CMSC 330: Organization of Programming Languages

Java 1.5, Ruby, and MapReduce

Overview

- Java 1.5 ←
  - ReentrantLock class
  - Condition interface - await( ), signalAll( )
- Ruby multithreading
- Concurrent programming
  - Parallel applications & languages
  - MapReduce

Lock Interface (Java 1.5)

```
interface Lock {
  void lock();
  void unlock();
  ... /* Some more stuff, also */
}
class ReentrantLock implements Lock { ... }
```

- Explicit Lock objects
  - Same as implicit lock used by synchronized keyword
- Only one thread can hold a lock at once
  - lock( ) causes thread to block (become suspended) until lock can be acquired
  - unlock( ) allows lock to be acquired by different thread

Synchronization Example (Java 1.5)

```
public class Example extends Thread {
  private static int cnt = 0;
  static Lock lock = new ReentrantLock();
  public void run() {
    lock.lock();
    int y = cnt;
    cnt = y + 1;
    lock.unlock();
    }
  }
  ...
}
```

***Lock**, for protecting the shared state*

***Acquires** the lock; only succeeds if not held by another thread, otherwise blocks*

***Releases** the lock*

ReentrantLock Class (Java 1.5)

```
class ReentrantLock implements Lock { ... }
```

- Reentrant lock
  - Can be reacquired by same thread by invoking lock( )
    - Up to 2147483648 times
  - To release lock, must invoke unlock( )
    - The same number of times lock( ) was invoked
- Reentrancy is useful
  - Each method can acquire/release locks as necessary
    - No need to worry about whether callers already have locks
  - Discourages complicated coding practices
    - To determine whether lock has already been acquired

Reentrant Lock Example

```
static int count = 0;
static Lock l =
    new ReentrantLock();

void inc() {
  l.lock();
  count++;
  l.unlock();
}
```

```
void returnAndInc() {
  int temp;

  l.lock();
  temp = count;
  inc();
  l.unlock();
}
```

- Example
  - returnAndInc( ) can acquire lock and invoke inc( )
  - inc( ) can acquire lock without having to worry about whether thread already has lock

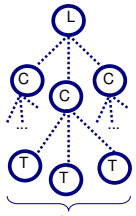
Condition Interface (Java 1.5)

```
interface Lock { Condition newCondition(); ... }
interface Condition {
  void await();
  void signalAll(); ... }
```

- Explicit condition variable objects
  - Condition variable C is created from a Lock object L by calling L.newCondition( )
  - Condition variable C is then associated with L
- Multiple condition objects per lock
  - Allows different wait sets to be created for lock
  - Can wake up different threads depending on condition

Condition – await() and signalAll()

- Calling await( ) w/ lock held
  - Releases the lock
    - But not any other locks held by this thread
  - Adds this thread to wait set for condition
  - Blocks the thread
- Calling signalAll( ) w/ lock held
  - Resumes all threads in condition's wait set
  - Threads must reacquire lock
    - Before continuing (returning from await)
    - Enforced automatically; you don't have to do it



Producer / Consumer Solution (Java 1.5)

```
Lock lock = new ReentrantLock();
Condition ready = lock.newCondition();
boolean bufferReady = false;
Object buffer;
```

```
void produce(Object o) {
    lock.lock();
    while (bufferReady)
      ready.await();
    buffer = o;
    bufferReady = true;
    ready.signalAll();
    lock.unlock();
  }
```

```
Object consume() {
    lock.lock();
    while (!bufferReady)
      ready.await();
    Object o = buffer;
    bufferReady = false;
    ready.signalAll();
    lock.unlock();
  }
```

- Uses single condition per lock (as in Java 1.4)

Producer / Consumer Solution (Java 1.5)

```
Lock lock = new ReentrantLock();
Condition producers = lock.newCondition();
Condition consumers = lock.newCondition();
boolean bufferReady = false;
Object buffer;
```

```
void produce(Object o) {
    lock.lock();
    while (bufferReady)
      producers.await();
    buffer = o;
    bufferReady = true;
    consumers.signalAll();
    lock.unlock();
  }
```

```
Object consume() {
    lock.lock();
    while (!bufferReady)
      consumers.await();
    Object o = buffer;
    bufferReady = false;
    producers.signalAll();
    lock.unlock();
  }
```

- Uses 2 conditions per lock for greater efficiency

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- Java 1.5
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- Concurrent programming
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Ruby Threads – Thread Creation

- Create thread using Thread.new
  - New method takes code block argument
    t = Thread.new { …body of thread… }
    t = Thread.new (arg) { | arg | …body of thread… }
  - Join method waits for thread to complete
    t.join
- Example

```
myThread = Thread.new {
   sleep 1                  # sleep for 1 second
   puts "New thread awake!"
   $stdout.flush            # flush makes sure output is seen
}
```

