Master in Information and Computer Sciences - Master in Information and Computer Sciences

Semestre 1

	CM (UE)	TD (UE)	ECTS
Module 1.1			6
Basic Algebraic Structures	30	15	3
Foundations of Computing	30		3
Module 1.2			6
Communication Theory	30		3
Networking	30		3
Module 1.3			3
Distributed Systems	30		3
Module 1.4			9
Intelligent Systems - Agents and Reasoning	30		3
Intelligent Systems - Information Retrieval and Learning	30		3
Intelligent Systems - Problem Solving	20	10	3
Module 1.5			3
Information Security Basics	30		3
Module 1.6			3
Reliable software-intensive systems	22	8	3

Semestre 2

	CM (UE)	TD (UE)	ECTS
Module 2.1			5
Algorithmic Decision Theory (optionnel)	45		5

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	CM (UE)	TD (UE)	ECTS
Module 2.2			0
Algorithms for Numbers and Public-Key Cryptography (optionnel)	45		5
Module 2.3			5
Dependable Systems (optionnel)	45		5
Module 2.4			5
Formal Methods (optionnel)	45		5
Module 2.5			5
Big Data Analytics (optionnel)	30	30	5
Module 2.6			5
Information Theory and Coding (optionnel)	45		5
Module 2.7			0
Intelligent Agents I (optionnel)	45	14	5
Module 2.8			5
Knowledge Discovery and Data Mining (optionnel)	30	15	5
Module 2.10			5
Networked Feedback Systems (optionnel)	30	15	5
Module 2.11			5
Optimisation for Computer Science (optionnel)	45		5
Module 2.12			5
Principles of Security Engineering (optionnel)	45		5
Module 2.13			5
Quality of Service in Computer Networks (optionnel)	45		5
Module 2.14			5
Symmetric Key Cryptography and Security of Communications (optionnel)	45		5

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	CM (UE)	TD (UE)	ECTS
Module 2.15			0
Introduction to Static Program Analysis (optionnel)	45		5
Module 2.16			0
Software Vulnerabilities: Exploitation and Mitigation (optionnel)	45		5

Semestre 3

	CM (UE)	TD (UE)	ECTS
Module 3.1			3
Intellectual Property	30		3
Module 3.6			4
Coding theory	30		4
Module 3.2			3
Advanced Project Management	30		3
Module 3.4			0
Computational Statistics (optionnel)	30		4
Module 3.5			0
Cryptocurrencies and the Cryptographic Blockchain (optionnel)	30		4
Module 3.7			0
Advanced Database Topics (optionnel)	30		4
Module 3.8			0
Autonomous Robot Software (optionnel)	30		4
Module 3.9			0
Intelligent Agents II (optionnel)	30		4

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	CM (UE)	TD (UE)	ECTS
Module 3.10			0
Machine Learning (optionnel)	30		4
Module 3.11			0
Management of Information Security (optionnel)	30		4
Module 3.12			0
Model-Driven Software Development (optionnel)	30		4
Module 3.13			0
Selected Topics in Network and System Security (optionnel)	30		4
Module 3.14			0
Open Network Security (optionnel)	30		4
Module 3.15			0
Parallel and Grid Computing (optionnel)	16	30	4
Module 3.16			0
Security Modelling (optionnel)	30		4
Module 3.17			0
Security Protocols (optionnel)	24	6	4
Module 3.18			0
Selected topics in Artificial Intelligence (optionnel)	30		4
Module 3.19			0
Software Engineering Environments (optionnel)	10	20	4
Module 3.21			0
Testing and Validation (optionnel)	26	4	4
Module 3.24			0
Computer Vision and Image Analysis (optionnel)	30		4

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	CM (UE)	TD (UE)	ECTS
Module 3.25			0
Connected and Autonomous Vehicles (optionnel)	30		4
Module 3.26			0
Fundamentals of causal learning (optionnel)	30		4

Semestre 4

	CM (UE)	TD (UE)	ECTS
Module 4.1			30
Master thesis			30

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Semestre 1

Basic Algebraic Structures

Module:	Module 1.1 (Semestre 1)
ECTS:	3
Objectif:	The course supplies those basic notions of algebra which are necessary for following higher courses in the frame of the Master MICS
Course learning outcomes:	* Explain basic algebraic structures such as groups and fields * Present proofs of properties of algebraic structures
Description:	1. Groups 2. Rings and Fields 3. An application: Public key encryption 4. Coset spaces and quotient groups 5. Polynomial rings over fields 6. Construction of field extensions. 7. Finite fields 8. Applications to Coding Theory (if time permits)
Modalité d'enseignement:	The course consists of lectures and exercises. The exercise will take place every second week and are related to the topics of the course.
Langue:	Anglais
Obligatoire:	Oui
Evaluation:	There will be a final written exam which will count for 100 percent. The exam will cover the lectures and the exercises
Remarque:	(1) The individual work on the exercises is highly recommended. (2) There is a typeset manuscript available for the lecture.
Professeur:	SCHLICHENMAIER Martin

Foundations of Computing

Module:	Module 1.1 (Semestre 1)
ECTS:	3
Objectif:	Basic knowledge of computability and computational complexity theory.
Course learning outcomes:	* List various computational models and their properties * Analyze and compare the complexity of problems
Description:	Mathematical Background/Definitions

- Problems/Solving Problems
- Computational Models
- Algorithms/Procedures

Computability Theory

- Unlimited Register Machine (URM)
- URM-Computability
- Partial /Primitive Recursive Primitive Functions
- Computable Functions

Other approaches to Computability

- Turing Computability (Turing Machines (TM) /Universal TM)
- Other Model's Computability (e.g., Lambda Calculus)
- Church-Turing's Thesis

Computational Complexity Theory

- Time Complexity: the classes P and NP; NP-Completeness
- Space complexity: Savitch's theorem, PSPACE and PSPACE-completeness
- Intractability: hierarchy theorems; exponential space completeness

Modalité d'enseignement: The course is organized as a series of 12 lectures.

Langue: Anglais

Obligatoire: Oui

Evaluation: 100% final exam

Communication Theory

Module: Module 1.2 (Semestre 1)

ECTS: 3

Objectif: Provide mathematical fundamentals of the physical layer like stochastic signals and systems, ML and MAP principle, modulation, and channel models.

Course learning outcomes:
* Describe fundamental parameters of signals, systems, and channels
* Take optimal stochastic decisions based on observations

Description:
* Signals and Systems
* Convolution
* Sampling
* Stochastic Signals and Noise
* Modulation and Demodulation
* The Maximum Likelihood Principle
* Sources and Channels

Modalité d'enseignement:
* Review of Stochastic Signals and Systems
* Digital Transmission and Modulation
* Demodulation

* Channel Models
* ML Principle
* Matched Filter
* Equalization

Langue: Anglais

Obligatoire: Oui

Evaluation: Final Exam (100%)

Professeur: SORGER Ulrich

Networking

Module: Module 1.2 (Semestre 1)

ECTS: 3

Objectif: Introduce higher networking layers and mathematical descriptions of network concepts as Multiple Access Control (ALOHA, collision detection and resolution), Error detecting and correcting codes, ARQ, routing and flow control, Queueing and QoS.

Description:
* Hierarchical Model of Network Functions (OSI Model, Service Access Points)
* Point-to-Point Data Transmission (synchronous and asynchronous multiplexing, packets)
* Error correcting and detecting codes, ARQ protocols
* Multiple Access Control (ALOHA, Slotted ALOHA, collision resolution, detection and avoiding)
* Routing and flow control
* Introduction to Queueing Theory
* Mobile Network Access Schemes
* Quality of Service Parameters in TCP/IP

Modalité d'enseignement: The course consists of a series of lectures with dedicated time slots for exercises

Langue: Anglais

Obligatoire: Oui

Evaluation: There is a final exam counting 70%.
Successful preparation, submission and participation in exercises is valued 30%

Professeur: ENGEL Thomas

Distributed Systems

Module: Module 1.3 (Semestre 1)

ECTS: 3

Objectif: The objective of the course is to provide an overview of the area of distributed systems with a focus on distributed algorithms. After successful completion of this course the student should be able to:

- Identify and explain the following concepts related to distributed systems: network topology, communication models, operation mode, failure model, scalability, complexity
- Explain the role and importance of distribution in a selection of related domains, e.g., mutual exclusion, fault tolerance Can list the relevant assumptions and requirements for each of these domains
- Understands the operation of the basic algorithms in each of these domains
- Can reason about the basic properties of these algorithms

Course learning outcomes:

* Identify and explain the following concepts related to distributed systems: network topology, communication models, operation mode, failure model, scalability, complexity
* Explain the role and importance of distribution in a selection of domains: mutual exclusion, self-stabilizing systems, disbributed snapshot, termination detection, leader election, consensus, fault tolerance
* List the relevant assumptions and requirements for each of these domains
* Explain the operation of the basic algorithms in each of these domains
* Analyze the basic properties of these algorithms

Description:

distributed systems. In details, it contains the following topics:
- Mutual exclusion
- Self-stabilizing systems
- Distributed snapshot
- Termination detection
- Leader election
- Consensus in distributed systems
- Fault tolerance
- Graph Algorithms

Modalité d'enseignement: The course consists of a series of lectures with dedicated time slots for exercises

Langue: Anglais

Obligatoire: Oui

Evaluation: We revise the numbers slightly: A final written exam will be counted for 70%, 30% being dedicated to the assignments.

