A Parallel Programming Course Based on an Execution Time-Energy Consumption Optimization Problem

Javier Cuenca
Department of Technology and Engineering of Computers, University of Murcia, Spain
Domingo Giménez
Department of Computing and Systems, University of Murcia, Spain

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Outline

1. Organization of the course
2. The optimization problem
3. Algorithmic techniques
4. Evaluating Teaching

Course description

Methodology of Parallel Programming

- Fourth year of Computer Science Degree, first semester.
- In the previous semester a course on Parallel Architectures.
- In the second year a course on Principles of Concurrent and Distributed Programming.
- Compulsory for specialization in Software Engineering, optional for specialization in Computer Engineering.
- Medium size class, around 35 students.
- Practical, Problem-based learning approach.

Syllabus

- Review of parallel architectures
- Parallel programming paradigms
- Parallel programming tools: OpenMP and MPI
- Analysis of parallel algorithms
- Methodology of parallel programming
- Parallel algorithmic schemes

Topics of the TCPP Curriculum - Architecture, Cross Cutting

- Review of parallel architectures

ARCHITECTURE		
Architecture classes	K	
Streams (e.g. GPU)		K
MIMD	K	
Multithreading	K	
Multicore	K	
Heterogeneous		K
Shared vs. distributed memory	C	
SMP	K	
NUMA	K	
Message Passing		C
Cache organization	K	
Impact memory hierarchy on software		C
Performance Metrics	K	
CROSS CUTTING		
Why and what is PDC	K	
Power		K
Cluster, Cloud, Grid	K	

Topics of the TCPP Curriculum - Programming

Programming		Methodology	
Parallel Programming Paradigms	C	Client server	K
Shared memory	C	Producer-consumer	C
Distributed memory	C	Scheduling and computation	C
Hybrid	K	Decomposition strategies	C
Task/thread spawning	C	Scheduling and mapping	K
SPMD	C	Data Distribution	K
Data Parallel	C		
Parallel loop	C		
Task and Threads	C		
Synchronization	C		
Critical regions	C		
Deadlocks	C		
Memory models	K		
Tools		**Algorithms**	
Language extensions	C	Performance monitoring	K
Compiler Directives pragmas	C	Performance metrics	C
Libraries	C	Speed-up	C
SPMD Notations	C	Efficiency	C
MPI	C	Amdahl's law	K
CUDA/OpenCL	K	Isoefficiency	C

Topics of the TCPP Curriculum - Algorithms

Analysis	
Asymptotics cost	C
Time	C
Space	C
Speedup	C
Cost	C
Methodology	
Termination detection	C
Dependencies	C
Broadcast	C
Asynchrony	C
Synchronization	C
Schemes	
Divide and Conquer	C
Algorithmic Problems	C
Matrix computations	K
Sorting	C
Graph search	C
Specialized computations	C

Course planning

The course is problem-guided.
A bi-objective time execution-energy consumption problem is proposed at the beginning of the course.
Work to be done by the students:

- Presentation on parallelism techniques or tools not in the course syllabus.
- OpenMP and MPI practicals with basic problems.

  Tools from the Spanish Parallel Programming Contest (`luna.inf.um.es`).

  The system evaluates the solutions automatically and in real time.

  Individual tutorials.
- Each student selects a technique to solve the problem. Presentation of the sequential technique selected and parallel algorithmic approaches for the proposed problem.
- Development of parallel versions (shared memory, message-passing and hybrid) and theoretical and experimental analysis.

A master-slave scheme

IN PARALLEL in each process P_i ($i = 0, \ldots, p-1$) DO
if $i = 0$ **then**
  for $j = 1$ TO $j = p - 1$ **do**
    Send task to P_j
  end for
  for $j = 1$ TO $j = p - 1$ **do**
    Receive solution from P_j
  end for
else
  Receive task from P_0
  Solve task
  Send solution to P_0
end if
END PARALLEL

Computational system

- p processors
- connected through an interconnection network.
- Heterogeneous in:
  - communication
  - computation
  - energy consumption

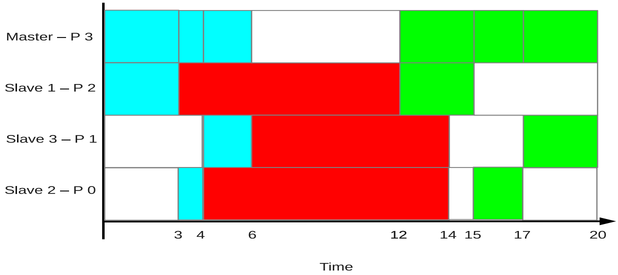
the costs vary depending on
$\Rightarrow$ the parts of the algorithm and the processor where they are carried out or the source and target processors involved in a communication
$\Rightarrow$ where the master and slave processes are assigned

processes-to-processors mapping problem

Parameters of the system

- Execution times:
  - $TimeComunT$, $p \times p$: costs of communications between two processors when sending-receiving a task.
  - $TimeComunS$, $p \times p$: costs of communications between two processors when sending-receiving a solution.
  - $TimeComputT$, of size p: cost of solving a task by a process in a processor.
- Energy consumption:
  - $EnerComunT$, of size p: on a processor working on the communication of a task.
  - $EnerComunS$, of size p: on a processor working on the communication of the solution.
  - $EnerComputT$, of size p: on a processor when working on the solution of a task.
  - $EnerInac$, of size p: when the processor is idle.

