Course guide
270020 - PAR - Parallelism

Unit in charge: Barcelona School of Informatics
Teaching unit: 701 - DAC - Department of Computer Architecture.
Degree: BACHELOR'S DEGREE IN INFORMATICS ENGINEERING (Syllabus 2010). (Compulsory subject).
Academic year: 2022 ECTS Credits: 6.0 Languages: Catalan, Spanish, English

LECTURER
Coordinating lecturer: EDUARD AYGUADÉ PARRA - DANIEL JIMENEZ GONZALEZ
Others:
Primer quadrimestre:
MARIO CESAR ACOSTA COBOS - 13, 42
ROSA MARIA BADIA SALA - 41
JOSE RAMON HERRERO ZARAGOZA - 11, 12, 13
DANIEL JIMENEZ GONZALEZ - 22, 41, 42, 43
PEDRO JOSÉ MARTÍNEZ FERRER - 23
JORDI TUBELLA MURGADAS - 21, 43
GLADYS MIRIAM UTRERA IGLESIAS - 11, 21, 22, 23, 24

PRIOR SKILLS
The capabilities are defined by the prior pre-requisites for the course.

REQUIREMENTS
- Prerequisite AC

DEGREE COMPETENCES TO WHICH THE SUBJECT CONTRIBUTES

Specific:
CT1.1B. To demonstrate knowledge and comprehension about the fundamentals of computer usage and programming. Knowledge about the structure, operation and interconnection of computer systems, and about the fundamentals of its programming.
CT5.1. To choose, combine and exploit different programming paradigms, at the moment of building software, taking into account criteria like ease of development, efficiency, portability and maintainability.
CT5.3. To design, write, test, refine, document and maintain code in a high level programming language to solve programming problems applying algorithmic schemas and using data structures.
CT5.6. To demonstrate knowledge and capacity to apply the fundamental principles and basic techniques of parallel, concurrent, distributed and real-time programming.
CT6.2. To demonstrate knowledge, comprehension and capacity to evaluate the structure and architecture of computers, and the basic components that compound them.
CT7.2. To evaluate hardware/software systems in function of a determined criteria of quality.
CT8.1. To identify current and emerging technologies and evaluate if they are applicable, to satisfy the users needs.

Generical:
G3. THIRD LANGUAGE: to know the English language in a correct oral and written level, and accordingly to the needs of the graduates in Informatics Engineering. Capacity to work in a multidisciplinary group and in a multi-language environment and to communicate, orally and in a written way, knowledge, procedures, results and ideas related to the technical informatics engineer profession.
TEACHING METHODOLOGY

The theory classes introduce all the knowledge, techniques, concepts needed to be put into practice problems in class and lab as well as personal work using a collection of problems. The two hours of laboratory sessions are also held weekly; active participation and performance during the laboratory sessions will be valued (work during the session, advancing as far as possible in order to achieve the objectives of each session). The course uses the C programming language and the OpenMP parallel programming model.

LEARNING OBJECTIVES OF THE SUBJECT

1. Ability to formulate simple performance models given a parallelization strategy for an application, that allows an estimation of the influence of major architectural aspects: number of processing elements, data access cost and cost of interaction between processing elements, among others.
2. Ability to measure, using instrumentation, visualization and analysis tools, the performance achieved with the implementation of a parallel application and to detect factors that limit this performance: granularity of tasks, equitable load and interaction between tasks, among others.
3. Ability to compile and execute a parallel program, using the essential command-line tools to measure the execution time.
4. Ability to apply simple optimizations in parallel kernels to improve their performance for parallel architectures, attacking the factors that limit performance.
5. Ability to choose the most appropriate decomposition strategy to express parallelism in an application (tasks, data).
6. Ability to apply the basic techniques to synchronize parallel execution, avoiding race conditions and deadlock and enabling the overlap between computation and interaction, among others.
7. Ability to program in OpenMP the parallel version of a sequential application.
8. Ability to identify the different types of parallelism that can be exploited in a computer architecture (ILP, TLP, and DLP within a processor, multiprocessor and multicomputer) and describe its principles of operation.
9. Ability to understand the basics of coherence and data sharing in shared-memory parallel architectures, both with uniform and non-uniform access to memory.
10. Ability to follow the course using the materials provided in English (slides, laboratory and practical sessions), as well as to do the mid-terms and final exams with the statement written in English.
11. If the foreign language competence is chosen, the ability to write the deliverables associated with laboratory assignments (partially or fully) in English.

