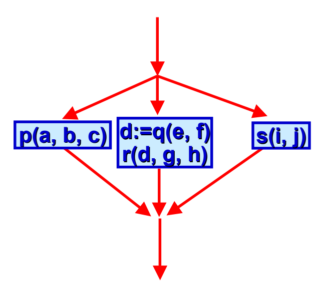
- *One-process-per-thread* is acceptable in personal computer with a single address space
  - This is too expensive in most OSes, since each operation on them requires a system call
  - Processes are general-purpose, so threads may pay the price of features they do not use
    - Processes are ***heavy-weight***
- *All-threads-on-one-process* are acceptable in simple languages for uniprocessors
  - This precludes parallel execution in a multiprocessor machine
  - System call will block the entire set of threads

Threads and Processes
Multiprocessors

- A multiprocessor OS may allocate processes to processors following one the following main strategies
- ***Coscheduling*** (a.k.a. *gang scheduling*): attempts to run each process in a different processor
  - Maximize parallelism
- ***Space sharing*** (a.k.a. *processor partitioning*): give an application exclusive use of some subset of the processors
  - Minimizing context switching cost and/or communication cost

Coroutines

- User-level threads are usually built on top of coroutines
  - Simulate parallel execution in a single processor
    - » p(a,b,c)
    - » d:=q(e,f) ; r(d,g,h)
    - » s(i,j)



- ***Coroutines*** are execution contexts that exist concurrently and execute one at a time
- Coroutines transfer control to each other explicitly (by name)

Coroutines
Example

- Screen-saver program

```
loop
  -- update picture on screen
  -- perform next sanity check
```

  - Successive updates and sanity checks usually depend on each other
    - » Save and restore state of the computation
  - Coroutines are more attractive for this problem

Coroutines
Example

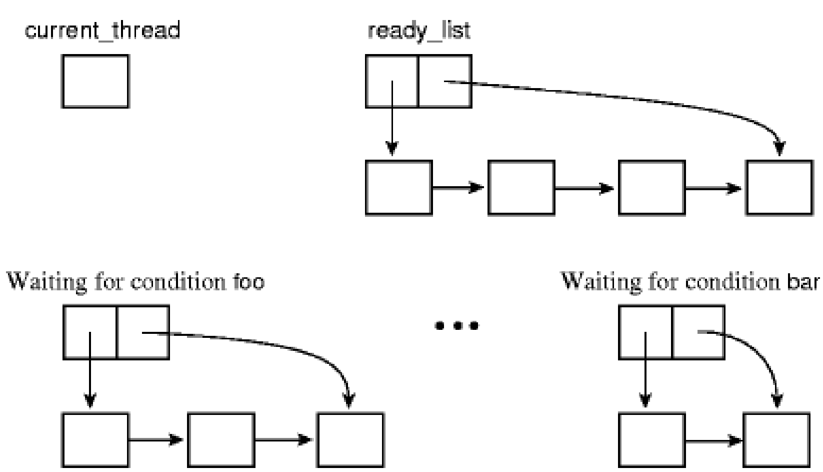
- A coroutine can detach itself from the main program
  - **detach** created the coroutine object
- Control can be transferred from one coroutine to another
  - **transfer** saves the program counter and resumes the coroutines specifies as a parameter
  - Transfers can occur anywhere in the code of the coroutine

```
us, cfs : coroutine

coroutine update_screen
    -- initialize
    detach
    loop
        ...
        transfer (cfs)
        ...

coroutine check_file_system
    -- initialize
    detach
    for all files
        ...
        transfer (us)
        ...
            transfer (us)
        ...
        transfer (us)
        ...

begin          -- main
    us := new update_screen
    cfs := new check_file_system
    resume (us)
```

Turning Coroutines Into Threads

- The programming language environment provides a ***scheduler*** in charge of transferring control automatically
- The scheduler chooses which threads to run first after the the current thread yields the processors
- The scheduler may implement preemption mechanism that suspend the current thread on a regular basis
  - Make processor allocation more fair
- If the scheduler data structures are shared, threads can run in multiple processors

Uniprocessor Scheduler



Scheduling

- **`reschedule`** is used to give up the processor
- **`yield`** is used to give up the processor temporarily
- Threads can wait on specific conditions
  - **`sleep_on`**
  - Intended for synchronization

```
procedure reschedule
    t : thread := dequeue (ready_list)
    transfer (t)

procedure yield
    enqueue (ready_list, current_thread)
    reschedule

procedure sleep_on (ref Q : queue of thread)
    enqueue (Q, current_thread)
    reschedule

procedure yield
    disable_signals
    enqueue (ready_list, current_thread)
    reschedule
    reenable_signals

disable_signals
if not desired_condition
    sleep_on (condition_queue)
reenable_signals
```