Ruby Threads – Locks

- Monitor, Mutex
  - Object intended to be used by multiple threads
  - Methods are executed with mutual exclusion
    - As if all methods are synchronized
  - Monitor is reentrant, Mutex is not
- Create lock using Monitor.new
  - Synchronize method takes code block argument

```
require 'monitor.rb'
myLock = Monitor.new
myLock.synchronize {
        # myLock held during this code block
}
```


Ruby Threads – Condition

- Condition derived from Monitor
  - Create condition from lock using new_cond
  - Sleep while waiting using wait_while, wait_until
  - Wake up waiting threads using broadcast
- Example

```
myLock = Monitor.new                    # new lock
myCondition = myLock.new_cond           # new condition
myLock.synchronize {
  myCondition.wait_while { y > 0 }      # wait as long as y > 0
  myCondition.wait_until { x != 0 }     # wait as long as x == 0
}
myLock.synchronize {
  myCondition.broadcast          # wake up all waiting threads
}
```


Parking Lot Example

```
require "monitor.rb"
class ParkingLot
    def initialize      # initialize synchronization
        @numCars = 0
        @myLock = Monitor.new
        @myCondition = @myLock.new_cond
    end
    def addCar
      …
    end
    def removeCar
      …
    end
end
```


Parking Lot Example

```
def addCar # do work not requiring synchronization
    @myLock.synchronize {
        @myCondition.wait_until { @numCars < MaxCars }
        @numCars = @numCars + 1
        @myCondition.broadcast
    }
end
def removeCar # do work not requiring synchronization
    @myLock.synchronize {
        @myCondition.wait_until { @numCars > 0 }
        @numCars = @numCars - 1
        @myCondition.broadcast
    }
end
```


Parking Lot Example

```
garage = ParkingLot.new
valet1 = Thread.new {       # valet 1 drives cars into parking lot
  while …
    # do work not requiring synchronization
    garage.addCar
  end
}
valet2 = Thread.new {       # valet 2 drives car out of parking lot
  while …
    # do work not requiring synchronization
    garage.removeCar
  end
}
valet1.join           # returns when valet 1 exits
valet2.join           # returns when valet 2 exits
```


Ruby Threads – Difference from Java

- Ruby thread can access all variables in scope when thread is created, including local variables
  - Java threads can only access object fields
- Exiting
  - All threads exit when main Ruby thread exits
  - Java continues until all non-daemon threads exit
- When thread throws exception
  - Ruby only aborts current thread (by default)
  - Ruby can also abort all threads (better for debugging)
    - Set Thread.abort_on_exception = true

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Parallelizable Applications of Interest

- Knowledge discovery: mine and analyze massive amounts of distributed data
  - Discovering social networks
  - Real-time, highly-accurate common operating picture, on small, power-constrained devices
- Simulations (games?)
- Data processing
  - NLP, Vision, rendering, in real-time
- Commodity applications
  - Parallel testing, compilation, typesetting, …

Multithreading (Java threads, pthreads)

\+ Portable, high degree of control

\- Low-level and unstructured
  - Thread management, synchronization via locks and signals essentially manual
    - Blocking synchronization is not compositional, which inhibits nested parallelism
  - Easy to get wrong, hard to debug
    - Data races, deadlocks all too common

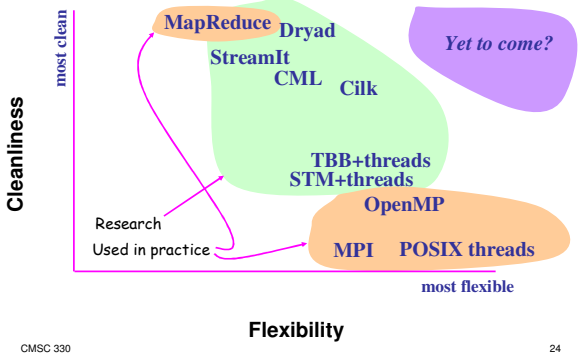
Parallel Language Extensions

- MPI – expressive, portable, but
  - Hard to partition data and get good performance
    - Temptation is to hardcode data locations, number of processors
  - Hard to write the program correctly
    - Little relation to the sequential algorithm
- OpenMP, HPF – parallelizes certain code patterns (e.g., loops), but
  - Limited to built-in types (e.g., arrays)
  - Code patterns, scheduling policies brittle

