Parallel Languages and Platforms

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Logistics

Today

- Finish Applications
- Parallel Languages and Platforms

Schedule

Tue 4/26	Applications Parallel Languages
Thu 4/28	Last Lecture Review
Mon 5/02	Course Evals Due Last Day of Classes
Mon 5/09	Final Exam 8:00-10:00am Lecture Location

Course Feedback

Official Student Rating of Teaching (SRTs)

- Official UMN Evals are done online this semester
- Available here: `https://srt.umn.edu/blue`
- **EVALUATE YOUR LECTURE SECTION: 001**
- **Due** Mon 5/02/2022 by 11:59pm
- Response Rate $\geq$ 80% $\rightarrow$ One Final Exam Question Revealed online

Menagerie of Parallel Languages and Platforms

Distributed Memory Only

Erlang, Map+Reduce / Hadoop, Job Schedulers

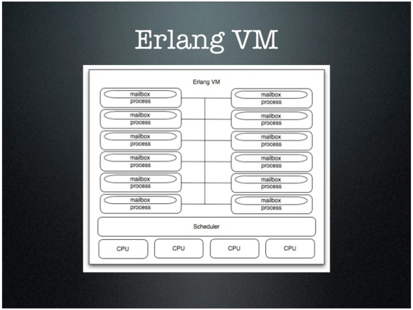
Shared Memory Only

Cilk, Clojure

Distributed + Shared

Unified Parallel C, Chapel

Erlang



Source

- Developed for distributed computation, telephony systems
- Virtual machine which mirrors many OS functions
- Process `spawn` to create *lightweight* procs
- `send/receive` clauses to share information among processes
- Facilities to contact a remote Erlang VM and talk to its processes

Erlang Sample straight from Wikipedia

```erlang
% Create a process on this machine and invoke the function
%   web:start_server(Port,MaxConnections)

ServerProcess = spawn(web, start_server, [Port, MaxConnections]),

% Create a remote process and invoke the function
%   web:start_server(Port, MaxConnections)
% on machine RemoteNode

RemoteProcess = spawn(RemoteNode, web, start_server, [Port, MaxConnections]),

% Send a message to ServerProcess (asynchronously). The message
% consists of a tuple with the atom "pause" and the number "10".

ServerProcess ! {pause, 10},

% Receive messages sent to this process
receive
    a_message -> do_something;
    {data, DataContent} -> handle(DataContent);
    {hello, Text} -> io:format("Got hello message: ~s", [Text]);
    {goodbye, Text} -> io:format("Got goodbye message: ~s", [Text])
end.
```

Erlang's Nature and Target

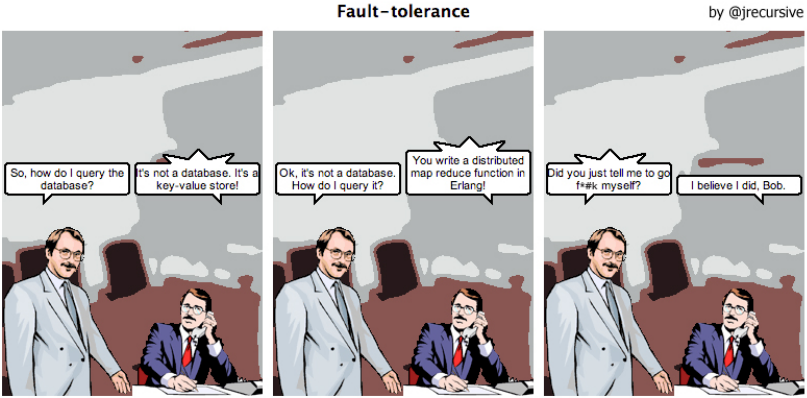
- Syntax and semantics are somewhat odd/archaic but can be "gotten used to"
- Targeted at client server architectures, computation distributed across many nodes
- Well known for robustness of the VM, fault-tolerance features to keep application going if participating nodes go down
- Not targeted at high-performance computation / scientific problems, more towards business, IT, web services

MapReduce (or more properly Map, Shuffle, Reduce)

