Course guide
270413 - PSD - Parallelism and Distributed Systems

Unit in charge: Barcelona School of Informatics
Teaching unit: 701 - DAC - Department of Computer Architecture.

Degree: BACHELOR’S DEGREE IN ARTIFICIAL INTELLIGENCE (Syllabus 2021). (Compulsory subject).

Academic year: 2023  ECTS Credits: 6.0  Languages: Catalan

LECTURER

Coordinating lecturer:

Others:

PRIOR SKILLS
Those acquired in the course Fundamentals of Computers (FC) conceptually preceding this course.

DEGREE COMPETENCES TO WHICH THE SUBJECT CONTRIBUTES

Specific:
CE05. To be able to analyze and evaluate the structure and architecture of computers, as well as the basic components that make them up.
CE07. To interpret the characteristics, functionalities and structure of Distributed Systems, Computer Networks and the Internet and design and implement applications based on them.
CE11. To identify and apply the fundamental principles and basic techniques of parallel, concurrent, distributed and real-time programming.

Generical:
CG2. To use the fundamental knowledge and solid work methodologies acquired during the studies to adapt to the new technological scenarios of the future.
CG3. To define, evaluate and select hardware and software platforms for the development and execution of computer systems, services and applications in the field of artificial intelligence.
CG5. Work in multidisciplinary teams and projects related to artificial intelligence and robotics, interacting fluently with engineers and professionals from other disciplines.
CG9. To face new challenges with a broad vision of the possibilities of a professional career in the field of Artificial Intelligence. Develop the activity applying quality criteria and continuous improvement, and act rigorously in professional development. Adapt to organizational or technological changes. Work in situations of lack of information and / or with time and / or resource restrictions.

Transversal:
CT3. Efficient oral and written communication. Communicate in an oral and written way with other people about the results of learning, thinking and decision making; Participate in debates on topics of the specialty itself.
CT6. Autonomous Learning. Detect deficiencies in one’s own knowledge and overcome them through critical reflection and the choice of the best action to extend this knowledge.

TEACHING METHODOLOGY

The course is based on classroom theory and laboratory sessions. The theory sessions combine lectures and the resolution of exercises, following the program set out in this syllabus and based on the use of own material (slides, collection of exercises, ...). During the sessions, the dialogue and discussions are encouraged to anticipate and consolidate the learning outcomes of the course.

Laboratory sessions cover the aspects related to programming and follow the same subjects in the course syllabus. They are practice sessions using a cluster architecture available from the Computer Architecture Department.
LEARNING OBJECTIVES OF THE SUBJECT

1. To acquire knowledge about the basic execution models and performance metrics
2. To acquire knowledge about the architecture of scalar processors and the techniques for exploiting ILP (instruction-level parallelism) and DLP (data-level parallelism)
3. Understand shared memory architectures, hardware support for memory coherence and synchronization
4. Understand the distributed memory architectures and the hardware support for data exchange
5. Acquire knowledge about accelerator-based architectures and their access to the memory hierarchy of the scalar processor
6. Acquire knowledge and apply the basic techniques of parallel programming, for shared- and distributed-memory multiprocessors
7. Ability to discuss and compare the resolution of problems and practical exercises, both in group work or autonomously
8. Understand the relation between the course and the AI area

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>Hours large group</td>
<td>30,0</td>
<td>20.00</td>
</tr>
<tr>
<td>Self study</td>
<td>90,0</td>
<td>60.00</td>
</tr>
</tbody>
</table>

Total learning time: 150 h

CONTENTS

**Execution models and performance metrics**

Description:
Presentation of the serial, multiprogrammed, concurrent and parallel execution models, together with the basic metrics that characterize their performance.

**Scalar processor architecture and code optimization**

Description:
This unit introduces the basic architecture of the scalar processor and the techniques for increasing parallelism at the instructional level (ILP: pipelined and superscalar design) and at the data level (DLP: vector units). Memory hierarchy optimization and vectorization.

**Shared-memory multiprocessors architecture and programming**

Description:
This unit introduces the UMA (uniform memory access time) and NUMA (non-uniform memory access time) shared-memory multiprocessor architectures, including bus and directory-based consistency mechanisms and the support for synchronization using atomic instructions. It also presents the architecture of a node within a cluster architecture and the components that make it up (processors with multiple execution cores, memory and buses). Parallelization of applications using the tasking model in OpenMP.

