MW : Master-Worker Middleware for Grids

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MWMotivation
MWDesign
MWSuccesses

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 API
  - The MW IPI (Infrastructure Programming Interface)
- **MW Successes**
  - The quadratic assignment problem—Solving nug30.
Motivation

1998, metaNEOS—Metacomputing Environments for Optimization.
- 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.
Optimization algorithms...

- 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.
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!
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!
- Dynamic/Fault-tolerant
- Reusable(!?)

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MW: Master-Worker Middleware for Grids
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
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()
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.
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!

- Conceptually, the there is a search tree than must be explored
- Different nodes are different independent searches
- Grid computing to the rescue!
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!
nug30 (a QAP instance of size 30) had been the “holy grail” of computational QAP research for \( \geq 30 \) 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>
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<tr>
<th>Number</th>
<th>Type</th>
<th>Location</th>
<th>How</th>
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<td>Glide-in (Condor-G)</td>
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</table>
NUG30 is solved!

14, 5, 28, 24, 1, 3, 16, 15, 10, 9, 21, 2, 4, 29, 25, 22, 13, 26, 17, 30, 6, 20, 19, 8, 18, 7, 27, 12, 11, 23

Wall Clock Time: 6:22:04:31
Avg. # Machines: 653
CPU Time: ≈ 11 years
Nodes: 11,892,208,412
LAPs: 574,254,156,532
Parallel Efficiency: 92%
KLAPS

Time

KLAPS

The master-worker paradigm can be effectively used to distribute many parallel scientific applications

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

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