Professeur: MAUW Sjouke, PANG Jun, ACCLAVIO Matteo

Intelligent Systems - Agents and Reasoning

Module: Module 1.4 (Semestre 1)

ECTS: 3

Objectif: The top-level objective of this course is to prepare the participants for the emerging age of ubiquitous intelligent systems and robots. To this end, the course aims at providing a solid background for studies in intelligent and/or adaptive systems with the intention of promoting the use of intelligent techniques in various areas of computer science and in cross-disciplinary interactions.
Special attention is given to the use of symbolic means for structured knowledge representation.

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Course learning outcomes:

After successfully completing this course, each student will be able to ...
- understand and explain the central role of the logical formalisms in knowledge based systems
- explain the difference between syntactical and semantical concepts of logical systems
- confidently handle and classify central model-theoretic notions of logical systems (including, but not limited to: interpretations, validity, satisfiabilty, ...)
- confidently handle and classify central proof-theoretic notions of logical systems (including, but not limited to: proof calculi, soundness, completeness, ...)
- define classical propositional logic and classical first-order logic; and evaluate given syntactical objects with respect to respective interpretation structures
- explain basic meta-logical results of the two above logics and their consequences
- use the introduced logical systems for representing facts and properties (e.g., given by natural language statements)
- model simple intelligent systems using classical logics
- apply existing computer software for modelling and assessing reasoning problems

Description:

The topics of the course are as follows:
- Semantics vs. proofs
- Propositional logic: Syntax and semantics
- First-order logic: Syntax and semantics
- Proof calculi, soundness and completeness
- Modelling natural language in formal logic

The exact lecture plan is as provided on the Moodle system and updated continuously.

Modalité d'enseignement:

The lecture is divided into two parts: (1) The lecturing activity and (2) the project part.

During the lecturing activity part (roughly two thirds of the course) there is one lecture each week and every lecture week is accompanied by an exercise sheet. The weekly exercise sheets must be worked on in pairs of two students. This requirement may be dropped if the number of students is low enough.

The exercises will be graded by the teaching assistant and returned to you in the following week.

During the project part, the students will work on small projects.

The results of these projects are presented by the students.

The course is concluded by a final written remote exam (implemented as a "take-home assignment").

Langue:

Anglais

Obligatoire:

Oui

Evaluation:

The grade is determined by the final exam and the project as follows: final exam 70%, project 30%.

If the average grade over all exercise sheets is above a given grade, the student gets a bonus onto the grading result from above. It is not possible to get more than twenty points as final grade.

More than or equal to 60%: +1 point

More than or equal to 85%: +2 points

If the exam is taken in a later session, the final grade will be determined only by that exam and the project results and bonuses are not considered.

Remarque: Learning material such as the exercise sheets and literature will be provided in the Moodle system.

Students are asked to read/prepare the indicated literature for each lecture.

Professeur: VAN DER TORRE Leon, STEEN Alexander

Intelligent Systems - Information Retrieval and Learning

Module: Module 1.4 (Semestre 1)

ECTS: 3

Objectif: In general, the field of Information Retrieval denotes the process of delivering answers (for example: link recommendations) to a requested search as well as its presentation in an user-friendly way. However, this kind of information presentation is not that easy as it seems, since a variety of different components of different research fields come into play. In particular, the presented answers should be as precise as possible and should satisfy the enquirer's request. But what, if the enquirer's terms are misspelled or ambiguous? What, if the enquirer uses wildcards? How can we guarantee that the best answers appear on top of the answer set? How can the search engine learn from the input it receives?

Course learning outcomes: The student should be able to understand the basic concepts of Information Retrieval, which concern the structure of a search engine, the processing of queries, the ranking and the evaluation of search results, the role of Feedback, and others, as well as a number of learning mechanisms in view of further applications like the classification of texts as a bridge to Knowledge Discovery (Semester 2) and Machine Learning (Semester 3).

Description: In the course, we discuss selected chapters of the book "Introduction to Information Retrieval" by Christopher Manning et al., which is also given at Stanford University The candidate learns to understand the fundamental aspects regarding information retrieval as well as its elementary concepts, particularly the components of a search engine, the role of Natural Language Processing, and evaluation strategies, query extensions, and ranking. We also foster on Google's PageRank and discuss several text classification methods.

Modalité d'enseignement: Lecture and Exercises

Langue: Anglais

Obligatoire: Oui

Evaluation: 100% Final Examination

Remarque: **REFERENCES**

* Christopher Manning et al. Introduction to Information Retrieval. Cambridge University Press.

* Russel, Norvig. Artificial Intelligence - A Modern Approach. Prentice Hall

Professeur: SCHOMMER Christoph

Intelligent Systems - Problem Solving

Module: Module 1.4 (Semestre 1)

ECTS: 3

Objectif: The objective of this lecture first consists in providing a structured approach to students in terms of optimization problem modeling. Next various solving techniques based on exact methods (A*, B&B, LP), approximated ones (heuristics, meta-heuristics, problem relaxation) and hybrids are described. Students are also taught how to validate the proposed solution by having a scientific approach

Description: Introduction to optimisation and decision problems
Linear programming, graphical interpretation and primal simplex
Branch&Bound, A*
The scheduling problem
List algorithms, greedies, heuristics
Meta-Heuristics and Evolutionary computation

Modalité d'enseignement: The course is organized as a series of theoretical lectures intermixed with hands-on exercises. A computer lab is also organised at the end of the lecture

Langue: Anglais

Obligatoire: Oui

Evaluation: Final Exam: 100%

Professeur: BOUVRY Pascal, KIEFFER Emmanuel

Information Security Basics

Module: Module 1.5 (Semestre 1)

ECTS: 3

Objectif: The objective of this course it to provide an introduction to information security

Course learning outcomes:
* explain the role of security protocols in the design of secure systems;
* use the standard building blocks for security protocols: nonces, symmetric and asymmetric encryption, hash functions;
* compare symmetric vs public key cryptography
* classify attacks by attack scenarios and by attack goals
* describe weaknesses of historical ciphers: substitution, transposition, WWII ciphers
* describe basic modes of operation of block ciphers: ECB, CBC, Counter mode
* describe the RSA public-key encryption scheme and the RSA signature scheme

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Description: The goal of this course is to provide basic background in Cryptography and IT security and to show what expertise in these areas is available in the laboratory of Algorithms, Cryptography and Security (LACS) and CSC. The topics cover symmetric and public key cryptography and security of protocols

Modalité d'enseignement: The course is based on lectures

Langue: Anglais

Obligatoire: Oui

Evaluation: 50%: project
50%: homework

Professeur: RYAN Peter Y A, BIRYUKOV Alexei, CORON Jean-Sébastien

Reliable software-intensive systems

Module: Module 1.6 (Semestre 1)

ECTS: 3

Objectif: Our daily lives depend on software-intensive systems with reliability and safety requirements such as embedded systems for automotive and aerospace applications, telecommunication and industrial infrastructures, as well as a variety of critical business applications. The course introduces the fundamentals of the design and verification of reliable software systems and illustrates the concepts with practical examples from the automotive, aerospace and industrial domains. The techniques and concepts learned in the course will be applied through practice exercises and a project.

Course learning outcomes:

- Know the types of applications having dependability constraints
- Understand the threats to and means of dependability such as redundancy and diversity
- Learn the main techniques, standards and processes to develop dependable software-intensive systems with illustration in the field of automotive and aerospace systems
- Understand what model-driven software engineering for dependable embedded systems entails
- Be able to assess the dependability with analytical models
- Understand when formal methods are appropriate verification techniques and what to expect from them. Get to know industrial applications of formal methods and existing tools
- Learn how to implement fault-tolerance mechanisms to increase the robustness of an application
- Get insights into how machine learning may reshape the design and verification of software-intensive systems

Description:

1. Introduction to dependability
   - Dependability attributes, means, and threats
   - Concepts of faults, errors, failures
   - Classification of SW/HW faults, and their characteristics
   - The importance of the fault-hypothesis
   - Fail-silence, fail-safe and fail-operational requirements: illustration with ADAS systems
   - Example of redundant architectures: 2-out-of-3, Triple Modular Redundancy, etc

- Illustration: Boeing 777 flight control system

2. Design and implementation of critical embedded systems
   - Critical embedded system architecture and technologies
   - Safety standards for systems and tools
   - Verification, validation and certification
   - Trend towards Model-Driven Engineering
3. Means to achieve and evaluate dependability
   - A focus on redundancy and diversity
   - Protecting from HW, protecting from SW faults
   - Software fault tolerance techniques: NVP, recovery blocks, data protection, using watchdog and self-test, etc
   - Dependability measures: MTTF, failure rate, reliability, MTTR, MTBF and availability
   - Dependability assessment by means of fault-tree analysis
4. Reliable computing platforms
   - Electrical and Electronic (E/E) architectures in transportation systems: automotive & avionics
   - Ethernet based communication architectures: topologies and protocols
   - OS services and real-time scheduling on modern platforms
   - Illustration: reliable computing platforms for automated driving applications
5. Machine learning for the design and verification of reliable software systems
   - Relevant concepts and techniques in machine learning (ML)
   - Main use-cases for ML: speeding up computation with prediction, generative models, configuration strategies
   - Illustration of the three use-cases in automotive E/E architecture design

Modalité d'enseignement: Each class includes a lecture followed by hands-on exercises or practical works on computers.

Langue: Anglais

Obligatoire: Oui

Evaluation:
- Practicals and project: 40%
- final exam: 60%

Remarque:
- A. Avizienis, J.C. Laprie, B. Randell, "Dependability and its threat: a taxonomy", IFIP Congress Topical Sessions 2004.
- R. Natella, D. Cotroneo, and H. S. Madeira, "Assessing dependability with software fault injection: A survey," ACM Comput. Surv., vol. 48, no. 3, pp. 44:1–44:55, Feb. 2016.

