



Course guide

270020 - PAR - Parallelism

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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: 2023 **ECTS Credits:** 6.0 **Languages:** Catalan, Spanish, English

LECTURER

Coordinating lecturer: DANIEL JIMENEZ GONZALEZ

Others: Primer quadrimestre:

MARIO CESAR ACOSTA COBOS - 13, 21, 41
EDUARD AYGUADÉ PARRA - 11
JOSE RAMON HERRERO ZARAGOZA - 41, 42, 43
DANIEL JIMENEZ GONZALEZ - 11, 12, 13
JESUS JOSE LABARTA MANCHO - 11, 23
PEDRO JOSÉ MARTÍNEZ FERRER - 43
ADRIÁN MUNERA SÁNCHEZ - 22
JORDI TUBELLA MURGADAS - 12
GLADYS MIRIAM UTRERA IGLESIAS - 21, 22, 23, 42

Segon quadrimestre:

MARIO CESAR ACOSTA COBOS - 11, 22
ROSA MARIA BADIA SALA - 43
JOSE RAMON HERRERO ZARAGOZA - 12, 42
DANIEL JIMENEZ GONZALEZ - 21, 41, 42, 43
PEDRO JOSÉ MARTÍNEZ FERRER - 41
JORDI TUBELLA MURGADAS - 11, 12, 13
GLADYS MIRIAM UTRERA IGLESIAS - 21, 22, 23

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 an 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.

General:

- 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

Type	Hours	Percentage
Self study	84,0	56.00
Hours small group	30,0	20.00
Hours large group	30,0	20.00
Guided activities	6,0	4.00

Total learning time: 150 h

CONTENTS

Introduction and motivation

Description:

Necessitat del paral·lelisme, paral·lelisme vs. concorrència, possibles problemes en l'ús concorrència: deadlock, lifelock, starvation, fairness, data races

Analysis of parallel applications

Description:

Mètriques 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 predicció i l'anàlisi de paral·lelisme i visualització de comportament: Paraver i Tareador

Shared-memory programming: OpenMP

Description:

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

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).

Parallel programming principles: task decomposition

Description:

Task decomposition vs. data decomposition. Descomposcio 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.



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).

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 :

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Full-or-part-time: 22h

Theory classes: 6h

Laboratory classes: 6h

Self study: 10h

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 :

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Full-or-part-time: 9h

Theory classes: 1h

Laboratory classes: 4h

Self study: 4h



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

Extra doubt session for the partial exam

Description:

The student can make the request for the problems he wants to review in advance, but he can also make requests during the session.

Specific objectives:

1, 2, 3, 4, 8, 9, 10

Related competencies :

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Full-or-part-time: 2h

Guided activities: 2h

Midterm exam

Specific objectives:

1, 5, 6, 7, 9, 10

Related competencies :

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Full-or-part-time: 12h

Guided activities: 2h

Self study: 10h



Training session: review of the solutions to the problems of the partial exam and general feedback of the errors found.

Description:

With this training session, students will be able to finish assimilating concepts from the first half of the semester.

Specific objectives:

1, 2, 3, 8, 9, 10

Related competencies :

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Full-or-part-time: 2h

Guided activities: 2h

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 :

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Full-or-part-time: 36h

Theory classes: 6h

Laboratory classes: 10h

Self study: 20h

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: 30h

Theory classes: 6h

Laboratory classes: 10h

Self study: 14h



Extra doubt session for the final exam

Description:

The student can make the request for the problems he wants to review in advance, but he can also make requests during the session.

Specific objectives:

1, 2, 3, 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: 2h

Guided activities: 2h

Final exam (Theory and Laboratory)

Description:

The laboratory part will be different from the theory part and will be a written exam on paper, related to what the students have worked on during the course.

Specific objectives:

1, 2, 3, 4, 5, 6, 7, 8, 9, 10

Related competencies :

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Full-or-part-time: 23h

Guided activities: 3h

Self study: 20h



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)
- FT: the mark in the theory part of the final exam (Units 1 to 5)
- FL: the laboratory mark in the laboratory part of the final exam (25%)

Additionally, they will be evaluated continuously:

- SL: laboratory follow-up reports (10%) which will also be used to evaluate the foreign language competence.
- AA: the mark of the online activities via Atenea carried out within the established period

applying the weighting indicated below:

$$N = 0.65*\max(FT, 0.35*P+0.65*FT) + 0.25*FL + 0.10*SL$$

If $N \geq 5.0$ then $NF = \min(10, N * (1 + AA/100))$; if not $NF=N$.

The final laboratory exam will be a written exam (on paper) that will be held on the same day as the final exam.

The foreign language competence will be evaluated from the reports delivered for the laboratory assignments. These reports should be written 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. The grade for the competence will be A (excellent), B (good), C (satisfactory), D (fail) or NA (Not evaluated).

BIBLIOGRAPHY

Basic:

- Grama, A.; Karypis, G.; Kumar, V.; Gupta, A. Introduction to parallel computing. 2nd ed. Harlow, England: Pearson Education, 2003. ISBN 0201648652.
- OpenMP application programming interface: version 5.0. OpenMP, 2018.

Complementary:

- Ayguade, E.; Ramon Herrero, J.R.; Jimenez, D.; Utrera, G. Parallelism - Unit 1: Why Parallel Computing. Departament d'Arquitectura de Computadors, 2022.
- Ayguade, E.; Ramon Herrero, J.R.; Jimenez, D.; Utrera, G. Parallelism - Unit 2: Understanding Parallelism. Departament d'Arquitectura de Computadors, 2022.
- Ayguade, E.; Ramon Herrero, J.R.; Jimenez, D.; Utrera, G. Parallelism - Unit 3: Introduction to parallel architectures. Departament d'Arquitectura de Computadors, 2022.
- Ayguade, E.; Ramon Herrero, J.R.; Jimenez, D.; Utrera, G. Parallelism - Unit 4: Mastering your task decomposition strategies: going some steps further. Departament d'Arquitectura de Computadors, 2022.
- Ayguade, E.; Ramon Herrero, J.R.; Jimenez, D.; Utrera, G. Parallelism - Unit 5: Data-aware task decomposition strategies. Departament d'Arquitectura de Computadors, 2022.
- Ayguade, E.; Ramon Herrero, J.R.; Jimenez, D.; Utrera, G. Parallelism: Collection of Exercises. Departament d'Arquitectura de Computadors, 2022.
- Ayguade, E.; Ramon Herrero, J.R.; Jimenez, D.; Utrera, G. Parallelism: Selection of Exams (with Solutions). Departament d'Arquitectura de Computadors, 2022.
- Ayguadé, E... [et al.]. Parallelism Laboratory Assignments. Departament d'Arquitectura de Computadors, 2022.
- Hennessy, J.L.; Patterson, D.A. Computer architecture: a quantitative approach. 6th ed. Elsevier, Morgan Kaufmann, 2019. ISBN 9780128119051.
- Culler, D.E.; Singh, J.P.; Gupta, A. Parallel computer architecture: a hardware/software approach. Morgan Kaufmann Publishers, 1999. ISBN 9781558603431.