**Distributed-memory multiprocessor architecture and programming**

Description:
This unit presents multiprocessor architectures of distributed memory based on message-passing through a scalable interconnection network. Parallelization of applications with the MPI programming model.
### Accelerators for artificial intelligence applications

**Description:**
This unit presents the architectures aimed at accelerating the most characteristic computing kernels in artificial intelligence applications: GPU (Graphics Processing Units), TPU (Tensor Processing Units), ... and their integration in the shared-memory nodes of a cluster architecture. Use case: accelerators for Deep Learning environments.

### ACTIVITIES

#### Execution models, performance metrics and analysis tools

**Description:**

**Specific objectives:**
1, 7

**Related competencies:**
- CE05. To be able to analyze and evaluate the structure and architecture of computers, as well as the basic components that make them up.
- CT3. Efficient oral and written communication. Communicate in an oral and written way with other people about the results of learning, thinking and decision making; Participate in debates on topics of the specialty itself.
- CT6. Autonomous Learning. Detect deficiencies in one’s own knowledge and overcome them through critical reflection and the choice of the best action to extend this knowledge.

**Full-or-part-time:** 14h
- Theory classes: 4h
- Laboratory classes: 4h
- Self study: 6h

#### Scalar processor architecture and application optimization

**Description:**

**Specific objectives:**
2, 7

**Related competencies:**
- CG3. To define, evaluate and select hardware and software platforms for the development and execution of computer systems, services and applications in the field of artificial intelligence.
- CE05. To be able to analyze and evaluate the structure and architecture of computers, as well as the basic components that make them up.
- CT3. Efficient oral and written communication. Communicate in an oral and written way with other people about the results of learning, thinking and decision making; Participate in debates on topics of the specialty itself.
- CT6. Autonomous Learning. Detect deficiencies in one’s own knowledge and overcome them through critical reflection and the choice of the best action to extend this knowledge.

**Full-or-part-time:** 20h
- Theory classes: 6h
- Laboratory classes: 4h
- Self study: 10h
Shared-memory multiprocessor architecture and OpenMP programming

Description:

Specific objectives:
3, 6, 7, 8

Related competencies:
CG9. To face new challenges with a broad vision of the possibilities of a professional career in the field of Artificial Intelligence. Develop the activity applying quality criteria and continuous improvement, and act rigorously in professional development. Adapt to organizational or technological changes. Work in situations of lack of information and / or with time and / or resource restrictions.
CG2. To use the fundamental knowledge and solid work methodologies acquired during the studies to adapt to the new technological scenarios of the future.
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CE11. To identify and apply the fundamental principles and basic techniques of parallel, concurrent, distributed and real-time programming.
CE05. To be able to analyze and evaluate the structure and architecture of computers, as well as the basic components that make them up.
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CT6. Autonomous Learning. Detect deficiencies in one's own knowledge and overcome them through critical reflection and the choice of the best action to extend this knowledge.

Full-or-part-time: 30h
Theory classes: 8h
Laboratory classes: 8h
Self study: 14h

OpenMP tutorial

Specific objectives:
3

Related competencies:
CG3. To define, evaluate and select hardware and software platforms for the development and execution of computer systems, services and applications in the field of artificial intelligence.
CE05. To be able to analyze and evaluate the structure and architecture of computers, as well as the basic components that make them up.

Full-or-part-time: 4h
Laboratory classes: 2h
Self study: 2h
Mid-term theory exam

Specific objectives:
1, 2

Related competencies:
CG3. To define, evaluate and select hardware and software platforms for the development and execution of computer systems, services and applications in the field of artificial intelligence.
CE05. To be able to analyze and evaluate the structure and architecture of computers, as well as the basic components that make them up.

