Overview of the PEBBL and PICO Projects: Massively Parallel Branch and Bound

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(New) Distinction between PEBBL and PICO

Specific applications

PICO -- Parallel Integer and Combinatorial Optimization
Specific to mixed integer programming

PEBBL -- Parallel Enumeration and Branch and Bound Library
Generic parallel branch and bound

Until summer 2006, PEBBL was part of PICO

- PEBBL was called the “PICO core”
- What is now PICO was called the “PICO MIP”
PEBBL and PICO are part of ACRO

* A Common Repository for Optimizers

http://software.sandia.gov/acro

- Collection of open-source software arising from work at Sandia National Laboratories
- Generally lesser GNU public license
PEBBL/PICO Applications

Direct use of PEBBL
• Peptide-protein docking (quadratic semi-assignment)

GNLP (includes PEBBL)
• PDE Mesh design
• Electronic package design

PICO (includes PEBBL)
• JSF inventory logistics
• Peptide-protein docking
• Transportation logistics
• Production planning
• Sensor placement
• ...
PEBBL/PICO Package Relationships

PEBBL

UTILIB

PICO

COIN

CGL

OSI

CLP

GLPK

Soplex

CPLEX

Revised: July 18, 2006 10:10
For remainder of talk, focus on PEBBL

PEBBL is a parallel “branch and bound shell”

Key features

- Object oriented design with serial and parallel layers
- Application interface via manipulation of problem states
- Variable search “protocols” as well as search orders
- Flexible, scalable parallel work distribution using processor clusters
- Non-preemptive thread scheduling on each processor
- Checkpointing
- (Enumeration support)
- Alternate parallelism support during ramp-up phase
Basic C++ Class Structure: Serial and Parallel Layers

- Tell PEBBL how to pack/unpack problem data
- Optionally custom-parallelize
  - Dynamic global data
  - Ramp-up phase

Diagram:
- Parallel Application
- PEBBL Parallel Layer
- Application
- PEBBL Serial Layer
PEBBL Structure: Serial and Parallel Layers

Application Development Sequence

Describe application to PEBBL

Debug in serial environment

Tell PEBBL how to pack and unpack problem/subproblem messages

Run in parallel environment without additional programming effort

(optional)

Enhance default parallelization: global information, ramp-up, etc.
PEBBL Serial Layer Design

- Class derived from `branching` holds data global to problem.
- Class derived from `branchSub` holds subproblem data and pointer back to global data (as in ABACUS).

Key point: problems in the pool remember their state.

Current Subproblem

Implemented so far:
- eager, lazy, "hybrid"
- heap, heap+dive, stack, FIFO-queue
PEBBL interacts with the application solely through virtual functions that cause state transitions ( / / / )
Search Handler: Lazy

Extract SP from pool

Try to bound

Try to Separate

Extract child

Insert child into pool

Pool consists of boundable subproblems
Search Handler: Eager

Extract SP from pool

Try to Separate

Extract child

Try to bound child

Insert child into pool

Pool consists of **bounded** subproblems
**Search Handler: “Hybrid”/General**

Pool can contain problems in any mix of states.

- **Look at SP from pool**
  - **Extract child**
  - **Insert child into pool**
  - **Delete SP from pool**

- **Try to advance one state**
- **Any other state**

- **separated**
  - **No more children**
Generality of Approach

Naturally accommodates an wide range of branch-and-bound algorithm variations

Most known variations are possible by combining

• Three existing handlers
• Stack and heap pools
• Proper implementation of virtual functions for application

Also:

• Other pool implementations are possible
• Other handlers possible
Parallel Layer: User-Adjustable Clustering Strategy

- Processors are collected into *clusters*
- One processor in the cluster is a *hub* (central controller for cluster)
- Other processors are *workers* (process subproblems)
- Optionally, a hub can be a worker too (depends on cluster size)
Extreme Case: Central Control

Worker
Processor 2

Worker
Processor 3

Worker
Processor 4

Worker
Processor 9

Worker
Processor 8

Worker
Processor 1

Worker
Processor 7

Worker
Processor 6
Extreme Case: Fully Decentralized Control
Work Transmission: Within a Cluster

Hub processes deal with *tokens* only. A token =

- # of creating processor
- Pointer to creating processor’s memory
- Serial number
- Bound
- (Any other information needed in work scheduling decisions)

Prevents irrelevant information from

- Overloading memory at hubs
- Wasting communication bandwidth in and out of hubs

Remaining subproblem information sent directly between workers when necessary
Within a Cluster: Adjustable Behavior

Worker has its own local pool (buffer) of subproblems

Chance of returning a processed subproblem (or child) into the worker pool:

• 0% ⇒ pure master-slave, hub makes all decision (fine for tightly-coupled hardware and time-consuming bounds).
• 100% ⇒ hub “monitors” workers but doesn’t make low-level decisions (better for workstation farms).
• Continuum of choices in between...

