CMSC 330: Organization of Programming Languages

Multithreading 2

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, or final local variables
- 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

Ocaml Threads – Thread Creation

- Create thread using Thread.create
  - method takes closure as its argument

    ```
    let t = Thread.create (fun x -> …body…) arg;;
    ```
  - Join method waits for thread to complete

    ```
    Thread.join t
    ```
- Example

```
let myThread = Thread.create (fun _ ->
   Unix.sleep 1;            (* sleep for 1 second *)
   print_string "New thread awake!";
   flush Pervasives.stdout  (* flush ensures output is seen *)
);;
```


Ocaml Threads – Locks & Conditions

- Mutex module
  - Not reentrant
  - Has lock, unlock functions

    ```
    let myLock = Mutex.create ();;
    Mutex.lock myLock;
              (* myLock held here *)
    Mutex.unlock myLock
    ```
- Condition module
  - Create condition directly
  - Sleep while waiting using wait (takes mutex arg)
  - Wake up waiting threads using broadcast

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

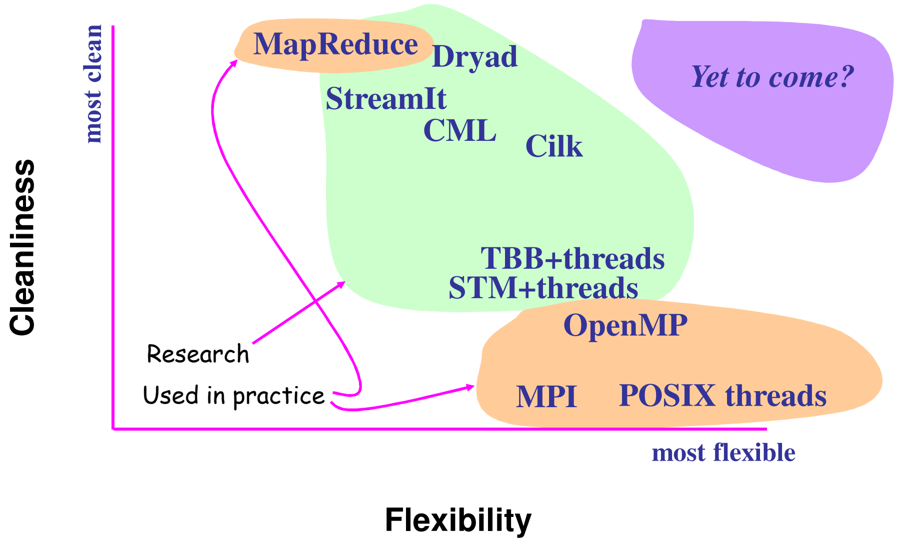
Parallel Language Extensions

- 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”)

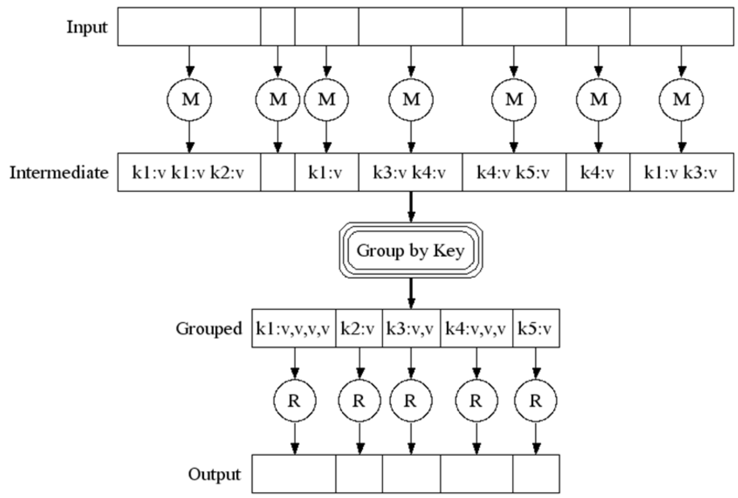
reduce(key=word, values=uniq_counts):
    Sum all “1”s in values list
    Emit result “(word, sum)”

see bob throw
see spot run

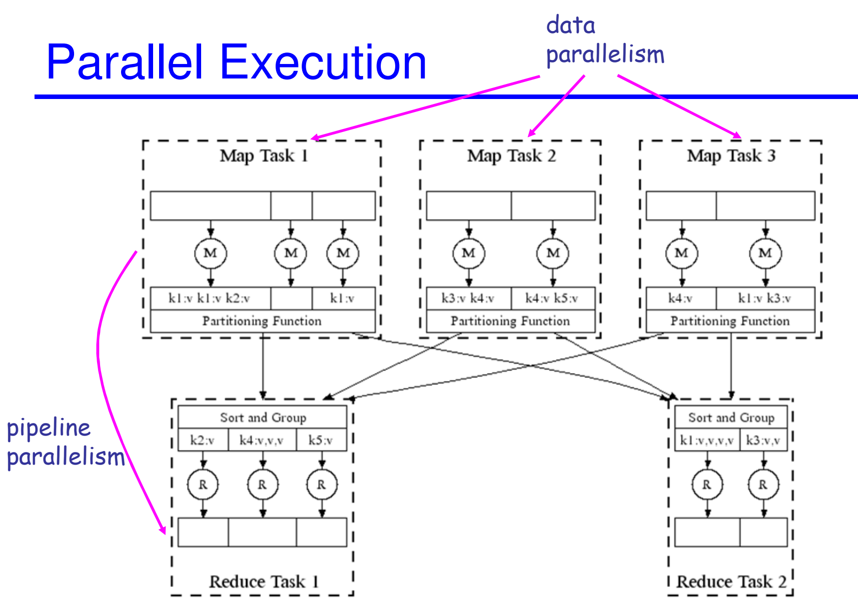
see	1
bob	1
run	1
see	1
spot	1
throw	1

bob	1
run	1
see	2
spot	1
throw	1

Execution



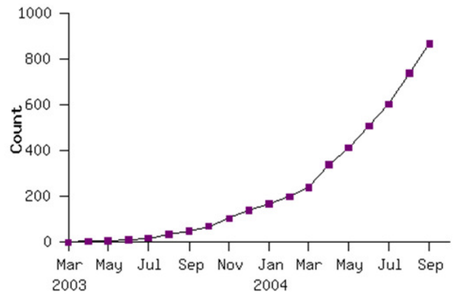
Parallel Execution



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 for Google Translate
clustering for Google News	popularity for Google Trends	...

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 2009 Google uses
  - 450,000 servers (2006), mostly commodity Intel boxes
  - 2TB drive per server, at least
  - 16GB memory per machine
  - More recent details are kept secret by Google
- More computing power than even the most powerful supercomputer