Professeur: NAVET Nicolas, HU Tingting

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Semestre 2

Algorithmic Decision Theory

Module:	Module 2.1 (Semestre 2)
ECTS:	5
Objectif:	The objective of this course is to introduce students to ADT, a new interdisciplinary field at the intersection of decision theory, discrete mathematics, theoretical computer science and artificial intelligence. ADT proposes new ideas, approaches and tools for supporting decision making processes in presence of massive databases, combinatorial structures, partial and/or uncertain information, and distributed, possibly inter-operating, decision makers. Such problems arise in several real-world decision making problems such as humanitarian logistics, epidemiology, risk assessment and management, e-government, electronic commerce, and the implementation of recommender systems
Course learning outcomes:	* Recognise and formulate problems that relate to Algorithmic Decision Theory (ADT) * Identify the operational complexity issues arising in ADT * Adapt some of the classical Operational Research and Decision Aid solving strategies to the ADT context * Implement an ADT solver for selected case studies
Description:	Varying with the main focus and the interest of the students, the content of the lectures may concern: 1) General introduction to algorithmic decision theory 2) Who wins the election ? An introduction to social choice theory 3) How to rank the candidates ? Main ranking rules 4) Building and aggregating performance measures 5) The American way: Multiple attributes value theory MAVT 6) The European way: Multiple criteria based decision aid MCDA 7) Best choice recommendation algorithms 8) Sorting and clustering algorithms 9) Inverse Decision Analysis
Modalité d'enseignement:	The course is organized as a series of theoretical lectures with hands-on exercises intermixed
Langue:	Anglais
Obligatoire:	Non
Evaluation:	The students may choose either to elaborate a project: 100% or to write a final exam: 100%
Remarque:	The following textbooks will be used in this course: - Evaluation and decision models: A critical perspective, D. Bouyssou, Th. Marchant et al. Kluwer 2000 - Aiding decisions with multiple criteria, D. Bouyssou, E. Jacquet-Lagrèze et al., Kluwer 2002 - Evaluation and decision models with multiple criteria: Stepping stones for the analyst, D. Bouyssou, Th. Marchant et al. Springer 2006

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Professeur: BISDORFF Raymond Joseph

Algorithms for Numbers and Public-Key Cryptography

Module: Module 2.2 (Semestre 2)

ECTS: 5

Objectif: The objective of this course it to provide an introduction to algorithms for numbers and their use in public-key cryptography.

Course learning outcomes:
* describe the basic algorithms for numbers: gcd, CRT, modular exponentiation, primality tests.
* list some basic properties of numbers: modular computation, Euler function, generators of multiplicative groups.
* explain the RSA algorithm for public-key encryption and signature.
* explain basic security proofs for public-key encryption and signature.

Description:
* basic basic algorithms for numbers: gcd, CRT, modular exponentiation, primality tests, etc.
* the RSA algorithm for public-key encryption and signature.
* main security notions for encryption and signature.
* basic security proofs for public-key encryption and signature.

Modalité d'enseignement: The course is based on lectures and practical sessions

Langue: Anglais

Obligatoire: Non

Evaluation: The final grade is based on homework only.

Professeur: CORON Jean-Sébastien

Dependable Systems

Module: Module 2.3 (Semestre 2)

ECTS: 5

Objectif: The course will introduce, using a software engineering perspective, the fundamentals of dependable systems: standards for dependability, fundamental concepts of dependability, engineering activities and dependability attributes and means, fault prevention, tolerance, removal and forecasting. Some reusable dependability mechanisms will be studied conceptually and implementation means to support dependable systems development will be presented and used.
A dependable system development project will be made and used for applying the concepts learned.

Course learning outcomes:

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Description:
1. Student/Teachers presentation
Lecture general rules - Introduction to Dependability
2. Critical Systems
Software Fault tolerance - big picture
3. Terminology
Dependability evaluation and assessment - Fault-tree modelling and analysis
4. Continuation
5. FT Basic Concepts Redundancy techniques and Reliability evaluation
Recovery Block
6. Measures: MTTF, failure rate, reliability, MTTR, MTBF, and availability
Fault-tree analysis and reliability block diagram - Redundancy
7. Exception Handling - N-Version Programming
8. Exception handling in Java
Backward and Forward recovery
9. Architectural issues in Software Fault-Tolerance
Analysis of Software Fault tolerance
10. N-version programming
Decision algorithms
Fail fast component
11. Dependability Modeling
Mini Project: dependability analysis (DRET)
12. Mini Project: modelling (Coordinated Atomic Actions)
13. Mini Project: implementation (CAA-DRIP framework)

Modalité d'enseignement: The course is organized as a series of theoretical lectures intermixed with hands-on exercises and practical work on computers

Langue: Anglais

Obligatoire: Non

Evaluation: continuous evaluation: 1/6
project deliverables: 2/3
project presentations: 1/6

Professeur: NAVET Nicolas, HU Tingting

Formal Methods

Module: Module 2.4 (Semestre 2)

ECTS: 5

Objectif: In this course, we will study a collection of techniques that are essential in the construction of large and highly reliable systems

Course learning outcomes:
* Explain the informal meaning of the basic process algebra operators
* Relate this informal interpretation to its formalization through axioms and transition rules
* Specify the behaviour of simple concurrent systems using process algebra
* Explain the meaning of a temporal logic formula
* Specify system requirements using the studied logics
* Evaluate the logic formulas on labelled transition systems

	* Explain the fundamental concepts in model-driven software development such as model, meta-model, modeling language, abstract syntax and semantics * Define a simple modeling language by giving its syntax and semantics * Evaluate and compare current model-driven technologies
Description:	The course will focus on the principles and applications of the following formal methods: * Alloy - a declarative modeling language based on first-order logic, for expressing complex structural constraints and behavior. The Alloy Analyzer is a constraint solver that provides fully automatic simulation and checking. The motivation for the Alloy project was to bring to Z-style specifications (Z being another formal language) the kind of automation offered by model checkers. * Process Algebras - Process Algebra is a formal description technique for complex computer systems, especially those involving communicating, concurrently executing components. It is a subject that touches many topic areas of computer science and discrete math. * Protocol Verification - a specification language based on process algebra extended with abstract data types is used to describe communicating systems. Interesting properties about the systems are expressed as temporal logic formulas. Model checking is employed as a method to formally verify whether the model defined by the system satisfies the properties. We have chosen these methods because they are based on complementary approaches for formal reasoning about systems. The course is tool-oriented in the sense that automatic tool support will be an essential part of the teaching units whenever possible. In this sense the lecture provides a more hands-on approach to theoretical concepts compared to courses in the first semester. Many examples and real-life case studies drawn from a variety of domains such as computer security, communicative systems and software engineering will be presented
Modalité d'enseignement:	The course is organized as a series of theoretical lectures with hands-on exercises intermixed
Langue:	Anglais
Obligatoire:	Non
Evaluation:	Final exam: 70% Assignments: 30%
Professeur:	KELSEN Pierre, MAUW Sjouke, PANG Jun

Big Data Analytics

Module:	Module 2.5 (Semestre 2)
ECTS:	5
Objectif:	The lecture provides an entry point to large-scale data management and distributed computing principles in recent NoSQL architectures. We start with an overview of distributed file systems and MapReduce in Apache Hadoop and then move on to more advanced analytical tasks based on the machine-learning libraries in Apache Spark. The lecture serves as an ideal basis for further topics in this area (such as Master seminars, projects and theses).
Course learning outcomes:	- Students become familiar with the usage of recent Big Data platforms such as Apache Hadoop and Spark - Student obtain an overview of both the theoretical foundations and practical applications of various Big Data and Machine Learning algorithms

- Students learn how to approach and solve different data-analysis tasks by a number of programming exercises with real-world datasets

Description:

The course consists of a combination of theory-oriented lectures and practical exercises, through which the students are guided by a series of real-world use cases and hands-on examples. Specifically, we focus on the following topics:

- Distributed File Systems (DFS) and MapReduce in Apache Hadoop
- Resilient Distributed Data (RDD) objects and DataFrames in Apache Spark
- Implementation of complex DataFlow programs in Spark using Scala
- Performing advanced analytical tasks in Spark's MLlib:
  - Distributed clustering and classification of objects
  - Decision trees and random forests
  - Recommender systems via matrix factorization
  - Text analysis via latent semantic indexing
  - Geospatial data analysis
  - Social-network analysis

Modalité d'enseignement: The course offers both theory lectures and practical exercise sessions. The lectures serve as theoretical basis for the algorithmic concepts which we then apply during the practical sessions. The solutions to the exercises are developed and demonstrated interactively with the tutors.