Backup “rebalancing” mechanism to make sure that hub controls enough subproblems

• Otherwise hub might be “powerless” in some situations
• Rebalancing uncommon for standard parameter settings
Work Transmission: Between Clusters

Load balancing between clusters via

- Random scattering upon subproblem creation, supplemented by...

Rendezvous load balancing:

- Non-hierarchical: there is no “hub-of-hubs” or “master-of-masters”
- Hubs are organized into a tree

- Periodic message sweeps up and down tree summarize overall load balance situation
- Efficient method for matching underloaded and overloaded clusters, followed by pairwise work exchange
- *Not* “work stealing” (receiver initiated)
- *Not* “work sharing” (sender initiated)
Non-Preemptive Threads on Each Processor

Each processor must do a certain amount of multi-tasking

Schedule multiple *threads* of control within each processor

- Each task gets a thread.
- Threads can share memory.
- We use a *scheduler* to allocate CPU time to threads.

Scheduler uses non-preemptive multitasking approach (*à la* old Macs, Win 3.x):
### Base Scheduler Setup

#### Message-Triggered Group
- **Typically waiting for messages**
- Incumbent value broadcast
- SP server
- SP receiver
- Hub
- Load balancing/termination detect
- Worker auxiliary

#### Base Computation Group
- Worker
- Incumbent search heuristic (optional)

### Description

- **Upper group:** each thread waits for a specific kind of message
  - Wakes up; processes message; posts another receive request; sleeps again

- **Base group:** usually ready to run
  - *Worker* does work usually handled by serial layer
  - Continuously adjusts amount of work at each invocation to try to match a target *time slice*
  - CPU time allocated in specifiable proportion via *stride scheduling*
Incumbent Search Thread

Implements application-specific search heuristic; could be:
- Tabu
- GA
- etc...

Can send messages to other processors
- *e.g.* a parallel GA

Has small quantum for easy interruption

Soaks up cycles when worker thread is blocked or waiting

Can adjust priority as run proceeds
- High early on
- Lower later when we’re probably just proving (near) optimality of current incumbent

Framework allows smooth blending of parallel search heuristics with branch-and-bound.
Termination

General issue with asynchronous message-passing programs.

Make sure:

- All the work is really gone
- There are no stray unreceived messages floating around

PICO uses the “four counters” method of Mattern et al

Handled by load balancing thread
Checkpointing (Relatively New)

- Systems crash
- Jobs exceed time quotas, ...

Don’t want to lose all your work when that happens!
- Periodically save state of computation
- Later, you can restart from the saved state

Implementation in PEBBL:
- Load balancer message sweep signals it’s time to checkpoint
- Workers and hubs turn “quiet”: don’t start new communication
- Use standard termination check logic to sense when all messages have arrived
- Each processor writes a (possibly local) checkpoint file

Restart options
- Normal: each processor reads its own file (possibly in parallel)
- Read serially, redistribute -- allows different number of processors
Ramp-Up: Starting the Search

There may be multiple sources of parallelism in any branch and bound application (not just MIP):

• Parallelism from large search tree (generic)
• Parallelism within each subproblem (application-specific)

Early in the search

• Tree is small
• Within-subproblem parallelism may be especially large
• So, there may be more parallelism available within subproblems than from the tree
• You also might not want to exploit tree parallelism too aggressively (likely to work on “non-critical” nodes)

Eventually, tree parallelism will probably dominate (and be safe)
• **Ramp-Up**: all processors redundantly develop top of tree, synchronously parallelizing some of each subproblem’s work
• Virtual function decides when tree parallelism is likely to be better
• **Crossover**: partition tree evenly (no communication!)
• Then start usual *asynchronous search* (different processors look at different leaves of the tree)
• PICO uses this feature: parallelizes strong-branching-like pseudocost initialization until tree offers more parallelism
PEBBL and PICO Availability

ACRO 1.0 available first week of August, 2006

http://software.sandia.gov/acro

Lesser GNU public license

Includes PEBBL 1.0 release:

- Should be stable
- Contains 57-page user guide (will probably grow soon)
- Also, feel free to contact us if interested

PICO -- areas that need more work:

- Cut finders (improve/replace current CGL finders)
- Cut management
- Incumbent heuristic (fairly extensive work done, but more needed)