STUDY LOAD

<table>
<thead>
<tr>
<th>Type</th>
<th>Hours</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hours small group</td>
<td>30,0</td>
<td>20.00</td>
</tr>
<tr>
<td>Self study</td>
<td>84,0</td>
<td>56.00</td>
</tr>
<tr>
<td>Hours large group</td>
<td>30,0</td>
<td>20.00</td>
</tr>
<tr>
<td>Guided activities</td>
<td>6,0</td>
<td>4.00</td>
</tr>
</tbody>
</table>

Total learning time: 150 h

CONTENTS

Introduction and motivation

Description:
Necessitat del paral·lelisme, paral·lelisme vs. concurrencia, possibles problemes en l’ús concurrencia: deadlock, lifelock, starvation, fairness, data races
**Analysis of parallel applications**

**Description:**
Métriques bàsiques: paral·lelisme, temps d'execució, speedup i escalabilitat. Anàlisi de l'impacte dels overheads associats a la creació de tasques i la seva sincronització i la compartició de dades. Eines per la prediccio i l'anàlisi de paral·lelisme i visualització de comportament: Paraver i Tareador.

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**Shared-memory programming: OpenMP**

**Description:**
Regions paral·leles, threads i tasques. Mecanismes de sincronització entre tasques i threads. Distribució de feina estàtica/dinàmica, granularitat.

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**Introduction to parallel architectures**

**Description:**
Paral·lelisme dins d'un processador (ILP, DLP i TLP) i entre els processadors que formen els multiprocessadors de memòria compartida SMP i ccNUMA (coherència de cache, consistència de memòria, sincronització).

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**Parallel programming principles: task decomposition**

**Description:**
Task decomposition vs. data decomposition. Descomposicio en tasques, granularitat i anàlisi de dependències. Identificació de patrons de paral·lelisme: iterative vs. divide and conquer task decompositions. Mecanismes per implementar la descomposició en tasques: creació de regions paral·leles i tasques; mecanismes per garantir task ordering i data sharing.

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**Parallel programming principles: data decomposition**

**Description:**
Descomposició de dades (descomposició geomètrica vs. estructures recursives) per arquitectures amb memòria compartida. Localitat en l'accés a les dades en arquitectures paral·leles de memòria compartida. Generació de codi en funció de la descomposició de dades. Breu introducció a les arquitectures de memòria distribuïda i la seva programació (cas concret: MPI).

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**Exam problems review**

**Description:**
En aquestes sessions es resoldran dubtes que l'estudiantat pugui tenir alhora de resoldre problemes d'examens.
### ACTIVITIES

**Assimilation of fundamental concepts and tools for modeling and analyzing the behavior of parallel applications**

**Description:**
Actively participate in sessions of theory/problems. Study the contents of Units 1 and 2 and perform the proposed exercises. Resolution of the assignments in the laboratory sessions and understanding of the obtained results.

**Specific objectives:**
1, 2, 3, 10

**Related competencies:**
G3. THIRD LANGUAGE: to know the English language in a correct oral and written level, and accordingly to the needs of the graduates in Informatics Engineering. Capacity to work in a multidisciplinary group and in a multi-language environment and to communicate, orally and in a written way, knowledge, procedures, results and ideas related to the technical informatics engineer profession.

**Full-or-part-time:** 18h
- Theory classes: 6h
- Laboratory classes: 6h
- Self study: 6h

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**Using OpenMP to express of parallelism in shared memory**

**Description:**
Actively participate in laboratory sessions. Do the suggested previous work/reading, solve the exercises during the laboratory sessions, analyse the obtained results, draw conclusions from the experiments and prepare the corresponding deliveries.

**Specific objectives:**
4, 7, 10, 11

**Related competencies:**
G3. THIRD LANGUAGE: to know the English language in a correct oral and written level, and accordingly to the needs of the graduates in Informatics Engineering. Capacity to work in a multidisciplinary group and in a multi-language environment and to communicate, orally and in a written way, knowledge, procedures, results and ideas related to the technical informatics engineer profession.

