Curriculum "Artificial Intelligence"

Objectives/visions *The adoption of Artificial Intelligence (AI) technologies is widely expanding in our society. Applications of AI include: self-driving cars, personal assistants, surveillance systems, robotic manufacturing, machine translation, financial services, cyber security, web search, video games, code analysis and product recommendations. Such applications use AI techniques to interpret information from a wide variety of sources and use it to enable intelligent, goal-directed behavior.*
Modern AI often involves self-learning systems that are trained on massive amounts of data, and/or interacting intelligent agents that perform distributed reasoning and computation. AI connects sensors with algorithms and human-computer interfaces, and extends itself into large networks of smart devices.

AI is a flourishing research field that is one of the driving forces of today's economy and as such is having increasing impact on society, both economical and social.

By blending standard classes with recitations and lab sessions, our program ensures that each student masters the theoretical foundations and acquires hands-on experience in each subject. Beside a core of theoretical units, the program includes more specialty-oriented electives so that students can round up their skills on leading edge applications and techniques.

A master degree in Artificial Intelligence opens career opportunities in companies that are building the next generation of intelligence and language understanding for their products: for example intelligent personal assistants, opinion mining systems, customer support system, biomedical applications, computer games, smart adaptive devices, robots, smart planning systems. The curriculum provides the skills for working in key positions, in knowledge-intensive companies or research centers. The department has strong connection with many leading companies like Google, Yahoo!, Microsoft, LinkedIn that are seriously investing in AI.

Studies plan

	Course name	CFU
	57 CFU OF:	
1	Artificial intelligence fundamentals	6
2	Machine learning (con WBI e WFU))	9
3	Human languages technologies (con WFU)	9
4	Distributed systems: paradigms and models (con WTW)	9
5	Intelligent systems for pattern recognition	6
6	Smart applications	9
7	Computational mathematics for learning and data analysis (con KD)	9
8-11	**30 CFU (2 da 9 e 2 da 6) OF:**	
	Algorithm engineering (KD)	9
	Data mining (KD)	9
	Mobile and cyber-physical systems (ICT)	9
	Information retrieval (KD)	6
	Computational neuroscience (ING)	6
	Social and ethical issues in computer technology	6
	Robotics (S.Anna)	6
	Semantic web (CNR)	6
	33 CFU OF:	
12	Free choice	9
	Thesis	24

Syllabus

Artificial intelligence fundamentals [6 CFU]
The course aims to offer a view of the classical/symbolic approach to Artificial Intelligence and serves as a basis for more in depth treatment of specific theories and technologies for building complete A.I. systems integrating different approaches and methods.

- *Advanced search*
- *Constraint satisfaction problems*
- *Knowledge representation and reasoning*
  - *Non-standard logics*
  - *Uncertain and probabilistic reasoning (Bayesian networks, fuzzy sets).*
  - *Foundations of semantic web: semantic networks and description logics.*
- *Rules systems: use and efficient implementation.*
- *Planning systems.*

Machine learning [9 CFU]
We introduce the principles and the critical analysis of the main paradigms for learning from data and their applications. The course provides the Machine Learning basis for both the aims of building new adaptive Intelligent Systems and powerful predictive models for intelligent data analysis.

- *Computational learning tasks for predictions, learning as function approximation, generalization concept.*
- *Linear models and Nearest-Neighbors (learning algorithms and properties, regularization).*
- *Neural Networks (MLP and deep models, SOM).*
- *Probabilistic graphical models.*
- *Principles of learning processes: elements of statistical learning theory, model validation.*
- *Support Vector Machines and kernel-based models.*
- *Introduction to applications and advanced models.*

Applicative project: implementation and use of ML/NN models with emphasis to the rigorous application of validation techniques.

Human language technologies [9 CFU]
The course presents principles, models and the state of the art techniques for the analysis of natural language, focusing mainly on statistical machine learning approaches and Deep Learning in particular. Students will learn how to apply these techniques in a wide range of applications using modern programming libraries.

- *Formal and statistical approaches to NLP.*
- *Statistical methods: Language Model, Hidden Markov Model, Viterbi Algorithm, Generative vs Discriminative Models*
- *Linguistic essentials (tokenization, morphology, PoS, collocations, etc.).*
- *Parsing (constituency and dependency parsing).*
- *Processing Pipelines.*
- *Lexical semantics: corpora, thesauri, gazetteers.*
- *Distributional Semantics: Word embeddings, Character embeddings.*
- *Deep Learning for natural language.*
- *Applications: Entity recognition, Entity linking, classification, summarization.*
- *Opinion mining, Sentiment Analysis.*
- *Question answering, Language inference, Dialogic interfaces.*
- *Statistical Machine Translation.*
- *NLP libraries: NLTK, Theano, Tensorflow.*

Distributed systems: paradigms and models [9 CFU] (vedi WTW)

Intelligent Systems for Pattern Recognition [6 CFU]

The course introduces students to the design of A.I. based solutions to complex pattern recognition problems and discusses how to realize applications exploiting computational intelligence techniques. The course also presents fundamentals of signal and image processing. Particular focus will be given to pattern recognition problems and models dealing with sequential and time-series data.

- *Signal processing and time-series analysis*
- *Image processing, filters and visual feature detectors*
- *Bayesian learning and deep learning for machine vision and signal processing*
- *Neural network models for pattern recognition on non-vectorial data (physiological data, sensor streams, etc)*
- *Kernel and adaptive methods for relational data*
- *Pattern recognition applications: machine vision, bio-informatics, robotics, medical imaging, etc.*
- *ML and deep learning libraries overview: e.g. scikit-learn, Keras, Theano*

A final project will introduce students to the implementation of a pattern recognition application or to the development of computational intelligence applications.