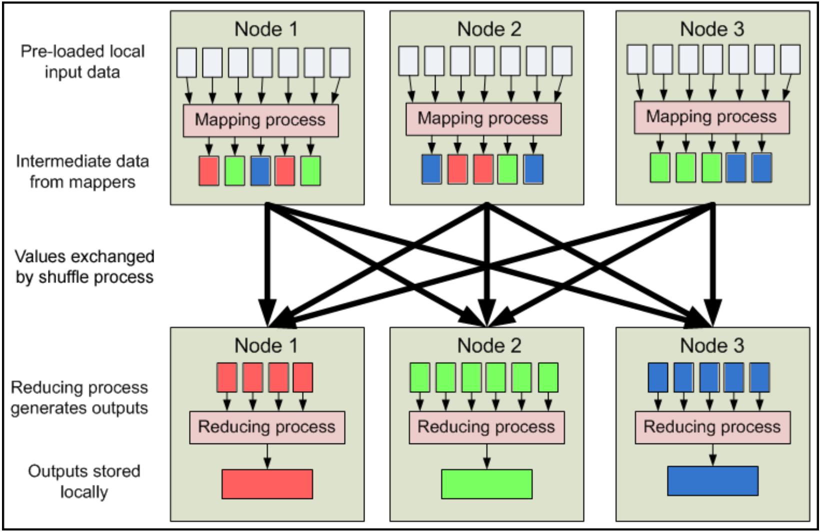
- A style of programming, inspired by functional programming

  ```
  (def doub-sum (reduce + 0 (map double '(1 2 3 4 5))))
  ```

- Targeted at big data: large distributed stores of data
  - Map: Transform / filter data in some way
  - Shuffle: Move data with same properties to same node
  - Reduce: Combine results on individual nodes



Basic Architecture of MapReduce



Source: Yahoo Developer Tutorial on MapReduce

Shameless Wikipedia Example: Document Word Counts

Pseudocode

```
function map(String name,
             String document):
  // name: document name
  // document: document contents
  for each word w in document:
    emit (w, 1)

function reduce(String word,
                Iterator partialCounts):
  // word: a word to count
  // partialCounts: list of
                    partial counts
  sum = 0
  for each pc in partialCounts:
    sum += pc
  emit (word, sum)
```

- Goal: produce frequency of each word in a document
- Nodes are each fed the document
- During `reduce()` *emit* pairs like `("apple",1)` and `("Dell",1)`
- System automatically sends pairs with key apple to the same nodes (redistribute)
- Nodes run `reduce()` to count apple occurrences, may redistribute further

Variety of Languages for MapReduce Framework

```
public static class MapClass extends MapReduceBase
  implements Mapper<LongWritable, Text, Text, IntWritable>
{
  private final static
    IntWritable one = new IntWritable(1);
  private Text word = new Text();
  public void
  map(LongWritable key, Text value,
      OutputCollector<Text, IntWritable> output,
      Reporter reporter) throws IOException
  {
    String line = value.toString();
    StringTokenizer itr = new StringTokenizer(line);
    while (itr.hasMoreTokens()) {
      word.set(itr.nextToken());
      output.collect(word, one);
    }
  }
}
public static class Reduce extends MapReduceBase
  implements Reducer<Text, IntWritable, Text, IntWritable>
{
  public void
  reduce(Text key, Iterator<IntWritable> values,
         OutputCollector<Text, IntWritable> output,
         Reporter reporter) throws IOException
  {
    int sum = 0;
    while (values.hasNext()) {
      sum += values.next().get();
    }
    output.collect(key, new IntWritable(sum));
  }
}
```

Code for Word Frequencies in a Document

← Java (Source)

Pig Latin ↓ (Source)

```
A = load './input.txt';
B = foreach A generate
      flatten(TOKENIZE((chararray)$0))
      as word;
C = group B by word;
D = foreach C generate COUNT(B), group;
store D into './wordcount';
```

MapReduce Framework Notes

- Primary contribution of implementations is distributing load across many machines efficiently
- When machines both store some data and participate in MapReduce, gain locality for speed
- Alternative to large database processing, may open up opportunities for parallelism to avoid read/write locks in traditional DBs
- Most frequently referenced implementation is Apache Hadoop

  But other implementations exist, some proprietary
- All implementation implement a MapReduce server/scheduler to which jobs are submitted

```
> javac MRWordCount.java
> java MRWordCount &
> bin/hadoop job -list
1 jobs currently running
JobId     State         StartTime   UserName
job_0001     1       1218506470390  kauffman
```

Job Schedulers

- Has long been the need for many parallel jobs to be run on individual systems/clusters
- Job schedulers offer frameworks for this: submit many programs to run, scheduler assigns resources
- `slurm`: a common scheduler used for instance on MSI systems
- Generic form of easy concurrency for variety of different programs, resources etc.

A sample `slurm` job submission script from MSI

```
#!/bin/bash -l
#SBATCH --time=8:00:00
#SBATCH --ntasks=8
#SBATCH --mem=10g
#SBATCH --tmp=10g
#SBATCH --mail-type=ALL
#SBATCH --mail-user=sample_email@umn.edu
cd ~/program_directory
module load intel
module load ompi/intel
mpirun -np 8 program_name < inputfile \
                          > outputfile
```

Cilk and CilkPlus

- Tutorial Here
- Extensions to C/C++ which enable easy spawning of threads (*strands*) to run functions concurrently
- Primary Additions are keywords to easily spawn functions

```
// Run func concurrently - separate thread
int x = cilk_spawn func(n);
...

// Wait for all running functions to finish
cilk_sync;


// Compile with cilk features enabled
> gcc -fcilkplus cilk-fib.c
```

- Examine: `cilk-fib.c`
- Contrast with PThread startup
- Alas, Cilk dropped from gcc

Clojure and Software Transactional Memory

- A lisp which runs on the Java Virtual Machine
- Design Goal: allow shared memory parallelism
- Realization:
  - Each data element has well-defined local/shared semantics
  - Data is immutable by default
  - Provides `atom` data types for atomic alterations
  - Other alterations to shared resources occur in `dosync` blocks
  - Software Transactional Memory (STM) system: try changing a shared area, if it changes, try again with the new current value
- Runs as an executable JAR

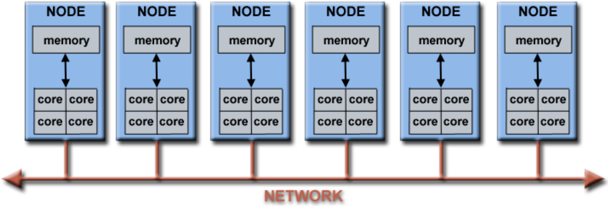
```
> java -jar clojure-1.8.0.jar
Clojure 1.8.0
user=> (def x (atom 0))
#'user/x
user=> x
#object[clojure.lang.Atom 0x6c372fe6 {:status :ready, :val 0}]
user=> @x
0
```

Picalc in Clojure

```clojure
;; Serial version with atomic updates
(defn calc-pi-atoms [iterations]
  (let [hits (atom 0)]
    (dotimes [i iterations]
      (let [x (rand) y (rand)]
        (if (<= (+ (* x x) (* y y)) 1)
          (swap! hits inc))))
    (double (* (/ @hits iterations) 4))))

;; Parallel version with atomic updates
(defn calc-pi-atoms [iterations nthreads]
  (let [hits (atom 0)]
    (doall (pmap ;; parallel map, force evaluation
      (fn [x]
        (dotimes [i (/ iterations nthreads)]
          (let [x (rand) y (rand)]
            (if (<= (+ (* x x) (* y y)) 1)
              (swap! hits inc)))))
      (range nthreads))) ;; map onto number of threads
    (double (* (/ @hits iterations) 4))))
```

Common HPC Parallel Platform



- MSI machines follow this config
- Cluster of machines, each with multiple cores
- Options to program:
  - Serial execution on each core/machine
  - Parallel shared memory execution on each machine
  - Parallel distributed memory execution on each core
  - **Mixed**: Distributed/Shared parallel execution

Mixing MPI and OpenMP

Unified Parallel C (requires special compiler)

- Extensions to the C language
- Aimed at BOTH shared memory and distributed memory
- Automatic `THREADS` and id `MYTHREAD` variables
- Thread is more generalized: might be same machine (shared) or different machine (distributed)
- Shared memory blocks

  `shared int all_hits[THREADS];`

  Access like `int x = all_hits[1];` will work locally (shared) or via MPI-style message passing if remote (distributed)
- Compiler/runtime automatically sets up sharing
- Standard locks
- Automatic loop parallelization via `upc_forall(..)` with some *affinity* control: which thread executes which iteration
- Control over layout of shared blocks of memory: which thread gets what section
- Examine `upc-shared-picalc.c`

Chapel by Cray

- Language Developed in 2009 as part of a competitive HPC effort
- Specifically developed for HPC to handle multiple types of concurrency
- C-esque syntax with type inference, first class functions, and higher-level concepts specifically devoted to common HPC settings (e.g. modeling physical domains)
- Specifically targets mixed shared / distributed memory computing
- Still actively developed but not widely adopted in HPC