Langue: Anglais

Obligatoire: Non

Evaluation: Practical exercises: 50%
Final written exam: 50%

Professeur: THEOBALD Martin

Information Theory and Coding

Module: Module 2.6 (Semestre 2)

ECTS: 5

Objectif: The objective of this course is to provide an understanding of fundamental communication limits and means of approaching them

Course learning outcomes:

* Compute fundamental communication limits
* Compress simple information sources
* Describe the fundamental blocks of digital communication systems (physical layer)
* Encode binary information with a convolutional code

Description:

The course contains:

- Shannon's concept of mathematically quantising information and uncertainty for a communication setup
- Explanations that both compression and error free transmission have an extremal rate which can be computed via entropy and mutual information
- Methods to compress sources
- Digital transmission techniques and their complexity for inter-symbol-interference channels
- Simple error correction codes, convolutional codes

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Modalité d'enseignement:	The course is organized as a series of theoretical lectures intermixed with exercises/ homework.
Langue:	Anglais
Obligatoire:	Non
Evaluation:	Final Exam: 75% Homework: 25%
Professeur:	SORGER Ulrich

Intelligent Agents I

Module:	Module 2.7 (Semestre 2)
ECTS:	5
Objectif:	The objective of this course is to introduce students to knowledge representation and reasoning methods for intelligent agent systems.
Course learning outcomes:	* Explain the nature and roles of different formal theories used for individual reasoning and autonomous agents, such as various modal logics, belief change formalisms, or methods for uncertainty management * Define and apply the basic concepts of one or two non-classical logics (e.g. modal logic and default logics), notably their semantics and proof calculi * Model intelligent systems using non-classical logics * Explain the philosophical foundations of individual reasoning.
Description:	The course has 4 parts: 1. Modal logics for agent reasoning 2. Conditional logic 3. Natural language semantics & non-monotonic logic 4. Formal argumentation
Langue:	Anglais
Obligatoire:	Non
Evaluation:	Final exam 65%; Homework 35%.
Professeur:	VAN DER TORRE Leon, STEEN Alexander

Knowledge Discovery and Data Mining

Module:	Module 2.8 (Semestre 2)
ECTS:	5
Objectif:	We understand Data Mining (Knowledge Discovery) as a life-cylce process from data to information and insights. In times of Big data, Data Mining has become a central interest both for industry and academia. In this course, we discuss several data-related aspects like preprocessing or pricacy as well as selected aspects of Machine Learning. An expansive

	definition of Data Mining, which is the derivation of insights from masses of data by studying and understanding the structure of the constituent data, and selected applications complete the course.
Course learning outcomes:	* Explain the fundamental concepts of data mining and knowledge discovery * List the properties of data relevant for deriving interesting and useful information/observation from that. * Explain machine learning algorithms and strategies to deploy the discovered results * Argue the importance of domain knowledge during the data analysis with its scope and limitations
Description:	* Definition and Process. * Data Mining, Data Science, and the Big Data Hype. * Data Quality and Preprocessing * Data Privacy and Security. * Data and Information Visualization. * Machine Learning for Clustering, Classification, Association Discovery, Sequential Pattern Analysis, and/or Time Series Analysis.
Modalité d'enseignement:	The course is organised as a lecture with integrated exercises. It follows the "Information Retrieval" course and will itself be continued in Semester 3 by a more intensive discussion about "Machine Learning". Each participant must be inscribed via Moodle. Course material will be uploaded regularly.
Langue:	Anglais
Obligatoire:	Non
Evaluation:	60% oral or written examination; 40% midterm tests
Remarque:	**Selected references:** * M. Berry, G. Linoff: Mastering Data Mining, John Wiley & Sons, 2000. * U. Fayyad, G. Piatetsky-Shapiro, P. Smyth, R. Uthurusamy: Advances in Knowledge Discovery and Data Mining, AAAI/MIT Press, 1996. * J. Han, M. Kamber: Data Mining: Concepts and Techniques, 2nd edition, Morgan Kaufmann, ISBN 1558609016, 2006. * I. Witten, E. Frank, M. Hall: Data Mining: Practical Machine Learning Tools and Techniques, 3nd Edition, Morgan Kaufmann, 2011.
Professeur:	SCHOMMER Christoph

Networked Feedback Systems

Module:	Module 2.10 (Semestre 2)
ECTS:	5
Objectif:	The objective of this course is to introduce students to networked feedback structures in interconnected information and communication technology in technical environments

Course learning outcomes:	* Identify feedback structures, decompose them and formulate continuous and sequential dynamics * Determine reliable discrete or continuous enclosures for structure-variations and uncertainties * Design controls with guaranteed dynamic tolerances * Design reliable automata in technical context
Description:	Introduction - networked feedback and feedforward - sampling, scheduling and communication - continuous system representations - dynamics and approximations - systems over the binary field - binary transfer function and stability - combined systems and decompositions - feedback design in multiloop structures
Modalité d'enseignement:	The course is organized as a series of lectures with practical simulation exercises
Langue:	Anglais
Obligatoire:	Non
Evaluation:	Final Exam: 70% Project: 30%

Optimisation for Computer Science

Module:	Module 2.11 (Semestre 2)
ECTS:	5
Objectif:	Different problems have different nature. In terms of complexity some problems are called intractable and can not be solved by classical computers. But there are also many other aspects of the nature of optimisation problems such as linearity, convexity, continuity, dynamicity, randomness that may lead the choice of different optimisation techniques
Course learning outcomes:	* Characterize problems * Identify the key concepts related to optimisation techniques * Use optimization frameworks * Implement optimization algorithms * Validate optimization algorithms and results * Validate approaches for solving optimization problems
Description:	This lecture confront the students to real instances of such problems. They are first asked to model the problem and next proposed solutions include exact methods, relaxations, approximations, heuristics and meta-heuristics. And these practical study cases are supported by the theoretical lectures on Problem Solving (1st semester)
Modalité d'enseignement:	The students are directly involved into research teams helping them to solve real problems illustrating the various approaches.

A mid term review is organized during which students present the problem model and at the end of the course, students will present the final results

Langue: Anglais

Obligatoire: Non

Evaluation: Project: 100%

Professeur: BOUVRY Pascal

Principles of Security Engineering

Module: Module 2.12 (Semestre 2)

ECTS: 5

Objectif: This course aims at teaching students the fundamental principles of engineering secure systems.More specifically the goals are:
- to give a broad understanding of how secure systems are designed and evaluated.
- to explain key security concepts and mechanisms as well as pitfalls.
- to describe how systems are attacked and defended: typical threats, vulnerabilities and counter-measures.
- to take a "system-based" approach, i.e. to take account of the whole system rather than just the technical, e.g. crypto algorithms and protocols

Course learning outcomes:
* Evaluate security systems and identify their vulnerabilities
* Propose countermeasures to vulnerabilities and attacks
* Evaluate security requirements

Description:
Intro (concepts, principles)
Policies and models (access control etc)
Information flow (enforceable policies)
Socio-technical aspects.
Physical security, locks, tamper resistance/evidence
Copyright, DRM, watermarking.
Privacy (Jonker)
Network security (malware, phishing, botnets…)
Security evaluation and testing
Advanced Protocols (PAKE, QKD, ZK, OT, …)
Misc topics (API, TCM, attack trees, game theory, ECC, MDD,…)
Secure voting systems

Modalité d'enseignement: lectures plus the mid-term exam

Langue: Anglais

Obligatoire: Non

Evaluation: The course will be evaluated based on a report (50%) and presentation (50%) at the end of the course

Professeur: RYAN Peter Y A

Quality of Service in Computer Networks

Module:	Module 2.13 (Semestre 2)
ECTS:	5
Objectif:	The objective of this course is to introduce quantitative measures for network performance (like throughput, error correction, delays, routing) for different network topologies to be applied to security protocols. It also sensibilises for differences between static and dynamic networks as well as centralised and de-centralised topologies concerning reliability and trust issues
Course learning outcomes:	* Describe performance metrics and list parameters of dedicated networks and protocols. * Name and reproduce definitions of relevant parameters that theoretically characterise the communication traffic incl. queues, routing and error probabilities * Analyze existing solutions according to their capabilities for throughput, error rate and security * Construct and adapt real world communication architectures and protocols with given Quality of Service requirements on the basis of the theoretical concepts
Description:	1. Intro 2. Recap: Random Processes 3. Recap: Homogeneous Markov Chains 4. Commutation Systems: Components and modules 5. Communication Traffic as Random Process 6. Routing and Flow Control 7. Introduction to Queueing Theory 8. QoS in TCP/IP
Modalité d'enseignement:	The course is organised as a series of lectures with dedicated time slots for exercises
Langue:	Anglais
Obligatoire:	Non
Evaluation:	70% Final Exam 30% Successful preparation, submission and active participation in exercise sessions
Professeur:	ENGEL Thomas

Symmetric Key Cryptography and Security of Communications

Module:	Module 2.14 (Semestre 2)
ECTS:	5
Objectif:	Introduction to symmetric cryptography and applied cryptography: the students will learn design and analysis principles for symmetric crypto primitives (ciphers, hash functions, MACs). They will be also introduced to the aspects of practical application of cryptography

Course learning outcomes:	* apply differential power analysis (DPA) to smartcard implementations of ciphers * explain hardware and software implementation issues for cryptographic primitives and security protocols * evaluate affects of cryptanalysis, side-channel attacks and traffic analysis on cryptographic primitives
Description:	The goal of the first half of this course is to introduce students to symmetric key cryptography, showing how ciphers and hash functions are designed and cryptanalyzed. We will start with some historical examples (M-209, Enigma) and then follow to the present day standards (DES, AES, KASUMI, SHA, GSM-A5/1, RC4, Bluetooth-E0, SNOW3G). In the second half of the course we will discuss broader applied cryptography and network security topics such as side-channel attacks, crypto-hacking, anonymity networks and digital currencies.
Modalité d'enseignement:	The course is organized as a series of theoretical lectures accompanied with practical exercise sessions
Langue:	Anglais
Obligatoire:	Non
Evaluation:	The grade for this class will be an average of the homework assignments given every week. Assignments are to be solved individually. There will be no final exam
Professeur:	BIRYUKOV Alexei

Introduction to Static Program Analysis

Module:	Module 2.15 (Semestre 2)
ECTS:	5
Objectif:	Through this course the student will learn the fundamental theoretical concepts and techniques of static analysis. The student will be able to use this knowledge to implement static analyses to solve concrete problems.
Course learning outcomes:	* The student should be able to critically read publications related to static analysis (research paper, etc.) * The student should be able to select an adapted approach to solve a specific static analysis problem * The student should be able to implement static analysis techniques
Description:	Static analyses are used in various situations, from compiler code optimization to security analysis of Android applications. This course provides the concepts and techniques underlying static program analysis. Topics include forward/backward data-flow analysis, inter-procedural analysis, pointer analysis and call graph construction. A particular focus will be given to recent and advanced techniques such as Android bytecode static analysis for security. The course will mix theory and practice. Students will implement simple analyses and complete a course project.
Modalité d'enseignement:	The course is organized as theoretical lectures intermixed with labs and also includes a final project.

