Load Balanced Parallel Simulated Annealing on a Cluster of SMP Nodes

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OUTLINE

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2. Hybrid communication method (HC) – nesting OpenMP in MPI
   - The reference method
   - The method with a single data exchange
4. Outer level load balancing
5. Inner level load balancing
6. Vehicle routing problem with time windows (VRPTW) – an example of a bi-criterion optimization problem
7. Experimental results
THE GOAL AND ALGORITHM OF SIMULATED ANNEALING

Finding the state of minimal (maximal) value of the cost function

- **End conditions met?**
  - Yes: Select a new solution from neighborhood
  - No: Take a random number

- **Is the new solution better?**
  - Yes: Accept current solution
  - No: End

- **Is the number < ceiling?**
  - Yes: Ceiling moves down in line with decreasing parameter called temperature
  - No: Ceiling moves up

The sequence of trials forms a chain

- **accepted**
- **not accepted**

- **Trials**
- **independent**
- **dependent**

- **Trials**

Really descending

- Ceiling moves down in line with decreasing parameter called temperature

- Sometimes climbing back on the crater edge to get a chance to find a deeper one

- The factor “sometimes” is reduced over the execution time

E.g., to go into the deepest crater on the moon
THE HYBRID COMMUNICATION METHOD – Nesting OpenMP in MPI

Hybrid character of the hardware

Parallelization uses two levels

INNER PARALLELIZATION
- Only up to a few threads are used
- Communication overhead is minimal relative to that between nodes
- Uses OpenMP

OUTER PARALLELIZATION
- Several SMP nodes
- Communication overhead is not negligible
- Uses MPI

SMP nodes
CPUs
Node interconnect
shared memory
THE REFERENCE HYBRID COMMUNICATION METHOD

Outer parallelization for communication between nodes

Each chain is divided into sub-chains by the factor of the number of nodes.

The process of generating every consecutive chain is performed without communication between nodes.

At the end, the best solution is picked up as the final one.

The maximal number of engaged nodes is limited by reasonable shortening of the chain length.

