MW : Master-Worker Middleware for Grids

Jeff Linderoth

Department of Industrial and Systems Engineering
Lehigh University

NSF Shared Cyberinfrastructure (SCI) Division
Principal Investigators Meeting
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MWMotivation
MWDesign
MWSuccesses
MWFuture

MWCollaborators

- Jean-Pierre Goux
  - Northwestern University and Argonne National Lab
- Wen-Han Goh, Sanjeev Kulkarni, Miron Livny, Steve Wright, Mike Yoder
  - University of Wisconsin-Madison
- Jerry Shen
  - Lehigh University
- Bill Hart
  - Sandia National Lab
Outline

- **MW Motivation**
  - MW History
  - Properties of Numerical Optimization Algorithms

- **MW Design**
  - The MW MPI Infrastructure and Programming Model

- **MW Successes**
  - The quadratic assignment problem—Solving nug30

- **MW Future**
  - Enhancements
  - New Applications
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  - The MW API
  - The MW IPI (Infrastructure Programming Interface)

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  - NSF Grant to explore solving large scale numerical optimization problems on metacomputing (Grid computing) platforms

- Question:
  - Will existing (at that time) grid toolkits allow users to easily build grid-enabled optimization solvers?

- Answer:
  - To understand the tool requirements, we must understand the characteristics of optimization algorithms.
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- Are iterative
- Generally not "pleasantly parallel"
- Use data
- Incrementally
- "Optionally" (Potentially computed instead of shared)
- Are weakly synchronous
- Can have their synchronization requirements reduced at a modest performance penalty
- Have a dynamic grain size
- The computation can "easily" be broken into pieces of variable size.
Broad Generalizations...

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Grid Toolkits. What did we want?

As numerical optimization researchers, we wanted a tool that would...

1. Be simple to use
2. Leverage a powerful platform ▶ Like a Condor-provided computational grid.
3. Be dynamic ▶ Use resources as they became available
4. Be Fault-tolerant ▶ Still compute the correct answer when machines fail
5. Be reusable for a large number of our algorithms!
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Master-Worker!

- Master assigns tasks to the workers
- Workers perform tasks, and report results back to master
- Workers do not communicate (except through the master)

- Simple!
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**MW**: A Master-Worker Grid Toolkit

- There are three abstraction in the master-worker paradigm: Master, Worker, and Task.

- **MW** is a software package that encapsulates these abstractions
  - API: C++ abstract classes
  - User writes 10 methods
  - The MWized code will transparently adapt to the dynamic and heterogeneous computing environment

- **MW** also has abstract layer to resource management and communications packages (an Infrastructure Programming Interface).
  - Condor/PVM
  - Condor/Files
  - Static/MPI
  - Single processor

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MW API

- **MW Master**
  - get_userinfo()
  - setup_initial_tasks()
  - pack_worker_init_data()
  - act_on_completed_task()

- **MW Task**
  - pack_work(), unpack_work()
  - pack_result(), unpack_result()

- **MW Worker**
  - unpack_worker_init_data()
  - execute_task()
MW API

- **MWMaster**
  - getuserinfo()
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- **MWMaster**
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  - `setup_initial_tasks()`
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- **MWTask**
  - `pack_work()`, `unpack_work()`
  - `pack_result()`, `unpack_result()`

- **MWWorker**
  - `unpack_worker_init_data()`
  - `execute_task()`
But wait there’s more!

- User-defined checkpointing of master
- (Rudimentary) Task Scheduling
  - MW assigns first task to first idle worker
  - Lists of tasks and workers can be arbitrarily ordered and reordered
  - User can set task rescheduling policies
- User-defined benchmarking
  - A (user defined) task is sent to each worker upon initialization
  - By accumulating normalized task CPU time, MW computes a performance statistic that is comparable between runs.
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Communication
- pack(), unpack(), send(), recv()
- Message buffer management routines
- Changes in machine state are passed to master as tagged messages (HOSTADD, HOSTDELETE, etc.)