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Scheduling

- In preemptive multithreading, multiplexing does not require to explicitly invoke **`yield`**
- Switching is driven by signals
  - *Force the current thread to yield*
- *Race conditions* may occur inside yield if signals are not disabled

```
procedure reschedule
    t : thread := dequeue (ready_list)
    transfer (t)

procedure yield
    enqueue (ready_list, current_thread)
    reschedule

procedure sleep_on (ref Q : queue of thread)
    enqueue (Q, current_thread)
    reschedule

procedure yield
    disable_signals
    enqueue (ready_list, current_thread)
    reschedule
    reenable_signals
```

Preemptive Multithreading

```
disable_signals
if not desired_condition
    sleep_on (condition_queue)
reenable_signals
```

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Multiprocessor Scheduling

- The goal of most languages that support parallel threads is to that *there should be no difference from the programmer point of view*
- This is an increasingly more important issue, since a very significant number of machines will be multiprocessors in the near future
  - At least, Intel is trying hard to do this…
- Multiprocessor thread scheduling requires additional synchronization mechanism that prevent race conditions

Concurrent Programming

- The two most crucial issues are
  - Communication
  - Synchronization
- ***Communication*** refers to any mechanism that allows one thread to obtain information from another
  - It is usually based on using *shared memory* or *message passing*
- ***Synchronization*** refers to any mechanism that allows the programmer to control the relative order in which operations occur in different threads

Shared Memory

- Example of synchronization: the ***semaphore***
  - P decrements a counter, and waits till it is non-negative
  - V increments a counter, waking up waiting threads

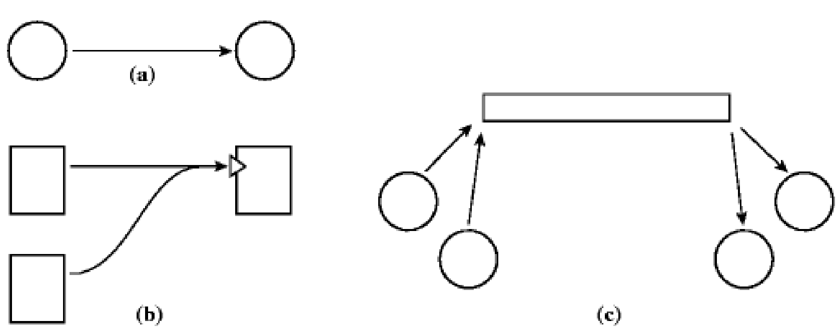
```
shared buf : array [1..SIZE] of bdata
shared next_full, next_empty : integer := 1, 1
shared mutex : semaphore := 1
shared empty_slots, full_slots : semaphore := SIZE, 0

procedure insert (d : bdata)
    P (empty_slots)
    P (mutex)
    buf[next_empty] := d
    next_empty := next_empty mod SIZE + 1
    V (mutex)
    V (full_slots)

function remove : bdata
    P (full_slots)
    P (mutex)
    d : bdata := buf[next_full]
    next_full := next_full mod SIZE + 1
    V (mutex)
    V (empty_slots)
    return d
```


Message Passing
Models

- (a) processes name each other explicitly
- (b) senders name input **ports**
- (c) a **channel** abstraction



Ada Example

```
task buffer is
    entry insert (d : in bdata);
    entry remove (d : out bdata);
end buffer;

task body buffer is
    SIZE : constant integer := 10;
    subtype index is integer range 1..SIZE;
    buf : array (index) of bdata;
    next_empty, next_full : index := 1;
    full_slots : integer range 0..SIZE := 0;
begin
    loop
        select
          when full_slots < SIZE =>
            accept insert (d : in bdata) do
                buf(next_empty) := d;
            end;
            next_empty := next_empty mod SIZE + 1;
            full_slots := full_slots + 1;
        or
          when full_slots > 0 =>
            accept remove (d : out bdata) do
                d := buf(next_full);
            end;
            next_full := next_full mod SIZE + 1;
            full_slots := full_slots - 1;
        end select;
    end loop;
end buffer;
```

```
-- producer:                -- consumer:
buffer.insert (3);          buffer.remove (x);
```


Reading Assignment

- Read Scott
  - Sect. 12.1.3
  - Sect. 12.2.4
  - Sect. 8.6
  - Sect 12.3 intro
  - Sect. 12.4 intro