Node interconnect

chain 1

chain 2

chain 3

chain n

A final solution
THE REFERENCE HYBRID COMMUNICATION METHOD

Inner parallelization for communication within nodes

Performing CPU-intensive trials in a parallel region

Select one solution common for all threads from all accepted ones

Fast comparison of the cost-function in a serial OpenMP master section

```c
for(l=0;l<NoOfTempRed;l++)
{
    #pragma omp parallel private(ii)
    {
        for(ii=0;ii<EpochLengthPerNode; ii=ii+SetOfTrialSize)
        {
            #pragma omp for schedule(static)
            for(i=0;i<SetOfTrialSize;i++)
                perform_trial();
            #pragma omp barrier
            #pragma omp master
            {
                select one solution common for all threads ...
            }
            #pragma omp barrier
    } /*end for (ii=0;...) */
} /*end of parallel region*/
{reduce the temperature ...
} /*end for(l=0;...)*/```
THE METHOD WITH A SINGLE DATA EXCHANGE

The idea
Incorporating one data exchange after elapsing a percent of the specified time limit (e.g. 50%, 70%)
During the exchange of the data the best solution is selected and mandated for all processes

The idea gives the possibility of:
• Heavy exploration of the search space during the first phase, i.e., a few (but only a few) paths can reach the area of the global minimum.
• Improvement of the best path during the second phase by all working processes (instead of only a few)

Many small groups of astronauts are looking independently for the deepest crater and hopefully, at least one group (=SMP node) is finding it

A short time before returning to earth, all groups are concentrated to the deepest crater found up to now. The last minutes, they all try to find the deepest location in that crater!
OUTER LEVEL LOAD BALANCING

The times for generating 8 sub-chains based on an example run

Optimization:

- Stopping and communicating after a fixed amount of time
- Stopping and communicating after a fixed number of temperature levels
INNER LEVEL LOAD BALANCING

The First Optimization Step

- Each single trial needs extremely different compute time
- Therefore with always 5 trials per thread:
- Better load balancing
INNER LEVEL LOAD BALANCING

The First Optimization Step

Before the optimization:
1 trial per a thread

- The average fastest trial
- 112% of the average

After the optimization:
5 trials per a thread

- The average value
- 51% of the average

*) Execution time for 4x5 trials on 4 threads
INNER LEVEL LOAD BALANCING

The Second Optimization Step

- Redefinition of a trial:
  - Finding a new valid solution \( S' \) in the neighborhood of \( S \)
    - the most time consuming function
  - Allowing a trial to abort this loop without result
    - causes better load balancing
  - Average trial time
    - more dominated by minimal trial size
  - Absolute maximal trial time
    - significantly reduced
INNER LEVEL LOAD BALANCING
The Second Optimization Step

Clustered trials

Separate trials

Before the redefinition
After the redefinition

112% of the average
66% of the average
51% of the average
29% of the average

*) Execution time for 4x5 trials on 4 threads
INNER LEVEL LOAD BALANCING – The Third Optimization Step

The easiest solution:

for(l=0; l<NoOfTempRed; l++)
{
    for(ii=0; ii<EpochLengthPerNode; ii=ii+SetOfTrialSize)
    {
        for(i=0; i<SetOfTrialSize; i++)
        {
            perform_trial();
        }
    } /*end for (ii=0;...) */
} /*end for (l=0;...) */

{select one solution common for all threads ... }

/*end for (ii=0;...)) */
{reduce the temperature ... }
} /*end for (l=0;...) */

~40 000

The optimized solution:

for(l=0; l<NoOfTempRed; l++)
{
    #pragma omp parallel private(ii)
    {
        for(ii=0; ii<EpochLengthPerNode; ii=ii+SetOfTrialSize)
        {
            #pragma omp for schedule(static)
            for(i=0; i<SetOfTrialSize; i++)
            {
                perform_trial();
            }
        } /*end for (ii=0;...) */
    } /*end of parallel region*/

{select one solution common for all threads ... }

/*end for (ii=0;...)) */
{reduce the temperature ... }
} /*end for (l=0;...) */

30-40ms *

~20

Third optimization: Reducing the fork-join overhead

0.16ms *

*System: NEC TX7 16x1.5Ghz Intel ItaniumII CPUs, 6MB L3 Cache
VEHICLE ROUTING PROBLEM WITH TIME WINDOWS

Goal
- Minimizing number of route legs
- Minimizing of the total travel distance

Constraints
- Customer and warehouse time windows
- Vehicle capacity
- Duration of servicing a single customer
- Customer’s demand

- Customer
- Warehouse
EXPERIMENTAL RESULTS* – THE FIRST OPTIMIZATION GOAL**

The number of final solutions with the minimal number of route legs (i.e., “good” solutions), generated within 100 runs

Presented values are the averages over the values obtained for 4 data files from Solomon’s benchmark set: R108, R111, RC105, RC108.

Constraints: Execution time \times \text{number of CPUs} = \text{constant}

* \text{Experiments carried out on NEC Xeon EM64T Cluster}

** \text{The previous work}

*** \text{Emulated usage of 4 OMP threads, based on results of tests of OMP parallelization carried out on NEC TX-7 system}
EXPERIMENTAL RESULTS – THE SECOND OPTIMIZATION GOAL

The relative distance from the value obtained by a sequential algorithm

Presented values are the averages over the values obtained for 4 data files from Solomon’s benchmark set: R108, R111, RC105, RC108.

Constraints: Execution time \times \text{number of CPUs} = \text{constant}
EXPERIMENTAL RESULTS – THE SECOND OPTIMIZATION GOAL

- seq
- HC4
- HC4-0.9
- HC4-0.7
- HC4-0.5

number of processors vs total distance for different optimization goals.
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