Smart applications [9 CFU]

The course aim is to explore methods and technologies for the development of smart connected applications, i.e. applications which exhibit intelligent behaviour -- through the use of artificial intelligence techniques introduced in other courses -- and that are deployed in immersive environments, including smart objects (as embodied by Internet of Things devices), mobile devices (smartphones, tablets), wearables (smartwatches, fitness trackers), home automation devices, web technologies, and cloud services and infrastructure. As such, applications considered for the course will include elements of context-awareness, sensor intelligence, spoken-language interfaces,

The course will be based around a single case study for a novel smart application; students will cooperate as a single team, under the leadership of the instructor, in the design and implementation of a complete solution. In addition to standard lectures, classroom activities will include workshop-like sessions, where alternative designs are discussed, decisions are taken, and tasks are assigned. Weekly homework on the various phases of the joint project will be assigned to the team, and results reviewed the following week. The final goal is the delivery of a fully-functioning prototype of a smart application addressing the initial problem.

While the specific technologies adopted for each case study will vary based on needs and opportunities, the following general themes will be explored in lectures (examples of specific subjects are noted next to each theme):

- *Introduction to the course and to the case study*
  - *examples: a voice-activated ambient assistant to answer student queries about the logistics of lectures in a classroom building, or autonomous software for a robotic rover for exploring inaccessible environments*
- *Common designs for smart applications*
  - *examples: fuzzy logic in control systems or cloud analysis of field sensors data streams*
- *Make or buy: selecting appropriate procurement strategies*
  - *example: writing your own RRN architecture vs. using cloud services*
- *Development platforms for smart objects*
  - *examples: Brillo (IoT devices) or Android TV (Smart TVs)*
- *Development platforms for smart architectures*
  - *examples: TensorFlow (server-side RNNs), or the Face Recognition API (mobile)*
- *Cloud services for smart applications*
  - *examples: Google Cloud Machine Learning API, Google Cloud Vision API, Google Cloud Speech API, or Deploying Deep Neural Networks on Microsoft Azure GPU VMs*
- *Deployment and operations*
  - *examples: cloud hosting vs. device hosting, or harnessing user feedback to drive improvement*
- *Measuring success: methods and metrics*
  - *examples: defining user engagement and satisfaction metrics, or assessing the naturalness of smart interactions*

Computational mathematics for learning and data analysis [9 CFU]

The course introduces some of the main techniques for the solution of numerical problems that find widespread use in fields like data analysis, machine learning, and artificial intelligence. These techniques often combine concepts typical of numerical analysis with those proper of numerical optimization, since numerical analysis tools are essential to solve optimization problems, and, vice-versa, problems of numerical analysis can be solved by optimization algorithms. The course has a significant hands-on part whereby students learn how to use some of the most common tools for computational mathematics; during these sessions, specific applications will be briefly illustrated in fields like regression and parameter estimation in statistics, approximation and data fitting, machine learning, artificial intelligence, data mining, information retrieval, and others.

- Multivariate and matrix calculus
- Matrix factorization, decomposition and approximation
- Eigenvalue computation
- Nonlinear optimization: theory and algorithms
- Least-squares problems and data fitting
- MATLAB and other software tools (lab sessions with applications)

Robotics [6 CFU]

The course introduces the fundamentals of robotics, viewed as an application domain for computer science, intelligent systems, and machine learning; provide students with the basic tools to integrate and program a robotic system, with special attention to the realization of perception-action schemes and behaviour control; improve students' experimental work capacity, through the analysis of case studies and laboratory work.

- *Introduction to robotics: main definitions, illustration of application domains*
- *Mechanics and kinematics of the robot*
- *Sensors for robotics*
- *Robot Control*
- *Architectures for controlling behaviour in robots*
- *Robotic Navigation*
- *Tactile Perception in humans and robots*
- *Vision in humans and robots*
- *Analysis of case studies of robotic systems*
- *Project laboratory: student work in the lab with robotic systems*

Semantic web [6 CFU]

The course presents Semantic web technologies, making the student able to design and implement knowledge bases based on ontologies encoded with Semantic Web languages, and offered access as Linked Data.

- *The architecture of the Web and the Semantic Web stack; URI.*
- *Resource Description Framework (RDF) and RDF Schema*
- *The query language SPARQL*
- *Linked data: creation of data sets from DB relations; access.*
- *Web Ontology Language (OWL): syntax and semantics*
- *Top ontologies: main definitions and examples (DOLCE and CRM)*
- *Specific ontologies, such as semantic sensor networks.*
- *Extraction of knowledge from KB's (DBpedia, Freebase)*
- *Project consisting in the creation of ontologies (use of Protegé).*

Computational modelling of complex systems [6 CFU] (non attivato)

The objective of this course is to train experts in systems modelling and analysis methodologies. Of course, this will require understanding, to some degree of detail, the mathematical and computational techniques involved. However, this will be done with the aim of shaping good modellers, that know the advantages/disadvantages/risks of the different modelling and analysis methodologies, that are aware of what happens under the hood of a modelling and analysis tool, and that can develop their own tools if needed.

The course will focus on advanced modelling approaches that combine different paradigms and analysis techniques: from ODEs to stochastic models, from simulation to model checking. Case studies from population dynamics, biochemistry, epidemiology, economy and social sciences will be analysed. Moreover, synergistic approaches that combine computational modelling techniques with data-driven methodologies will be outlined.

- *Modelling with ODEs: examples*

- *(Timed and) Hybrid Automata: definition and simulation techniques*
- *Stochastic simulation methods (Gillespie's algorithm and its variants)*
- *Hybrid simulation methods (stochastic/ODEs)*
- *Rule-based modelling*
- *Probabilistic/stochastic model checking: principles, applicability and tools*
- *Statistical model checking*
- *Process mining (basic notions)*