Using virtual processors for SPMD parallel programs

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December 2003

Abstract

In this paper I describe some results on the use of virtual processors technology for parallelize some SPMD computational programs. The tested technology is the INTEL Hyper Threading on real processors, and the programs are MATLAB scripts for floating points computation. The conclusions of the work concern on the utility and limits of the used approach. The main result is that using virtual processors is a good technique for improving parallel programs not only for memory-based computations, but in the case of massive disk-storage operations too.

1 Introduction

The processors virtualization technology permits to split a real physical processor into two virtual chips, so that the operating system, as MS Windows or Linux, of a computer can use the virtual processors as two real chips. Example of such technology is Intel's Hyper Threading [1]. The hardware can so be considered as a symmetric multi-processor machine and the software can use it as a true parallel environment.
In this work I show some results obtained with parallel computations using Matlab [2] programs on Intel technology. The physical and logical characteristics of the used machine are presented in the following tables:

| Hardware            |                  |
|---------------------|------------------|
| Type                | HP Compaq ProLiant DL380 |
| Processors          | 2 Intel Xeon 2.40 GHz |
| Ram                 | 1.5 GB            |
| Storage             | 6 SCSI disks 36.5 GB - Raid 5 |

| Software            |                  |
|---------------------|------------------|
| Operating System    | MS Windows Server 2000 |
| Matlab              | v. 5.3           |

The Matlab programs used for these experiments was based on cycles of floating-point computations.

2 The parallel Matlab environment

The package Matlab has not a native support for parallel elaboration and multithreading [3]. Yet, there are some extensions, as tools and libraries [4], for the use of a parallel environment on multi-processors hardware. With the biprocessor machine I have preferred the method of splitting a given computation on multiple instances of the runtime Matlab program. A single master instance starts the slave copies and assigns to each of them the same set of instructions on different sets of data. Hence I have simulated a SPMD computation on the machine.

In this way the parallel environment is simple, because there is not need of external libraries or calls to interfaces, and flexible, because to a single slave copy it can be assigned a set of different instructions for realizing a MPMD computation.

With this method the exchange of messages among independent processes is a problem. The only way to communicate from one Matlab copy to another is the use of shared files. In a second type of experiments I show that this method is not critical for the time execution if one uses fast mass-storage as SCSI or FiberChannel systems.
2.1 The SPMD programs

In the experiments I have defined a master Matlab function which writes to a shared file system the .m scripts to be executed by slaves Matlab copies. These copies are launched in background mode for the parallel execution. The master program controls the end of the computations using a simple set of lock-files. The slaves finish their work, save on files the results and cancel the own lock-file. The master reads the sets of data from these files for other possible computations. Now I describe the principal code of the program.

This is the declaration of the function masterf. The lockarray variable is an array for testing the presence of the lock-files during the slaves computation. The finalres is an array for the collection of the partial results from slaves. The string computing is the mathematical expression to use in the computation.

```matlab
function [elapsedtime,totaltime,executiontime]=masterf(nproc,maxvalue,step,computing)

% MASTERF: master function for parallel background computation.
% % sintax:
% [elapsedtime,totaltime,executiontime]=masterf(nproc,maxvalue,step,computing)
% % input parameters:
% % nproc = number of processes;
% % maxvalue = sup-limitation of the data-array to process; the inf-limitation is 0;
% % step = difference from two consecutive numbers in the data-array;
% % computing = the string of the mathematical expression to compute;
% % output parameters:
% %
% % elapsedtime = total elapsed time to complete the execution of the computation;
% % totaltime = sum of the single slaves CPU-time to complete the single computation;
% % executiontime = single slaves CPU-time to complete the assigned computation;

ostype=computer;
tottime=0.;
lockarray=0:nproc-1;
numbervalues=maxvalue;
computingstring=[' ' computing];
finalres=[];

for i=0:nproc-1
    filelock = strcat(workdir,'filelock',int2str(i));
    fid=fopen(filelock,'wr');
end
```

After the assignment of the own value to variable workdir, working directory of Matlab, a cycle writes on storage the slaves lock-files.
fwrite(fid,’’);
fclose(fid);
end

In the next fragment of program, the master sets the commands for the writing of an appropriate Matlab .m script for every slave process. Such script contains the instruction for determining the CPU-time spent on calculus, the expression of the mathematical computation, the instruction to save on storage the data computed and the CPU-time, finally the instruction to delete the lock-file.

for i=0:nproc-1
    if (i==0) middlestep=0; else middlestep=1; end
    infdata=i*(numbervalues/nproc) + middlestep*step;
    supdata=(i+1)*(numbervalues/nproc);
    fileworker = strcat(workdir,'fileworker',int2str(i),'.m');
    commandworkertmp = ...
        strcat('x=',num2str(infdata),':',num2str(step),':',num2str(supdata),...
            '; t1=cputime; ',computingstring,...
            '; t2=cputime-t1; save out',int2str(i));
    commandworker = ['cd ' workdir '; ' commandworkertmp ...
            '; y t2; ' 'delete filelock'int2str(i) '; exit;'];
    fid = fopen(fileworker,'wt');
    fwrite(fid,commandworker);
    fclose(fid);
end

After the instructions for determining the CPU-time and the elapsed-time (tic) spent by the master program, a cycle launches the slaves Matlab runtimes. In the case of Windows operating system, the startcommand string is ”start”, an OS command for the background running of an executable program, and the osstring string is ”dos”. In the case of Unix-like operating system, the string are ”sh” and ”unix” respectively. Each slave executes immediately the fileworker script, as shown by the Matlab ”-r” parameter.

t1 = cputime;
tic;
for i=0:nproc-1
    fileworker = strcat('fileworker',int2str(i));
    commandrun = [startcommand ' matlab -minimize -r ' fileworker];
    eval(strcat([osstring,'(';',','commandrun',',',');']));
end

In the next fragment of code the master program executes a cycle for determining the end of slaves computations. It controls if the lockarray variable has some process’s rank non negative. In this case, it attempts to open the relative lock-file; if the file still exists, the master closes it, else the lockarray process position is set to -1. The pause instruction can be useful for avoiding
an excessive frequency, hence an high cpu-time consuming, in the "while" cycle.

lockarraytmp = find(lockarray > -1);
while (length(lockarraytmp) > 0)
    pause(.1);
    for i = lockarraytmp
        fid = fopen(strcat('filelock',int2str(i-1)),'r');
        if (fid < 0)
            lockarray(i) = -1;
        else
            fclose(fid);
        end
    end
    lockarraytmp = find(lockarray > -1);
end

At the end, the master reads the partial slaves computation outputs and stores them in an array. At this point the master cpu-time and elapsed time are registered too. The total execution time is defined as sum of the slaves computation cpu-time, and is useful for comparison with the execution time in the case $nproc = 1$. The single slave execution time is defined as the arithmetic mean of all the partial execution times.

for i = 0:nproc-1
    partialres = load(strcat('out',int2str(i)));
    finalres = [finalres partialres];
end

eelapsedtime = toc;
totaltime = cputime - t1;

for i = 0:nproc-1
    fps = load(strcat('out',int2str(i)));
    tottime = tottime + fps.t2;
    executiontime = tottime/nproc;
end

3 Tests and results

For the tests I have used the following values for the masterf parameters:

$nproc$: from 1 to 8;
$maxvalue$: $m \times 10000$, where $m = 1, 2, 3$;
$step$: 0.001;
$computing$: $y = 5432.060708 \times \cos((\sin(x^{9.876}))^{−1.2345})$. 

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I have also tested the program without the slaves saving of partial computations results and their final master load, for determining the influence of the I/O storage operations on the times of execution.

The following are the results obtained with four tests for every type of experiment. The values are arithmetic means approximated to two decimals and they are expressed in seconds; the numbers from 1 to 8 are the value of nproc, while ”m” is the factor parameter in the maxvalue expression.
I have not reported the elapsed-times, because they weren’t different from the cpu-times registered, probably due to the fact that, during the experiments, the server was dedicated only to the computations.

Tables of results.
All the values are expressed in seconds.

1.a Medium execution cpu-times for process, no data storage:

| m | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   |
|---|-----|-----|-----|-----|-----|-----|-----|-----|
| 1 | 39.32 | 20.89 | 14.60 | 11.49 | 11.86 | 8.73 | 9.15 | 7.29 |
| 2 | 77.56 | 40.83 | 29.20 | 23.41 | 22.31 | 23.19 | 17.93 | 19.02 |
| 3 | 137.75 | 69.70 | 51.67 | 35.28 | 34.91 | 36.98 | 32.46 | 34.86 |

2.a Total execution cpu-times, no data storage:

| m | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   |
|---|-----|-----|-----|-----|-----|-----|-----|-----|
| 1 | 41.01 | 22.11 | 16.19 | 13.67 | 18.42 | 17.10 | 18.17 | 16.20 |
| 2 | 78.40 | 41.89 | 30.74 | 24.81 | 26.78 | 34.69 | 33.68 | 32.95 |
| 3 | 139.05 | 75.66 | 59.38 | 38.83 | 40.28 | 49.69 | 48.98 | 48.27 |

1.b Medium execution cpu-times for process, with data storage:

| m | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   |
|---|-----|-----|-----|-----|-----|-----|-----|-----|
| 1 | 42.78 | 20.59 | 15.99 | 14.61 | 11.05 | 8.89 | 11.56 | 10.94 |
| 2 | 99.93 | 52.66 | 38.59 | 25.22 | 20.71 | 18.60 | 18.55 | 18.70 |
| 3 | 151.03 | 80.49 | 57.33 | 39.65 | 28.83 | 36.03 | 44.16 | 44.76 |
Total execution cpu-times, with data storage:

| m  | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   |
|----|-----|-----|-----|-----|-----|-----|-----|-----|
| 1  | 49.55 | 28.70 | 26.69 | 27.26 | 17.98 | 18.92 | 17.78 | 17.76 |
| 2  | 131.66 | 68.50 | 54.33 | 40.53 | 38.00 | 38.37 | 36.76 | 40.69 |
| 3  | 201.65 | 102.90 | 75.03 | 58.94 | 60.97 | 66.52 | 67.92 | 67.83 |

Analysis of results

From the results of the previous section, I deduce the following observations:

1. In table 1.a the gain in execution speed is good from 1 to 4 processes, while from 5 to 8, and in particular in the case m=3, the gain is low; this fact can be due to the excess load on the dual-processor machine when \( nproc > 4 \);

2. In the same table the speedup [5] is quasi-linear from 1 to 4, hence the algorithm and the parallel environment used are an optimized SPMD implementation if one is interested only on pure computation time;

3. In table 2.a the value \( nproc = 4 \) gives the best performance as total execution time; hence, if one is interested on the time spent by the master to verify when the slaves finish their job, the four virtual processors guaranteed by Hyper Threading technology show the best efficiency in the case of four running processes;

4. With exclusion of the case \( nproc = 1 \), when the master must verify only a single process, in the case m=3 the difference between the times rows of 2.a and 1.a is smallest in the case \( nproc = 4 \); hence in this case too the total time registered by the master is optimized respect to the slaves execution time;

5. In the case of data storage, the preceding conclusions are not so clear, probably due to the fact that the reading-writing of small files is in general optimized by the RAID 5 technology on a multi-disks system; this fact seems to be confirmed by the great difference, 50 seconds, from the times registered in the case m=3 and \( nproc = 1 \) in tables .b;
6. In table 2.b one can note that for \( m=3 \) the best result is in the case \( nproc=4 \);

7. In tables .b, in the case \( m=3 \) the difference between the times rows is smallest in the case \( nproc=4 \) too;

8. From tables 2.b, one can note that for \( m=1 \) the best speedup (8 processes) respect to the case \( nproc=1 \) is 2.78, while for \( m=3 \) the best (4 processes) is 3.42; hence the virtual processors seem to have a better performance with a large amount of data to compute, probably due to the fact that in this case the parallel computations have a greater relevance respect to the physical operations on storage system.

### 4.1 Conclusions

From the previous facts one can deduce that a virtual processors technology as Hyper Threading can be a good choice for running SPMD programs in the case that

- the number of parallel processes is equal to the number of virtual processors;
- the data to be computed have a large amount, particularly when their distribution among processes and the merging of final results are based on files stored on fast storage system.

### 5 Acknowledgements

I wish to thank Ernesto Montagnoli, Mario Bubola and Filippo Rossetti, chief and members of Infrastructures and Systems Area at ICT Department, Riello Group, for the permission to execute this work on the ProLiant server and for technical assistance.

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This is a short but clear paper by Cleve Moler, co-founder of Mathworks,
where the author discusses why there isn’t a parallel version of Matlab;
the article has date 1995, but in its essential philosophy is still valid.

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A Web page for a list of parallel extensions, as libraries and tools, to
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[5] Peter Pacheco, Parallel programming with MPI, Morgan Kaufmann, 1997
One of the best book for an introduction to parallel programming and its
technical aspects; it focuses on the Message Passing Interface.