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Langue: Anglais

Obligatoire: Non

Evaluation: 50% assignments and project
20% readings and exercises
30% exam(s)

Remarque: Maybe needed textbooks

Professeur: LE TRAON Yves, BARTEL Alexandre

Software Vulnerabilities: Exploitation and Mitigation

Module: Module 2.4 (Semestre 2)

ECTS: 5

Objectif: Through this course students will understand software vulnerabilities from memory corruptions to command injections.
Both the defensive and offensive aspects will be studied: students will learn how to mitigate, find aNd exploit software vulnerabilities.

Course learning outcomes: * Students should be able to critically read publications related to software vulnerabilities (research paper, etc.)
* Students should be able to identify vulnerable code and write robust code preventing vulnerabilities from being introduced in the code.
* Students should be able to exploit simple known vulnerabilities.

Description: Our lives and our societies rely on computer programs (software).
Every day, we use devices running software written in millions of lines of code because it makes our lives easier.
However, the complexity and the size of existing software, added to the fact that humans write most of the software,
introduce bugs.
Some of these bugs, called vulnerabilities, can be exploited by an attacker to compromise a device or leak information.
Have you ever wondered how programmers make their code more robust to avoid introducing vulnerabilities?
Have you ever wondered how attackers can find vulnerabilities and exploit them to take control of a remote device on
the Internet or of your smartphone?
Have you ever wondered how attacker can dump an entire database containing personal information about millions of
users?
In this course, you will learn both how to defend against vulnerabilities and how to exploit vulnerabilities.
This course covers memory corruption vulnerabilities such as buffer or heap overflow, type confusion, or use after free.
It also covers more high level vulnerabilities such as SQL injection or confused deputy.

The course will mix theory and practice.

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On the offensive side, you will implement simple programs to exploit vulnerabilities.
On the defensive side, you will correct vulnerable programs to prevent exploitation but also learn how to use techniques such as fuzzing to find new vulnerabilities.

Modalité d'enseignement:	The course is organized as theoretical lectures intermixed with labs and also includes a final project.
Langue:	Anglais
Obligatoire:	Non
Evaluation:	Rating: 50% assignments and project 20% readings and exercises 30% final exam
Professeur:	BARTEL Alexandre, LE TRAON Yves, KLEIN Jacques

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Semestre 3

Intellectual Property

Module:	Module 3.1 (Semestre 3)
ECTS:	3
Objectif:	The objective of the course is to promote greater awareness of intellectual property as one of the most important assets of a company in the global market environment
Course learning outcomes:	* Explain in what sense intellectual property is an asset for a company * Differentiate between patents, trademarks and copyright * Compare different types of licences
Description:	I. Intellectual property an asset of your company Ii. Trade secrets Iii. What is an invention? Iv. What is a patent of invention? V. Invention report and record form Vi. From the invention to a patent Vii. Patent grant procedures Viii. Patent rights & patent infringement Ix. Patents as a source of information X. Trademarks Xi. Registered designs & design patents Xii. Copyright Xiii. Licensing of ip-rights Xiv. The intellectual property audit
Modalité d'enseignement:	The course is organized as a series of theoretical lectures with hands-on exercises intermixed
Langue:	Anglais
Obligatoire:	Oui
Evaluation:	Final Exam: 70% Project: 30%
Professeur:	KIHN Pierre

Coding theory

Module:	Module 3.3 (Semestre 3)
ECTS:	4

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Objectif: This course aims to provide a deep understanding of the theory of error correcting codes. Specific topics are: Use of algebraic properties in engineering science; practical ways to approach Shannon's bounds

Course learning outcomes:
* Compute and bound fundamental parameters of error correcting codes
* Construct, encode, and decode Reed-Solomon and binary BCH Codes
* Partition a code space and employ this for the construction of error correcting codes
* Use belief propagation for error correction

Description:
Introduction
Linear Codes
Decoding
Bounds
Trellis Description
Reed Solomon and BCH Codes
(Generalised) Concatenated Codes
The Turbo Principle

Modalité d'enseignement: The course is organized as a series of theoretical lectures intermixed with exercises/homework

Langue: Anglais

Obligatoire: Oui

Evaluation:
Final Exam: 75%
Project: 25%

Professeur: SORGER Ulrich

Advanced Project Management

Module: Module 3.2 (Semestre 3)

ECTS: 3

Objectif: The objective of this course is to familiarize students with advanced techniques for project management, both in theory and in practice

Course learning outcomes:
* Describe the nine main knowledge areas of Project Management
* Identify the main characteristics and elements in an interdisciplinary project
* Define scope and construct the work breakdown structure of a project
* Select and employ project management standards and methods

Description:
Introduction to Project Management (review)
Project Scope Management
-Define project scope
Project Work Breakdown Structures (WBS)
Project Planning
-Develop project WBS and planning
Monitoring and Controlling Projects

-Project rescoping and replanting
Project Closure

Modalité d'enseignement: The course is a lecture including a project case study where students will research and development on selected subjects in advance project management methodologies and standards. We use the chalkboard, presentation slides, e-Learning support and real projects to illustrate the need of project management

Langue: Anglais

Obligatoire: Oui

Evaluation: The course examination is oral. Students will defend in small groups of 2 to 4 their content research results on the assigned Project Management process, methodology or standard. The examination takes place in winter and summer semester (re-exam)

Remarque:

Professeur: CORONADO Sergio

Computational Statistics

Module: Module 3.4 (Semestre 3)

ECTS: 4

Objectif: The objective of this course is to introduce the students to the R language and environment for statistical computing and graphics (a GNU project). In particular, the course proposes effective data handling and storage solutions as well as useful operators for calculations on arrays, in particular matrices. A selected collection of intermediate tools for data analysis, graphical facilities for data analysis and display either on-screen or on hardcopy will be illustrated from examples of statistical analyses. Finally, the course will by the way familiarise the students with a well-developed, simple and effective programming language which includes conditionals, loops, user-defined recursive functions and input and output facilities

Course learning outcomes:
* Recognise data analysis and graphics problems that may be efficiently solved with the help of the R resource.
* Handle efficiently large statistical data sets
* Compute statistical results for data analysis case studies
* Construct print-ready and interactive graphics for data exploration case studies
* Design and implement data analysis algorithms and graphics in the R language

Description: Varying with the main focus and the interest of the students, the content of the lectures may concern:
1) Introduction to statistical computation tools in Python, C++ and R
2) Traps and watch, as well as best practice for generating uniform random numbers
3) Implementing various random variable generators
4) Monte Carlo simulation and integration techniques
5) Incremental quantiles estimation
6) Random graphs generators
7) Statistical diagram drawing tools

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Modalité d'enseignement:	The course is organized as a series of theoretical lectures with hands-on exercises intermixed
Langue:	Anglais
Obligatoire:	Non
Evaluation:	The students may choose either to elaborate a project: 100% or to write a final exam: 100%
Remarque:	The following textbooks will be used in this course: - William H. Press, Saul A. Teukolsky, William . Vetterling, Brian P. Flannery, Numerical Recipes: the Art of scientific computing 3rd Edition, Cambridge University Press 2007 - W. John Braun, Duncun J. Murdoch, A first course in statistical programming with R, Cambridge Universivity Press 2007 - Jim Albert, Bayesian Computation with R, Springer 2007 - Christian P. Rober, George Casella, Introducing Monte Carlo Methods with R, Springer 2010
Professeur:	BISDORFF Raymond Joseph

Cryptocurrencies and the Cryptographic Blockchain

Module:	Module 3.5 (Semestre 3)
ECTS:	4
Objectif:	The blockchain is a paradigm shift for cryptographic protocols. The objective of the course is to understand the mechanism of the blockchain and its applications to cryptocurrencies such as Bitcoin and to smart contracts as in Ethereum.
Course learning outcomes:	*Hands on knowledge of some cryptographic primitives used in the blockchains *In-depth study of blockchain technologies
Description:	* The blockchain and Byzantine fault tolerance. * Proofs of work: design and implementation * Cryptocurrencies: the Bitcoin protocol. * Blockchain-based smart contracts: Ethereum * Zero-Knowledge Succinct Non-interactive Argument of Knowledge (zk-SNARK) and the Zcash cryptocurrency protocol.
Modalité d'enseignement:	The course is based on projects that can be done in pairs and the final presentation.
Langue:	Anglais
Obligatoire:	Non
Evaluation:	the final grade is based on the grade for the project and technical quality of the final presentation.
Professeur:	BIRYUKOV Alexei, CORON Jean-Sébastien

Advanced Database Topics

Module:	Module 3.7 (Semestre 3)

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ECTS: 4

Objectif: The seminar provides an overview of current research topics and trends in the broad area of databases. We cover a variety of advanced database aspects such as temporal and probabilistic database models, distributed databases, graph databases, as well as respective applications in the context of information extraction, natural-language processing (NLP) and machine learning (ML). The seminar serves as an ideal basis for further topics in this area (such as Master projects and theses).