Example



TimeComunT

Source/Target	0	1	2	3
0	1	1	2	2
1	2	1	3	2
2	2	3	2	2
3	1	2	3	2

TimeComunS

Target/Source	0	1	2	3
0	1	2	1	2
1	1	2	2	2
2	2	2	3	2
3	2	3	3	3

Processor:	0	1	2	3
TimeCompuT	10	8	9	12
EnerComunT	10	12	8	14
EnerComunS	12	14	10	14
EnerCompuT	100	80	90	110
EnerInac	4	7	5	2

assignation $\pi = (2,3,1,0) \Rightarrow Time(\pi) = 20,\ Energy(\pi) = 2910$

Types of algorithms

- Incomplete exact methods (Backtracking, Branch and Bound and Greedy algorithms), with some pruning strategy.
- Distributed metaheuristics (Scatter search, Genetic algorithms, Ant colony, Particle swarm optimization, etc.)
- Neighborhood metaheuristics (Hill climbing, Tabu search, Guided local search, Variable neighborhood search, Simulated annealing, GRASP, etc.)

Each student works with a method and gives a presentation for the classmates on the application of the method to the optimization problem.

Incomplete Backtracking

- Sequential:
  A scheme with a pruning routine. Experiments with different pruning techniques. A maximum number of descendants for each node. A minimum execution time and energy consumption can be associated to a node with a partial assignment. Explore the nodes with the highest estimations. Use of a joint indicator, or a part of the nodes with each objective.
- Shared-memory:
  The master generates nodes up to a certain level, starts the slaves, which do backtracking from the nodes dynamically assigned to them.
- Message-passing:
  The master sends nodes to the slave processes and these send back the results to the master.
  Communications if the information about the best solutions is shared. Analysis of the influence of the frequency of communications in the execution time and the Pareto front.
- Hybrid:
  Static cyclic distribution among processes and dynamic assignation to the threads in each process.
- Study of speed-up and scalability, and of the influence of the pruning and the sharing of information in the execution time and the Pareto front.

Genetic Algorithm

- Sequential:

  Identify population, individual representations and possible forms of the basic routines, and develop a high level genetic scheme.

  Tune the values of the parameters and the routines to the mapping problem.
- Shared-memory:

  Independent parallelization of the basic routines.
- Message-passing:

  Island scheme. The number of generations to exchange information is one of the parameters to be tuned.
- Hybrid:

  An island scheme with threads working on the application of the basic functions at each island.
- Study of speed-up and scalability, and of the influence of some parameters (number of islands, size of generations and migrations, etc) on the execution time and the Pareto front.

Tabu Search

- Sequential:

  Identify set and element representations and possible forms of the basic routines, and develop a high level Tabu search.

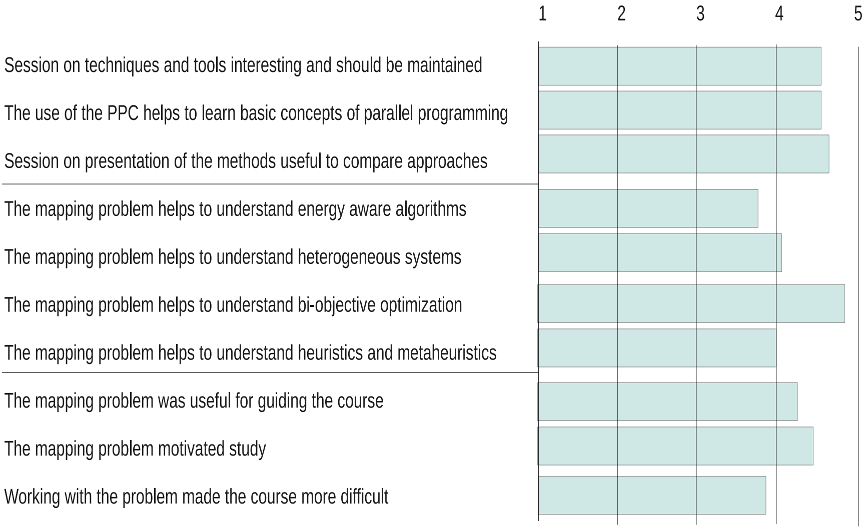
  Tune the values of the parameters and the routines to the mapping problem.
- Shared-memory:

  Select a number of nodes to explore at each step depending on the number of threads, or conduct several independent searches.
- Message-passing:

  Independent searches at each process, with different initial solutions and search strategies.
- Hybrid:

  Independent search in each thread.
- Study of speed-up and scalability, and of the influence of knowledge sharing on the execution time and the Pareto front.

Questionnaire



- The students found the organization of the course appropriate.
- The problem selected to guide the course was useful for a deeper learning of concepts previously studied.
- Working with a challenging problem is perceived as interesting.
- The students consider the organization of the course did not suppose an important increase in their work load.

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Questions? Comments? Recommendations?