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

Distributed-memory multiprocessor architecture and MPI programming

Description:
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Specific objectives:
4, 6, 7, 8

Related competencies:
CG9. To face new challenges with a broad vision of the possibilities of a professional career in the field of Artificial Intelligence. Develop the activity applying quality criteria and continuous improvement, and act rigorously in professional development. Adapt to organizational or technological changes. Work in situations of lack of information and / or with time and / or resource restrictions.
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CE11. To identify and apply the fundamental principles and basic techniques of parallel, concurrent, distributed and real-time programming.
CE05. To be able to analyze and evaluate the structure and architecture of computers, as well as the basic components that make them up.
CE07. To interpret the characteristics, functionalities and structure of Distributed Systems, Computer Networks and the Internet and design and implement applications based on them.
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CT6. Autonomous Learning. Detect deficiencies in one's own knowledge and overcome them through critical reflection and the choice of the best action to extend this knowledge.

Full-or-part-time: 24h
Theory classes: 4h
Laboratory classes: 8h
Self study: 12h
### MPI tutorial

**Description:**

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**Specific objectives:**

4

**Related competencies**:

CG3. To define, evaluate and select hardware and software platforms for the development and execution of computer systems, services and applications in the field of artificial intelligence.

CE05. To be able to analyze and evaluate the structure and architecture of computers, as well as the basic components that make them up.

CE07. To interpret the characteristics, functionalities and structure of Distributed Systems, Computer Networks and the Internet and design and implement applications based on them.

**Full-or-part-time**: 4h

Laboratory classes: 2h

Self study: 2h

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### Accelerator architecture for artificial intelligence applications

**Description:**

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**Specific objectives:**

5, 6, 7, 8

**Related competencies**:

CG9. To face new challenges with a broad vision of the possibilities of a professional career in the field of Artificial Intelligence. Develop the activity applying quality criteria and continuous improvement, and act rigorously in professional development. Adapt to organizational or technological changes. Work in situations of lack of information and / or with time and / or resource restrictions.

CG2. To use the fundamental knowledge and solid work methodologies acquired during the studies to adapt to the new technological scenarios of the future.

CG3. To define, evaluate and select hardware and software platforms for the development and execution of computer systems, services and applications in the field of artificial intelligence.

CG5. Work in multidisciplinary teams and projects related to artificial intelligence and robotics, interacting fluently with engineers and professionals from other disciplines.

CE11. To identify and apply the fundamental principles and basic techniques of parallel, concurrent, distributed and real-time programming.

CE05. To be able to analyze and evaluate the structure and architecture of computers, as well as the basic components that make them up.

CT3. Efficient oral and written communication. Communicate in an oral and written way with other people about the results of learning, thinking and decision making; Participate in debates on topics of the specialty itself.

CT6. Autonomous Learning. Detect deficiencies in one's own knowledge and overcome them through critical reflection and the choice of the best action to extend this knowledge.

**Full-or-part-time**: 10h

Theory classes: 4h

Self study: 6h
Final exam

**Specific objectives:**
1, 2, 3, 4, 5

**Related competencies:**
CG3. To define, evaluate and select hardware and software platforms for the development and execution of computer systems, services and applications in the field of artificial intelligence.
CE05. To be able to analyze and evaluate the structure and architecture of computers, as well as the basic components that make them up.
CE07. To interpret the characteristics, functionalities and structure of Distributed Systems, Computer Networks and the Internet and design and implement applications based on them.

**Full-or-part-time:** 22h
Guided activities: 2h
Self study: 20h

Laboratory mid-term exam

**Specific objectives:**
6

**Related competencies:**
CE11. To identify and apply the fundamental principles and basic techniques of parallel, concurrent, distributed and real-time programming.
CT6. Autonomous Learning. Detect deficiencies in one’s own knowledge and overcome them through critical reflection and the choice of the best action to extend this knowledge.

**Full-or-part-time:** 10h
Guided activities: 2h
Self study: 8h

**GRADING SYSTEM**

There are two exams for the theory part and one for the laboratory part:
- PT: mid-term theory exam (20%)
- FT: final theory exam (35%)
- FL: final laboratory exam (35%)

Additionally, they will be evaluated continuously:
- SL: laboratory monitoring reports (10%) which will also be used to assess the CT3 and CT6 transversal competencies.

The Final Grade (NF) of the course is obtained from
\[
NF = 0.30 \times FL + 0.15 \times SL + \text{MAX} (0.55 \times FT; 0.20 \times PT + 0.35 \times FT)
\]

**BIBLIOGRAPHY**

**Basic:**