Course learning outcomes:
- Students become familiar with recent trends and research topics in the broad area of databases and applications
- Students learn which approaches and tools are best suited for a given problem setting
- Students learn how to prepare both an oral presentation and a written report on a given research subject
- The course serves as an ideal preparation for further Master projects and theses in this area

Description: The seminar is organized in the form of weekly student presentations based on the recent literature (such as research papers, journal articles and/or book chapters). Specifically, we focus on the following topics and applications:
- Probabilistic and temporal databases
- Distributed databases
- Graph databases
- Applications:
  - Indexing and query processing
  - Sampling and approximation
  - Entity resolution and deduplication
  - Data integration and fusion
  - Provenance management
  - Information extraction (with applications to NLP and ML)

Modalité d'enseignement: The course offers both theory lectures and tutored exercise sessions.

Langue: Anglais

Obligatoire: Non

Evaluation: Seminar Presentation: 40%, Final Written Report: 40%, Active Participation: 20%

Professeur: THEOBALD Martin

Autonomous Robot Software

Module: Module 3.8 (Semestre 3)

ECTS: 4

Objectif: After the course, the students will have:
1. an overview of software and programming issues in robotics
2. An overview of knowledge representation and reasoning challenges for robotics
3. hands-on experience with ROS software and Nao robots in the CSC robolab

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Description: This course is a collaboration between computer science (Leon van der Torre) and engineering (Holger Voos)
The course consists of fifty percent lectures and fifty percent practicals. In the lectures, Holger Voos gives an introduction to robotics, and Leon van der Torre discusses knowledge representation and reasoning for robotics. For the practicals, the students learn how to use ROS for building software for the Nao robots. ROS software is the de facto standard robot framework, widely used for component based robotic software engineering. The CSC robotlab is a collaborative research between CsC and SnT departments of the University of Luxembourg. We use NAO robots for research and education. For details checkout the project and publication sections on our website.

http://robolab.gforge.uni.lu/

Modalité d'enseignement:
- 7 lectures for theory
- 7 lectures for practicals
- 1 week presentations
Each week, there will be a fixed afternoon where the CSC robolab is reserved for the students

Langue: Anglais

Obligatoire: Non

Evaluation: Project based, the students have to write some software and give a presentation on it

Remarque: Teaching material:
- theory: Background material in textbooks
 - R. Arkin: Behavior-based Robotics (Complex Adaptive Systems). MIT Press, 1998.
 - R. Murphy: Introduction to AI robotics. MIT Press, 2001.
 - K. Berns, E. von Puttkamer, Autonomous Land Vehicles: Steps towards Service Robots
- practicals: ROS wiki

Professeur: VOOS Holger, OLIVARES MENDEZ Miguel Angel, SANCHEZ LOPEZ Jose Luis

Intelligent Agents II

Module: Module 3.9 (Semestre 3)

ECTS: 4

Objectif: The objective of this course is to introduce students to formal methods for normative reasoning for agents (deontic logic)

Course learning outcomes: * Capture the intuition behind rules and regulations, and how they relate to real life scenarios. Explain the nature and roles of the formal theories used for collective reasoning and multiagent systems, such as game theory, social choice theory, normative reasoning, dialogue and argumentation

	* Define the basic concepts of one or two logics for collective reasoning (e.g. deontic logic, action logics), notably its semantics and its proof calculi * Model intelligent distributed systems using normative multiagent systems and deontic logic * Explain the philosophical foundations of collective reasoning
Description:	Lectures: - rules and regulations - standard deontic logic - input/output logic - project
Modalité d'enseignement:	The course is organized as a series of theoretical lectures intermixed with practicals
Langue:	Anglais
Obligatoire:	Non
Evaluation:	Part I - Rules and Regulations: Homework: 10% Project: 40%% Part II - Deontic Logic: Homework: 10% Final exam: 40%
Remarque:	**Literature:** Handouts will be distributed during the course. In addition, the handbook of deontic logic provides background material
Professeur:	VAN DER TORRE Leon, MARKOVICH Réka

Machine Learning

Module:	Module 3.10 (Semestre 3)
ECTS:	4
Objectif:	The course "Machine Learning" is part of a course trilogy that is preceded by a course on 'Information Retrieval' (Semester 1) as well as by a course on 'Knowledge Discovery and Data Mining' (Semester 2), respectively. Originally having been a subfield of Artificial Intelligence, Machine Learning has nowadays established as an own research direction, whose main concern is building mathematical models capable of learning from the sample data. This course provides a detailed overview of various machine learning algorithms and techniques,such as regression, classification, clustering, time series modeling, supervised, semi supervised and unsupervised learning, etc.

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Course learning outcomes:
- Learn the fundamental concepts of machine learning.
- Learn the foundations of artificial neural networks and deep learning.
- Optimize, evaluate and debug the machine learning algorithms.
- Learn strategies to implement your own machine learning project.

Description: The course is a mixture of lectures and practical studies. While one part of the course will continue to deepen the theoretical foundations, with special emphasis on the artificial neural networks and deep learning; the second part is devoted to practical implementation of machine learning algorithms. All concepts presented during the lectures will be implemented and interactively demonstrated in practical exercise sessions. The students will undertake team-based, real-world project assignments to gain hands-on experience. At the end of semester, a workshop will be organized, where the teams will present results, as well as strengths, and weaknesses of their approaches.

Modalité d'enseignement: Lectures and practical exercise sessions.

Langue: Anglais

Obligatoire: Non

Evaluation:
- 50% : Presentation and documentation of the project results.
- 50% : Written Test

Remarque: REFERENCES

- C. M. Bishop, Pattern Recognition and Machine Learning, Springer, 2006.
- I. Goodfellow, Y. Bengio, A. Courville, Deep Learning, MIT press, 2016.
- A. Zhang, Z. C. Lipton, M. Li, and A. J. Smola, Dive into Deep Learning, 2020.
- S. Raschka, and V. Mirjalili, Python Machine Learning, Third Edition, 2019.

Professeur: DESPOTOVIC Vladimir

Management of Information Security

Module: Module 3.11 (Semestre 3)

ECTS: 4

Objectif: The objective of this course is to prepare students to start a practical experience as Information Security Officer and to assume such responsibility in his future professional activities. The student will understand that her/his work consists mainly in the planning, coaching, designing of solutions and convincing both senior management and information users on the needs and effectiveness of security

Course learning outcomes:
* List typical tasks of a information security manager.
* Explain the standard approach to managing security (ISO 27001).
* Explain basics of information risk management (ISO 27005), like asset valuation, impact and occurrence assessment, risk treatment plans, risk acceptance.
* Apply a fast risk assessment method (by ENISA) to a small virtual organisation.
* Compare different approaches for risk assessment.

	* Assess metrics to measure security (ISO 27004) and tactics to implement security (ISO 27003). * Recognise practical aspects of an Information security policy, including incident management, business continuity management, asset classification, awareness rising. * Propose an information security policy for a small organisation.
Description:	This course presents the core requirements and guidelines of ISO standards on security management, risk assessment and risk management, security policies, and awareness raising: • Practical aspects of information security • Standard approach to managing security (ISO 27000, 27001, 27002, 27003, 27004, ...) • Basics of information risk management (ISO 27005), like asset valuation, impact and occurrence assessment, risk treatment plans, risk acceptance, ... • Applying a fast risk assessment method (e.g. ENISA) on a small virtual organisation SME and learning more detailed risk management method (e.g. TRICK-light). • Practical aspects of an Information security policy, including incident management, business continuity management, asset classification, awareness rising
Modalité d'enseignement:	The course is organized as a series of theoretical lectures with hands-on exercises and discussion of the solution of group and individual exercises intermixed
Langue:	Anglais
Obligatoire:	Non
Evaluation:	Final Exam: 50% Exercices: 50%
Professeur:	HARPES Carlo

Model-Driven Software Development

Module:	Module 3.12 (Semestre 3)
ECTS:	4
Objectif:	This course has two main objectives: first the student will be taught a firm theoretical foundation for the fundamental concepts in model-driven software development. Second the student will be confronted with current frameworks, tools and techniques in this field
Course learning outcomes:	* Explain the fundamental concepts of model-driven software development * Formally define a new modeling language via its syntax and semantics * Evaluate current techniques and frameworks in model-driven software development * Read and present research papers in the area
Description:	Introduction, Review of Alloy Fundamental Concepts: Models, Metamodels, Modelling Hierarchies; Syntax and Semantics of Modelling Languages, Denotational Semantics, Operational Semantics: Graph Transformations versus Alloy; Frameworks and tools: the Eclipse Modelling Framework (EMF); Graphical Modelling (Sirius); the Lightning Tool; the Unified Modelling Language (UML).

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Modalité d'enseignement: The course is organized as a series of theoretical lectures intermixed with hands-on exercises

Langue: Anglais

Obligatoire: Non

Evaluation: Final Exam: 60%
Project: 40%

Remarque: The following textbooks will be used in this course:
- Daniel Jackson, Software Abstractions, MIT Press, Revised edition, 2012.
- Anneke Kleppe, Software Language Engineering, Addison-Wesley, 2009.

Professeur: KELSEN Pierre

Selected Topics in Network and System Security

Module: Module 3.13 (Semestre 3)

ECTS: 4

Objectif: The objective of this course is an elaborated, active understanding of distributed vs. centralized communication security and privacy concepts and their application to cooperative environments. The course creates links between the fundamental concepts and applied scenarios with references to ongoing research activities within the SECAN-Lab research group.