Two Directions To A Solution

- Start with clean, but limited, languages/abstractions and generalize
  - MapReduce (Google)
  - StreamIt (MIT)
  - Cilk (MIT)
- Start with full-featured languages and add cleanliness
  - Software transactional memory
  - Static analyzers (Locksmith, Chord, …)
  - Threaded Building Blocks (Intel)

Space of Solutions



Kinds of Parallelism

- Data parallelism
  - Can divide parts of the data between different tasks and perform the same action on each part in parallel
- Task parallelism
  - Different tasks running on the same data
- Hybrid data/task parallelism
  - A parallel pipeline of tasks, each of which might be data parallel
- Unstructured
  - Ad hoc combination of threads with no obvious top-level structure

MapReduce: Programming the Pipeline

- Pattern inspired by Lisp, ML, etc.
  - Many problems can be phrased this way
- Results in clean code
  - Easy to program / debug / maintain
    - Simple programming model
    - Nice retry / failure semantics
  - Efficient and portable
    - Easy to distribute across nodes

Thanks to Google, Inc. for some of the slides that follow

Map & Reduce in Lisp / Scheme

- (map ***f list***)
- (map square '(1 2 3 4))
  - (1 4 9 16)
- (reduce + '(1 4 9 16) 0)
  - (+ 1 (+ 4 (+ 9 (+ 16 0))))
  - 30
- (reduce + (map square '(1 2 3 4)) 0)

Unary operator

Binary operator

MapReduce a la Google

- map(key, val) is run on each item in set
  - emits new-key / new-val pairs
- reduce(key, vals) is run for each unique key emitted by map()
  - emits final output

Count Words in Documents

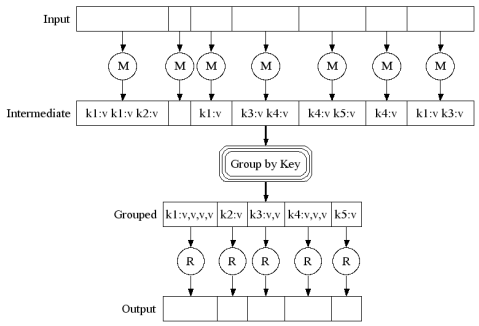
- Input consists of (url, contents) pairs
- map(key=url, val=contents):
  - For each word *w* in contents, emit (w, "1")
- reduce(key=word, values=uniq_counts):
  - Sum all "1"s in values list
  - Emit result "(word, sum)"

Count, Illustrated

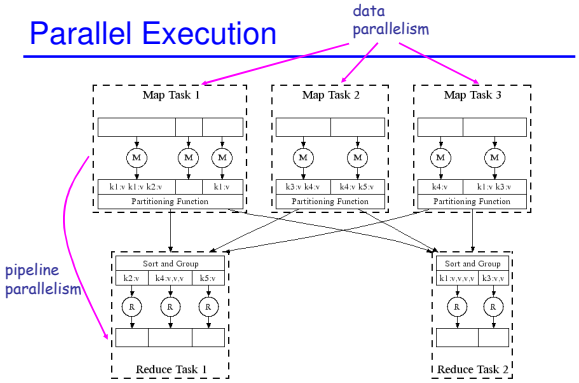
map(key=url, val=contents):
For each word *w* in contents, emit (w, "1")

reduce(key=word, values=uniq_counts):
Sum all "1"s in values list
Emit result "(word, sum)"

Execution



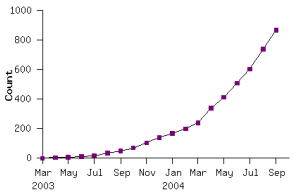
Parallel Execution



Key: no implicit dependencies between map or reduce tasks

Model is Widely Applicable

MapReduce Programs In Google Source Tree 2004



Example uses:

distributed grep	distributed sort	web link-graph reversal
term-vector / host	web access log stats	inverted index construction
document clustering	machine learning	statistical machine translation
...	...	...

The Programming Model Is Key

- Simple control makes dependencies evident
  - Can automate scheduling of tasks and optimization
    - Map, reduce for different keys, embarassingly parallel
    - Pipeline between mappers, reducers evident
- map and reduce are pure functions
  - Can rerun them to get the same answer
    - In the case of failure, or
    - To use idle resources toward faster completion
  - No worry about data races, deadlocks, etc. since there is no shared state

Compare to Dedicated Supercomputers

- According to Wikipedia, in 2006 Google uses
  - 450,000 servers from 533 MHz Celeron to dual 1.4GHz Pentium III
  - 80GB drive per server, at least
  - 2-4GB memory per machine
  - Jobs processing 100 terabytes of distributed data
- More computing power than even the most powerful supercomputer