Resource Management
- set_target_num_workers(int num_workers)
- get_worker_info(MWWorkerID *): MWWorkerID class has members such as architecture, operating system, machine speed, etc.
- start_worker(MWWorkerID * )
MW Applications

- **MWFATCOP** (Chen, Ferris, Linderoth) – A branch and cut code for linear integer programming
- **MWMINLP** (Goux, Leyffer, Nocedal) – A branch and bound code for nonlinear integer programming
- **MWATR** (Linderoth, Shapiro, Wright) – A trust-region-enhanced cutting plane code for linear stochastic programming and statistical verification of solution quality.
- **MWQAP** (Anstreicher, Brixius, Goux, Linderoth) – A branch and bound code for solving the quadratic assignment problem.
The Quadratic Assignment Problem

- Assign facilities to locations
- QAP is NP-Hard
  - No known algorithm is “significantly better” than complete enumeration
  - Examining $10^9$ configurations per second, for $n = 30$ would take $8,411,113,007,743,213$ years, or $\approx 420,555$ Universe Lifetimes.
How Patient are You?

- If 8,411,113,007,743,213 years is a bit long to wait, you might try Branch and Bound.
  - Feasible solution ⇒ upper bound
  - Relaxed problem ⇒ lower bound

A detailed algorithmic description of branch and bound

1. Is solution to relaxed problem feasible?
   - Yes? YAHOO!
   - No? Break problem into smaller pieces. Goto 1

- Conceptually, the there is a search tree than must be explored
- Different nodes are different independent searches
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The Devil In The Details

- Fitting the B & B algorithm into the master-worker paradigm is not groundbreaking research
- We must avoid contention at the master
- Reduce arrival rate: Have machines work on a task for a sufficiently long time (Dynamic Grain Size)
- Increase service rate: Do not have workers pass back many nodes. Keep master’s list of tasks small.
- Balancing efficiency considerations with search considerations was very important!
- We contend that with appropriate tuning, many algorithms can be shoehorned into the master-worker paradigm!
- MW can be a grid computing workhorse!
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nug30 (a QAP instance of size 30) had been the “holy grail” of computational QAP research for $> 30$ years.

In 2000, we set out to solve this problem.

Using a mathematically sophisticated and well-engineered algorithm, we still estimated that we would require 11 CPU years to solve the problem.
The nug30 Computational Grid

<table>
<thead>
<tr>
<th>Number</th>
<th>Type</th>
<th>Location</th>
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<tbody>
<tr>
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<tr>
<td>Avg. # Machines:</td>
<td>653</td>
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<td>CPU Time:</td>
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<td>Nodes:</td>
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Workers
Rollout

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  - Web: [http://www.cs.wisc.edu/condor/mw](http://www.cs.wisc.edu/condor/mw)
  - Mailing List: email majordomo@cs.wisc.edu with email body: subscribe mw

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  - Improve robustness, documentation, and ease of use
  - Broaden and strengthen user base
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- Protein structure comparison (Sandia)
- Molecular Docking (UCSD/UW-Madison)
- Statistics: multiclass support vector machines (UW-Madison)
- Optimization: Multistage stochastic linear programming, nonconvex quadratic programming, mixed integer linear programming (Lehigh)
- Metaheuristics for combinatorial optimization (Polytech’Lille, France)

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MWEnhancements

▶ “Data Streaming”
  ▶ Some master-worker type algorithms would benefit greatly from being able to keep a (low-bandwidth) data channel open between master and worker during execution of a task
  ▶ Will be used in advanced distributed numerical optimization algorithms

▶ We want the enhancements to MW to be driven by its community of users!
  ▶ Improved or dynamic load balancing?
  ▶ Better interfaces (A Gui to steer/monitor?)
  ▶ More RMComm implementations?
  ▶ Other ideas???
MWEnhancements

▶ “Data Streaming”
  ▶ Some master-worker type algorithms would benefit greatly from being able to keep a (low-bandwidth) data channel open between master and worker during execution of a task
  ▶ Will be used in advanced distributed numerical optimization algorithms

▶ We want the enhancements to MW to be driven by its community of users!
  ▶ Improved or dynamic load balancing?
  ▶ Better interfaces (A Gui to steer/monitor?)
  ▶ More RMComm implementations?
  ▶ Other ideas???
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Maybe yours too!

The master-worker paradigm is nicely suited to a Grid implementation

We really believe that master-worker is the “right” paradigm for distributed computing on the Grid

MW can make implementing master-worker algorithms for the Grid easier
Conclusions

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We want **YOU** to join the **MW** community of users

http://www.cs.wisc.edu/condor/mw
http://www.mcs.anl.gov/metaneos/nug30