Course learning outcomes:
* Describe existing concepts to set-up centralized and distributed secure communication systems and protocols.
* Name and reproduce definitions for quantitative parameters linked to anonymity, privacy and reputation systems
* Analyze and compare existing privacy-enabled systems for cooperative and non-cooperative environments
* Construct, adapt and assess real world communication architectures and protocols for a distributed cooperative communication problem

Description: This course will provide an overview of the topic of security and privacy in computer networks. Concrete topics and application scenarios can vary depending on the particular focus of the methods discussed.
Typically, the methods of SECAN-Lab involve data analytics for network management, software defined networking, machine learning, algebraic graph transformation, symbolic execution, device and network fingerprinting, deterministic and probabilistic medium access control, routing strategies applied to scenarios around vehicular communications, network management and forensics, cybersecurity, anonymity and privacy, financial technologies and others.

Modalité d'enseignement: The course consists of two to three parts:

In the first part, a set of lectures gives an introduction to the topics including some necessary background. If the number of students is not too large, it is followed by a second part, a seminar-style preparation of the state-of-the-art, where students give a presentation on the topics described above. The third part consists of a hands-on implementation to apply the developed knowledge in a concrete, research-oriented, scenario.

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Langue: Anglais

Obligatoire: Non

Evaluation: 70% Final exam
30% Assignments (presentation, written summary and practical results)

Professeur: ENGEL Thomas

Open Network Security

Module: Module 3.14 (Semestre 3)

ECTS: 4

Objectif: The goal of this course is to introduce challenges in securing computer systems and networks. The curse covers the foundations of system and network security. It introduces basic security and privacy concepts as building blocks for later specialization.

Course learning outcomes:
* Master the epidemiological models for malware propagation and network-centric attacks
* Assess the security of networks and software systems.
* Explain the techniques for worm containment and detection.
* List statistical and machine learning approaches for network traffic monitoring

Description: In the scope of this course, we explore the following topics:
Introduction and general concepts.
Definitions, security goals, attacker models.
Symmetric encryption.
Integrity protection.
Asymmetric encryption.
Certificates and public key infrastructure (PKI).
Authentication and key agreement.
Kerberos.
Security protocols (IPSec, DNSSec, Kerberos, SSH, TLS, etc.).
Spam, botnets, phishing.
Anonymity and privacy.
Machine learning and intrusion detection.
Wireless security.

Modalité d'enseignement: Lectures, exercises, practical design and implementation of lab experiments, presentation of own contributions

Langue: Anglais

Obligatoire: Non

Evaluation: Final exam, active participation in exercises, practical assignments and presentation.

Professeur: ENGEL Thomas

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Parallel and Grid Computing

Module:	Module 3.15 (Semestre 3)
ECTS:	4
Objectif:	Today, parallel computing is omnipresent across a large spectrum of computing platforms. At the microscopic level, processor cores have used multiple functional units in concurrent and pipelined fashions for years, and multiple-core chips are now commonplace with a trend toward rapidly increasing numbers of cores per chip. At this level, GPU also start to enter the area. At a more macroscopic level, one can now build clusters of hundreds to thousands of individual (multi-core) computers. Such distributed-memory systems have become mainstream and affordable in the form of commodity clusters. Furthermore, advances in network technology and infrastructures have made it possible to aggregate parallel computing platforms across wide-area networks in so-called grids. An efficient exploitation of parallel and distributed platforms requires a deep understanding of both architecture, software and infrastructure mechanisms and of advanced algorithmic principles. The aim of this course is thus twofold. It aims at introducing the main trends and principles in the area of high performance computing infrastructures, illustrated by examples of the current state of the art. It intends to provide a rigorous yet accessible treatment of parallel algorithms, including theoretical models of parallel computation, parallel algorithm design for homogeneous and heterogeneous platforms, complexity and performance analysis, and fundamental notions of scheduling and work-stealing
Course learning outcomes:	* Identify the key concepts related to parallel computing * Solve problems using a parallel decomposition * Use parallel programming platforms, models and frameworks * Implement algorithms using MPI
Description:	Parallel computing architectures Introduction to parallel computing using MPI Programming labs based on MPI on UL clusters
Modalité d'enseignement:	A couple of theoretical lectures are proposed to described parallel computing computing architectures, design and implementation methods. This lecture is intensive in terms of C/C++ programming coupled with parallel libraries such as MPI
Langue:	Anglais
Obligatoire:	Non
Evaluation:	Project: 100%
Professeur:	VARRETTE Sébastien, PINEL Frédéric

Security Modelling

Module:	Module 3.16 (Semestre 3)
ECTS:	4
Objectif:	The objective of the course is to provide an overview of techniques used to model and analyze the security of systems. After successful completion of this module the student should be able to - understand the role of modelling in the design and analysis of secure systems - understand the role of modelling in defining security properties and attacker capabilities. - select a suitable modeling technique for a given problem - apply a given modelling technique to a specific domain or problem - assess the security of a given system through its modeling - compare modelling techniques with respect to expressive power and suitability for a given domain - identify the limitations of modelling techniques with respect to real-world security
Course learning outcomes:	* select a suitable modeling technique for a given problem * apply a given modeling technique to a specific domain or problem * assess the security of a given system through its modeling * compare modeling techniques with respect to expressive power and suitability for a given domain * describe new trends in security modeling * identify the limitations of modeling techniques with respect to real-world security
Description:	The following topics will be presented during the class - The characterization of secrecy properties as process equivalence or indistinguishability. - Commitment schemes and zero-knowledge proofs - Quantum cryptography, in particular quantum key distribution - Verifiable voting schemes - Provable security
Modalité d'enseignement:	The course is organized as a series of 9 theoretical lectures and 4 seminar sessions. The lectures are mostly based on recent research papers. A set of exercises is proposed as a homework to be solved by the students. A set of topics will be proposed near the beginning of the course. Each student is asked to pick one topic and present it by giving a 20 min presentation. A research report, taking into account the feedback obtained during the seminar, will be written by the student.
Langue:	Anglais
Obligatoire:	Non
Evaluation:	Homework: 20% Presentation + research report: 80%
Professeur:	RYAN Peter Y A

Security Protocols

Module: Module 3.17 (Semestre 3)

ECTS: 4

Objectif: The objective of the course is to provide students with an in-depth knowledge of the methods and tools for the specification, design and analysis of security protocols in different domains

Description:

Review of basic cryptography

Protocol specification

Protocol execution model

Adversary Models

Security properties

Secrecy

Authentication

Privacy, Anonymity, Untraceability

Automatic Verification of Security Protocols

Non-Repudiation Protocols

Fair Exchange Protocols

Time permitting, one or more of the following topics will be covered.

Distance Bounding

RFID Protocols

Secure Multi-Party Computation Protocols

Modalité d'enseignement: The course is organized as a series of lectures with homework assignments

Langue: Anglais

Obligatoire: Non

Evaluation: Evaluation: Homework 30% + Final Exam 70%

Professeur: MAUW Sjouke, HORNE Ross James, RAMIREZ CRUZ Yunior

Selected topics in Artificial Intelligence

Module: Module 3.18 (Semestre 3)

ECTS: 4

Objectif: The objective of this course is to prepare the student for individual research work (e.g. a Master/ PhD thesis) in Artificial Intelligence, Knowledge Representation and Logic by studying research literature on a specific topic and possibly realizing a small project. It offers a gentle introduction into current research issues linked to the modeling of intelligent agents, paying special attention to those addressed in the Interdisciplinary Lab for Intelligent and Adaptive Systems (ILIAS).

Course learning outcomes:

* Analyze a specific research problem in Artificial Intelligence (AI) and existing ways to tackle it

* Explain and apply corresponding advanced techniques in AI

* Read, analyse, and discuss research papers in AI

* Present and explain research work in AI

The topics can vary. In the past years we have discussed causal reasoning, defeasible reasoning, real-world argumentation, story modeling, generalized reasoning under uncertainty, epistemic decisions, reasoning about actions, defeasible argumentation, general probabilistic reasoning, as well as explanation in AI.

Description: To deal with a higher number of students, the seminar in the WS 2020 (2nd half) will offer two parallel branches addressing two different themes:

STAI Branch I: "Knowledge Evolution - From belief revision and machine learning to theory dynamics".

The relevant knowledge of intelligent agents, or agent communities, is often incomplete, uncertain, speculative, incorrect, if not inconsistent. An important task for them is therefore to gather new information by observation, communication, experimental interaction, and induction/ theory construction. The resulting input, be it data with meta-data, or first- and higher-order structured knowledge, typically forces the agents to reassess or revise their previous attitudes towards beliefs and theories, which is a demanding task.

Problems related to the dynamics of knowledge are discussed in many disciplines, including Artificial Intelligence, Logic, Information theory, Stochastics/Statistics, not to forget Philosophy of Science, Epistemology, Cognitive Science, and Linguistics. Knowledge evolution is clearly a genuinely interdisciplinary topic. In AI, the main corresponding research areas are belief revision, nonmonotonic inference, probabilistic reasoning, and machine learning.

In this seminar we are going to read, discuss, and criticize a number of foundational and research-level texts dealing with concepts and formal techniques for modeling and analyzing knowledge evolution, all this from an interdisciplinary perspective.

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STAI Branch II: "AI & Ethics and Explainability: The debate on the ethics of AI"

The recent evolution of AI systems and their increasing use in sensitive contexts (e.g. e-health) or in applications with social and political implications (e.g. social networks, administrative decisions) have raised several concerns about the ethical consequences of AI, how ethics can be embedded into AI systems, and what are the values they should uphold. In addition, from a practical perspective, "engineering ethics" into AI systems raises a novel set of challenges pertaining to the autonomy of AI agents as well as the way they reason about ethics.

Explainability and understandability of AI systems are key issues related to AI Ethics. Many of the most successful existing AI systems rely on blackbox machine learning algorithms whose inner workings are opaque or non-understandable for humans. This makes these systems hard to design, debug, update, and control. The domain of eXplainable AI (XAI) emerged to make the decisions and behaviours of AI systems sufficiently explainable, thereby improving their trustworthiness and increasing their acceptability. The recent literature of XAI falls into mainly three sub-topics: machine learning interpretability, agent explainability, and understandable robots.

Problems related to AI ethics are discussed in many disciplines, including Ethics, Law, Psychology, Cognitive Science, Human-Computer Interaction, Philosophy, and of course, Artificial Intelligence.

Modalité d'enseignement:

Langue: Anglais

Obligatoire: Non

Evaluation: - 1 presentation (50%)

- Participation during lectures (15%)

- Course project (35%)

Professeur: WEYDERT Emil, STEEN Alexander, NAJJAR Amro

Software Engineering Environments

Module: Module 3.19 (Semestre 3)

ECTS: 4

Objectif: At the end of this course, the student should be capable to understand the concepts, principles and practices related to DevOps along with their role in the software engineering life cycle, both from a theoretical and practical viewpoint.

Course learning outcomes:

· **LO1:** Set up a Deployment pipeline for a particular software development project

· **LO2:** Define, and perform a classification of tools based on quality attributes

· **LO3:** Use and integrate existing tools

· **LO4:** Produce a scientific report

· **LO5:** Plan, coordinate, and report activities in a multi-participant project

Description:

DevOps (the combination of Development and Operations) is a new cultural shift that has emerged as response to the need of ensuring high quality for a particular software system, while reducing the time since a new change is introduced into such a software system until it makes it into production. In this manner, organizations aimed at applying this cultural shift need to make use of advanced software development methods. In this course, particular attention will be given to continuous integration, automated deployment and software delivery. These methods are chained one after the other, forming what is known as deployment pipeline.

Beside the software engineering aspects, DevOps also includes other two important dimensions: culture, and management. Culture corresponds to the required skills to be able to collaborate with other people in a professional manner, whereas management is related to the ability to find trade-offs and make decisions such that the expected outcomes are satisfy while respecting the imposed constraints. The three dimensions are equally important, so they are the focus of the course.

Modalité d'enseignement:

The course is centred around a project. The aim of the project is to let students incrementally develop a continuous delivery pipeline. Students are expected to deliver one or more components of such a pipeline by each milestone deadline.

In order to attain this objective, the course is organised as a combination of traditional lectures with in-class activities. The course starts by a series of lectures introducing the fundamental concepts and practices related to DevOps. Then practical sessions are organized such that teams report on their progress about the project. Thus, teams guided by the teaching staff, will not only design a DevOps pipeline, but also develop, extend or simply setup existing software engineering tools to achieve the implementation of such a pipeline and then demonstrate its functioning.

The number of students on each team will depend on the size of the class, but ideally, they will be made of up to 3 students.

Langue: Anglais

Obligatoire: Non

Evaluation:

· Project deliverables (40%)

·In-class assessment (20%)

· Project Checkpoints (20%)

·Project Peer review (20%)

Another method for repeat exams than the one indicated is to be used.

Remarque:

• DevOps: A Software Architect's Perspective, SEI, Addison-Wesley Professional; 1 edition (May 28, 2015).

• Continuous Delivery: Reliable Software Releases through Build, Test, and Deployment Automation
(Addison-Wesley Signature Series (Fowler)) Addison-Wesley Professional; 1 edition (August 6, 2010)

Professeur: GUELFI Nicolas, CAPOZUCCA Alfredo

Testing and Validation

Module: Module 3.21 (Semestre 3)

ECTS: 4

Objectif: The goal of testing and validation is to assess the consistency/ conformity of a product with respect to its specification.
These activities are thus crucial and costly activities for software companies, and eventually aim at providing a controlled level of trust
in the final product before it is delivered to the client (and then during maintenance)

Course learning outcomes:
* participate in the software testing process of a company
* carry out research in the area of software testing, diagnosis, validation
* develop new models and solutions for applied software testing

Description: Testing is related to all the design stages of
the development process and must deal with many application contexts
(embedded systems, information systems …) and various dimensions of
complexity (programming-in-the-small, in-the-large and in-the-duration).
This course reminds the principles of software testing, the main techniques and introduces new advanced techniques (similarity-based, securit testing...)

Modalité d'enseignement: The course is composed of a set theoretical courses which are illustrated with practical exercises (lab and paper exercises). The content of the course vary from one year to another taking into account the progress of the domain (MBT, code-based approaches)

Langue: Anglais

Obligatoire: Non

Evaluation: The students will be evaluated through homeworks, typically review/report on an advanced testing technique, and a final presentation.

Professeur: LE TRAON Yves, PAPADAKIS Michail

Computer Vision and Image Analysis

Module: Module 3.24 (Semestre 3)

ECTS: 4

Course learning outcomes:
Understanding of fundamental concepts in computer vision and imaging
Analyzing a specific research problem in computer vision
Implementing, testing, and evaluating existent solutions

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Description: This course gives an overview of the fundamental tools of computer vision and image analysis, with a presentation of
selected timely research topics, consolidated through a dedicated practical class project.
This course serves as an introduction to the field and its concepts. At the end of the course, students should have grasped major tools used in Computer Vision. It is also a preparation to pursue research in the field or related ones (e.g.
master project, PhD thesis).

* Introduction, review of mathematical tools
* Visual sensing and data structure
* Image filtering and processing
* Feature extraction and matching
* Multi-view imaging
* Motion estimation and tracking
* Image/object classification and scene understanding
* 3D Vision
* Deep Learning: from basics to applications

Modalité d'enseignement: The course offers a combination of theory and practice. The main framework is a series of lectures with their exercise
sessions essential for a thorough understanding of important theoretical concepts. Exposure to practical research is ensured.
Organization: through guest lectures and one class project. The project is a major part of the course. It consists in implementing, testing, analyzing and presenting a recently published work in computer vision. This is to be performed in groups of two to three students.

Langue: Français

Obligatoire: Non

Evaluation: Homeworks: 30%
Class Project: 50%
Final Exam: 20%

Professeur: AOUADA Djamila

Connected and Autonomous Vehicles

Module: Module 3.25 (Semestre 3)

ECTS: 4

Objectif: This class gives an introduction to the emergent topic of connected and autonomous vehicles. This class focuses on practical experience and places a major emphasis on projects.

After attending the theoretical lectures that introduce each topic, students will work on applying the concepts using small scale RC cars.

The different projects build on each other towards a final assessment that will have students compete in an autonomous race.

Course learning outcomes:

? Understand the challenges associated with connected and autonomous vehicles
? Get an overview of vehicular communication systems and their applications
? Be able to describe the sensors types, as well as their strengths and weaknesses
? Learn the software architecture of a autonomous vehicles
? Develop Python programs for an embedded device running on a small-scale RC car
? Argue implementations choices in written project report

Description:

The class alternates between theoretical lectures and hands-on projects. Labs or office hours will be organised to support students during projects.

All the projects are based on building autonomy for real RC cars that will run on test tracks.

The lectures and projects will cover the following topics:

? Introduction to Connected and Autonomous Vehicles, current state of the art
? Introduction to Deep Learning for Visual Perception
? Wheeled Robot Kinematics and Localisation
? Motion Planning
? Robot Control

Langue: Anglais

Obligatoire: Non

Evaluation: The grading is entirely based on hands-on projects realised throughout the course. There is no theoretical exam in this class.

Remarque: Depending on the size of the audience, projects may be realised in groups of students. Active participation of all students in each group is mandatory and will be assessed.

Professeur: FRANK Raphaël, VARISTEAS Georgios, ROBINET François

Fundamentals of causal learning

Module: Module 3.26 (Semestre 3)

ECTS: 4

Objectif: The modern toolkit for data analysis contains a large variety of instruments, both generic and specialized. All these tools can be used to analyze and extract useful connections from digital data. The theory behind guarantees that the resulting patterns will reflect the existing correlations, however not causal relationships. At the same time, in many applications the desired outcome is the cause-effect model. This course aims to discuss the conditions under which the correlation does imply causation and to present the research direction that studies these conditions in a general form – Causal Learning.

Course learning outcomes:

The students will learn

1) the difference between statistical and causal models,

2) conditions under which causal inference is possible and

3) will get familiar with currently available approaches and techniques for causal learning.

Additionally, this course will form basis for further Mater or PhD thesis in the theory and/or application of Machine Learning and Data Science.

Description: The following topics will be considered:

1. Statistical and causal models

2. Assumptions for causal inference

3. Multivariate Causal Models

4. Learning cause-effect models

5. Connections to Machine Learning

Modalité d'enseignement: Lectures intermixed with exercises

Langue: Anglais

Obligatoire: Non

Evaluation: 50% assignments and 50% final examination

Remarque: References:
1) Peters, Jonas, Dominik Janzing, and Bernhard Schölkopf. Elements of causal inference: foundations and learning algorithms. MIT press, 2017.
2) additional resources will be provided during lectures

Professeur: ALEKSANDROVA Marharyta

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Semestre 4

Master thesis

Module: Module 4.1 (Semestre 4)
ECTS: 30
Langue: Anglais
Obligatoire: Oui
Professeur: SORGER Ulrich