**Full-or-part-time:** 44h
- Laboratory classes: 22h
- Self study: 22h

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**Assimilation of the fundamental aspects in parallel architectures**

**Description:**
Actively participate in sessions of theory/problems. Study the contents of Unit 4 and perform the proposed exercises.

**Specific objectives:**
8, 10

**Related competencies:**
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**Full-or-part-time:** 12h
- Theory classes: 6h
- Self study: 6h
Midterm exam

Specific objectives:
1, 5, 6, 7, 9, 10

Related competencies:
G3. THIRD LANGUAGE: to know the English language in a correct oral and written level, and accordingly to the needs of the graduates in Informatics Engineering. Capacity to work in a multidisciplinary group and in a multi-language environment and to communicate, orally and in a written way, knowledge, procedures, results and ideas related to the technical informatics engineer profession.

Full-or-part-time: 12h
Guided activities: 2h
Self study: 10h

Assimilation of the fundamentals for task decomposition

Description:
Actively participate in sessions of theory/problems. Study the contents of Unit 5 and perform the proposed exercises. Apply new knowledge when solving the associated laboratory assignments.

Specific objectives:
5, 6, 10

Related competencies:
G3. THIRD LANGUAGE: to know the English language in a correct oral and written level, and accordingly to the needs of the graduates in Informatics Engineering. Capacity to work in a multidisciplinary group and in a multi-language environment and to communicate, orally and in a written way, knowledge, procedures, results and ideas related to the technical informatics engineer profession.

Full-or-part-time: 18h
Theory classes: 8h
Self study: 10h

Assimilation of the fundamentals for data decomposition

Description:
Actively participate in sessions of theory/problems. Study the contents of Unit 6 and perform the proposed exercises. Apply new knowledge when solving the associated laboratory assignments.

Specific objectives:
5, 6, 10

Related competencies:
G3. THIRD LANGUAGE: to know the English language in a correct oral and written level, and accordingly to the needs of the graduates in Informatics Engineering. Capacity to work in a multidisciplinary group and in a multi-language environment and to communicate, orally and in a written way, knowledge, procedures, results and ideas related to the technical informatics engineer profession.

Full-or-part-time: 18h
Theory classes: 8h
Self study: 10h
Midterm problems review

Description:
Study the solution proposed for the problems in the mid-term exam and contrast it with the solution delivered. Discussion of the differences observed.

Specific objectives:
9, 10

Related competencies:
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Full-or-part-time: 7h
Guided activities: 3h
Self study: 4h

Final exam

Specific objectives:
4, 5, 6, 7, 8, 9, 10

Related competencies:
G3. THIRD LANGUAGE: to know the English language in a correct oral and written level, and accordingly to the needs of the graduates in Informatics Engineering. Capacity to work in a multidisciplinary group and in a multi-language environment and to communicate, orally and in a written way, knowledge, procedures, results and ideas related to the technical informatics engineer profession.

Full-or-part-time: 19h
Guided activities: 3h
Self study: 16h

GRADING SYSTEM

The grade for the course (NF) is calculated based on the following components (all assessed out of 10):
- P: the mark of the mid-term exam (includes Units 1 to 3)
- F: the mark in the final exam (Units 1 to 5)
- L: the laboratory mark
- AA: the mark of the online activities via Atenea carried out within the established period

applying the following weighting:
\[ N = 0.75 \times \max(F, 0.35 \times P + 0.65 \times F) + 0.25 \times L \]
If \( N \geq 5.0 \) then \( NF = \min(10, N \times (1 + AA/100)); NF = N \) otherwise.

The laboratory mark (L) is obtained from the grades obtained in the deliverables, modulated by the attendance to the laboratory sessions, the active participation and performance and the result of a possible interview at the end of the course. By active participation, we refer to the reliable demonstration of being working on the laboratory assignment, advancing as far as possible to achieve each session's objectives.

The foreign language competence will be evaluated from the reports delivered for the laboratory assignments. These reports should be written (partially or fully) in English and they will require reading the laboratory assignment description (also in English) as well as the OpenMP specifications. Both the structure of the written document and the ability to transmit the results and conclusions of the work will be used to evaluate the competence (following a rubrics document). The grade for the competence will be A (excellent), B (good), C (satisfactory), D (fail) or NA (Not evaluated).
BIBLIOGRAPHY

Basic:

Complementary: