Lecture 26: Parallelism & Concurrency

CSC 131
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Shared Memory

Semaphores

- Three operations:
  - InitSem(S: Semaphore; value: integer)
    - start w/ initial non-negative value as capacity
  - Wait(S: Semaphore) -- *grab resource if available*
    - if S > 0 then S := S-1 else suspend in queue assoc. w/ S
  - Signal(S: Semaphore) -- *release*
    - If processes waiting then wake up, else S := S + 1

Protect Critical Section

Pattern of use:

```
Wait(S);    -- grab token
{
    Critical region
}
Signal(S);  -- release token
```

Solve producer-consumer

Producer-Consumer

Suppose have Buffer[0..MaxBuffSize-1]

```
Main program:
    CreateProcess(Producer,WorkSize);    -- create producer
    CreateProcess(Consumer,WorkSize);    -- create consumer
    BufferStart := 0;  BufferEnd := -1; Count := 0;
    InitSem(NonEmpty, 0)             -- semaphore w/o non-empty slots
    InitSem(NonFull, MaxBuffSize)
                                 -- semaphore w/MaxBuffSize open slots
    InitSem(MutEx,1)                 -- semaphore for mutual exclusion
    StartProcesses
end;
```

Producer-Consumer

```
Procedure Producer;
begin
    loop
        read(ch);          -- generate ch somehow
        Wait(NonFull);
        Wait(MutEx);
        BufferEnd := (BufferEnd + 1) % MaxBuffSize;
        Buffer[BufferEnd] := ch;
        Count := Count+1;
        Signal(MutEx);
        Signal(NonEmpty);
    end loop;
end;
```

Producer-Consumer

```
Procedure Consumer;
begin
   loop
      Wait(NonEmpty);
      Wait(MutEx);
      ch := Buffer[BufferStart];
      BufferStart := (BufferStart + 1) % MaxBuffSize;
      Count := Count-1;
      Signal(MutEx);
      Signal(NonFull);
      Write(ch)   -- use ch as desired
   end loop
end;
```

Questions

- Why is Mutex semaphore needed?
- What happens if interchange order of Wait's in each?
- Semaphores very low level -- easy to make mistakes!

Monitors

- High level concept due to Per Brinch Hansen
  - originally developed for Simula
- Provide ADT w/condition variables, each of which has an associated queue
- *Suspend* (wait) enqueues process while *continue* dequeues processes

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Producer-Consumer w/ Monitor

```
type buffer = monitor;

var store: array[0..MaxBuffSize-1] of char;
    BufferStart, BufferEnd, BufferSize: integer;
    nonfull, nonempty: queue;

begin (* initialization *)
   BufferEnd := -1;
   BufferStart := 0;
   BufferSize := 0
end;
```

Producer-Consumer w/ Monitor

```
procedure entry insert(ch: char);
begin
    if BufferSize = MaxBuffSize then suspend(nonfull);
    BufferEnd := (BufferEnd + 1) % MaxBuffSize;
    store[BufferEnd] := ch;
    BufferSize := BufferSize + 1;
    continue(nonempty)
end;

procedure entry delete(var ch: char);
begin
   if BufferSize = 0 then suspend(nonempty);
   ch := store[BufferStart];
   BufferStart := (BufferStart + 1) % MaxBuffSize;
   BufferSize := BufferSize -1;
   continue(nonfull);
end;
```

Producer-Consumer w/ Monitor

```
type producer = process (b: buffer);
var ch: char;
begin
    while true do begin
        read(ch);
        b.insert(ch)
    end;
end

type consumer = process(b: buffer);
var ch: char;
begin
    while true do begin
        b.delete(ch);
        write(ch)
    end
end;
```

```
var p: producer;
     q: consumer;
     b:buffer;
begin
   init b,
   p(b),
   q(b)
end.
```

Java
Parallelism & Concurrency

Before Parallelism

- Program on single processor:
  - One call stack (w/ each stack frame holding local variables)
  - One program counter (current statement executing)
  - Static fields
  - Objects (created by new) in the heap (nothing to do with heap data structure)

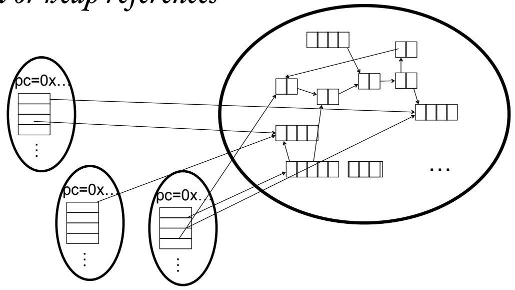
Multiple Theads/Processors

- New story:
  - A set of threads, each with its own call stack & program counter
  - No access to another thread's local variables
  - Threads can (implicitly) share static fields / objects
  - To communicate, write somewhere another thread reads

Shared Memory

Threads, each with own unshared call stack and current statement (pc for "program counter") local variables are numbers/null or heap references

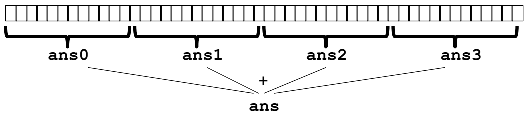
Heap for all objects and static fields



Parallel Programming in Java

- Creating a thread:
  1. Define a class C extending Thread
     - Override `public void run()` method
  2. Create object of class C
  3. Call that thread's start method
     - Creates new thread and starts executing run method.
     - Direct call of run won't work, as just be a normal method call
  - *Alternatively, define class implementing Runnable, create thread w/it as parameter, and send start message*

Parallelism Idea



- Example: Sum elements of an array
  - Use 4 threads, which each sum 1/4 of the array
- Steps:
  - Create 4 thread objects, assigning each their portion of the work
  - Call start() on each thread object to actually run it
  - Wait for threads to finish
  - Add together their 4 answers for the final result

First Attempt

```
class SumThread extends Thread {
  int lo, int hi, int[] arr;//fields to know what to do
  int ans = 0; // for communicating result
  SumThread(int[] a, int l, int h) { … }
  public void run(){ … }
}

int sum(int[] arr){
  int len = arr.length;
  int ans = 0;
  SumThread[] ts = new SumThread[4];
  for(int i=0; i < 4; i++){// do parallel computations
    ts[i] = new SumThread(arr,i*len/4,(i+1)*len/4);
    ts[i].start(); // use start not run
  }
  for(int i=0; i < 4; i++) // combine results
    ans += ts[i].ans;
  return ans;
}
```

What's wrong?

Correct Version

```
class SumThread extends Thread {
  int lo, int hi, int[] arr;//fields to know what to do
  int ans = 0; // for communicating result
  SumThread(int[] a, int l, int h) { … }
  public void run(){ … }
}

int sum(int[] arr){
  int len = arr.length;
  int ans = 0;
  SumThread[] ts = new SumThread[4];
  for(int i=0; i < 4; i++){// do parallel computations
    ts[i] = new SumThread(arr,i*len/4,(i+1)*len/4);
    ts[i].start(); // start not run
  }
  for(int i=0; i < 4; i++) // combine results
    ts[i].join(); // wait for helper to finish!
    ans += ts[i].ans;
  return ans;
}
```

See program ParallelSum

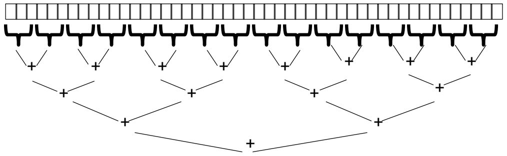
Thread Class Methods

- void start( ), which calls void run( )
- void join( ) -- blocks until receiver thread done
- Style called fork/join parallelism
  - Code on previous slide generates error message as join can throw exception
    InterruptedException
- Some memory sharing: arr field
- Later learn how to protect using synchronized.

Actually not so great.

- If do timing, it's slower w/ small arrays than sequential!!
- Want code to be reusable and efficient as core count grows.
  - At minimum, make #threads a parameter.
- Want to effectively use processors available *now*
  - Not being used by other programs
  - Can change while your threads running

Divide & Conquer



- Divide in half, w/ one thread per half.
  - Each half further subdivided w/ new threads, etc. until down to single elements
  - Depth is O(log n), which is optimal
  - Then total time w/numProc processors
    O(n/numProc + log n)

straight-line code cost
in step 1

each layer is O(1) in parallel

In practice

- Creating all threads and communication swamps savings so
  - use sequential cutoff about 1000
  - Don't create two recursive threads
    - one new and reuse old.
    - Cuts number of threads in half.

EfficentDivideConquerParallelSum

Even Better

- Java threads too heavyweight -- space and time overhead.
- ForkJoin Framework solves problems
- Added in Java 7.

To Use Library

- Create a ForkJoinPool
- Instead of subclass Thread, subclass RecursiveTask<V> (or RecursiveAction)
- Override compute, rather than run
- Return answer from compute rather than instance vble
- Call fork instead of start
- Call join that returns answer
- To optimize, call compute instead of fork (*rather than run*)
- See *ForkJoinFrameworkDivideConquerParallelSum*

Handling Concurrency in Java

See ATM example